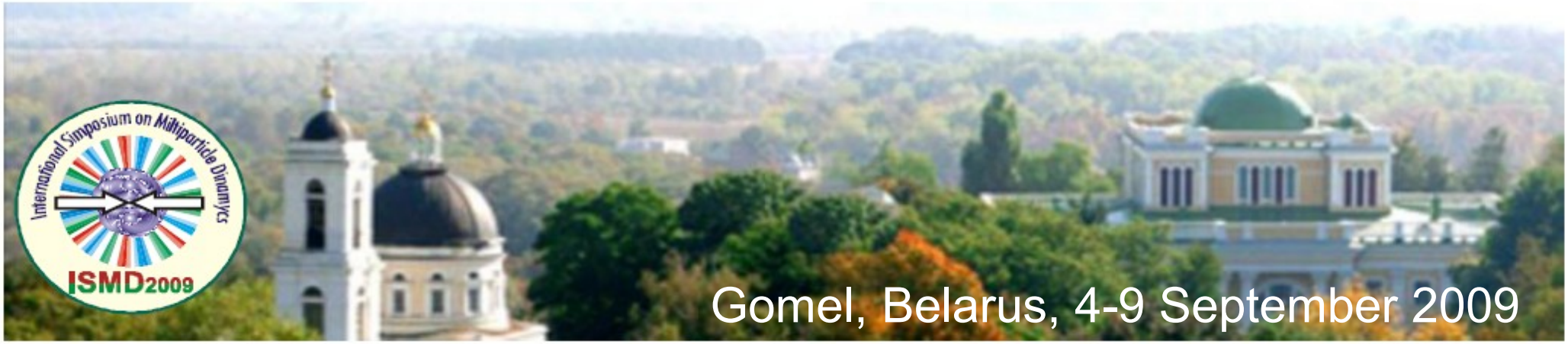
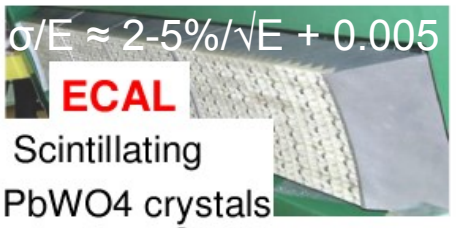
CMS status and early physics plans

Constantin Loizides

for the CMS collaboration



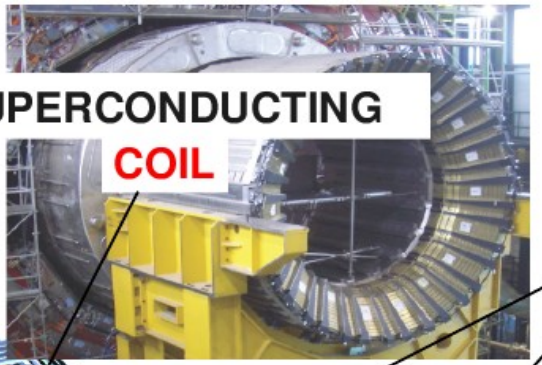
Compact Muon Solenoid



$\sigma/E \approx 2\text{-}5\%/\sqrt{E} + 0.005$

ECAL

Scintillating PbWO4 crystals



SUPERCONDUCTING COIL

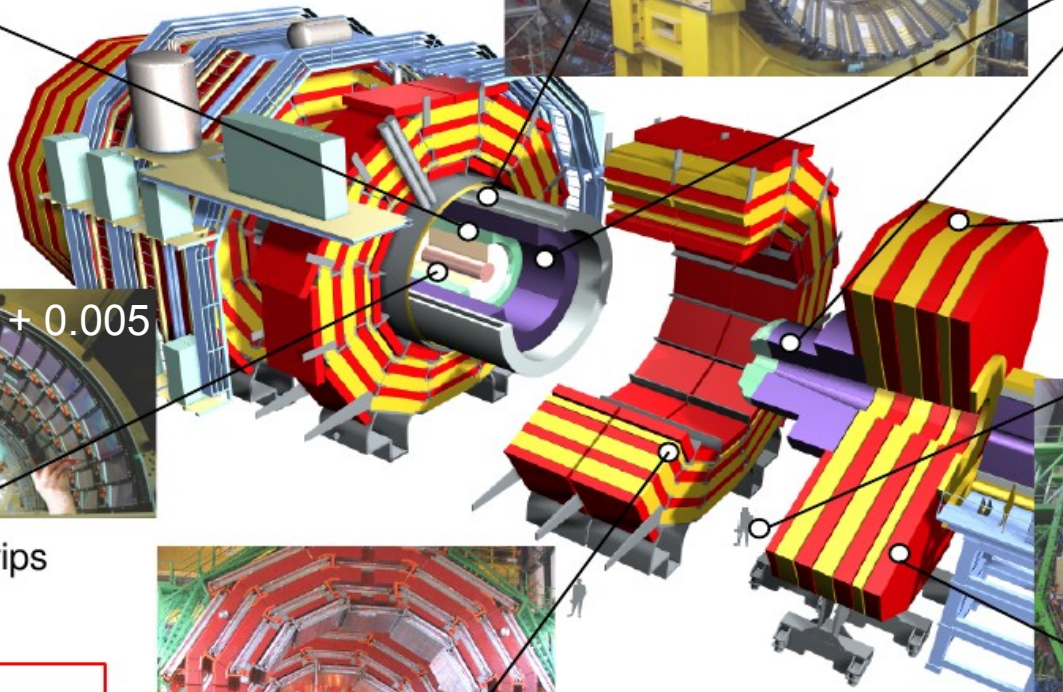
HCAL

Plastic scintillator/brass

$\sigma/E \approx 100\%/\sqrt{E} + 0.05$ GeV

IRON YOKE

human



$\sigma/p_T \approx 1.5\text{x}10^{-4} p_T + 0.005$

TRACKER

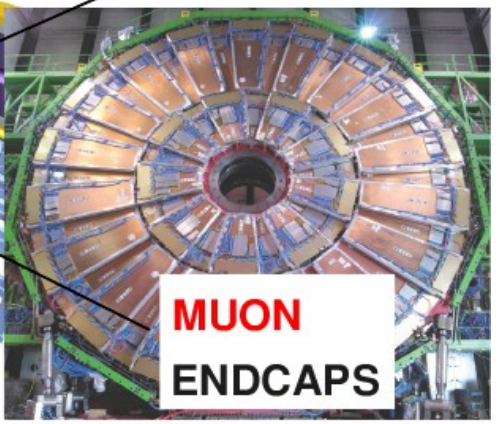
Silicon Microstrips

Si Pixels

MUON BARREL

Drift Tube Chambers (**DT**)

Resistive Plate Chambers (**RPC**)



MUON ENDCAPS

Cathode Strip Chambers (**CSC**)

Resistive Plate Chambers (**RPC**)

Length: 21.6 m

Diameter: 15 m

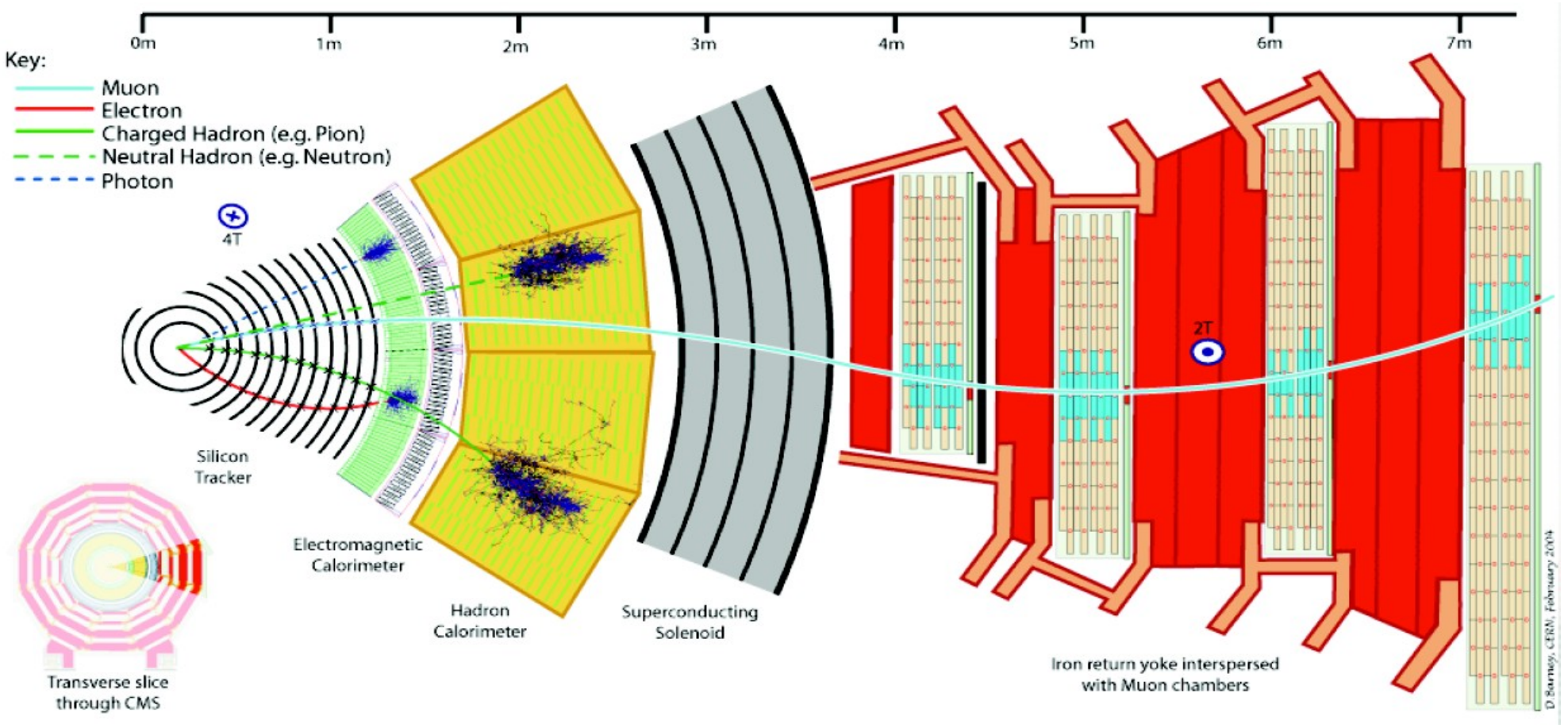
Weight: ~14000 tons

Magnetic Field: 4 Tesla

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

Detector concept

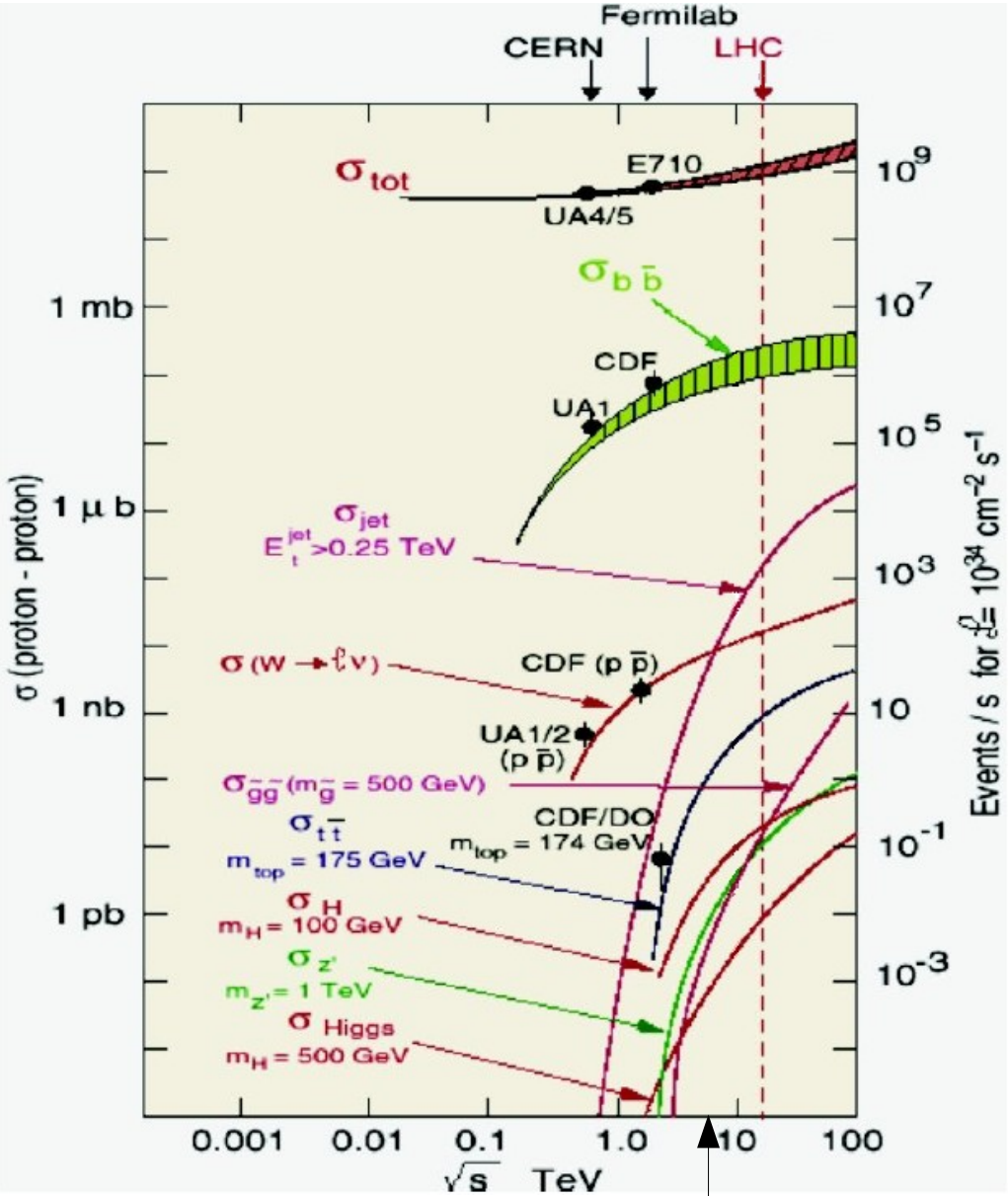
Nearly 4π, hermetic redundant, Russian-doll design



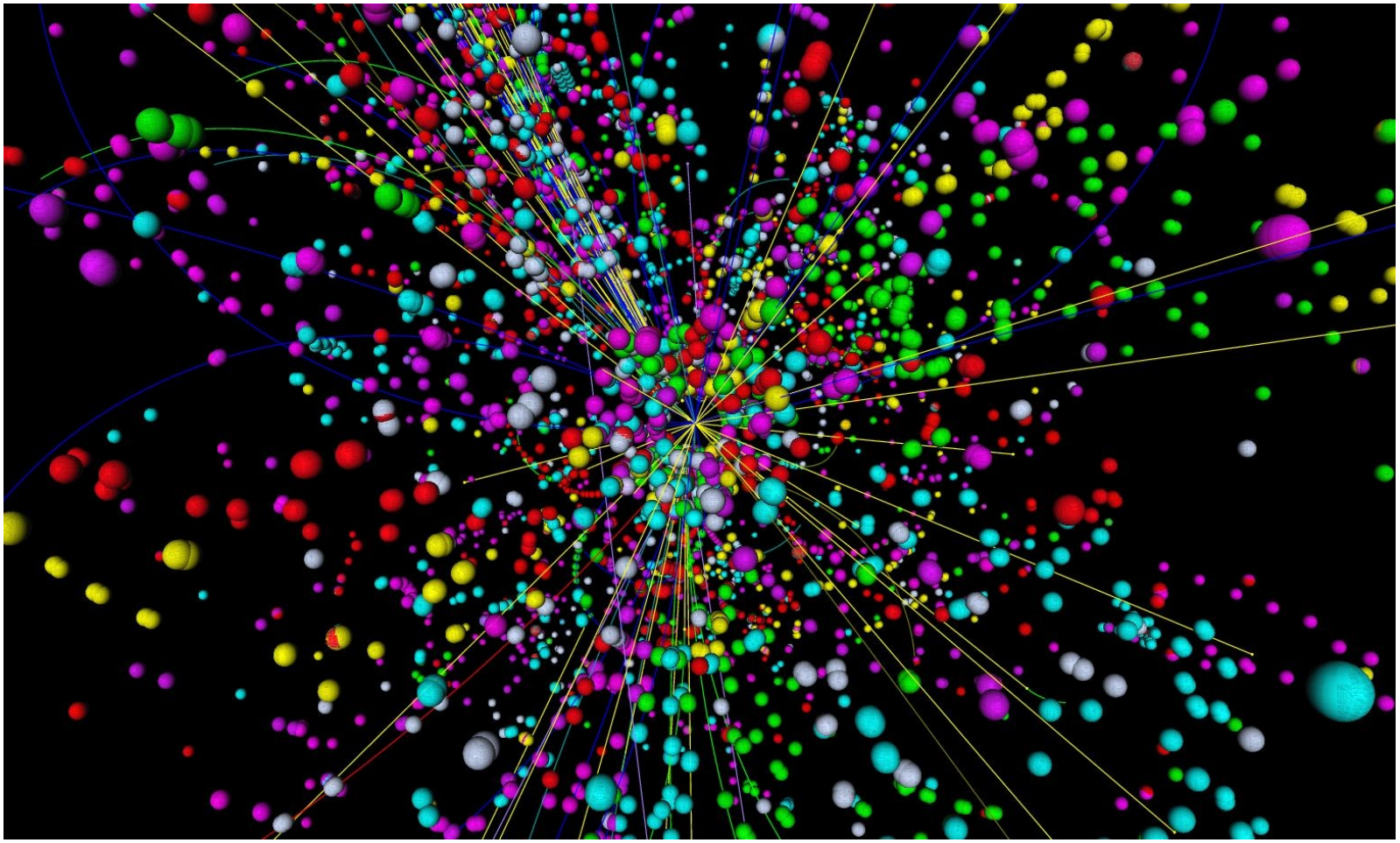
And Missing Transverse Energy (MET) for anything that does not interact

Physics overview

- Production relative to σ_{tot}:
  - bb at 10^{-3},
  - W→lν at 10^{-6}
  - Higgs(160GeV) at 10^{-11}
- 40Mhz beam crossing, only about 300Hz tape writing: ~10^{-5}
- Fast and sophisticated selection process essential: trigger



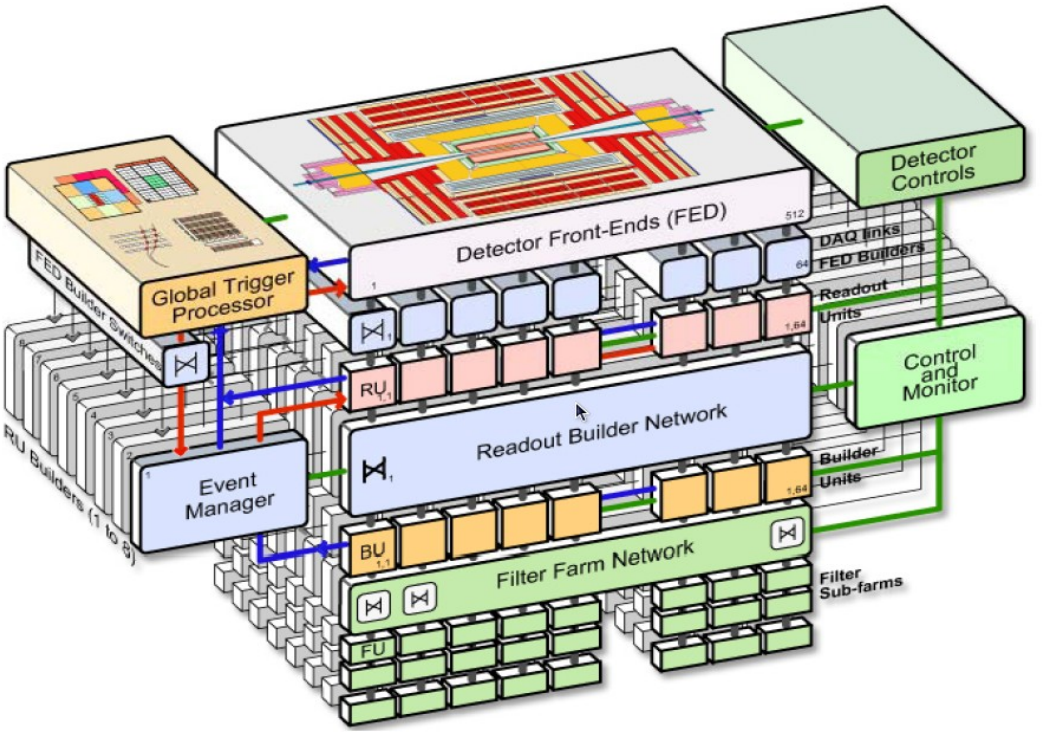
The trigger challenge



Have to “understand” this sort of image 40 million times per second

CMS DAQ/Trigger system

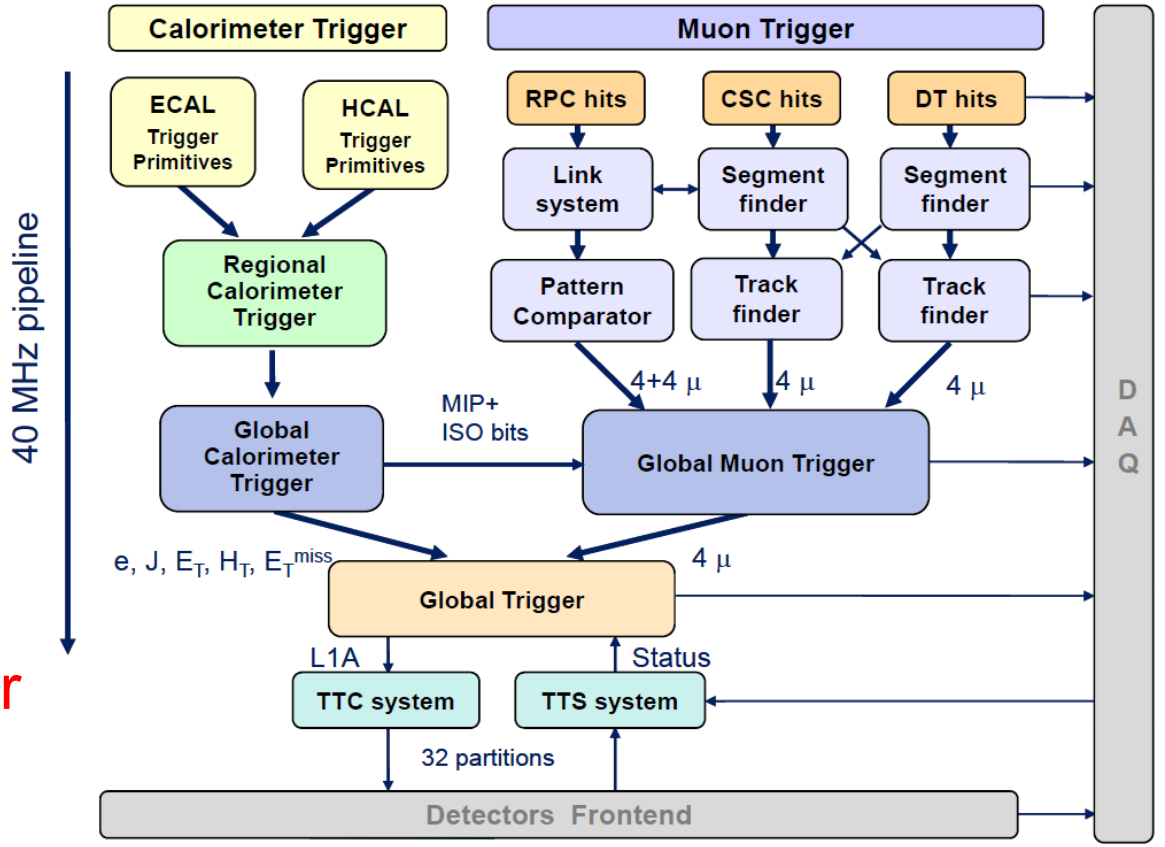
- Level-1: hardware trigger
  - Reduce to 100Khz
- High-level trigger: software trigger
  - Parallel readout (up to 16 slices)
  - Has logical steps (L2, L3)
  - Reduce to O(100) Hz



BU=Builder Unit
FU=Filter Unit

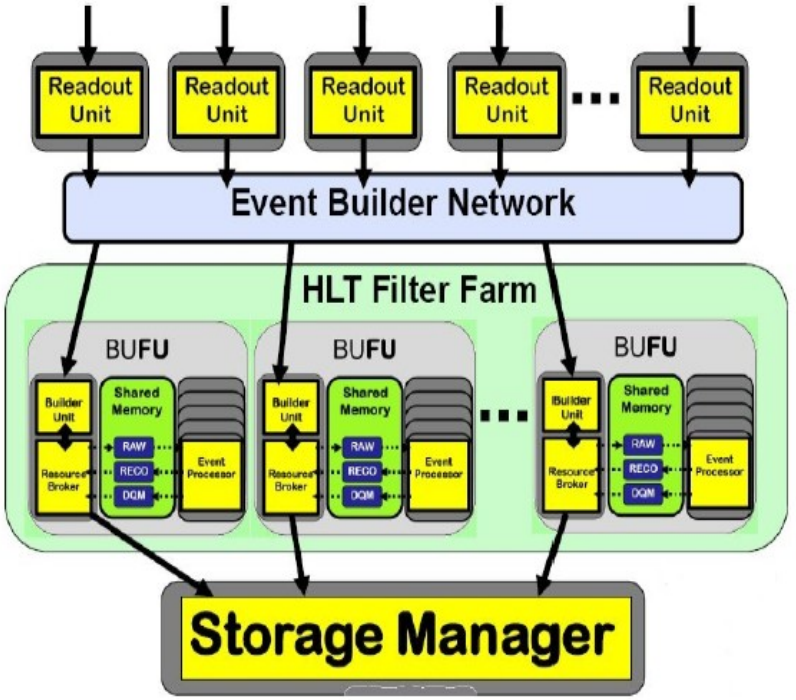
Level-1 trigger data flow

- 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



HLT data flow

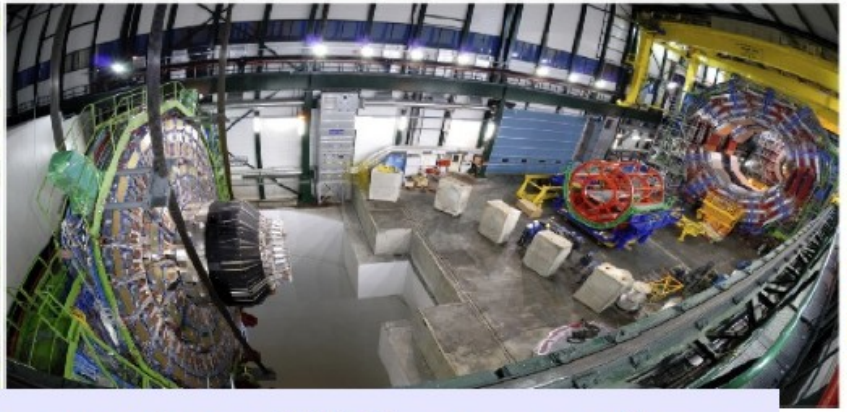
- HLT Level-2
  - Unpack muon, ecal, hcal data
  - Based on L1 seeds perform local reconstruction
  - Apply L2 algorithms and filter
- HLT Level-3
  - Unpack tracker locally (mostly pixel)
  - Perform local reconstruction based on L2 results
  - Apply L3 algorithms and filters
- Send accepted events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



Transfer from P5 to CERN

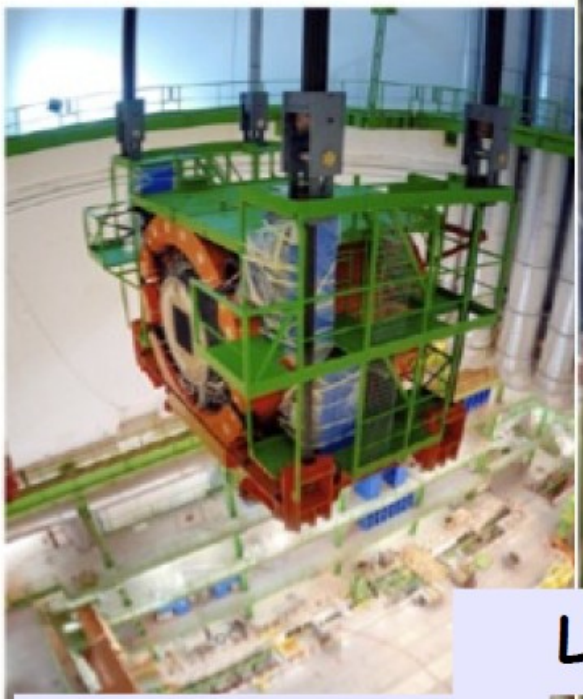
Tier-0:
Prompt reconstruction
Calibration streams
Archival copy of data
Distribution to Tier-1

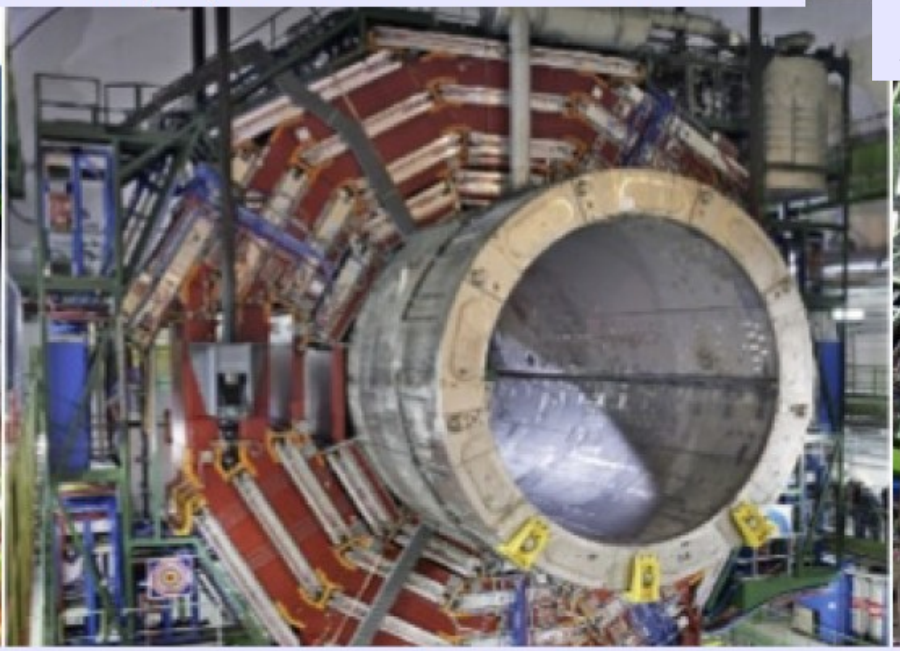
CMS commissioning in pictures

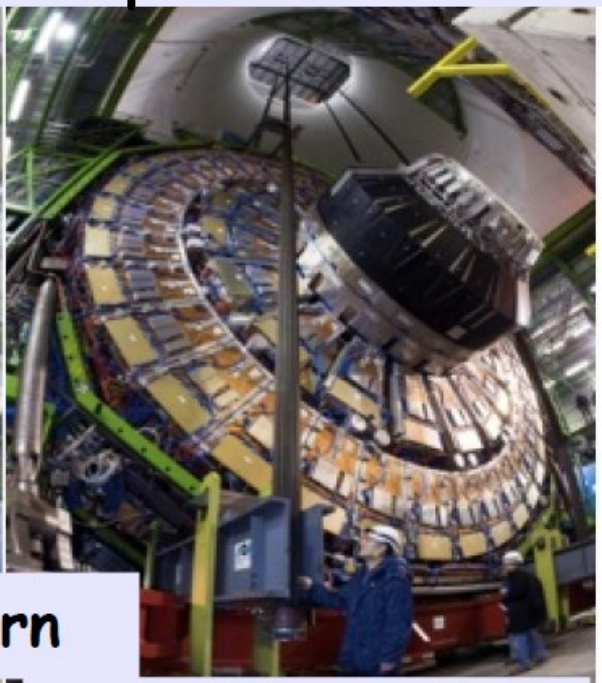


May 2006 – cavern empty, CMS on surface

Insertion of Silicon Strip Tracker Dec 08

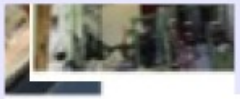






Lowering detector in the cavern

1 Nov06 HF-

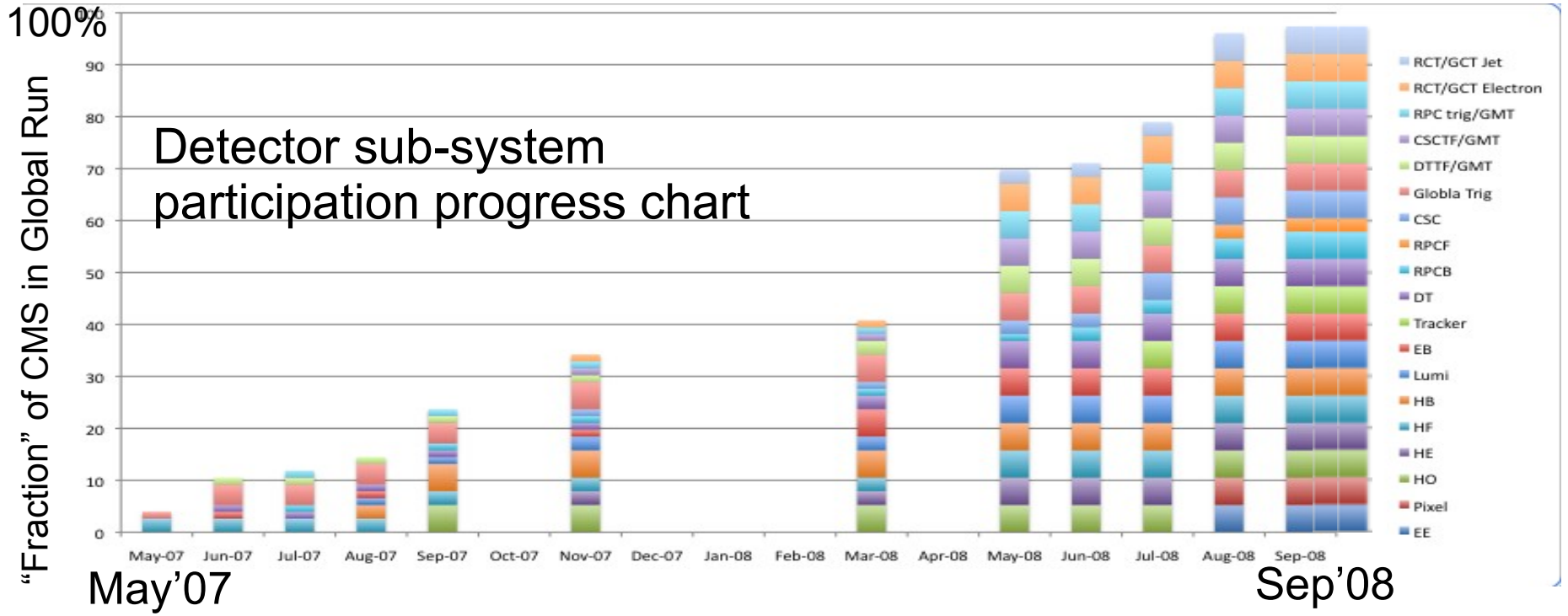


9 Feb07 YB0

15 Jan08 YE-1

CMS commissioning underground

- Started May 2007 – few to 10 day “global runs” / month
  - Integrate 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 beam in 2008

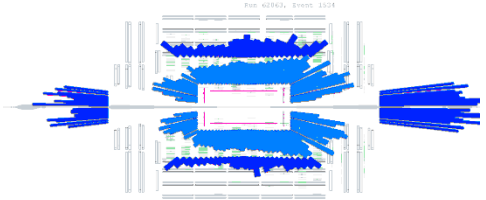
- Splash events
  - Synchronization tests (4-9 Sep): Beam (450 GeV, $4x10^9$ p) hits collimators 150m upstream of CMS
  - Use to study occupancy, synchronization and bad channels
- Beam halo events
  - Circulating beams (Sep 10-11): Beam protons interacting with beam elements and gas
  - Use to commission forward detectors

All systems on except tracker and magnet

Beam splash events

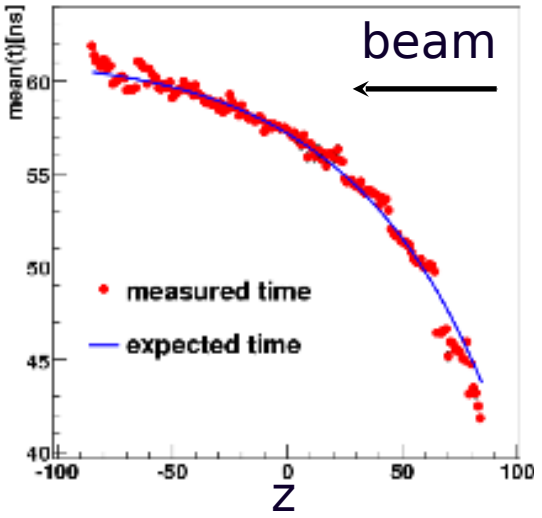
170TeV

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

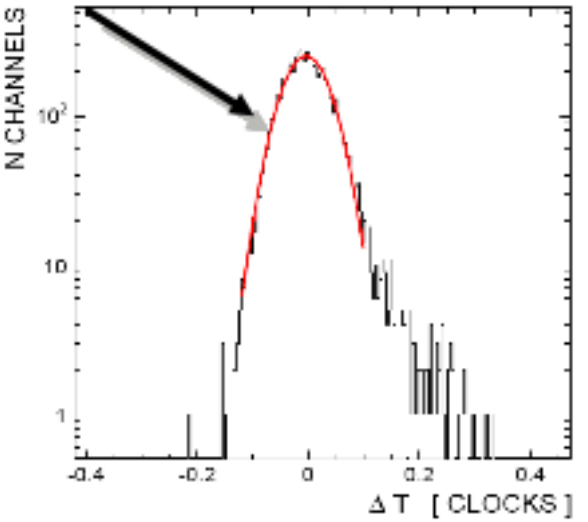


1000TeV

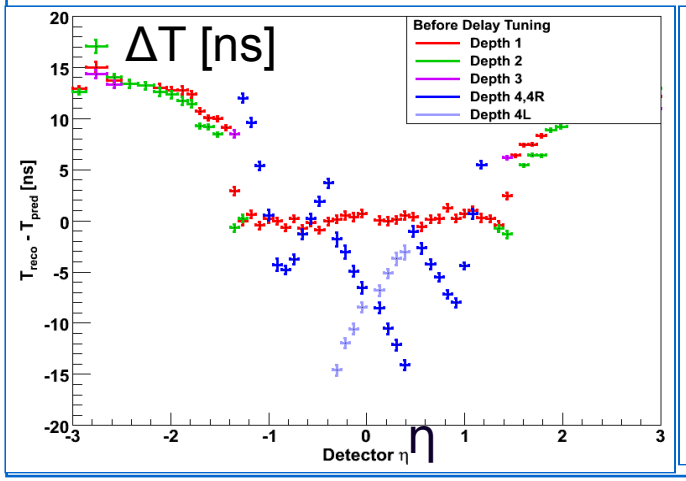
ECAL

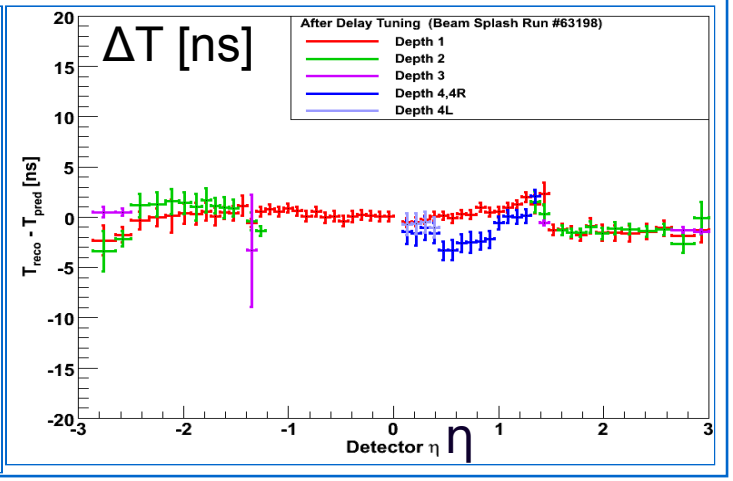


1 ns



HCAL





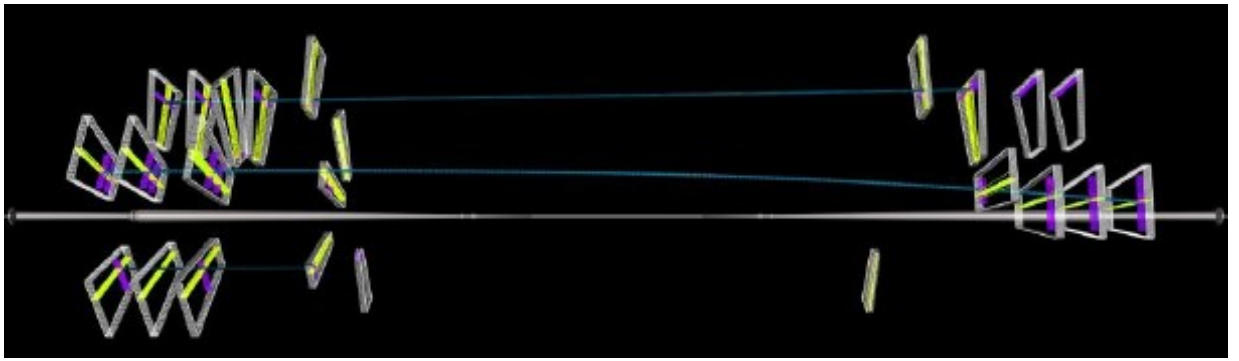
Before delay tuning

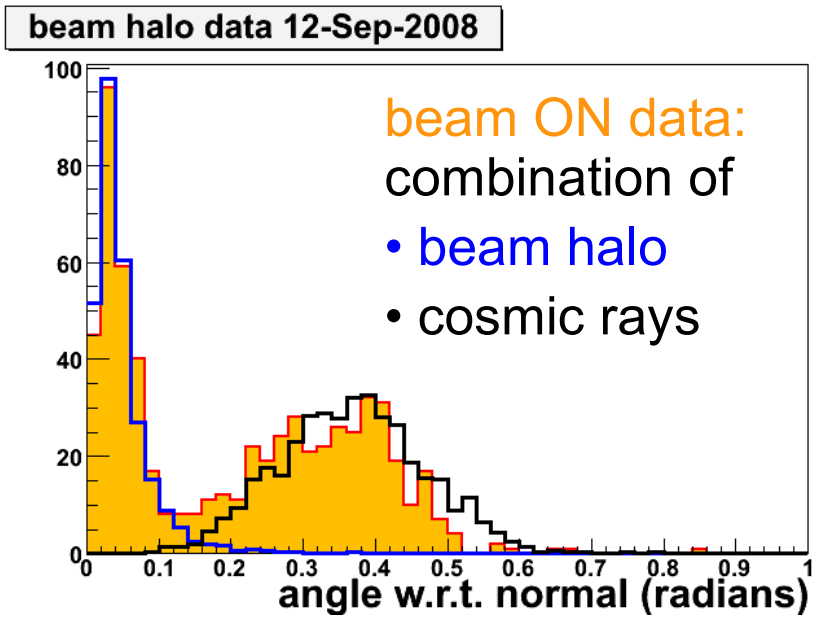
After delay tuning

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

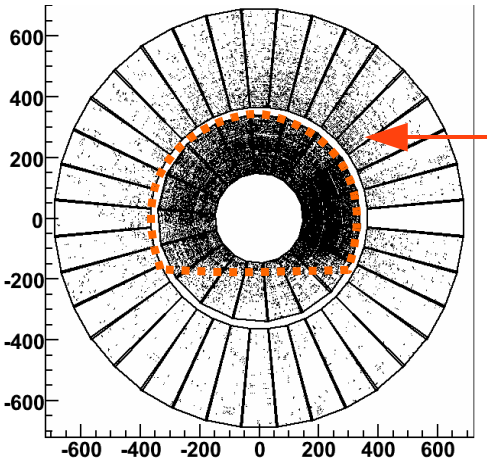
Muons go almost parallel to the beam:
A perfect X-ray of the muon Endcap





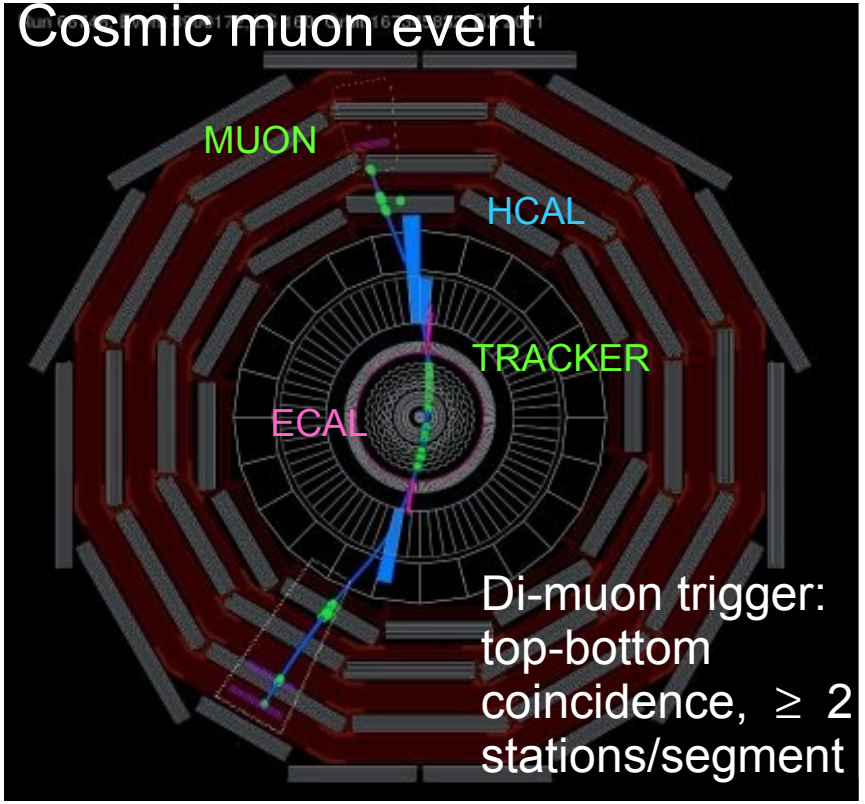
Reconstructed track angle wrt transverse plane

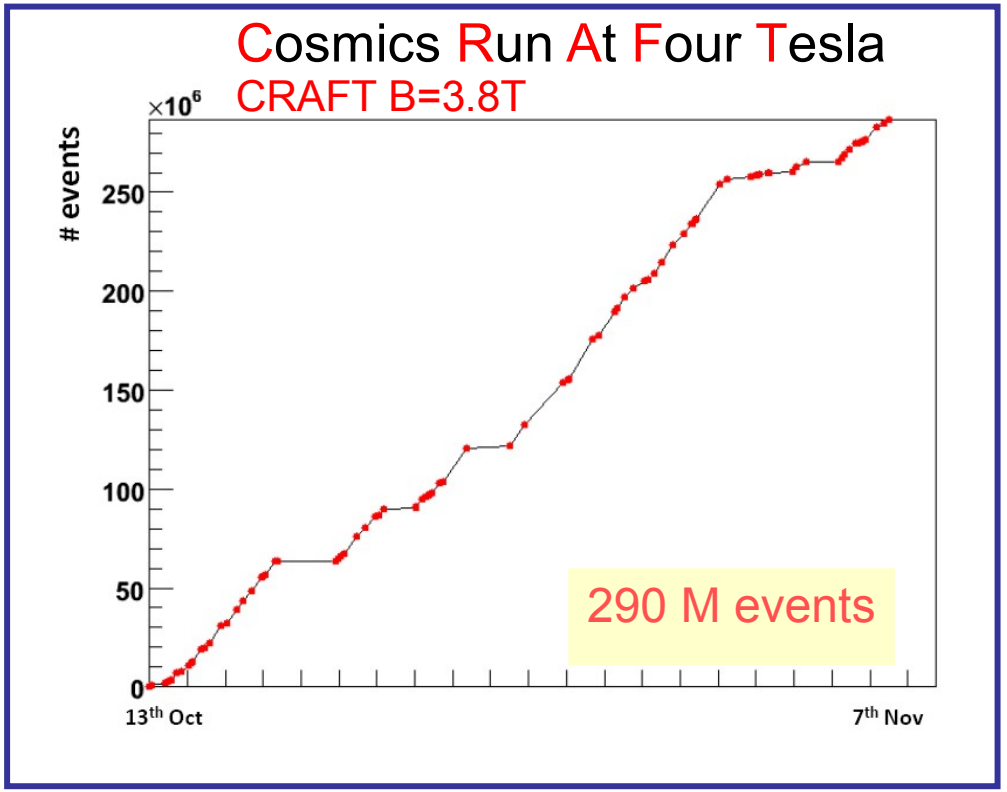
CSC Hit Distribution



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

Cosmic run at operating field (CRAFT)





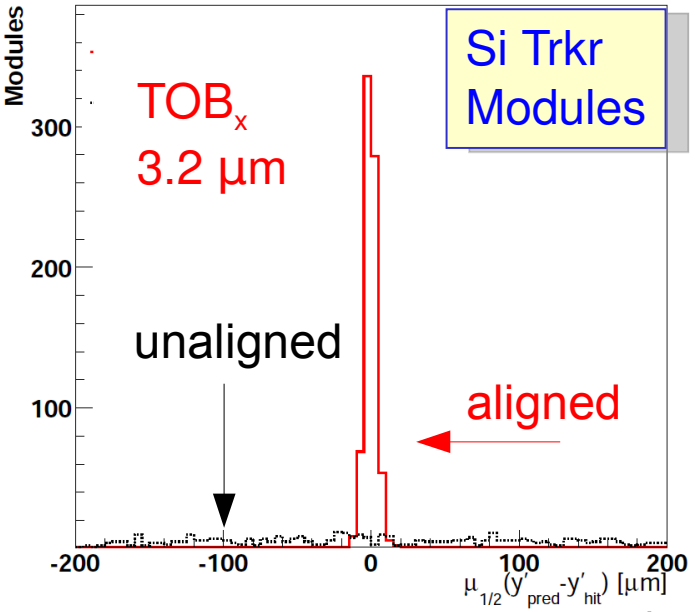
- Great data to enhance detector and software quality
  - Equivalent > 10 pb^{-1}
- ~25 papers in preparation (to be submitted by end of Sept 09)

- 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

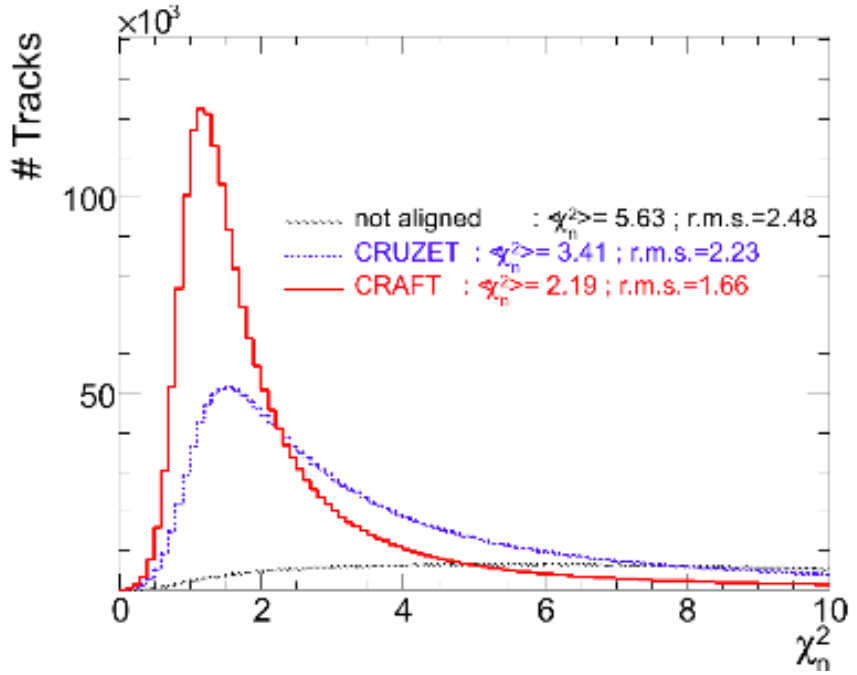
Tracker alignment

CRAFT

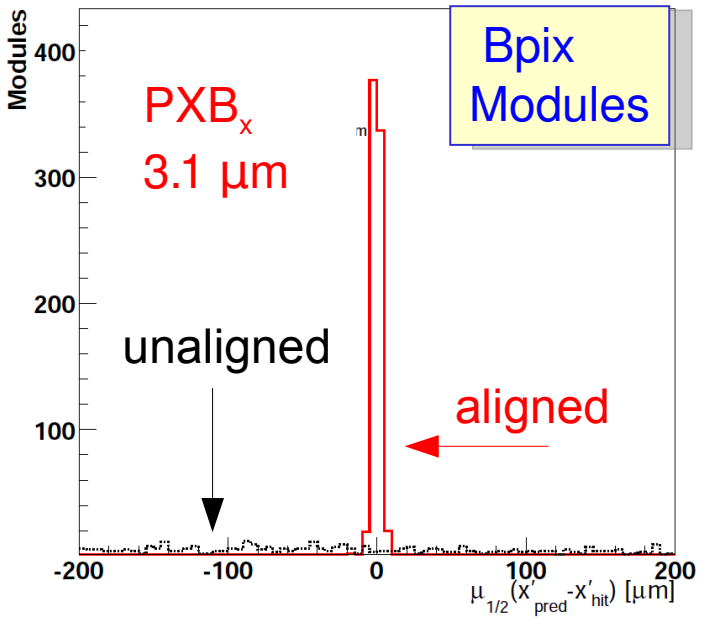
13 layers in the Barrel
14 layers in the Endcaps
9.6M strips
66M pixels
More than 200 m² Si



Residual hit distribution (in x)



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

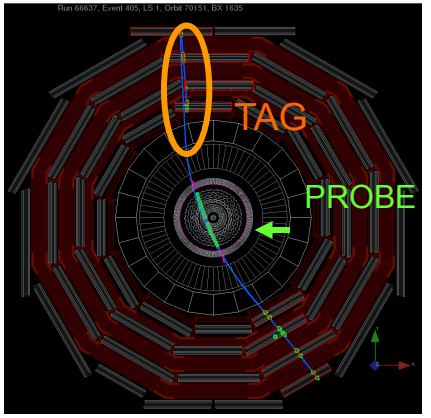


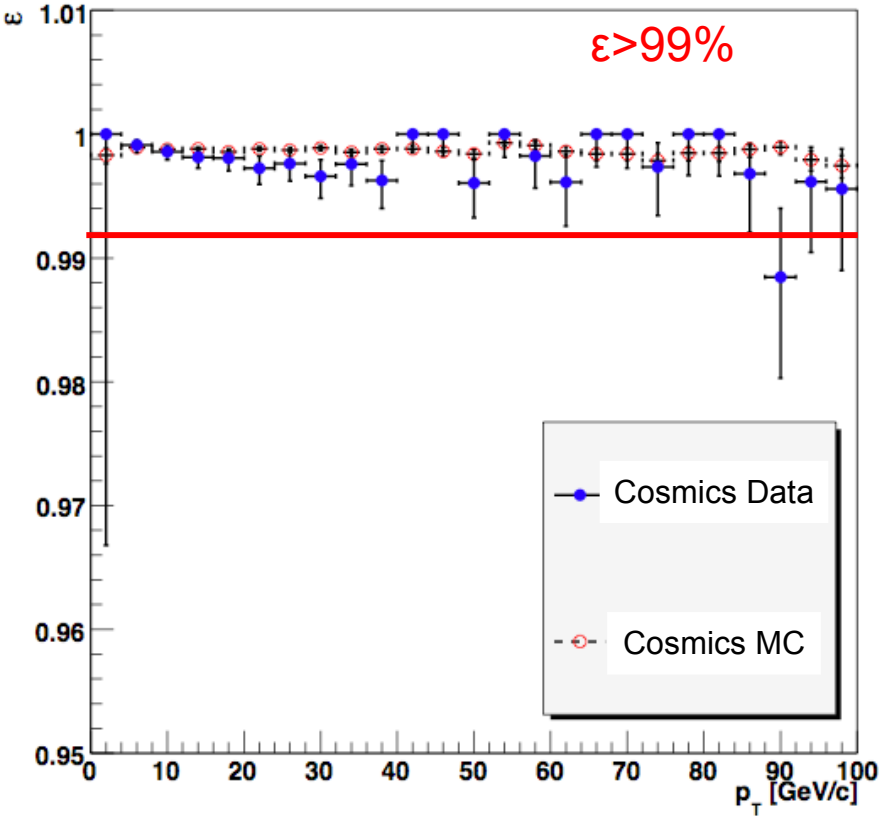
Tracker performance: Efficiency

CRAFT

Tag-and-Probe method:

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





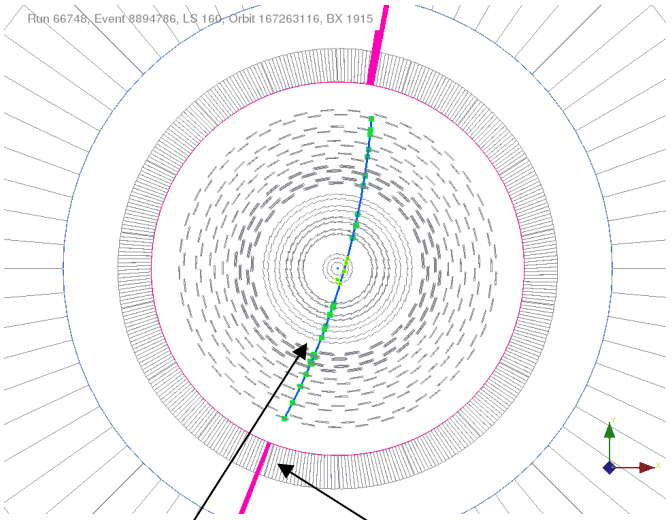
Achieved high tracking reconstruction efficiency demonstrated using cosmic muons:

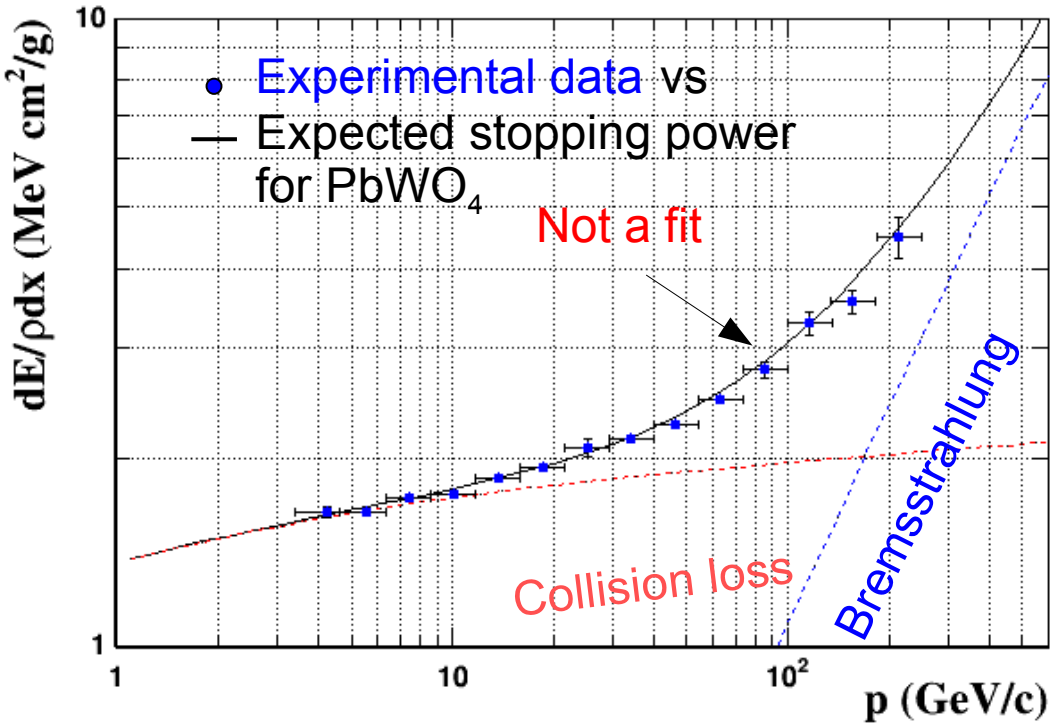
- Strip Tracker
  - TOB: 98%
  - TIB/TID: 96.6%
  - TEC+ : 99.2%
  - TEC-: 97.8 %
- Pixels
  - Barrel: 99.1%
  - Forward: 94.0%

ECAL response to muons

CRAFT

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

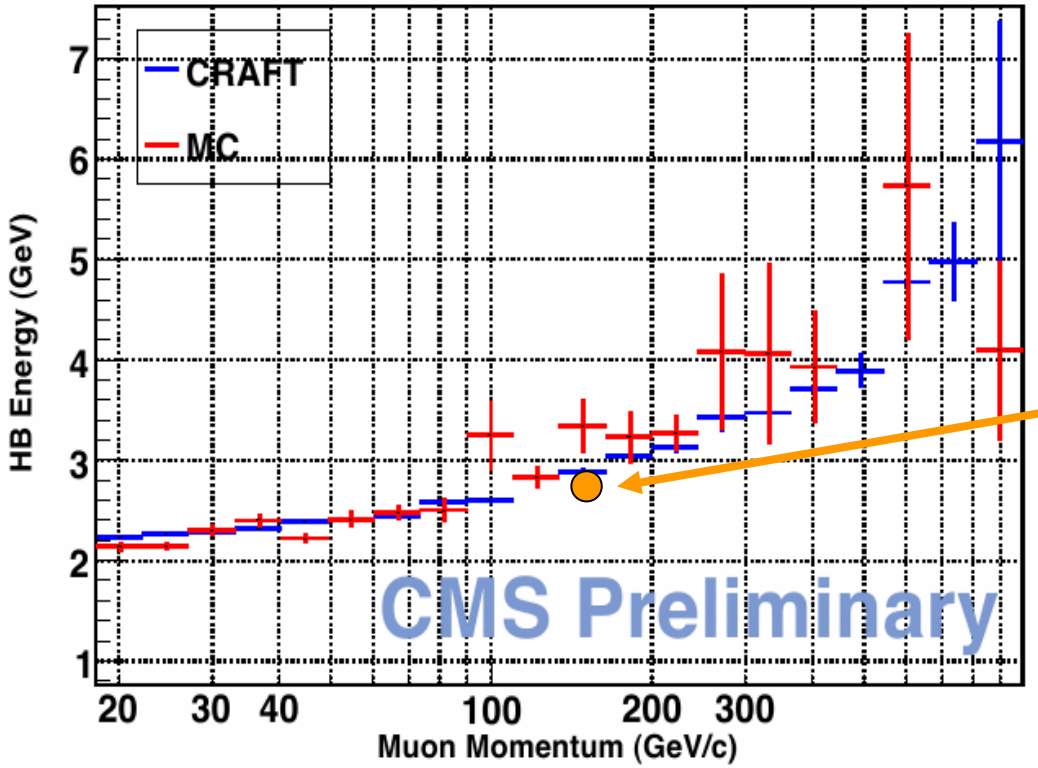
dx: is the length traversed in ECAL crystals

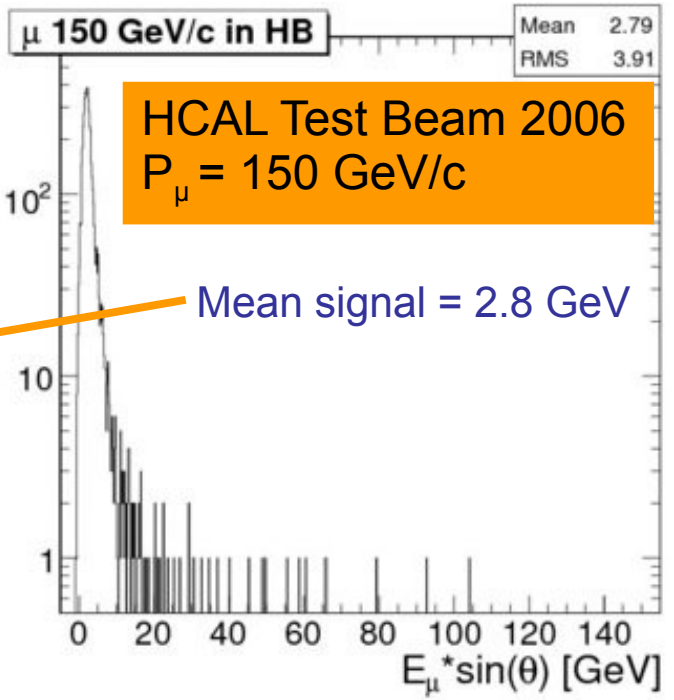
dE/ρdx energy deposit matched to the track corrected for muon path length

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

HCAL response to muons

CRAFT





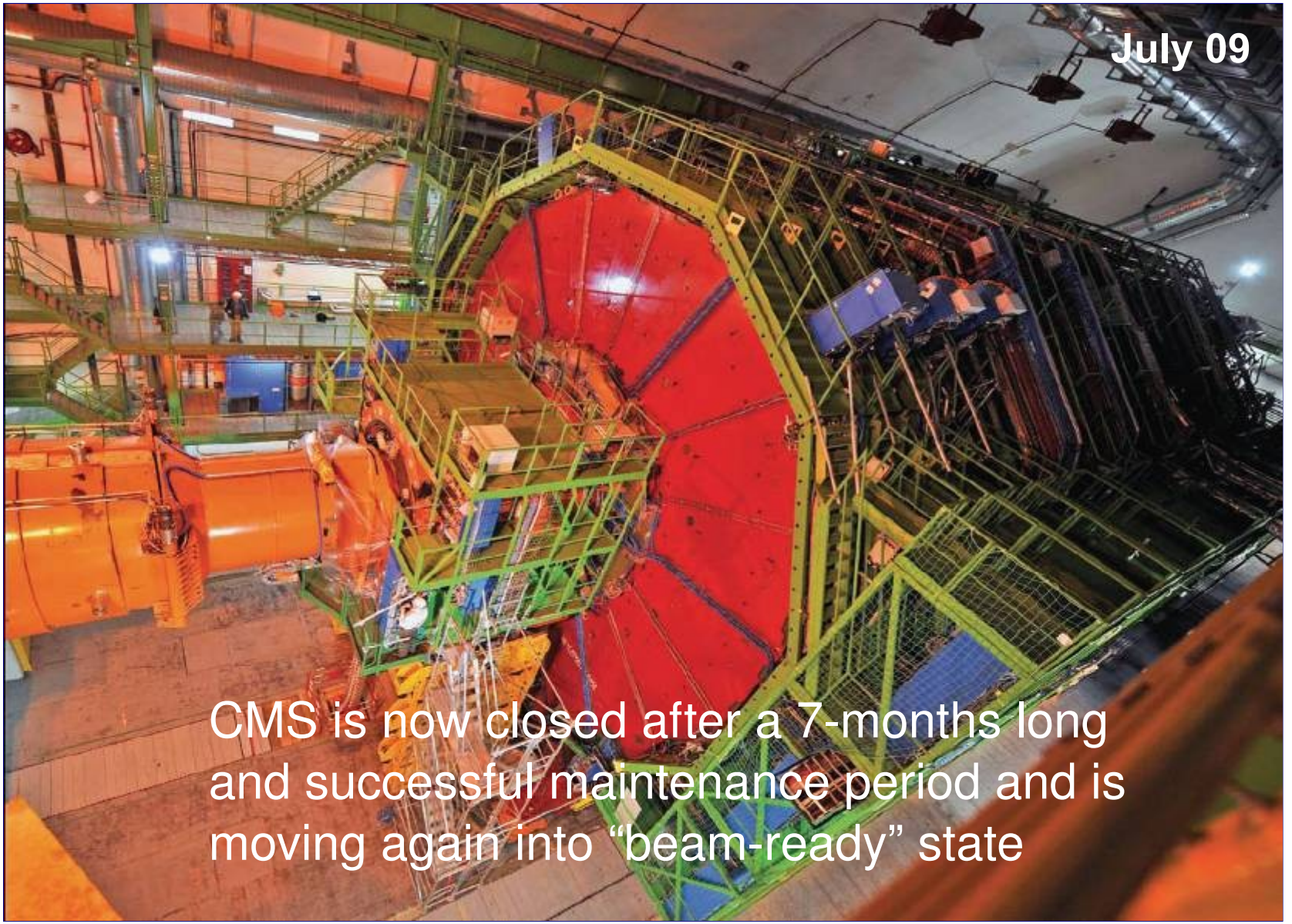
HCAL barrel energy:
signal corrected for muon path length in HCAL

Good agreement of CRAFT response with MC and test beam results

08-09 “Shutdown” - CMS Activities

- Dec 08 - Jul 09: Detector opened. Some highlights:
  - Installation and commissioning of pre-shower Ecal ($1.65<\eta<2.6$)
  - Removal, repair and re-insertion of forward pixel system
  - Installation of Castor calorimeter ($5.2<\eta<6.6$)
  - Revision of tracker cooling plant
  - Re-commissioning of CMS (global runs, CRUZET)
  - Preparation of software for 2009 data taking and MC production at 10 (and 7) GeV cms energy
  - 6 week long cosmic run at operating field (ended 31 Aug)
- Ongoing
  - Evaluate if upgrade of HLT/DAQ system to SLC5 before data taking is feasible
  - Move to stable data-taking prior to LHC beam

Preparing for beam in 2009

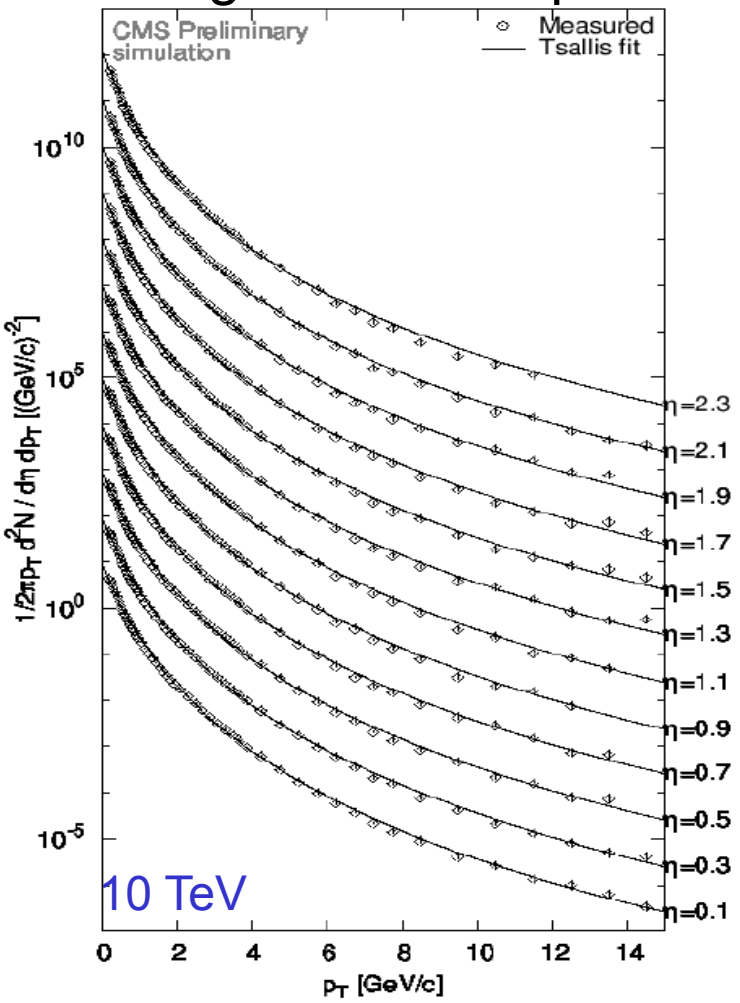


Early physics program (2009/10 run)

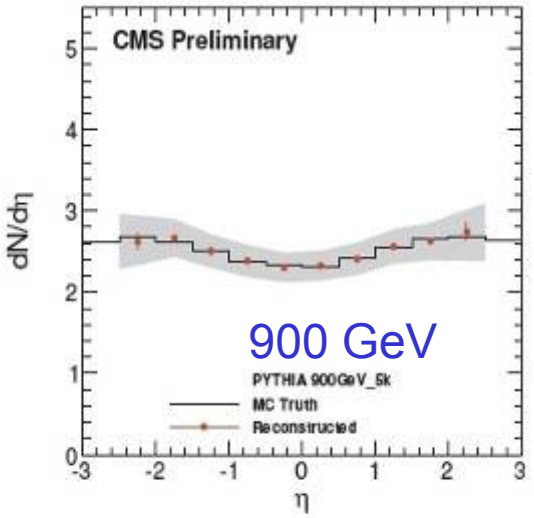
- Detector commissioning – much already done using cosmics/testbeam,..
- Early beam: splash events, first collisions at injection energy, then at 7 TeV
  - Detector synchronization, alignment with beam-halo events, minimum-bias events. Earliest in-situ alignment and calibration
- Early beam - collisions, up to 10-20 pb^{-1} @ 7 TeV
  - Commission trigger, start "physics commissioning" – "rediscover SM":
    - Physics objects; measure jet and lepton rates; observe W, Z, top
    - And, of course, first look at possible extraordinary signatures…
- 7 TeV, up to 100 pb^{-1} measure Standard Model, start searches
  - Approx per pb^{-1}: 3000 W $\rightarrow$lν; 300 Z $\rightarrow$ll; 5 ttbar $\rightarrow$μ+X
    - Improved understanding of physics objects; jet energy scale from W$\rightarrow$ jj'; extensive use (and understanding) of b-tagging
    - Measure/understand backgrounds to SUSY and Higgs searches
  - Early look for excesses from SUSY & Z' resonances.
- Collisions at higher energy: extend searches;
  - Explore large part of SUSY and resonances at ~ few TeV
  - ~ 1000 pb^{-1} entering Higgs discovery era
- Pb+Pb pilot run at 4(?) ATeV with 1/20 design lumi
  - Global observables: yields, spectra, flow

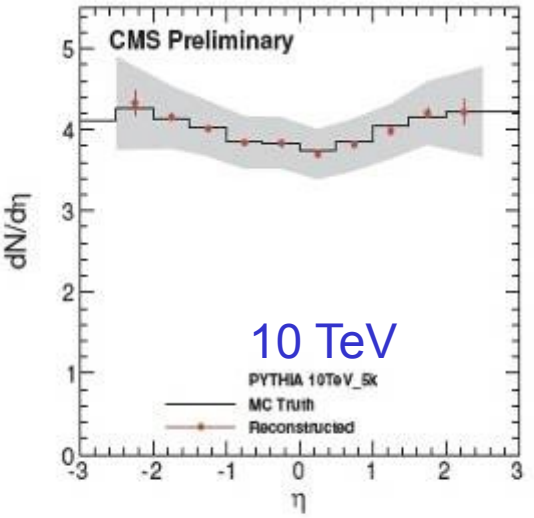
Minimum bias

Charged hadron spectra



Charged Hadron Multiplicity (5k events)



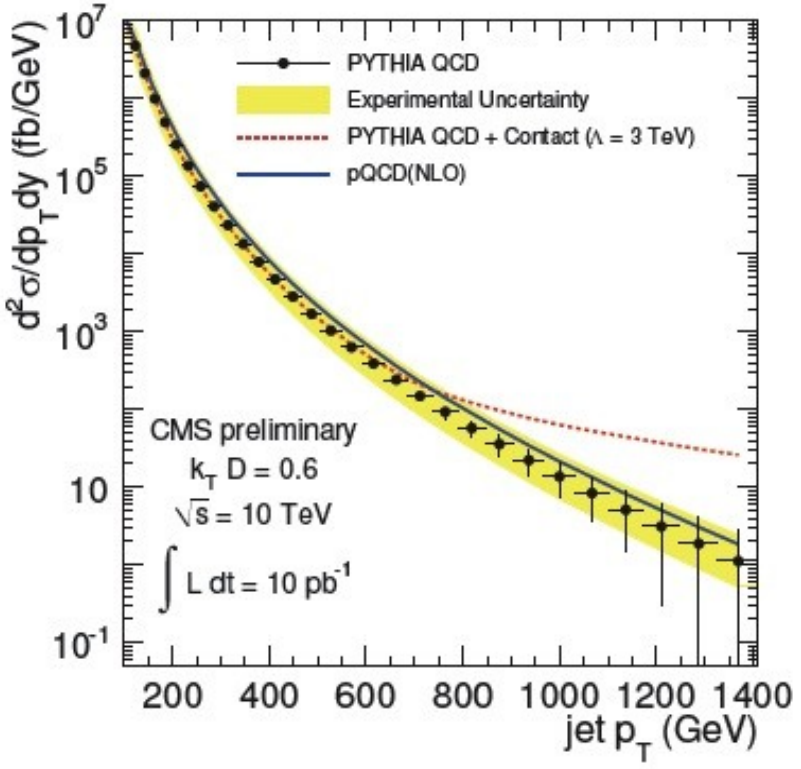


- Measure charge multiplicity and track spectrum
  - Reference for HI
  - Help dealing with pileup events later when pp lumi will be increased

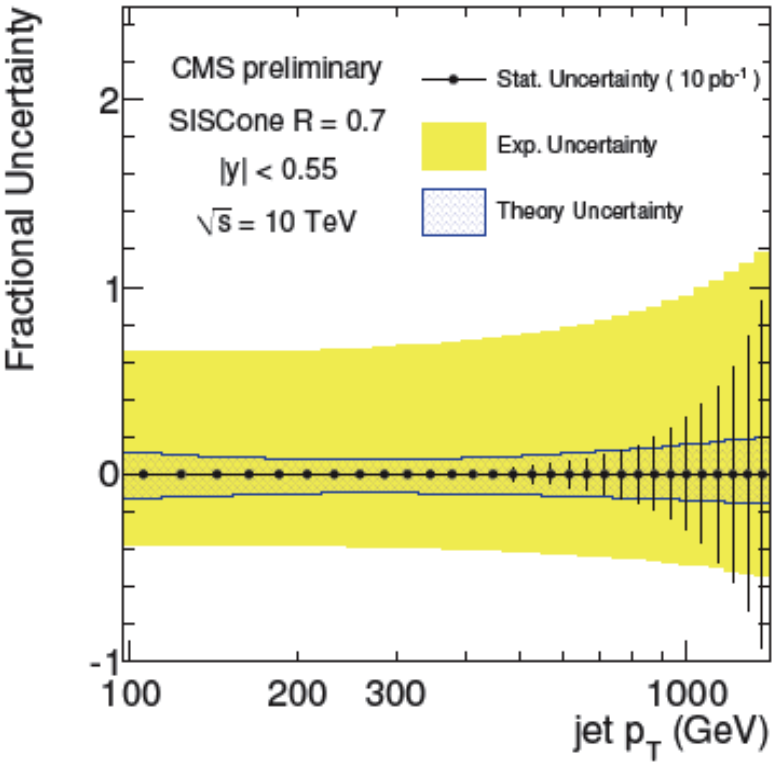
See talk by Prafulla Behera

QCD jet measurements

Startup inclusive jet measurement using k_T and SISCone



Inclusive jet cross-section measurement (k_T) for 10 pb^{-1} data



Inclusive jet cross-section uncertainties (SISCone) for 10 pb^{-1} data

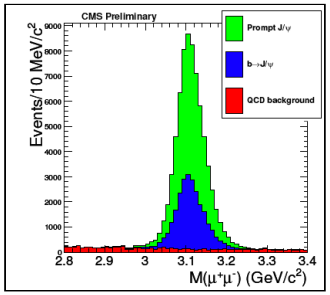
The roadmap for discoveries

Roadmap towards discoveries with leptons at LHC

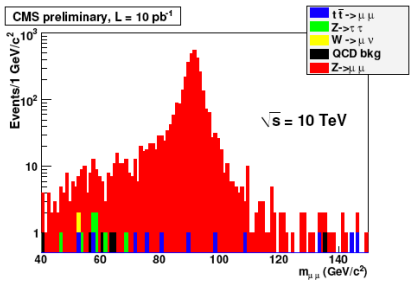
0 10 20 30 40 50 60 70 80 90 100 110 120 130

$\int \mathcal{L} dt\ (\mathrm{pb}^{-1})$

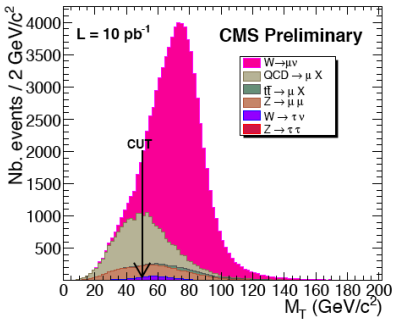
J/Ψ & Υ resonances (few pb^{-1})



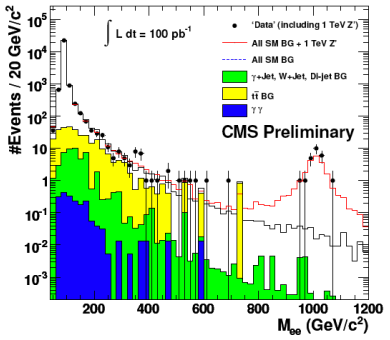
Z peak (10pb^{-1})



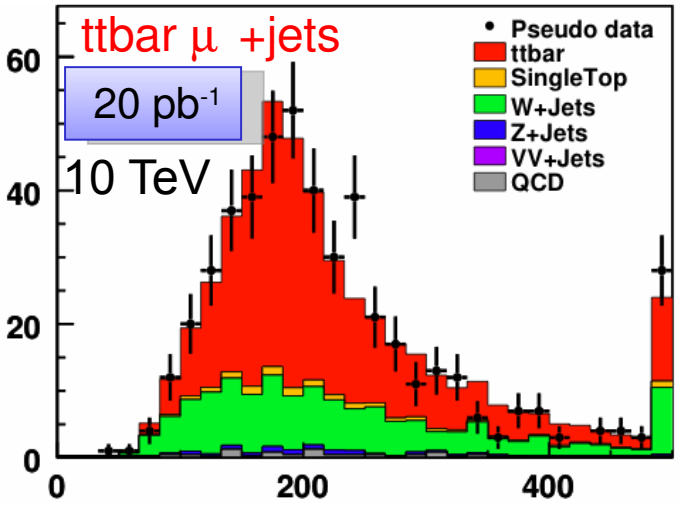
W cross-section measurement

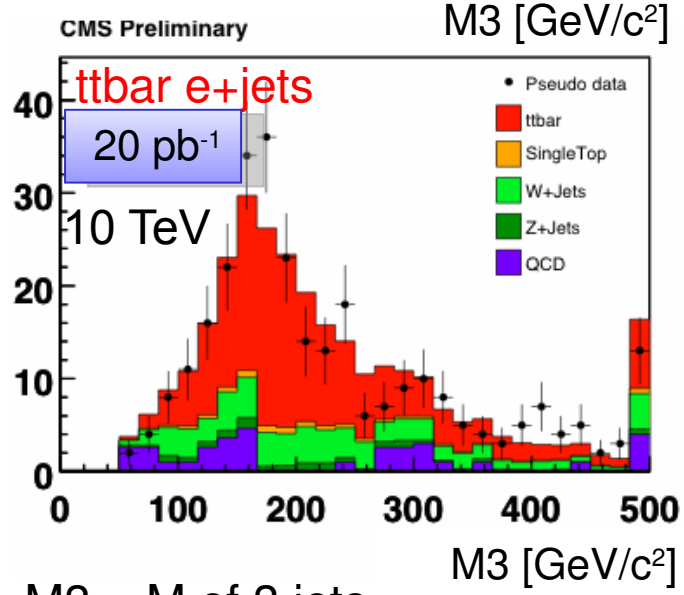


Look @ DY spectrum beyond M_{ll}> 700 GeV/c^2



Top quark studies

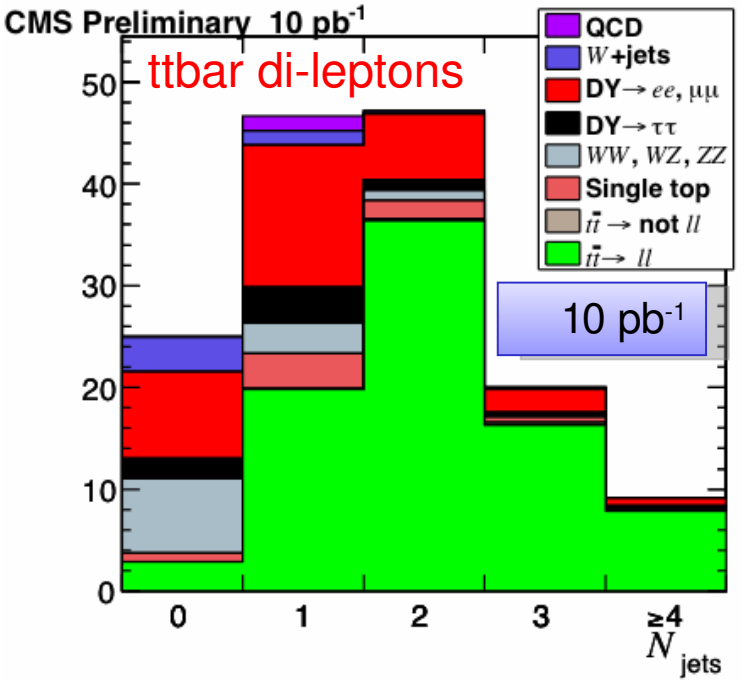




M3 = M of 3 jets with highest vector sum

Top production is excellent testbed for the understanding of:
lepton id. (incl. taus), jet corrections, jet energy scale, b tagging, ….

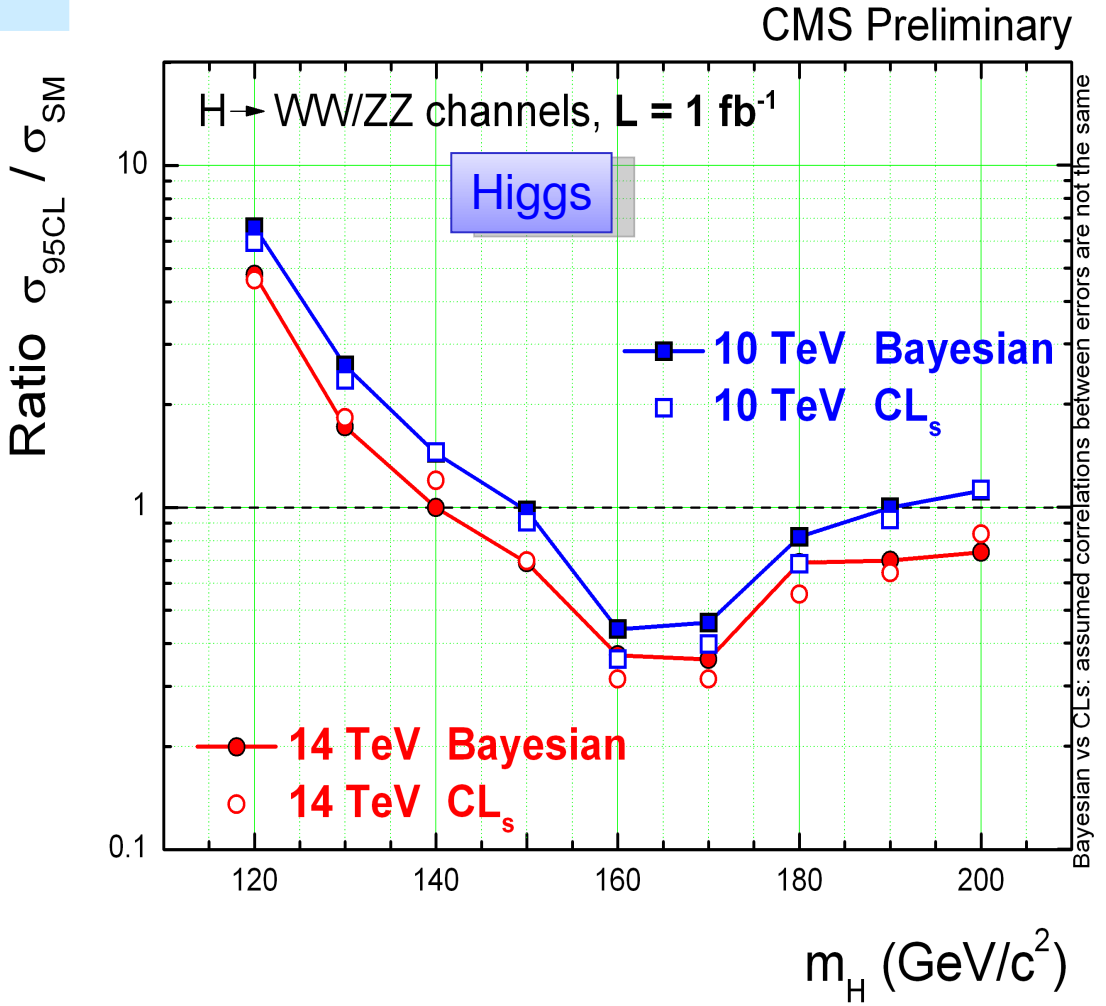
Mostly w/o use of b-tagging, robust selections



Higgs boson

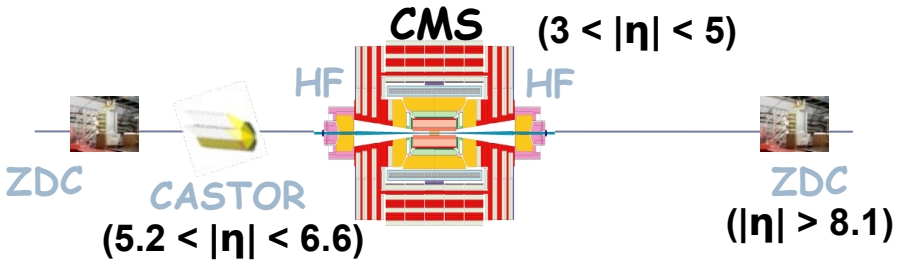
At 10 TeV, with ~200 pb^{-1} reach 160-170 GeV sensitivity as at Tevatron

Benchmark Luminosities:
~ 0.1 fb^{-1}: exclusion limits start carving into SM Higgs cross section
> 0.5 fb^{-1}: discoveries start to become possible in the region excluded by Tevatron (MH~160-170 GeV)
~ 5-10 fb^{-1}: SM Higgs could be discovered (or excluded) in full mass range (MH~110-500 GeV)

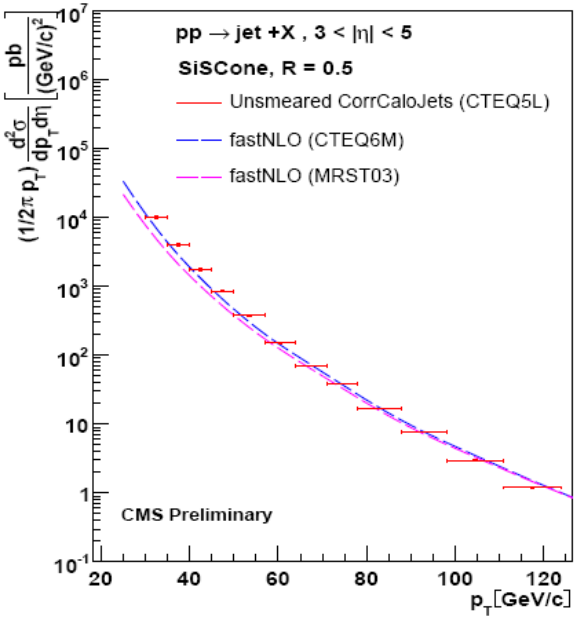


See talk by Majid Hashemi

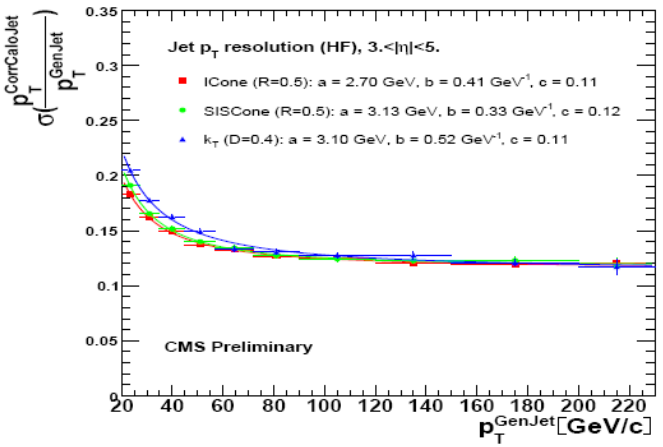
Forward jets



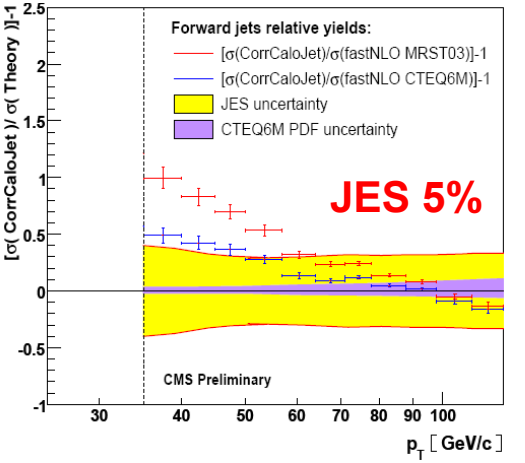
- Single inclusive forward jet spectrum with 1 pb^{-1}
- Jets reconstructable in HF from p_T ~ 35 GeV
- Very good (better than at mid-rapidities) energy and position resolutions (due to large forward boost)
- Main systematic source from jet energy scale (JES)



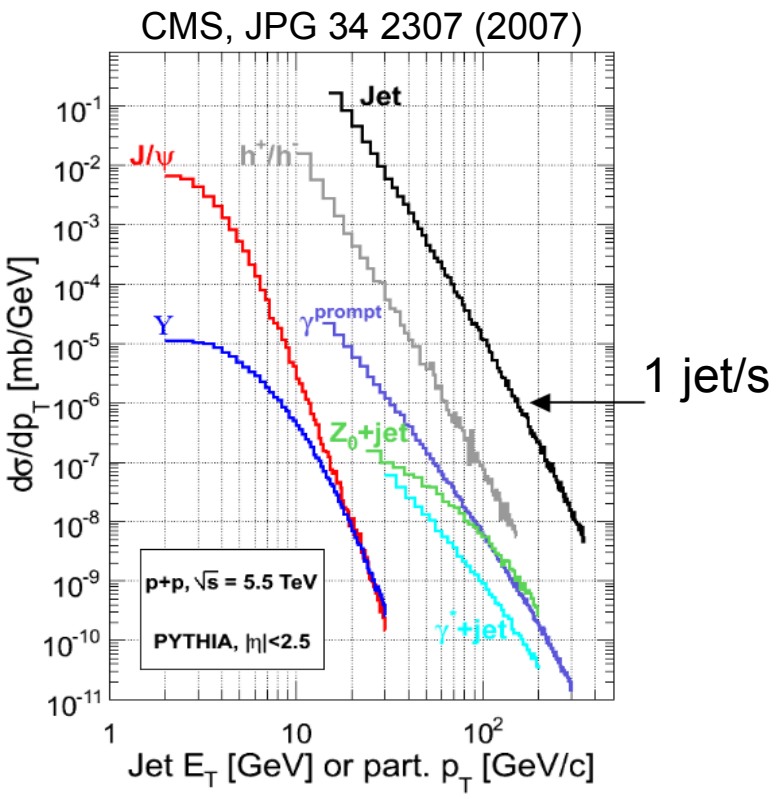
Jet energy resolution in HF

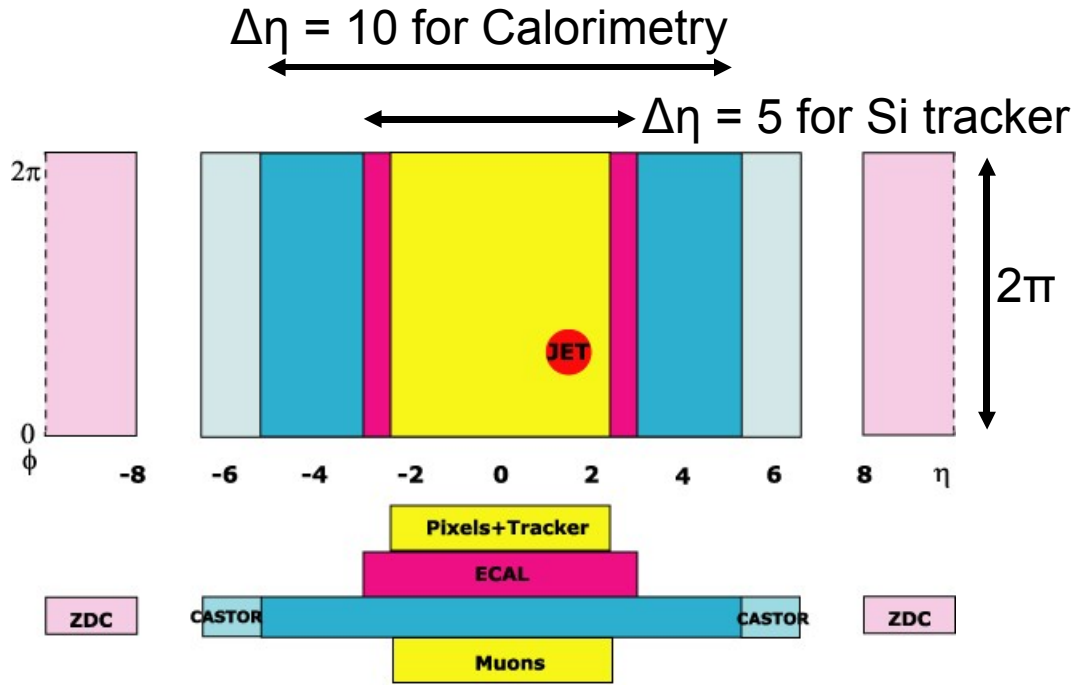


With improved JES, possible to constrain low-x gluon density



CMS as a HI experiment



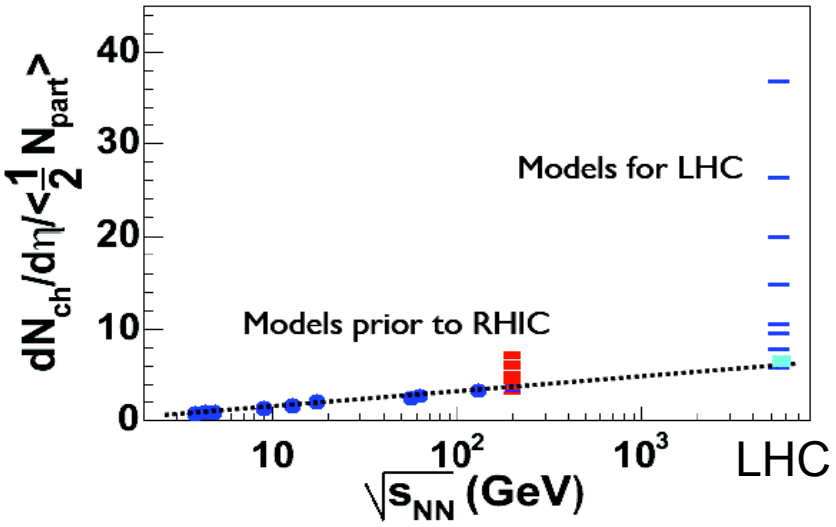


Capabilities

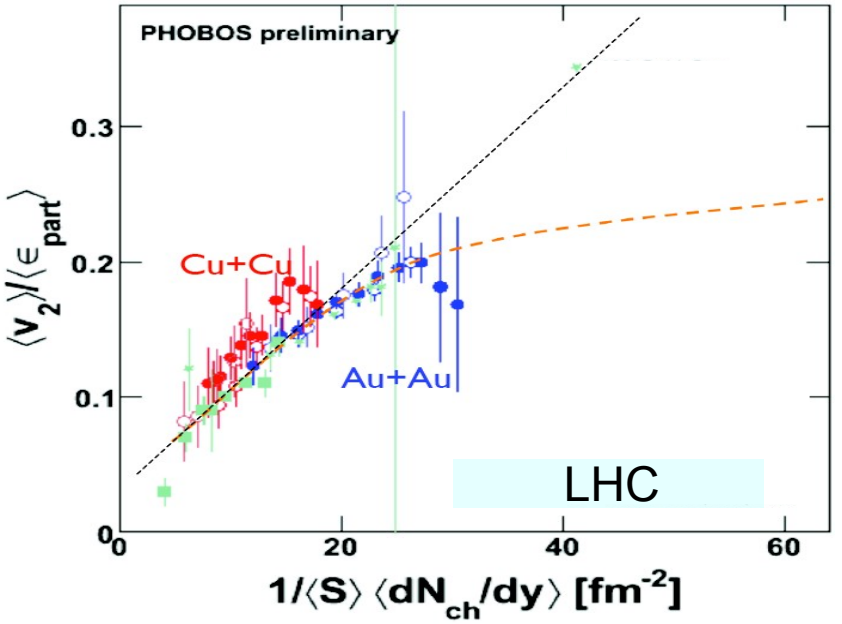
High-precision tracking over $|\eta| < 2.5$
Muon identification over $|\eta| < 2.5$
High resolution calorimetry over $|\eta| < 5$
Forward coverage
Large bandwidth: DAQ + Trigger

- 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

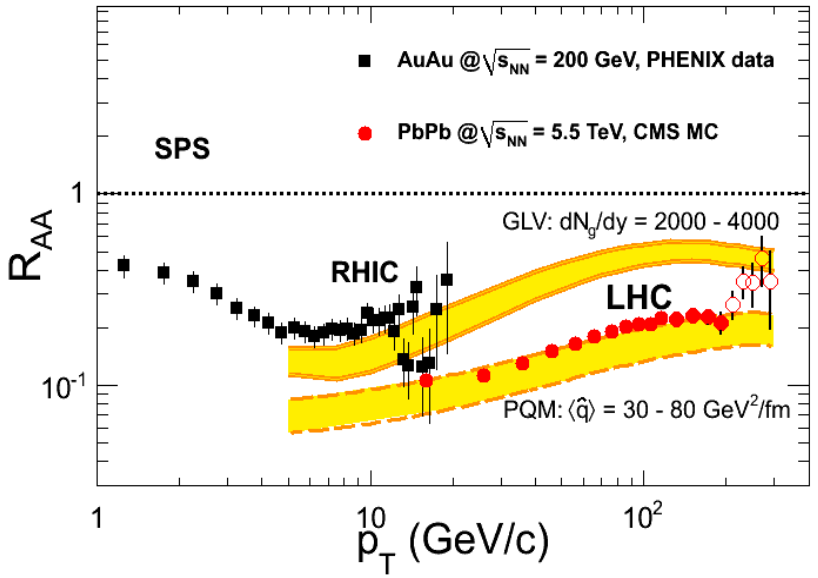
Expectations for Pb+Pb run in 2010



~1 day: Multiplicity → Initial density



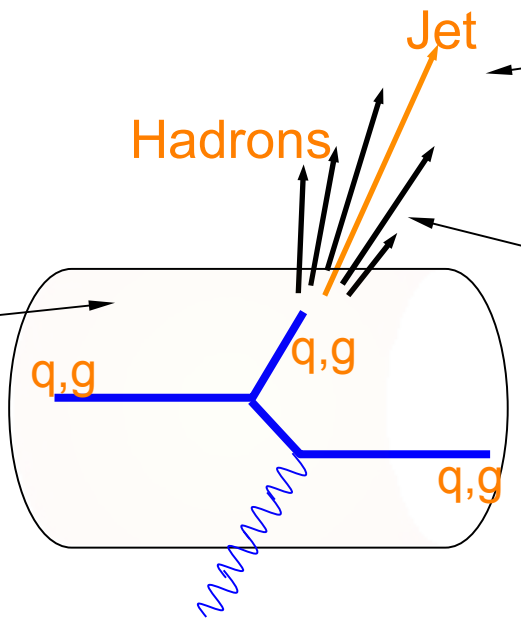
~1 week: Does v_2 saturate?



~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



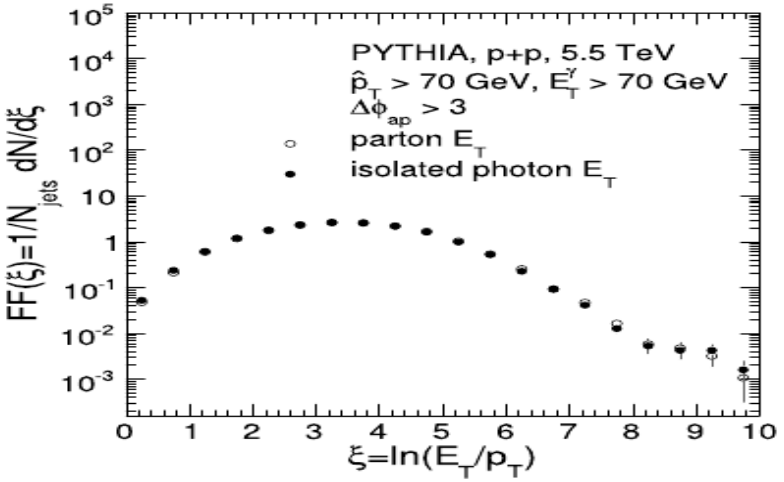
Jet axis provides parton direction

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

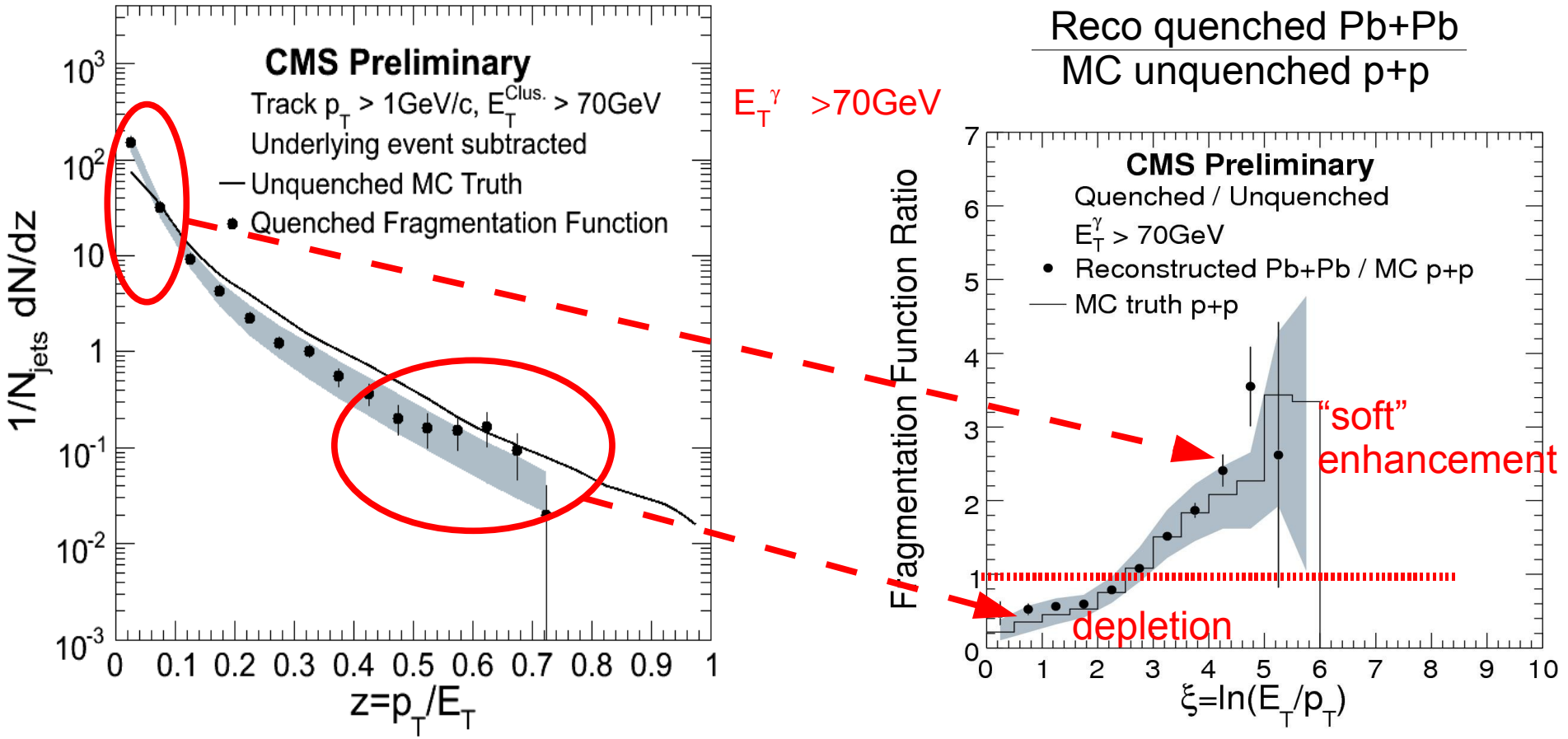
Measure jet fragmentation function: $dN/d\xi$ with $\xi = -\log z = \log p_T/E_T$



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 $z < 0.7$)

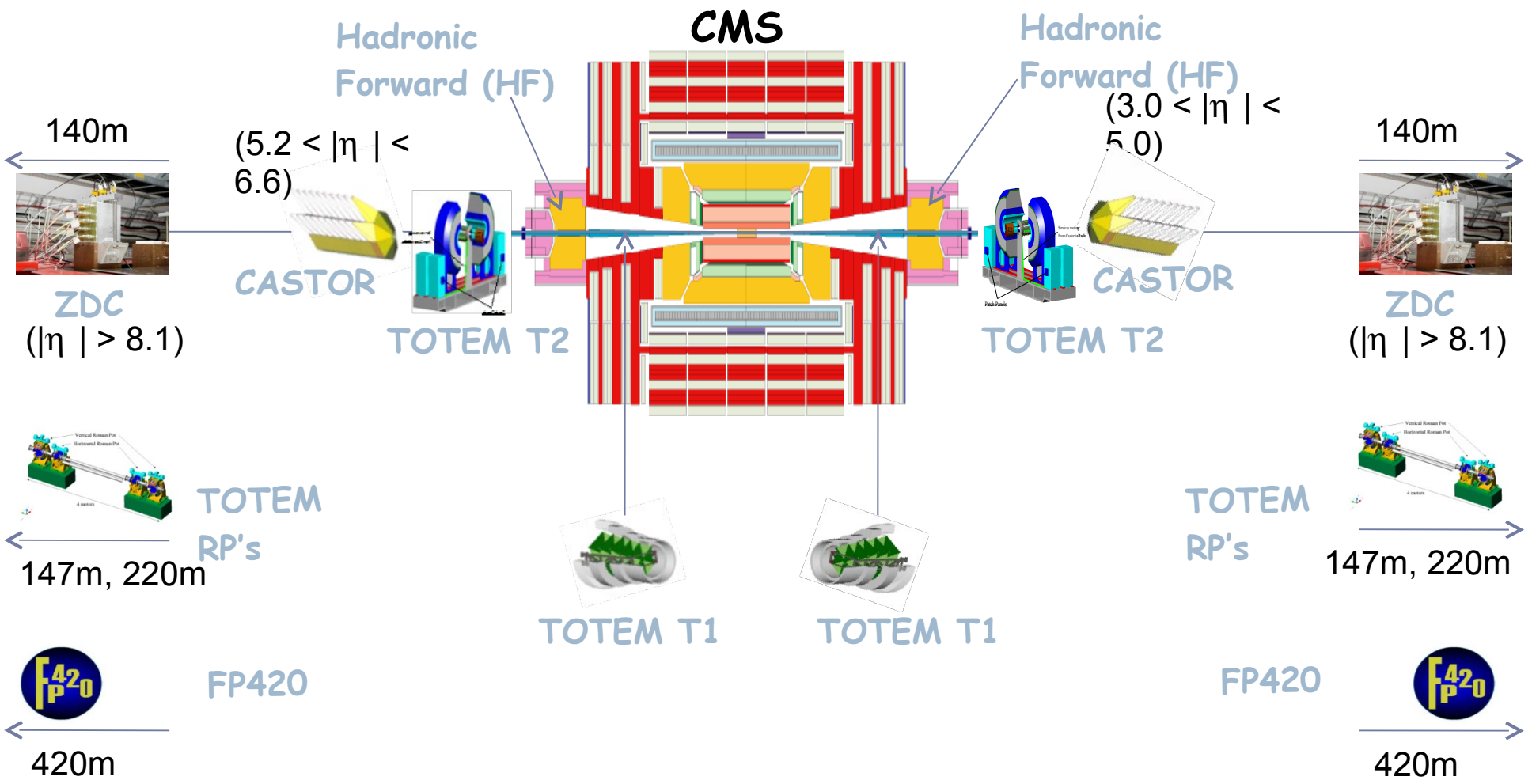
CMS, JPG 35 104166 (2008)

Summary

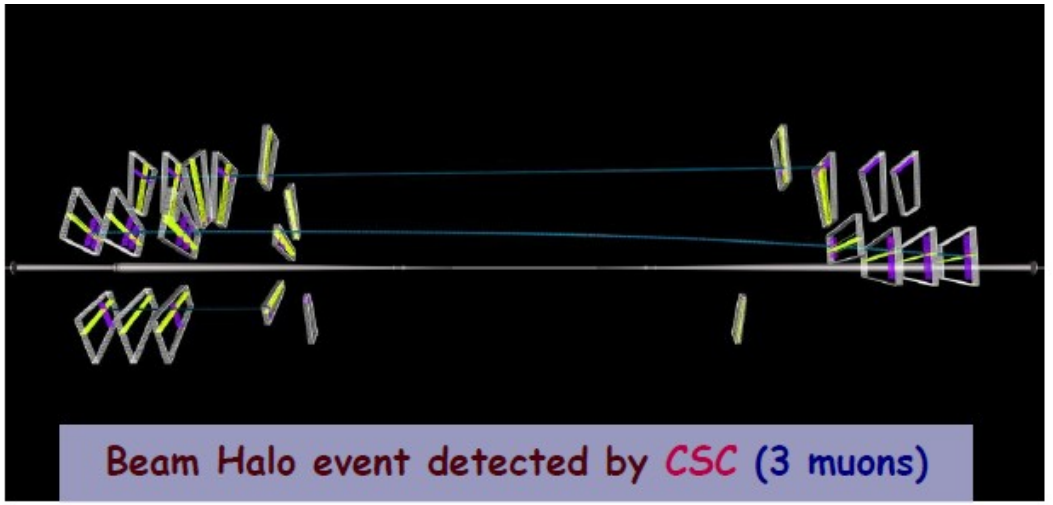
- During fall 2008, LHC beam & cosmics run, the sub-detectors, online, offline, computing and analysis systems all performed well.
- The ensuing shutdown included broad maintenance activities and a programme of carefully selected repairs interleaved with the installation of the preshower and castor detector.
- A lot of very useful information has been extracted from the CRAFT08 data. Plan to publish ~25 papers by end of Sept 09.
- The software, computing systems and analysis systems are being exercised in CRAFT09 and by generating, (and soon) distributing and analysing 200M events to update 10 TeV “physics analyses” (and soon 7 TeV) using the software release intended for data taking.
- Already the early physics program for 2009/10 running conditions is extremely rich and exciting
- CMS will (again) be ready, and eager, for LHC beam.

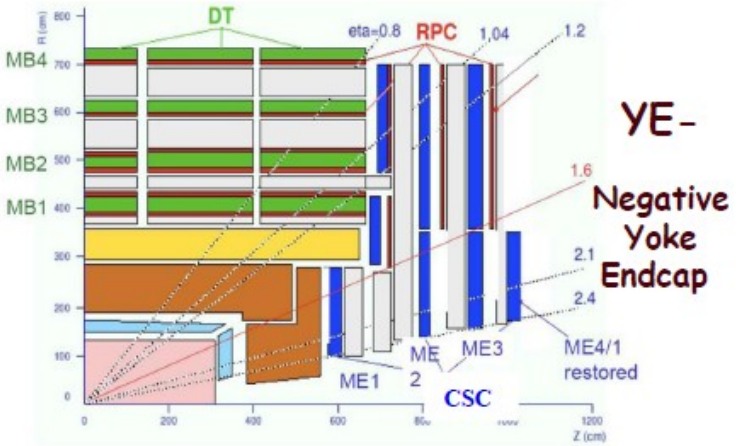
Extra

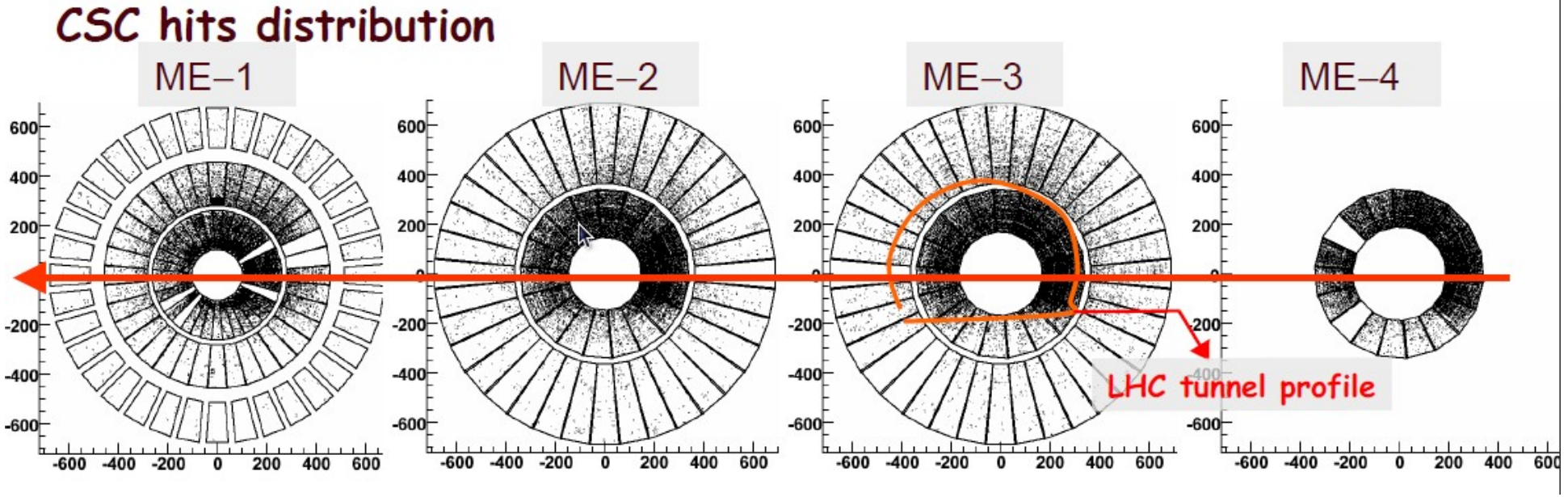
Forward capabilities at P5



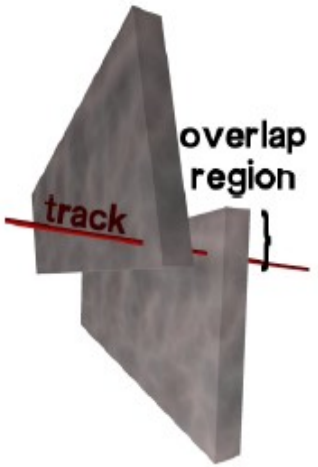
Beam halo events



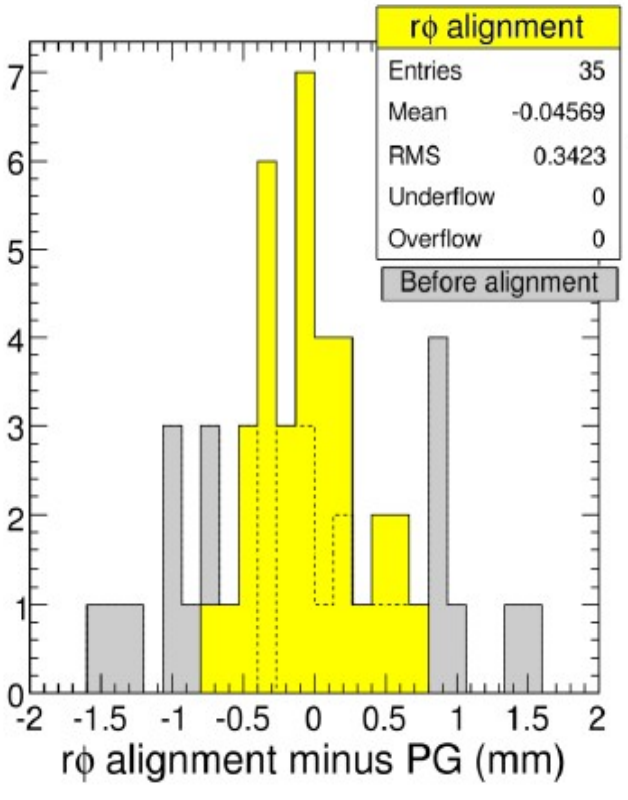


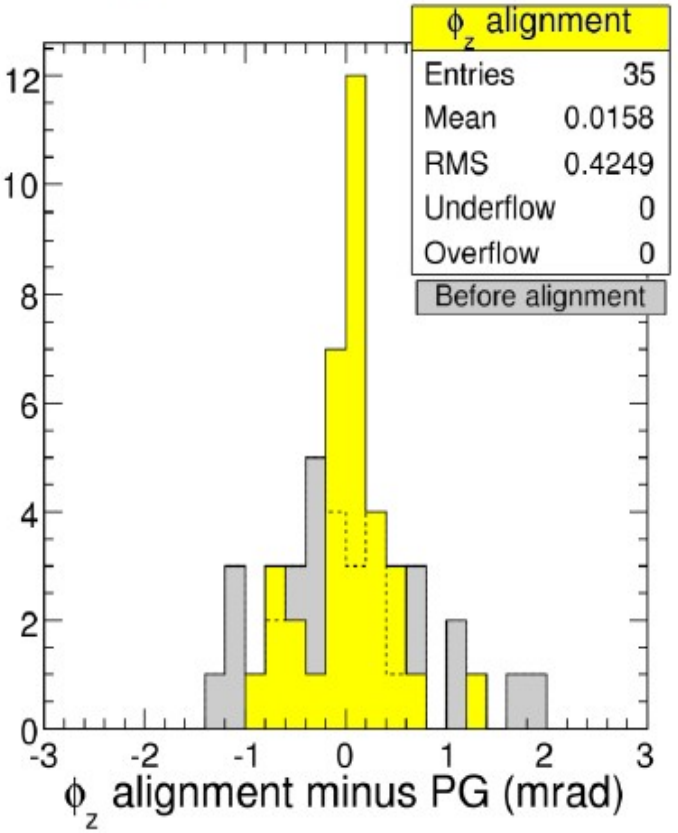


Beam halo events



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!

Prospects for 2009/10 run

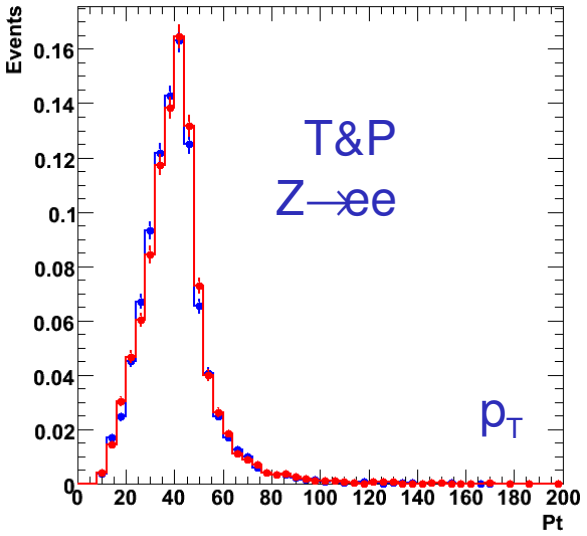
- Following a meeting with the LHC people, experiments and CERN management the plan to restart has been agreed.
- Once collisions at injection energy are established will move to collision at 7 TeV center-of-mass energy.
- In consultation with experiments and LHC operation will move to higher energy once some luminosity will be accumulated by the experiments and experience gained by the machine operations.

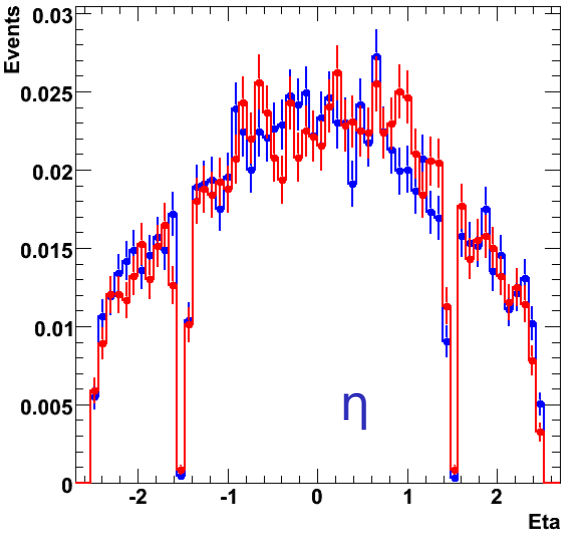
Analysis objects

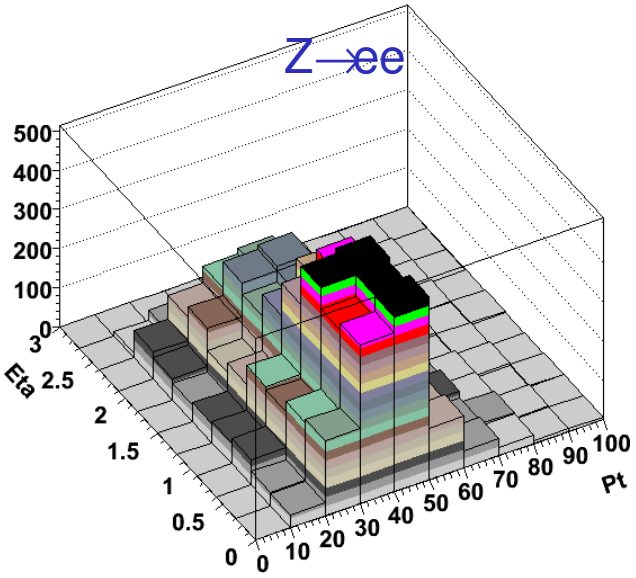
Data driven methods: Physics objects identification

Tag and Probe (T&P): identify a physics object in an unbiased way in order to study efficiencies.

e.g. $Z \rightarrow ee$ events: one tight electron (tag); the other can be a probe, provided the invariant mass of the pair is $\approx M_Z$







Efficiency from T&P: 94.36±0.24
Efficiency from MC truth: 94.63±0.24

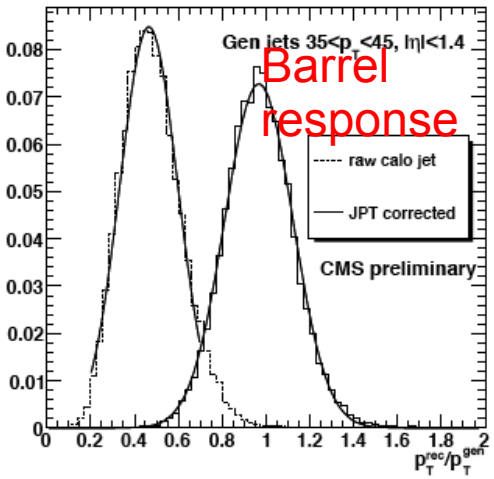
} (for 10 pb^{-1}) @ 14 TeV

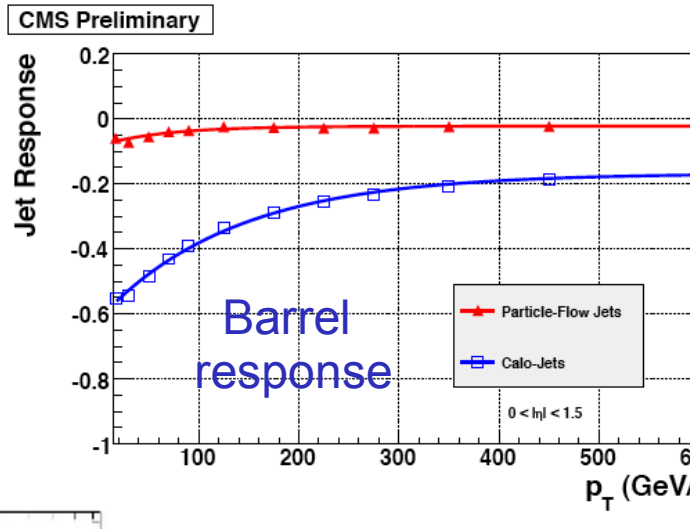
Analysis objects

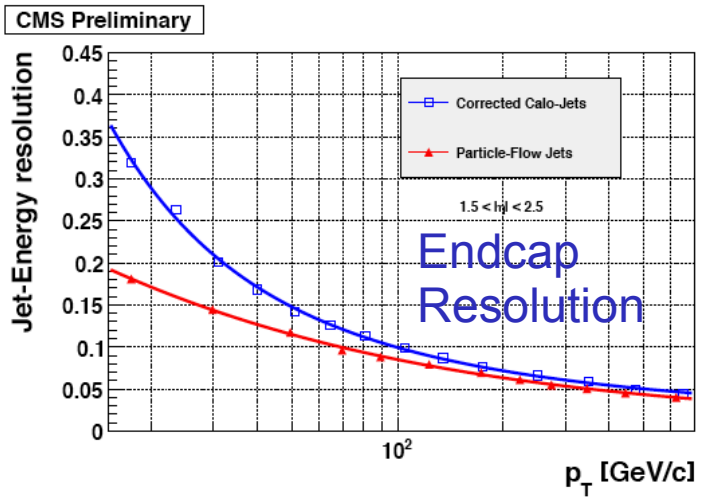
Jets+Tracks (JPT)

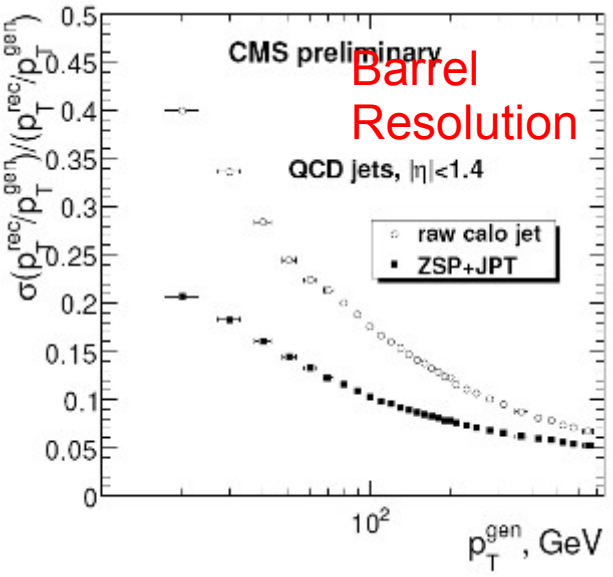
Example: Use of tracks in reconstructing jets

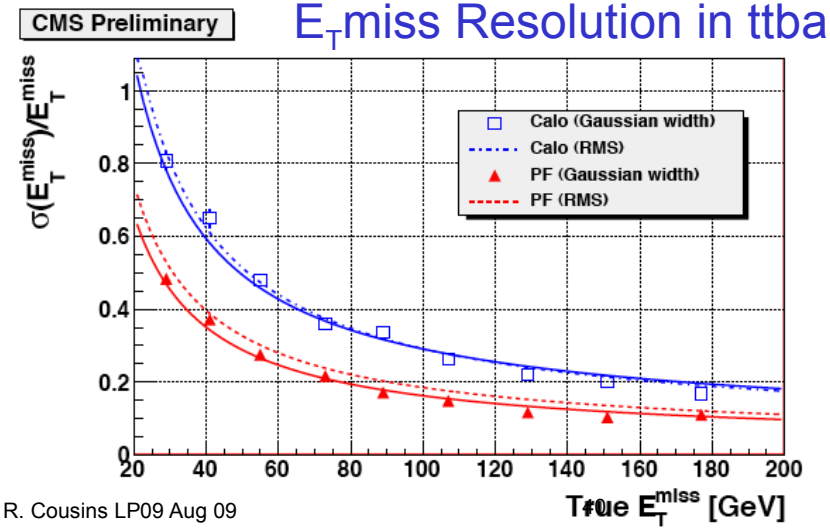
"Particle Flow"





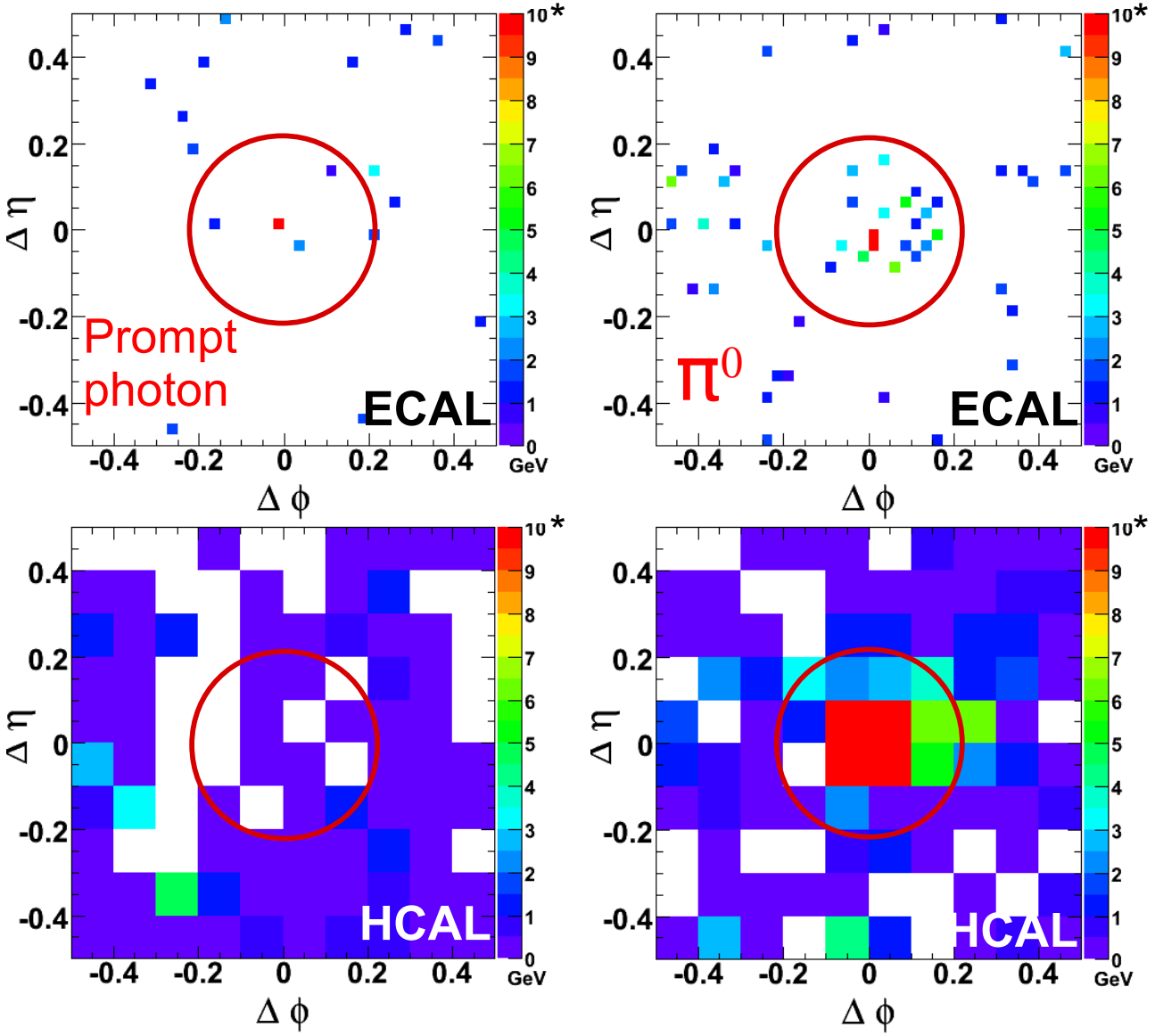






Photon ID variables

- Selection variables
  - Cluster shape in ECAL
  - ECAL/HCAL energies in cones with R≤0.5
    - Background subtraction
  - Track isolation
- Total of 21 variables
  - Linear discriminant analysis (Fisher) and cut optimization using TMVA
  - Many variables are correlated: Not yet investigated which to keep or drop

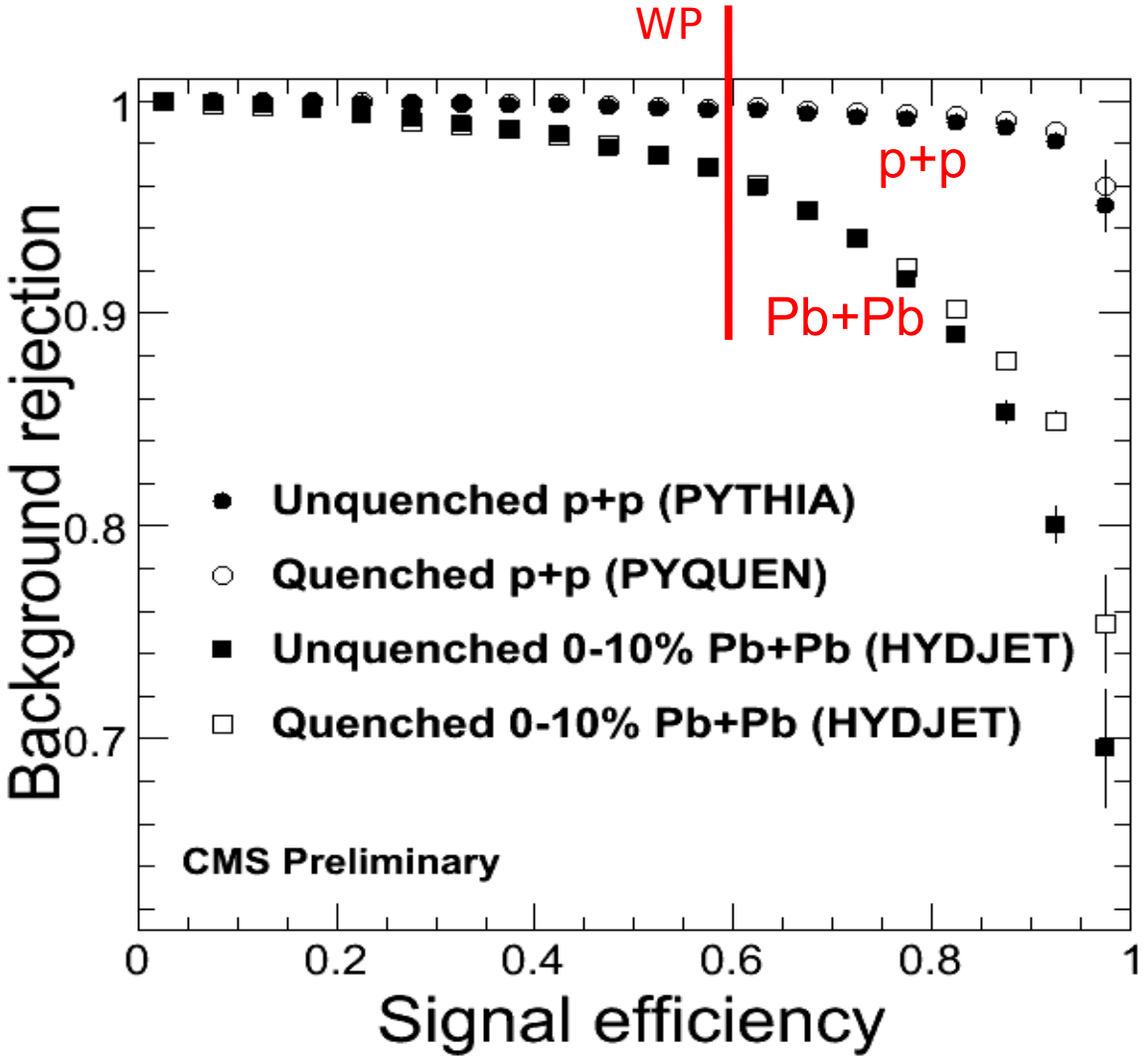


TMVA: http://tmva.sourceforge.net

*) Maximum set to 10 GeV

Photon identification performance

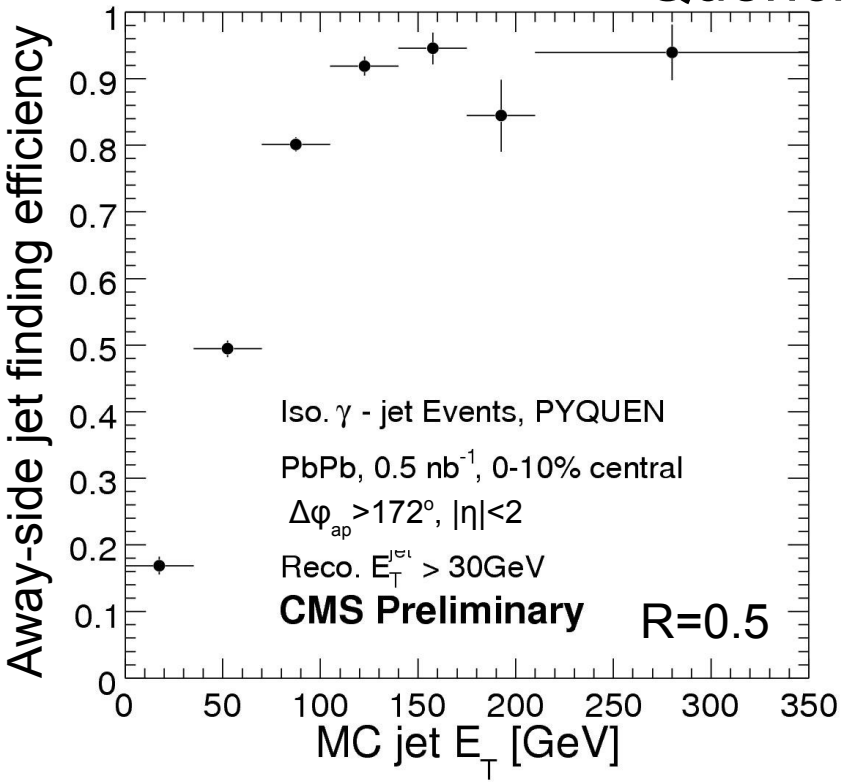
- Set working point to 60% signal efficiency
- Leads to 3.5% false acceptance (96.5% rejection)
- Training was done on unquenched samples only

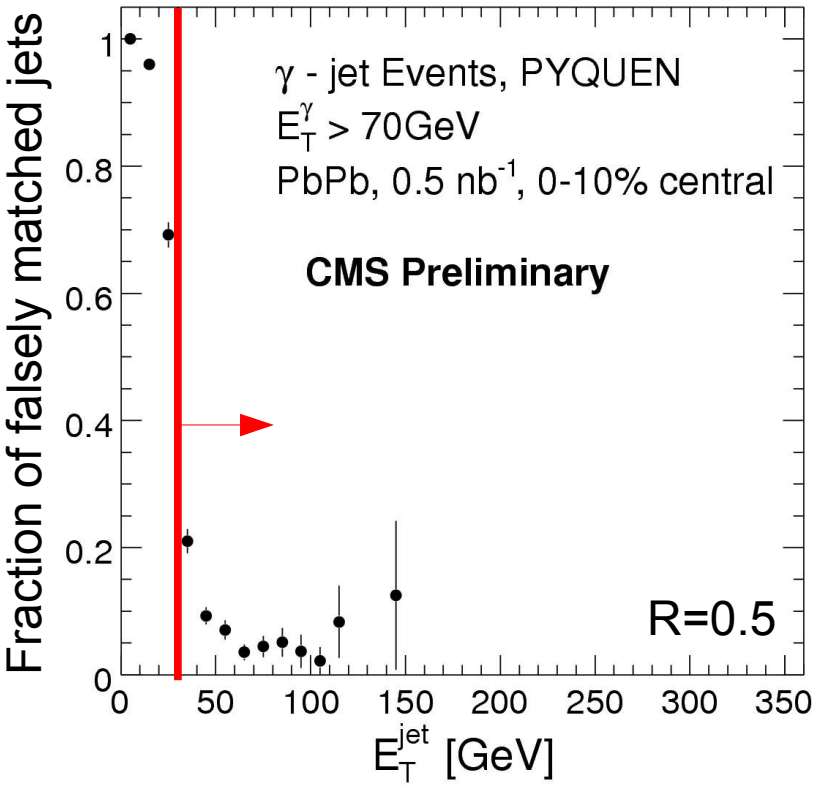


For quenched Pb+Pb S/B improves from 0.3 to 4.5 after cuts

Away-side jet finding (for tagged jets)

Quenched Pb+Pb





- Select away-side jet with $\Delta(\gamma,\text{jet}) > 172^0$, $|\eta| < 2$ and $E_T > 30$ GeV
  - The energy cut reduces the false rate to 10% level
    - Analysis does not use jet energy otherwise
  - Jet finding efficiency rises sharply
    - Main source (~30%) of systematic uncertainty in reconstructed FFs