First Collisions with the CMS Detector at LHC

Alexei Raspereza
DESY Hamburg

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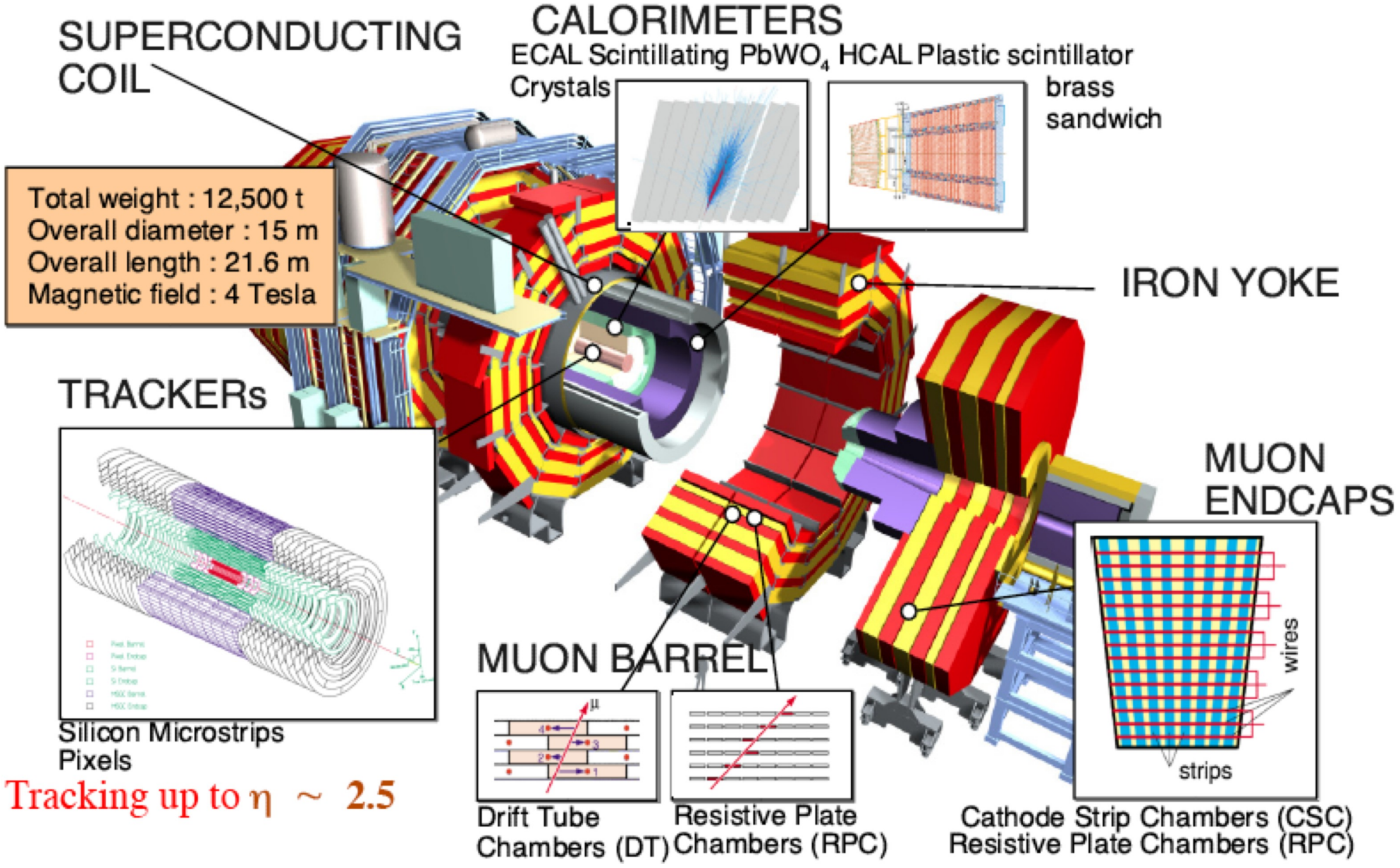
The CMS detector



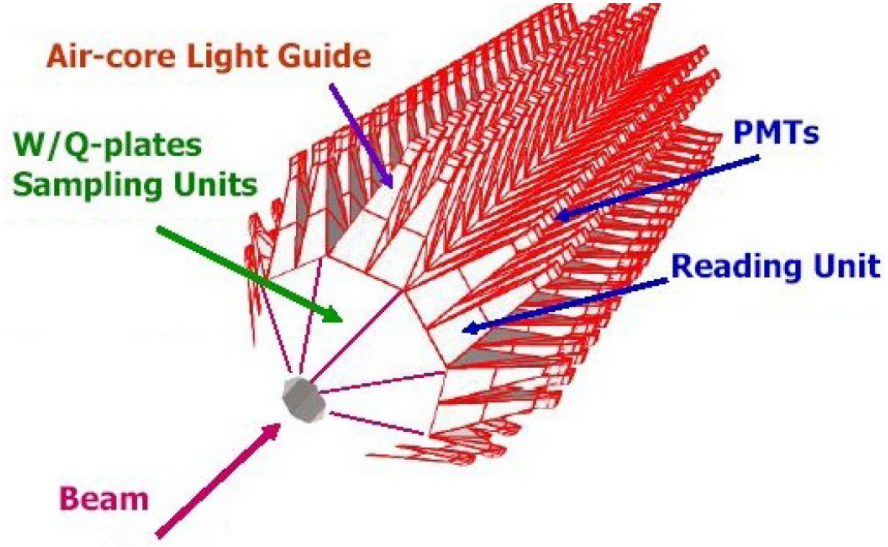
↣ Tracking up to $\eta \sim 2.5$

Preparation for First Collisions

- **LHC and CMS operations in 2009 were preceded by extensive preparatory work**
- **DESY and UHH contributions**
  - Construction and commissioning of Beam Condition Monitor and CASTOR
    - BCM : measures beam halo ⇒ protection of tracker from bad beam conditions
    - CASTOR : calorimeter for forward physics and QCD
  - Tracker alignment and development of Data Quality Monitor
  - Computing (Tier-2 and NAF)
  - Physics : Top, Higgs, SUSY, QCD

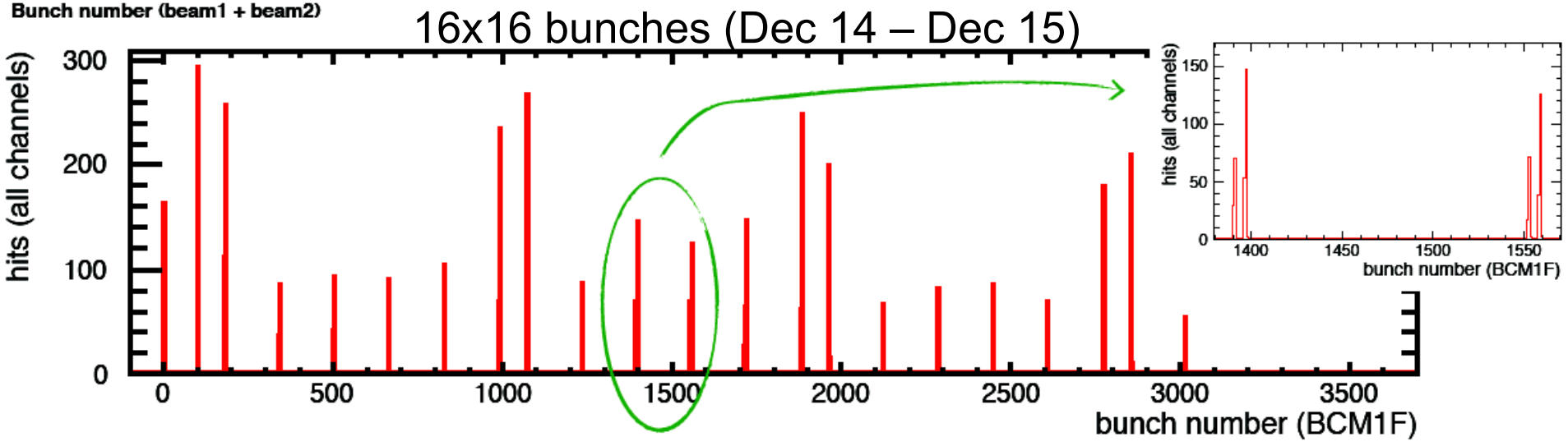
Commissioning of CASTOR & BCM

- **Installation of CASTOR completed in 2009**
  - Fully equipped (> 99% of channels give signal, 92% see LED)
  - Taking data within the CMS data stream



- Beam condition monitor : extensively tested during LHC commissioning

Excellent time resolution allows to tag single bunches!

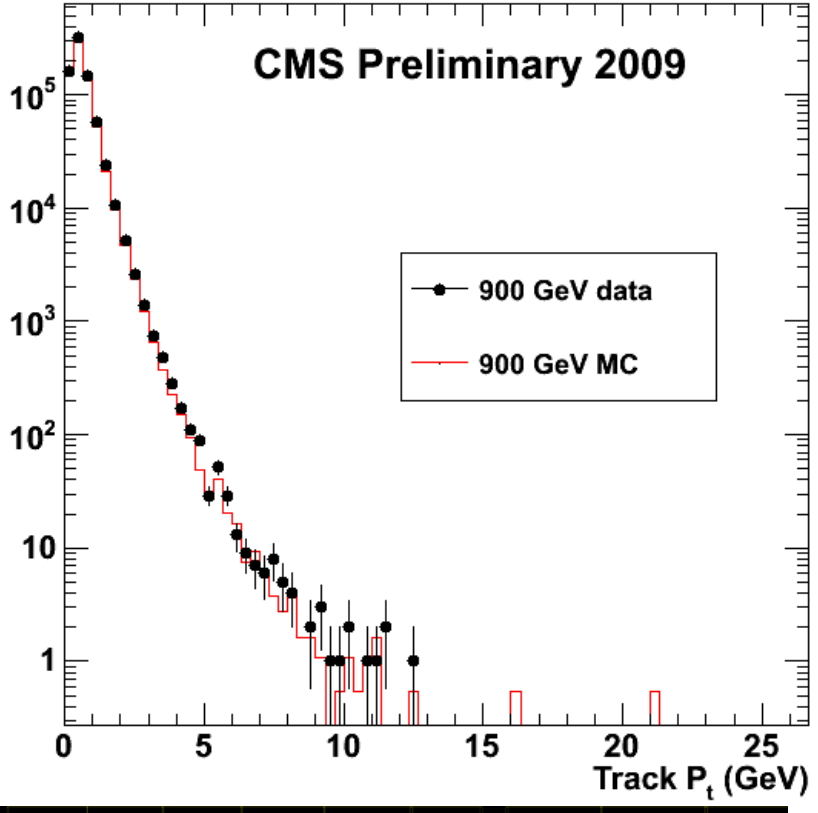


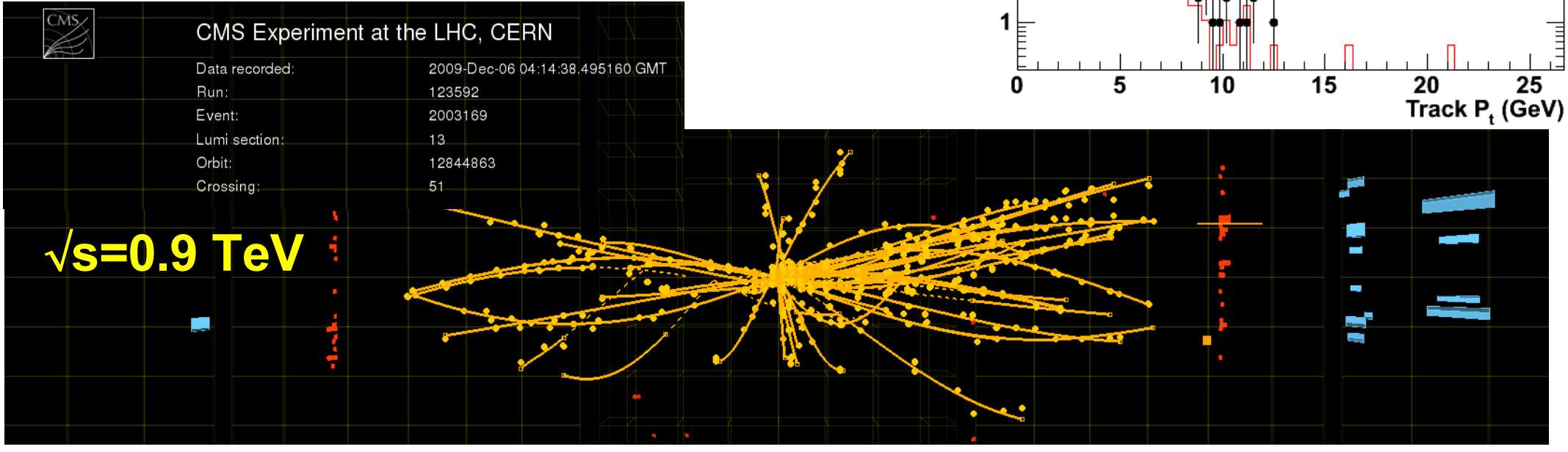
LHC Run: November-December 2009

- Inaugural LHC run in November-December 2009
- CMS collected 10 μb^{-1} @ 900 GeV and $0.4 \mu b^{-1}$ @ 2.36 TeV
- Large fraction of operational channels in tracker
  - 98.4% operational for pixels
  - 97.2% operational for strips
- Valuable data for
  - Detector calibration
  - Validation of reconstruction tools
  - Monte Carlo tuning
  - **Initial physics studies which resulted in first publication!**

Track Reconstruction

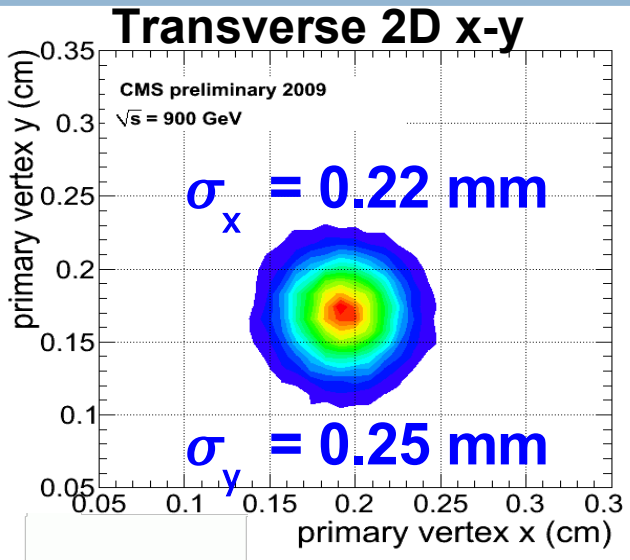
- Charged tracks reconstructed with Kalman filter technique
  - Difficult task in dense environment
- Algorithm shown to have high efficiency on cosmic tracks and MC
- p_T distribution in agreement with MC
  - $p_T/\sigma(p_T) > 10, \geq 8$ tracker hits

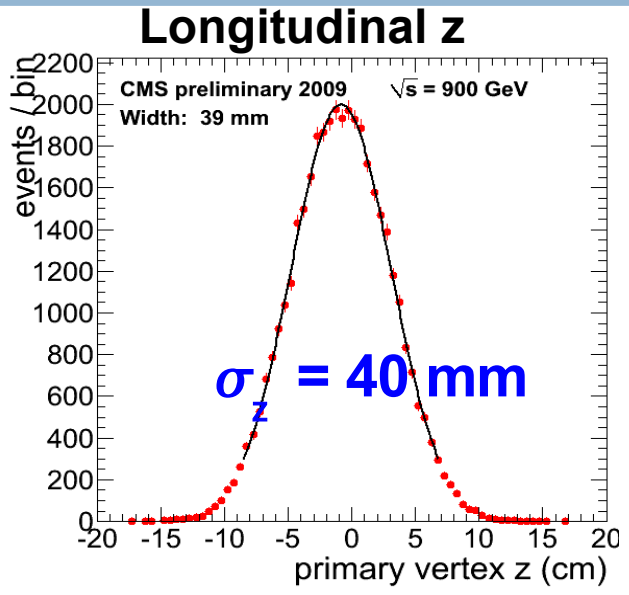




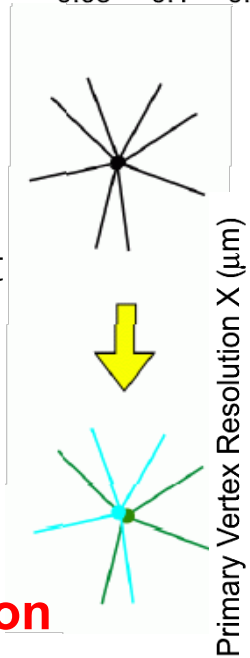
Primary Vertex Reconstruction

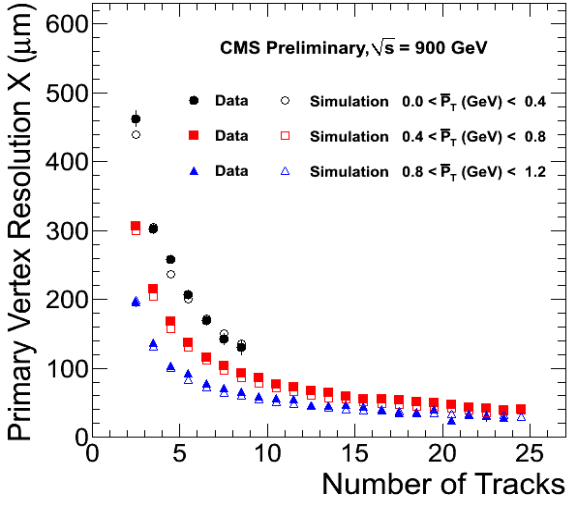
- Primary vertex distribution from single run
  - Beam width estimated with Gaussian fit

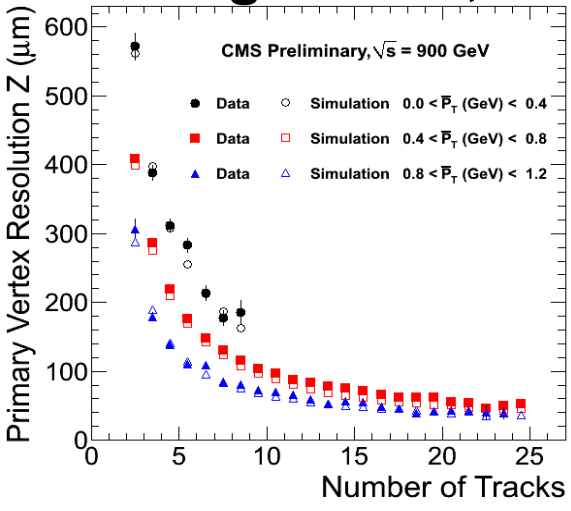




- Data-driven evaluation of primary vertex resolution
  - split tracks into two independent sets and compare fitted vertices
  - resolution : σ of Gaussian fit to $\frac{x_1 - x_2}{\sqrt{2}}$



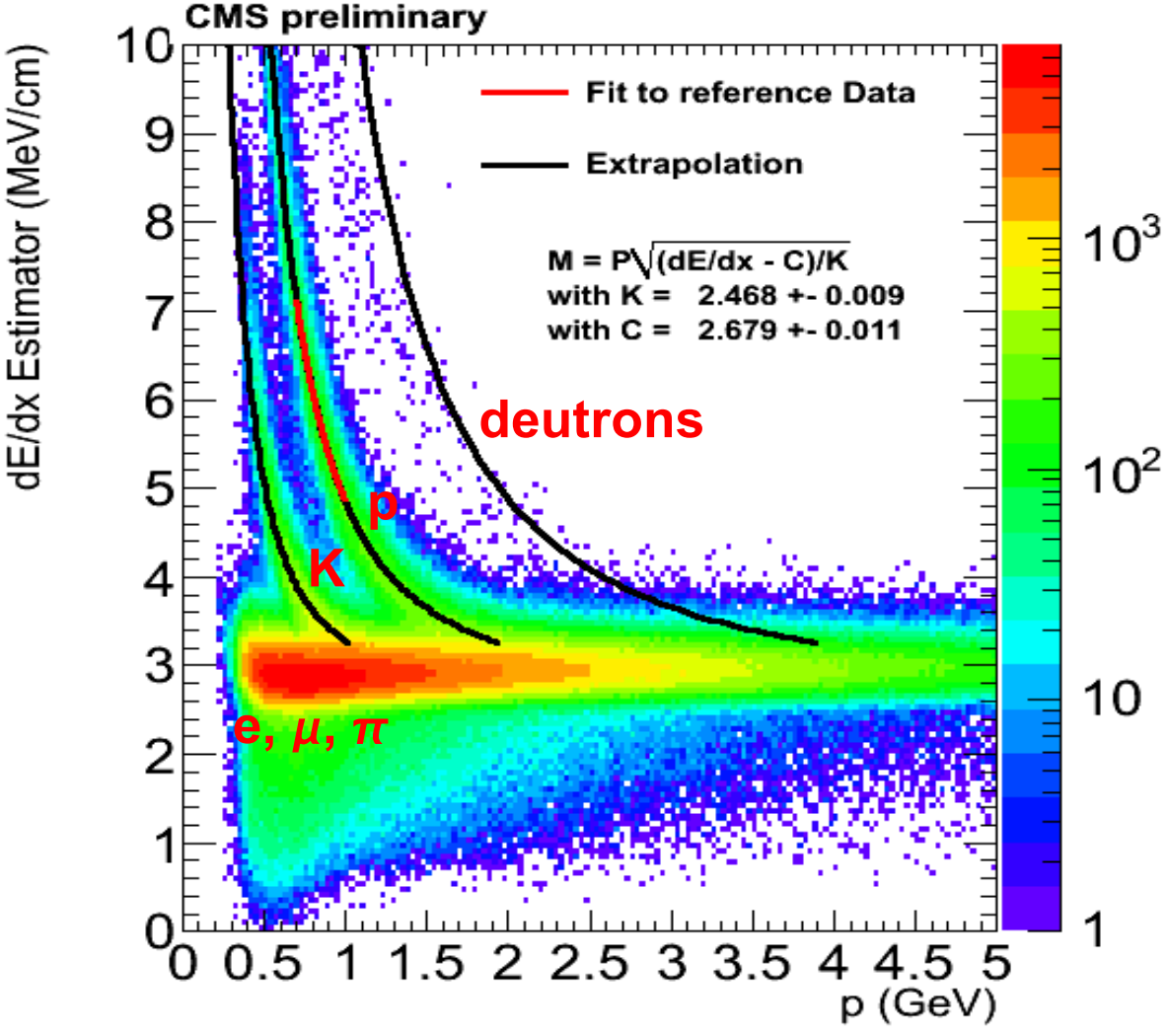


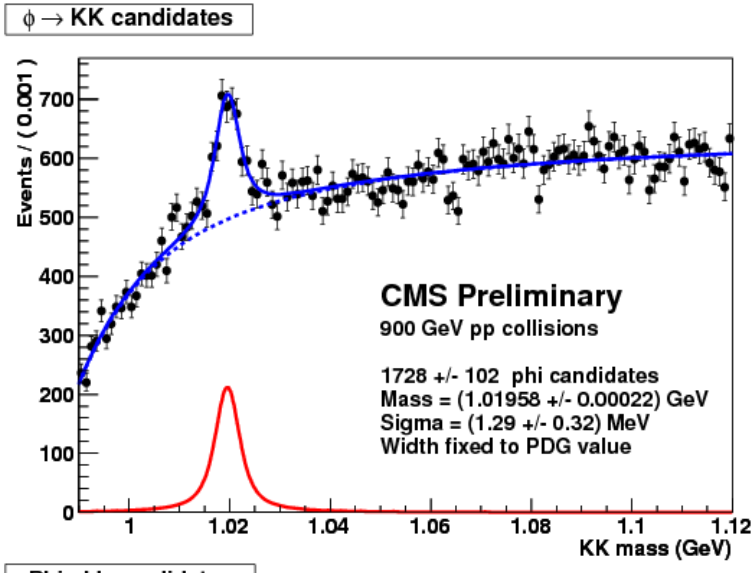


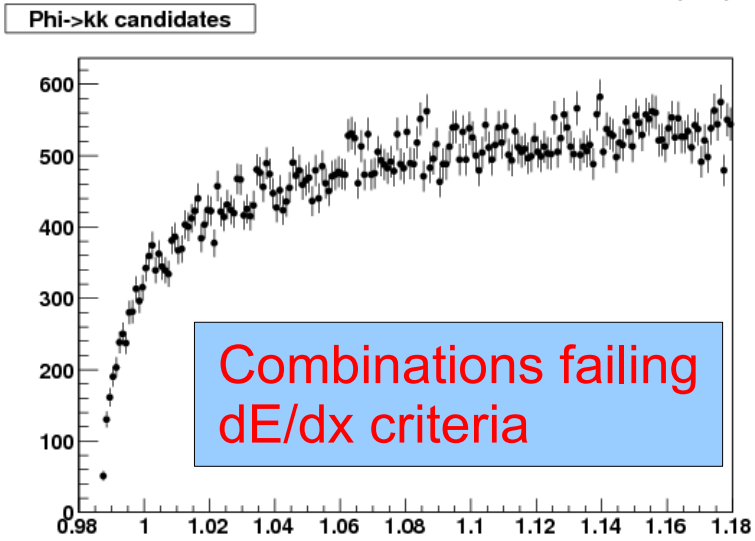
Very good agreement with simulation
⇨ accuracy of alignment well modeled in Monte Carlo

dE/dx Measurements

- Motivation : search for heavy stable (long-lived) charged particles
- Application in analysis of first collisions : search for $\phi \rightarrow K^{+}K^{-}$

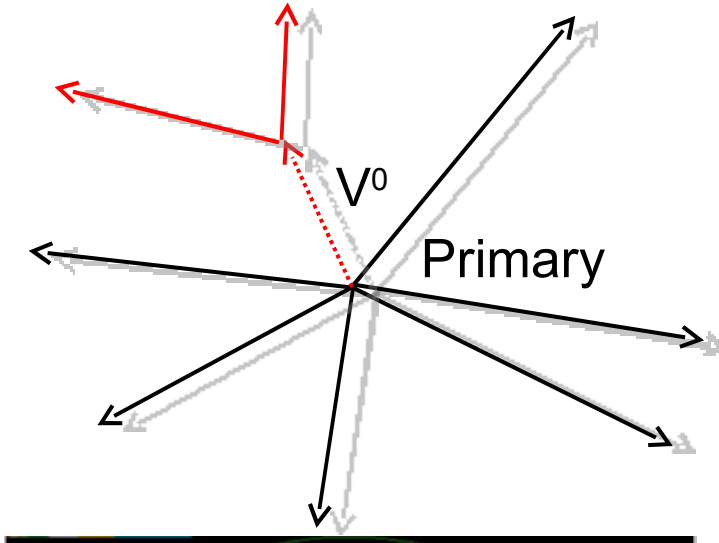


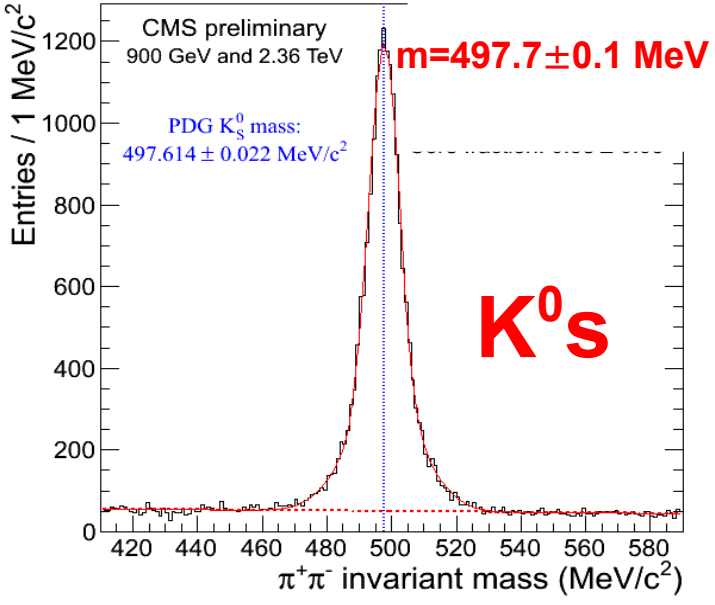


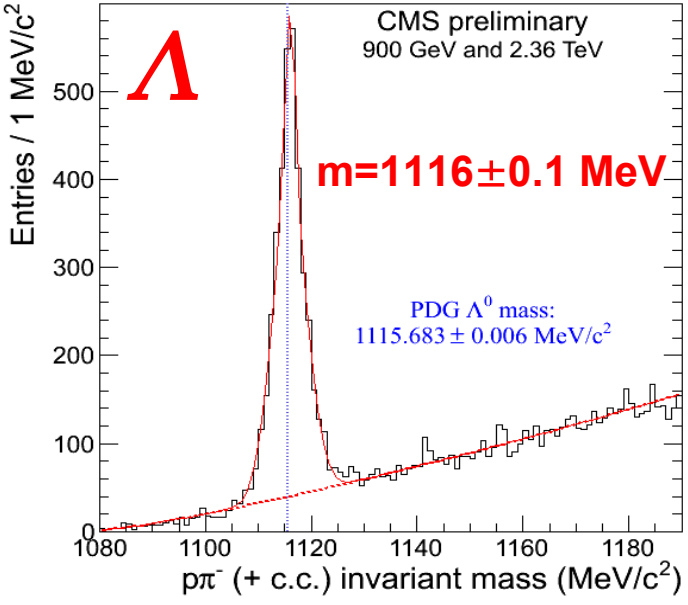


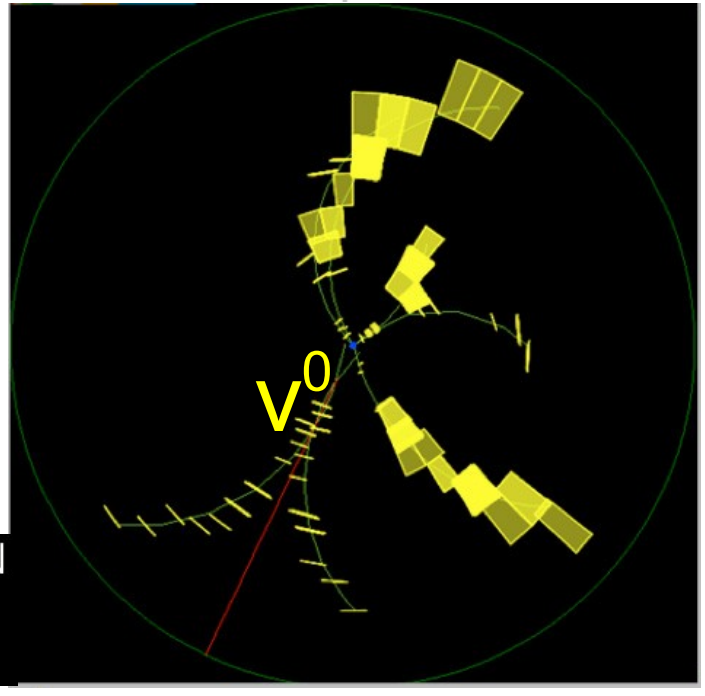
K^0s and Λ Reconstruction

- Two opposite charge tracks compatible with common vertex (V^0)
- Transverse distance from V^0 to beam spot $> 10\sigma$ to avoid fake V^0's composed from the primary vertex tracks



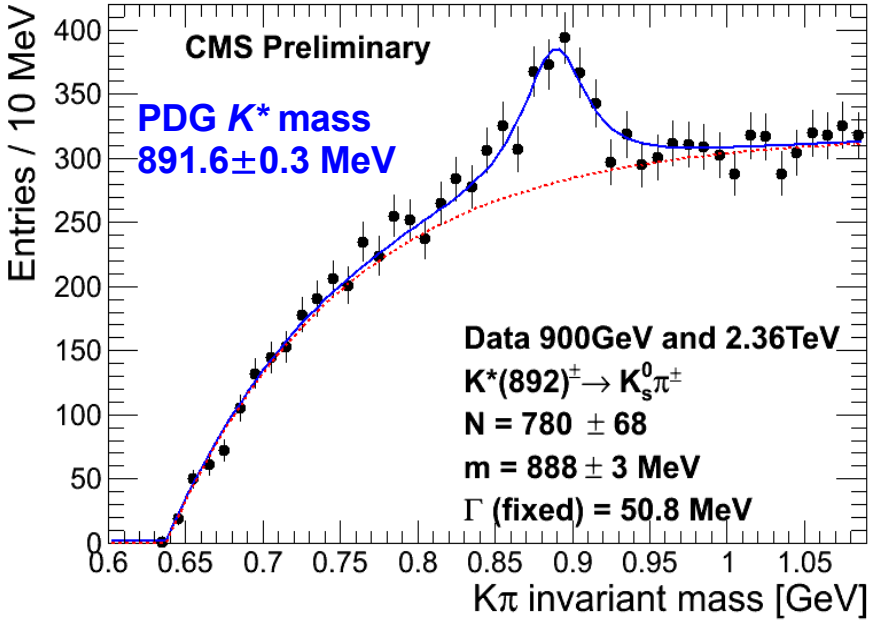




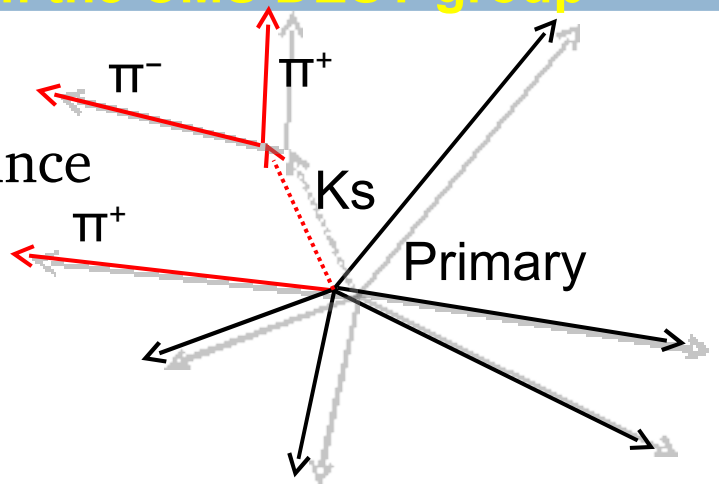


$K^*(892)^{\pm}$ and $\Xi^{\pm}$ Signals

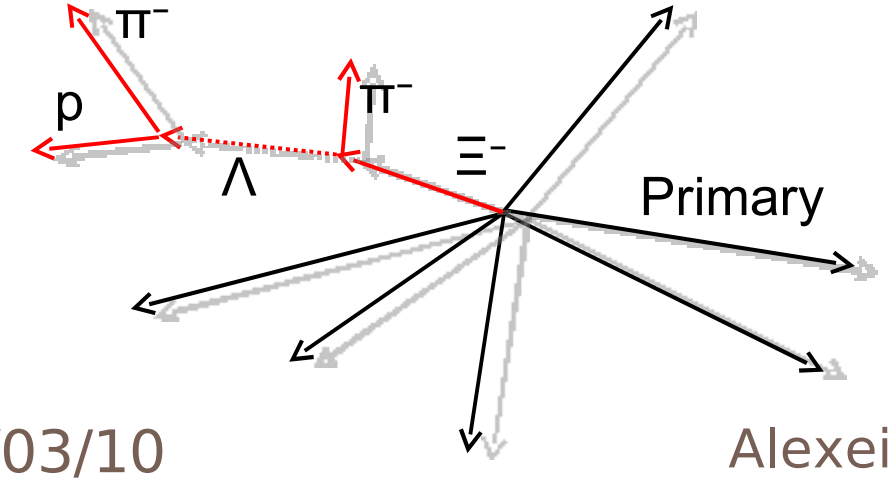
Contribution from the CMS DESY group

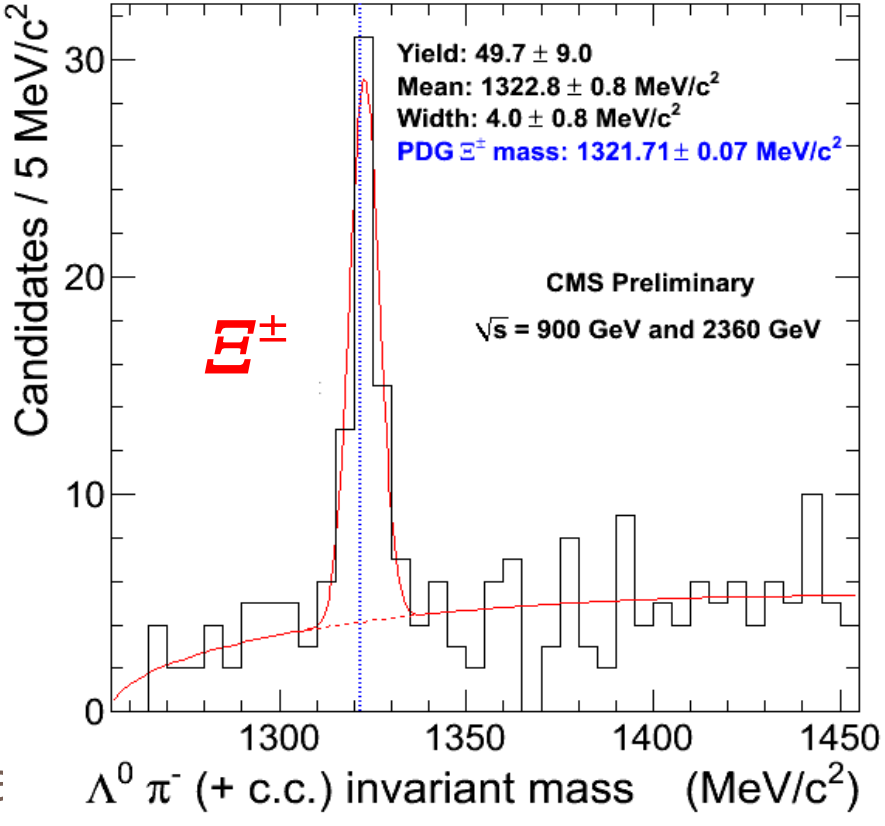


Decay of strong resonance
$K^*(892)^{\pm} \rightarrow K^0 s + \pi^{\pm}$



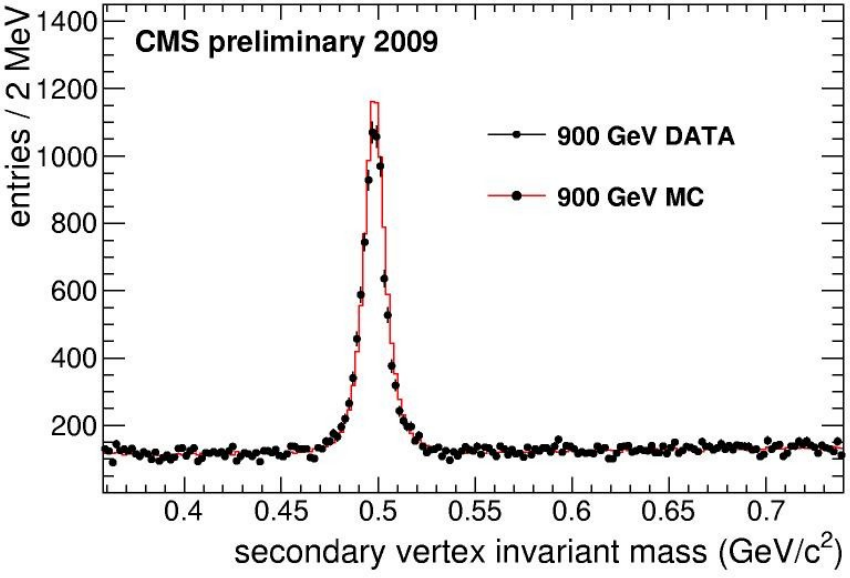
Cascade decay of doubly strange baryon Ξ



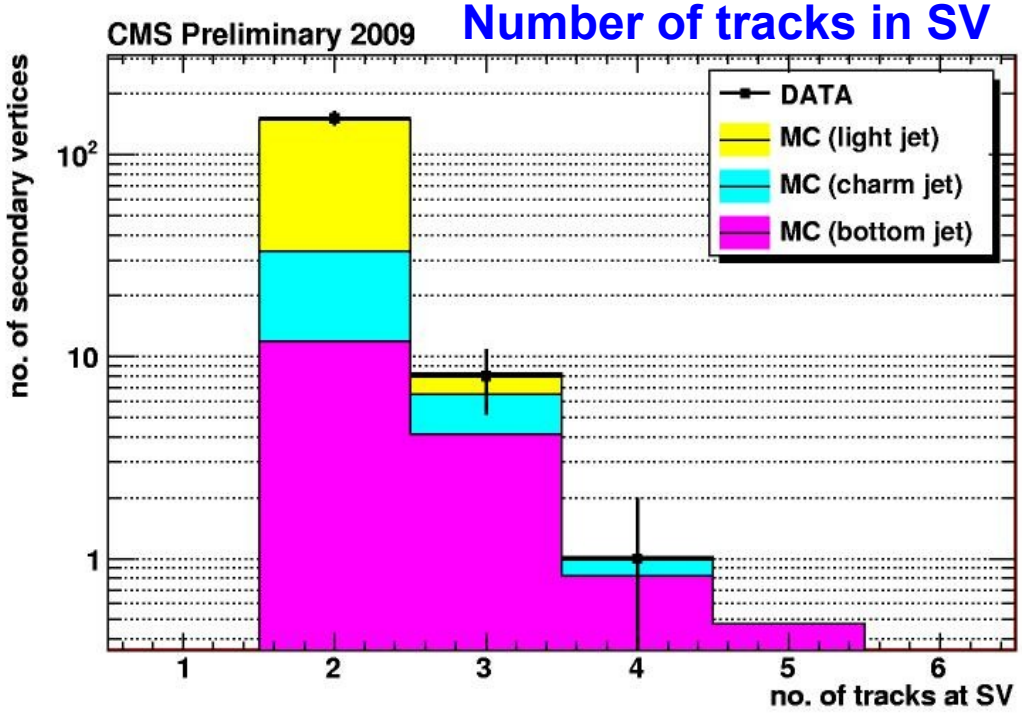


Secondary Vertices (SV) in First Collisions

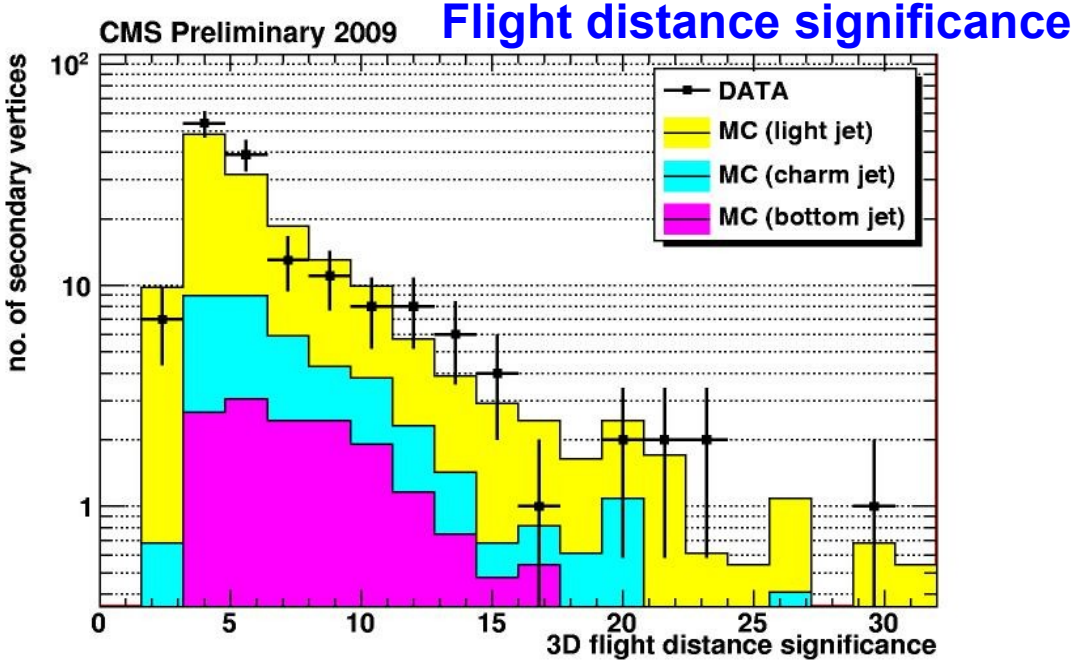
- K^0s mass peak obtained with relaxed cuts on SV indicates that inclusive SV finding works well for b-tagging
- Tighter selection criteria to reject V0's, nuclear interactions and fakes
  => nice agreement between data and simulations



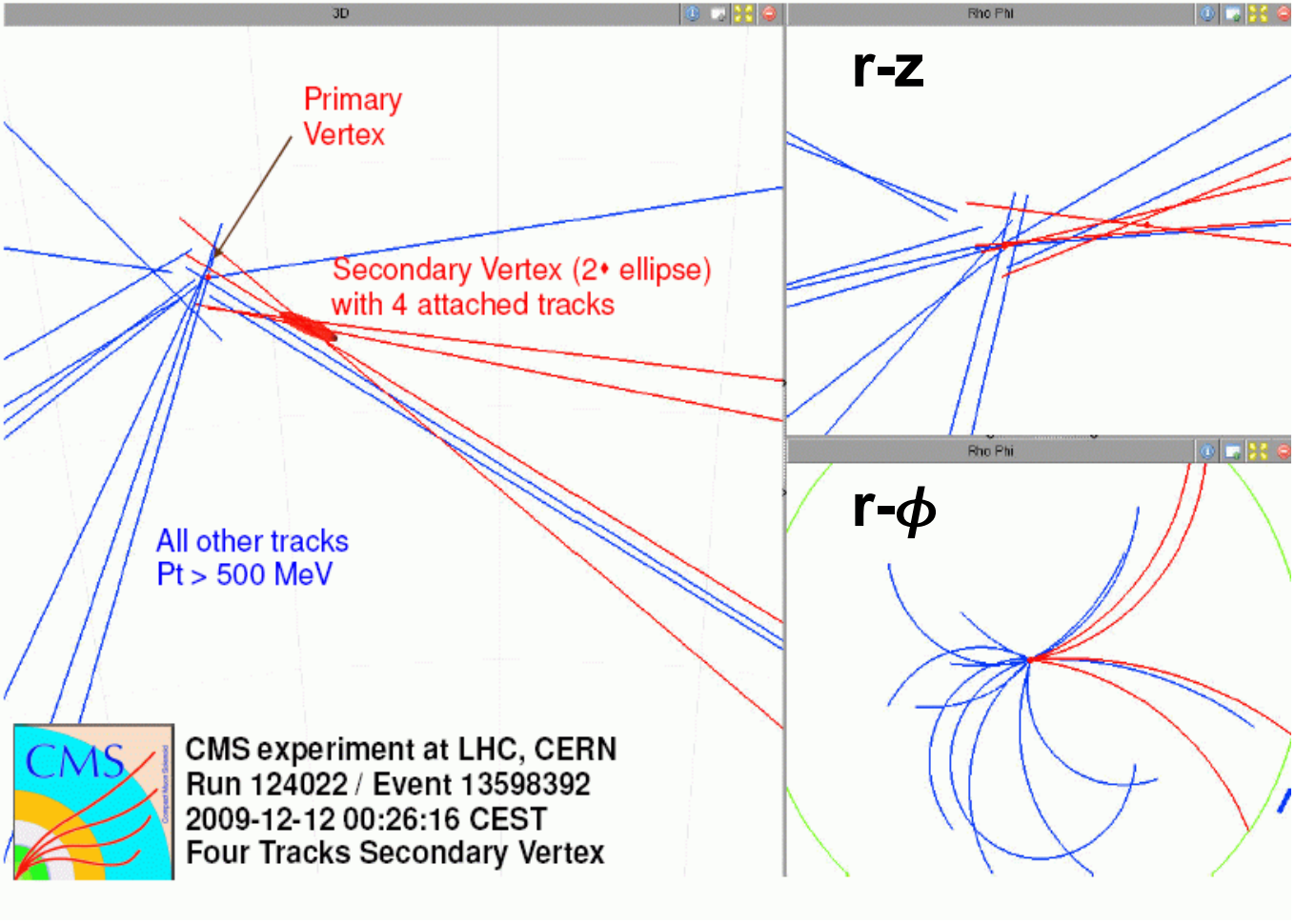
Number of tracks in SV



Flight distance significance



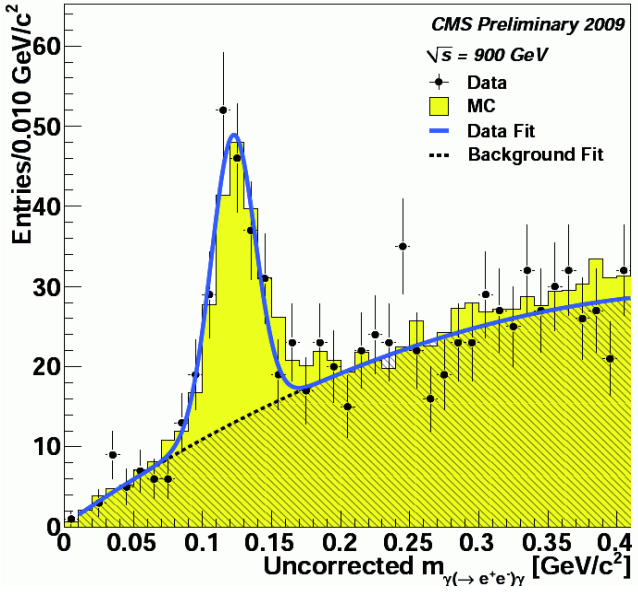
Secondary Vertex Candidate

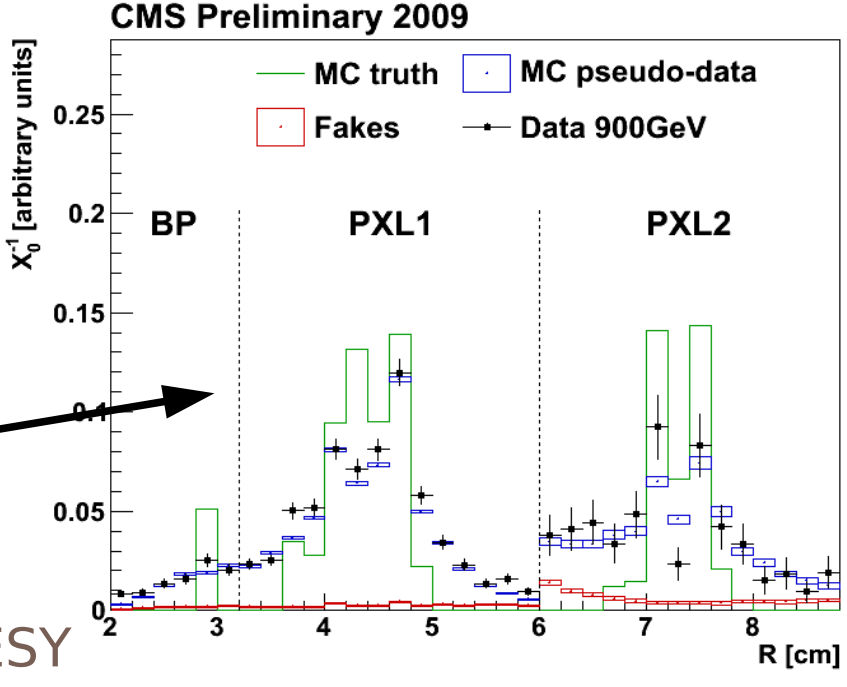


- **Recorded @ $\sqrt{s} = 900$ GeV**
- **Vertex belongs to jet with**
  - $p_T = 10\ GeV/c$
  - $\eta = -1.42$, $\varphi = 0.20$
- **18 tracks @ primary vertex**
- **4 tracks @ secondary vertex**
- **Vertex $\chi^2/ndof = 1.67/5$**
- **Vertex mass = 1.64 GeV**
- **L3D/σ = 0.26/0.037 [cm] = 7**

Electromagnetic Objects in First Collisions

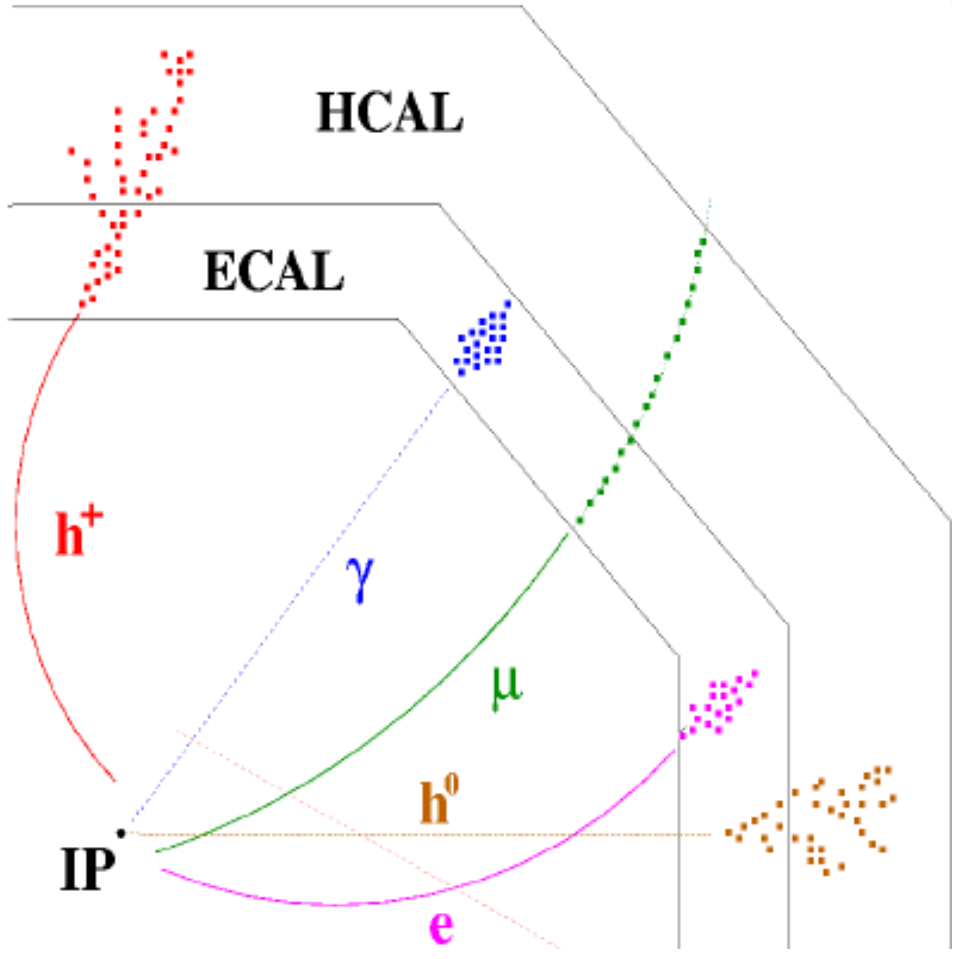
- $\pi^0 \rightarrow (e^+e^-)\gamma$, one photon is detected in ECal, another is reconstructed as conversion
- Conversions :
  - 2 opposite charge tracks compatible with common vertex located within tracker material
  - tracks are parallel at vertex position
- Photons :
  - ECal cluster in barrel, $E_T > 300$MeV
  - No HCal activity behind ECal cluster
  - Primary vertex and ECal cluster position define photon momentum vector
- ***Compelling signal in the reconstructed mass distribution, nicely reproduced by simulation***
- Conversions ⇒ radiography of CMS detector study of material budget distribution





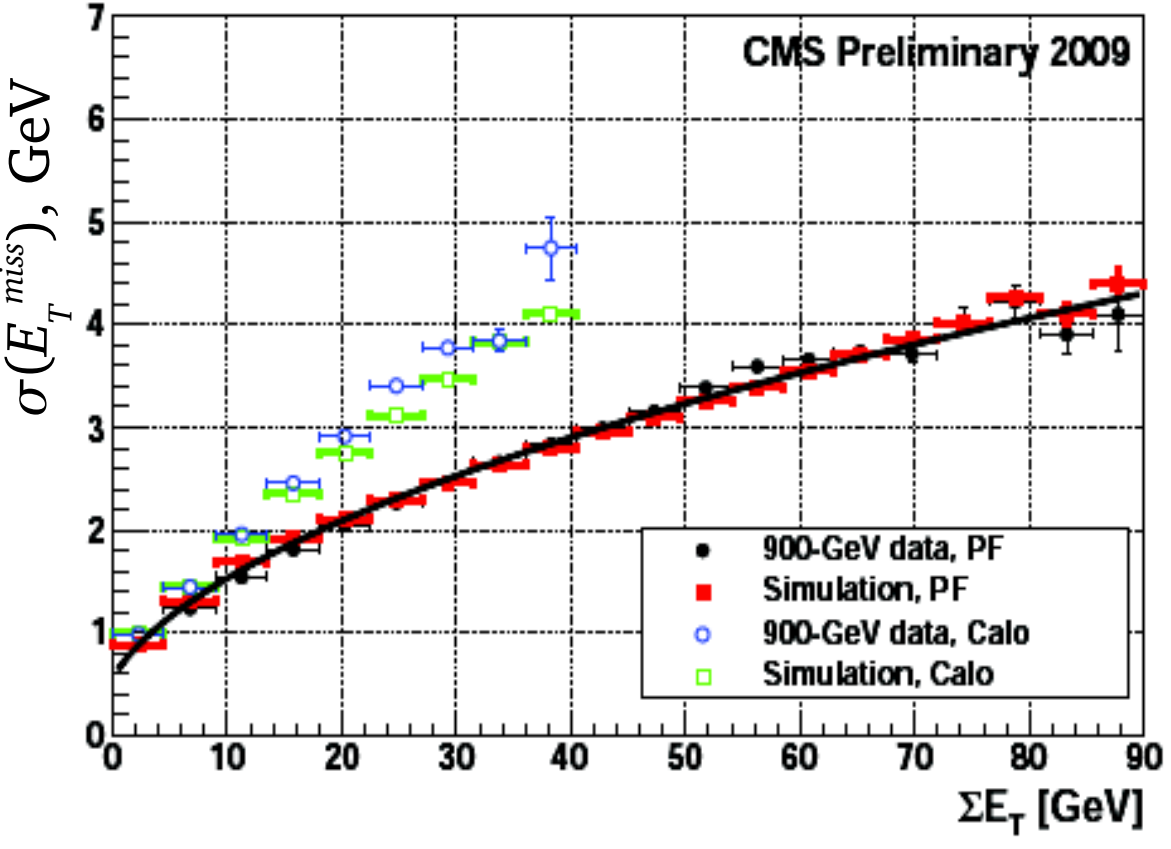
Particle Flow Commissioning

- **Particle Flow concept : reconstruction of individual particles based on complementary information from all sub-detectors**
- Provides most accurate jet and E_t^{miss} measurements
  - Charged hadrons ≈65% of jet energy
    - signature : tracks + ECal/HCal clusters
    - measured with tracker
  - Photons ≈20% of jet energy
    - signature : ECal cluster non associated with track
    - measured with ECal
  - Neutral hadrons ≈15% of jet energy
    - signature : ECal/HCal clusters non associated with track
    - measured with calorimeters
- Reconstructs/identifies isolated leptons [e, μ]



Missing E_T with Particle Flow

- Minimal bias events : small E_T^{miss}
  - ideal sample for testing resolution on E_T^{miss}
- Parameterized as function of $\sum E_T$
  - $\sigma(E_T^{miss}) = a \oplus b\sqrt{\sum E_T}$
- **Considerable improvement compared to calorimeter based reconstruction!**

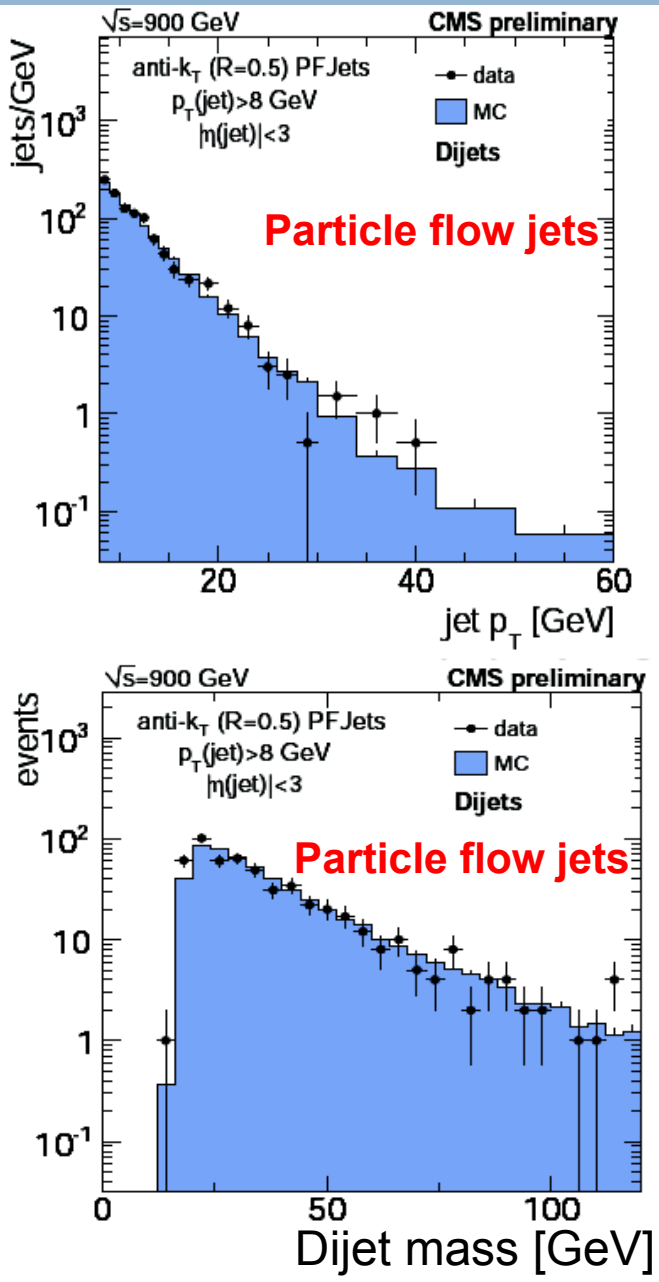


Di-Jets in First Collisions

- Di-jets : two jets
  - balanced in p_T
  - back-to-back in azimuth
- Clean sample dominated by real jets
  - Fakes are unlikely to have balancing counter-part
  - Loose jet ID compared to inclusive jet sample can be used to enhance statistics

⇒ Selected sample verifies :

- jet modeling in Monte Carlo
- jet reconstruction procedure
- relative jet calibration (p_T balance of jets w.r.t. control central region ⇒ flattened response in η)

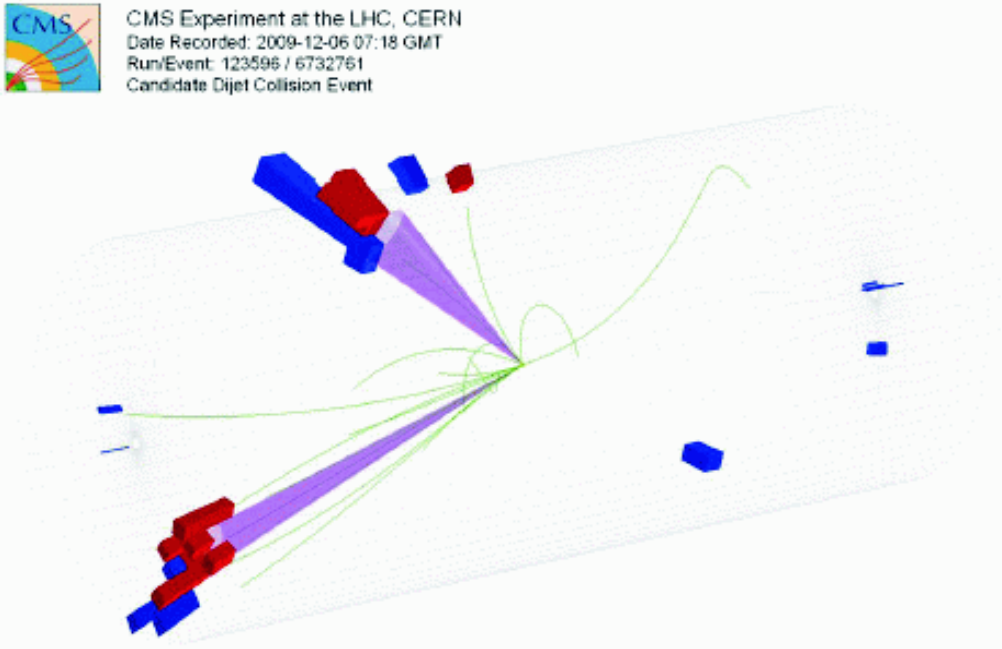


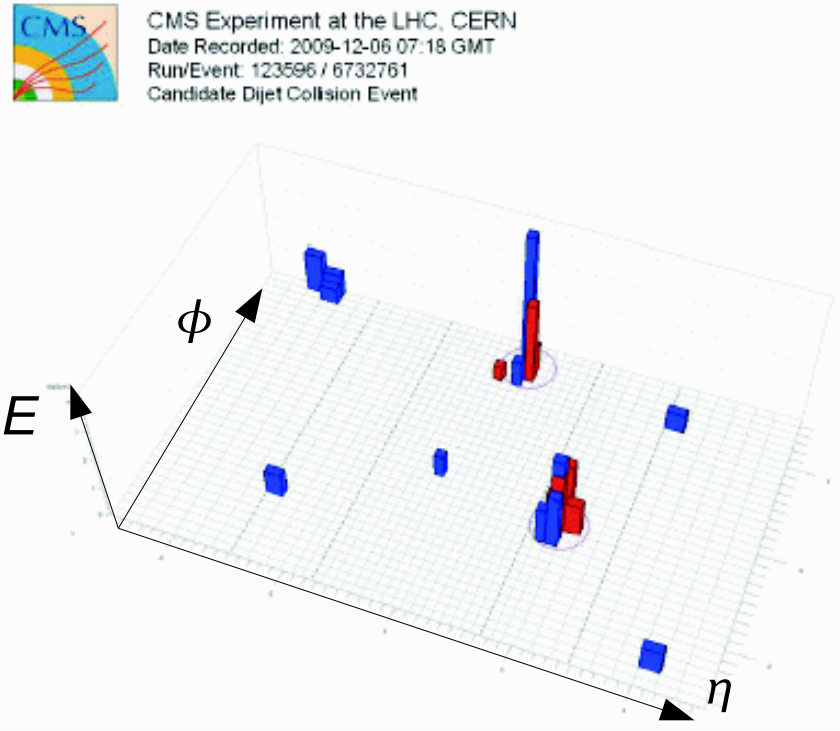
Candidate Di-jet Event

Anti-K_T algorithm with cone size R=0.7

	Jet 1	Jet 2
Corrected p_T (GeV)	24	26
η	0.3	2.0
ϕ	2.5	-0.7
EM Energy Fraction	0.5	0.6

⇐ back-to-back in ϕ

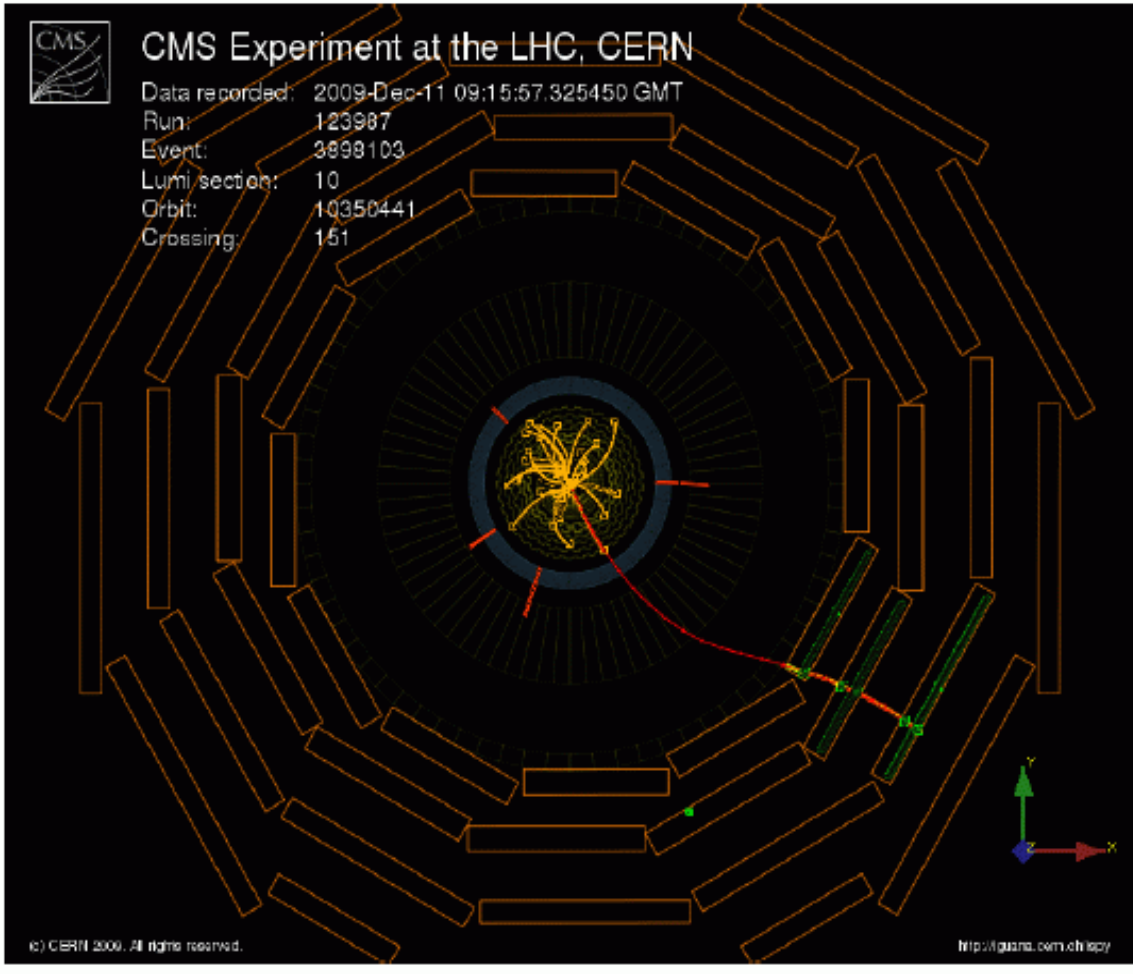




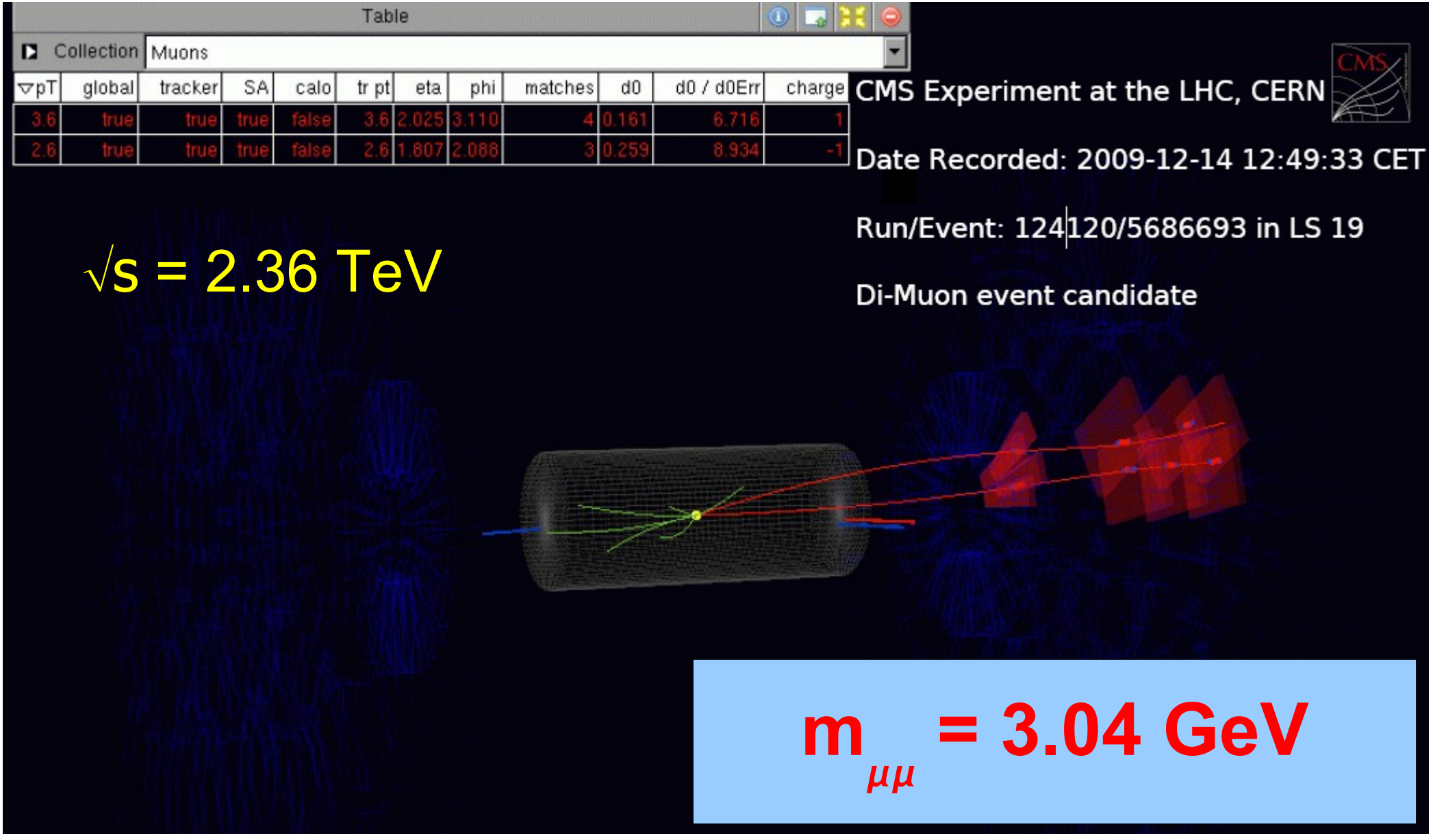
Muons in the CMS Detector

- Compact **Muon** Solenoid – detector is particularly efficient in muon reconstruction
- Muons are objects composed of the following constituents
  - Standalone track reconstructed in the muon system
  - Matched to the track in the inner tracker
  - Calorimeter signal compatible with MIP
- Main source of muons in the first collisions
  - on-flight decays of $K^{\pm}$ and $\pi^{\pm}$
  - Cosmics in-time with collisions (tracks are likely displaced from primary vertex)

Barrel muon candidate

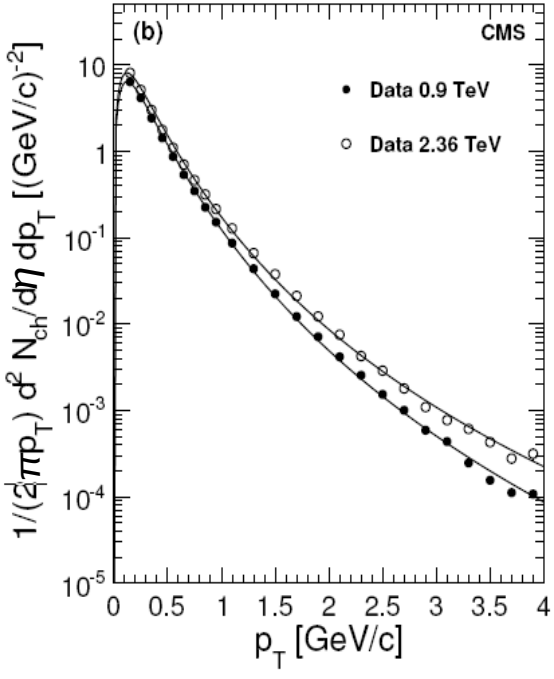


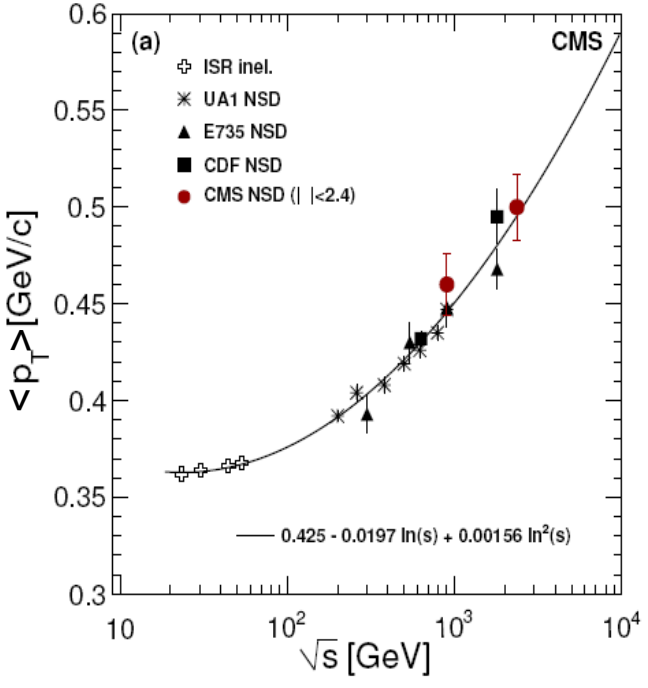
$J/\Psi \rightarrow \mu^+\mu^-$ Candidate



First CMS Paper From Collision Data

- Kinematic properties of collision products in min bias events => topic of the first physics CMS publication with collision data
  - Measurement of inclusive charged-hadron kinematic distributions at new physics frontier => first step towards understanding of underlying events for hard processes at design LHC luminosity





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

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 0.46 ± 0.01 (stat.) $\pm$ 0.01 (syst.) GeV/c at 0.9 TeV and 0.50 ± 0.01 (stat.) $\pm$ 0.01 (syst.) 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 3.48 ± 0.02 (stat.) $\pm$ 0.13 (syst.) and 4.47 ± 0.04 (stat.) $\pm$ 0.16 (syst.), respectively. The results at 0.9 TeV are in agreement with previous measurements and confirm the expectation of near equal hadron production in $p\bar{p}$ and pp collisions. The results at 2.36 TeV represent the highest-energy measurements at a particle collider to date.

KEYWORDS: Hadron-Hadron Scattering

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Summary

- First collisions at $\sqrt{s} = 0.9$ and 2.36 TeV have been collected by CMS in the fall 2009
- Recorded data are of utmost value, allowing for:
  - Commissioning of reconstruction algorithms
  - Detector calibration
  - Initial physics studies
- CMS detector, software and analysis chain are in excellent shape
- Amazingly good agreement between data and simulation
  $\Rightarrow$ efforts invested in development of the full detector simulation software pay back
- **First CMS publication with collision data** : measurement of inclusive kinematic distributions of charged hadrons at new energy frontier
- More papers, including physics results from first collisions, coming soon

Outlook

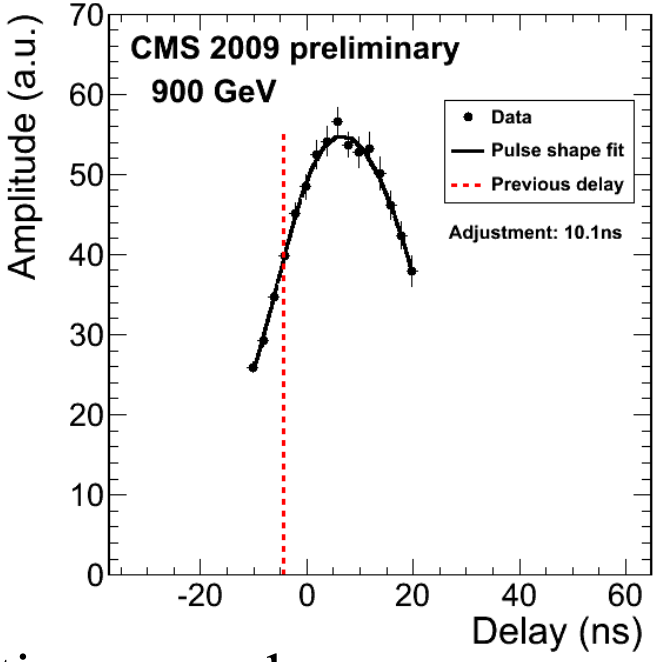
- **Prospects for 2010-2011 run ($\sqrt{s}$ = 7 TeV)**
  - **2010 : L ~ $10^{28} \rightarrow 10^{32}$ $cm^{-2}s^{-1}$**
    $\Rightarrow$ total of 100-200 pb^{-1}
  - **2011 : L ~ 1$\rightarrow$few 10^{32} $cm^{-2}s^{-1}$ $\Rightarrow$ $\geqslant$100 pb^{-1}/month**
    $\Rightarrow$ total of ~ 1 fb^{-1}
  - **2012 : shut-down**

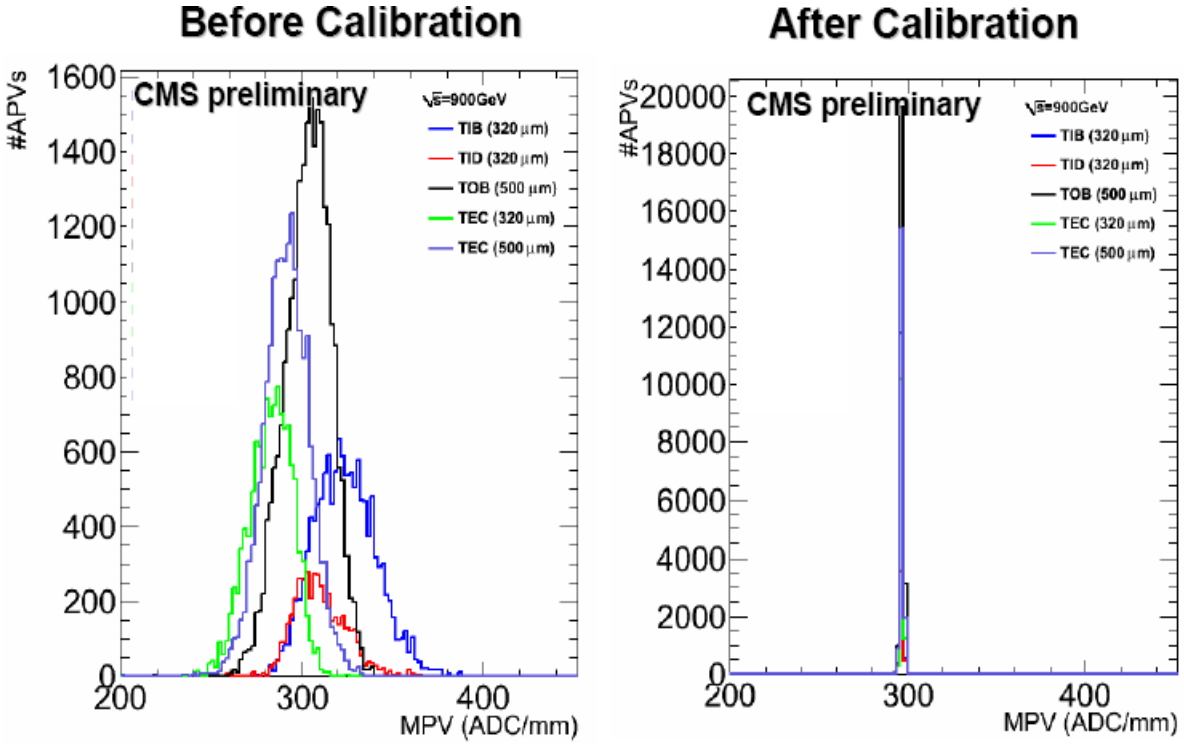
- **Looking forward to first data @ 7 TeV and preparing for electroweak, top and new physics !**

Backup slides

Silicon Strip Tracker

- Time delay scan to determine maximum charge collection
- Sensor efficiency measured with reconstructed tracks
  - >99.9% excluding known bad modules
- Cluster Signal/Noise ratios measured
  - High (19-24) and in agreement with expectation

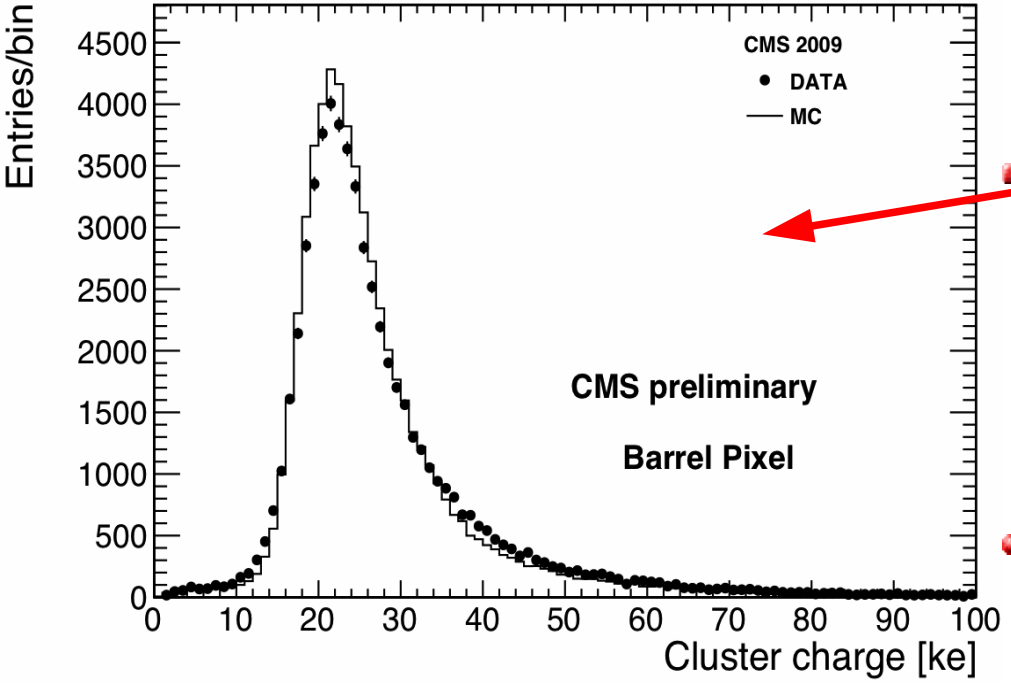




- Calibration procedure
  - For every module: fit normalized cluster charge distribution by Landau (use only tracks with pT>1GeV and at least 8 hits)
  - Extract MPV from the fit and compute the gain : G = MPV/300
  - Conversion factor (ADC/mm ⇒ MeV/cm) from cosmic data

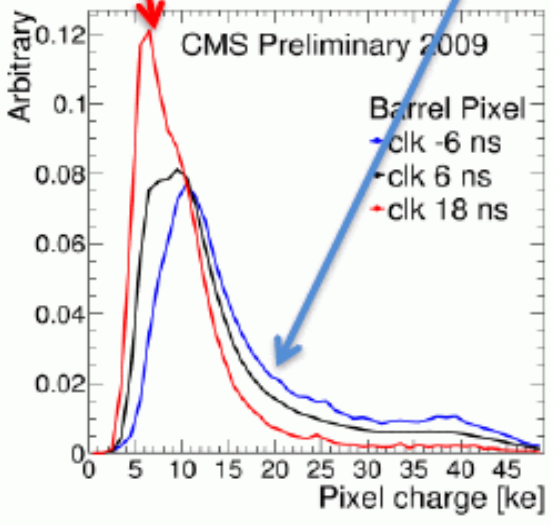
Silicon Pixel Detector

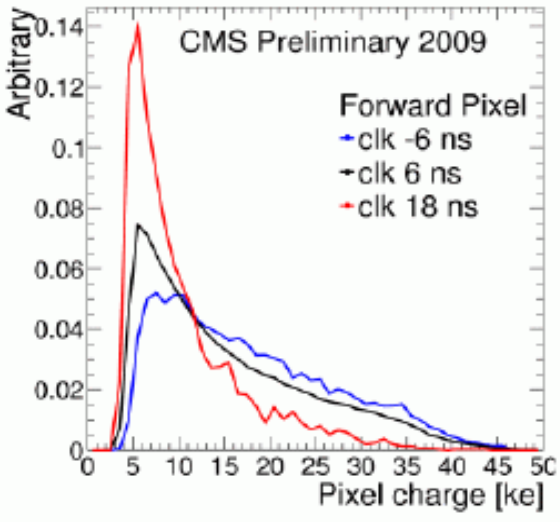
- Charge collection must be synchronized with bunch crossings
  - Pixel charge sampled @ 25 ns
- Timing scan
  - Optimize signal shape
  - Avoid biased selection



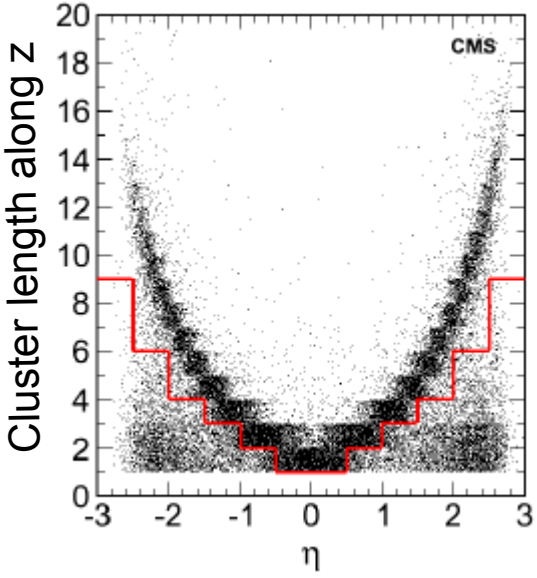
Little too late – getting less charge

Little too early – bias to pick big pulses



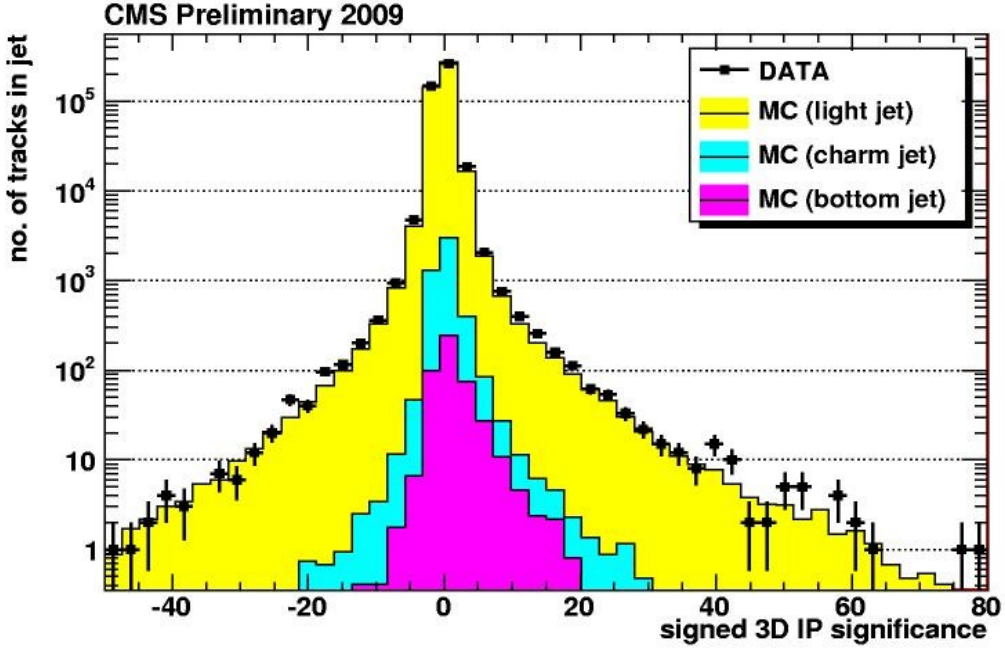


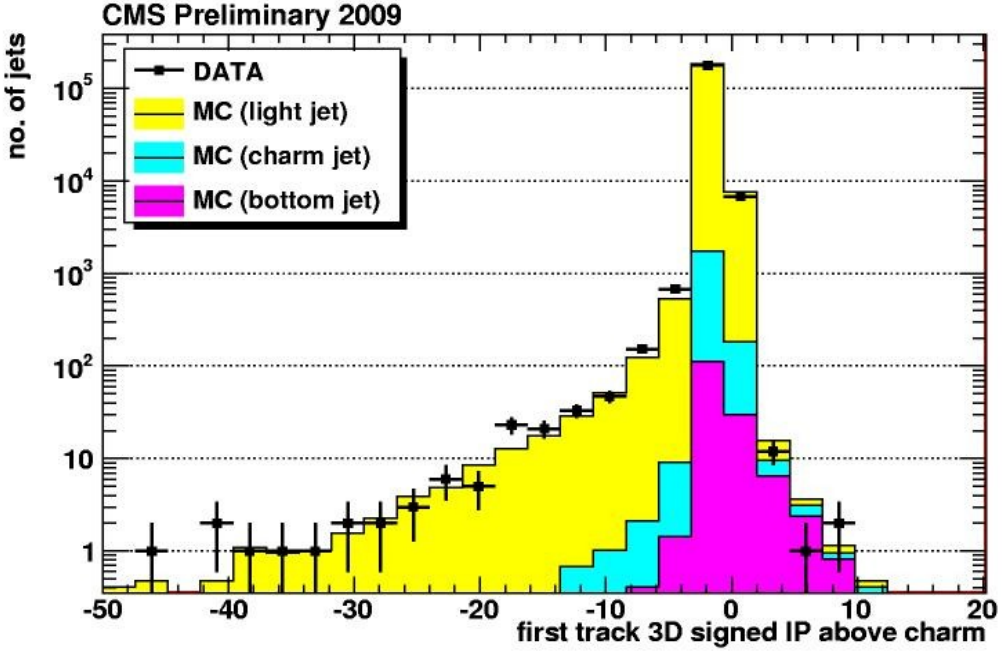
- Charge corrected for track incident angle
  - clusters above red line are likely from IP; below – background
- Good agreement with simulation



B-Tagging Related Variables

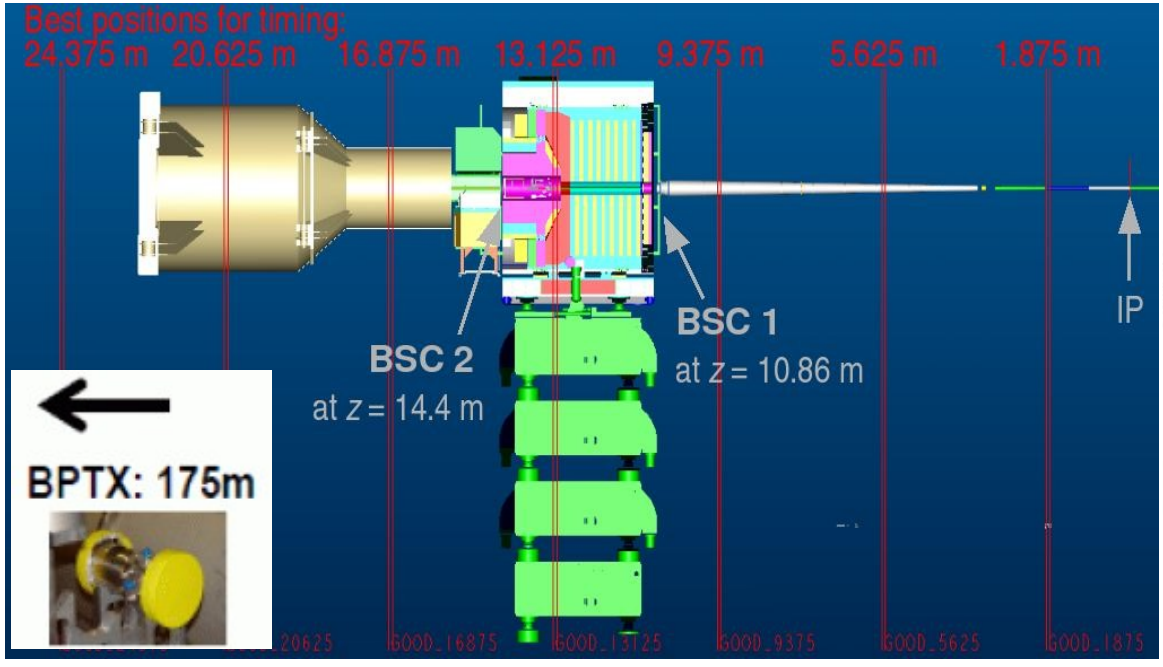
- Very limited # of b-jets in first collisions (Anti-K_T algorithm with cone size=0.7 is used)
  - Few well-defined jets/tracks with momenta appropriate for b-tagging @ high $\sqrt{s}$
  - Impact parameters and secondary vertices are mainly studied to understand bkgd and fakes
- 3-dimensional impact parameter:
  - First track above charm : 4-vector sum is updated by adding tracks in decreasing order of 3D IP Significance (pion mass hypothesis is assumed) until invariant mass $\geqslant$1.5GeV (~2/3 of D^0 mass). The last track added is first track above charm

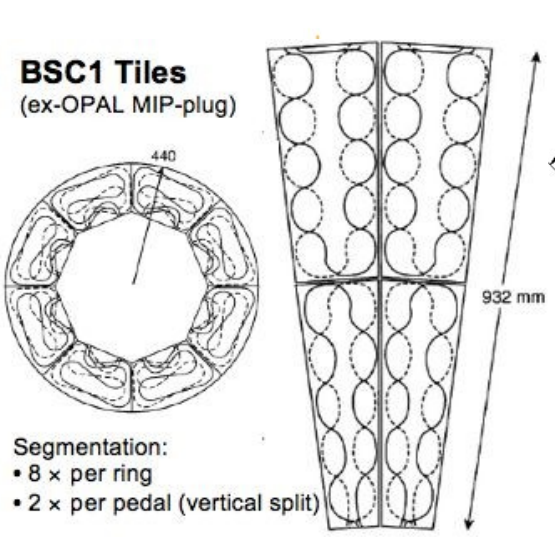


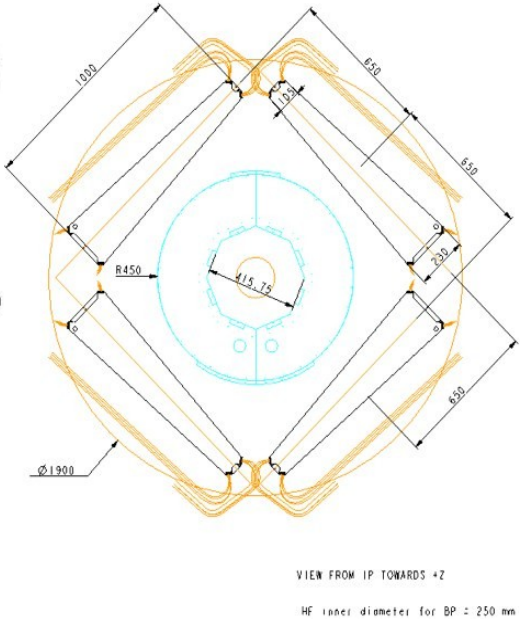


Recording Collision Data. Minimal Bias Trigger

- First collision data are taken with loose trigger conditions ⇒ minimal bias events
  - Min bias trigger : hit in any Beam Scintillator Counters (BSC1) (inner ring) in coincidence with a signal from the two Beam Pick-Up Timing for eXperiments (BPTX) ⇒ two bunches crossing IP



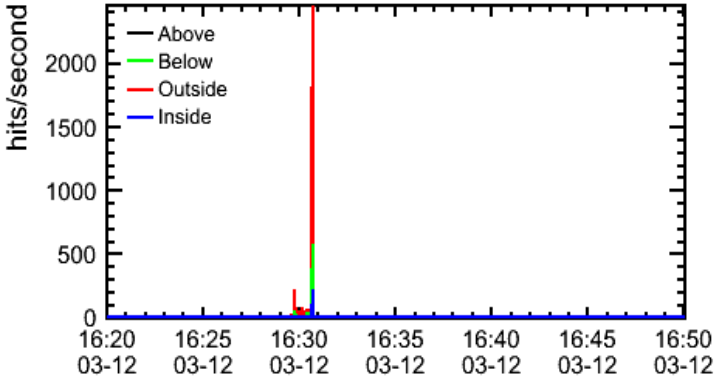


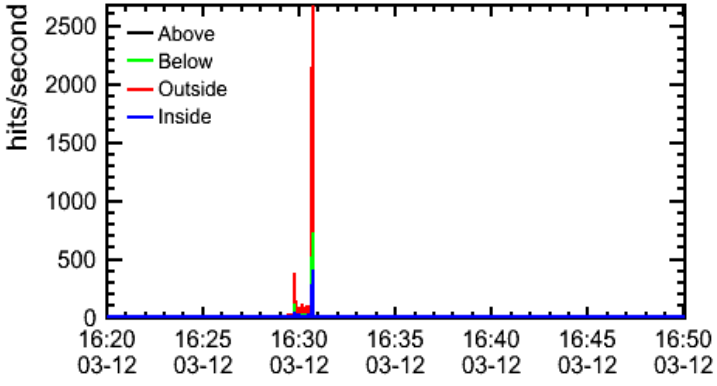


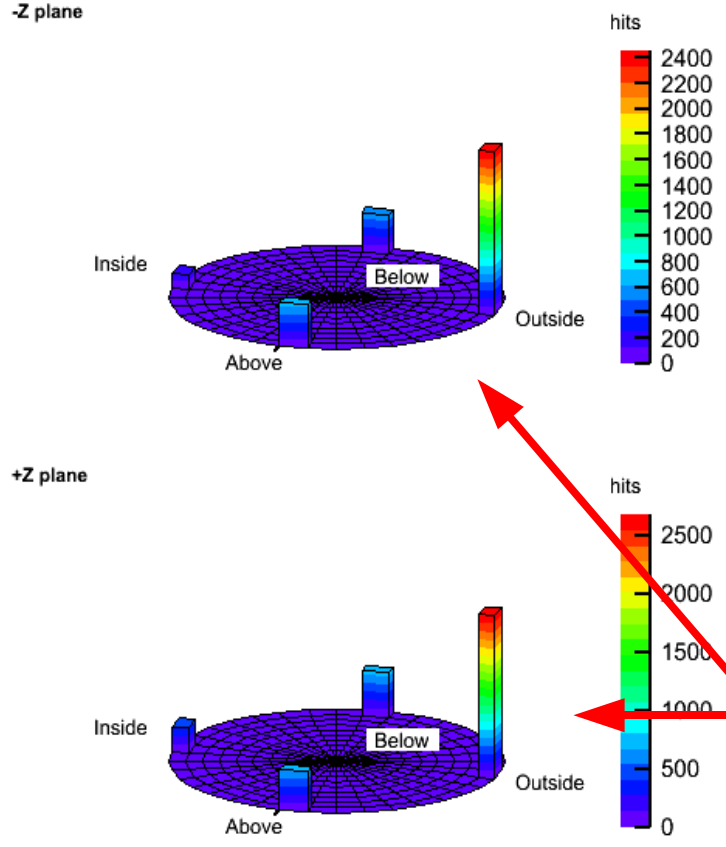
  - Any two hits from the BSC1 outer pedals on opposite sides of IP, consistent with the time difference of 73 ns (twice distance from BSC1 to IP) are used as a beam halo veto

Beam Movement Detected by BCM1F during Collision Run

- Relative response of the four diamond sensors placed at ϕ=0º, 90º, 180º , 270º around beam-pipe is sensitive to beam movements







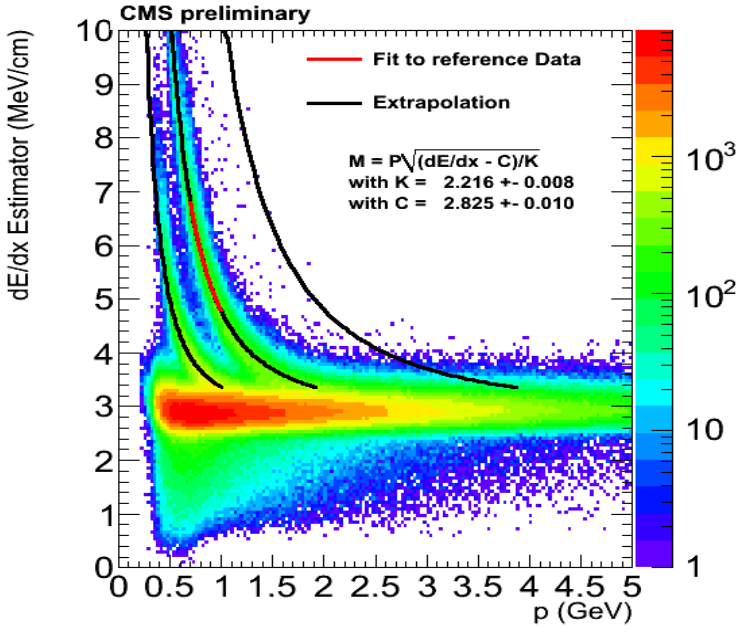
Equal response of all sensors
⇒ beam @ nominal position
(center of beam pipe)

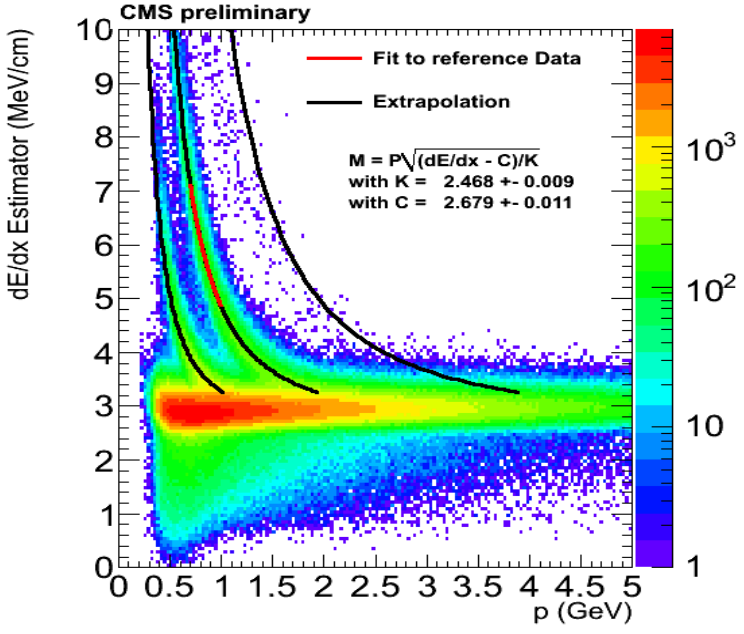
Increased response in one of the sensors compared to others indicates movement of beam towards this sensor

Beam moved away from LHC ring center

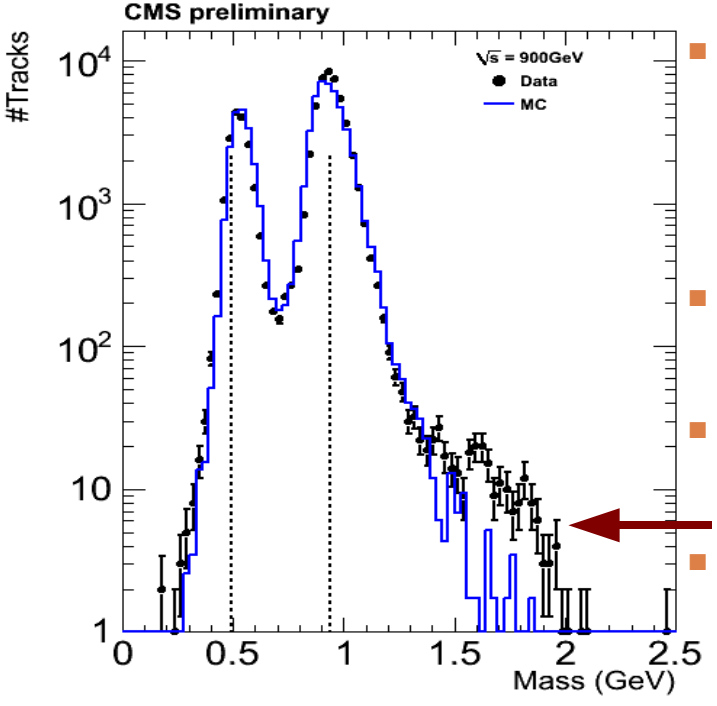
- http://www.desy.de/~rasp/bcm1f_beam_movement.gif

dE/dx Measurements





- motivation : search for Heavy Stable (Long-lived) Charged States
- $\frac{dE}{dx} = K\frac{m^2}{p^2} + C$ reproduces Bethe-Bloch with accuracy better than 1% for $0.4<\beta<0.9$
- Parameters *K* and *C* are regarded as universal
  - extracted from the fit to the proton line
  - momentum restricted to [0.7,1.0] GeV/c

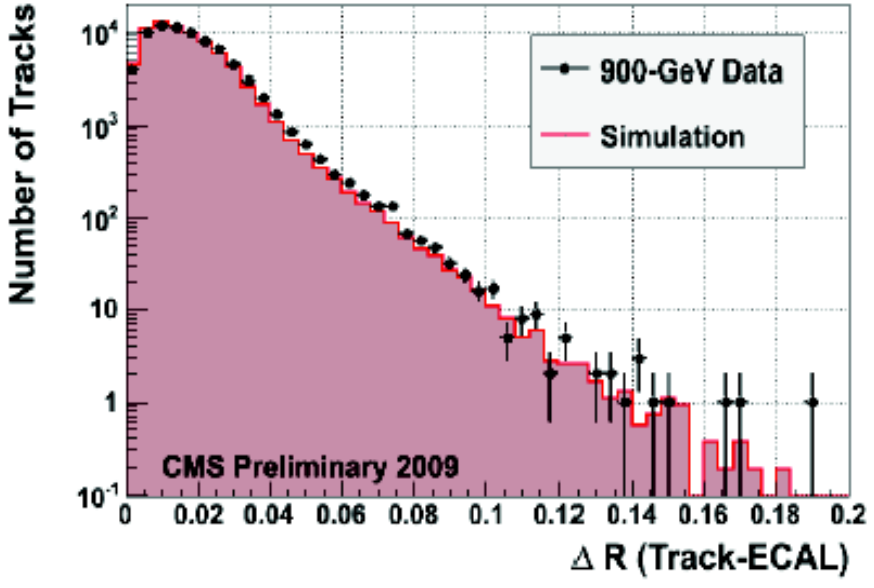


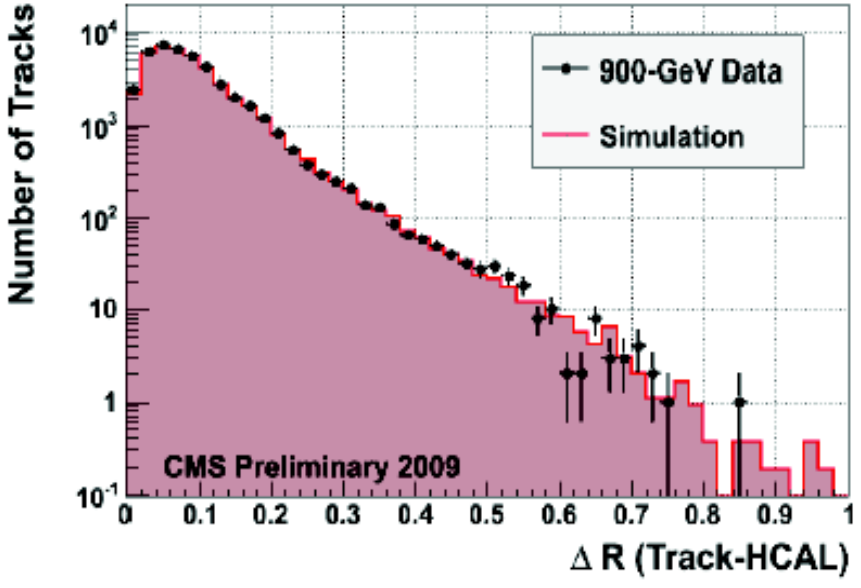
- Mass reconstructed from dE/dx measurement
  - p<2GeV, dE/dx>4.1 MeV/cm
- Separately fitted *K* and *C* for data and MC
- Clear peaks corresponding to kaons and protons
- Additional peak attributed to deutrons (not visible in Monte Carlo)

Particle Flow Commissioning

- **Efficient track-cluster association is prerequisite to avoid double-counting of energy!**

Track-cluster distance distribution : $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$





Agreement with simulation validates track cluster link efficiency, alignment between tracker and calorimeters and energy sharing between ECal and HCal

Dimuons in First Collisions

- Expectation for dimuon events in first collision data
  - Global muons alone 2 GeV < $m_{\mu\mu}$ < 4 GeV
    - 0.07 dimuons @ 900 GeV
    - 0.01 dimuons @ 2.36 TeV
- Considering only global muons, S/B in the mass window 3.0-3.2 GeV is 14/1
- If we see opposite sign muon pair with 3.0 GeV < $m_{\mu\mu}$ < 3.2 GeV it is likely to be J/Ψ candidate rather than background muon pair

Three opposite sign muon pairs are observed after dedicated selection

One dimuon has mass 3.04 GeV

Vertex fit probability = 57%

first muon : global muon, χ^2/ndf= 0.97
second muon : global muon, χ^2/ndf= 0.46