Title: LHC: The Countdown

Date: Jun 02, 2008 09:00 AM

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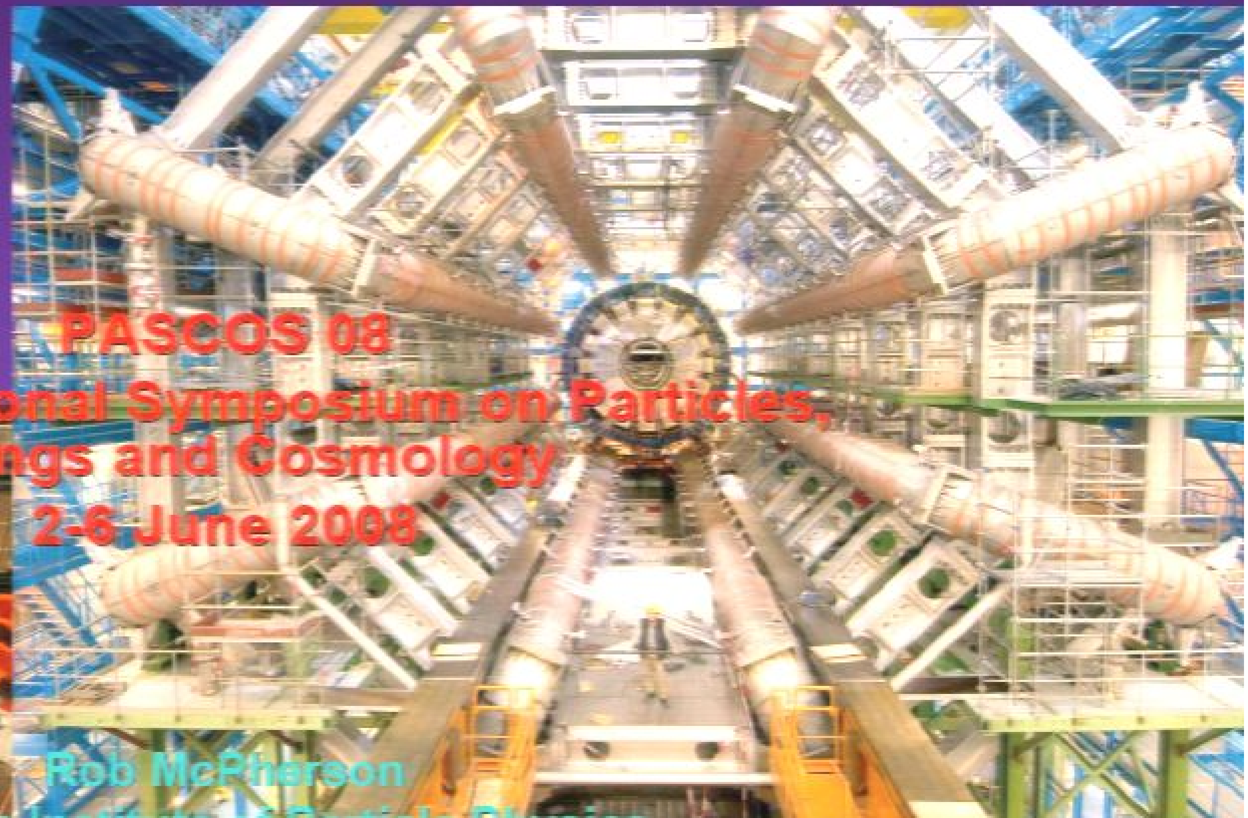
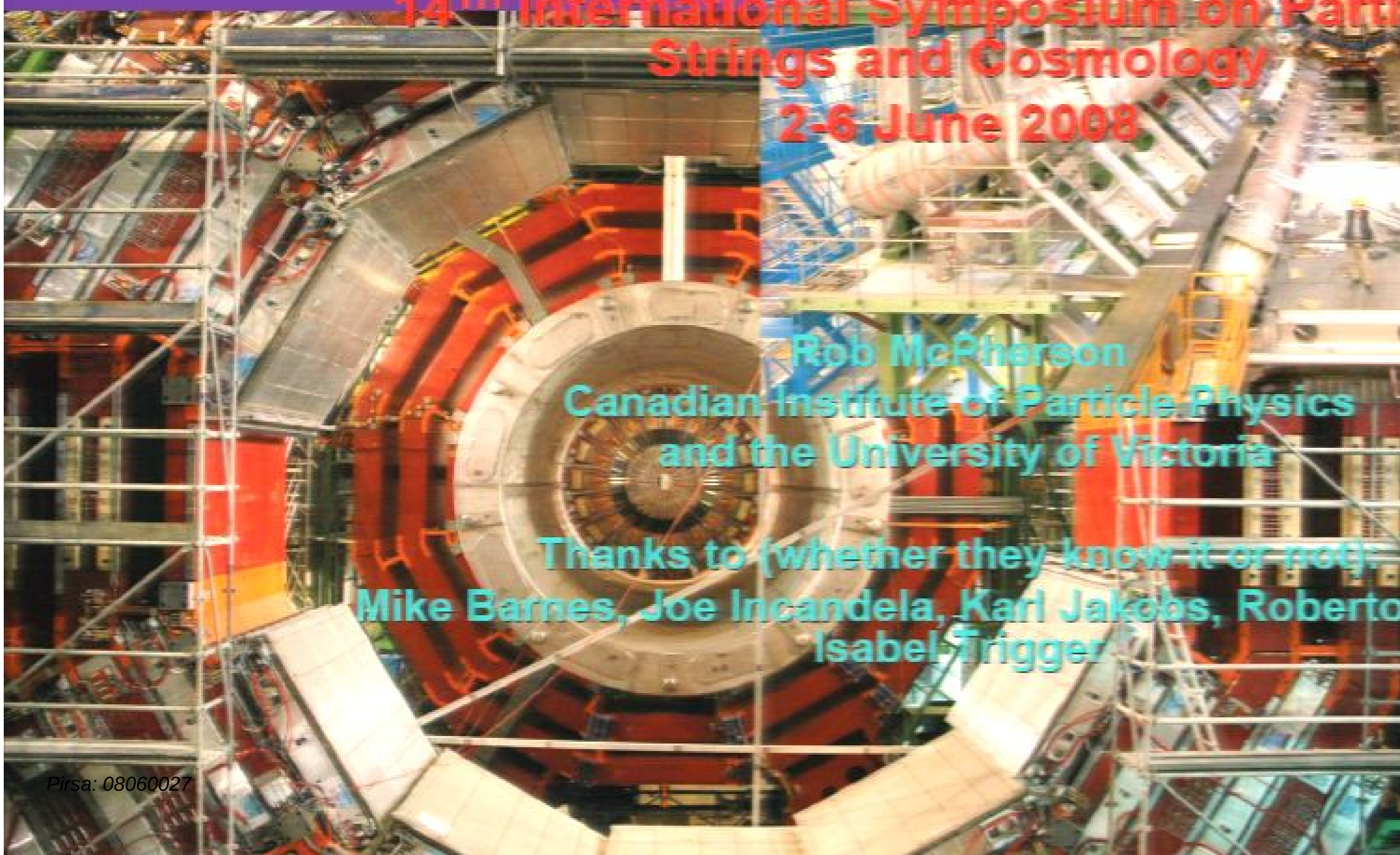
Abstract: The CERN Large Hadron Collider is nearing completion. Both the ATLAS and CMS experiments are being completed, and the accelerator is proceeding through cool-down to cryogenic temperatures in preparation for first beam. The timescales and prospects for first beam, collisions and physics will be discussed, and the early physics program of the LHC high PT experiments reviewed.

LHC: The Countdown





PASCOS 08

14TH International Symposium on Particles, Strings and Cosmology

2-6 June 2008

Rob McPherson

Canadian Institute of Particle Physics and the University of Victoria

Thanks to (whether they know it or not):
Mike Barnes, Joe Incandela, Karl Jakobs, Roberto Saban, Isabel Trigger

Outline of this talk

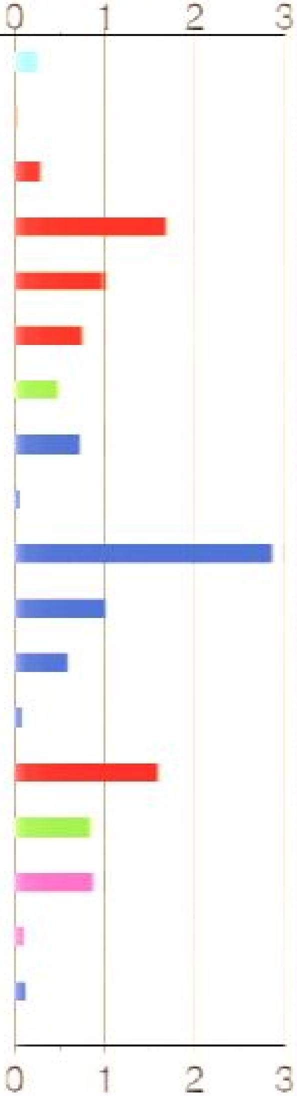
- Very brief overview of why we want to probe the Terascale
  - Seems like we've been waiting so long for the LHC that I could skip this … but I'd feel guilty
- LHC accelerator: status
  - Briefly review progress cooling and plans for next ~ 1 year
- ATLAS and CMS: status
  - Detectors preparing for first collisions
- Prospects for 2008-2009
  - Day 0: first collisions
    - Probably at $\sqrt{s}$ = 10 TeV
    - Autumn 2008 (run to mid November)
    - Detector shake-down, first analyses
  - Day 1: first physics run
    - $\sqrt{s}$ = 14 TeV
    - Starting spring 2009
    - Lumi: ~ 1 fb^{-1} / experiment
      - Very difficult to predict

… will focus on days 0-1

Why the Terascale? I

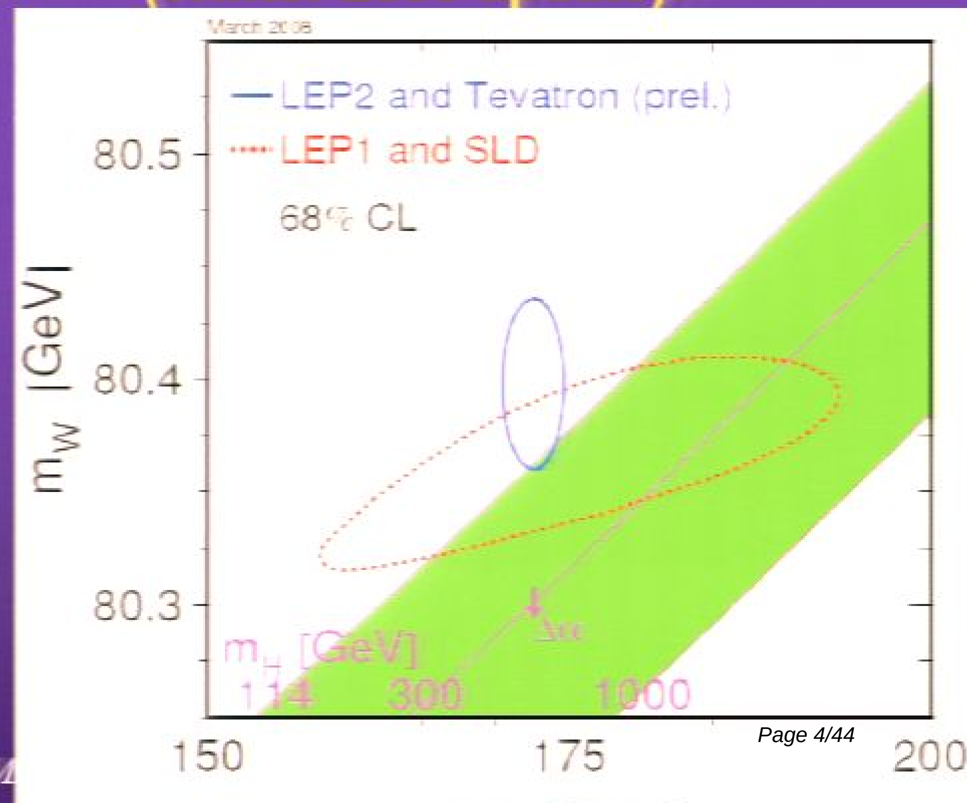
Global Data Fits

	Measurement	Fit
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02758 ± 0.00035	0.02767
m_Z [GeV]	91.1875 ± 0.0021	91.1874
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959
σ_{had}^0 [nb]	41.540 ± 0.037	41.478
R_l	20.767 ± 0.025	20.743
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01643
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1480
R_b	0.21629 ± 0.00066	0.21581
R_c	0.1721 ± 0.0030	0.1722
$A_{fb}^{0,b}$	0.0992 ± 0.0016	0.1038
$A_{fb}^{0,c}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1480
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.398 ± 0.025	80.377
Γ_W [GeV]	2.097 ± 0.048	2.092
m_t [GeV]	172.6 ± 1.4	172.8



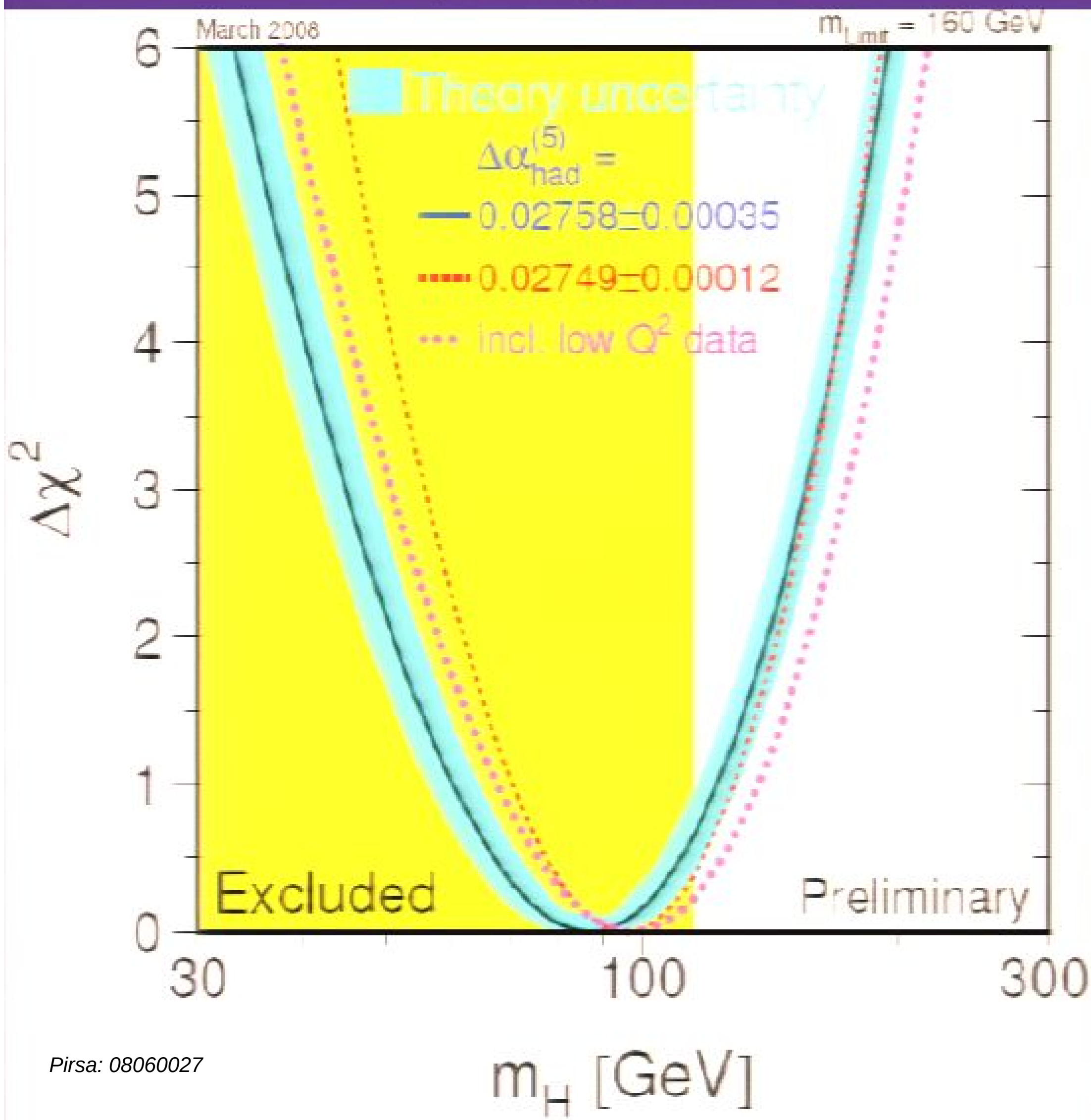
March 2008

- Many independent measurement
  - Most LEP, Tevatron, SLD
- Good Agreement if Higgs (or Higgs-like object) light
- Pick MW vs Mtop plane
  - Show direct + indirect results (Winter 2008 update):



Why the Terascale? II

EW Fits: MH only free Param.
Data from LEP, SLD, Tevatron

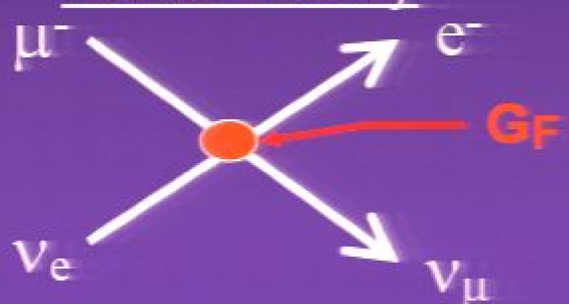


- MH (winter 2008)
  - χ^2 minimum:
    - 87 GeV
  - Direct Search LEP:
    - > 114 GeV @ 95% C.L.
  - Indirect EW fit constraints:
    - < 160 GeV @ 95% C.L.
  - Including LEP direct search limit
    - < 190 GeV @ 95% C.L.
- Strong interest:
  - Find H^0_{SM} (if it exists)
- If no H^0_{SM}
  - Strong dynamics < 1 TeV ?
- If H^0_{SM} :
  - Fine-tuning of M_H annoying if no new physics by ~ 1 TeV
    - Cancel loops or cut-off theor at Terascale

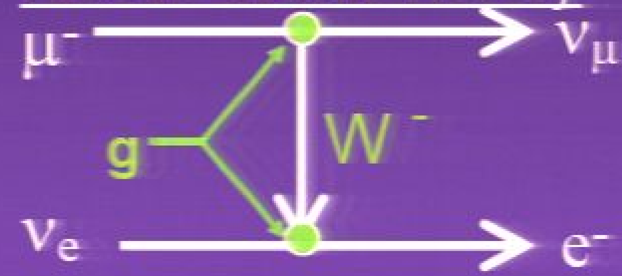
Can we guess what "new physics" is?

- Consider analogy to ~40+ years ago
  - Standard Model (EW part anyway) was deduced from hints

Fermi Theory



Electro-Weak Theory



For scales << M_W, $2\sqrt{2}G_F = g^2/2M_W^2$

\>> M_W, Rates $\propto g^2/E^2$

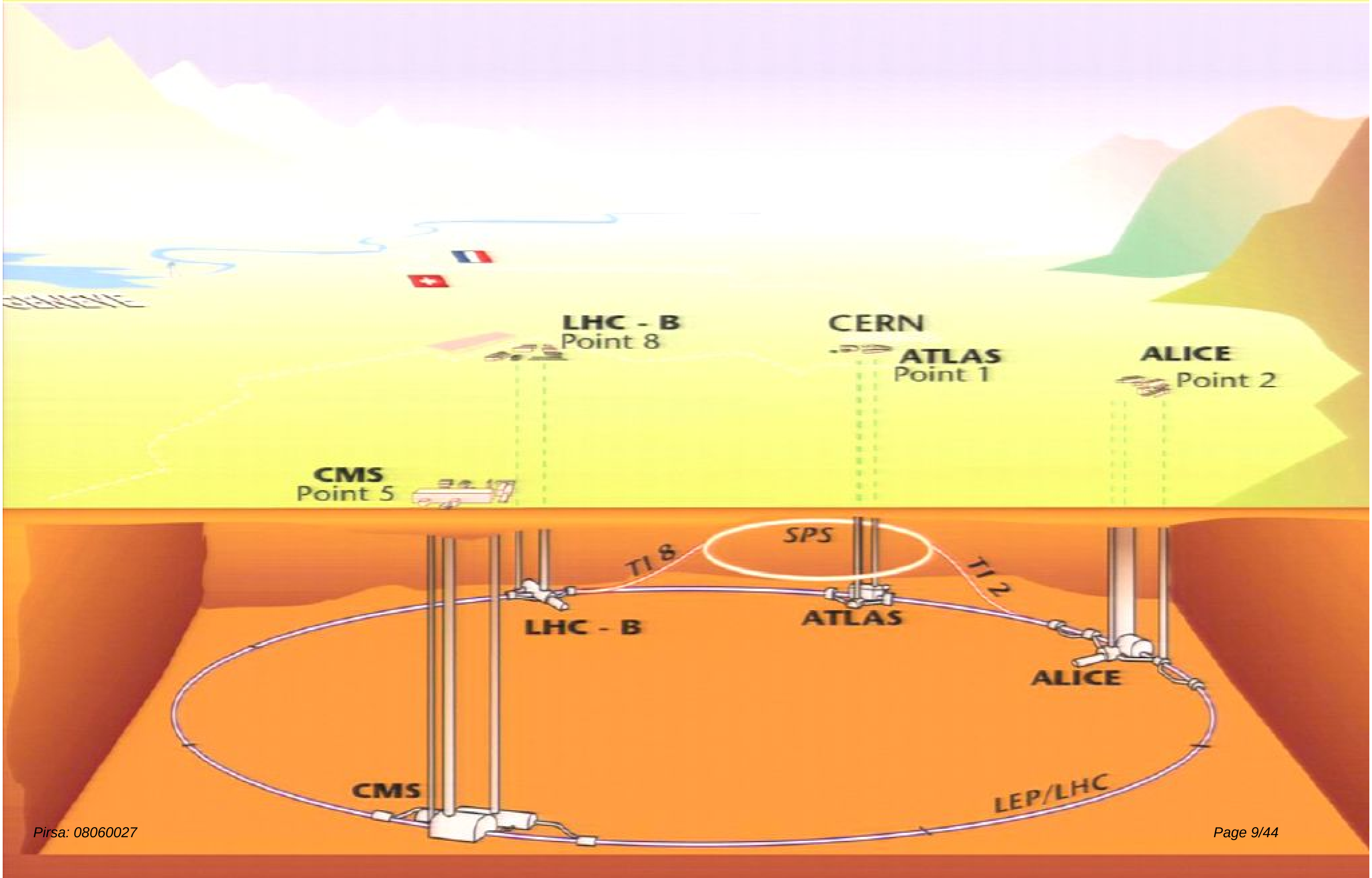
- Why do we have no compelling model of physics BSM today?
- Possibilities:
  - They're not making theorists like they used to ...
  - Or maybe things are a bit less obvious this time?
- Smoking guns for new physics we can confirm experimentally today?
  - Higgs mass fine-tuning seems to beg for Terascale physics but doesn't tell us what.
  - Small m_ν with large ν mixing: any ties? Hard to know.
  - Few hundred GeV dark matter: intriguingly close to Terascale
    - SUSY? Or other solution with CDM candidate?

Next generation project requirements

- Solid Higgs coverage to ~ 1 TeV
  - Any SM Higgs should show up by 200 GeV, but maybe life is a bit more interesting than that
  - Find the Higgs, or particle acting like the Higgs in loop effects observed in precision EW measurements
  - Measure its properties, see if it is SM Higgs
- Sensitivity to any physics, strongly or weakly coupled, above 1 TeV
  - SUSY is a favourite model ⇒ ensure complete coverage
  - But one of the other models may win out ...
  - Keep O(100 GeV) CDM in mind
    - Build hermetic detectors with good anomalous missing energy discovery potential
  - Or: it could be something completely different
    - Must have complete coverage for any TeV-scale new physics

- The Large Hadron Collider

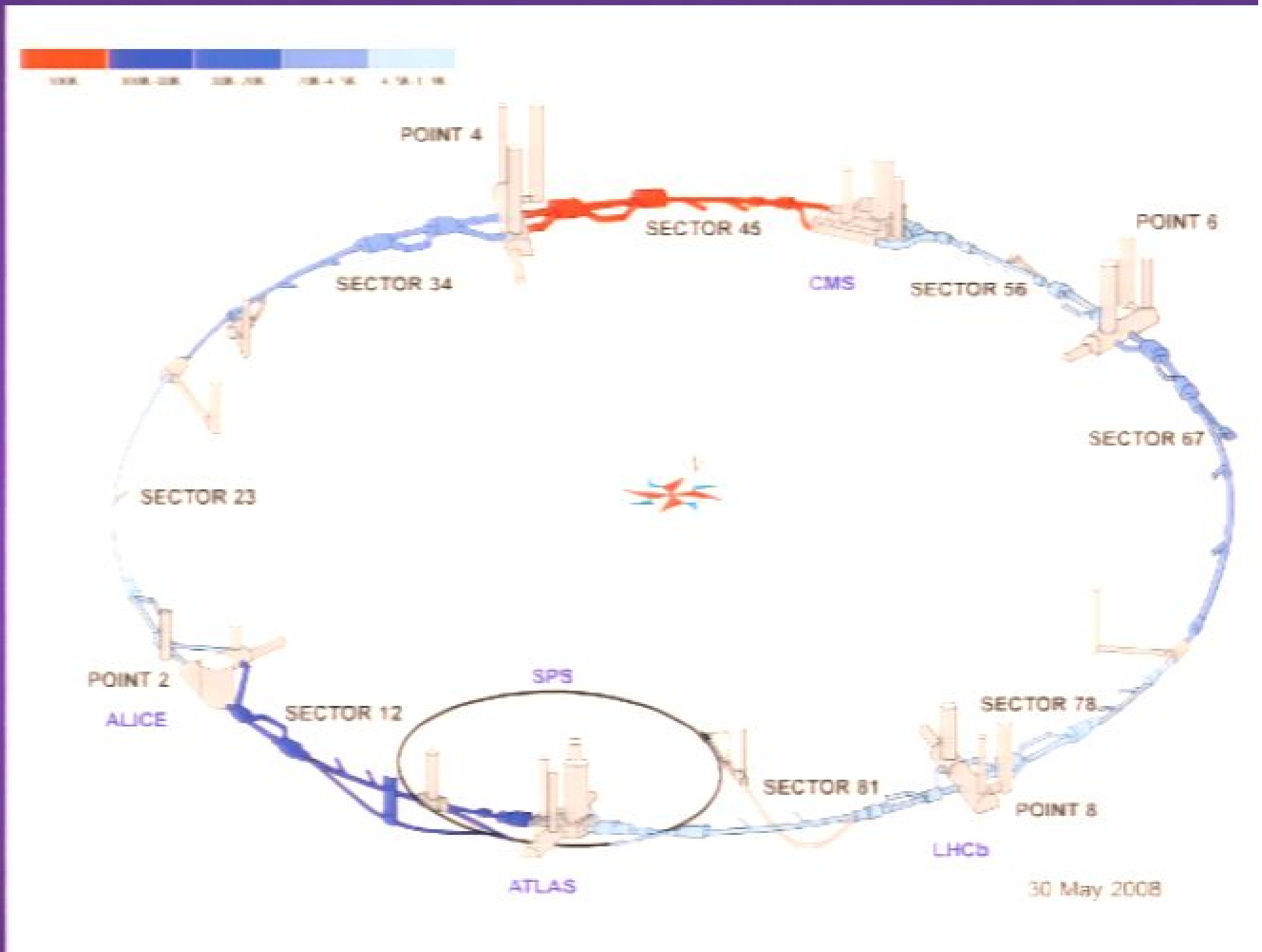
LHC



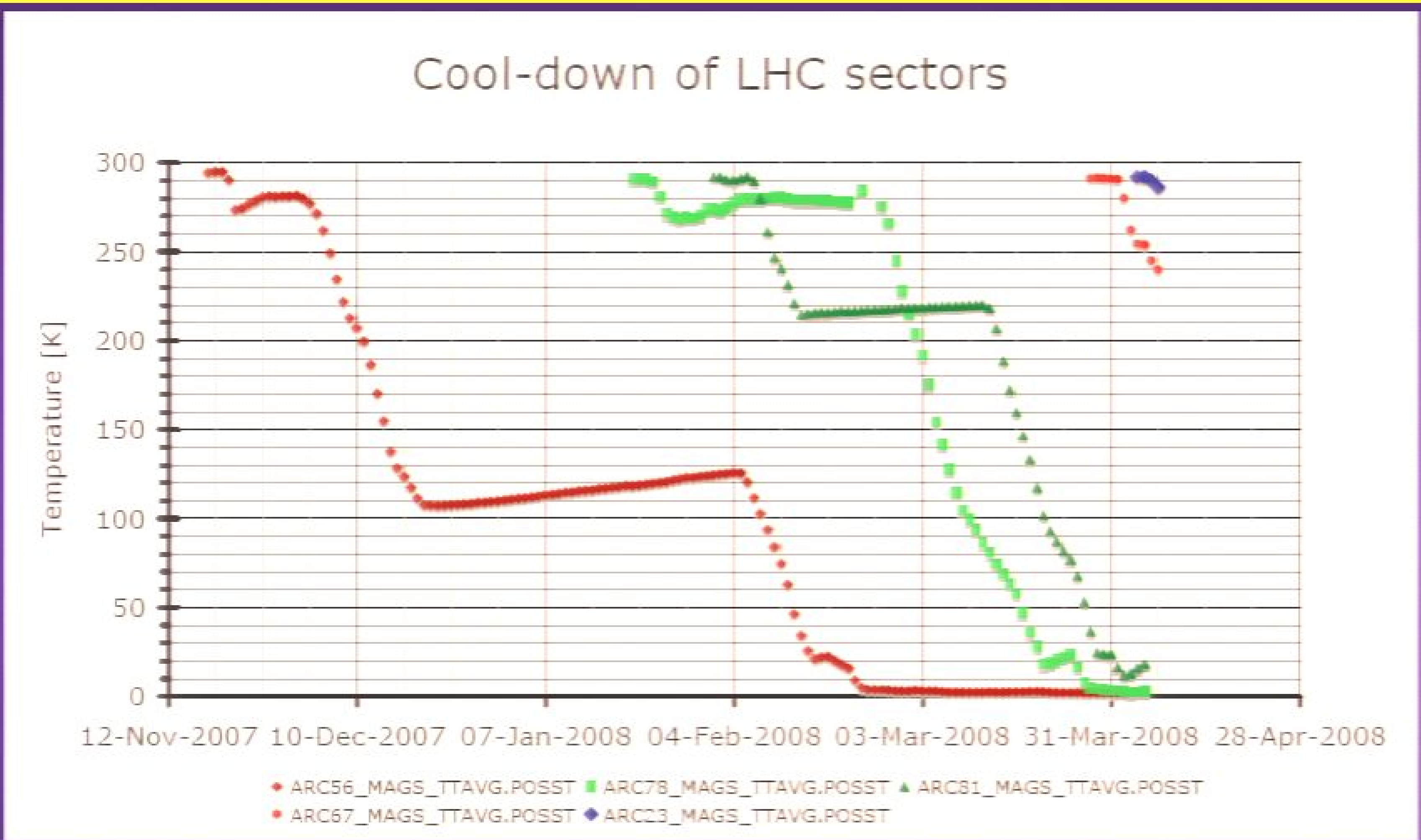
LHC - B
Point 8
CERN
ATLAS
Point 1
ALICE
Point 2
CMS
Point 5
SPS
TI 8
TI 2
LHC - B
ATLAS
ALICE
CMS
LEP/LHC

LHC Cryo Temp. status: 30 May 2008

- LHC uses primarily superconducting magnets running at superfluid He temperatures (~ 2 Kelvin)
- 4 sectors currently ~ 2 K
- 3 sectors well into cooling ramp-down
- 1 sector just started cooling
  - Sector 4-5: previously had "inner-triplet" problem, required more fixes after a cool-down/warm-up cycle



Recent Octant cool-downs

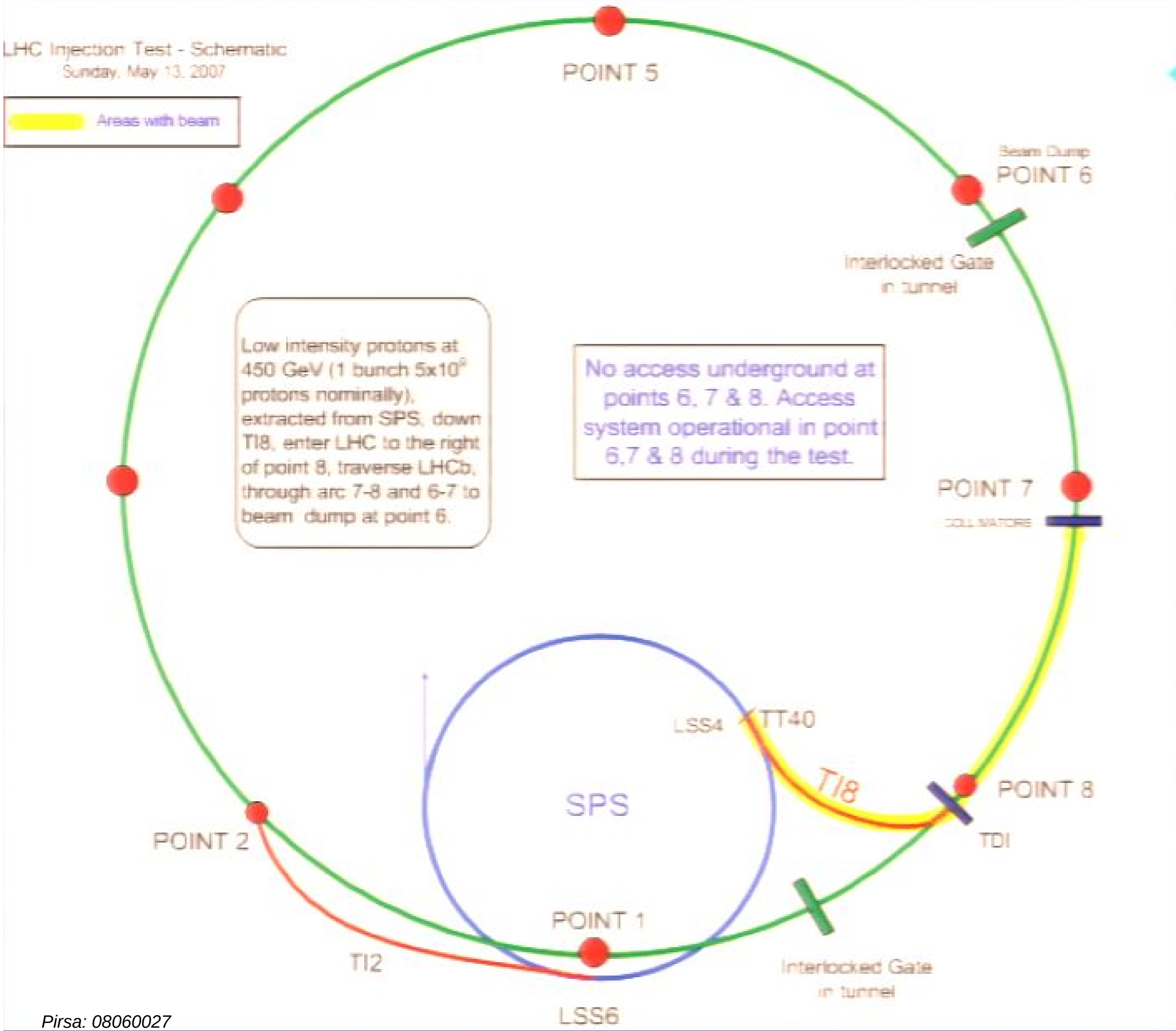


- Typically 6 weeks to cool-down (so far)
- Compressing to ~ 4 weeks now

LHC: experience from powering tests

- Sectors 45 and 56 undergoing powering tests
  - Achieved magnet currents equivalent to > 5.5 TeV beam energies without problems
  - Required more magnet training quenches than anticipated to go to higher magnet currents
  - Understanding how long it will take to train all magnets to get to full energy (7 TeV beam energy)
- Current plans
  - Run at $\sqrt{s}$ = 10 TeV in 2008
  - Winter shutdown: scheduled to start 15 November 2008
  - Complete training of magnets in winter 08-09 shutdown
  - Turn on with $\sqrt{s}$ = 14 TeV in spring 2009

Injection tests



- First beam into LHC machine:
  - Injection tests into sector 7-8
  - Must put in a plug: tests Canadian-built kicker magnets
  - Beam injected near Point 8 and circled to (almost) Point 7

LHC status today

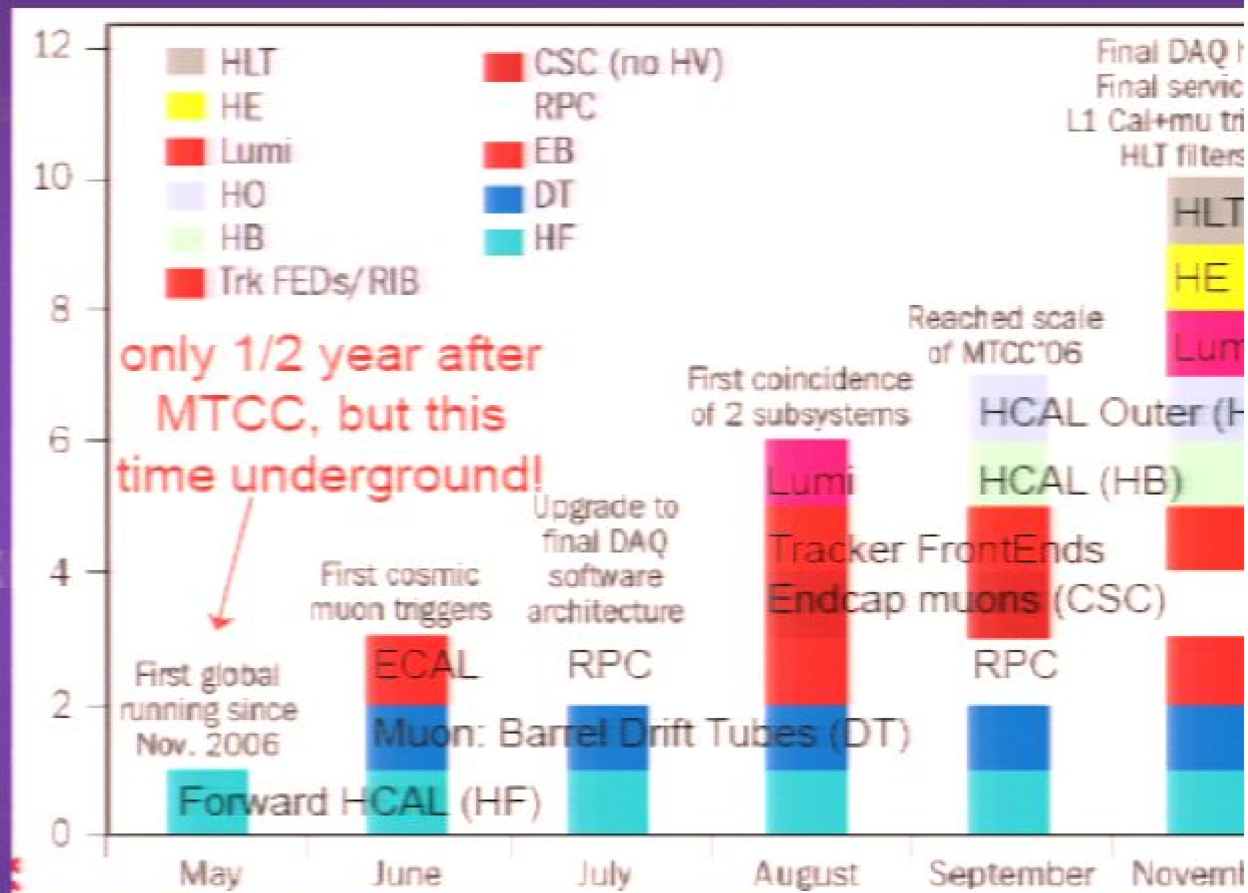
Sector	Average T [K]	Status
12	170	Cool down
23	2	Cool down
34	20	Cool down
45	290	Commissioned to 5 TeV except for the triplet Inner triplet now connected Cool down started 29 May 2008
56	2	Fully commissioned to 5 TeV Dipoles and quadrupoles being trained to 7 TeV
67	5	Cool down
78	2	Partially tested in June 2007 Inner triplet connected Powering tests
81	2	Powering tests

- **Early July:** Expect all sectors cold
- **Mid July:** Experimental caverns closed
- **End July:** First particles injected. Commissioning with beams and collisions starts.
- **After ~ 2 more months:** $\sqrt{s}$ = 10 TeV collisions
- **By November:** might reach ~ 10^{32} /cm^2/s & integrate few 10's pb^{-1}

- Commissioning ATLAS and CMS

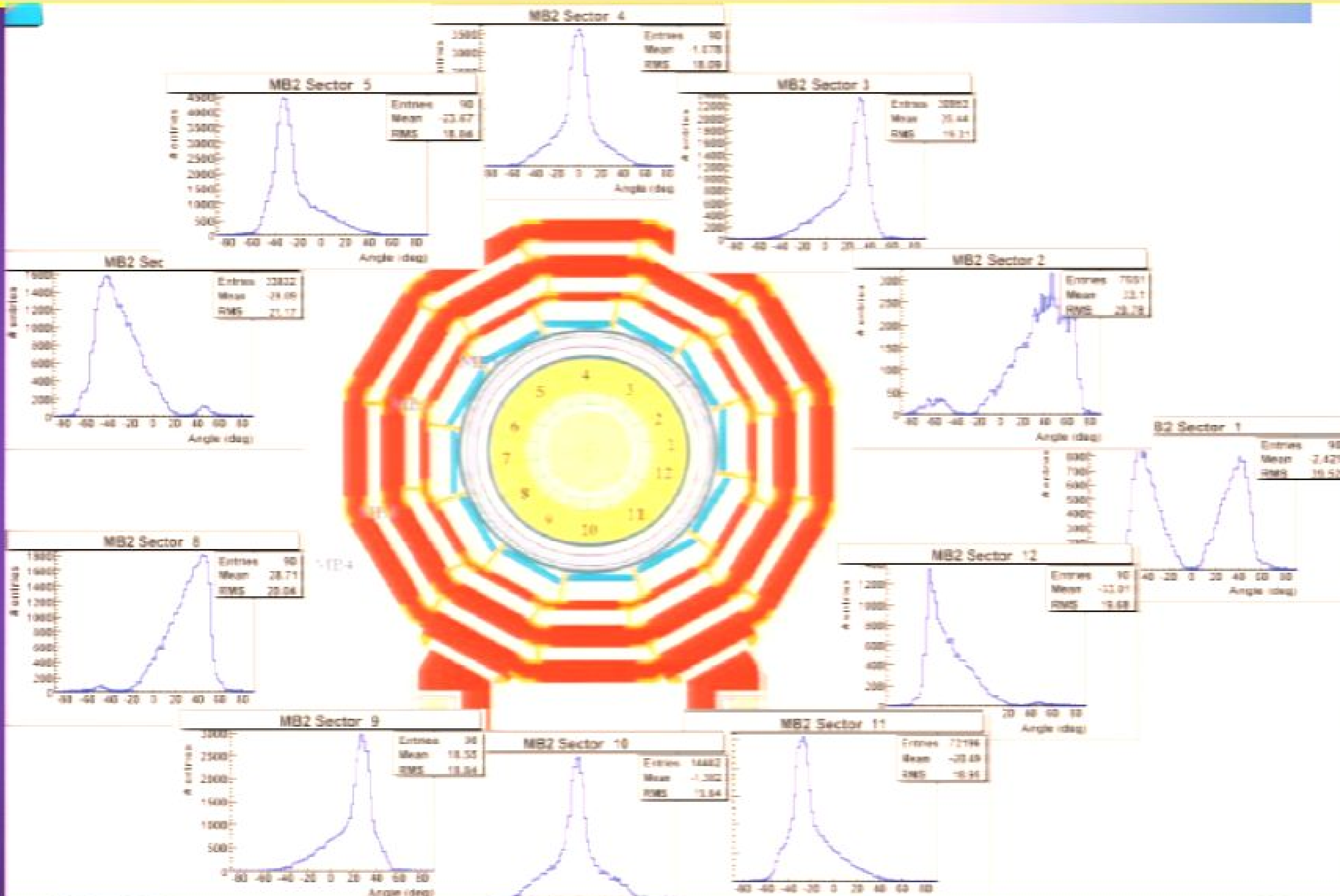
CMS in 2007

- System integration
  - Power, cooling, controls
  - DAQ
  - Triggers
    - Level 1
    - High-level
  - Real-time monitoring
- Increasingly complex global runs …
- Complete detector coming together for collision data-taking



(2007)

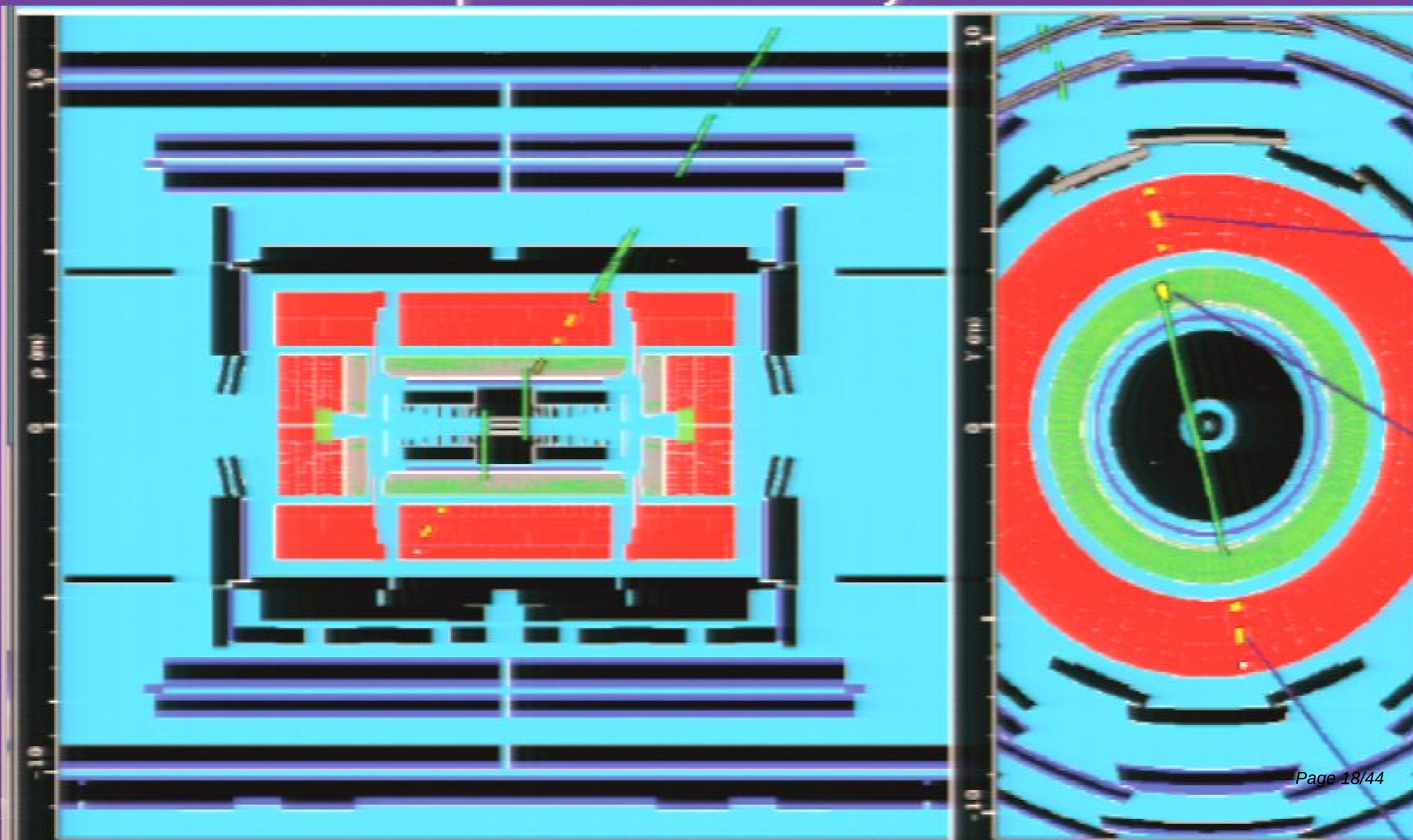
CMS: cosmic muon running



- First results from cosmic muon data:
  - Single-hit resolution of barrel drift tubes < 280 μm

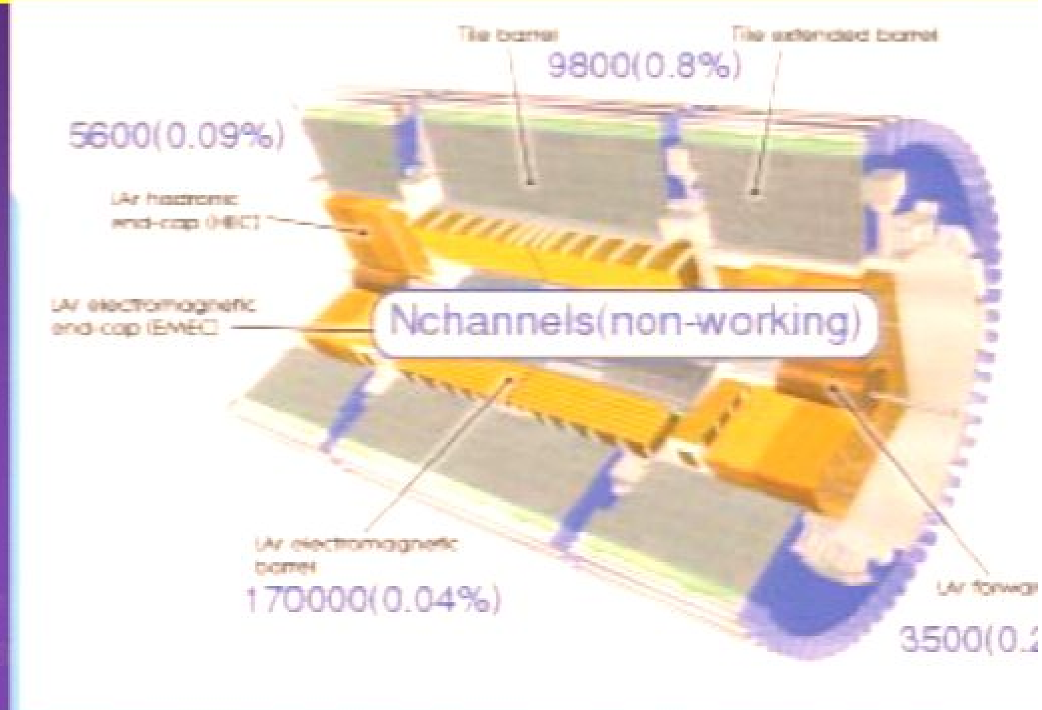
ATLAS commissioning progress

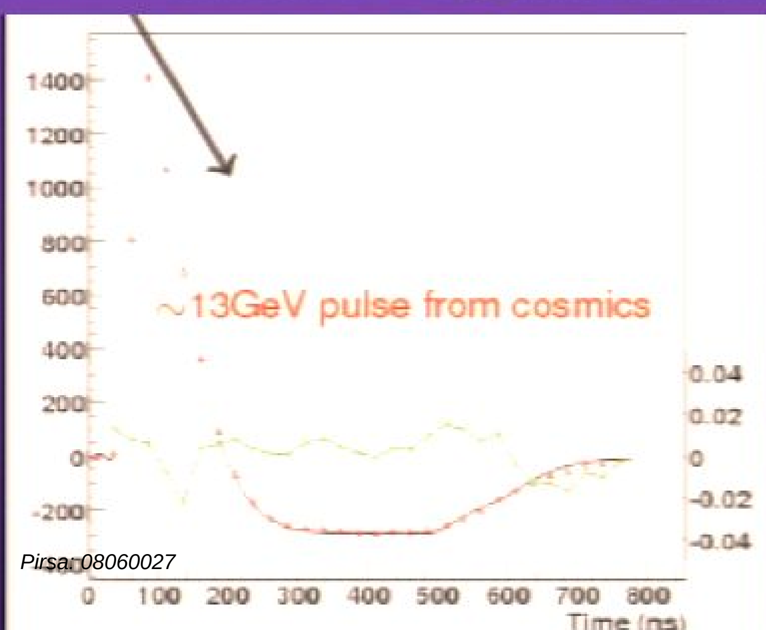
- Complete DAQ, controls, Level 1 trigger, High Level trigger integration
- "Full Dress Rehearsal" of computing / reconstruction chain at full event data taking rates
  - Including world-wide LHC computing grid data access
- Tests of real detector data acquisition with cosmic ray muons

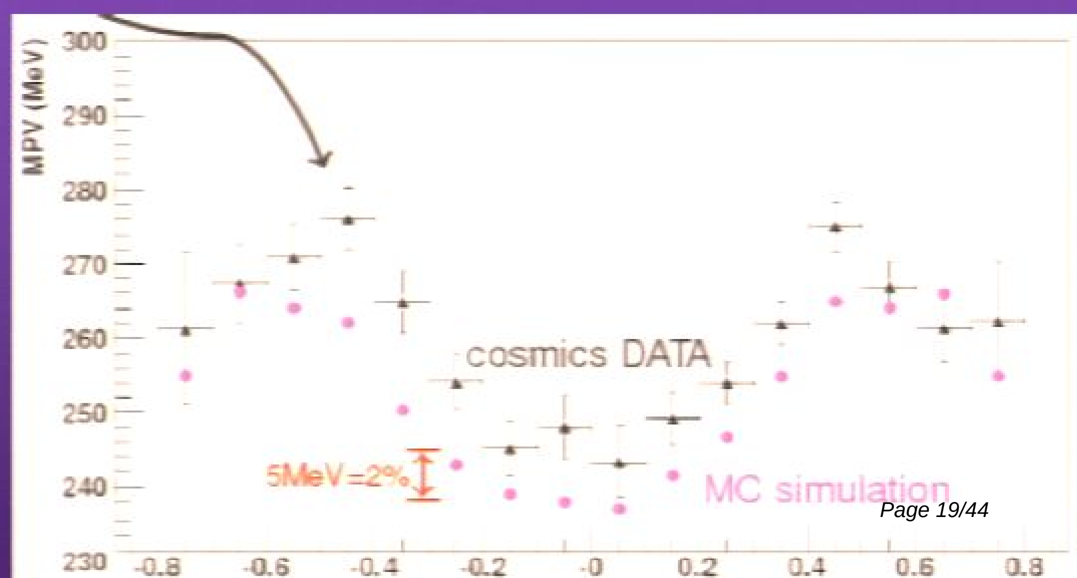


ATLAS Commissioning: calorimeters

- Calorimeters have been installed and stable for more than a year
  - Eg: Liquid argon at 88K with < 10 mK rms
- Cosmic data-taking for about 2 years
  - LAr pulse shapes consistent with expectations
  - EM energy scale uniformity already verified to < 2% with cosmic muons







- Plans with early data

Detector Performance

	Expected Day 0	Goals for Physics
ECAL uniformity	~ 1% ATLAS ~ 4% CMS	< 1%
Lepton energy scale	0.5—2%	0.1%
HCAL uniformity	2—3%	< 1%
Jet energy scale	<10%	1%
Tracker alignment	20—200 μm in Rφ	O(10 μm)

Timeline from Day 0

- Complete detector calibrations
  - Fine tracking alignment + alignment with other systems
  - EM energy scale, muon momentum scale, hadronic energy scale
  - b-tagging
  - Constant monitoring of detector conditions/problems with data
- First Standard Model physics measurements
  - Underlying event at $\sqrt{s}$ = 14 TeV: absolutely critical
  - Demonstrate ability to measure critical Standard Model processes, especially in regions "near" new physics
- First searches for BSM physics
  - Initially: high cross-section, low (understood) background
  - But ready in all channels from very beginning

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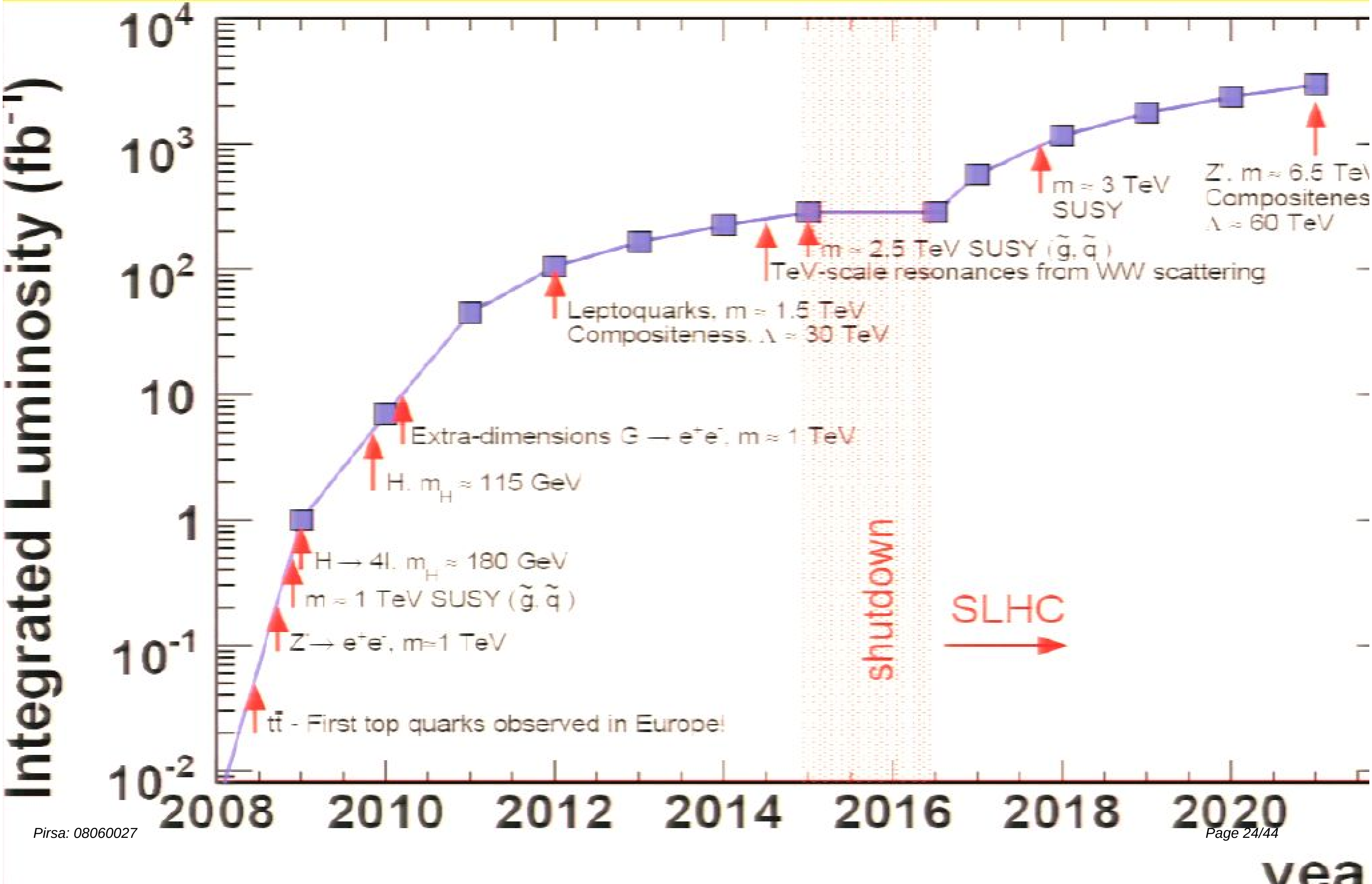
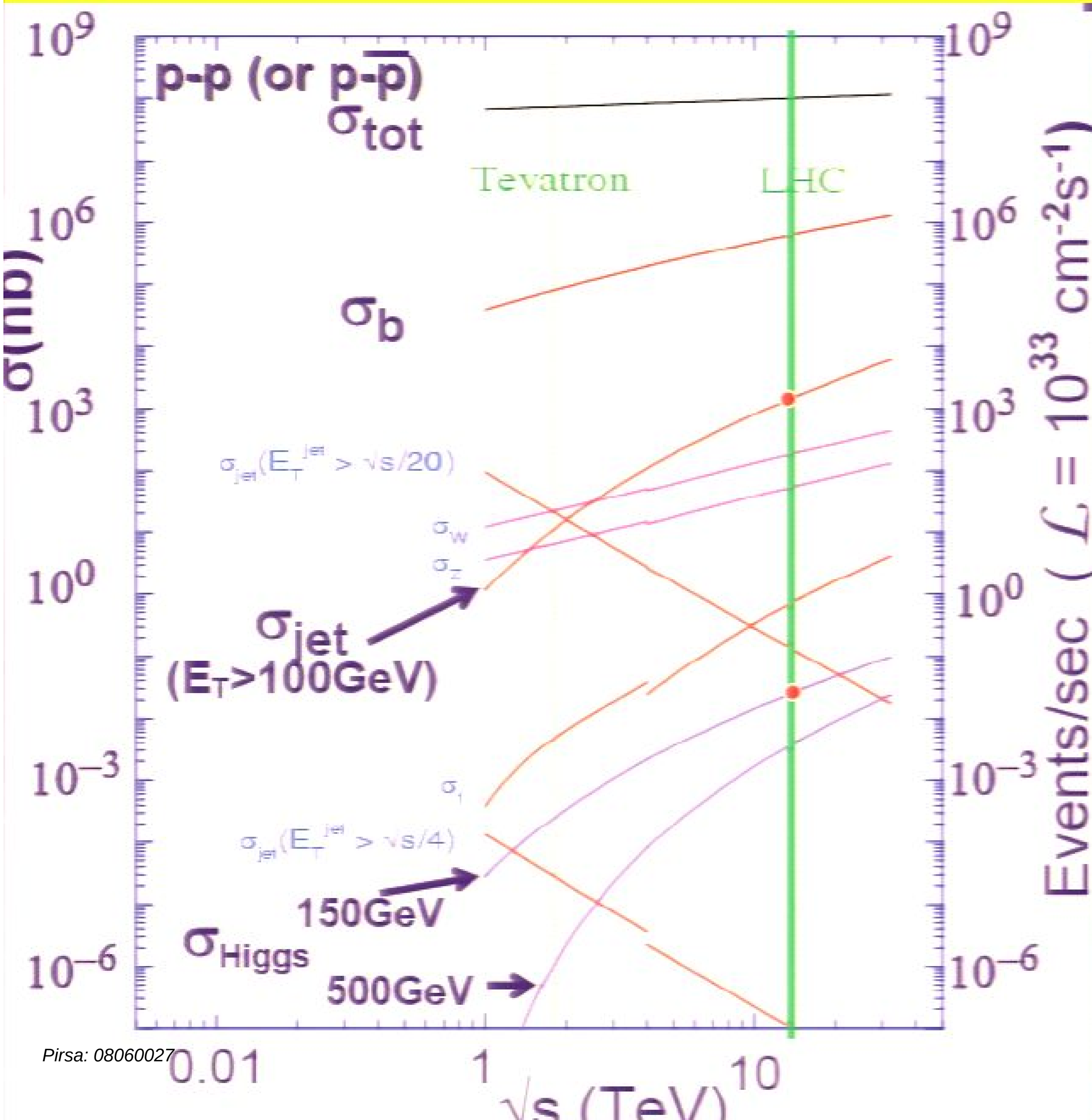
Possible Performance of LHC



The environment: cross-sections

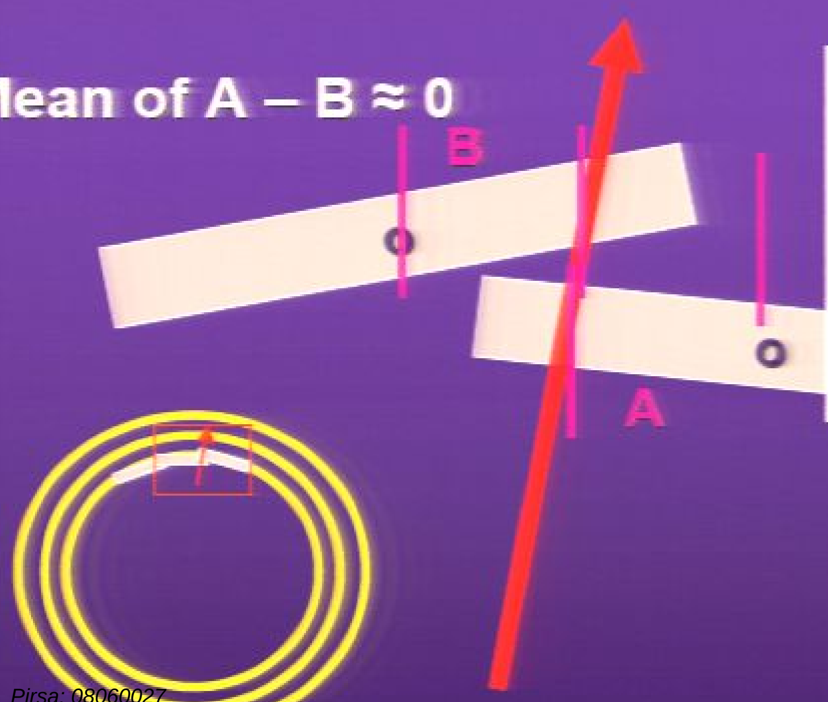


Channel	Recorde [1 fb^{-1}]
$W \rightarrow \mu\nu$	7 x 10^6
$Z \rightarrow \mu\mu$	1 x 10^6
$tt \rightarrow \mu + X$	0.1 x 10
Jets p_T>150GeV (if 10% bandwidth)	~10^6
Min Bias (10% bandwidth)	~10^6 (can be large
$\tilde{g}\tilde{g}$ (M~1 TeV)	10^2-10^3

Tracker alignment

- Large min-bias samples can be used for inner detectors
- Also need muons for alignment of muon system
  - Also provided low multiple scattering samples for inner trackers
- Global χ^2 techniques will be used eventually, but simpler local overlap methods will probably provide initial alignment
  - Eg: Overlap residual = inner hit residual – outer hit residual
- Example from ATLAS using cosmic ray muons

Mean of A – B ≈ 0



Global SCT-TRT barrel misalignments

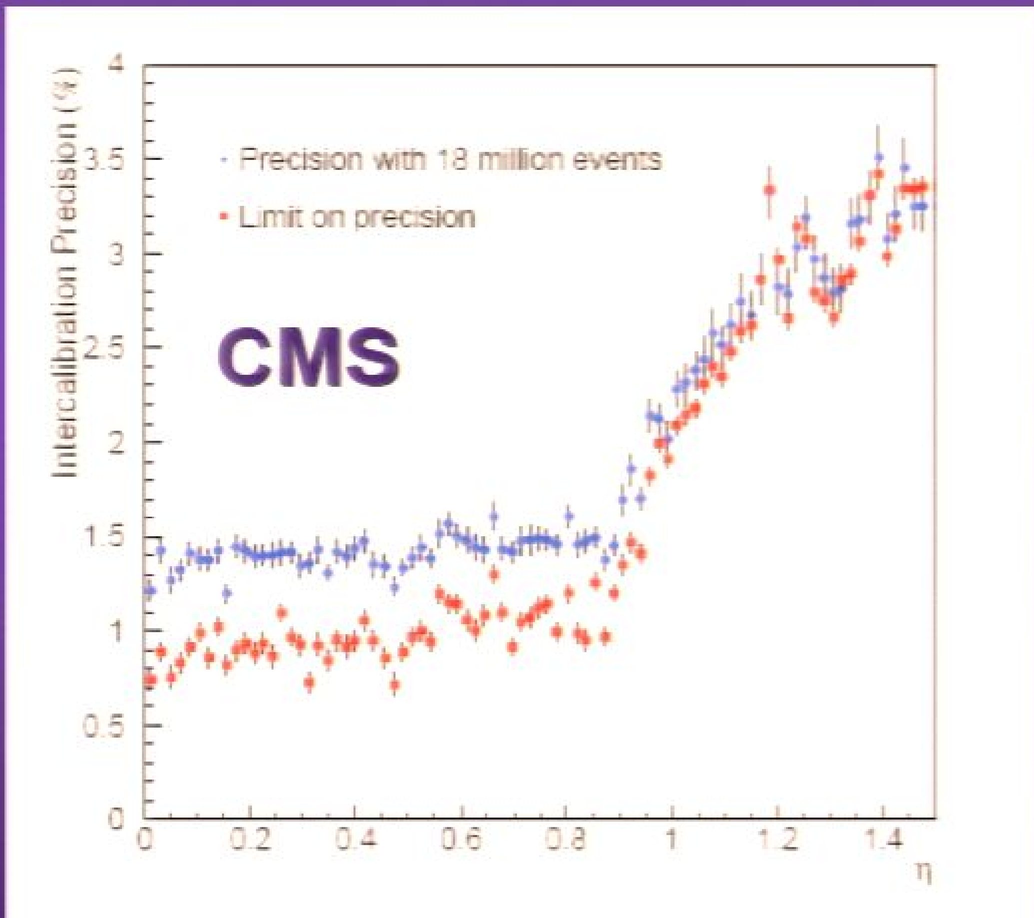
Displacement	Survey	Cosmics
Δx(mm)	$-0.300 \pm .008$	$-0.290 \pm .007$
Δrot-y(mrad)	$+0.221 \pm .006$	$+0.285 \pm .021$

comparison between survey measurements and results fro[m] reconstructed *cosmics* tracks (after alignment)

- Survey + hardware alignment systems working very well already
- Will be quickly checked with early data
  - 10 pb-1 is enough
- Very promising for early b-tagging

ECAL uniformity: min bias

- Can also use minimum bias events for early ECAL uniformity calibrations (before large $Z \rightarrow ee$ statistics available)
- Eg of CMS study with a few days of data-taking at 10^{33} $cm^{-2}s^{-1}$



- Quickly approach the 1% level in barrel
- Should have enough data in 2008 to make significant progress

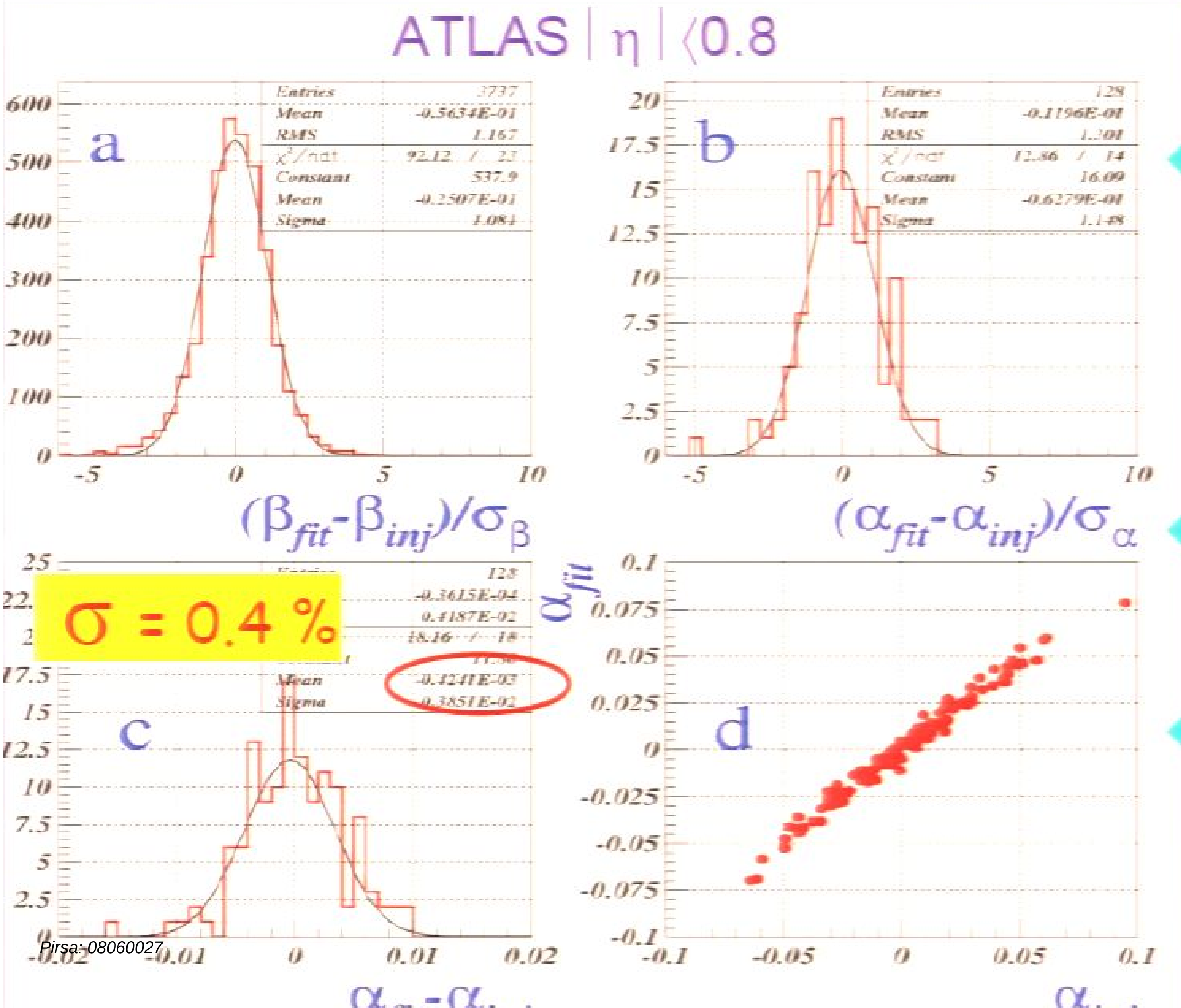
$Z \rightarrow ee, \mu\mu$: e/μ scales

- $Z \rightarrow ll$: clean calibration channel for leptons
  - High rate (eg, 0.5 – 1 Hz @$10^{33}cm^{-2}s^{-1}$, depending on trigger)
  - Nearly uniform η/ϕ coverage
  - Absolute mass scale near M_Z
  - $Z \rightarrow ll\gamma$ will also be used for photon scale
- $Z \rightarrow ee$: example of a simple method
  - Split calorimeter in 2D (η/ϕ) "towers" around electronics
  - Assume each "tower" needs scale correction α_i
  - Solve for "pairs" (can be overlapping) of α_i with M_Z constraint

$$E_i^{new} = E_i^{true} * (1 + \alpha_i)$$

$$M_{ij} = M_{ij}^{true} * (1 + \frac{\alpha_i + \alpha_j}{2}) = M_{ij}^{true} * (1 + \frac{\beta_{ij}}{2})$$

Z→ee: Example using mis-calibrated MC



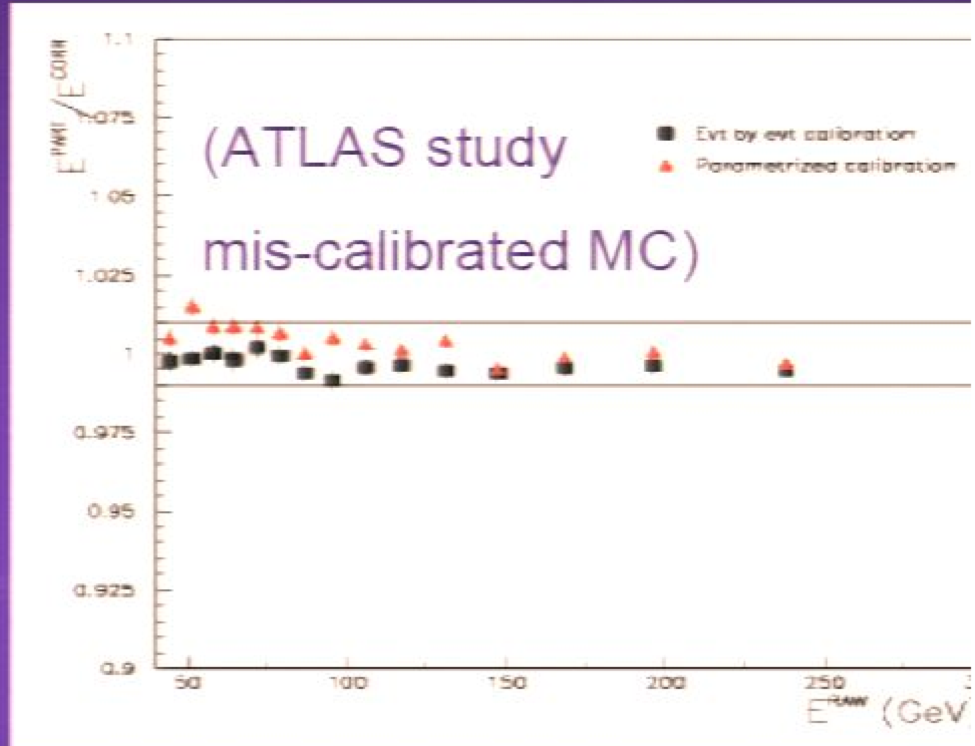
- Uses 170k Z→ee events
  - About 2-3 day running at $10^{33}cm^{-2}s^{-1}$ (1-200 pb^{-1})
- 448 η–φ region to η=2.5
  - $\Delta\eta\times\Delta\Phi = 0.2 \times 0.$
- Adjust "tower" size with increasing data

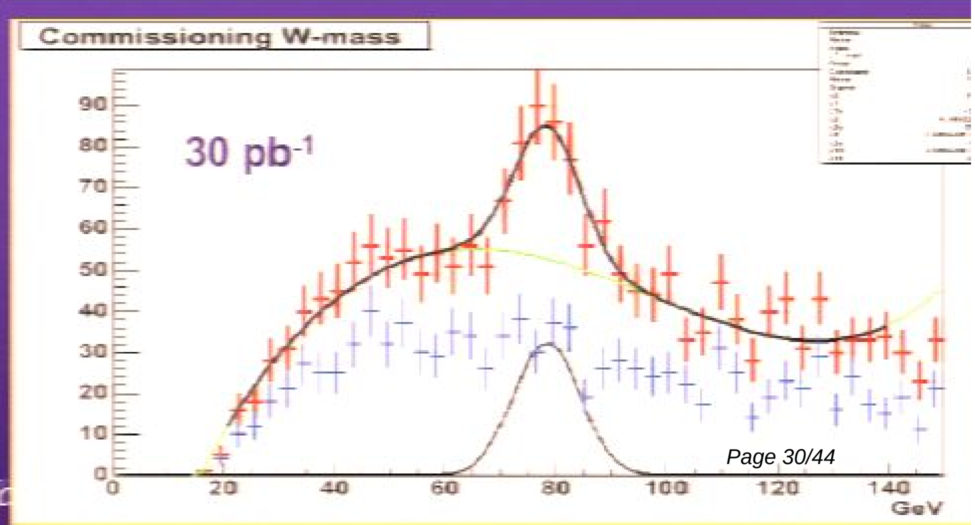
W → jet jet: Jet Energy Scale

- Use the mass constraint of the W in ttbar events, to set the JES / rescale jet to parton energy
  $\alpha = E_{parton} / E_{jet}$

$$Mjj = \sqrt{2Ej1Ej2(1-\cos\theta j1j2)} = MW$$

  - Take into account E, η and ϕ in the minimization procedure and corrected energies and angles.
  - E of parton and jet agree within ~ 1% over the range 50-250 GeV
  - Pros: Good statistics, easily triggerable, small physics backgrounds.
  - Cons: Only light q jets, limitations in E and η reach.



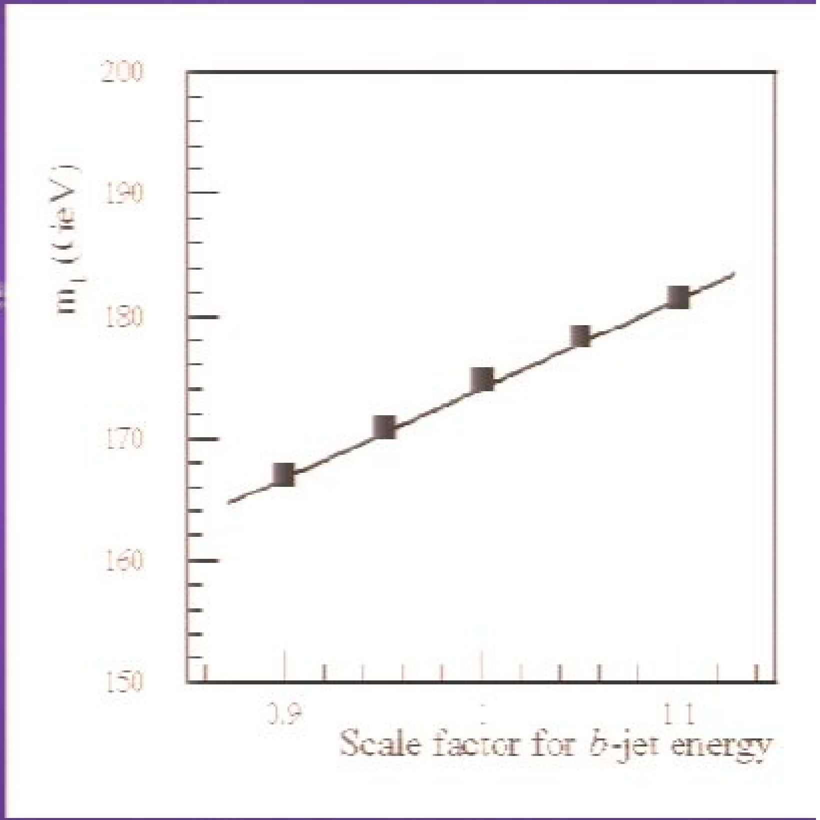


Top Mass: early analysis

- Initially low luminosity and imperfect detector
  - Worry about
    - Early b-tagging
    - jet energy scale
    - detector problems
- Initially uncertainty on b-jet energy scale dominant:

b-jet scale uncertainty	δM_{top}
1%	0.7 GeV
5%	3.5 GeV
10%	7 GeV

(10% on q-jet scale → 3 GeV on M_{top})

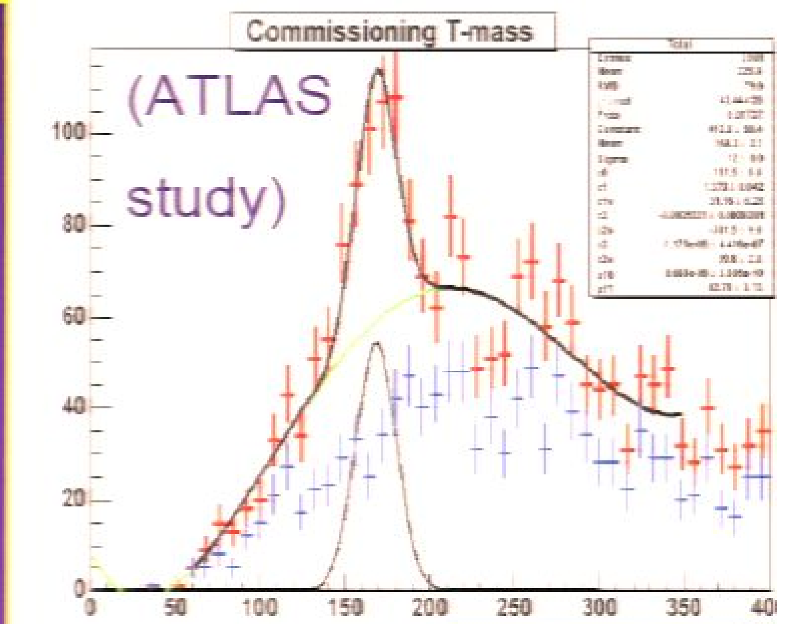


- Important to understand UE
  - → can have a large effect (as large as 5 GeV on m_t)

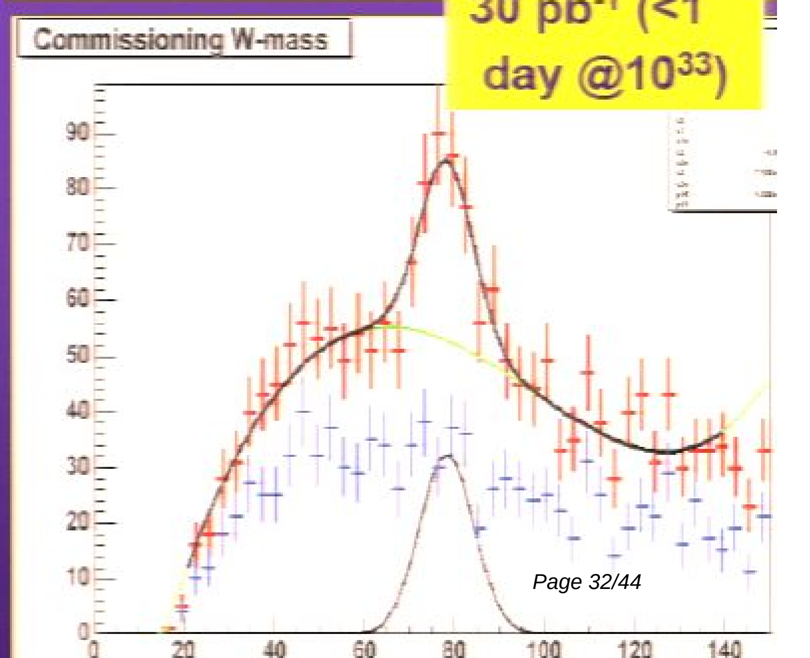
Top Mass : without b-tag

- Most important background for top: W+4 jets
  - Leptonic decay of W, with 4 extra 'light' jets
- Selection:
  - Isolated lepton with P_T>20 GeV
  - Exactly 4 jets (ΔR=0.4) with P_T>40 GeV
- Reconstruction:
  - Select 3 jets with maximal resulting P_T
- Identify W peak (also useful for JES calibration)
- Select highest p_T 2 jet combination
  - W peak visible in signal
  - No peak in background
- W and Top peaks visible with 30 pb^{-1}

30 pb^{-1}	σ(stat)
Mtop	3.2 GeV



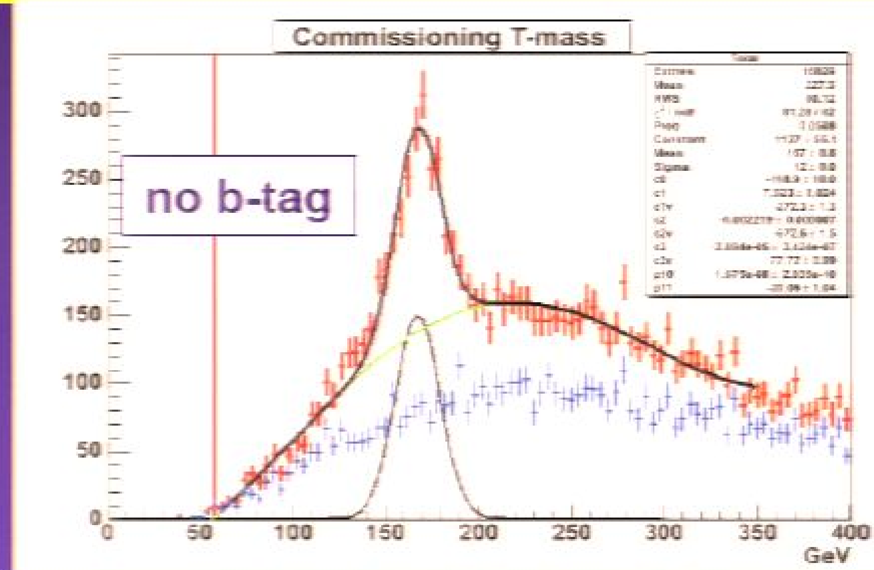
30 pb^{-1} (<1 day @10^{33})

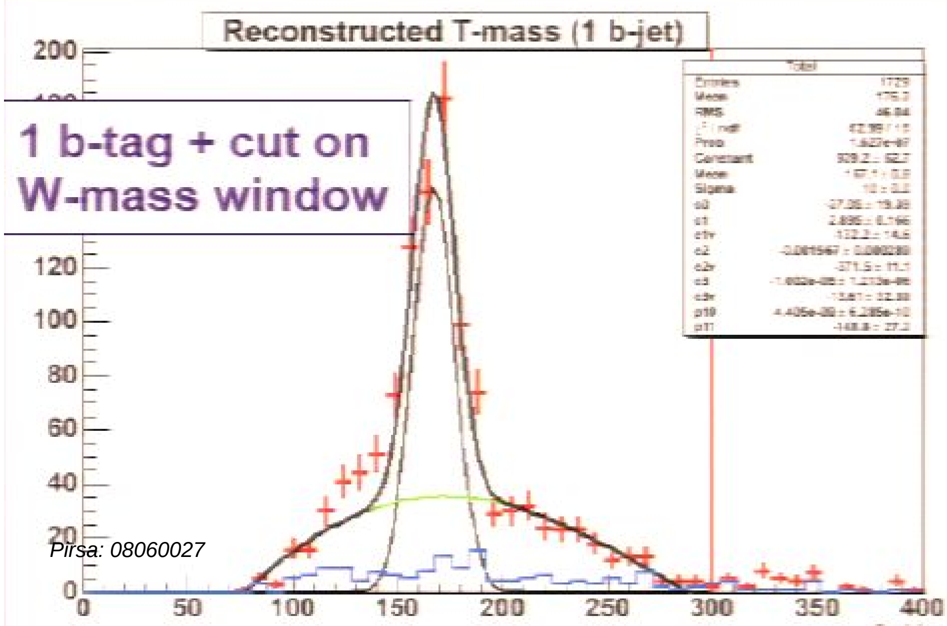


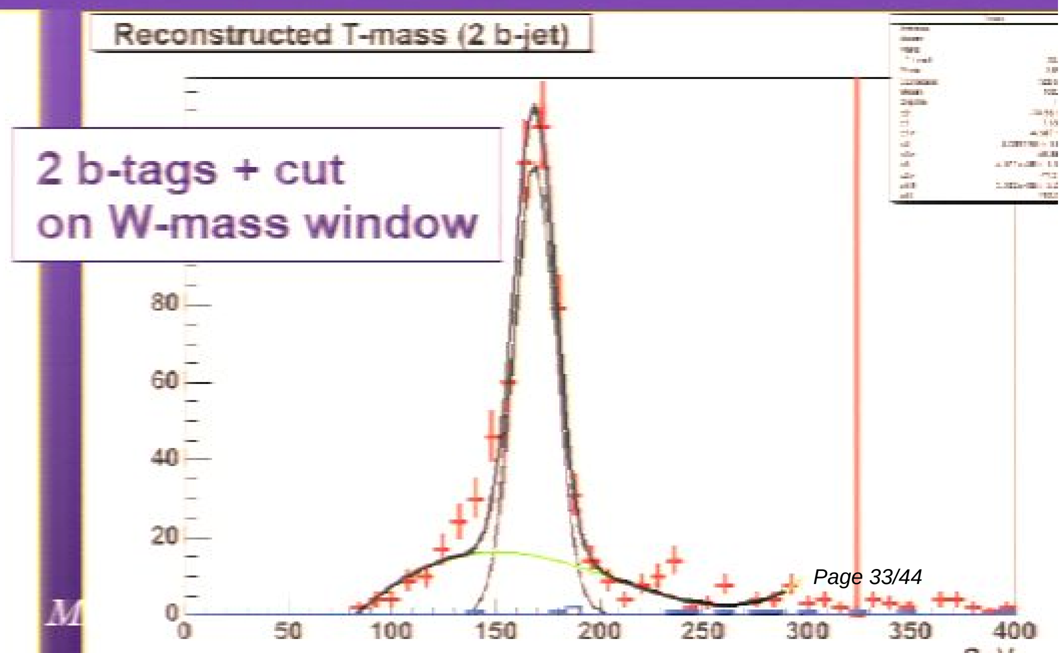
A bit more data ..

150 pb^{-1}	σ(stat)
Mtop	0.8 GeV

- Quickly hit systematics limit
- Will move to b-tag analyses when possible
  - Background composition changes: jet combinatorics from top becomes more and more important

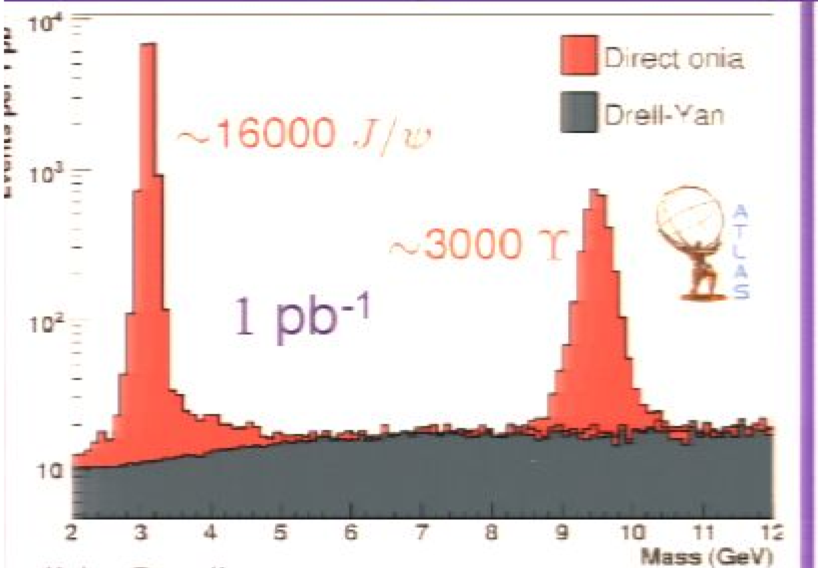


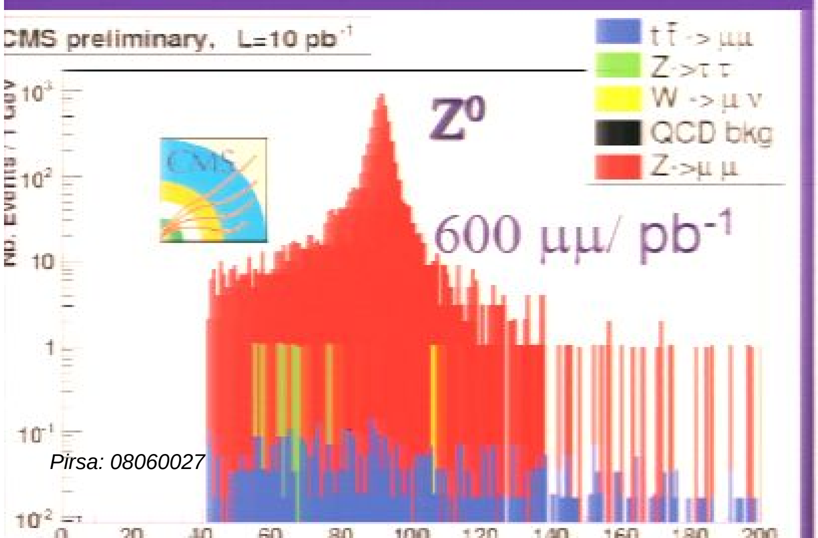


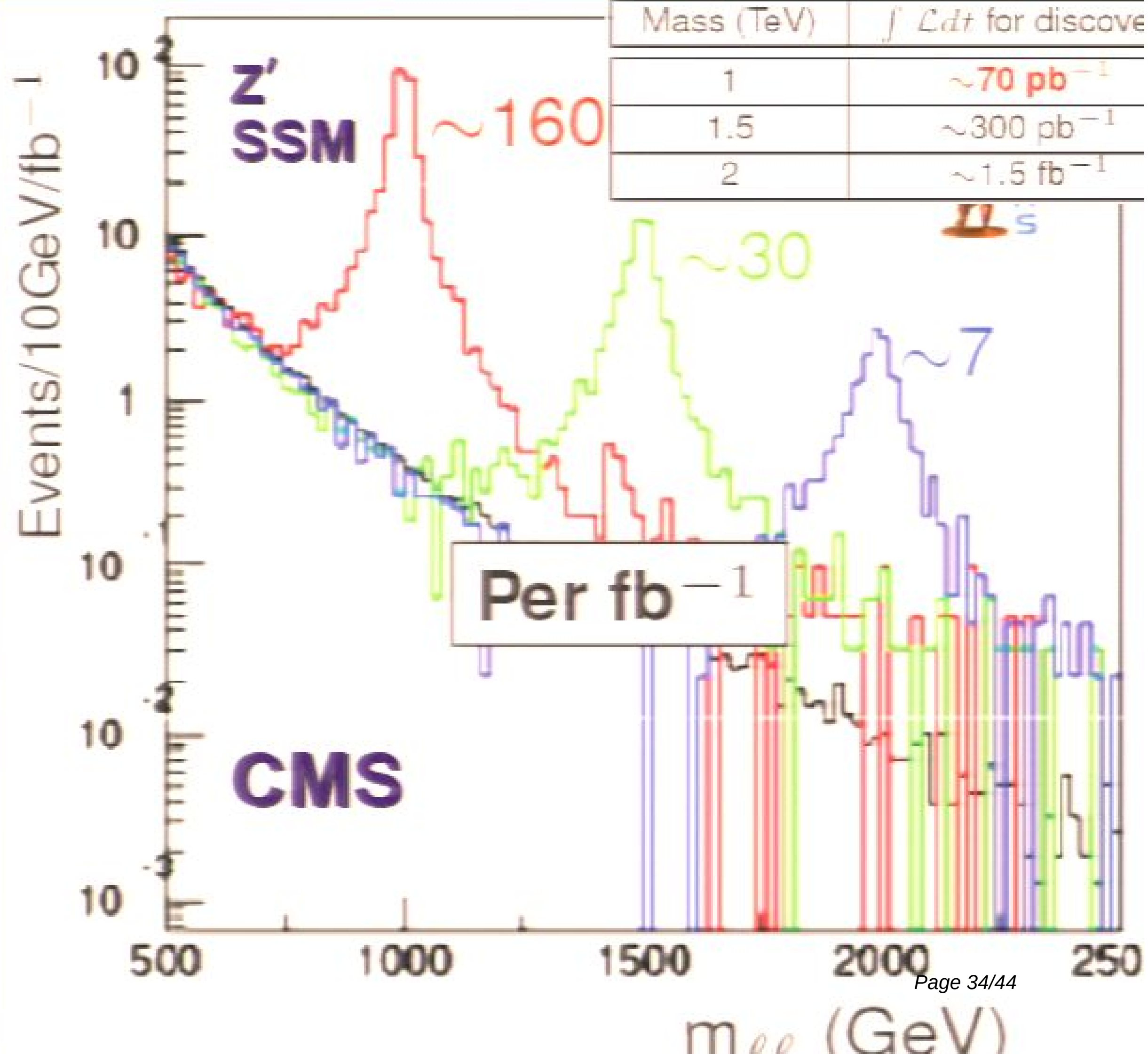


Z′ → ee/μμ: early golden search

- Search for high mass Z′ resonance decaying to ee or μμ
- First verify with SM peaks, then extend to high masses



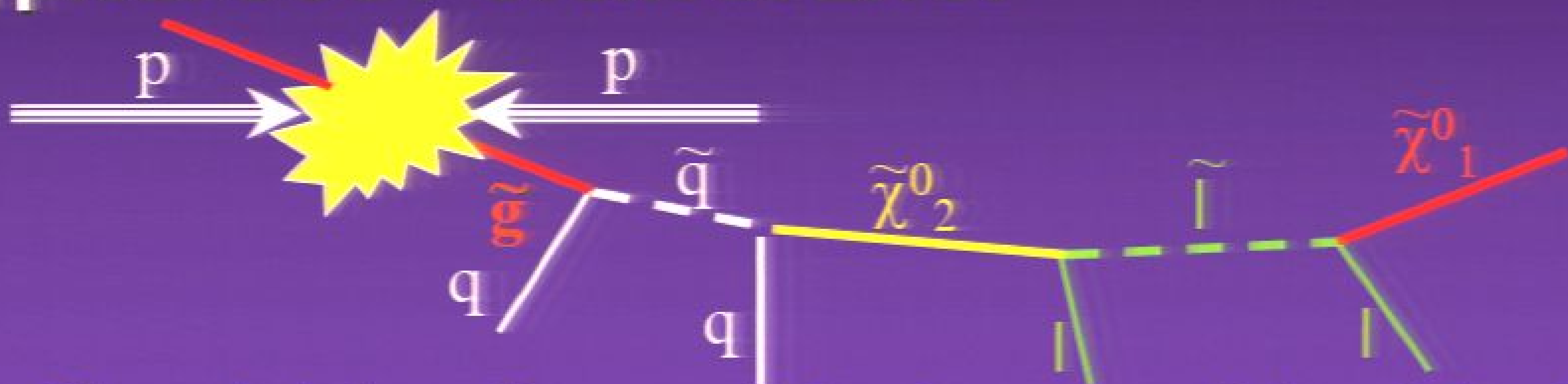




Mass (TeV)	∫ $\mathcal{L}dt$ for discove
1	~70 pb−1
1.5	~300 pb−1
2	~1.5 fb−1

SUSY Searches

- Typical SUSY event at LHC:

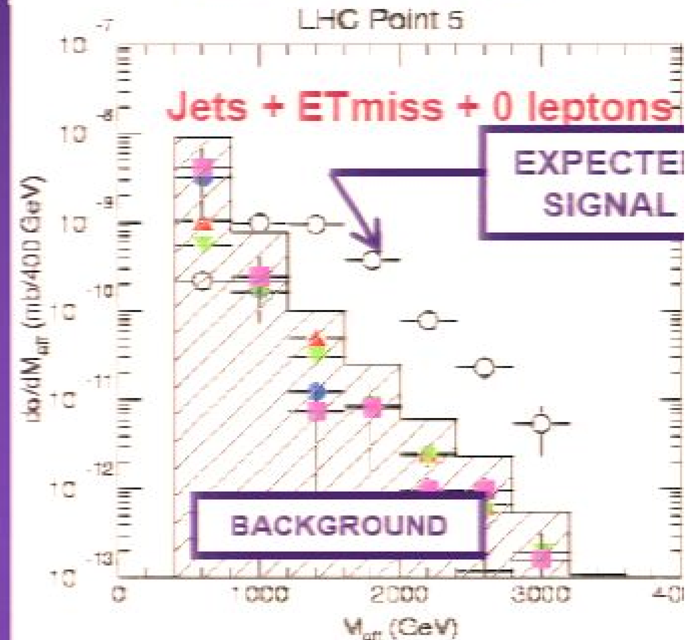


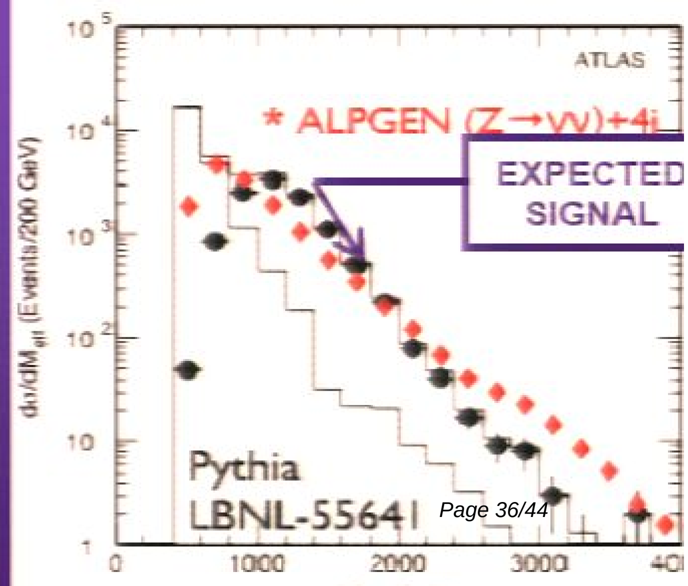
- Strongly interacting sparticles (squarks, gluinos) dominate production
  - Can have high cross-sections $\Rightarrow$ good candidate for early discovery
- sleptons, gauginos etc. $\tilde{g}$ cascade decays to LSP.
- Long decay chains and large mass differences between SUSY states
  - Many high pT objects observed (leptons, jets, b-jets).
- If R-Parity conserved LSP stable and sparticles pair produced.
  - Large ETmiss signature
  - Canonical theory with a cold dark matter candidate
- Closest equivalent SM signature $t \rightarrow Wb$ with $W \rightarrow l\,\nu$

Inclusive SUSY: Background Estimation

- Inclusive signature: jets + n leptons + E_T^{miss}
- Main backgrounds:
  - Z + n jets
  - W + n jets
  - ttbar
  - QCD
- Greatest discrimination power from E_T^{miss}
- Generic approach to QCD background estimation:
  - Select low E_T^{miss} background calibration samples;
  - Extrapolate into high E_T^{miss} signal region.
- Extrapolation is non-trivial.
  - Must find variables uncorrelated with E_T^{miss}
- Developing data-driven methods for predicting backgrounds with minimal Monte Carlo reliance
- ATLAS Example: ~ 1 TeV SUSY scale, look at $M_{eff}=\Sigma|p_T^i| + E_T^{miss}$

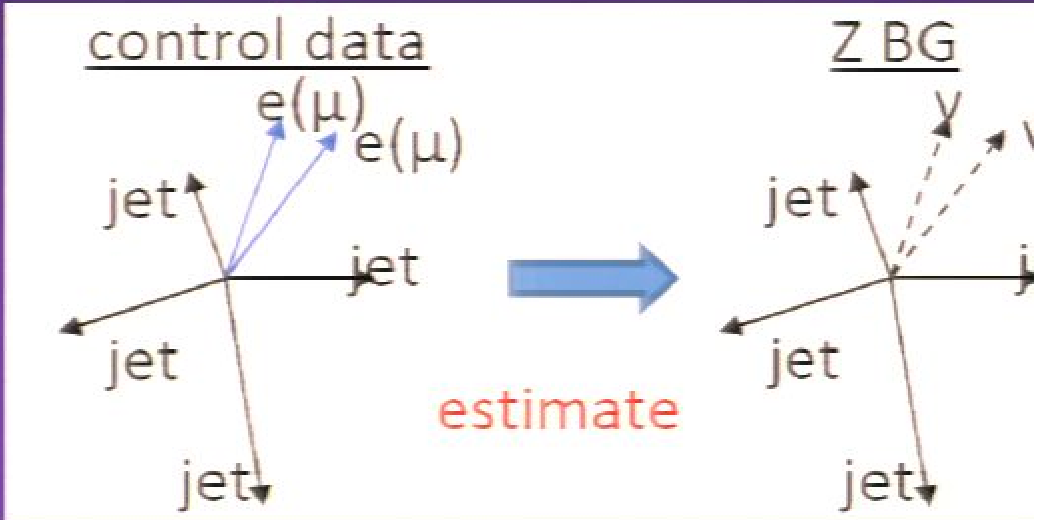
MSUSY~1 TeV

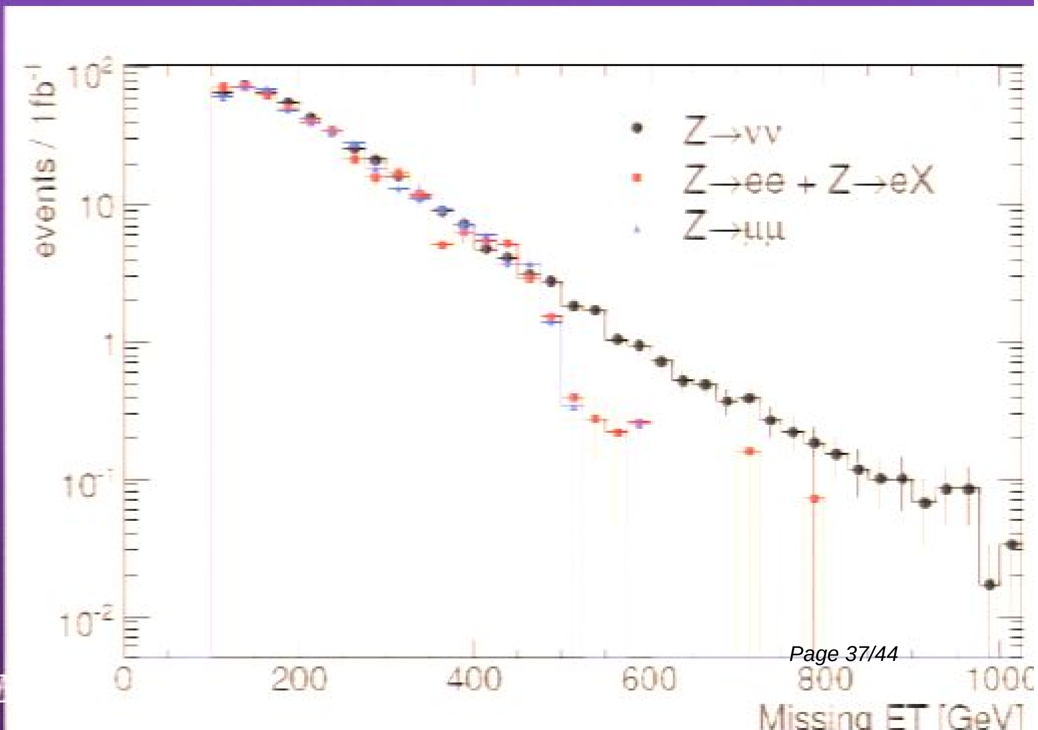




SUSY example: estimating $Z \to \nu\nu$ background with data

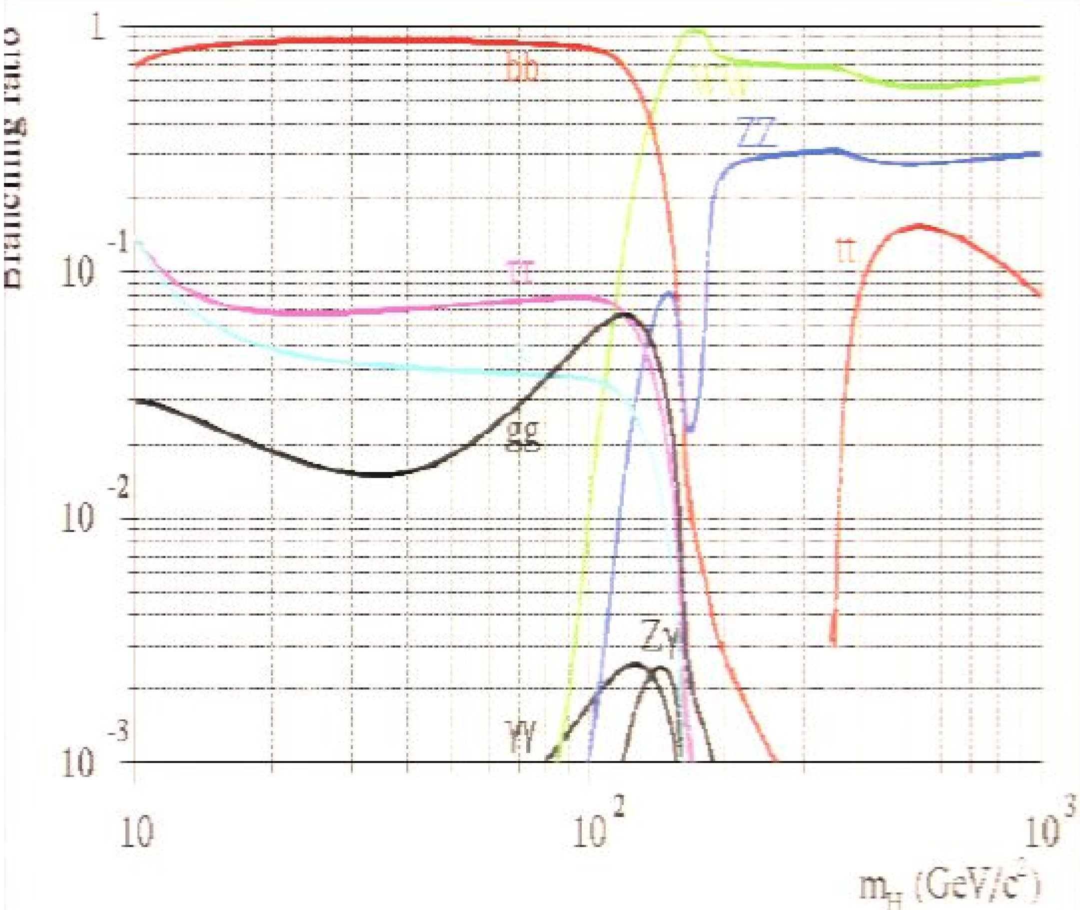
- Significant background to SUSY searches
- Can estimate using $Z \to ee/\mu\mu$ and correcting for e/μ acceptance and branching fraction
- Difficulty: statistics for $Z \to ee/\mu\mu$ run out even here with 1 fb^{-1}
  - ATLAS Study:



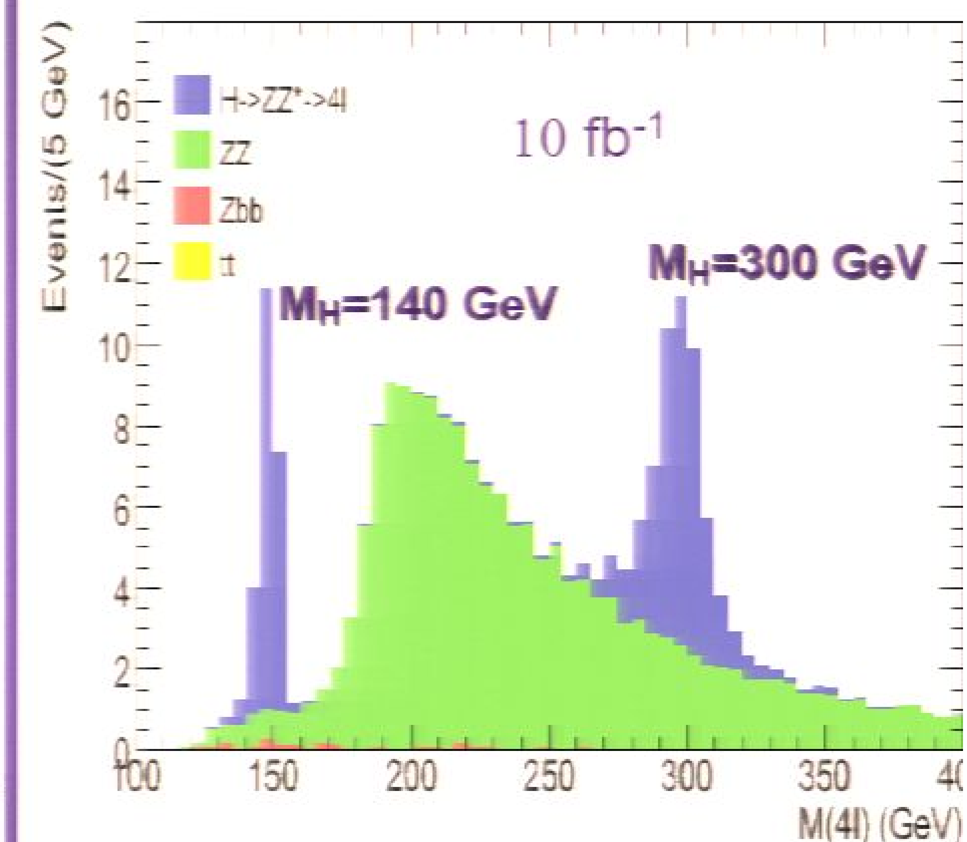


Direct SM Higgs Search: depends on mass

SM Higgs: branching fractions



ATLAS study: $H \rightarrow ZZ^{(*)} \rightarrow 4\,\ell$

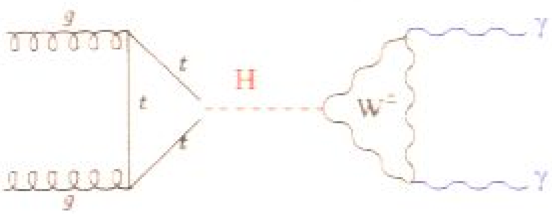


- Electron / muon reconstruction probably OK with early data
  - ⇒ Higher mass Higgs is possible (say, > 130 GeV)
- Might think of observation in 2009

Lower mass Higgs Harder

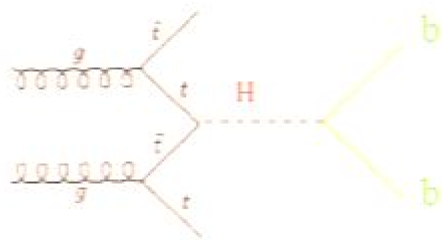
3 channels contribute ~ 2σ with 10 fb^{-1}

$H \to \gamma\gamma$



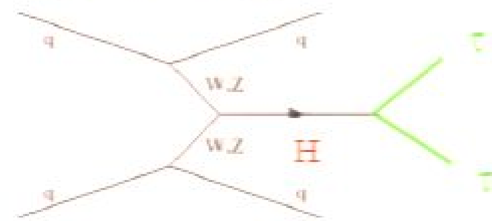
- EM resolution
- EM uniformity
- γγ mass:
  - σ/m < 1%

$ttH \to tt\,bb \to b\ell\nu\, bjj\, bb$



- Good b-tagging
- Reduce QCD background:
  - 4 b-tags
- Hadronic transverse mass resolution

$qqH \to qq\tau\tau$



- Forward jet tag
- Good central jet veto
  - ⇒ τ ID

- b-tagging, final EM resolution/uniformity, forward jet reco ...
  - ⇒ Lower mass Higgs (eg: < 130 GeV) will take significant detector/data understanding
    - (Not just a luminosity question ...)

Summary

- The first priority of early LHC collisions will be to push detector understanding
  - Calibrations
  - Dead/hot channel characteristics/understanding
  - Dead material understanding ...
- Basic Standard Model measurements critical
  - Underlying event, parton distribution functions, ...
  - SM processes “near” possible new physics
  - Top/W masses will be systematics dominated from early on
- First searches for clean processes with high cross-sections next
  - High mass Z’, SUSY are strong candidates
    - Data-driven background estimation for SUSY will be a challenge
- SM Higgs
  - Heavier mass (> 140 GeV) SM Higgs will be discovered “early”
    - first few fb^{-1} (2009?)
  - Lighter SM Higgs will take more time
  - But that’s not really what we want to discover in any case ...

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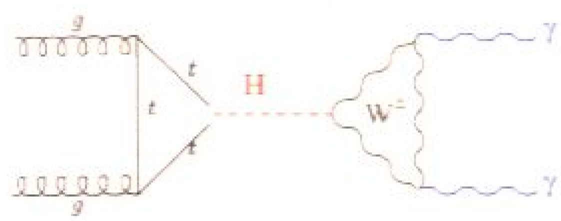
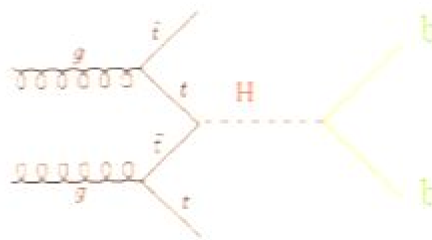
$H \rightarrow \gamma\gamma$



$t\bar{t}H \rightarrow t\bar{t}\, b\bar{b} \rightarrow b\ell\nu\, bjj\, bb$



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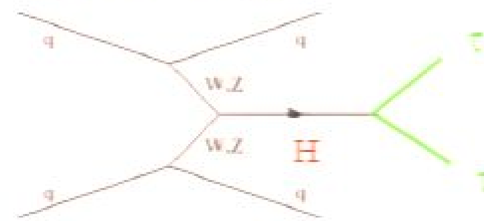

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Pascos08McPherson.pdf - Adobe Reader

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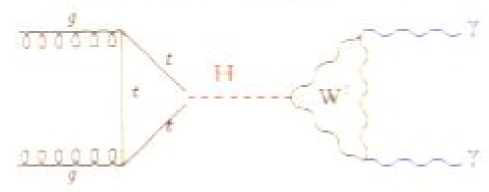

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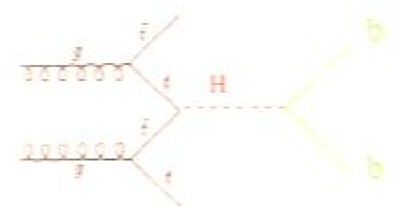

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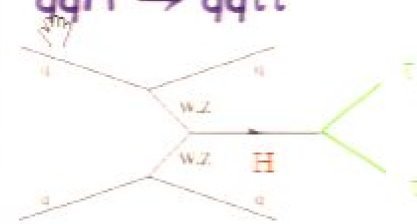

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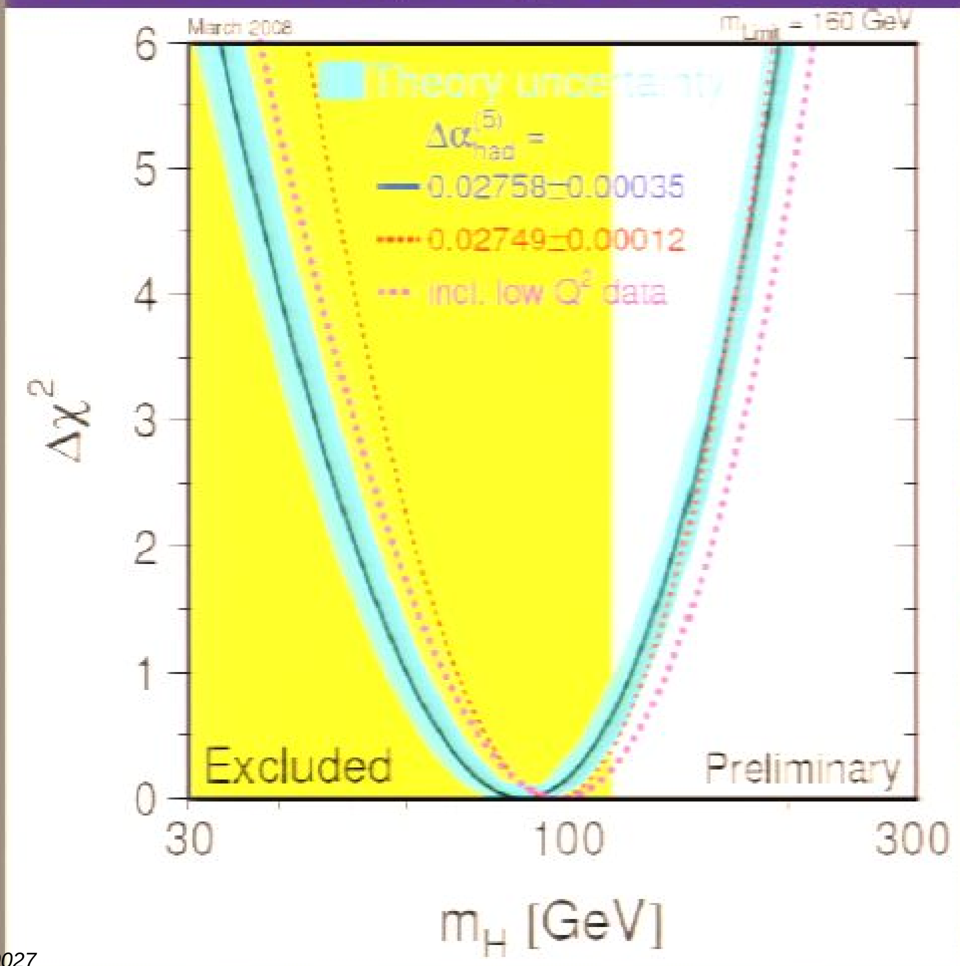
Why the Terascale? II

EW Fits: MH only free Param.
Data from LEP, SLD, Tevatron



- MH (winter 2008)
  - χ^2 minimum:
    - 87 GeV
  - Direct Search LEP:
    - > 114 GeV @ 95% C.L.
  - Indirect EW fit constraints:
    - < 160 GeV @ 95% C.L.
  - Including LEP direct search limit
    - < 190 GeV @ 95% C.L.
- Strong interest:
  - Find H^0_{SM} (if it exists)
- If no H^0_{SM}
  - Strong dynamics < 1 TeV ?
- If H^0_{SM} :
  - Fine-tuning of M_H annoying if no new physics by ~ 1 TeV
    - Cancel loops or cut-off theory at Terascale

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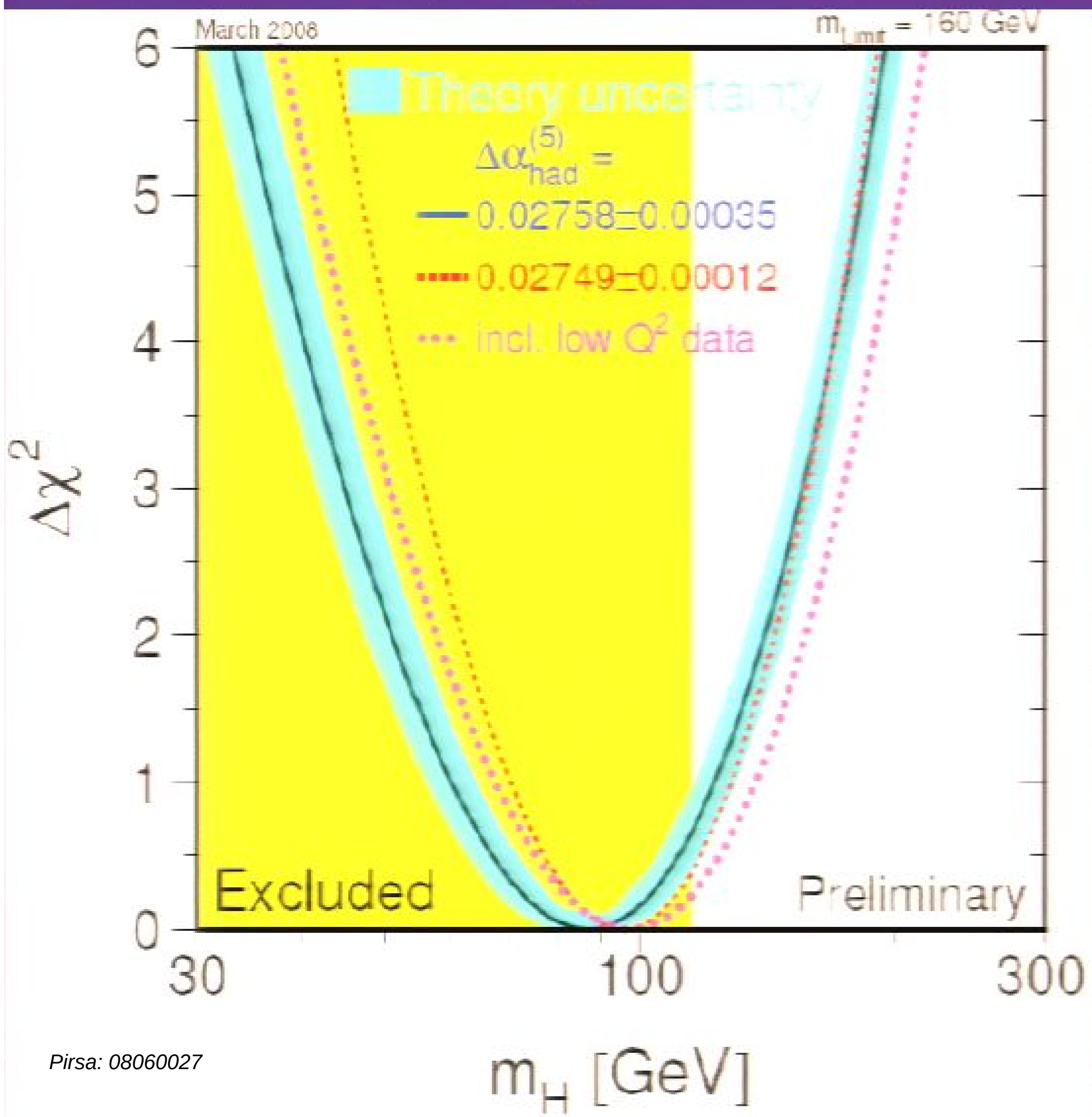

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