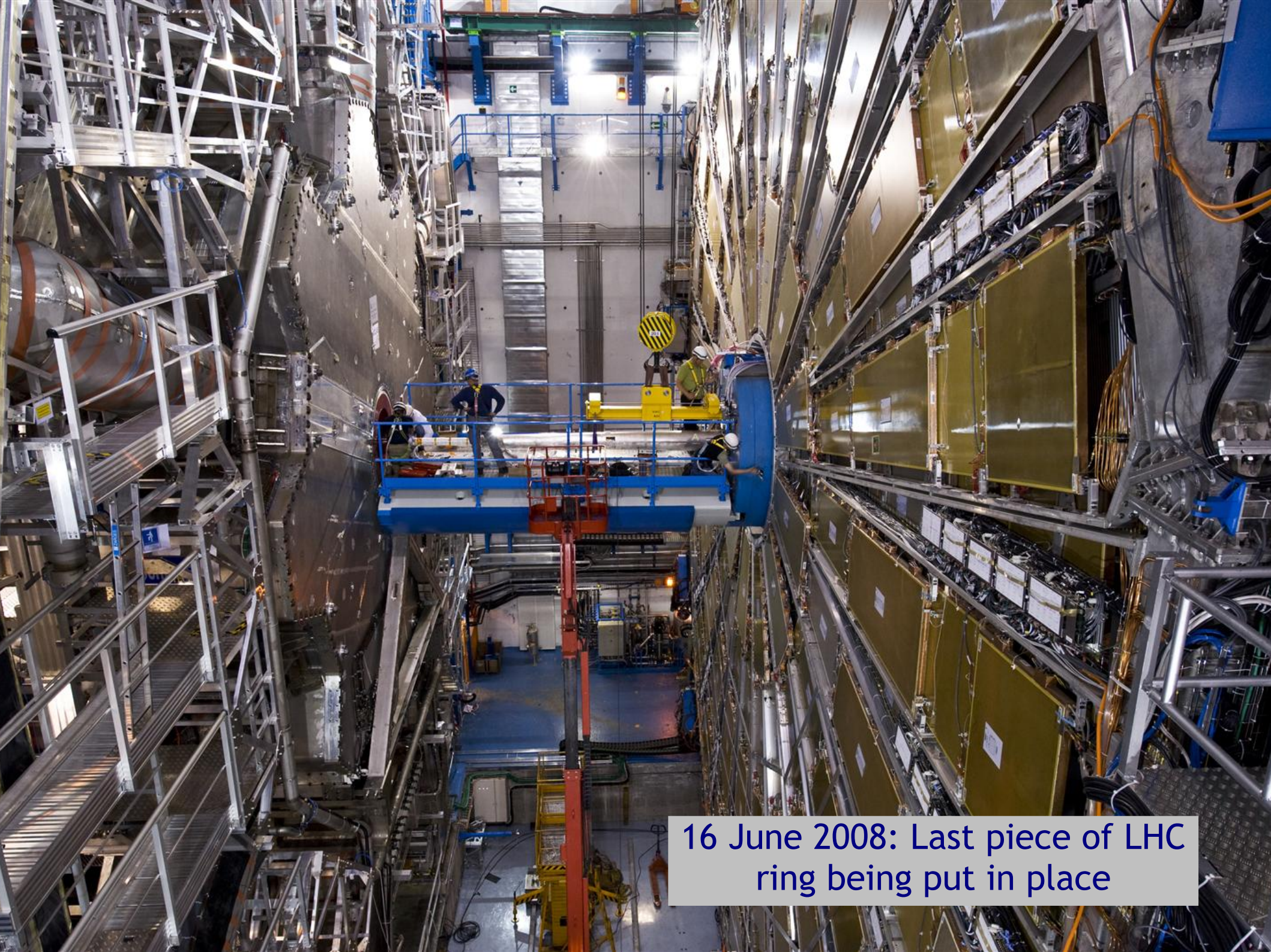
LHC Prospects

Dave Charlton
(University of Birmingham)

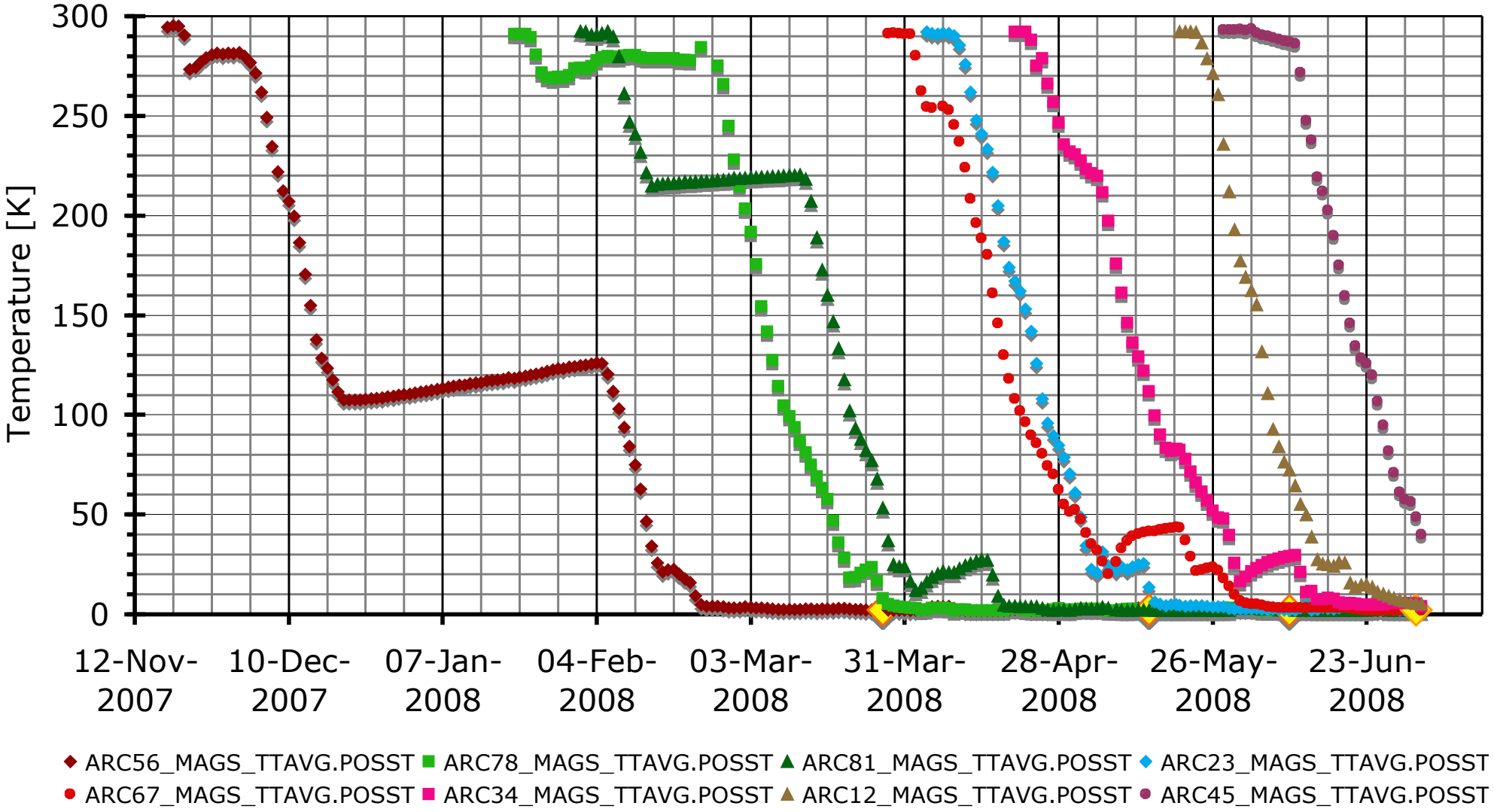
- **Machine Status**
- **Experiment Status (ATLAS,CMS)**
- **A Few Words on Physics**

Not the talk I had hoped to give you today



16 June 2008: Last piece of LHC ring being put in place

Magnet cool-down



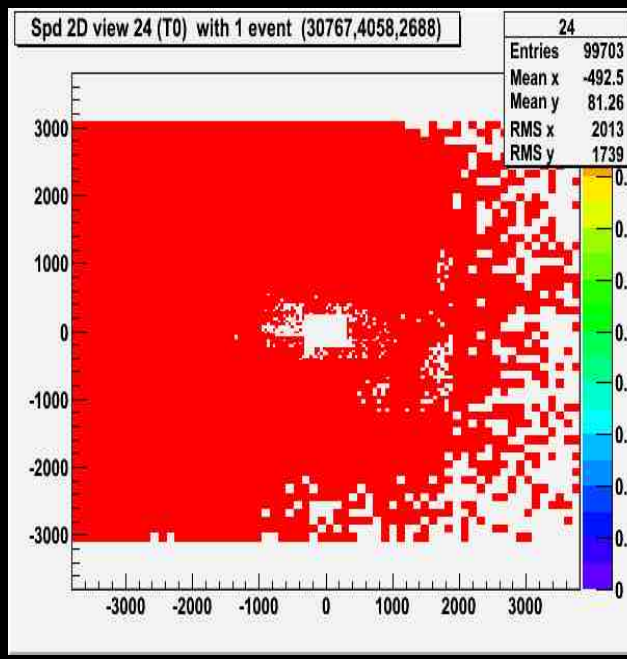
TED events (stop of Beam 2)

First Beam!

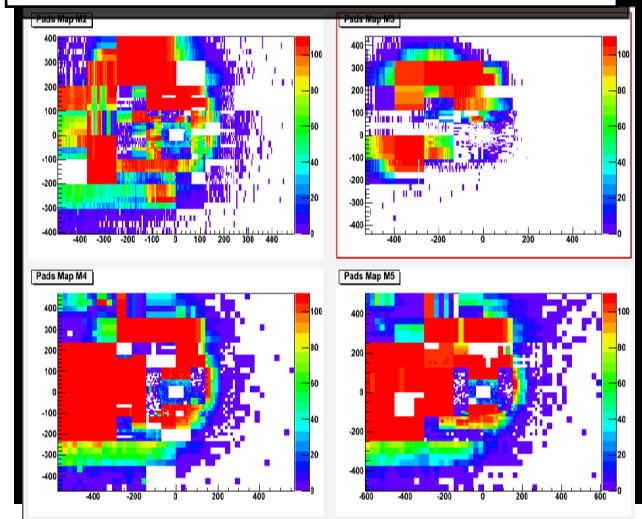
Muon tracks cross LHCb in the "wrong" direction

LHCb sees tracks from the LHC injection tests on August 24

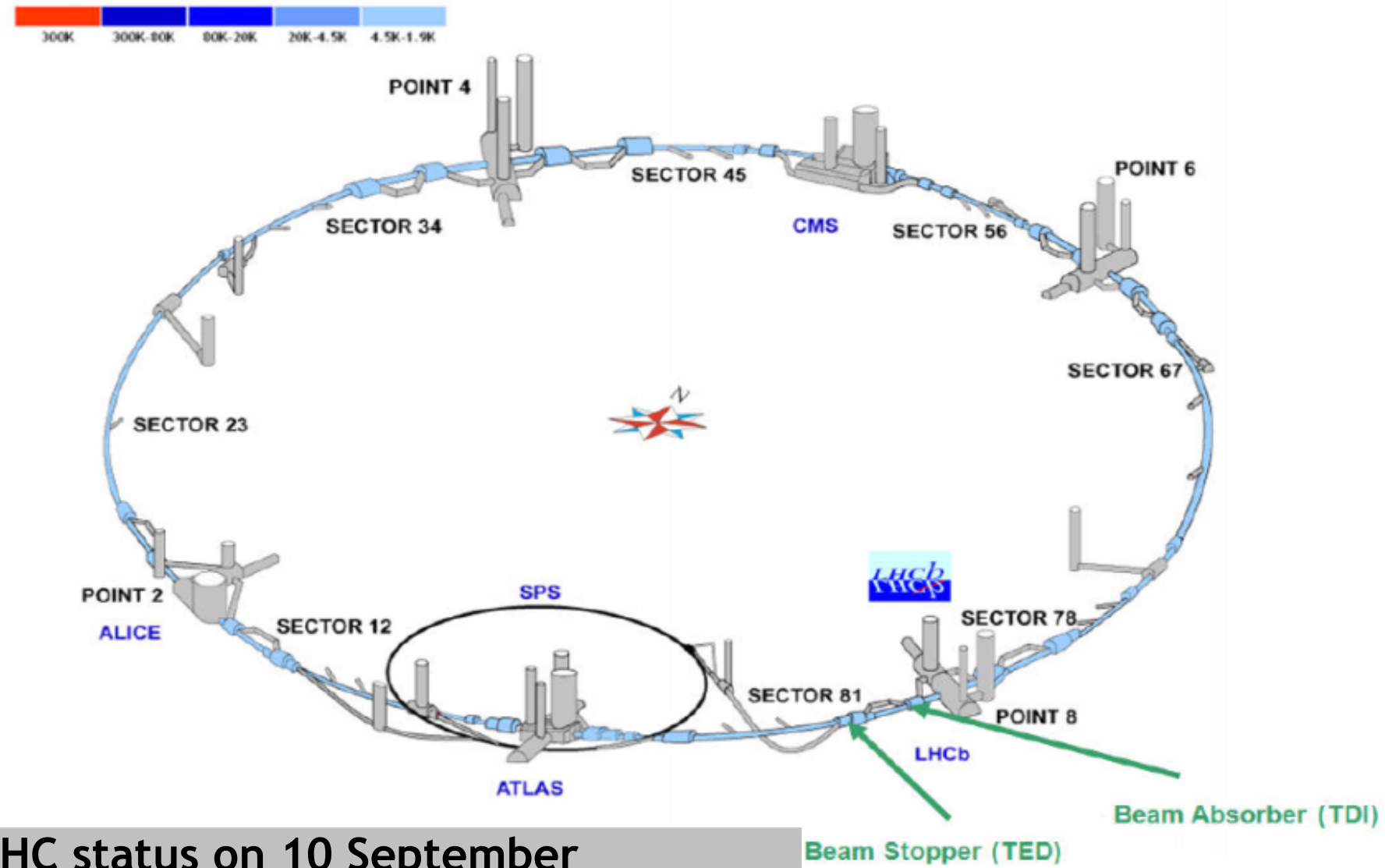
SPD (provided trigger)



Muon chambers



VELO
(Run 30933, Event 14)



LHC status on 10 September

- Whole machine cold (1.9K)
- Planned to run at $\sqrt{s}$=10 TeV in 2008
- 7/8 sectors tested up to 9.3 kA ($\rightarrow E_{beam} \approx 5.5$ TeV)
- Sector 34 tested to $E_{beam} \approx 4$ TeV

BIG BANG

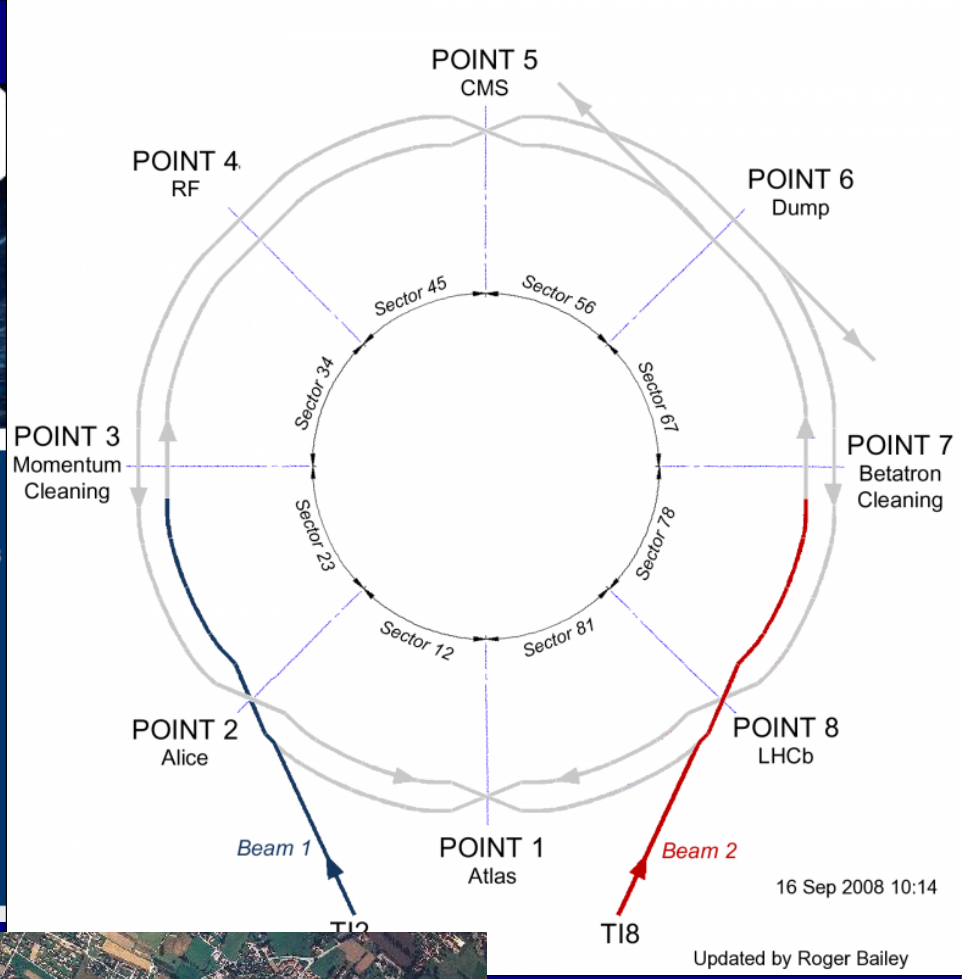
BBC RADIO 4

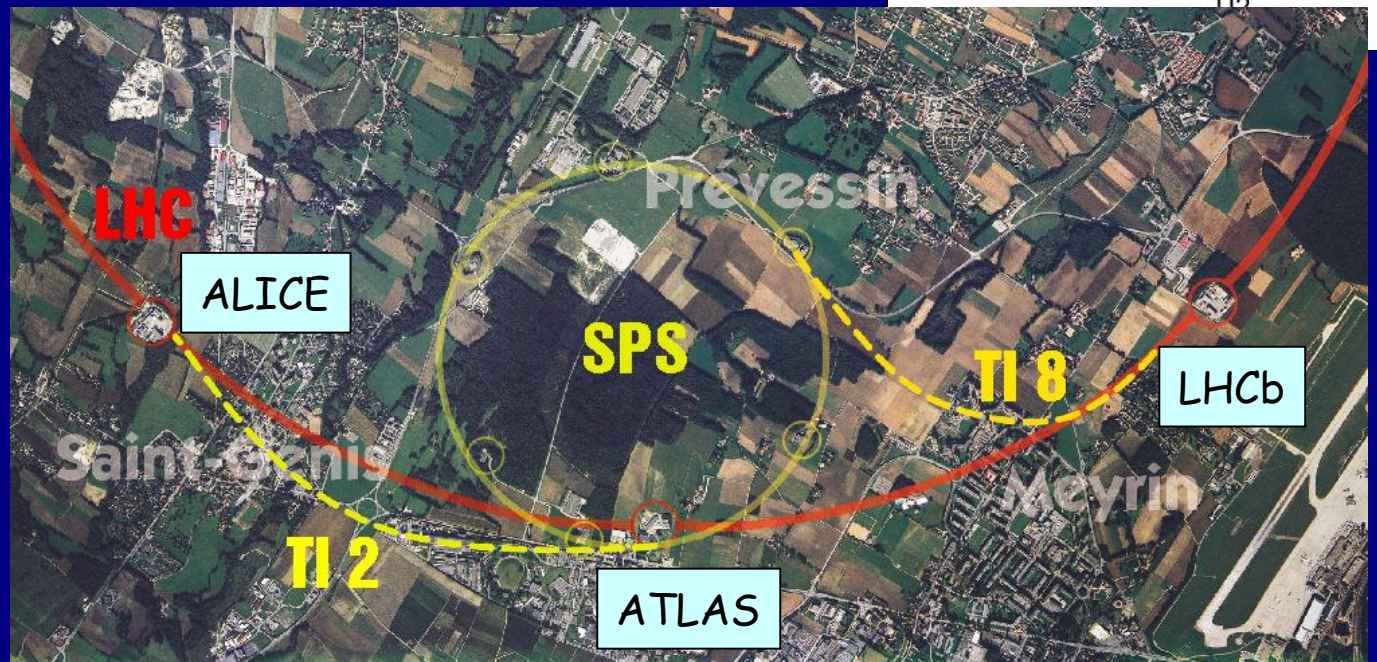
Torchwood: Lost Souls

Torchwood came to Radio 4 in a specially-commissioned drama as part of Radio 4's Big Bang Day.

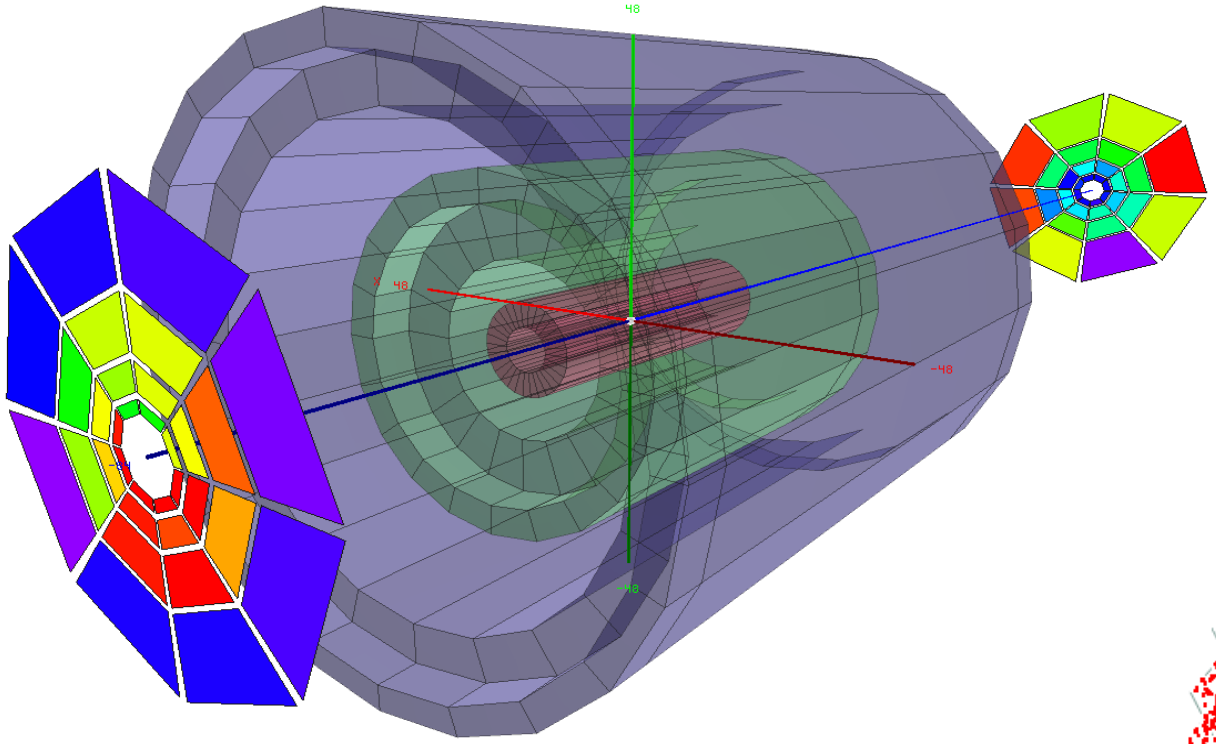
Find out more.

Big Bang Day | Big Bang Day Videos | BBC News LHC Guide | Torchwood: Lost Souls



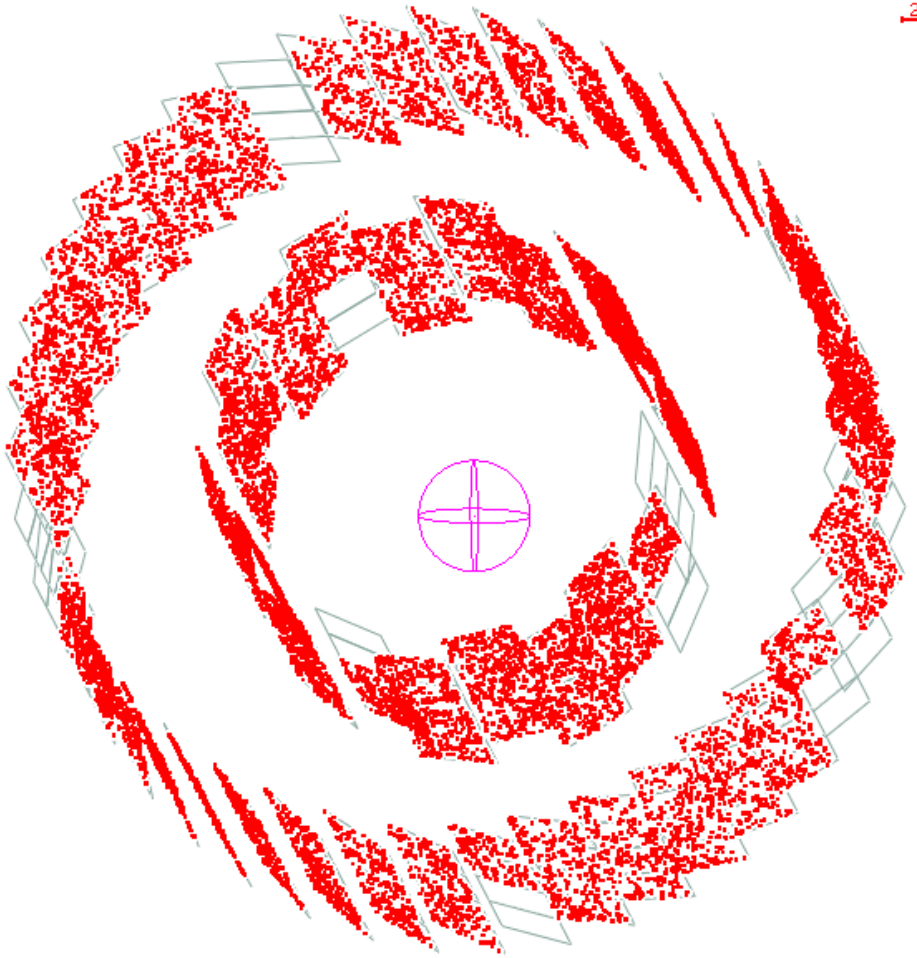


First Beam on 10 September



V0 hits on 10.9.2008, shortly after 9 am

SPD hits on 10.9.2008, shortly after 9 am

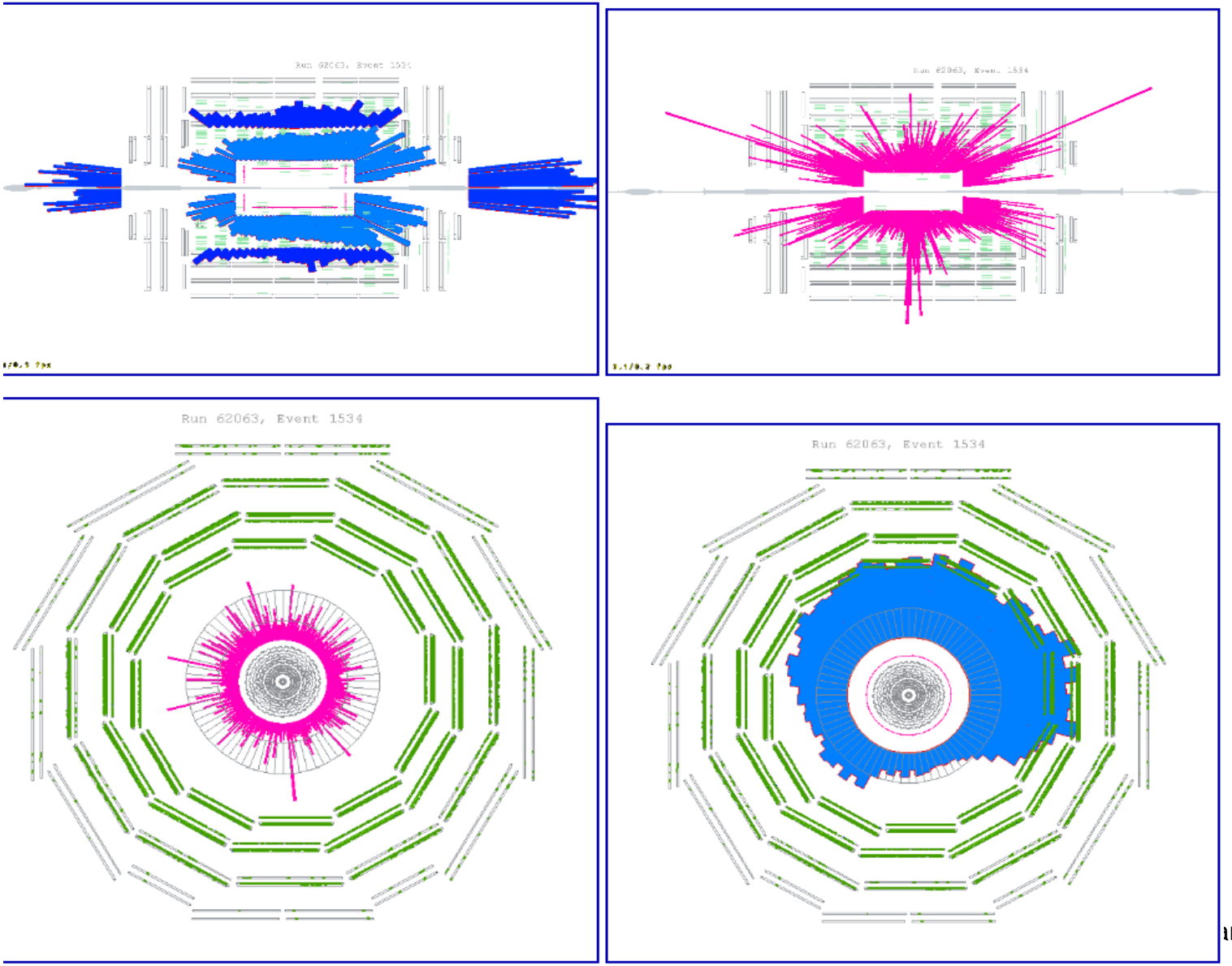


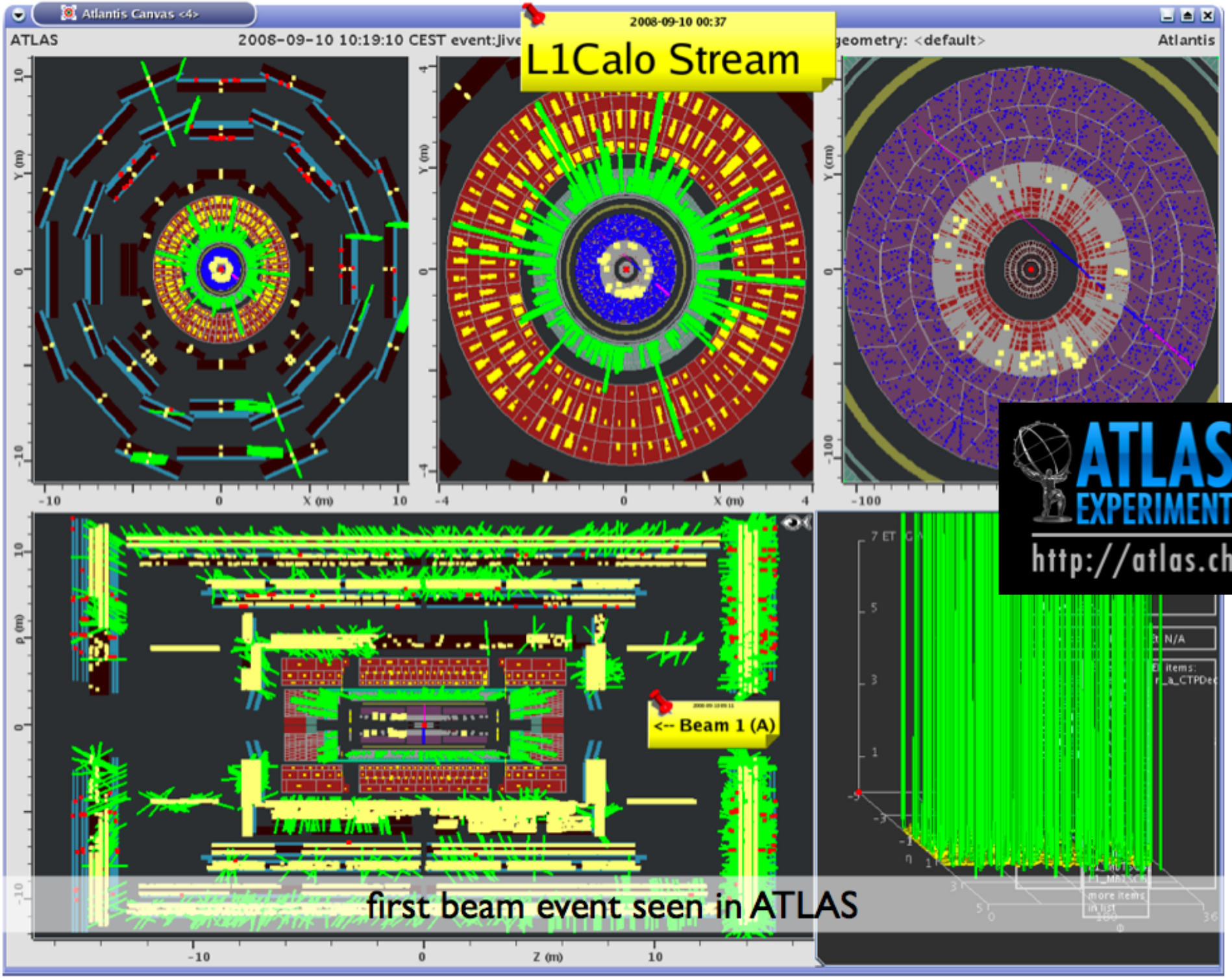
On 10 September, collimators 140m upstream of each experiment closed, as first beam sent around: “beam splash” events

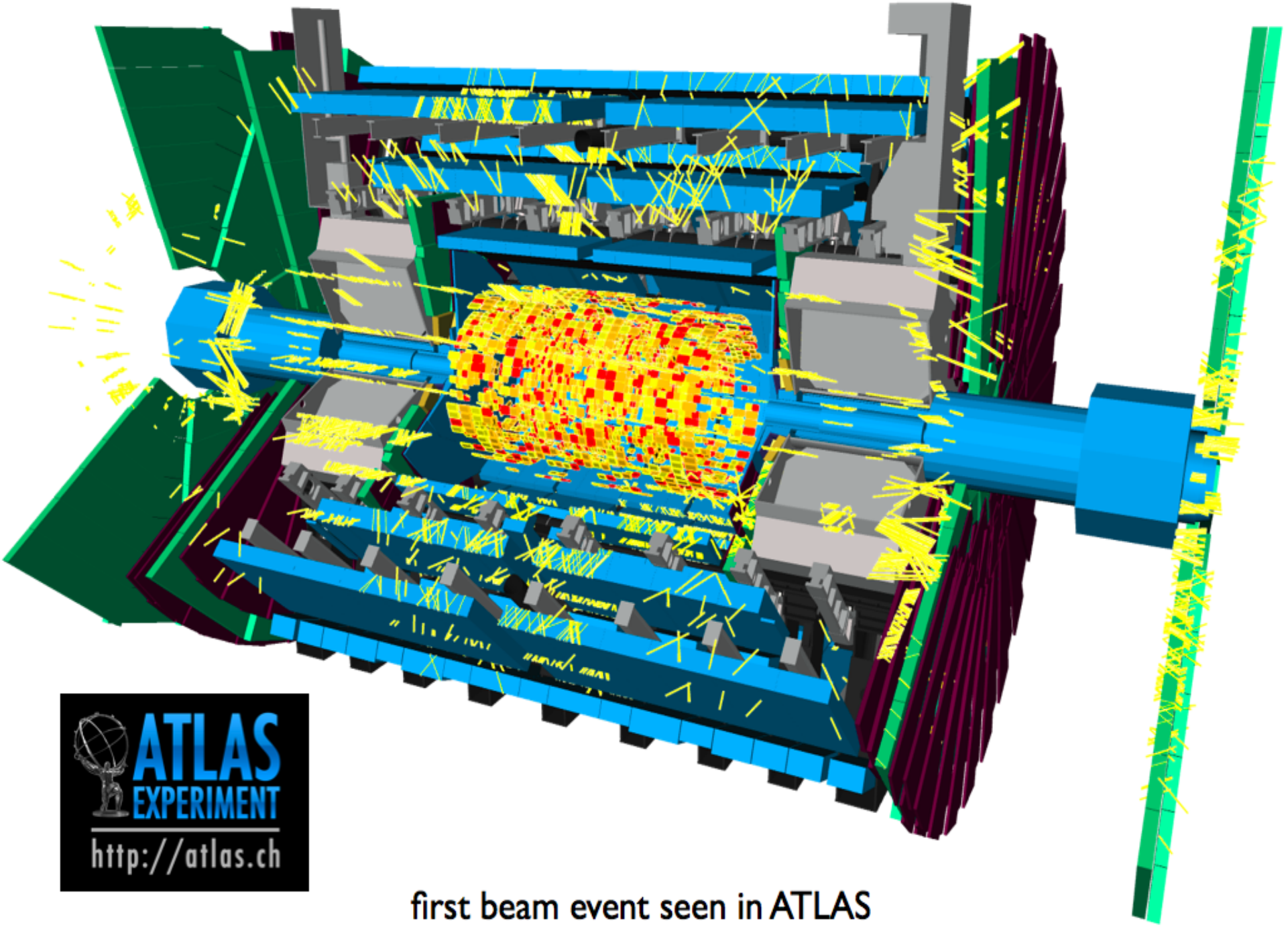
First Events: Collimators Closed

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

ECAL- pink; HB,HE - light blue; HO,HF - dark blue; Muon DT - green; Tracker Off

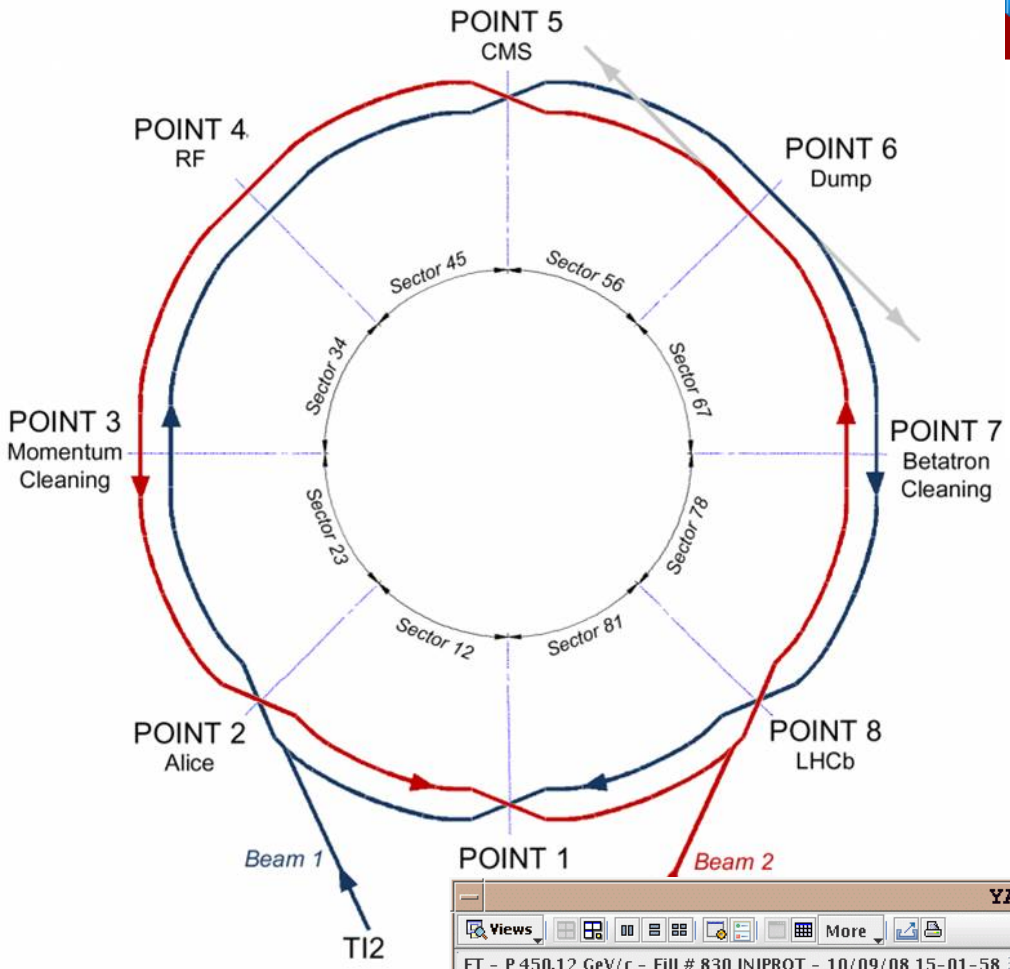



Atlantis Canvas <4>
ATLAS
2008-09-10 10:19:10 CEST event:Jive
geometry: <default>
Atlantis
2008-09-10 00:37
L1Calo Stream
ATLAS EXPERIMENT
http://atlas.ch
<-- Beam 1 (A)
first beam event seen in ATLAS



first beam event seen in ATLAS

er 2008



LIVE BREAKFAST

Page last updated at 16:01 GMT, Thursday, 4 September 2008 17:01 UK

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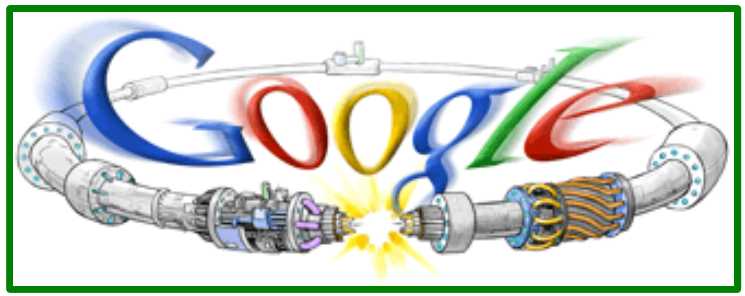
'Big Bang' experiment starts well

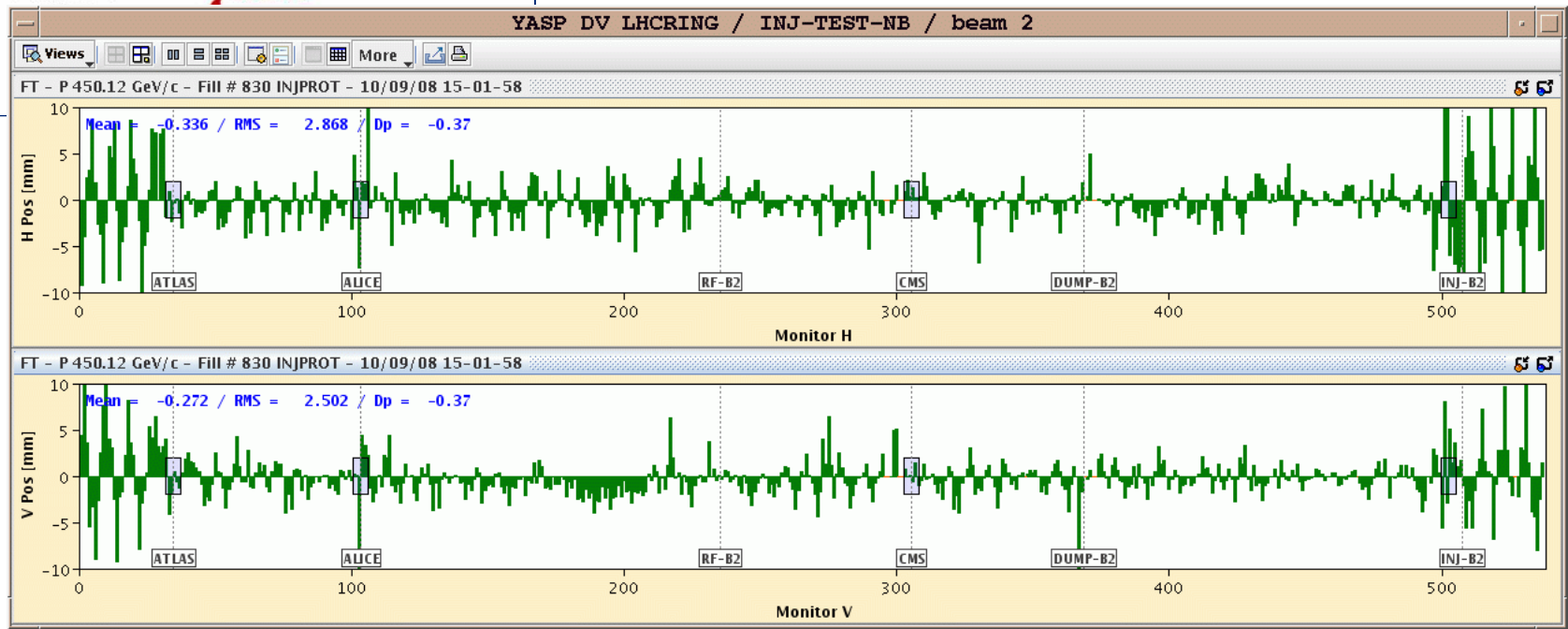
Guide | Science | Engineering | Computing | Q&A | Analysis

The Large Hadron Collider (LHC) will smash two beams of particles head-on at super-fast speeds, recreating the conditions in the Universe moments after the Big Bang, writes BBC science reporter Paul Rincon.

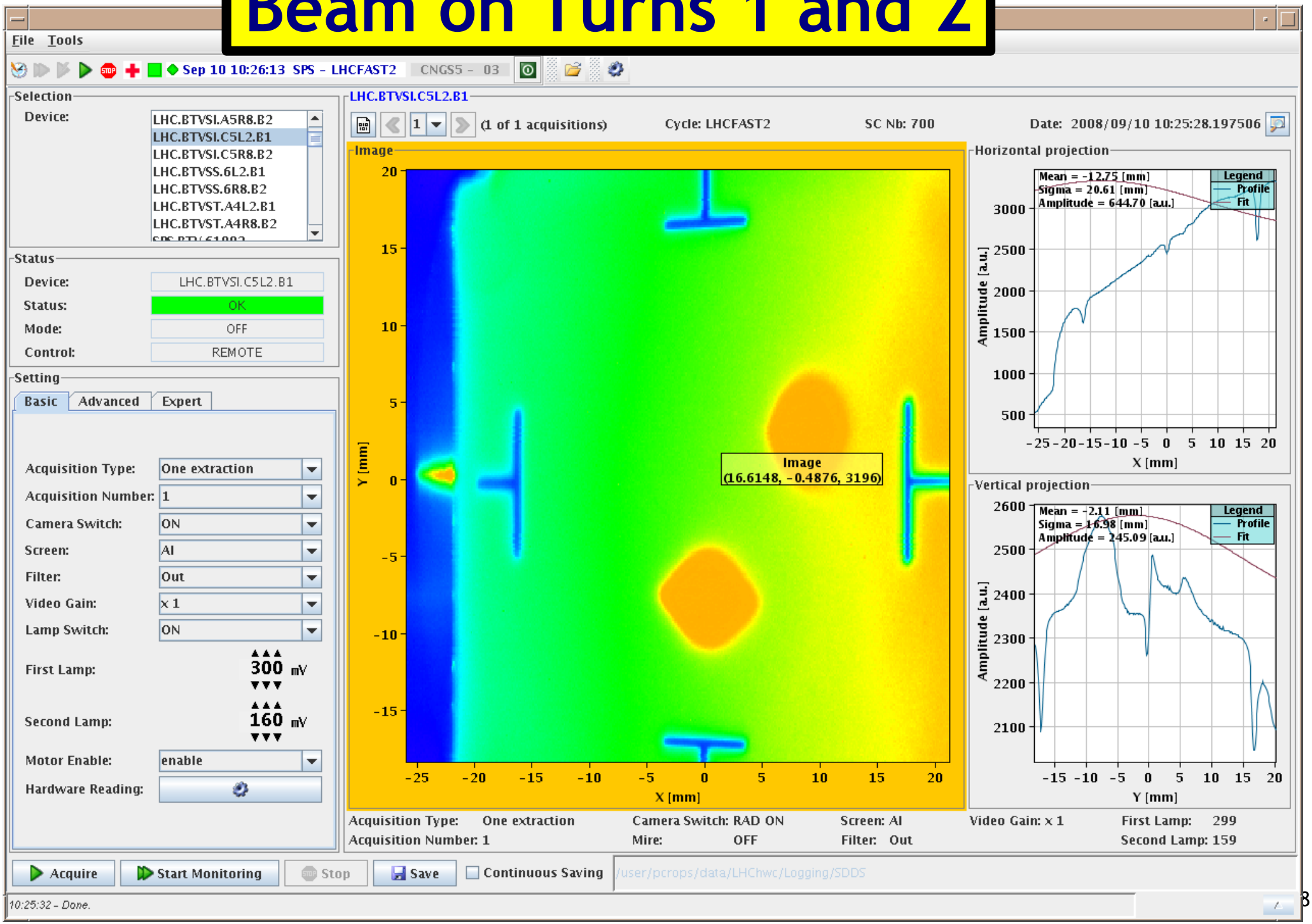
Scientists hope to see new particles

SEE ALSO
- Earth 'not at risk' from collider
  23 Jun 08 | Science & Environm
- Failure during Cern magnet test
  03 Apr 07 | Science & Environm

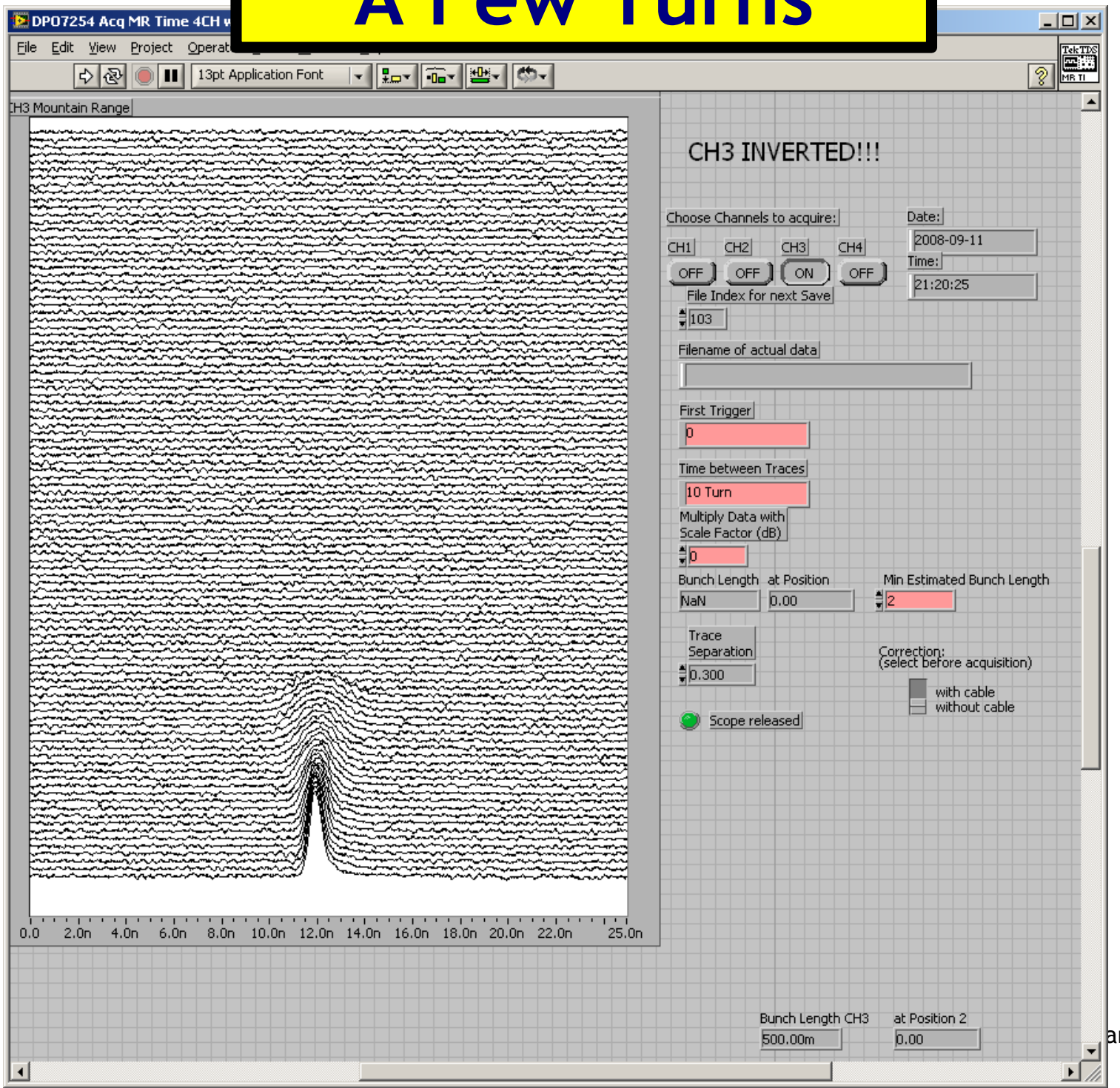




Beam on Turns 1 and 2



A Few Turns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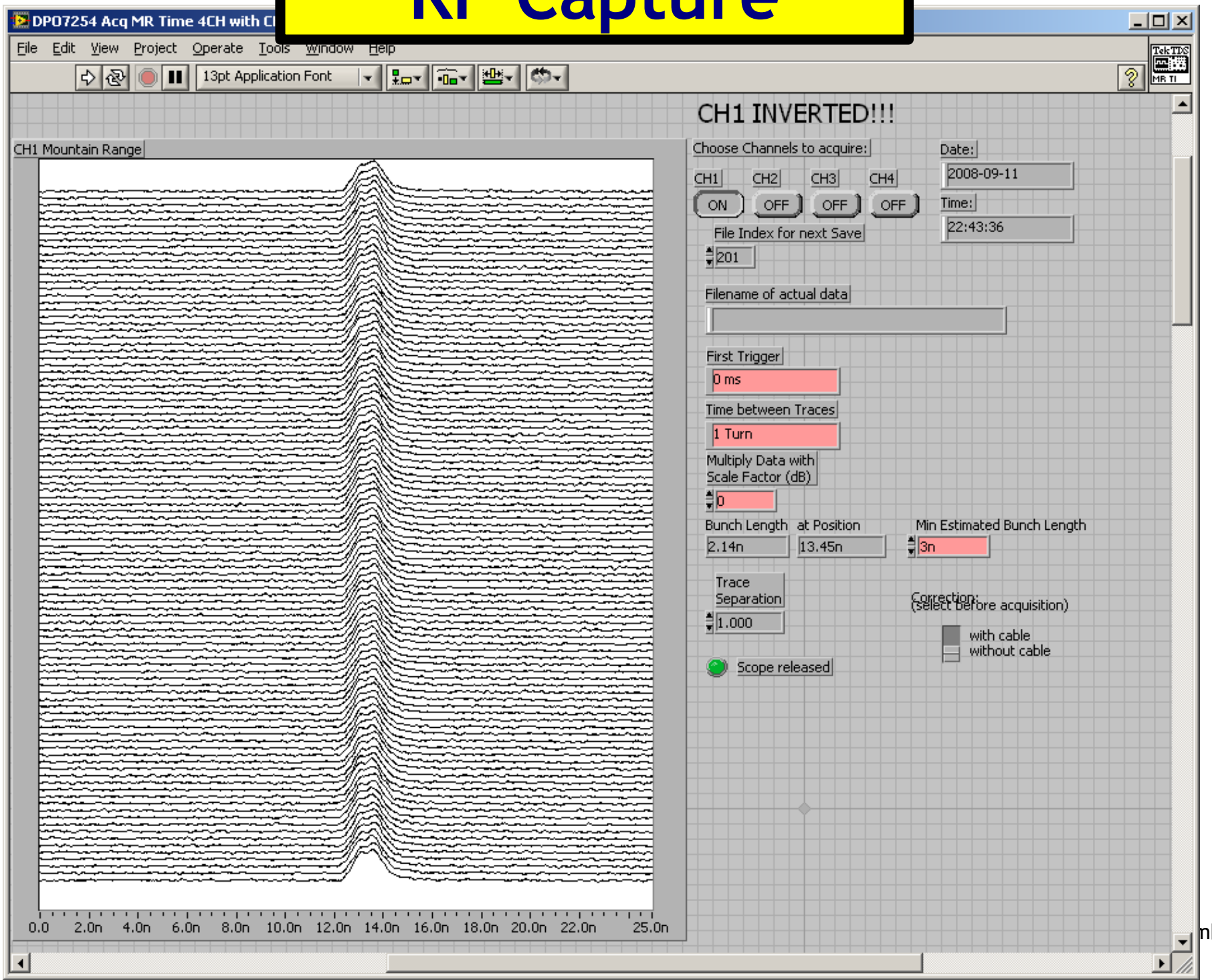
CH3 Mountain Range
0.0 2.0n 4.0n 6.0n 8.0n 10.0n 12.0n 14.0n 16.0n 18.0n 20.0n 22.0n 25.0n
CH3 INVERTED!!!
Choose Channels to acquire:
CH1 CH2 CH3 CH4
OFF OFF ON OFF
Date:
2008-09-11
Time:
21:20:25
File Index for next Save
103
Filename of actual data
First Trigger
0
Time between Traces
10 Turn
Multiply Data with Scale Factor (dB)
0
Bunch Length
NaN
at Position
0.00
Min Estimated Bunch Length
2
Trace Separation
0.300
Correction: (select before acquisition)
with cable
without cable
Scope released
Bunch Length CH3
500.00m
at Position 2
0.00

RF Capture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Choose Channels to acquire:
CH1 CH2 CH3 CH4
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Date:
2008-09-11
Time:
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File Index for next Save
201
Filename of actual data
First Trigger
0 ms
Time between Traces
1 Turn
Multiply Data with Scale Factor (dB)
0
Bunch Length
2.14n
at Position
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Min Estimated Bunch Length
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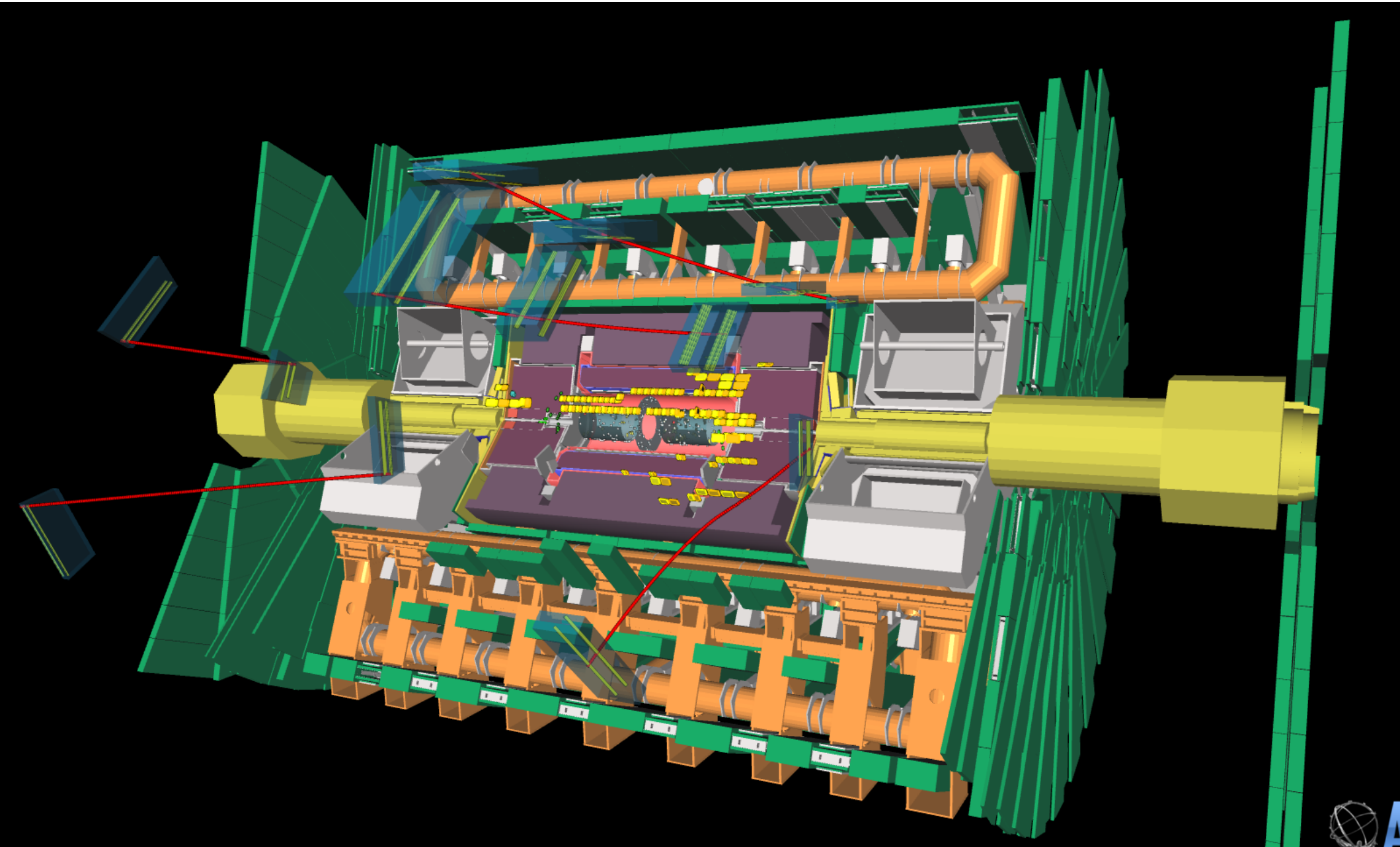
Correction:
(select before acquisition)
with cable
without cable
Scope released



Experiment Status

All four experiments: ready and waiting!

ATLAS/CMS very largely complete, small pieces missing, eg:

- ATLAS: muon chambers in barrel/endcap overlap region
- CMS: preshower detector in endcap

Plus additional “staged” parts, such as trigger processing capacity

Beam splash events tremendously useful – especially for timing

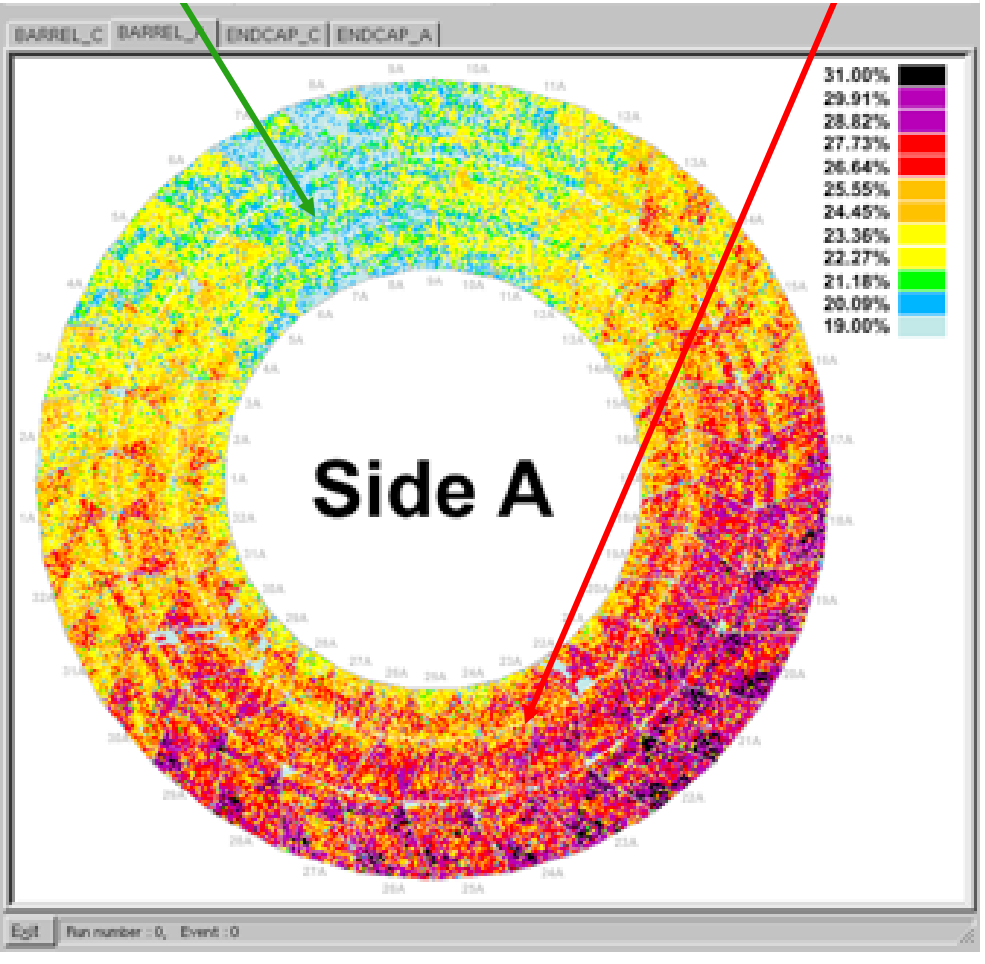
The few days of single beam less so: beam conditions were too clean!

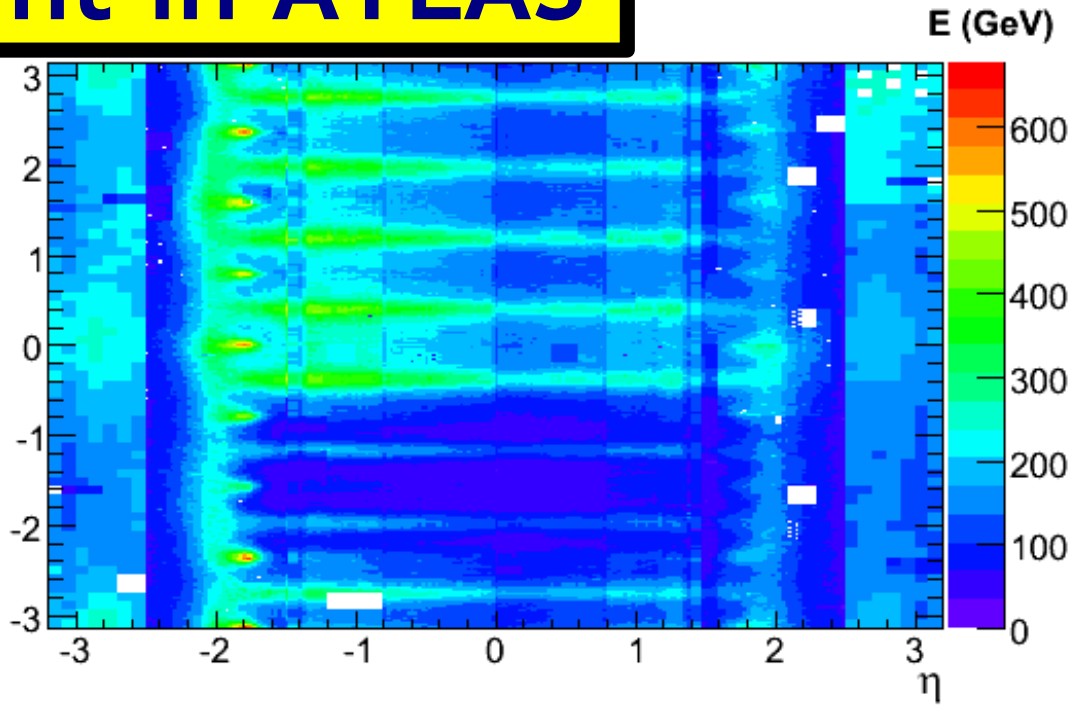
Splash event in ATLAS

D Froidevaux

Timing of all TRT readout channels could be performed with accuracy of ~ 1 ns per event! Differences in colour due to cosmic timing:

Top: early **Bottom: late**





2D display in η–ϕ of energy deposited in LAr EM calorimeter per cell (layer 2):

- **structures seen are due to material between collimators and calorimeter (mostly 8-fold structure of end-cap toroid coils)**
- **energy seen per event is huge!**

Incident on 19th September

After P Jenni (CERN)
ICPP Istanbul, 27-10-08,

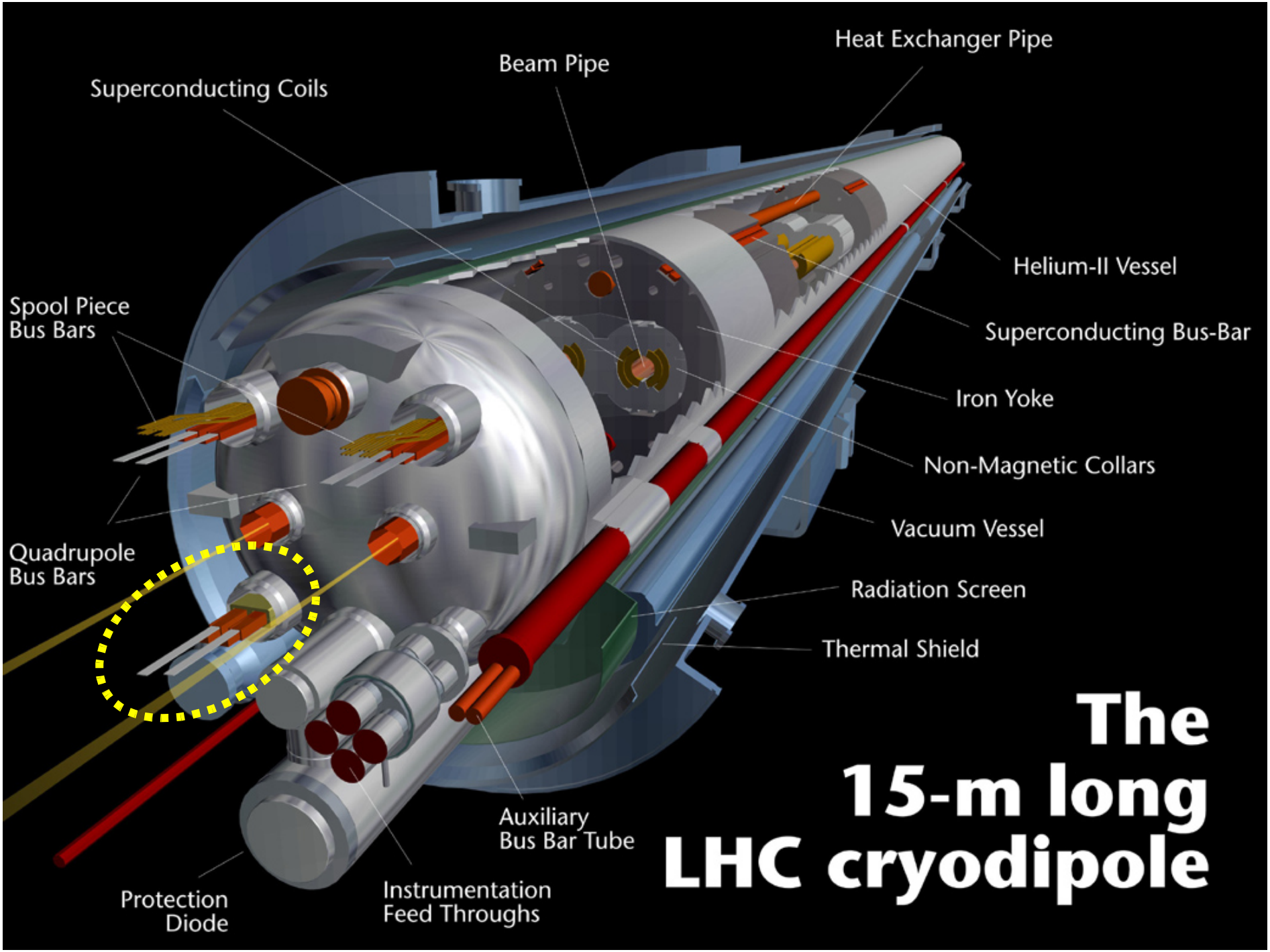
The LHC decided to use the few days of down-time to continue work on powering tests

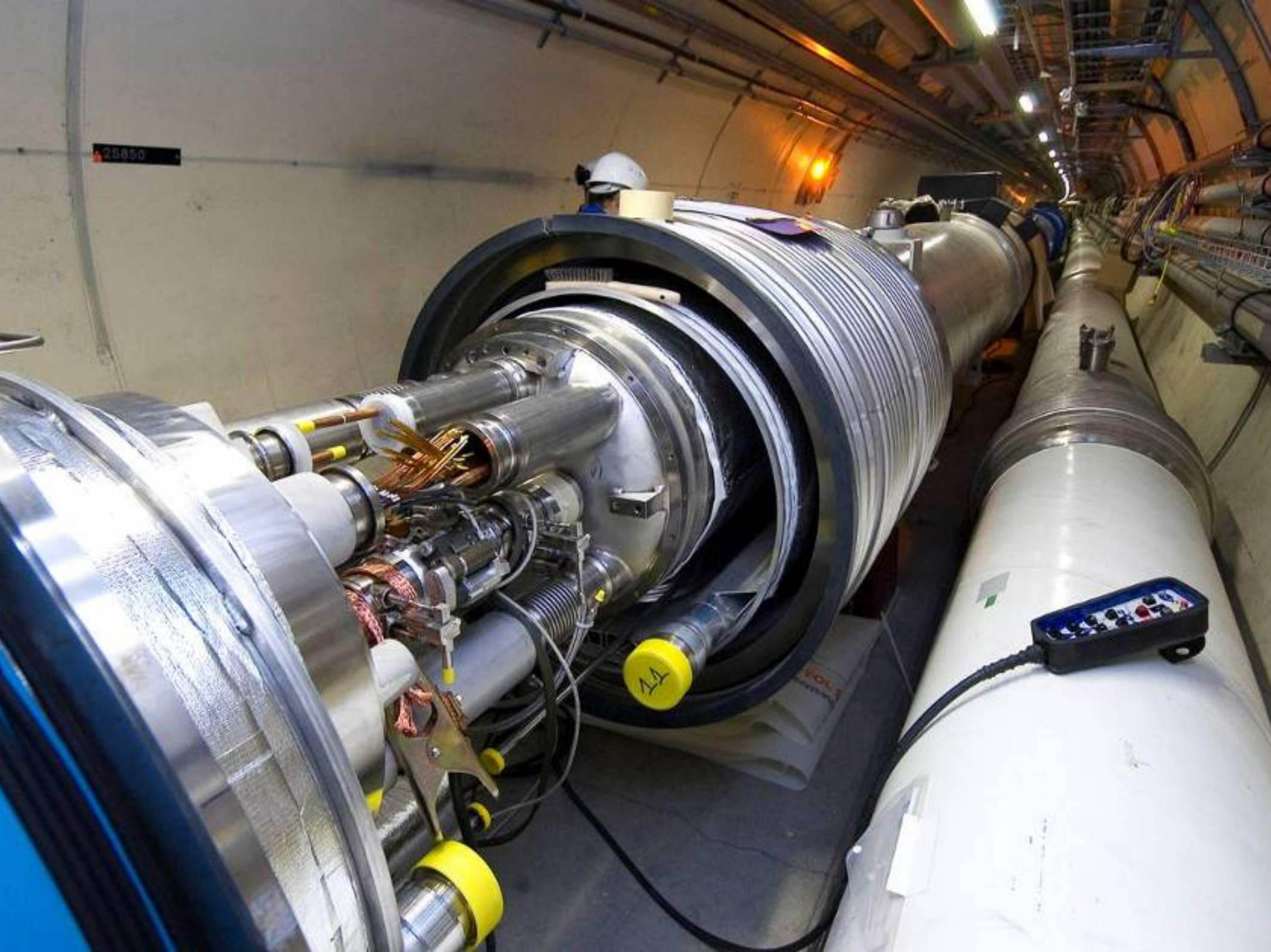
During commissioning of the last main bend circuit to 5 TeV an incident occurred resulting in the triggering of quench heaters of about 100 magnets and a large He discharge into the tunnel

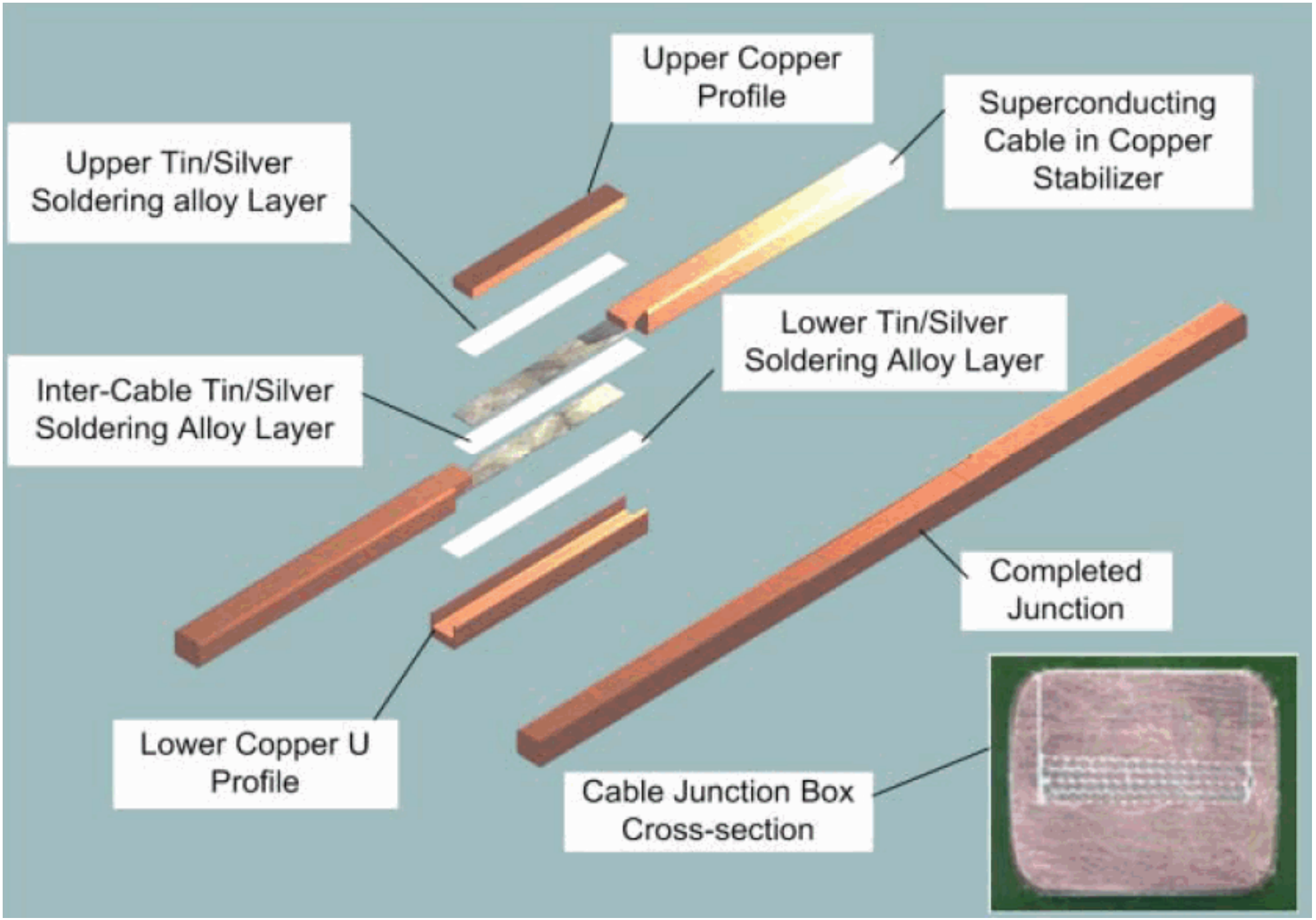
This resulted in mechanical damage in a part of this sector

The cause was a faulty electrical connection between two magnets, and the repair work actions have now started, about 30 magnets will have to be replaced

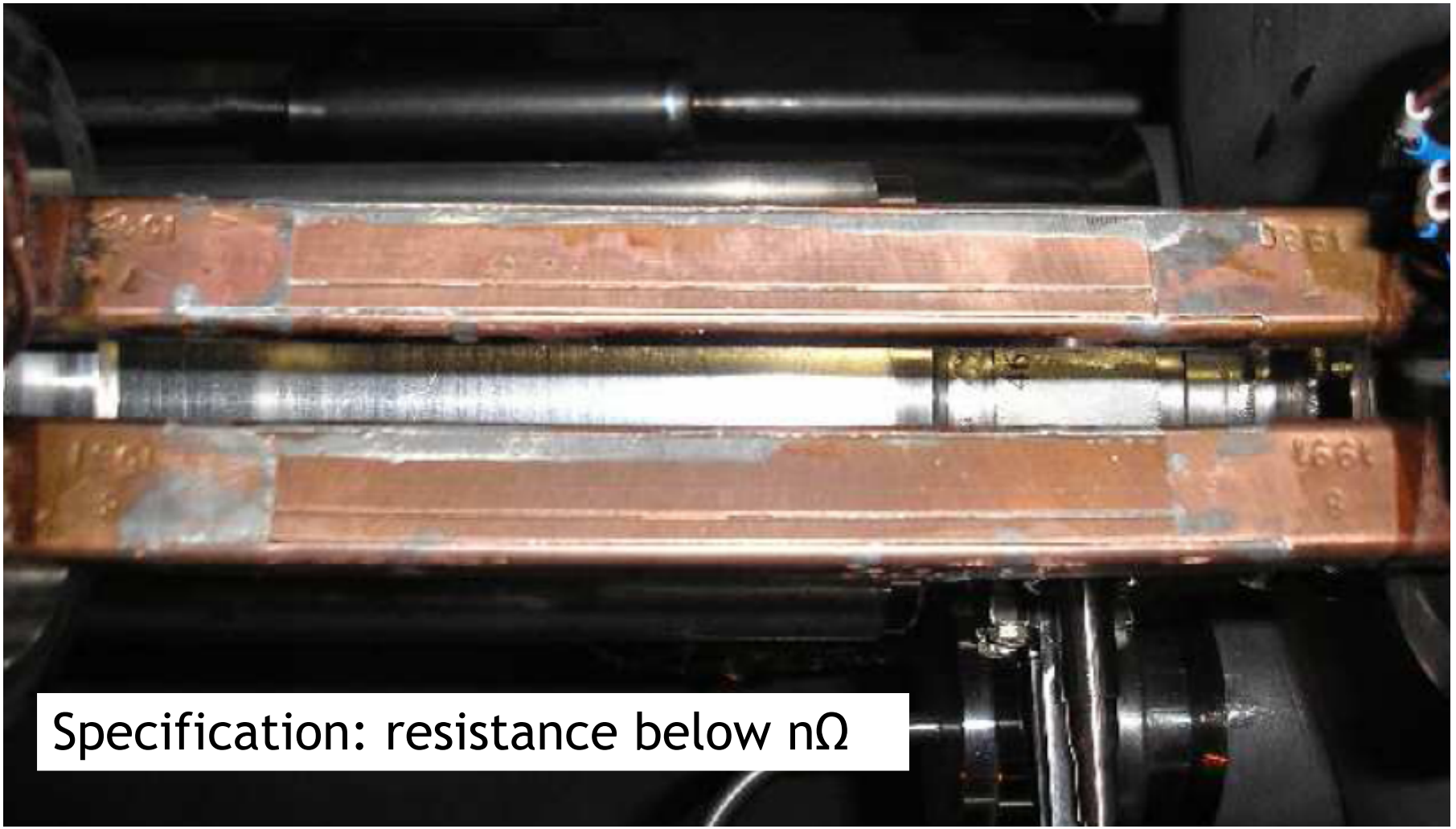
The exact start-up schedule is not yet known, it will be after the winter shut-down in spring (the ATLAS planning is to be ready in May 2009)


Heat Exchanger Pipe
Beam Pipe
Superconducting Coils
Helium-II Vessel
Spool Piece
Bus Bars
Superconducting Bus-Bar
Iron Yoke
Non-Magnetic Collars
Vacuum Vessel
Quadrupole
Bus Bars
Radiation Screen
Thermal Shield
The
15-m long
LHC cryodipole
Auxiliary
Bus Bar Tube
Protection
Diode
Instrumentation
Feed Throughs

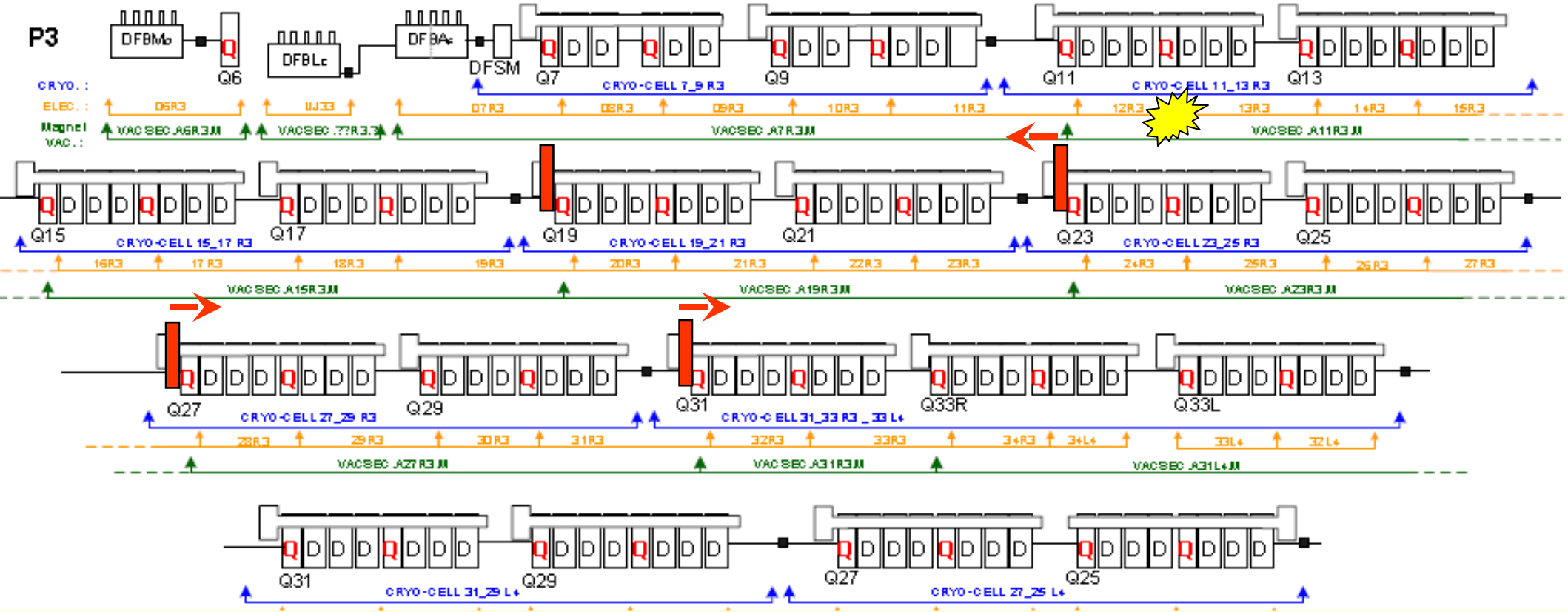

25850


Upper Copper Profile
Superconducting Cable in Copper Stabilizer
Upper Tin/Silver Soldering alloy Layer
Lower Tin/Silver Soldering Alloy Layer
Inter-Cable Tin/Silver Soldering Alloy Layer
Completed Junction
Lower Copper U Profile
Cable Junction Box Cross-section

Soldered Interconnect



Damaged Zone



Insulating vacuum barrier every 2 cells in the arc → **Some moved**

- Considerable collateral damage over few hundred metres
- Contamination by soot of beam pipes
- Damage to super-insulation blankets
- Large release of Helium into the tunnel (6 of 15 tons)


FEIN Elektrowe

Ongoing repairs and plans

- 53 magnets (39 dipoles and 14 quadrupoles) transported to surface for repairs or cleaning. Will be re-installed by end of March.
- Three sectors warmed up: Sector 34, Sector 12 (a resistive interconnect detected inside one dipole → dipole will be replaced), Sector 56 (various repairs).
- Dedicated system for early detection of abnormal electrical resistance on the high-current busbars will be installed in the whole machine.
- Number and size of He relief valves will be increased to mitigate the consequences of any incident giving rise to massive release of He in the insulation vacuum closure. Will be made in the three warm sectors in Winter 2009, and in the rest of the machine in the Winter 2010 shutdown and later.
- The mechanical fixation to the concrete floor of the quadrupoles at the location of the vacuum barriers will be strengthened.
- Additional planned consolidation and maintenance work will be performed.

According to the present plan, the full machine will be cold again on 1st July 2009, ready for the powering tests.

The path toward higher and higher luminosity

J.Wenninger
CERN-FNAL HC School
June 2007

Parameter	Phase A	Phase B	Phase C	Nominal
k / no. bunches	43-156	936	2808	2808
Bunch spacing (ns)	2021-566	75	25	25
N (10^{11} protons)	0.4-0.9	0.4-0.9	0.5	1.15
Crossing angle (μ rad)	0	250	280	280
$\sqrt{(\beta^*/\beta^*_{nom})}$	2	$\sqrt{2}$	1	1
σ * (μ m, IR1&5)	32	22	16	16
L ($cm^{-2}s^{-1}$)	$6x10^{30}$-10^{32}	10^{32}-10^{33}	$(1-2)x10^{33}$	10^{34}
Year ? (a guess)	2009	2010	2010-2011	> 2011
∫ Ldt ? (my guess)	some 10's pb^{-1}	few fb^{-1}	O(10 fb^{-1})	O(100 fb^{-1})

Note: at regime, ~ $6x10^6$ s of pp physics running per year
→ ~ 0.6 fb^{-1} /year if L= 10^{32}
~ 6 fb^{-1} /year if L= 10^{33}
~ 60 fb^{-1} /year if L= 10^{34}

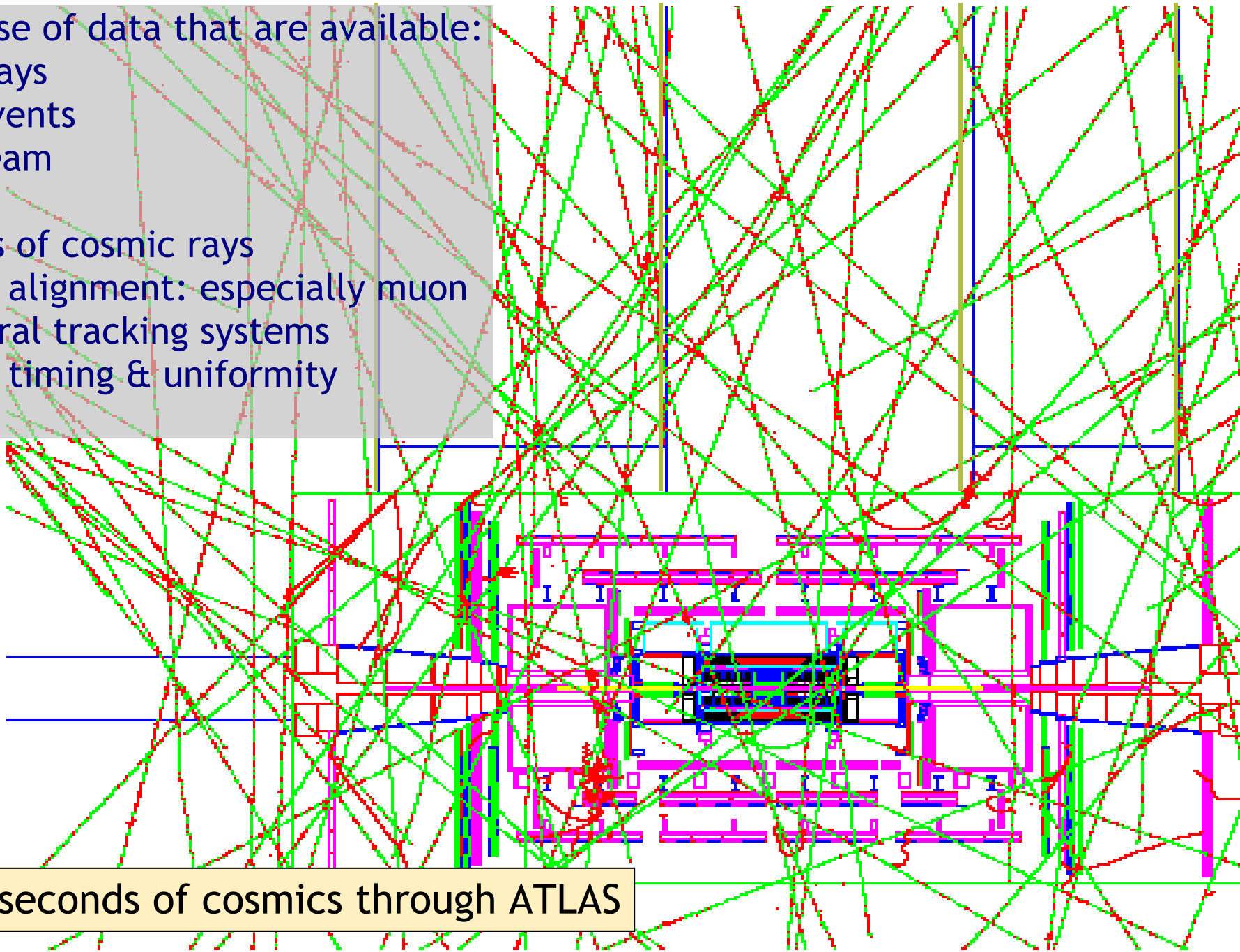
Commissioning with 2008 Data

Very much use of data that are available:

- Cosmic rays
- Splash events
- Single beam

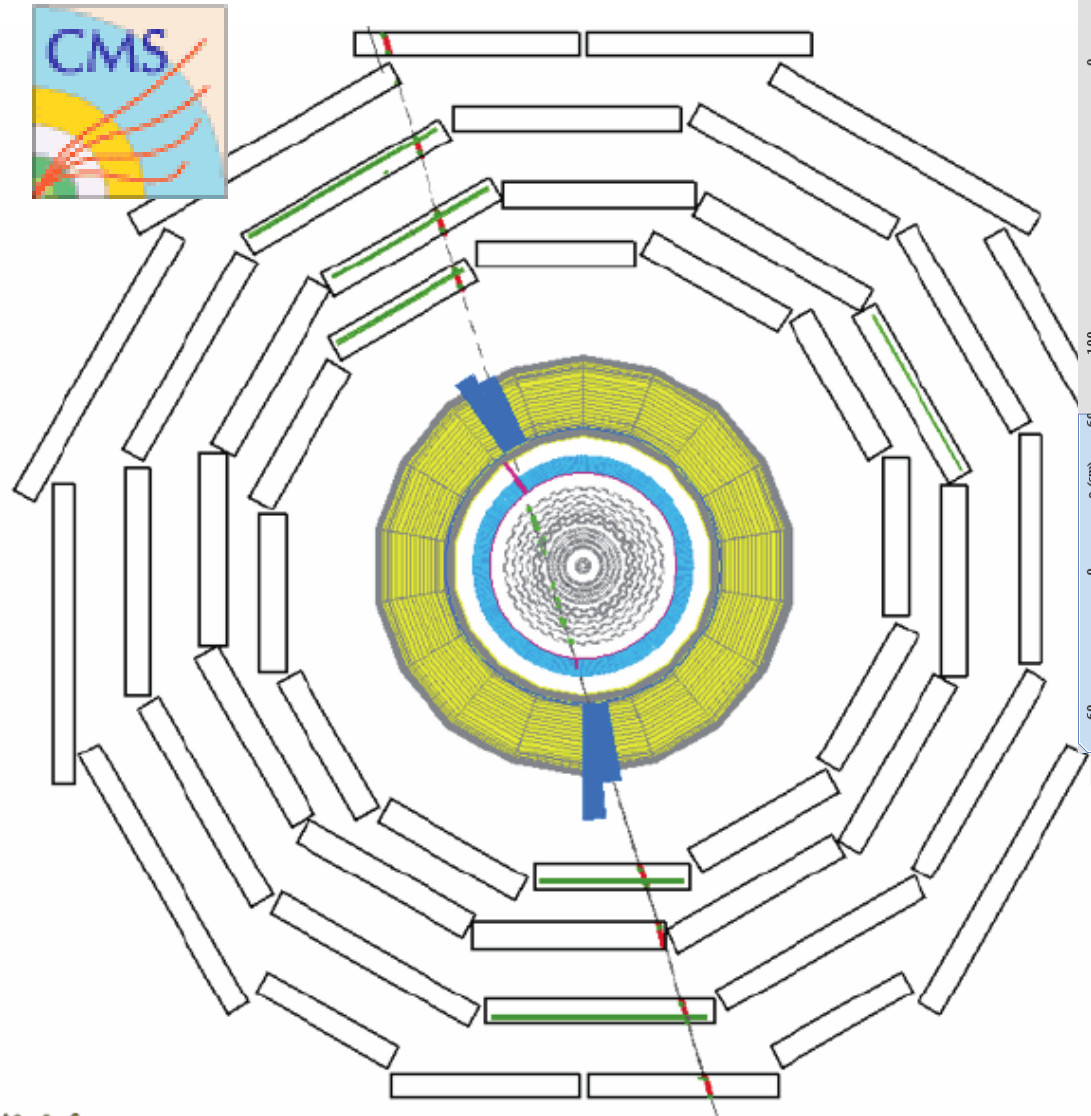
Many months of cosmic rays

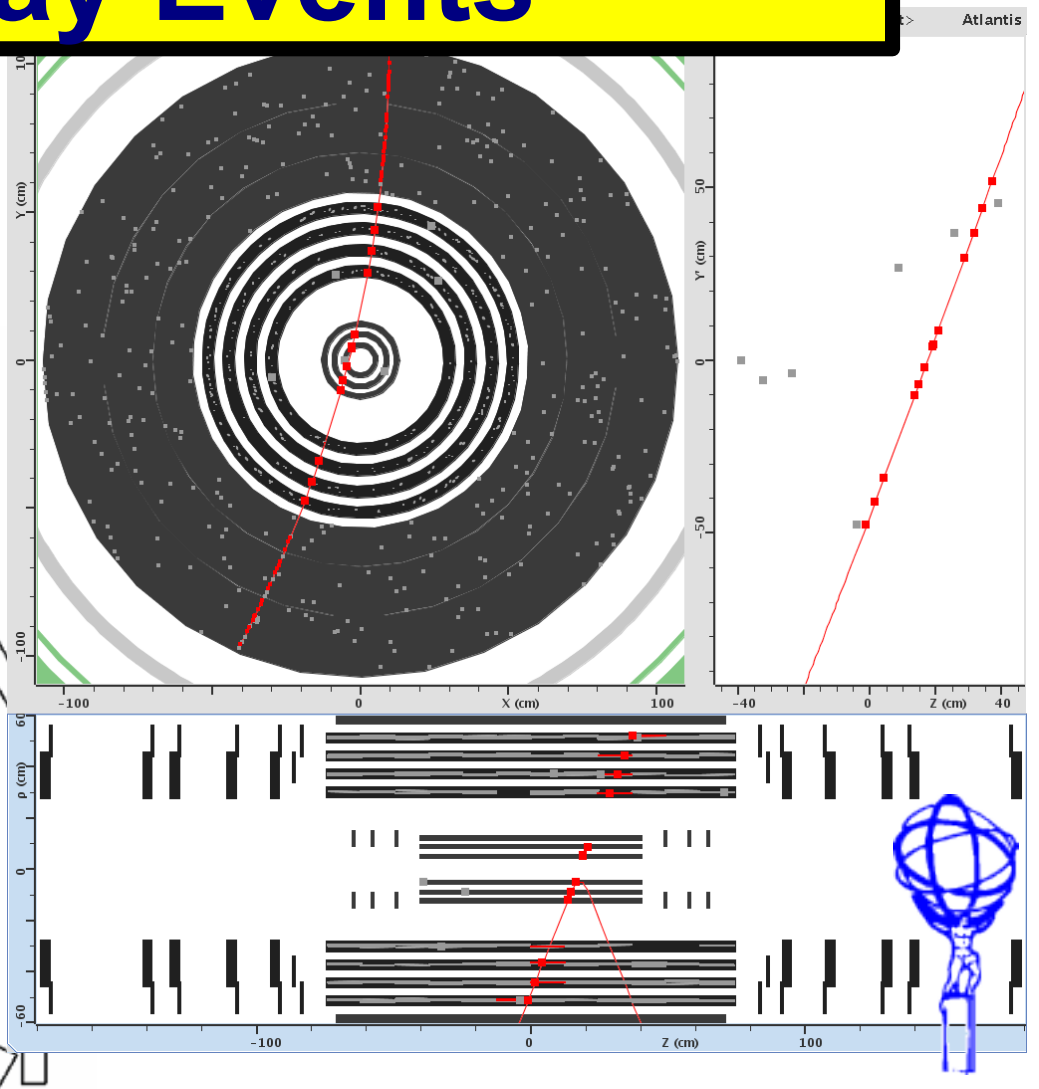
- Detector alignment: especially muon and central tracking systems
- Detector timing & uniformity
- ...



10 milliseconds of cosmics through ATLAS

Cosmic-Ray Events



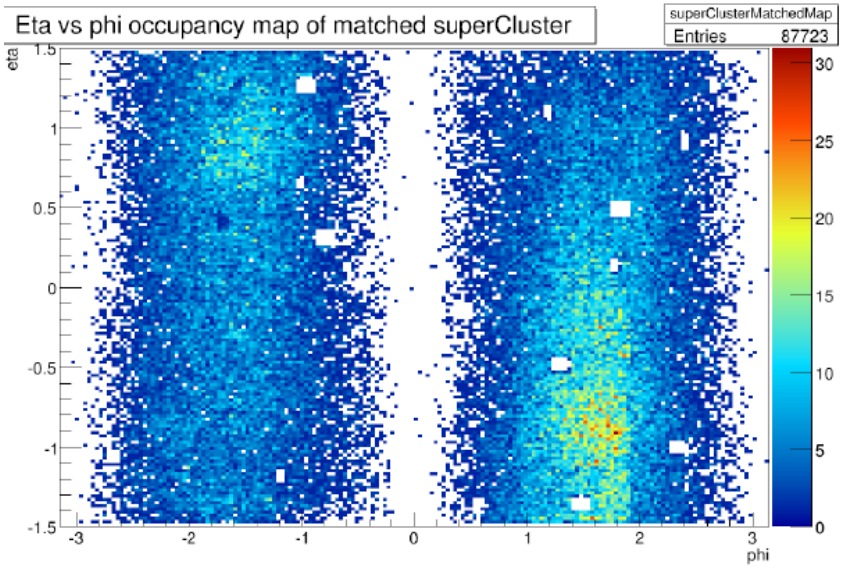


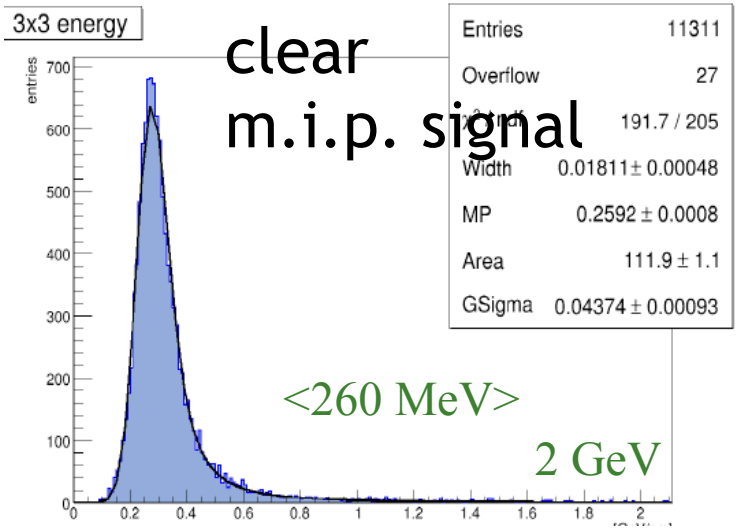
Dave Charlton(Birmingham), 20 December 2008

Example: CMS Electromagnetic Calorimeter

A "Dee" of endcap ECAL

Barrel ECAL clusters matching muon tracks

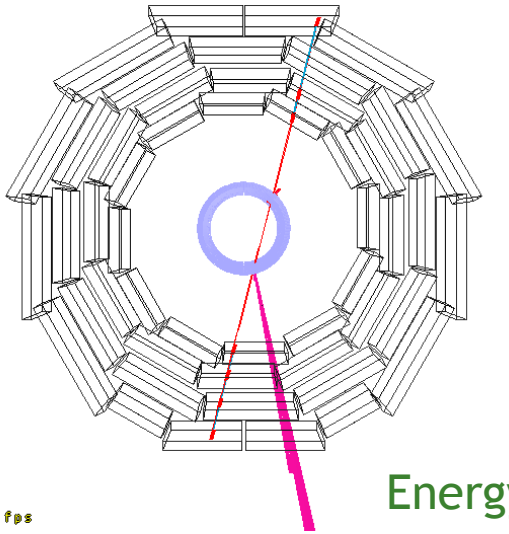




clear m.i.p. signal

<260 MeV>

2 GeV



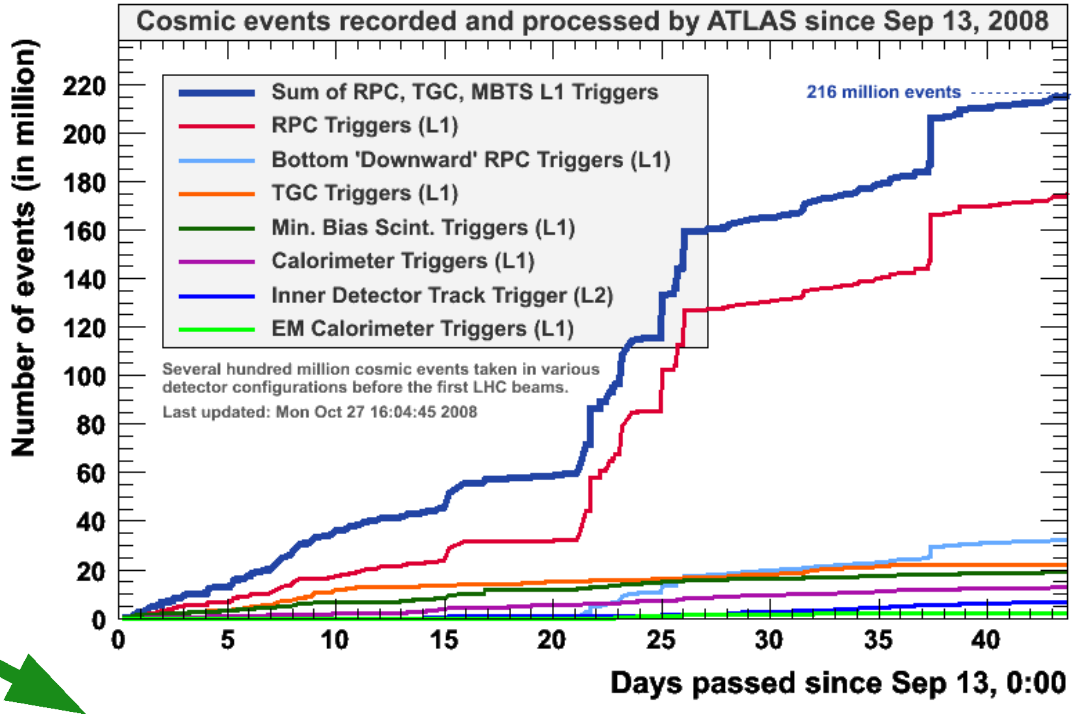
sometimes:

huge energy deposition from cosmic muon in ECAL

Energy: 250 GeV

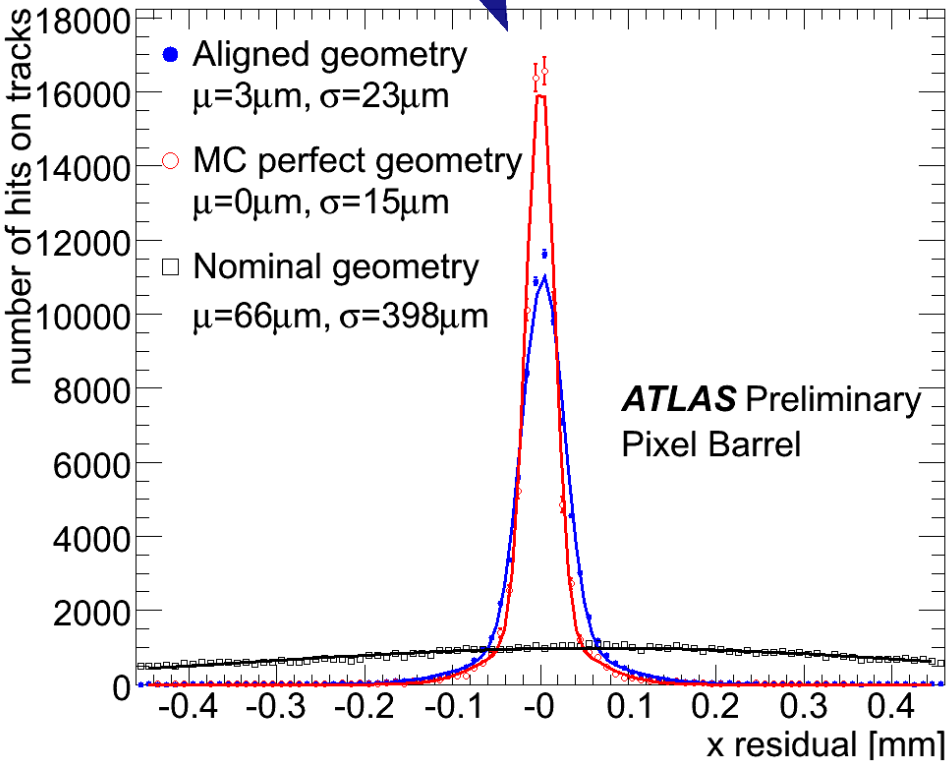
Using Cosmics

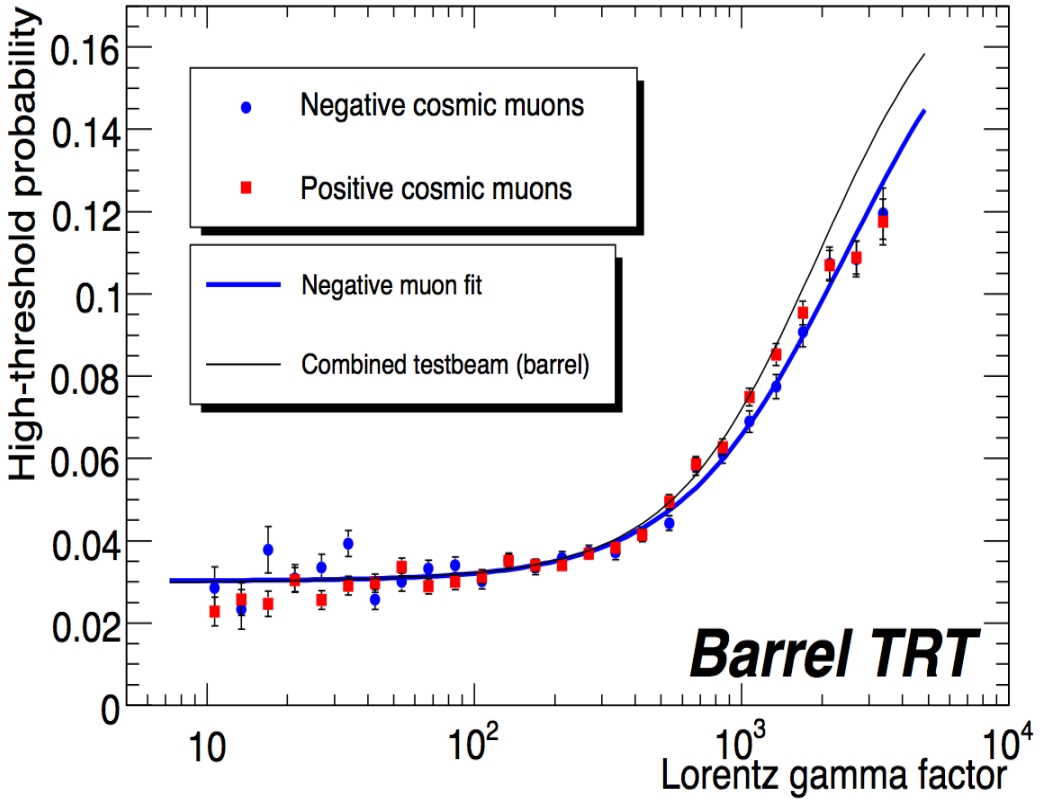
>200 million cosmic ray events since Sept



See transition radiation turn-on with μ !

Pixel detector alignment



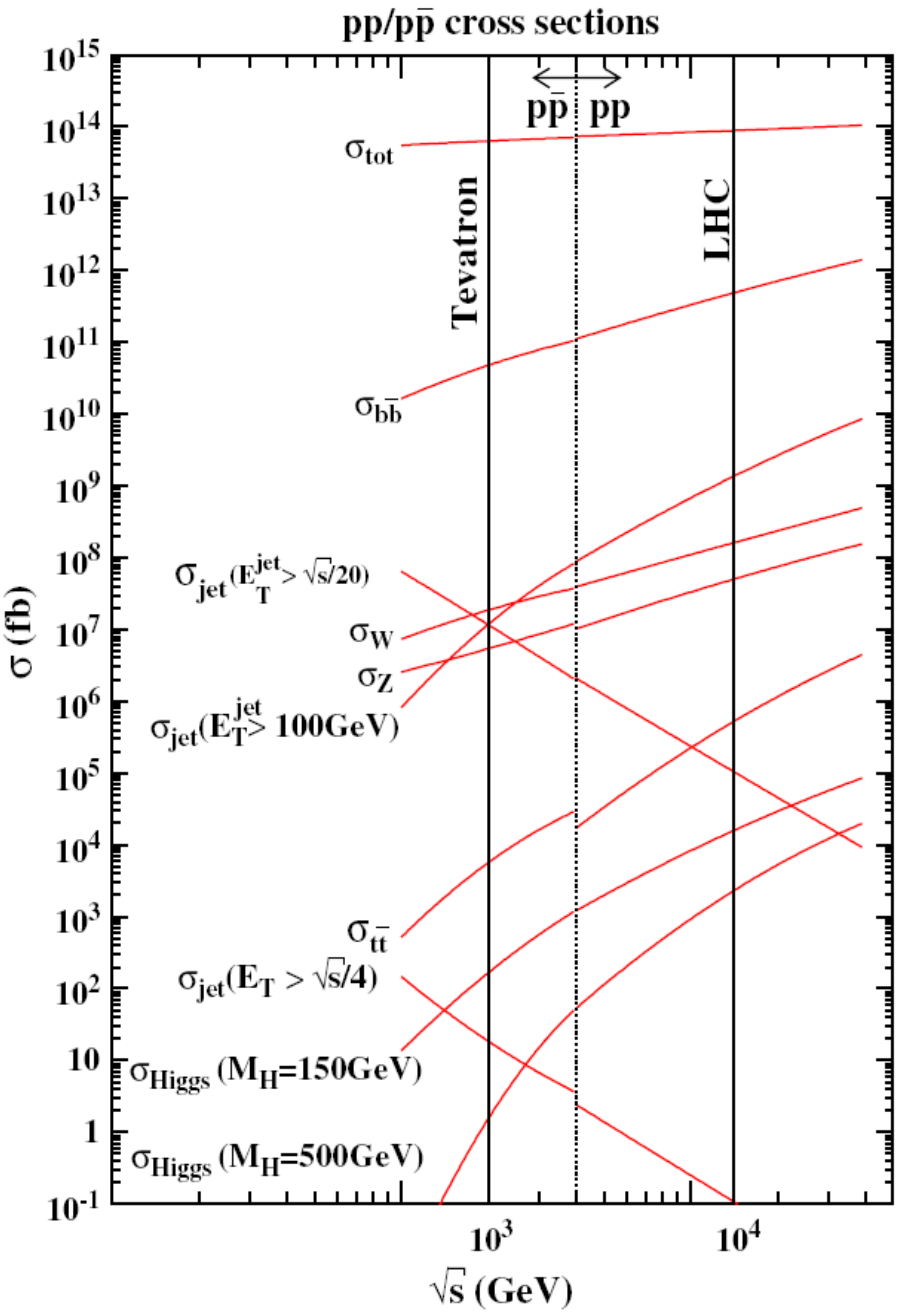


Physics Commissioning

First collisions: work to establish detector and trigger performance, measure Standard Model processes

- Min bias – timing in, tracking & calorimeter uniformity & performance
- Dijets – calorimeter uniformity, jet uniformity and inter-calibration
- γ-jet – photon ID, jet energy scale
- J/ψ – μ ID, tracking performance (e ID)
- bb – lifetime-based b-tagging
- W/Z – e/μ ID, resolutions, efficiencies, τ ID (in time), missing E_t
- Z+jets – jet energy scale
- Top – many things, once we have statistics...

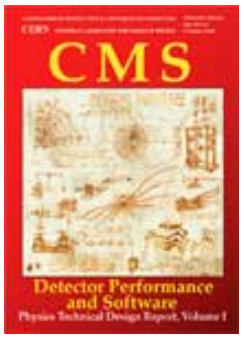
You will need to be patient – this will take some time...

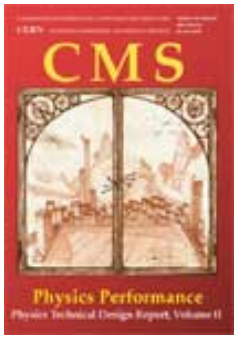


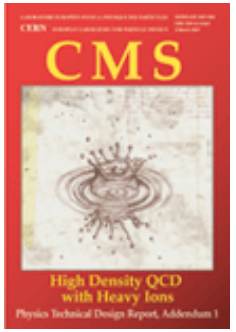
Recent Summaries

CMS "Physics TDR" 2006/7

Vol I : CERN-LHCC-2006-001
Vol II : JphysG 34 (2007) 995-1579
Vol II : JphysG 34 (2007) 2307-2455







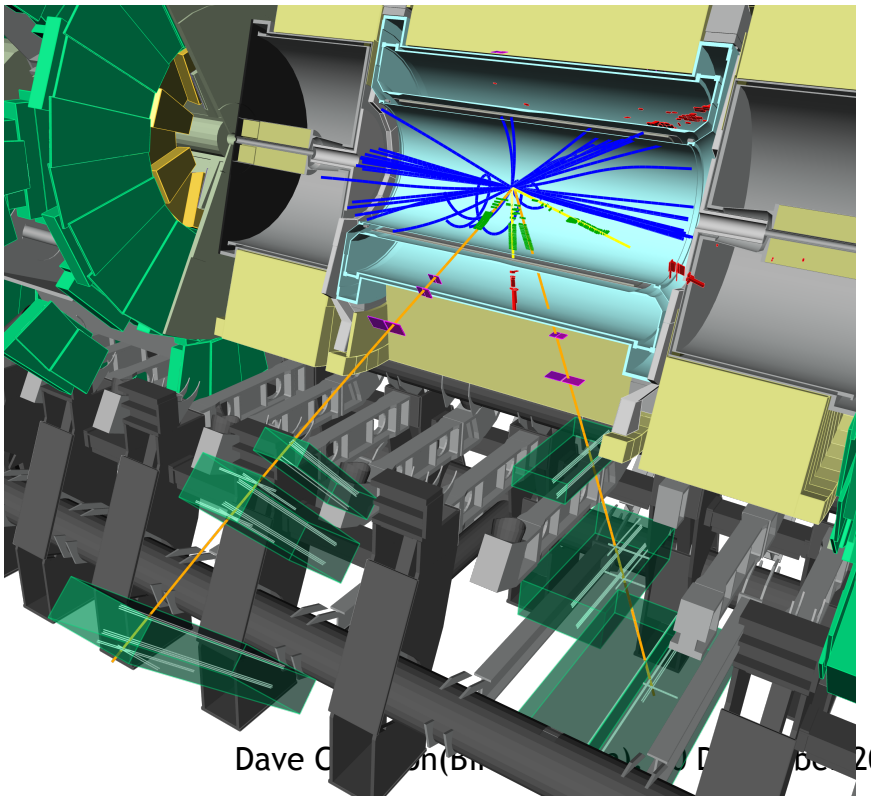
Both cases:

Comprehensive reviews of physics capabilities, mainly for first years of LHC operation

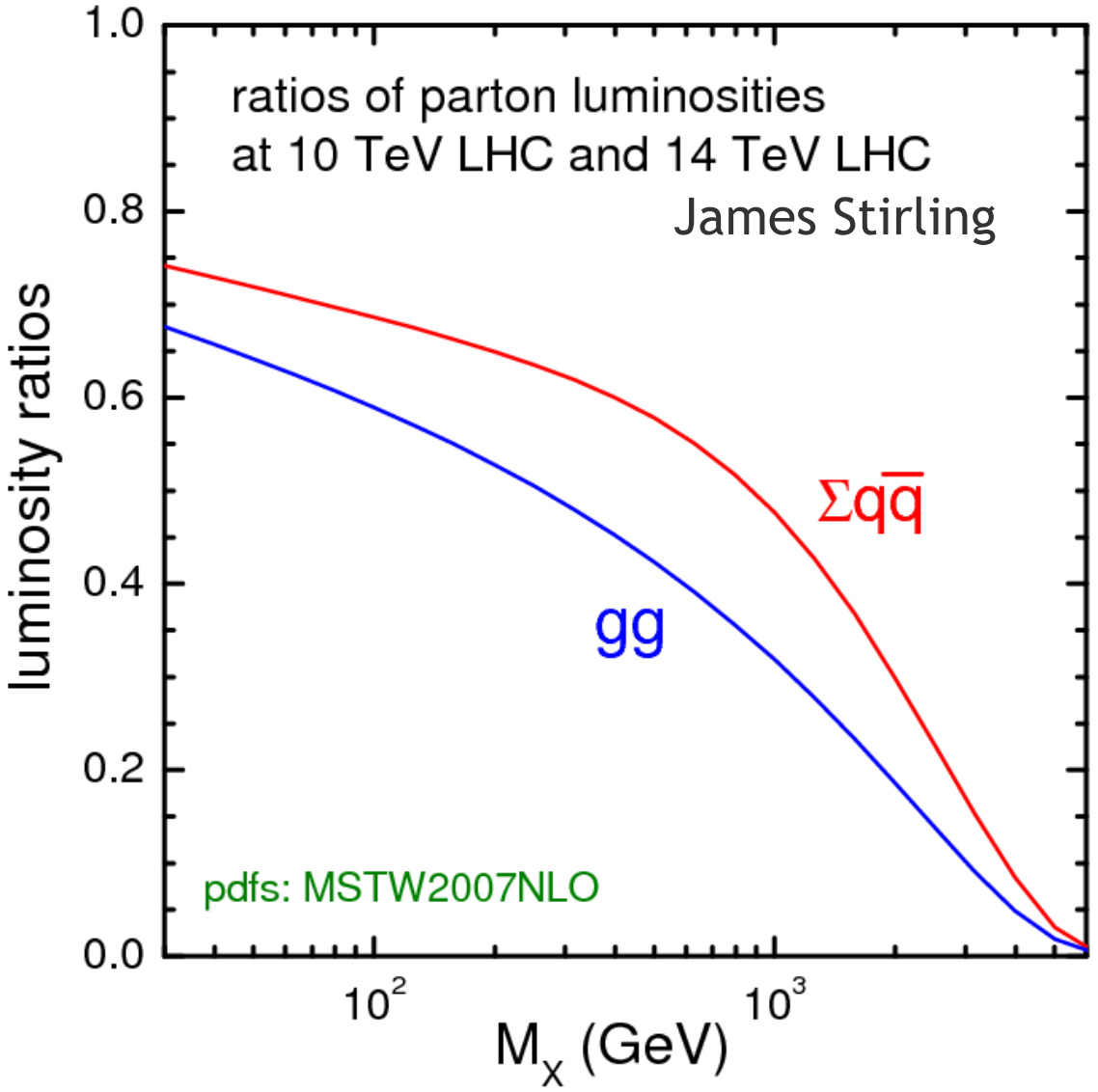
ATLAS "CSC book" Dec 2008

Expected Performance of the ATLAS Experiment
Detector, Trigger and Physics

CERN-OPEN-2008-020; to appear next week, also on the arXiv



10 vs 14 TeV?



At 10 TeV, lower cross-section for high mass objects due to lower parton luminosities...

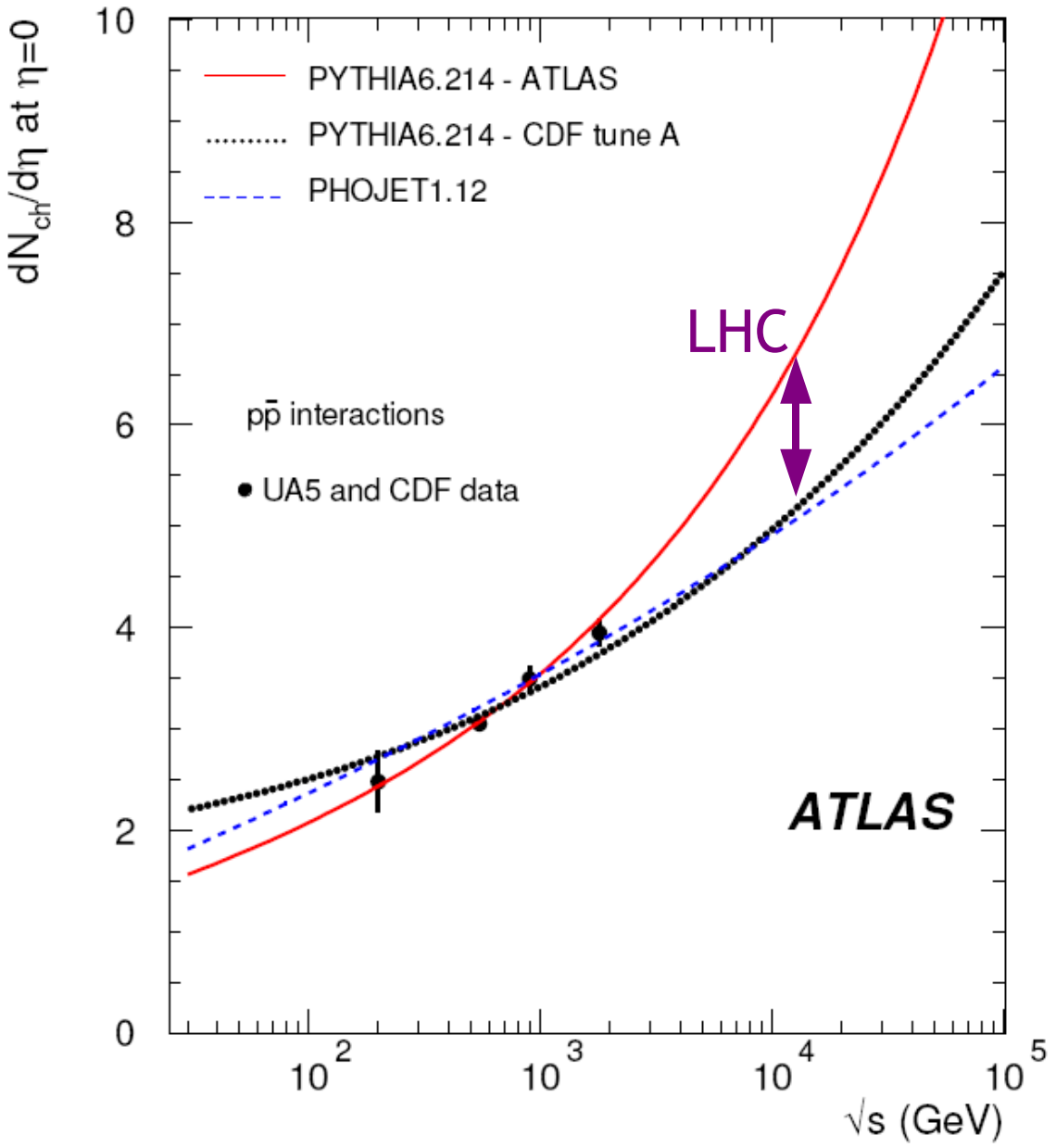
Below about 200 GeV, the suppression is <50% (process dependent)

- e.g. $t\bar{t}$ ~ factor 2 lower cross-section (still 50x Tevatron)

Above ~2-3 TeV the effect is more marked

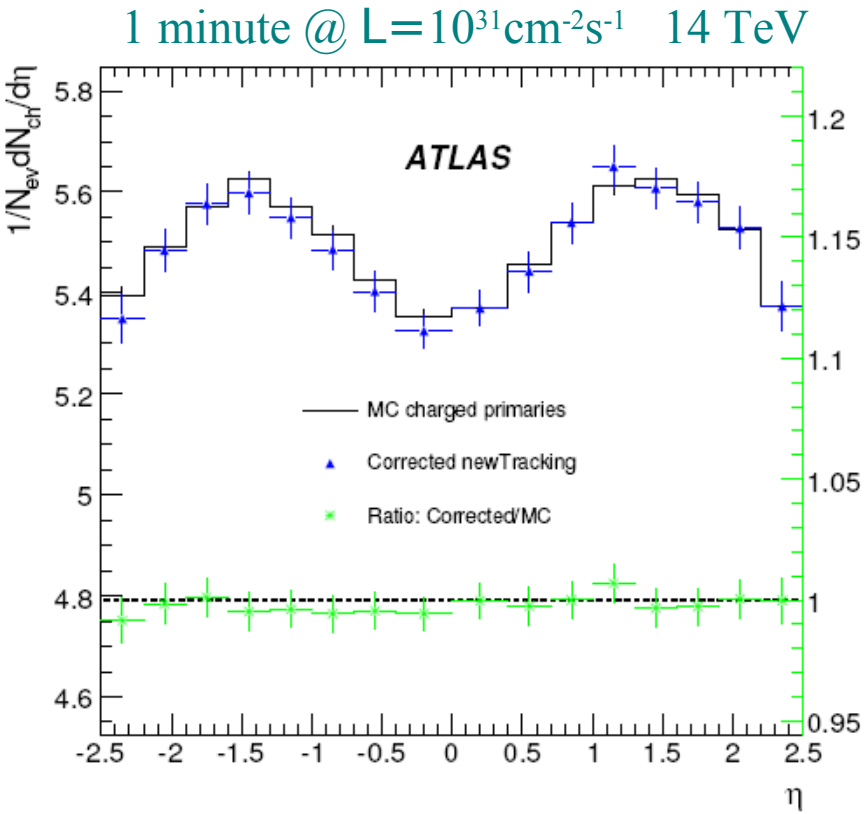
The rest of the talk discusses $\sqrt{s}$=14 TeV capabilities

Minimum Bias



Central charged particle multiplicity (η=0)

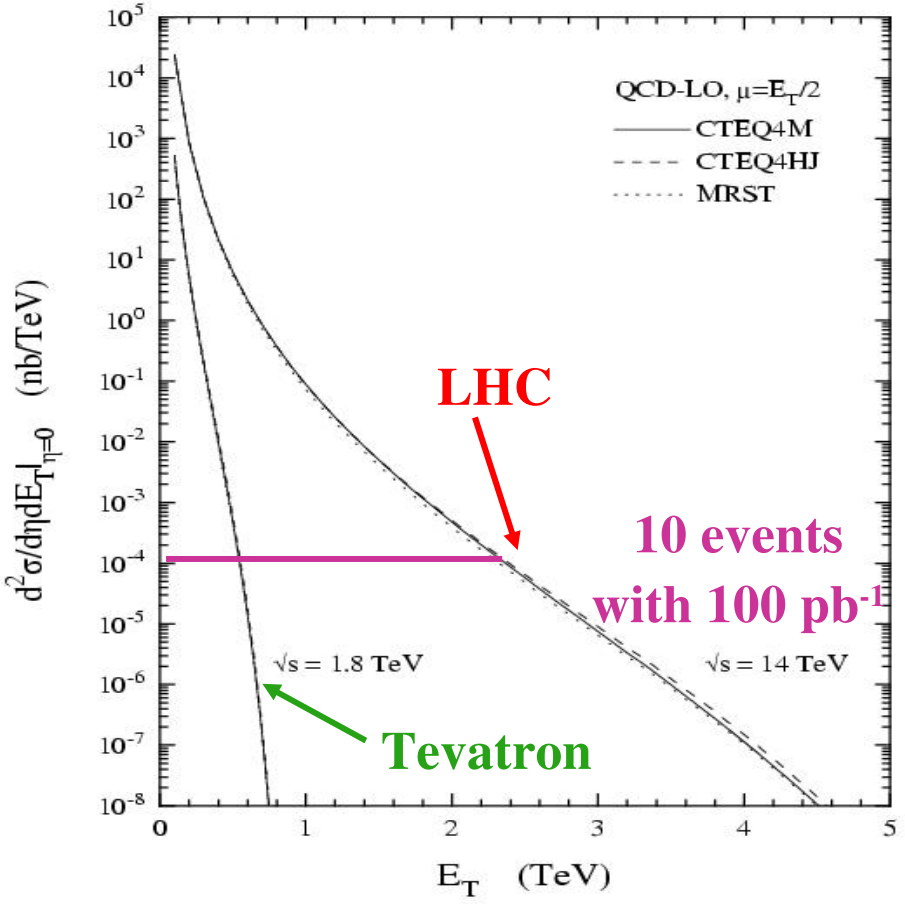
- requires min-bias triggers, beam-gas backgrounds, and inner tracking to be understood
- requires **very** little data for measurement

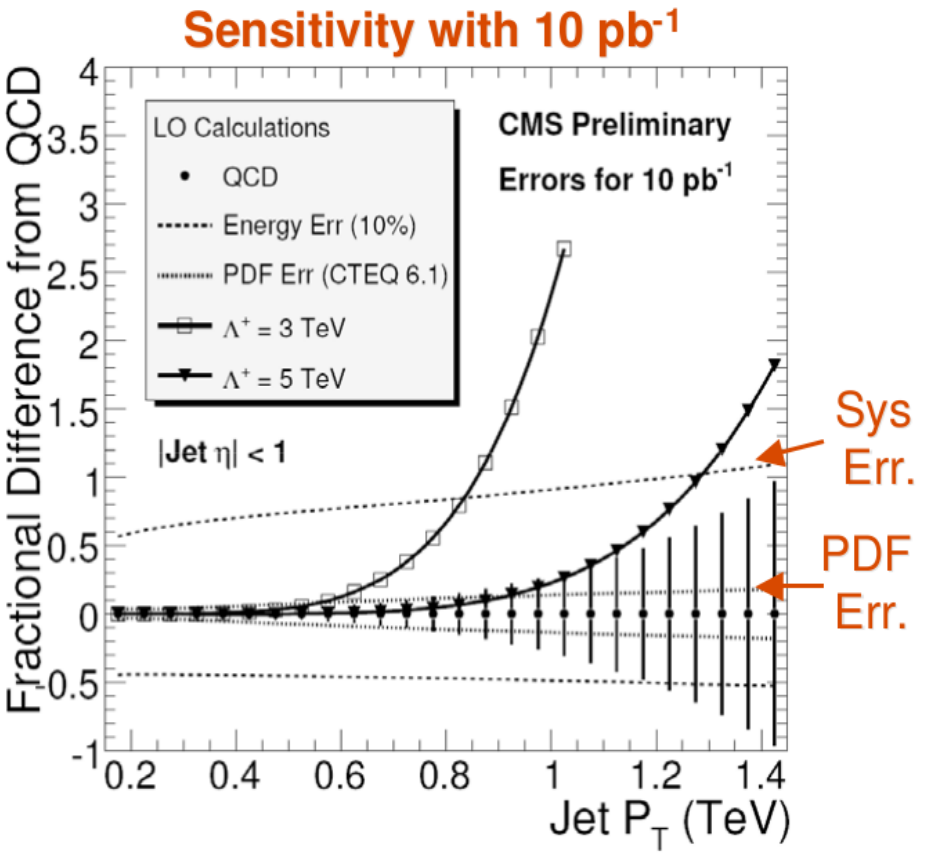


Jets

Huge cross-sections – very rapidly gain sensitivity beyond Tevatron

- Provided jet energy scale uncertainty under control
- Sensitive to new physics (compositeness models) with little data

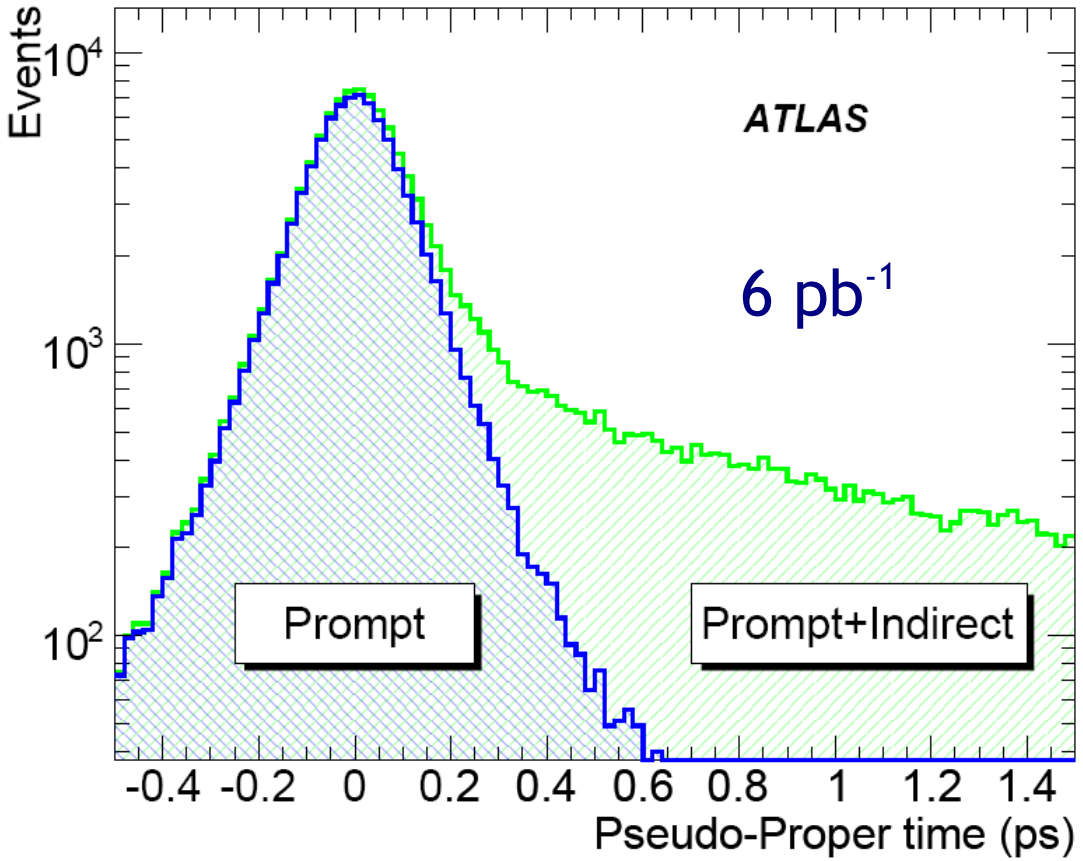


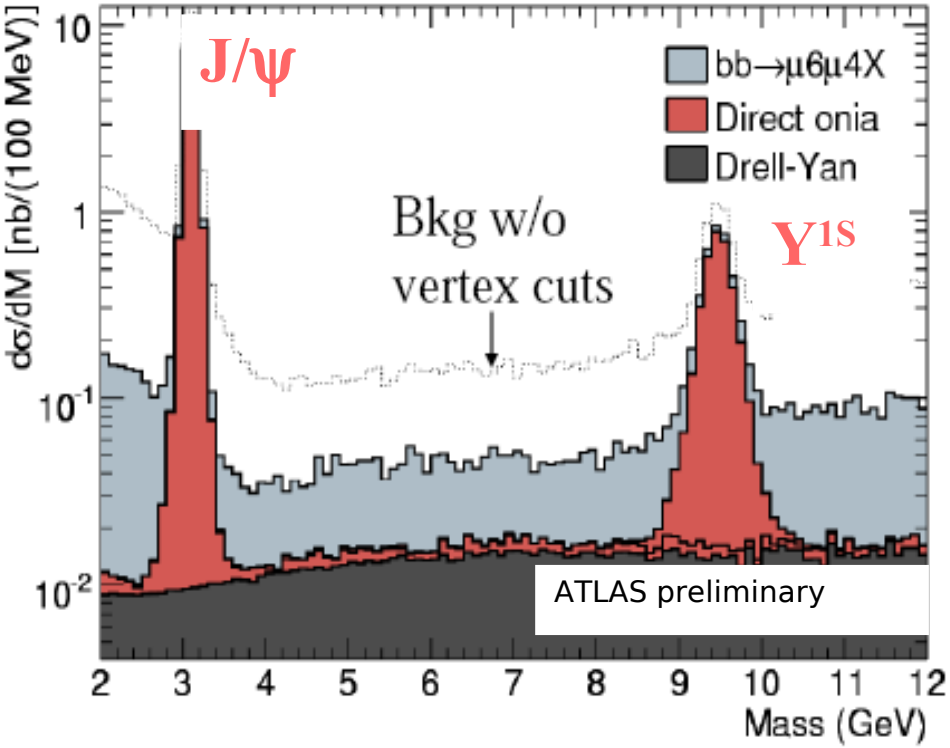


J/ψ

Huge statistics very fast, especially in μμ channel

- important standard candle for commissioning





With 1 pb^{-1} could already measure

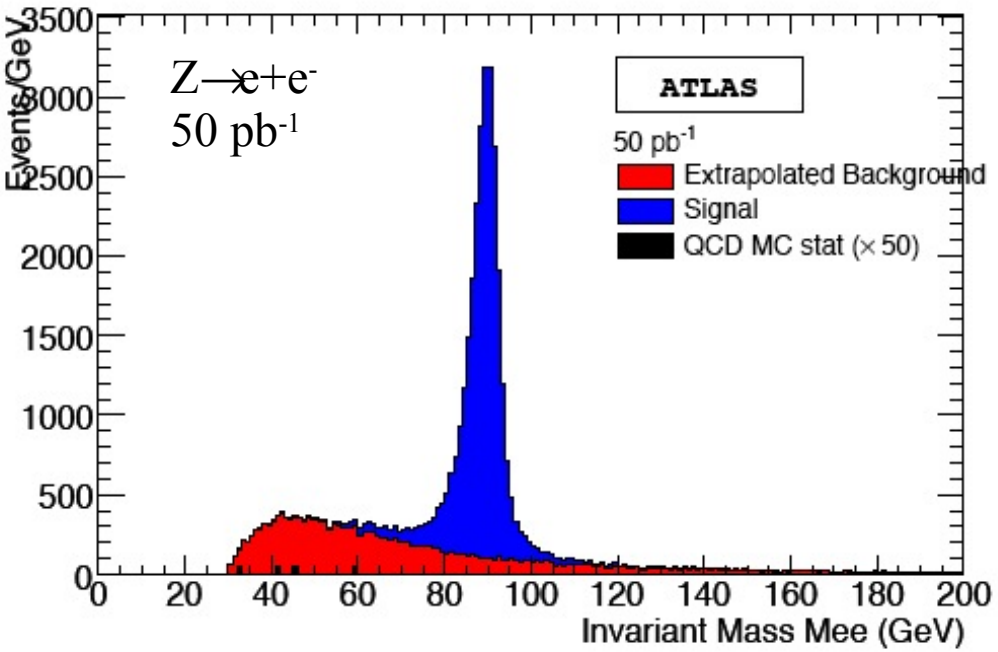
R = σ(bb->J/ψ)/σ(pp->J/ψ)

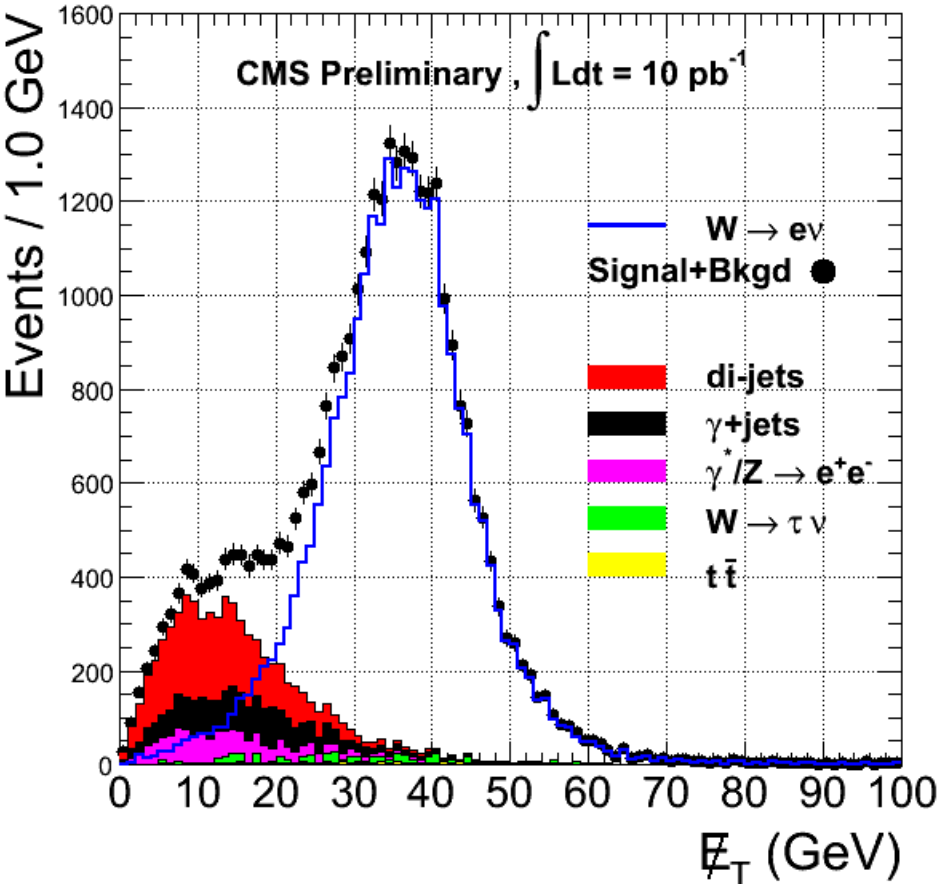
with <5% statistical precision

provided: muon trigger working; tracking understood well enough

W and Z

Clean selections anticipated: excellent lepton ID





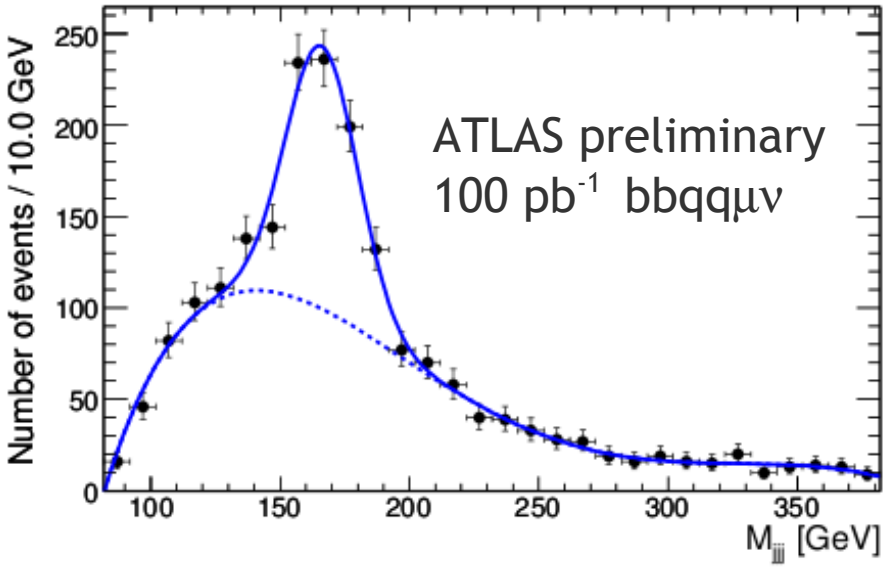
25k Z→ee for 50 pb^{-1}

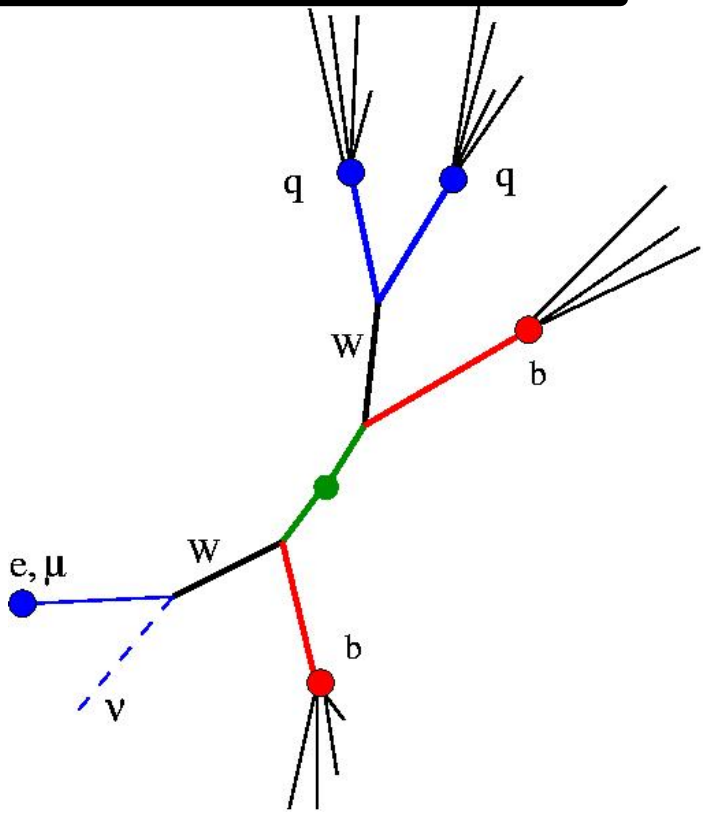
Quickly dominated by systematics

Initial precision of W/Z cross sections 4-5%

Top Physics

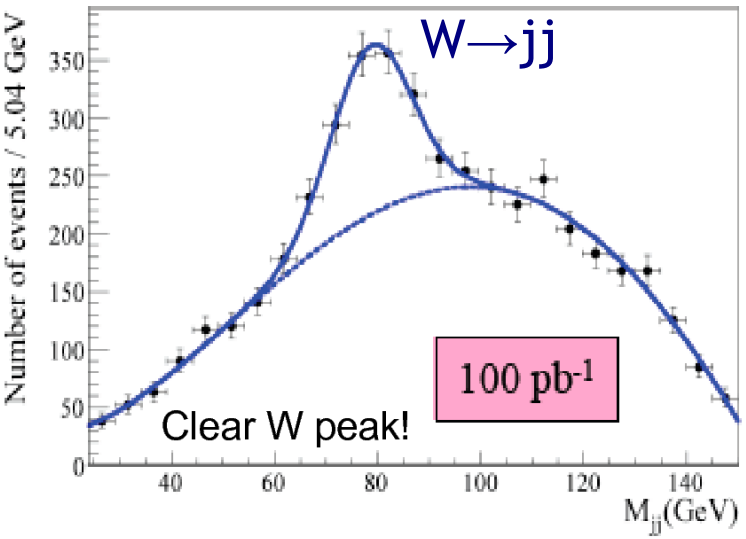
Top ($t\bar{t}$) cross-section at 14 TeV ~ 850 pb
Cf Tevatron ~ 7 pb NLO + corrections





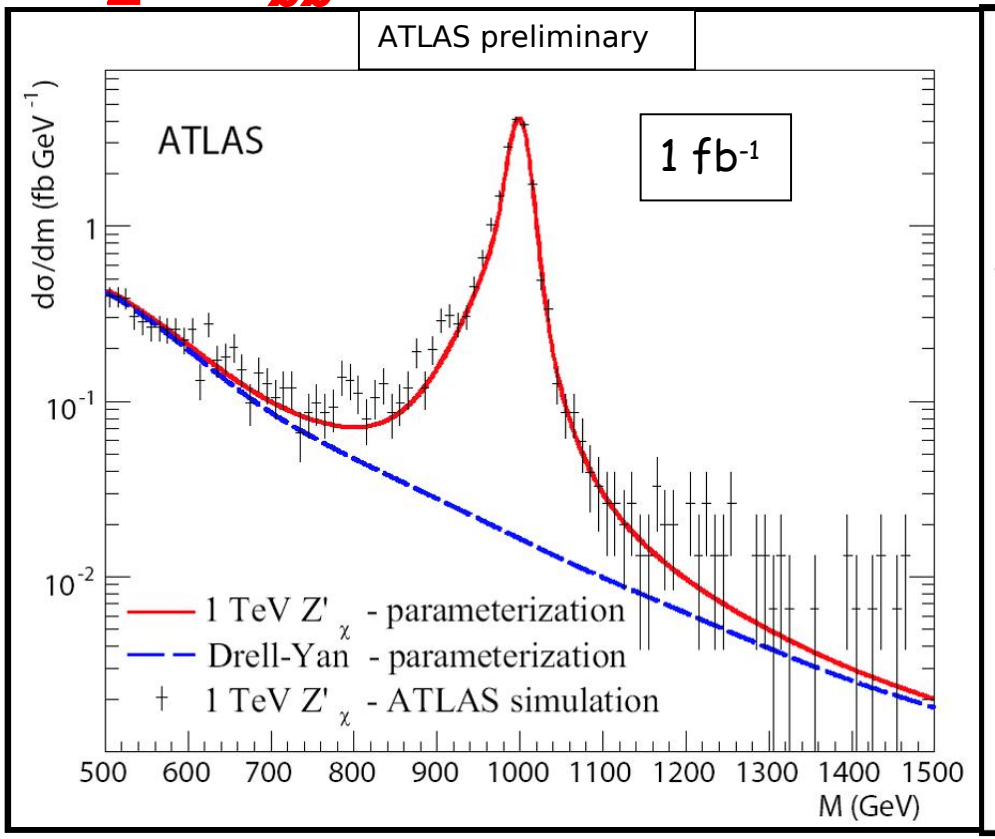
Invaluable channel for data-driven calibration

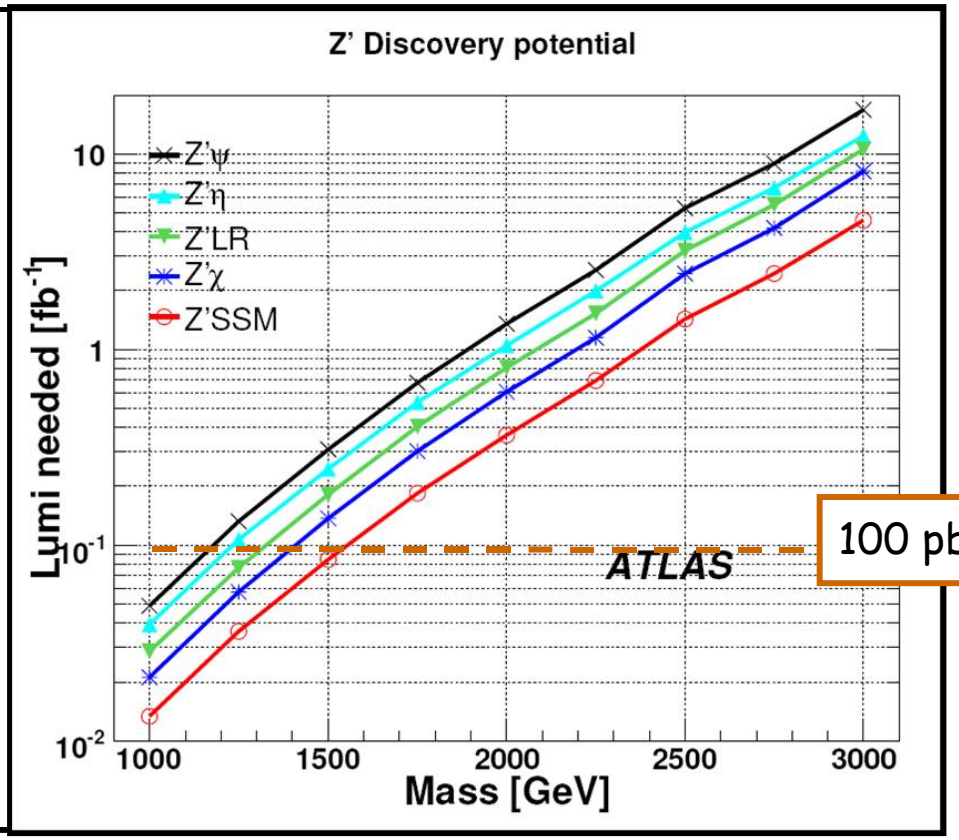
- can select without b-tags
- commission b tagging
- general performance
- calibrate the light jet energy scale with W→jj



New Physics in Earliest Data?

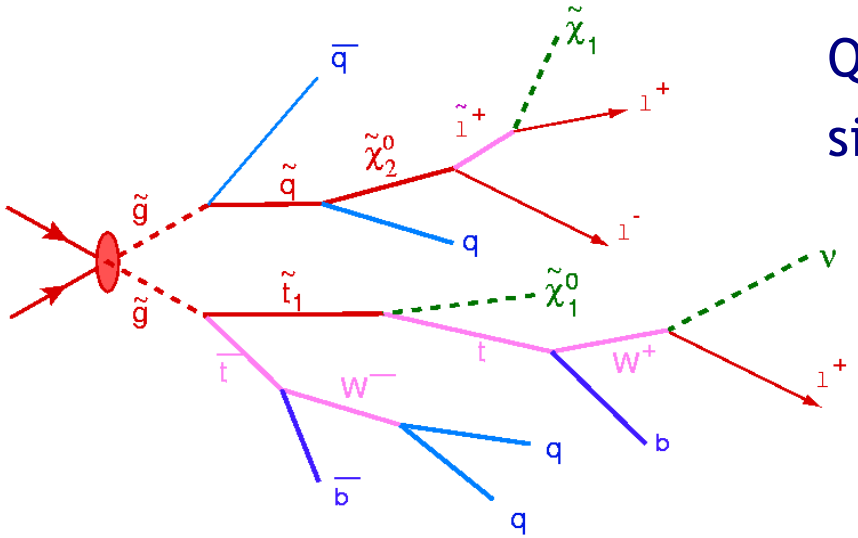
$Z' \rightarrow \ell\ell$

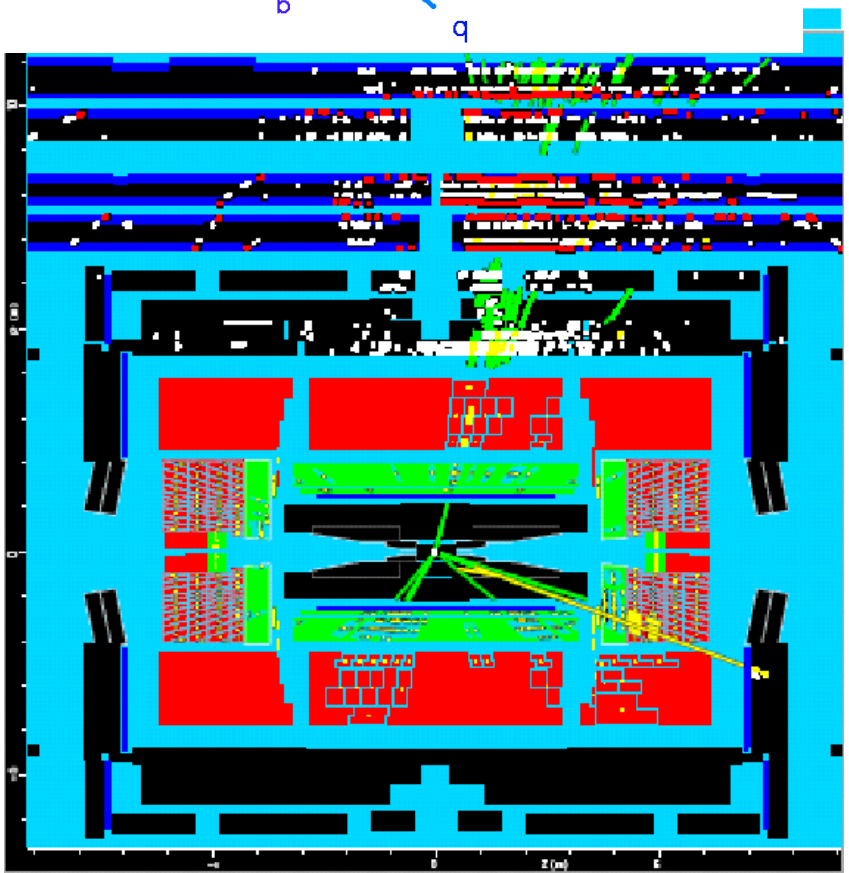




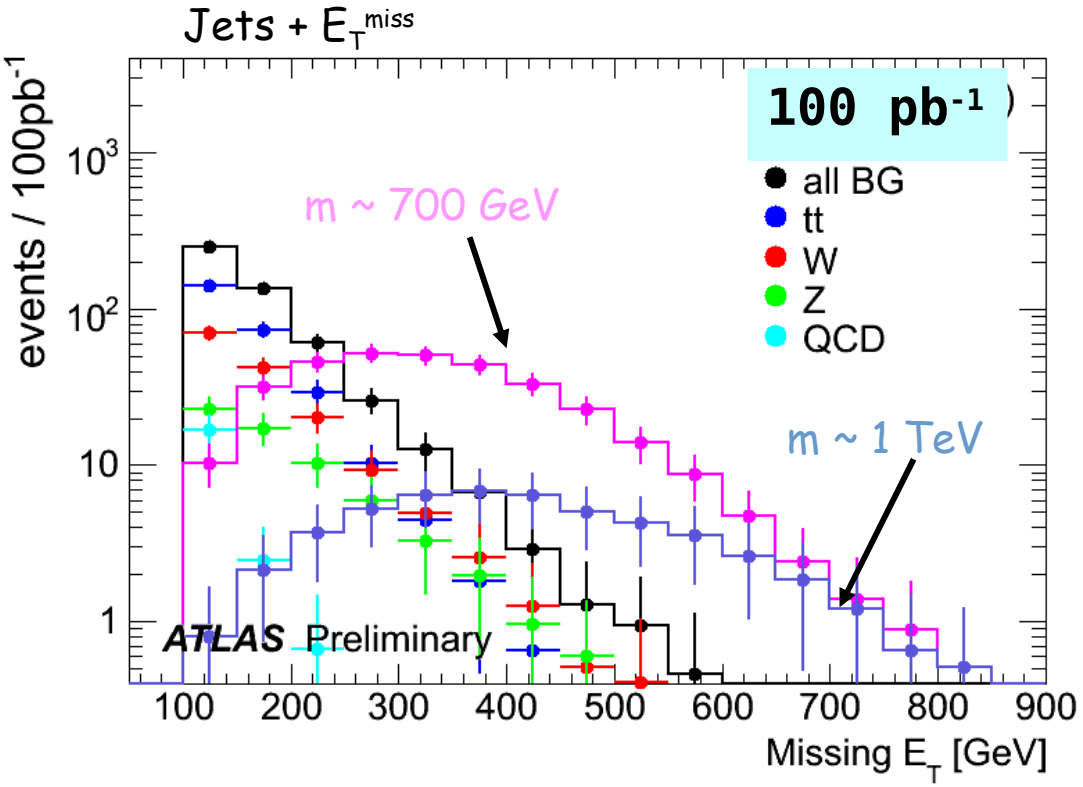
- Z' mass peak on top of small Drell-Yan background
- with 100 pb^{-1} large enough signal for discovery up to m ~ 1.5 TeV
  σ(10 TeV) ~ ½ σ(14 TeV)
- ultimate calorimeter performance not needed
- ultimate reach (300 fb^{-1}) ~ 5 TeV

SUSY





QCD production of squarks, gluinos – E_T^{miss} signatures



Need to understand whole detector well to rely on E_T^{miss}

→ problem will be to know if an excess is real, and what it is...

SUSY

Extrapolate from fully simulated benchmark points to other regions of (m_0, $m_{1/2}$, tanβ)

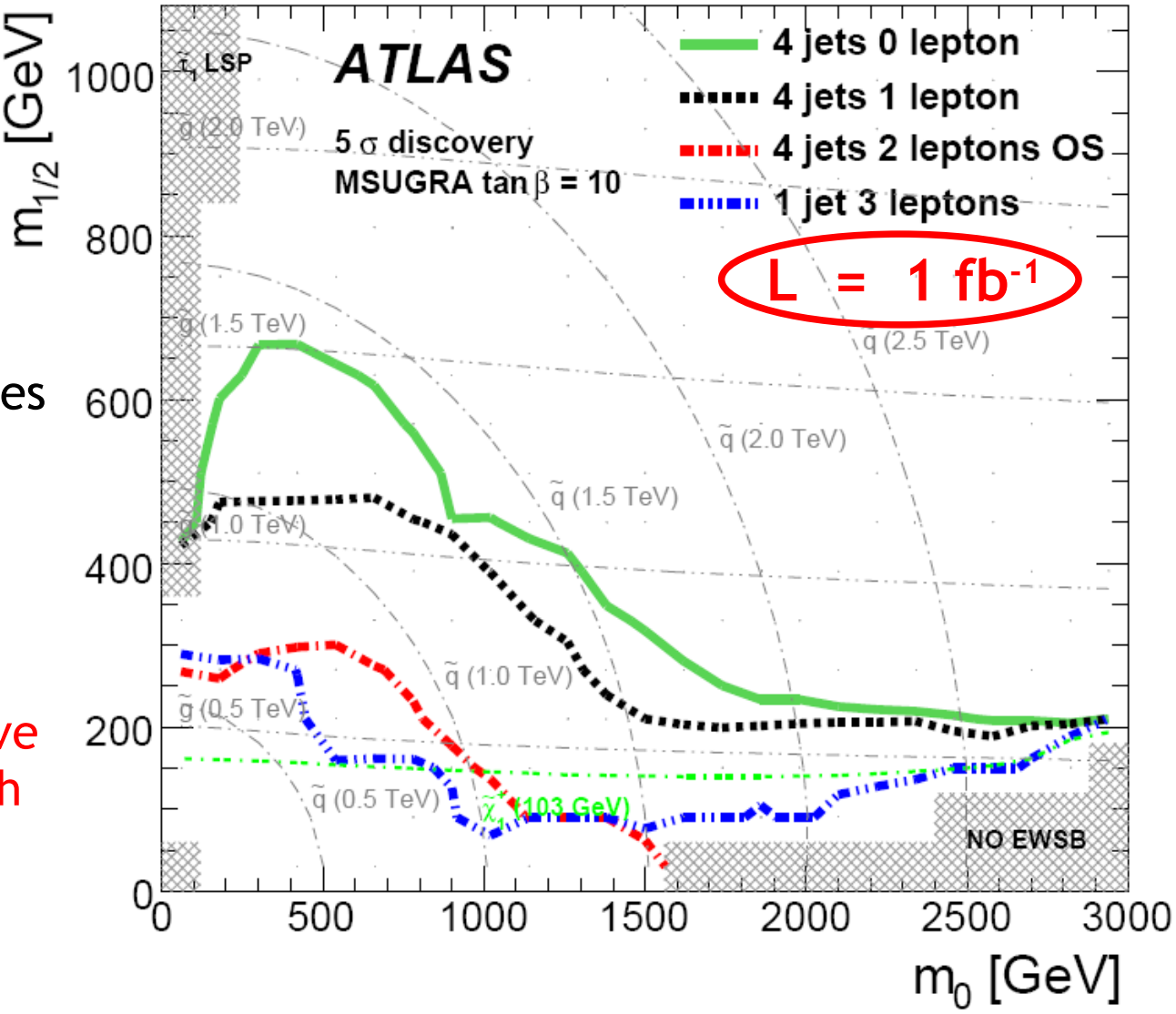
Reach for squark and gluino masses using 4-jets+0-lepton channel:

0.1 fb^{-1} → M ~ 750 GeV

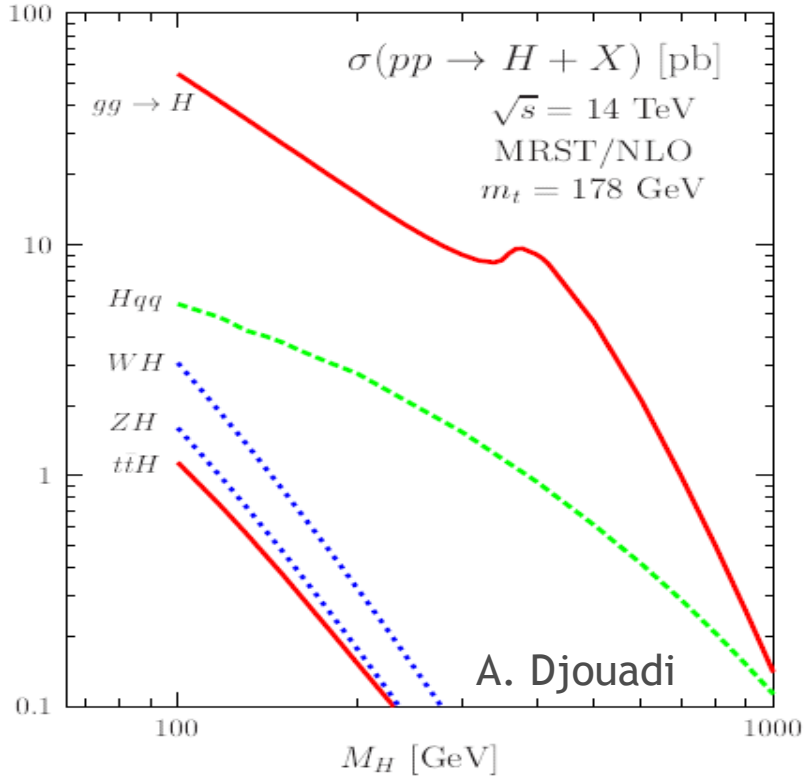
1 fb^{-1} → M ~ 1350 GeV

10 fb^{-1} → M ~ 1800 GeV

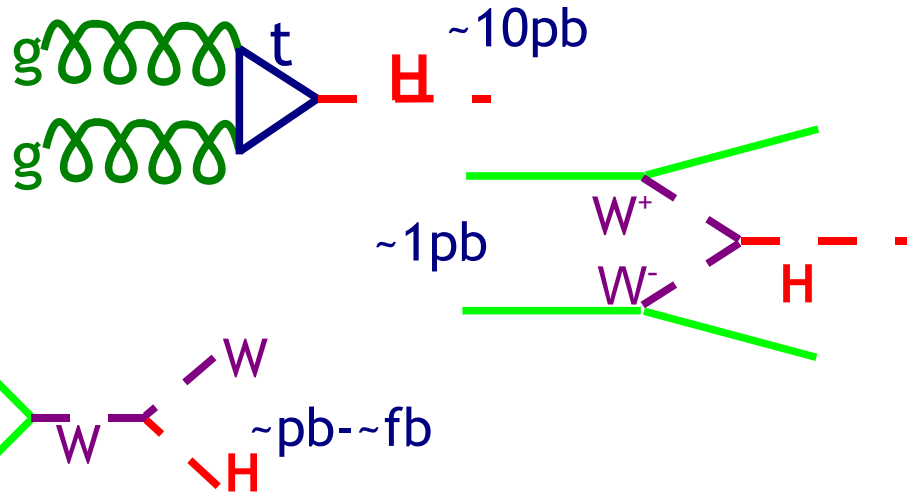
Sensitivity rather quickly at/above Tevatron limits via channels with leptons



SM Higgs Search



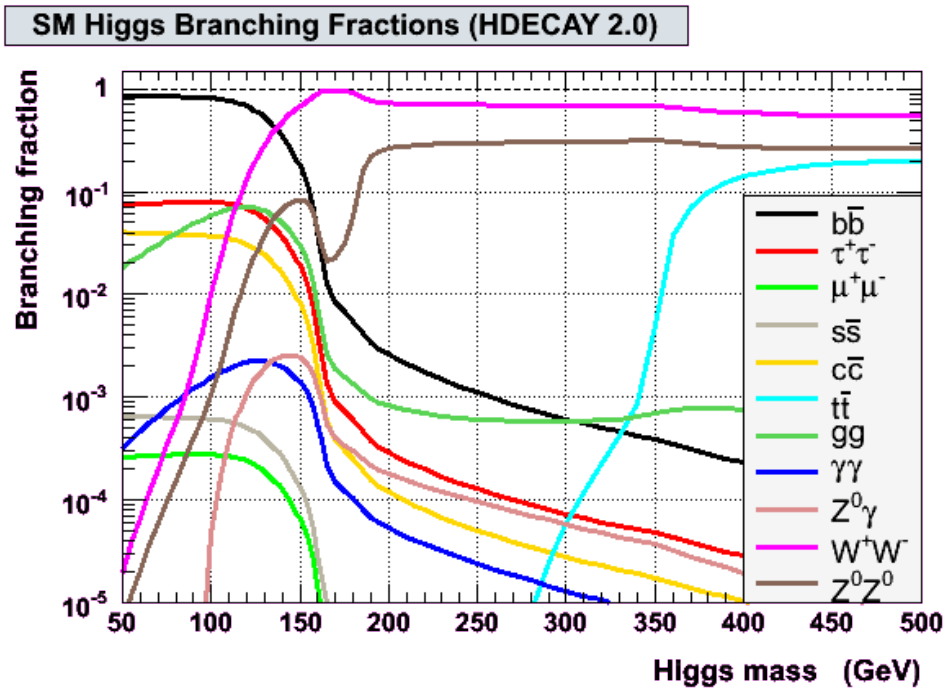
Production mechanisms (examples):



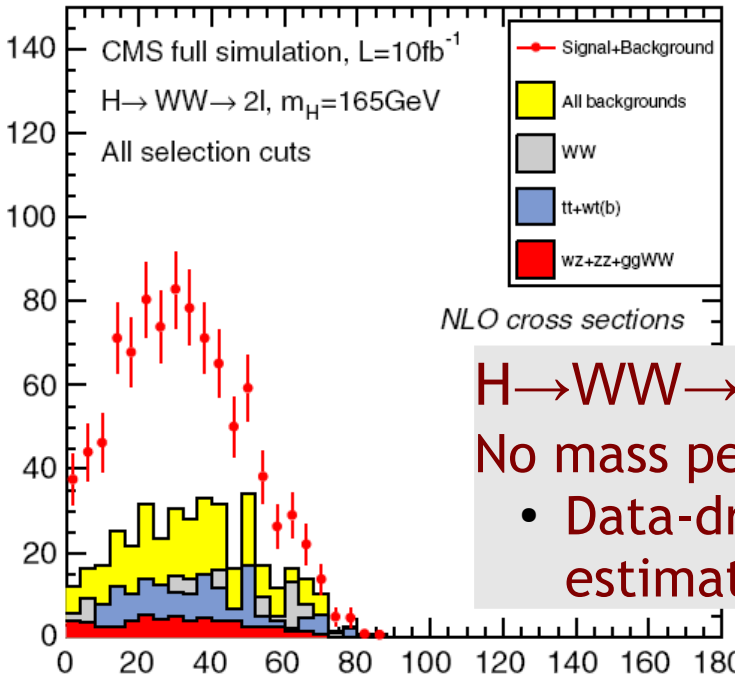
Decay – strongly dependent on m_H

- low m_H – bb dominates
  - ττ, γγ also important
- high m_H – WW/ZZ dominate

Wide mix of search topologies



Higgs Signals

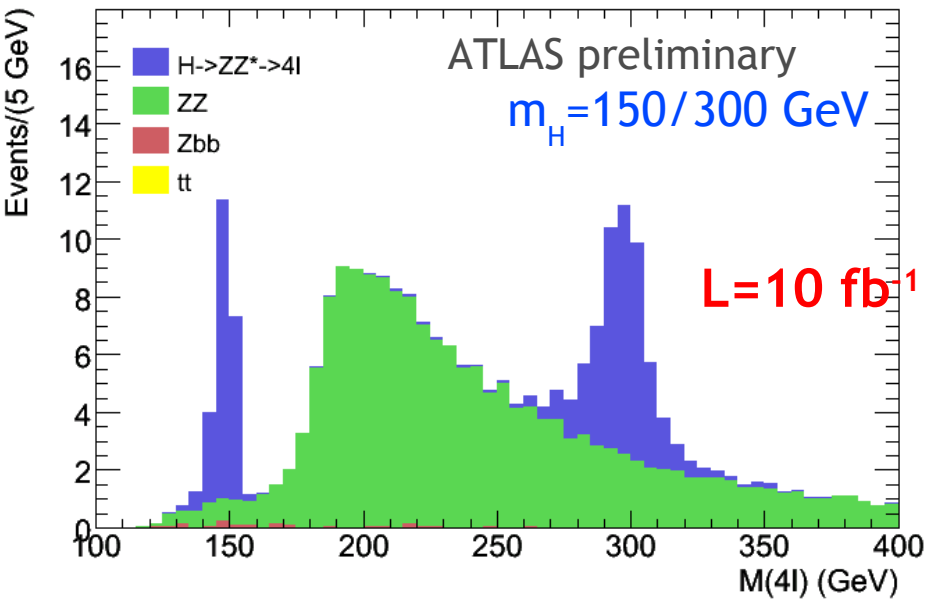


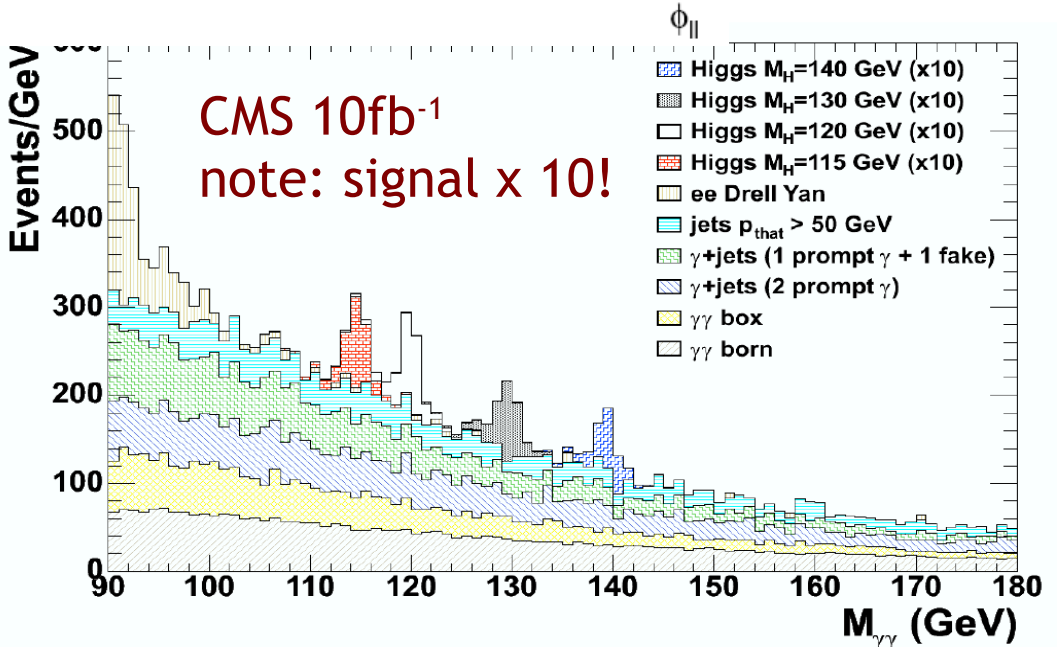
H→WW→2ℓ2ν

No mass peak

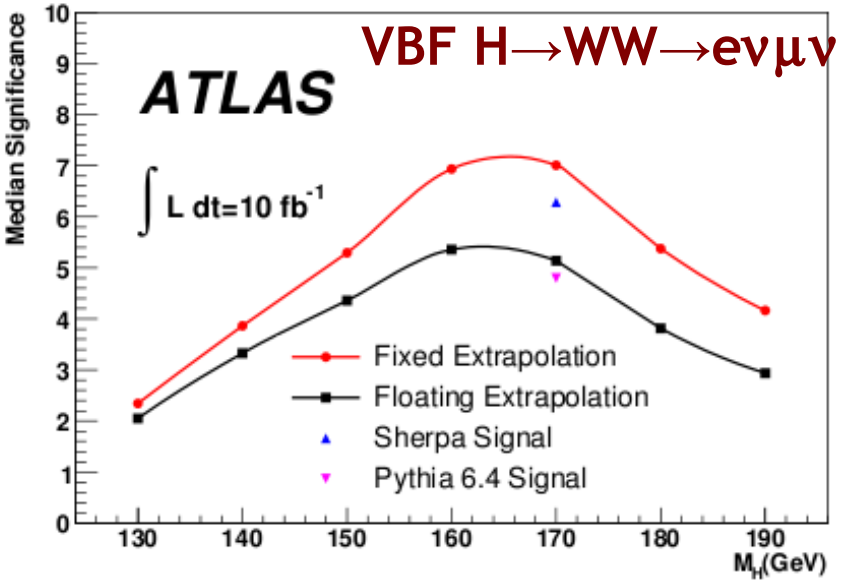
- Data-driven bkgd estimates

H→ZZ(*)→4ℓ



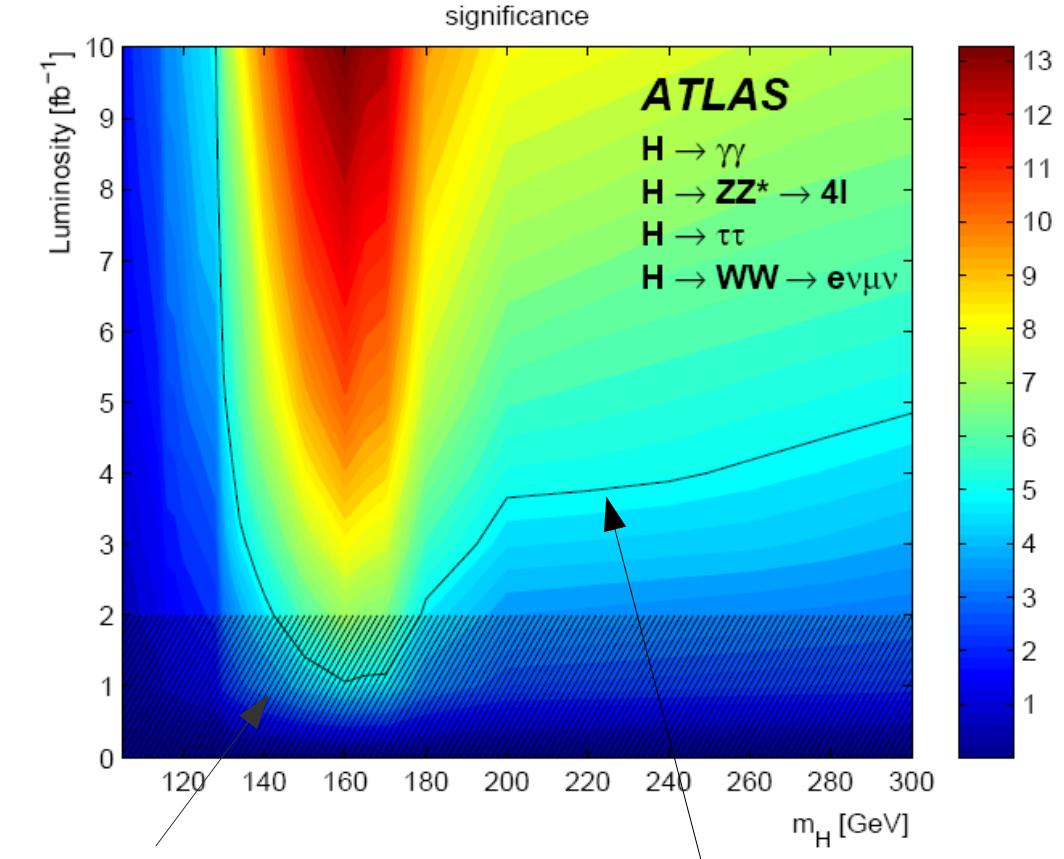


VBF H→WW→eνμν



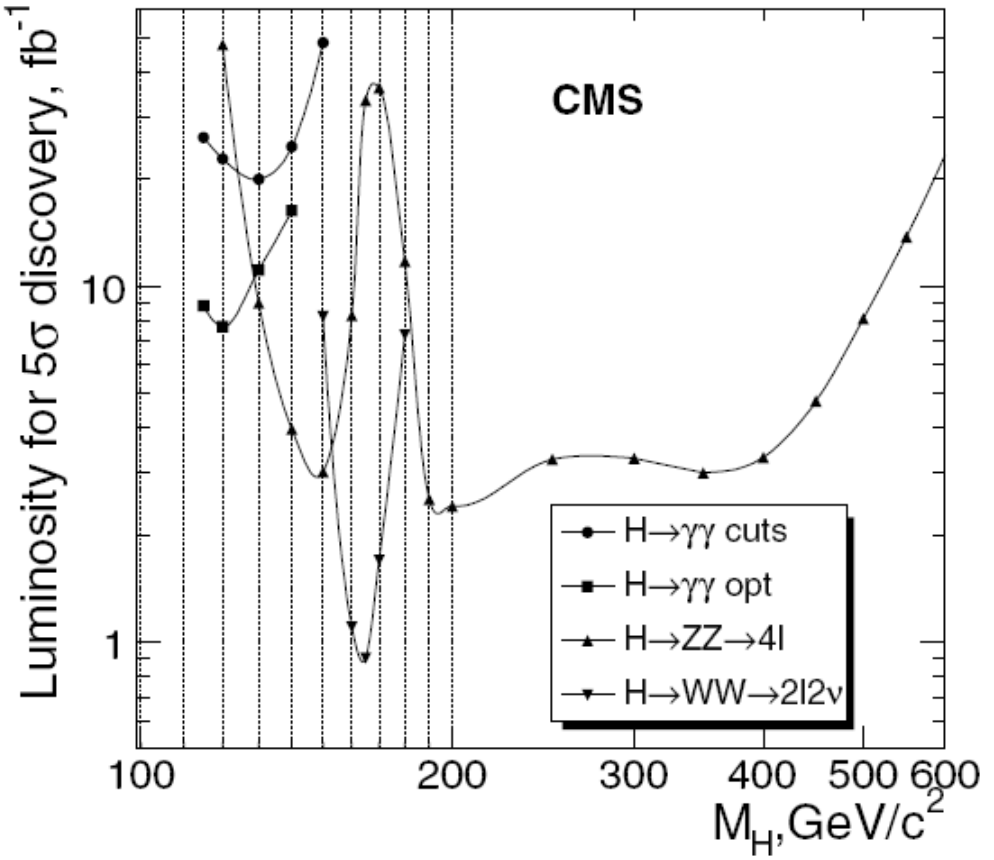
SM Higgs Prospects

Discovery



Statistical method less reliable

5σ

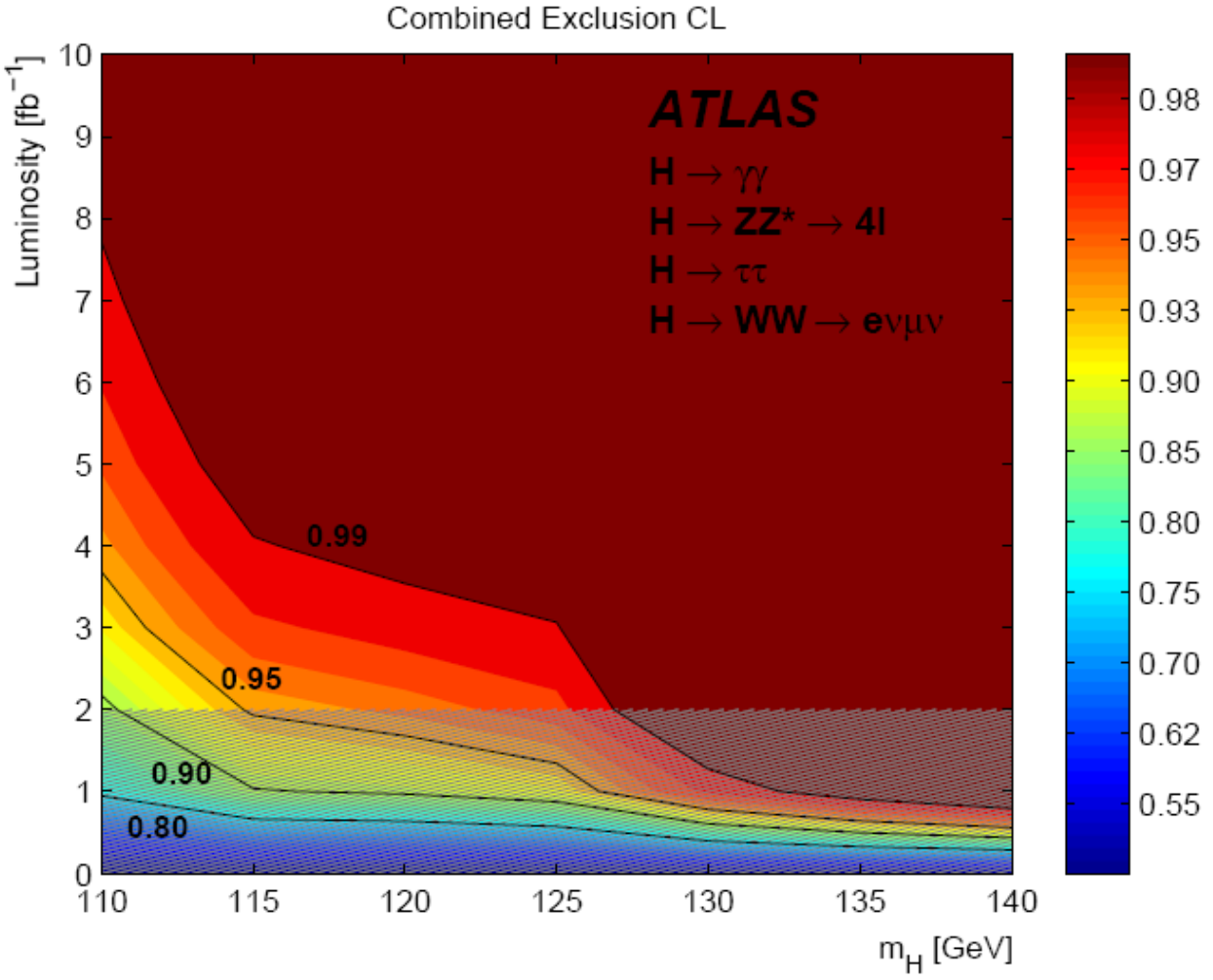


ATLAS: 5σ sensitivity at 2 fb^{-1} over 143-179 GeV

Not all channels included – for most complex channels we need to measure backgrounds with data

SM Higgs Prospects

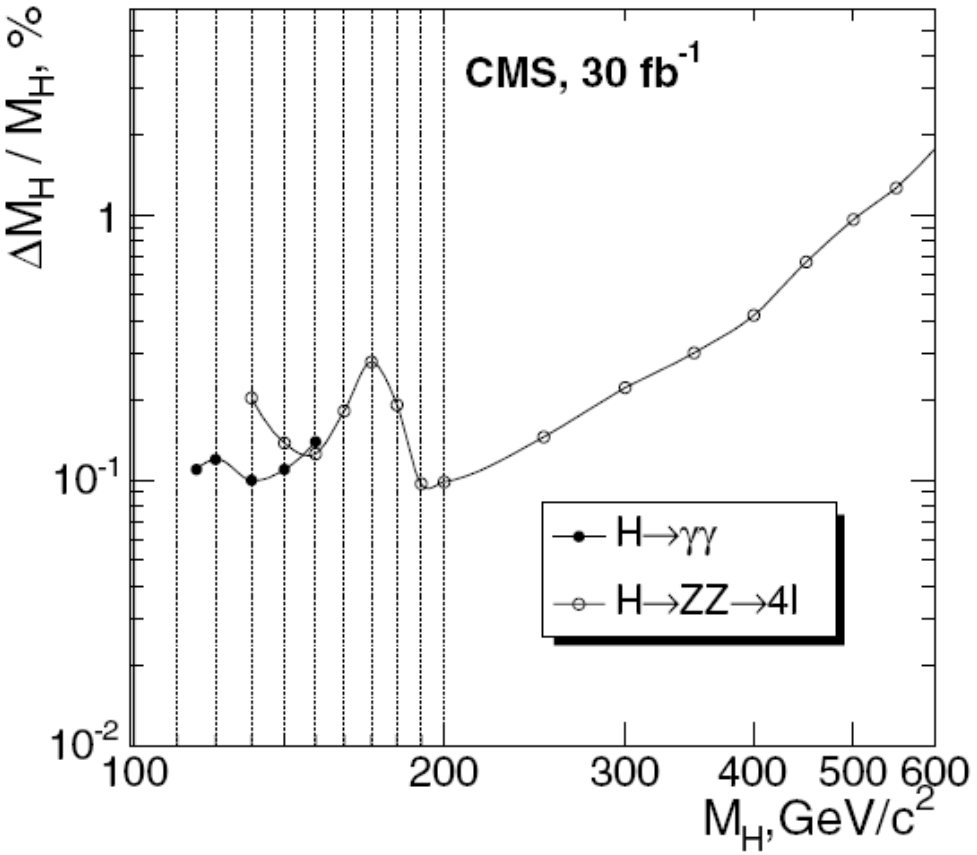
Exclusion: not what we want, but probably relevant at start...

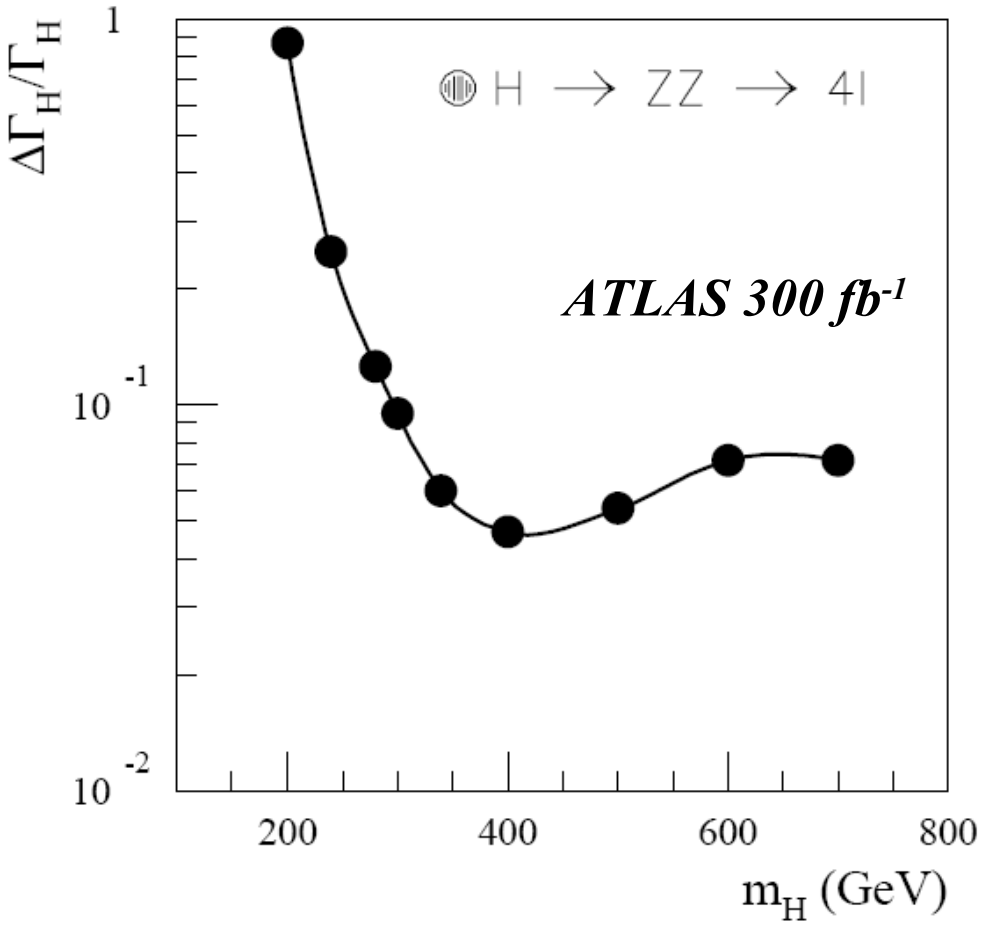


ATLAS: 95% CL sensitivity from 115 GeV with 2 fb^{-1}

SM Higgs Prospects

Higgs Properties – Mass and Width

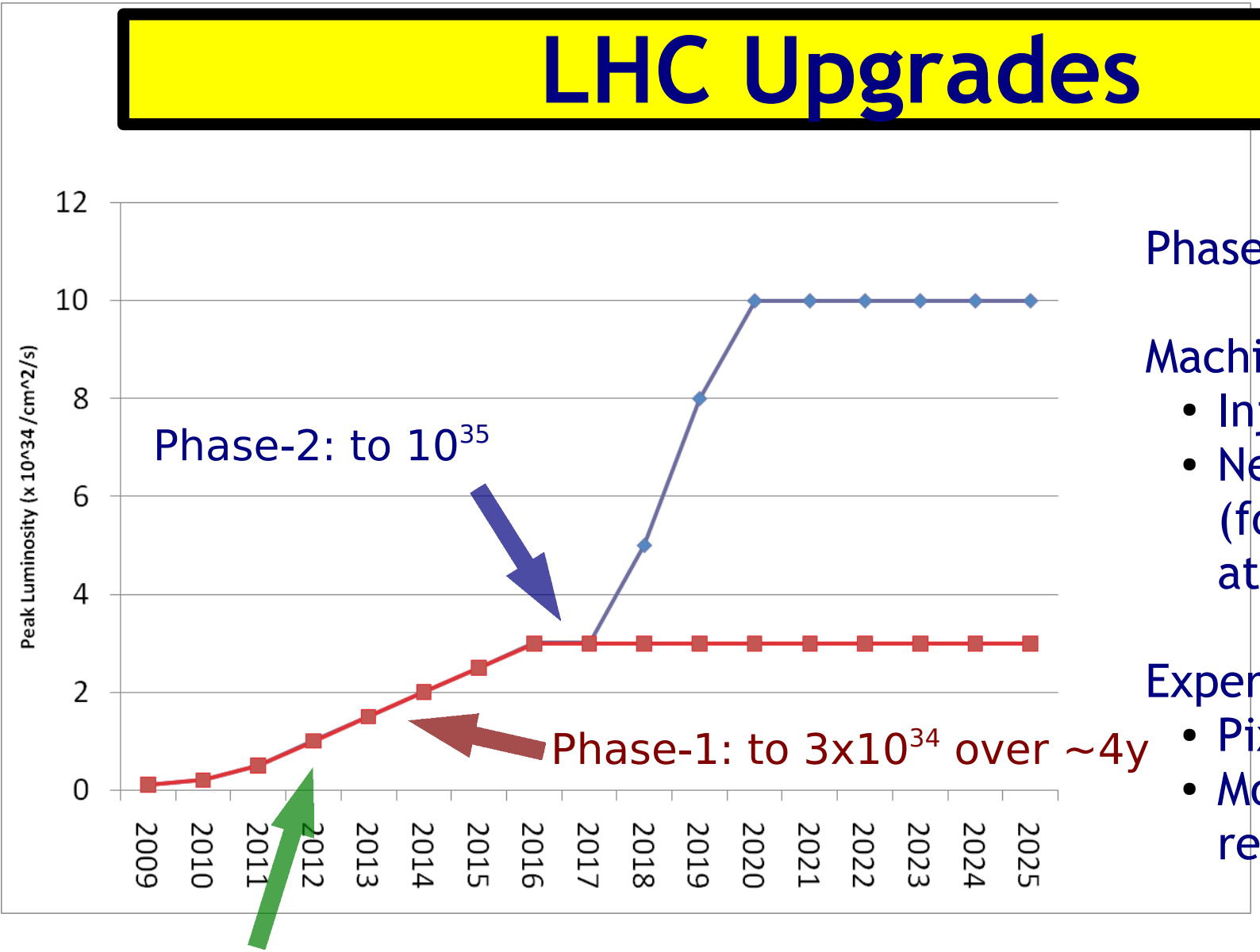




statistical precision on Higgs mass measurement (~ not limited by systematic uncertainties)

Long term!

LHC Upgrades



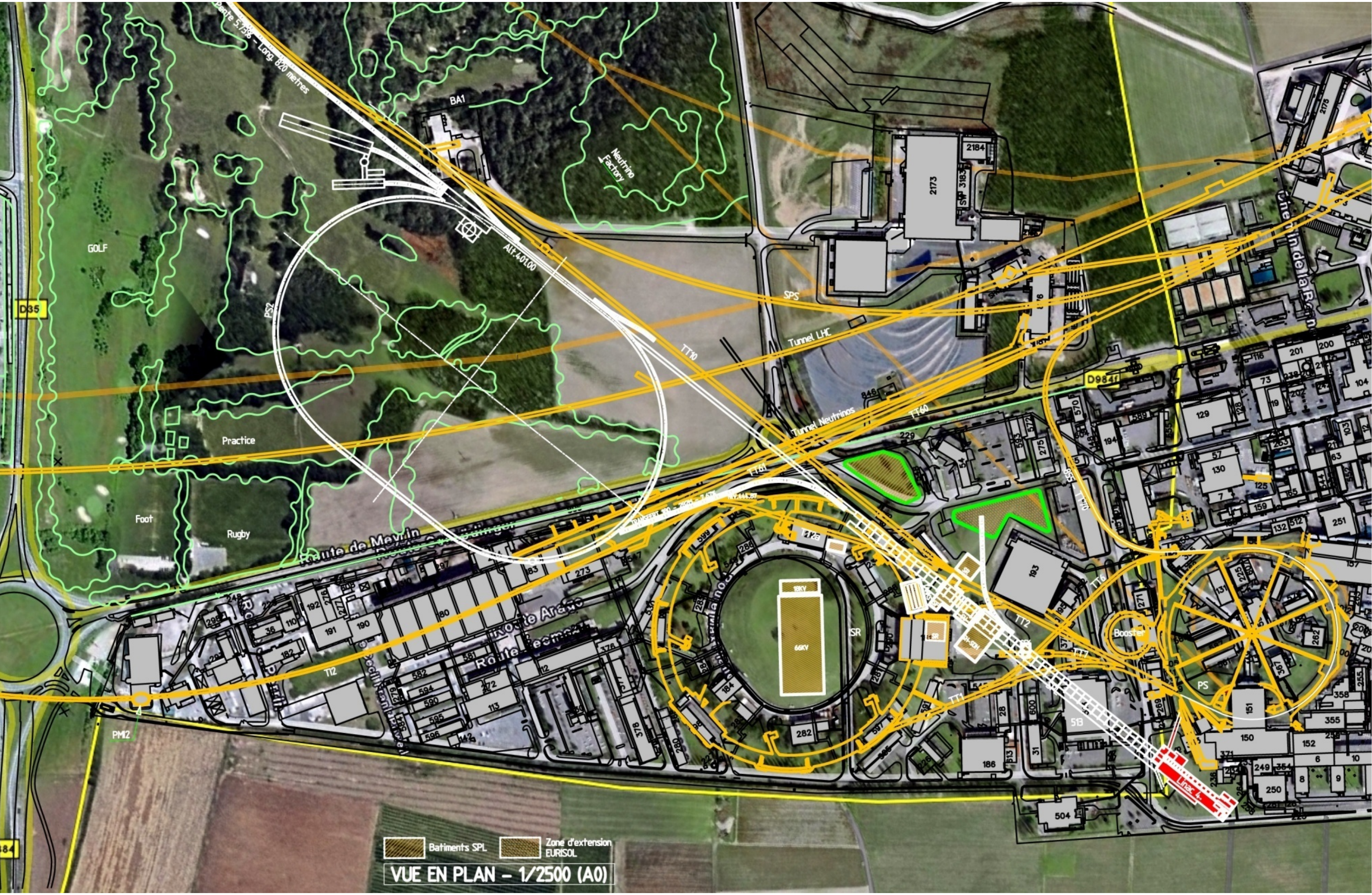
Phase-1:

Machine:

- Injector upgrades
- New inner triplets (focussing magnets at experiments)

Experiments:

- Pixel det. upgrades
- Modest trigger & readout upgrades


Neutrino Factory
BA1
GOLF
D35
PS2
Practice
Foot
Rugby
Route de Meyrin
Route Arago
SPS
Tunnel LHC
Tunnel Neutrinos
TT10
TT60
TT2
ISR
Booster
PS
Linac 4
D984
PM2
TI2
2173
2184
193
150
Batiments SPL
Zone d'extension EURISOL
VUE EN PLAN – 1/2500 (A0)

Phase-2 (sLHC)

"Super-LHC" ~ 2017?

Luminosity ~ 10^{35} cm^{-2} s^{-1}

10 x pre-phase 1

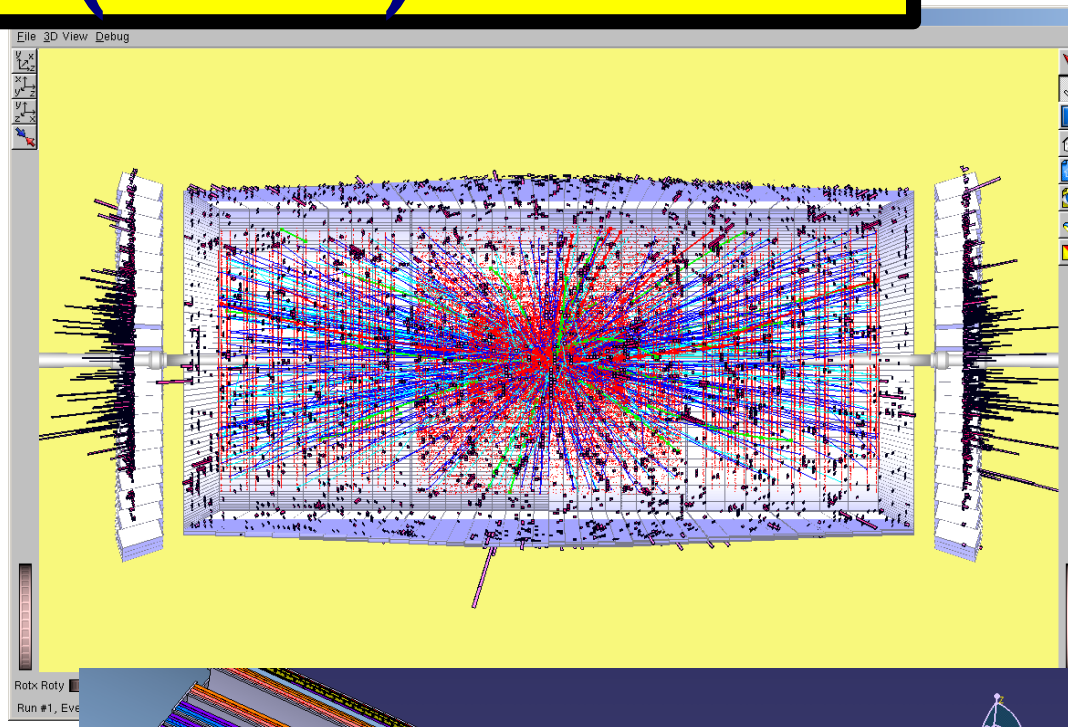
300-400 evts / beam crossing

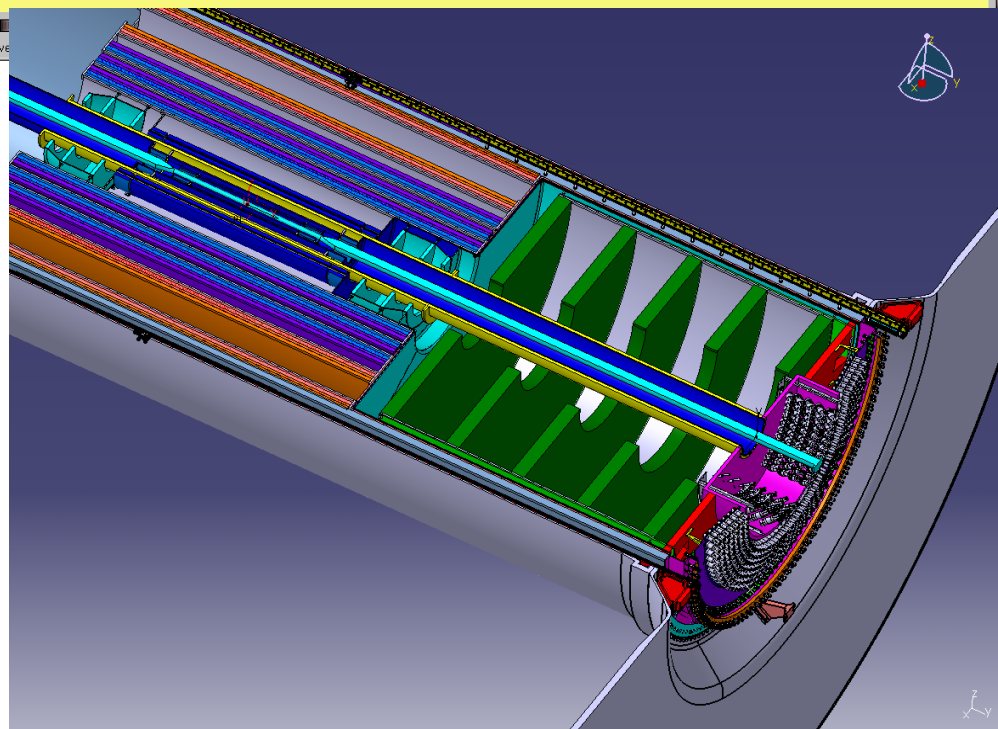
Machine:

- Various scenarios, mainly increasing bunch current

Experiments:

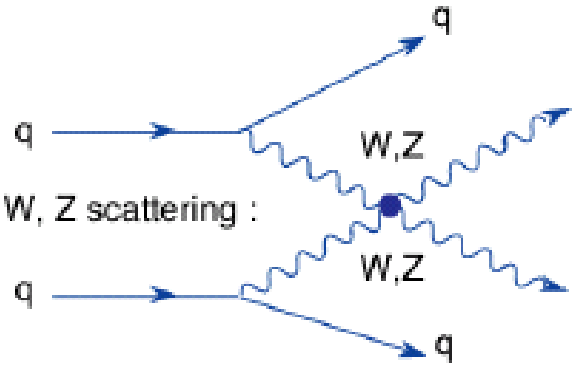
- Tracker replacement – need > 1 year shutdown
- Many readout electronics changes



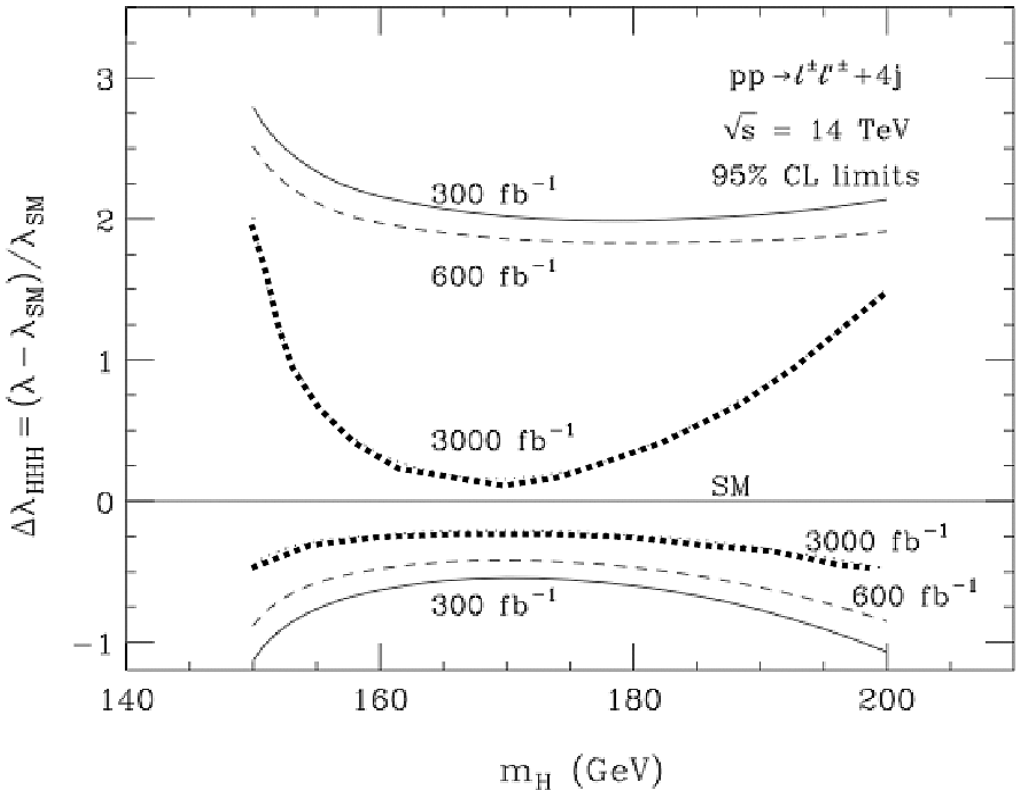


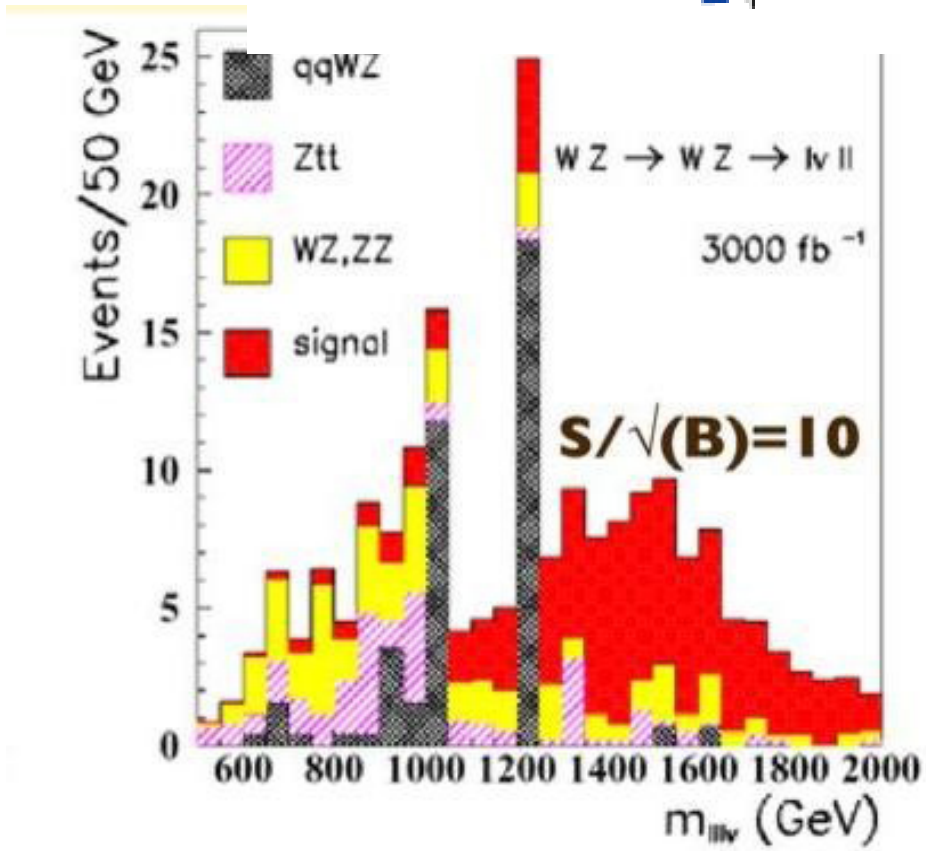
SLHC Physics

Depends what we find at "LHC-I"
A couple of examples...



Higgs self-coupling...





Closing Thoughts

For all working on the LHC, 2008 was an unexpected year
Unbelievable highs
Some fairly dreadful lows...

We need a better year in 2009: *so far* it looks like we will get it

Experiments are ready, and have had months of cosmics to understand and tune

But the start-up will be cautious, and the performance in 2009 will have to be seen

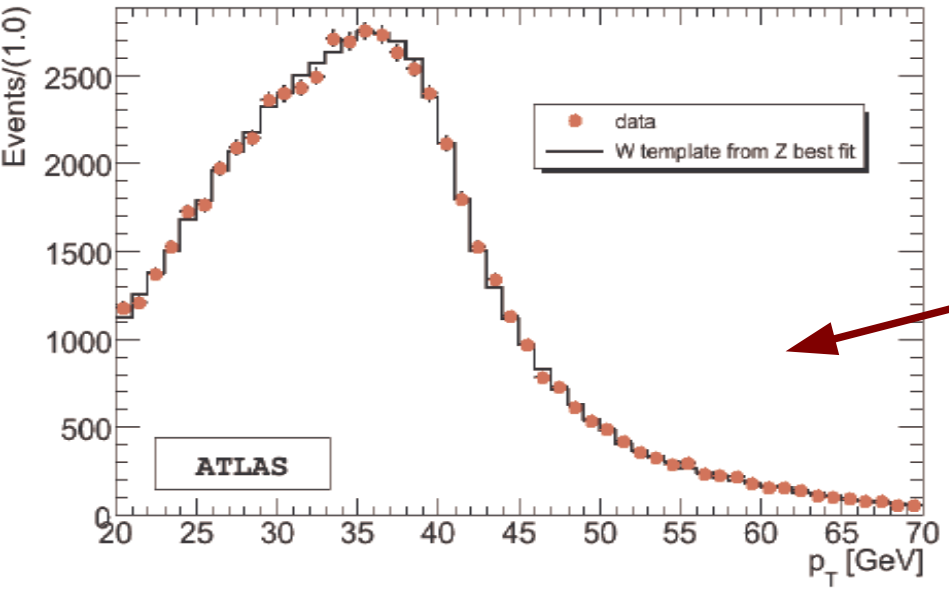
This is the start of the >20-year operation of this new machine

Please keep your expectations under control!

Thanks to: K Desch, L Evans, L Fayard, D Froidevaux, F Gianotti, N Hessey, P Jenni

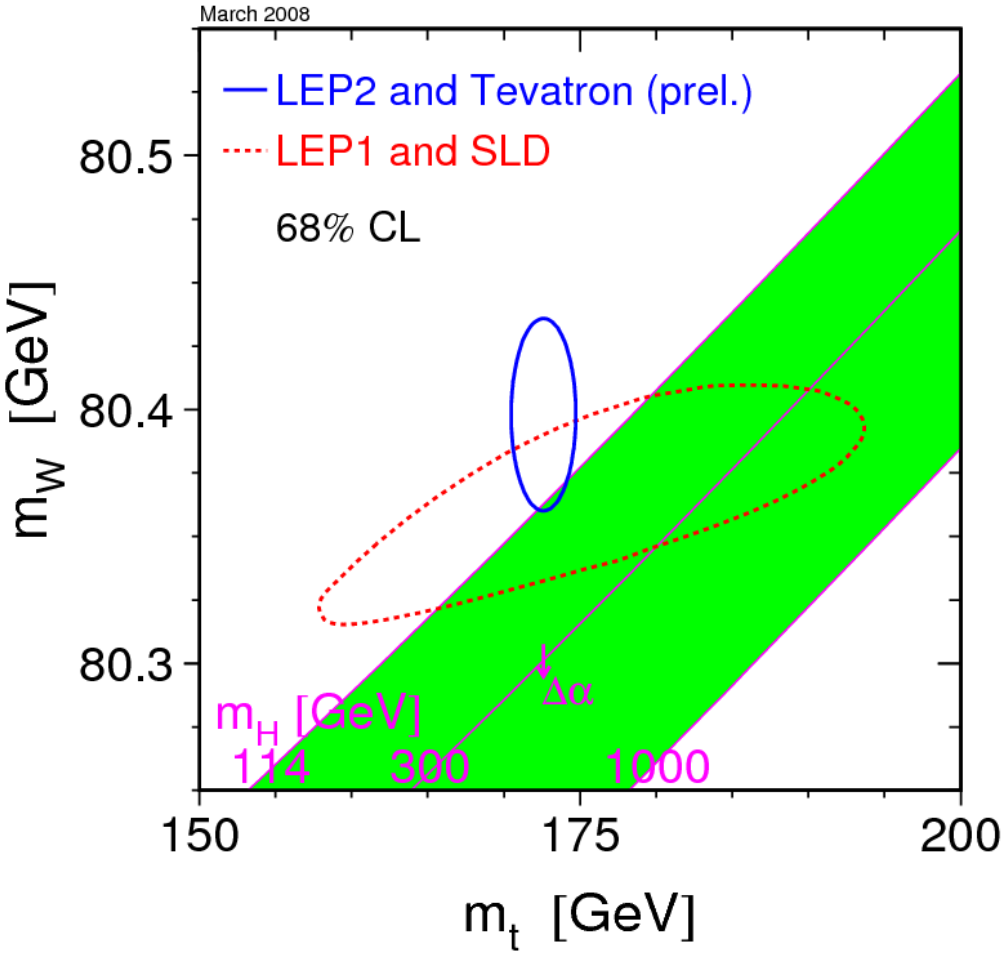
Didn't make the cut...

W Mass



W mass measurement at LHC will be very tough, but it also should get started – even with 2008 data

error <~200 MeV with 15 pb^{-1}



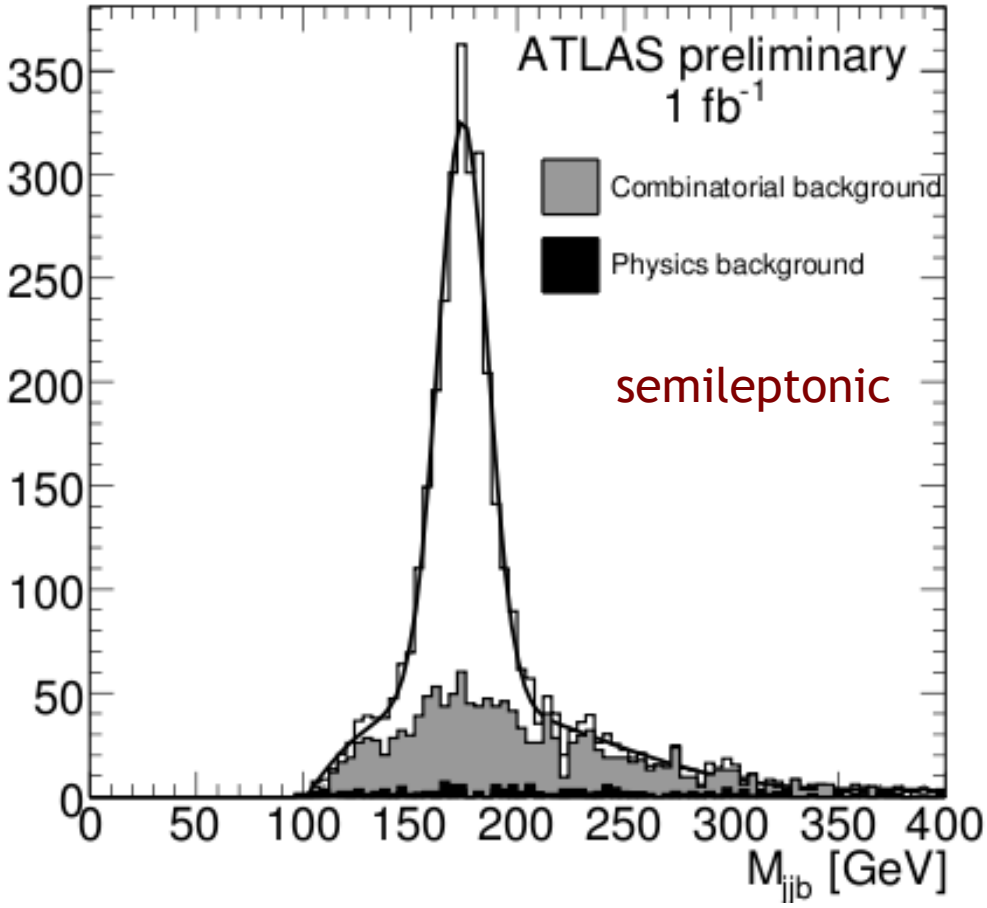
Data-driven techniques to control systematics with Z events – very high Z statistics will come

Eventual error Δm_W ~ 10 MeV?

cf. current world average Δm_W~25 MeV

Top Mass

With more data and a well-understood detector, can select very clean $t\bar{t}$ samples, using b tagging



Top mass error will be limited by challenging systematics (b-jet energy scale) – no shortage of statistics!

- probably need ~10 fb^{-1} to measure Δm_t ~ ±1 GeV
- cf current Tevatron average 1.2 GeV

Need clever methods in the longer term...

Single Top

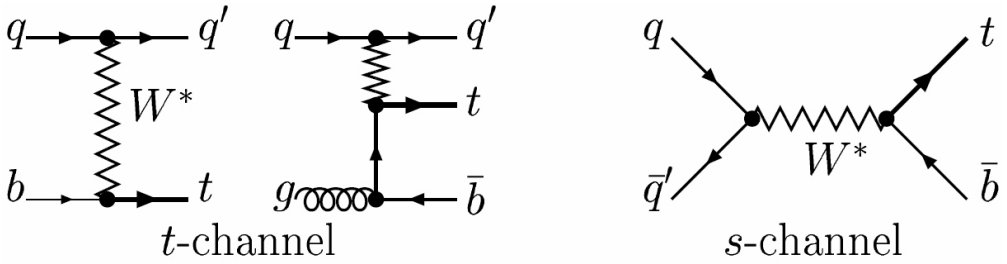
Electroweak production of top quarks also sizable @ LHC

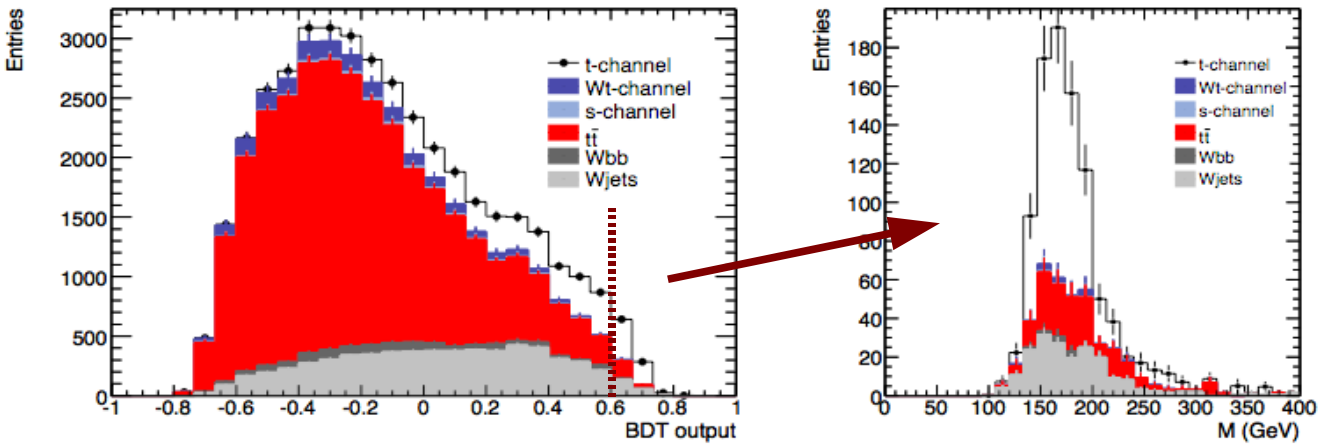
σ ~ 320 pb

40% of $t\bar{t}$ cross-section

Various production process/final-state topologies

Most promising "t-channel"





Measure t-channel cross-section to ~±10% with 10 fb^{-1}

s- and tW-channels are hard – must measure backgrounds from data to establish signals > 10 fb^{-1}

Boosted Decision Tree multivariate analysis

At the CERN Council meeting last Friday, Lyn Evans, Head of the LHC Project, gave an update on the work carried out since the accident in September. He ended his presentation to the delegations with a video, which he dedicated to the staff. You can share this moment of emotion by clicking on the video link here: http://cdsweb.cern.ch/record/1151297?ln=fr

When you walk through a storm
Hold your head up high
And don't be afraid of the dark
At the end of a storm
There's a golden sky
And the sweet silver song of a lark
Walk on through the wind
Walk on through the rain
Though your dreams be tossed and blown
Walk on, walk on, with hope in your heart
And you'll never walk alone
You'll never walk alone
Walk on, walk on, with hope in your heart
And you'll never walk alone
You'll never walk alone