Imperial College London

PHENO 2009 Symposium
University of Wisconsin (Madison), 13/05/2009

LHC Alive!

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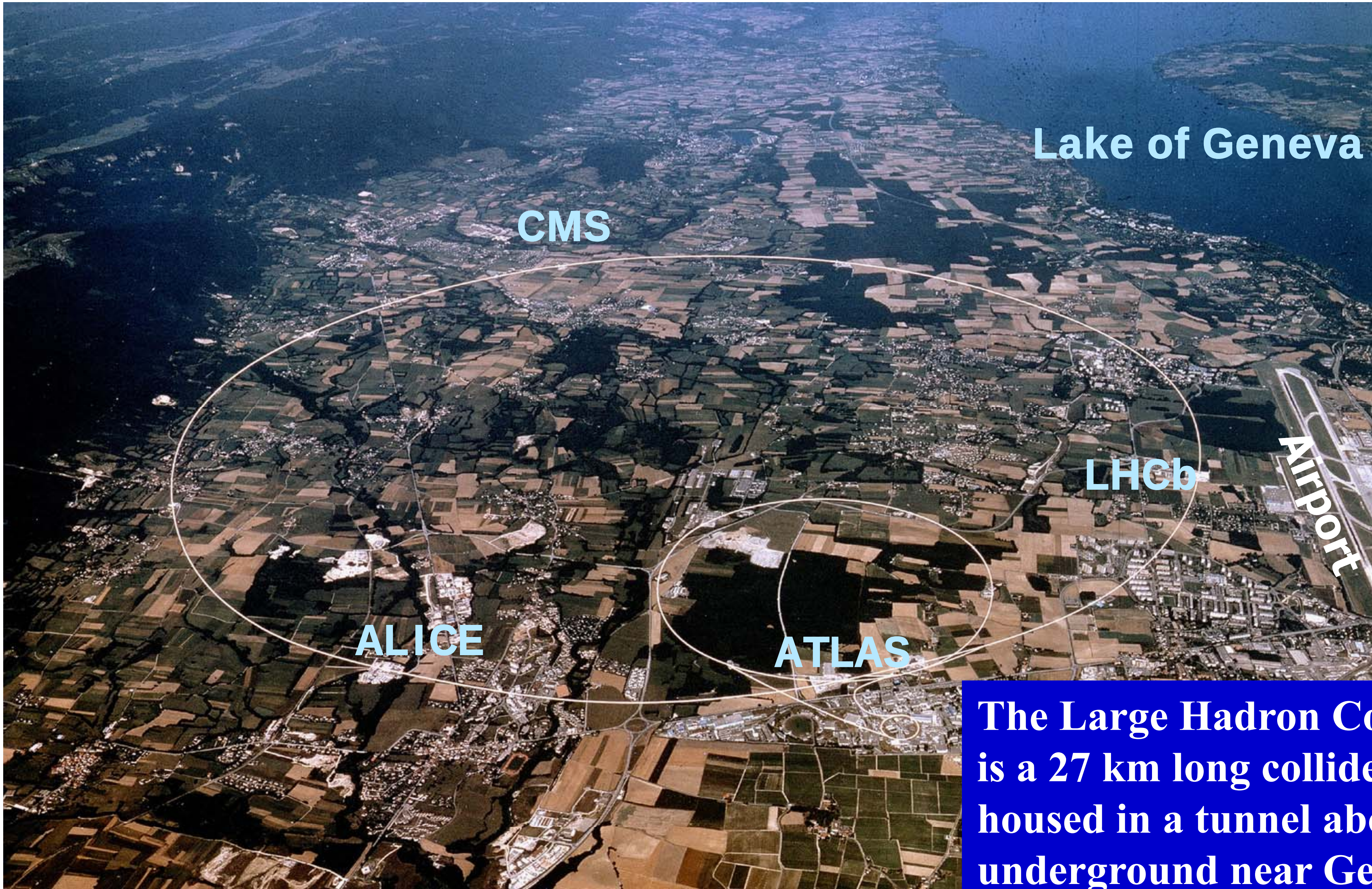
On behalf of the CMS and ATLAS Collaborations

Large Hadron Collider



The Large Hadron Collider is a 27 km long collider ring housed in a tunnel about 100 m underground near Geneva

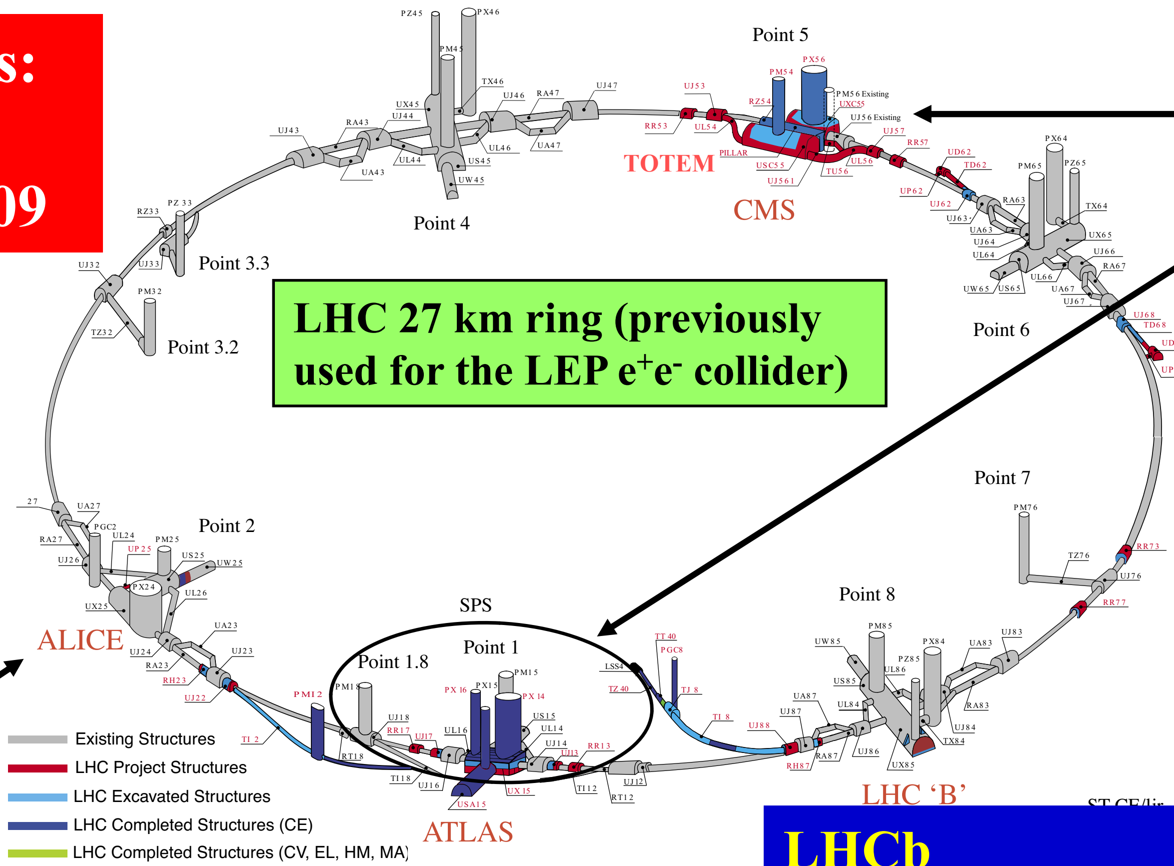
Large Hadron Collider

- **pp:** $\sqrt{s}$ = 10-14 TeV, L_{design} = 10^{34} cm^{-2} s^{-1} (after 2012-2013)
  $L_{initial}$ < few x 10^{33} cm^{-2} s^{-1}
  $\sqrt{s}$(LHC) ~ 7 $\sqrt{s}$ (Tevatron), L_{design} (LHC) ~100 L_{design} (Tevatron)
- **Heavy ions:** (e.g. Pb-Pb at $\sqrt{s}$ ~ 1000 TeV)

First collisions: expected in November 2009

ATLAS and CMS
pp, general purpose

LHC 27 km ring (previously used for the LEP e^+e^- collider)

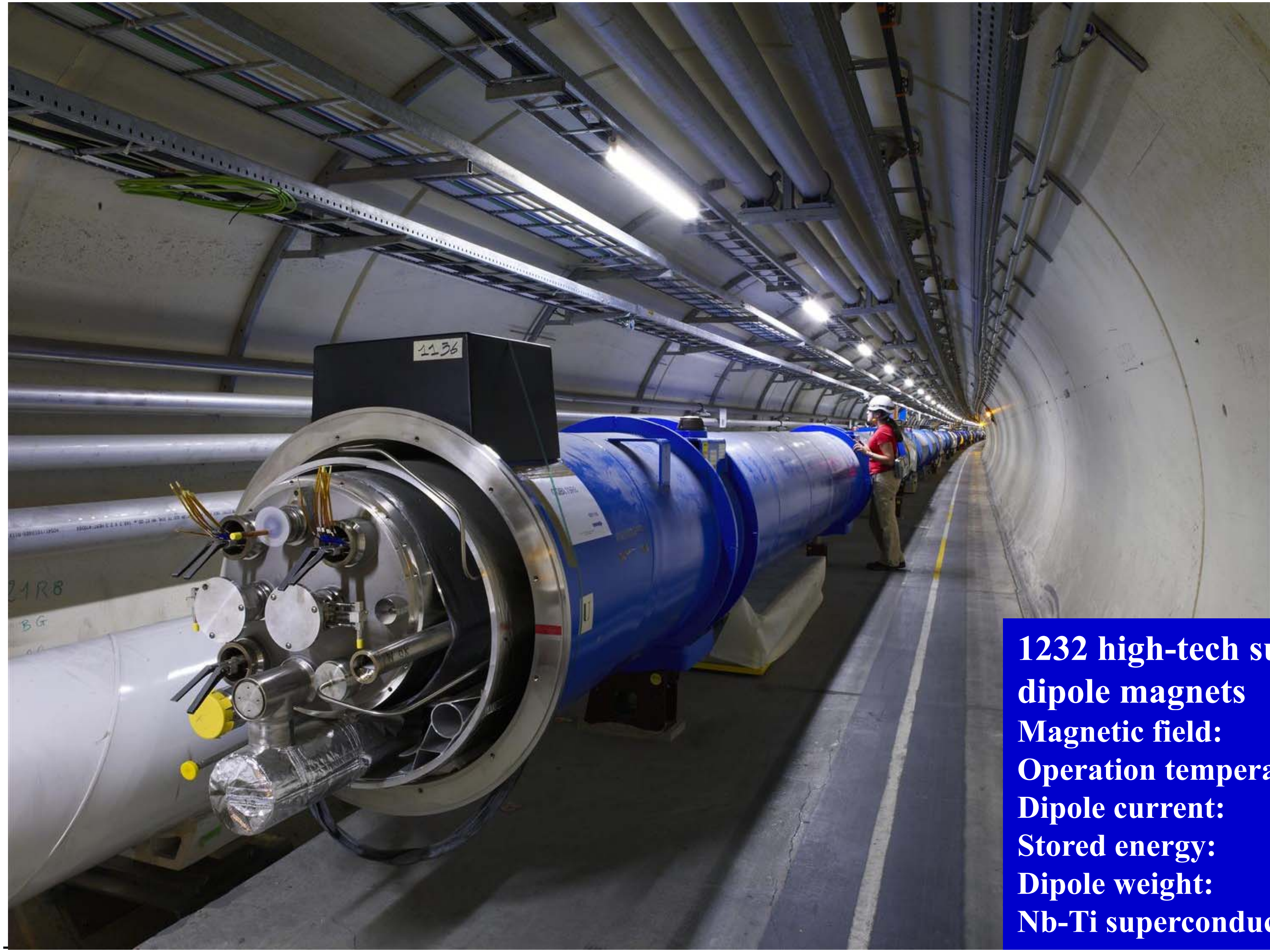


Plus two experiments with very forward detectors at
Point-1: LHCf
Point-5: Totem

ALICE
ion-ion
p-ion

LHCb
pp, B-physics, CP-violation

LHC: dipole magnets



1232 high-tech superconducting dipole magnets

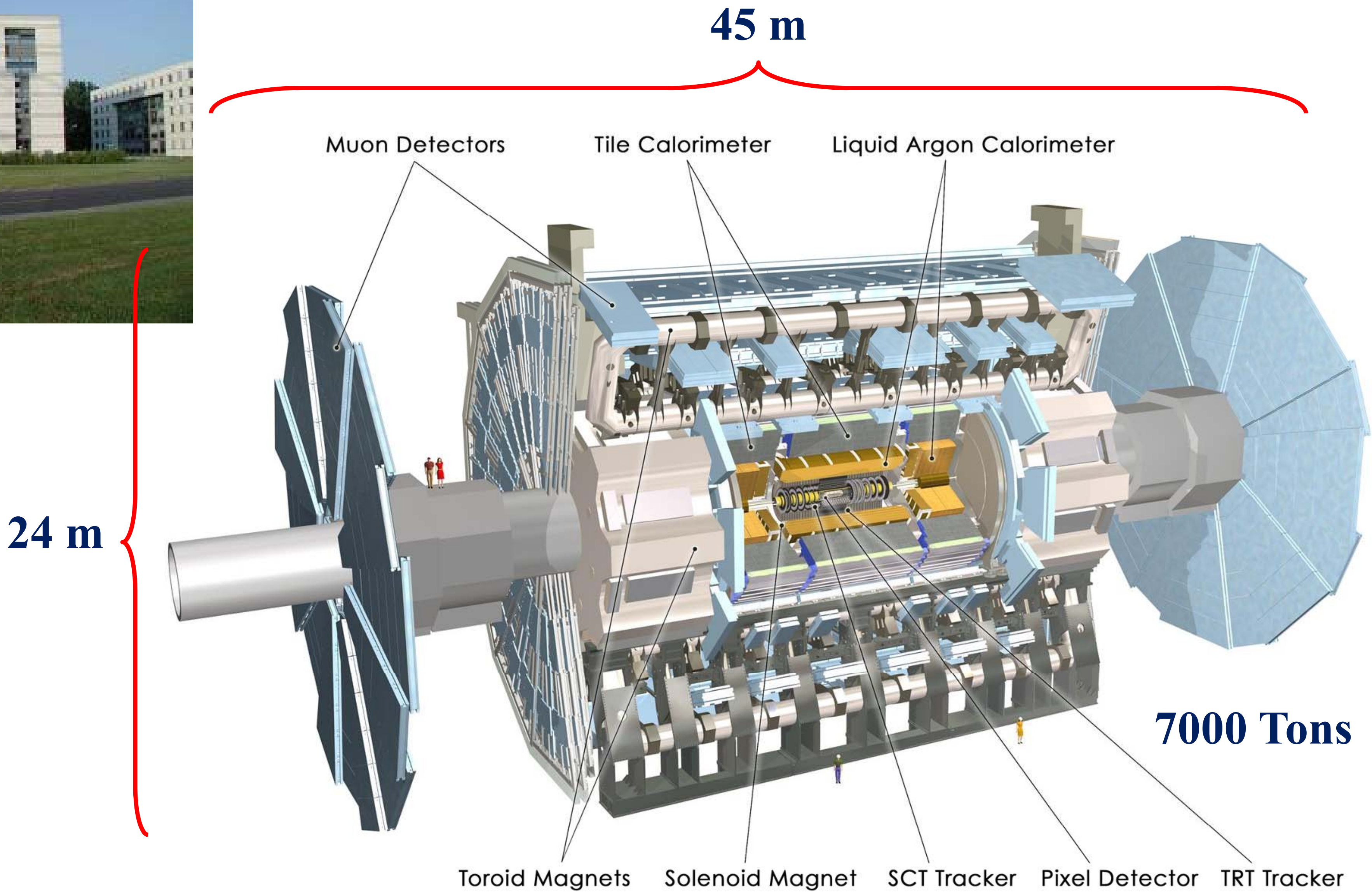
Magnetic field:	**8.4 T**
Operation temperature:	**1.9 K**
Dipole current:	**11700 A**
Stored energy:	**7 MJ**
Dipole weight:	**34 tons**
Nb-Ti superconducting cable:	**7600 km**

LHC: Focusing magnets

Special quadrupole magnets ('Inner Triplets') to focus beams to reach highest luminosity at their interaction in the centre of the experiments

ATLAS Detector

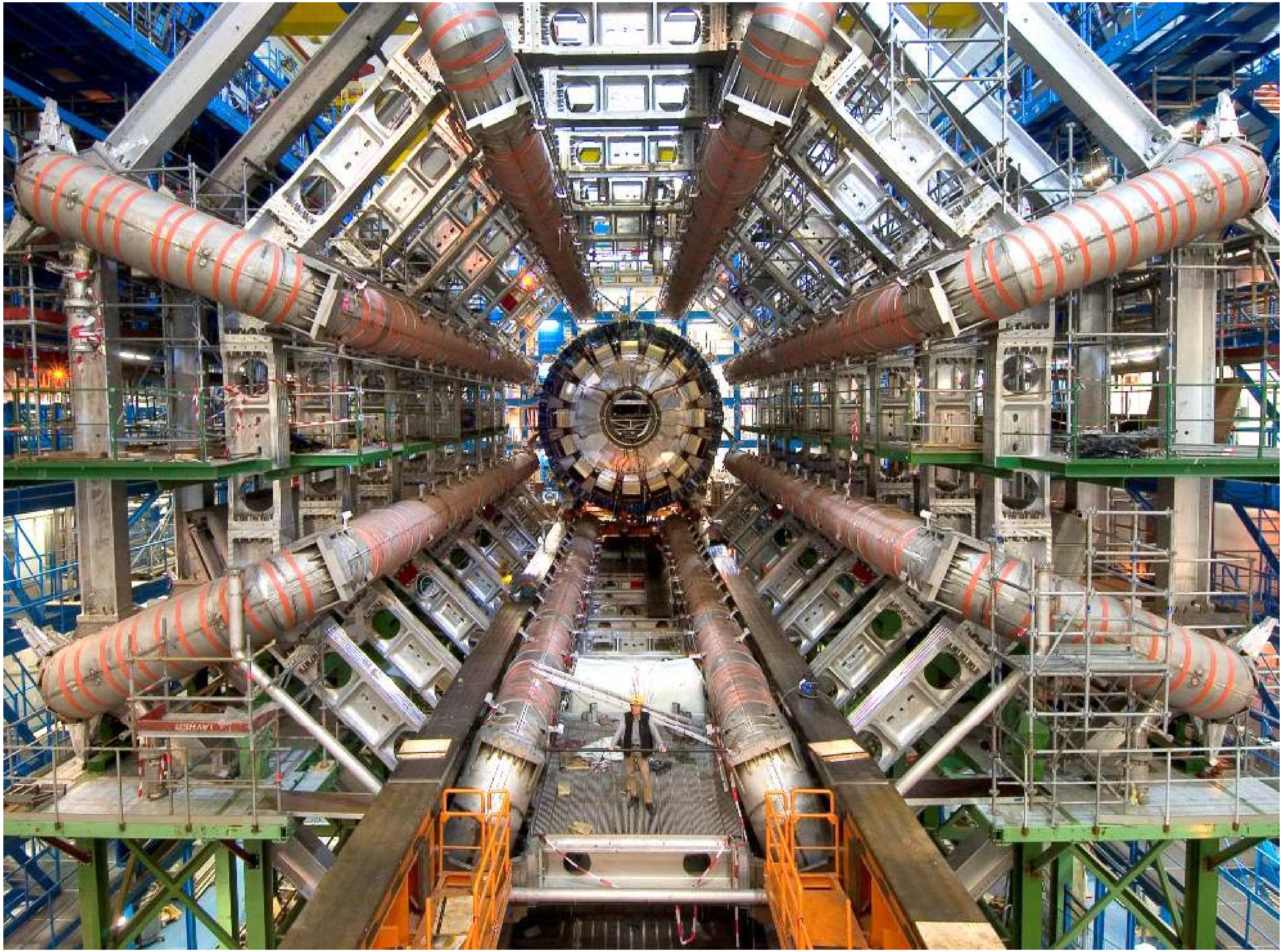
ATLAS superimposed to
the 5 floors of building 40



7000 Tons

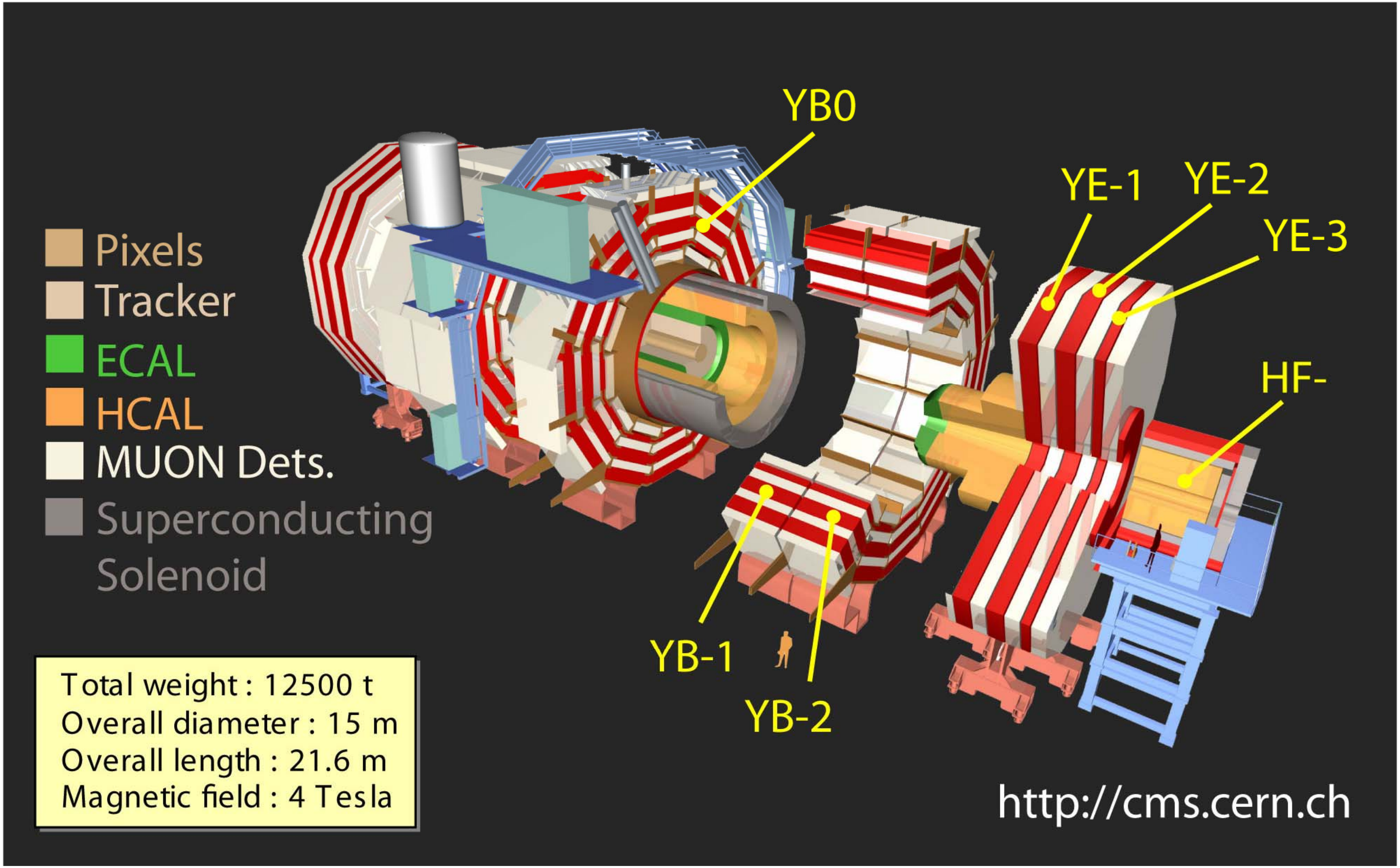
ATLAS Cavern June 2003

ATLAS: toroid magnets



ATLAS: Closure of LHC beampipe ring 16th June 2008

CMS Detector



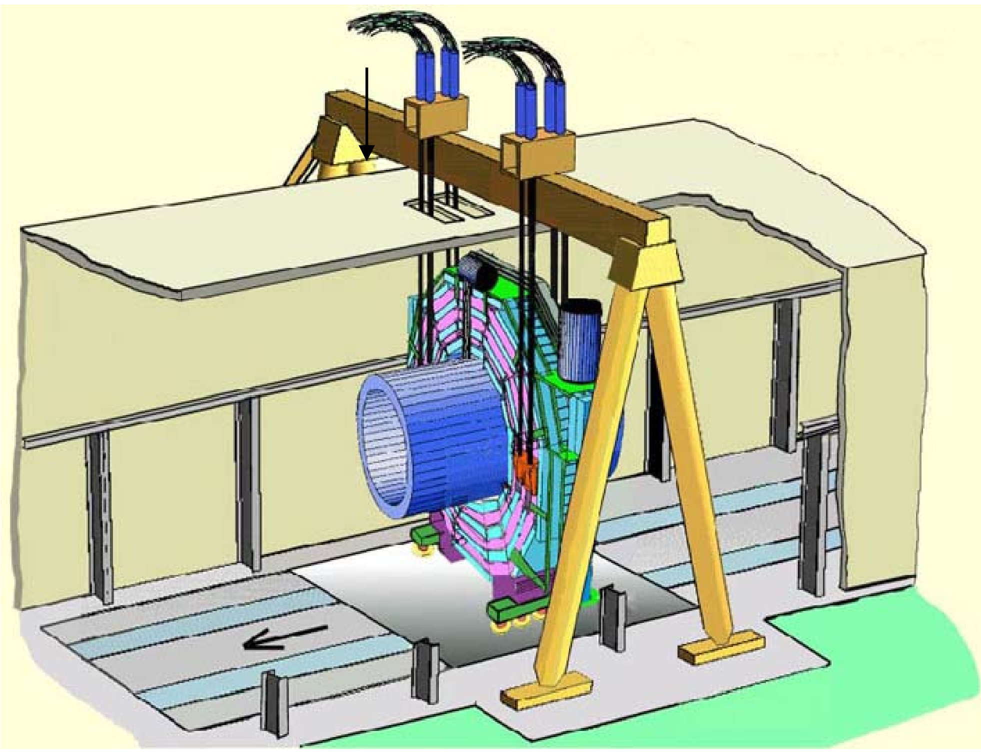
CMS: surface assembly

CMS yoke was ready in 2003

CMS: lowering of central wheel YB0

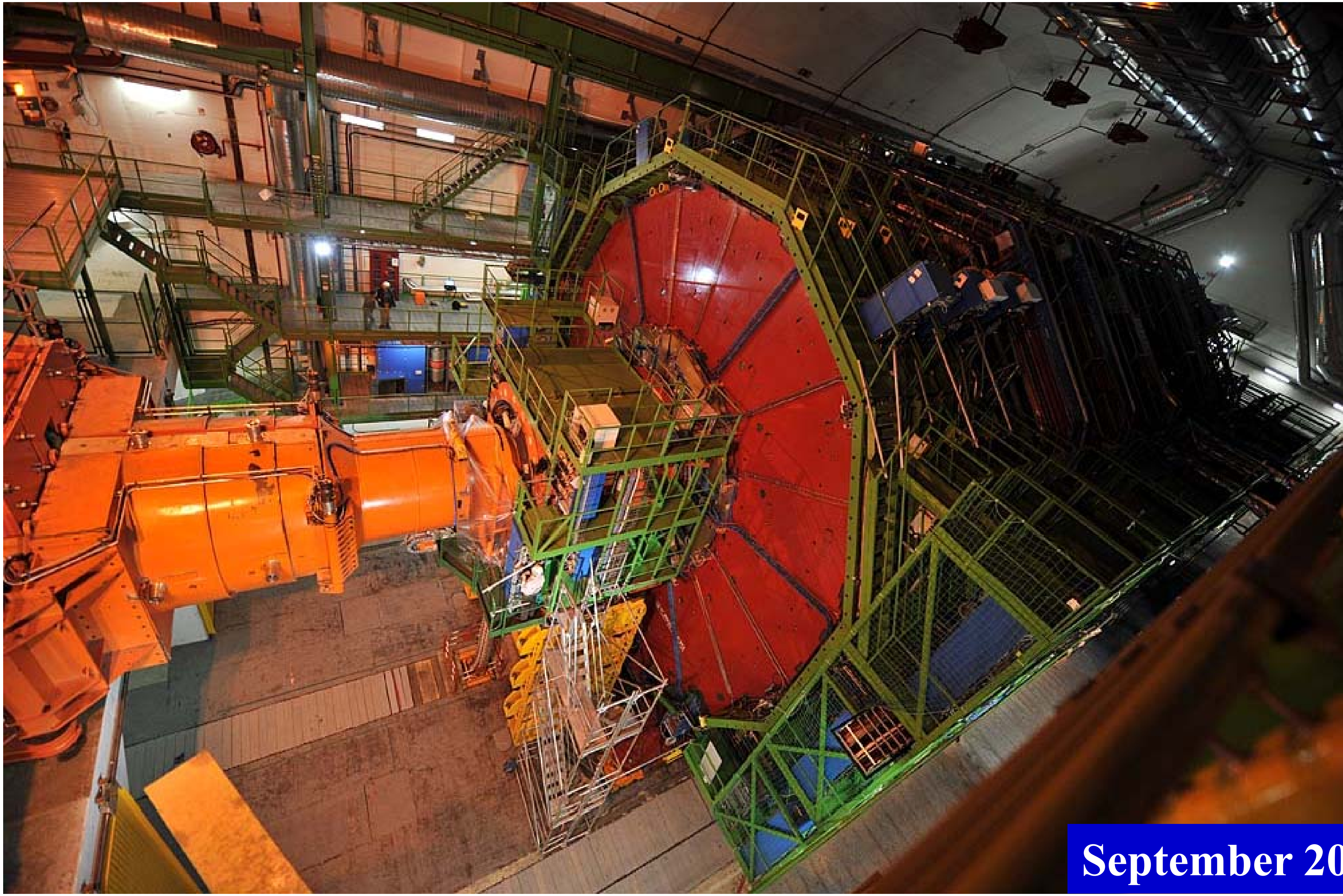
The central, heaviest slice (2000 tons) including the solenoid magnet lowered in the underground cavern in Feb. 2007

In total 15 slices were installed in this way



February 2007

CMS closed ready for beam!

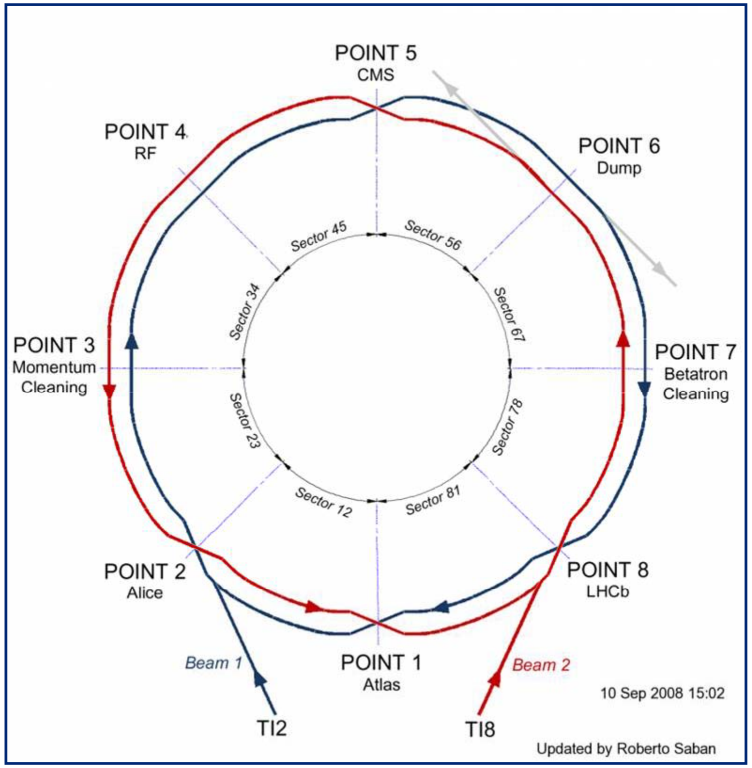


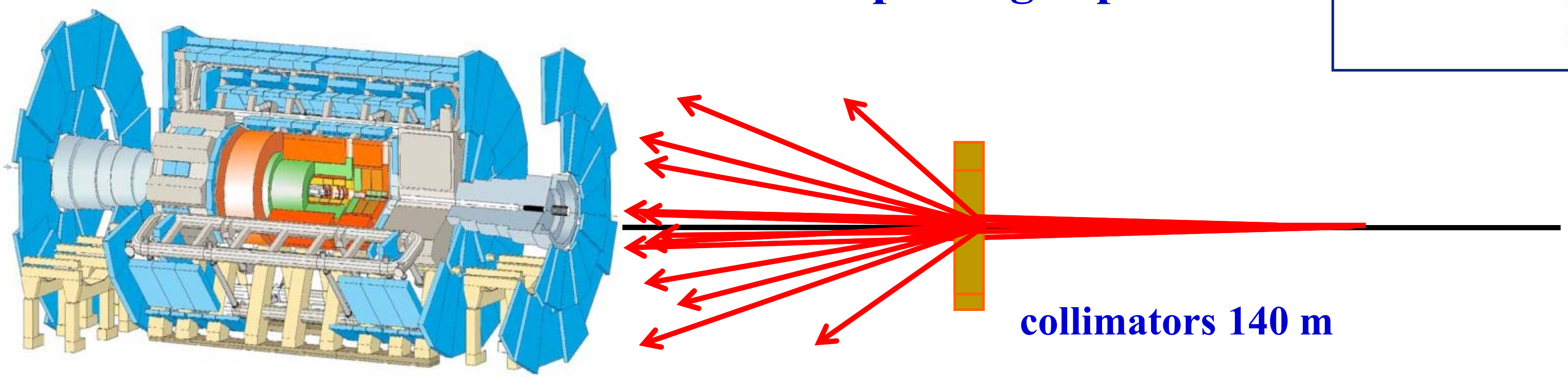
September 2008

First LHC Beam September 2008

After almost 20 years of design and construction the experiments started taking data with LHC beams

- **Sunday/Monday 7-8 September**
  Single shots of Beam 1 (clockwise via ALICE) onto collimator 150 m upstream of CMS, ~ 1 hour
- **Tuesday 9-September 2008**
  20 shots of Beam 1 onto collimator 150m upstream of CMS
- **Wednesday 10 September 2008**
  Nice splash events observed when beam onto collimators
  100-1000 TeV observed in the CMS/ATLAS calorimeters
  Halo muons observed once beam started passing experiments



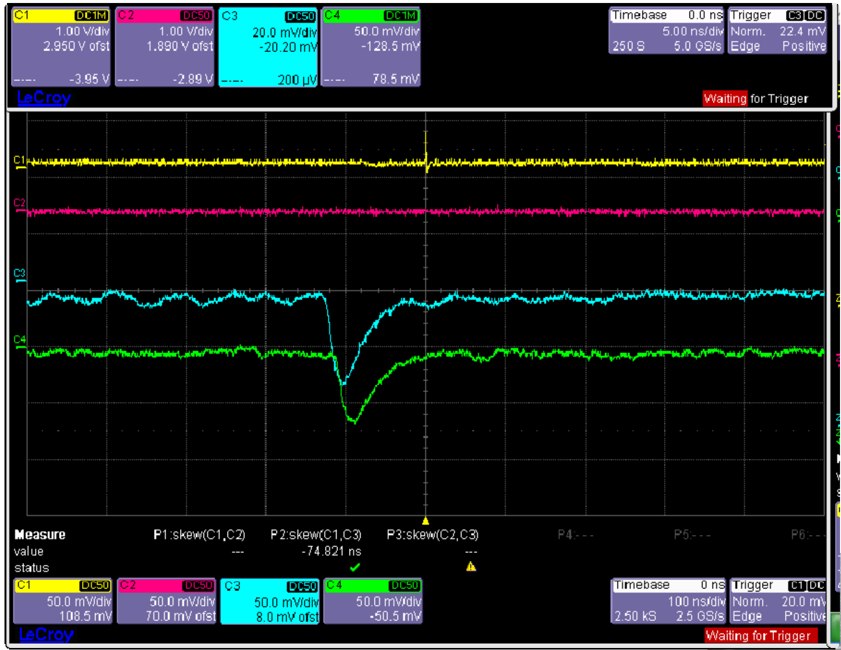


Beam splash events onto all four detectors

LHC Control Room: 10^{th} of Sept. 2008

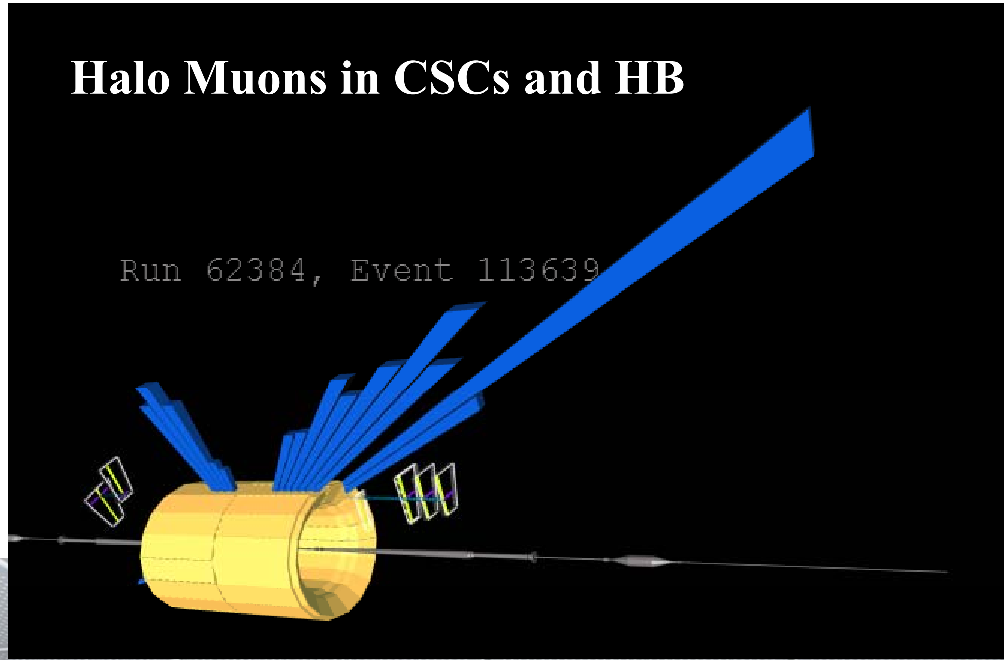
ATLAS Control Room: 10th of Sept. 2008

First Events: beam going through CMS



Beam Pickup (ch1) CMS Beam Condition Monitors (ch 3, 4)

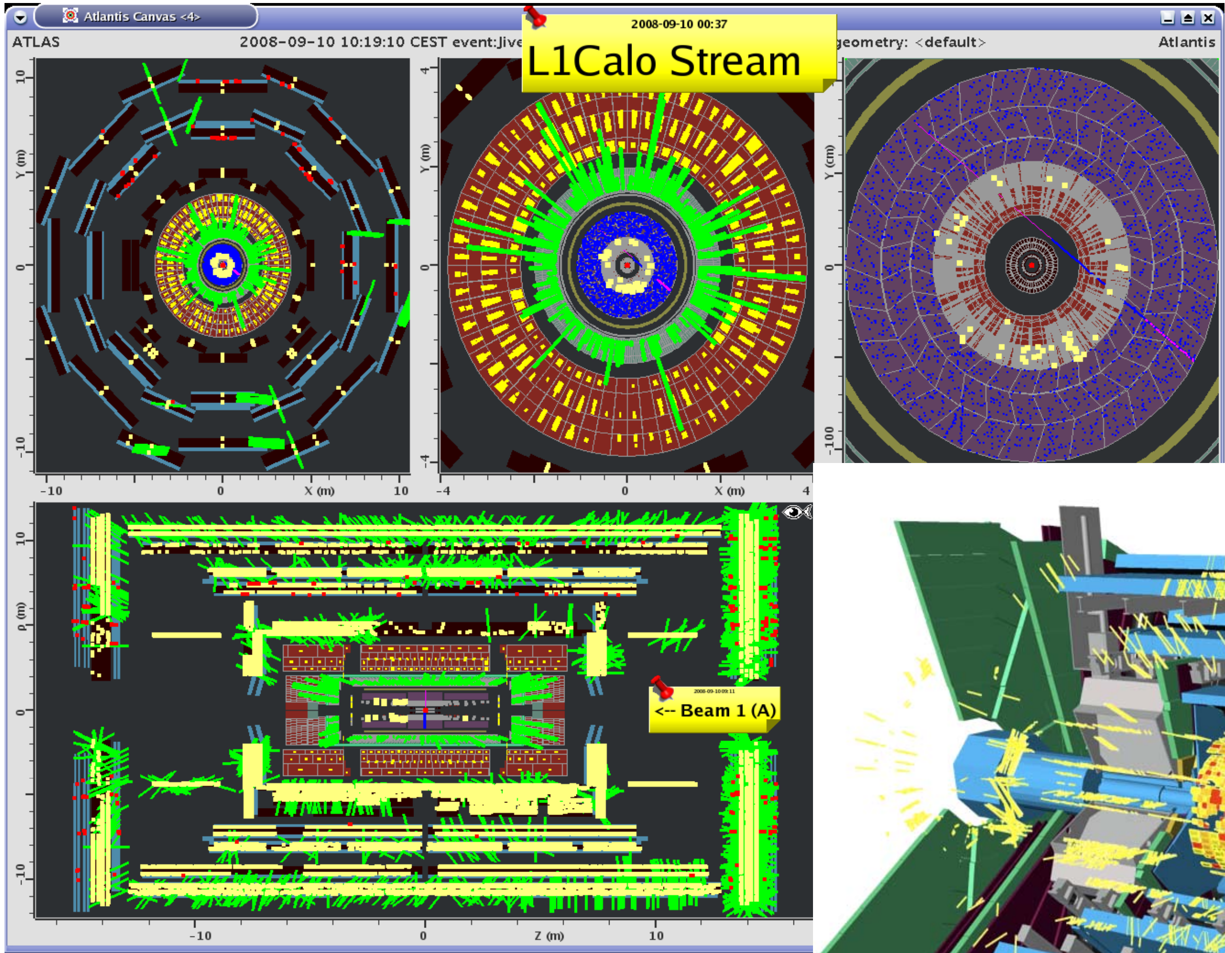
Halo Muons in CSCs and HB



Point 5 Control Room

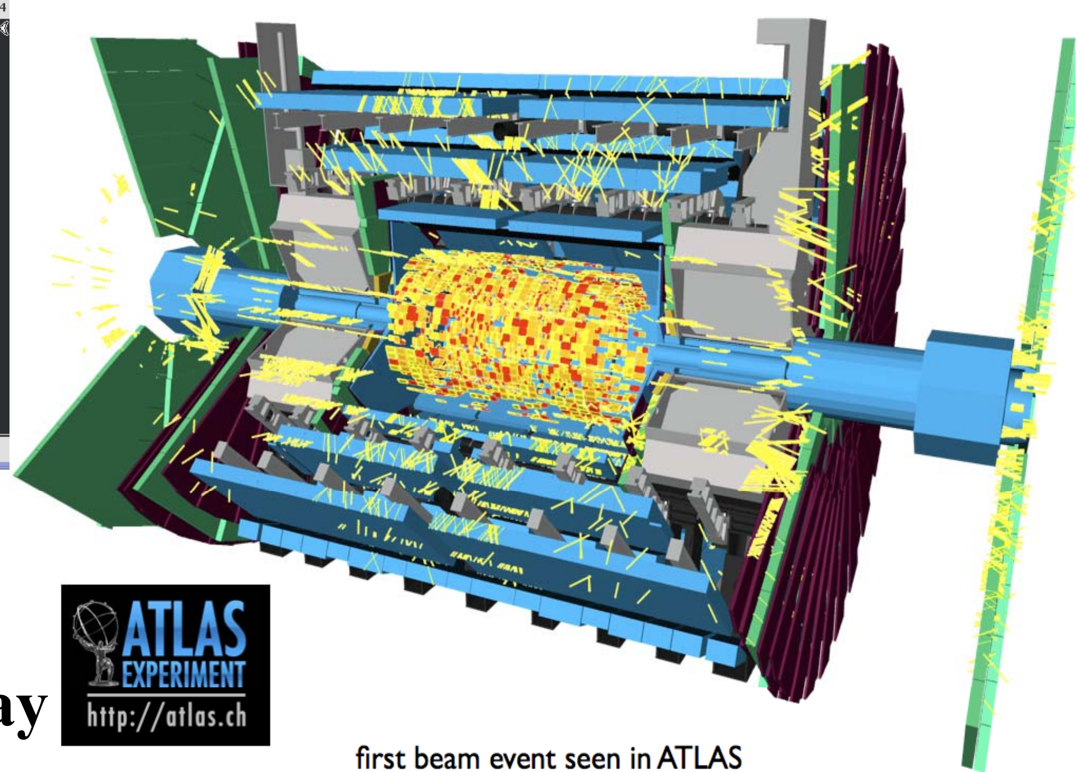
CMS Centre Meyrin

ATLAS: first events with collimators closed



The very first beam-splash event from the LHC in ATLAS at 10:19, 10th September 2008

Online display



first beam event seen in ATLAS

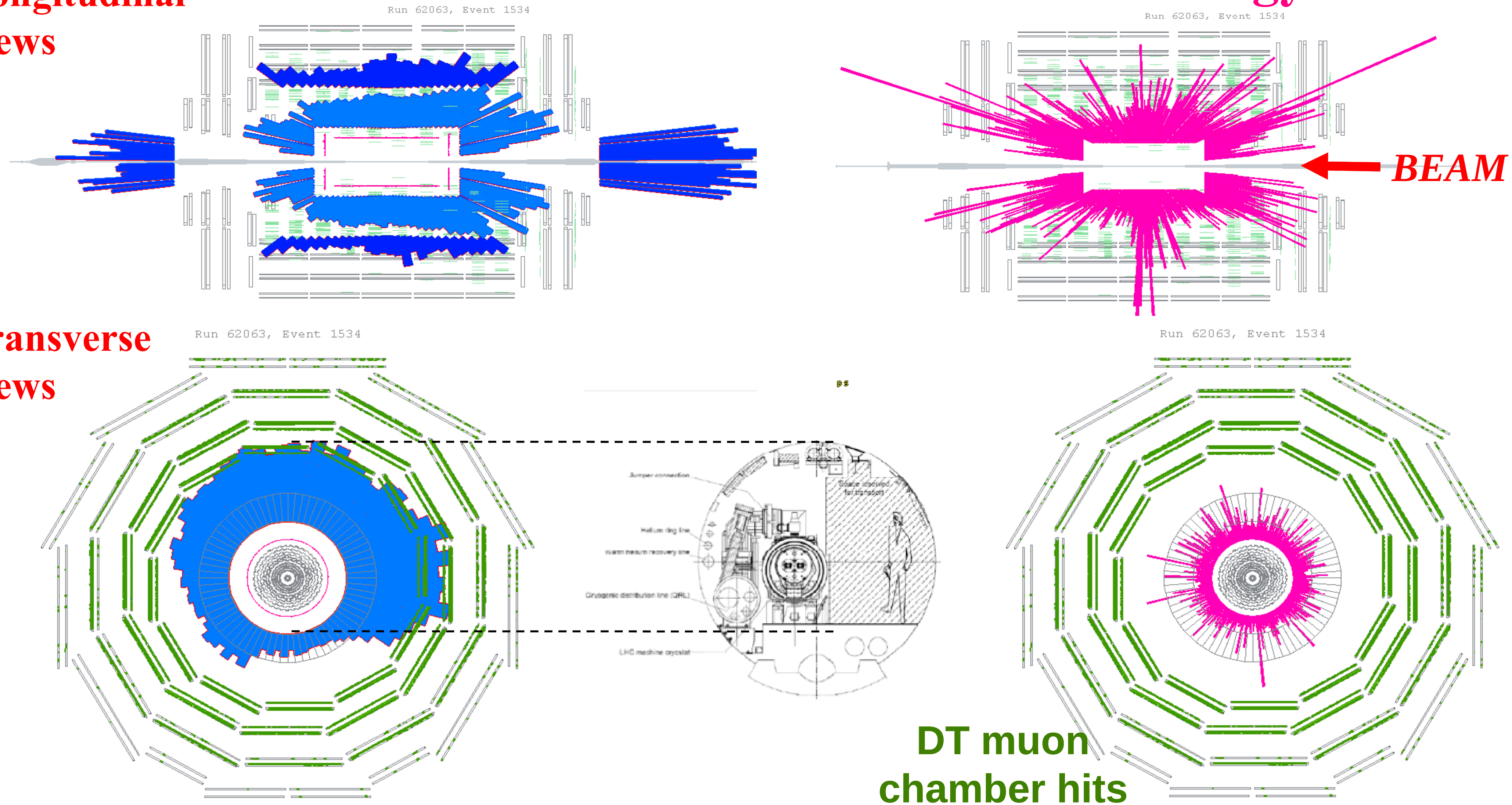
Offline display

CMS: first events with collimators closed beam-splash events

~2.10^9 protons on collimator ~150 m upstream of CMS

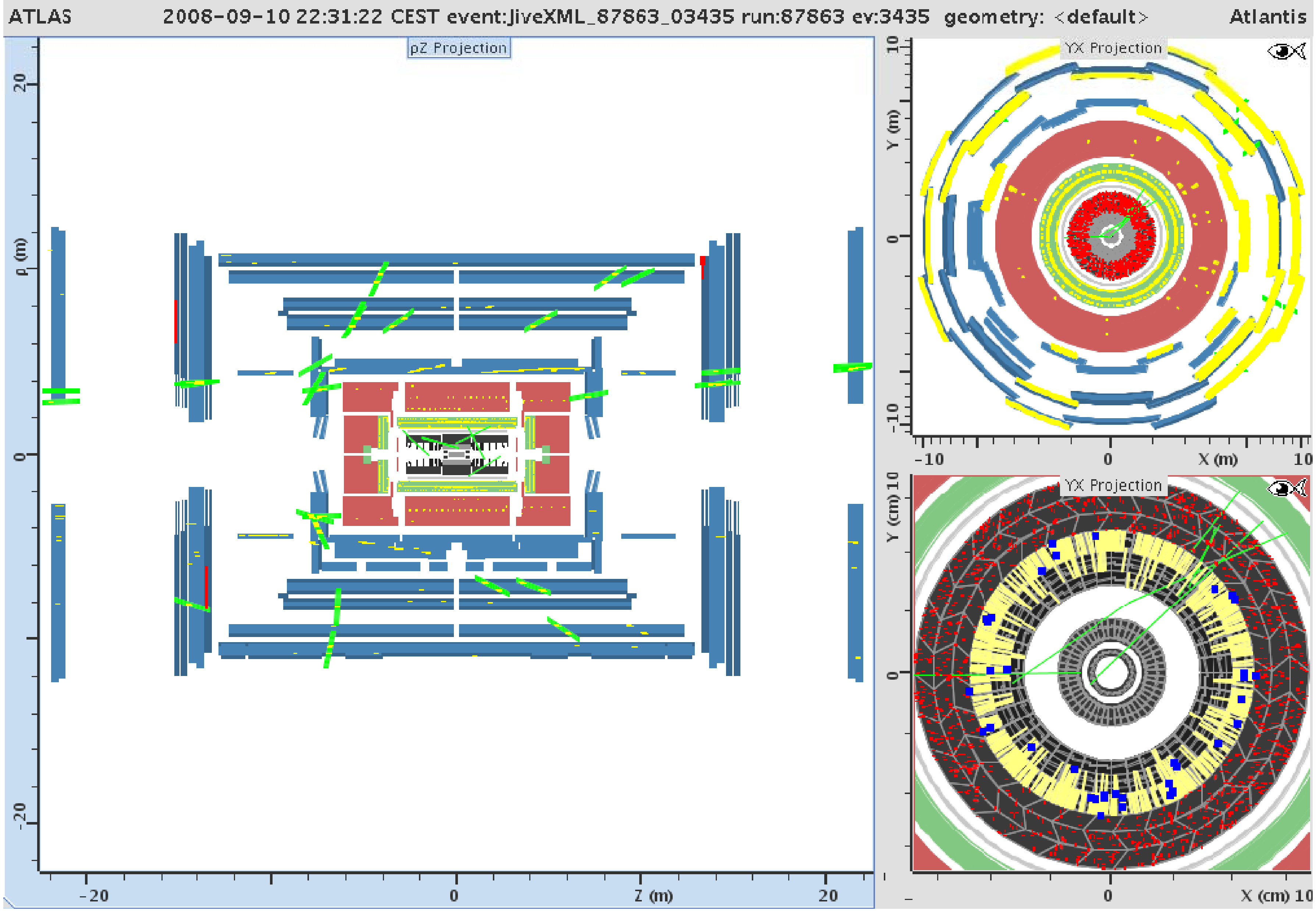
Longitudinal views — **HCAL energy** — **ECAL energy**

Transverse views



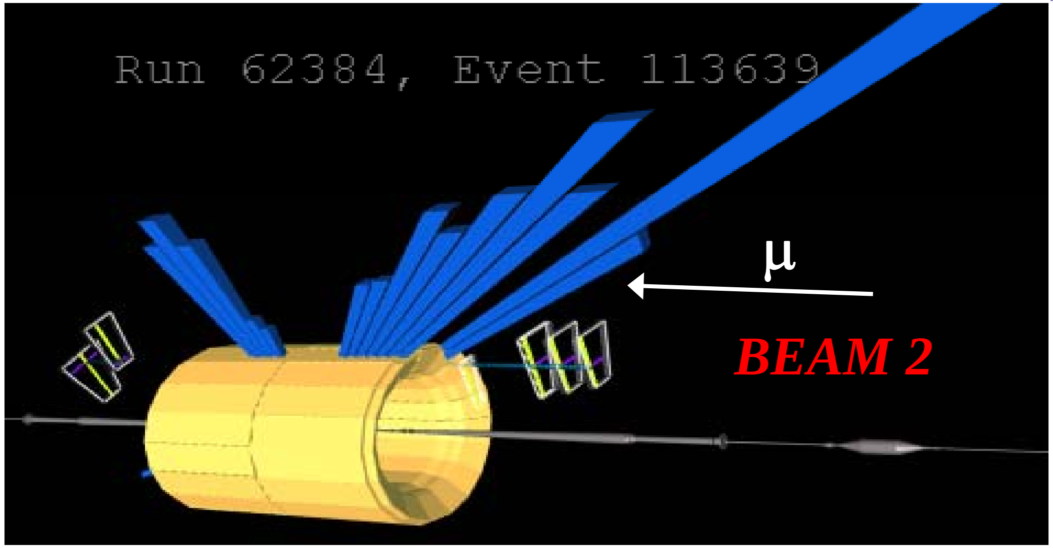
ATLAS: beam-halo event

A busy beam-halo event with tracks bent in the Toroids

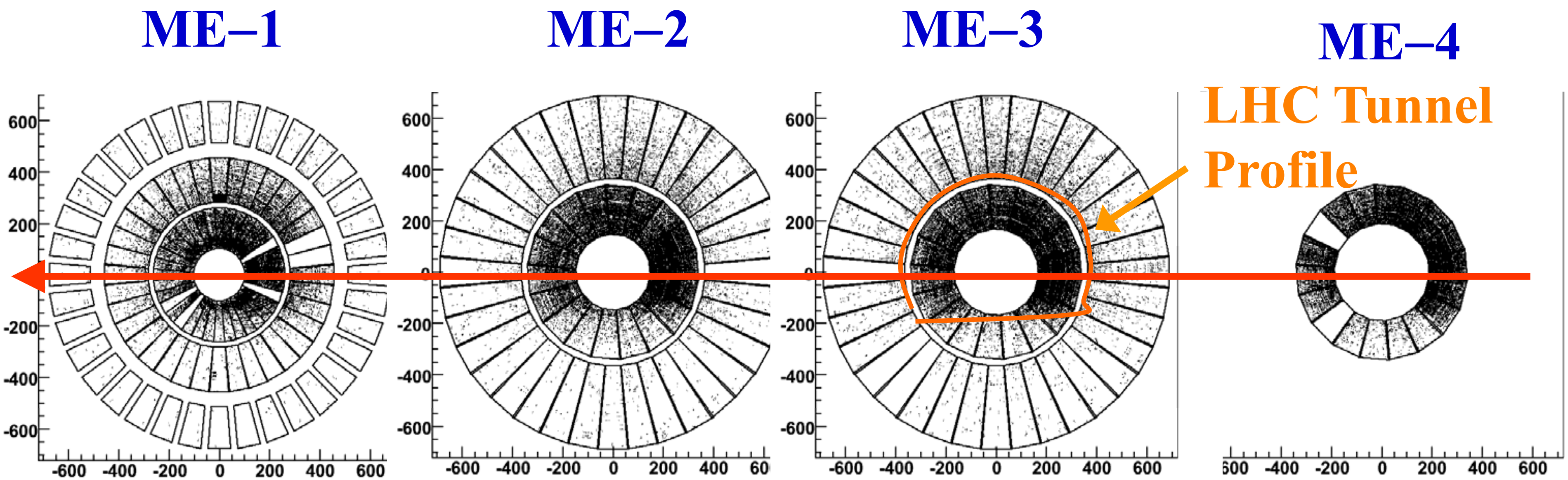


CMS: beam-halo events

Beam Halo: **Muons outside of beam-pipe, arising from decays of pions created when off-axis protons scrape collimators or other beamline elements**



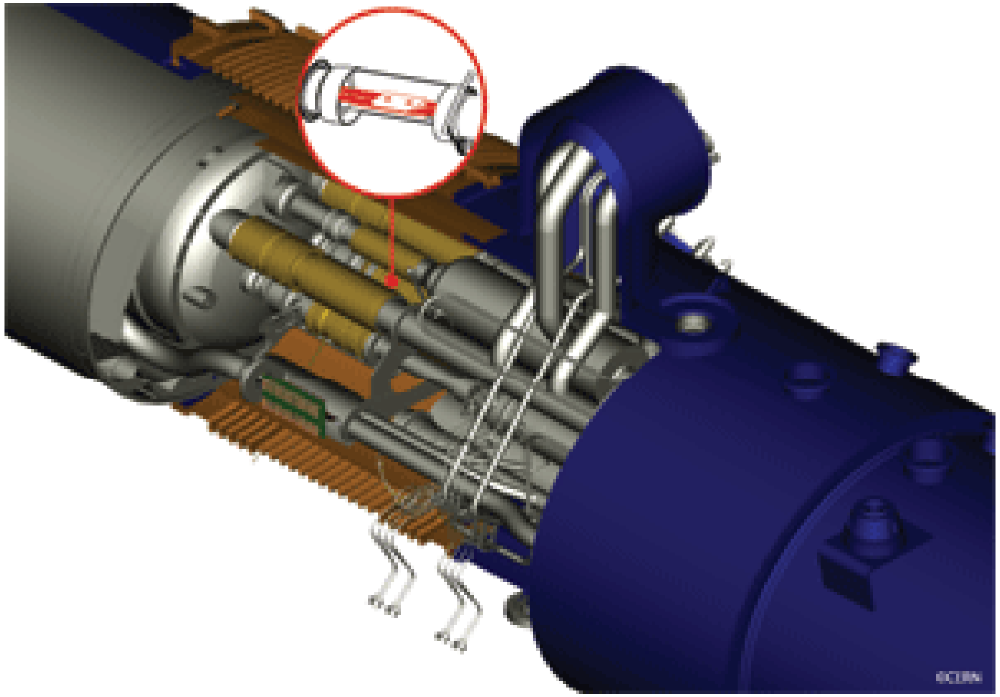
CSC Hit Distribution from Beam Halo Events

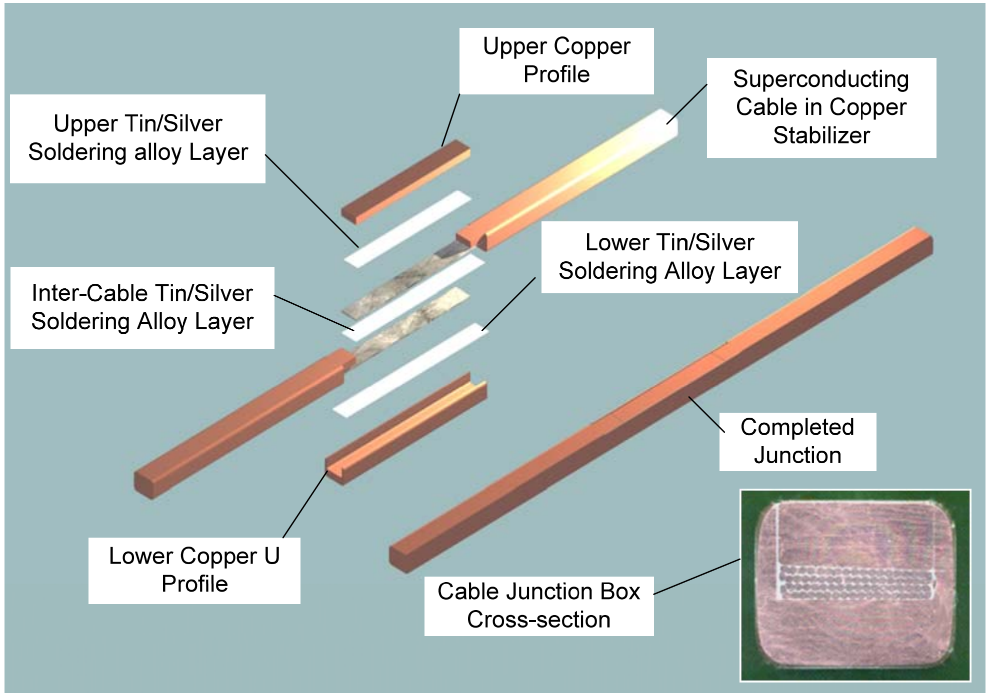


Incident 19th September 2008

- During commissioning of the last main bend circuit to 5 TeV and incident occurred resulting in the trigger of quench heaters of about 100 magnets and a large Helium discharge into the tunnel
- The 7 other octants of the LHC had been commissioned to 5 TeV (and well above) without problems

At 8.7 kA (corresponding to ~ 5.1 TeV), a resistive zone appeared in the superconducting busbar between quadrupole Q24 and the neighboring dipole (probably due to a bad welding 'splice')

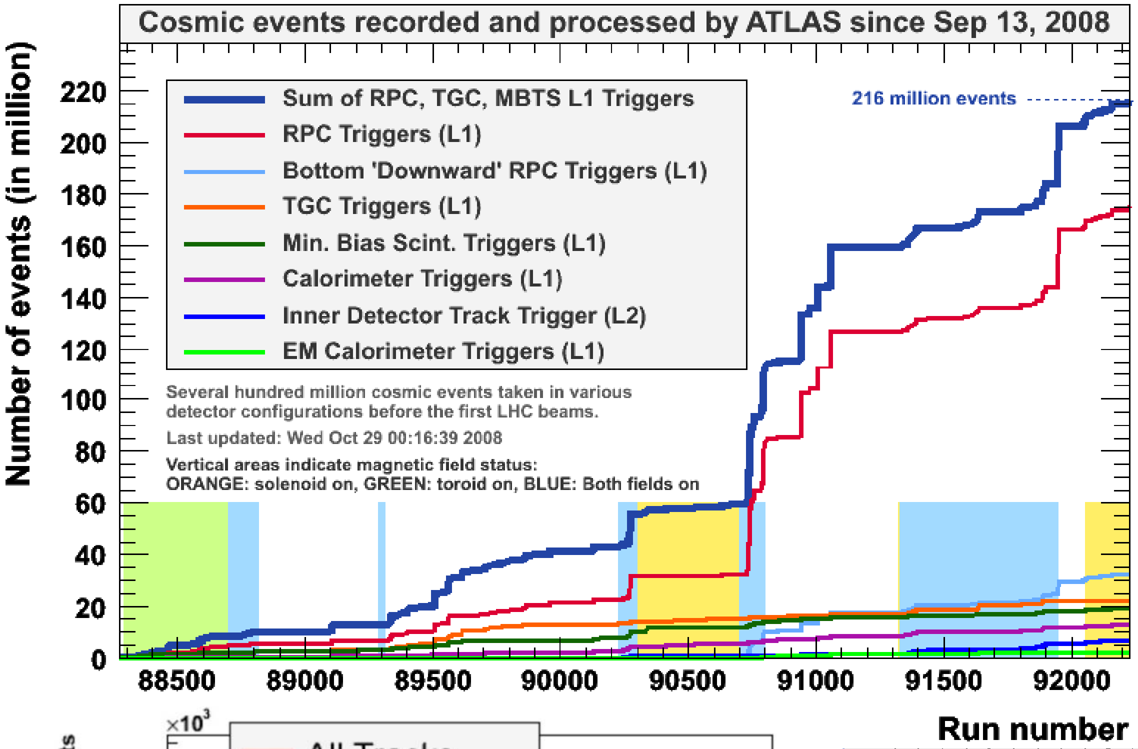


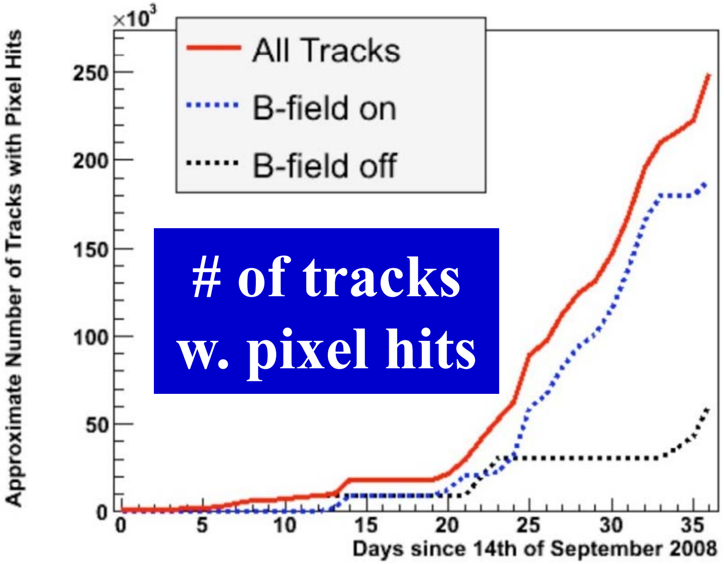


Interconnection of two LHC magnets

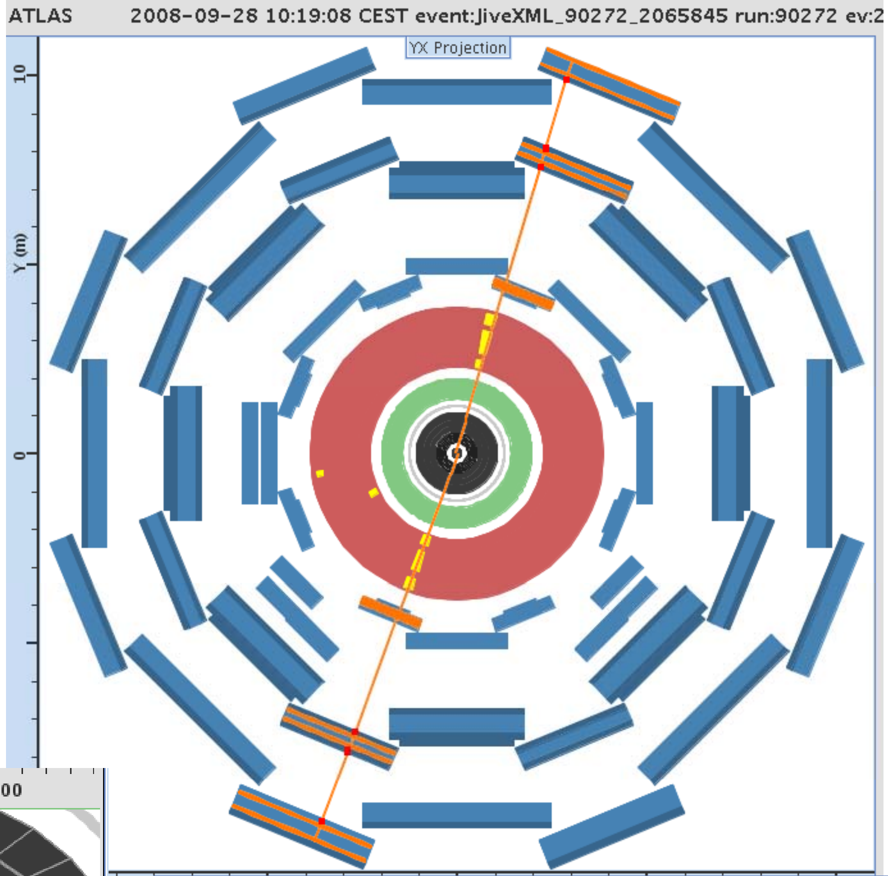
ATLAS: Cosmic Runs after LHC incident

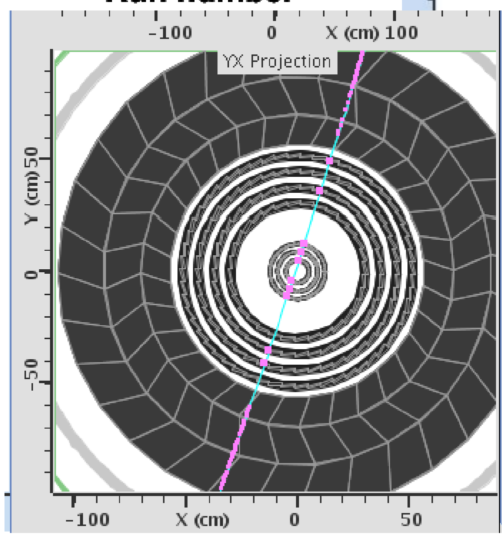
of cosmic triggers

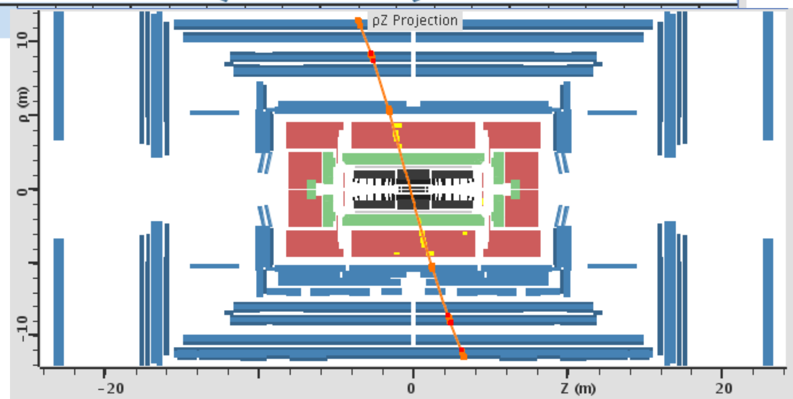




of tracks w. pixel hits



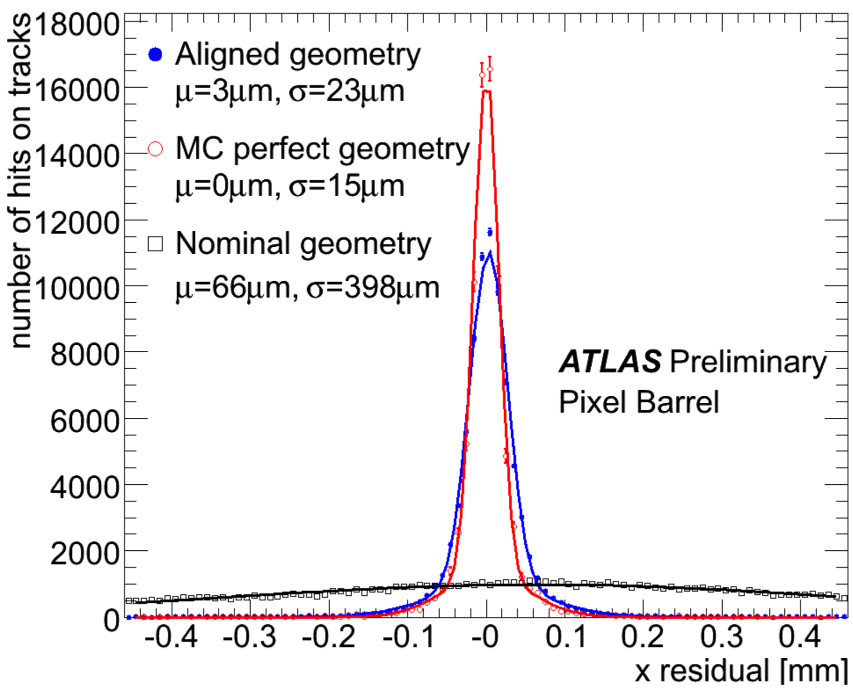


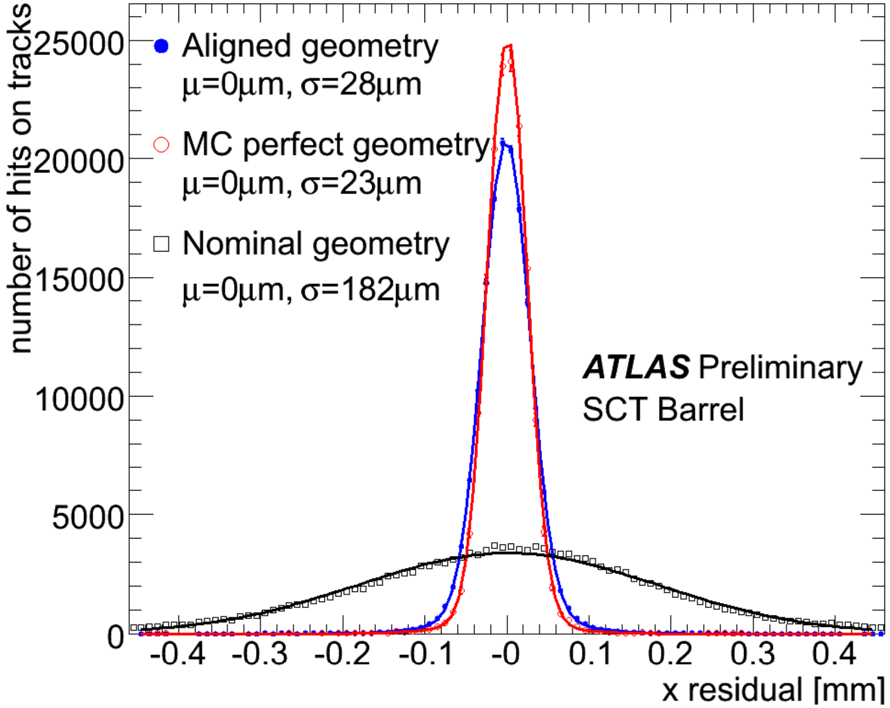


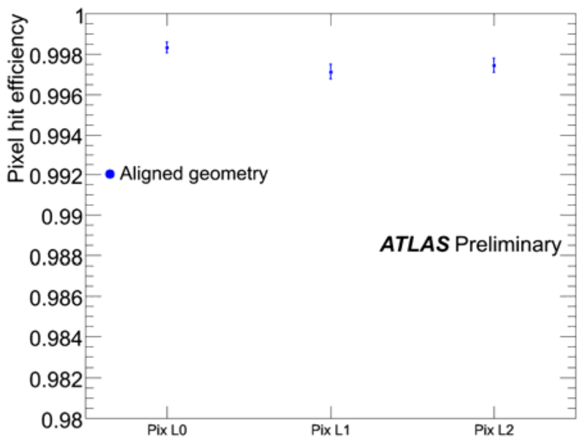
ATLAS Commissioning with cosmics: tracker alignment/hit efficiency

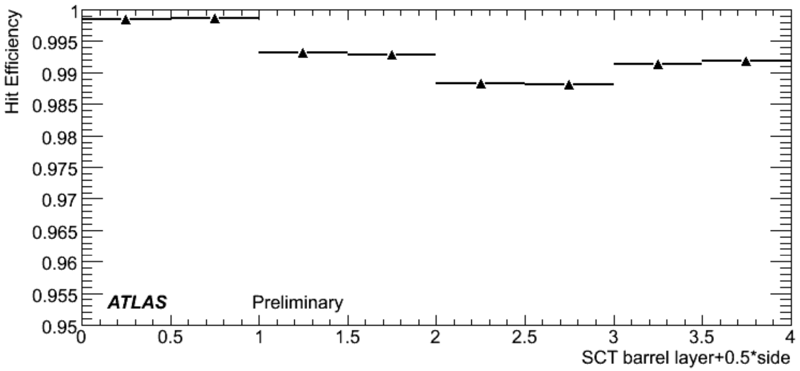
Pixels/Silicon alignment with cosmics

Achieved precision ~ 25 µm

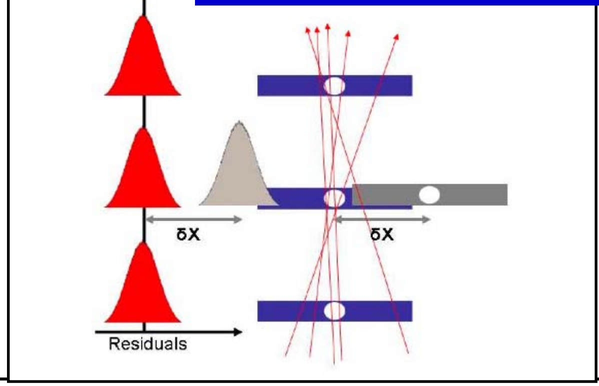




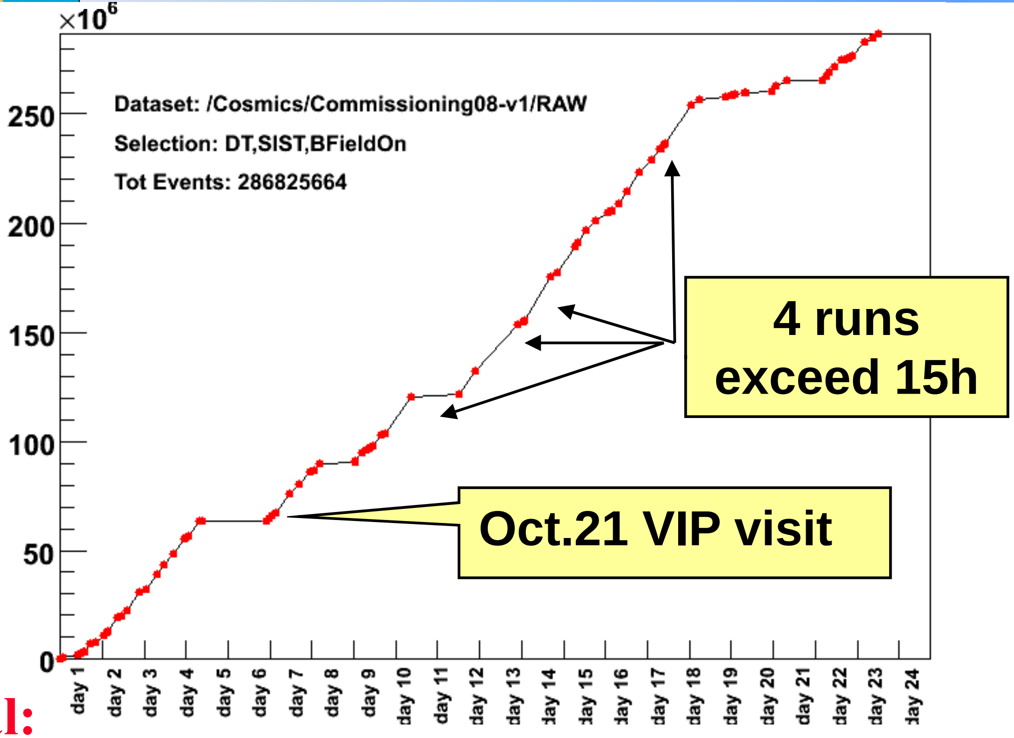


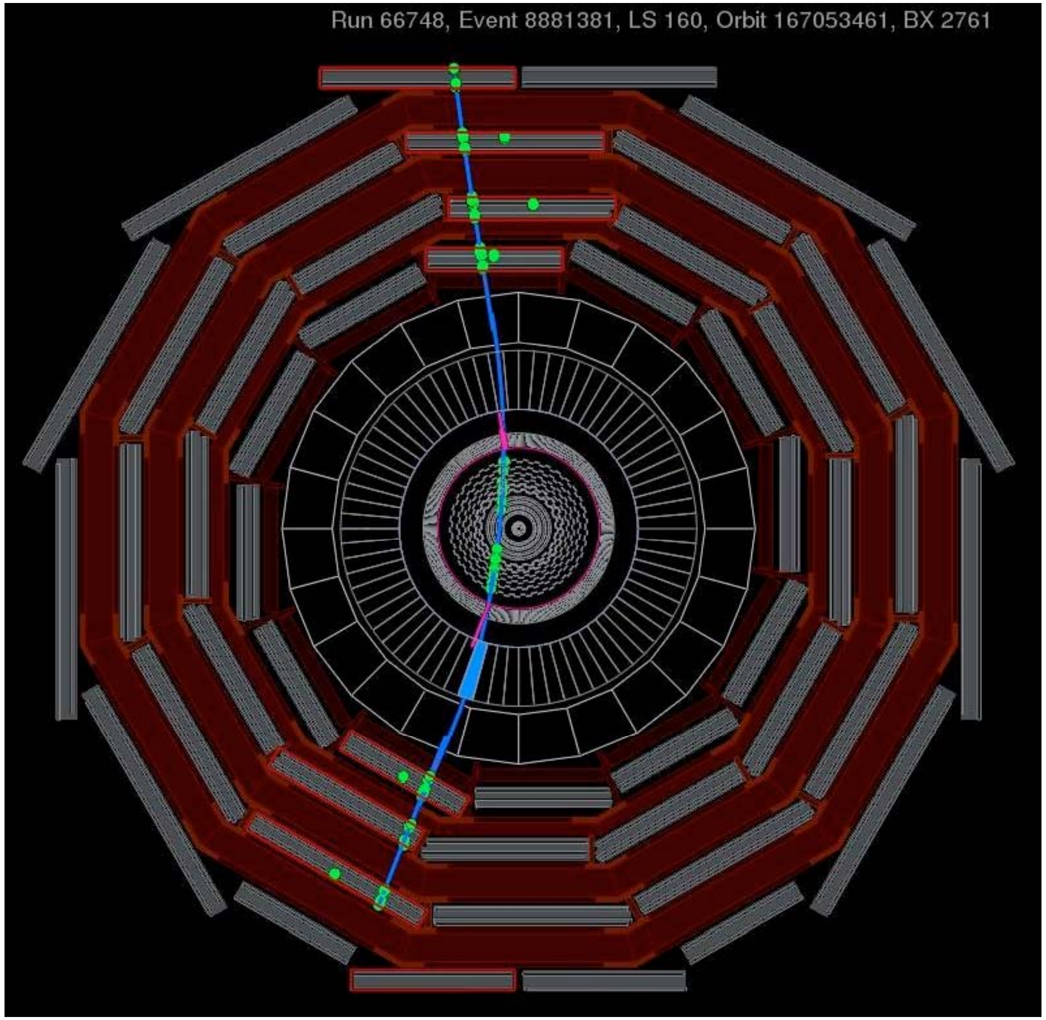


Residuals: distance between fitted track & hits in individual layers



CRAFT: CMS Cosmic Run @ 4 Tesla





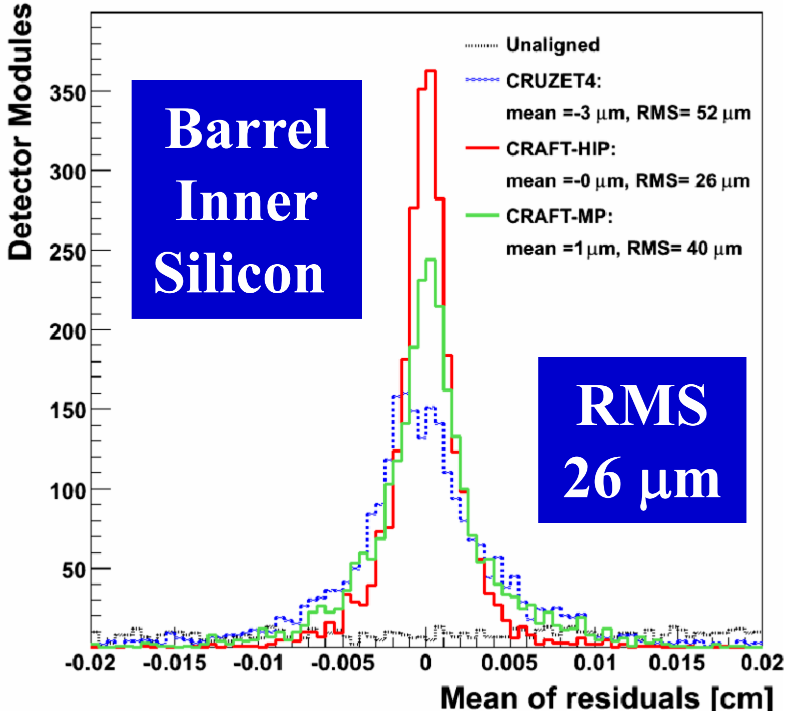
Goal:

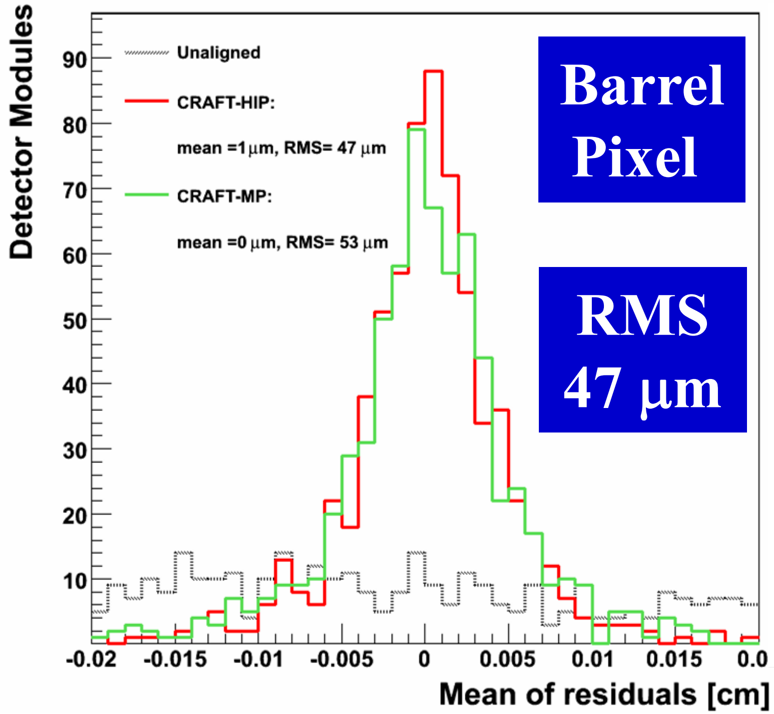
- Run CMS for 4 weeks continuously to further gain operational experience
- Study effects of B field on detector components
- Collect 300M cosmic events w. tracking detectors

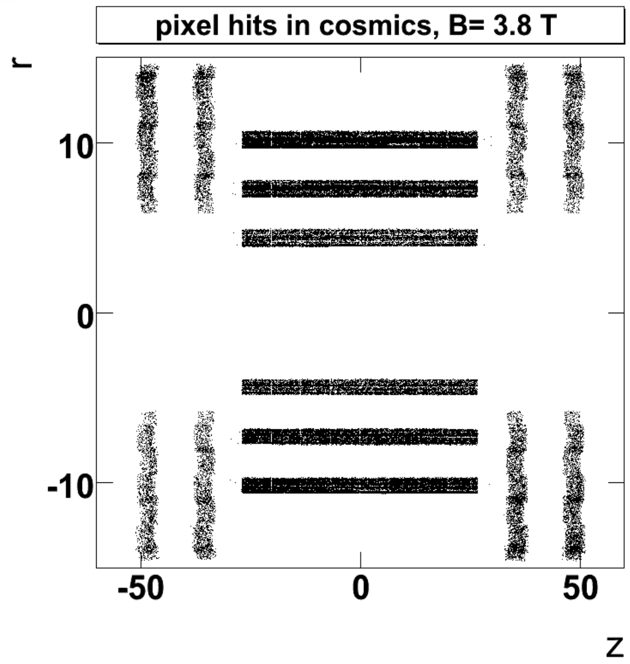
Facts:

- Ran 4 weeks continuously from 13-Oct to 11-Nov 2008: 19 days with B=3.8T
- 370M cosmic events collected in total
- 290M with B=3.8T and with strip tracker and DT in readout: 194M with all components in

CMS Commissioning with cosmics: tracker alignment

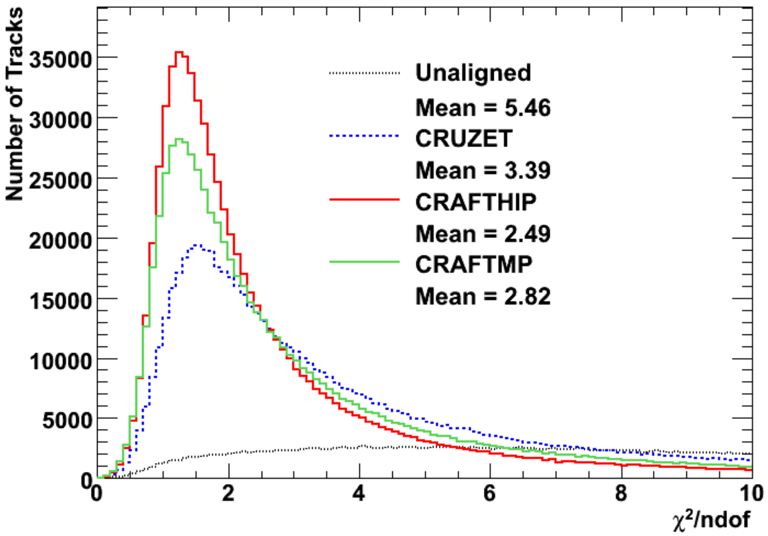






Pixel Occupancy

Mean of the residual distribution per sensor: sensitive to module displacements



Using 4M tracks for alignment & 1M for validation

- Unaligned: nominal geometry
- CRUZET: geometry obtained from B=0T runs using Hits and Impact Point method and survey constraints
- CRAFTHIP: geometry obtained from Hits and Impact Point algorithm on CRAFT data, including survey constraints
- CRAFTMP: geometry obtained from Millepede algorithm on CRAFT data

Conclusion Chamonix 2009 Meeting

- Conclusion 5 TeV/beam for Physics for 2009/2010 run
- Machine Protection will be tested with beam (at 0.5 TeV energy levels)
- 4 TeV "on the way" to 5 TeV

Steve Myers (LHC Coordinator)

- Estimated integrated luminosity
  - during first 100 days of operation.. $\approx 100 pb^{-1}$
    - Peak L of 5.10^{31} η (overall) = 10% gives $0.5 pb^{-1}$/day
    - Peak L of 2.10^{32} η (overall) = 10% gives $2.0 pb^{-1}$/day
  - During next 100 days of operation.. $\approx 200 pb^{-1}$?
- Then towards end of year ions (to be planned in detail soon)

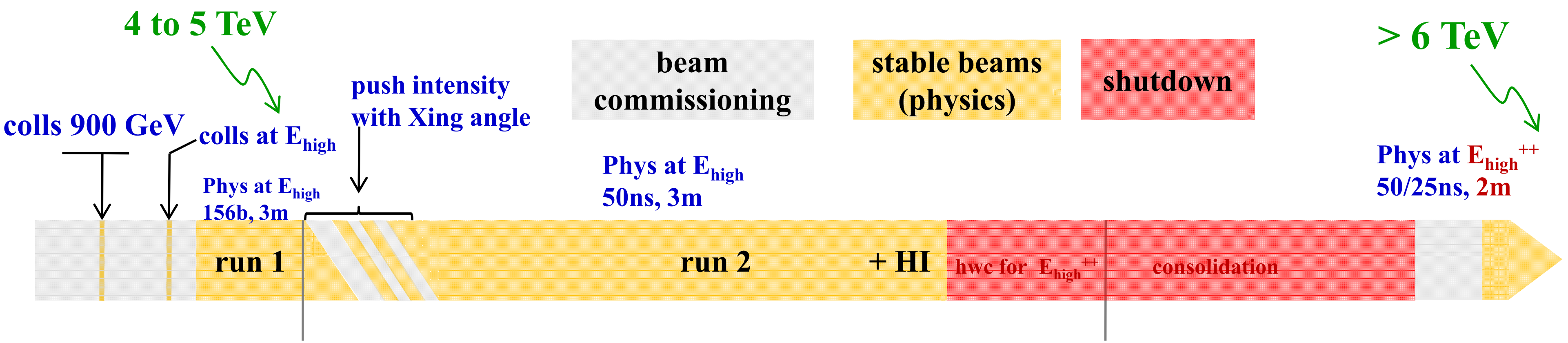
LHC Running Schedule 2009-2010

Gains 20 weeks of LHC physics (independent of "slip")

Year	2009											2010														
Month	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
Baseline	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH		SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	SH	SH	SH	SH
	24 weeks physics possible																									
Base '	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	SH	SH	SH	SH	SH	SH
	44 weeks physics possible																									
Delay (4W)	SH	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	SH	SH	SH	SH	SH
Delay (8W)	SH	SH	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	SH	SH	SH	SH

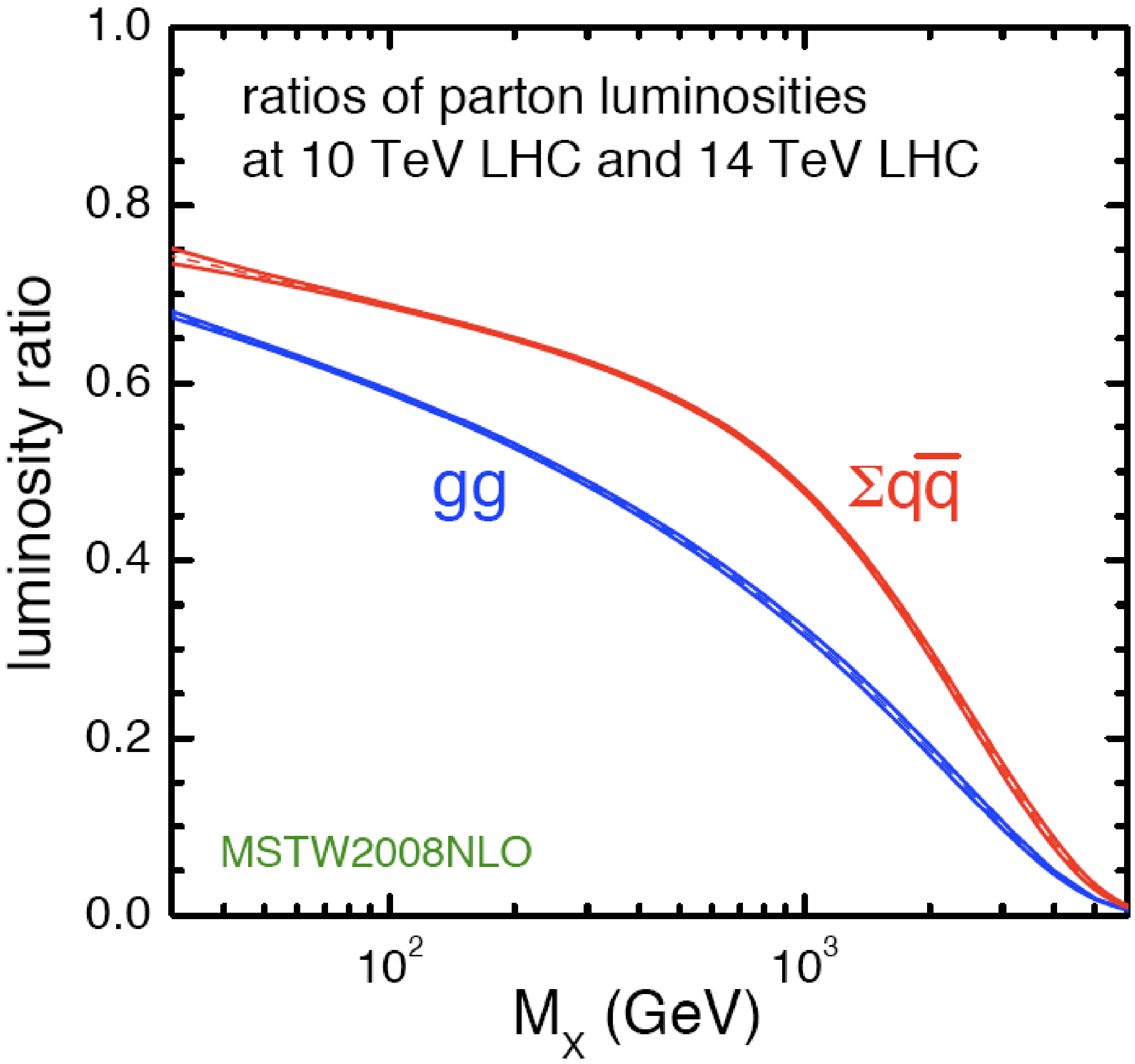
Gain 20 weeks of physics in 2010 by running during winter months

HIGH price Electricity



Parton Luminosities at 10 and 14 TeV

Ratios of cross-sections at 10/14 TeV for processes induced by gg and qq



At 10 TeV

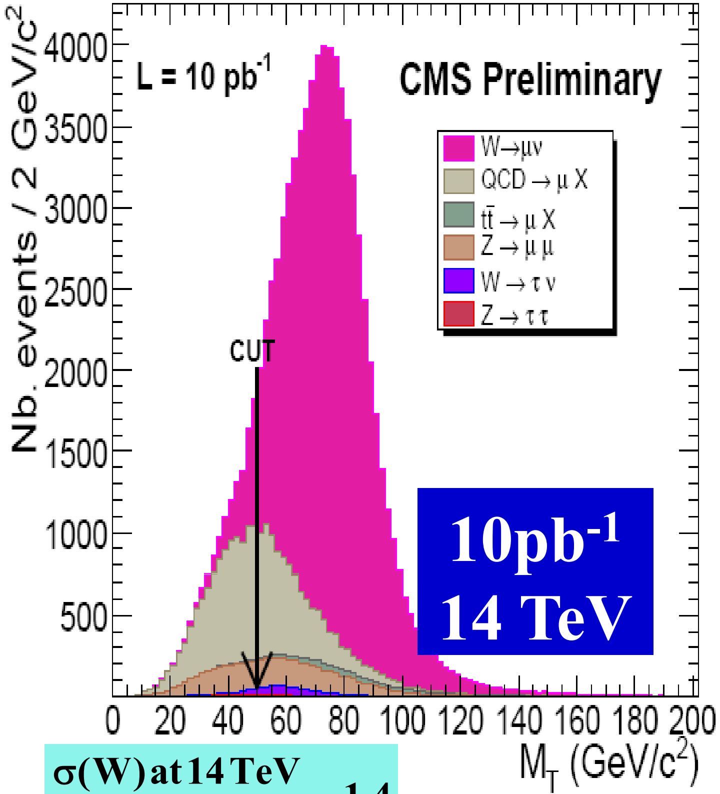
More difficult to produce high mass objects

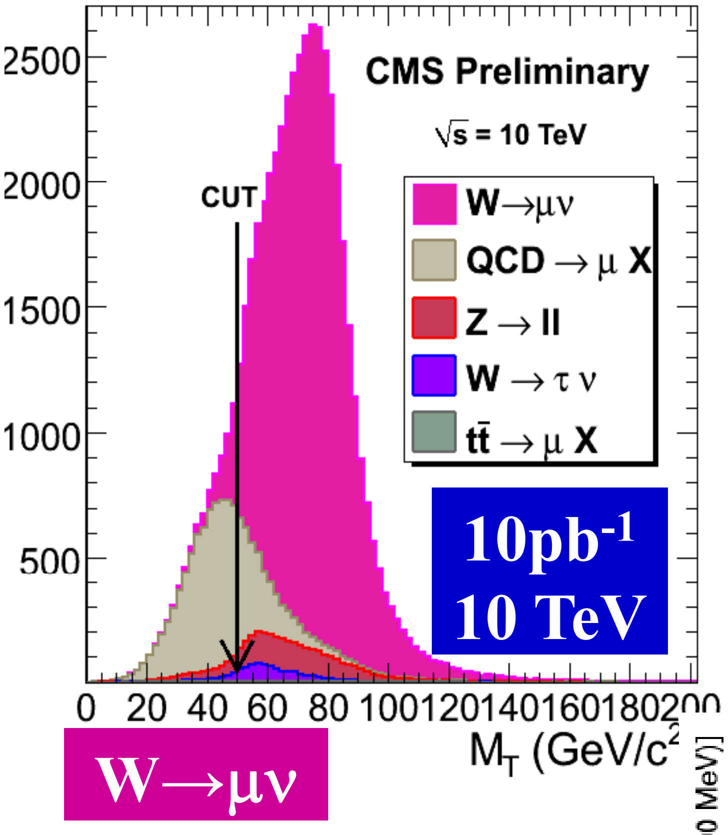
< 300 GeV the suppression is <50% (process-dependent)

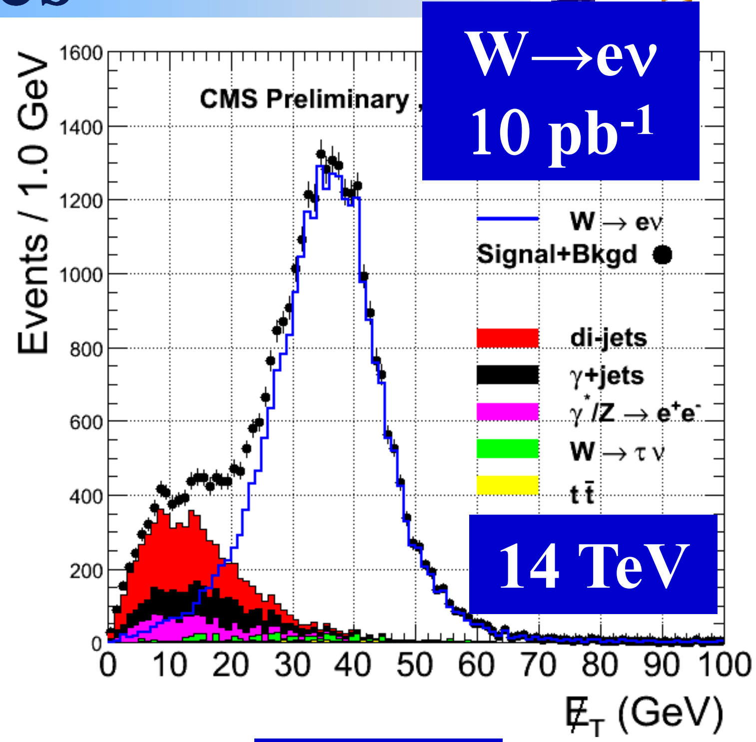
eg. tt cross section is a factor 2 lower

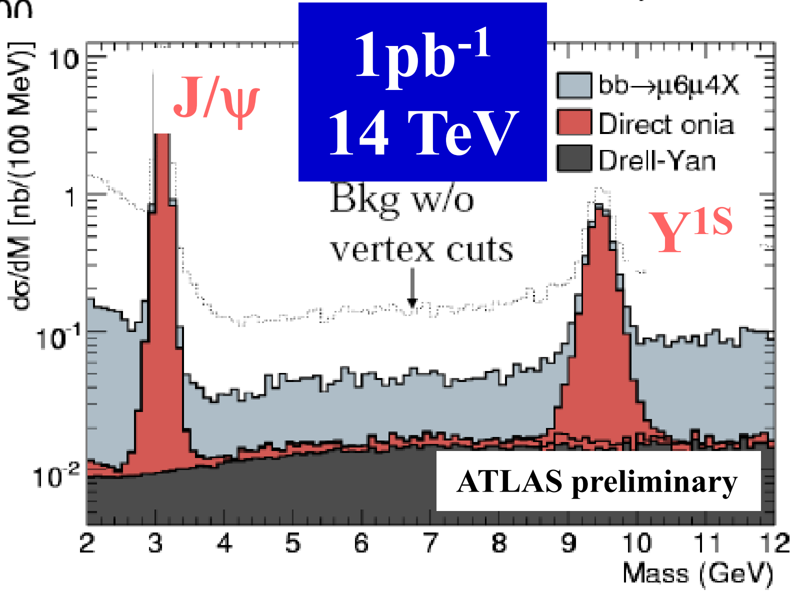
Above ~1 TeV effects more marked

Standard Model Candles: W boson/resonances







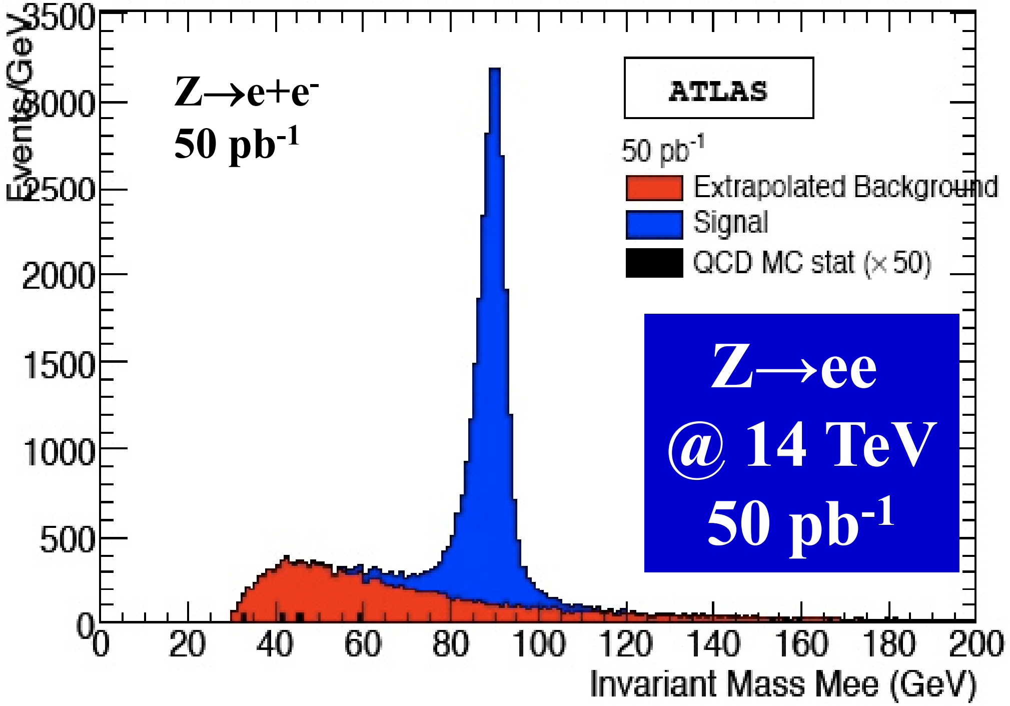


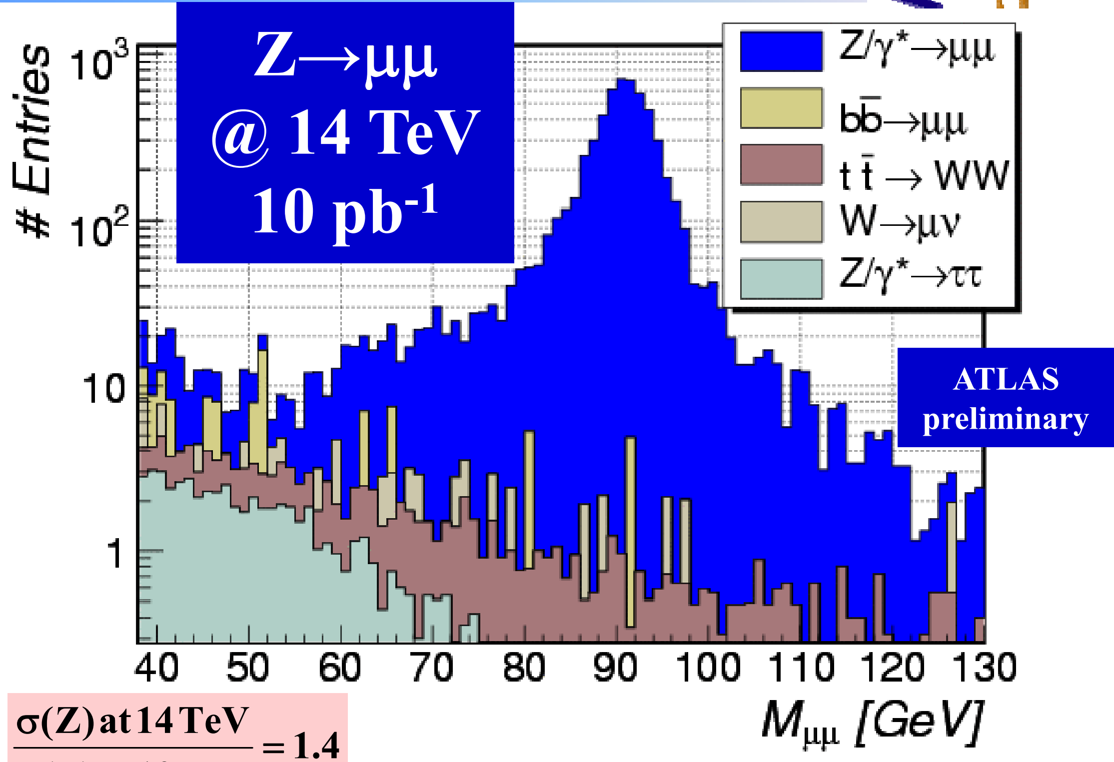
$$\frac{\sigma(W)\,\text{at}\,14\,\text{TeV}}{\sigma(W)\,\text{at}\,10\,\text{TeV}} = 1.4$$

Standard Model Candles

- tracker momentum scale, trigger performance, detector efficiency, sanity checks, …
- Muon Spectrometer alignment, ECAL uniformity, energy/momentum scale of full detector, lepton trigger and reconstruction efficiency

Standard Model Candle: Z boson





$$\frac{\sigma(Z)\,\text{at}\,14\,\text{TeV}}{\sigma(Z)\,\text{at}\,10\,\text{TeV}} = 1.4$$

- 25k $Z \rightarrow ee$ with 50 pb^{-1} at 14 TeV

Precision σ ($Z \rightarrow ee$) ~ 4-5%

ATLAS

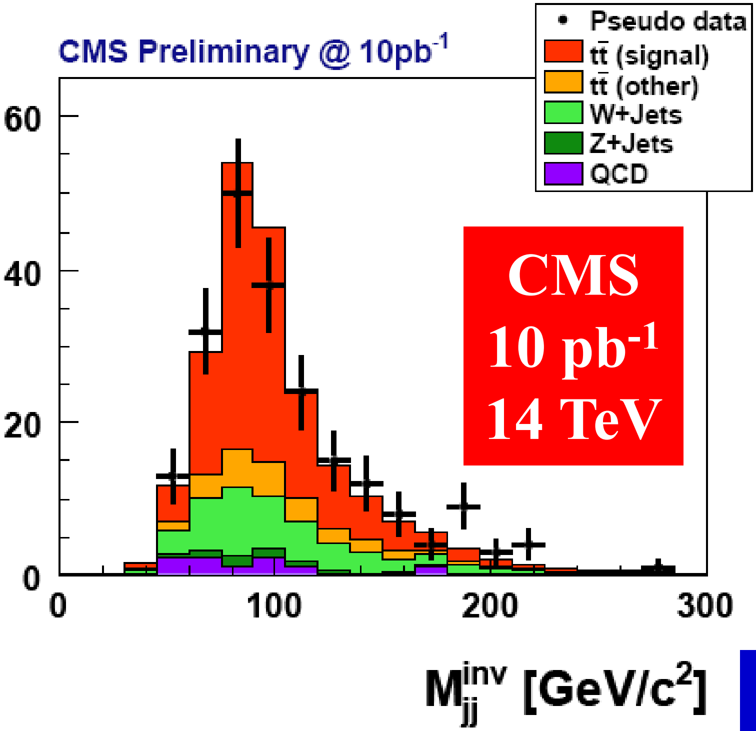
- $Z \rightarrow \mu\mu$ with 100 pb^{-1} at 14 TeV

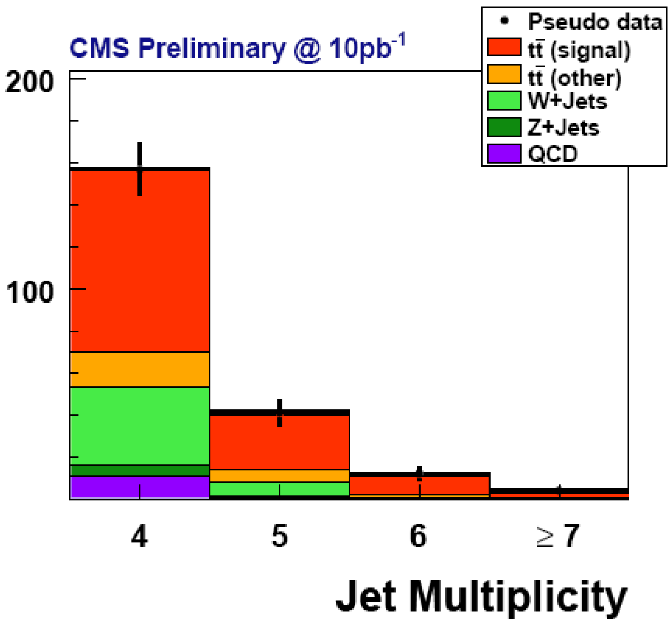
Precision σ ($Z \rightarrow \mu\mu$) <2% (exp), ~10% (lumi)

CMS Sizeable sample of $Z \rightarrow \mu\mu$ events expected in early 10 TeV data: useful in detector understanding & calibration

CMS	# of Events 10 pb^{-1} @ 14 TeV	# of Events 10 pb^{-1} @ 10 TeV
$Z \rightarrow \mu\mu$	5197	4390
$W \rightarrow \mu\nu$	0	0
ttbar	17	7
QCD	6	3

Top physics: semileptonic channel





muon semileptonic channel

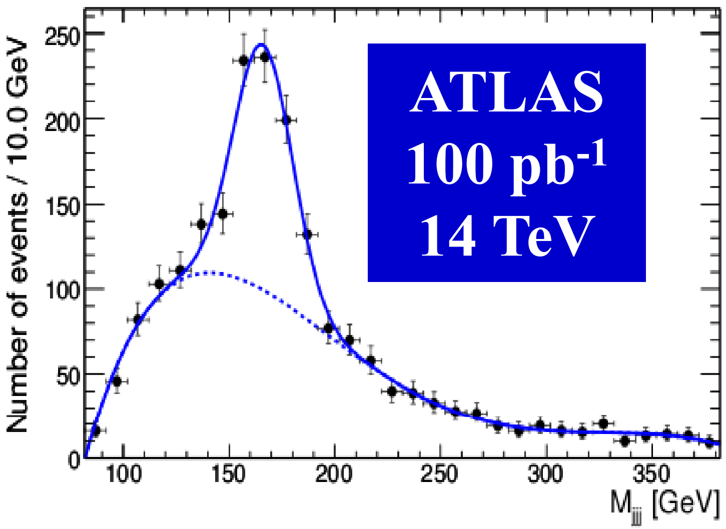
CMS	# of Events 10 pb^{-1} @ 14 TeV	# of Events 10 pb^{-1} @ 10 TeV
ttbar	153	45
W	67	32

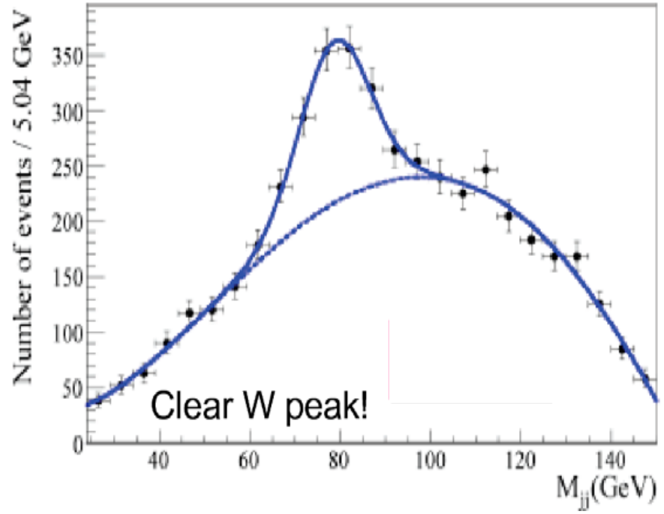
PYTHIA

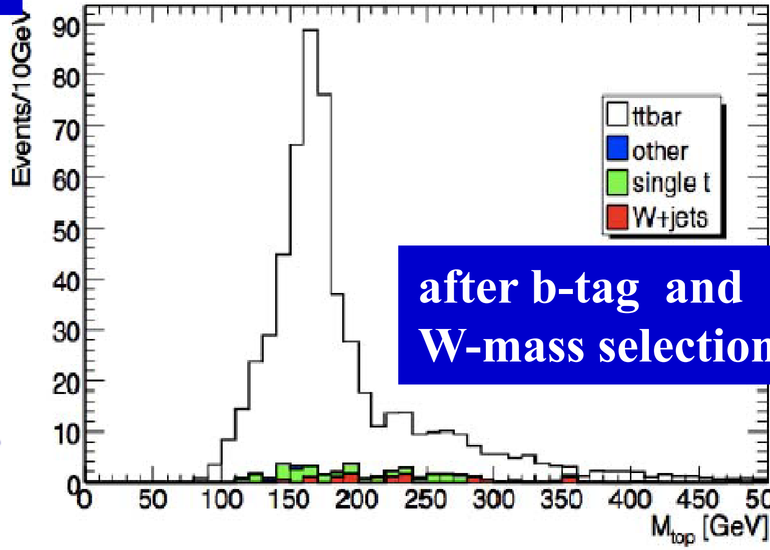
$$\frac{\sigma(t\bar{t})\,\text{at}\,14\,\text{TeV}}{\sigma(t\bar{t})\,\text{at}\,10\,\text{TeV}} = 2.3$$

$$\frac{\sigma(W)\,\text{at}\,14\,\text{TeV}}{\sigma(W)\,\text{at}\,10\,\text{TeV}} = 1.4$$

tt → Wb Wb → ℓνb qqb

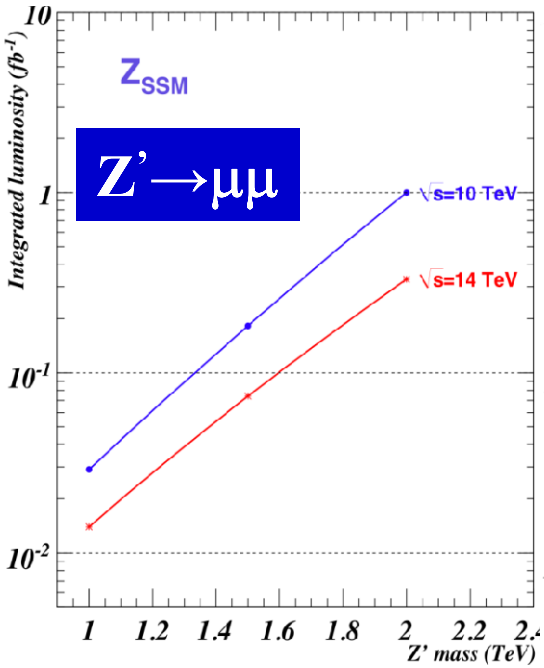


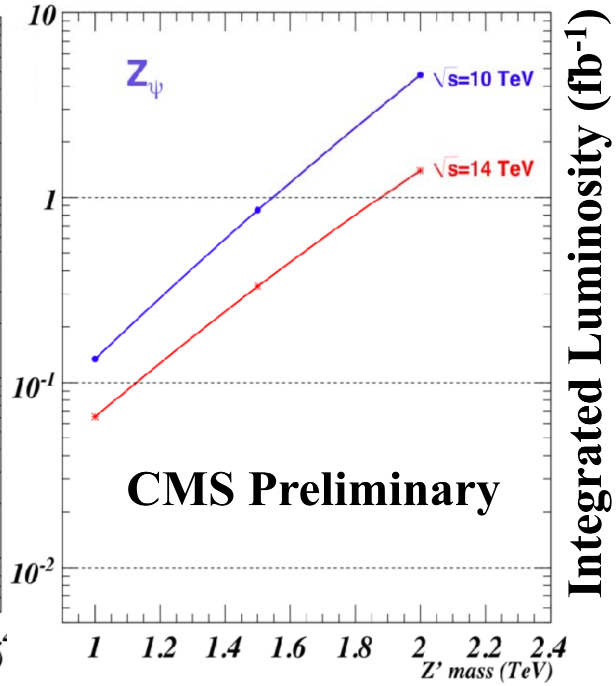




after b-tag and W-mass selection

Search for New Resonances: Z'

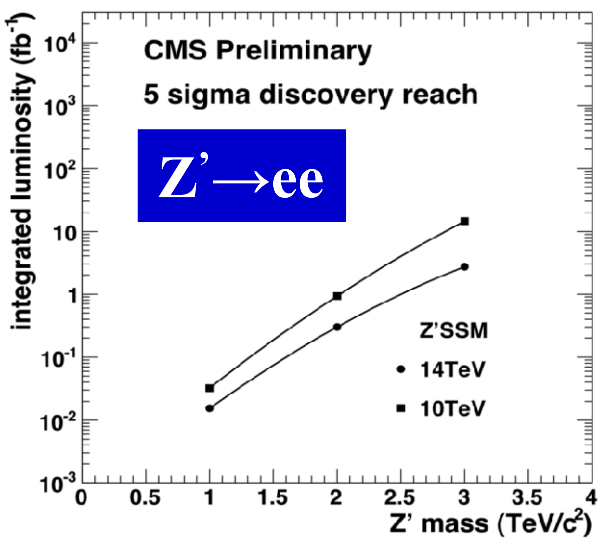


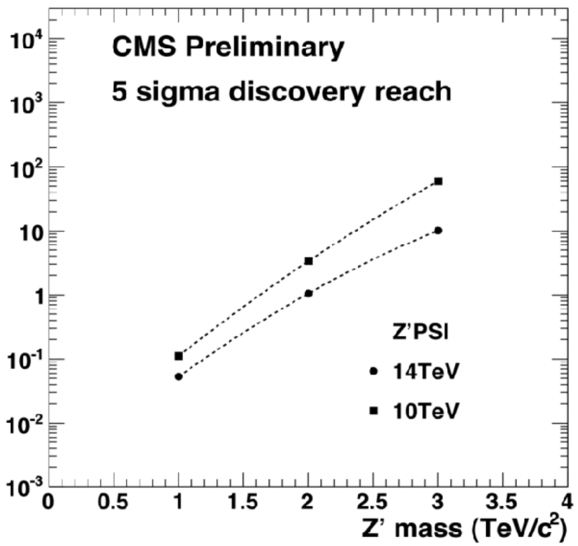


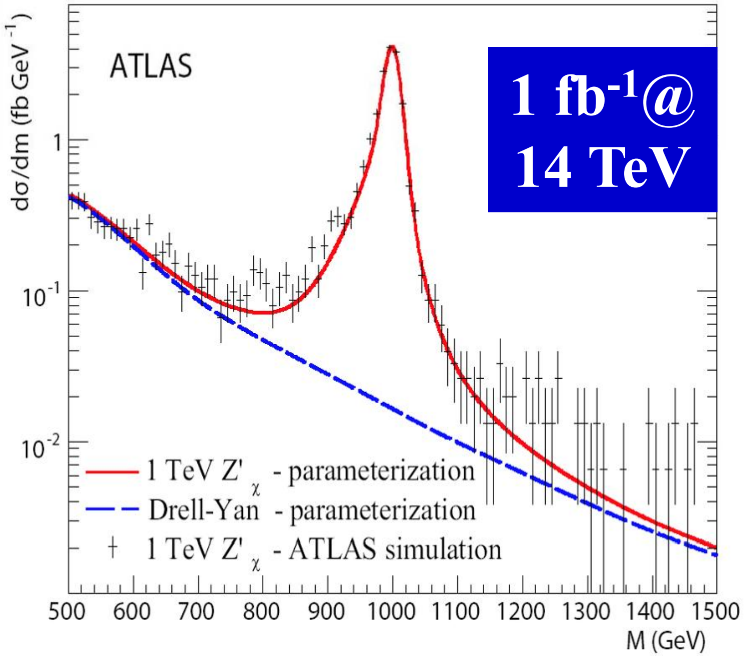
Z_Ψ & Z_{SSM}: two extremes in "reach"

Z' mass (TeV)	σ(14 TeV) / σ(10TeV)
1	2
2	3

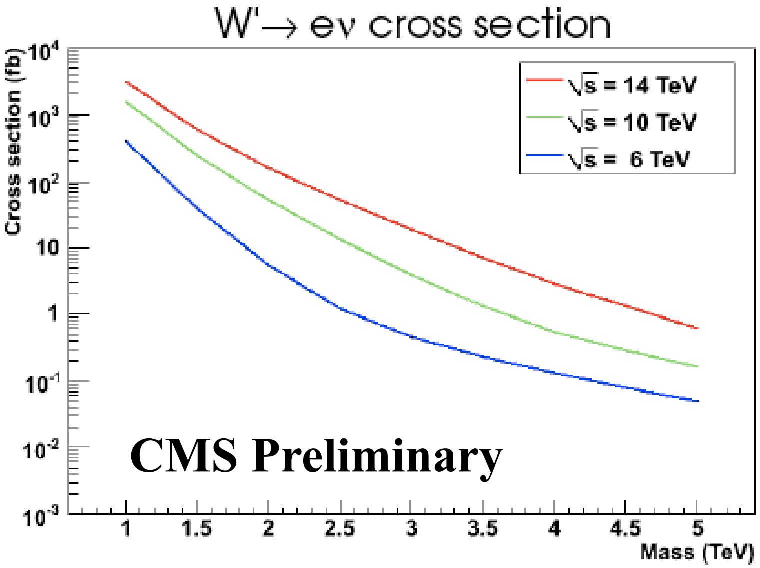
With 100 pb^{-1} @ 10 TeV Z' discovery up to ~1.5 TeV

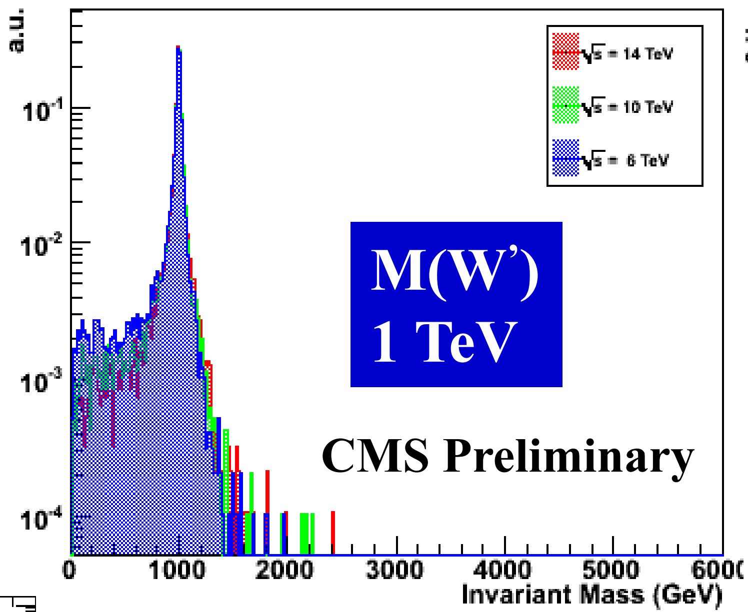


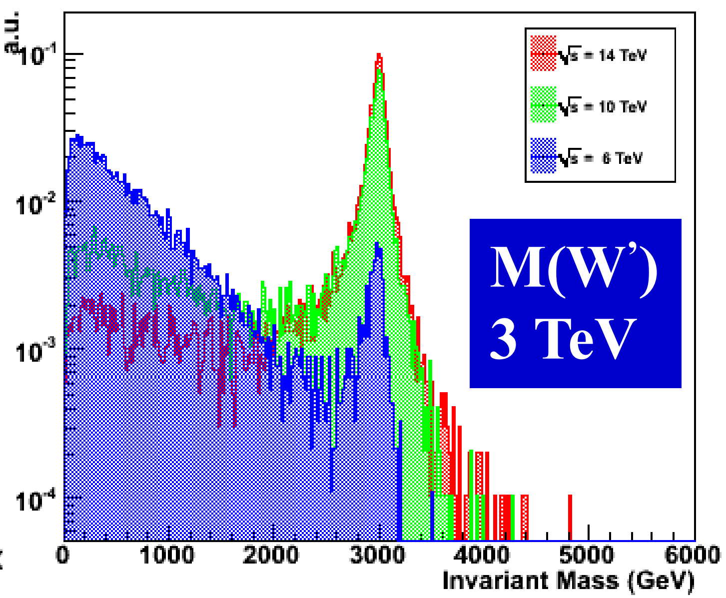


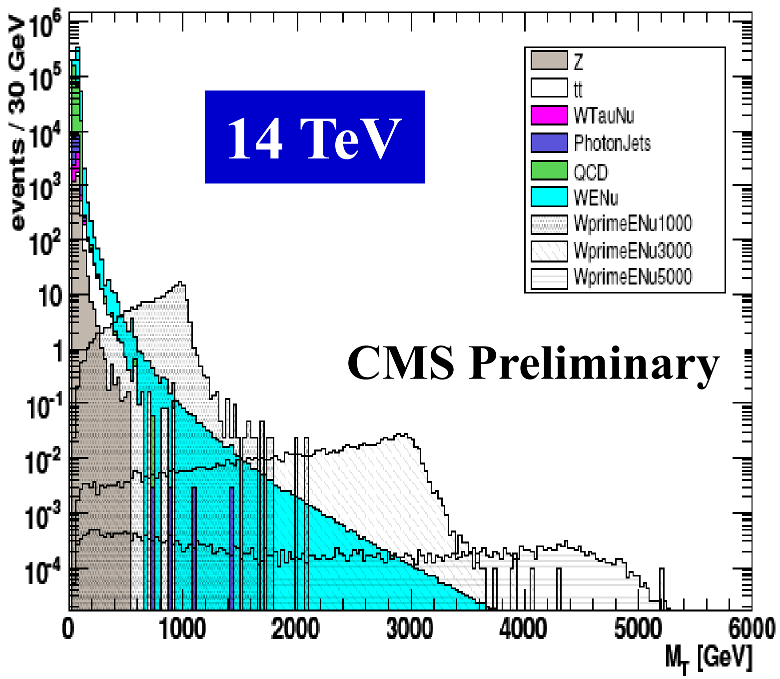


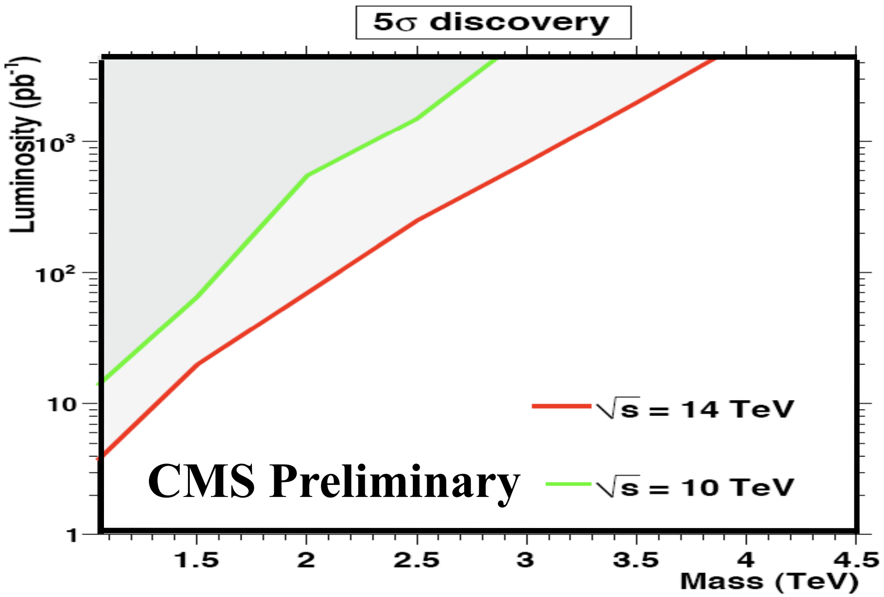
Search for new resonances: W'









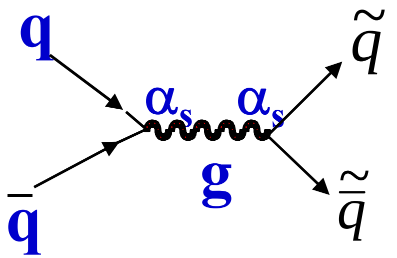


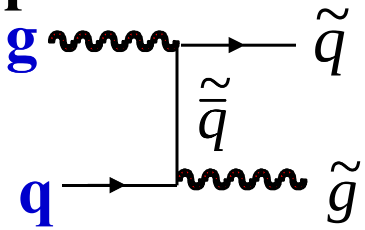
With 100 pb^{-1}
@ 10 TeV
W' discovery
up to ~1.5 TeV

SUSY: sparticle production at the LHC

- Squarks and gluinos produced via strong processes $\rightarrow$ large cross-section

E.g.





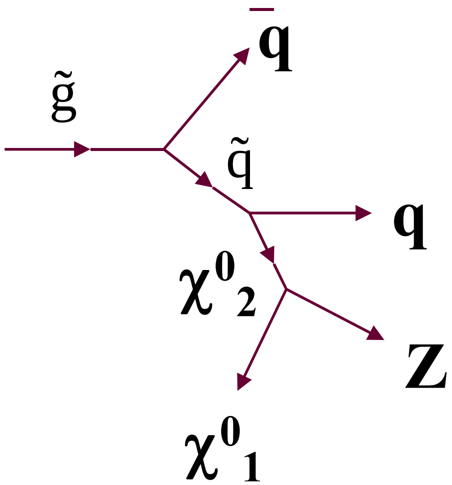
M (GeV)	σ (pb)
500	100
1000	1
2000	0.01

For $m(\tilde{q},\tilde{g}) \sim 1\,\mathrm{TeV}$ ~ 100 events produced with 100 pb^{-1}

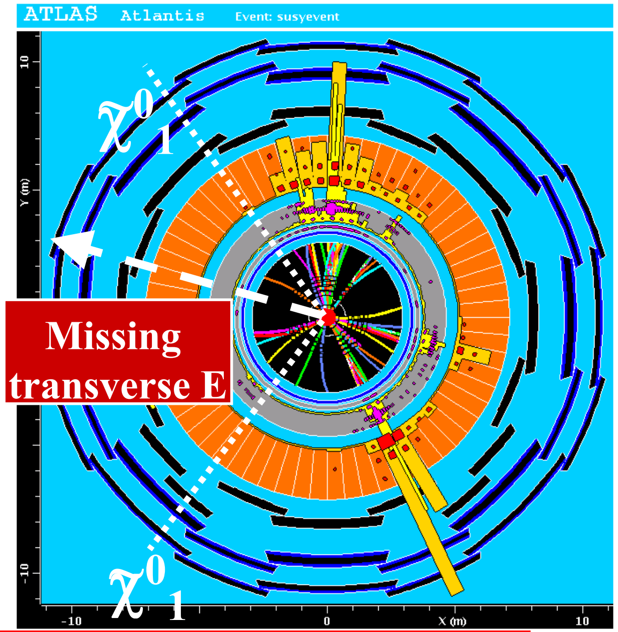
- Charginos, neutralinos, sleptons direct production occurs via EW processes $\rightarrow$ much smaller rate (produced more abundantly in squark and gluino decays)

$\tilde{q}\,\tilde{q}\,,\,\tilde{q}\,\tilde{g}\,,\,\tilde{g}\,\tilde{g}$ production are the dominant SUSY process @ LHC if accessible

$\tilde{q},\tilde{g}$ heavy (present Tevatron limits: m>300-400GeV) $\rightarrow$ cascade decays favored

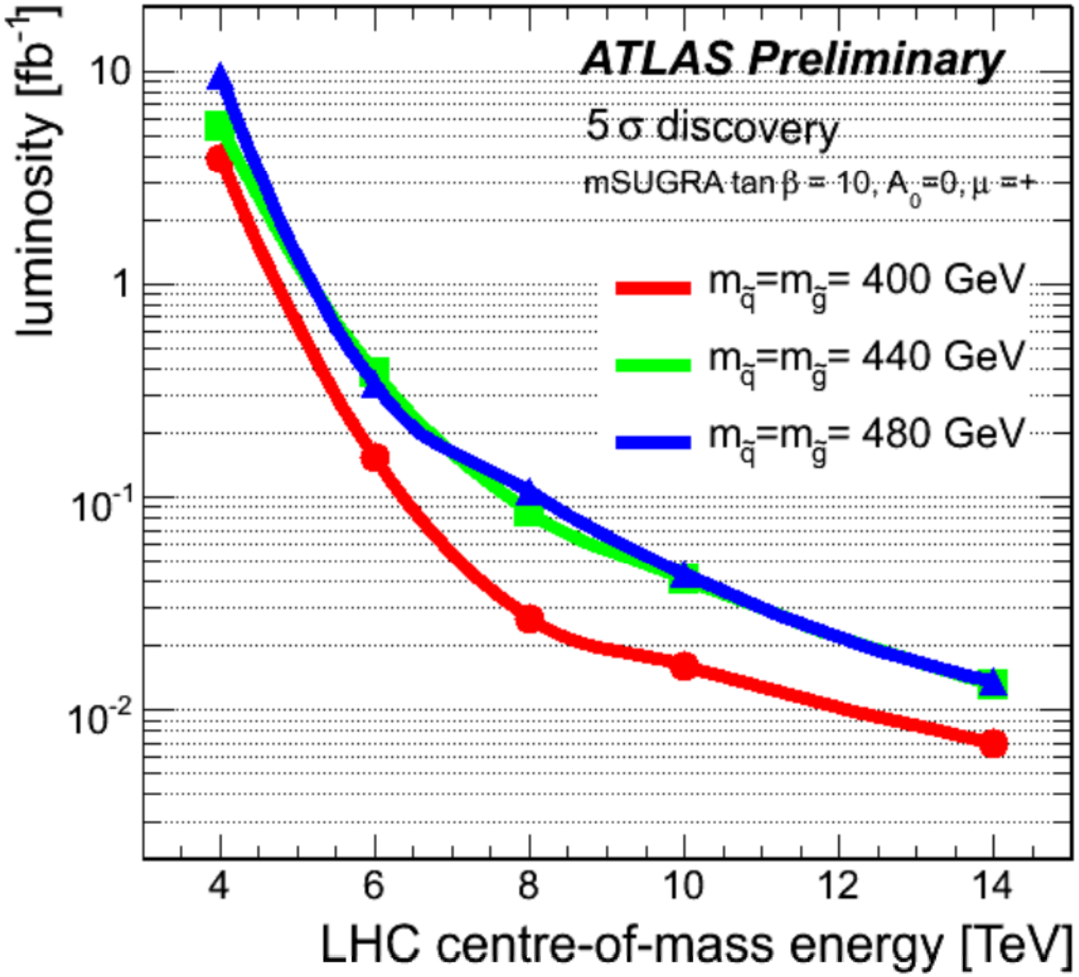


Lightest neutralino is stable, neutral & weakly interacting $\rightarrow$ missing energy in final state



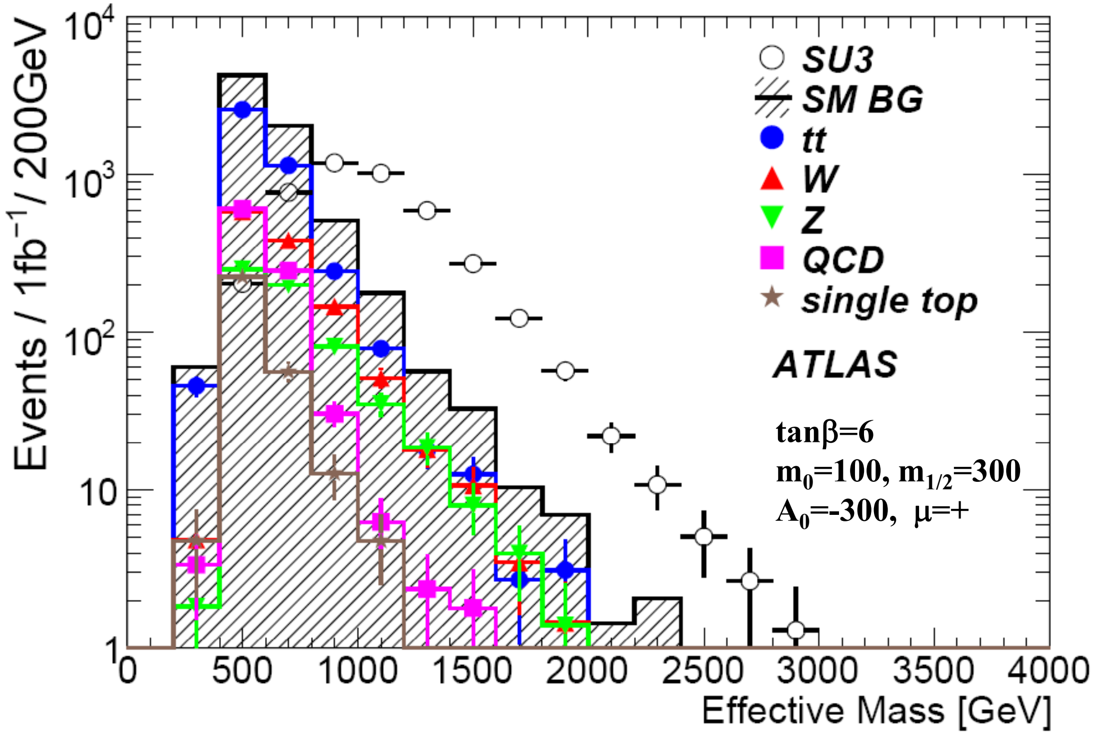
spectacular signatures (many jets, MET, leptons)

SUSY Searches



Reach for equal Squark- Gluino masses:

- $0.1\ fb^{-1} \Rightarrow M \sim 750$ GeV
- $1\ fb^{-1} \Rightarrow M \sim 1350$ GeV
- $10\ fb^{-1} \Rightarrow M \sim 1800$ GeV

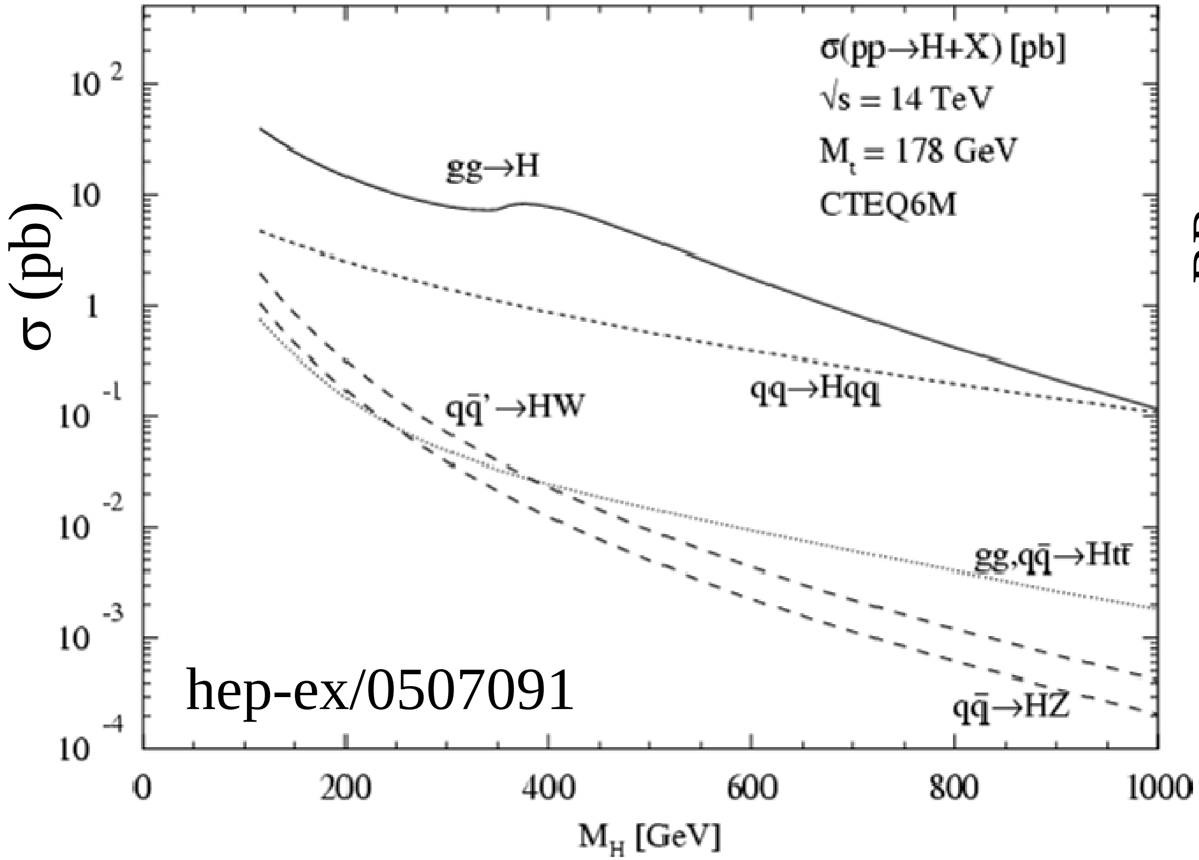


Deviations from Standard Model due to SUSY at TeV scale can be observed fast !

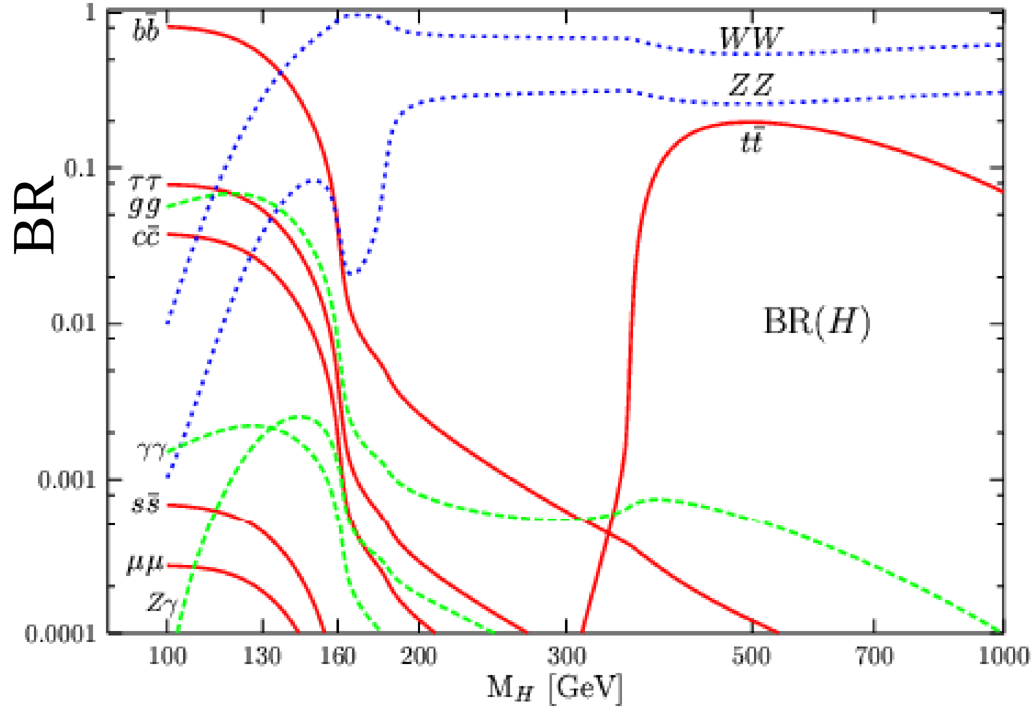
$$M_{eff} = \not{p}_t + \sum_{1}^{4} p_t^{jet}$$

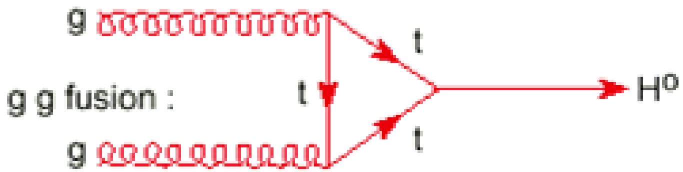
Average M_{eff} correlated with mass of strong interacting SUSY particles

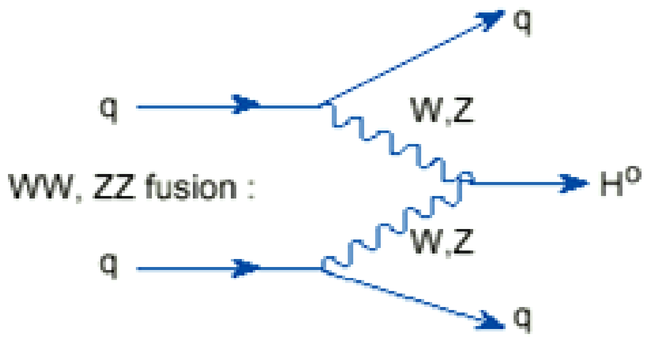
Standard Model Higgs Boson Search

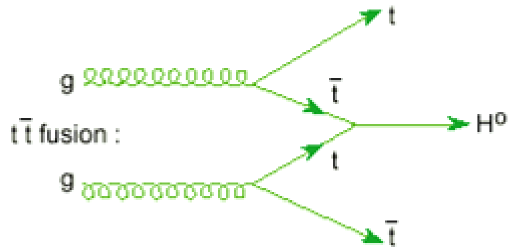


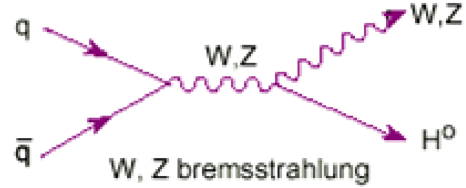
Djouadi, Kalinowski, Spira



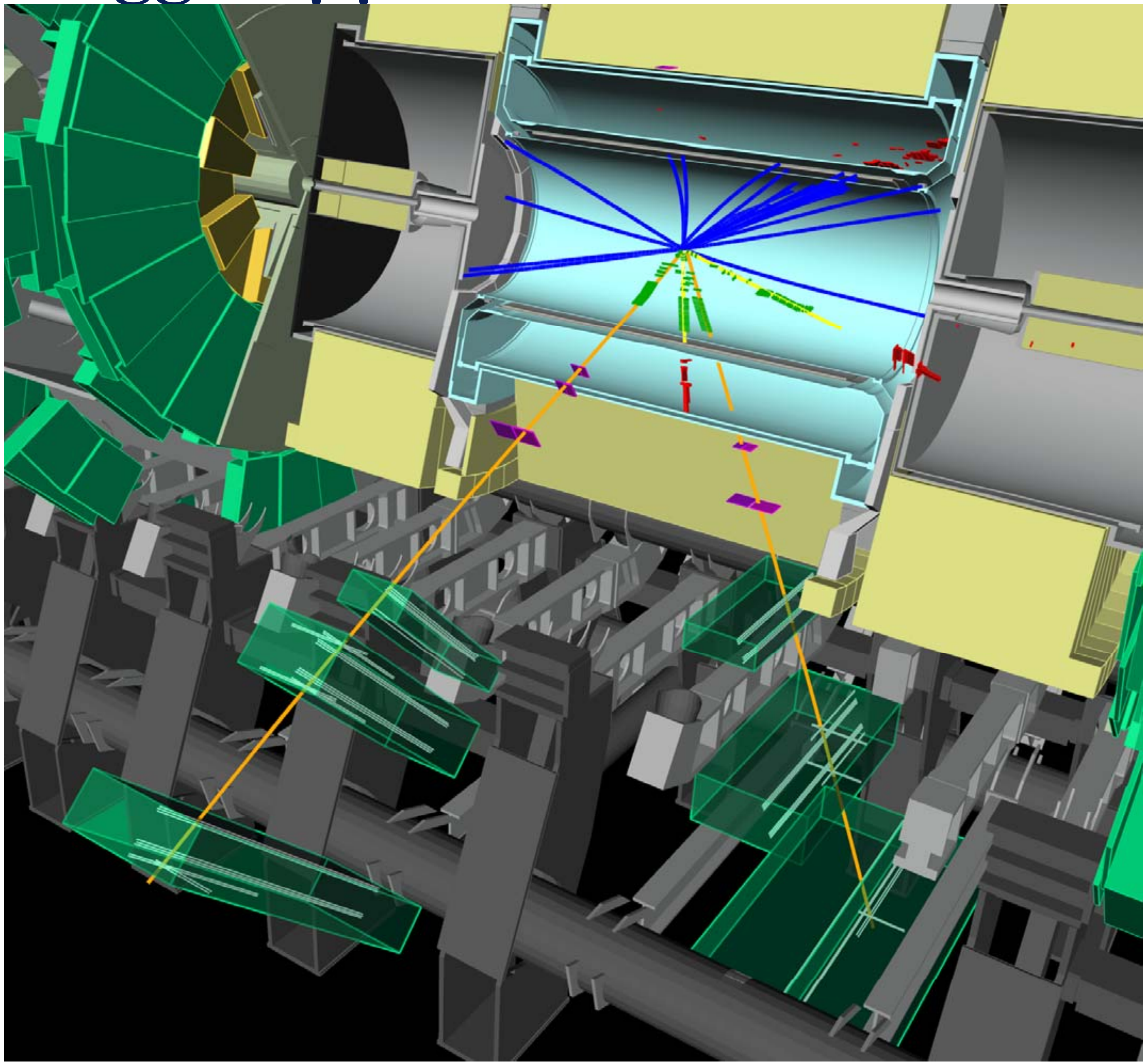






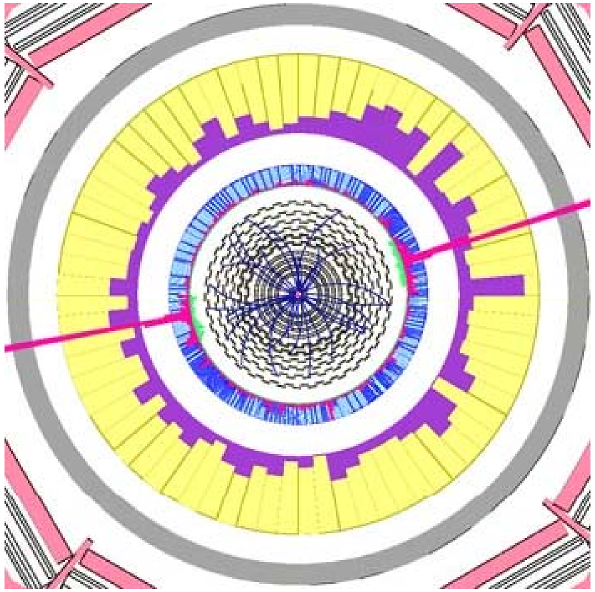


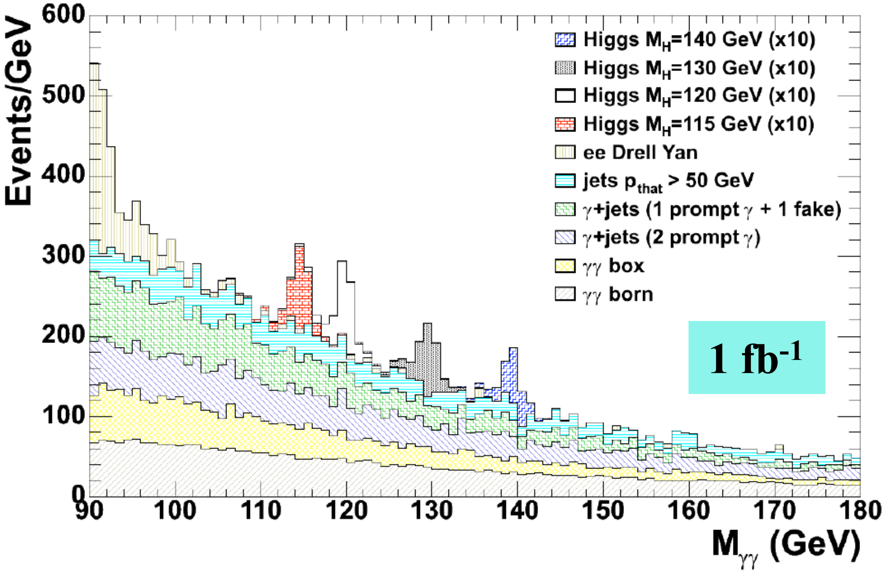
Simulation of a 130 GeV mass Higgs→μμee event in ATLAS



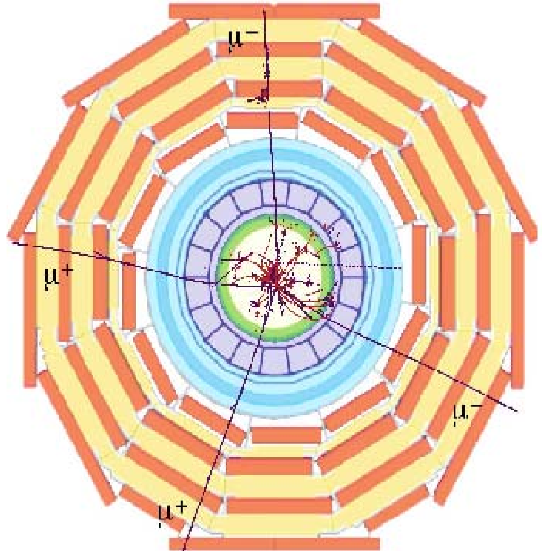
Standard Model Higgs in CMS

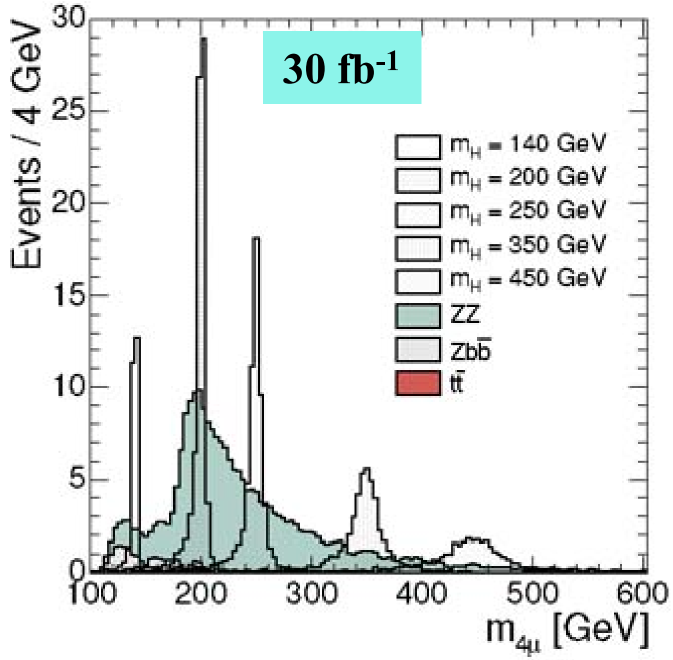
$H \to \gamma\gamma$



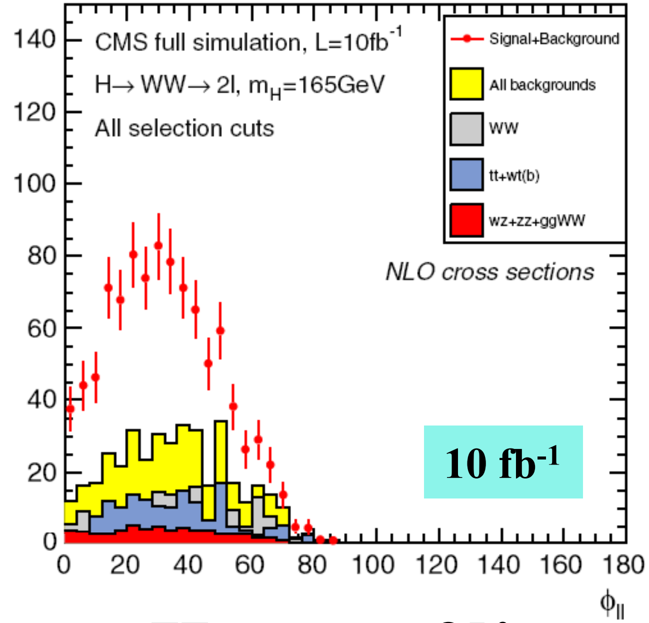


$H \to ZZ^* \to 4l$

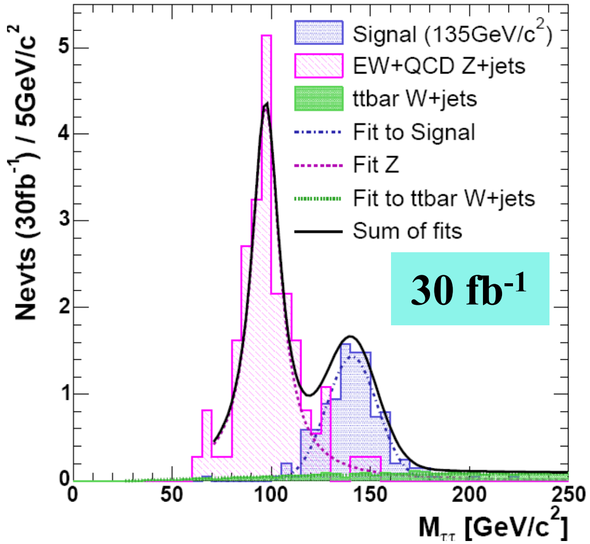




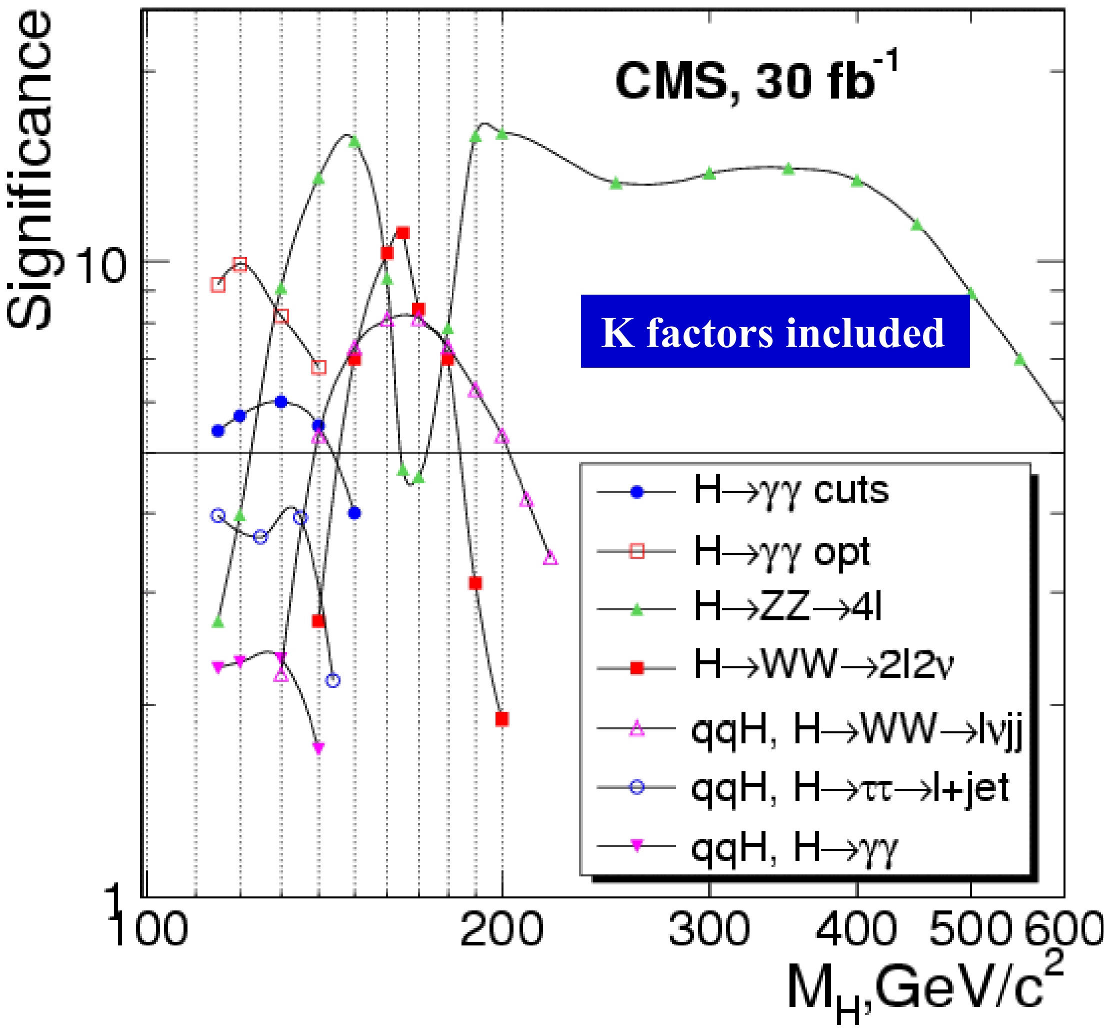
$H \to WW^* \to 2l2\nu$

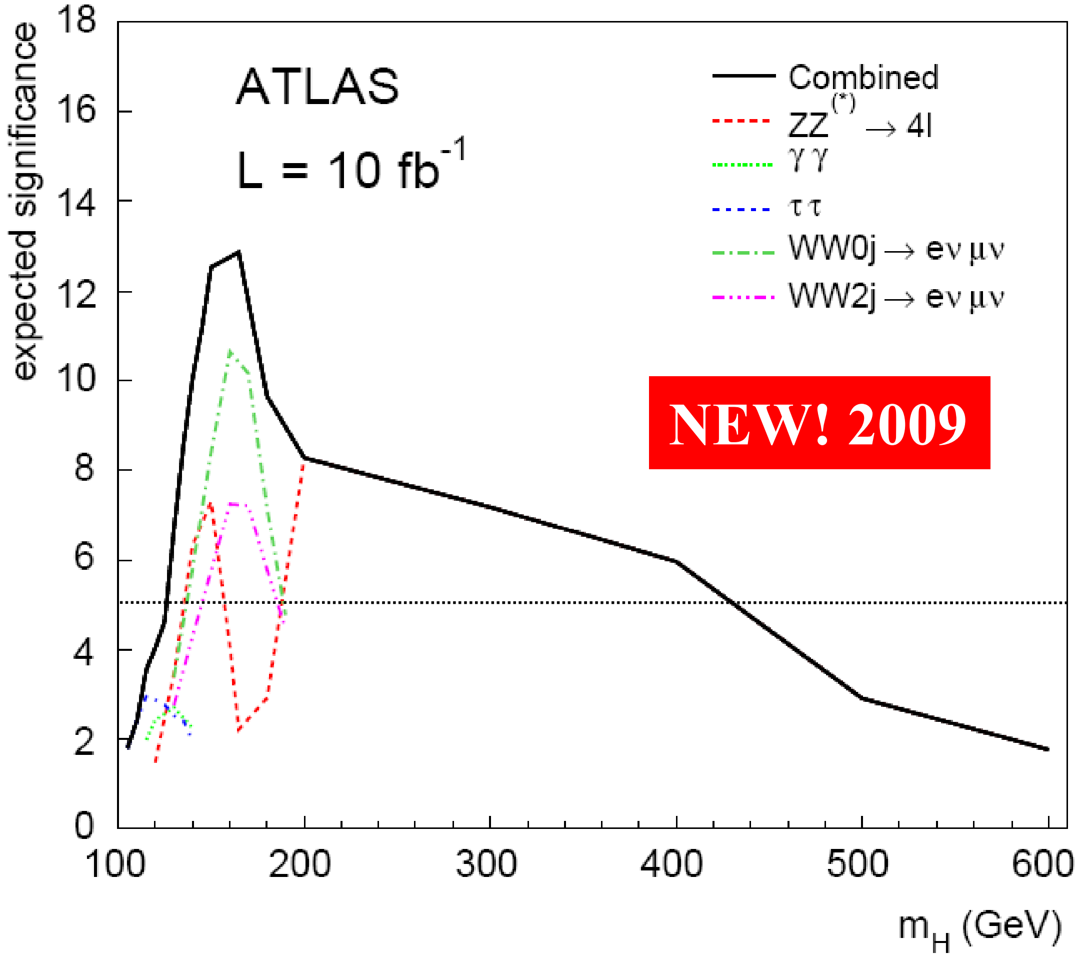


$qqH \to \tau\tau \to 2l\,jet$



Higgs discovery potential

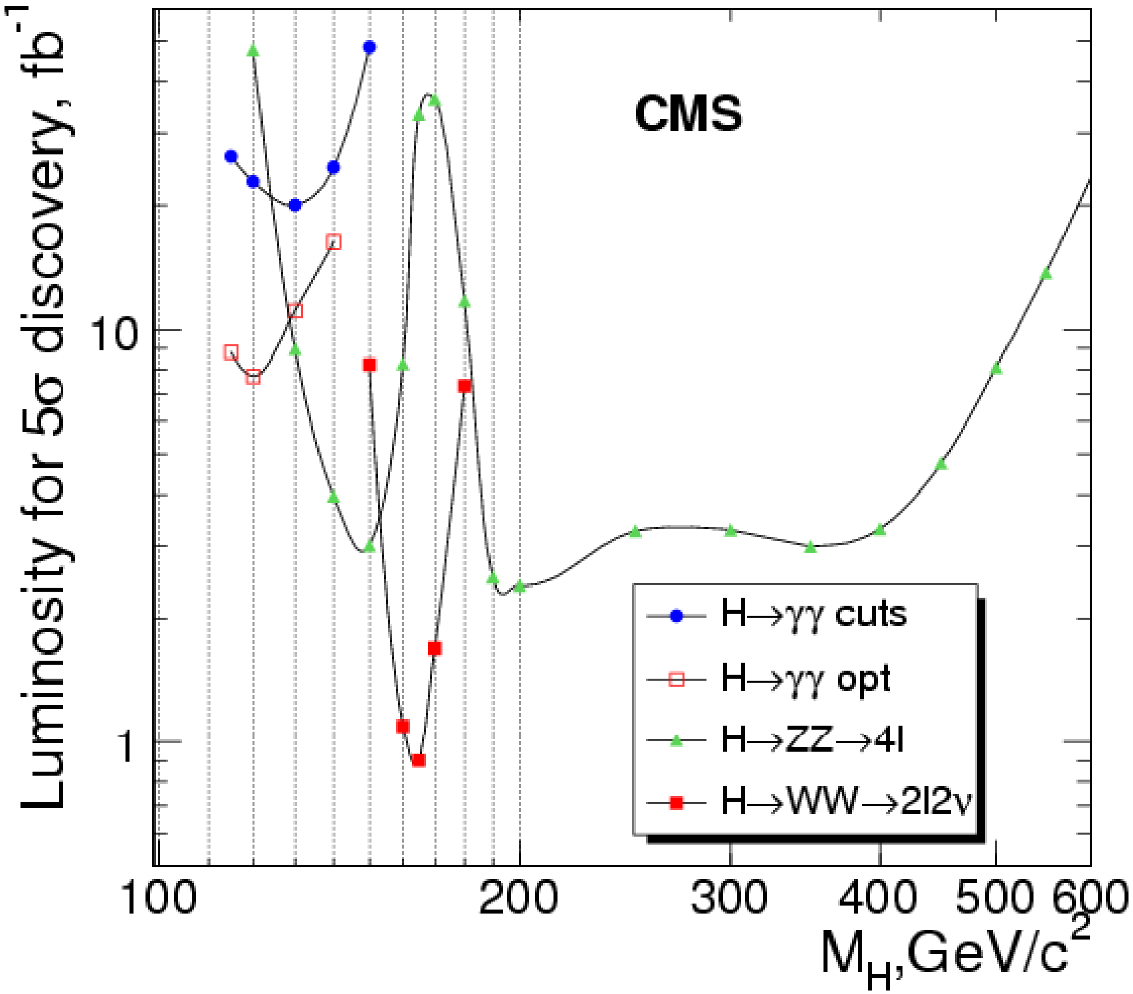


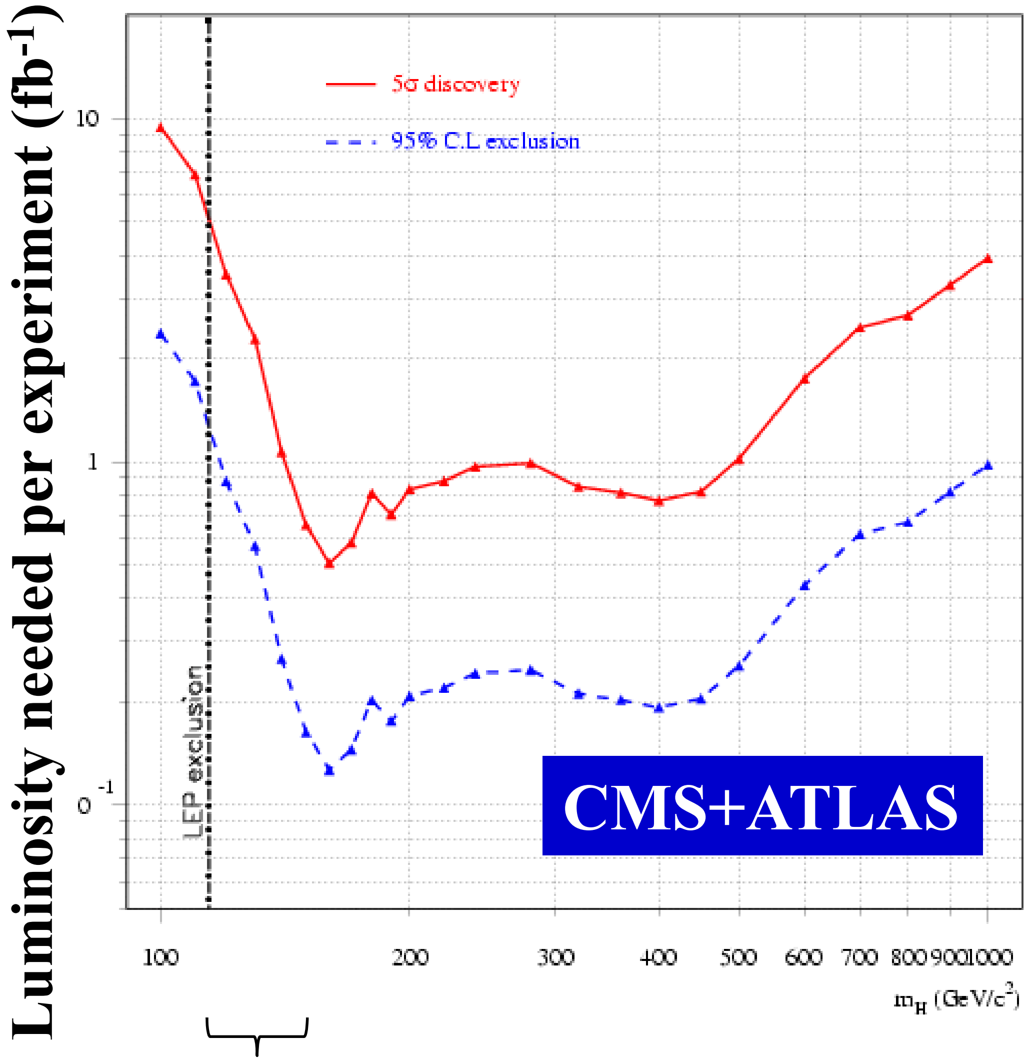


Similar performance/sensitivity expected in both experiments

In the low mass region the CMS Higgs→γγ optimized analysis better performance

Higgs discovery potential



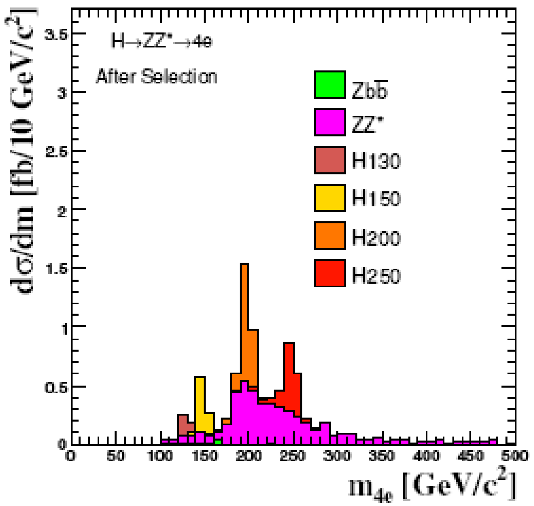


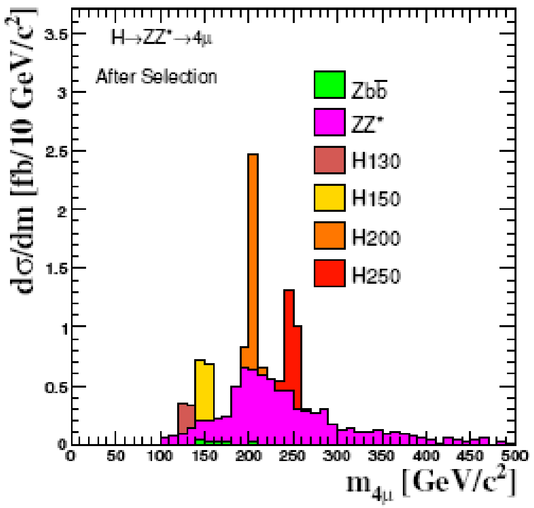
With 10 fb^{-1} per experiment discover SM Higgs boson in large mass range

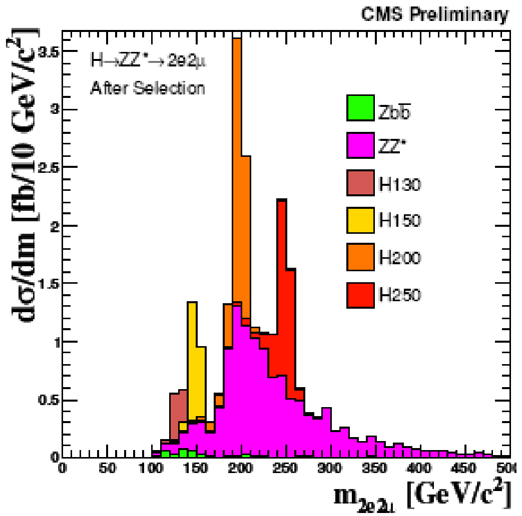
Most difficult region

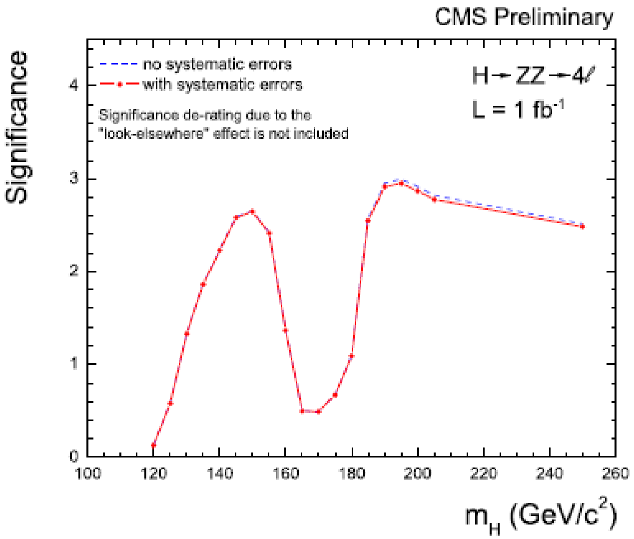
CMS Higgs→ZZ* /WW* sensitivity with 1 fb^{-1} @ 14 TeV

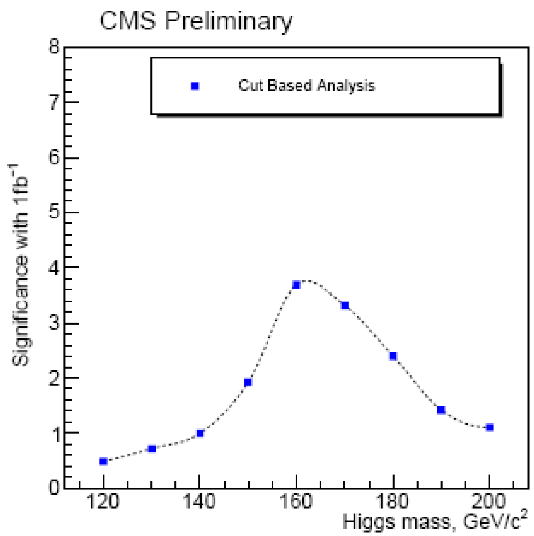
CMS, 1 fb^{-1} @ 14 TeV Higgs →ZZ*

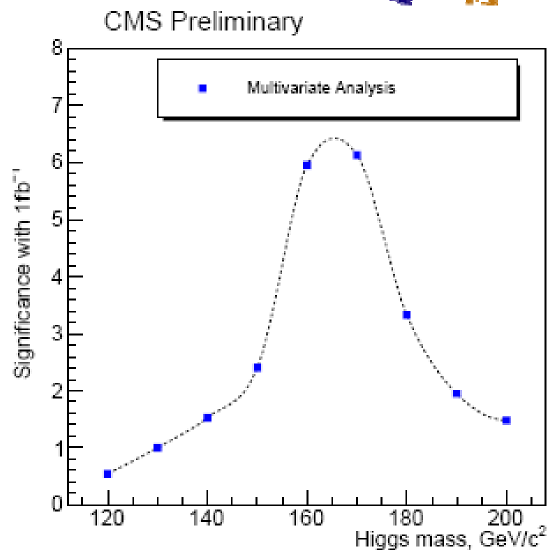




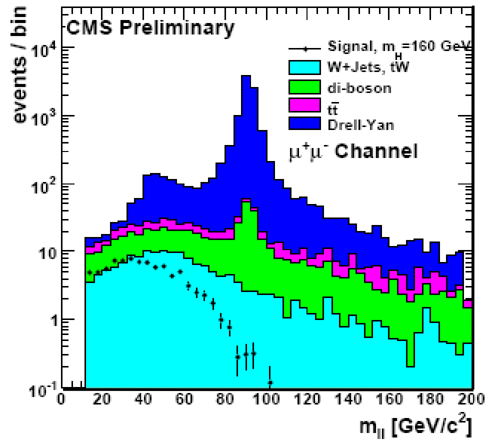


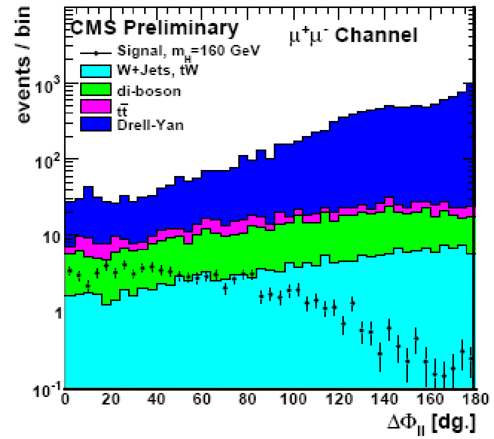






CMS, 1 fb^{-1} @ 14 TeV Higgs →WW*



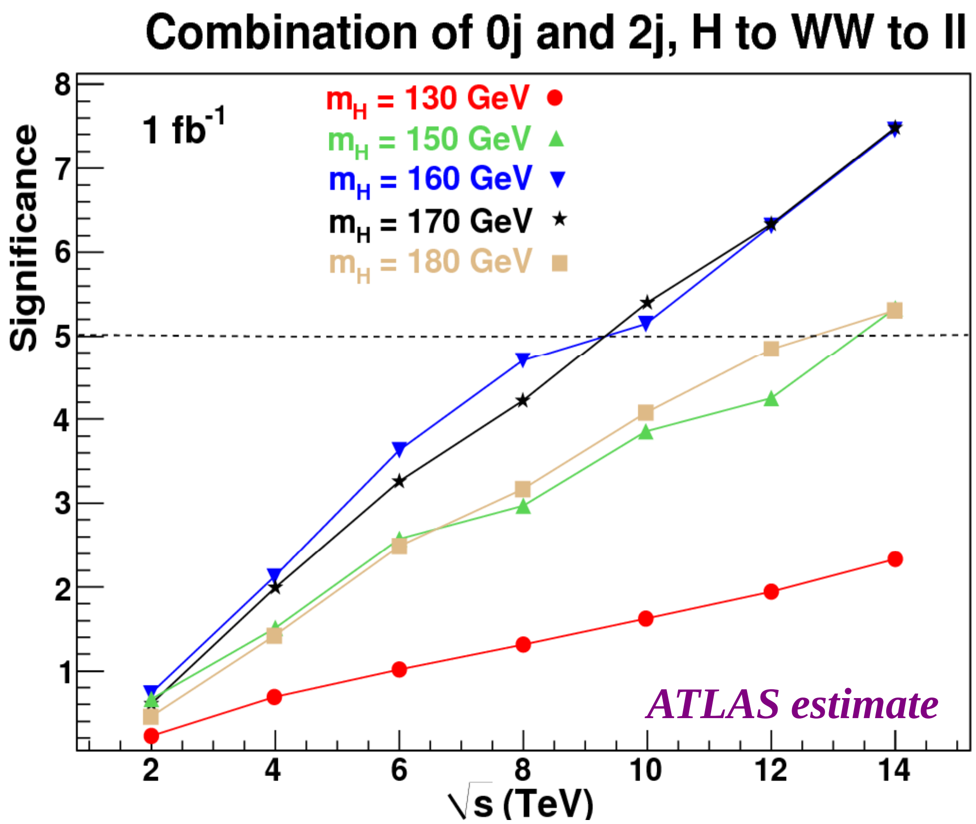


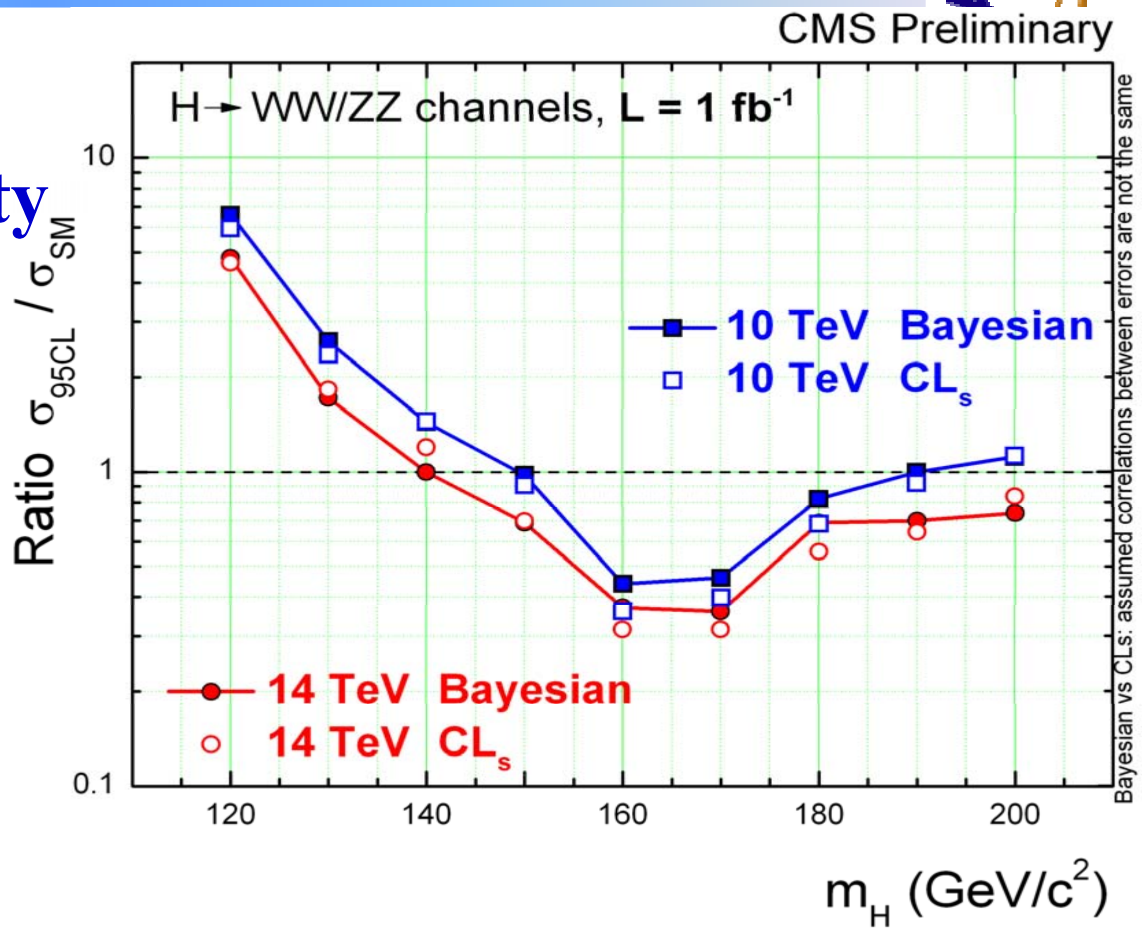
Higgs search @ 10 TeV

14 TeV →10 TeV:

loss of a factor of 1.5 in sensitivity

or <u>factor of 2 in luminosity</u>





With roughly ~200 pb^{-1} reach sensitivity for SM Higgs with m_H~160-170 GeV

(comparable to the current Tevatron sensitivity)

Summary

- After almost 20 years of design and construction the experiments started successfully taking data with LHC beams on the 10^{th} of September 2008

- Operation interrupted shortly after by an incident due to a faulty electrical connection between two magnets. Repairs progressing well and the revised schedule foresees first collisions at 10 TeV at the end of 2009

- Commissioning of the experiments in the underground caverns with cosmics has demonstrated excellent detector quality and has allowed first alignment, calibration and timing studies to be made with the final detectors

  → experiments ready to do good physics with first collision data

Summary

With the first 100-200 pb^{-1} collision data at 10 TeV

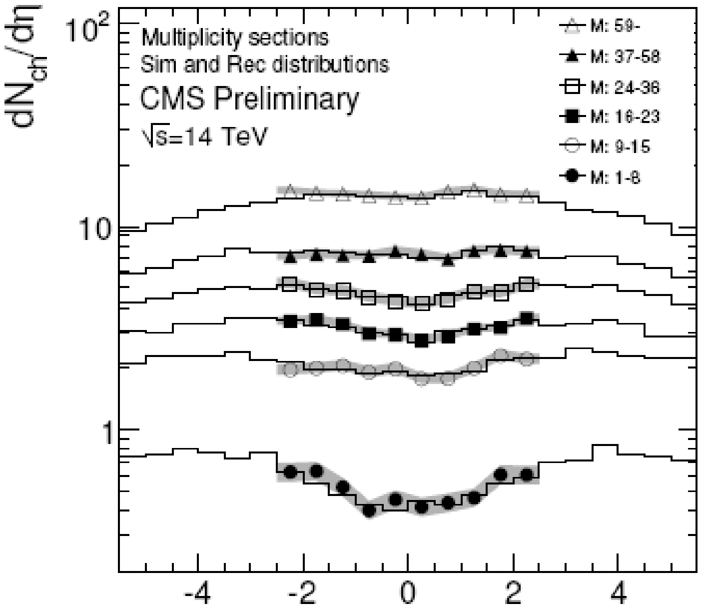
- **Re-Establish the Standard Model**
  - Measure particle multiplicity in minimum bias
  - Measure QCD jet cross sections
  - Measure W/Z jet cross section with ~10% precision and improve knowledge on proton PDFs
  - Observe first top signals with 50 pb^{-1} and measure ttbar cross sections with 100-200pb^{-1}
  - First tuning of MC (minbias, underlying event, tt, W/Z+jets, QCD jets, ...)

- **Searches**
  - Discover SUSY up to gluino masses of ~1 TeV
  - Discover Z' up to masses of ~1 TeV
  - With 200pb^{-1} reach sensitivity for SM Higgs with m_H~160-170 GeV
  - Other surprises ...

BACKUP

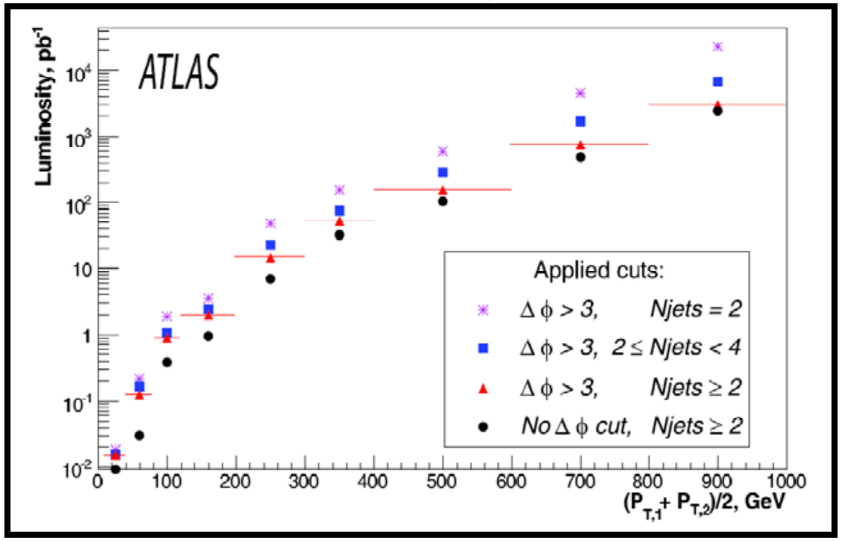
First QCD measurements

Charged Particle Multiplicity



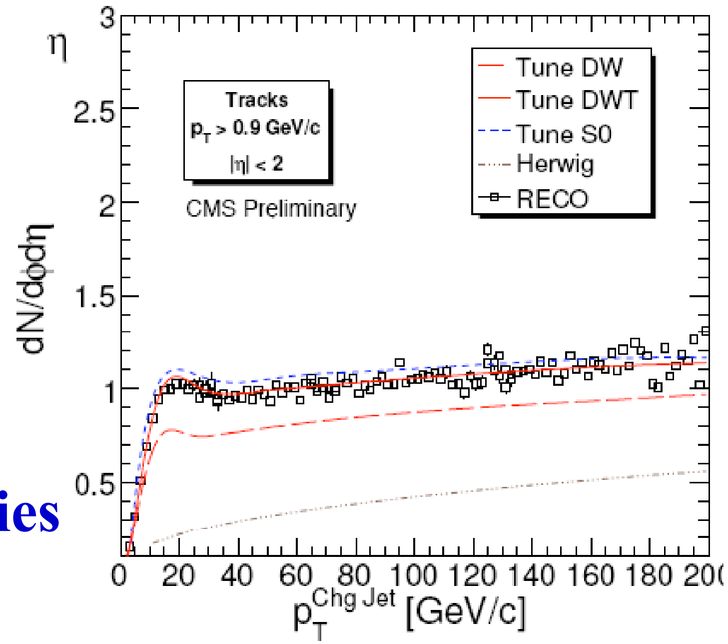
$dN_{ch}/d\eta$ in different bins of multiplicity in the first pixel layer

QCD Dijets p_t balance



Integrated luminosity required to reach a 0.5% precision (p_T balance fit mean) for various p_T ranges in the region 0.7<η<0.8 with different selection cuts

Underlying Event studies

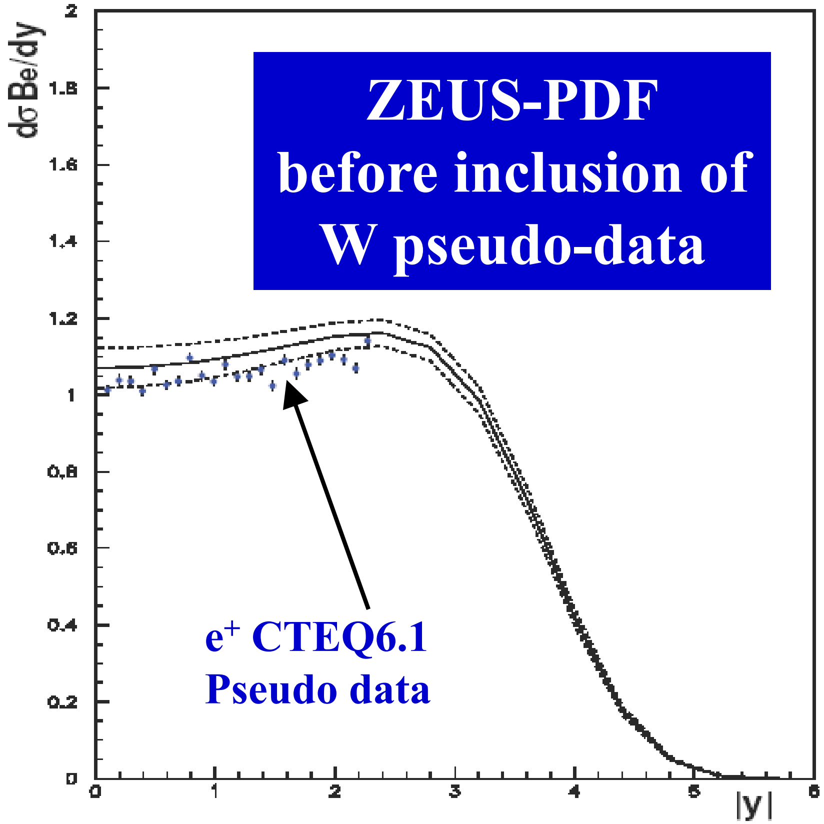


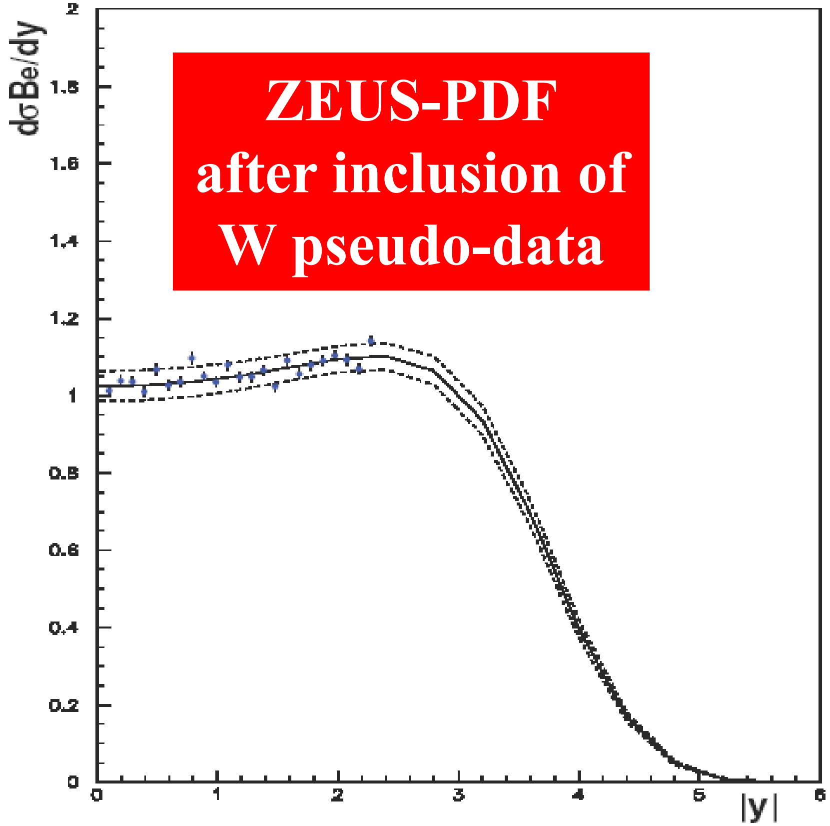
Densities $dN/d\eta d\phi$ for tracks p_t>0.9 GeV as a function of the leading charged jet p_t in the transverse plane for 100 pb^{-1} @14TeV

Constraining the PDFs with LHC Data

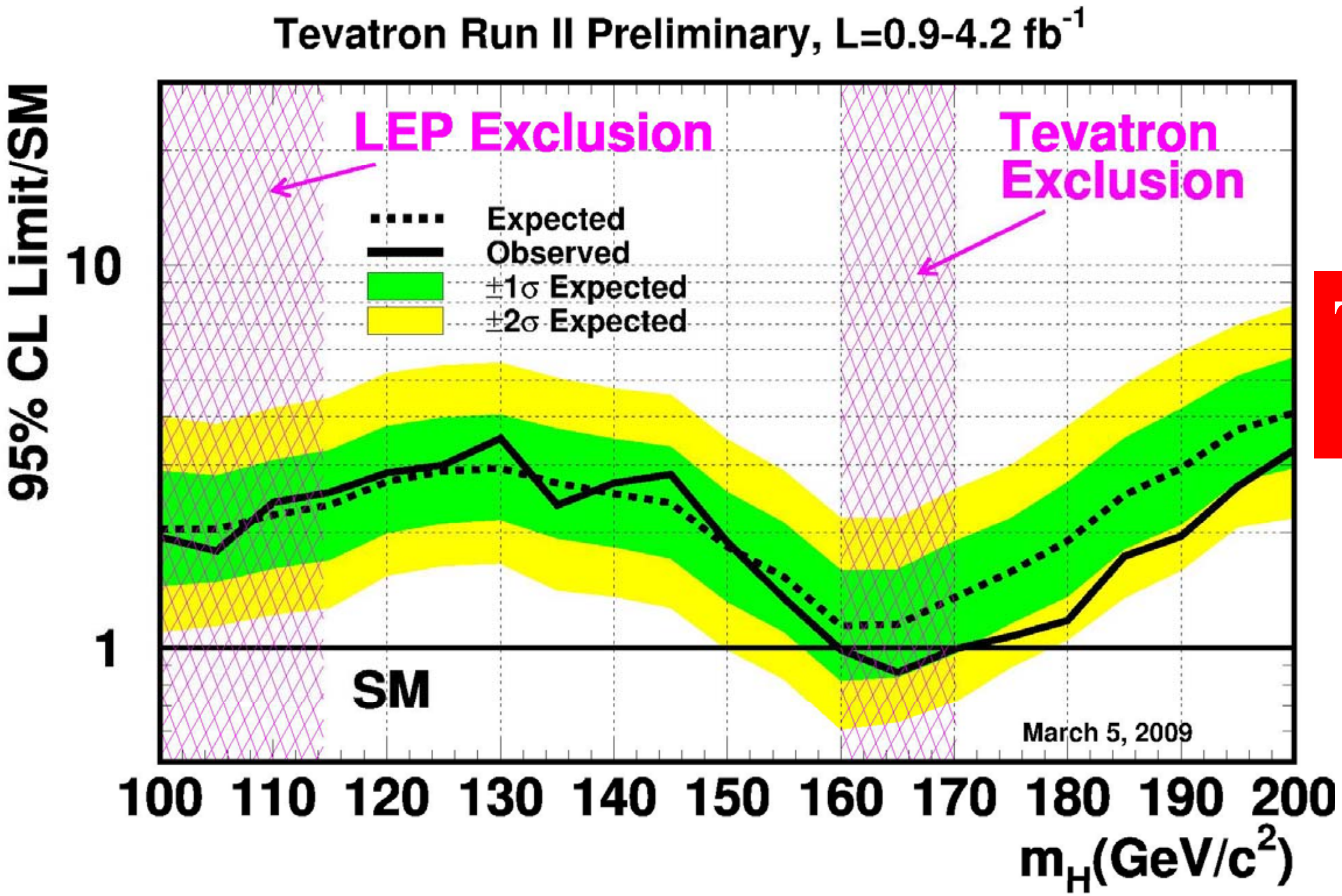
- W and Z cross sections predicted exactly for LHC
- Rapidity for lepton decays sensitive to PDFs
- Simulate events (HERWIG6.505+CTEQ6.1) with addition of a random 4% “systematic error” scatter on these pseudo-data. Redo the PDF fit including them.
- Error on parameter λ ($xg(x) \sim x^{-\lambda}$) reduced by 35%

hep-ex/0509002v1





Recent Tevatron Higgs Search Result



The LHC will confirm the outcome soon! ☺

Higgs boson in the mass range 160-170 GeV excluded
- Expected limits of 1.1 (1.4) x sSM at 160 (170) GeV

S. Pagan Griso
Moriond QCD 2009