Title: Experimentalist View of the LHC

Date: Aug 09, 2007 02:00 PM

URL: http://pirsa.org/07080012

Abstract:

hep-ex-discovery@LHC.cern.ch

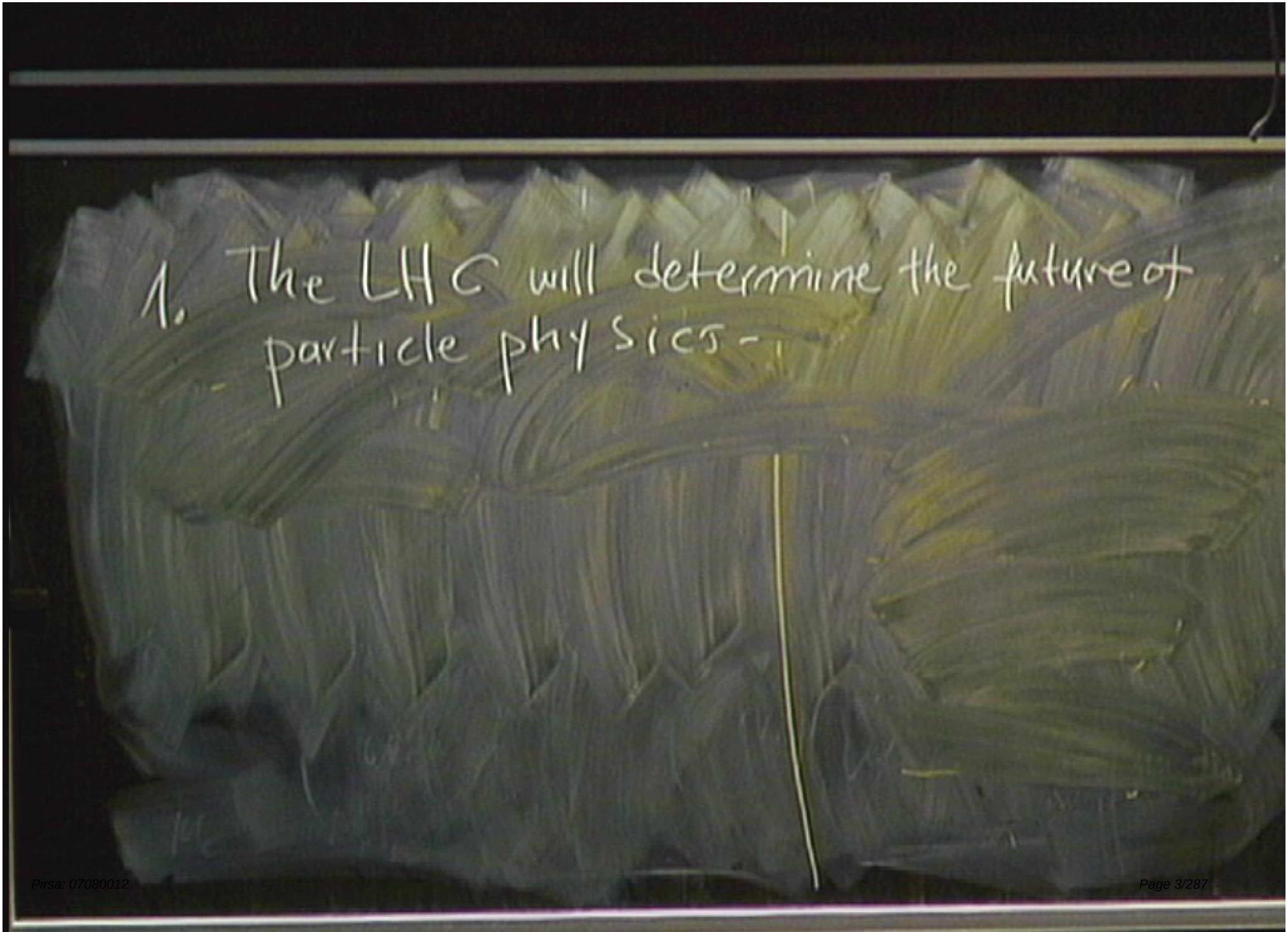
http://cmsdoc.cern.ch/~smaria/perimeter07/

Maria Spiropulu

CERN-PH

Perimeter Institute, Summer School on Particle Physics, Cosmology and Strings.

August 9, 2007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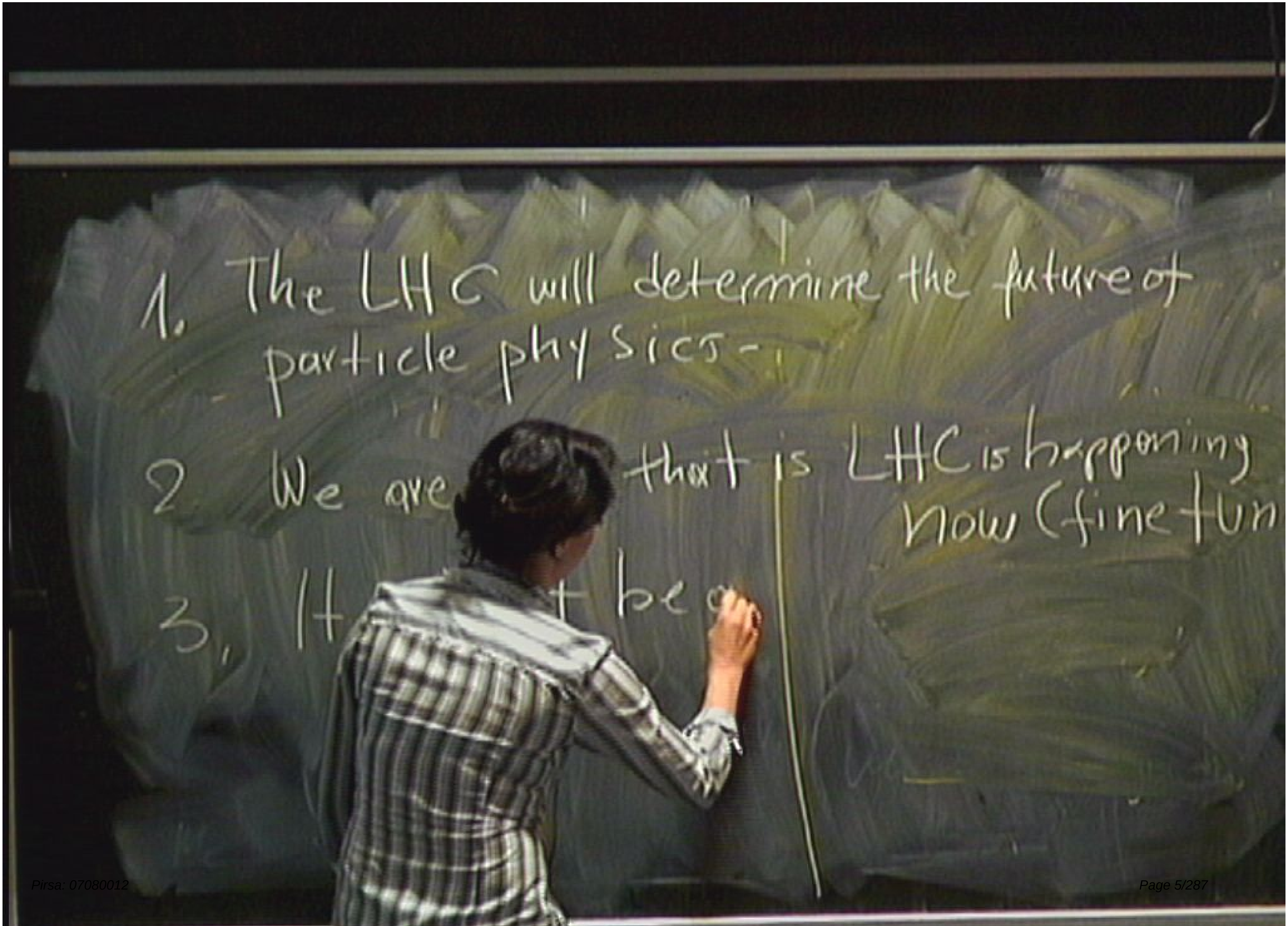
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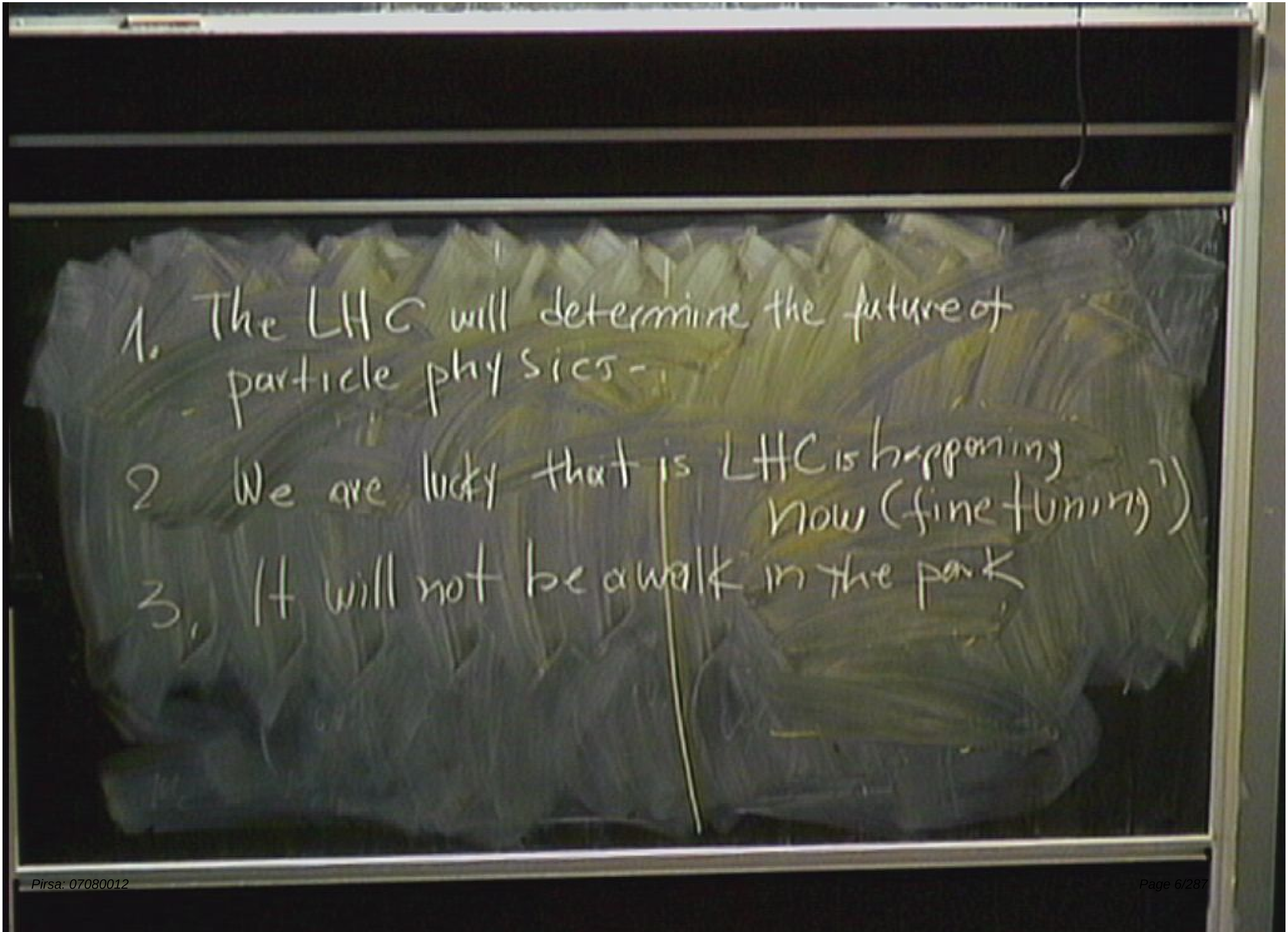
1. The LHC will determine the future of particle physics -
2 We are lucky that is LHC is happening now (fine tuning?)
3. It will not be a walk in the park

Outline

24 years and counting

Mission Statement

The "Machine"
- The Large Hadron Collider

Status of the LHC Experiments

The LHC Physics Besides the Standard Model
- SUSY@LHC program of work
- ATLAS+CMS SUSY search Highlights

Engineering the Discovery Plan

Wisdom from the Past

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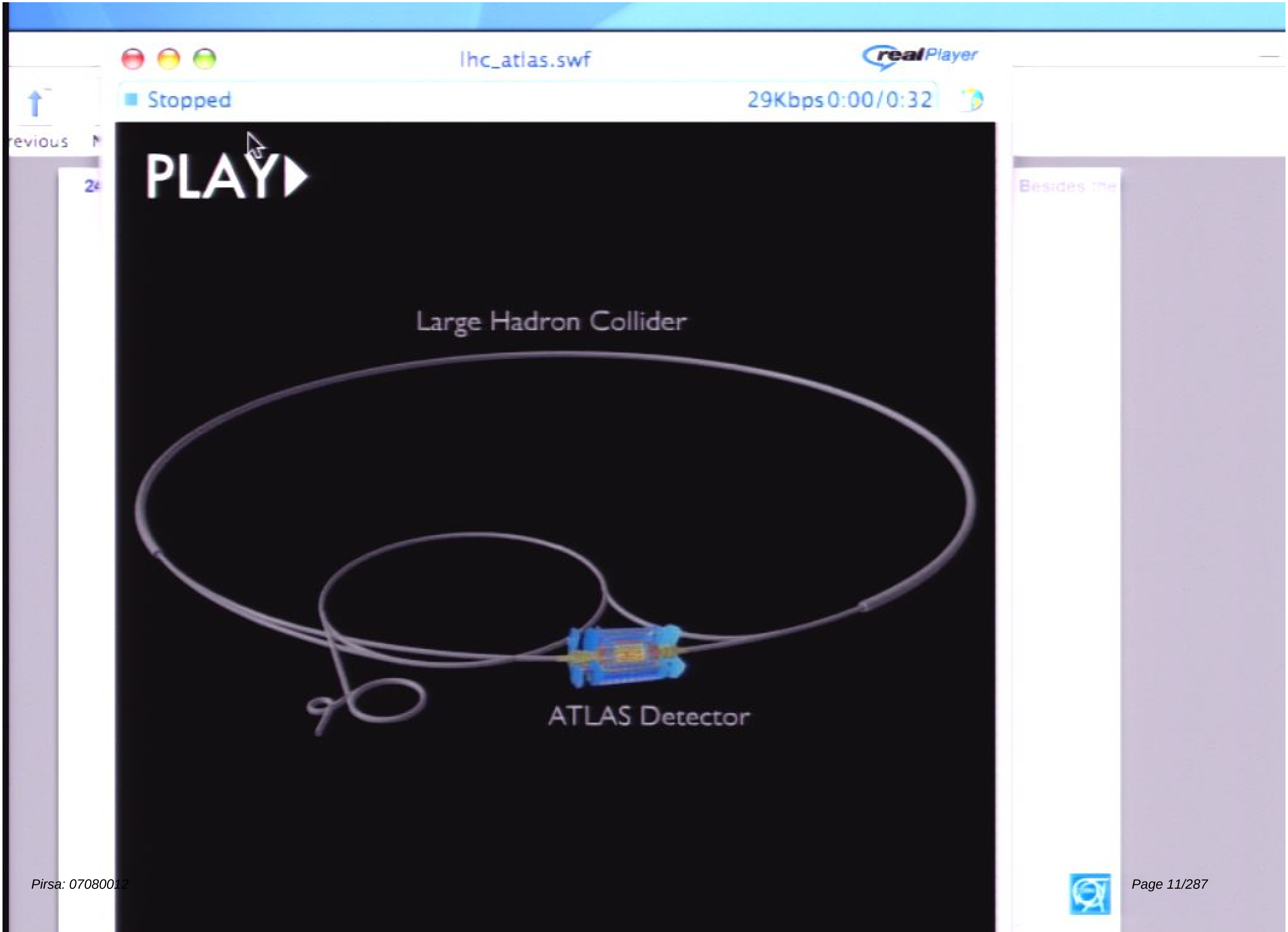
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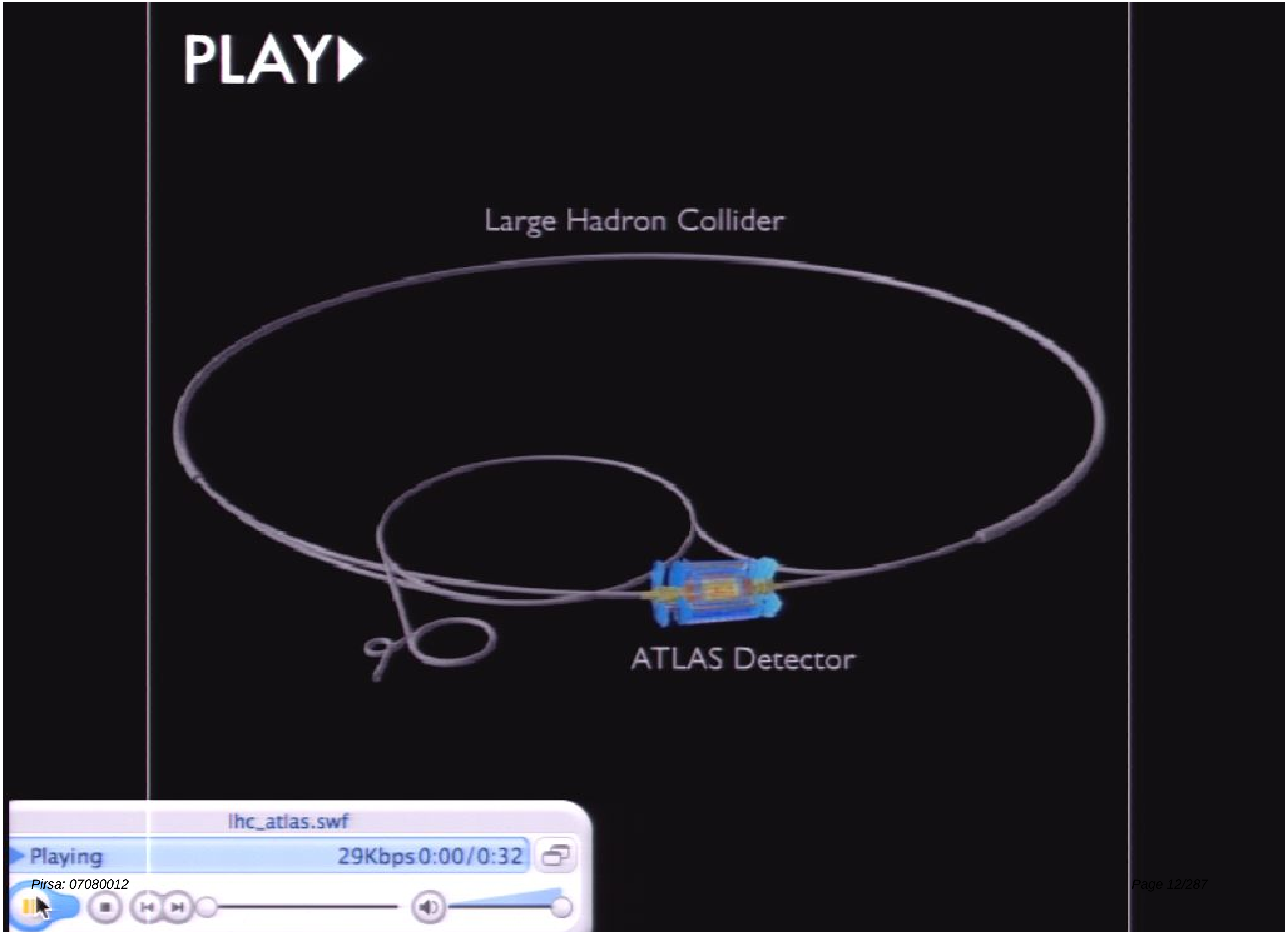
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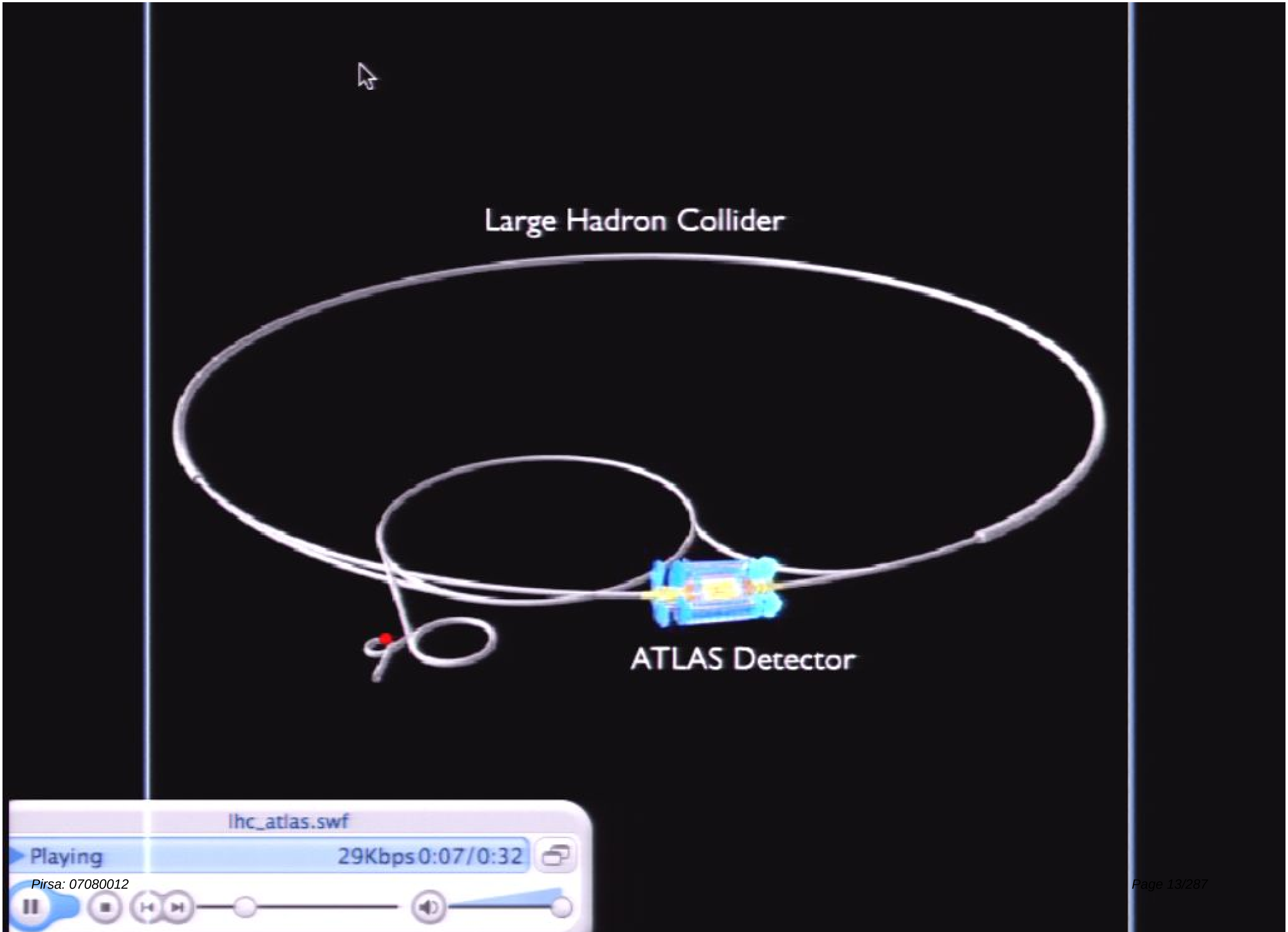
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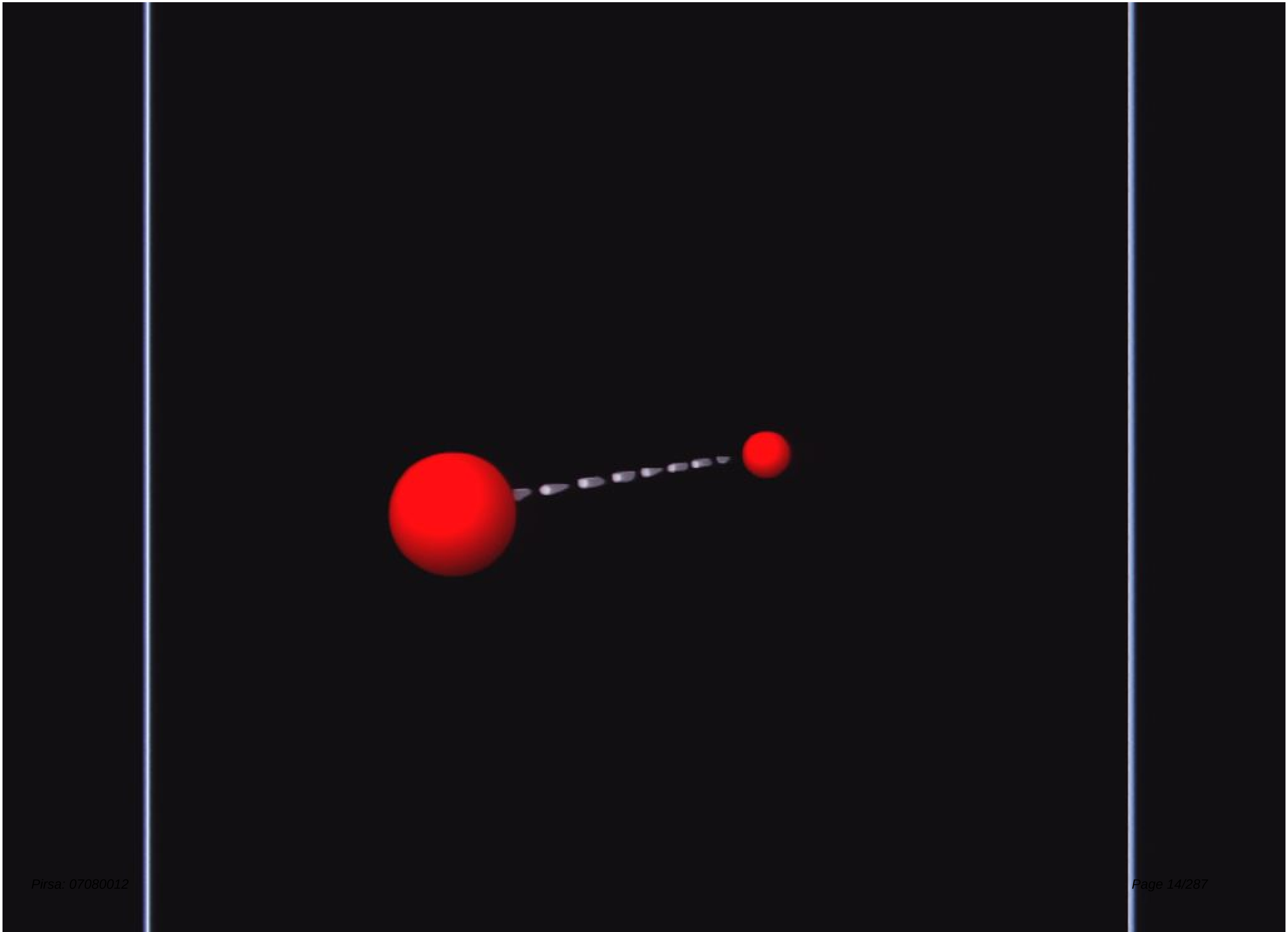

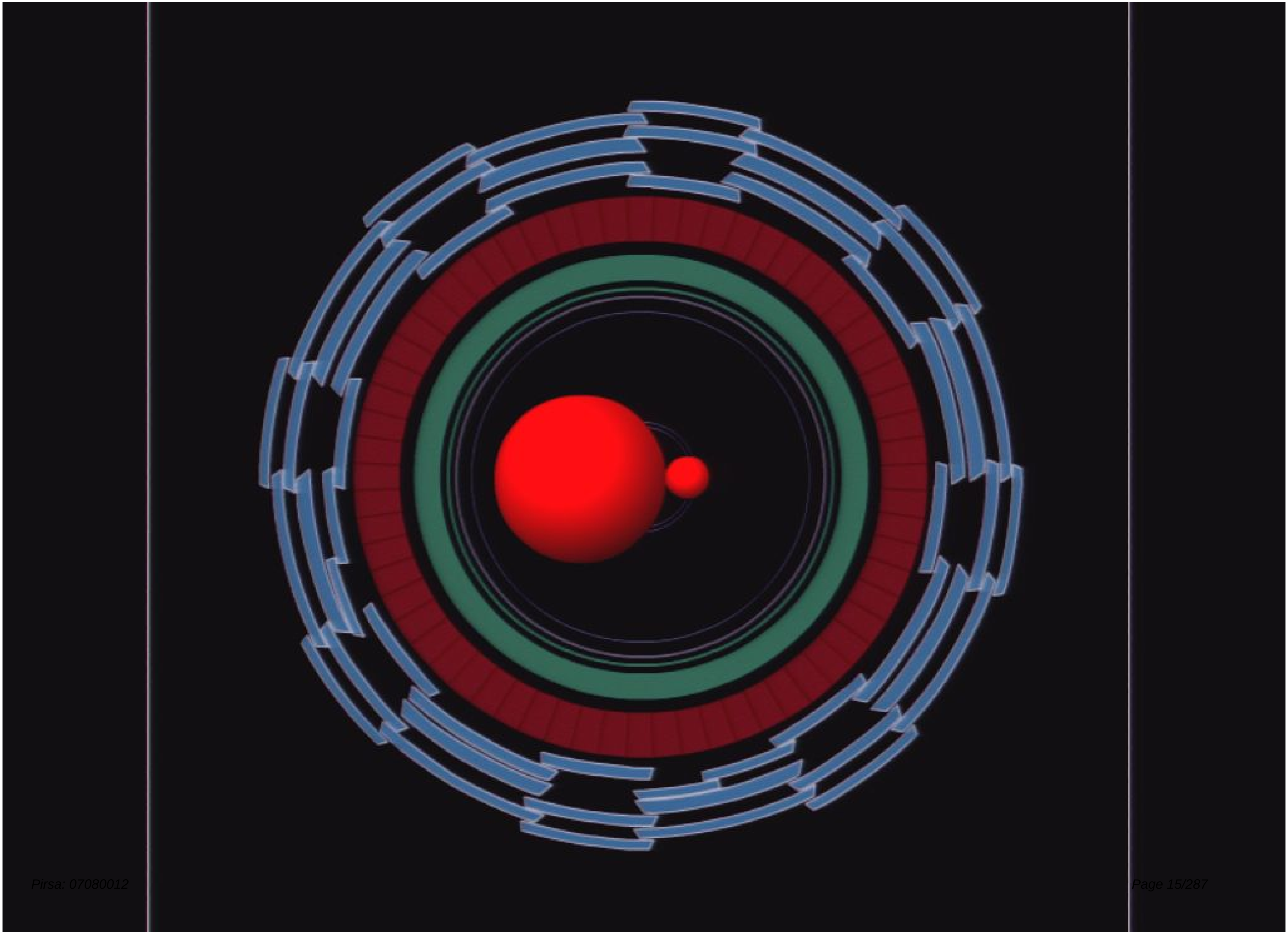

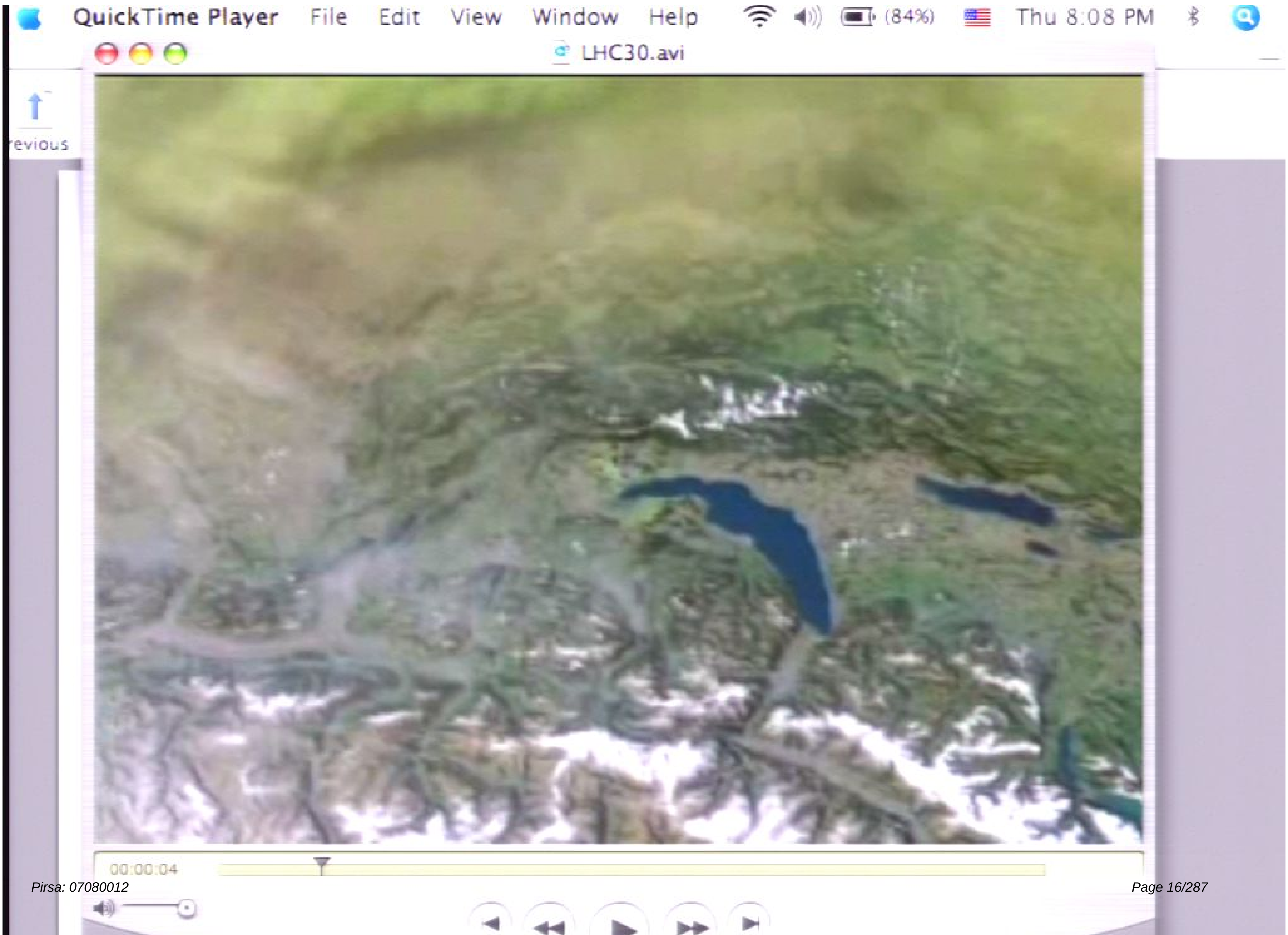
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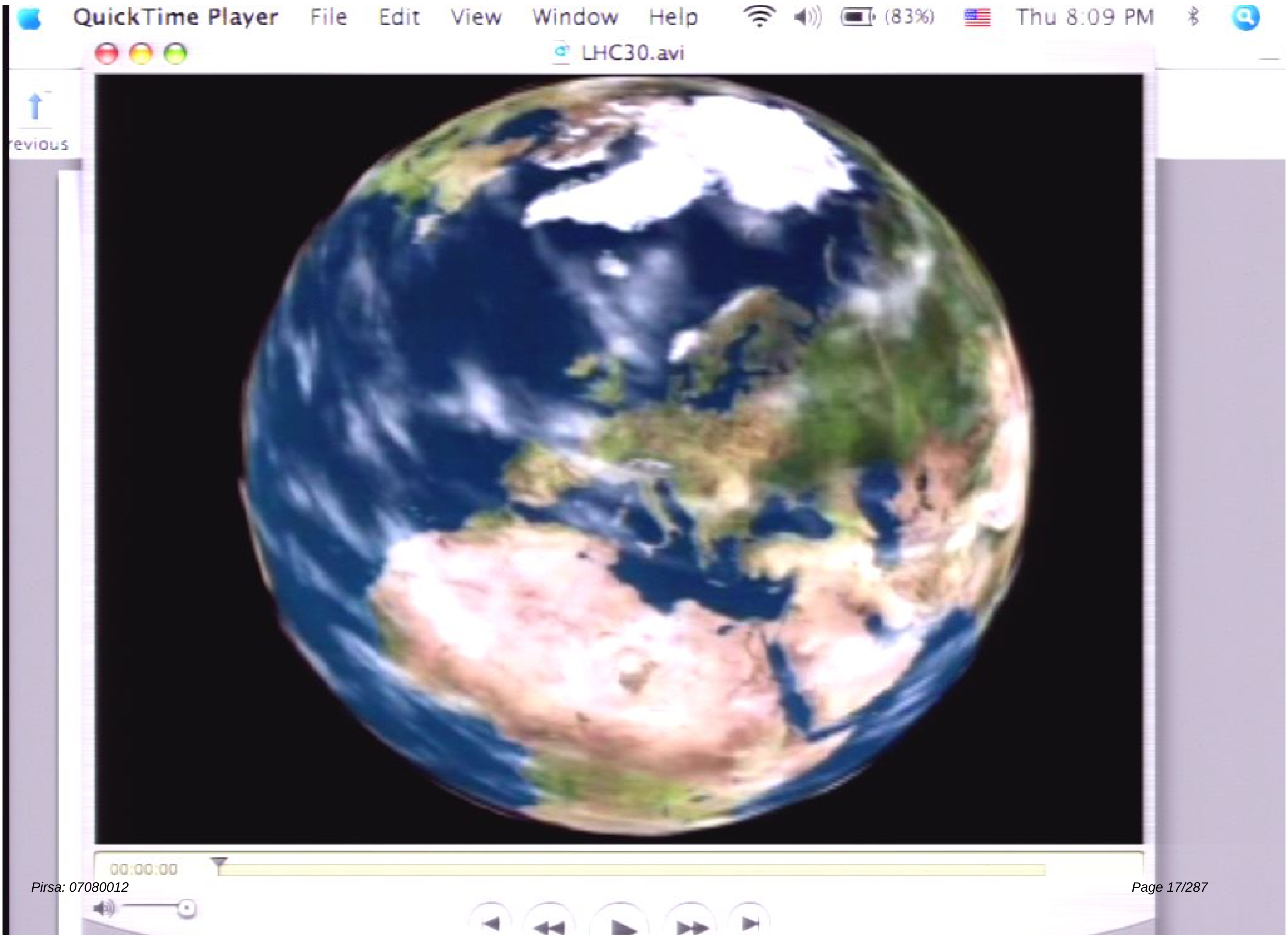
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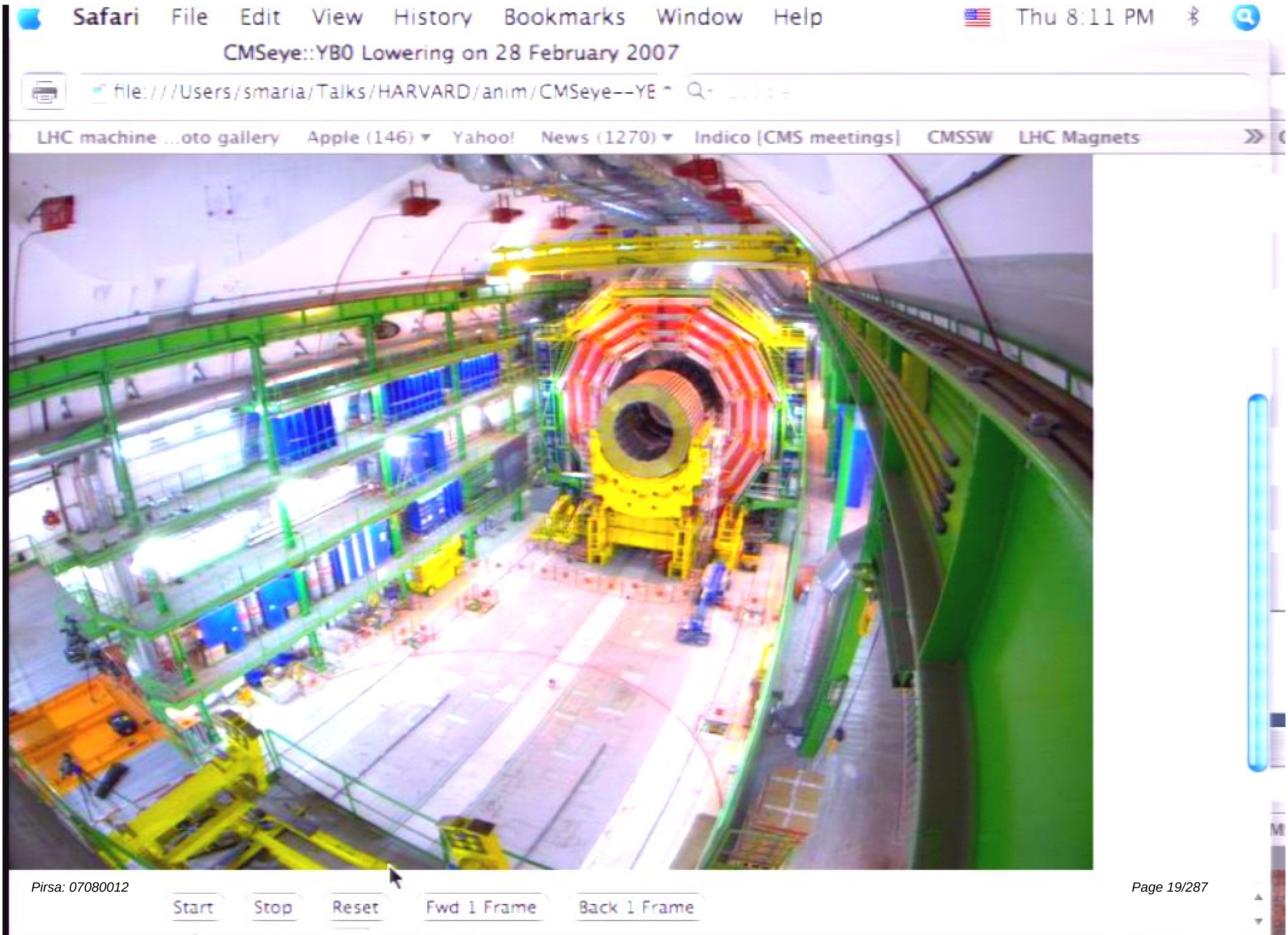
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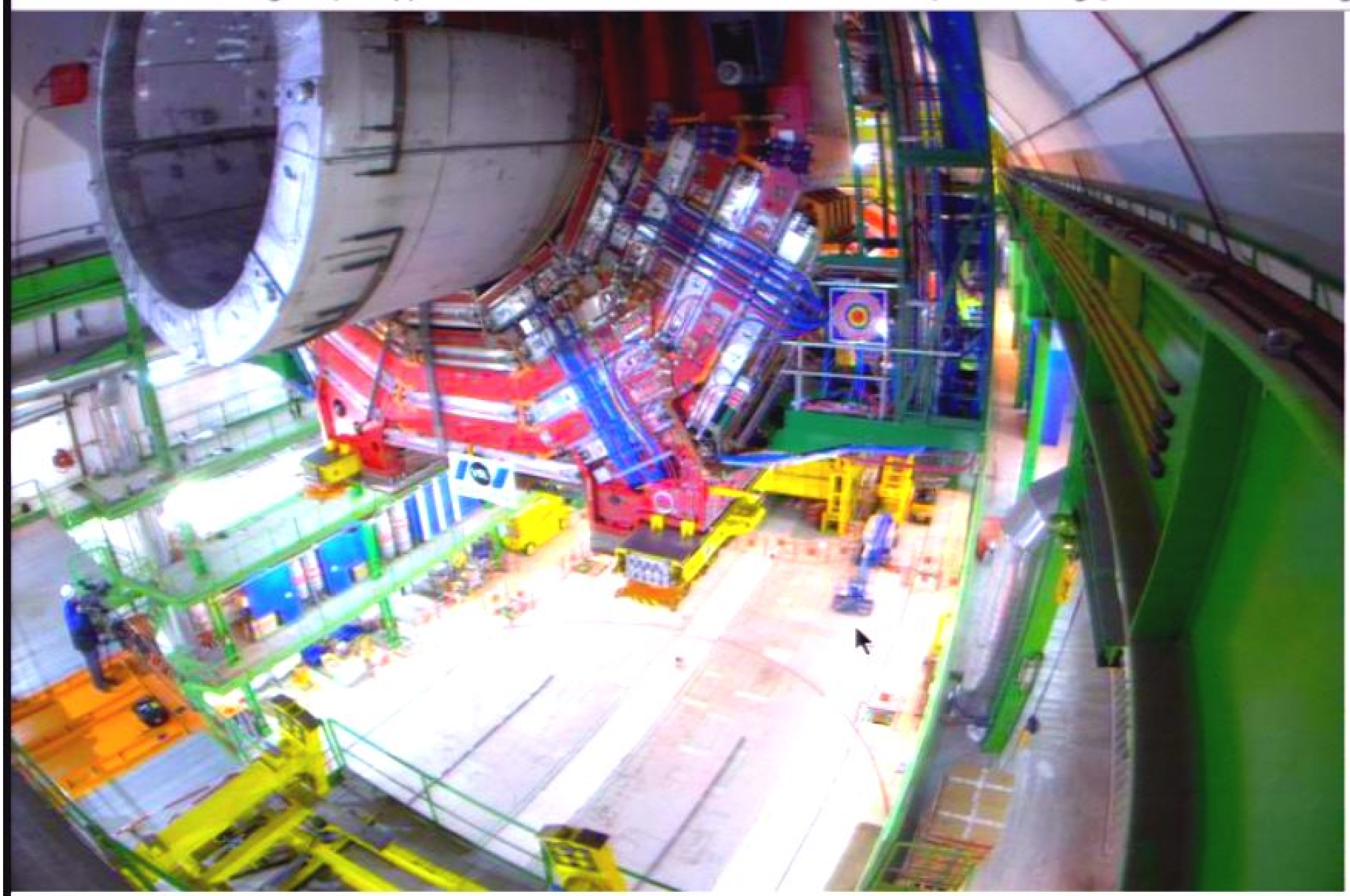

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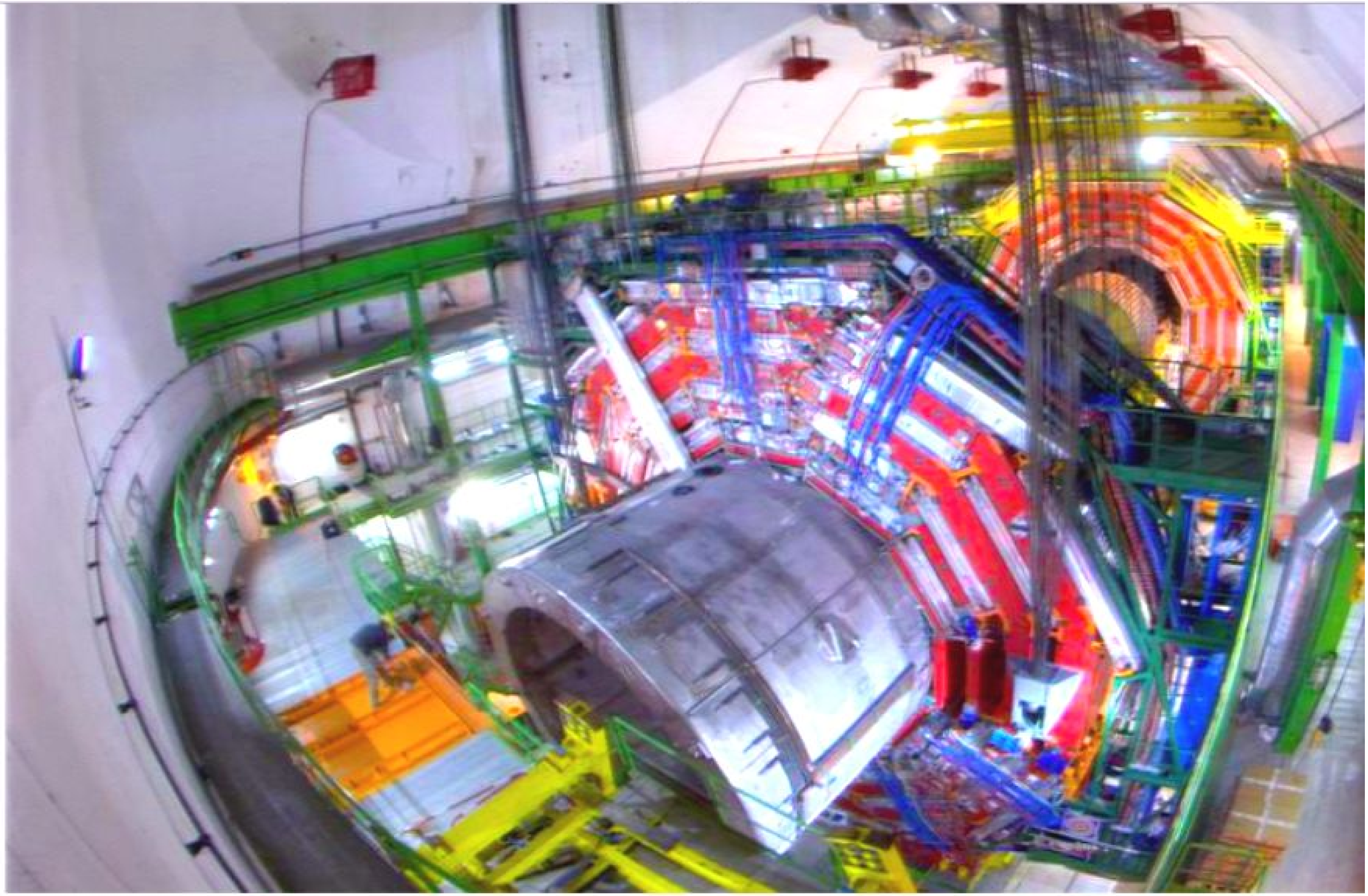

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[...] the Large Hadron Collider (LHC) [is] the right machine for further significant advance in the field of high energy physics research and for the future of CERN [...]The accelerator will produce not only higher energy but also a higher luminosity [...] than has been achieved before and it will reveal the behavior of fundamental particles of matter which has never been studied. [from Council report]

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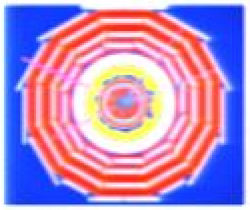
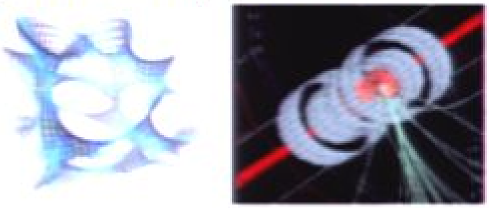
The major physics scope of the LHC

- Find and characterize the new particles that compose the dark matter of the universe

- Find the Higgs particle



- Find new particles, forces, extra dimensions of space



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The machine

High Energy High Luminosity Frontier

The machine


French-Swiss border
CERN main site
Geneva Airport
LHC accelerator

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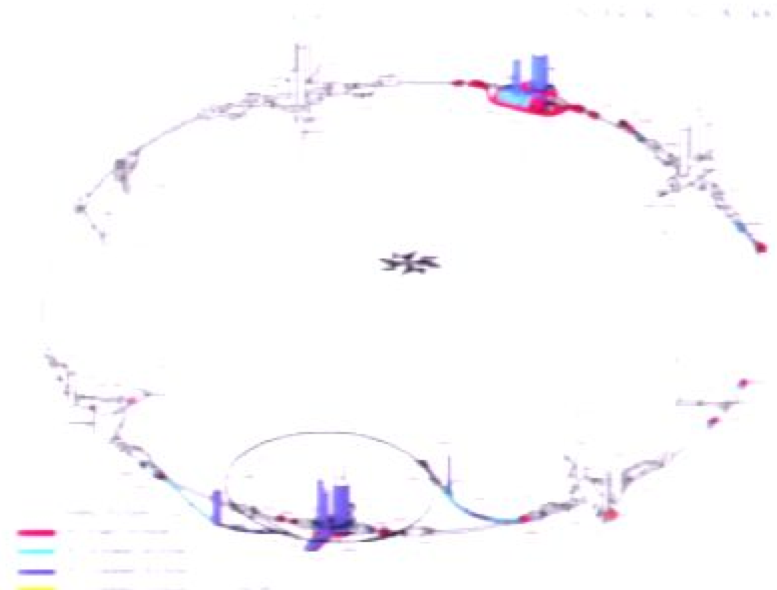
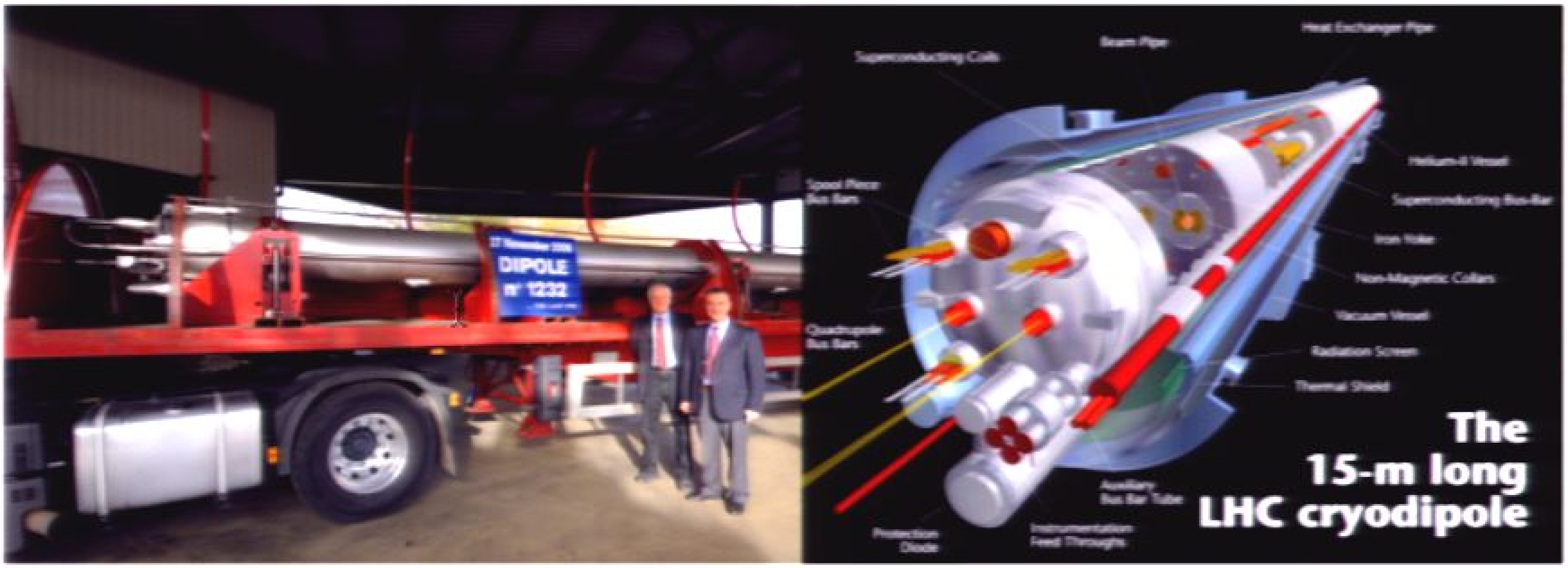
The Large Hadron Collider



- 14 TeV center of mass proton-proton collider. Located in the franco-swiss border close to Geneva Switzerland, installed in the 27 Km LEP tunnel ~100 m underground. ~1232 superconducting dipole bending magnets, 392 quadrupole focusing magnets; together with sextuples, octaples, decapoles and other correctors, about 8,000 magnets in total. [30 s movie]

1232 Cryodipoles: The bending force



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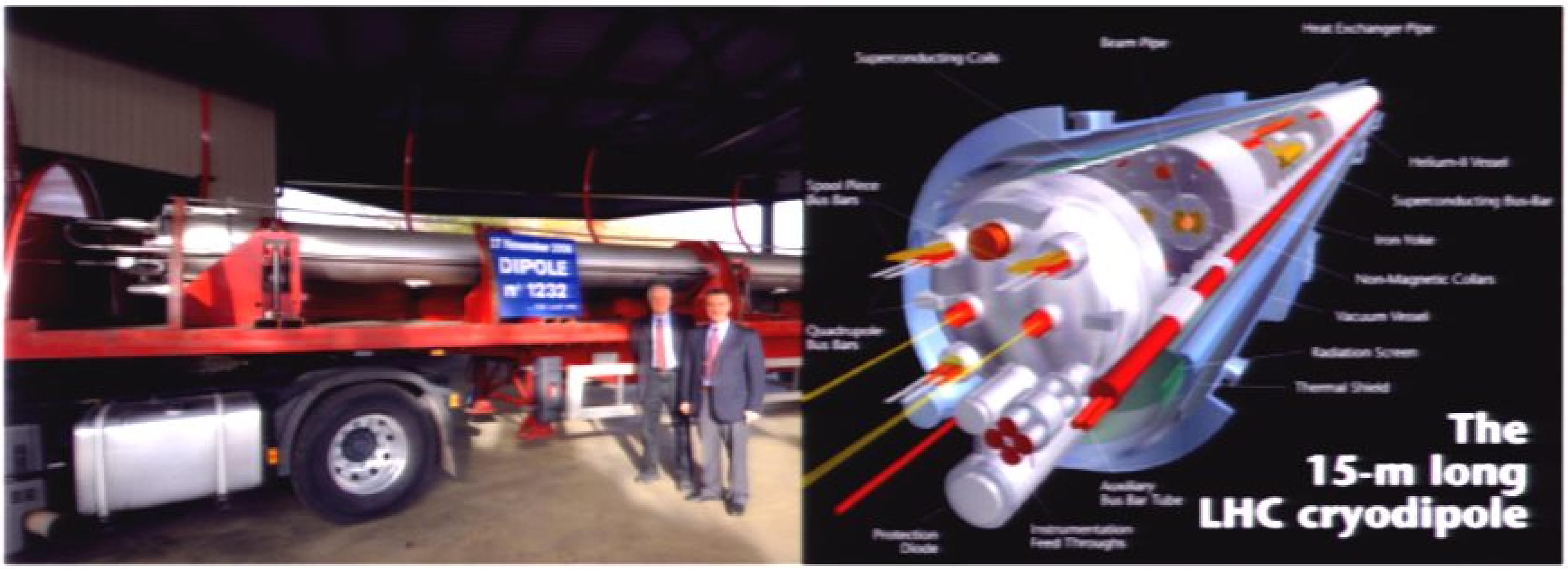

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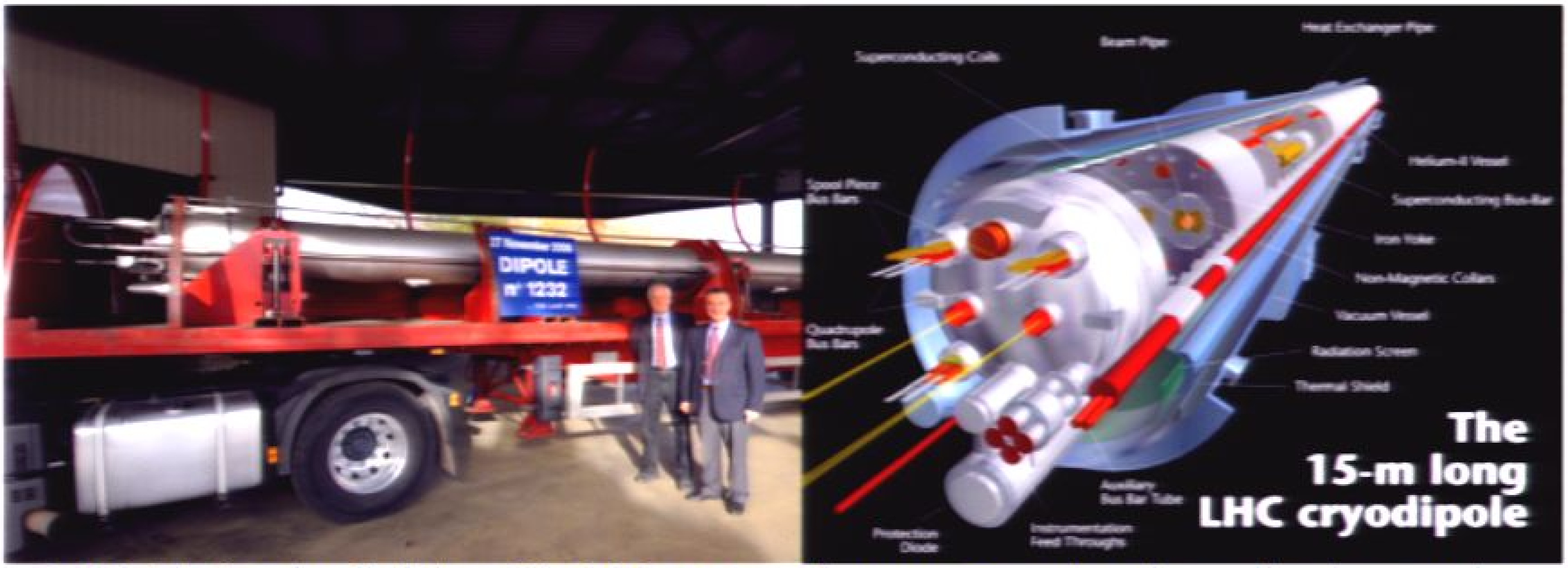

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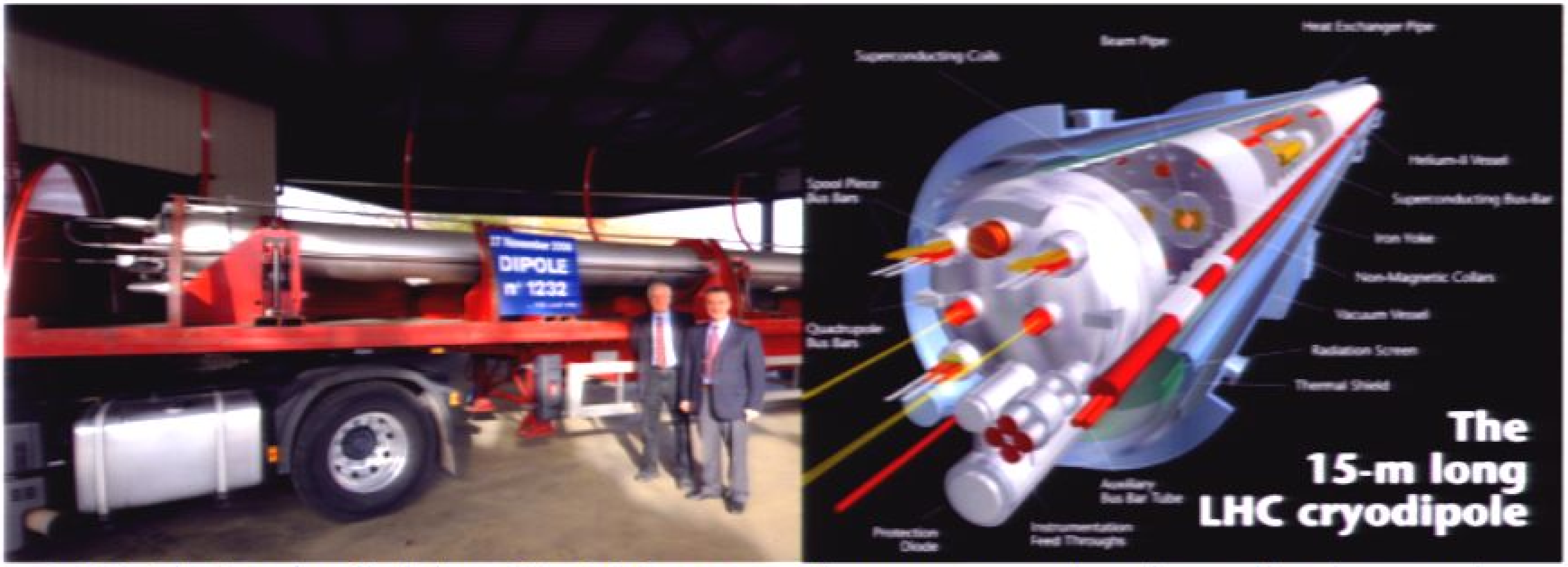

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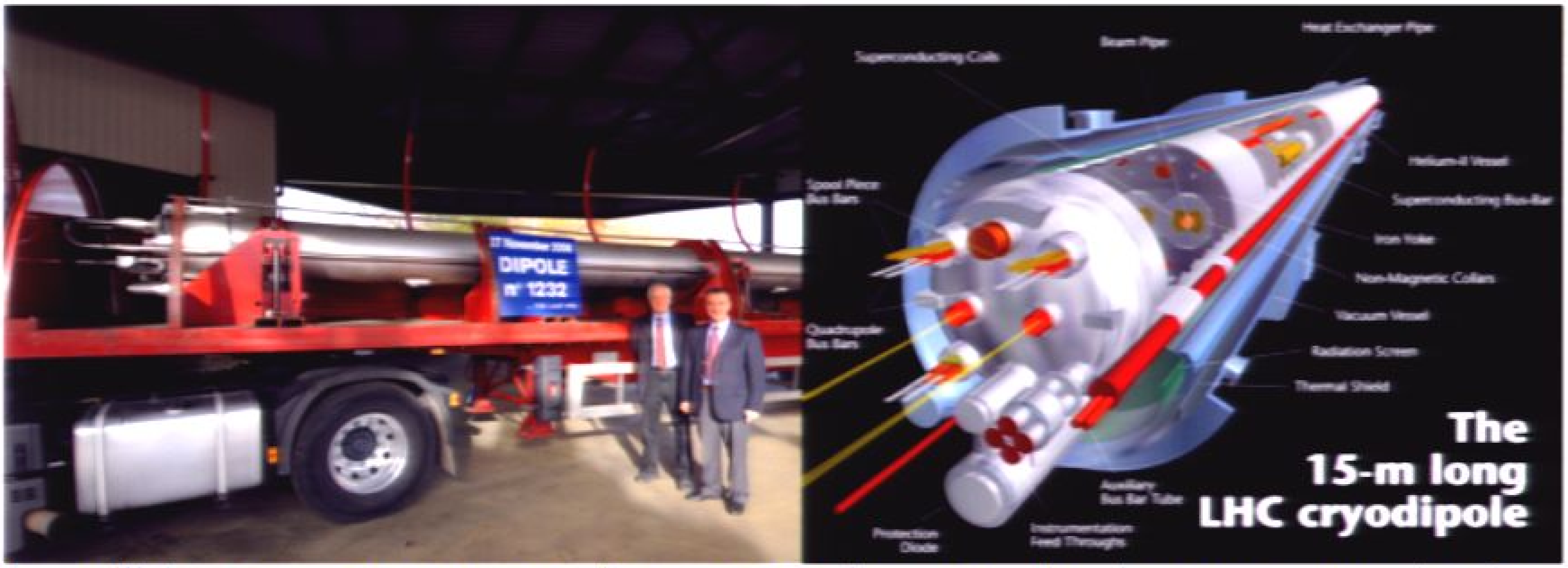

To collide two counter-rotating proton beams, the beams must be in separate vaccum chambers (in the bending sections) with opposite B field direction: The are TWO LHCs: The twin-bore design was proposed by John Blewett, BNL in 1971.

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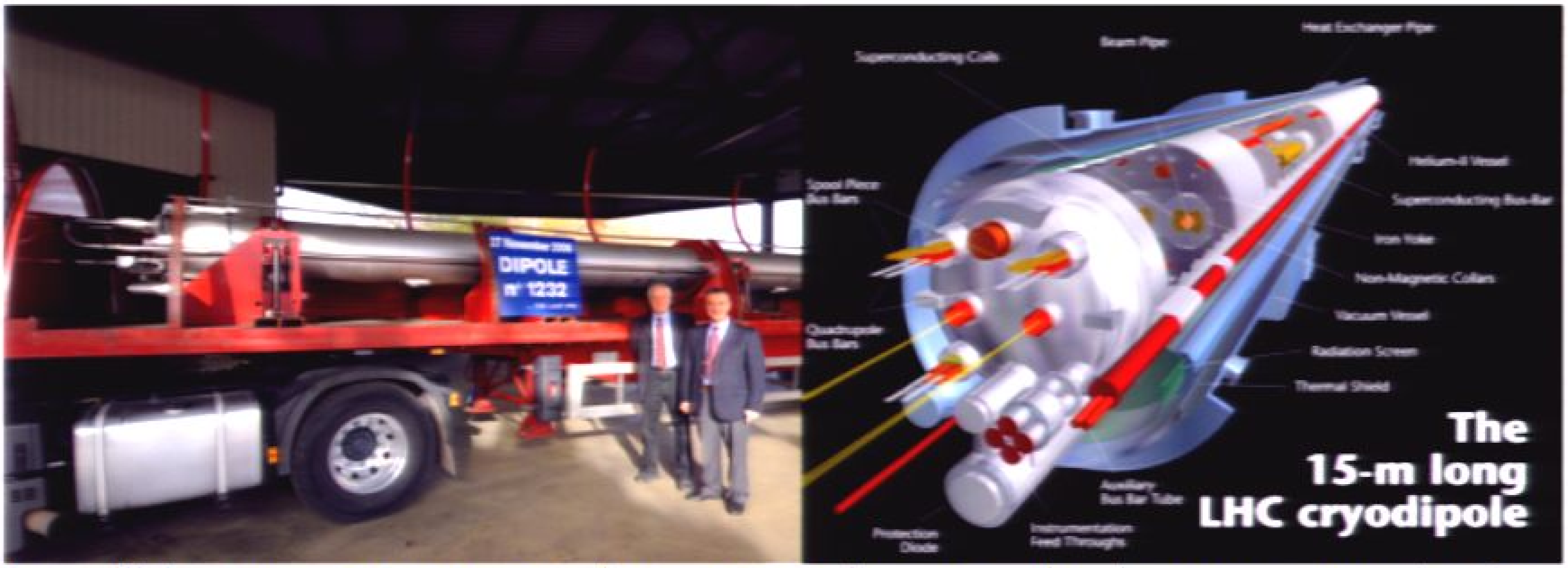

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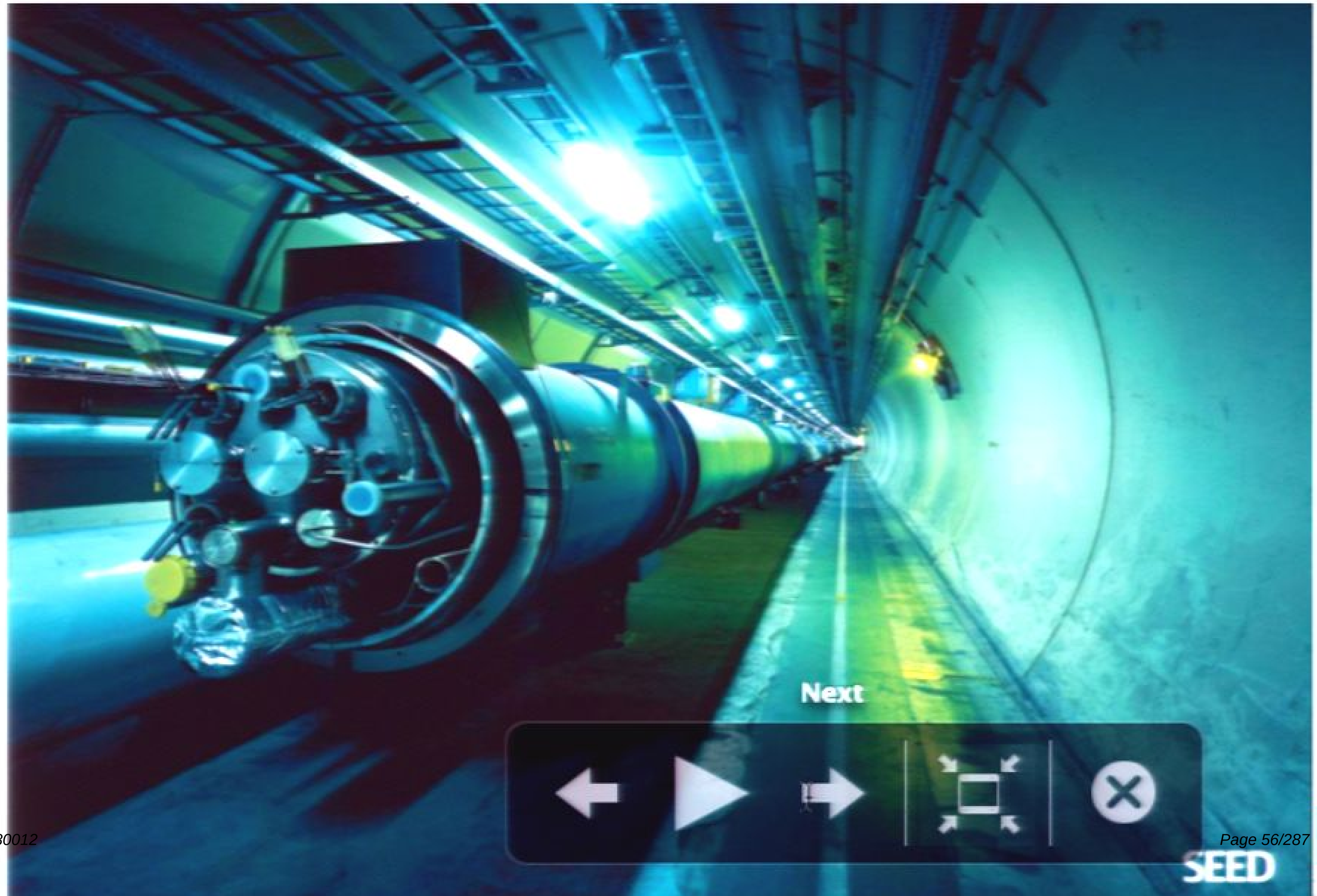

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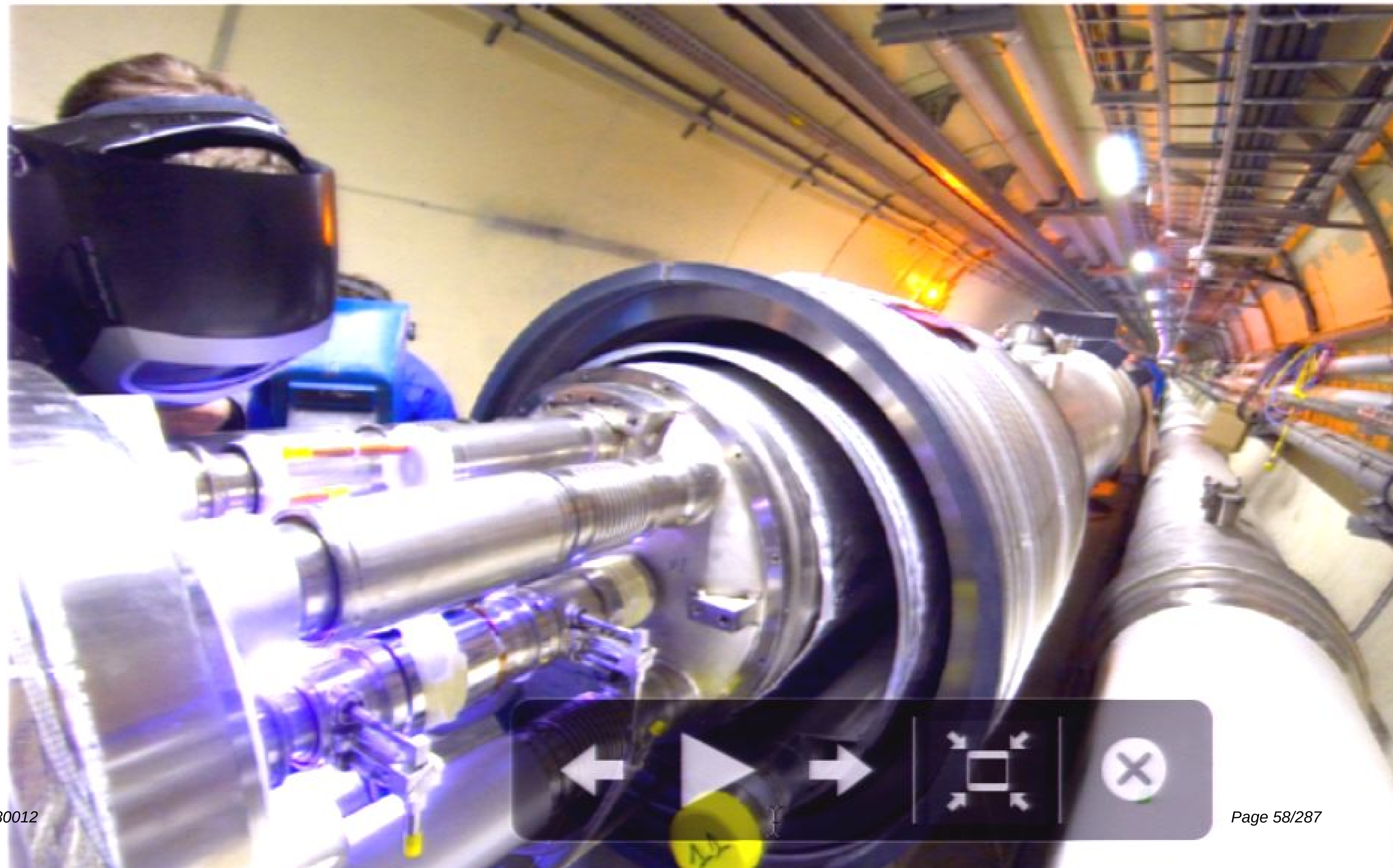
point the QRL

interconnecting dipoles



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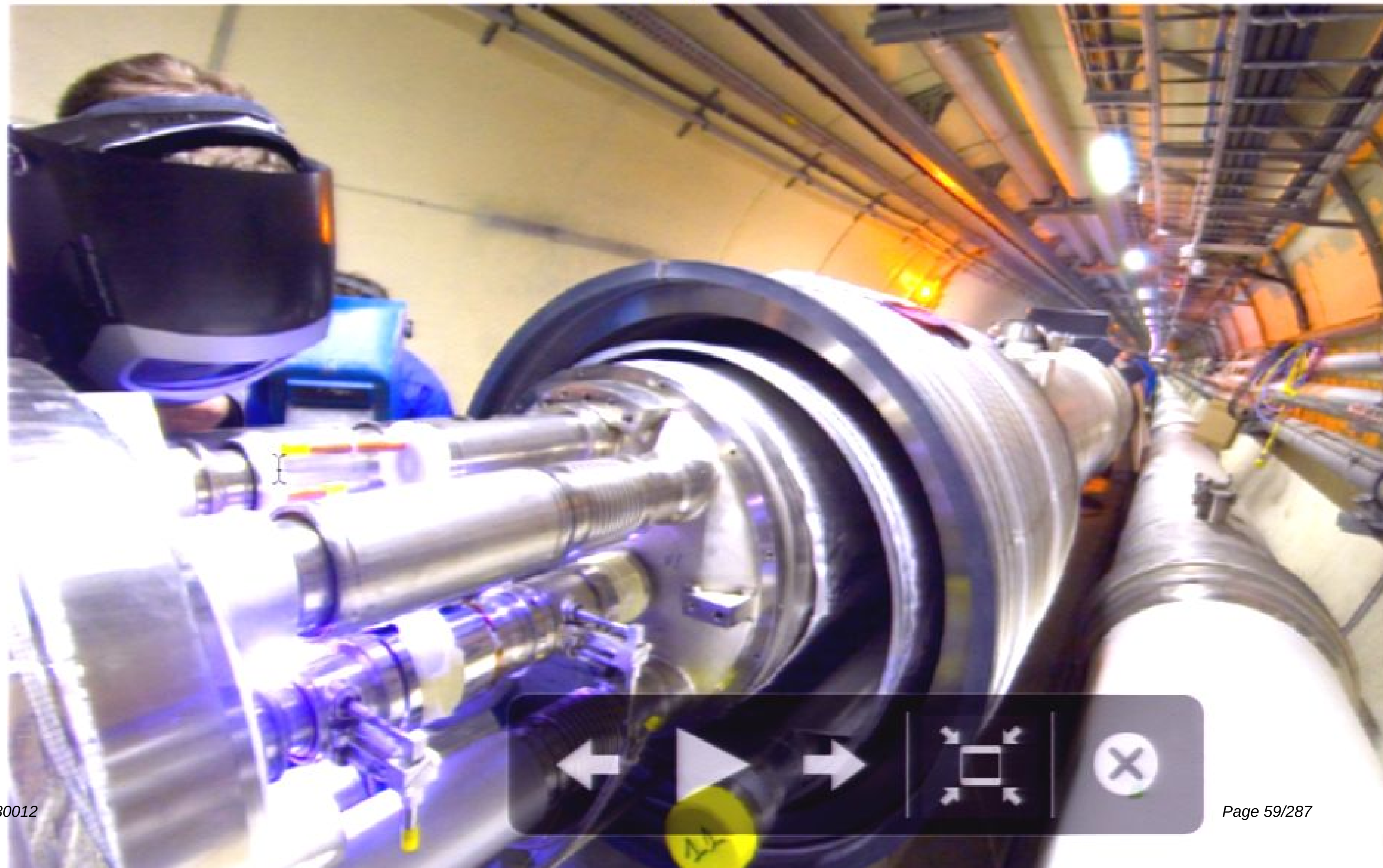
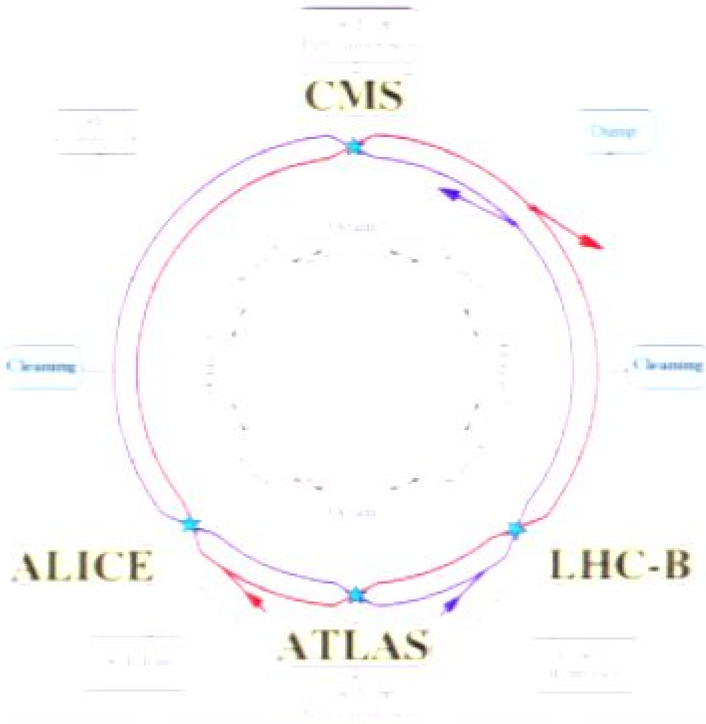


The machine

High Energy High Luminosity Frontier

Schematic View of the LHC



- IP1=ATLAS (general purpose)
- IP5=CMS (general purpose)
- IP2=ALICE (ion-ion, p-ion)
- IP8=LHCb (pp, B-physics, CP-violation)

- Design: 2808×2 bunches of protons, 10^{11} protons/bunch accelerated to 7 TeV; The total energy of each beam: $2808 \times 1.15 \times 10^{11}$ protons per bunch $\times$ 7 TeV = 0.185 M_{Planck} = 362 MJoules $\longrightarrow$ Absolutely NO accidents allowed : if the beam is steered wrongly a surface of 1/10 mm will be subjected to 4 Terawatts of proton beam power $\sim$ detonation of 86 Kg of TNT!

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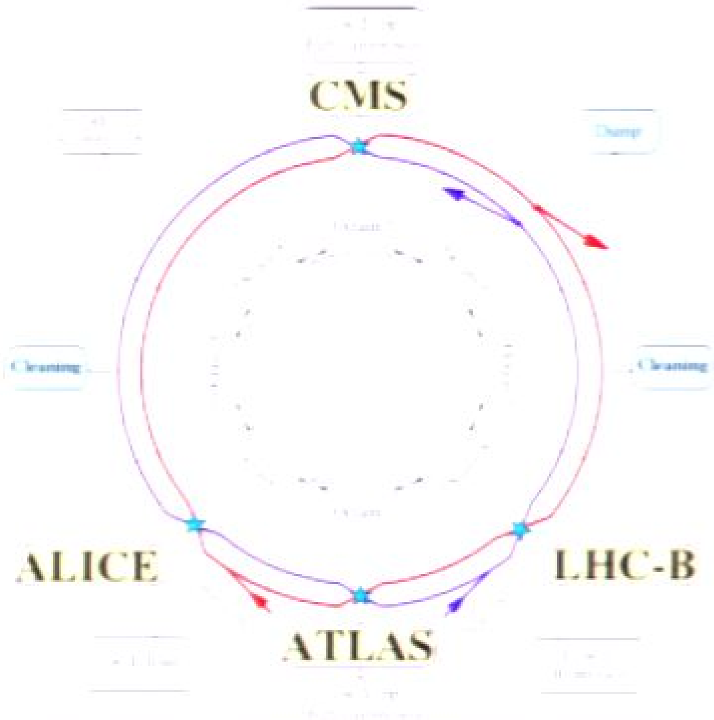

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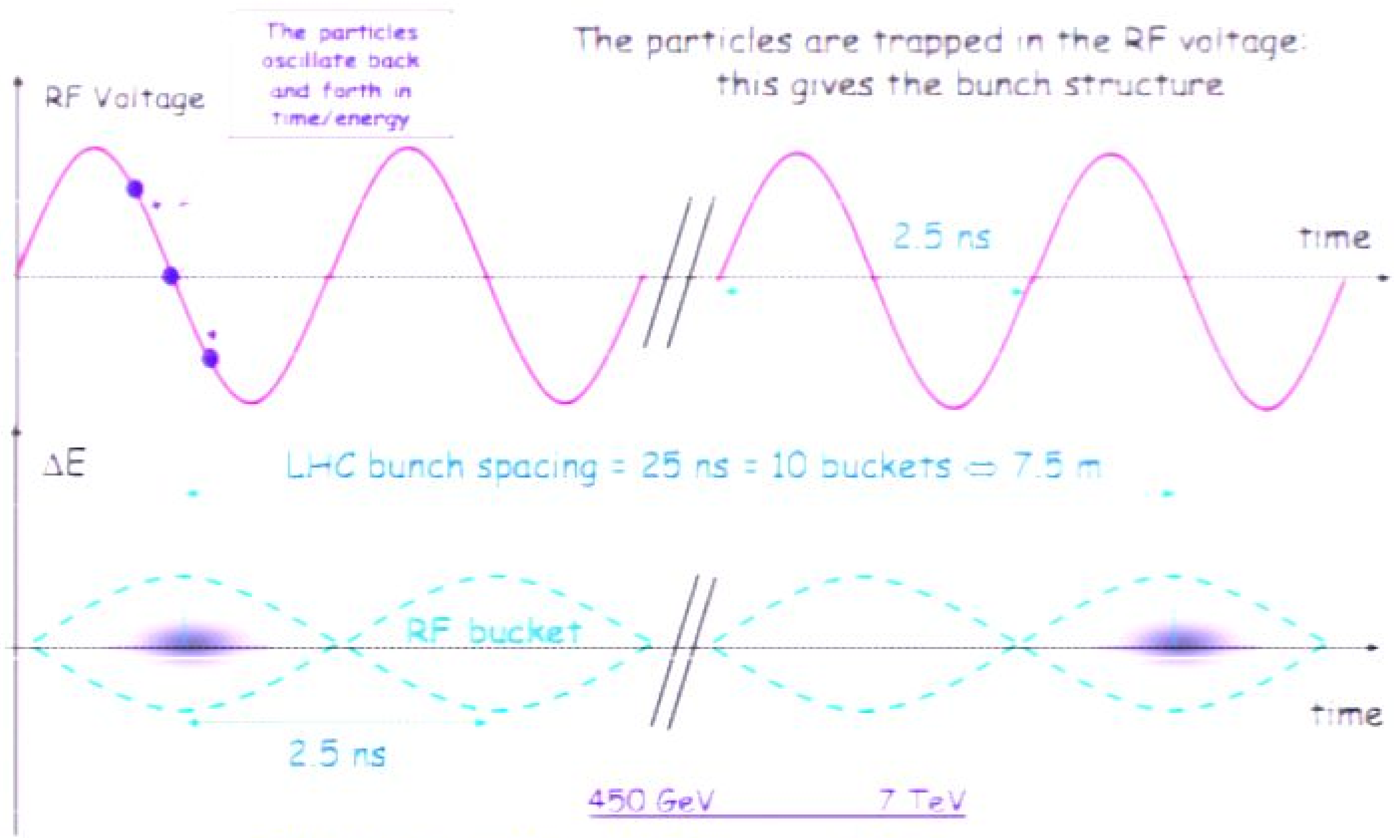
The beam

RF buckets and bunches

The particles are trapped in the RF voltage: this gives the bunch structure



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RMS bunch length	11.2 cm	7.6 cm
RMS energy spread	0.031%	0.011%

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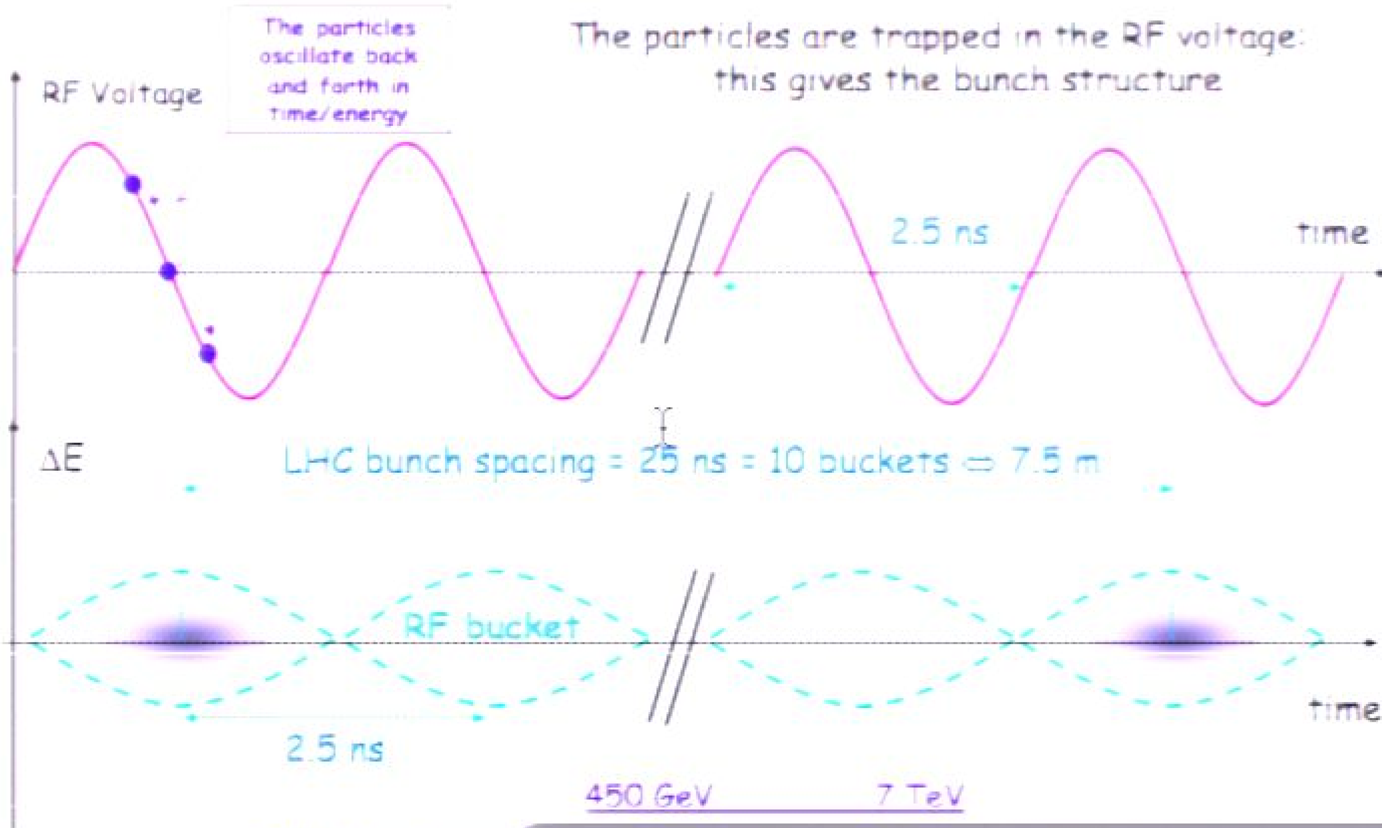

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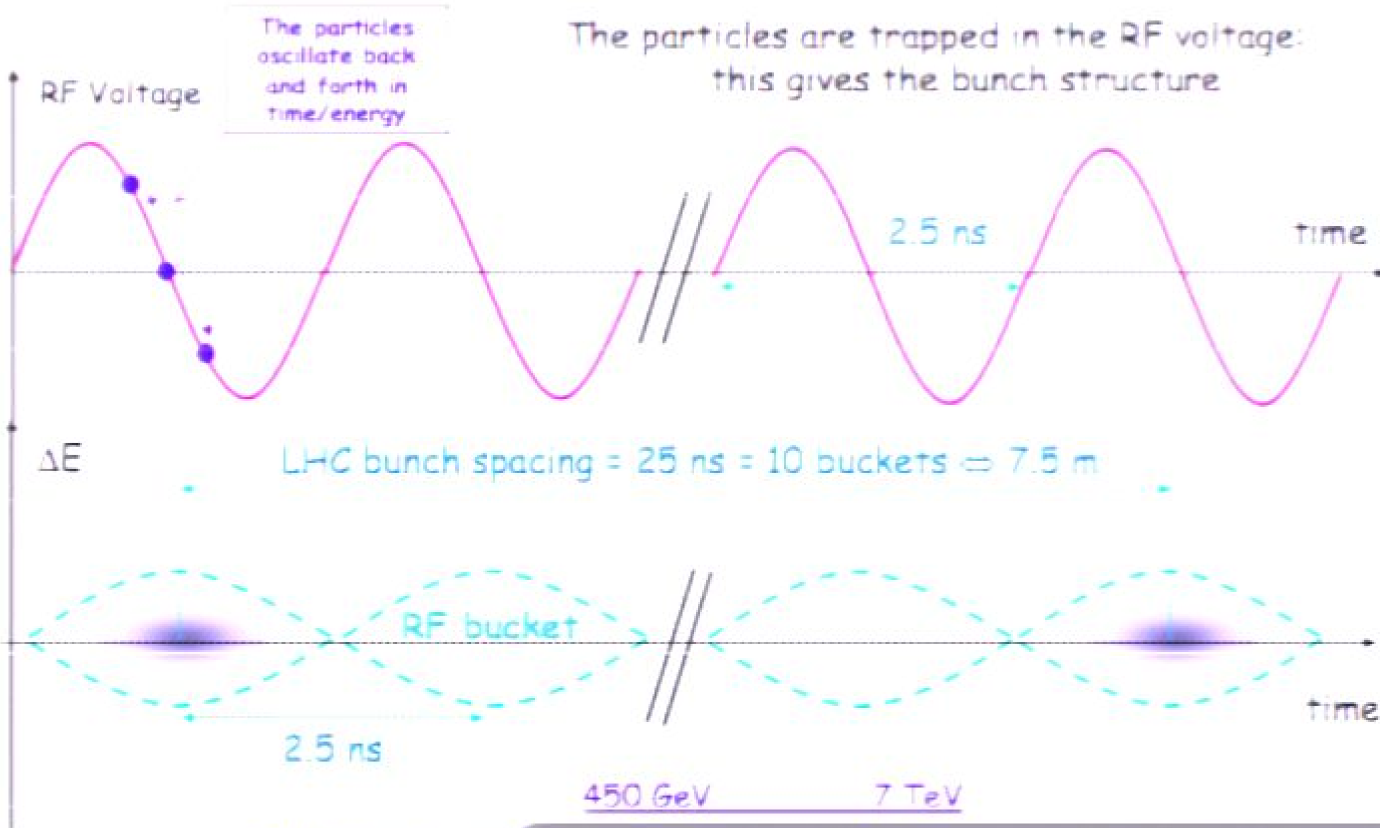

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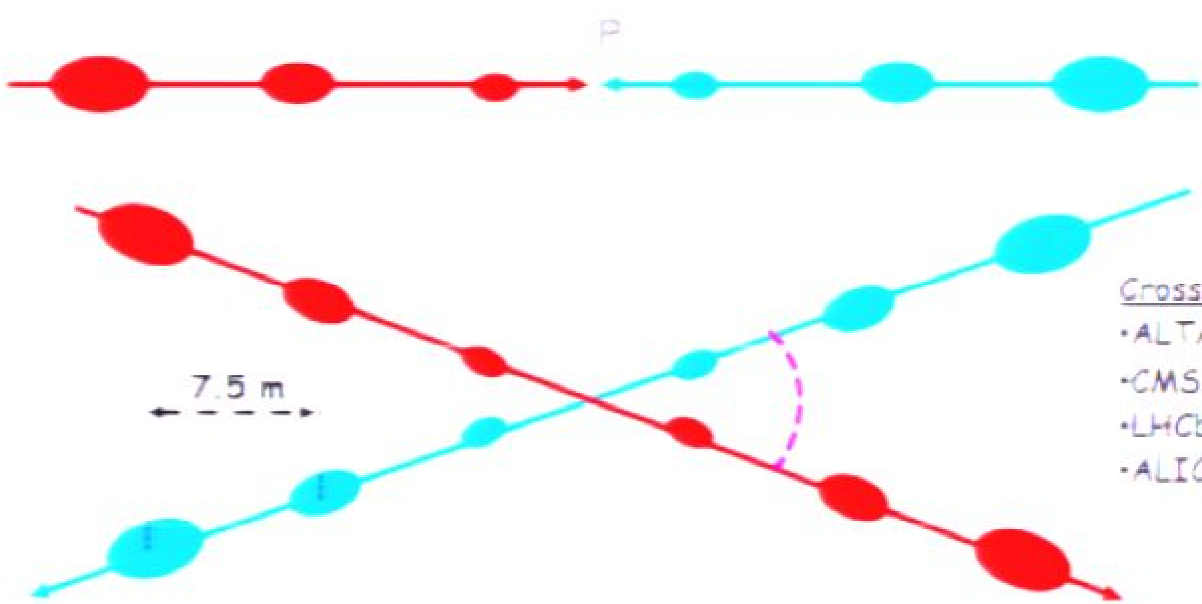
Every collision adds to the "beam-beam budget" we must avoid unnecessary direct beam encounters where the beams share a common vacuum (IPs) COLLIDE WITH A CROSSING ANGLE IN ONE PLANE:



Crossing planes & angles

•ALTAS	Vertical	280 µrad
•CMS	Horizontal	280 µrad
•LHCb	Horizontal	300 µrad
•ALICE	Vertical	400 µrad

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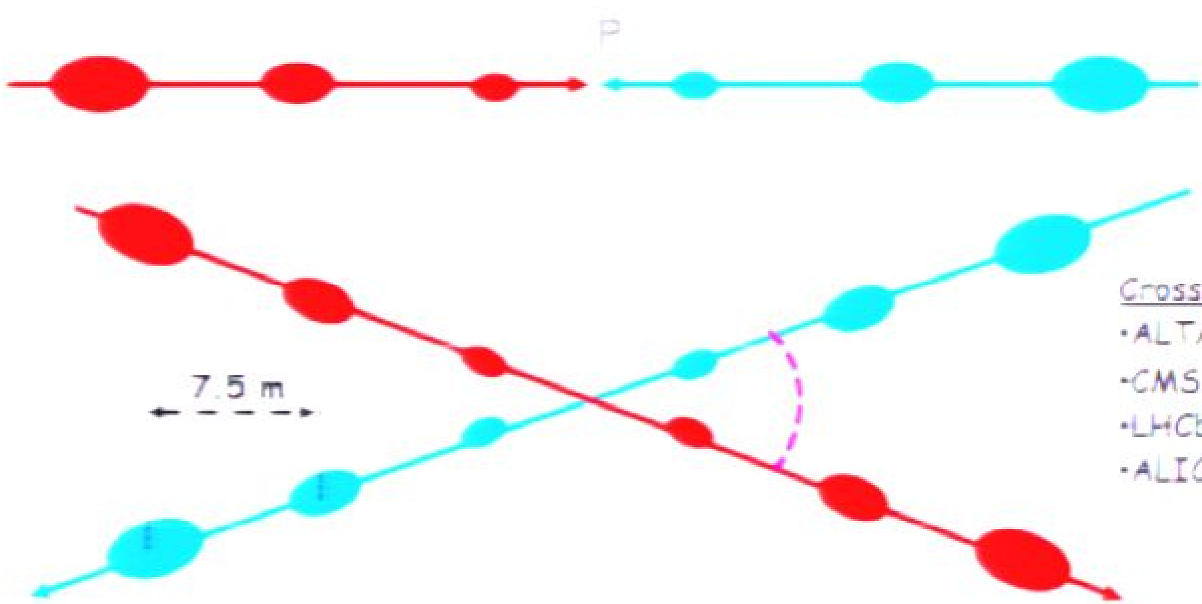

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RF acceleration

- The LHC RF system operates at 400 MHz
- It is composed of 16 superconducting cavities (@4.5 K), 8 per beam.
- Peak accelerating voltage of 16 MV/beam (*cf* 3600 MV/beam at LEP), accelerating field of 5MV/m.

	Synchrotron radiation loss
LHC @ 7 TeV	6.7 keV /turn
LEP @ 104 GeV	~3 GeV /turn

The LHC beam radiates a sufficient amount of visible photons to be actually observable with a camera ! (total power ~ 0.2 W/m)

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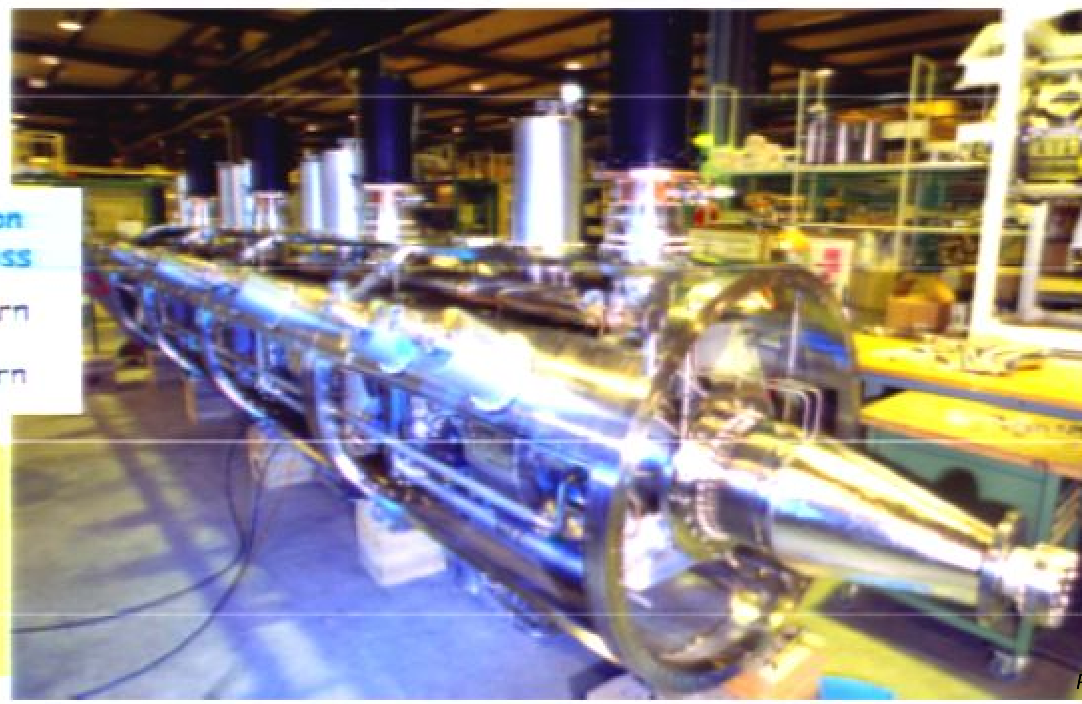
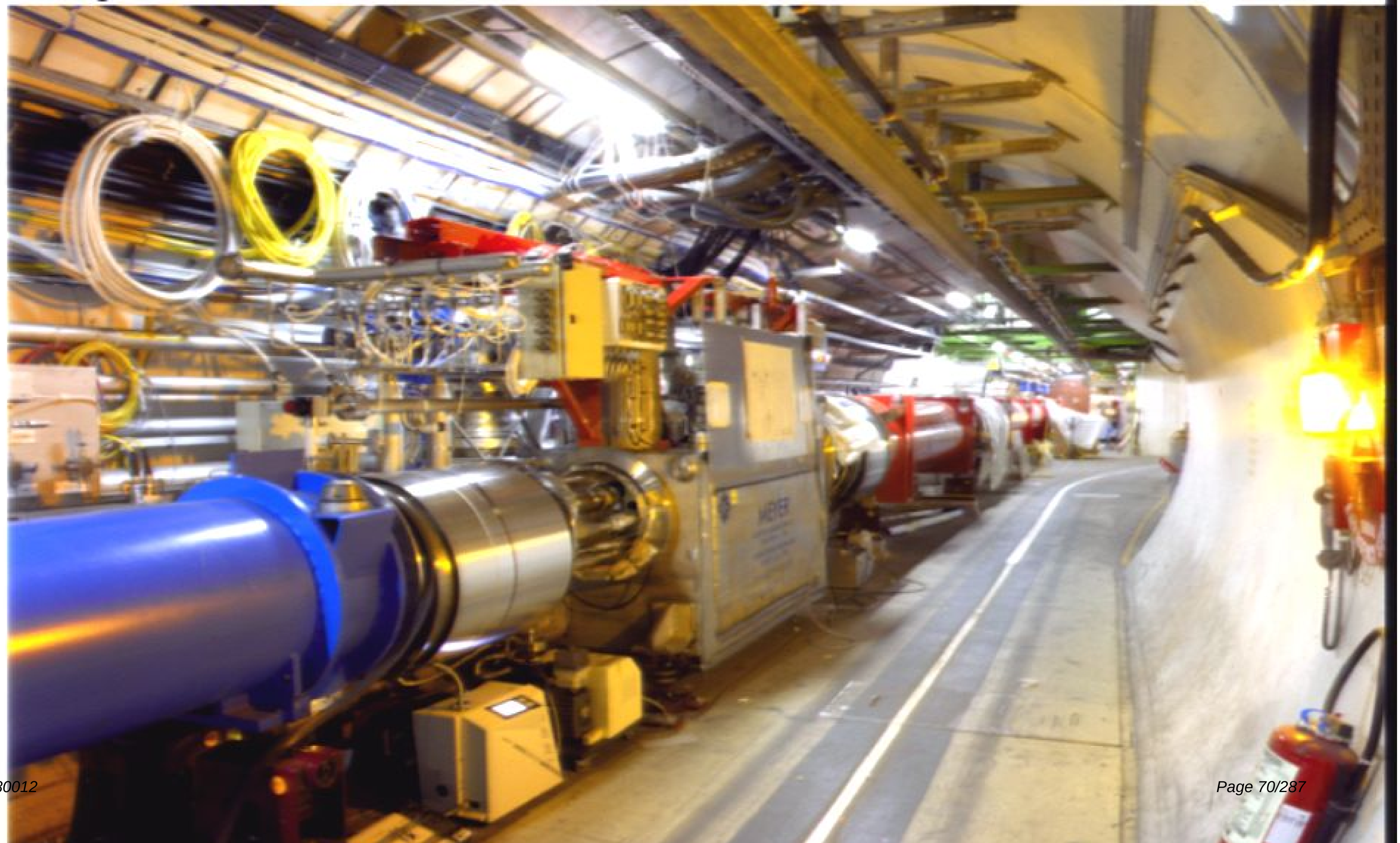
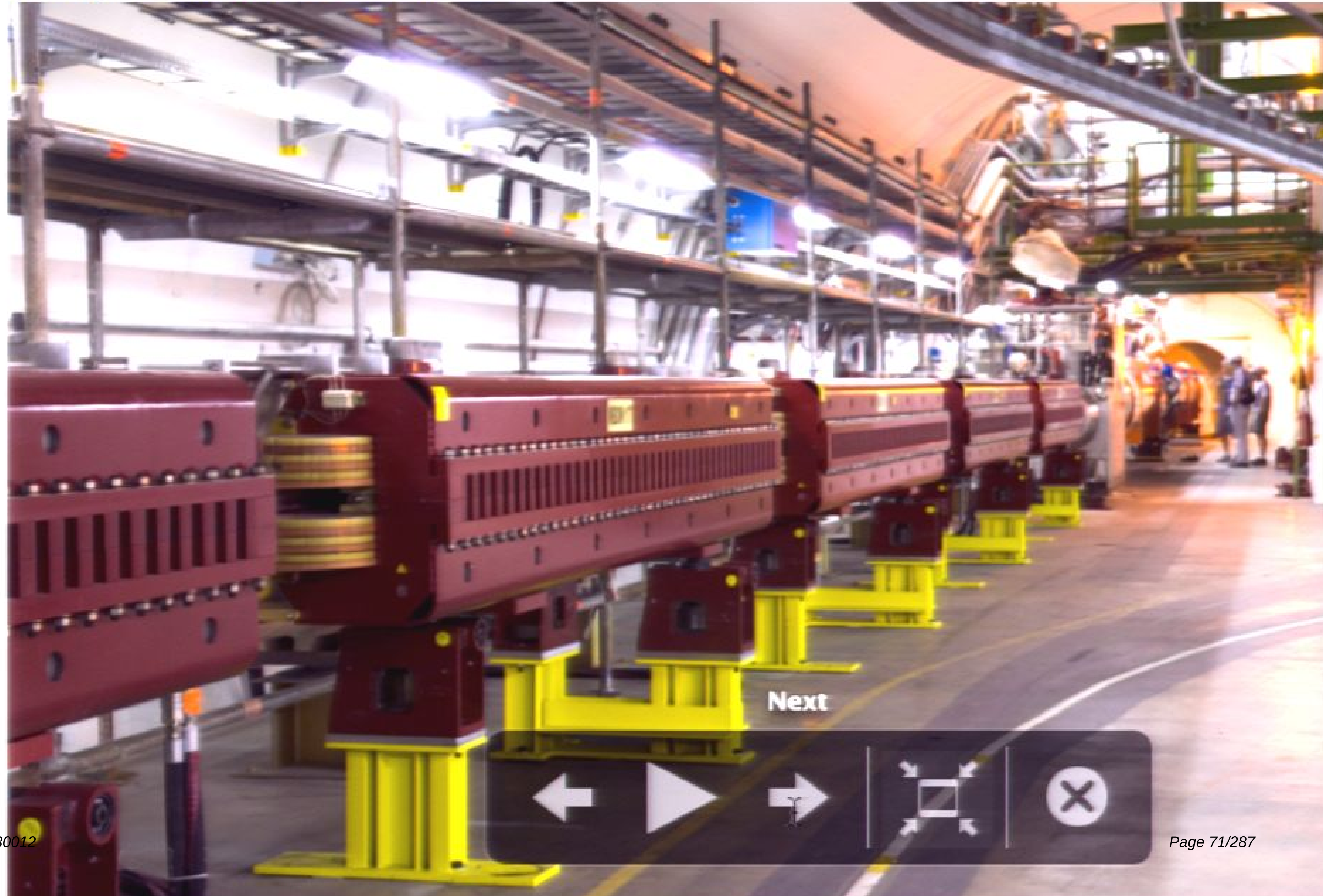


Tunnel Views

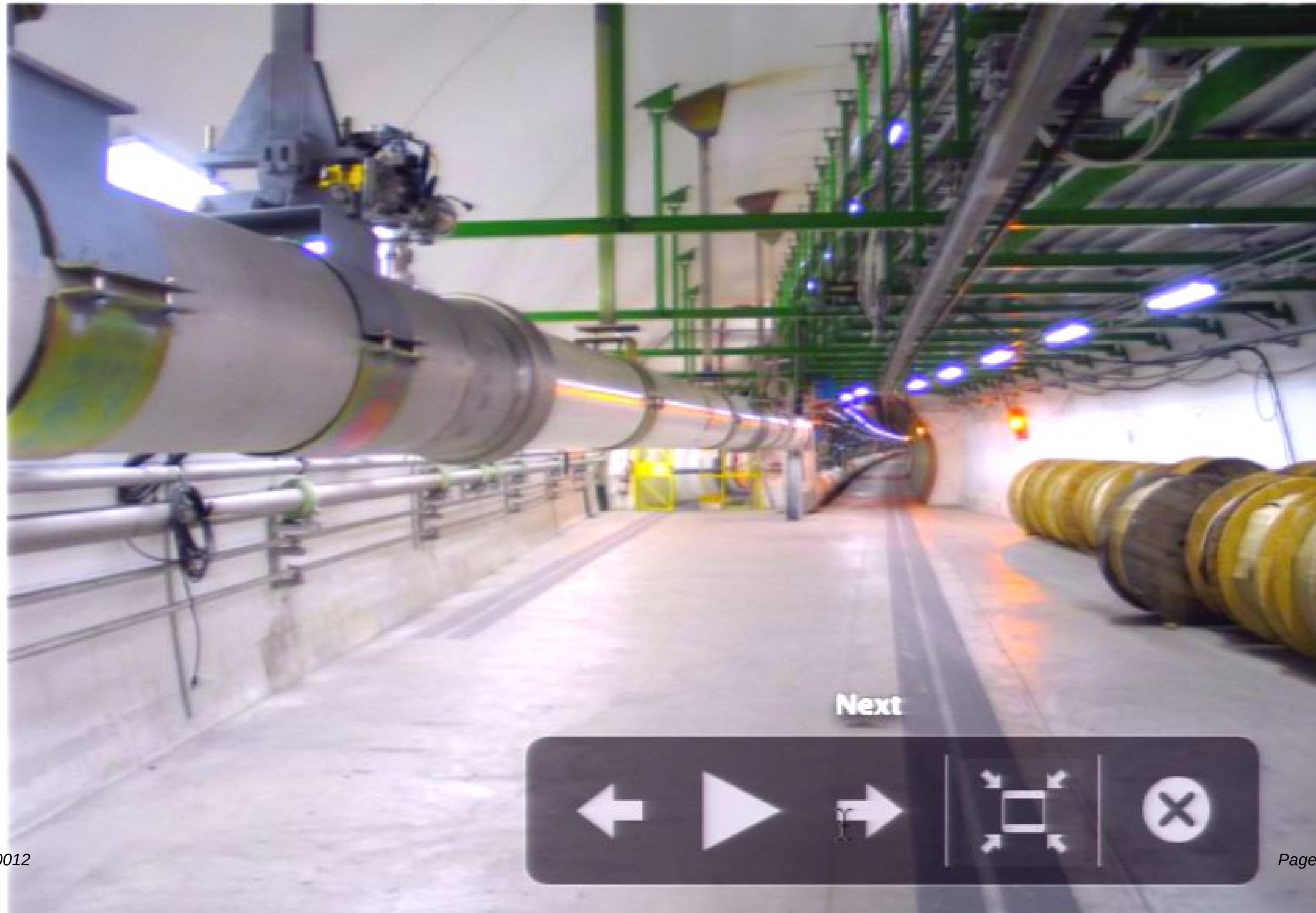
straight section IP8 LHCb



straight section IP1 ATLAS



Junction of TI8 and the LHC - note the QRL (cryogenic distribution line) going up to make way for injection line magnets



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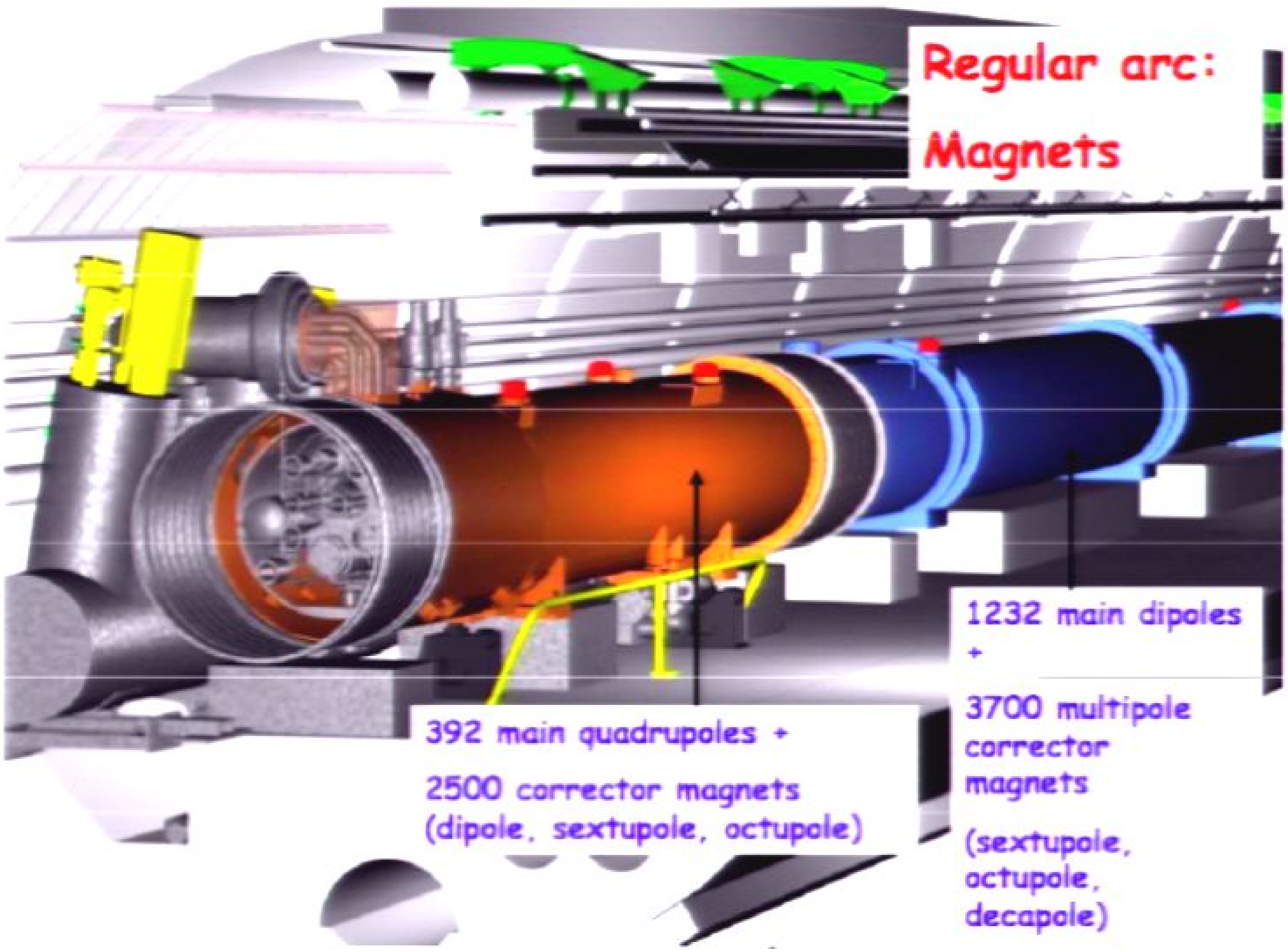
Tunnel Instrumentation



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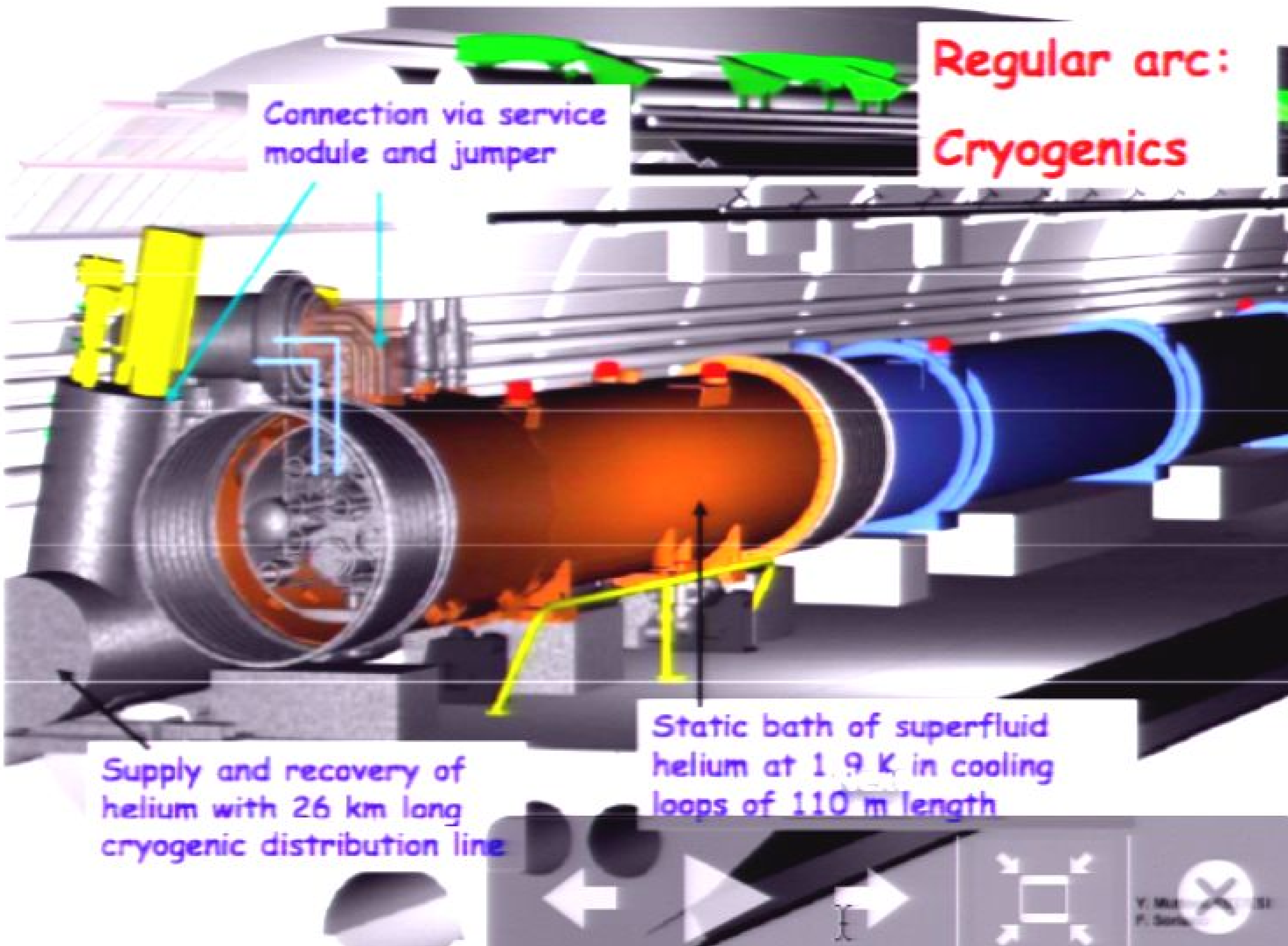

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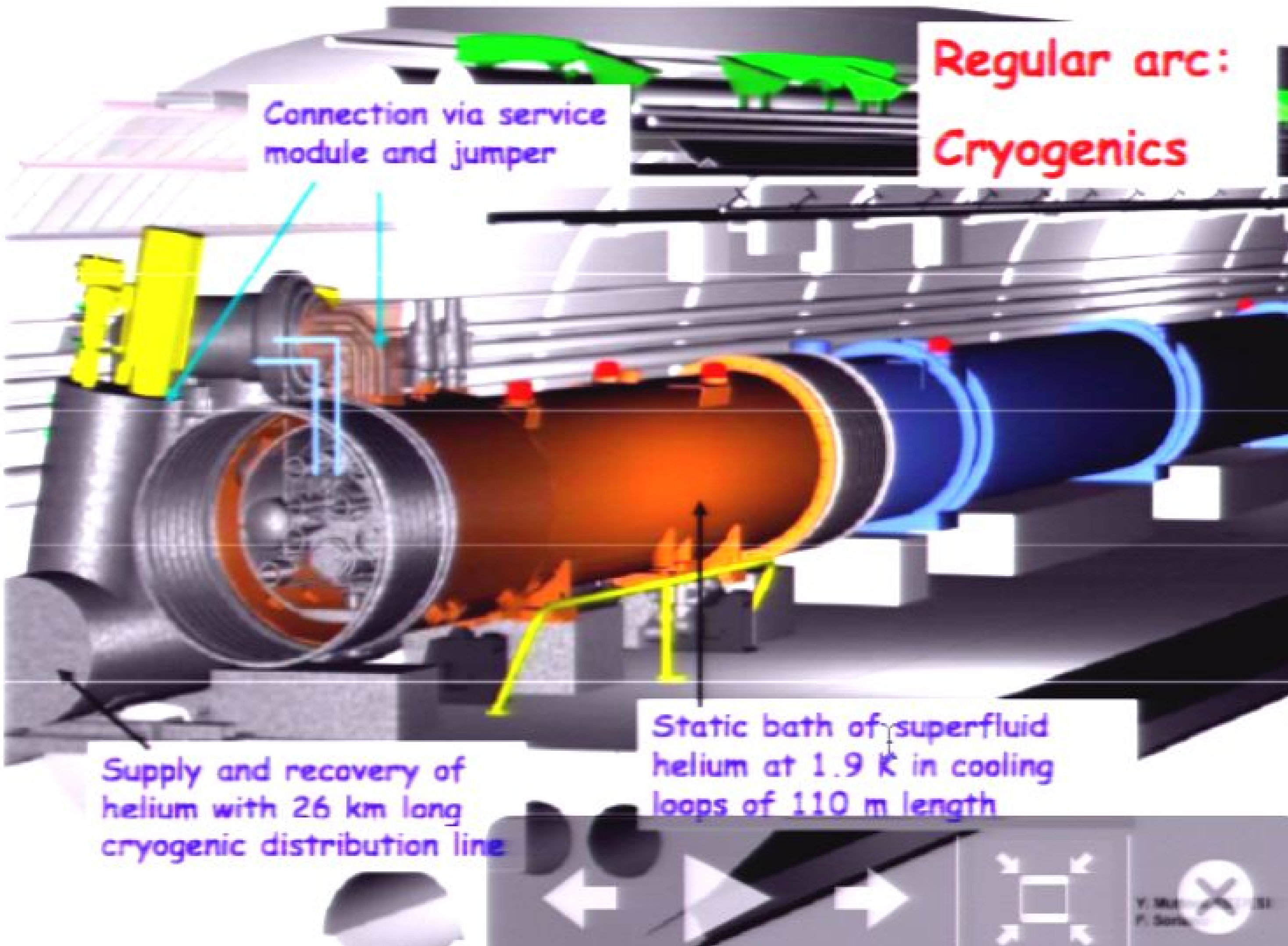

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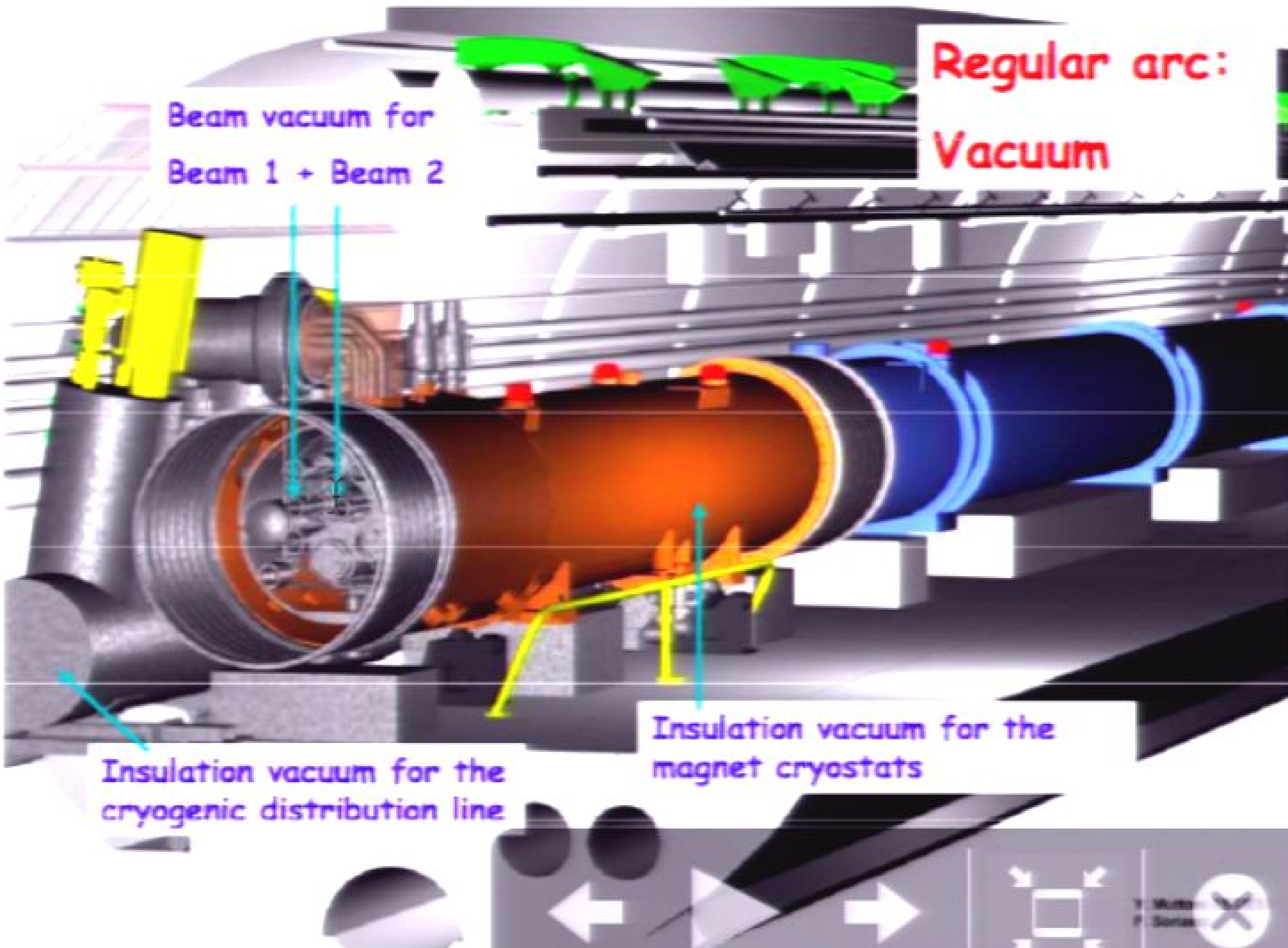
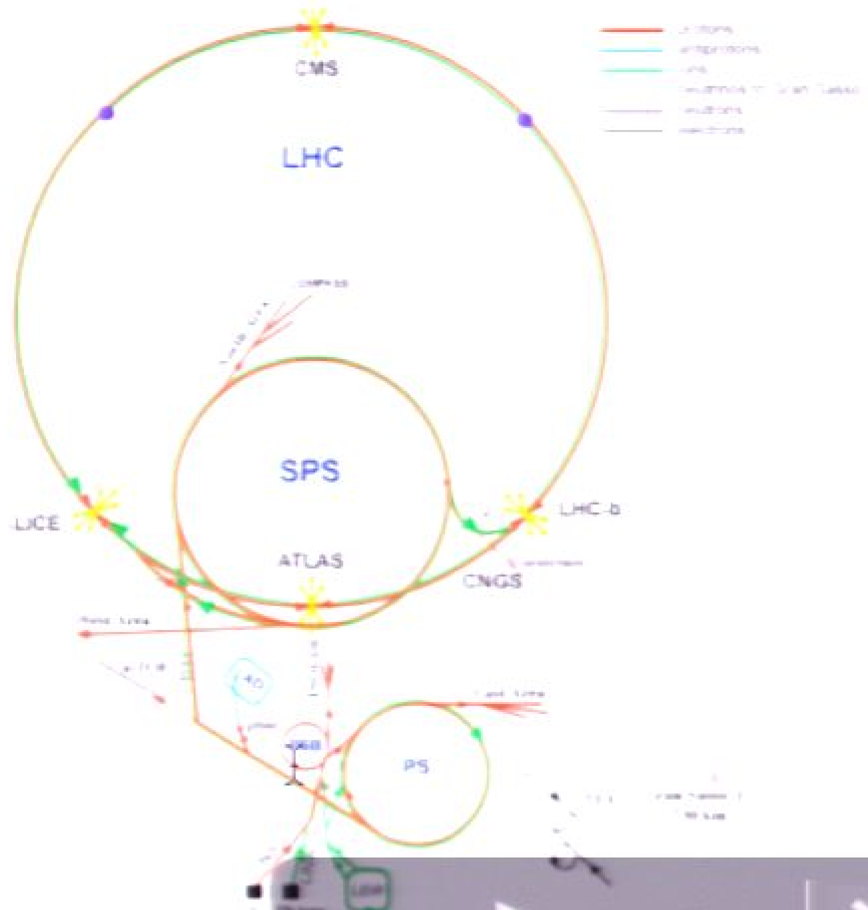


Accelerator Complex



Schedule

Lyn Evans
SPC 18-June-2007

General LHC Schedule

- Engineering run originally foreseen at end 2007 now precluded by delays in installation and equipment commissioning.
- 450 GeV operation now part of normal setting up procedure for beam commissioning to high-energy
- General schedule being reassessed, accounting for inner triplet repairs and their impact on sector commissioning
  - -- All technical systems commissioned to 7 TeV operation, and machine closed April 2008
  - -- Beam commissioning starts May 2008
  - -- First collisions at 14 TeV c.m. July 2008
  - -- Pilot run pushed to 156 bunches for reaching 10^{32} cm^{-2} s^{-1} by end 2008
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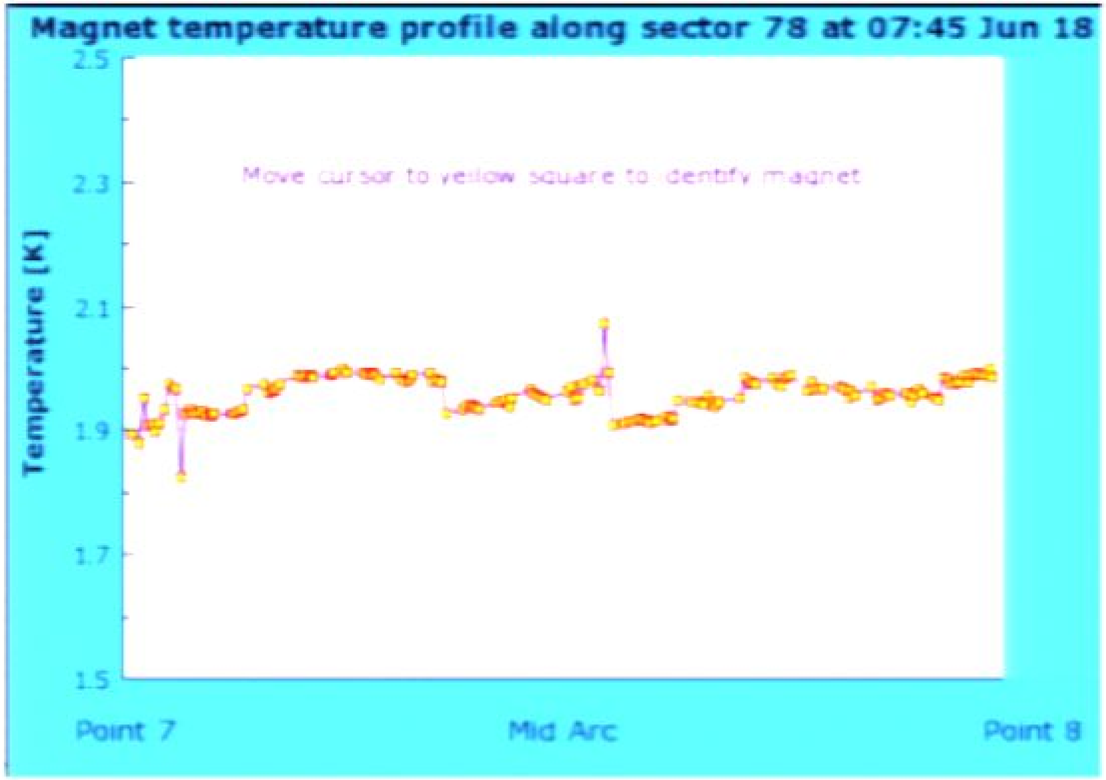

1 sector=3.3 Km, 154 dipoles. The first sector was cooled-down in Feb 07.

Timely cool-down of all sectors determines the schedule.

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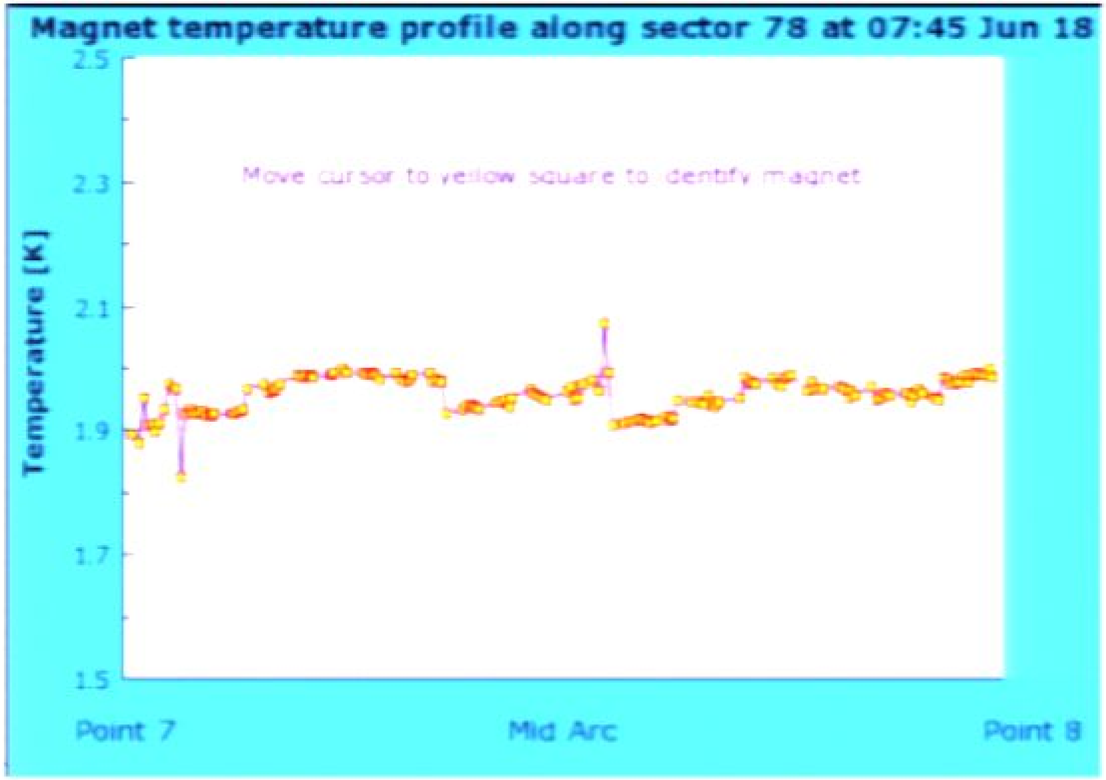

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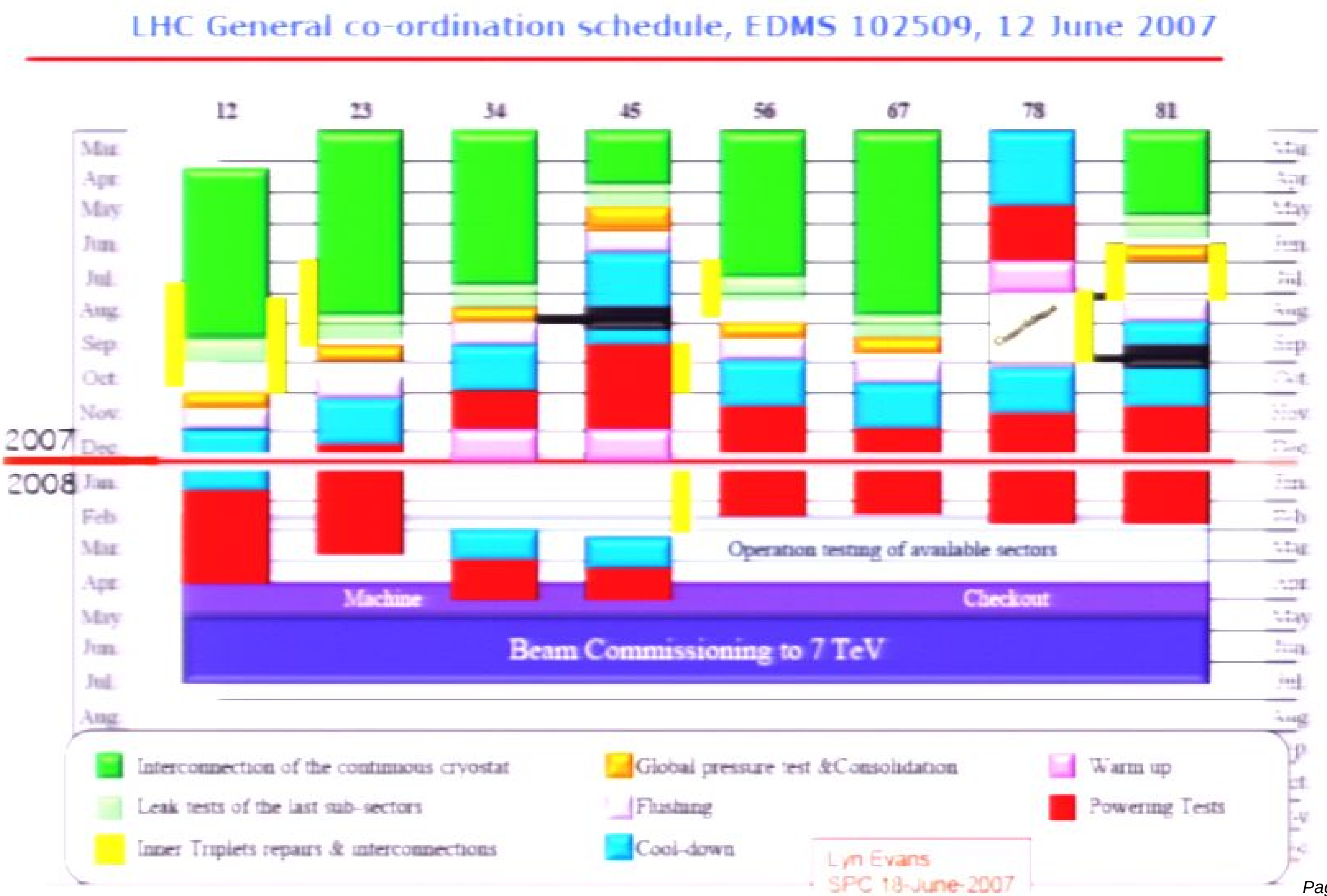
LHC General co-ordination schedule, EDMS 102509, 12 June 2007
12
23
34
45
56
67
78
81
2007
2008
Operation testing of available sectors
Machine
Checkout
Beam Commissioning to 7 TeV
Interconnection of the continuous cryostat
Leak tests of the last sub-sectors
Inner Triplets repairs & interconnections
Global pressure test &Consolidation
Flushing
Cool-down
Warm up
Powering Tests
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Commissioning stages

The steps toward the design luminosity:

- number of bunches and bunch intensity
- crossing angle
- less focusing at the collision point (larger β^*)

Parameter	Phase A	Phase B	Phase C	Nominal
k / no. bunches	43-156	936	2808	2808
Bunch spacing (ns)	2021-566	75	25	25
N (10^{11} protons)	0.4-0.9	0.4-0.9	0.5	1.15
Crossing angle (μrad)	0	250	280	280
$\sqrt{(\beta^*/\beta^*_{nom})}$	2	$\sqrt{2}$	1	1
σ^* (μm, IR1&5)	32	22	16	16
L ($cm^{-2}s^{-1}$)	$6\times10^{30}-10^{32}$	10[illegible]-10^{33}	$(1-2)\times10^{33}$	10^{34}

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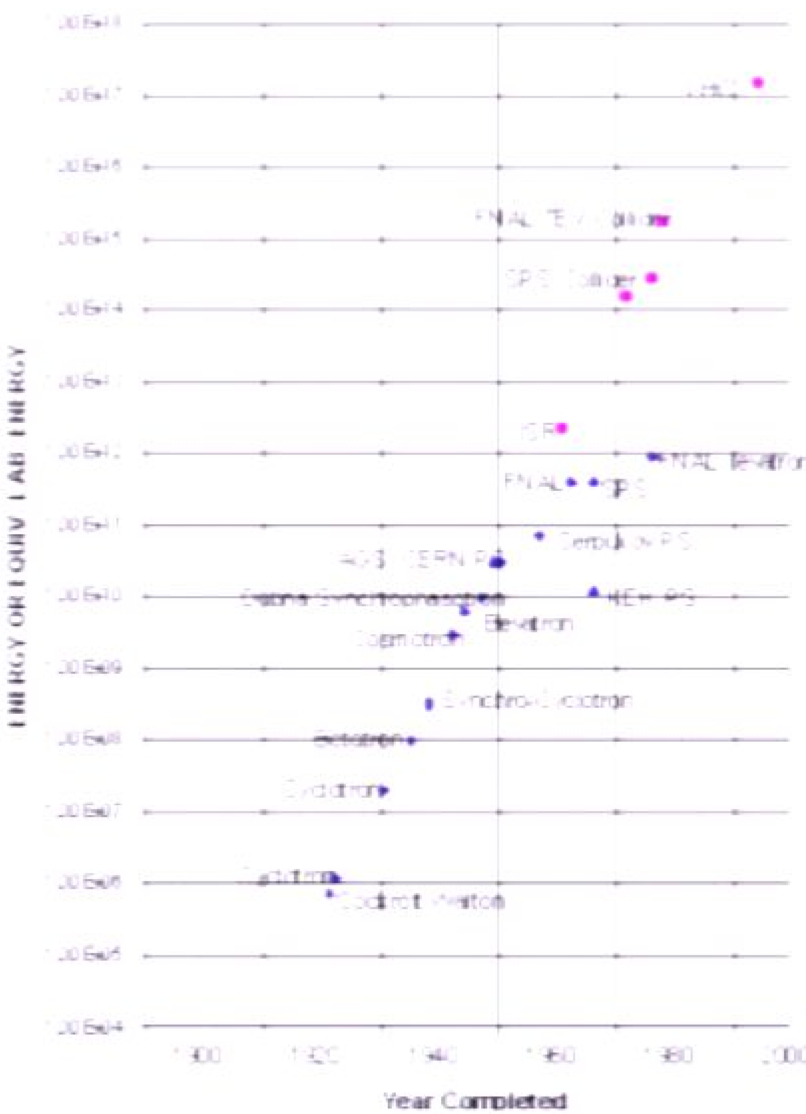

The Luminosity

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total inelastic [non-diffractive] cross section 60 millibarns. [1 barn=10^{-24} cm^2]

- long range inelastic strong interactions modelled by meson exchange as in the original Yukawa theory [back of the envelope calculation, $\sigma = \pi \mathrm{range}^2$] will give this answer as well!

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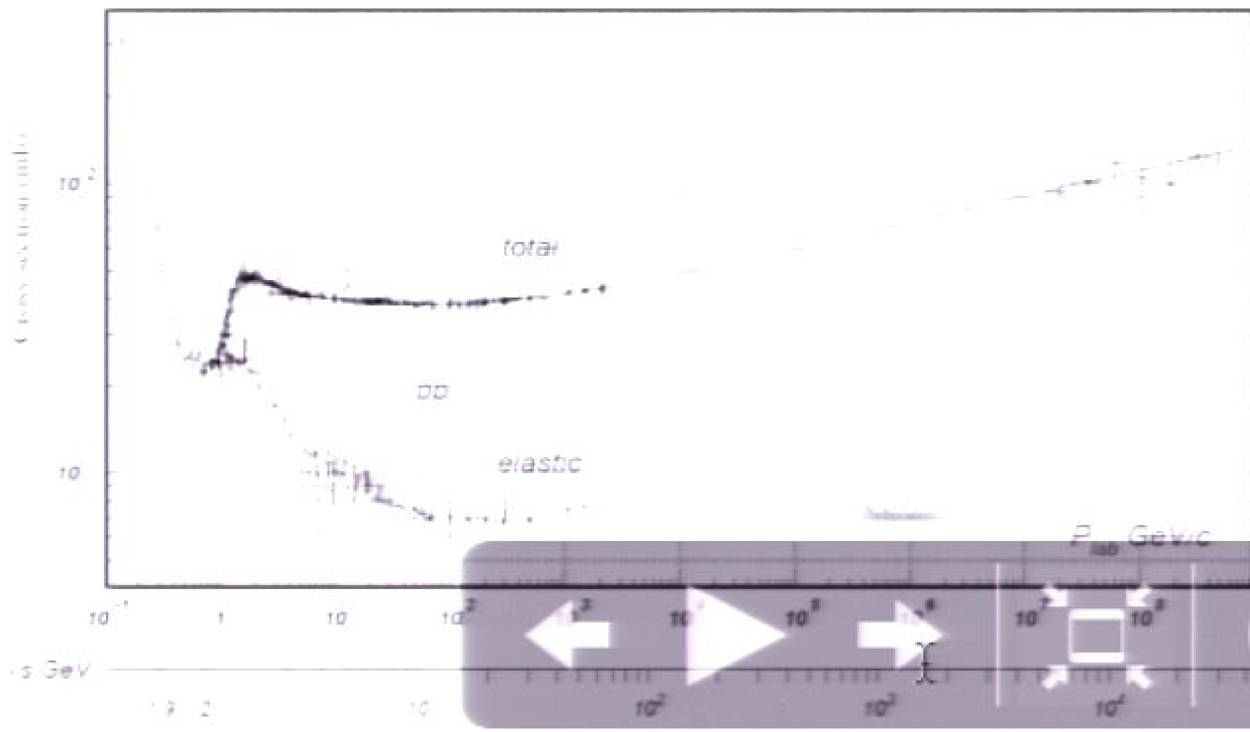

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The rate that the 2808 proton bunches "cross" eachother at each interaction region = 2808 c/27000$\sim 3 \times 10^7$ Hz

• each bunch crossing produces >20 proton-proton scatterings! • bunch crossings every 25 ns; in 25 ns light travels 7.5m, much less than the size of the detectors! No electronic system can read the data from the entire detector and decide to do anything with it before the next event comes about! Readout is intergated over many bunch crossings!

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integrated luminosity

$\int \mathcal{L} dt = L$; units cm^{-2} or fb^{-1}. One year is about $\pi \times 10^7$s. One "collider running year" [or Snowmass year] is $1/\pi$ this. So the integrated luminosity over a year at the LHC is $10^{41}\mathrm{cm}^{-2} \longrightarrow$ 100 fb^{1}. Compare with the total integrated luminosity of the Tevatron after 10 years of running which is 2 fb^{-1}!

- Caveat: Design luminosity at the LHC is a subject matter of 2010
- Experiments are preparing for the first 2008 1 fb^{-1}

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the harvest [example]

process	cross section in fb
pair of 500 GeV jets	10,000
SUSY with 1 TeV superpartners	3,000
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10-15 PB/year

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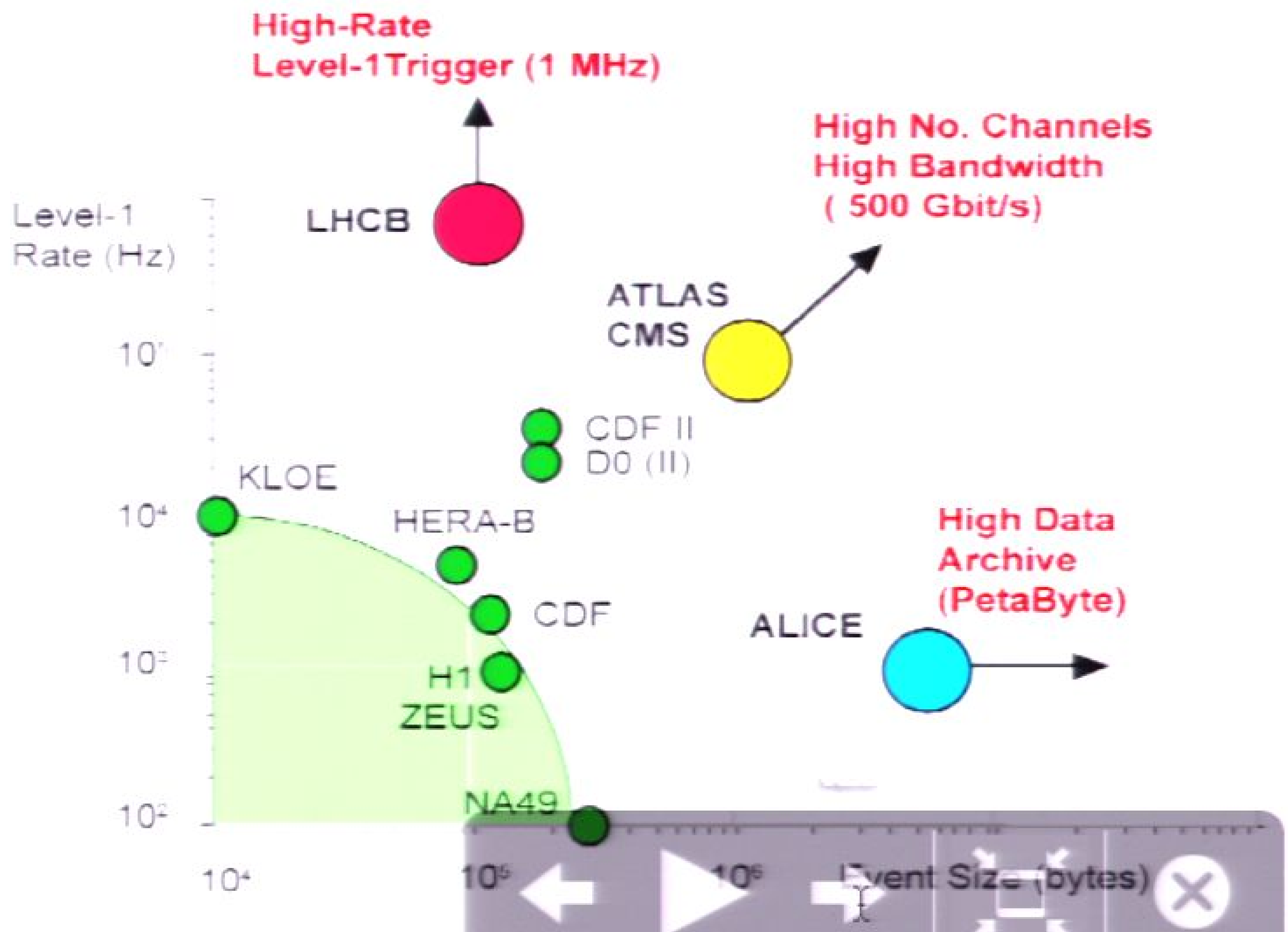
A lot of data


High-Rate
Level-1Trigger (1 MHz)
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(500 Gbit/s)
Level-1
Rate (Hz)
LHCB
ATLAS
CMS
CDF II
D0 (II)
KLOE
HERA-B
CDF
H1
ZEUS
NA49
High Data
Archive
(PetaByte)
ALICE
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10⁵
10⁶
Event Size (bytes)

The Answer is the Trigger/DAQ Architecture

- The triggers pipeline the data coming out of the detector subsystems (to buy a little time), then decide quickly which events are sufficiently interesting to pass along to the next layer of filtering.
- There are enough layers of triggers to reduce the original 40 MHz event rate down to 100-200 Hz of interesting events, which are then permanently "written to tape" for later analysis (analysis "offline")
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- The triggers pipeline the data coming out of the detector subsystems (to buy a little time), then decide quickly which events are sufficiently interesting to pass along to the next layer of filtering.
- There are enough layers of triggers to reduce the original 40 MHz event rate down to 100-200 Hz of interesting events, which are then permanently "written to tape" for later analysis (analysis "offline")
- a good trigger is a fast trigger that keeps all the interesting events and is reprogrammable to respond to detector understanding and possible change of the physics targets

Nota Bene

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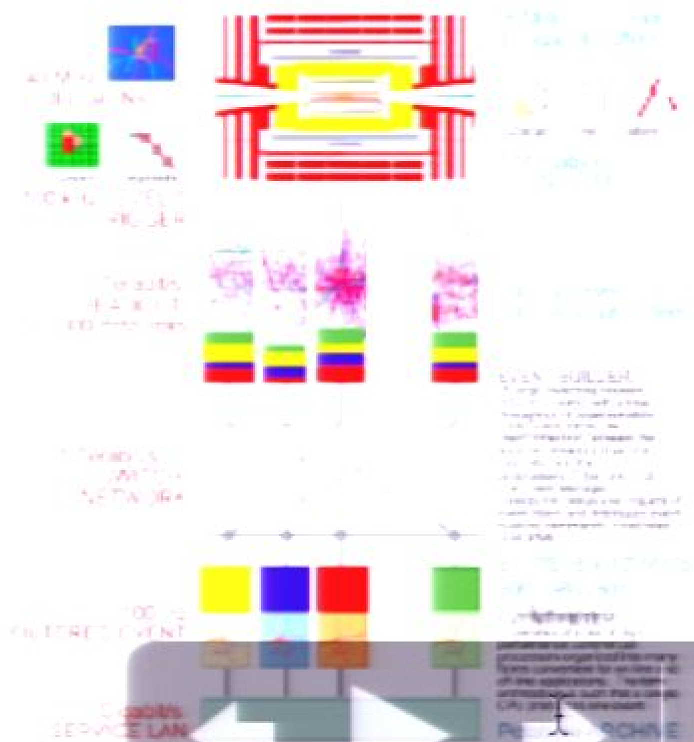
Example

The Answer is the Trigger/DAQ Architecture

CMS Triggers and DAQ



Example

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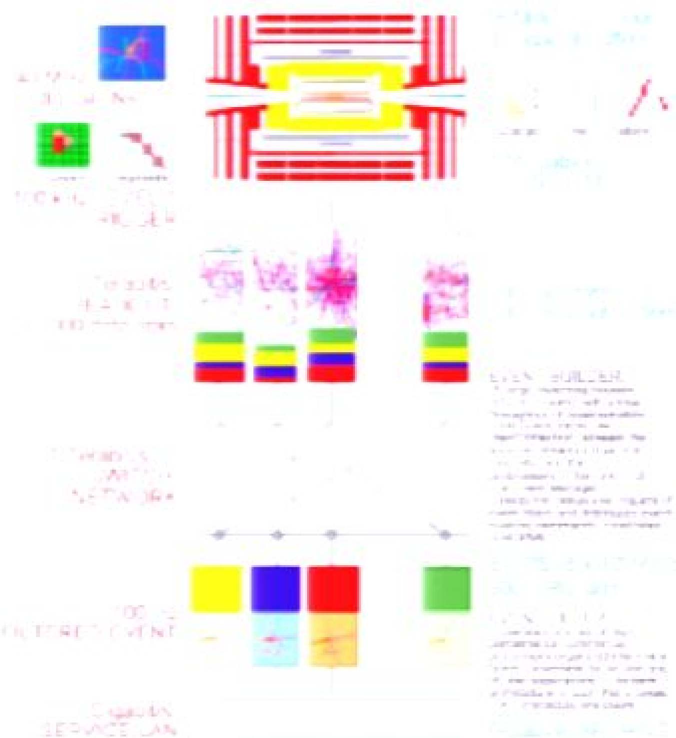

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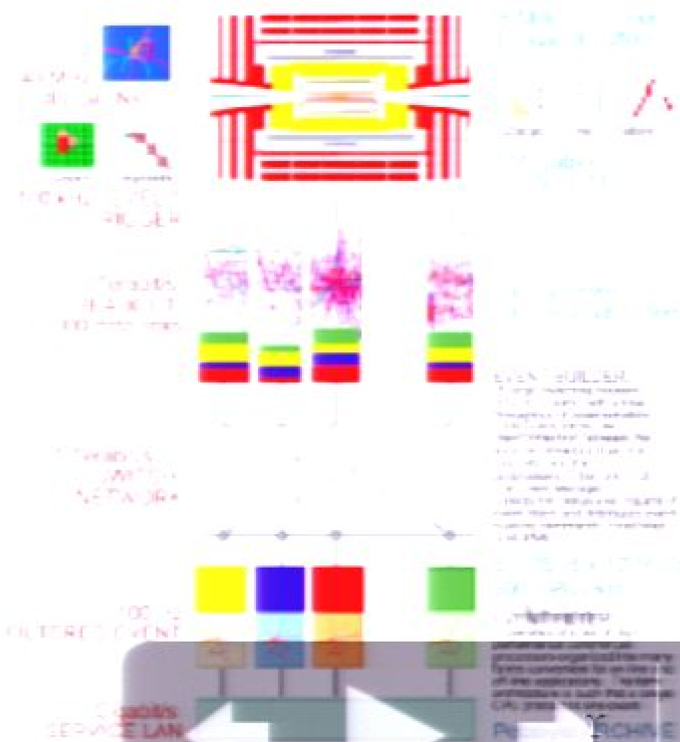

And the Grid

- The vast ammount of data cannot be stored at any one single place
- the Grid architecture with the distributed analysis model is a huge global enterprise.
- The data from the LHC experiments will be distributed around the globe, according to a four -tiered model. A primary backup will be recorded on tape at CERN, the "Tier-0" centre of LCG. After initial processing, this data will be distributed to a series of "Tier-1" centres, large computer centres with sufficient storage capacity for a large fraction of the data, and with round-the-clock support for the Grid.
- The "Tier-1" centres will make data available to Tier-2 centres, each consisting of one or several collaborating computing facilities. Individual scientists will access these facilities through "Tier-3" computing resources, which can consist of local clusters in a University Department or even individual PCs, and which may be allocated to LCG on a regular basis.

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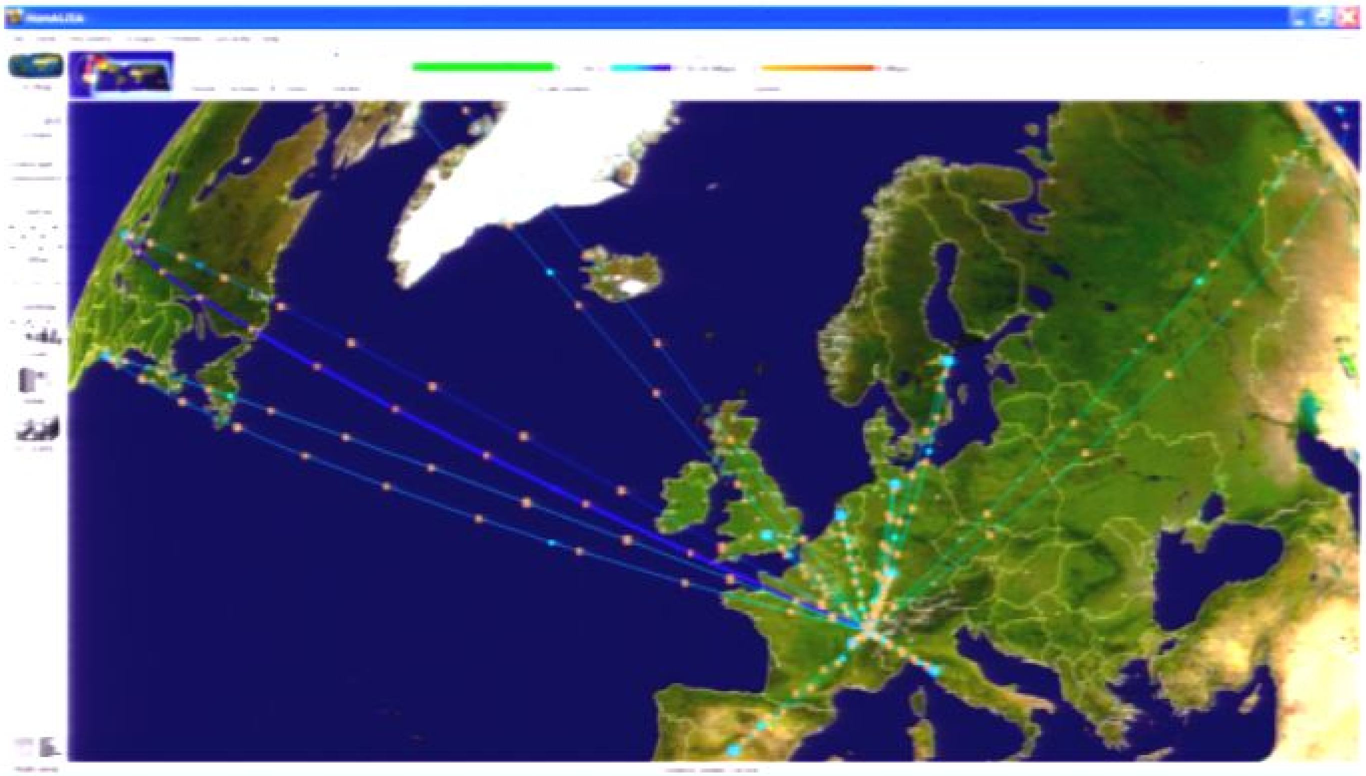
The GRID



- monitoring >40,000 computers, 120 computing centers, 40 countries.

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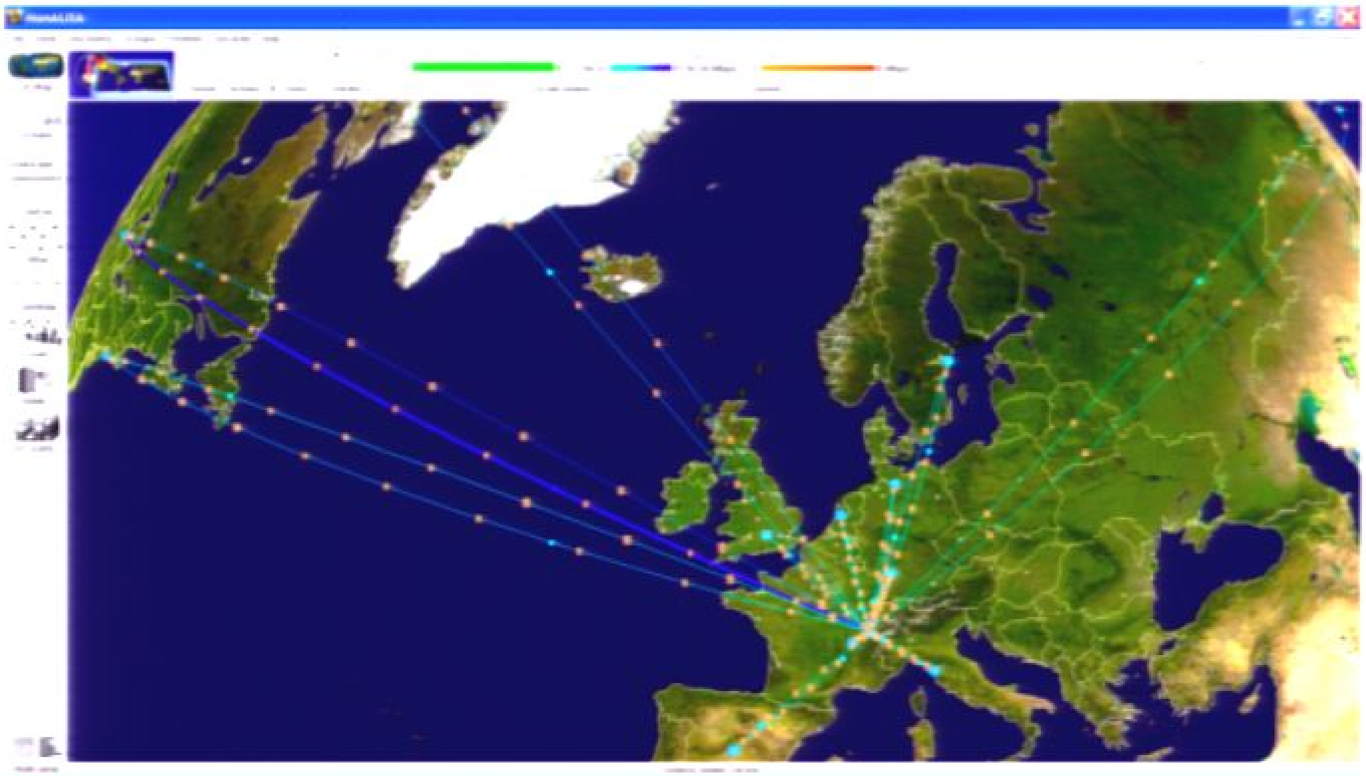

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A lot of data: Impact on Detector Design

- The large luminosity of the LHC is required such that we get a chance to capture the data from smaller than the standard model cross section processes.
- Even before we go the two general puprose detectors, we can see the impact on the detector design:
  - The detector subsystems must have fast repsonse [20-50 ns] → very challenging readout electronics
  - The segmentation should be fine to minimize the chance of overalap of say a photon from the Higgs event with a photon from a min-bias event from a neighboring bunch crossing → very large number of readout channels and high cost
  - the detectors must be highly resistent to lethal radiation dose →special materials, tight quality control

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Impact on event content

- We saw that each recorded "event" consists of >20 different 14 TeV collisions
- most of them have large impact parameter and produce relatively low momentum particles in the final state; we call them "minimum bias" collisions and they involve nonperturbative QCD → to understand them we have to model them from the actual LHC data!
- although min-bias are "soft" at the LHC a typical event will contain more than 1 TeV of "soft" energy from min-bias collisions (*cf* the most energetic hard scattering was a 1.36 TeV collision at the Tevatron)
- we refer to as "pile-up" the integrated min-bias interactions over many bunch crossings

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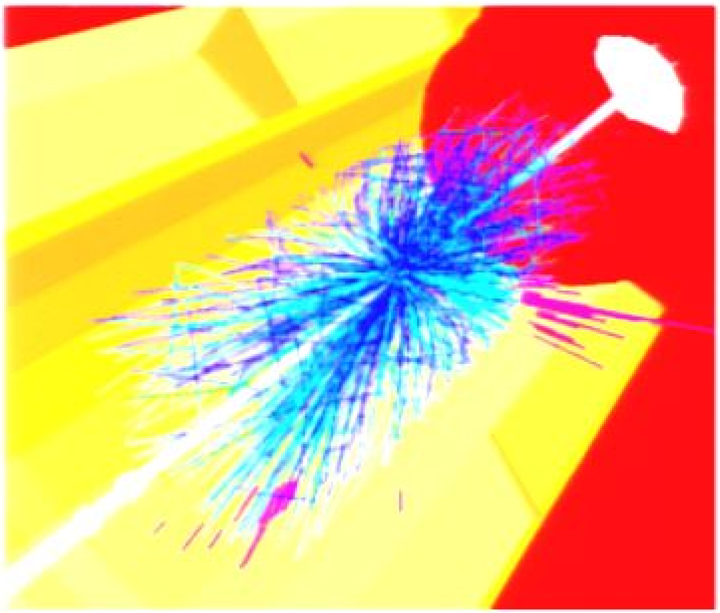
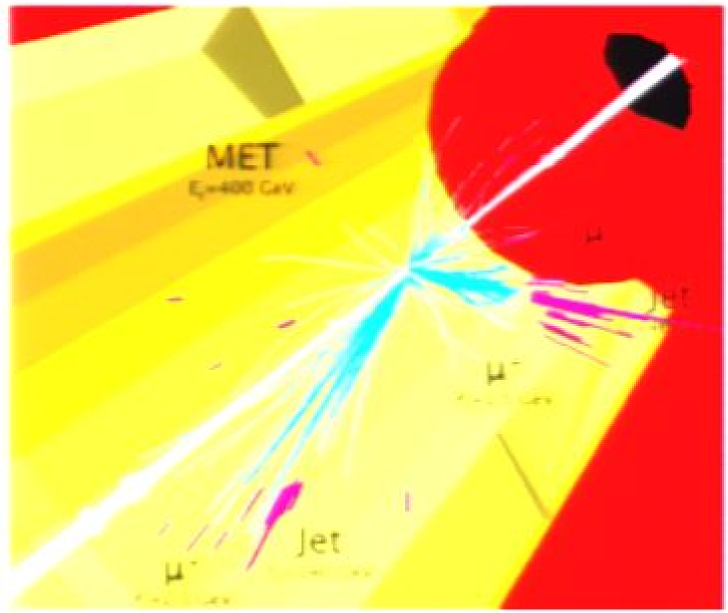
Visual Impression





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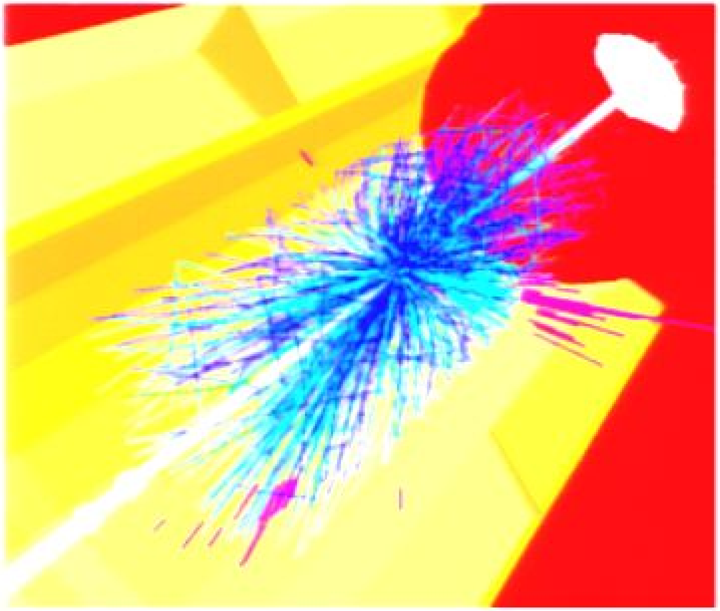

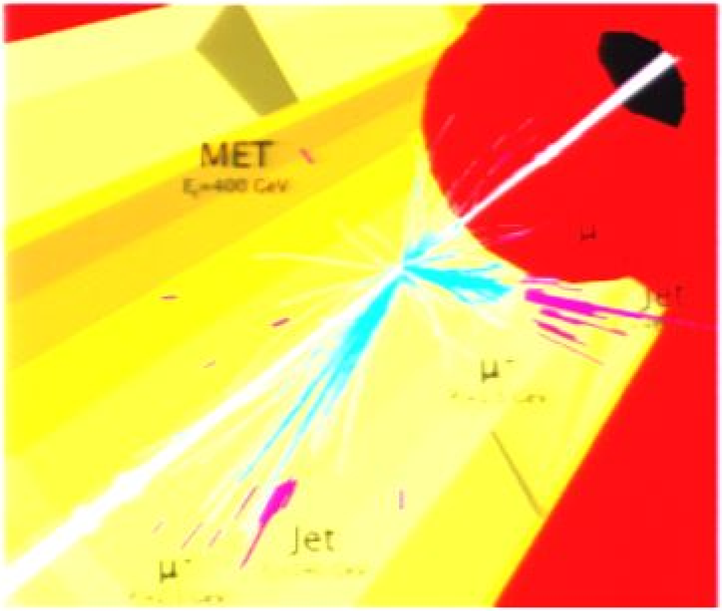

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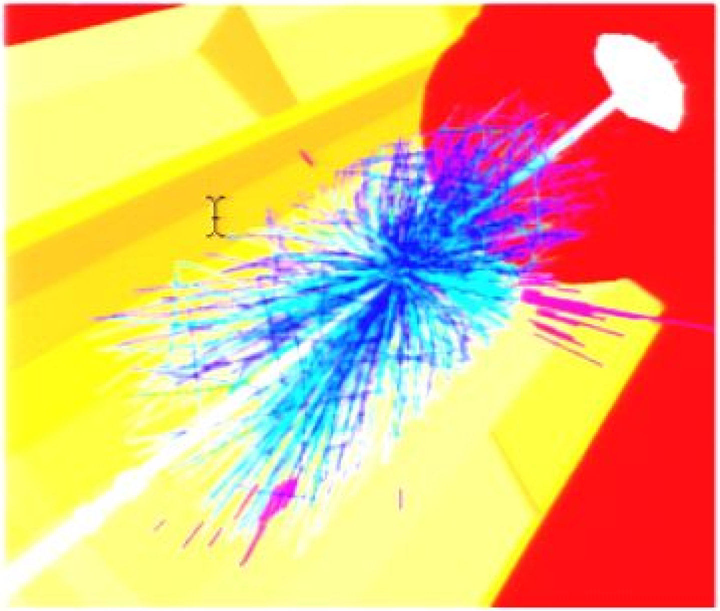

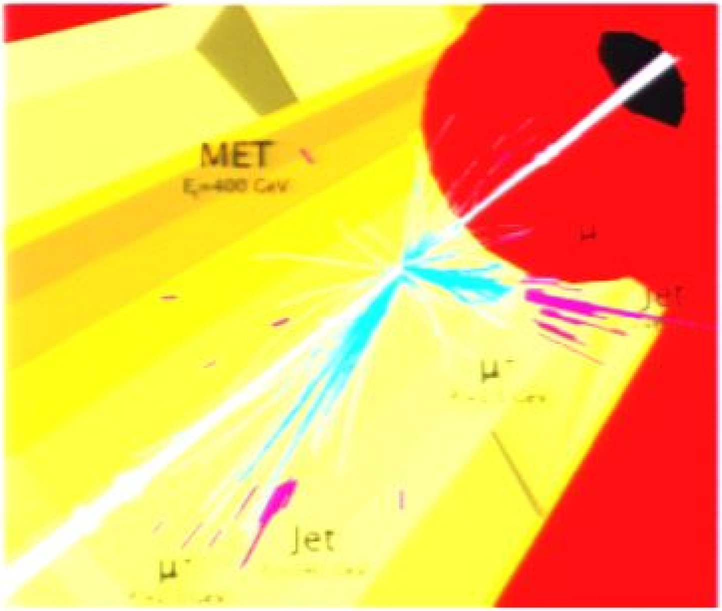

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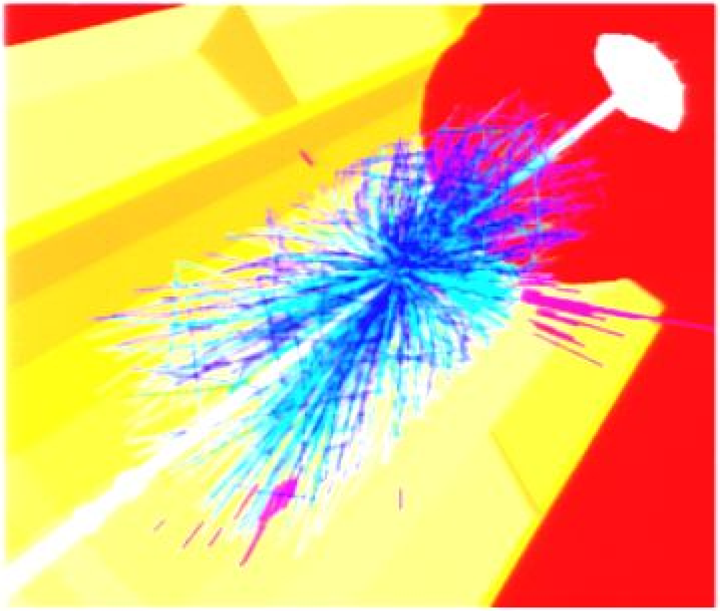
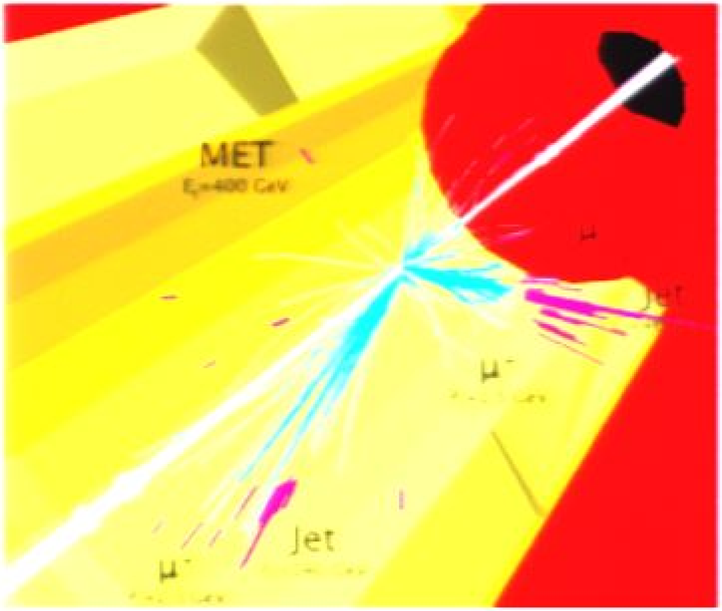

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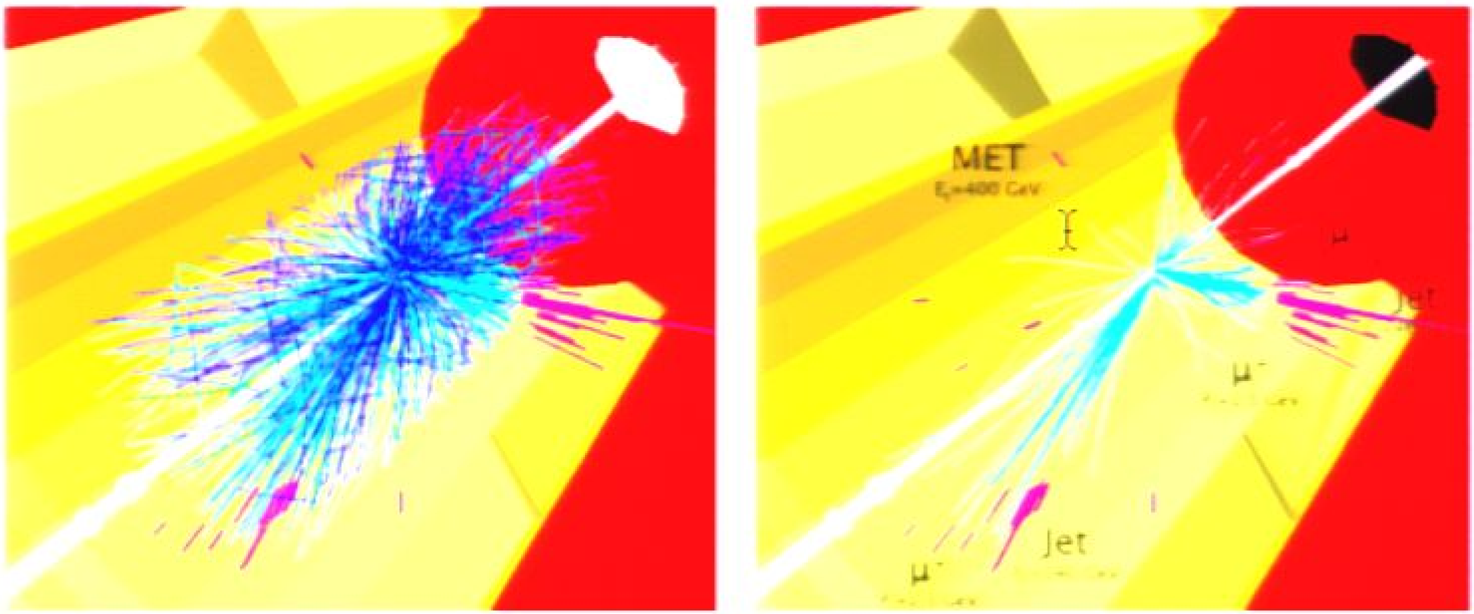

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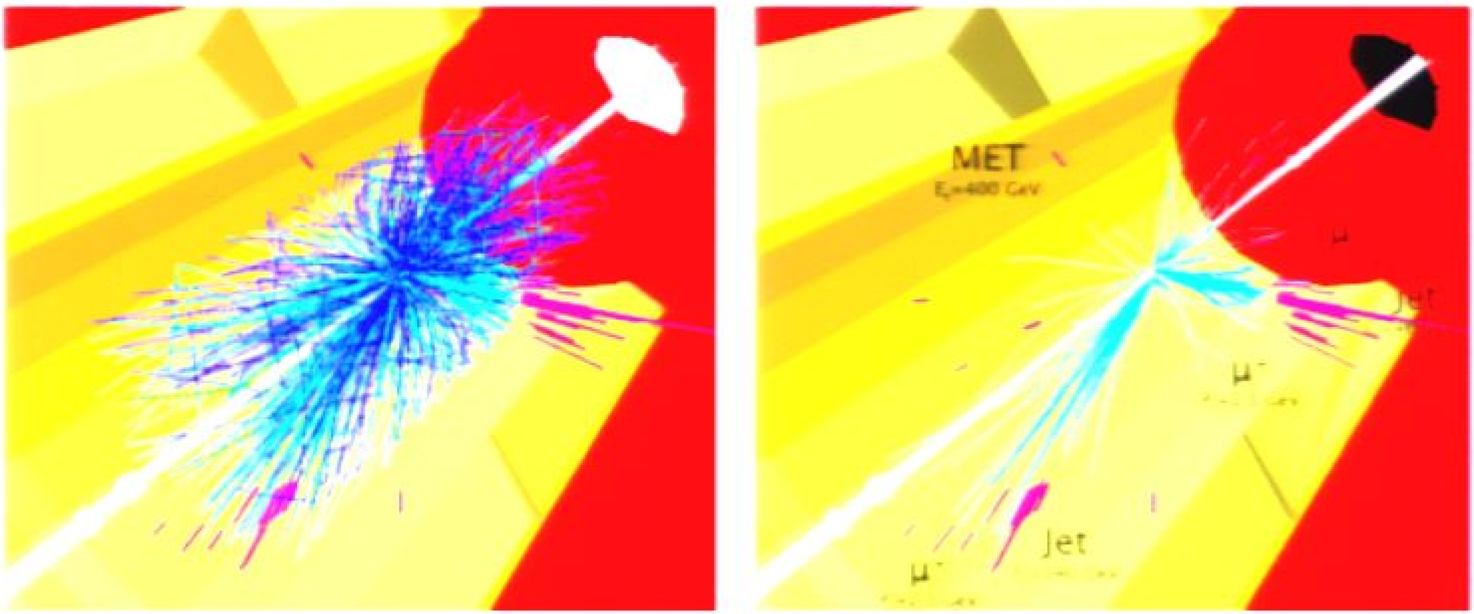

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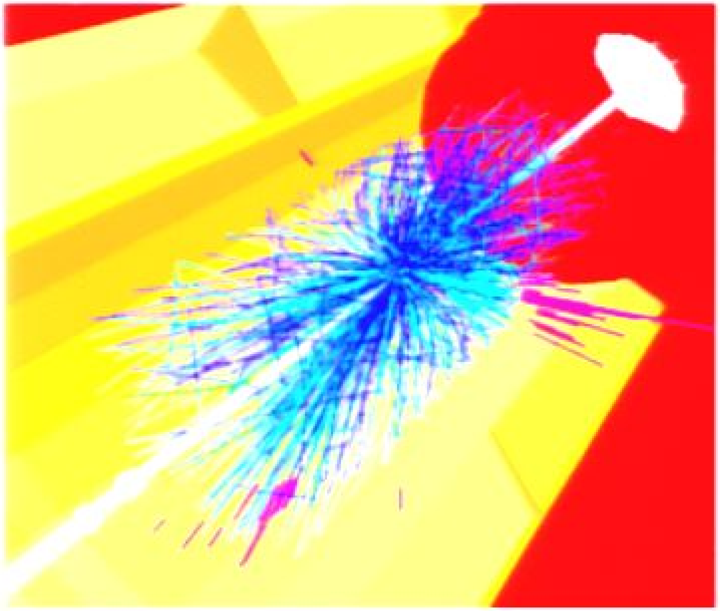

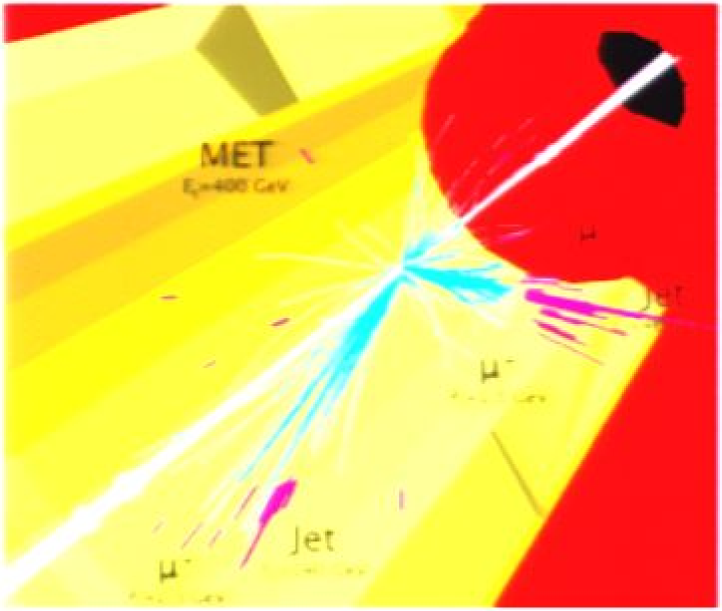

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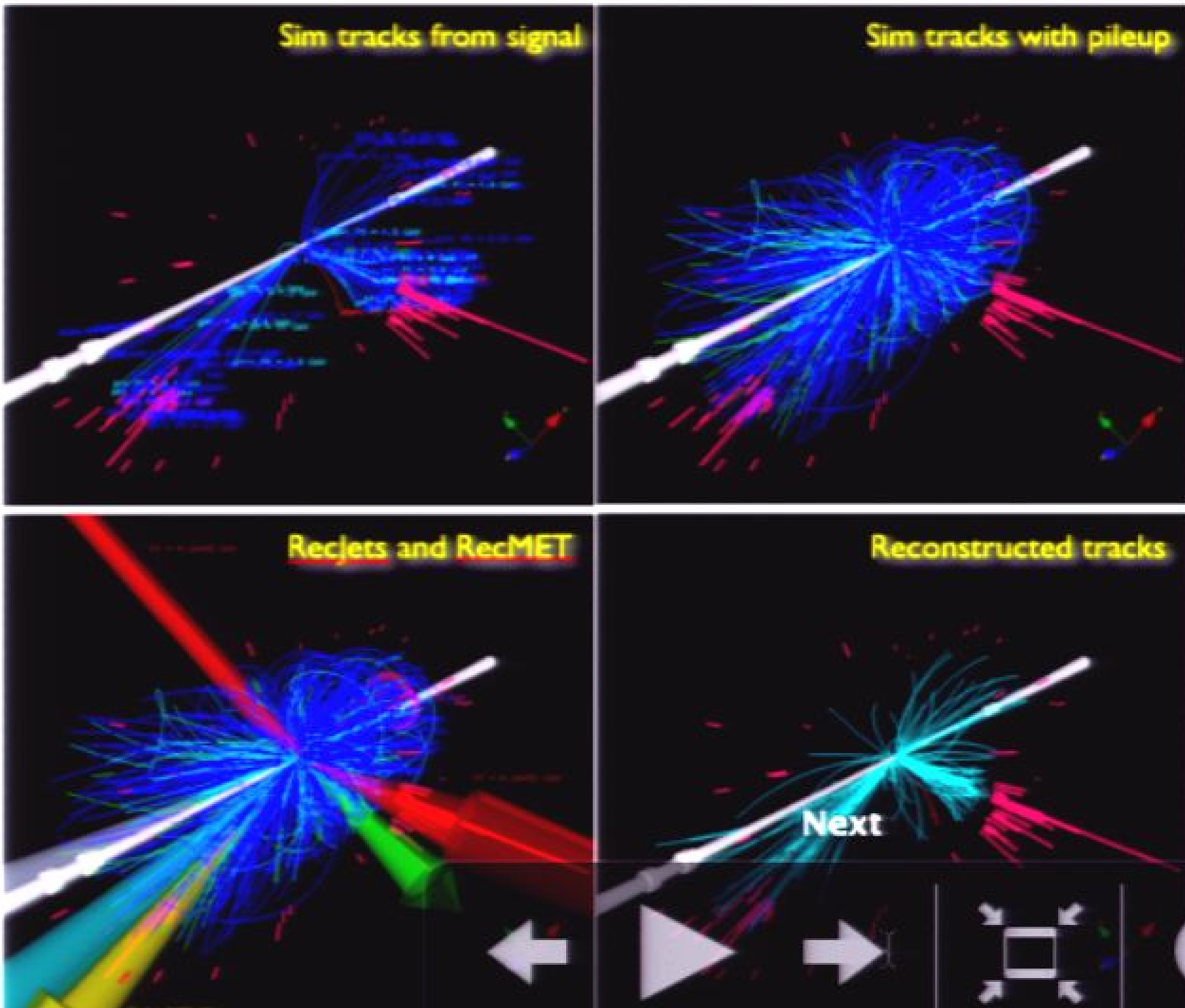

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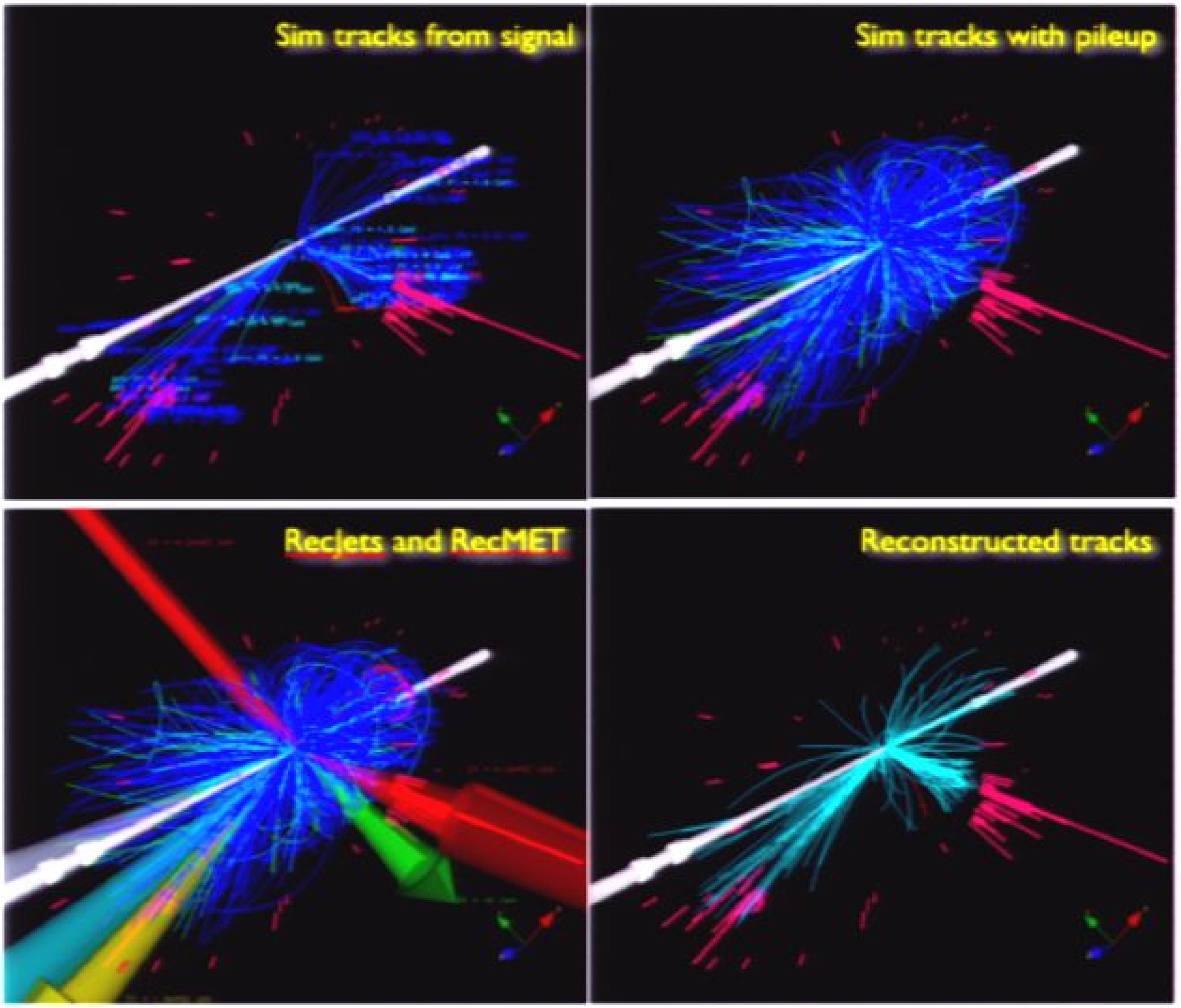

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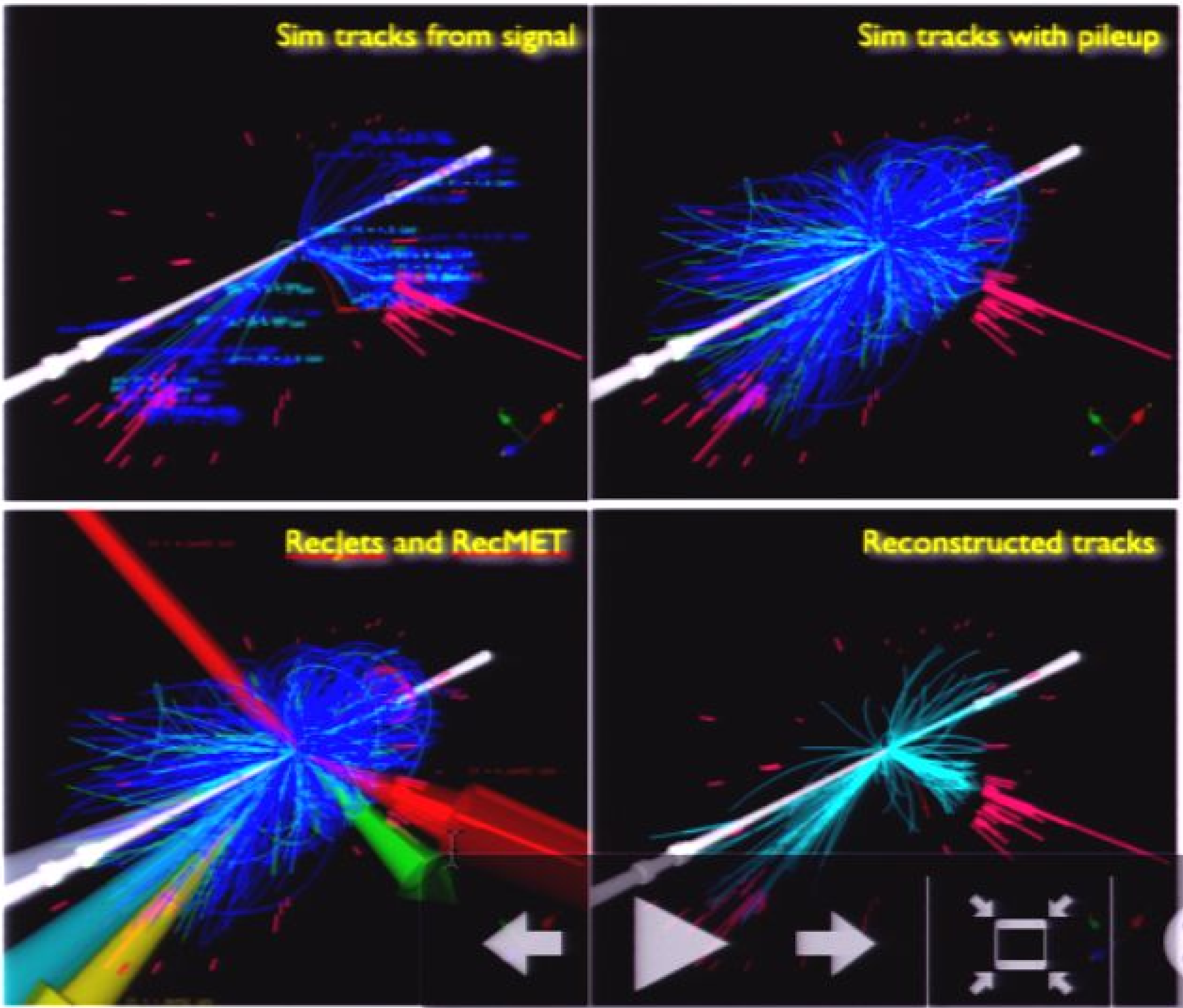

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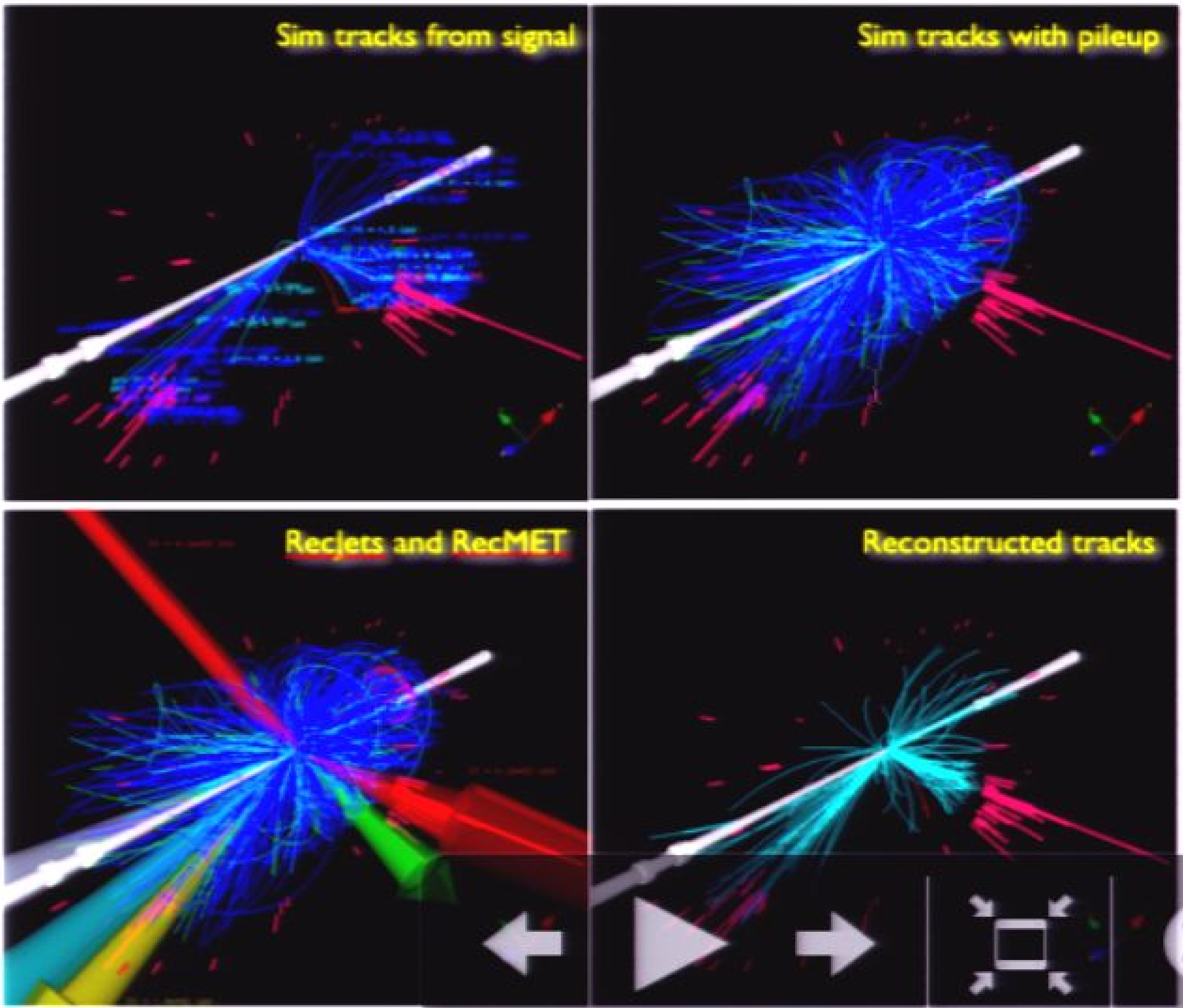
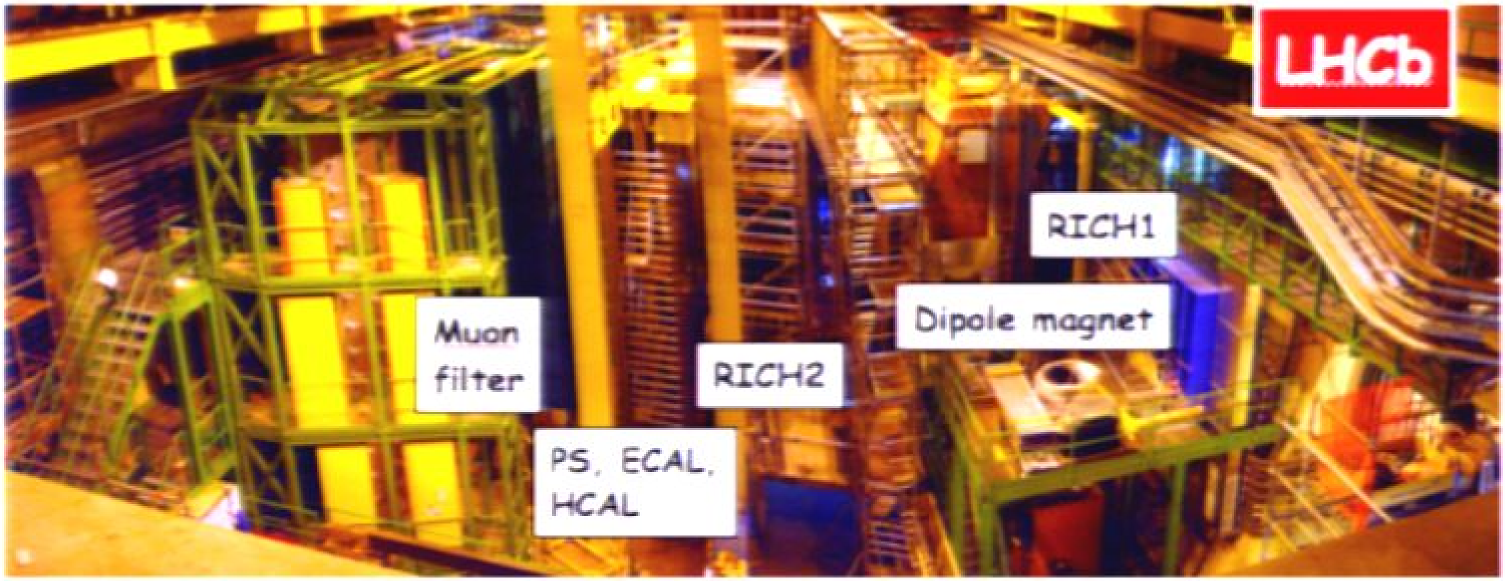


Outline

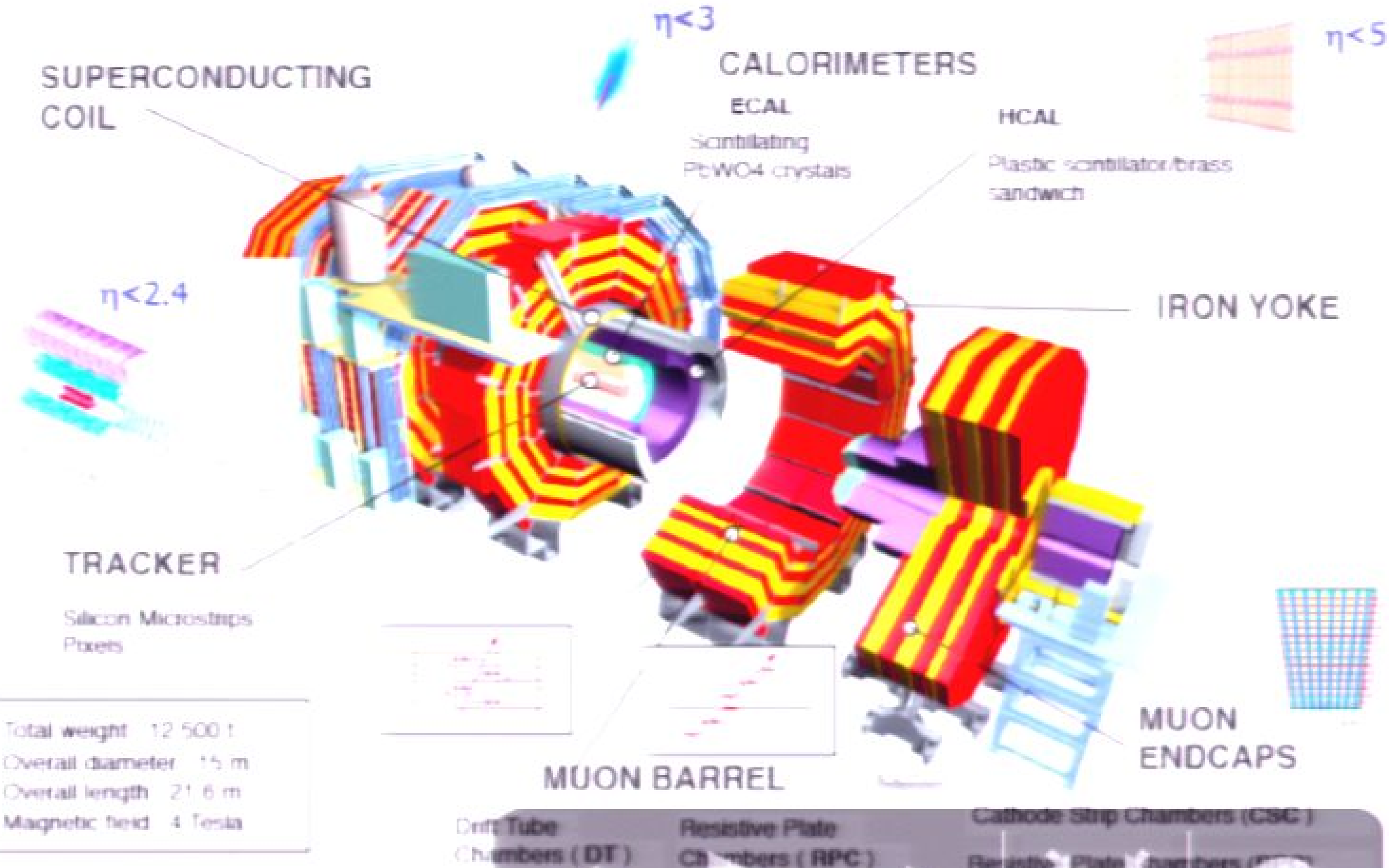
Status of the LHC Experiments

Status of ATLAS and CMS



- LHCb and ALICE are on track
- here highlights from CMS and ATLAS

CMS: Compact Muon Solenoid detector at LHC



Total weight 12 500 t
Overall diameter 15 m
Overall length 21.6 m
Magnetic field 4 Tesla

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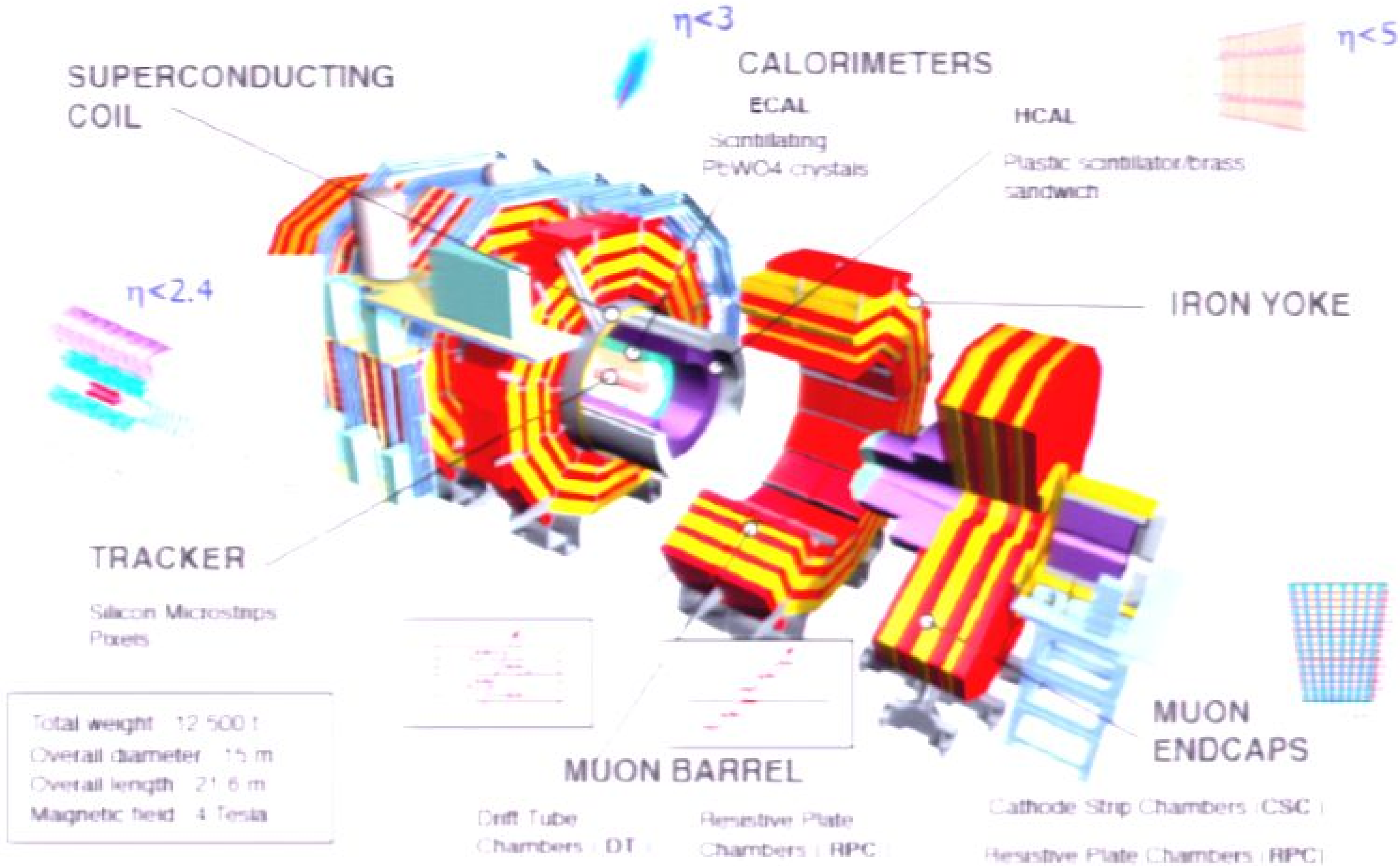

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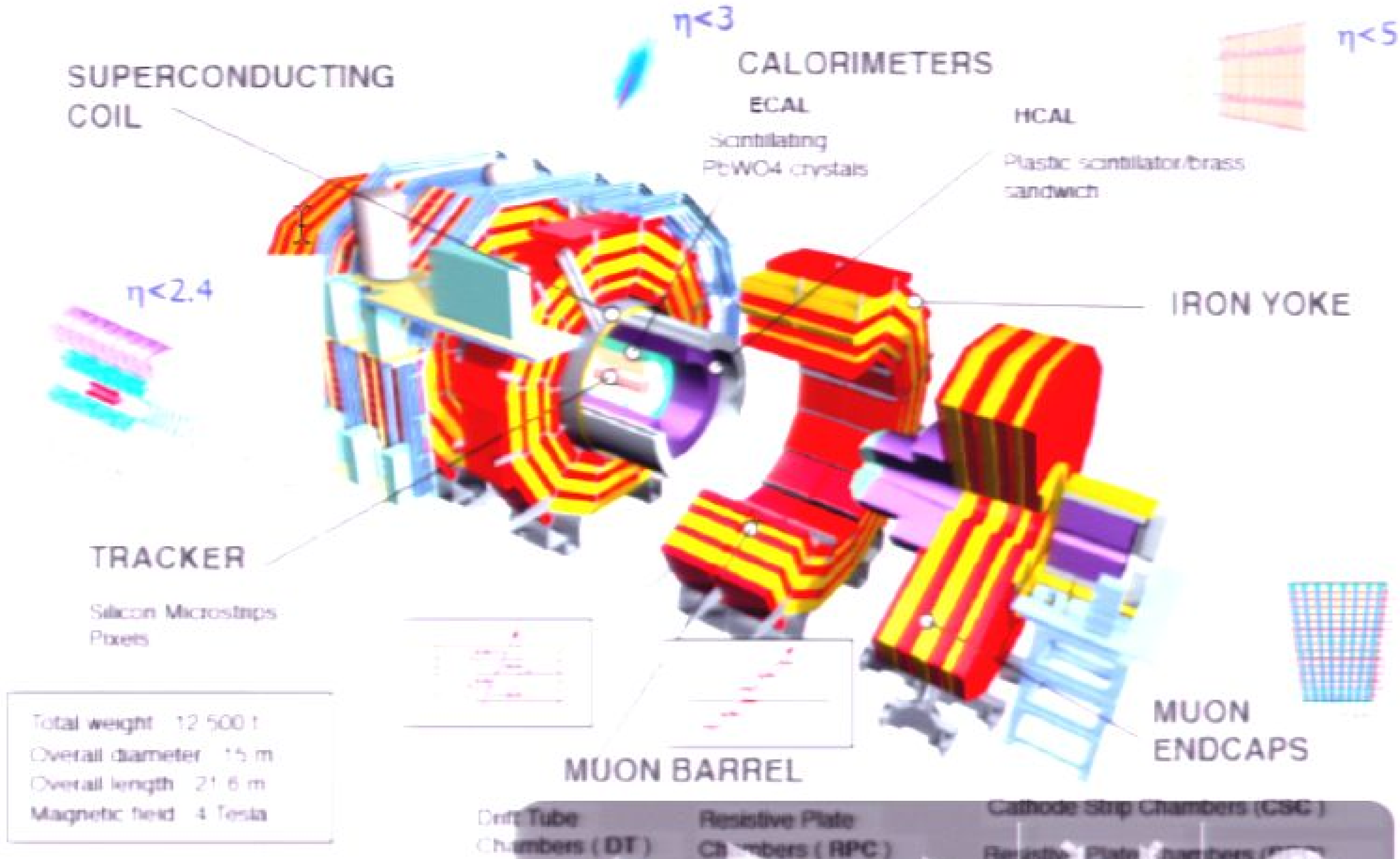

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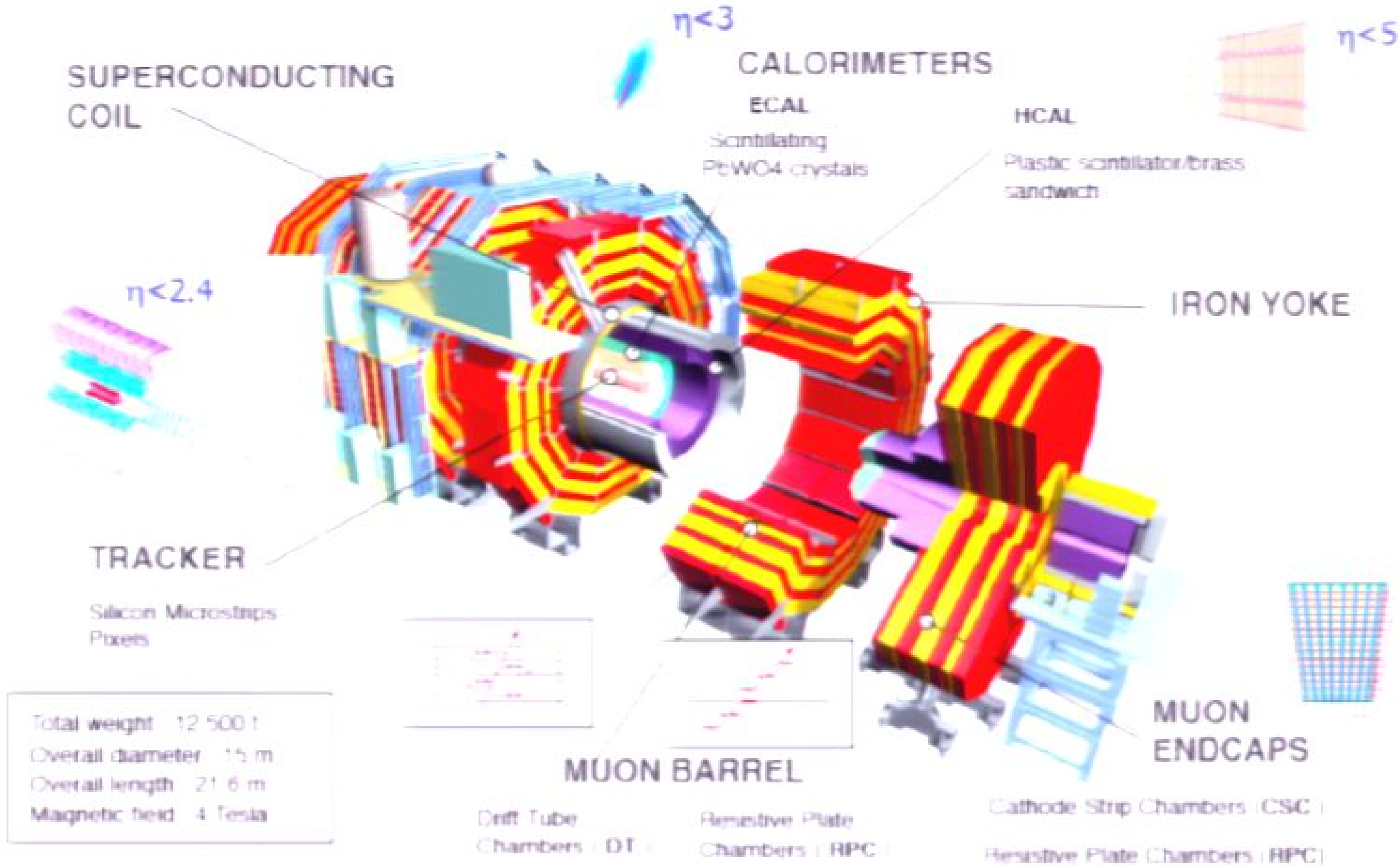
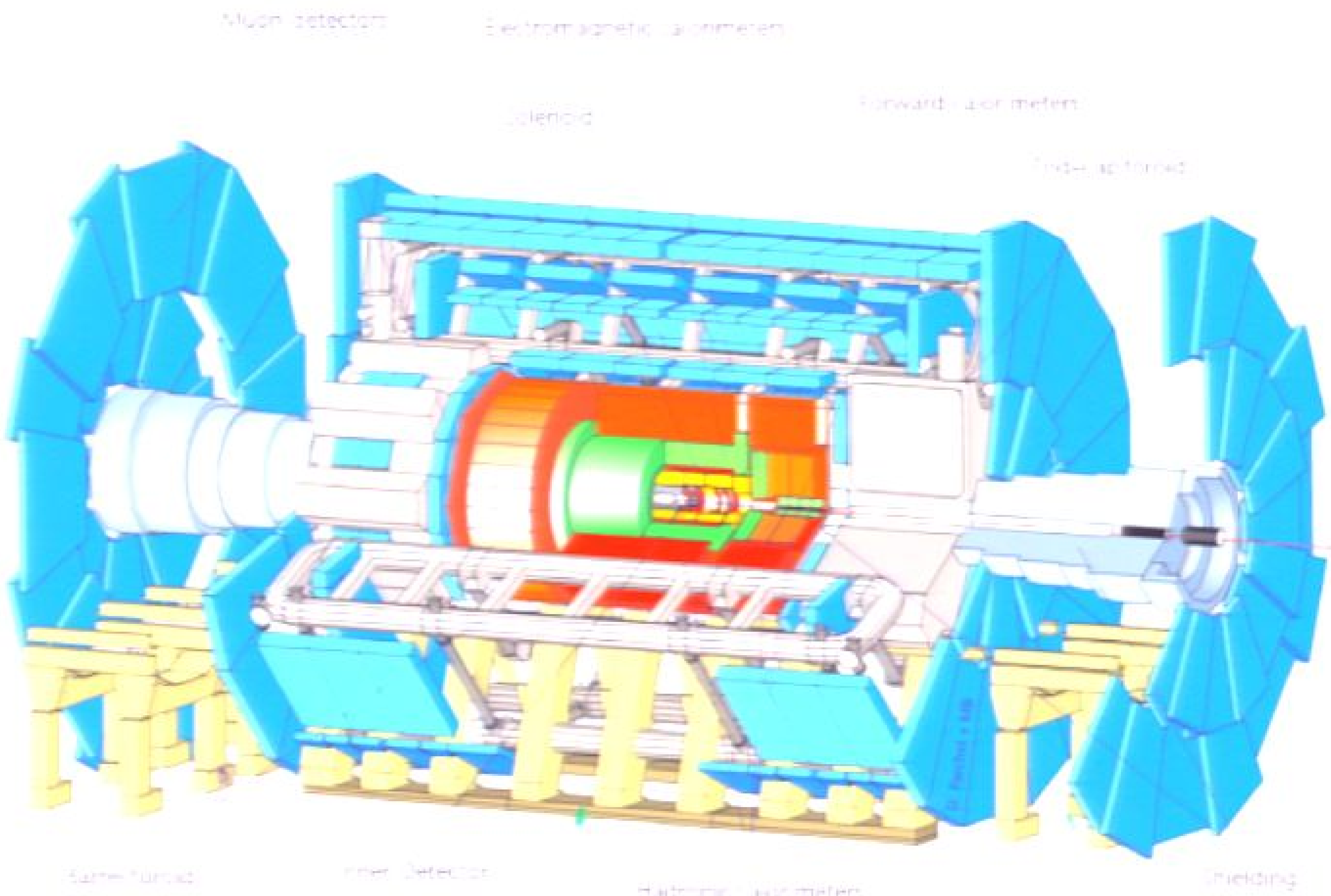


ATLAS: A Toroidal LHC AparratuS



- Tracking Si pixels and strips; Transition Radiation Detector • Calorimetry EM : Pb-LAr with Accordion shape, HAD: Fe/scintillator Cu/W-LAr ; •Muon Spectrometer : air-core toroids with muon

	ATLAS	CMS
weight (tons)	7,000	12,500
diameter (m)	22	15
length (m)	46	20
magnetic field for tracking (T)	2	4
solid angle coverage $\Delta\eta \times \Delta\phi$	$2\pi \times 5.0$	$2\pi \times 5.0$
cost in M CHF	550	550

Object	Weight (tons)
Boeing 747 [fully loaded]	200
Endeavor space shuttle	368
ATLAS	7,000
Eiffel Tower	7,300
USS John McCain	8,300
CMS	12,500

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Member States	61
Non-Member States	64
USA	49
Total	174

	Nr of Scientific Authors
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USA	547
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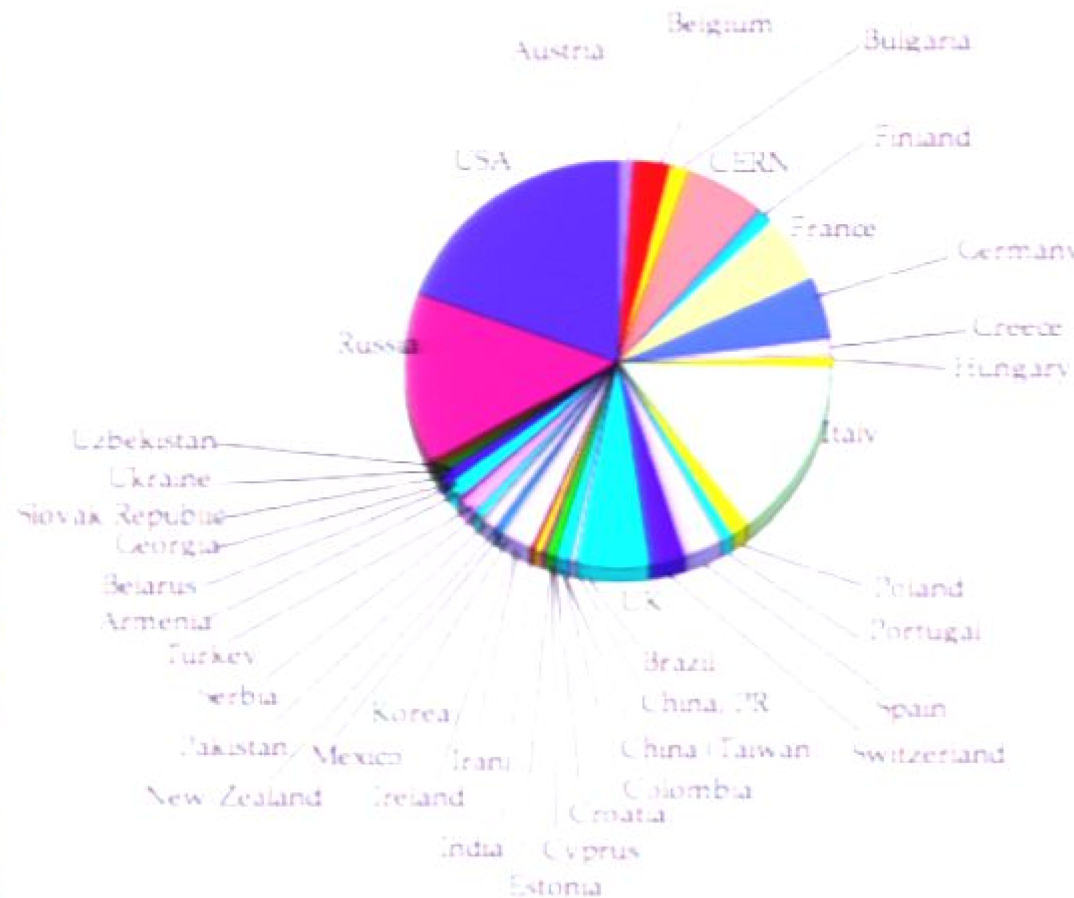
Associated Institutes	
Number of Scientists	46
Number of Laboratories	8



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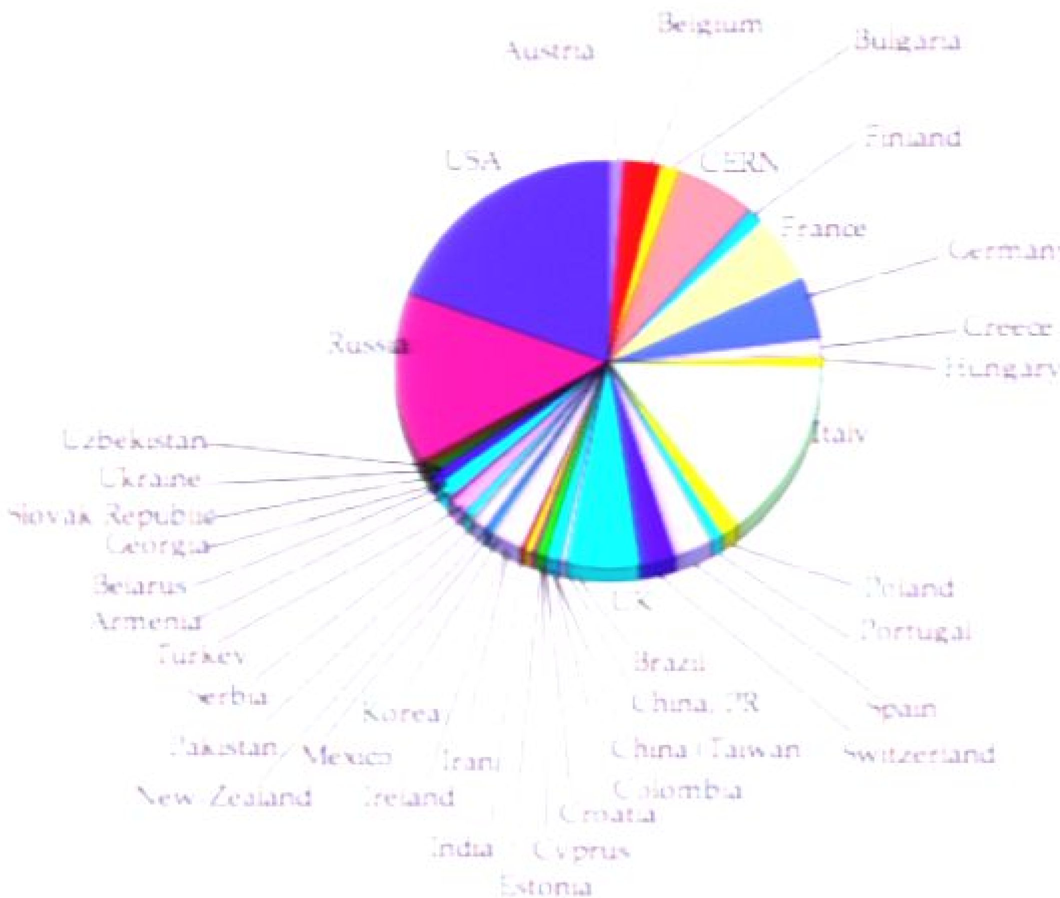

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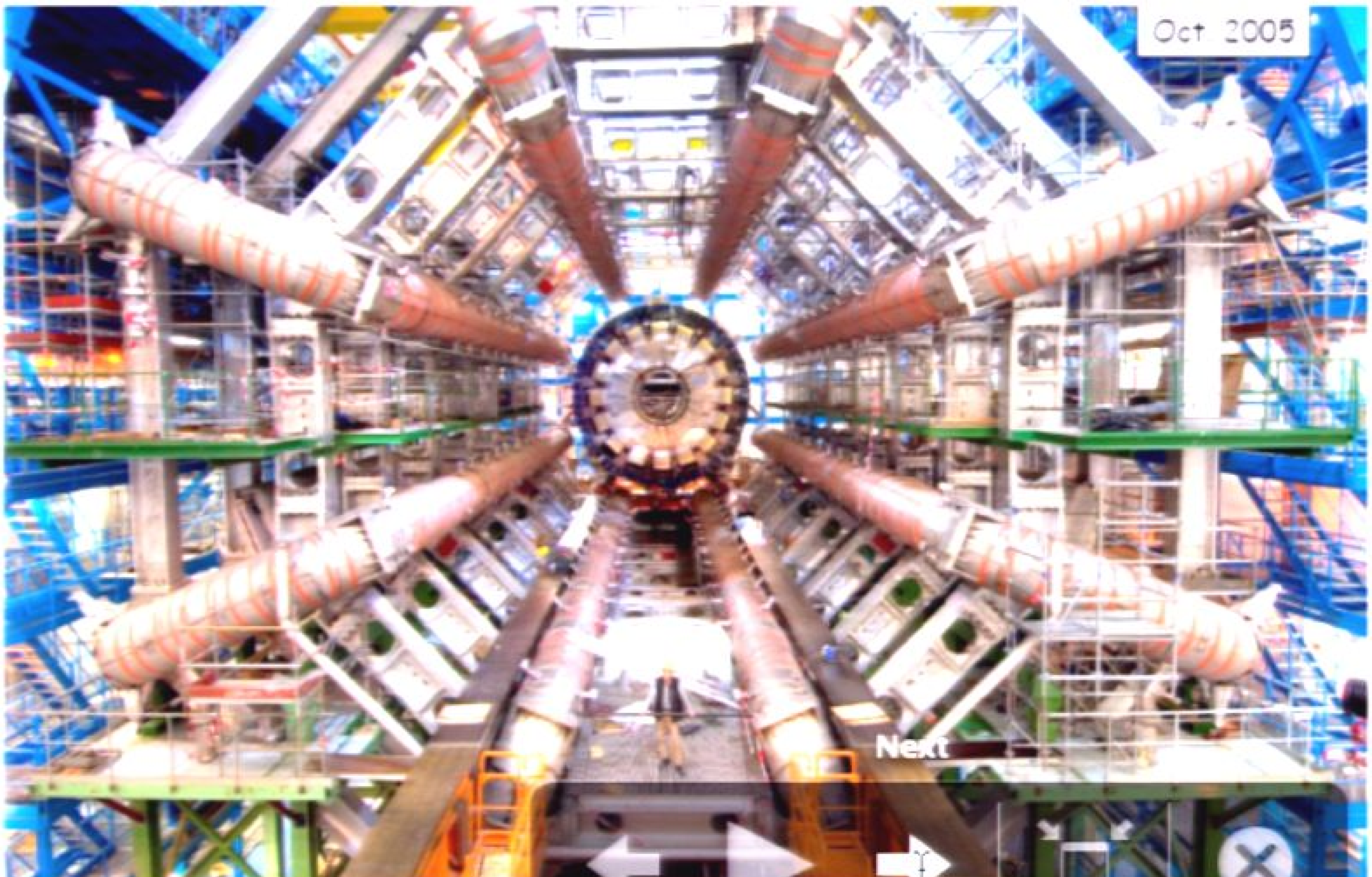
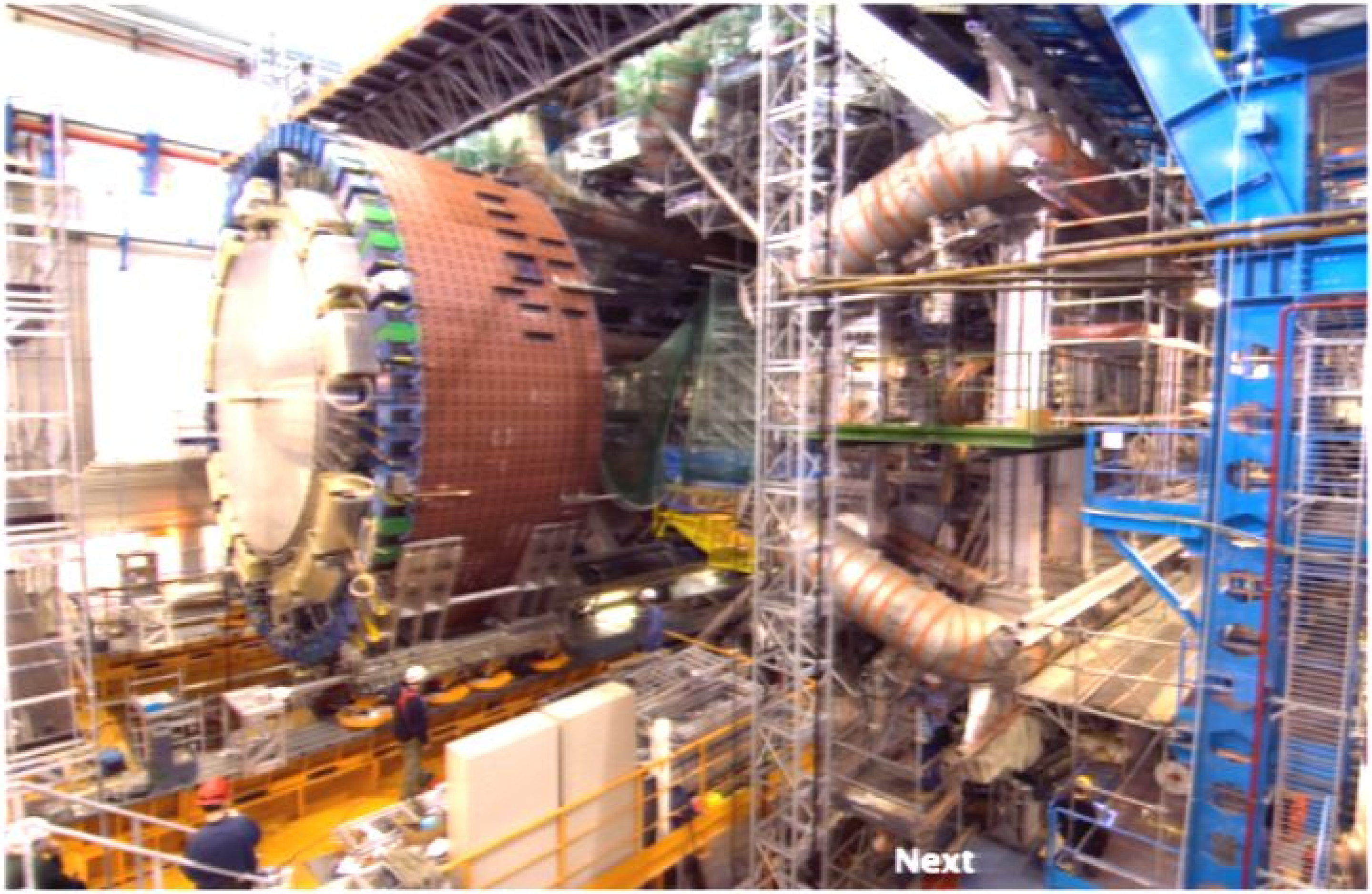
ATLAS in cavern-2005

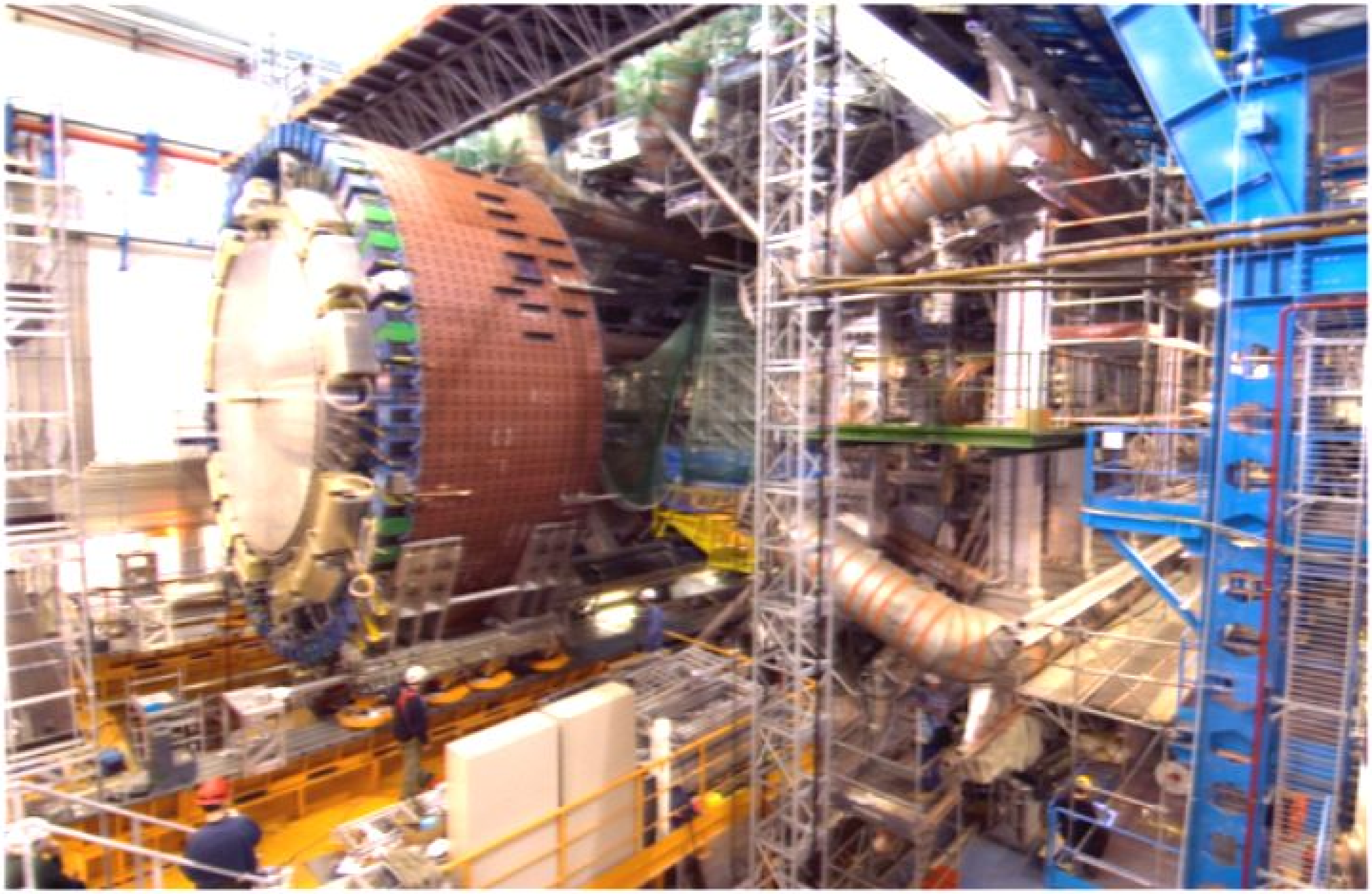


ATLAS EndCap Calorimeter



- One end-cap calorimeter (LAr EM, LAr HAD, LAr Forward inside same cryostat, surrounded by HAD Fe/Scintillator Tilecal) being moved inside the barrel toroid

ATLAS EndCap Calorimeter



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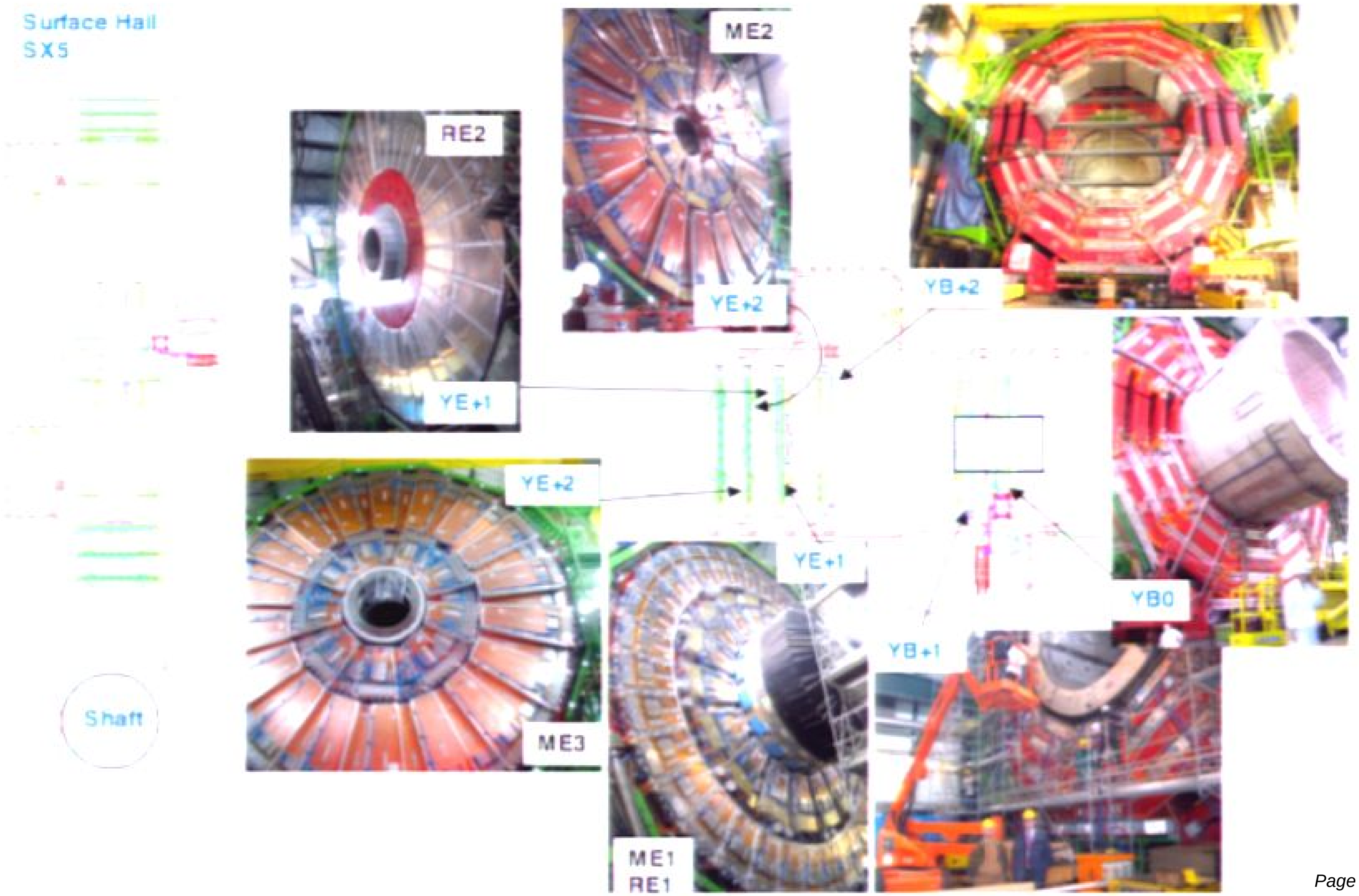
CMS surface assembly



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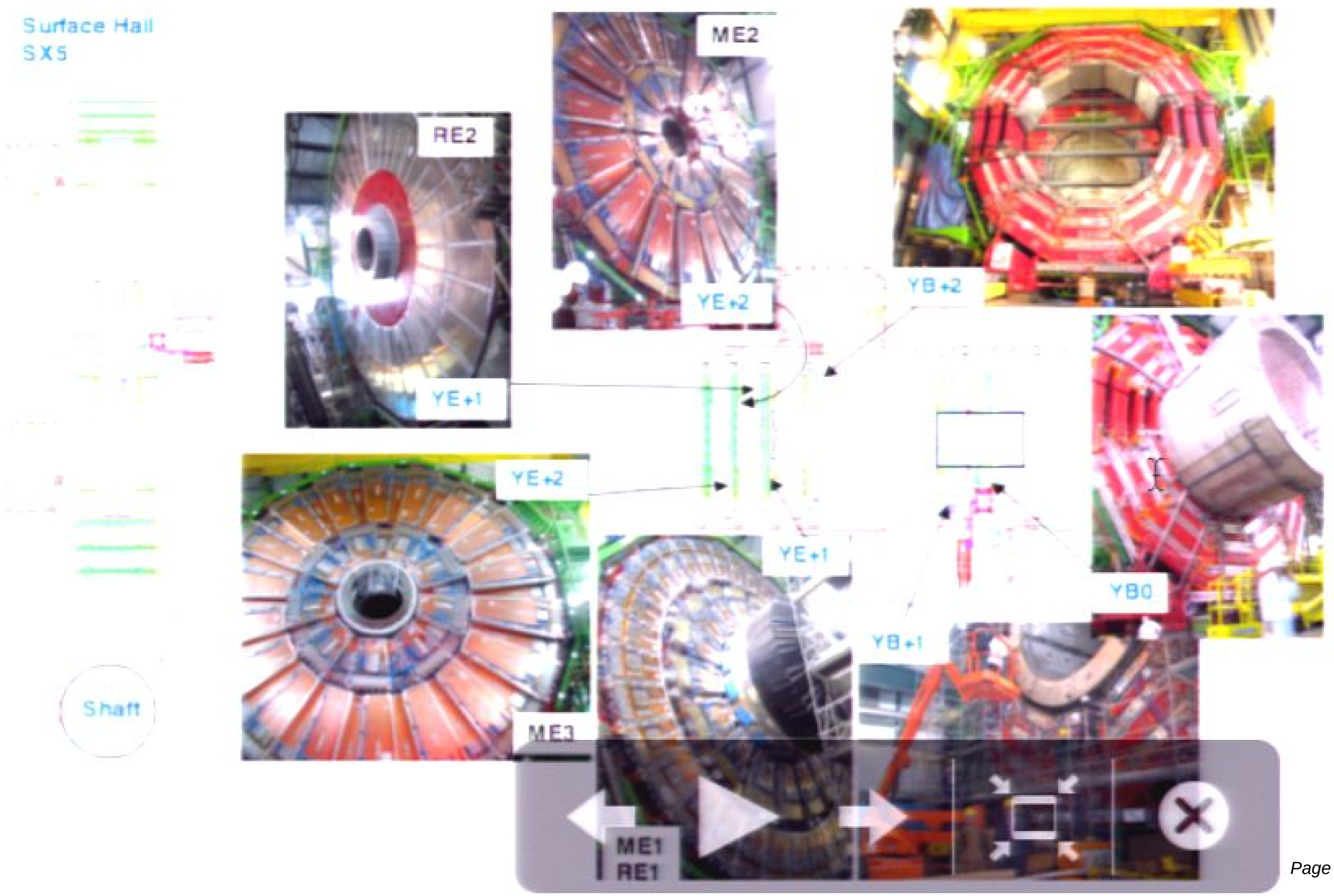
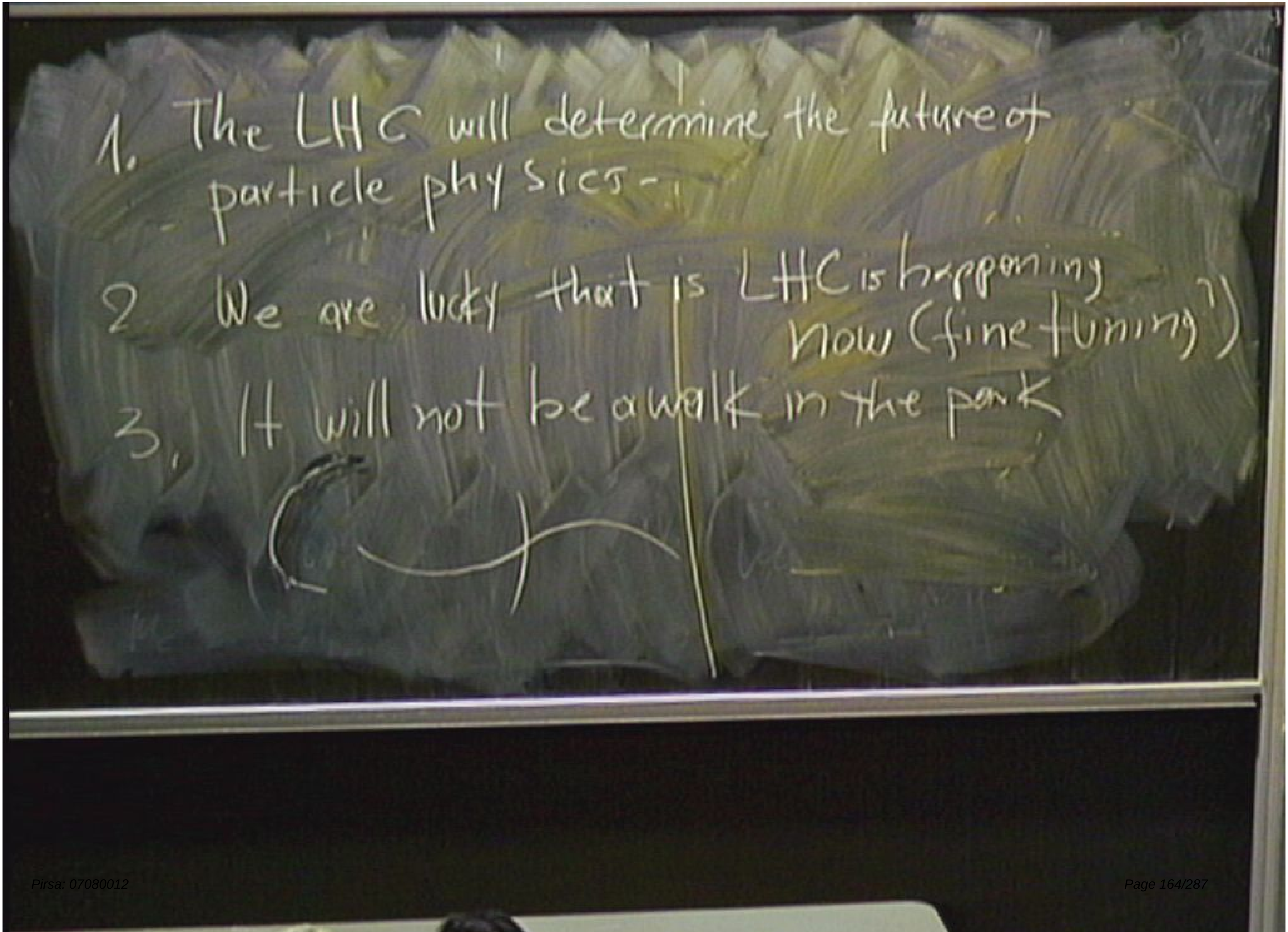
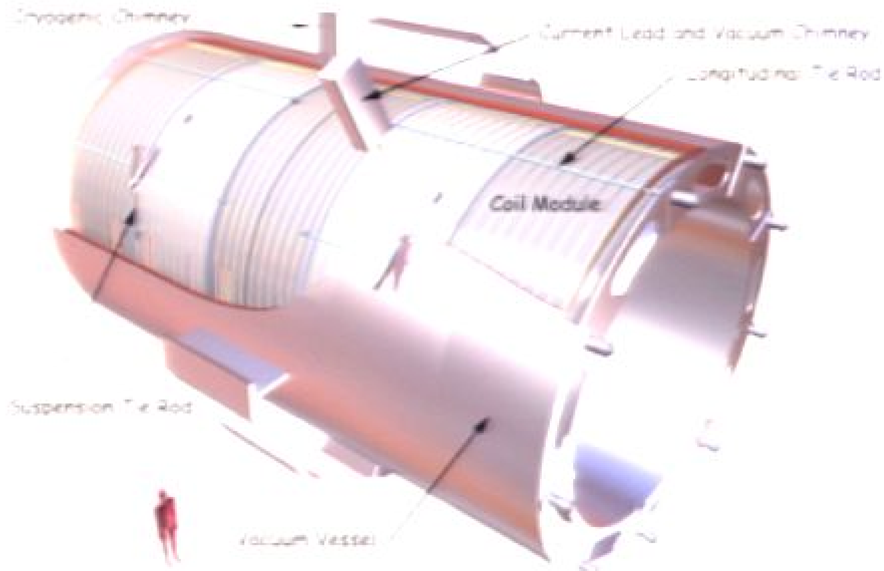
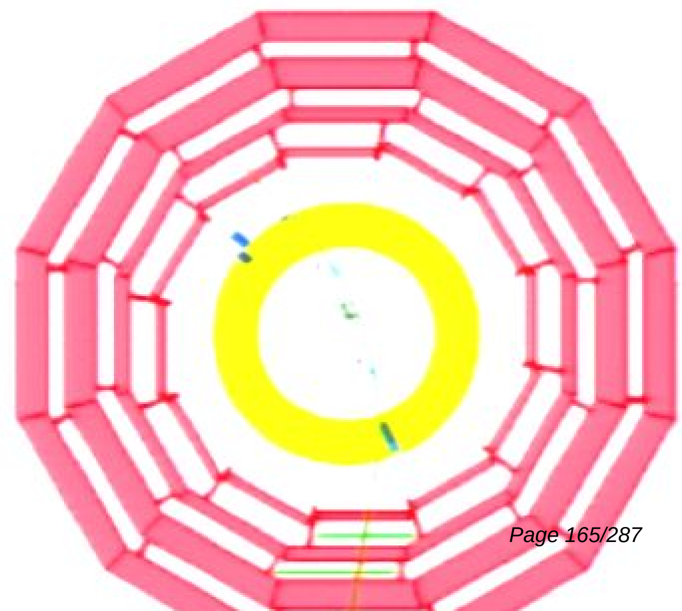



1. The LHC will determine the future of particle physics -
2 We are lucky that is LHC is happening now (fine tuning?)
3. It will not be a walk in the park

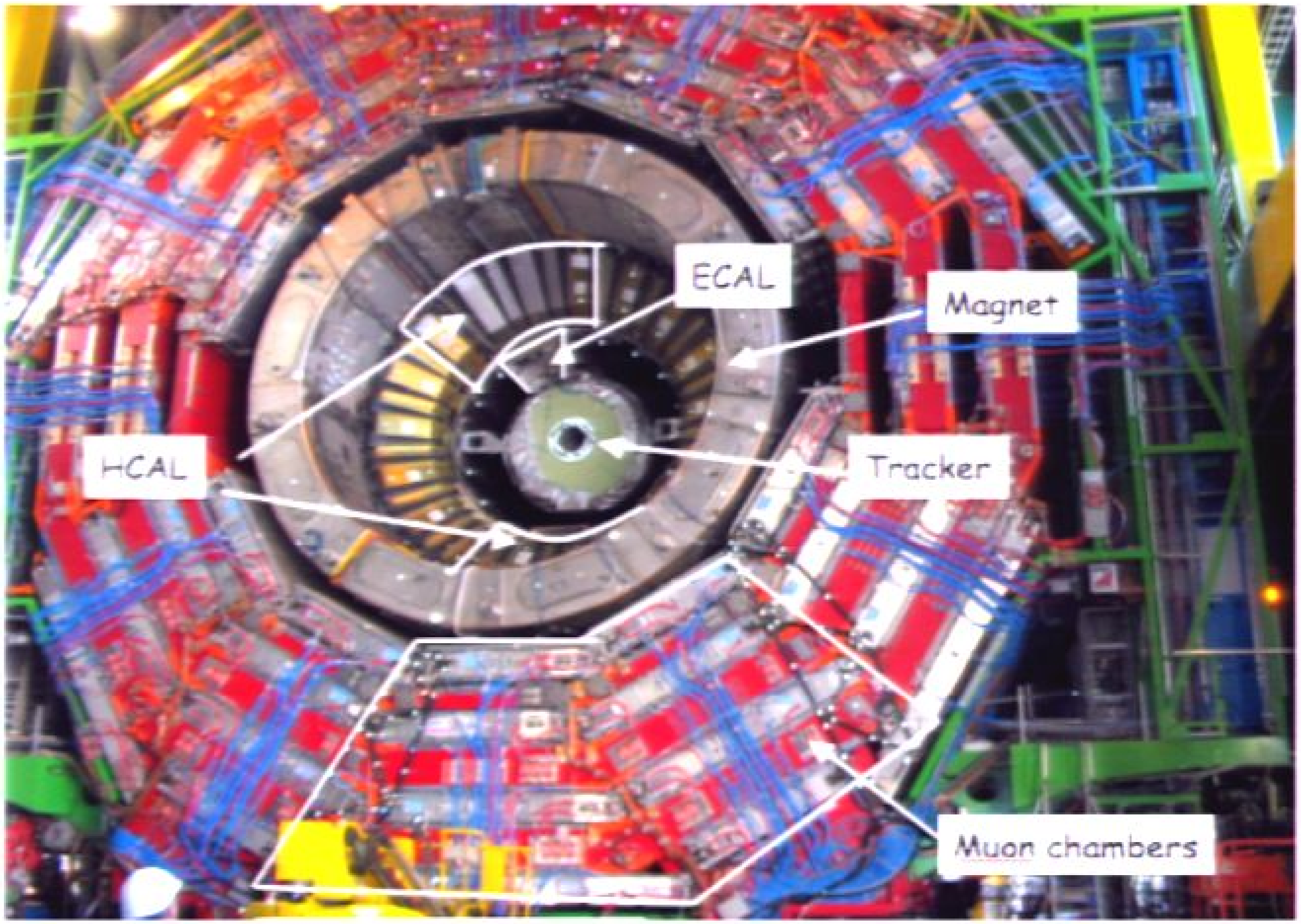
CMS superconducting solenoid



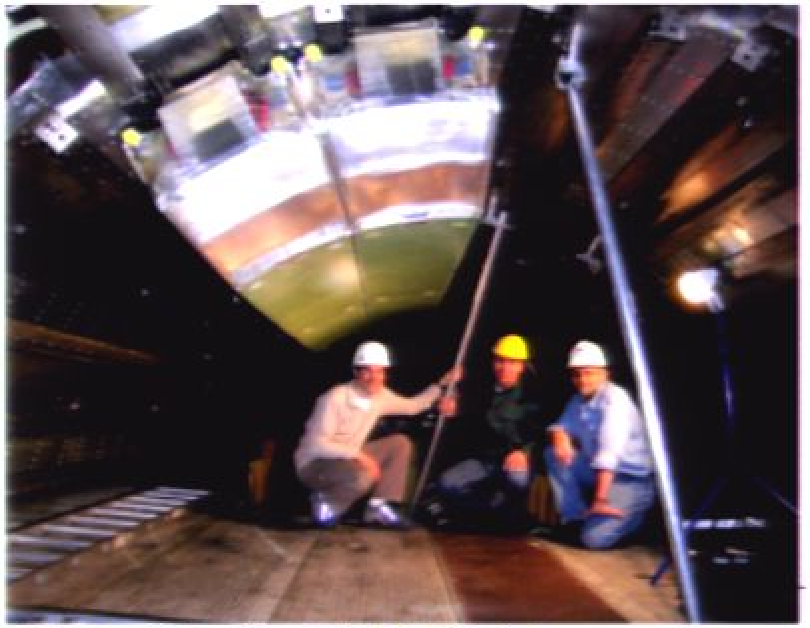


- Magnet length 12.5 m; Diameter 6 m; Magnetic field 4 T; Nominal current 20 kA; Stored energy 2.7 GJ! ; the most energetic magnet ever built+you can drive a truck into it. . ,

CMS surface configurations for the Magnet and Cosmic Slice Test



CMS ECAL



ALL 61.5k $PbWO_4$ barrel crystals have been delivered. Endcap crystal delivery from Russia and China is ongoing and foreseen to end in March 2008. First endcap Dee will be ready for insertion end of Feb. 2008. Construction of second endcap will be finished by early summer 2008.

CMS continues detailed tests of Gravity

[30 s movie: lowering YB0: the core central part of CMS with the solenoid]

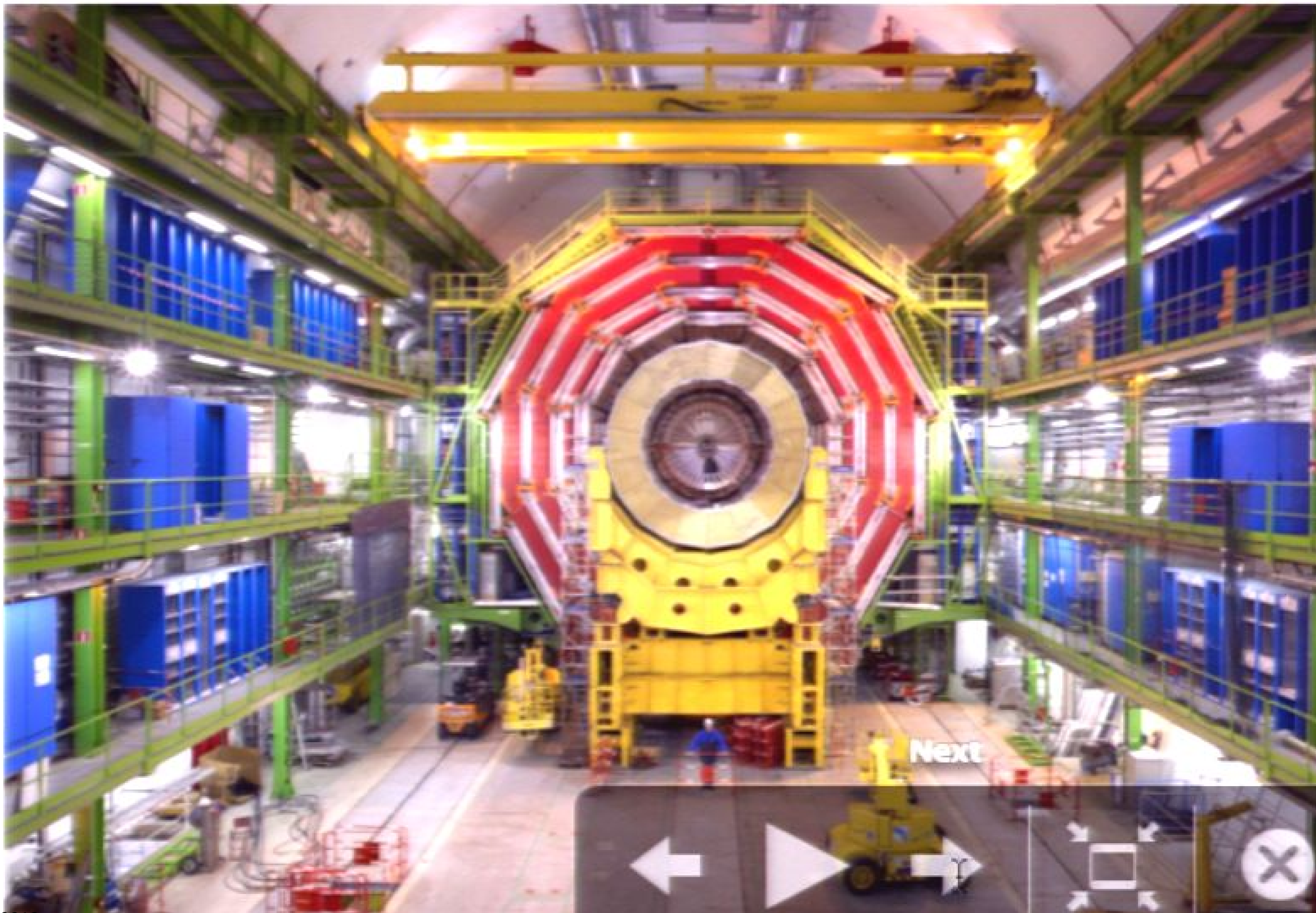
CMS continues detailed tests of Gravity

[30 s movie: lowering YB0: the core central part of CMS with the solenoid]

CMS continues detailed tests of Gravity

[30 s movie: lowering YB0: the core central part of CMS with the solenoid]

CMS at the pit now



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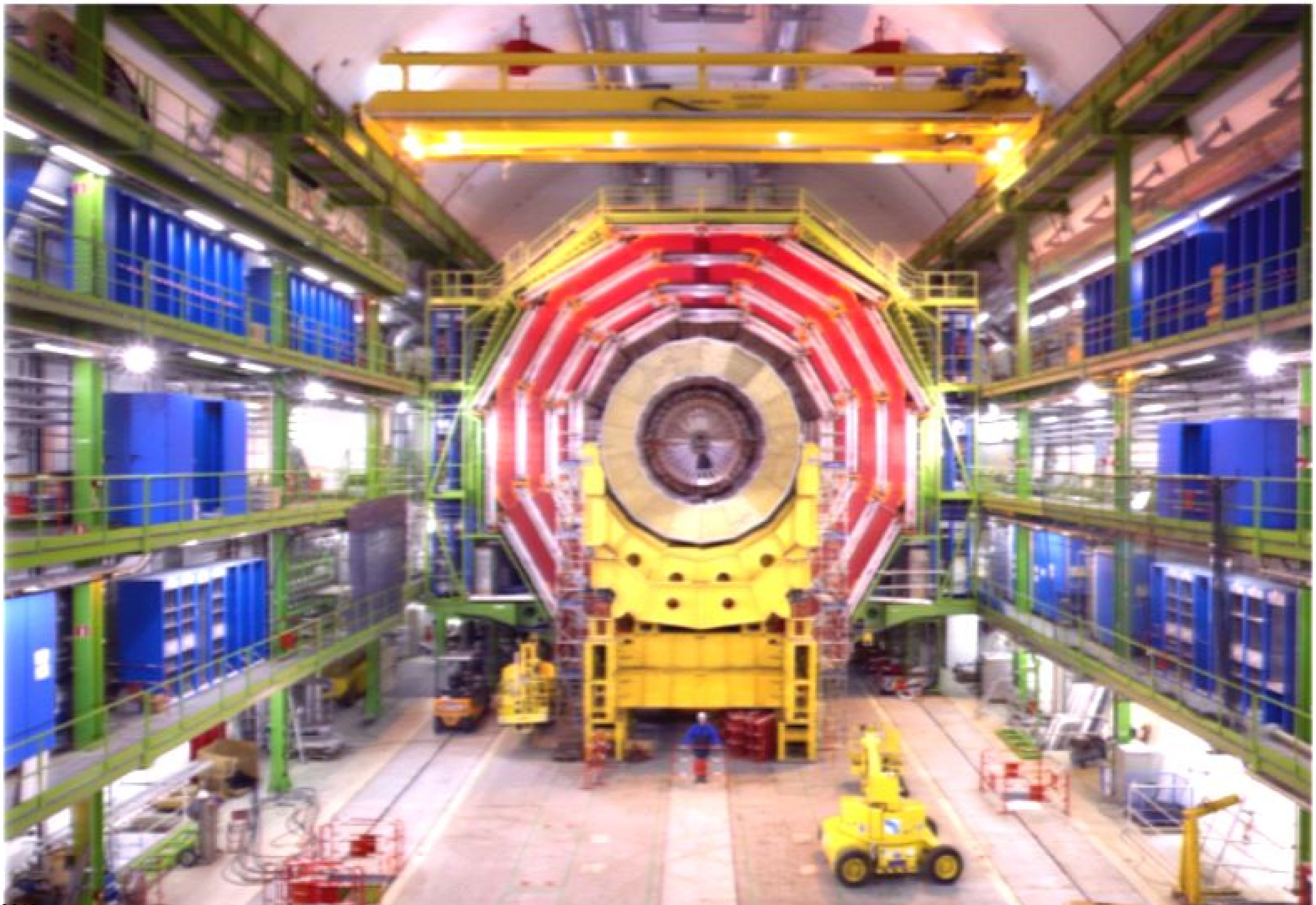

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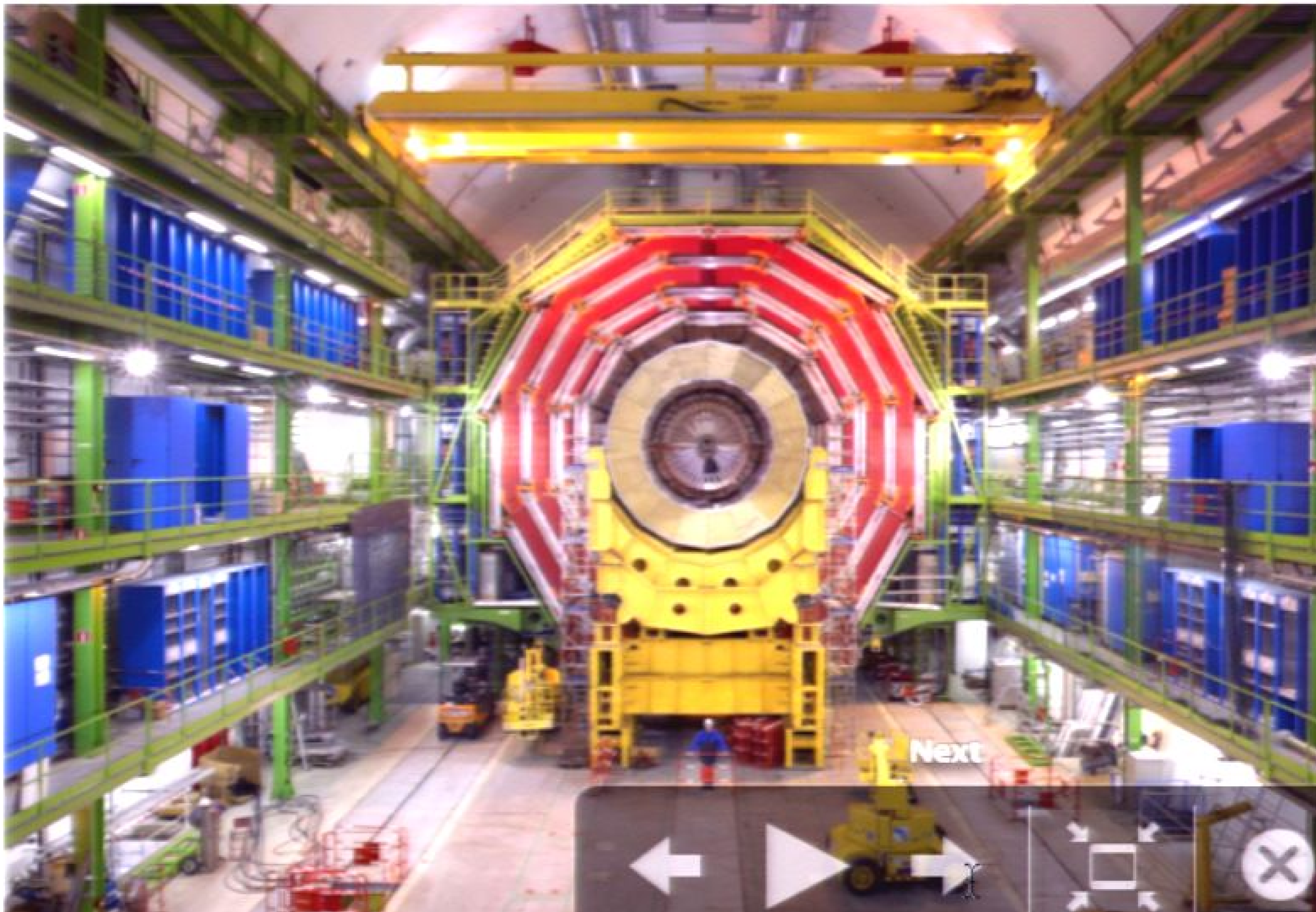
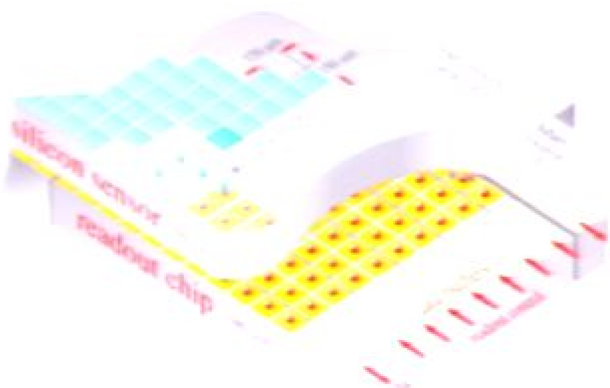
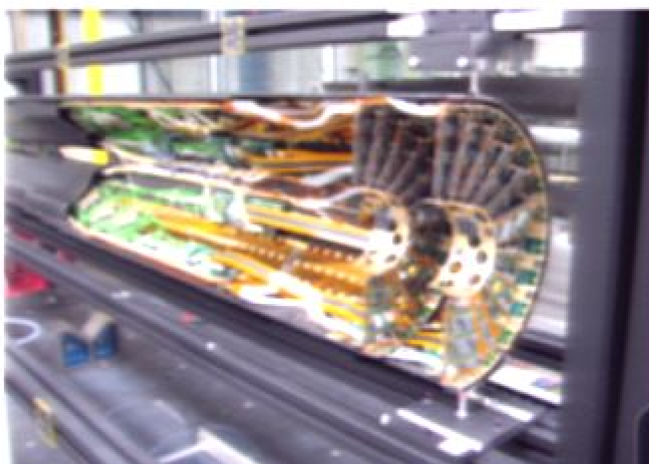


Silicon (pixels (L), SST (R))





alignment goal: 30 μ 04.08
SST istallation: starting
SST cosmic commissioning:
$\mathcal{O}$(M) recorded cosmic events
Pixel installation: <summer 08

Schedule

Both experiments are in status of commissioning and integration in preparation for data in summery 2008.

May 07 and few days every end of month	commissioning/global runs/ cosmics/test data
Sep. 07	CSA07
Oct-Dec 07	cosmics/integration
Feb 08	beam pipe close
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Apr 08	close CMS for 14 TeV run
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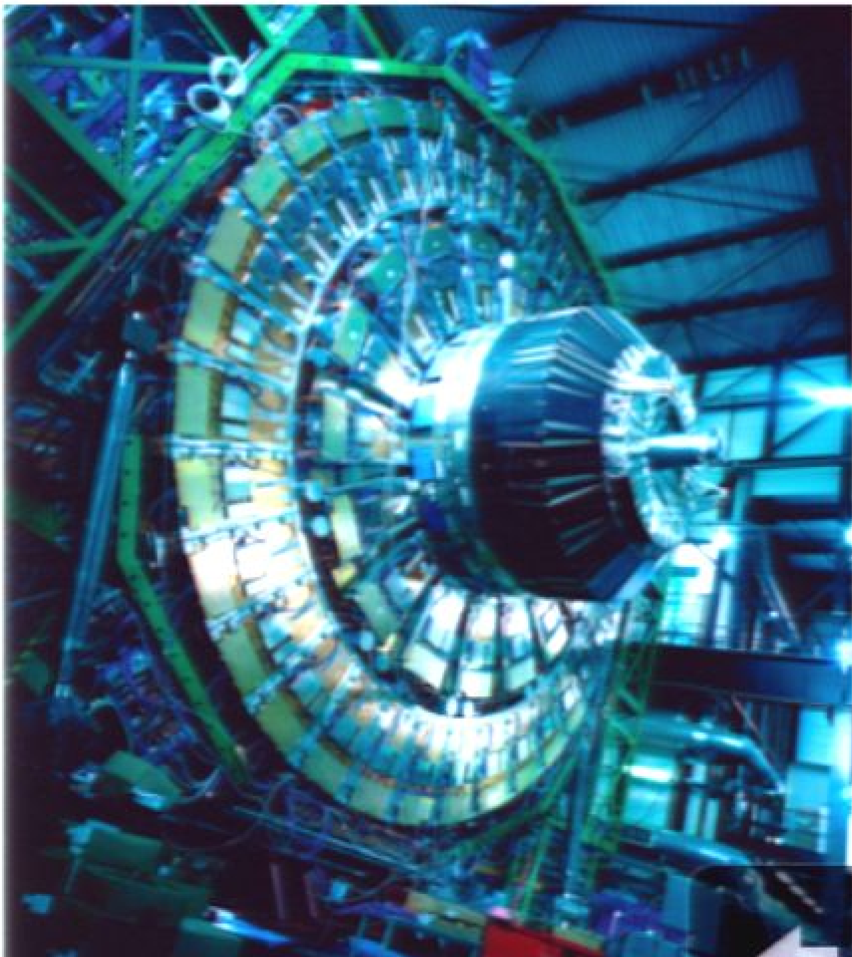
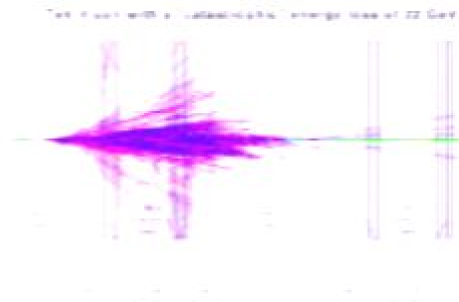
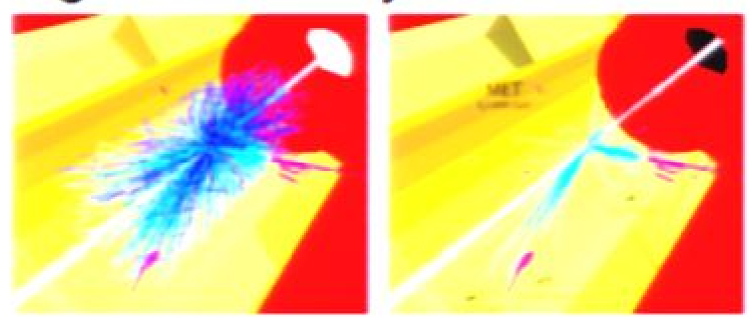
big and challenging



- high energy



- high luminosity



- high data rates (trigger, GRID)
- ...not a walk in the park

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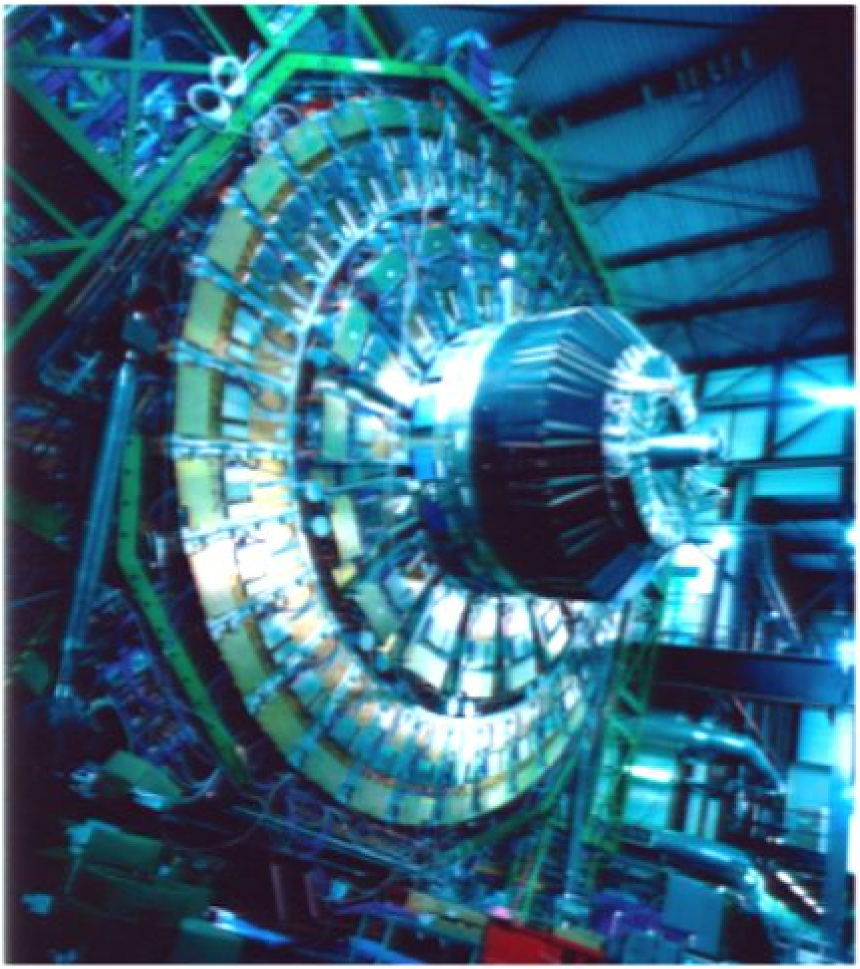

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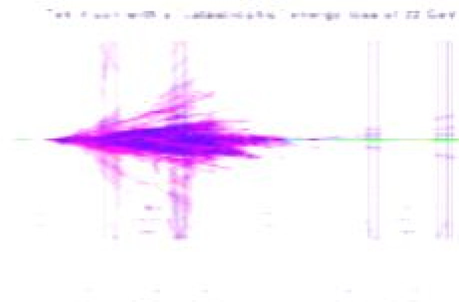

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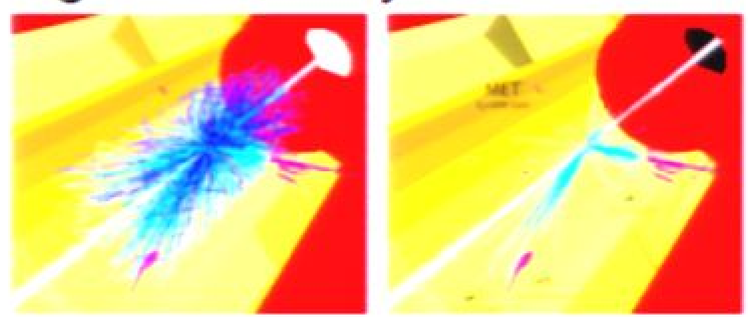

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Detector Concept

- The detectors designed to identify most of the very energetic particles emerging from the proton-proton collisions, and to measure as efficiently and precisely as feasible their trajectories and momenta.
- The interesting particles are produced over a wide range of energies (from a few hundred MeV to a few TeV) and over the full solid angle. They therefore need to be detected down to small polar angles (θ) with respect to the incoming beams (a fraction of a degree corresponding to pseudorapidities η up to 5, where $\eta = -log[\tan(\theta/2)]$.
- No detectable particle should escape unseen.
- The design is "cylindrical onion"

The homework assigement is then...

Why ATLAS and CMS are so differently designed?

you can say they are "dual"

Clue1: Benchmark design requirement

Measure the momentum of 1 TeV muon to no worse than 10% precision

you can say they are "dual"

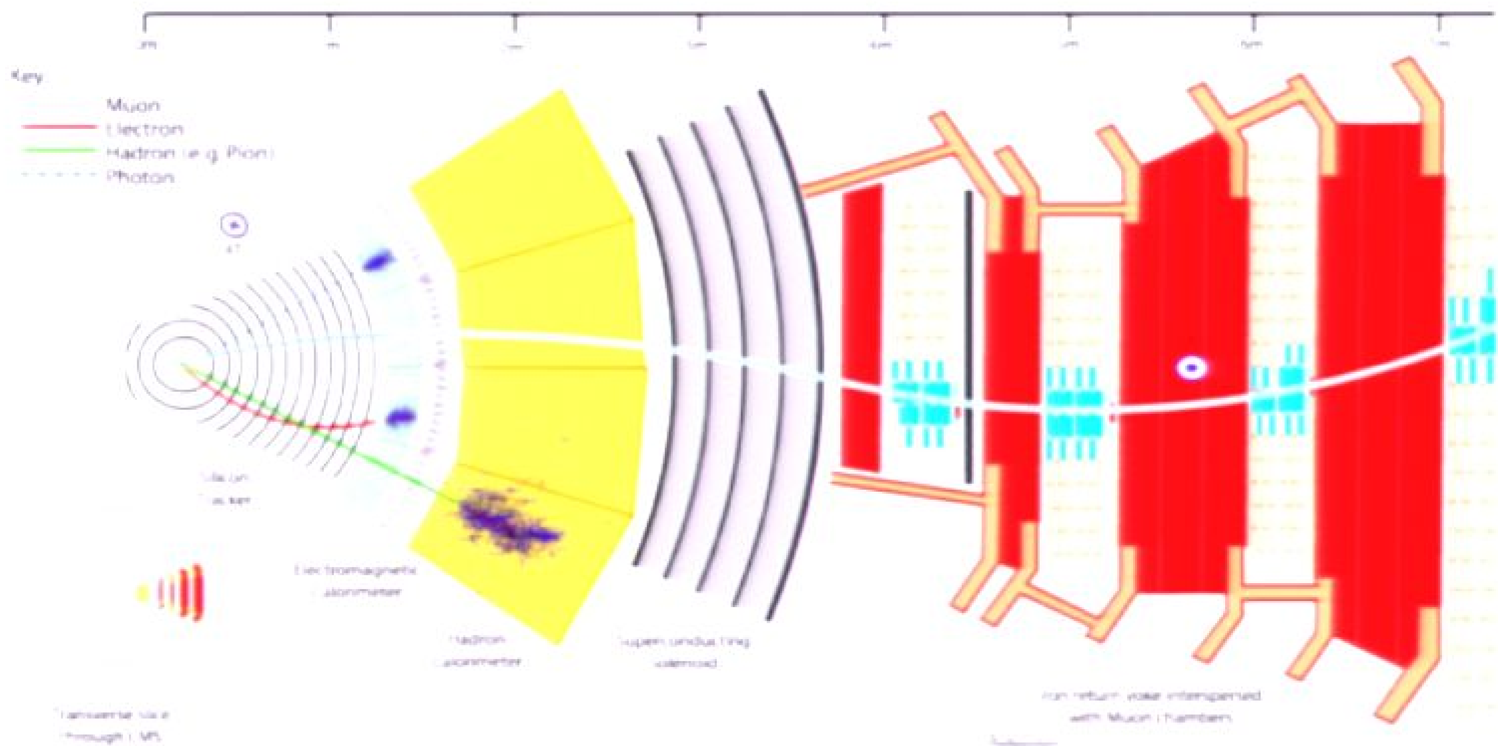
Clue1: Benchmark design requirement

Measure the momentum of 1 TeV muon to no worse than 10% precision

Clue2: Benchmark design requirement has at least 2 solutions!

Homework

Because $\frac{\Delta p}{p} \sim \frac{1}{BL^2}$ where B is the magnetic field strength and L is the distance over which the bending of the muon takes place.



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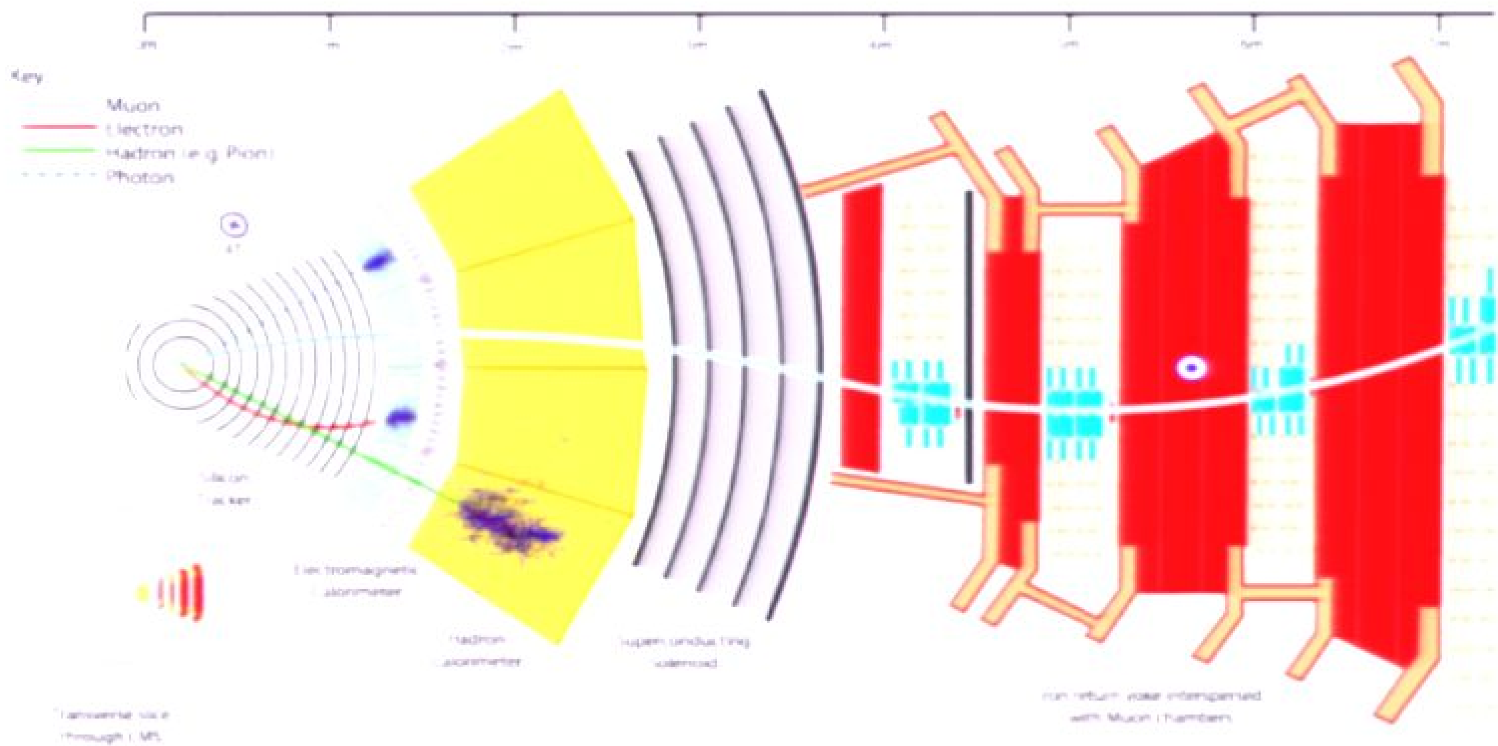

Physics objects

- jets (calorimetry/tracking)
- missing E_T (calorimtery)
- electrons/photons (calorimetry/tracking)
- muons (tracking, muon chambers)
- hadronic taus (narrow jets)
- b's (jets with secondary vertex)
- top, W, Z (as reconstruction/calibration examples)

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Physics Objects @14 TeV

- jets from a highly boosted top are on top of each-other
- 44% of the energy of a P_T=35 GeV electron in the barrel is lost in brems (algorithms to recover ok)
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- material before calorimetry in ATLAS and CMS ~dark matter of the universe (interactions with matter complicate reconstruction)

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Coordinates and solid angle segmentation (η, ϕ)

- The origin $x = y = z = 0$ is at the nominal collision point in the geometrical center of the detector
- The z direction is the direction of the proton beam; the detector solid angle segmentation is designed to be invariant under boost along the $z-$direction. ϕ is the azimuthal angle about the $z-$axis η (*pseudorapidity*) is related to the polar angle θ by the relation:

$$\eta \equiv -\ln \tan \frac{\theta}{2} \qquad (1)$$

- The pseudorapidity, η,is equivalent to the *rapidity*, of a particle in the limit of $p >> m$, where p is the momentum of the particle and m its mass. The rapidity Y, is defined by

$$Y \equiv \frac{1}{2} \ln \frac{E + p_z}{E - p_z} \qquad (2)$$

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If Y is expanded in terms of η and $\alpha = m/P_T$)

$$Y = \frac{1}{2}\ln\left(\frac{\sqrt{\cosh^2\eta + \alpha^2} + \sinh\eta}{\sqrt{\cosh^2\eta + \alpha^2} - \sinh\eta}\right)$$

$\sim \eta - .5\alpha^2 \tanh\eta + O(\alpha^3)\ \eta(3)$

- The rapidity Y of a particle transform linearly under a boost, $Y \rightarrow Y + constant$. Taking the derivative shows that segmentation in rapidity is Lorentz invariant, $dY \rightarrow dY$. The rapidity is a function of the particle's mass and polar angle and is not used to define the angular segmentation. Pseudorapidity depends only on the polar angle and is approximately Lorentz invariant under $z-$ boosts for high P_T particles. It is used to define angular segmentation.Being transverse to the $z-$direction the ϕ is also invariant under z-boosts and is the orthogonal solid angle variable.

Jets

- Hadronic jets: final state of outgoing partons (subject to fragmentation) in a a hard scattering
- Jet reconstruction algorithms: Clumping "clusters" of final state particles (towers, hadrons, tracks) into "jets" so that their kinematic properties (momenta) are related to the original parton
- Jet measurements: tests of QCD, mass reconstruction, search for new physics: (test of QCD predictions[PDFs x-section 'jet constituent') is deposited by a massless particle striking the tower center and by summing the 4-momenta of all the towers(i) that by clustering construct the jet: .

$$E = \sum_i (E_i^{em} + E_i^{had})$$

$$p_x = \sum_i (E_i^{em} \sin\theta_i^{em} + E_i^{had} \sin\theta_i^{had}) \cos\phi_i$$

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Jets: Assignment

Show that jets are approximately circular in $\eta\phi$

Jets Algorithms: Requirements

- Detector Independence: There should be no dependence on cell type, numbers, or size.
- Theoretically Well Behaved: IR/Collinear Safe, no ad-hoc clustering parameters. [IR safety: soft radiation between two jets may cause a merging when above seed threshold. Collinear safety: jet not reconstructed if the seed energy is below threshold being split among several detector towers; number of jets depending on seed E_T ordering]
- Order Independence: Equivalence at the parton, particle, and detector levels.
- Fully Specified: Energy, angles, and underlying event should be clearly and completely defined. If necessary, pre-clustering, merging, and splitting algorithms must be completely described.
- Boost Invariant.

missing transverse energy ($\not{E}_T$)

Neutrinos do not interact in the detector. From transverse momentum conservation, the presence of undetected neutrinos results in transverse energy imbalance in the detector which is proportional to the neutrino momentum and it is called missing E_T or $\not{E}_T$ or MET or $P_T{}^{miss}$.[Since the longitudinal component of the colliding partons momentum is unknown, only the transverse component of the neutrino momentum is measured.]
The raw $\not{E}_T$, is defined as the negative vector sum of the transverse energy in the calorimeter: At the online level, $\vec{\not{E}}_T$ is the vector sum of all calorimeter towers, both electromagnetic and hadronic, and is defined as

$$\vec{\not{E}}_T = \sum_{towers} (E_i \sin\theta_i)\hat{n}_i \tag{5}$$

where E_i is the energy of the *ith* tower, and $\hat{n}_i$ is a transverse unit vector pointing to the center of each tower. θ_i is the polar angle of the line pointing from $z = 0$ to the *ith* tower. The sum extends to $|\eta_d| < 5$.

Outline

The LHC Physics Besides the Standard Model

SUSY@LHC program of work

ATLAS+CMS SUSY search Highlights

"Let me stress that I do not believe that the standard theory will long survive as a correct and complete picture of physics"

Shelly Glashow, Stockholm 1979

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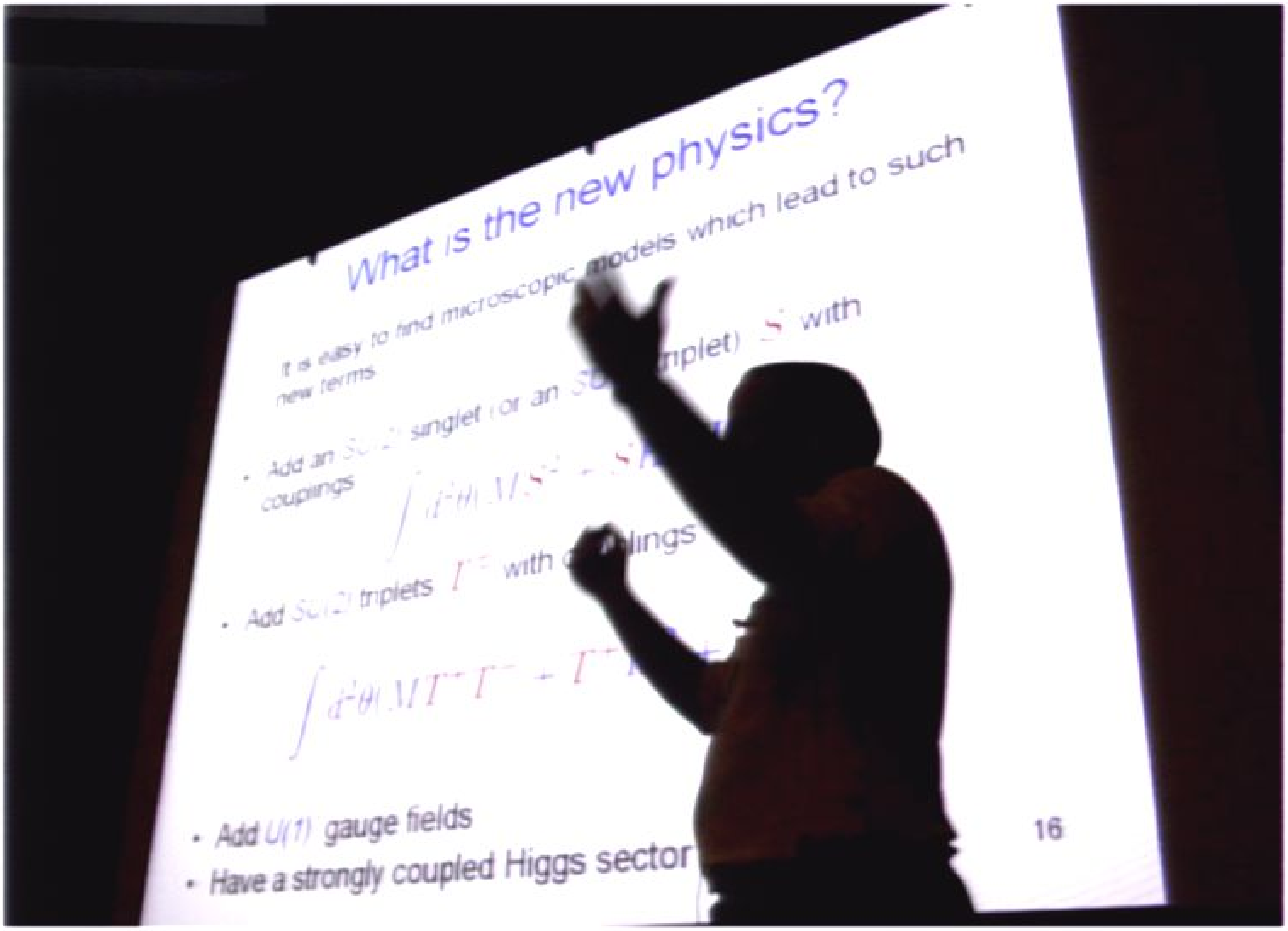

Strings 07. (Nati assumes) The LHC will discover some of the particles in the MSSM. These include some or all of the 5 massive Higgs particles of the MSSM. No particle outside the MSSM will be discovered (and concludes) There could be measurable deviations from MSSM relations at the LHC.These could point to new higher energy physics.

Top 2 Experimental Manifestations of New Physical Mechanisms (the known unknowns)

- the W and Z boson measured masses
- the dark matter

The expectation is then that the LHC will discover a new sector of particles associated with electroweak symmetry breaking and dark matter: $\longrightarrow$
Look for SUSY or "SUSY-mutation" in multijets+missing energy final state and 1xx GeV WIMP/neutralino dark matter candidate(s).

Top 1 Current Experimental Hint for Low Mass SUSY

m_t=171.4 GeV and going down (currently 170.9)

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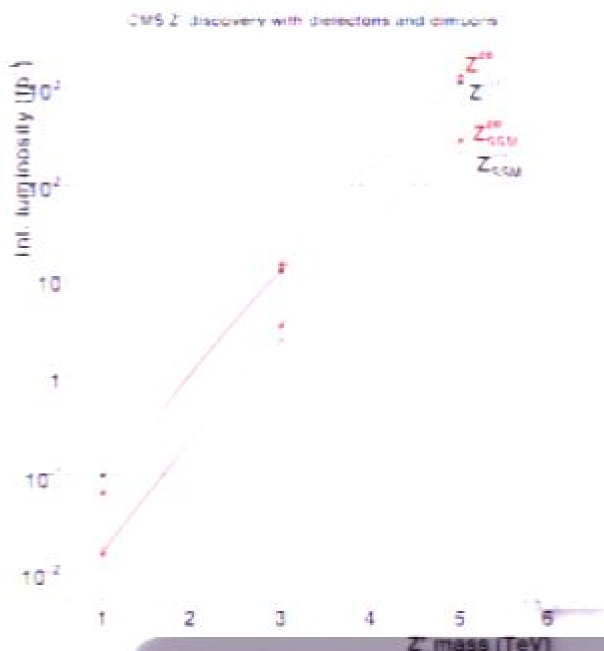
i.e. Z-primes because they are easy to be discovered fast if they are 1 TeV heavy



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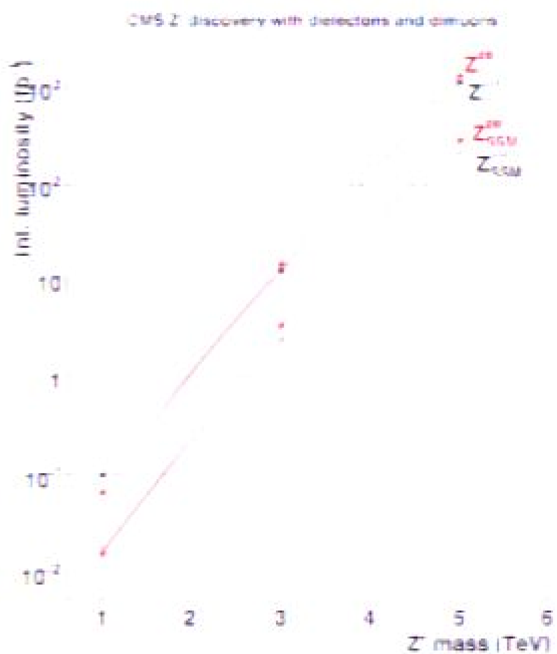

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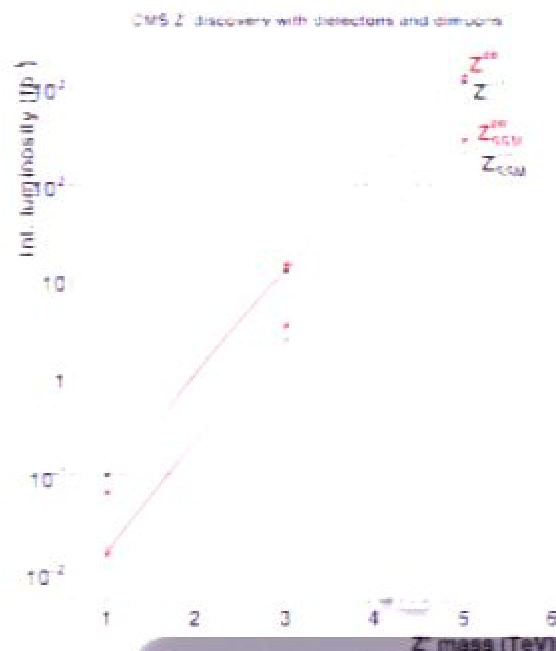

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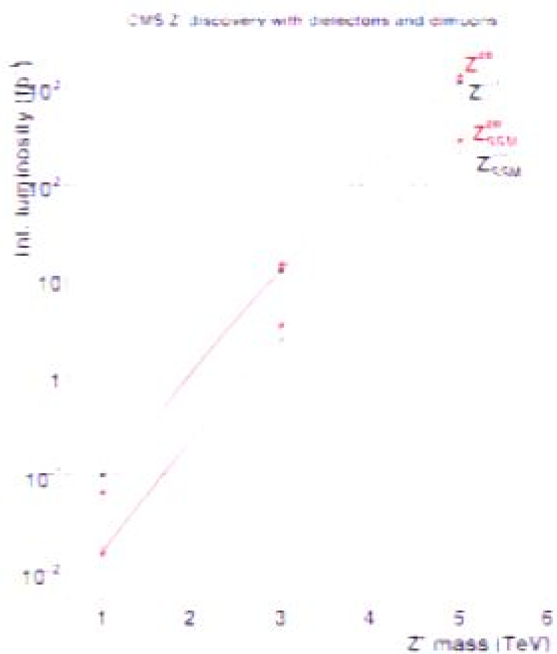

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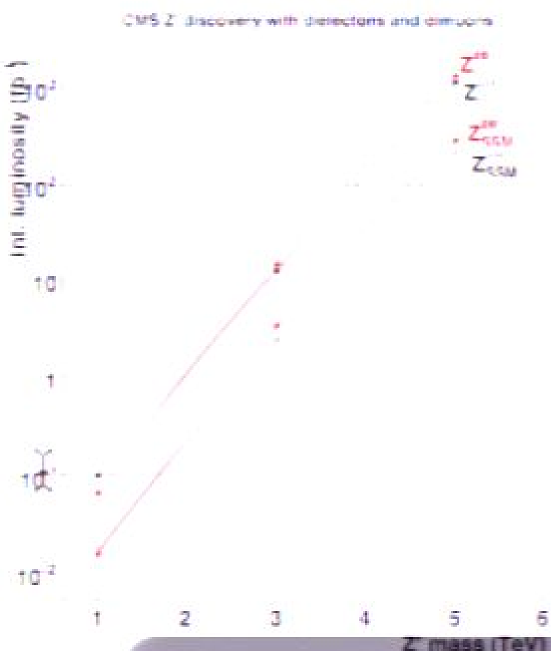

ATLAS/CMS program of work

ATLAS CSC SUSY Notes

- SUSY1 : Data-driven Estimation of Z/W backgrounds to SUSY
- SUSY2 : Data-driven Estimation of top Backgrounds to SUSY
- SUSY3 : Data-driven Estimation of QCD Backgrounds to SUSY
- SUSY4 : Estimation of Heavy Flavor backgrounds and associated systematic
- SUSY5 : Searches and inclusive studies for SUSY events
- SUSY6 : Exclusive measurements for SUSY events
- SUSY7 : Gaugino direct productions
- SUSY8 : Studies for Gauge mediated SUSY

ATLAS CSC Exotics Notes

- Black Holes
- Dibosons
- Lepton+jets
- Dileptons
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ATLAS/CMS program of work

- Leptonic searches (SUSY) [WG1]
  - Search for SUSY in ≥ 1 lepton+E_T^{miss}+jets at 14 TeV in the electron and muon channels ($\mathcal{O}$(100 pb^{-1})).
  - in dilepton pairs+ E_T^{miss}+jets at 14 TeV in the electron and muon channels ($\mathcal{O}$(100 pb^{-1})).
  - Search for SUSY in trileptons + jets at 14 TeV. (1 fb^{-1}).
- Hadronic searches (SUSY) [WG2]
  - Search for SUSY in 0 lepton + E_T^{miss}+ jets at 14 TeV ($\mathcal{O}$(100) pb^{-1}).
  - in $b\bar{b}$ + E_T^{miss} + jets at 14 TeV ($\mathcal{O}$(100) pb^{-1}).
  - in di-tau + E_T^{miss} at 14 TeV ($\mathcal{O}$(100) pb^{-1}).
- HSCP and photonic searches (GMSB) [WG3]
  - Search and reconstruction of heavy stable charged particles at 14 TeV using TOF and dE/dx (500 pb^{-1}, model dependent).
  - Search for GMSB using prompt photons at 14 TeV (500 pb^{-1}).
- High Energy Pair Searches (U(1)$'$/ED/other) [WG4]
  - Search for TeV mass resonances in diEM events at 14 TeV (100 pb^{-1} $\mathcal{O}$(fb^{-1}))
  - in dimuon events at 14 TeV (100 pb^{-1})
  - in dijet events at 14 TeV ($\mathcal{O}$(fb^{-1}))

Alerts and Emphases in the Past Year

- Trigger aware analyses
- Data-driven background estimates, use of control samples
- Understanding of Standard Model QCD associated production of anything at $\sqrt{s} = 14$ TeV (especially W/Z/top, see talk by Michelangelo Mangano)
- Engineering of "first data" strategies – i.e. shifting gears to the pb^{-1} from the fb^{-1}
- Engineering of faster, simpler navigation/orientation compass in the vast parameter space

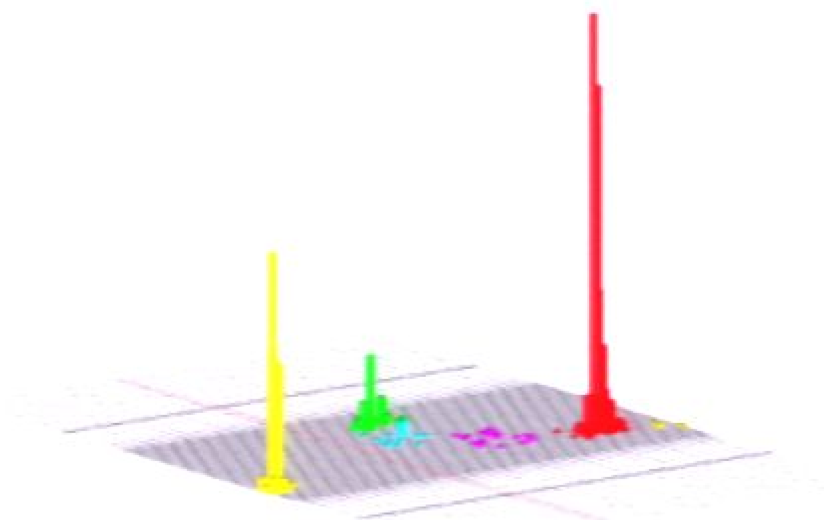
First Data and SUSY

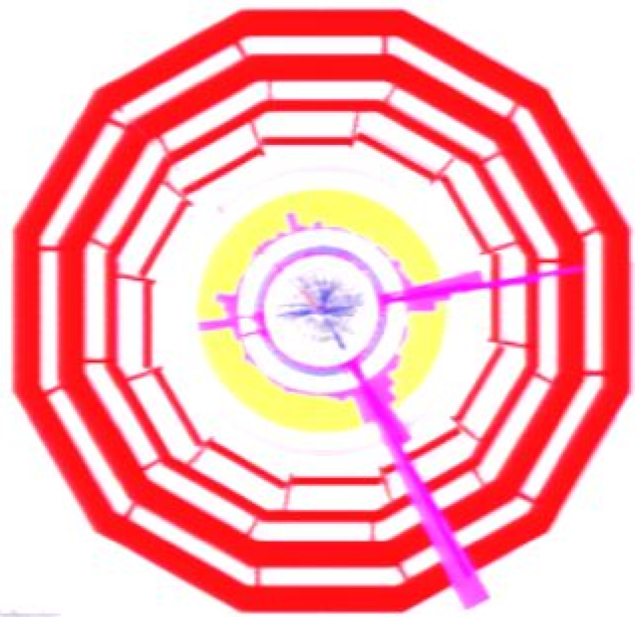
General Stategy (SUSY06, Giacomo P. /Maria S. for ATLAS/CMS)

- Choose signatures identifying well defined decay chains
- Extract constraints on masses, couplings, spin from decay kinematics/rates
- try to match emerging pattern to tentative template models
- having adjusted template models to measurements, try to find additional signatures to discriminate different options

Canonical Dark Matter Searches Using Missing Energy

E_T^{miss}=360 GeV, $E_T(1)$=330 GeV, $E_T(2)$=140 GeV, $E_T(3)$=60 GeV

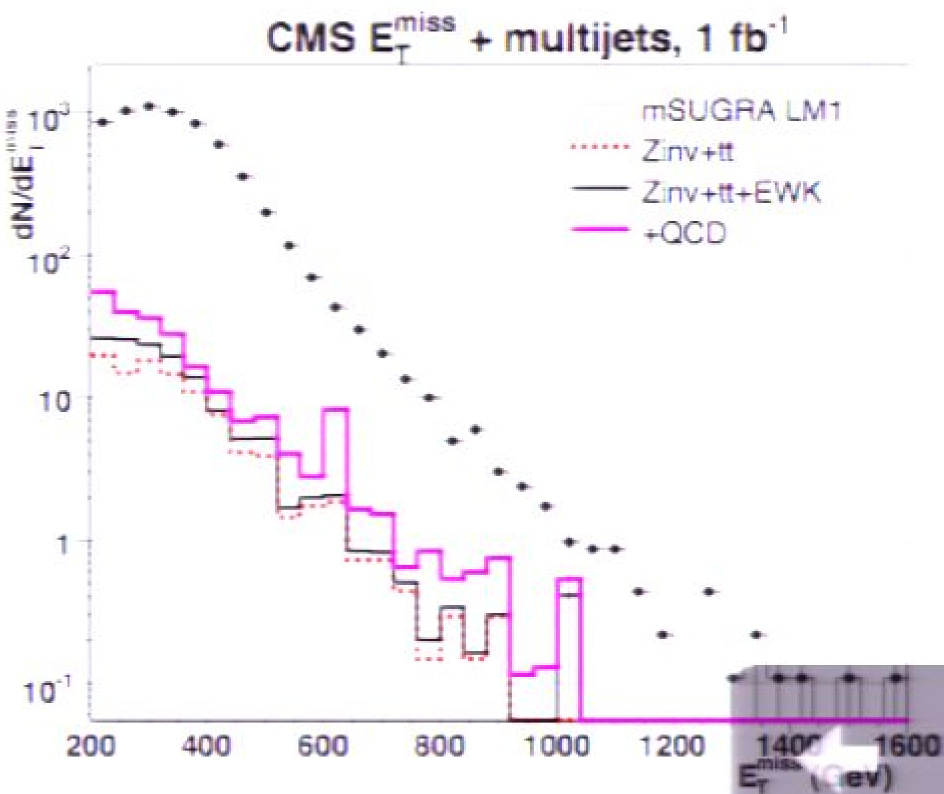




LHC can discover such events fast. Their cross section is huge : 10,000 to 1,000,000 events per year...

Inclusive Signatures with Missing Energy

E_T^{miss} +jets, gluino=600 GeV, neutralino=100 GeV



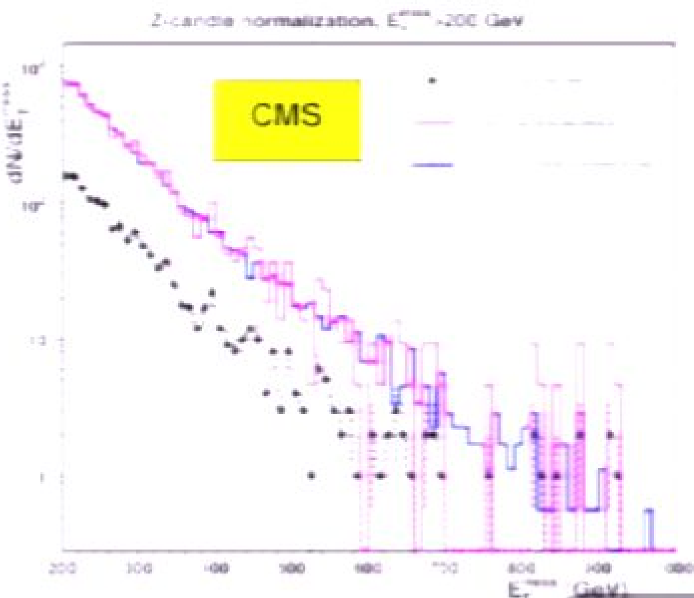
- fast-track to discovery of "low mass" SUSY $\mathcal{O}(10)$ pb^{-1} b/c of signal cross section – control of systematics using SM processes (e.g. Z+jets, top)
- the time between $\mathcal{O}(10)$ and $\mathcal{O}(100)$ pb^{-1} of well understood data will be critical for the discovery and characterization of SUSY

Standard Model Candles and Handles

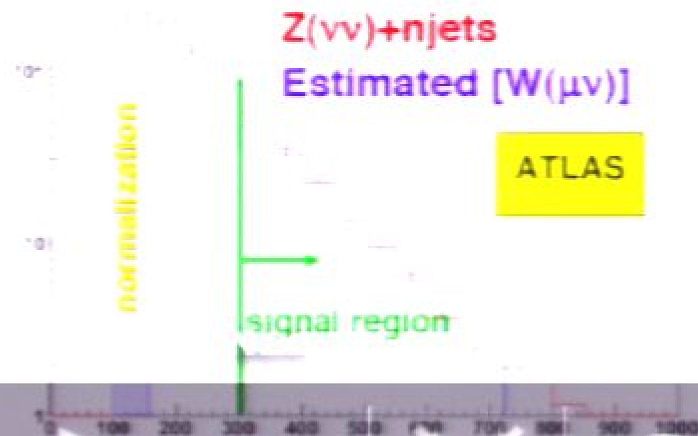
Example

The *Z* candle

W/Z+jets Background



- MC to data normalization avoids systematics due to QCD scale, PDFs, ISR FSR, jet energy scale ...



- CMS : Systematic uncertainty dominated by luminosity, measured ratio R and ρ: 5% precision expected with ~1.5 fb-1

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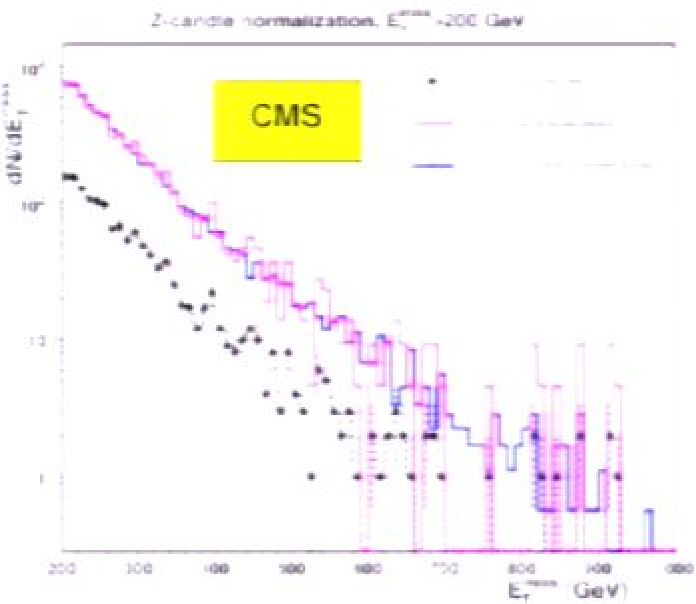

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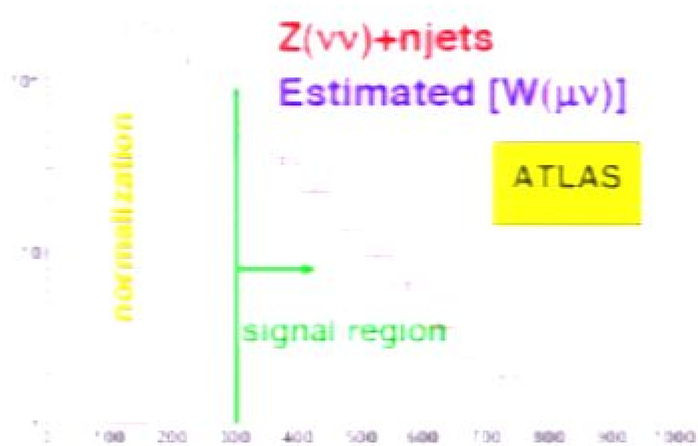

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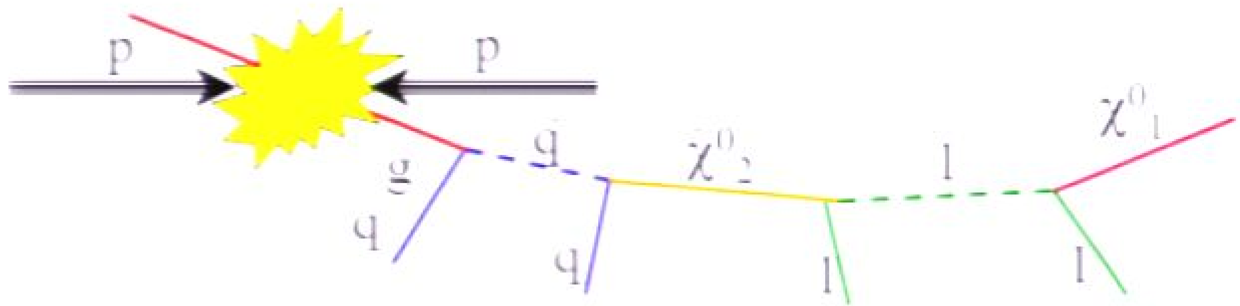
First/Fast Mass Clues (dileptons)



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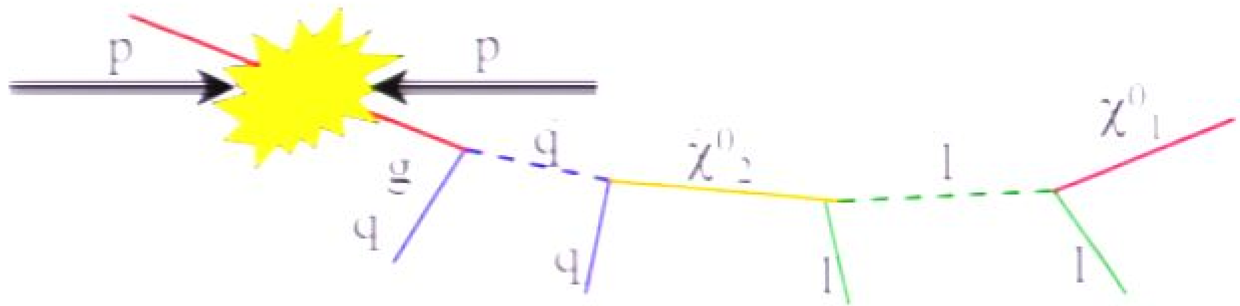
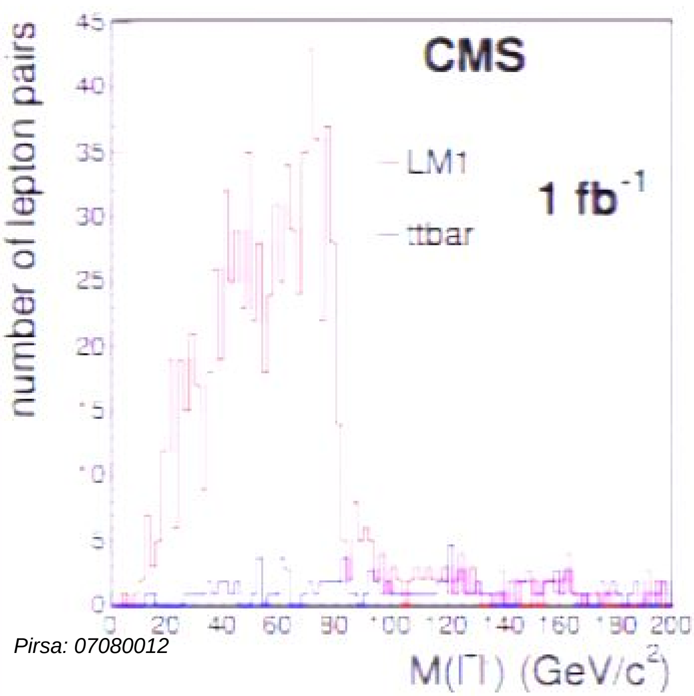
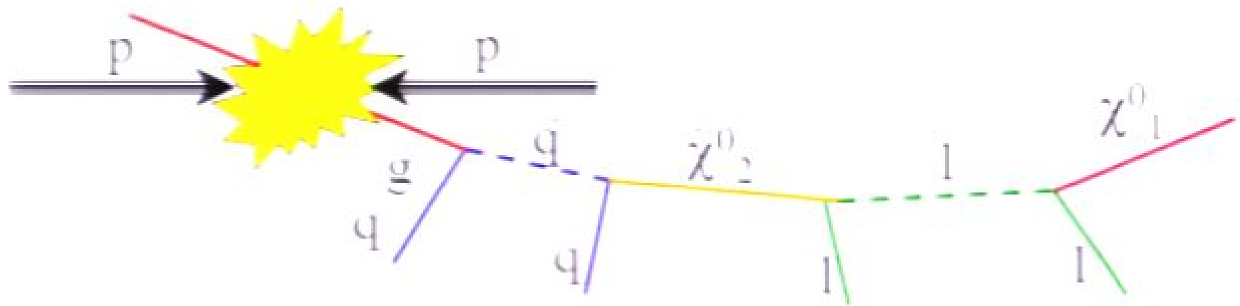
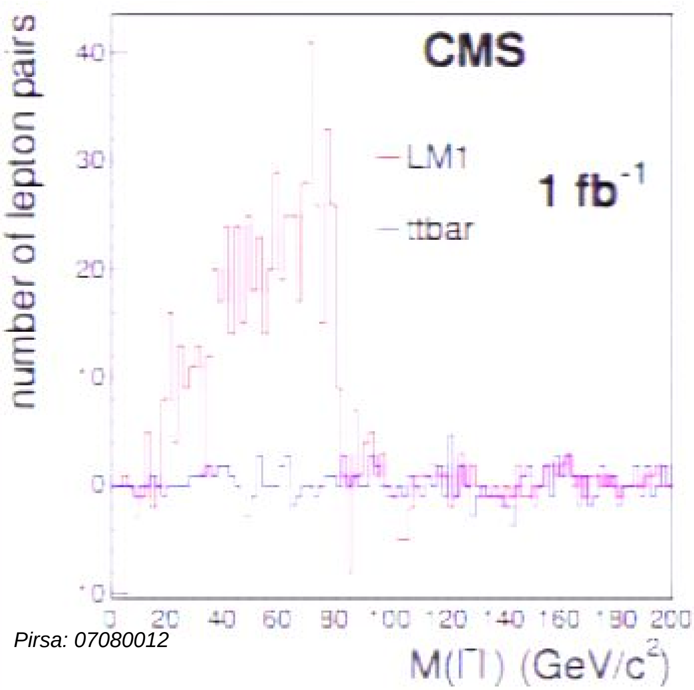




- SFOS dilepton+jets+E_T^{miss}
- $t\bar{t}$:WW+j:Z+j:other$\sim$ 6:1:1:1
- flavor subtraction ($e^-\mu^+ + e^+\mu^-$) to supress chargino, W, $t\bar{t}$, WW, "other"
- L1+HLT trigger path required
- overall systematic on the background 20% (JES dominated)
- 5σ discovery with $\sim$ 20 pb^{-1} (of data understood as expected with 1 fb^{-1}).

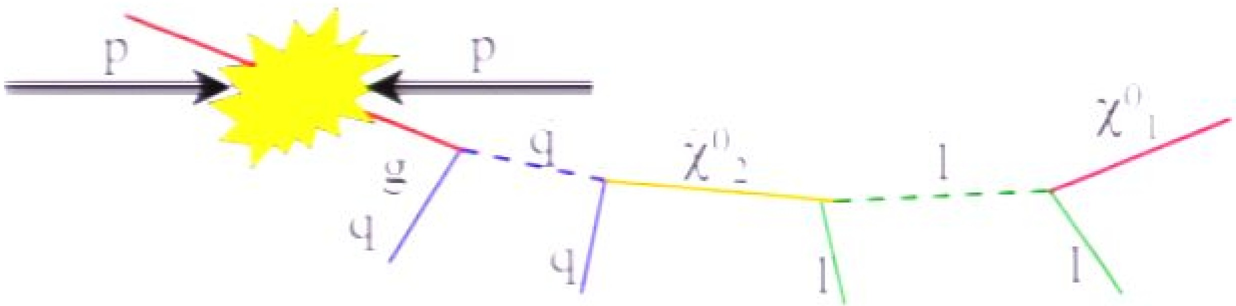
First/Fast Mass Clues (dileptons)

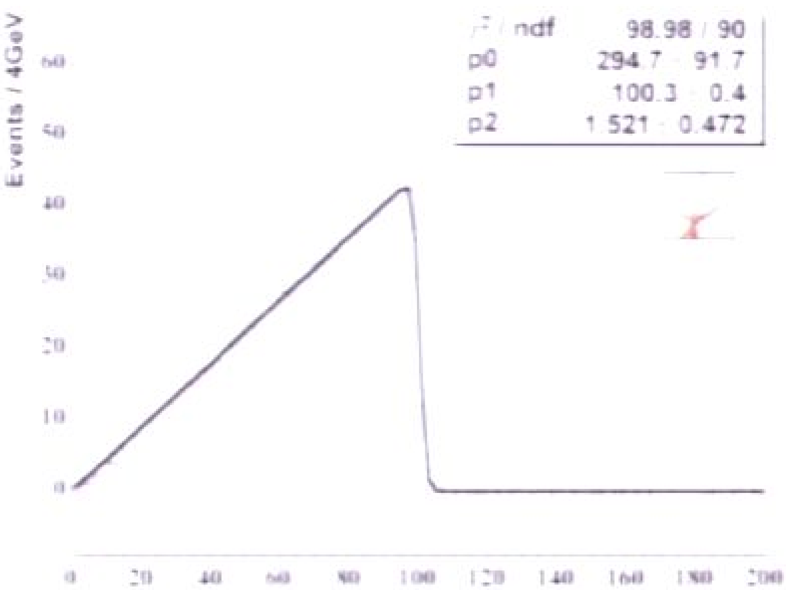




- $M_{\ell\ell}^{max} = M(\tilde{\chi}_2^0)\sqrt{1 - \frac{M^2(\tilde{\ell}_R)}{M^2(\tilde{\chi}_2^0)}}\sqrt{1 - \frac{M^2(\tilde{\chi}_1^0)}{M^2(\tilde{\ell}_R)}}$
- $M_{\ell\ell}^{max}$(meas)= 80.42 ± 0.48 GeV/c^2, *cfr* with
- expected $M_{\ell\ell}^{max}$= 81 GeV/c^2 [given $M(\tilde{\chi}_1^0)$ = 95, $M(\tilde{\chi}_2^0)$= 180 and $M(\tilde{\ell}_R)$ = 119 GeV/c^2]

First/Fast Mass Clues (dileptons)





- $m_0 = 100$ GeV, $m_{1/2}$ = 300 GeV ,A_0 = -300 GeV, tan β = 6 sgn(μ) = +1 [ATLAS SU3 test-point]
- $M_{\ell\ell}^{max}$(meas)= 100.3 ± 0.4 GeV/c^2 with 4.20 fb^{-1} (Geant-4 based simulation, no systematics)
- ATLAS-preliminary

towards SUSY reconstruction

Lepton+Jet Endpoint

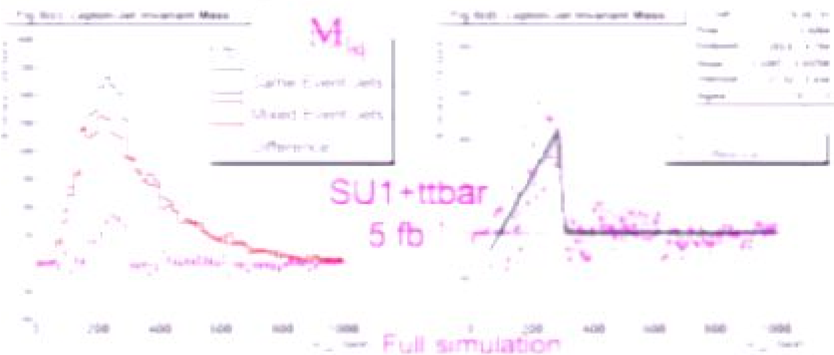
$\tilde{q}_L \to q\tilde{\chi}_2^0 \to ql^{\pm}\tilde{l}_R \to ql^{\pm}l^{\mp}\tilde{\chi}_1^0$

$$M_{lq}^{max} = \sqrt{\frac{(M_{\tilde{q}_L}^2 - M_{\tilde{\chi}_2^0}^2)(M_{\tilde{\chi}_2^0}^2 - M_{\tilde{l}}^2)}{M_{\tilde{\chi}_2^0}^2}}$$

Event selection:

- one lepton (electron, muon) p_T > 20 GeV, $|\eta|$<2.5, chi2/dof<10 for muon
- EMlikelihood > 0.95, lepton isolation cut E_T < 10GeV in 0.45 cone
- Cone7 (R=0.7) jets, ΔR(lepton,jet)>0.7
- to reduce lepton+jets and dilepton ttbar background
  - leading and second leading jet with E_T > 200 GeV
  - transverse mass M_T < 60GeV or M_T > 100GeV
  - E_T miss > 250 GeV

- Use mixed event technique to subtract combinatorial jet background: randomly pair jets from a different event (satisfying same event selection) with the lepton
- Assumptions of the technique: The jet from signal decay chain and the jet from the decay of the other squark have similar kinematic distributions. And the squarks are produced at rest so the event is roughly spherical. Both are valid for SU1 but not for ttbar
- Subtract mixed-event-jet distributions from same-event-jets distribution to obtain an inferred "correct jet" distribution (normalization correction applied)
- Statistical significance of discovery is 5σ with 5 fb
- Expected endpoint: 284 GeV
- Fitted endpoint: 283.6±4.8 GeV

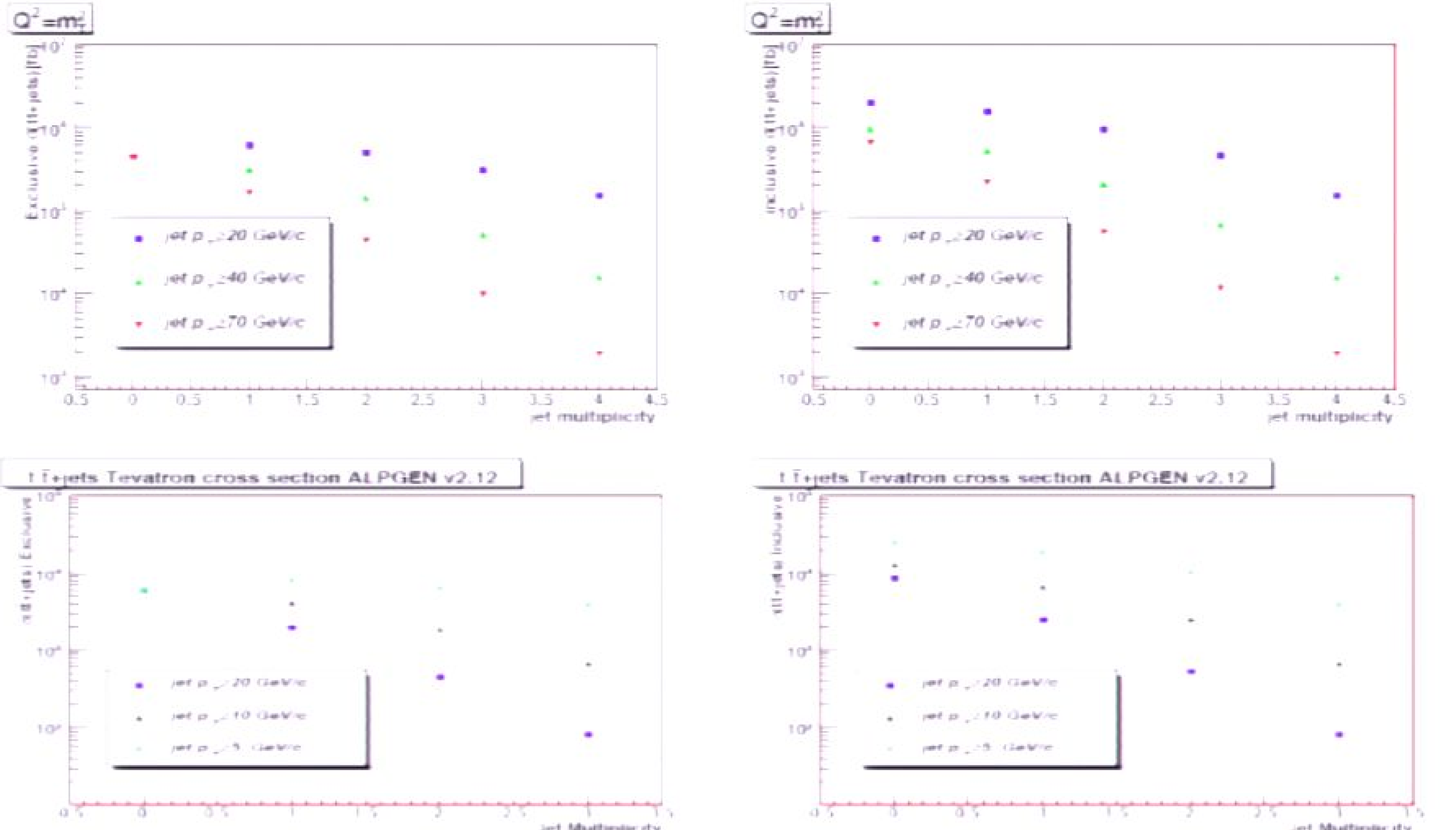


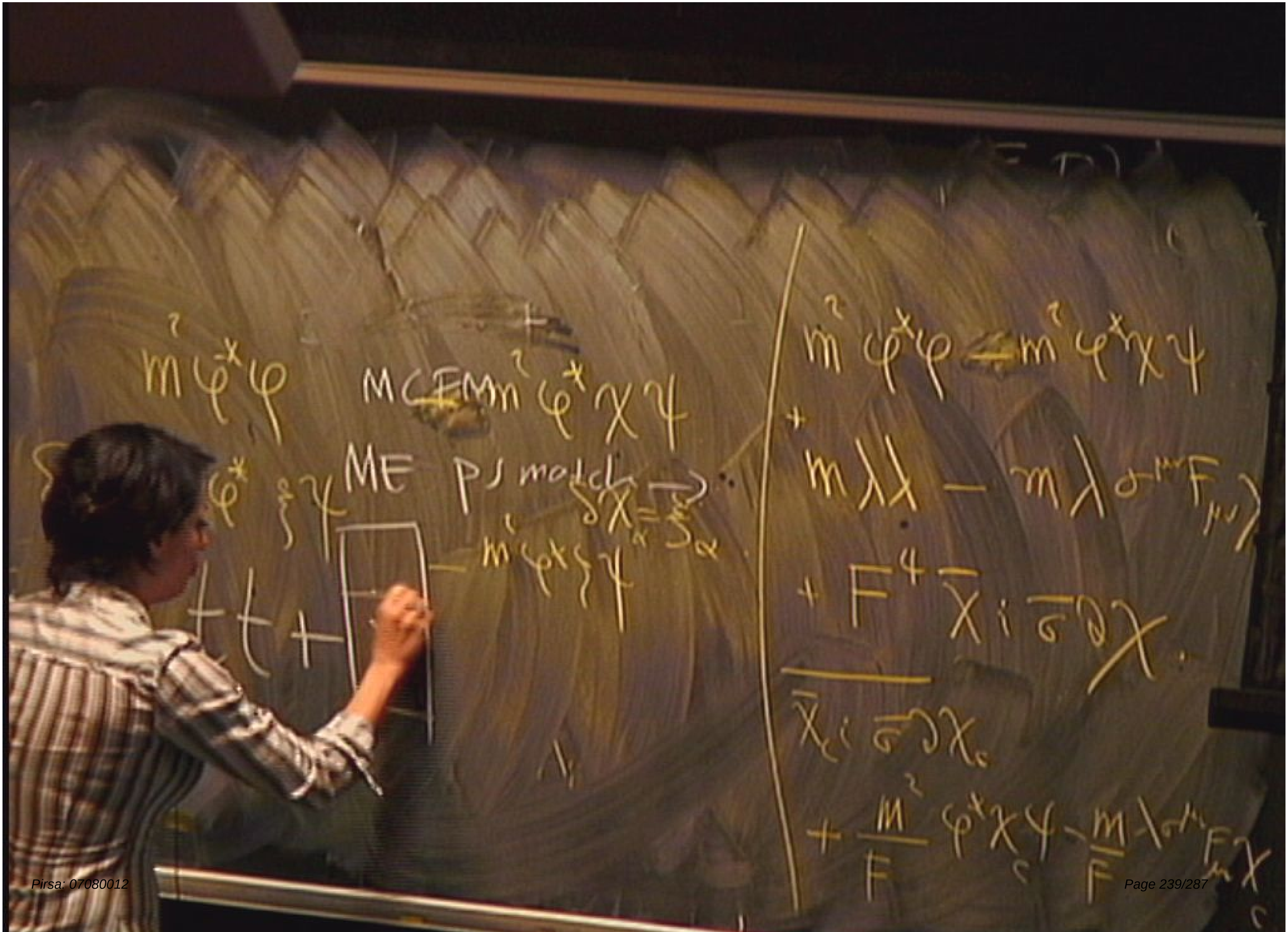
ATLAS note: Cooke et al ATL-COM-PHYS-2007-002

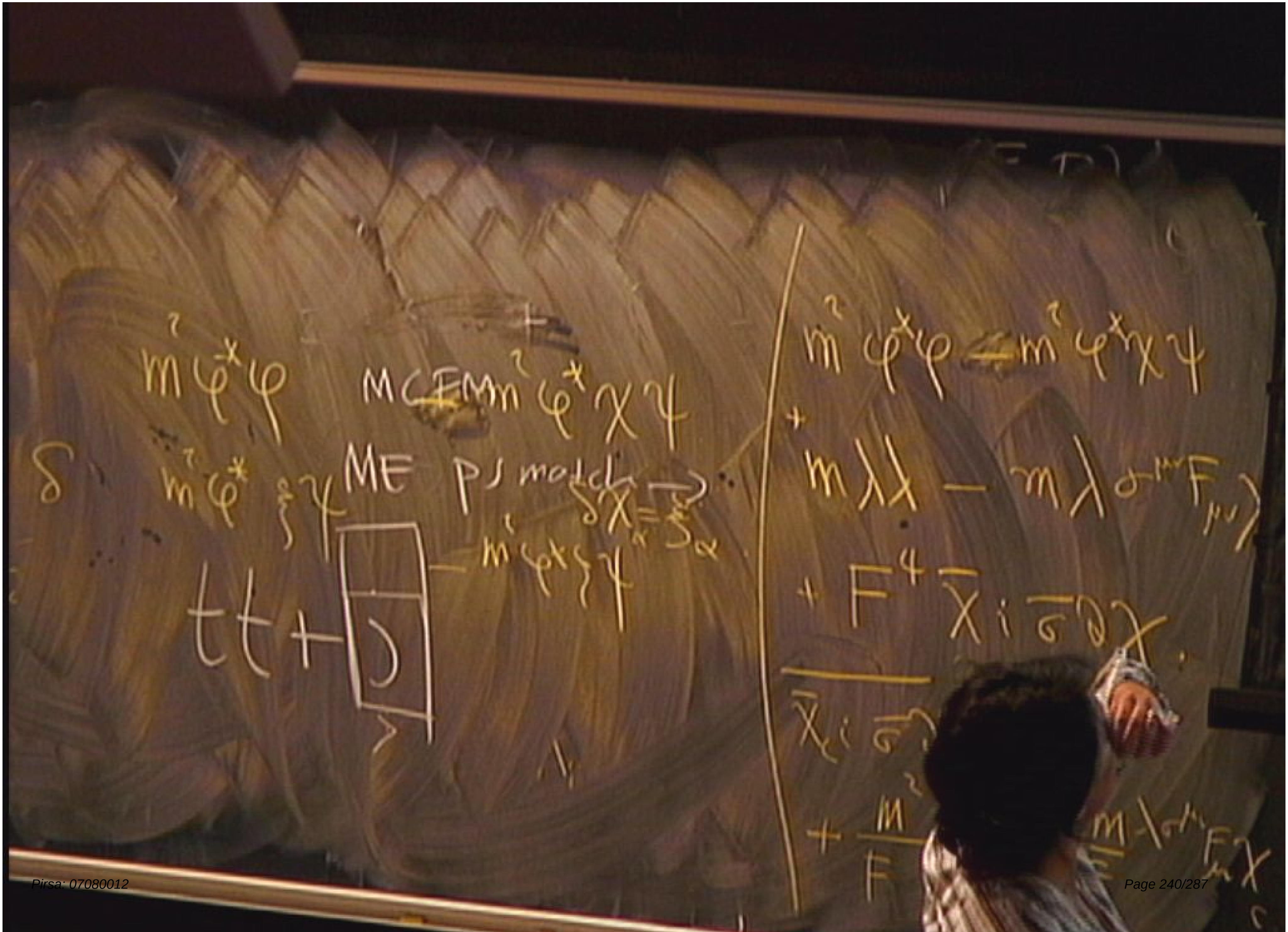
Spin measurements, SFITTER, FITTINO results (usually require large luminosity

Top QCD Matters @LHC: non trivial

MS, M.Pierini **ALPGEN, tt+Njets... (see also MLM)**






m²φ*φ
ME PJ match
m²φ*φ m²φ*χψ
+ mλλ − mλσ^μν F_μν χ
+ F⁴ − χ̄ i σ̄∂χ

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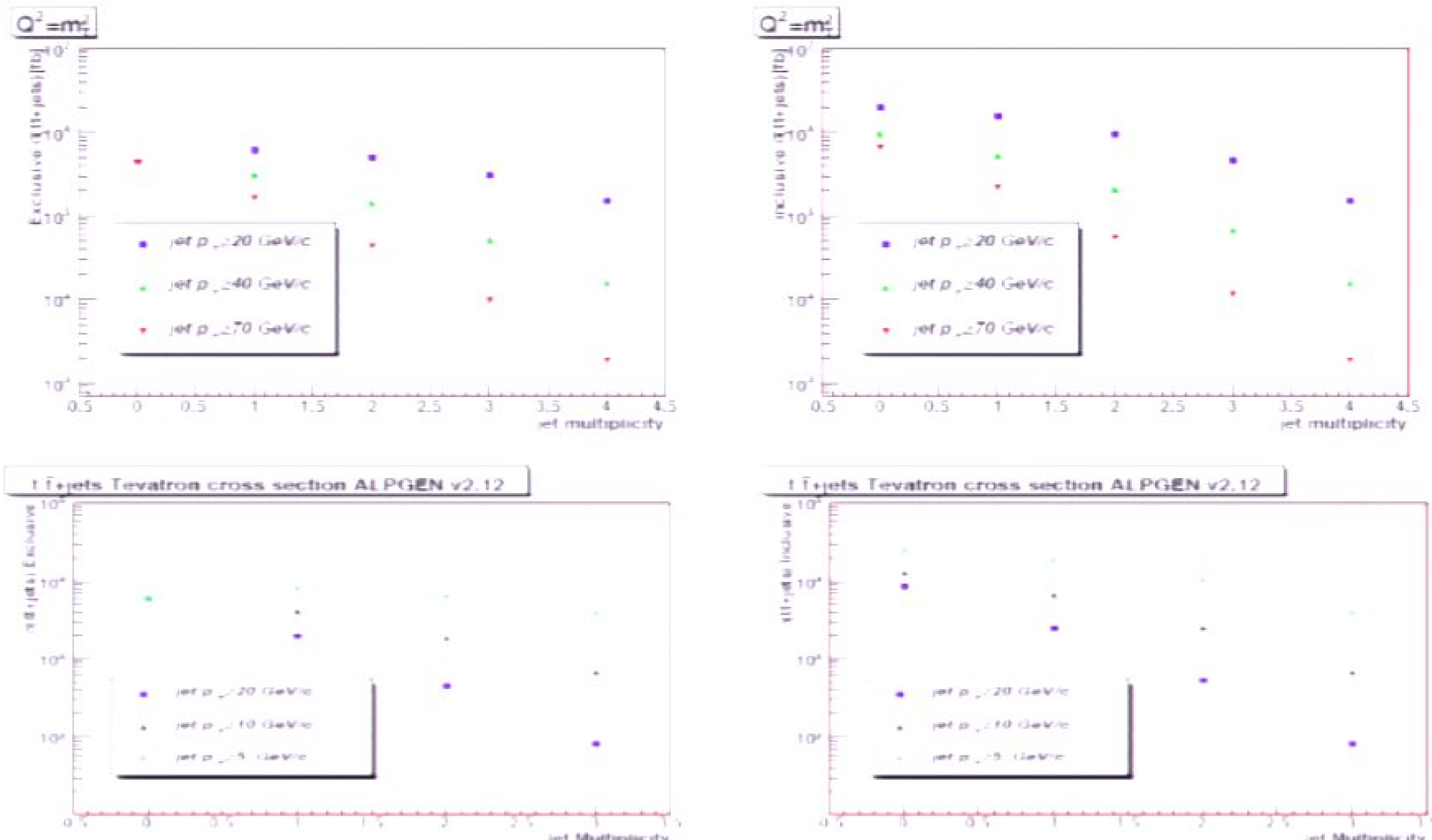
MS, M.Pierini **ALPGEN, tt+Njets... (see also MLM)**



$m^2 \varphi^* \varphi$ $\quad M(F/M) m^2 \varphi^* \chi \psi$

$\delta \quad m^2 \varphi^* \xi \psi$ $\quad$ ME PJ match $\rightarrow$ $\delta \chi = \xi$

$m^2 \varphi^* \xi \psi \quad \xi_\alpha$

$tt + \boxed{D}$

720

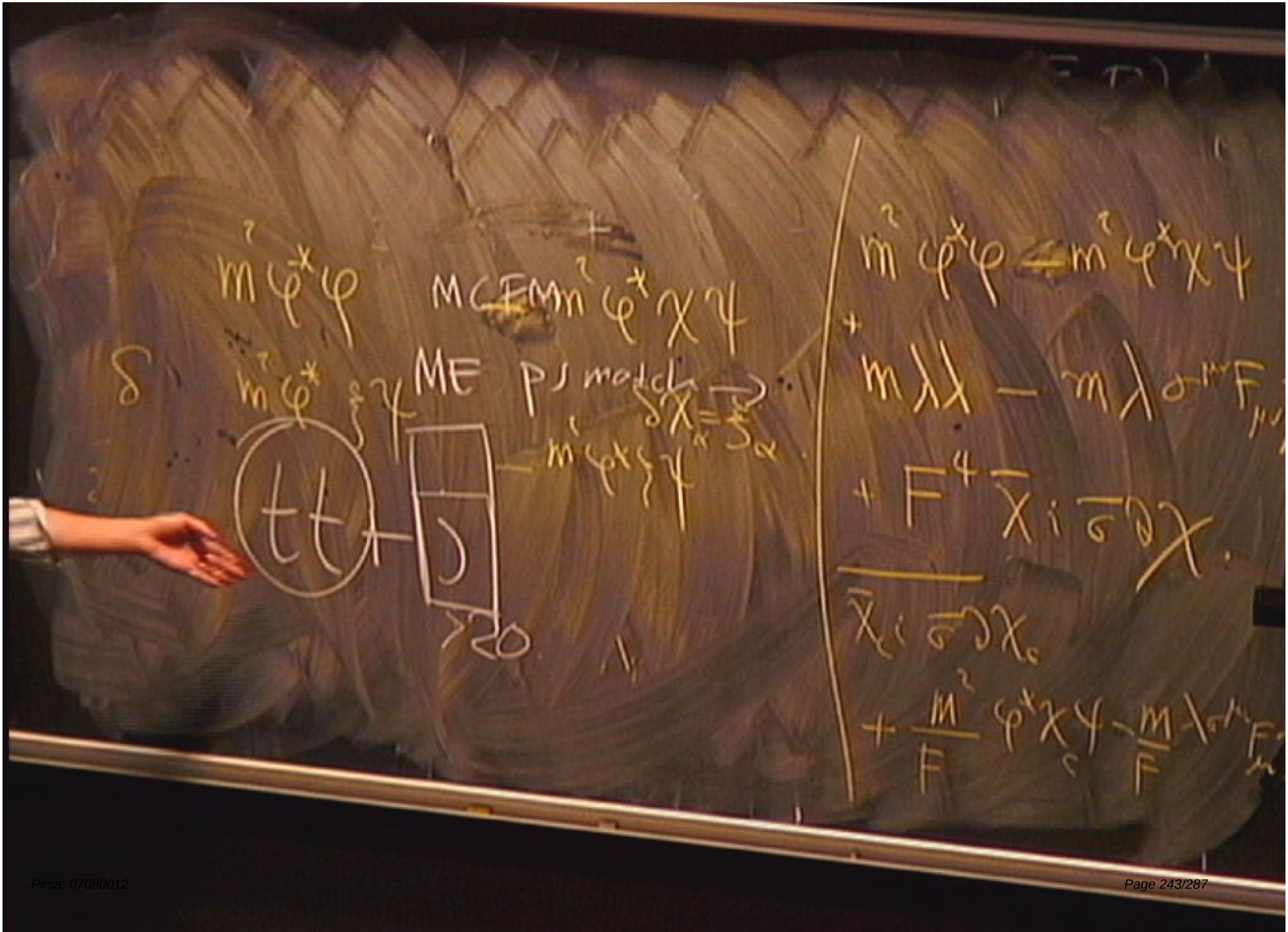
$m^2 \varphi^* \varphi \leftarrow m^2 \varphi^* \chi \psi$

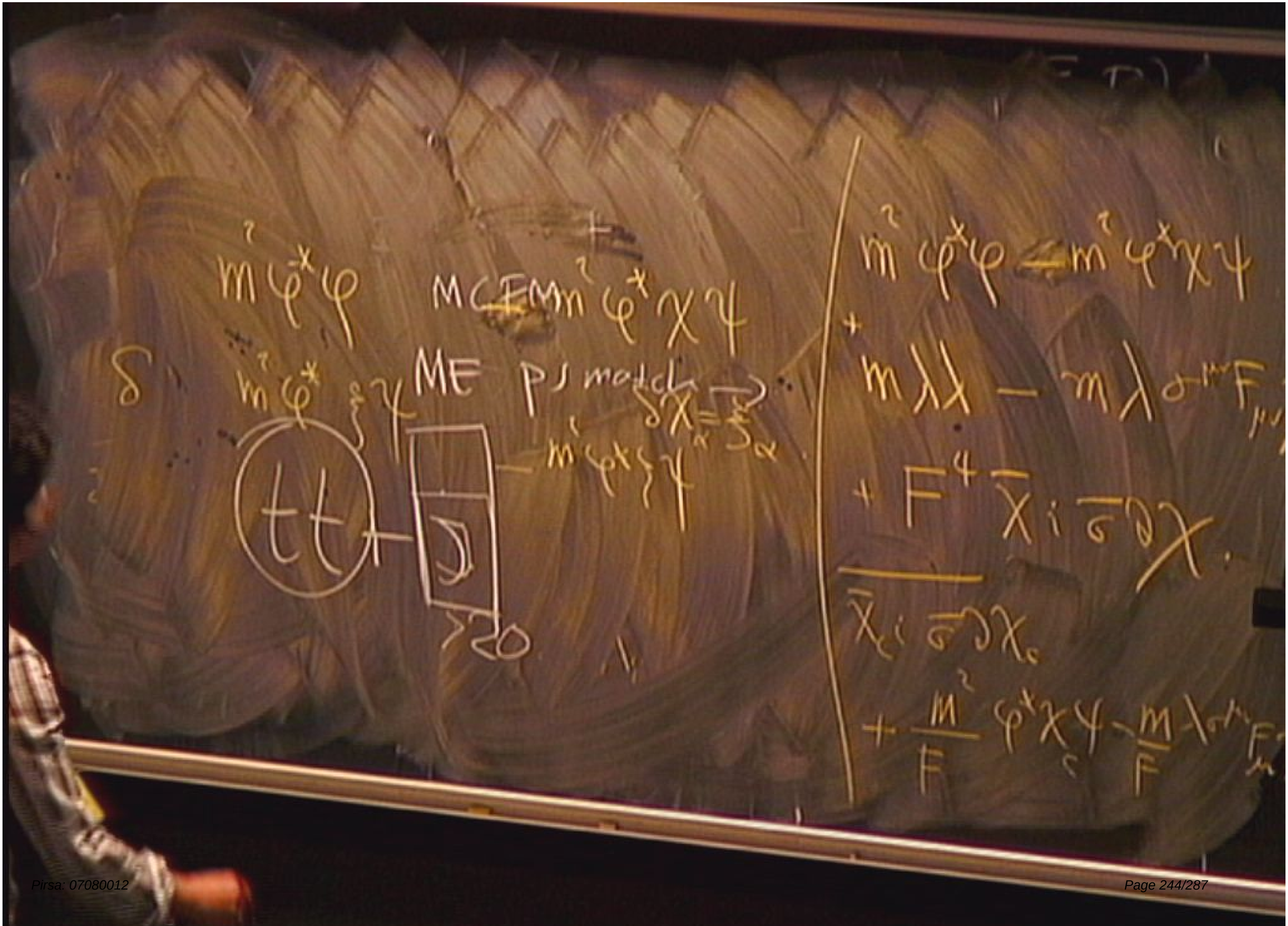
$+ m\lambda\lambda - m\lambda \sigma^{\mu\nu} F_{\mu\nu}$

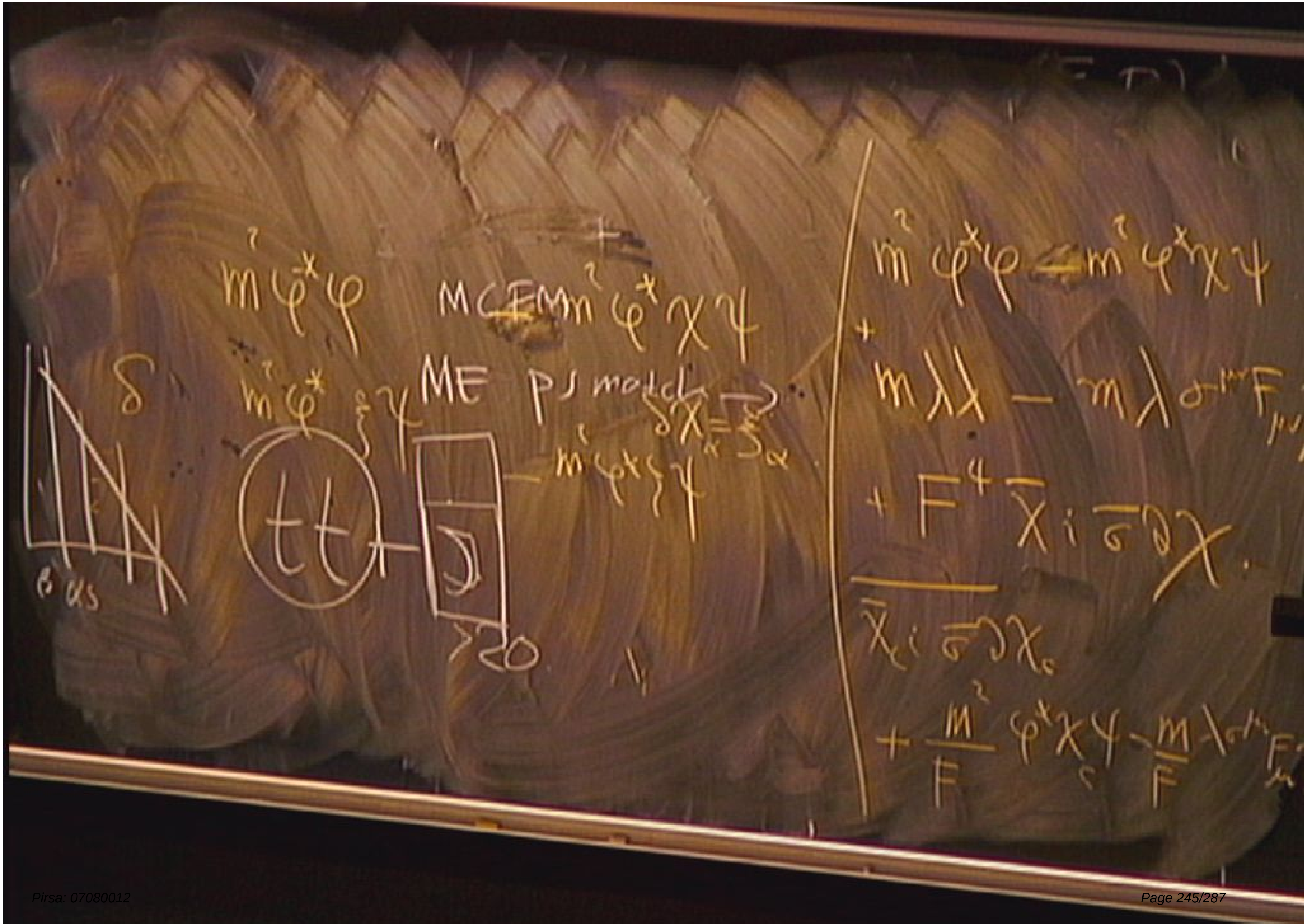
$+ F^4 \bar{\chi} i \bar{\sigma} \partial \chi.$

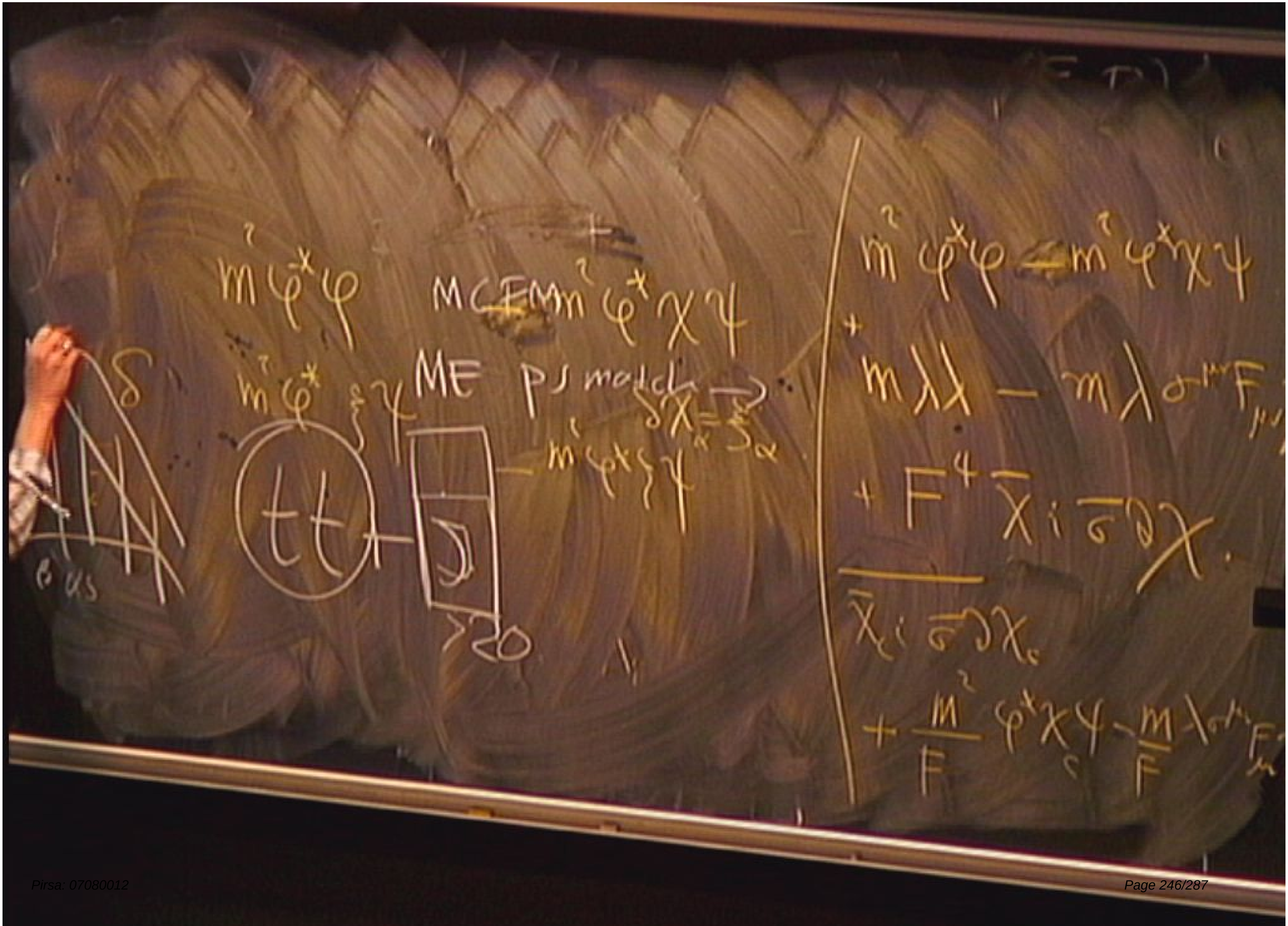
$\bar{\chi}_c i \bar{\sigma} \partial \chi_c$

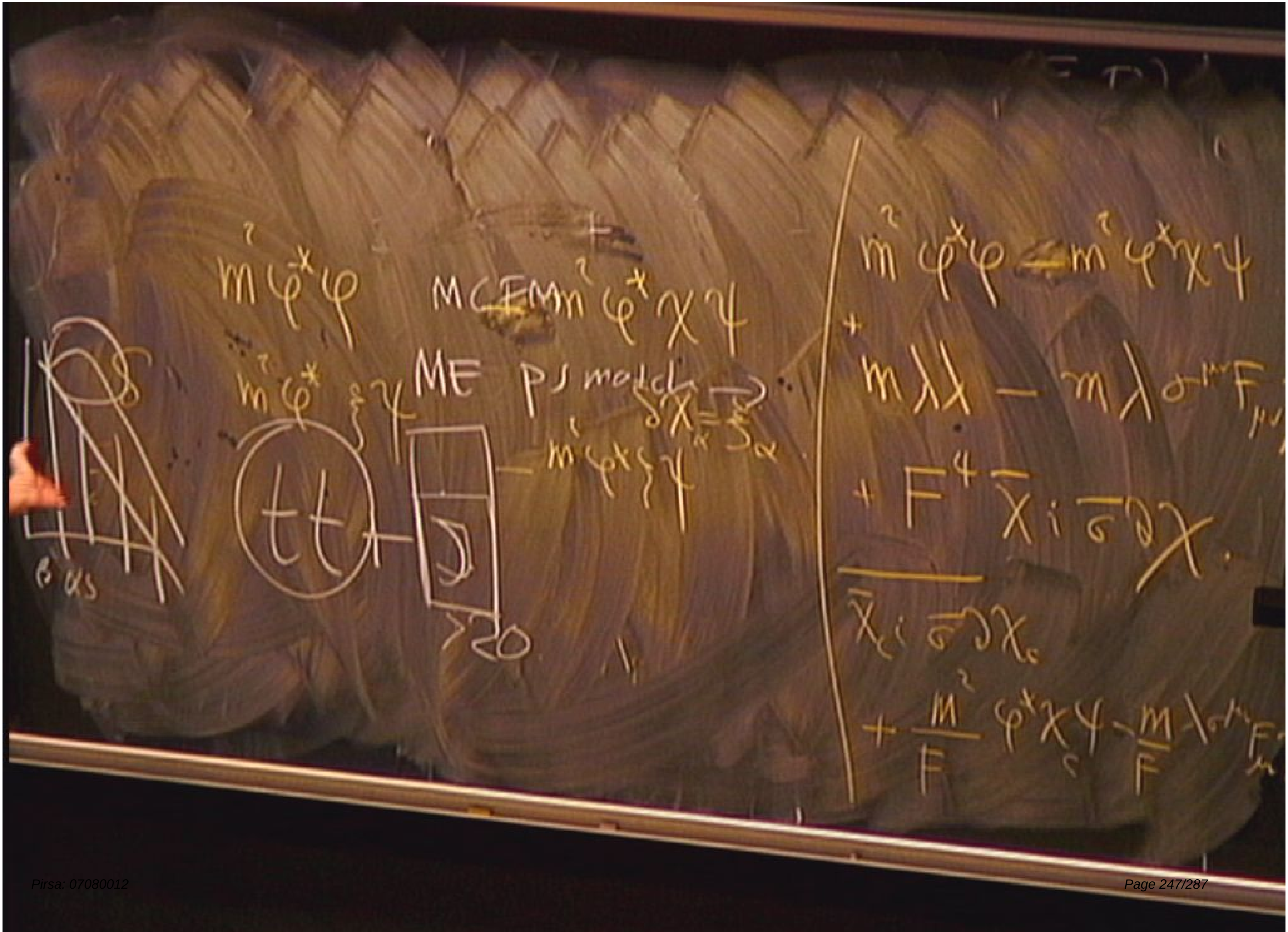
$+ \frac{M^2}{F} \varphi^* \chi_c \psi - \frac{M}{F} \lambda \sigma^{\mu\nu} F_{\mu\nu}$


ME
pJ match
>20




ME
pJ match




MCFM
ME
PJ match
720

Top QCD Matters @LHC: non trivial

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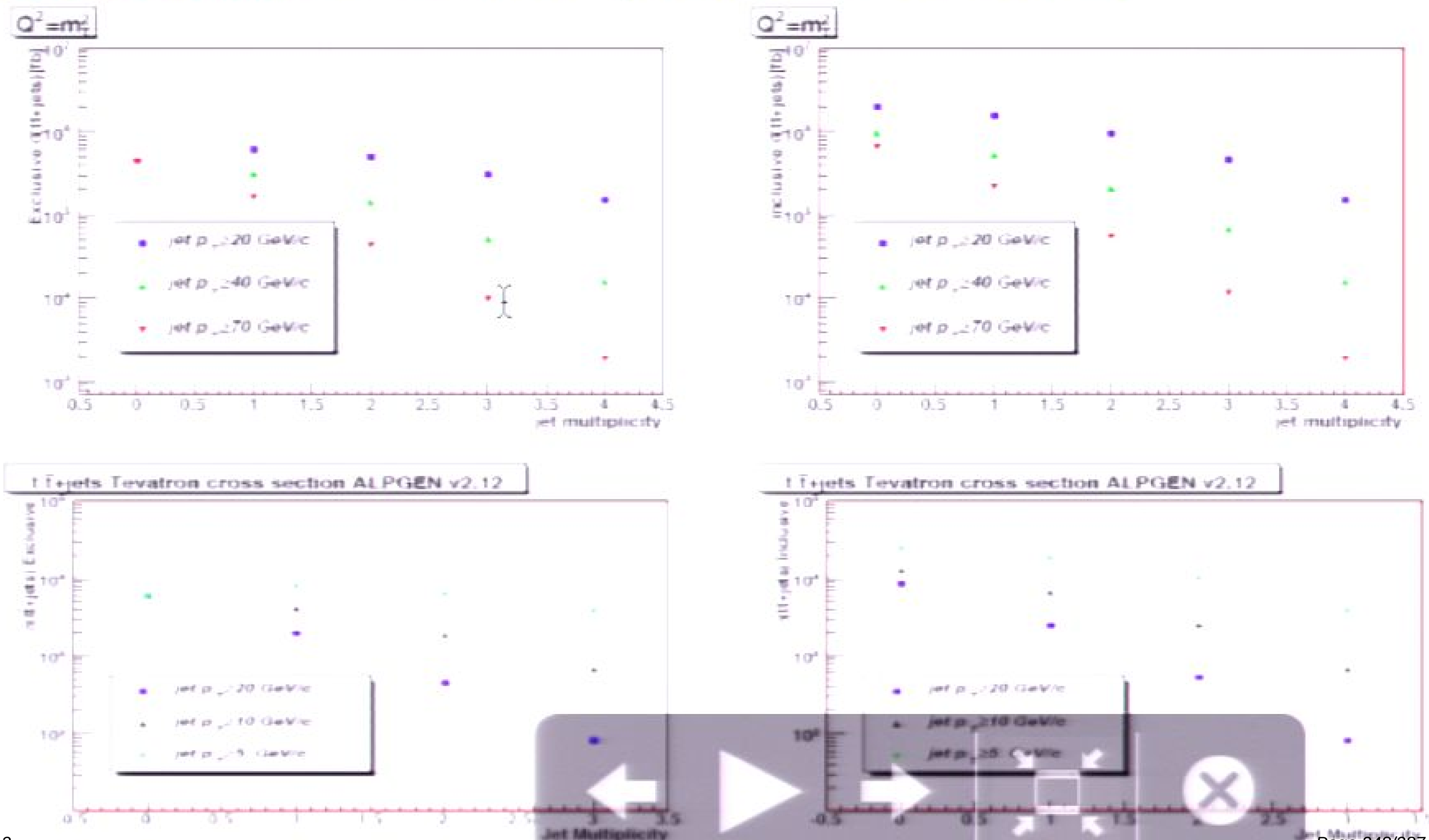

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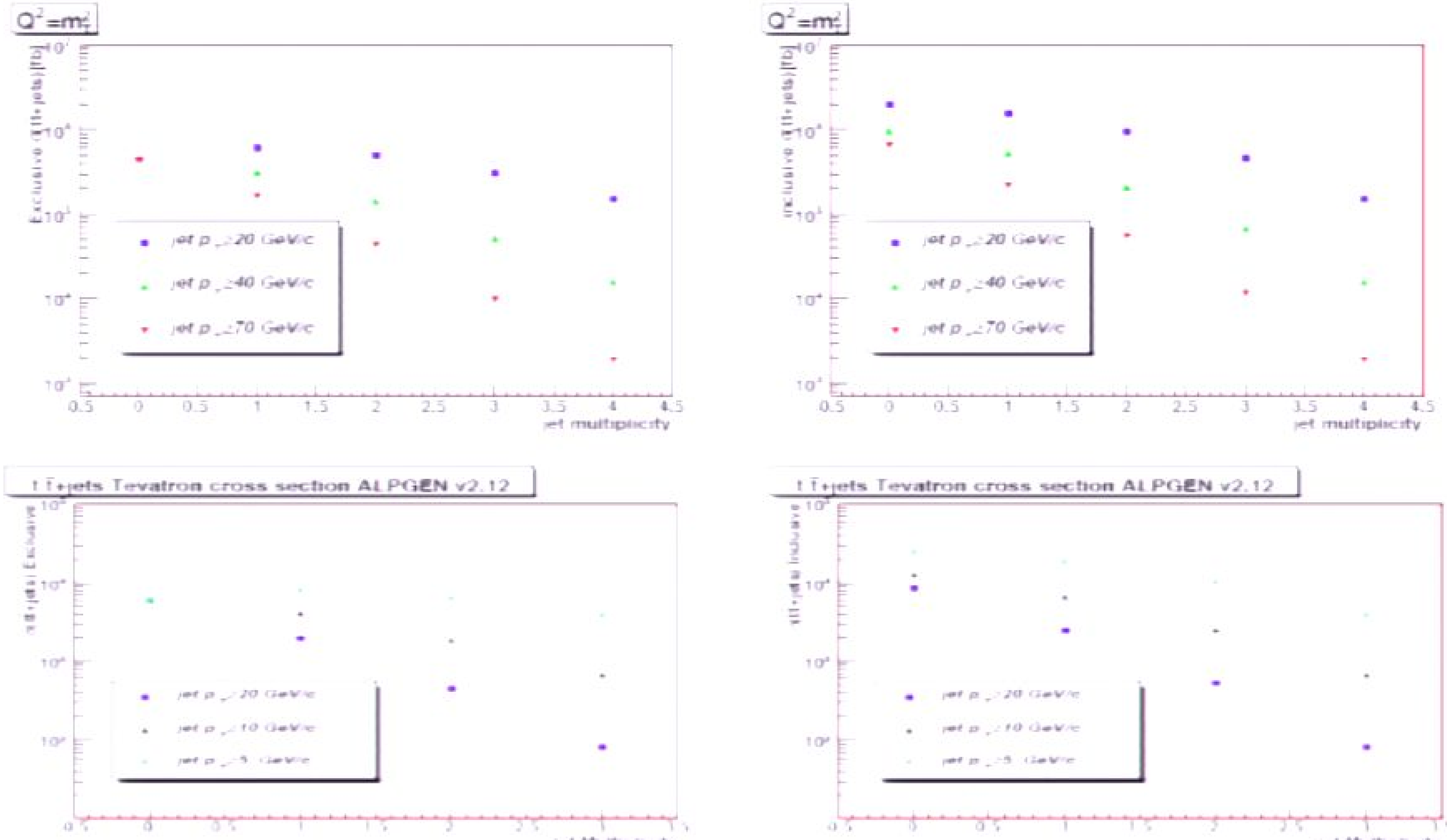

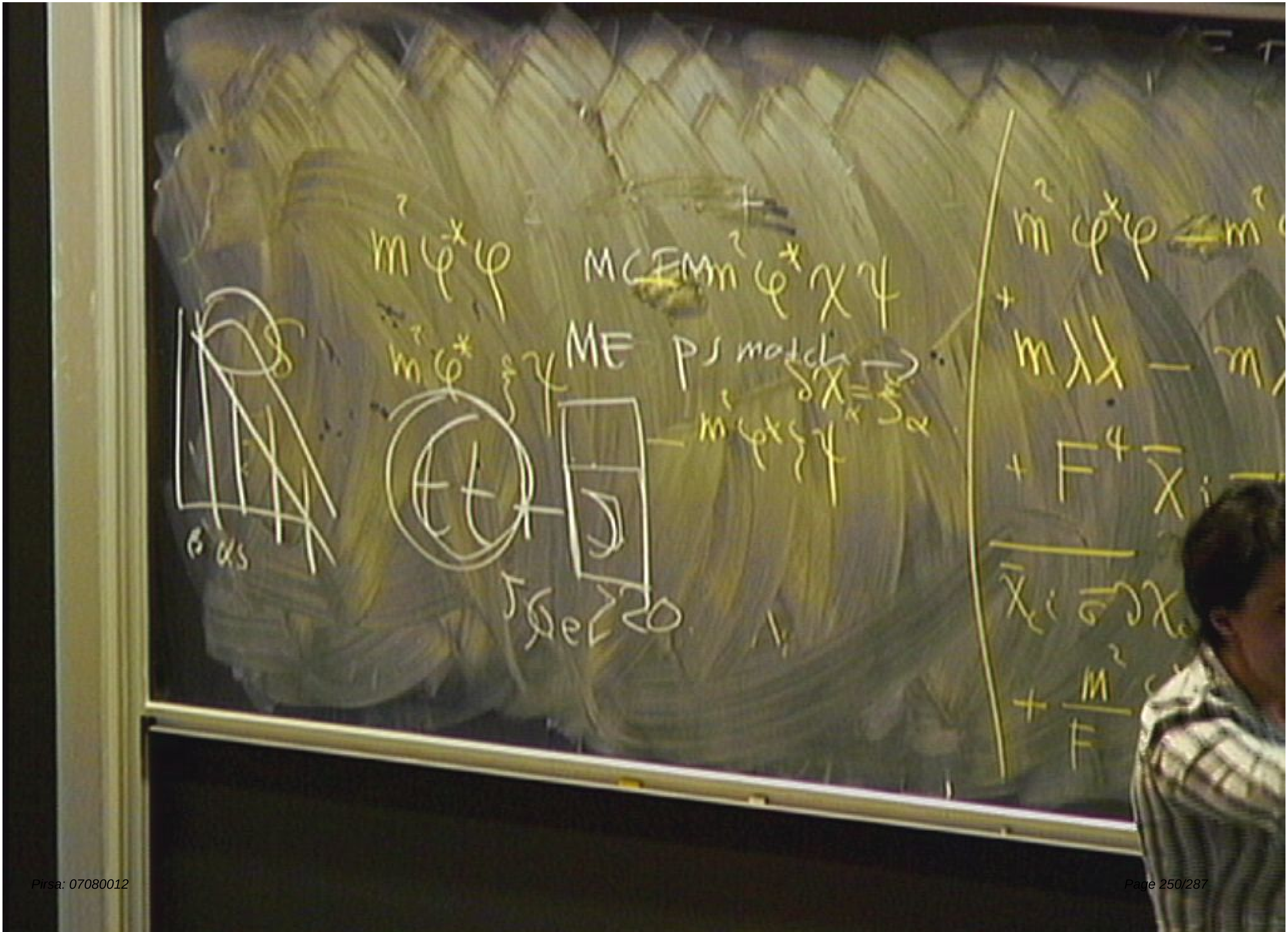

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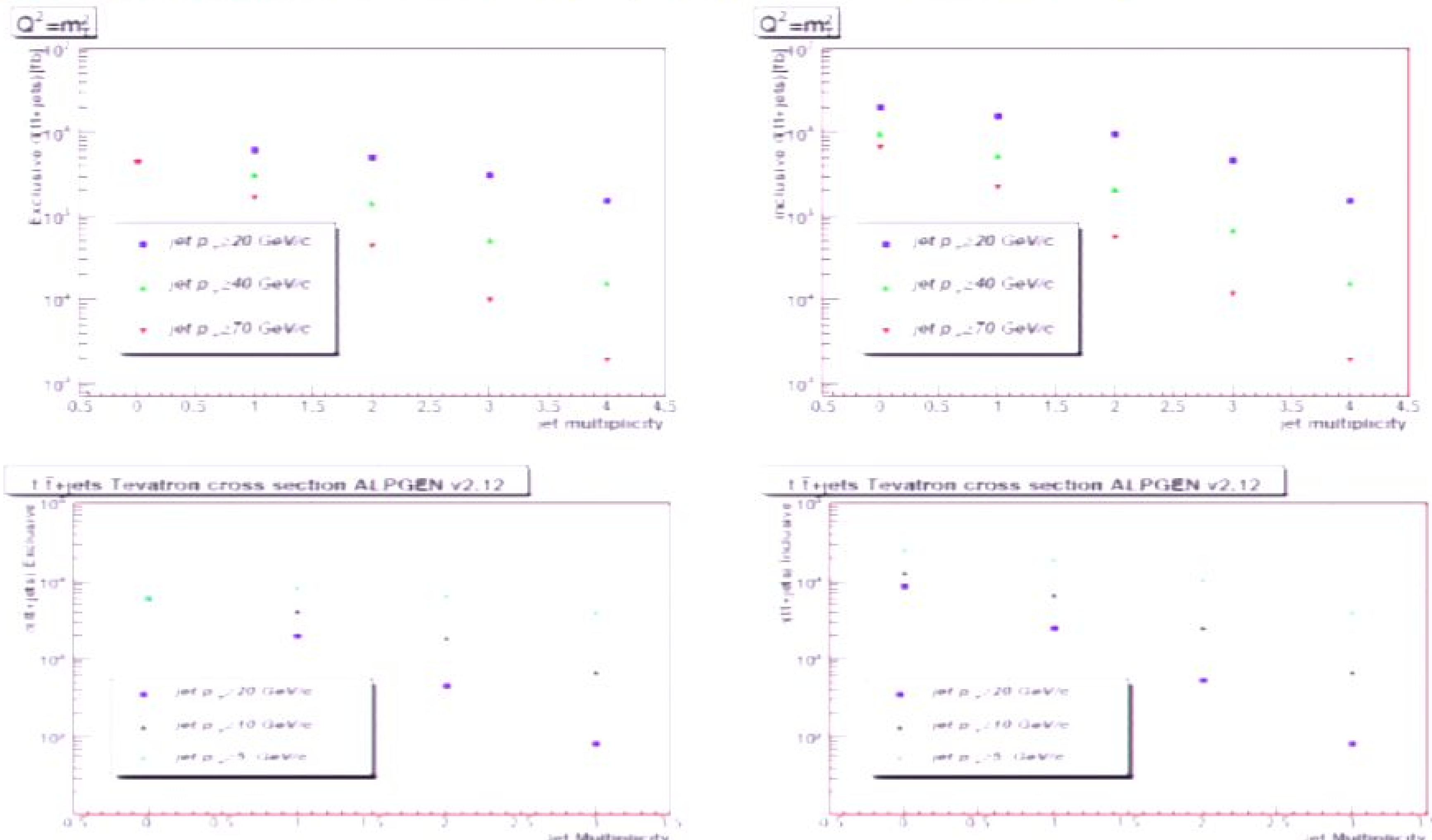

CMS SUSYBSM discovery plan

- Search for SUSY (Evidence for excess) in >1 lepton+E_T^{miss}+jets at 14 TeV in the electron and muon channels (100 pb^{-1}).
- Search for SUSY (Evidence for excess) in opposite sign dilepton pairs+ E_T^{miss}+jets at 14 TeV in the electron and muon channels (20 pb^{-1})
- Search for SUSY (Evidence for excess) in same-sign dilepton pairs + E_T^{miss}+jets at 14 TeV in the electron and muon channels (200 pb^{-1})
- Search for SUSY (Evidence for excess) in Z^0 leptonic decays+ E_T^{miss}+jets at 14 TeV in the electron and muon channels (100 pb^{-1})
- Search for LVF SUSY (Evidence for excess) in $e-\mu$ final state at 14 TeV (500 pb^{-1})
- Search for SUSY (Evidence for excess) in trileptons + jets at 14 TeV. ($\sim fb^{-1}$)
- Search for SUSY (Evidence for excess) in $b\bar{b}$ + 1 lepton at 14 TeV.
- Search for SUSY (Evidence for excess) in 0 lepton + E_T^{miss} + jets at 14 TeV (10 pb^{-1})
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- Search for SUSY (Evidence for excess)in top hadronic decays+ E_T^{miss} at 14 TeV (200 pb^{-1})
- Serach for SUSY (Evidence for excess) in opposite-sign ditau + E_T^{miss} at 14 TeV (200 pb^{-1})
- Search for GMSB (Evidence for excess) in prompt photon final states at 14 TeV (500 pb^{-1})
- Search for GMSB (Evidence for excess) in non-pointing photons at 14 TeV (1 fb^{-1})
- Search and reconstruction of heavy stable charged particles at 14 TeV using TOF and dE/dx (500 pb^{-1})
- ....

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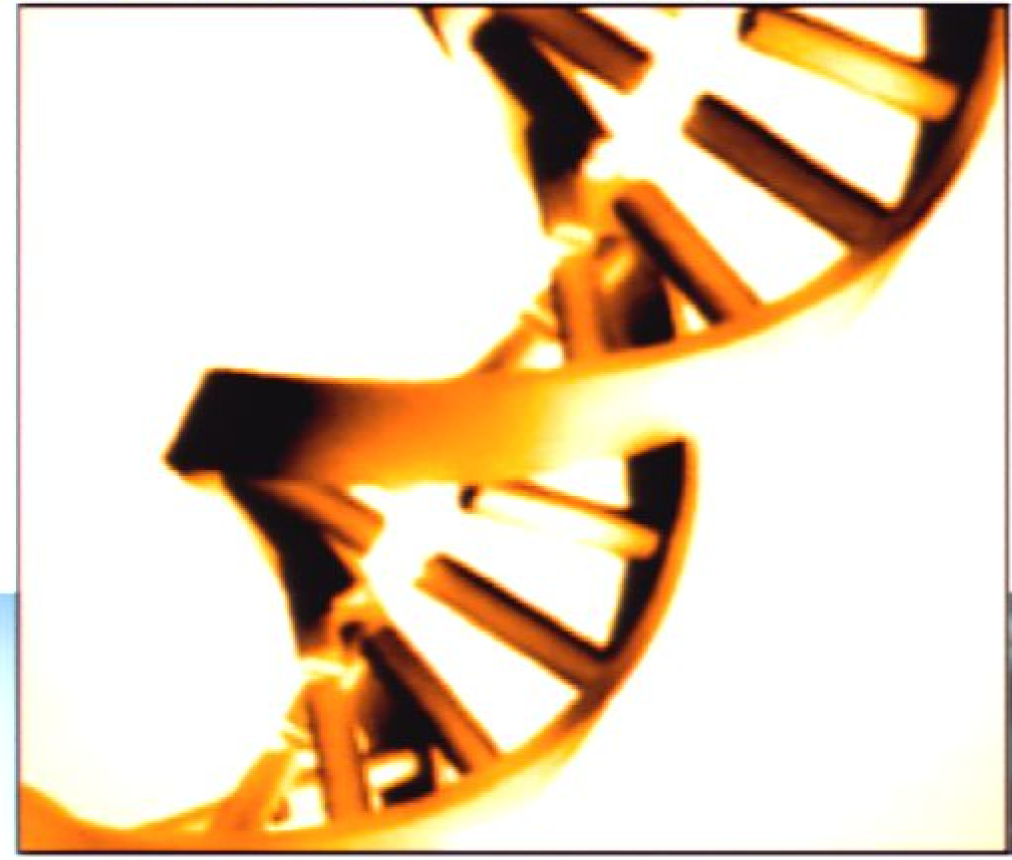
- ....

Some Discovery signatures

- canonical inclusive
  - jets+ E_T^{miss} (*)includes strategies for beam halo/noise, first data
  - jets+ ℓ + E_T^{miss}
  - same-sign dimuon + E_T^{miss}
  - opposite-sign same flavor dielectron and dimuon + E_T^{miss}
  - opposite-sign same flavor hadronic ditau + E_T^{miss}
- higher reco object inclusive
  - $Z + E_T^{miss}$
  - t hadronic + E_T^{miss}
  - $h^0(b\bar{b}) + E_T^{miss}$

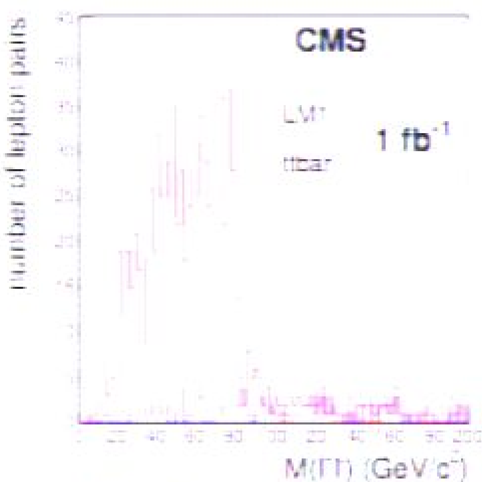
is it an amoeba or is it Sharon Stone?

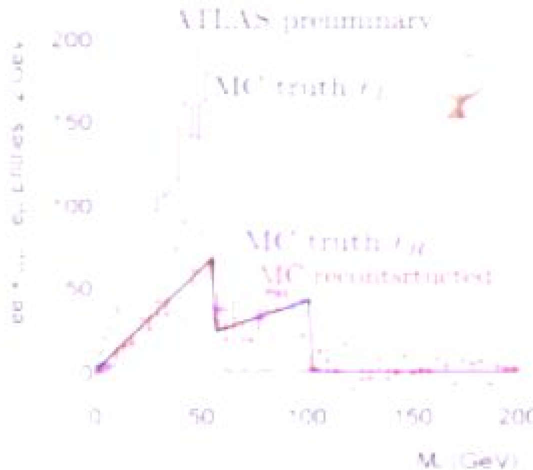
decoding the compositions of primary constituents

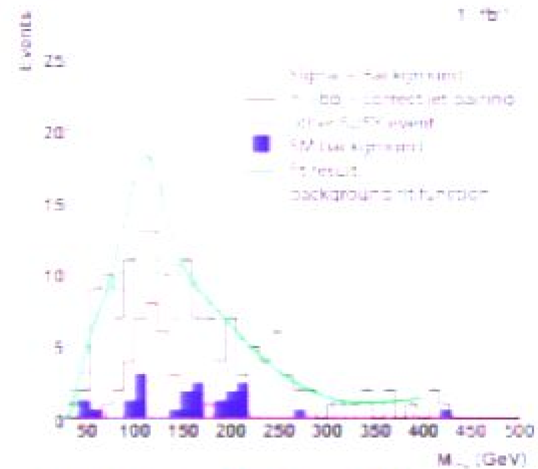


- Just like decoding DNA we have to decode the signals we will observe. And we do expect more similarities than differences, so fast discrimination will require smart and simple measurements.

Features directly from the kinematics







- But can we also tell the twins apart? Just as DNA is "what" we are but not "who" we are, we have to find additional traits and put the pieces together in order to orient and navigate in the vast parameter spaces of the models.

Towards Systematic and Deeper Mining of the Event

Examples of the simple questions to ask and answer (fast) and recent examples of works:

- excess of SS dileptons $\rightarrow$?
- $++ / --$ =2 $\rightarrow$?
- excess if OS dileptons $\rightarrow$?
- triangle in dilepton invariant mass $\rightarrow$?
- double triangle $\rightarrow$?
- no triangle $\rightarrow$?
- Z^0 and no triangle $\rightarrow$?
- Z^0 and triangle $\rightarrow$?
- ratios: $1\ell/2\ell/3\ell/4\ell$, jets
- ... more "footprint" homeworks

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- ... more "footprint" homeworks

Arkani-Hamed, Toro, Shuster et al Very clever "marmoset" solutions to the navigation problem: see Olympics and black boxes challenges

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Gunion et al. Mass Determination in SUSY-like events with Missing Energy

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A number of post-modern multivariate very sophisticated analyses with DTs, NNs, fancy statistics etc: with care and caveats

N.B. Prerequisite path of Discovery Work

- understand detectors and SM backgrounds
- control/understand: trigger, initial calibrations, scales, resolutions, efficiencies...
- minimize poorly estimated standard model backgrounds
- use SM "candle"/control samples (W/Z/top) to estimate backgrounds as possible
- use ratios as much as possible to get rid of luminosity dependence and other cross section related systematics
- adapt methods for background extraction as a function of luminosity
- have in place MC tools and reasonable "significance" calculations

Outline

Wisdom from the Past

W-s and Z's: from 1976 to ALPGEN

Intermediate-boson and dilepton production in hadronic interactions*

R. B. Palmer, E. A. Paschos, N. P. Samios, and Ling-Lie Wang

Extrapolating from 1975

- BNL 400 GeV collidr proposal
- s/M_W^2 Tevatron $\sim$500 $\rightarrow \sigma = 16$ nb
- s/M_W^2 LHC $\sim$30000 $\rightarrow \sigma = 12$ nb
- The Tevatron W-inclusive cross section is (measured) 8 nb
- The LHC is $\sim$ 20 nb

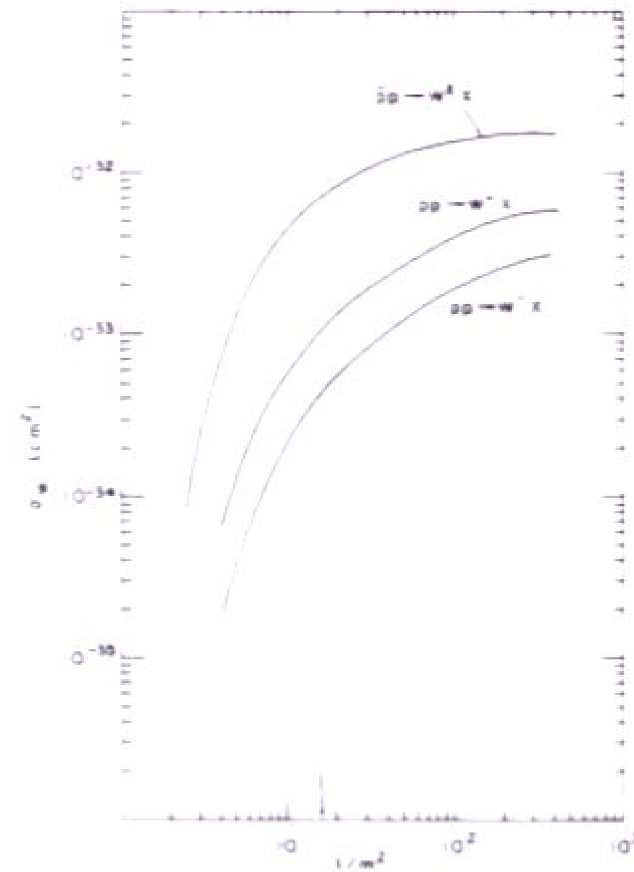
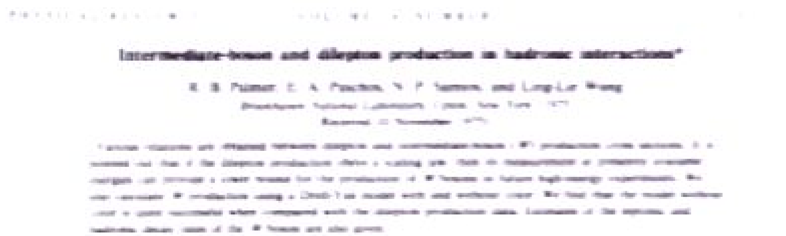


FIG. 6. Production cross section for $pp \rightarrow W^+X$ and $\bar{p}p \rightarrow W^{\pm}X$, calculated from the model given in Sec. III. The arrow points to the s/M^2 value corresponding to the production of a 100-GeV W meson by a [illegible] GeV/c-on-200-GeV/c storage mac[illegible]

W-s and Z's: from 1976 to ALPGEN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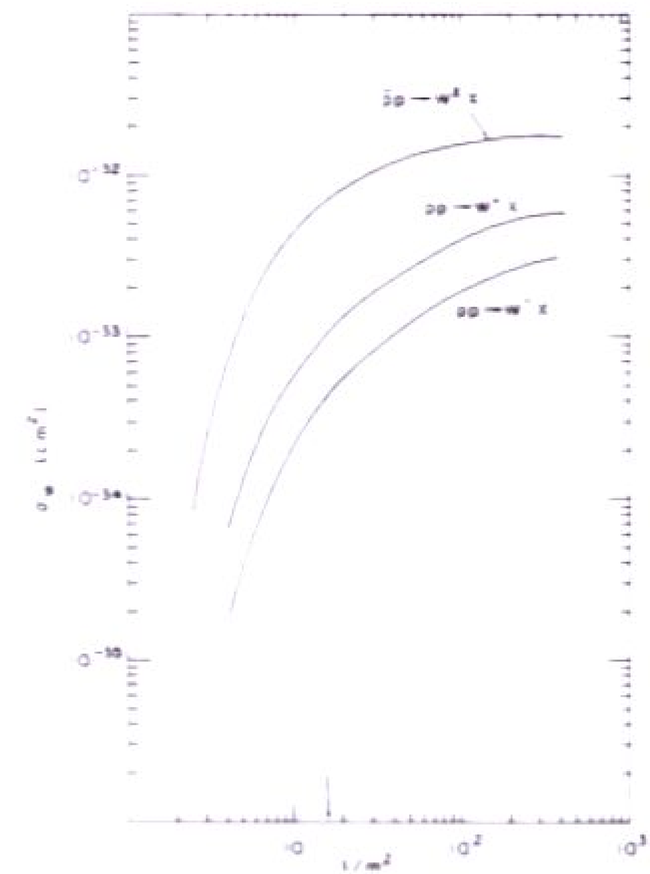
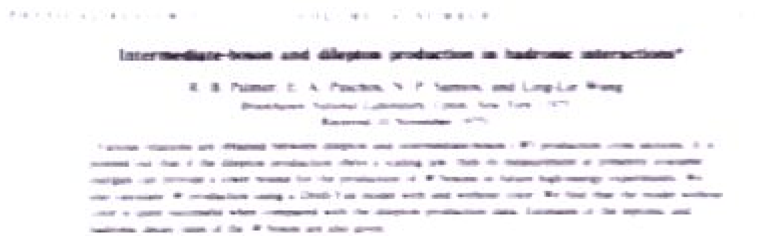


FIG. 6. Production cross section for $pp \to W^{\pm} X$ and $\bar{p}p \to W^{\pm} X$, calculated from the model given in Sec. III. The arrow points to the s/M^2 value corresponding to the production of a 100-GeV W meson by a 200-GeV/c-on-200-GeV/c storage machine.

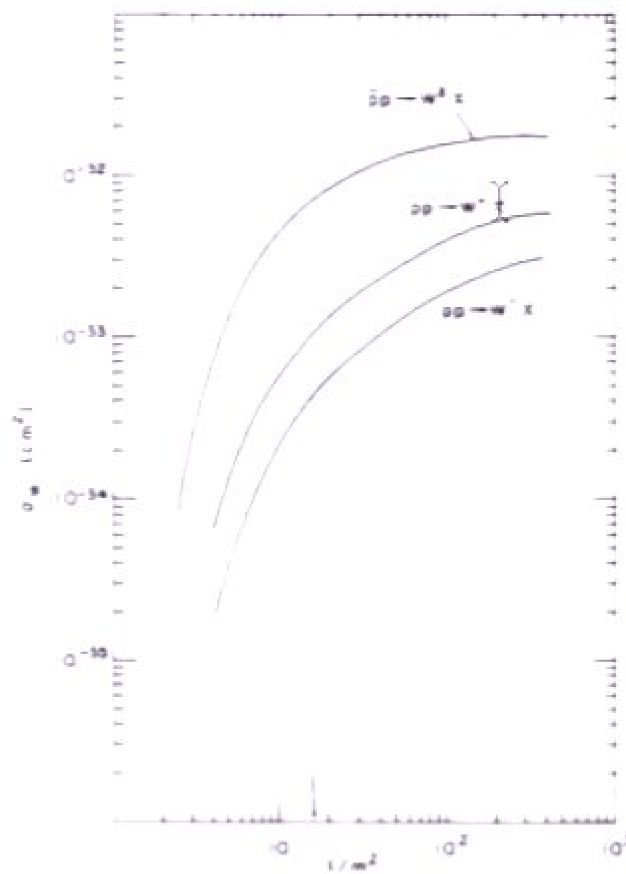
W-s and Z's: from 1976 to ALPGEN



Intermediate-boson and dilepton production in hadronic interactions*

Extrapolating from 1975

- BNL 400 GeV collidr proposal
- s/M_W^2 Tevatron ~500 $\rightarrow \sigma = 16$ nb
- s/M_W^2 LHC ~30000 $\rightarrow \sigma = 12$ nb
- The Tevatron W-inclusive cross section is (measured) 8 nb
- The LHC is ~ 20 nb



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W-s and Z's: from 1976 to ALPGEN

Intermediate-boson and dilepton production in hadronic interactions*

R. B. Palmer, E. A. Paschos, N. P. Samios, and Ling-Lie Wang
Brookhaven National Laboratory, Upton, New York

Extrapolating from 1975

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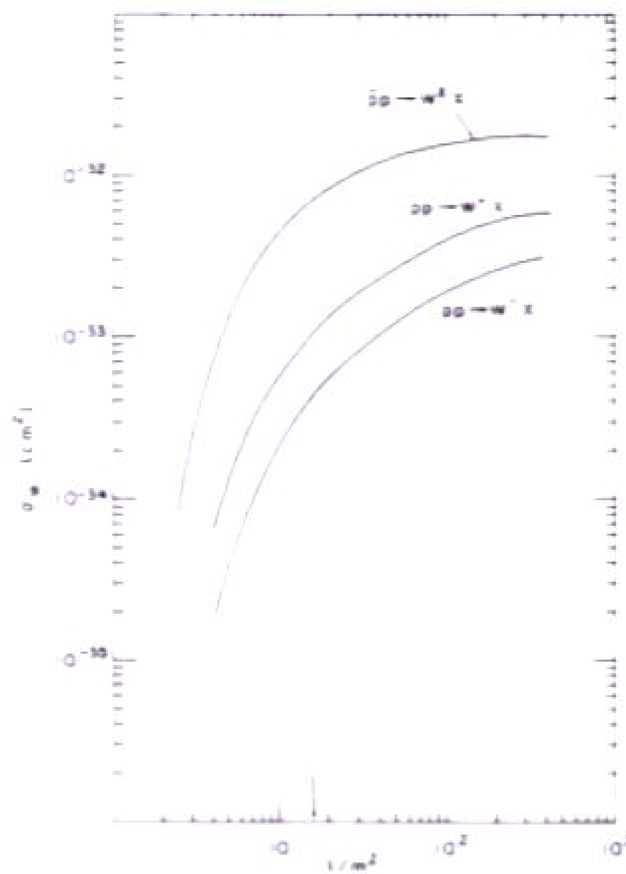

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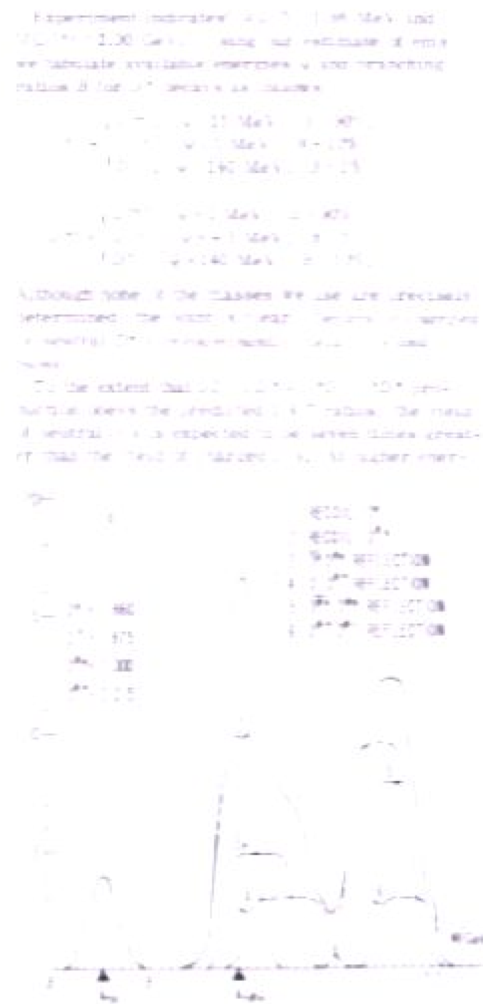
Resonances, Reflections: a non-trivial discovery example from 30 years ago (MLM digged this)

$K\pi$ and $K3\pi$ spectra 2.08.76 PRL 37 (76) 255



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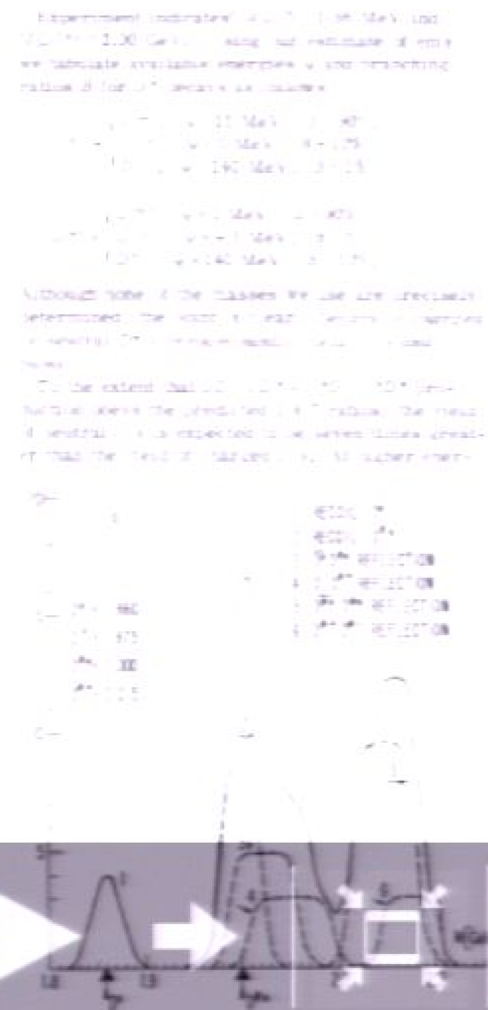

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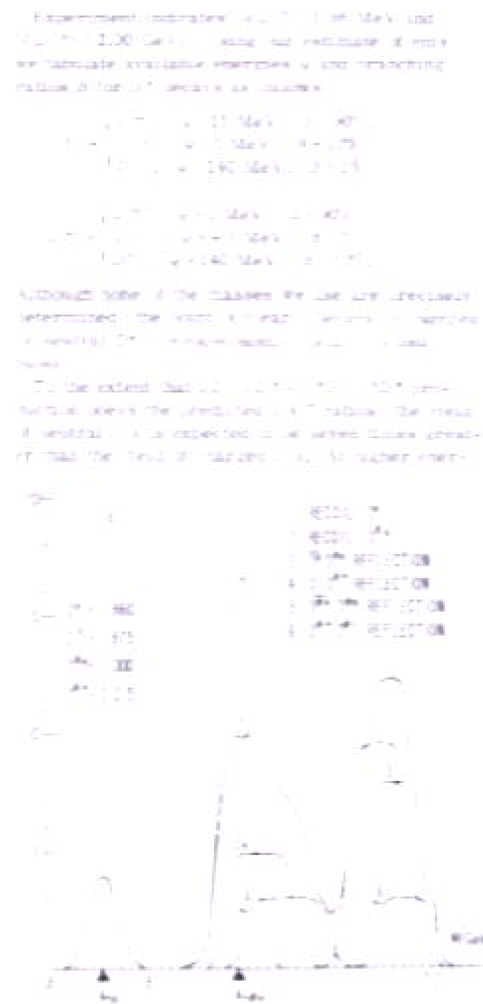


...excerpts

Observation in e^+e^- Annihilation of a Narrow State at 1865 MeV/c^2 Decaying to $K\pi$ and $K\pi\pi\pi$

G. Goldhaber,* F. M. Pierre,† G. S. Abrams, M. S. Alam, A. M. Boyarski, M. Breidenbach, W. C. Carithers, W. Chinowsky, S. C. Cooper, R. G. DeVoe, J. M. Dorfan, G. J. Feldman, C. E. Friedberg, D. Fryberger, G. Hanson, J. Jaros, A. D. Johnson, J. A. Kadyk, R. R. Larsen, D. Lüke,‡ V. Lüth, H. L. Lynch, R. J. Madaras, C. C. Morehouse, H. K. Nguyen,** J. M. Paterson, M. L. Perl, I. Peruzzi,†† M. Piccolo,†† T. P. Pun, P. Rapidis, B. Richter, B. Sadoulet, R. H. Schindler, R. F. Schwitters, J. Siegrist, W. Tanenbaum, G. H. Trilling, F. Vannucci,‡‡ J. S. Whitaker, and J. E. Wiss

Lawrence Berkeley Laboratory and Department of Physics, University of California, Berkeley, California [illegible] and Stanford Linear Accelerator Center, Stanford University, Stanford, California [illegible]

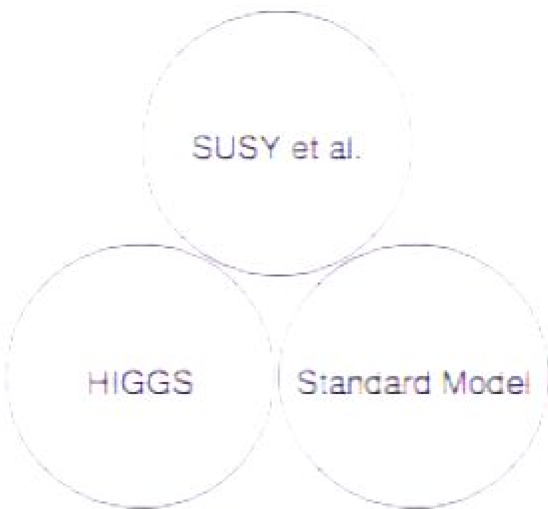
Received 14 June 1976

We present evidence, from a study of multihadronic final states produced in e^+e^- annihilation at center-of-mass energies between 3.9 and 4.6 GeV, for the production of a new neutral state with mass [illegible] MeV/c^2 and decay width less than [illegible] MeV/c^2 that decays to $K^\pm\pi^\mp$ and $K^\pm\pi^\mp\pi^\pm\pi^\mp$. The recoil-mass spectrum for this state suggests that it is produced only in association with systems of comparable or larger mass.

is charm found? De Rujula, Georgi, Glashow, PRL 37,(76) 398

In summary, it may be fruitful to search for charmed states—both mesons and baryons—at e^+e^- energies of 4–6 GeV. Peaks in invariant masses of several final hadrons are expected, accompanied by rich and energy-dependent structure in the recoil-mass spectra. Dozens of new hadrons await discovery.

We wish to thank Professor Gerson Goldhaber for discussing the data with us prior to publication.



SUSY is marking the engineering of the discovery path of beyond the standard model signatures[which consist of more that SUSY and SUSY-like frameworks and duals]:

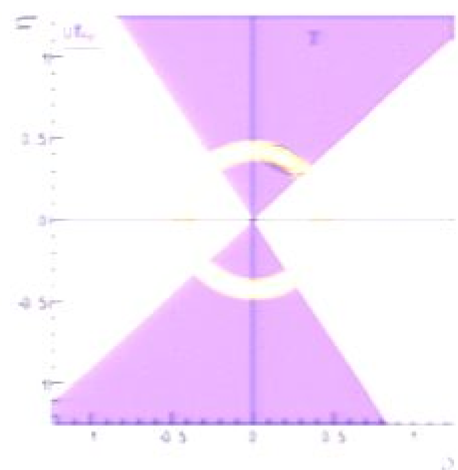
- SUSY
- Heavy Stable Charged Particles
- $U(1)'$
- Technicolor
- Compositeness
- Flavor violation
- Little higgs
- Extra dimensions
- Black holes
- ...

Flavor for SUSY and beyond @LHC

flavor has caused SUSY a lot of suffering...

In order to disentangle new physics effects, we should first determine CKM parameters by "tree-level" processes.

Fit from tree level processes



|Vub|, $f_{\phi/\gamma}$ $V_{ub} = |V_{ub}| e^{-i\gamma}$

+ Bd mixing and CP asymmetries
+ Bs mixing and CP asymmetries
+ ε_K and B(K->πνν)

We know (or constrain) which sector is affected by new physics
Improvement of $f_{\phi/\gamma}$ is essential.

More on the essential measurements for new physics searches at the B-factories and LHCb at the flavor session.

with the discovery of any new physics@LHC the role of flavor will be revised and upgraded into tool for navigation and characterization of the new physics

Theory-Experiment crossing

Since the time of Fermi, it took LHC to bring theory and experiments back close together

Das Nullte Theorem der Wissenschaftgeschichte

lautet dass eine Entdeckung (Regel,Gesetzmässigkeit, Einsicht), die nach einer Person bennant ist, nicht von dieser Person herrührt

–E.P. Fischer, Fremde Federn, Im Gegenteil, July 24 2006, Die Zeit (from J. D. Jackson's "the first and the famous" collection) my message: Work and make the discoveries with care and respect to the data: the famous are often not the first and the first are often not famous but this is irrelevant in particular at a monumental time like the LHC one. Getting it right is important.

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Since the time of Fermi, it took the threat of the LHC to bring theory on shell

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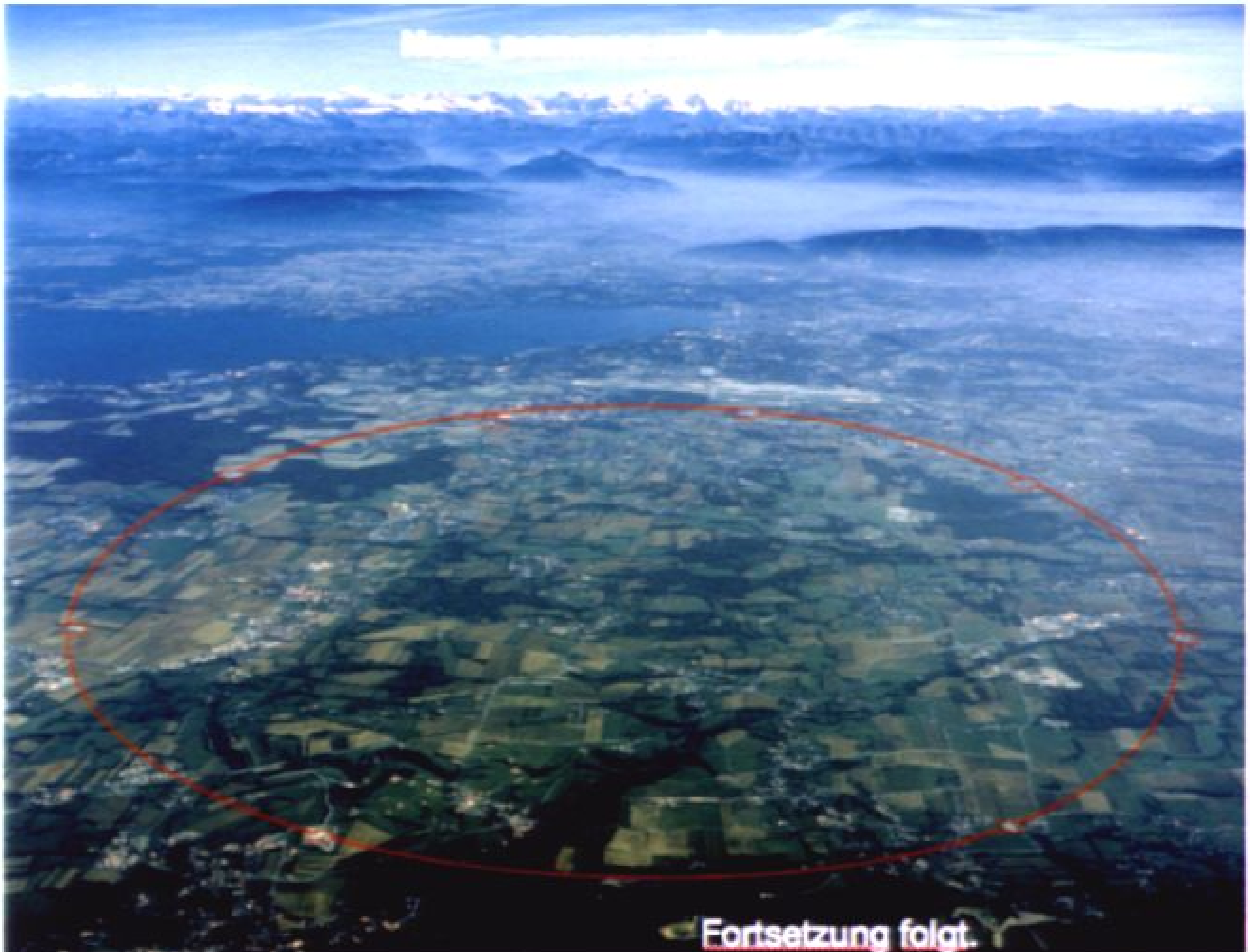
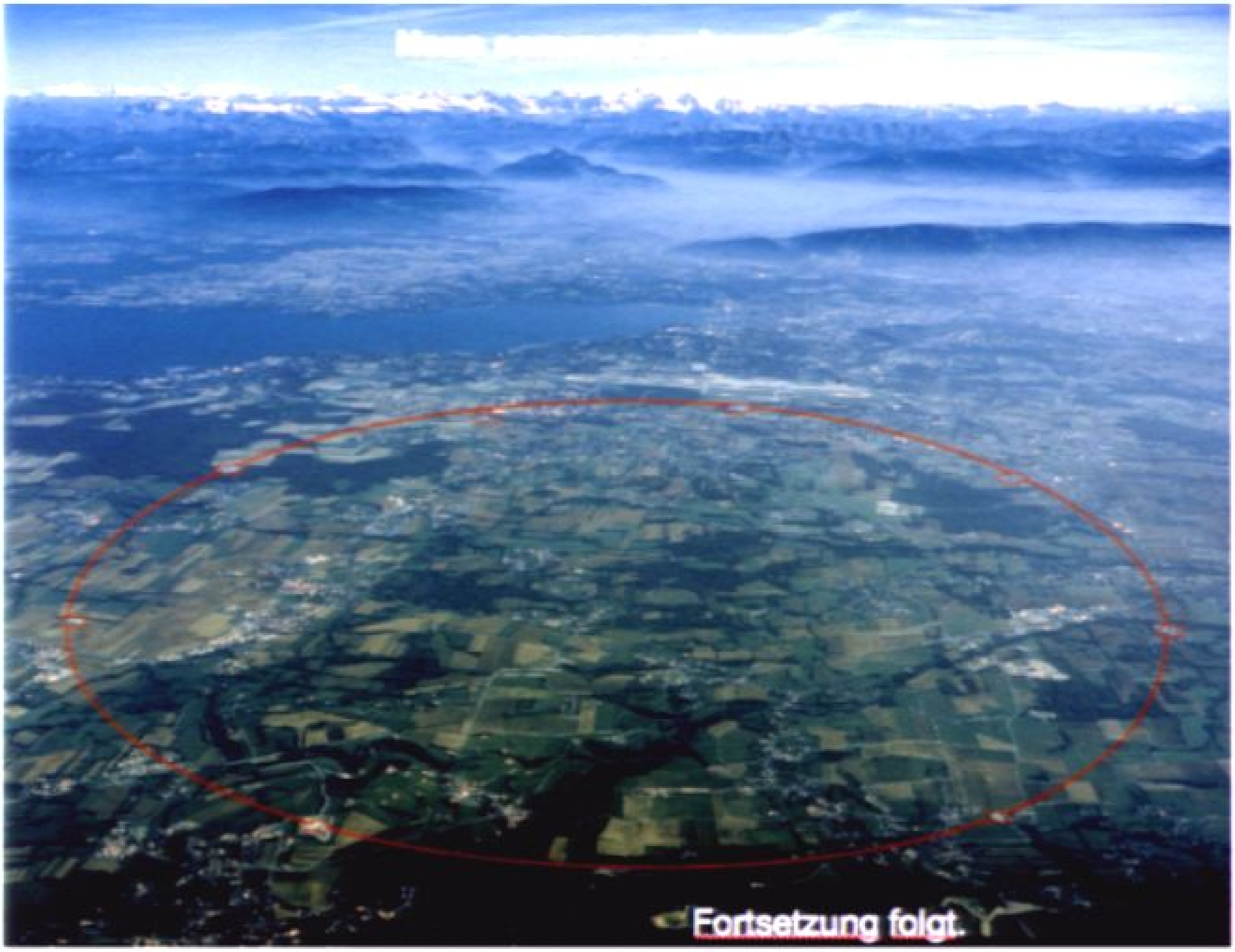
Since the time of Fermi, it took the threat of the LHC to bring theory on shell

Theory-Experiment crossing

getting finally to experimental discoveries: PRICELESS



"faster, better, simpler, smarter" with the LHC data: The field needs the LHC input at the $\mathcal{O}(\mathrm{pb}^{-1})$ time scale. Move to the data without strong pre-conceived ideas (i.e. escape the tyranny of MSSMs)



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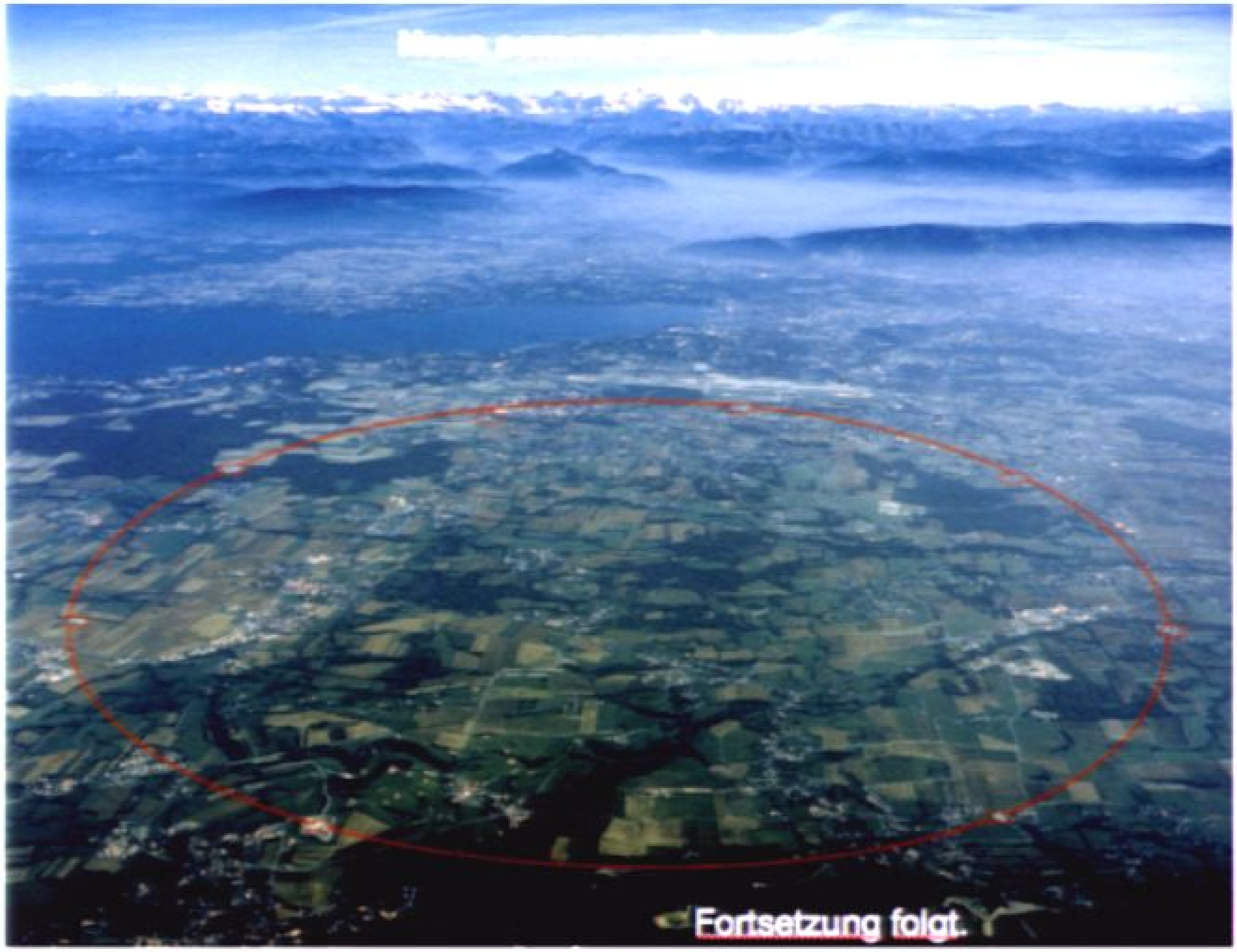

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hep-ex-discovery@LHC.cern.ch

http://cmsdoc.cern.ch/~smaria/perimeter07/

Maria Spiropulu

CERN-PH

Perimeter Institute, Summer School on Particle Physics, Cosmology and Strings.

August 9, 2007