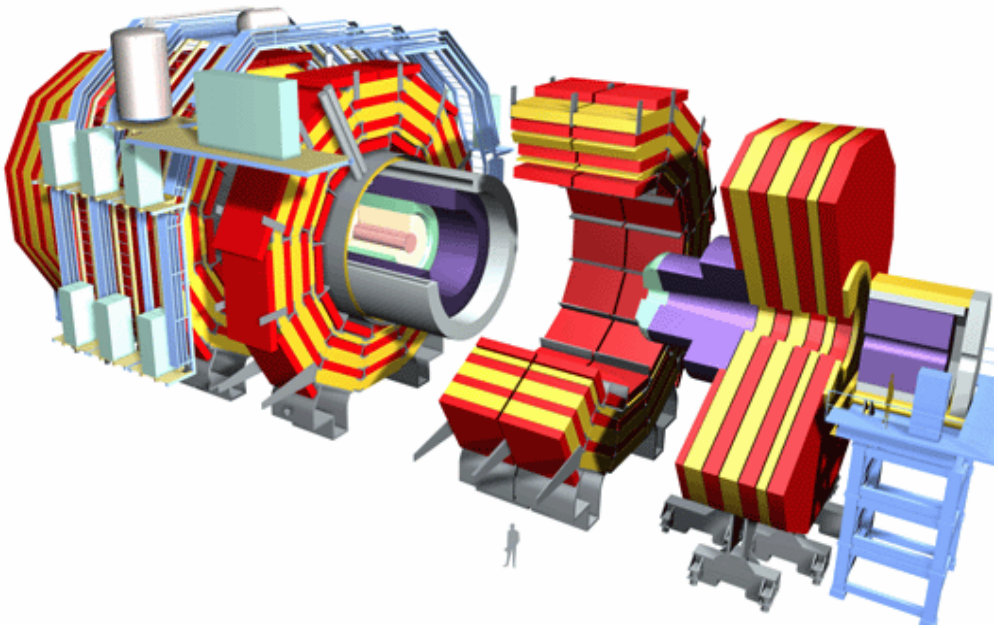
Heavy Ion Physics with the CMS Detector at the LHC



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Rice University

for the CMS Collaboration

DPF Meeting 2004

UC Riverside, 30 Aug. 2004

Heavy Ions at the LHC

- **LHC will accelerate and collide heavy ions at energies far exceeding the range of existing accelerators.**

	AGS	SPS	RHIC	LHC
$\sqrt{s_{NN}}$[GeV]	5	20	200	5500
E increase		x4	x10	x28
y range	±1.6	±3.0	±5.3	±8.6

The increase of beam energy will result in:

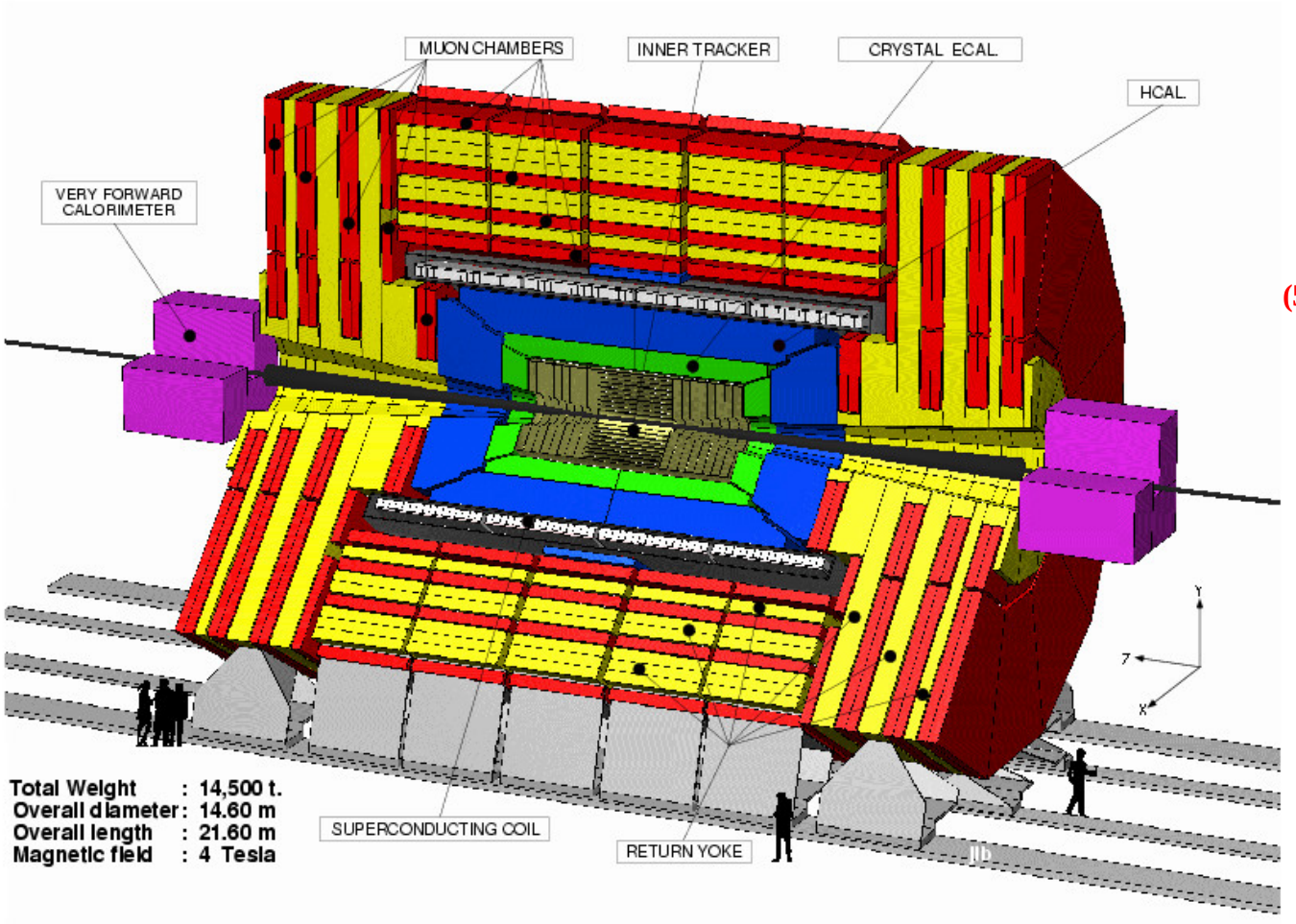
- Extended kinematic reach for pp, pA, AA
- New properties of initial state, saturation at mid-rapidity
- A hotter and longer lived partonic phase
- Increased cross sections and availability of new hard probes

- **New energy regime will open a new window on hot and dense matter physics!**

Physics Measurements in CMS

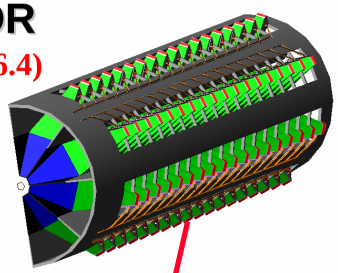
- **Soft Physics and Global Event Characterization**
  - Centrality
  - Charged Particle Multiplicity – Wide Rapidity Range
  - Spectra + Correlations – π^0, Direct Photons, Decay Topology
  - Azimuthal Asymmetry (Flow)
  - Energy Flow in Wide Rapidity Range
- **High p_T Probes:**
  - Quarkonia (J/ψ ,Υ) and heavy quarks
  - High p_T jets, detailed studies of jet fragmentation, centrality dependence, azimuthal asymmetry, quark flavor dependence, leading particle studies
  - High energy photons, Z^0
  - Jet-γ, Jet-Z^0 (medium effect on jets)
  - Leading particle correlations
  - Multi-jet events
- **Forward Physics**
  - X~10^{-6} Saturation, Color Glass Condensate, Limiting Fragmentation,
  - Ultra Peripheral Collisions

CMS Detector

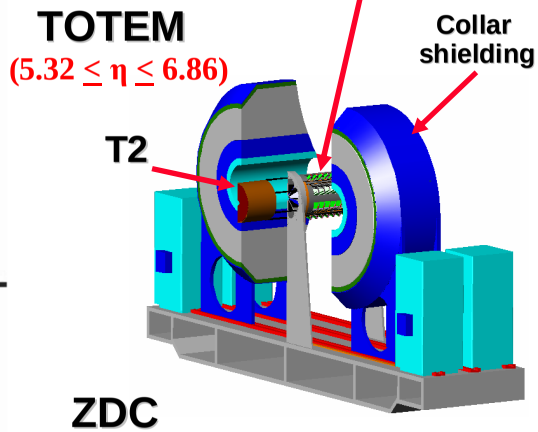


Forward Detectors

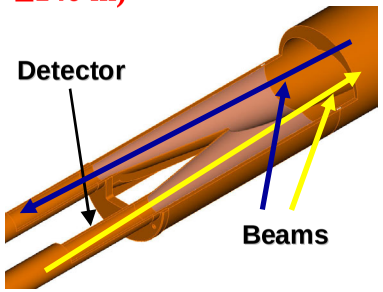
CASTOR
$(5.2 \leq \eta \leq 6.4)$



TOTEM
$(5.32 \leq \eta \leq 6.86)$



ZDC
$(z = \pm 140\ m)$

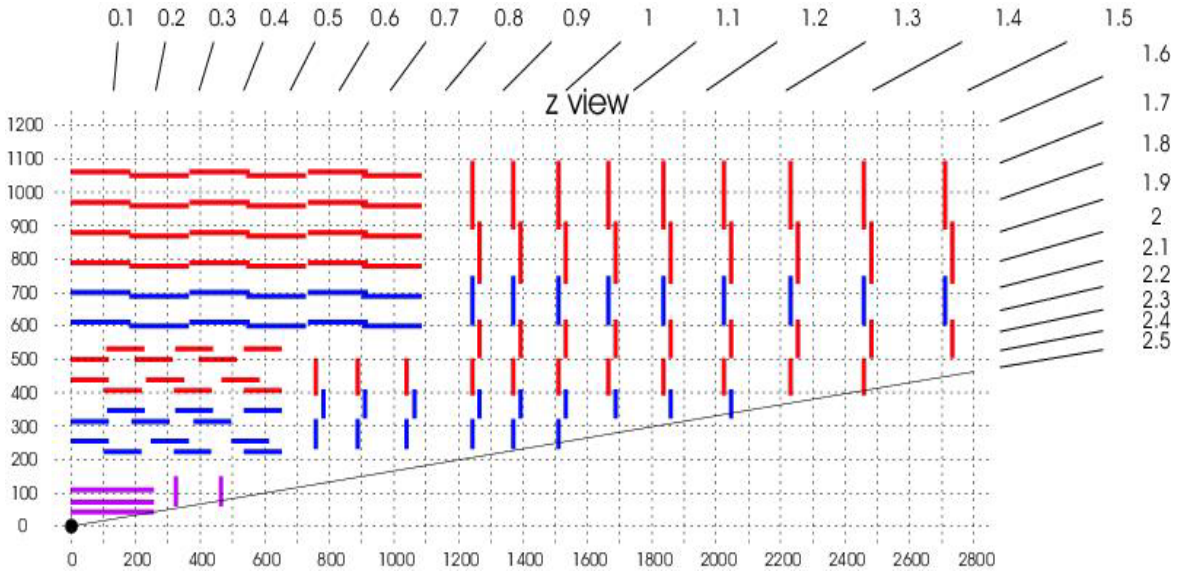


CMS as a Detector for Heavy Ion Physics

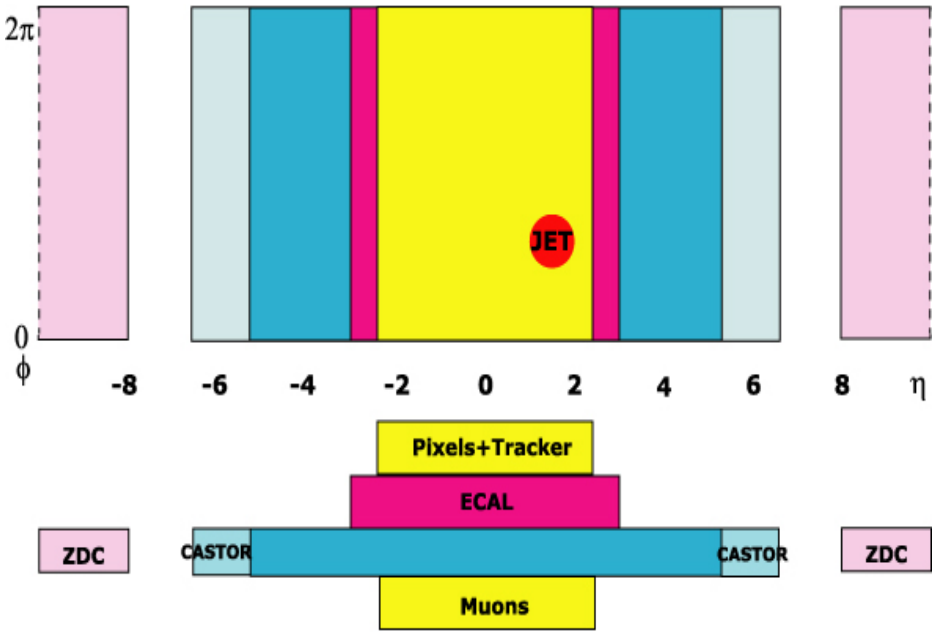
- **Muon**
  - Wide rapidity range $|\eta| < 2.4$
  - $\sigma_m \sim 50$ MeV at Υ
- **ECAL**
  - **Barrel**
    - $|\eta| \leq 1.48$
    - $\Delta\eta x \Delta\phi = 0.0175 \times 0.0175$
    - Resolution: $0.027/\sqrt{E} \otimes 0.0055$
  - **Endcap**
    - $1.48 \leq |\eta| \leq 3$
    - Preshower $1.65 \leq \eta \leq 2.6$
- **HCAL**
  - **Barrel+Endcap**
    - $|\eta| \leq 3$
    - $\Delta\eta x \Delta\phi = 0.087 \times 0.087$
    - Resolution: $1.16/\sqrt{E} \otimes 0.05$
  - **Forward HCAL - HF**
    - $3 \leq |\eta| \leq 5$
    - $|\eta| < 6.4$ including CASTOR

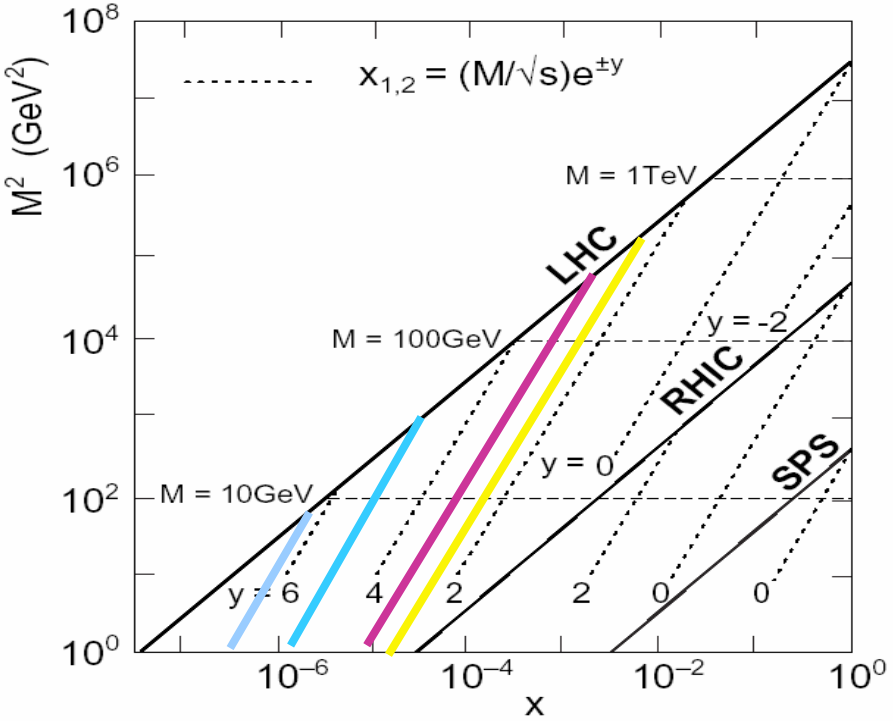
Silicon Tracker

- **Pixel Detector**
  - 3 barrel layers and 2 forward layers on each side
  - 100x150 μm pixel size
  - Low occupancy: 2% for pixel L1 @ dN/dη = 5000
- **Strip Detector**
  - 10 barrel layers of single- and double-sided silicon, 9 forward layers on each side



Detector Coverage





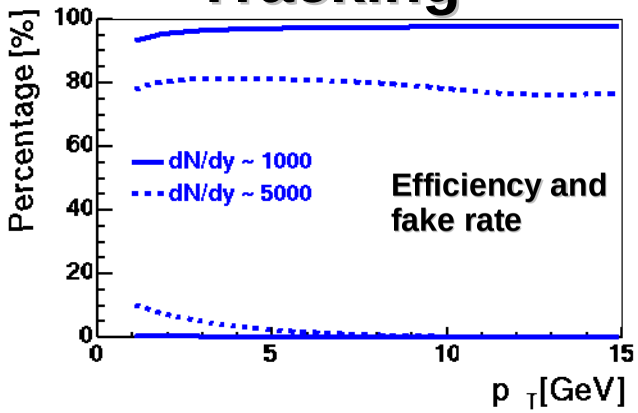
Large Range of Hermetic Coverage

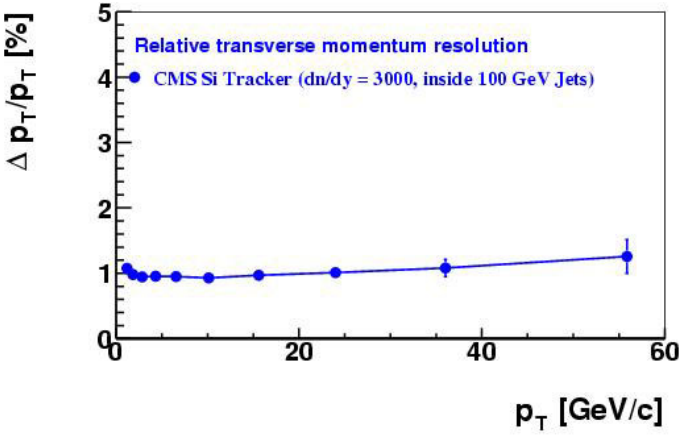
in η, x and Q^2

Unique Forward Capability

Reconstruction Performance

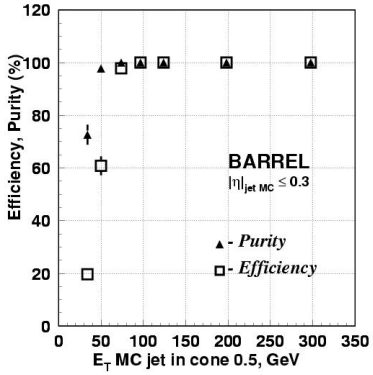
Tracking

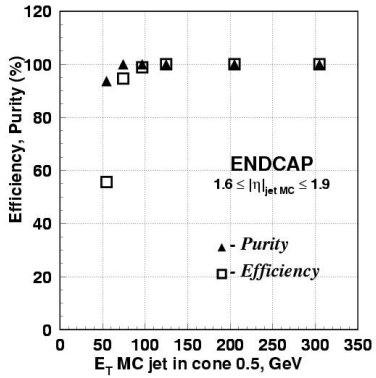


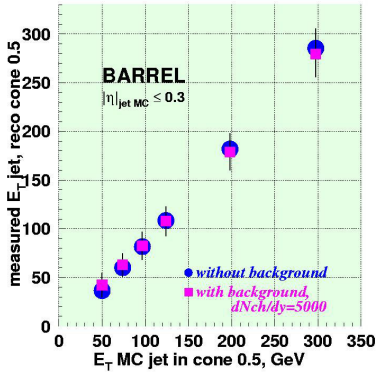


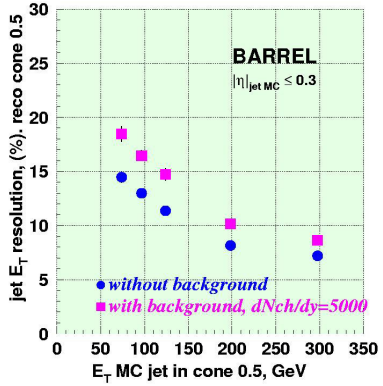
High track reconstruction efficiency and low fake rate even at very high track density

Jets – Calorimeters Alone



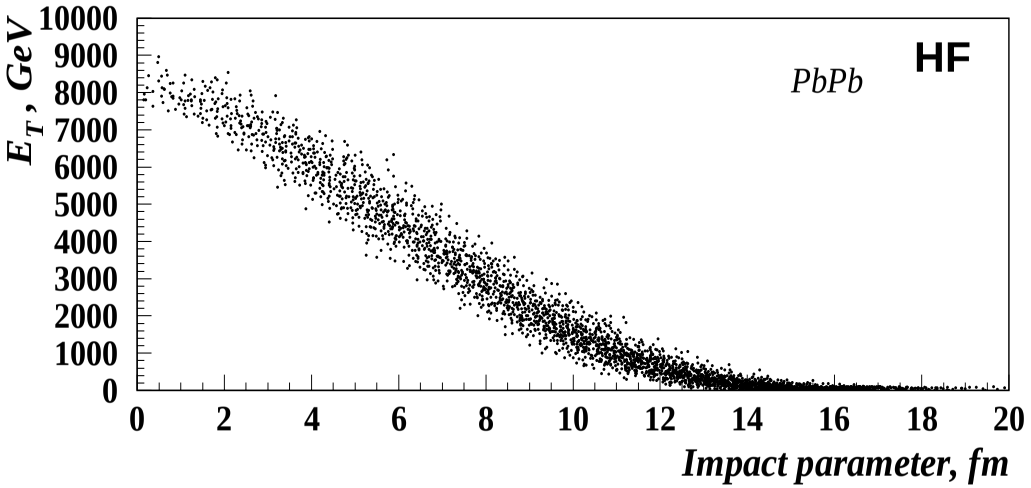


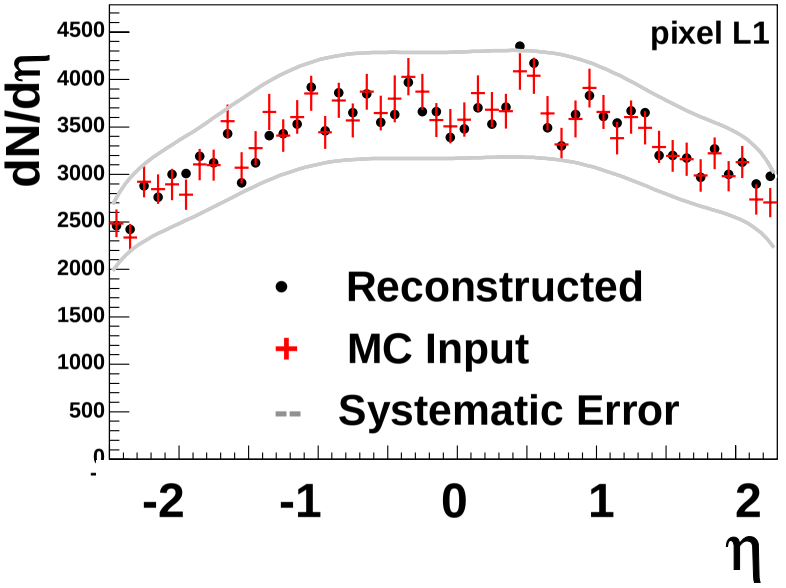


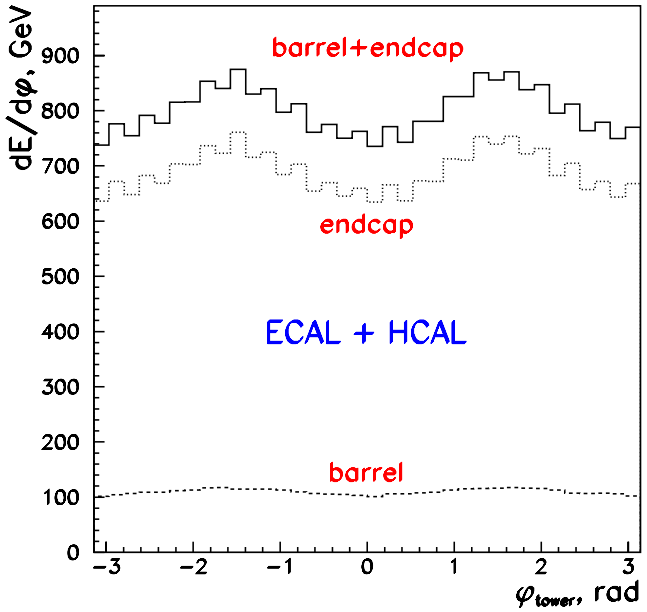


Energy resolution for 100 GeV jets is ≈ 16%

Global Event Characterization







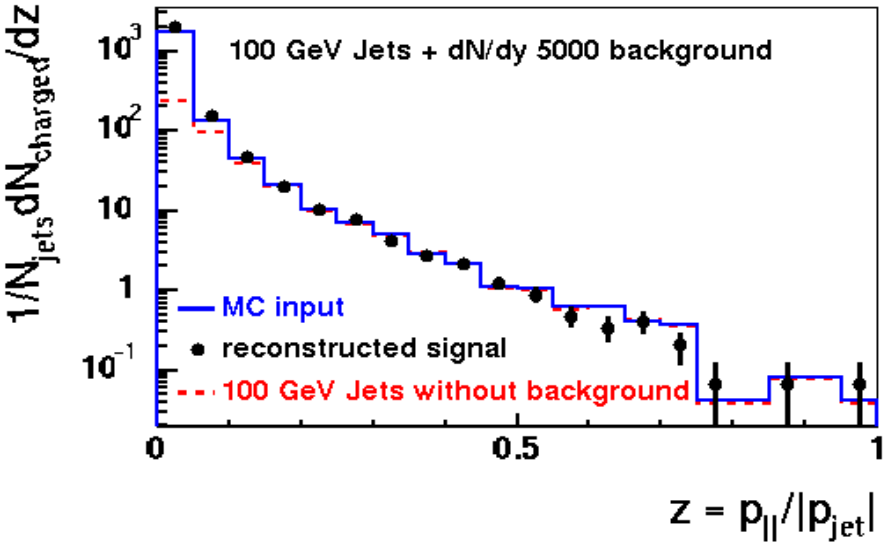
Impact Parameter

Multiplicity

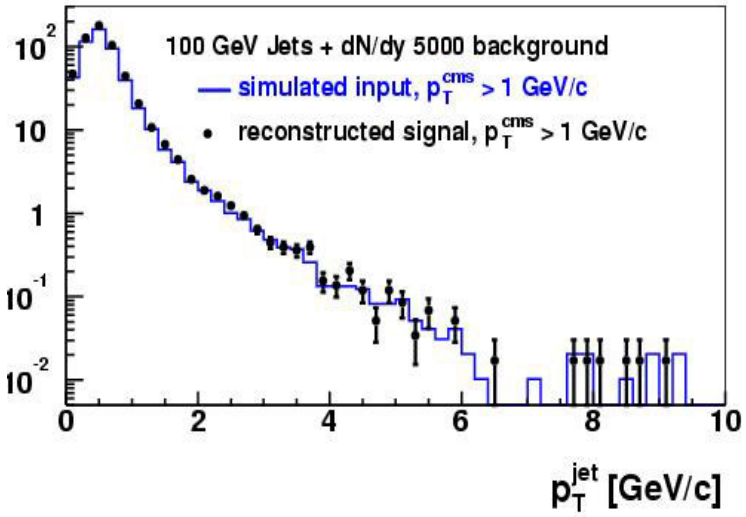
Energy Flow

Jet Fragmentation

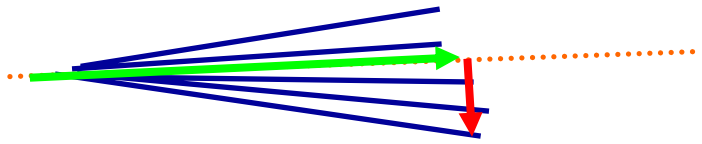
Longitudinal momentum fraction z along the thrust axis of a jet



p_T relative to thrust axis



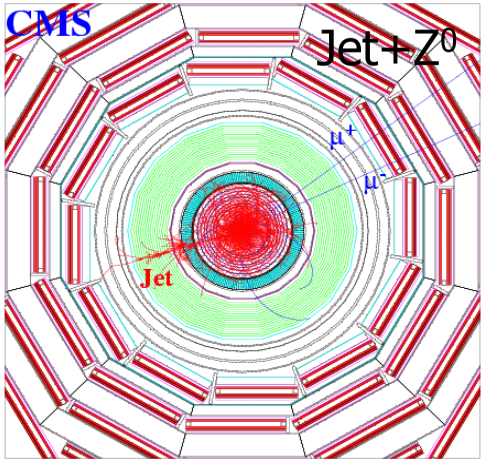
- **Fragmentation function for 100GeV Jets embedded in dN/dy ~5000 events.**
- **Use charged particles and possibly electromagnetic clusters**



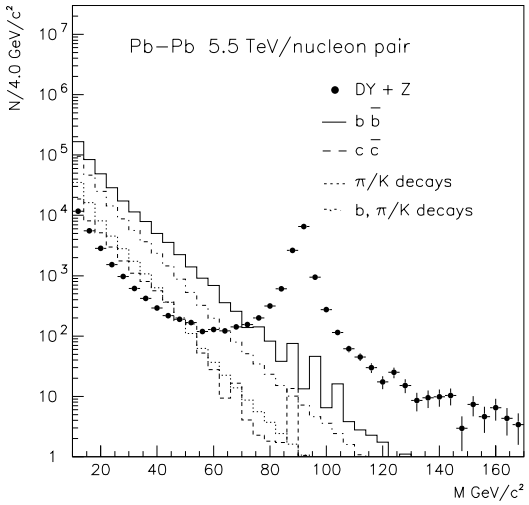
Balancing γ or Z^0 vs Jets

Z+jet event in the Heavy Ion collision

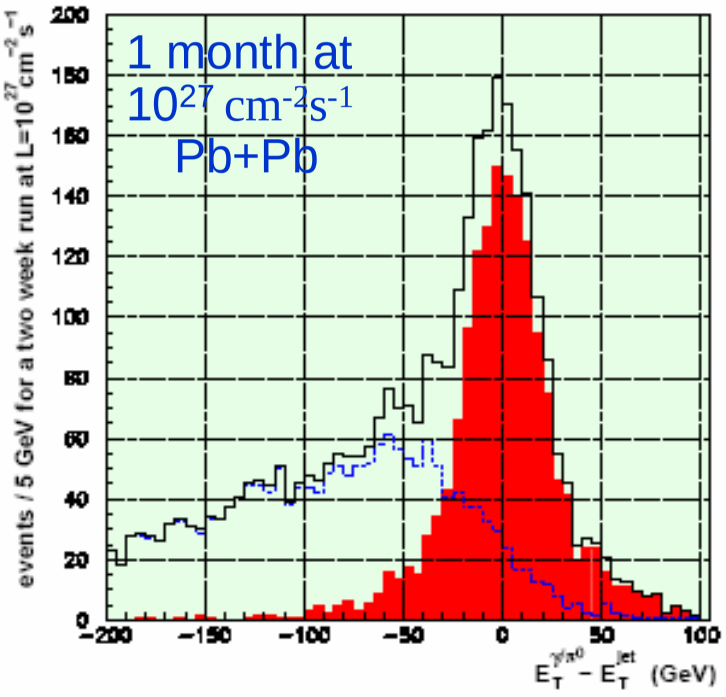
dNch / dY = 5000



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

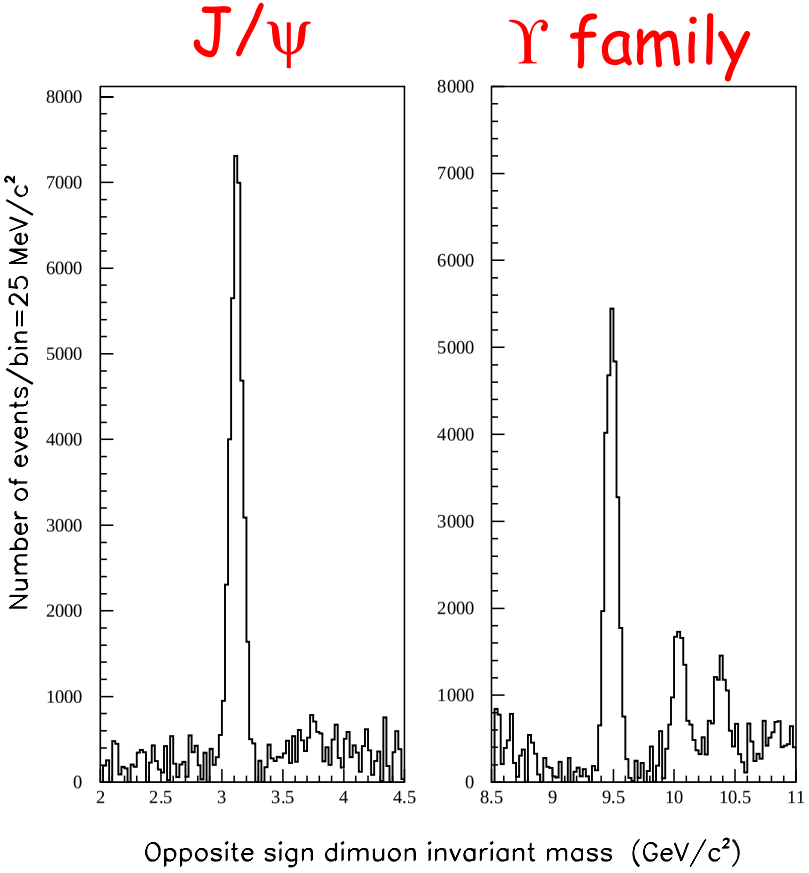


E_{Tjet}, γ>120 GeV in Barrel



Study of jets with known parton energy (medium effect on jets)

Quarkonia in CMS



σ_M = 50 MeV

Yield/month
(with 50% duty factor)

	Pb+Pb	Kr+Kr	Ar+Ar
L	10^{27}	7×10^{28}	10^{30}
J/Ψ	28.7k	470k	2200k
Ψ′	0.8k	12k	57k
ϒ	22.6k	320k	1400k
ϒ′	12.4k	180k	770k
ϒ′′	7k	100k	440k

Conclusions

- **LHC will extend energy range - in particular high p_T reach - of heavy ion physics**

- **CMS will take advantage of its superb capabilities**
  - **Excellent coverage**
  - **Superior momentum resolution @ 4T field**
  - **High mass resolution for Quarkonia**
  - **Centrality, Multiplicity, Energy Flow to very low p_T**
  - **New High Level Trigger algorithms for HI**
  - **Zero Degree Calorimeter, CASTOR and TOTEM provide unique access to forward physics**

  ✓**Essentially no modification to the detector hardware**

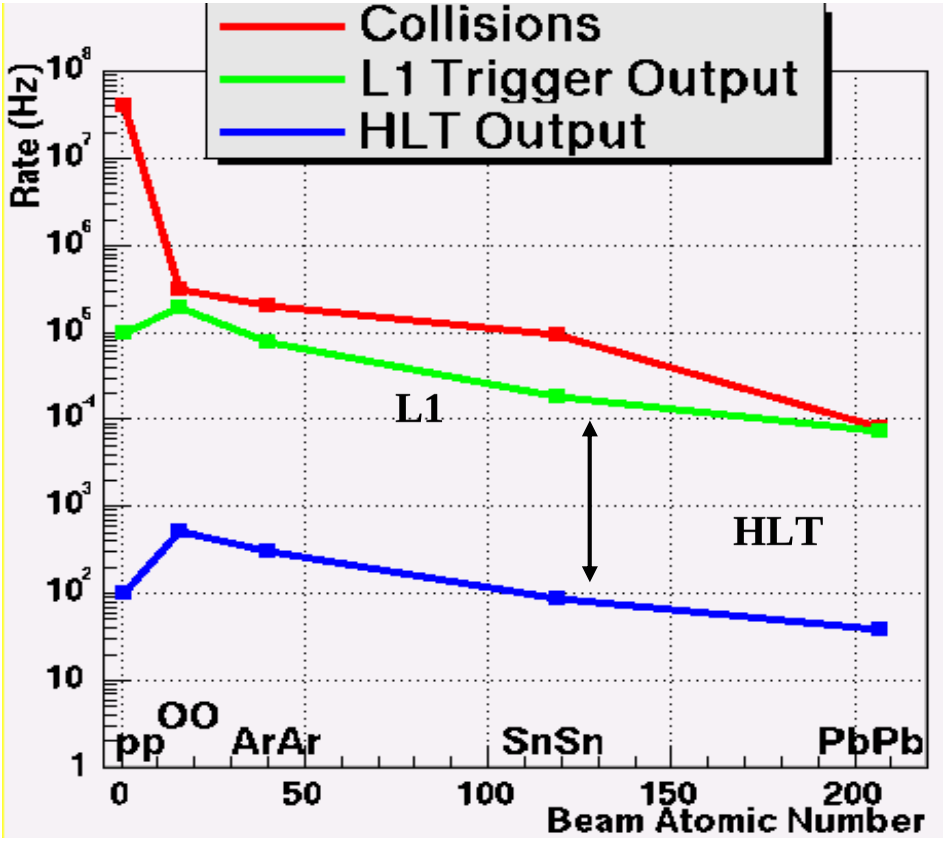
  ✓**Heavy Ion program is well integrated into overall CMS Physics Program**

The End

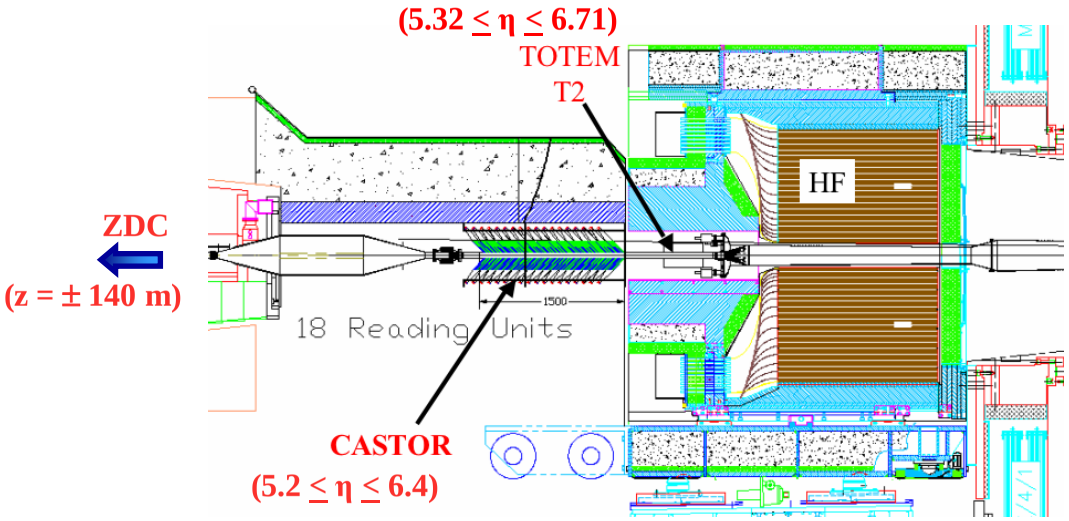
THANK YOU!

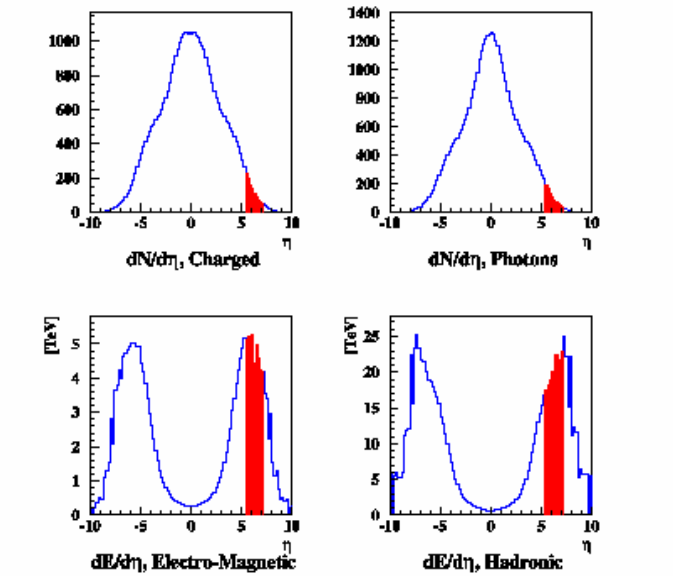
High Level Trigger (HLT)

- L1 in AA has larger backgrounds than in pp due to underlying event. Efficient trigger requires more careful analysis.
- High Occupancy but Low Luminosity. We can read most of the events up to High Level Trigger and do partial reconstruction.
- 50 events/sec written to tape



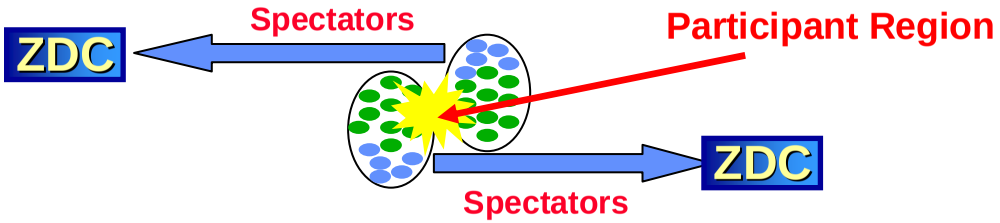
Forward Detectors: CASTOR and TOTEM

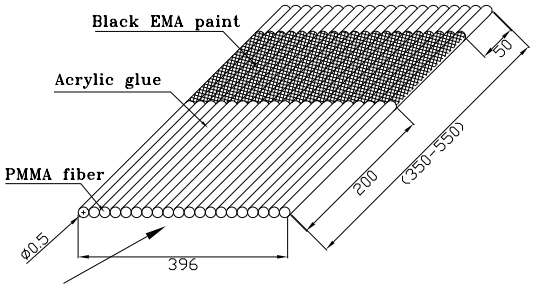




- Near Hermetic coverage (out to |η|<7 with CASTOR & TOTEM)
- Physics
  - Centrality
  - Nuclear PDFs - particularly gluon distributions
  - Momentum fractions x ~ 10^{-6} – 10^{-7} at scales of a few GeV^2 in pp
  - Diffractive processes (10-20% of total cross section at high energies)
  - Limiting Fragmentation
  - Peripheral and Ultra-Peripheral collisions
  - DCC, Centauros, Strangelets ……

Zero Degree Calorimetry for CMS





Beam pipe splits ~140 m from IR

ZDC LOCATION