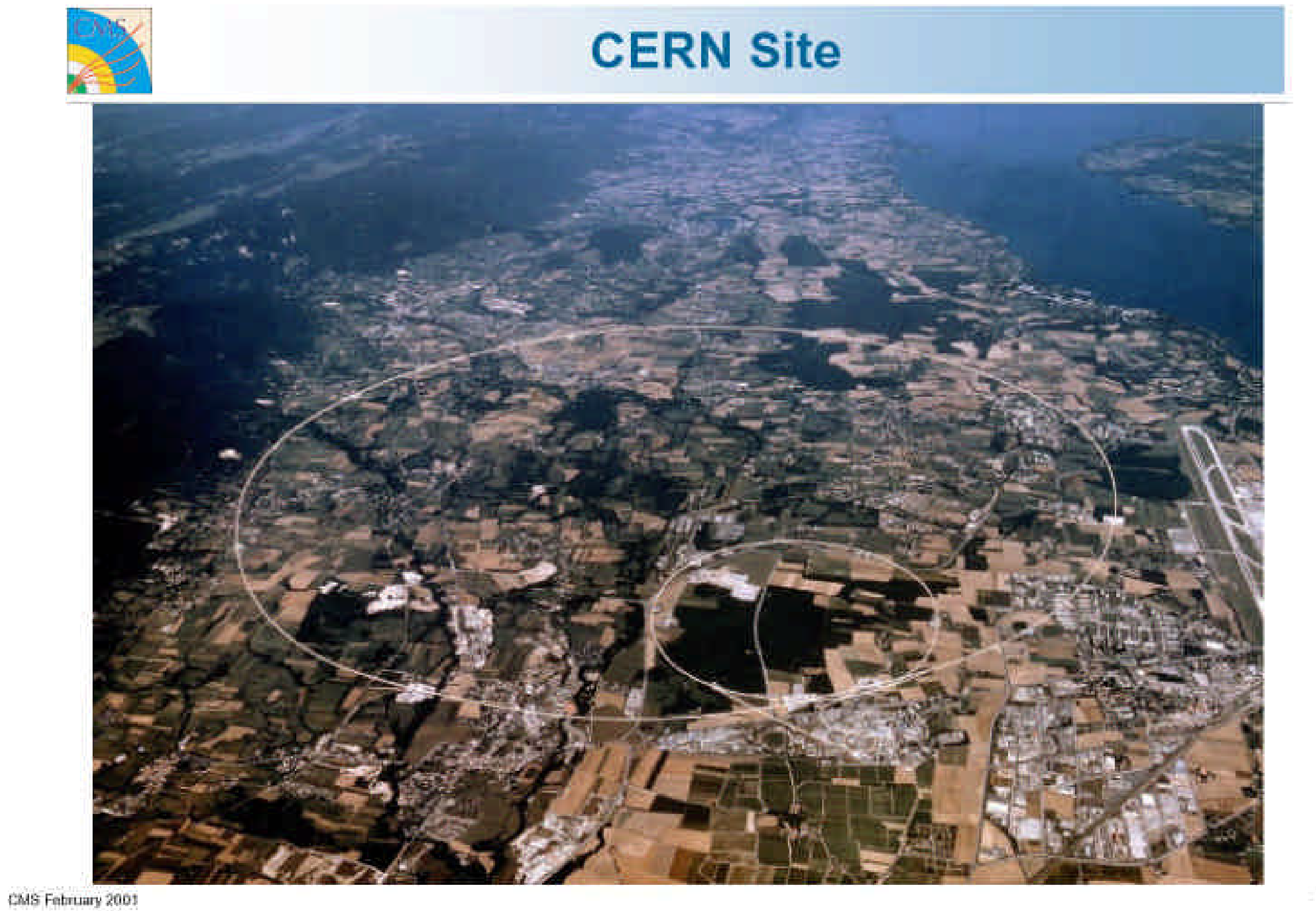
Heavy Ion Physics at the LHC: experimental prospects

Bolek Wyslouch

MIT

Collage of transparencies from D.Brandt, T. Humanic, J. Schukraft, P. Yepes, J. Nagle, JP Revol and many others

Large Hadron Collider at CERN



pp at $\sqrt{s}=14$ TeV PbPb at $\sqrt{s_{NN}}=5.5$ TeV

The physics landscape: PbPb collisions SPS->RHIC->LHC

	SPS(17)	**RHIC**(200)	**LHC**(5500)
dN_{ch}/dy	500	700	3000-8000
ϵ [GeV/fm^3] ($t_0 = 1$ fm/c)	≈ 2.5 1	$\approx 3.5 - 7.5$ 2	$\approx 15 - 40$ 10
V_f [fm^3]	$\approx 10^3$ 1	$\approx 7 * 10^3$ 7	$\approx 2 * 10^4$ 20
τ_{QGP} [fm/c]	≤ 1 1	$1.5 - 4$ 3	4-10 7
τ_0	≥ 1	≈ 0.5	≤ 0.2
τ_{QGP}/τ_0	1	6	≥ 30

U. Wiedemann, 2001

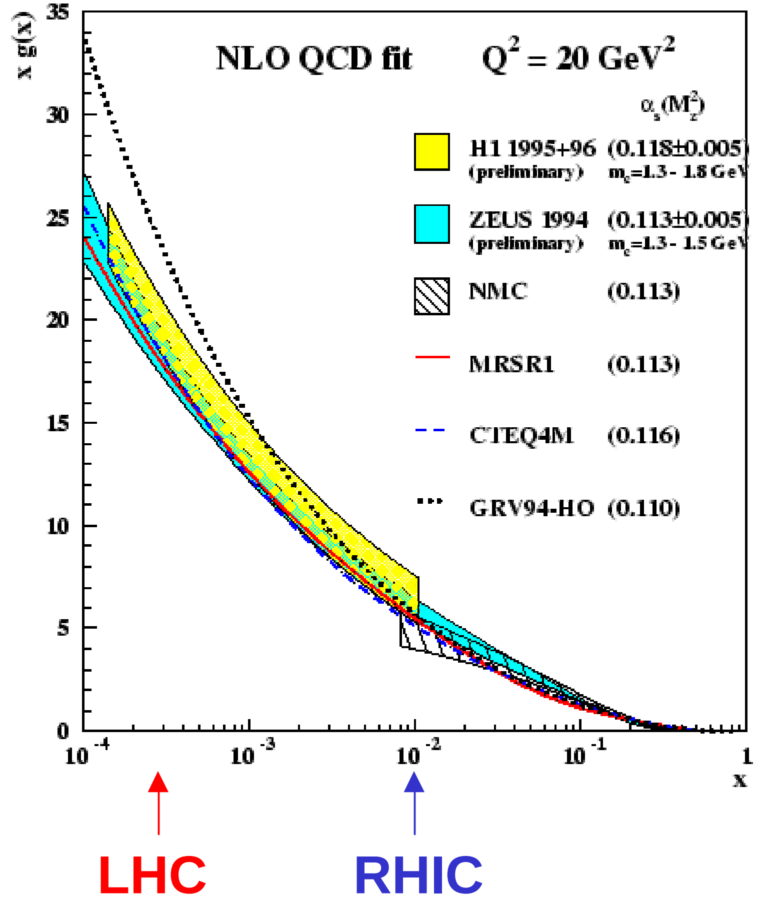
Unprecedented Gluon Densities

HERA experiments have observed a dramatic increase in the gluon density at low x.

This increase must end at some point when the gluon density saturates.

Large Hadron Collider Pb-Pb collisions probe the gluon structure below x~10^{-3} - 10^{-6}.

Note that xg(x) is enhanced by $A^{1/3}$ ~ 6 in Pb over the proton.

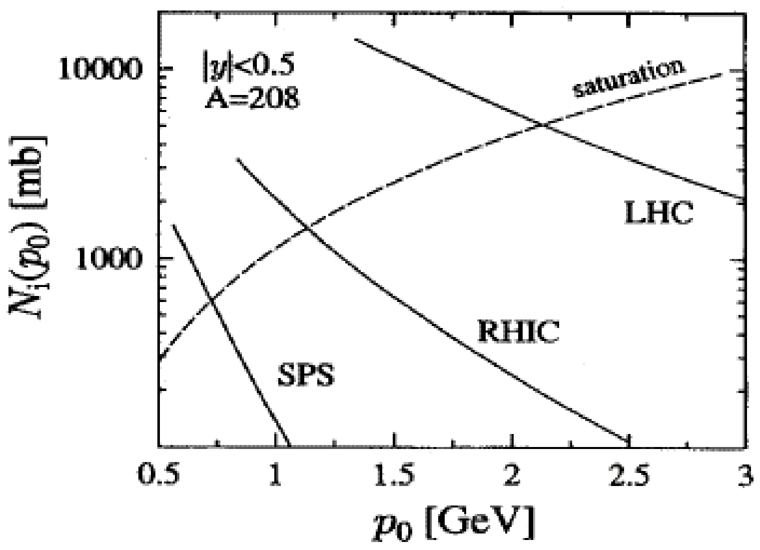


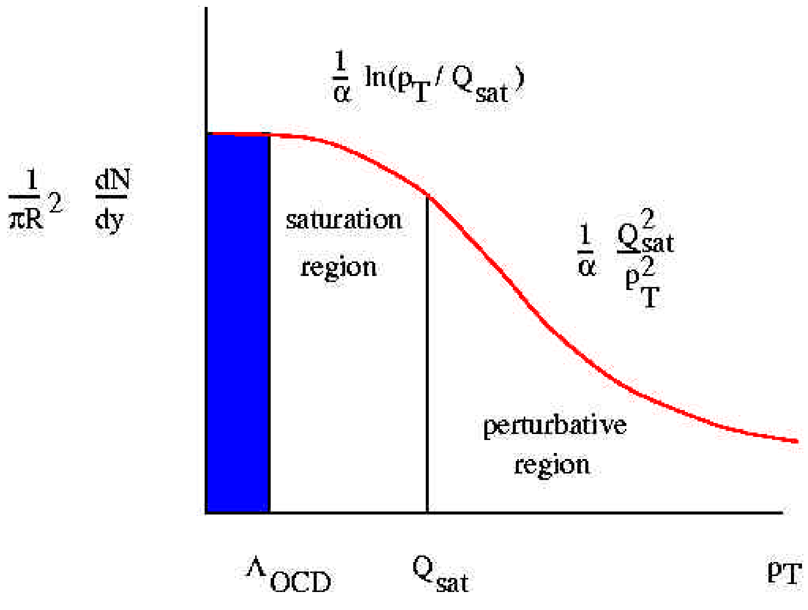
Saturation scale

The saturation scale is much larger at the LHC than at RHIC.

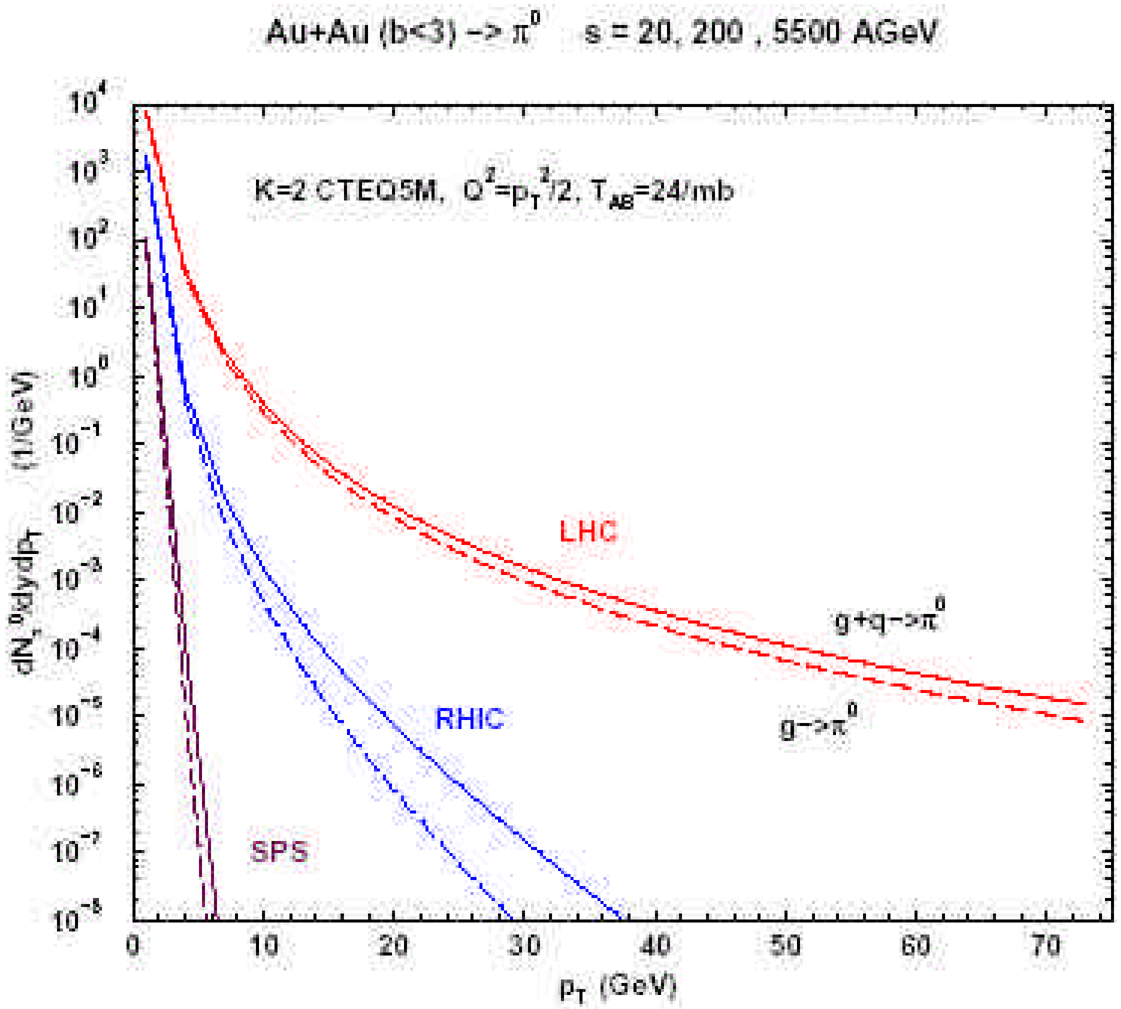
Thus, the initial partonic state may be dominated by the saturation region (color glass condensate).

Also, the cross section for high p_T processes is much larger, thus yielding better pQCD calibrated probes of the created gluon plasma.





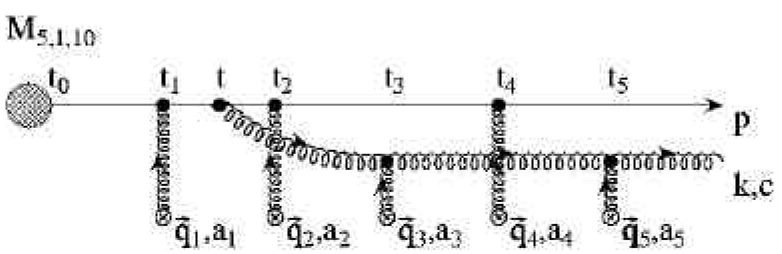
Production of high p_T particles: π^0

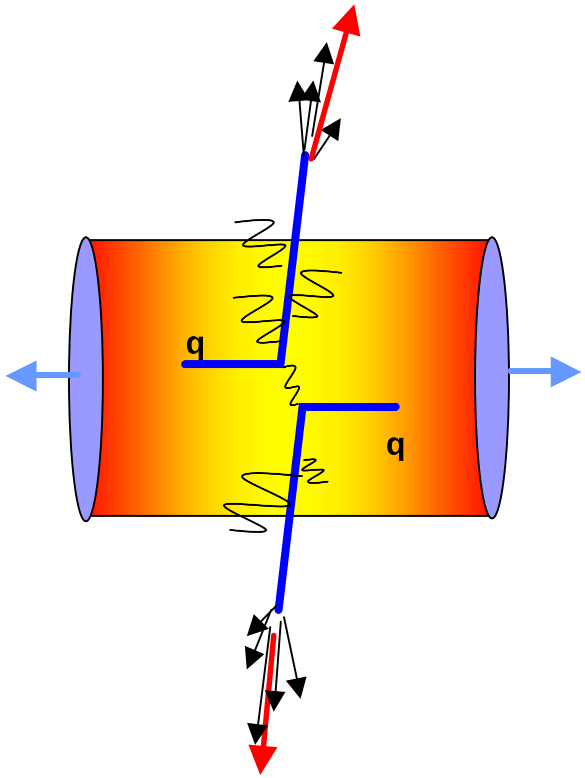


Jet Probes of the Plasma:
Jets clearly identified

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

Coherence among these radiated gluons leads to $\Delta E \ \alpha \ L^2$





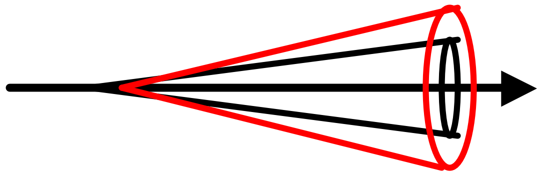
Measure the modification of jet properties as we change the gluon density and path length.

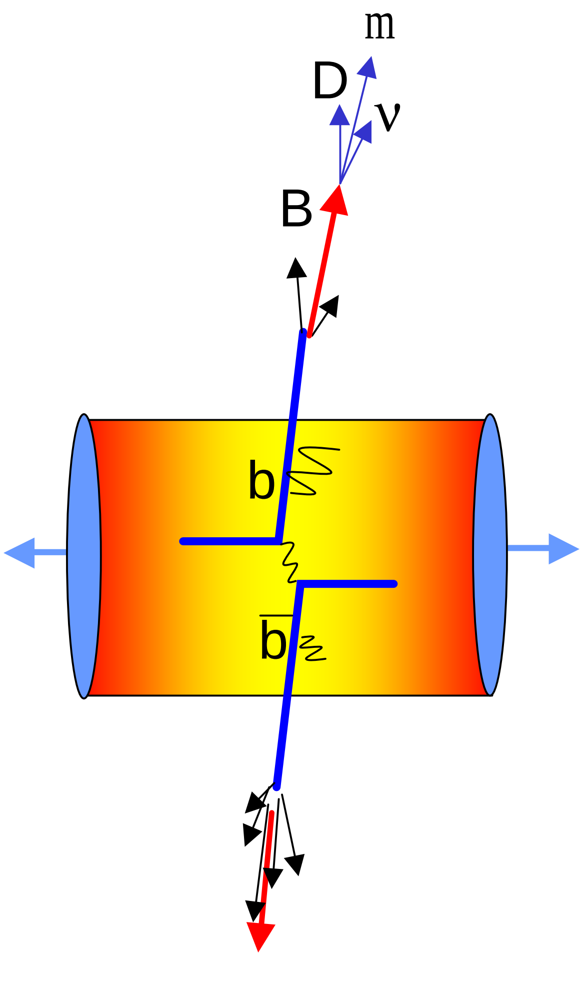
Baier, Dokshitzer, Mueller, Schiff, hep-ph/9907267
Gyulassy, Levai, Vitev, hep-pl/9907461
Wang, nucl-th/9812021
and many more…..

Beauty Jets

Radiative quark energy loss is qualitatively different for heavy and light quarks.

Finite velocity of heavy quarks at finite p_T leads to suppression of co-linear gluon emission (“dead-cone” effect).

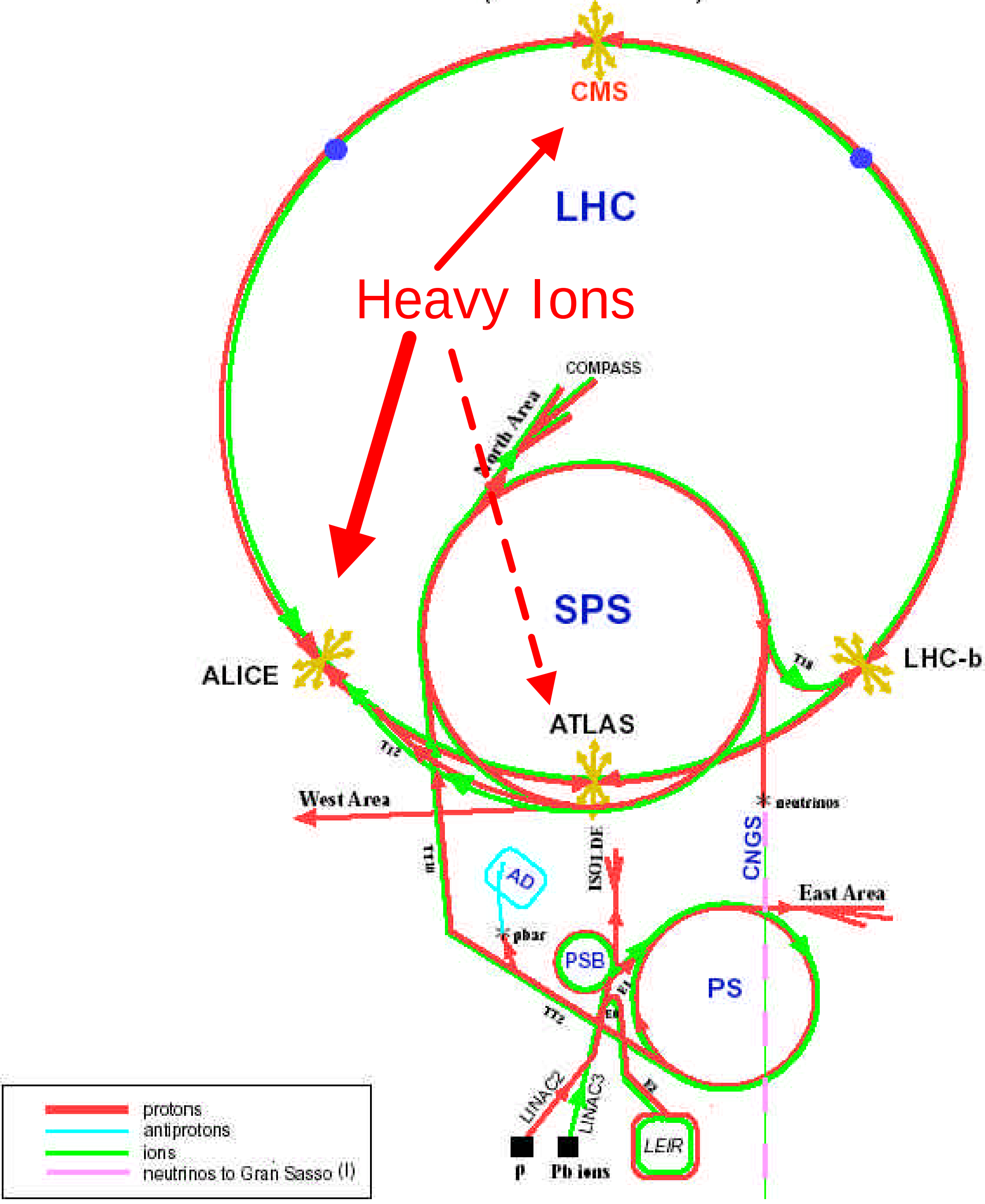




Y.L.Dokshitzer and D.E. Kharzeev, hep-ph/0106202

RHIC vs LHC: Availability of hard probes

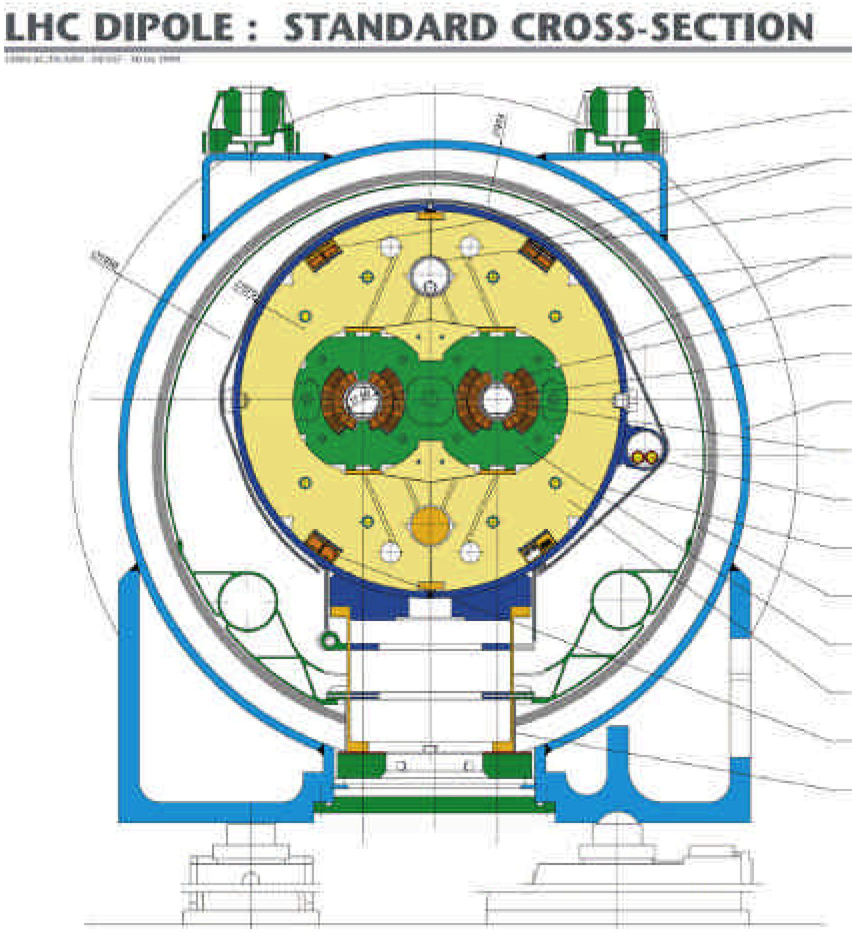
- Open charm
- Open beauty
- Inclusive jets (clearly identified)
- Tagged jets: γ-jet, jet-jet, W, jet-Z^0
- Direct photons
- Ratios of leading particles $\bar{p}/p$, $\bar{\Lambda}/\Lambda$
- J/Ψ, Ψ' suppression
- Υ, Υ' suppression



CERN accelerator complex

- Schedule being revised now
- Expect pp beams in April 2007
- Expect HI beams in 2008 (?)
- 9 months pp/year
- 1 month HI/year

LHC magnets



- Dual bore superconducting magnets
- Max field in the coil 8.76 T
- ~27 kilometers
- 7 TeV/charge
- $\sqrt{s_{NN}}$=5.5 TeV for PbPb
- pp, AA, pA possible

LHC design parameters
Daniel Brandt,
MIT workshop,
Feb 8, 2002

- A recent "near miss" for AA capabilities:
  - Injection from PS to SPS difficult->big effect on design luminosity
- Solved by redesigning acceleration scheme

LHC as Pb-ion collider:

Number of Experiments	2
Energy per charge [TeV]	7
Centre-of-mass energy [TeV]	1148
Transv. norm. emitt. ϵ^* [μm]	1.5
β at the IP (coll.) β^* [m]	0.5
r.m.s. beam radius at IP σ^* [μm]	15
Longit. emittance ϵ_l [eVs/Q]	2.5
r.m.s. bunch length σ_s [cm]	7.5
r.m.s. energy spread σ_E/E (10^{-4})	1.137
Bunch spacing t_b [ns]	100
Number of bunches per ring k	592
Filling time per ring [min]	9.8
Number of ions per bunch N_b	7.0×10^7
IBS growth time (coll.) τ_ϵ [h]	15
Luminosity half-lifetime $\tau_{1/2}$ [h]	4.2
Initial luminosity [$cm^{-2}s^{-1}$]	1.0×10^{27}

LHC luminosity

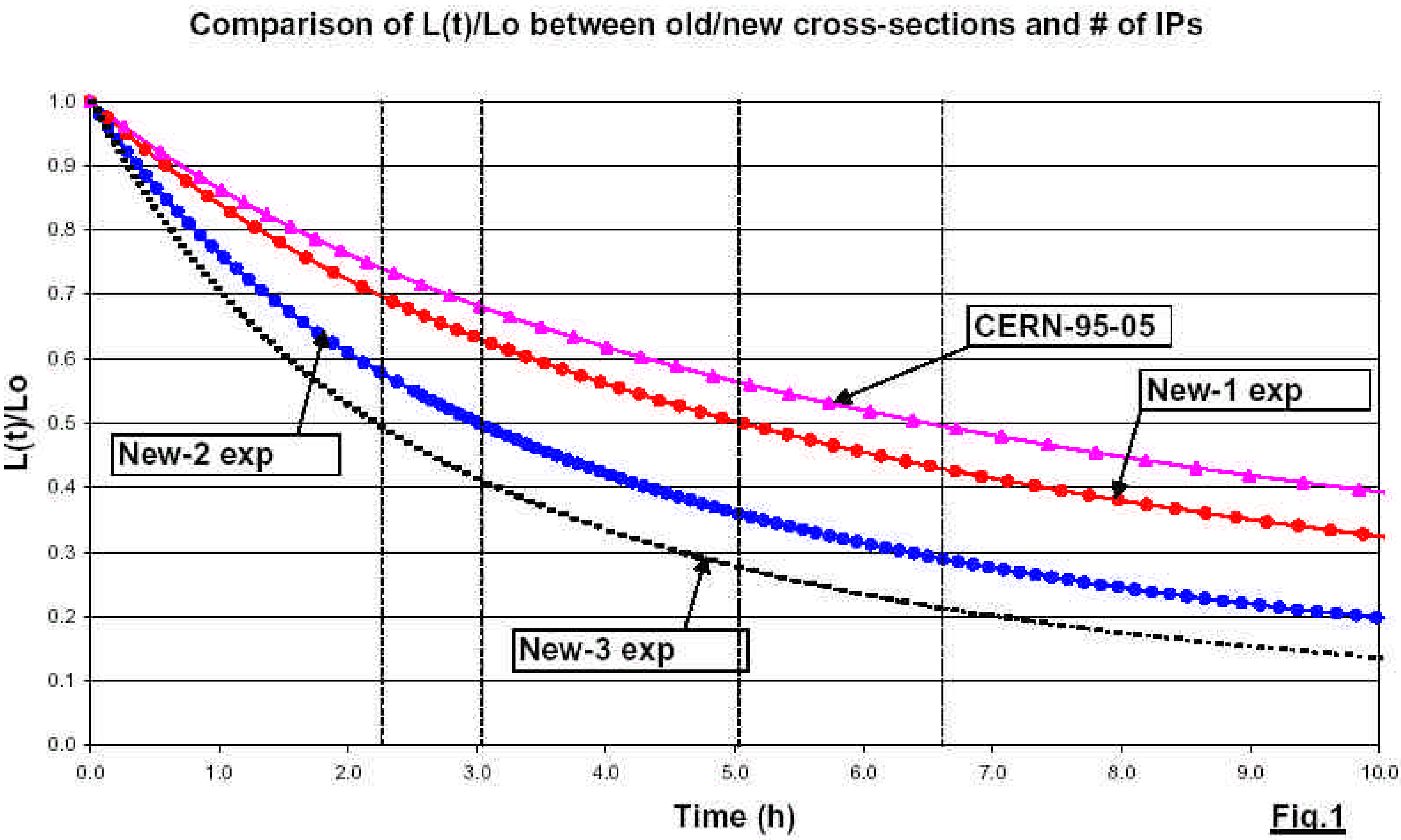
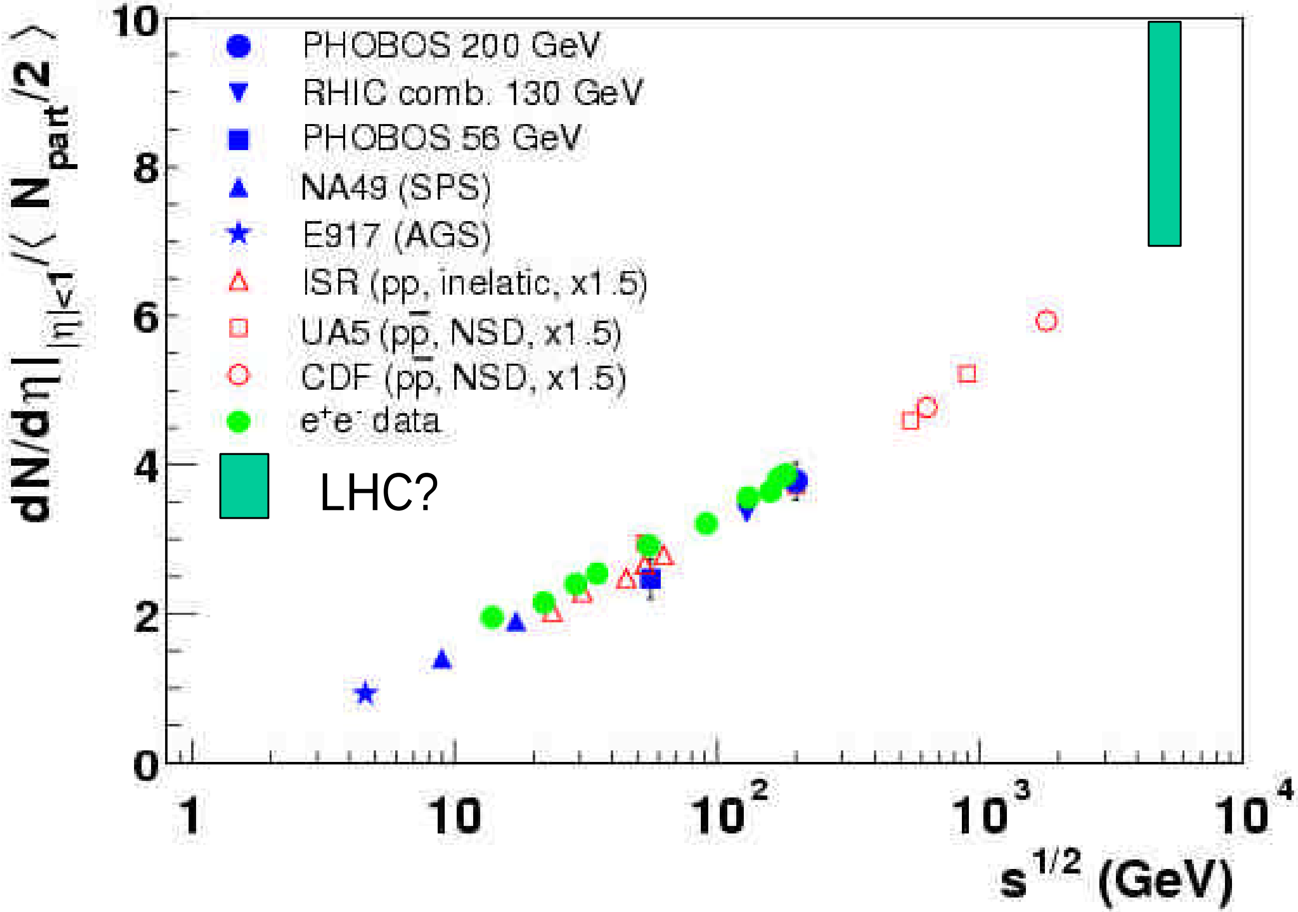


Fig.1

LHC ions and expected luminosities (per experiment, assume 2 experiments)

Ion	$\mathcal{L}_0$ [cm^{-2}s^{-1}]	$\mathcal{L}_{1/2}$ [h]	T$_{opt}$ with T$_f$ [h]	<L> with T$_f$ [cm^{-2}s^{-1}]
Pb^{82}_{208}	1.0×10^{27}	4.2	5.7	4.2×10^{26}
Sn^{50}_{120}	1.7×10^{28}	5.2	6.5	7.6×10^{27}
Kr^{36}_{84}	2.3×10^{28}	11.7	9.0	1.3×10^{28}
Ar^{18}_{40}	6.4×10^{28}	≈ 30	14.5	4.3×10^{28}
O^{8}_{16}	2.1×10^{29}	≈ 60	20.0	1.6×10^{29}

Designing LHC experiments



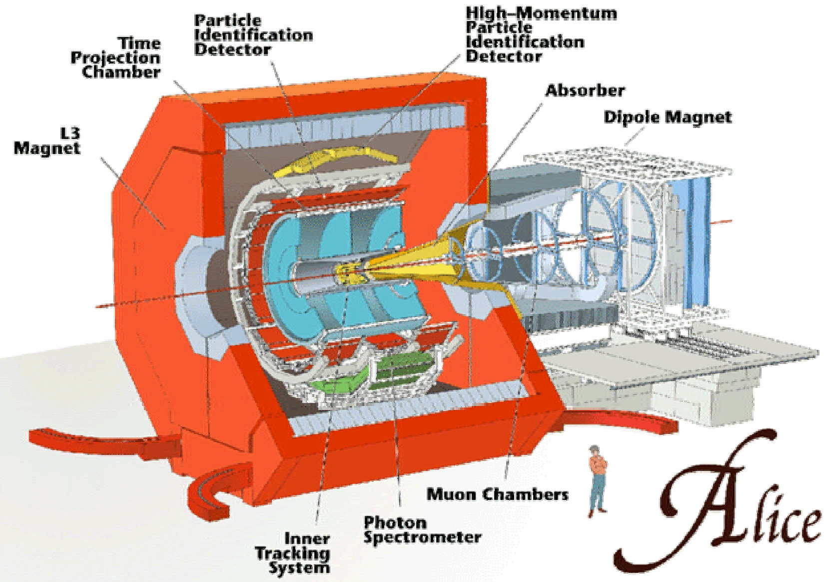
Steinberg extrapolated: dN/dη~1400

LHC detectors are being designed for

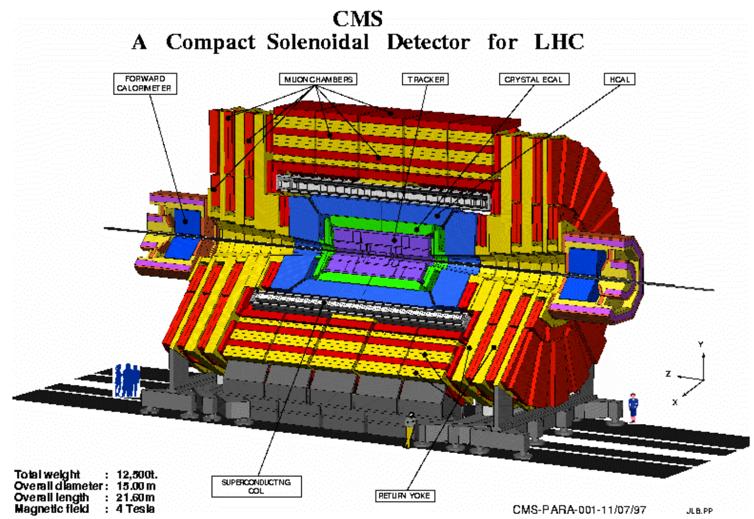
dN/dy~8000

Peter Steinberg, 2002

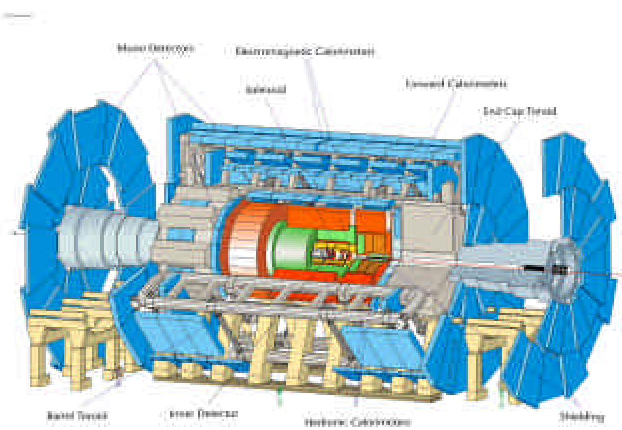
The experiments



ALICE: dedicated HI experiment



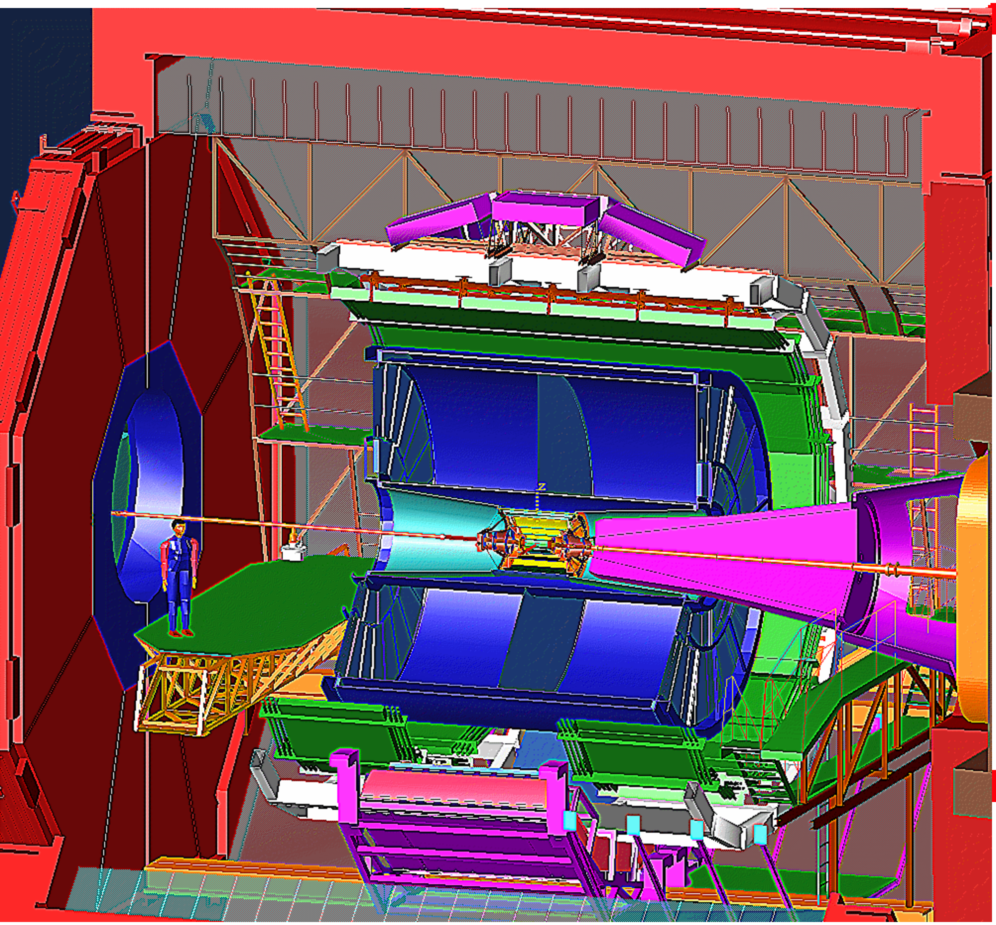
CMS: pp experiment with HI program



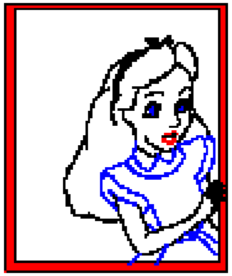
ATLAS: pp experiment, recent HI interest

ALICE

A Large Ion Collider Experiment



- observables: event-by-event $h^{\pm}, e, \gamma, \mu$

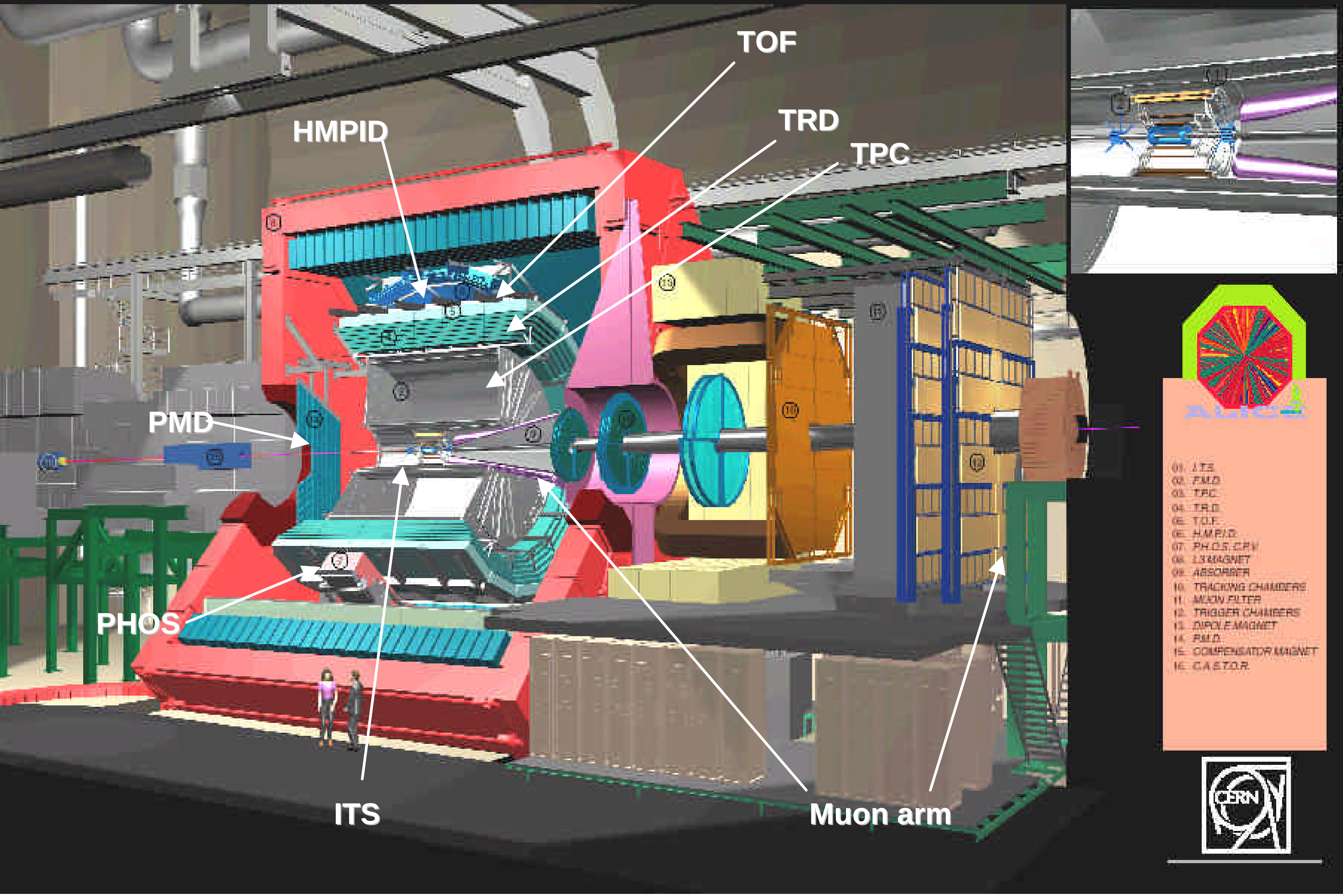


$0 < p_t < 20$ GeV
$0 < m < 10$ GeV

- hadrons, electrons
  - precision tracking in weak field
  - PID: dE/dx (Silicon + TPC) and TOF or RICH
  - vertex detector (Hyperon decays)
- photons
  - e.m. calorimeter
- muons
  - forward spectrometer (Debeye screening)

Milestones

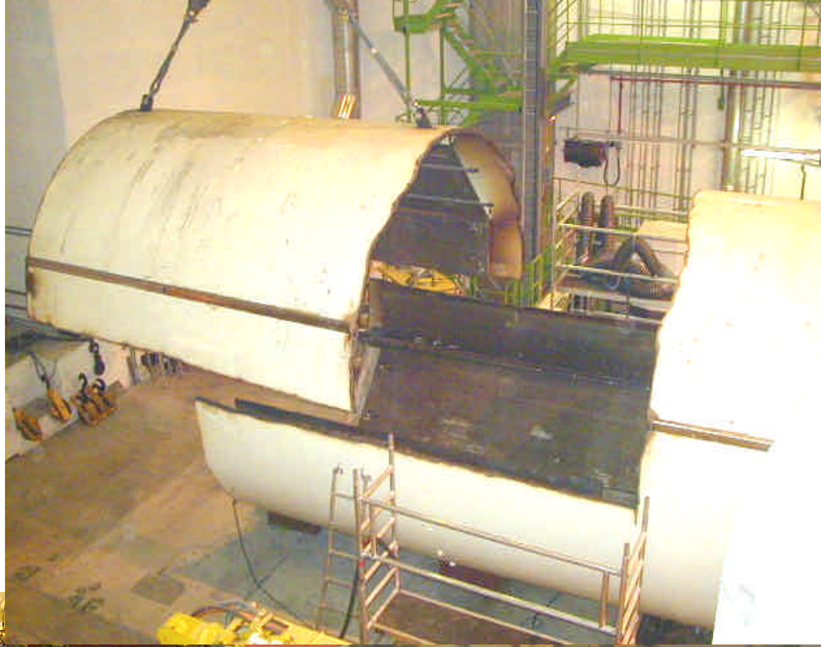
LoI	April 1993
Technical Proposal	Dec. 1995
Muon Arm addendum	Oct. 1996
Approval	Febr. 1997
running	startup of LHC

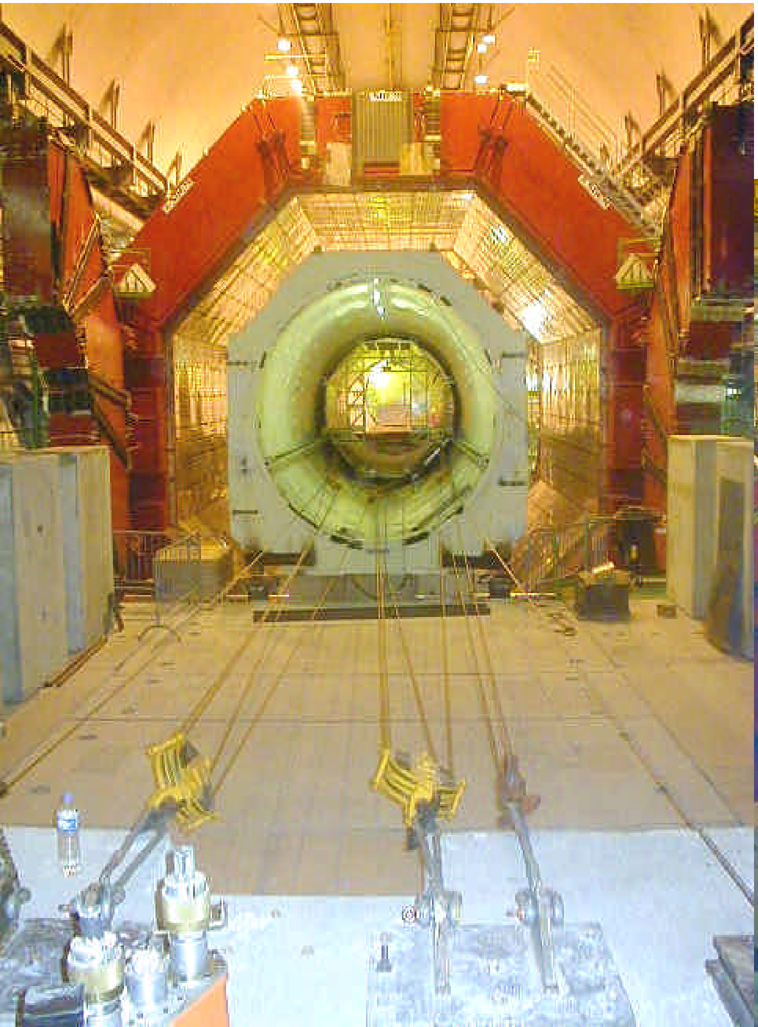


ALICE Detector

ALICE @ Point2

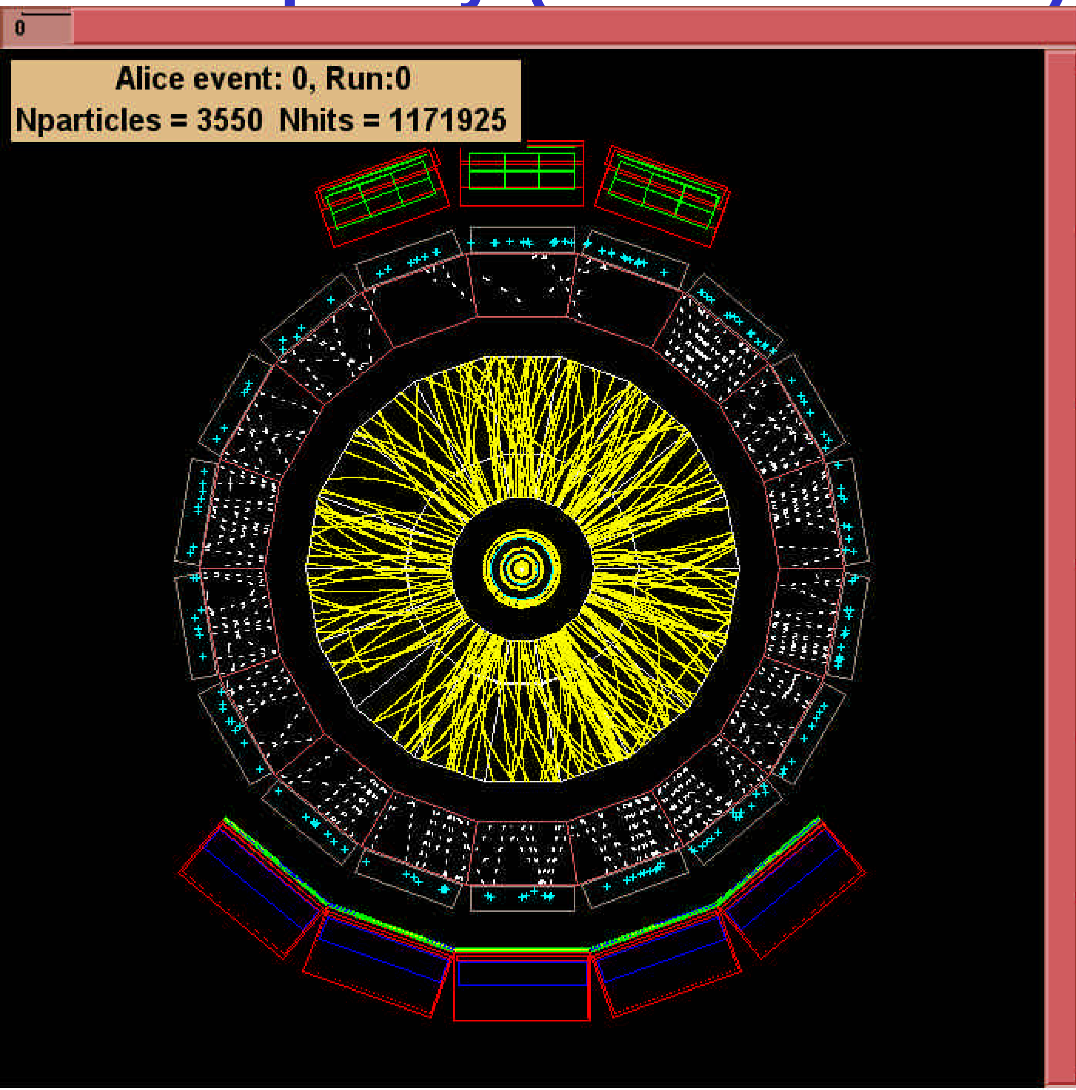
- Making room for ALICE...



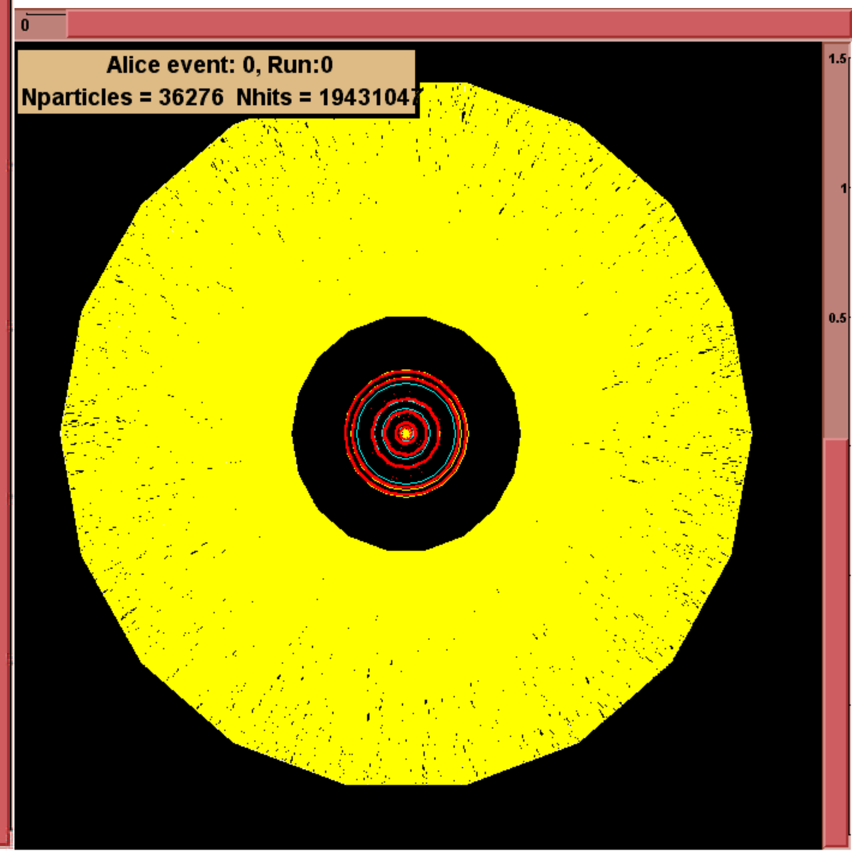


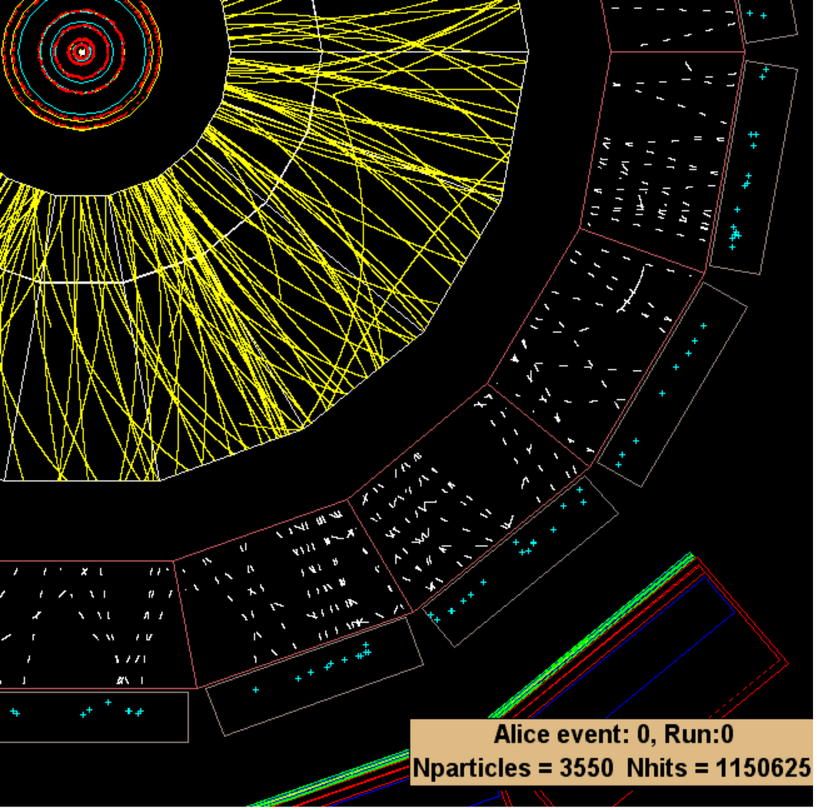
ALICE In action…

- **Full simulation of ALICE (shown is a 2^{0} q slice) with Pb-Pb events at max multiplicity (dN/dh ~8000)**



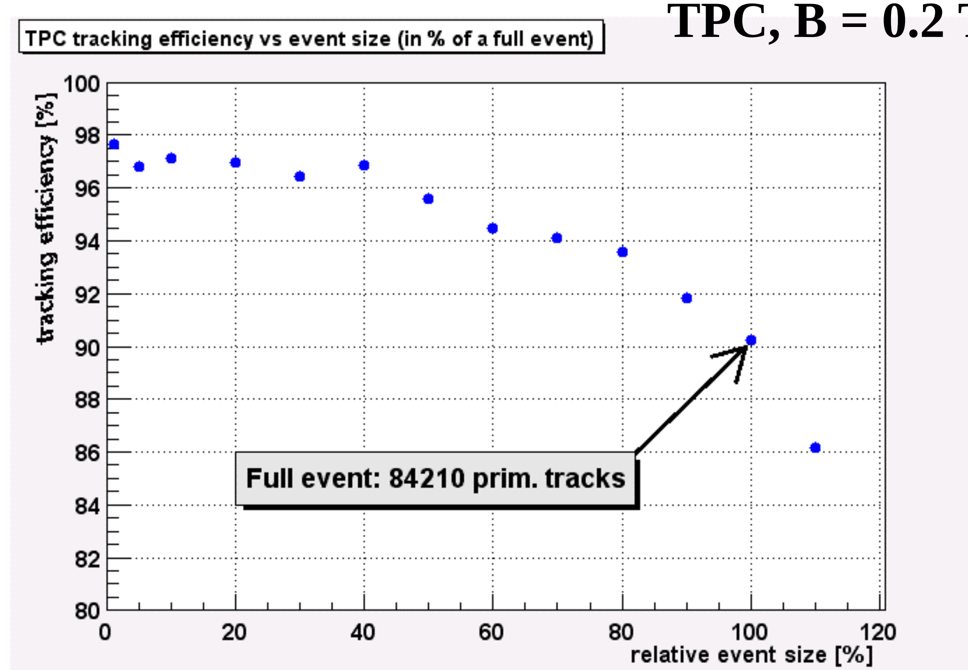
For full event:



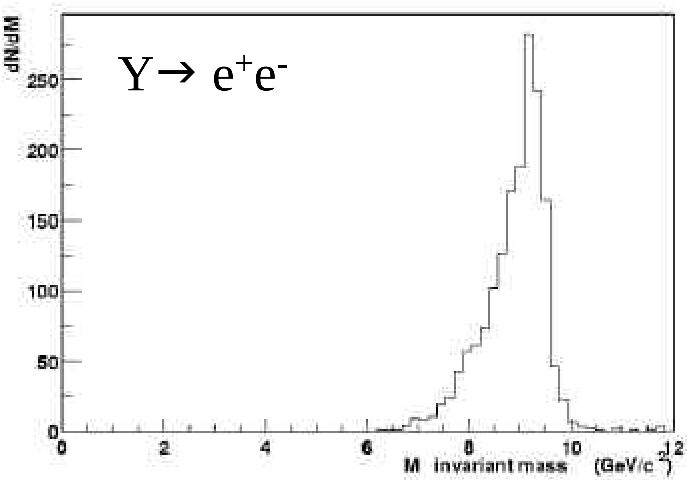


Tracking in ALICE

TPC, B = 0.2 T

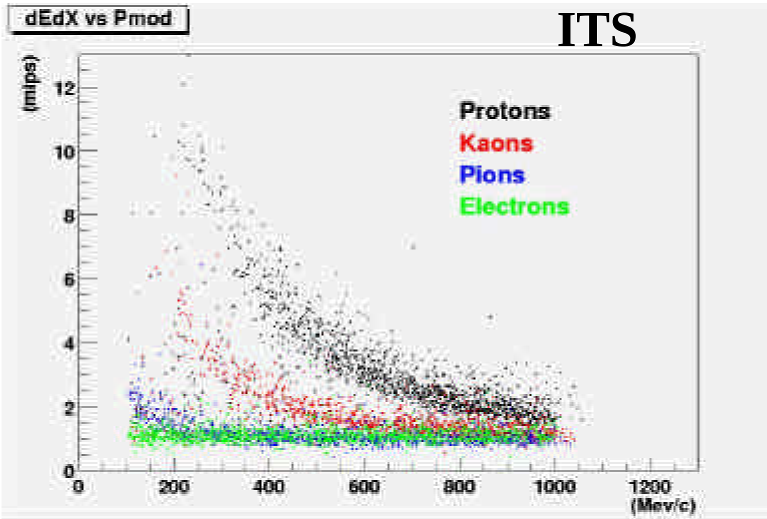


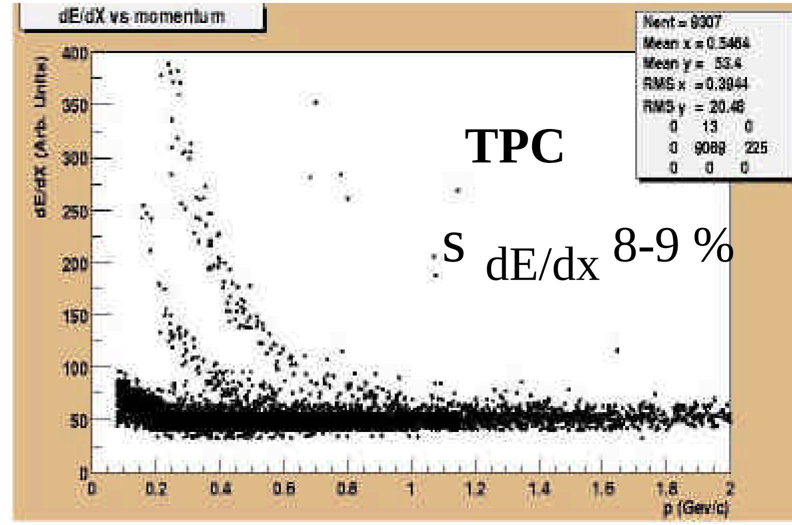
"Global tracking": Y mass resolution

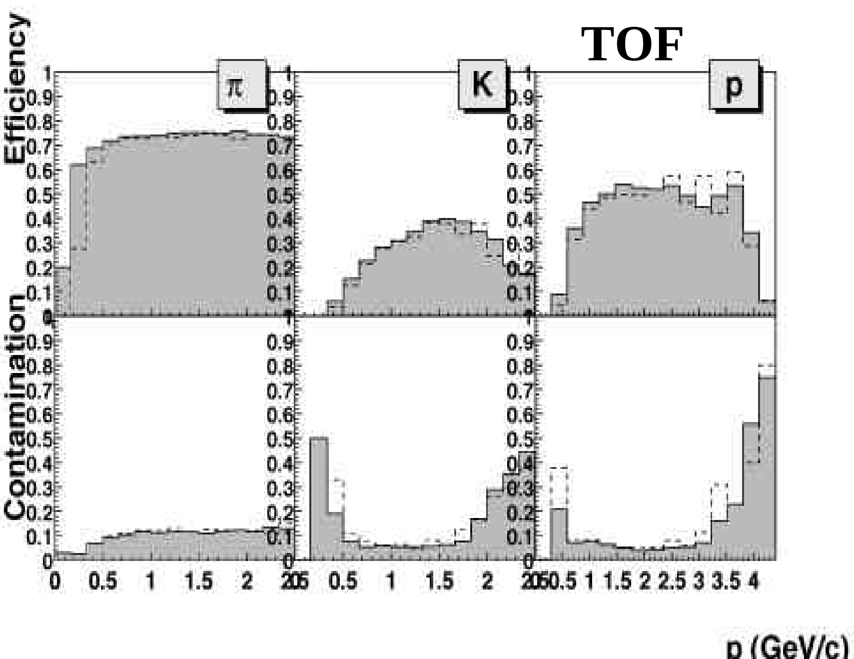


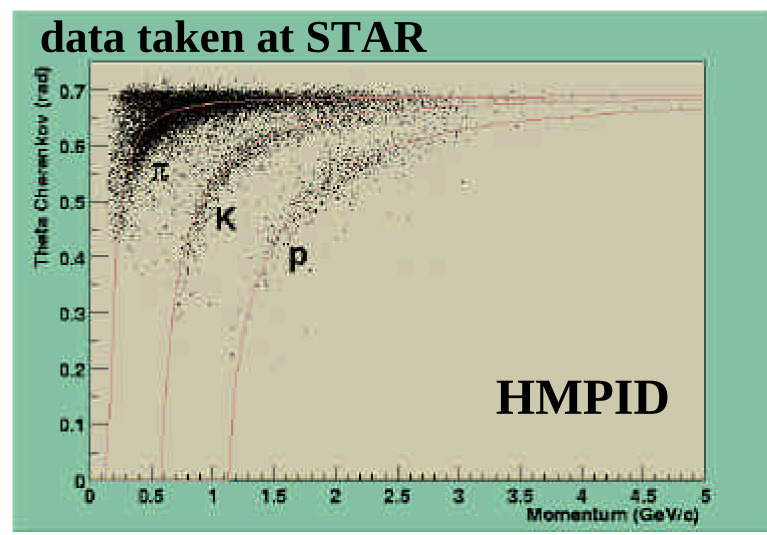
Dp/p (%)	< p_t >		p_t > 5 GeV/c	
magnetic field (T)	0.2	0.5	0.2	0.5
TPC	2.4	1.2	8.5	5.8
TPC+ITS	1.6	0.7	3.4	1.4

Particle Identification in ALICE



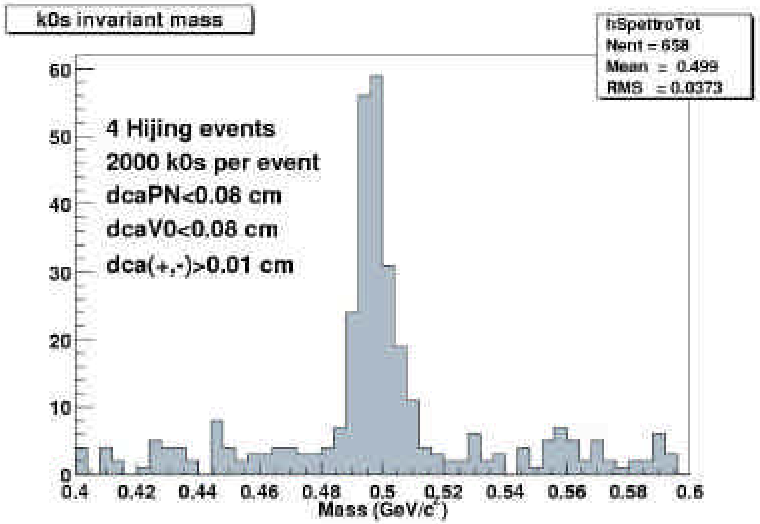




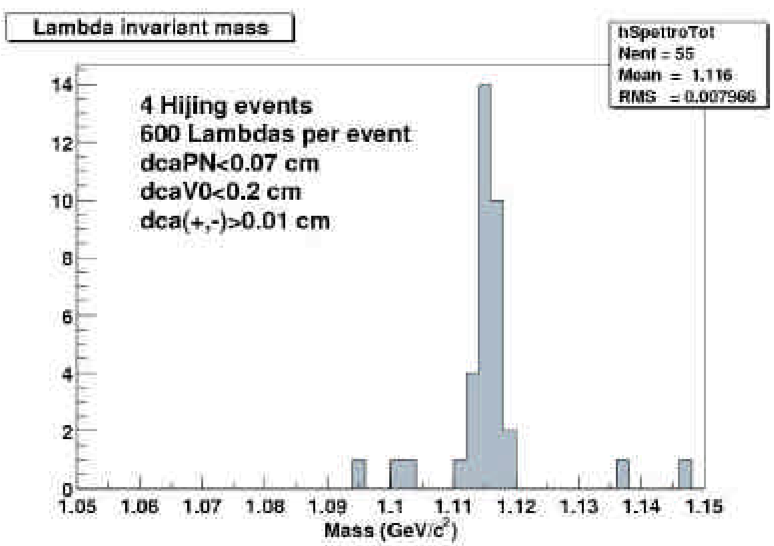


PID from decay topology and invariant mass

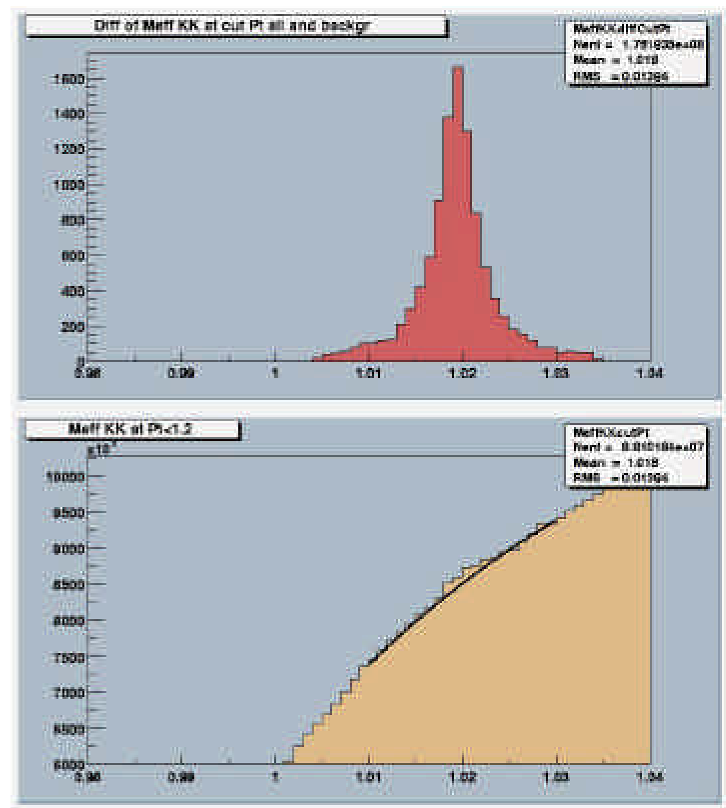
$K^0 \rightarrow \pi^+\pi^-$ invariant mass

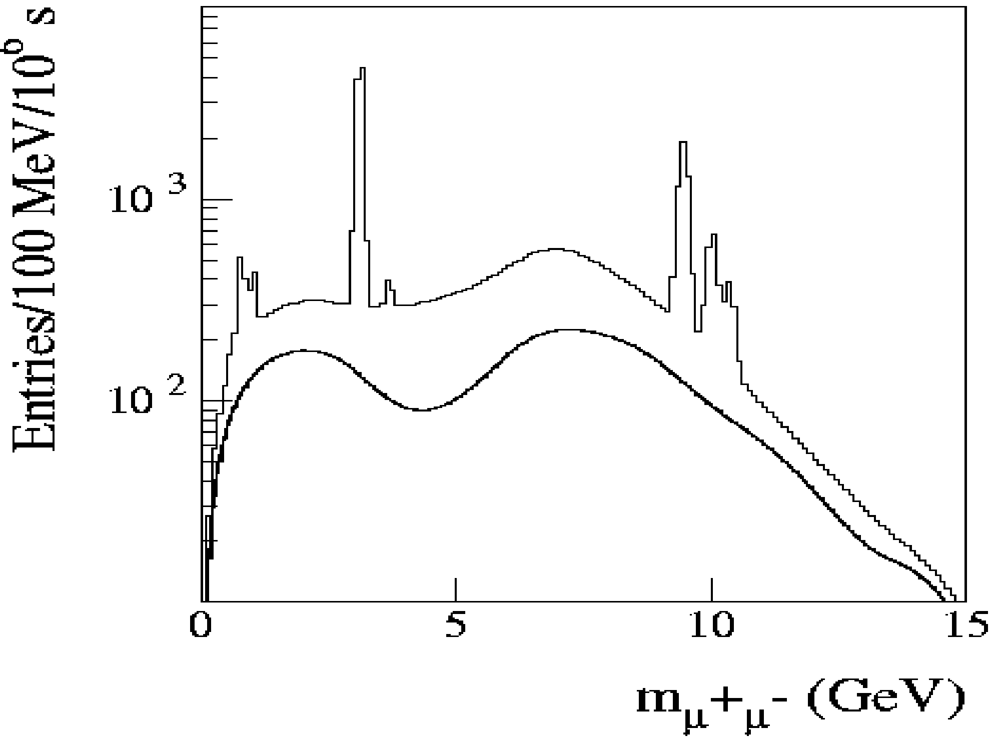


$\Lambda \rightarrow p\pi^-$ invariant mass



$\phi \rightarrow K^+K^-$ invariant mass

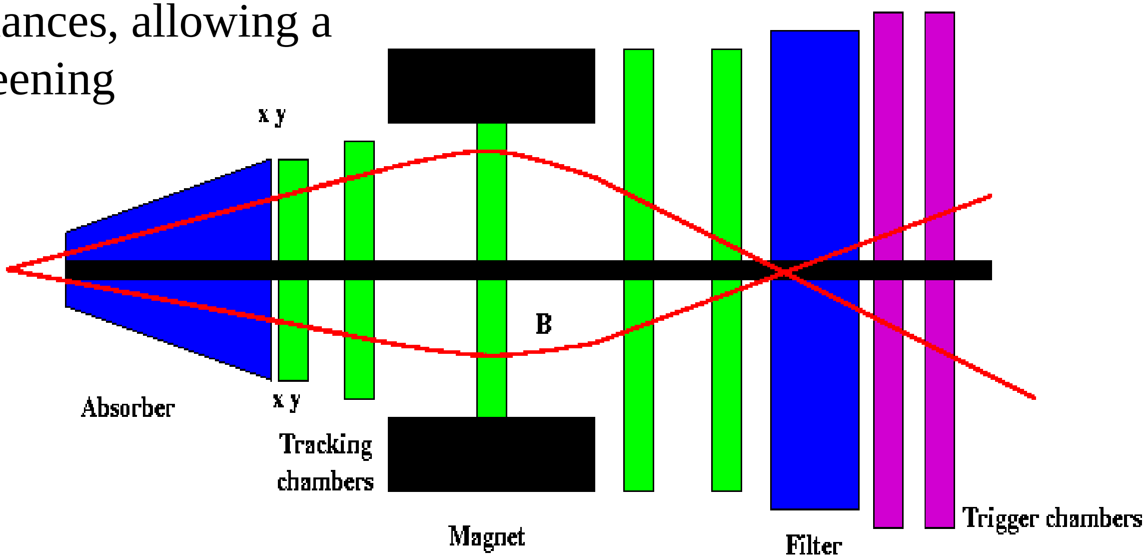




Dimuon Spectrometer

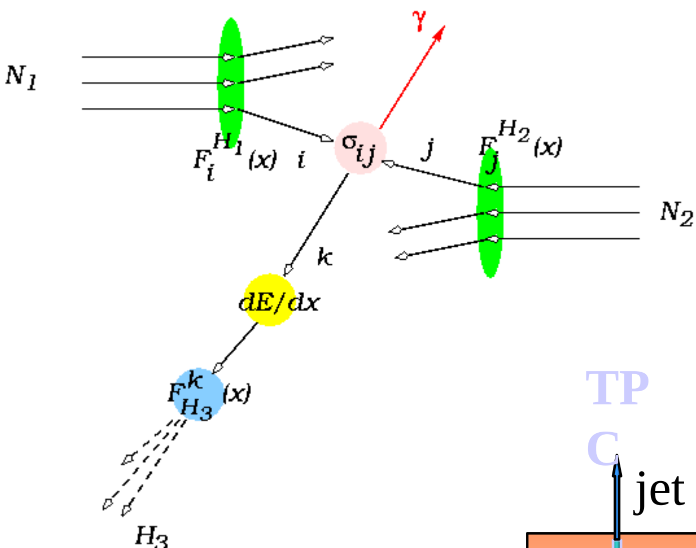
- Study the production of the J/Ψ, Ψ', Υ, Υ' and Υ'' versus the centrality of the reaction
- Resolution of 70 MeV on the J/Ψ and 100 MeV on the Υ
- overall performance improved with updated detector design (TDR addendum approved in 2001)

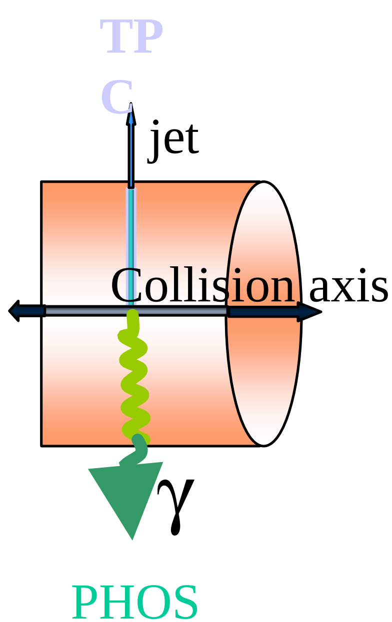
Plot of 1-month Pb run result, showing the good separation of the various resonances, allowing a systematic study of Debye screening

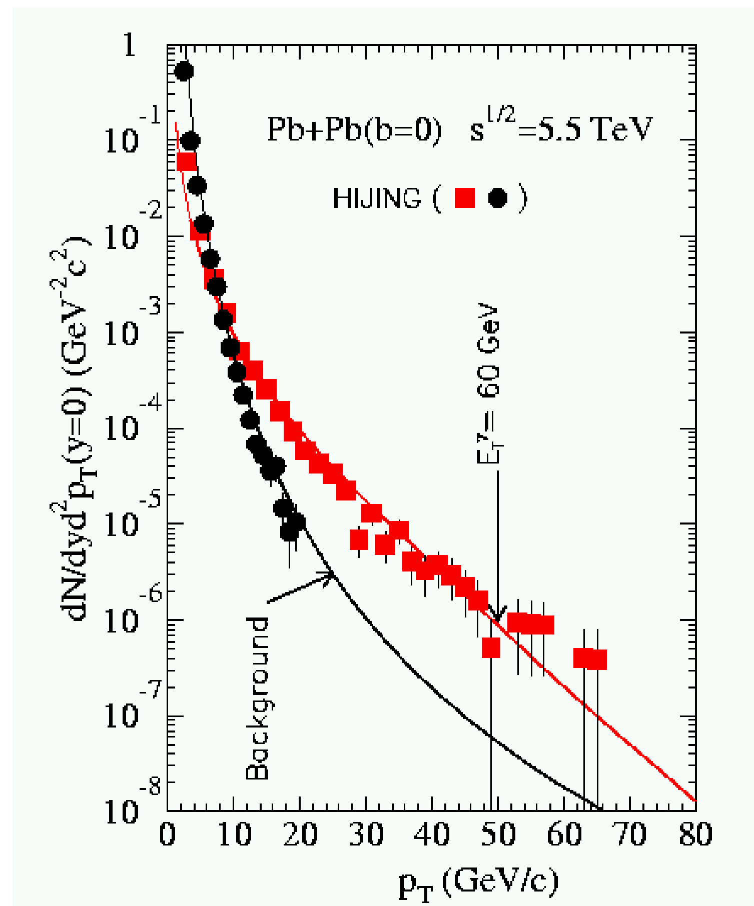


g-jet tagging

Tag the jet with a photon emitted in the opposite direction: $E^{jet}_T = E_T^g$

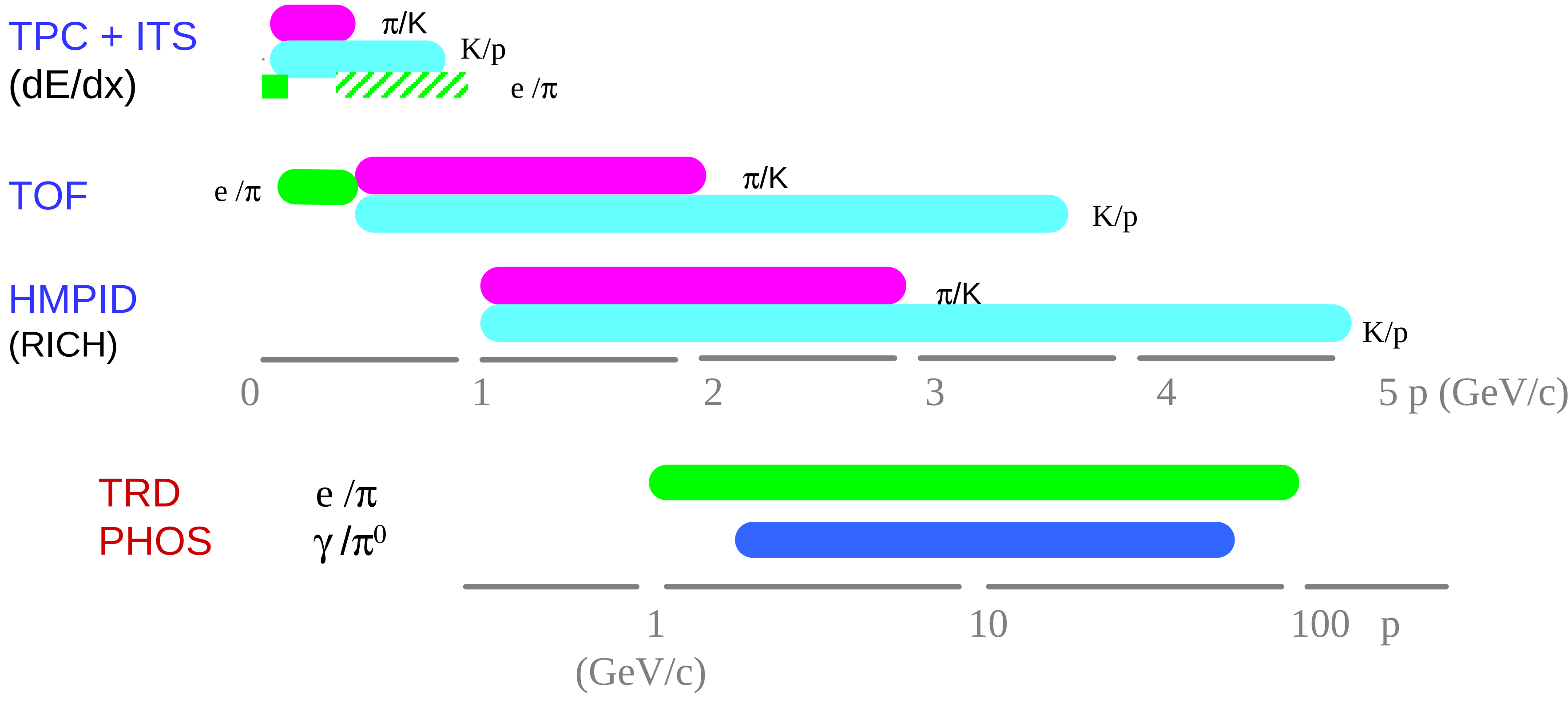




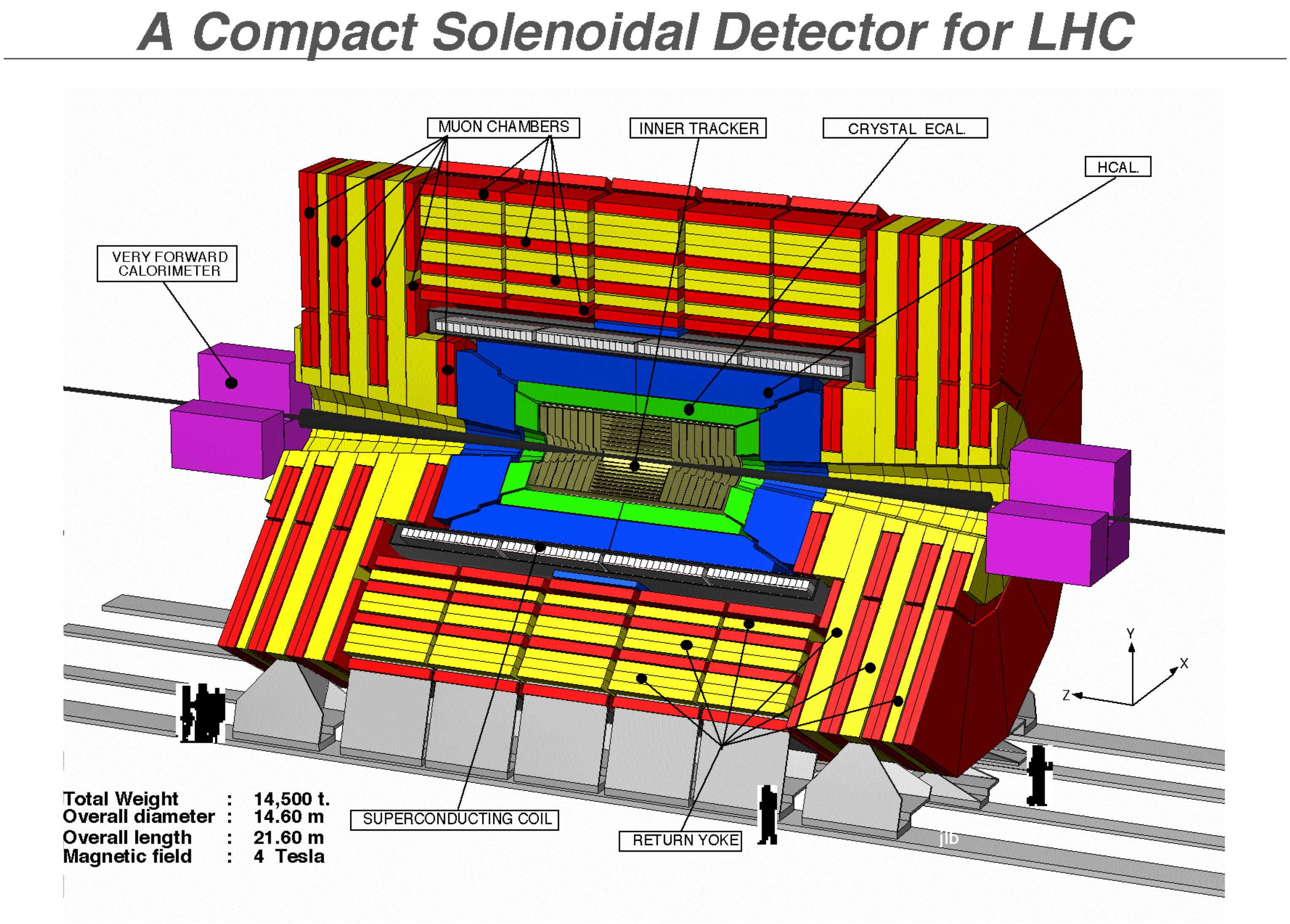


X.N. Wang et al. Phys. Rev. C55, 3047 (1997)

Particle Identification in ALICE



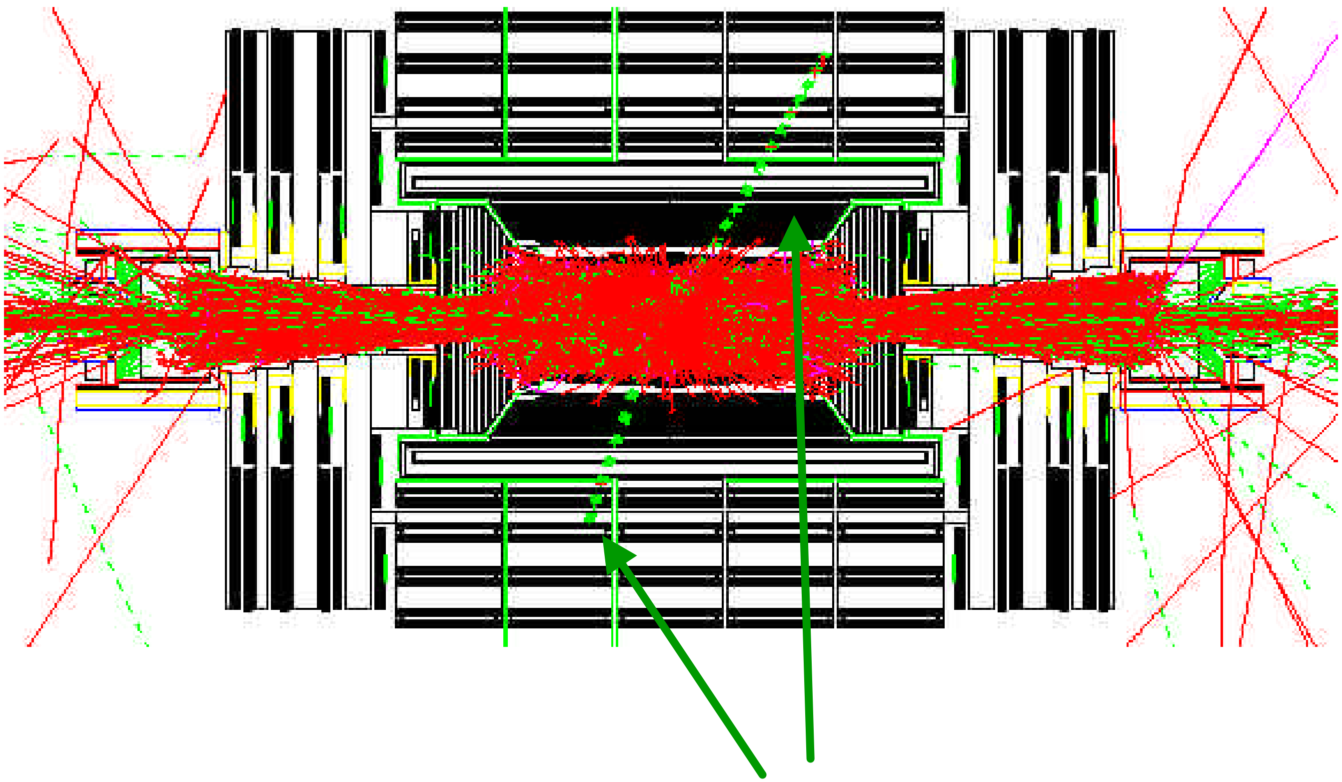
CMS: High pt edge of HI physics



Extending CMS

HI compared to pp:

Higher multiplicity of low pt particles
Lower luminosity and event rate

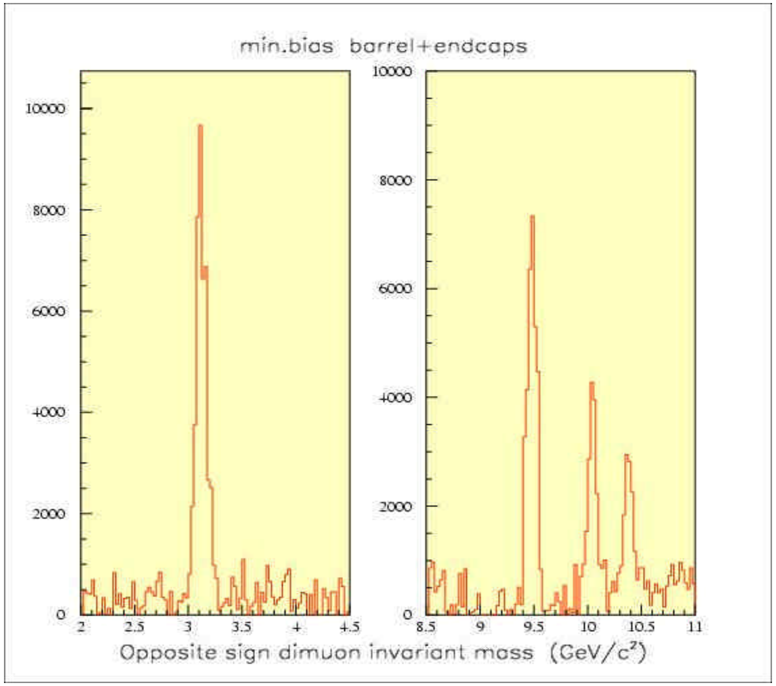


Pb-Pb

$\Upsilon \rightarrow \mu\mu$

Quarkonia CMS

J/ψ Υ family



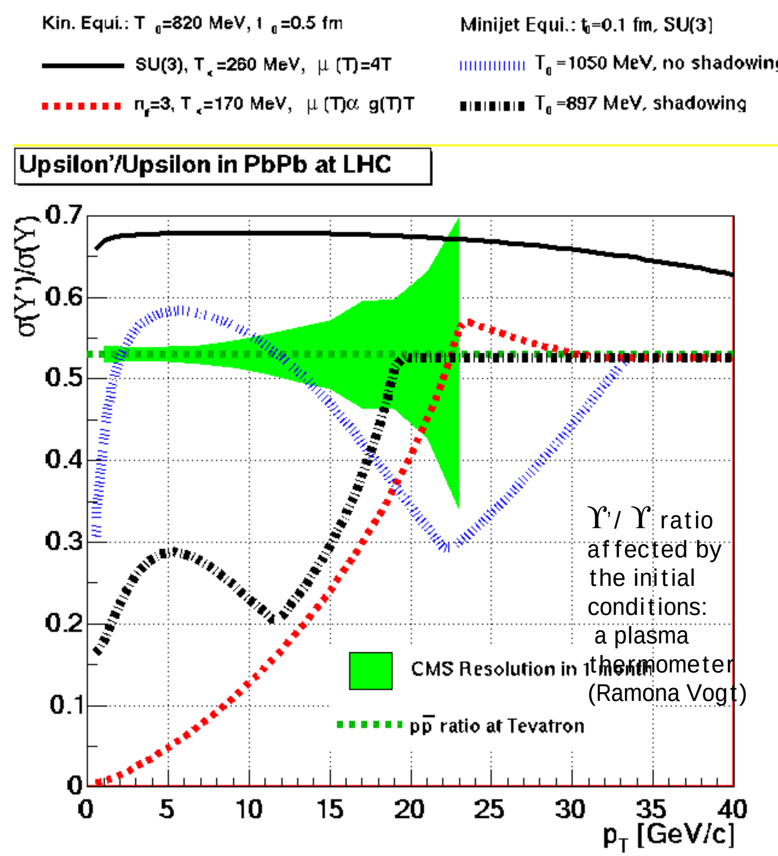
Yield/month (kevents, 50% eff)

	Pb+Pb	Sn+Sn	Kr+Kr	Ar+Ar
J/psi	28.7	210	470	2200
psi'	0.8	5.5	12	57
Upsilon	22.6	150	320	1400
Upsilon'	12.4	80	180	770
Upsilon"	7	45	100	440

Detailed studies using full simulation, reconstruction, background subtraction dN/dy studied from 2500 to 8000

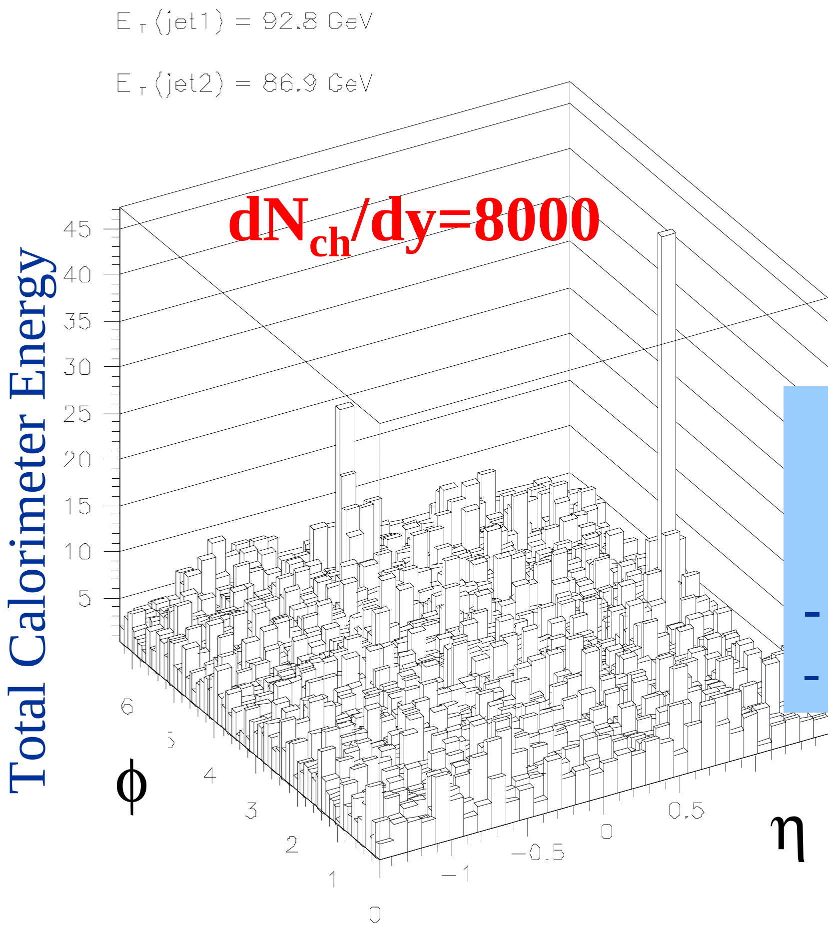
Very large event rate

Uses muon detector, outer tracker, pixels



Jets in CMS

Jet quenching
- monojet/dijet enhancement
- jet-$Z^0 \to \mu\mu$ or jet-γ



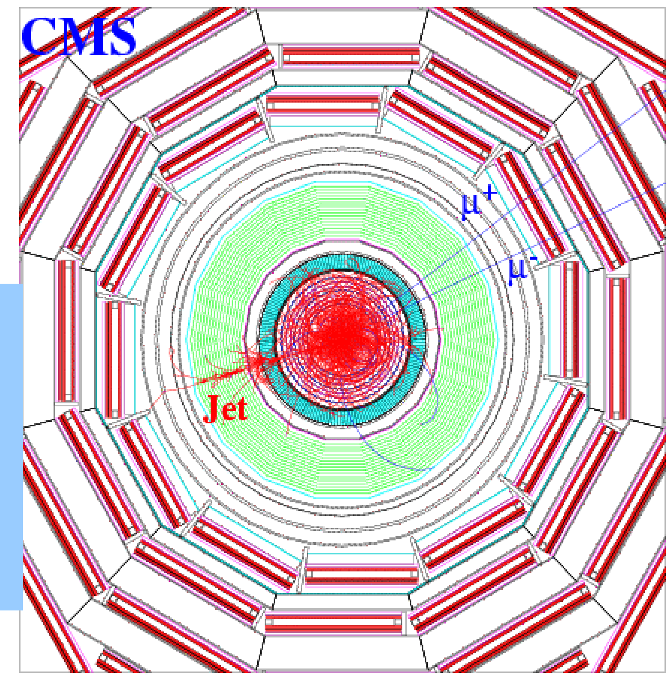
Jet Finding

100 GeV E_T

- $\varepsilon \sim 100\%$
- $\sigma(E_T)/E_T = 11.6\%$.

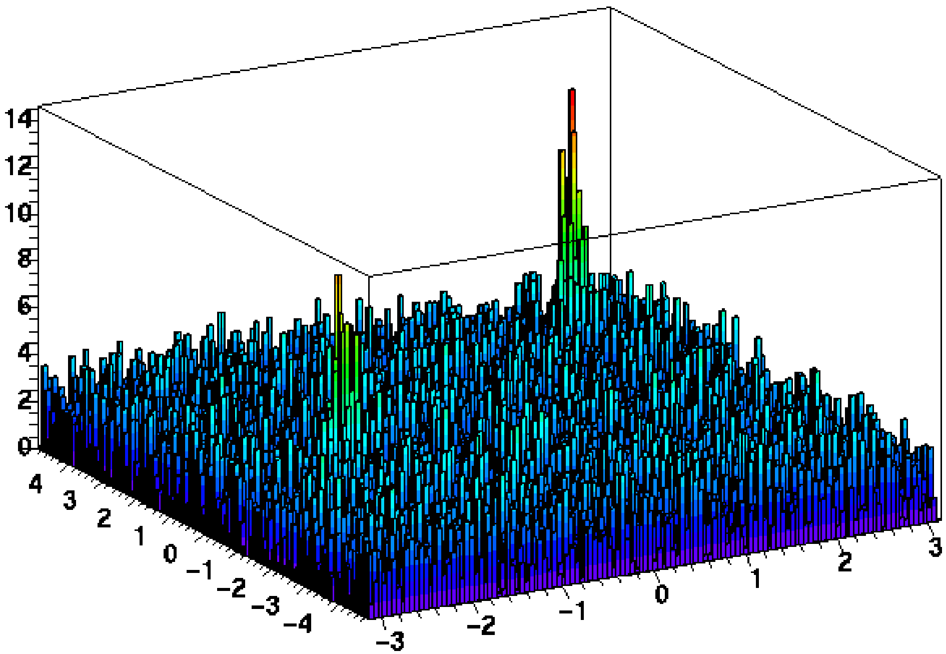
Z+jet event in the Heavy Ion collision

dNch / dY = 5000



Pt(Z) = Et(Jet) = 100 GeV.

ATLAS calorimetry

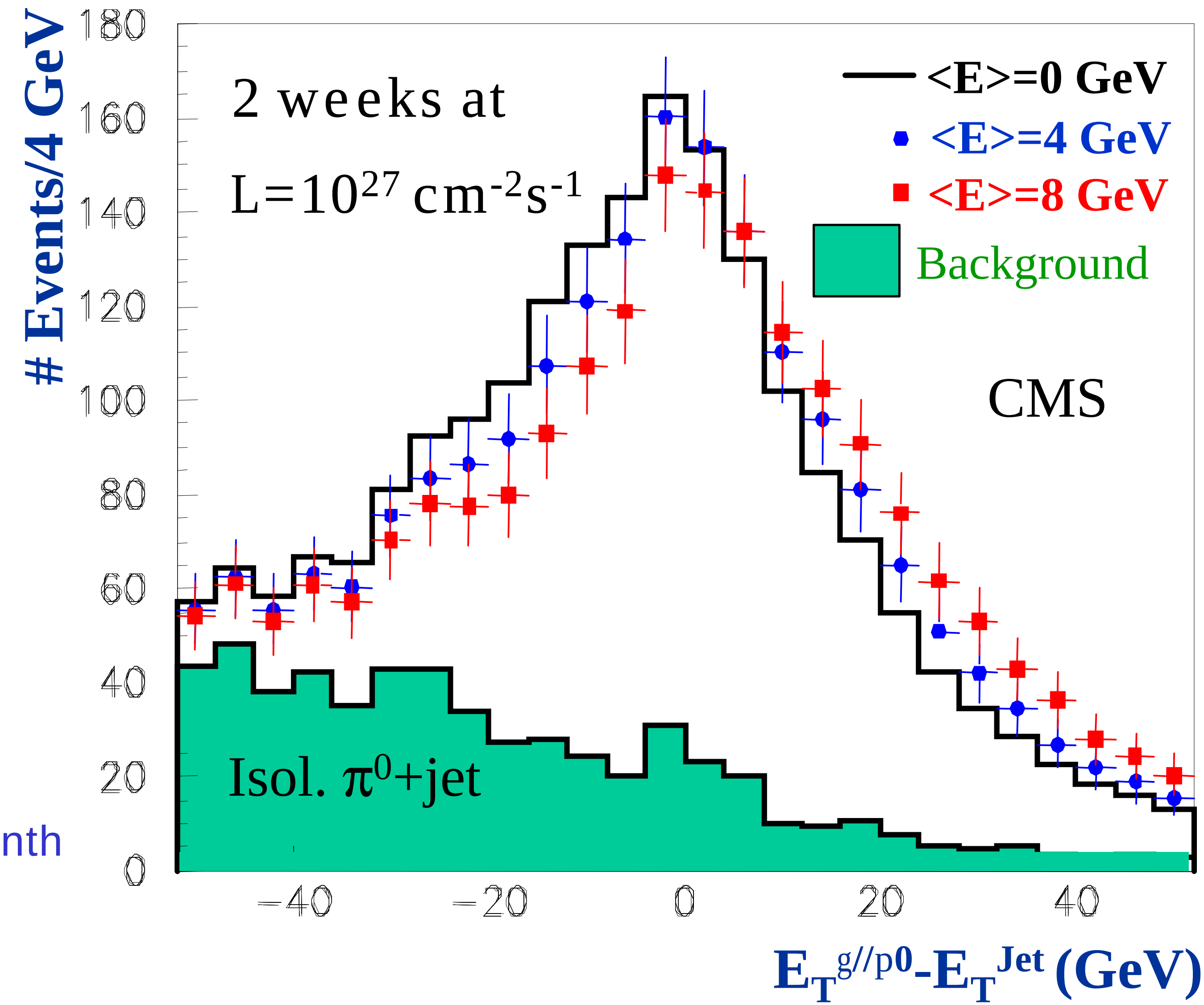


200 GeV jet overlay on
central Pb-Pb event
with ATLAS segmentation

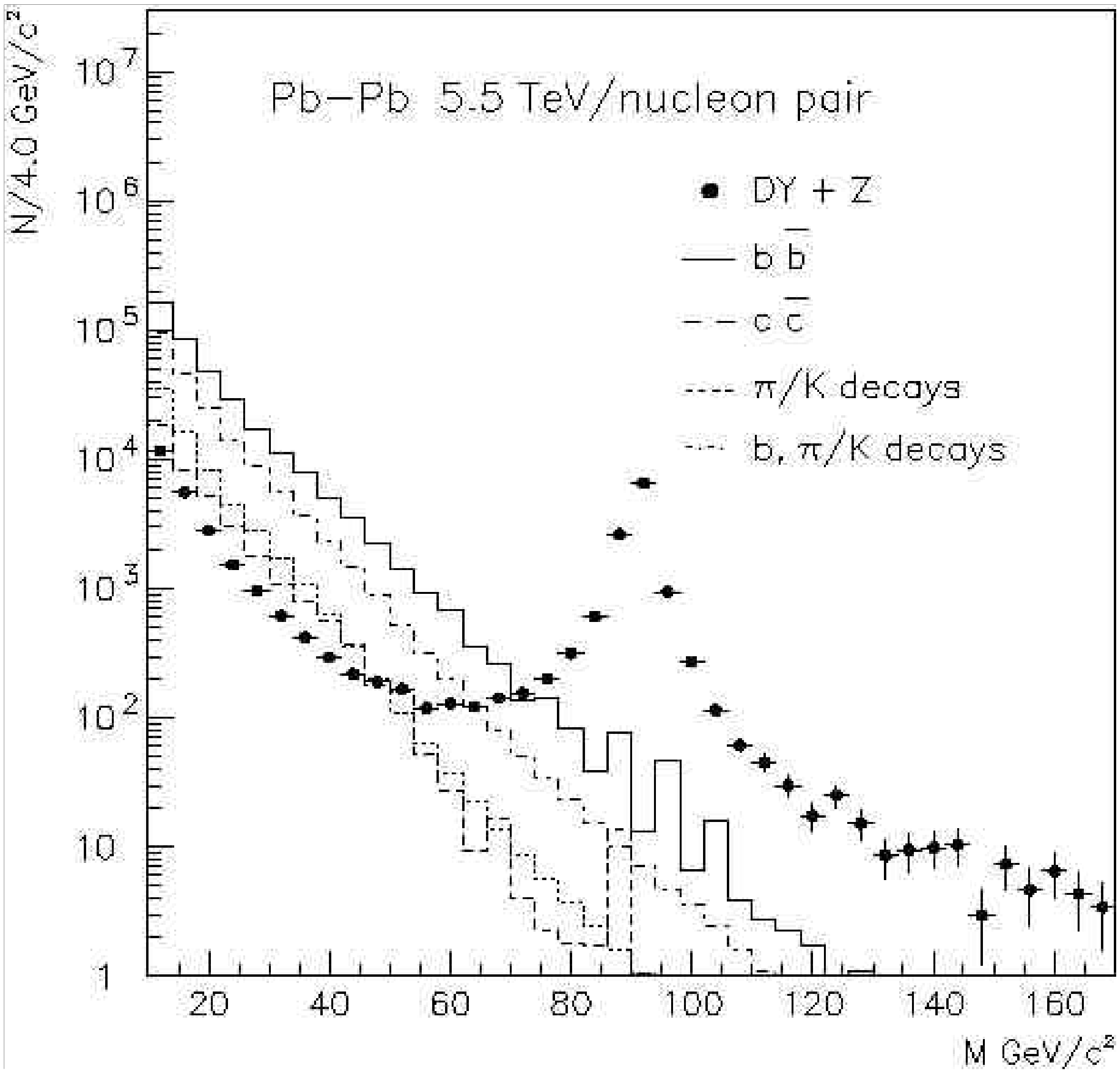
Balancing Photons and Jets: Energy loss for quarks

- $E_t^{jet,\,\gamma}$>120 GeV in the barrel
- 1 month:
  - 900 events for Pb-Pb

Jet+Z^0 also possible
100-200 events per month



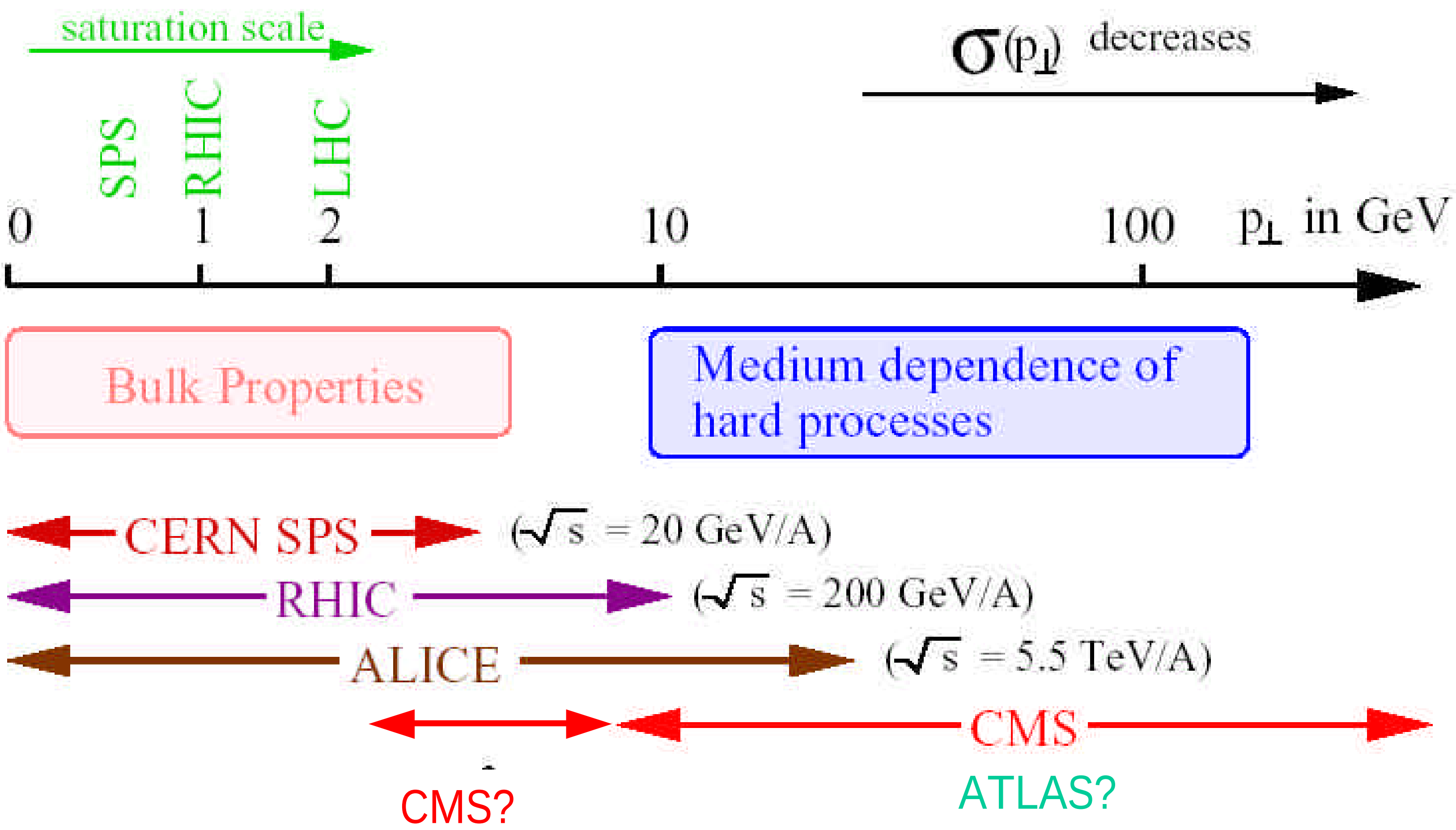
Z^0 production (CMS)



Summary

- LHC will collide heavy ions at unprecedented energies
  - Plasma hotter, larger and longer lived
  - More hard probes available to study hot nuclear matter
- Experiments are being readied
  - Wide spectrum of capabilities
- The knowledge gained at RHIC will be extended to new energy domain

P_T scales at LHC



Charged particles at LHC

Complementarity of experiments

- ATLAS & CMS optimized for high P_T and high luminosity.
- LHCb optimized for B physics (forward region only).
- TOTEM is dedicated to the measurement of total and elastic cross section, and diffractive processes (absolute calibration of the luminosity).
- ALICE optimized for Heavy ions, hence ideal for low P_T and high multiplicity (but will also go to relatively high P_T in certain cases)

(Charged particles not including muons)