Overview on the LHC status and prospects

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Outline:

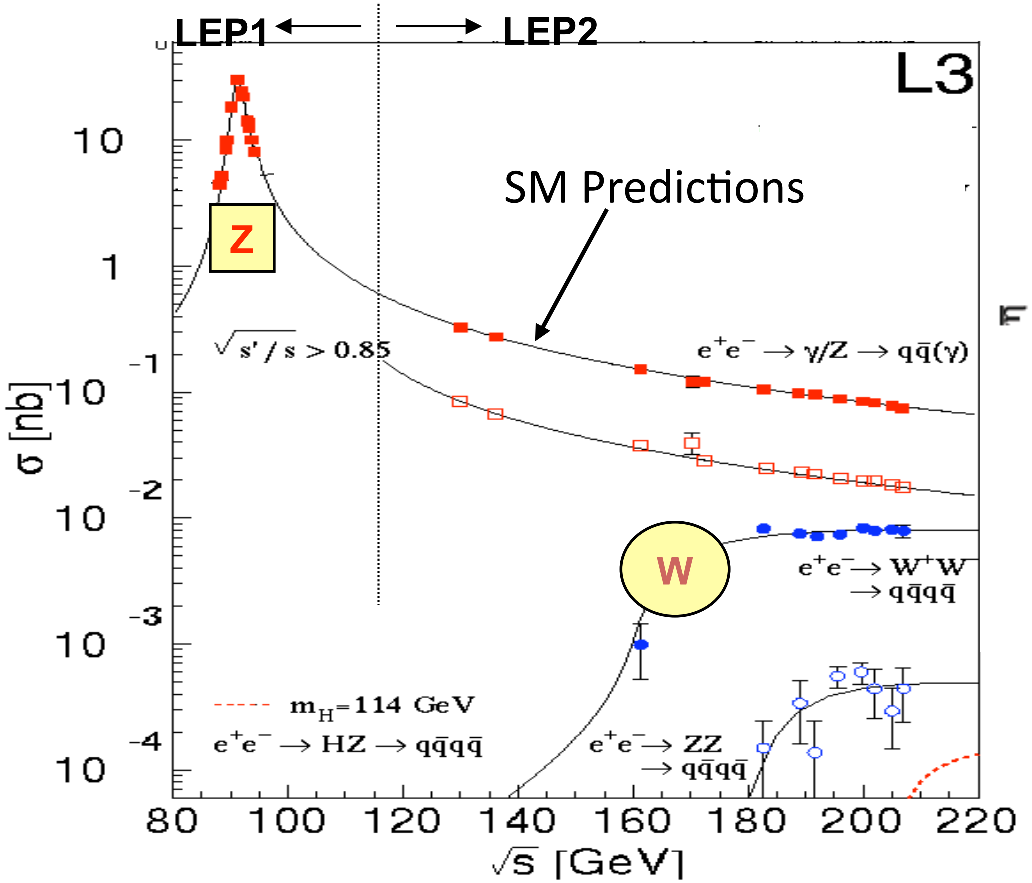
- *Introduction*
- *Readiness of experiments for data taking*
- *LHC incident on September 19*
- *LHC repair and preparation for the 2009/2010 Run*
- *Prospects for Physics with 2009/2010 data*

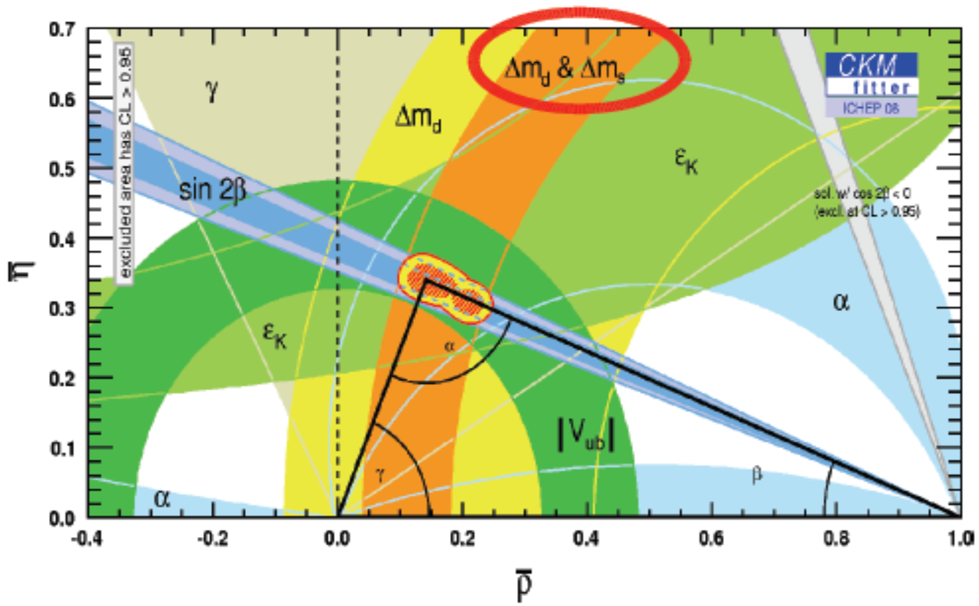
Introduction:

Brief Reminder on LHC and Experiments

Successes of the Standard Model

LEP, SLC, Tevatron and B-factories established that Standard Model really describes the physics at energies up to √s ~ 100 GeV





- ***Standard Model is precisely tested theory***

Missing ingredient, Higgs particle, has been searched for decades but not yet found

- ***Standard Model does not provide the whole picture…***

LHC Physics Goals

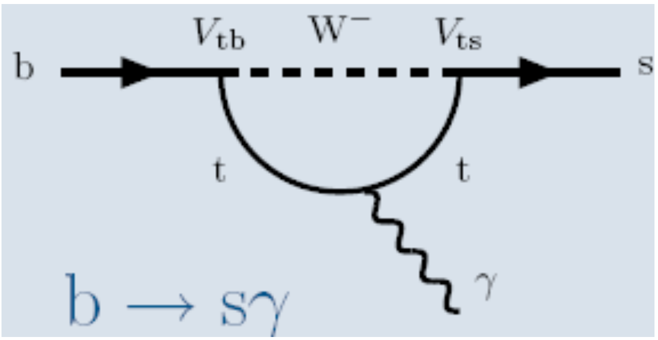
Main Goals:

- ***Search for the SM Higgs boson over ~ 115 < m_H < 1000 GeV***
- ***Search for New Physics beyond the SM***

- Explore TeV-scale directly (ATLAS & CMS) and indirectly (LHCb)

Footnote: *LHCb strategy is to look for quantum interference effects of NP in the processes mediated by loops*

An example: polarization of photons in radiative penguin B decays



$b \to \gamma(L) + (m_s/m_b) \times \gamma(R)$

$\phi\gamma$ produced in B_s and $\underline{B}_s$ decays do not interfere in SM → corresponding $A_{CP} = 0$

Significantly non-zero A_{CP} indicates a presence of NP

- ***Study phase transition at high density from hadronic matter to quark-gluon plasma (ALICE)***

Various Scenarios to happen in the next few years

ATLAS CMS high p_T physics	BSM	Only SM	BSM	
LHCb flavour physics	Only SM	BSM	BSM	
Particle Physics	☺	☺	☺	

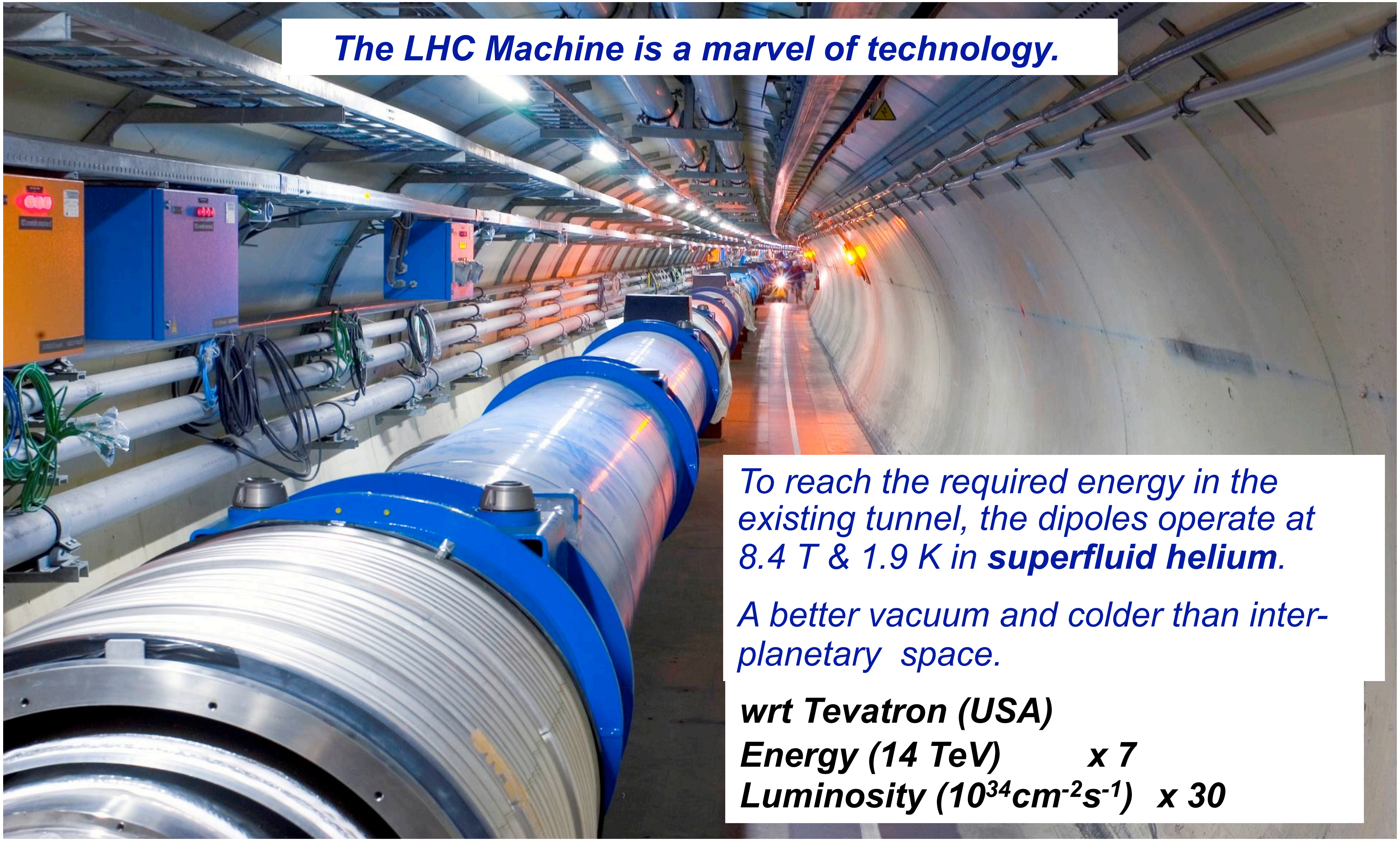
No space left for the 4th possibility

Even if 4th possibility → Measurements of virtual effects will set the scale of New Physics

CERN Site

Large Hadron Collider
27 km circumference
About 100 m underground
Lake Geneva
CMS
LHCb
ALICE
ATLAS

The LHC Accelerator



The LHC Machine is a marvel of technology.

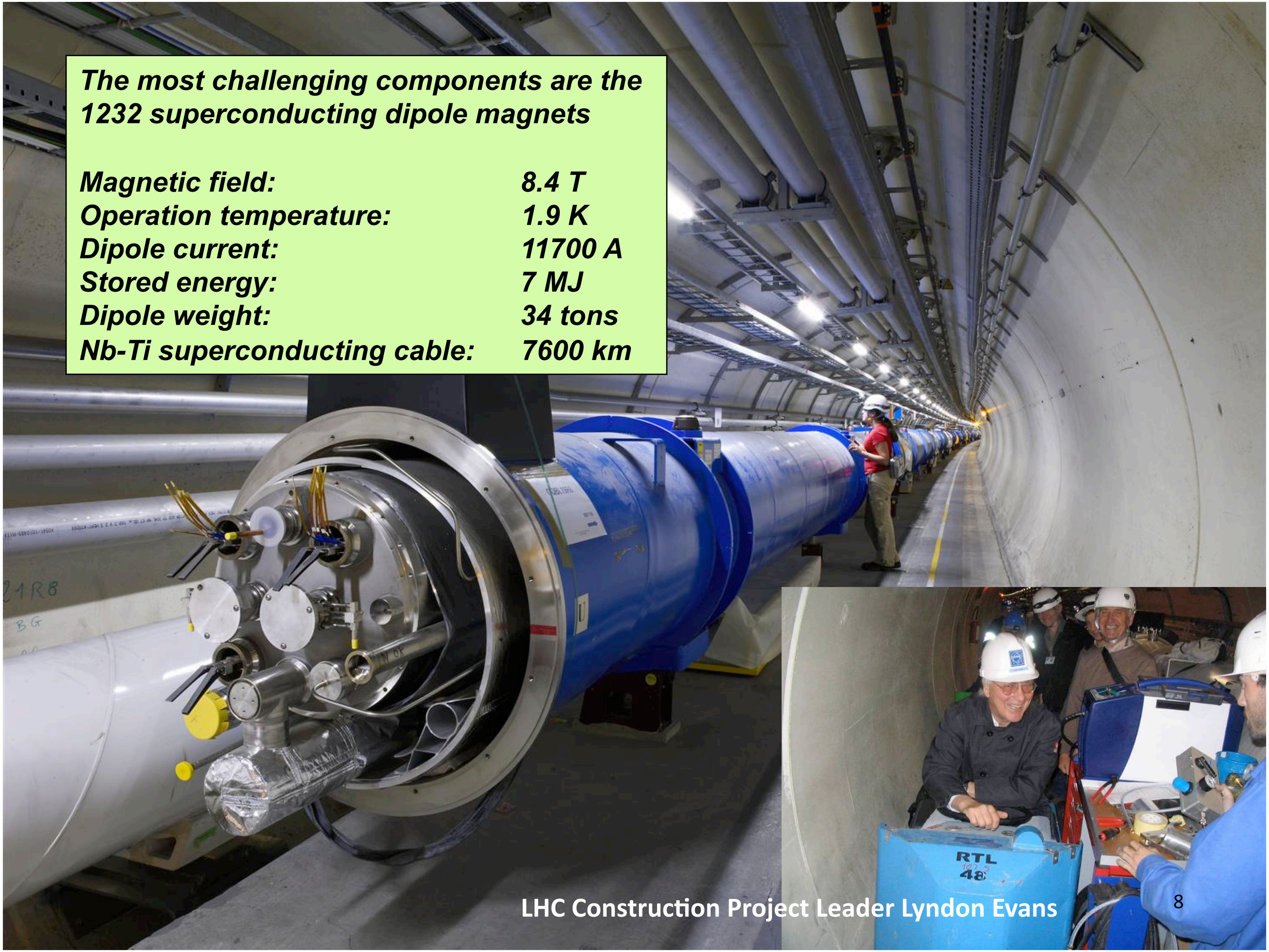
*To reach the required energy in the existing tunnel, the dipoles operate at 8.4 T & 1.9 K in **superfluid helium**.*

A better vacuum and colder than inter-planetary space.

wrt Tevatron (USA)
Energy (14 TeV) x 7
Luminosity ($10^{34} cm^{-2} s^{-1}$) x 30

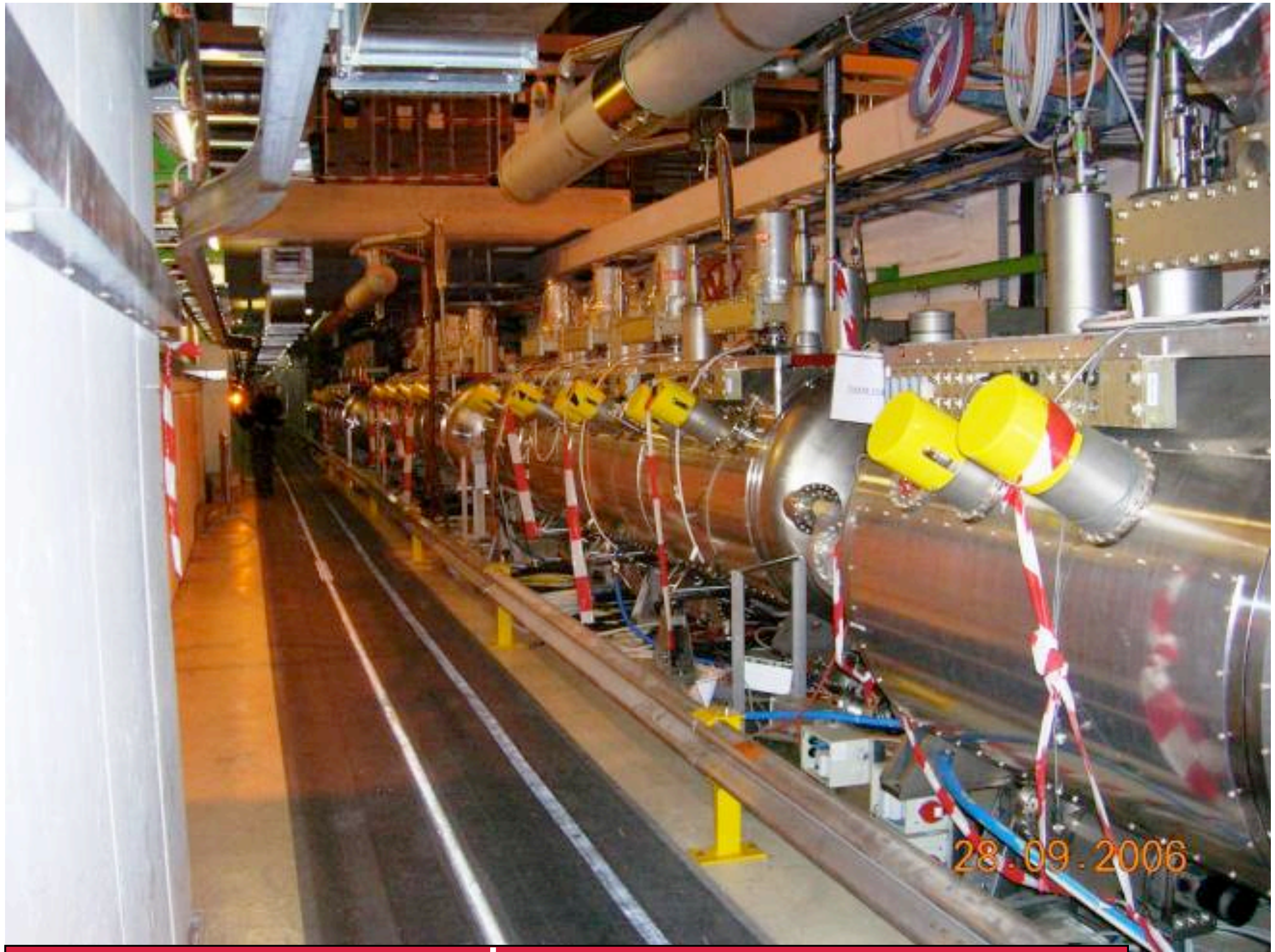
The most challenging components are the 1232 superconducting dipole magnets

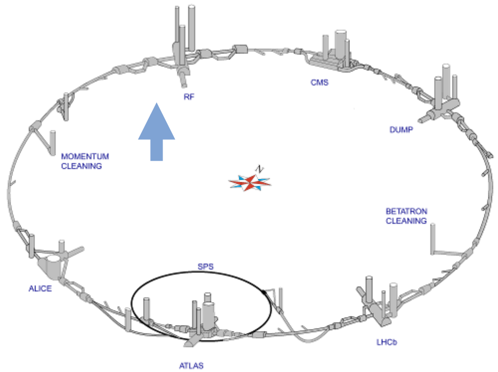
Magnetic field:	***8.4 T***
Operation temperature:	***1.9 K***
Dipole current:	***11700 A***
Stored energy:	***7 MJ***
Dipole weight:	***34 tons***
Nb-Ti superconducting cable:	***7600 km***



LHC Construction Project Leader Lyndon Evans

The particle beams are accelerated by superconducting Radio-Frequency (RF) cavities





The acceleration is not such a big issue in pp colliders (unlike in e^+e^- colliders), because of the ~ $1/m^4$ behaviour of the synchrotron radiation energy losses [~ E^4_{beam}/Rm^4]

	LHC at 7 TeV	LEP at 100 GeV
Synchrotron radiation loss	6.7 keV/turn	3 GeV/turn
Peak accelerating voltage	16 MV/beam	3600 MV/beam

Special quadrupole magnets ('Inner Triplets') are focussing the particle beams to reach highest densities at their interaction point in the centre of the experiments

The LHC Collaborations

CMS
2900 Physicists
184 Institutions
38 countries

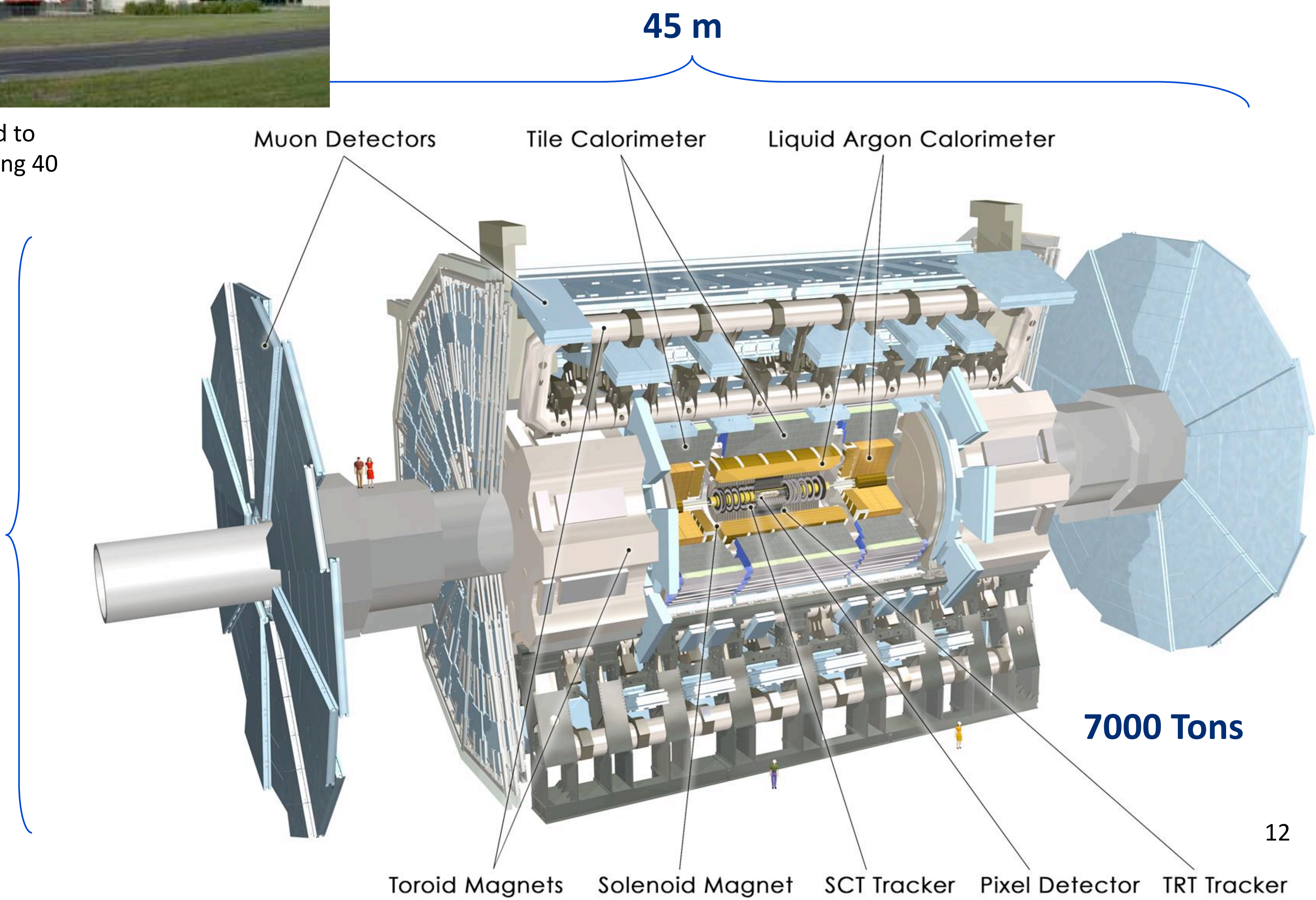
LHCb
700 Physicists
52 Institutions
15 countries

ATLAS
2800 Physicists
169 Institutions
37 countries

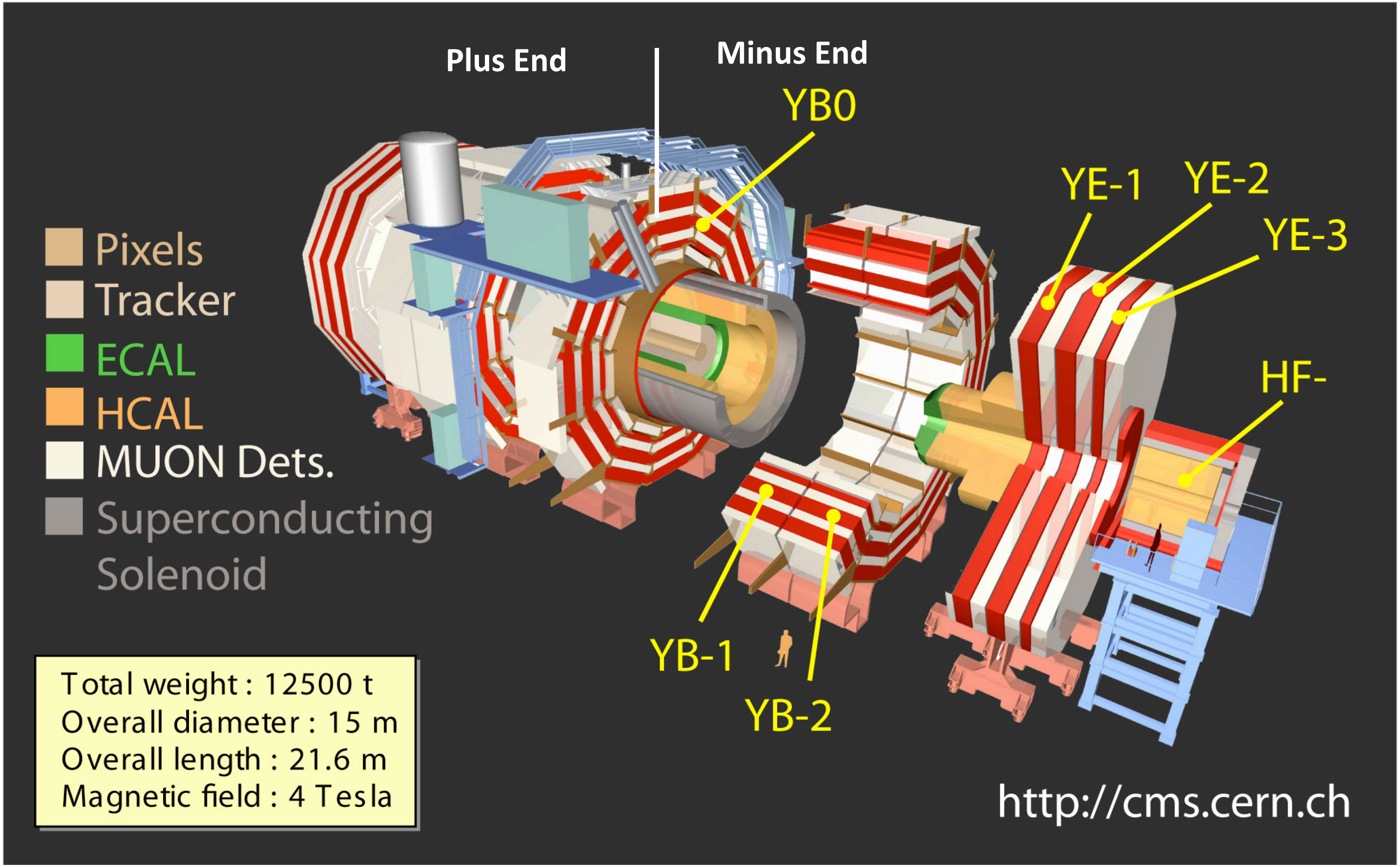
ALICE
1000 Physicists
105 Institutions
30 countries

The ATLAS Detector

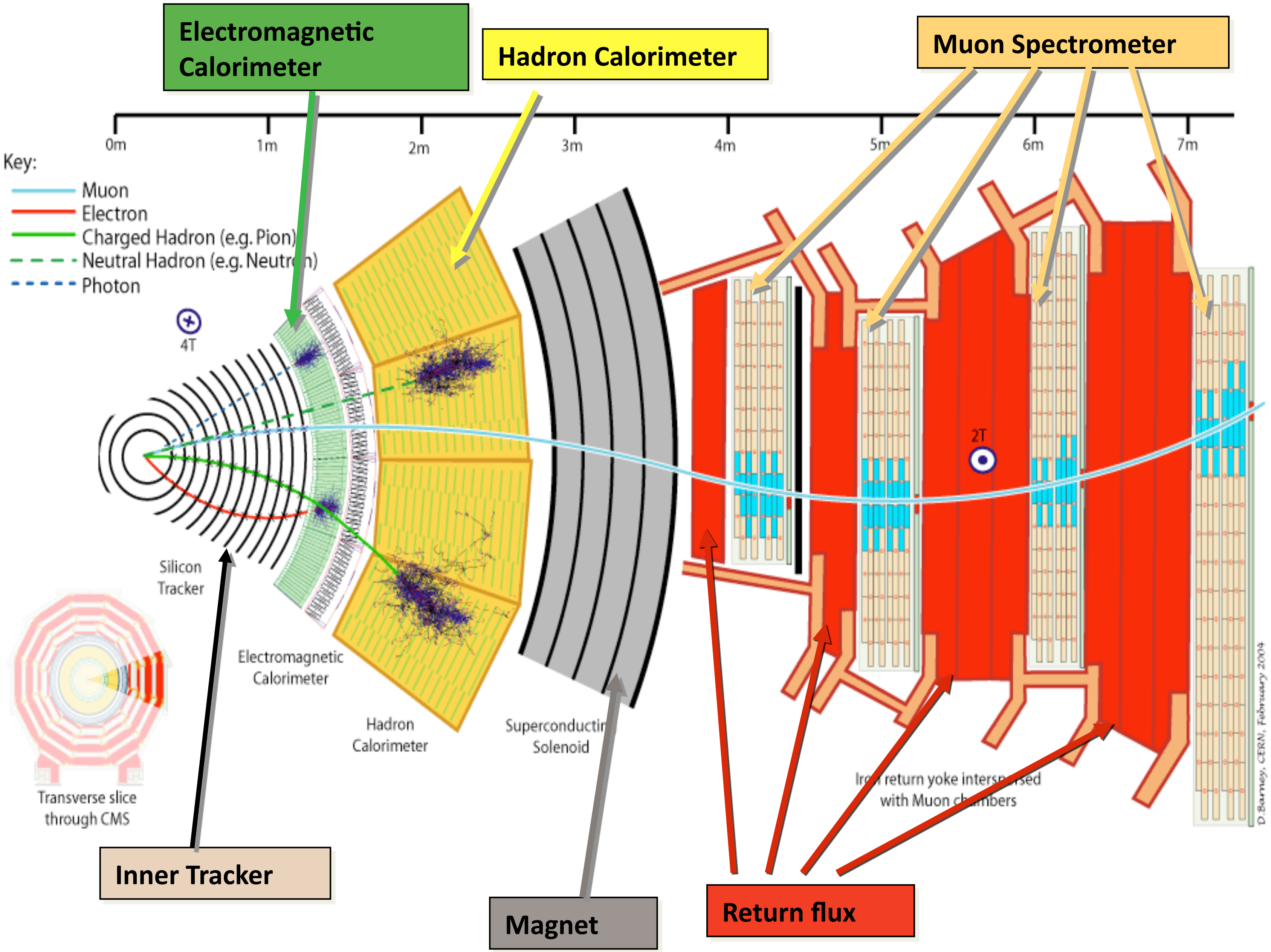
ATLAS superimposed to
the 5 floors of building 40



The CMS Detector



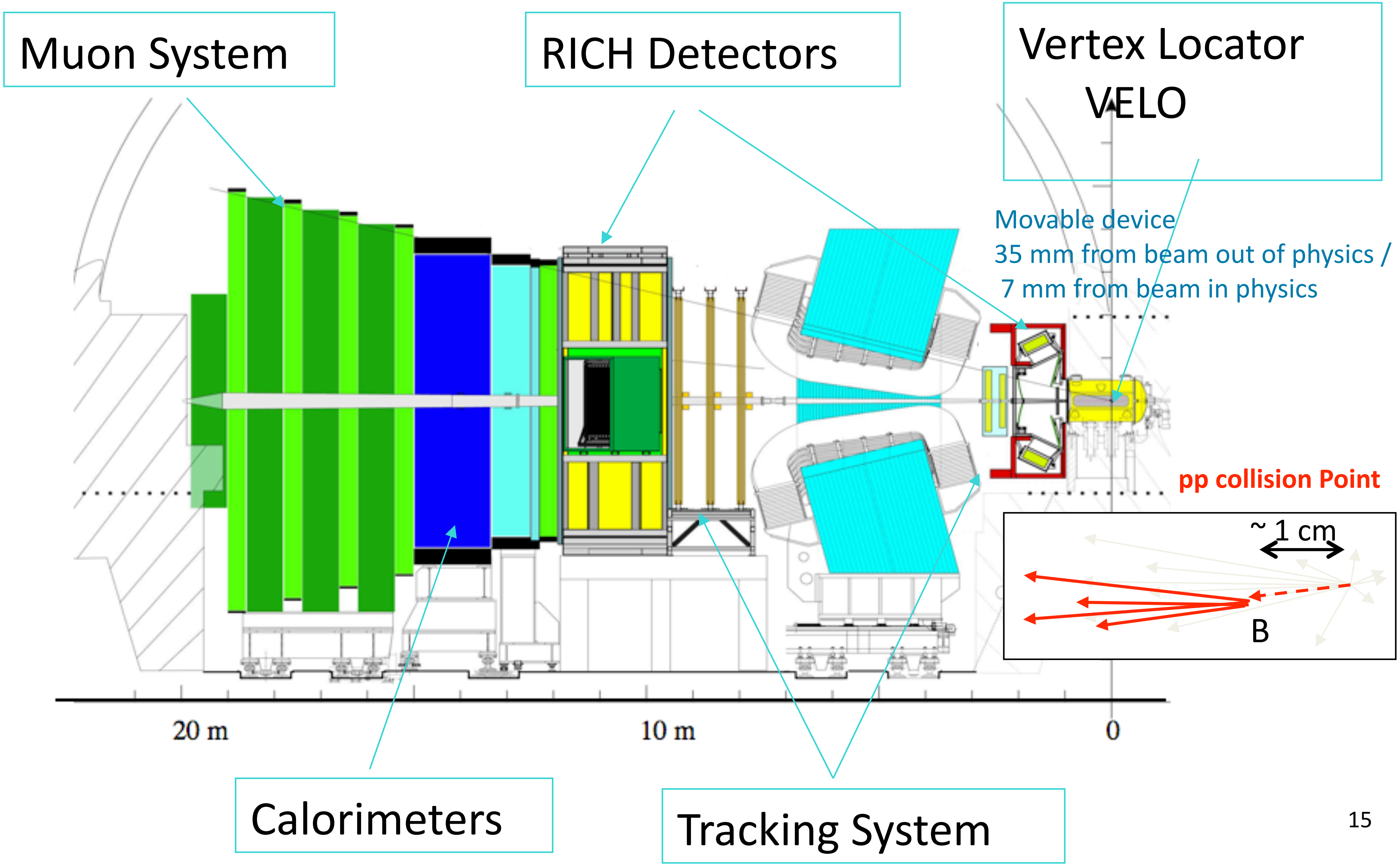
A slice through CMS



The LHCb Detector

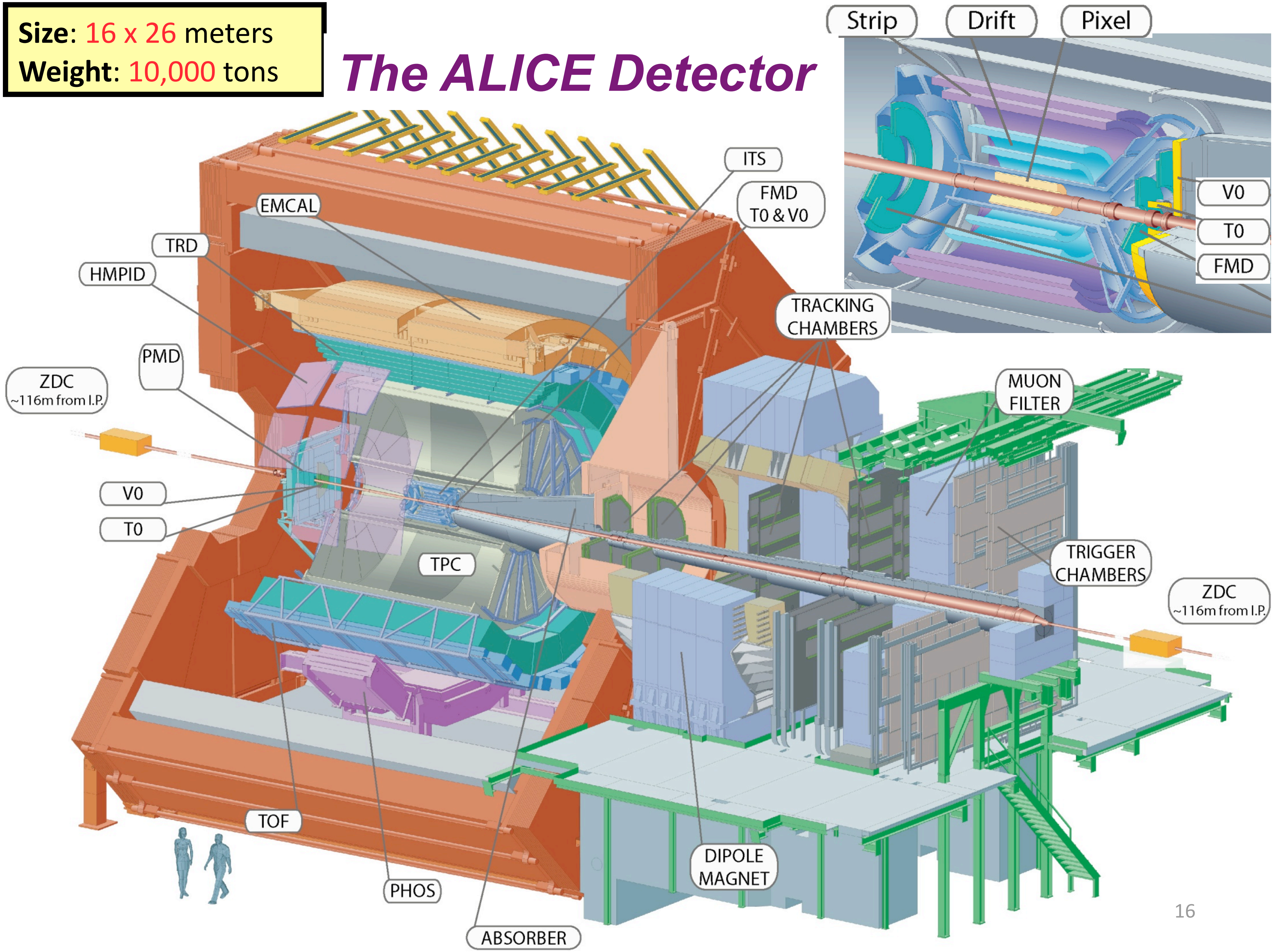
- looks like a slice of GPDs

- with much improved PID capabilities



Size: 16 x 26 meters
Weight: 10,000 tons

The ALICE Detector



Readiness of the LHC detectors for physics

All detectors have shown TDR performance during Cosmics and LHC synchronization Runs (TED)

Strategy to prepare LHC Detectors for physics

- *Strict quality controls during detector construction in order to meet performance requirements*

- *15 year long **test beam** campaign in order to understand (and calibrate large parts of the detectors) and validate/tune software tools*

- *Detailed simulation of realistic detector including misalignments, material non-uniformities, etc. in order to test and validate calibration/ alignment strategies*

- ***Commissioning of completed detectors in the underground caverns using cosmic rays and "LHC beams"***

- *Commissioning and calibration with physics*
  Understanding SM backgrounds to New Physics

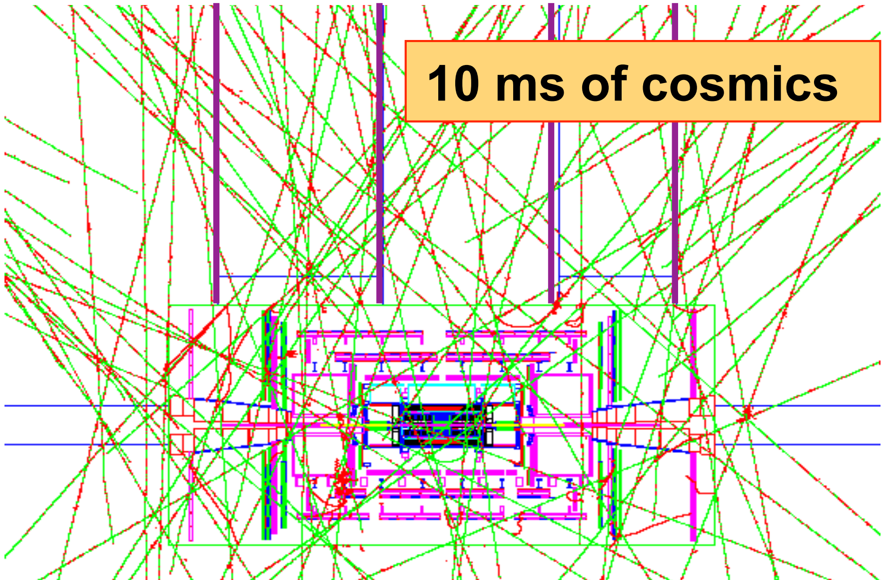
- ***Discovery of New Physics …***

Commissioning with cosmics in the underground cavern

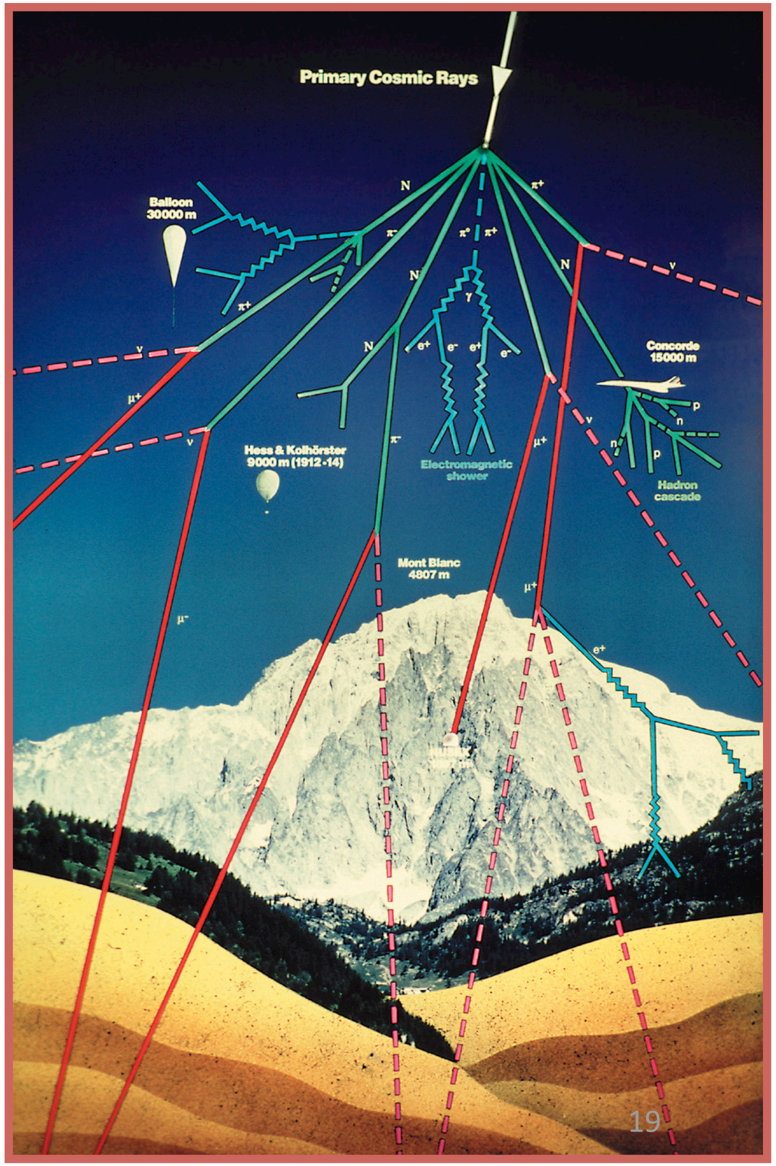
(the first real data in situ …)

Started more than three years ago. Very useful to:

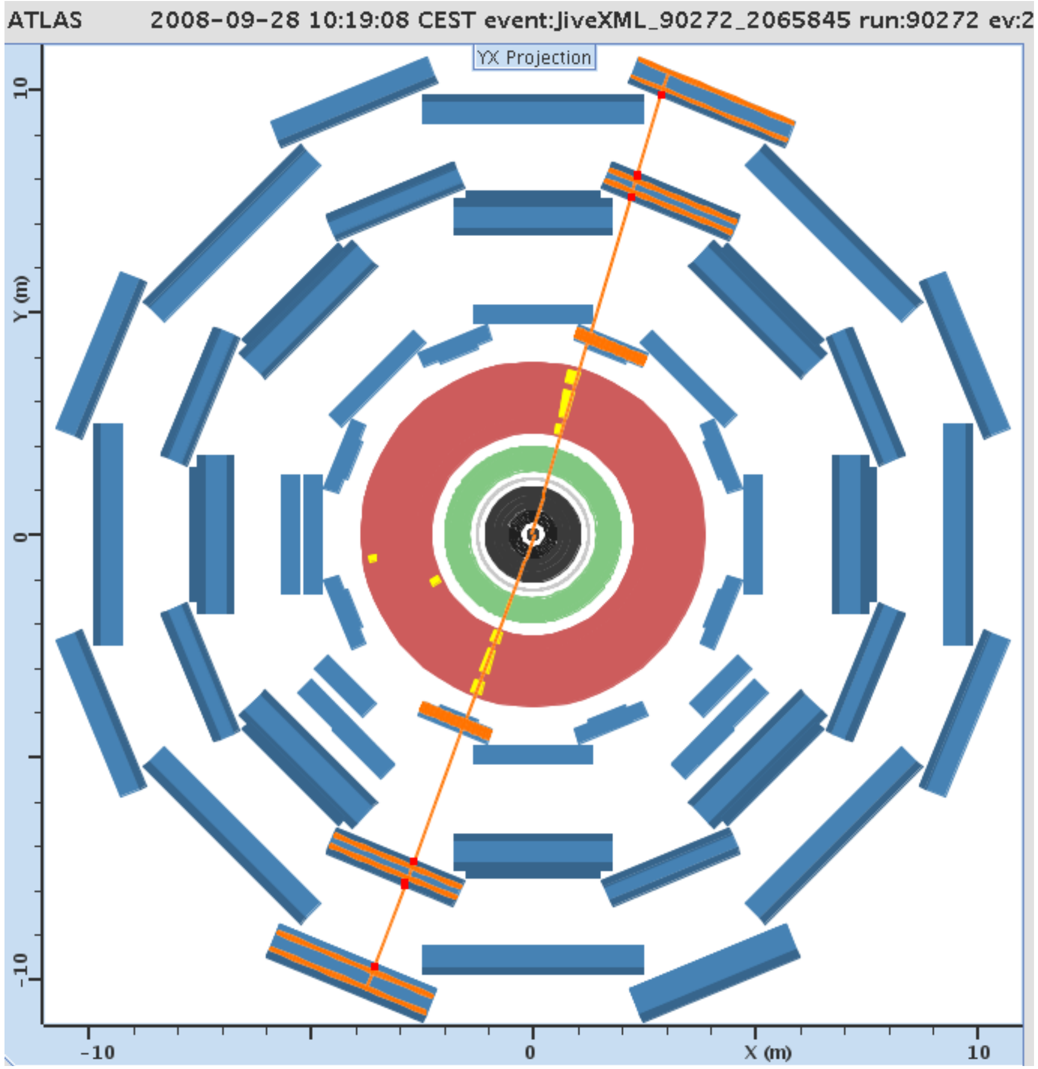
- *Run an increasingly more complete detector with final trigger, data acquisition and monitoring systems. Data analyzed with final software*
- *Shake-down and debug the experiment in its final position → fix problems*
- *Perform first calibration and alignment studies*

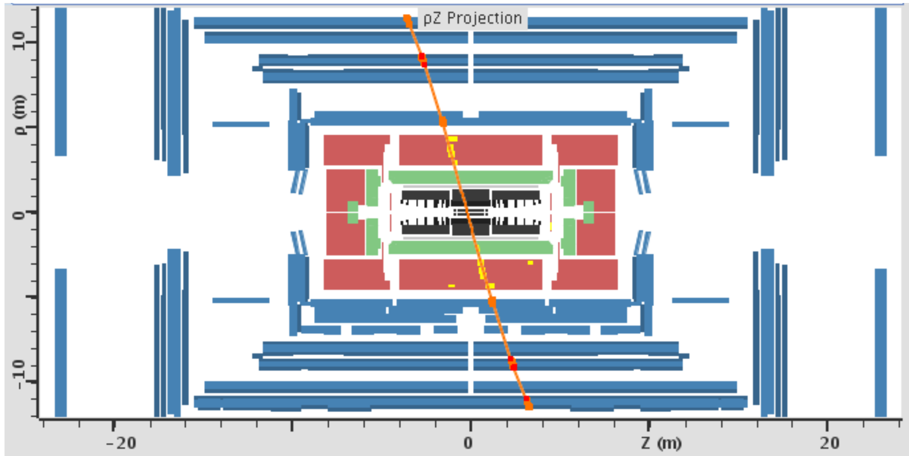


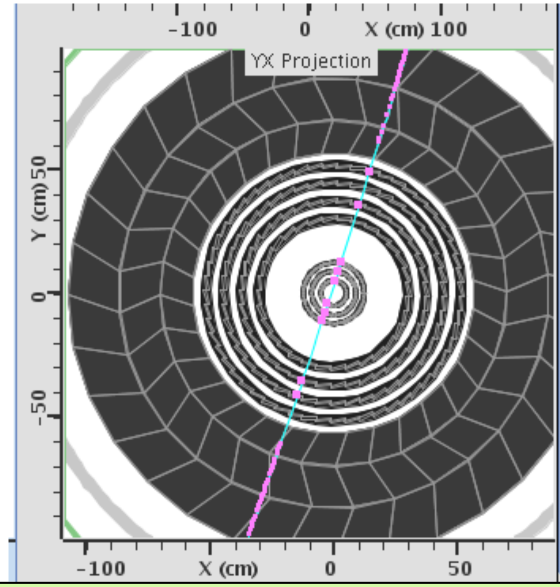
Rate of cosmics in ATLAS: 0.5-100 Hz (depending on sub-detector size and location)



A cosmic muon traversing the whole detector. Recorded on 28 September 2008





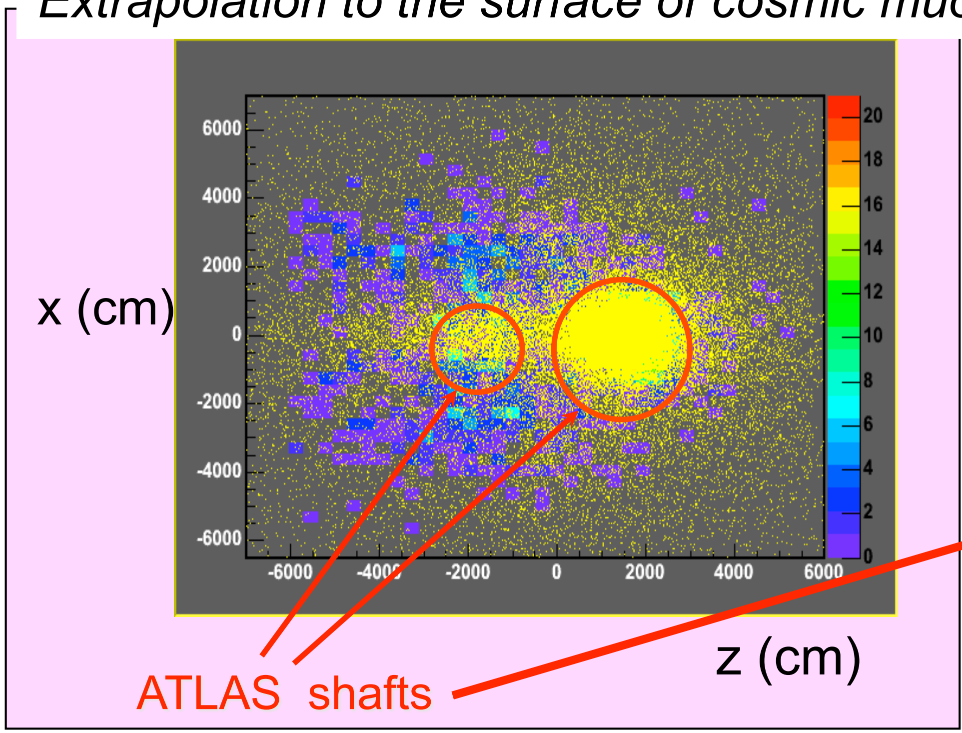


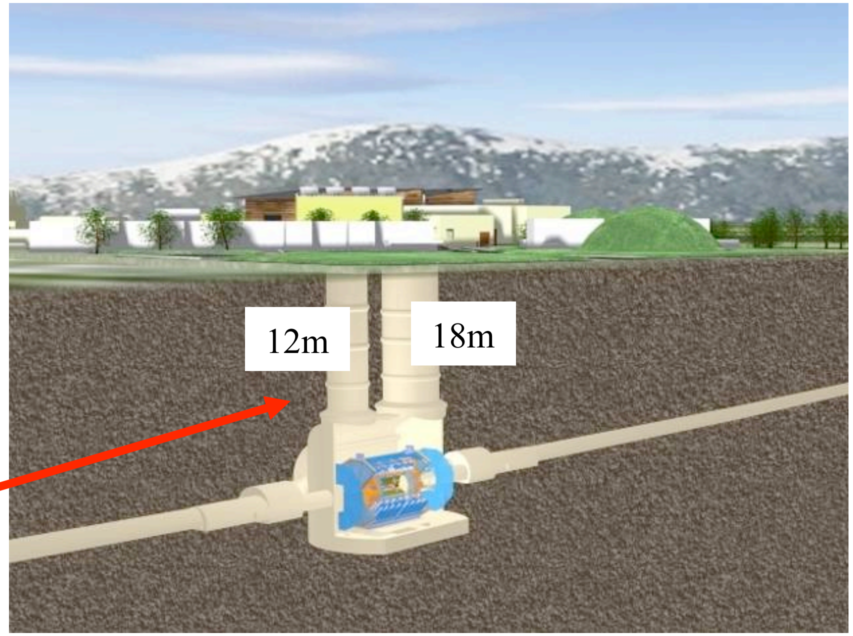
~ 500 million cosmics muons recorded August-November 2008 (1.2 PB raw data)

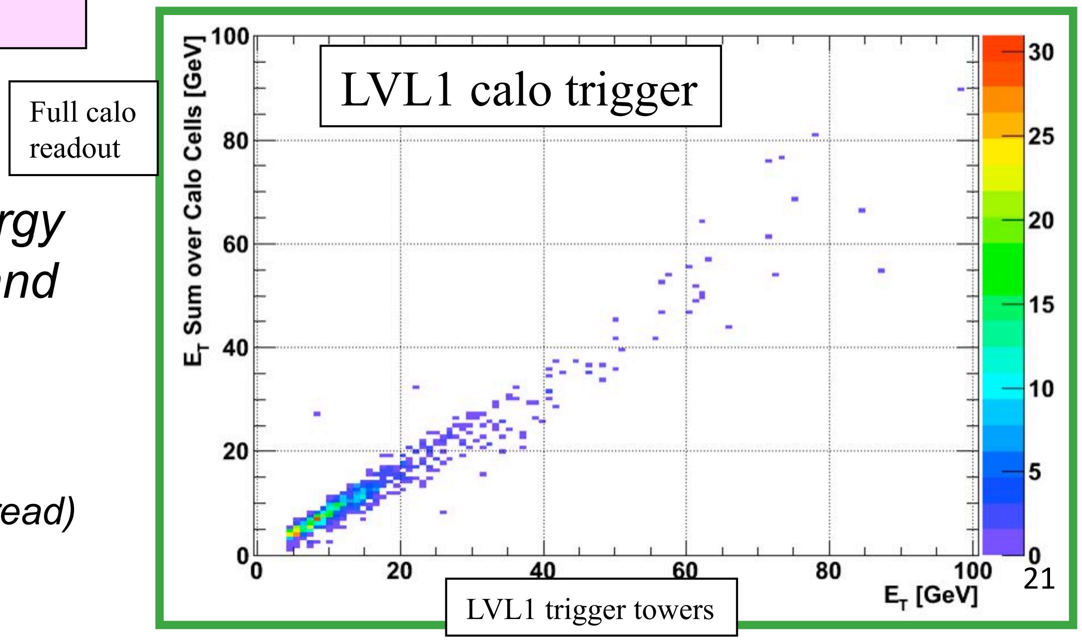
Examples of trigger performance with cosmics data

ATLAS preliminary

Extrapolation to the surface of cosmic muon tracks reconstructed by RPC chambers



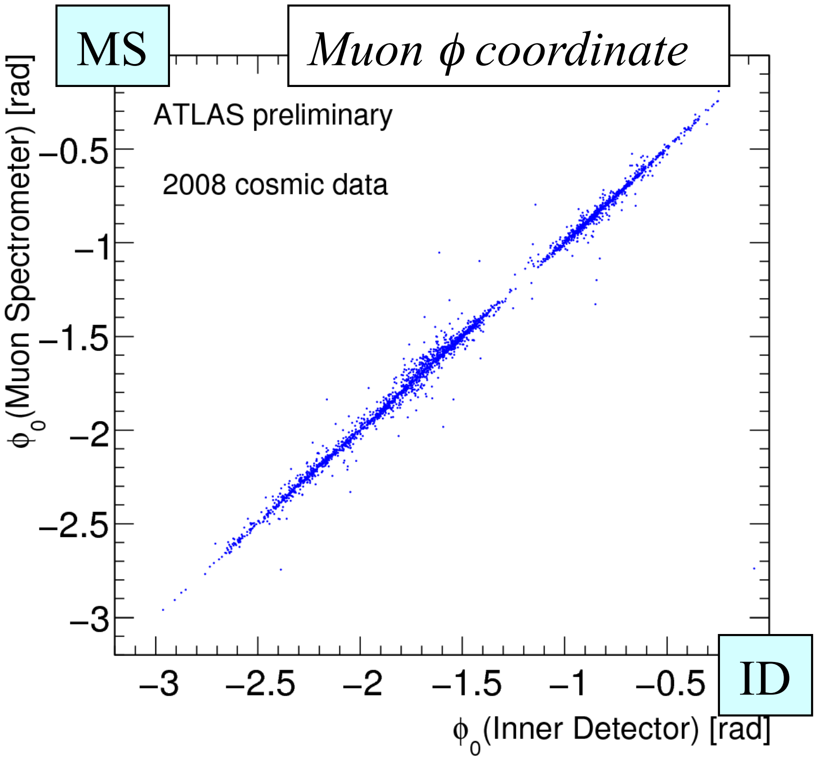


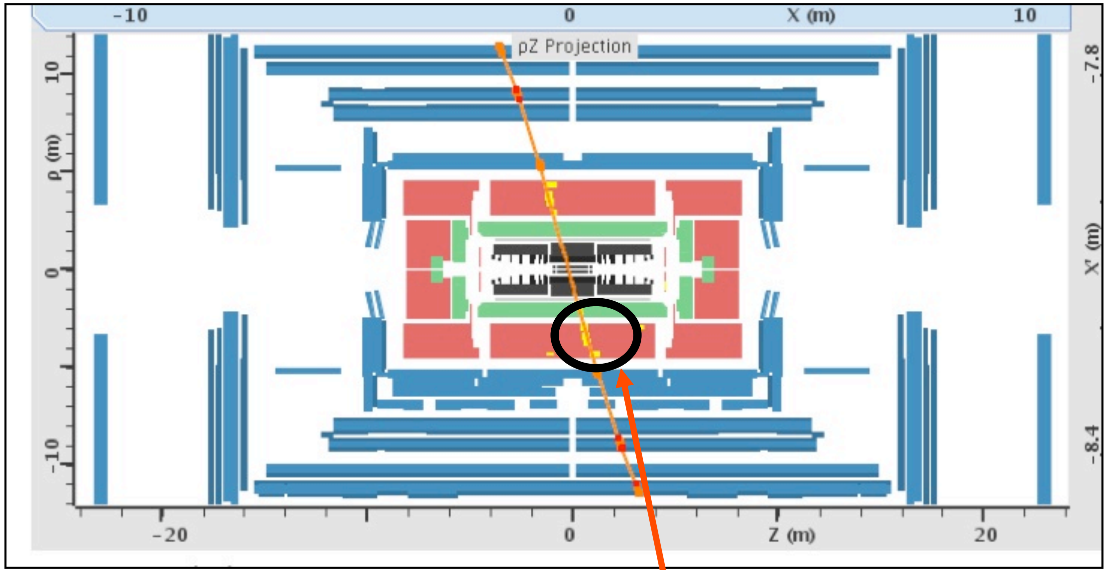


Perfect correlation *between muon energy measured with full calorimeter readout and energy measured in trigger towers ($\eta x \phi$=0.1x0.1) by LVL1 Calo trigger*

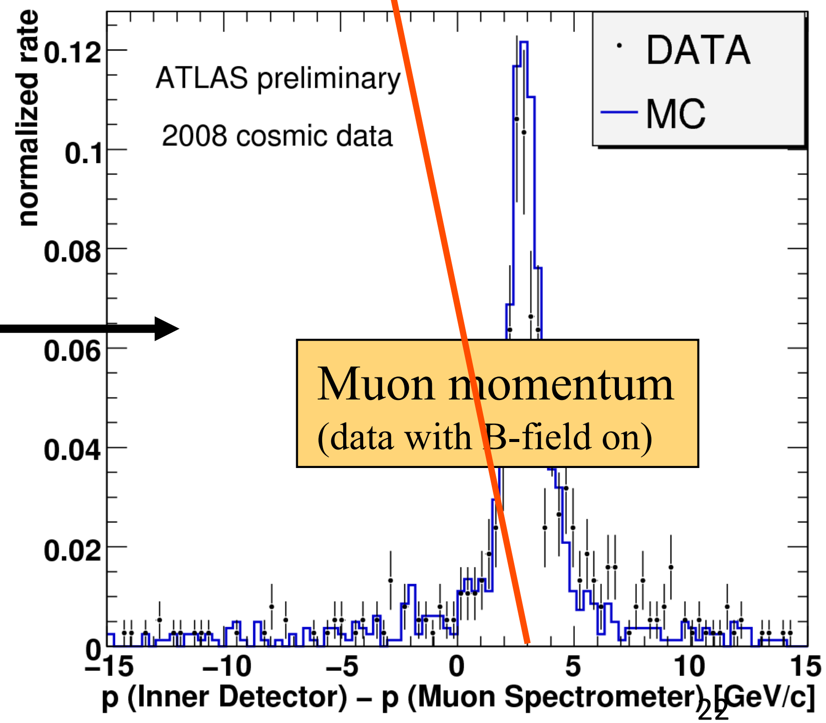
Initial calibration (final calibration will reduce the spread)

Correlation between measurements in the Inner Detector and Muon Spectrometer



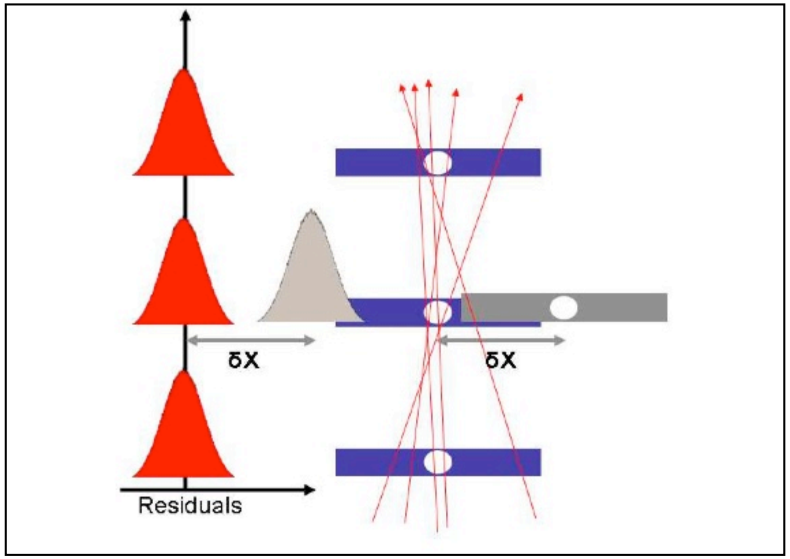


Difference between the muon momentum measured in the Inner Detector and in the Muon System for tracks in the bottom part of the detector
*(**~ 3 GeV energy loss in the calorimeter**)*

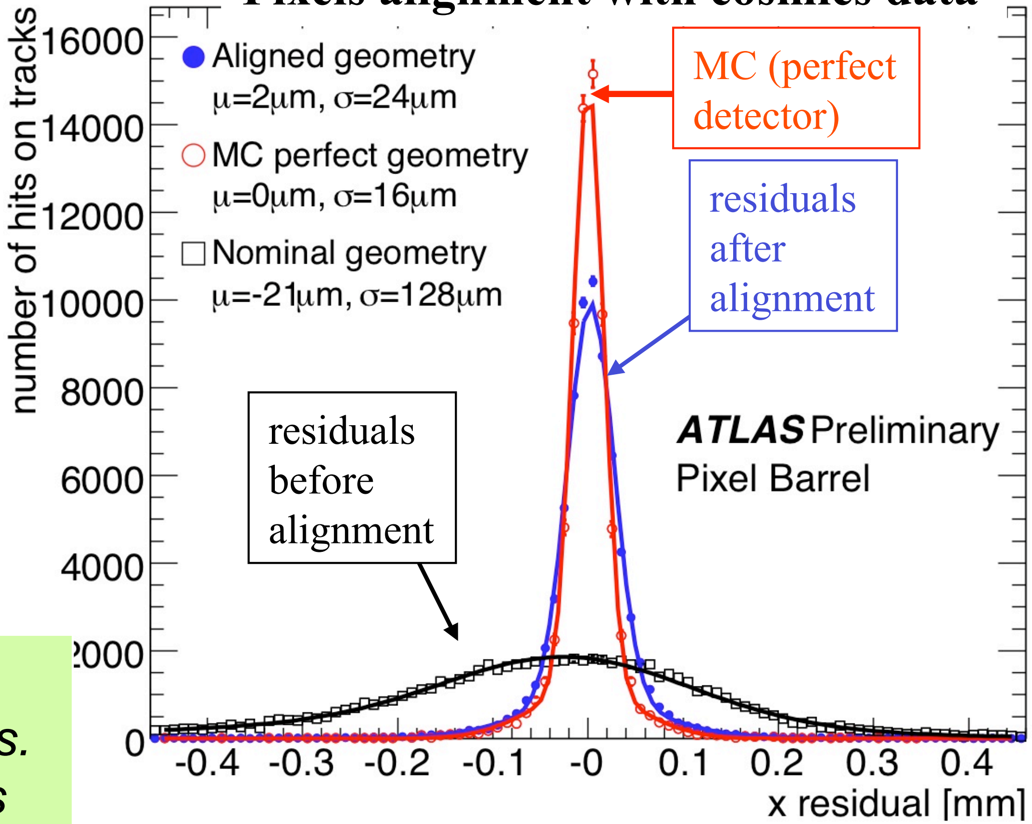


Precision studies: alignment of the ATLAS Inner Detector

Alignment of the Pixels and SCT detector modules must be known to a few microns for a precise reconstruction of the track parameters
The detector alignment is performed using tracks (from cosmics now, pp collisions later) and an iterative procedure that minimizes the hit residuals globally
~ 36000 degrees of freedom: 6000 detector modules x 6 unknown (3 position coordinates + 3 rotation angles per module)



Pixels alignment with cosmics data



Residuals: distance between the fitted track and the hits in the individual layers. After alignment: distribution of residuals peaks at zero with σ compatible with detector resolution

Achieved in best illuminated modules: ~ 25 μm

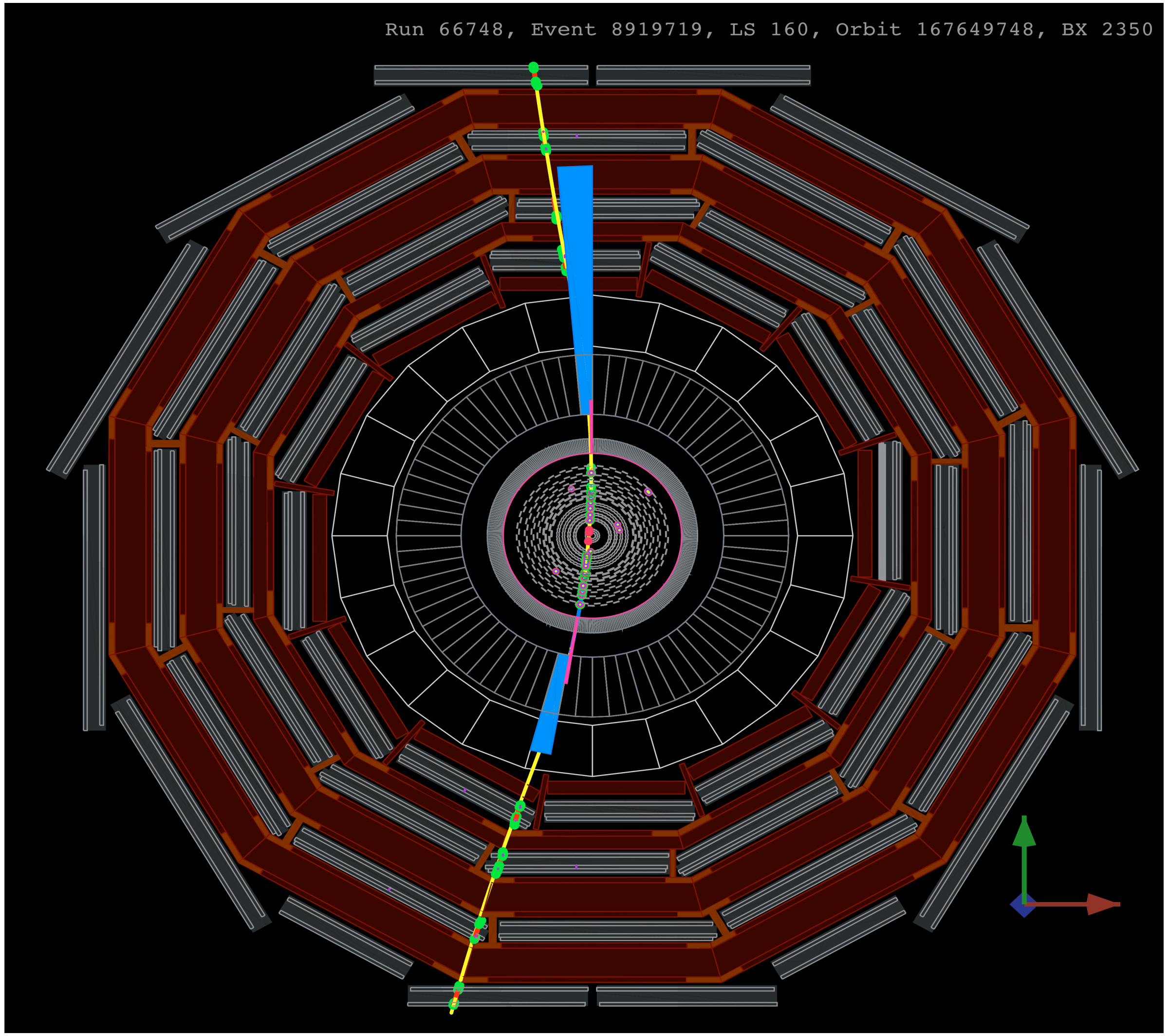
CMS Cosmic Run

CRAFT:
Cosmics Run at Four Tesla

Oct-Nov'08: Ran CMS for 6 weeks continuously to gain operational experience

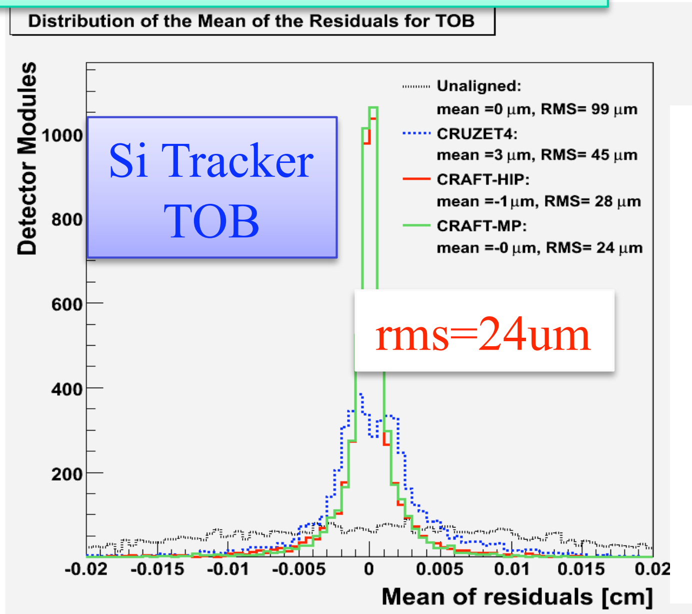
Collected 300M cosmic events with tracking detectors and field (≈ 70% live-time). About 400 TB of data distributed widely

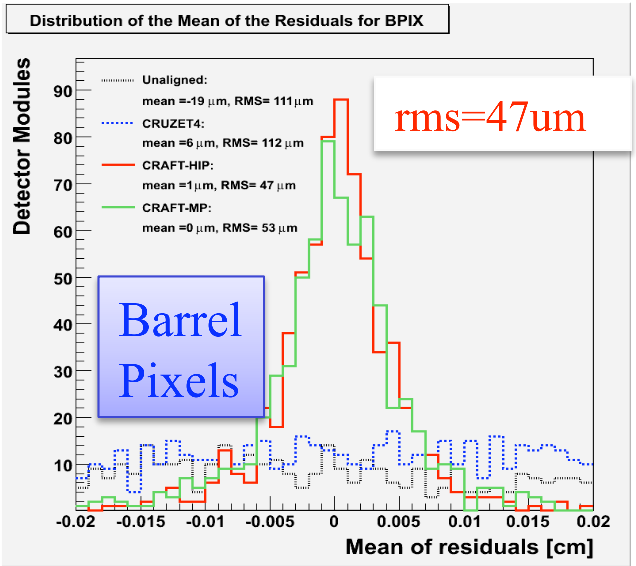
- 87% have a standalone muon track reconstructed
- 3% have a global muon track with strip tracker hits (~7M)
- 3-4×10^{-4} have a track with pixel hits (~70k)



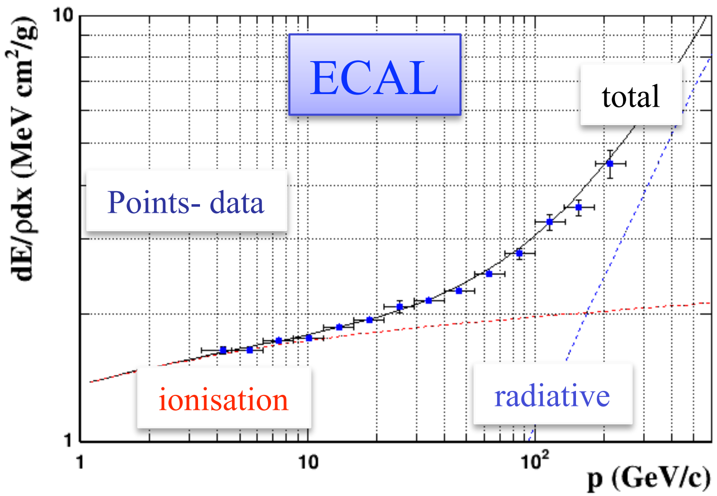
CMS Cosmic Run

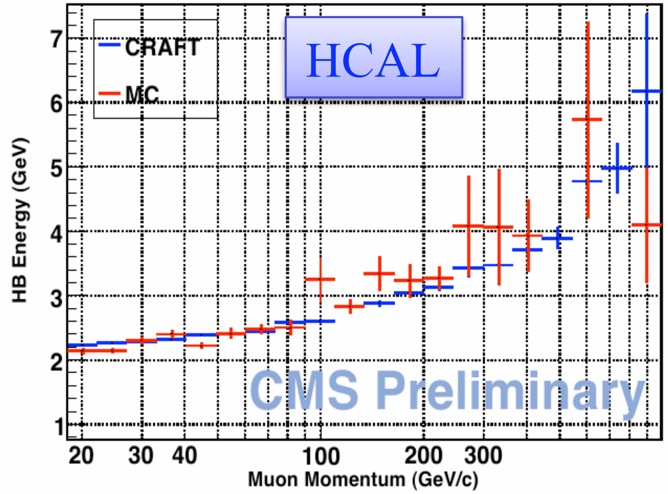
Alignment in Inner Tracker



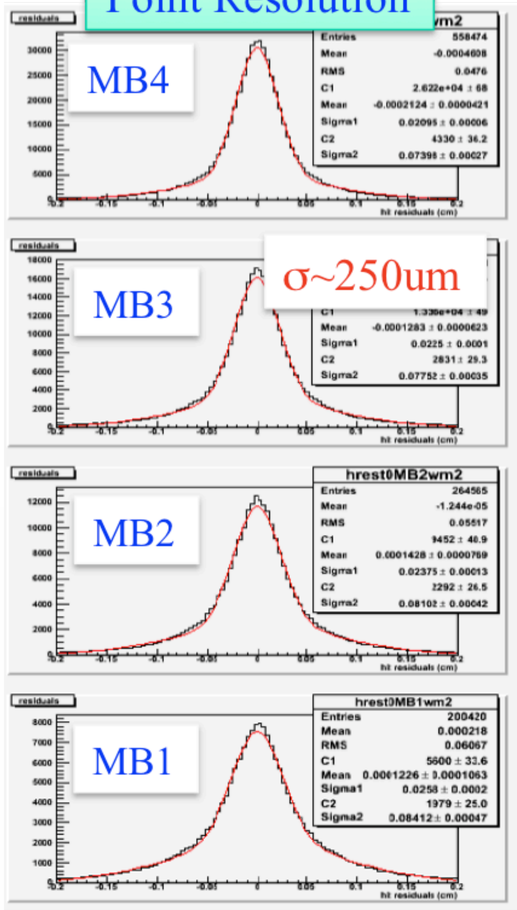


Energy deposited by muons





Muon Chambers
Point Resolution



ALICE: TPC Performance

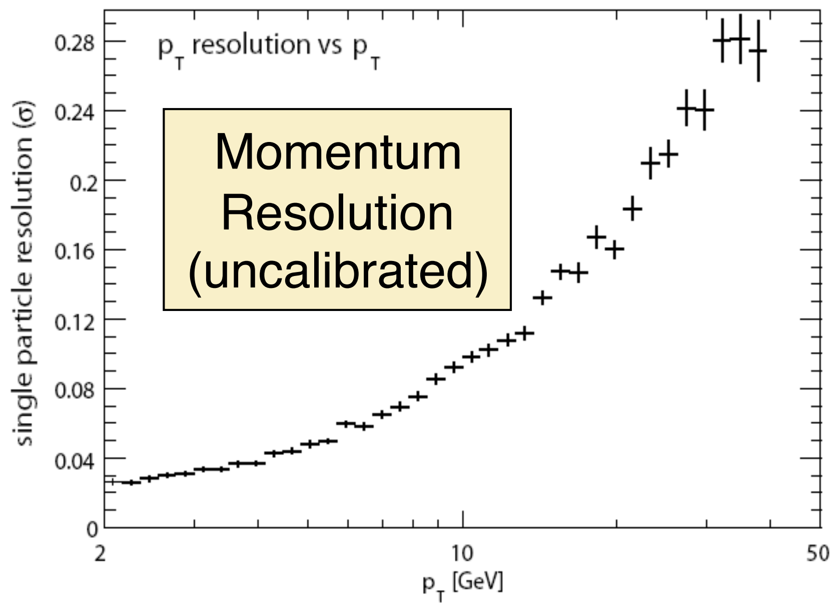
First preliminary results from cosmics

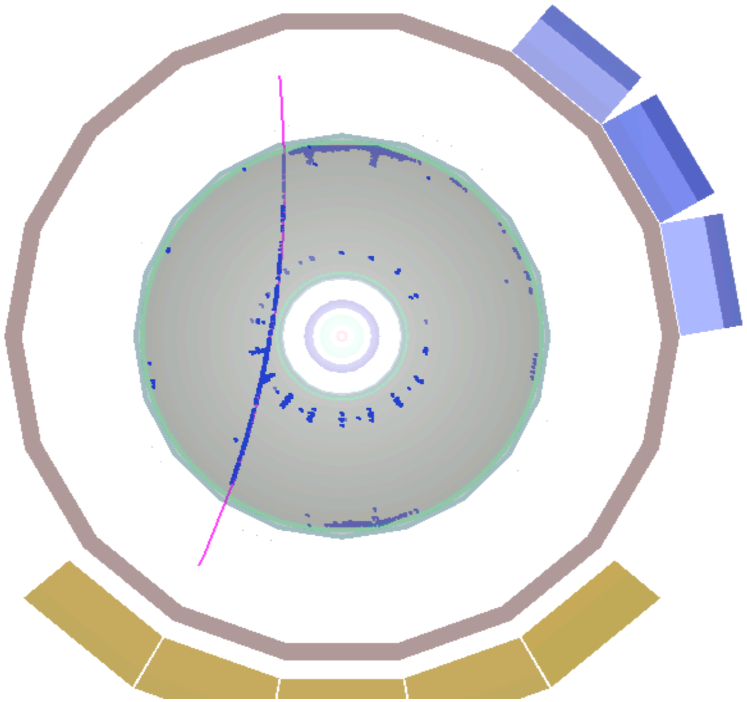
dE/dx resolution *< 6% (goal: ~ 5.5%)*

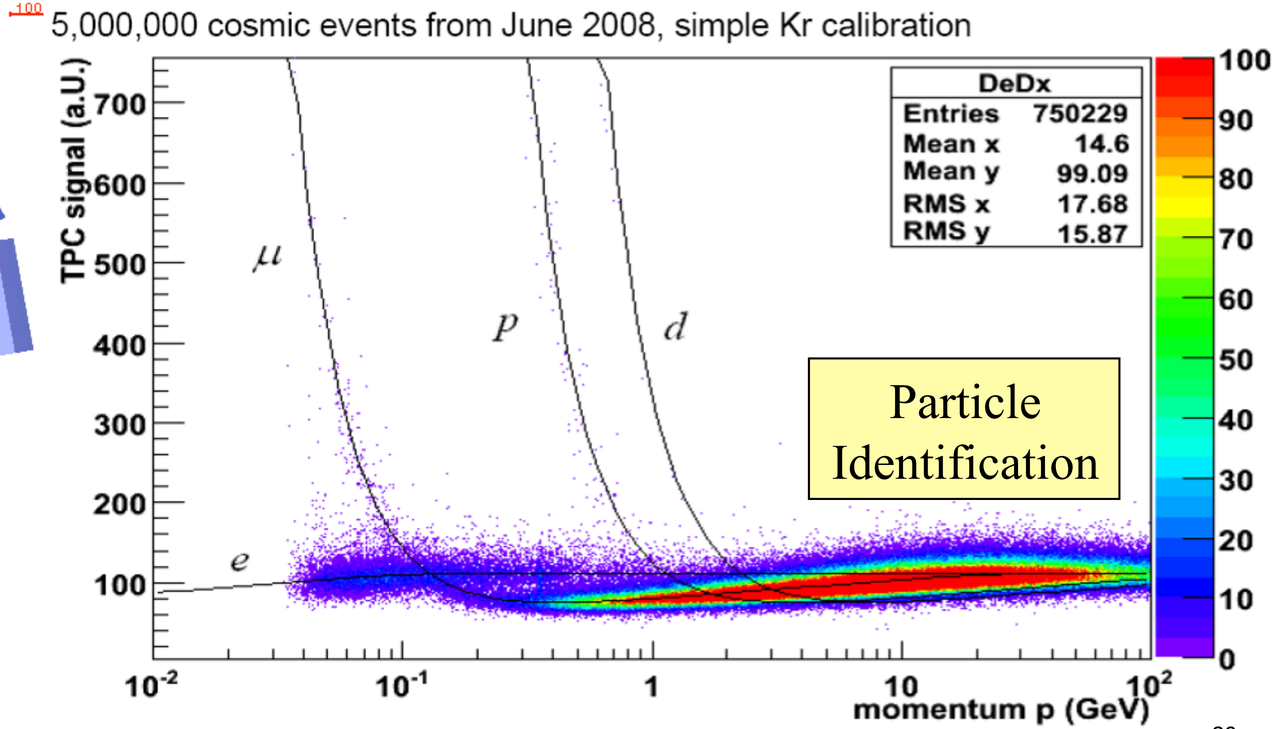
p_t resolution

~ 10% @ 10 GeV w/o calibration

(goal: ~ 5% @ 10 GeV)

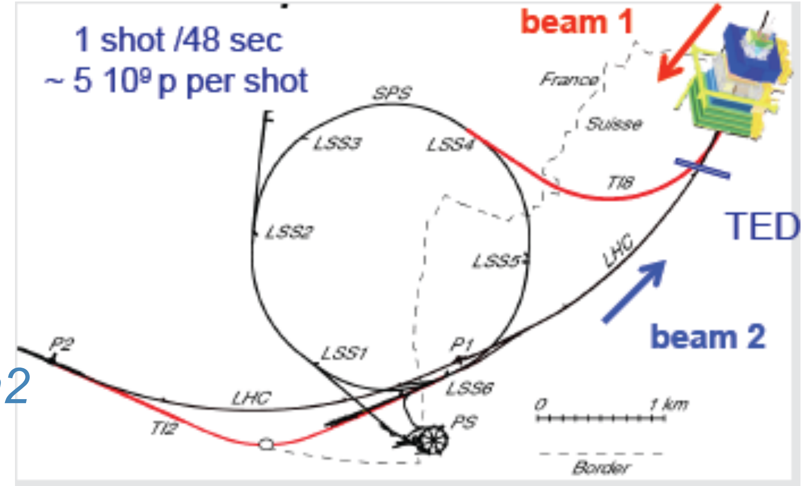




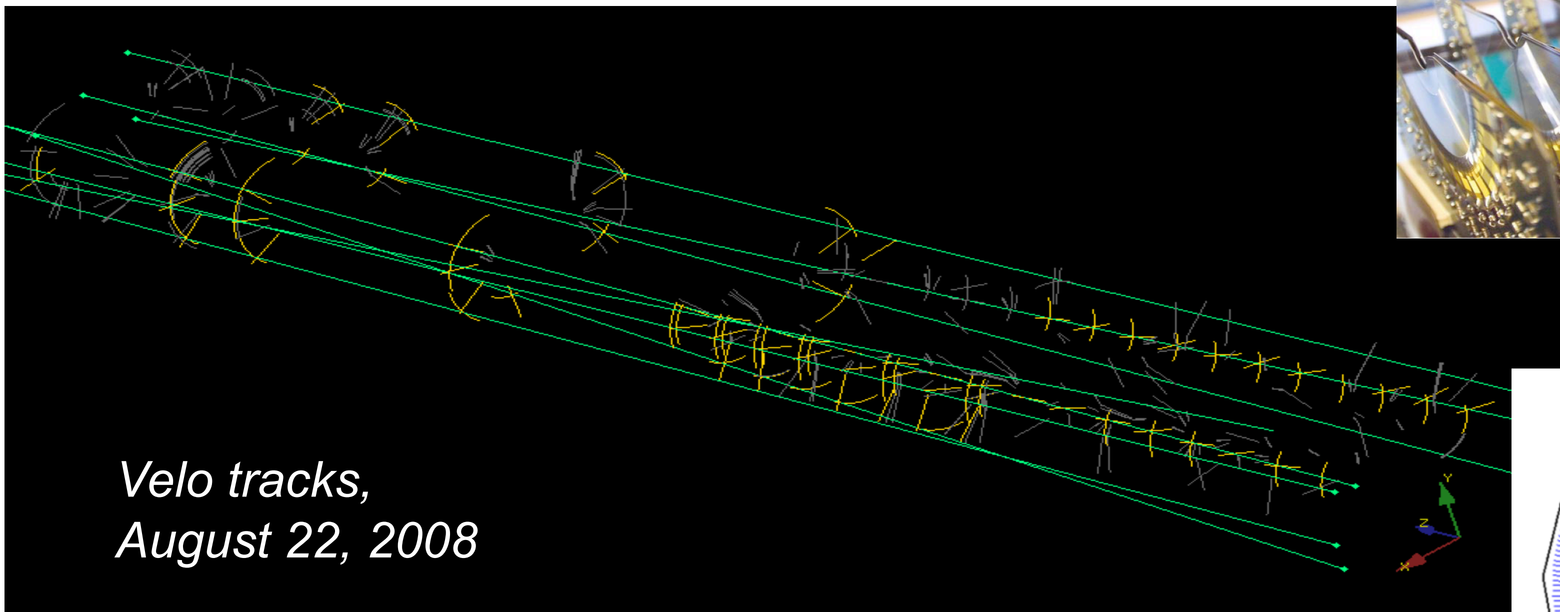


Alignment of LHCb using TED Runs

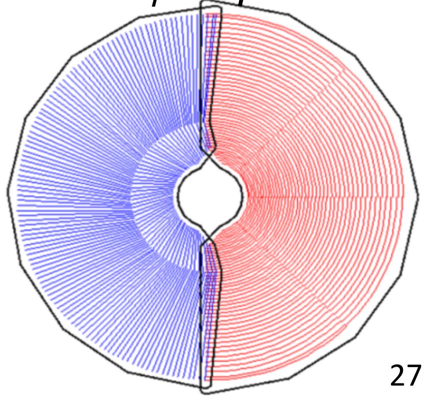
- *Beam 2 dumped on injection line beam stopper (TED)*
  - *Located 340m before LHCb along beam 2*
  - *Wrong direction for LHCb*
  - *High flux, centre of shower O(10) particles/cm2*



TED tracks reconstructed in VELO almost on-line



21 stations of Si wafer pairs with r and ϕ strip readout

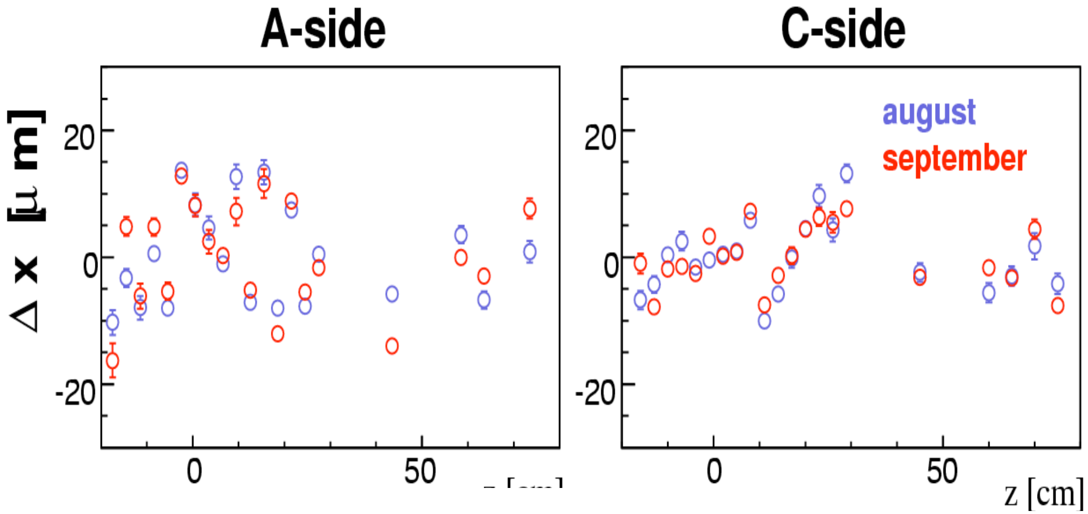


LHCb VELO alignment with TED data

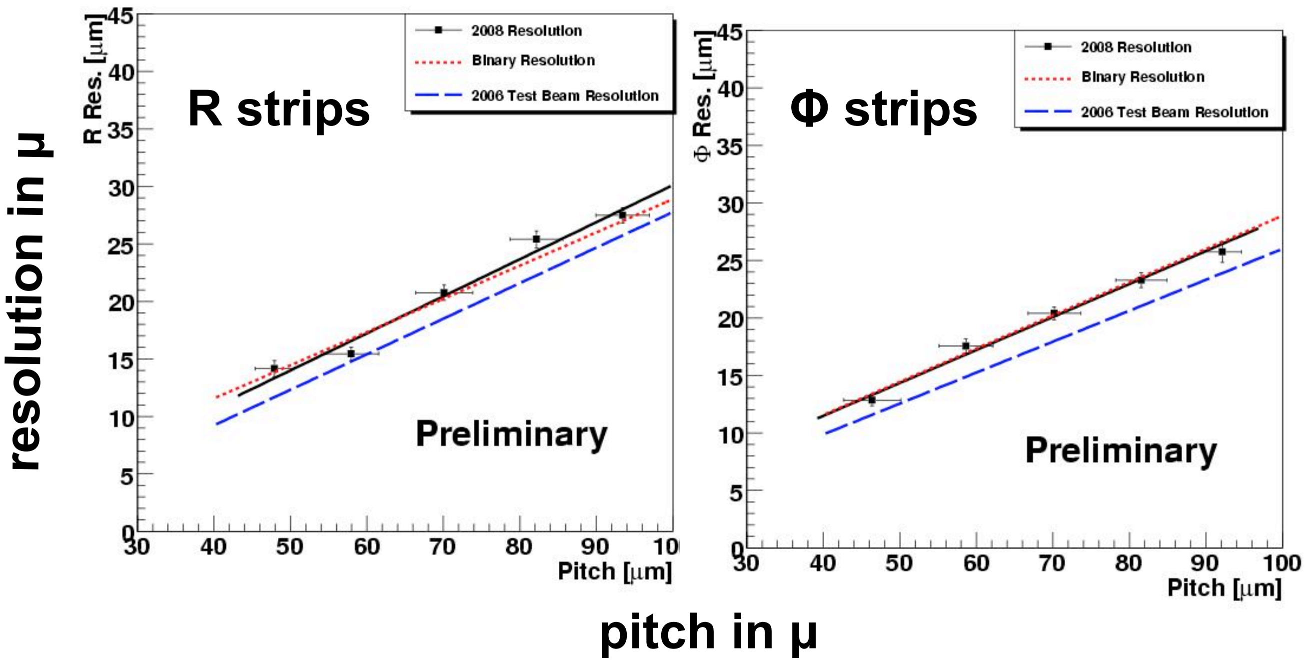
(TED tracks perfect for VELO alignment: cross detector almost parallel to z)

Translation in X of VELO modules extracted from twoTED runs

- *good agreement between two runs (change with respect to survey less than 20 micron)*



z of module [cm]



Resolution estimated from VELO hit residuals agrees well with expectations

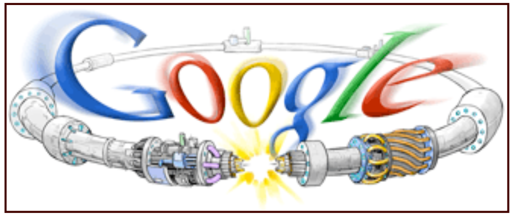
Further improvement possible

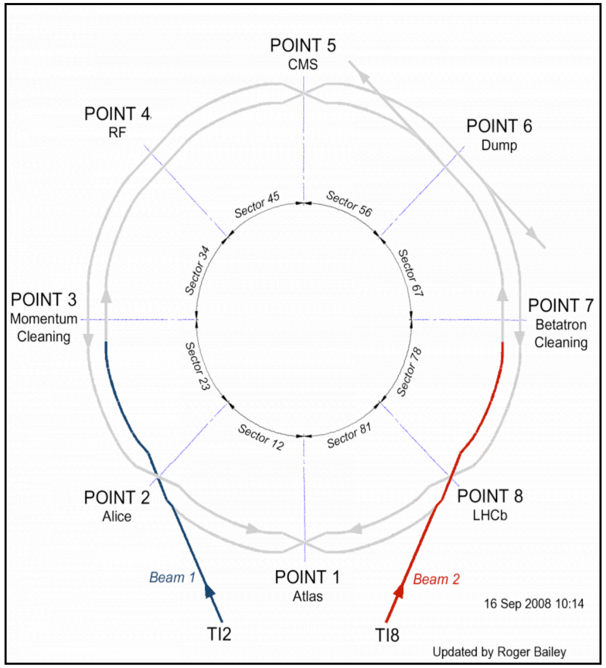
10 September 2008: LHC inauguration day

First (single) beams circulating in the machine

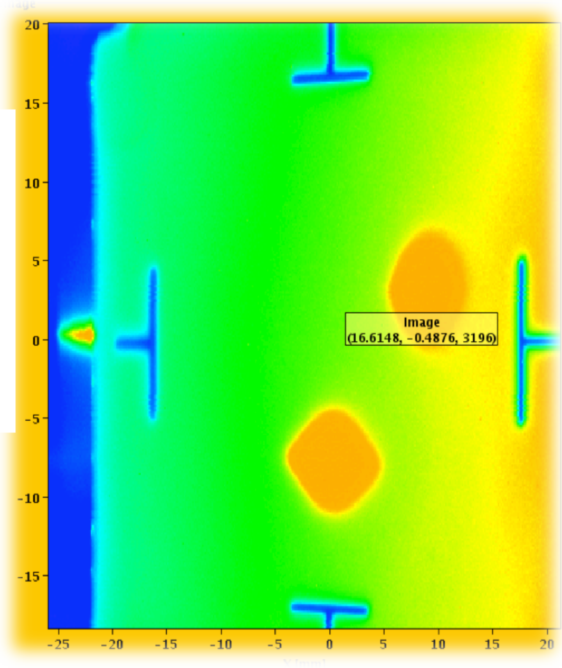
Five CERN DGs, from conception to realization: Schopper, Rubbia, Llewellyn Smith, Maiani, Aymar (from right to left)

First Turn! 10 Sept 2008





10:30 am
Two beam spots on a screen near ALICE indicate that Beam 1 has made 1 turn



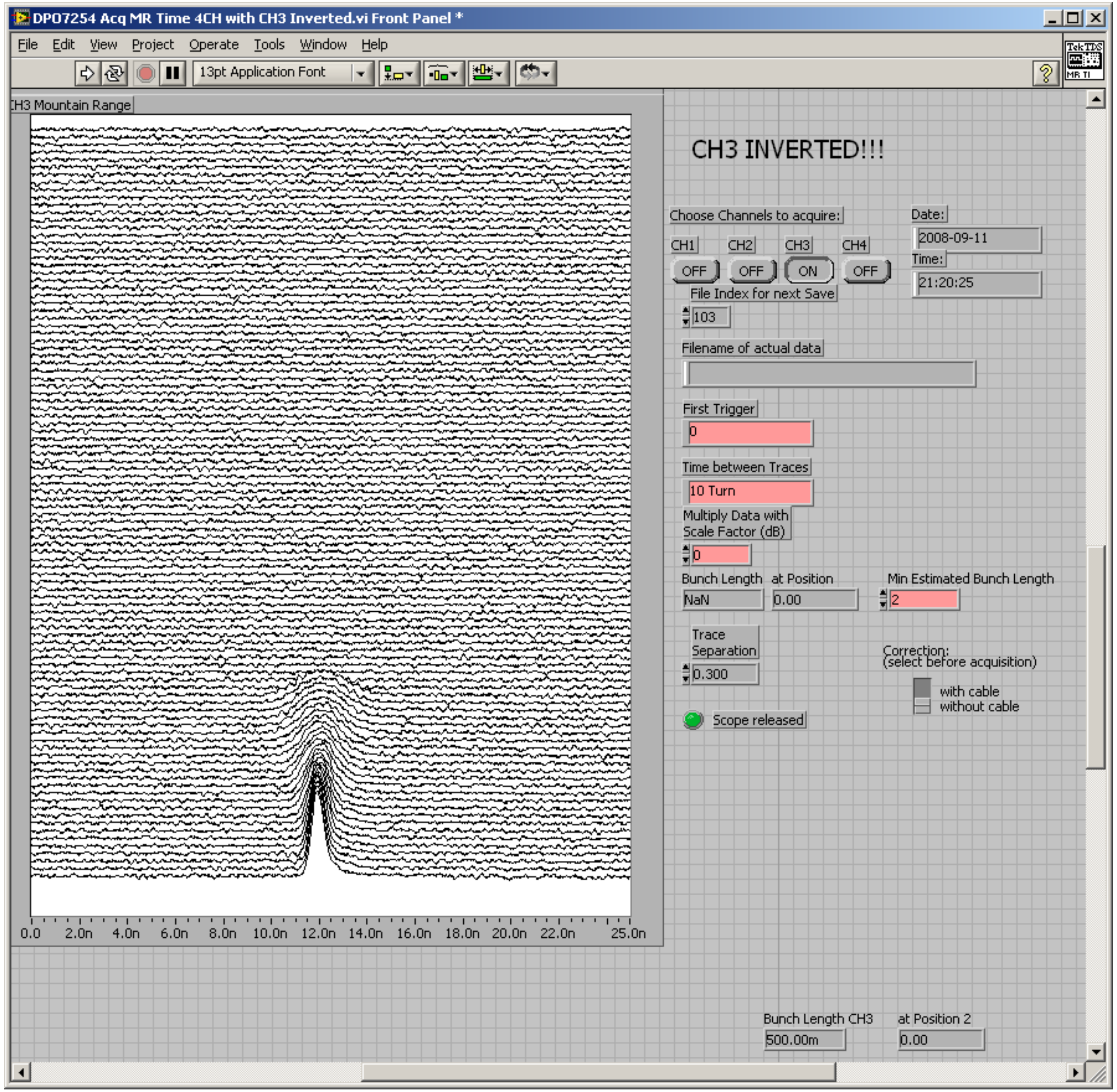
10:30 : Beam 1 (clockwise) around the ring (in ~ 1 hour), makes ~ 3 turns, then dumped

15:00 : Beam 2 (counter-clockwise) around the ring, makes 3-4 turns, then dumped

22:00 : Beam 2 circulates for hundreds of turns …

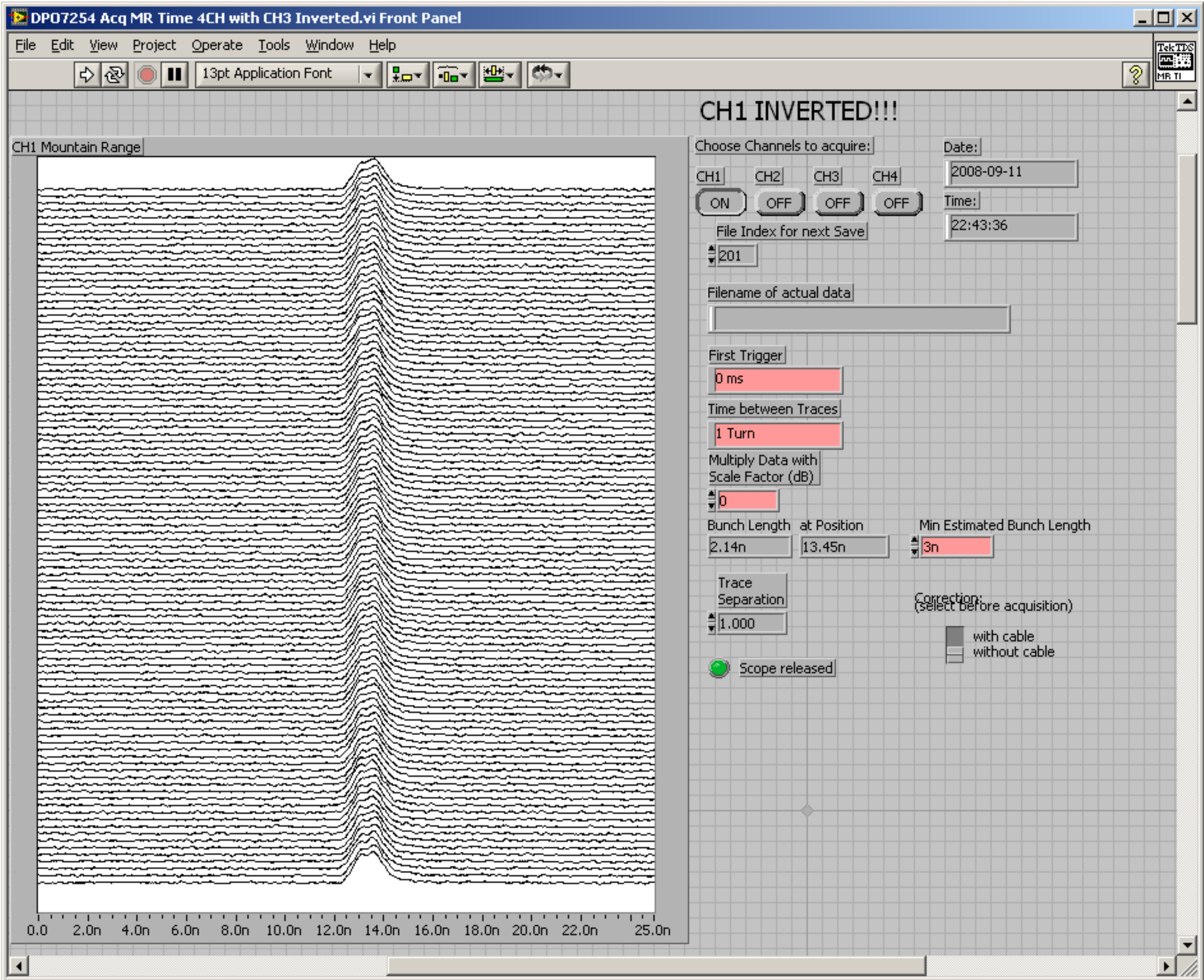
Beam Energy: 450 GeV, Beam Intensity: 2 x 10^9 protons per bunch

*No RF, debunching in ~ 25*10 turns, i.e. roughly 25 ms*



Courtesy E. Ciapala

Capture with optimum injection phasing, correct reference

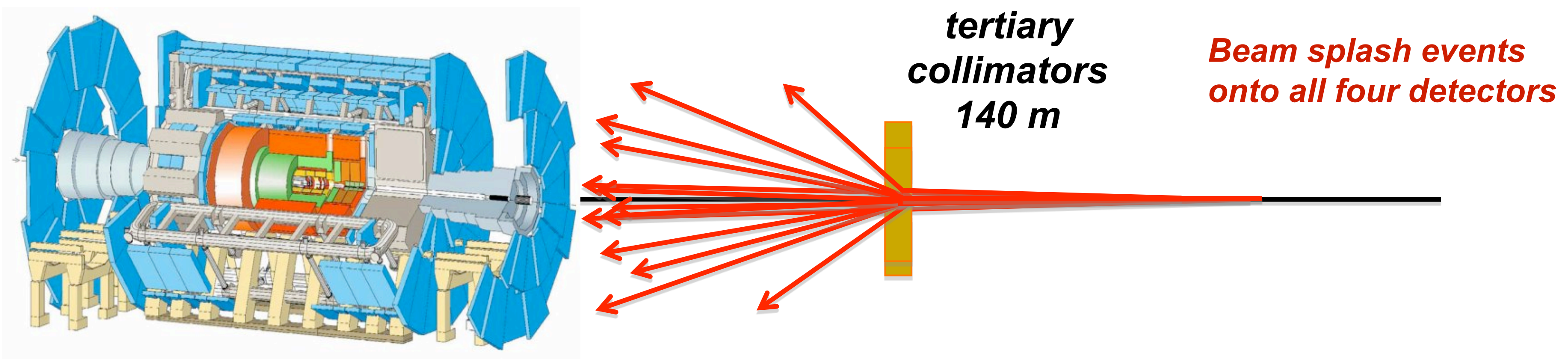


Courtesy E. Ciapala

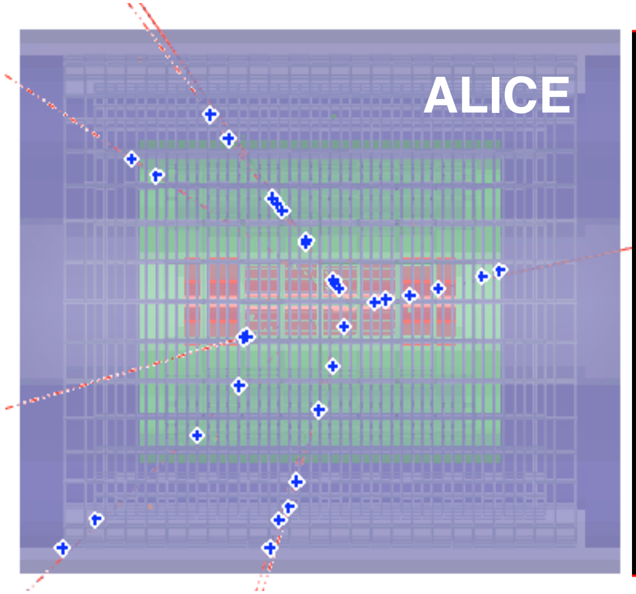
First LHC Single Beam on 10th September 2008

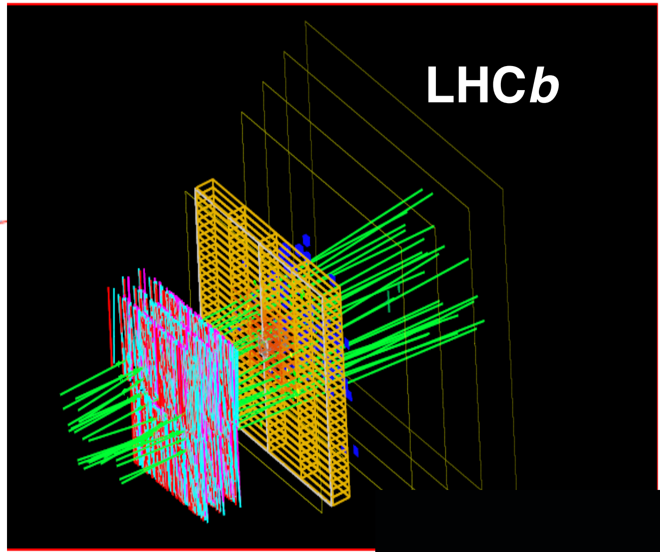
- Beam splash events have been successfully recorded by all four experiments

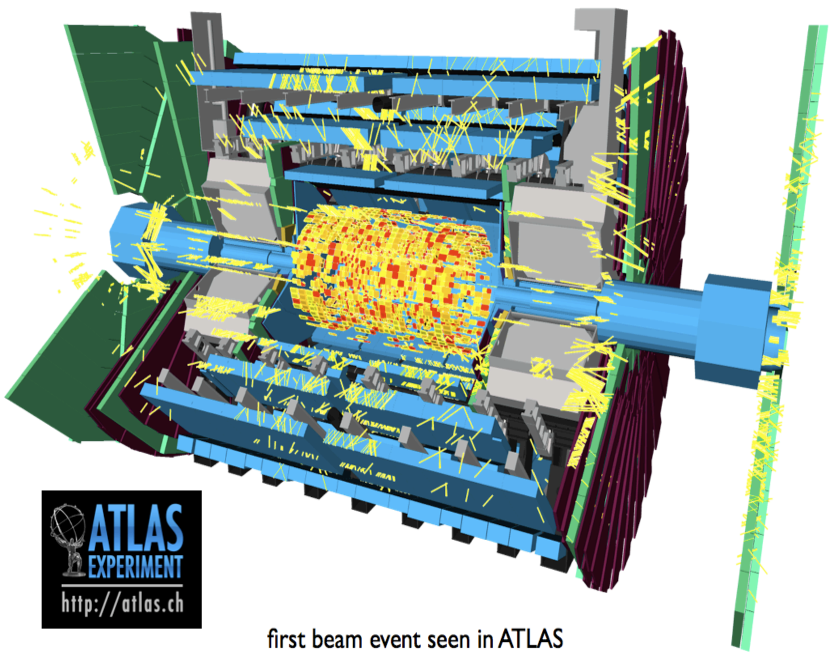
- Reconstruction worked almost on-line

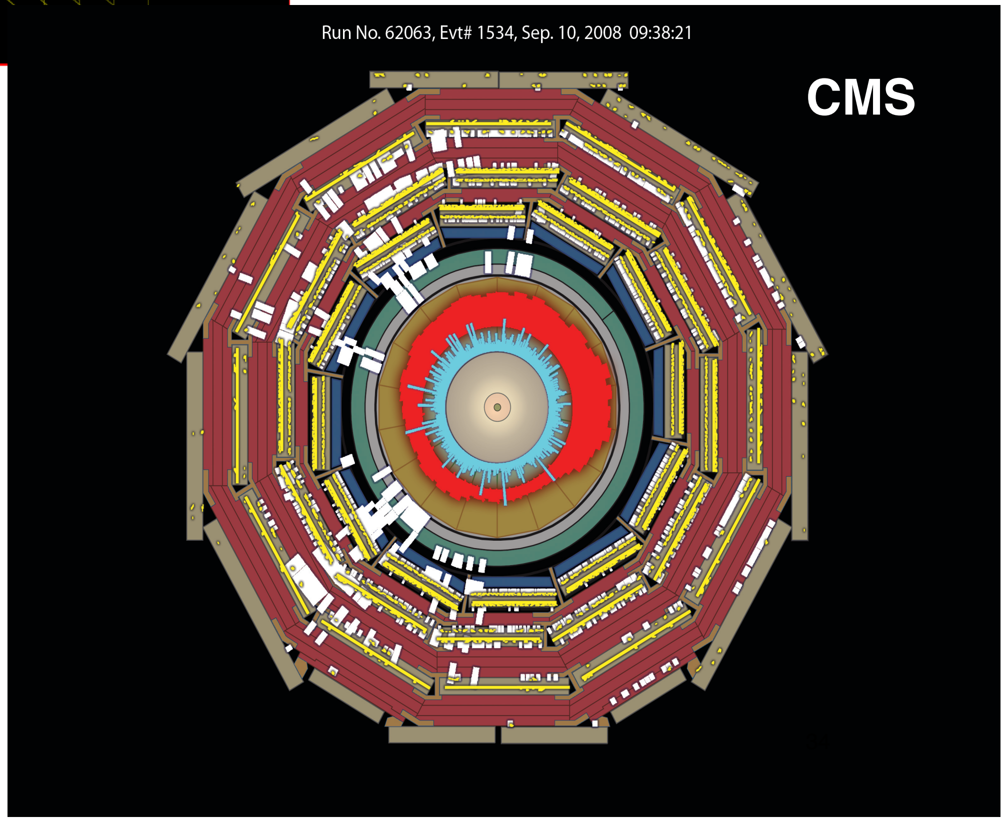


First LHC Beam: Events Recorded by 4 Experiments









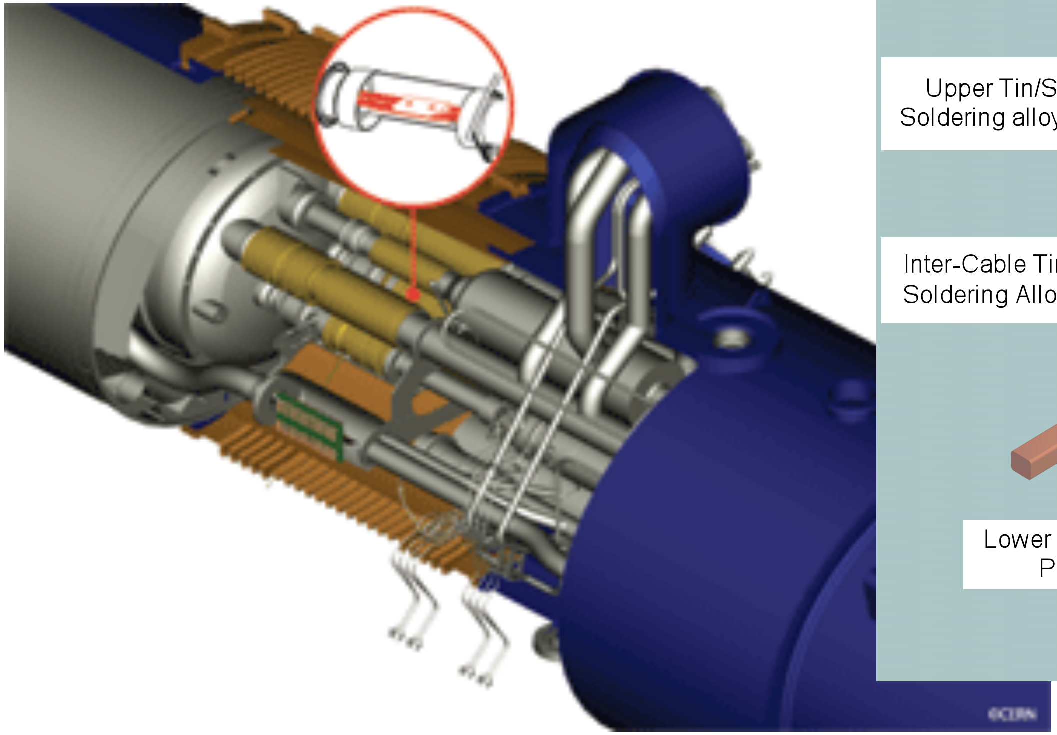
LHC Incident on 19th September and measures being taken to repair

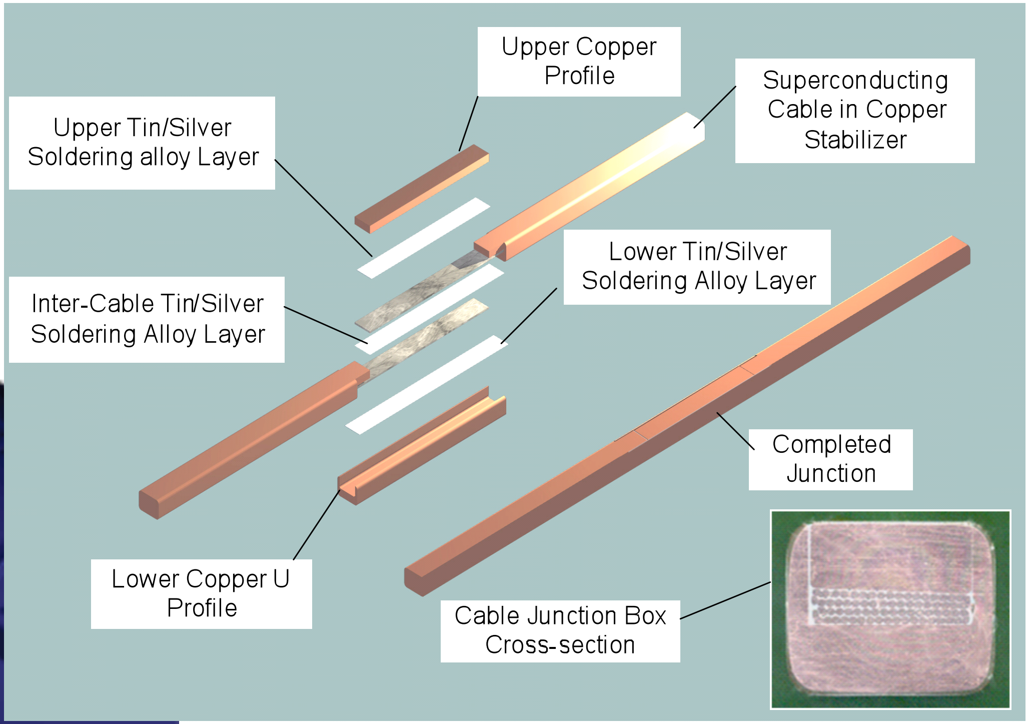
Preparation for 2009/2010 Run

Incident on 19th September 2008

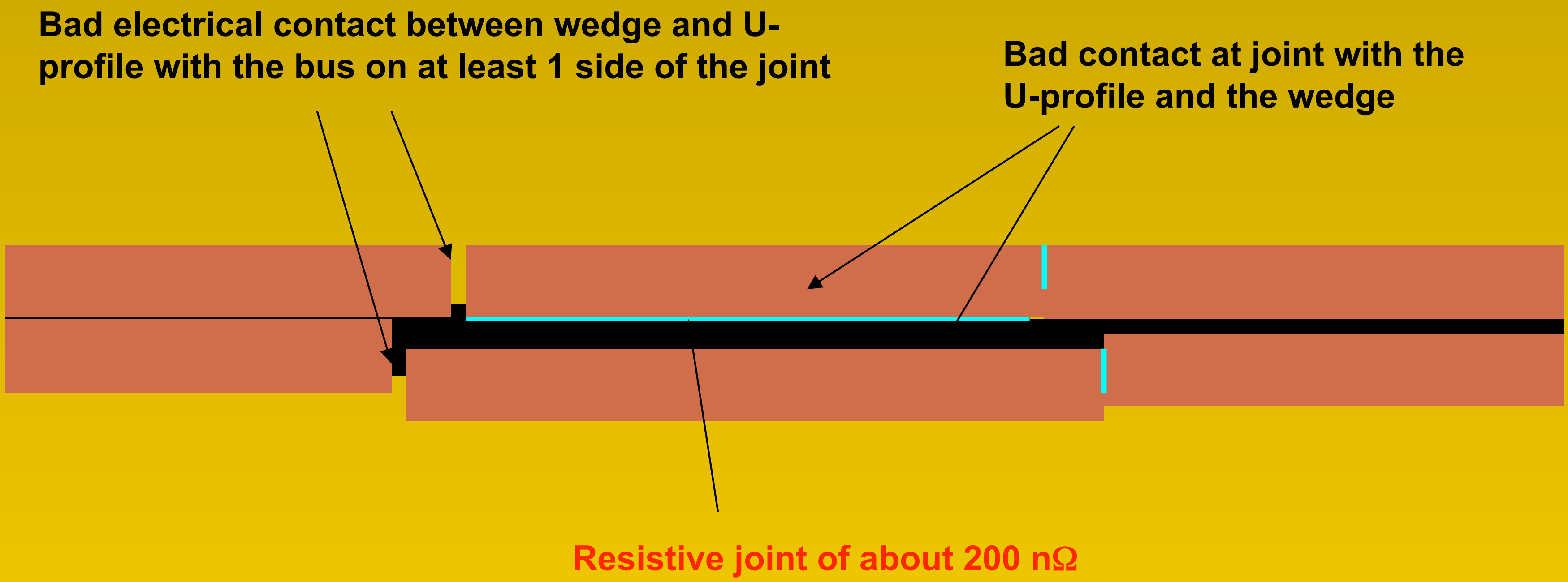
The LHC decided to use a few days of down-time due to a 'standard' power converter fault to finish work on powering tests in sector 3-4 (all other sectors were tested to 5.5 TeV equivalent currents)

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')



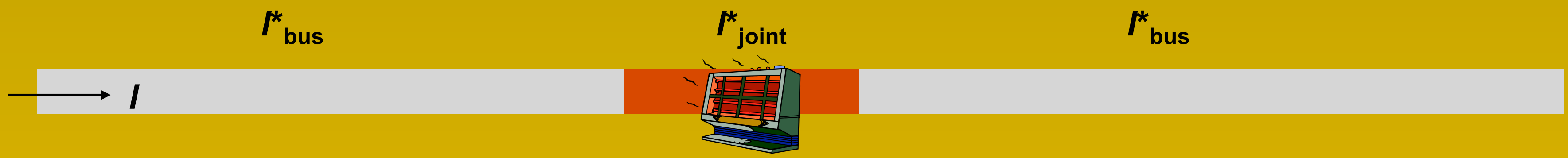


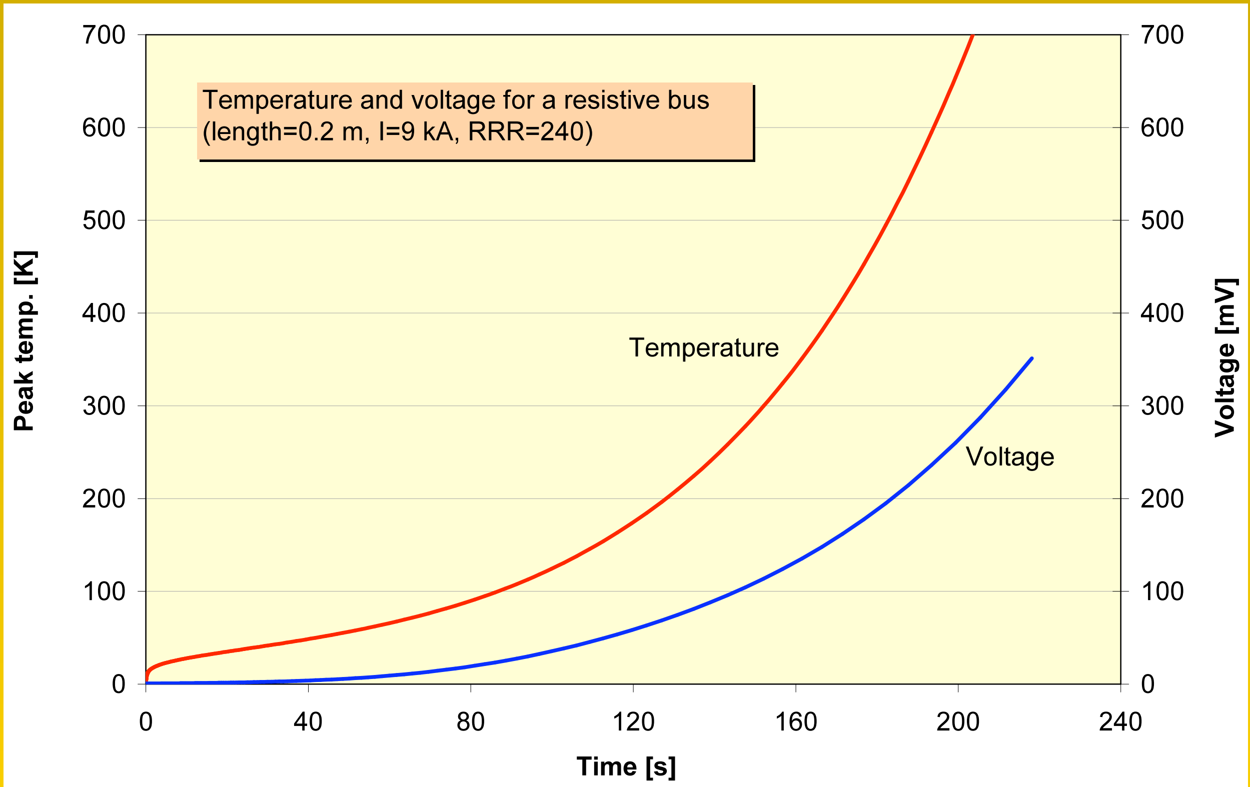
The incident: most likely scenario



Assume a highly insulated resistive joint, so $I^*_{joint}<I^*_{bus}$.

*Thermal run-away will occur when the Joule heating exceeds the cooling (**$I > I^*_{joint}$**). The run-away will be **localized** (and hence the voltage relatively small) when the adjacent bus acts as a "quench stopper", i.e. when **$I<I^*_{bus}$**.*

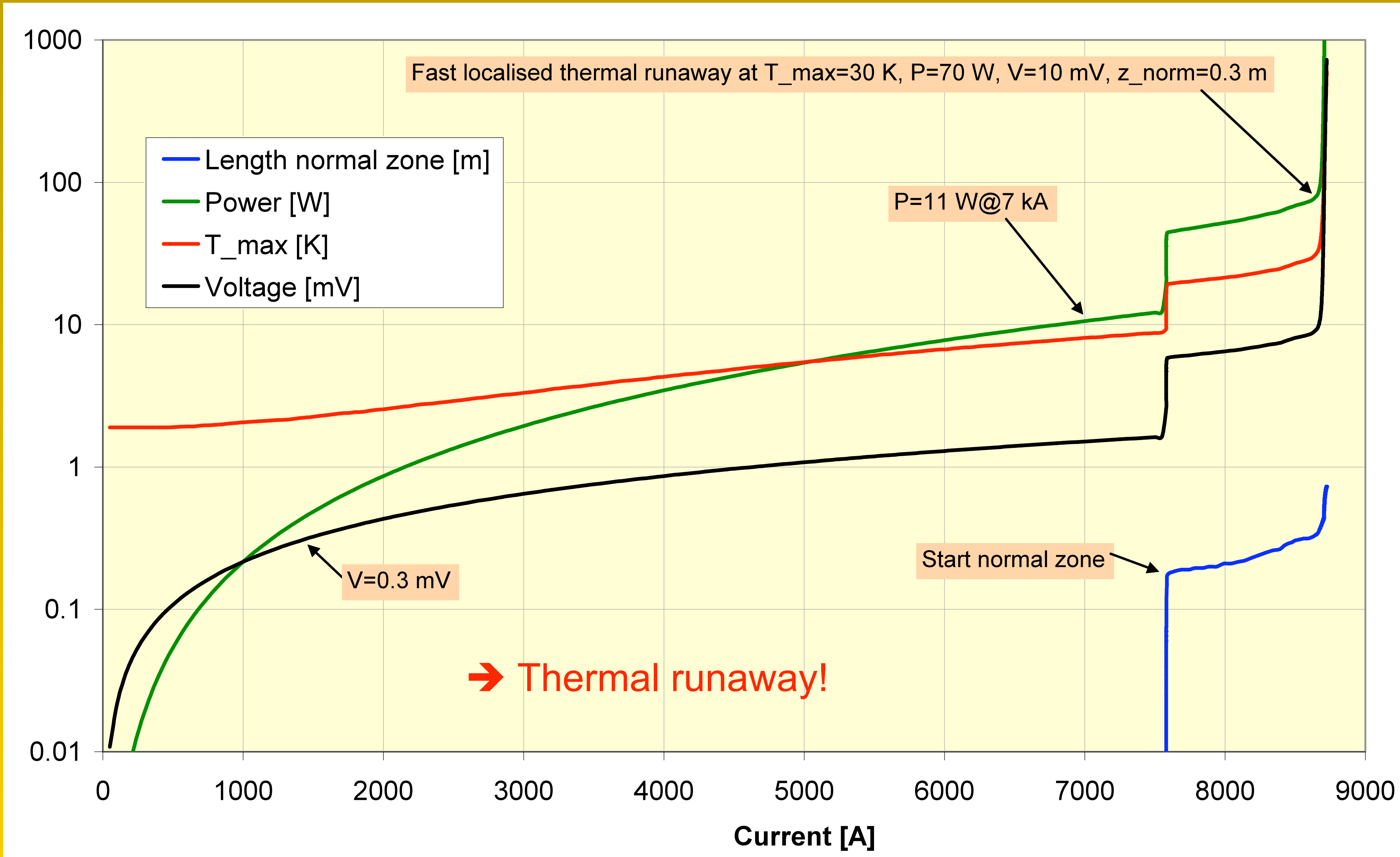




Conclusion:

The solder of the joint is already melting even before the voltage reaches the 1 V threshold!!

Simulation of the incident



LHC Incident on 19 Sept. 2008

- ***Most likely, an electrical arc developed, which punctured the He enclosure***

- ***Large amounts of He gas were released into the insulating vacuum of the cryostat:***

  - *Self actuating relief valves opened releasing a large amount of He in the tunnel, but could not handle huge pressure*

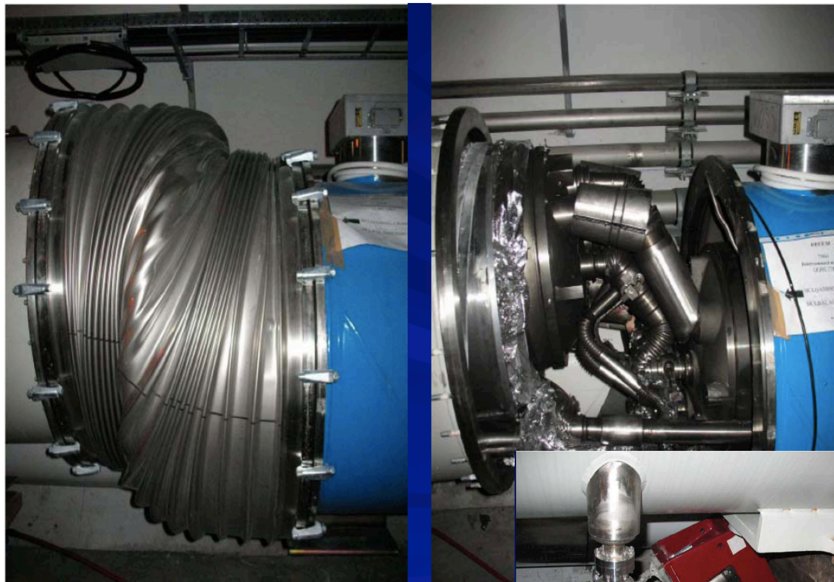
  - *Shock wave within 2 cells (about 300 m)*

  - *Collateral mechanical damage in part of this sector*

  - *53 magnets have been removed to be repaired and reinstalled (2 other magnets will be replaced)*

- Damaged interconnects and super-insulation

- Perforated beam tubes → pollution of the vacuum system with soot and debris from super insulation

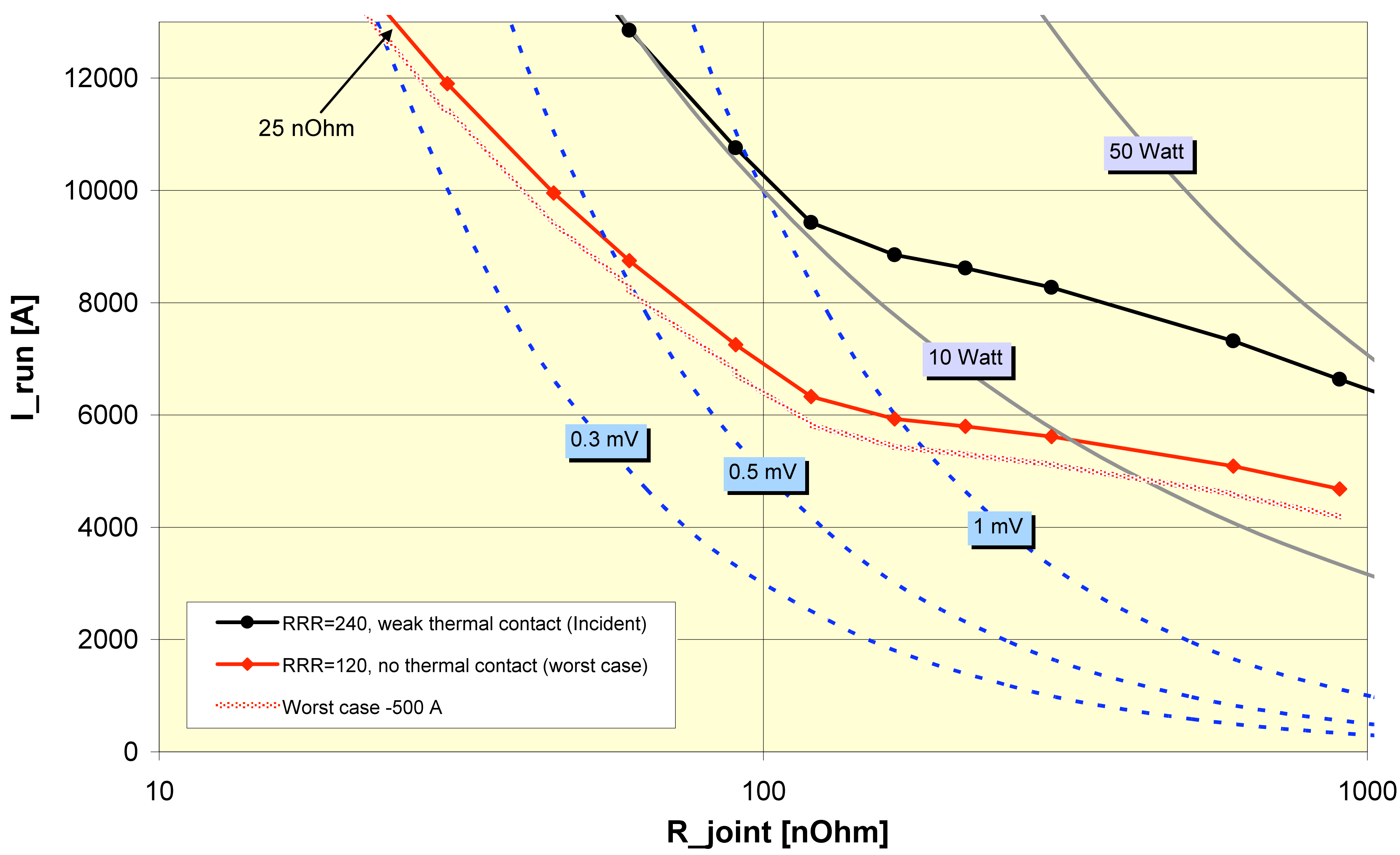


Several quadrupoles Displaced by up to 50 cm

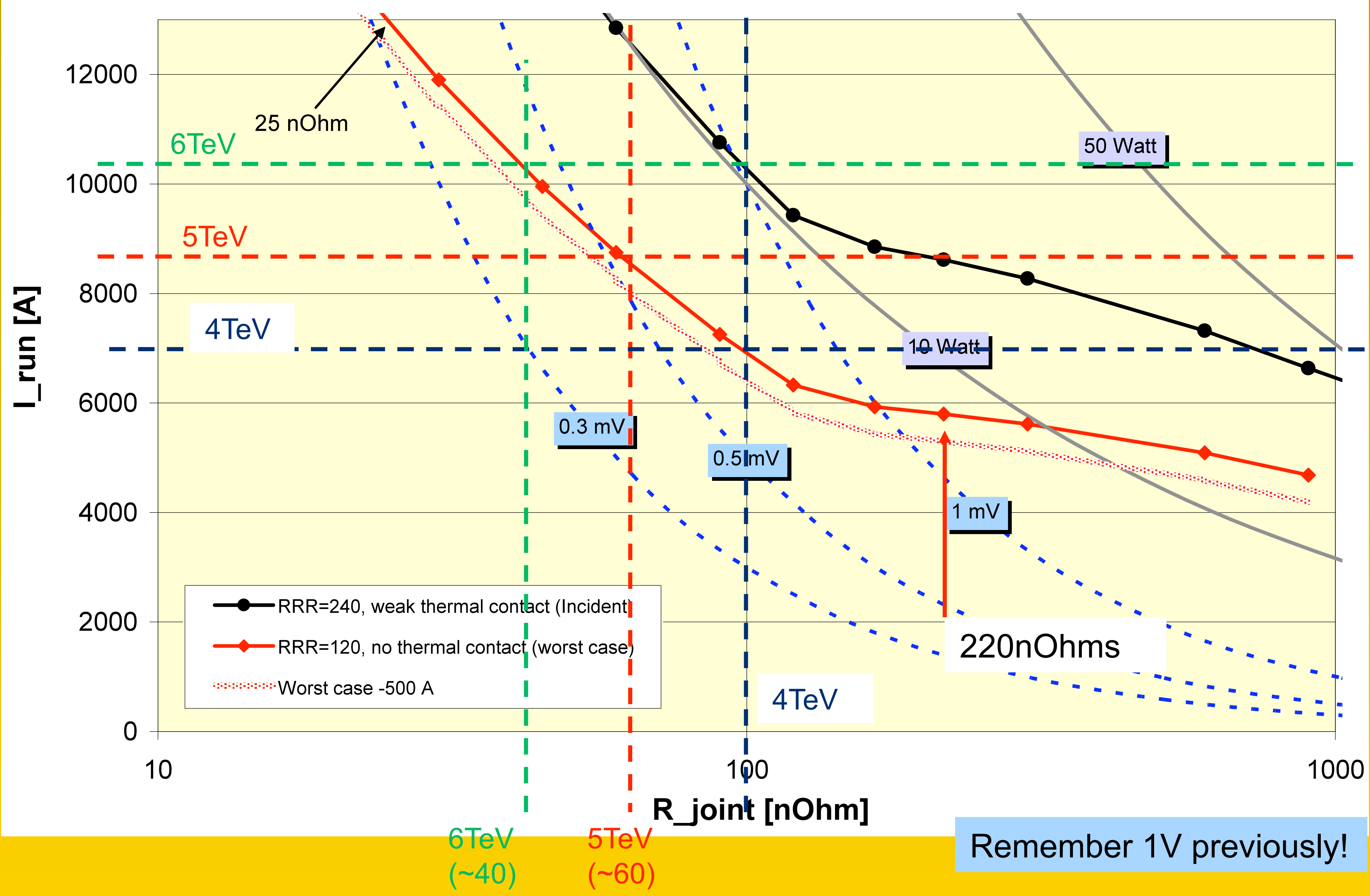
LHC repair and restart

- *The four warm sectors will be equipped with extra pressure relief valves (PRVs) on all dipole cryostats.*
- *The four cold sectors will get extra PRVs on all short straight section cryostats. This can be done with the sectors cold and is adequate for 5 TeV operation.*
- *The quench protection system will be upgraded everywhere to cover all busbar splices.*
- *The whole machine will be cold by mid August, ready for first injected beam in late September.*
- *The machine will run at 5 TeV until autumn 2010 after which the remaining 4 sectors will be equipped with PRVs and will be prepared for high energy operation.*

Setting for the new QPS upgrade

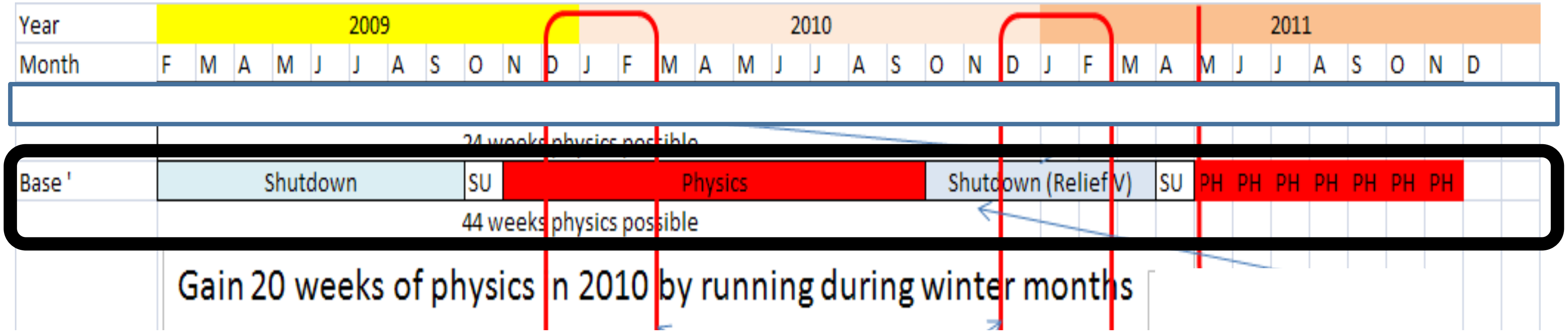


Setting for the new QPS upgrade



Remember 1V previously!

Summary of the New LHC Schedule



Current Plan:

- Machine ready for start-up operation again in October 2009

- Run the LHC over winter until September 2010

- This first physics run will be at 10 TeV collision energy

- At the end of the run, a first run with heavy ion collisions (Pb-Pb) is also foreseen

Prospects for physics with 2009/2010 data

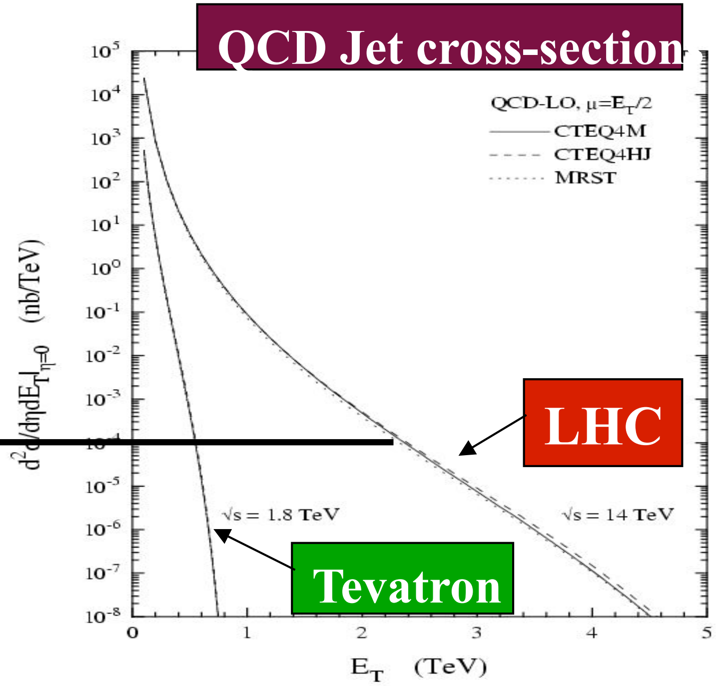
First physics data at LHC

~100 pb^{-1} per experiment may be collected within a month

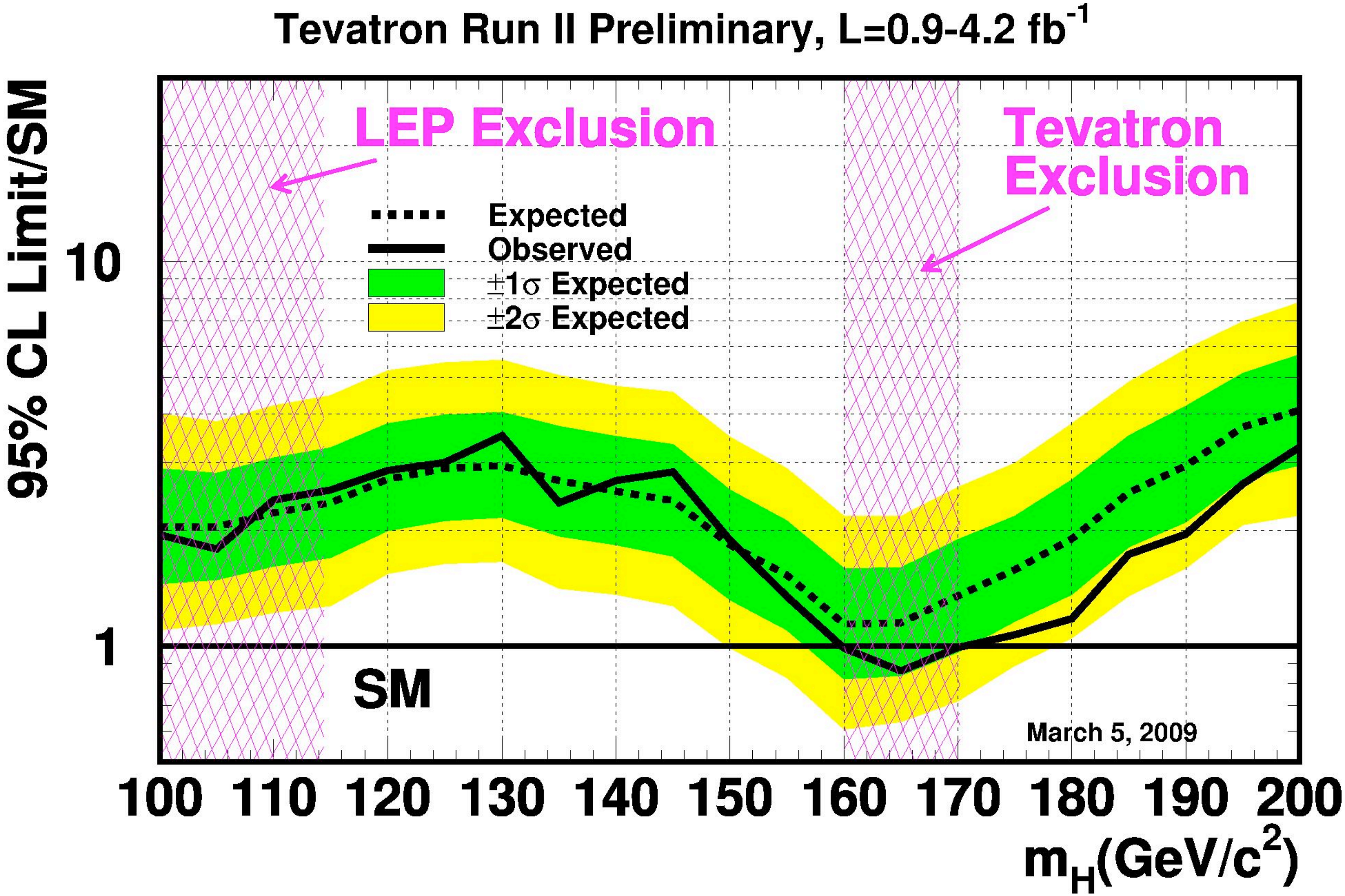
Channels (<u>examples</u> …)	**Events to tape for 100 pb^{-1} (ATLAS) Similar for CMS**	**Total statistics from LEP and Tevatron**
$W \rightarrow \mu\nu$	$\sim 10^6$	$\sim 10^4$ LEP, $\sim 10^{6-7}$ Tevatron
$Z \rightarrow \mu\mu$	$\sim 10^5$	$\sim 10^6$ LEP, $\sim 10^{5-6}$ Tevatron
$tt \rightarrow WbWb \rightarrow \mu\nu + X$	$\sim 10^4$	$\sim 10^{3-4}$ Tevatron
QCD jets $p_T > 1$ TeV	$> 10^3$	---
$\tilde{g}\tilde{g}$ $m = 1$ TeV	~ 50	---

Will jump immediately into a new territory …

10 events with 100 pb^{-1}



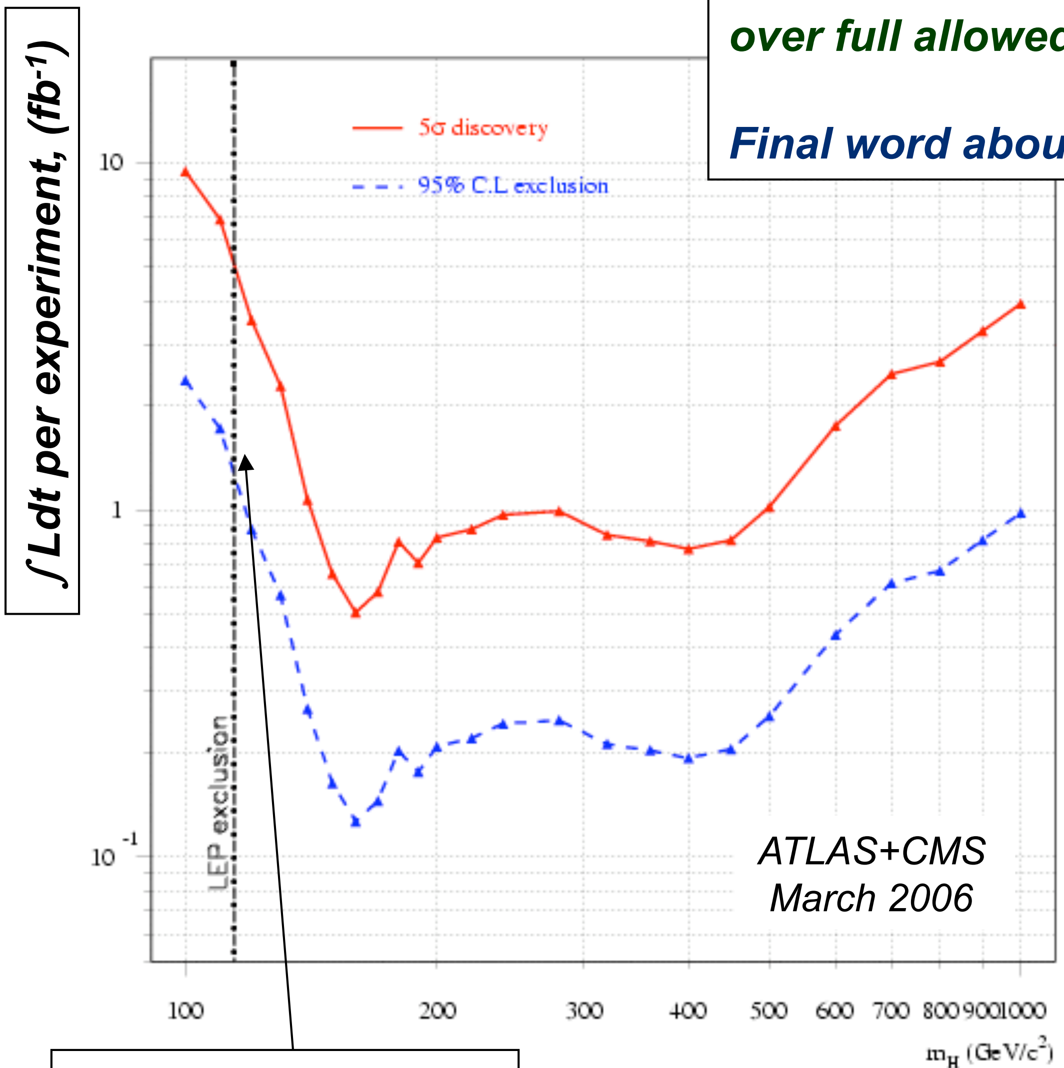
Higgs Search at Tevatron (March 2009)



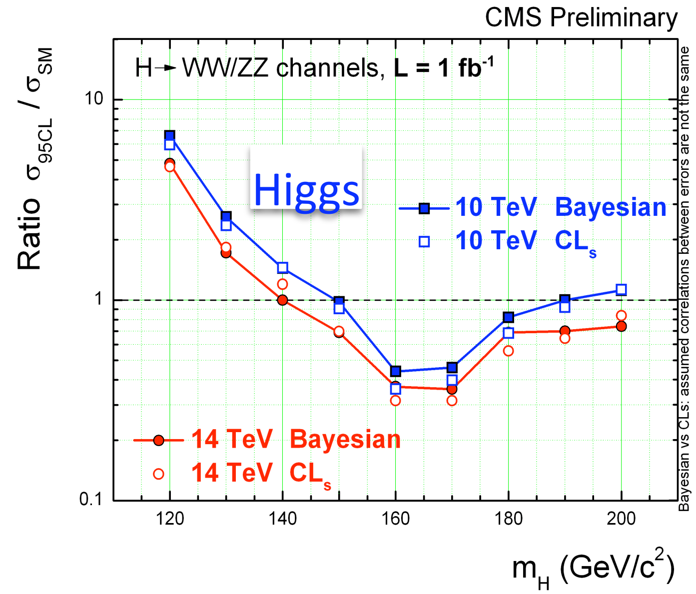
ATLAS + CMS: SM Higgs @ 14 TeV

With 1 fb^{-1}: 95% C.L. exclusion
5 fb^{-1}: 5σ discovery
over full allowed mass range

Final word about Higgs mechanism by 2012 ?



Most difficult region

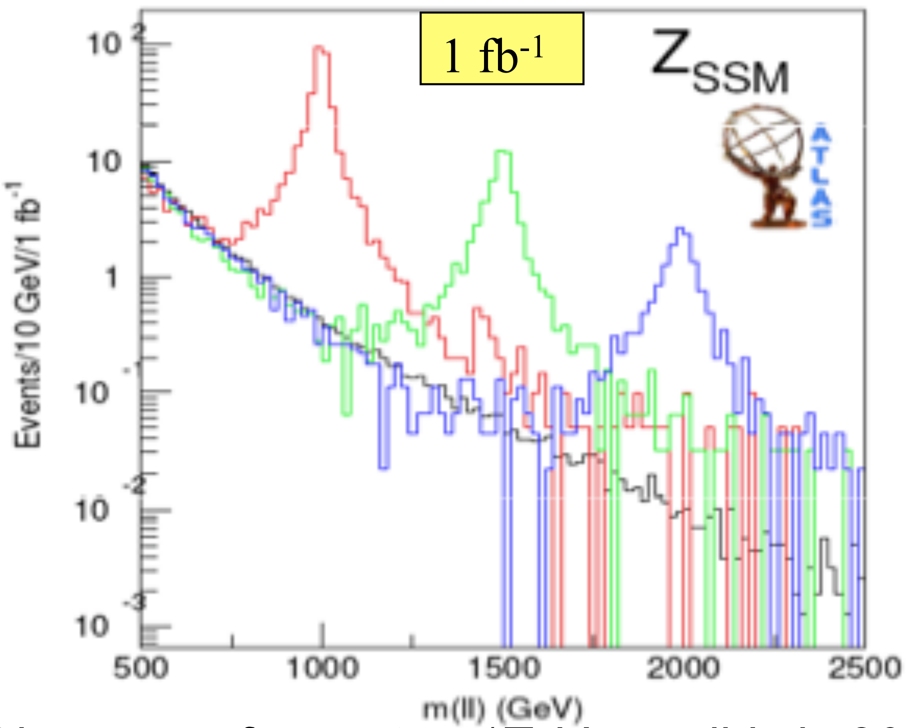


With 200 pb^{-1}, reach current Tevatron sensitivity for Higgs

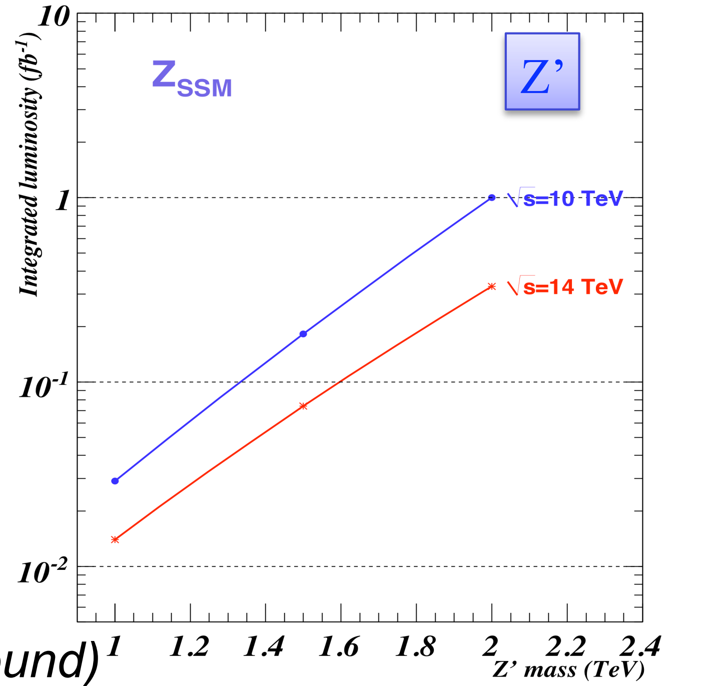
One of the best candidates for early discovery :
a narrow resonance with mass ~ 1 TeV

ATLAS:
$Z' \rightarrow e^+e^-$ with SM-like couplings (Z_{SSM})

Mass	Expected events for 1 fb^{-1} (after all analysis cuts)	Integrated luminosity needed for discovery (corresponds to 10 observed evts)
1 TeV	~ 160	~ 70 pb^{-1}
1.5 TeV	~ 30	~ 300 pb^{-1}
2 TeV	~ 7	~ 1.5 fb^{-1}

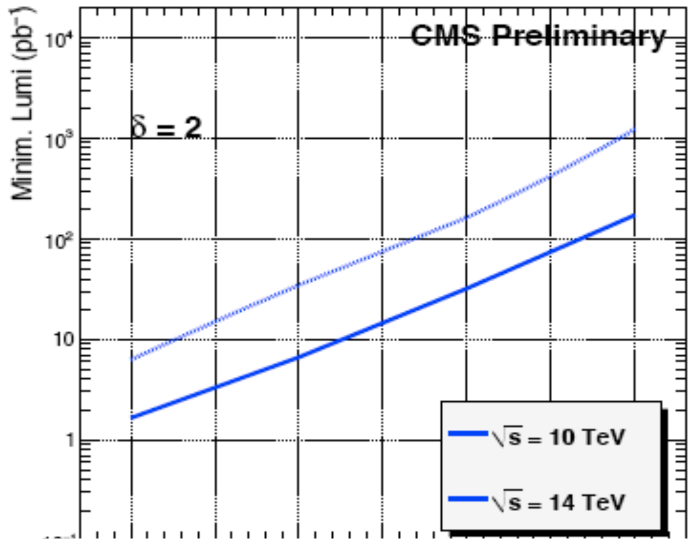


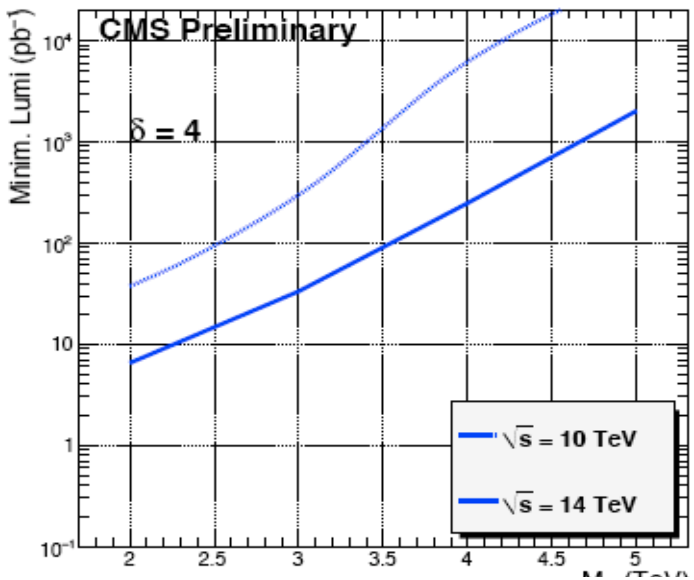
Signals and background are scaled from 14 TeV; plots are indicative for CMS reach



Discovery of m up to ~1TeV possibly in 2009/2010
(narrow mass peak on top of small Drell-Yan background)

Extra Dimensions (ArcaniDimopoulosDvali monojets)



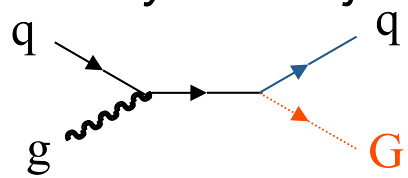


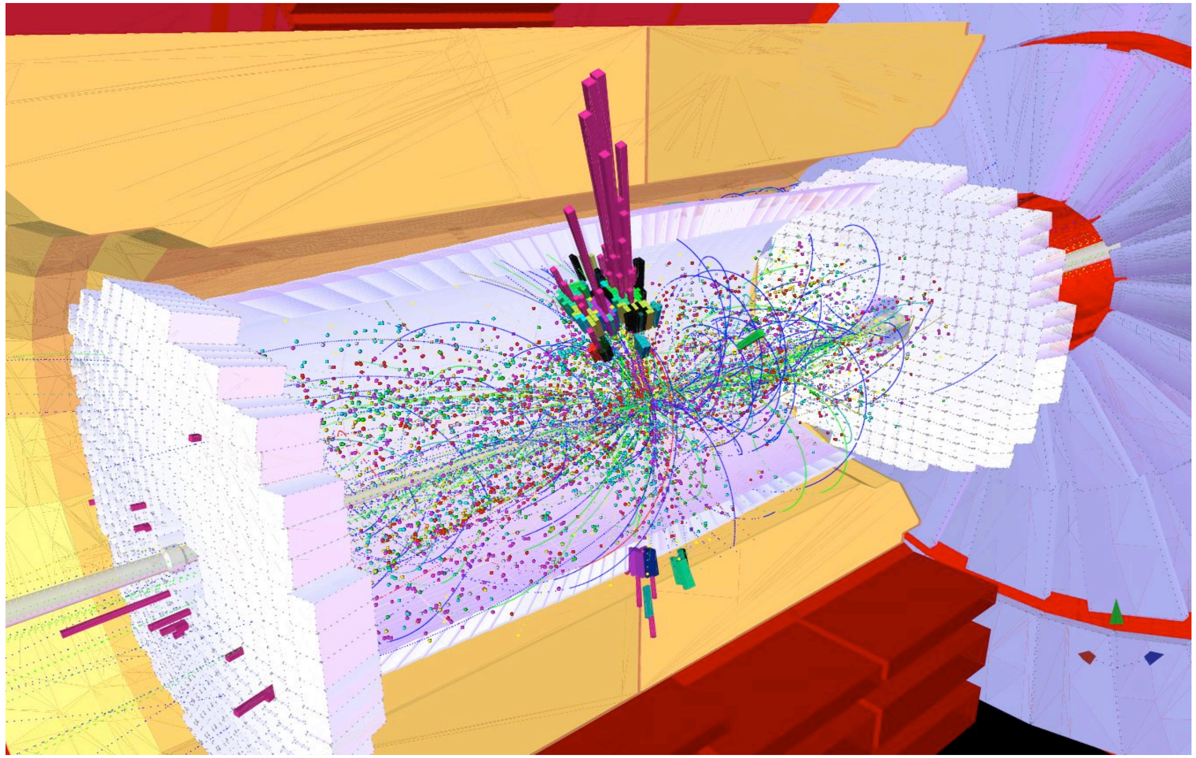
M_D, TeV

4+δ dimensional space:

Production of a Graviton is balanced by a monojet:

*qq/qg/gg → g**G***





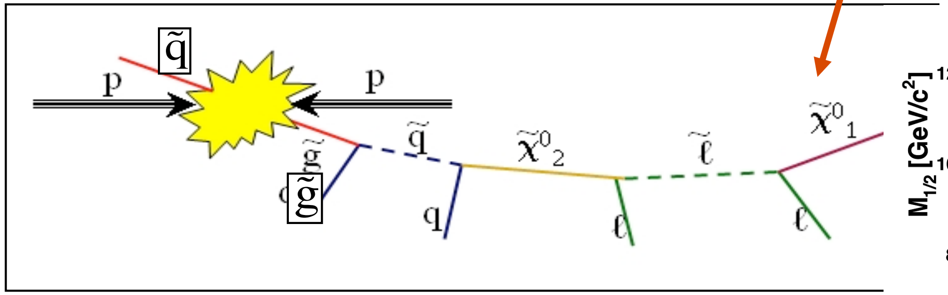
Cross-section $\sigma \approx \frac{1}{M_D^{\delta+2}}$

M_D = gravity scale

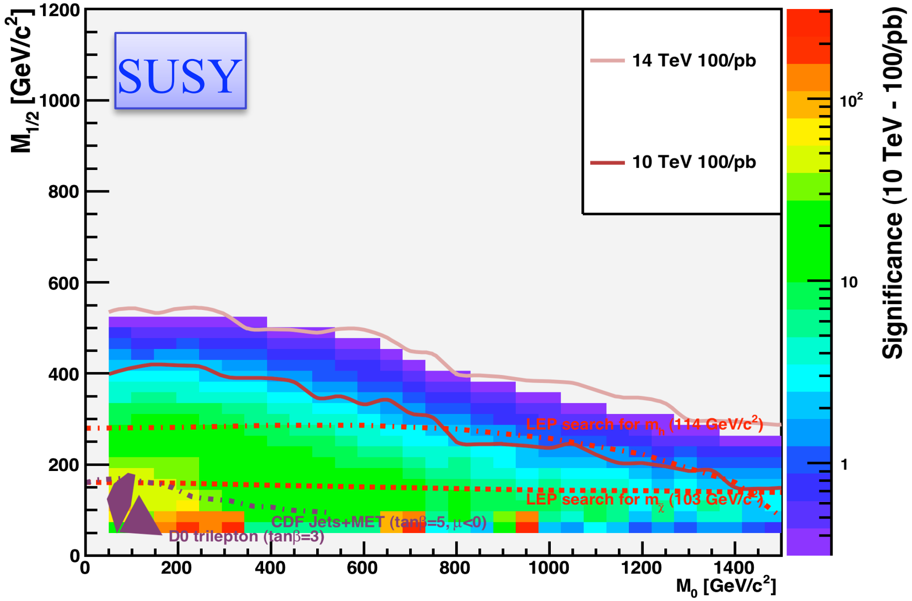
δ = number of extra-dimensions

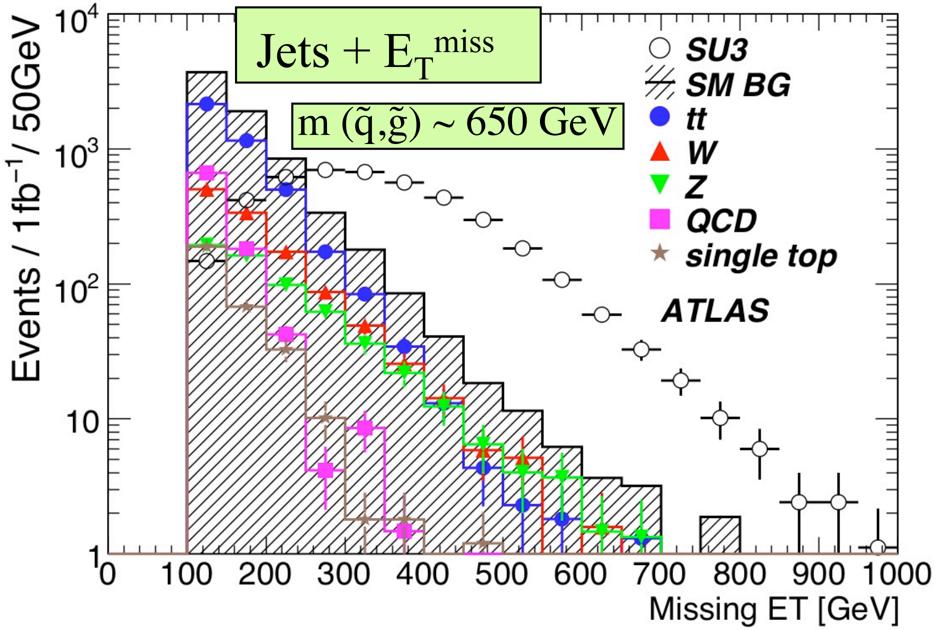
Possible quick discovery of SUSY at LHC

Large (strong) cross-section for $\tilde{q}\tilde{q}, \tilde{g}\tilde{q}, \tilde{g}\tilde{g}$ production → *Expect ~1evt./day at L~10^{31}(m~1TeV)*
Spectacular signatures (many jets, leptons, missing E_T)



Indicative CMS reach





Planning for future facilities would benefit a lot from quick determination of scale of New Physics. With ~ 1 fb^{-1} LHC could tell if "standard" SUSY accessible to √s ≤1 TeV ILC

LHC reach for gluino mass

∫Ldt of well understood data	Discovery
0.1-1 fb^{-1} (2010)	~1.1 TeV
≥1 fb^{-1} (2010-2011)	~1.7 TeV
300 fb^{-1} (ultimate)	2.5-3 TeV

Prospects for indirect search for NP (LHCb)

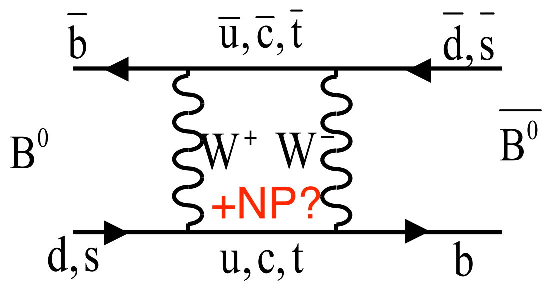
Search for New Physics in CP-violation and Rare Decays

Key Measurements	Accuracy in 1 nominal year (2 fb^{-1})
❑ In CP – violation	
✓ ϕ_s	**0.023**
✓ γ in trees	4.5°
✓ γ in loops	10°
❑ In Rare Decays	
✓ $B \rightarrow K^*\mu\mu$	$\sigma(s0) = 0.5\ GeV^2$
✓ **$B_s \rightarrow \mu\mu$**	**3σ measurement down to SM prediction**
✓ Polarization of photon in radiative penguin decays	$\sigma(H_R/H_L) = 0.1$ (in $B_s \rightarrow \phi\gamma$) $\sigma(H_R/H_L) = 0.1$ (in $B_d \rightarrow K^*e^+e^-$)

B_s-B_s mixing phase ϕ_s

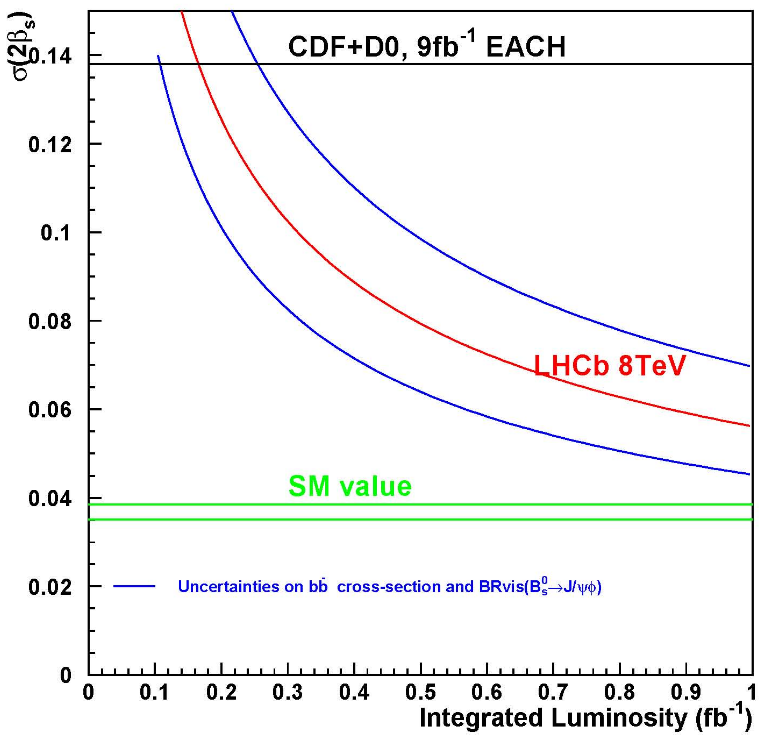
Sensitive to NP effects in the box diagrams

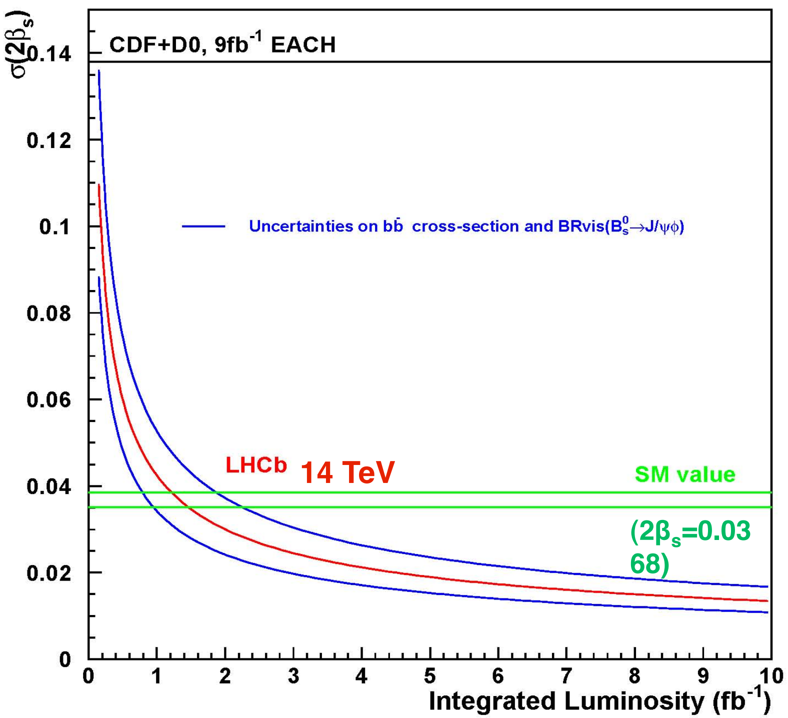
- $\phi_s = \phi_{s(SM)} + \phi_{s\,(NP)}$
- $\phi_{s(SM)} = -\,2\beta_s = -2\lambda^2\eta \sim -0.04$



Tevatron: ~2.2σ away from SM

(central Tevatron value -0.77)



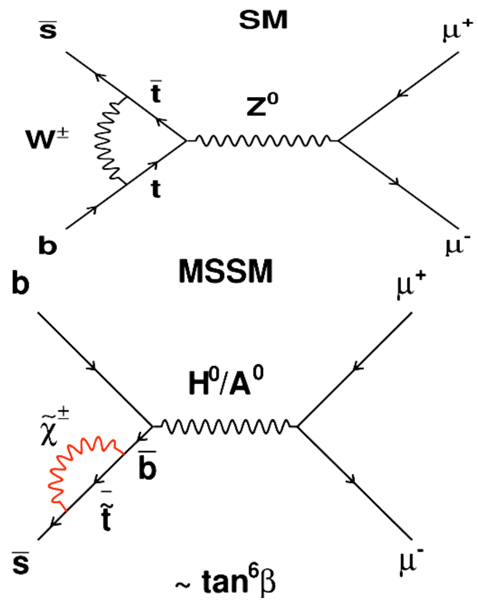


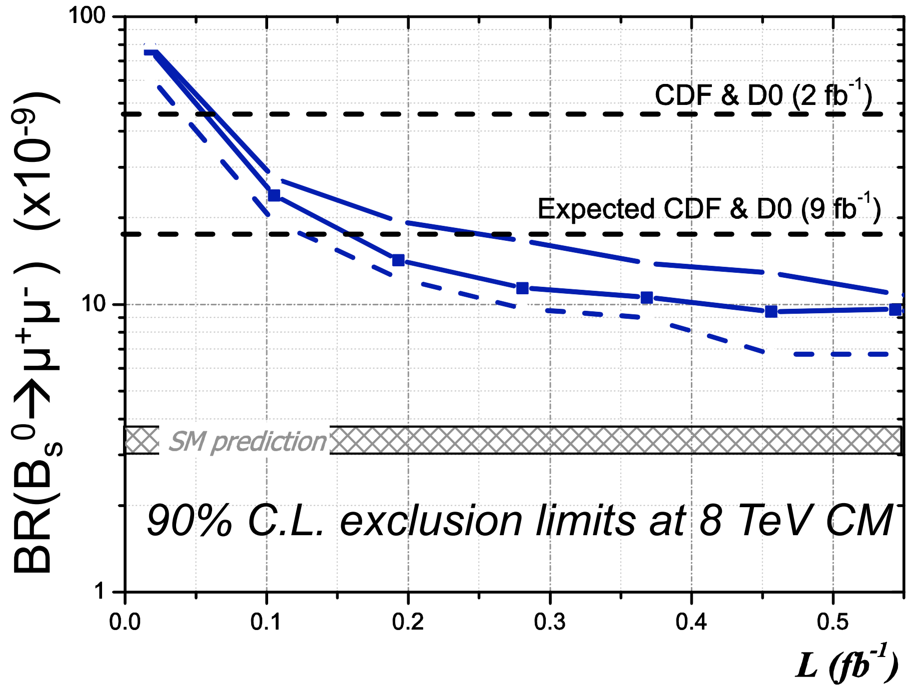
→ With ~0.3 fb^{-1} LHCb should improve on expected Tevatron limit

New Physics in $B_s \to \mu\mu$ decay

Small BR in SM: (3.35 ± 0.32) ×10^{-9} sensitive to NP

- *Could be strongly enhanced in SUSY*
  In MSSM scales like ~$\tan^6\beta$
  *Current limit from CDF: < **47 ×10^{-9}***
  *Expected with 9 fb^{-1}: **< 20× 10^{-9}** ~5 times higher than SM**!***





→ With ~0.3 fb^{-1} LHCb should improve on expected Tevatron limit with 9 fb^{-1}

SUMMARY

- *LHC operation last year has been interrupted by an incident on Sept. 19*
- *Repairs are progressing well. The 53rd final replacement magnet was lowered into the accelerator tunnel on 30 April. Next steps are connecting the magnets together and installing much improved LHC monitoring and safety system. Finally extra pressure relief valves will be installed*
- *The LHC is scheduled to restart in autumn and to run continuously until October 2010*
- *Experiments are well prepared for physics. Excellent detector quality has been demonstrated using cosmic rays and LHC beams. This should be further improved with the first collisions data*

Ambitious Goals for 2009/2010 Run *(up to ~300 pb^{-1})*

Direct searches for NP (ATLAS & CMS):

- *Hints for SUSY up to gluino masses of ~ 1 TeV*
- *Discover Z' up to masses of ~ 1 TeV*
- *Surprises …*

Indirect searches for NP (LHCb):

- *probing NP in loops (with improved sensitivity wrt Tevatron) for*

$B_s \rightarrow \mu\mu$ & B_s *mixing phase* ϕ_s

Spare Slides

Heavy-ion physics with ALICE

There will be a nominal PbPb@4TeV run at the end of 2010

- fully commissioned detector & trigger
  - alignment, calibration available from pp
- first 10^5 events: global event properties
  - multiplicity, rapidity density
  - elliptic flow
- first 10^6 events: source characteristics
  - particle spectra, resonances
  - differential flow analysis
  - interferometry
- first 10^7 events: high-p_t, heavy flavours
  - jet quenching, heavy-flavour energy loss
  - charmonium production
- yield bulk properties of created medium
  - energy density, temperature, pressure
  - heat capacity/entropy, viscosity, sound velocity, opacity
  - susceptibilities, order of phase transition

- **early ion scheme**
  - 1/20 of nominal luminosity
  - $\int L dt = 5 \cdot 10^{25}$ cm^{-2} s^{-1} x 10^6 s
    0.05 nb^{-1} for PbPb at 5.5 TeV
    $N_{pp\ collisions} = 2 \cdot 10^8$ collisions
    400 Hz minimum-bias rate

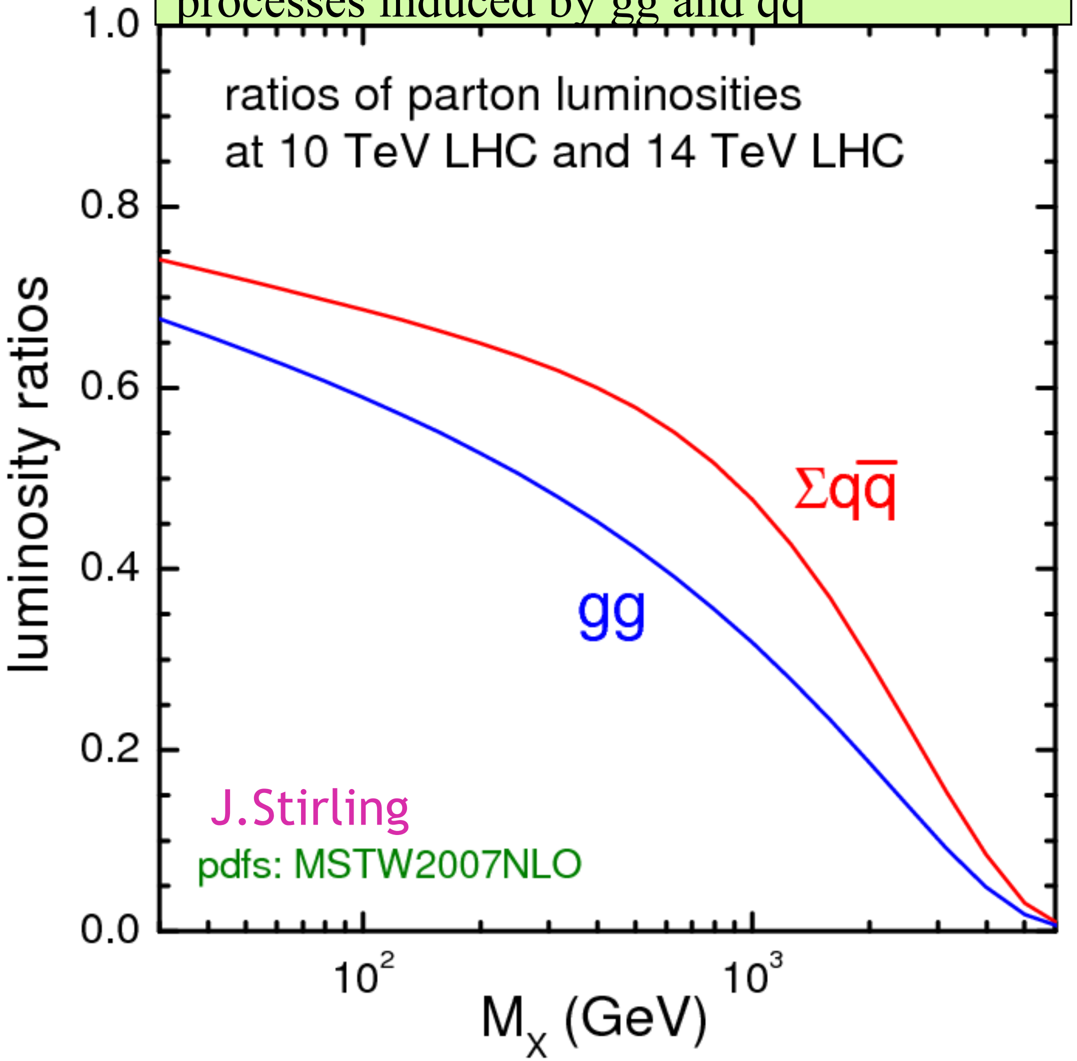
    20 Hz central (5%)
  - muon triggers:
    ~ 100% efficiency, < 1kHz
  - centrality triggers:
    bandwidth limited
    $N_{PbPbminb} = 10^7$ events (10Hz)
    $N_{PbPbcentral} = 10^7$ events (10Hz)

	ATLAS ≡ A Toroidal LHC ApparatuS	CMS ≡ Compact Muon Solenoid
MAGNET (S)	Air-core toroids + solenoid in inner cavity 4 magnets Calorimeters in field-free region	Solenoid Only 1 magnet Calorimeters inside field
TRACKER	Si pixels+ strips TRT → particle identification B=2T $\sigma/p_T \sim 5\text{x}10^{-4}\ p_T \oplus 0.01$	Si pixels + strips No particle identification B=4T $\sigma/p_T \sim 1.5\text{x}10^{-4}\ p_T \oplus 0.005$
EM CALO	Pb-liquid argon $\sigma/E \sim 10\%/\sqrt{E}$ uniform longitudinal segmentation	$PbWO_4$ crystals $\sigma/E \sim 2\text{-}5\%/\sqrt{E}$ no longitudinal segm.
HAD CALO	Fe-scint. + Cu-liquid argon (10 λ) $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$	Cu-scint. (> 5.8 λ +catcher) $\sigma/E \sim 100\%/\sqrt{E} \oplus 0.05$
MUON	Air → $\sigma/p_T \sim$ 10 % at 1 TeV standalone (~ 7% combined with tracker)	Fe → $\sigma/p_T \sim$ 15-30% at 1 TeV standalone (5% with tracker)

CMS assets: excellent e and μ energy and momentum resolution
ATLAS assets: hadron calorimetry (jet, E_T^{miss}) and particle identification

10 TeV vs 14 TeV

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



At 10 TeV, more difficult to create high mass objects...

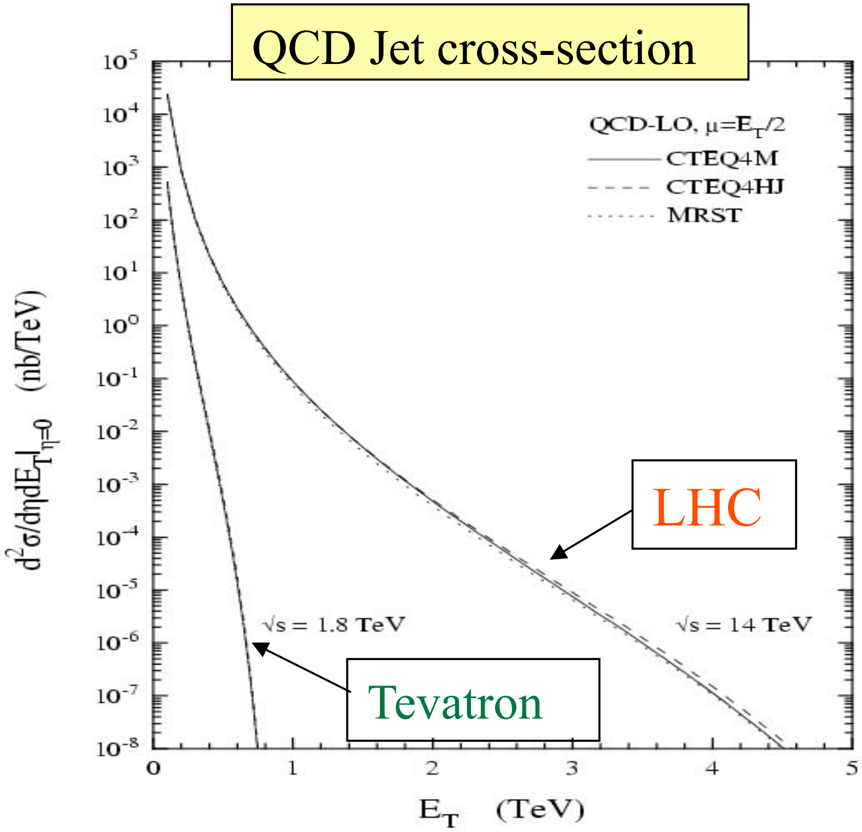
Below about 300 GeV, this suppression is <50% (process dependent)
e.g. tt ~ factor 2 lower cross-section

Above ~ 1 TeV the effect is more marked

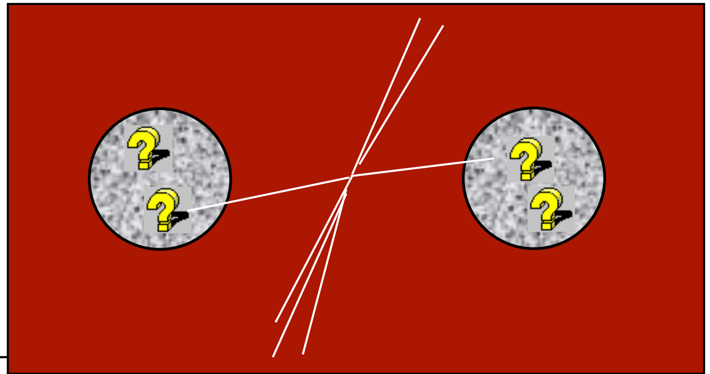
Results shown here are for $\sqrt{s}$=14 TeV

Jet rates and cross-section

- Explore E_T (jet) > 500 GeV after few weeks at 10^{31} $cm^{-2}s^{-1}$
- With 100 pb^{-1} (end 2009 ?) expect >10^3 events with E_T(jet) > 1 TeV; can measure cross-section to ~ 30%
- Exceeding fast Tevatron reach for quark compositeness (today: Λ>2.7 TeV):
  LHC sensitivity: Λ~5 (8)TeV for 10^2 (10^3) pb^{-1}
- Systematic uncertainties on PDF and jet E-scale can fake compositeness
  (initially at the level of 15-20 TeV)
  → jet angular distribution better probe
  in early days

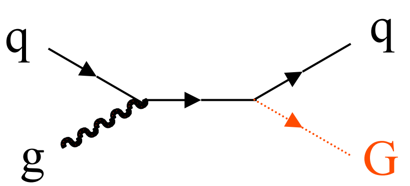


If quarks are composite : new qq → qq interactions with strength ~$1/\Lambda^2$, $\Lambda \equiv$ scale of New Physics.
⇒ expect excess of high-p_T central jets compared to SM
The higher Λ the smaller the excess.
LHC ultimate sensitivity up to $\Lambda \approx$ 40 TeV



Extra-dimensions (ADD models)

Look for a continuum of Graviton KK states :



→ topology is jet(s) + missing E_T

(due to G escaping in the extra-dimensions)

Cross-section $\sigma \approx \frac{1}{M_D^{\delta+2}}$

M_D = gravity scale

δ = number of extra-dimensions

ATLAS, 100 fb^{-1}

	$\delta = 2$	$\delta = 3$	$\delta = 4$
M_D^{max}	9 TeV	7 TeV	6 TeV

Discriminating between models:

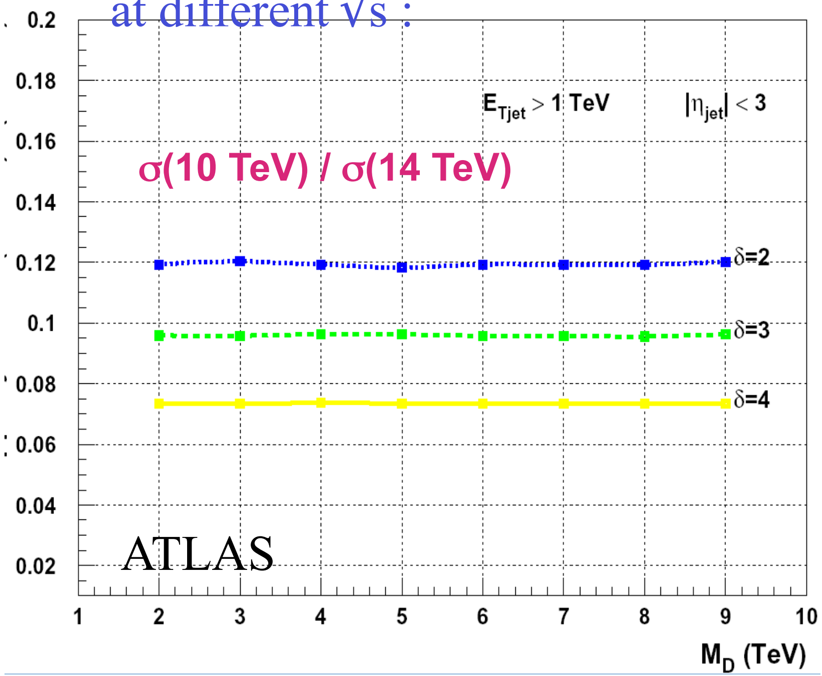
-- SUSY : multijets plus E_T^{miss} (+ leptons, …)

-- ADD : monojet plus E_T^{miss}

To characterize the model need to measure M_D and δ

Measurement of cross-section gives ambiguous results: e.g. δ=2, M_D= 5 TeV very similar to δ=4, M_D= 4 TeV

Solution may be to compare data at different $\sqrt{s}$:



Good discrimination between various solutions possible with expected <5% accuracy on σ(10)/σ(14) for 50 fb^{-1}

G → e+e- resonance with m ~ 1 TeV

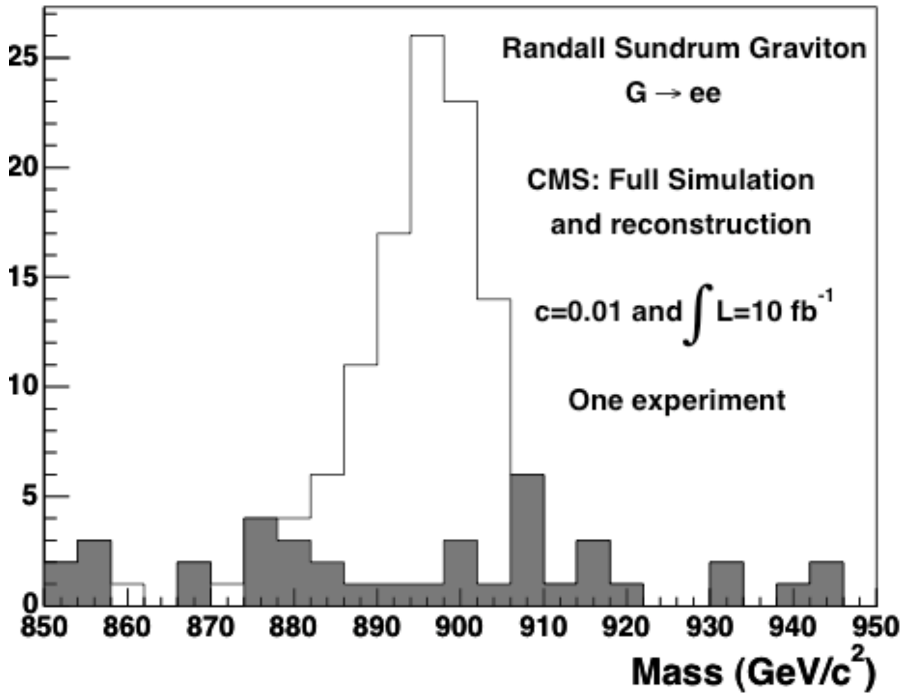
predicted in Randall-Sundrum Extra-dimensions

BR (G → ee ≈ 2%), c = 0.01 (small/conservative coupling to SM particles)

Mass (TeV)	Events for 10 fb^{-1} (after all cuts)	$\int L\,dt$ for discovery (≥ 10 observed events)
0.9	~ 80	1.2 fb^{-1}
1.1	~ 25	4 fb^{-1}
1.25	~ 13	~ 8 fb^{-1}

CMS

- large enough signal for discovery with $\int L dt$ < 10 fb^{-1} for m < 1.3 TeV
- dominant Drell-Yan background small
- signal is mass peak above background



ATLAS, 100 fb^{-1}, m_G=1.5 TeV

Graviton (s=2) or Z' (s=1) ?
→ look at $e^{\pm}$ angular distributions