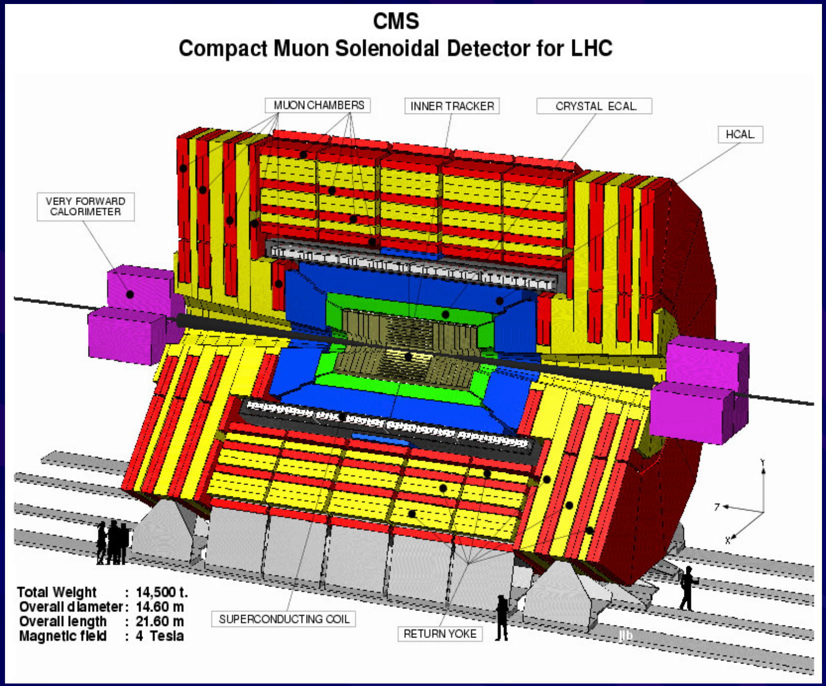
Heavy Ion Physics with CMS

David Hofman

UIC



<u>CMS Heavy-Ion Groups:</u>

Adana, Athens, Basel, Budapest, CERN, Demokritos, Dubna, Ioannina, Kiev, Krakow, Los Alamos, Lyon, Minnesota, MIT, Moscow, Mumbai, N. Zealand, Protvino, PSI, Rice, Sofia, Strasbourg, U Kansas, Tbilisi, UC Davis, UI Chicago, U. Iowa, Yerevan, Warsaw, Zagreb

PHYSICS AT LHC

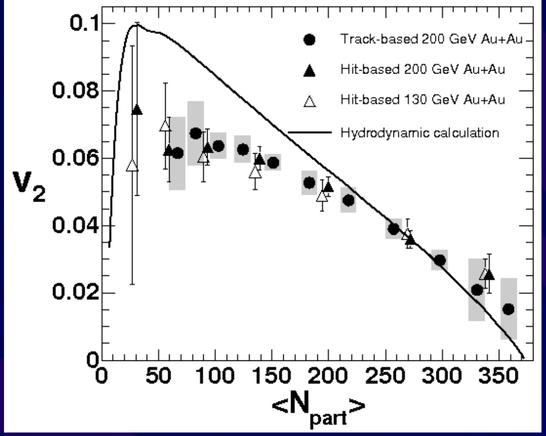
3-8 July 2006

CRACOW POLAND

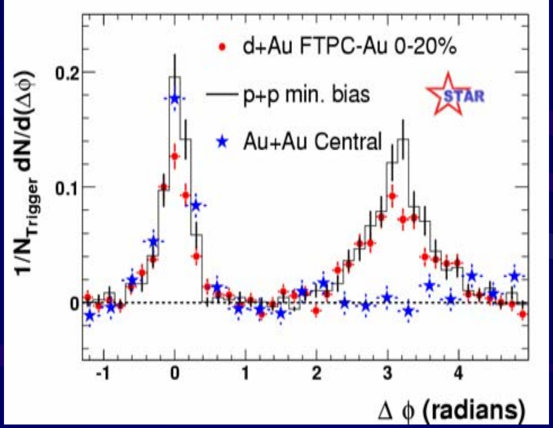
Insight from RHIC

- Importance of covering both soft and hard sectors.
- Challenges to both detector construction and triggering.
- Be prepared for surprises.

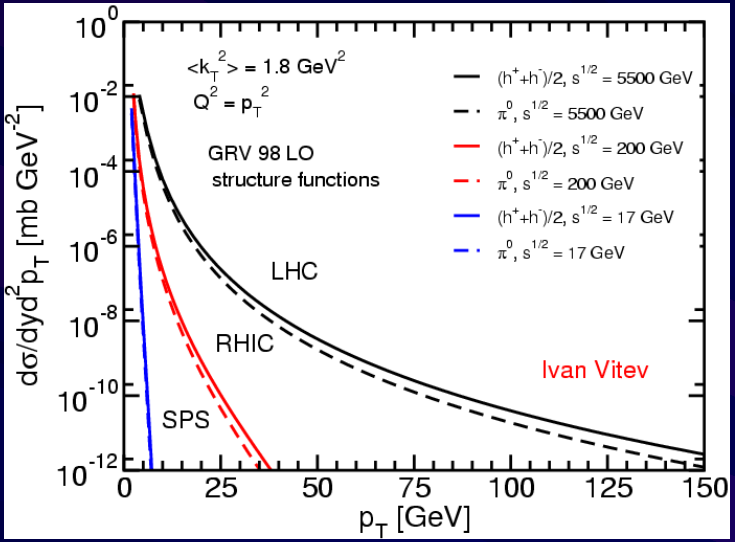
Elliptic Flow: PHOBOS NPA 757, 28

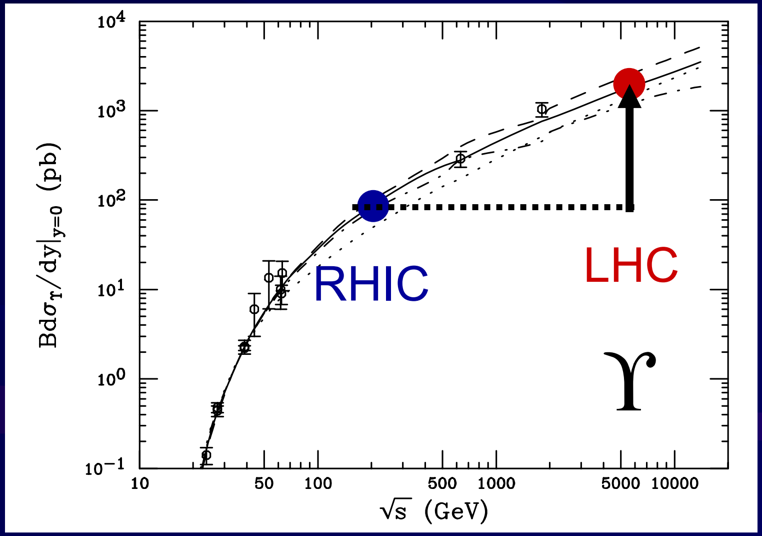


Jet Suppression: STAR PRL 91, 072304



Heavy Ions: From RHIC to the LHC





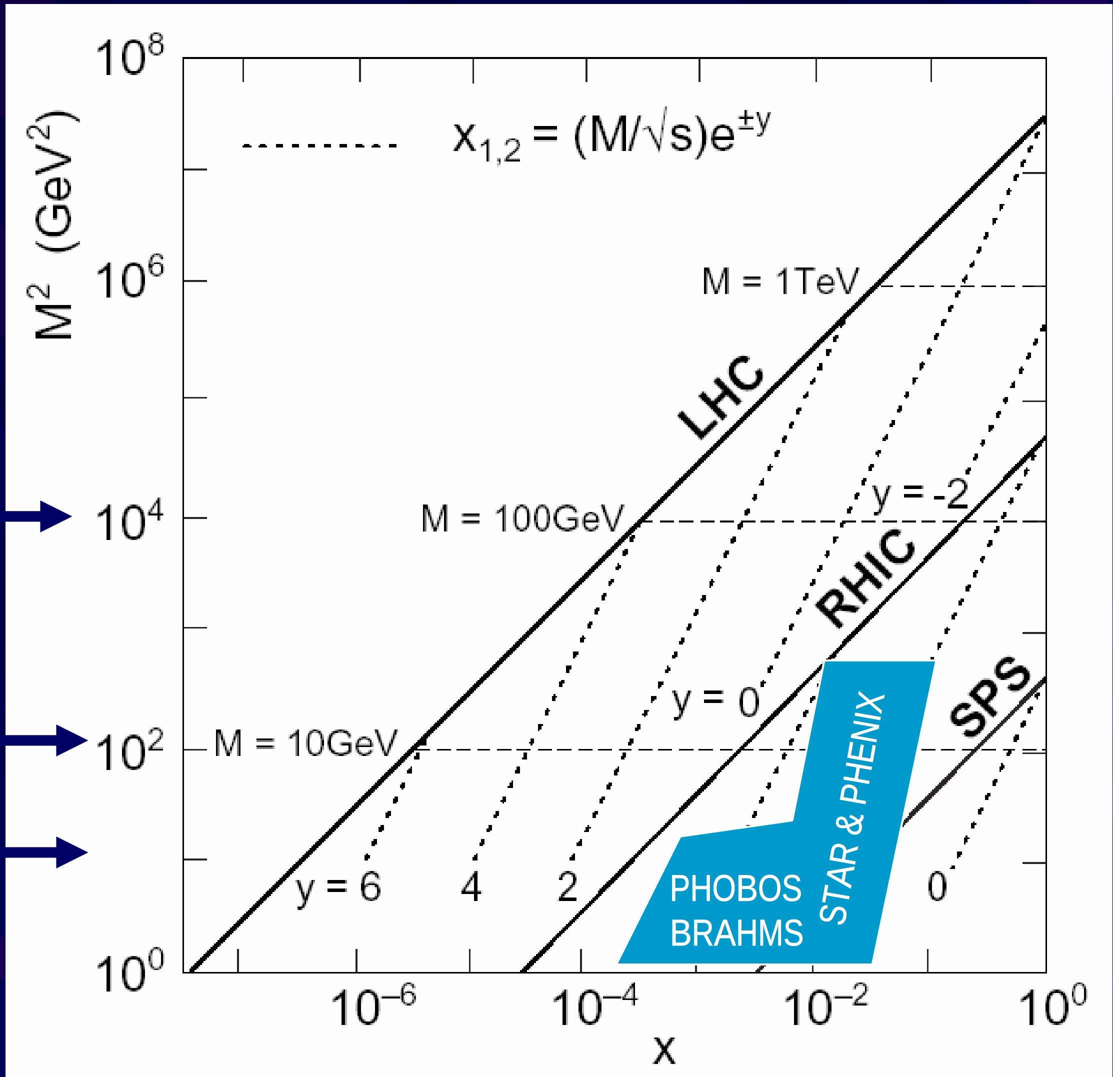
- Factor 28 increase in energy to $\sqrt{s_{NN}}$=5.5 TeV
- High Luminosity
- Large Cross sections
  - High p_T particles
  - Jets, which are now directly identifiable
  - J/ψ and ϒ-family production
- GOAL: Study matter at the highest energy density

Expanded Kinematics at the LHC

Z^0

Υ

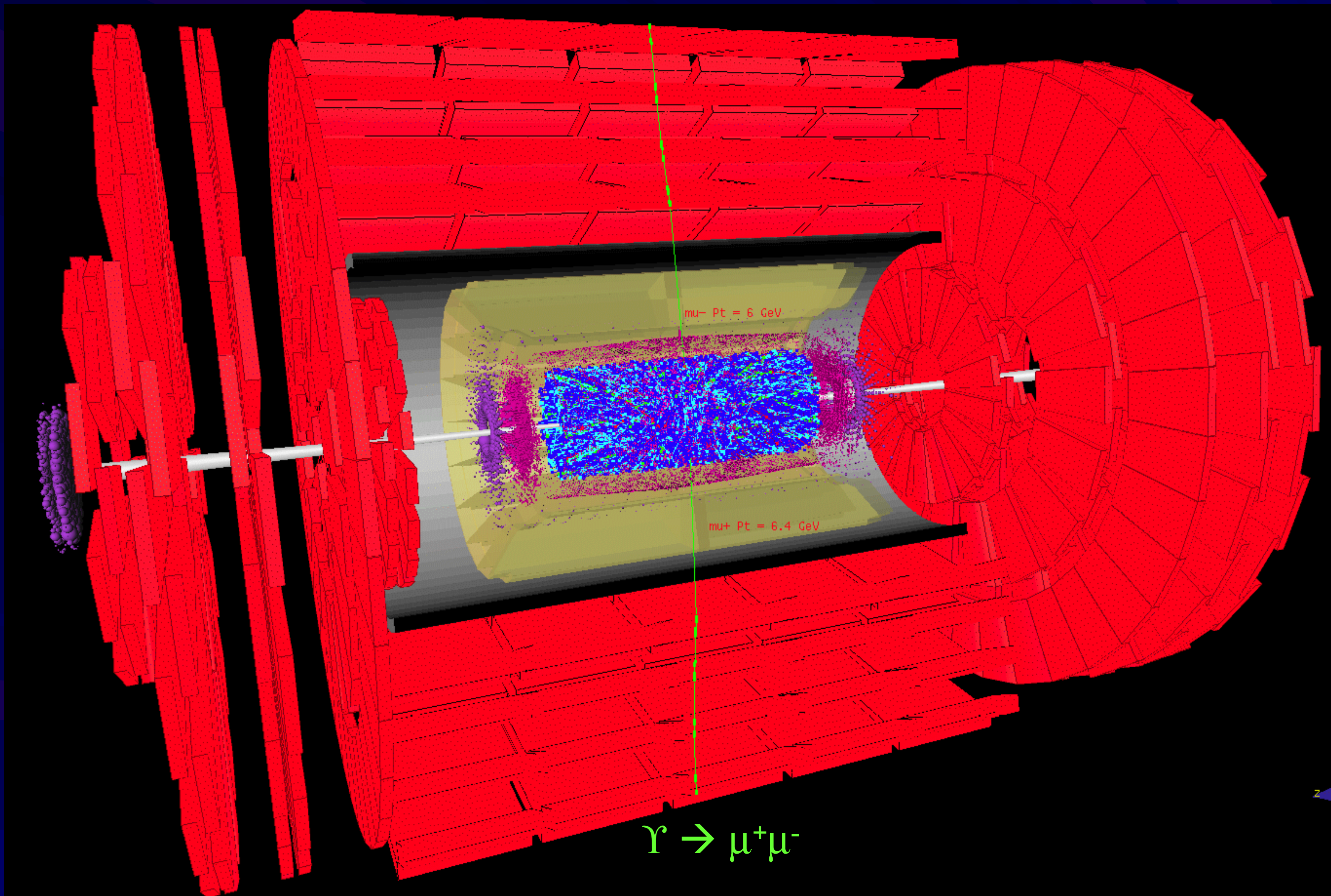
J/ψ



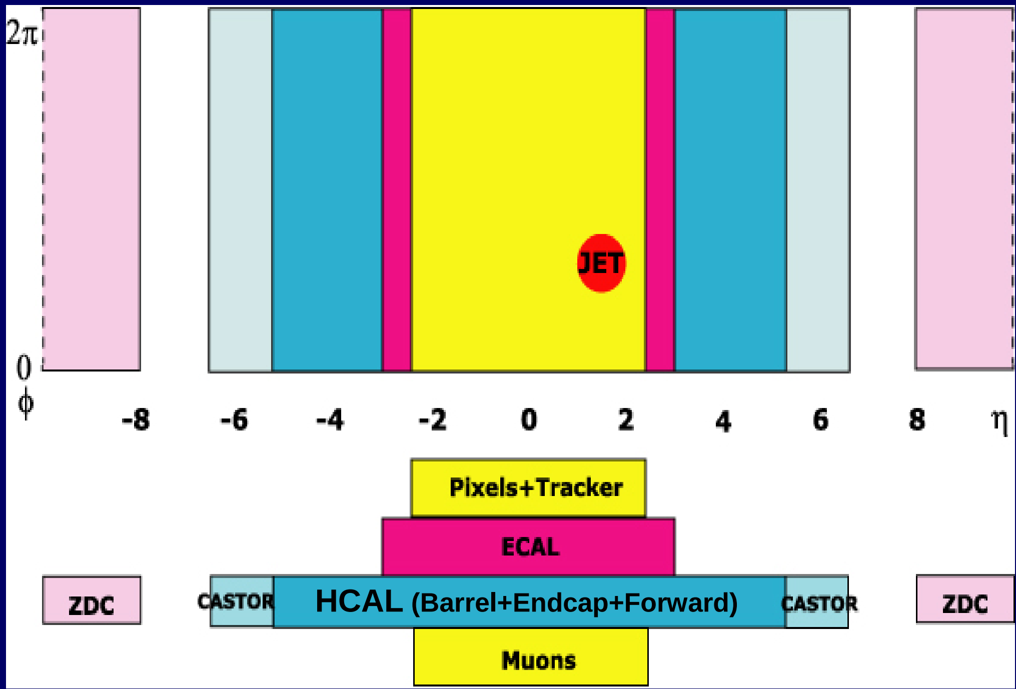
LHC provides access to the widest range of Q^2 and x

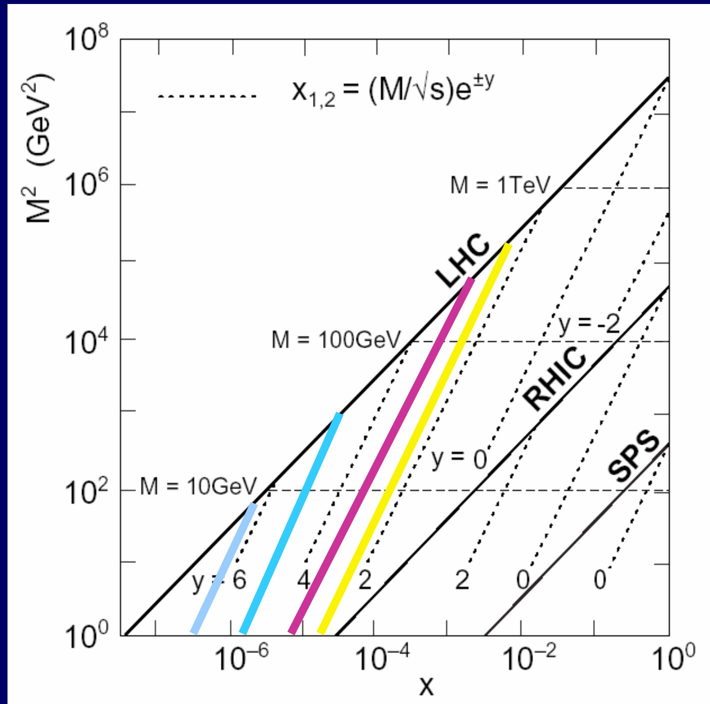
Heavy-Ions in CMS

MC simulation/visualization of Pb+Pb event ($dN_{ch}/d\eta|_{\eta=0}$ ~ 3000)
using the pp software framework



Overview: CMS Detector Coverage





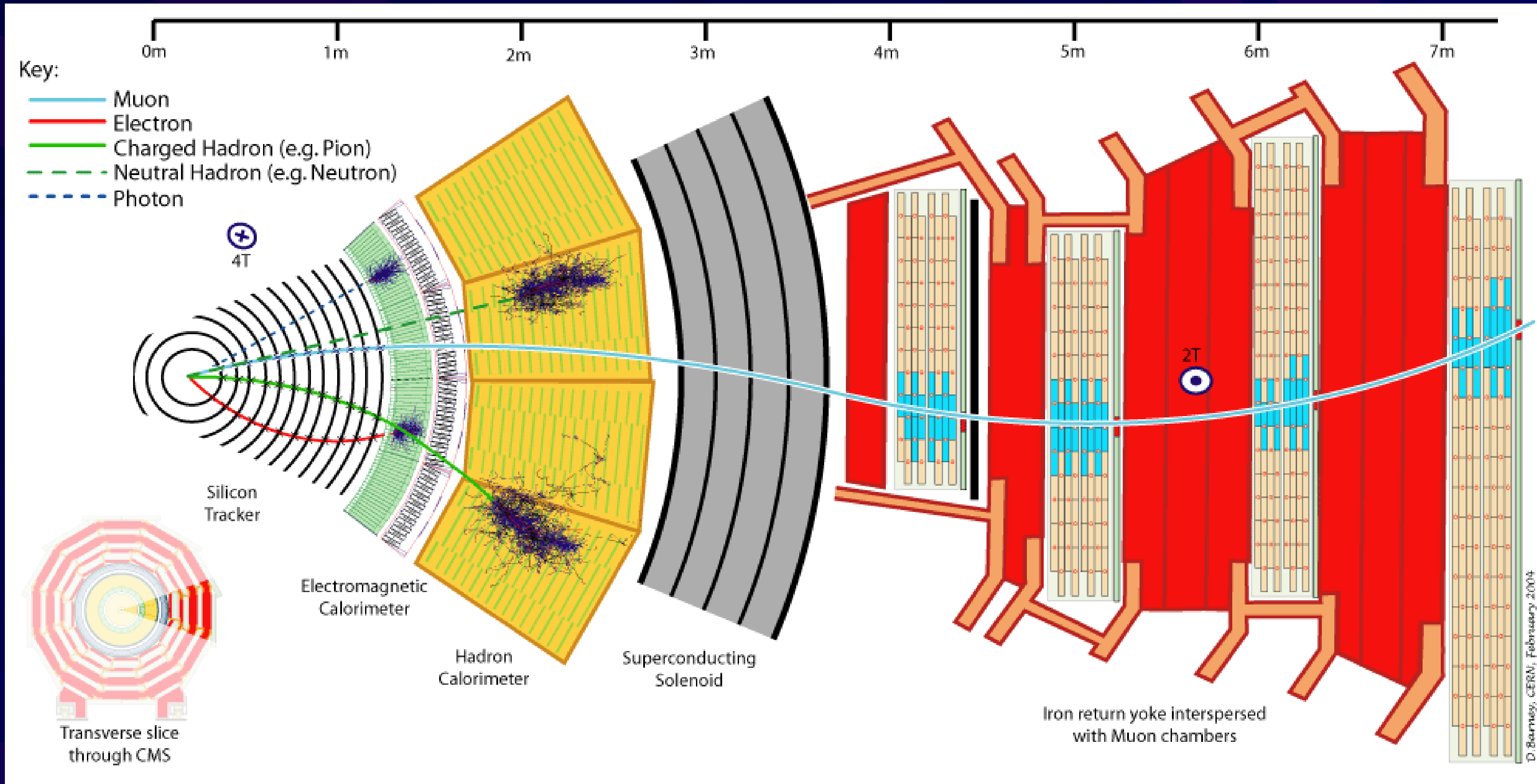
Large Range of Hermetic Coverage:

Tracker, muons	$\lvert\eta\rvert < 2.4$
ECAL + HCAL	$\lvert\eta\rvert < 3$
Forward HCAL	$3 < \lvert\eta\rvert < 5$
CASTOR	$5.2 < \lvert\eta\rvert < 6.6$
ZDC	

High Bandwidth Trigger & DAQ
Sophisticated High Level Trigger Capability

Central Region of CMS

Tracking + Ecal + Hcal + Muons for |η|<2.4



Si TRACKER

Silicon Microstrips and Pixels

CALORIMETERS

ECAL

Scintillating $PbWO_4$ crystals

HCAL

Plastic scintillator/brass sandwich

MUON BARREL

Drift Tube Chambers (**DT**)

Resistive Plate Chambers (**RPC**)

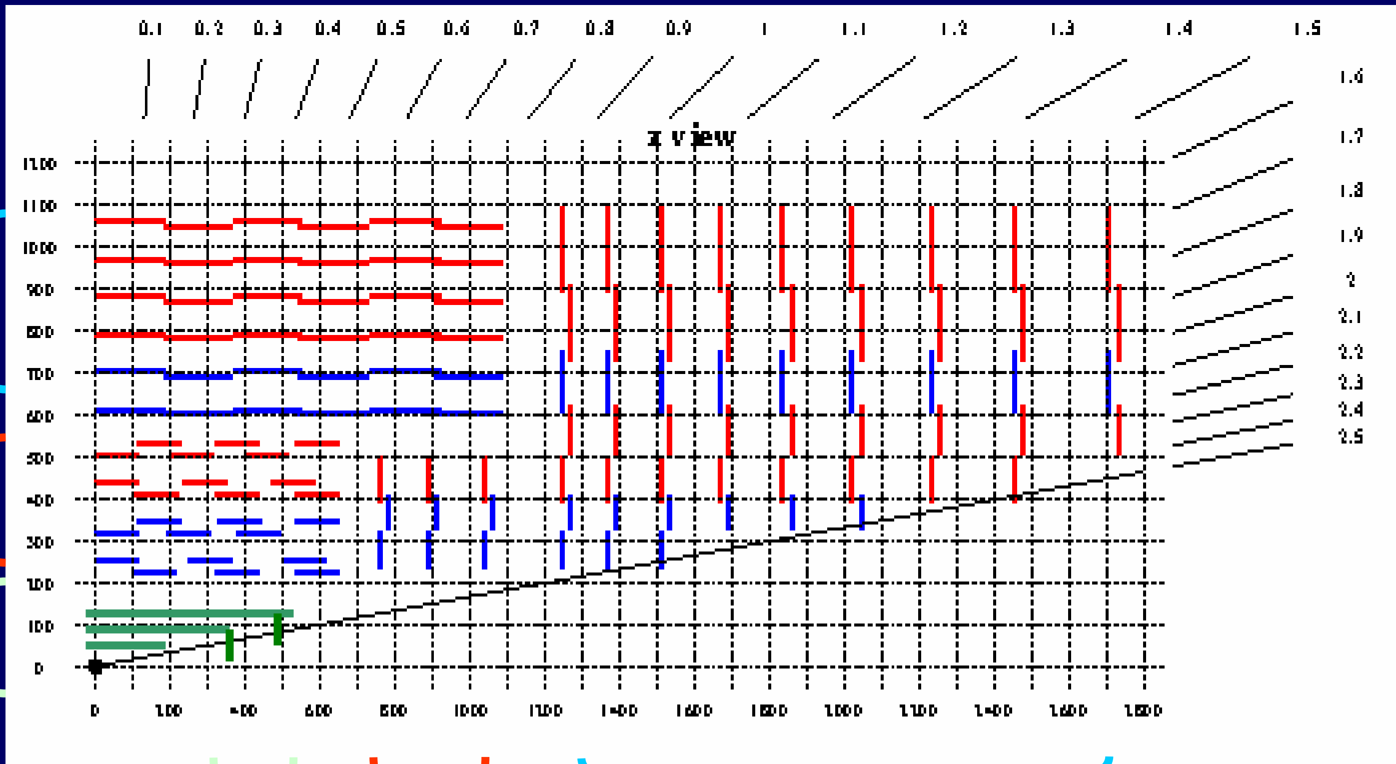
Silicon Tracker Layout

— 1 Single detector — 2 detectors back to back

6 layers Outer Barrel

4 layers Inner Barrel

3 layers Pixel Barrel



2 Pixel Disks 3 Disks 9 Disks in the End Cap

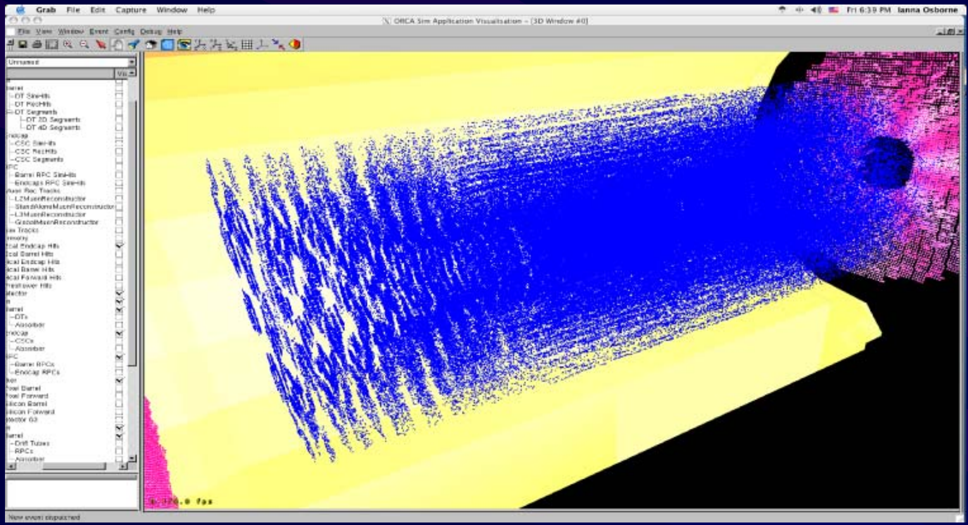
Pixel: 100x150μm^2, Inner Strips: 80μmx6.1cm, Outer Strips: ~150μmx9.1cm

70M Pixel channels, 11M Strip channels

Tracker in a HI Environment

Simulated Central Pb+Pb Event

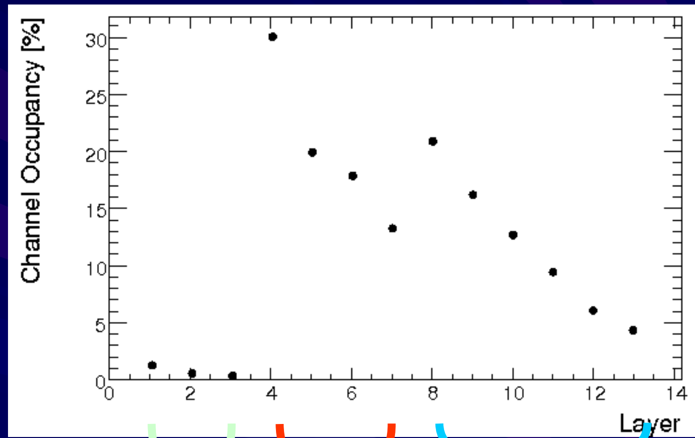
(HIJING+OSCAR+IGUANA)



Simulation $dN_{ch}/d\eta|_{\eta=0}$ ~ 3000

↓

Channel Occupancy



Pixel Detector Occupancy of < 2%

(less than 10% for outermost layers)

→ Key for successful tracking
→ Excellent soft physics capabilities

Including Pulse Height Information

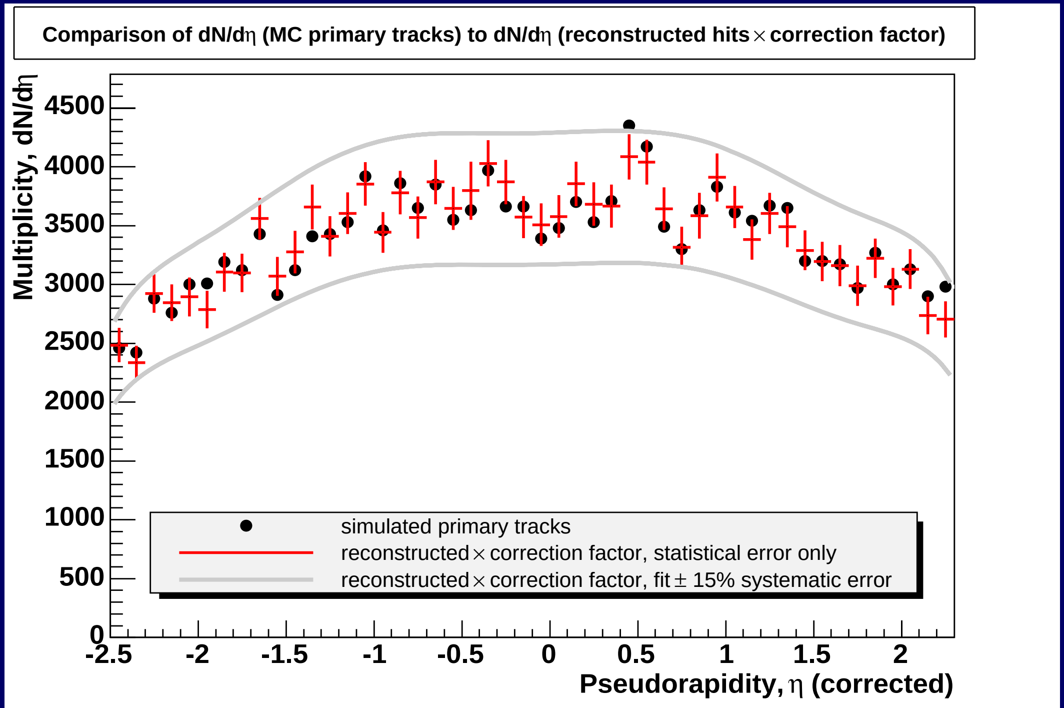
→ Allows correction of detector effects
→ Provides useful dE/dx information

Charged Particle Multiplicity: $dN_{ch}/d\eta$

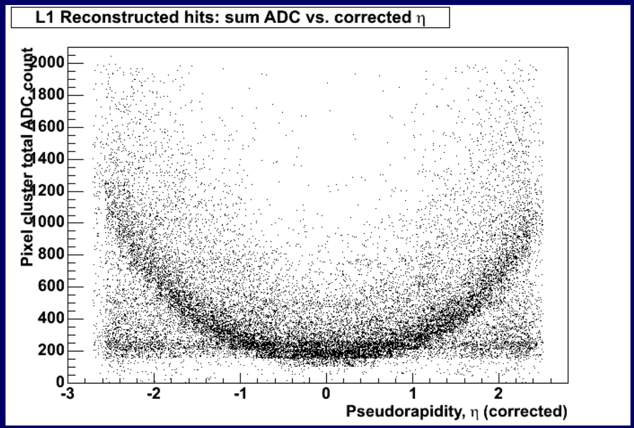
- High granularity pixel detectors
- Pulse height in individual pixels to reduce background
- Very low p_T reach, p_T>26 MeV (counting hits!)

Single Pb+Pb Event

Single layer hit counting in innermost pixel barrel layer



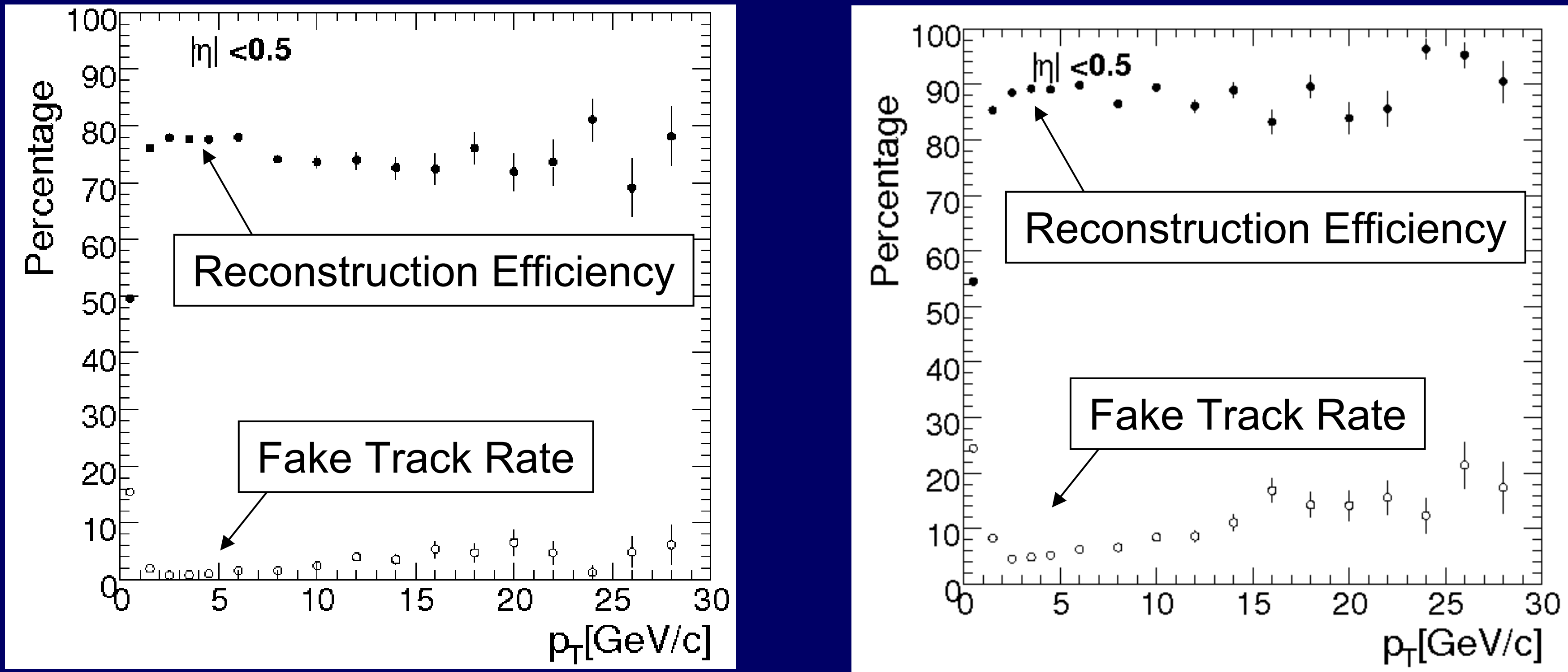
cosh η dependence of SumADC



Track Finding Capability

(Pb+Pb collisions; $dN_{ch}/d\eta|_{\eta=0} \sim 3000$)

Optimized for Low Fake Rate | Optimized for High Efficiency

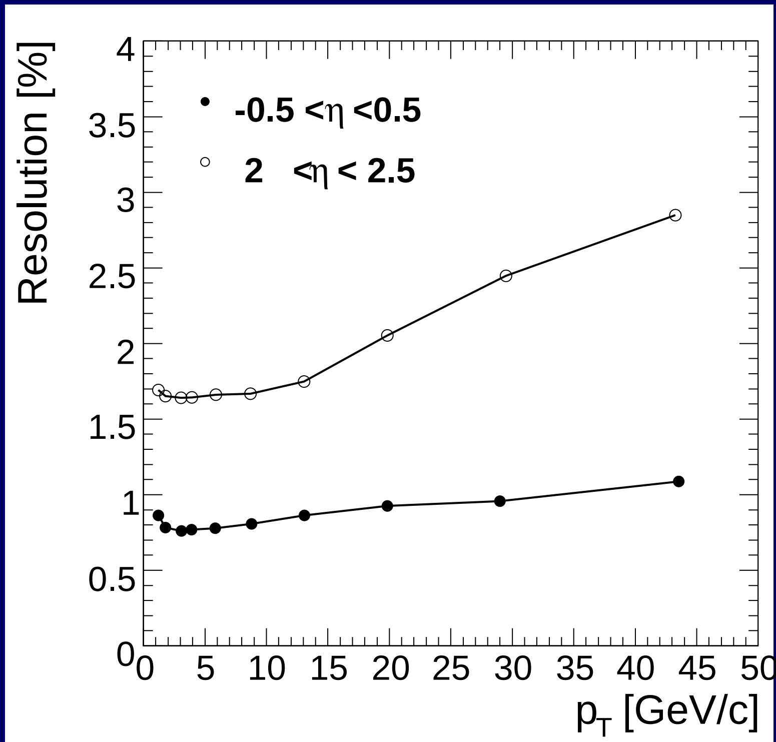


Efficiency ~ 75% with Fakes < 5% ⟷ Efficiency ~ 88% with Fakes ~ 10%

Track Reconstruction Performance

(Pb+Pb collisions; $dN_{ch}/d\eta|_{\eta=0} \sim 3000$)

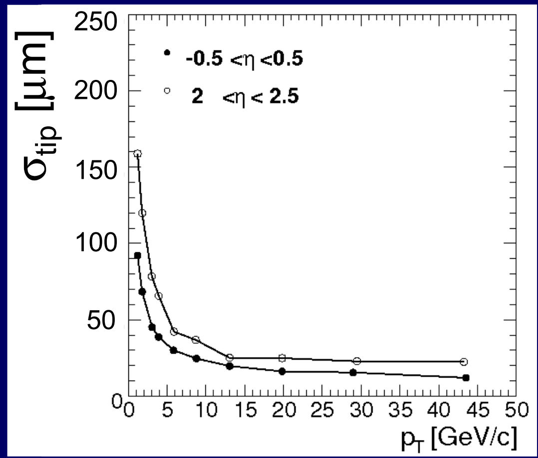
Momentum Resolution



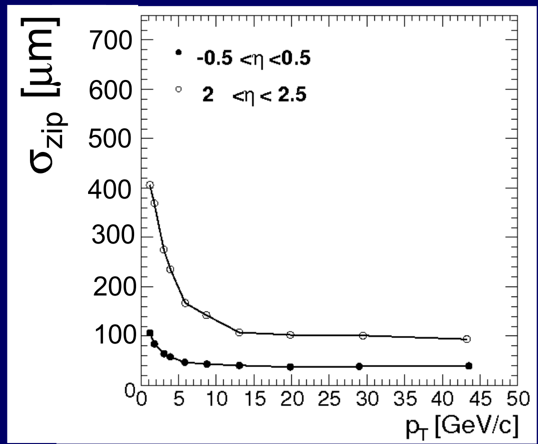
→ Excellent resolution at the highest particle densities

Track-pointing Resolution

Transverse (σ_t~20 μm)

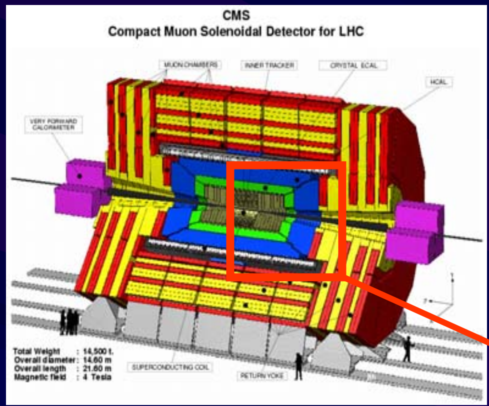


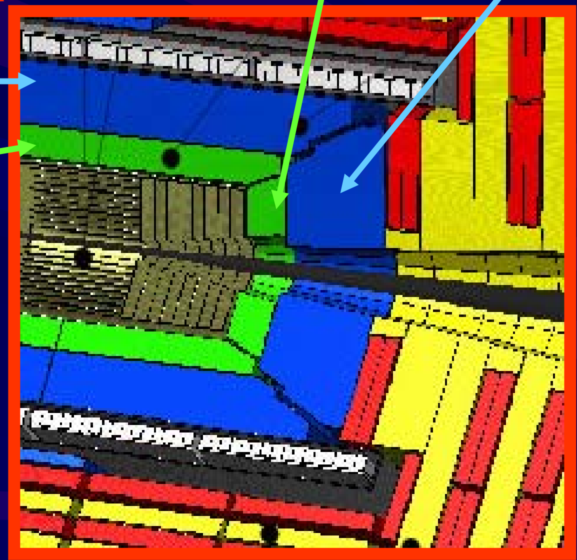
Longitudinal (σ_l~50 μm)



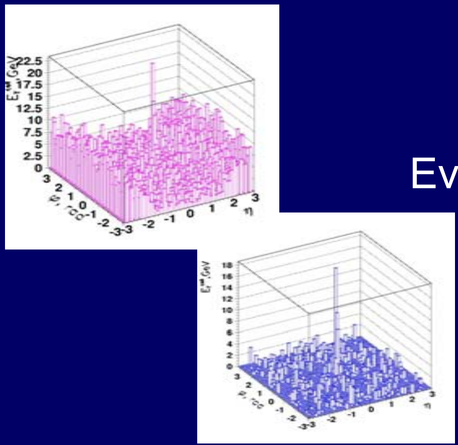
Central Calorimetry Layout

|η| < 3





Jet Reconstruction in a HI Environment



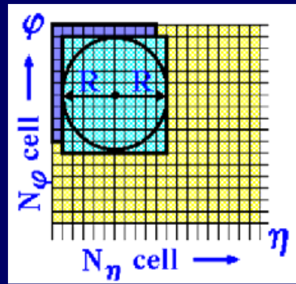
Central Pb-Pb Collision

HIJING, $dN_{ch}/d\eta|_{\eta=0}$ ~ 5000

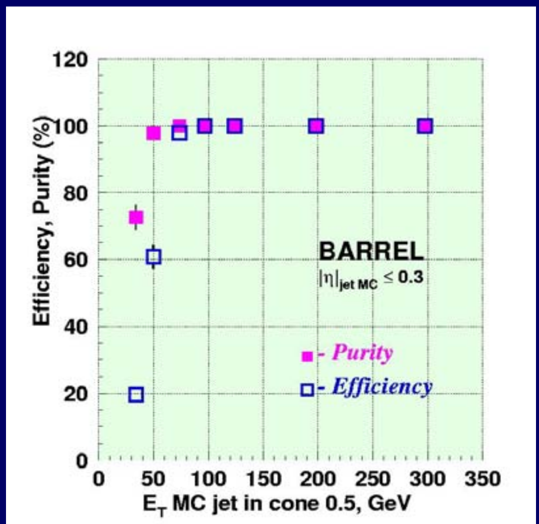
Event-by-Event η-dependent background subtraction

+

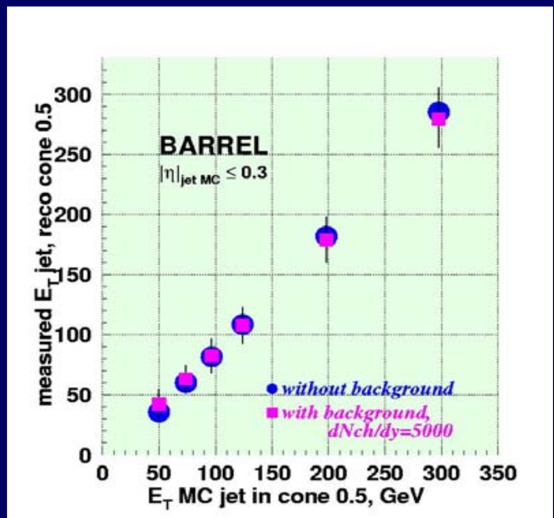
Iterative jet cone-finder algorithm



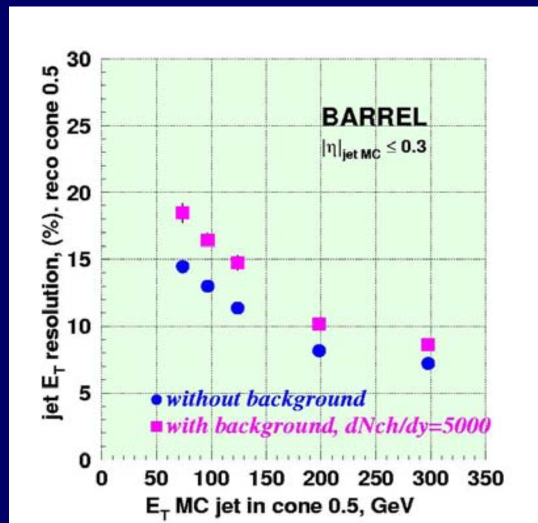
Efficiency, purity



Measured jet energy



Jet energy resolution

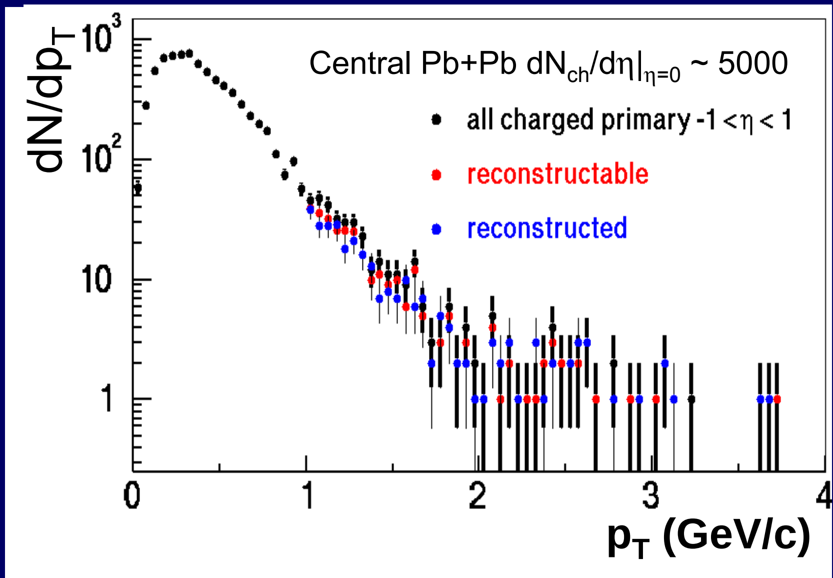


Jet spatial resolution: $\sigma(\phi_{rec} - \phi_{gen}) = 0.032$; $\sigma(\eta_{rec} - \eta_{gen}) = 0.028$

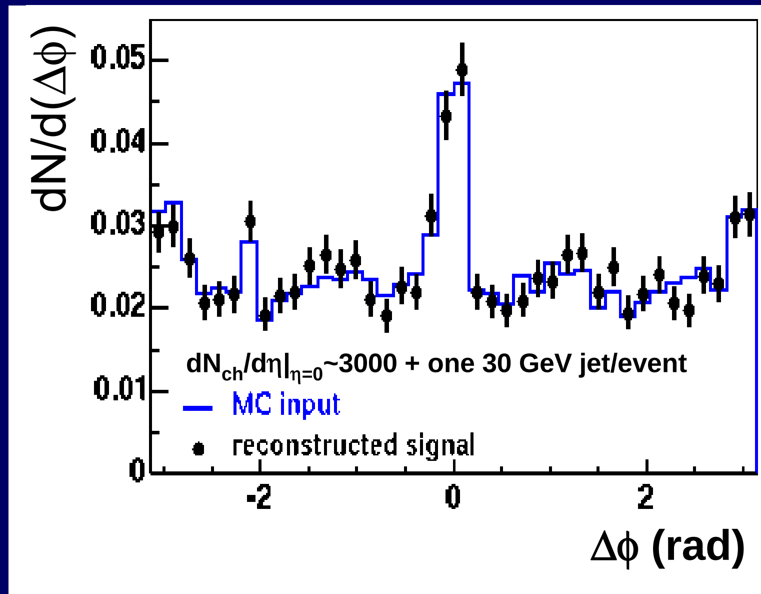
→ Similar Results for Endcap

Jet studies using the tracking

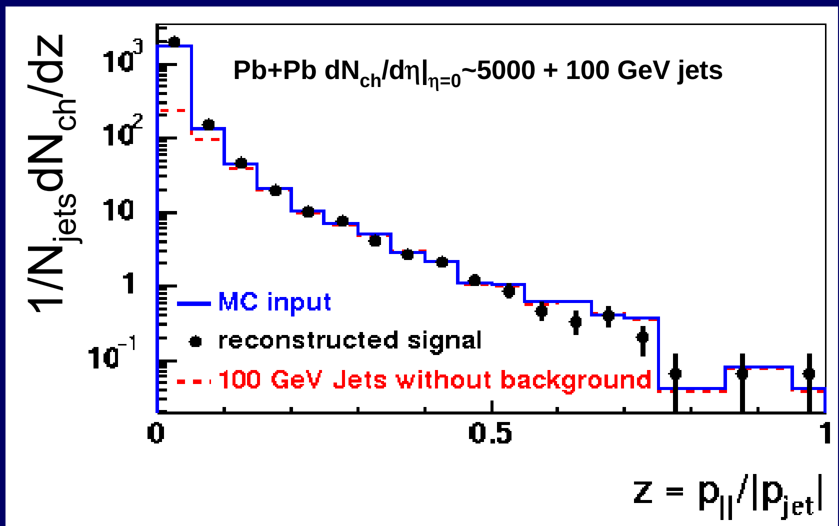
Centrality dependence of p_T spectra



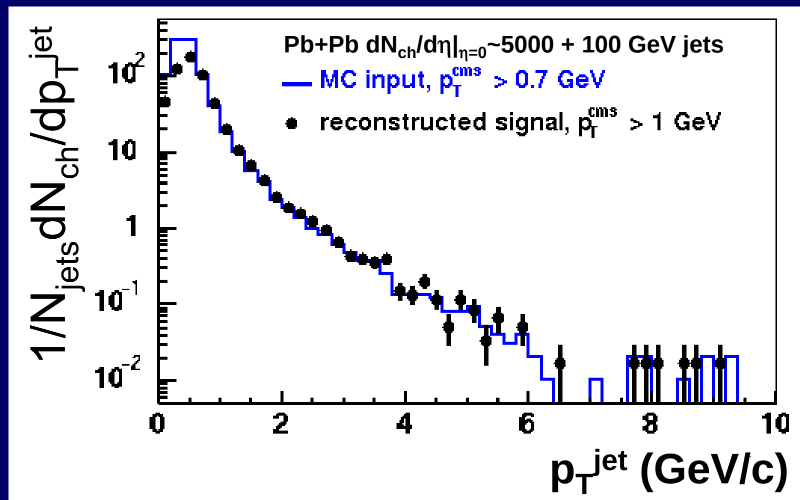
Azimuthal correlations:



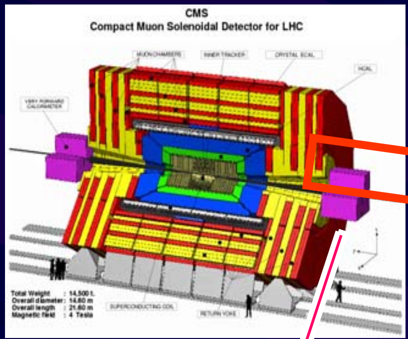
Fragmentation functions:



p_T with respect to jet axis:



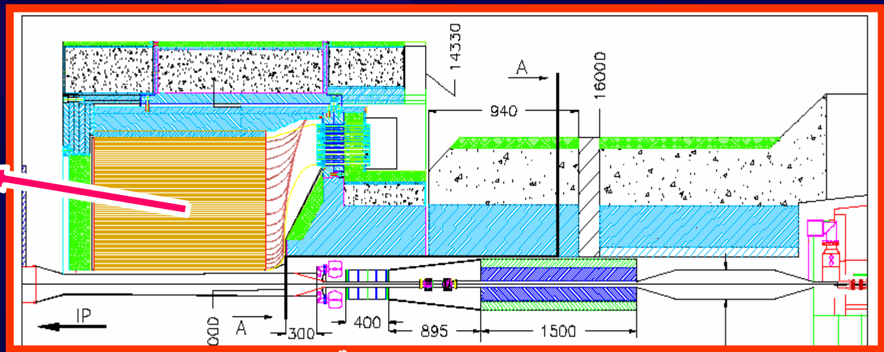
Forward Region Layout

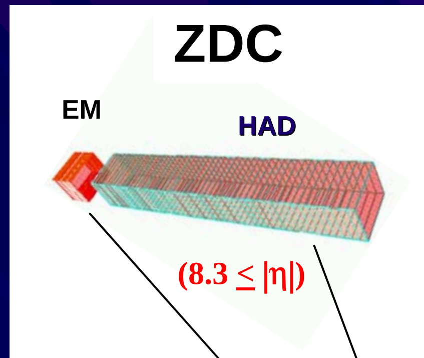


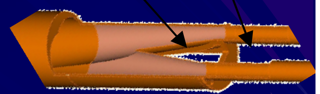
$|\eta| > 3$

Forward HCal

$(3 \leq |\eta| \leq 5)$

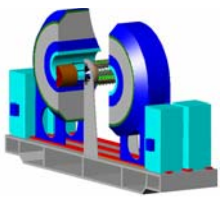






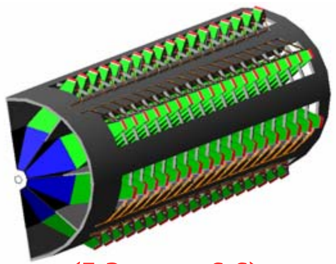
$(z = \pm 140$ m$)$

TOTEM



$(5.3 \leq \eta \leq 6.7)$

CASTOR

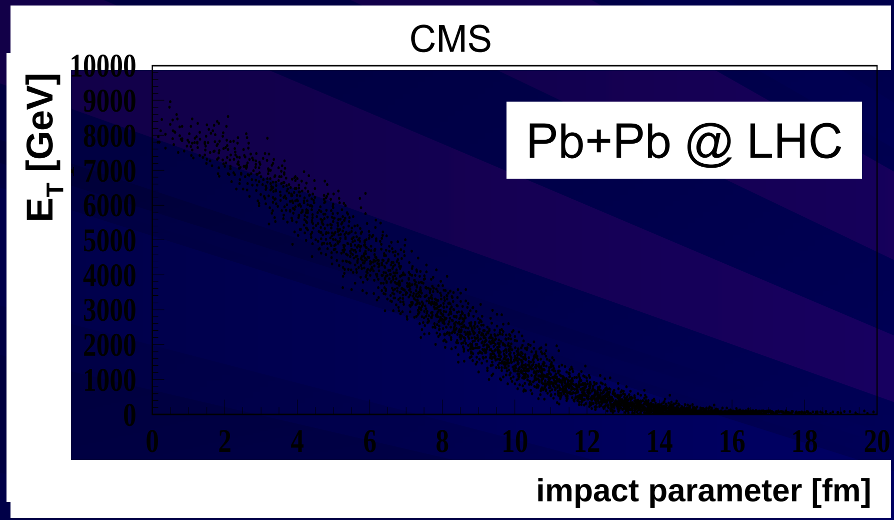


$(5.2 \leq \eta \leq 6.6)$

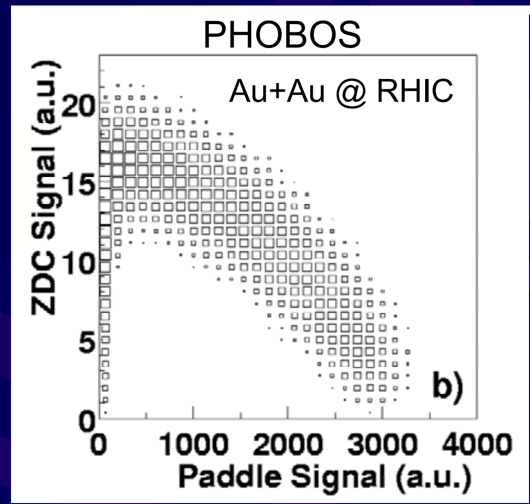
Excellent Event Characterizations

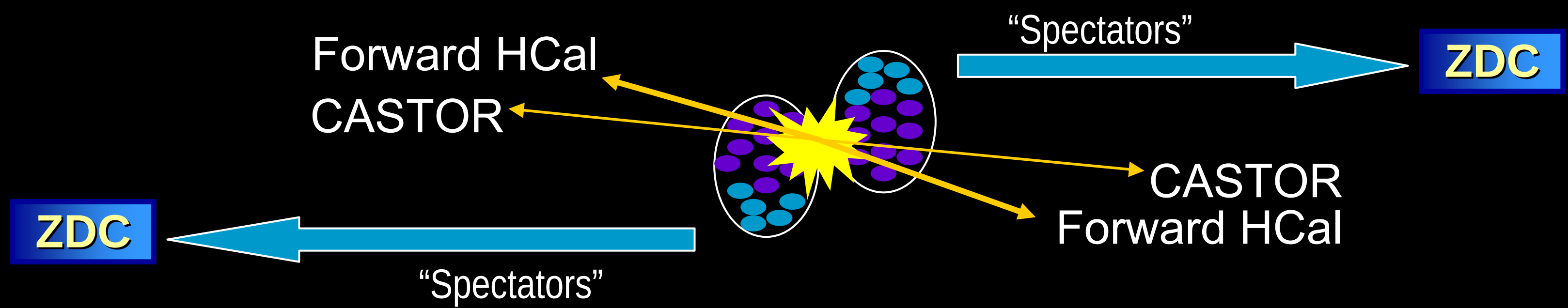
Good Event Selection and Centrality Determination

Energy in Forward HCal



Correlations with the ZDC

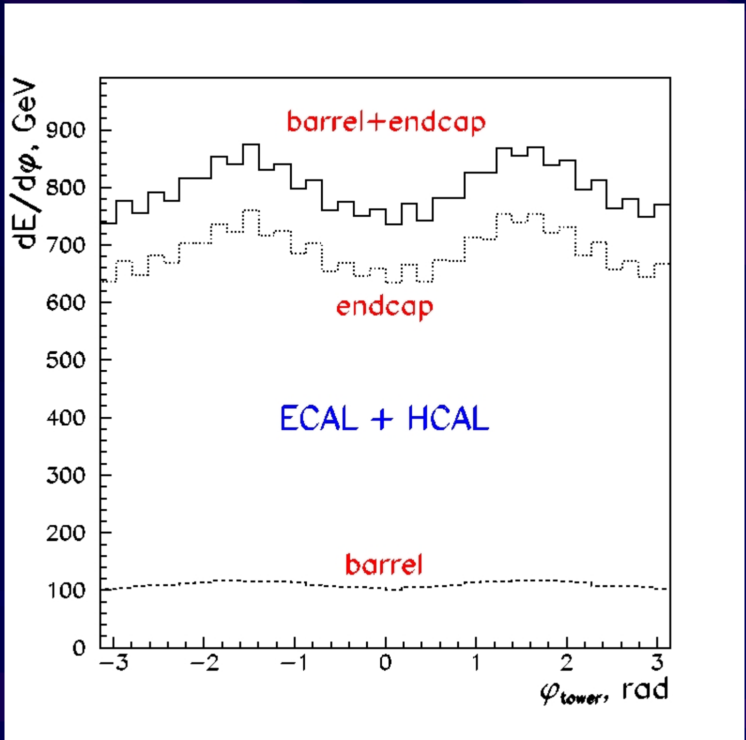


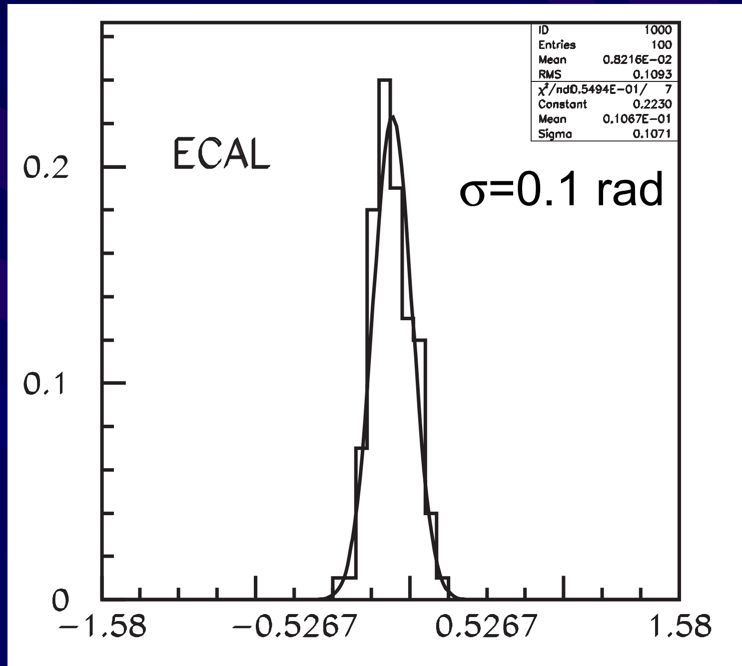


Event Characterizations II

Reaction-Plane Determination

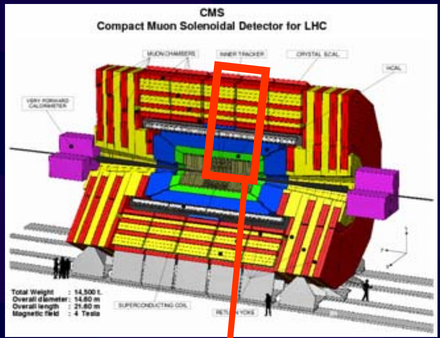
Single Pb+Pb collision (Hydro) at b=6 fm



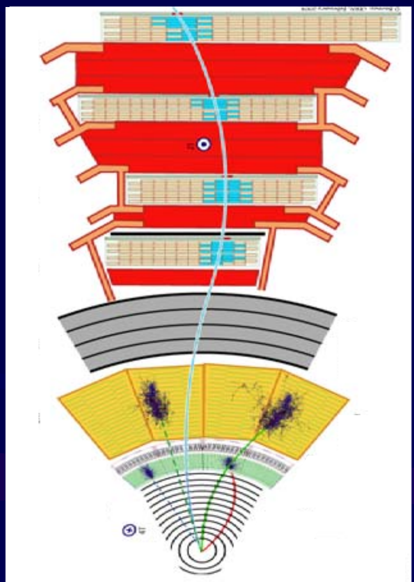


Event plane determination

Muons



μ^+ Track



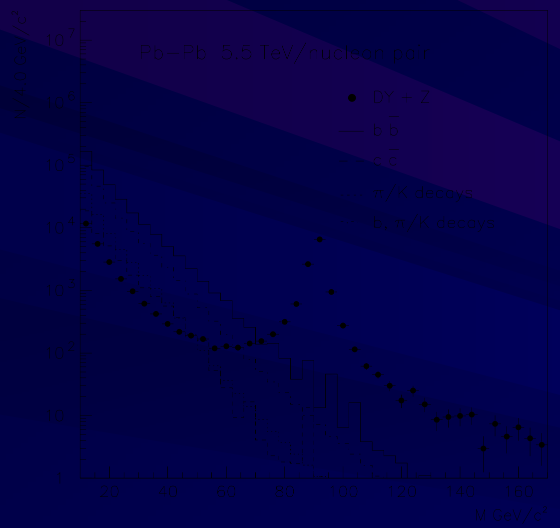
- Excellent Coverage
  - In central rapidity region and 2π
- Cal + Magnet Iron Absorbs Hadrons
  - Barrel $p_T^{\mu} > 3.5$ GeV/c
  - Endcap $p_T^{\mu} > 1.5$ GeV/c
- Triggering available at all levels
- Tag from Muon chambers, momentum resolution from the Silicon Tracker
- Excellent Mass resolution in Pb+Pb event with $dN_{ch}/d\eta|_{\eta=0} \sim 3000$
  - $\sigma_M = 54$ MeV/c^2 for $\Upsilon \rightarrow \mu^+\mu^-$ ($|\eta|<0.8$)
  - $\sigma_M = 90$ MeV/c^2 for $\Upsilon \rightarrow \mu^+\mu^-$ ($|\eta|<2.4$)
- Reconstruct Z^0 boson

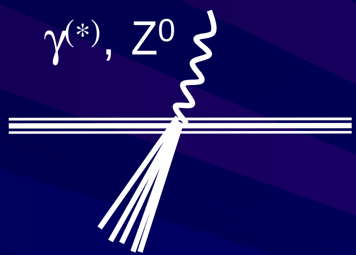
Quarkonia

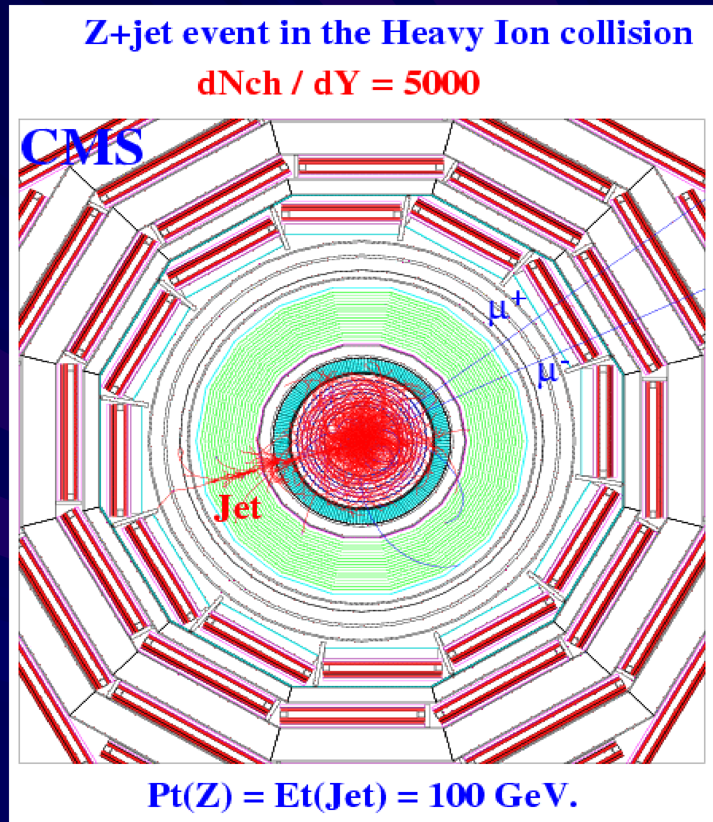
Upcoming talk by Bolek Wyslouch

Balancing γ, γ^* or Z^0 vs Jets

$Z^0 \rightarrow \mu^+\mu^-$

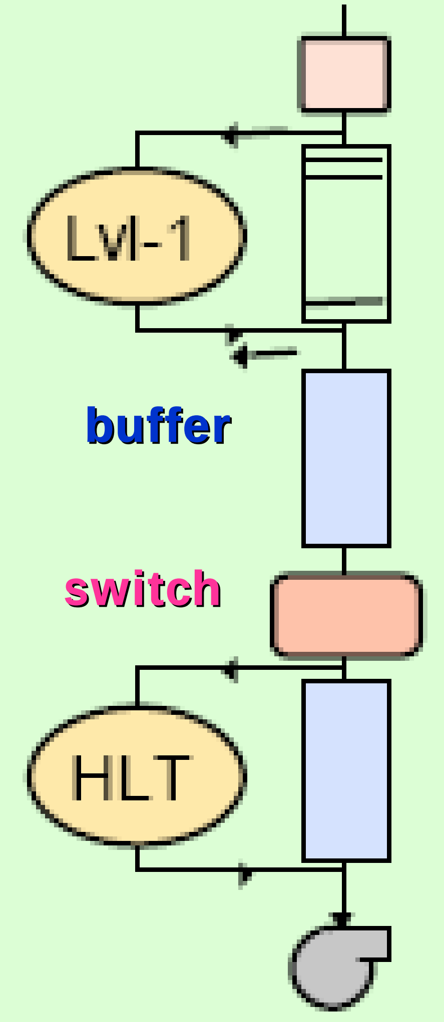






→ Study of jets with known energy – learn about quark energy loss

Triggering in Heavy Ions



Level 1 trigger
- Uses custom hardware
- Muon tracks + calorimeter information
- Decision after ~ 3μsec

Level-1	Pb+Pb	p+p
Collision rate	3kHz (8kHz peak)	1GHz
Event rate	3kHz (8kHz peak)	32MHz
Output bandwidth	100 GByte/sec	100 GByte/sec
Rejection	none	99.7%

High level Trigger
- ~1500 Linux servers (~10k CPU cores)
- Full event information available
- Runs "offline" algorithms (~3 sec per HI event)

High Level Trigger	Pb+Pb	p+p
Input event rate	3kHz (8kHz peak)	100kHz
Output bandwidth	225 MByte/sec	225 MByte/sec
Output rate	10-100Hz	150Hz
Rejection	97-99.7%	99.85%

Heavy Ion Physics Program in CMS

Soft physics and global event characterization

- Centrality and good event selection
- Charged particle multiplicity
- Azimuthal asymmetry (Flow)
- Spectra + Correlations

High p_T Probes

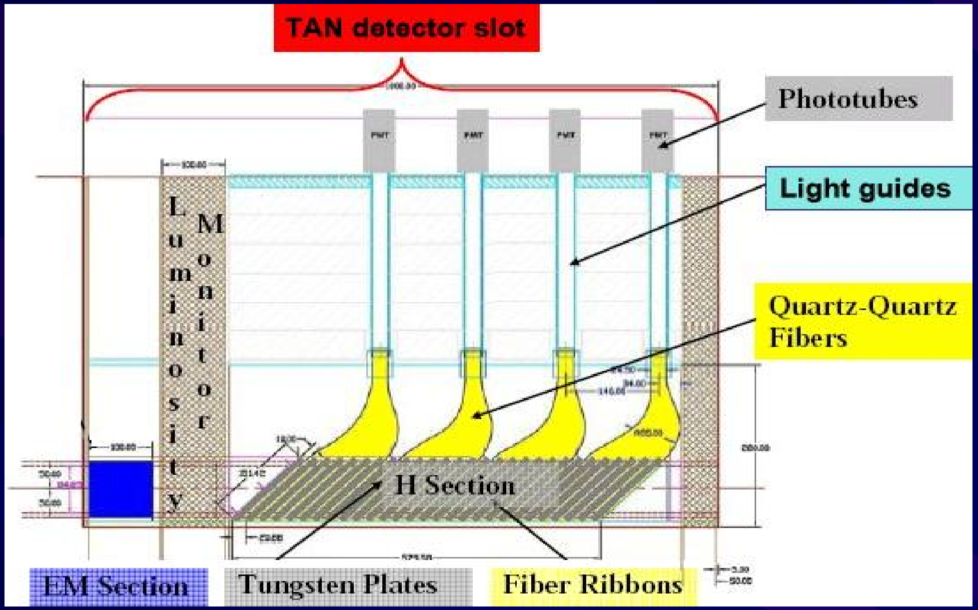
- High p_T Jets - detailed studies of jet fragmentation, centrality dependence, azimuthal asymmetry, flavor dependence, leading particle studies
- High energy photons, Z^0
- jet-γ, jet-Z^0, multijet events
- Quarkonia (J/ψ, Υ) and heavy quarks

Forward Physics

- Limiting Fragmentation, Saturation, Color Glass Condensate
- Ultra Peripheral Collisions
- Exotica

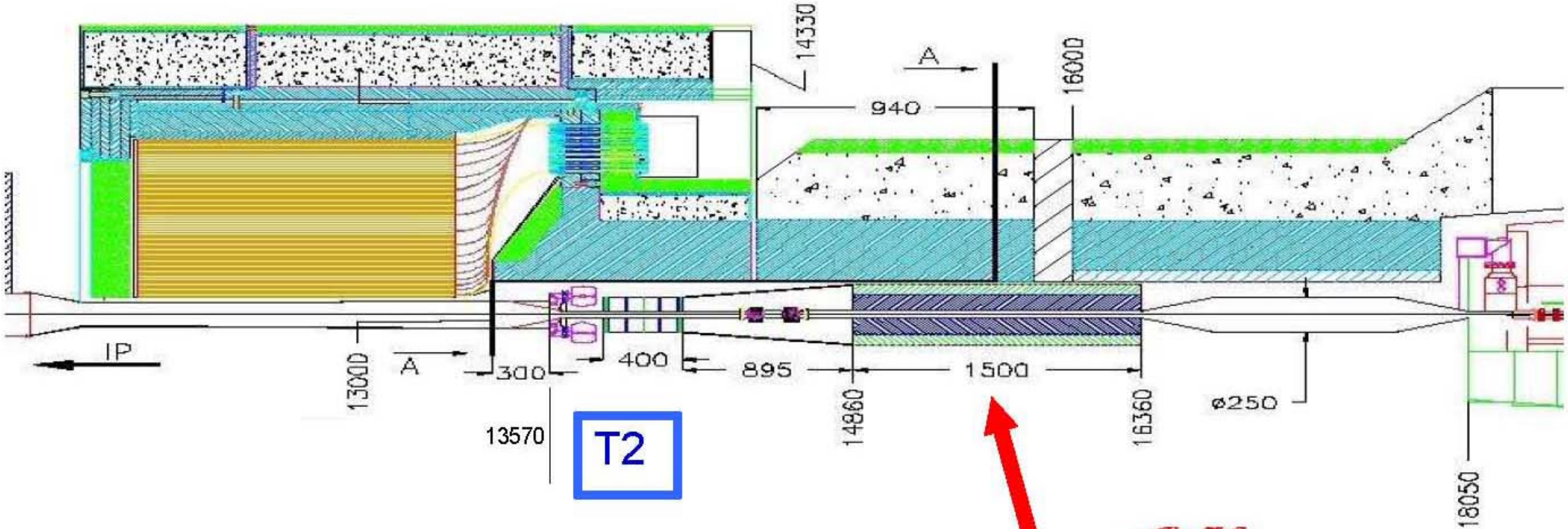
Backups

Zero Degree Calorimeter

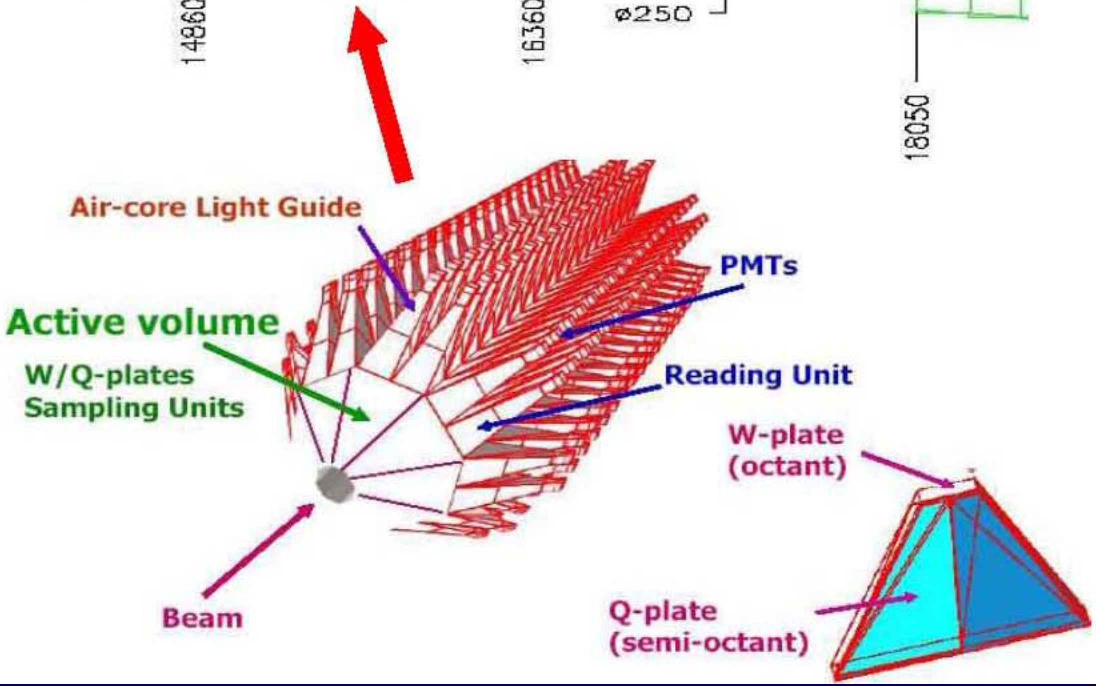


- Tungsten-quartz fibre structure
- electromagnetic section: $19X_0$
- hadronic section $5.6\lambda_0$
- Rad. hard to ≈20 Grad (AA, pp low lum.)
- Energy resolution: ≈10% at 2.75 TeV
- Position resolution: ≈2 mm (EM sect.)

CASTOR



- Tungsten plates + quartz fibres
- Cherenkov sampling calorimeter
- Light-guides + APDs readout
- Azimuth segmented (8 octants)
- EM section: 11.2 cm ~ 19 X_0
- HAD+EM sections: 136 cm~ 10 λ_I
- 192 channels



TOTEM (T2)

- TOTEM GEM ("Gas Electron Multiplier") charged particle telescope detector: