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

Bolek Wyslouch
MIT
for the CMS Collaboration

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The Physics Landscape: Pb+Pb Collisions SPS->RHIC->LHC

	SPS(17)	**RHIC**(200)	**LHC**(5500)
$dN_{ch}/d\eta$	350	700	3000-8000 ?
ϵ [GeV/fm^3] ($t_0 = 1$ fm/c)	≈ 2.5 1	$\approx 3.5 - 7.5$ 2	$\approx 15 - 40$ 10
V_f [fm^3]	$\approx 10^3$ 1	$\approx 7 * 10^3$ 7	$\approx 2 * 10^4$ 20
τ_{QGP} [fm/c]	≤ 1 1	$1.5 - 4$ 3	4-10 7
τ_0	≥ 1	≈ 0.5	≤ 0.2
τ_{QGP}/τ_0	1	6	≥ 30

CMS as a Detector for Heavy Ion Physics

■High Resolution and High Granularity Calorimetry

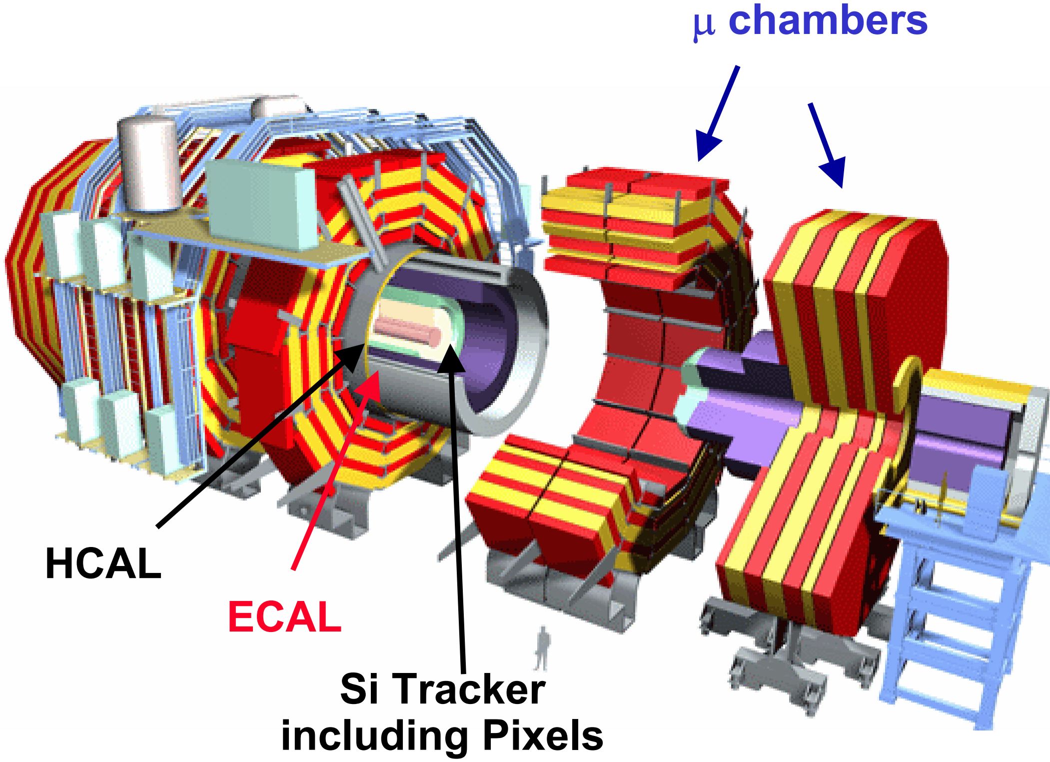
- $\Delta\eta \mathbf{x} \Delta\phi$ **(barrel)**
  - ◆ ECAL:0.0174x0.0174
  - ◆ HCAL: 0.087x0.087
- **Resolution (barrel)**
  - ◆ ECAL:$0.027/\sqrt{E} \otimes 0.0055$
  - ◆ HCAL:$1.16/\sqrt{E} \otimes 0.05$
- **Hermetic coverage up to $|\eta|<5$ ($|\eta|<7$ *proposed using CASTOR*)**
- **Zero Degree Calorimeter (*proposed*)**

■Tracking μ from Z^0, J/ψ, Υ

- **Wide rapidity range $|\eta|<2.4$**
- **Efficient suppression of π, $K \rightarrow \mu$ background**
  - ◆ ECAL at 1.3 m from the beam
  - ◆ μ chambers behind HCAL
  - ◆ reject “kinks” using tracker
- **Excellent $M_{\mu\mu}$ mass resolution ~50 MeV @ Υ**

■DAQ and Trigger

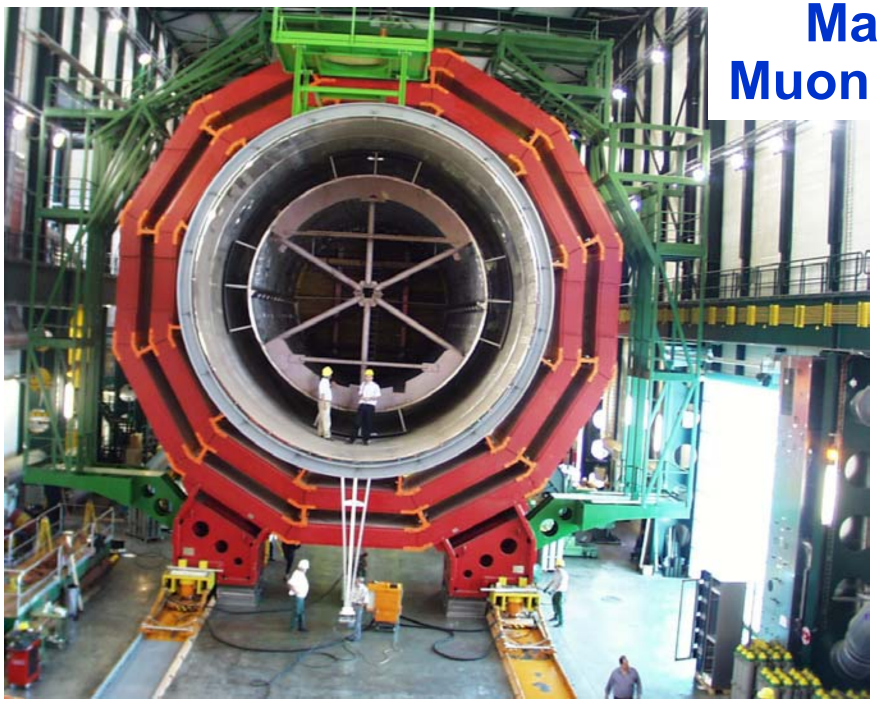
- **High rate capability for AA, pA, pp**
- **High Level Trigger capable of full reconstruction of most HI events in real time**



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**
- **CMS can use highest luminosities available at LHC both in AA and pA modes**

CMS under construction

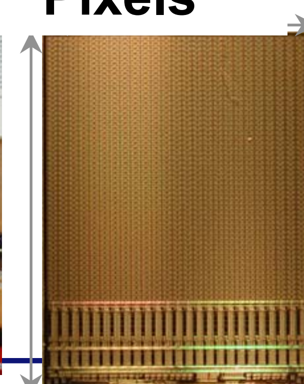


Magnet & Muon Absorber

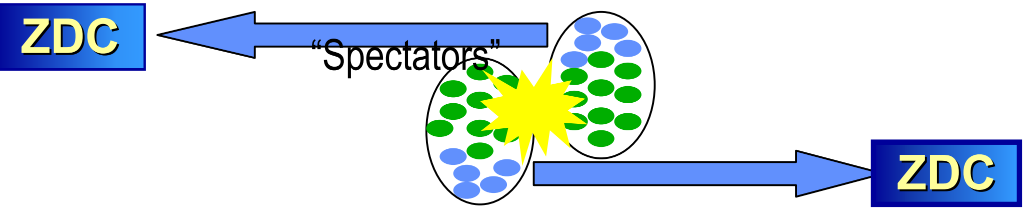
Hadron Calorimeter

Electromagnetic Calorimeter

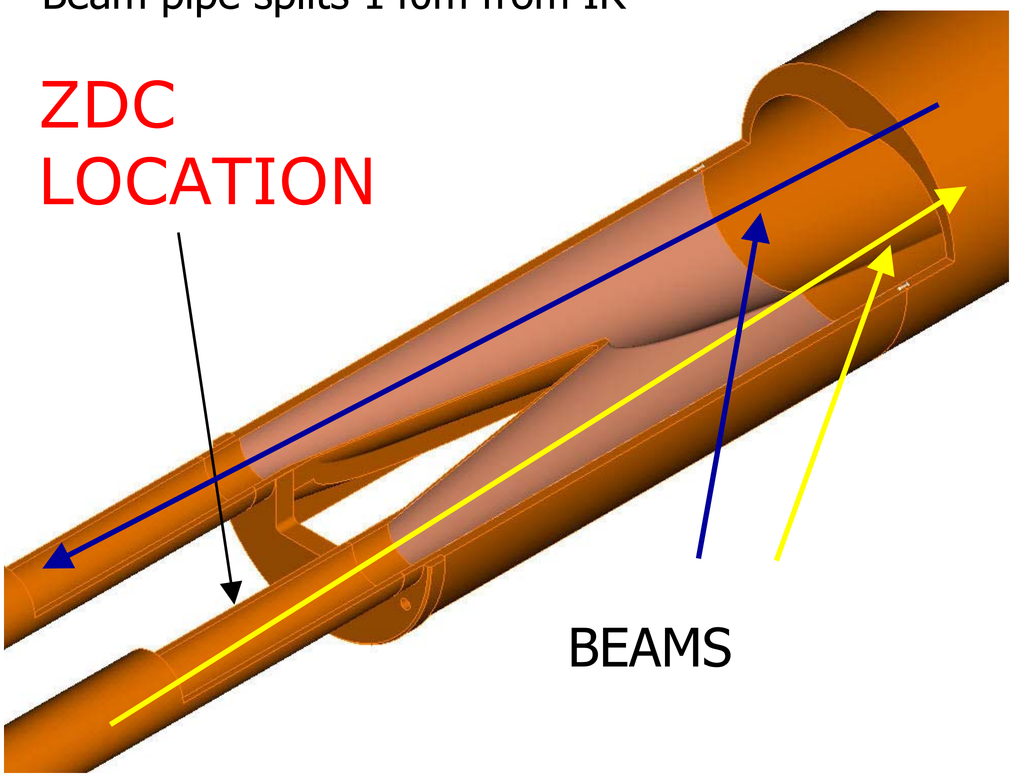
Si tracker & Pixels

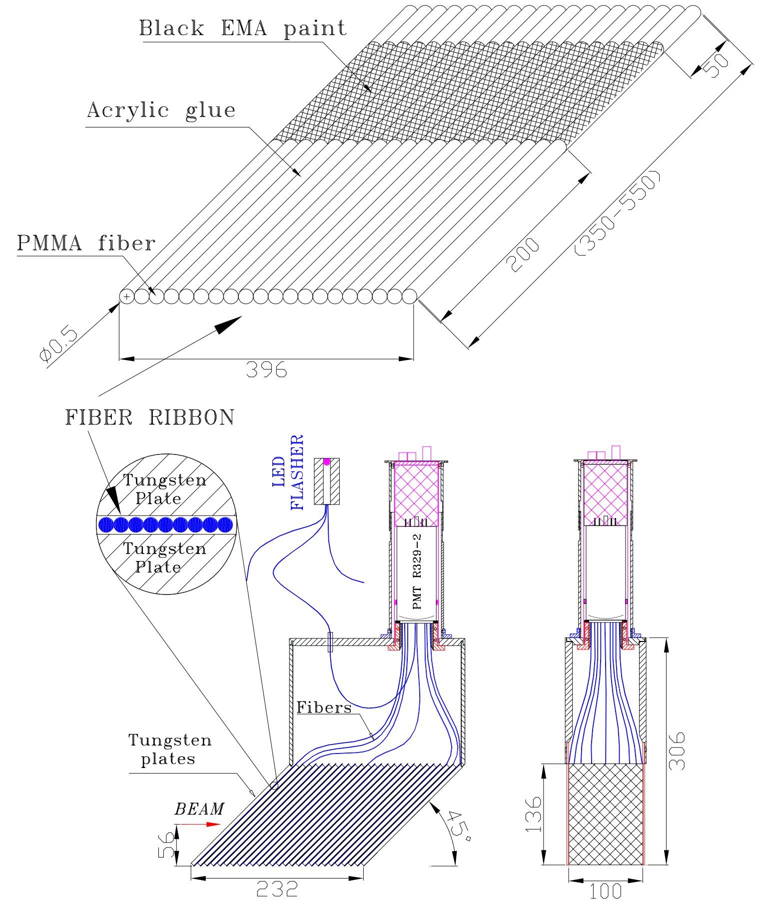


Zero Degree Calorimetry for CMS



Beam pipe splits 140m from IR

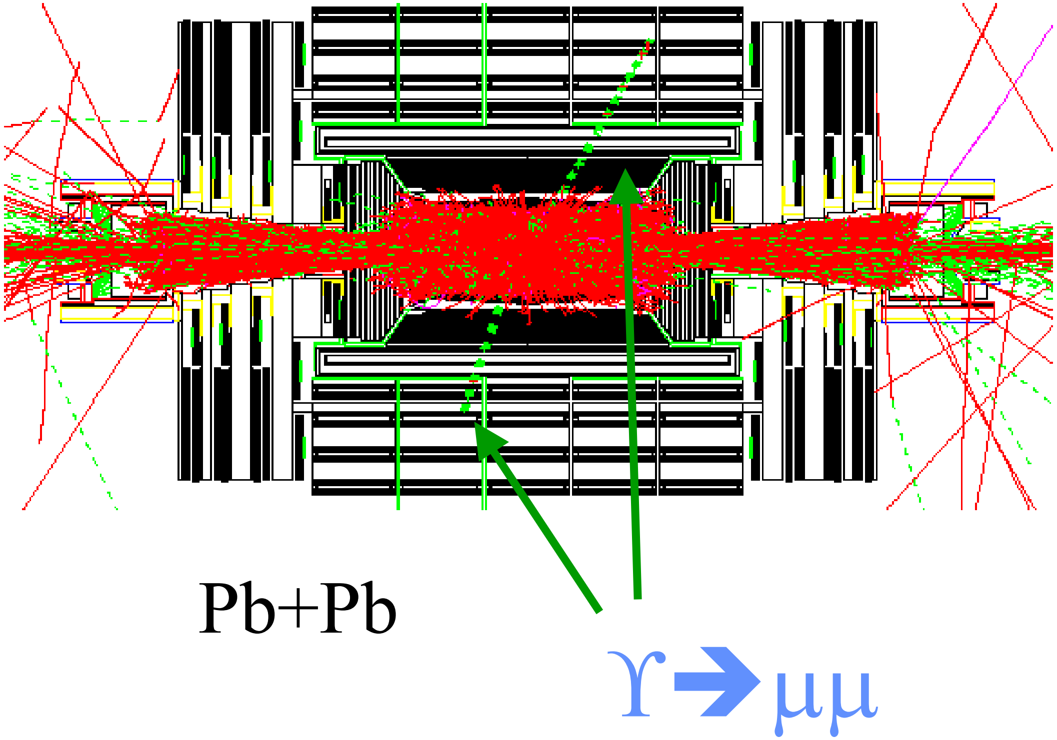


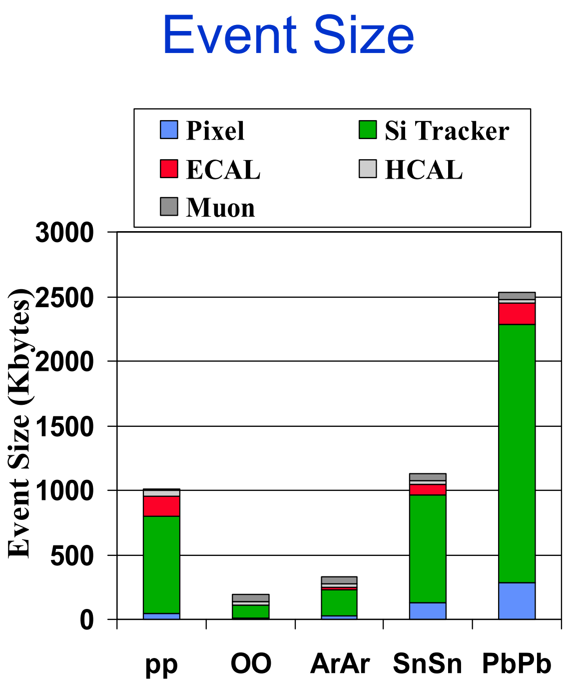


Extending CMS

HI compared to pp:

Higher multiplicity of low pt particles
Lower luminosity and event rate

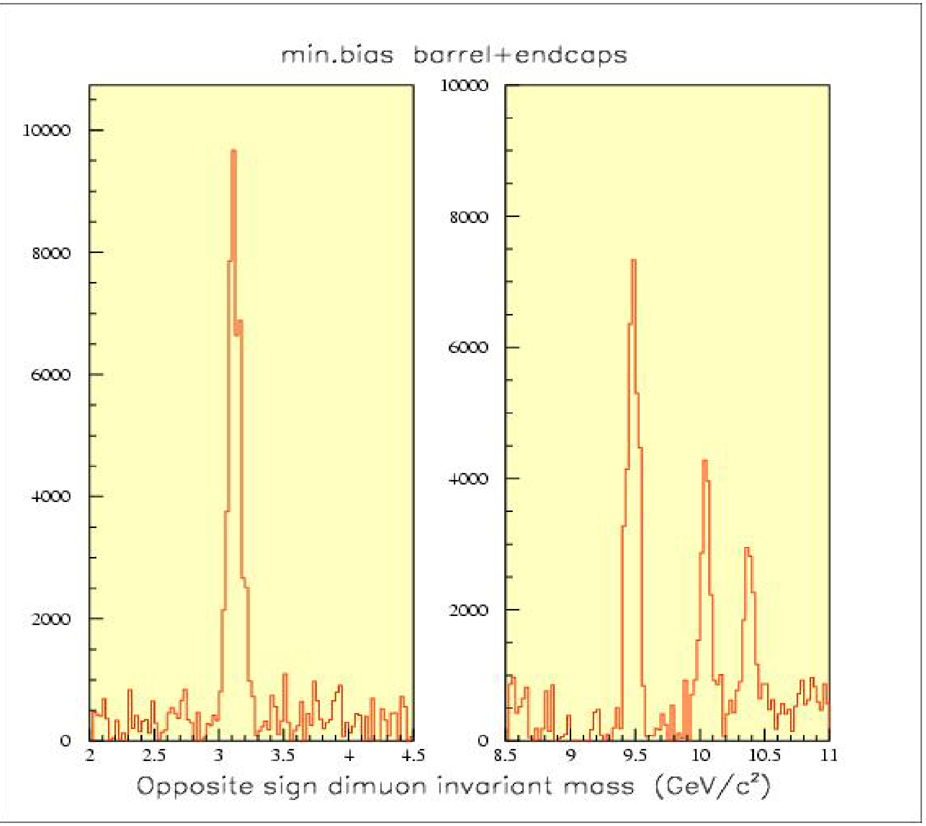




CMS is designed for high luminosity pp
pp events are large to account for pileup effects

Quarkonia in CMS

J/ψ ϒ family



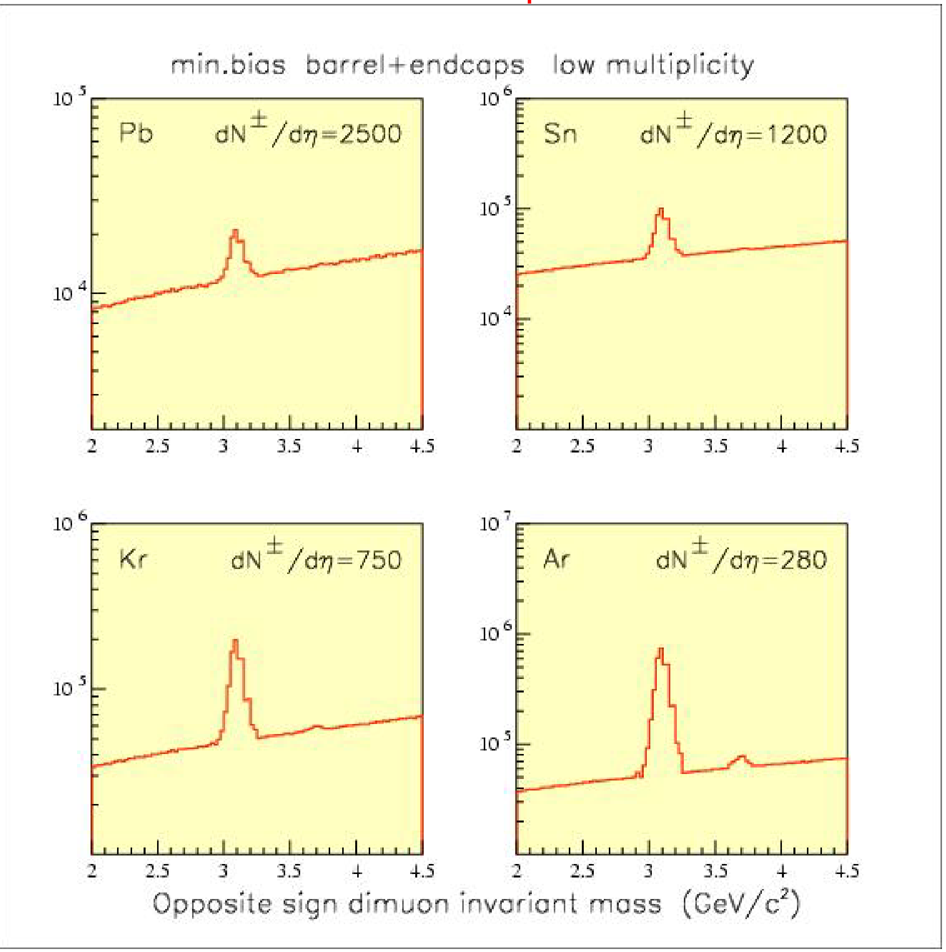
Yield/month (kevents, 50% eff)
Nominal luminosity for each ion species

	Pb+Pb	Sn+Sn	Kr+Kr	Ar+Ar
L	10^{27}	1.7 10^{28}	6.6 10^{28}	10^{30}
J/ψ	28.7	210	470	2200
ψ'	0.8	5.5	12	57
Y	22.6	150	320	1400
Y'	12.4	80	180	770
Y''	7	45	100	440

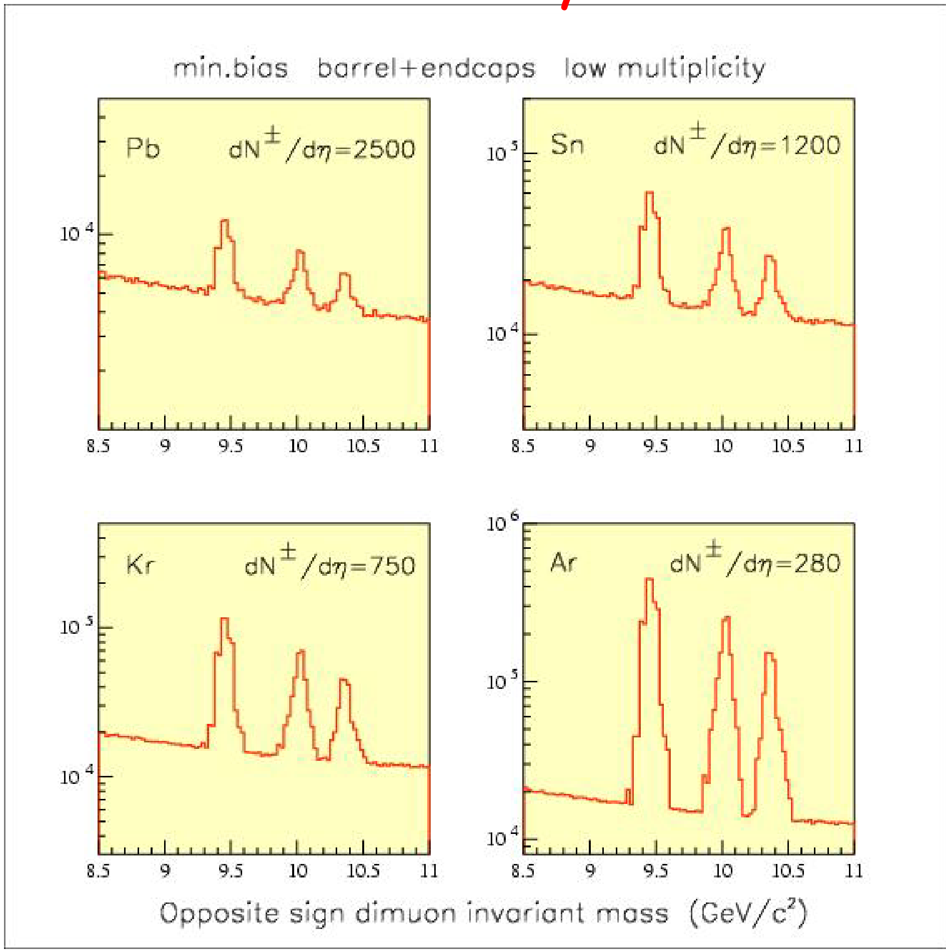
Pb+Pb, 1 month at L=10^{27}

Quarkonia from Different Ion Species

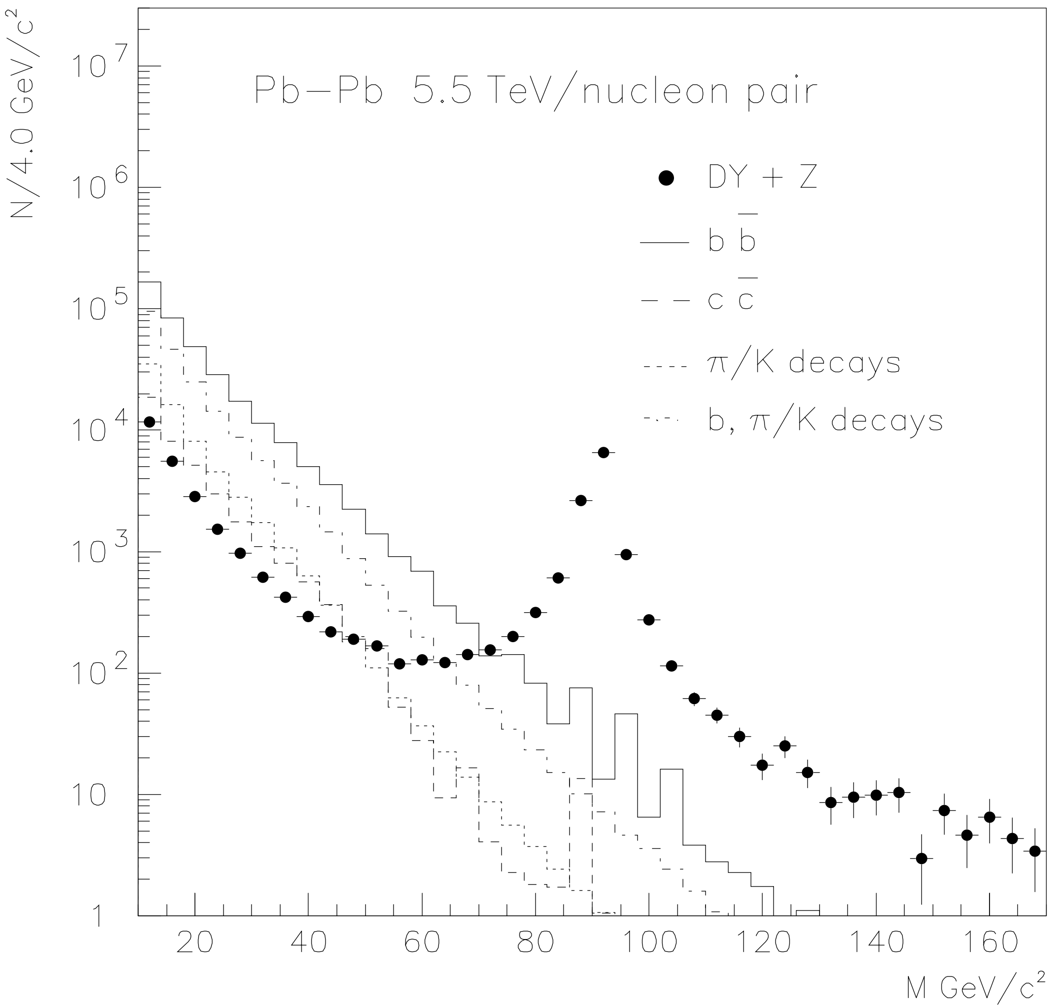
J/ψ



Υ family



High Mass Dimuon, Z^0 Production

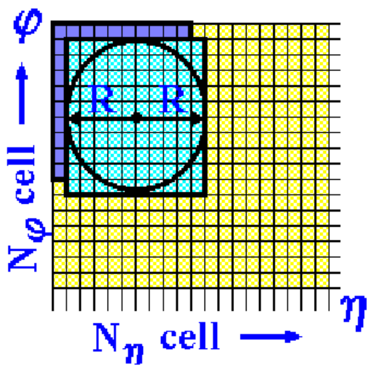


- **$Z^0 \to \mu\mu$ can be reconstructed with high efficiency**
  - **A probe to study nuclear shadowing**
  - **Z^0 also proposed as reference for Υ production.**
- **Dimuon continuum dominated by b decays**
  - **Heavy quark energy loss**
- **High statistics (1 month):**

Channel ($M_{\mu\mu} > 10$ GeV)	Barrel+Endcap
$Z \to \mu^+\mu^-$	1.1×10^4
$B\bar{B} \to \mu^+\mu^-$, $P_t^\mu > 5$ GeV	1.2×10^5
$B \to J/\Psi \to \mu^+\mu^-$, $P_t^\mu > 5$ GeV	1.3×10^5

Jet Reconstruction in CMS

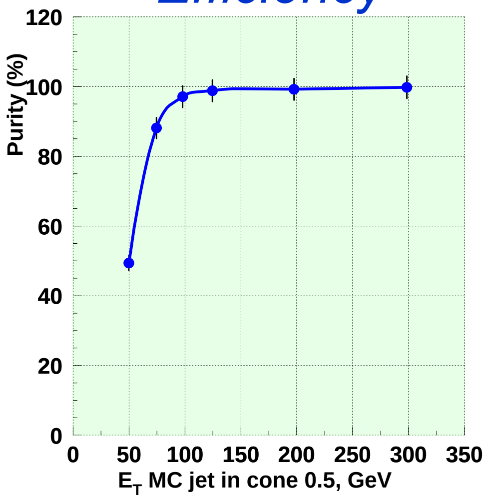
Window Algorithm



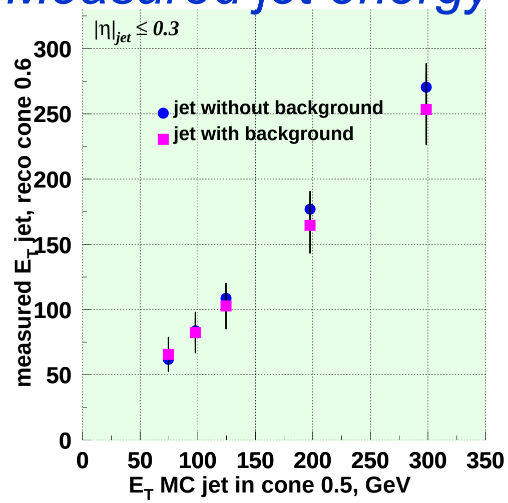
- Subtract average pileup
- Find jets with sliding window
- Build a cone around E_T^{max}
- Recalculate pileup outside the cone
- Recalculate jet energy

Full jet reconstruction in Pb+Pb central collisions (dN/dy~8000)

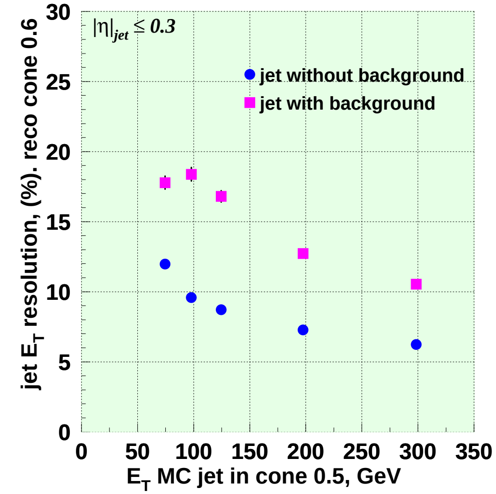
Efficiency



Measured jet energy



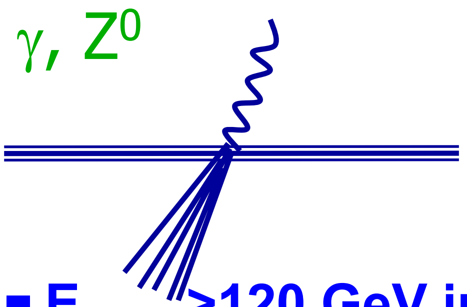
Jet energy resolution



Jet spatial resolution: $\sigma(\phi_{rec} - \phi_{gen}) = 0.045$, $\sigma(\eta_{rec} - \eta_{gen}) = 0.051$

better than size of HCAL tower

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

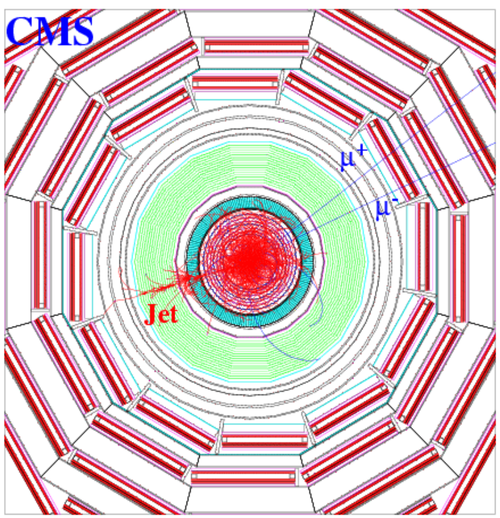


- $E_{Tjet, \gamma}$>120 GeV in the barrel

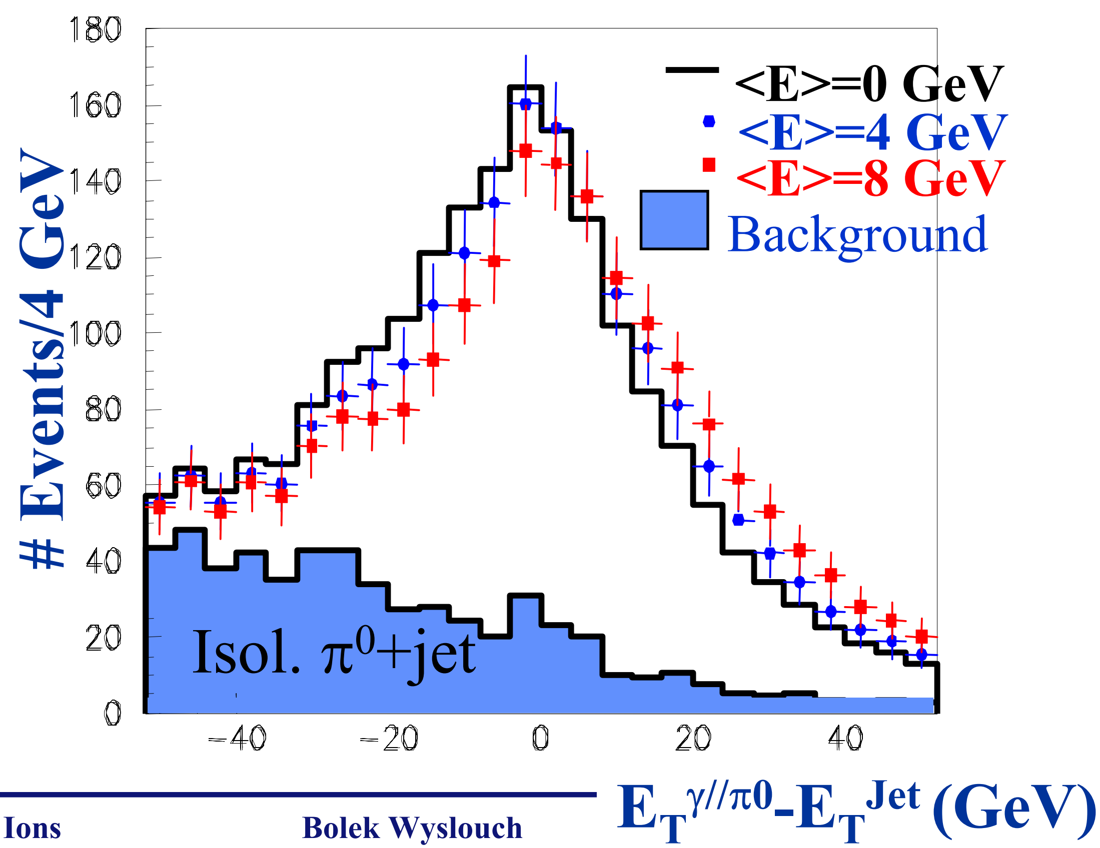
1 month at 10^{27} $cm^{-2}s^{-1}$ Pb+Pb

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

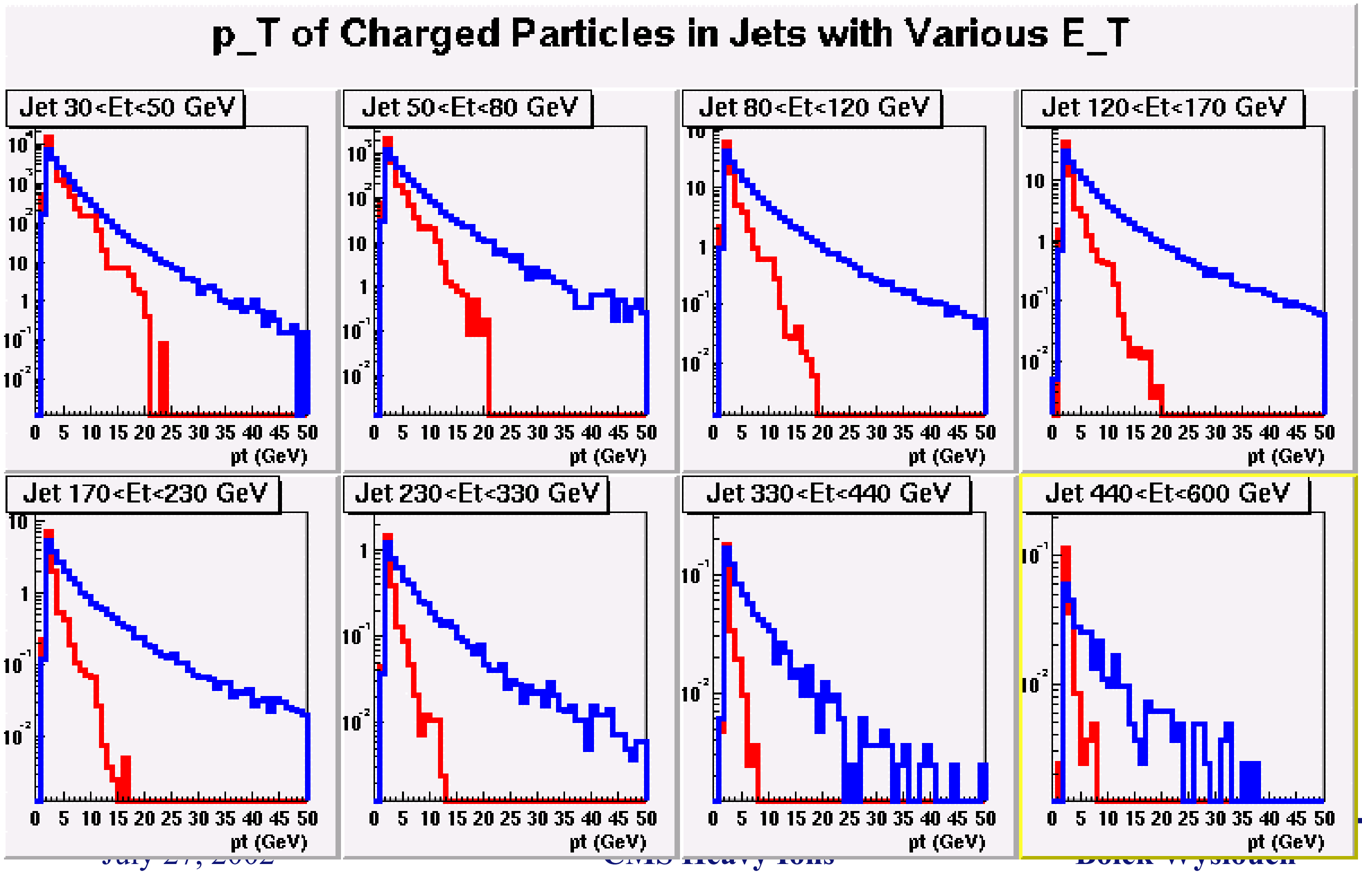


Jet+Z^0



Jet Fragmentation, Effect of Nuclear Matter on Jet Structure

- **Find jets using calorimetry**
- **Study charged particle momenta inside of a jet using the tracker**
- **For this study use 4-5 outer layers of the tracker (use conservative resolution obtained in pp studies: AA plausible with low occupancy in outer layers)**



Particles in jet

Background

Similar analysis can be done with π^0

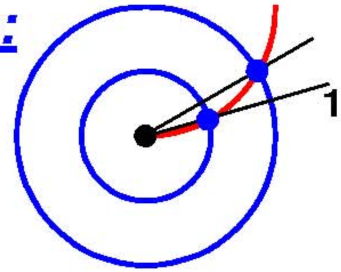
Conclusions

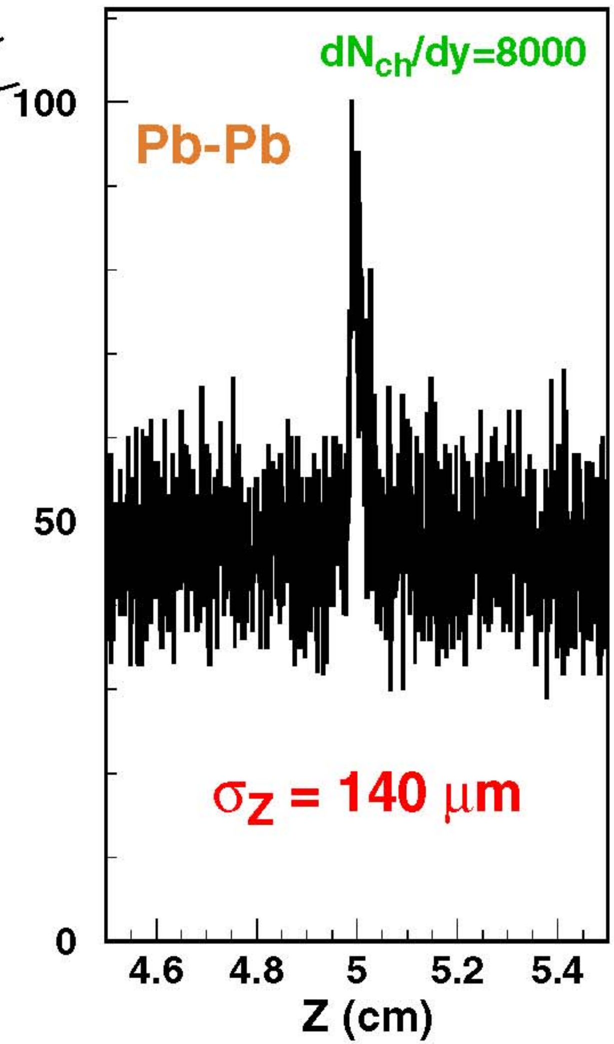
- LHC will extend energy range and in particular high p_T reach of heavy ion physics
- CMS is preparing to take advantage of its capabilities
  - Excellent coverage and resolution
    - Quarkonia
    - Jets
  - Essentially no modification to the detector hardware
  - New High Level Trigger algorithms
  - Zero Degree Calorimeter and CASTOR as relatively minor additions
- The knowledge gained at RHIC will be extended to new energy domain

μμ reconstruction: algorithm

Primary vertex determination:

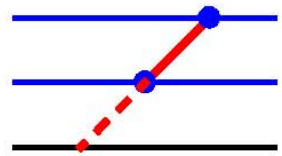
- select pairs of pixel hits with $\Delta\phi$ giving 0.5 GeV < p_T < 5 GeV
- extrapolate each pair in RZ to the beam line





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