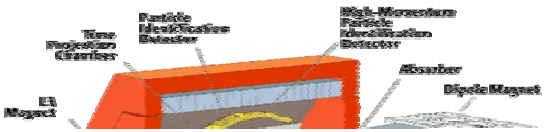
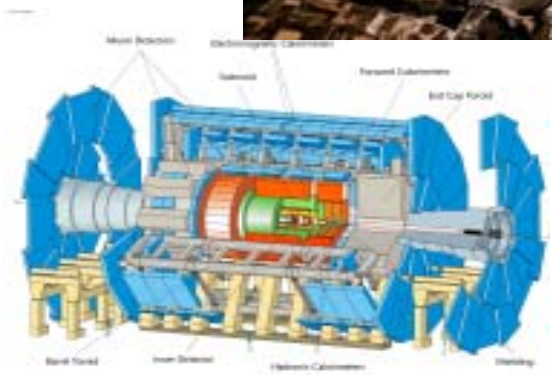
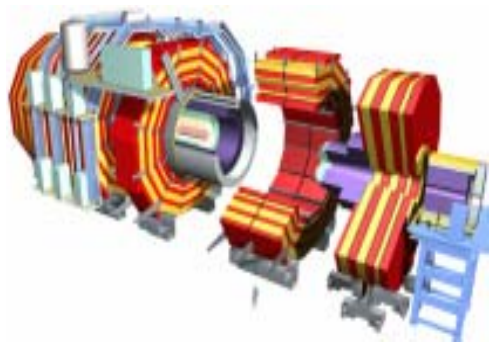
Physics opportunities with LHC as a heavy-ion collider, experimental perspective







Summary of physics opportunities

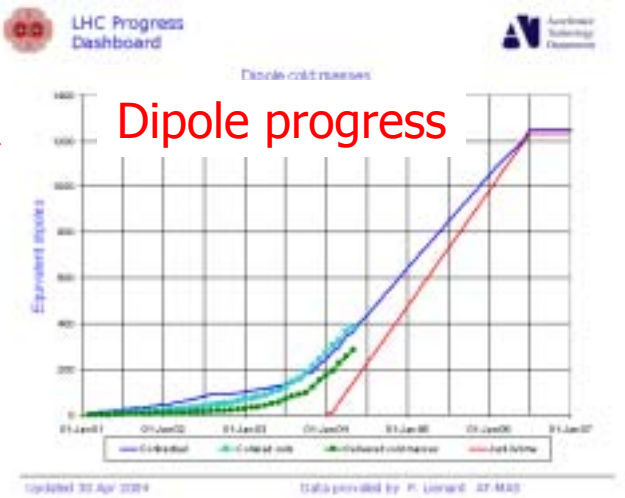
- LHC will accelerate and collide heavy ions at energies far exceeding the range of existing accelerators
  - The increase of beam energy will result in:
    - Extended kinematic reach for pp, pA, AA
    - New properties of initial state, saturation at mid-rapidity
    - A hotter and longer lived partonic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

Colliding Pb ions in LHC

- p+p operations start in April 2007
- Pb+Pb expected one year later
  - Each year expect several weeks of HI beams (10^6s effective)
  - CERN HI community wants a short exploratory run in 2007
- Future includes other ion species and pA collisions

R. Aymar, CERN DG:
"CERN will make every effort to ensure that there are collisions at the end of summer 2007"



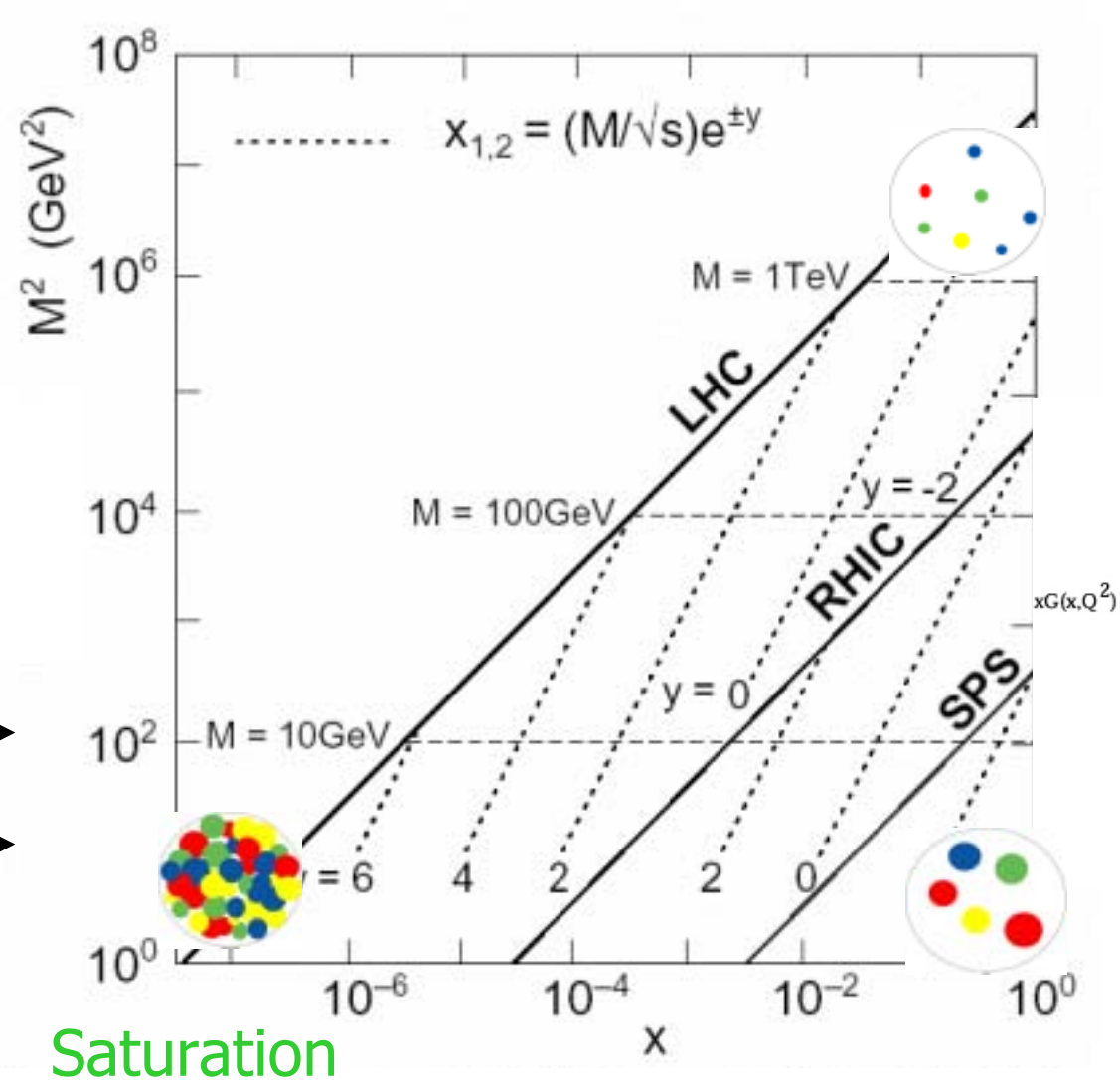
Pb+Pb parameters

Parameter	Nominal	Early
$\sqrt{s_{NN}}$ [TeV]	5.5	5.5
Ions/bunch	7 10^7	7 10^7
Bunches	592	62
Transverse beam size (RMS)	16 μm	23 μm
Longitudinal beam size (RMS)	8 cm	8 cm
Peak Luminosity [$cm^{-2}s^{-1}$]	1 10^{27}	5.4 10^{25}

Other ions (selected)

System	L_0 [$cm^{-2}s^{-1}$]	$\sqrt{s_{NN\ max}}$ [TeV]	Δy
Pb+Pb	1 10^{27}	5.5	0
Ar+Ar	6 10^{28}	6.3	0
O+O	2 10^{29}	7.0	0
pPb	1 10^{30}	8.8	0.5
pp	1 10^{34}	14	0

Kinematics at the LHC



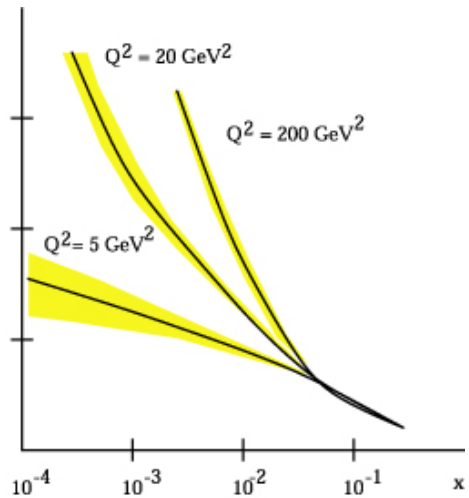
Z^0 →

Υ →

J/ψ →

Saturation

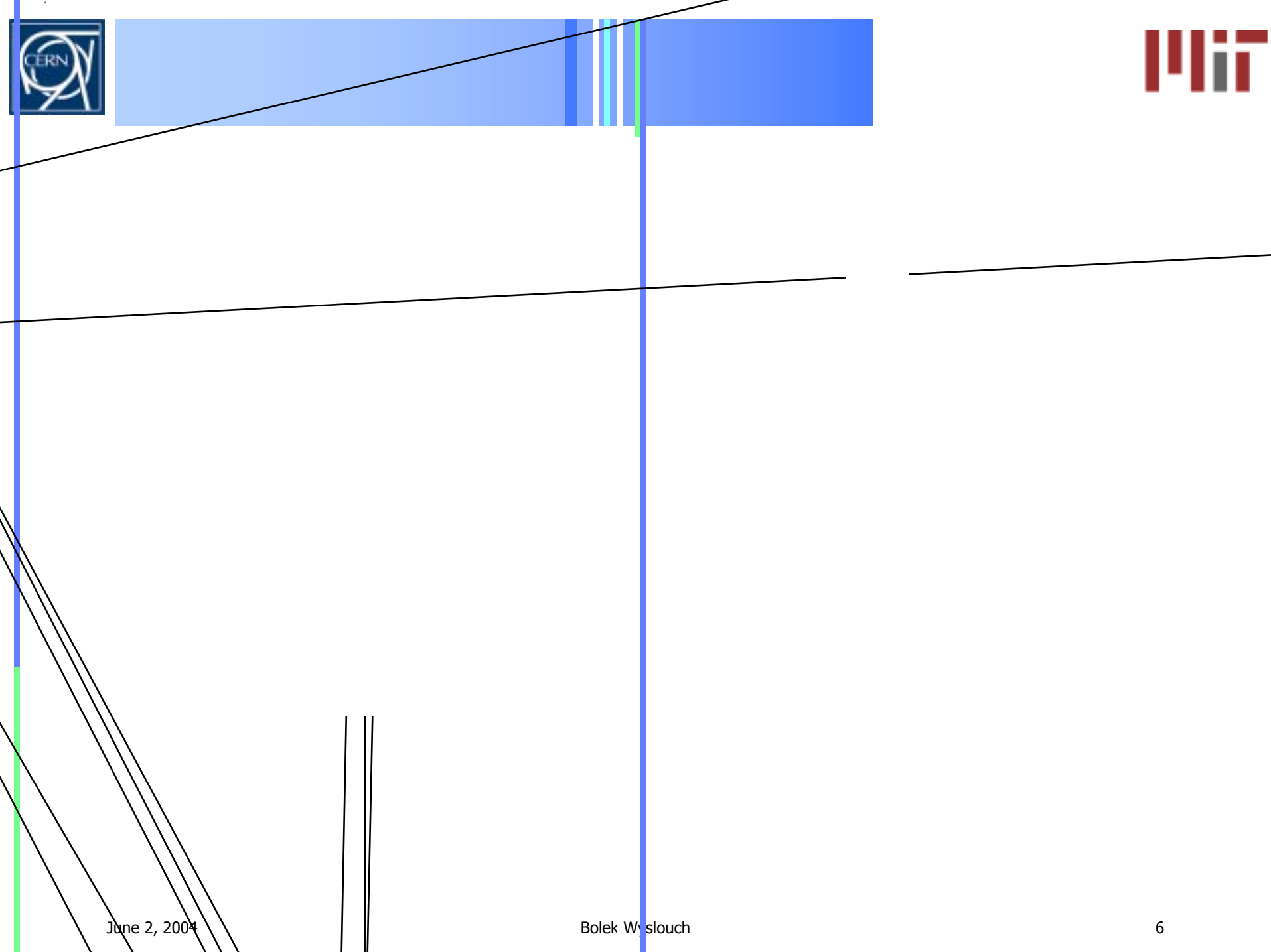
Access to widest range of Q^2 and x



Gluon density has to saturate at low x

Quark Gluon Plasma

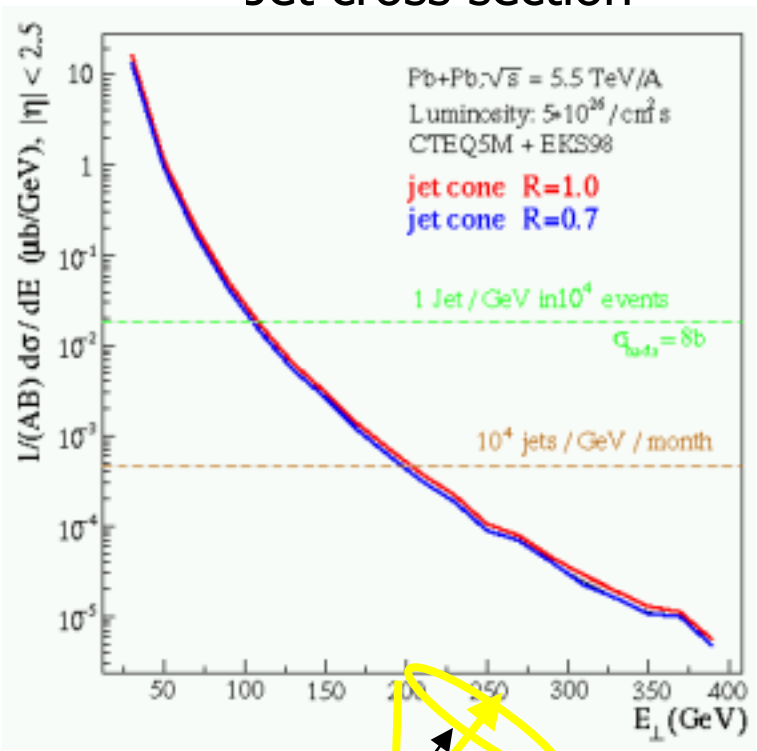
- Data from SPS & RHIC shows new and unexpected properties of hot nuclear matter
- Jet quenching, strong elliptical flow, d+Au data indicate that we have produced strongly interacting color liquid
- LHC will significantly increase energy density
  - new properties of the QGP
    - Continuation of strong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

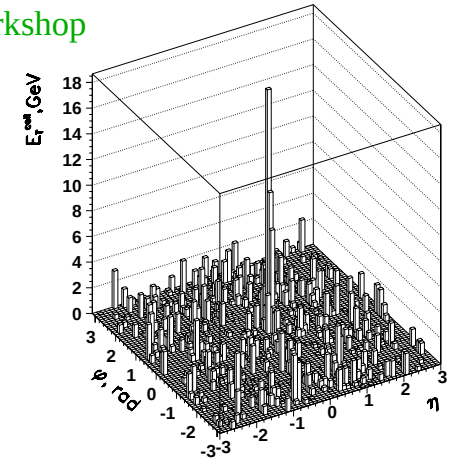


High rates of identified jets at the LHC

A. Accardi and N. Armesto, CERN TH Workshop

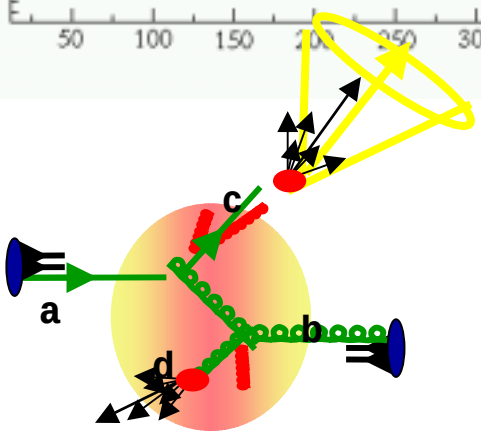
Jet cross section

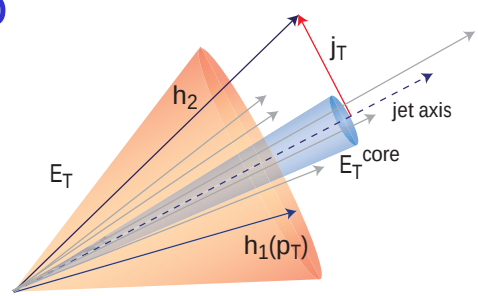




Jets identifiable well above background
- -parton energy
- -parton direction

- Detailed studies of true single jets
  - Jets shape and fragmentation modified by the medium
  - Jet tomography
- Detailed studies of multiple jets, correlations including jets
  - Dijet/monojet ratio
  - Jet-γ
  - Jet-Z^0
  - Multi jets





Rates of hard probes

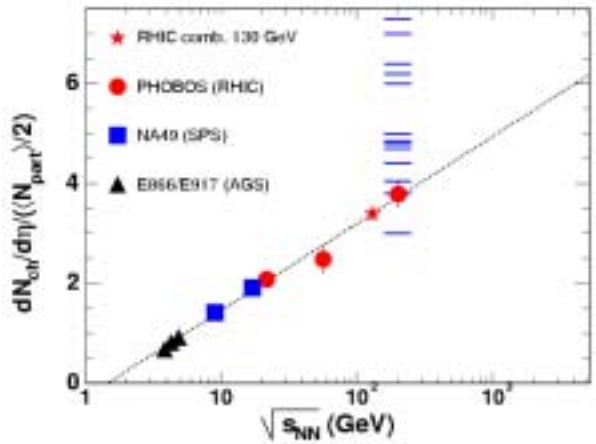
Average luminosity ~ ½ of peak

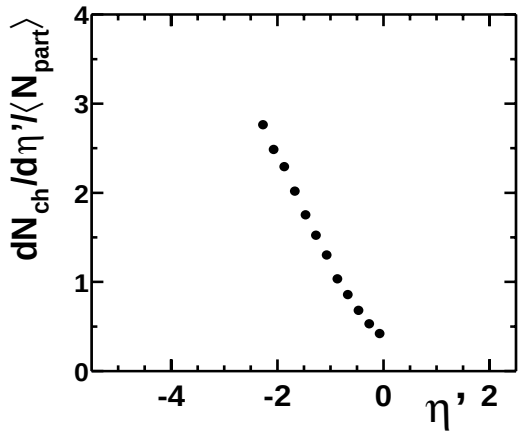
From CERN "Yellow Report on Hard Probes in HI Collisions"

	Pb+Pb $\sqrt{s_{NN}} = 5.5$ TeV $\mathcal{L} = 5 \times 10^{26}$ cm^{-2}s^{-1}	pPb $\sqrt{s_{NN}} = 8.8$ TeV $\mathcal{L} = 1.4 \times 10^{30}$ cm^{-2}s^{-1}
Process	Yield/10^6 s	Yield/10^6 s
	$\lvert\eta\rvert \leq 2.4$	
Jets: jet($p_T > 50$ GeV)	2.2×10^7	1.5×10^{10}
Jets: jet($p_T > 250$ GeV)	2.2×10^3	5.2×10^6
Gauge Bosons: Z^0	3.2×10^5	6.8×10^6
Gauge Bosons: W^+	5.0×10^5	1.1×10^7
Gauge Bosons: W^-	5.3×10^5	1.1×10^7
	all phase space	
Heavy Quarks and Quarkonia: $c\bar{c}$	9.0×10^{10}	2.0×10^{12}
Heavy Quarks and Quarkonia: $b\bar{b}$	3.6×10^9	8.2×10^{10}
Heavy Quarks and Quarkonia: $J/\psi \to \mu^+\mu^-$	2.4×10^7	5.5×10^8
Heavy Quarks and Quarkonia: $\Upsilon \to \mu^+\mu^-$	1.5×10^5	3.5×10^6
Heavy Quarks and Quarkonia: $\Upsilon' \to \mu^+\mu^-$	3.7×10^4	8.4×10^5
Heavy Quarks and Quarkonia: $\Upsilon'' \to \mu^+\mu^-$	2.2×10^4	5.2×10^5

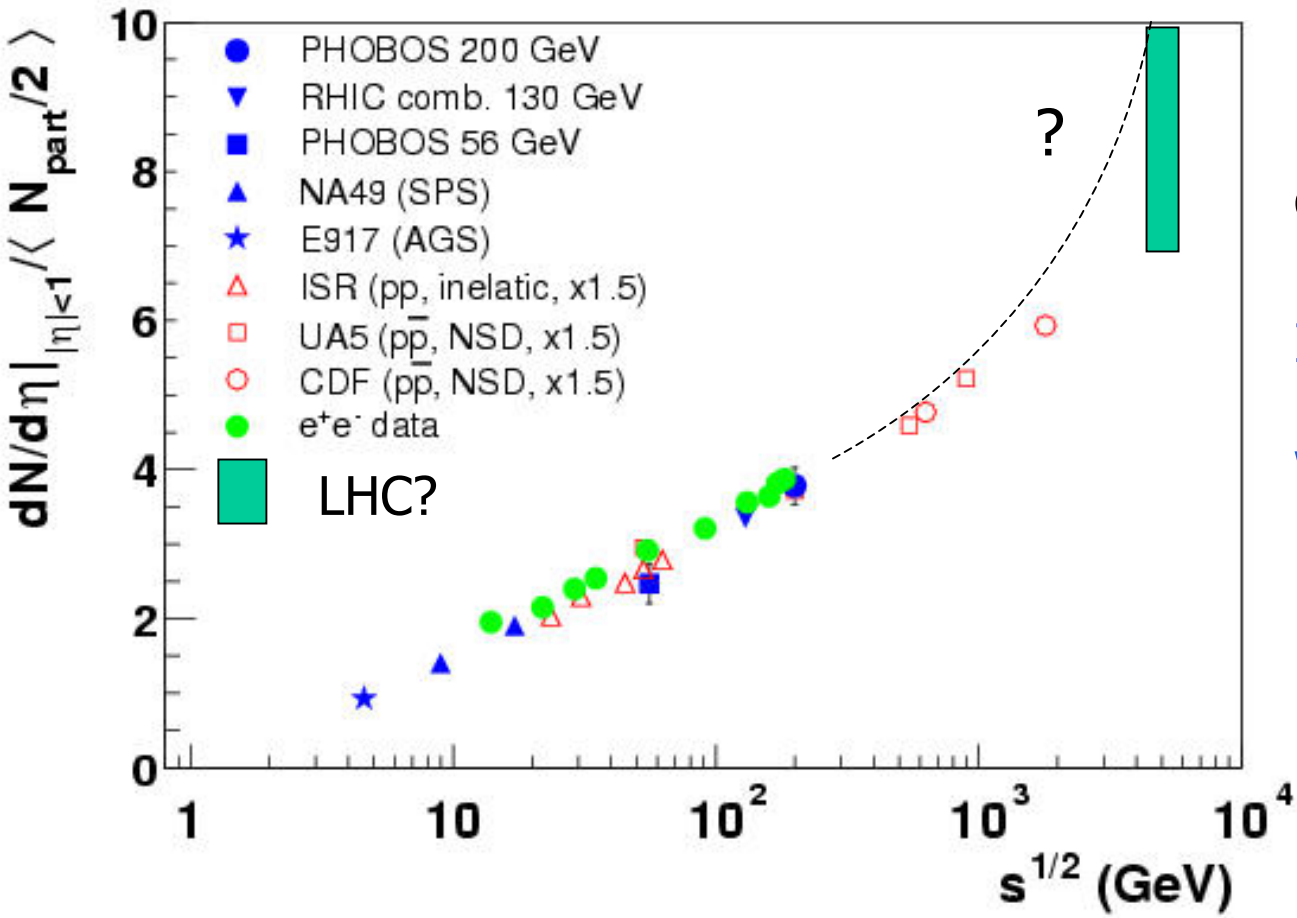
Refinement of RHIC results at the LHC: What lies beyond ?

- Many phenomena measured at RHIC have surprisingly simple energy dependence, will this continue at the LHC ?
- Hydrodynamic limit, will it hold?





The most basic soft physics measurement



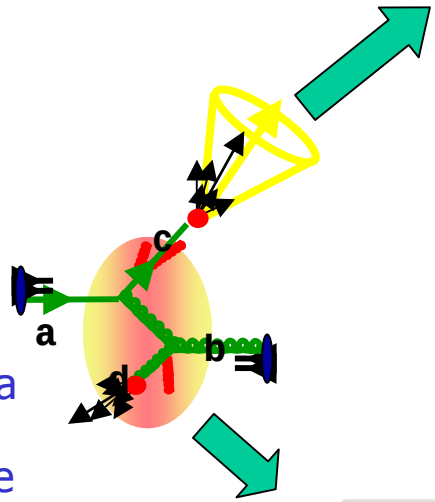
Extrapolated to LHC:
$dN/d\eta \sim 1400$

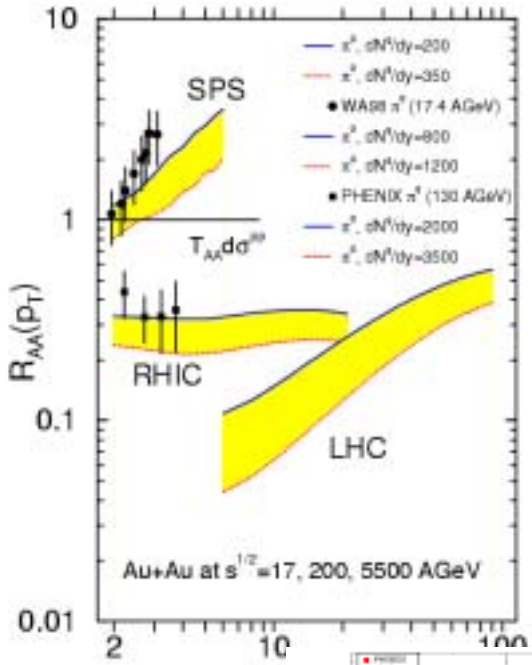
Is it saturation that makes it so low? Will it increase at higher energies?

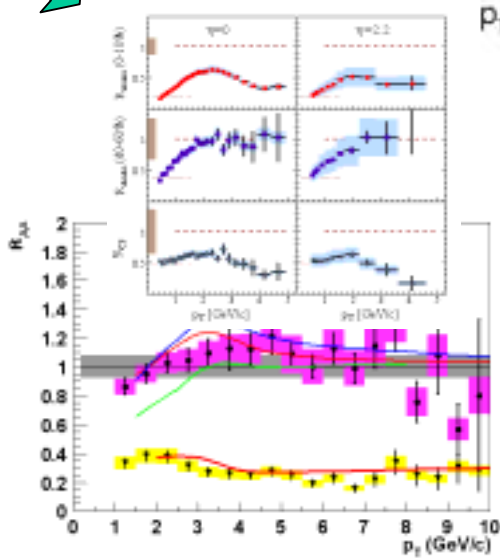
Note: this is an important experimental issue!

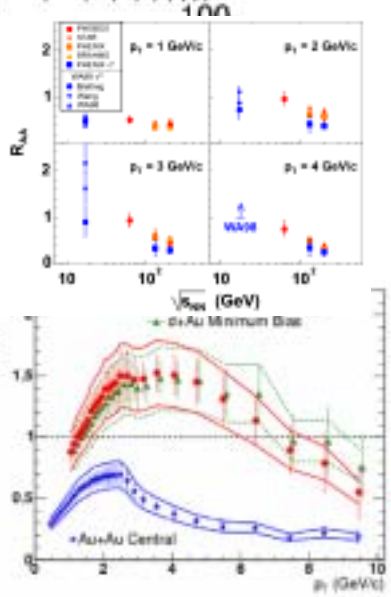
Why study heavy ion collisions at the LHC? E.g. jet quenching

- From first principles:
  - Highest collision energies will create higher temperatures and longer lived partonic state: unique conditions for creation and study of Quark Gluon Plasma
- Guided by experiment:
  - We found novel phenomena at RHIC that require detailed understanding. The data at LHC energies will provide an additional and important experimental input towards understanding of sQGP, wQGP or whatever nature decided to produce at high energies

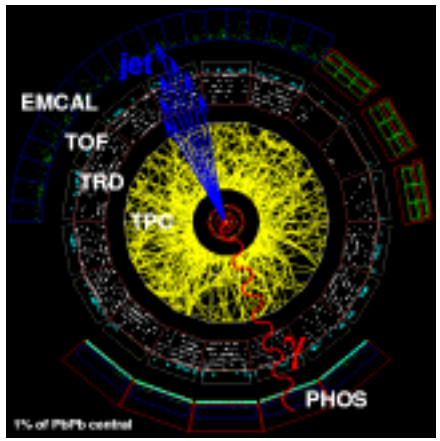


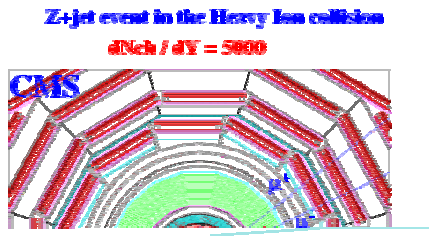






New processes at the LHC



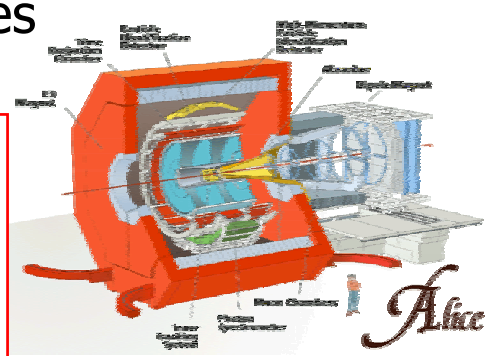


The experiments

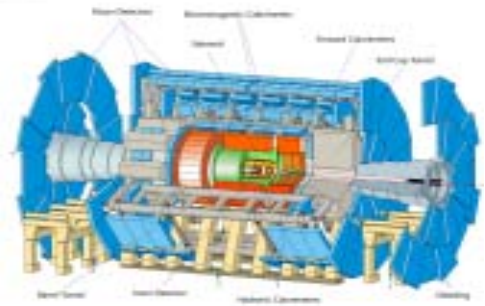
State of the art: expect performances exceeding that of most existing detectors

Complementary and redundant experiments will allow detailed studies of hot nuclear matter and the discoveries of new phenomena

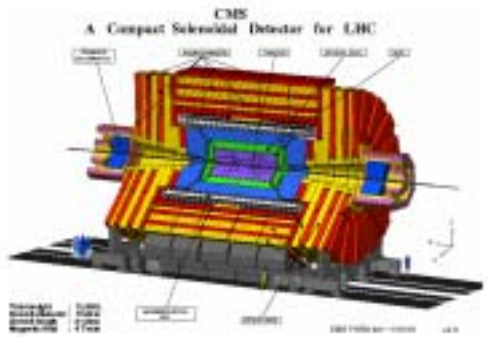
ALICE: Dedicated HI experiment with large suite of detectors optimized for high efficiency tracking and particle identification across large range of momenta from below ~100 MeV to above 100 GeV



ATLAS: Large acceptance, calorimetric system particularly well suited for detailed jet studies. A multi-purpose detector, designed to study relatively high p_T particles with p_T>~1 GeV

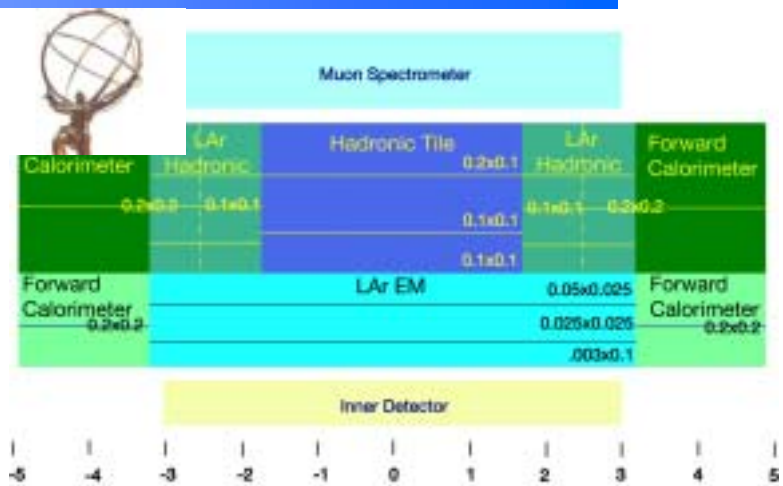


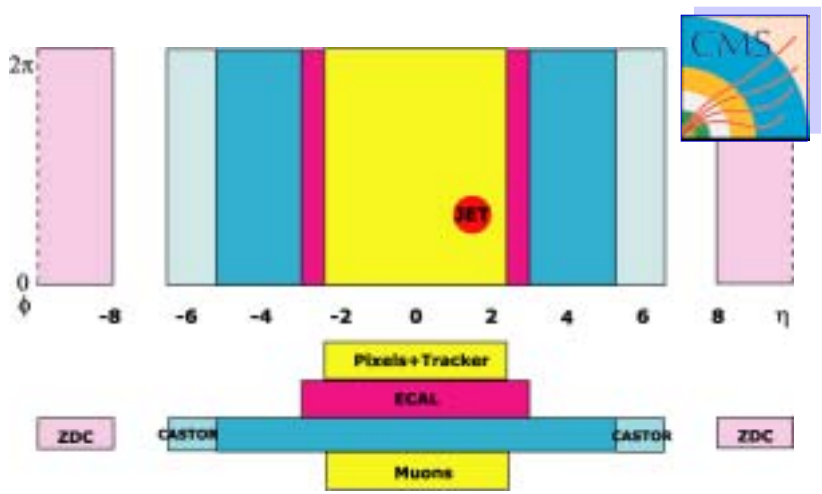
CMS: Particularly large calorimetric detector coverage, including very forward, and good momentum resolution due to high B field. A multi-purpose detector, designed to study relatively high p_T particles with p_T>~1 GeV.

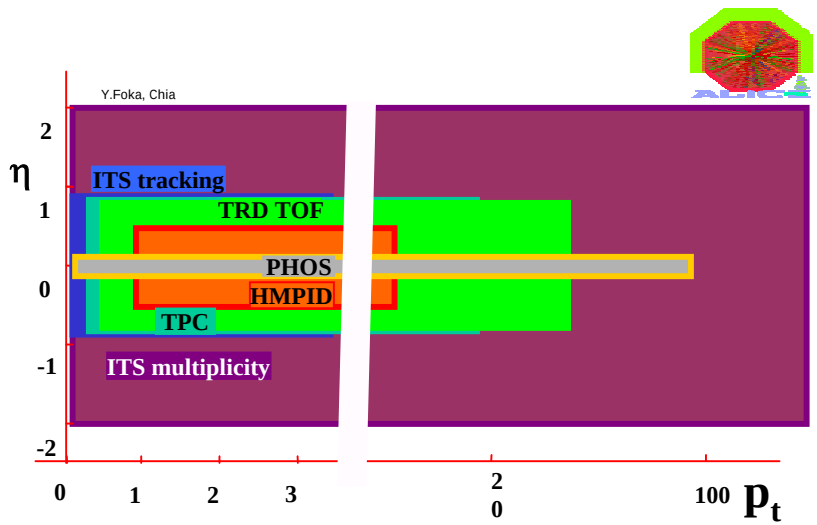


Important differences between experiments acceptance and p_T range

- Different B field: 0.5T, 2T, 4T
- Different emphasis on hermeticity
- Different emphasis on particle ID
- Different DAQ capabilities
- Different detector technologies







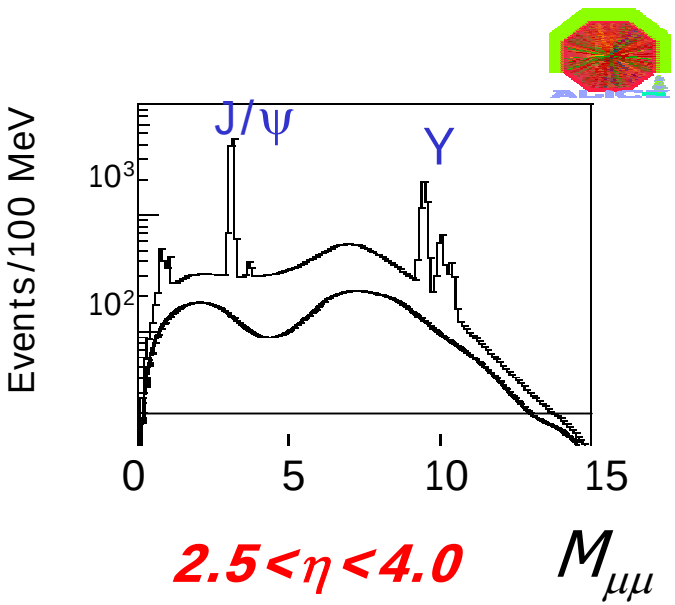
Best physics: Run all three experiments ! US contributions important to all

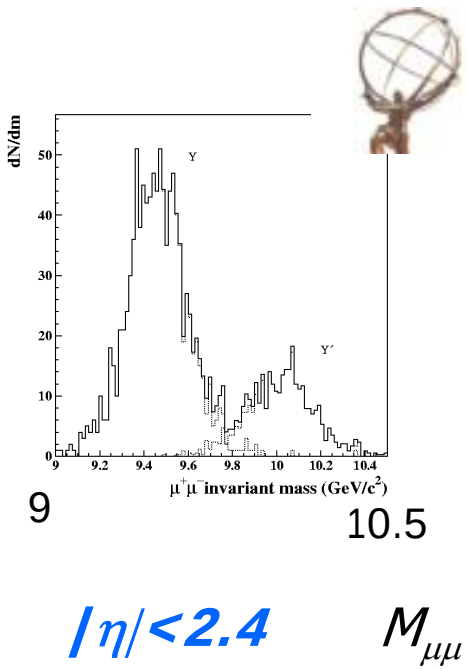
Quarkonia at the LHC: complementarities between the experiments

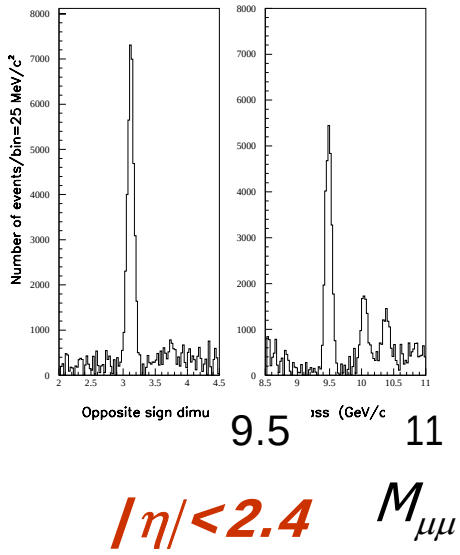
J/ψ and Υ family will be observed by all experiments with high statistics and across large range of p_T : $O(10^4)$/year

Unique opportunity at LHC: study the "melting" of three distinct states belonging to the same quarkonium family over large p_T range: QGP Thermometer

Renewed interest in J/ψ: charm coalescence: large number of cc pairs, recent lattice results indicate high melting temperature







pA physics

- Link between pp and AA physics
  - test of predictive power of QCD: factorization for hard probes
  - "calibration" of nuclear, nonperturbative effects for semi-hard probes (from few to few-tens GeV)
  - unprecedented kinematic range in x and Q^2 for nPDF determination
  - Baseline cross sections for QGP probes, can be used to effectively separate initial and final state effects
- Novel QCD phenomena
  - Low-x: multi parton interactions, diffractive processes etc.

Summary: physics opportunities at the LHC

- LHC will open a new chapter in the studies of hot nuclear matter
  - the increased energy density will likely lead to new phenomena across whole p_T range
  - the new probes will allow unique studies of the produced medium
  - Higher energy will refine and enhance RHIC results
- The construction of the accelerator and the experiments is progressing well
  - First data in 2007/2008
- The suite of the planned experiments will allow a wide range of precise and high statistics measurements