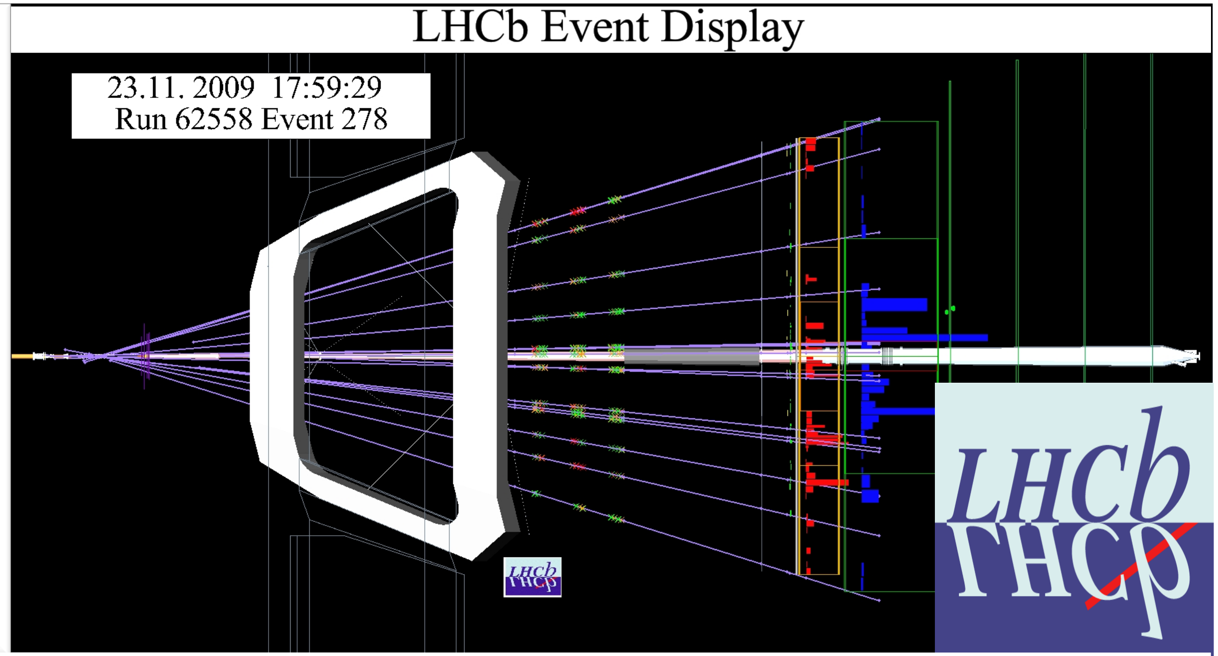
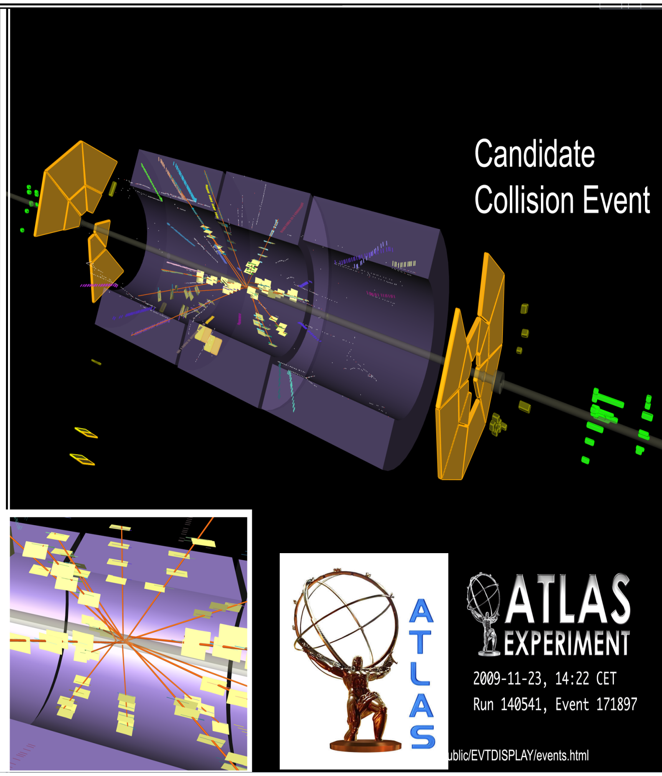
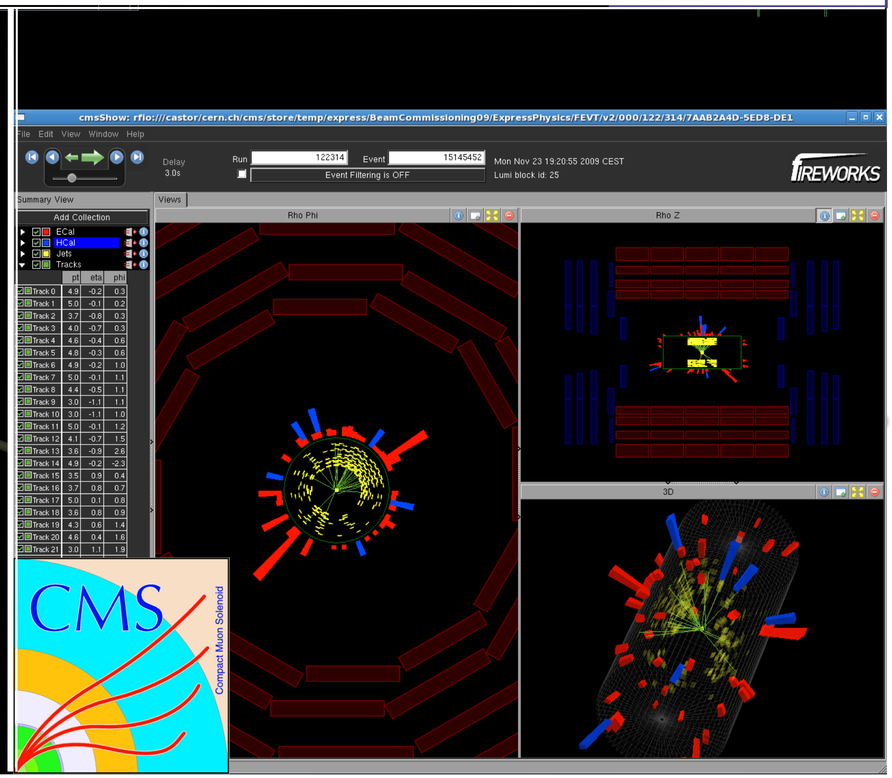
Early Hadron Physics at the LHC

Andrew Askew

Dec. 4, 2009







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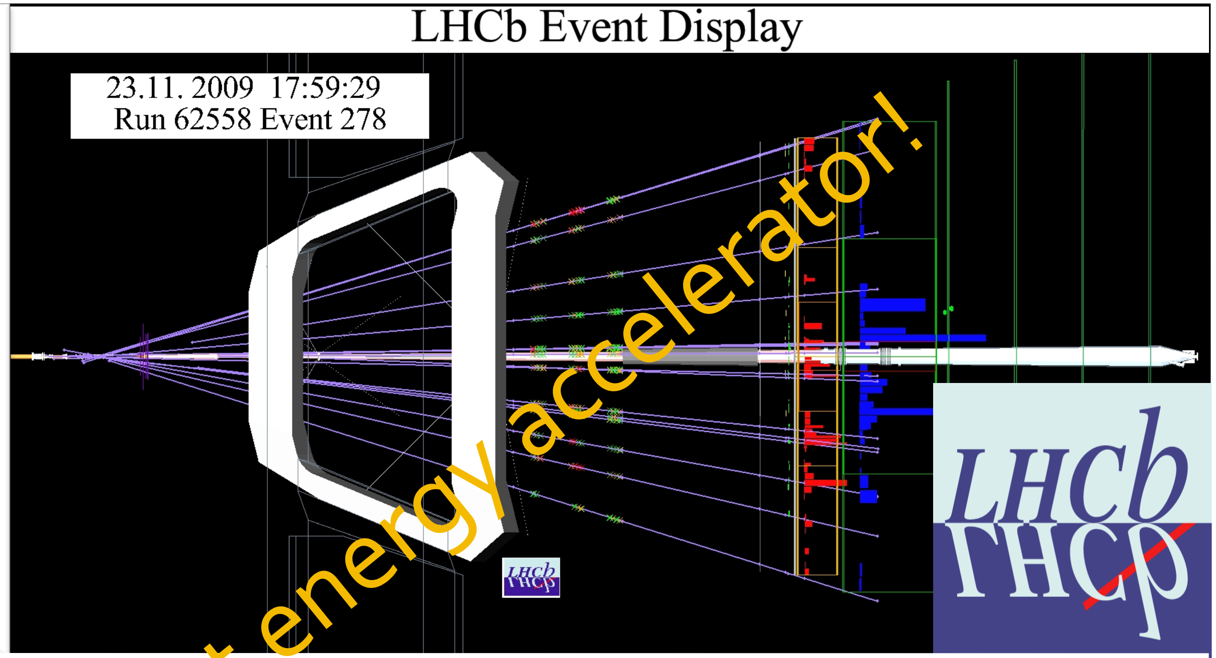
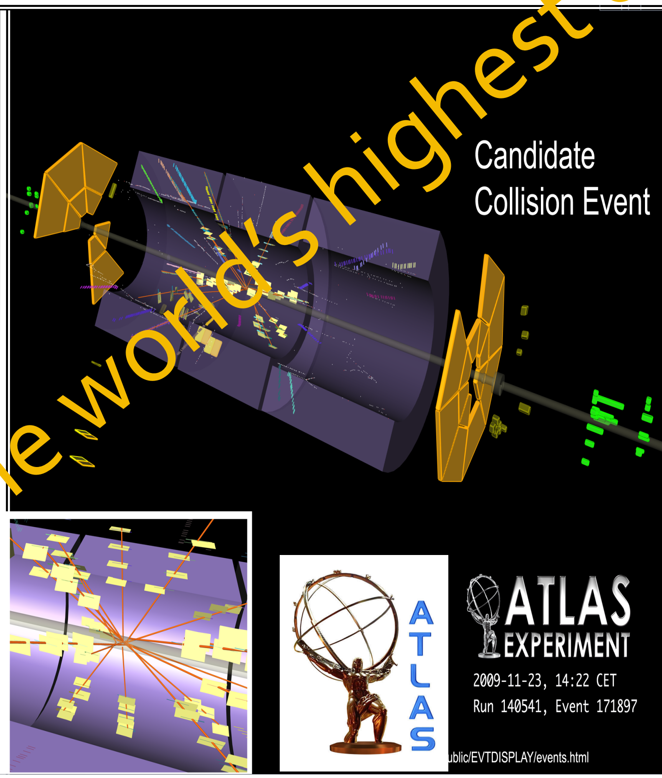
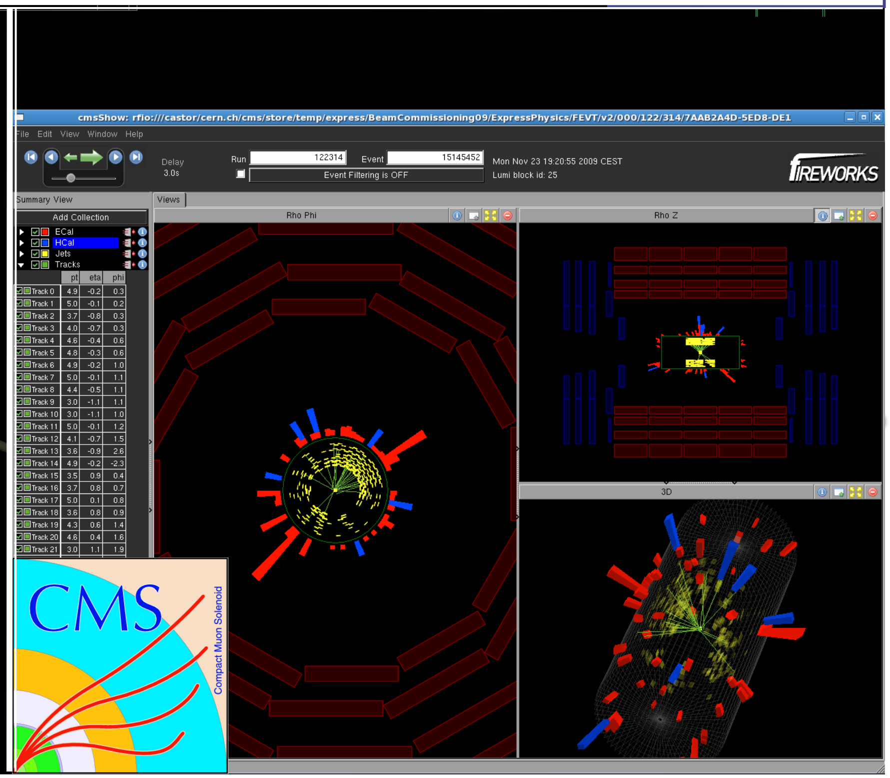
Now the world's highest energy accelerator!





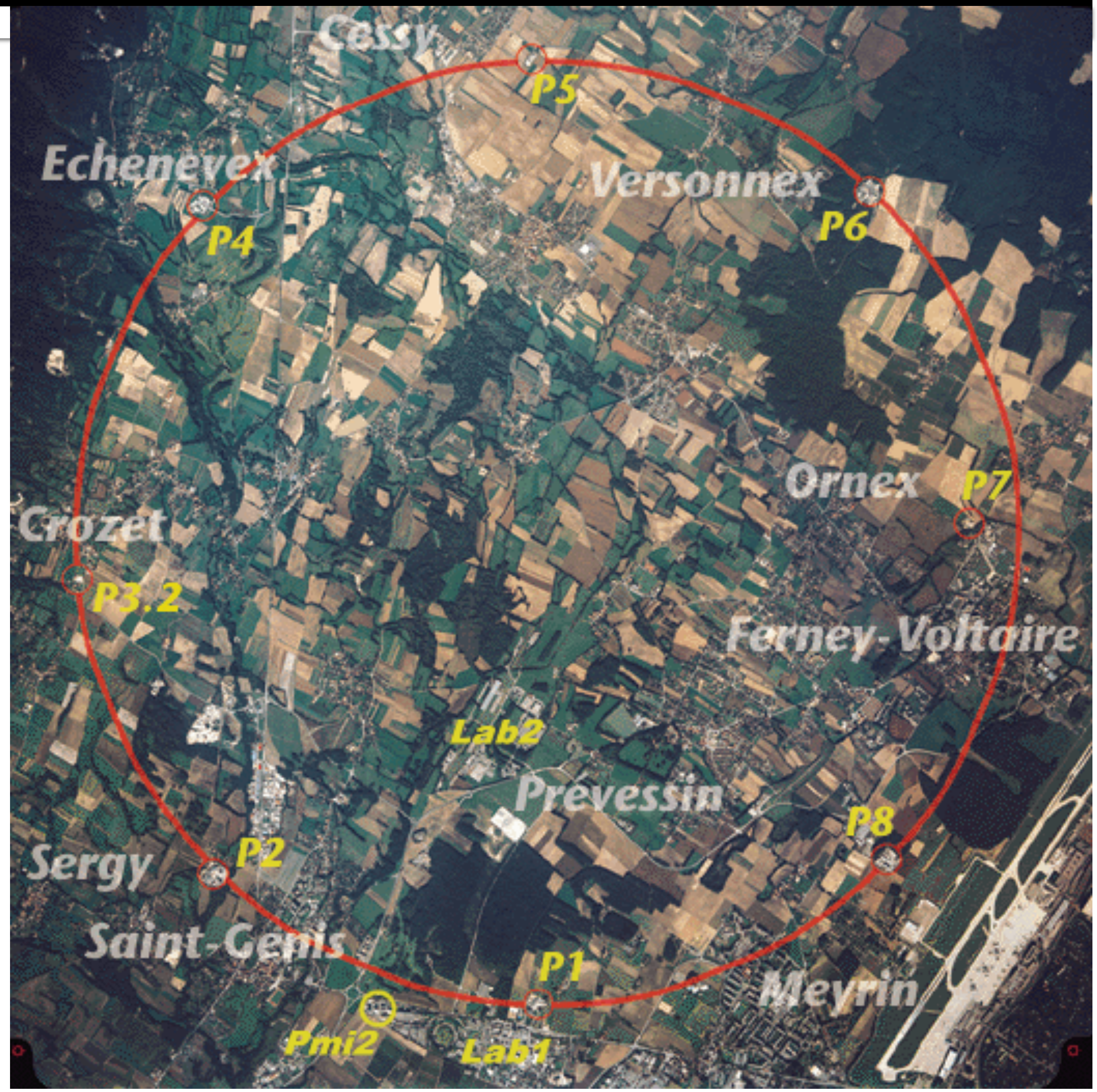


Outline:

- The LHC and You!
- Readiness for data:
  - Cosmic running
  - Beam splash and early data
- Expected Early results…

An 'overview'

- You are HERE.
- The CERN LHC is home to four experiments, only three of which I'll mention today:
  - CMS, ATLAS
  - LHCb

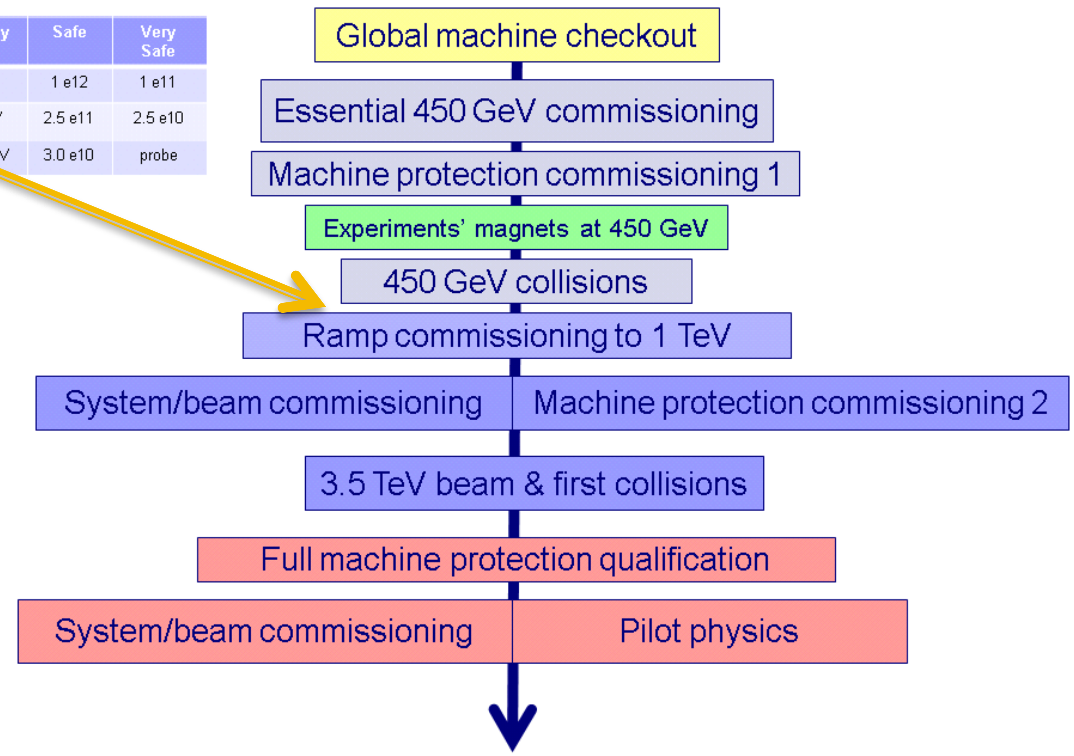


LHC Plans/Status:

- According to the most current plan, we are (approximately) here.
- LHC functioning well so far, will shut down for 2009 on Dec. 19th.
- Startup on Jan. 4th, expect to integrate some ~100 pb^{-1} in 2010 at 7 TeV.

Then onwards and upwards (ultimately to 14 TeV, L_I~10^{34})!

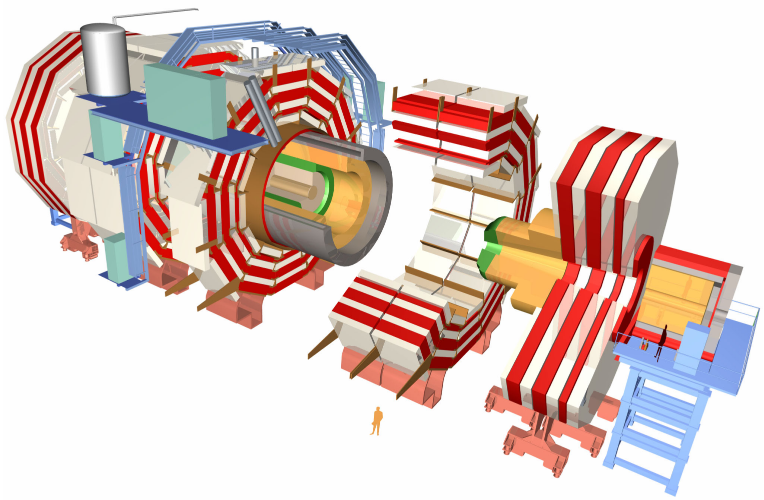
Energy	Safe	Very Safe
450	1 e12	1 e11
1 TeV	2.5 e11	2.5 e10
3.5 TeV	3.0 e10	probe

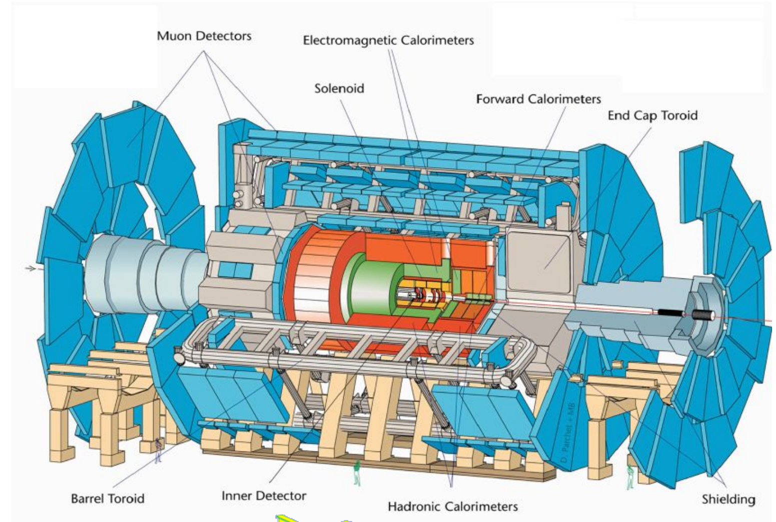


Thus:

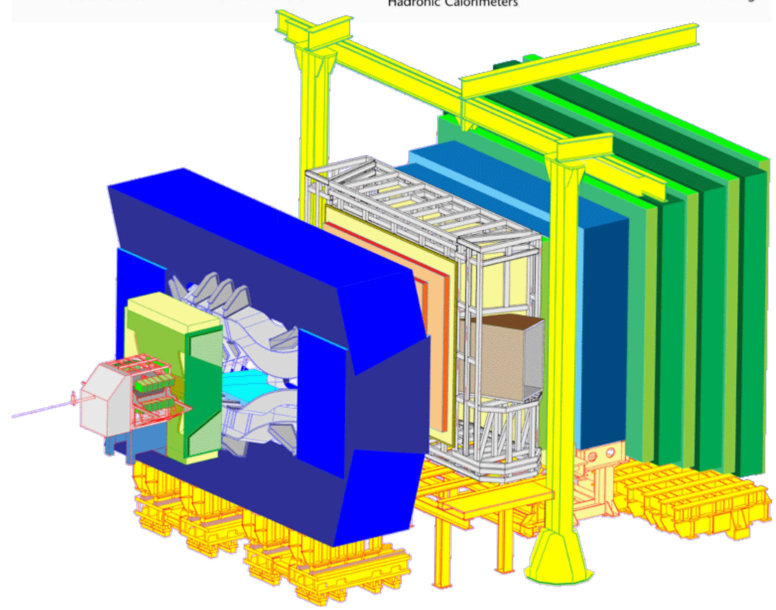
- When one says "hadron physics at the LHC", it leaves one in a conundrum:
  - It's the "Large HADRON Collider", therefore everything we do could be construed as "hadron physics".
  - More precisely though, the hadrons we study are typically hadrons involving b-quarks (and to some extent c-quarks).
    - Large rates of heavy quarkonia, though challenging to pick them out.
    - Fertile grounds for exotics, tests of models, and QCD in general.

The Detectors:

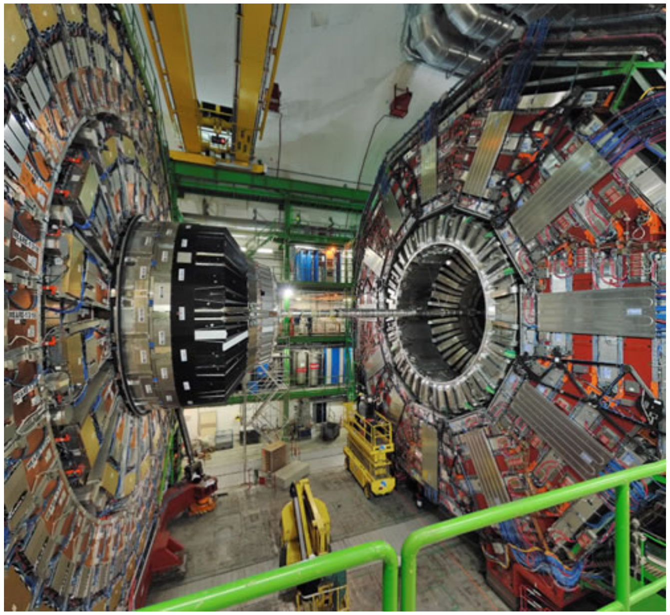


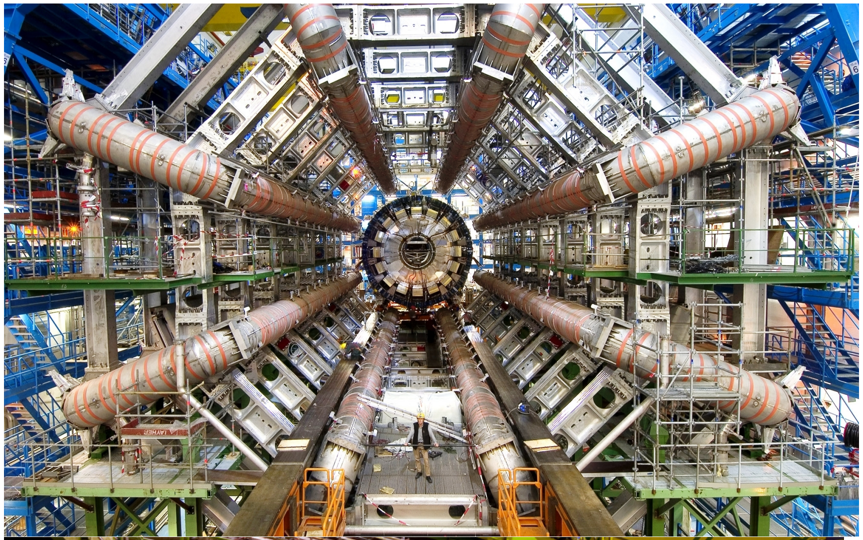


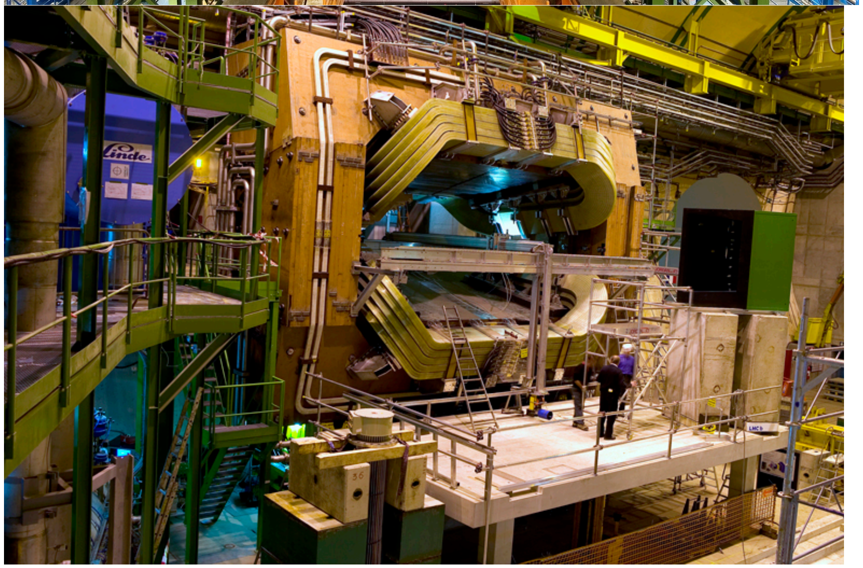
- CMS and ATLAS are multi-purpose detectors, whereas LHCb is (as the name implies) dedicated to studying b-quarks.



The Detectors: Which Exist!





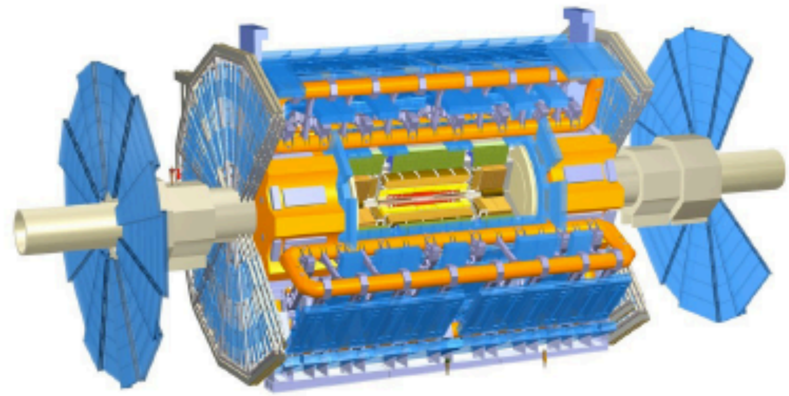


- So not only do the detectors exist on paper, they are fully assembled apparatuses.

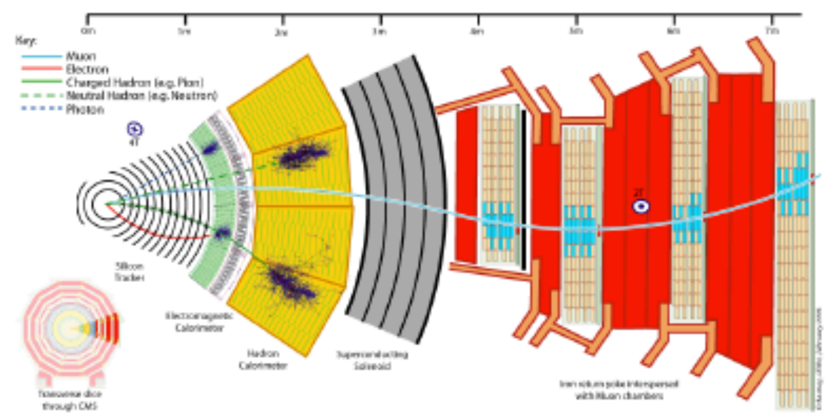
ATLAS and CMS:

- General purpose detectors, concentrated at central rapidities, designed for high instantaneous luminosity.
- Heavy dependence on muons for triggering on B events.

ATLAS

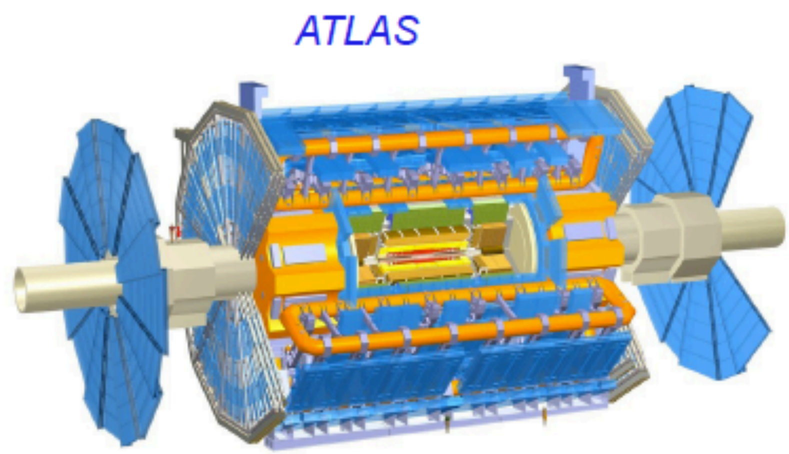


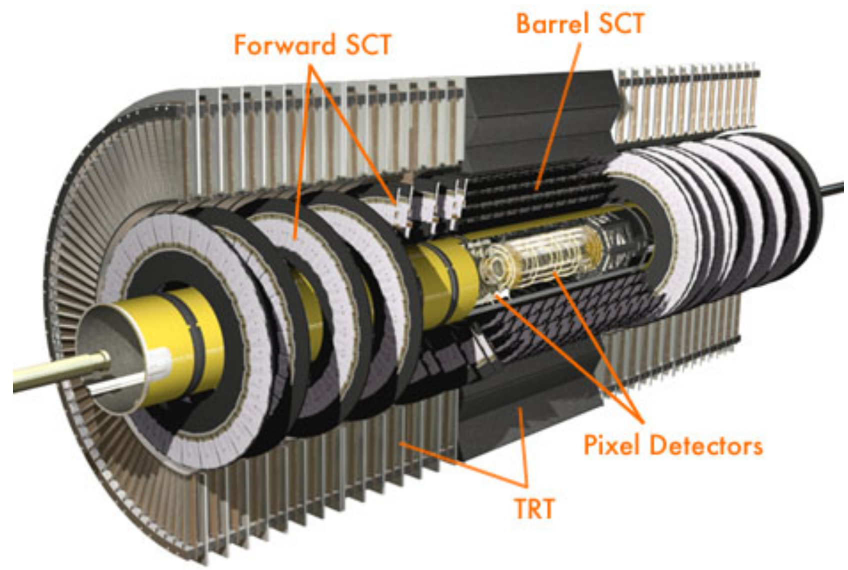
CMS



ATLAS:

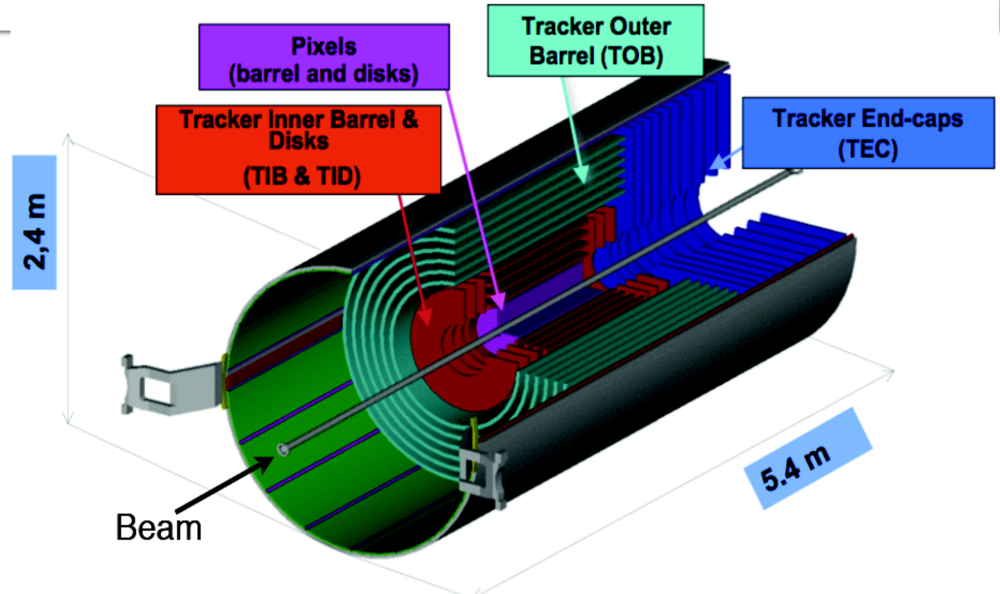
- Inner tracking consists of a precision pixel detector (for displaced vertices), surrounded by semiconductor tracker (SCT), surrounded by a transition radiation tracker (TRT). All inside 2 T solenoid.

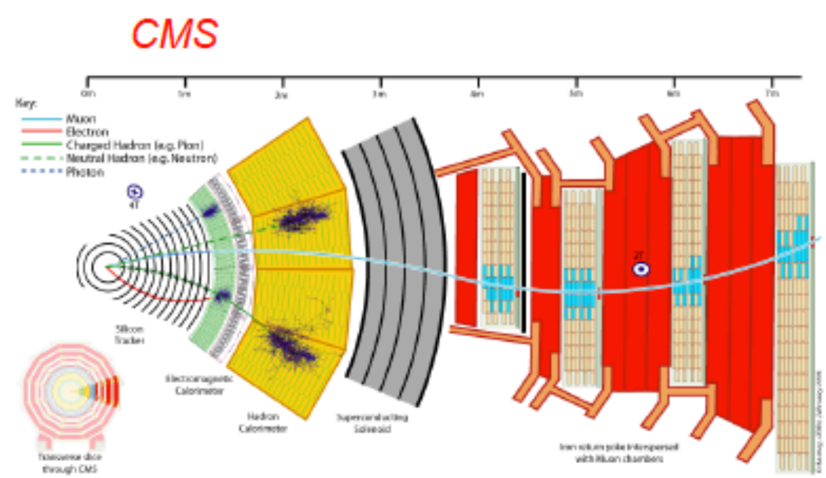




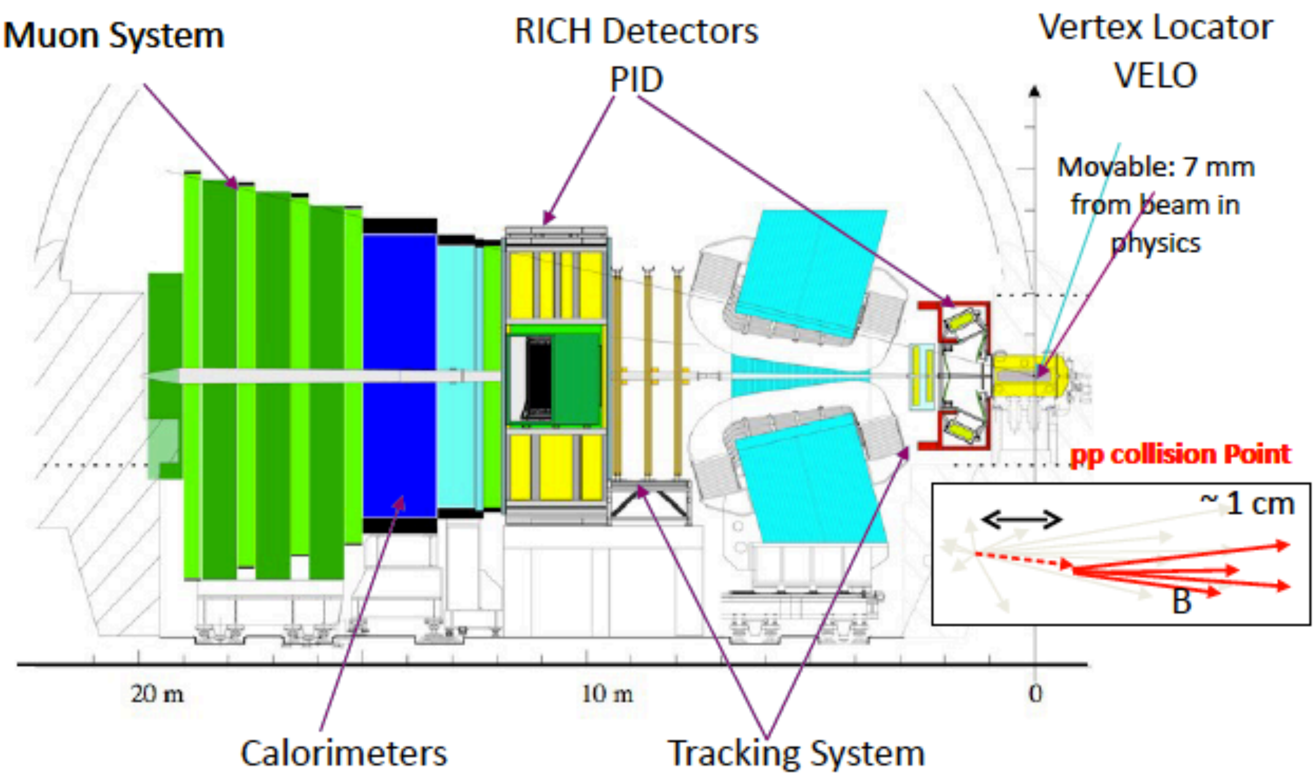
CMS:

- Inner tracking consists of a precision pixel detector (for displaced vertices), surrounded by a silicon strip tracker. All inside 4 T solenoid.

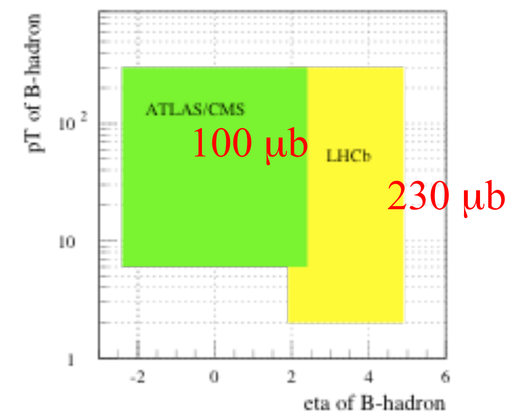




LHCb:



bb production cross section at √s=14 TeV



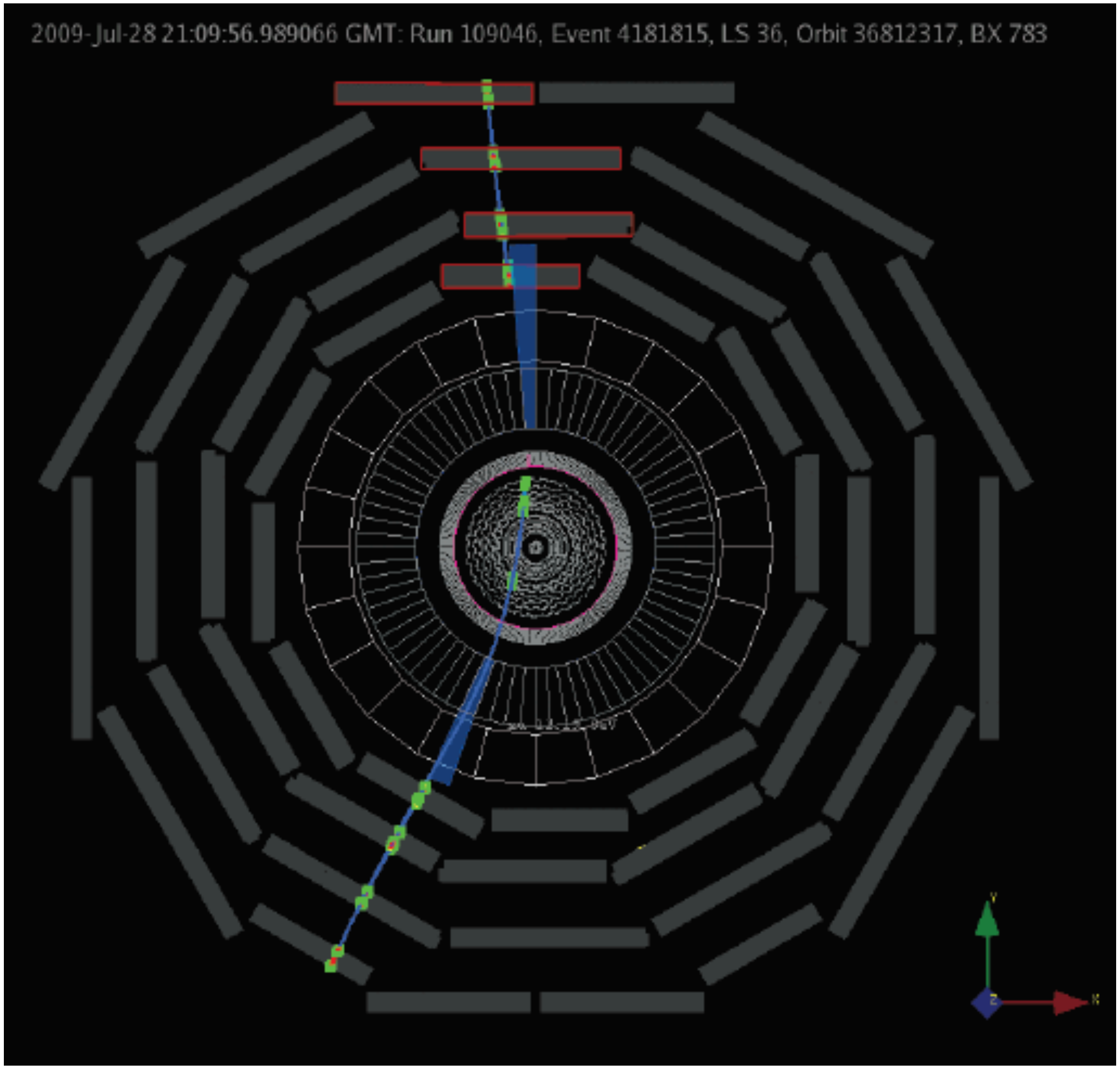
- Single arm spectrometer, dedicated particle identification, concentrated on one section of rapidity. Can trigger on hadronic B decays, designed for dedicated, low instantaneous luminosity study of beauty.

Our delayed start…

- In Sept. 2008, there was an 'issue' with LHC startup. Vacuum and cryo were lost, a sizable amount of He was lost, and mechanical damage was done.
- Repairs could not be completed before the end of the year, thus LHC operations were delayed until mid- (and now late-)2009.
- We have not been idle! Life gives you lemons…

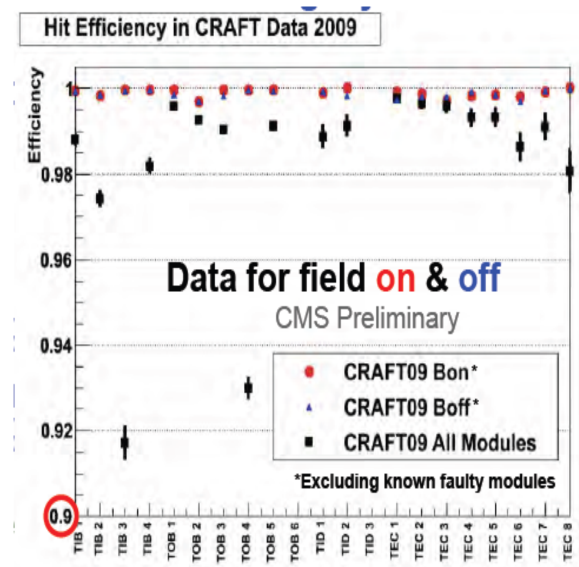
Life gives you lemons… you collect cosmic muons?

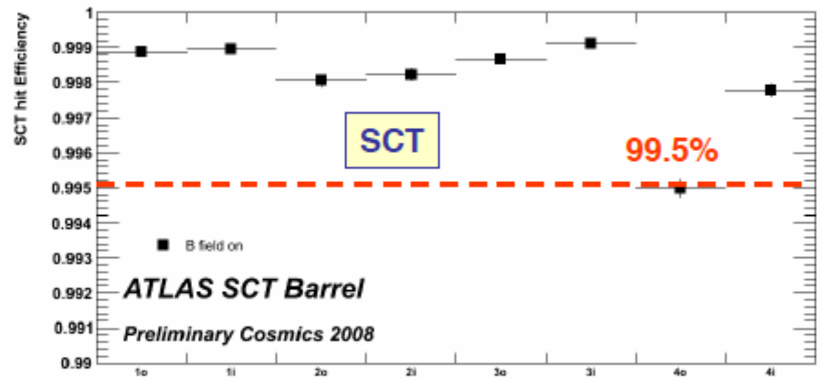
- I'm well aware that isn't how the saying goes.
- Since the initial difficulties with LHC startup in 2008, the detectors have each conducted extensive cosmic ray runs:
  - Better alignments
  - More operating experience.



ATLAS/CMS Tracker eff

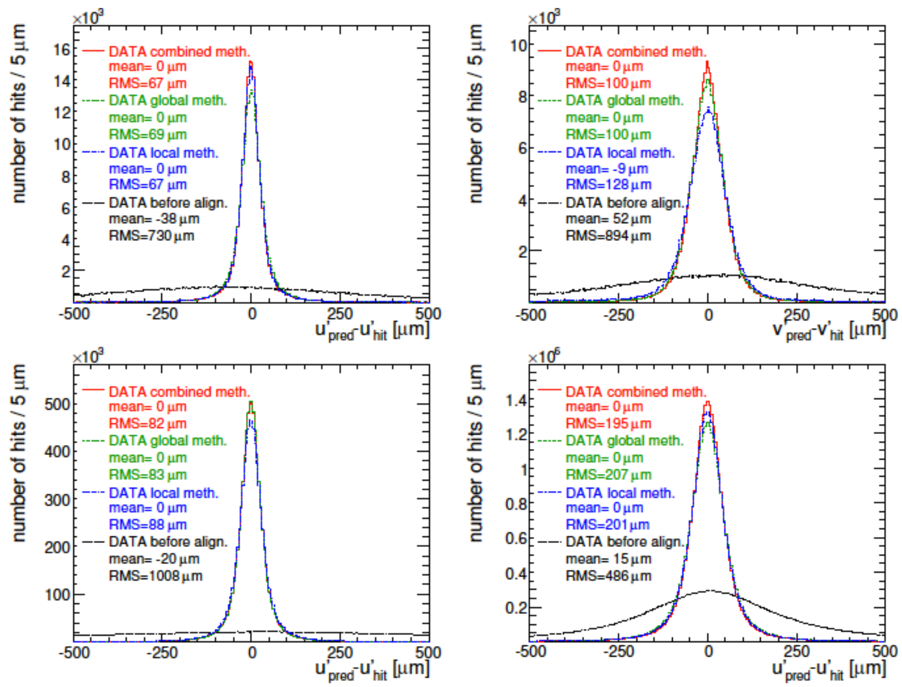
- Efficient tracking is essential for displaced vertex identification, and efficient tracking starts with efficient trackers.
- Each of these demonstrates performance in the as installed silicon trackers for CMS and ATLAS, VERY good performance.





CMS Tracker alignment

- ALIGNED tracking is also necessary, misalignments degrade both efficiency and precision for reconstructing tracks and vertices.
- Using cosmic ray muons, trackers are approaching their "perfect" alignments, in advance of physics running.



ATLAS Tracker Alignment

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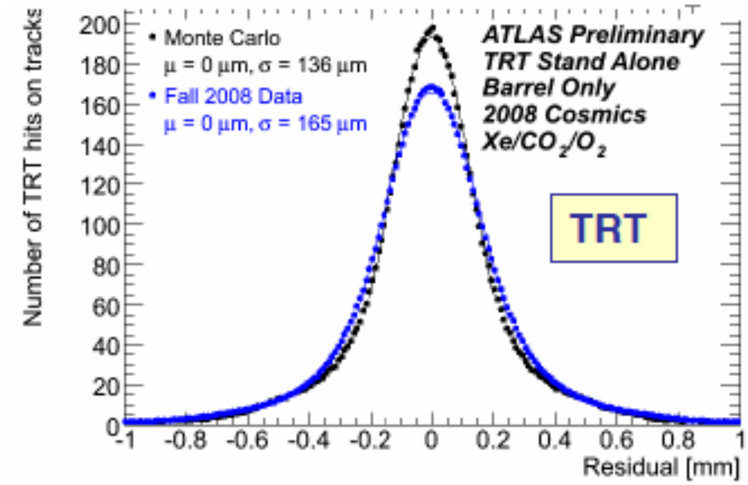
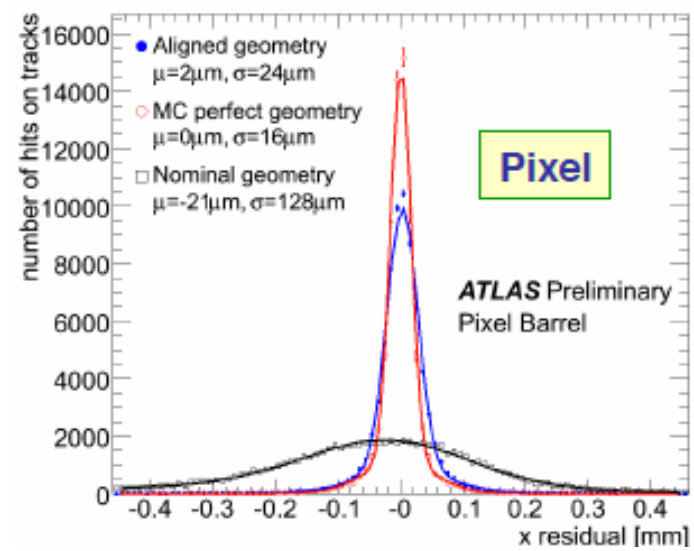
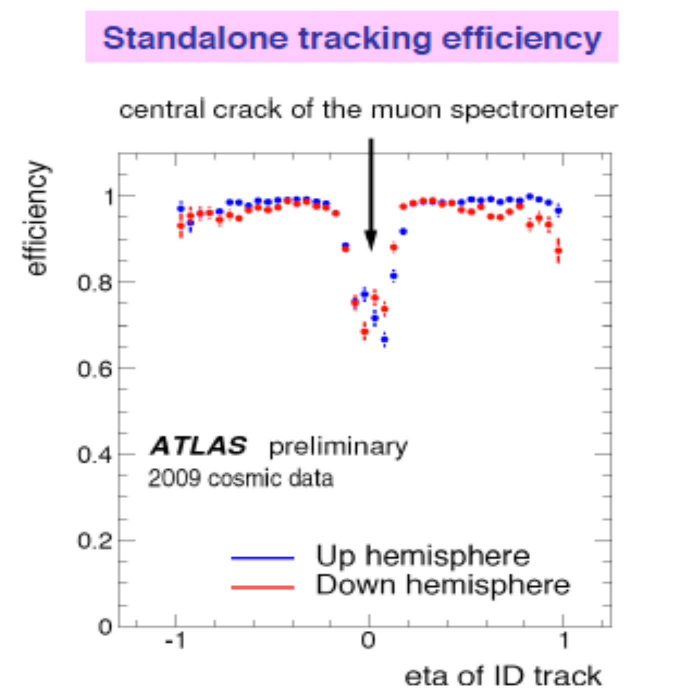
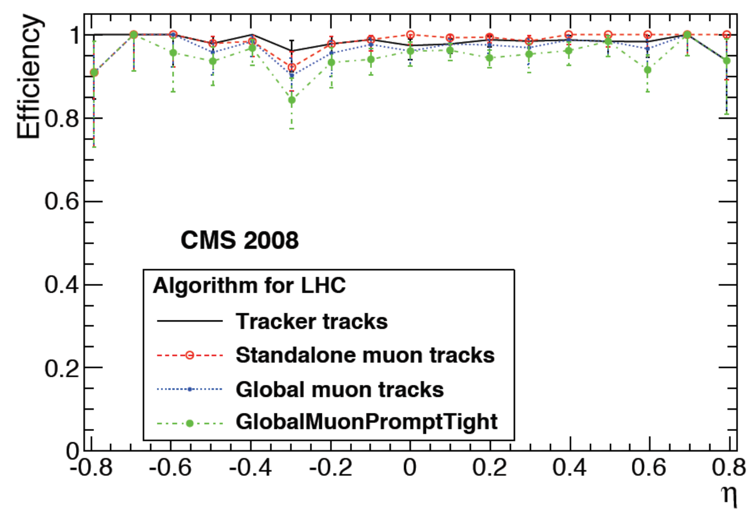




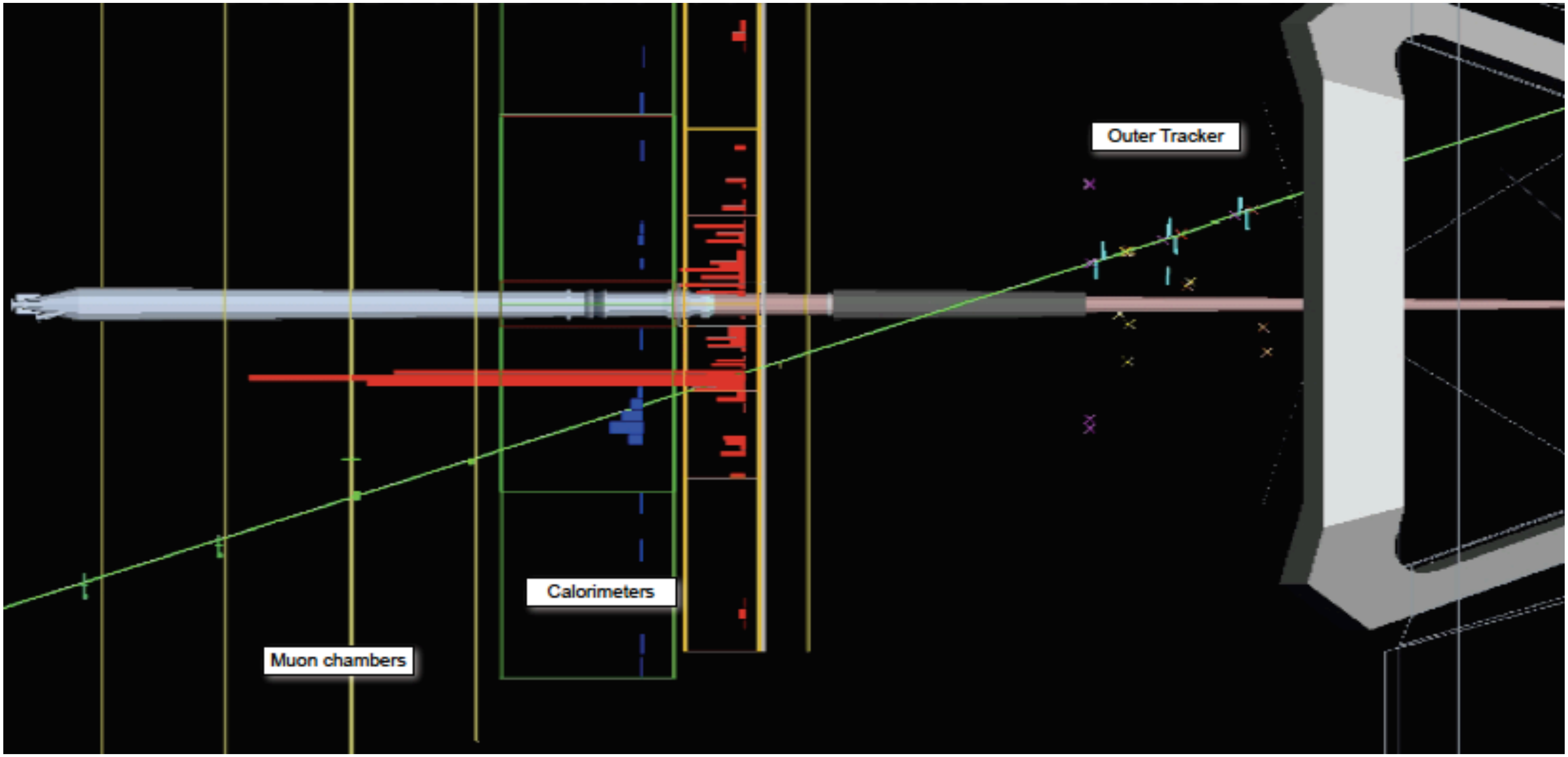
ATLAS/CMS Muon id

- Both ATLAS and CMS are highly dependent on reconstructing muons (both for analysis and triggering).
- Both show very good performance at identifying muons within cosmic runs.





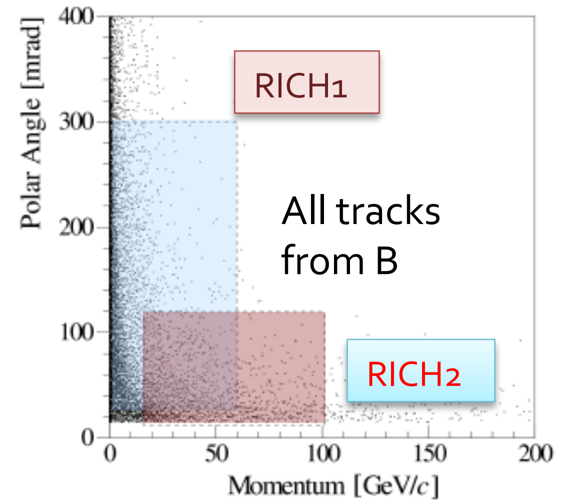
LHCb cosmics

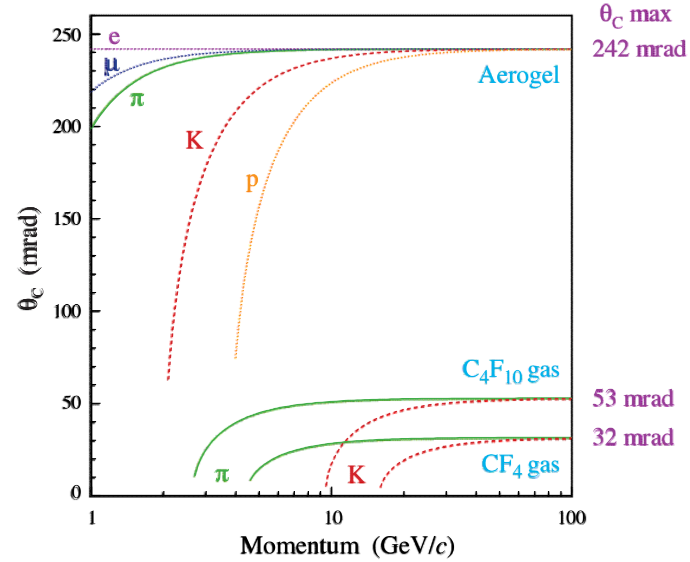


- Over 1.8 M cosmics, far fewer than CMS/ATLAS, since LHCb is oriented very differently.

LHCb cosmics: RICH

- LHCb has two separate RICH detectors. Different radiators preserve π-K separation over different momentum ranges.
- Sadly, not that many cosmics will cross either of them.

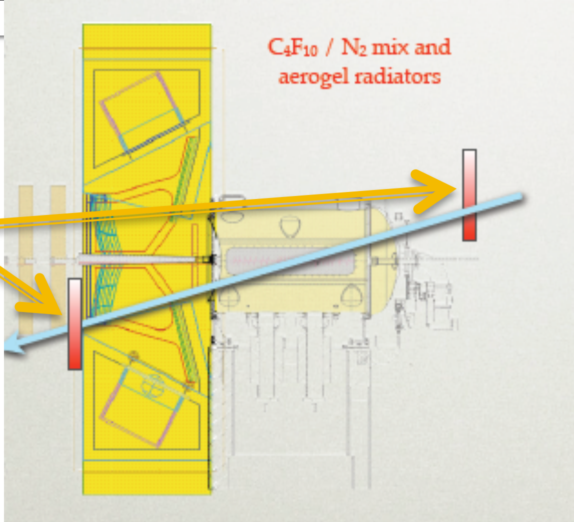


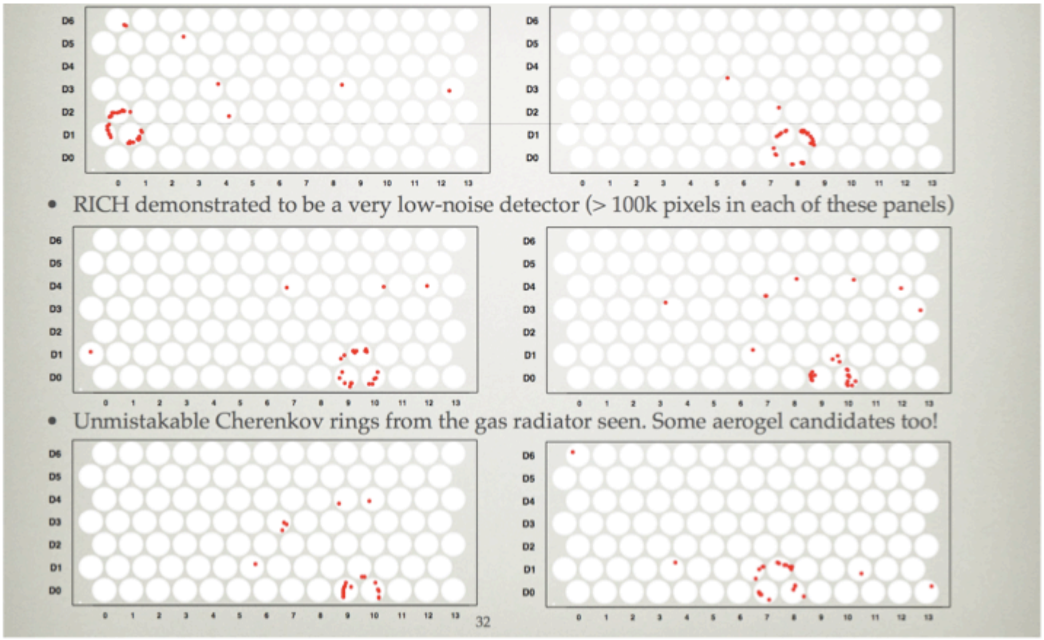


LHCb cosmics: RICH

- Ring images first observed from cosmic ray events.
- Note that in each of these panels has many MANY pixels, thus showing how low noise a detector this really is.

Extra scintillators for cosmic trigger.





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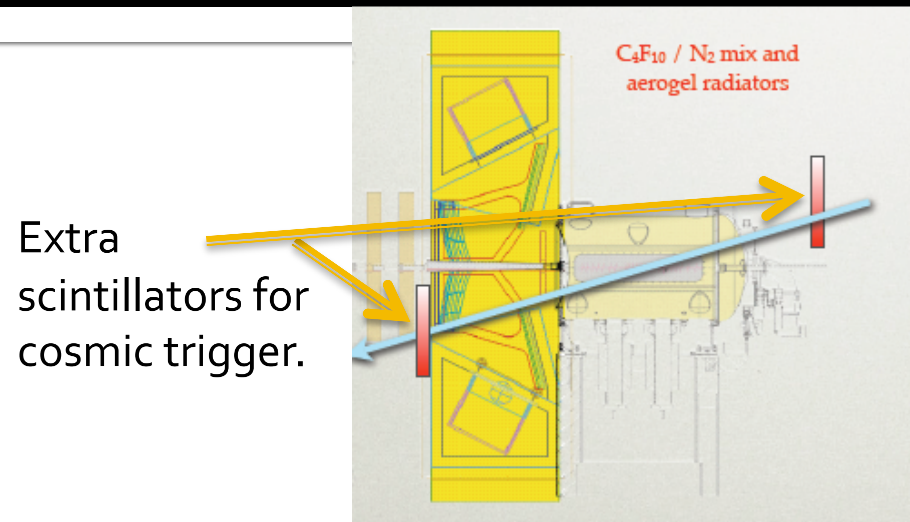
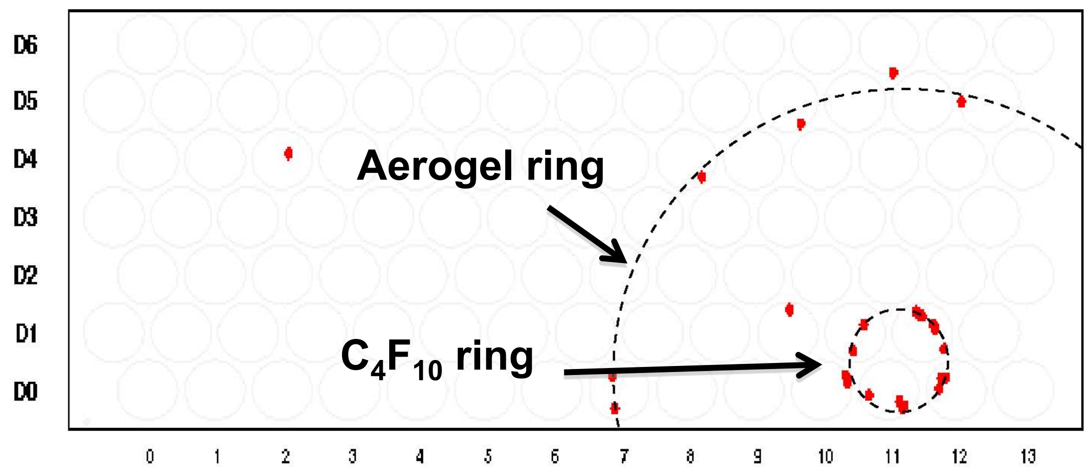
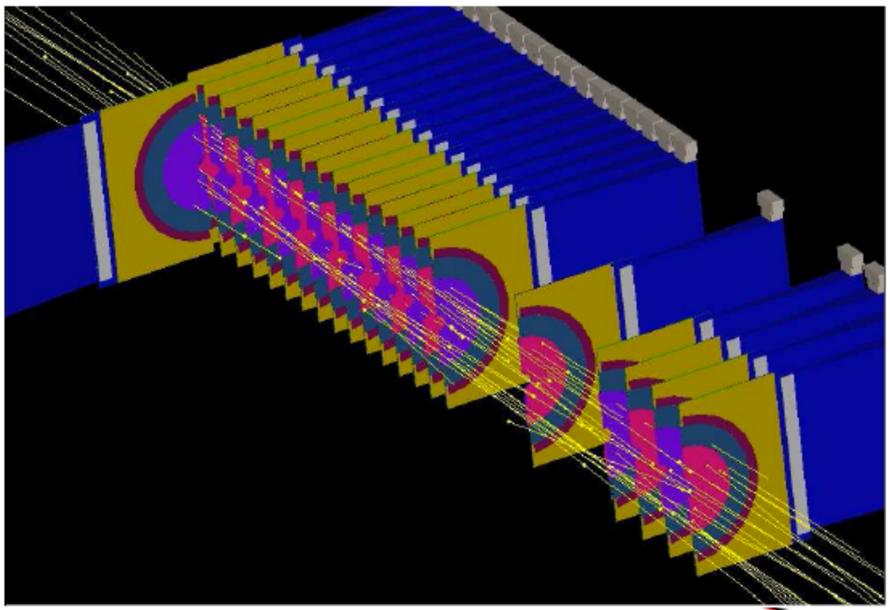
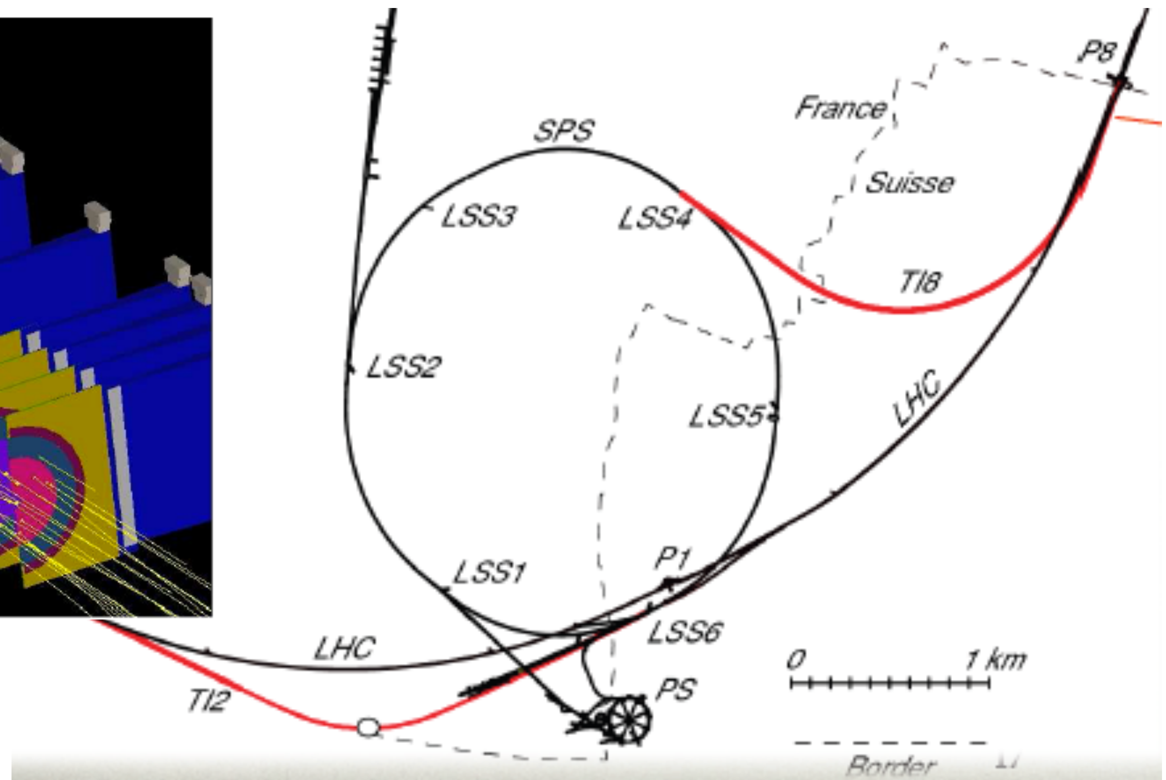




LHCb TED Runs

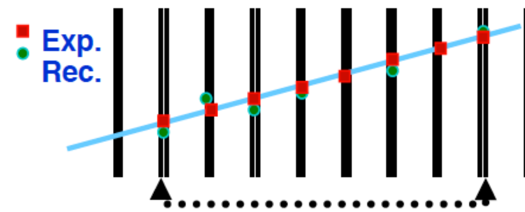
- Transition-line End Dump data:
  - First chance for small area detectors to see tracks, traverse detector in “wrong” direction…

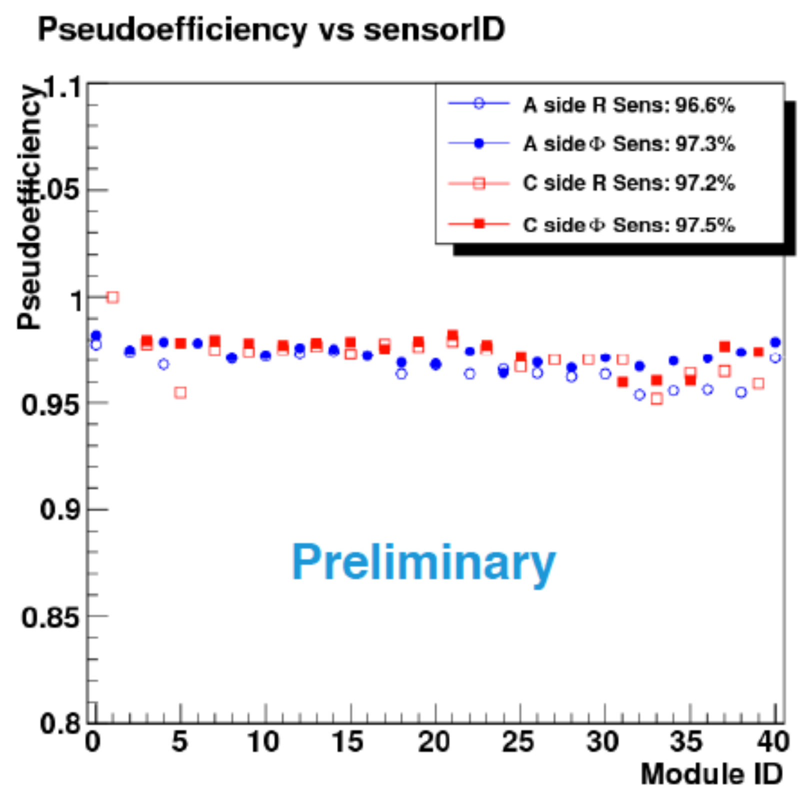




LHCb VELO efficiency:

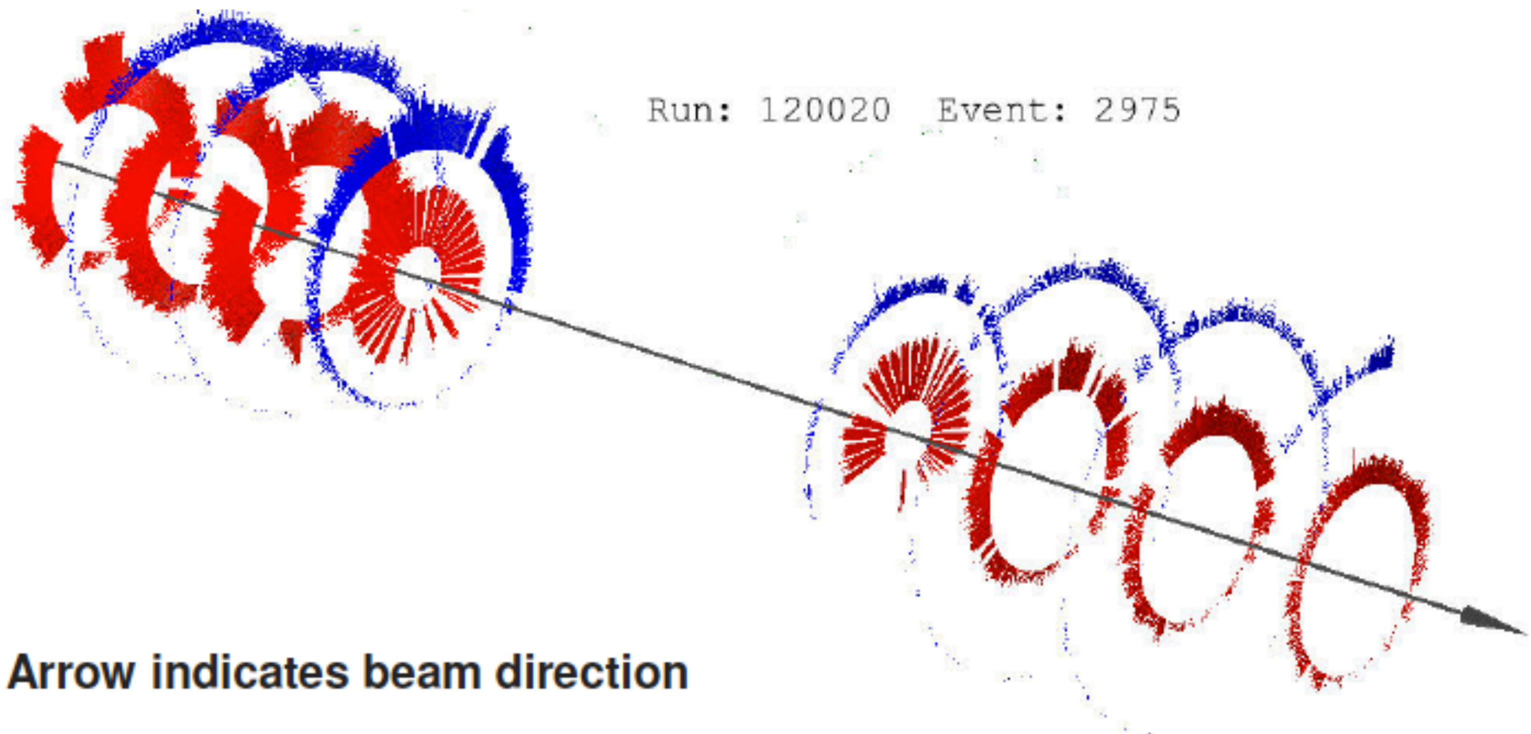
- Calculate "pseudoefficiency":
  - Exclude layer from consideration, fit track, and search for hit at extrapolated position within the layer in question.





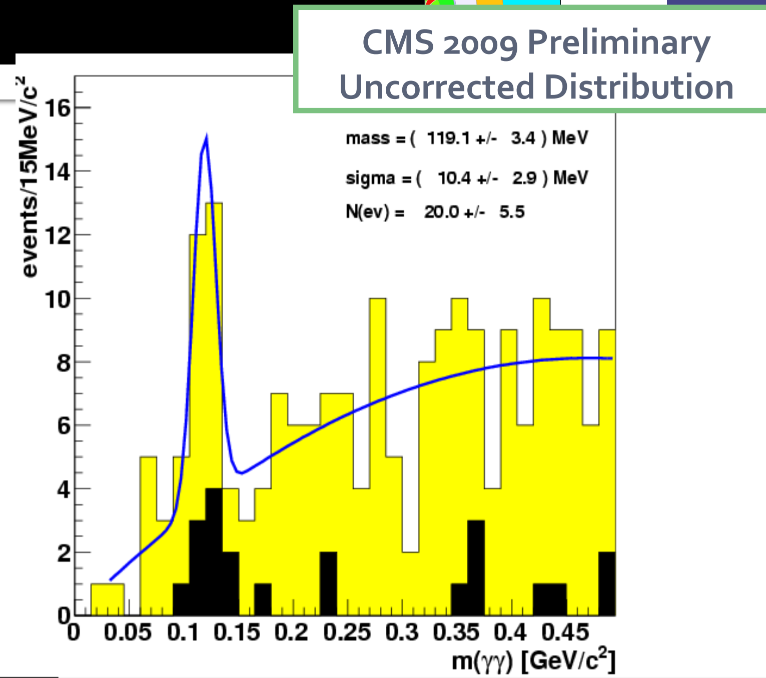
Beam splash

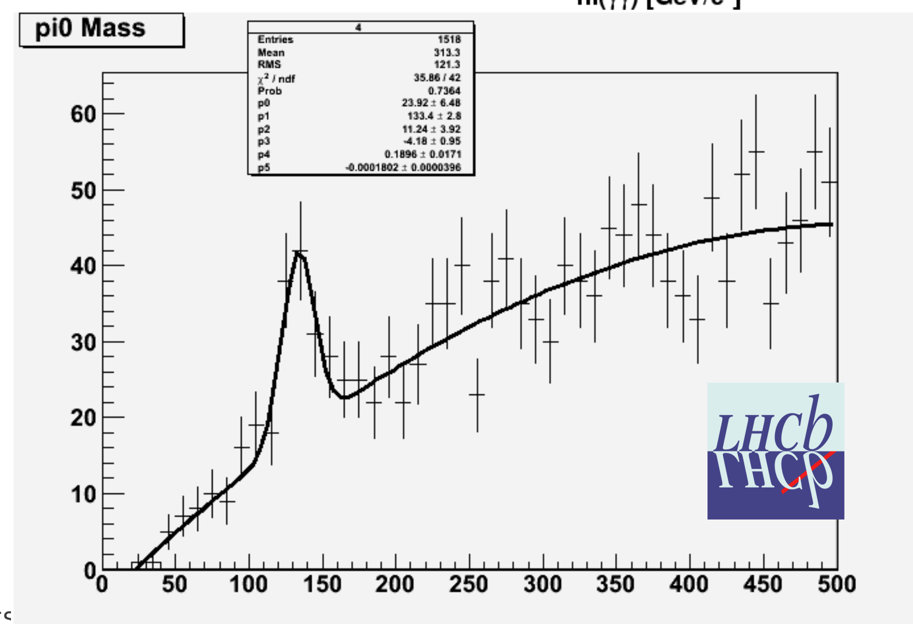
- LHC has provided "Beam Splash" events which allow for the illumination of the higher η detectors. This particular one comes from CMS.



Our first hadrons!

- Both LHCb and CMS have used their electromagnetic calorimetry to reconstruct the π^0 peak! Our first resonance from collisions!





Underlying event

- At 7 TeV (and higher eventually), one of the very first measurements that all the experiments (ATLAS/CMS in particular) are going to have to do is to measure the underlying event, for tuning of the MC generators.
- This is very tracker centric!
  - Doing this measurement doesn't just let you tune your generator, it puts real scrutiny on track reconstruction (in collision environment), which is going to be needed for EVERYTHING else.

Underlying event:

- The measurement is deceptively simple:
  - Particle (track) multiplicity in different bins of rapidity, for different trigger conditions, and as low a p_T as can be tolerated.
  - This is much easier said than done!

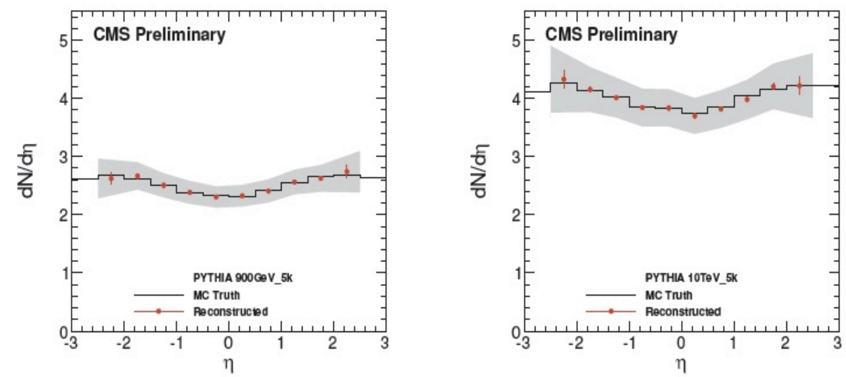
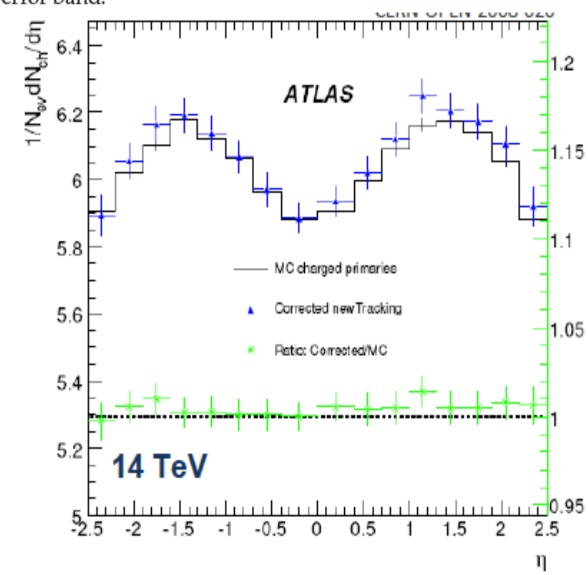
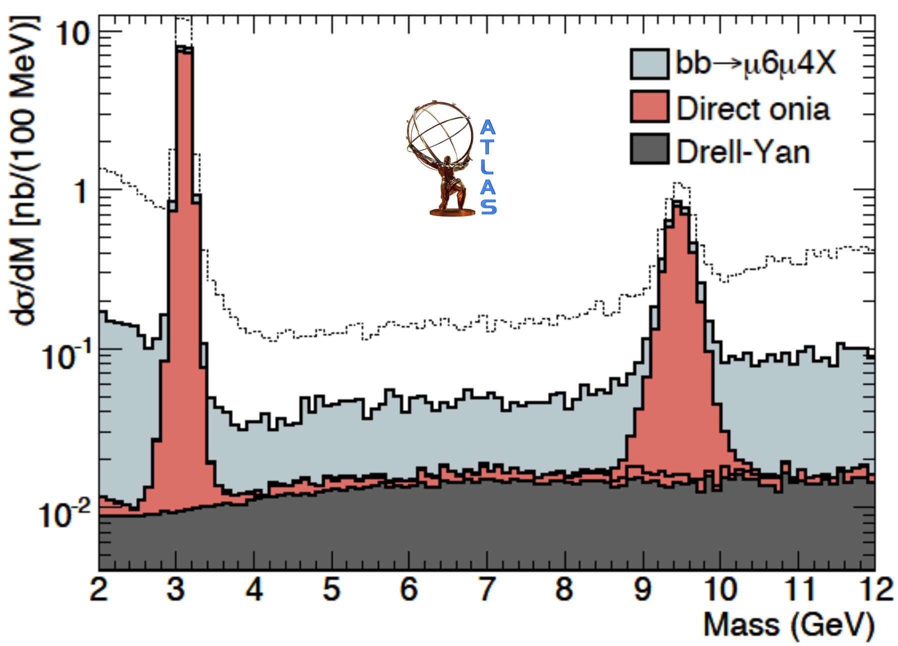


Figure 7: The measurement of $dN/d\eta$ in p+p at 900 GeV(left panel) and 10 TeV(right panel). Error bars show statistical errors using 5k events. The shaded area corresponds to 7.5 - 13.5% systematic error band.



Early Data:

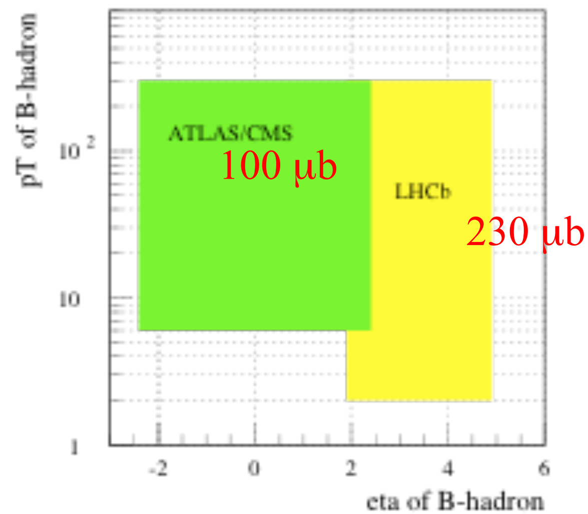
- Have gone through many iterations of:
  - "We'll turn on and find the Higgs!"
  - "No, first we'll turn on and look for the Z°."
- When in reality, we'll turn on and look for the J/ψ.



Early B results

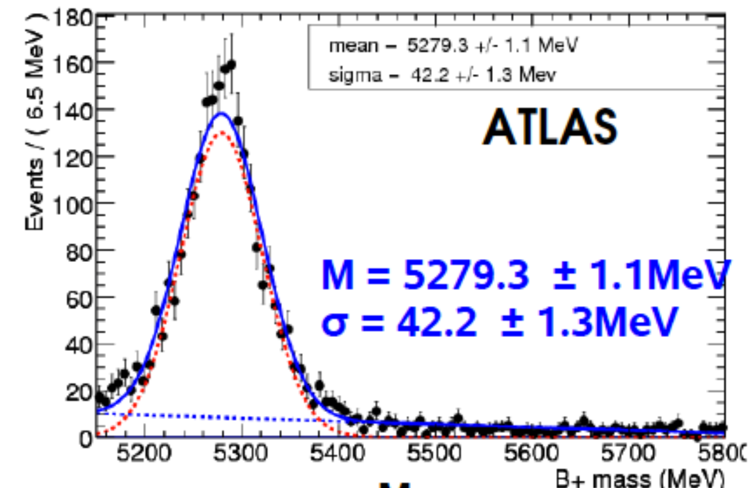
- The the first real hadron physics task will be to test the detector performance with well understood decays, like B^+.
  - All three detectors depend on decays of $B^+ \to J/\psi K^+$, with subsequent decay of $J/\psi \to \mu\mu$.
  - $J/\psi \to \mu\mu$ will in general be one of the first calibration samples for detector performance.

$b\bar{b}$ production cross section at $\sqrt{s}=14$ TeV

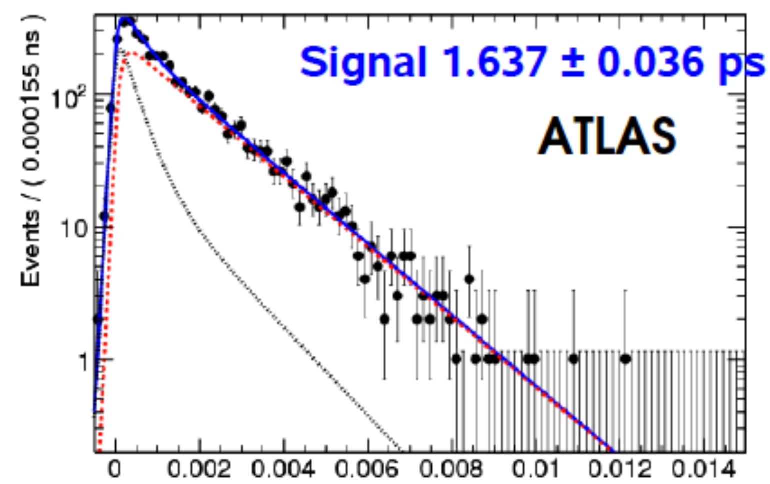


ATLAS B^+ early result:

- ATLAS, fully simulated inclusive b-bbar, 10 pb^{-1} at 14 TeV.
- Requires dimuon trigger, $p_T^{\mu}>6$ (4) GeV
- Will aim to perform mass/lifetime measurement for detector performance, as well as differential cross section.



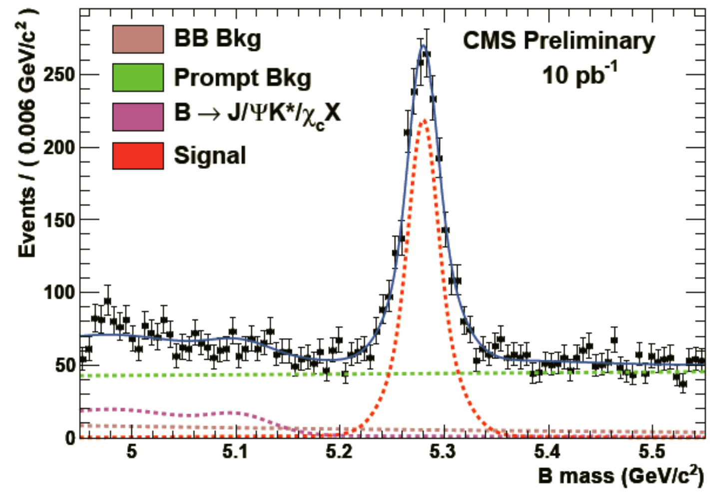
Mass

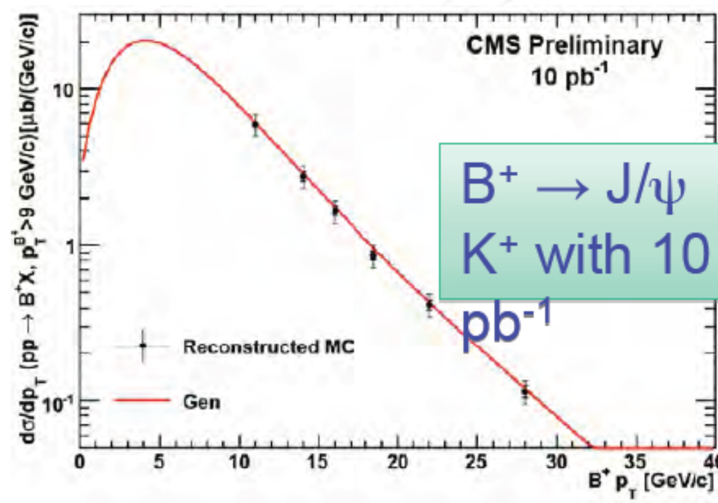


Proper time (ns)

CMS B^+ Early result

- CMS, fully simulated, 10 pb^{-1} at 10 TeV.
- Requires dimuon trigger, $p_T^{\mu}>3$ GeV
- Will aim to perform mass/lifetime measurement for detector performance, as well as differential cross section.





$B^+ \rightarrow J/\psi\ K^+$ with 10 pb^{-1}

LHCb early results (1):

- LHCb plans to use B^+ as an early source to study flavor tagging for B_s. This is part of a unified selection to take as much as possible from data and not simulation.

	Yield ($2fb^{-1}$)	B(bb)/S	B(prompt J/ψ)/S
$B_s \to J/\psi\phi$	117k	0.5	1.6
$B_d \to J/\psi K^*$	489k	1.5	5.2
$B^+ \to J/\psi K^+$	942k	0.3	1.6

- Trigger uses lifetime-unbiased di-muons:
  - L0: p_T>1.5GeV,
  - Total trigger efficiency (with mass cut) ~70%
- Event yield after trigger and selection ($2fb^{-1}$) ~ 117k
  - >50% uncertainty due to bb cross-section and BR($B_s \to J/\psi\phi$)

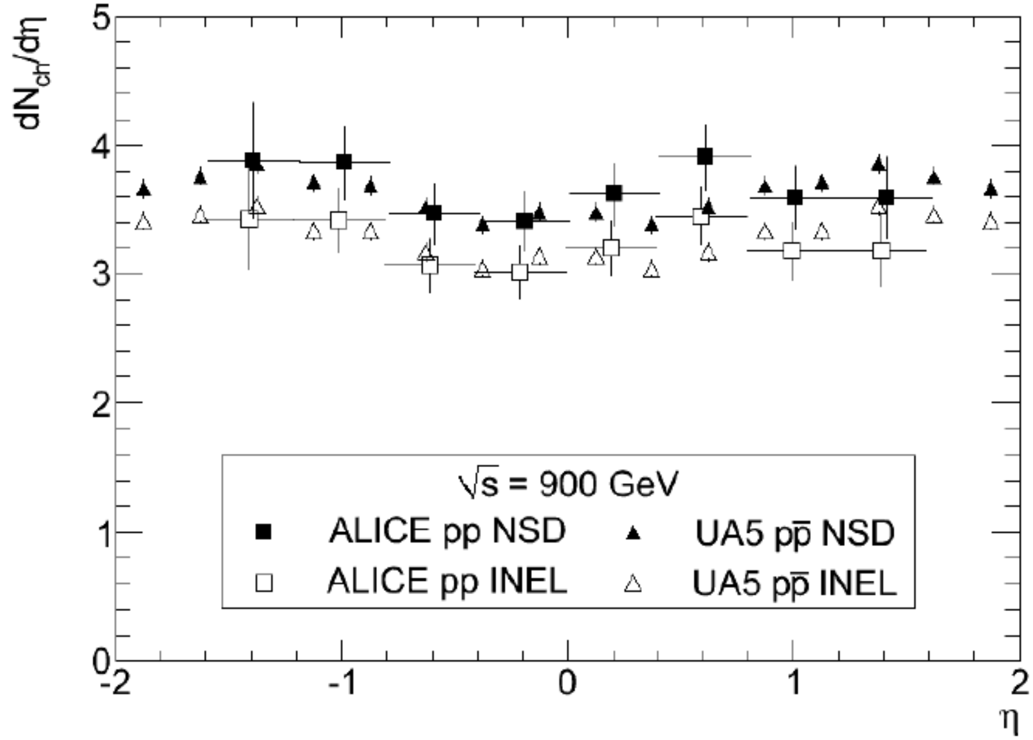
Summary:

- Detectors are fully installed, and as of last week receiving some collisions at injection energy.
- First goals have to be to see the performance of the detectors with beam.
  - Start from tracks (underlying event), which leads to muons (and $J/\psi \rightarrow \mu\mu$), then to B^+, and then the rest (B^0, B_s, B_c, Λ_b...)
- You'll be hearing more from us (very) soon!

BACKUPS

ALICE…

- ALICE has actually already submitted a paper for publication with a VERY early measurement of underlying event.

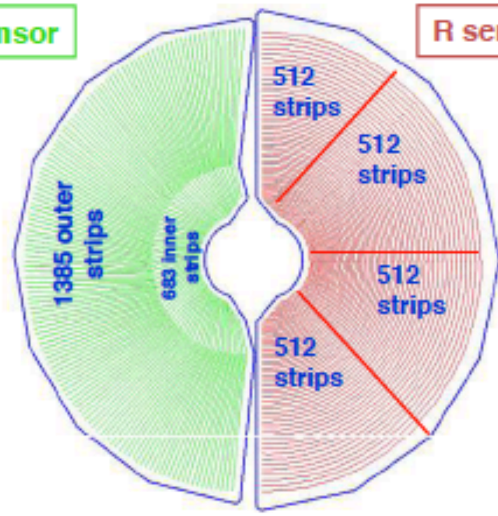


arXiv:0911.5430

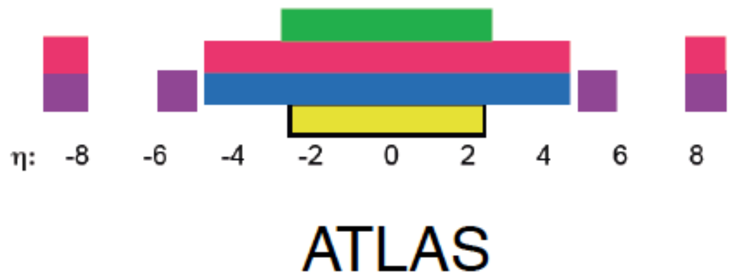
BACKUP LHCb VELO

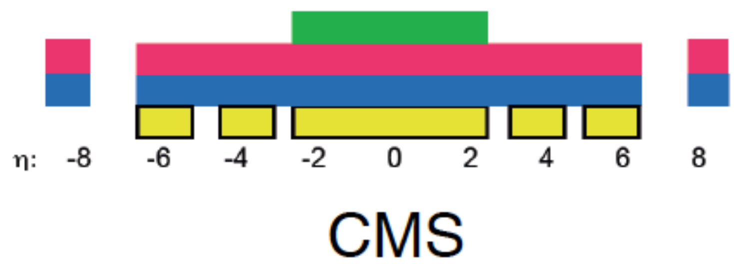
VELO – sensors

- **Highly segmented; n^+ on n**
- **2048 strips per sensor**
- **Radiation tolerant. Expected ratiation dose:**
  - $1.3 \cdot 10^{14} n_{eq}/cm^2$/year at r = 0.8 cm
  - $5 \cdot 10^{12} n_{eq}/cm^2$/year at r = 4.2 cm
- **Design operation at -7 degrees**

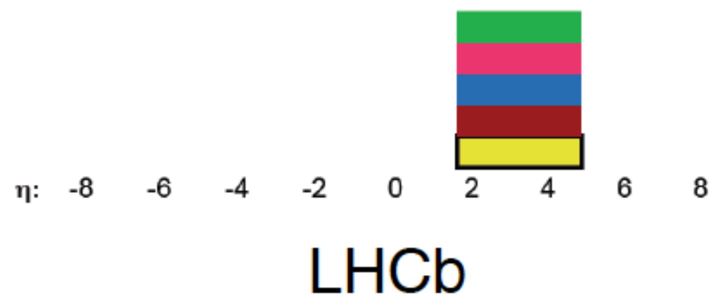


Φ sensors	R sensors
▪ Measure the azimuthal angle ▪ Stereo angle 20° for the inner strips (10° for the outer strips) ⇒ 2 regions ▪ Pitch: 36 -97 μm	▪ Measure the radial distance ▪ Divided in quadrants ▪ Pitch: 40 -102 μm



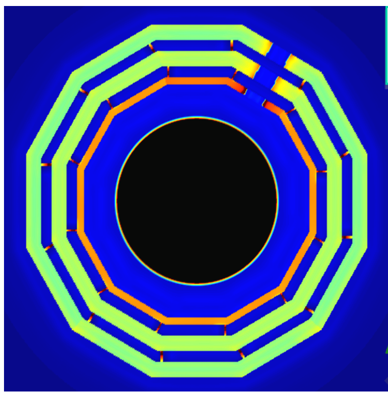


- LHCb is very different than ATLAS/CMS. In a large way this is very complementary.

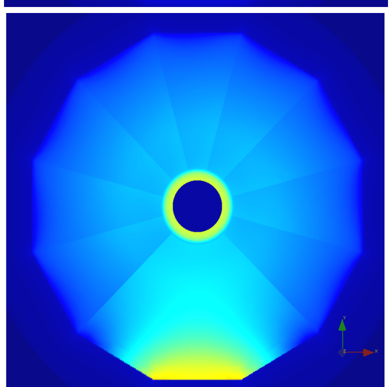


BACKUP: CMS Field maps

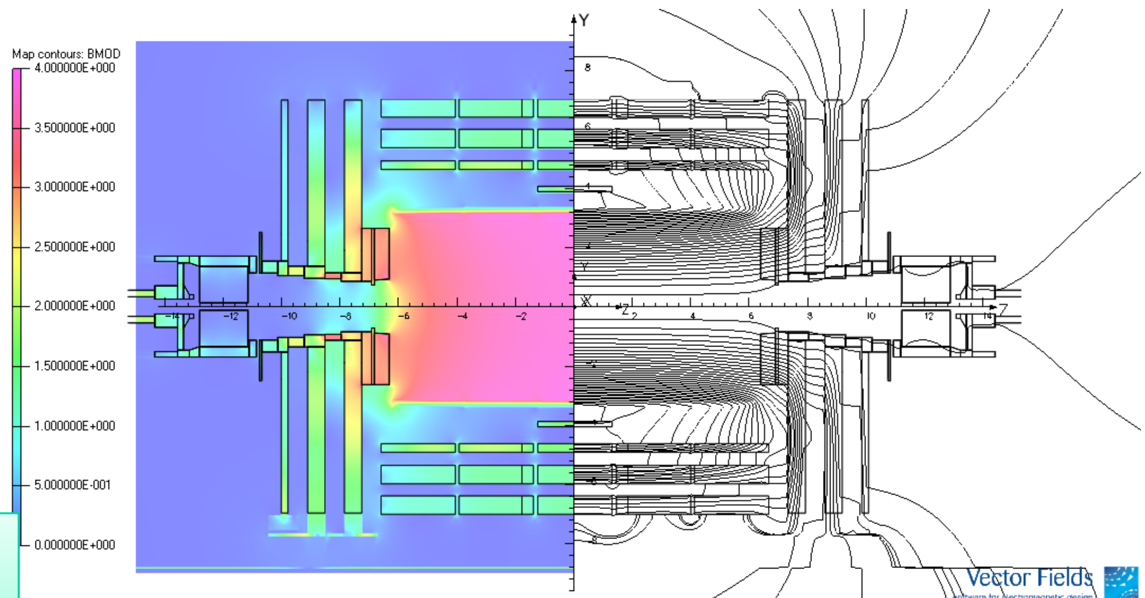
- Required additional adjustments for scaling near supports. Data/MC agreement now better than 2% in yoke.



Chimneys

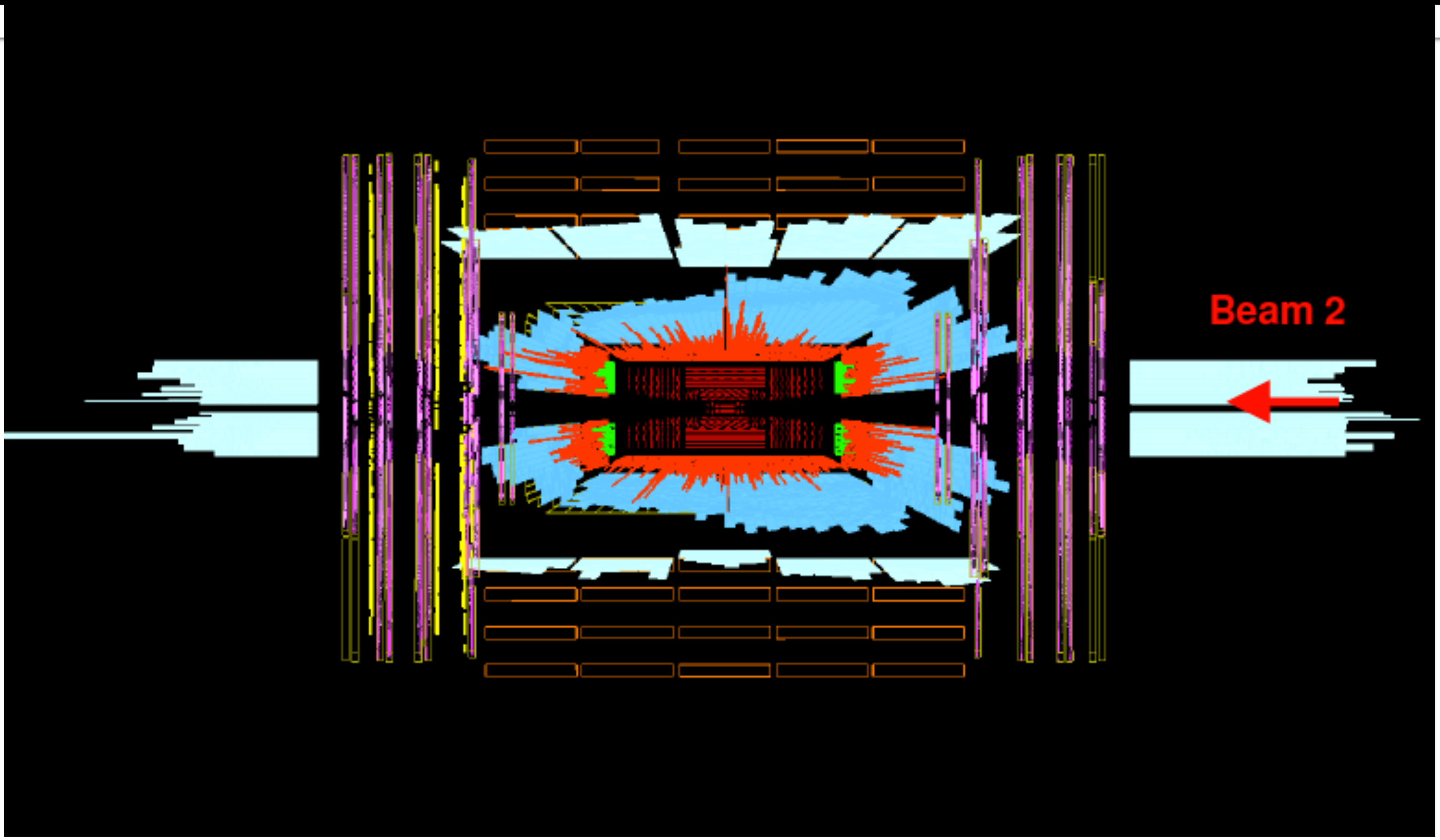


Feet



4Wb / line
YZ plane

Splash Events (1)



- Recent circulating beam in sectors of LHC. Run into a target to control the stop of the beam, voila! Splash!

Splash Events (2):