Year-1 (Heavy-Ion) Physics with CMS at the LHC

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For the 26th Winter Workshop on Nuclear Dynamics

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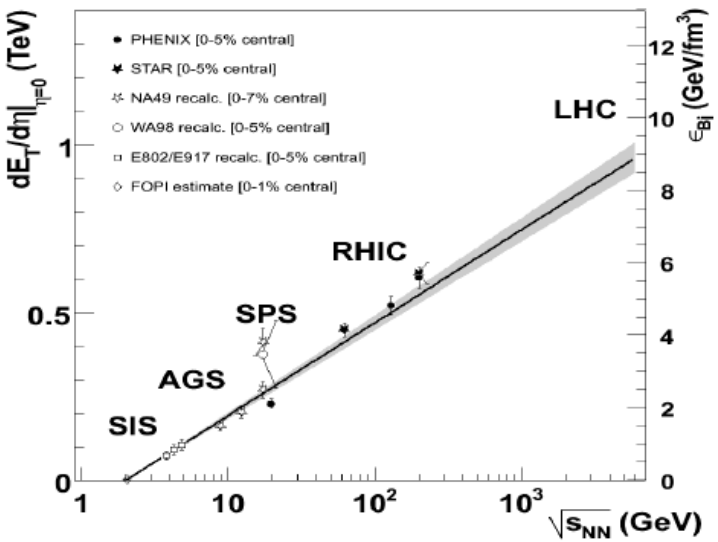
Outline

- LHC (Large Hadron Collider)
- CMS (Mostly about forward angles)
- December results and future projections

What is New at LHC?

	AGS	SPS	RHIC	LHC
$\sqrt{s_{NN}}$ (GeV)	5	20	200	5500
Increasing factor		x4	x10	x28
η range	±1.6	±3.0	±5.3	±8.6

- LHC energies are far exceeding previous heavy-ion accelerators
  - A hotter, denser, and longer lived partonic matter



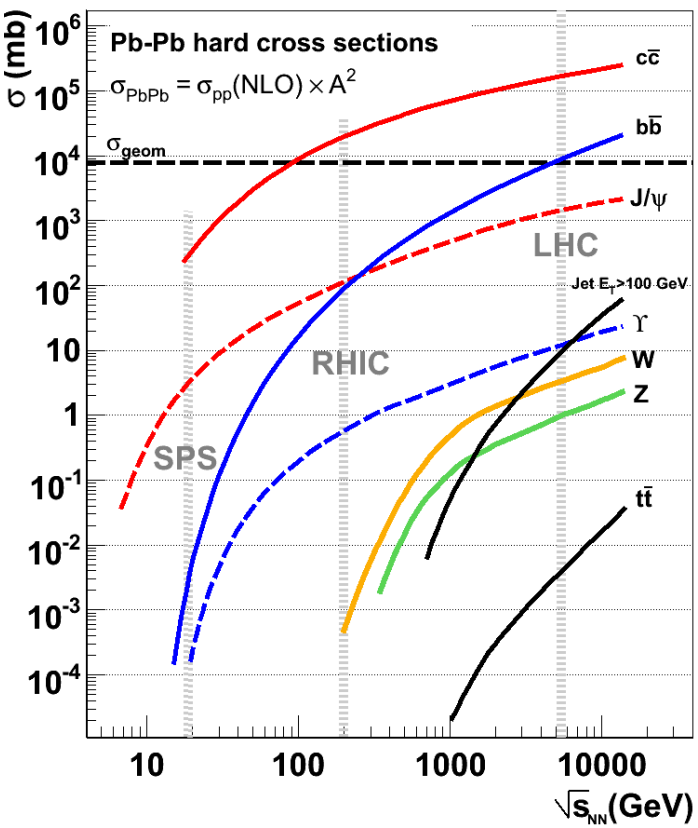
For central collisions ,

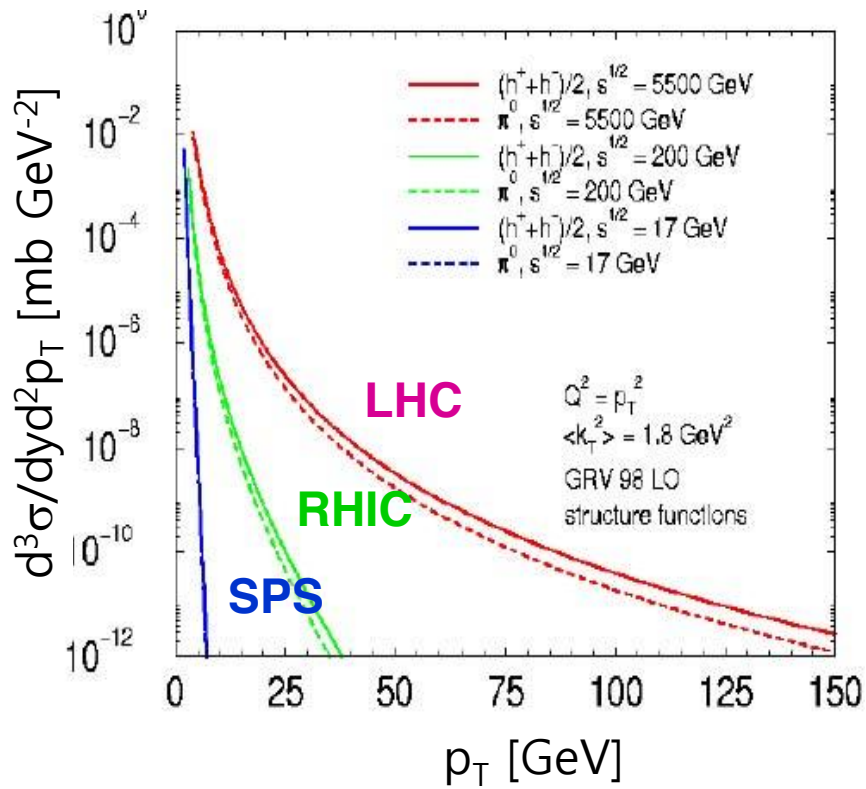
$$\varepsilon_{Bjorken} \cong \frac{1}{\tau_0(\pi R^2)} \frac{dE_T}{d\eta} \gtrsim 10 \text{ GeV/fm}^3$$

with $\tau_0 \lesssim 1$ fm/c

Production Rate at LHC

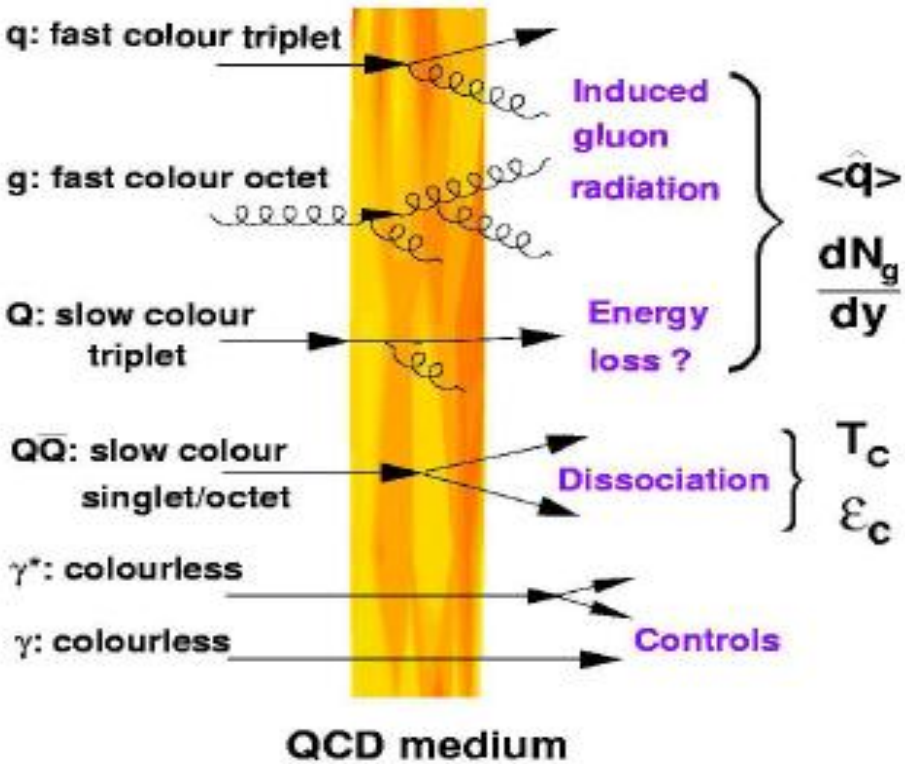
- Large rates of various hard probes over a larger kinematic range
- Plenty of heavy quarks (*b* & *c*)
- Weakly interacting probes are available ($W^{\pm}$ & Z^0)





The Quark Gluon Plasma

Hard probes are abundant at the LHC
Allow quantitative measurements of e.g. temperature, density, transport coefficients of the QGP



Key Parameters of "Early" Pb Ion Beam (from LHC Design Report)

Parameter	Units	Early Beam	Nominal
Energy per nucleon	TeV	2.76	2.76
Initial ion-ion Luminosity L_0	$cm^{-2}\ s^{-1}$	$\sim 5 \times 10^{25}$	1×10^{27}
No. bunches, k_b		62	592
Minimum bunch spacing	ns	1350	99.8
β^*	m	1.0	0.5 /0.55
Number of Pb ions/bunch		7×10^7	7×10^7
Transv. norm. RMS emittance	μm	1.5	1.5
Longitudinal emittance	eV s/charge	2.5	2.5
Luminosity half-life (1,2,3 expts.)	h	14, 7.5, 5.5	8, 4.5, 3

Goal for 2-3 years (?) beyond

At full energy, luminosity lifetime is determined mainly by collisions ("burn-off" from ultraperipheral electromagnetic interactions) $\sigma \approx 520$ barn

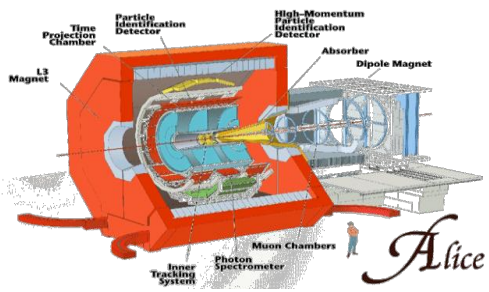
J.M. Jowett, LHC Performance Workshop, Chamonix, 6/2/2009 6

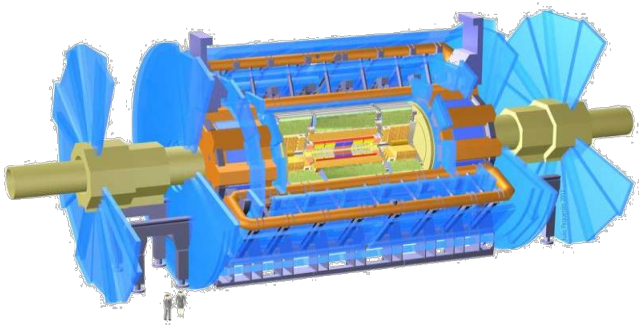
Note from Chamonix meeting: Early Pb Beam will have lower energy. 10TeV pp corresponds to 4 TeV in Pb+Pb (1.97 TeV/nucleon)

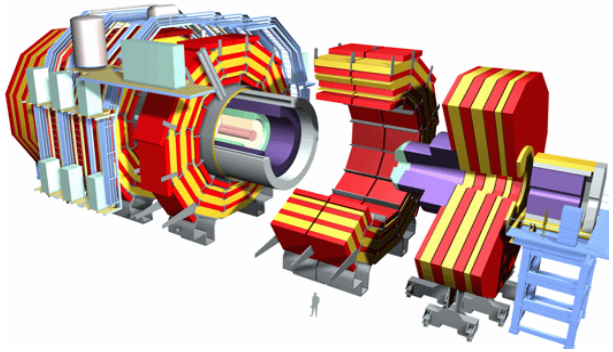
Pb+Pb	Coll. Energy	Max. Coll. Rate	Ave. Coll. rate	CPU Budget /Event
Year-1	~ 4 TeV	~150Hz	~100Hz	~60s
Nominal	5.5 TeV	~8kHz	~3kHz	~2s

During Year-1 run no selection will be applied in the HLT and all events will be written to tape

The three LHC heavy-ion experiments







- ALICE: dedicated HI experiment
- Largest HI community (~1000)
- Tracking (|η|<1-2): TPC + ITS + TRD
- 0.5 T solenoid magnet
- EMCal under discussion
- Forward muon spectrometer

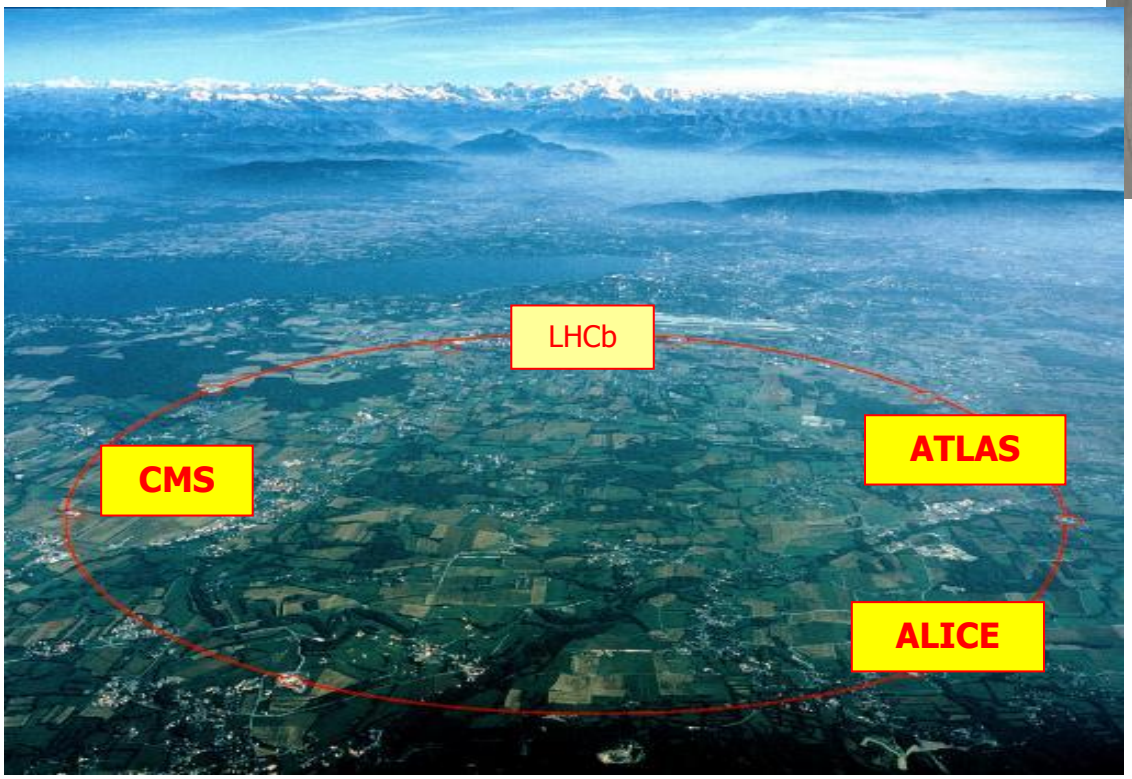
- Strongest capabilities:
  low-p_T, light-quark PID, ...

- ATLAS & CMS: multipurpose (pp) + HI program
- People: ~50/2000 (ATLAS), ~70/2300 (CMS)
- |η|<2.5: Full tracking, muons
- |η|<5: Calorimetry
- 4 T (CMS), 2 T (ATLAS) mag. field

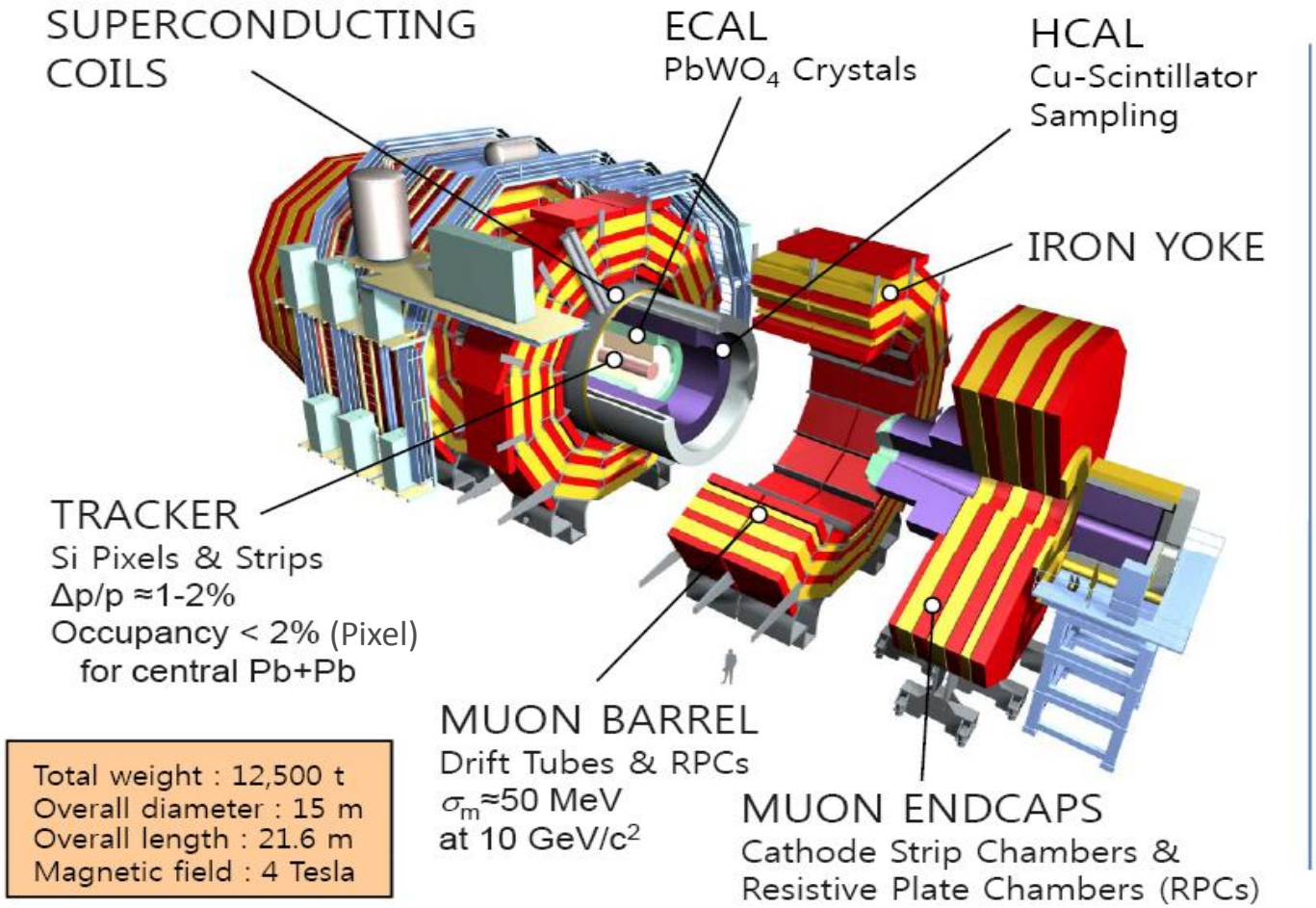
- Forward detectors (CMS)
- Strongest capabilities: hard-probes, Y, full jet reco, heavy-Q jet PID, jet-Z,γ

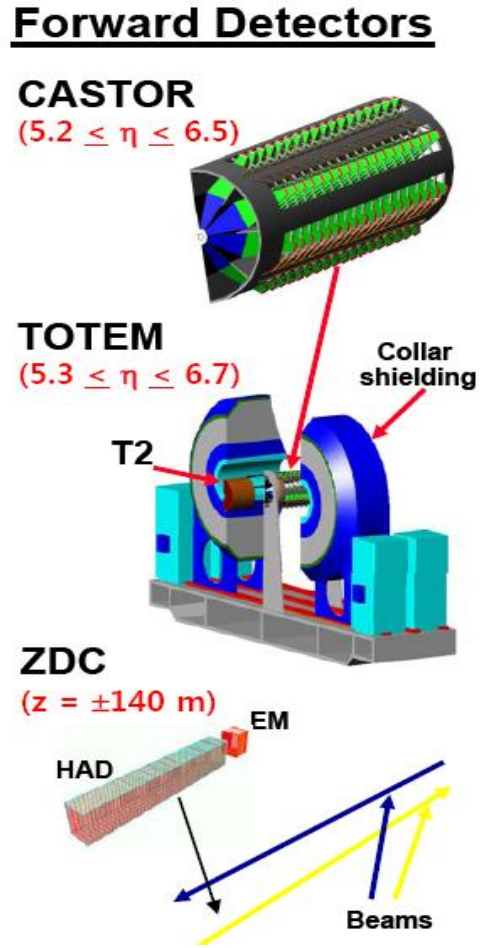
Large Hadron Collider (LHC) @ CERN

1 ring: 26.66 km circumference
  8.33 T superconducting coils
  25 ns crossing time



The CMS Detector

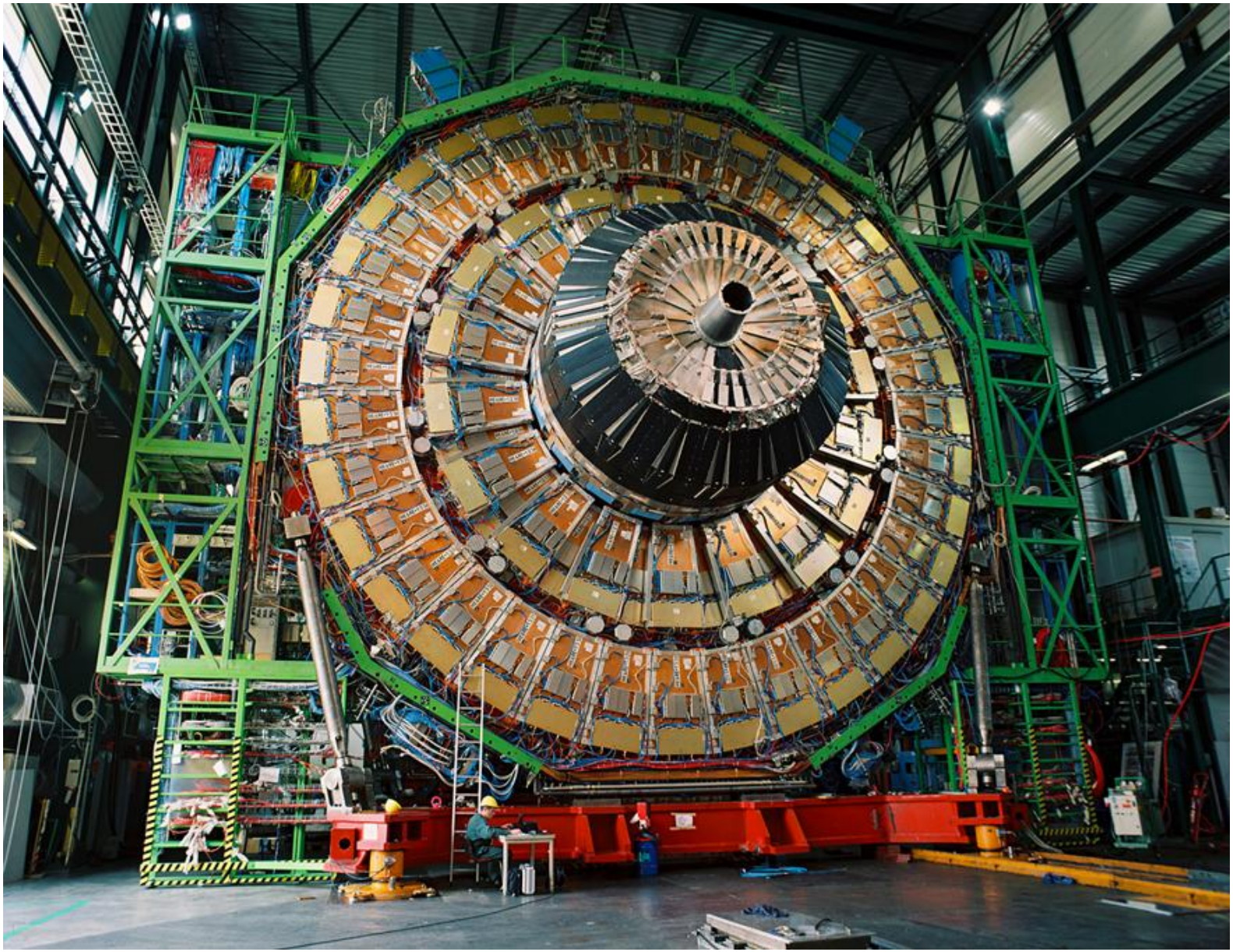




Large Range of Hermetic Coverage:

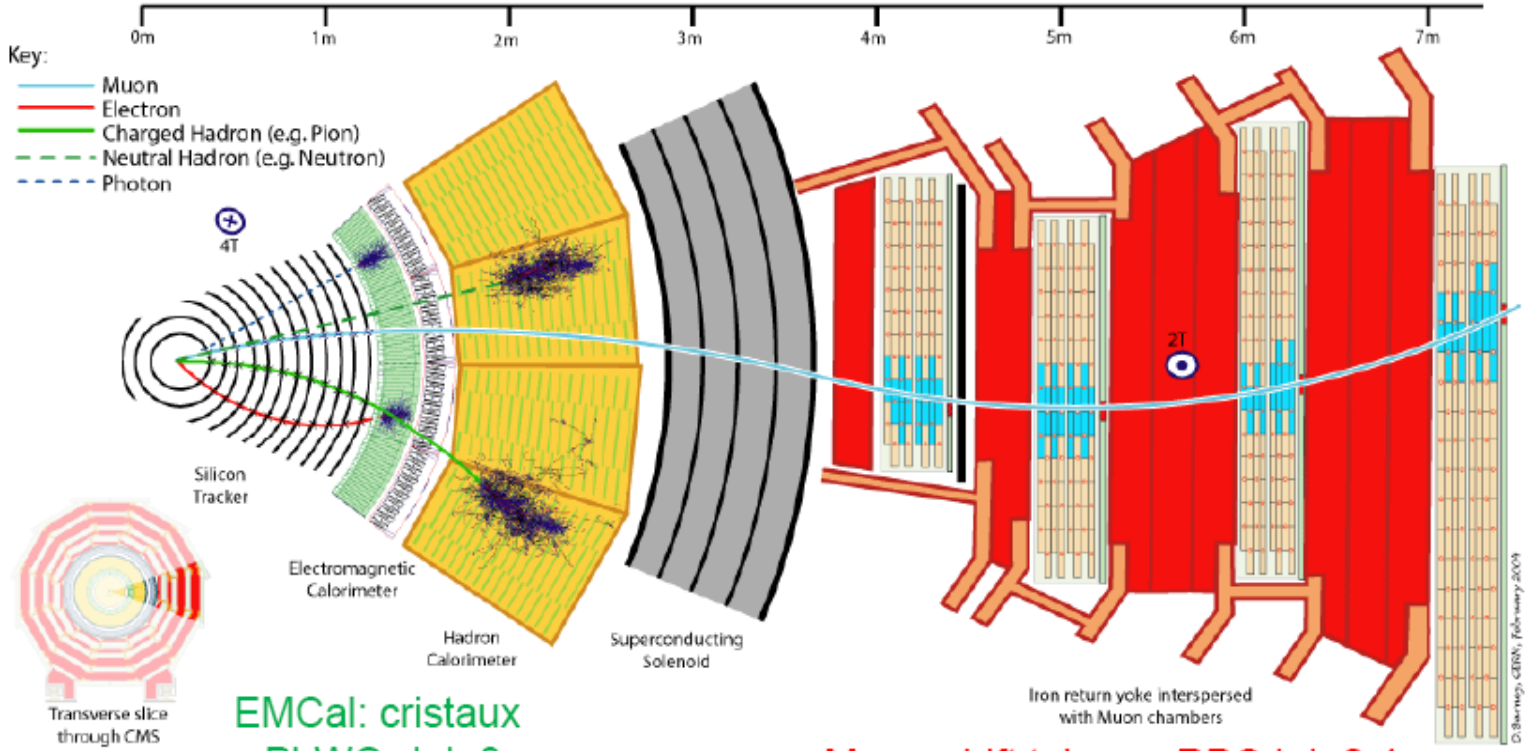
Tracker, muons	$\lvert\eta\rvert < 2.4$	**ECAL + HCAL**	$\lvert\eta\rvert < 3$
Forward HCAL	$3 < \lvert\eta\rvert < 5$	**ZDC**	$8.3 < \lvert\eta\rvert$

Innermost Endcap Disk



Compact Muon Solenoid

Détection des particules |η|<2.4



EMCal: cristaux $PbWO_4$ |η|<3

Muon: drift tubes + RPC |η|<2.4

Silicium: pixels (3) and strips (10) |η|<2.4

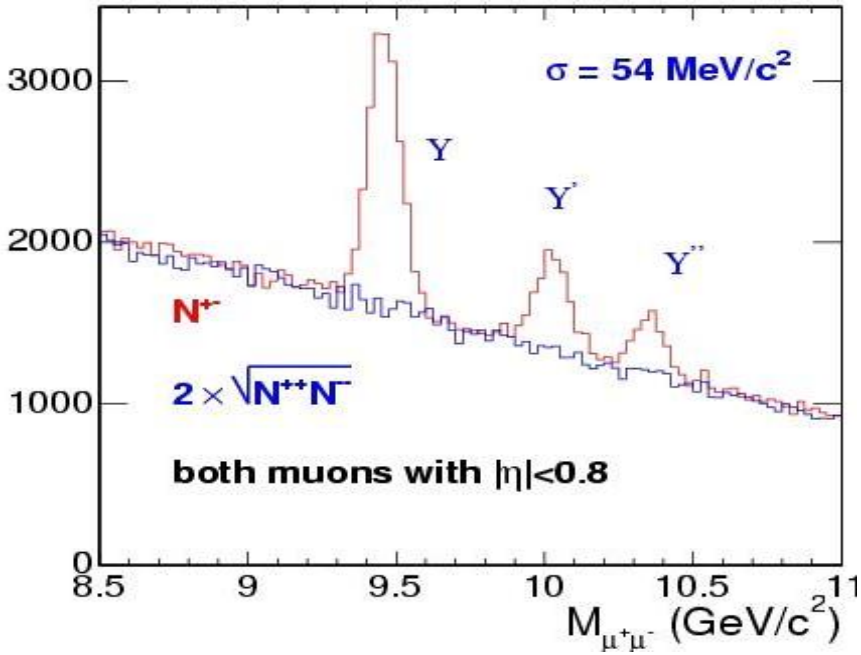
HCal: Scintillateur |η|<5

+ Extensions à grand angle

Some of CMS capabilities

- CMS excels at high p_T measurements in Pb+Pb
  - Fast, flexible DAQ + Trigger
    - Jet, photon, muon trigger
  - High resolution, large acceptance calorimeters
    - Jets, photons
  - High resolution, large acceptance tracker
    - Charged hadrons from 100 MeV to 100's of GeV

- The excellent capabilities CMS give the unique possibility of measuring both soft and hard probes of the dense medium state:
  - Multiplicity
  - Soft and hard spectra of charged particles
  - Fragmentation Function from $\gamma-$ Jet correlations
  - Photons
  - Jets
  - Quarkonia



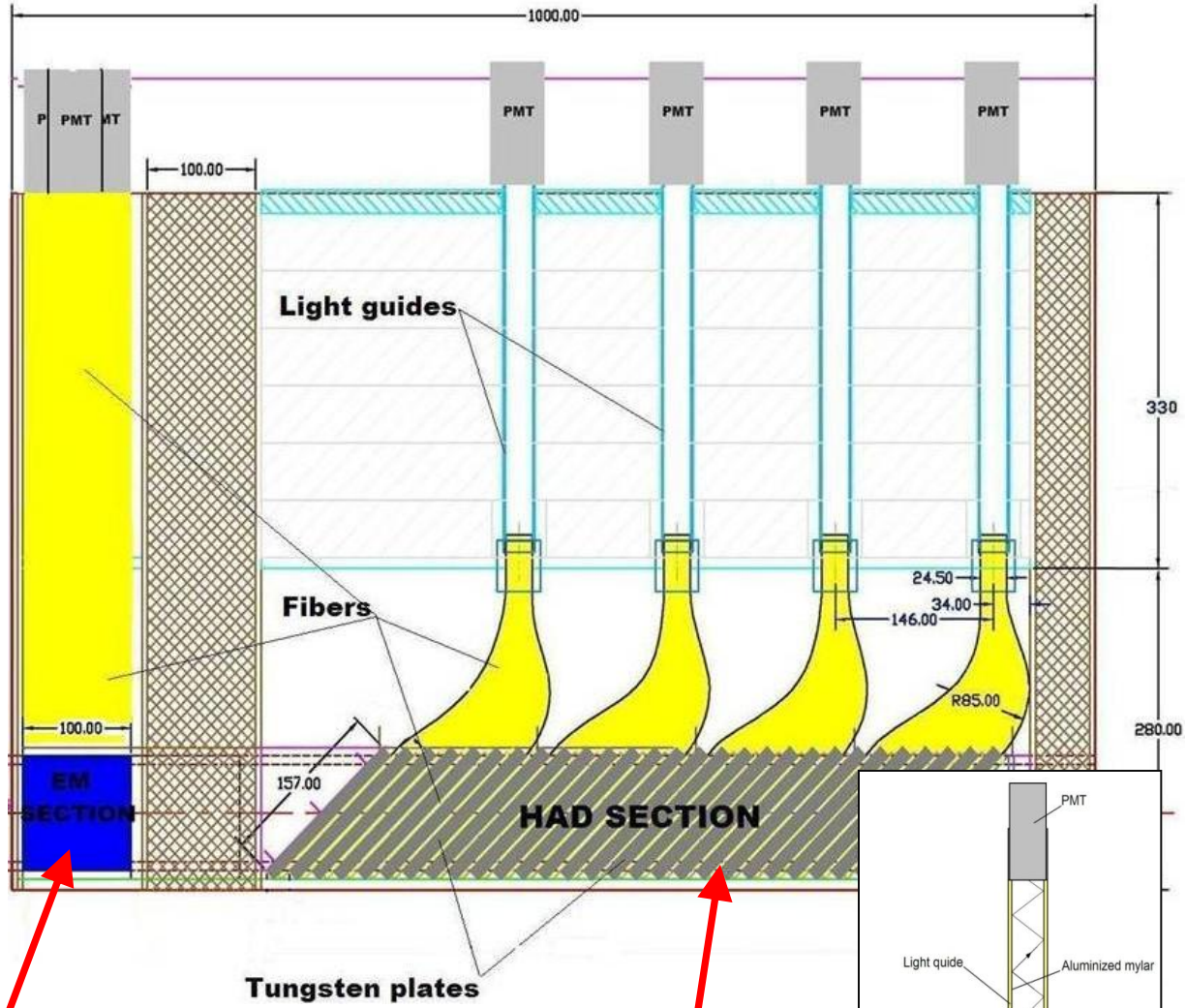
Excellent resolution for upsilon states

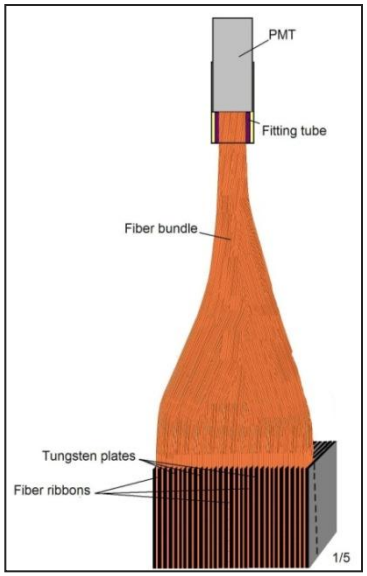
I expect the second excited state to melt in the hot QGP. If so, the third peak would be only from excited upsilons formed at the surface. Study details by looking at the amplitude of the third peak as a function of centrality and angle wrt the reaction plane and of other variables.

ZDC Design

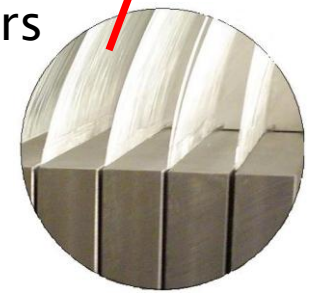
Tungsten stops beam. Kinetic energy of n, γ produces showers of charged particles, which make Čerenkov light in fibers.

N,γ

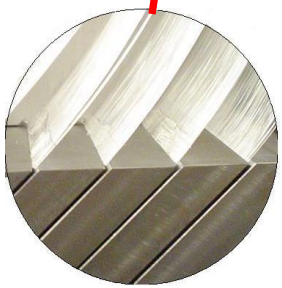


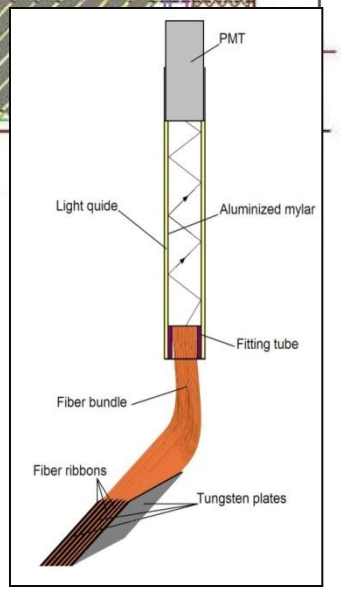


EM has 5 horizontal towers



HAD section has 4 longitudinal towers

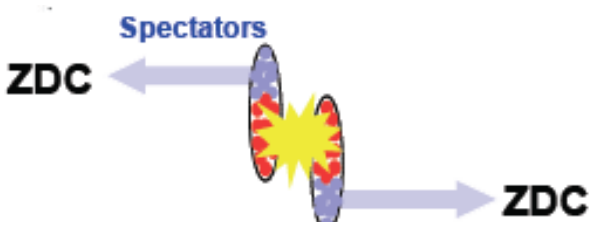


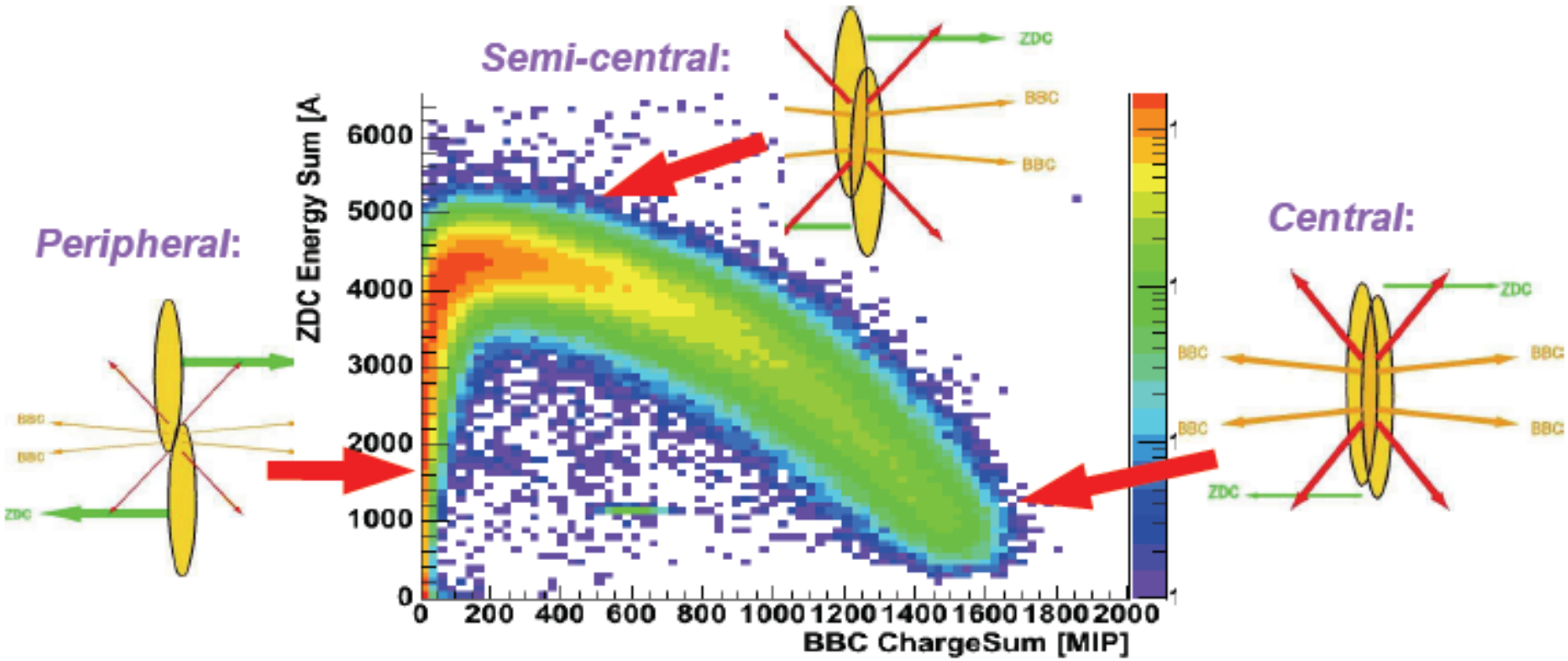


ZDC Physics Goals

Measuring Reaction Centrality

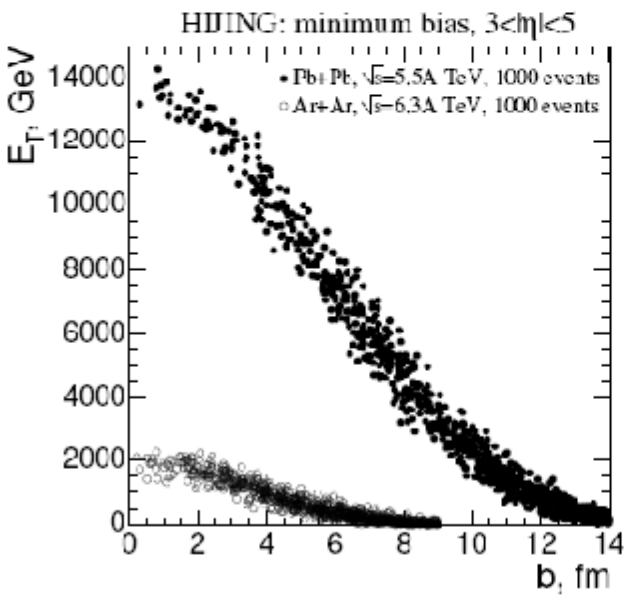
- ZDC measures spectator neutrons



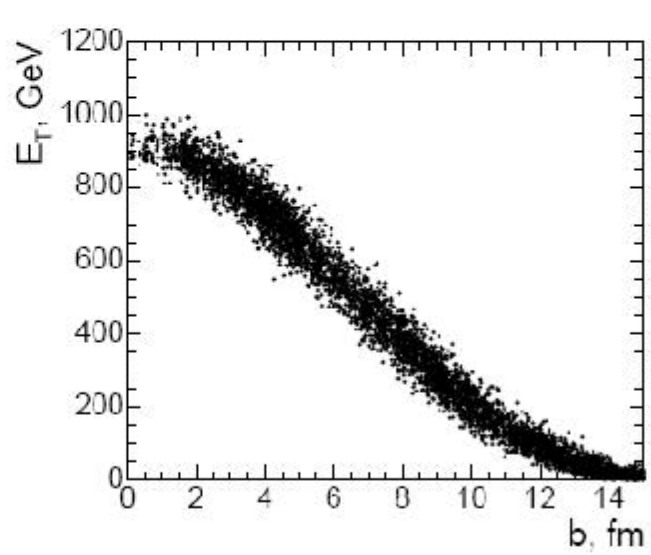


Other measures of impact parameter

In forward calorimeter HF
$3 < \eta < 5.2$



In CASTOR
$5.2 < \eta < 6.7$



New, useful physics from p-p collisions in December

$dN_{ch}/d\eta$ at 2.36 TeV Allows for better extrapolation to energies used in heavy-ion calculations.

Expect to get $dN_{ch}/d\eta$ at 7 TeV (3.5 TeV beams) in February. This will bracket 4 and 5.5 TeV/nucleon heavy ion runs.

>10 μb^{-1} at 900 GeV (injection energy) gave $dN_{ch}/d\eta$ values that agree with other measurements (Tevatron).
CMS is working well. Measurements agree with MC.

The present plan

Resume proton experiments in mid February at 7 TeV.
Some increase in energy during the year.

Pb beam setup during last two weeks of October.
Pb-Pb experiments during November at some energy well under 5.5 TeV/nucleon, 4 Tev/nucleon likely.

Search for Stranglets

Edwin Norbeck and Yasar Onel
University of Iowa

(not submitted to the 3000 people in the CMS collaboration)

For the 26th Winter Workshop on Nuclear Dynamics

Ocho Rios, Jamaica 8 January 2010

Stranglets

Norbeck's observations

- Defined here as light nuclei with enough strange quarks to reduce Z/A below that of lead.
- Thought to be a common object seen in the core of cosmic ray showers (in mountain top detectors).
- Typical reaction: cosmic iron on nitrogen.
- How could such a reaction produce a stranglet?

Cosmic ray stranglets

- Cannot be formed from hot quark-gluon plasma. Nucleons (P, N, Λ_o) from hot QGP do not stick together to form nuclei.
  [J. Ellis *et al* J. Phys. G **35** (2008) 115004]
- Suggest formed by Ks, etc. from QGP getting into the spectators.
- For Fe on N there is always much spectator matter.
- Would like to make them with Pb-Pb and see them in the Zero Degree Calorimeter.

Lifetimes

- Lifetimes of hyper nuclei with two Λ_o is similar to that of a single Λ_o, 200-300 ps.
- Assuming the lifetime of a strange quark in a strangelet is 300 ps, the mean distance to decay, $\gamma c\tau$, is
  9.6 m at 100 GeV/nucleon (RHIC)
  260 m at 2.75 TeV/nucleon (LHC)
  96 km at 1000 TeV/nucleon (cosmic rays)
- With many strange quarks, the lifetime of the stranglet may be shorter.
- Look for stranglets in a zero degree calorimeter. Distance from IP to ZDC is 18 m for STAR and 140 m for CMS.
- For CMS, 84 m gets stranglet beyond last magnet.

STAR stranglet search

- Looked at 4% most central collisions and found none [Phys. Rev. C **76** (2007) 011901(R)]
- “Good” place to look because fewest background neutrons.
- But stranglets would only be produced in peripheral collisions.

CMS stranglet search

- Look for large signal in hadronic part of ZDC.
- Determine impact parameter from HF ($3 < \eta < 5$).
- Look for signals larger than for expected number of neutrons.
- STAR already has such data. Can we search STAR data for strangelet events?

Energy dependence
RHIC vs LHC

- LHC energy more like cosmic rays
- More Ks at the higher energy

Mechanism

K^- more likely to react with spectator than K^+

Conclusions about “stranglets”

- Spectator nuclei with reduced Z/A likely produced in suitably non-central collisions, particularly at LHC.

- Need some good quantitative calculations.

- Short lived stranglets that could reach mountain-top cosmic ray detectors may not live long enough to reach ZDCs.