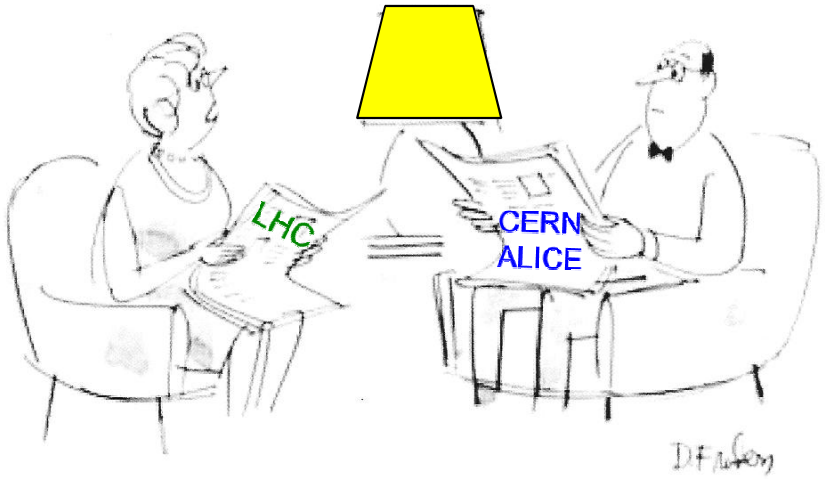
ALICE @ LHC

THE COMPLETE CARTOONS OF THE NEW YORKER



"There always seems to be something going on in Geneva, and I never know quite what it is."

Dana Fradon (1/30/1965)

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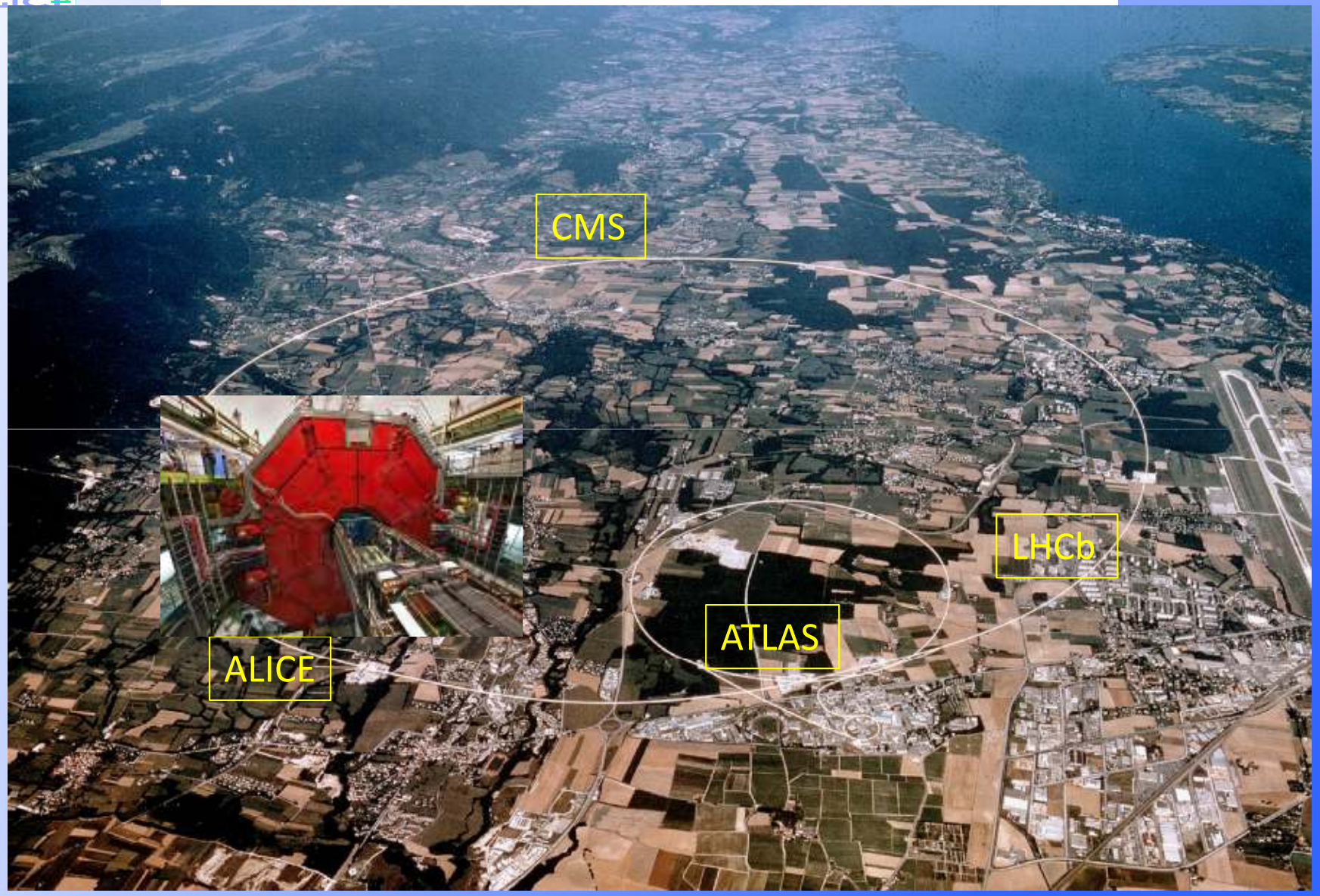
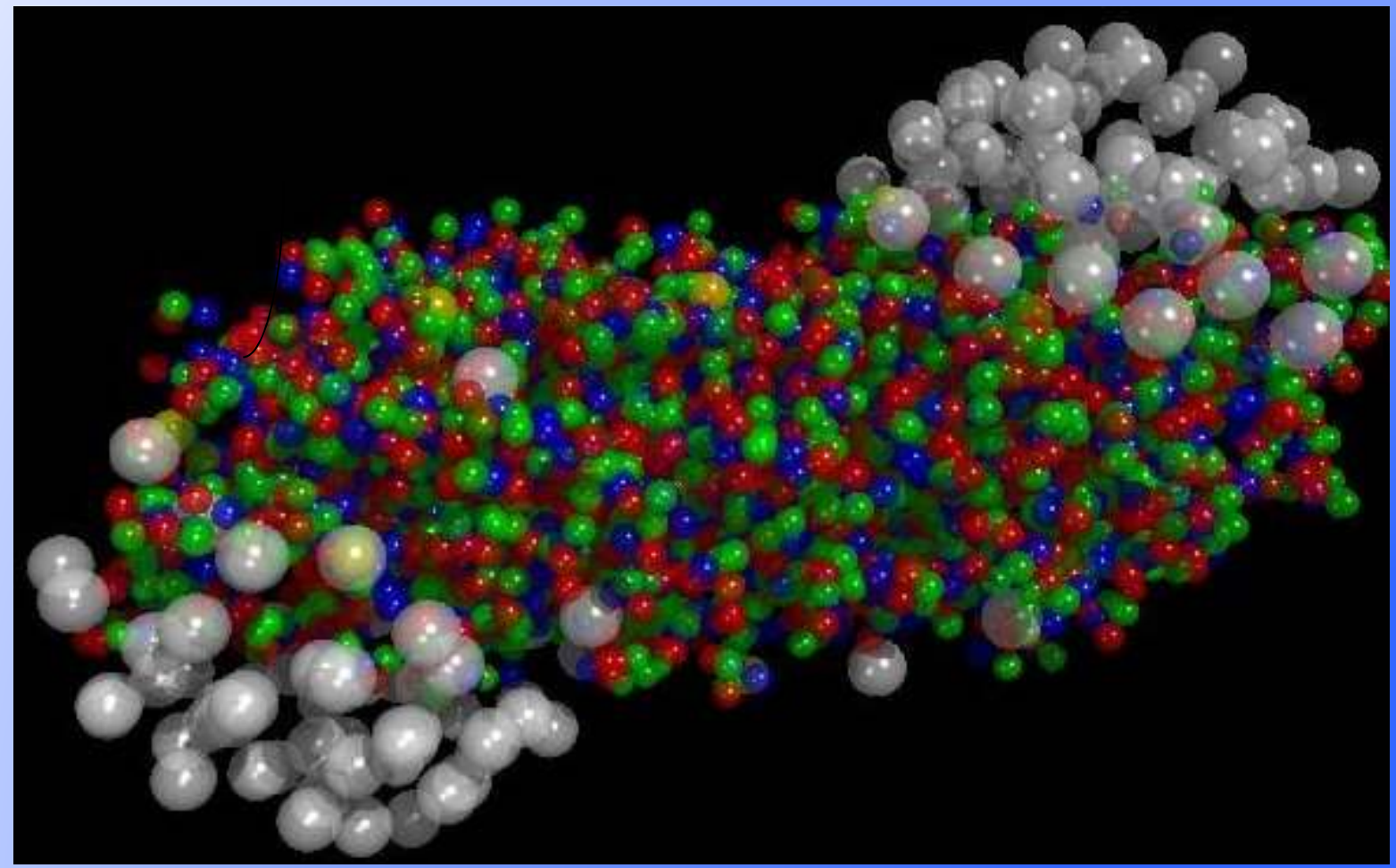
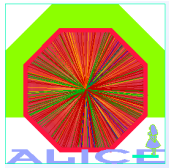
ALICE : A Large Ion Collider Experiment @ LHC



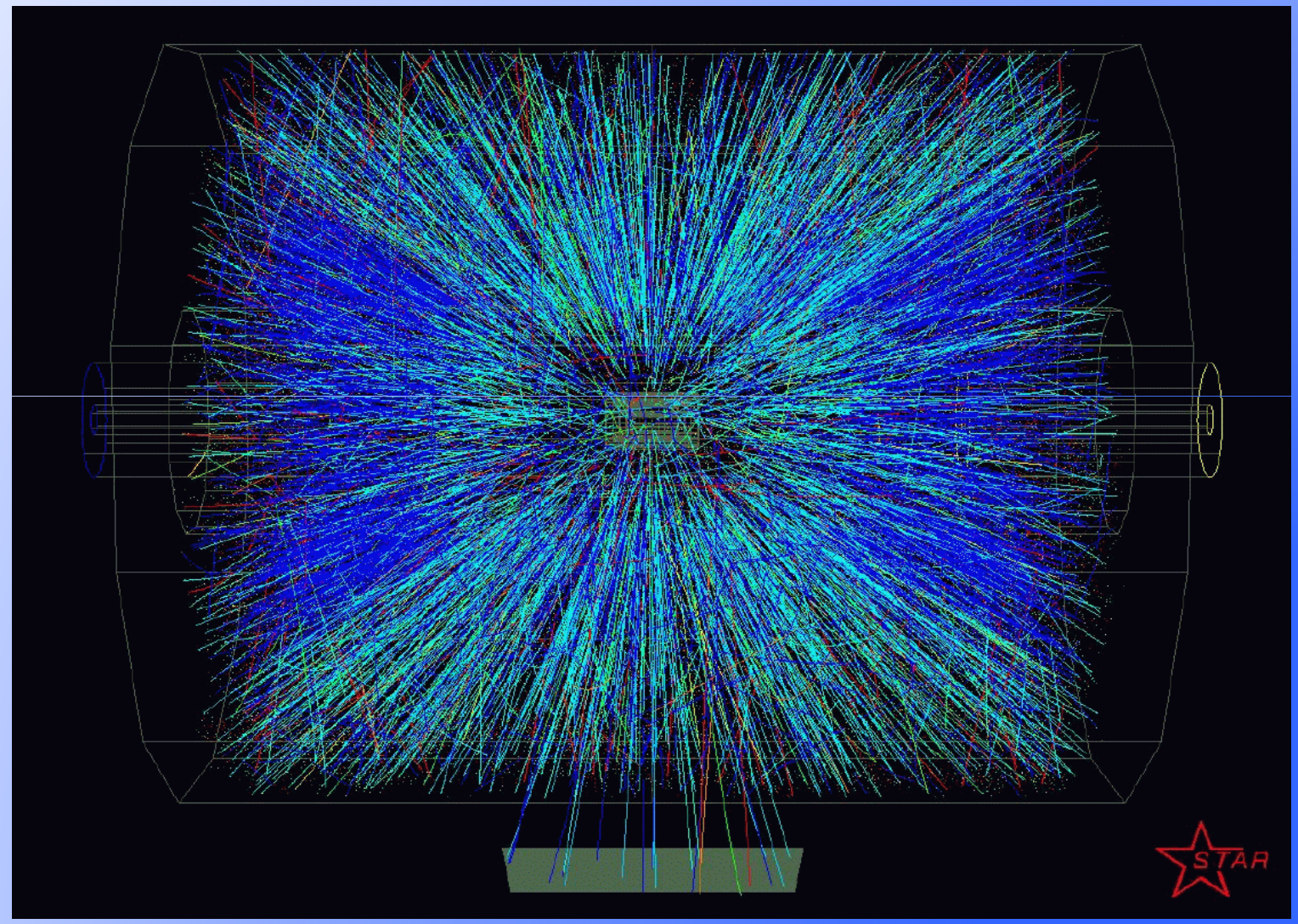
A snapshot of the collision of 2 Lead nuclei (Pb)
… with the shutter speed at 10^{-23} seconds !



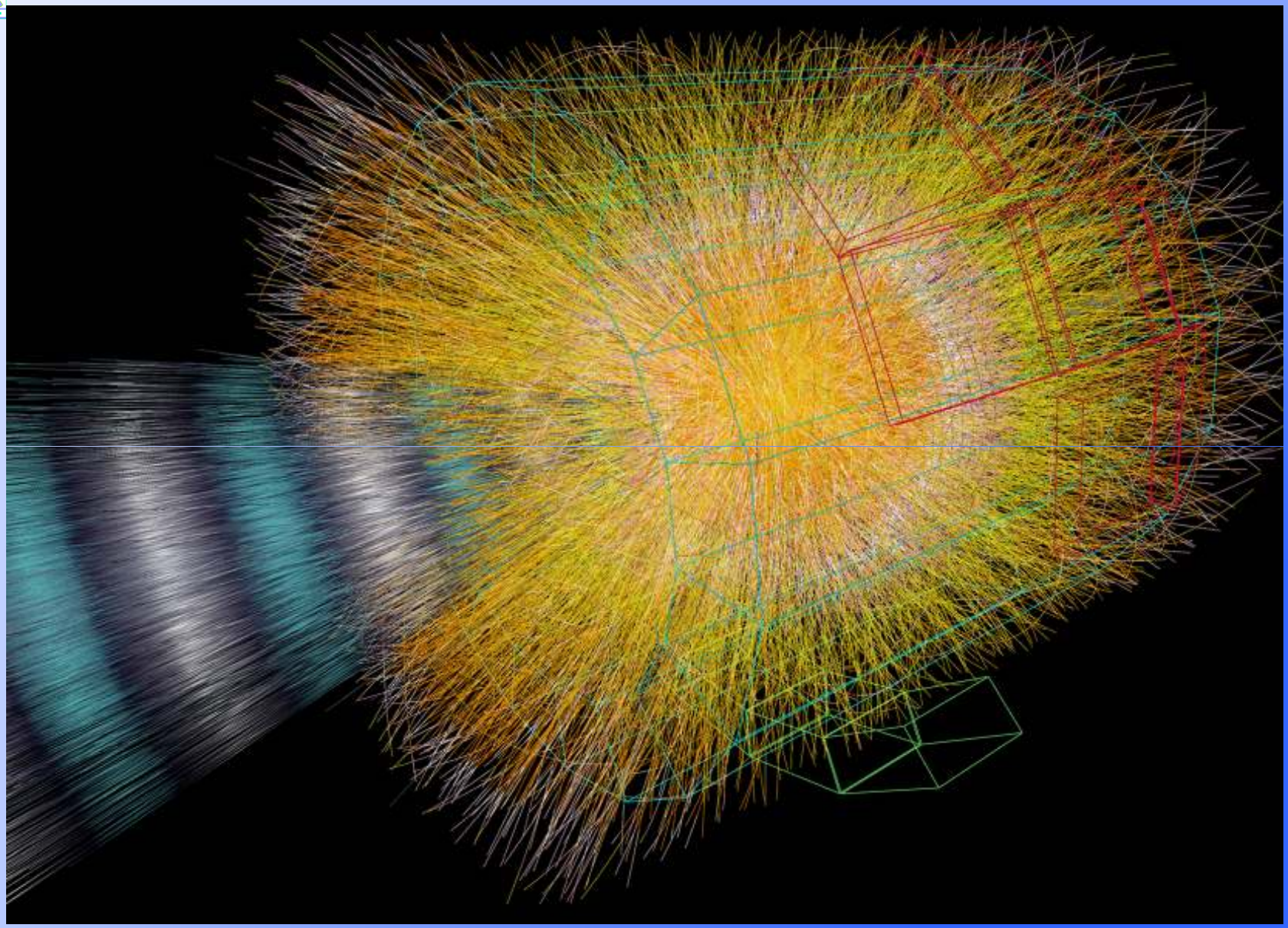
Lot's of production …

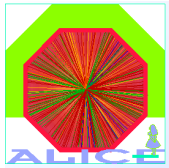


At RHIC: $^{197}Au+^{197}Au$ at $\sqrt{s_{nn}}$=200GeV
About 9000 particles produced per central collision



Many more in ALICE with Pb+Pb at LHC. But how Many?





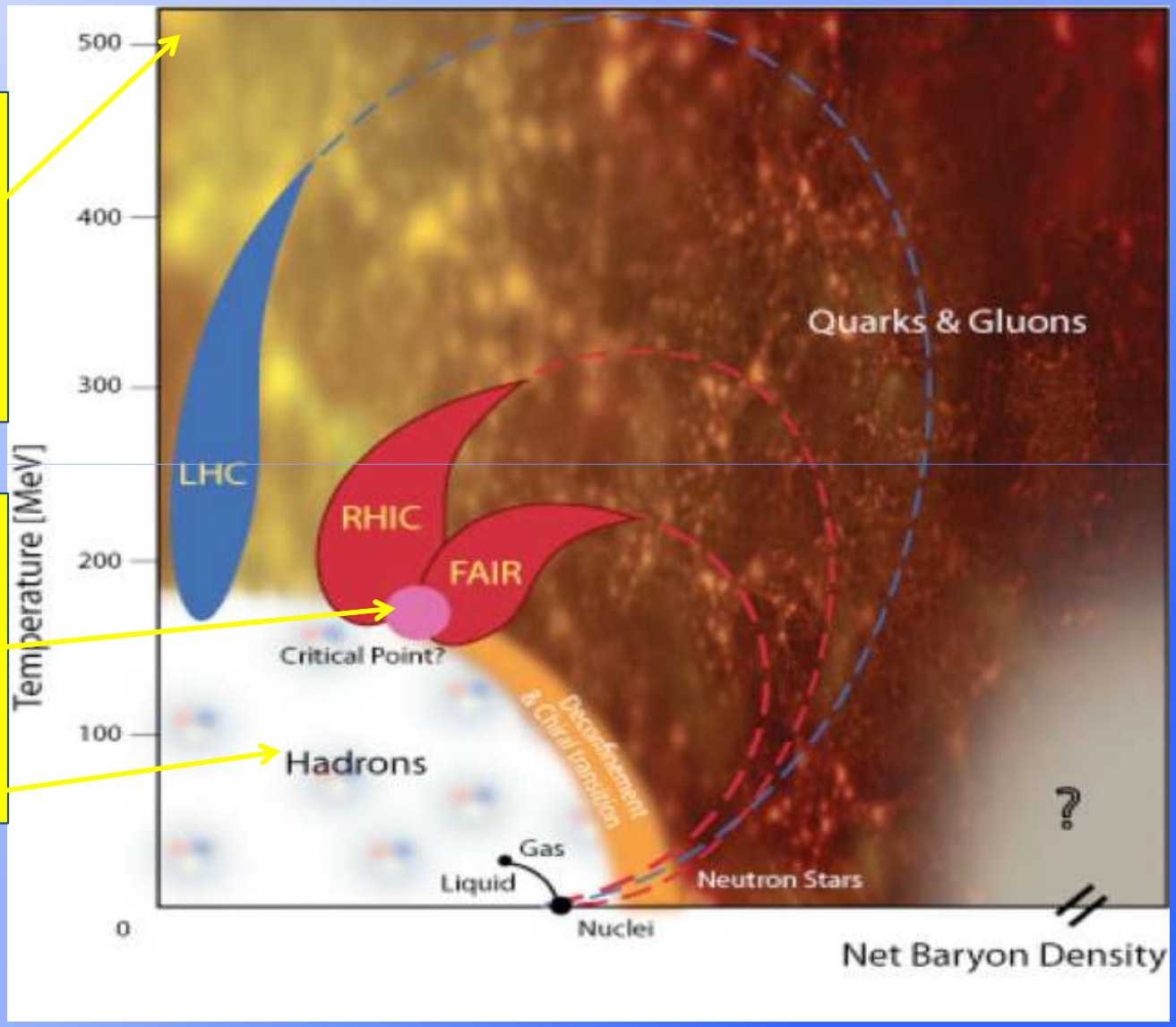
ALICE

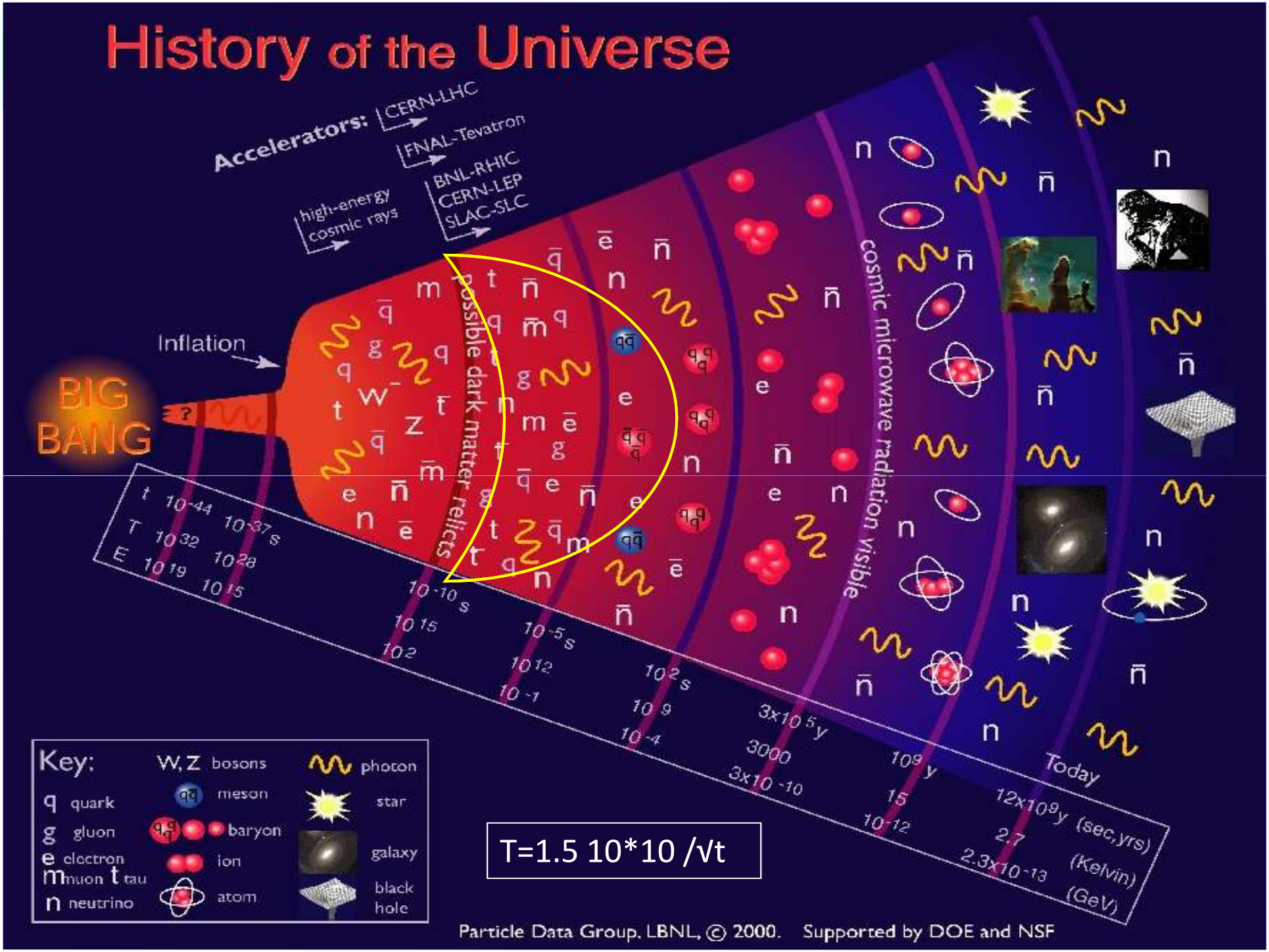
- ALICE designed to study the physics of PARTONIC MATTER (QGP)
- Heavy Ion collisions @ 30 times higher energy than RHIC
  => new physics regime
- Designed to cope with extreme particle multiplicities, up to dN/dη=8000.
- Large dynamic range: 100 MeV < pt < 100 GeV
- Excellent PID and tracking
- Measure hadronic and leptonic observables
- Data rate up to 10kHz, large event size 100-200 MB

Ultra-Relativistic Heavi Ion collisions at LHC

LHC:
Partonic matter
QGP
√s≈30 times RHIC energy and 230 times SPS energy

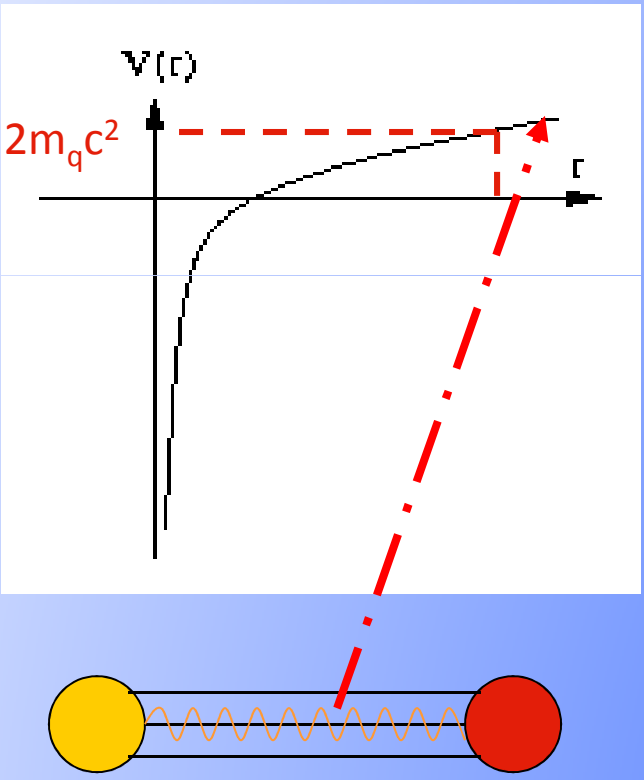
SPS:
Onset of deconfinement
Critical point?
Chiral symmetry?
Hadron physics



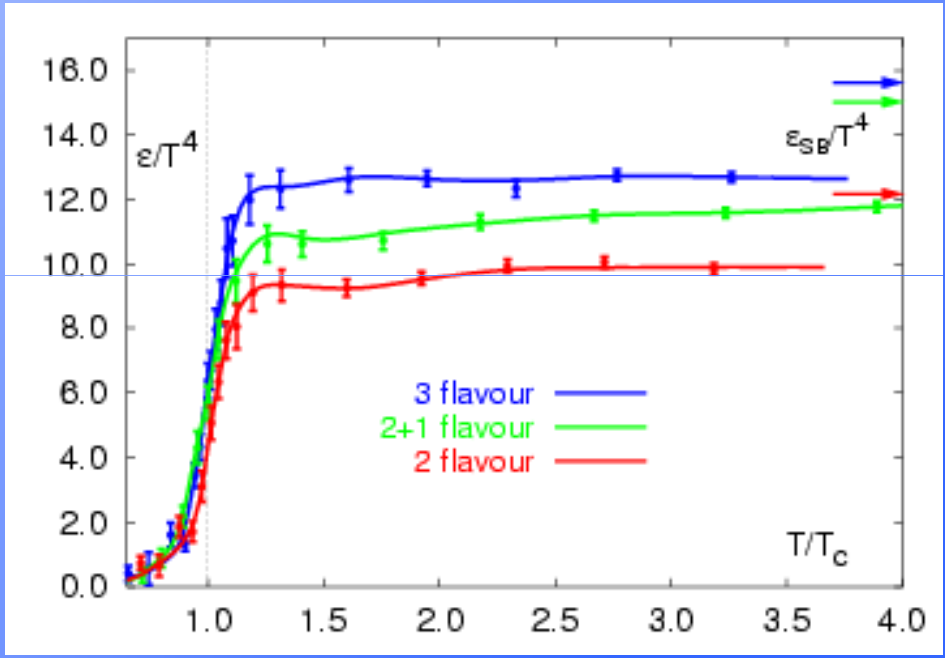

History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relicts
cosmic microwave radiation visible
t 10-44 10-37 s
T 1032 1028
E 1019 1015
10-10 s
1015
102
10-5 s
1012
10-1
102 s
109
10-4
3x105 y
3000
3x10-10
109 y
15
10-12
Today
12x109 y (sec,yrs)
2.7 (Kelvin)
2.3x10-13 (GeV)
Key:
q quark
g gluon
e electron
m muon t tau
n neutrino
W,Z bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
T=1.5 10*10 /√t
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

QCD

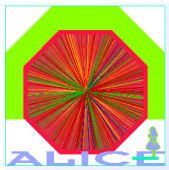
Confinement



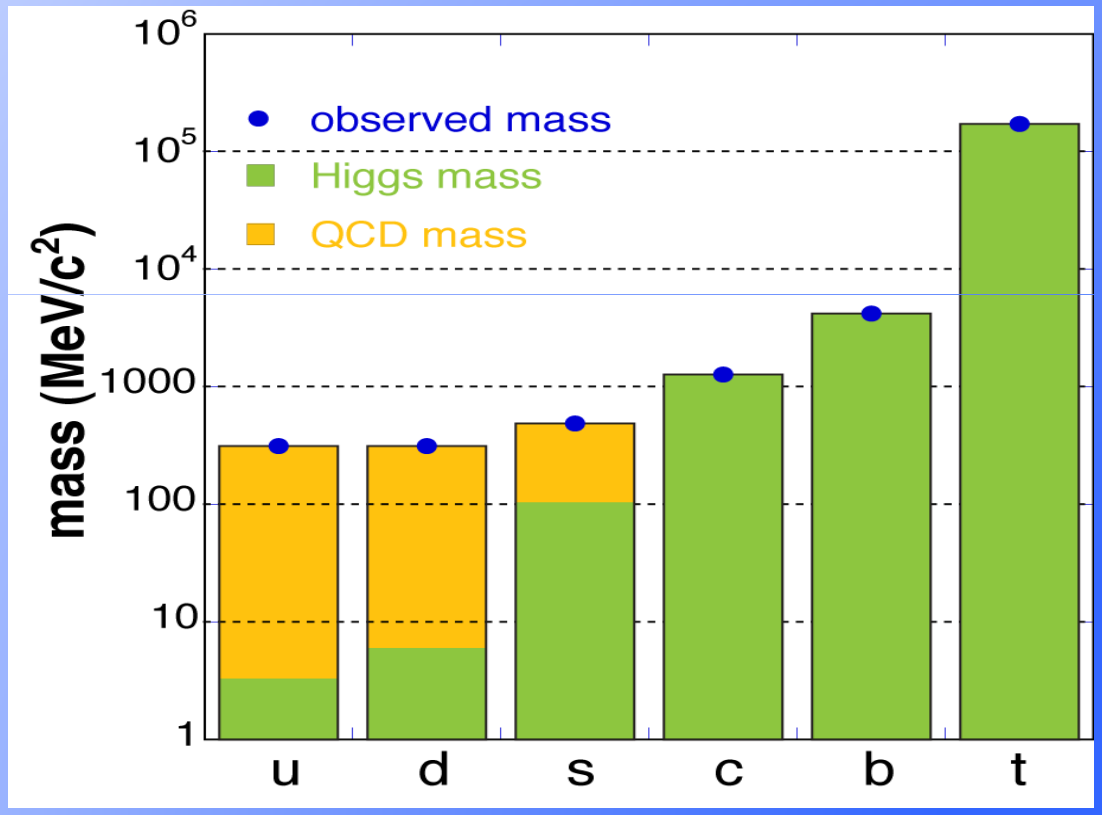
HG-QGP phase transition



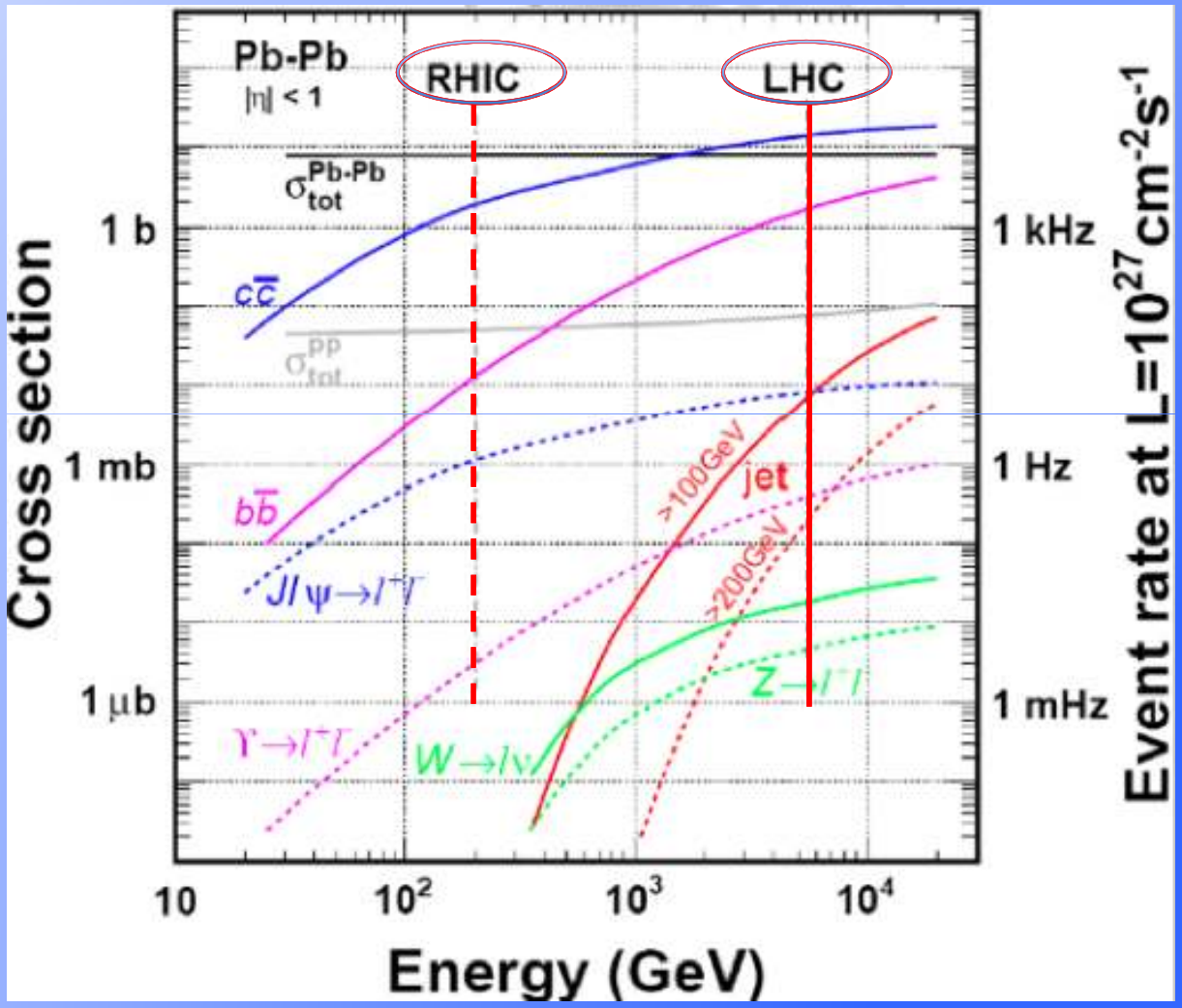
SPS **RHIC** **LHC**

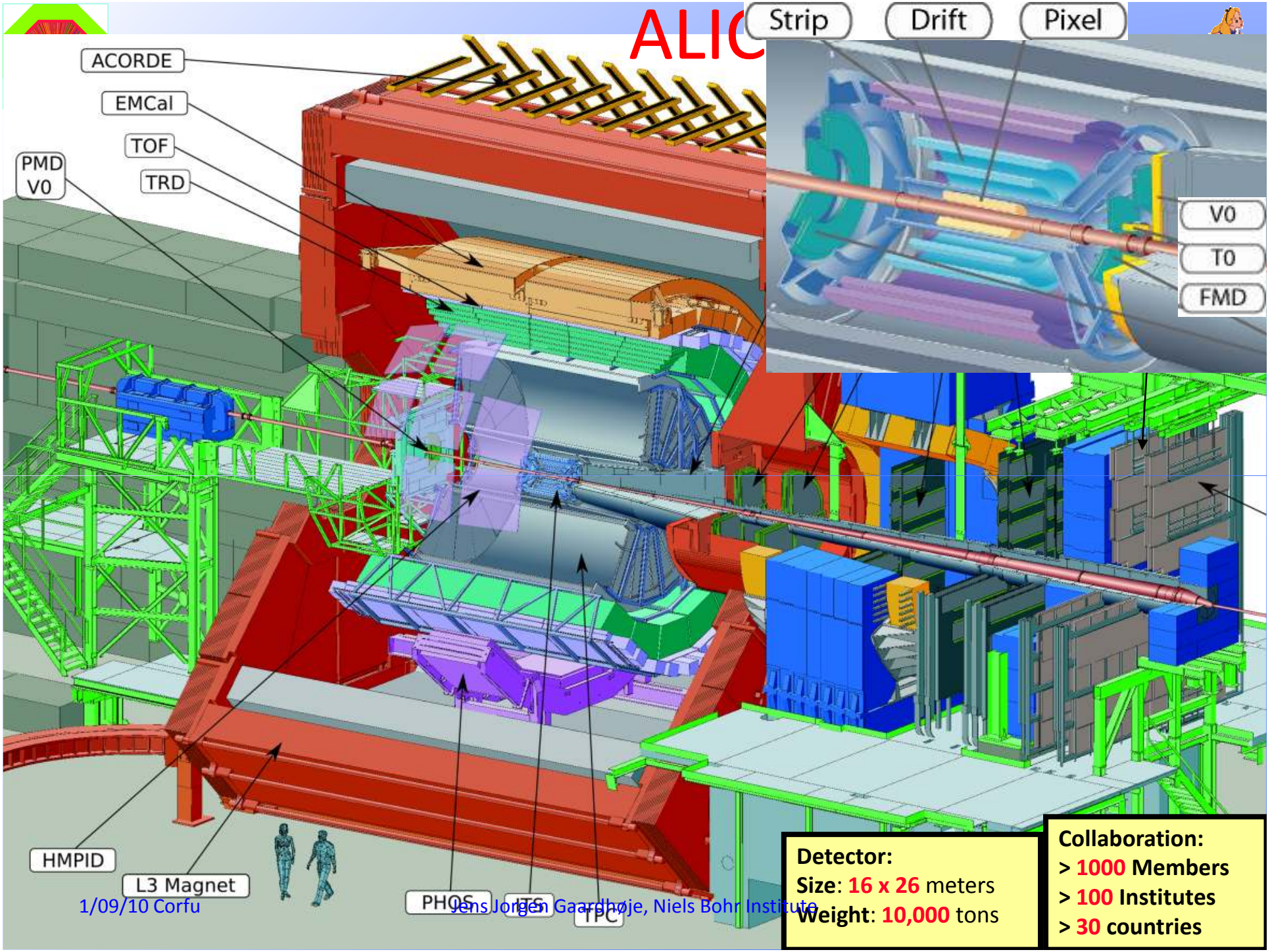


Quark Mass:
Chiral symmetry breaking and coupling to quark condensate gives most of the mass of light quarks



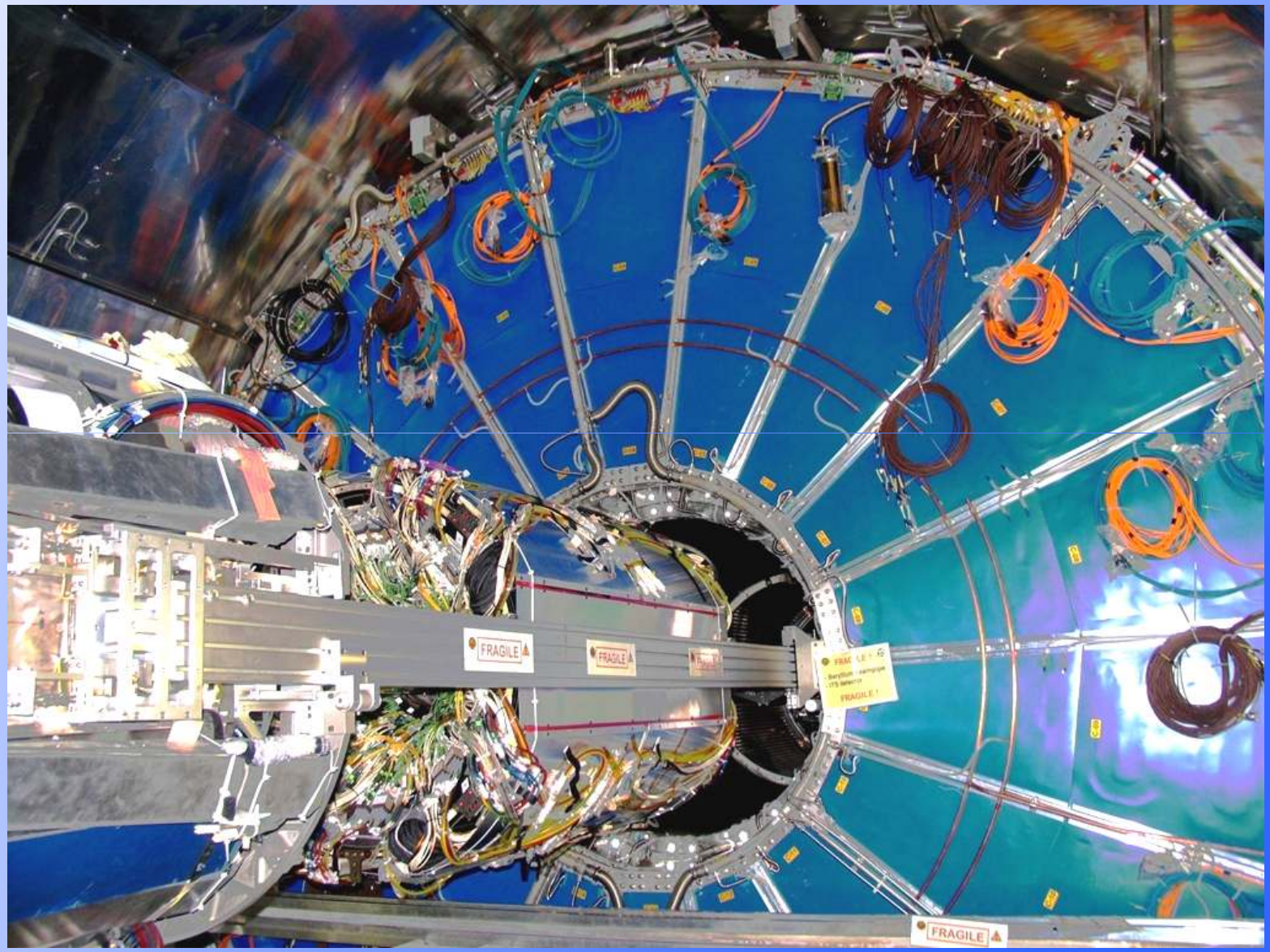
Greatly increased rates for
heavy flavors, quarkonia lepton decays, jets,… at LHC




ALIC
Strip
Drift
Pixel
ACORDE
EMCal
TOF
TRD
PMD
V0
V0
T0
FMD
HMPID
L3 Magnet
PHOS
ITS
TPC
Detector:
Size: 16 x 26 meters
Weight: 10,000 tons
Collaboration:
> 1000 Members
> 100 Institutes
> 30 countries

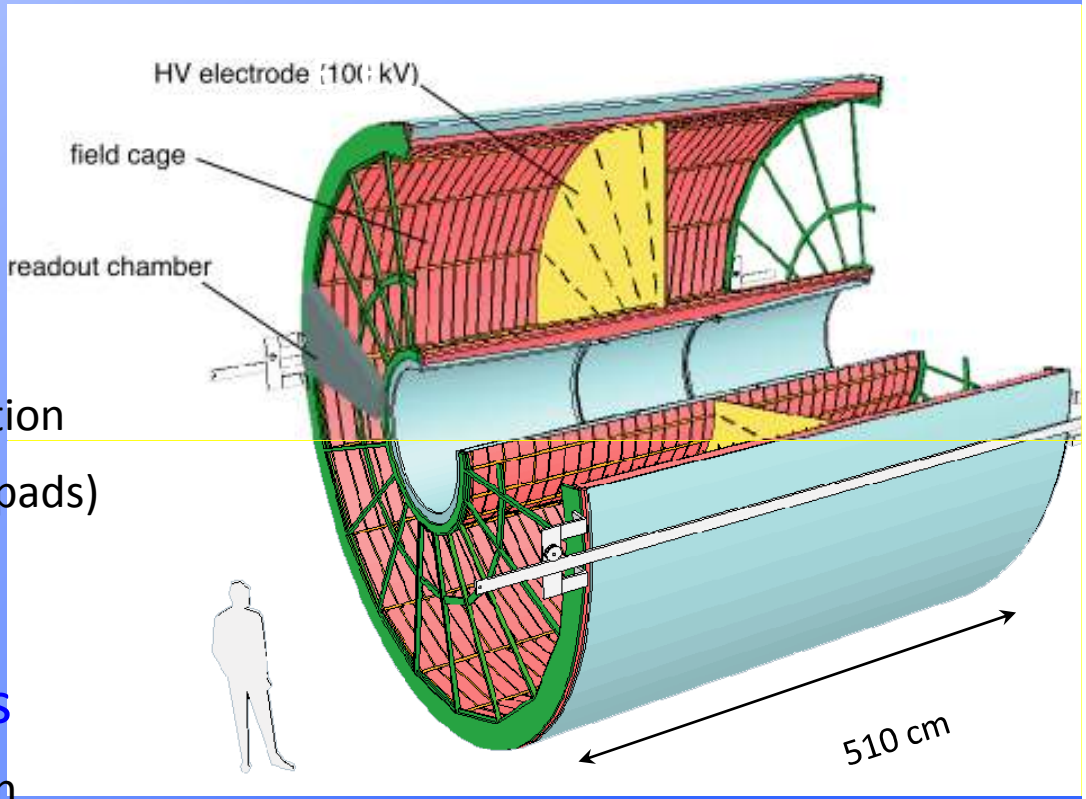
ALICE 5 years ago

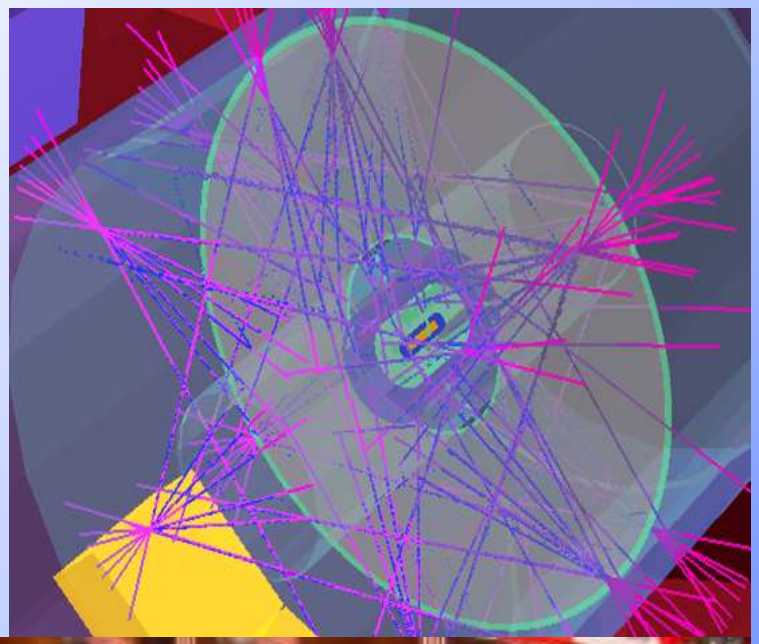
ALICE inner tracker, TPC and FMD



ALICE TPC

- minimal material budget
  - ☺ composite materials => 3.5% X0
  - ☹ sensitive to stress and deformations
- high track density
  - ☺ low diffusion & low space charge 'cool' drift gas ($Ne/CO_2/N_2$)
  - ☹ electric field (400 V/cm), V_{drift} calibration
  - ☺ high granularity (550k few mm wide pads)
  - ☹ tight tolerances in construction
- advanced readout electronics
  - ☺ digital pulse shaping and 0-supression
  - ☺ > 2 kHz readout of 0.5×10^9 10 bit ADC's

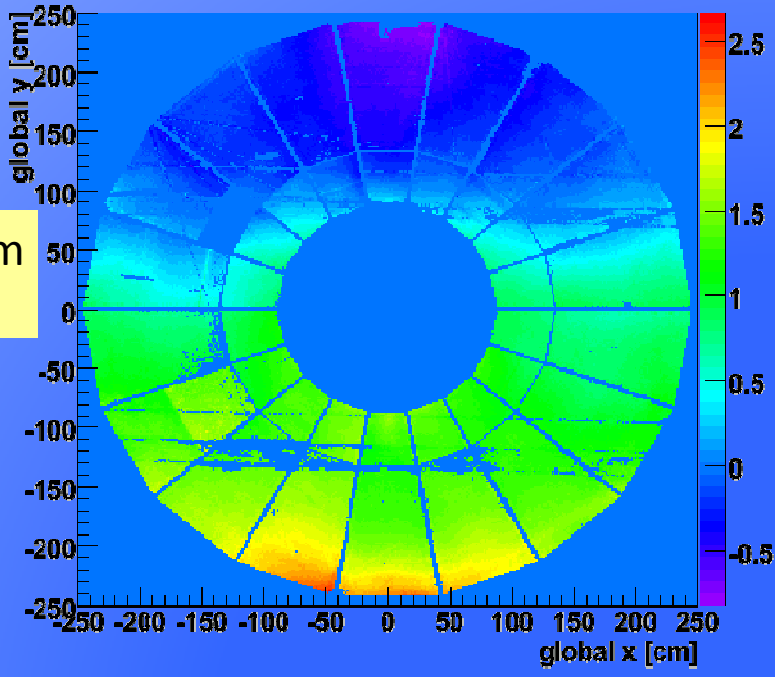




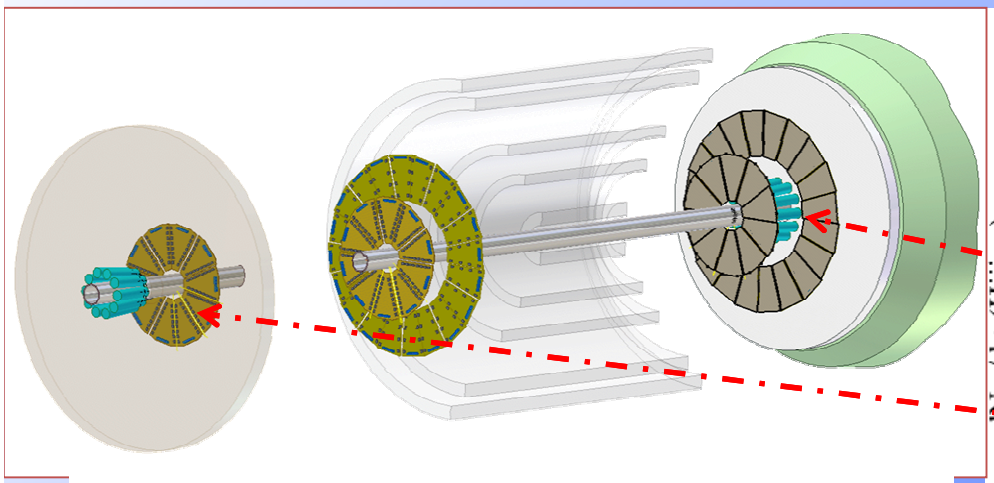
266nm UV Laser for TPC
Crucial for V_{drift} &
ExB space charge correction.

warm
cold

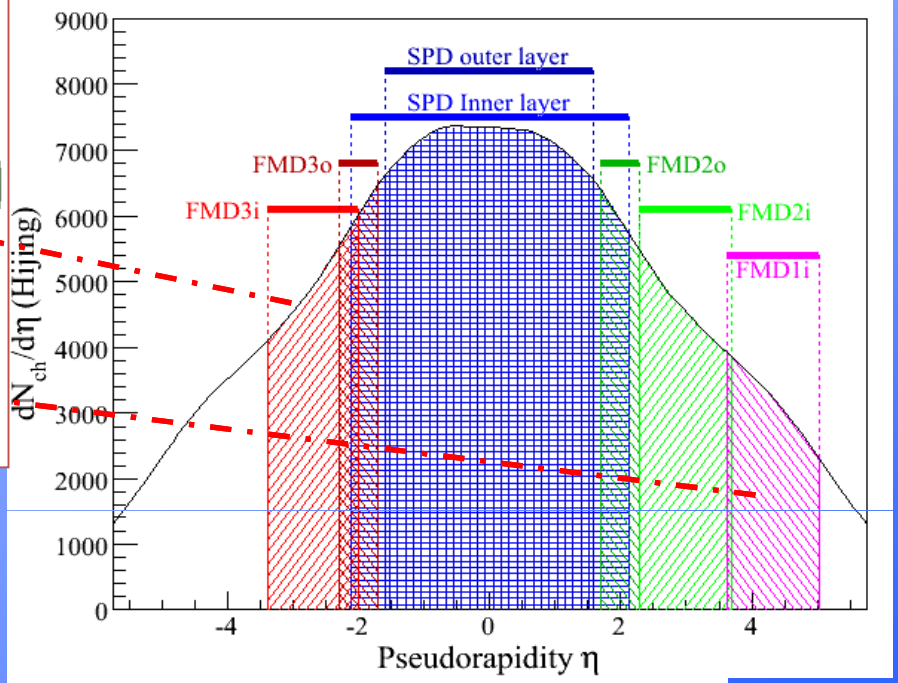
Laser Photo electrons from central electrode arrival time

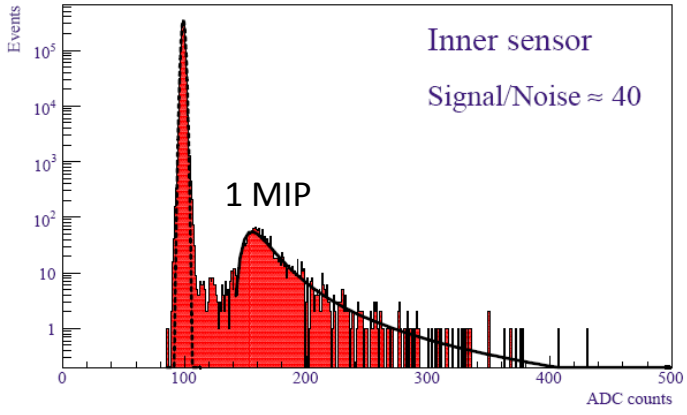


ALICE Forward multiplicity Detector (FMD)



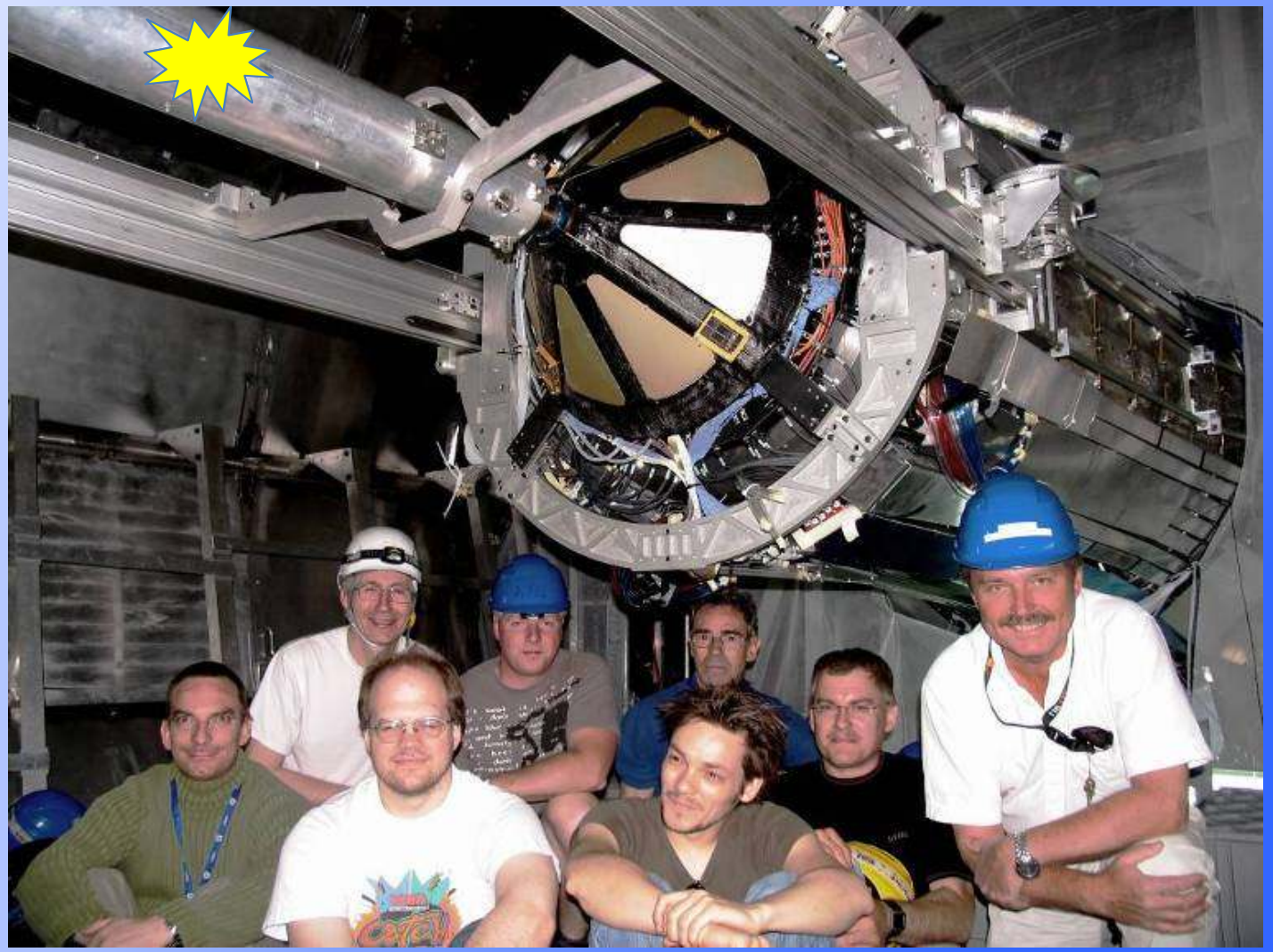
FMD: 51200 Si-strips in 5 rings at high eta

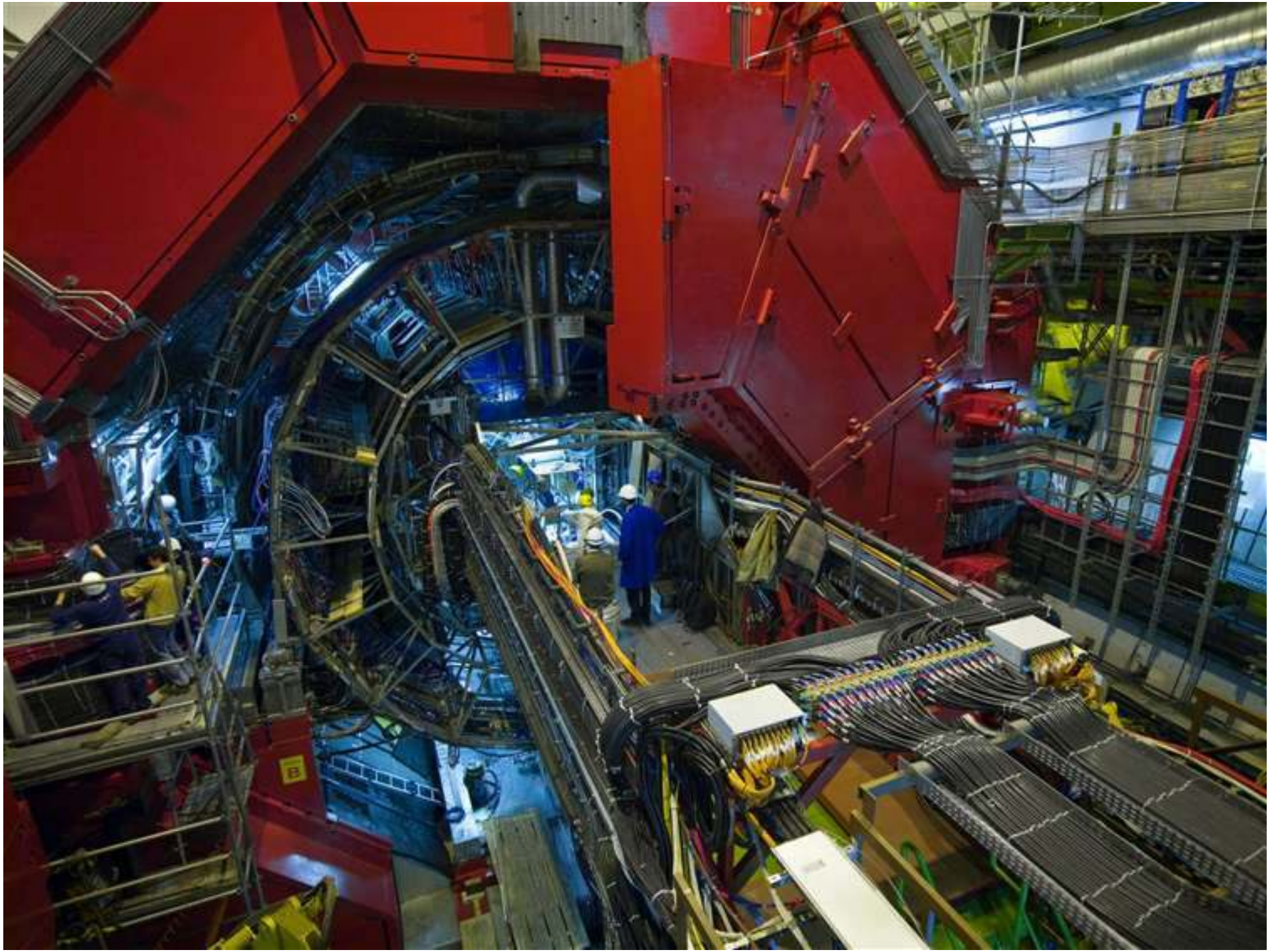


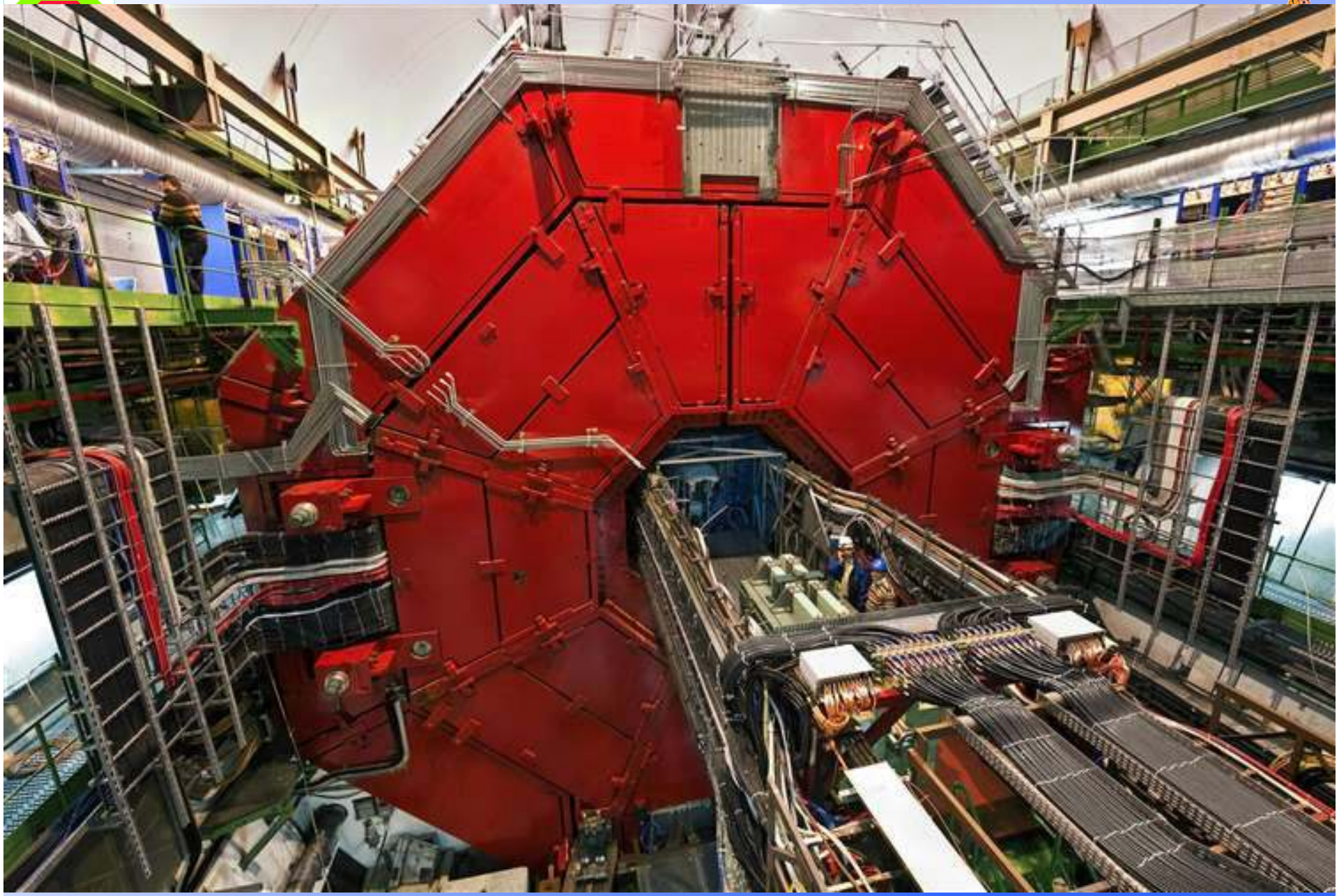


Excellent energy response

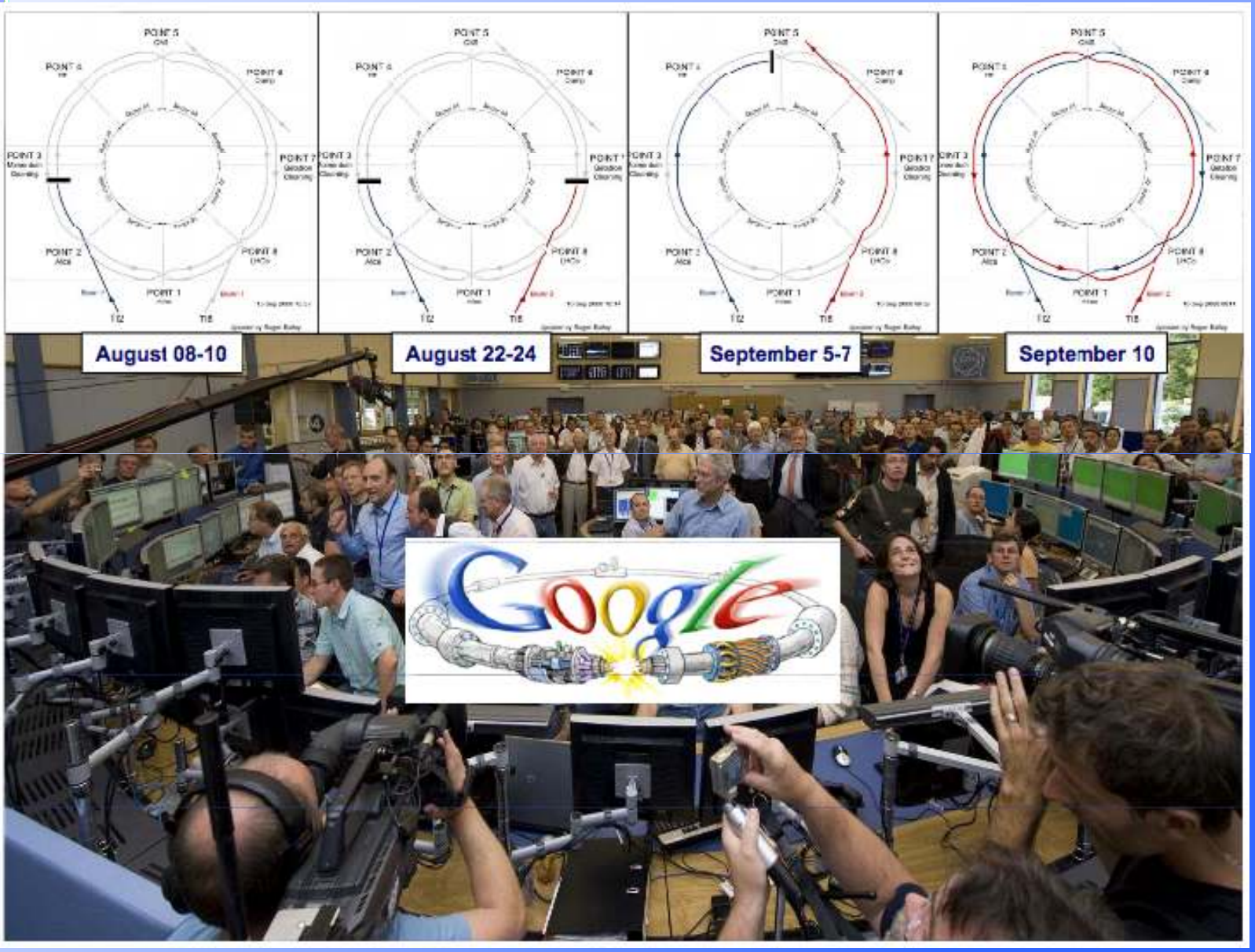
FMD installation close to the IP (2008)







LHC Startup 10/9/2008: 100 million hits on CERN's homepage ,
> 1.5 billion viewed LHC news clip on TV

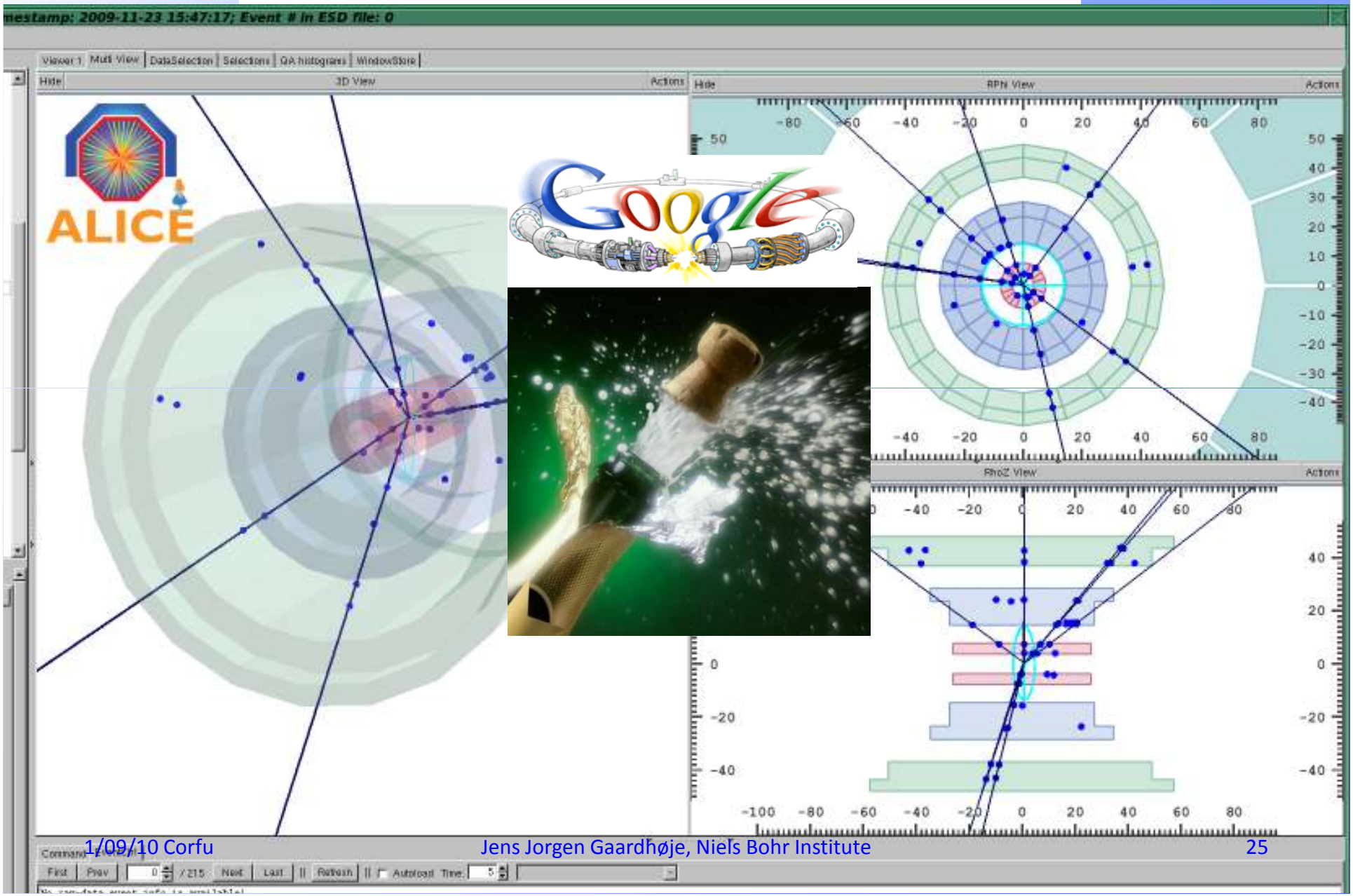


Fear of, or hope for, Black Holes ?

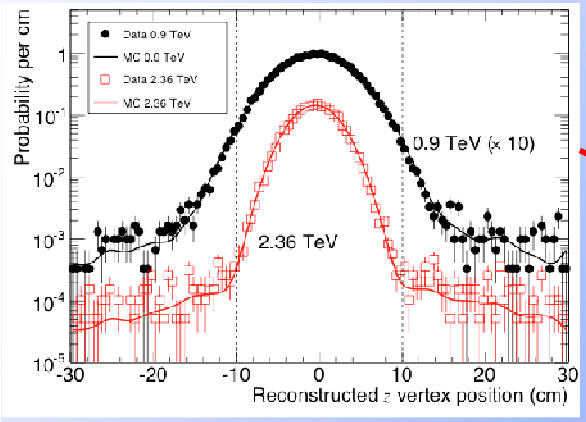
But, 10 days later: a Black Day => a year of delay

BACK AGAIN

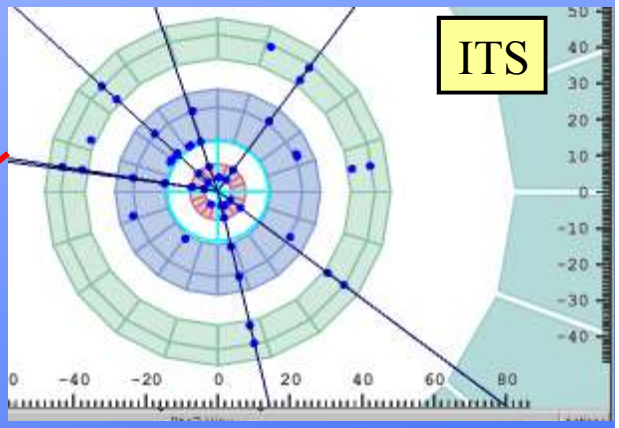
23 Nov. 2009. First p+p @ 900 GeV

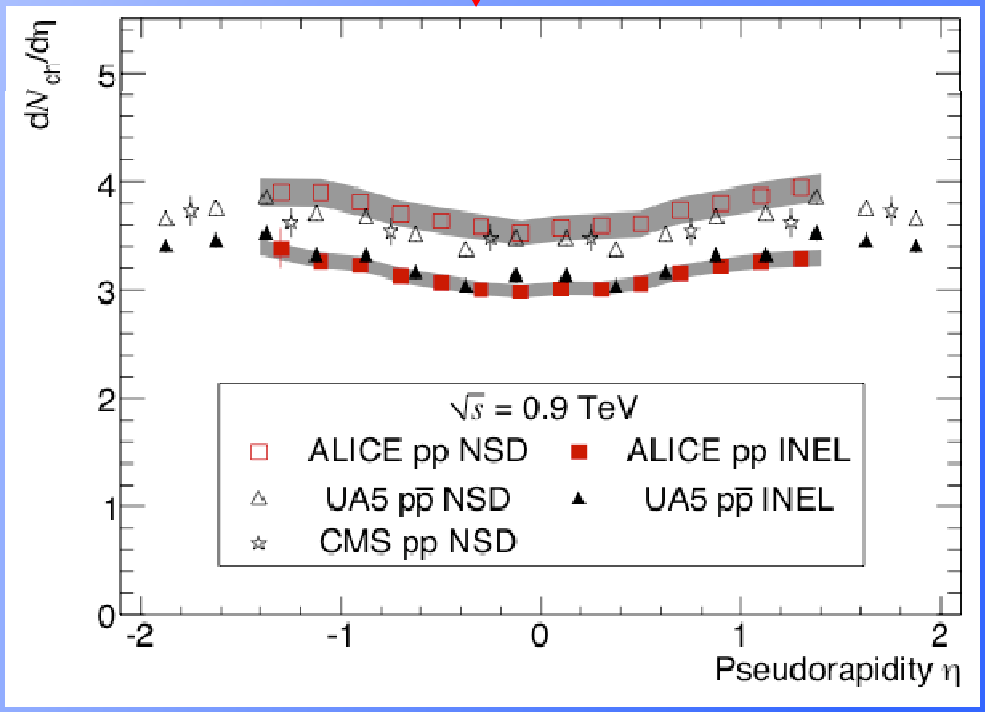


First ALICE results with p+p



Apply vertex cut
& Count tracklets in ITS

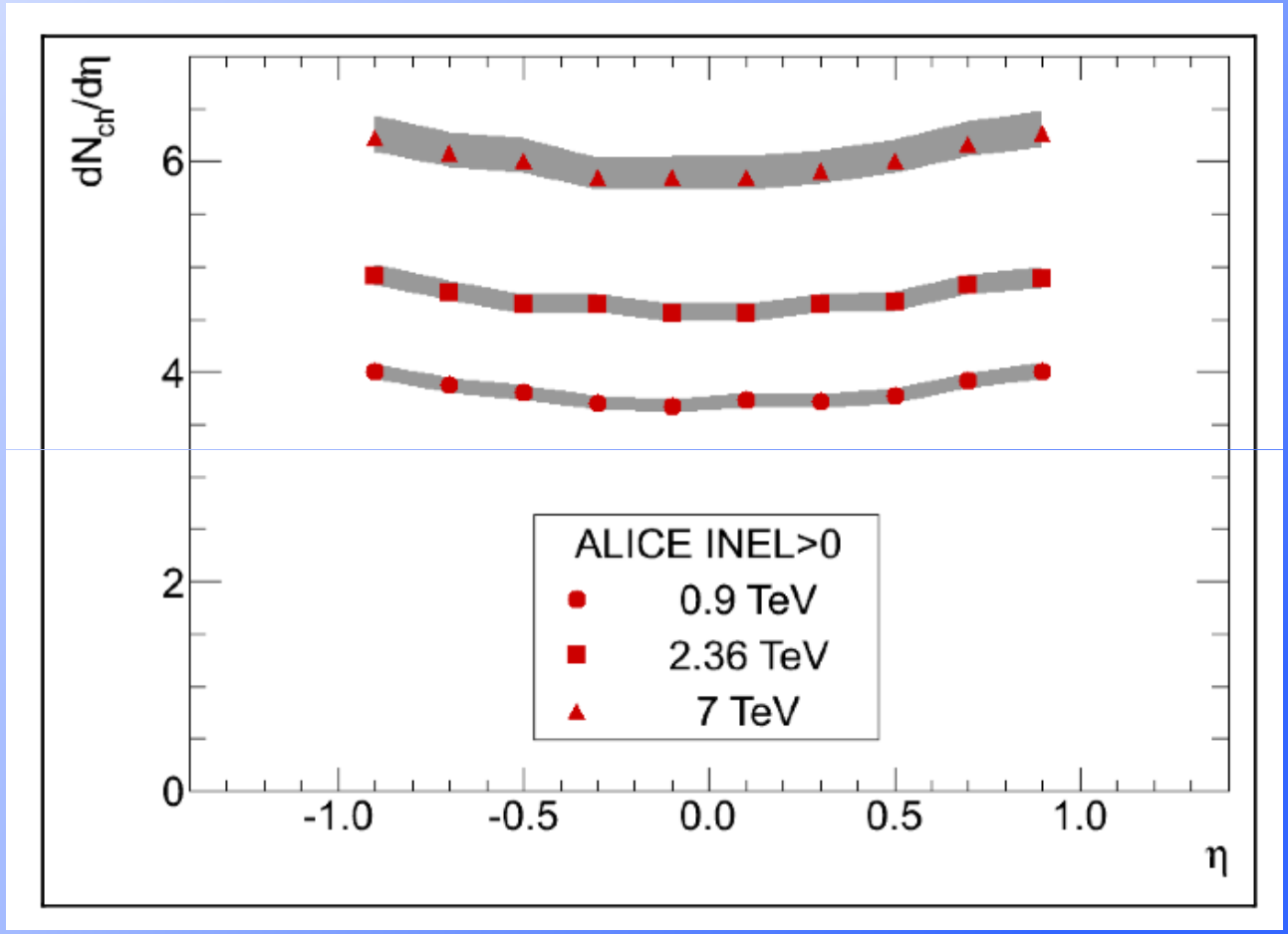




At 900 GeV can compare to old data from UA5 experiment at SPS.

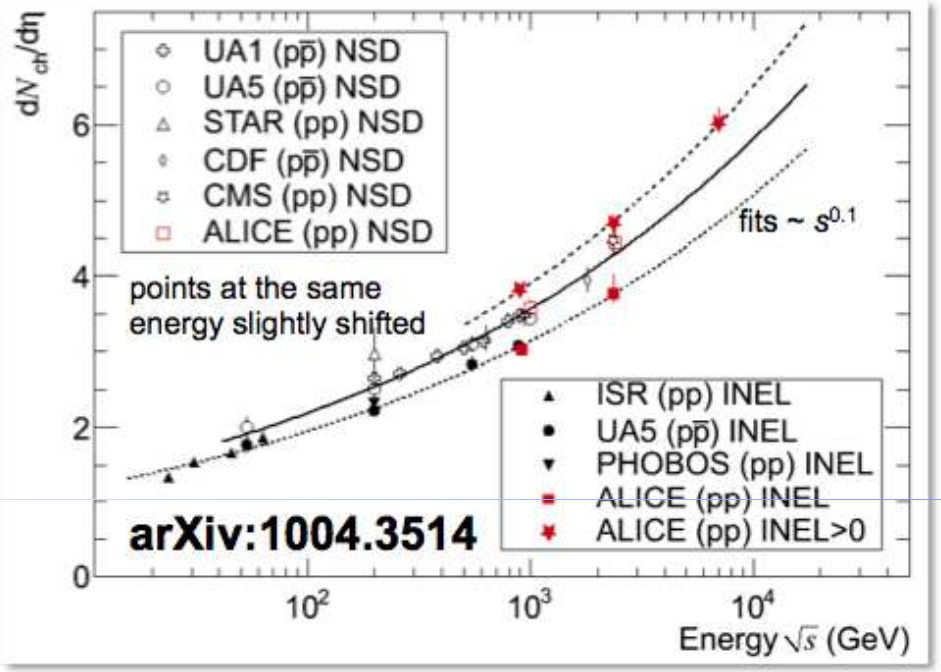
First LHC data publication. Submitted 6 days after data taking

ALICE mid-rapidity multiplicity for 0.9, 2.36, 7 TeV

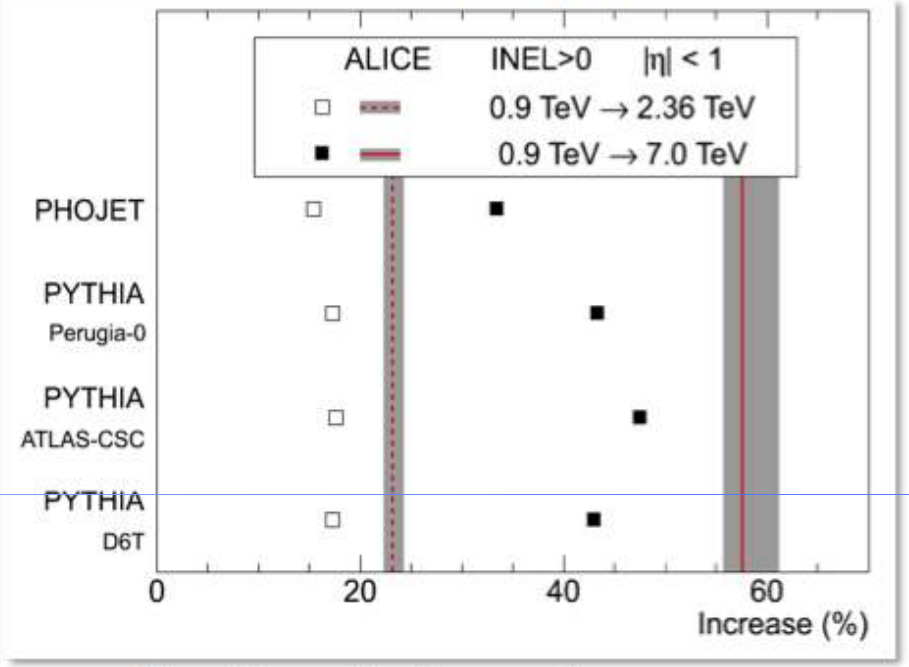


ALICE: subm. to Eur. Phys. Jour. (2010)

ALICE: Charged particle multiplicity in p+p @ 0.9,2.36 &7 TeV



arXiv:1004.3514

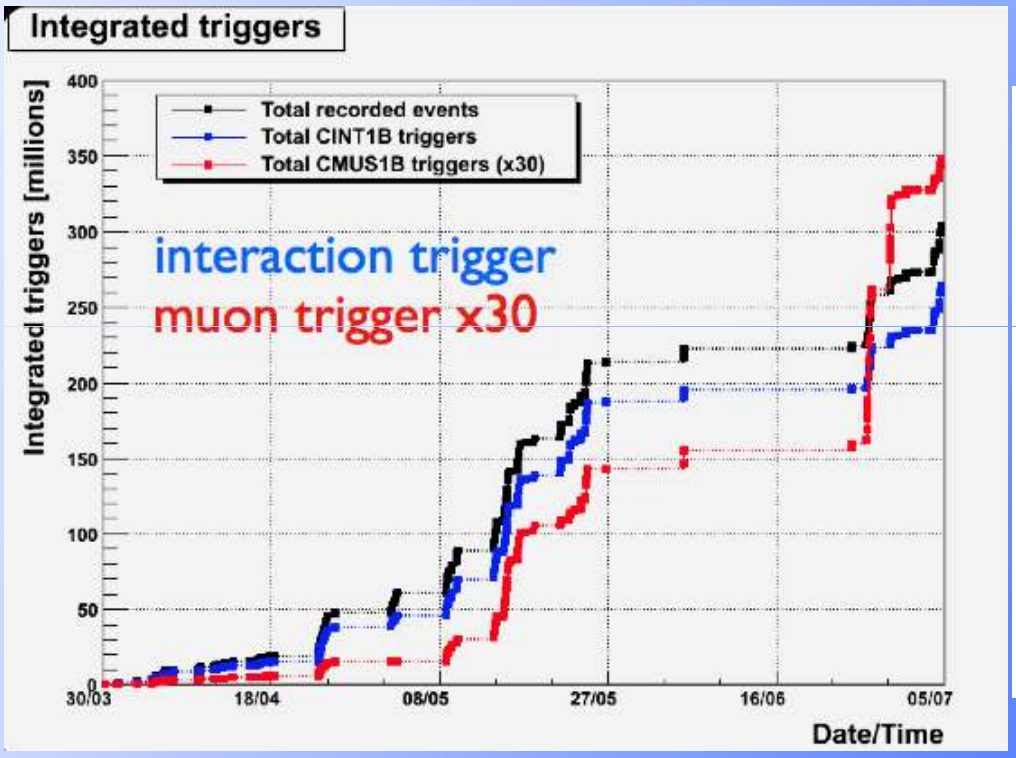


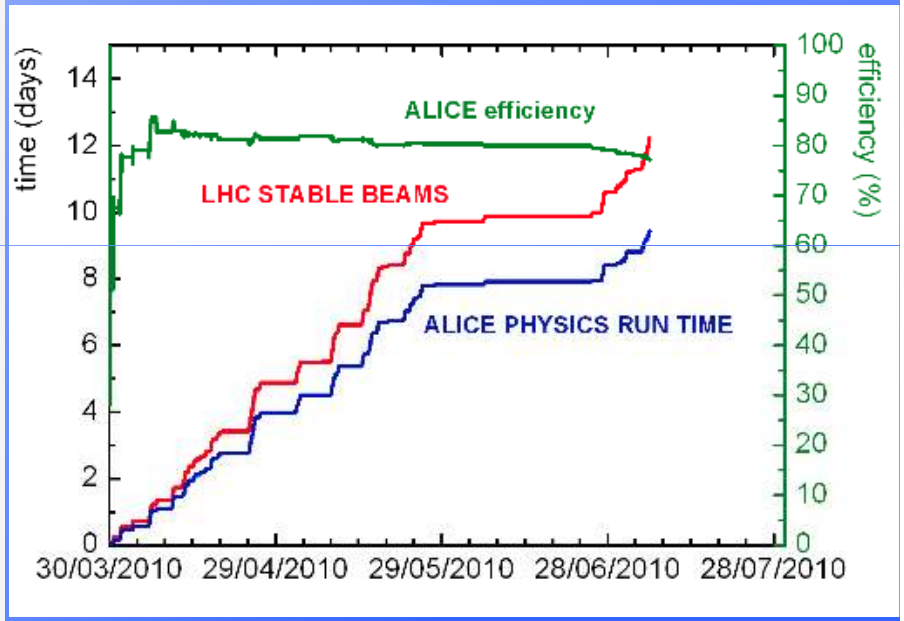
Power law dependence fits well

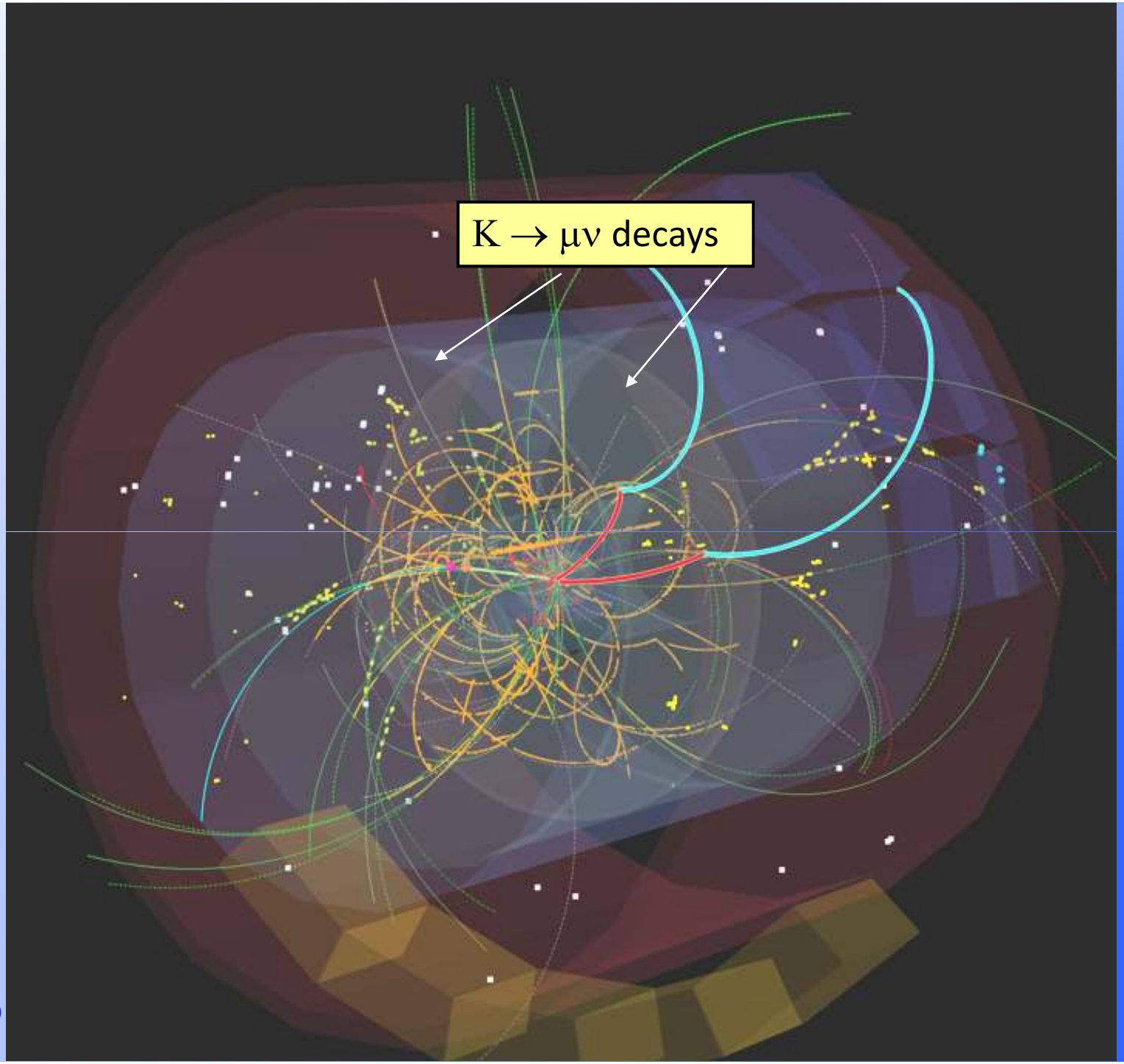
Significantly larger increase from 0.9 to 7 TeV than in MCs

Increase in dN_{ch}/dh in $\|\eta\| < 1$ for INEL > 0 arXiv:1004.3514	√s	ALICE (%)	MCs (%)
	0.9 → 2.36 TeV	$23.3 \pm 0.4\ ^{+1.1}_{-0.7}$	15 – 18
	0.9 → 7 TeV	$57.6 \pm 0.4\ ^{+3.6}_{-1.8}$	33 – 48

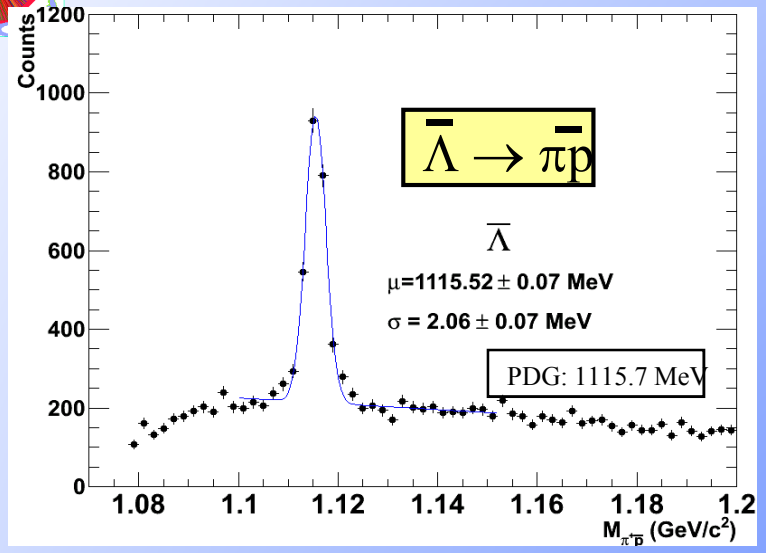
Rapidly settle into stable running …

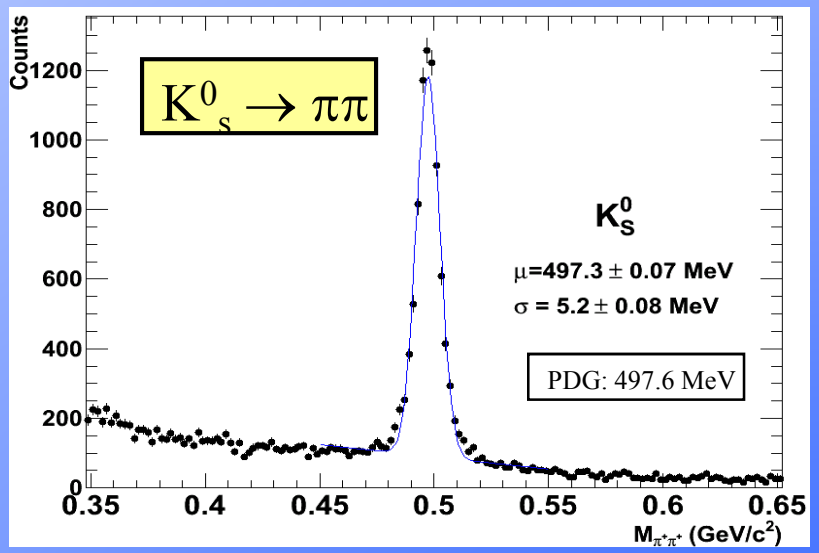


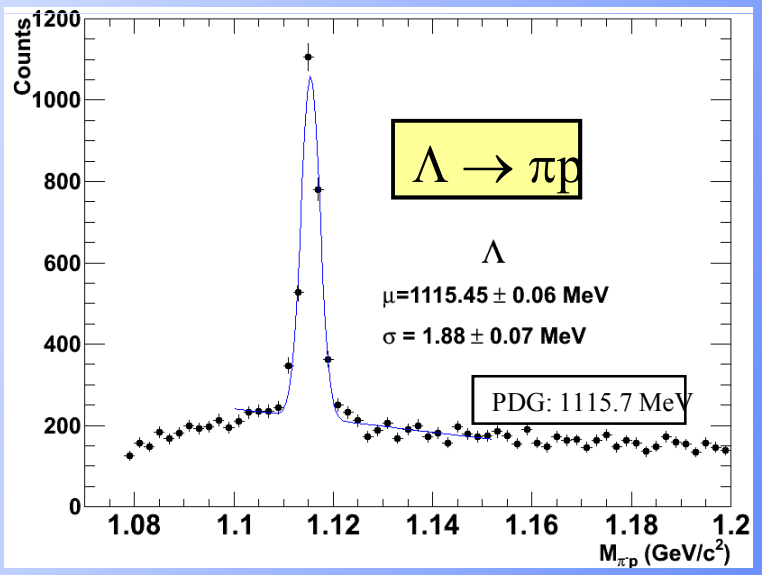


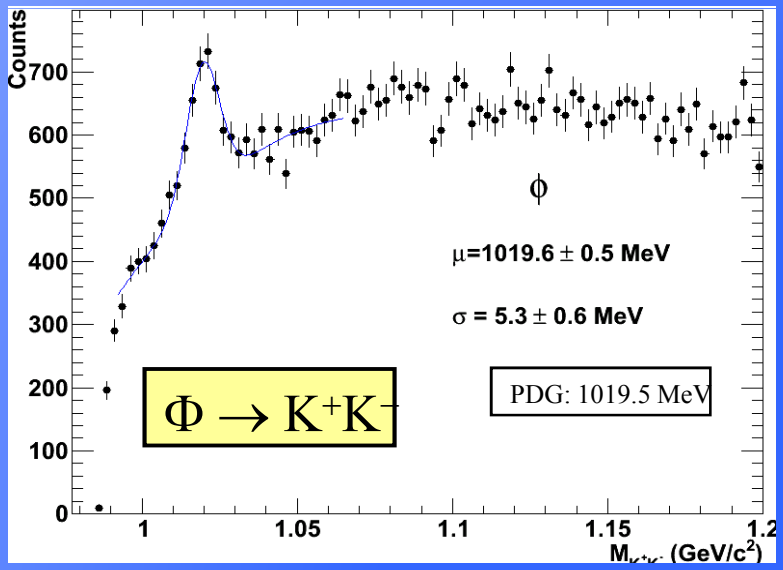

K → μν decays

Checking the PDG…



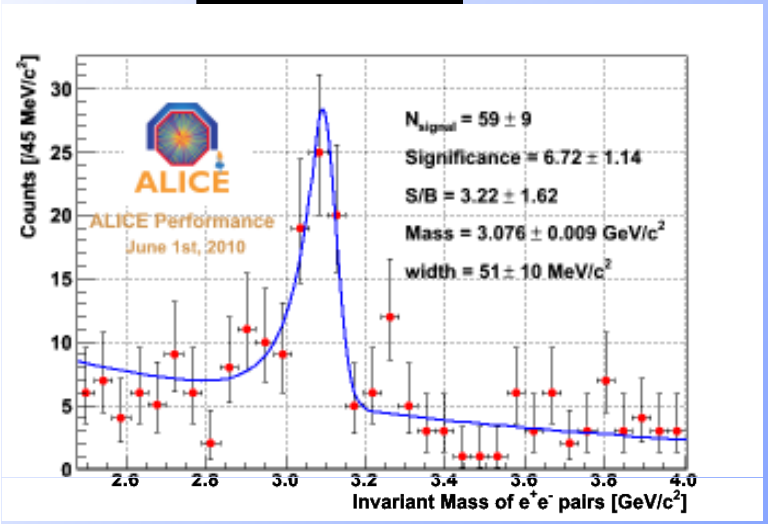




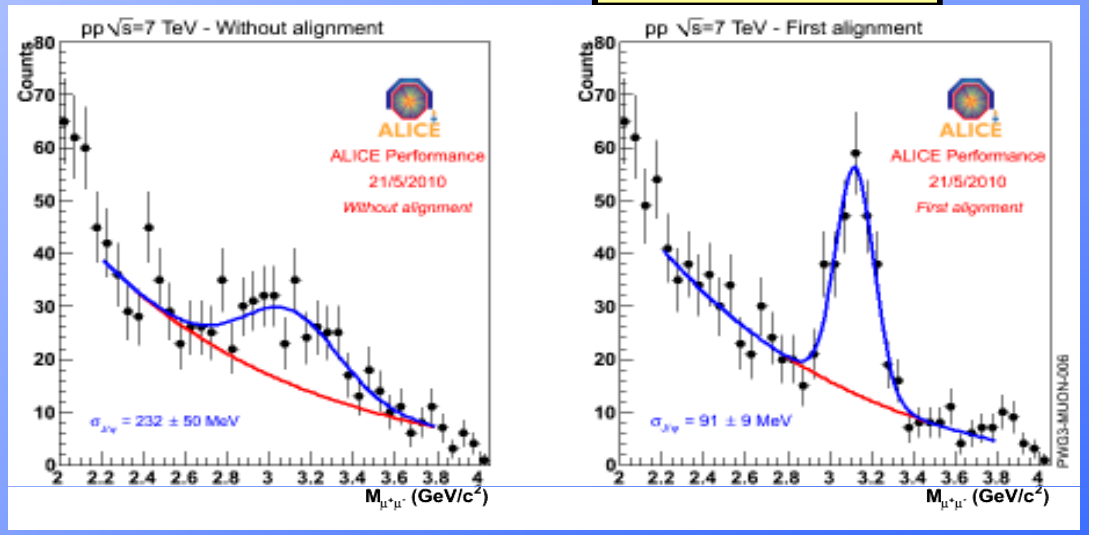


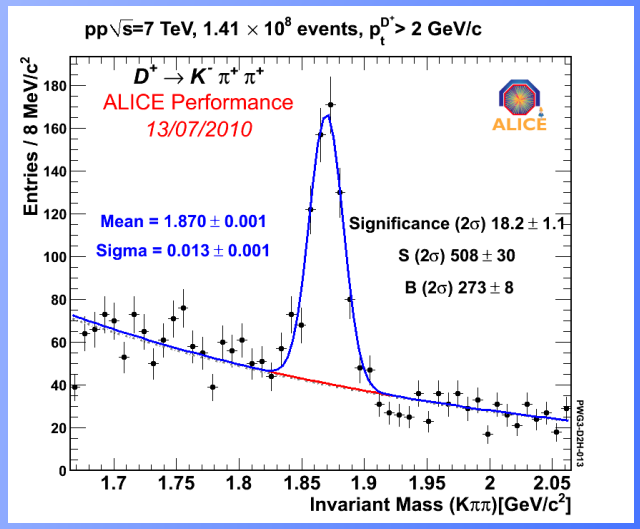
Work in progress: J/Ψ , charm, …

J/Ψ → e^+e^-
central barrel

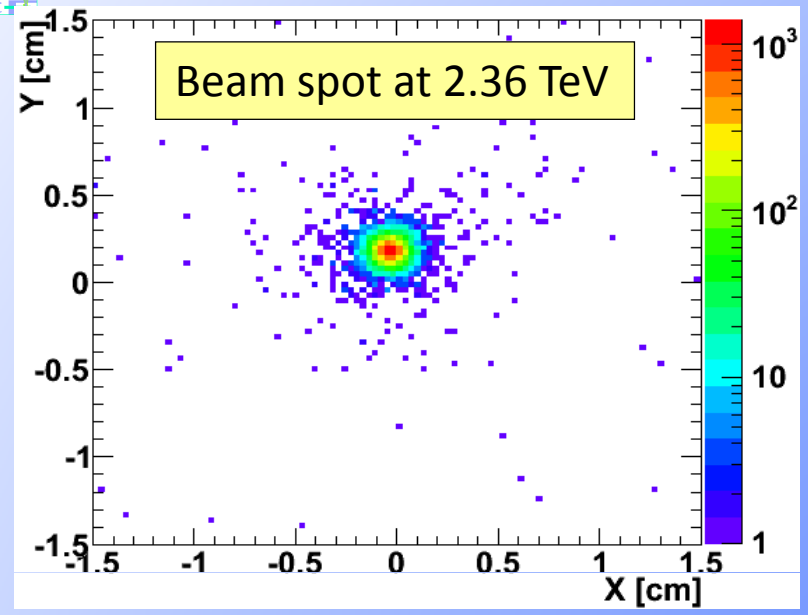


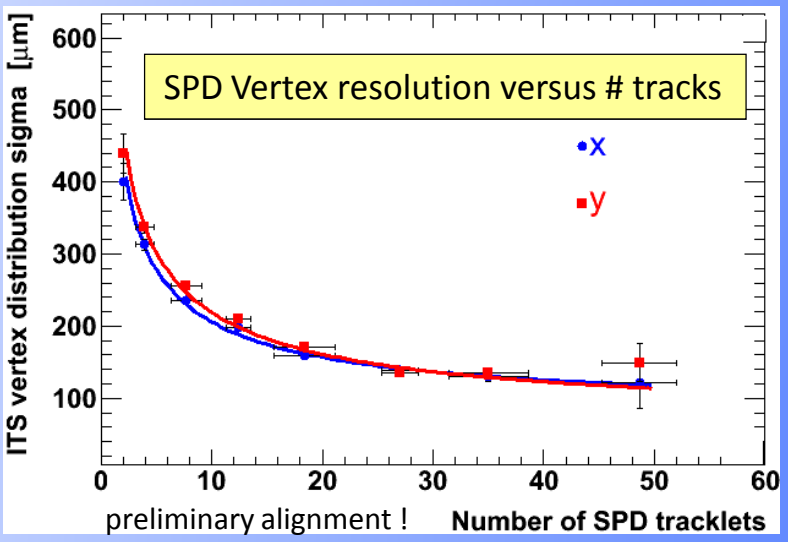
J/Ψ → $\mu^+\mu^-$
Muon Arm

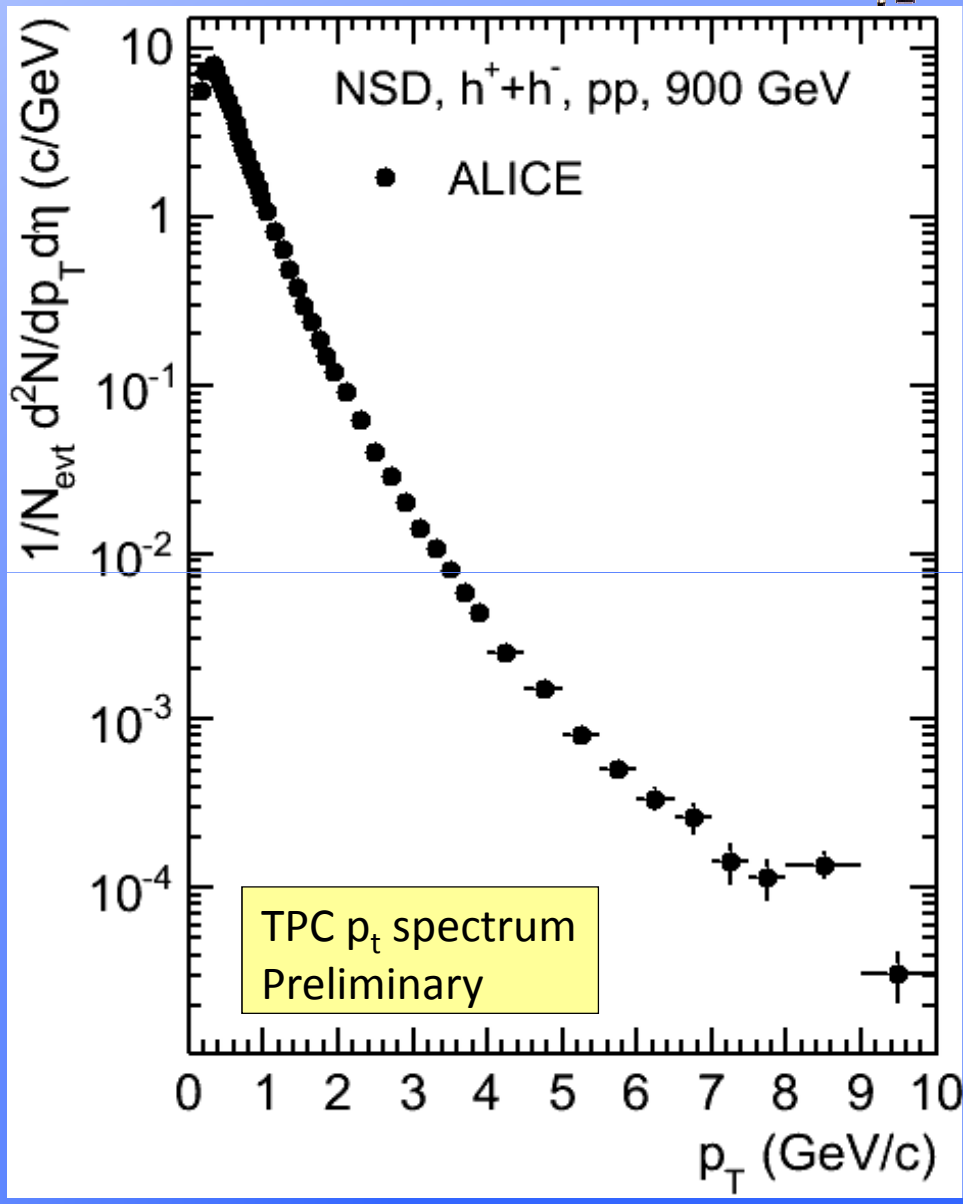




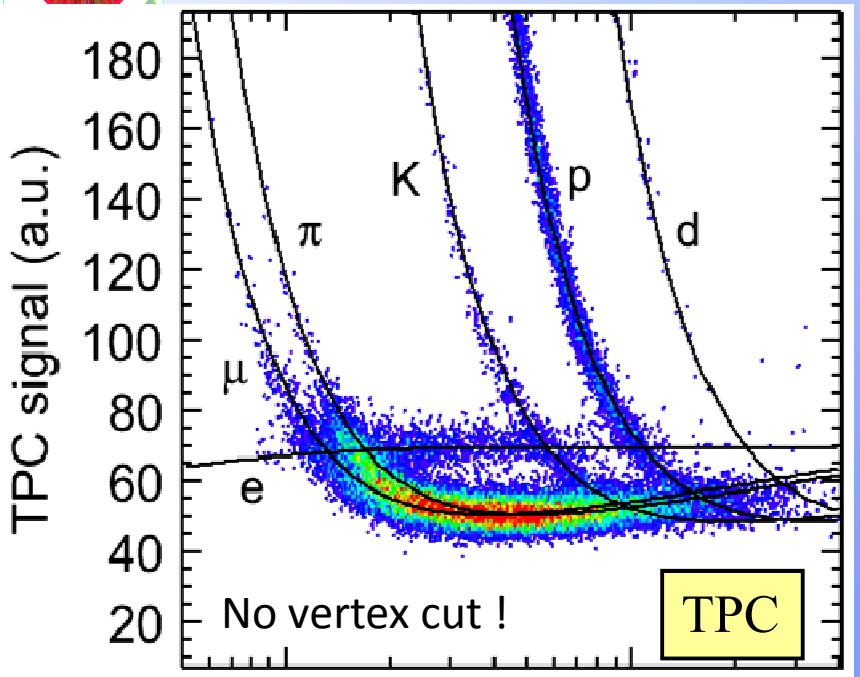
Tracking works beautifully

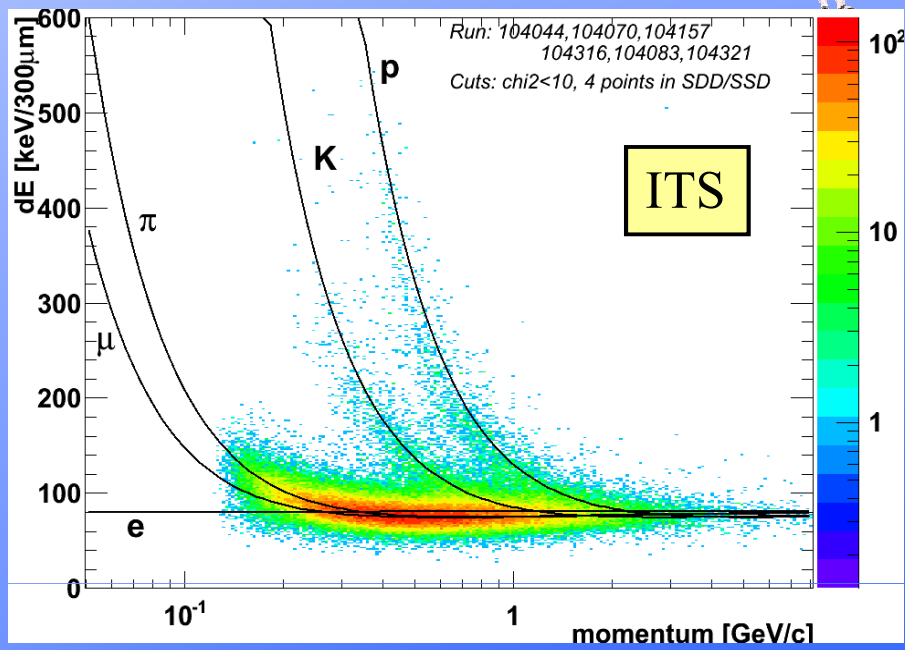


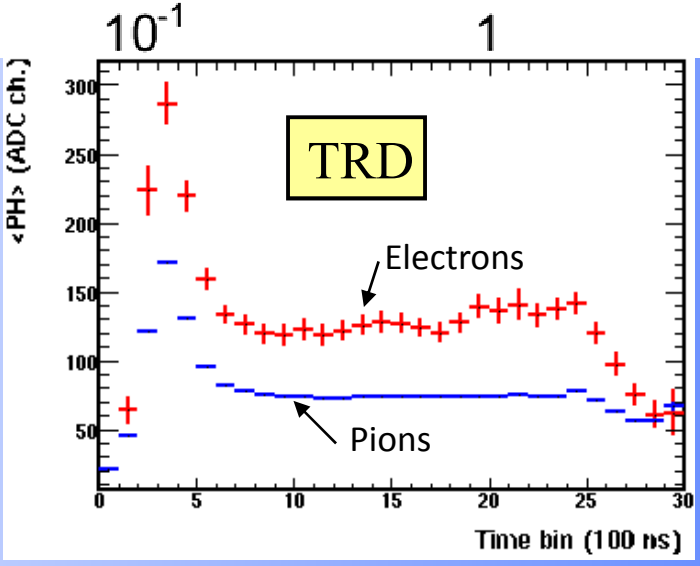


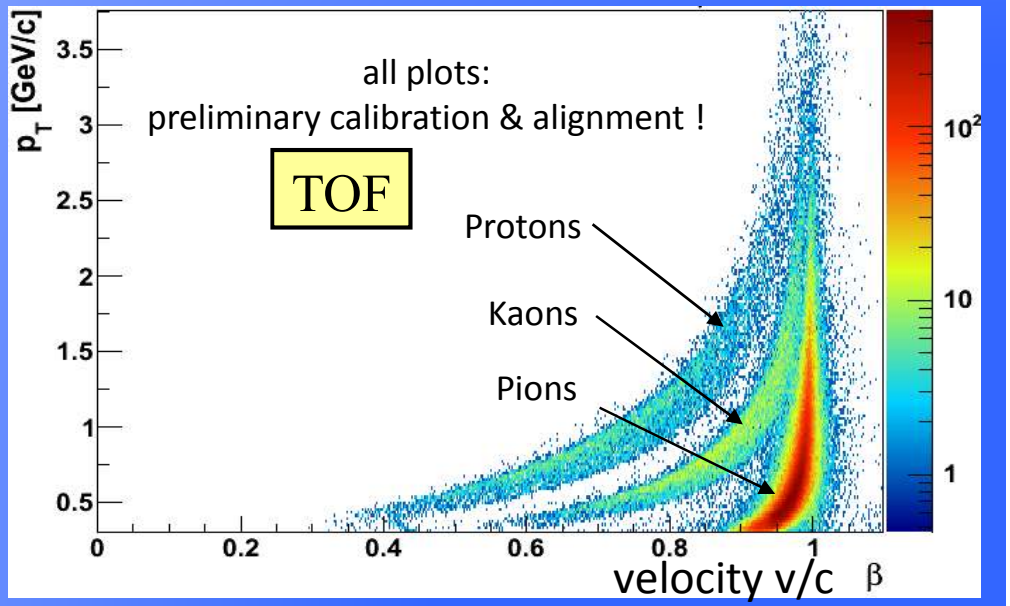


ALICE: excellent PID

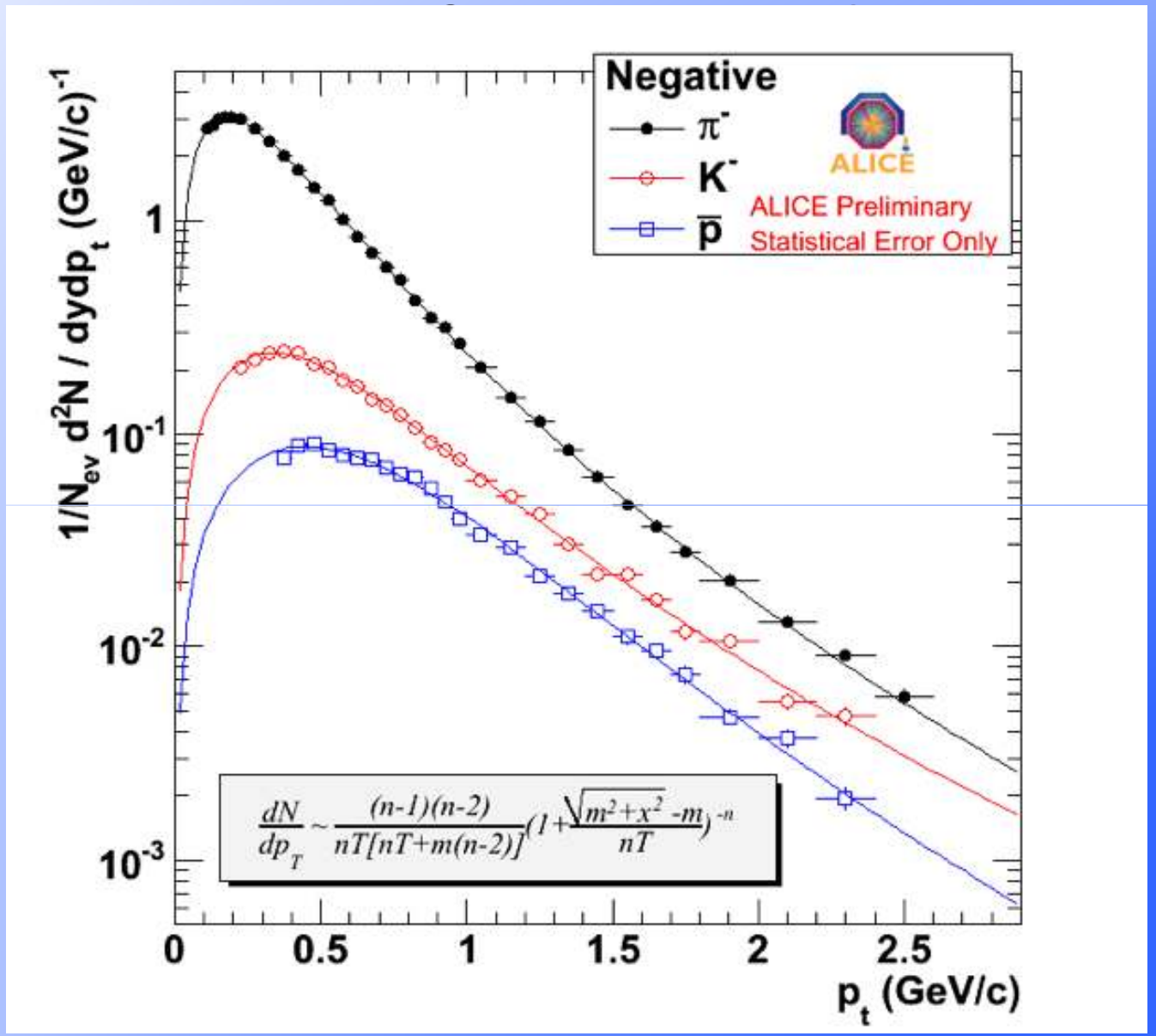




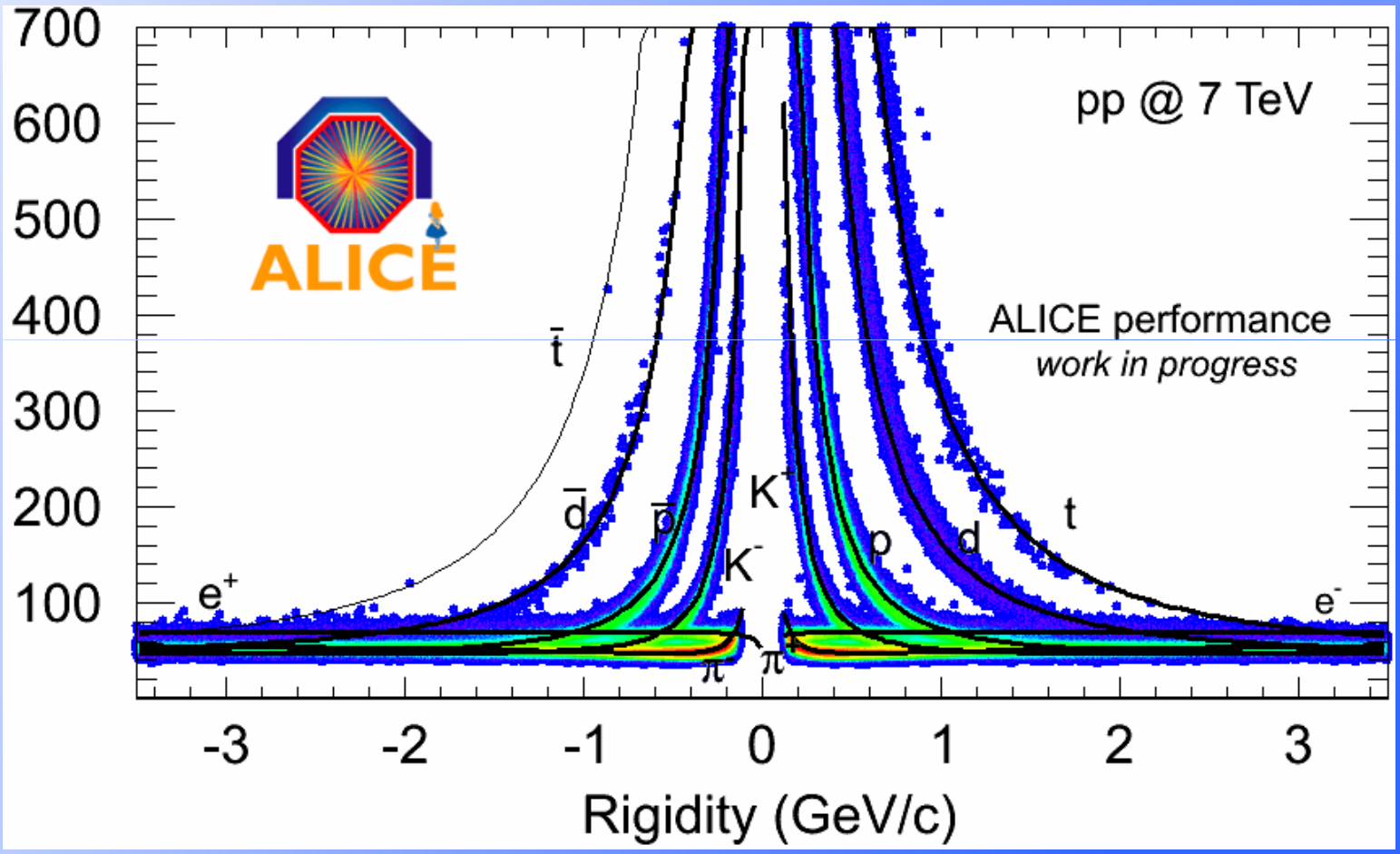




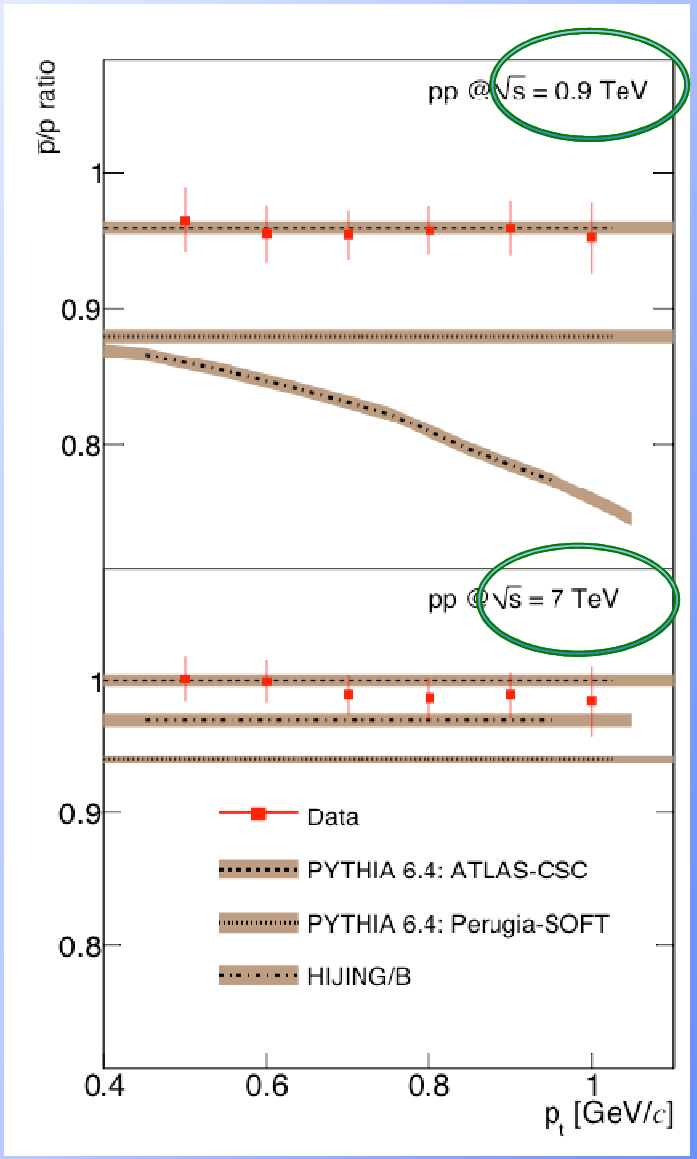
ALICE Identified Particle spectra

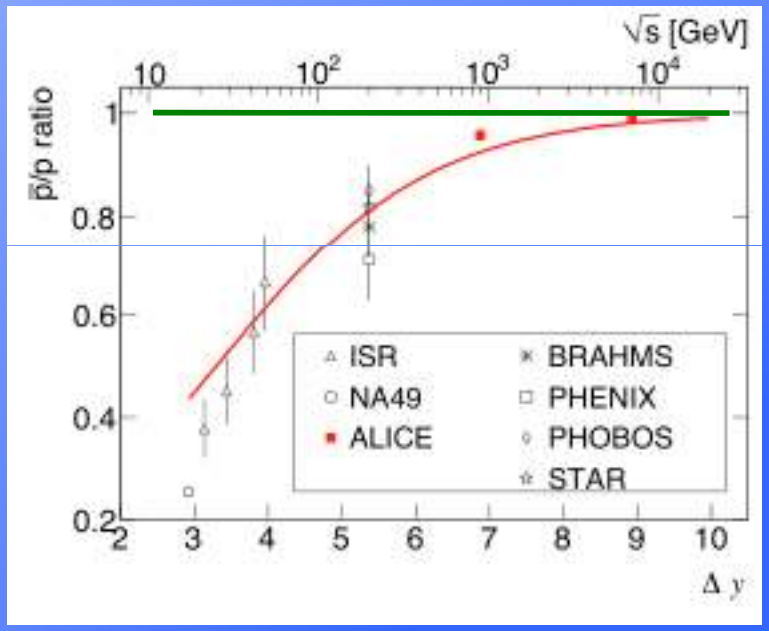


Antinuclei


700
600
500
400
300
200
100
ALICE
pp @ 7 TeV
ALICE performance
work in progress
$\bar{t}$
$\bar{d}$
$\bar{p}$
K^+
K^-
e^+
π
π
p
d
t
e^-
-3
-2
-1
0
1
2
3
Rigidity (GeV/c)

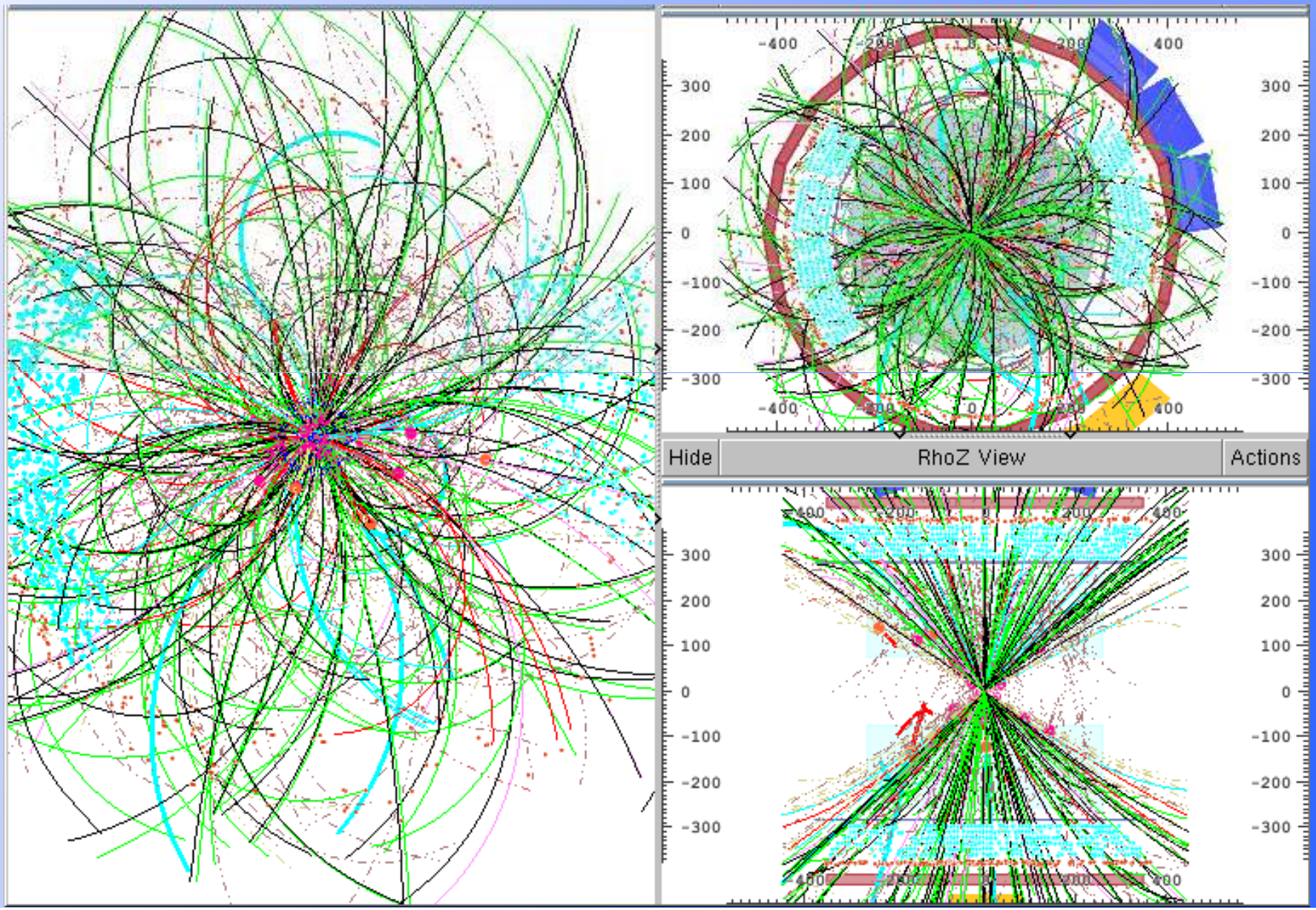
Antiproton/proton ratio at y=0



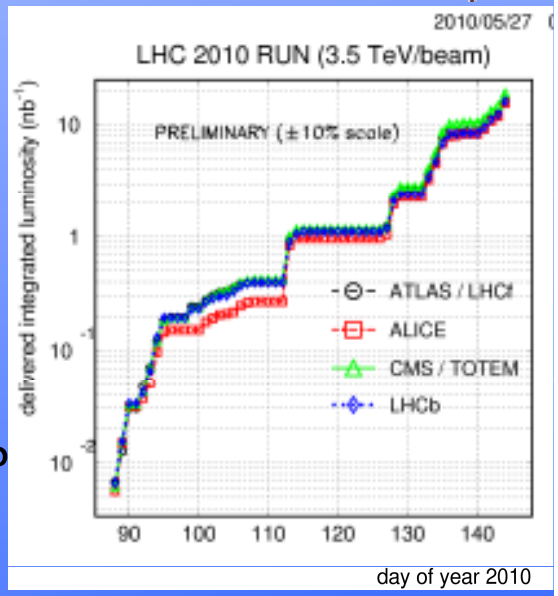


ALICE: Phys. Rev. Lett. 105 (2010)

Also in p+p we see high multiplicities…



Plans



- 2010-11: p+p (7TeV) & Pb+Pb (2.75 TeV.A)
- 2012: shutdown (LHC magnet interconnects)
- 2013-15: p+p (14TeV)+ Pb+Pb (5.5TeV.A), p+A?
- 2016: shutdown Det.upgrades (incl. ALICE)
- 2017-19: p+p (14TeV)+ Pb+Pb (5.5TeV.A), p+A, A+A?
- 2020: shutdown IR quads+det. Upgrades.Higher L.?
- 2021-?: Hard probes program.

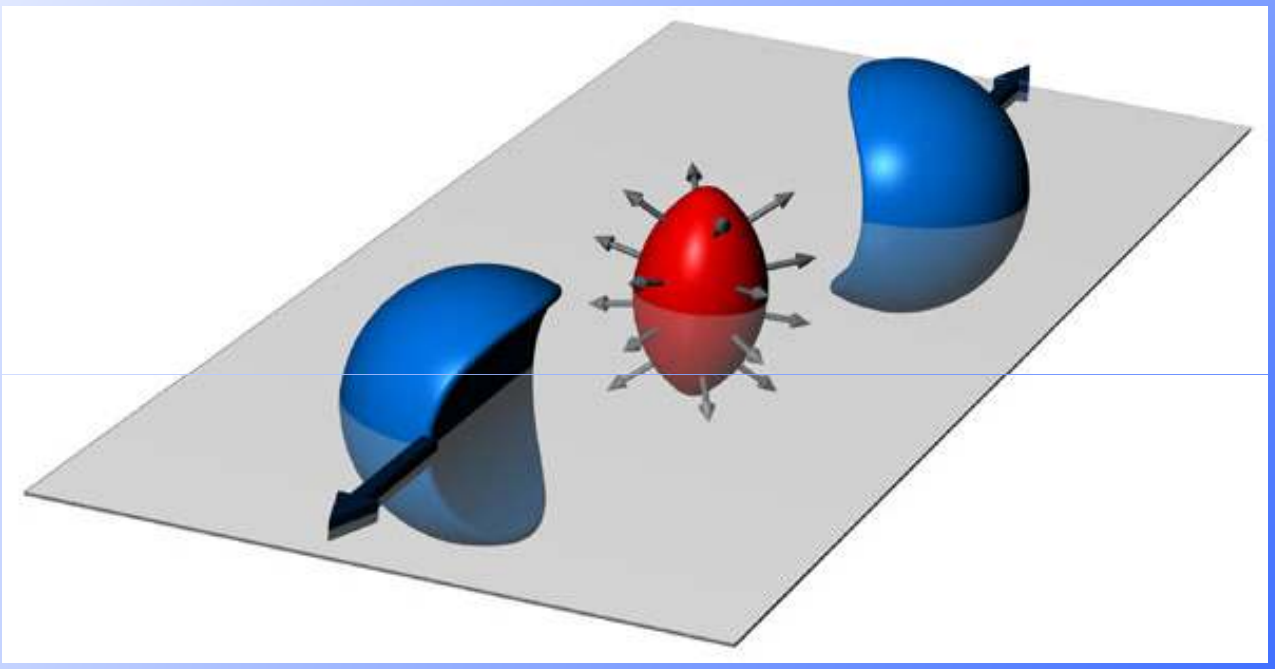
- ALICE upgrades: Inner tracker, VHMPID, Forward calorimeter, …

- ATLAS and CMS: complementary HI programs for multiplicity, flow, hard probes, quarkonia sup, jet physics and quenching, …

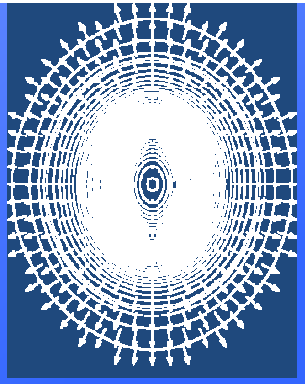
Physics with the Pb+PB run in Nov-Dec 2010

- Elliptic flow: Thermalization, hydrodynamics
- Jet quenching: QGP tomography
- Multiplicity : Gluon Saturation?
- Stopping: Baryon Transport, energy loss
- Direct photons: QGP temperature
- Quarkonia suppression, enhancement
- Heavy Quarks , etc, etc...

Elliptic flow



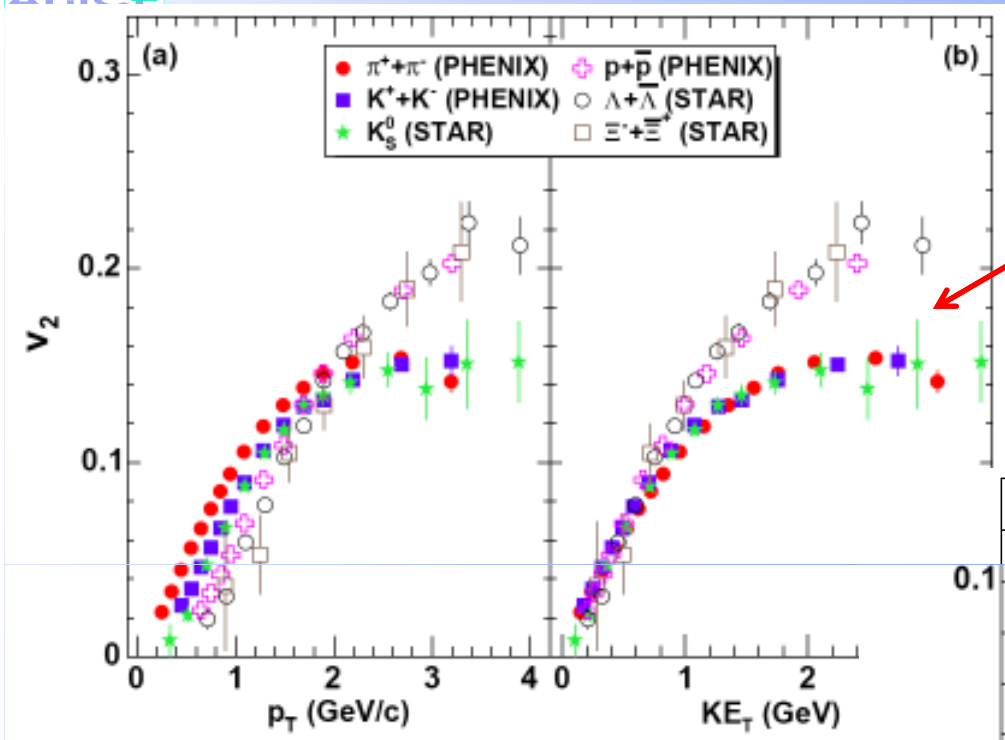
Spatial anisotropy translates into momentum
Anisotropy due to bulk collective motion



$$\frac{Ed^3N}{dp^3} = \frac{d^3N}{p_T dp_T dy d\phi} = \frac{d^3N}{2\pi\, p_T dp_T dy}[1+2v_1\cos(\phi-\Phi_R)+2v_2\cos 2(\phi-\Phi_R)+\cdots]$$

Hydro models reproduce v_2. Require short interaction times and large cross sections => Liquid

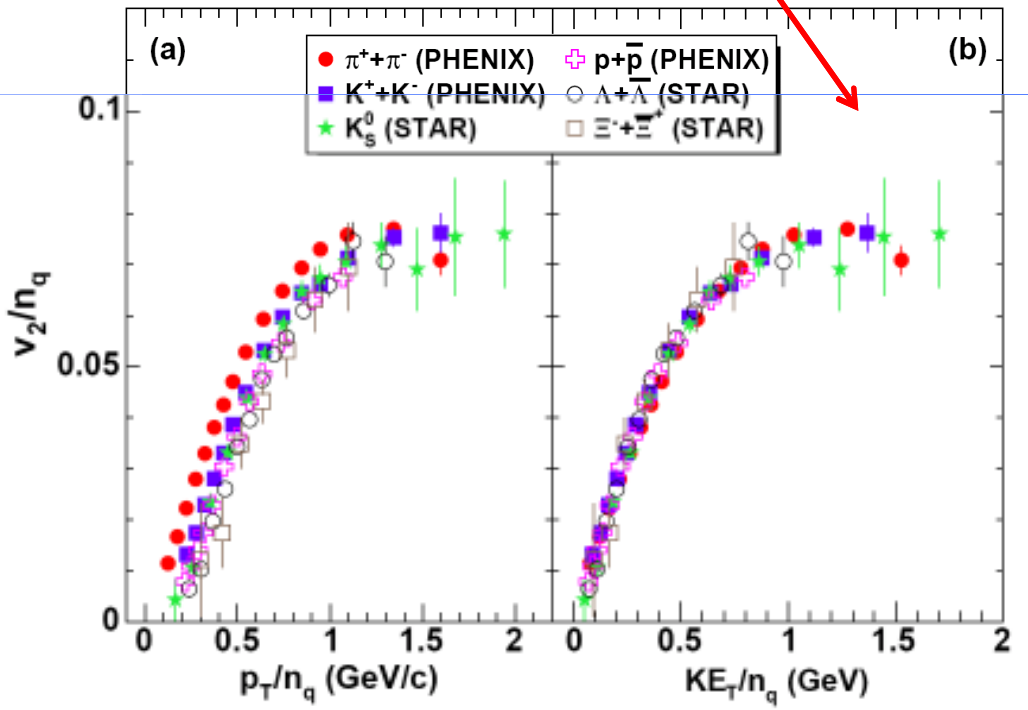
Elliptic flow (v_2) appears universal after constituent quark scaling



STAR: PRC**72** (2005) 014904

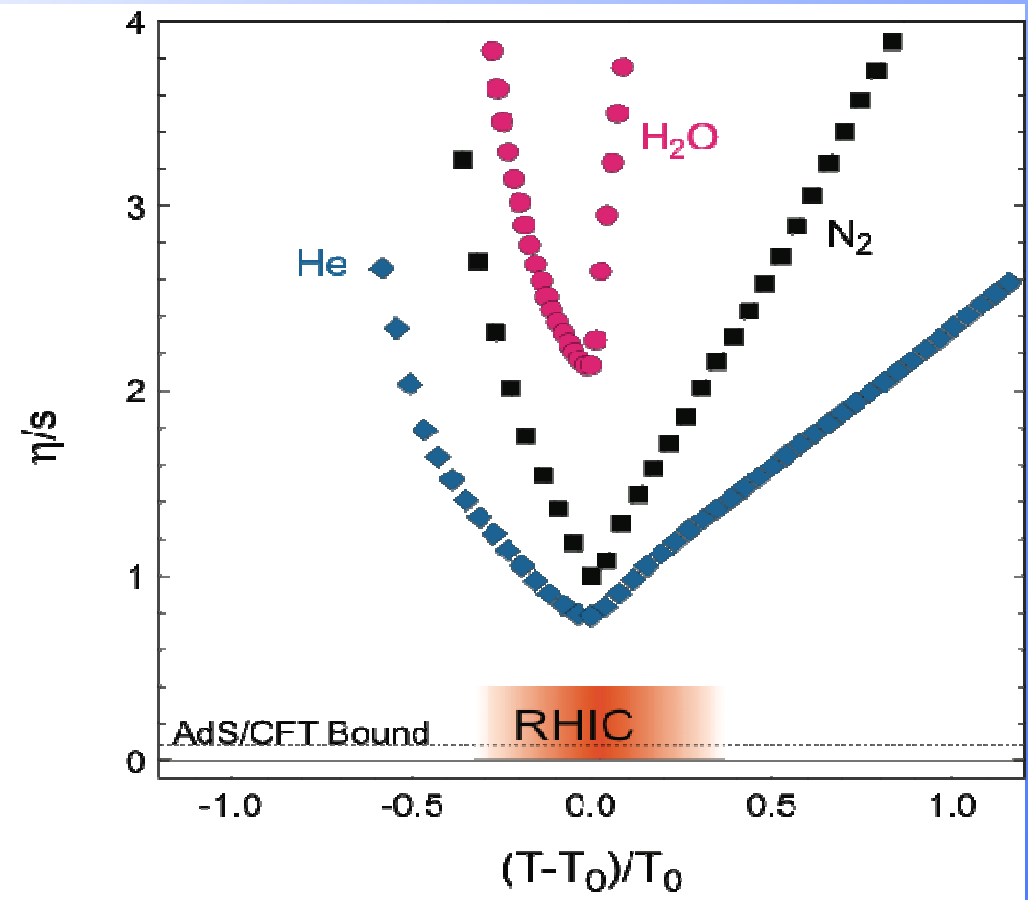
Different Meson and Baryon flow falls on universal curve after scaling by n(quarks)

PHENIX :PRL**98** (2007) 162301



$$KE_T \equiv \sqrt{m^2 + p_T^2}$$

Flow in Heavy Ion Collisions may show lowest possible viscosity



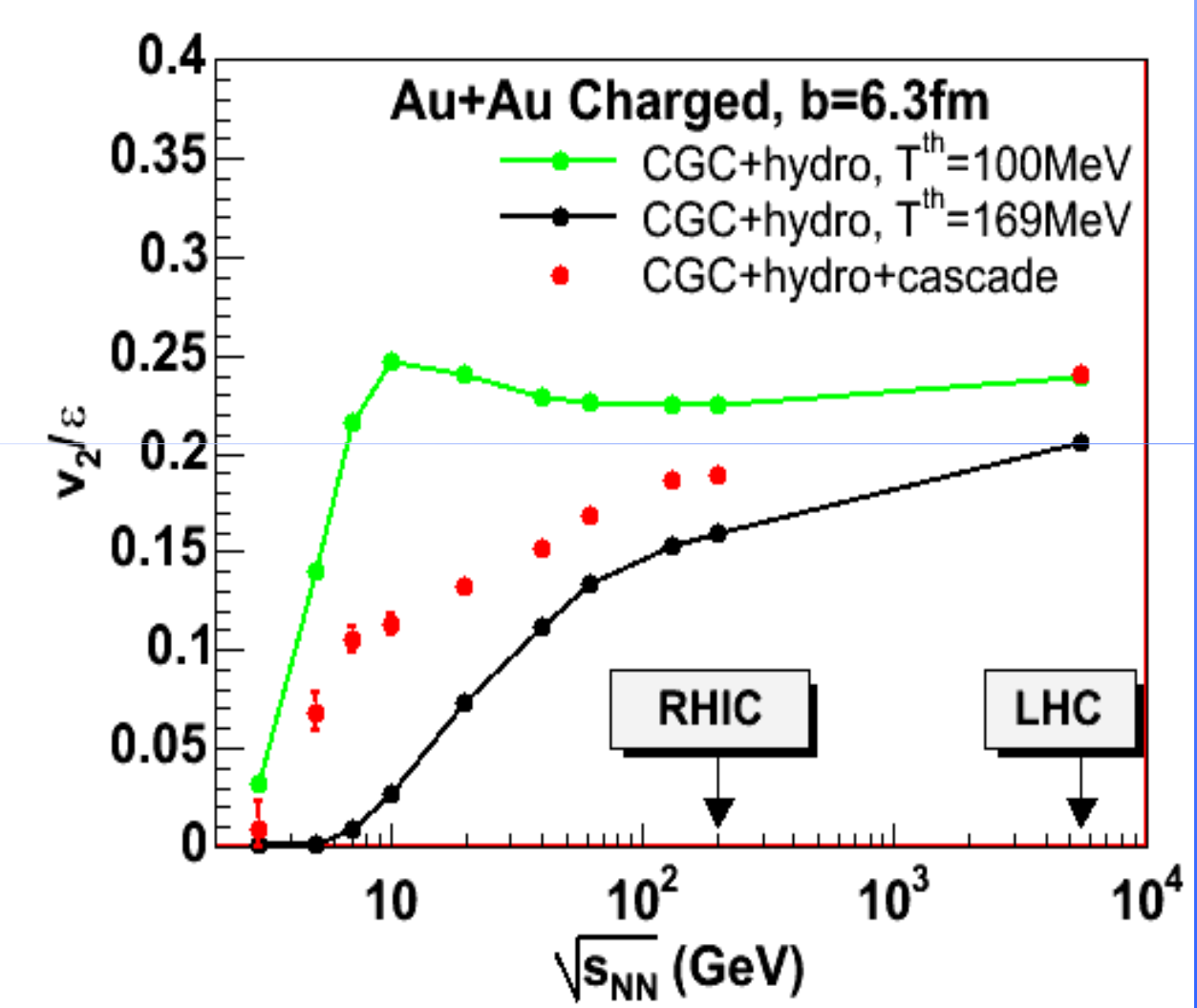
Duality between string theory in AdS metric and Conformal Field theory.

Suggest that lowest η/s =1/4π, i.e close to RHIC results.

Expect that partonic matter at LHC may have higher viscosity even if closer to ideal gas phase.

Kotvun, Son, Starinets, PRL **94** (2005) 111601

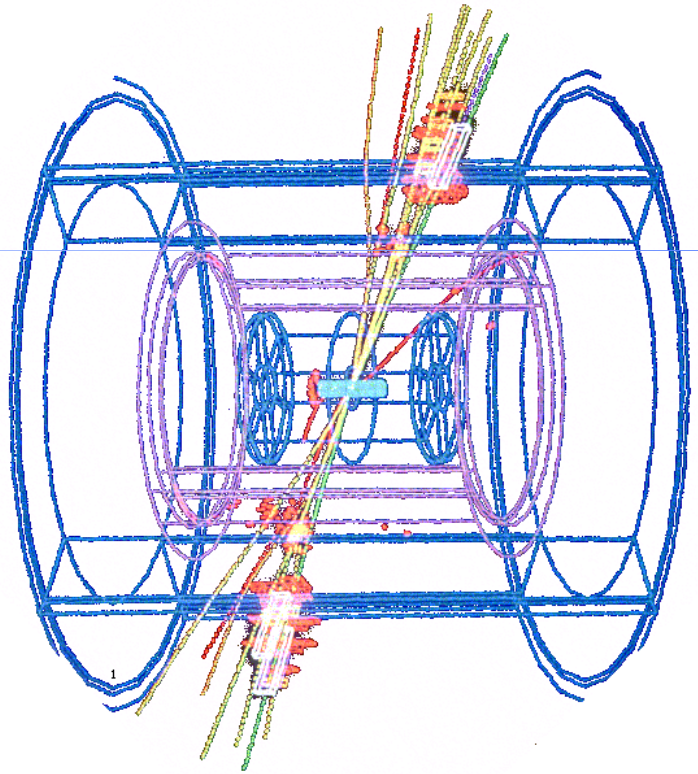
Elliptic flow predictions for LHC



Elliptic flow at LHC is expected to be completely dominated by partonic phase.

Hirano et al.

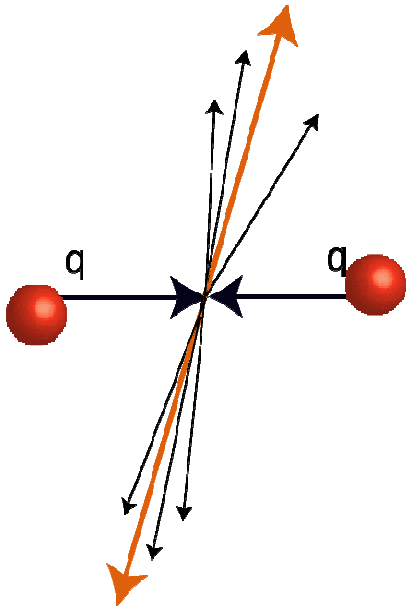
Hard scattering - Jets



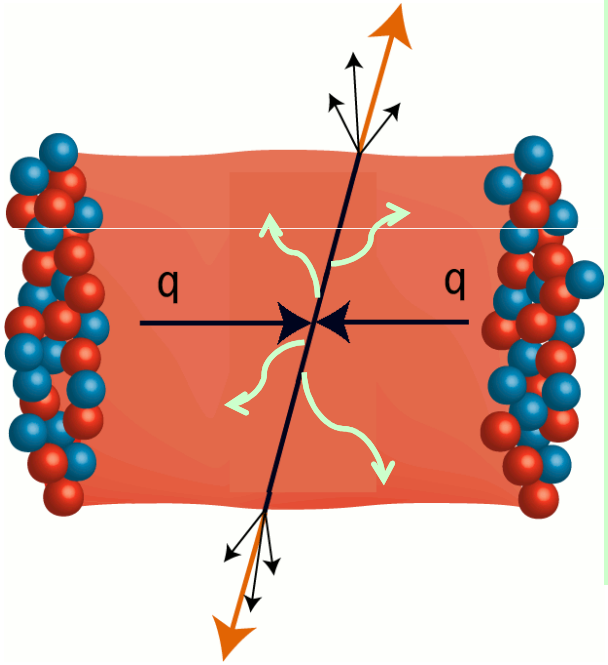
UA5

Jet suppression: p+p vs. A+A collisions

p+p

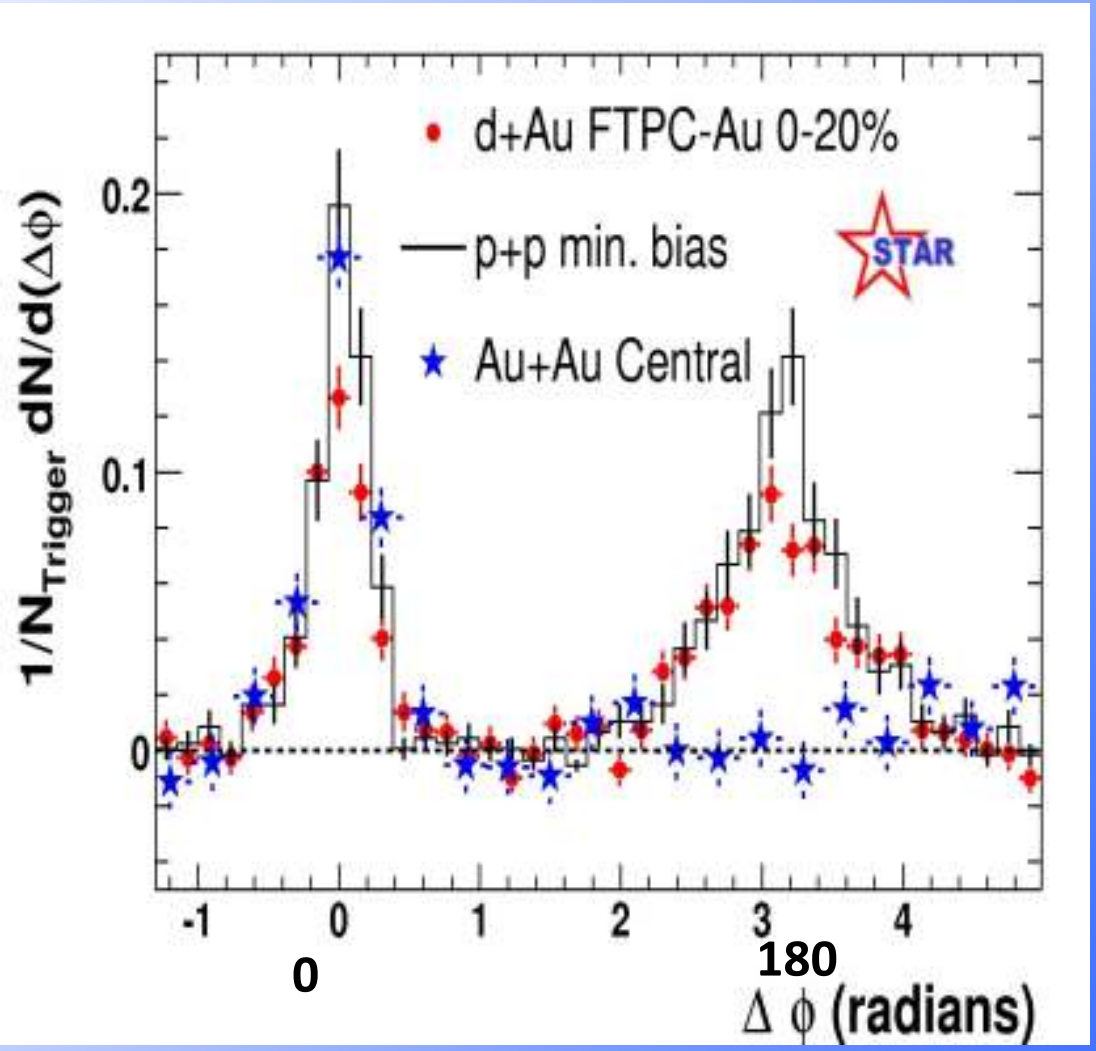


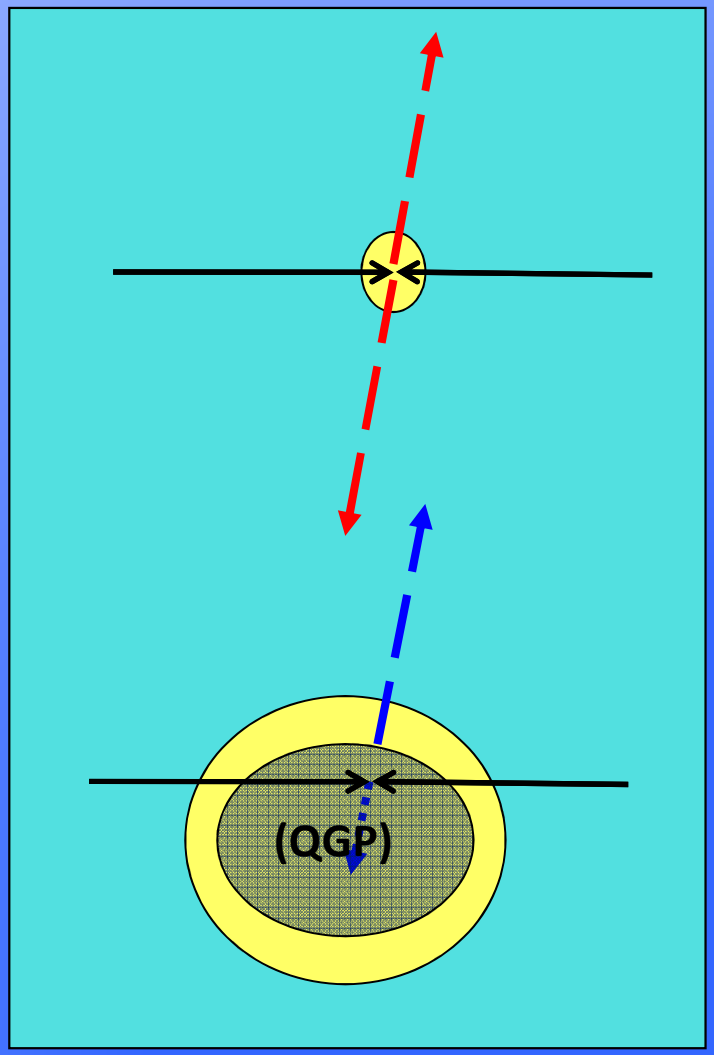
Au+Au



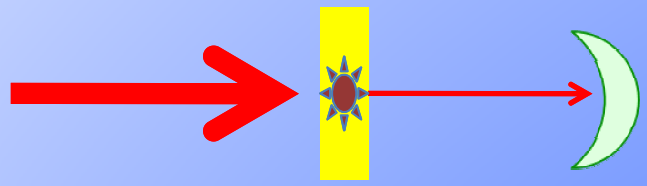
Jet may be modified or suppressed due to interaction of scattered parton with medium, e.g. via gluon bremsstrahlung.

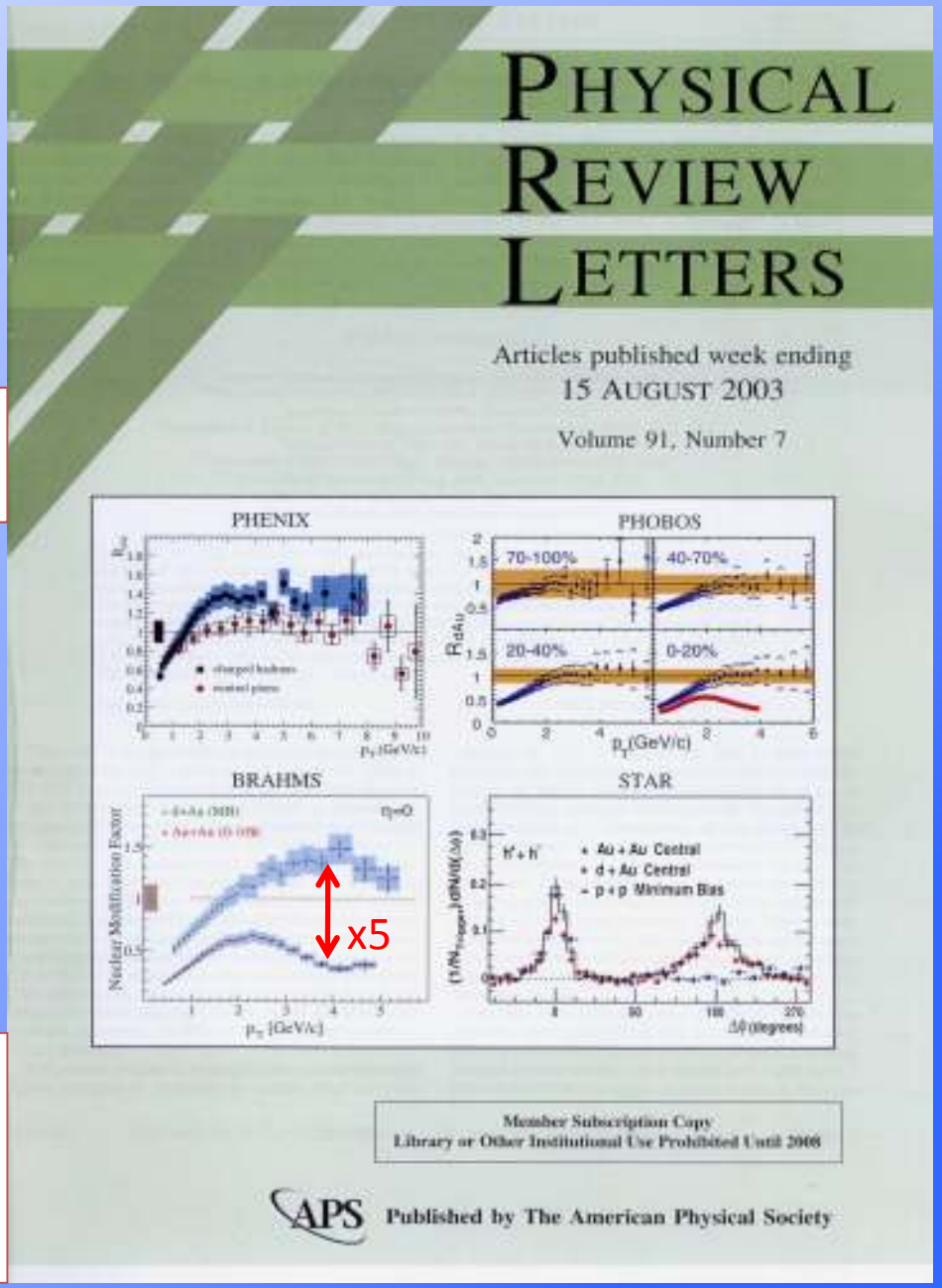
Jet suppression at RHIC





Tomography

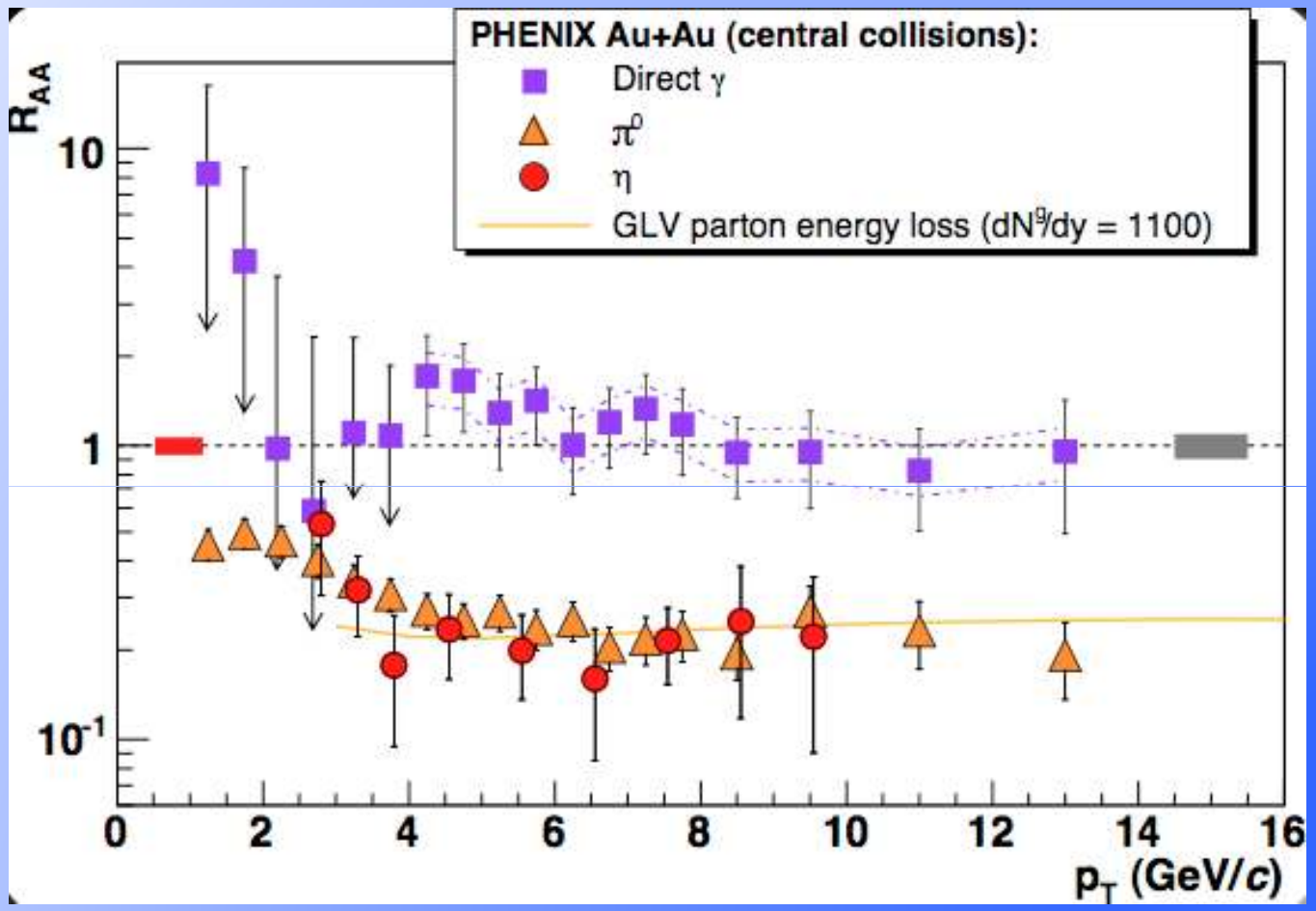




Jet Quenching
Phys. ReV. Lett. 91 (2003)

=> **liquid Quark-Gluon medium** (sQGP).
See RHIC White papers
Nucl. Phys. A.757 (2005) 1-27

Direct photons validate binary collisions scaling



Photons

Mesons

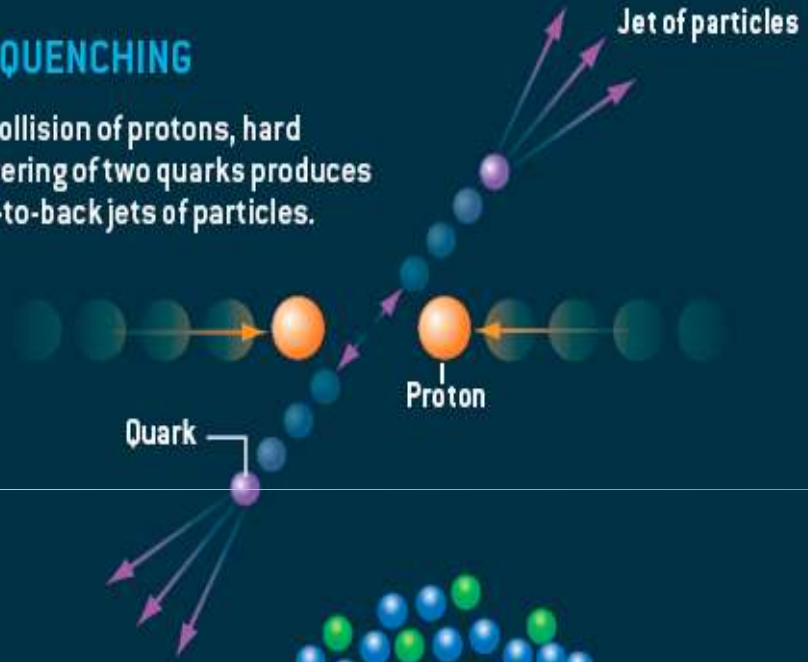
Nuclear modification factor: $R_{AA} = (dN/dp_t(A+A)) \ / \ (Nbin * dN/dp_t(p+p))$

EVIDENCE FOR A DENSE LIQUID

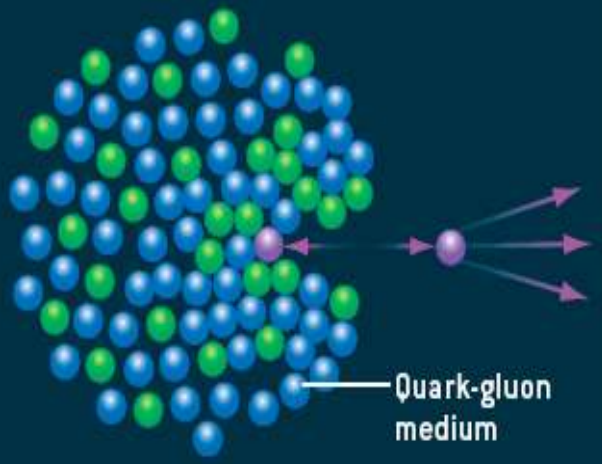
Two phenomena in particular point to the quark-gluon medium being a dense liquid state of matter: jet quenching and elliptic flow. Jet quenching implies the quarks and gluons are closely packed, and elliptic flow would not occur if the medium were a gas.

JET QUENCHING

In a collision of protons, hard scattering of two quarks produces back-to-back jets of particles.

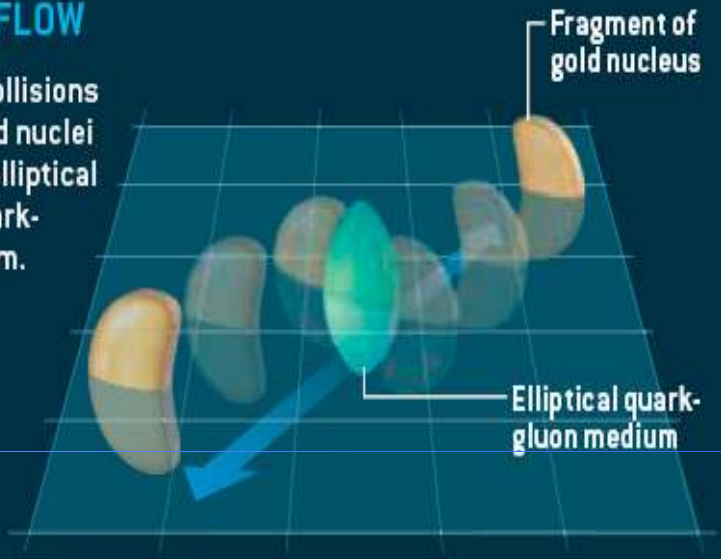


In the dense quark-gluon medium, the jets are quenched, like bullets fired into water, and on average only single jets emerge.

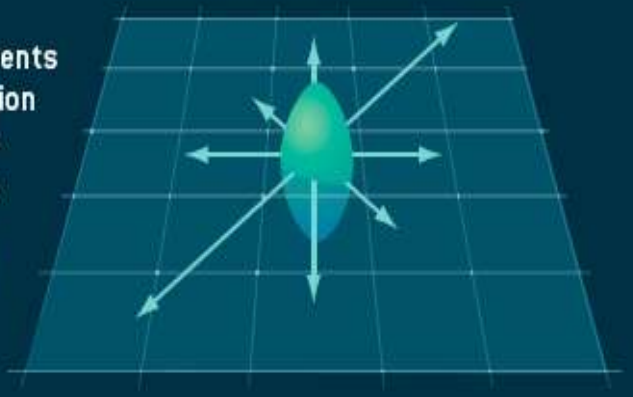


ELLIPTIC FLOW

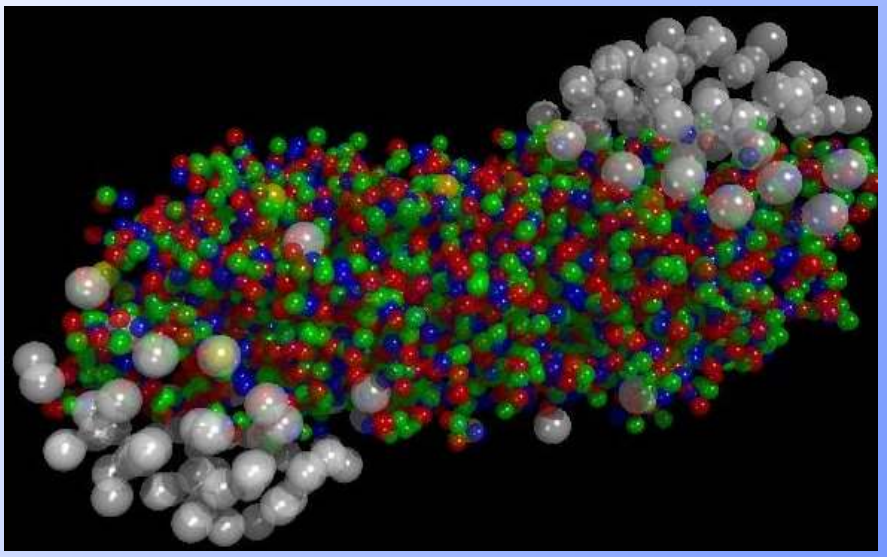
Off-center collisions between gold nuclei produce an elliptical region of quark-gluon medium.

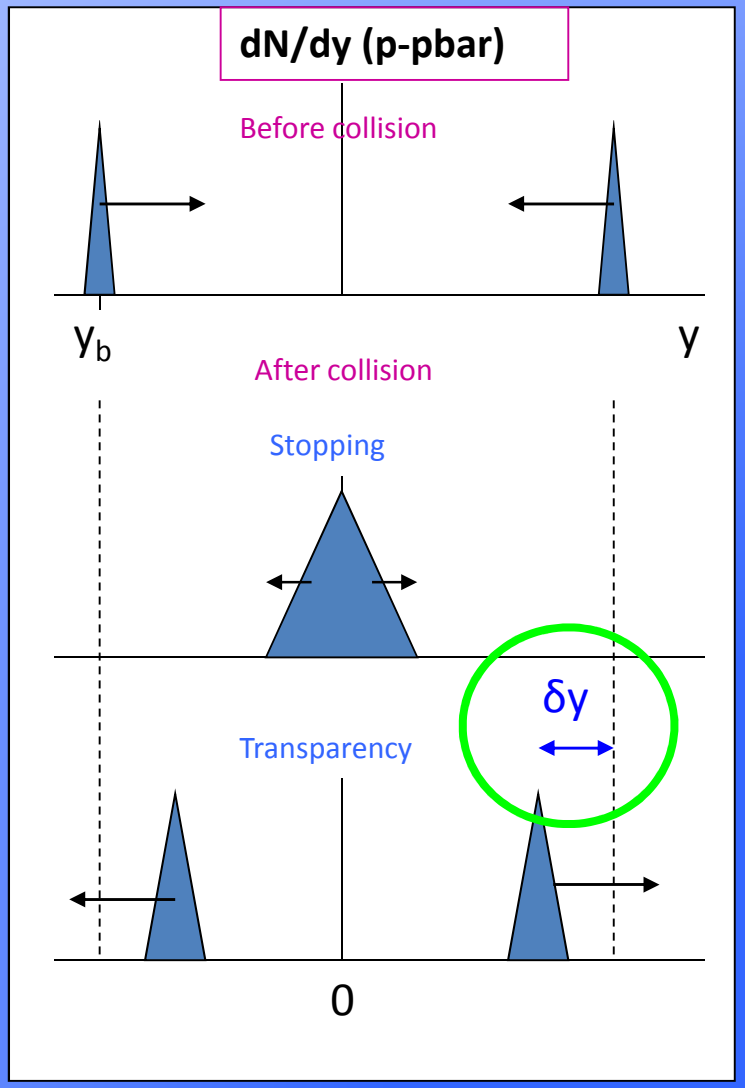


The pressure gradients in the elliptical region cause it to explode outward, mostly in the plane of the collision (*arrows*).



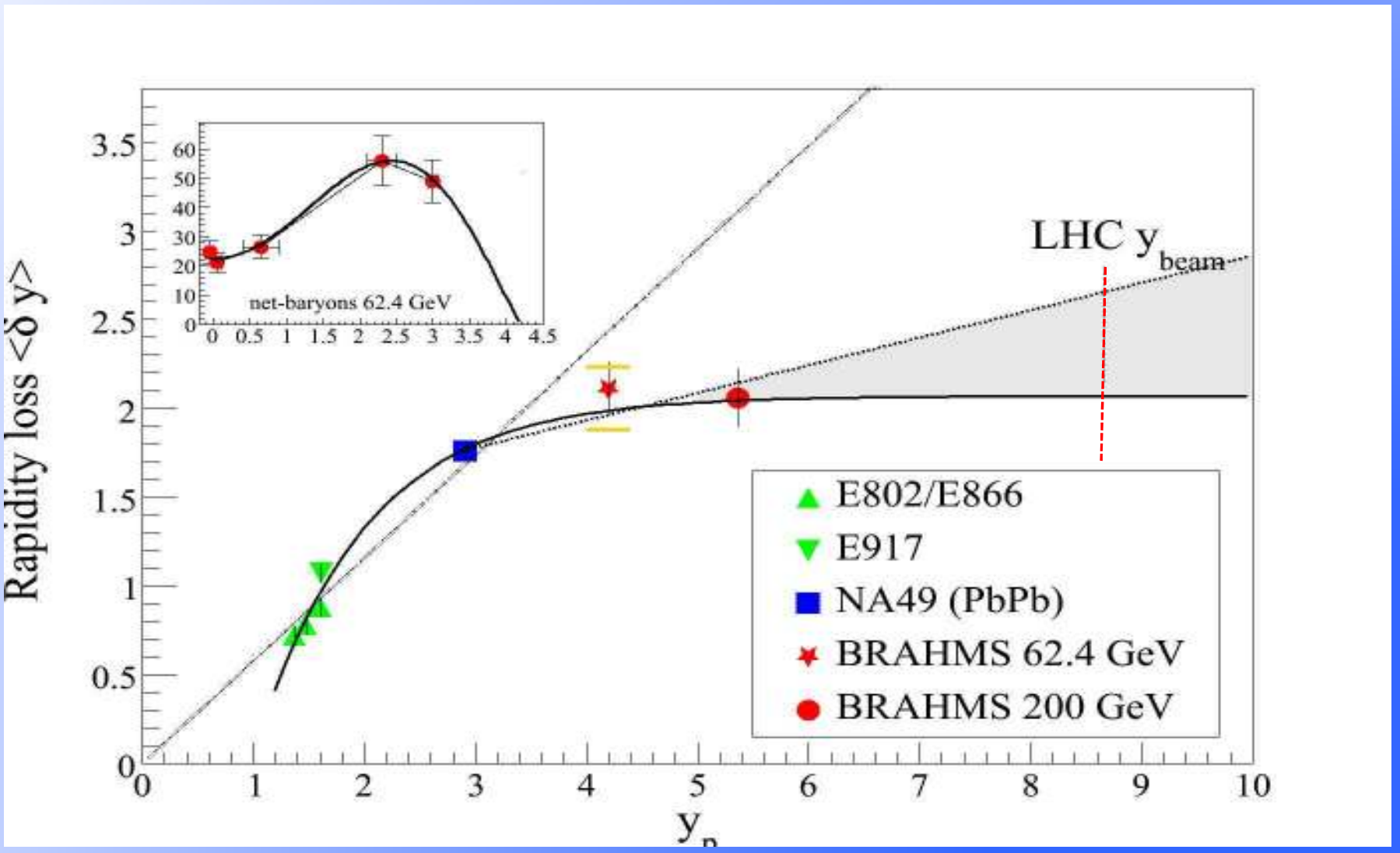
Rapidity shift: a measure of beam energy loss

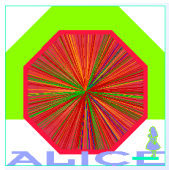




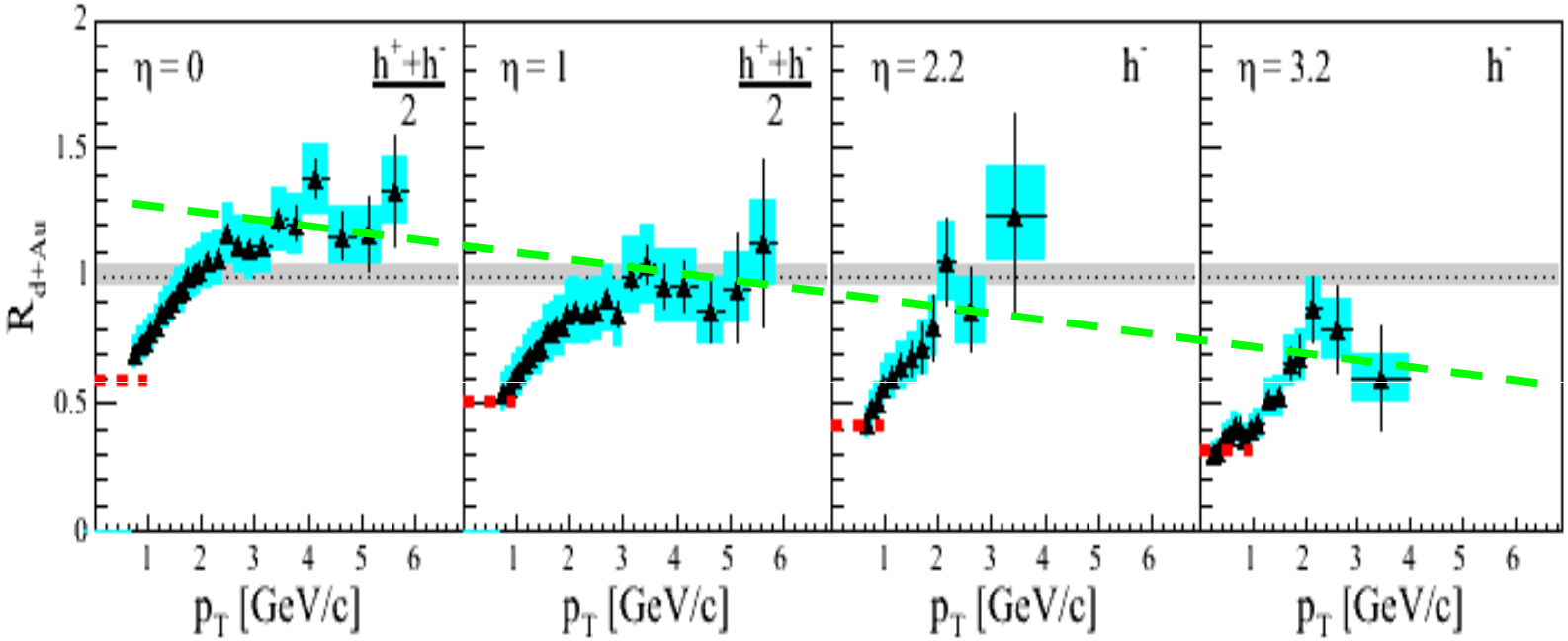
$E = m_t \cosh(y)$

Systematics of Nuclear Stopping vs. Rapidity or E_{beam}





At RHIC (d+Au @ 200 GeV)
Jet suppression sets in from y=0 to y=3.2



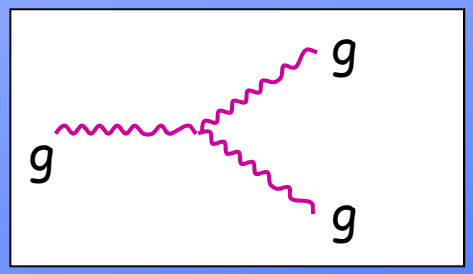
BRAHMS collaboration PRL 93 (2004) 242303

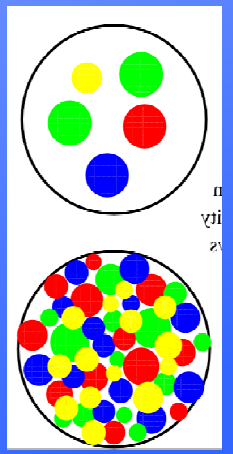
No suppression expected in d+Au. Particle production limited by other means?

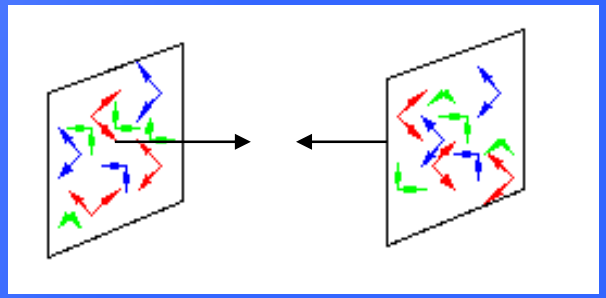
Why?
Color Glass Condensate?

- CGC = Color Glass Condensate: a primer
- Nucleons contain gluons.
- In QCD gluons can split into lower momentum gluons.
- This will lead to an infrared catastrophe for low momentum gluons
- Low momentum gluons have large wavefunctions.
- When gluon density gets large, gluons fuse again
- This leads to a saturation of the gluon density
- Nucleons and Nuclei may be seen as a condensate of low momentum gluons
- This is the BEC of the strong interaction.

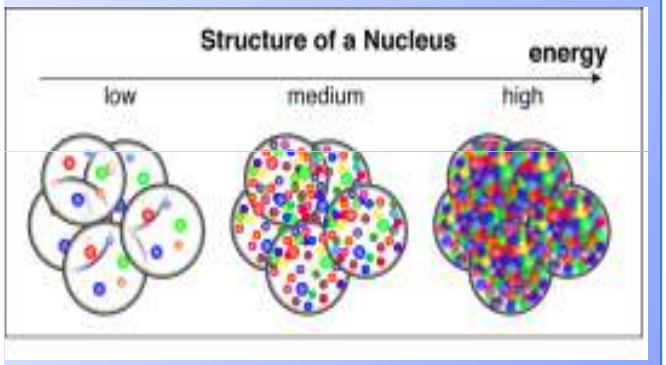
- Particle production arises mainly from gluon-gluon collisions
- Consequently, the number of produced particles may be limited

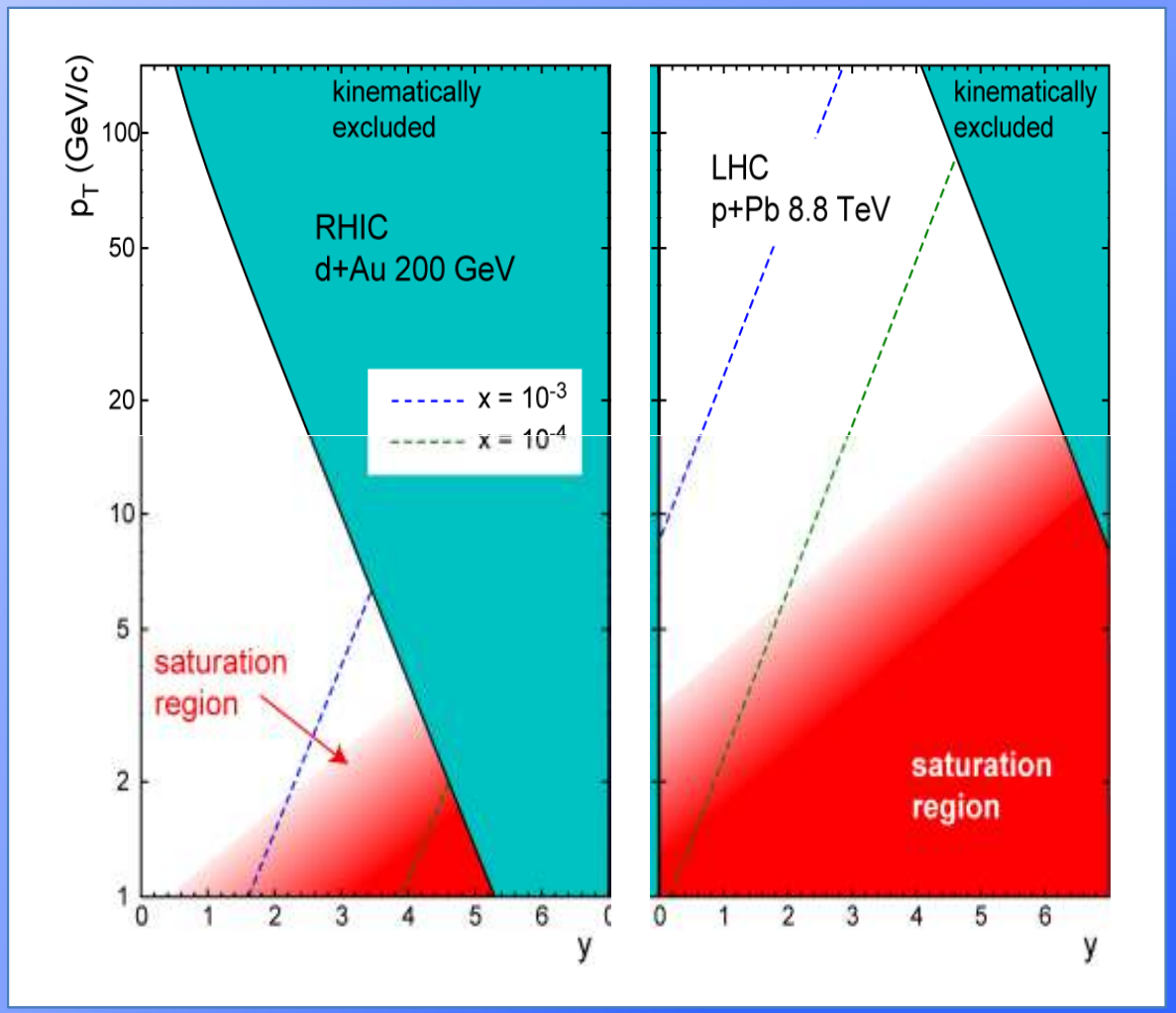






Gluon Saturation at LHC





Thanks
& Looking forward to much great new physics in the years to come!