Title: Results on Searches from the CMS Experiment at the LHC

Date: Nov 11, 2011 01:00 PM

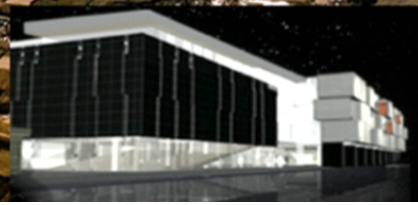
URL: http://pirsa.org/11110096

Abstract: The LHC has just concluded this year's proton-proton run at 7 TeV CM energy, producing more than 5fb-1of data.
While the full data sample collected by the CMS experiment will be analyzed over the winter, many of the present searches
for new physics have been completed with 1-2 fb-1. In this talk we will present the most recent updates on the search analyses in CMS, including the Higgs search, searches for supersymmetry, and a plethora of other BSM models, such as extra dimensions, Z's, W_R, leptoquarks, and more.
We'll also show the short-term and longer-term plans of the collider and experiments.

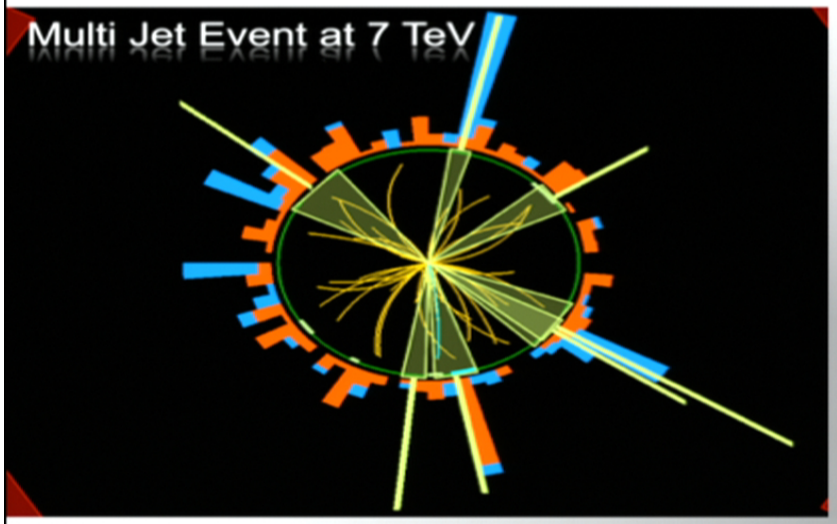
# Results on Searches from the CMS Experiment at the LHC

Albert De Roeck
CERN, Geneva, Switzerland
Antwerp University Belgium
Davis University USA

November 11 2011



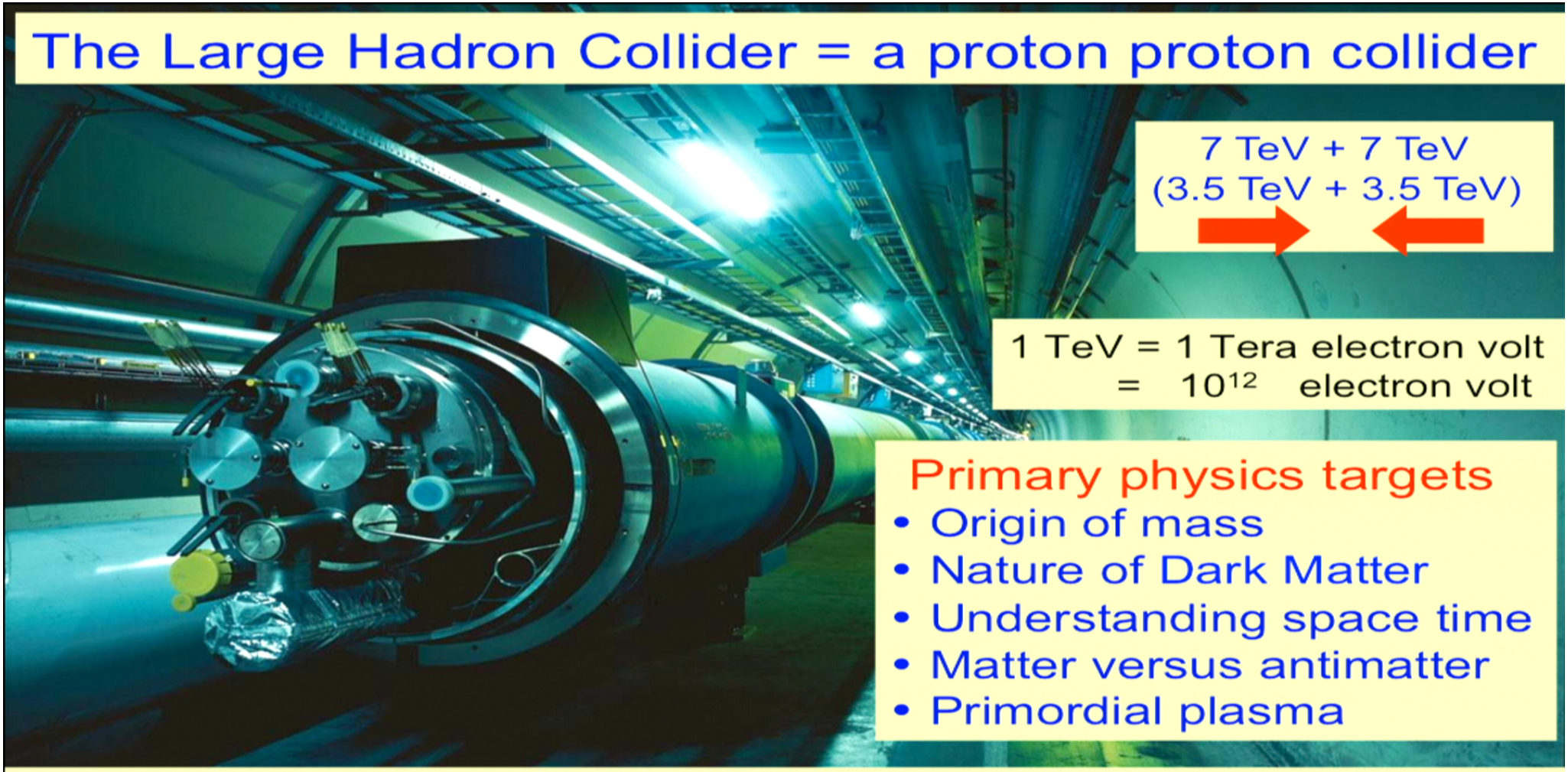
PERIMETER PI INSTITUTE FOR THEORETICAL PHYSICS




# Outline

- Introduction
- A Few Standard Model results
- The search for the Higgs
- Supersymmetry
- Extra Dimensions
- Other "conventional" BSM signatures
- New BSM signatures

# The Large Hadron Collider = a proton proton collider



7 TeV + 7 TeV
(3.5 TeV + 3.5 TeV)

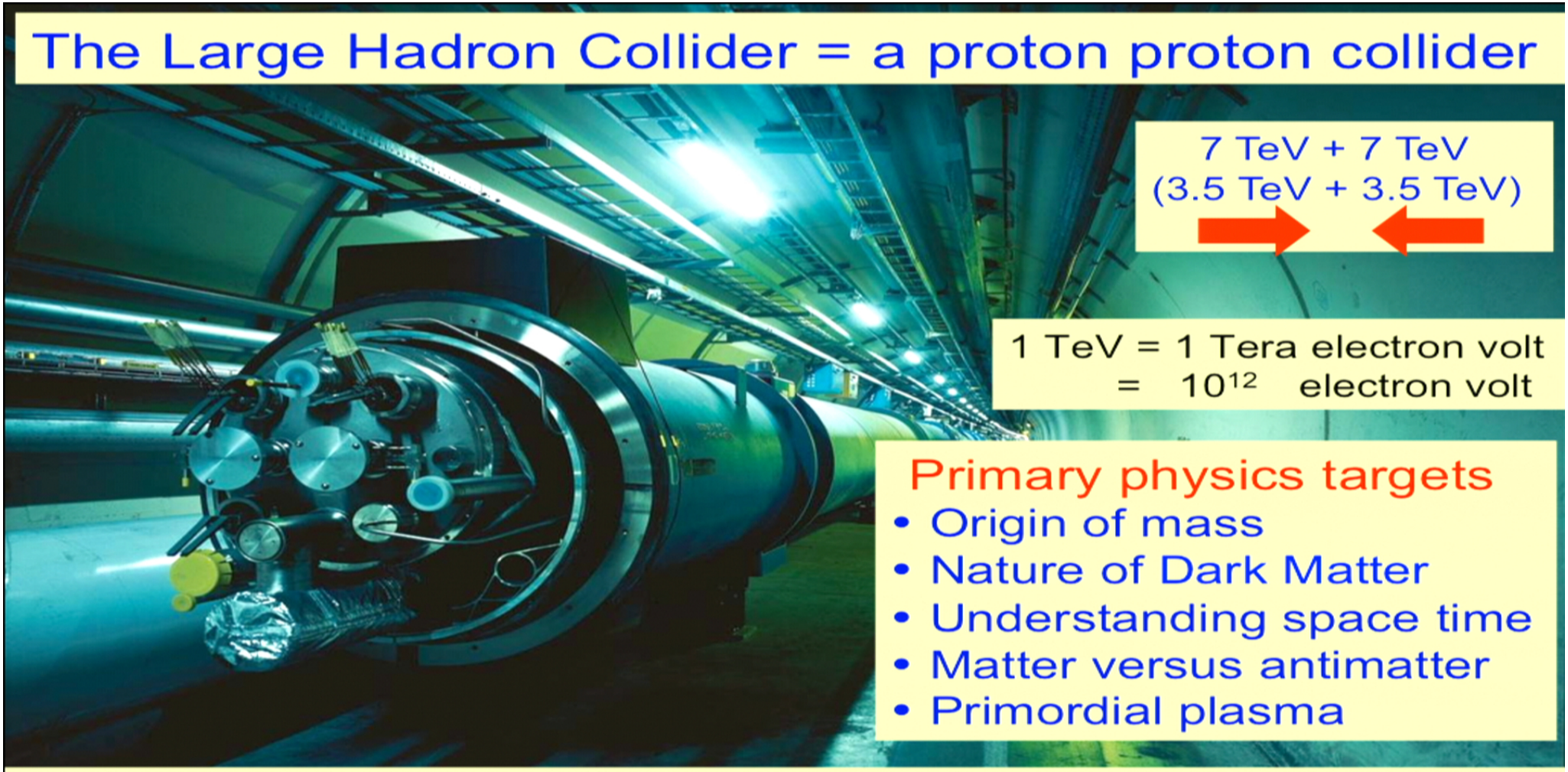
1 TeV = 1 Tera electron volt
= $10^{12}$ electron volt

Primary physics targets

- Origin of mass
- Nature of Dark Matter
- Understanding space time
- Matter versus antimatter
- Primordial plasma

The LHC is a Discovery Machine
The LHC will determine the Future course of High Energy Physics

# The Large Hadron Collider = a proton proton collider



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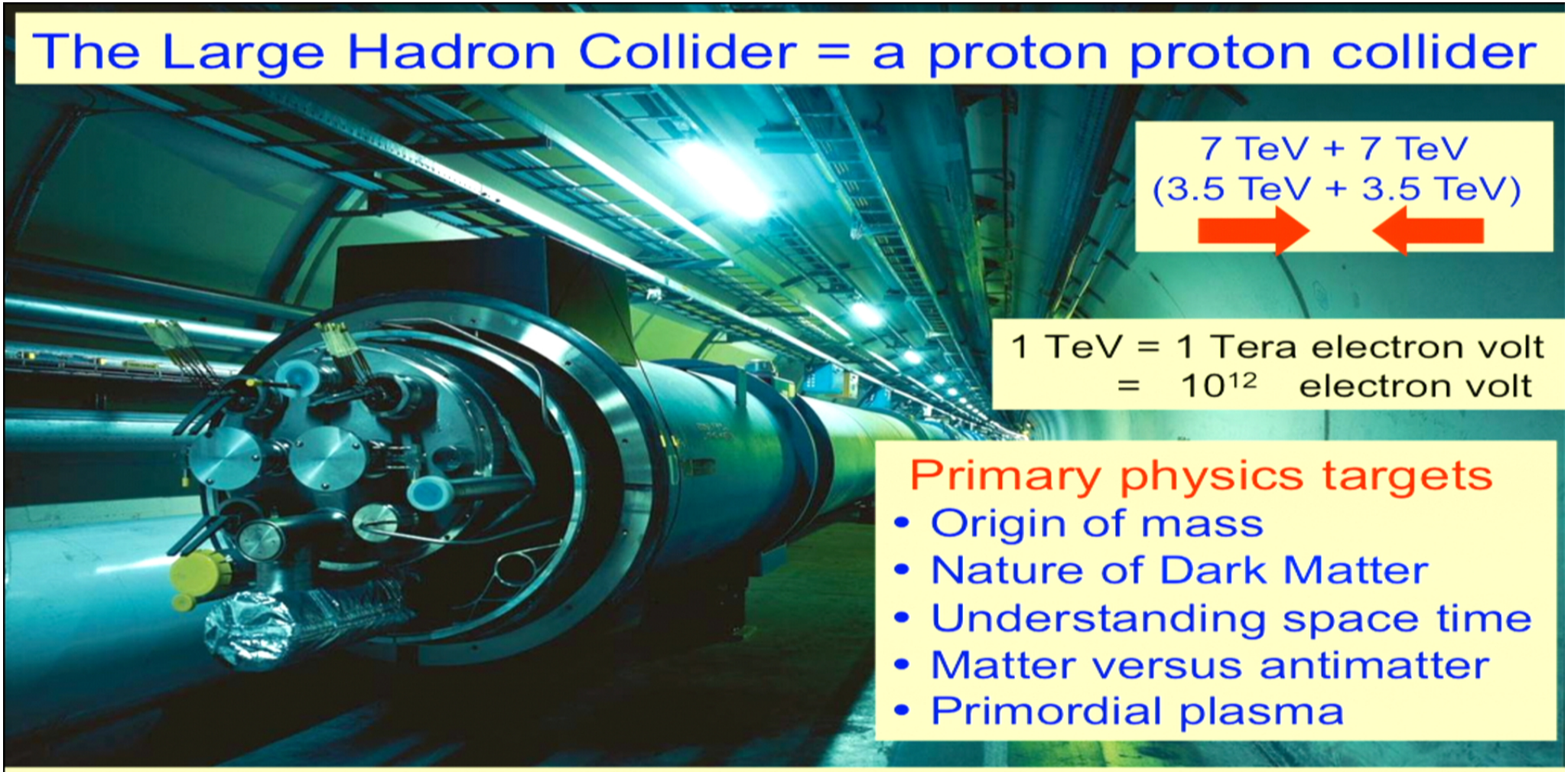

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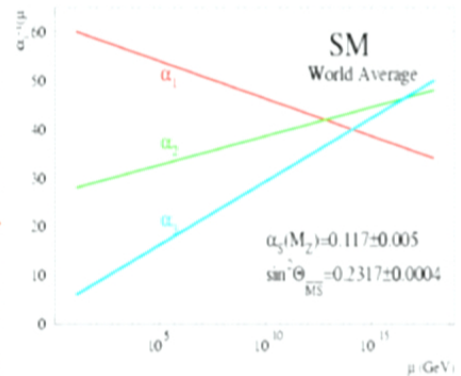
# Physics case for new High Energy Machines

Understand the mechanism Electroweak Symmetry Breaking

Discover physics beyond the Standard Model

Reminder: The Standard Model
- tells us how but not why
  3 flavour families? Mass spectra? Hierarchy?
- needs fine tuning of parameters to level of $10^{-30}$ !
- has no connection with gravity
- no unification of the forces at high energy

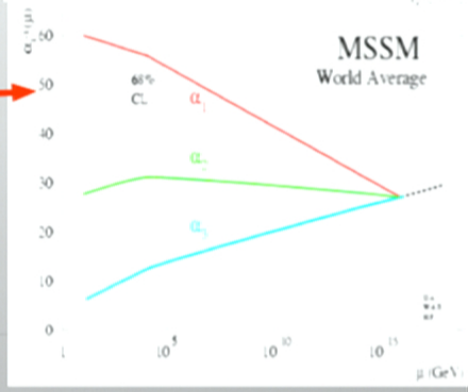


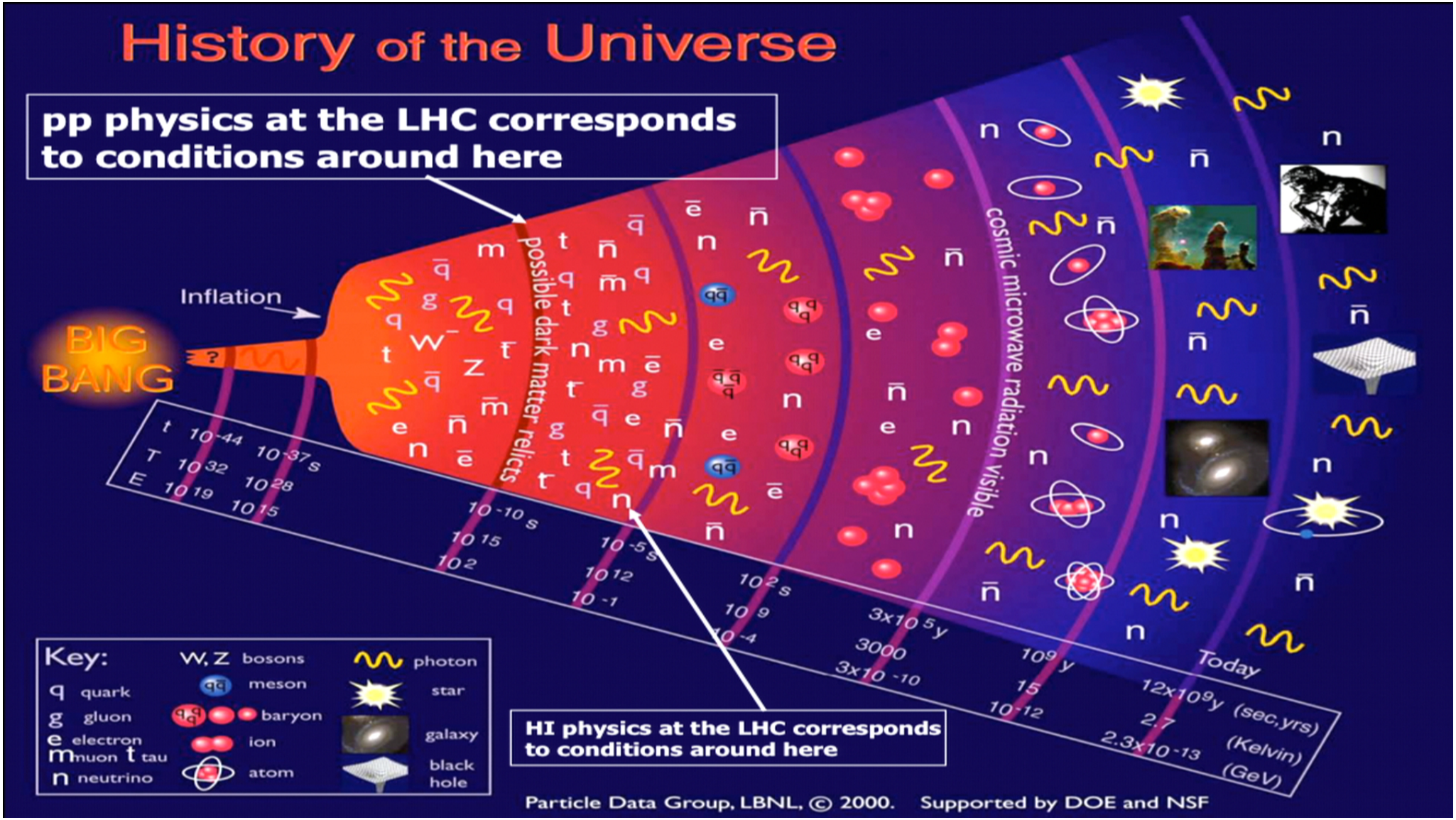

Most popular extensions these days

If a Higgs field exists:
- Supersymmetry
- Extra space dimensions

If there is no Higgs below ~ 700 GeV
- Strong electroweak symmetry breaking around 1 TeV

Other ideas: more symmetry & gauge bosons, L-R symmetry, quark & lepton substructure, Little Higgs models, Technicolor, Hidden Valleys…



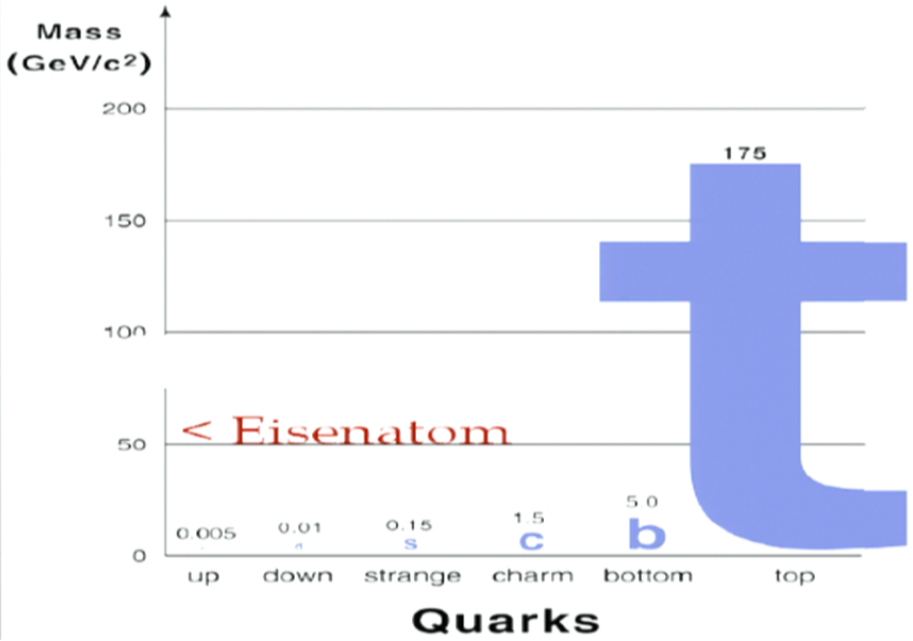

History of the Universe
pp physics at the LHC corresponds to conditions around here
Inflation
BIG BANG
possible dark matter relicts
cosmic microwave radiation visible
Today
HI physics at the LHC corresponds to conditions around here
Key:
q quark
g gluon
e electron
m muon t tau
n neutrino
W, Z bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
(sec,yrs)
(Kelvin)
(GeV)
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

# The Origin of Particle Masses

A most basic question is why elementary particles have masses (and so different masses)

The mass mystery could be solved with the 'Higgs mechanism' which predicts the existence of a new elementary particle, the 'Higgs' particle (theory 1964, P. Higgs, R. Brout and F. Englert)

Peter Higgs




The Higgs (H) particle has been searched for since decades at accelerators, but not yet found…

The LHC will have sufficient energy to produce it for sure, if it exists

Francois Englert

# Supersymmetry

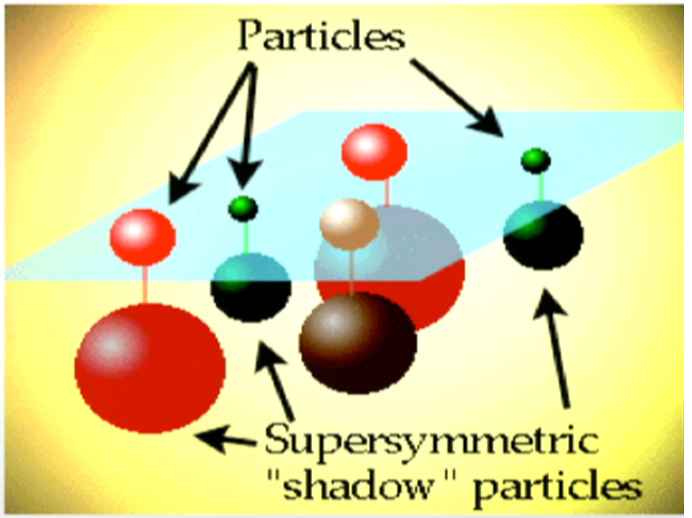
**(Julius Wess and Bruno Zumino, 1974)**

**Establishes a symmetry between fermions (matter) and bosons (forces):**

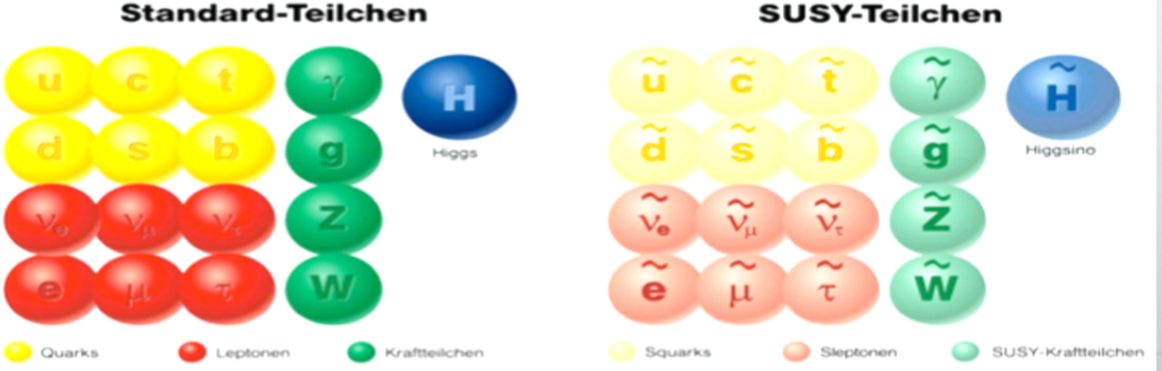
- **Each particle p with spin s has a SUSY partner $\tilde{p}$ with spin s -1/2**

- **Examples** $q\ (s=1/2) \rightarrow \tilde{q}\ (s=0)$ **squark**

  $g\ (s=1) \rightarrow \tilde{g}\ (s=1/2)$ **gluino**




**Our known world** **Maybe a new world?**




Motivation:
- Unification (fermions-bosons, matter-forces)
- Solves some deep problems of the Standard Model

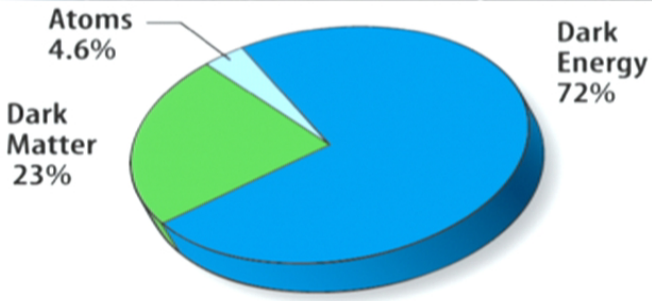
# Dark Matter in the Universe

**Astronomers found that most of the matter in the Universe must be invisible Dark Matter**

Vera Rubin ~ 1970

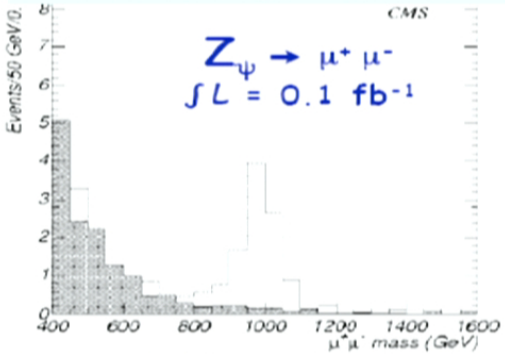
**'Supersymmetric' particles ?**

F. Zwicky 1898-1974

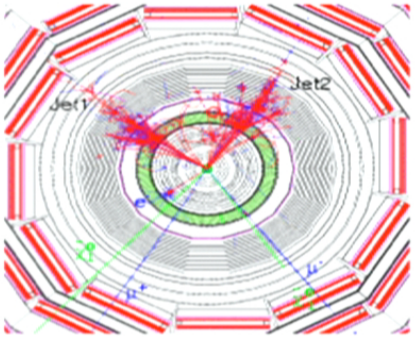


# New Physics at High Energies?

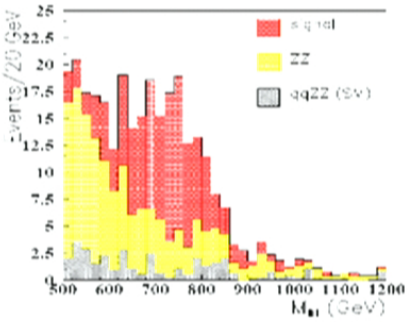
## New Gauge Bosons?



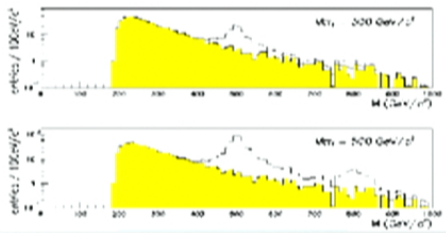

## Supersymmetry



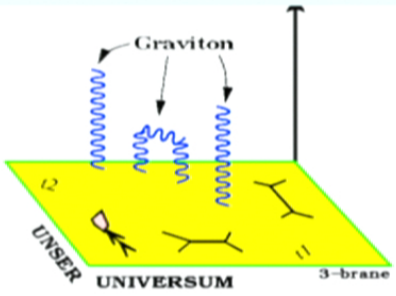

## ZZ/WW resonances?



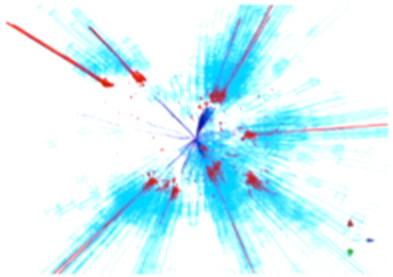

## Technicolor?



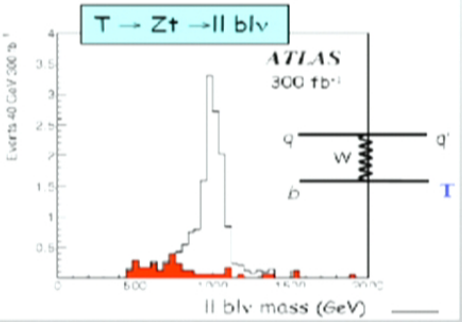
## Extra Dimensions?



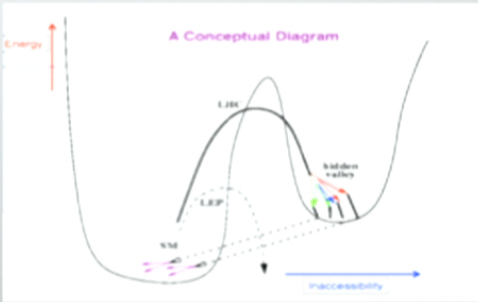

## Black Holes???



## Little Higgs?




## Hidden Valleys?




We do not know what is out there for us…
A large variety of possible signals. We have to be ready for that

# Theory Space

# Theory Space


Note that during the last 3-4 Years we –LHC experimentalists- got more models to deal with than we needed…

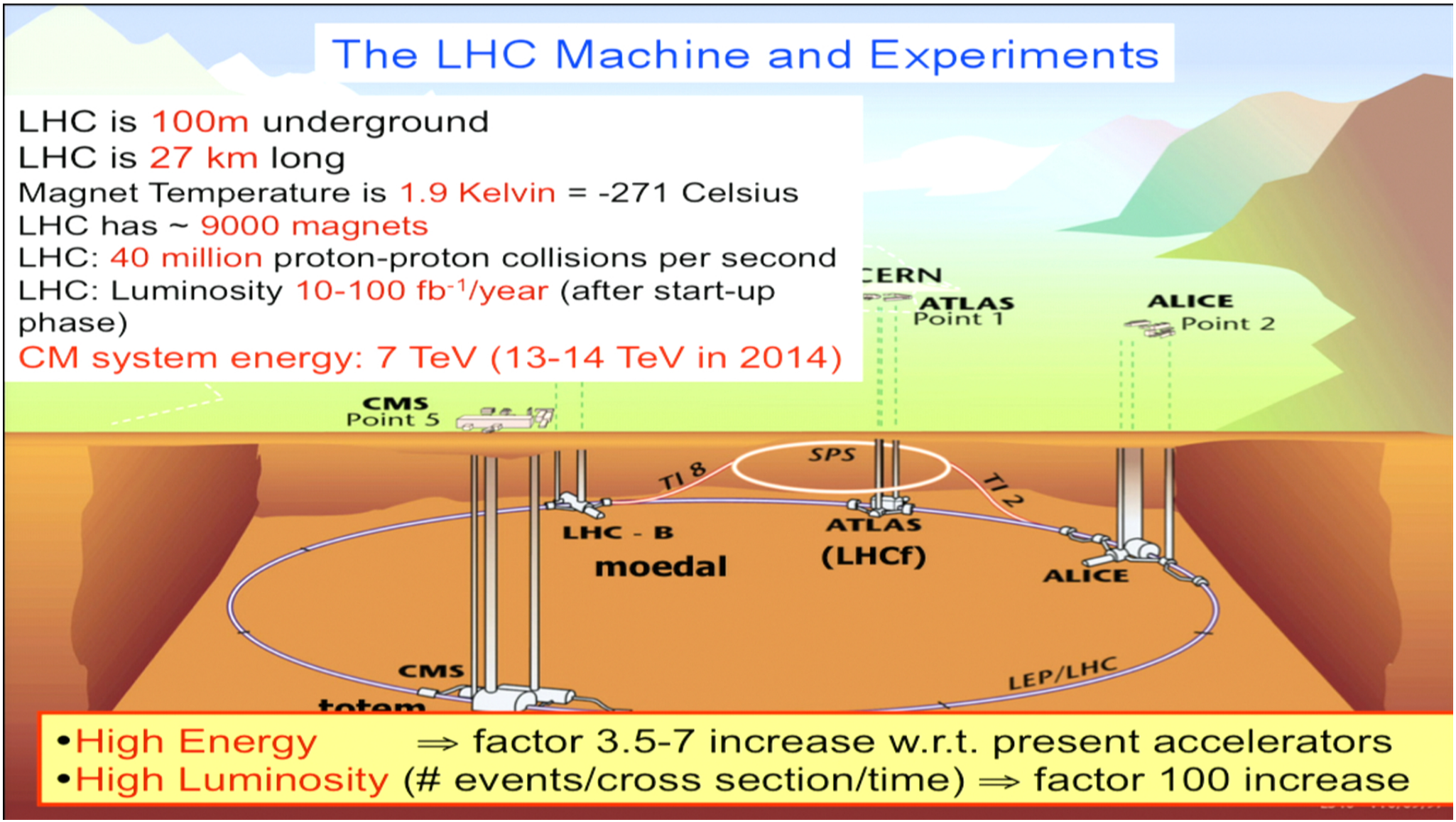
Some theorists found it a challenge to invent a model with signatures difficult for the experiments:
heavy stable charged particles, hidden valley models, Quirks…

NOW WE STRIKE BACK!!

But remember that these are still early days!!

# The LHC Machine and Experiments

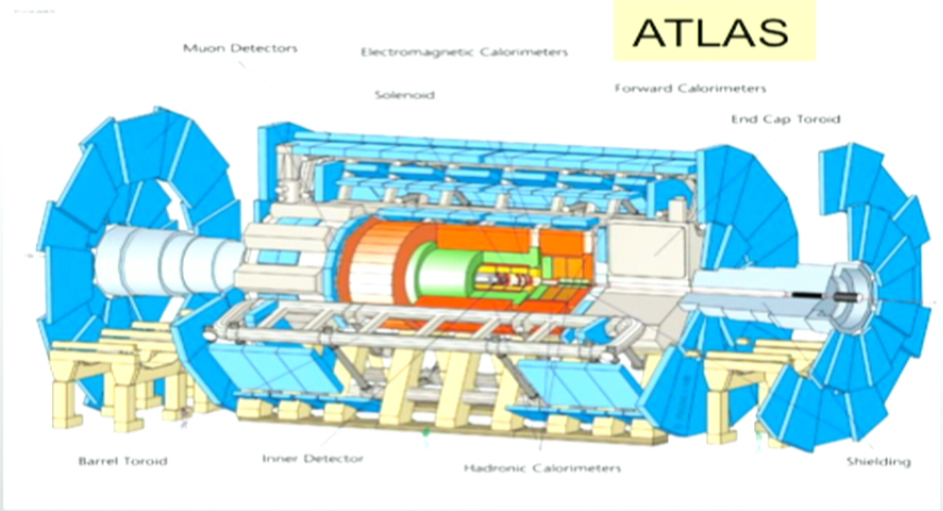
LHC is 100m underground
LHC is 27 km long
Magnet Temperature is 1.9 Kelvin = -271 Celsius
LHC has ~ 9000 magnets
LHC: 40 million proton-proton collisions per second
LHC: Luminosity 10-100 $fb^{-1}$/year (after start-up phase)
CM system energy: 7 TeV (13-14 TeV in 2014)



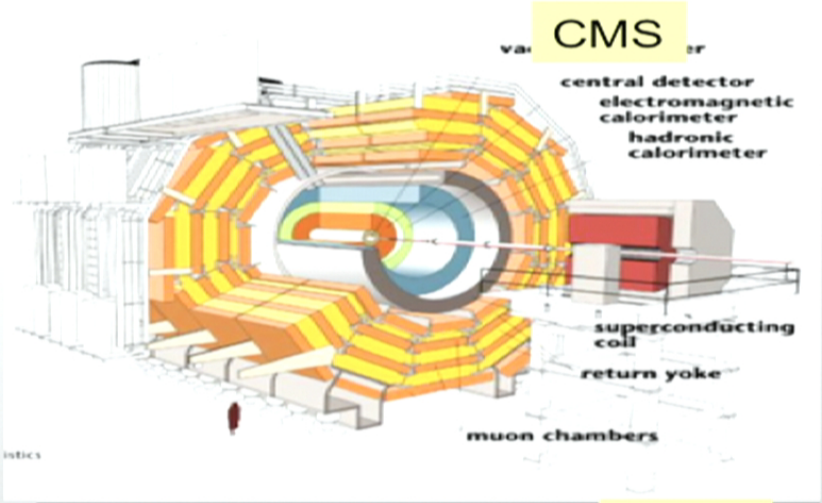

- High Energy ⇒ factor 3.5-7 increase w.r.t. present accelerators
- High Luminosity (# events/cross section/time) ⇒ factor 100 increase

# The Four Central Experiments

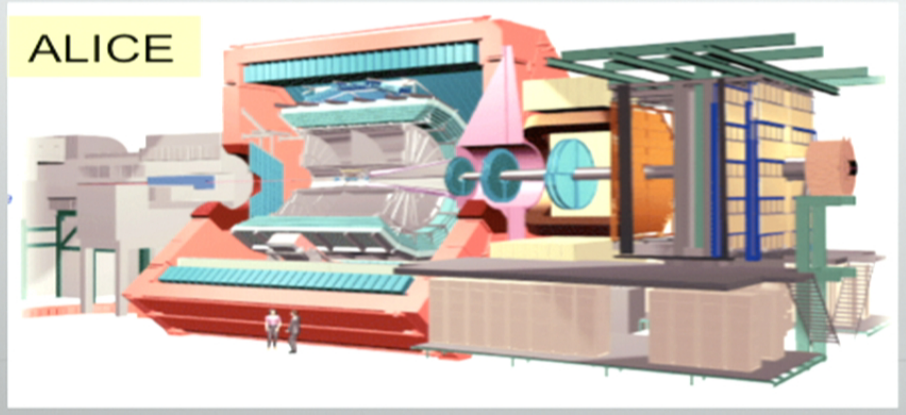
ATLAS



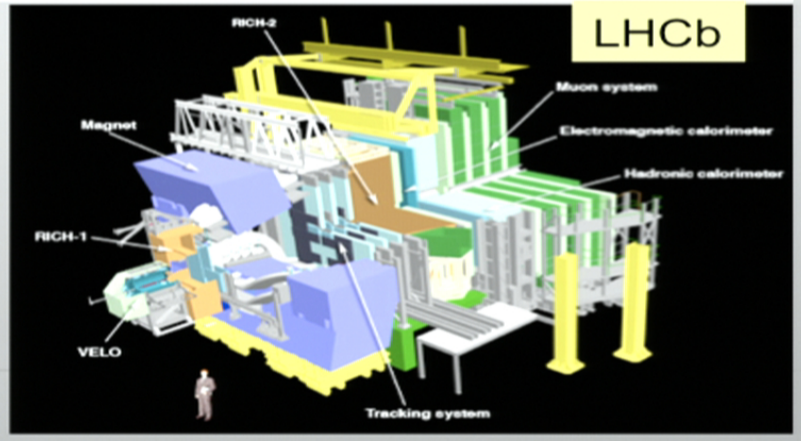

CMS




ALICE

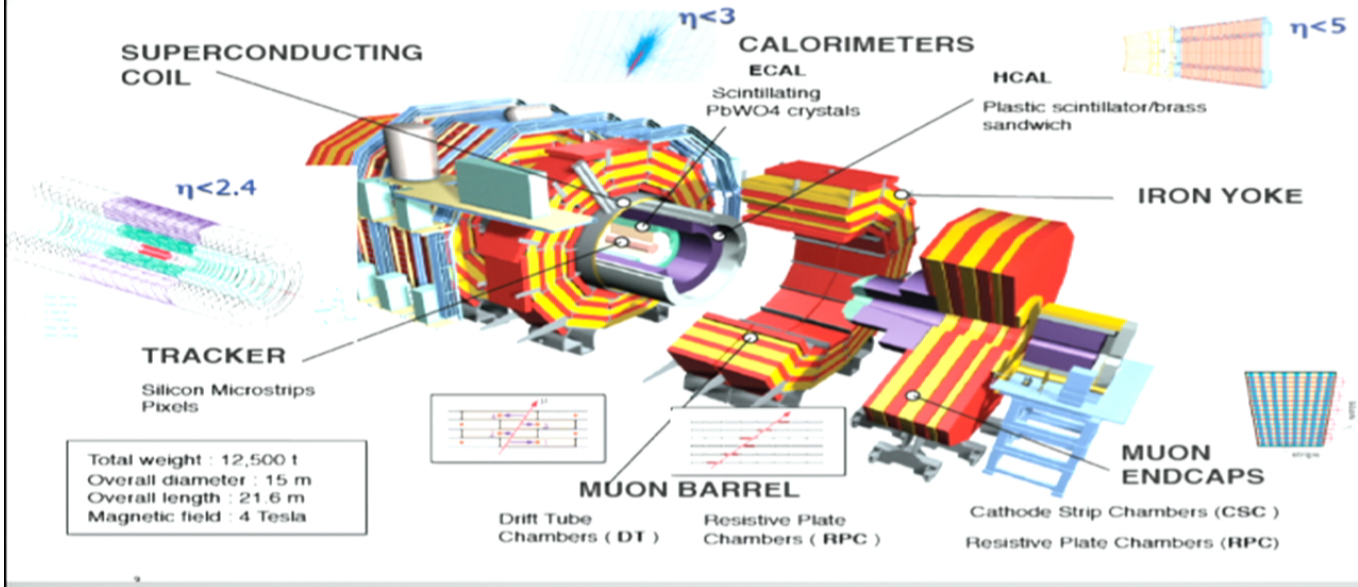


LHCb

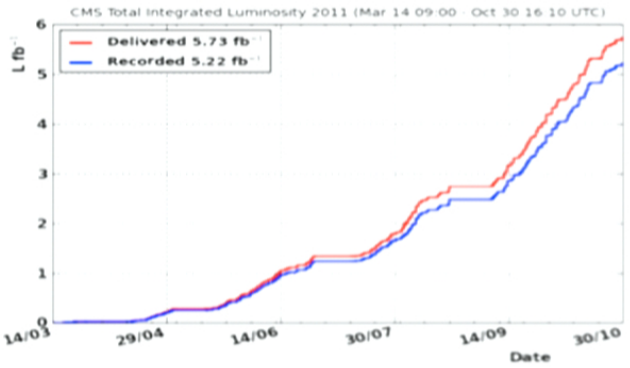


# CMS & 2011 pp Run

## CMS Experiment




## Total luminosity

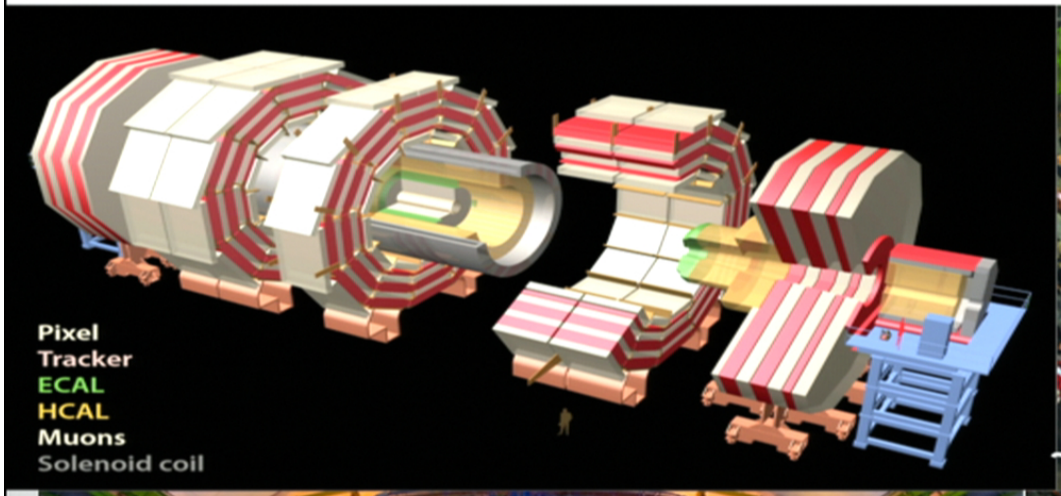



- CMS Experiment: General purpose - large acceptance detector
- LHC running now with 1380 bunches and $\sim 3.5 \cdot 10^{33} cm^{-2} s^{-1}$ luminosity

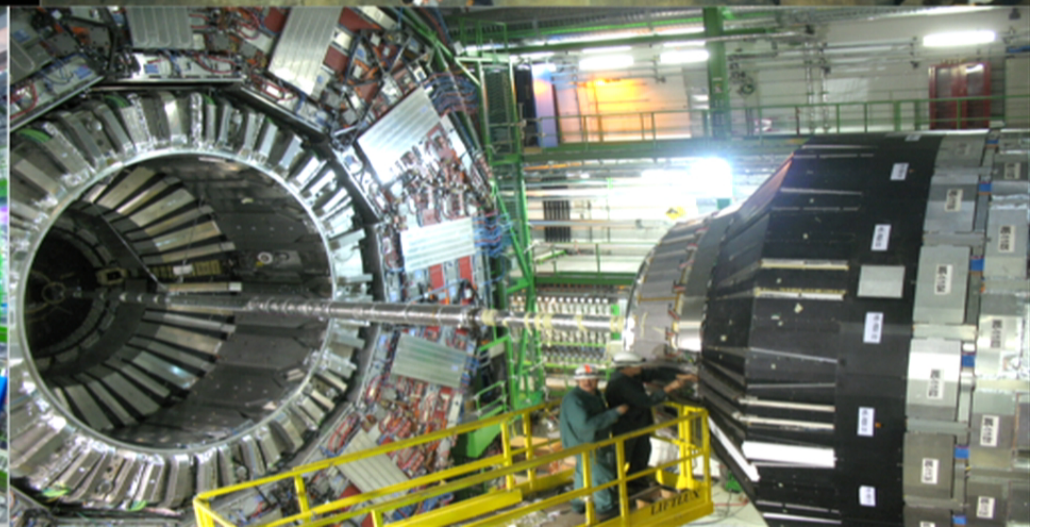
-> 5.7 $fb^{-1}$ delivered and 5.2 $fb^{-1}$ recorded

This week: Heavy Ion running is starting

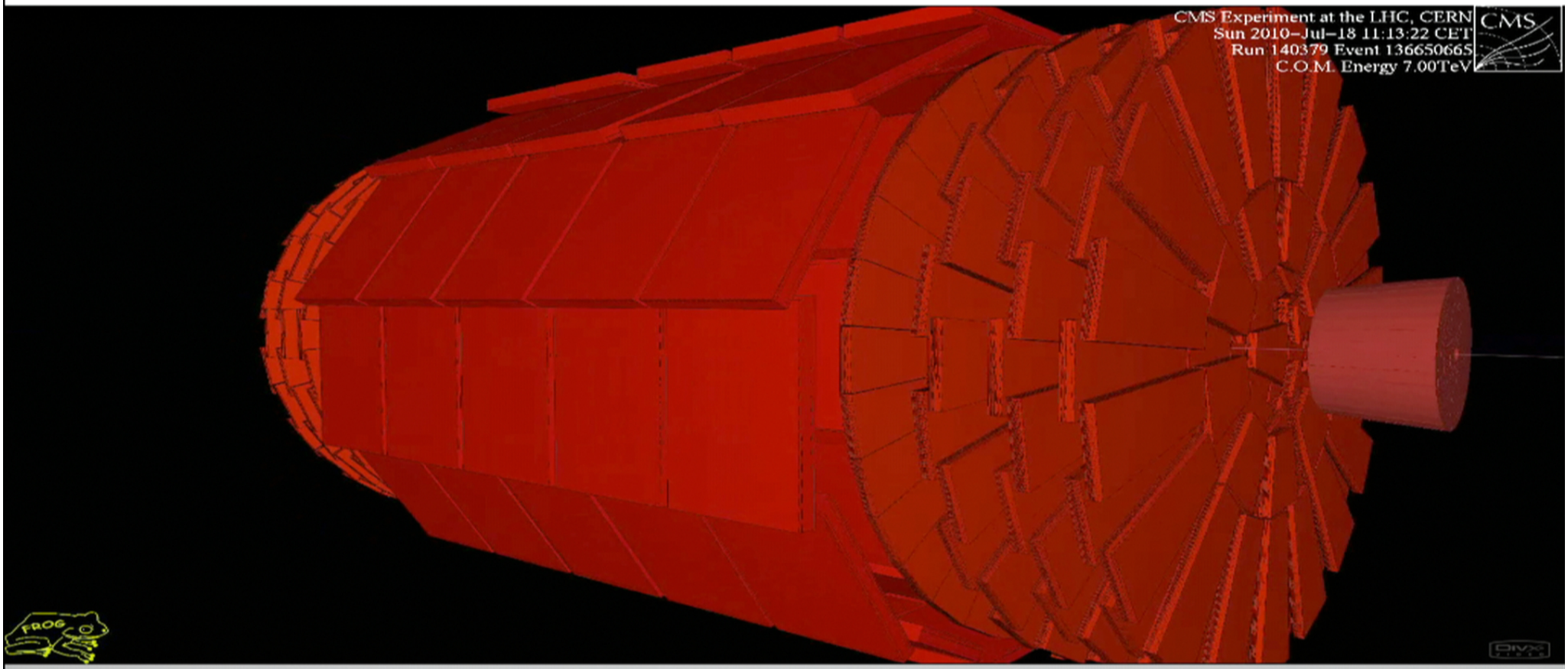
# The CMS Collaboration: >3170 scientists and engineers, >800 students from 185 Institutions in 39 countries .







# March 30 2010: Start of the 7 TeV Run




An event containing "top" quarks

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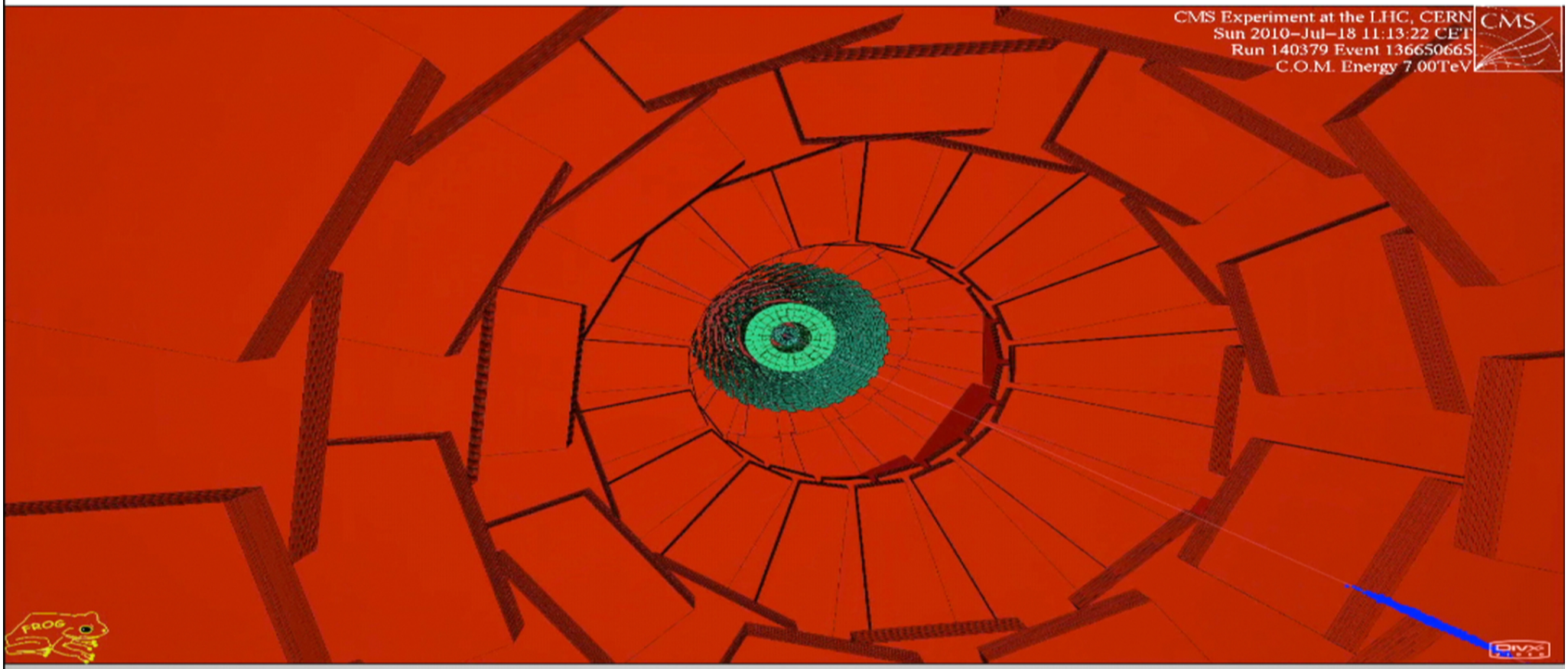


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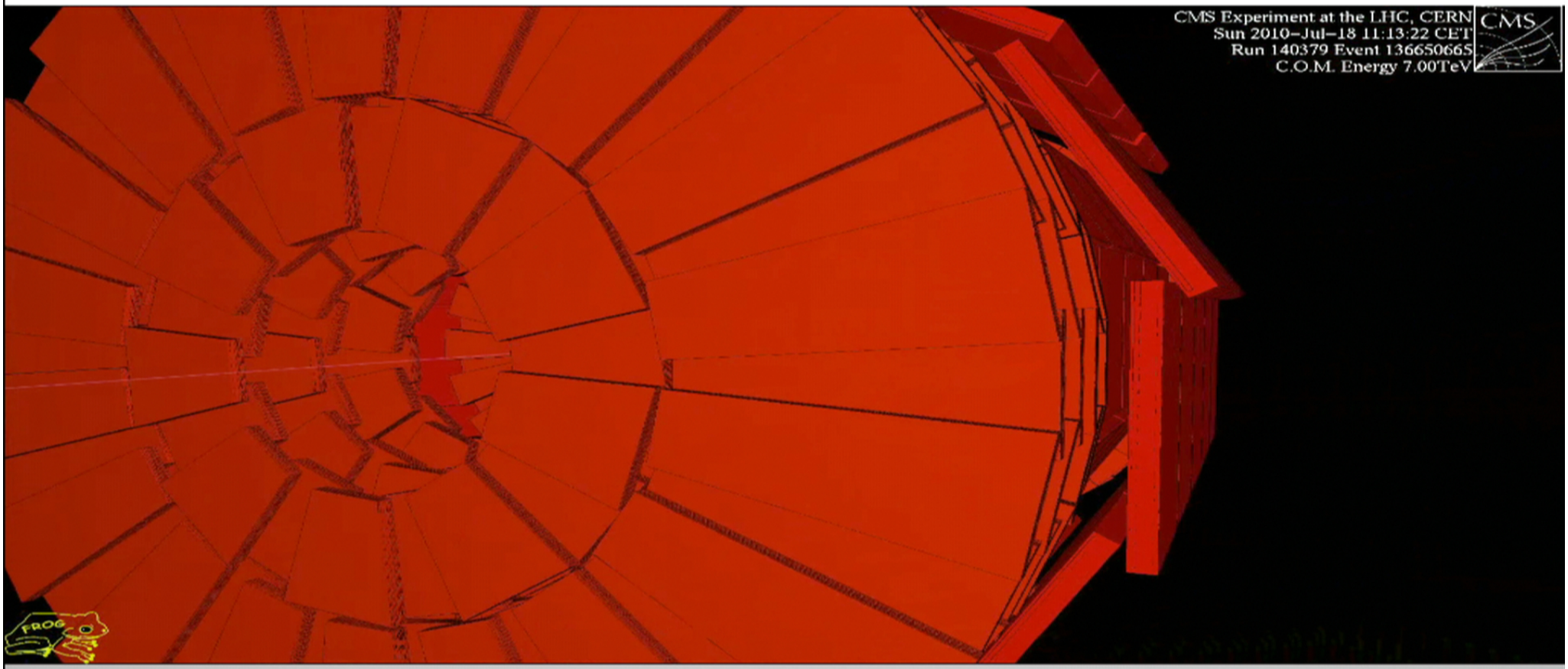
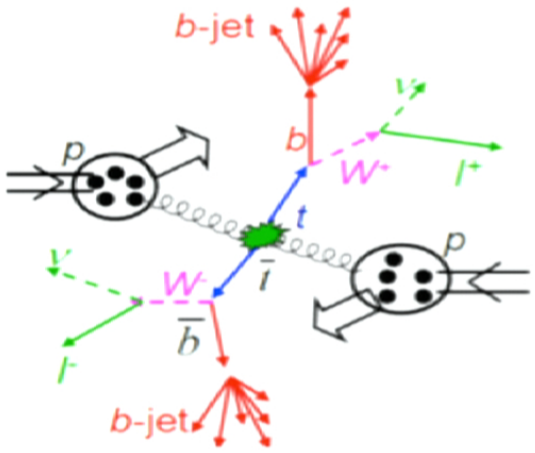
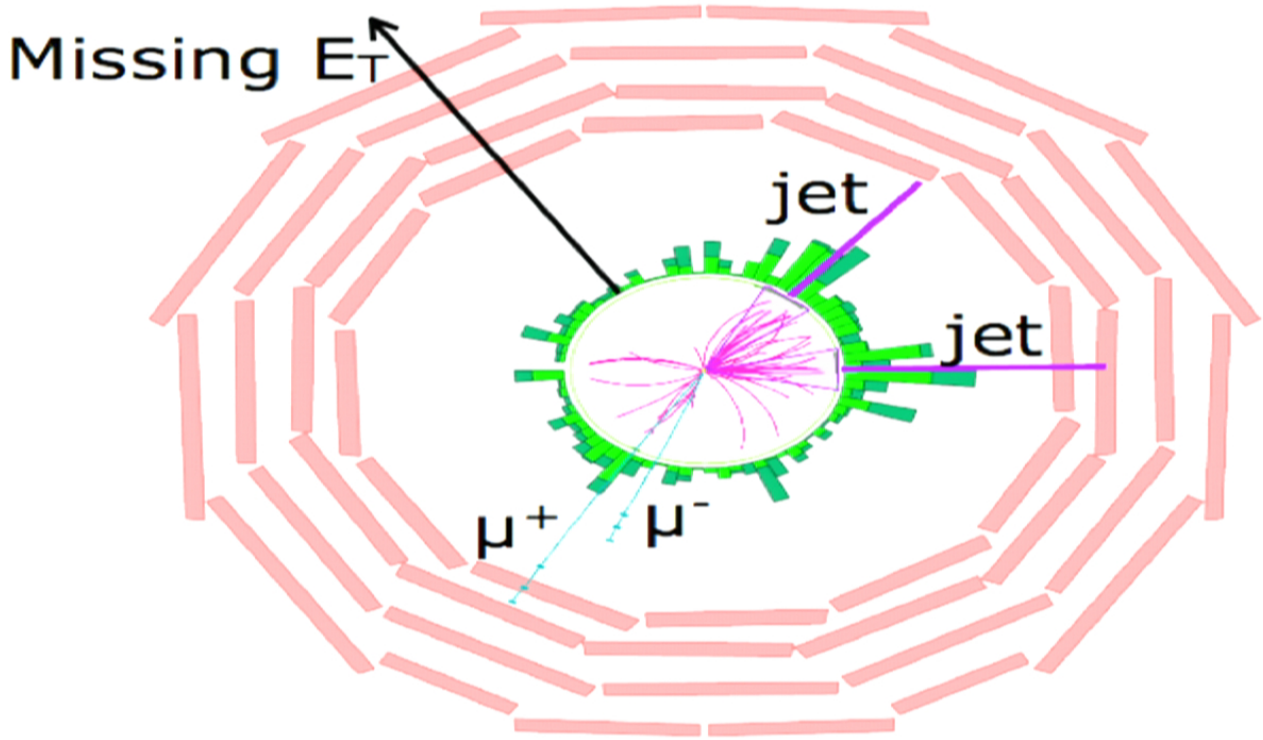



An event containing "top" quarks

# Candidate Event for Top Production

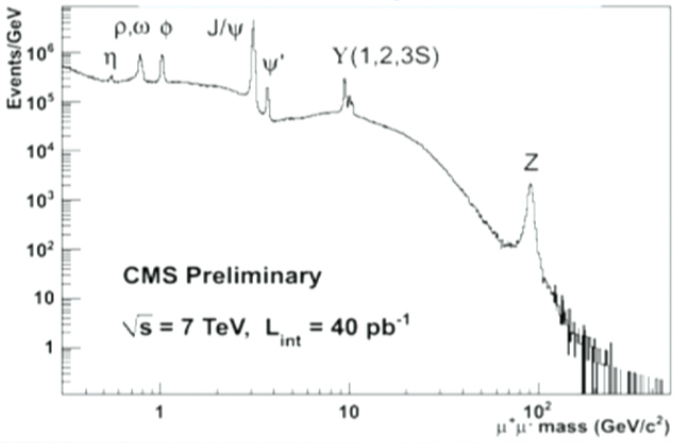


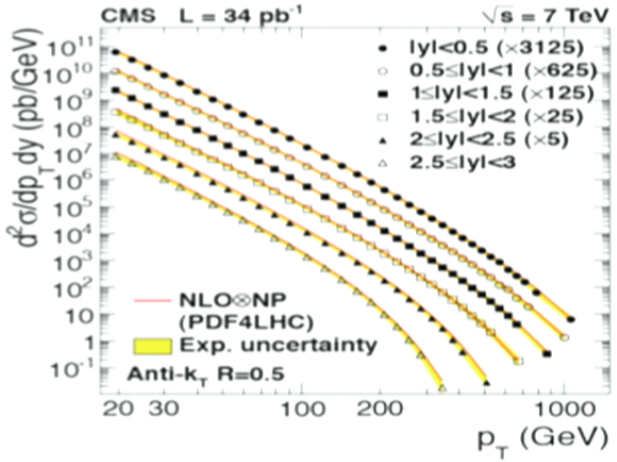

Top Di-Muon Candidate Event

# Standard Model: EWK and QCD

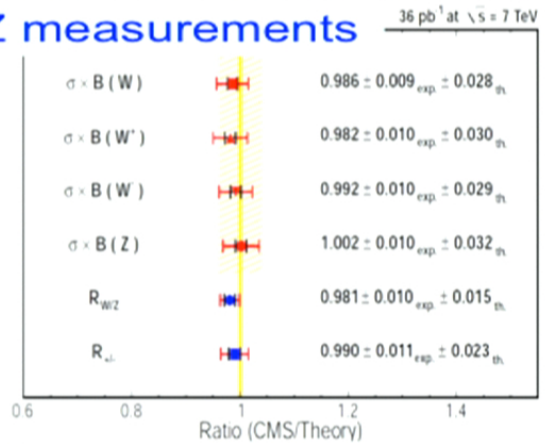
## Di-muon spectrum



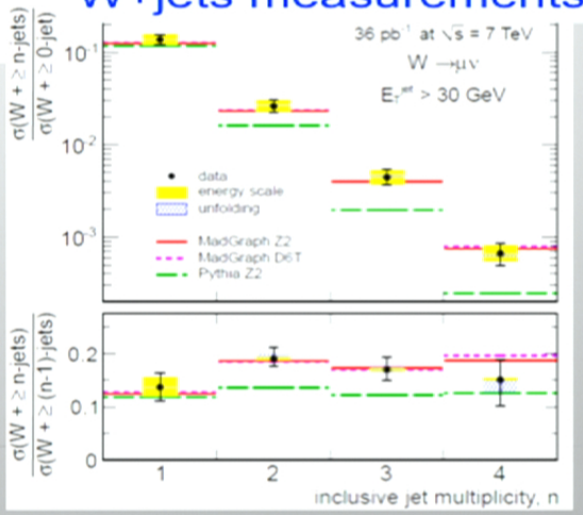

## Inclusive Jets



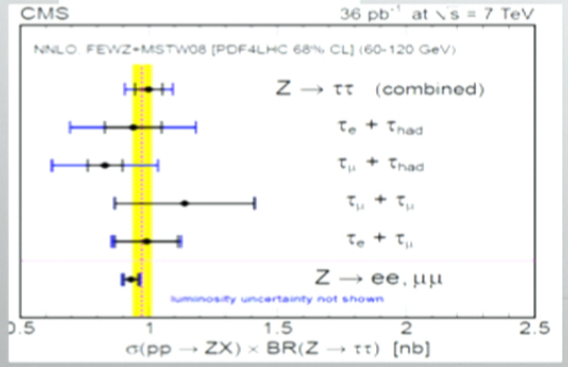

## W/Z measurements



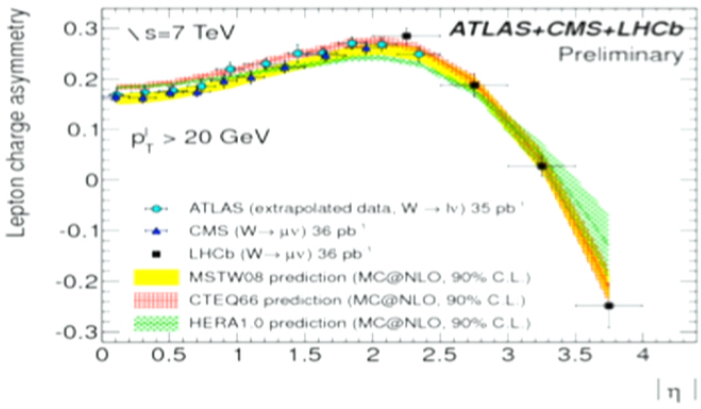

## W+jets measurements



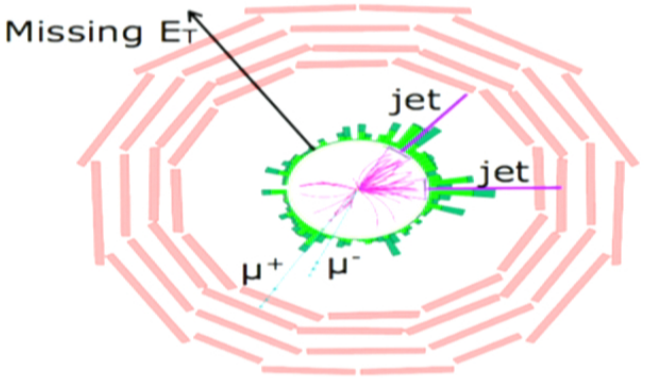

## Z-> TauTau




## W charge asymmetry

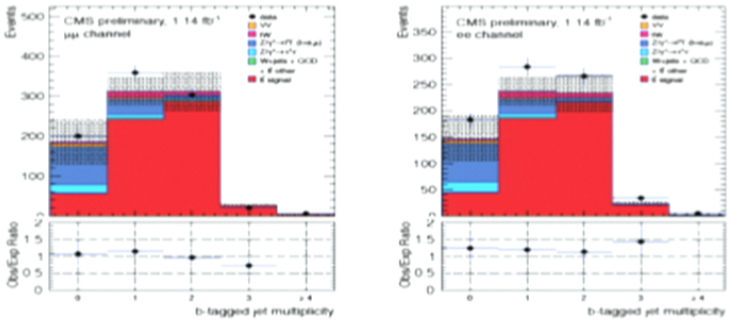


# Standard Model: Top quark

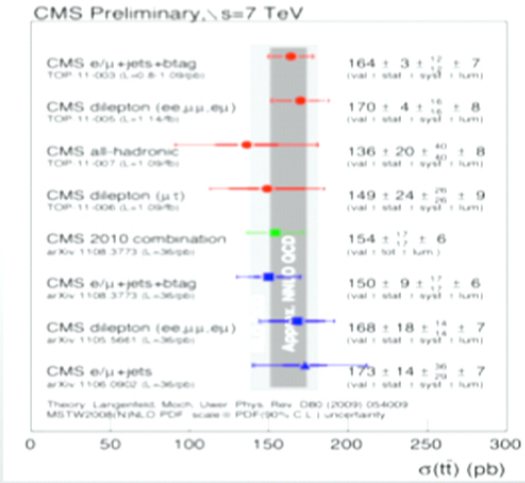



Top Di-Muon Candidate Event

## Di-lepton + btag Selection

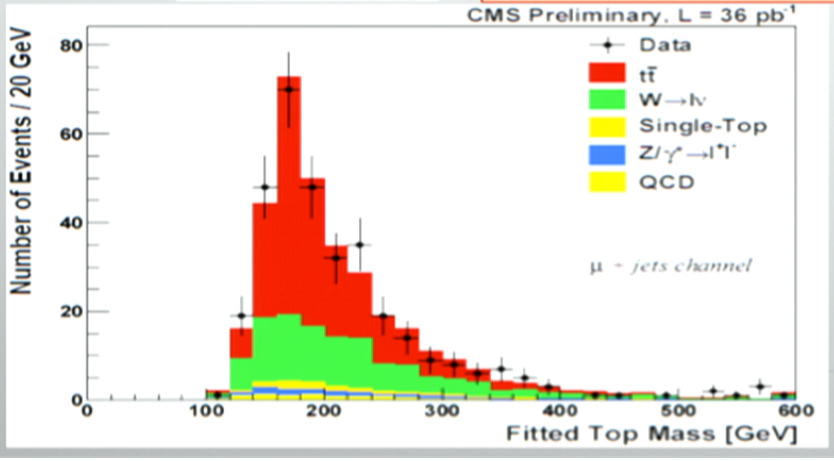



## Top cross section




## Top Mass

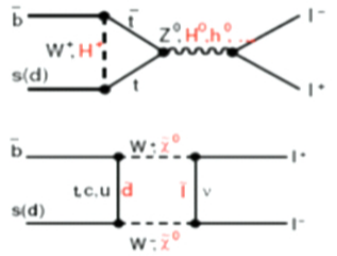
$$m_t = 173.4 \pm 1.9(\text{stat}) \pm 2.7(\text{syst}) \text{ GeV}.$$

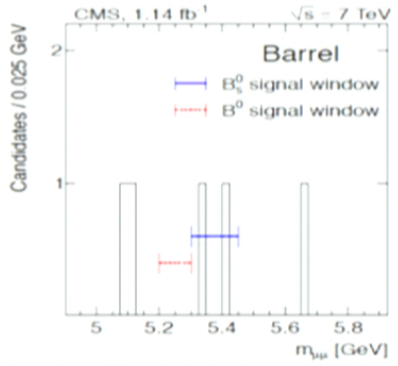


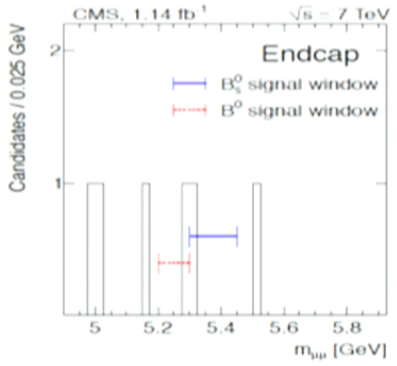

$\Delta m(t-\bar{t}) =$
$-1.20 \pm 1.21(\text{stat}) \pm 0.47(\text{syst})$ GeV

# Search for $B_{s(d)} \rightarrow \mu\mu$

- Decays are highly suppressed in the SM
  - BR($B_s \rightarrow \mu\mu$): $(3.2\pm0.2)\times10^{-9}$, $B_d \rightarrow \mu\mu$: $(1.0\pm0.1)\times10^{-10}$
- Indirect sensitivity to new physics
  - MSSM: $BR \propto (\tan\beta)^6$
- Blind analysis
  - $B^+ \rightarrow J/\psi\, K^+$ used for normalization
  - $B^0 \rightarrow J/\psi\, \phi$ used as control regions for efficiencies
  - Events observed in the unblinded windows are consistent with bkg. plus SM expectations.
- CMS BR Limits at 95% CL
  - $B_s \rightarrow \mu^+\mu^- < 1.9\times10^{-8}$
  - $B_d \rightarrow \mu^+\mu^- < 4.6\times10^{-9}$



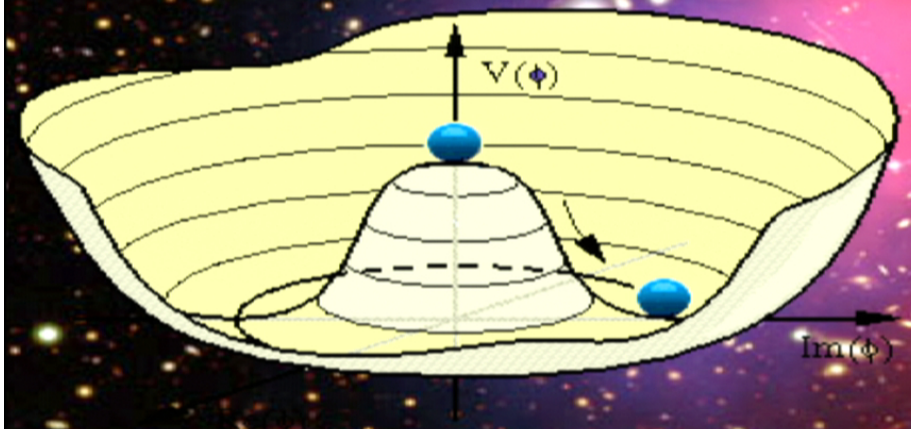



# LHC: Exploring the Terascale


"Data are coming! Data are coming!"

# The Hunt for the Higgs

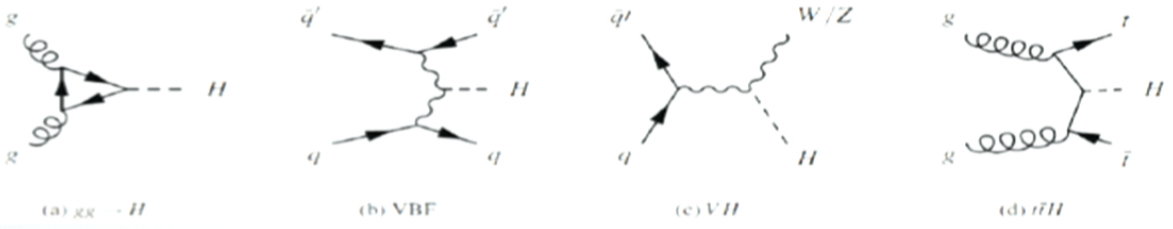
Where do the masses come from?




Scalar field with at least one scalar particle

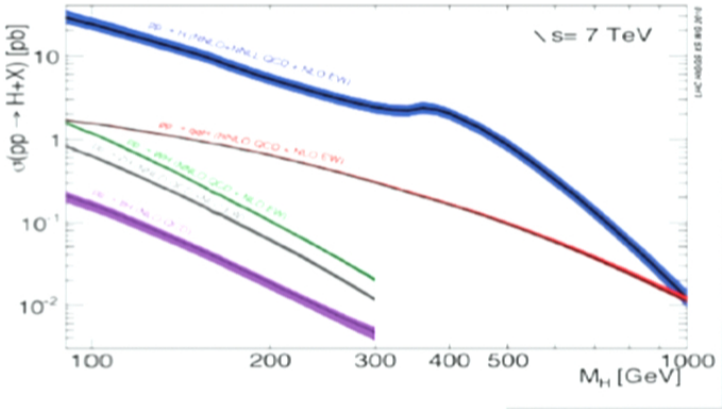
The key question: Where is the Higgs?

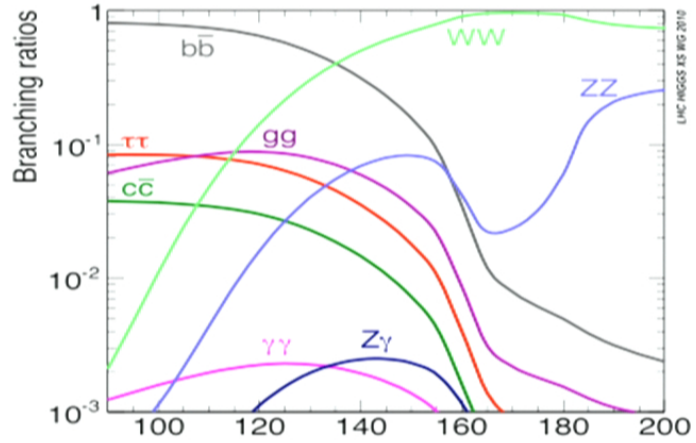
# Overview of Higgs Searches

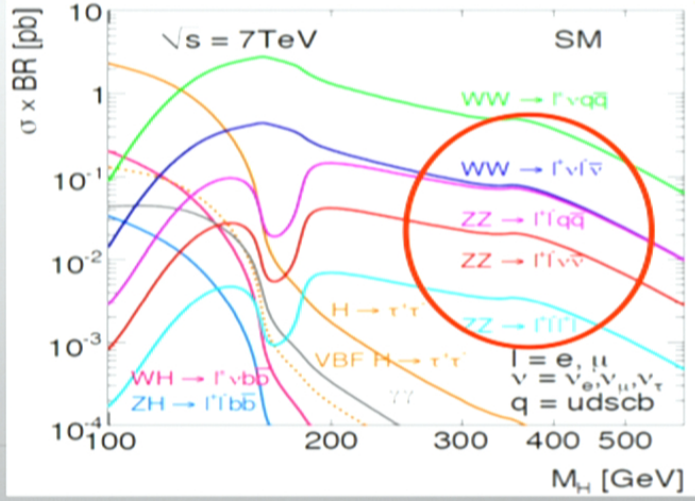



## Channels studied

- Light Higgs
  - H→bb
  - H→tau tau
  - H→2 photons
  - H→WW
  - H→ZZ→4l
- Medium to Heavy Higgs
  - H→WW→2l2v (+jets)
  - H→ZZ→ (2l2j, 2l2v, 4l, 2l2τ)

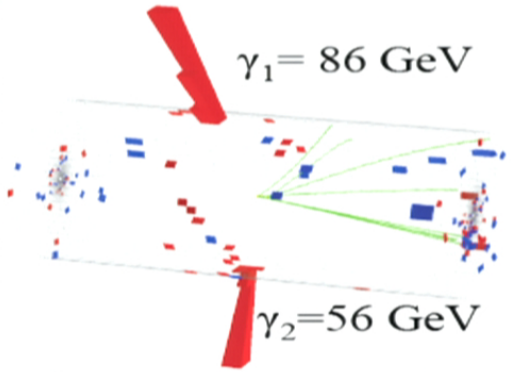


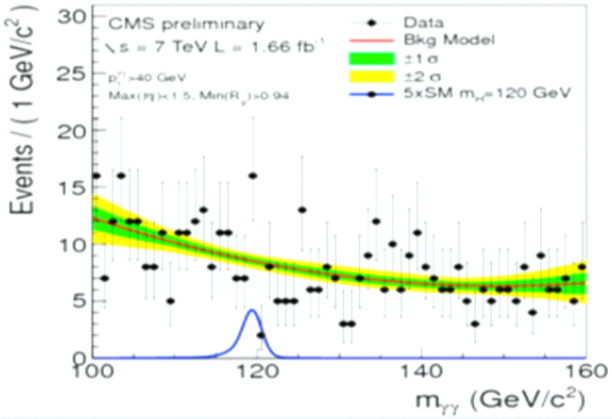



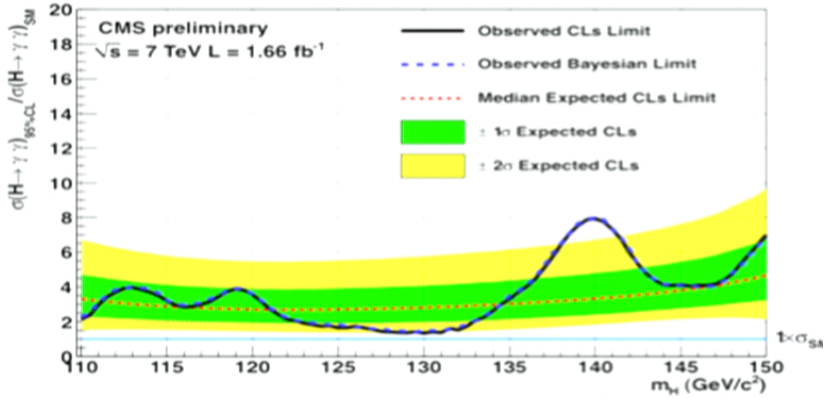
# H→ 2 Photons and 2 W's

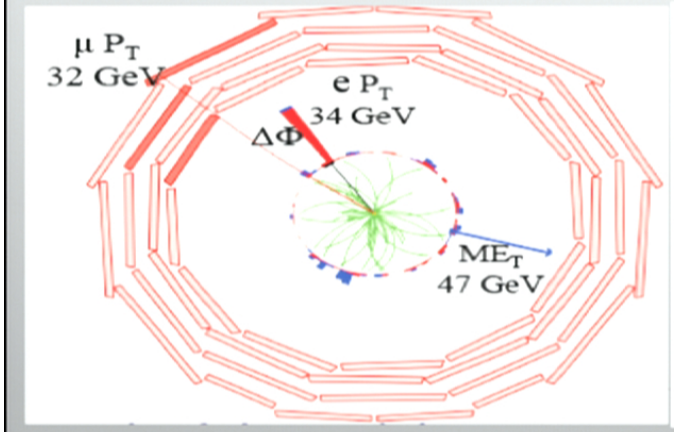
CMS-HIG-11-021, 014

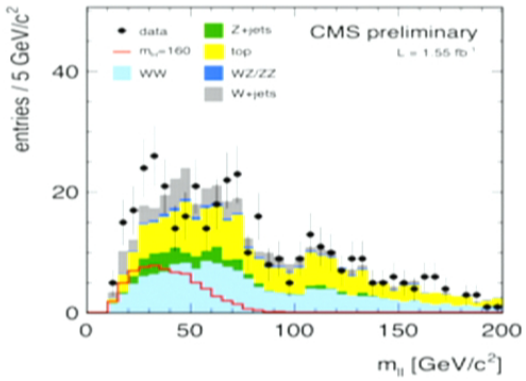


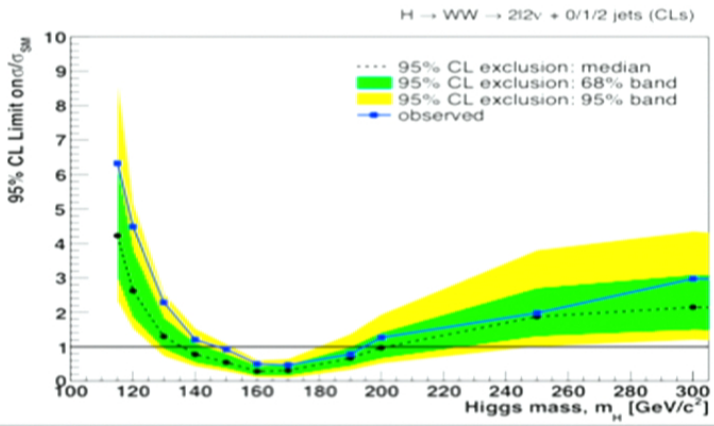

Signature: 2 energetic, isolated γ, narrow mass peak



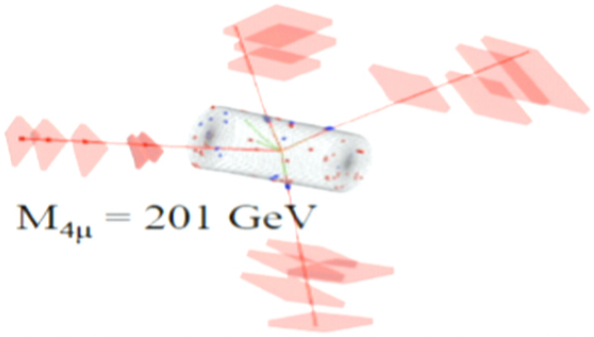



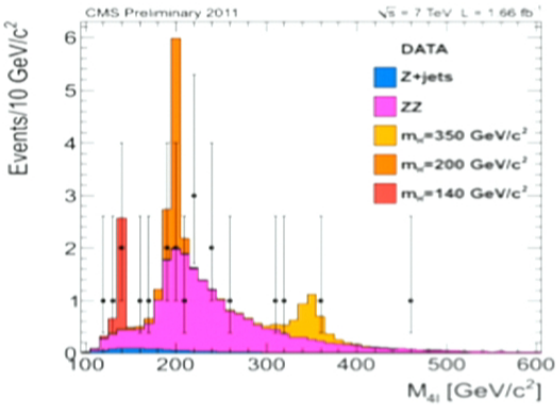



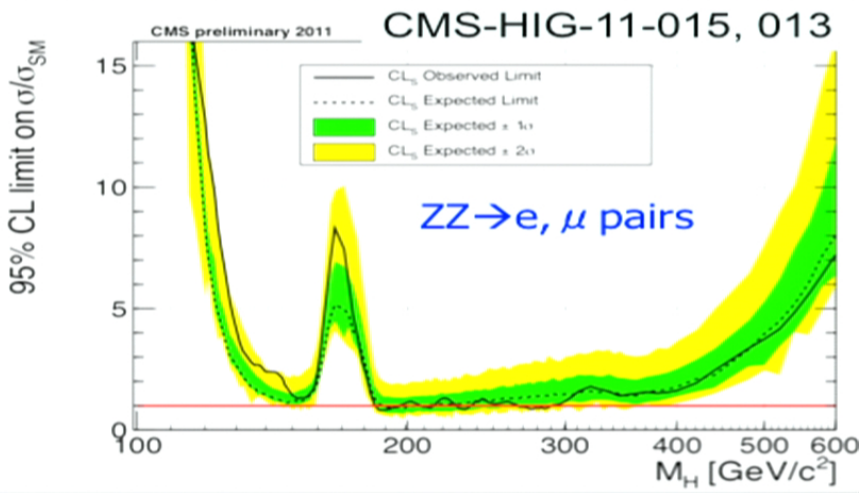



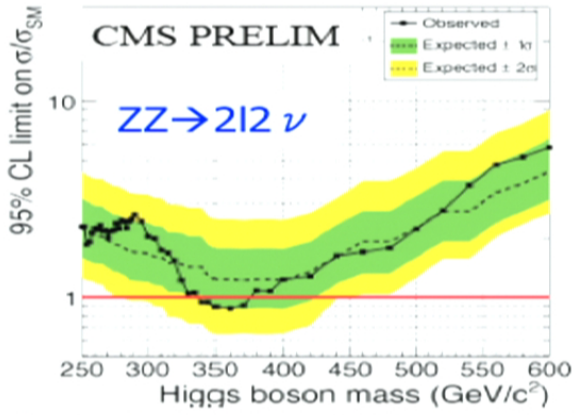
# H→ZZ Channel

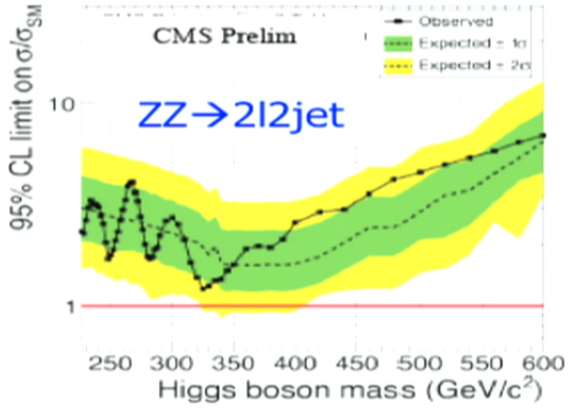


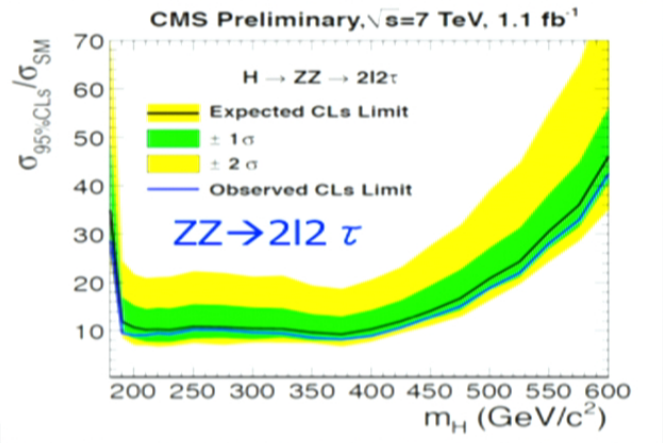



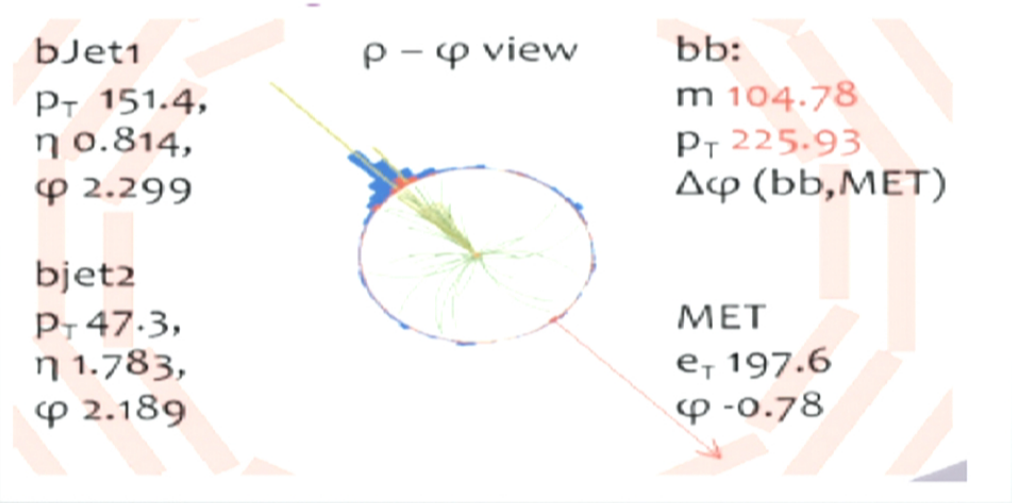

4lepton mass resolution is O(2-3) GeV



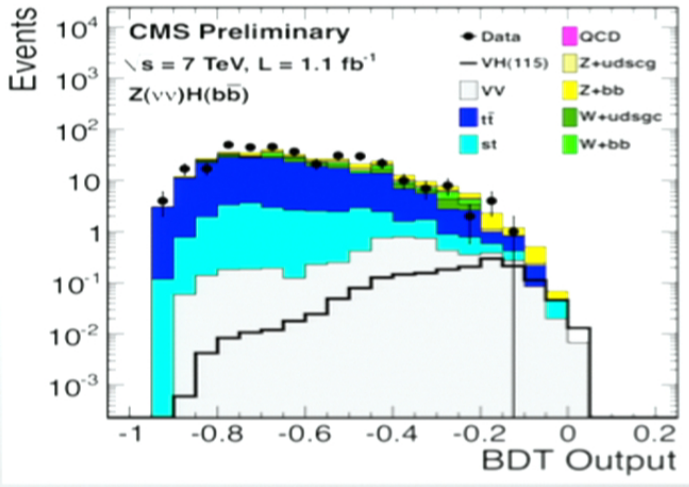



# H→bb Channel

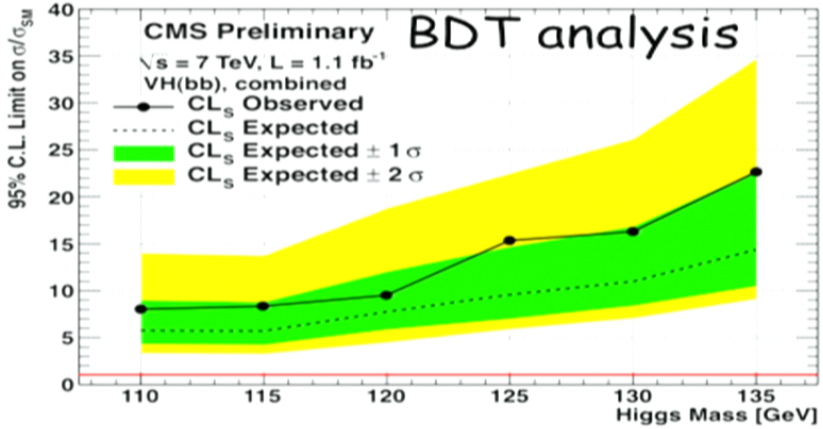



PAS HIG-11-012



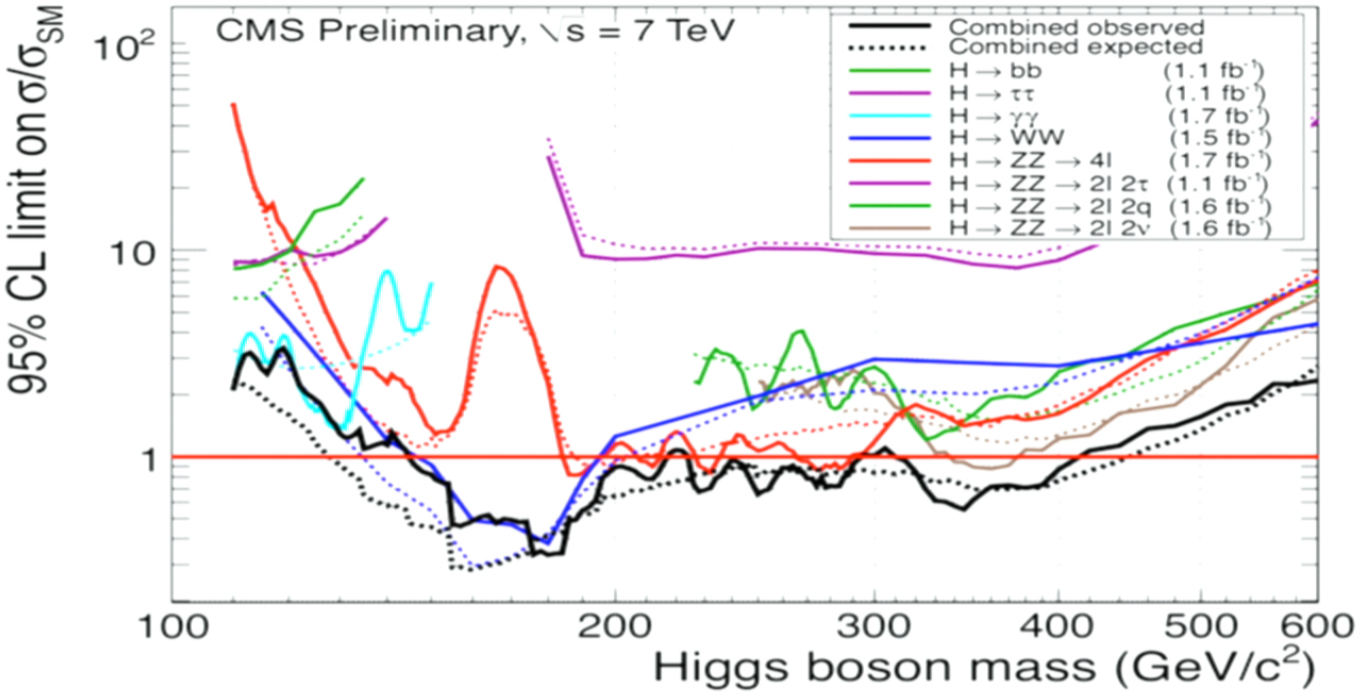

## Challenging at the LHC

- Associated production with W/Z
- Boosted W/Z topology, with H back-to-back with W/Z
- 2 b-jets (~10% mass resolution)
- 5 topologies studied:
  - WH → μνbb, evbb
  - ZH → μμbb, eebb
  - ZH → νvbb:



# Summary of all Searches (CMS)

CMS-HIG-11-022

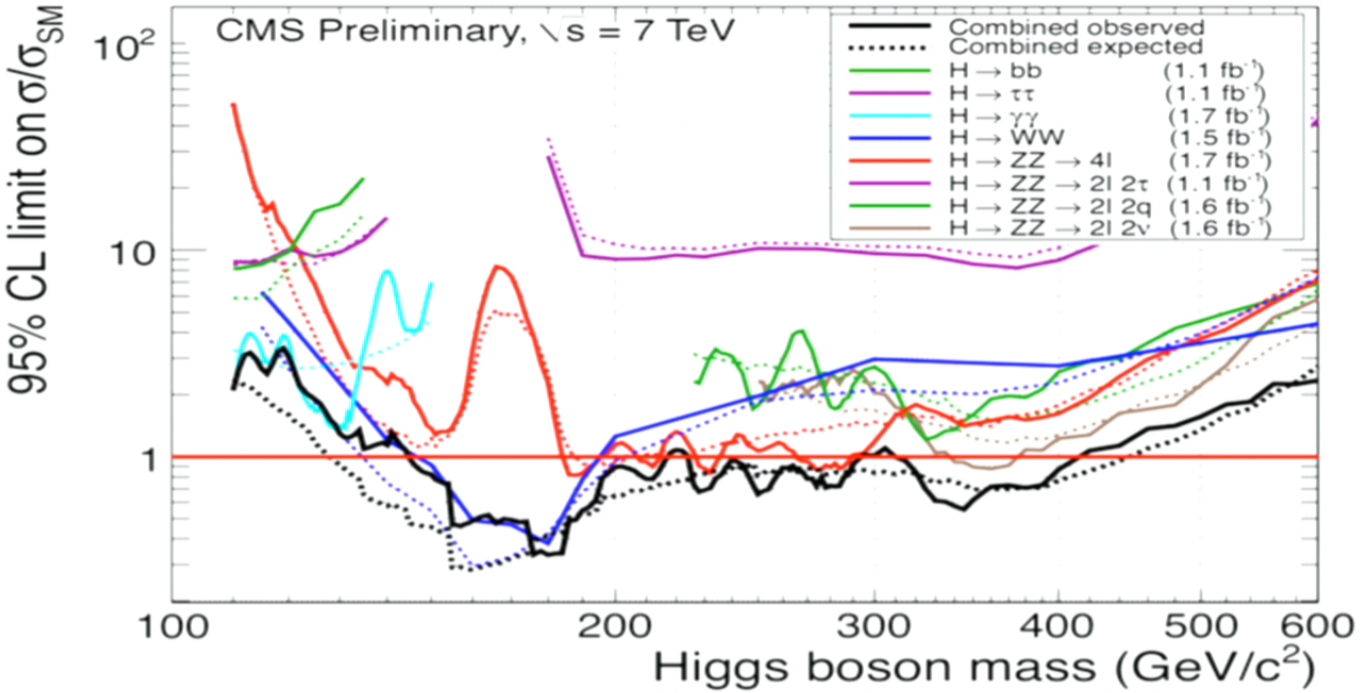



Σ (all this work)

- Solid lines: observed limits @ 95% CL
- Dashed lines: expected limits

# Summary of all Searches (CMS)

CMS-HIG-11-022

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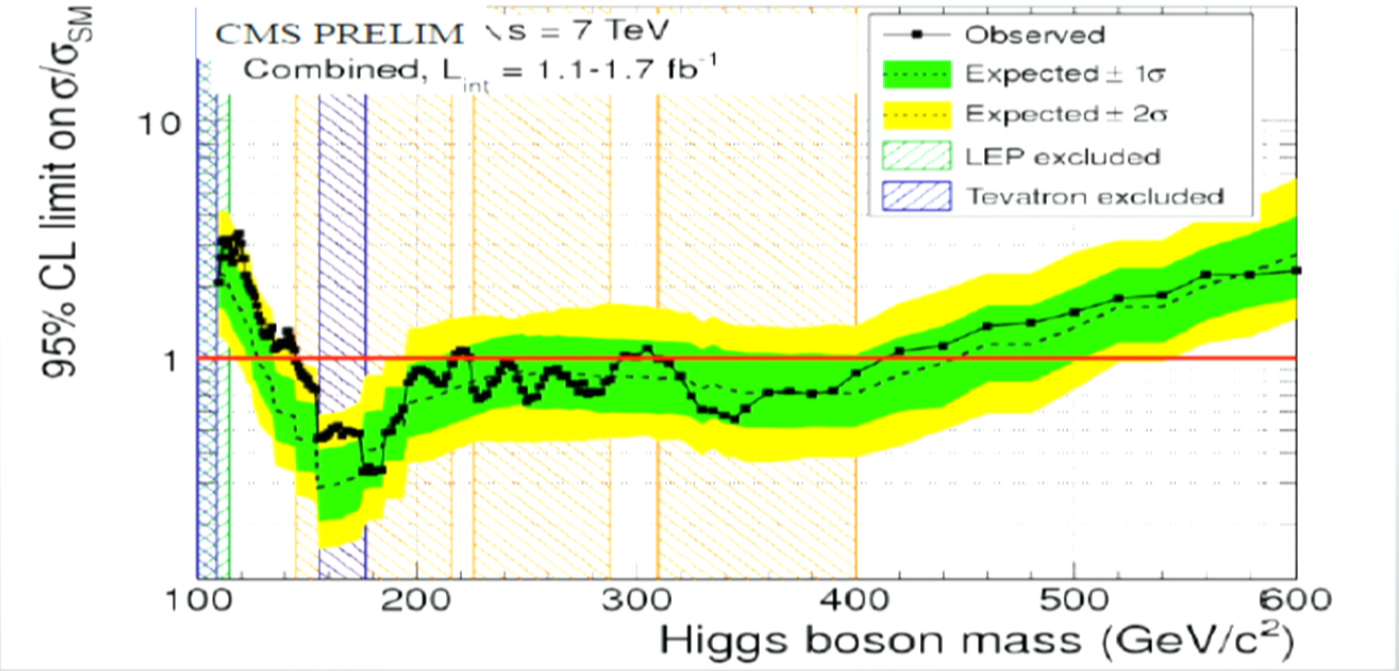
# Higgs Summary So Far

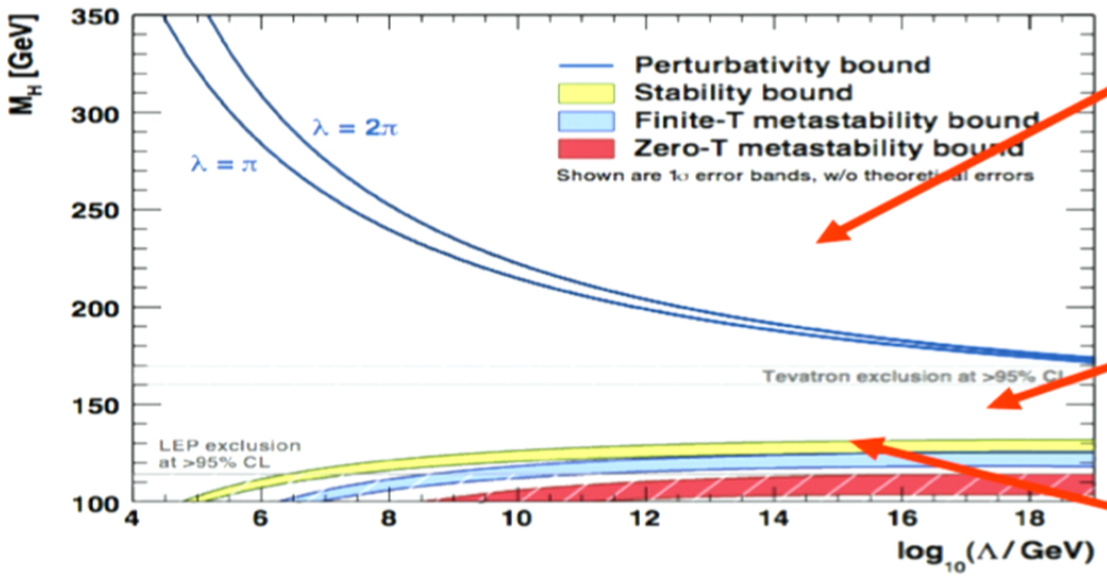



Expected 95% CL exclusion mass range: 130-440 GeV
Observed 95% CL exclusion mass range: 145-216, 226-288, 310-400 GeV

Combine ATLAS+CMS: Will be released next week
Next: full 2011 data analysis Spring 2012? LHC+Tevatron combination?

# A Light Higgs: Consequences

A light Higgs implies that the Standard Model cannot be stable up to the GUT or Planck scale ($10^{19}$ GeV)




The effective potential blows up, due to heavy top quark mass

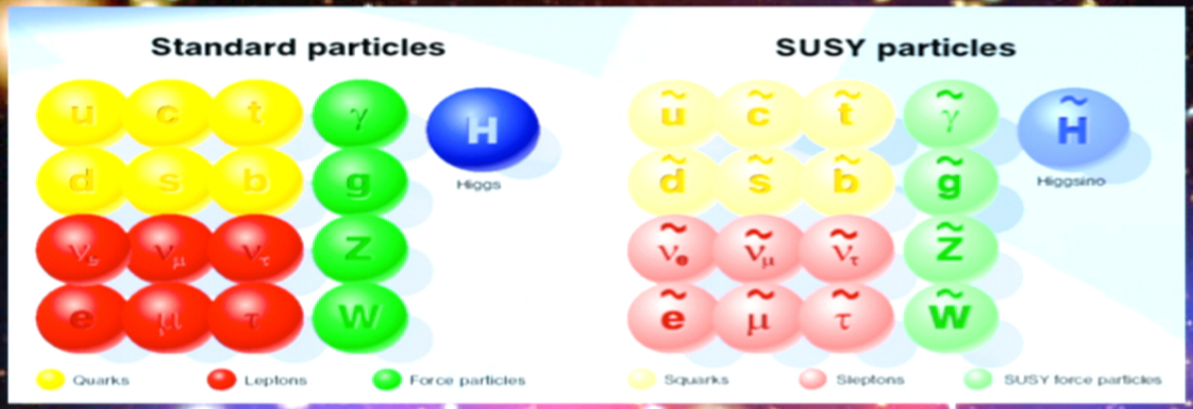
**Allowed corridor** but needs strong fine-tuning...

The electroweak vacuum is unstable to corrections from scales $\Lambda >> v = 246$ GeV

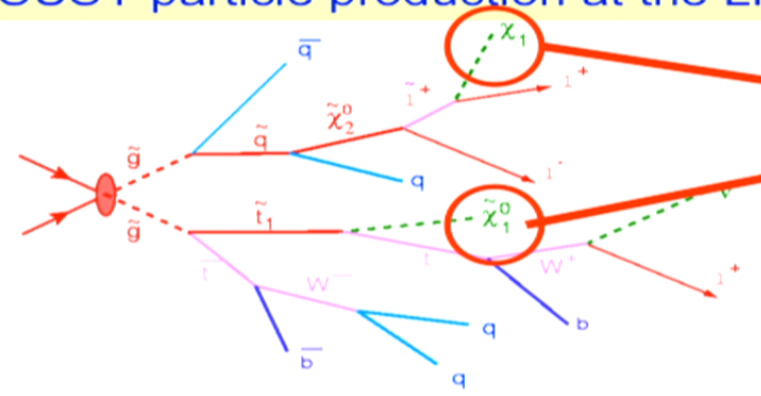
New physics expected in TeV range

Harigaya
Matsumoto
Murayama

# Searches for Supersymmetry

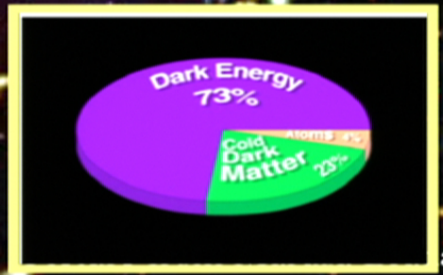



SUSY particle production at the LHC



Assume "R-Parity" Conservation

Candidate particles for Dark Matter
⇒ Produce Dark Matter in the lab



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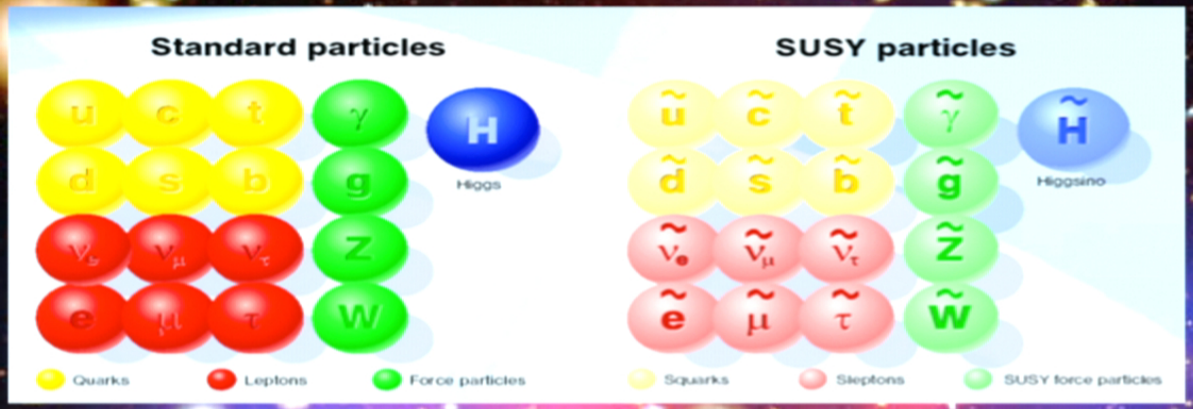


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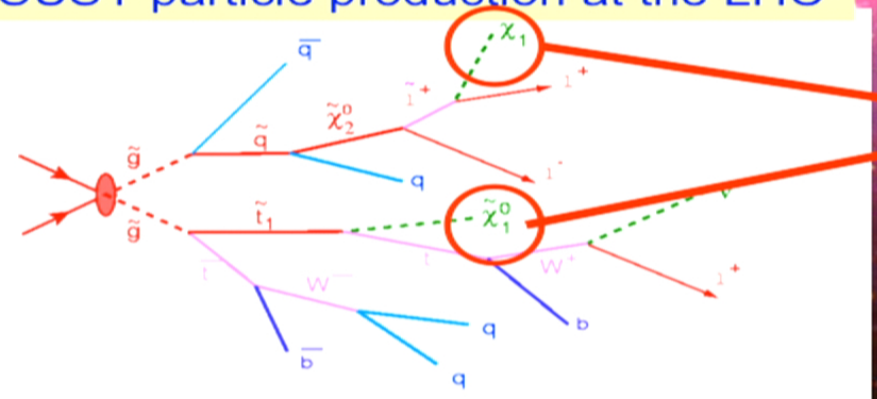

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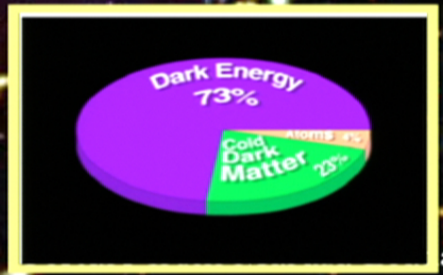


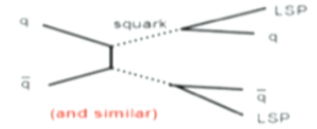
# SUSY Searches in CMS

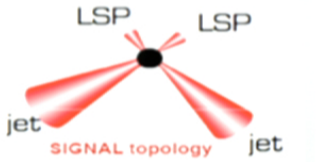
| 0-leptons | 1-lepton | OSDL | SSDL | ≥3 leptons | 2-photons | γ+lepton |
|---|---|---|---|---|---|---|
| Jets + MET | Single lepton + Jets + MET | Opposite-sign di-lepton + jets + MET | Same-sign di-lepton + jets + MET | Multi-lepton | Di-photon + jet + MET | Photon + lepton + MET |

**Large** SM backgrounds **Low**

sensitivity to strongly produced SUSY

sensitivity to gauge-mediated SUSY



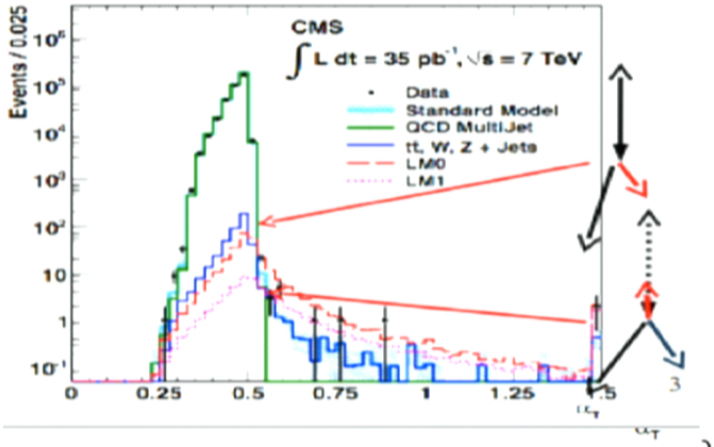





Example: Jets plus MET channel

$$\alpha_T = \frac{E_{T\,j2}}{M_{T\,j1\,j2}} = \frac{\sqrt{E_{T\,j2}/E_{T\,j1}}}{\sqrt{2(1-\cos\Delta\varphi)}}$$

- Control jet SM background with the $\alpha_T$ variable
- No jet SM background expected for $\alpha_T > 0.5$



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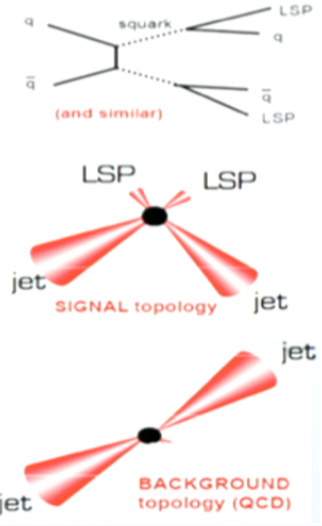


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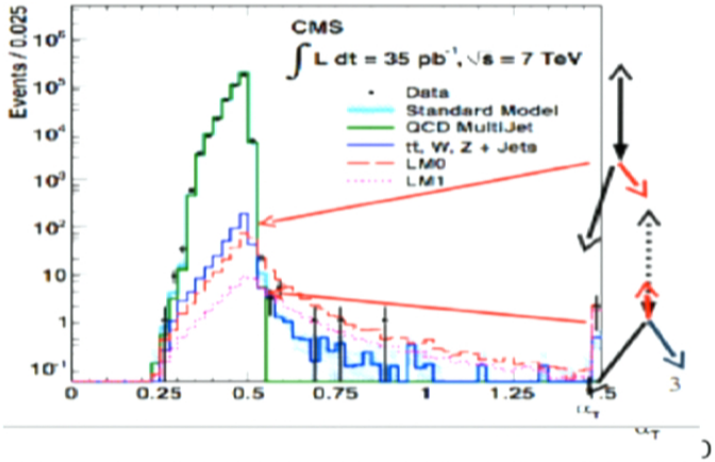
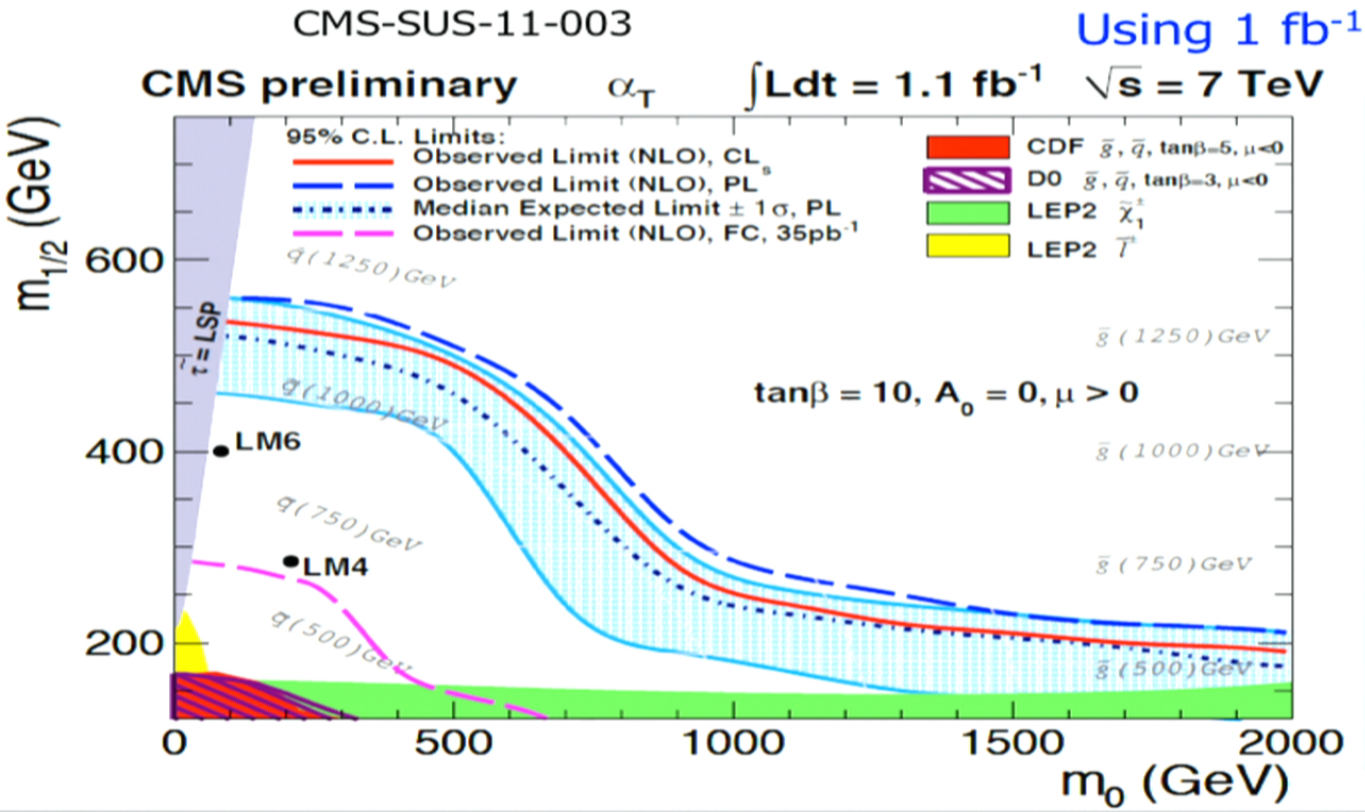


# Jets + Missing $E_T$ Channel




So far Constrained Minimal Supersymmetric Standard Model CMSSM is often used as a benchmark model for presenting the search results...

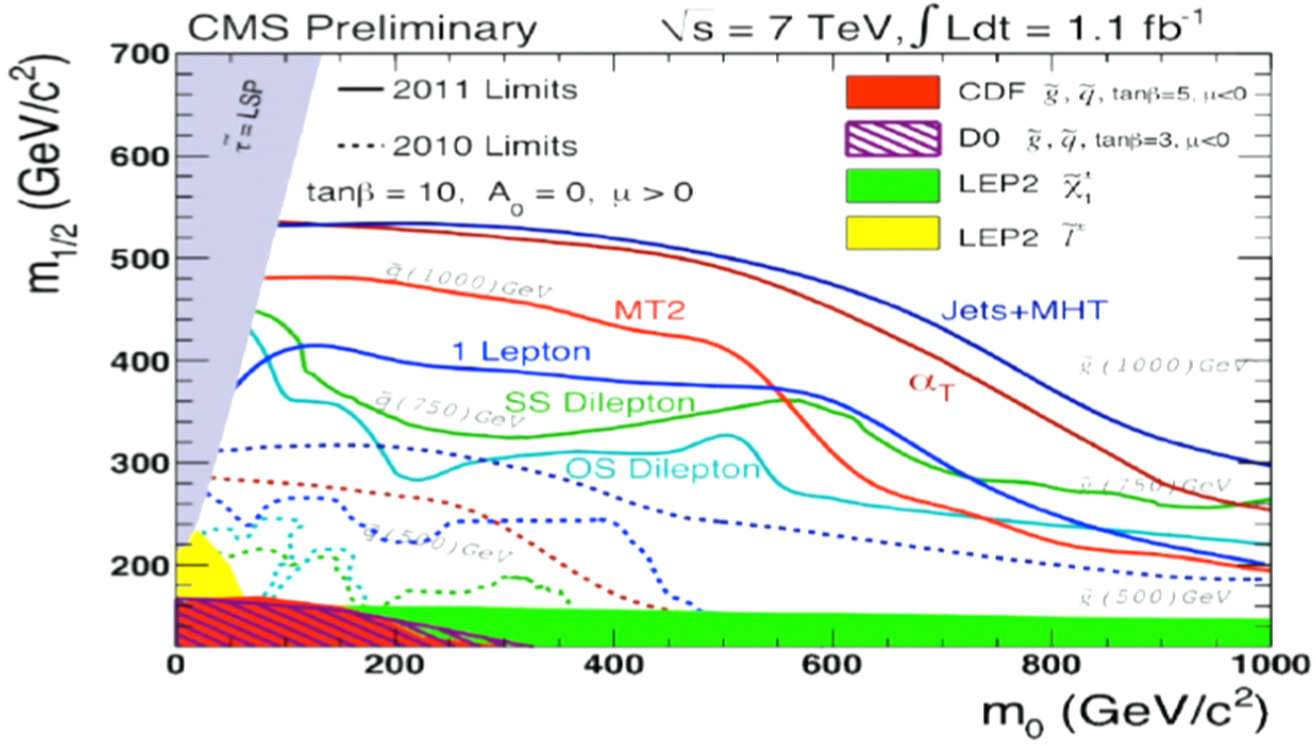
The CMSSM has 4 parameters
-$m_{1/2}$: universal gaugino mass at GUT scale
- $m_0$: universal scalar mass at GUT scale
-tanβ: vev ratio for 2 Higgs doublets
-$A_0$: trilinear coupling
and the sign of Higgs mixing parameter $\mu$

Within the Constrained MSSM model we are crossing the border of excluding gluinos up to 1TeV and squarks up to 1.25TeV

# SUSY Summary:lepton and hadronic channels

## CMS summary of channels with new data

Using 1 $fb^{-1}$




Results of three SUSY analyses completed on full summer 2011 data $\alpha_T$ , MHT, MT2, (Razor), Same Sign and Opposite Sign dileptons...

CMS-SUS-11-003
CMS-SUS-11-004
CMS-SUS-11-005
CMS-SUS-11-010
CMS-SUS-11-011
CMS-SUS-11-015

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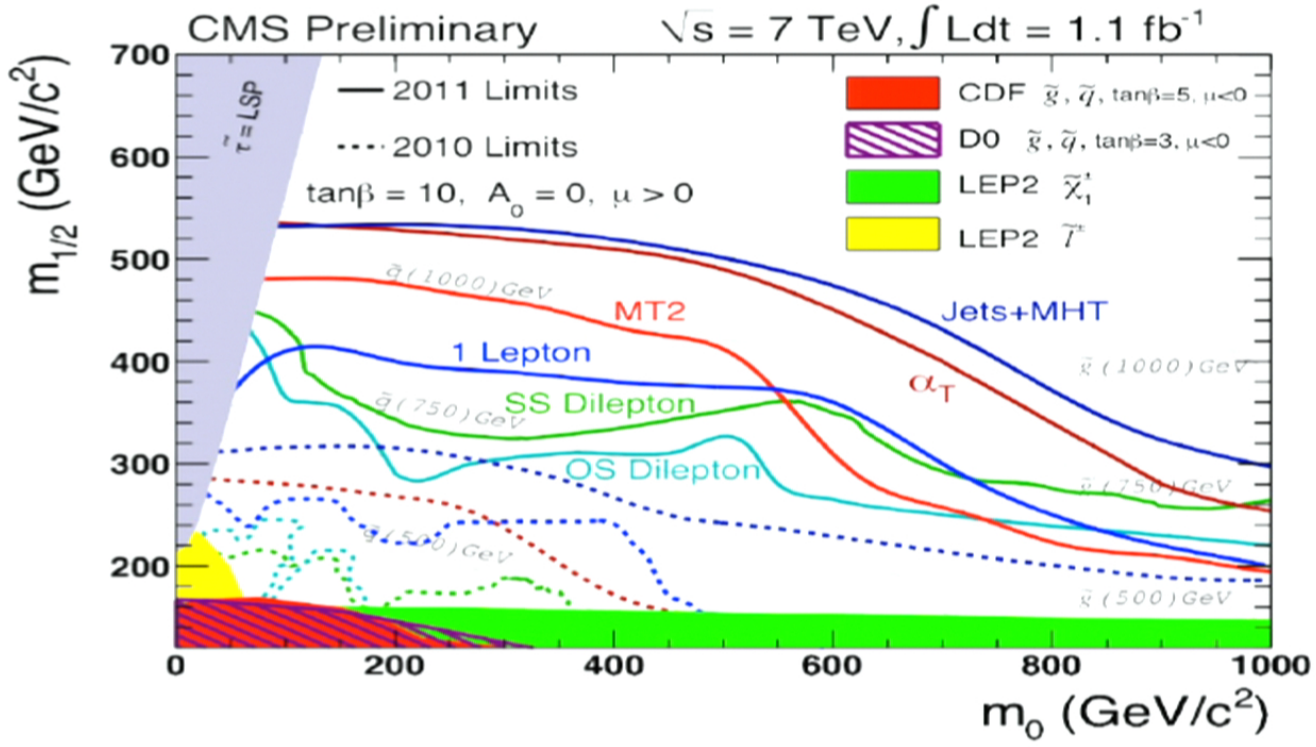


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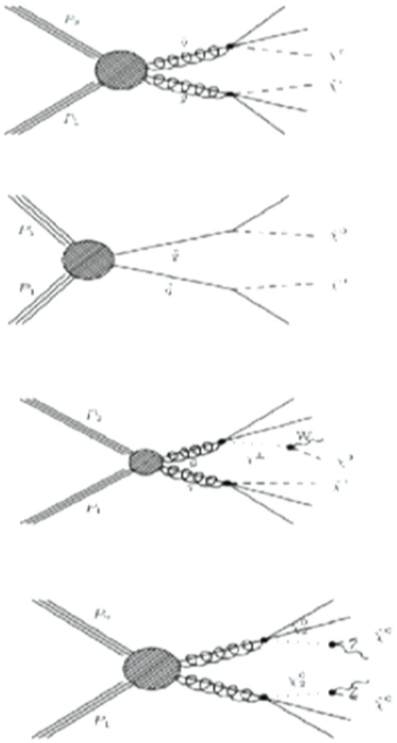
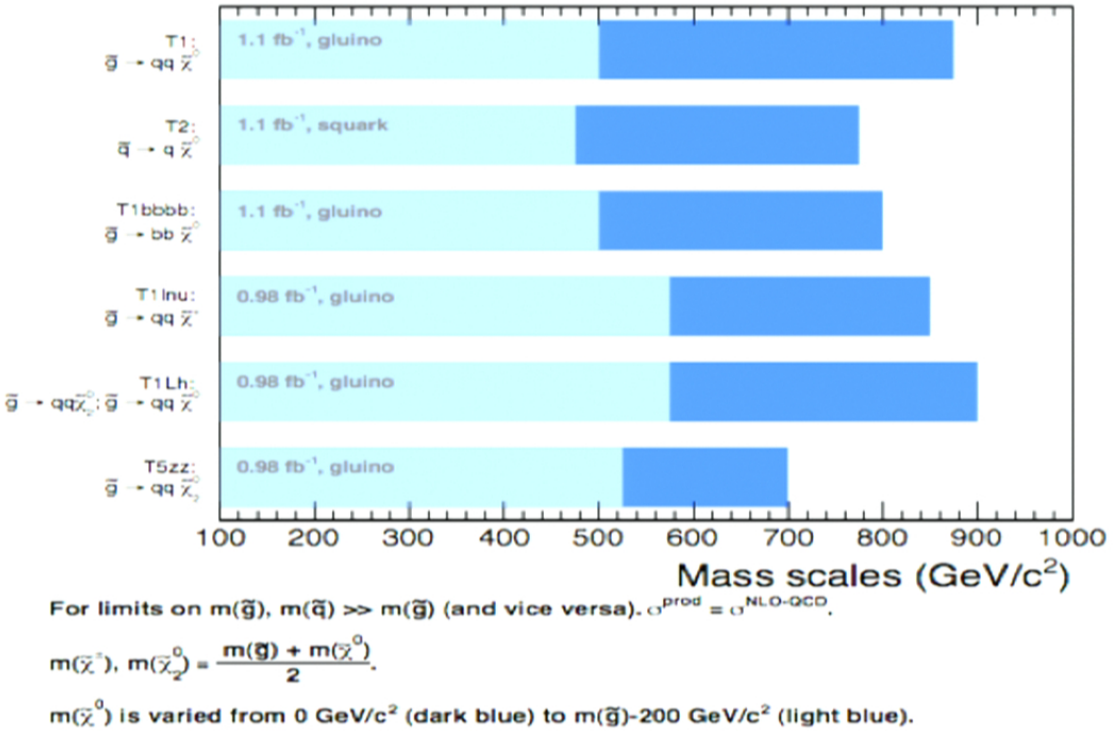
CMS-SUS-11-003
CMS-SUS-11-004
CMS-SUS-11-005
CMS-SUS-11-010
CMS-SUS-11-011
CMS-SUS-11-015

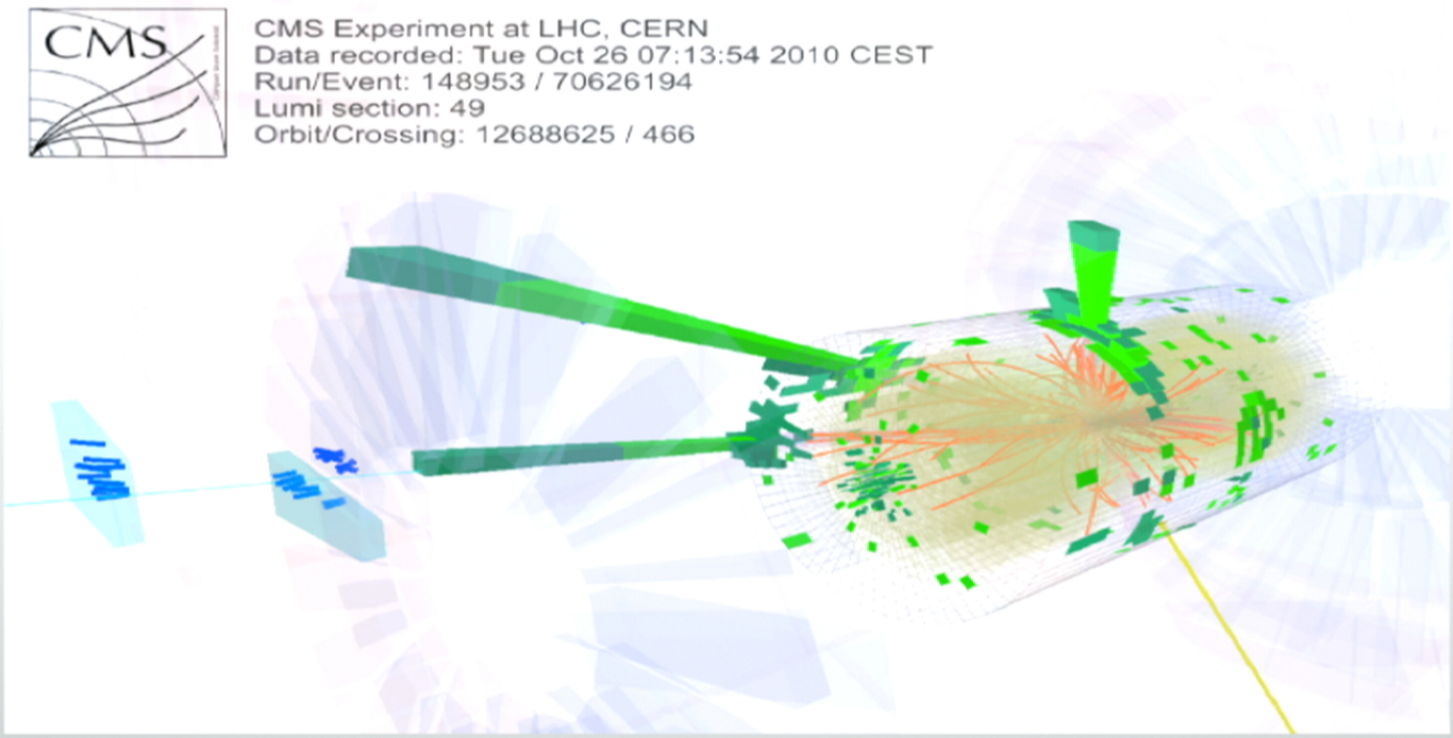
# Interpretation in Simplified Models






How to present best the experimental data? (N. Toro and P. Schuster et al.)
Clearly an important discussion with the community; see also eg CERN workshop

# ...Some Interesting Events...



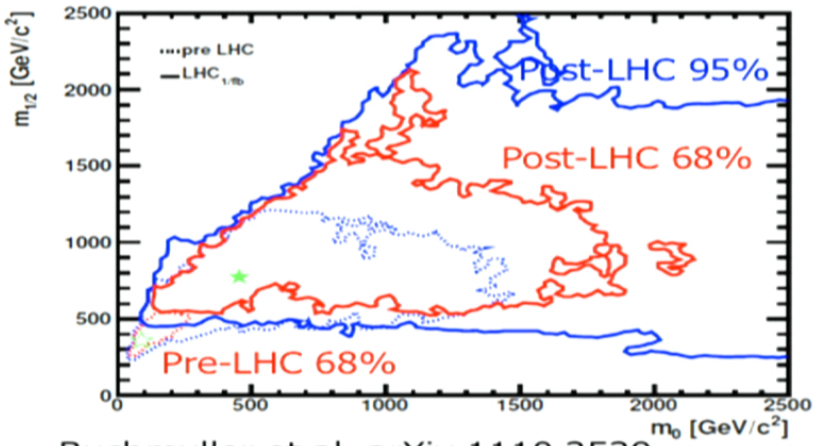

- Event with five jets and large missing transverse energy
- Total sum of transverse momentum $H_T$= 1132 GeV and missing transverse energy $H_{TMiss}$ = 693 GeV

# Impact of LHC Summer Results on SUSY

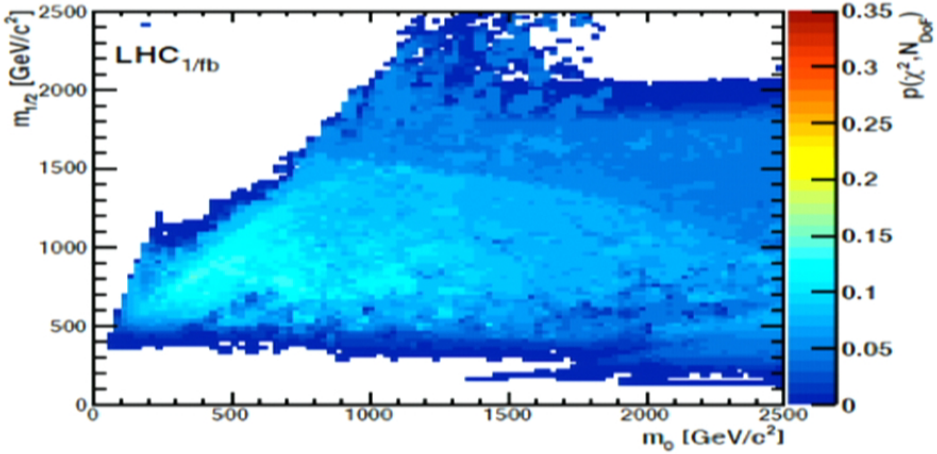
*Simultaneous fit of CMSSM parameters $m_0$, $m_{1/2}$, $A_0$, $\tan\beta$ ($\mu$>0) to more than 30 collider and cosmology data (e.g. $M_W$, $M_{top}$, g-2, BR(B→Xγ), relic density)*

"Predict" on the basis of present data what the preferred region for SUSY is (in constrained MSSM SUSY)

NEW




Buchmuller et al. arXiv 1110.2529




Include the 1 fb$^{-1}$ SUSY searches (jet+MET), $B_s \rightarrow \mu\,\mu$ and XENON100

$\chi^2$ probability: P($\chi^2$) for CMSSM

Before EPS/LP11: 43%  Including EPS/LP11 results: <16%

LHC direct searches significantly constrain allowed CMSSM parameter space!

# What is Next?

- Think beyond the simplest or most constrained models and optimize searches
  - pMSSM
  - NMSSM
  - Degenerate mass spectra
  - Light 3rd generation
  - Split SUSY
  - RPV SUSY
  - …
- How much of the "theory space" do we really cover? May have to revise our searches for other scenarios
- More ideas at the LPCC Workshop@CERN (Aug'11- June '12)

A lot!!

## Missing something?

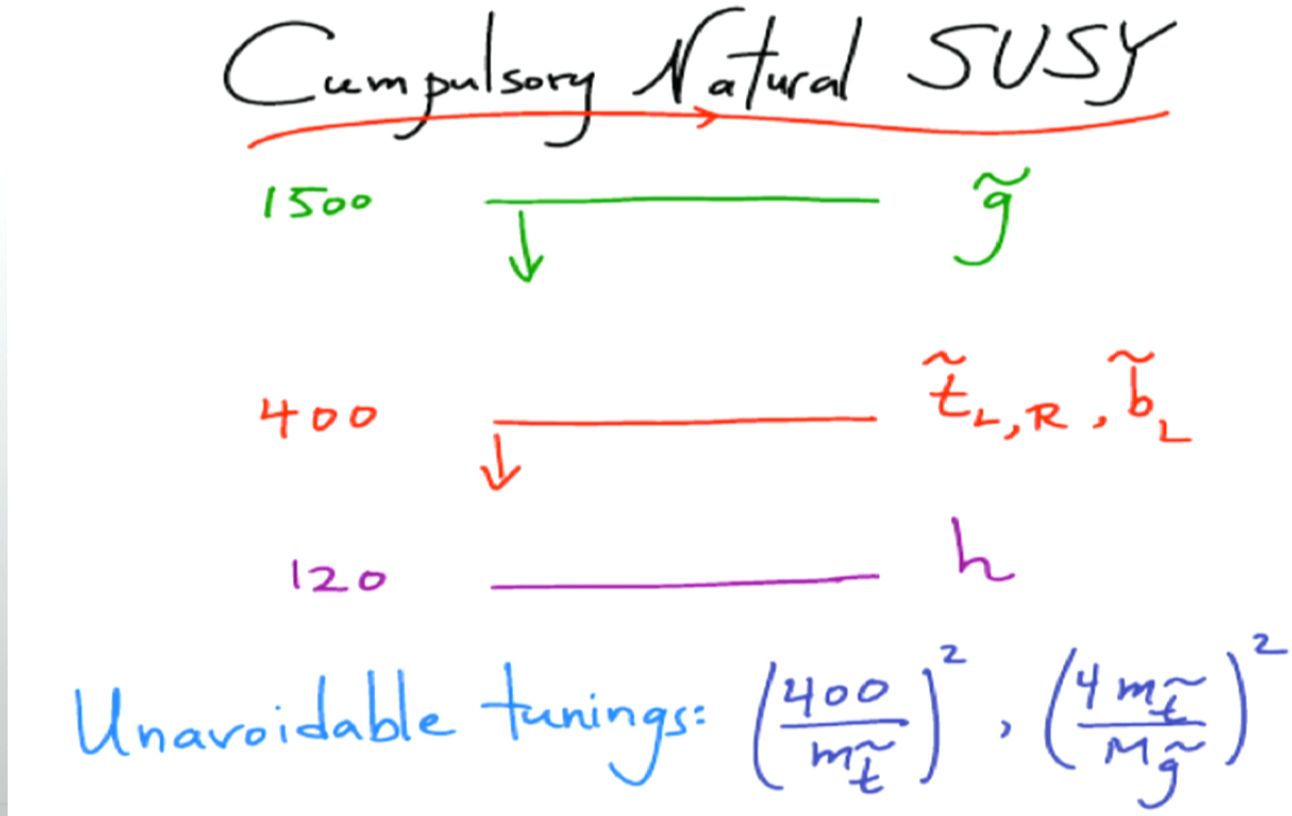
- Important to push limits up, but with more statistics more important to systematically close windows for light sparticles with suppressed xsec…

… e.g.

| "Flavor-Split" spectra (heavy 1st-2nd gen squarks, gluino below 1-1.5 TeV, light 3rd gen) | "Squashed" spectra (everything below ~500GeV but splittings are small, O(10GeV)) | Low MET scenarios (not necessarily RPV) |
|---|---|---|

# What is really needed from SUSY

N. Arkani-Ahmed
CERN 1/11/11



# Hidden SUSY?

Theorist exploring SUSY space for more difficult signatures for the LHC

Eg workshop at UC-Davis this week: Hidden SUSY

- Light stop Next to lightest Sparticle
- Collective R-partity violation
- Minimum Flavor SUSY
- Stealth SUSY….


collective RPV

$W \supset \lambda_1\, udD + \lambda_2\, UdD + \lambda_3 Udd$

- any decay from a superpartner to SM fields must use all three couplings
- but only one couplings needs to be probed at a time, if the decays are sequential

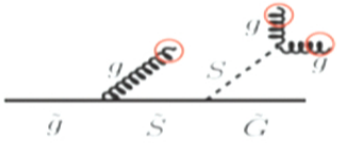
$m_{N_1} > m_D > m_U$

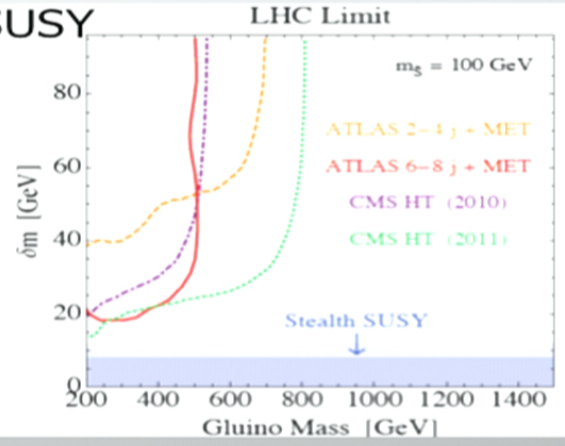
- probing more couplings means higher-multiplicity final states:

$\tilde{N}_1 \to 5j$

Stealth SUSY

- Gluino LVSP
- 6-jet Final States
- Low missing $E_T$
- *False resonances*



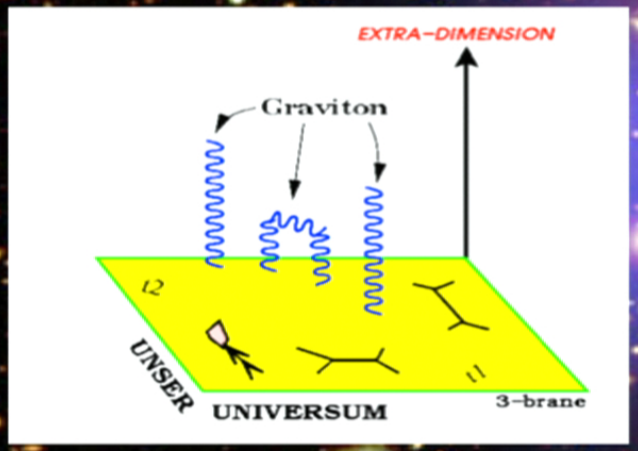

Often many soft jets involved: challenging for the experiments

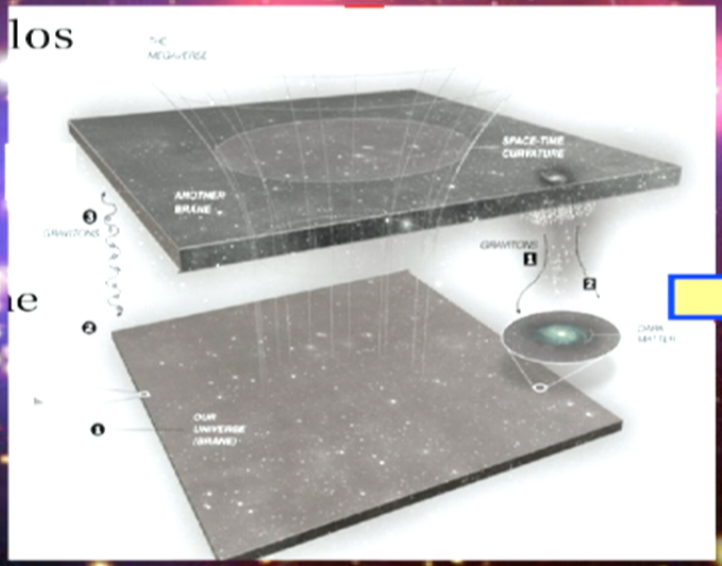
# Extra Space Dimensions

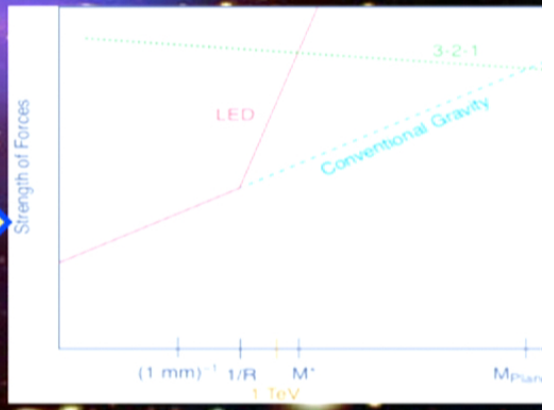
**Problem:**

$$m_{EW} = \frac{1}{(G_F \cdot \sqrt{2})^{\frac{1}{2}}} = 246\ \text{GeV}$$

$$M_{Pl} = \frac{1}{\sqrt{G_N}} = 1.2 \cdot 10^{19}\ \text{GeV}$$



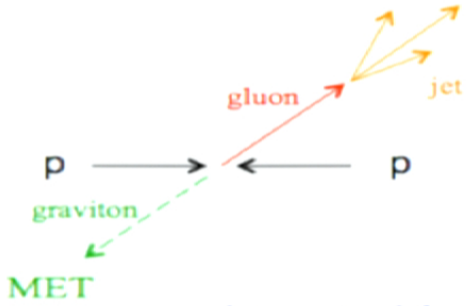




Gravity becomes strong!

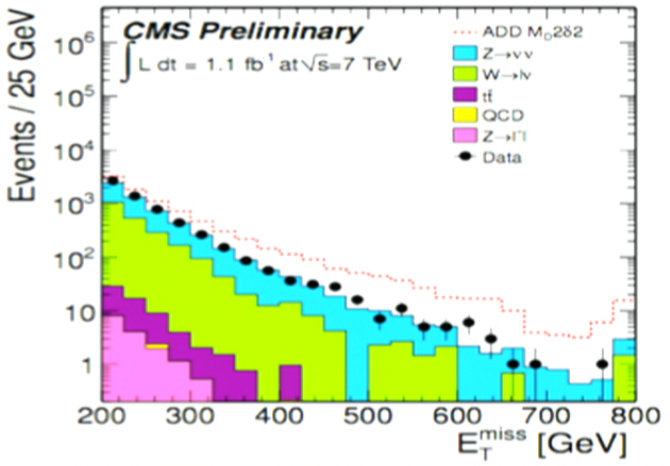
# Search for Extra Dimensions

## Mono-jet final state +Missing $E_T$ (ADD)

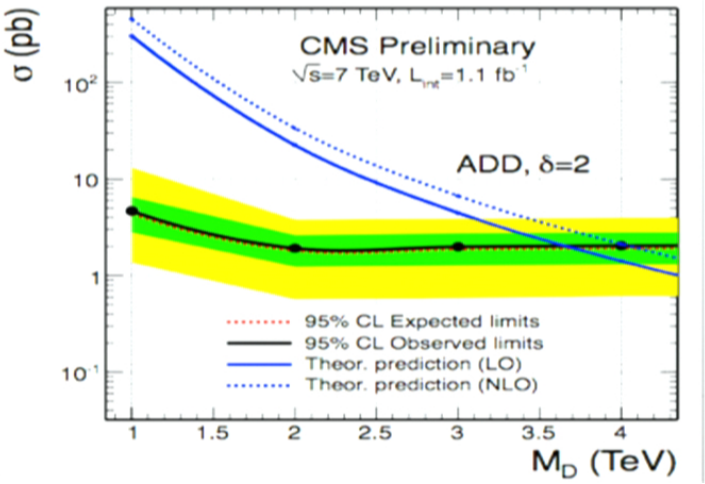
CMS-EXO-11-059

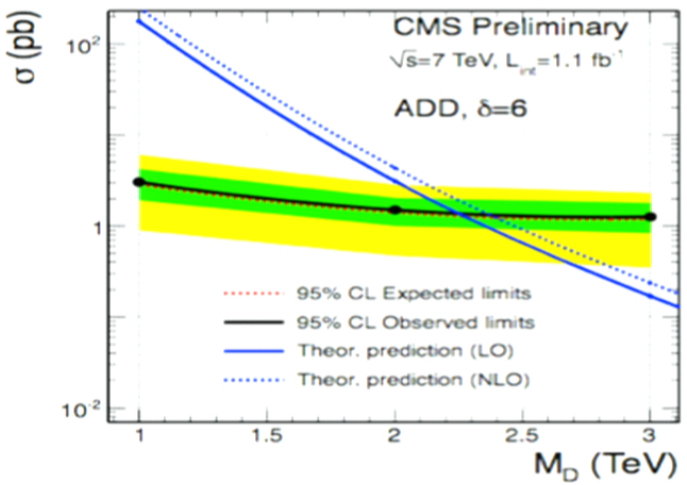



$p_T$ jet > 110 GeV
MET > 200 GeV




Lower Limit on the Planck Scale
versus number of extra dimensions

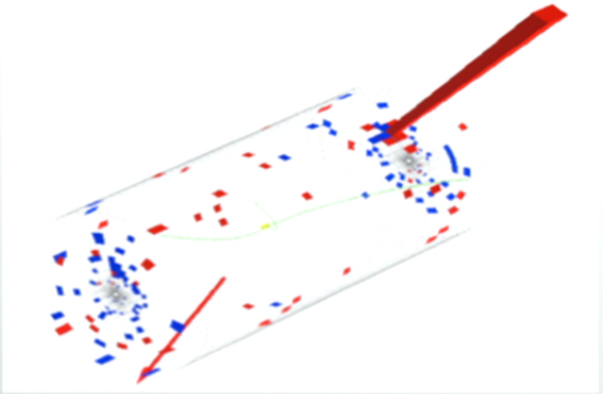



Limits on $M_D$ between 2 and 4 TeV

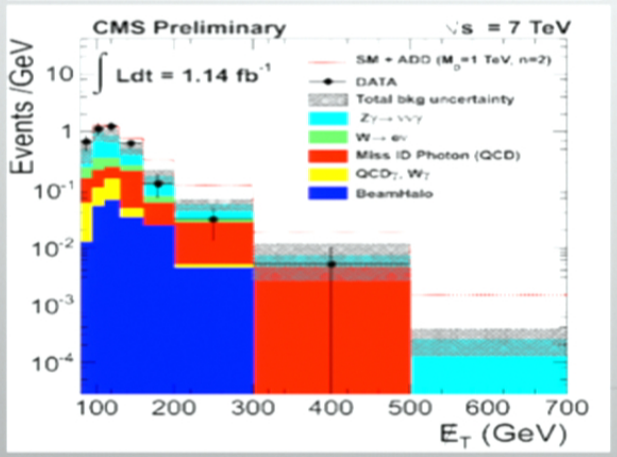
# Search for Extra Dimensions

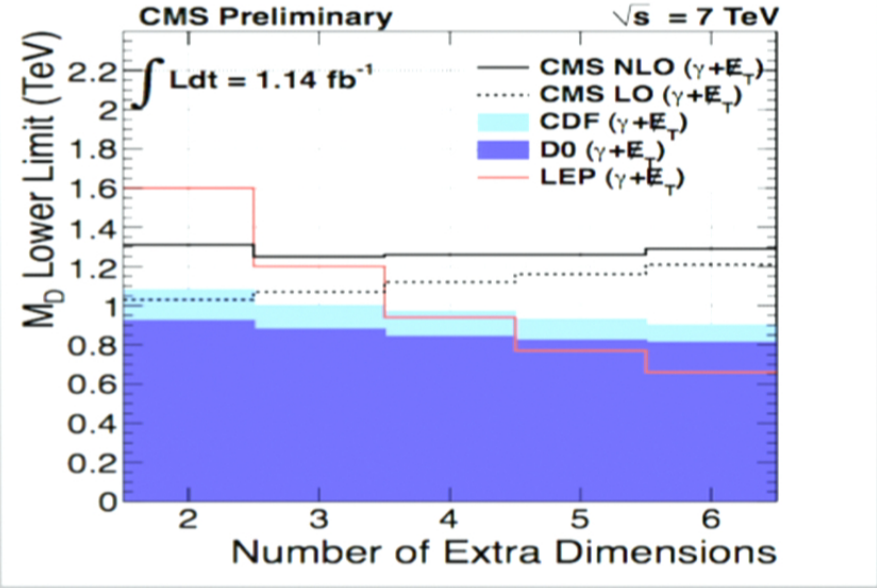
## Mono-photon final state +Missing $E_T$ (ADD)

$E_\gamma > 95$ GeV & MET>80 GeV

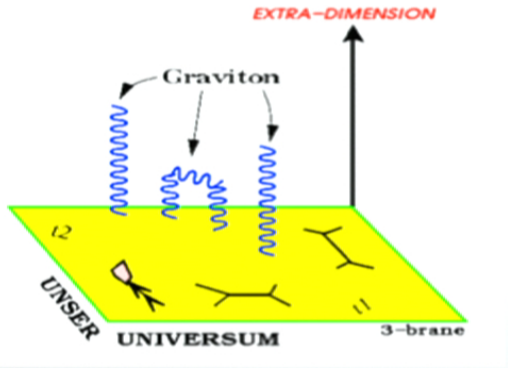
CMS-EXO-11-058



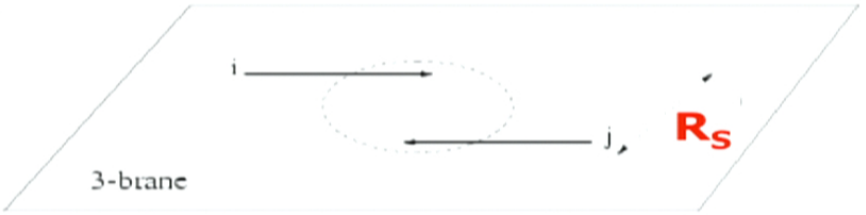




Limit: $M_D > 1.25$ TeV

# Search for Micro Black Holes




Extra Dimensions!

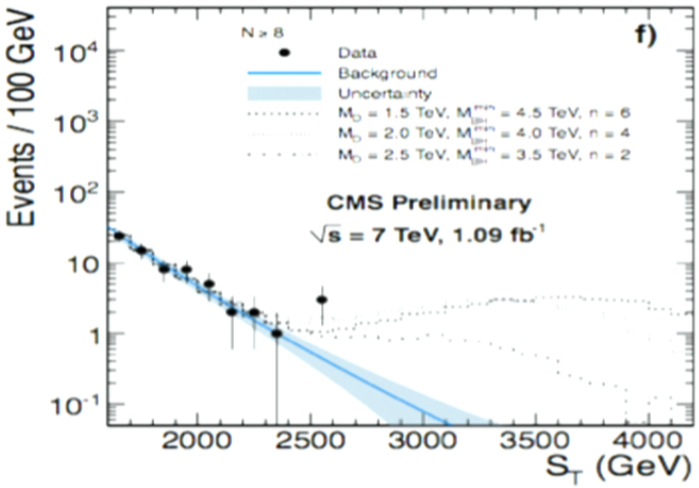


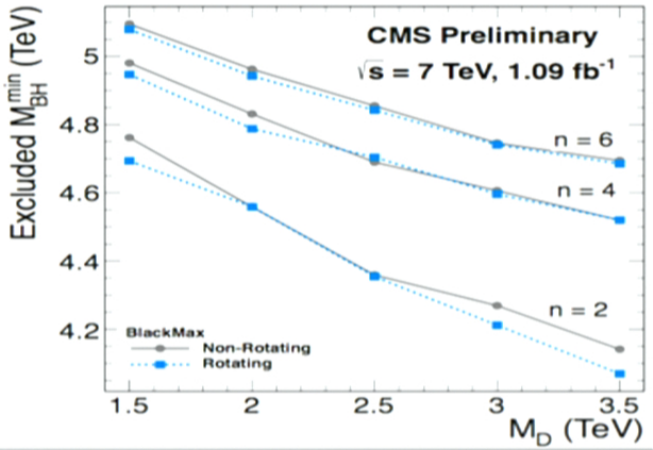

Planck scale
a few TeV?

CMS-EXO-11-071

Look for the decay producs of an evaporating black hole

- Define $S_T$ to be the scalar sum of all high $p_T$ objects found in the event
- Look for deviations at high $S_T$

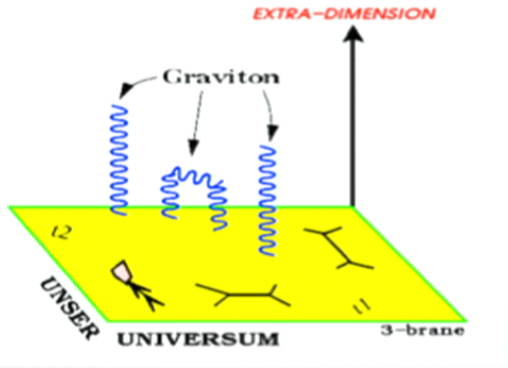



Black hole masses excluded in range ~5 TeV depending on assumptions

47

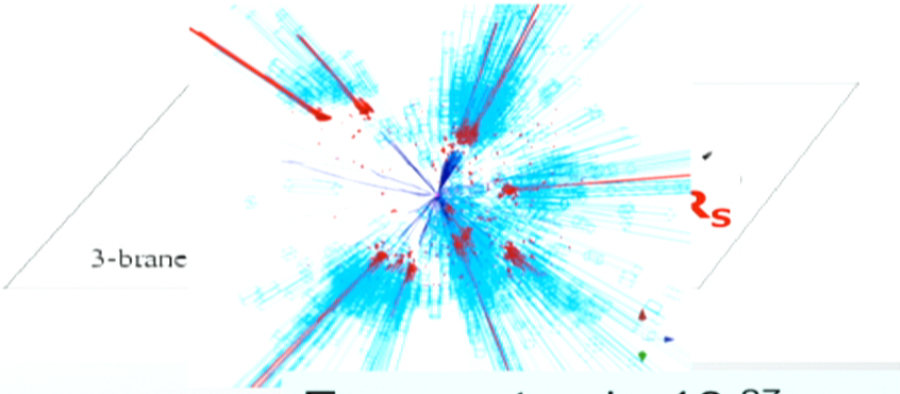
# Search for Micro Black Holes




CMS-EXO-11-071

Extra Dimensions!

Planck scale
a few TeV?




Evaporates in $10^{-27}$ sec

Look for the decay producs of an evaporating black hole

- Define $S_T$ to be the scalar sum of all high $p_T$ objects found in the event
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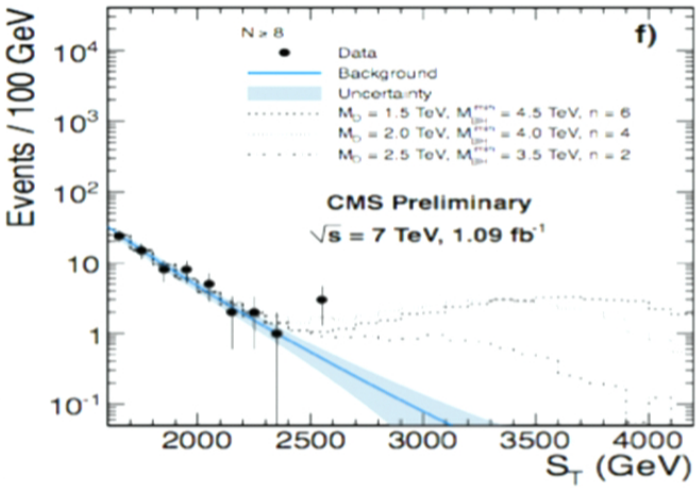


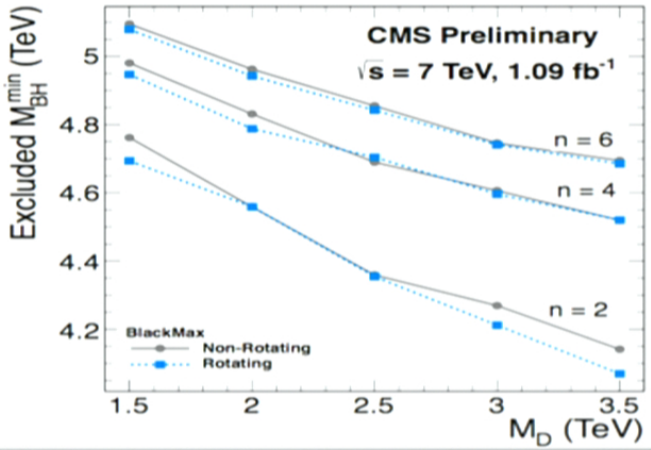


Black hole masses excluded in range ~5 TeV depending on assumptions


Black Holes
Hunters
at the LHC…

# Other Searches

- New Gauge bosons
- Colored resonances
- Objects decaying into top quarks
- Strong EW symmetry breaking eg topcolor
- $4^{th}$ Generation of quarks and leptons
- Substructure /contact interactions
- Technicolor
- Long lived particles
- Dark/Hidden Sector particles
- …and more…

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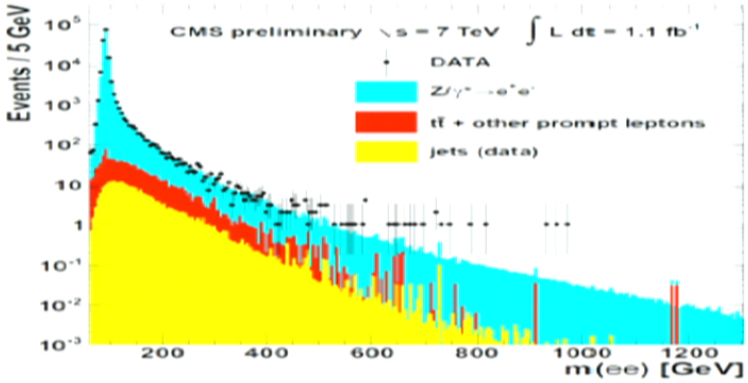
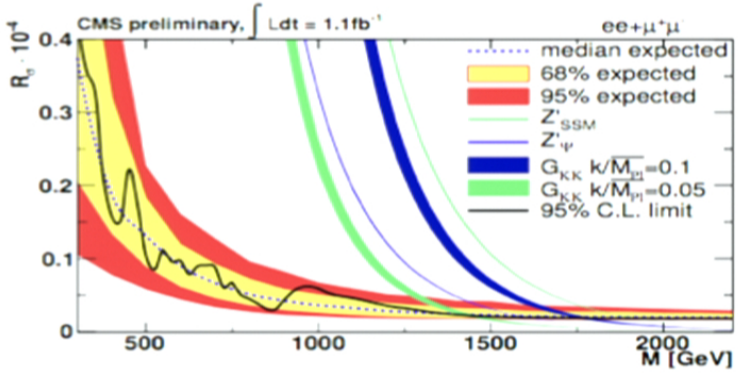
# Search for $G_{KK}$ & New Gauge Bosons

Study of the channels $Z' \rightarrow \mu\ \mu$ , ee



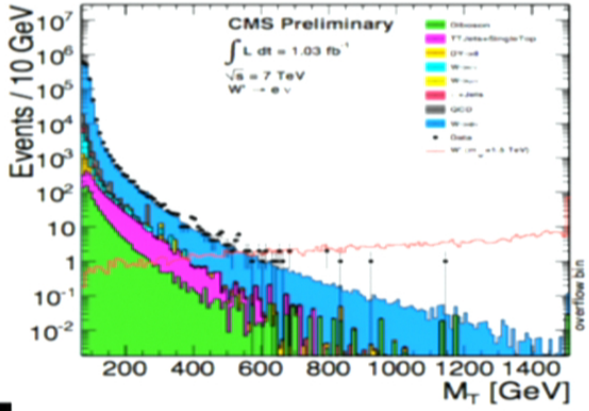


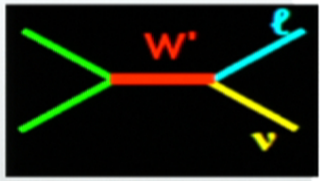
CMS-EXO-11-019



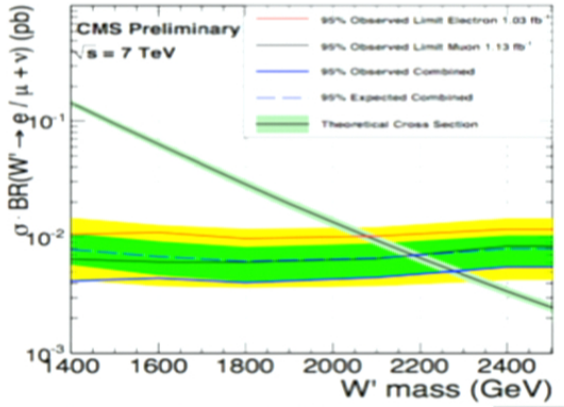

$G^*$ (k/$m_{pl}$=0.1)

Study of the channels $W' \rightarrow \mu\ \nu$ ,e $\nu$



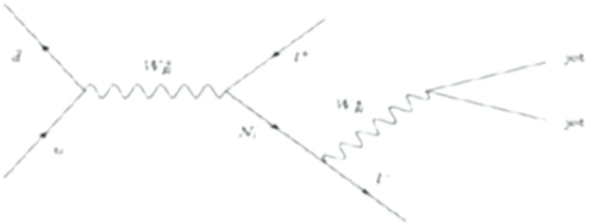

CMS-EXO-11-024




Exclude (SSM) Z' up to 1.94 TeV and $G_{KK}$ up to 1.78 TeV or @ 95% CL and new W' bosons up to ~2.27 TeV @ 95% CL

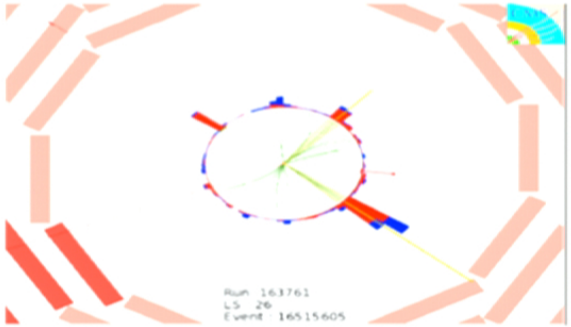
# Heavy Neutrinos in $W_R$ Decays

## Left-right symmetric extension of the Standard Model

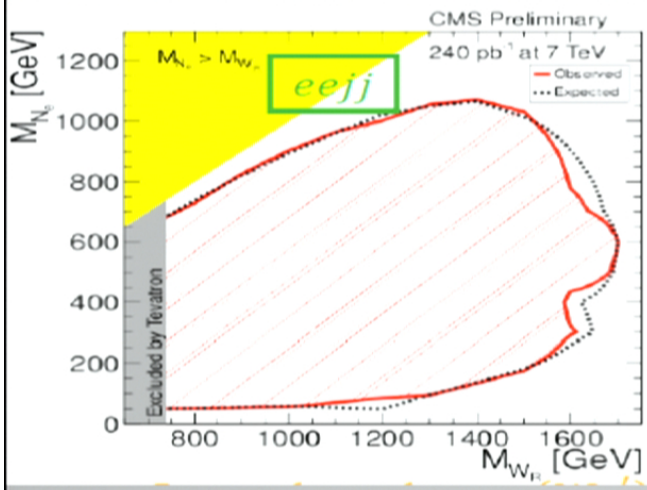


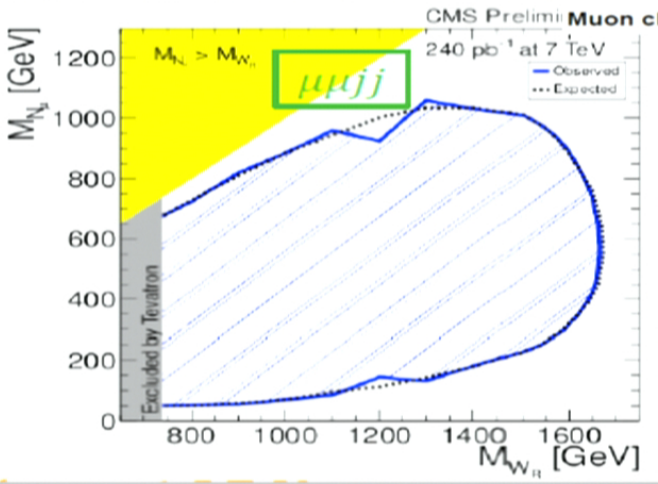
CMS-EXO-11-002

Select events with
2 leptons and 2 jets



Muon channel: Event with $M_{\mu\mu}$ = 331 GeV, $M_{\mu\mu jj}$ = 881 GeV




Large exclusion range in mass of the $W_R$ and heavy neutrino

Tevatron excludes
$W_R \sim$ 780 GeV

# Long Lived Particles

Split Supersymmetry

- The only light particles are the Higgs and the gauginos
  - Gluino can live long: sec, min, years!
  - R-hadron formation (eg: gluino+ gluon): slow, heavy particles

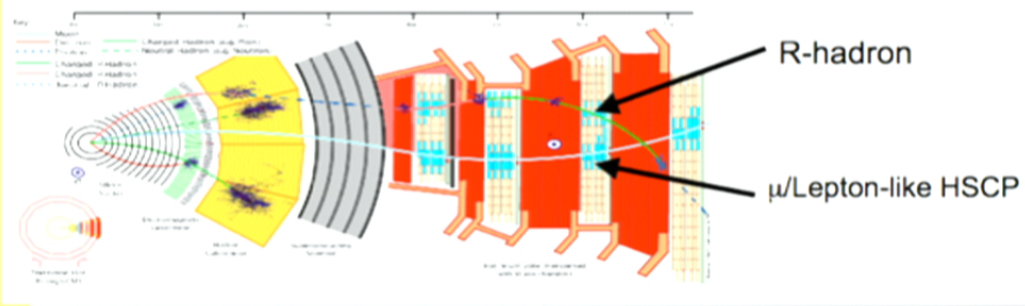
Gravitino Dark Matter and GMSB

- In some models/phase space the gravitino is the LSP
- ⇒ NLSP (neutralino, stau lepton) can live 'long'
- ⇒ non-pointing photons

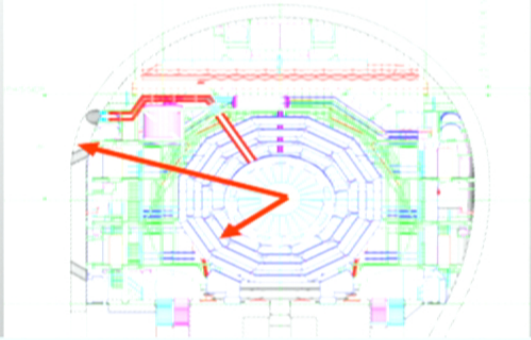
Hidden Valley models… RPV models

Plethora of possibilities for long lived neutrals

⇒Challenges to the experiments!




EG: K. Hamaguchi,M Nojiri,ADR hep-ph/0612060
ADR, J. Ellis et al. hep-ph/0508198



Sparticles stopped in the detector,walls of the cavern, or dense 'stopper' detector. They decay after hours---months…

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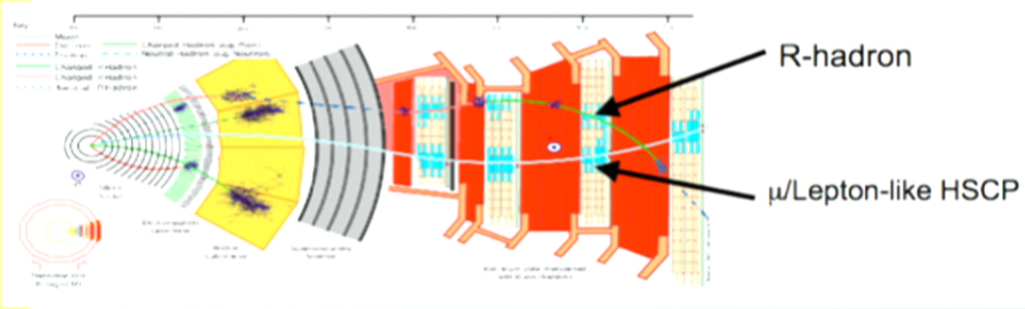


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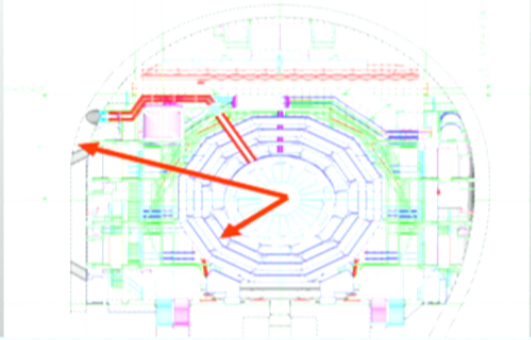
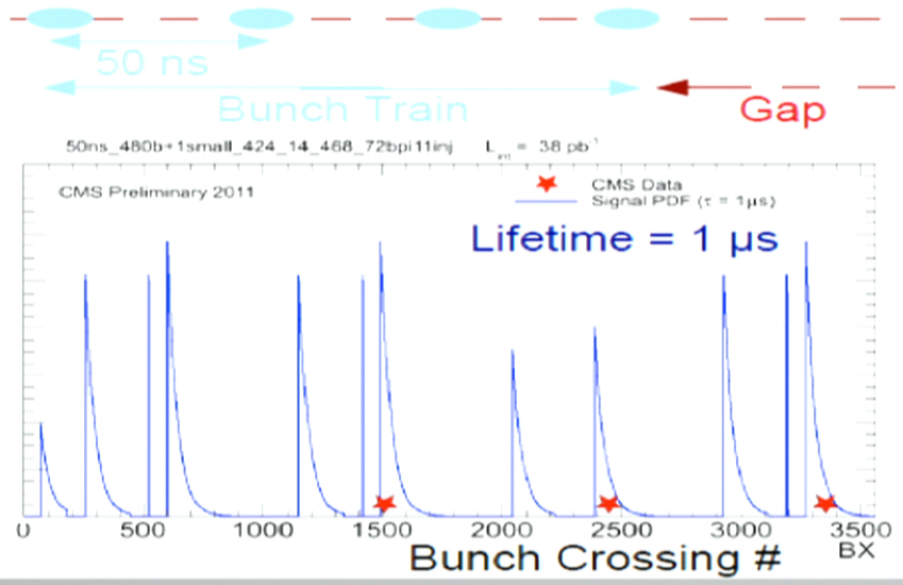
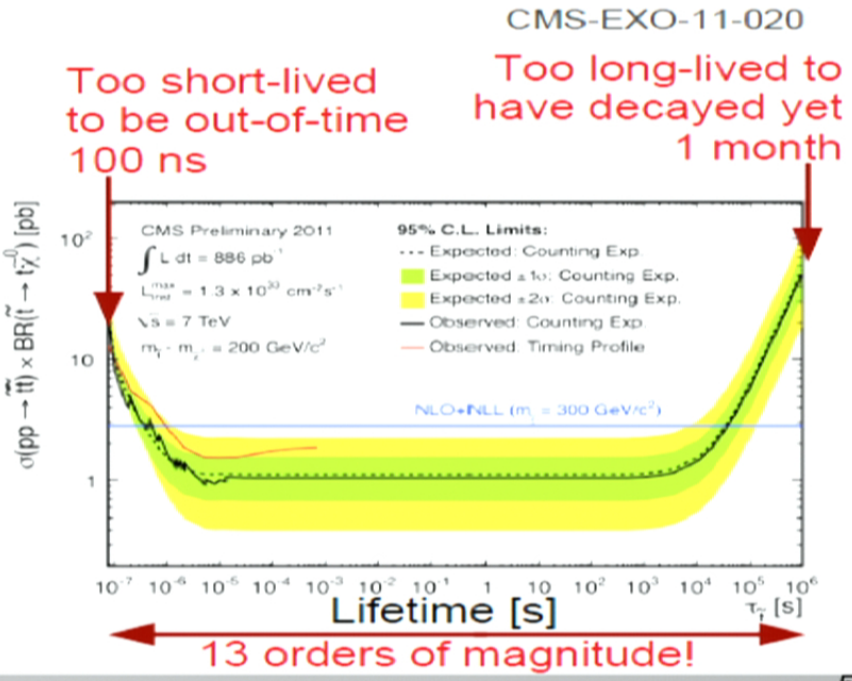


Sparticles stopped in the detector,walls of the cavern, or dense 'stopper' detector. They decay after hours---months…

# Search for Stopped Gluinos

- Out-of-time decay of heavy particles stopped in the detector
- Look for signal **without** collisions:
  - → When no beam in the machine
  - → Between bunch trains



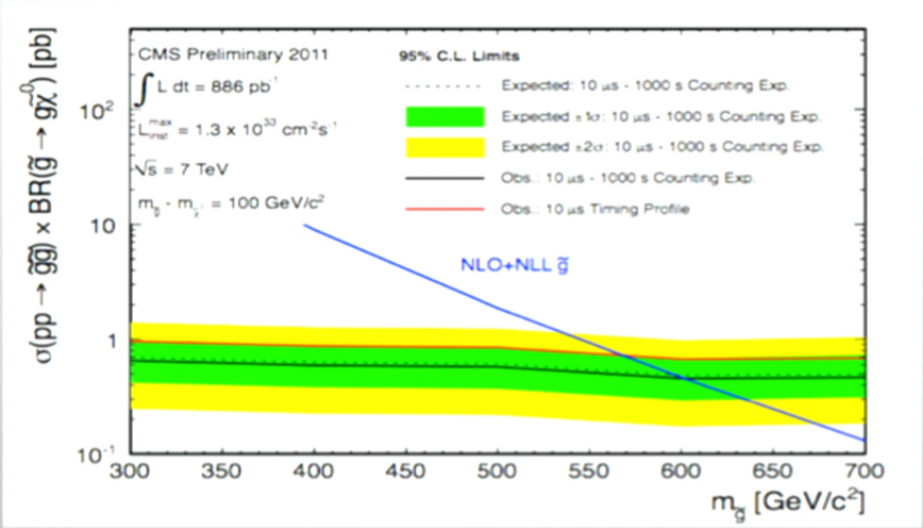



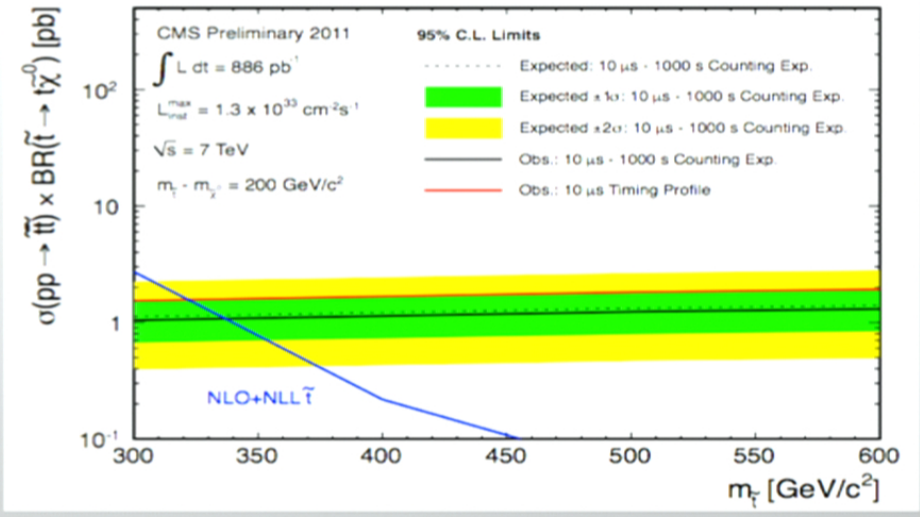
# Search for Stopped Gluinos

Search for Heavy Stable Charged Particles that stop in the detectors and decay a long time afterwards (nsec, sec, hrs…)

Special data taking after the beams are dumped and during beam abort gaps

CMS-EXO-11-020



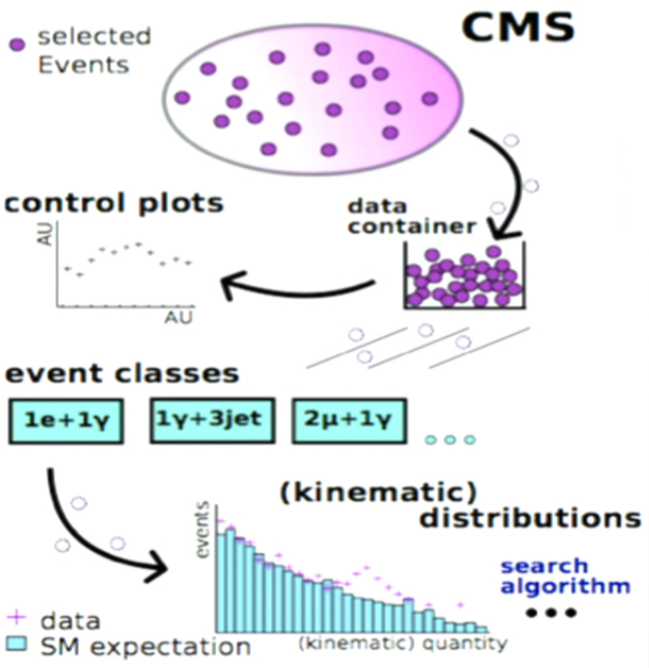




95% CL Limits: Stopped Gluinos > 600 GeV, Stopped Stop quarks> 337 GeV

60

# Can we miss something?

CMS-EXO-10-021

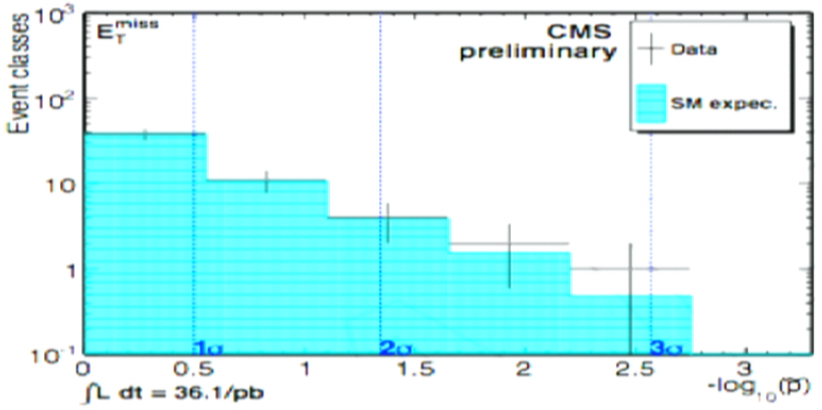



Model independent search

- Divide events into exclusive classes
- Study deviations from SM predictions in a statistical way

**Distributions in each class**

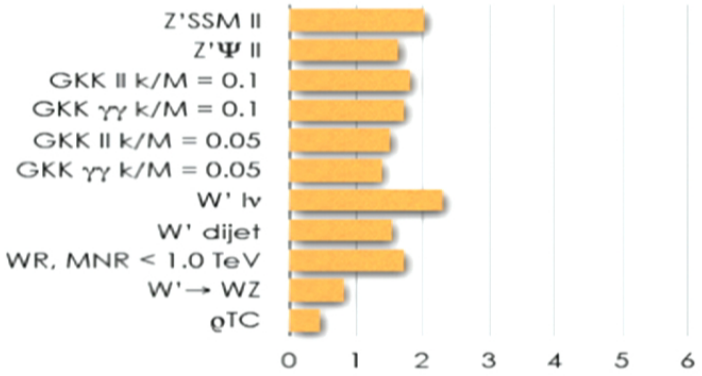
- $\sum p_T$ - Most general
- $M_{inv}^{(T)}$ - Good for resonances
- MET - Escaping particles

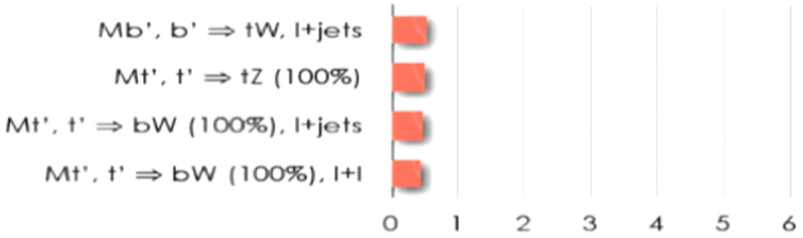


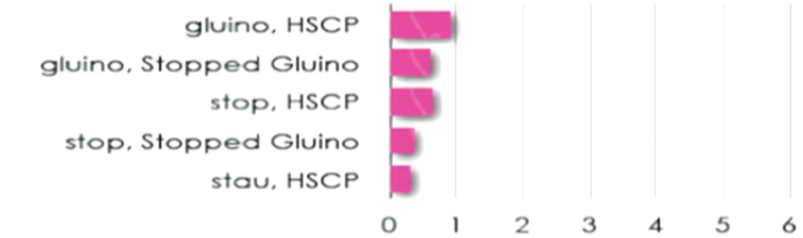

Probability distribution as expected for 35 $pb^{-1}$

Look at & watch the outliers...

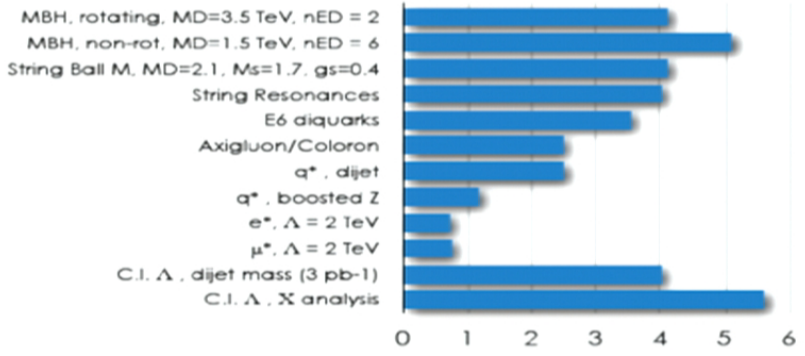
# Summary of the Searches









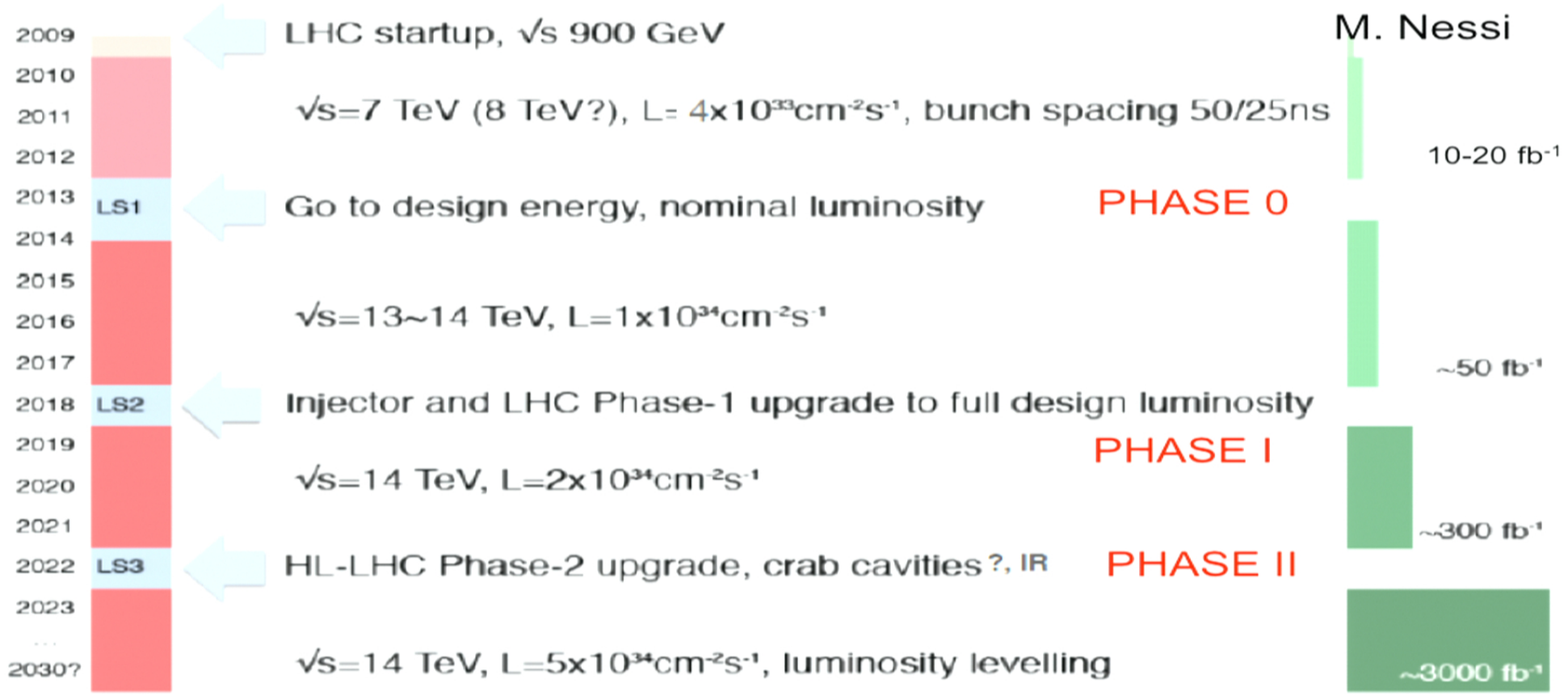
Since September 2011

# Summary of the Searches

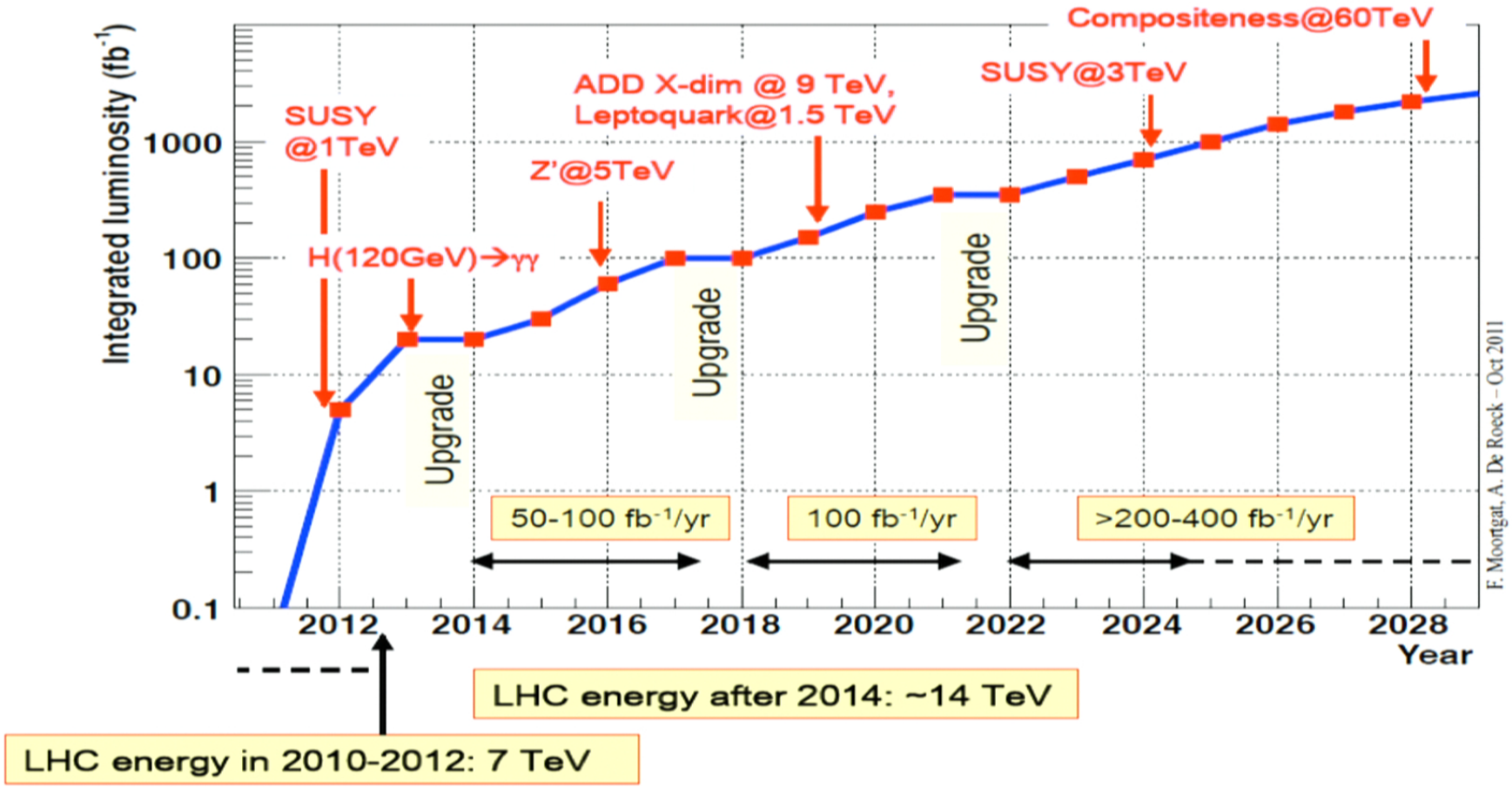
New signatures for new physics yet
→ Simple Summary (LP11: H. Bachacou)

| | Lower Limit (95% C.L.) |
|---|---|
| SUSY ($m_{\tilde{q}} = m_{\tilde{g}}$) | 1 TeV |
| Gauge bosons (SSM) | 2 TeV |
| Excited quark | 3 TeV |

# LHC Future Schedule



# The Future?


Compositeness@60TeV
SUSY@3TeV
ADD X-dim @ 9 TeV,
Leptoquark@1.5 TeV
SUSY
@1TeV
Z'@5TeV
H(120GeV)→γγ
Upgrade
Upgrade
Upgrade
50-100 fb⁻¹/yr
100 fb⁻¹/yr
>200-400 fb⁻¹/yr
Integrated luminosity (fb⁻¹)
1000
100
10
1
0.1
2012
2014
2016
2018
2020
2022
2024
2026
2028
Year
F. Moortgat, A. De Roeck – Oct 2011
LHC energy after 2014: ~14 TeV
LHC energy in 2010-2012: 7 TeV

# The Future

Luminosity upgrade scenario for the LHC machine

- High Luminosity: HL-LHC
- Higher Energy: HE-LHC
- Electron–proton LHeC

Ellis, Gianotti, ADR
hep-ex/0112004+ few updates

Units are TeV (except $W_L W_L$ reach)
$\int$Ldt correspond to 1 year of running at nominal luminosity for 1 experiment

| PROCESS | LHC 14 TeV 100 fb$^{-1}$ | LH-LHC 14 TeV 1000 fb$^{-1}$ | HE-LHC 28 TeV 100 fb$^{-1}$ | VLHC 40 TeV 100 fb$^{-1}$ | VLHC 200 TeV 100 fb$^{-1}$ | ILC 0.8 TeV 500 fb$^{-1}$ | CLIC 5 TeV 1000 fb$^{-1}$ |
|---|---|---|---|---|---|---|---|
| Squarks | 2.5 | 3 | 4 | 5 | 20 | 0.4 | 2.5 |
| $W_L W_L$ | $2\sigma$ | $4\sigma$ | $4.5\sigma$ | $7\sigma$ | $18\sigma$ | $6\sigma$ | $90\sigma$ |
| Z' | 5 | 6 | 8 | 11 | 35 | 8† | 30† |
| Extra-dim ($\delta$=2) | 9 | 12 | 15 | 25 | 65 | 5-8.5† | 30-55† |
| q* | 6.5 | 7.5 | 9.5 | 13 | 75 | 0.8 | 5 |
| $\Lambda$compositeness | 30 | 40 | 40 | 50 | 100 | 100 | 400 |
| TGC ($\lambda_\gamma$) | 0.0014 | 0.0006 | 0.0008 | | 0.0003 | 0.0004 | 0.00008 |

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# How does it feel to be a (BSM) Theorist?


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# Summary: The Searches are on!

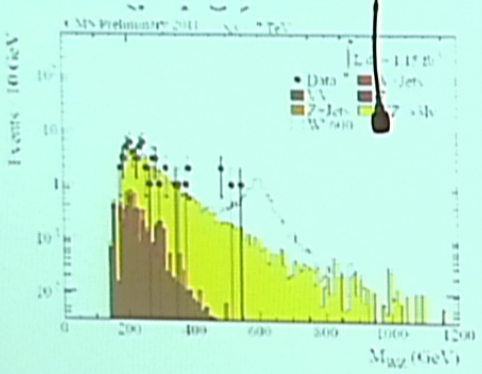
- The LHC has entered new territory. The ATLAS and CMS experiments are ready for searches for new physics. The most popular example is SUSY, but many other New Physics model searches are covered.
- No clear sign of new physics yet in the first 1-2 $fb^{-1}$ at 7 TeV.

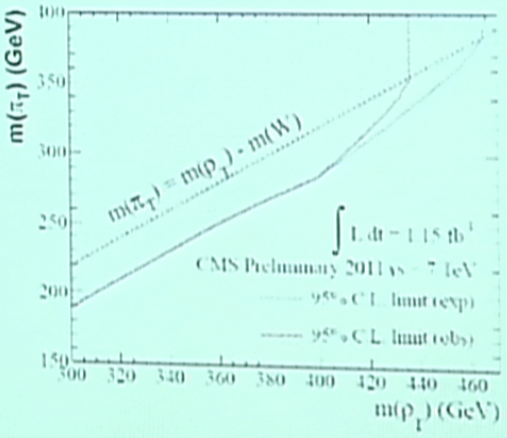
  Starts to cut into the 'preferred SUSY region'. The air for constrained models is getting very thin. We' ll need to dig deeper. Input from our theory colleagues welcome!
- Some analyses have been released only with 35 $pb^{-1}$ so far so these have a lot of headroom left.
- The LHC did its part so far with a great run in 2011. Expect between 10 and 20 $fb^{-1}$ by end of 2012, and perhaps a slightly higher energy in 2012,which would help for searches

# Searching for Technicolor

$$W'(\rho_{TC}) \rightarrow WZ \rightarrow 3\ell\nu\ (\ell = e, \mu)$$

Technicolor ~ QCD (color force); Higgs is composite




$W'_{SSM}$: 784 GeV

$\rho_{TC}$: 382 GeV ($M_{\pi TC} = \frac{3}{4} M_{\rho TC}$-25 GeV)

$\rho_{TC}$: 436 GeV ($M_{\rho TC} < M_{\pi TC} + M_W$)

EXO-11-041

First search after TeVatron: Exclusion limits on SSM (784 GeV) and techni-color models (382-436 GeV)