Heavy Ion Physics at ATLAS and CMS

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for

ATLAS and CMS

Workshop on Physics at the LHC era

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Outline

- Heavy Ion Physics
- From RHIC to LHC
- Performance in ATLAS and CMS
- Outlook

Why Heavy Ions at the LHC?

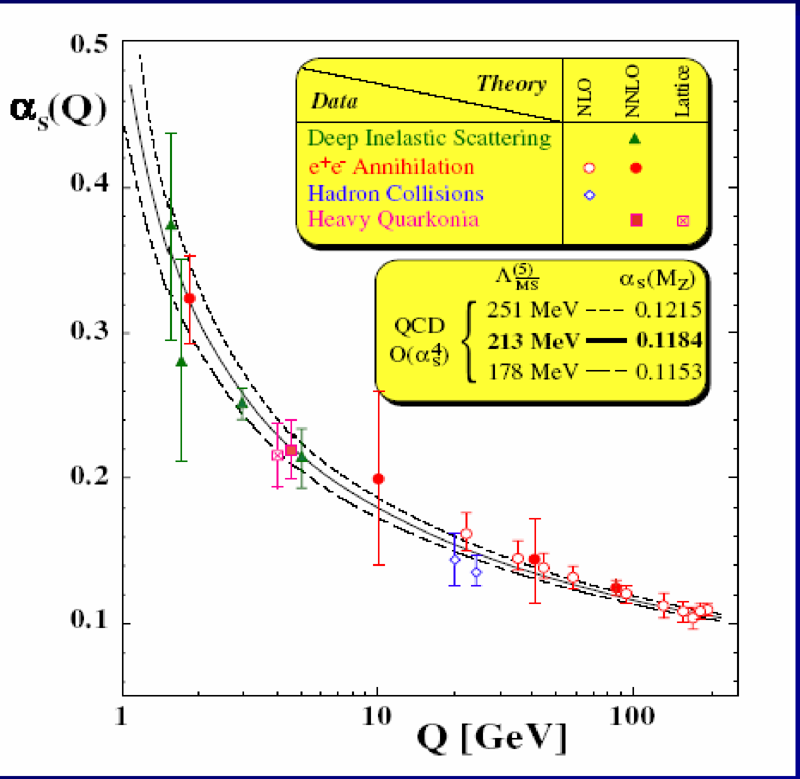
- QCD is the fundamental theory of strong interactions.

$$L_{QCD} = -\frac{1}{4} F^{\alpha}_{\mu\nu} F^{\mu\nu}_{\alpha} - \sum_n \overline{\psi}_n \left(\partial - ig\gamma^{\mu} A^{\alpha}_{\mu} t_{\alpha} - m_n \right) \psi_n$$

- QCD is well studied/tested in the few particles and large Q^2– i.e. in perturbative limit

- Heavy Ions provide a new opportunity to study **QCD in small** Q^2 **and many-particle regime**

QCD Coupling Constant



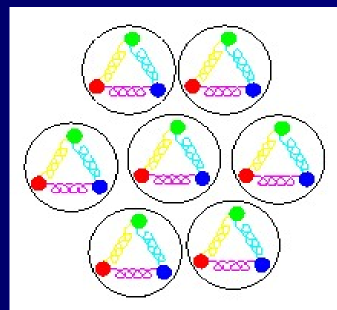
NP

HEP

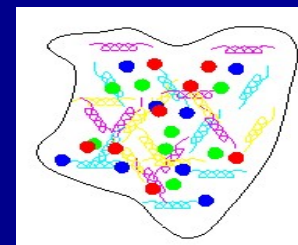
non perturbative at long range/low energy

asymptotic freedom at short range / high energy

Matter under Extreme conditions



Heat
Compression



Normal Nuclear Matter

Quark Gluon Plasma

- Quark-Gluon Plasma (QGP) is a state of QCD and is considered to be the primordial matter of the Universe
  - Quarks and gluons are deconfined
  - Chiral symmetry is restored (quarks are massless)

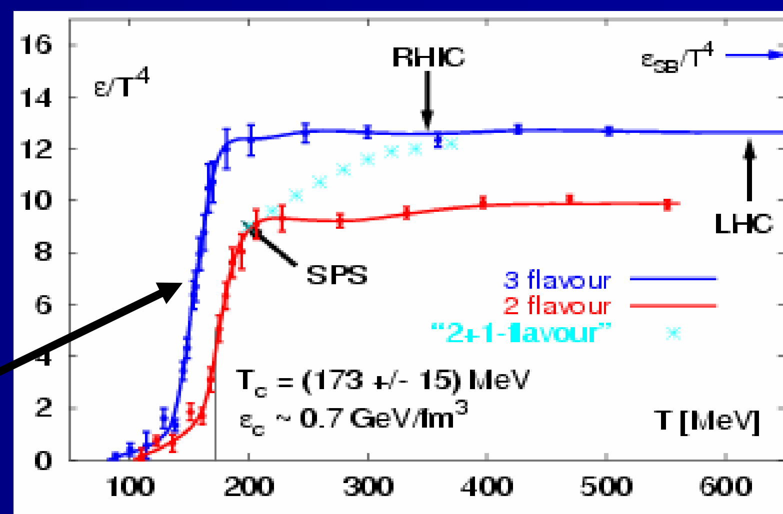
- HI collisions provide unique opportunity to study matter limit of QCD
  - Another calculable limit of QCD
    - – Asymptotic freedom via high temperature
  - Only matter we can create in the laboratory whose properties are entirely determined by *fundamental*, *non-Abelian* interaction

Lattice QCD calculations

- The nature of this bath of quarks and gluons cannot be calculated directly with Quantum Chromodynamics.
- Teraflop-scale computers simulate equilibrium QCD (assume thermal system)

- Predict phase transition:

$$T_c \sim 170\ MeV \quad or \quad 10^{12}\ F$$
$$\varepsilon_c \sim 0.7\ GeV\ /\ fm^3$$



A fundamental "phase transition" that can be studied in the lab

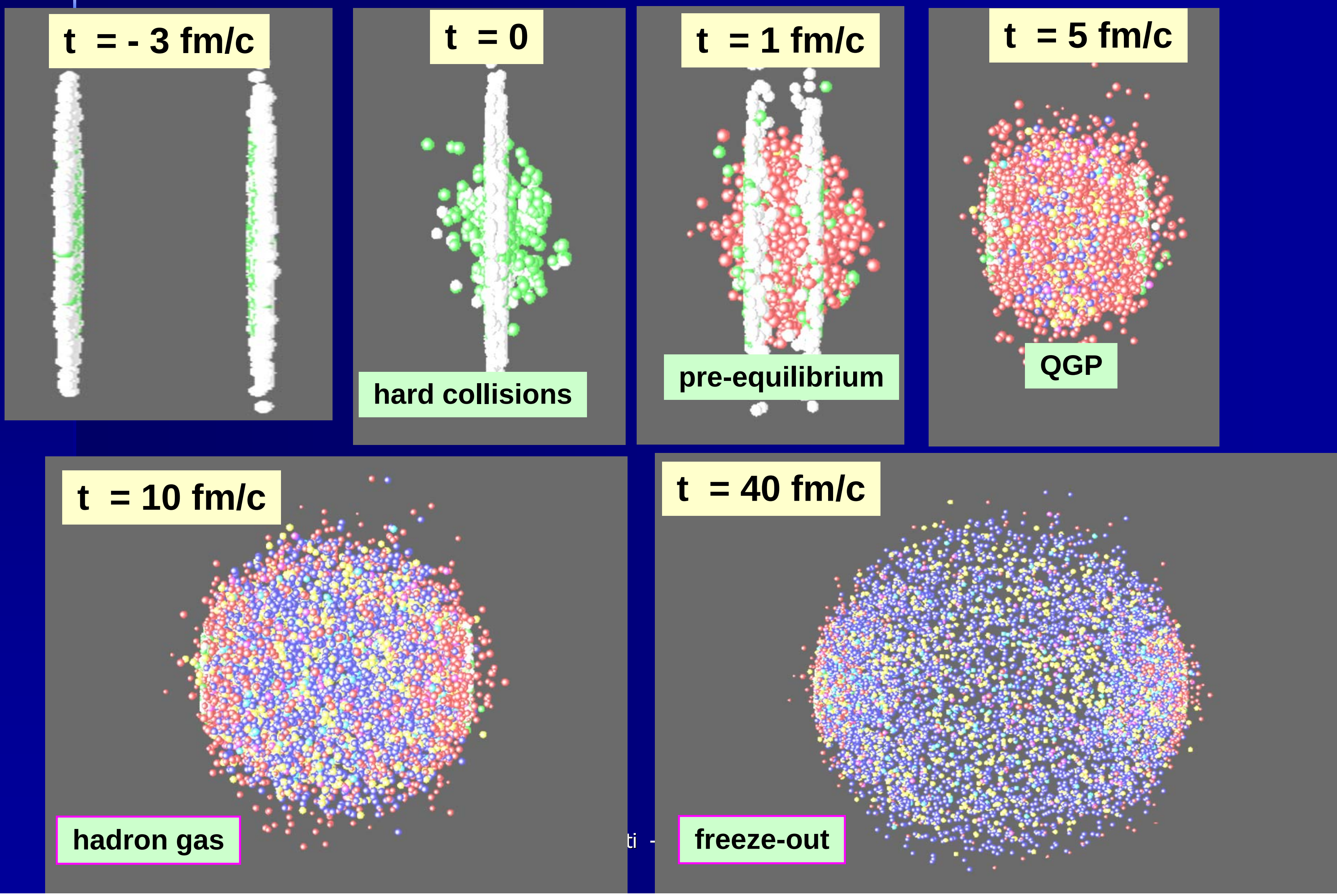
Direct consequence of asymptotic freedom.

LHC Heavy Ion Program

- Machine
  - Energy
    - E(beam)=7* Z/A→√s = 5.5.TeV/A or 1.14 PeV for Pb-Pb
  - Heavy Ion Running
    - Typically 4 weeks/ year
    - Luminosity 10^{27} cm^{-2} s^{-1} (Pb)

      ⇨ 10 kHz rates
- Experiments
  - ALICE: experiment designed for HI
  - ATLAS and CMS: have a major and rich HI program

Stages during HI Collision



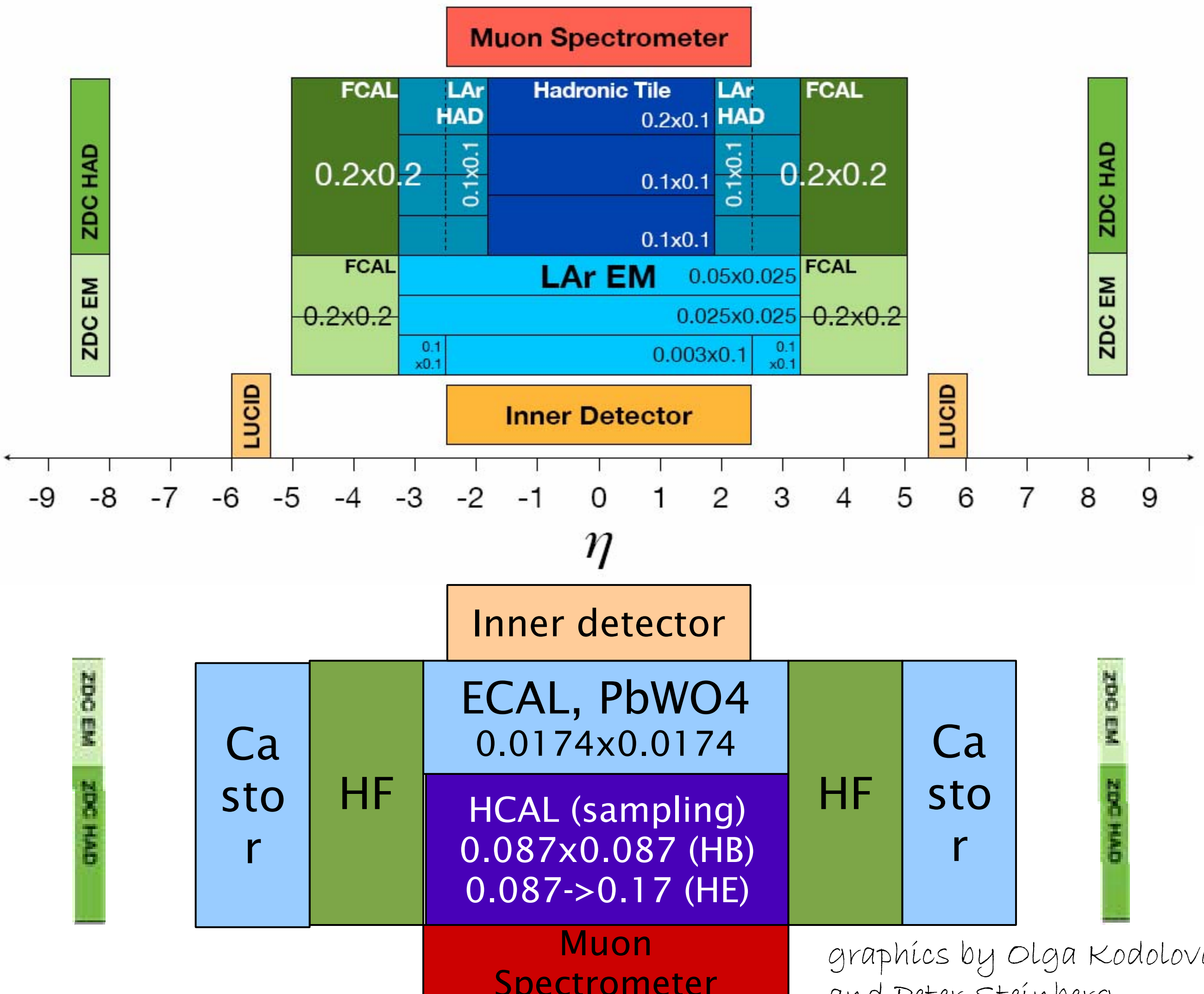
Heavy Ion Physics at LHC

- LHC: factor 30 jump in center of mass energy with respect to RHIC

Central collisions	SPS	RHIC	LHC
$s^{1/2}$(GeV)	17	200	5500
dN_{ch}/dy	430	700	2- 8 $\times 10^3$
ε (GeV/fm^3)	2.5	3.5-10 $\times$ 4 -10	15- 40
V_f(fm^3)	10^3	7×10^3	2×10^4
τ_{QGP} (fm/c)	< 1	1.5- 4.0 $\times$ 3	4-10

The ATLAS and CMS detectors

Different technologies but close acceptances – cross-checks possible.
Unprecedented acceptance for A+A physics both in p_T and rapidity, with full azimuth



graphics by Olga Kodolova and Peter Steinberg

ATLAS:

Inner detector (|η|<2.5)
ECAL (|η|<3.2)
HCAL (|η|<3.2)
HF (3.2<|η|<5)
Muon (|η|<2.7)
Lucid (5.5<|η|<6)
ZDC (|η|>8)

CMS:

Inner detector (|η|<2.5)
ECAL (|η|<3)
HCAL (|η|<3)
HF (3<|η|<5)
Muon (|η|<2.4)
Castor (5<|η|<6.7)
ZDC (|η|>8)

Heavy Ion Physics Program at LHC

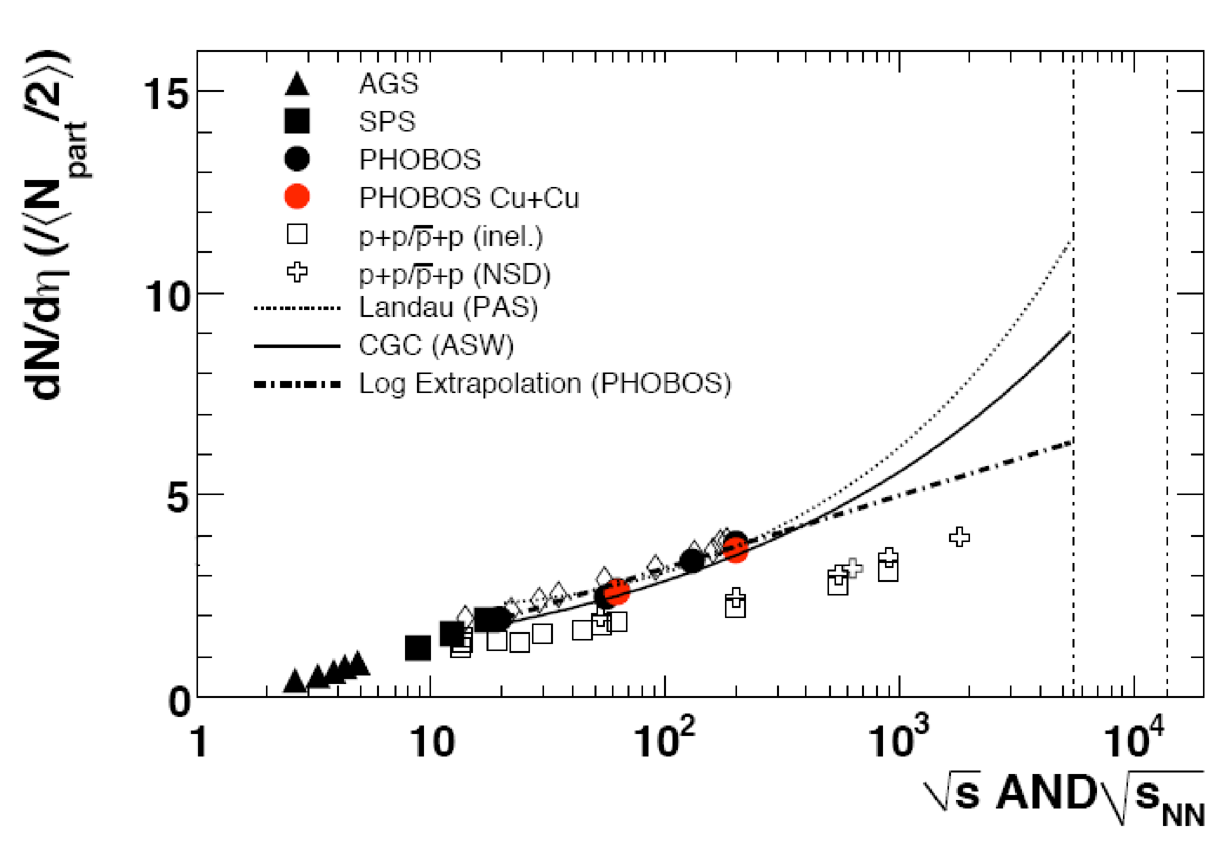
- LHC will accelerate and collide heavy ions at energies far exceeding the range of existing accelerators:
  - Extended kinematic reach for pp, pA, AA
  - A hotter and longer lived partonic phase
  - Increased cross sections of hard probes
  - New experimentally accessible hard probes
- Some examples of what we hope to do:
  - First 15 min of running at low luminosity ~ 10^5 events:
    global event properties and hadronic observables
    - **multiplicity**
    - **elliptic flow**
  - first few days of running ~ 10^7 events:
    high-pt, heavy flavor
    - **jet quenching, photon, heavy-flavour energy loss**
    - **quarkonium production**

GLOBAL EVENT PROPERTIES:

- Characterize gross properties of initial state
- Test saturation predictions
- Probe early collective motion

Charged Particle Density vs c.m. energy

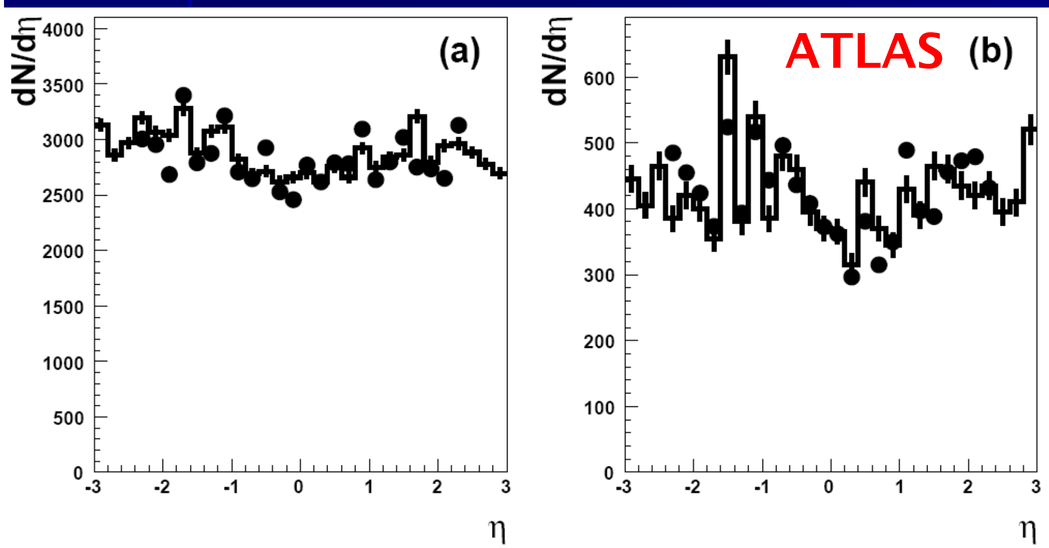
- First estimate of energy density
- Saturation, CGC ?



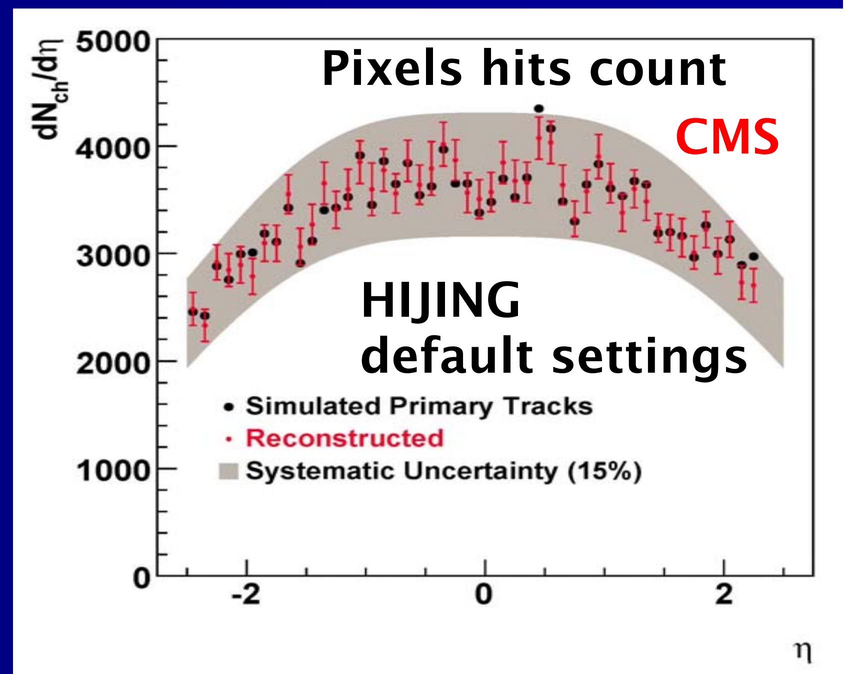
Multiplicity measurements

One event

- Silicon Hits

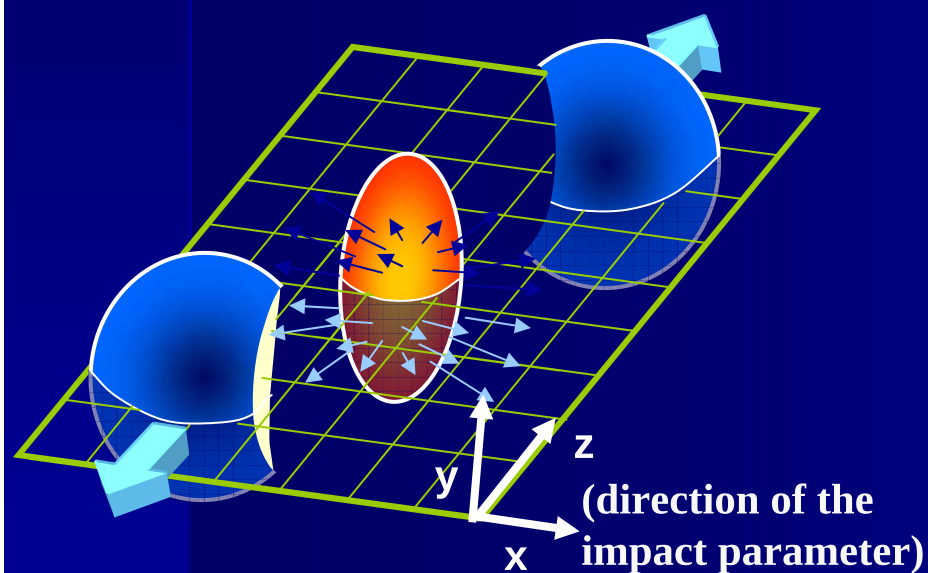


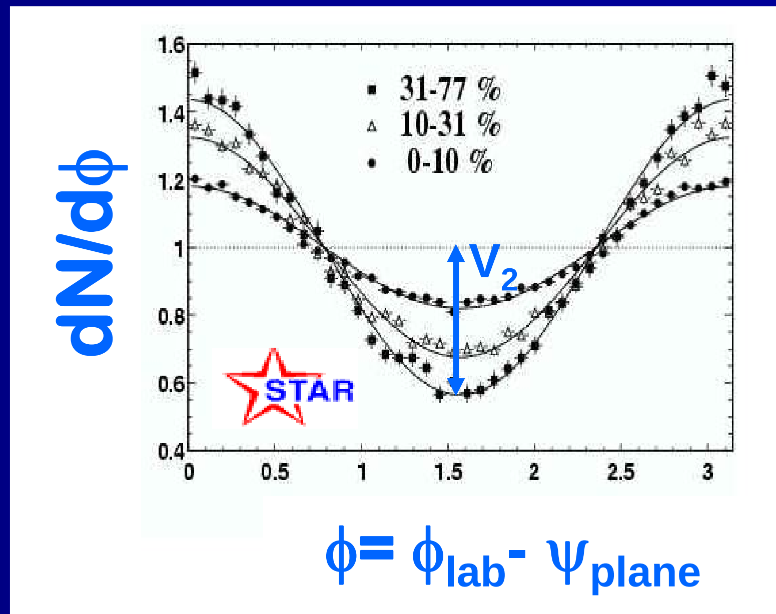
- hit count in pixels using dE/dx cut



Collective flow in heavy ion collisions

In non central collisions there is large initial spatial anisotropy.
The degree to which this translates into momentum space is a measure of the pressure gradient



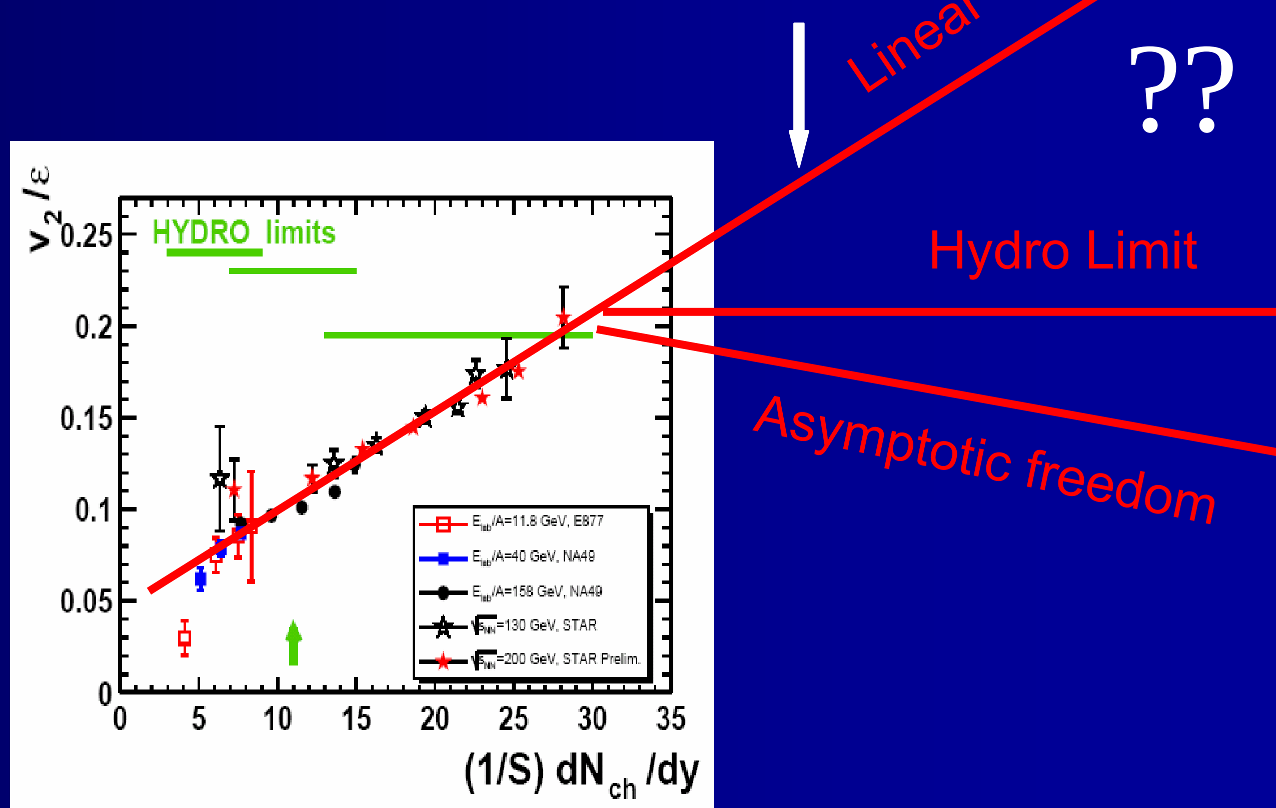


$dN/d\phi \sim 1 + 2\, v_2(p_T) \cos(2\phi) + \ldots$

"elliptic flow"

Flow at RHIC

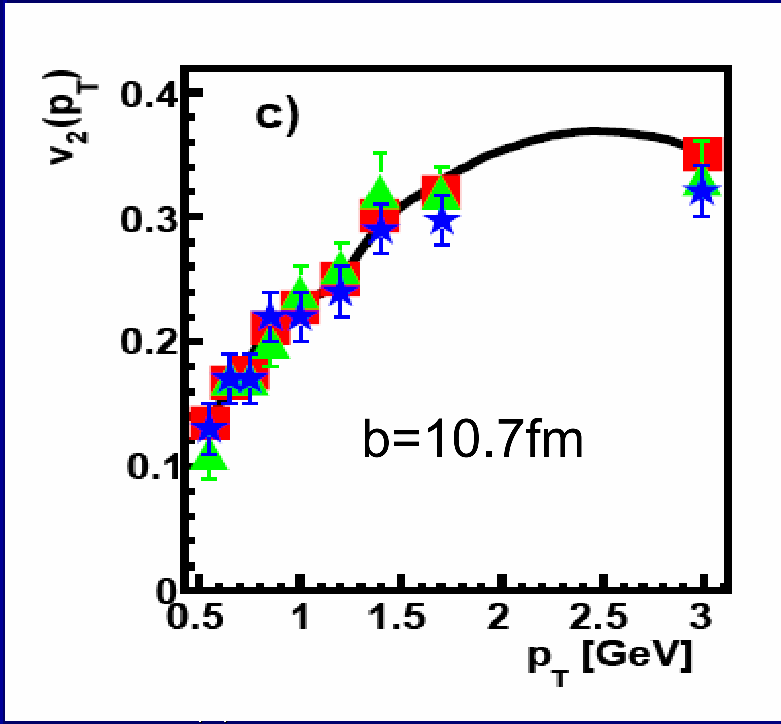
- Hydrodynamics with small viscosity describes heavy ion reactions



Elliptic Flow in ATLAS and CMS

- **ATLAS**

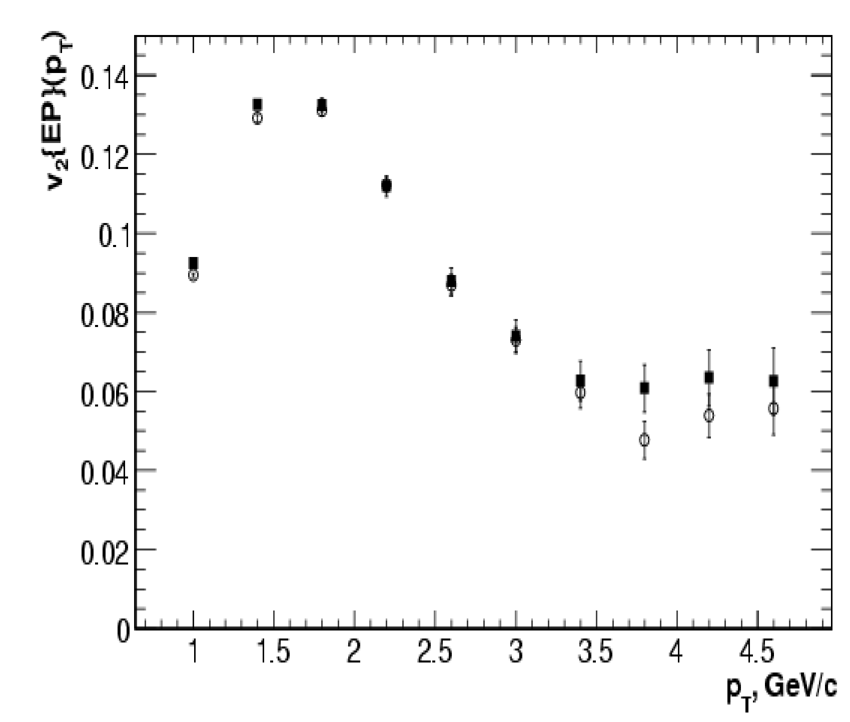
  Flow included in HIJING using parametrization from RHIC
- **3 separate methods are shown**



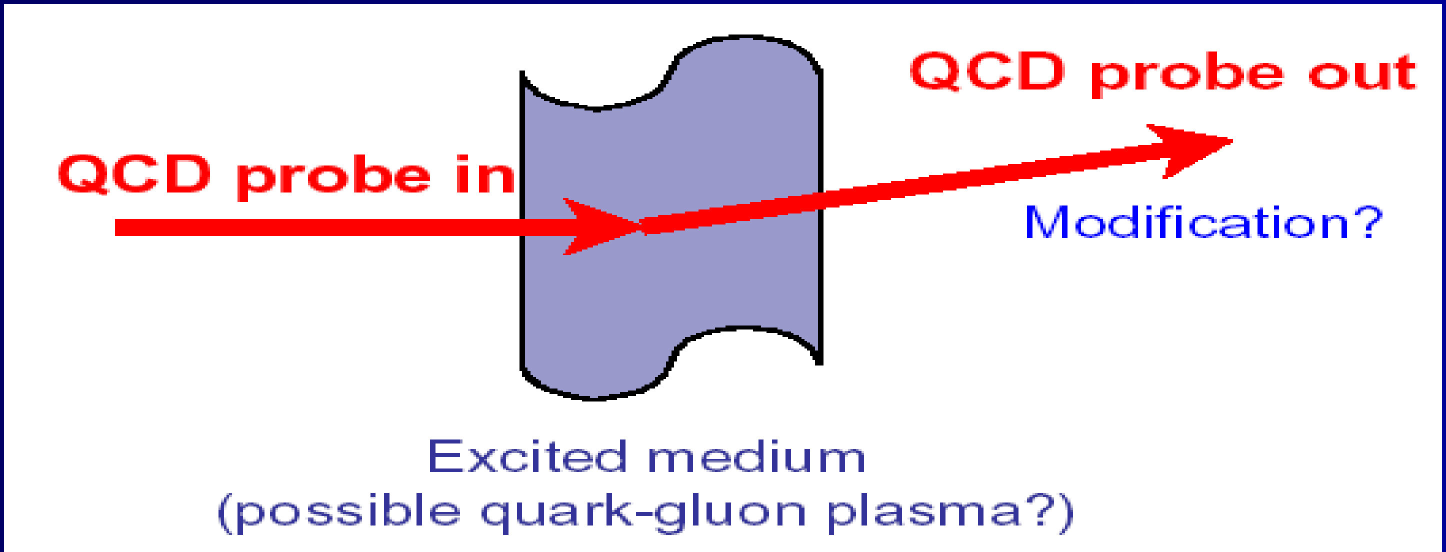
- **CMS**

  HYDJET

  Flow measured using reaction plane and tracker

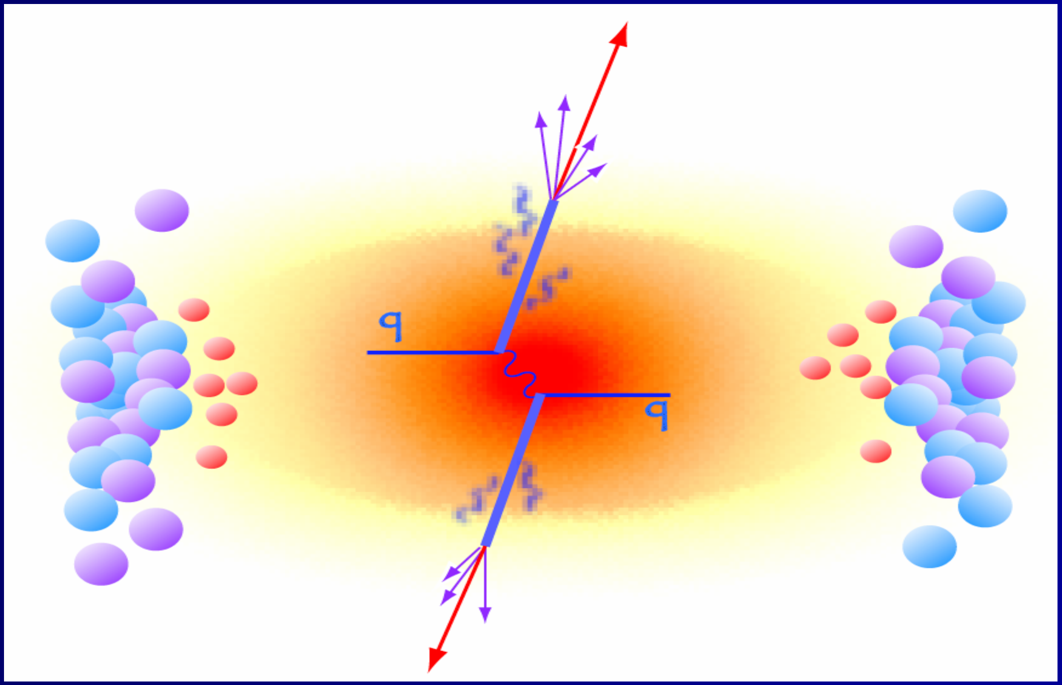


Hard Probes



- Hard probe rates can be calculated with pQCD
- Results with no medium (pp) define the benchmark for the probe;
- Results in hot medium and their difference with defined expectation provides a **characterization of the medium.**

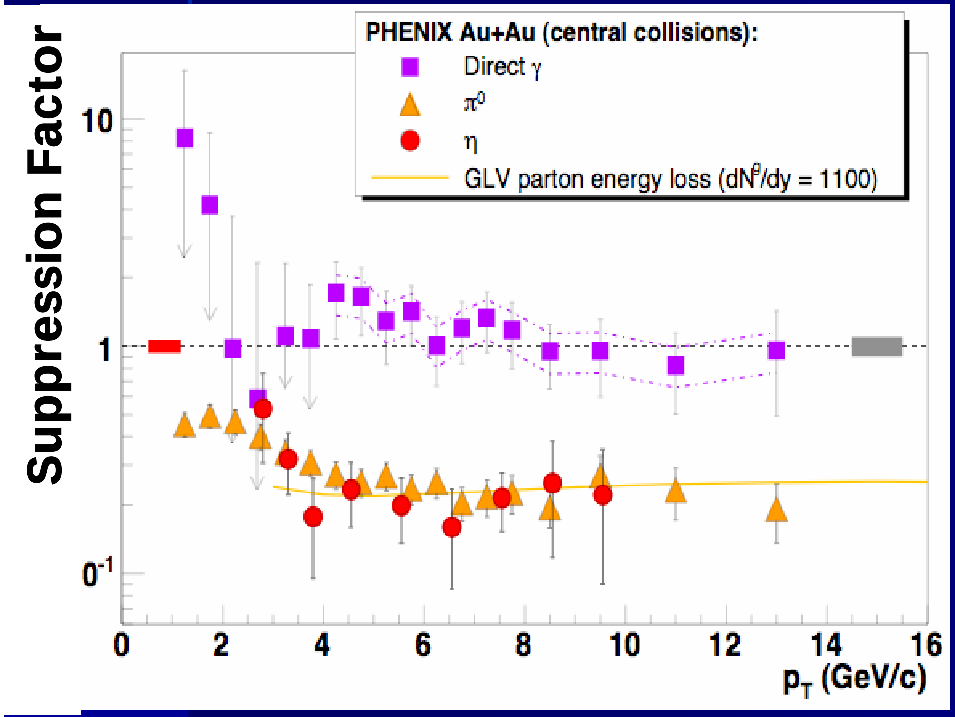
Jet Tomography

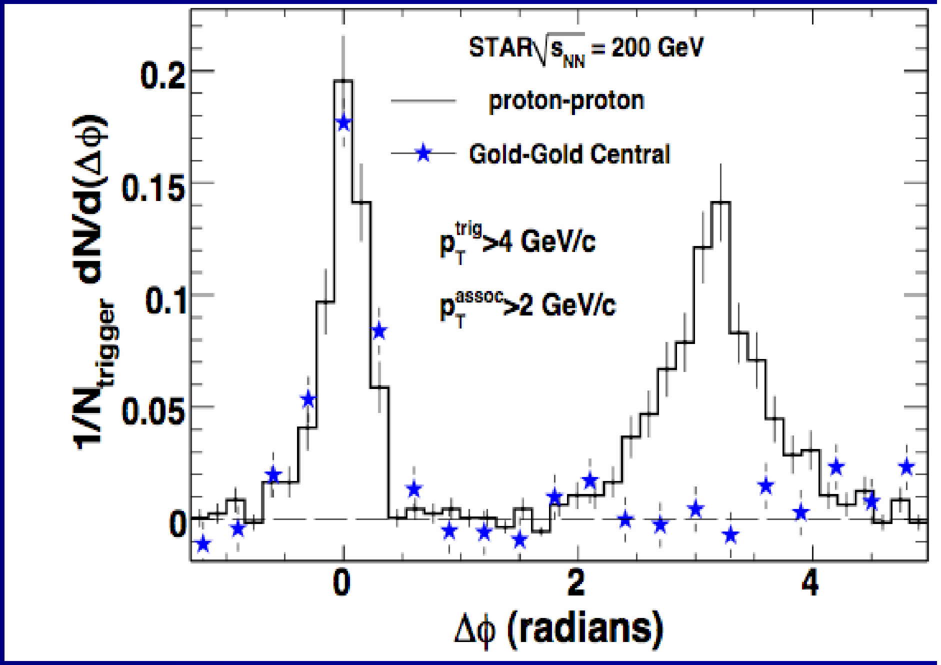


- Partons are expected to lose energy via induced gluon radiation in traversing a dense colored medium.

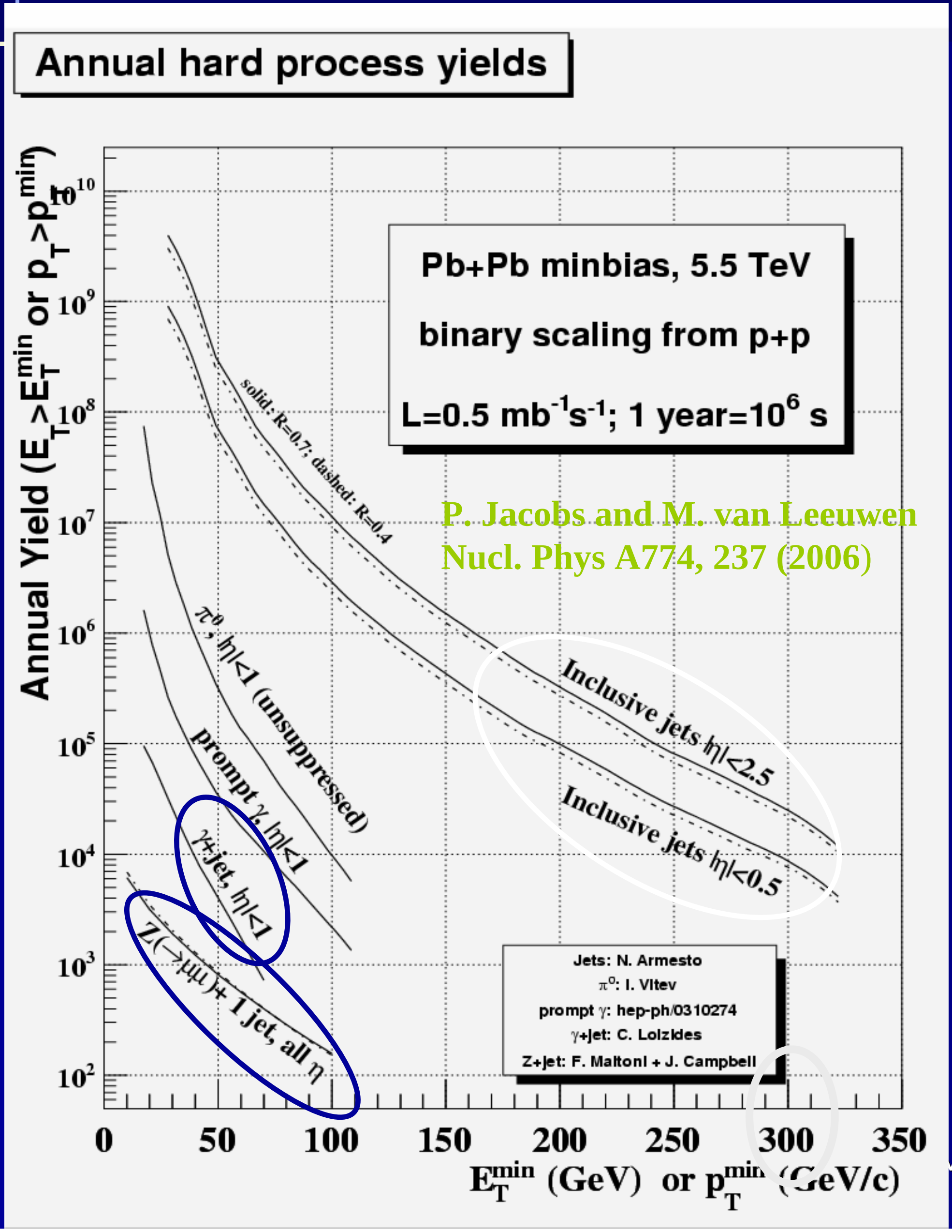
Discovery of Jet Quenching at RHIC

- Measure using (Leading) high-p_T hadrons and photons





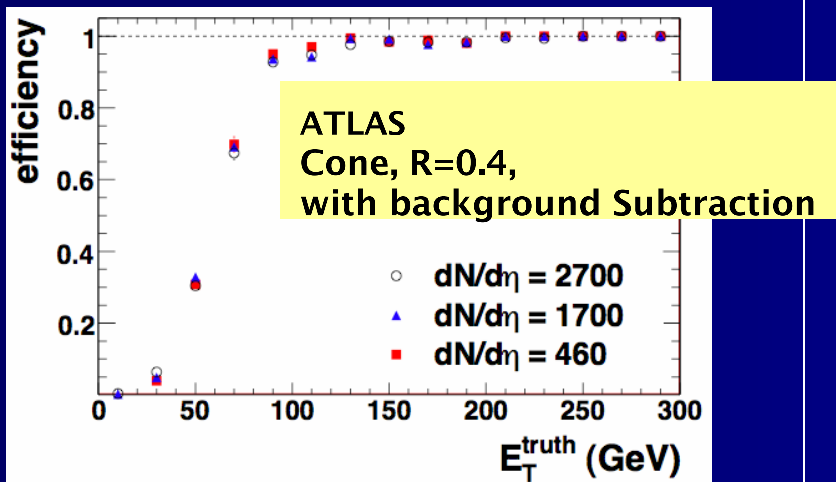
Jet Rates at LHC

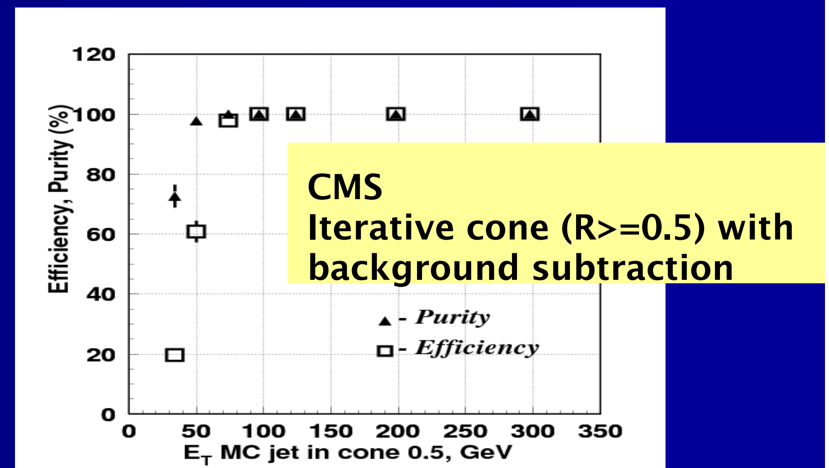


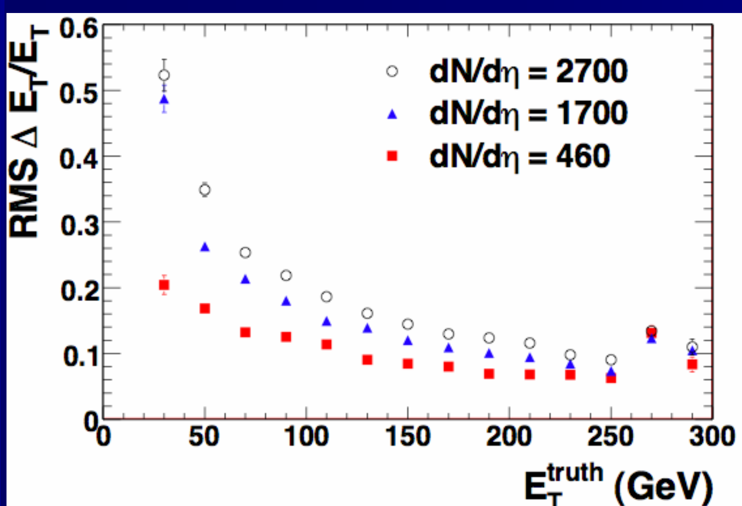
- High p_T, large rates
- b jets, di-jet, γ-jet
- Also full jet measurement not leading hadrons

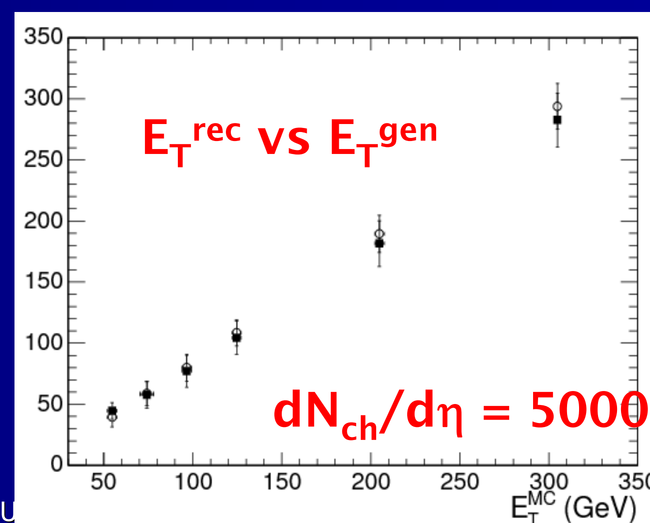
“Full” Jet Measurements at LHC

After subtraction of the “underlying event” background



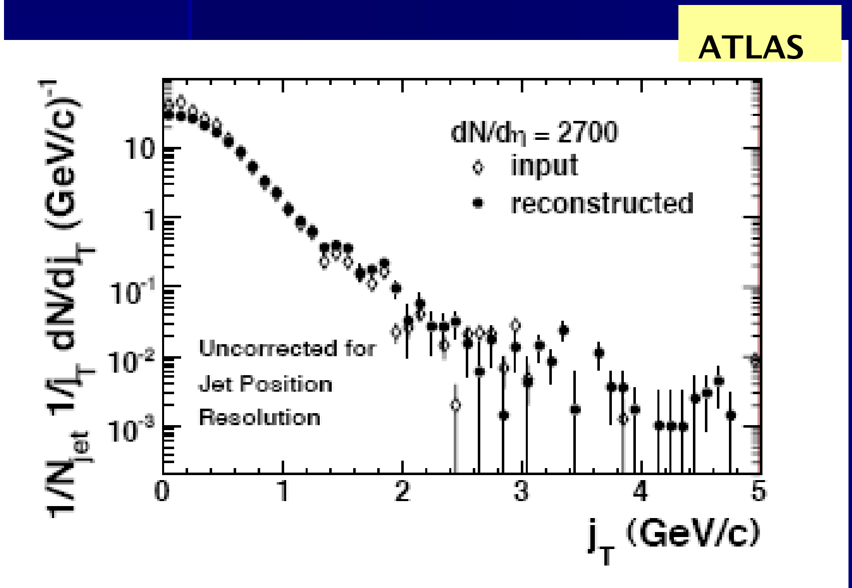


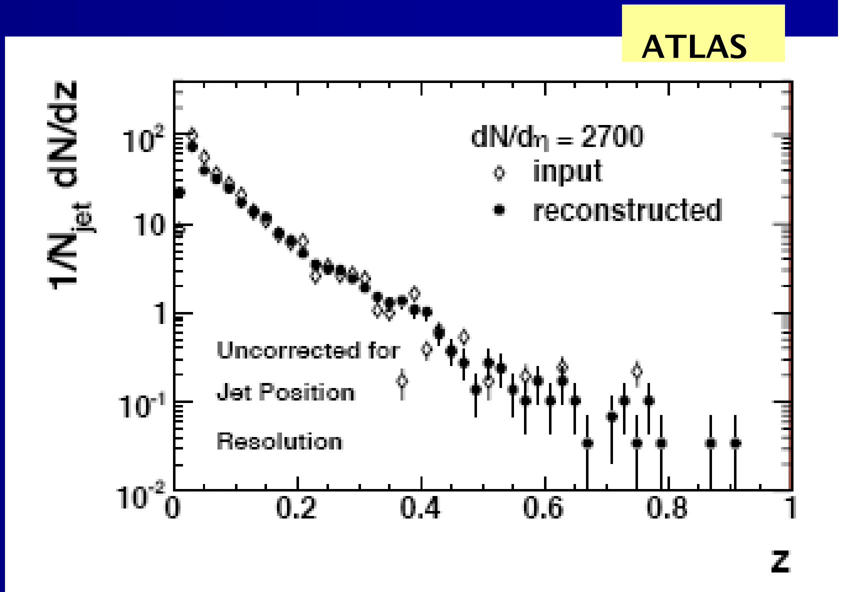




Fragmentation Functions

- Well measured fragmentation function both in j_T and z
- Will provide direct access to radiative energy loss





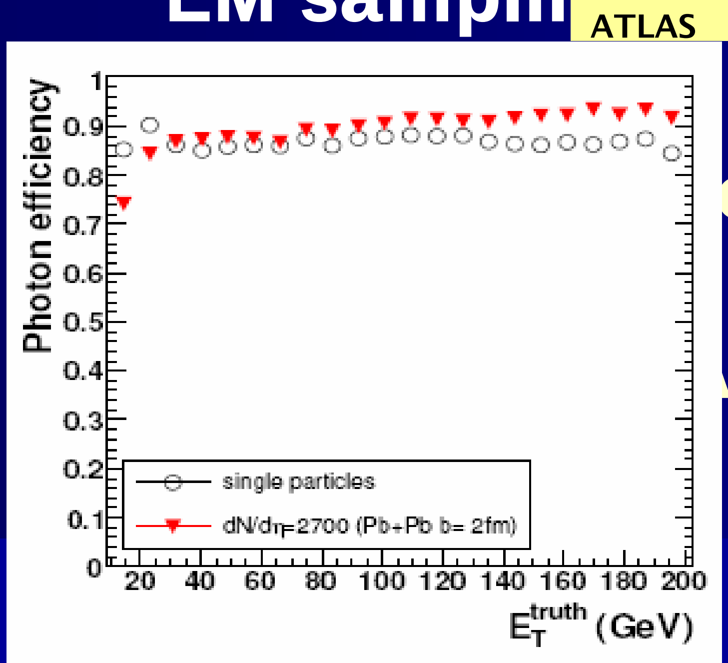
Photon measurement at LHC

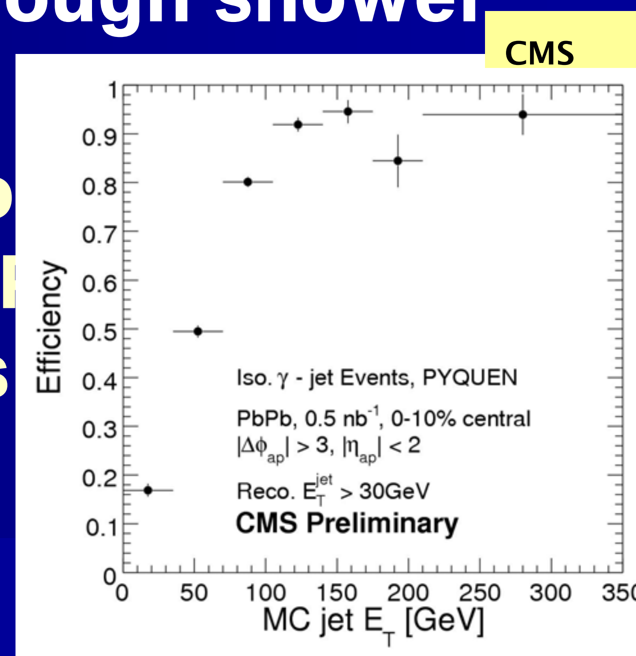
- Excellent photon reconstruction will allow direct photon and γ-jet measurements:
  - ATLAS uses **direct identification in first EM sampling layer through shower**

on reco

m and

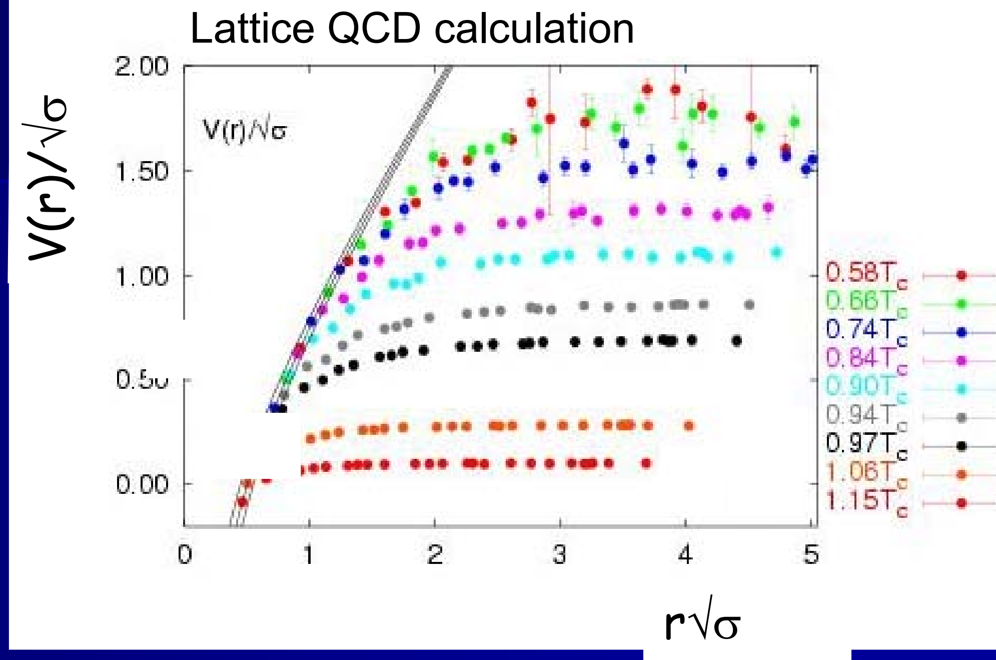
nalysis

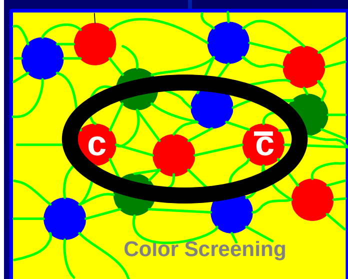




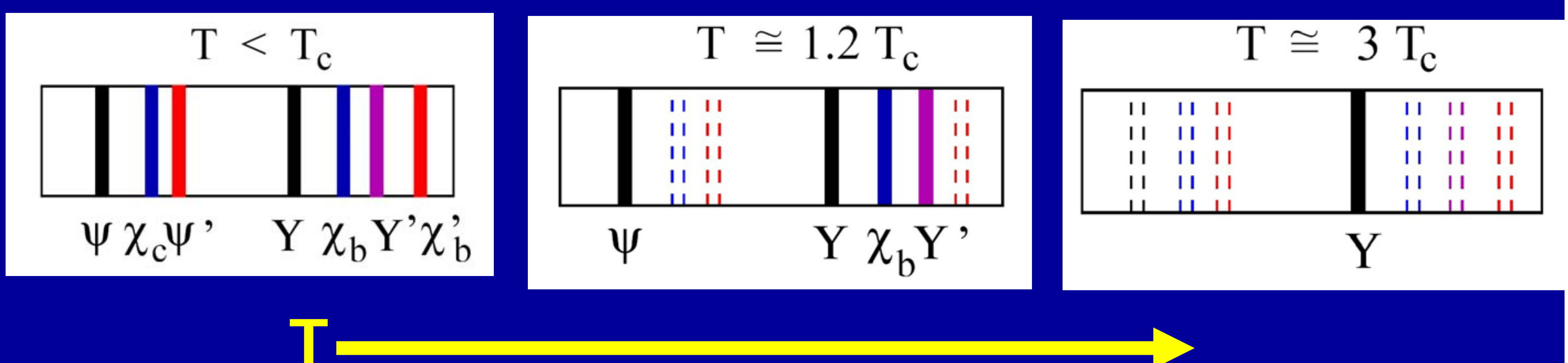
Deconfinement

- Lattice QCD makes a clear prediction for the onset of deconfinement.

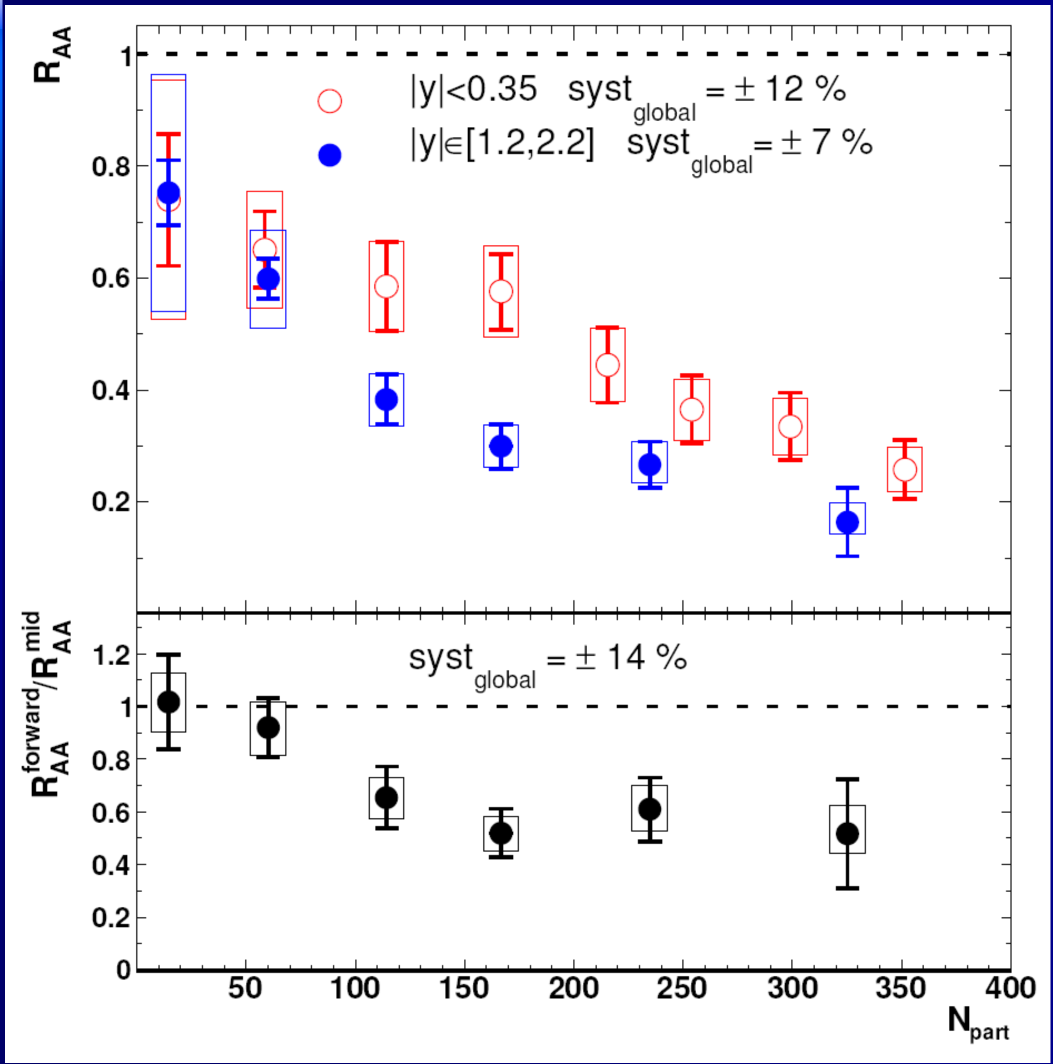




- Different Quarkonia states test the degree of color screening and measure the temperature.



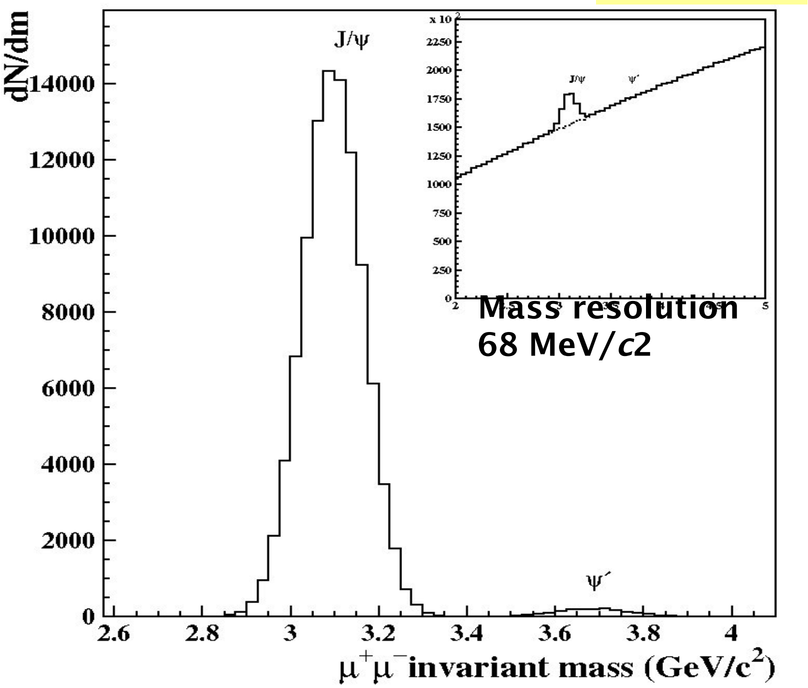
J/ψ suppression at RHIC



- Smooth suppression with increasing collision centrality
- Forward rapidity more suppressed than mid-rapidity
- very similar suppression at RHIC and SPS...

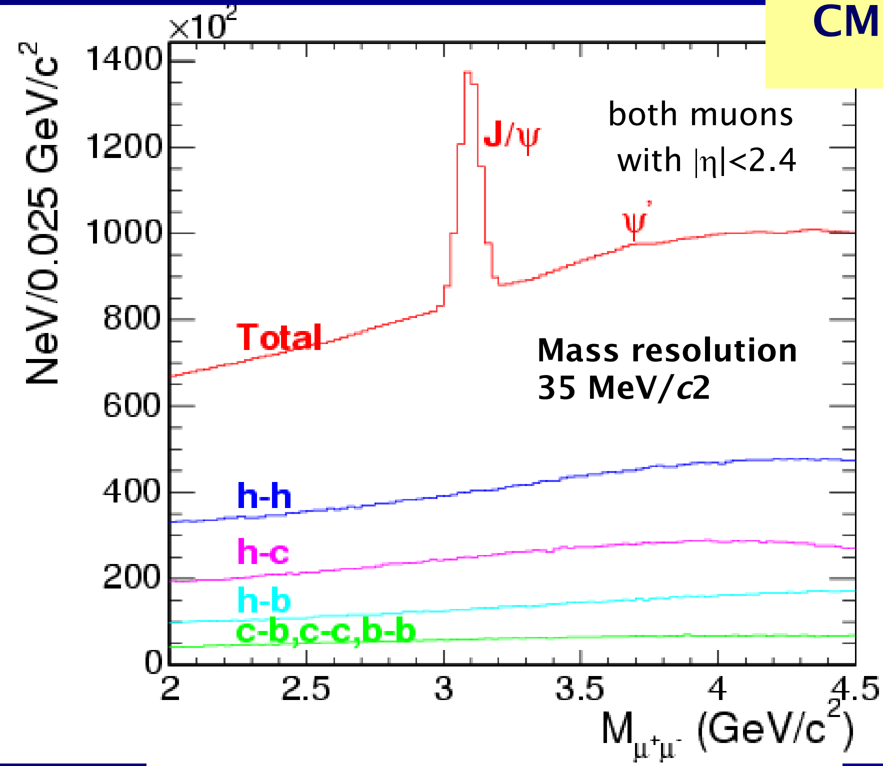
J/ψ Measurement at the LHC

ATLAS



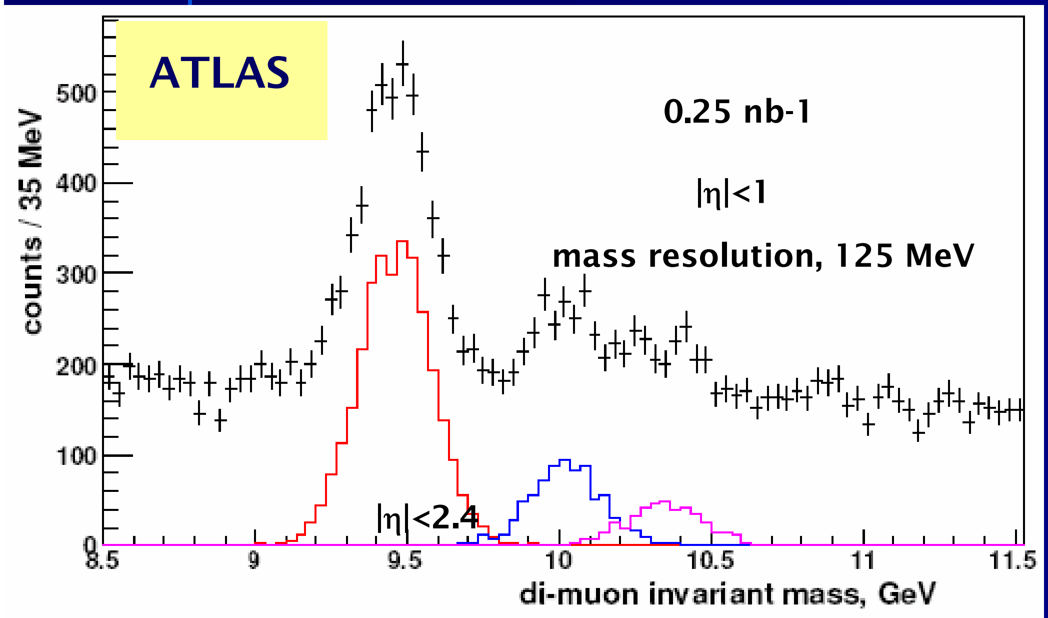
~100k J/ψ per month, tagging method

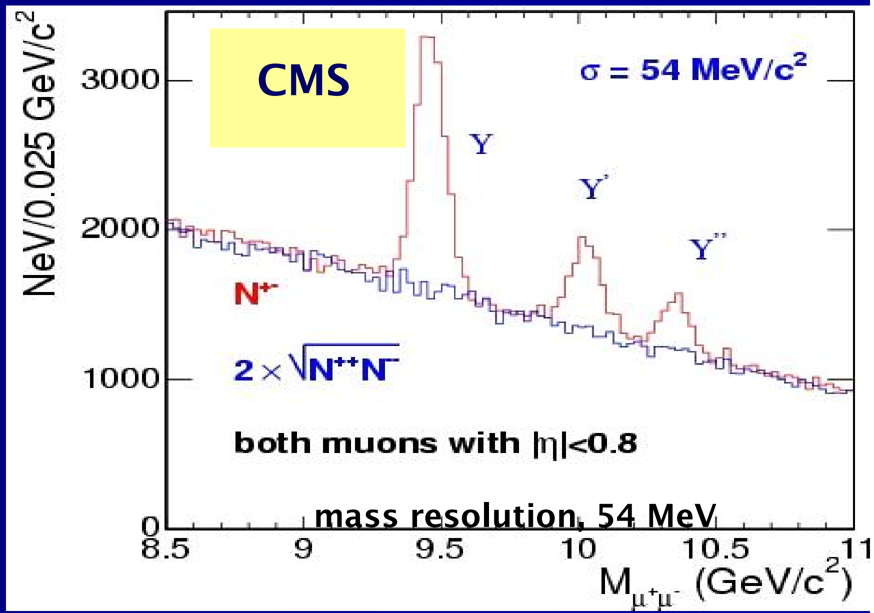
CMS



Expected rate
(per month, 10^6 s, 0.5 nb^{-1}):
J/ψ ~ 180 kevents

Upsilon Measurement at LHC





Upsilon rates in 1 month of running:
(at nominal luminosity)

- Υ ~ 25 kevents,
- Υ' ~ 7 kevents,
- Υ" ~ 4 kevents

Conclusions

- The LHC with Heavy Ions is a fantastic discovery machine with a very rich Physics program:
  - ➢ The first 15 minutes; $L_{int}=1\mu b^{-1}$
    - Event multiplicity, elliptic flow
  - ➢ The first month; $L_{int}=0.1\text{-}1nb^{-1}$
    - Rare high p_t processes: jets, quarkonia

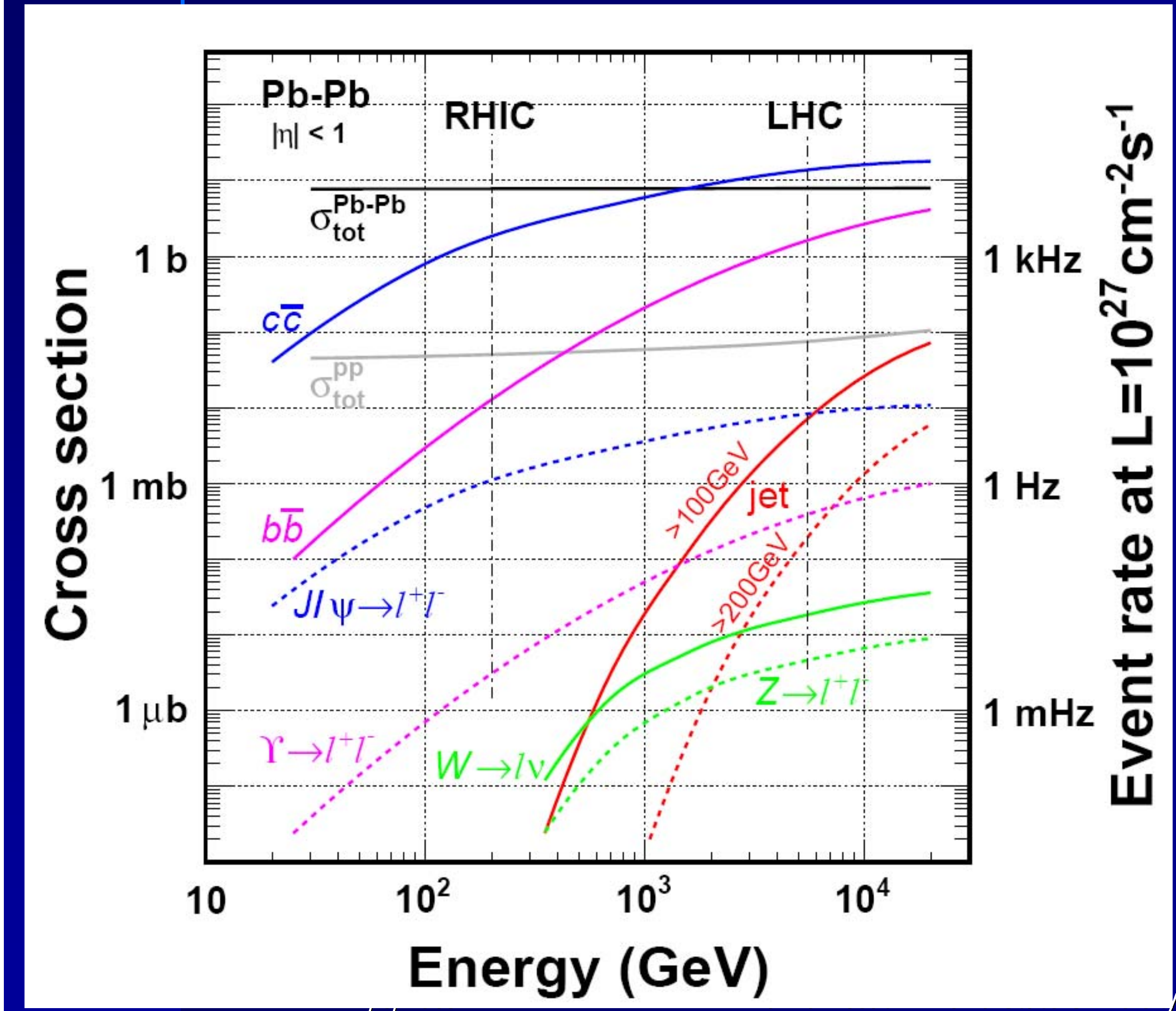
- ATLAS and CMS have unprecendented capabilities to make measurements over a large kinematic range for important signatures of the Quark Gluon Plasma

- The experiments will be commissioned and ready (thanks to the proton run)

➡ Important results already from the very start of running with nuclear beams

END

LHC: Cross-sections and Rates



Cross-sections of interesting probes expected to increase by factors

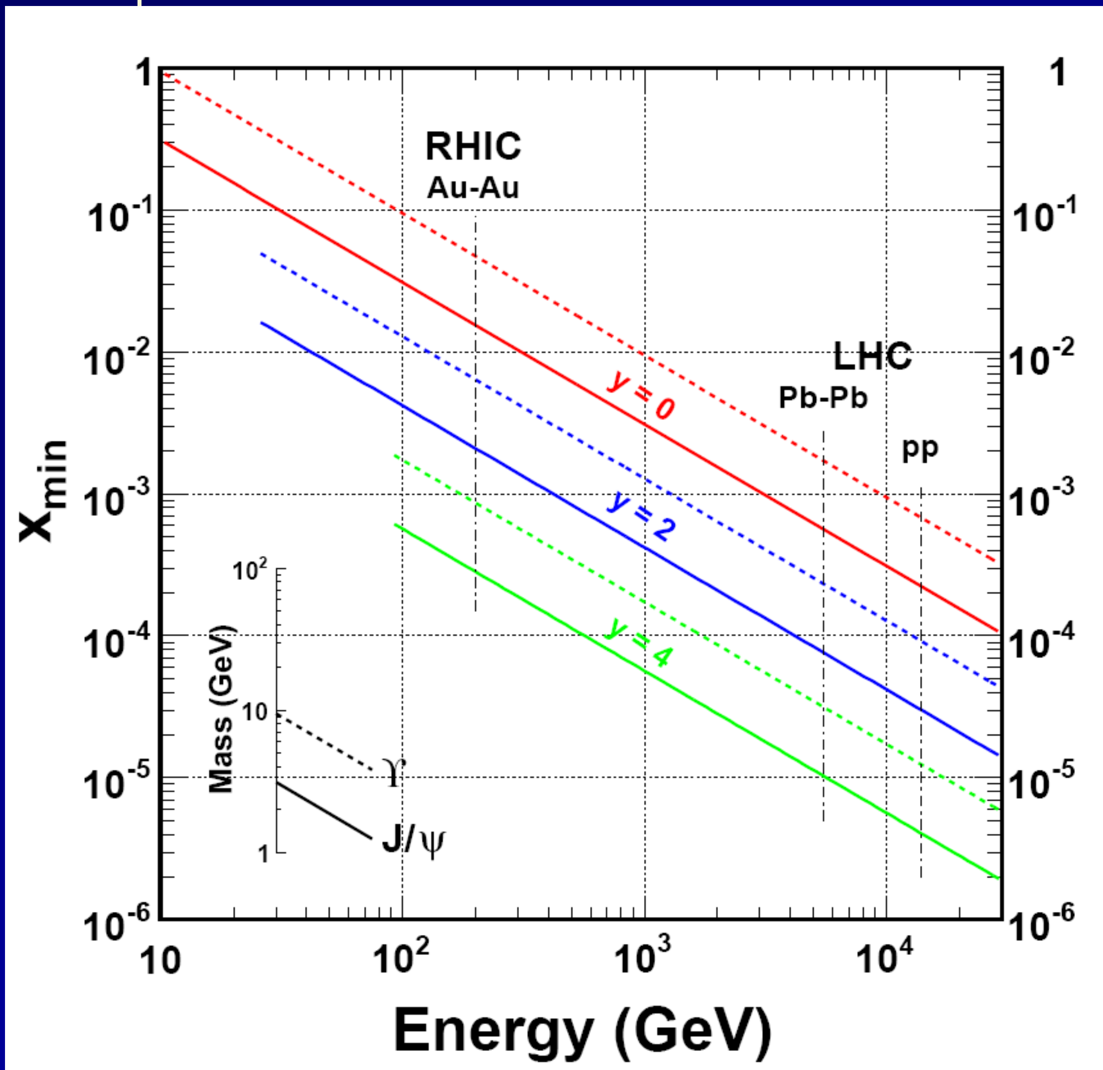
~ 10 ($c\bar{c}$) to

~ 10^2 (bb) to

~ > 10^5 (very high p_T jets)

Hard probes of the medium accessible at LHC

LHC: extending the low-x Reach



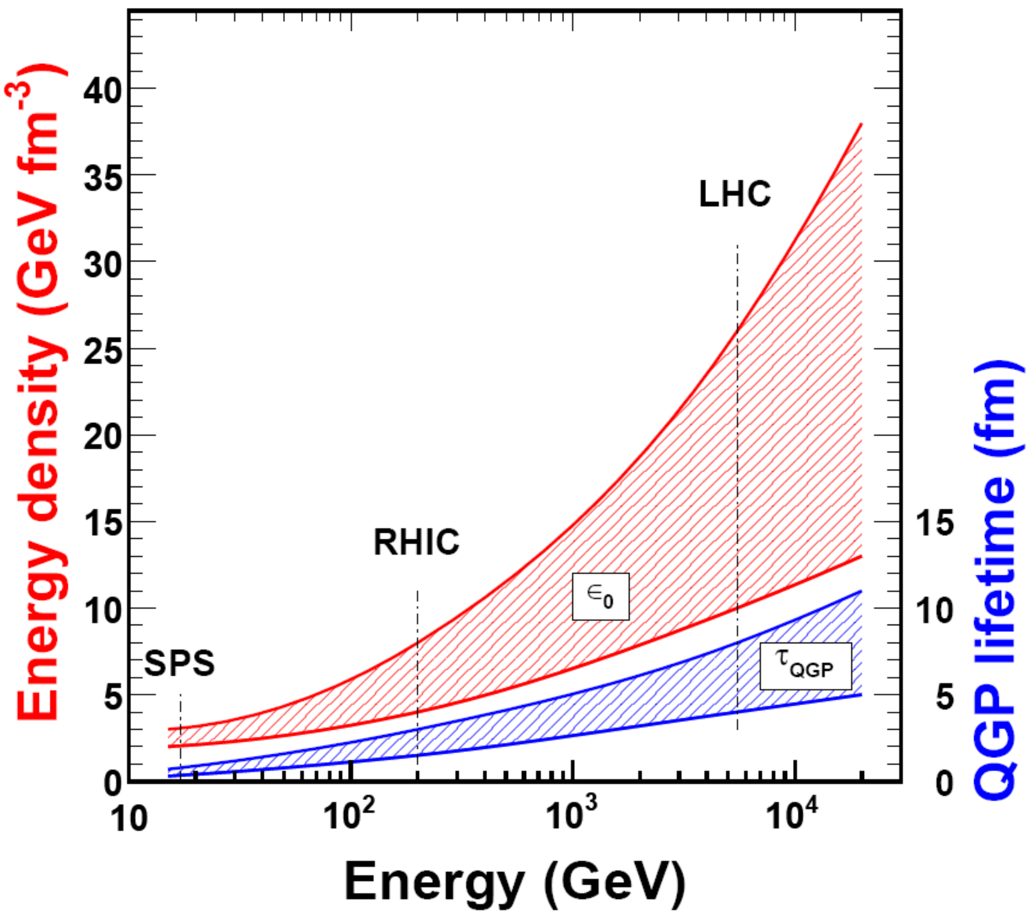
RHIC as opened the low-x frontier finding indications for new physics (Colour Glass Condensate CGC)

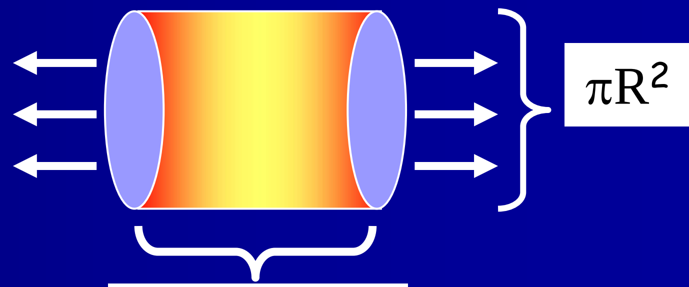
x = 2 p (parton) / √s

LHC will lower the x- frontier by another factor 30 due to energy and by 3 due to larger rapidity

Can reach x = 3 * 10^{-6} in pp,
10^{-5} in PbPb

QGP





$$dz = c\tau_0 dy$$

Energy Density

$$\varepsilon_0 = \frac{dE_T}{dy}\frac{1}{\pi R^2 \tau_{thermalization}}$$

Summary of Ions

The desired species for a systematic HI study are as follow

Collision	R (fm)	Luminosity ($cm^{-2}s^{-1}$)	dN_{ch}/dy (maximum)	Interaction rate
p+p	~1	1×10^{34}	<250	1 GHz
$^{208}Pb+^{208}Pb$	7.1	1×10^{27}	<8000	8 kHz
$^{40}Ar+^{40}Ar$	4.1	6×10^{28}	<800	200 kHz
$p+^{208}Pb$		1×10^{30}	<150	2 MHz
$p+^{40}Ar$		1×10^{31}	<120	6 MHz