Heavy Ion Physics with the CMS Experiment at the Large Hadron Collider

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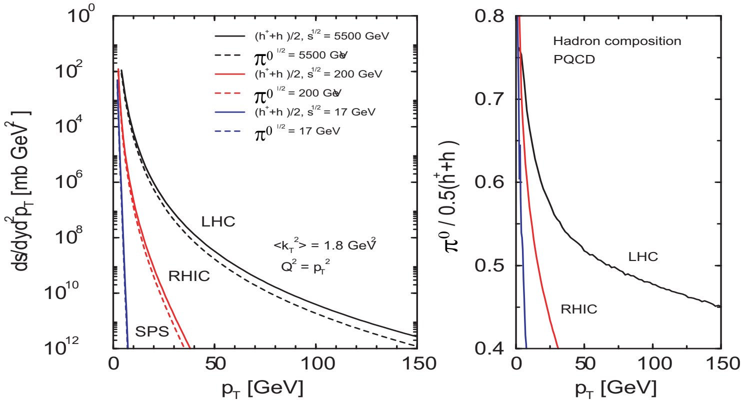
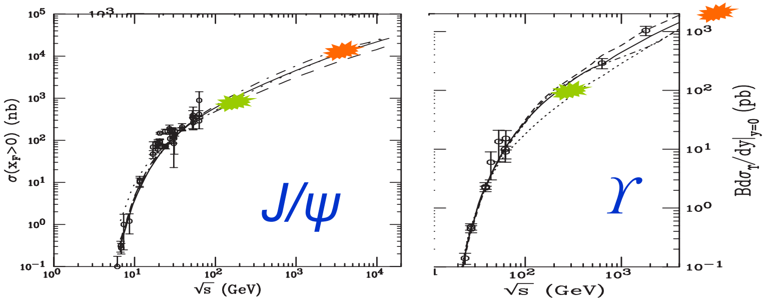
MIT
for the CMS Collaboration

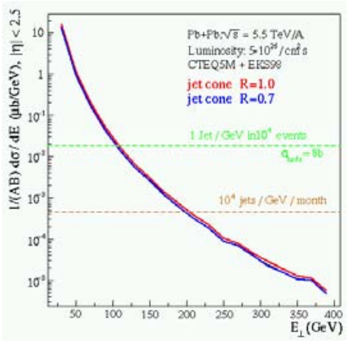
Quark Matter 2004, Oakland, CA

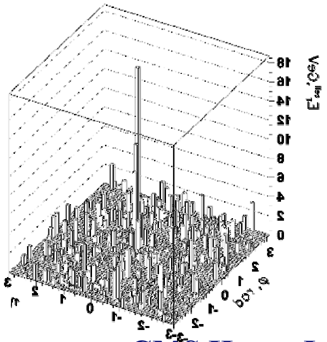
CMS HI groups: *Athens*, *Auckland, Demokritos, Dubna, Lyon, MIT, Moscow, Rice, Tbilisi, U Ioannina, U Iowa, U Kansas, UC Davis, UI Chicago, UC Riverside,*

Heavy Ion Physics at the LHC









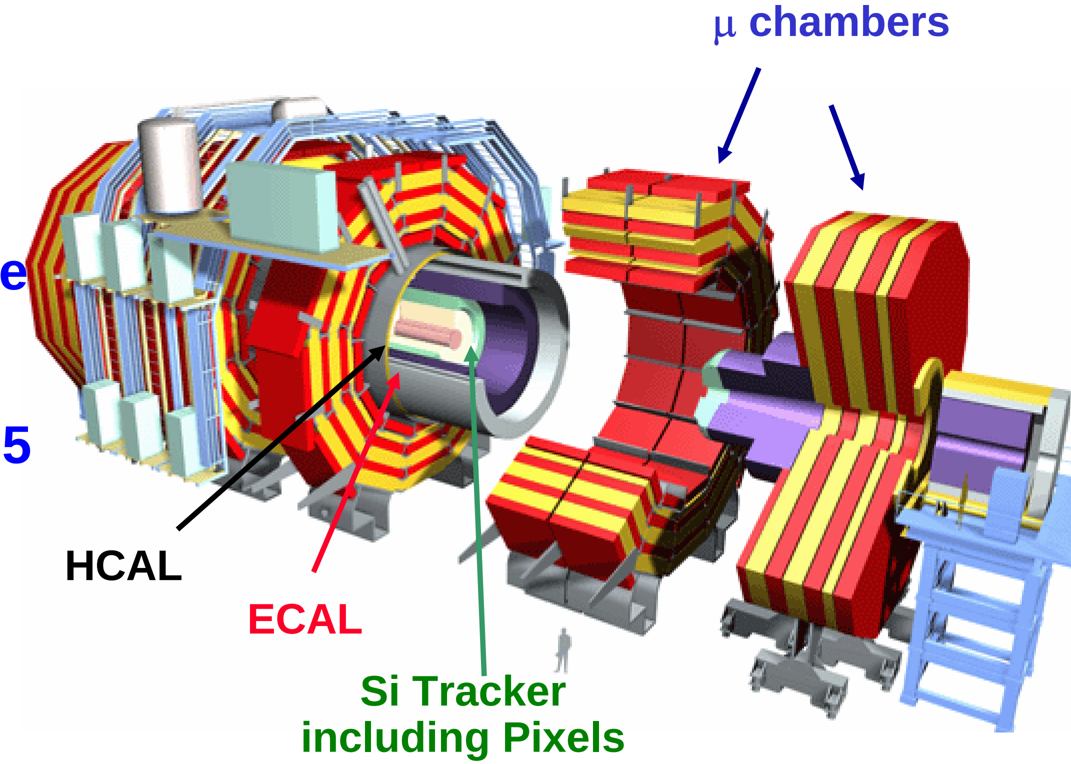
- **Medium modification at high p_T**
  - **Copious production of high p_T particles**
- **Different “melting” for members of ϒ family**
  - **Large cross section for *J/ψ* and ϒ family production**
- **Correlations, scattering in medium**
  - **Large jet cross section, jets directly identifiable**

CMS as a Detector for Heavy Ion Physics

- **Fine Grained High Resolution Calorimeter**
  - Hermetic coverage up to $|\eta|<5$
  - ($|\eta|<7$ proposed using CASTOR)
  - Zero Degree Calorimeter (proposed)
- **Tracking μ from Z^0, J/ψ, Υ**
  - Wide rapidity range $|\eta|<2.4$
  - σ_m ~50 MeV at Υ
- **Silicon Tracker**
  - Good efficiency and low fake rate for $p_T>1$ GeV
  - Excellent momentum resolution $\Delta p/p$~1% for $p_T<25$ GeV and higher

Fully functional at highest expected multiplicities
Detailed studies at ~3000-5000 and cross-checks at 7000-8000

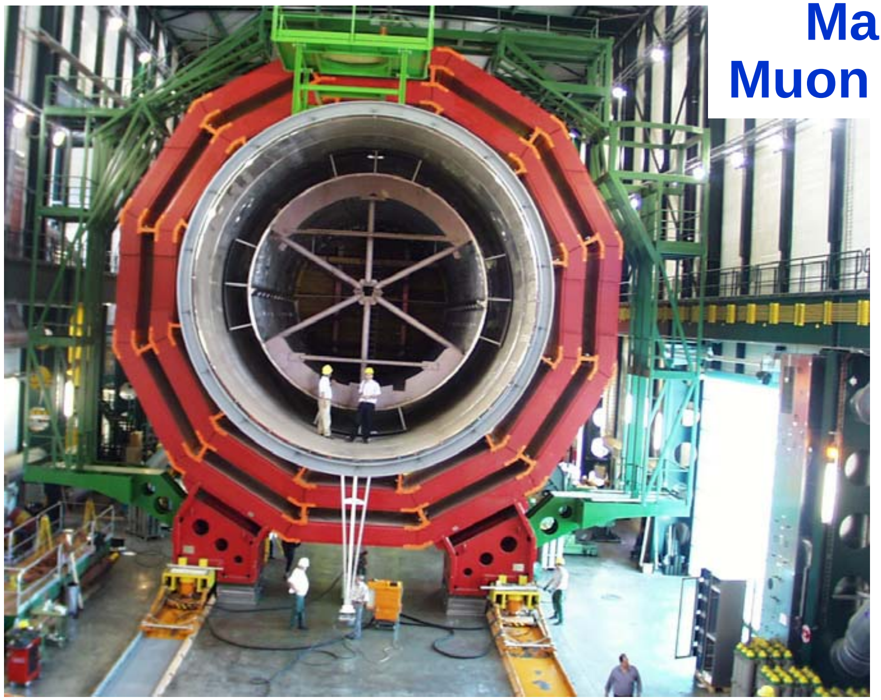
- **DAQ and Trigger**
  - High rate capability for AA, pA, pp
  - High Level Trigger capable of full reconstruction of most HI events in real time



CMS as a Heavy Ion Experiment

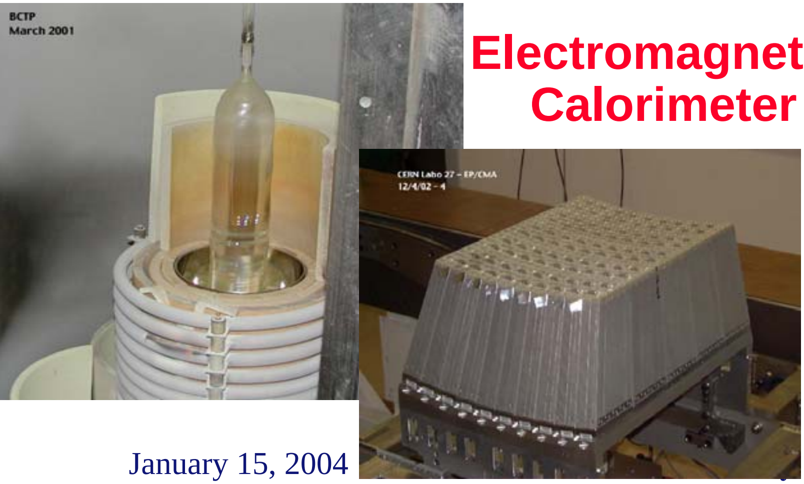
- **Excellent detector for high p_T probes:**
  - **High rates and large cross sections**
    - quarkonia (J/ψ ,Υ) and heavy quarks ($b\bar{b}$)
    - high p_T jets
    - high energy photons
    - Z^0
  - **Correlations**
    - jet-γ
    - jet-Z^0
    - multijets
- **Global event characterization**
  - **Energy flow to very forward region**
  - **Charged particle multiplicity**
  - **Centrality**
  - **Azimuthal asymmetry**
- **CMS can use highest luminosities available at LHC both in AA and pA modes**

CMS under construction



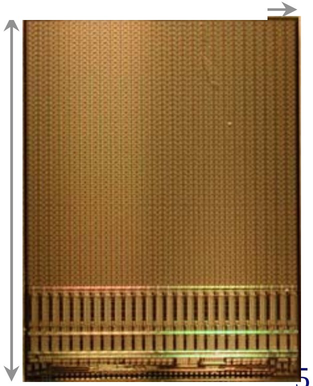
Magnet & Muon Absorber

Hadron Calorimeter

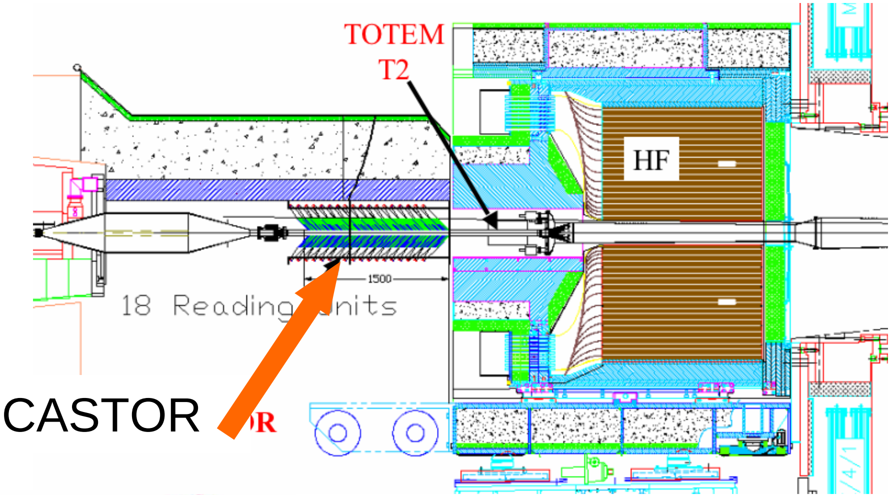


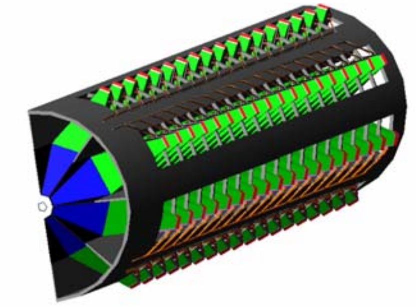
Electromagnetic Calorimeter

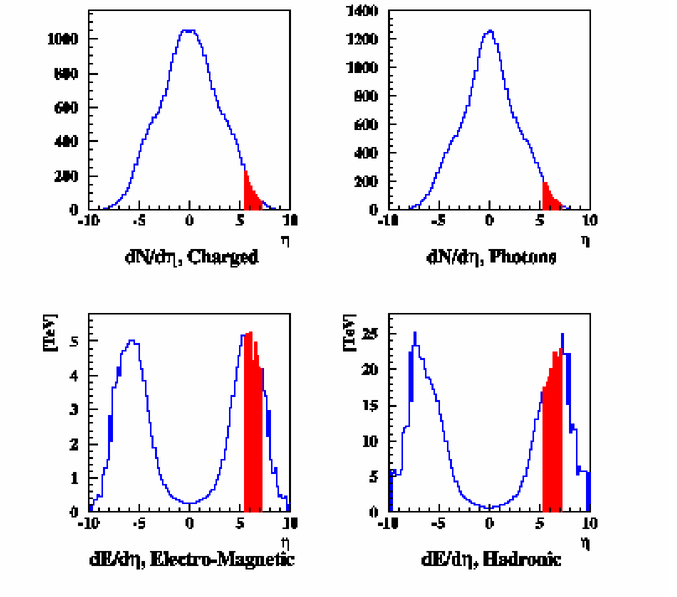
Si tracker & Pixels



CMS Very Forward Region
CASTOR, TOTEM and ZDC







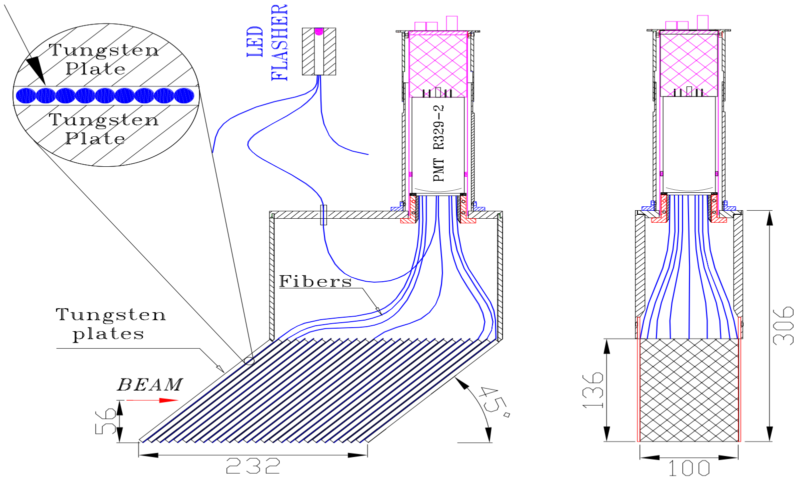
CASTOR Coverage

- Multiplicity and hermetic coverage to |n|<7
- Zero Degree Energy
- Physics:
  - Centrality
  - Limiting Fragmentation
  - Peripheral and ultra-peripheral collisions
  - Low-x, Color-Glass Condensate
  - DCC, Centauros, Strangelets

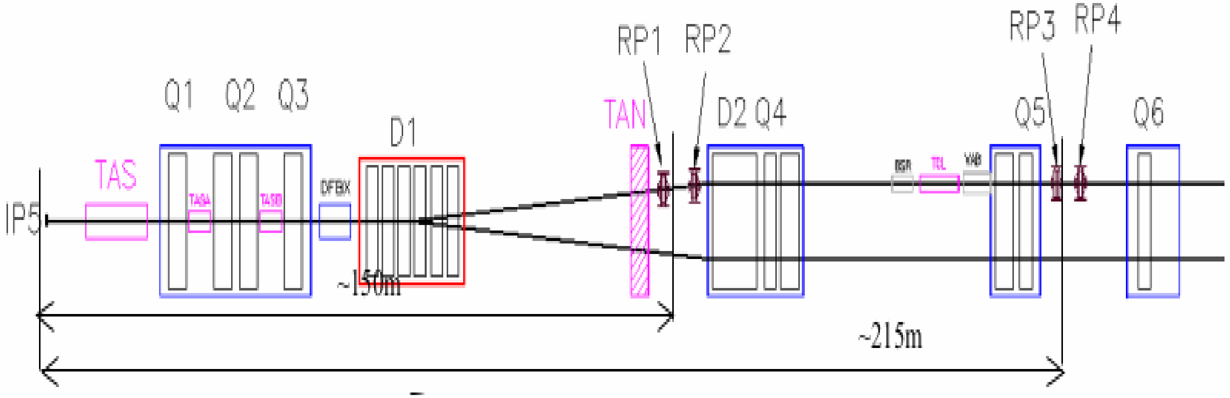
Poster: M. Murray

CMS Very Forward Region CASTOR, TOTEM and ZDC

ZDC



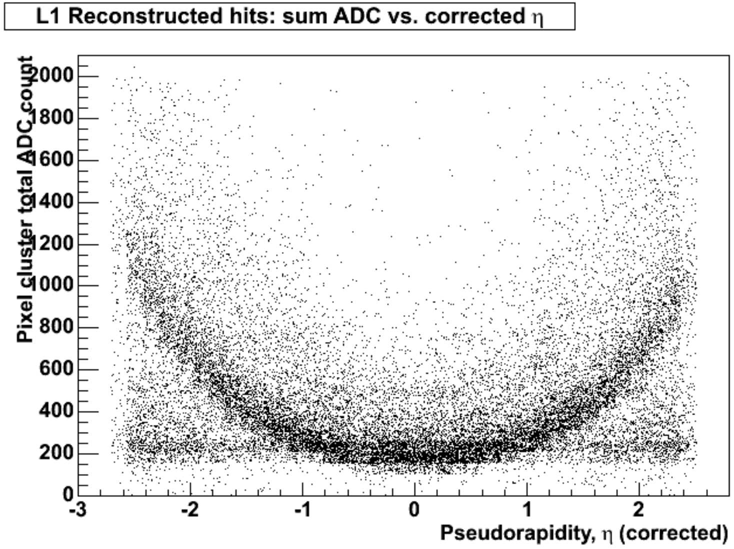
TOTEM: Roman Pots

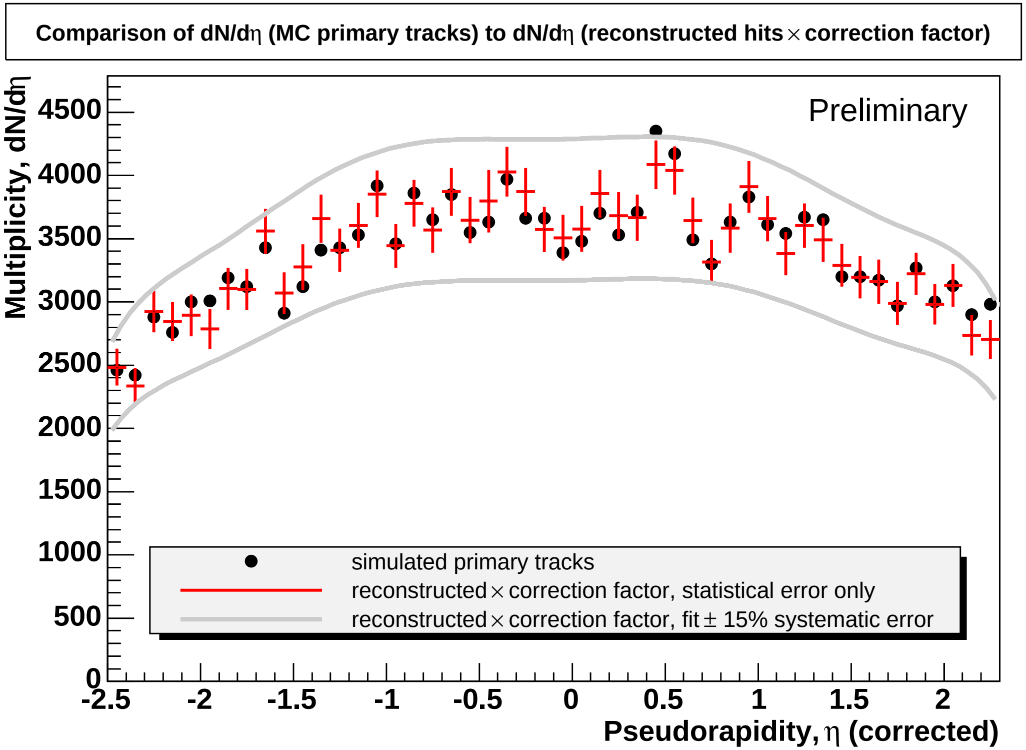


Global Measurements: $dN_{ch}/d\eta$ (single event) a la Phobos

- Use high granularity pixel detectors
- Use pulse height measurement in individual pixels to reduce background
- Very low p_T reach, p_T>26 MeV ! (inner pixel layer at R~45 mm)

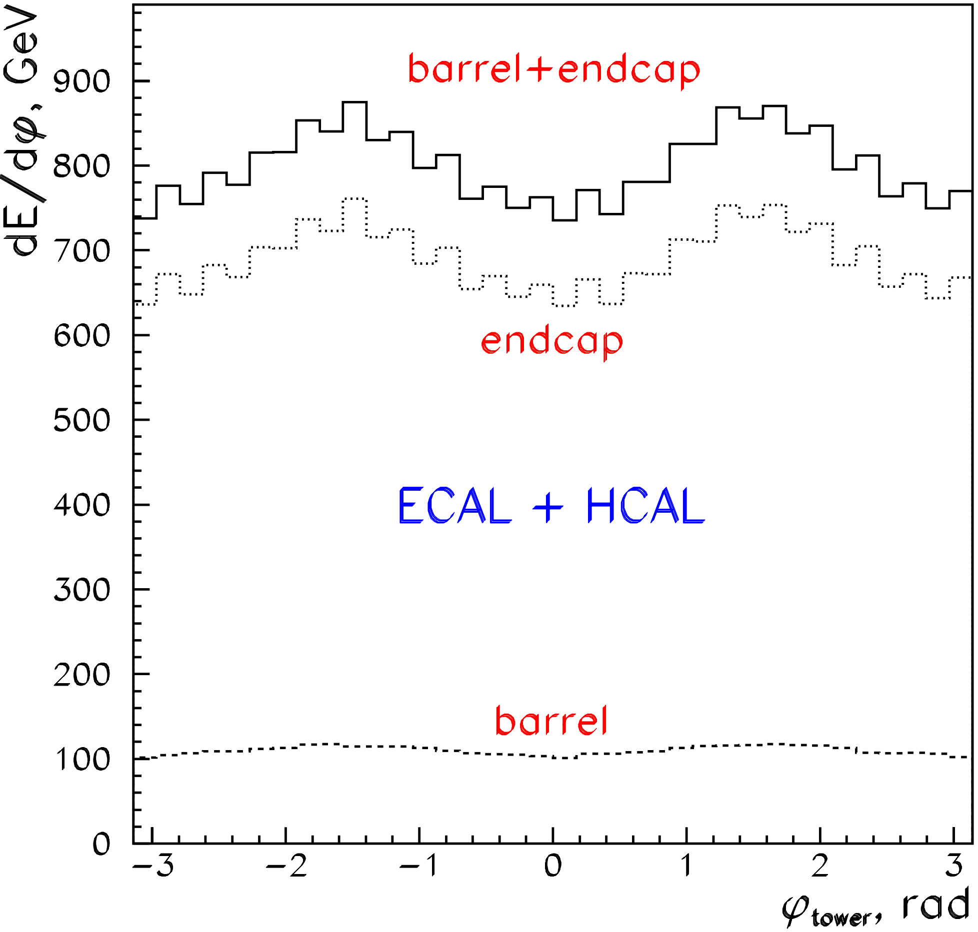
E_{pixel}

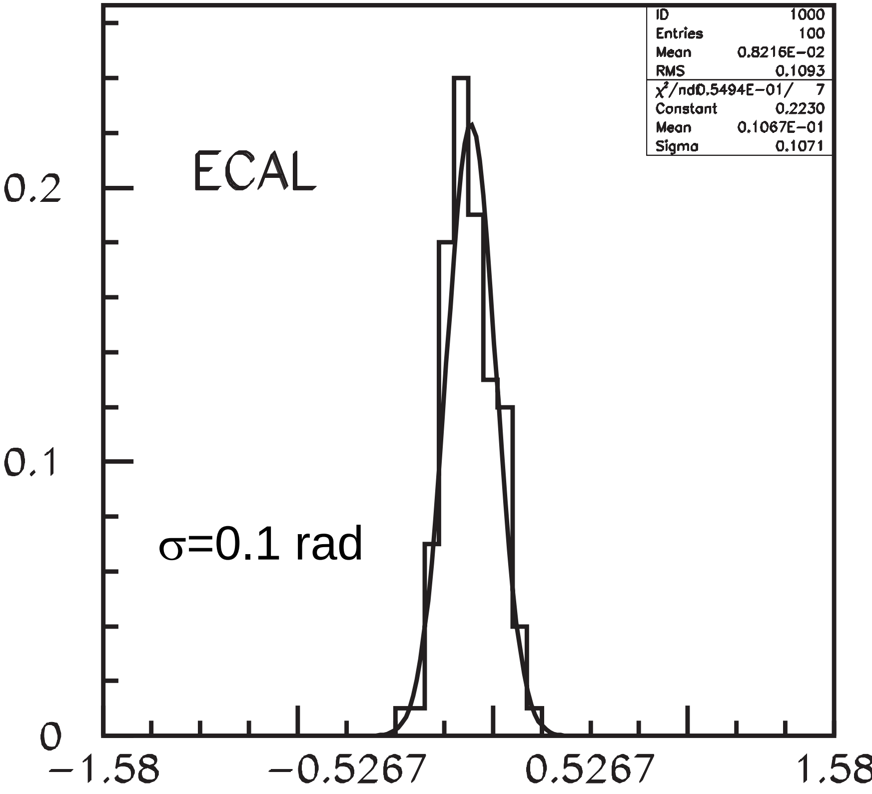




Azimuthal asymmetry, calorimeters

- Use highly segmented calorimeters to determine event plane
- Simulations of Pb+Pb with b=6 fm

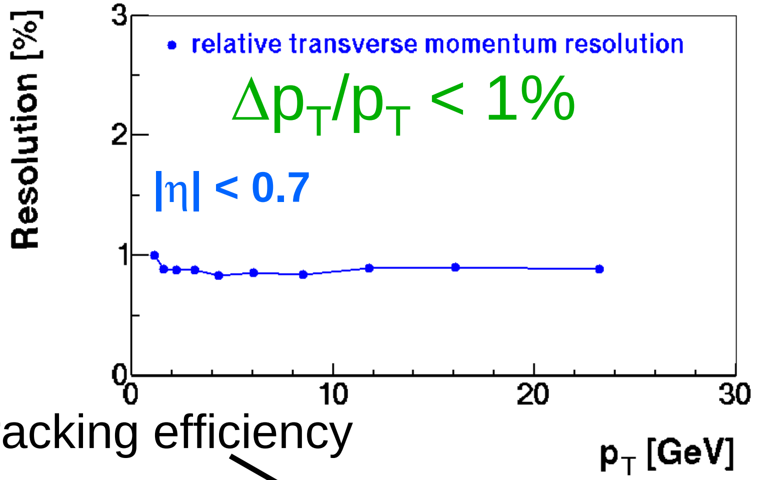




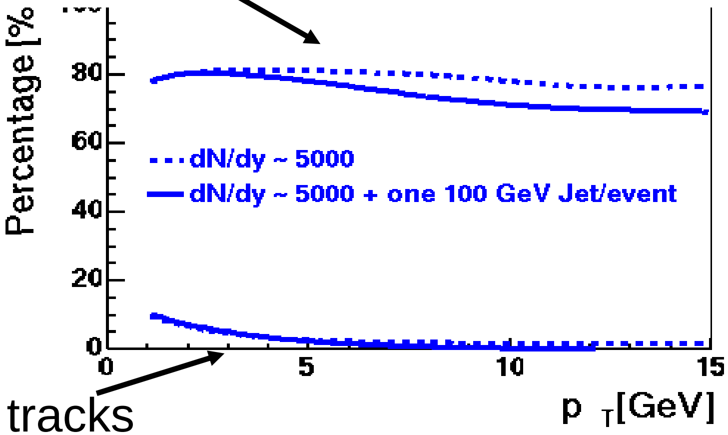
Event plane determination

Performance of the Track Reconstruction: Inside-Out

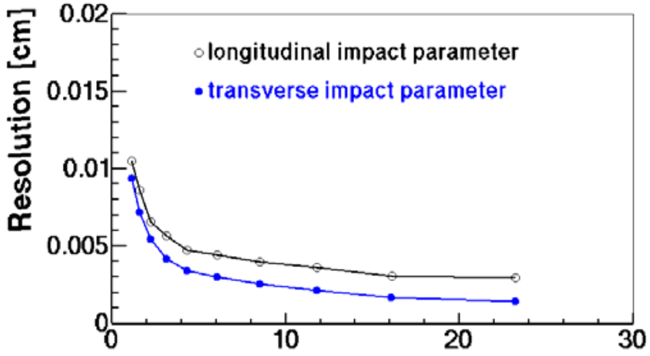
- **Match Reconstructed tracks to MC input on a hit by hit basis**
  - **(Event sample: dN/dy ~3000 + one 100 GeV Jet/Event)**

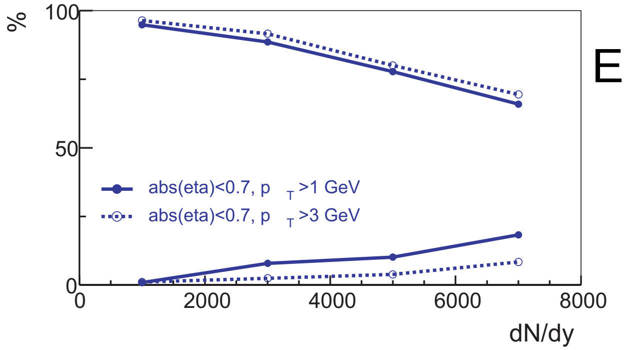


Tracking efficiency



Fake tracks





Efficiency

Fakes

- **The increased local track density in a jet-cone leads to a decrease in reconstruction efficiency of ~5-10%**
- **Can be corrected for since jets will be reconstructed by the calorimetry**

Poster: C. Roland

$\mu\mu$ reconstruction: algorithm

Primary vertex determination:

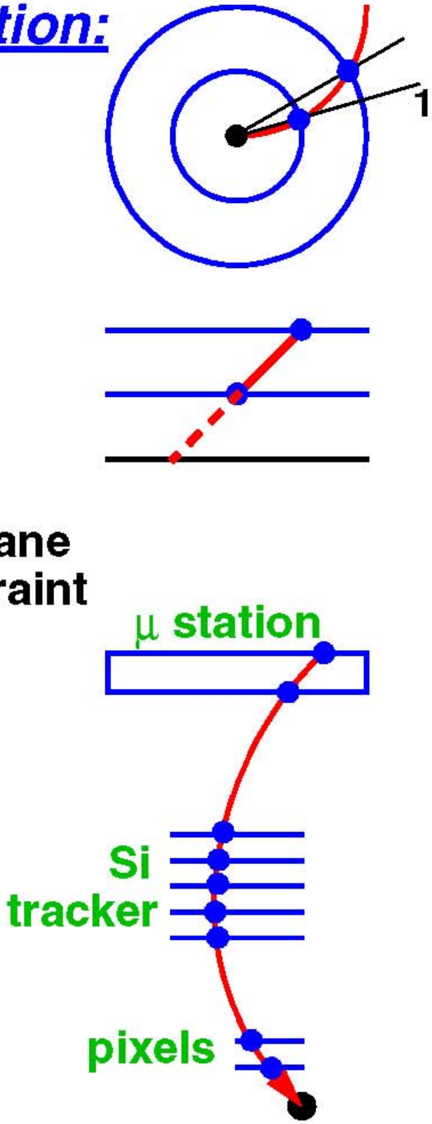
- select pairs of pixel hits with $\Delta\phi$ giving 0.5 GeV < p_T < 5 GeV
- extrapolate each pair in RZ to the beam line

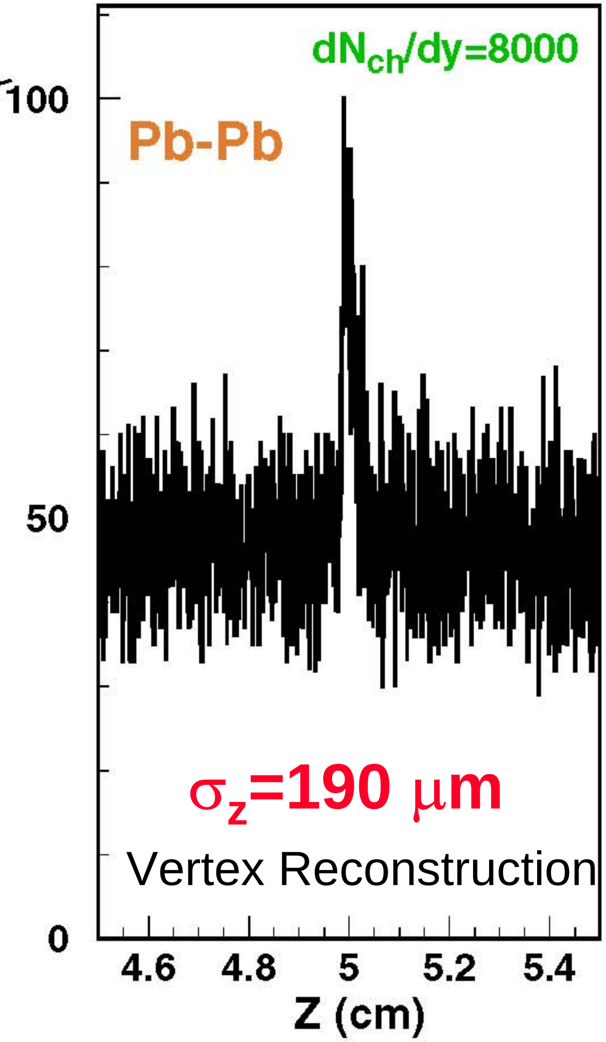
Track finding:

- select tracks in 1st μ station
- extrapolate inwards from plane to plane using vertex constraint

Track selection by cuts:

- fit quality (χ^2)
- kink sensitive variable
  $\Sigma\,(\phi_{pred} - \phi_{meas})^2 / \sigma_\phi^2$
  to kill $\pi, K \rightarrow \mu$
- vertex constraint





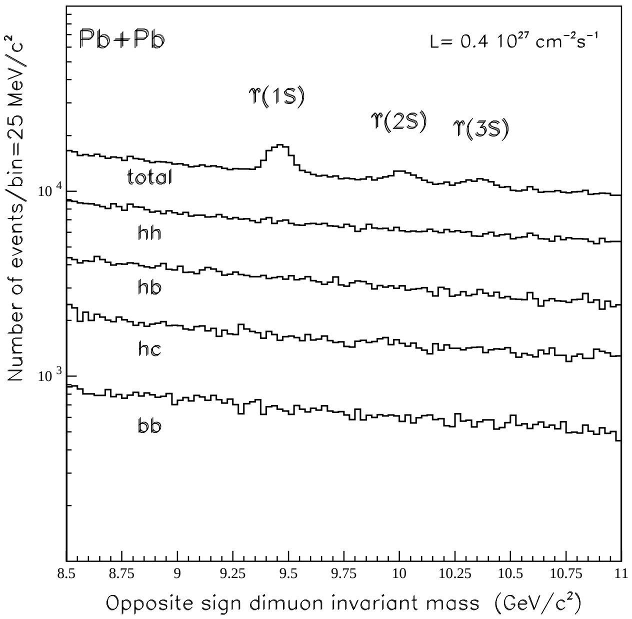
σ_z=190 μm

Vertex Reconstruction

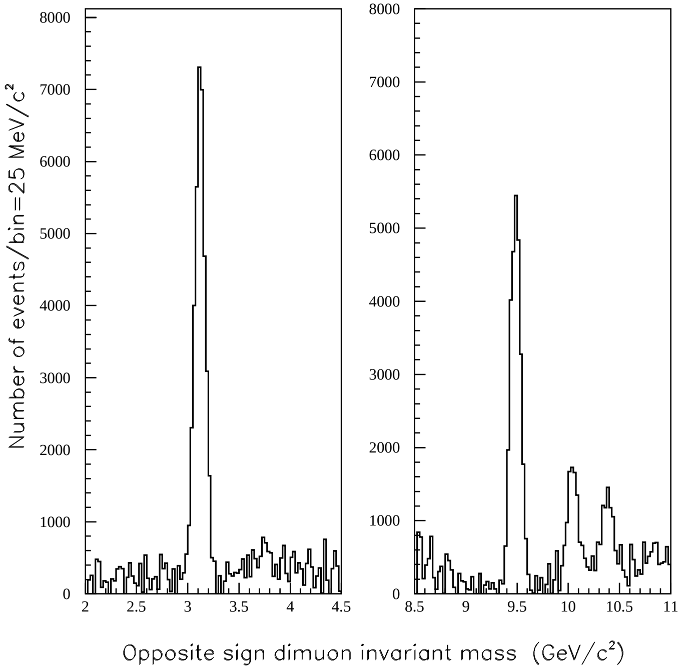
Outside-In

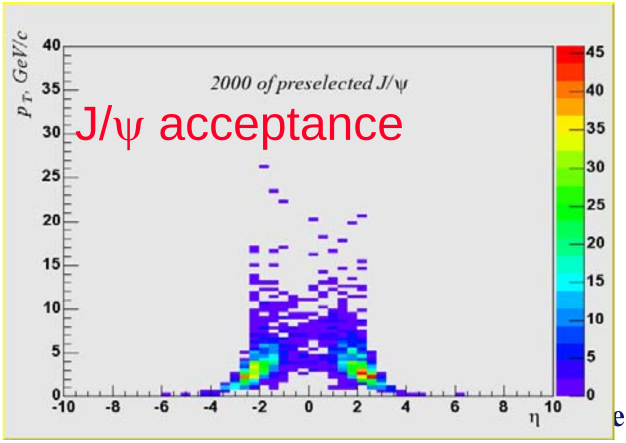
Quarkonia in CMS

ϒ Family region $M_{\mu+\mu-}$



J/ψ ϒ family





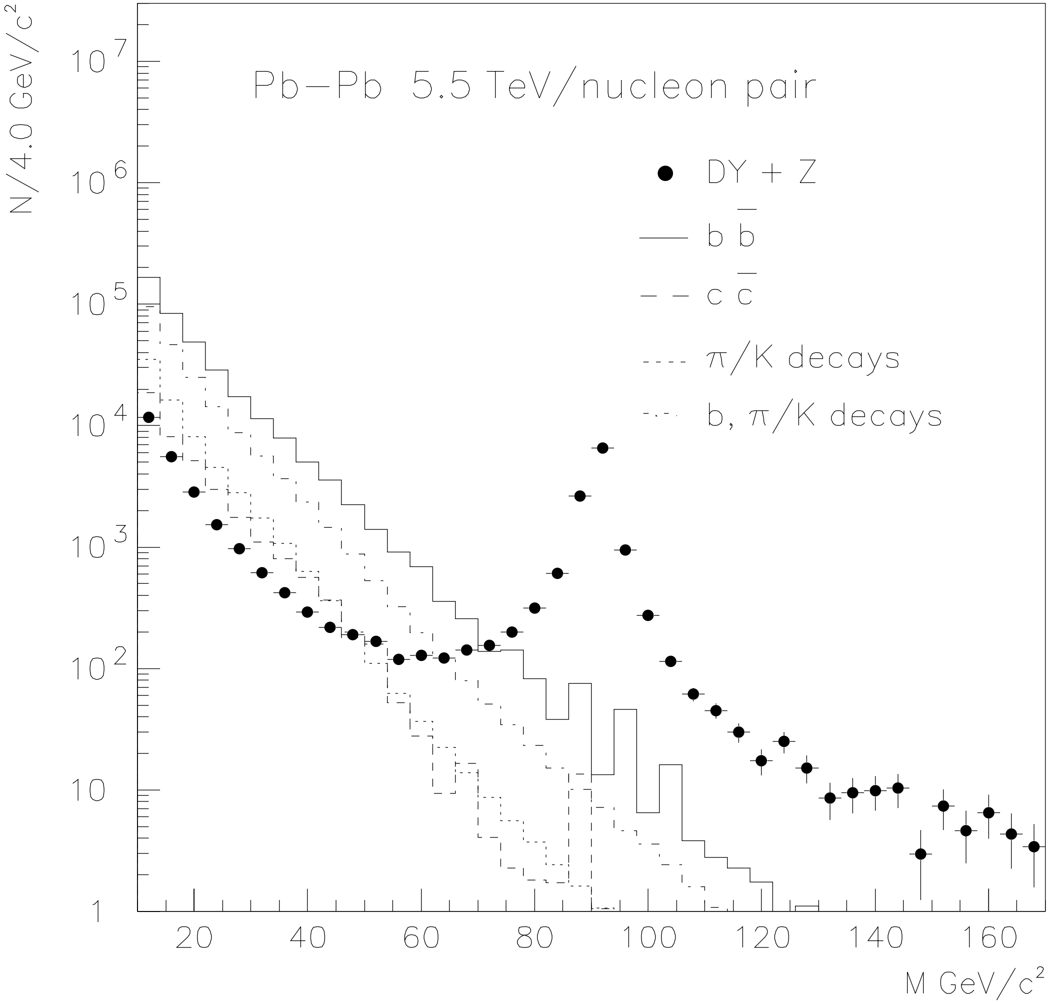
J/ψ acceptance

$\sigma_{M\Upsilon}$=50 MeV

Expect ~24k J/ψ and ~ 18/5/3 k ϒ,ϒ′,ϒ″
After one month of Pb+Pb running at L=$10^{27}cm^{-2}s^{-1}$
with 50% efficiency

Poster: M. Bedjidian

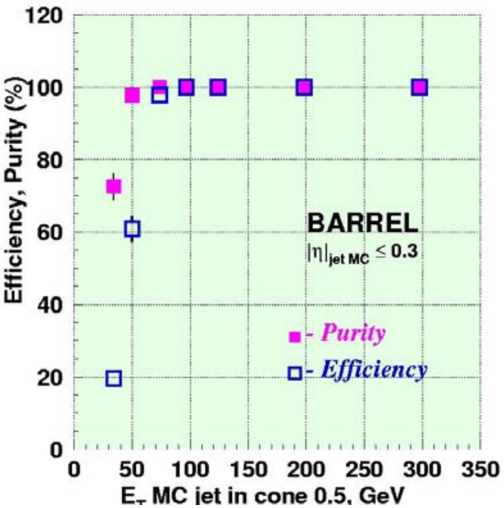
High Mass Dimuon, Z^0 Production

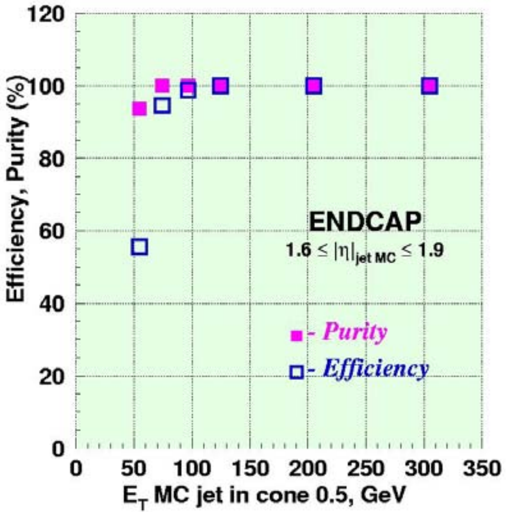


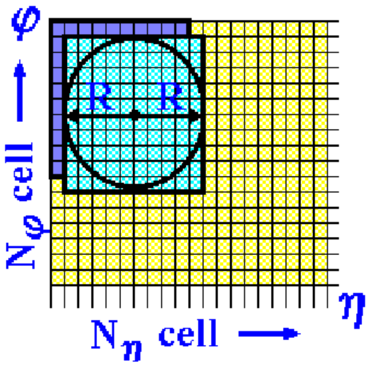
- **Z^0->μμ can be reconstructed with high efficiency**
  - **A probe to study nuclear shadowing**
  - **Z^0 also proposed as reference for ϒ production.**
- **Dimuon continuum dominated by b decays**
  - **Heavy quark energy loss**
- **High statistics (1 month):**

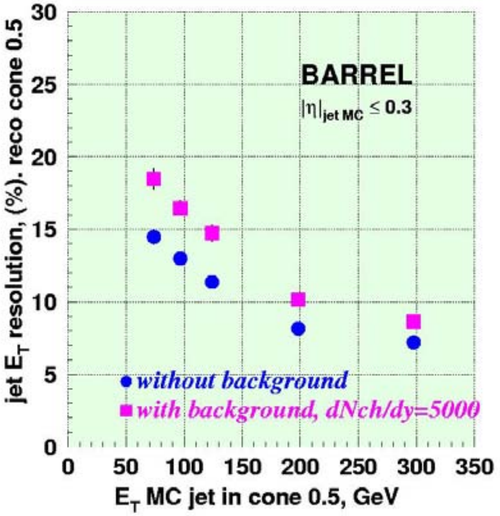
Channel ($M_{\mu\mu}$> 10 GeV)	Barrel + Endcap Events
$Z \to \mu^+\mu^-$	1.1 10^4
$BB \to \mu^+\mu^-$, P^{μ}_T>5 GeV	1.2 10^5
$B \to J/\psi \to \mu+\mu-$, P^{μ}_T>5 GeV	1.3 10^5

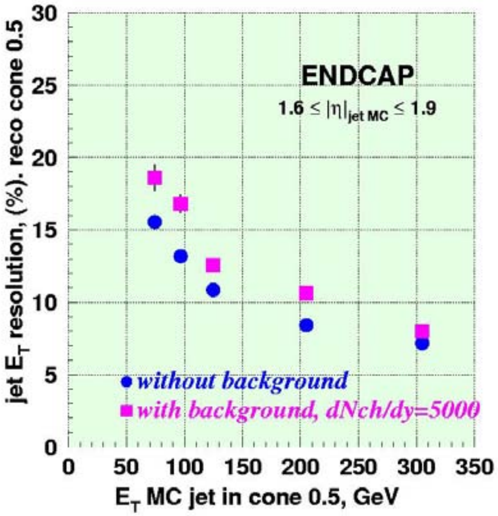
Jet Reconstruction in CMS using Calorimeters

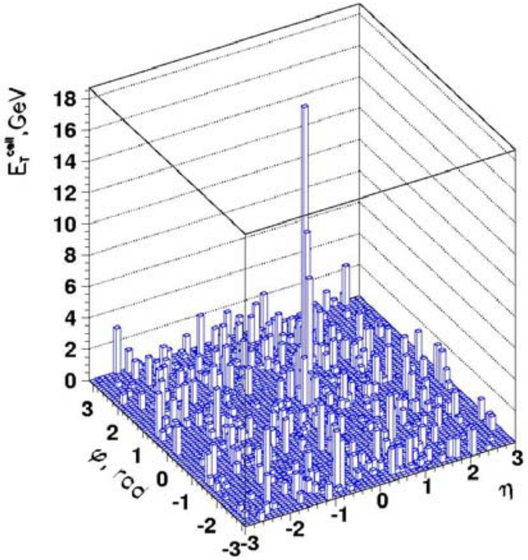




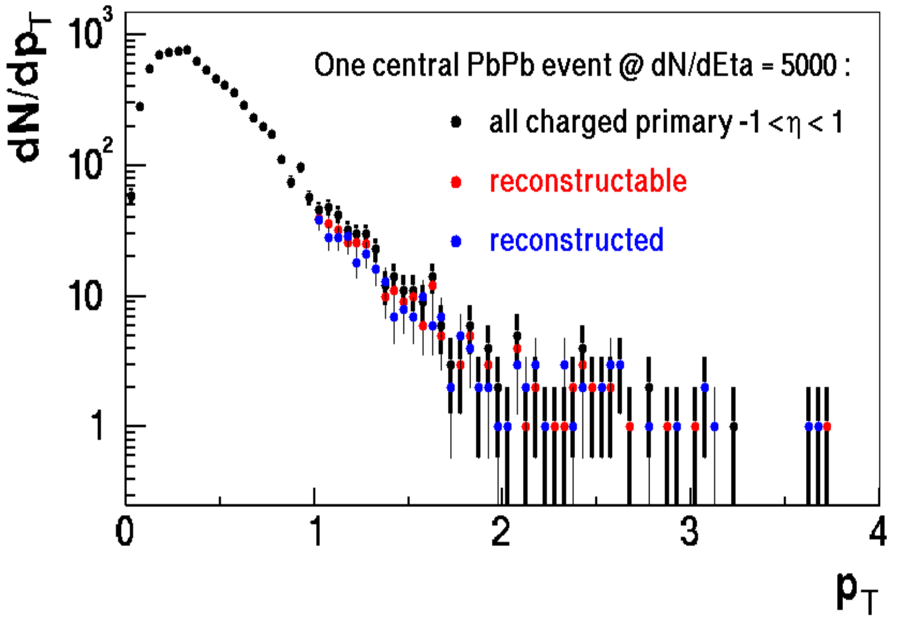


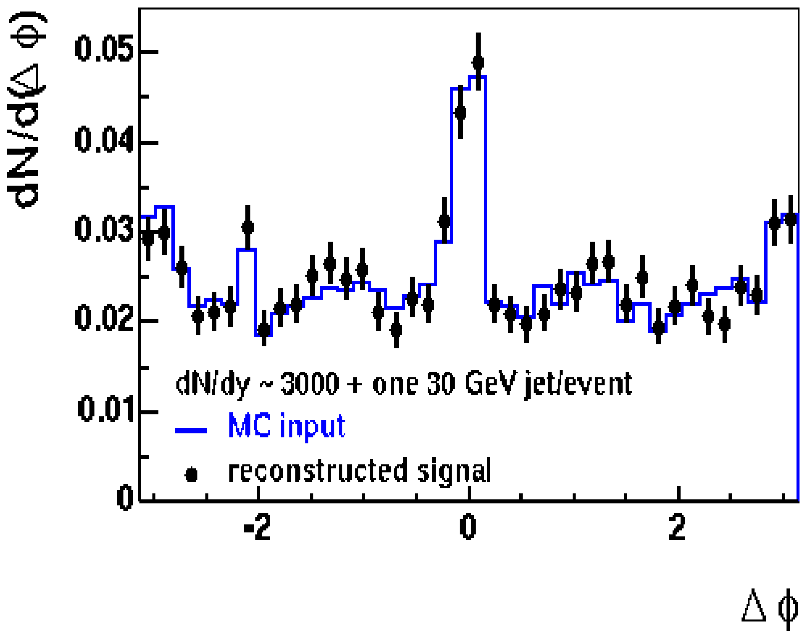






Charged Particle Jet Studies in CMS



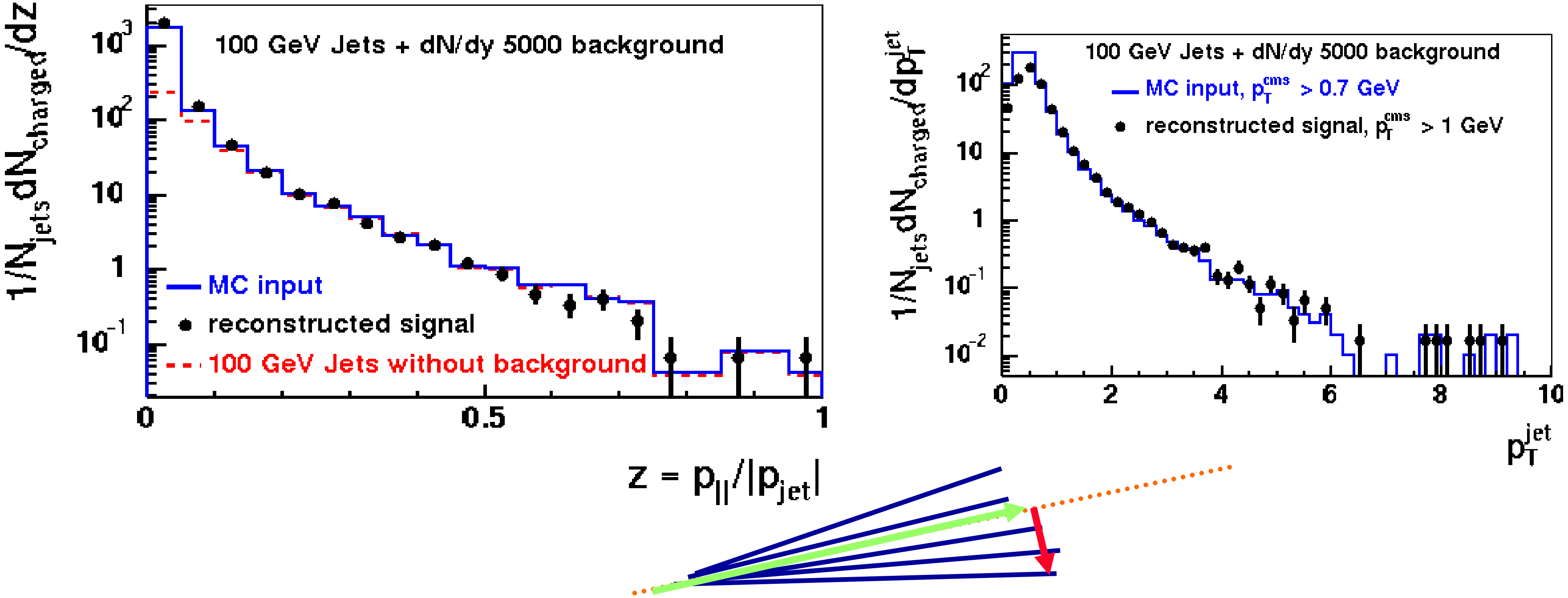


- **Detailed study of phenomena which are already apparent at RHIC**
- **Study the centrality dependence of:**
  - **Charged particle spectra starting at p_T~1 GeV**
    - Possibly lower p_T cutoff with reduced B field
  - **Back-to-back correlations a la STAR**
  - **Azimuthal asymmetry vs. p_T**

Jet fragmentation

Longitudinal momentum fraction z along the thrust axis of a jet:

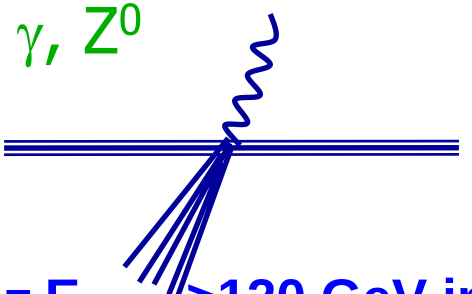
p_T relative to thrust axis:



Fragmentation function for 100 GeV Jets embedded in dN/dy ~5000 events.

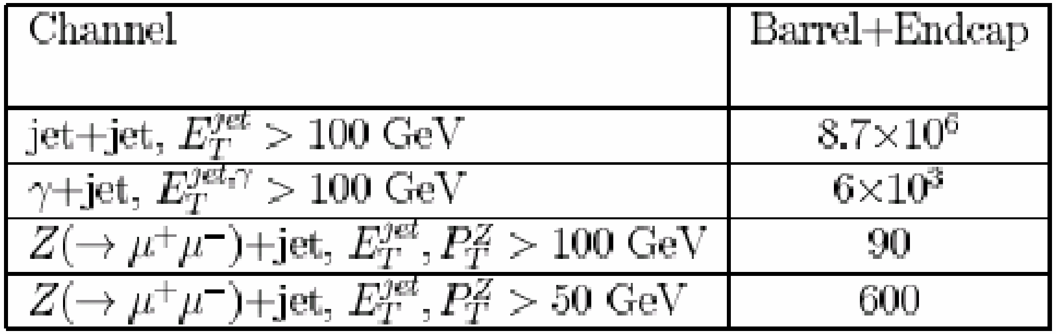
High precision tracking out to high momenta will allow for detailed jet shape analysis to study the energy loss mechanism

Balancing γ or Z^0 vs Jets: Quark Energy Loss



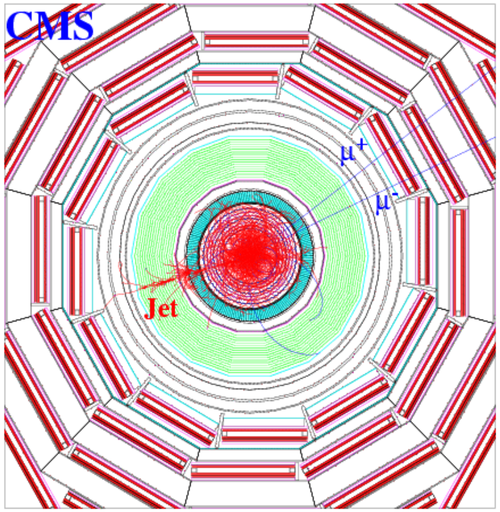
- $E_{Tjet,\gamma}$>120 GeV in the barrel

1 month at 10^{27} cm^{-2}s^{-1}
Pb+Pb

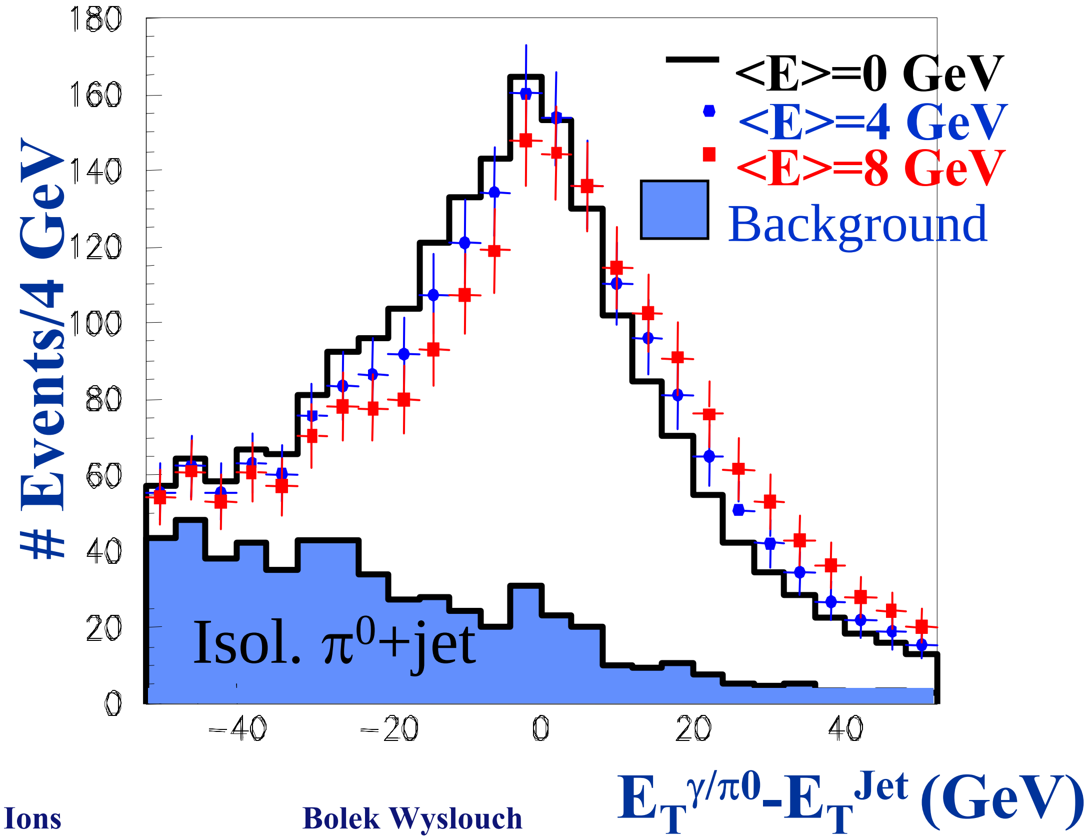


Channel	Barrel+Endcap
jet+jet, $E_T^{jet} > 100$ GeV	8.7×10^6
γ+jet, $E_T^{jet,\gamma} > 100$ GeV	6×10^3
$Z(\to\mu^+\mu^-)$+jet, $E_T^{jet}, P_T^Z > 100$ GeV	90
$Z(\to\mu^+\mu^-)$+jet, $E_T^{jet}, P_T^Z > 50$ GeV	600

Z+jet event in the Heavy Ion collision



Jet+Z^0



Conclusions

- LHC will extend energy range and in particular high p_T reach of heavy ion physics
- CMS is preparing to take advantage of its capabilities
  - Excellent coverage and resolution
    - Quarkonia
    - Jets
  - Centrality, Multiplicity, Energy Flow reaching very low p_T
  - Essentially no modification to the detector hardware
  - New High Level Trigger algorithms
  - Zero Degree Calorimeter, CASTOR and TOTEM as important additions extending forward coverage
  - Heavy Ion program is well integrated into overall CMS Physics Program
- The knowledge gained at RHIC will be extended to the new energy domain