Heavy Ion Physics at CMS

Olga Kodolova

Institut de Physique Nucléaire de Lyon

and

Scobeltcyn Insitute of Nuclear Physiscs

Moscow State University

for CMS collaboration

LHC days in Split, October, 5-9, 2004

From SPS and RHIC to LHC:

Increase energy $\sqrt{\bar{S}}$=17-200 -> 5500 GeV

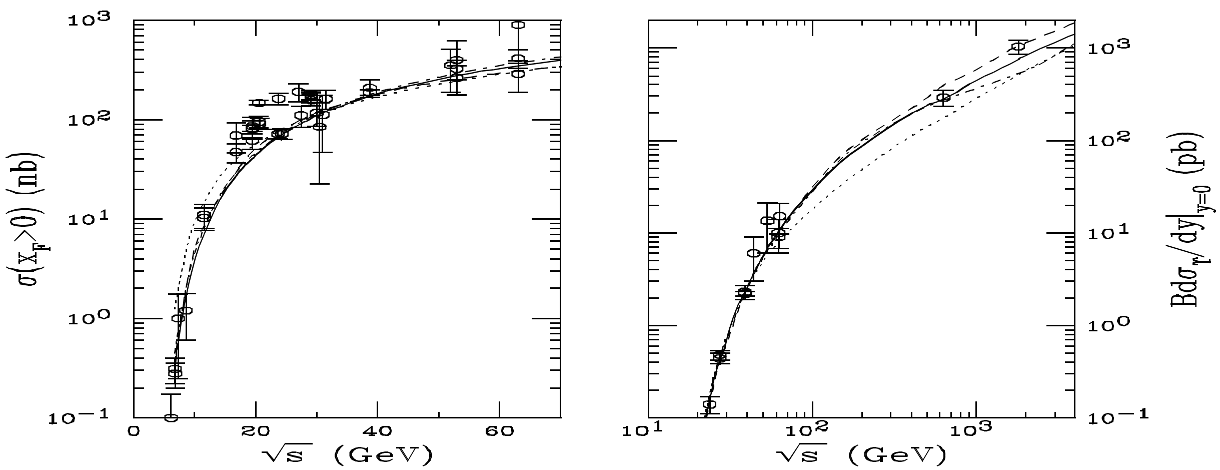
Plasma hotter and longer lived than at RHIC

Unprecedented Gluon densities

Access to lower x, higher Q^2

Availability of new probes

- Quarkonia with high expected statistics (J/ψ, ψ'; Y,Y',Y")



Large cross-section for J/ψ and Y families

Different melting for Y,Y',Y"

- Z^0 with high expected statistics. The possibility to use E_T balance of $Z^0(\gamma^*)$+jet to observe medium induced energy loss.

- Large cross-section for heavy-quarks (b,c):

- observation of medium induced energy loss in high mass dimuon spectrum and secondary J/ψ

- high-p_T jets clearly observable and identifiable. Medium modification at high-p_T

Heavy Ion program at CMS

- Excellent detector for high p_T probes:
  - High rates and large cross sections
    - quarkonia (J/ψ ,Y) and heavy quarks (bb)
    - 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 as a detector for Heavy Ion Physics

Muon stations cover $|\eta|<2.4$

Silicon Tracker

Wide rapidity range $|\eta|<2.4$

Excellent momentum resolution $\Delta p/p<2\%$ for p_T less than 100 GeV

4 Tesla magnetic field

The possibility to resolve Y states

Fine Grained High resolution calorimeter

Hermetic coverage up to $|\eta|<5$

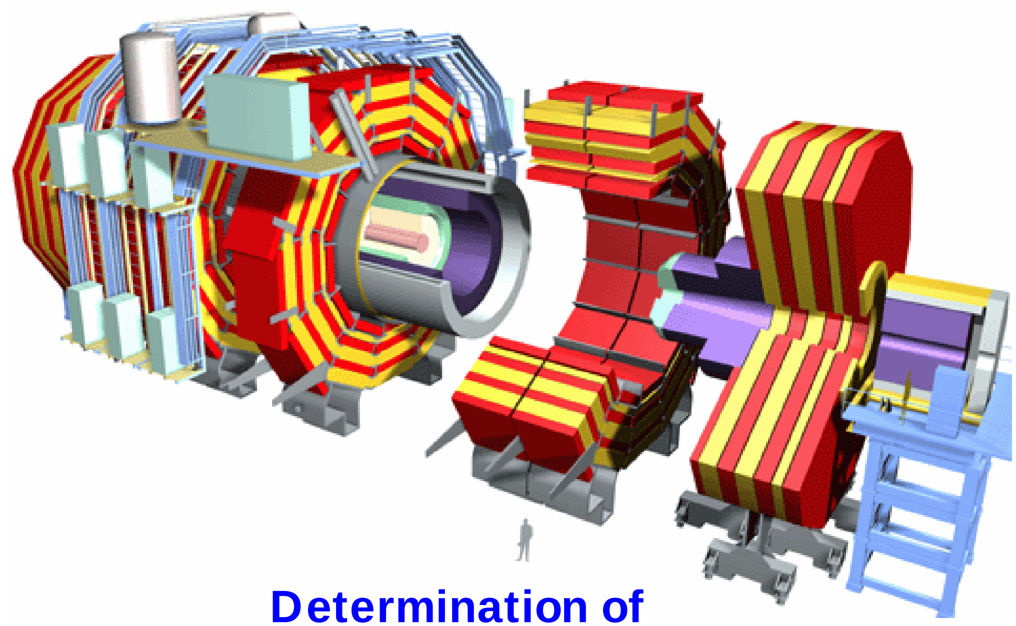
$|\eta|<7$ using CASTOR

Zero-degree calorimeter proposed

DAQ and Trigger

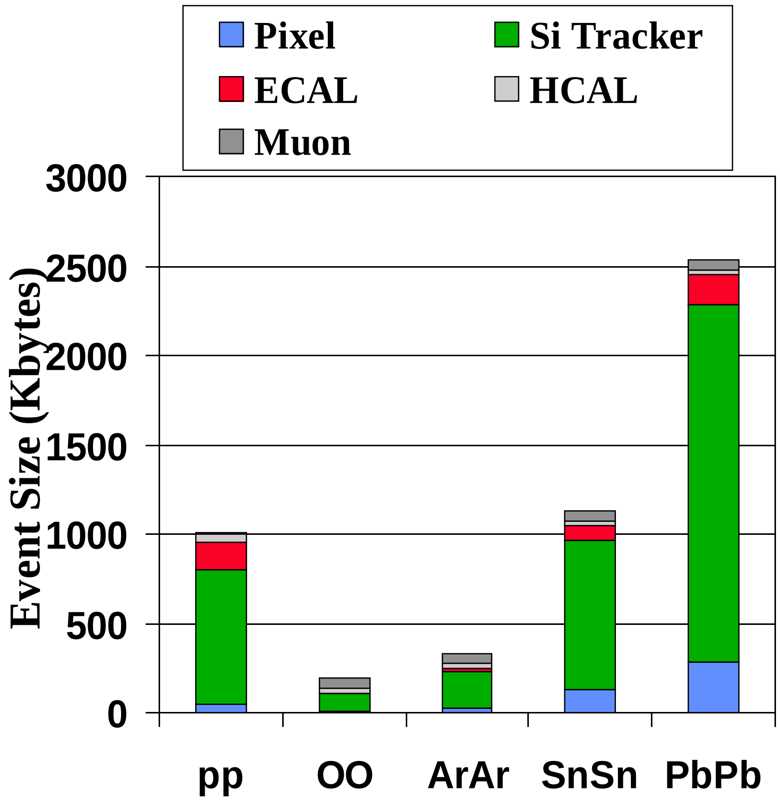
high rate capability for AA, pA, pp

inspection of fully built events at high level trigger of the most of HI events.

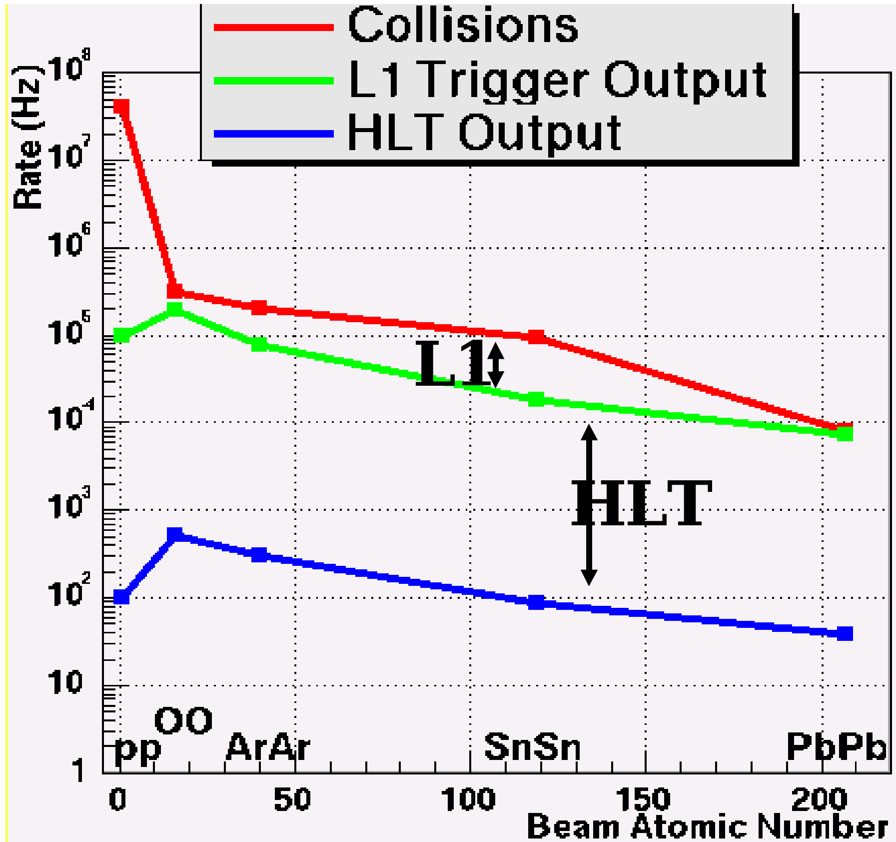


Determination of event centrality using calorimeters and ZDC

Event rates

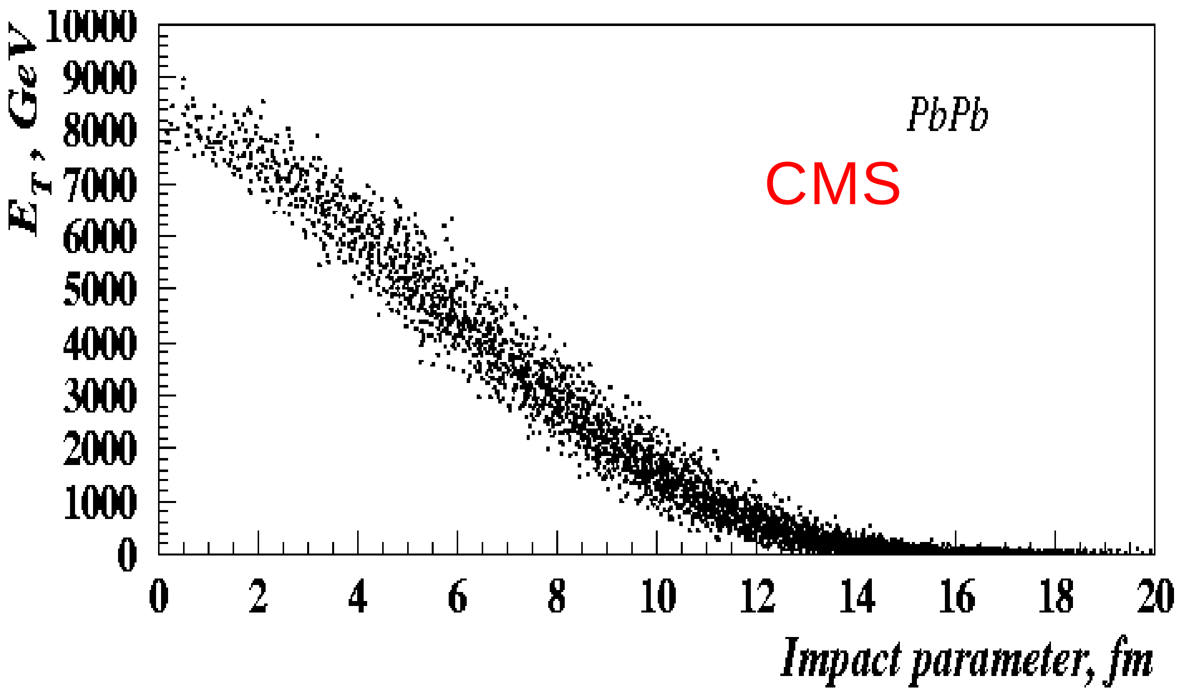


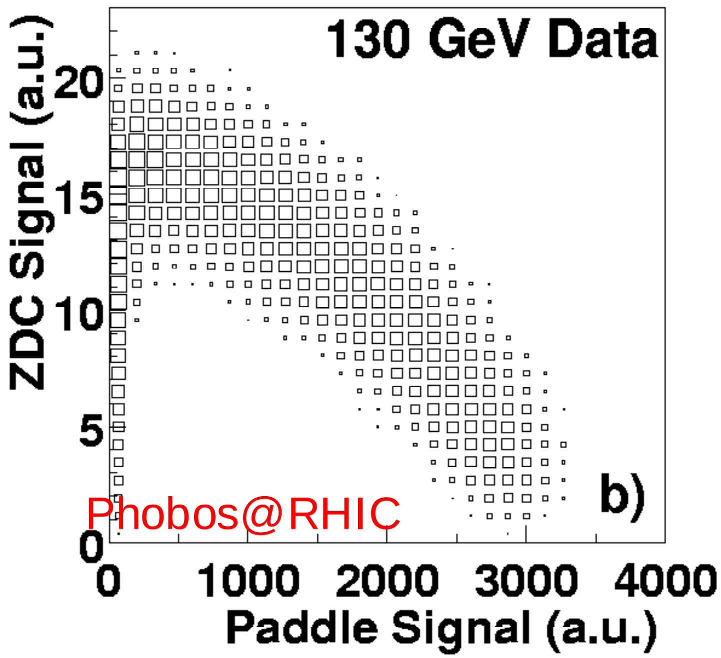
Event Size

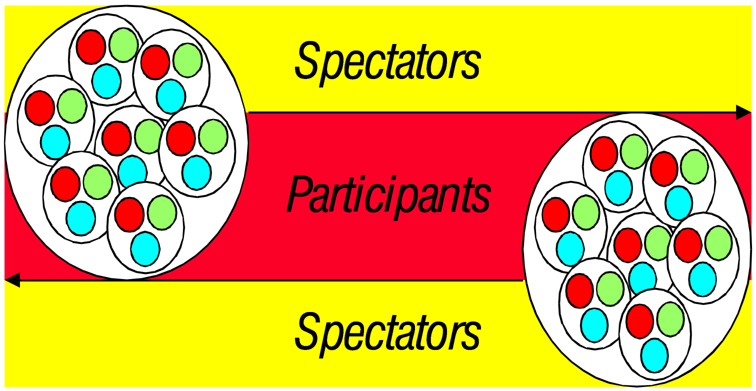


Rate reduction mainly performed at HLT

Centrality determination





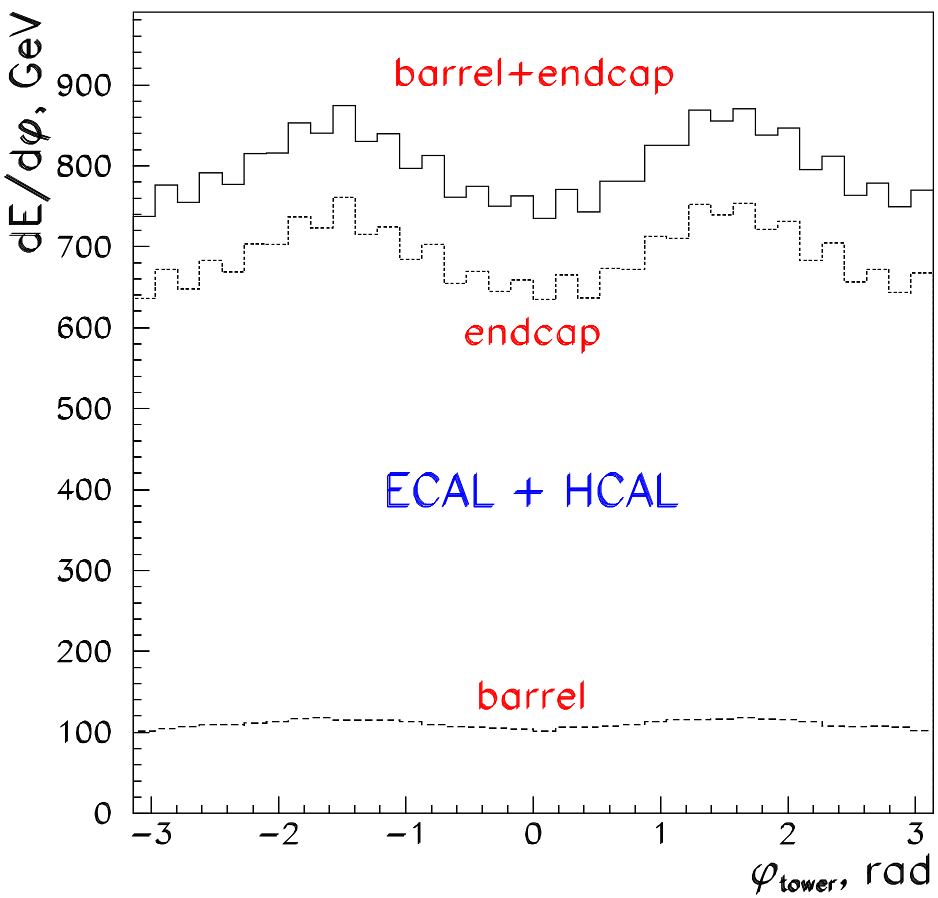


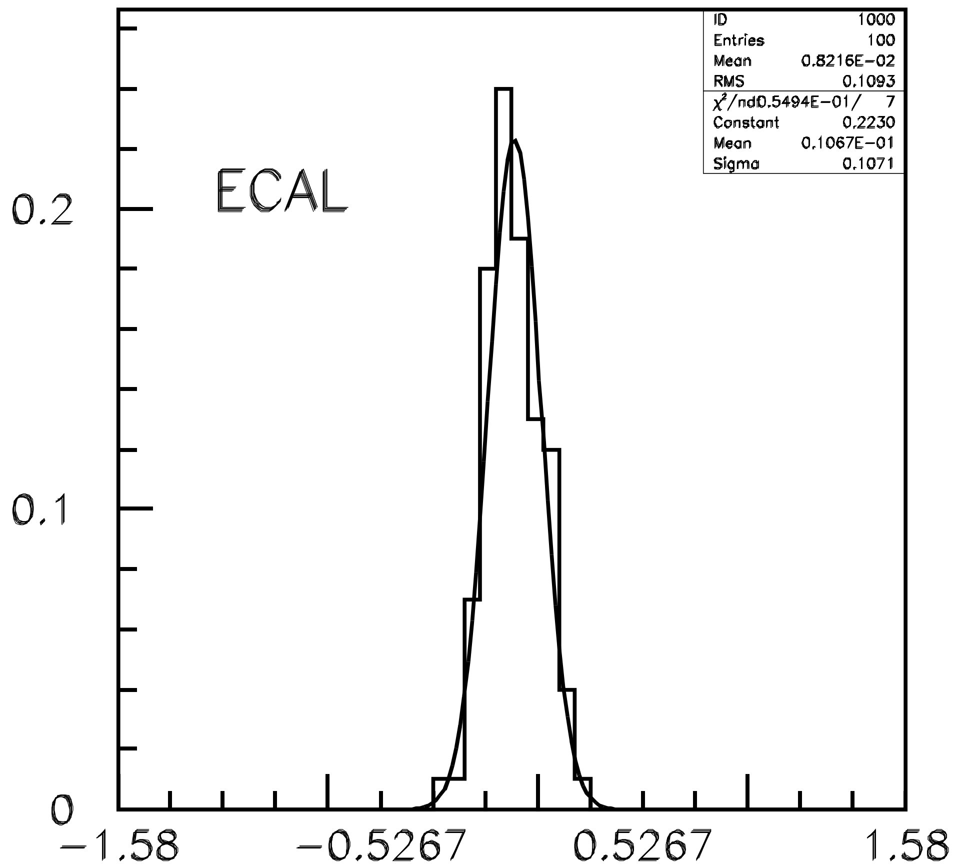
In CMS HF and CASTOR will provide measurement equivalent to PHOBOS

ZDC improves resolution at large b

Azimuthal assymetry, calorimeters

- calorimeters are used to determine event plane
- azimuthal assymetry can be estimated with CMS calorimeters with and without the determination of event plane

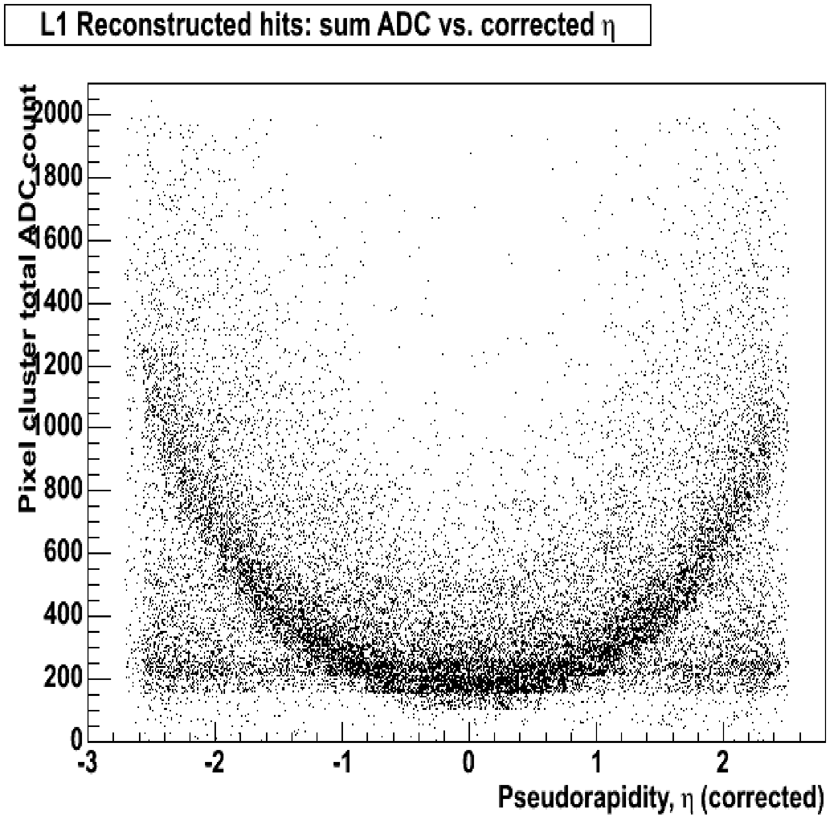


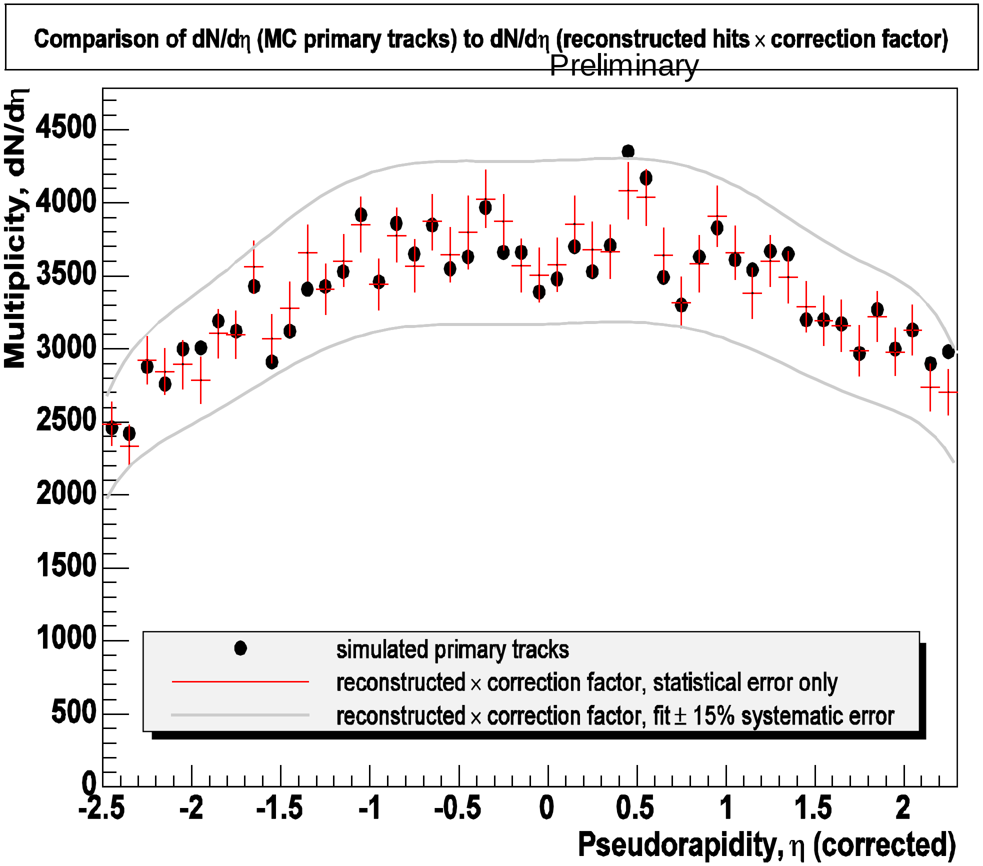


Simulations of Pb+Pb with b=6 fm with HYDRO model

Global measurements: dNch/dη (single event) a la PHOBOS

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





$\mu\mu$ reconstruction algorithm

Primary vertex determination

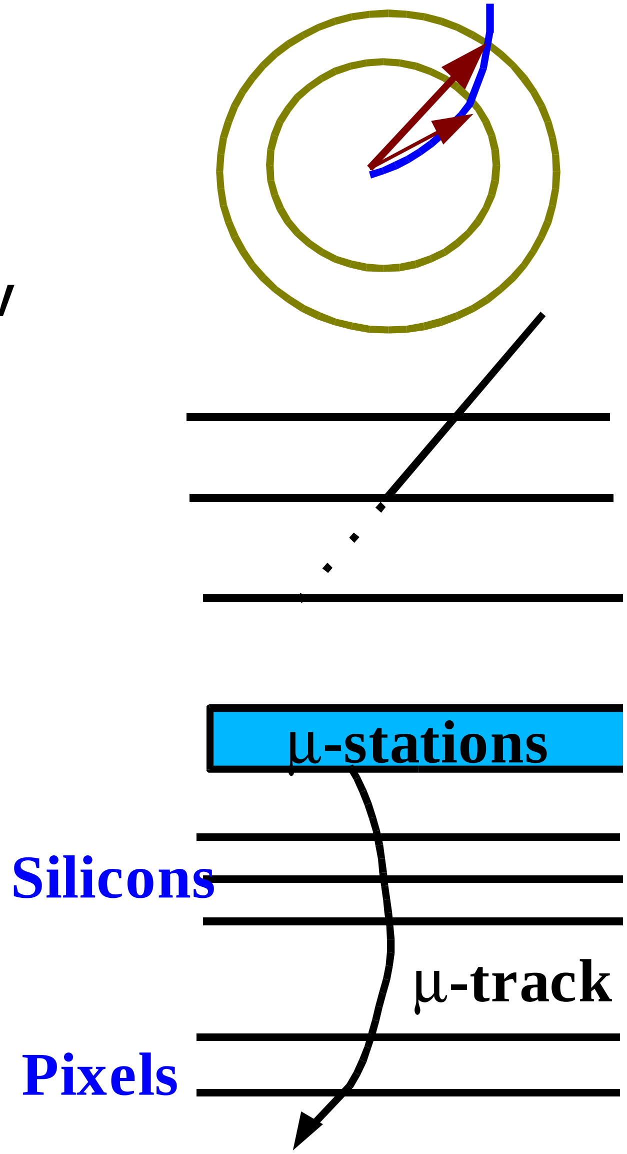
- select pairs of pixel hits with $\Delta\phi$ giving $0.5<p_T<5$ GeV
- extrapolate each pair in RZ to the beam line

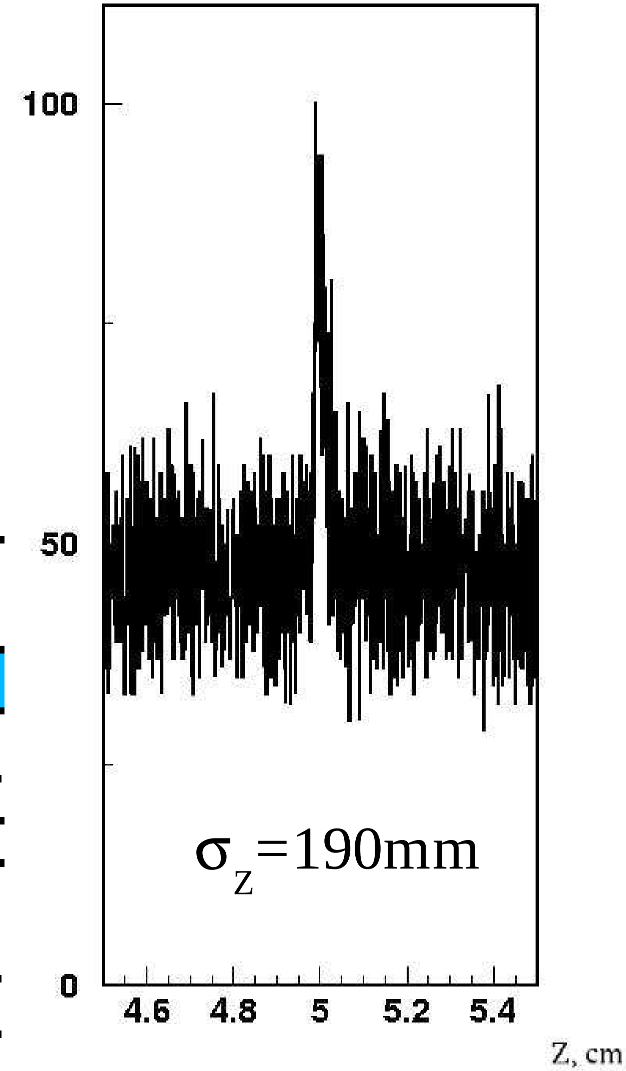
Track finding

- start from track candidate in muon stations
- extrapolate inwards from plane to plane using vertex constraints

Track selection by cuts

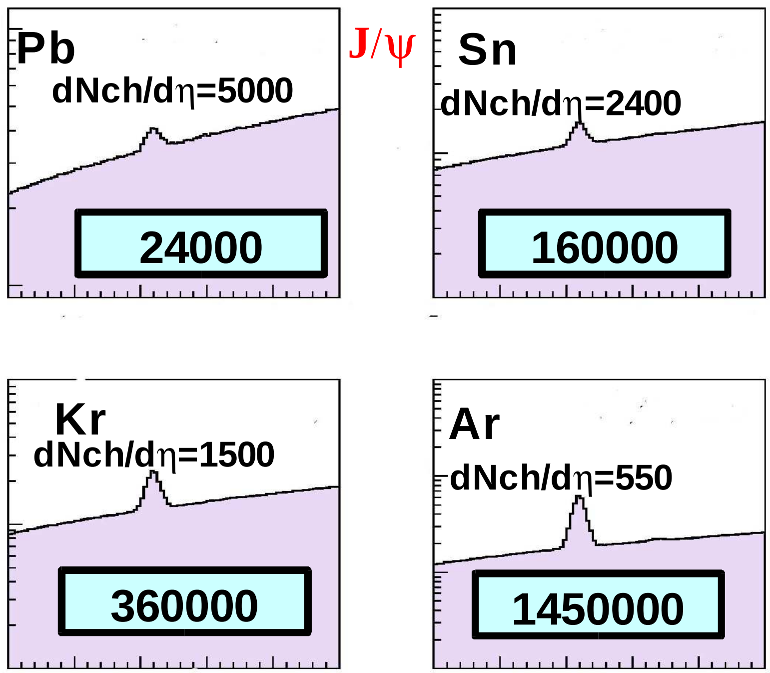
- fit quality (χ^2)
- vertex constraint



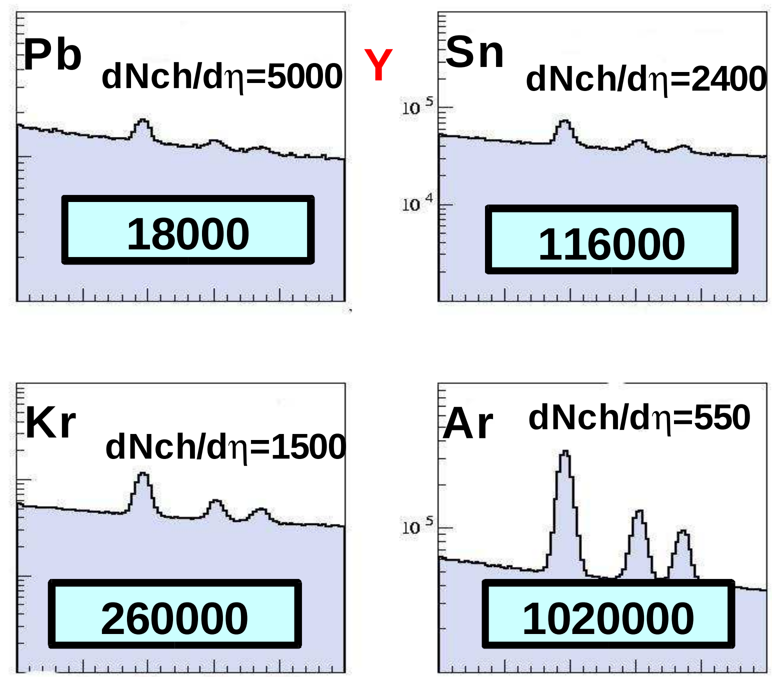


J/ψ and Υ spectra for different nuclei, high multiplicity assumption

For Pb-Pb at integrated luminosity 0.5 nb^{-1}



Opposite sign dimuon invariant mass, GeV/c^2



Opposite sign dimuon invariant mass, GeV/c^2

0.03 % of J/ψ events in barrel+endcap

Combinatorial background:

π/K decays into μ

cc and bb production

Mixed sources

No trigger: cut p_T>3.5 GeV/c

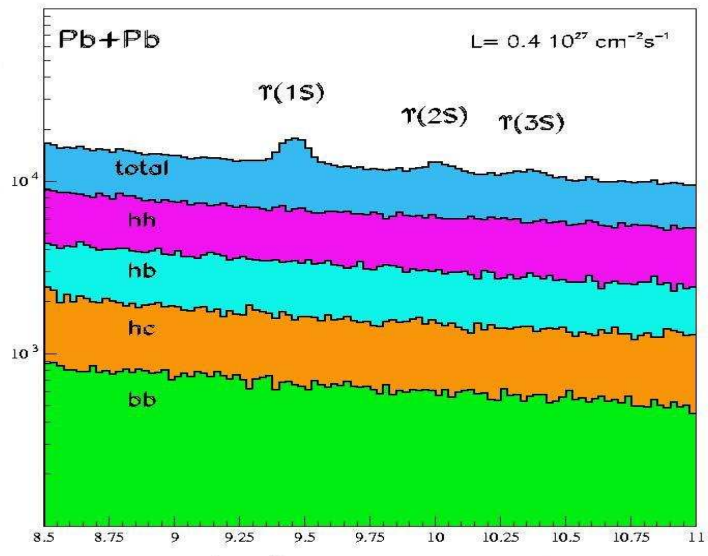
16 % of Υ events in barrel+endcap

Detailed simulation of reconstruction efficiency and mass resolution

Background contribution

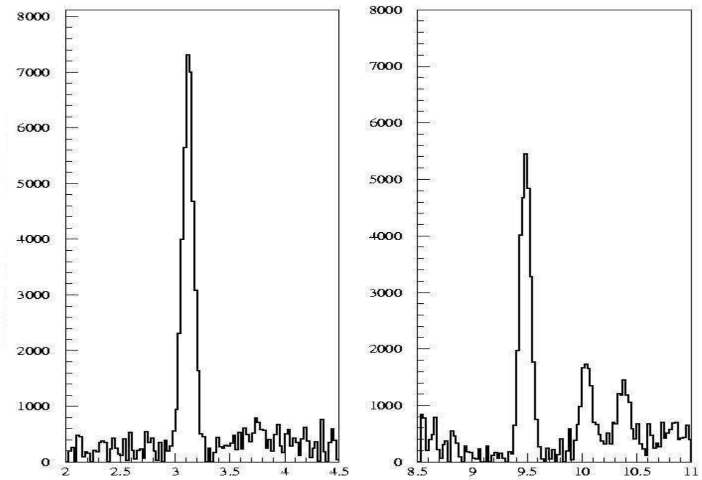
Signal/background ratios (high multiplicity-low multiplicity)

The contribution of dimuon background sources



Opposite sign dimuon invariant mass, GeV/c^2

After subtraction of uncorrelated dimuon pairs with like-sign dimuon soectrum (NA50 methodics)



Opposite sign dimuon invariant mass, GeV/c^2

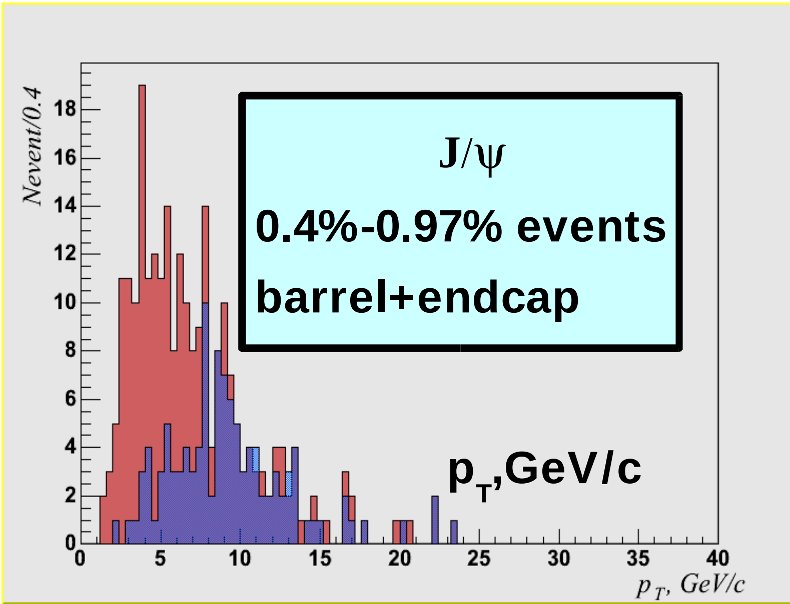
		PbPb	SnSn	KrKr	ArAr
S/B	J/y	0.2-0.5	0.4-1.1	0.7-1.8	2.0-6.8
	ϒ	0.4-0.9	0.7-1.9	1.5-4.3	5.3-15.6
S/sqrt(S+B)	ϒ	69-93	220-276	396-460	925-978
	ϒ'	24-38	84-123	165-218	447-512
	ϒ''	16-26	55-86	113-157	325-391

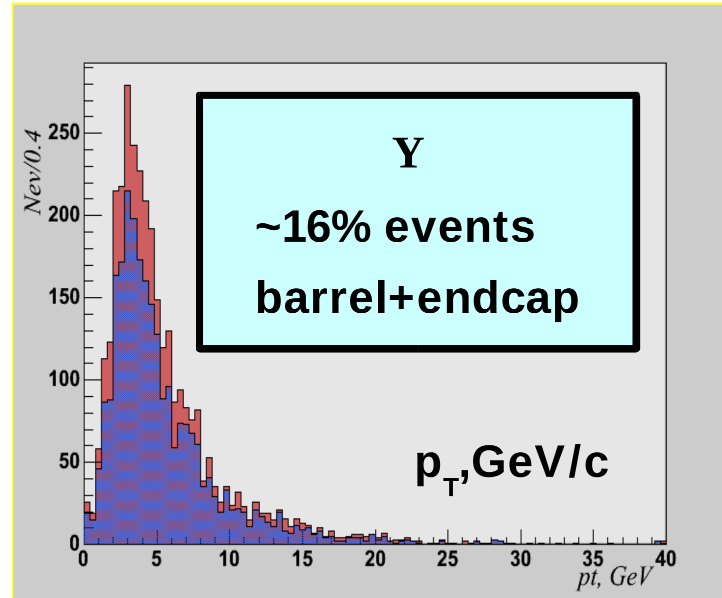
Mass window +-50 MeV/c^2

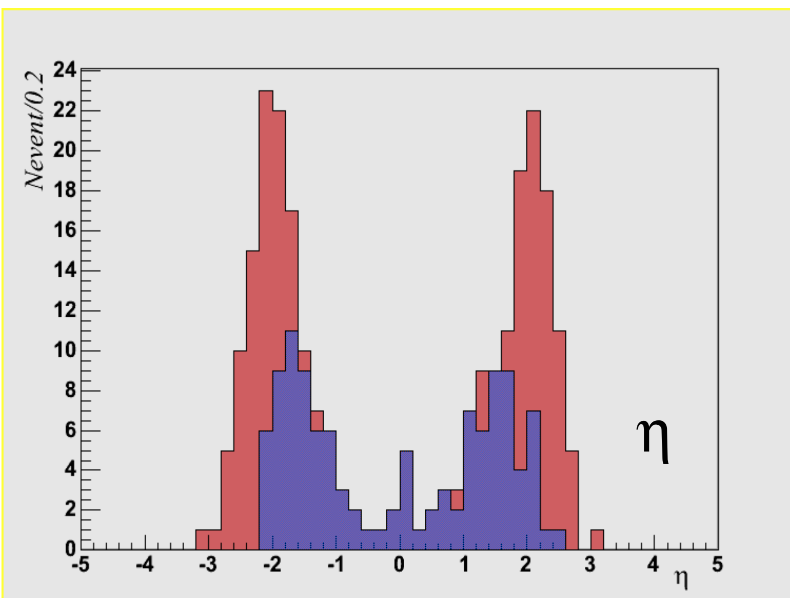
Signal/background ratios (high multiplicity-low multiplicity)

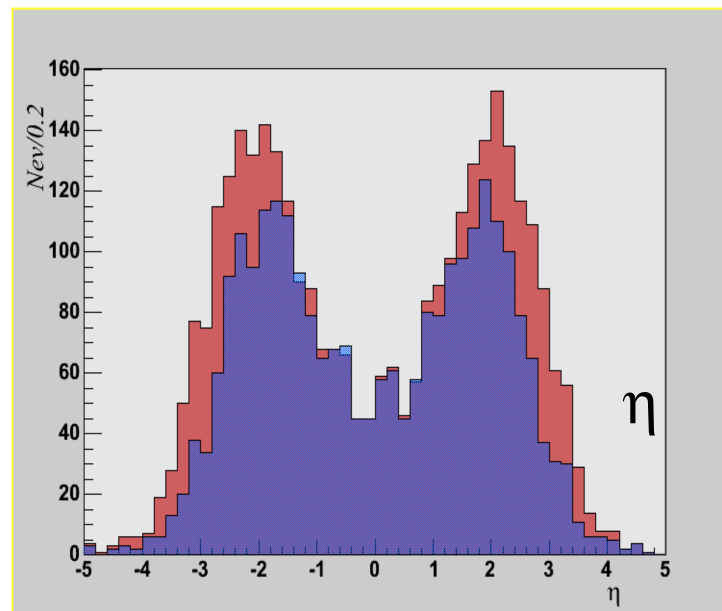
J/ψ and Y trigger study: different trigger options

pp default (red histograms), HI optimized (blue histograms)







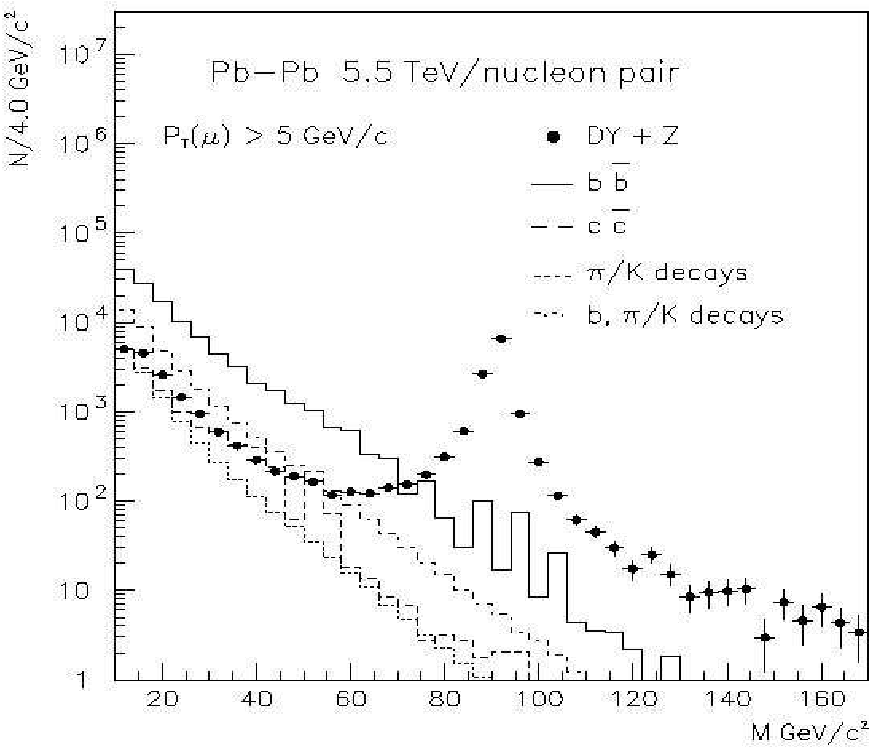


Z ->μ+μ- detection at CMS

$\sigma^{AA} = A^{2\alpha}\sigma^{pp}$ with $\alpha=1$

σ^{pp} was taken from PYTHIA, correction k=2 for cc and bb and k=1.3-1.5 for Z, W, tt

HIJING was used for AA event



The expected number of

$Z \to \mu^+\mu^-$: ~$10^4/1.3\times10^6$ s

of Pb-Pb running at $L=10^{27}cm^{-2}s^{-1}$.

Z can be measured with muon system alone and with muon+tracker systems.

Z+jet events

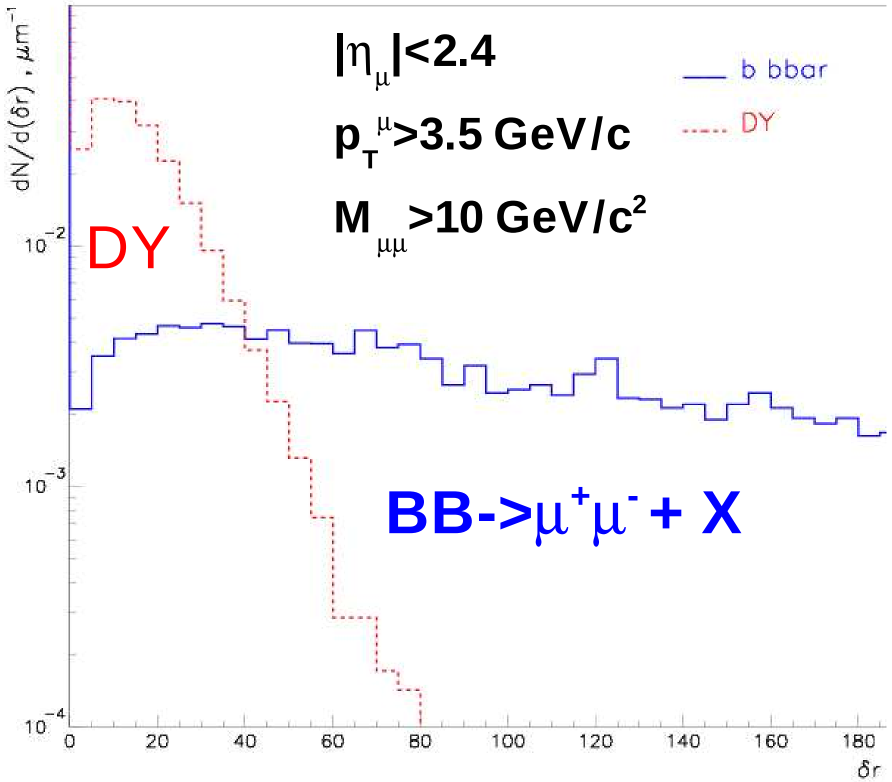
The expected number of Z+jet for jet E_T>50 GeV/c and $|\eta_{jet}|$<1.5: $900/1.3\times10^6$ s of Pb-Pb run at $L=10^{27}cm^{-2}s^{-1}$.

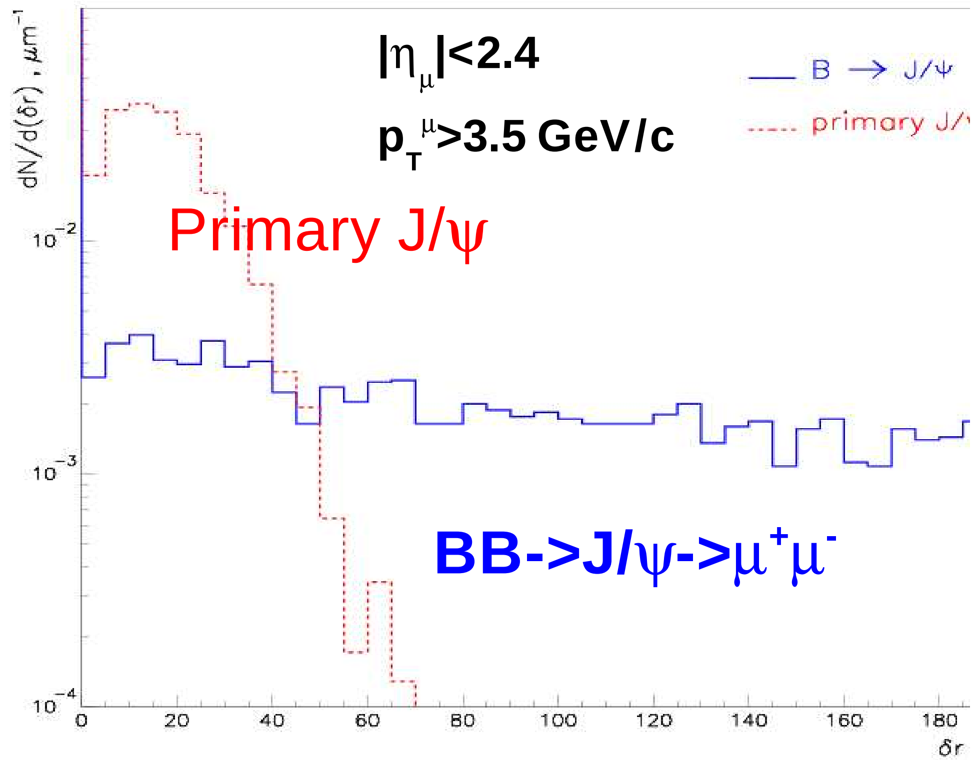
Z+jet events with P_T^Z measured from pair $\mu^+\mu^-$ should allow to study effects of jet quenching using energy balance $E_T^{jet}=P_T^Z$

Heavy-quark b,c- >μ /J/ψ +X

Secondary vertex finding and correlated background rejection

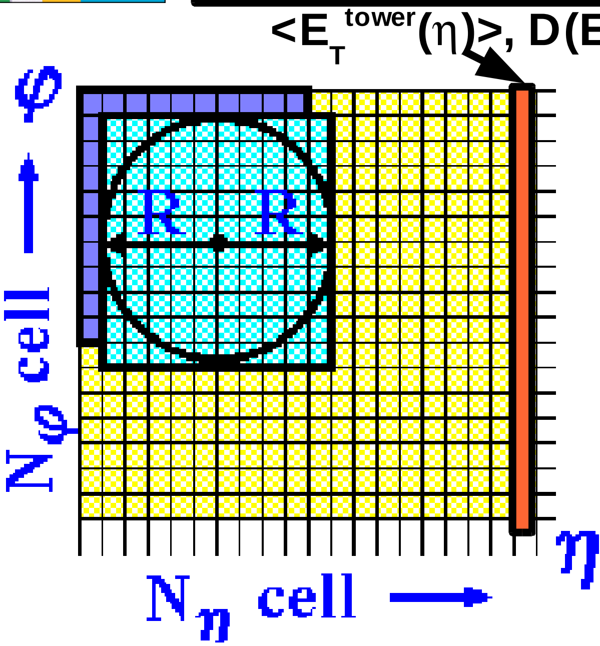
dr is transverse distance between the intersection points with the beam line (points with minimal distance to the beam axis) belonging two different muon tracks.



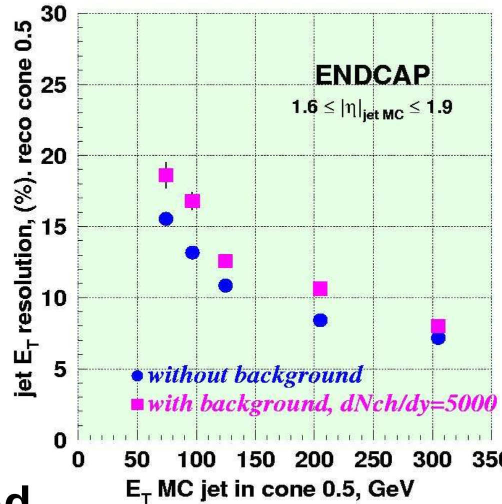


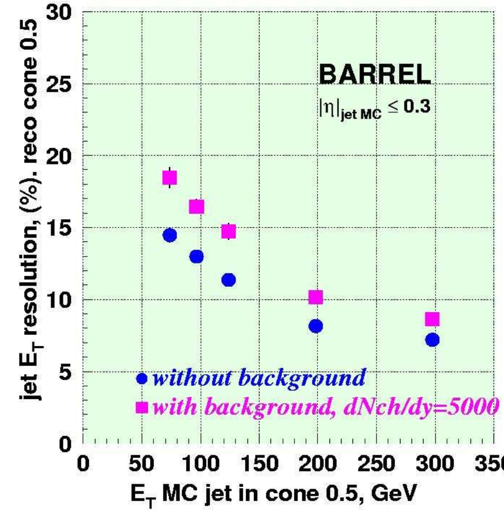
b-quark energy loss affects B-jet fragmentation and modification dimuon spectra depending on mechanism of heavy-quark production (for BB->$\mu^+\mu^-$) and intensity of jet quenching.

Jet Reconstruction in CMS using Calorimeters



$$\text{Resolution} = \frac{D(E_T^{reco}/E_T^{gene})}{\langle E_T^{reco}/E_T^{gene} \rangle}$$





1) $<E_T^{tower}(\eta)>$, $D(E_T^{tower})(\eta)$ are calculated.

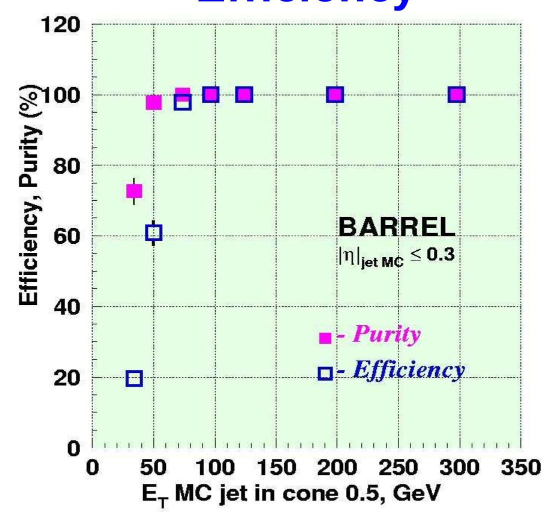
2) $E_{T\,new}^{tower}(\phi,\eta) = E_T^{tower}(\phi,\eta) - <E_T^{tower}(\eta)> - D(E_T^{tower})(\eta)$

3) Jets with ETjet>ETcut are found with iterative cone algorithm

4) $<E_T^{tower}(\eta)>$, $D(E_T^{tower})(\eta)$ are recalculated without towers occupied by jets and subtracted from the each tower.

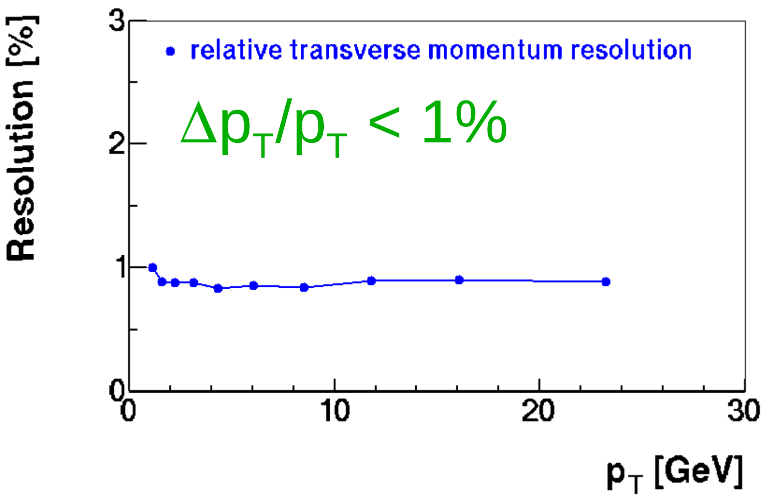
5) Jets are found again with the iterative cone algorithm.

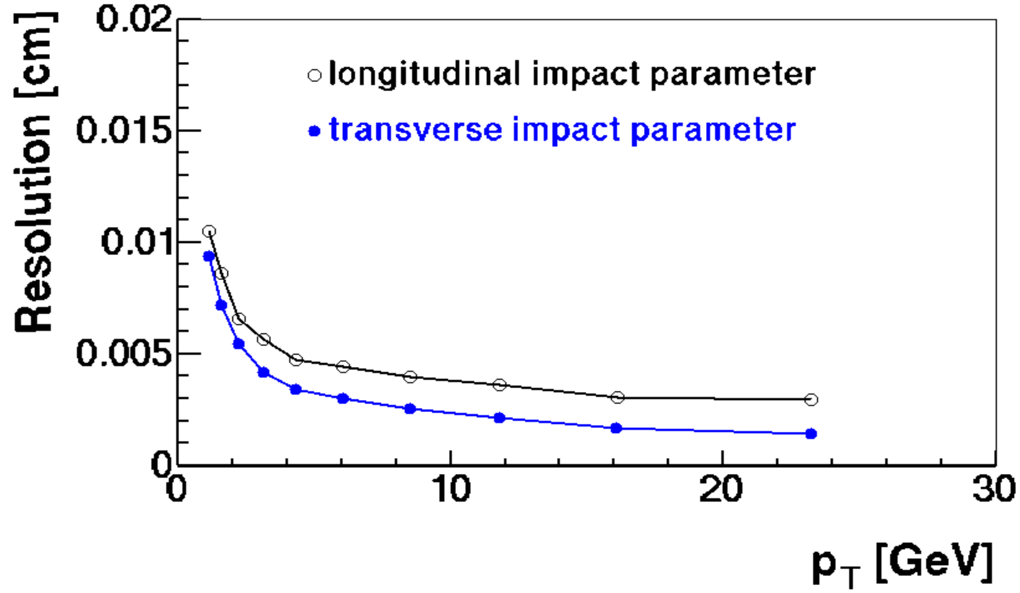
Efficiency

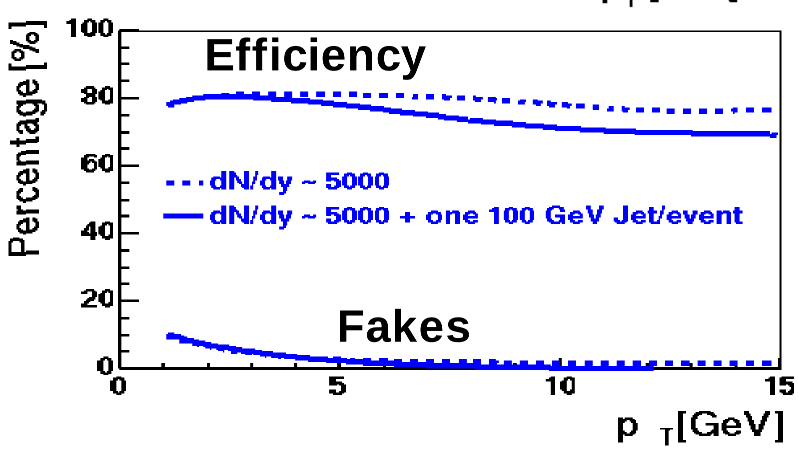


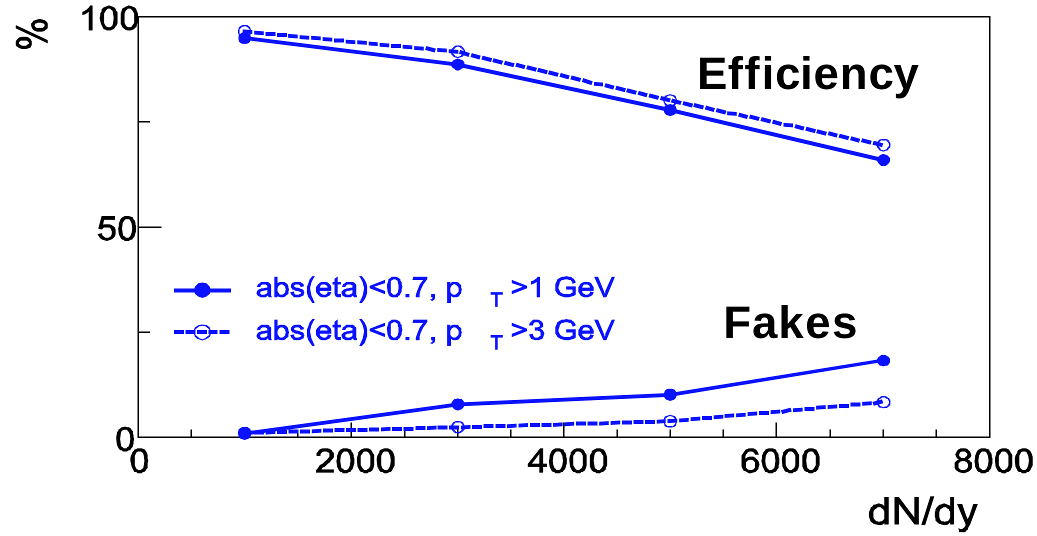
Track reconstruction: inside-outside

- Match Reconstructed tracks to MC input on a hit by hit basis

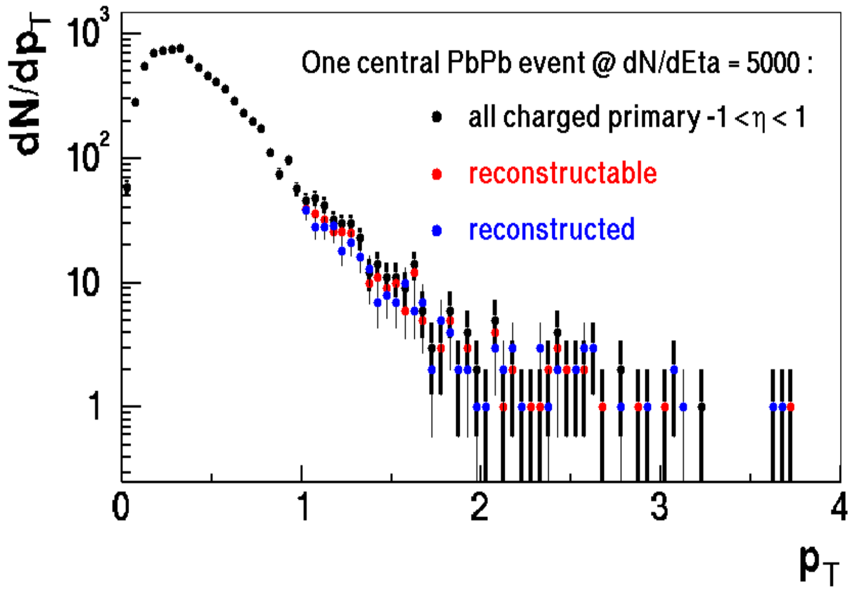


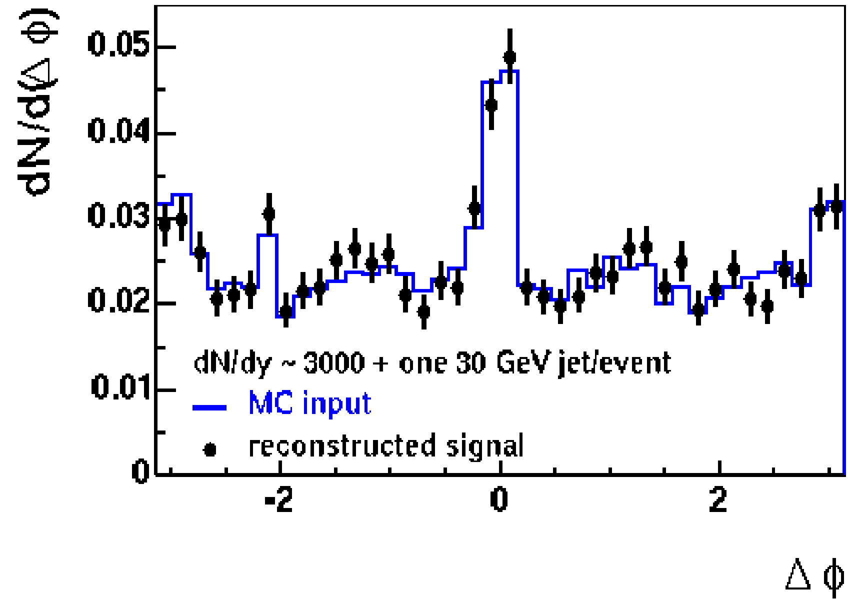






Charged particle jet study in CMS

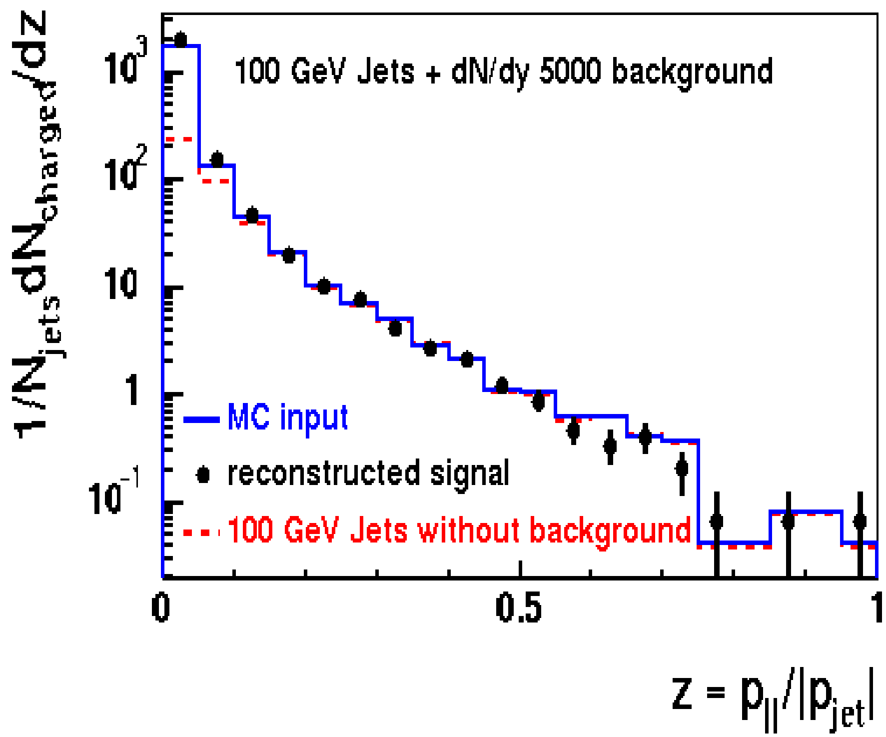




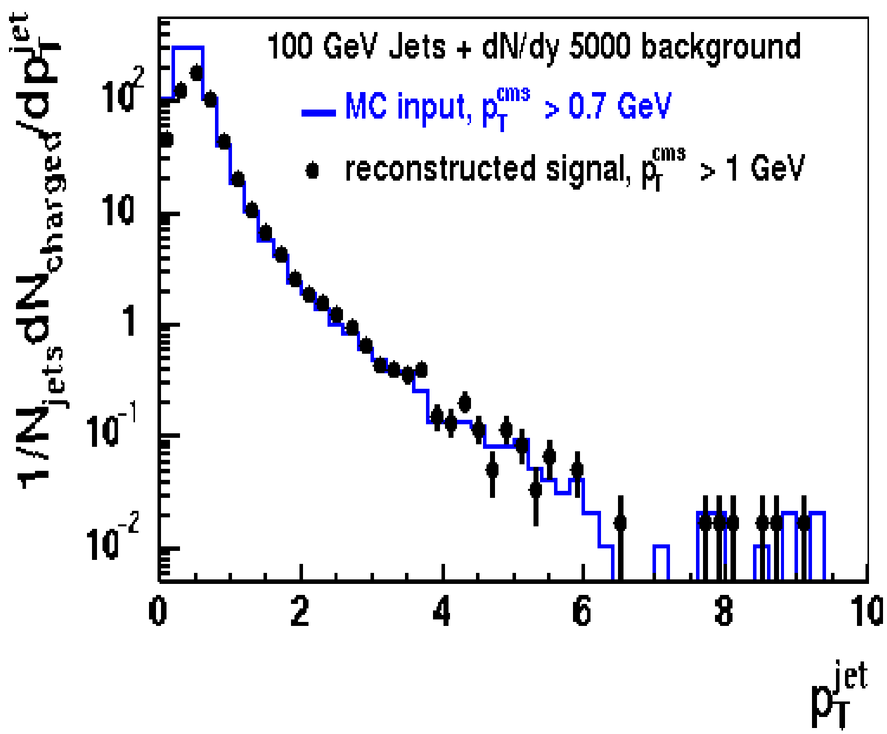
- **Detailed study of phenomena which are already apparent at RHIC**
- **Study the centrality dependence of:**
  - **Charged particle spectra starting at p_T~1 GeV**
    - **Possibly lower p_T cutoff with reduced B field**
  - **Back-to-back correlations a la STAR**
  - **Azimuthal asymmetry vs. p_T**

Jet shapes and fragmentation

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

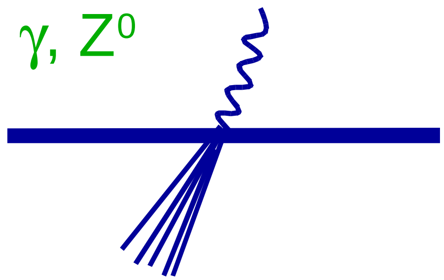


p_T relative to thrust axis:



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

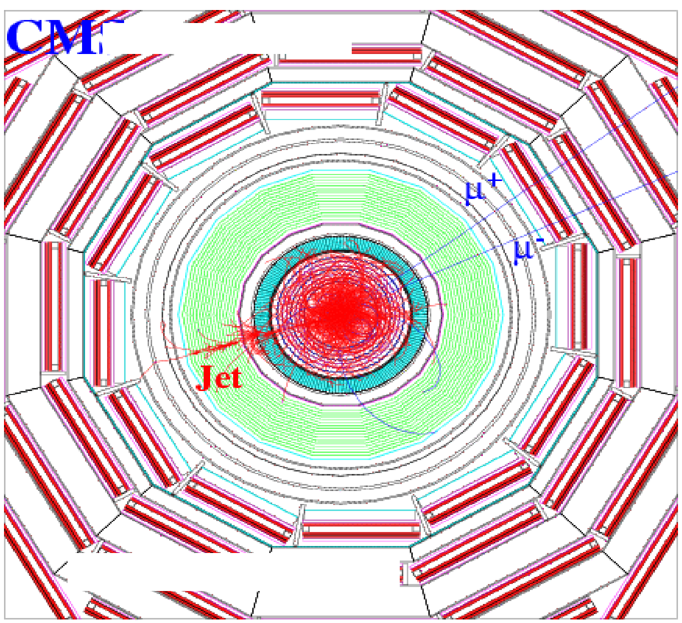
Balancing γ or Z^0 vs Jets: Quark Energy Loss



Channel	*Barrel+endcap*
Jet+jet	**4.3×10^6**
γ+jet	**3.0×10^3**
Z->$\mu^{+}\mu$ + jet, ETet>50 GeV	**4×10^2**

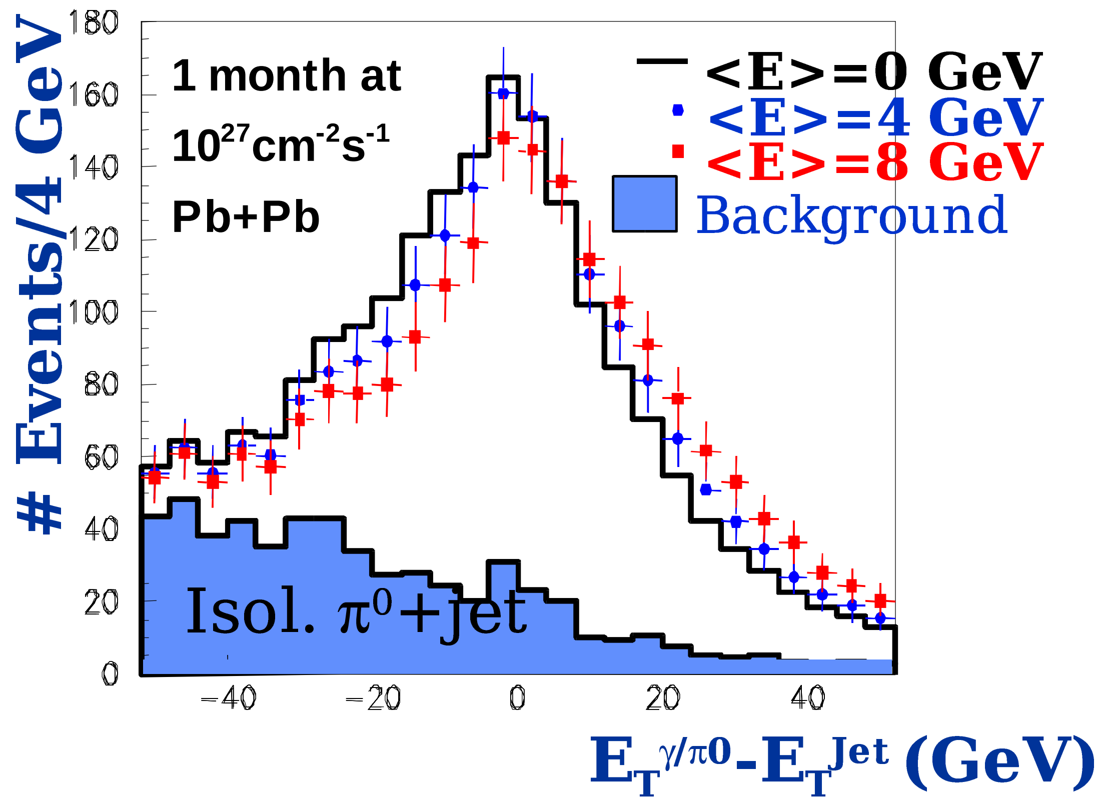
Z+jet event in the Heavy Ion collision

dNch / dY = 5000



Pt(Z) = Et(Jet) = 100 GeV.

Jet+Z^0



Summary (I)

Excellent coverage and resolution for high p_T probes

- dimuons

- quarkonia

- states are well separated

- the number of events/month is enough to carry out correlation studies (P_T,event centrality,...).

- significances for Y are between 70 for PbPb and 1000 for ArAr

- bb->$\mu^+\mu^-$+X, b->J/ψ + X channels can be separated from that of Drell-Yan with secondary vertex reconstruction

- Z can be measured independently in muon system and in the muon + tracker system

-jets

- jets can be reconstructed in calorimeters with high efficiency and purity

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

Summary(II)

- correlations

  Z/γ+jet imbalance study could provide a unique tool to investigate jet quenching

Global event characterization

- charged multiplicity measurements

  Pixel detectors give possibility to measure the multiplicity of charged particles with p_T>26 MeV/c

- event centrality

  The impact parameter of event can be estimated with energy depostited in HF with the accuracy about 1 fm.

- azimuthal assymetry

  The event plane can be determined with use of CMS calorimeters.

  The azimuthal assymetry parameter can be determined with CMS calorimeters

DAQ and Trigger

High rate capability for AA, pA, pp allows to build event at High Level Trigger