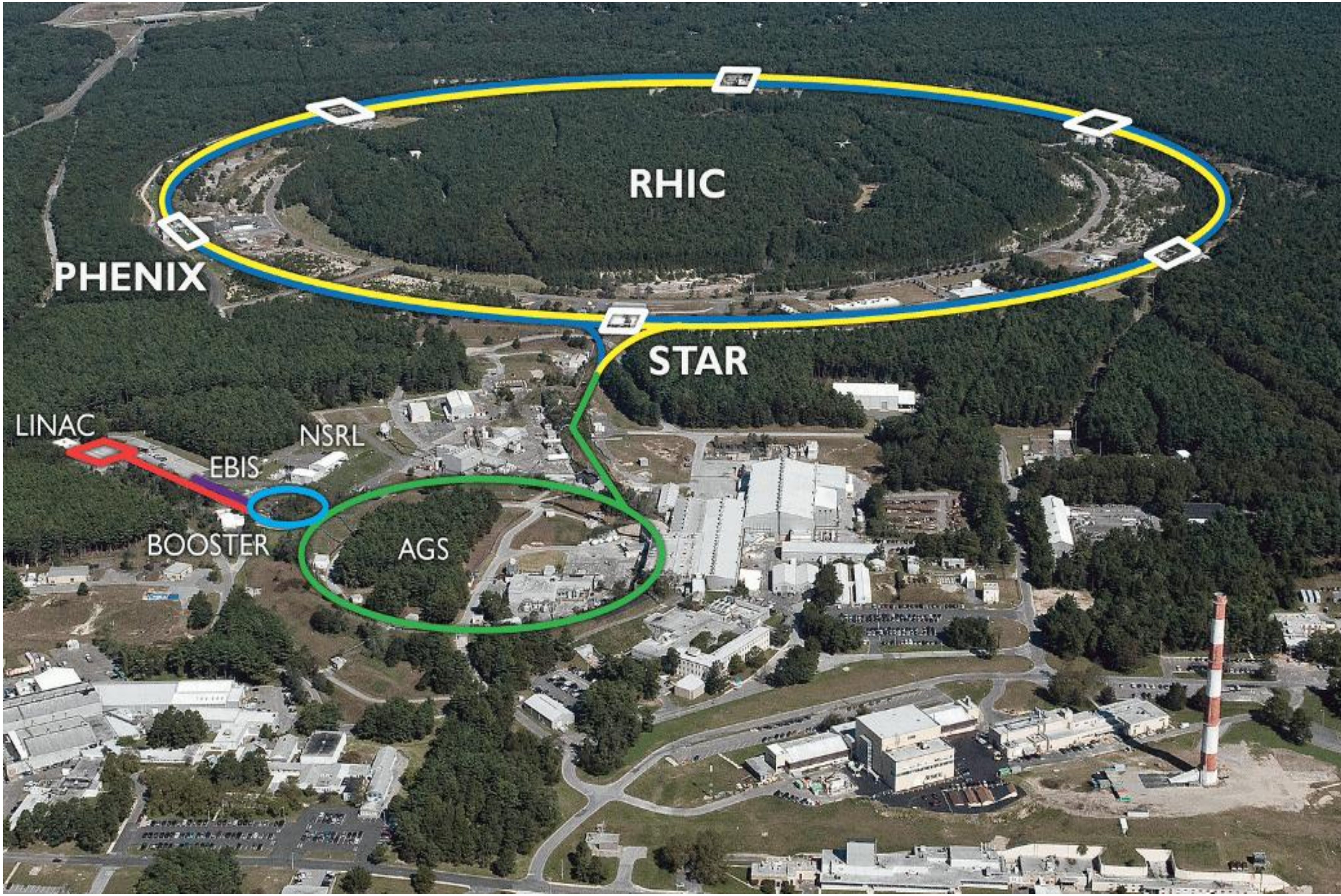
PHENIX detector upgrade
PHENIX → sPHENIX

NPD RAS session, in Protvino, RUSSIA

Nov. 7, 2013

V.Babintsev, IHEP

for the PHENIX Collaboration


RHIC
PHENIX
STAR
LINAC
NSRL
EBIS
BOOSTER
AGS

PHENIX detector (RHIC)

Philosophy :

- ✓ High rate capability and granularity at cost of acceptance
- ✓ Good mass resolution & particle ID
- ✓ Trigger for rare events

$\pi0/\gamma/\eta$ **detection (central and forward)**

Electromagnetic Calorimeter, MPC

$\pi+/\pi-$ **(central)**

Drift Chamber

Ring Imaging Cherenkov Counter

J/ψ (central and forward)

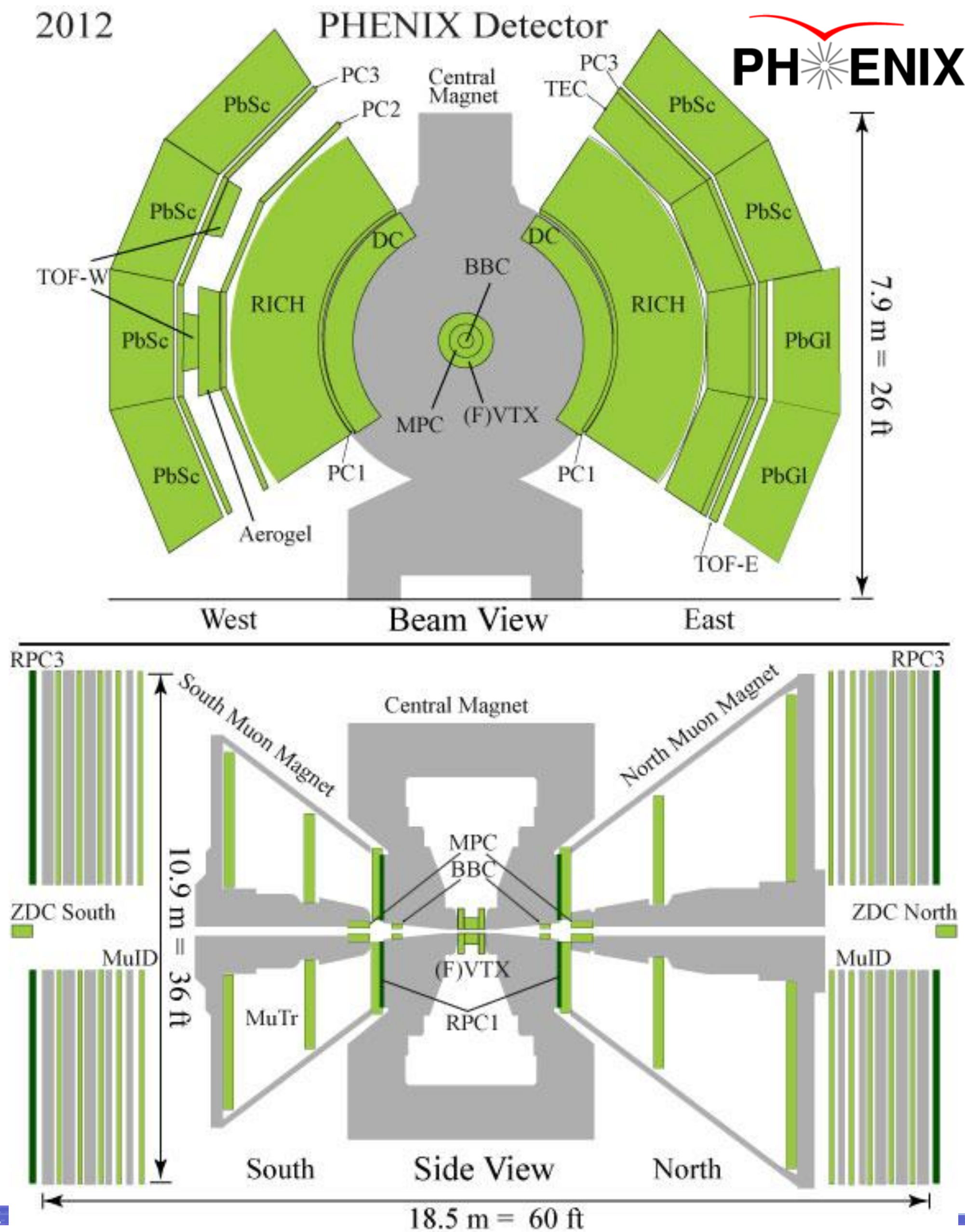
Muon Id/Muon Tracker

Resistive Plate Chambers (RPC)

Relative Luminosity

Beam Beam Counter (BBC)

Zero Degree Calorimeter (ZDC)



main results of PHENIX (RHIC)

PHENIX

The new form of QCD was discovered -

dense and strongly-interacting quark-gluon plasma or sQGP

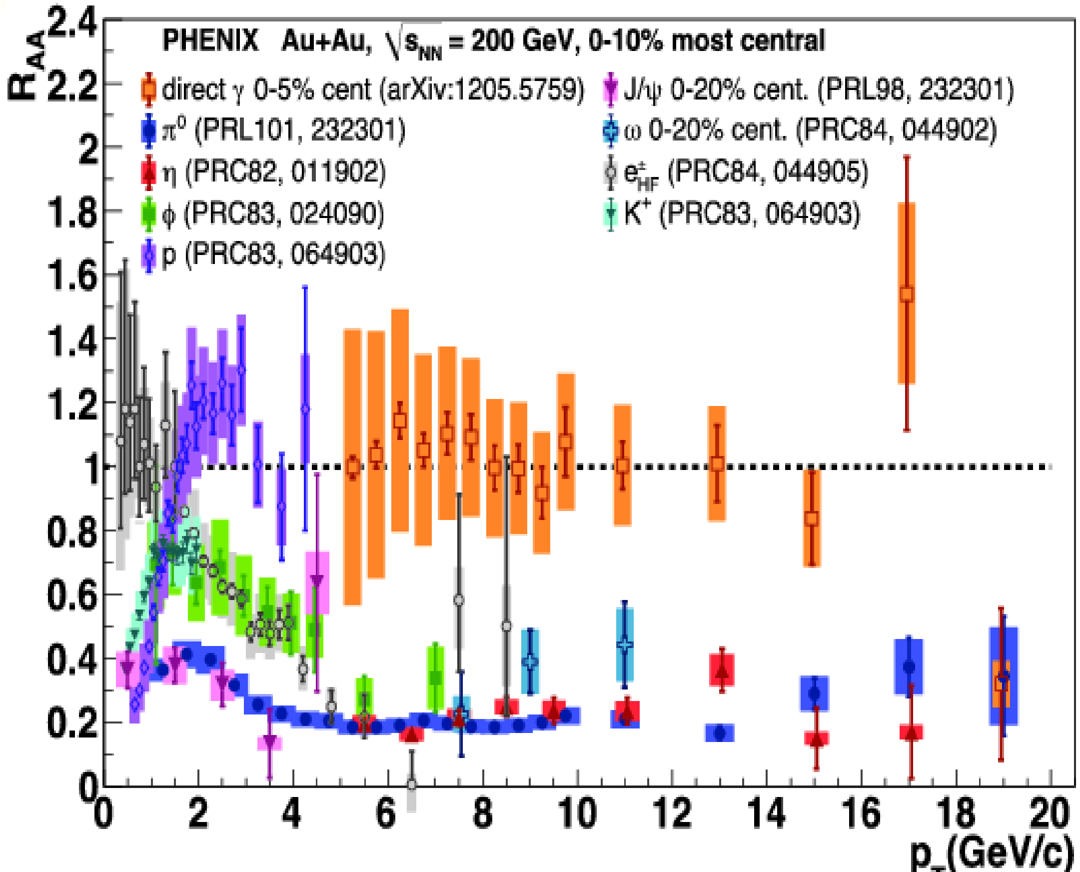
published NPA750 (2005) 1-171,1-283 :

- strong suppression of high PT hadrons in central ions collisions (jet quenching) and absence of suppression in dAu collisions
- strong anisotropic flow – elliptic flow v2(PT) of azimuthal distribution
- anomalously large proton and anti-proton yields at high PT in ions collisions
- low viscosity and high opacity

sQGP matter behaves as a nearly perfect relativistic fluid

Status of R_{AA} in AuAu at $\sqrt{s_{NN}}$=200 GeV 2013

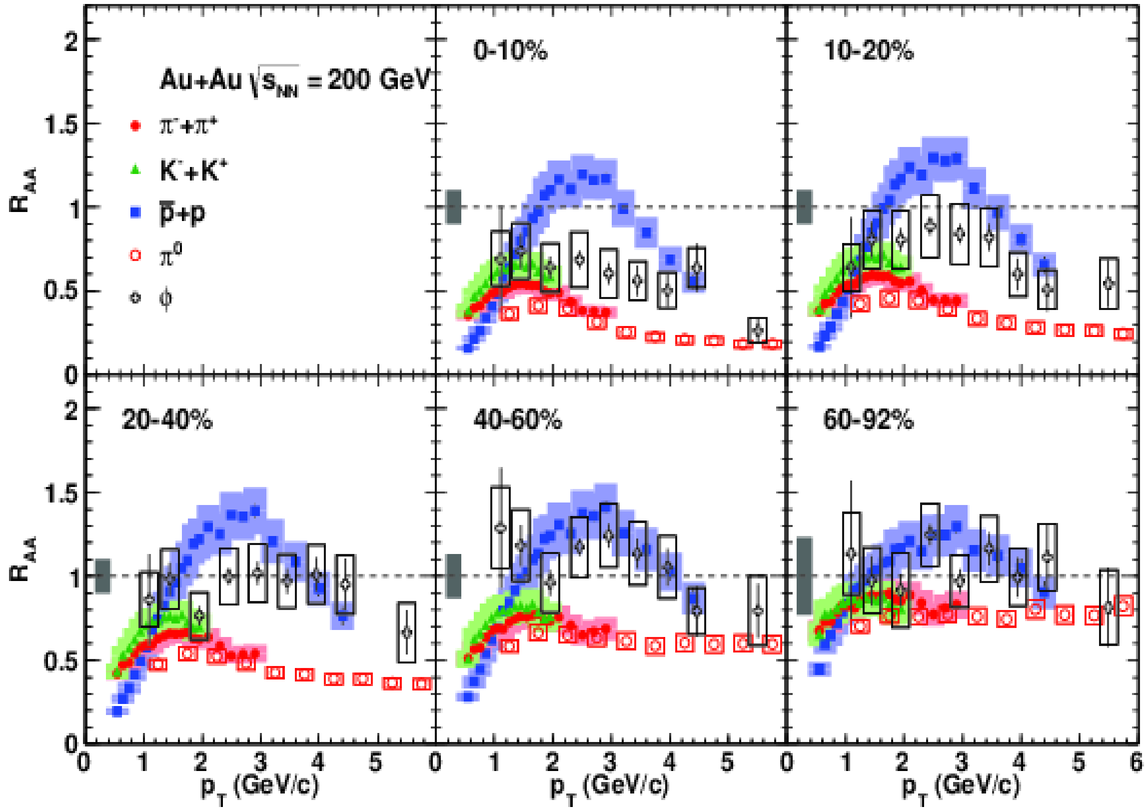
PHENIX



particle ID is crucial: different particles behave differently

Notable are that ALL particles are suppressed for p_T>2 GeV/c (except for direct-γ), even electrons from c and b quark decay; with one notable exception: the protons are enhanced-(baryon anomaly)

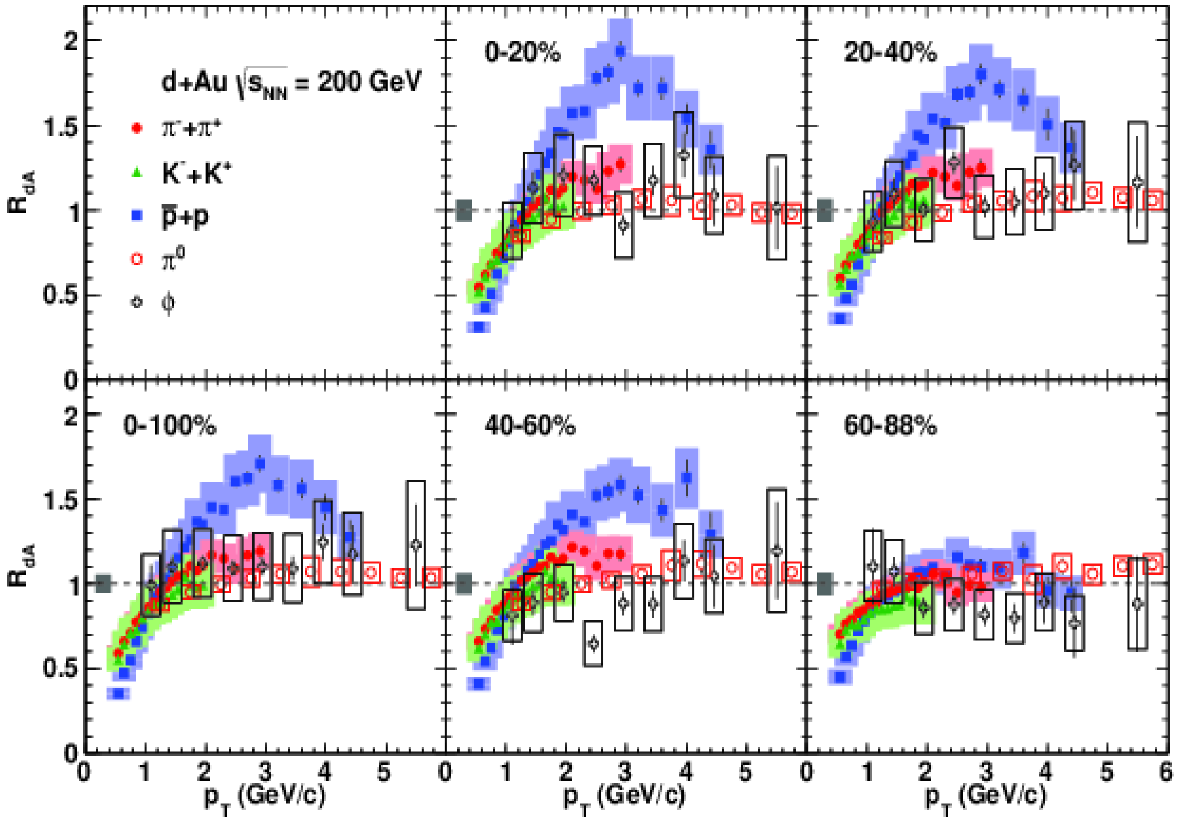
R_{AA} of $\pi/K/p$ for different centralities



arXiv:1304.3410

- Pions and kaons have clear and monotonic centrality dependence, protons do as well with the exception of the most peripheral
- Peripheral R_{AA} for protons still shows appreciable modification

R_{dA} of $\pi/K/p$ for different centralities



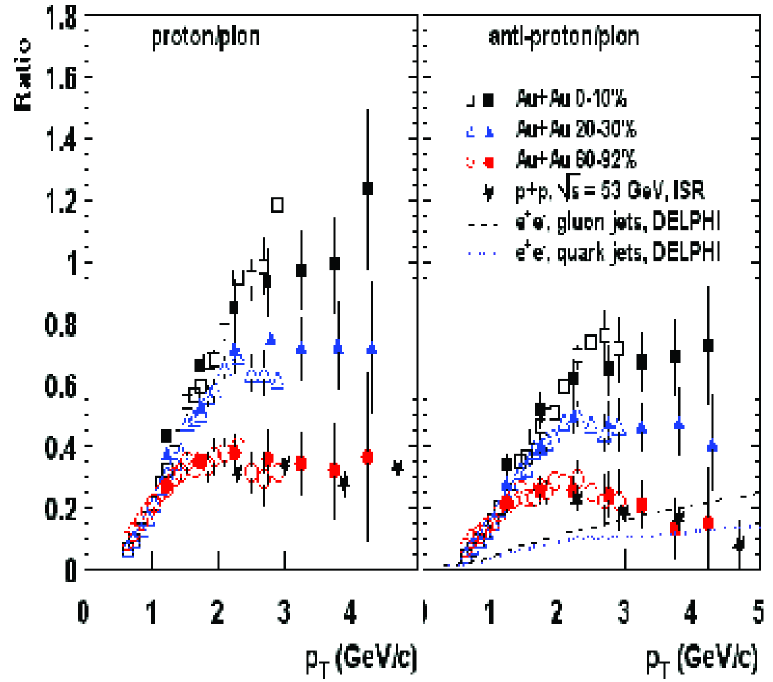
arXiv:1304.3410

- Strong centrality dependence for protons
- Minimal centrality dependence for pions and kaons, consistent within uncertainties

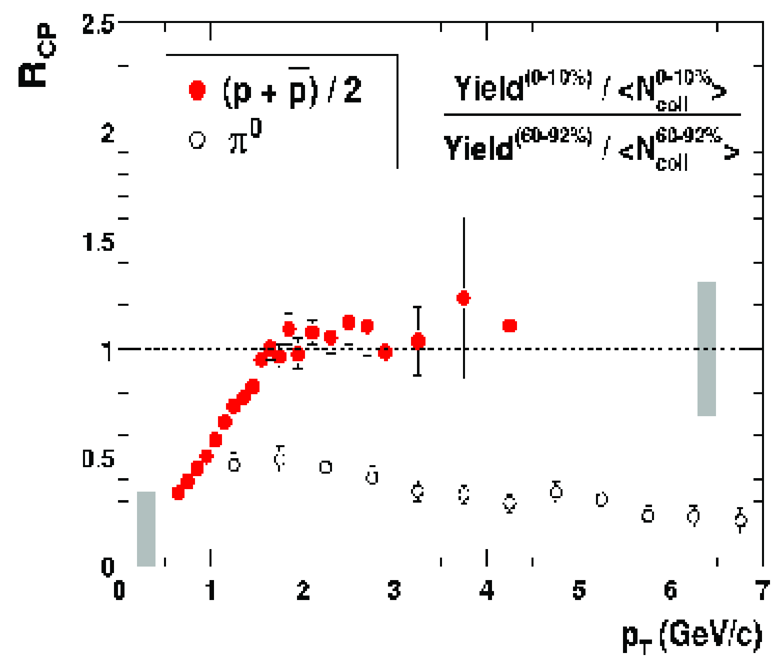
Motivation: the baryon ”anomaly”

Au+Au @ 200 GeV

p/π ratios



R_{CP}

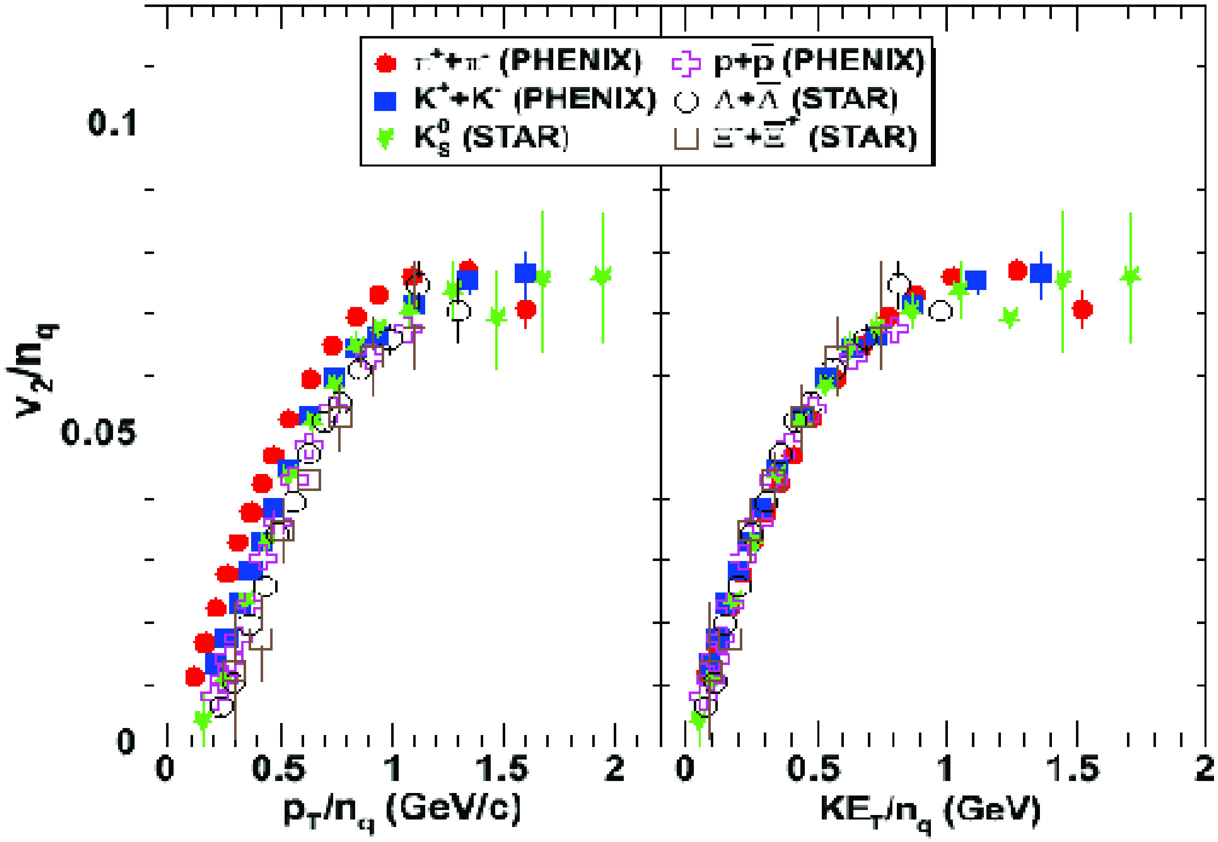


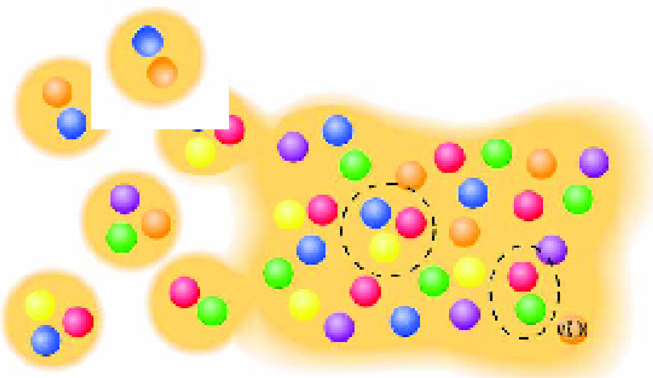
Phys. Rev. Lett 91, 172301 (2003)

- Pions are suppressed in central Au+Au events at 200 GeV
- No suppression seen for 2-4 GeV/c protons
- The suppression patterns depend on particle species

Quark number Scaling

New PHENIX article on the scaling properties of elliptic flow: nucl-ex/0608033



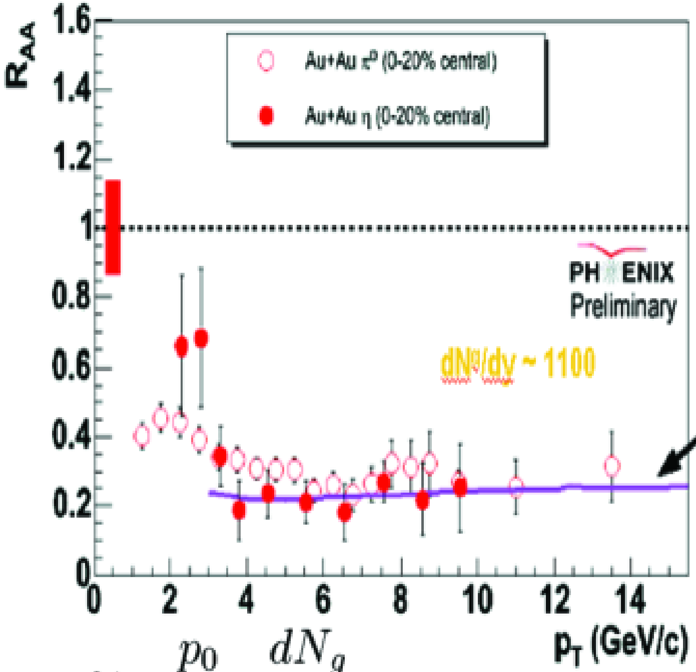


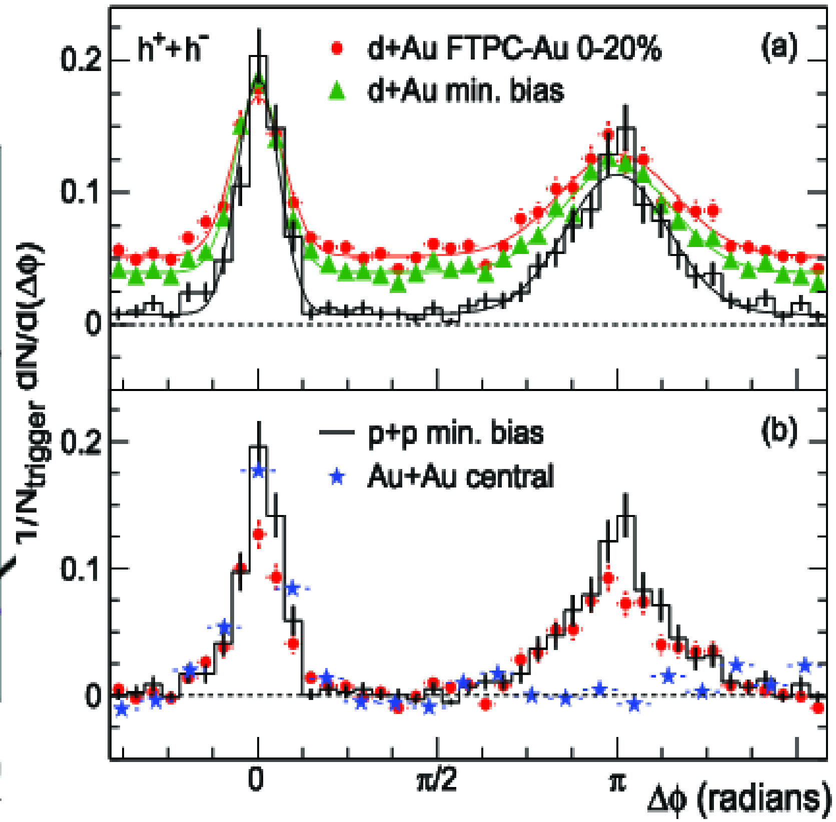
- Apparent Quark number scaling
- Hadron mass scaling at low KE_T (KE_T < 1 GeV) is preserved.

Consistent with quark degrees of freedom in the initial flowing matter

Jet Quenching and QGP Density

$$R_{AA} = \frac{\mathrm{Yield}_{AuAu} / \langle N_{binary} \rangle_{AuAu}}{\mathrm{Yield}_{pp}}$$





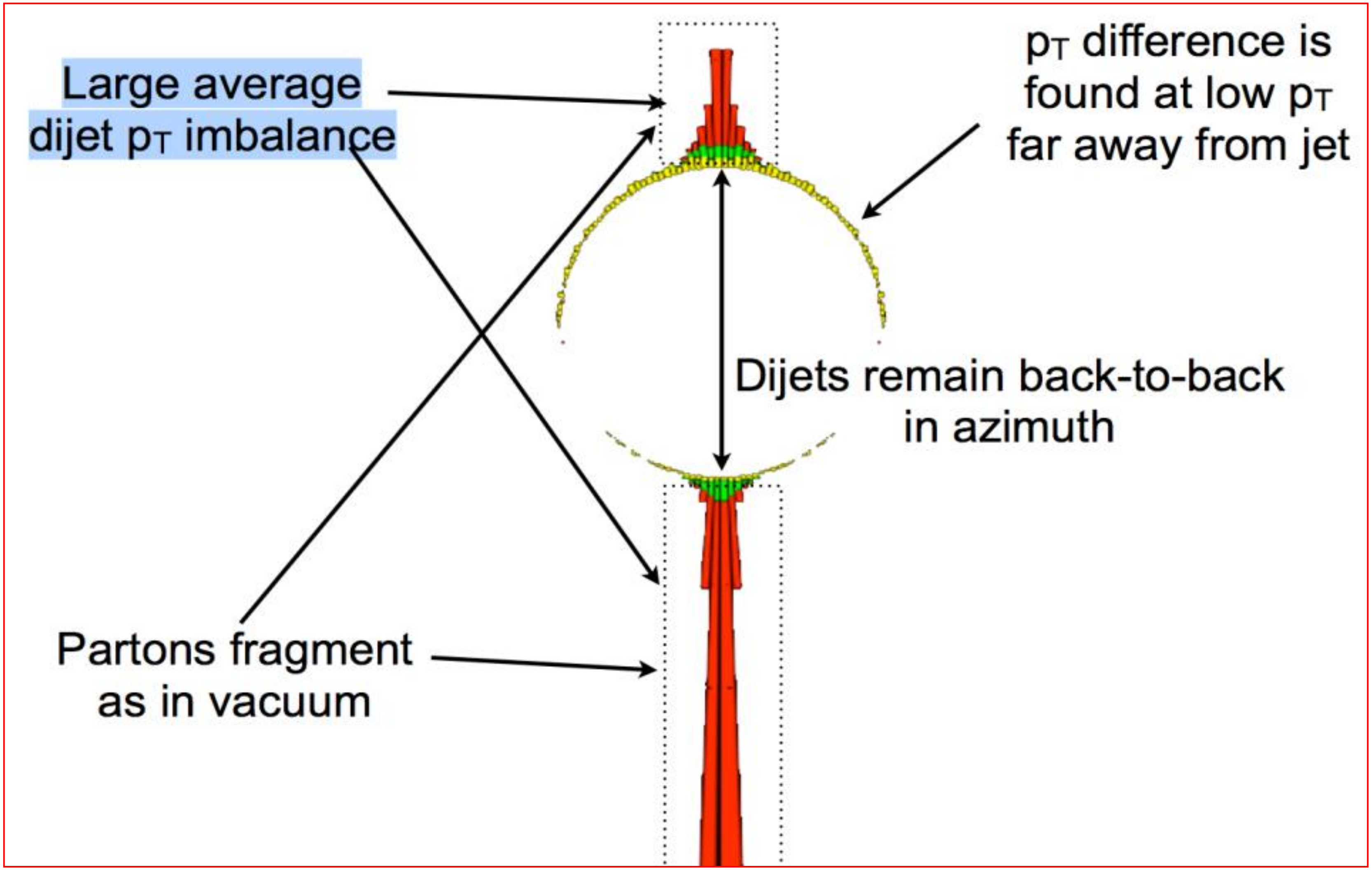
$$\epsilon \approx \frac{p_0}{\tau_0 \pi R^2} \frac{dN_g}{dy}$$

$$\approx 15-20 \frac{\mathrm{GeV}}{\mathrm{fm}^3},\ \epsilon_A \simeq 0.16 \frac{\mathrm{GeV}}{\mathrm{fm}^3}.$$

Gyulassy-Levai-Vitev(GLV) formalism

Gyulassy, Levai, Vitev, NPB 594(2001)371

Jet Quenching



NEXT STEP — QGP PROPERTIES

PHENIX

- how perfect is 'near-perfect' liquid QGP and its properties ?
- the spatial distribution of quarks/ gluons in nucleons and nuclei ?
  the dynamics of partons at very small and very large momentum fraction (x) ?
- quasiparticles and excitations in QGP
- direct photons
  proton-jet, photon-jet, jet-hadron correlations
- the physics of gluon saturation , gluon polarisation ?
- fast partons interactions with nuclear matter ?
  quark and gluon jets quenching and sQGP response ?
- high statistics upsilons and open heavy flavor
- quark and gluon contributions to the proton spin ?

Method : significant PHENIX upgrade

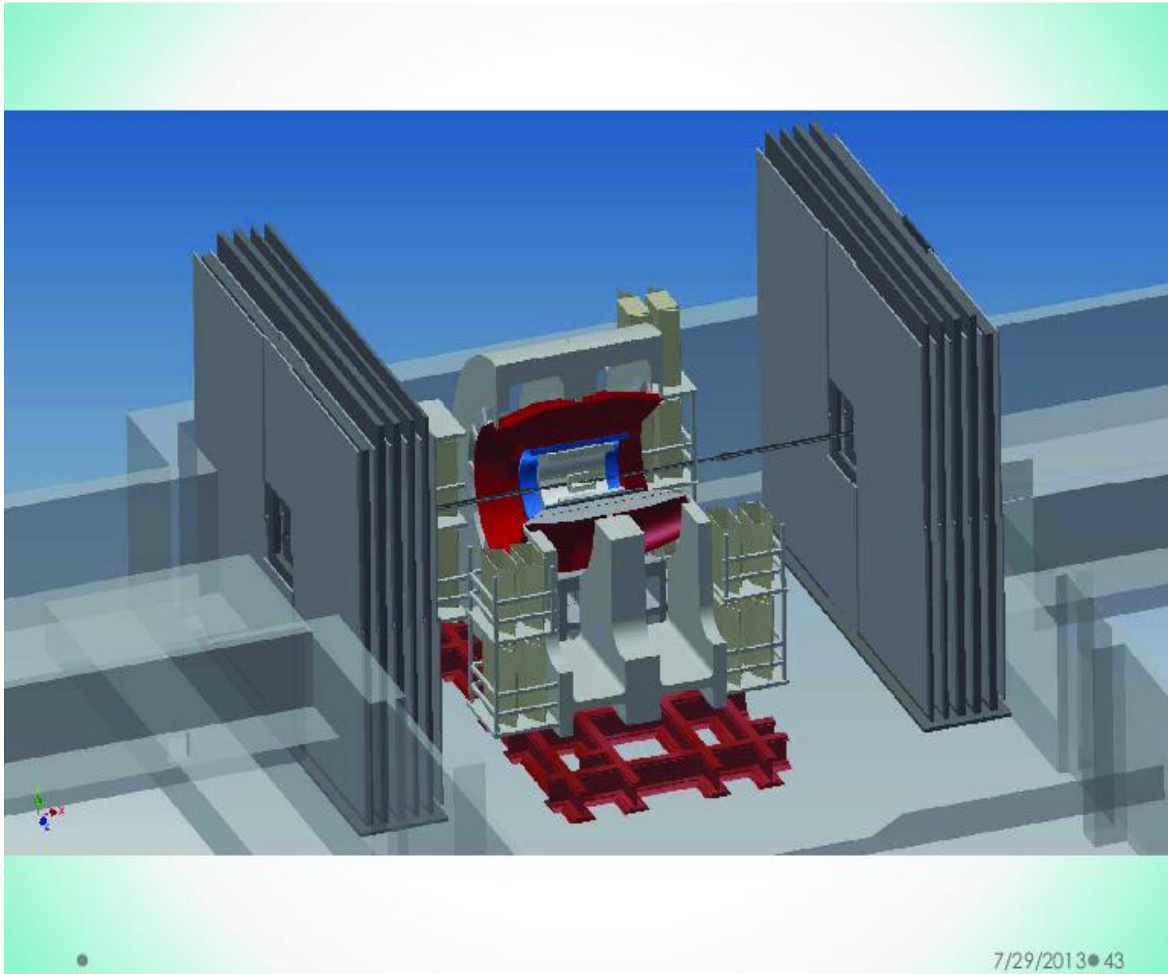
for full jet reconstruction in 4 pi detector geometry

sPHENIX detector requirements

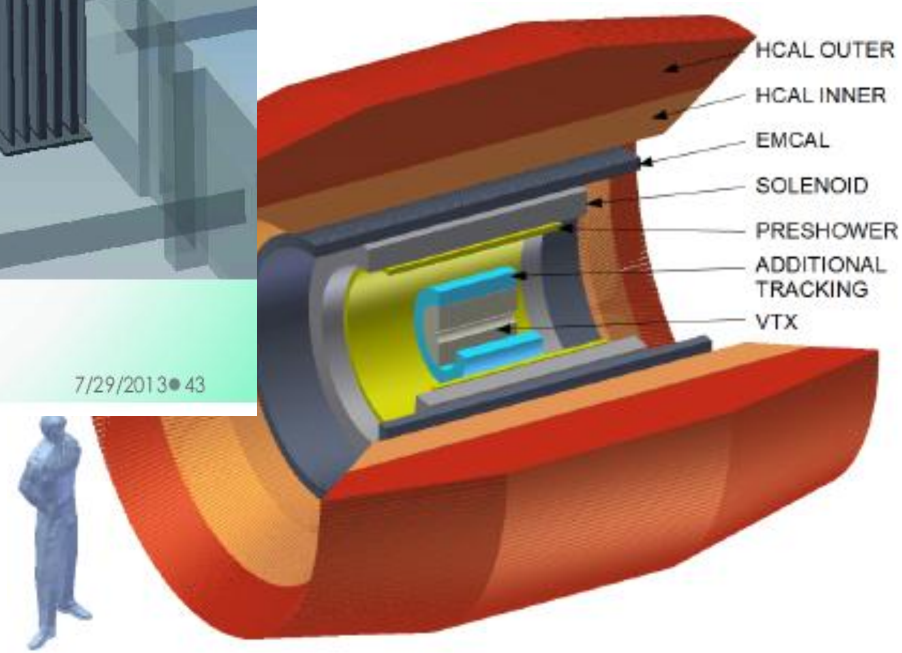
- uniform acceptance over 2 units of pseudorapidity and full azimuth
- high rate capabilities, fast readout, deadtimeless data acquisition
- precision inner and outer tracking with high momentum resolution
- full coverage hadronic calorimetry
- highly segmented electromagnetic calorimetry
- photon / pi0 separation up to 40 GeV
- electron identification over a broad momentum range
- displaced vertex tagging of heavy flavor decays

The 'full' understanding of jet physics require both the measurement of dijets and direct photon-jet physics

sPHENIX



7/29/2013 43

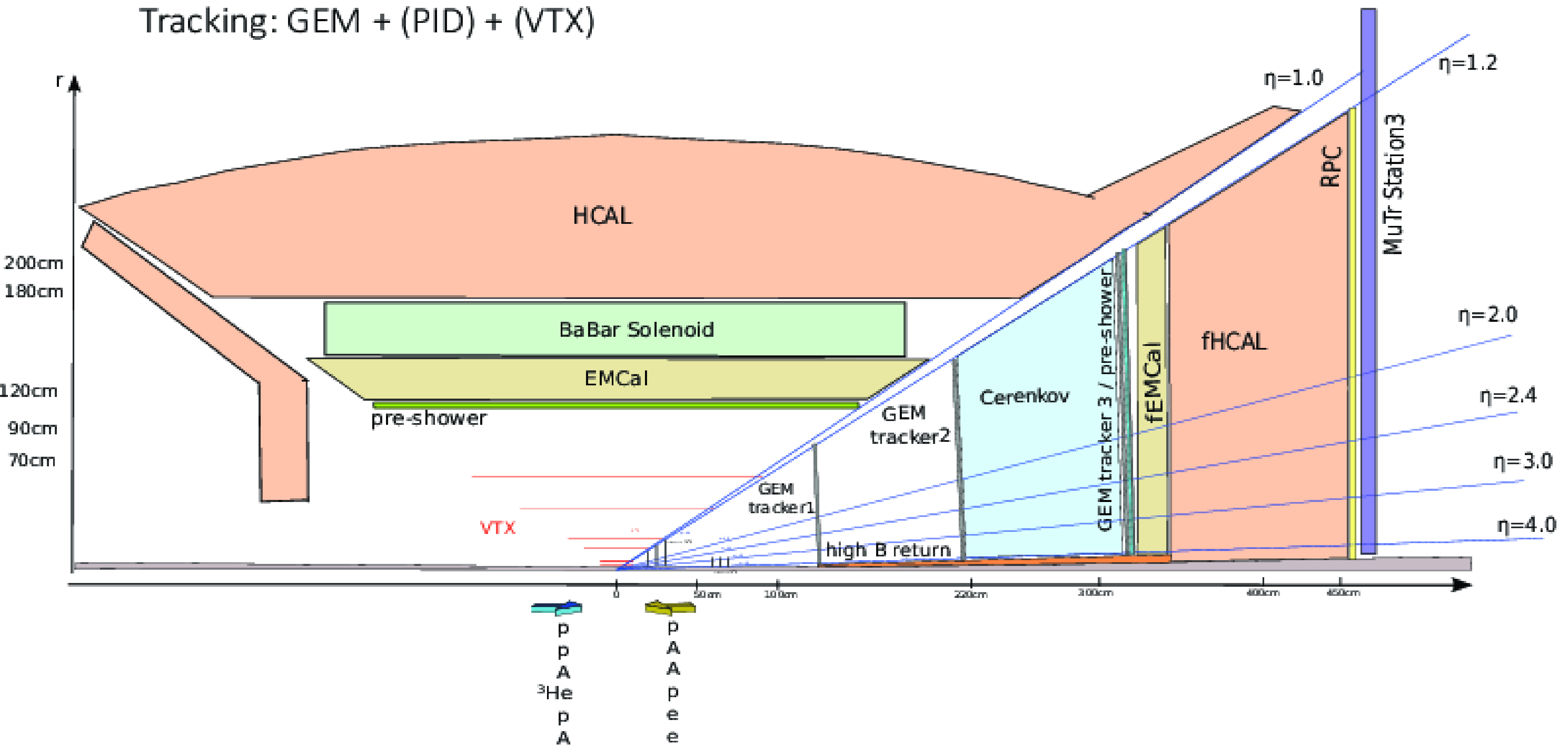


HCAL OUTER
HCAL INNER
EMCAL
SOLENOID
PRESHOWER
ADDITIONAL TRACKING
VTX

sPHENIX – concept design

Jet and charged particle capability is the key

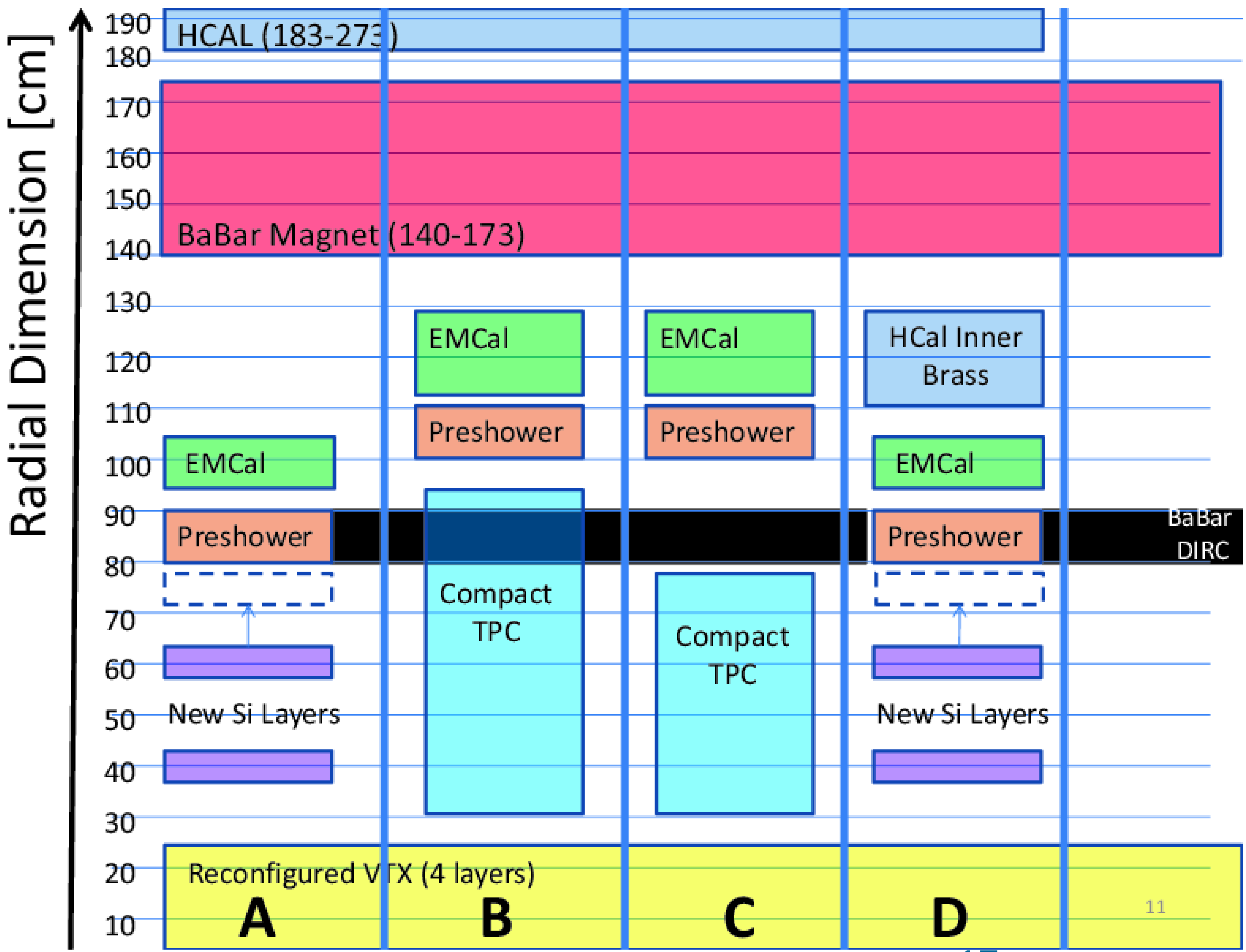
Jet : Hcal + (EMCal)
Tracking: GEM + (PID) + (VTX)



BaBar solenoid

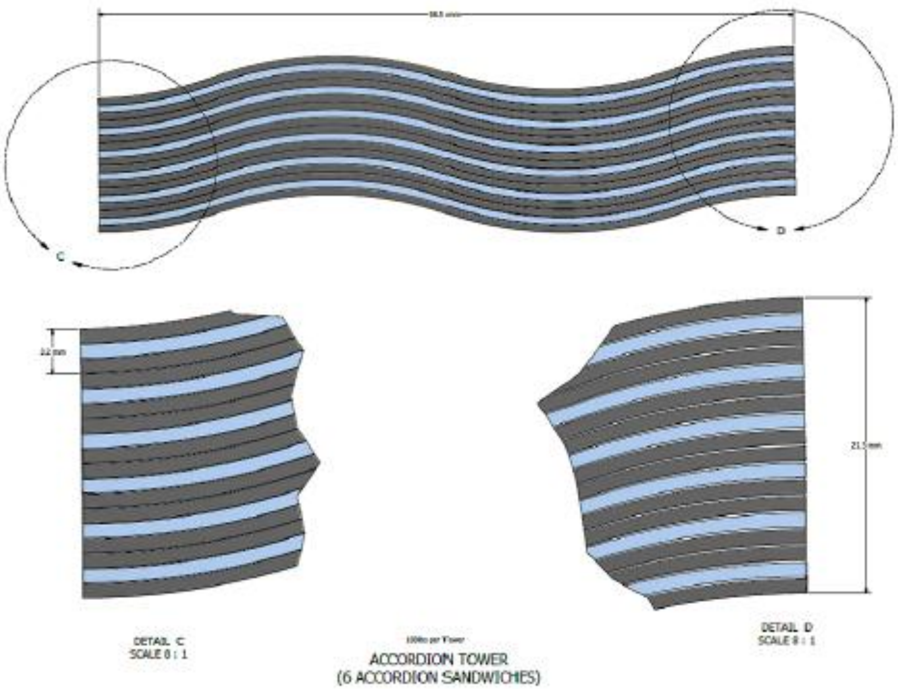
- A major positive update to the MIE considerations :
- BaBar Magnet from SLAC recently made available!
- Major parameters:
  - 1.5 T solenoid
  - Inner radius: 140 cm (x 2 compared to MIE)
  - Outer radius: 173 cm
  - Length: 385 cm

Central part variants of sPHENIX

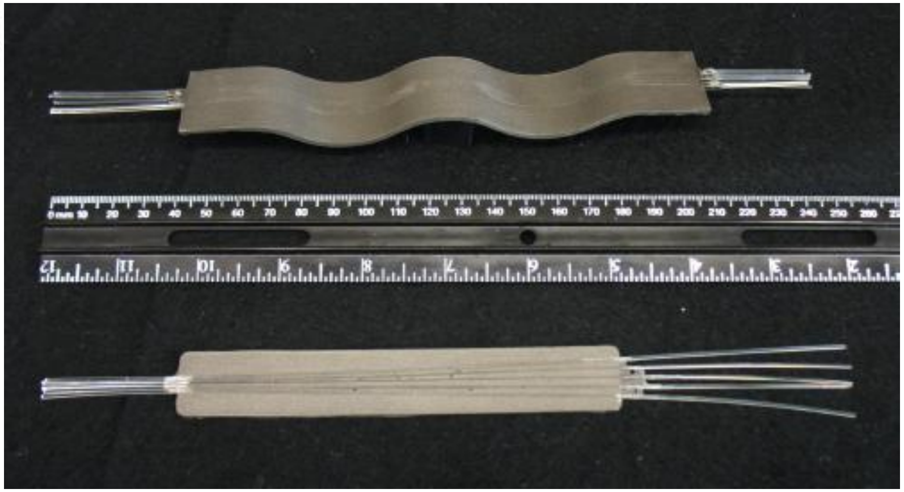


Electromagnetic calorimeter

- Accordion tungsten scintillating-fiber calorimeter
  - compact
- Silicon photomultiplier (SiPM) readout
  - small, high gain, no high voltage required, work in a magnetic field



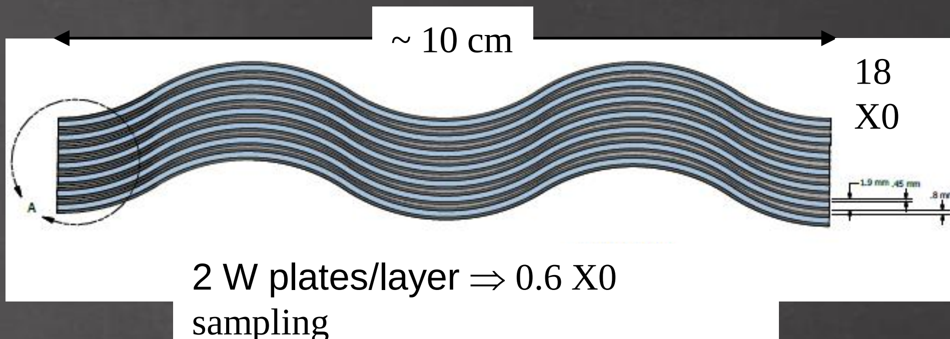
Accordion tower
= 6 accordion sandwiches



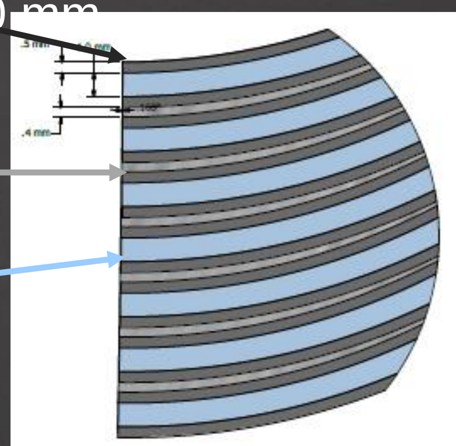
Scintillating fiber in tungsten powder epoxy polymer

Tungsten-SciFi Epoxy Sandwich

Uniform thickness, thin pure tungsten metal sheets with wedge shaped SciFi + tungsten powder epoxy layer in between

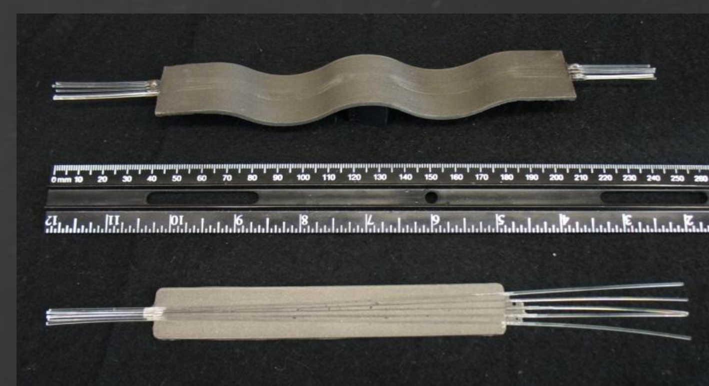


Pure tungsten metal sheet (ρ ~ 19.3 g/cm3) Thickness: 2x1.0 mm



Tungsten powder epoxy (ρ ~ 10-11 g/cm3) 0.08-0.2 mm

Scintillating fibers 1.0 mm



X0 = 5.3 mm

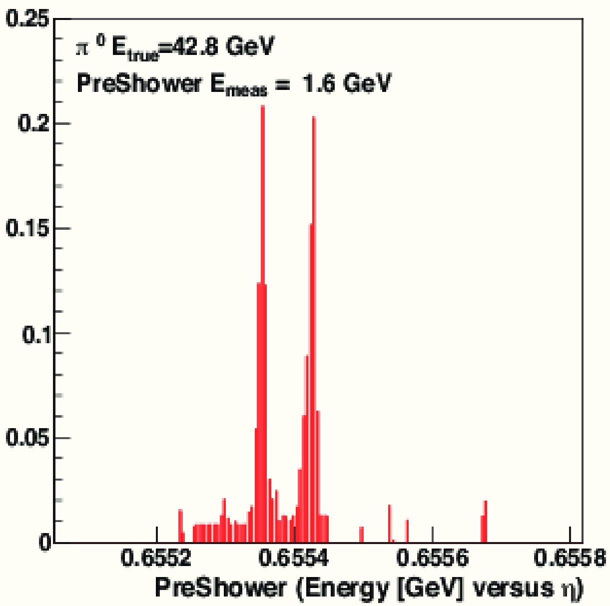
RM = 15.4 mm

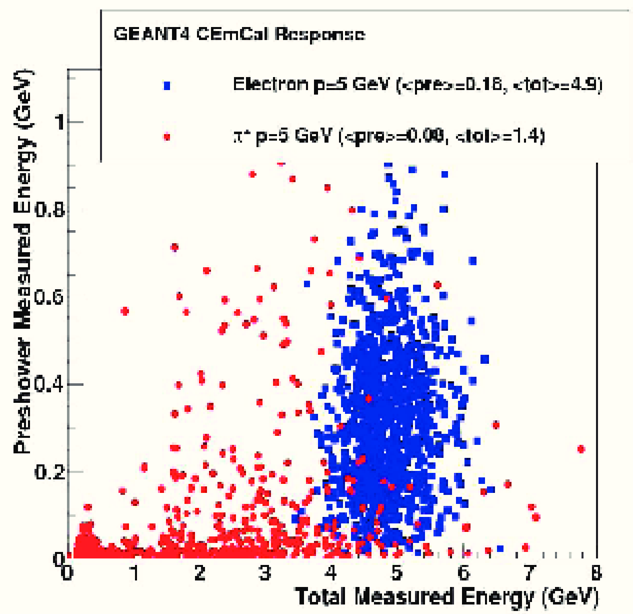
EMCAL parameters

Accordion design similar to ATLAS Liquid Argon Calorimeter :

- layered accordion of tungsten plates and scin fibers
- volume increases with radius but SC thickness does not increase
- tungsten thickness 2*1.0 mm and tungsten powder epoxy thickness
  0.08 -0.20 mm between layers
  SC fibers thickness 1 mm
- $X0$ = 5.3 mm, RM = 15.4 mm
- η coverage - $\pm$ 1.1, ϕ coverage -2π
- $\Delta\eta \times \Delta\phi = 0.024 \times 0.024$
- module -7 layers : 2 cm tower, 10 cm depth, 1.4 m long
- 25 k towers
- $\sigma/E \approx 12\% / \sqrt{E}$

Pion rejection



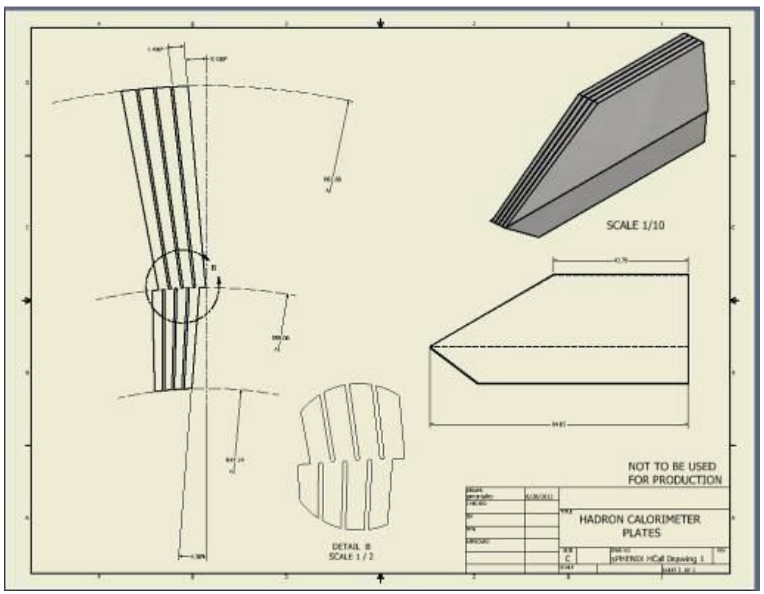


charged pion rejection ~200 using
pre-shower and p/E matching

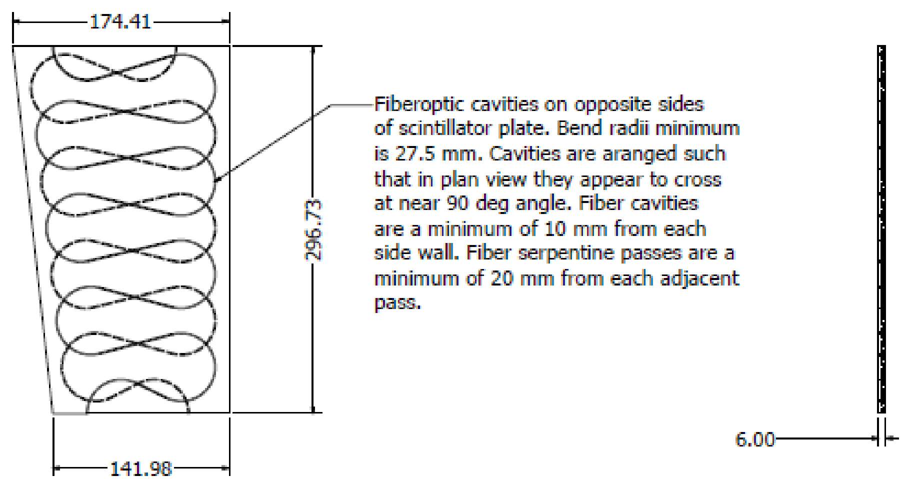
Hadronic calorimeter

PHENIX

- Steel-scintillator calorimeter
  - ~1 λ_{int} EMC + ~5 λ_{int} HC
  - Wavelength shifting fiber embedded in scintillator for light collection
  - Flux return for magnetic field

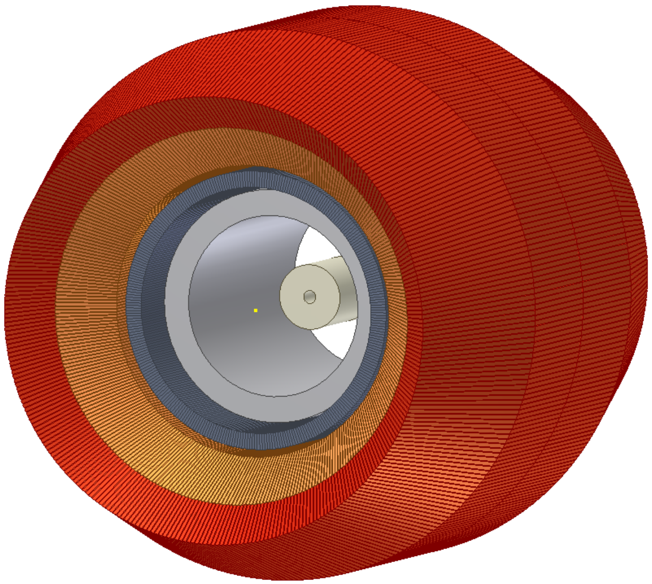


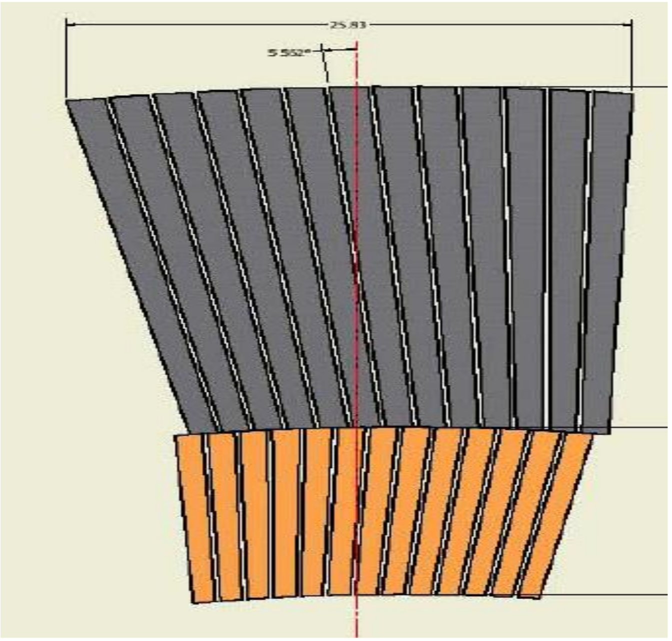
Fin structure of inner & outer segments oriented at an angle of ±5 degree



Scintillator tile with a wavelength shifting fiber along a serpentine path

Hadron Calorimeter

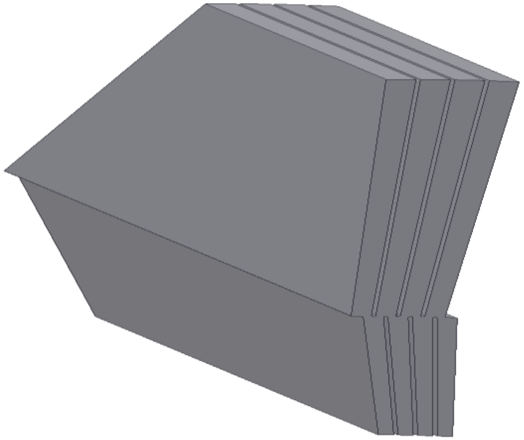




60 cm
3.5 λabs

30 cm
1.5 λabs

4 inner and 4 outer
plates joined together to
form one section



Sampling fraction changes with depth

HCAL parameters

PHENIX

Steel Scintillator sandwich :

- inner : SC width 0.6 cm, iron width 4.4 cm

  tilt angle 13.26^0

- outer: iron width 9.4 cm

  tilt angle 10.68^0

- tower 10 x 10 cm
- 3k towers
- $\sigma/E \approx 100\% / \sqrt{E}$

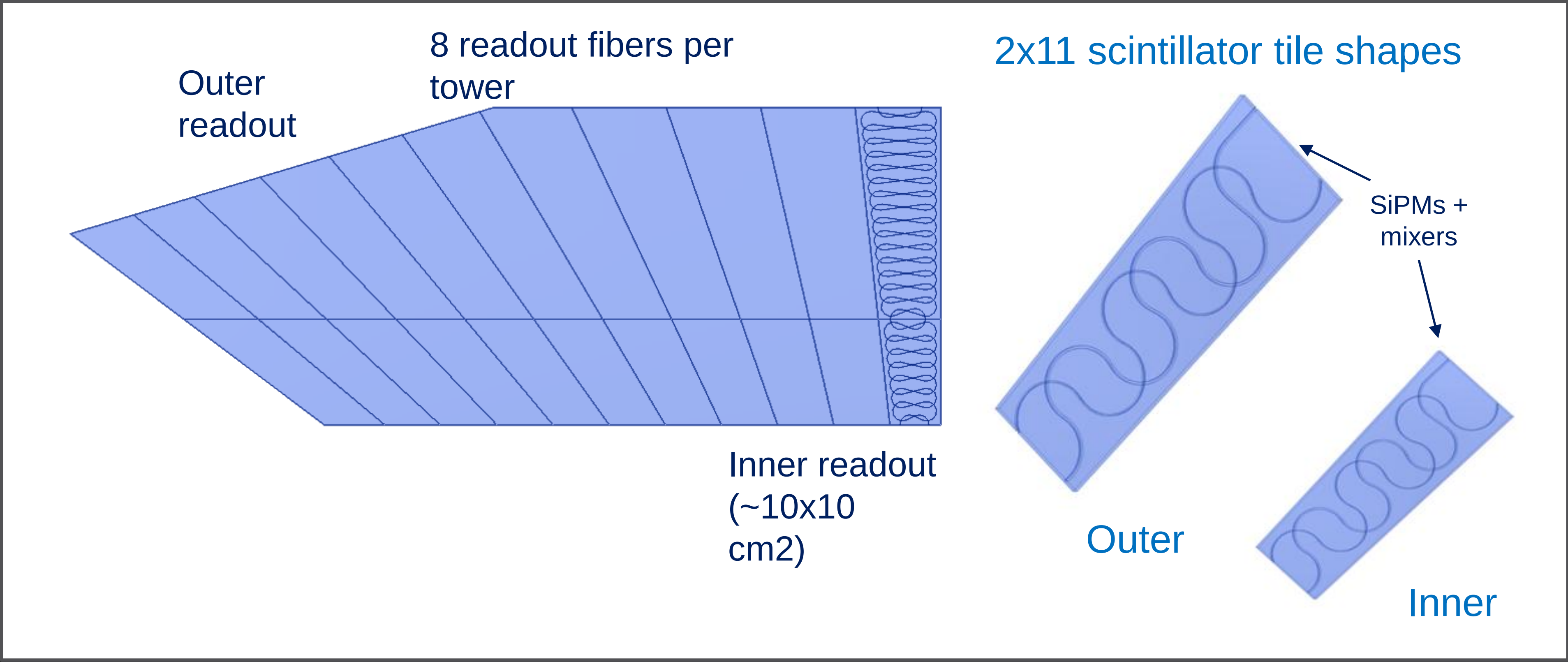
HCAL Readout

Similar to T2K:

- Scintillating tiles with WLS fibers embedded in serpentine grooves
  - (Scint: extruded polystyrene made in Russia, WLS: Kuraray Y11)

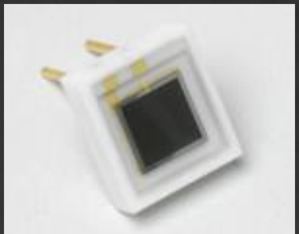
Fibers embedded in grooves on both sides of tile

Expect ~ 12 p.e./MIP/tile (T2K) ⇒ ~ 400 p.e./GeV in HCAL



SiPM Readout

Common readout for both EMCAL and HCAL



S10362-33-25C

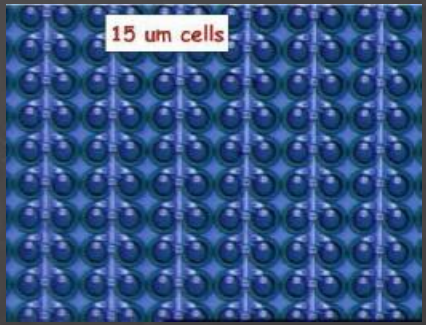
EMCAL segmentation ~ .024 x .024 (η x ϕ) $\Rightarrow$ ~ 25K channels
HCAL segmentation ~ 0.1 x 0.1 $\Rightarrow$ ~ 3K channels

3x3 mm2,14.4K pixels (25 μm)
G ~ 2 x 105, peak PDE ~ 25% @ 440 nm

Considering various devices:

- SiPMs: Hamamatsu, AdvanSiD, SensL,…
- Possibly APDs

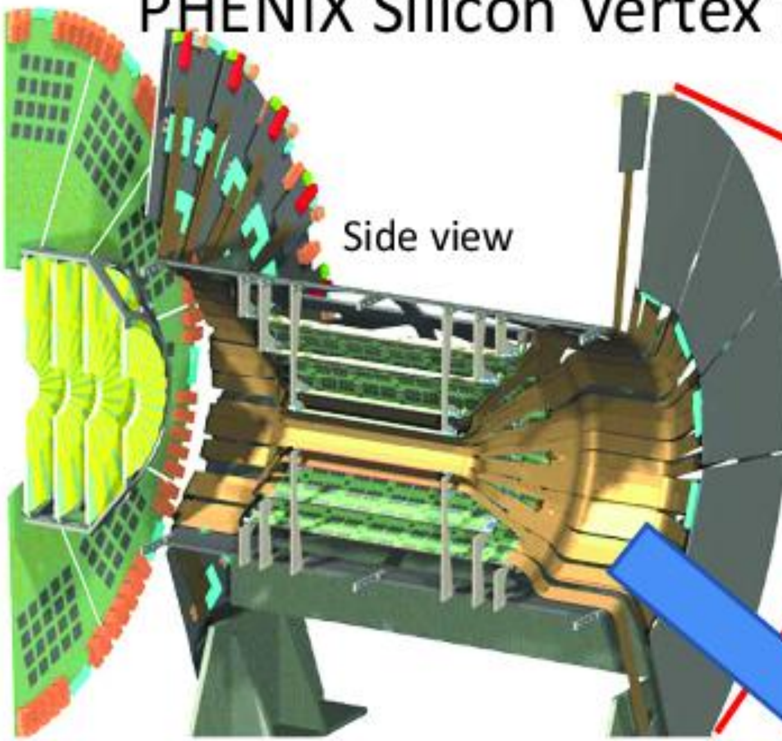
New, highly pixellated SiPMs are becoming available

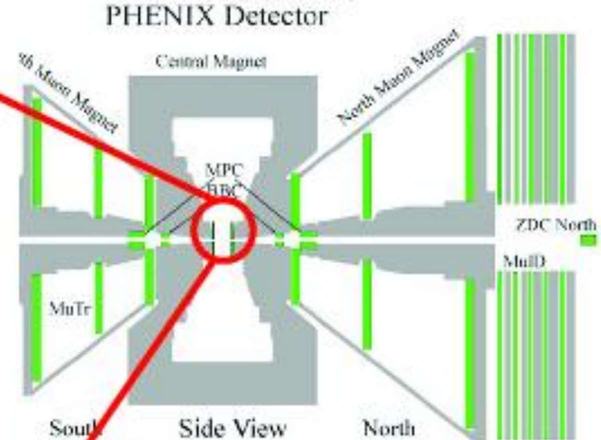


Hamamatsu MPPC-15 μm being developed for CMS

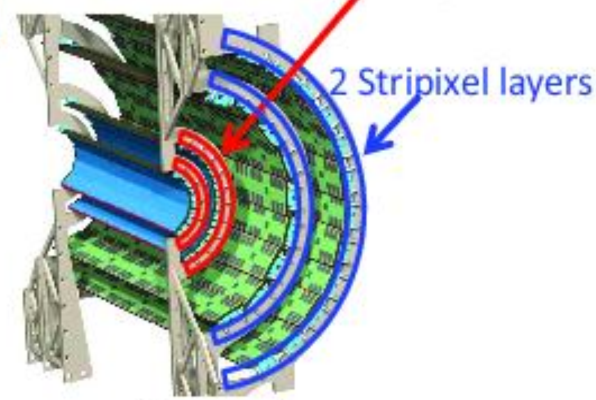
- Want dynamic range ~ few x 103
  10 MeV - 20 GeV per tower
- Due to saturation, must tune light levels to give ~ 5 - 10,000 p.e.
- Avoid noise at 1 p.e. level
- Requires bias stabilization with temperature compensation and control
  dVbr/dT ~50 mV/° C $\Rightarrow$ dG/dT ~ 10% /° C
- Radiation damage should not be a problem

PHENIX Silicon Vertex Tracker (VTX)





Silicon Vertex Detector (VTX)
Placed at the center of PHENIX



Beam view

- Coverage: $|\eta| < 1.2$, $\Delta\phi \sim 2\pi$
- 4 Layers: 2 inner layers of Pixel detector
- 2 outer layers of Stripixel detector
- Spatial resolution:
  σ(DCA) ~ 100μm
  ~ 50 μm after alignment
- Material: X/X_0 ~ total 10%
- Stand-alone Tracking Capability

Laser Electron Gamma Sourse TPC

TPC

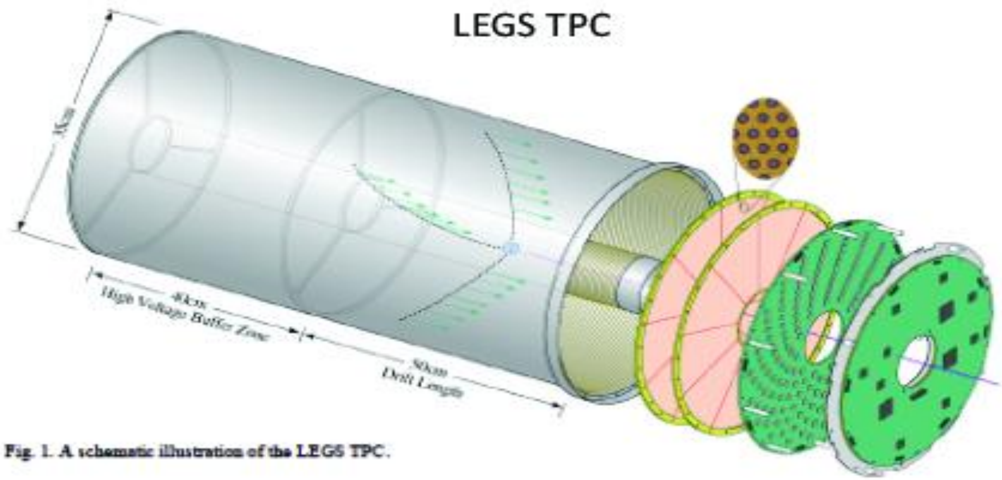


Fig. 1. A schematic illustration of the LEGS TPC.

Chevron-type readout pattern with a pad size 2mm × 5mm

Achieved pos. res. 200 µm

ePHENIX TPC:

R=15-80cm, |z|<95cm

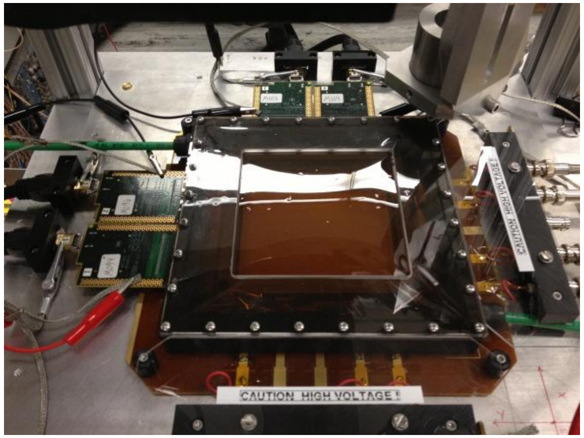
Gas mixture with fast drift time: 80% Ar, 10% CF_4, 10% CO_2

For 650 V/m -> 10cm/µs -> Drift time 10 µs

2×10mm pads –> 180k pads (both ends readout)

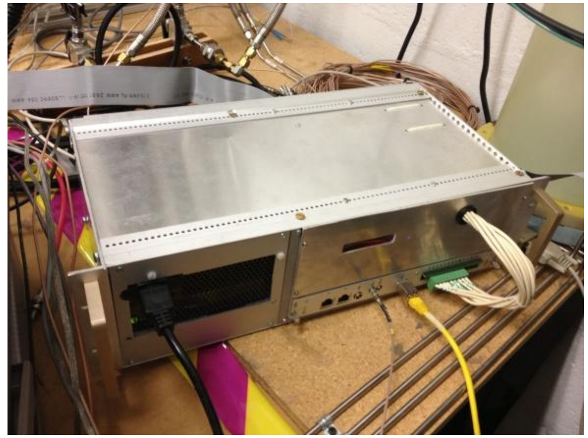
Pos. resolution 300 µm (twice longer drift distance tha LEGS) and 40 readout rows => $\sigma_p/p \sim 0.4\%\times p$

Minidrift GEM Detector with XY Readout

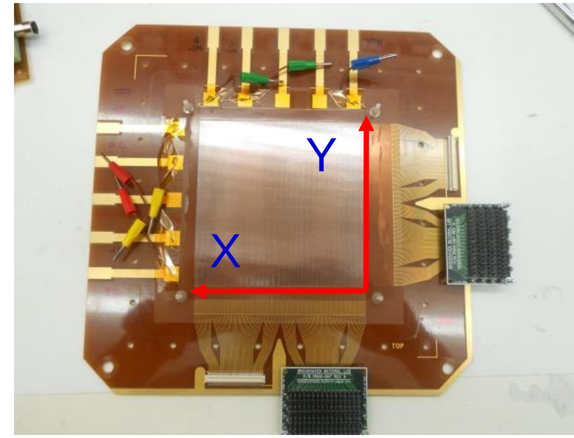


Std. 10x10cm CERN 3-GEM Det.
- Ar/CO2 (70/30)
- Gain ~ 6500
- ~17mm Drift Gap
- Drift Time ~600ns

B.Azmoun

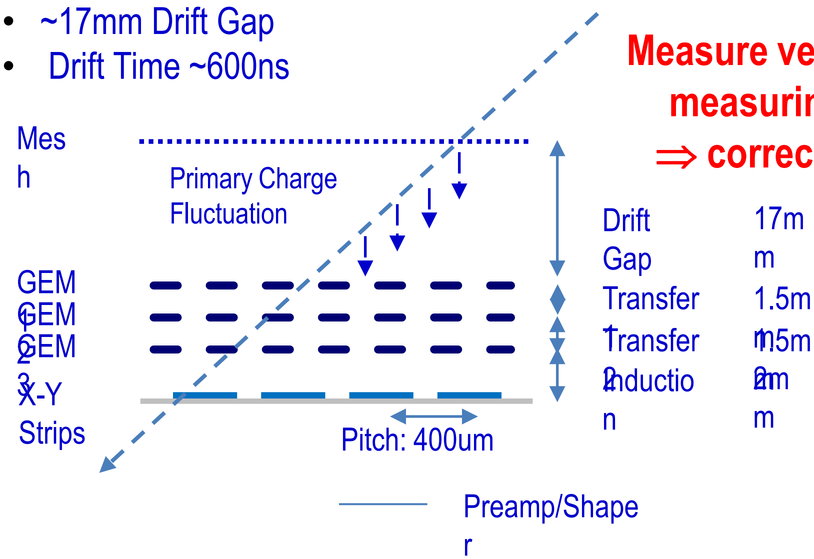


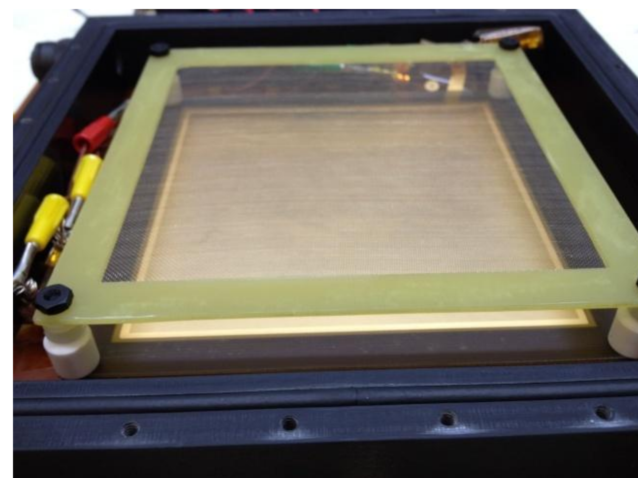
SRS /512 channels APV 25
- 30 x 25ns Time Samples
- RCDAQ Readout (M.Purschke)



COMPASS style Readout:
- 256 x 256 X-Y Strips
- ~10cm x 400um pitch

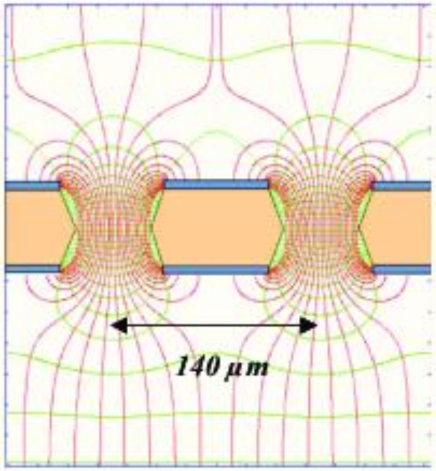
Measure vector at each measuring station
⇒ correct for angle



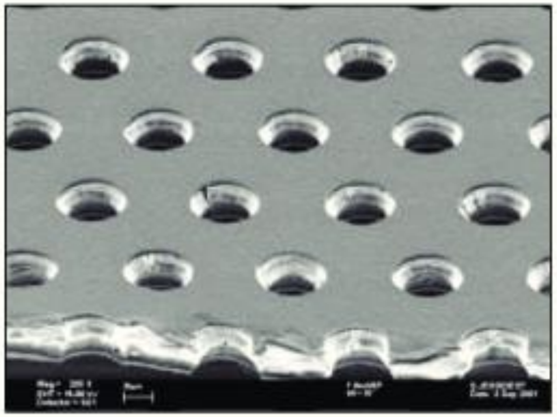


GEM

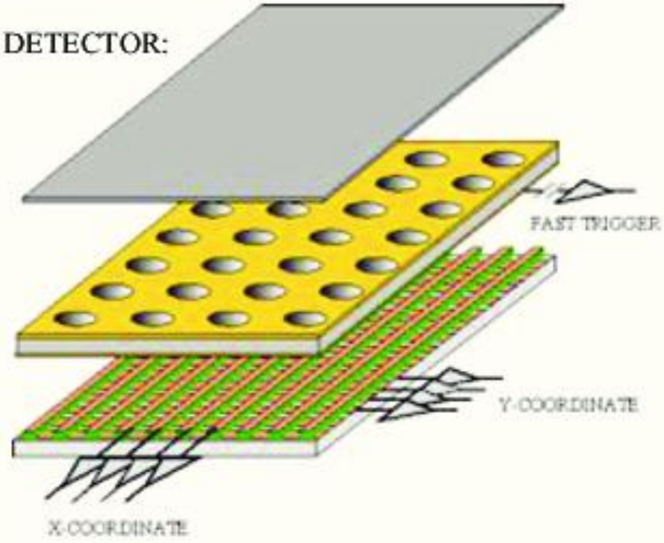
GEM:
GAS ELECTRON MULTIPLIER



50 µm Cu-clad kapton foils
with high density of holes

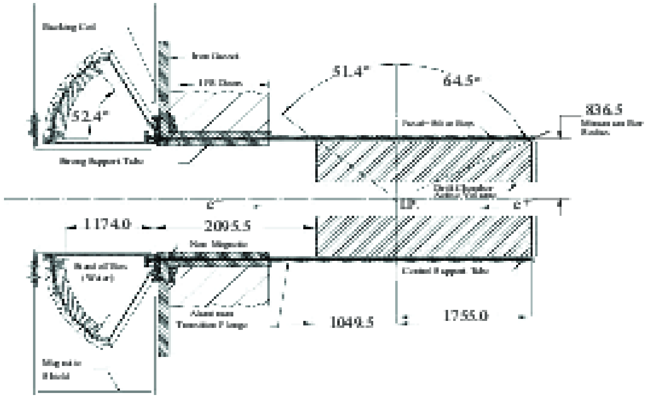


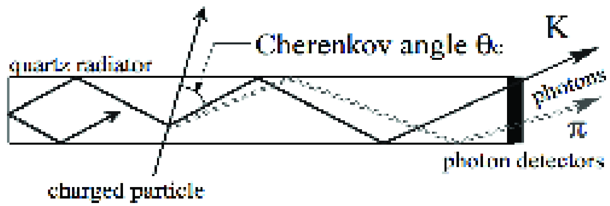
2-D GEM DETECTOR:



F. Sauli,
Nucl. Instr.and Meth. A386(1997)531

Hadron PID: DIRC





BaBar DIRC

Quartz radiator bars, Cerenkov light internally reflected

No focusing => Large water filled expansion volume

PMT for readout

ePHENIX DIRC

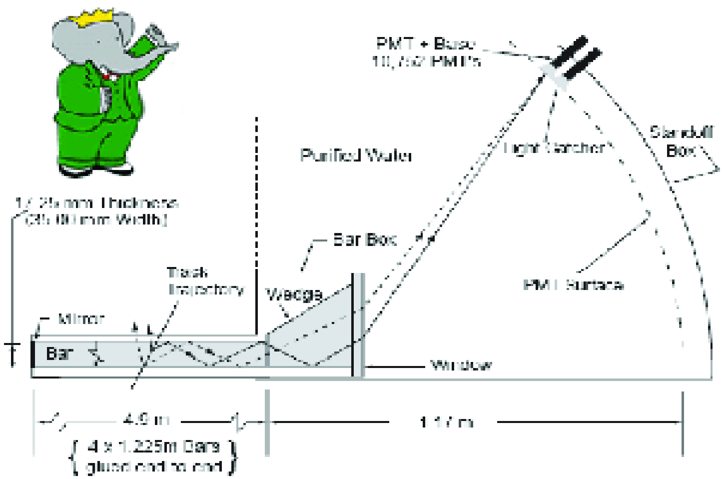
Mirror Focusing to avoid large expansion region

Pixelated multi-anode PMT for readout

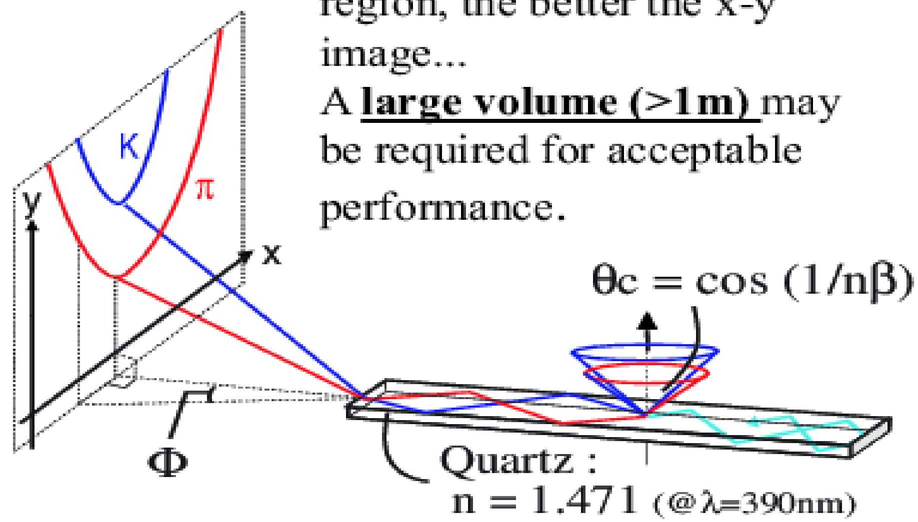
Ring resolution limits PID at higher p

Detection of Internally Reflected Cherenkov (DIRC) Light

- Charged particles of same momentum but different mass (e.g., K and π) emit Cherenkov light at different angles.
- Detect the emitted photons in 2+ dimensions (x,y,t)
- BaBar DIRC as a model:



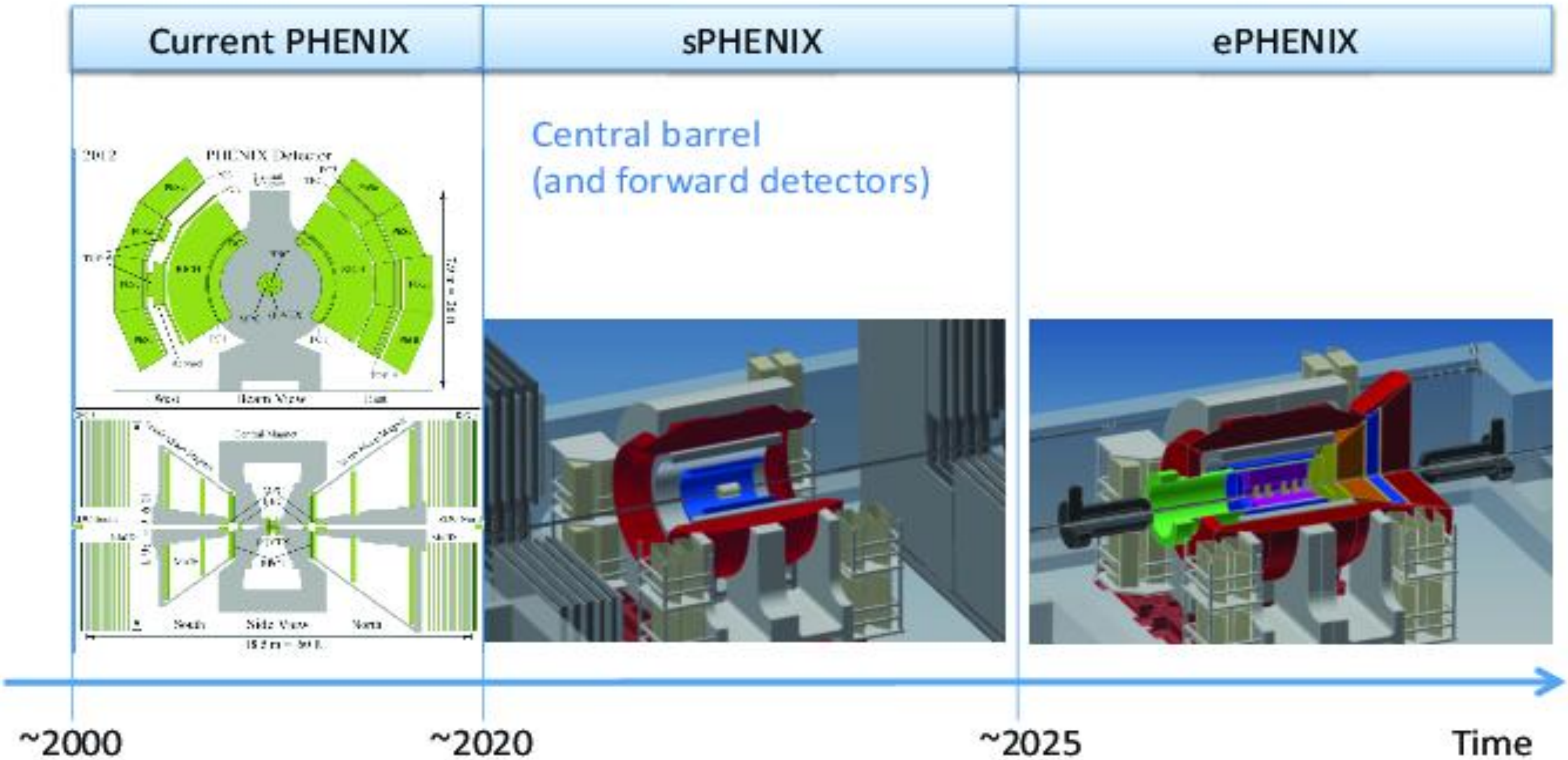
The larger the expansion region, the better the x-y image...
A **large volume (>1m)** may be required for acceptable performance.



NIM A515 (2003) 680-700.

Years	Beam Species and Energies	Science Goals	New Systems Commissioned
2013	• 510 GeV pol p+p	• Sea quark and gluon polarization	• upgraded pol'd source • STAR HFT test
2014	• 200 GeV Au+Au • 15 GeV Au+Au	• Heavy flavor flow, energy loss, thermalization, etc. • Quarkonium studies • QCD critical point search	• Electron lenses • 56 MHz SRF • full STAR HFT • STAR MTD
2015-2016	• p+p at 200 GeV • p+Au, d+Au, ^{3}He+Au at 200 GeV • High statistics Au+Au	• Extract η/s(T) + constrain initial quantum fluctuations • More heavy flavor studies • Sphaleron tests	• PHENIX MPC-EX • Coherent electron cooling test
2017	• No Run		• Electron cooling upgrade
2018-2019	• 5-20 GeV Au+Au (BES-2)	• Search for QCD critical point and deconfinement onset	• STAR ITPC upgrade
2020	• No Run		• sPHENIX installation
2021-2022	• Long 200 GeV Au+Au w/ upgraded detectors • p+p/d+Au at 200 GeV	• Jet, di-jet, γ-jet probes of parton transport and energy loss mechanism • Color screening for different QQ states	• sPHENIX
2023-24	• No Runs		• Transition to eRHIC

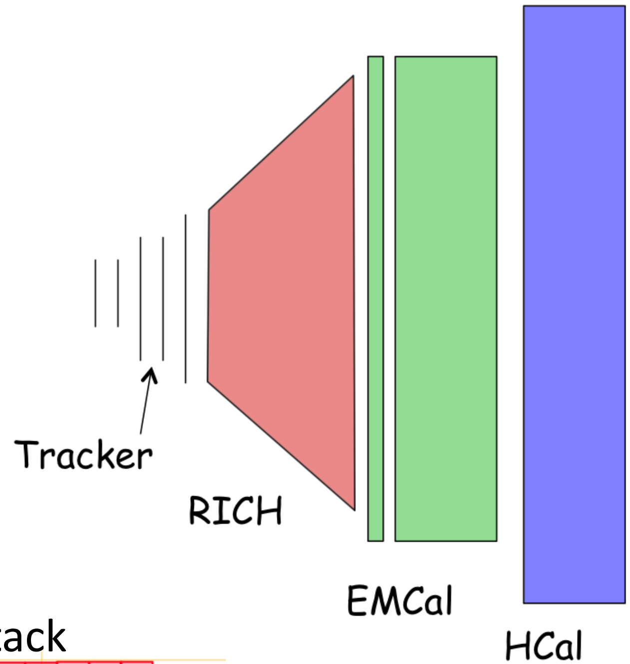
PHENIX Plan of Evolution to eRHIC Era

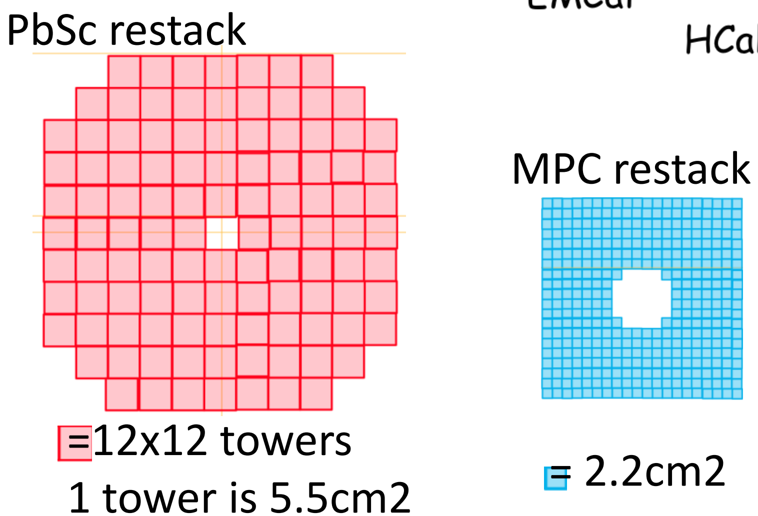


BACKUP

sPHENIX — forward design

- **Rely on central magnet field**
  - Studying other field/magnet possibilities
- **EMCal based on restack of current PHENIX calorimetry**
  - PbSc from central arm (5.52 cm2)
  - MPC forward arm (2.2 cm2)
- **For tracker considering GEM technology**
- **Interest of HI in forward direction may influence choices based on expected multiplicity.**



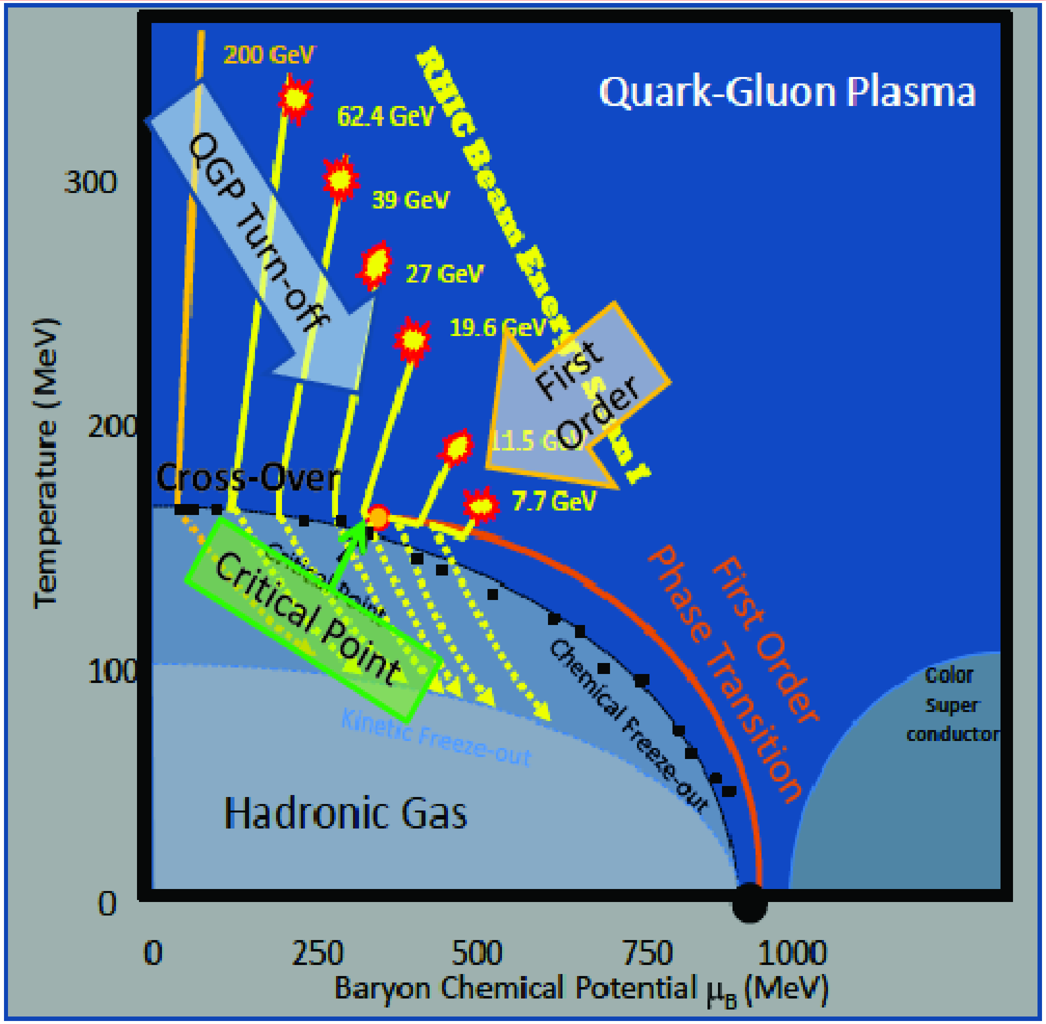


The RHIC Beam Energy Scan I

PHENIX

- We built RHIC to find the QGP.
  And we did it!

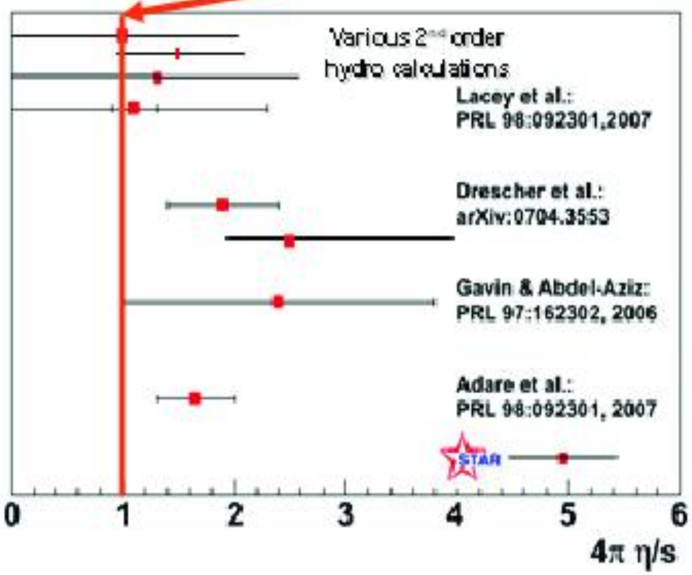
- But QGP is a new and complicated phase of matter. We have made huge progress in understanding its nature. At high energy, we expect a **cross-over** transition. At lower energy there should be a **first order** transition and a **critical point**.

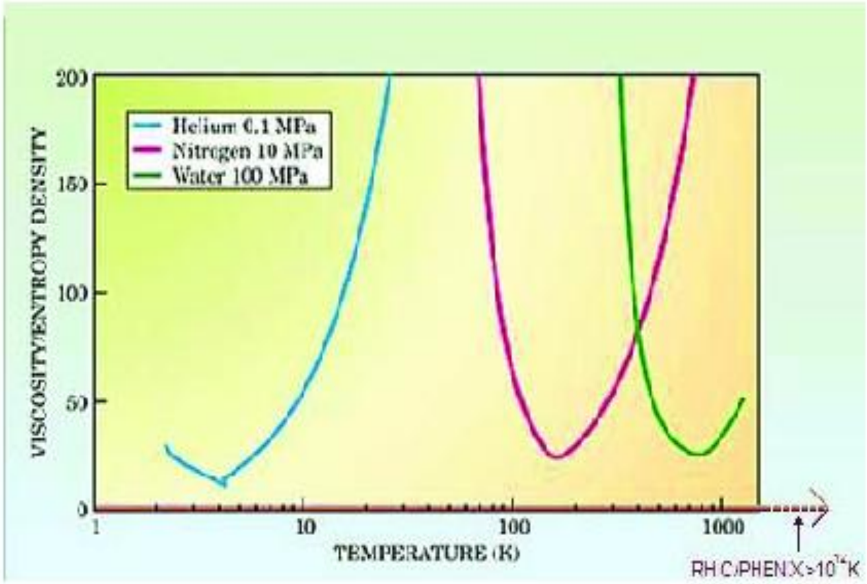


As perfect fluid as possible

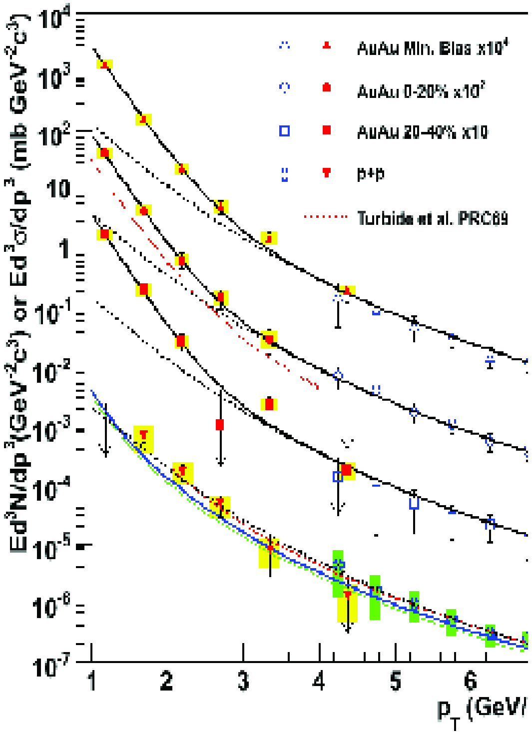
PHENIX

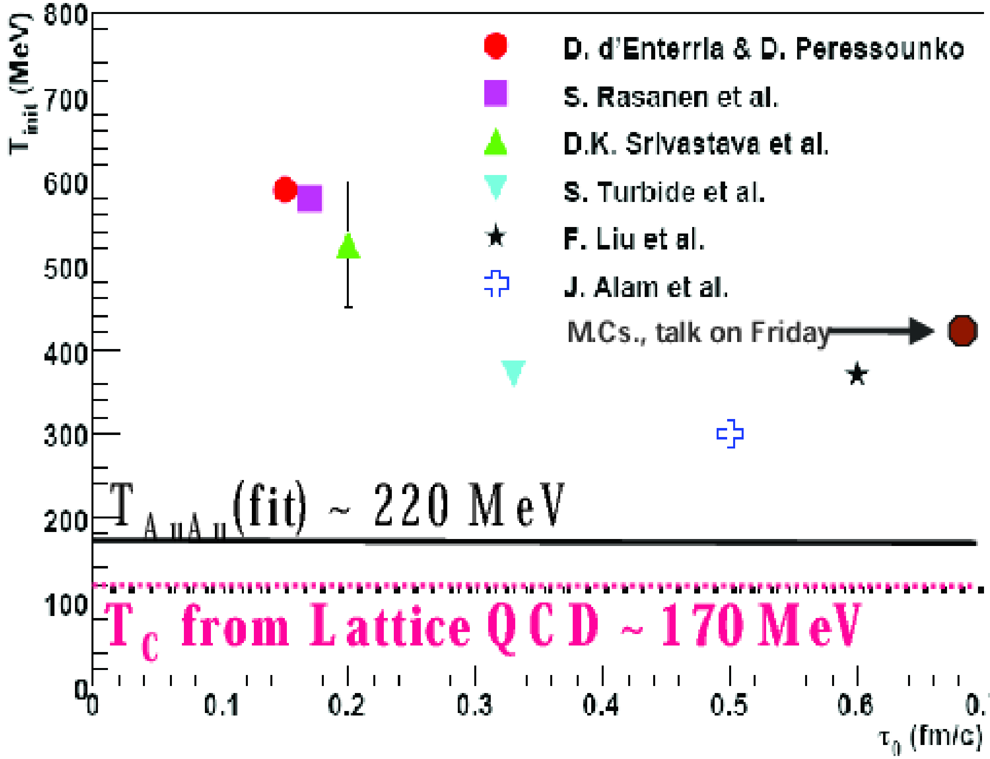
- Kinematic viscosity η/s lower than that of superfluid helium
- Conjectured limit: $1/4\pi$ (via AdS/CFT)





Initial temperature from direct γ





Directly from data: $T_{ini} > T_{AuAu} \sim 220$ MeV

Modell-calculations: $T_{ini} = 300 - 600$ MeV (with $\tau_0 = 0.15 - 0.6$ fm/c)

M. Cs. talk on Friday ($T_{ini} \approx 440$ MeV from photon spectra)

Lattice QCD: $T_c \sim 170$ MeV

A. Adare et al., PHENIX Collaboration
Phys. Rev. C81, 034911 (2010)
Phys. Rev. Lett. 104, 132301 (2010)

Hadron PID

DIRC

-1<η<1
Mirror focusing ?
Threshold for π/K/p:
    0.2/0.7/1.5 GeV

Gas RICH (CF4)

1<η<4
Mirror focusing
Threshold for π/K/p:
    4/15/29 GeV
6 azimuthal segments
Photodetection: GEM with CsI
    Area 6×0.3m^2 –> 96k ch
    In gas volume!

Aerogel

1<η<2
Proximity focused
Threshold for π/K/p:
    0.6/2/4 GeV