First results and status of the CMS experiment

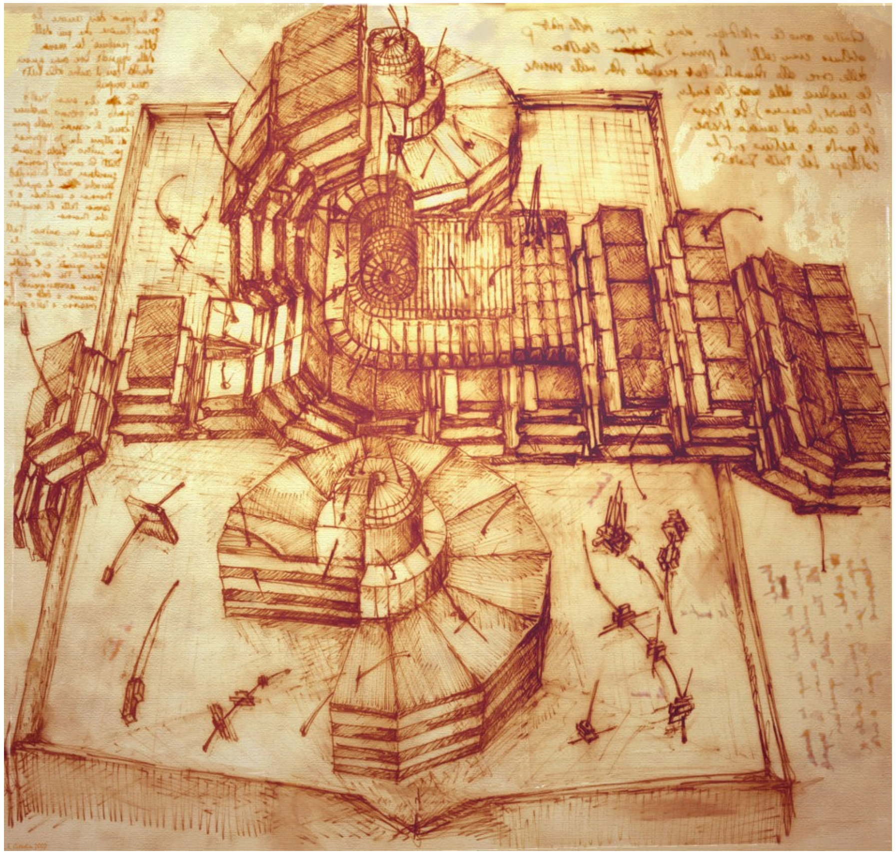
Constantin Loizides

HIC for FAIR colloquium, Frankfurt, January 28, 2010

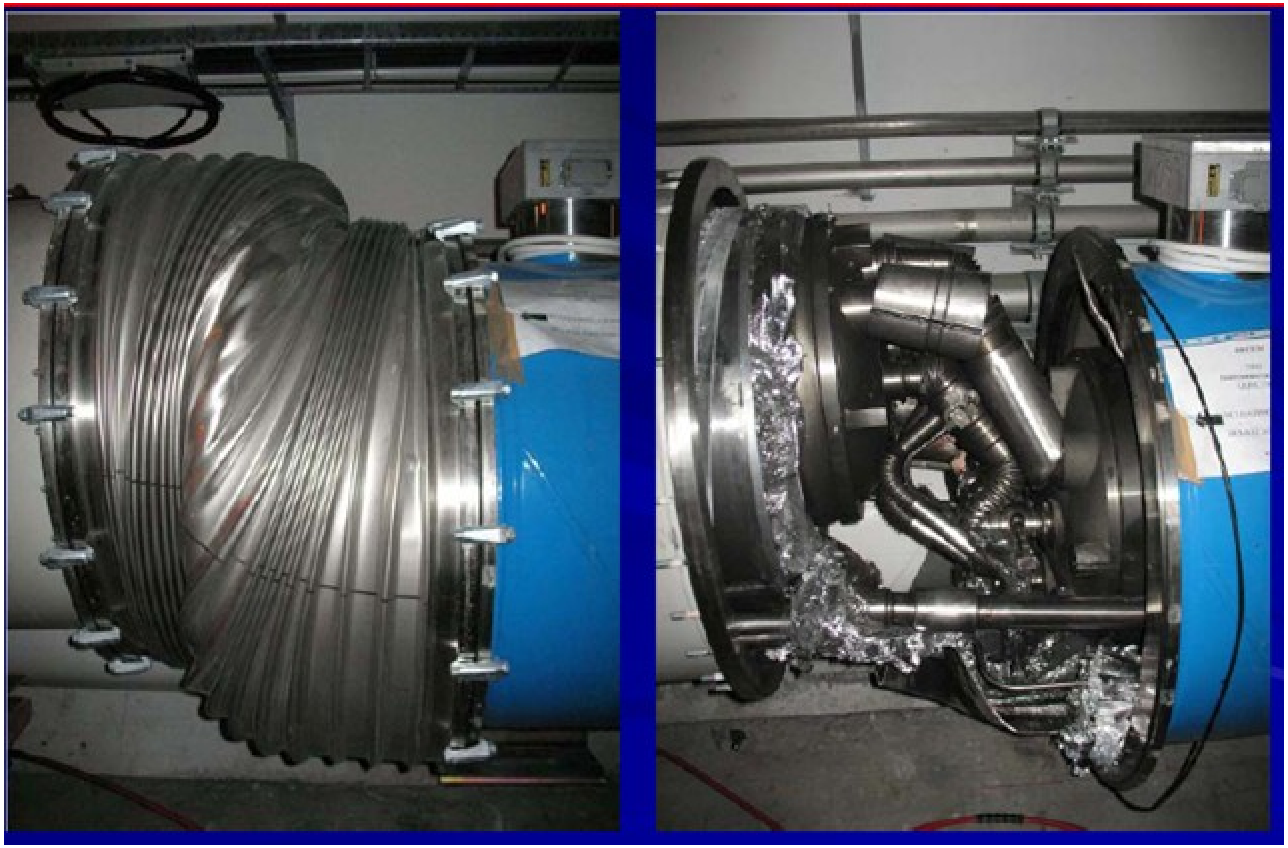
Overview

After 20 years of R&D,
detector building,
commissioning and
preparation

- LHC is up and running
- CMS is in physics commissioning mode
- Detector performance is according to design
- First collision results



A review of how we got from this

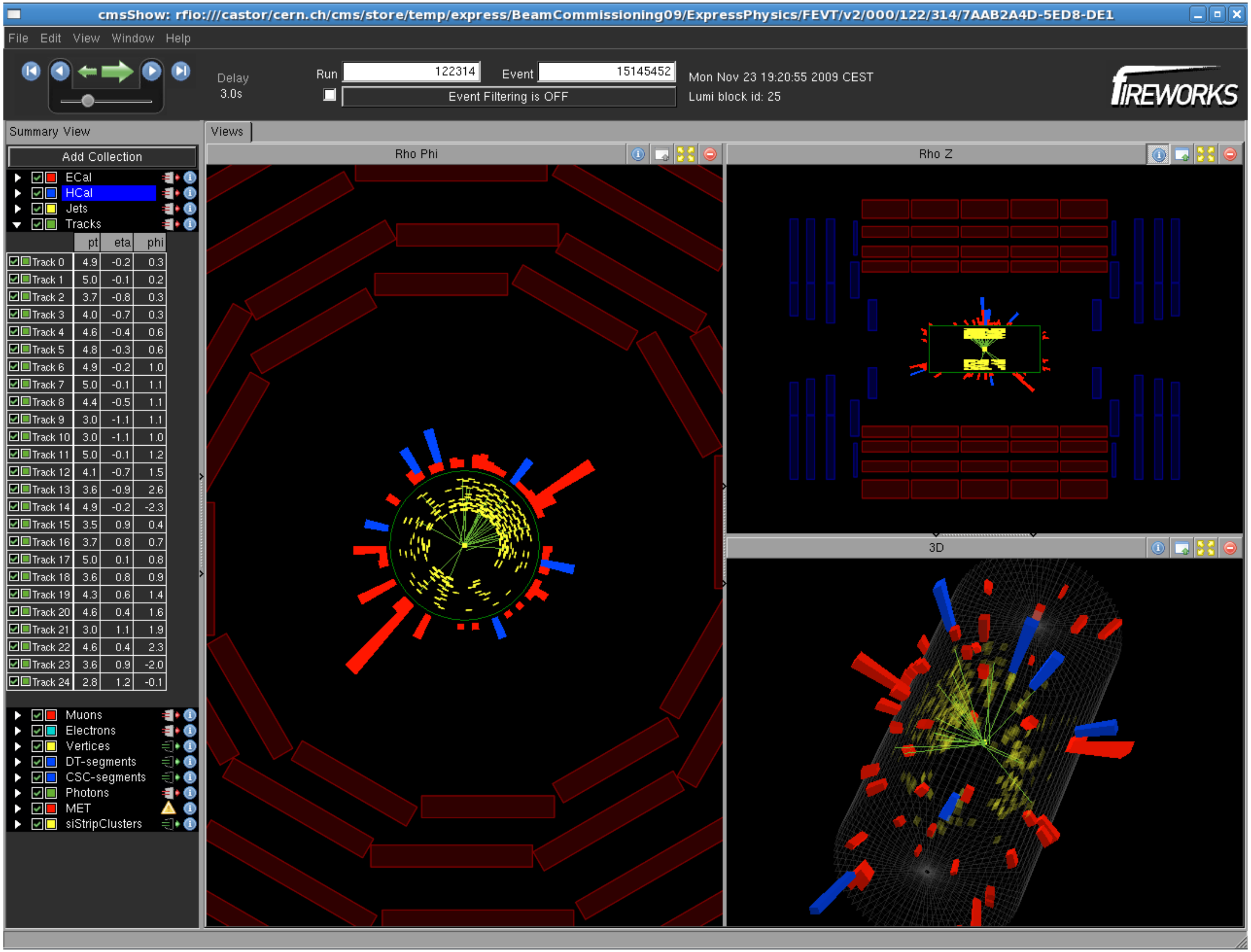


19 September 2008 (*)

(*) Picture released in December 2008

Details about the accident
M.Lamont, arXiv:0906.0347

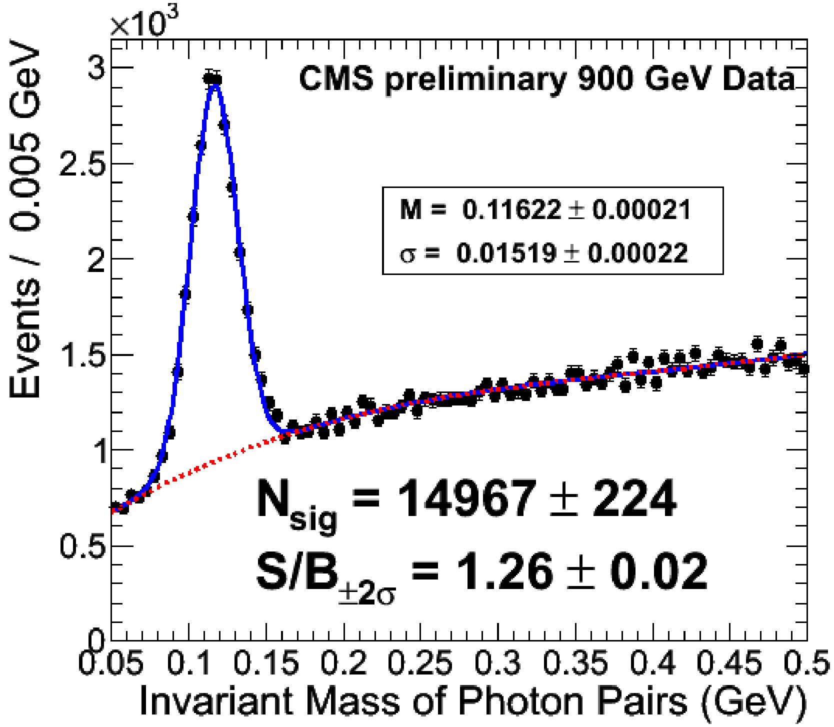
...to this



	pt	eta	phi
Track 0	4.9	-0.2	0.3
Track 1	5.0	-0.1	0.2
Track 2	3.7	-0.8	0.3
Track 3	4.0	-0.7	0.3
Track 4	4.6	-0.4	0.6
Track 5	4.8	-0.3	0.6
Track 6	4.9	-0.2	1.0
Track 7	5.0	-0.1	1.1
Track 8	4.4	-0.5	1.1
Track 9	3.0	-1.1	1.1
Track 10	3.0	-1.1	1.0
Track 11	5.0	-0.1	1.2
Track 12	4.1	-0.7	1.5
Track 13	3.6	-0.9	2.6
Track 14	4.9	-0.2	-2.3
Track 15	3.5	0.9	0.4
Track 16	3.7	0.8	0.7
Track 17	5.0	0.1	0.8
Track 18	3.6	0.8	0.9
Track 19	4.3	0.6	1.4
Track 20	4.6	0.4	1.6
Track 21	3.0	1.1	1.9
Track 22	4.6	0.4	2.3
Track 23	3.6	0.9	-2.0
Track 24	2.8	1.2	-0.1

First collisions in CMS – Monday, 23 November 2009

... but also to this

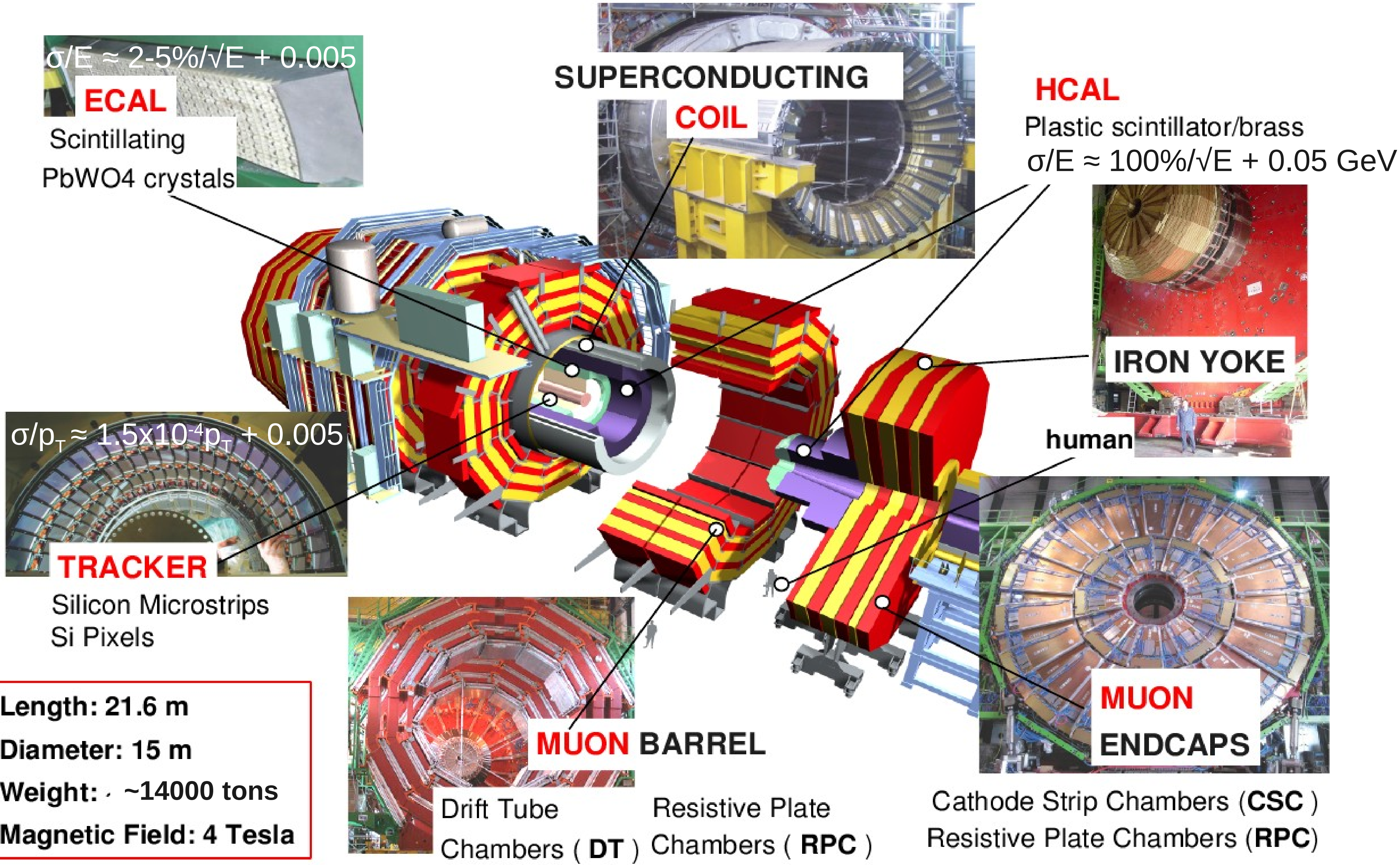


First CMS results shown publicly at CERN – Thursday, 26 November 2009

See presentations by all experiments at
http://indico.cern.ch/conferenceDisplay.py?confId=74907

Prelude: CMS commissioning

Compact Muon Solenoid

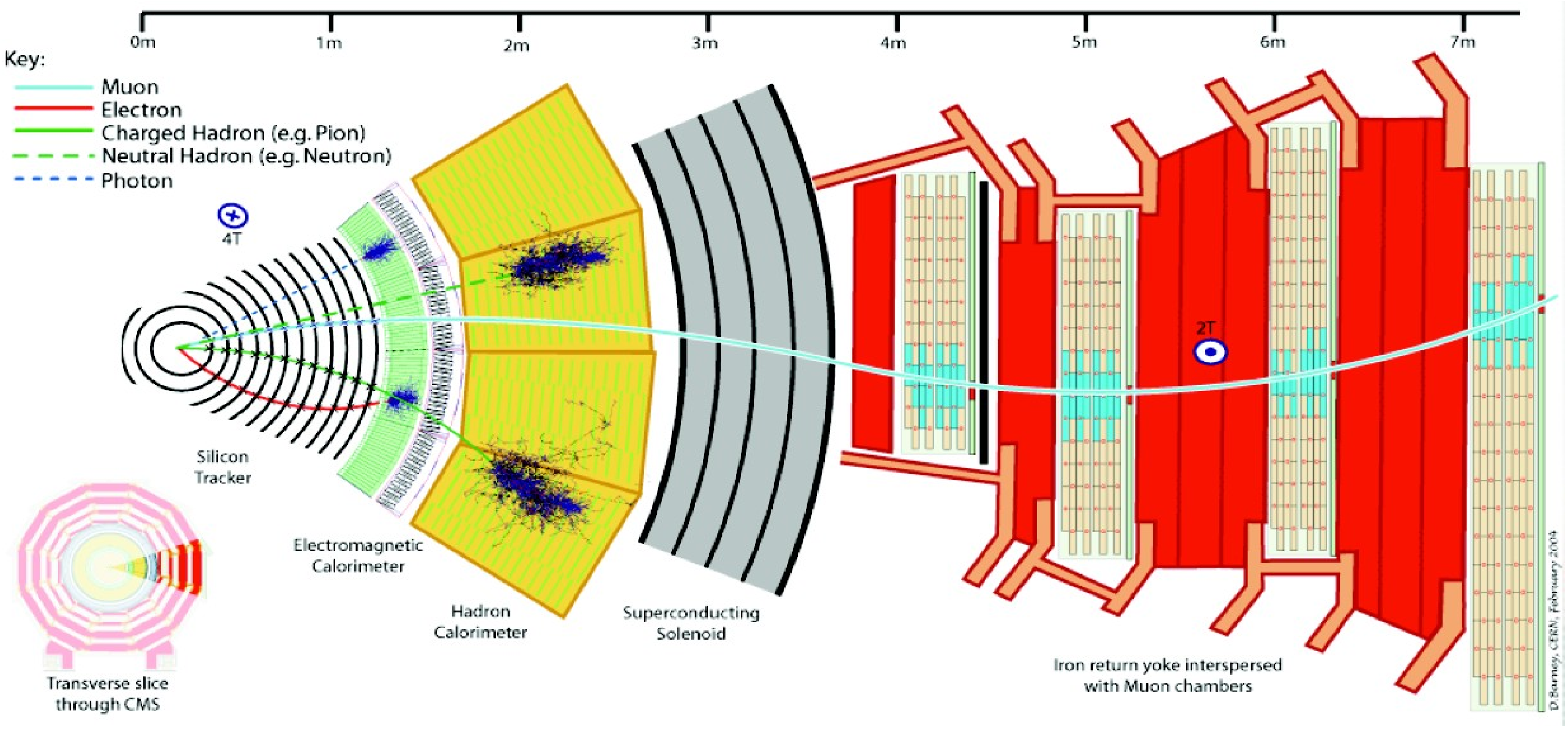


Length: 21.6 m
Diameter: 15 m
Weight: ~14000 tons
Magnetic Field: 4 Tesla

Muon: $\sigma/p_T \approx 1\%$ @ 50GeV to 5% @ 1TeV

Compact Muon Solenoid

Nearly 4π, hermetic redundant, Russian-doll design

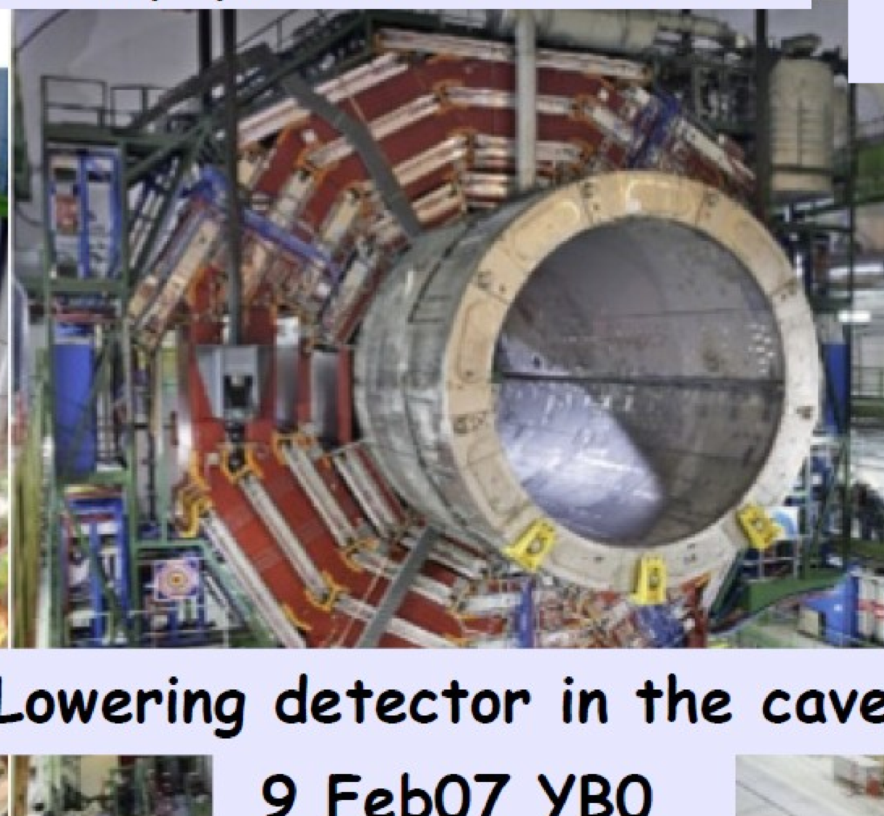


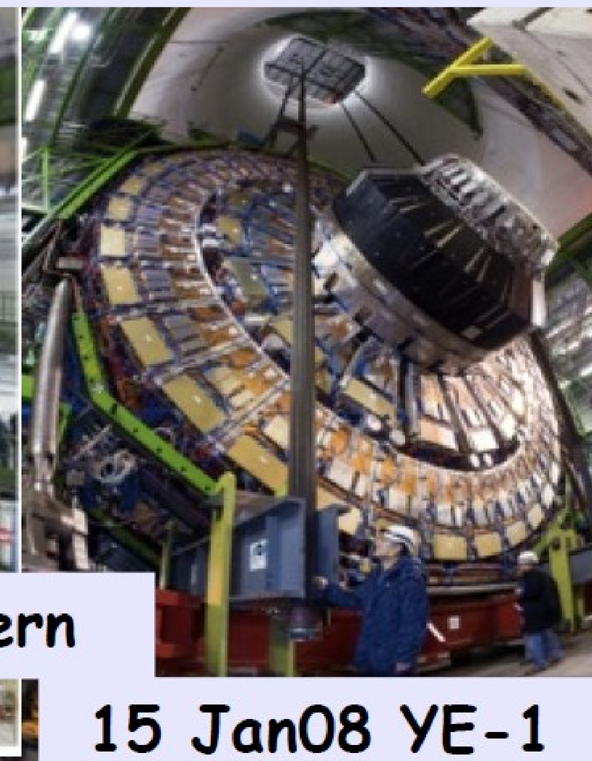
And Missing Transverse Energy (MET) for anything that does not interact

CMS commissioning in pictures

May 2006 - cavern empty, CMS on surface

Insertion of Silicon Strip Tracker Dec 07





Lowering detector in the cavern

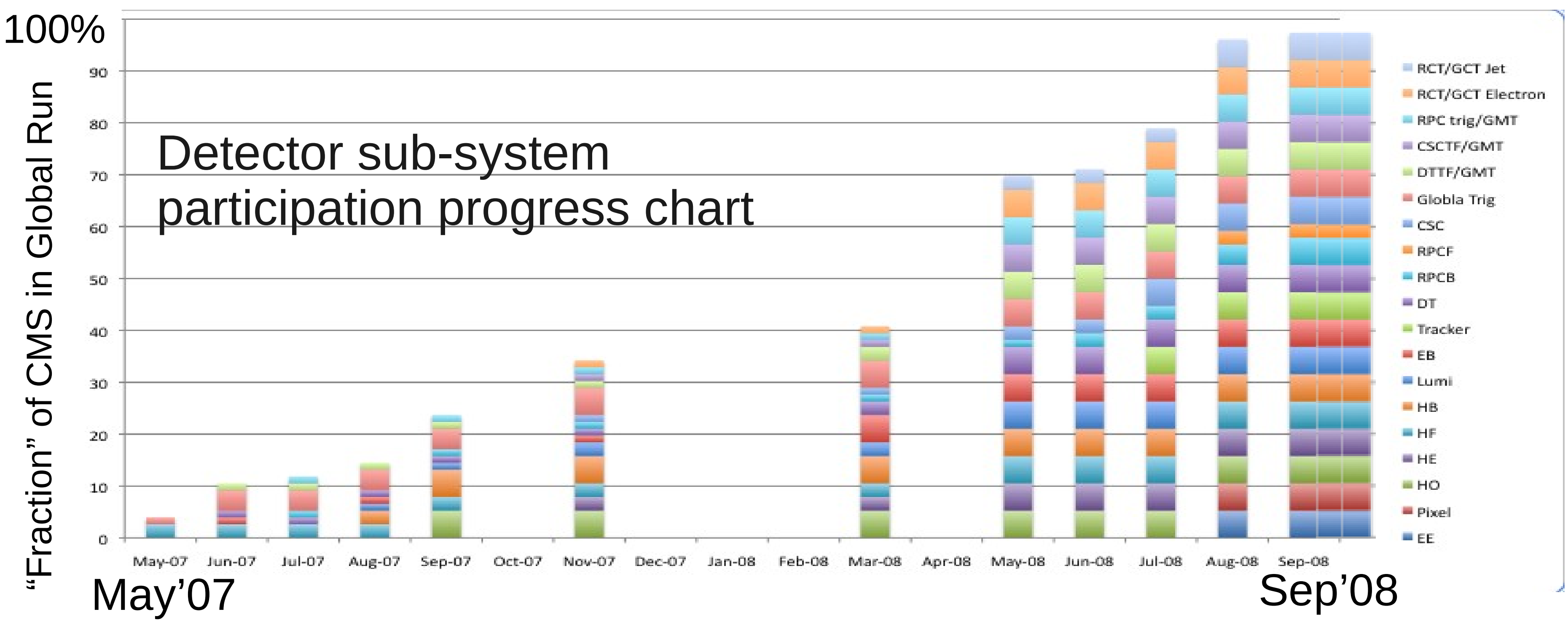
1 Nov06 HF-

9 Feb07 YB0

15 Jan08 YE-1

CMS commissioning underground

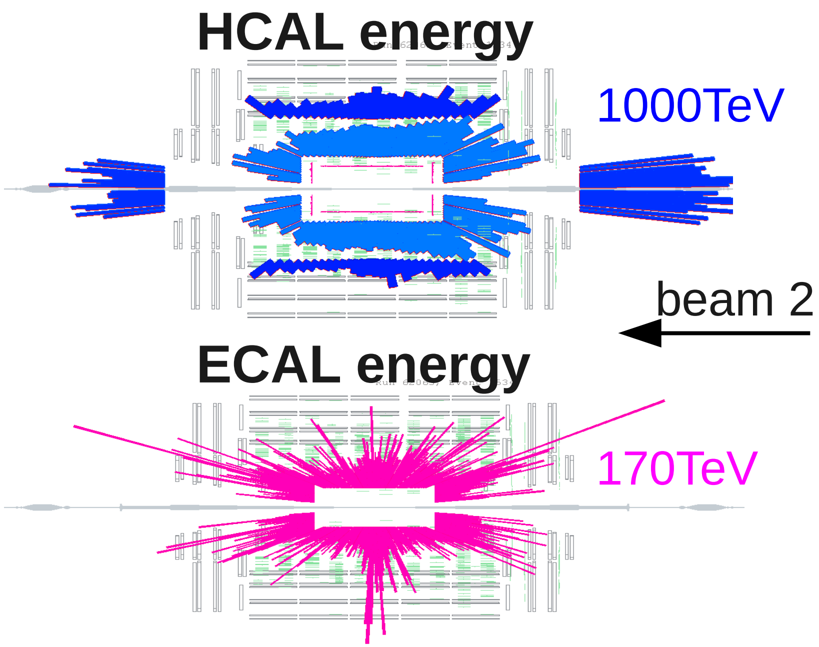
- Started May 2007 – few to 10 day “global runs” / month
  - Integrate the various CMS detector systems into DAQ
  - Test the trigger (L1, HLT) systems (cosmics / random triggers)
  - Exercise data transfer to Tier 0,1,2 , reconstruction, alignment and calibration workflows
  - Study readout synchronization and detector performance

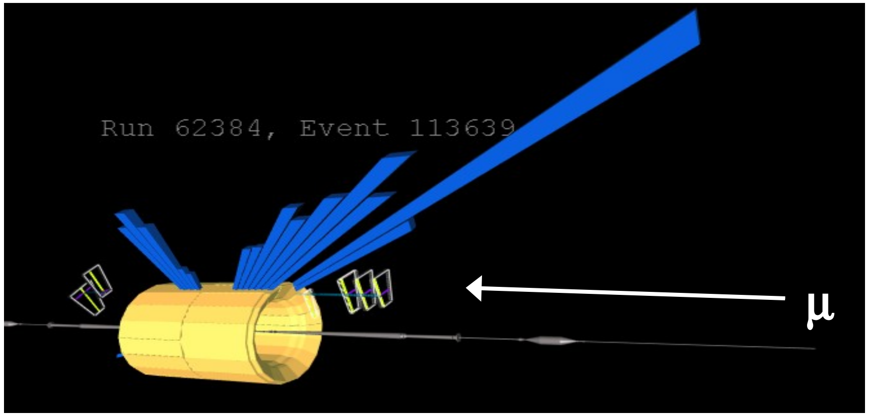


Closure of CMS prior to beam in 2008

First LHC beams in 2008

- Splash events
  - Synchronization tests (4-9 Sep): Beam (450 GeV, 4x10^{9} p) hits collimators 150m upstream of CMS
  - Use to study occupancy, synchronization and bad channels
- Beam halo events
  - Circulating beams (Sep 10-11): Beam protons interacting with beam elements and gas
  - Commission forward detectors
- But program cut short due to the major fault in sector 34 of the LHC





Sept 08 to Oct 09 shutdown

Activities during shutdown

- Continuous preparation while waiting for LHC to get repaired (and beam)
- Cosmics Runs At Four Tesla (aka CRAFT) and without field interleaved with detector improvement
- Major detector accomplishments:
  - Installation and commissioning of the pre-shower ECAL ($1.65<\eta<2.6$)
  - Installation of one CASTOR calorimeter ($5.2<\eta<6.6$)
  - Installation of overpressure protection
  - Removal, repair and re-insertion of forward pixel system
  - Revision of tracker cooling plant
- Preparation for HI data taking

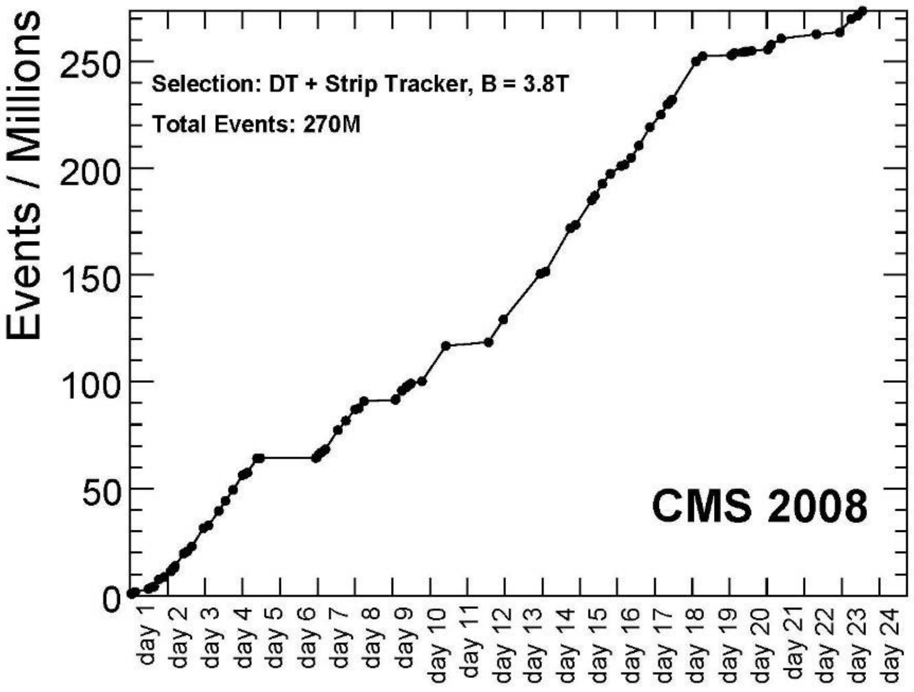
The Cosmic Runs At Four Tesla

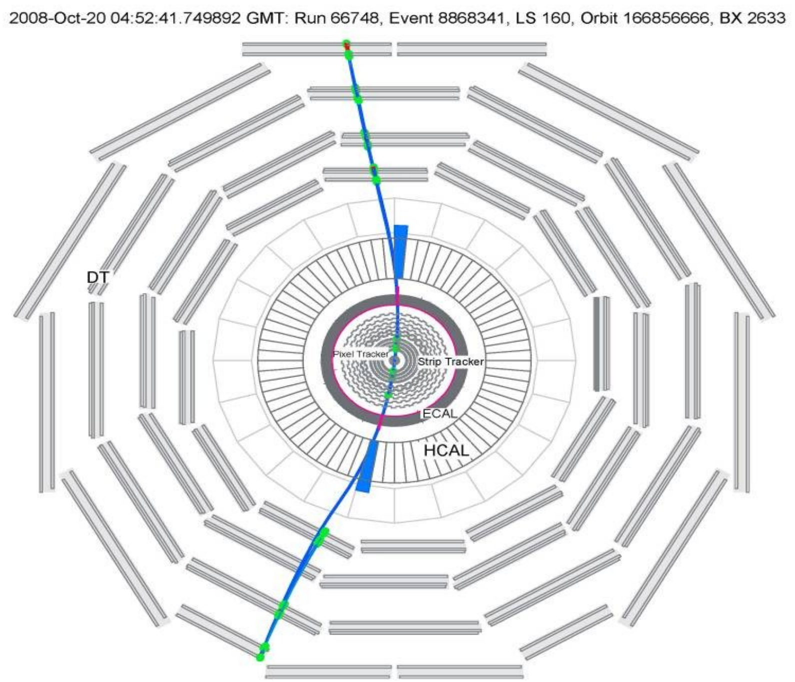
- CRAFT08:
  - 23 days from Oct.13 – Nov.11, 2008
  - 270M cosmic triggers with B=3.8T

Followed by extensive detector work, then:

- CRAFT09:
  - 40 days from July 23 – Sept.1, 2009
  - 320M cosmic triggers with B=3.8T

- Commissioning the experiment with magnet at operating field
- Operate the experiment for an extended period of time (4 weeks)

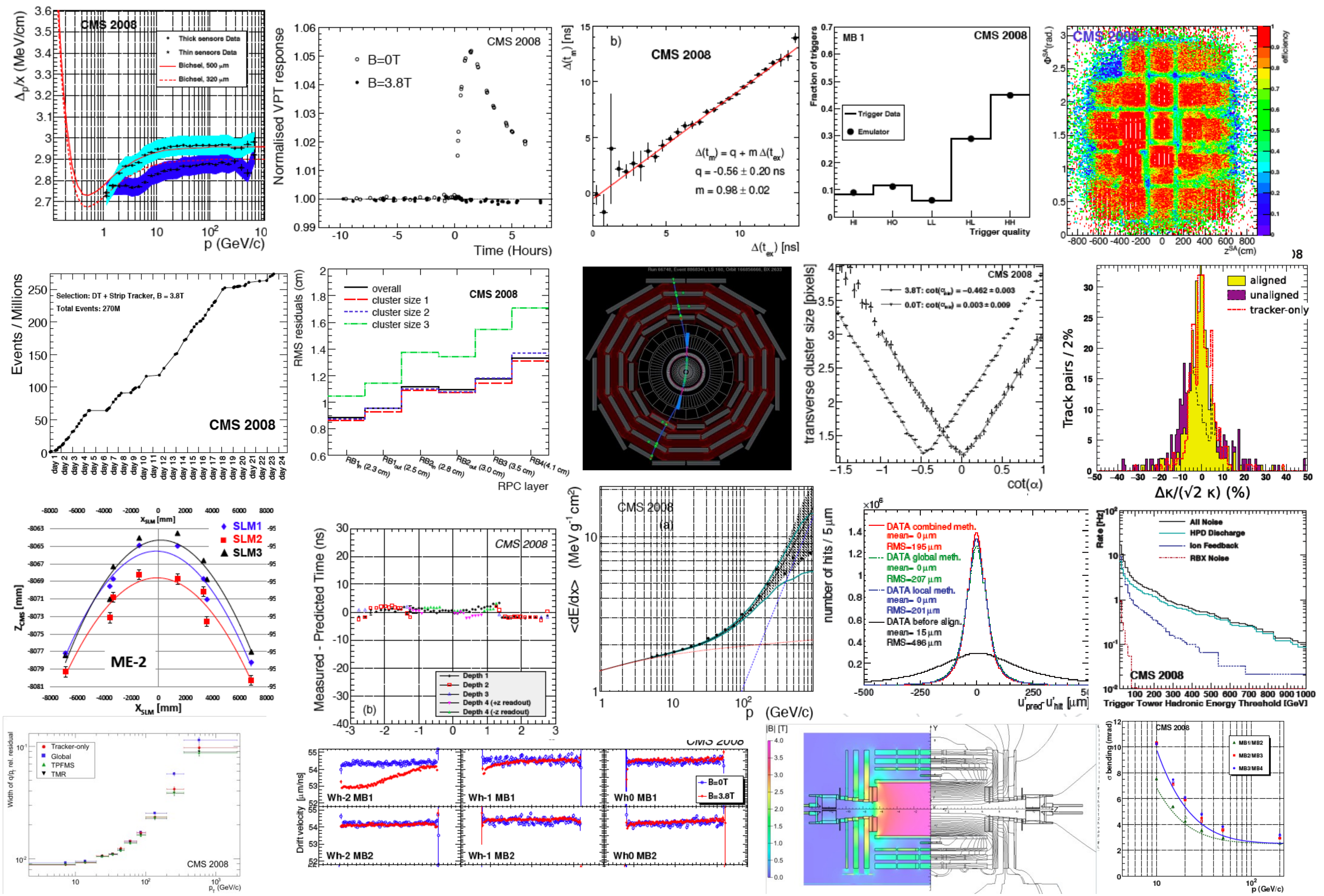




Detector performance publications

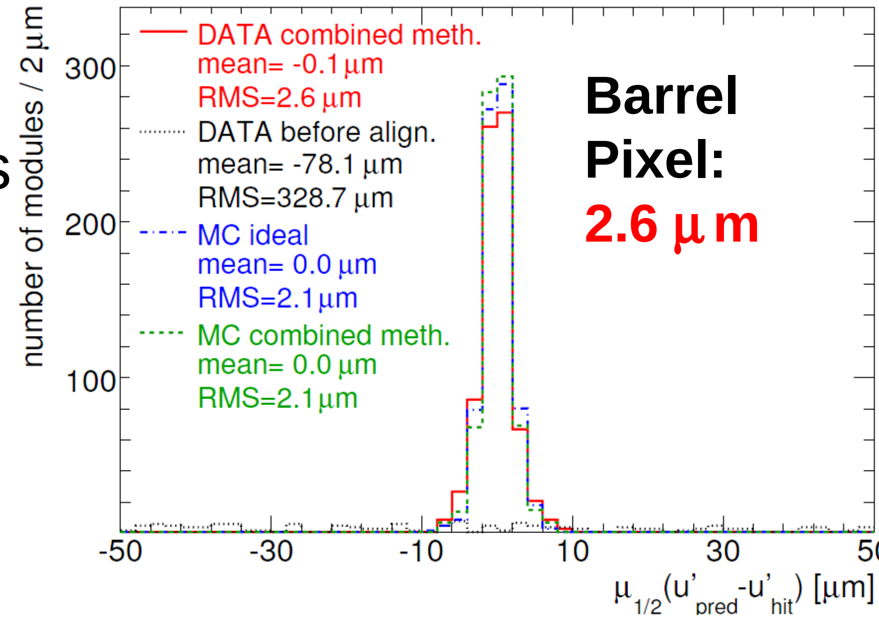
- 23 CMS detector performance papers (500 pages!) submitted to the Journal of Instrumentation based on data from CRAFT08 and 2008 beams
  - Available on arXiv:
    - http://arxiv.org/find/all/1/au:+CMS/0/1/0/all/0/1?skip=0&query_id=9f85c0e5eae277b4
  - To appear in a single volume of JINST
- Coverage:
  - Performance of all major detector systems, including trigger
    - Reconstruction: Tuning and improved robustness
    - Validation of software and computing workflows
  - Precision mapping of magnetic field in the steel return yoke
  - Performance of track and muon reconstruction algorithms
  - Alignment and calibration
- Feed back into realistic simulation

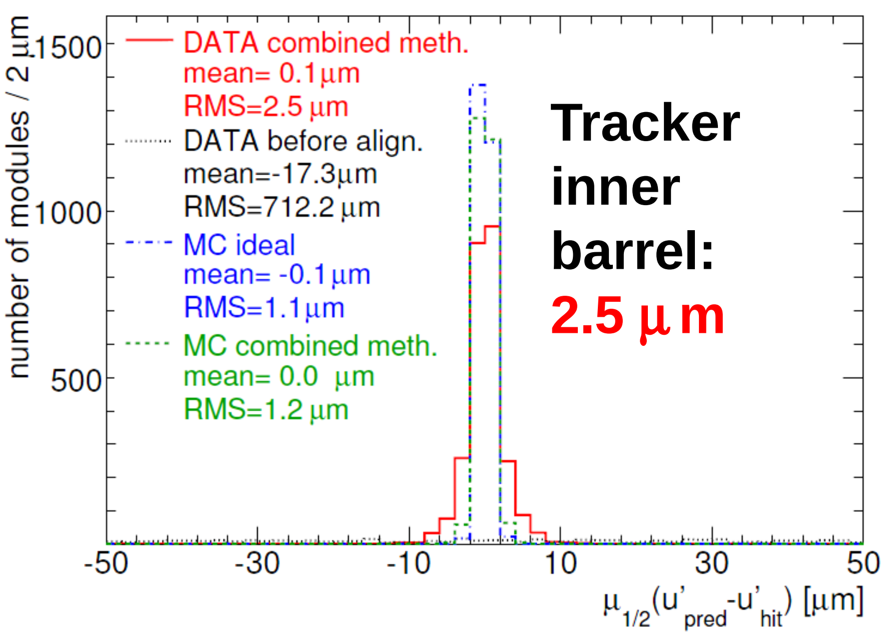
Detector performance publications

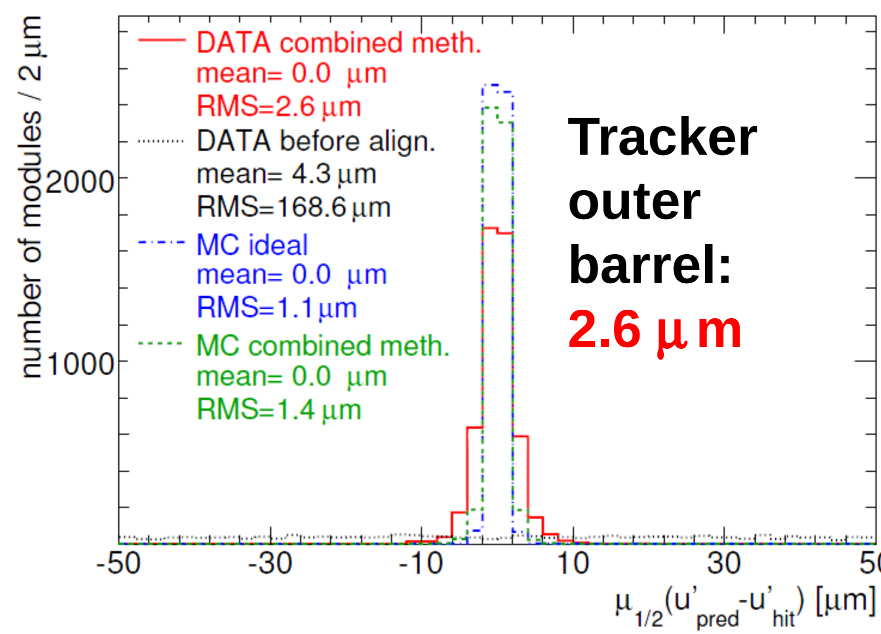


Alignment of tracker systems

- Distributions of the means of the residuals, barrel components
- Much improved from the survey accuracy of O(100μm)
- Close to ideal alignment even before collisions

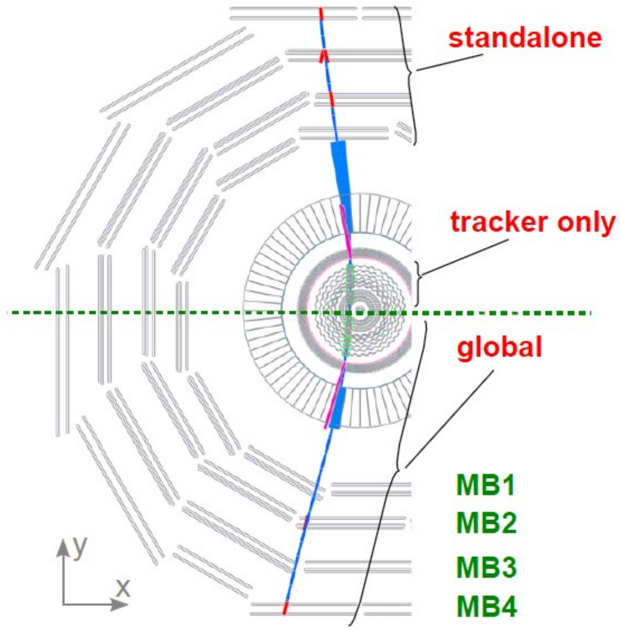


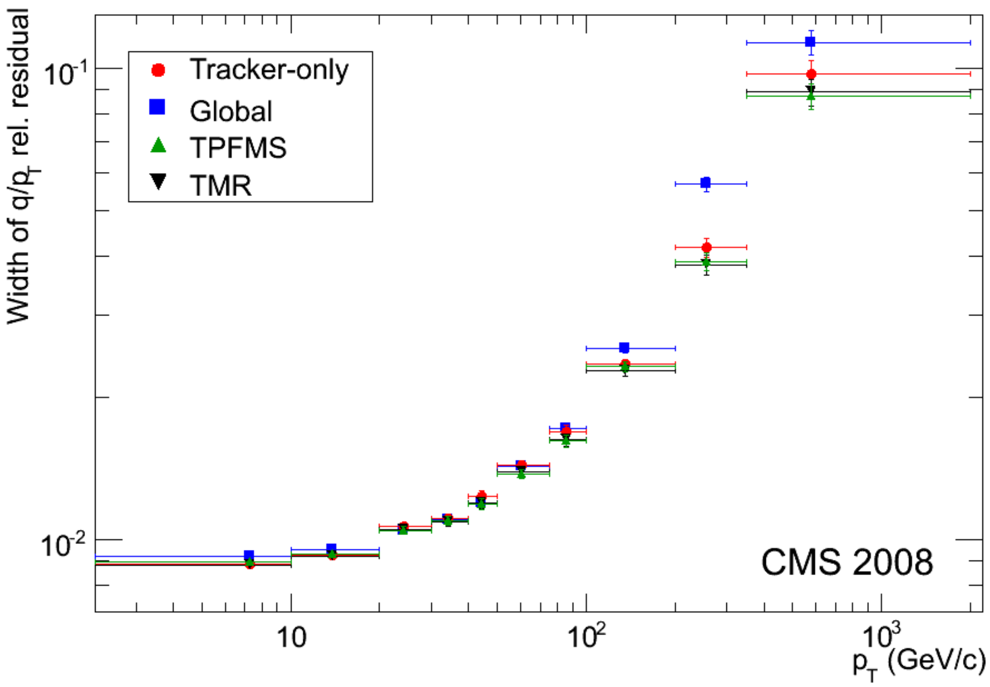




Tracking performance

- Efficiency and resolution measurements
  - Tag a muon in the muon detectors and study the inner tracker (or vice versa)
  - Split a cosmic track into 2 “legs” and compare them
- Silicon tracking efficiency
  - 99.5% for muons passing completely through and detector and close to the beamline
- Muon momentum resolution
  - 1% for p_T=10 GeV, increasing to 8% for p_T~500 GeV (should improve to 5% when detectors are perfectly aligned)





MC studies: What to expect in 2010

- Re-evaluation of the CMS performance for the 2009/10 run assuming 10 TeV and 200-300 pb^{-1}

  http://cms-physics.web.cern.ch/cms-physics/CMS_Physics_Results.htm

- 2010 discovery potential – some highlights:
  - *W* charge asymmetry: constrain PDF (100 pb^{-1})
  - SUSY & opposite-sign 2μ: reach exp. limit (200 pb^{-1})
  - Leptoquarks in e/μ + jet: 300-500 GeV (100 pb^{-1})
  - 4th generation $b' \to tW$: 500 GeV (300 pb^{-1})
  - Majorana neutrinos in 2ℓ+2j: 150 GeV (200 pb^{-1})
  - Large Extra dimensions in 2γ: 2.5 TeV, n=4 (100 pb^{-1})

"The difference between theory and real life is small in theory but large in life"

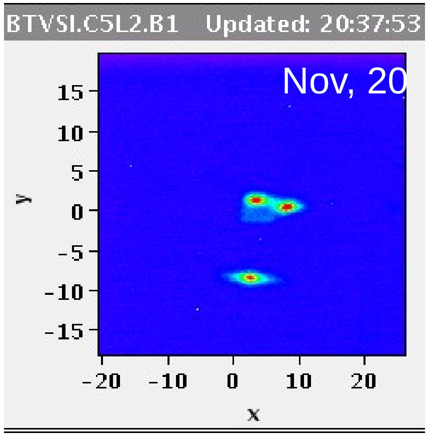
Detector understanding

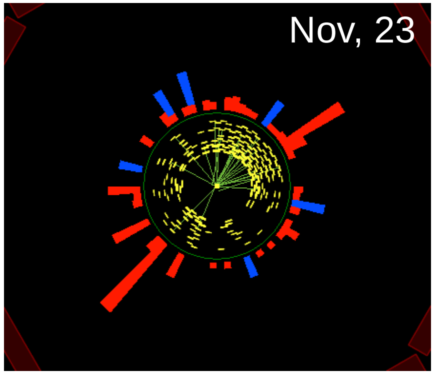
- “Why should we believe that the simulation correctly describes the detector performance?”
  - Good question!
- Tevatron experience: It takes a long time to commission & understand collider experiments
  - Accelerator, detector, trigger, background, underlying event, software: very complicated, interconnected problems
- Claim:
  - CRAFT experience has made a difference
  - First data distributions agree well with simulations

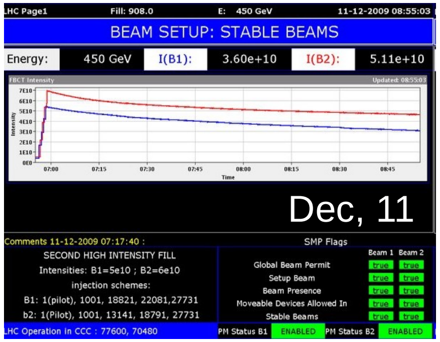
The
November 20 to December 16
revolution

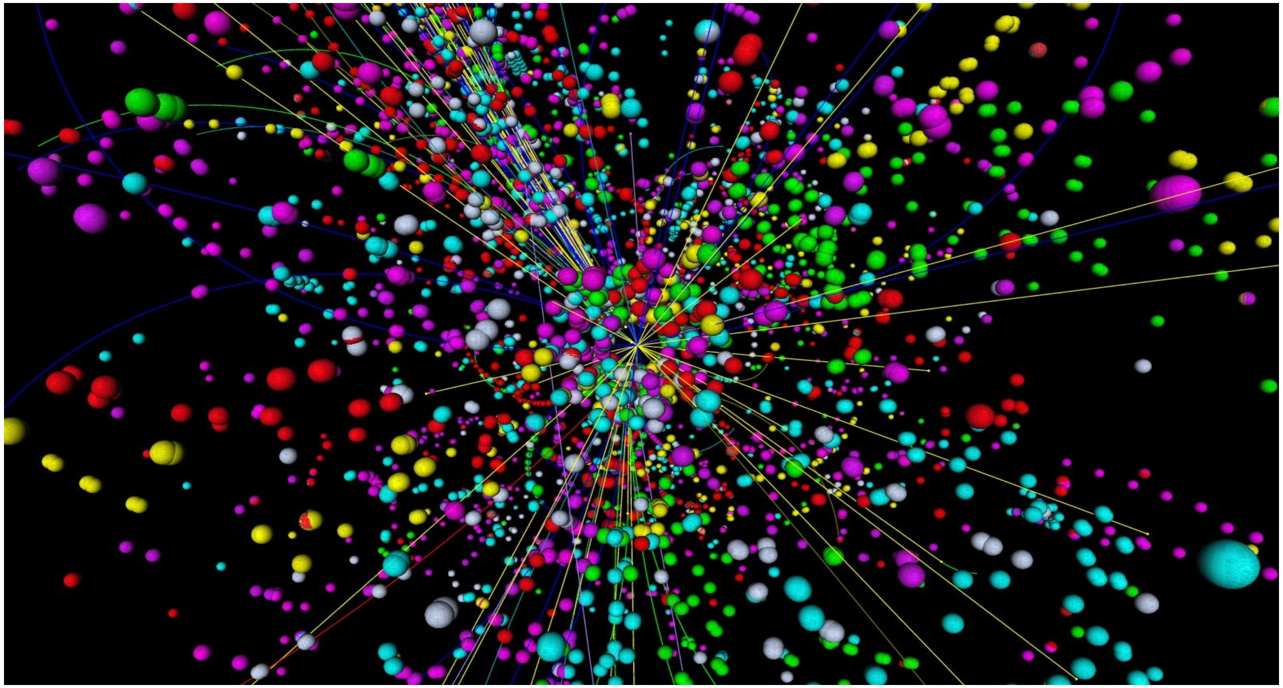
The LHC start-up 2009

- Injection Tests Oct.23-25 & Nov.7-9
- Nov.20, 18:00, Start of 2009 beam circulation
  - First beam 1 circulation by 20:40
  - RF captured beam 1 for several minutes by 21:50, 4 hours after start!
  - Beam 2 captured by 0:10
- Nov.23, First collisions at 900 GeV
  - 13:30, both beams in, evidence for collisions at ATLAS (P1), LHCb, and ALICE
  - 19:00, Second attempt for CMS (P5), tuning, collisions seen! About 30min.
- Dec.6, First physics fills
  - 5:00, collisions, 4 proton bunches/beam, ~4 hours
- Dec.8, Acceleration
  - 21:44: both beams ramped to 1.18 TeV each
- Dec.11, Higher proton intensities (7E10)
  - Starting to accumulate luminosity at 900 GeV
- Dec.14, Collisions at 2.36 TeV
  - 4:00: about 2 hours of highest energy pp collisions
  - 21:00: still higher intensity 900 GeV collisions (16 bunches, 1.8E11)







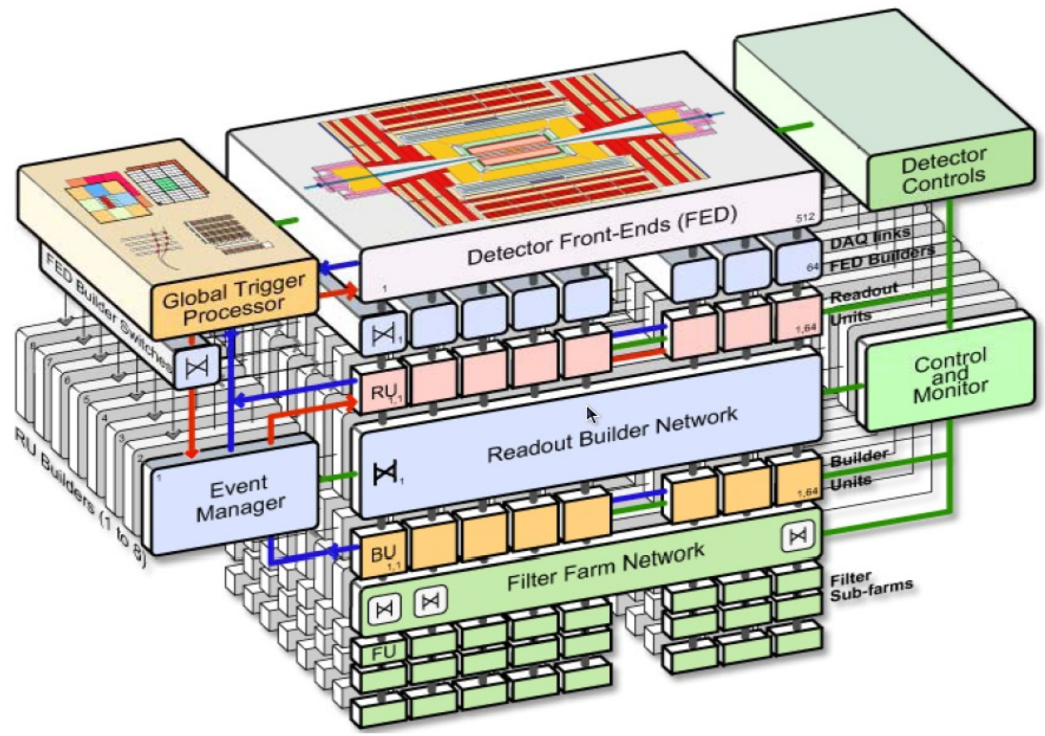


Find events “of this kind” in collisions at up to 40 Mhz

“The trigger does not determine which physics model is right, only which physics model is left”

The CMS trigger system

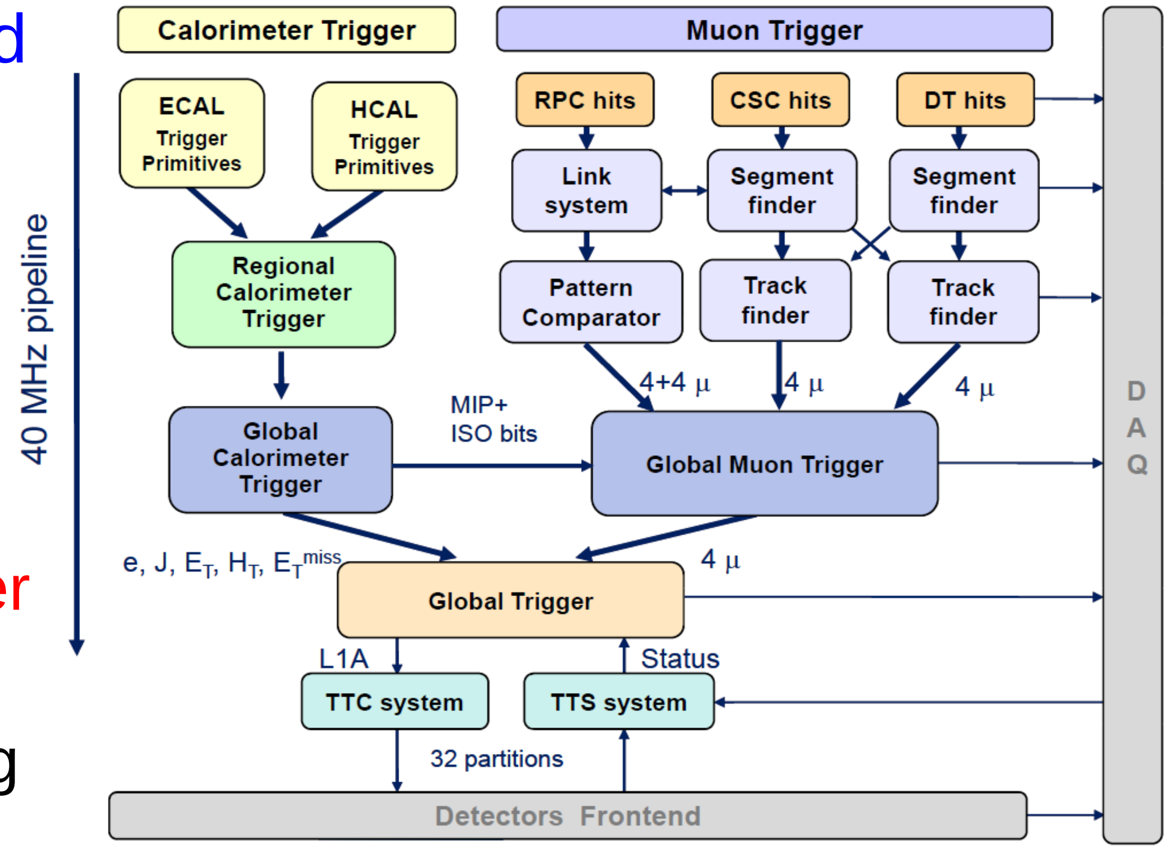
- Level-1:
  hardware trigger
  - Reduce from
    40Mhz to 100Khz
- High-level trigger:
  software trigger
  - Parallel readout
    (up to 16 slices)
  - Has logical steps
    (L2, L3)
  - Reduce to O(100) Hz



BU=Builder Unit
FU=Filter Unit

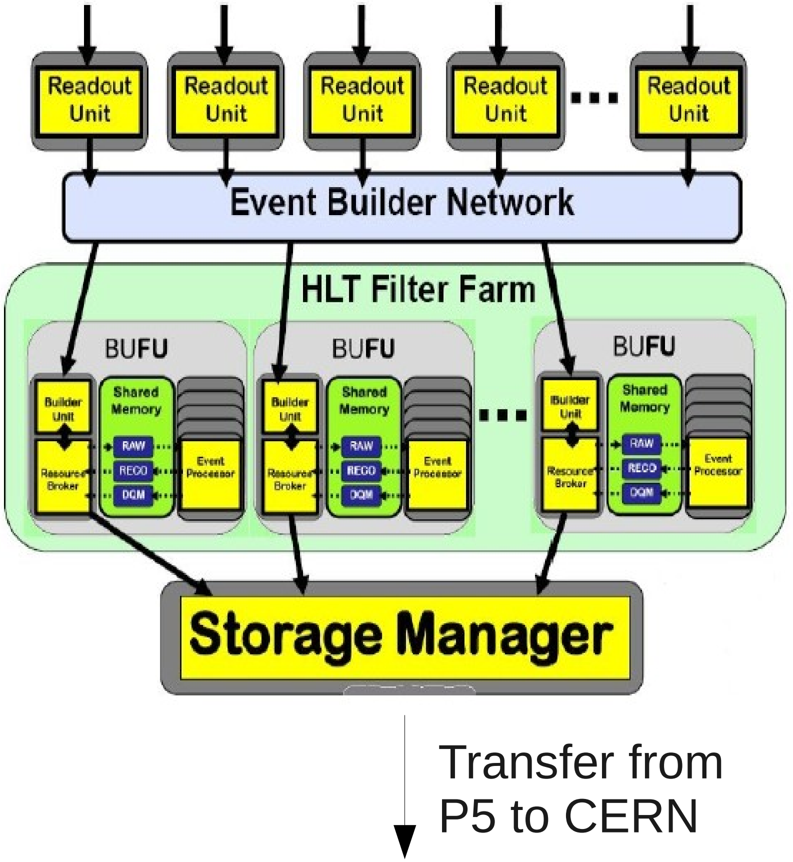
The Level-1 trigger

- Mainly, calorimeter and muon detector based
  - Electron, Muon, jet and MET objects
- Tracker not included
  - No L1 possibility of displaced track trigger
  - Limits enrichment of hadronically decaying heavy-flavors
  - Track trigger upgrade planned
- Additionally, triggers for min.bias physics



The High Level Trigger

- HLT Level-2
  - Unpack muon, ecal, hcal data
  - Based on L1 seeds perform local reconstruction
  - Apply L2 algorithms and filter
- HLT Level-3
  - Unpack tracker locally (mostly pixel)
  - Perform local reconstruction based on L2 results
  - Apply L3 algorithms and filters
- Send accepted events to permanent storage at Tier-0



Tier-0:
Prompt reconstruction
Calibration streams
Archival copy of data
Distribution to Tier-1

The 2009 trigger strategy

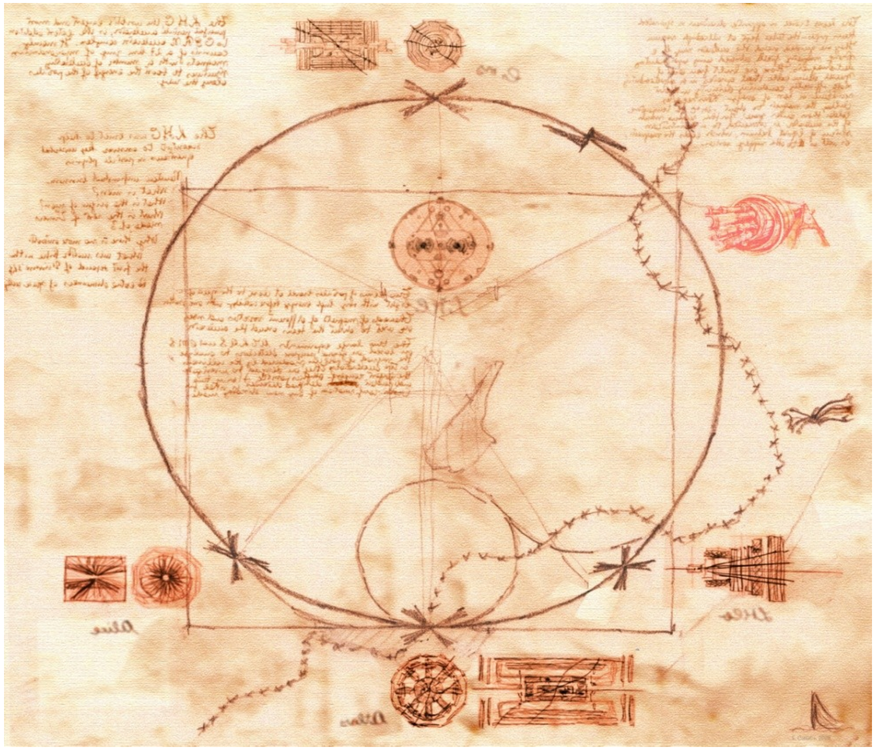
- Adapt to rapidly changing conditions
  - Beam “splashes” and circulating beam
  - Two (unstable) beams with magnetic field off
  - Two (stable) beams with magnetic field (and tracker) on
- Write out as many events as possible
  - Do not unnecessarily reject events
  - Capture as many bunches with protons as possible
    - Rate from 11 to 88 kHz
  - Capture all events with any detector activity
    - Rate up to 600 Hz

The CMS trigger @ 0.9 and 2.36 TeV

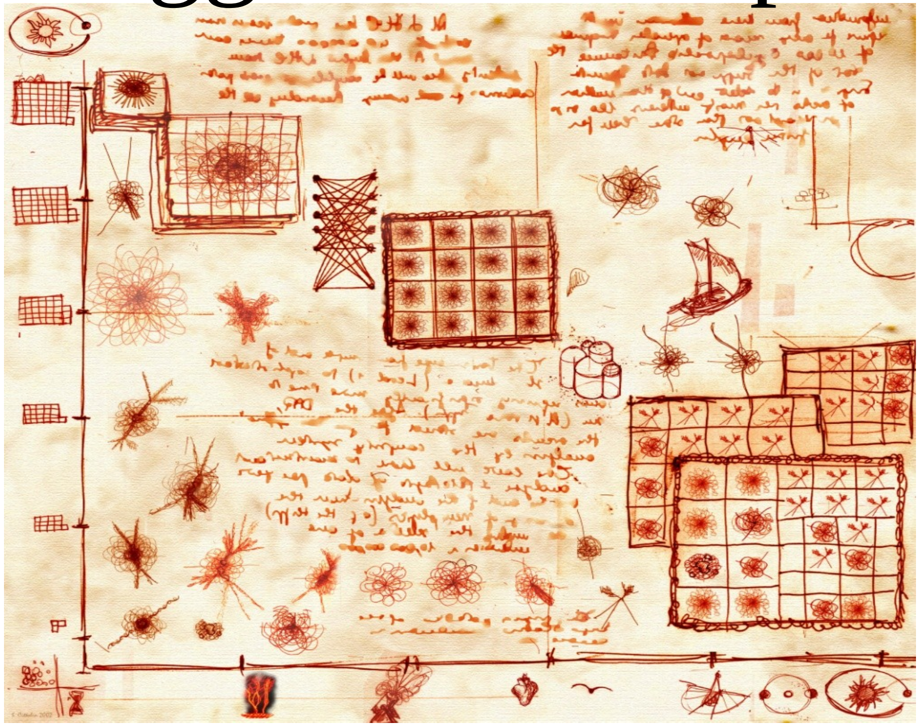
- Trigger Rate for MB: 0.5 – 15 Hz
- Efficiency > 90%

- The early collisions menu
  - Zero-bias (ie. filled bunch coincidence), beam-gas (unpaired filled bunch): PRESCALED
  - Suite of minimum bias triggers: UNPRESCALED
    - Based on beam scintillators, HCAL, ECAL, pixels
  - "L1 activity"
    - Accept any event for which L1 has fired within ±2 bunch crossings of filled bunch coincidence signal
  - "HLT activity"
    - Accept any event for where HLT finds detector activity > noise
    - Catch events which L1 may have missed (synchronization or other rare problem)
  - Disable HLT with a L3 (ie. tracking component)
    - Not really exercised with CRAFT data

LHC has delivered

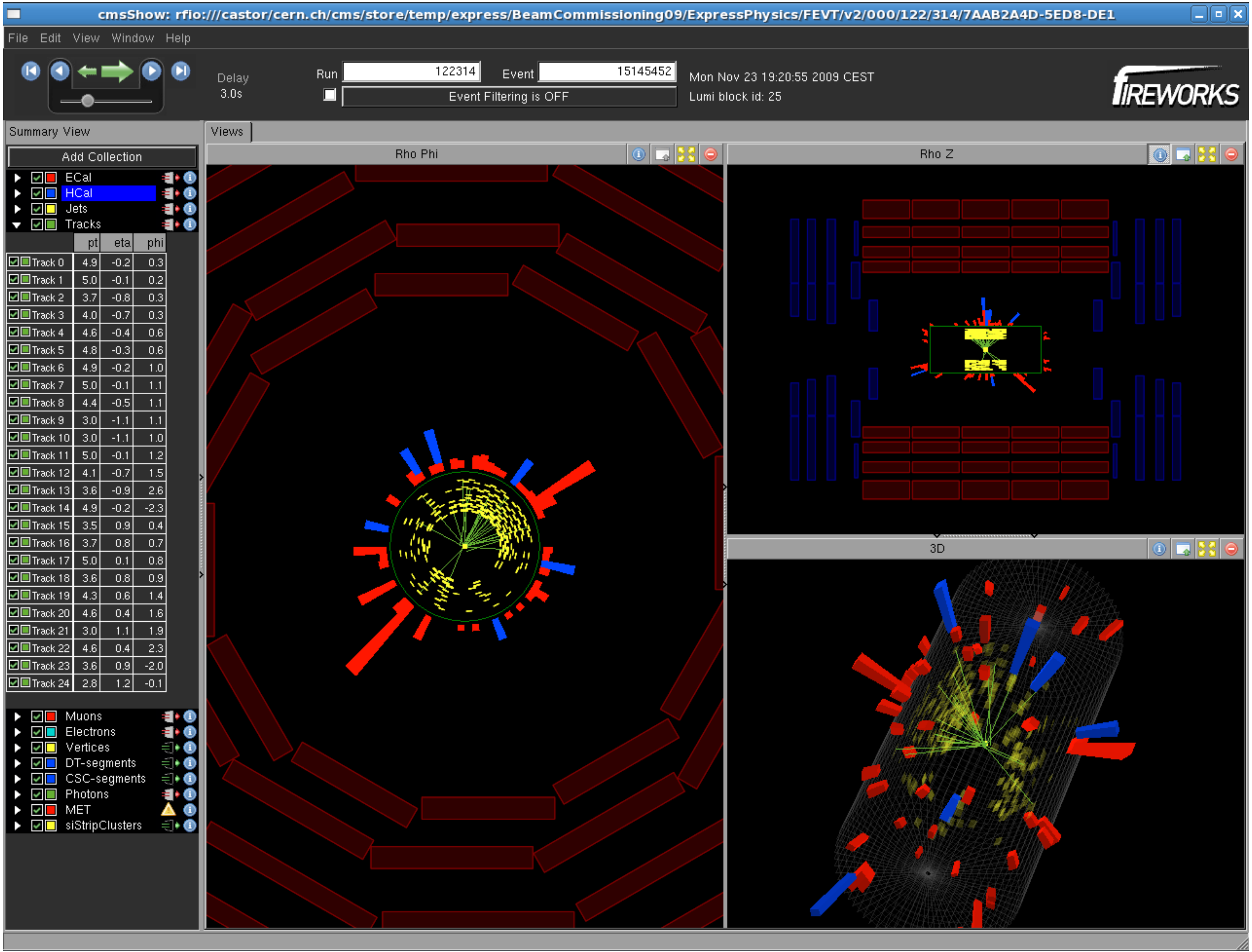


Trigger has accepted

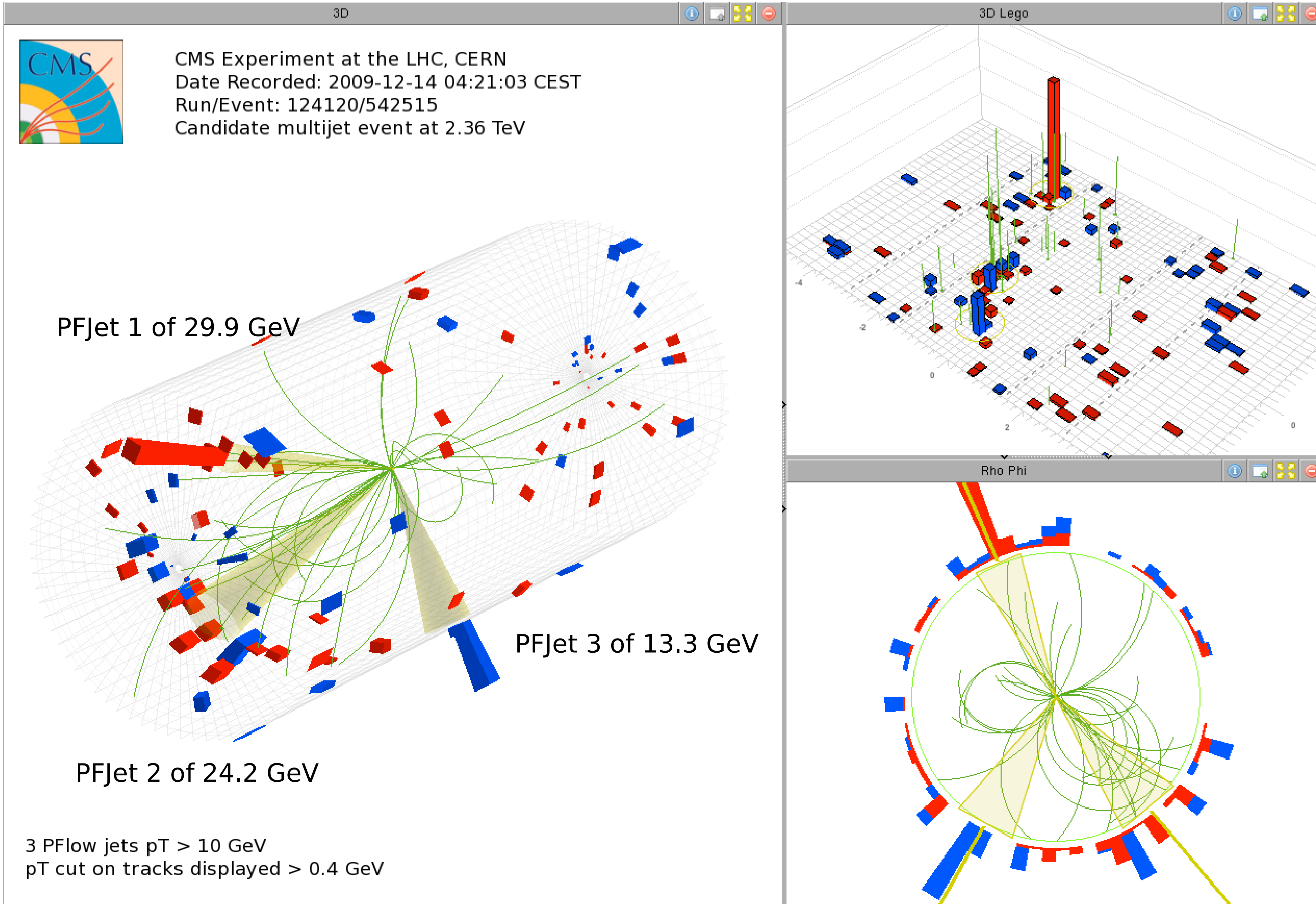


- CMS will analyze
  - 900 GeV (~350K min.bias events or ~10μb^{-1})
  - 2.36 TeV (20K min.bias events or < 1μb^{-1})

First collisions – 23 Nov 2009



Multi-Jet event at 2.36 TeV



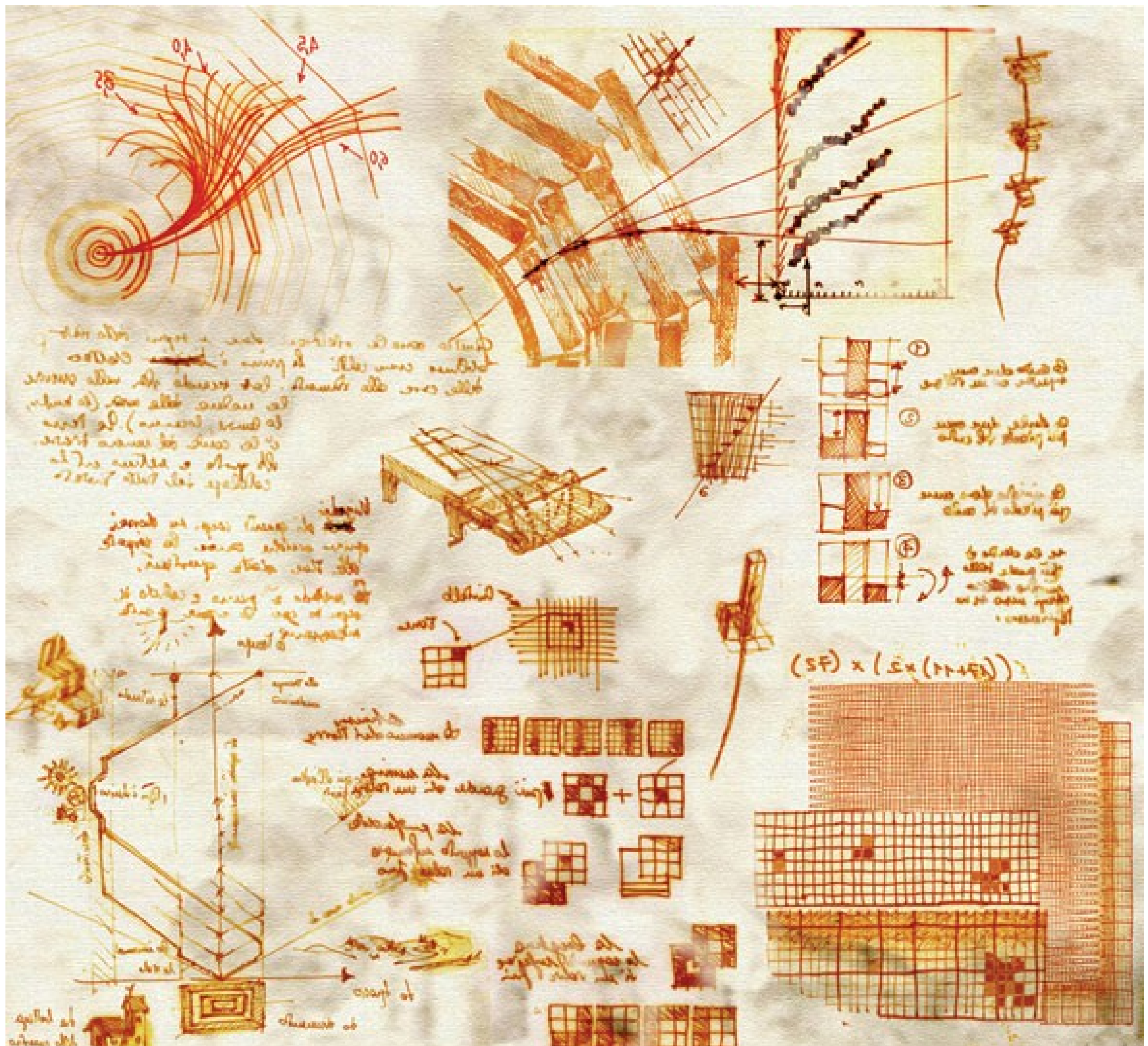
Detector performance

Calorimetry

Jets(*)

Tracking

Particle-Id



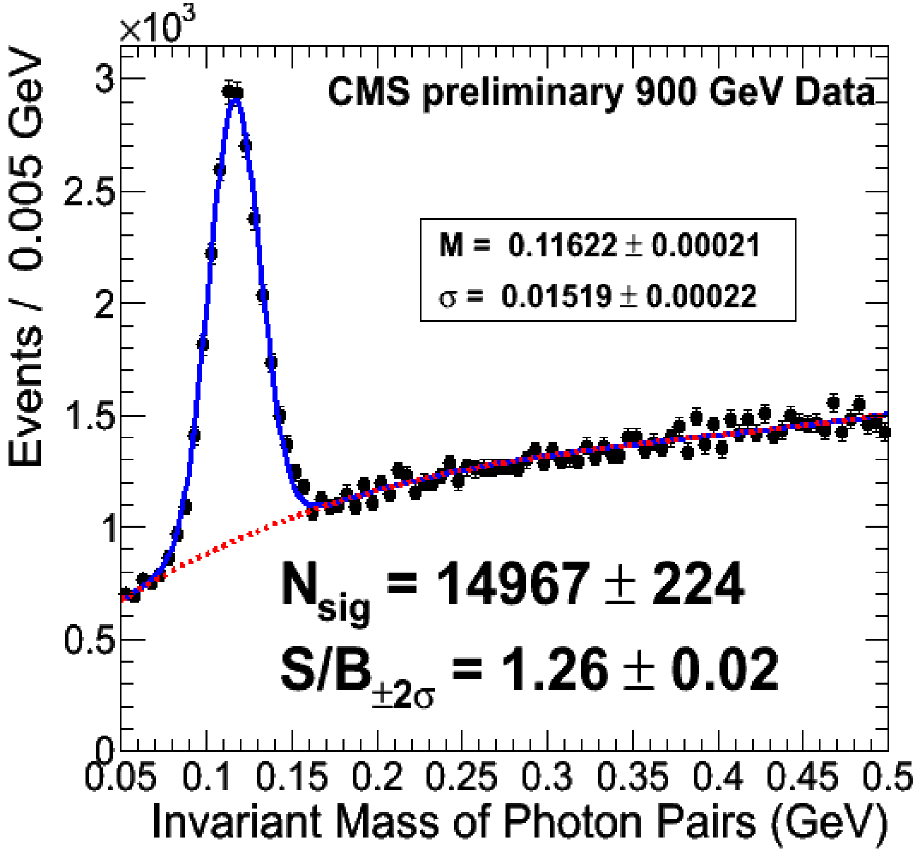
Muons(*)

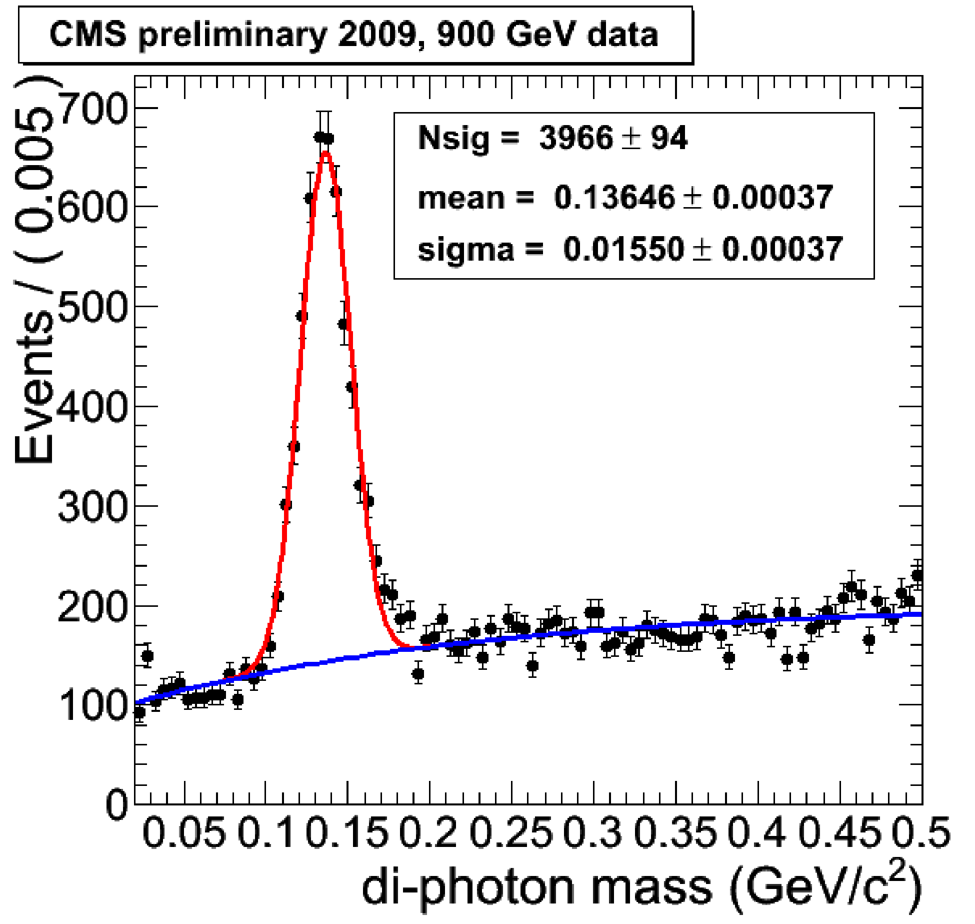
Particle flow(*)

Electrons(*)

*) See http://indico.cern.ch/conferenceDisplay.py?confId=76398

Calorimetry: $\pi^0 \rightarrow \gamma\gamma$

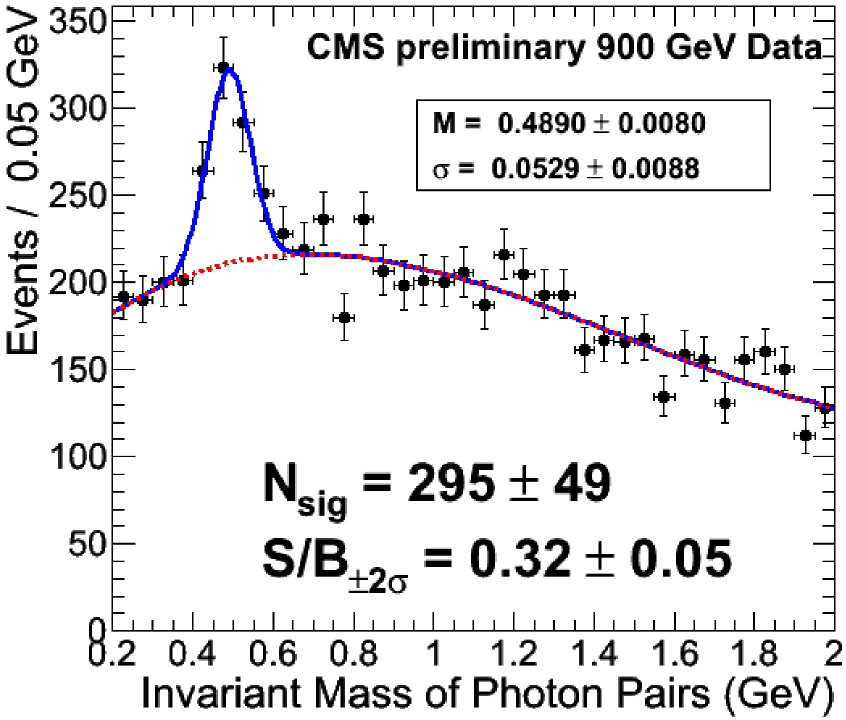




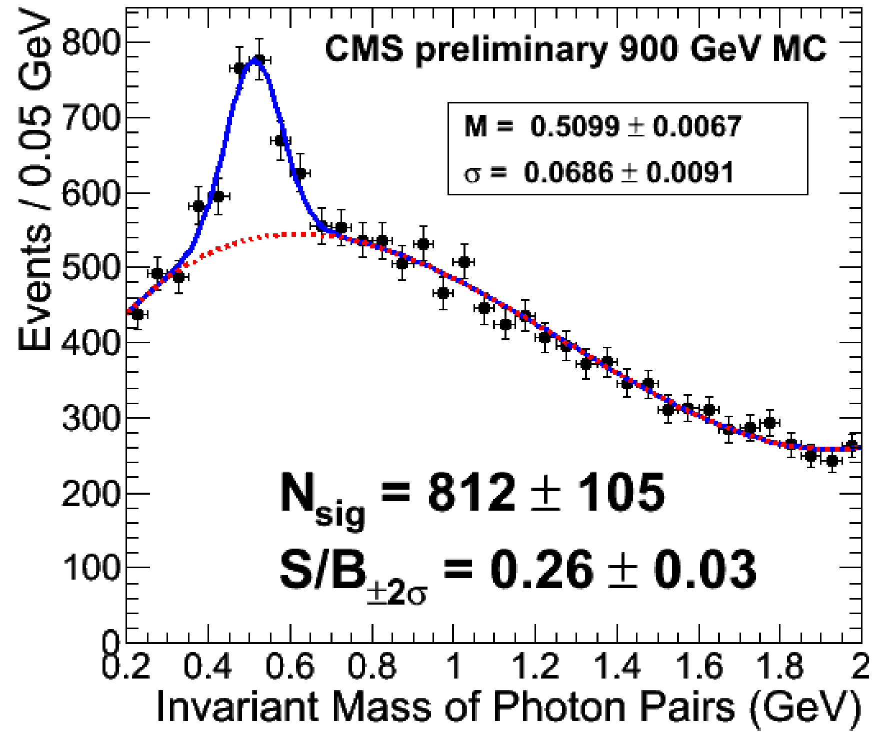
- Data and MC (uncorrected)
- Identical S/B, mass and width similar
- Mass is low in both mostly due to the readout threshold (100 MeV/crystal) and conversions

Using out-of-the-box MC corrections

Data

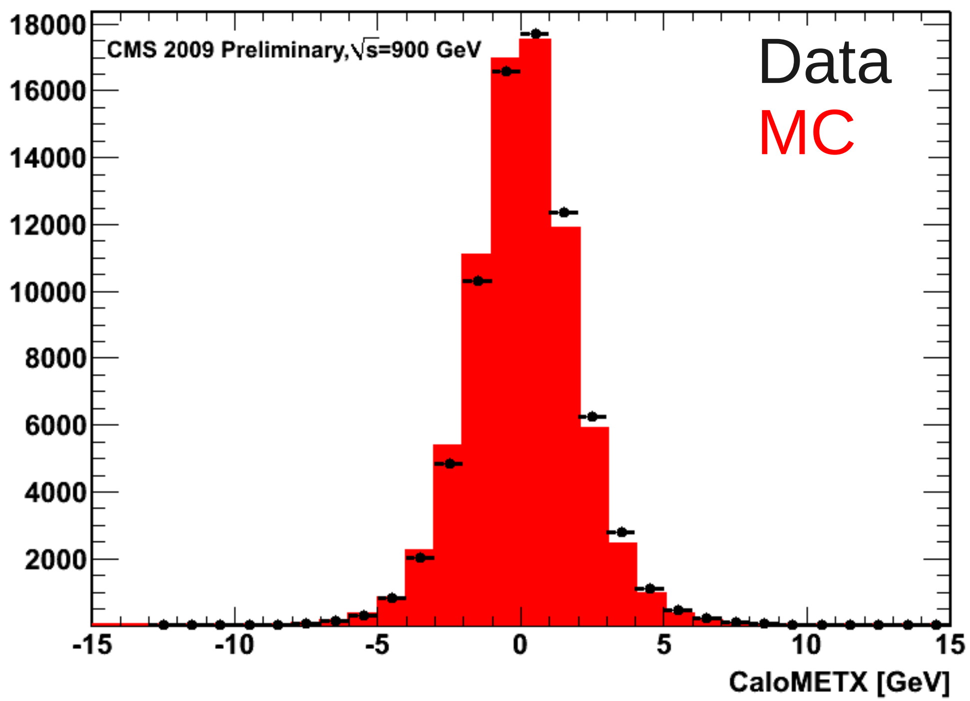


Simulation

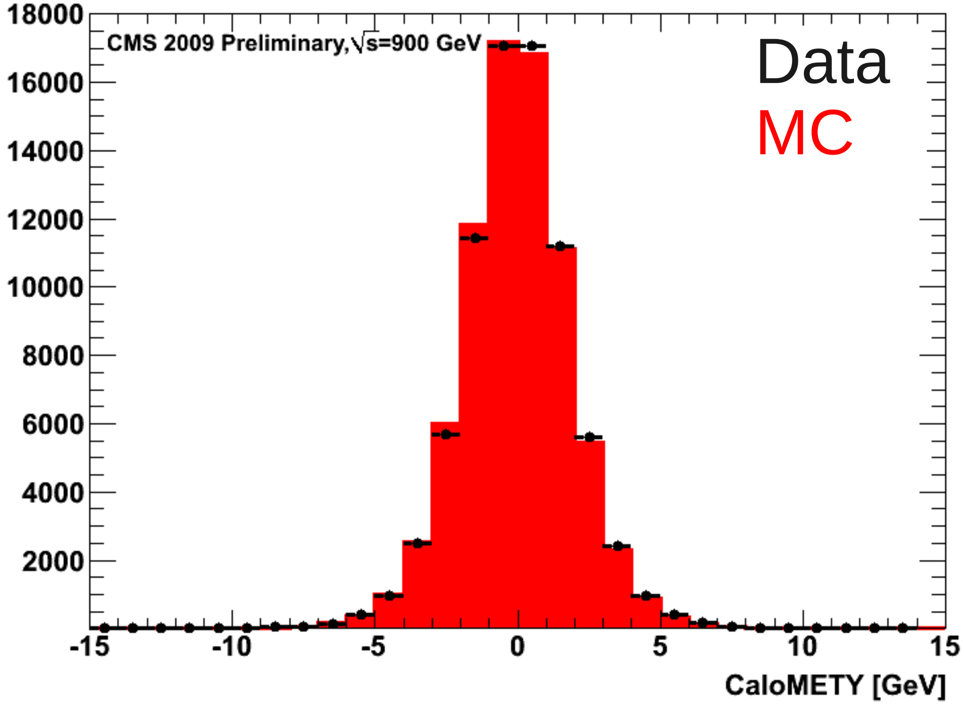


- Mass and width compatible with MC
- η yield scale as expected (π^0 candle)
  - $N(\eta) / N(\pi^0) = 0.020 \pm 0.003$ DATA (left)
  - $N(\eta) / N(\pi^0) = 0.021 \pm 0.003$ MC (right)

Calorimetry: Missing E_T

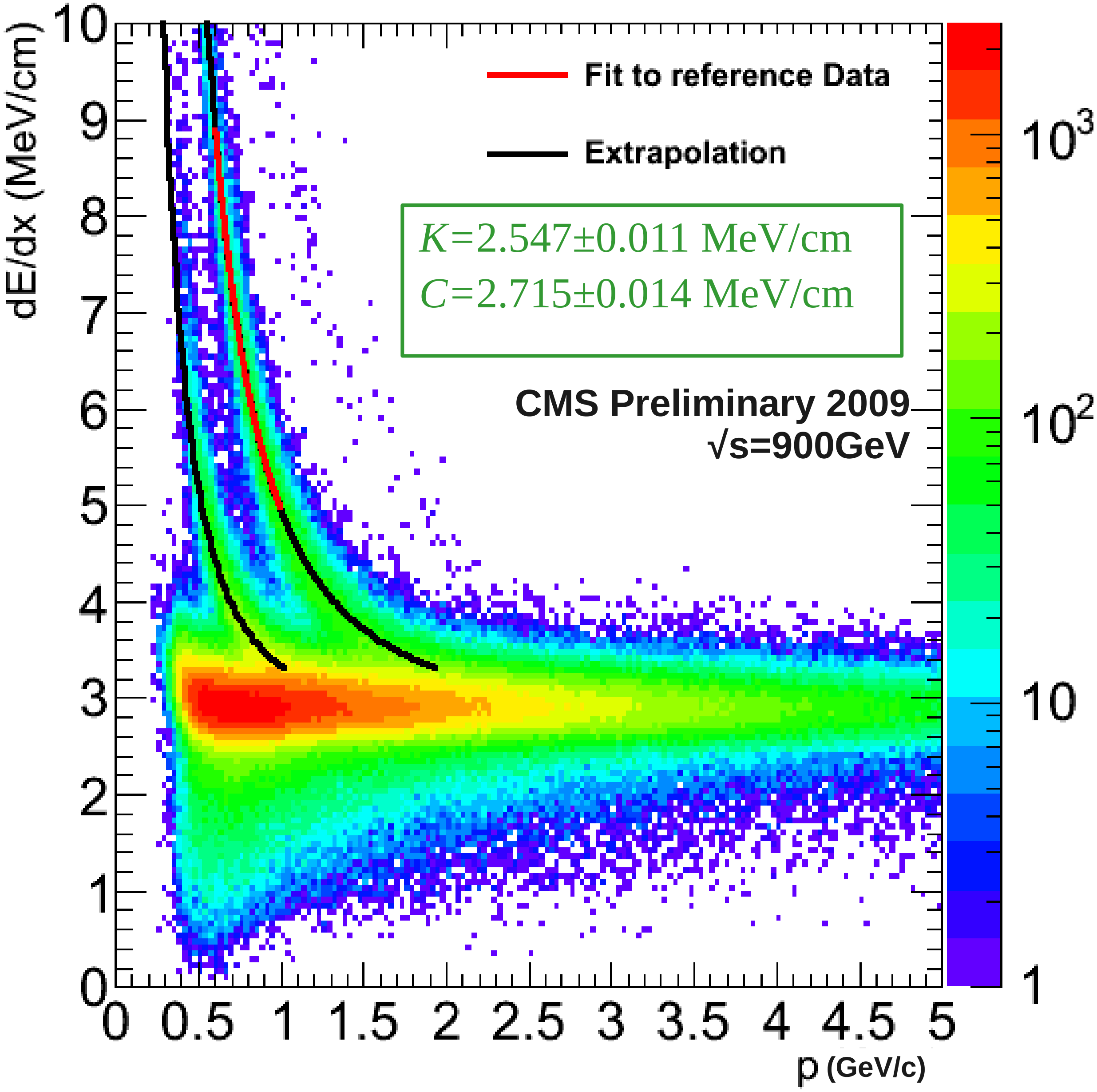


METx (GeV)



METy (GeV)

Tracking: dE/dx as particle ID

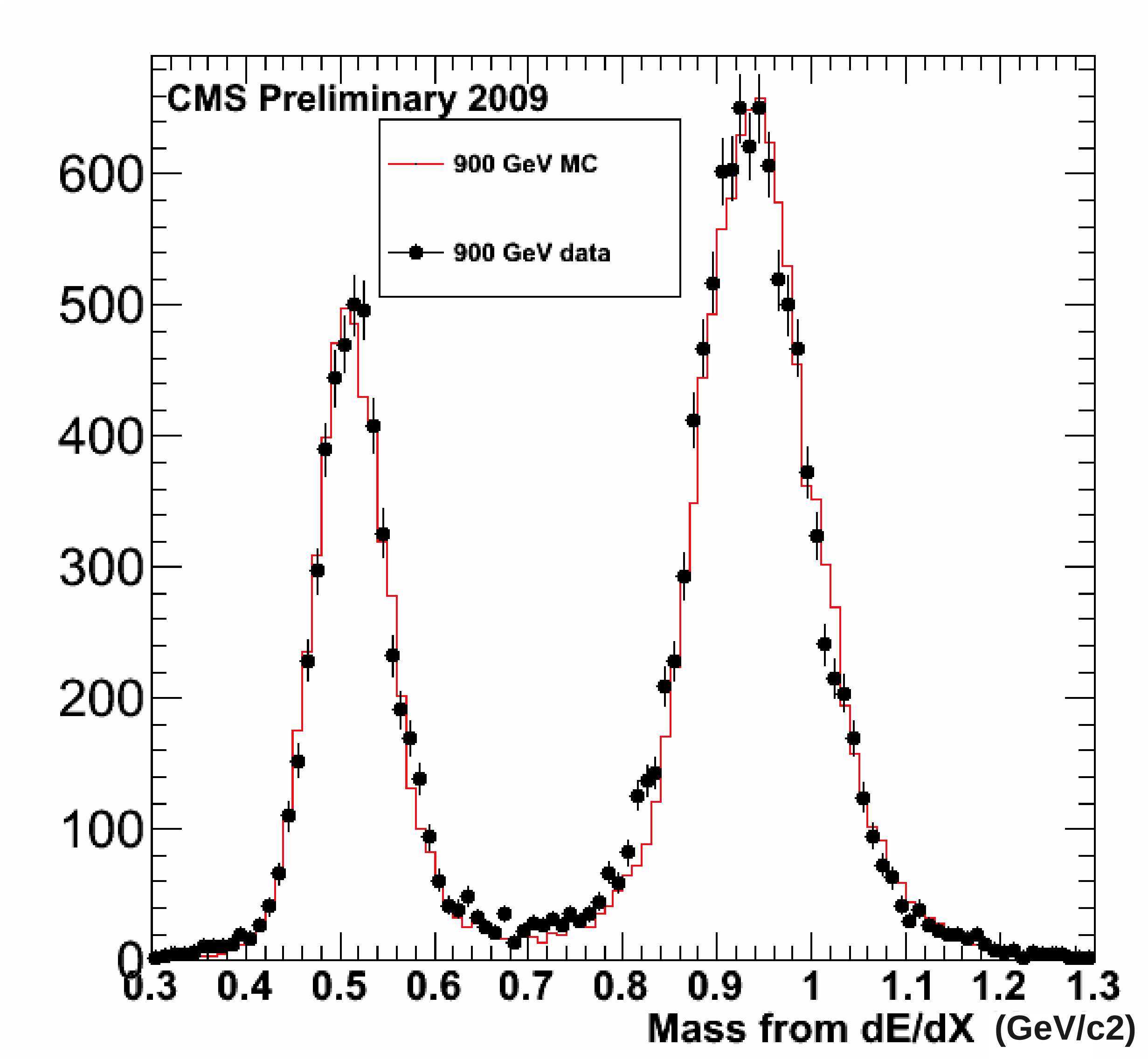


- dE/dx distribution can be fitted for various particles

$$\frac{dE}{dx} = K \frac{M^2}{p^2} + C$$

- Use reference data for protons (red line)
- Extrapolate behaviour for kaons and protons at higher momentum (black lines)
- Calculating mass by using dE/dx and p, and inverting formula

Tracking: dE/dx as particle ID



Mass distribution of particles with dE/dx>4.15 MeV/cm

Tracks with
- P < 2 GeV/c
- # Silicon Strip hits > 10
- |d0| < 2 cm, dz < 15 cm

Protons and kaons nicely separated

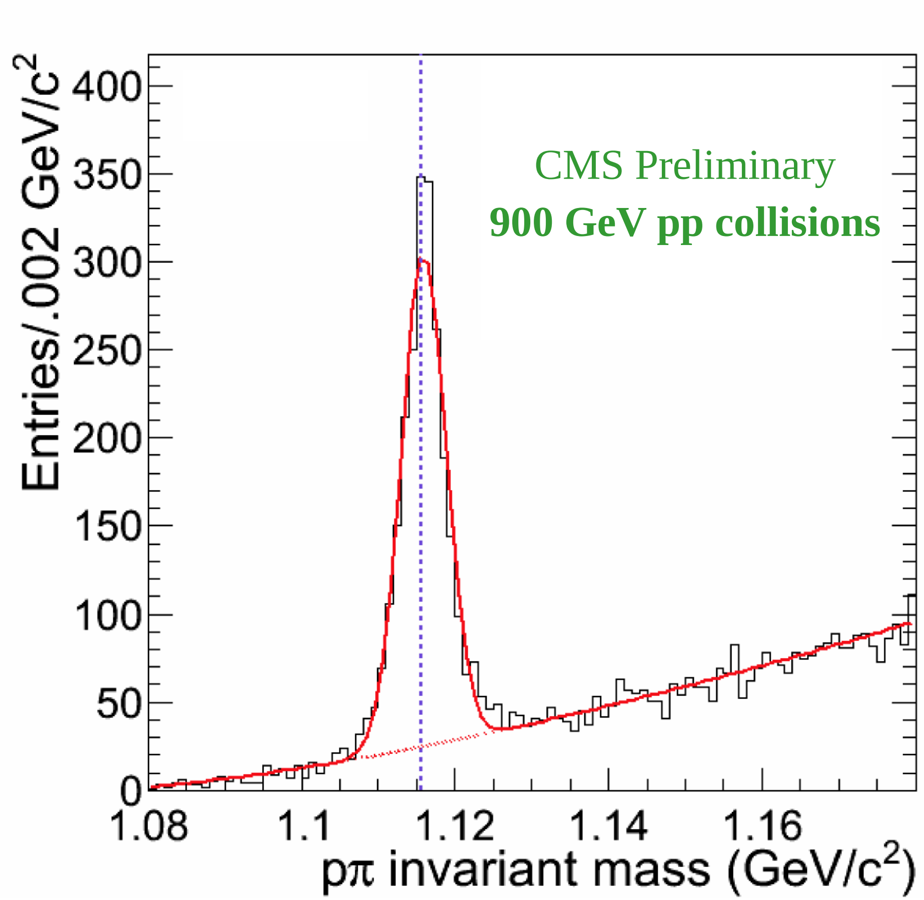
Tracking: Resonances

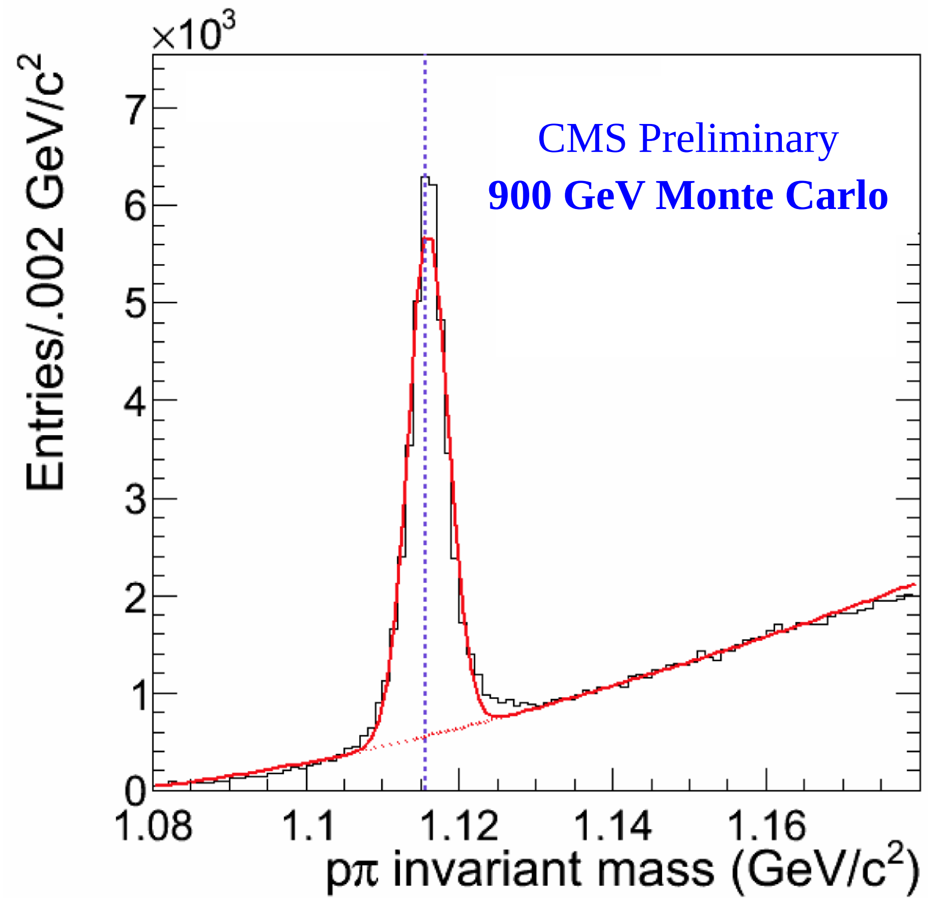
CMS Preliminary
900 GeV pp collisions
M = (1115.9 ± 0.1) MeV/*c*2
σ = (2.93 ± 0.08) MeV/*c*2

Λ

Uses dE/dx information
to reduce background

CMS Preliminary
900 GeV Monte Carlo
M = 1116 MeV/*c*2
σ = 2.6 MeV/*c*2





Single Gaussian Fits (From a sample of ~240k minimum bias events)

Tracking: Resonances

$\phi \rightarrow K^+K^-$

CMS Preliminary: **900 GeV pp collisions**

1318 ± 95 ϕ candidates

M = (1.01937 ± 0.00030) GeV/*c*2

σ = (1.69 ± 0.50) MeV/*c*2

Γ: fixed at PDG2009 value (4.260 MeV/*c*2)

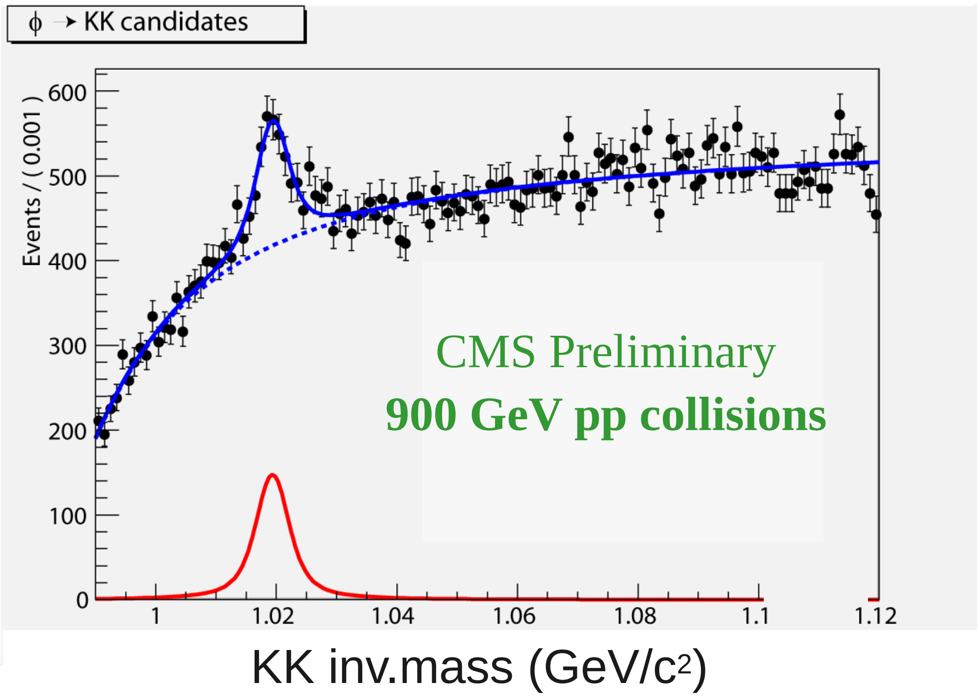
CMS Preliminary: **900 GeV Monte Carlo**

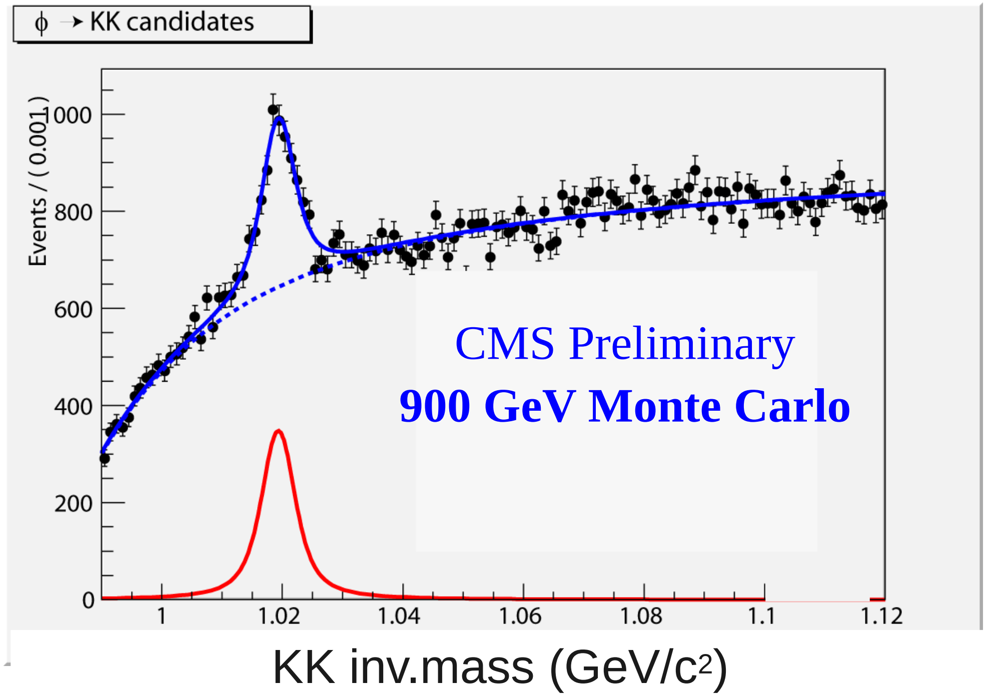
M = (1.01935± 0.00016) GeV/*c*2

σ = (1.64 ± 0.23) MeV/*c*2

Γ: fixed at PDG2001 value (4.458 MeV/*c*2)

[used to generate Monte Carlo sample]

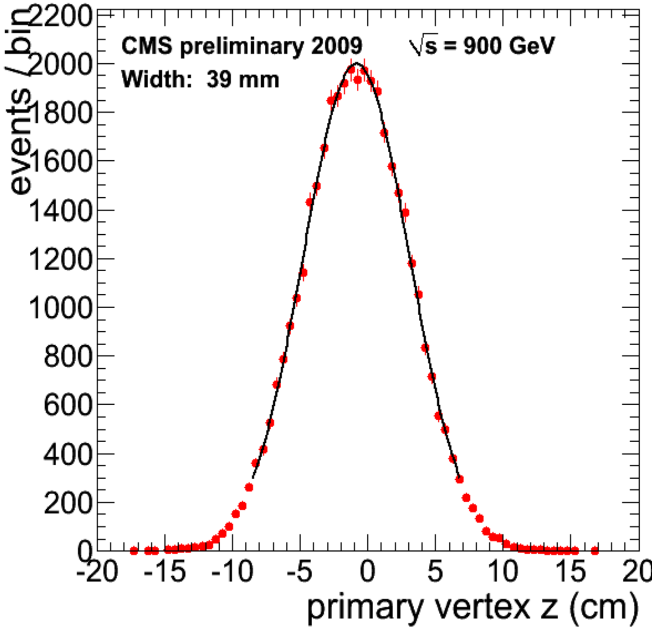


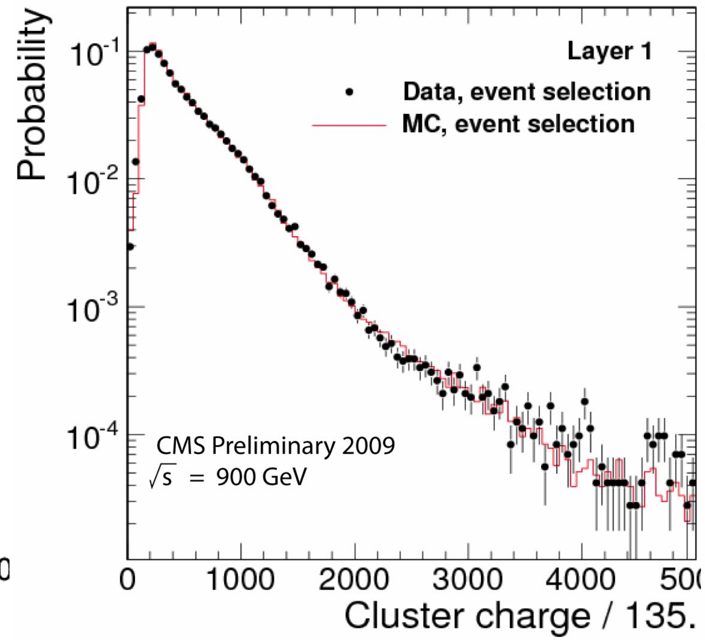


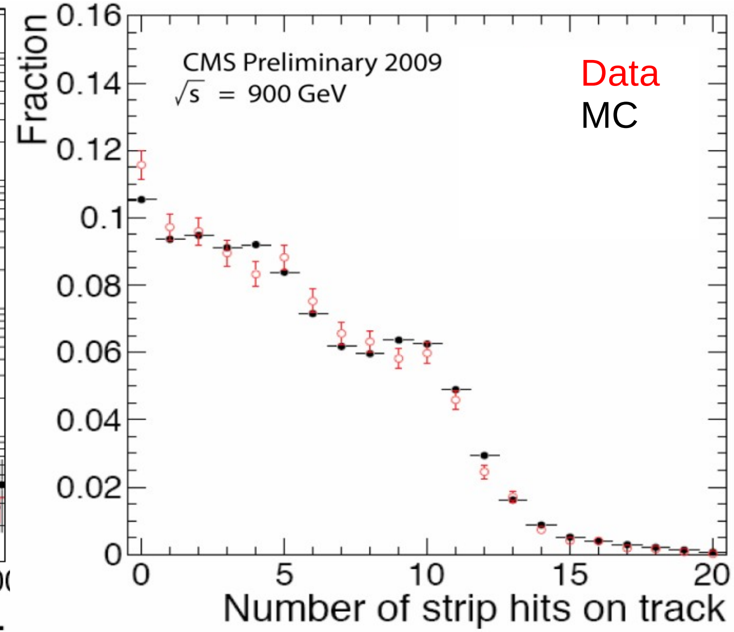
Fit: Gaussian convoluted with Breit-Wigner

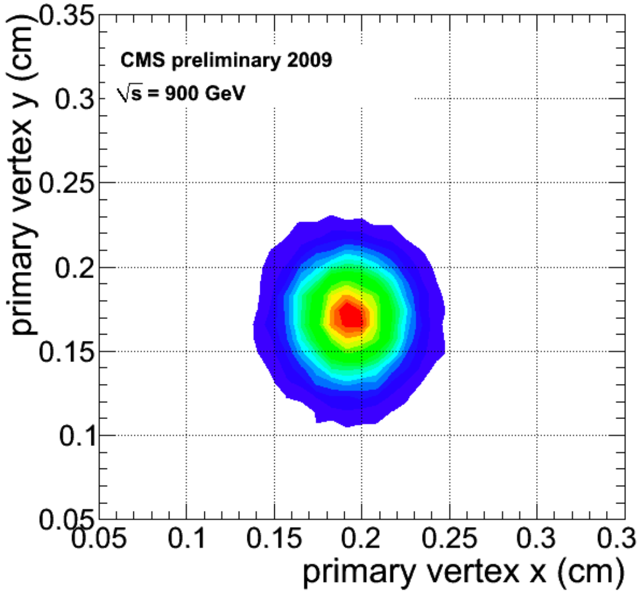
Uses dE/dx information to reduce background

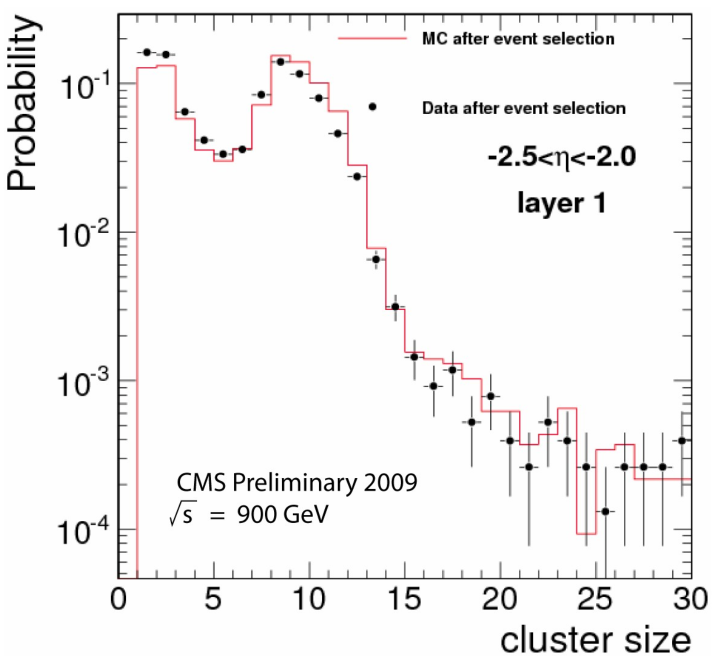
Tracking: Data vs Monte Carlo

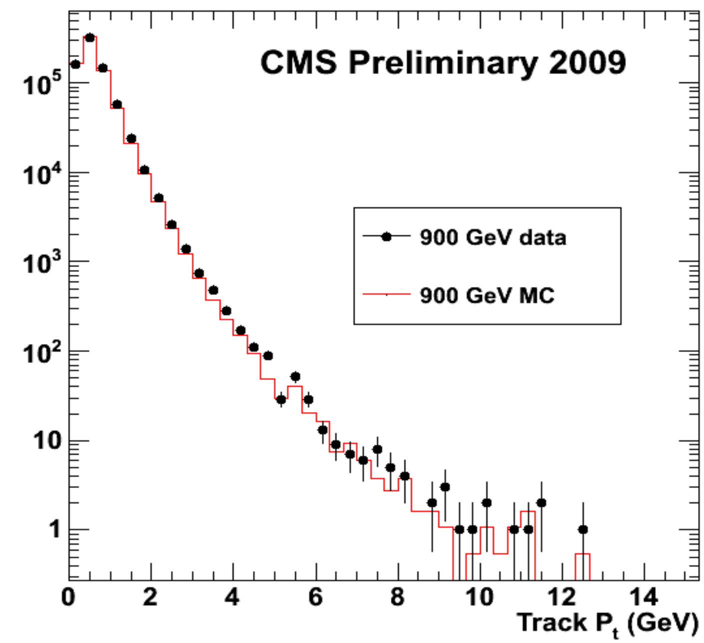






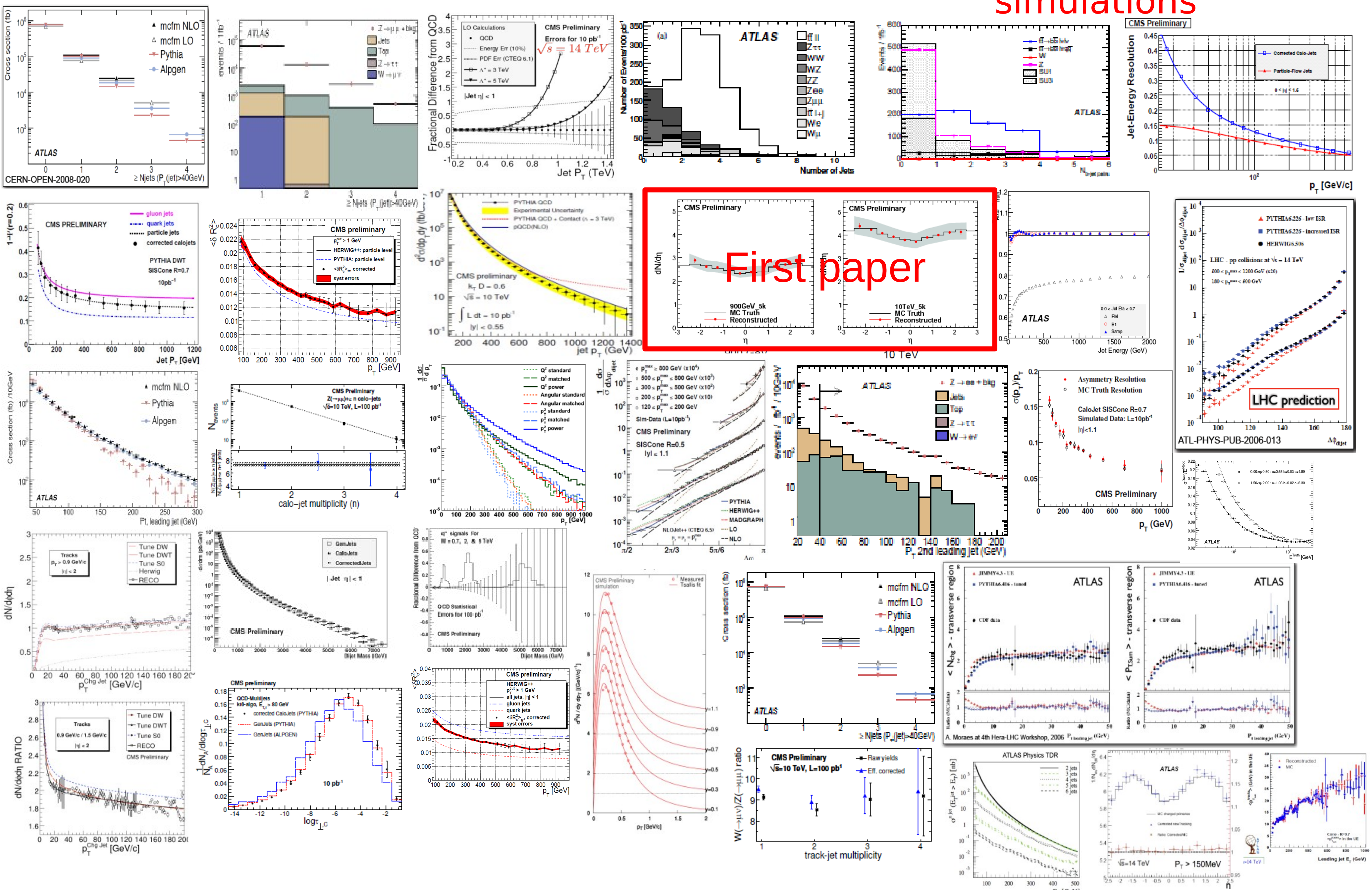






The QCD menu

Monte Carlo simulations



Some of these analyses are being prepared for upcoming winter conferences!

First CMS physics paper

Transverse-momentum and pseudorapidity distributions of charged hadrons in pp collisions at $\sqrt{s} = 0.9$ and 2.36 TeV

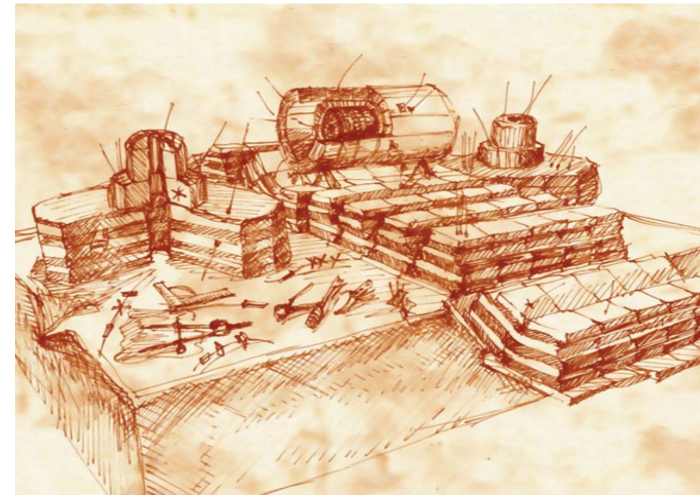
The CMS Collaboration

Abstract

Measurements of inclusive charged-hadron transverse-momentum and pseudorapidity distributions are presented for proton-proton collisions at $\sqrt{s} = 0.9$ and 2.36 TeV. The data were collected with the CMS detector during the LHC commissioning in December 2009. For non-single-diffractive interactions, the average charged-hadron transverse momentum is measured to be [redacted] GeV/c at 0.9 TeV and [redacted] GeV/c at 2.36 TeV for pseudorapidities between -2.4 and +2.4. At these energies, the measured pseudorapidity densities in the central region, $dN_{ch}/d\eta|_{|\eta|<0.5}$, are [redacted] and [redacted], respectively. The results at 0.9 TeV are in agreement with previous measurements and confirm the expectation of near equal bulk hadron production between $p\bar{p}$ and pp collisions. The results at 2.36 TeV represent the highest-energy measurements at a particle collider to date.

To be submitted soon ...

(arXiv:1002.0621v1 [hep-ex])



"It was the first light that shone
which our hopes depended on.
We were alone, in a crowded city,
trying to measure multiplicity...
It was not longer than an instant
two hills appeared, far but not distant.
How high the hill, not previously heard,
pixels, tracklets, tracks, all the same word!
However; early light casts long shadows;
as comments pile up the analyst bows.
In the end no one failed;
but it was 'patience' that prevailed.
I know it would be such a pity;
if we couldn't master low pt."

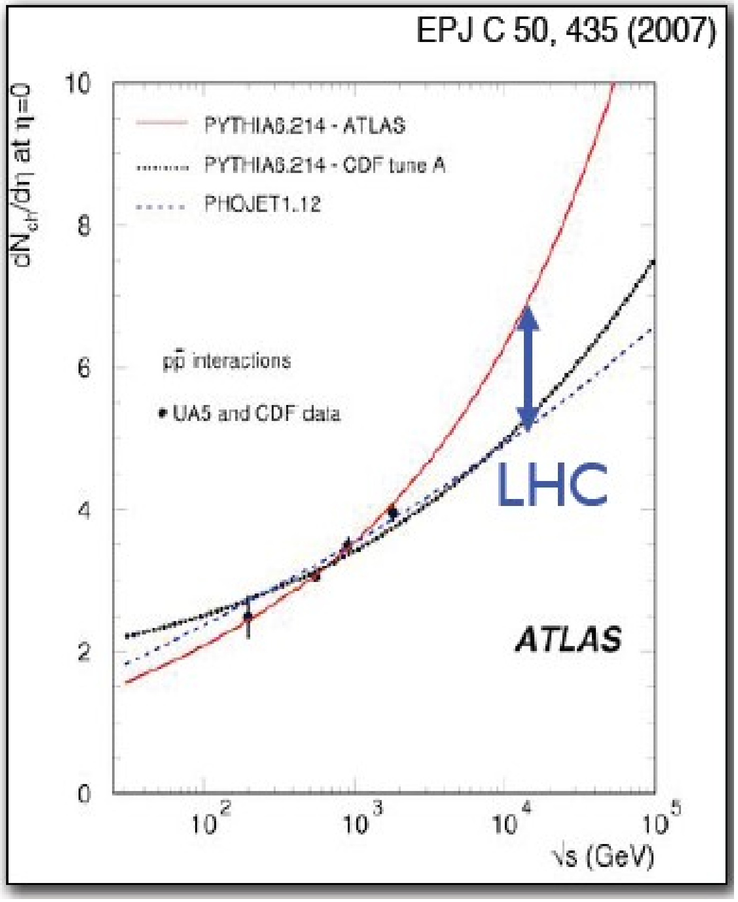
Yetkin Yilmaz, MIT grad. student

Minimum bias at LHC

- Traditionally defined as Non-Single Diffractive events:

$$\sigma_{tot} = \sigma_{elas} + \sigma_{sd} + \underbrace{\sigma_{dd} + \sigma_{nd}}_{\text{NSD}}$$

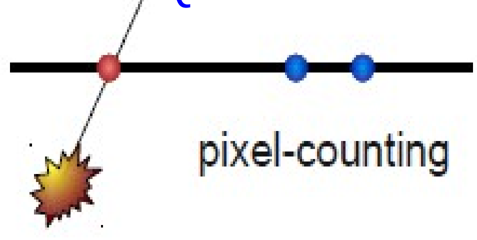
- Large model dependence on LHC expectations / predictions based on lower energy data
  - Need to understand properties of inelastic events as they will be background due to pileup at higher luminosities
  - Heavy-ion reference data



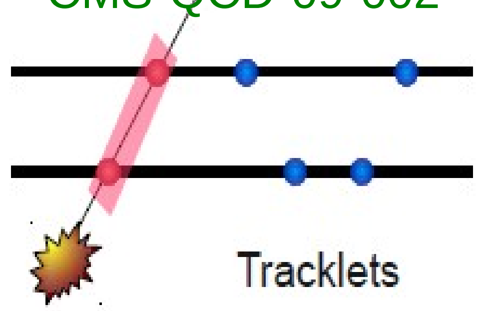
Analysis methods

- Three independent analyses techniques:
  - Use only cluster hits in pixel detectors
  - Use “primitive” tracks (“tracklets”) formed by correlating hits in two layers of the pixel detector projected to the vertex
  - Use fully reconstructed tracks
  - All methods have been evaluated with MC simulations for various pp energies and generators before data taking started

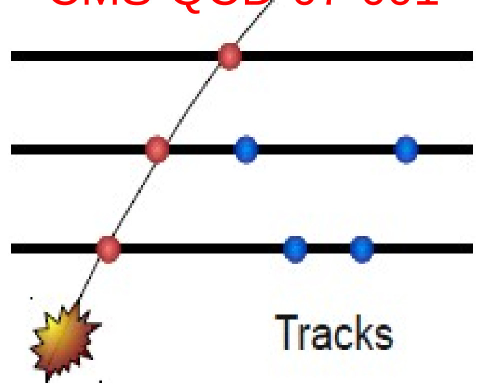
CMS-QCD-08-004



CMS-QCD-09-002

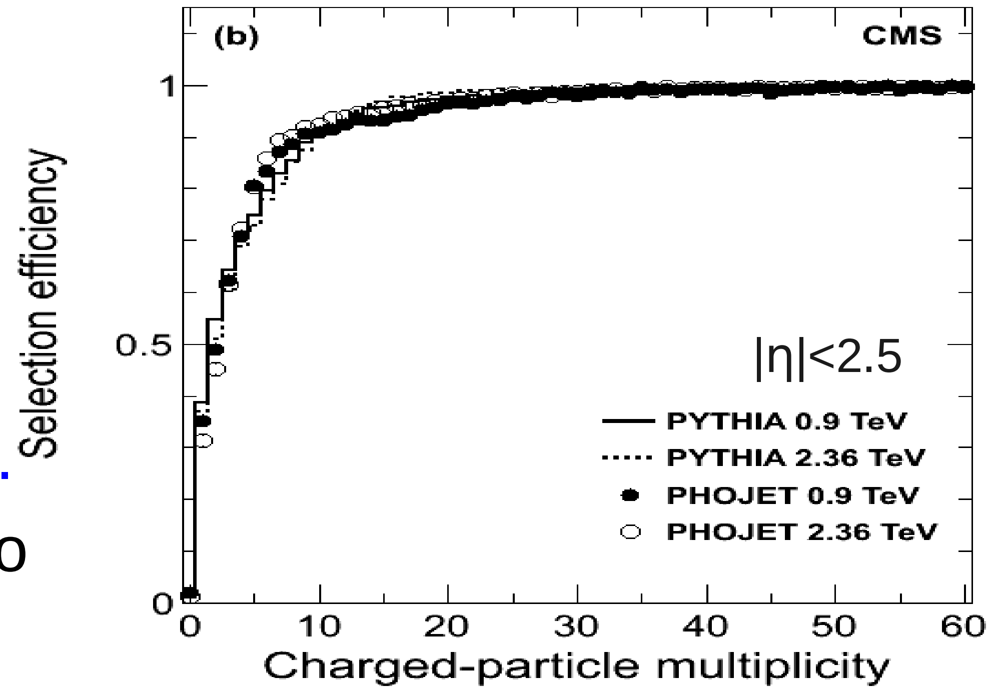


CMS-QCD-07-001



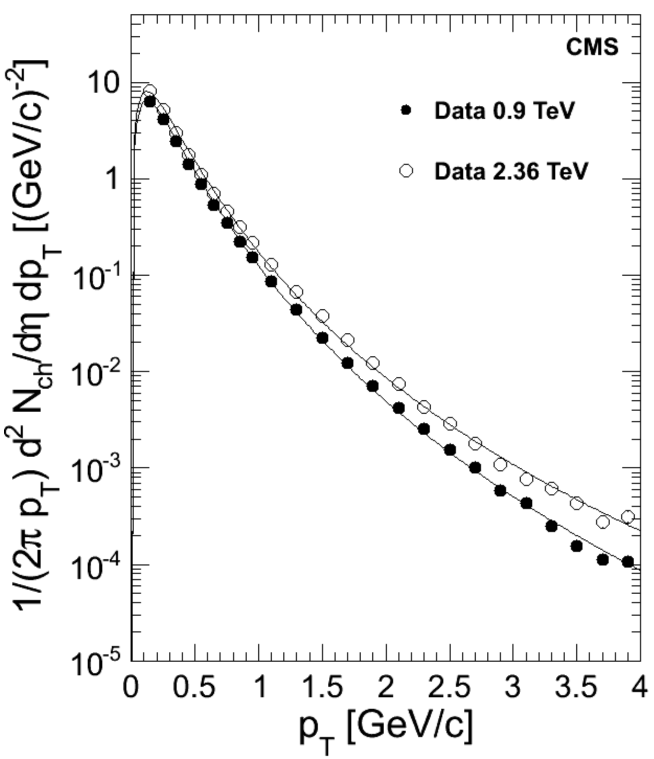
Triggering & event selection

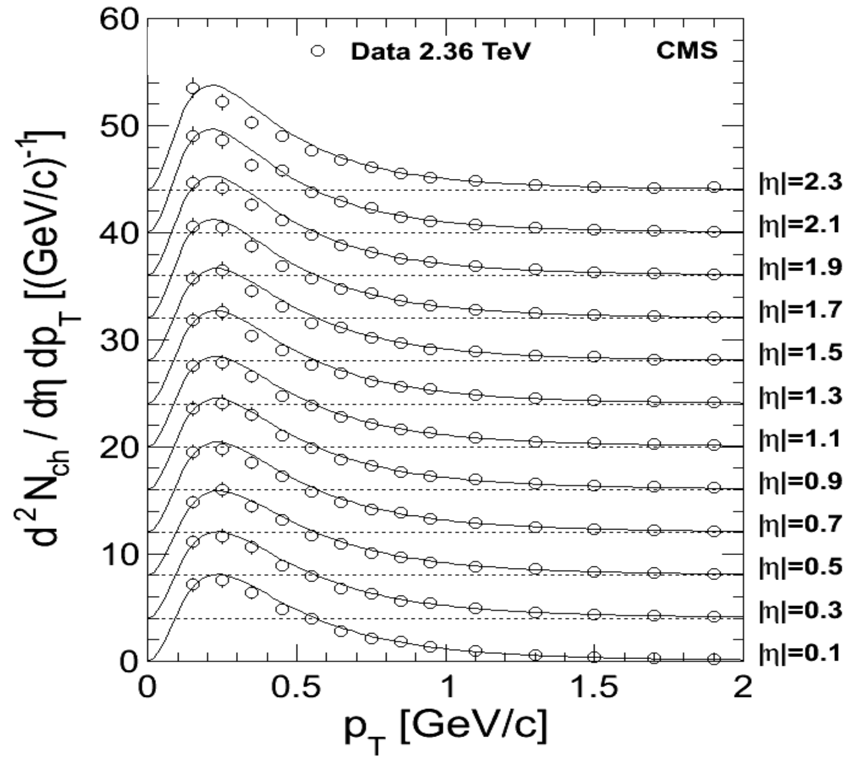
- Use combination of triggers
  - Zero Bias (ZB), ZB+track at HLT, beam scintillators, forward calorimeters
    - Use data from unpaired bunches to estimate background
  - PYTHIA and PHOJET for NSD cor.
    - Fraction of SD events leaking into SD sample: ~6%
    - Dominant source of the systematic uncertainty: ~3%



	PYTHIA				PHOJET			
Energy	0.9 TeV		2.36 TeV		0.9 TeV		2.36 TeV	
	Frac.	Sel. Eff.	Frac.	Sel. Eff.	Frac.	Sel. Eff.	Frac.	Sel. Eff.
SD	22.5%	16.1%	21.0%	21.8%	18.9%	20.1%	16.2%	25.1%
DD	12.3%	35.0%	12.8%	33.8%	8.4%	53.8%	7.3%	50.0%
ND	65.2%	95.2%	66.2%	96.4%	72.7%	94.7%	76.5%	96.5%
NSD	77.5%	85.6%	79.0%	86.2%	81.1%	90.5%	83.8%	92.4%

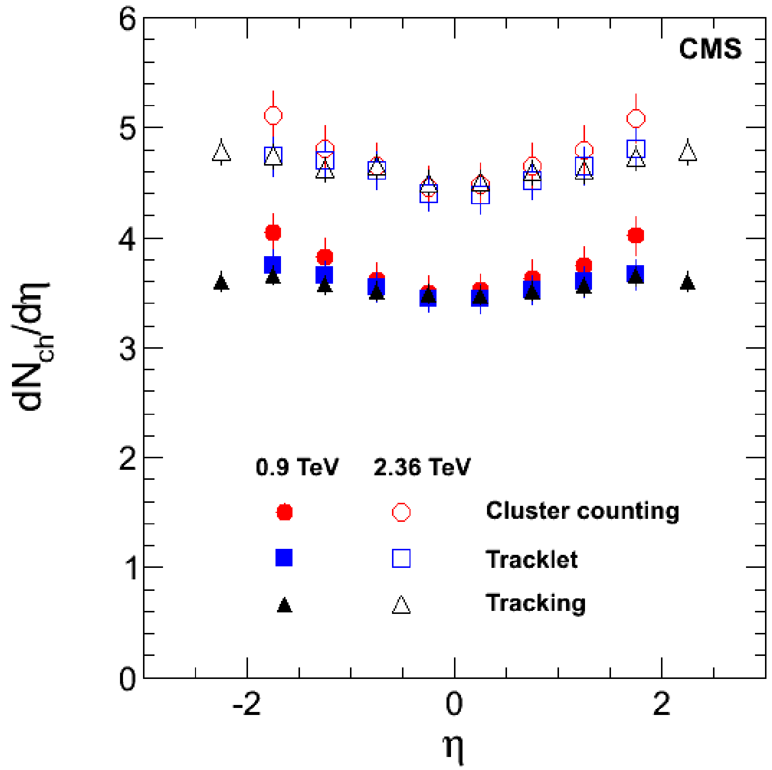
Transverse momentum distributions



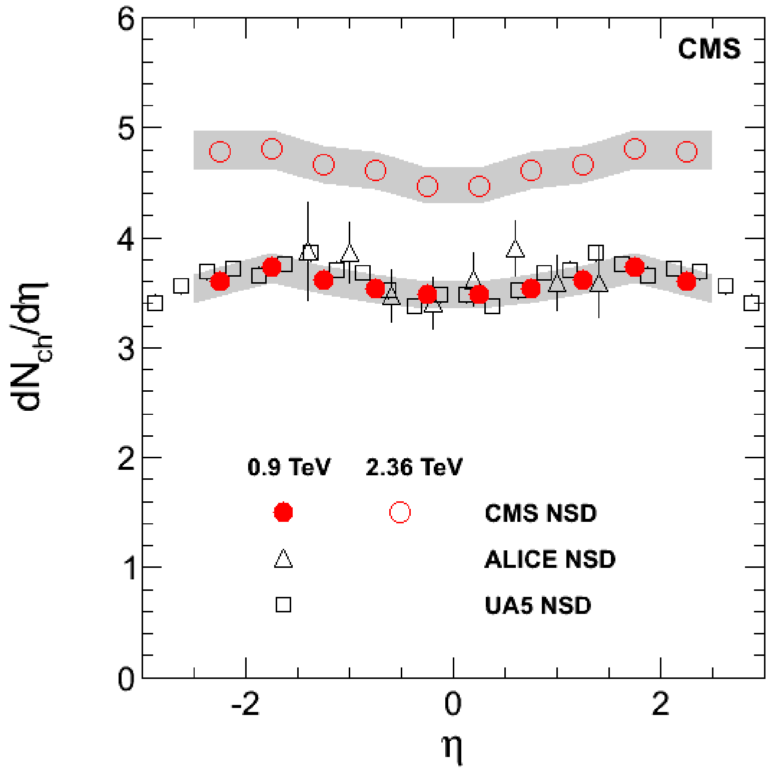


Systematic errors (not shown) amount to about 4%

Pseudorapidity distributions



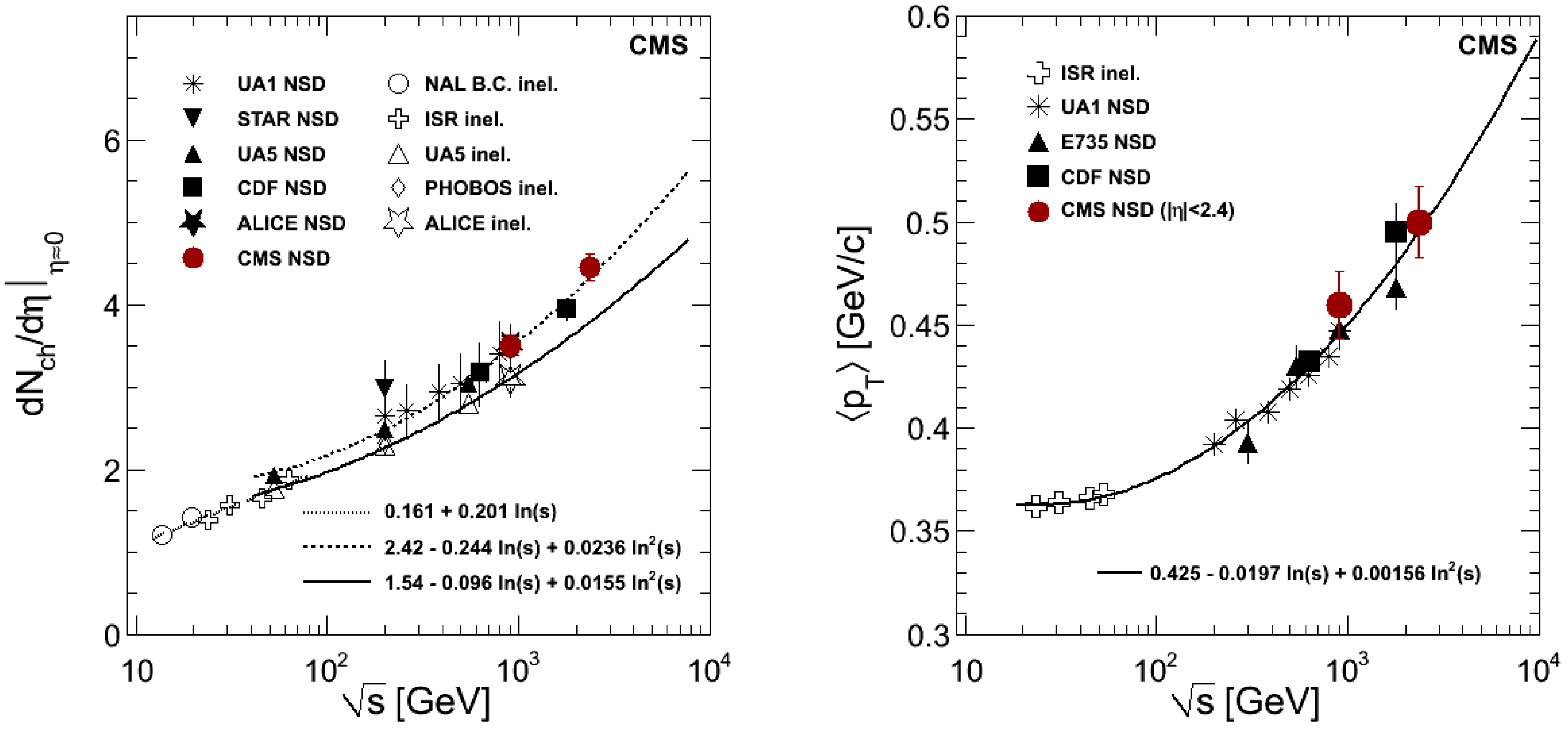
Individual methods: Errors are syst. excluding those common to all methods



Weighted averaged (and symmetrized) results with overall systematic error

First LHC physics paper:
ALICE collaboration, EPJC 65, 1 (2010) 111

Energy dependence



Energy dependence consistent with previous trend. CMS point (unlike others) includes the systematic error.

Summary

- The CMS detector is working beautifully
  - Its performance is according to design
  - Its behavior is reproduced by Monte Carlo simulations
  - Our level of understanding in this early phase of commissioning is very advanced
  - The first CMS physics paper will soon be submitted

- The highest collider energy ever, combined with the expected integrated luminosity puts us in the best position for new discoveries as early as the end of this year

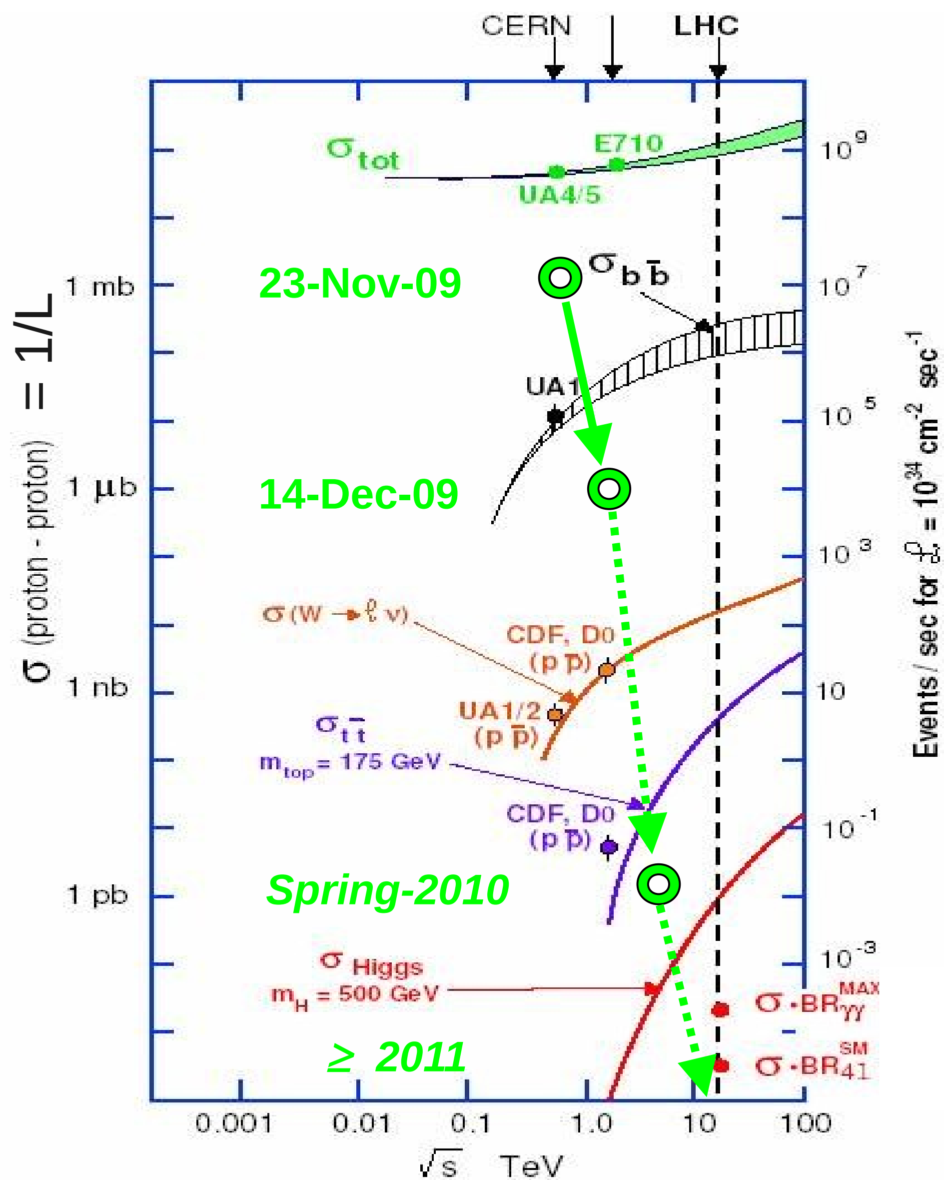
- CMS continuous to be ready, and eager, for LHC beam.

Epilogue

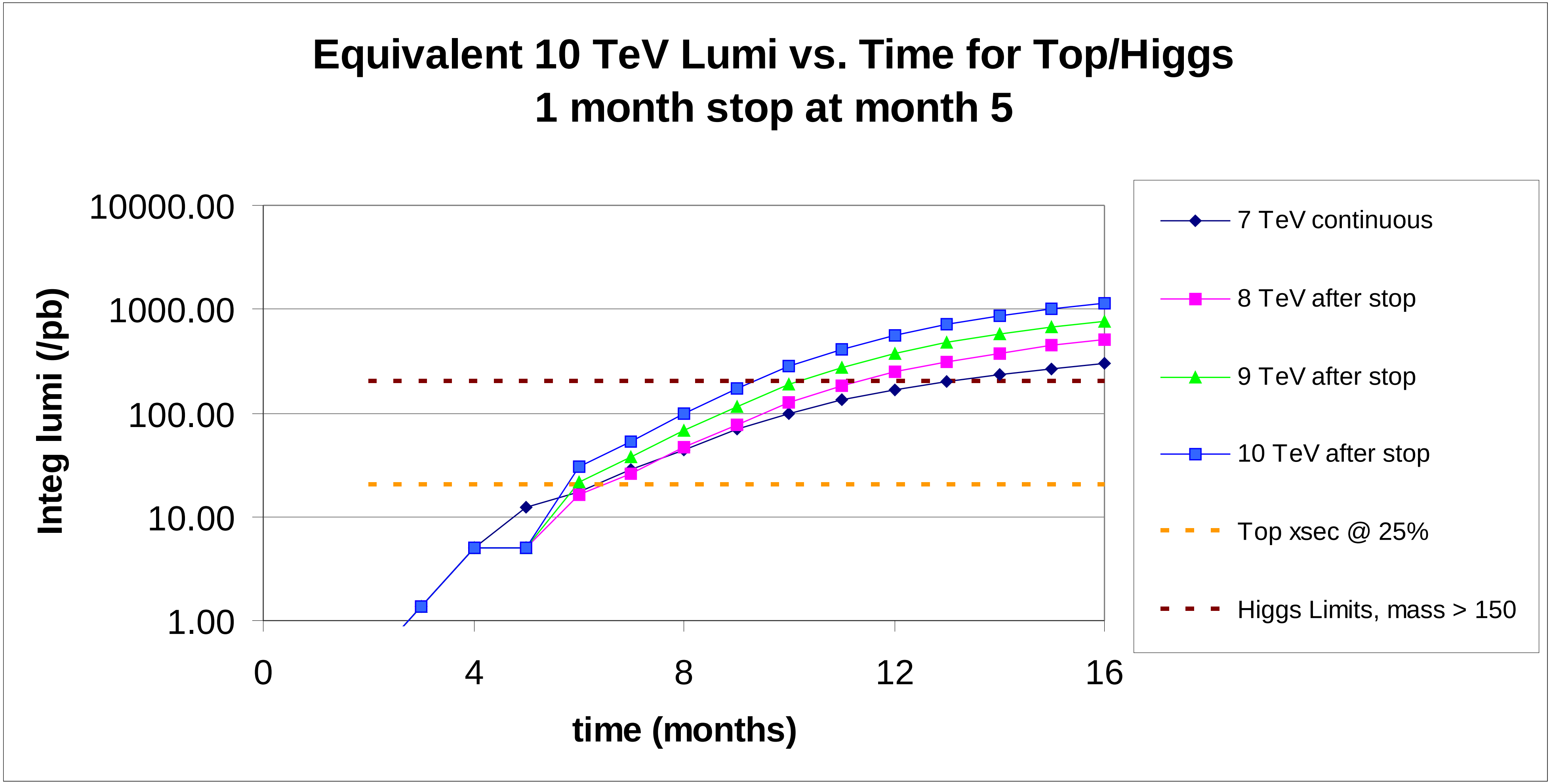
What will happen next?

- Resume operations in Feb 2010 with operations at 3.5 TeV beam energy
  - Deemed safe with remaining anomalous resistance in some splices between magnets
- Possible step up to 4 or 5 TeV beam energy after ~3 months, requiring one month to reestablish physics, and running another 4-5 months
- Heavy ion run for ~1 month at end
- LHC plan is being discussed together with experiment's representatives at the Charmonix meeting

http://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=67839



"Reading tea leaves": Higgs

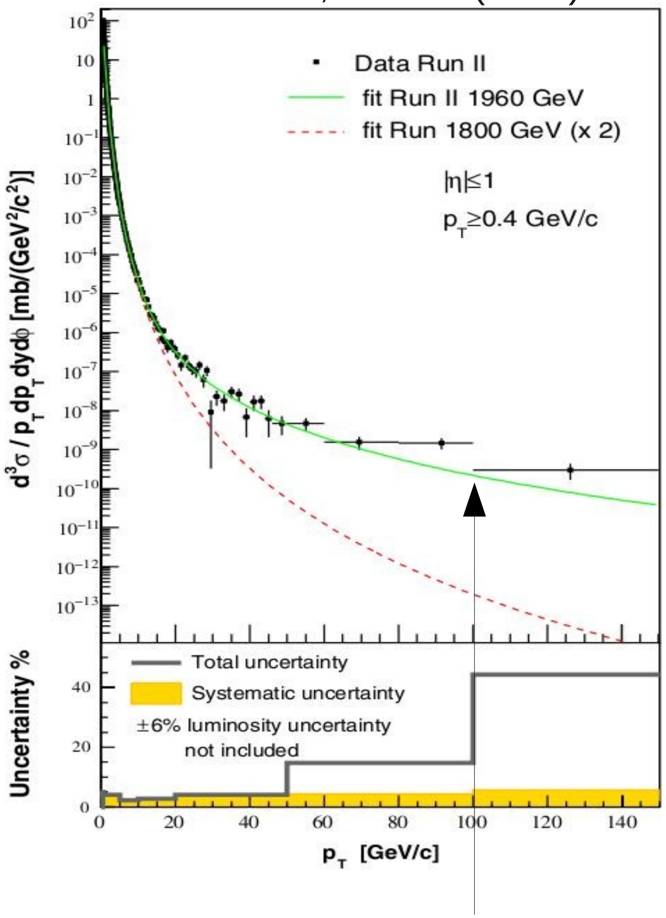


- Energy increase and a long run would favor getting to competitive Higgs limits
- Clearly, safety of the machine has top priority

A word about 2.x TeV runs at LHC

- Reference data for HI run?
  - Relevant cms energy per nuc.pair is 2.75 for 7 TeV and 4 for 10 TeV pp
- Interpolate for reference data from existing measurements at lower energy to the energies reached in pp at LHC
- Is CDF data usable?
  - Either incompatible with pQCD or has a serious exp. flaw
- Better cross check and measure ourselves if we get a chance for it
  - Win-win situation

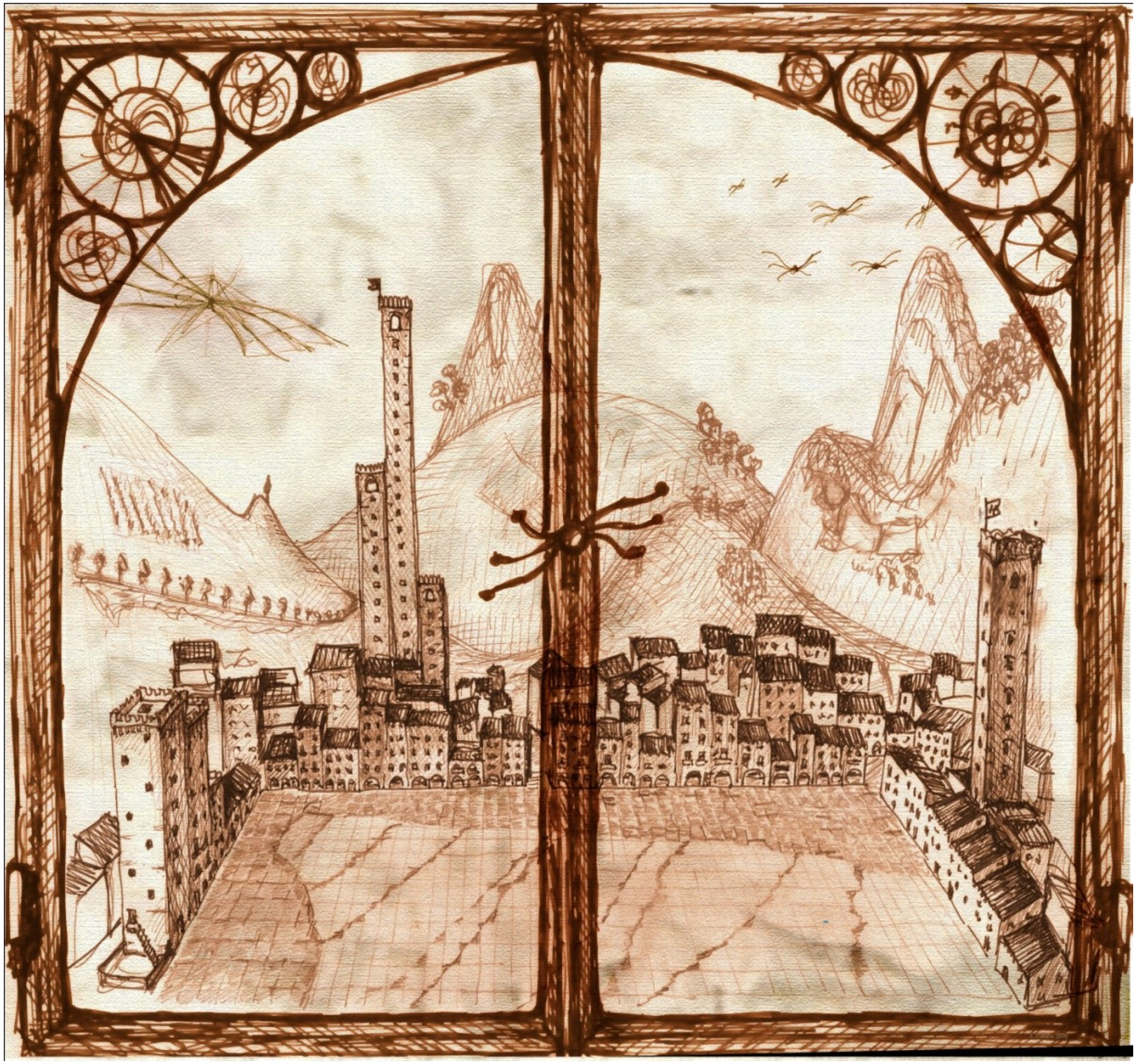
PRD 79, 112005 (2009)



$$f = A\left(\frac{p_0}{p_T + p_0}\right)^n + B\left(\frac{1}{p_T}\right)^s$$

Is this data compatible with pQCD?

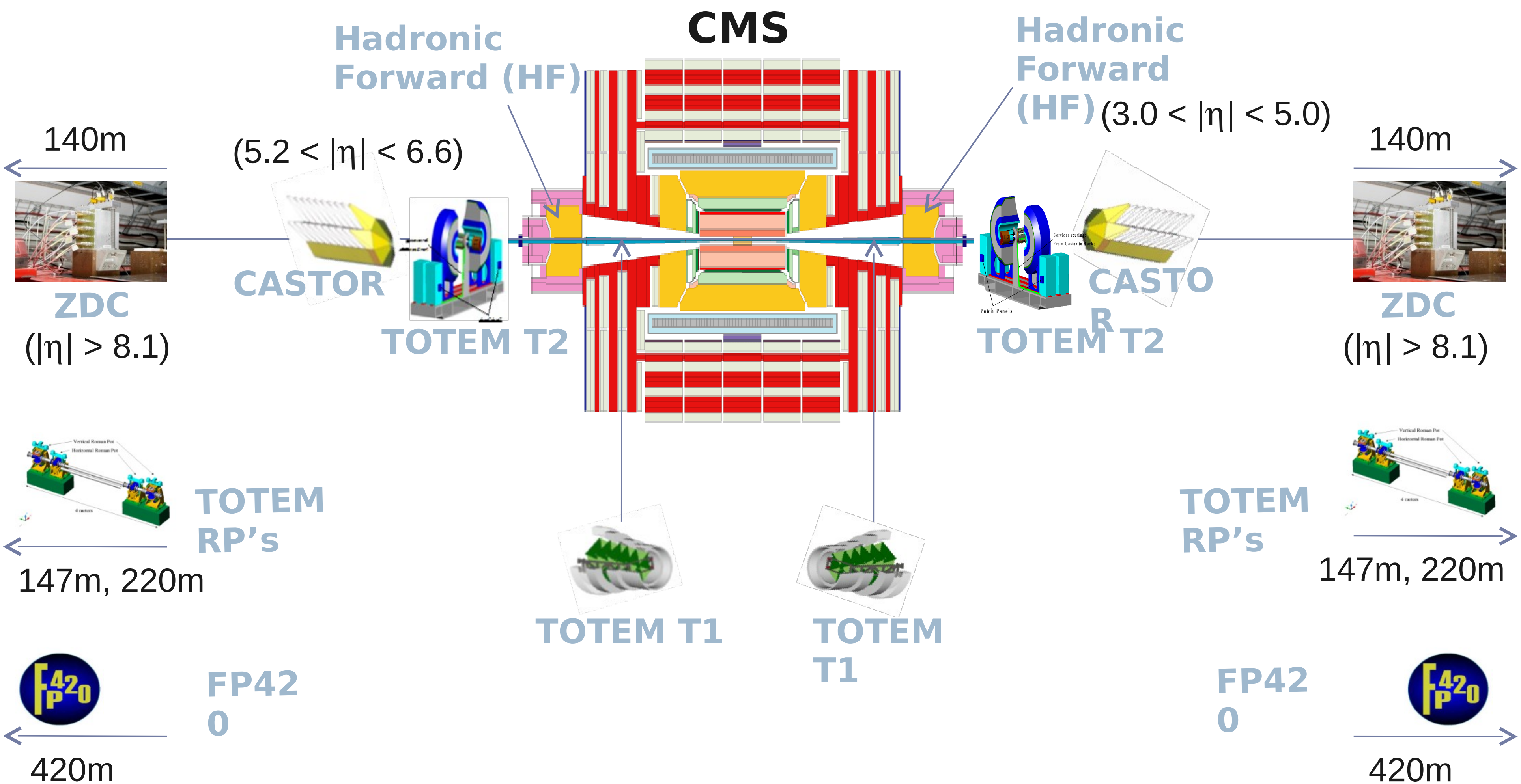
The beginning of the journey



Credit for “Da Vinci” drawings: Sergio Cittolin

Extra

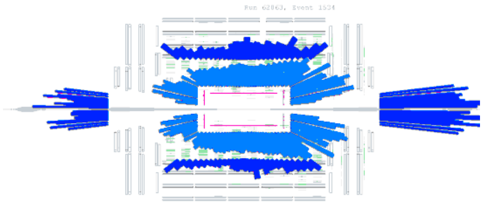
Forward capabilities at P5



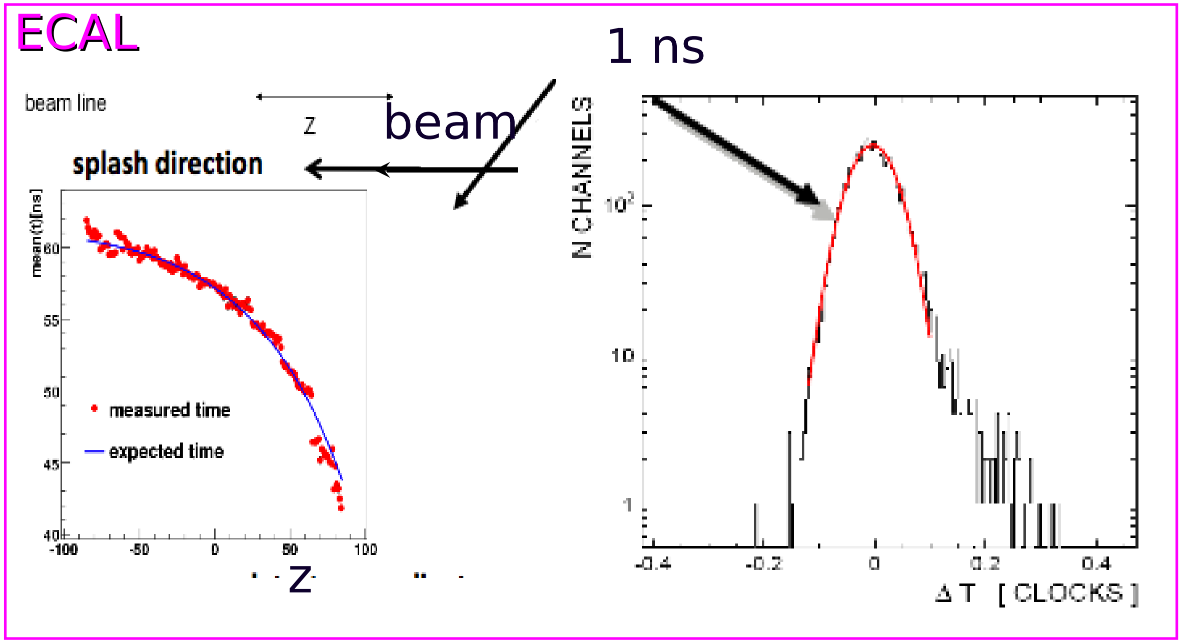
Beam splash events

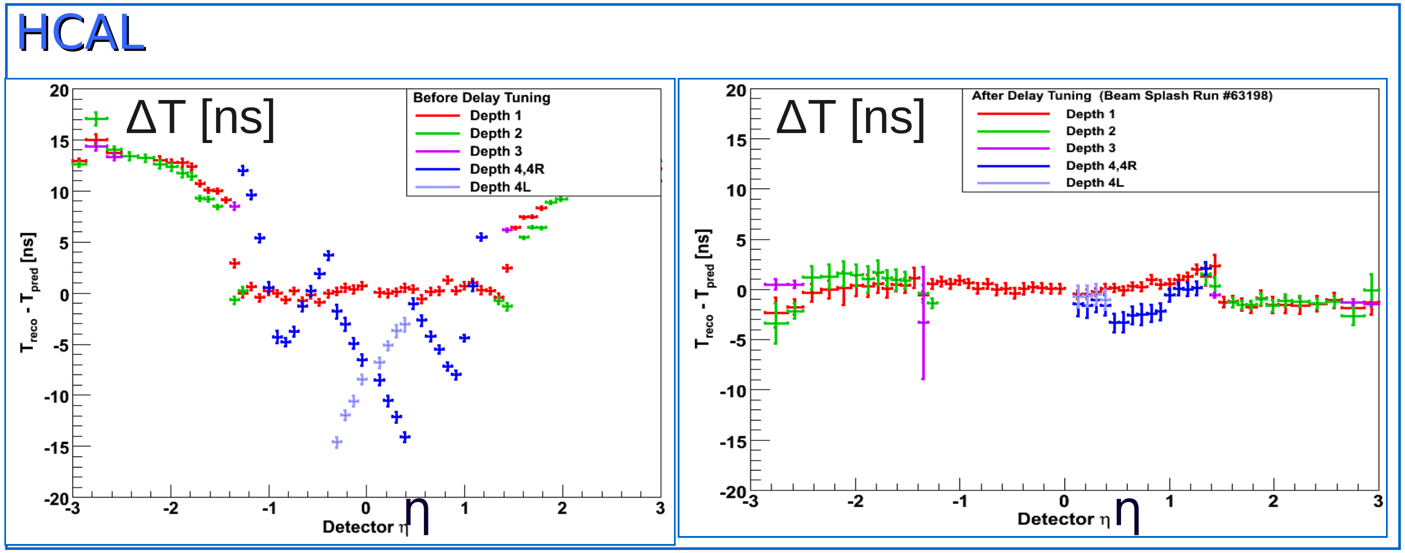
170TeV

- In splash events all channels fire
- Synchronize in one go all calorimeters
- Time of arrival follows detector geometry



1000TeV





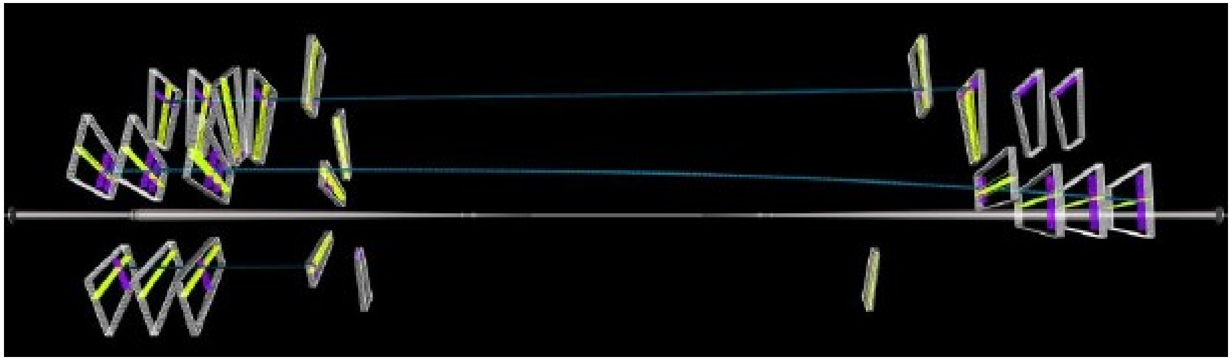
Before delay tuning

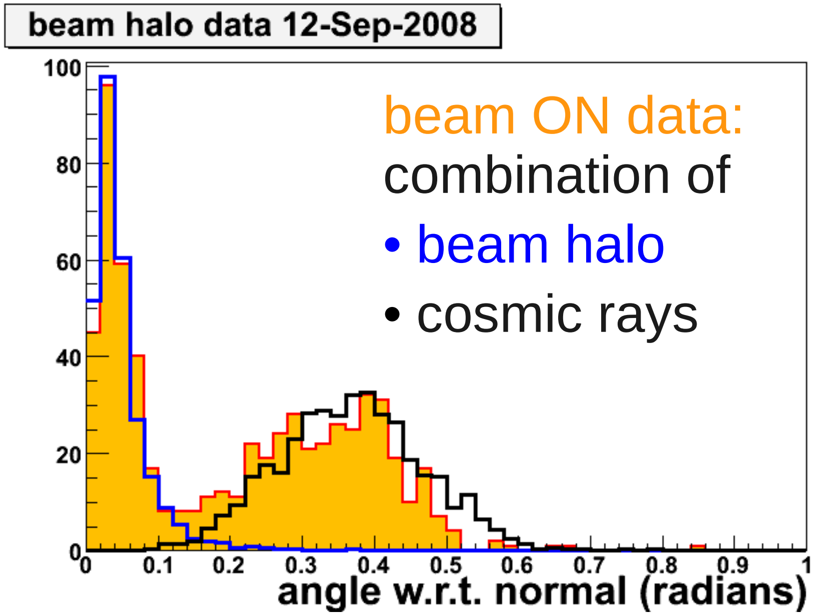
After delay tuning

Beam halo events

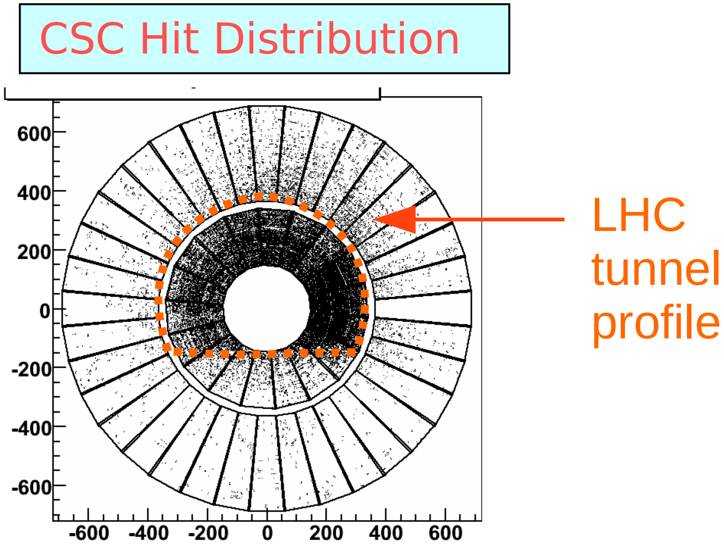
Beam Halo: muons outside of beam-pipe, arising from decays of pions created when off axis protons scrape collimators or other beamline elements

Muons go almost parallel to the beam:
A perfect X-ray of the muon Endcap



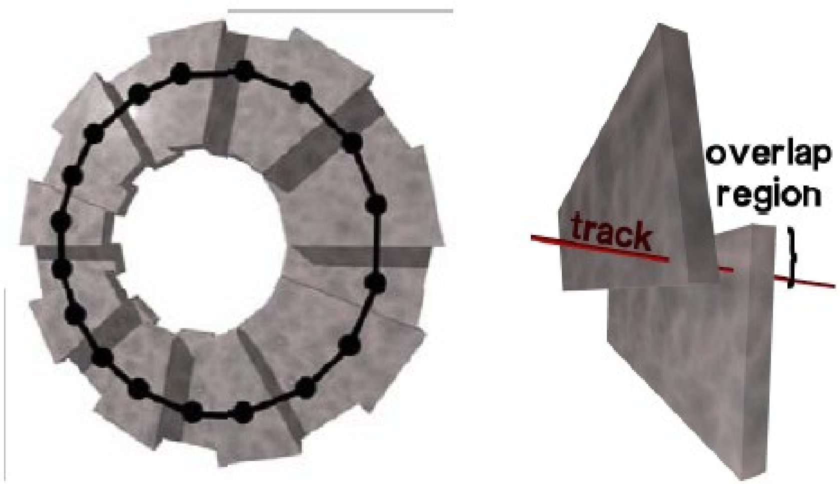


Reconstructed track angle wrt transverse plane

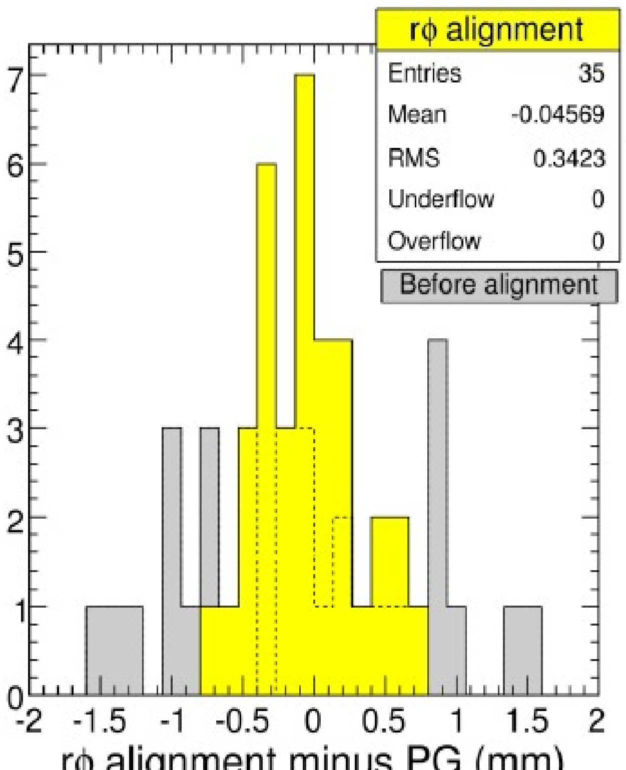


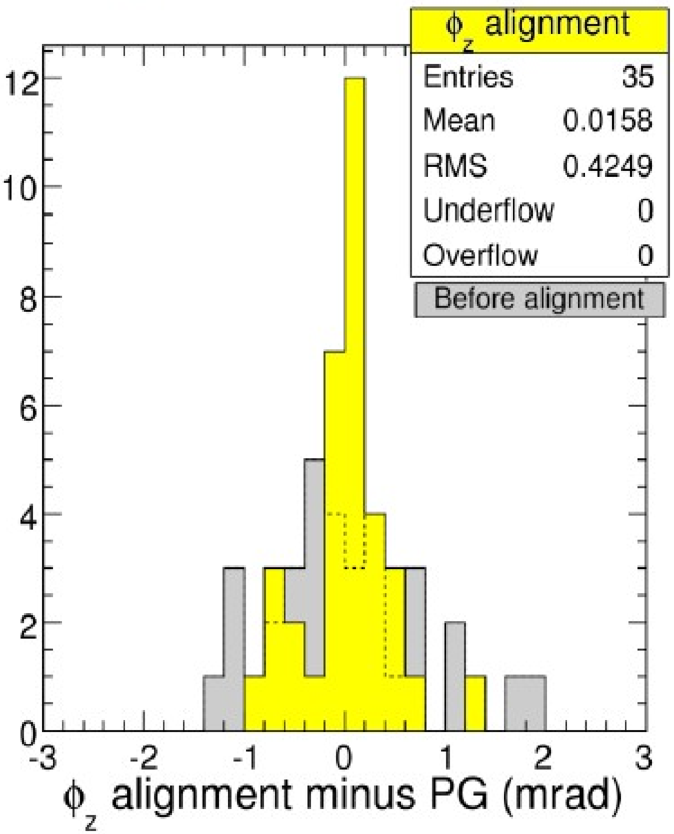
CSC alignment improved:
0.27 μm in rφ plane
0.35 μm in φ_z

Beam halo events



Alignment done using tracks passing through two overlapping chambers Relative position determined by requiring consistency between track segments (and within a ring)





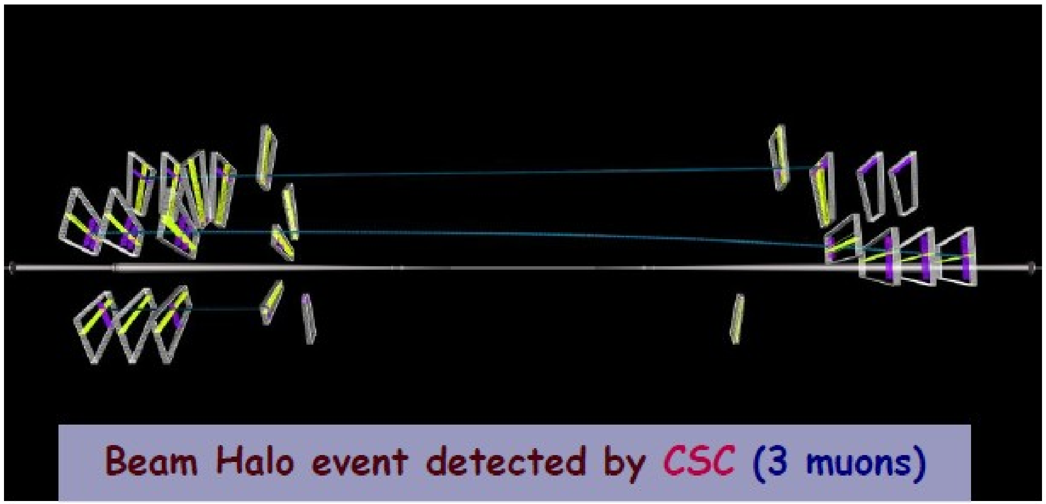
Accuracy achieved:

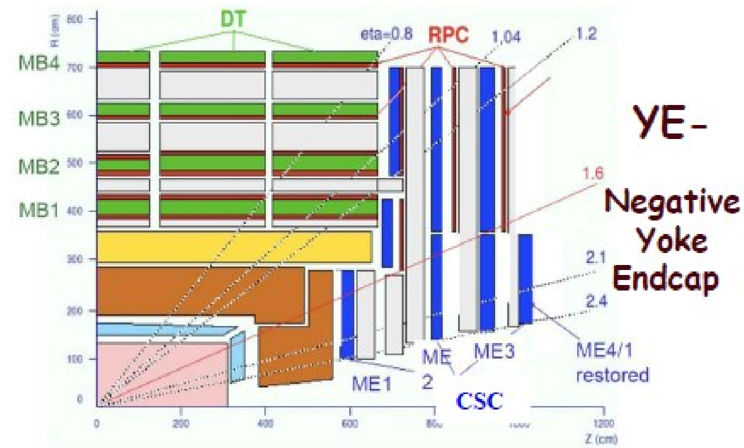
270 μm in rφ plane

0.35 mrad in φ_z

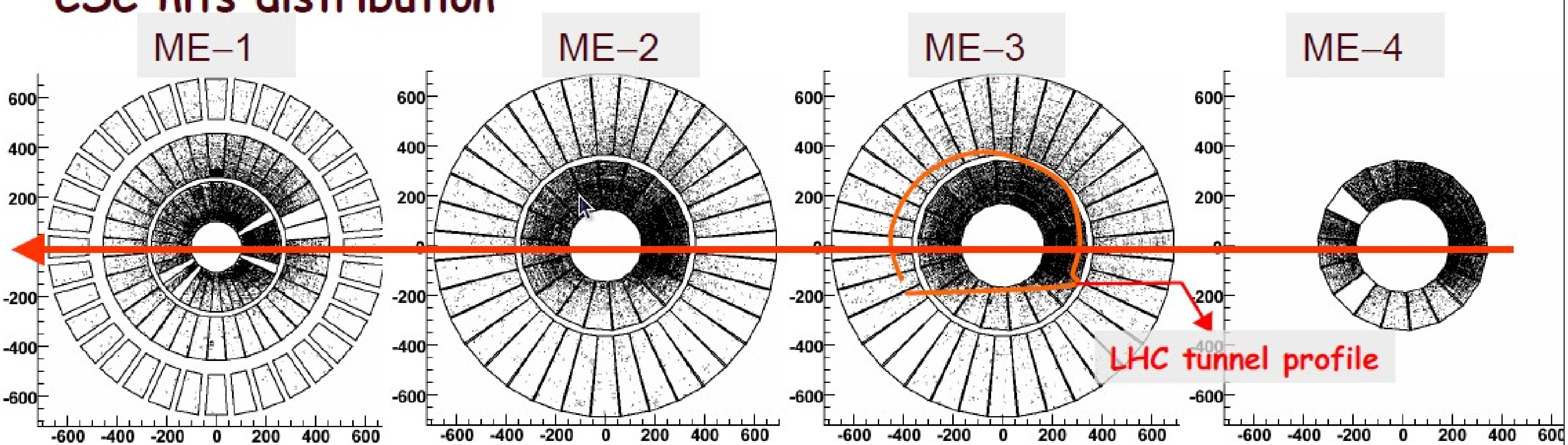
Initial alignment goal reached in 9 min of LHC beam!

Beam halo events



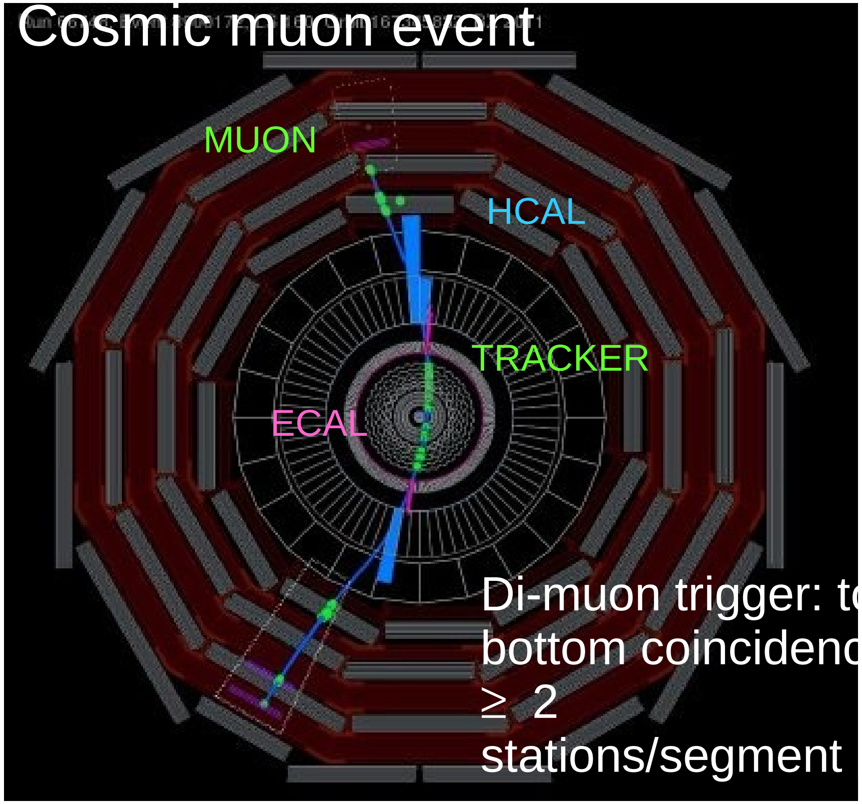


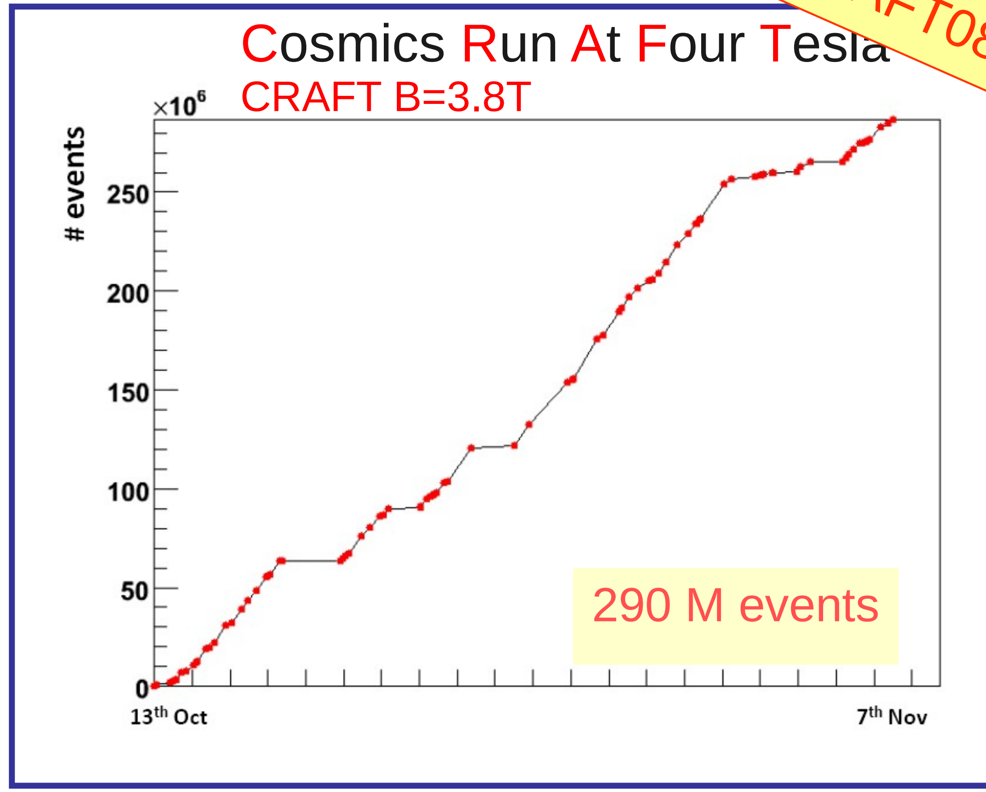
CSC hits distribution



Cosmic run at operating field (CRAFT)

CRAFT08





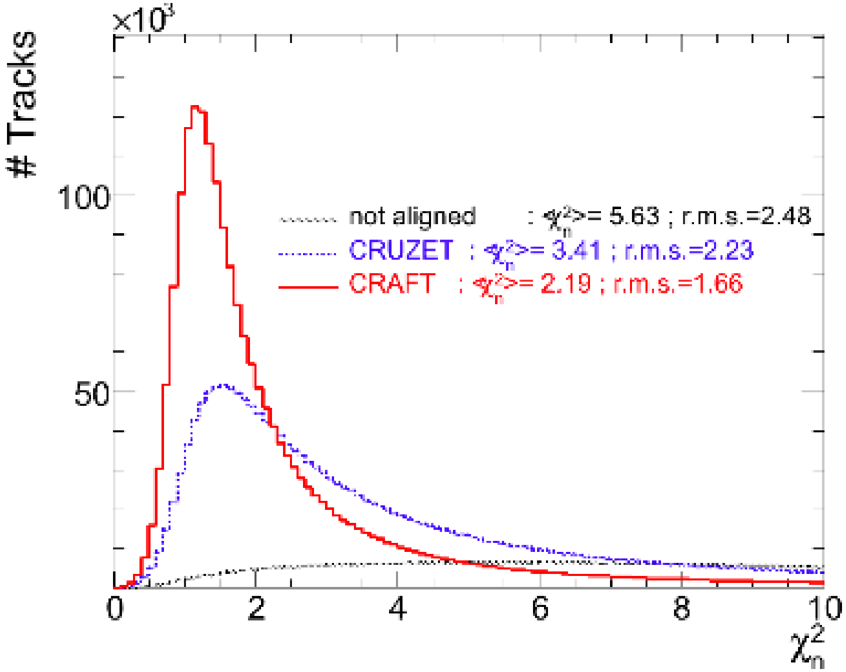
- Great data to enhance detector and software quality
  - Equivalent > 10 pb^{-1}
- ~25 papers in preparation (to be submitted by end of Sept 09)

- 400 TB of data distributed
- Data taking efficiency of 70% (24/7)
- 87% have a muon track
- 3% muon track with tracker hits
- 30.000 events have track with pixel hits

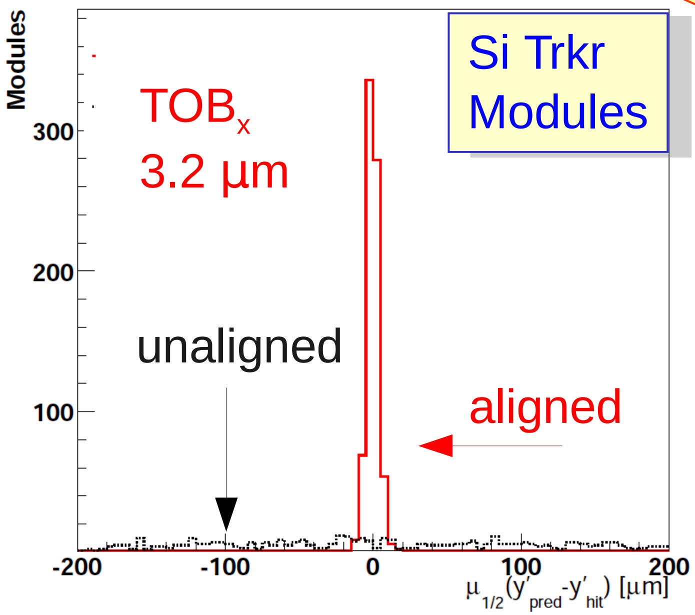
Tracker alignment

CRAFT08

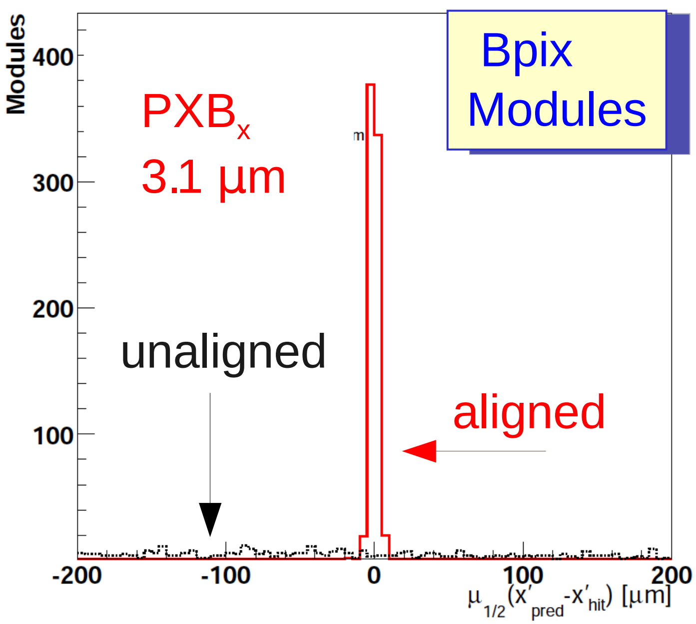
13 layers in the Barrel
14 layers in the Endcaps
9.6M strips
66M pixels
More than 200 m² Si



Large improvements as seen from χ^2 distribution (no alignment errors included)



Residual hit distribution (in x)

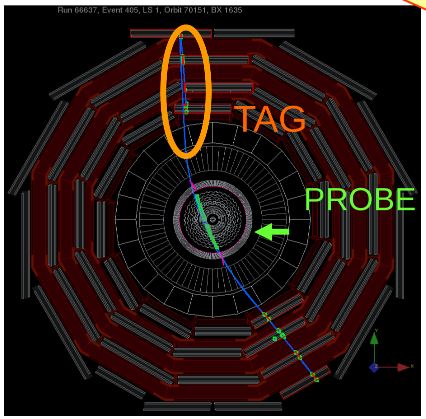


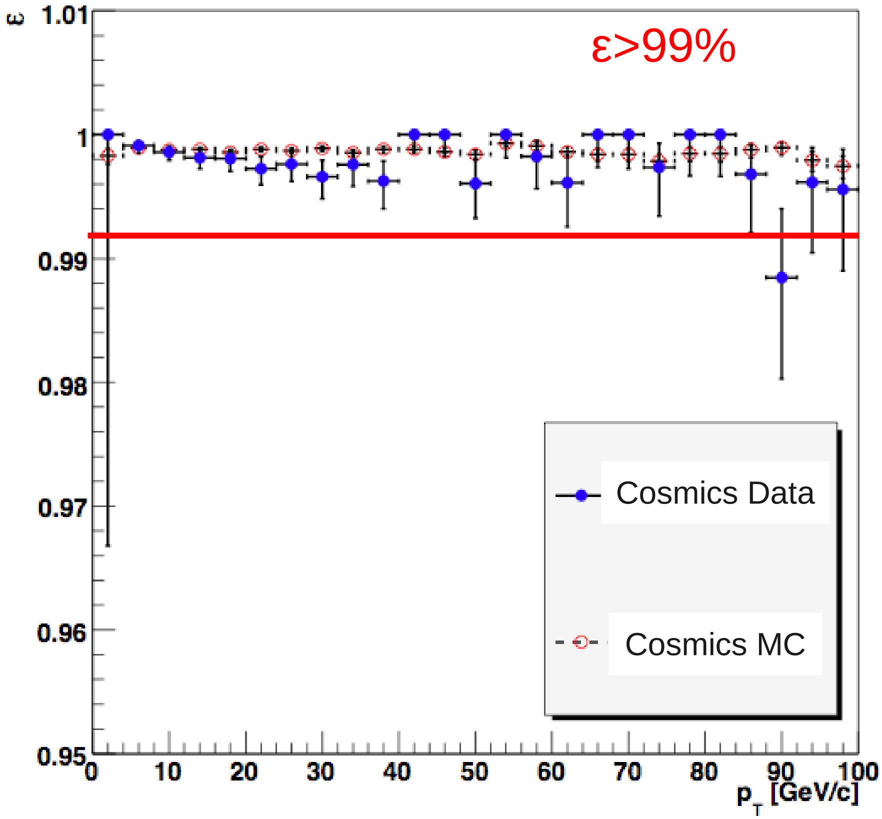
Tracker performance: Efficiency

CRAFT08

Tag-and-Probe method:

- Tag : Standalone upper muons pointing to the tracker near the origin (LHC-like tracks)
- Probe : Tracker muons





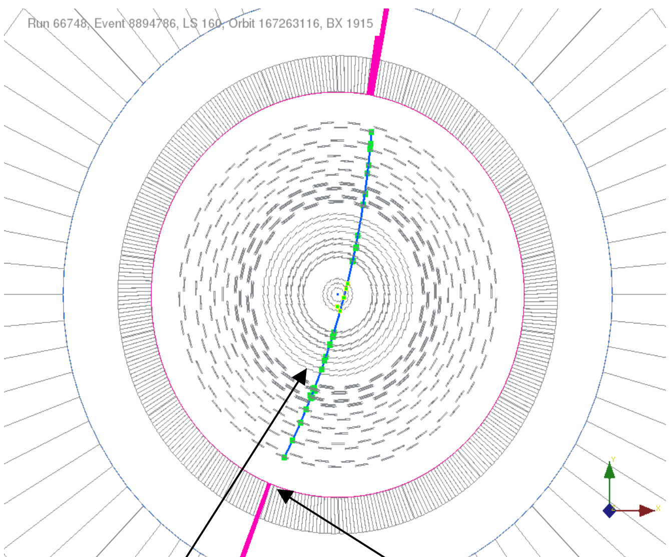
Achieved high tracking reconstruction efficiency demonstrated using cosmic muons:

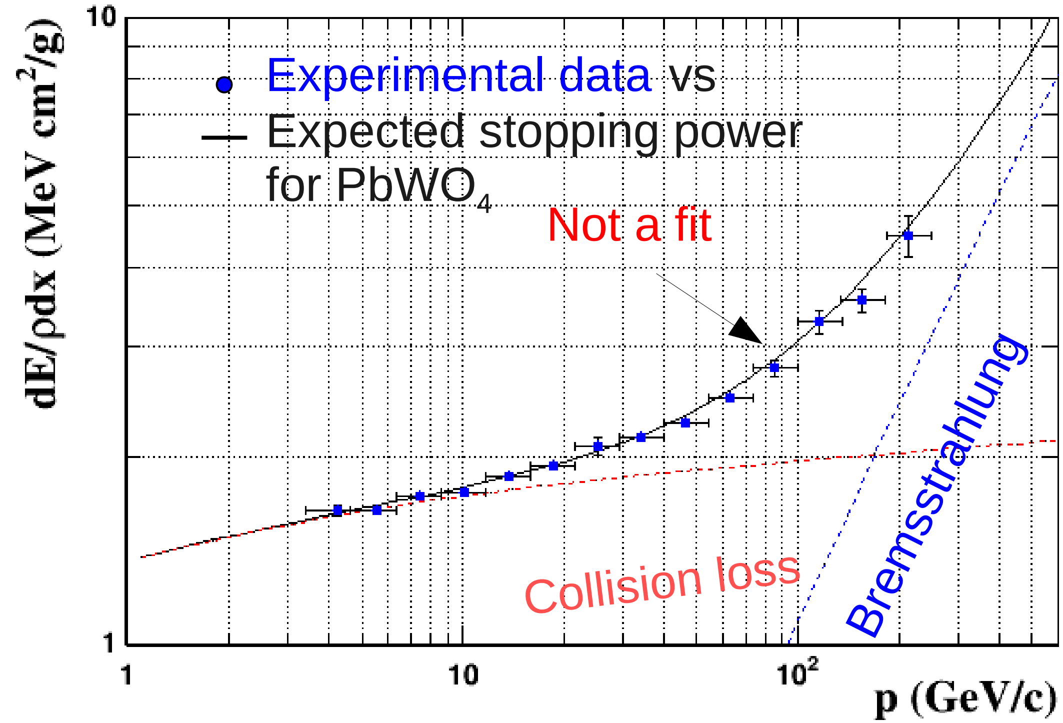
- Strip Tracker
  - TOB: 98%
  - TIB/TID: 96.6%
  - TEC+ : 99.2%
  - TEC-: 97.8 %
- Pixels
  - Barrel: 99.1%
  - Forward: 94.0%

ECAL response to muons

CRAFT08

Validate calibration: Measure energy deposition vs muon momentum



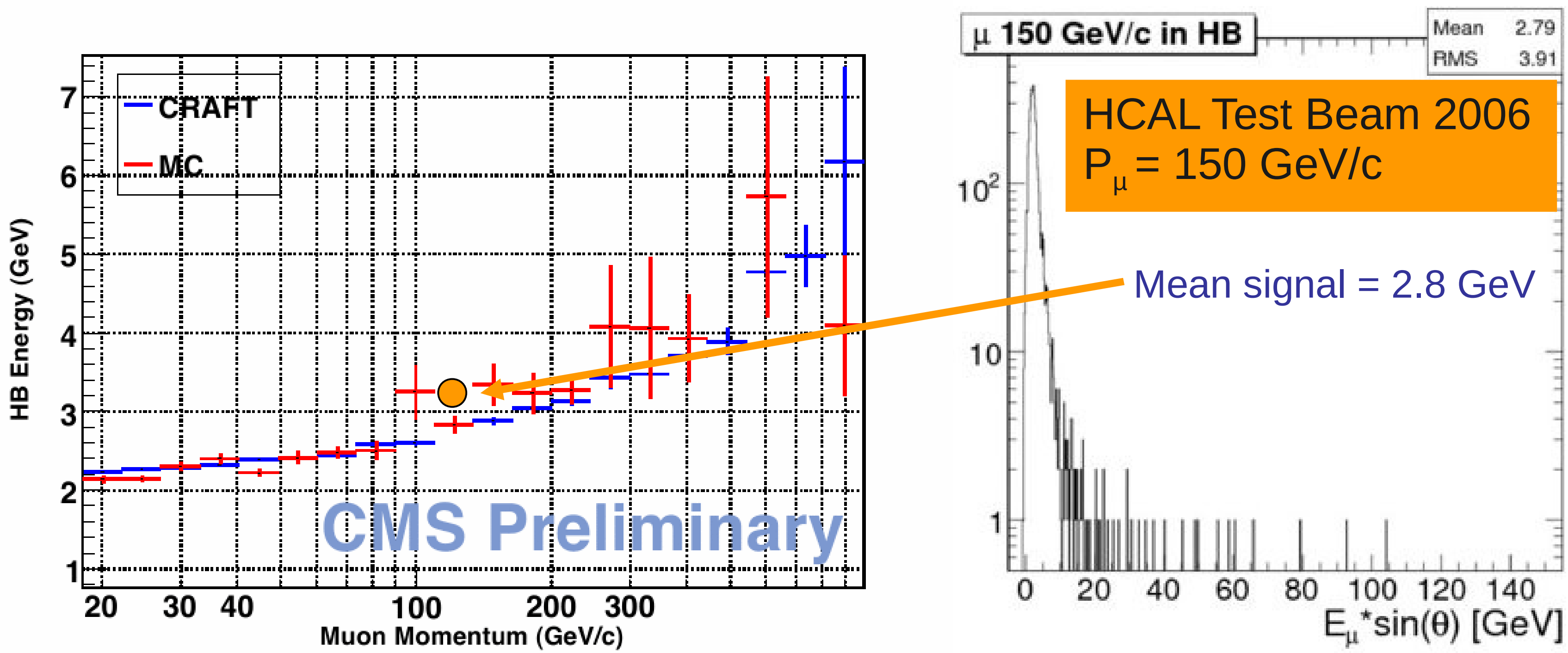


momentum p measured in the tracker
dE: energy from ECAL cluster, measured in the ECAL lower half
dx: is the length traversed in ECAL crystals
dE/ρdx energy deposit matched to the track corrected for muon path length

Tracker momentum matches well with ECAL energy loss, energy scale is correct

HCAL response to muons

CRAFT08

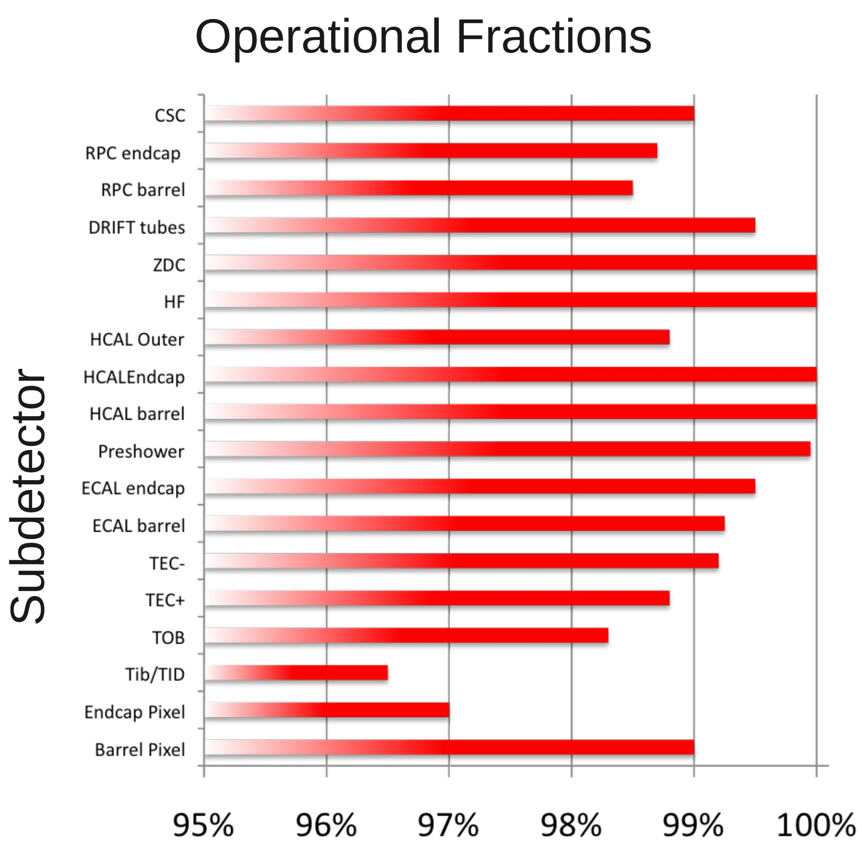


HCAL barrel energy:
signal corrected for muon path length in HCAL

Good agreement of CRAFT response with MC and test beam results

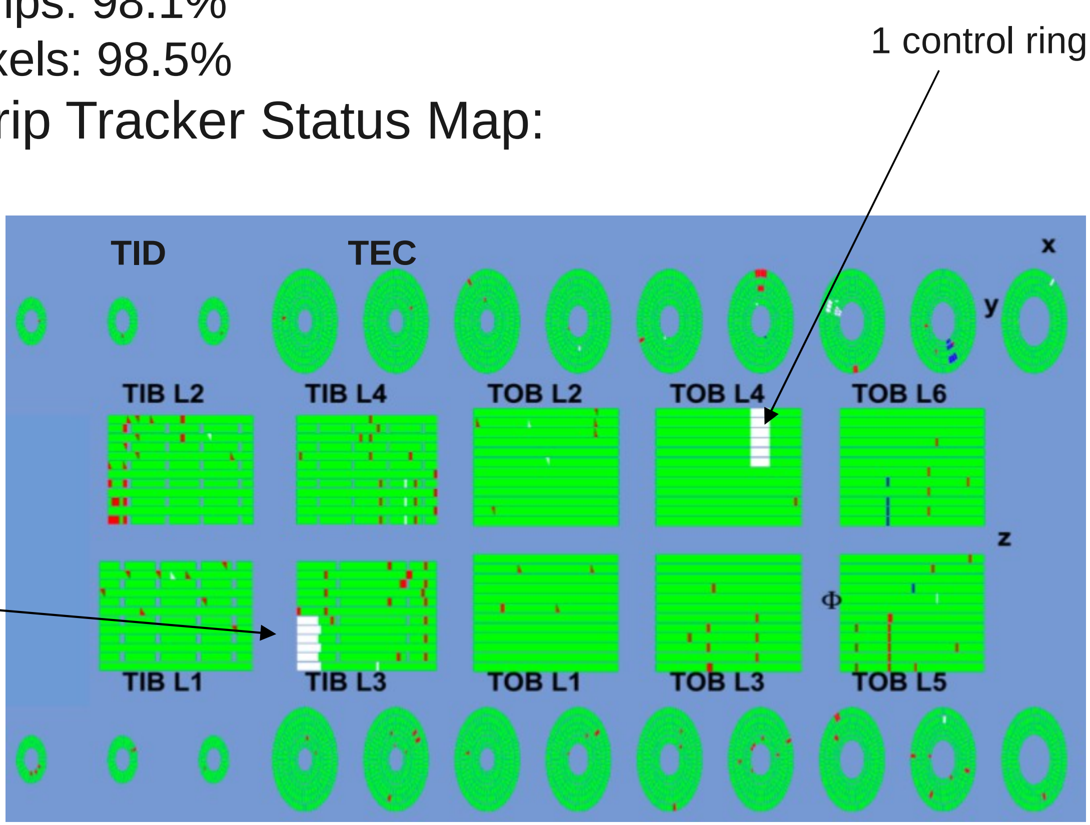
Detector status during CRAFT 09

CRAFT09



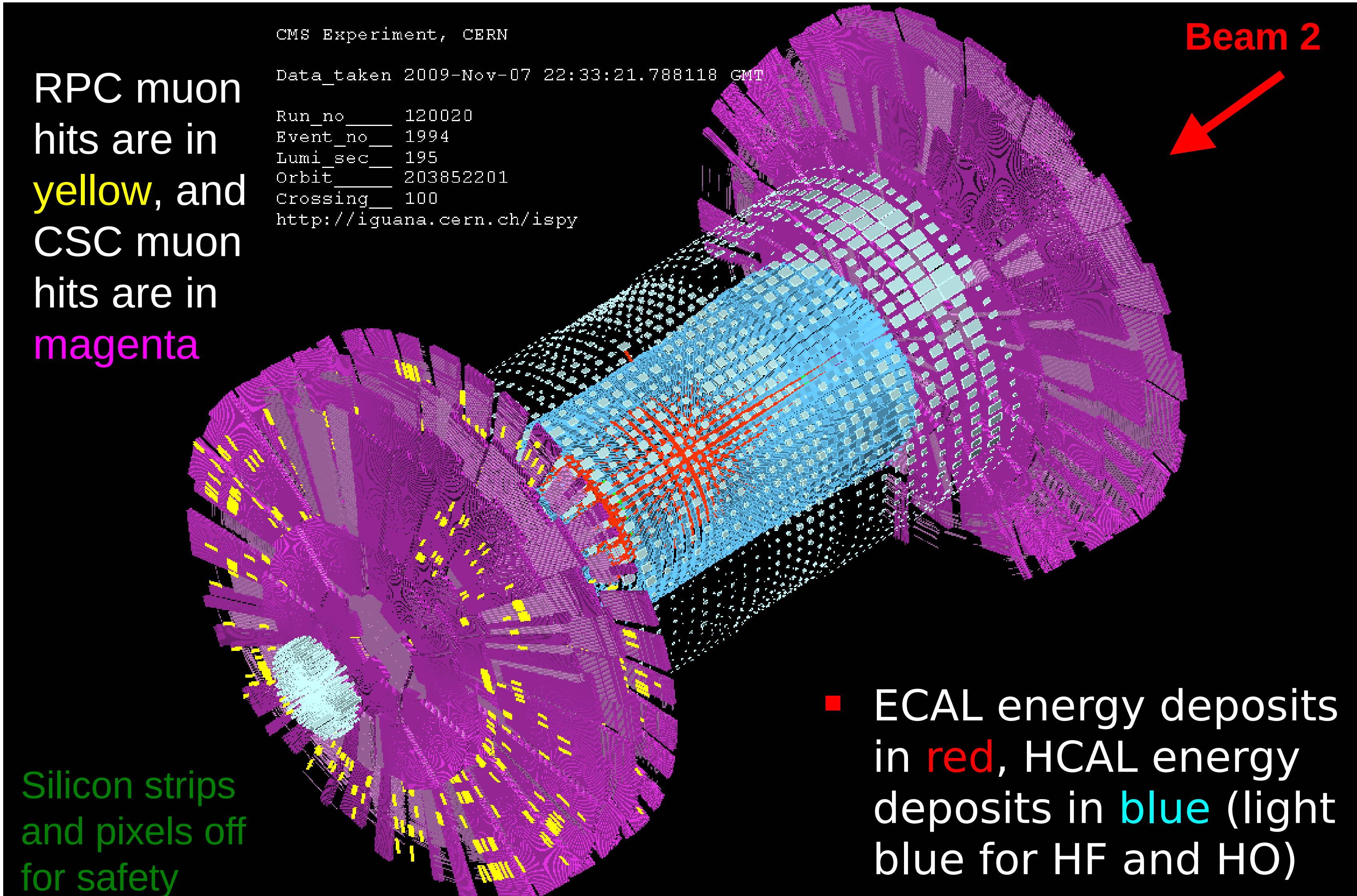
Average CRAFT09
data-taking efficiency: 71%
Without service disruptions: > 80%

Strips: 98.1%
Pixels: 98.5%
Strip Tracker Status Map:



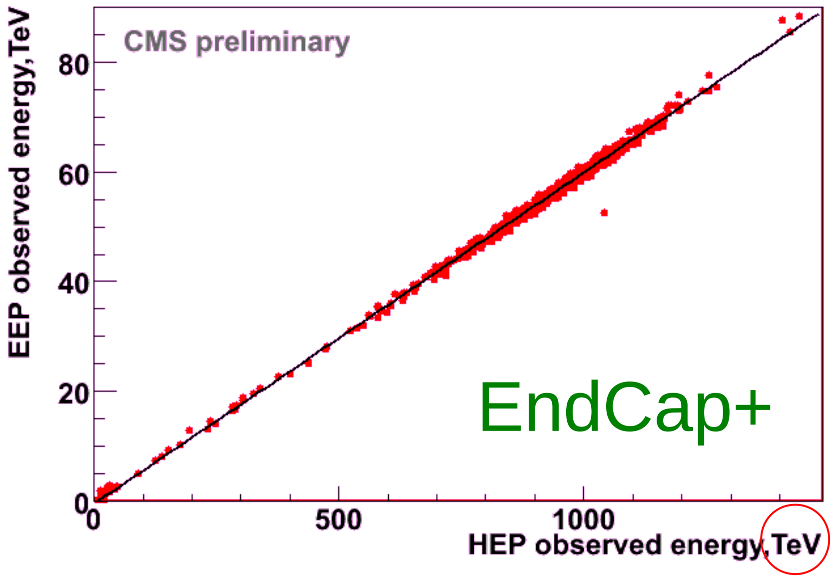
Beam splash 2009

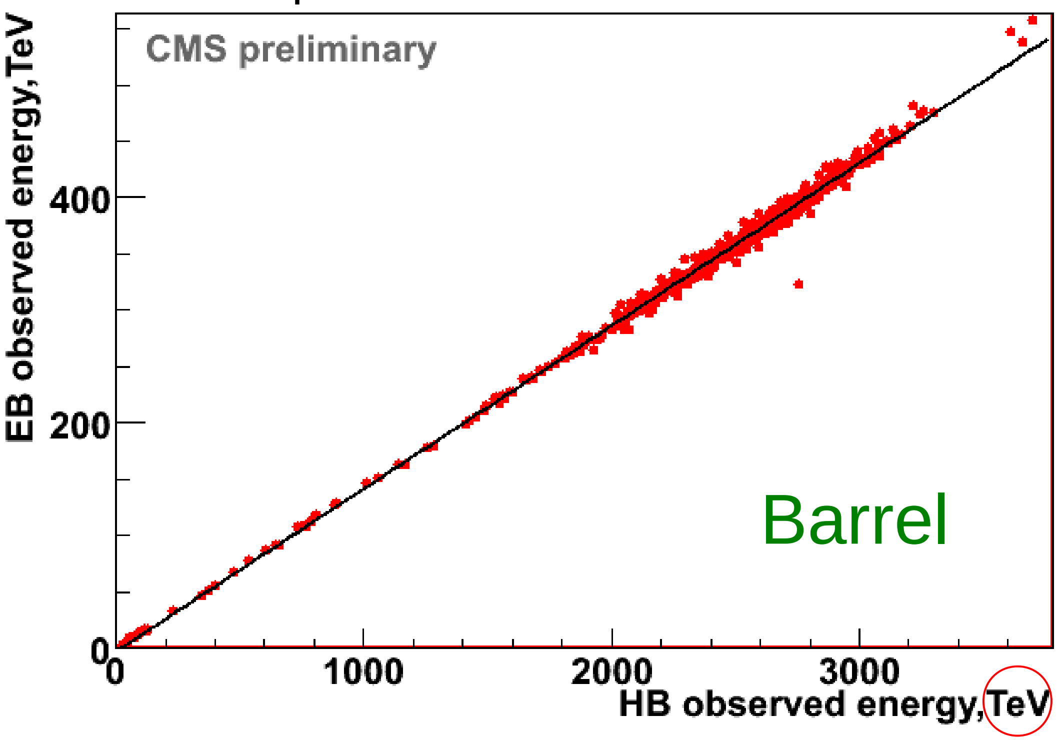
Nov.7-9, 2009 injection tests

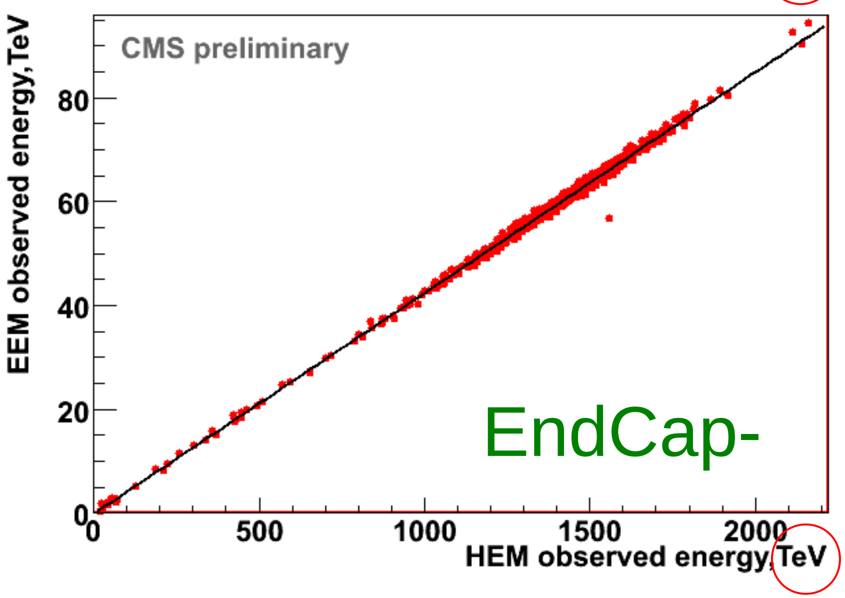


ECAL vs HCAL observed energy

- O(1000) splash events in a wide range of beam intensity
- Good linear correlation between ECAL and HCAL measured energies
  - Responce in EndCap+ lower than EndCap- to particle losses from material in CMS





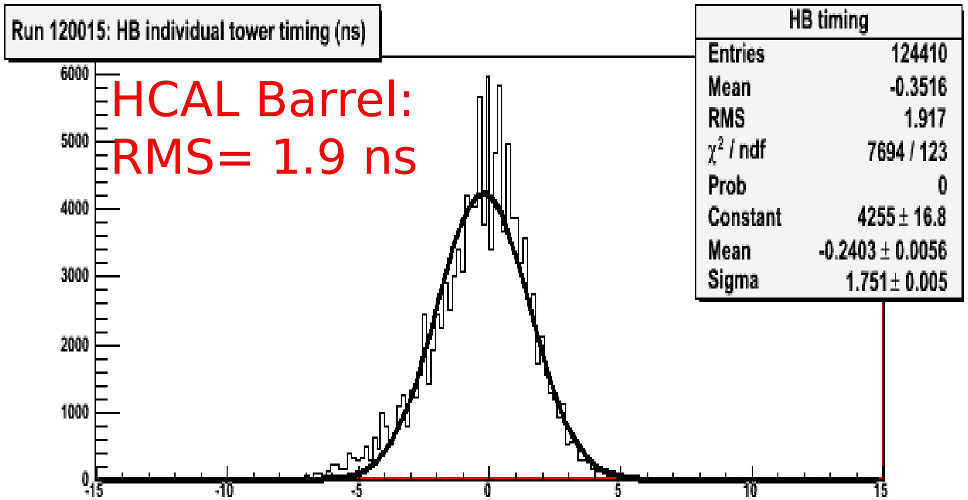


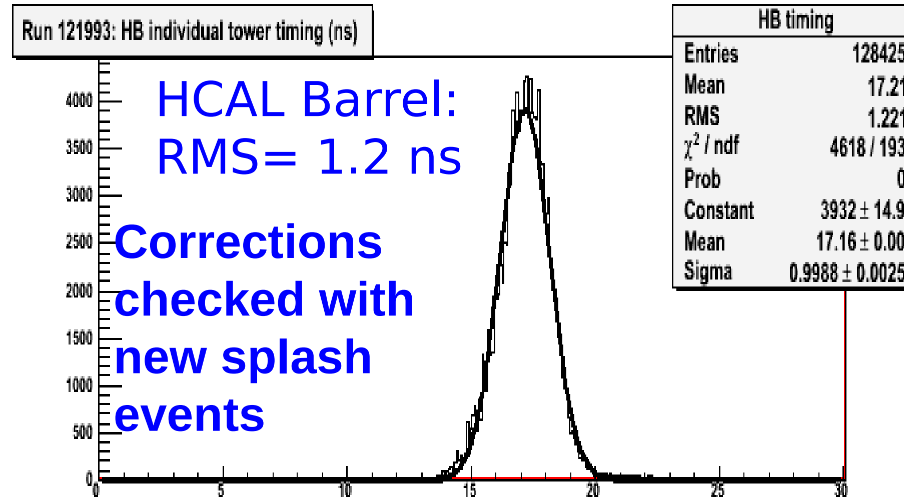
O(1M) muons per event ➔ 1000's of TeV/event!

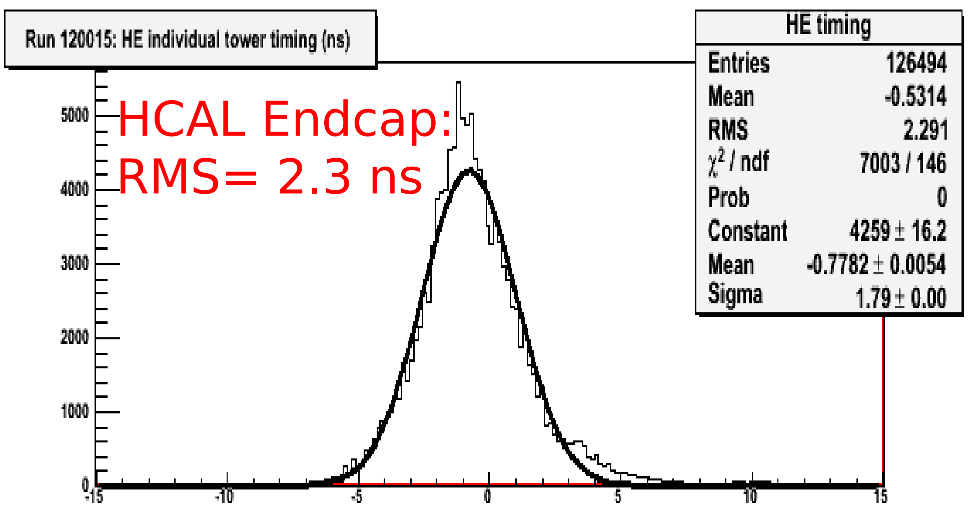
Synchronization HCAL

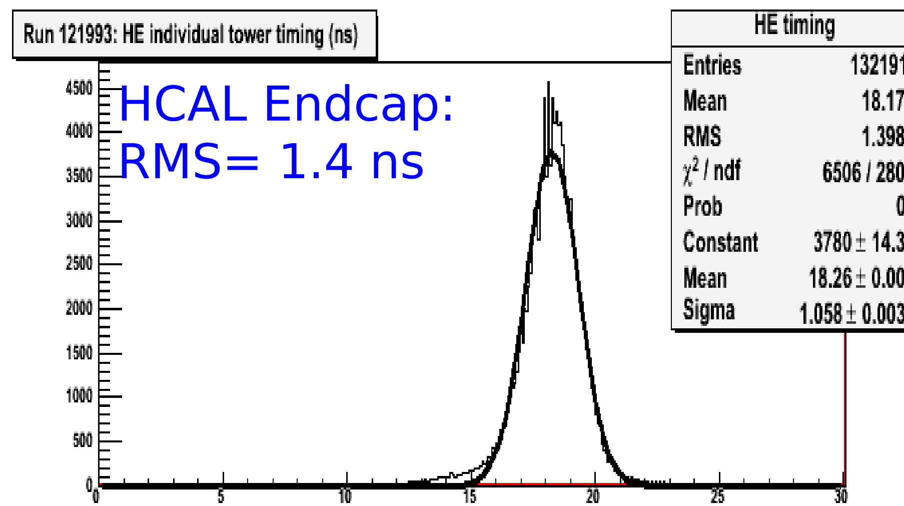
Splash09 - Before

Splash09: After





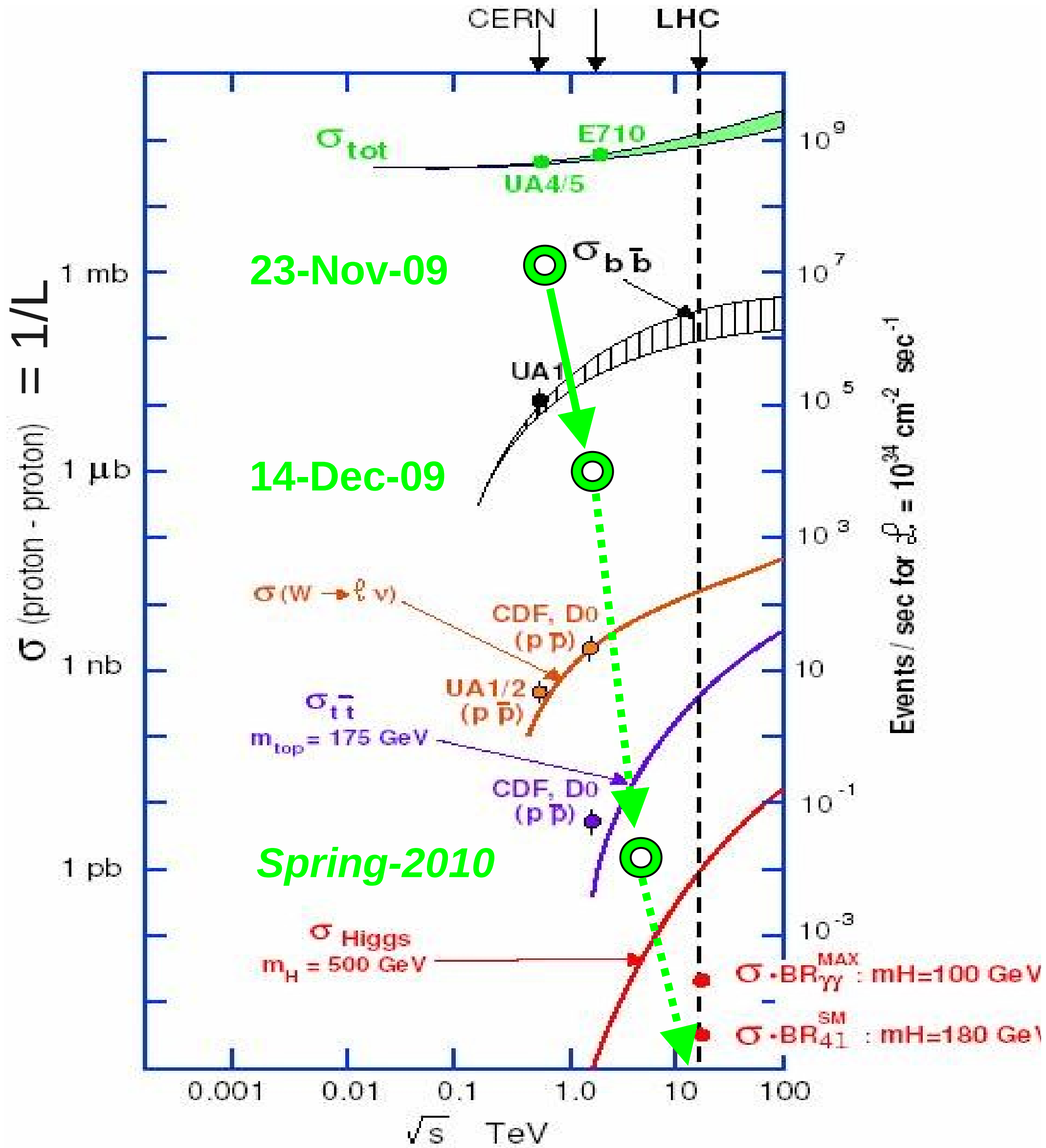




Similar timing improvements were achieved in ECAL Endcap and Preshower

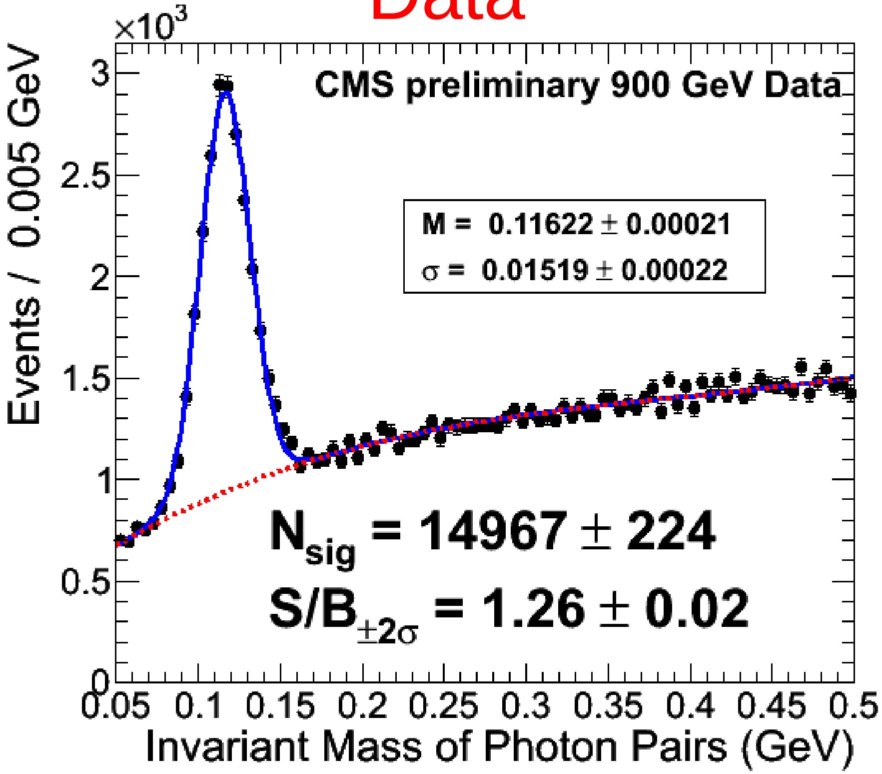
The LHC start-up 2009

- First collisions on Nov.23 at 900 GeV
  - ~0.1 Hz collisions
  - L ~ few 10^{24} $cm^{-2}s^{-1}$
- In Dec, collisions at 900 and 2236 GeV
  - ~10 Hz collisions
  - L ~ few 10^{26} $cm^{-2}s^{-1}$
- Ultimately, the LHC program should give
  - 14 TeV
  - 10^9 Hz collisions
  - L ~ 10^{34} $cm^{-2}s^{-1}$

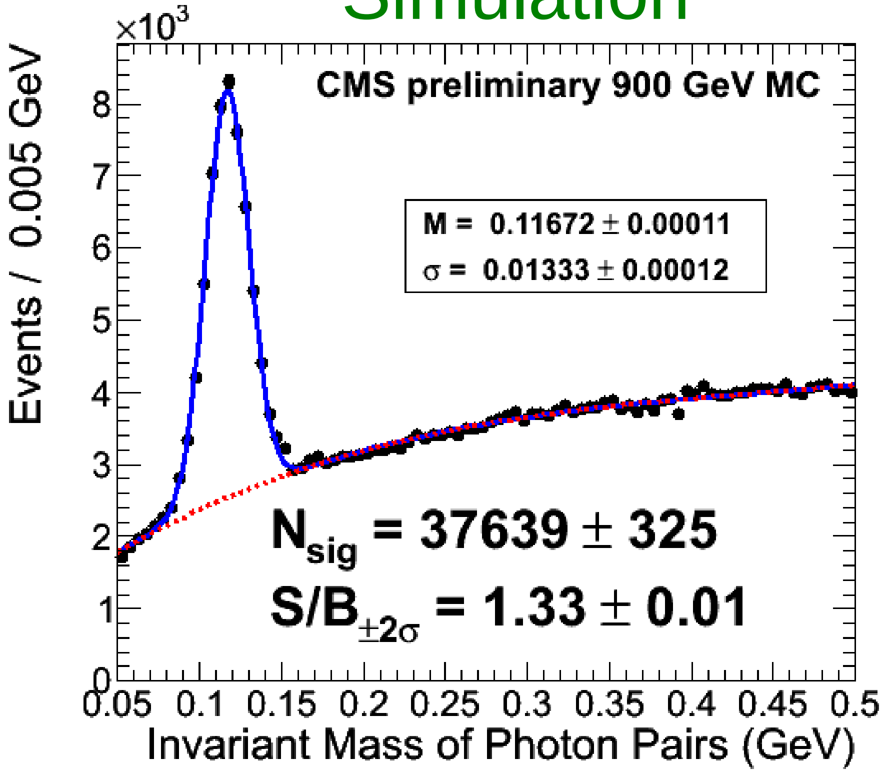


Calorimetry: $\pi^0 \to \gamma\gamma$

Data



Simulation



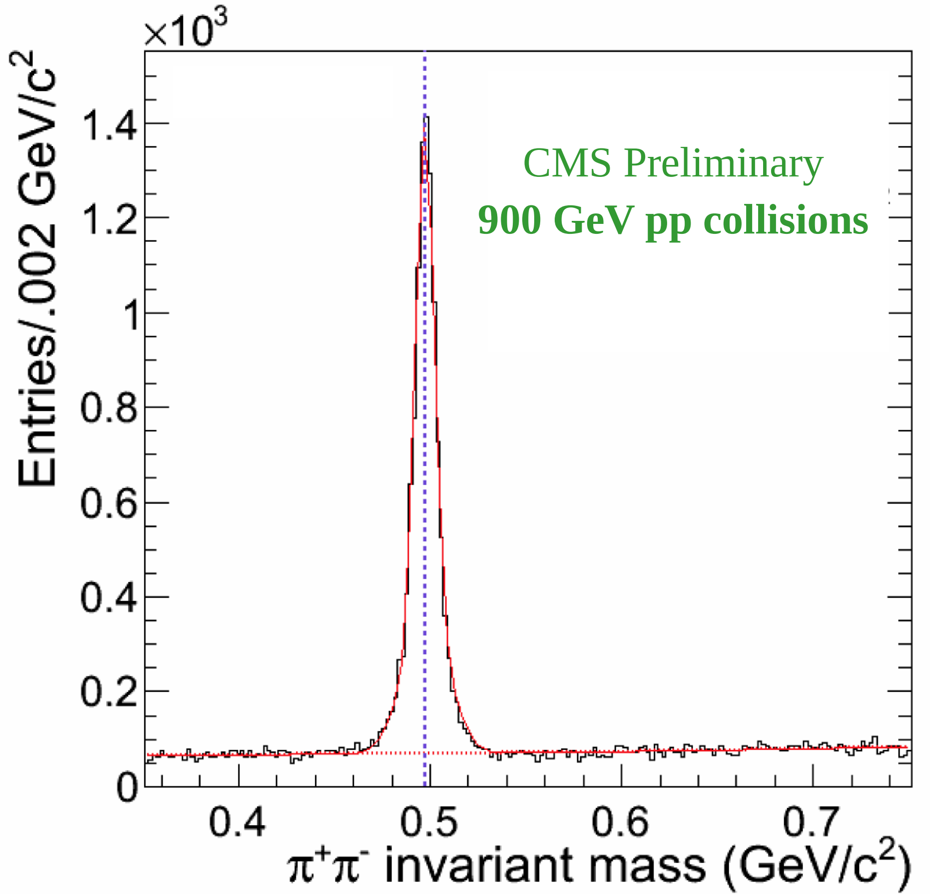
- Mass uncorrected for effects of the readout threshold of ECAL that had to be lowered, and material effects
- Data will be used to inter-calibrate the ECAL crystals, precision expected is O(1%)

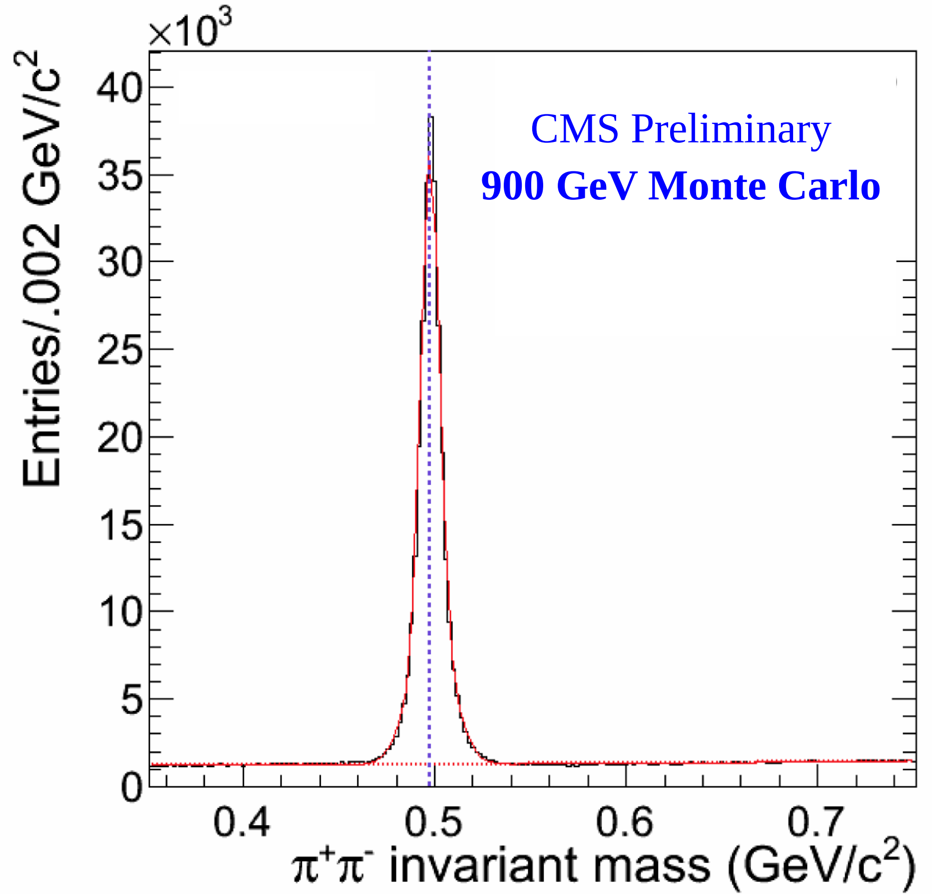
Tracking: Resonances

CMS Preliminary
900 GeV pp collisions
M = (497.58 ± 0.07) MeV/*c*2
σ1 = (4.74 ± 0.16) MeV/*c*2
σ2 = (11.57 ± 0.57) MeV/*c*2

K^0_s

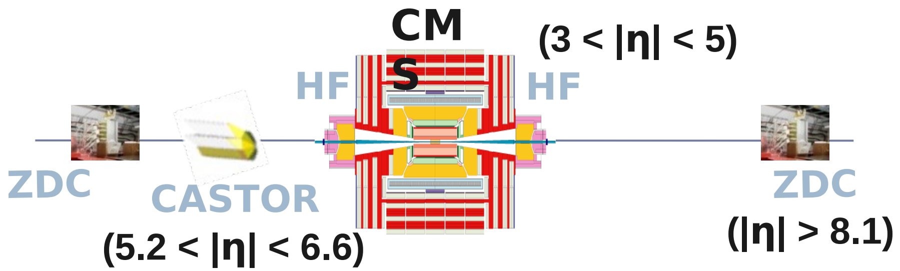
CMS Preliminary
900 GeV Monte Carlo
M = 497.97 MeV/*c*2
σ1 = 4.4 MeV/*c*2 ,
σ2 = 10.4 MeV/*c*2



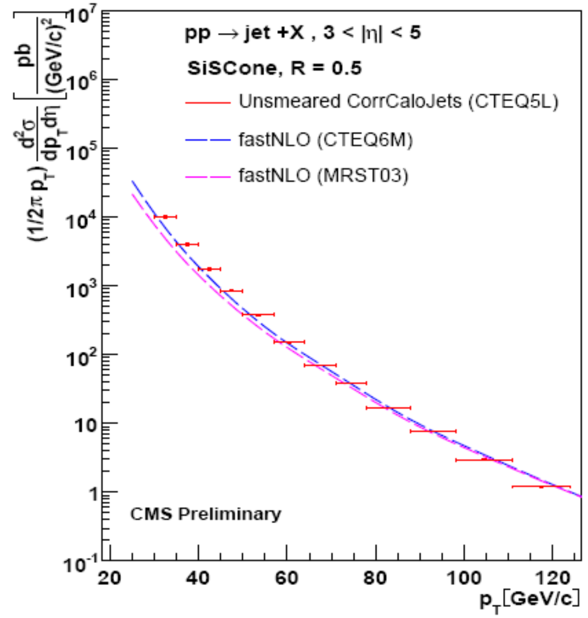


Double Gaussian Fits (From a sample of ~240k minimum bias events)

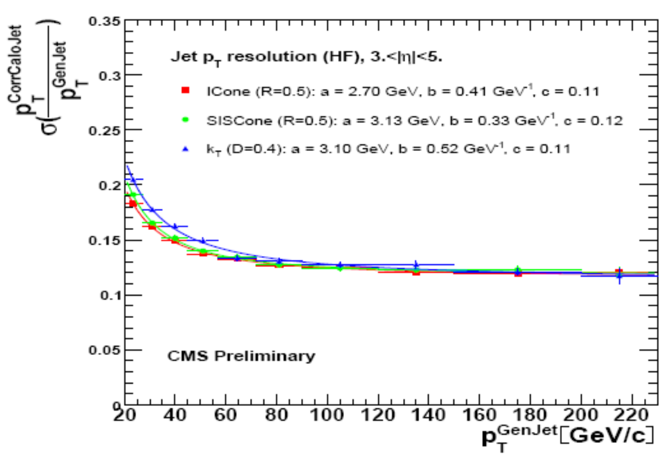
Forward jets



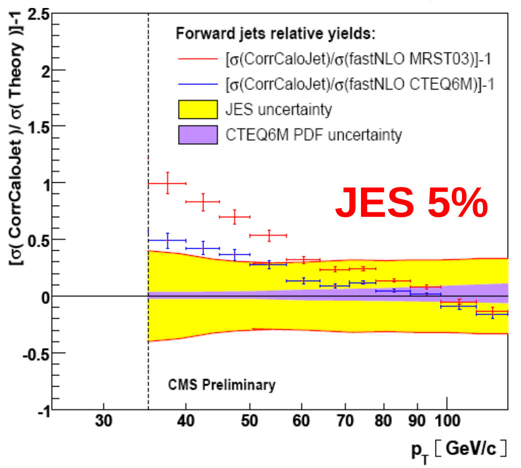
- Single inclusive forward jet spectrum with 1 pb^{-1}
- Jets reconstructable in HF from p_T ~ 35 GeV
- Very good (better than at mid-rapidities) energy and position resolutions (due to large forward boost)
- Main systematic source from jet energy scale (JES)



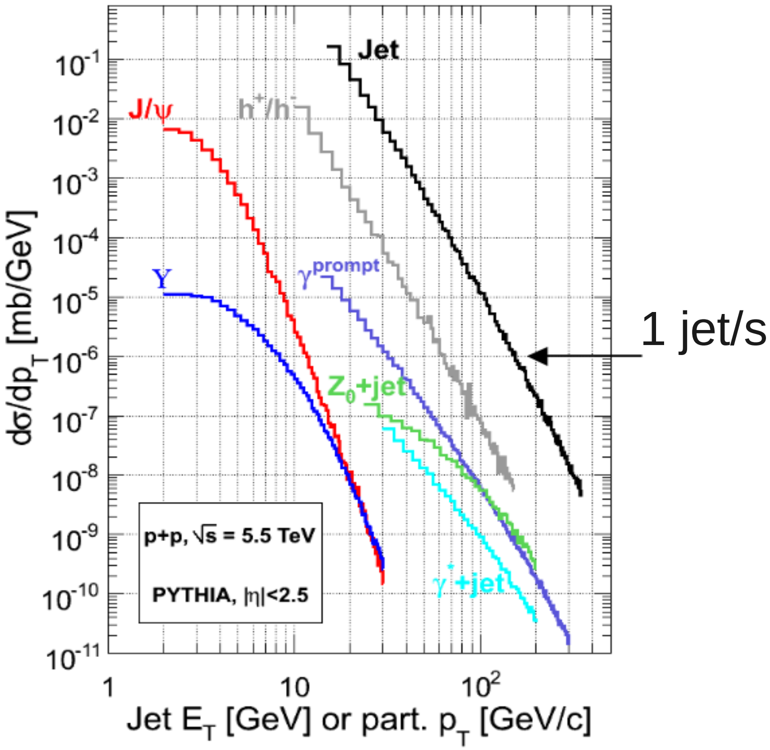
Jet energy resolution in HF

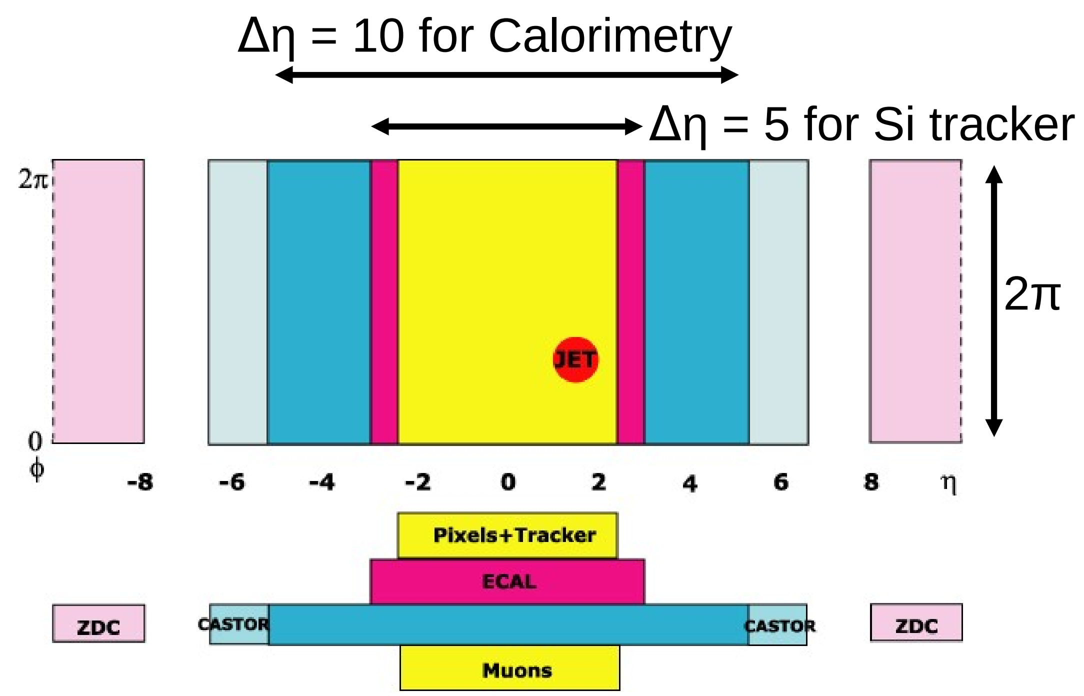


With improved JES, possible to constrain low-x gluon density



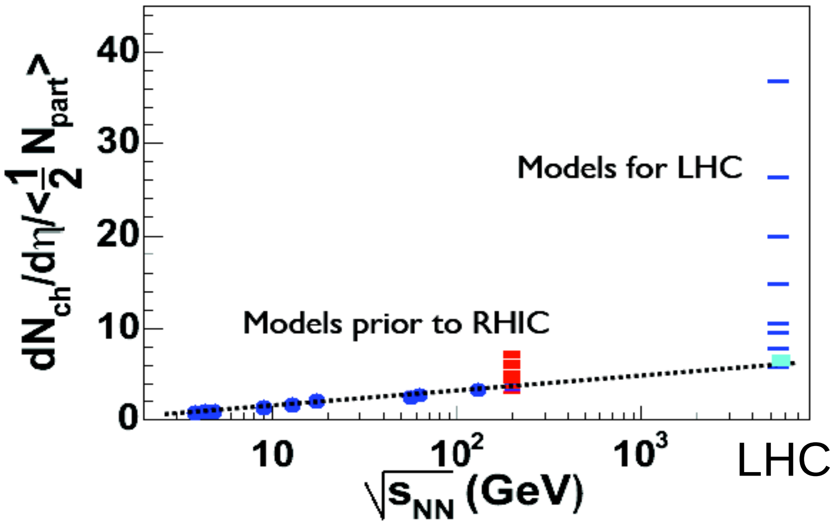
CMS as a HI experiment



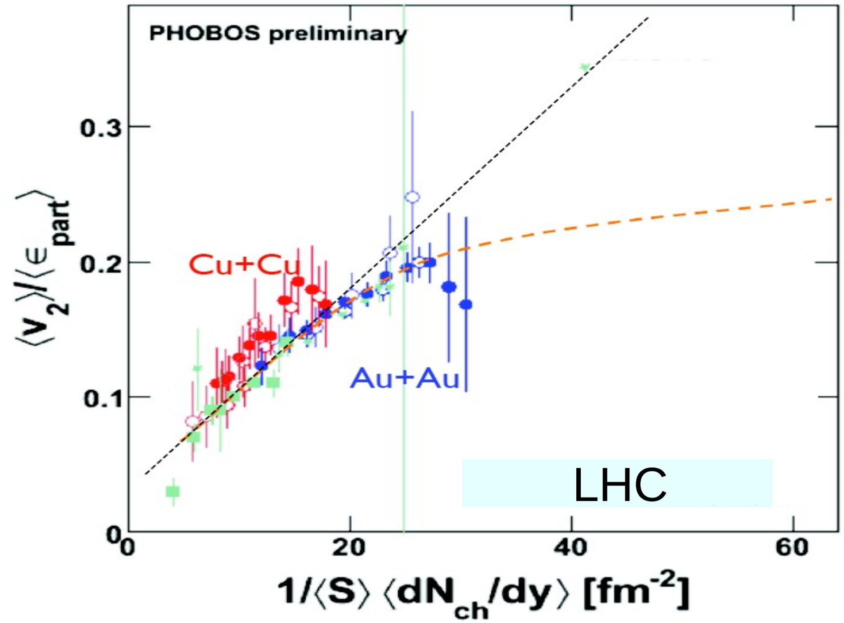


- Large (mid-rapidity) acceptance (tracker and calorimetry)
  - Also large forward coverage
- DAQ+HLT capable to inspect every single Pb+Pb event
  - Large statistics for rare probes

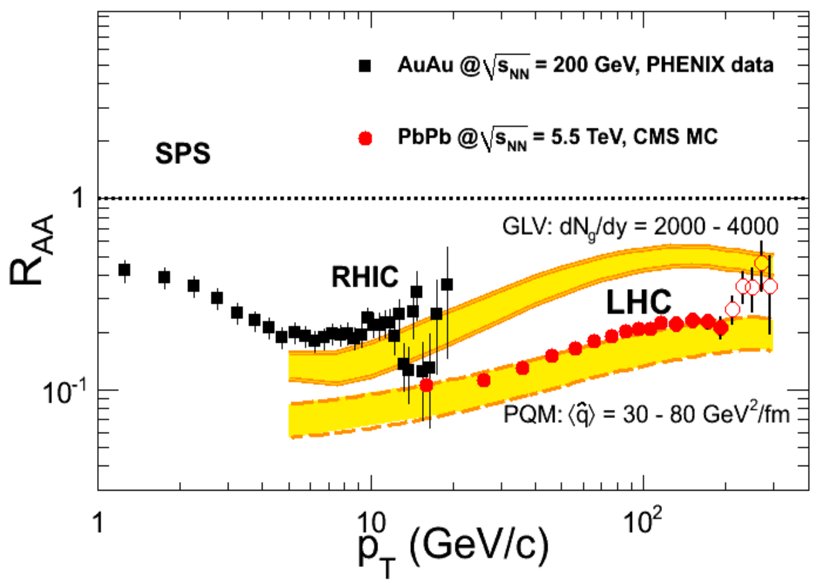
Expectations for Pb+Pb run in 2010



~1 day: Multiplicity → Initial density



~1 week: Does v_2 saturate?



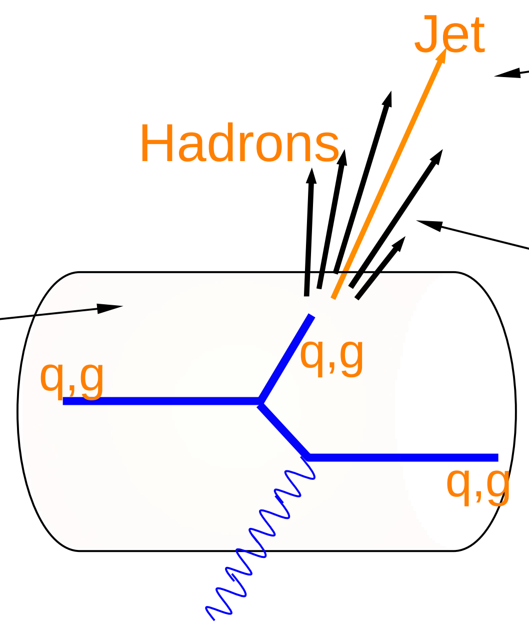
~1 month: Is the medium black?

Once we have these qualitative answers: Perform program of precision measurements of medium properties

Example study: Photon-tagged jet FF

Jet axis provides parton direction

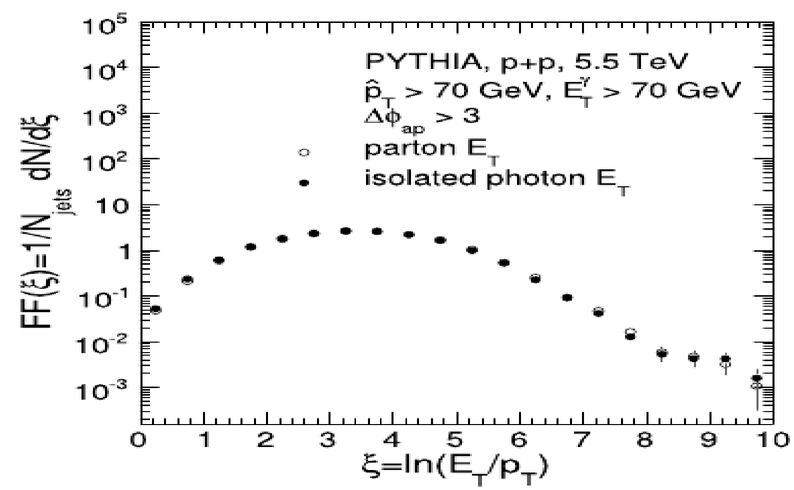
Multiplicity and flow measurements characterize density, path length



Charged hadron tracks used to calculate $z = p_T/E_T$

Photon energy tags parton energy E_T

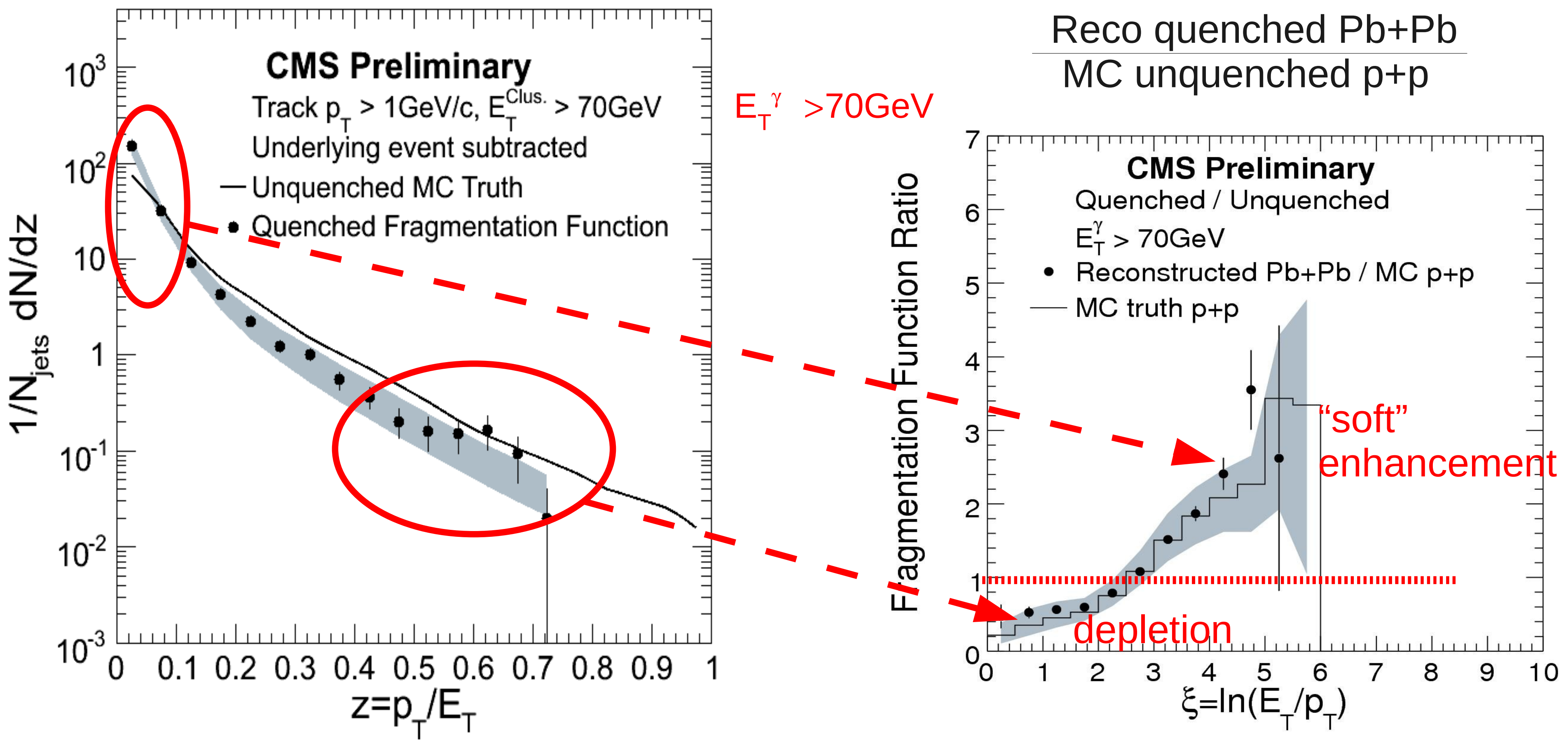
Measure jet fragmentation function:
$dN/d\xi$ with $\xi = -\log z = \log p_T/E_T$



All results based on GEANT-4 simulations using full reco algorithms for one run-year statistics at design lumi and at 5.5 TeV

CMS, JPG 35 104166 (2008)

Example study: FF ratio result



Medium modification of fragmentation functions can be measured with high significance for $0.35 < \xi < 5$ (or $z < 0.7$)

CMS, JPG 35 104166 (2008)