



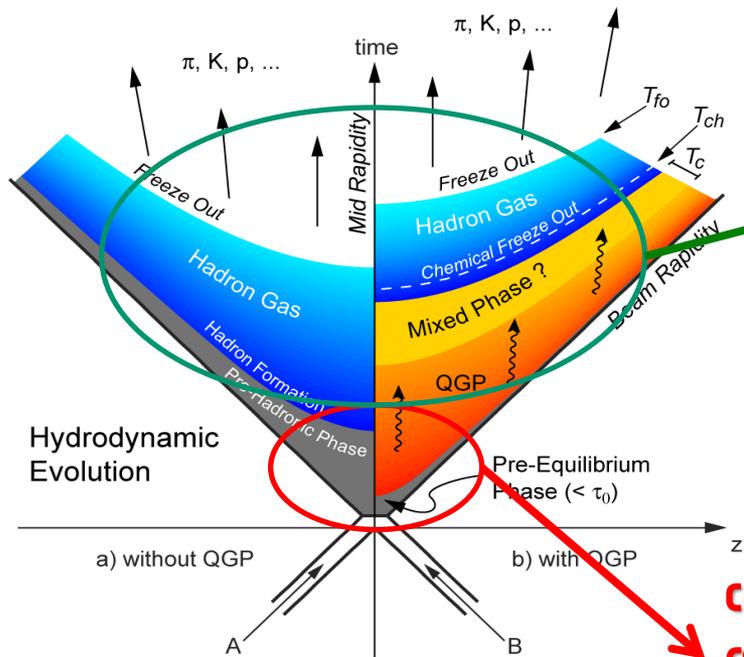
# CMS

Compact Muon Solenoid

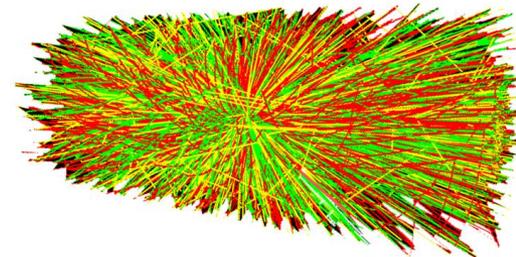
## *Recent Results from CMS Heavy Ion at LHC*

***15<sup>th</sup> April 2011***

***Inkyu PARK***  
***Dept. of Physics, University of Seoul***



Hydrodynamics  
Medium viscosity  
QCD EoS



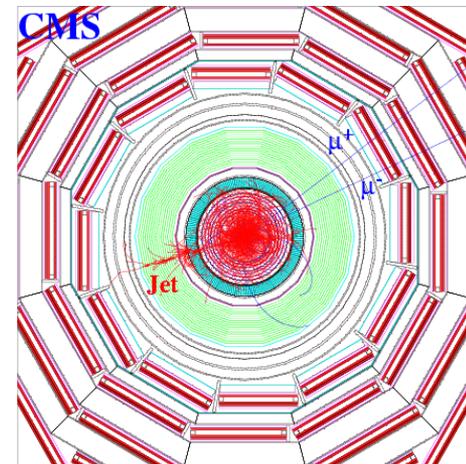
### SOFT observables

- $dN_{ch} / d\eta$
- Low  $p_T$  spectra
- Elliptic flow
- Thermal photons
- ...

Color charge density, Transport coefficient, QCD  $E_c$  &  $T_c$

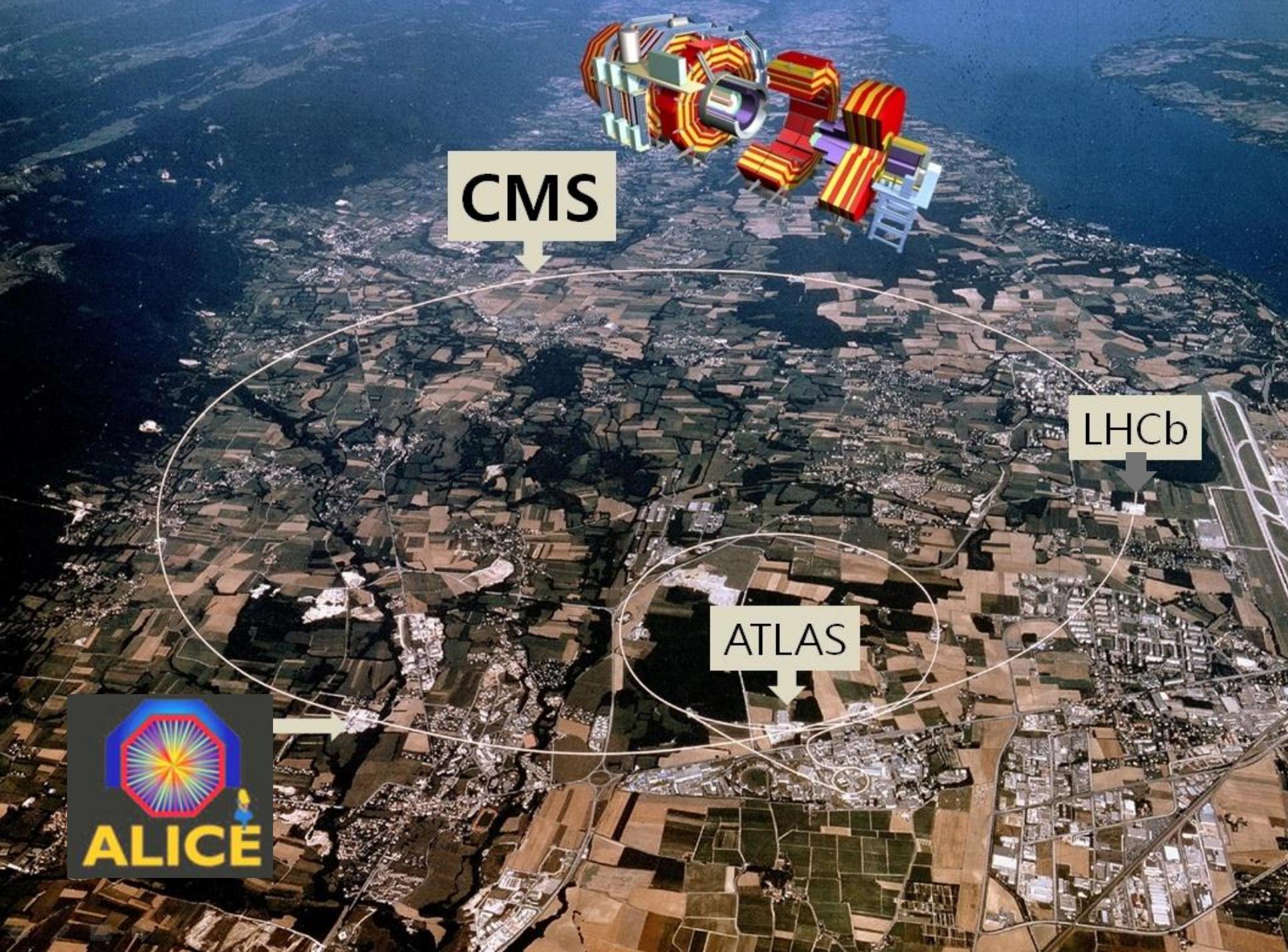
### Hard observables

- High  $p_T$  spectra
- Jets
- $\gamma$  ( $\gamma^*$ ,  $Z^0$ )-jet correlation
- Quarkonia
- ...



LHC / LHiC

as a new tool for HI Physics



**CMS**

**LHCb**

**ATLAS**





# 2010 LHC HI run



3.5TeV+3.5TeV

→ E=7TeV



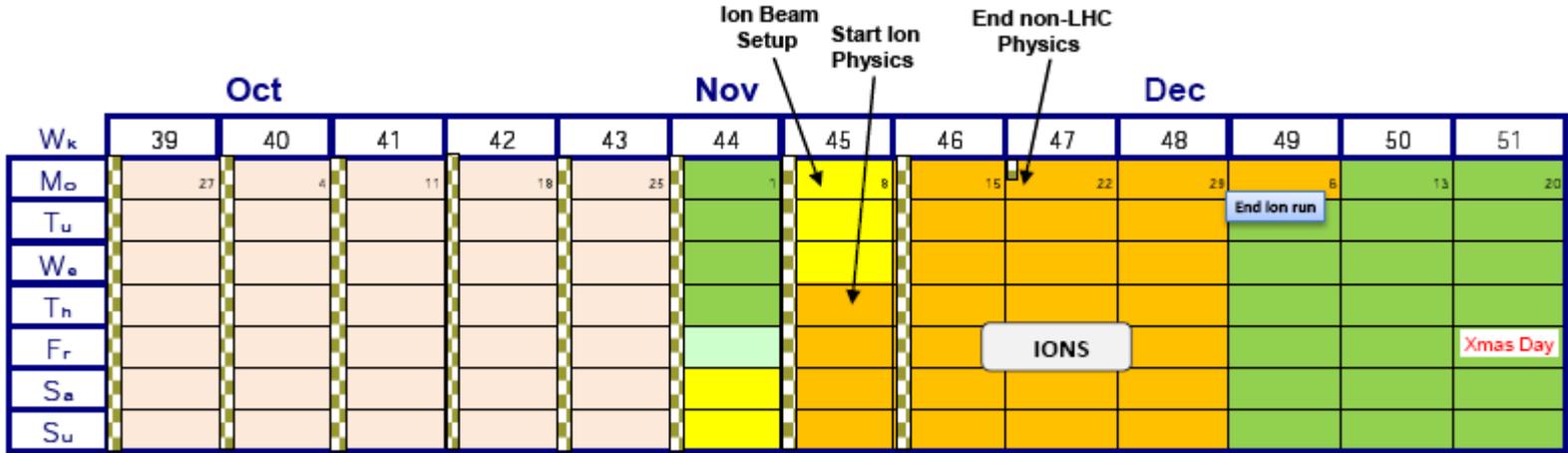
1.38ATeV+1.38ATeV

→ E=2.76ATeV

$^{208}_{82}Pb$

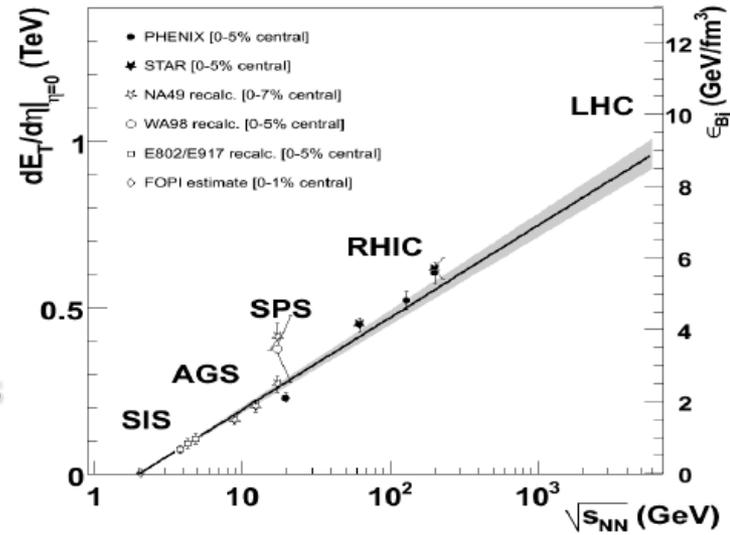
$$3.5 \cdot \frac{82}{208} = 1.38\text{TeV}$$

- Technical Stop
- Recommissioning with beam
- SPS et al - physics
- Ion run
- Ion setup



## □ A big energy jump!

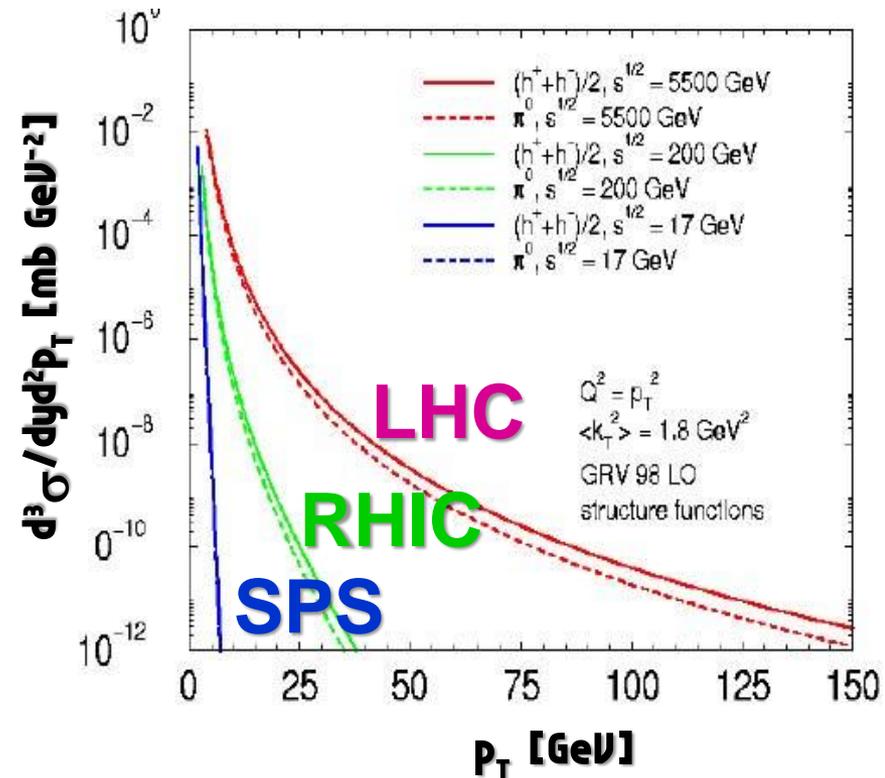
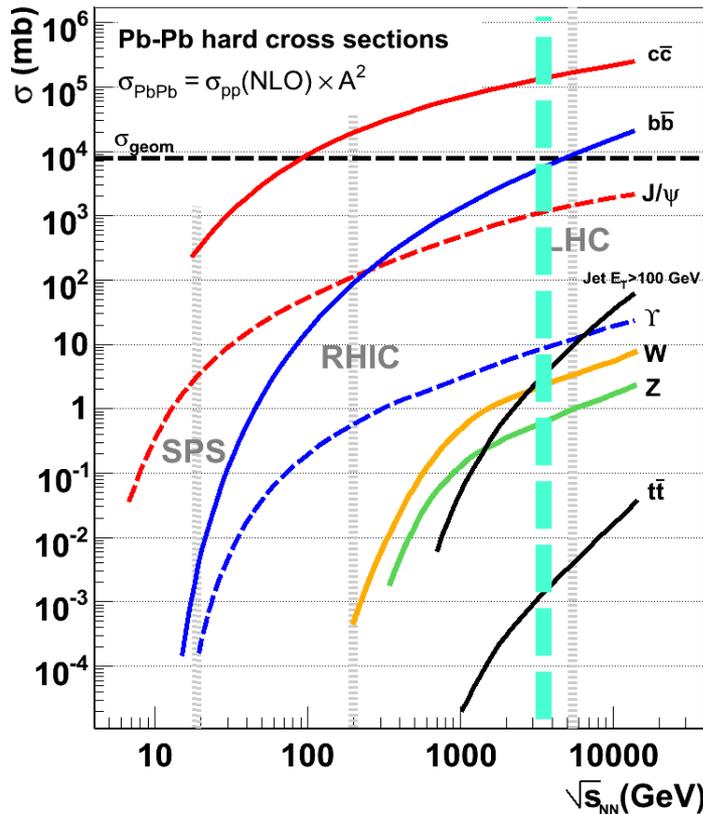
- Extended kinematic reach for pp, pA, AA
- New properties of the initial state, possible gluon saturation
- A hotter and longer lived partonic phase
- Increased cross sections, new hard probes



$$e_{Bjorken} @ \frac{1}{t_0(pR^2)} \frac{dE_T}{dh} \approx 3 \times 10 \text{ GeV/fm}^3, \text{ with } t_0 \approx 1 \text{ fm/c}$$

	AGS	SPS	RHIC	LHC (2010)	LHC(nomi nal)
$\sqrt{s_{NN}}$	5 GeV	20 GeV	200 GeV	2.76 TeV	5.5 TeV
E increase		x 4	x 10	x 14	x 2

- ❑ Various hard probes over a larger kinematic range
- ❑ Plenty of heavy quarks (b & c)
- ❑ Weakly interacting probes are available ( $W^\pm$  &  $Z^0$ )

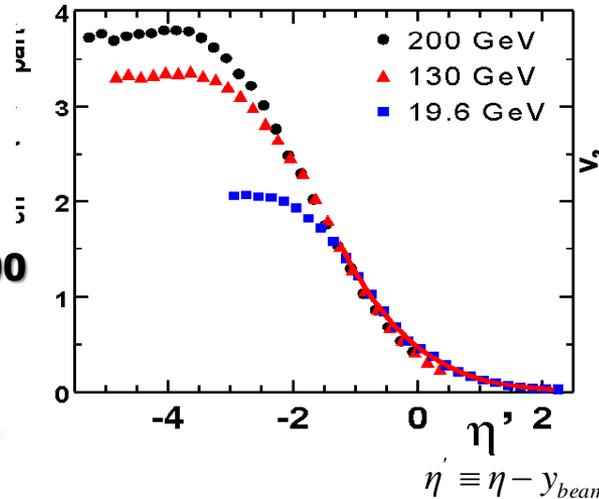
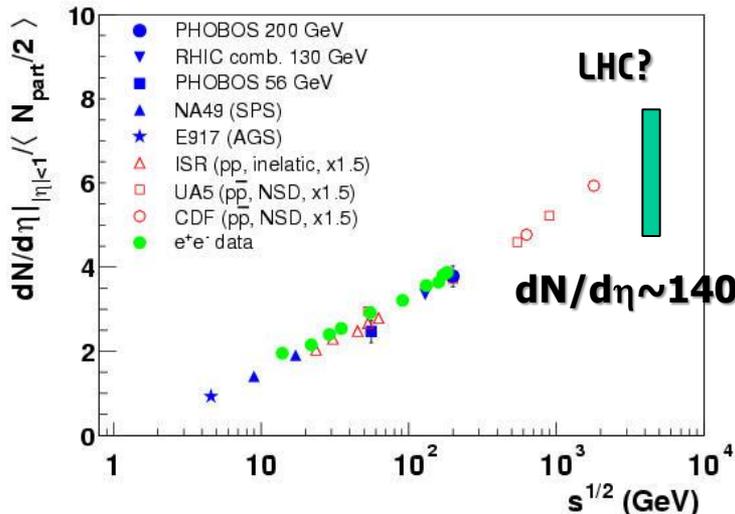




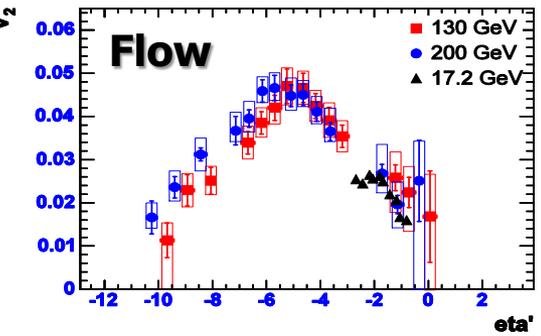
# Soft observables: RHIC → LHC



- RHIC shows a simple energy dependence. How about at the LHC?

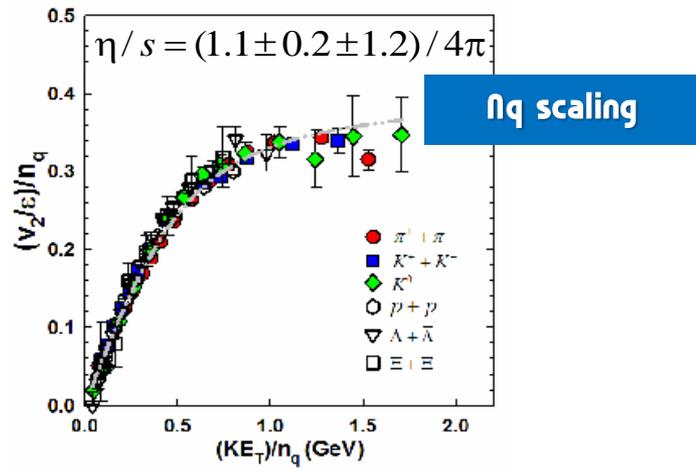
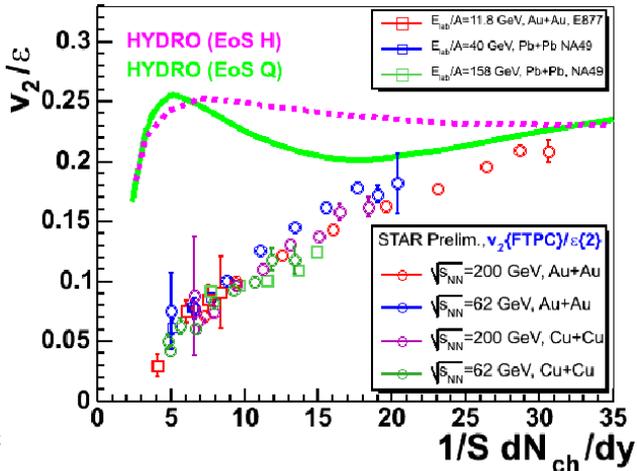
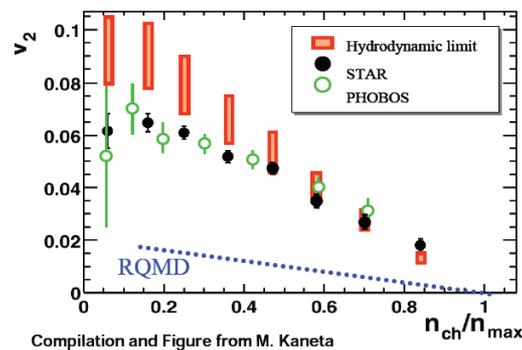


*Charged particle multiplicity, limited fragmentation*



- RHIC prefers Hydrodynamic limit. How about at the LHC?

PHOBOS: Phys. Rev. Lett. 89, 222301 (2002)  
STAR: Phys. Rev. Lett. 86, 402 (2001)



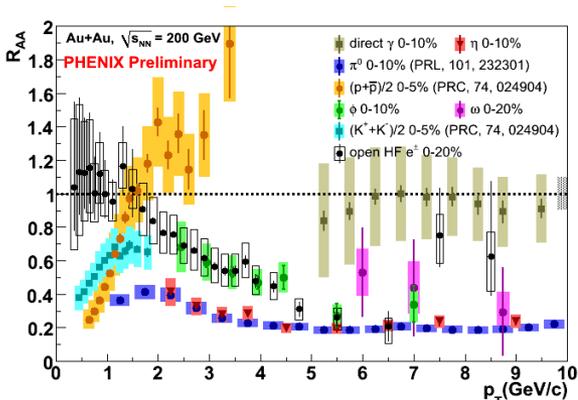


# Hard observables: RHIC $\rightarrow$ LHC

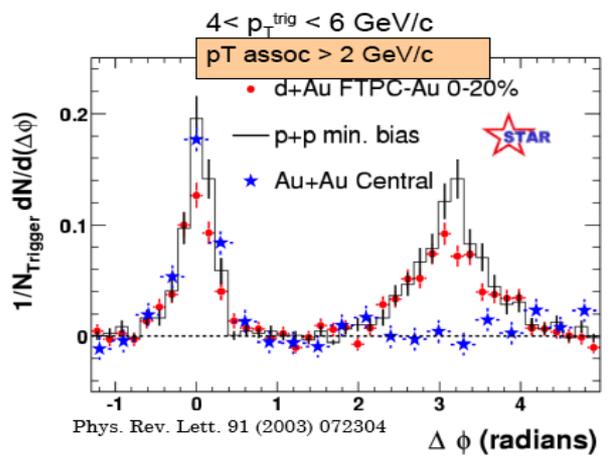
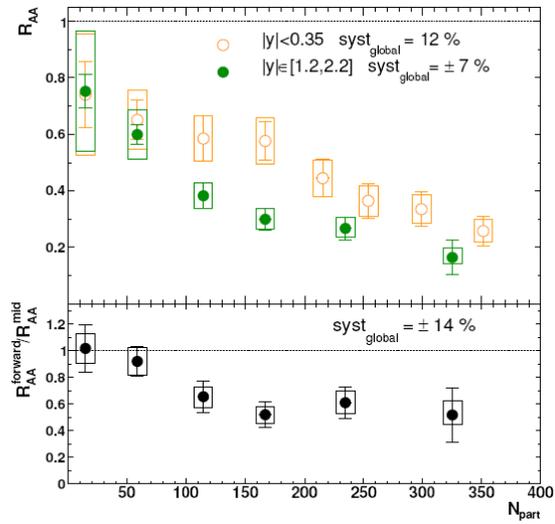


**Jet quenching: strong interaction of high- $p_T$  hadrons with dense medium**

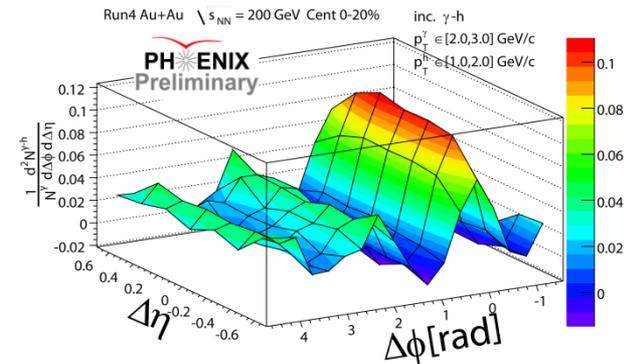
**Strongly coupled hot & dense matter**



**J/ $\psi$  suppression: SPS  $\approx$  RHIC, larger at forward (CGC?)**



**Jets are modified in medium.**



- **Data from SPS & RHIC show new and unexpected properties of hot nuclear matter**
  - **Jet quenching, strong elliptical flow, d+Au- control data indicate that we have produced strongly interacting color liquid**
- **LHC significantly increases energy density**
  - **new properties of the QGP**
    - **Continuation of strong coupling regime?**
    - **Weakly interacting Plasma?**
  - **New discoveries are guaranteed!**

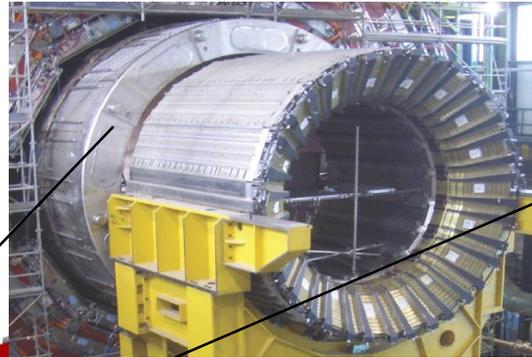
# CMS as detectors for HI Physics



**ECAL**

Scintillating PbWO4 crystals

4 Tesla  
Superconducting  
**COIL**



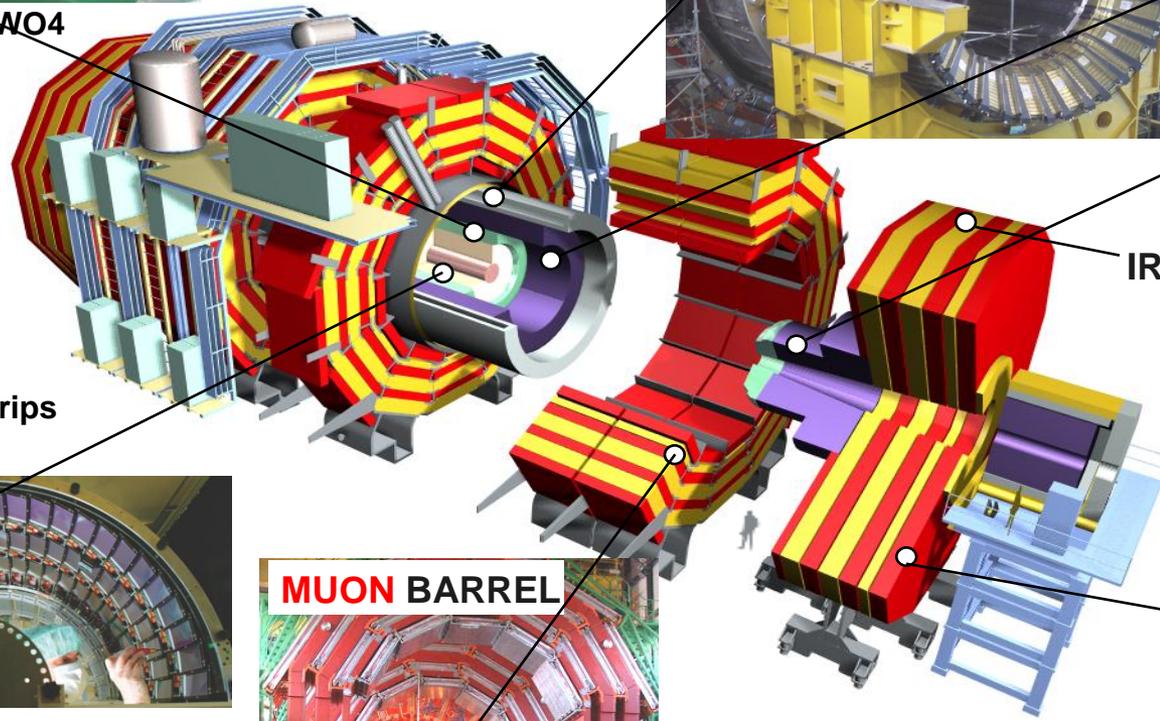
Plastic scintillator/brass sandwich  
**HCAL**



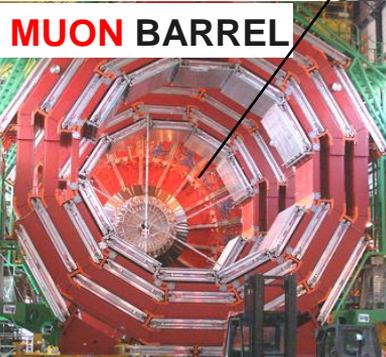
**TRACKER**  
Silicon Microstrips  
Si Pixels



**Length: 21.6 m**  
**Diameter: 15 m**  
**Weight: ~12500 tons**



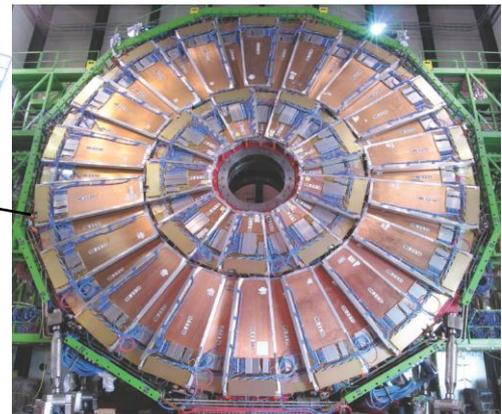
**IRON YOKE**



**MUON BARREL**

Drift Tube  
Chambers ( DT )  
Resistive Plate  
Chambers ( RPC )

**MUON ENDCAPS**



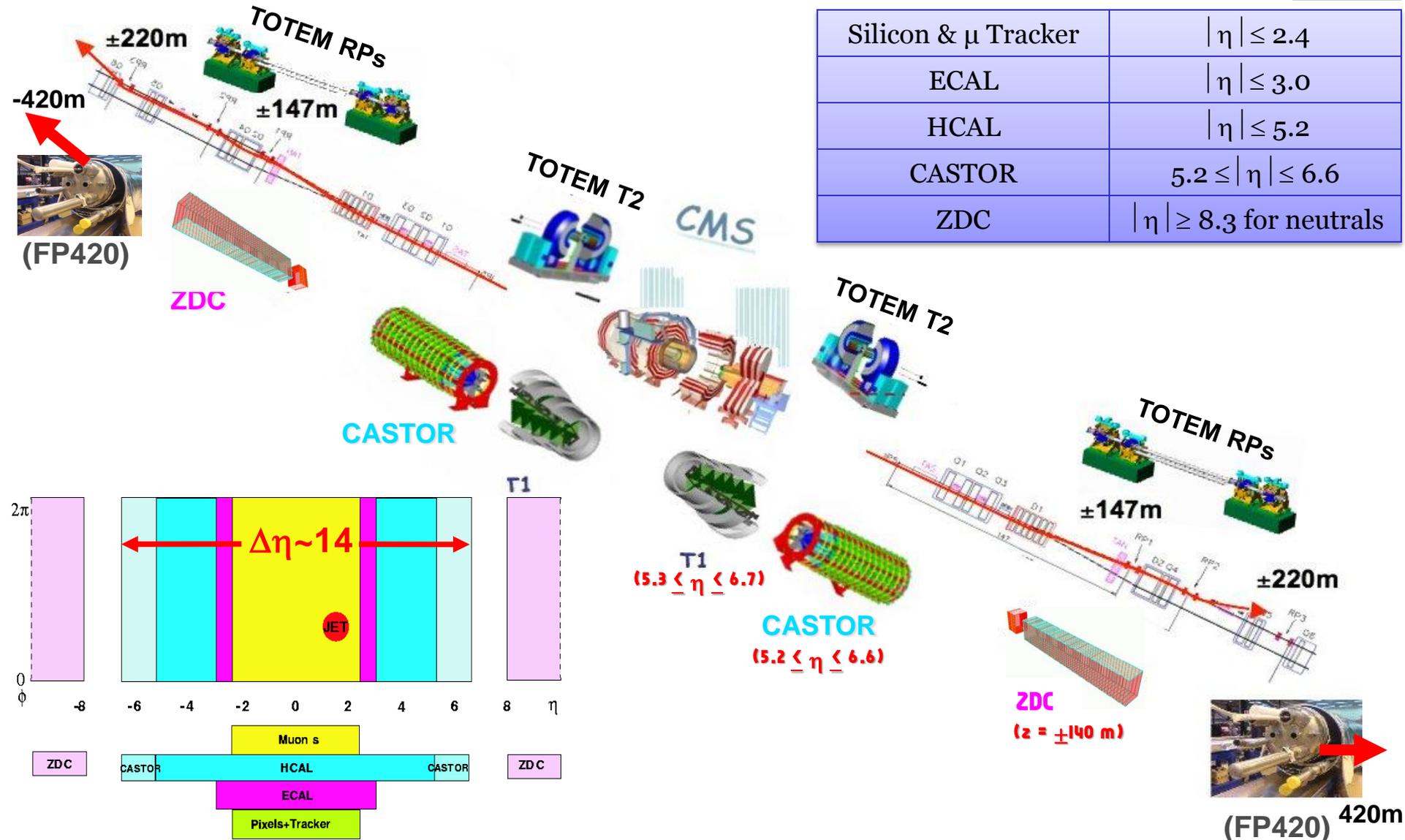
Cathode Strip Chambers ( CSC )  
Resistive Plate Chambers ( RPC )



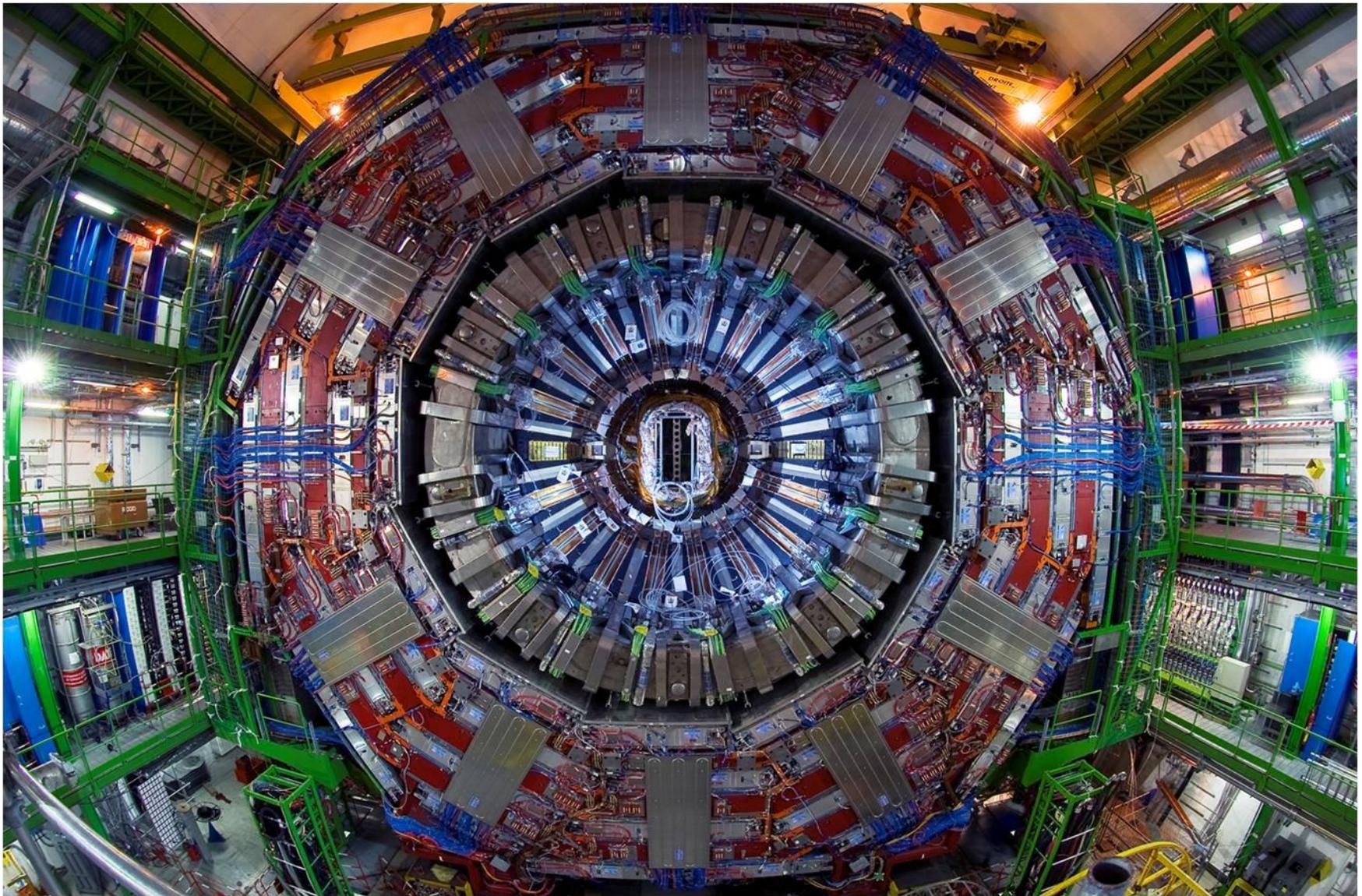
# CMS add-ons

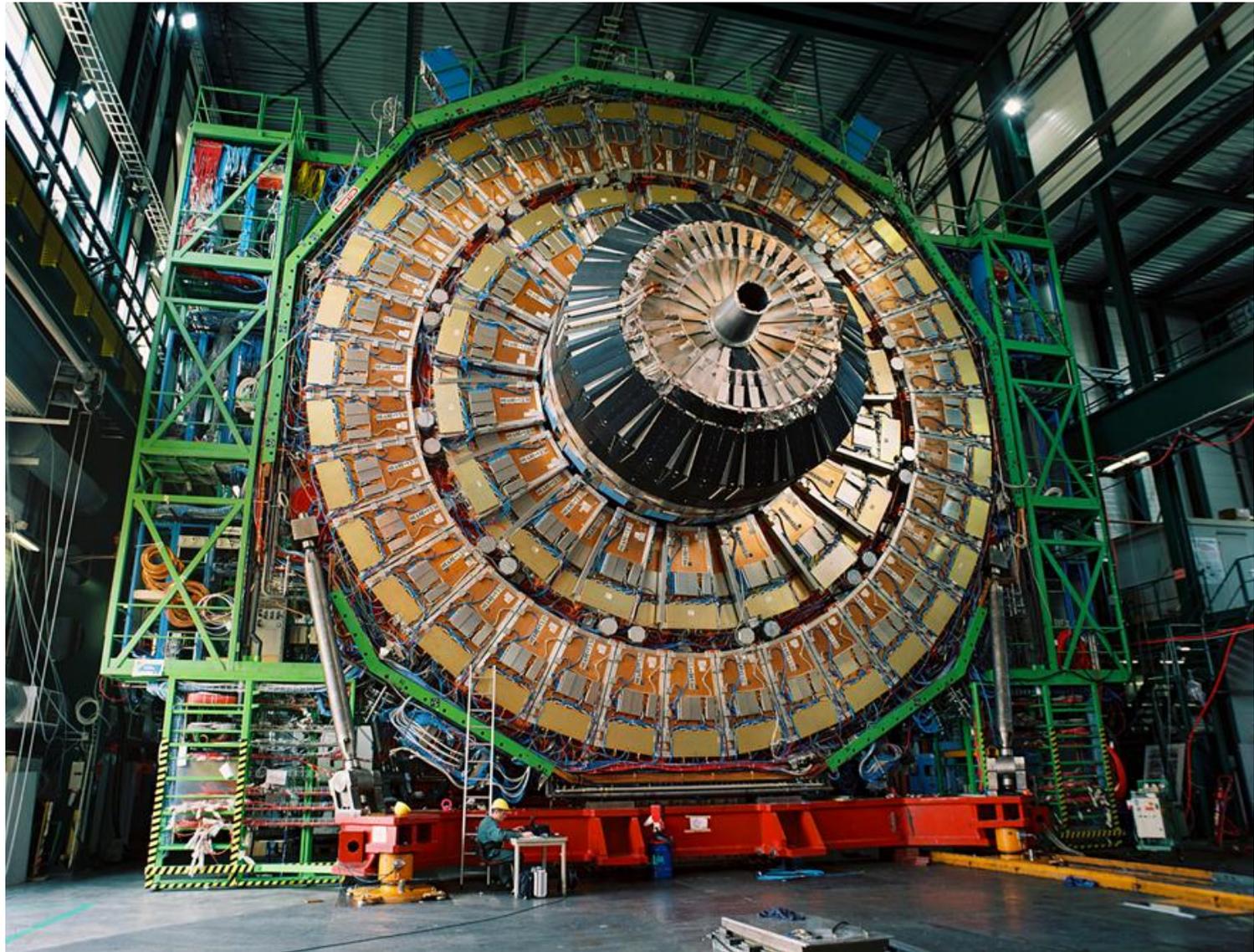


Silicon & $\mu$ Tracker	$ \eta  \leq 2.4$
ECAL	$ \eta  \leq 3.0$
HCAL	$ \eta  \leq 5.2$
CASTOR	$5.2 \leq  \eta  \leq 6.6$
ZDC	$ \eta  \geq 8.3$ for neutrals





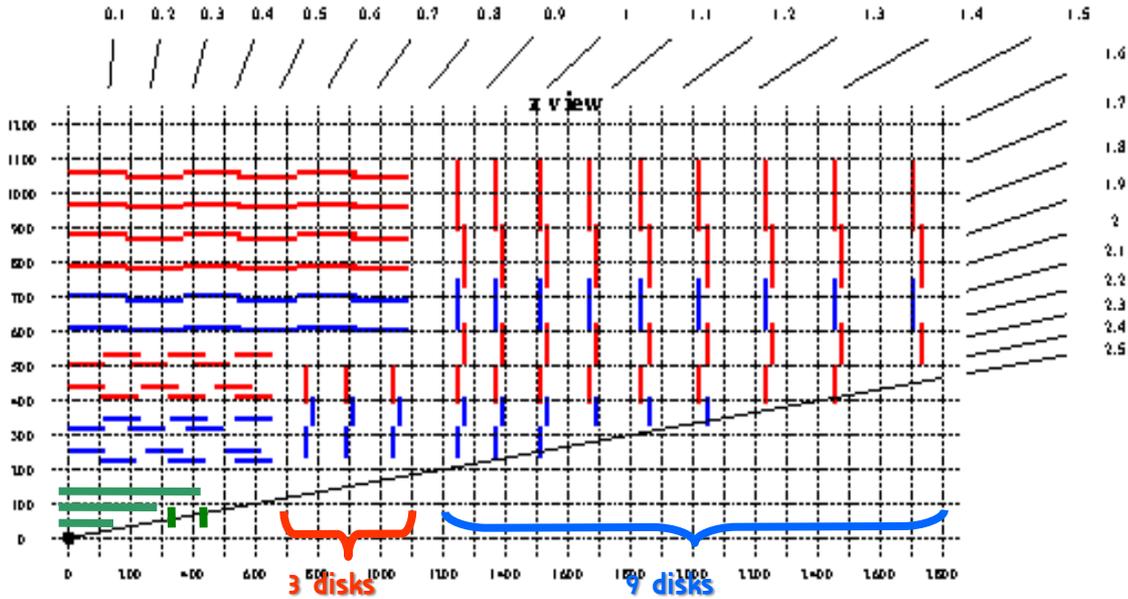




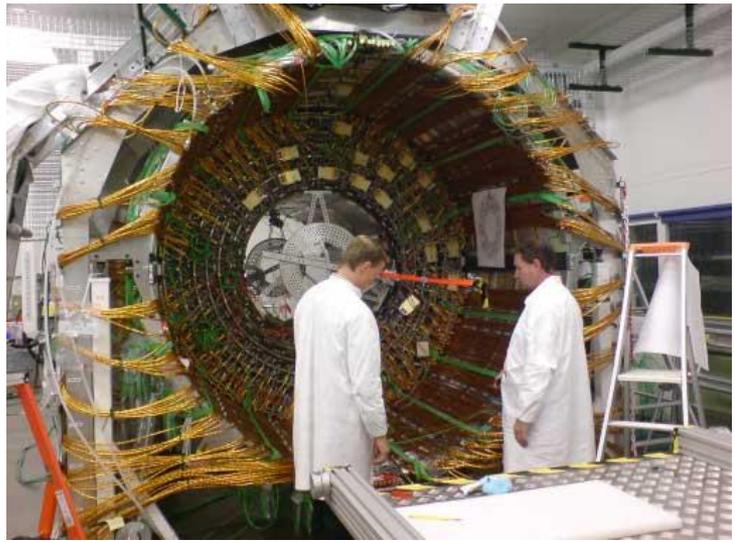
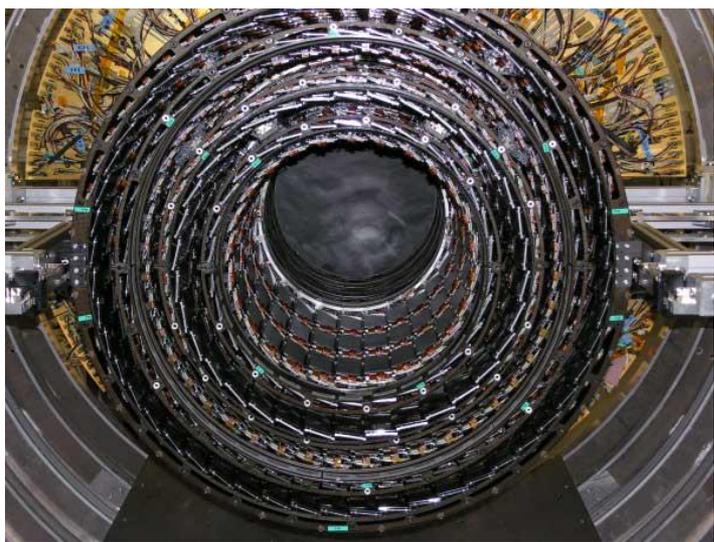
6 layers  
Outer  
Barrel

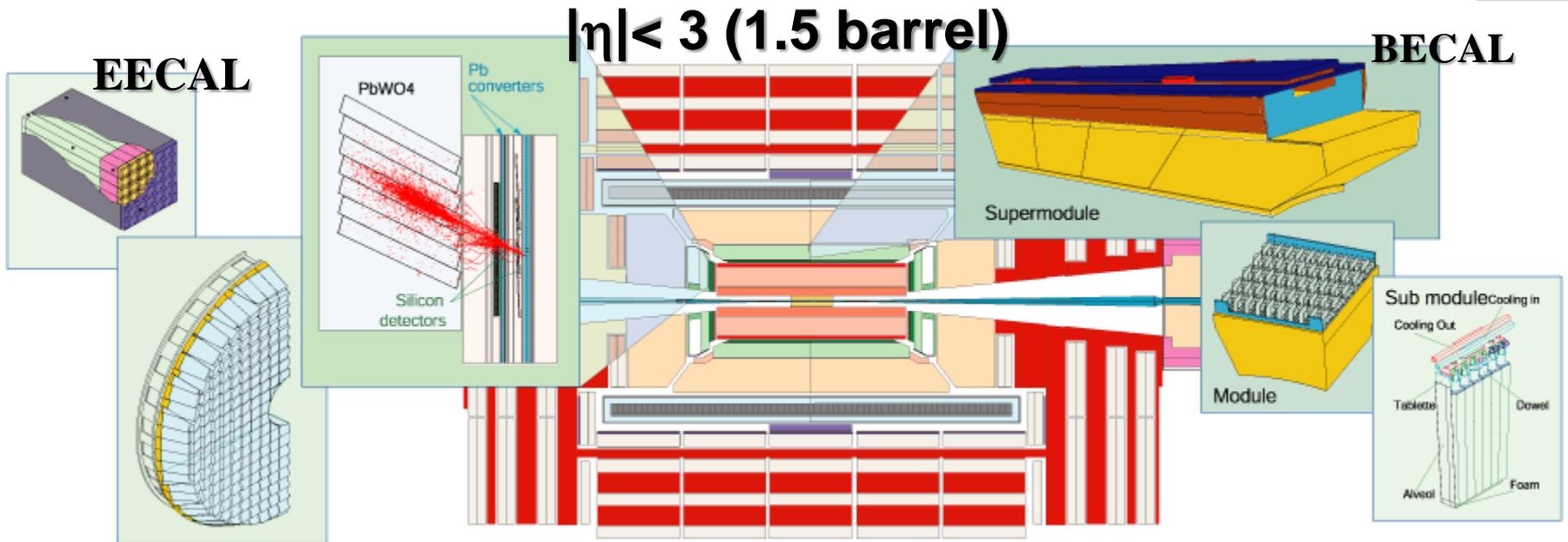
4 layers  
Inner  
Barrel

3 Pixel  
Layers

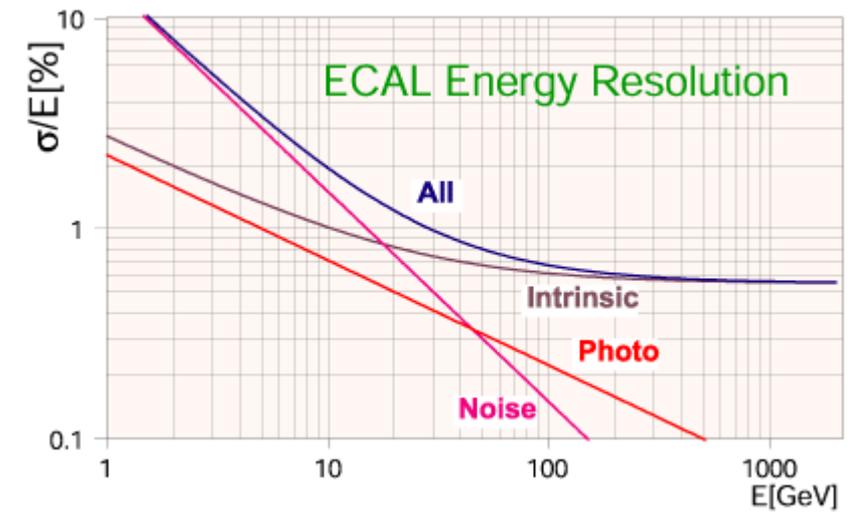


**Total 66M Si Pixels**  
**Occupancy < 2% at  $dN_{ch}$**   
 **$1 d n \approx 3500$**



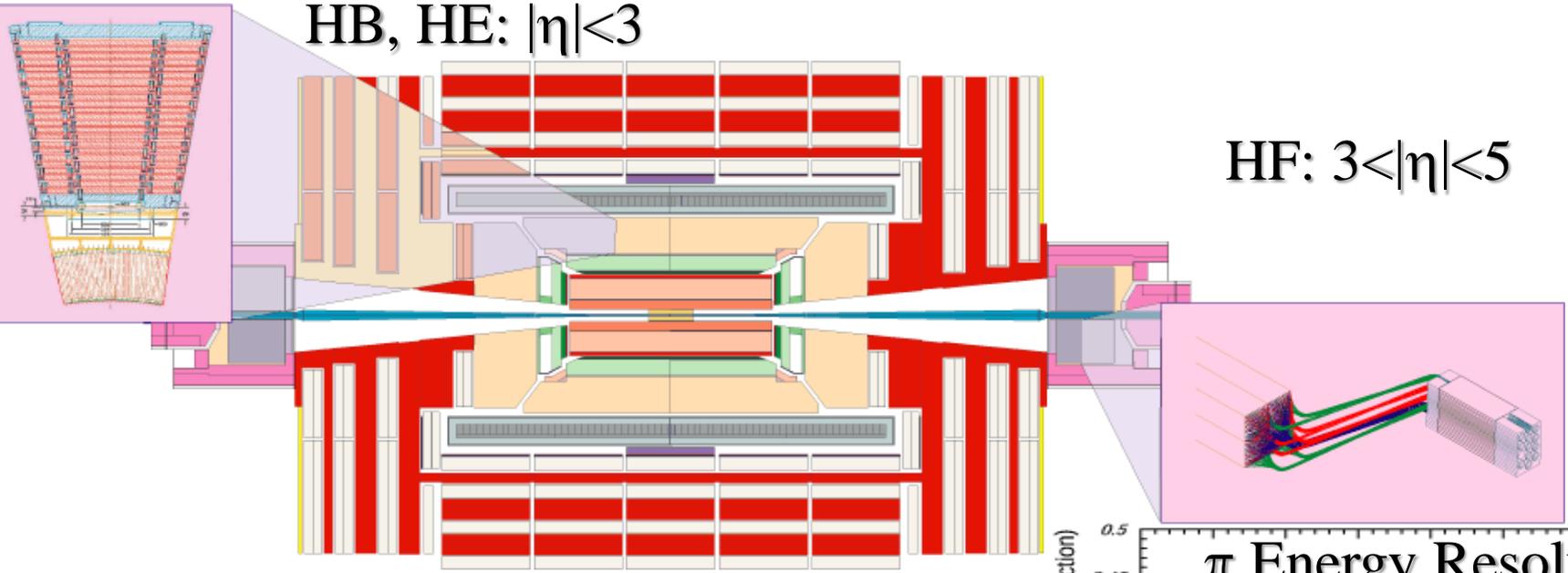


- 76000 PbWO<sub>4</sub> crystals
  - Granularity in  $\Delta\eta \times \Delta\phi$  :
  - 0.0174 x 0.0174 (Barrel) and
  - 0.0174 x 0.0174 to 0.05x0.05 (Endcap)

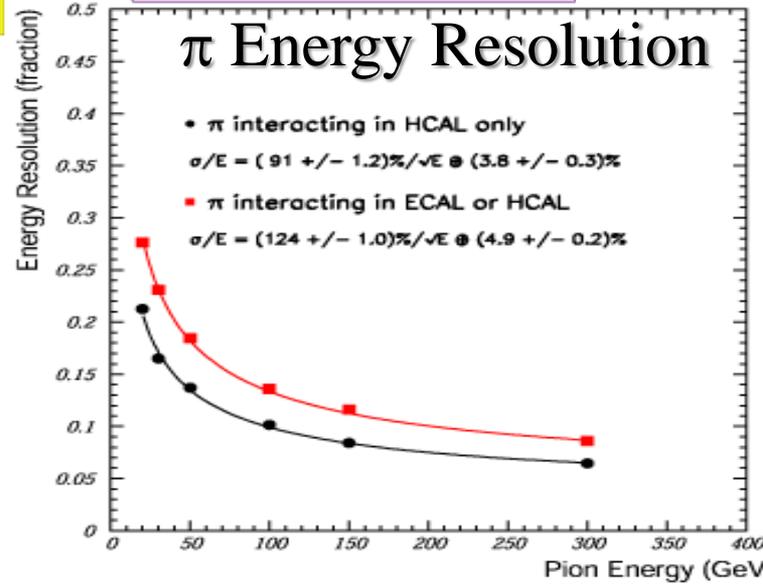


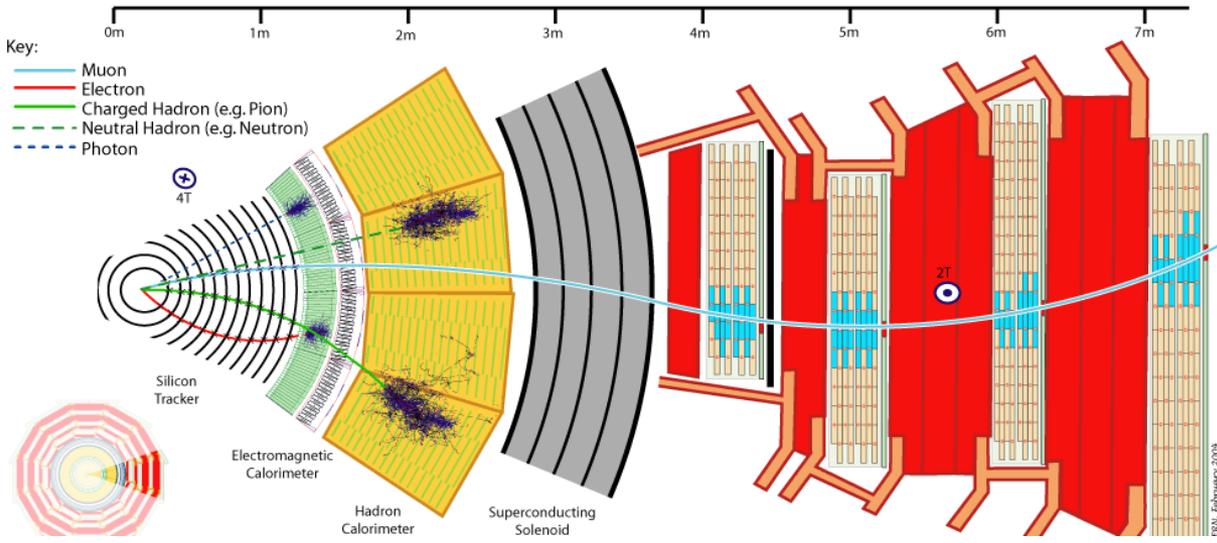
HB, HE:  $|\eta| < 3$

HF:  $3 < |\eta| < 5$

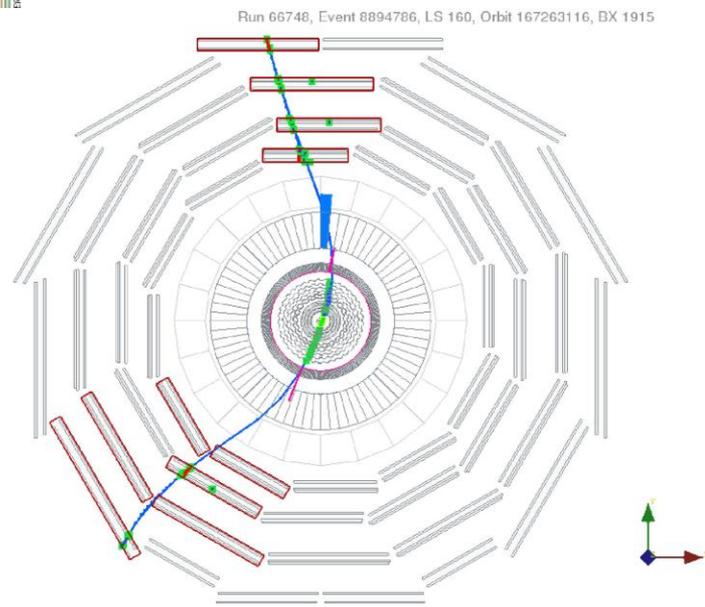


- ❑ Barrel (HB) and Endcap (HE): Cu/Scintillator
- ❑ Forward (HF): Fe/Cerenkov(fiber)
- ❑ High granularity:  $\Delta\eta \times \Delta\phi$ 
  - $0.087 \times 0.087$  (barrel)
  - $0.087 - 0.35 \times 0.087 - 0.175$  (endcap)
  - $0.152 - 0.3 \times 0.175$  (HF)
- ❑ 5.15 interaction lengths at  $\eta=0$
- ❑ Dynamic range: 5 MeV-3 TeV



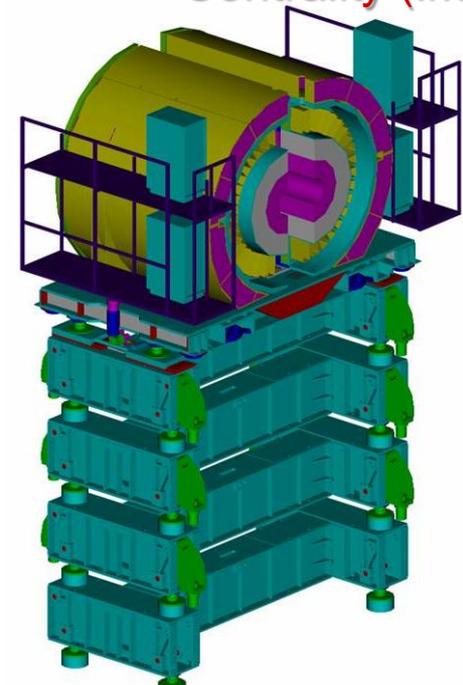


## Cosmic muon

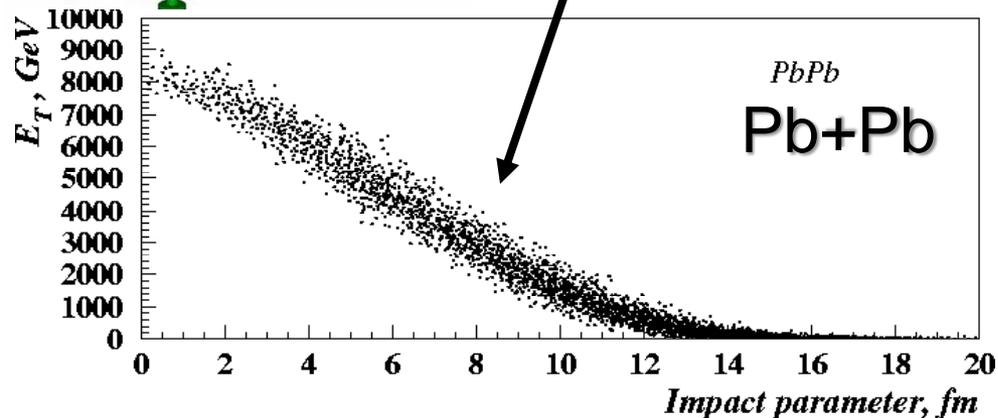


For 100GeV muons  
 $dp_T/p_T \sim 2\%$  with Inner tracker  
 $dp_T/p_T \sim 8-16\%$  with vertex constraints

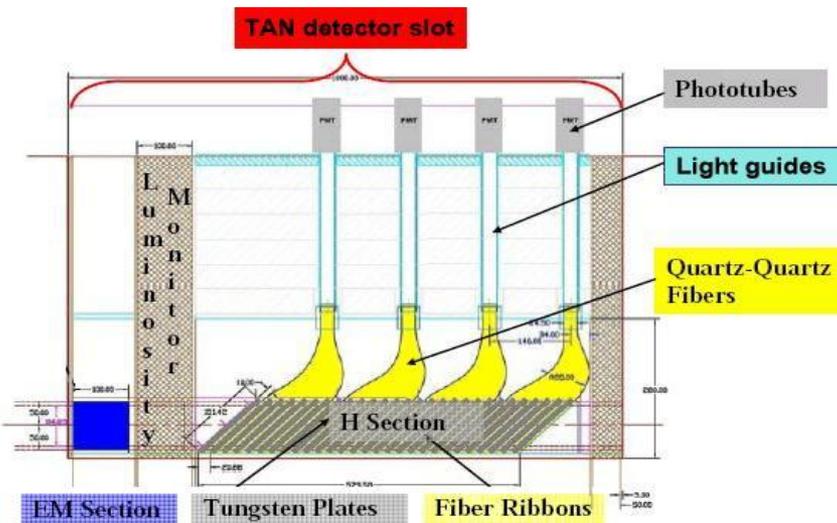
Centrality (impact parameter) determination is needed for physics analysis



Energy in the forward hadronic calorimeter



## Zero Degree Calorimeter



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

## □ CMS Heavy Ion institutions:

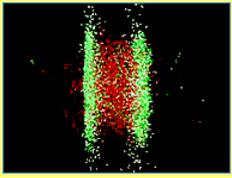
– 13 countries, 25 institutions, > 100 participants, ~10 koreans

- CERN, Croatia (Zagreb), Greece (Athens, Ioannina), France (Lyon, Paris), Hungary (Budapest), India (Mumbai), Korea (Seoul, Korea Univ.), Lithuania (Vilnius), New Zealand (Auckland), Portugal (Lisbon), Russia (Moscow), Turkey (Cukurova), USA (Colorado, Iowa, Kansas, Los Alamos, Maryland, Minnesota, MIT, Vanderbilt, UC Davis, UI Chicago)



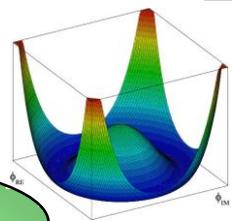


# Korea CMS Collaboration

**Heavy Ion**

**Higgs search**

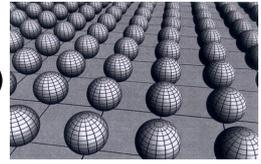


**QCD**

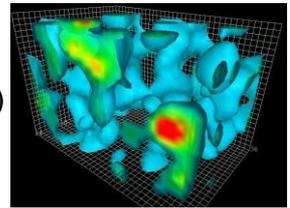
**Beyond SM**



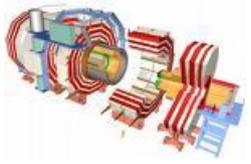
**ExtraD**



**SUSY**



**Detector R&D**



**Computing**



**Operational Committee**

**6 universities:**  
 KU, KNU, SKKU,  
 UoS, CNU, KWNU

**12 faculties,**  
**10 post-doc researchers,**  
**28 graduate students**



# Korea CMS Heavy Ion team



Soft observable:  
Elliptic flow



Hard observable:  
Quarkonia (J/psi, Y)

**Prof. I.C. Park**  
**Dr. C.W. Park**  
**S.K. Kang**  
**M.K. Choi**  
**G.M. Ryu**

**Prof. K.S. Sim**  
**Prof. B.S. Hong**  
**D.H. Moon**  
**H.C. Kim**  
**J.H. Kim**  
**M.H. Cho**

# Recent results



# Excuse us!



- ❑ Most of CMS results are to be approved soon for Quark Matter 2011, which will be held in May
  - results & plots are not allowed before the conference
- ❑ Korea CMS made major contributions in muon analysis (J/Psi) and flow ( $v_2$ )
  - J/Psi will be presented in QM by D.H. Moon
  - $v_2$  are in the process of approval (a CMS note)
- ❑ In March 4, CMS showed only limited results in a HI@LHC workshop.
  - Thus, I could only pick up few slides from this approved plots
  - $Z^0$  in Hot & Dense matter, Jet imbalance
- ❑ Most of approved results will be shown in QM2011



# Latest survey



HI at the LHC: a first assessment (04 March 2011)

http://indico.cern.ch/conferenceDisplay.py?confid=118273

HI at the LHC: a first assessment (04 March 2011)

## HI at the LHC: a first assessment

04 March 2011 CERN  
Europe/Zurich timezone

**Overview**

- Timetable
- Registration
  - Registration Form
- List of registrants
- Video Services

A discussion of the first results from the 2010 heavy ion run of the LHC, with an assessment of their theoretical implications.

The meeting will be broadcast via EVO (detailed info will appear at the time of the meeting in the "Video Services" item on the left menu bar)

For those attending, information on accommodation, access to CERN and laptop registration is available from <http://lpc.web.cern.ch/LPCC/index.php?page=visit>

**Dates:** 04 March 2011 (08:00-18:30)  
**Timezone:** Europe/Zurich  
**Location:** CERN  
 Room: TH Theory Conference Room  
**Chairs:** Mangano, Michelangelo  
 Wiedemann, Urs  
 Salam, Gavin

<http://indico.cern.ch/event/118273>  
 Last modified: 04 March 2011 20:32

Powered by Indico

## ALICE

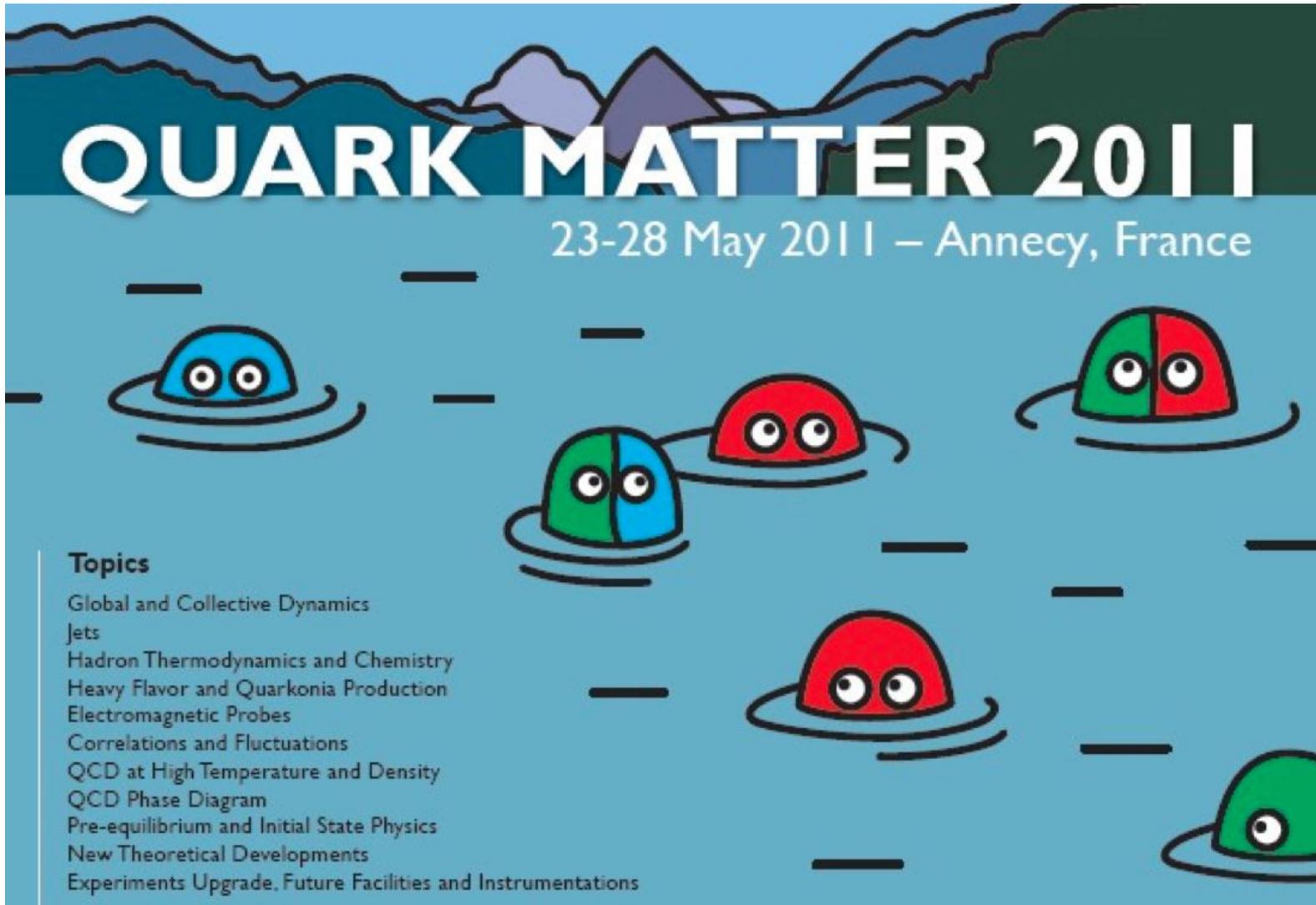
- V<sub>2</sub>, multiplicity
- Jet quenching

## CMS

- Jet, J/Psi

## ATLAS

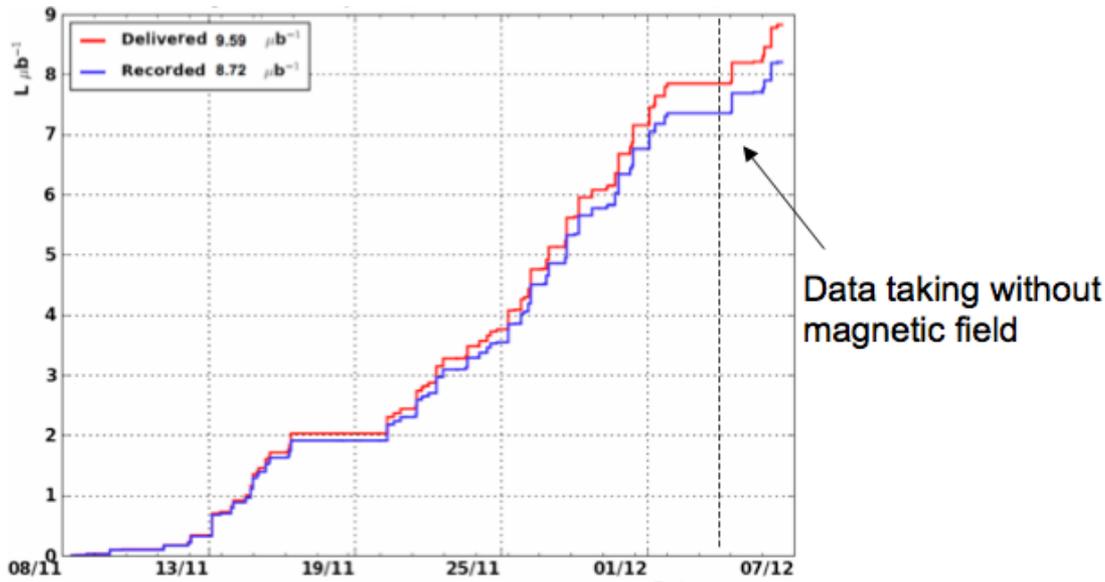
- Jet, J/Psi



The poster features a blue background with a dark blue mountain range at the top. The title 'QUARK MATTER 2011' is written in large white letters. Below the title, the dates '23-28 May 2011' and location 'Annceny, France' are displayed. The central illustration shows several colorful, cartoonish quarks (blue, red, green) with eyes, floating in a light blue liquid. Some quarks are paired together, representing hadrons. The quarks are surrounded by horizontal black dashes, suggesting a medium or field.

## Topics

- Global and Collective Dynamics
- Jets
- Hadron Thermodynamics and Chemistry
- Heavy Flavor and Quarkonia Production
- Electromagnetic Probes
- Correlations and Fluctuations
- QCD at High Temperature and Density
- QCD Phase Diagram
- Pre-equilibrium and Initial State Physics
- New Theoretical Developments
- Experiments Upgrade, Future Facilities and Instrumentations



- ❑ 2010 Mar-Nov: pp  $\sim 40 \text{ pb}^{-1}$
- ❑ 2010 Nov-Dec : Pb-Pb  $\sim 9 \mu\text{b}^{-1}$

## □ Di-muon trigger

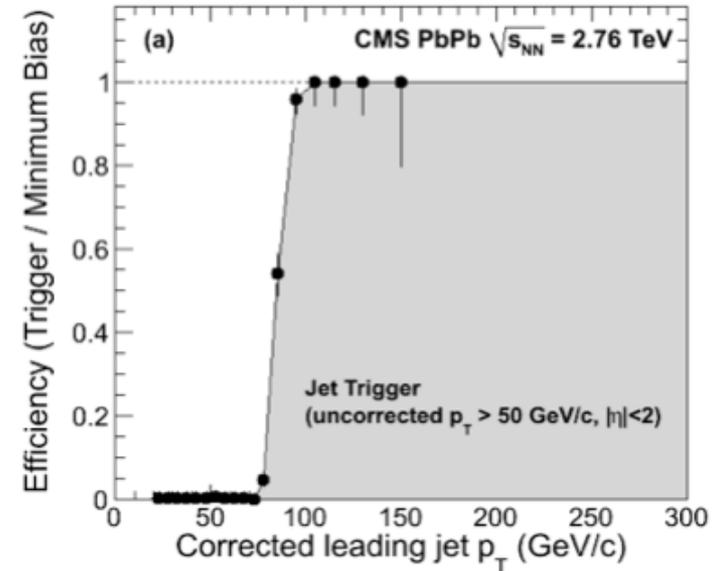
- Level1: 2 hits in the muon system
- HLT: 2 tracks with muon hits with  $P_t > 3 \text{ GeV}$

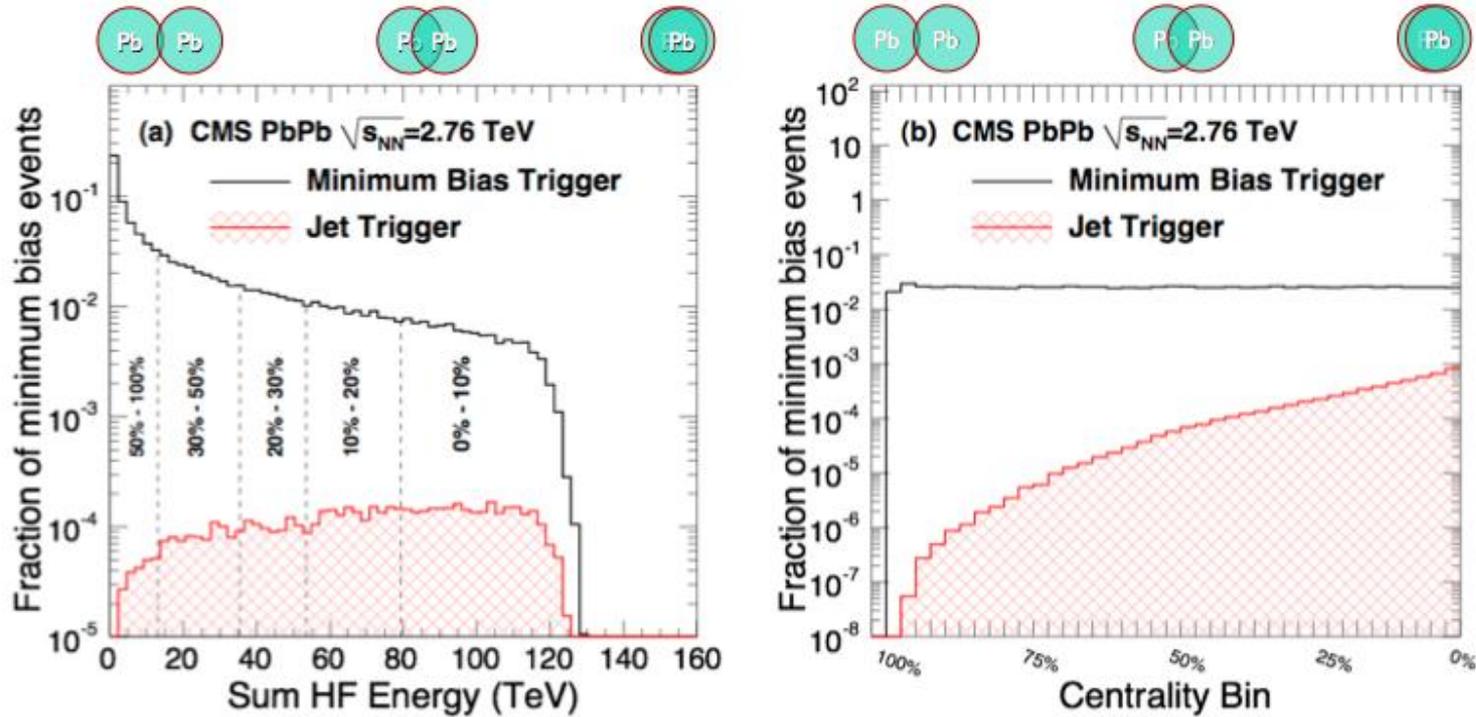
## □ Jet trigger

- Level1: A jet with Uncorrected  $E > 30 \text{ GeV}$
- HLT: A jet with bkg subtracted  $E > 50 \text{ GeV}$

## □ Min-bias trigger

- Both HF coincidence ( $\sim 97\%$ )



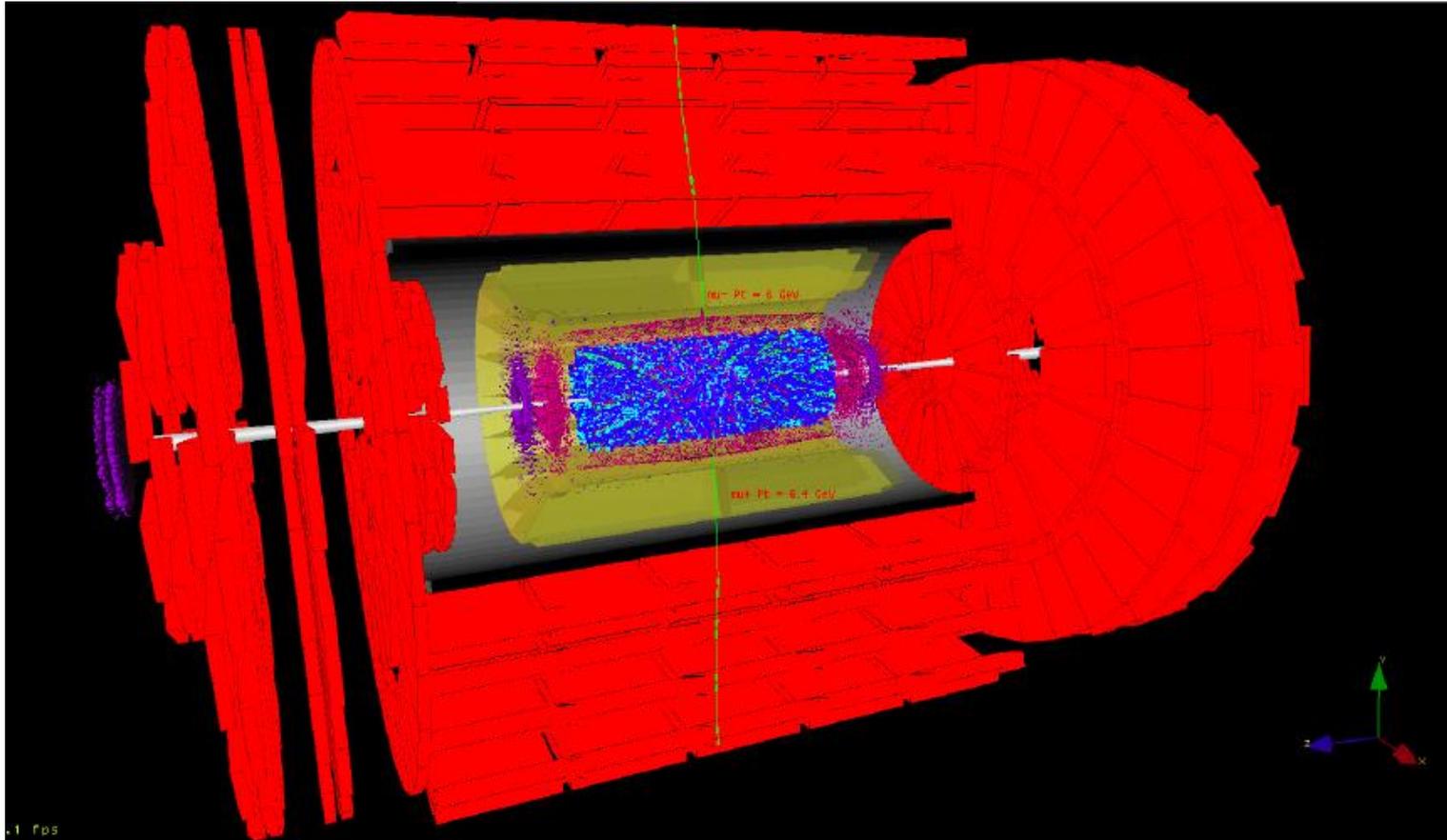


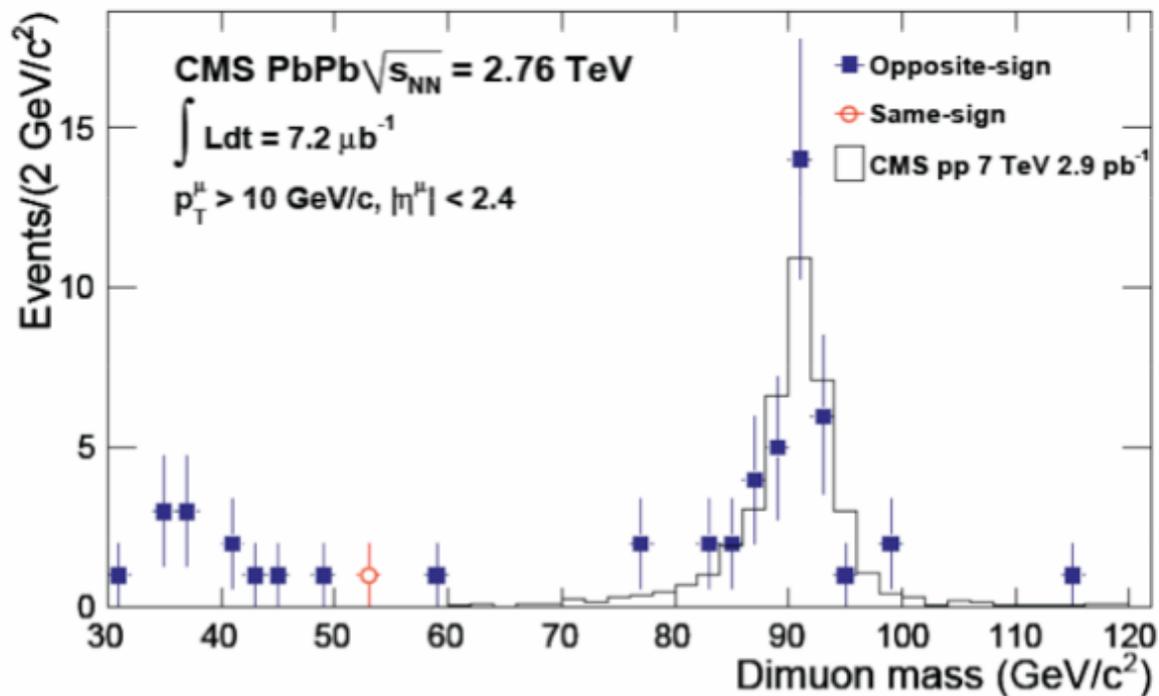
□ HF (Forward Hadron Calorimeter) energy  
 → participants → centrality

from C. Roland talk on 2011/03/04 in “HI at the LHC: a first assessment”

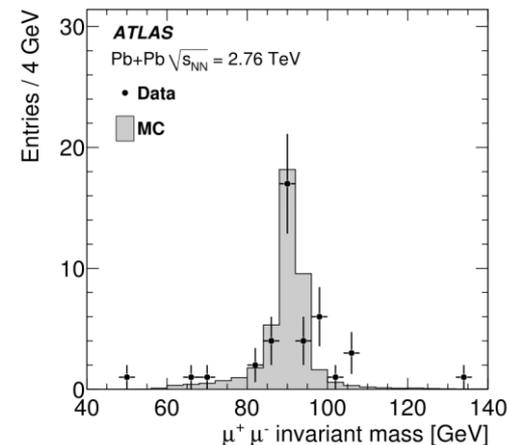
# Muons in Hot & Dense matter

**Pb+Pb event with  $\mu^+\mu^-$**





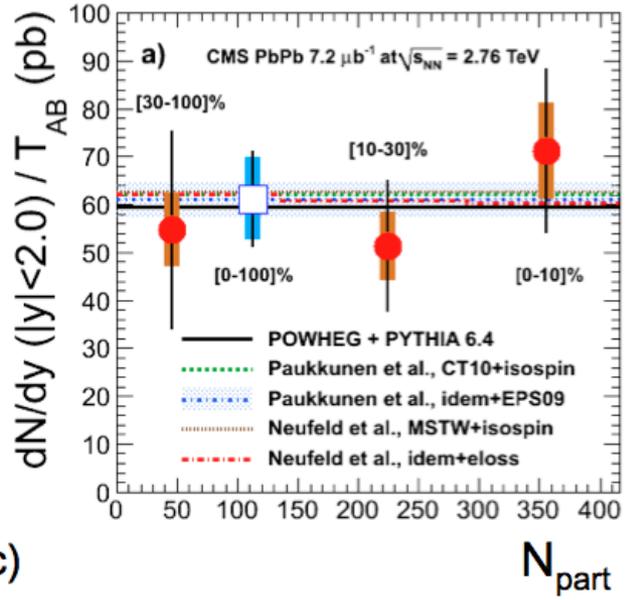
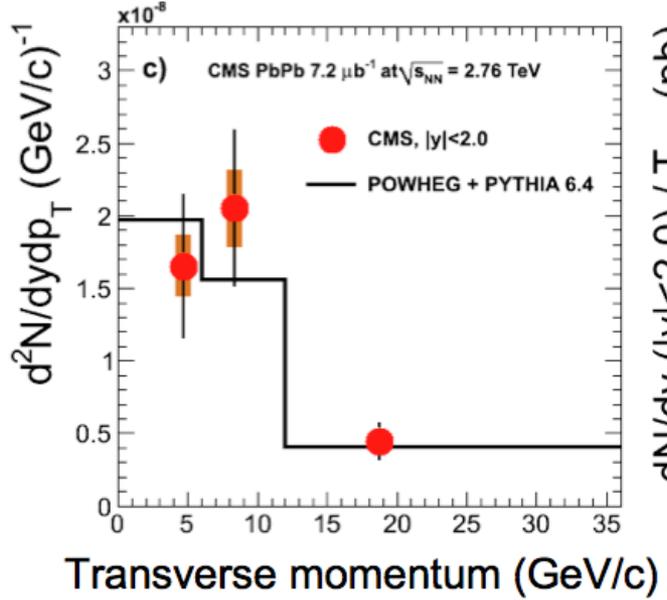
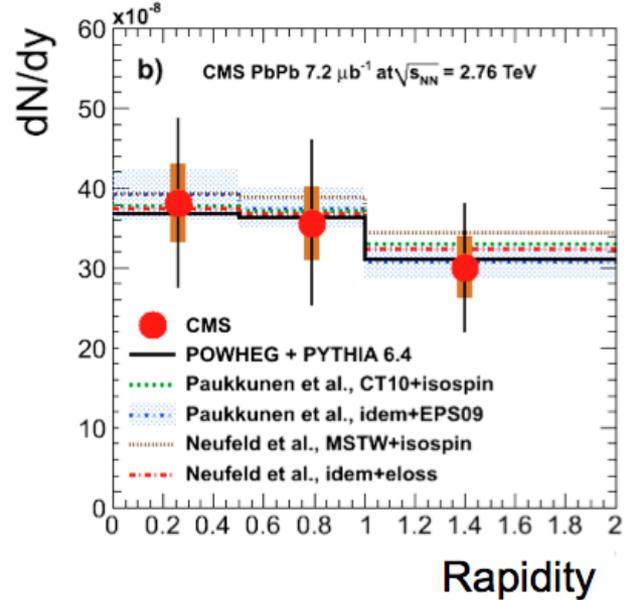
One of main  
**KCMS**  
 contributions



□ 39 Z<sup>0</sup> were reconstructed

- Not sensitive yet for any mass difference observation
- 38 Z found in ATLAS

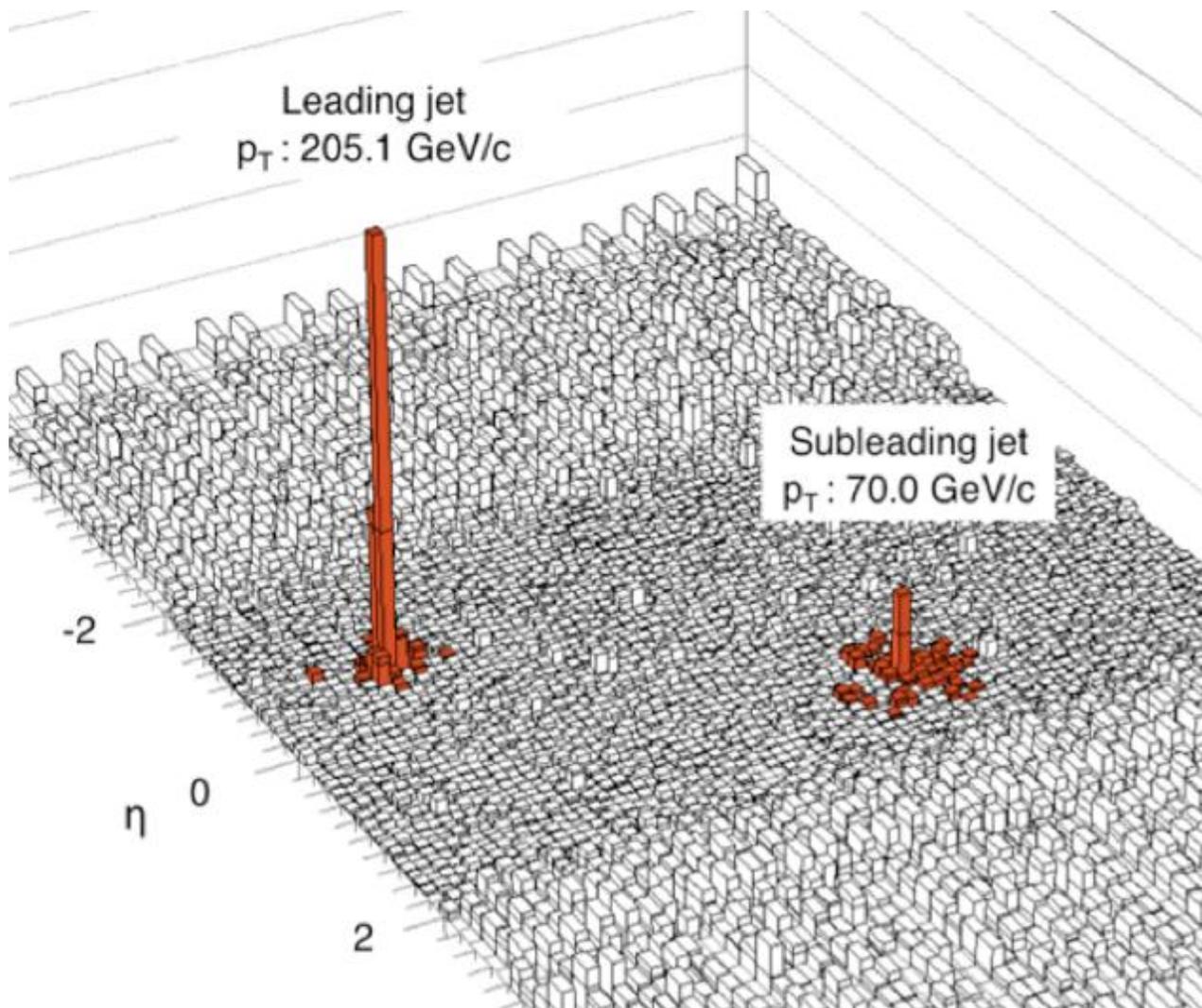
*from C. Roland talk on 2011/03/04 in "HI at the LHC: a first assessment"*

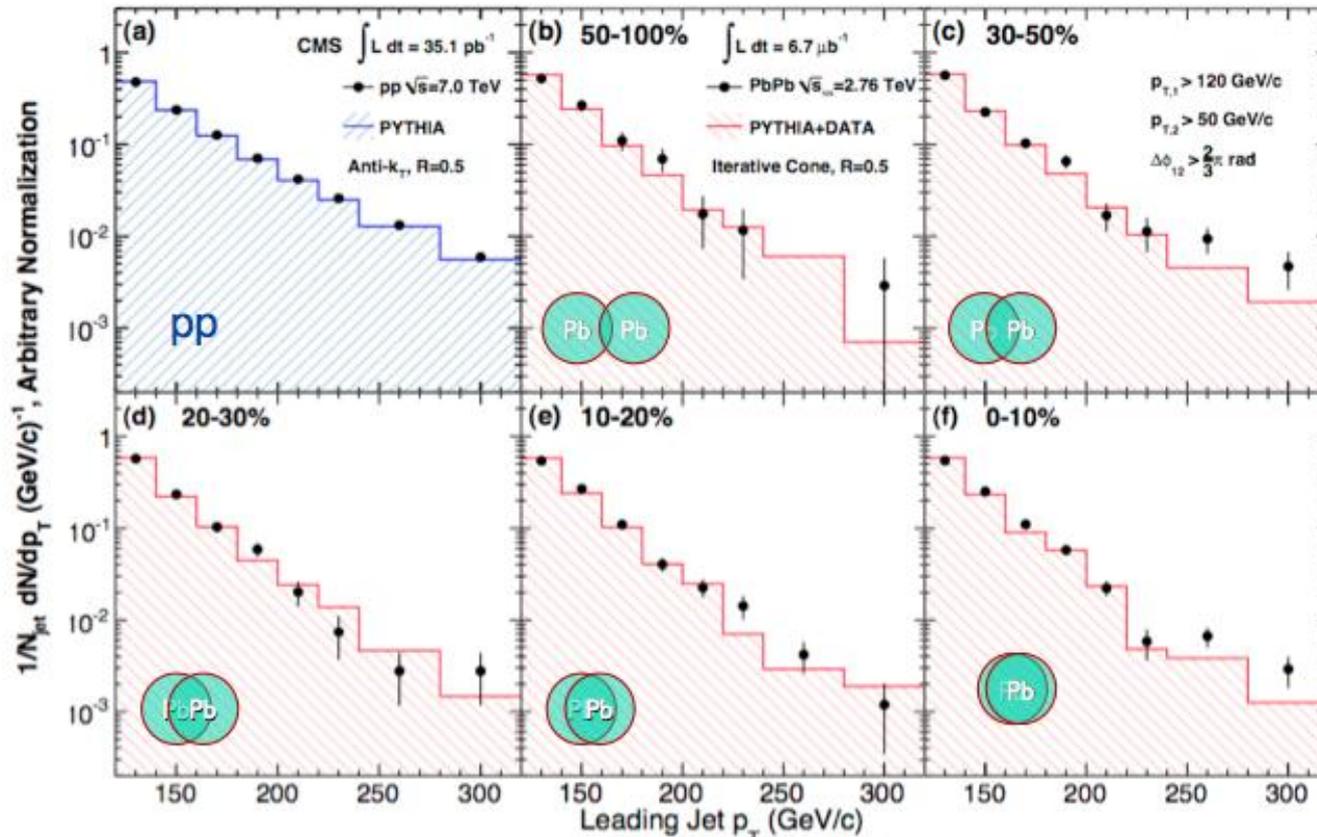


## □ Differential distributions are consistent with pQCD

- **Eta**
- **Pt**
- **Npart**

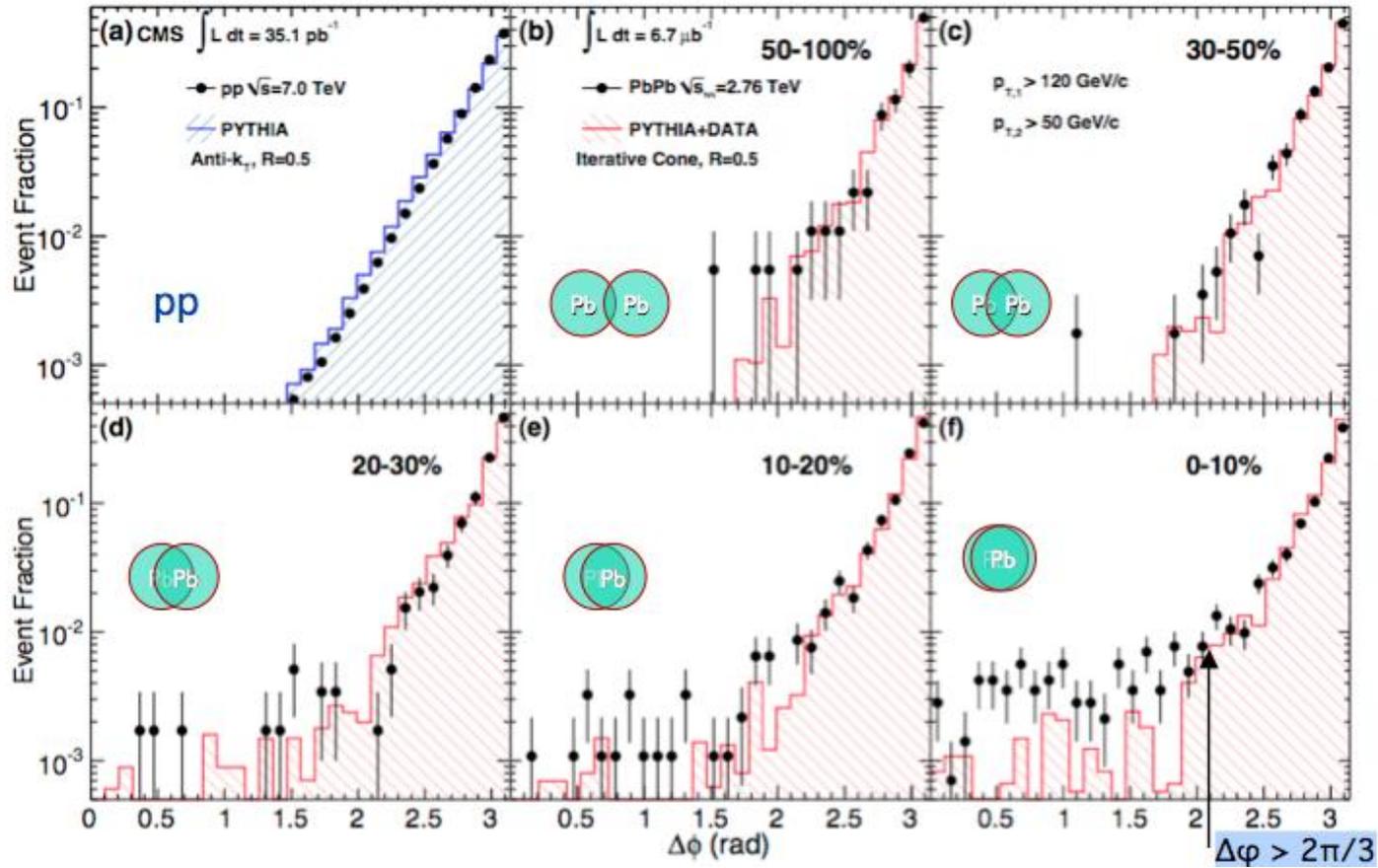
from C. Roland talk on 2011/03/04 in “HI at the LHC: a first assessment”





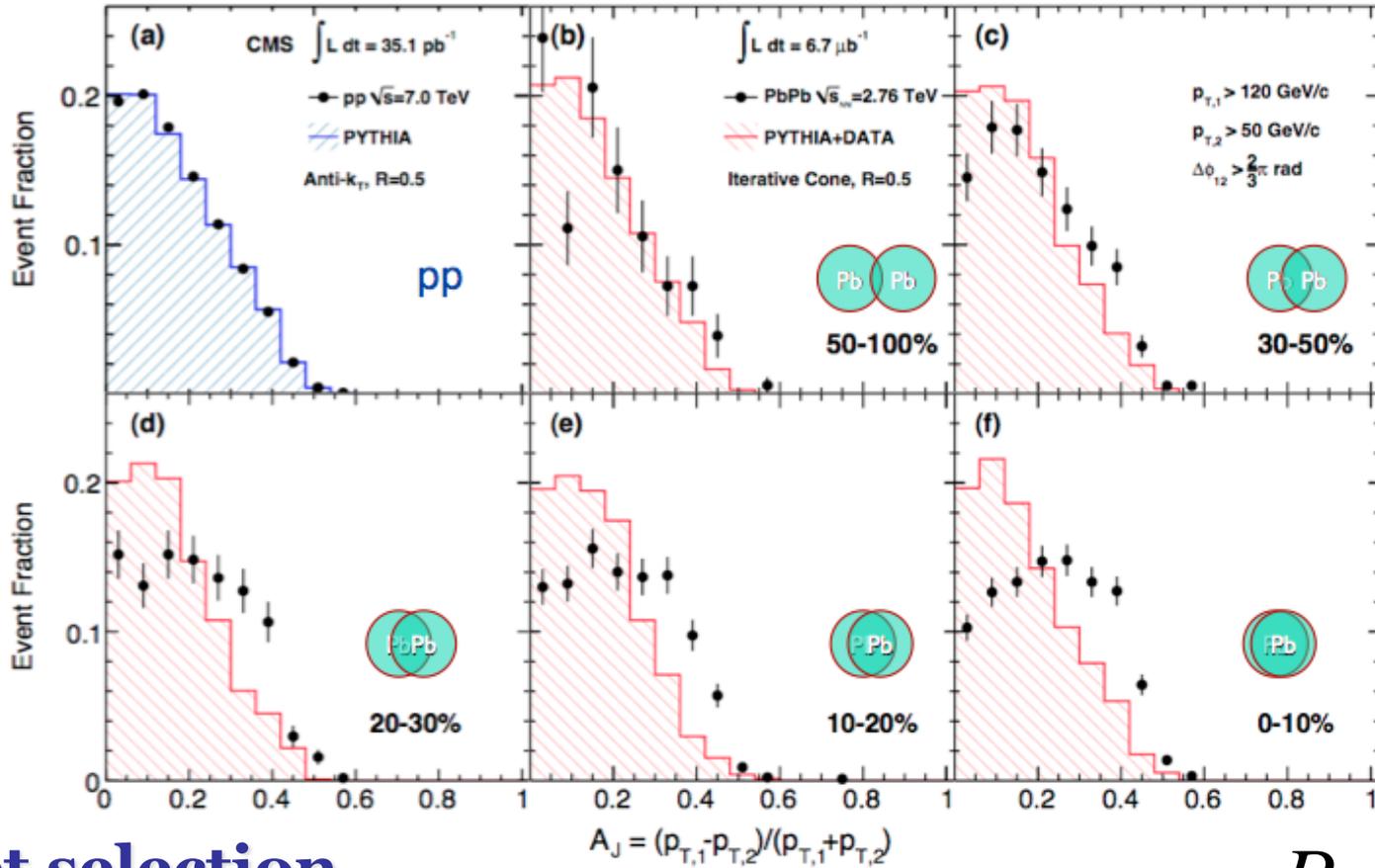
□ Leading jet distributions are well described by PYTHIA+Bkg Data model

*from C. Roland talk on 2011/03/04 in “HI at the LHC: a first assessment”*



□ No serious discrepancy was observed

from C. Roland talk on 2011/03/04 in “HI at the LHC: a first assessment”

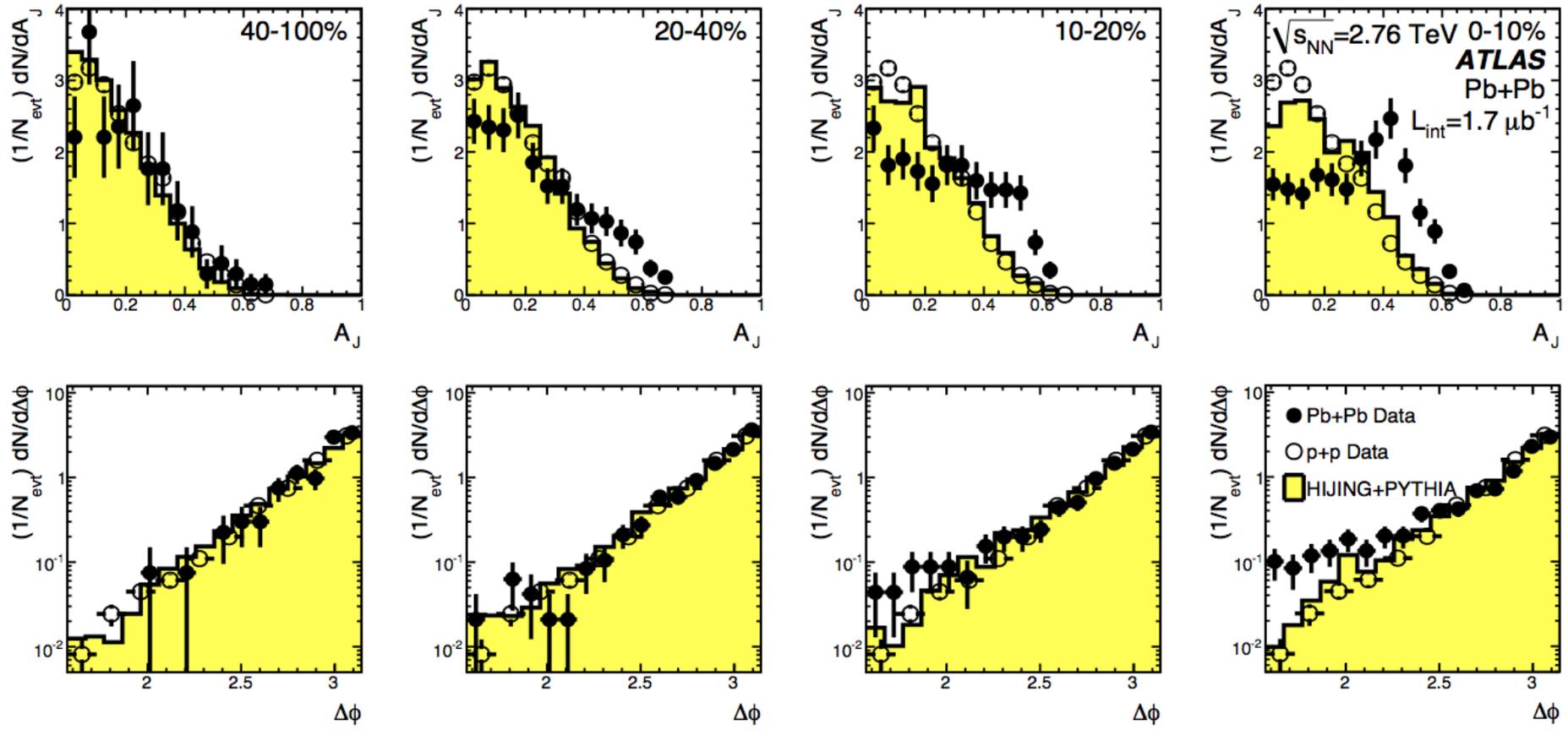


## □ Dijet selection

- $|\eta| < 2.0$ ,  $\Delta\phi > 2/3 \pi$
- $J_1 > 120 \text{ GeV}$ ,  $J_2 > 50 \text{ GeV}$

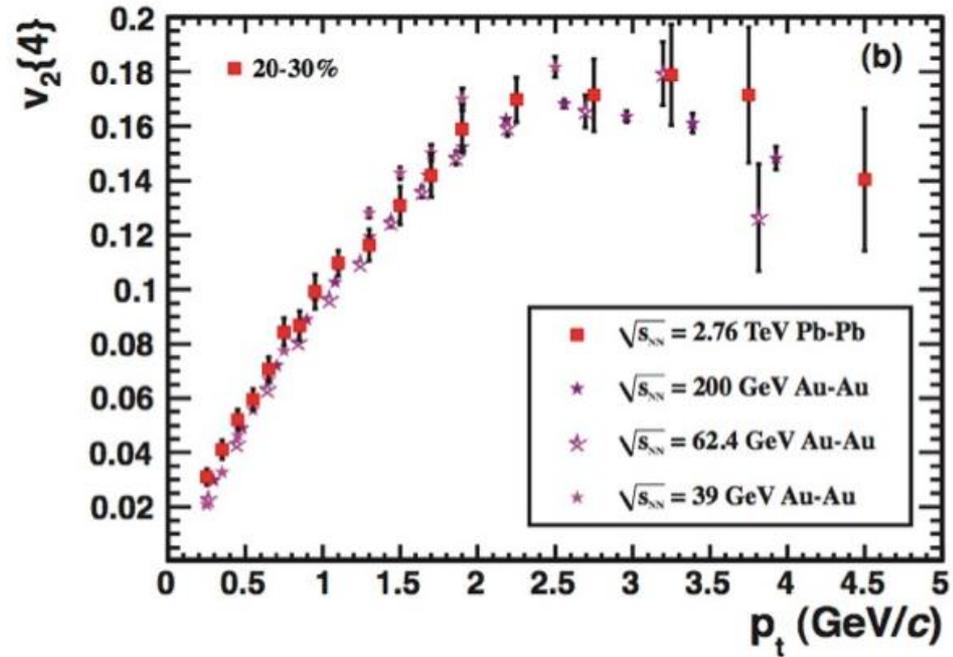
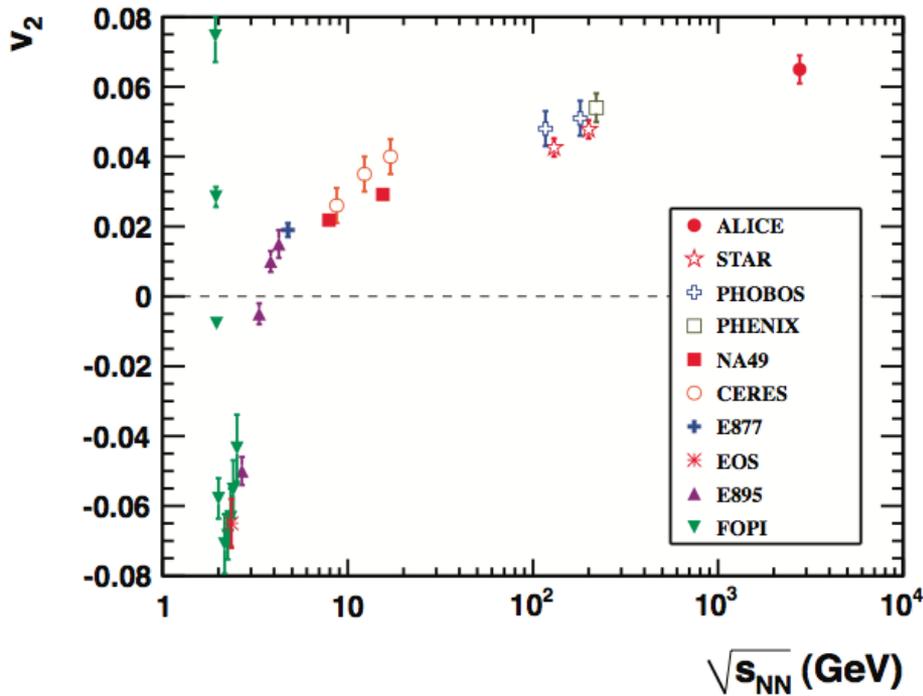
$$A = \frac{P_{T1} - P_{T2}}{P_{T1} + P_{T2}}$$

from C. Roland talk on 2011/03/04 in "HI at the LHC: a first assessment"



□ ATLAS PRL 105, 252303

– Strong jet quenching



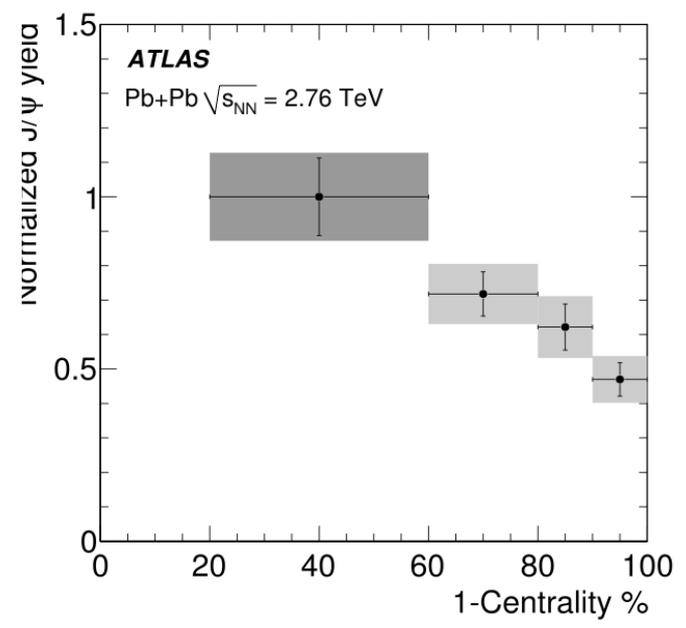
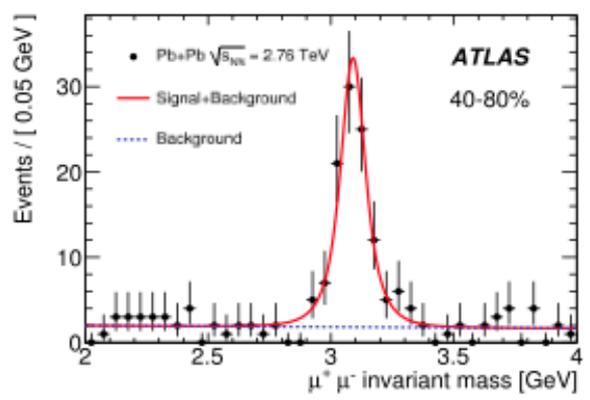
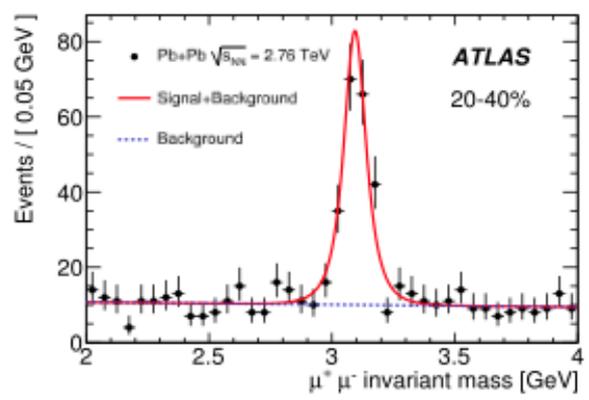
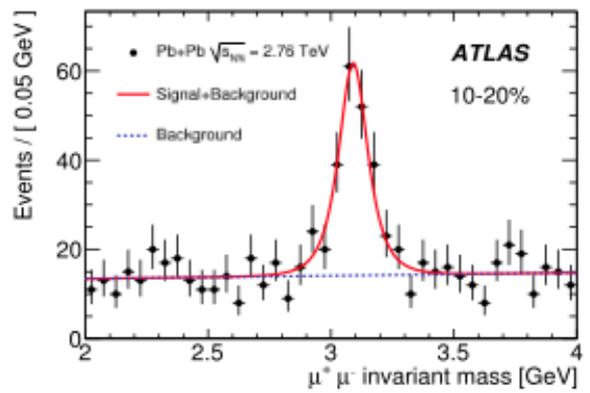
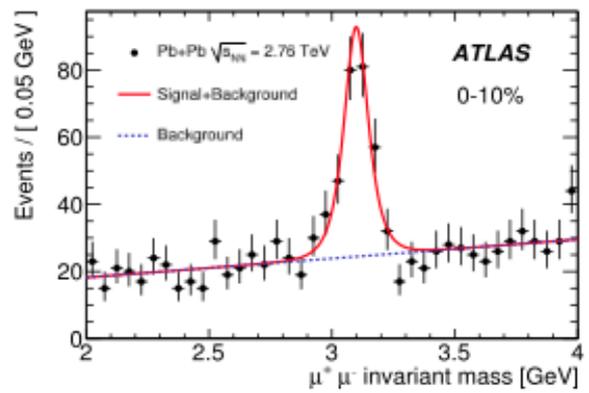
□ ALICE PRL 105 (2010), 252302

– Linear increase, ~30%.

□ arXiv:1102.3010

– Same flow from 39GeV to 2.76TeV

**CMS will be  
at QM2011**



□ ATLAS Phys. Lett. B697, 294-312

-CMS

CMS will be in QM2011



# Summary



- Most of CMS HI results will be presented in May
  - QM is in May, and today isn't a good day to show anything before the main ceremony.
- Only some of official/approved plots were shown
  - Long range two particle correlation was published
  - $Z_0$  in HI were reported
  - Large jet momentum imbalance was observed
- Soft probes, e.g.  $v_2$ , results will shortly be available
  - KCMS : I.C. park
- J/Psi, Y results will be shown in QM
  - KCMS : DH Moon → QM speaker