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

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for the CMS Collaboration

Physics at LHC 2004

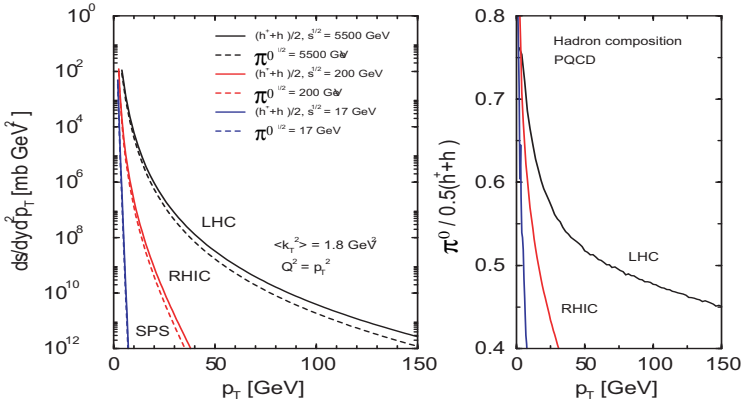
Vienna, 15 July 2004

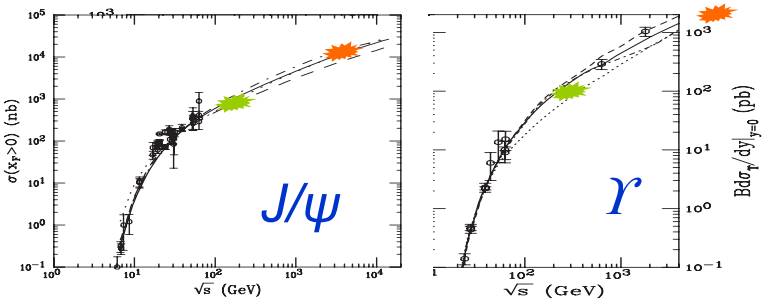
Summary of physics opportunities

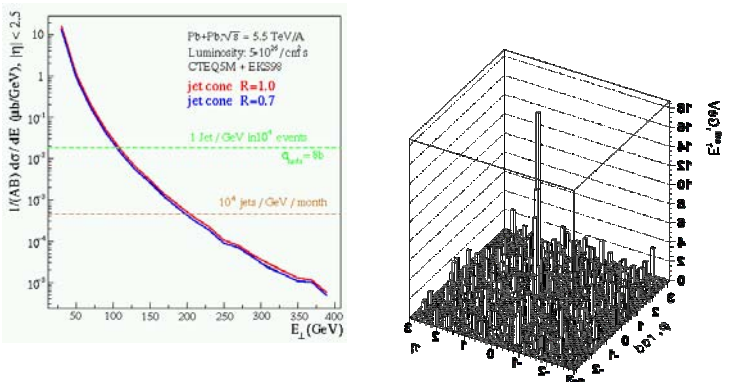
- **LHC will accelerate and collide heavy ions at energies far exceeding the range of existing accelerators**
  - **The increase of beam energy will result in:**
    - Extended kinematic reach for pp, pA, AA
    - New properties of initial state, saturation at mid-rapidity
    - A hotter and longer lived 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: another large energy jump!**

	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

Heavy Ion Physics at the LHC

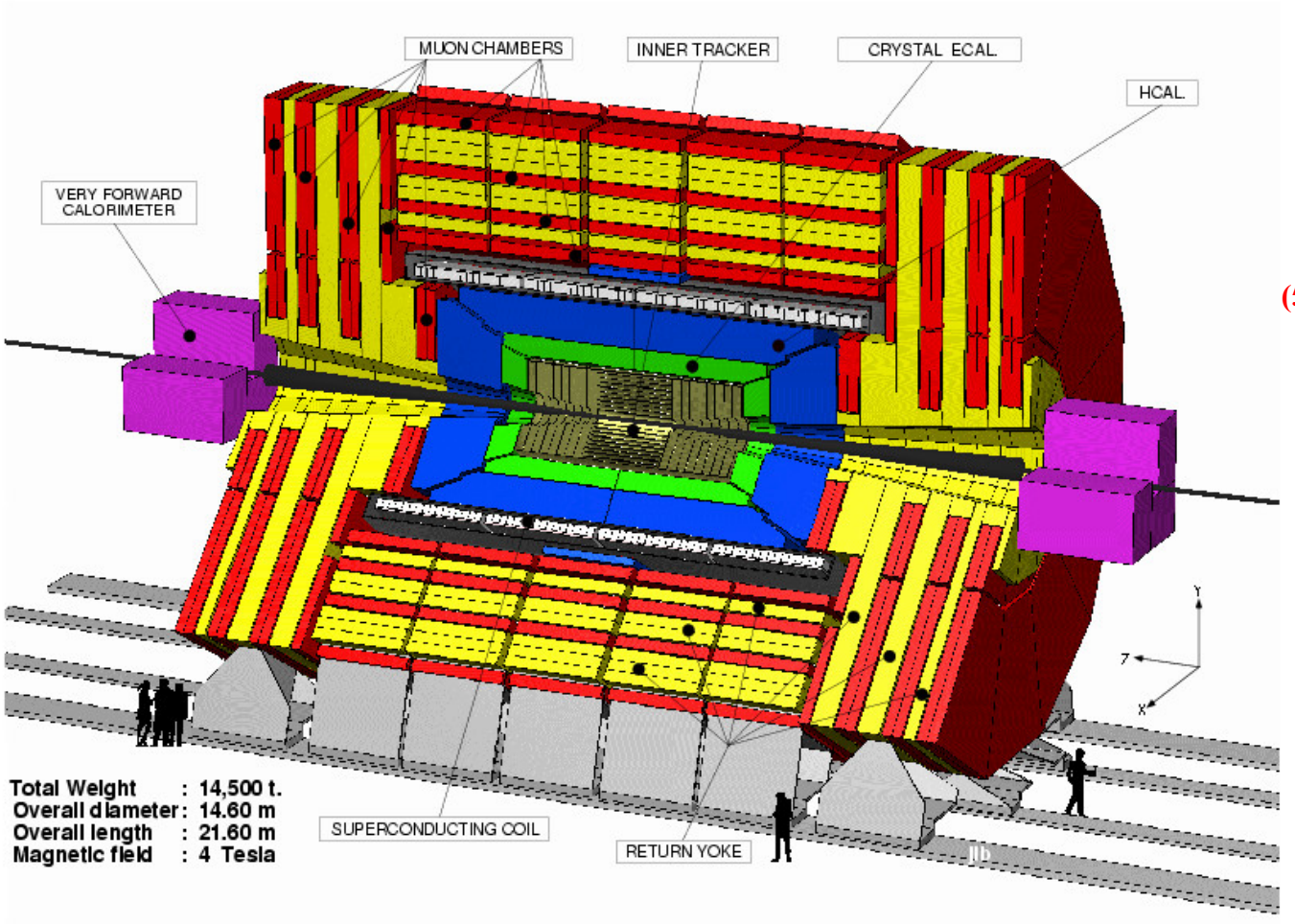






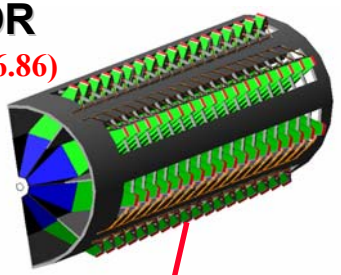
- **Medium modification at high p_T**
  - **Copious production of high p_T particles**
- **Different "melting" for members of Υ family**
  - **Large cross section for J/ψ and Υ family production**
- **Detailed studies of medium effects on jets**
  - **Jets shape and fragmentation modified by the medium**
  - **Jet tomography**
  - **Dijet/monojet ratio**
  - **Jet-γ**
  - **Jet-Z^0**
  - **Multi jets**

CMS Detector

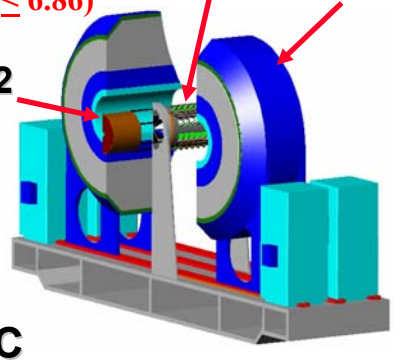


Forward Detectors

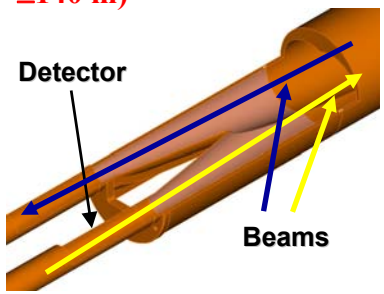
CASTOR
$(5.32 \leq \eta \leq 6.86)$



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



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

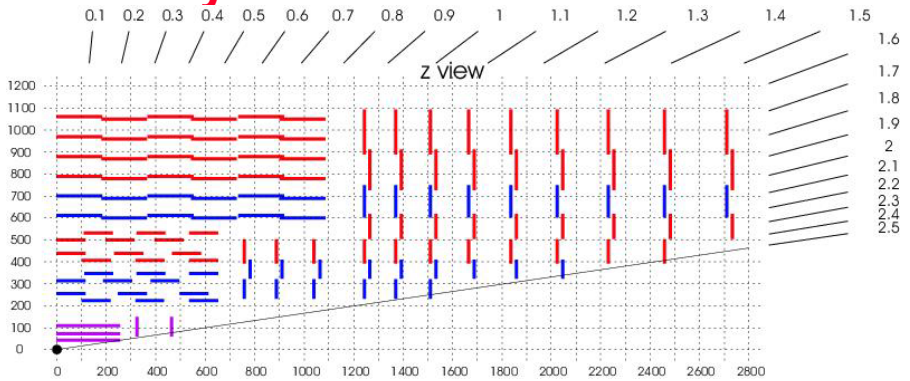


CMS as a Detector for Heavy Ion Physics

- **Muons**
  - **Wide rapidity range $|\eta| < 2.4$**
  - **σ_m~ 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**
    - $3 \leq |\eta| \leq 5$
    - $|\eta| < 7$ including CASTOR
- **Zero Degree Calorimeter**
- **TOTEM and CASTOR**

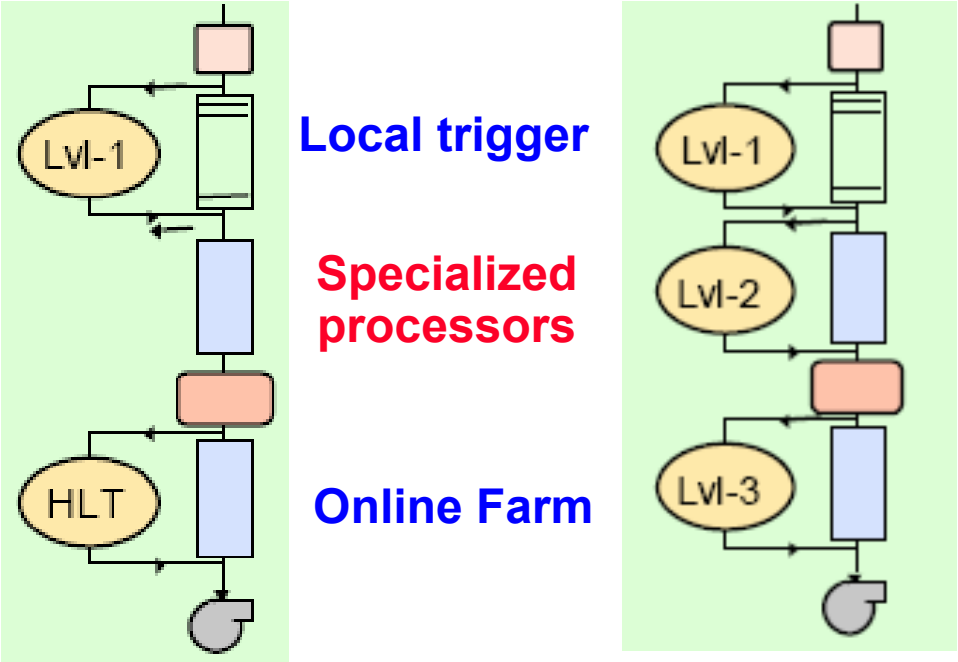
Silicon Tracker

- **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**



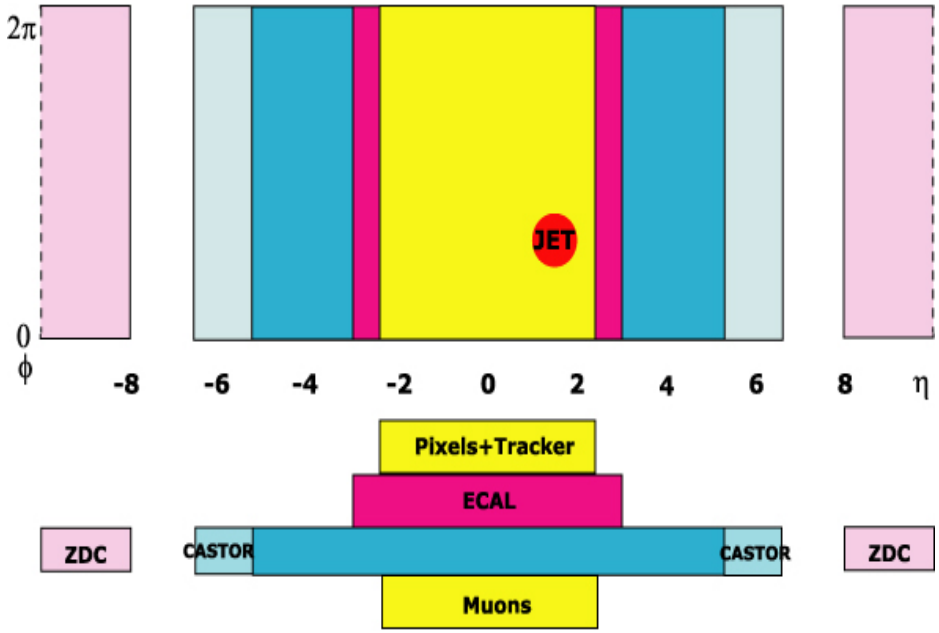
Data Acquisition and Trigger

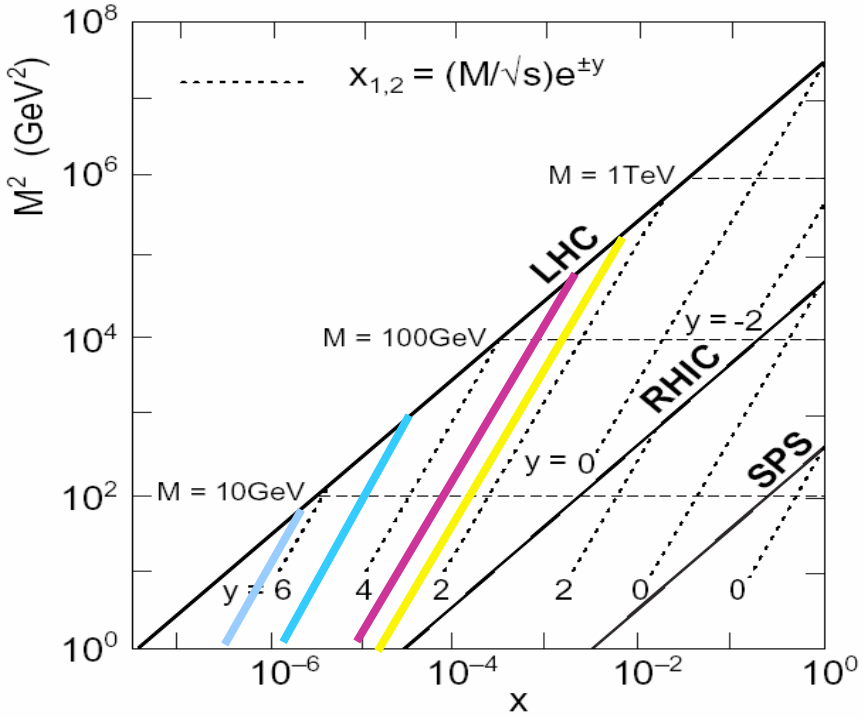
- **CMS has a two-level DAQ/Trigger architecture:**
  - **Low level hardware trigger (L1)**
    - Muon track segments
    - Calorimetric towers
    - No tracker data
    - Output rate: a few kHz
  - **Powerful online farm (HLT) doing event building and traditional L2, L3,…, LN triggering. Full event information available**
    - L2 –use only muon + calorimeter information
    - L3 –add tracker information
    - Output to tape: ~40Hz
- **Online Farm**
  - **Racks filled with processors**
  - **Associated networking and storage**



- **Every event accepted by L1 trigger must pass through online farm (HLT)**

Detector Coverage





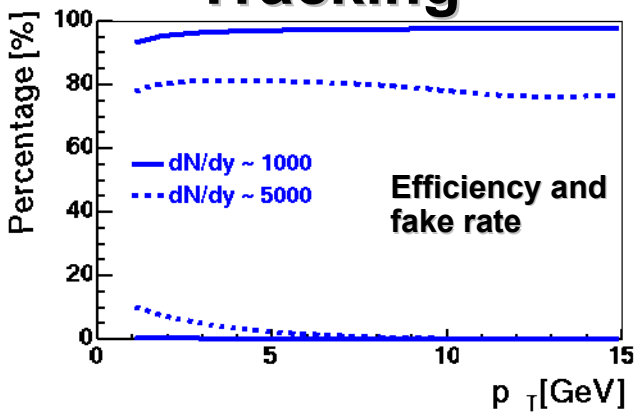
Large Range of Hermetic Coverage

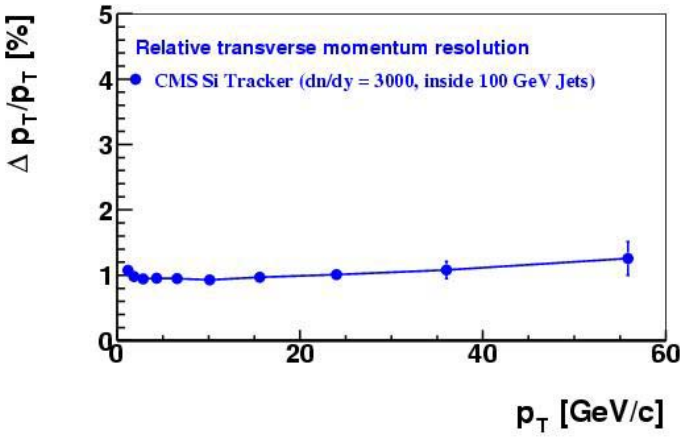
in η, x and Q^2

Unique Forward Capability

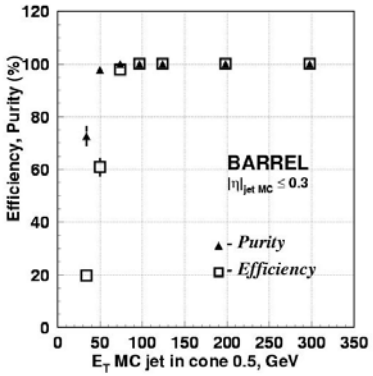
Reconstruction (Baseline Studies)

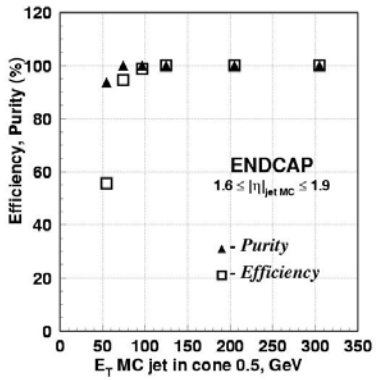
Tracking

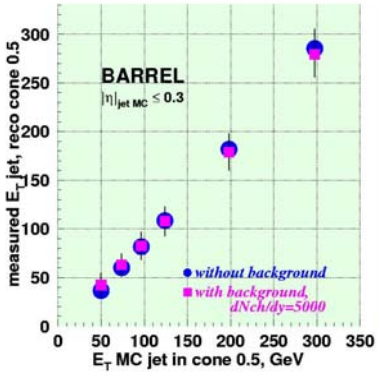


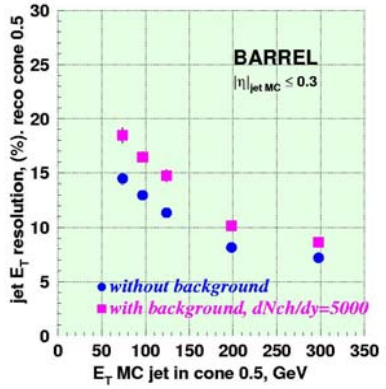


Jets – Calorimeters Alone









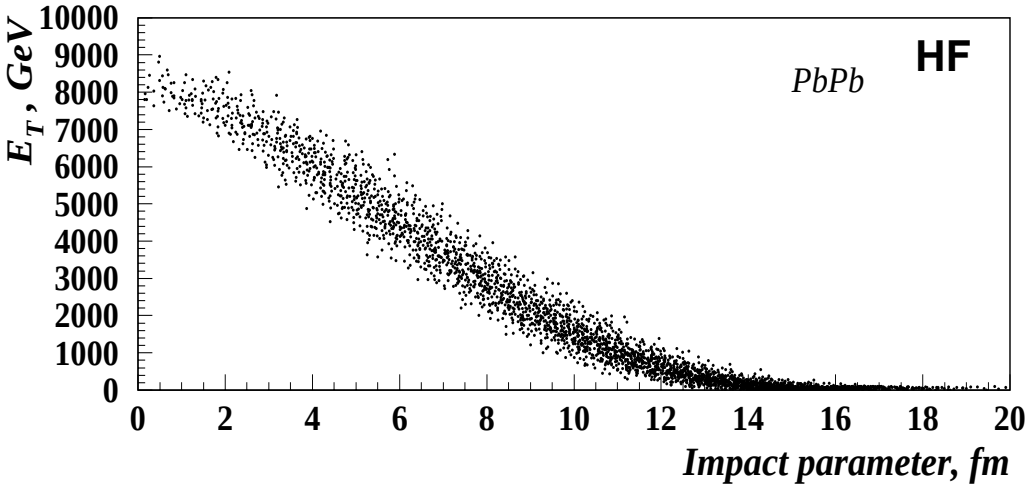
High track reconstruction efficiency and low fake rate even at very high track density

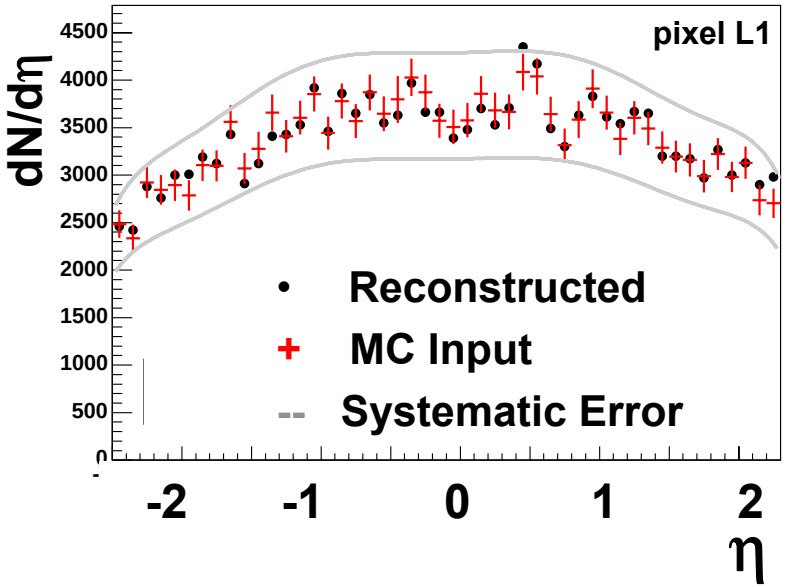
Energy resolution for 100 GeV jets is ≈ 16%

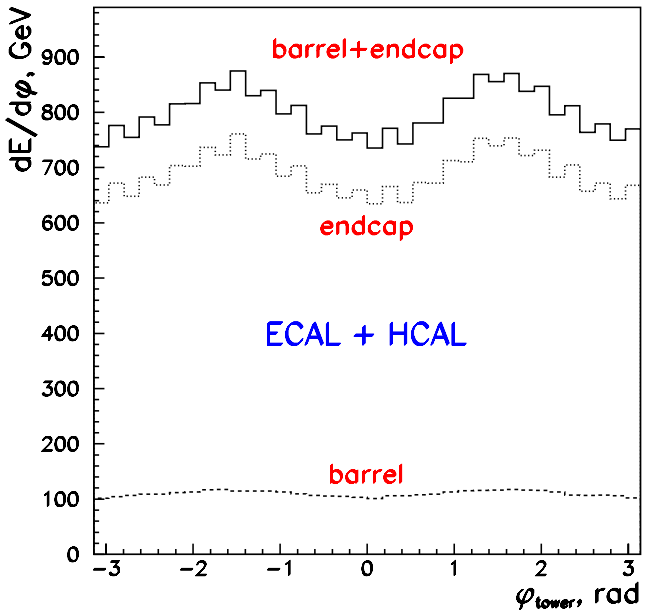
Physics Measurements in CMS

- **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
  - Leading particle correlations a la RHIC
  - Multijet events (*e.g.* 3 Jet)
- **Forward Physics**
  - X~10^{-6} Saturation, Color Glass, Limiting Fragmentation,
  - Ultra Peripheral Collisions
  - Exotica

Global Event Characterization







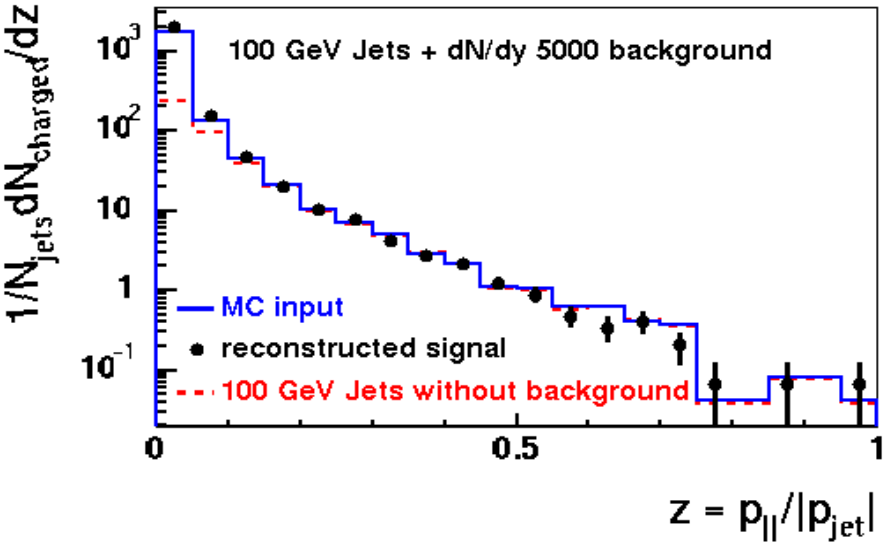
Impact Parameter

Multiplicity a la PHOBOS

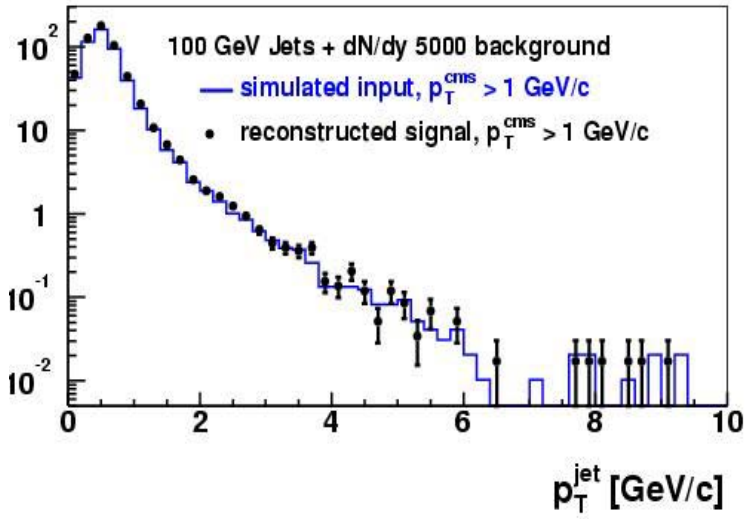
Flow of Energy and Particle Number

Jet Fragmentation

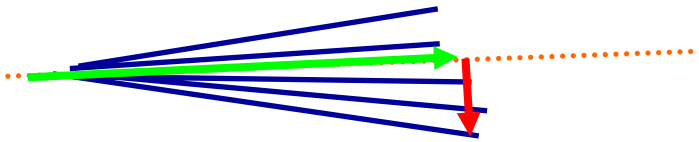
Longitudinal momentum fraction z along the thrust axis of a jet:



p_T relative to thrust axis:



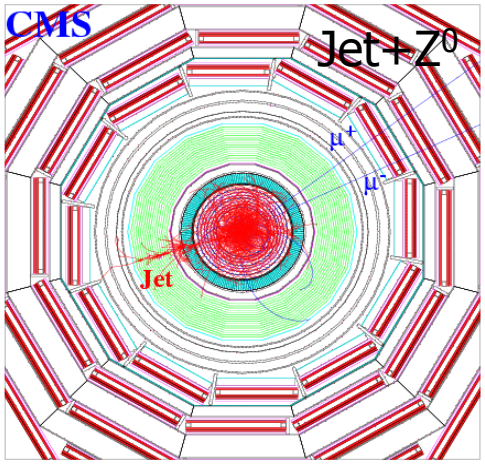
- **Fragmentation function for 100GeV Jets embedded in dN/dy ~5000 events.**
- **Use charged particles and possibly electromagnetic clusters**



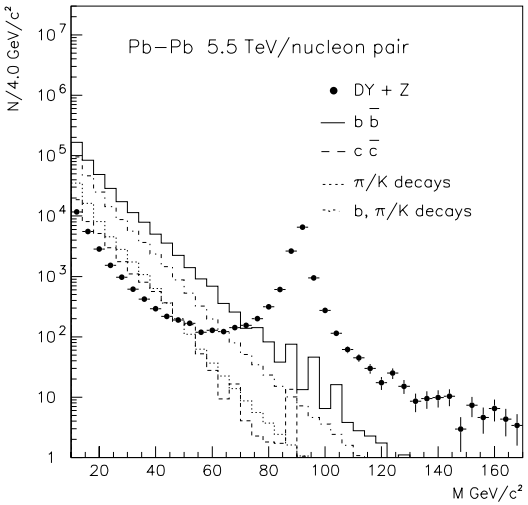
Balancing γ or Z^0 vs Jets

Z+jet event in the Heavy Ion collision

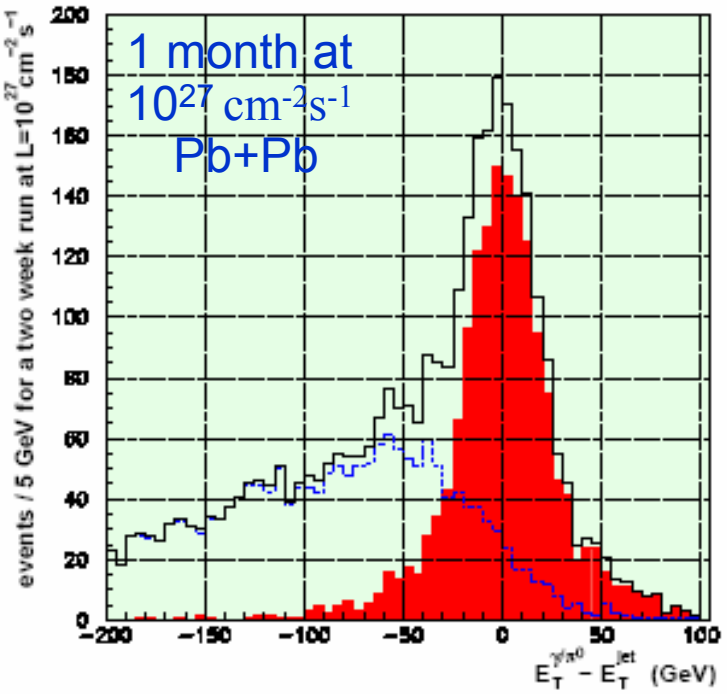
dNch / dY = 5000



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

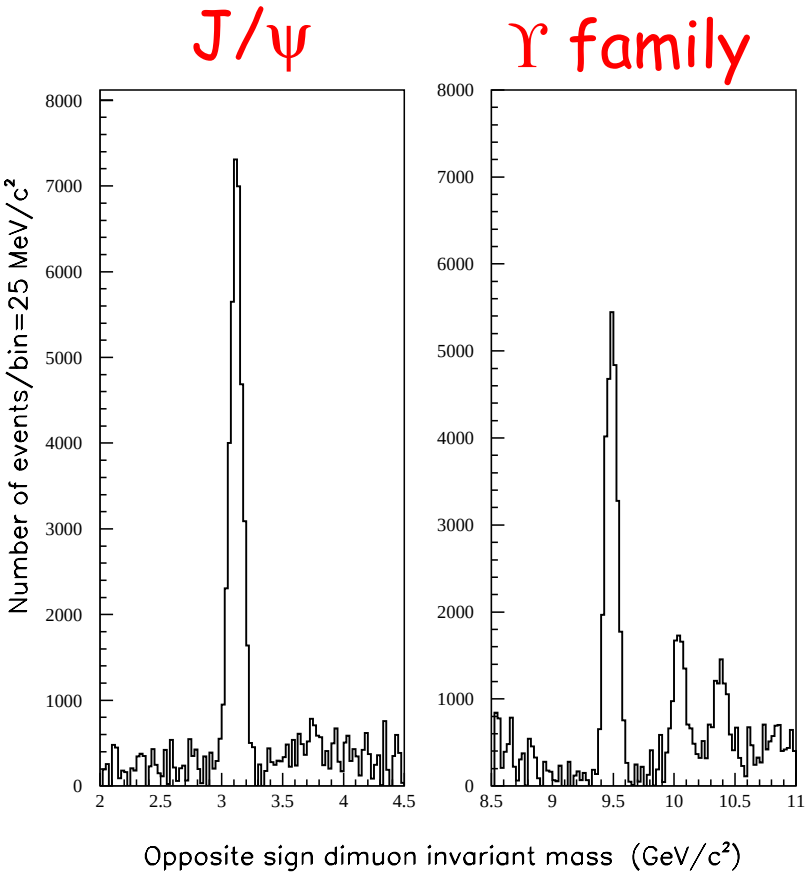


E_{Tjet}, $_{\gamma}$>120 GeV in Barrel



Study of jets with known parton energy

Quarkonia in CMS



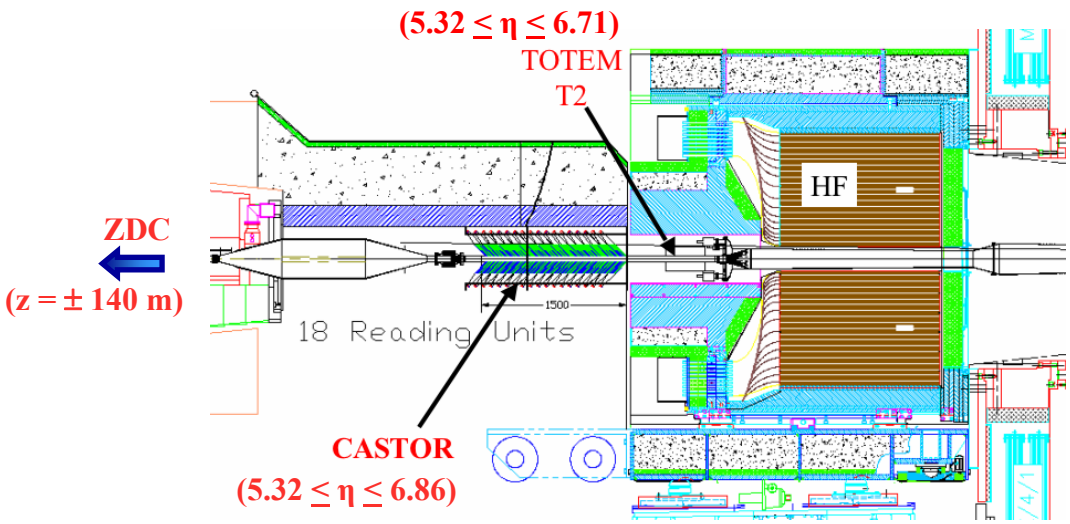
σ_M = 50 MeV

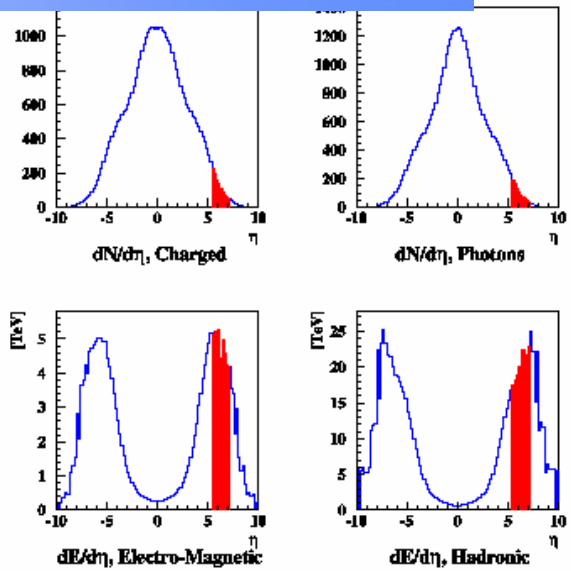
Yield/month
(with 50% duty factor)

	Pb+Pb	Kr+Kr	Ar+Ar
$\mathcal{L}$	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

More details in Olga Kodolova's talk later today

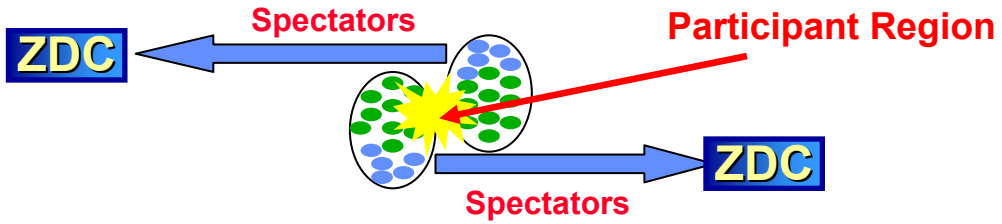
Forward Detectors: CASTOR and TOTEM

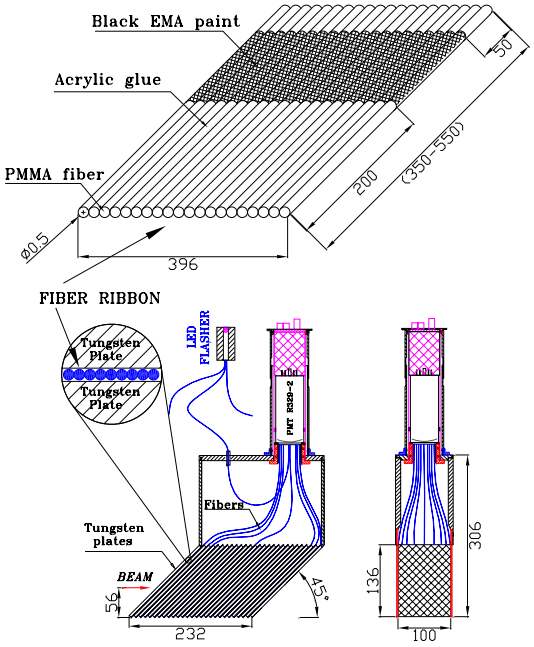




- Near Hermetic coverage (out to |η|<7 with CASTOR)
- Physics
  - Centrality
  - Nuclear PDFs - particularly gluon distributions
  - Momentum fractions x ~ 10^{-6} – 10^{-7} at scales of a few GeV^2 in pp
  - Diffractive processes (10-20% of total cross section at high energies)
  - Limiting Fragmentation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

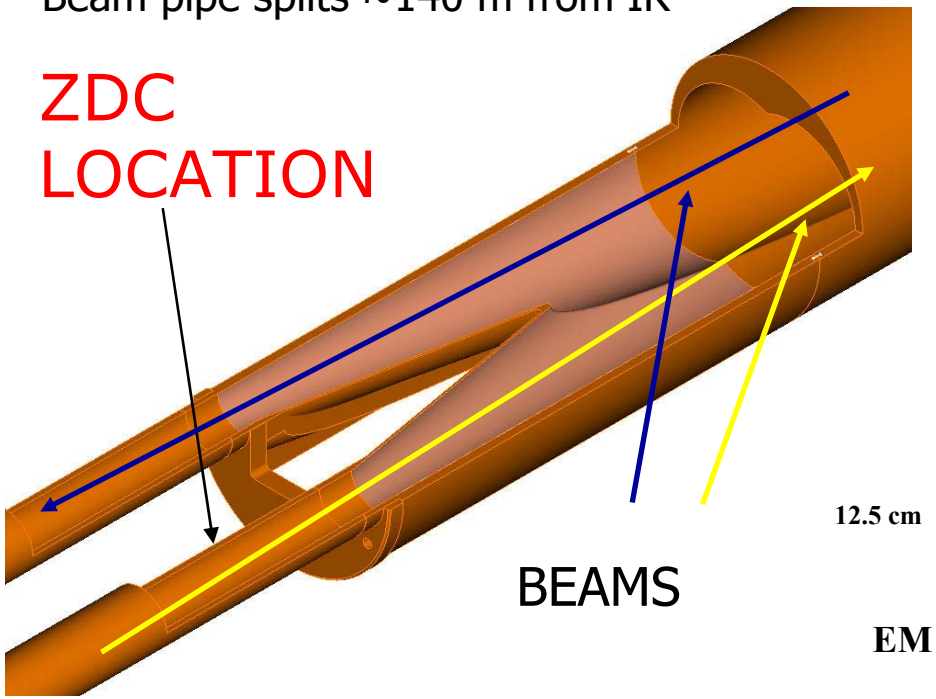
Zero Degree Calorimetry for CMS

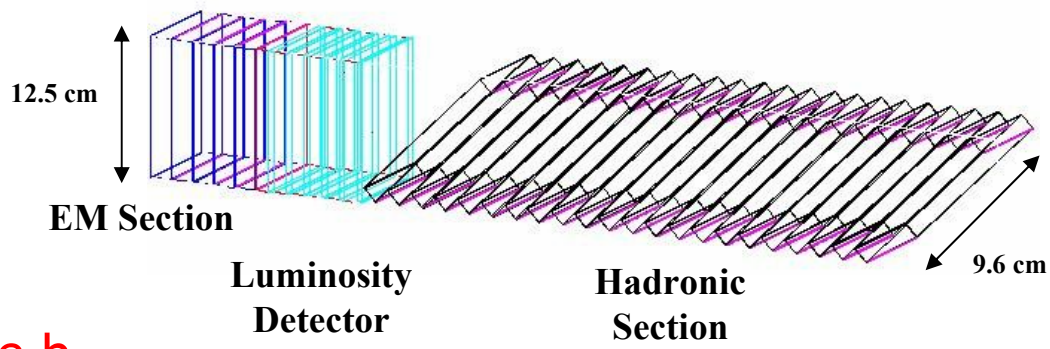




Beam pipe splits ~140 m from IR

ZDC LOCATION





ZDC improves resolution at large b

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