Performance of CMS Tracker in Heavy Ion Collisions

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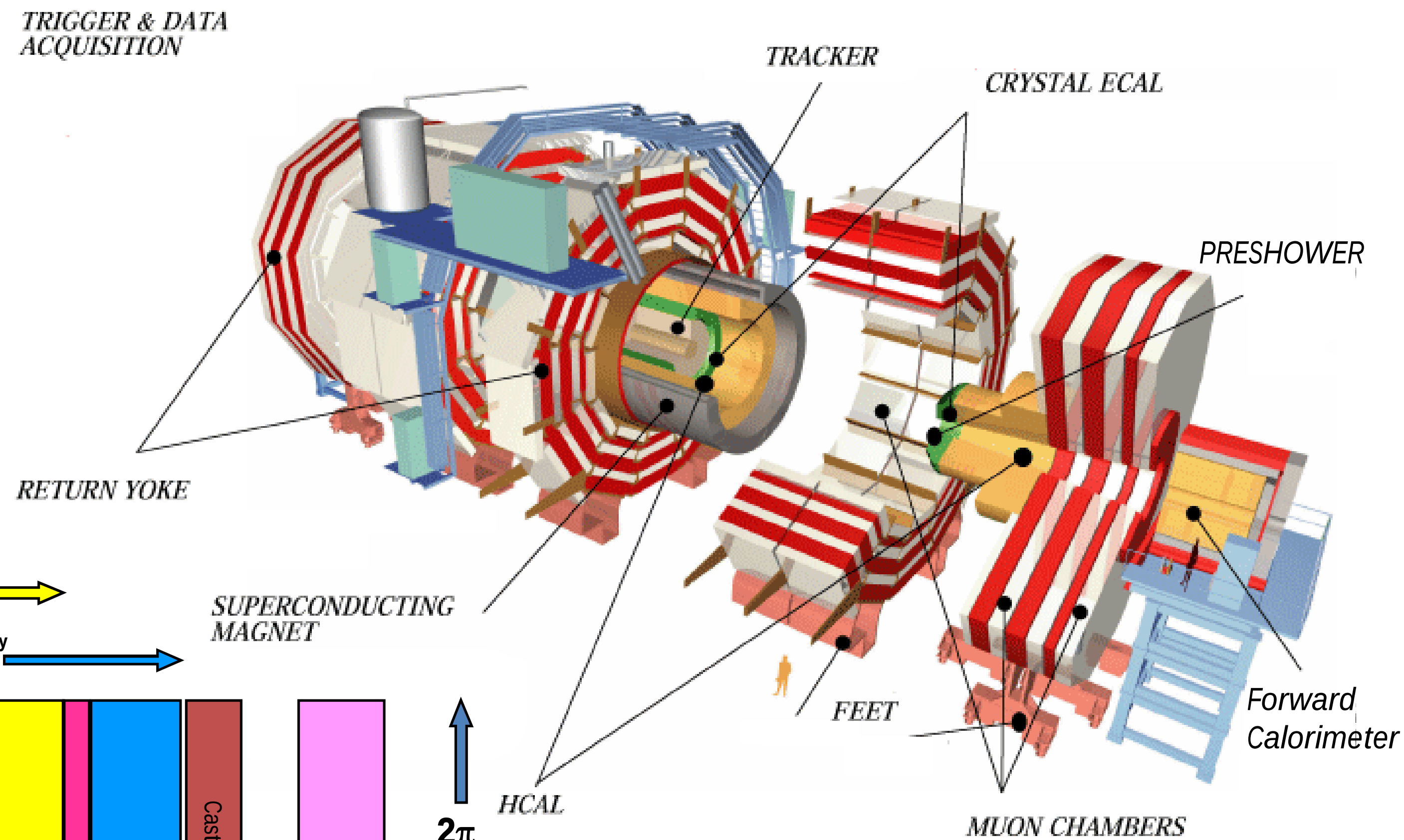
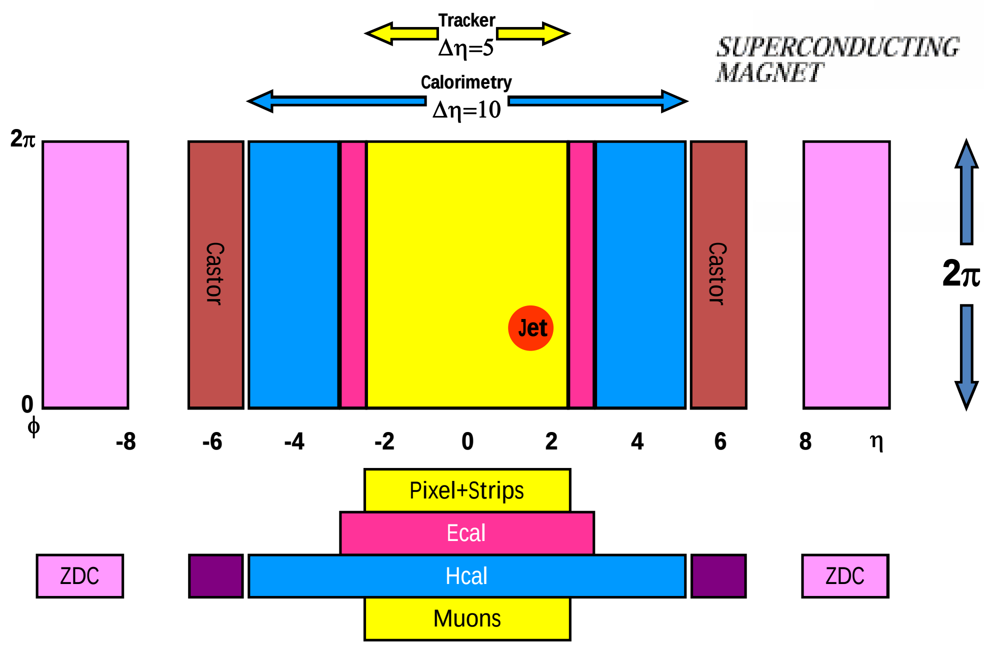
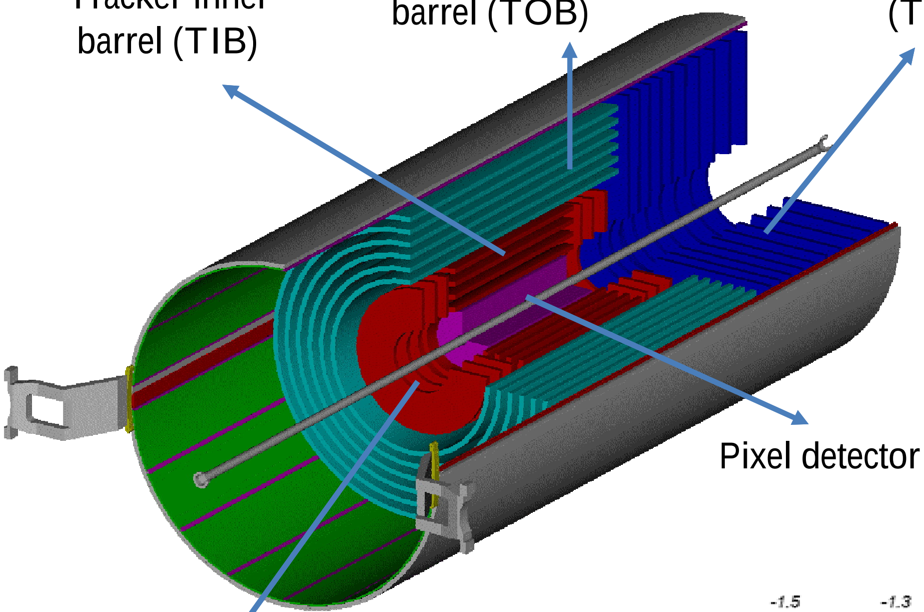
For the CMS Collaboration

CMS Detector



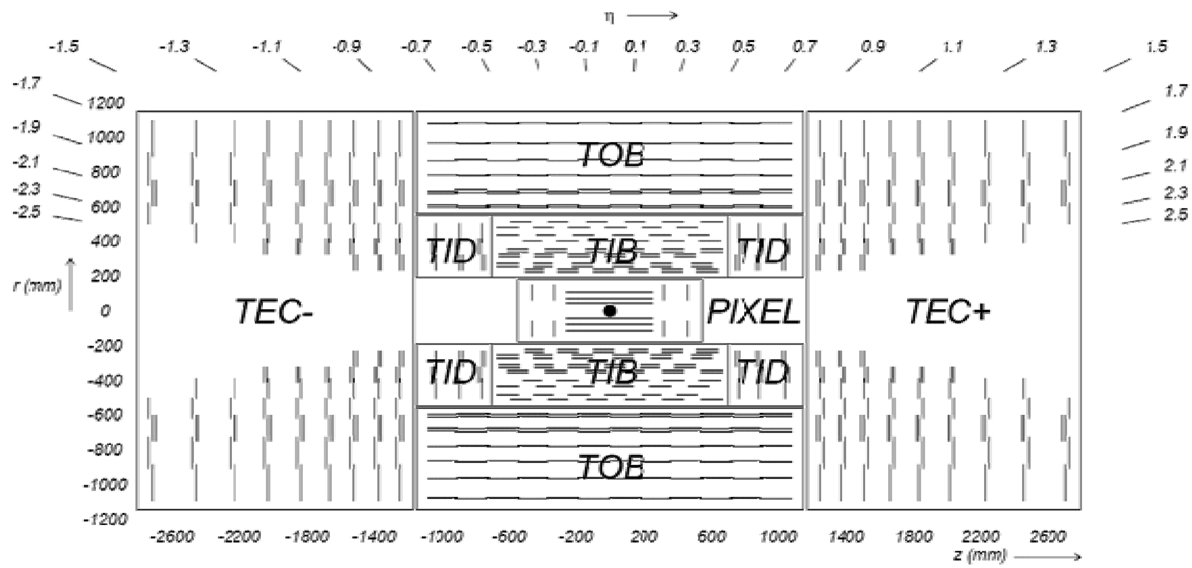


The Silicon Tracker @ CMS



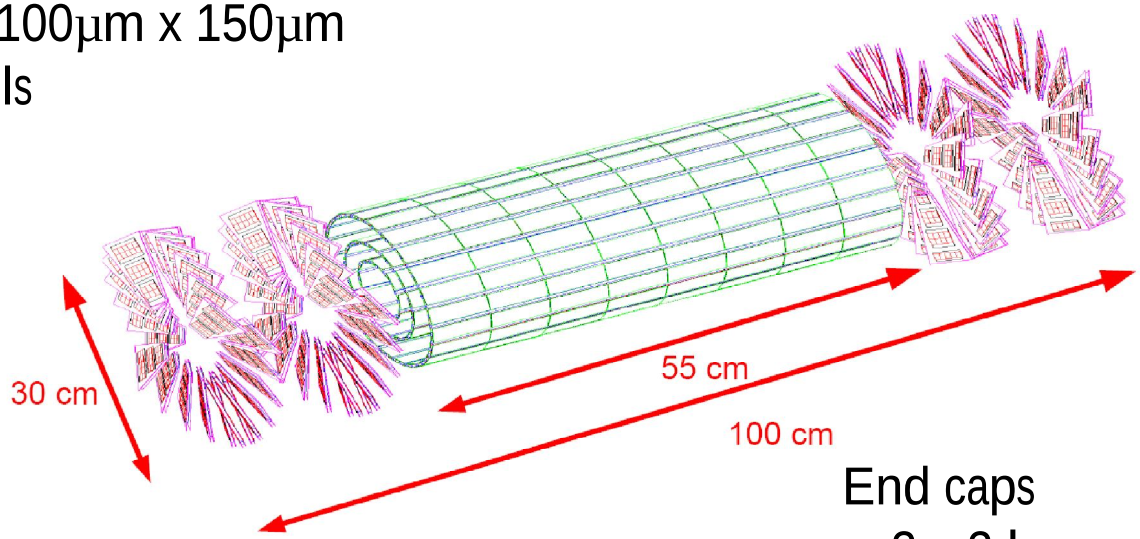
Design based on

- Radiation hardness
- High granularity
- Fast readout (25 ns bunch crossing)



Pixel Detector

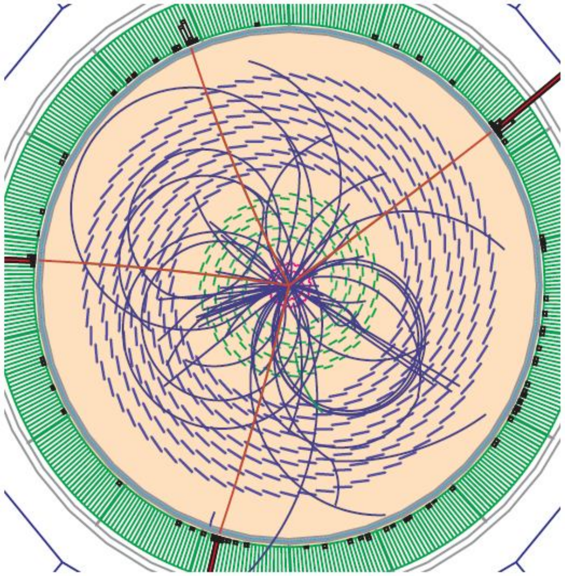
Barrel
- 3 layers
- 768 modules
- R = 4.4 / 7.3 / 10.2 cm
- Pixel size 100μm x 150μm
- 48 M pixels

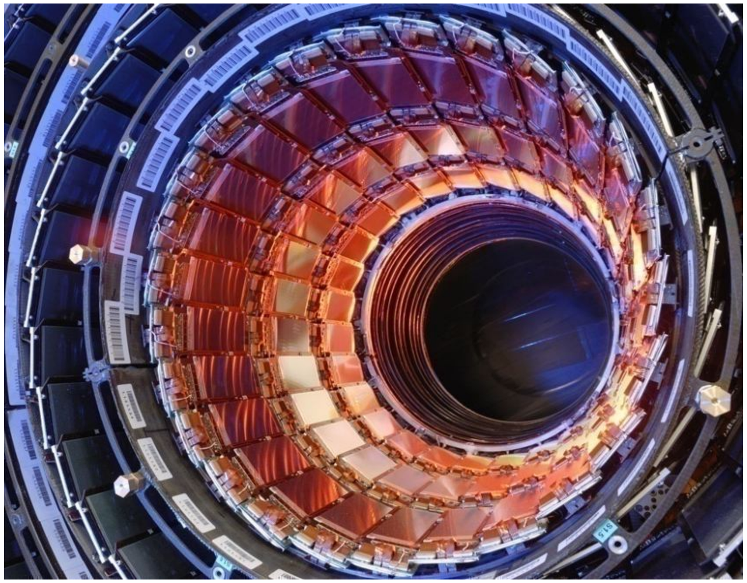


End caps
- 2 x 2 layers
- 672 modules
- |z| = 34.5 / 46.5 cm
- Pixel size 100μm x 150μm
- 18 M pixels

Silicon Strip Detector

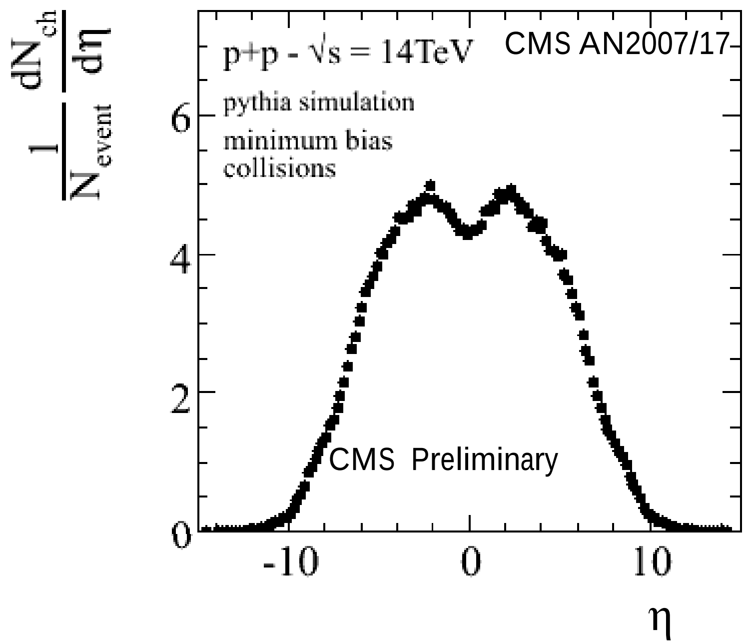
- TIB - Tracker Inner Barrel 4 layers, 2724 modules
- TID - Tracker Inner Disks 2x3 disks, 816 modules
- TOB - Tracker Outer Barrel 6 layers, 5208 modules
- TEC - Tracker End Caps 2x9 disks, 6400 modules





- 24,244 silicon micro-strip sensors
  - 15 different sensor geometries
- Readout 72,784 APV25 chips
  - Signals amplified, shaped, buffered
  - Analogue to digital conversion takes place in the service cavern, in Front End Driver (FED) boards

p+p vs. Heavy Ion Multiplicity



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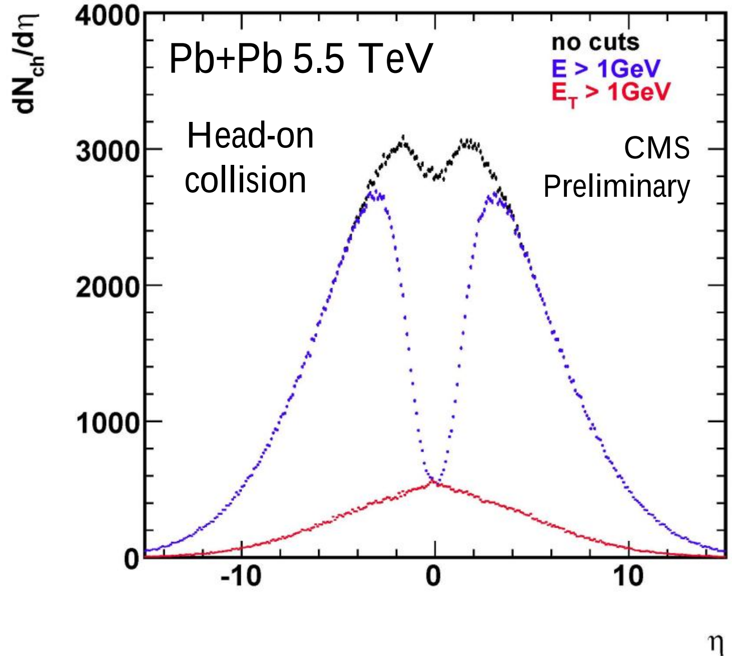
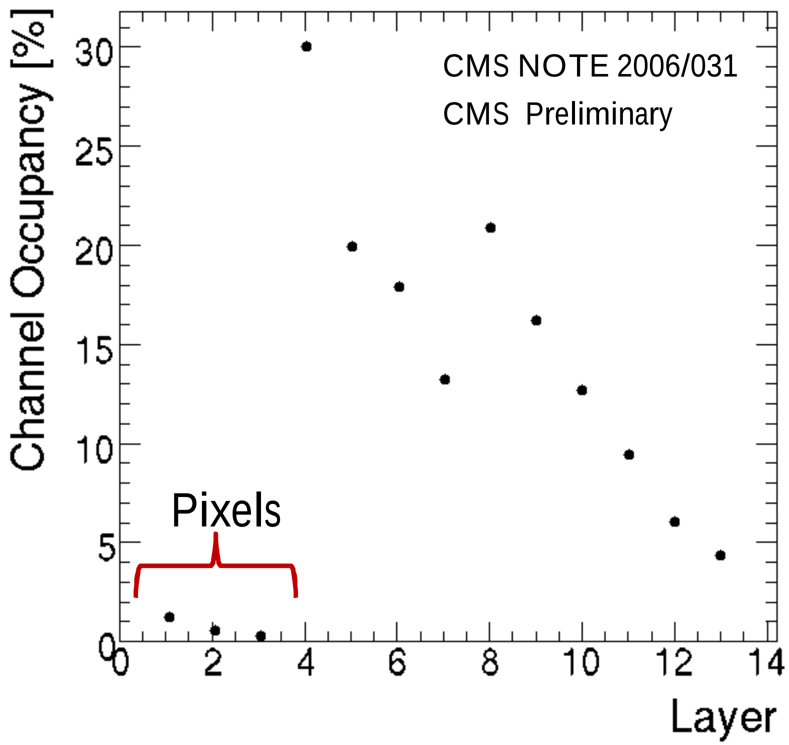


- Use HYDJET tuned to $dN/d\eta_{\text{charged}, \eta=0} \sim 3000$ (Central Collisions)
  - Wide multiplicity distribution
  - Contains a significant amount of "mini" jets
  - E.g. 90 collisions of p_{That} > 10GeV per central Pb+Pb interaction

HYDJET v1.2: hep-ph/0312204

Occupancy in the Silicon Tracker



Occupancy in central Pb+Pb Events:

- ~1% in pixel layers
- Up to 30% in strip layers @ dN/dy ~ 3000

First Pb+Pb Multiplicity Measurement

Single Pixel Layer : $dN_{ch} / d\eta$

- Charged particle pseudorapidity distribution can be reconstructed from the hits in the pixel detector
  - Silicon dE/dx information can used to remove additional background at high pseudorapidity

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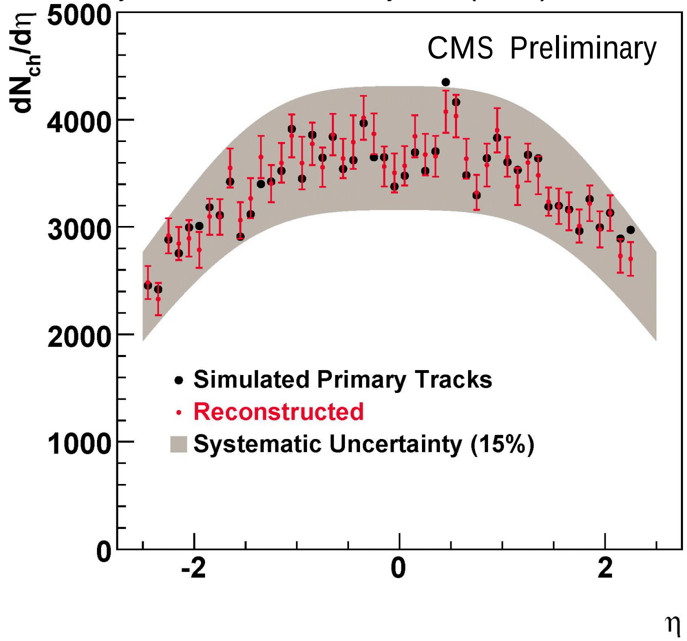
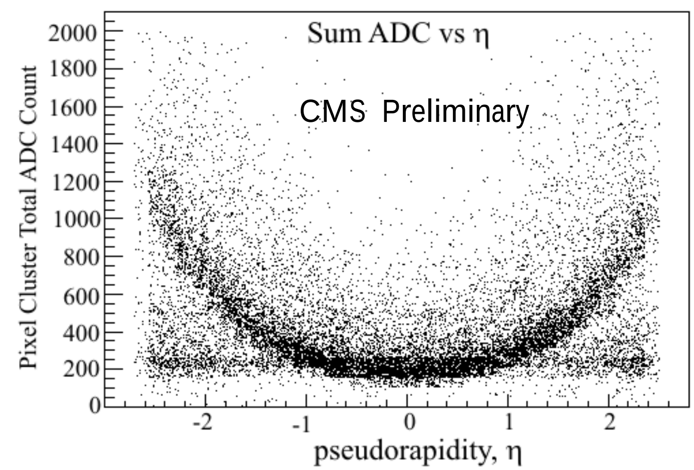
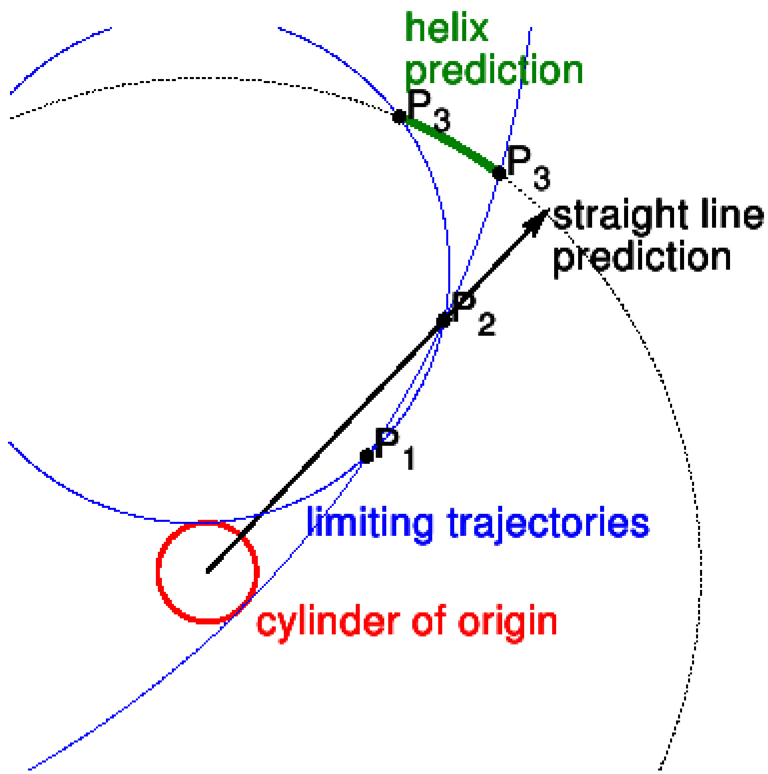




Low p_T Pixel Triplet Tracks



- Use pixel hit triplets,
  - Pixel cluster shape filter
  - Pixel track cleaning and merging, pixel tracks with 3–8 hits
  - Constrain triplets with previously found primary vertex

- Filtering: strip cluster width filter

- Smoothing: retry failed fits with last points successively removed

- Cleaning: clean seeds, expect to produce only a single global track

Low p_T Pixel Triplet Performance in Pb+Pb

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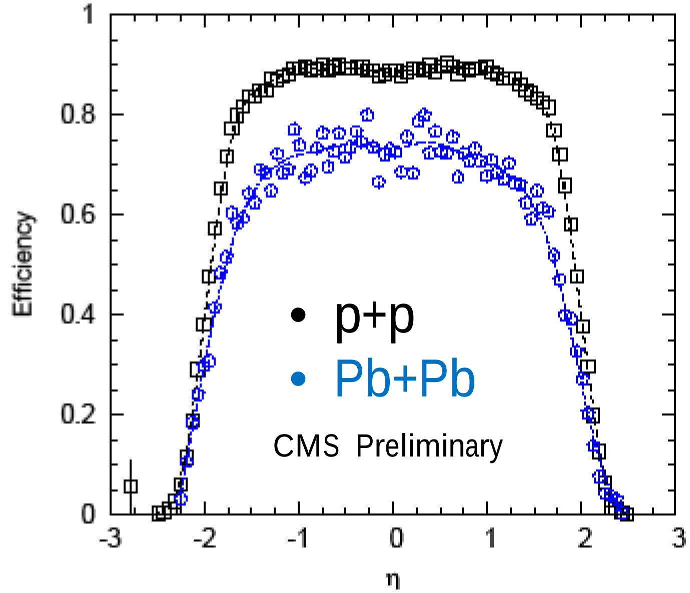
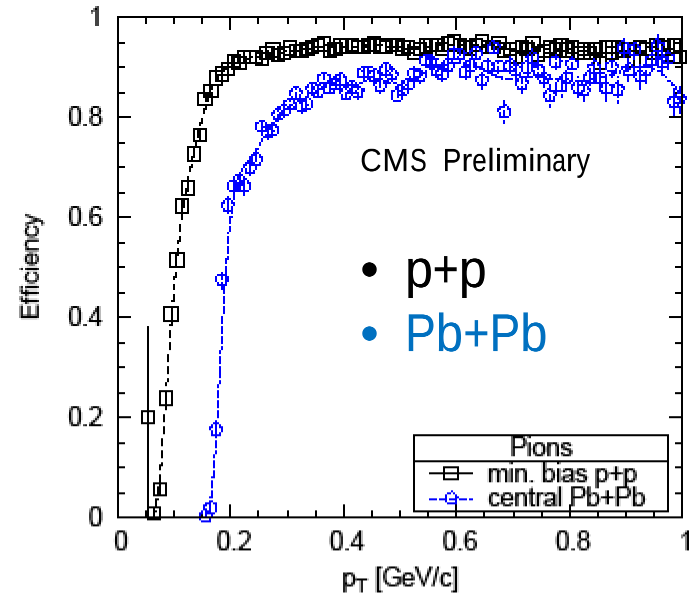
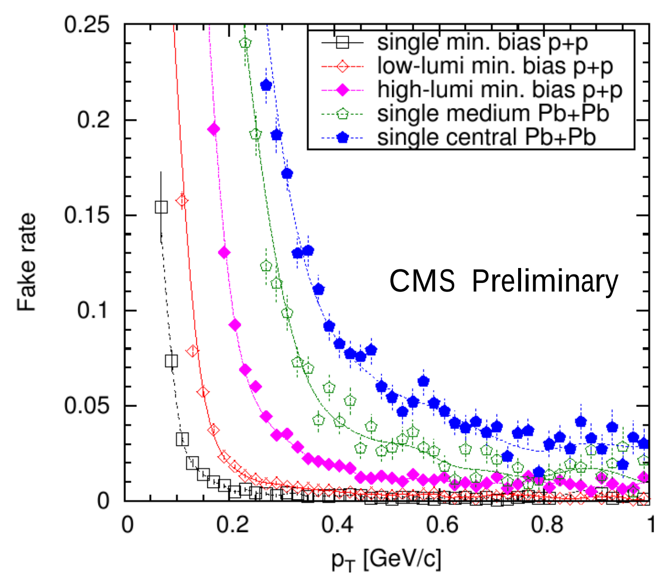


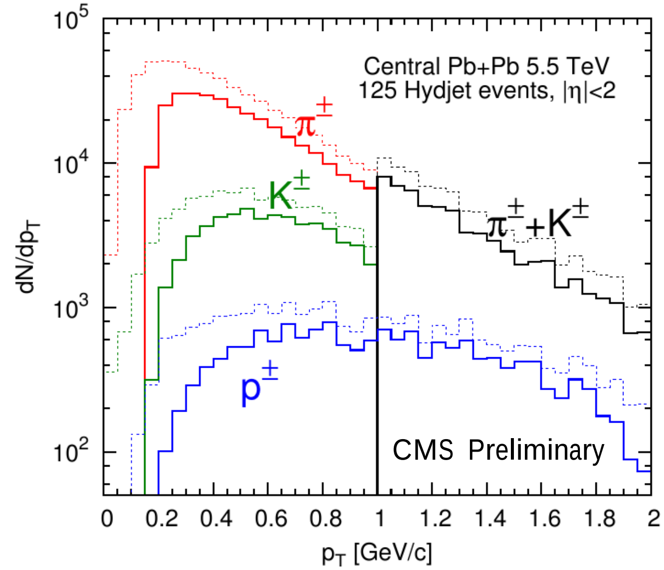




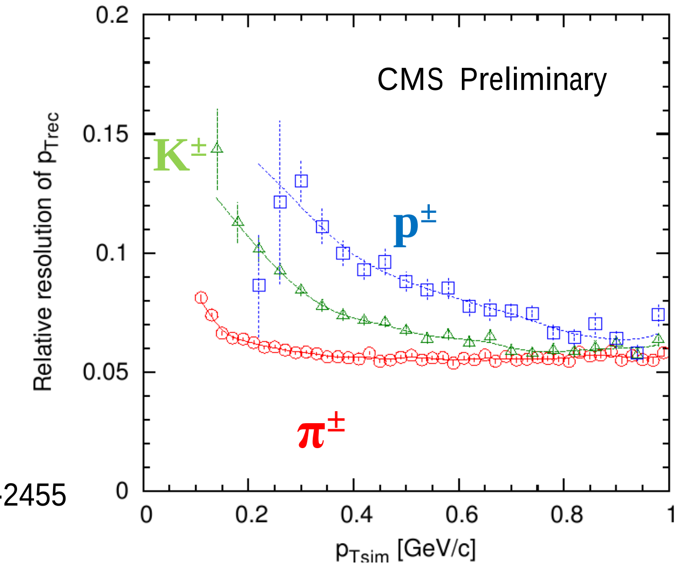
- Good tracking efficiency down to about 0.2 GeV/c transverse momentum (|η|<1.0)
- Fake rate in central Pb+Pb is about 4% at 1GeV/c

Low p_T Identified Hadron Spectra in Pb+Pb

- Silicon dE/dx information combined with triplet tracking is used for particle identification
- The dotted histogram is the simulated p_T distribution and the solid histogram is reconstructed spectra



- Reconstructed track p_T resolution with respect to the generated track p_T



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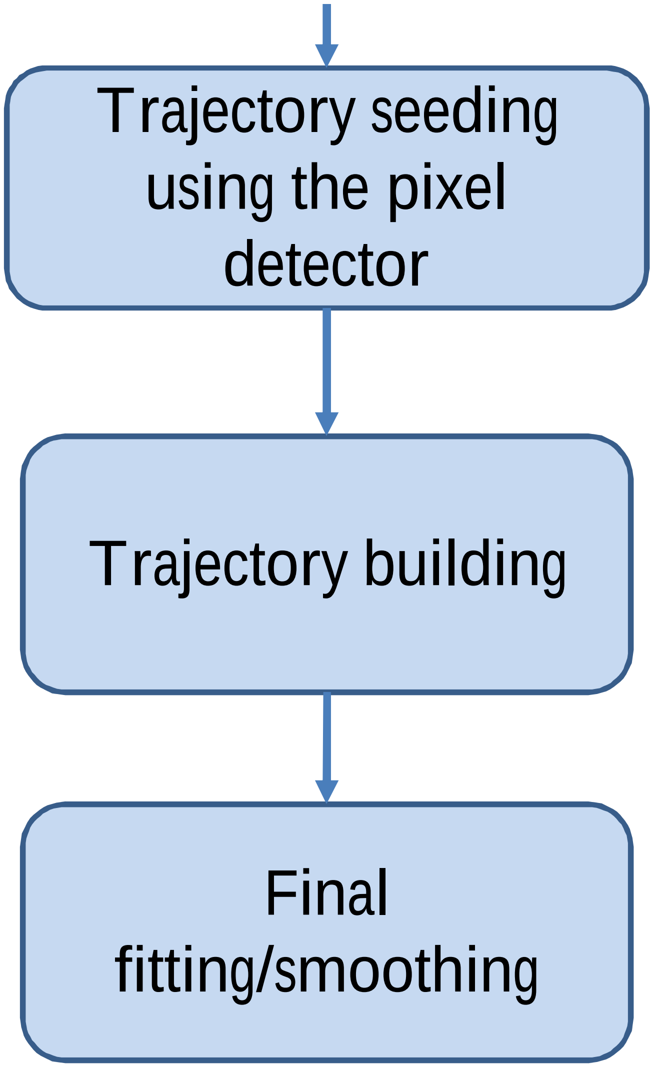
High p_T Tracking

- Standard p+p tracking
  - Pixel and strip silicon detectors
  - Kalman filter Algorithm

- For Heavy Ion reconstruction a modification is required to deal with the high multiplicity

Standard p+p Algorithm

Kalman Filter
default p+p algorithm



Modifications to the Algorithm for Heavy Ions

Nucl.Instrum.Meth.A566:123-126,2006.

Seeding

Three pixel hit combinations (Pixel triplets)

Compatibility check with primary event vertex

↓

Trajectory building

Special error assignment to merged hits

↓

Final fitting/smoothing

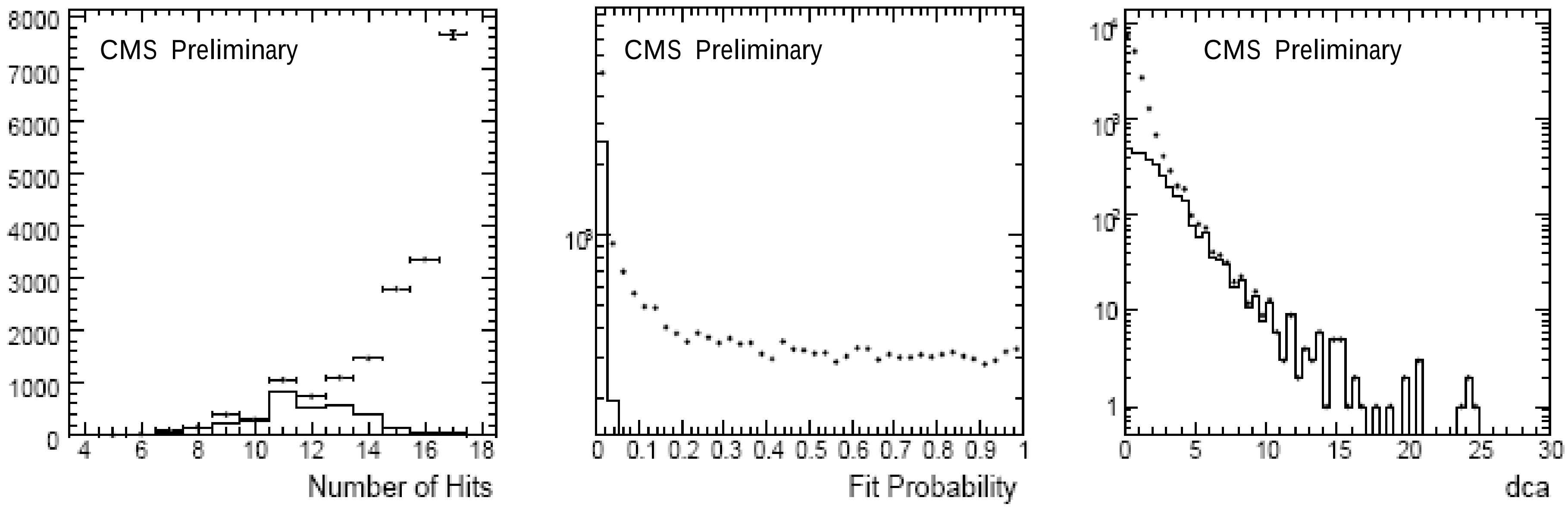
Allow only one track per trajectory seed

Final fit with split stereo layers

Track Quality for Heavy Ions

Markers are all the reconstructed tracks
Histogram only the fake tracks

CMS NOTE 2006/031

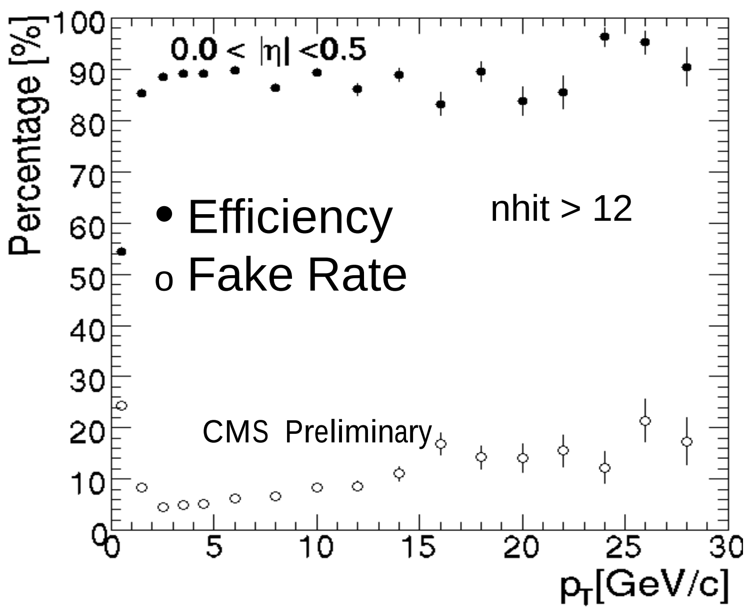


To reduce the fake tracks, the following track quality cuts are used :

- More than 12 hits on track (stereo layer → 2 hits)
- Require fit probability > 0.01
- Cut on compatibility with primary vertex

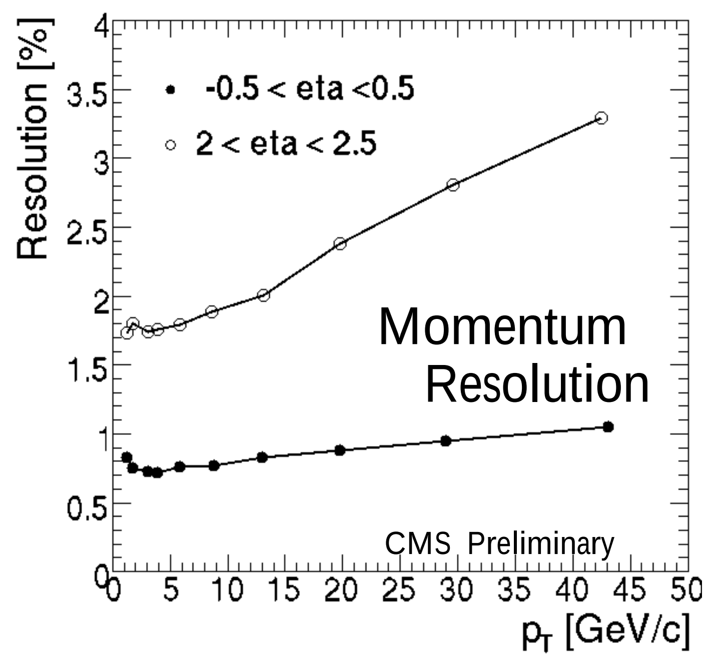
High-p_T Tracking Performances in Pb+Pb

- Track quality cuts have to balance between high efficiency and low fake rate
  - cuts to be defined by specific analysis
- The resolution of the track offset at the event vertex is better than 50 μm, improving to 20 μm for p_T above 10 GeV/c
- The DCA resolution in a heavy-ion environment is $\sigma_{r\Phi}$ ~20 μm in the transverse plane and σ_{rz} ~ 50 μm in the longitudinal plane



Data Sample:
Central
HYDJET
100GeV Jet/Ev.

CMS NOTE 2006/031



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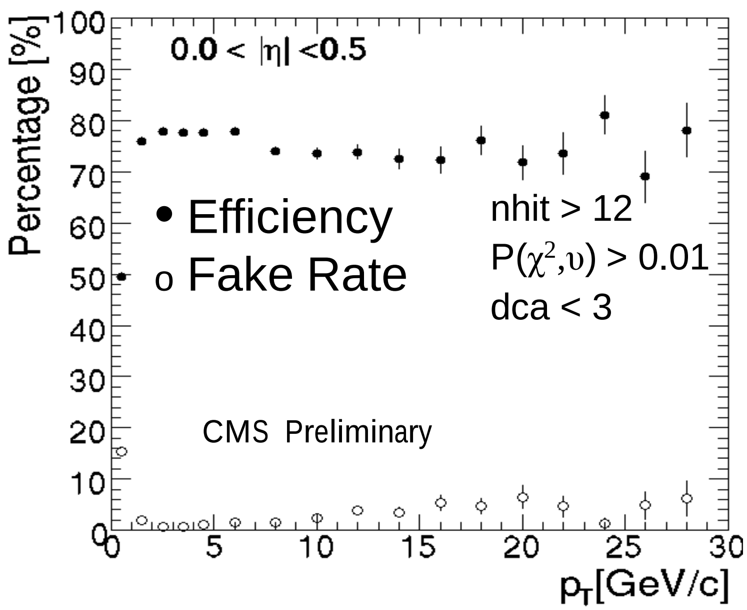

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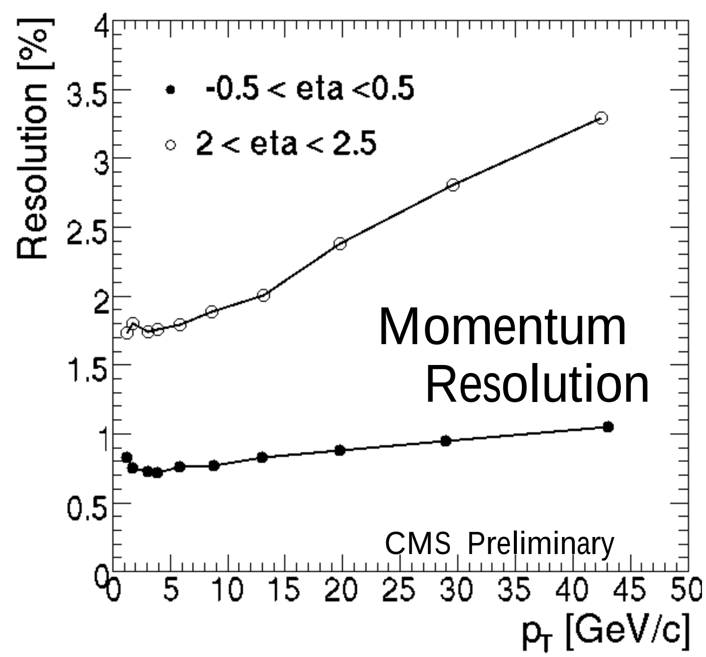
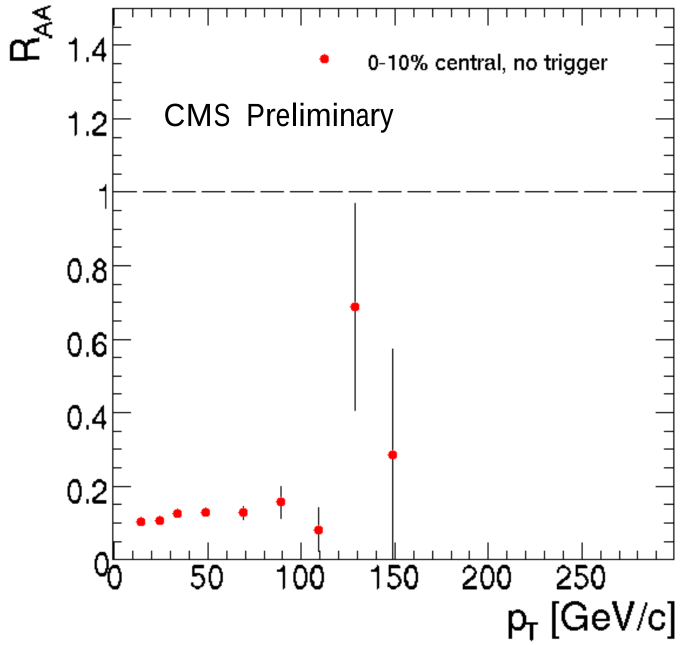
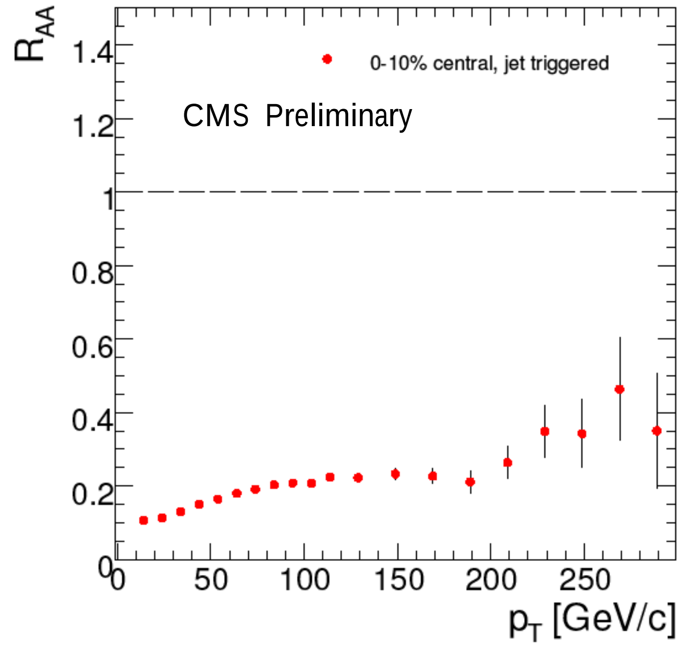


High p_T Physics Reach in Pb+Pb





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$$R_{AA}(p_T) = \frac{1/\langle N_{coll}\rangle}{1/\sigma_{pp}^{inel}} \frac{d^2N_{AA}/dp_T d\eta}{d^2\sigma_{pp}/dp_T d\eta}$$

- Results for one full luminosity LHC heavy ion run (10^6sec)
- High-p_T hadron suppression : Statistical reach to >100 GeV/c for minimum bias data and >250 GeV/c for jet trigger in CMS high level trigger

Hardware/Readout Effects

The readout chain of the CMS Tracker is optimized for proton-proton collisions.

- Pixels : Low occupancy
  - Large data volume
  - Look for buffer overflows
- Si Strips : High occupancy
  - Common Mode Noise (CMN) correction non-trivial
  - Highly Ionizing Particles (HIP)

- Readout/hardware effects are well under control
  - More studies in progress

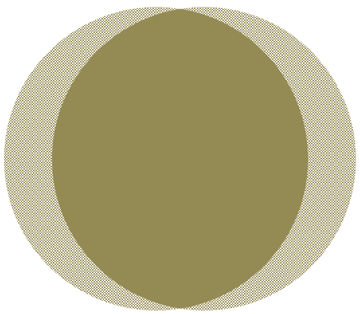
Summary

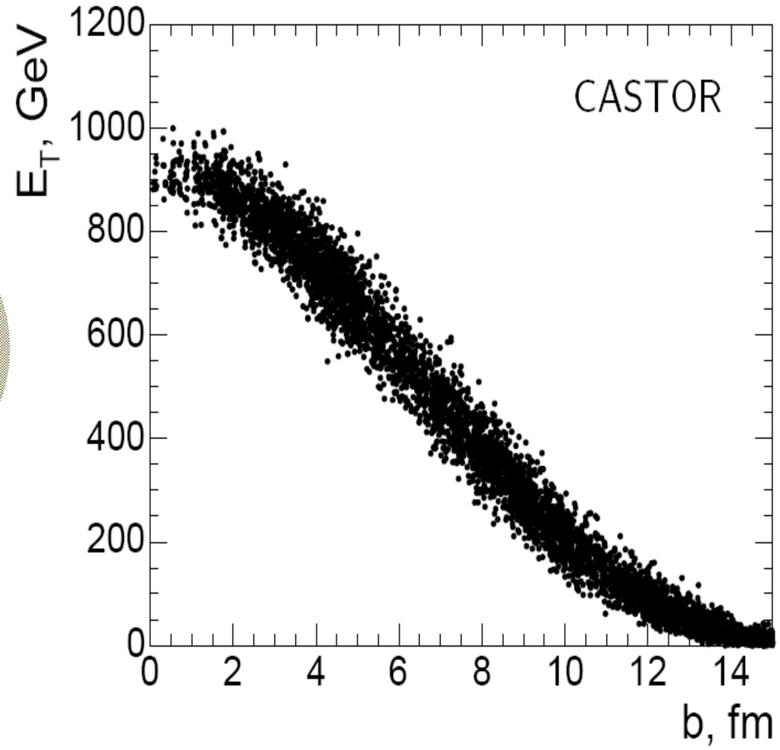
- CMS Silicon tracker has a very good track reconstruction capability for heavy ions
  - 80% tracking efficiency with a control over fake rate
  - p_T coverage starts at 0.2 GeV/c
  - Low p_T /High p_T η coverage out to 2.5 units
  - Possible π/K/p separation via dE/dx in silicon in the range p_T~0.2--1.5 GeV/c

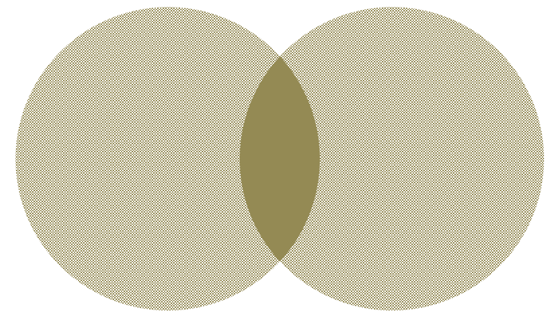
- Physics capabilities of silicon tracker in CMS studies thus far include
  - $dN_{ch}/d\eta$ with single layer of the pixel detector
  - Low p_T charged particle spectra and PID with pixel triplet tracks
  - High p_T charged particle spectra (R_{AA}) with full tracking

Backup slides

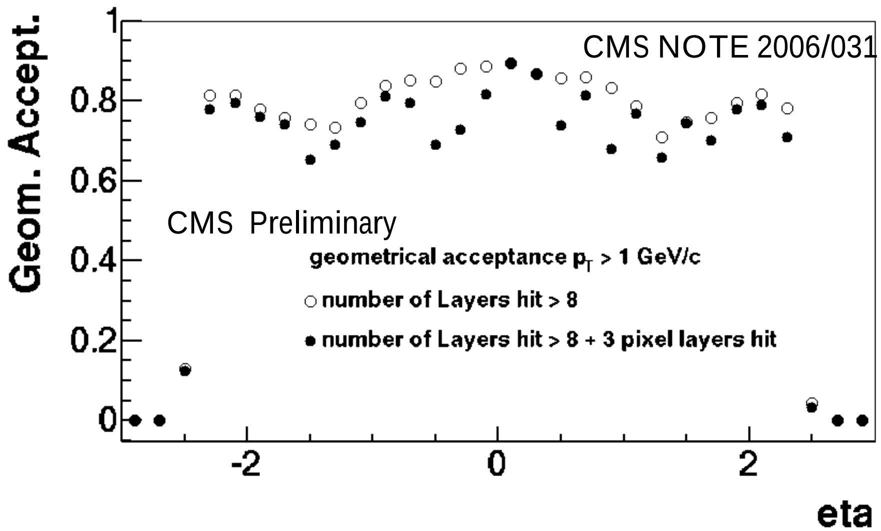
Centrality in Heavy Ions

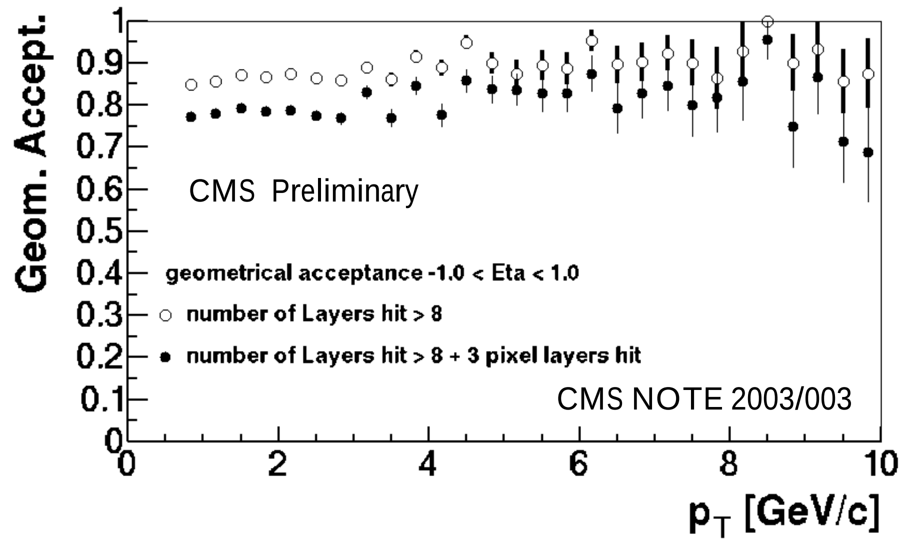






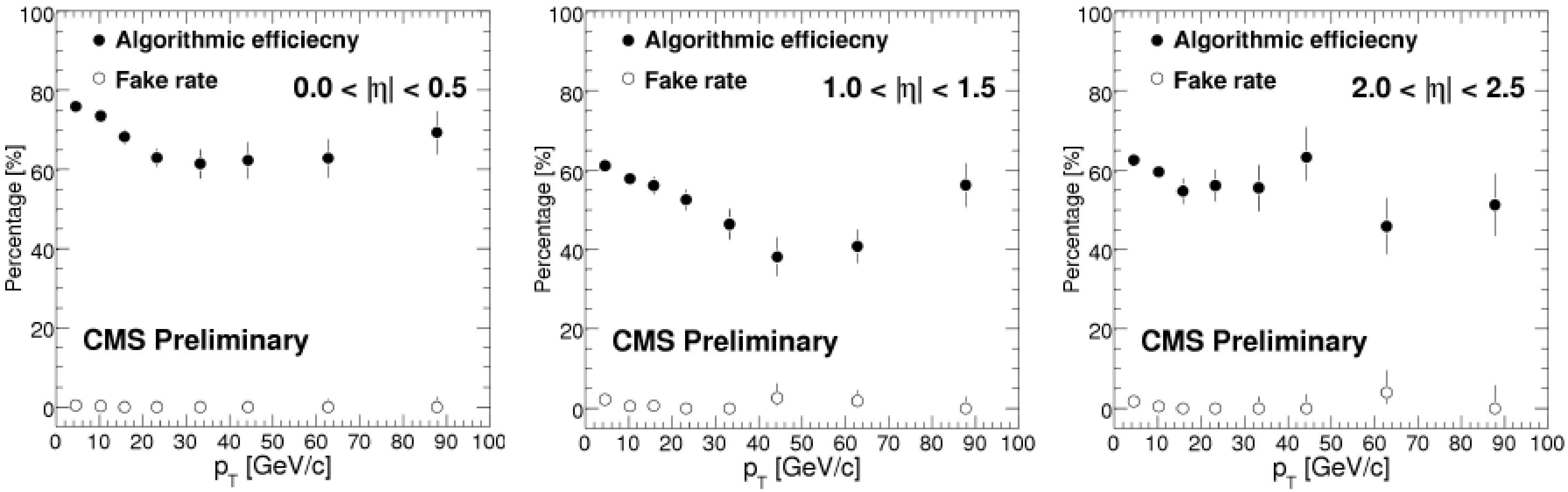
Geometrical Acceptance





- Require the track to cross more than 8 detector layers (~12 hits) and hits in three pixel layers
- Geometrical acceptance ~80%

High p_T tracking in Pb+Pb



CMS AN-2007/051

Pixel Readout

Readout buffers can saturate due to :

- Static Effects
  - Large hit multiplicity within one (central) event
  - Independent of collision history
- Dynamic Effects
  - Many subsequent events within one readout cycle
  - Dominant effect at high luminosity
  - Negligible at 8 kHz (a readout cycle takes a few μs)

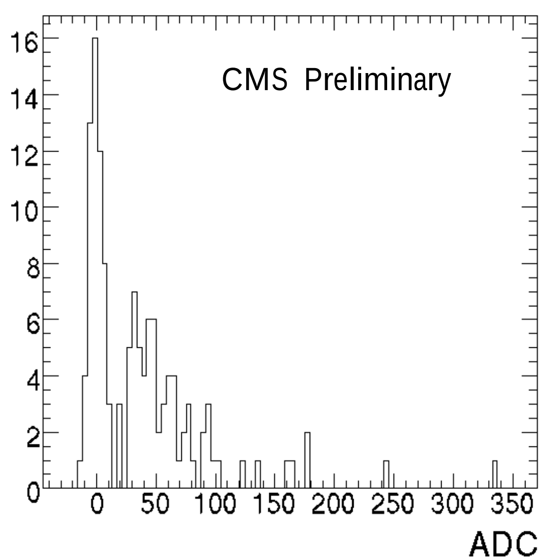
Pixel : Read Out Chip

- Each Read Out Chip (ROC), reads out an array of 52 x 80 pixels.
  - Organized in double columns (DCOL) of 160 pixels, which can take 31 hits before being reset
  - In central events a fraction of 8×10^{-5} of all double columns see more than 31 hits
  - This number does not scale with dN/dy but is probably related to local track density caused by jets contained in the event

- For each link connecting an ROC to an FED 1000 hits can be buffered
  - The buffers are sufficiently large to fit heavy ion events

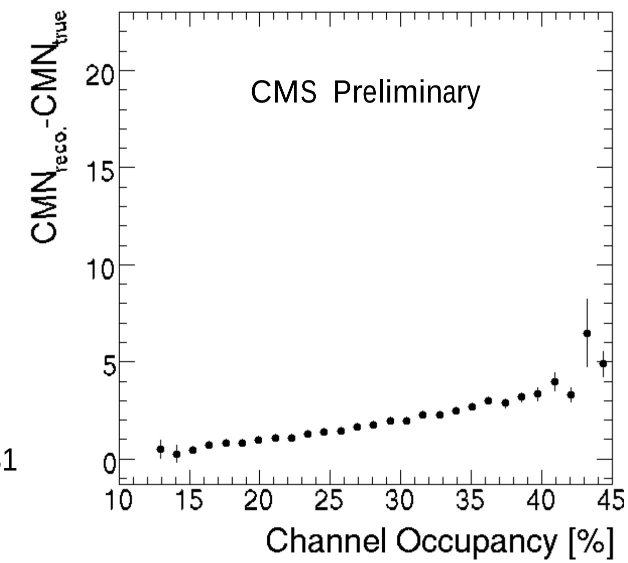
Si Strips : Common Mode Noise

- Need to subtract Common Mode Noise (CMN)
- By default done by a zero-suppression module on the readout chip (APV25)
  - Simple and fast algorithm implemented in FED firmware
  - Current default relies on an event-by-event baseline calculation using the median of all ADCs per Readout Chip
  - For heavy ions : perform multiple iterations to reject signal strips
  - Can be done on the front end or on the HLT processor farm
  - Loss of tracking efficiency is not significant



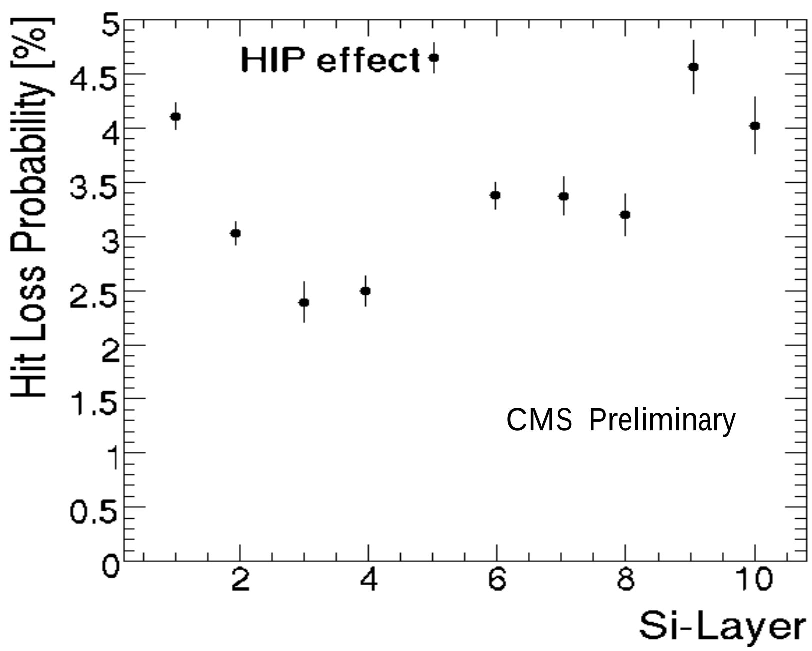
3 iteration median

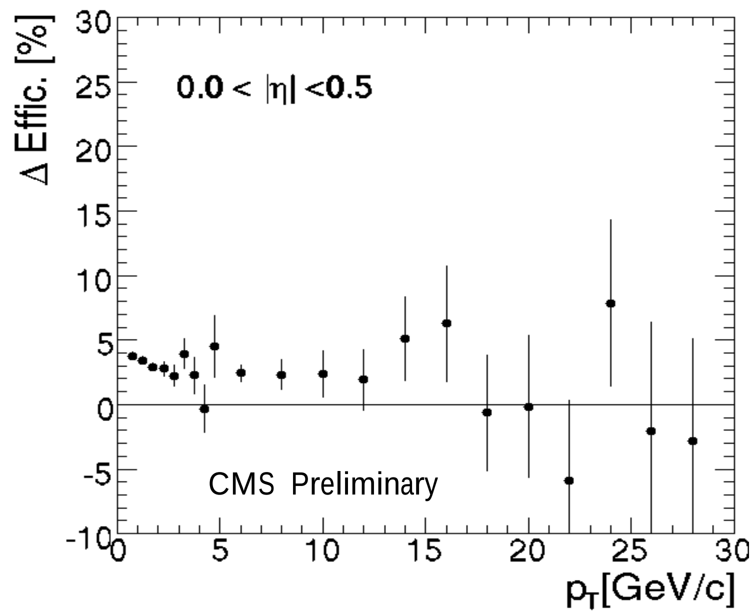
CMS NOTE 2006/031



Highly Ionizing Particles

- Charge deposited in the silicon by highly ionizing particles saturates the APV
  - Many particles (high occupancy) increases the probability of a HIP
- The hit loss due to the HIP effect incurs a loss of ~5% tracking efficiency

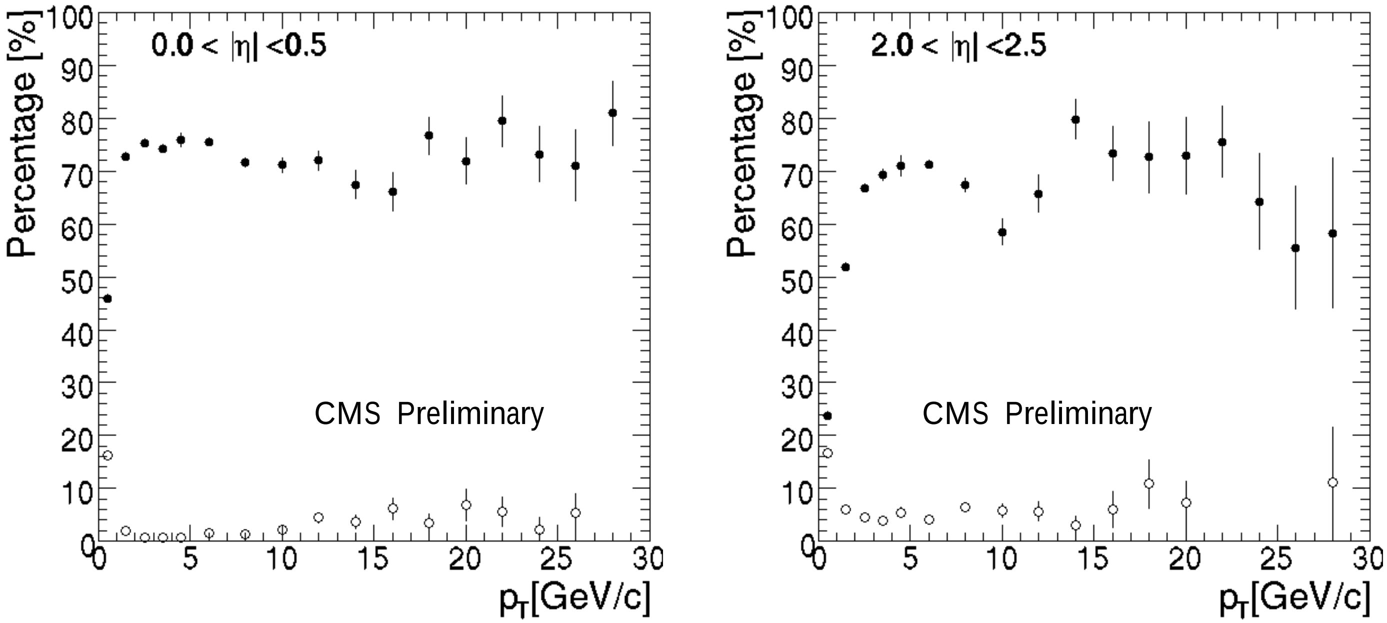




CMS NOTE 2006/031

Algorithmic Efficiency Including Hardware/Readout Effects

CMS NOTE 2006/031



When including all hardware effects in the simulation we still get good efficiency and very low fake rate