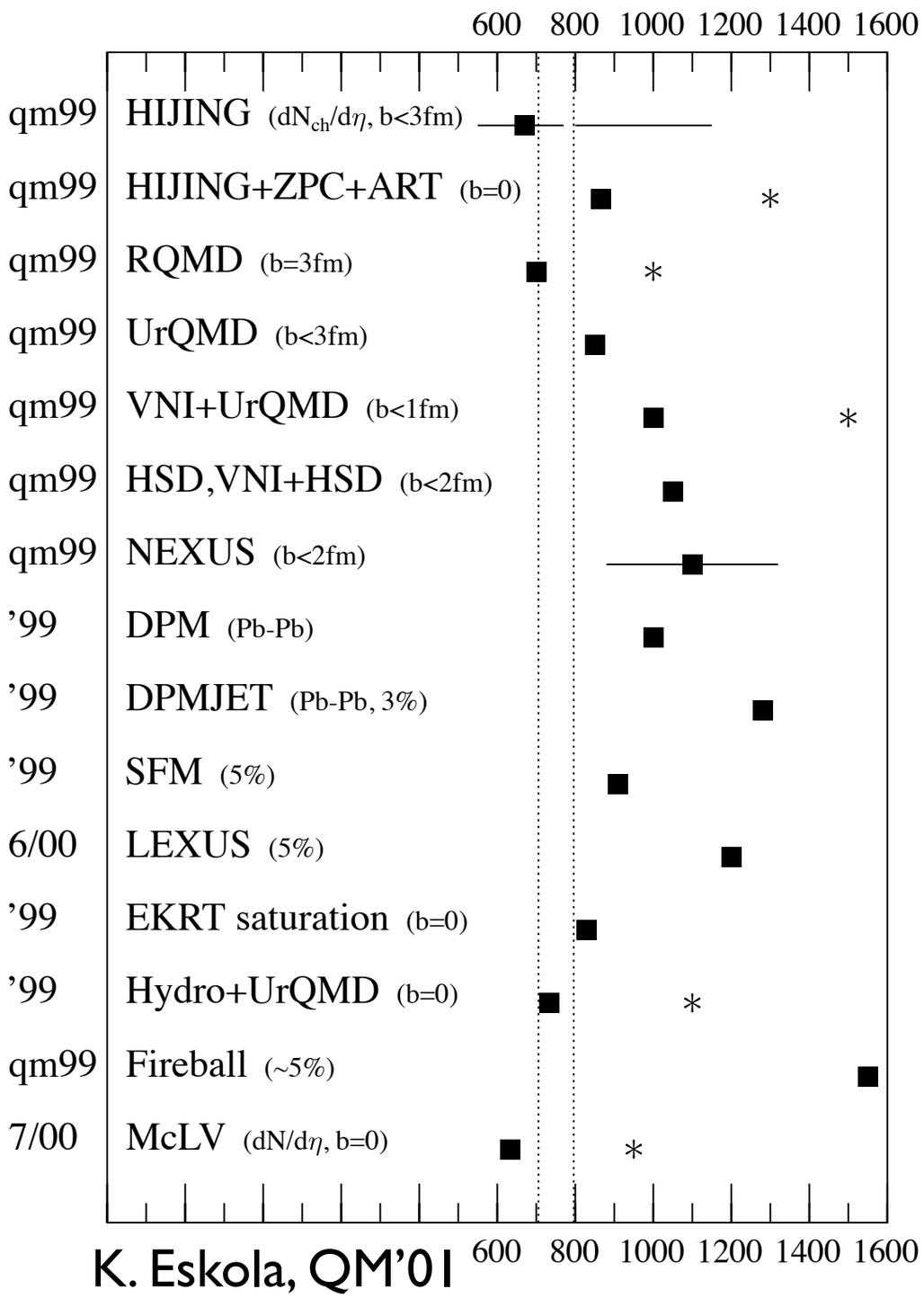
PHENIX heavy-ion science goals and upgrade strategies beyond 2015*

David Morrison
for the PHENIX Collaboration

*M. Grosse-Perdekamp will talk tomorrow about plans for spin and evolution to ePHENIX

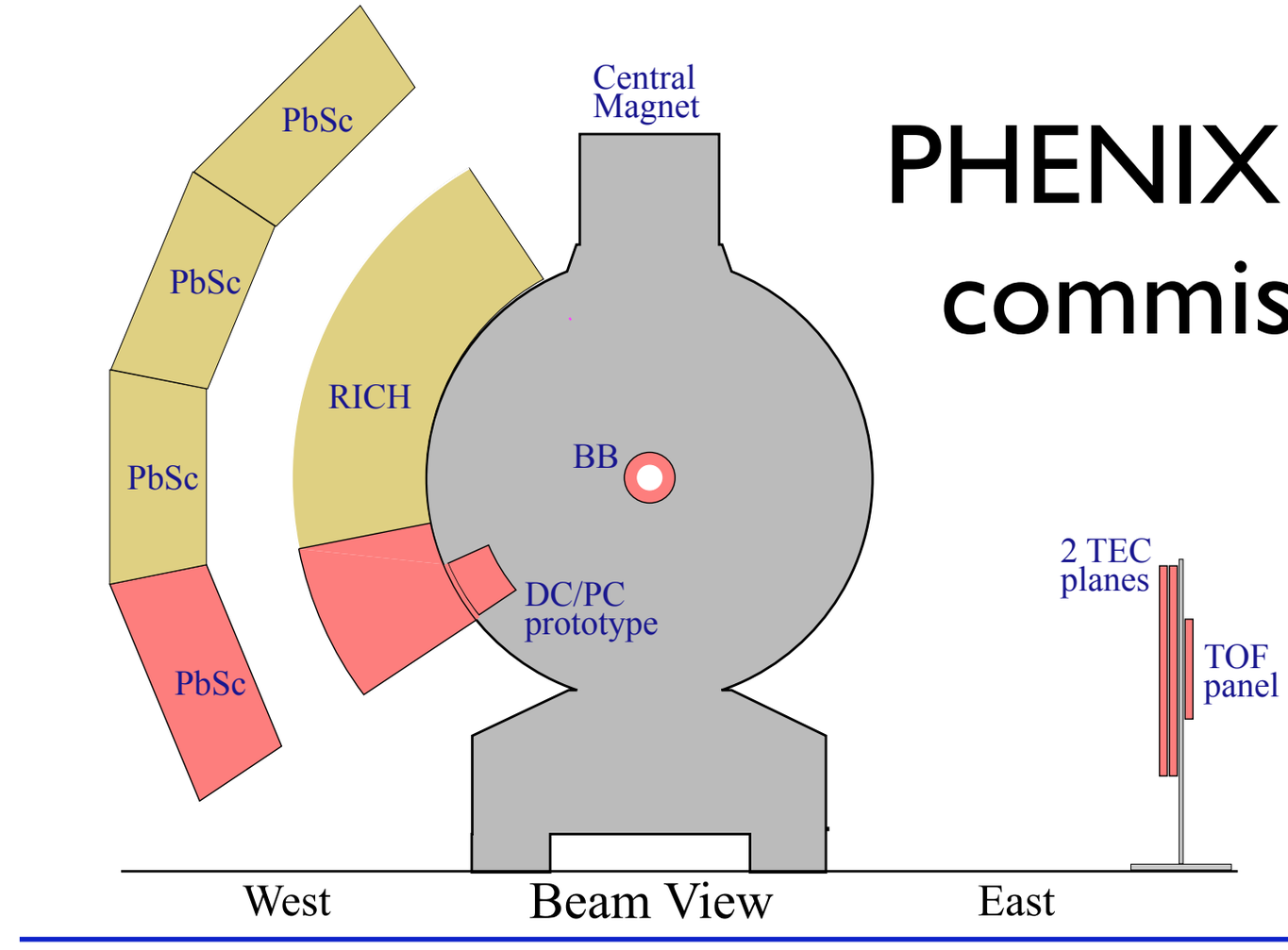


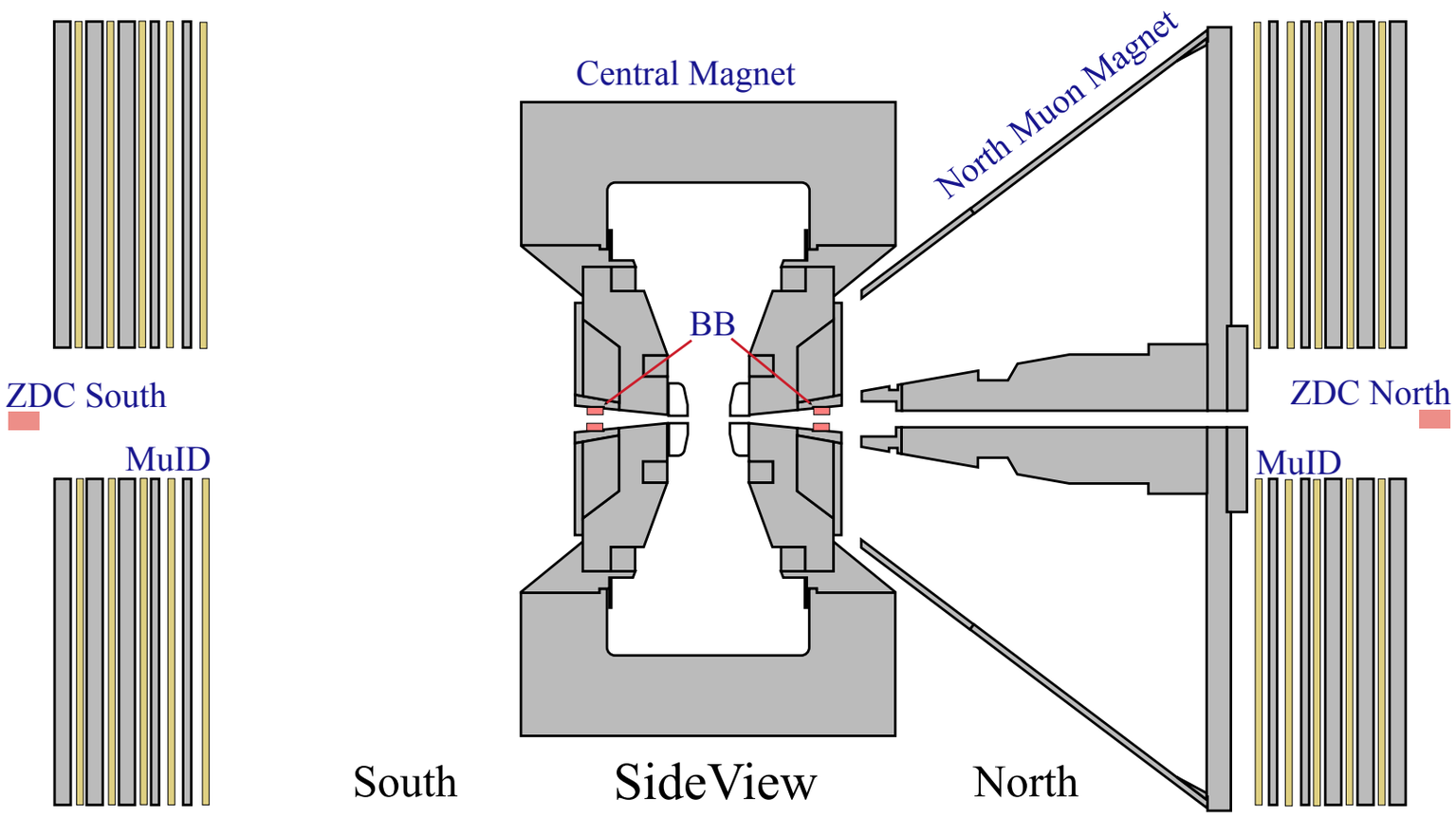
K. Eskola, QM'01

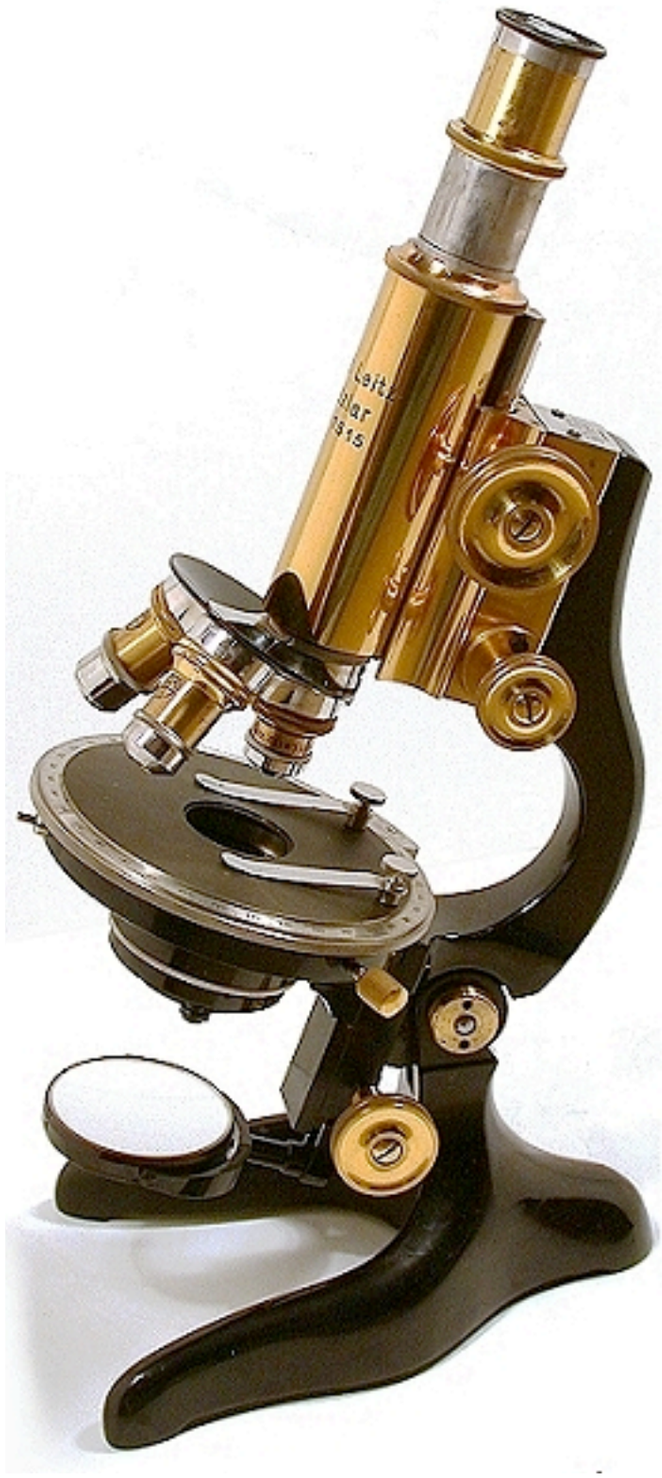
"... back in the olden days."
– J.D.

- multiplicity estimates varied *a lot*
- "double HIJING"
- ideal gas QGP?
- v2 ~ 0?
- black holes?

PHENIX during 1999 commissioning run

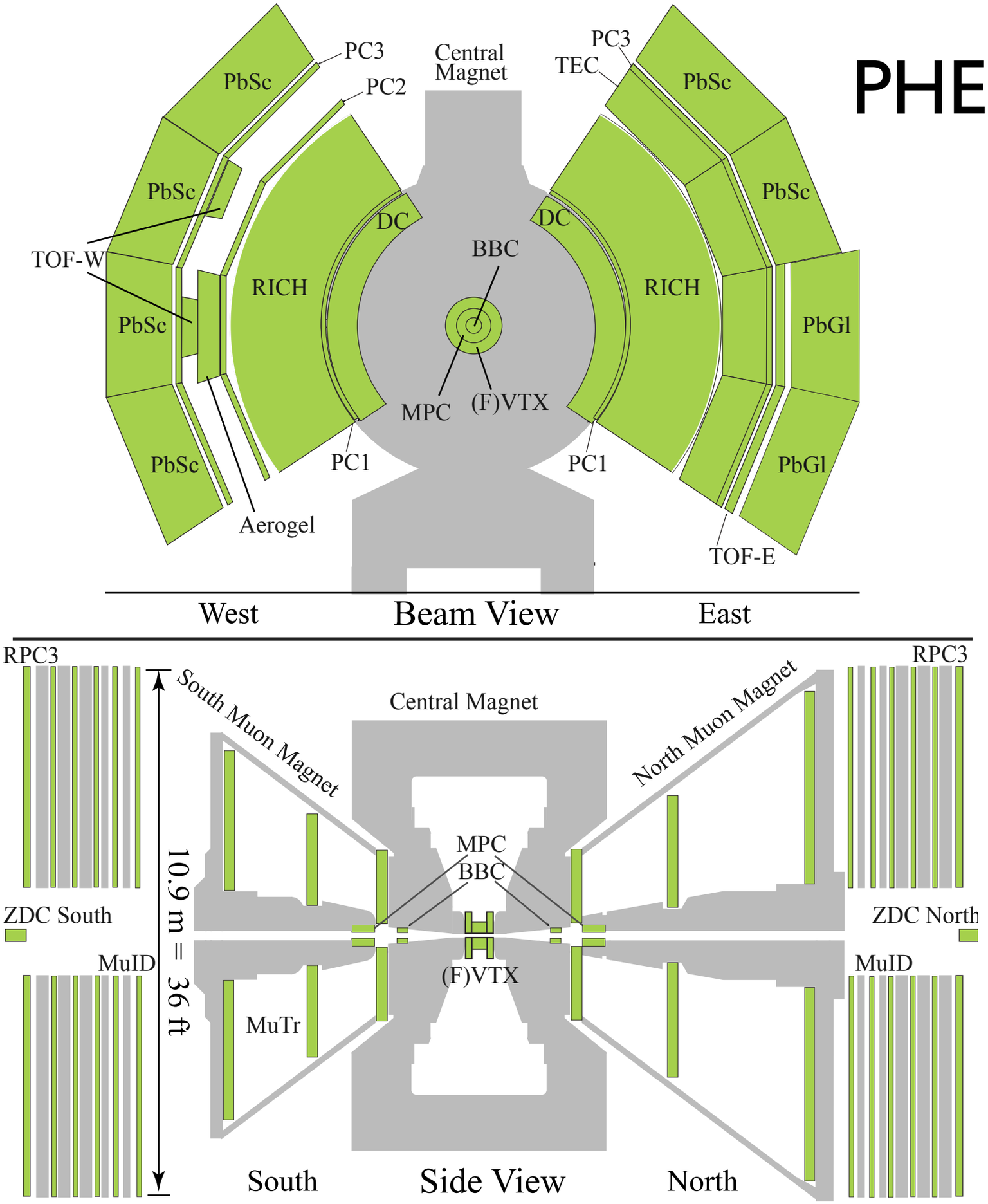






selective acceptance
but
excellent capabilities
within that
acceptance

PHENIX now

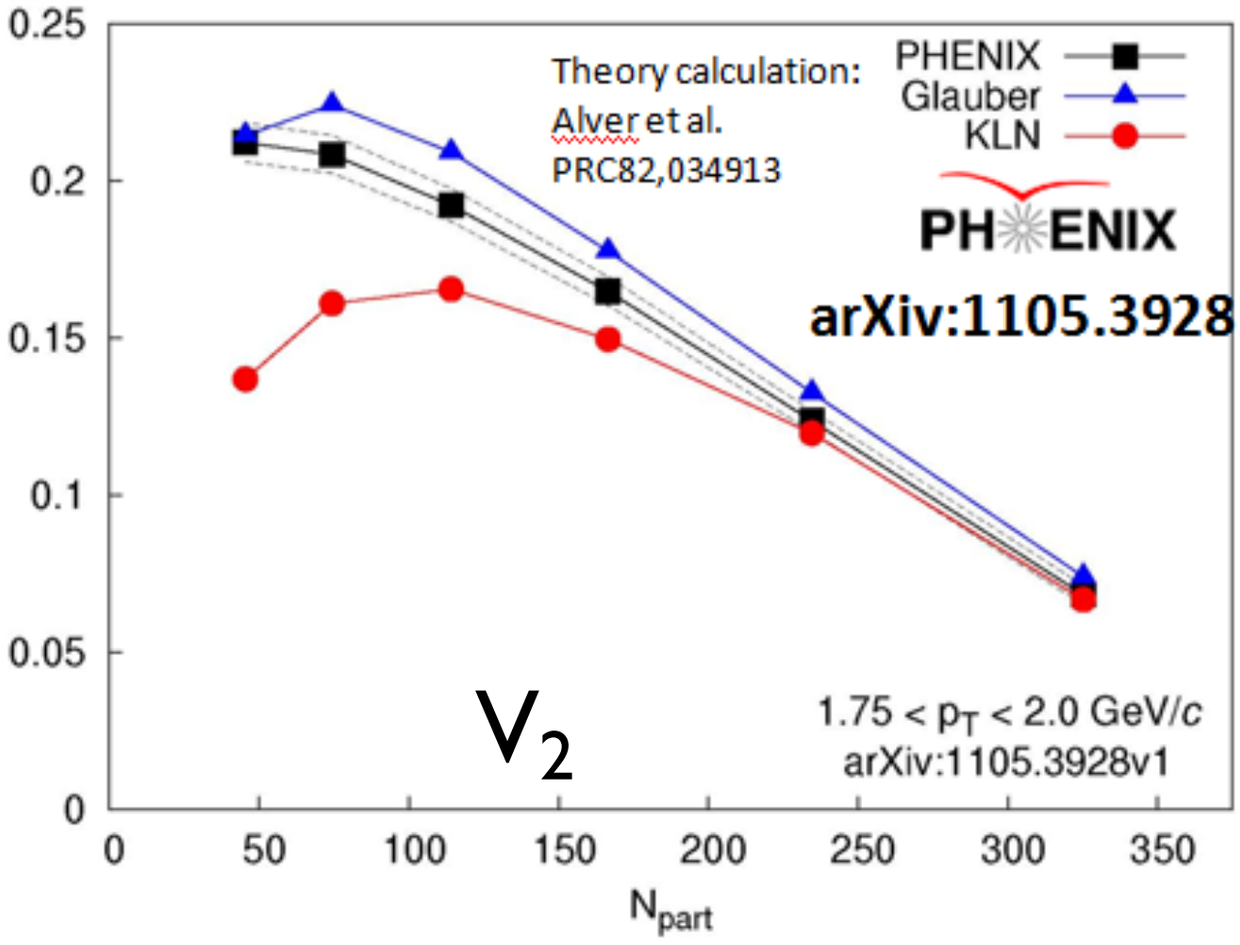

PbSc
PC3
PC2
Central Magnet
TEC
PC3
PbSc
PbSc
PbSc
DC
DC
TOF-W
BBC
RICH
RICH
PbSc
PbGl
MPC
(F)VTX
PbSc
PC1
PC1
PbGl
Aerogel
TOF-E
West
Beam View
East
RPC3
South Muon Magnet
Central Magnet
North Muon Magnet
RPC3
MPC
BBC
ZDC South
ZDC North
10.9 m = 36 ft
MuID
(F)VTX
MuID
MuTr
South
Side View
North

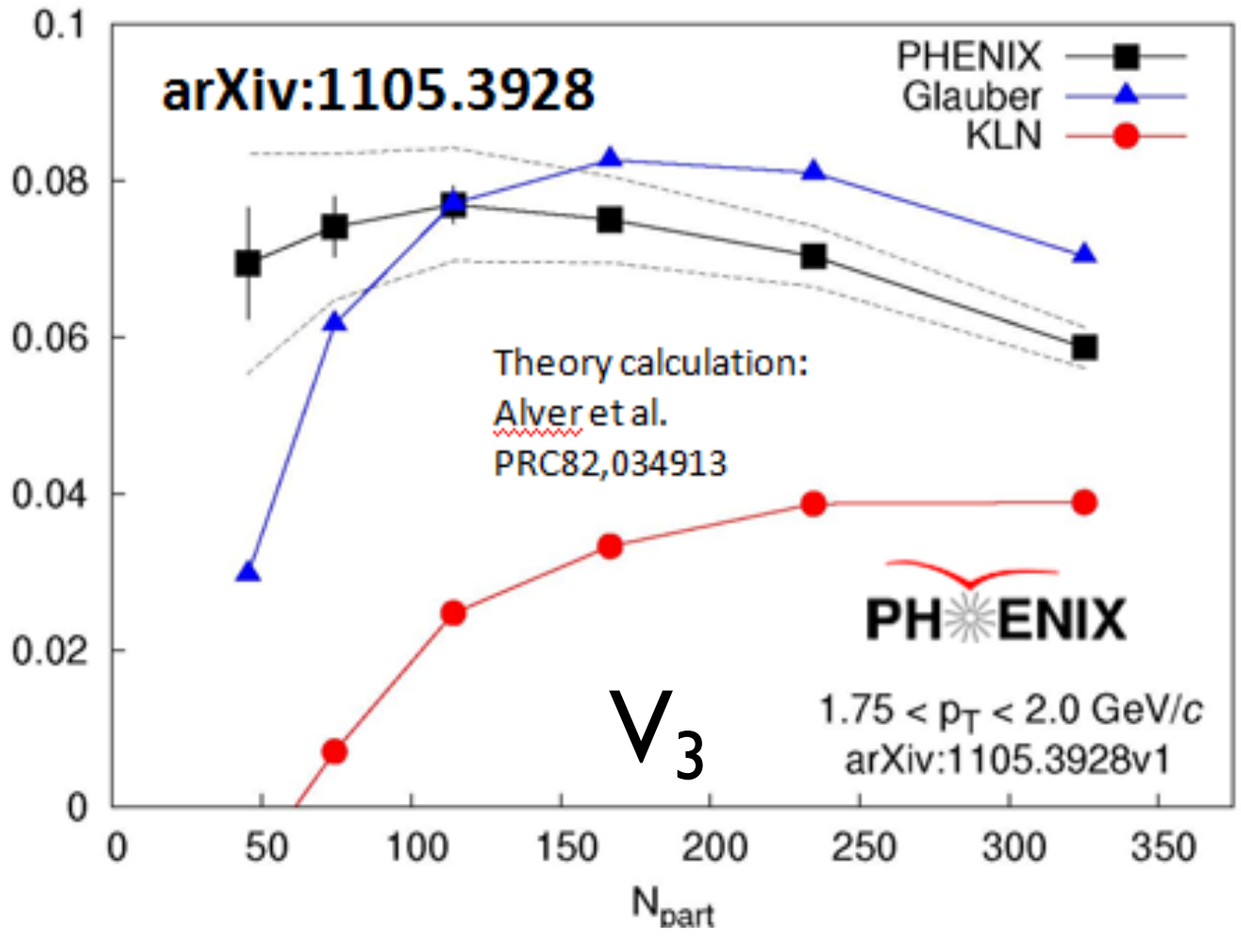
we now have a *very* nice microscope*

Carry out physics program described by M. Leitch

*In fact, VTX has quite large acceptance.

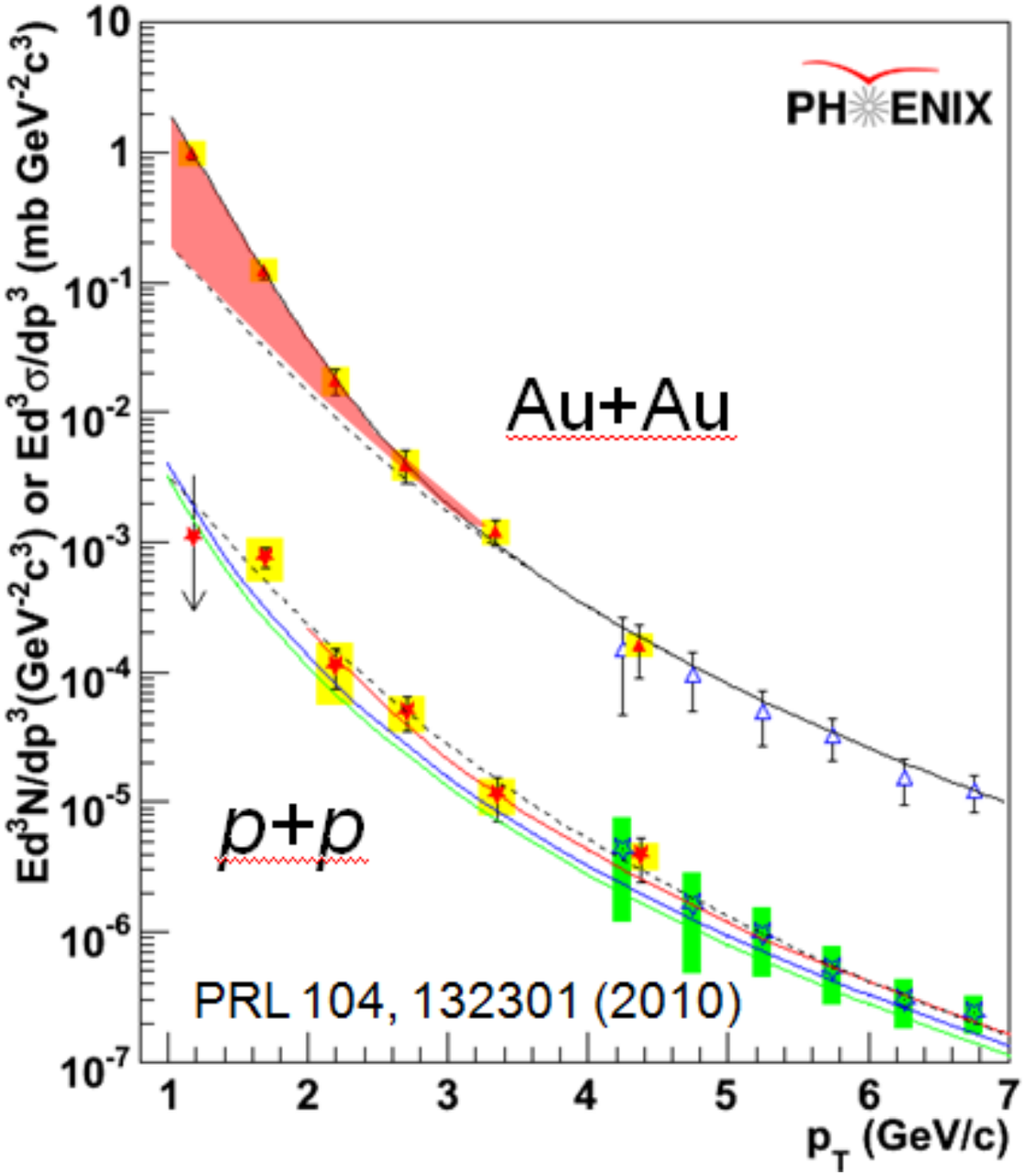
How have we been using our "microscope" lately?

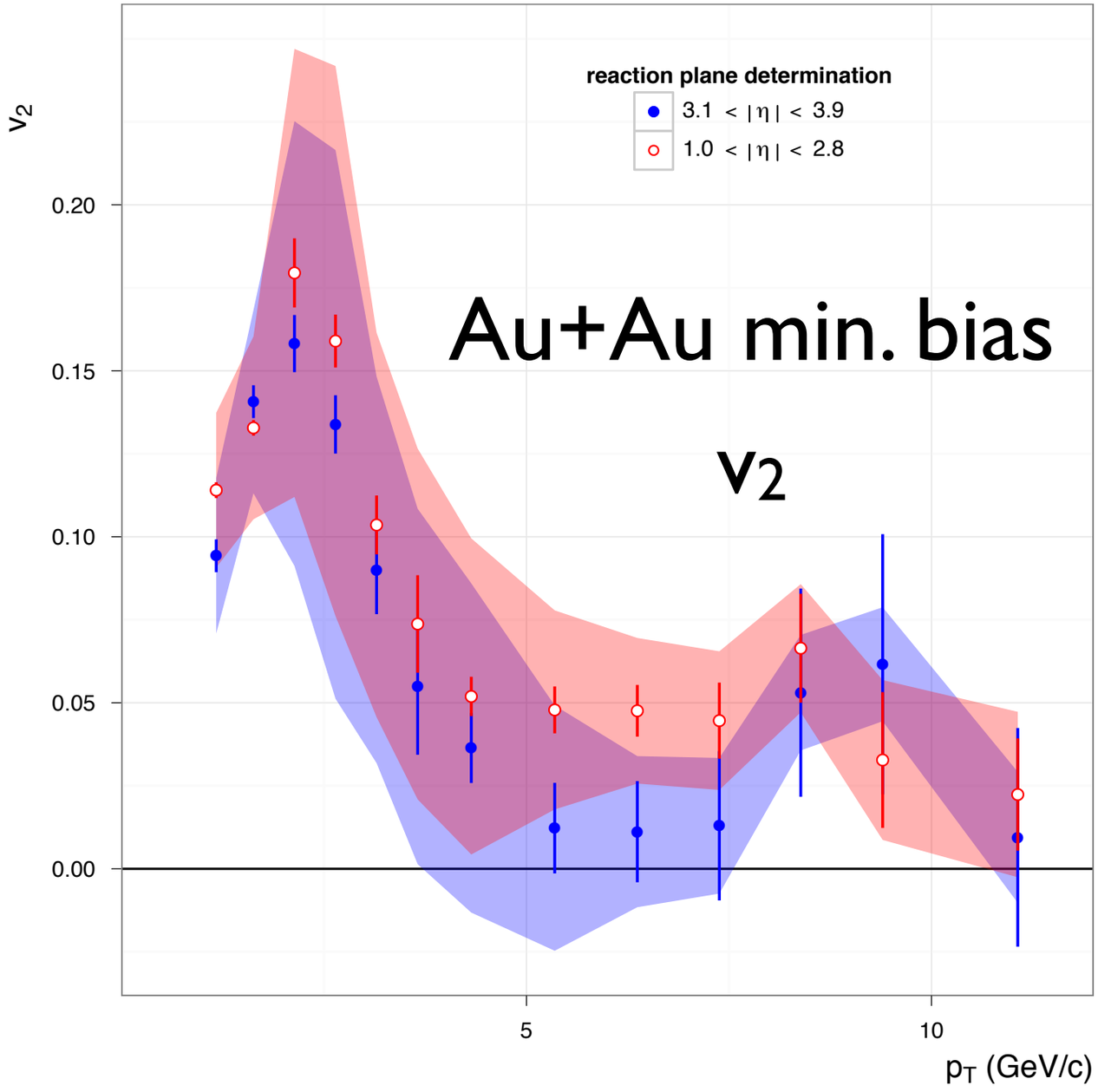




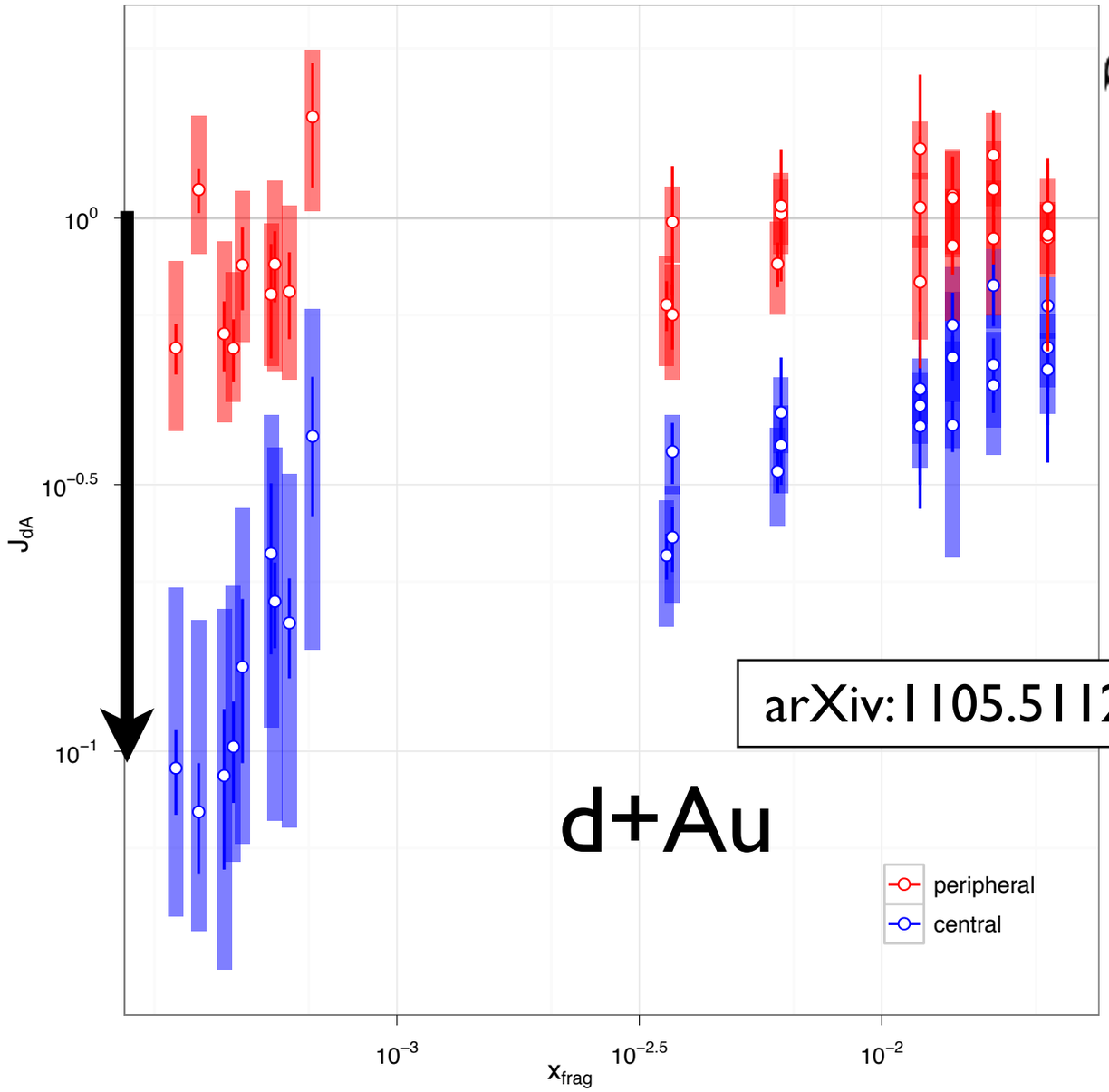
v_2 and v_3 (and v_n)
Glauber initial state and $\eta/s \sim 1/4\pi$ favored,
given current state of calculations

thermal photons T_i =300–600 MeV

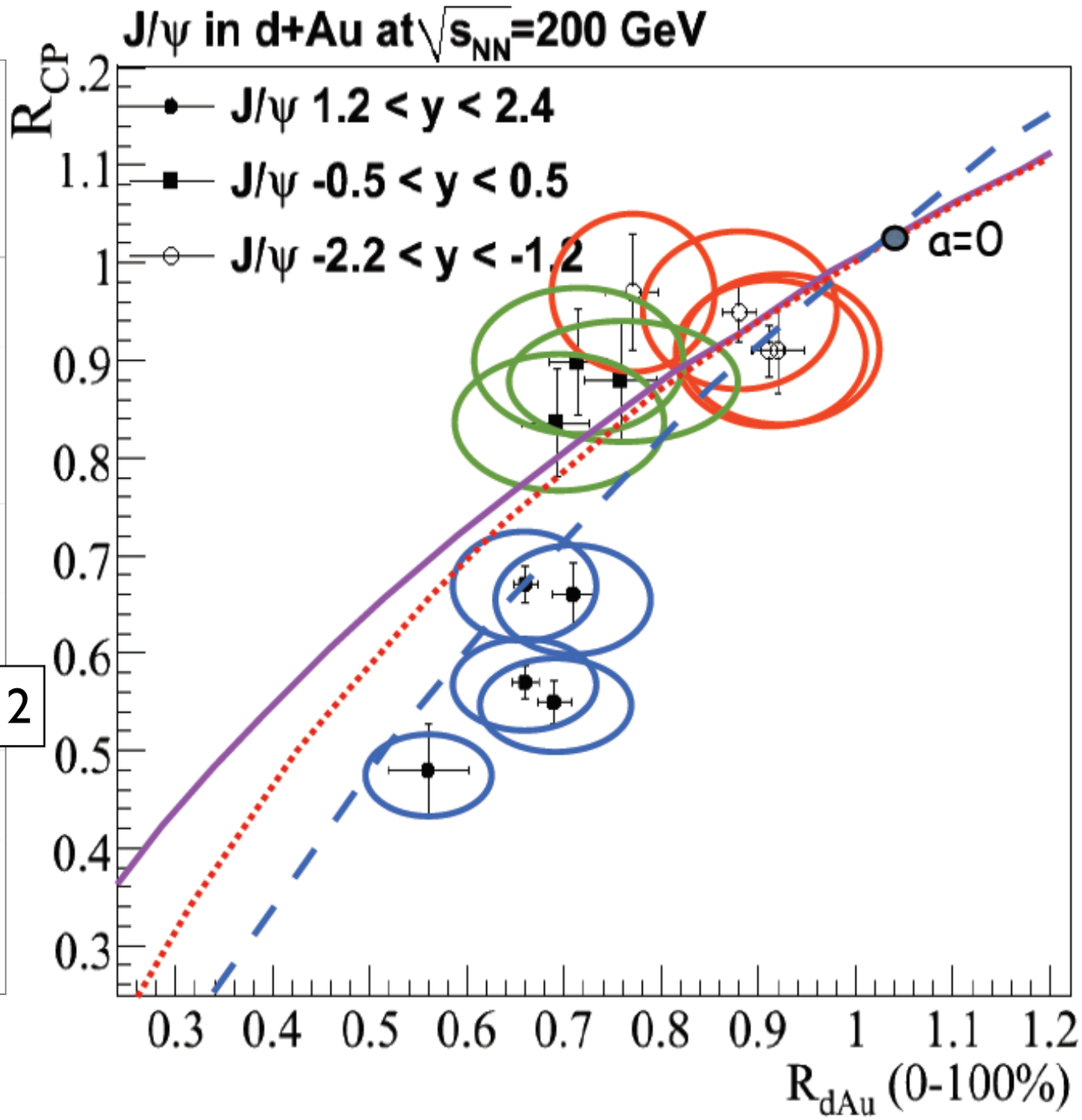




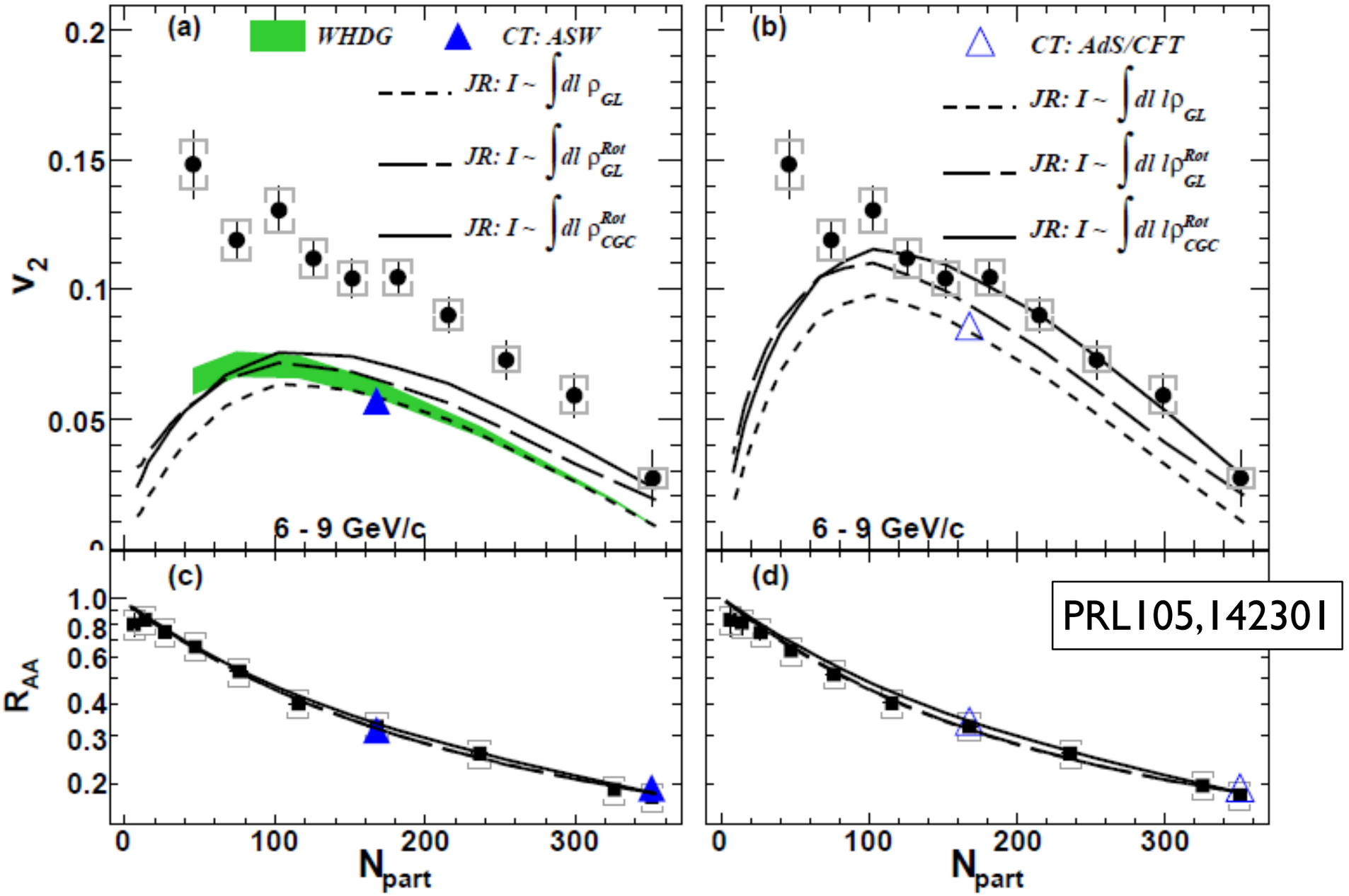
di-hadron suppression at small x: gluon saturation?



detailed study of CNM effect on J/ψ



R_{AA} and v_2 at high p_T
$\Delta E \sim (\text{path length})^3$ favored



PRL105,142301

The PHENIX Experiment at RHIC

Decadal Plan 2011–2020

Brookhaven National Laboratory

Relativistic Heavy Ion Collider

October, 2010

Spokesperson	Barbara Jacak *Stony Brook University*
Deputy Spokesperson	Jamie Nagle *University of Colorado*
Deputy Spokesperson	Yasuyuki Akiba *RIKEN Nishina Center for Accelerator-Based Science*
Operations Director	Ed O'Brien *Brookhaven National Laboratory*
Deputy Operations Director for Upgrades	Mike Leitch *Los Alamos National Laboratory*
Deputy Operations Director for Operations	John Haggerty *Brookhaven National Laboratory*

http://www.bnl.gov/npp

Thinking behind the 2015++ heavy-ion plan

- incrementally adding to PHENIX doesn't paint a compelling future physics program
- soft physics extremely interesting, but on 2015++ timescale, will largely be done
- focus on compelling physics questions, figure out needs, prioritize, be willing to make trade-offs
- work to understand RHIC & LHC complementarity
- maybe the surest course forward is an ambitious one

Questions for 2015++

- Are quarks strongly coupled to the quark-gluon plasma at all interaction distance scales?
- What are the detailed mechanisms for parton-QGP interactions and responses? Are the interactions coherent over the entire medium length scale, what are the dominant energy loss mechanisms?
- Are there quasi-particles in the medium? What are their masses (m) and widths (Γ)?
- Is there a relevant color screening length in the quark-gluon plasma?
- How is rapid equilibration and entropy production achieved?
- What is the nature of color charge in large nuclei? What role does gluon saturation and the EMC effect play in nucleus-nucleus collisions? How do these modifications evolve?

Questions

Observables

Needs

Quarks strongly coupled
Interaction mechanisms

Jets, Dijets,
γ - Jet (FF, radiation)

Quasiparticles in medium

Charm/Beauty Jets

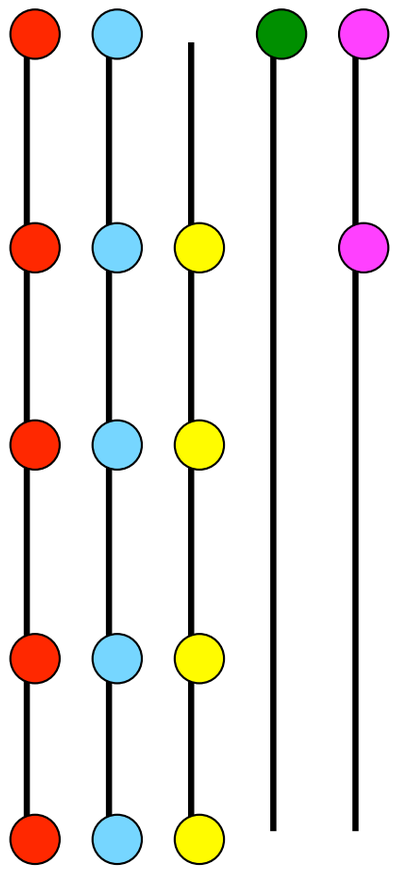
Screening Length

J/ψ at multiple energies

Upsilons (all states)

Thermal Behavior
Thermalization time

Direct γ^* flow

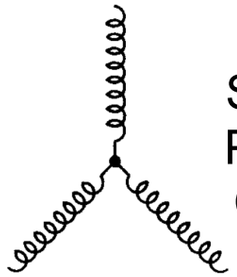


- Large Acceptance
- High Rate
- Electron ID
- Photon ID
- Excellent Jet Capabilities (HCAL)

Probe Integrates Over a Range of Q^2

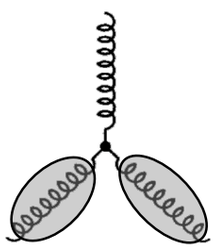
Q^2

P_T Initial Parton



pQCD Scattering from Point-Like Bare Color Charges

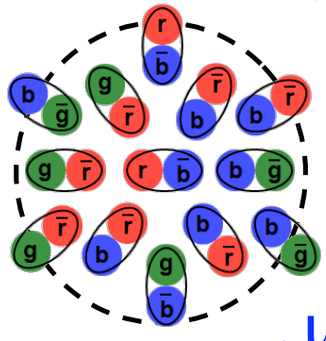
What scale sets this transition?



Scattering from Thermal Mass Gluons?

What scale sets this transition?

pQCD Scattering From Quasiparticles with size ~ μ_{Debye}

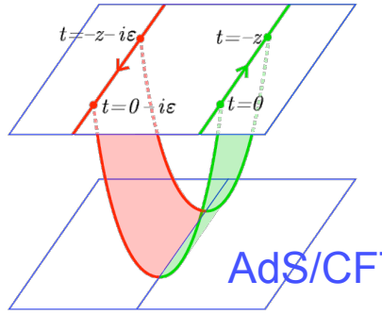


?→

← ?

Strong Coupling No Quasiparticles

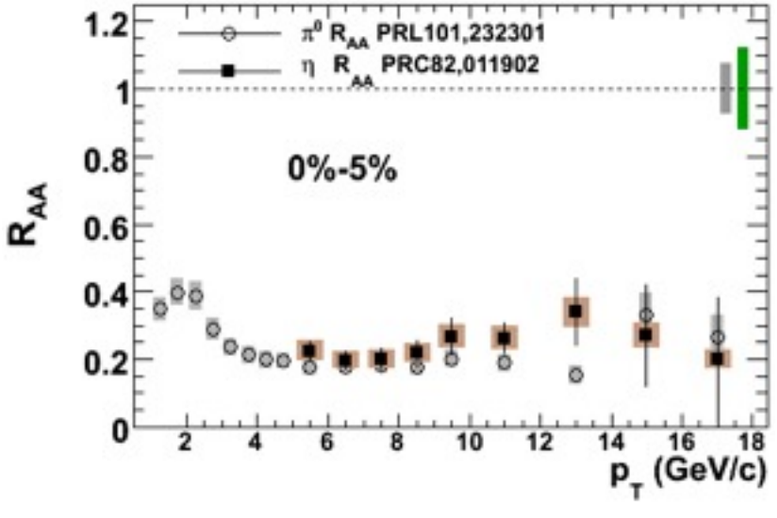
$\mu_{Debye} \rightarrow 0$



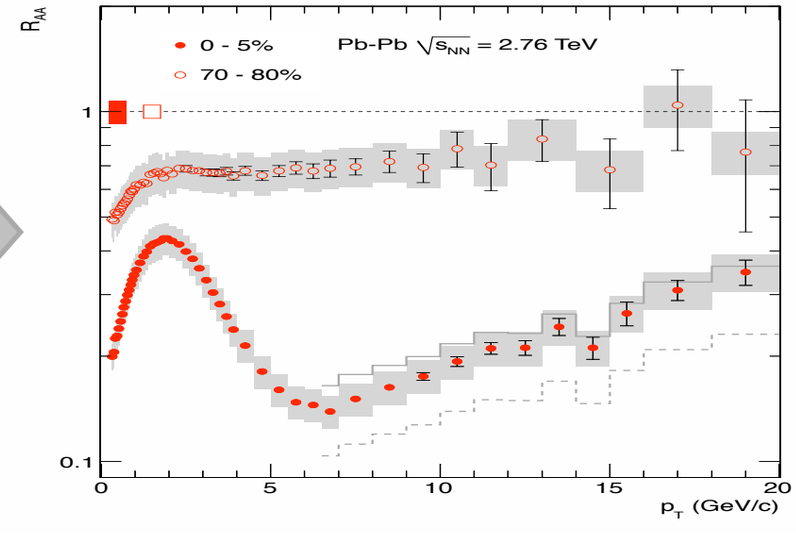
T_c

W. Horowitz

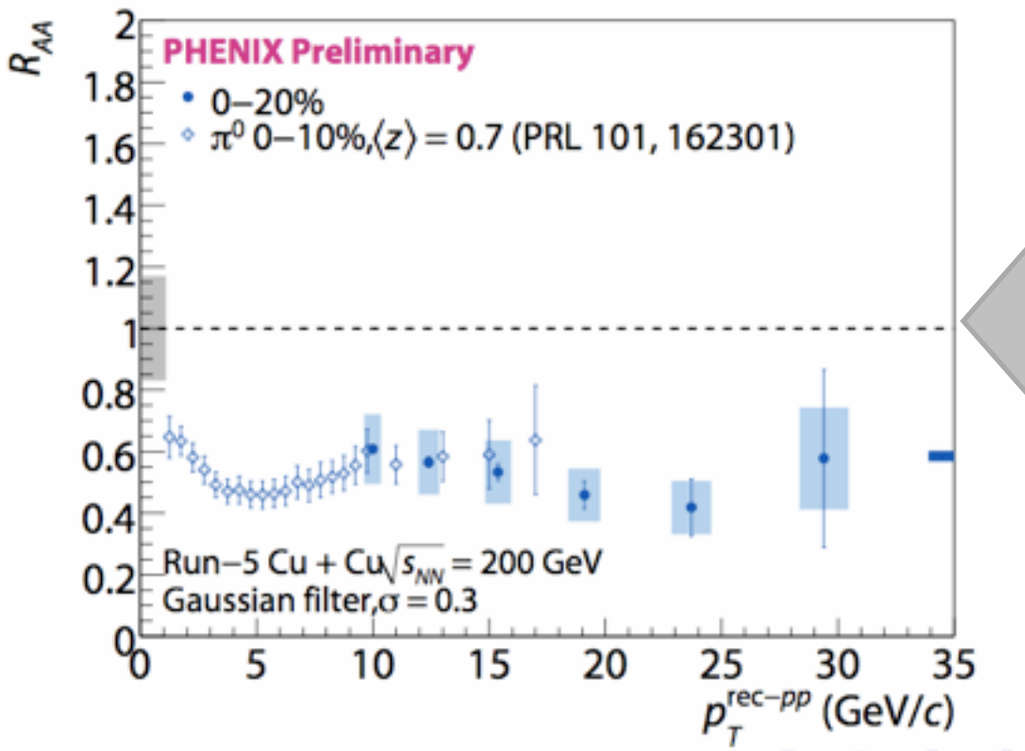
1 & 2 particles @ RHIC



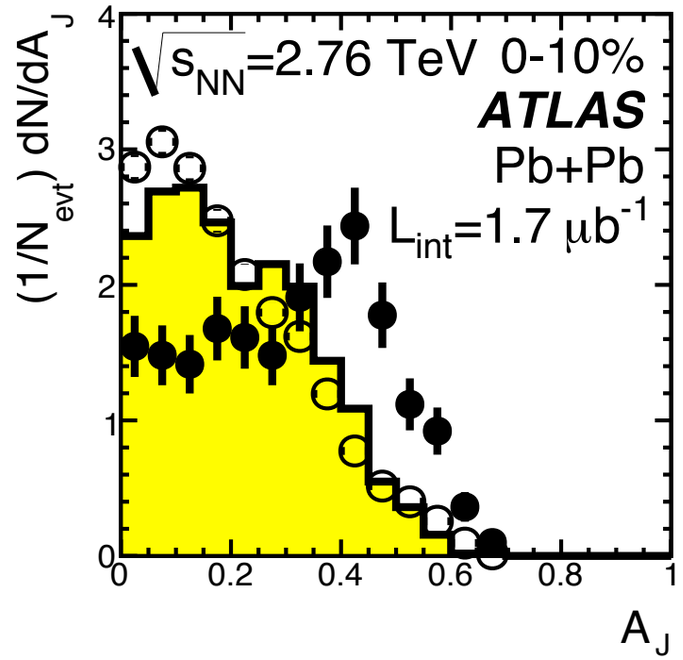
1 & 2 particles @ LHC



jets @ RHIC



jets @ LHC

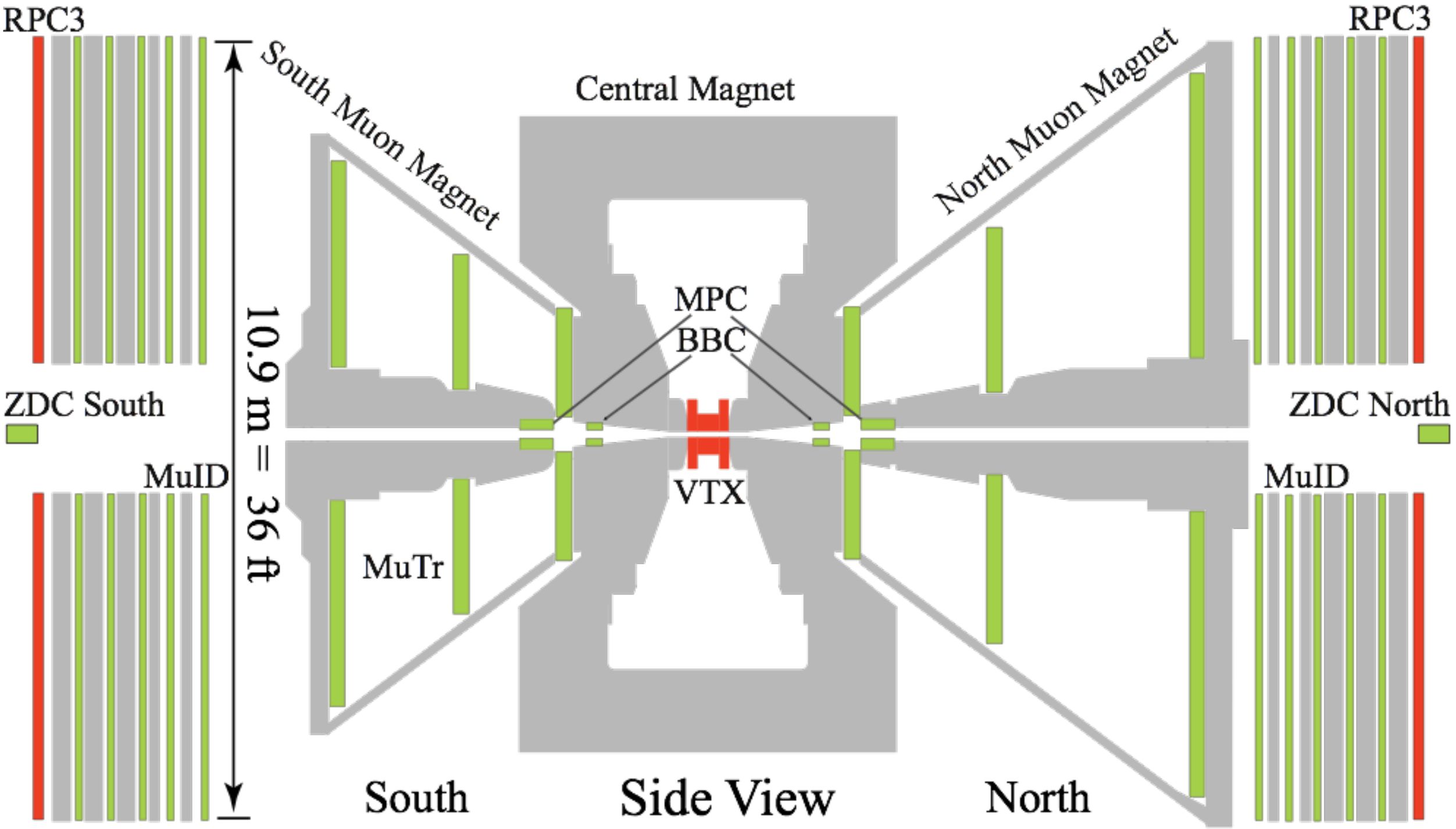


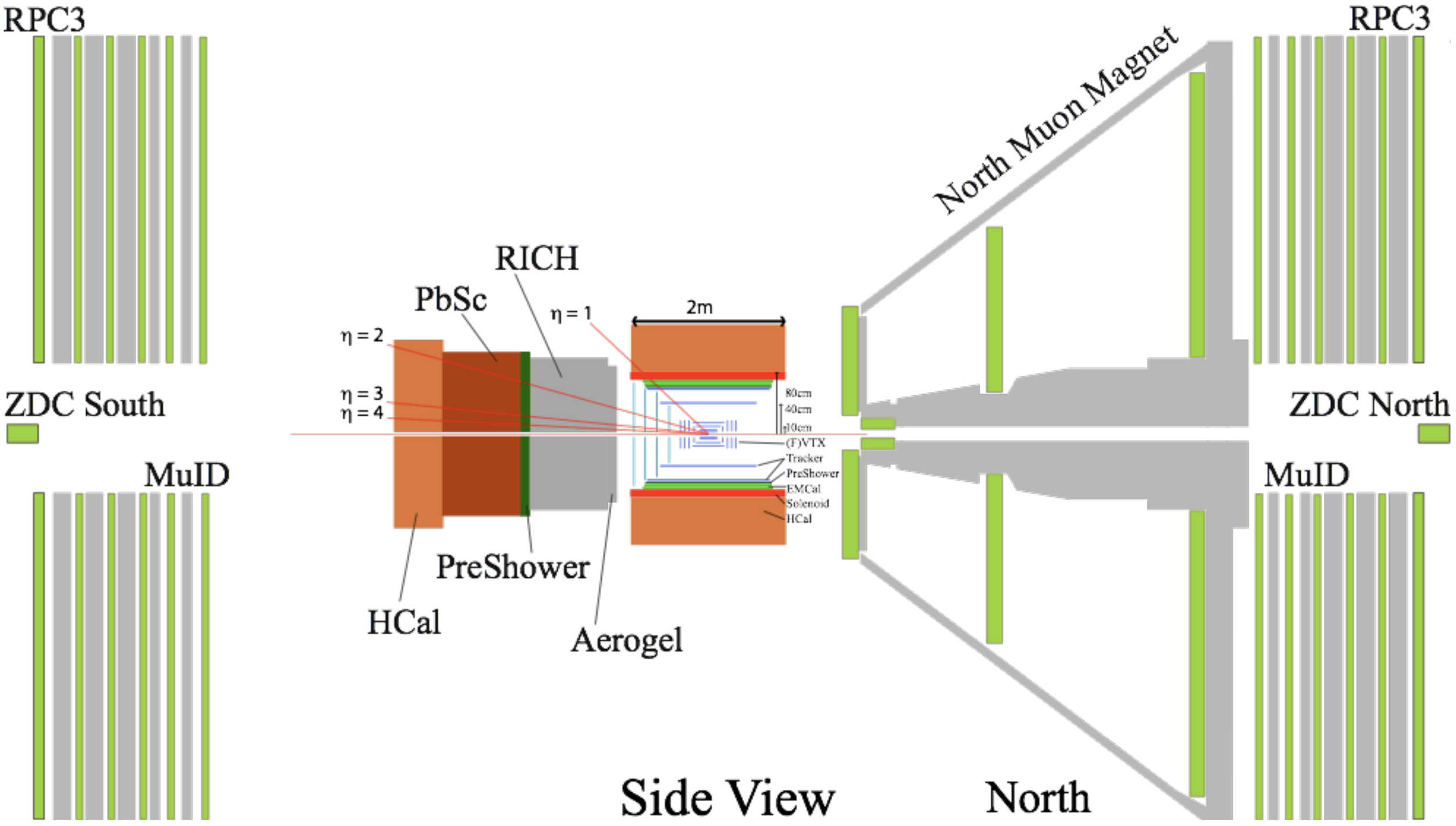
What's needed?

- Establish length dependence of energy loss.
- Establish energy dependence of energy loss.
- Measure medium modification of angular and momentum distribution of radiated energy.
- Measure quark mass dependence of energy loss.

- Many opportunities at RHIC and LHC:
  - Tagged jets (energy, flavor)
  - Angle dependence
  - System size dependence
  - Fully reconstructed jets
- A world-class jet detector at RHIC is needed

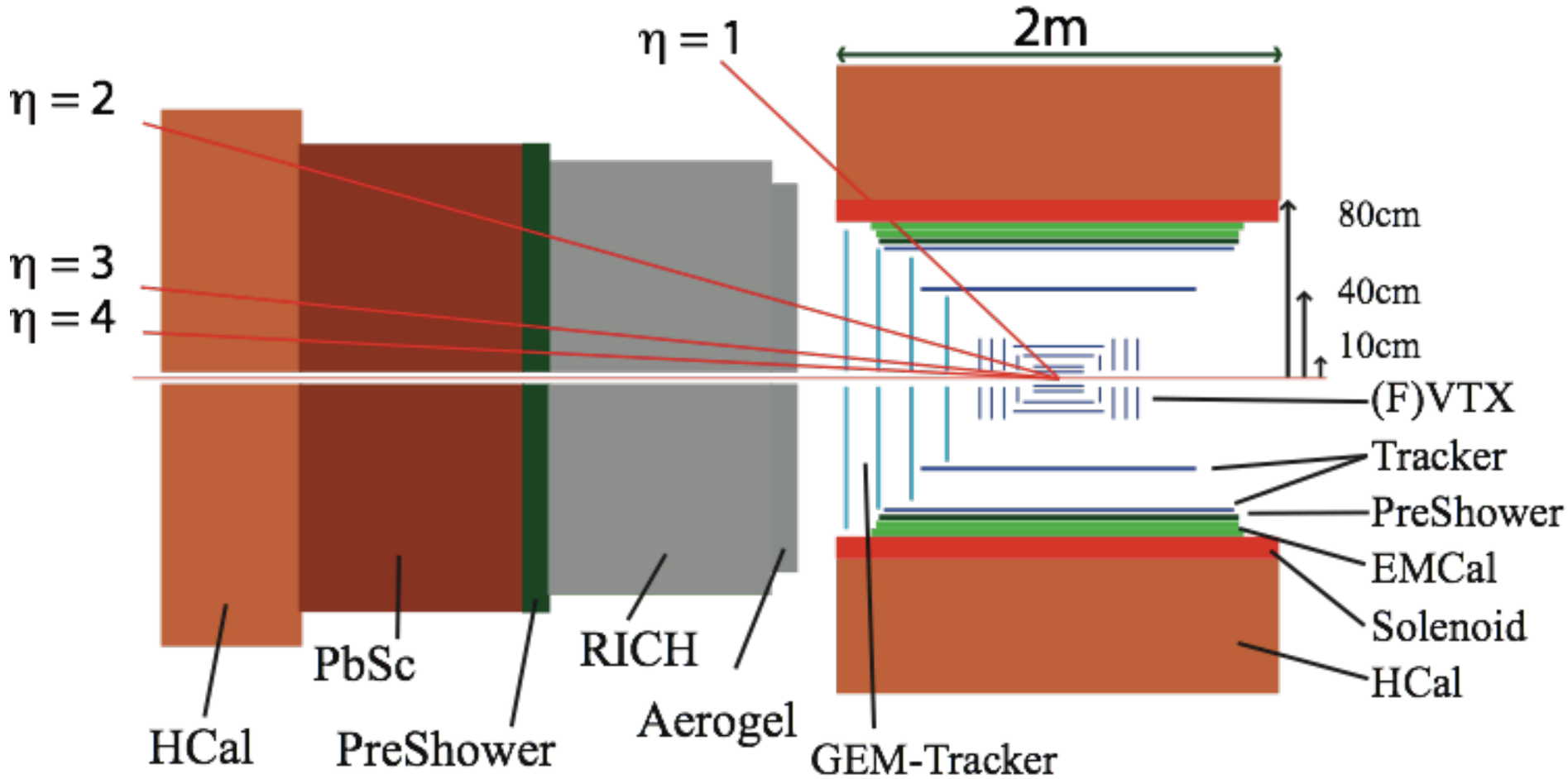
B. Mueller, Hard Probes 2010


RPC3
South Muon Magnet
Central Magnet
North Muon Magnet
RPC3
MPC
BBC
ZDC South
ZDC North
10.9 m = 36 ft
MuID
VTX
MuID
MuTr
South
Side View
North



Retain F/VTX + infrastructure (incl. very fast data acquisition)

sPHENIX strawman



dimensions, technology, additional capabilities still under investigation

Quark Matter 2011 (May 22-28) a Watershed:

Impressions and lessons learned, continued:

3) RHIC's importance substantiated – the nature of the matter produced does not change much from RHIC to LHC collisions; LHC analyses very rapid since based on techniques already perfected over years at RHIC.

4) The power and scope of the LHC exp'ts is very clear! The broader momentum range and higher multiplicity of outgoing particles, the higher-energy emerging jets, the finer granularity of some subsystems – all allow prolific characterization of QGP matter very similar to that at RHIC. On the other hand, probably only one more Pb+Pb run at LHC before 2015.

5) Watch out especially for CMS, which may well dominate future jet and quarkonium analyses (without DOE support for ATLAS heavy ions)!

6) Excellent presentations by 5 strong collaborations, with mostly corroborative results ⇒ a heady, but not long-term sustainable, experience!

7) Challenge for RHIC: give greatest emphasis in future plans to exploiting those capabilities that are unique or world-leading at RHIC !

S. Vigdor, PAC Meeting (and this morning)

Quark Matter 2011 (May 22-28) a Watershed:

Impressions and lessons learned, continued:

3) RHIC's importance substantiated – the nature of the matter produced does not change much from RHIC to LHC collisions; LHC analyses very rapid since based on techniques already perfected over years at RHIC.

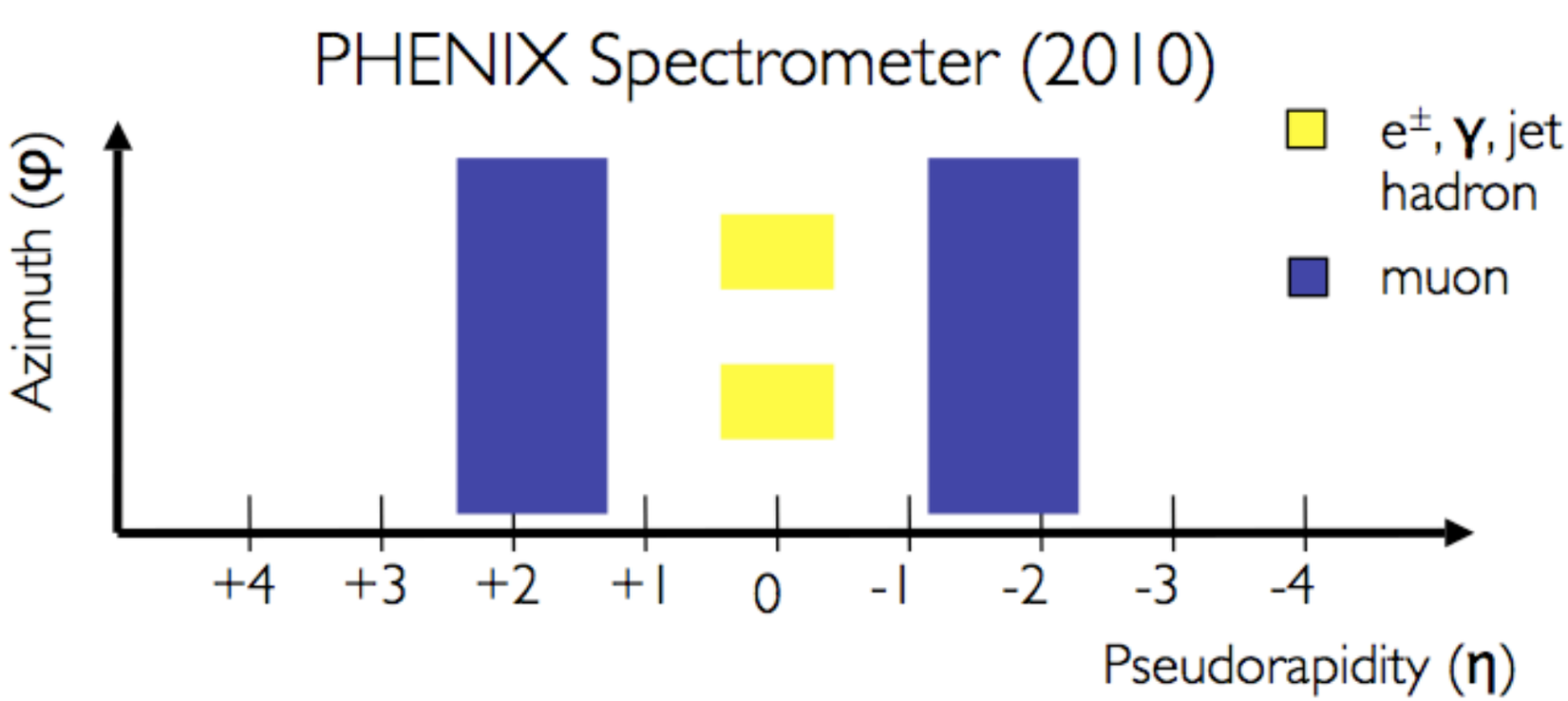
4) The power and scope of the LHC exp'ts is very clear! The broader momentum range and higher multiplicity of outgoing particles, the higher-energy emerging jets, the finer granularity of some subsystems – all allow prolific characterization of QGP matter very similar to that at RHIC. On the other hand, probably only one more Pb+Pb run at LHC before 2015.

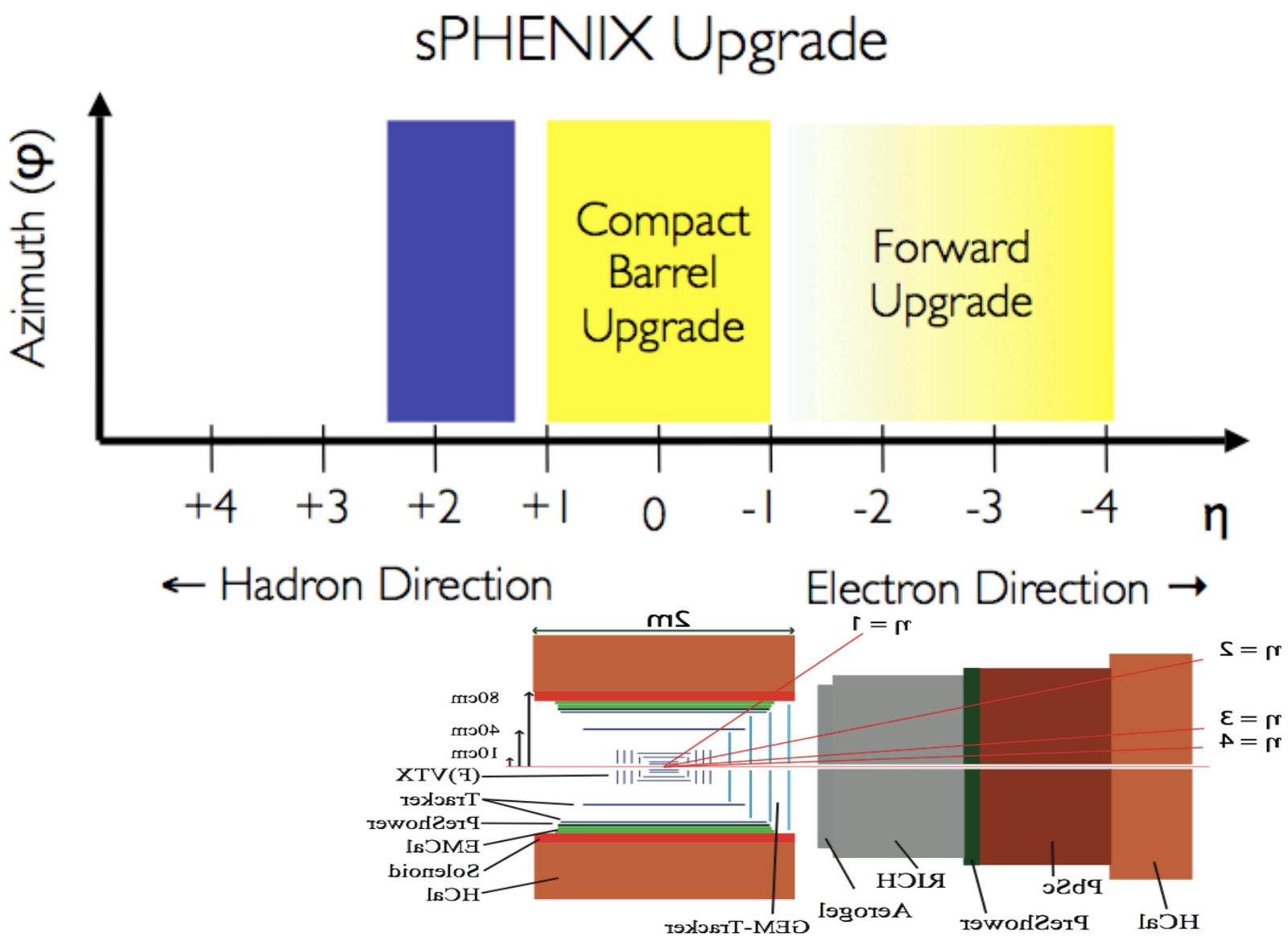
5) Watch out especially for CMS, which may well dominate future jet and quarkonium analyses (without DOE support for ATLAS heavy ions)!

6) Excellent presentations by 5 strong collaborations, with mostly corroborative results ⇒ a heady, but not long-term sustainable, experience!

7) Challenge for RHIC: give greatest emphasis in future plans to exploiting those capabilities that are unique or world-leading at RHIC !

S. Vigdor, PAC Meeting (and this morning)


PHENIX Spectrometer (2010)
e±, γ, jet
hadron
muon
Azimuth (φ)
+4
+3
+2
+1
0
-1
-2
-3
-4
Pseudorapidity (η)


sPHENIX Upgrade
Azimuth (φ)
Compact
Barrel
Upgrade
Forward
Upgrade
+4
+3
+2
+1
0
-1
-2
-3
-4
η
← Hadron Direction
Electron Direction →

timeline

ALICE, ATLAS, CMS

2010 2020

VTX
FVTX

separated charm, bottom

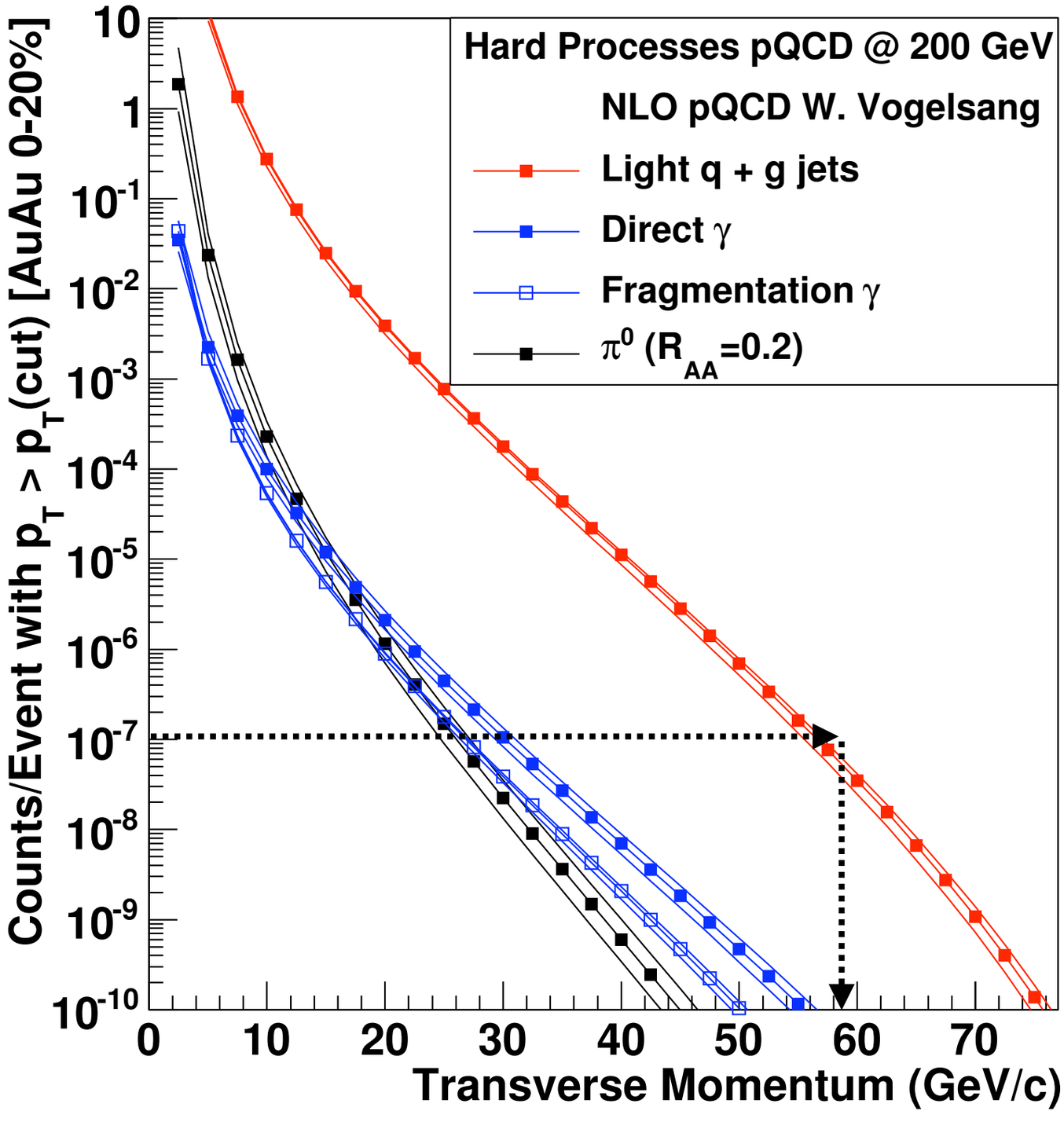
HFT
MTD

separated charm, bottom
+
large acceptance
+
upsilons (45%, $|\eta| < 0.5$)

sPHENIX

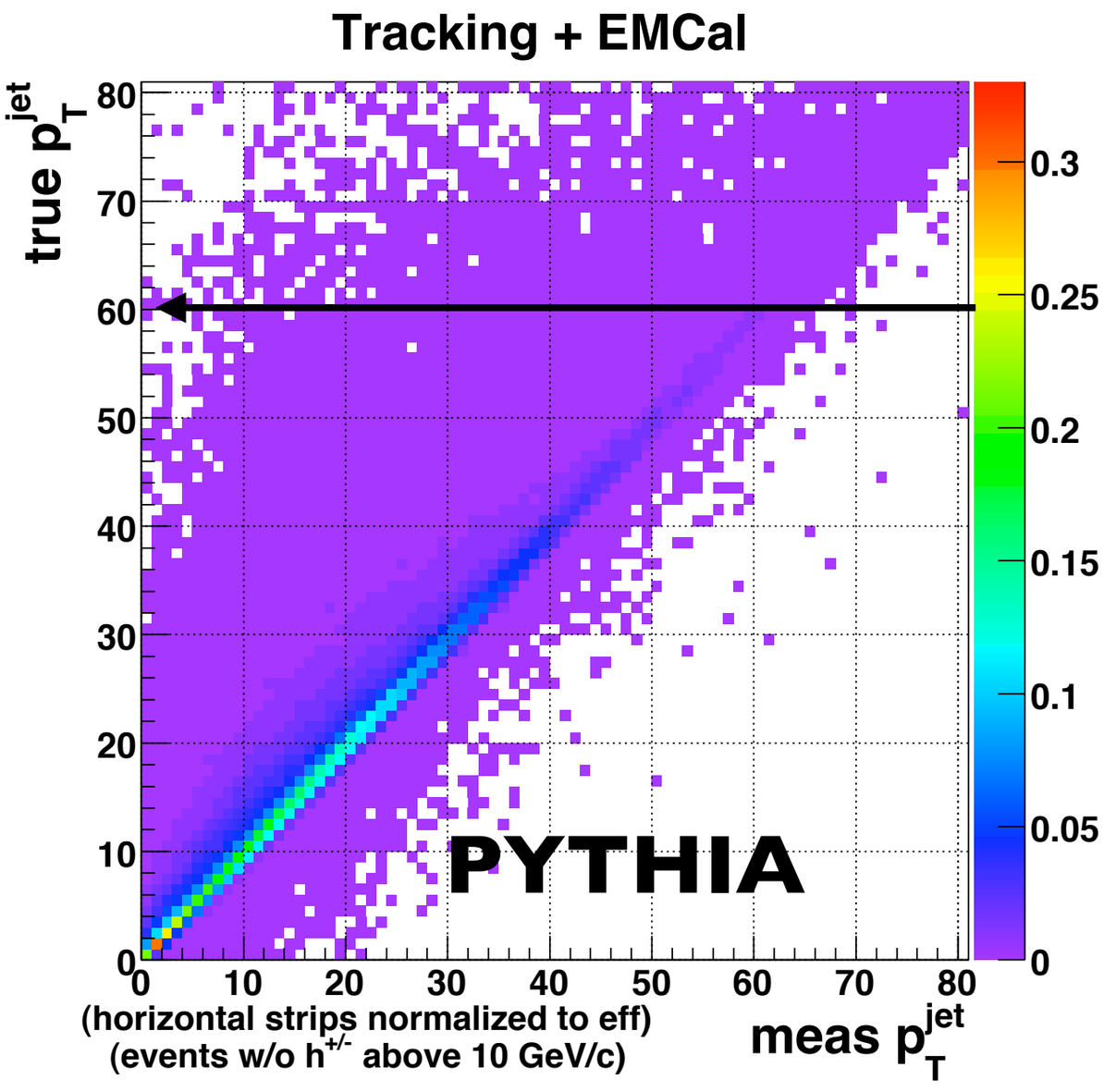
large acceptance
+
50 billion min. bias / year
+
jets

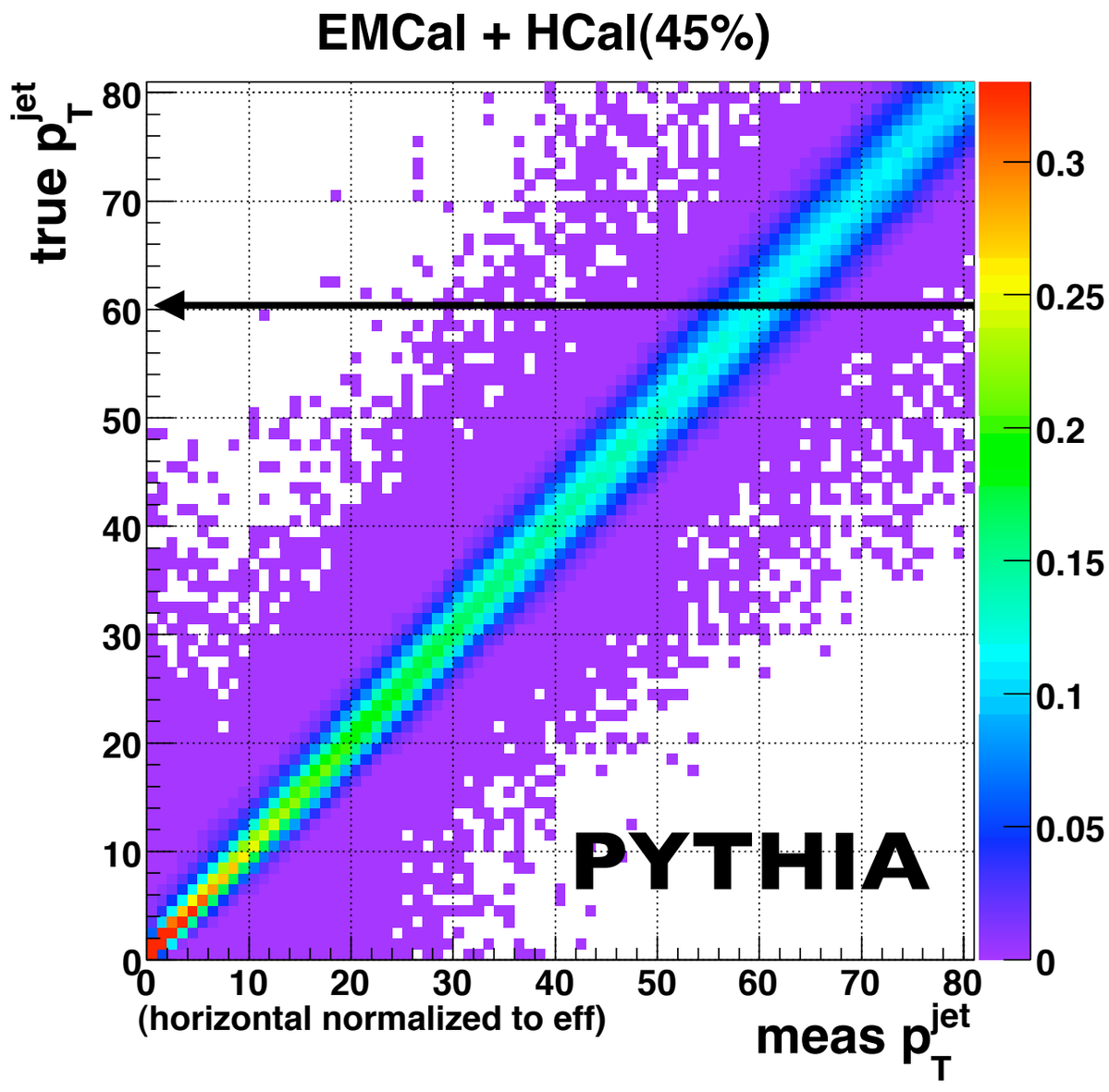
jet, photon, and π^0 rates in $|\eta| < 1$



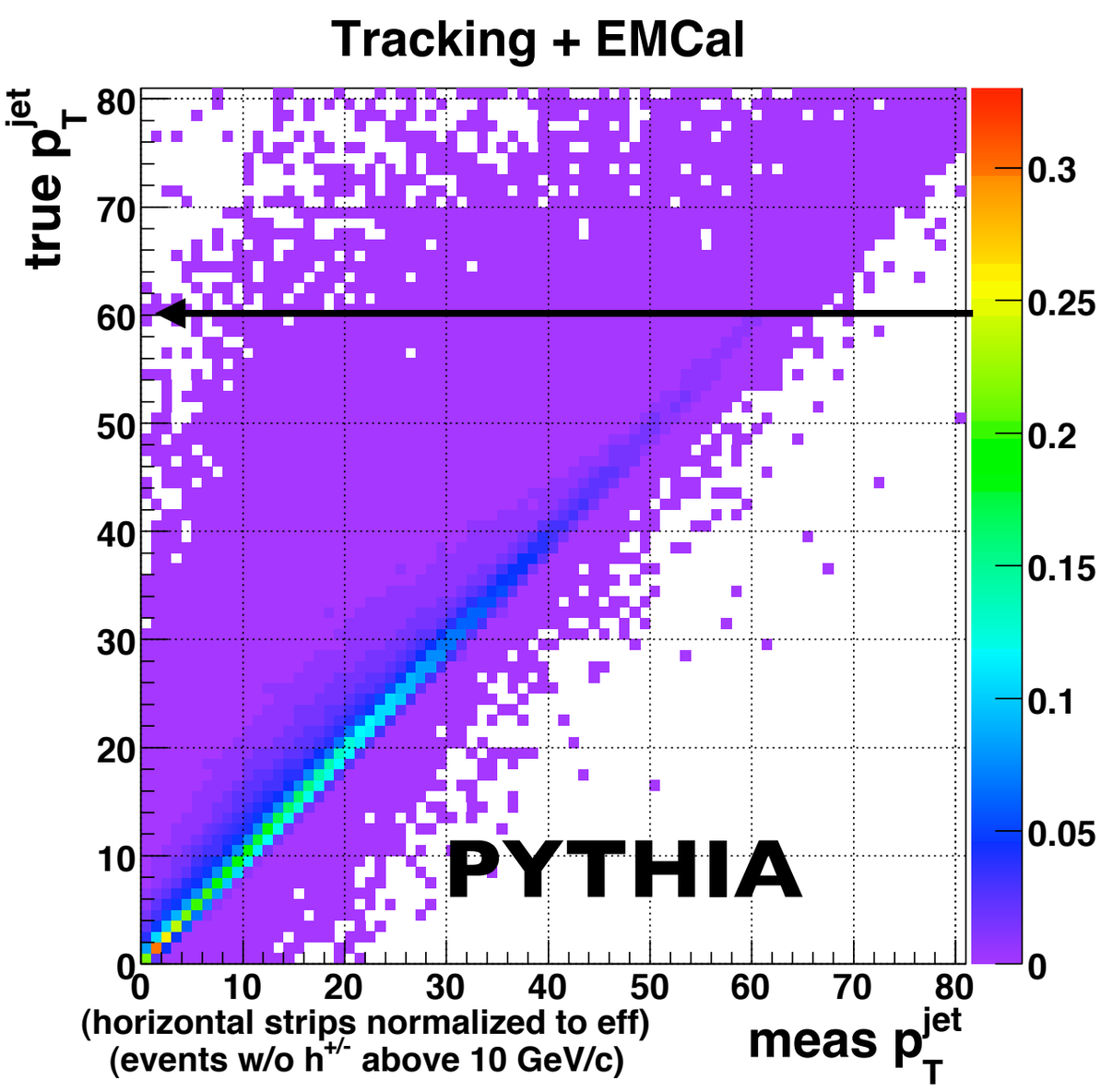
(50x10^9 events $\Rightarrow$ 10^{10} central events)

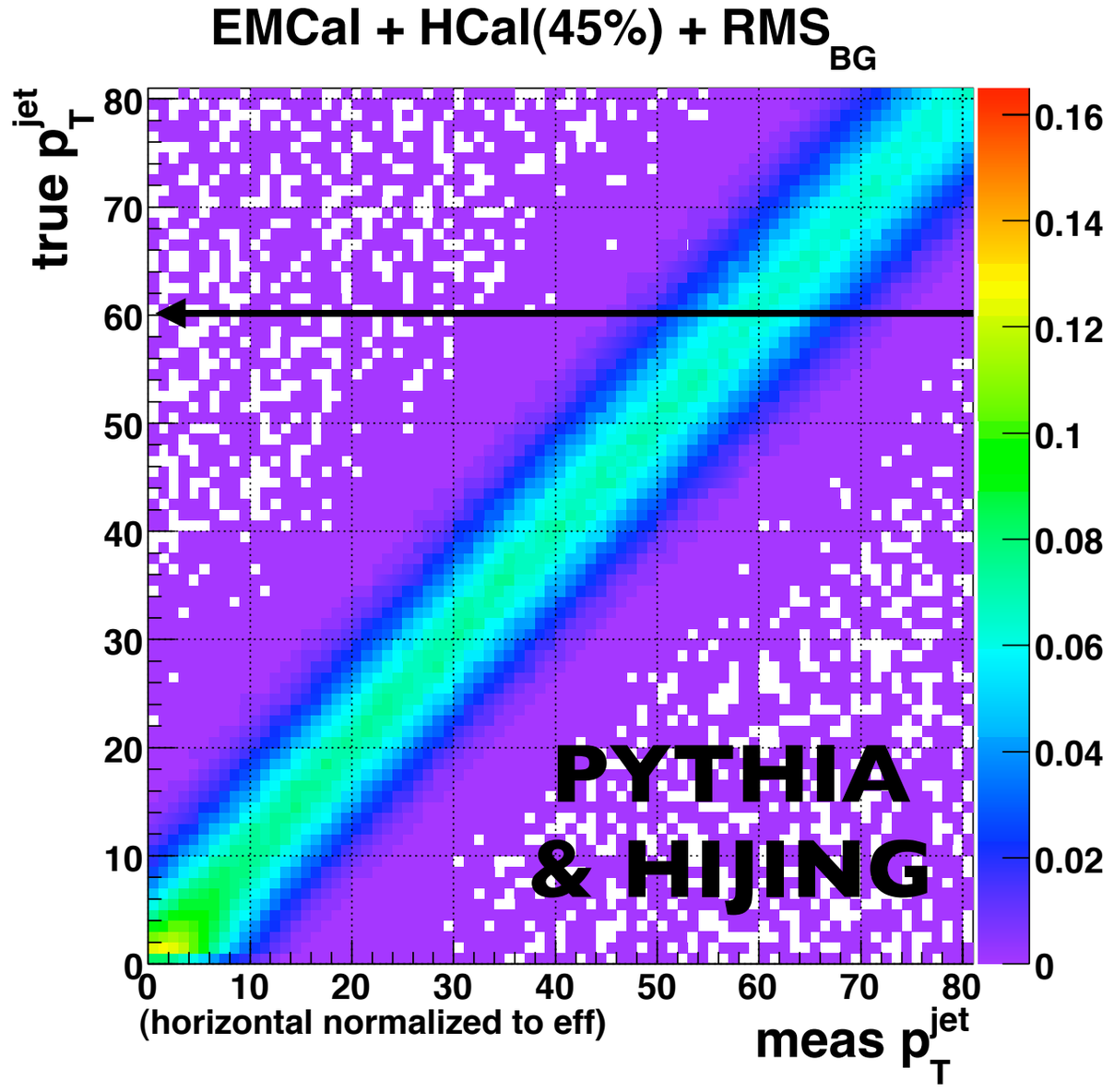
W. Vogelsang, private comm.



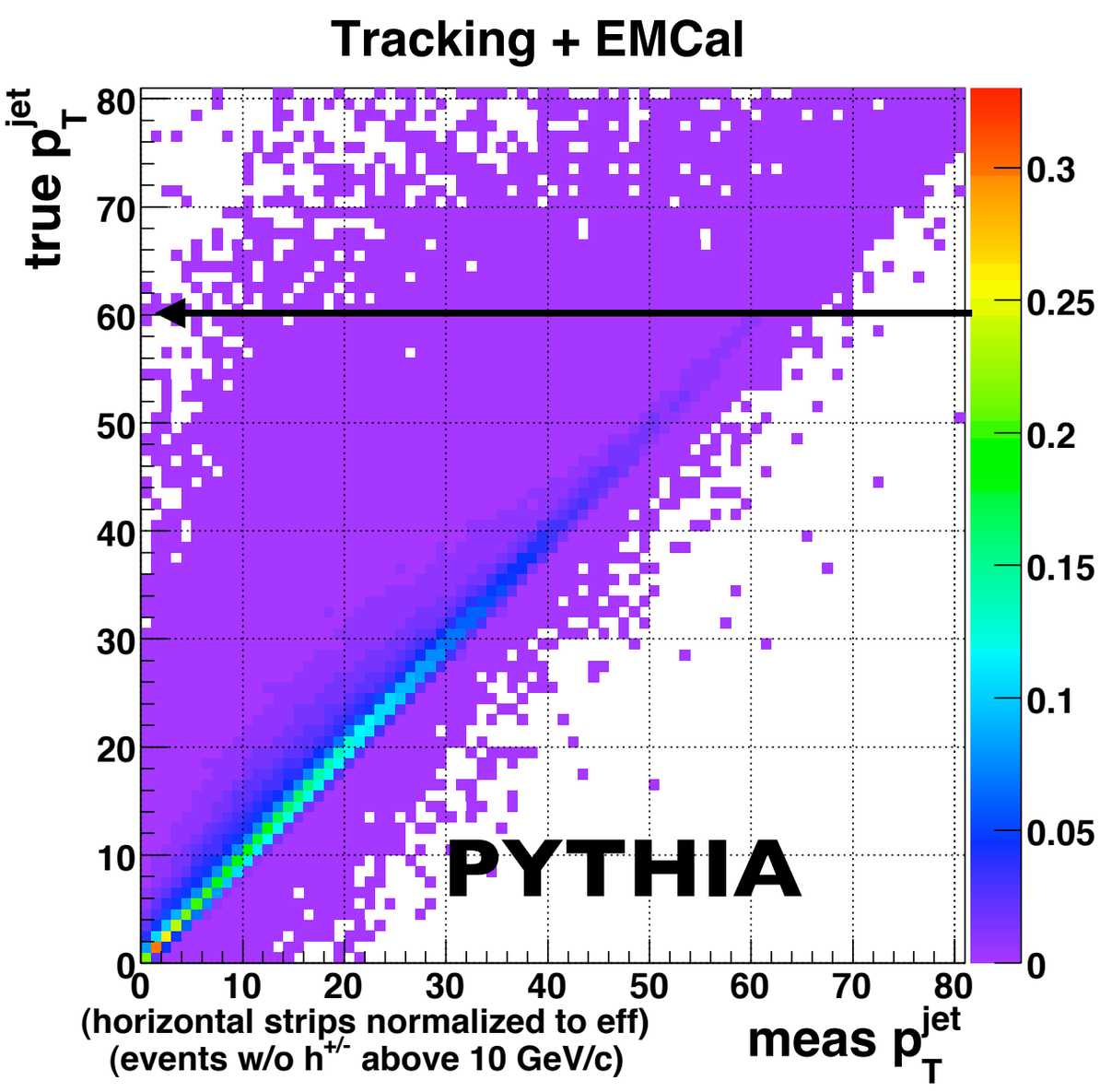


CDF, D0, ATLAS, CMS, ALEPH, DELPHI, OPAL, L3, UA1, UA2, SLD, ILD, SiD

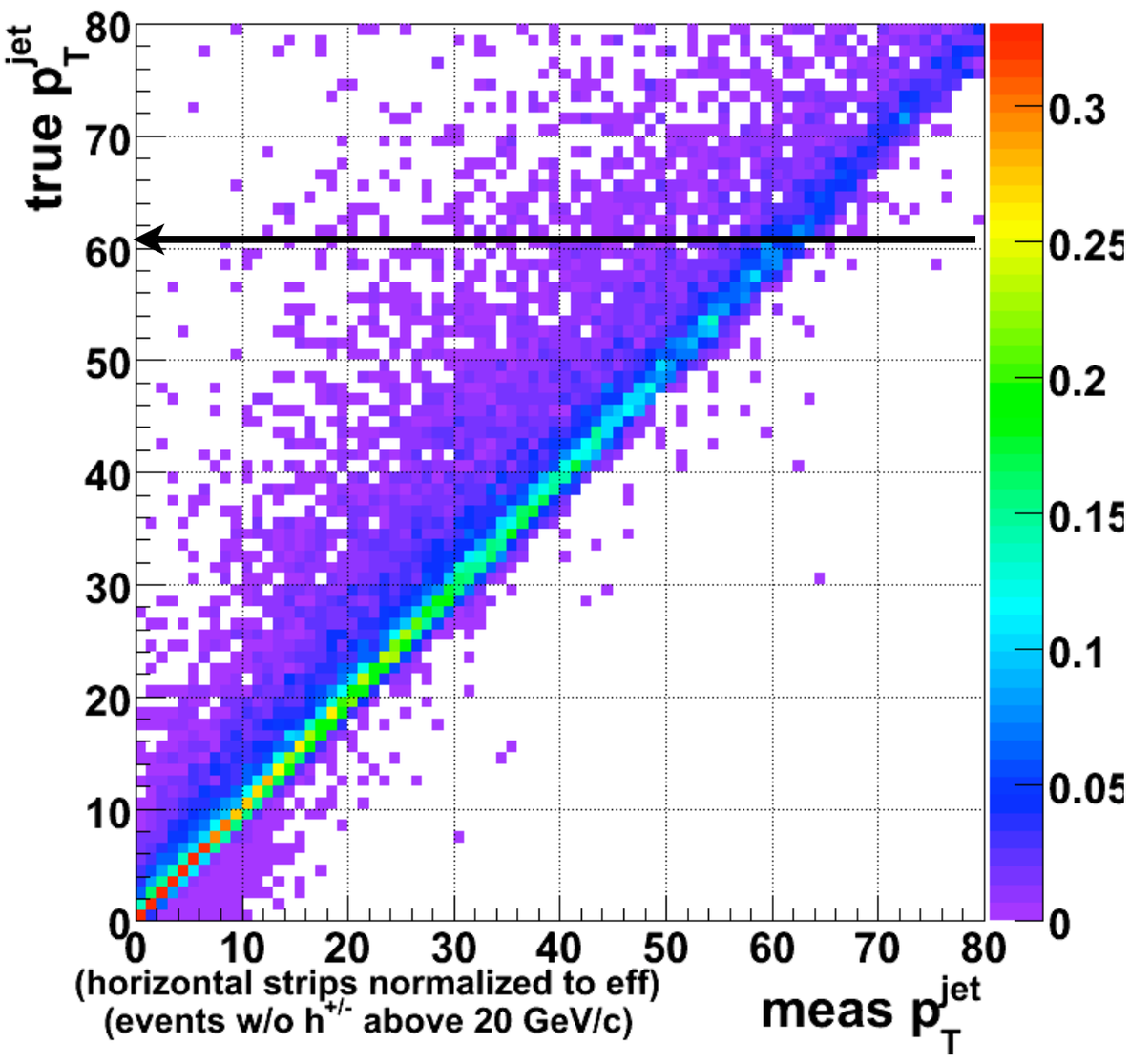




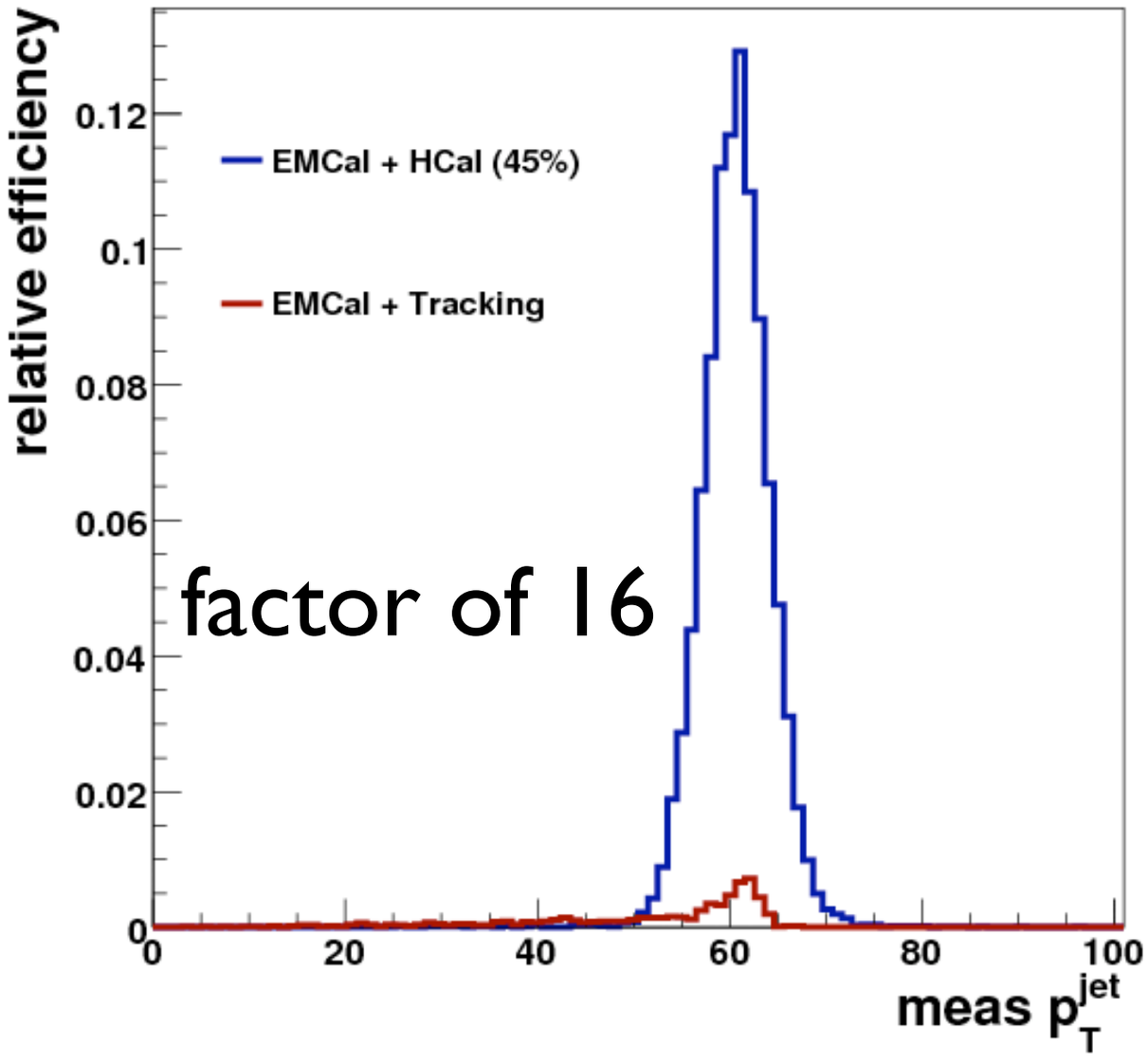
CDF, D0, ATLAS, CMS, ALEPH, DELPHI, OPAL, L3, UA1, UA2, SLD, ILD, SiD



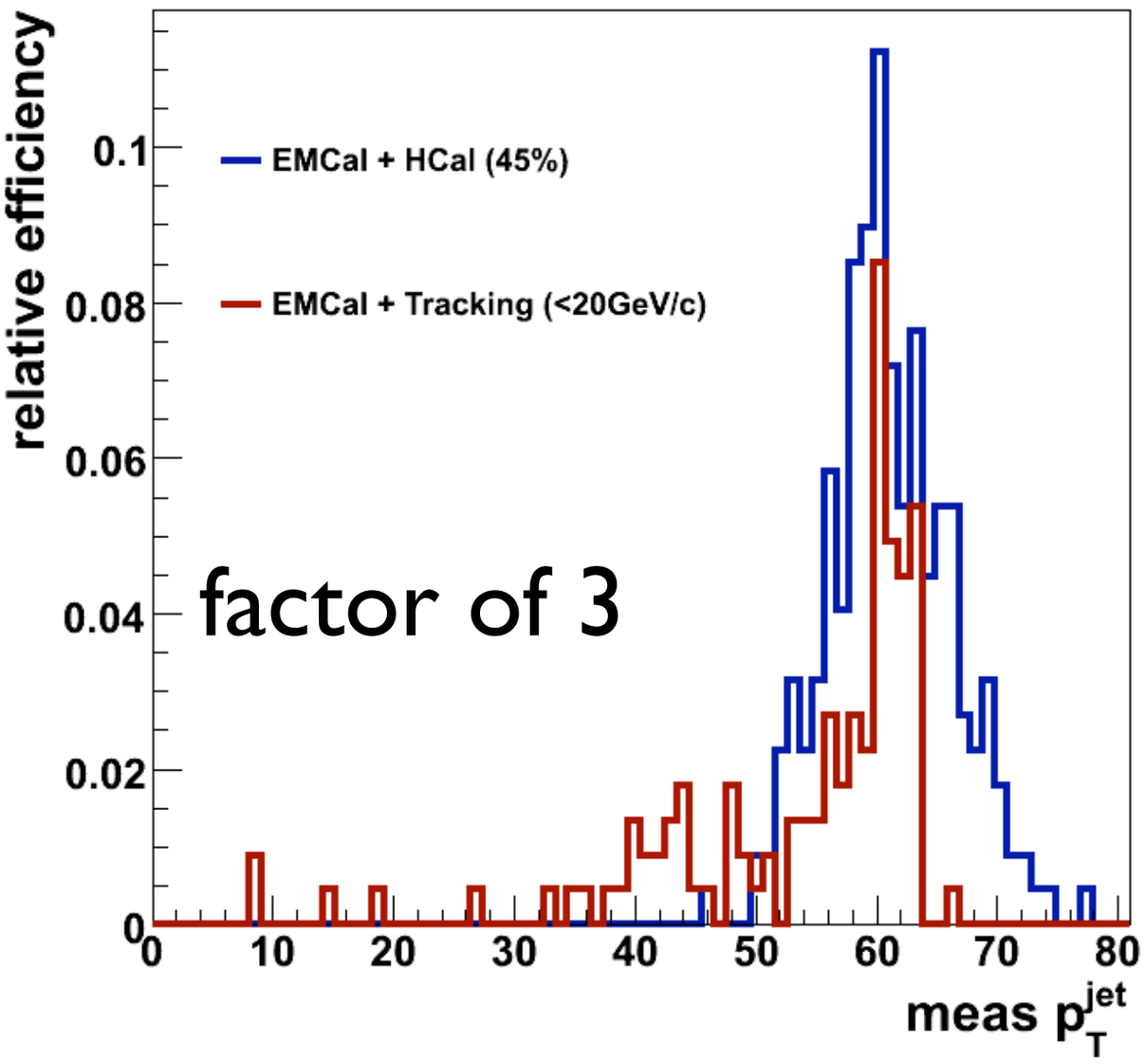
10 GeV cutoff



20 GeV cutoff

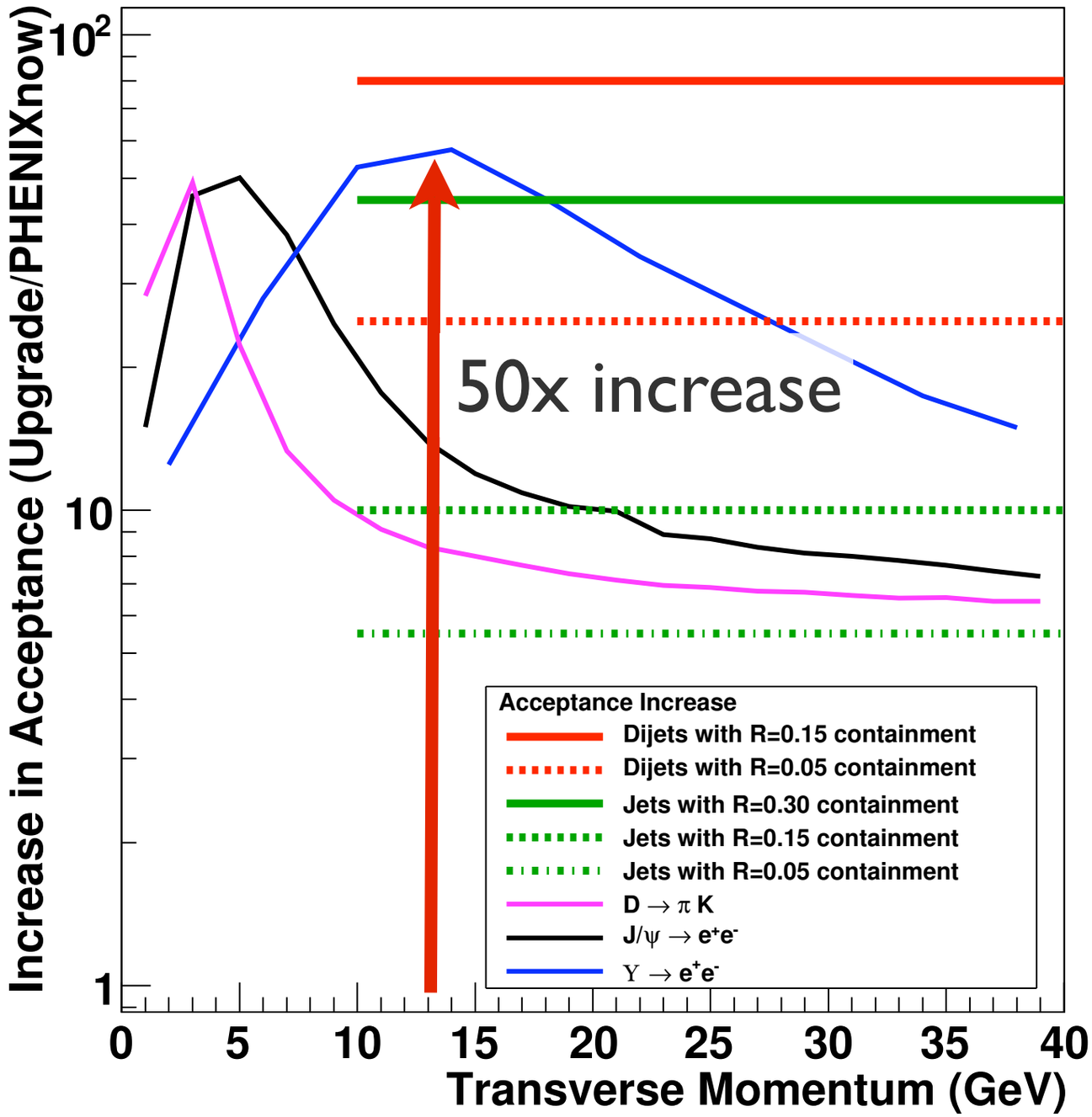


10 GeV cutoff

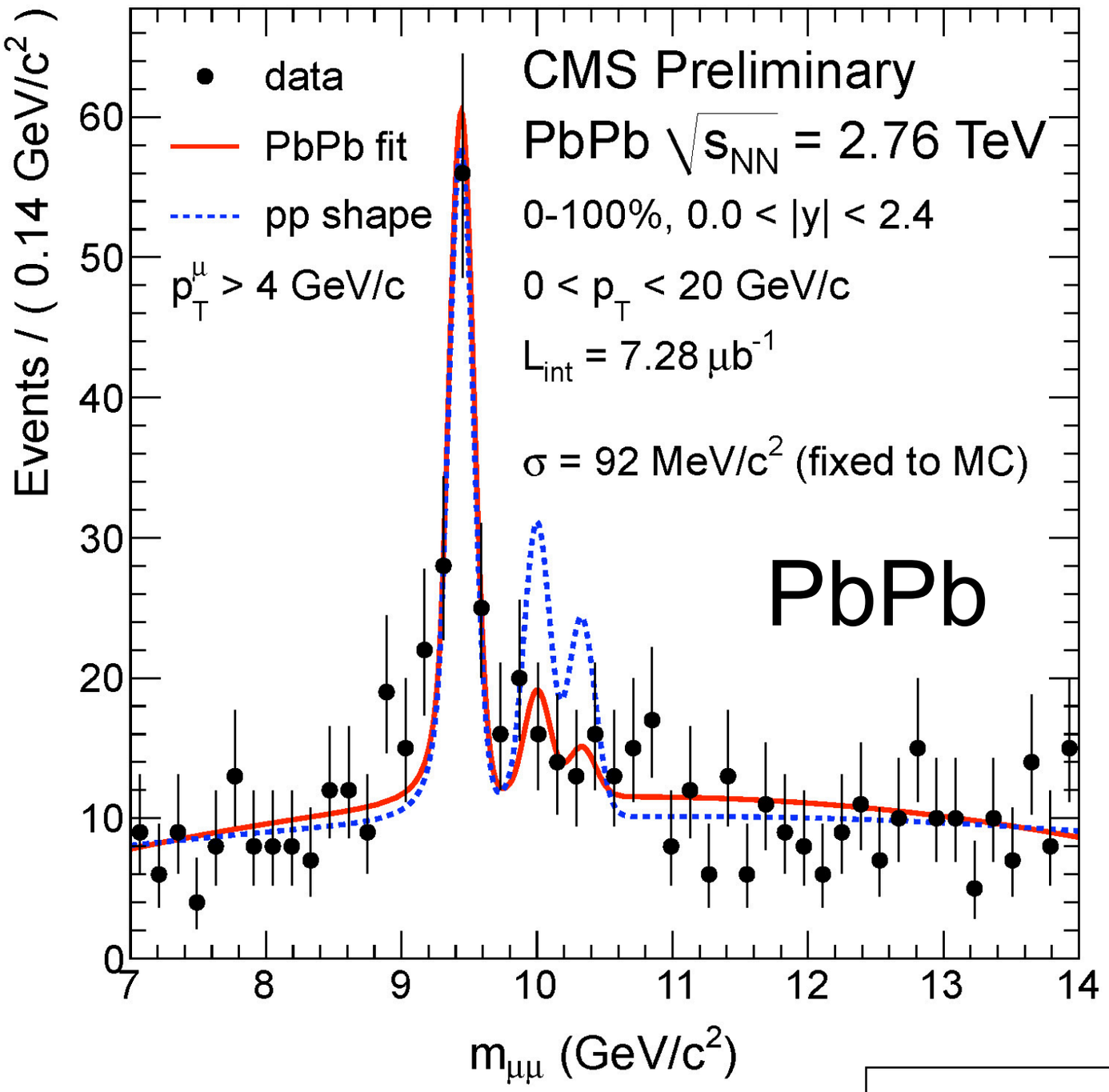


20 GeV cutoff

Not just jets. Heavy flavor too.

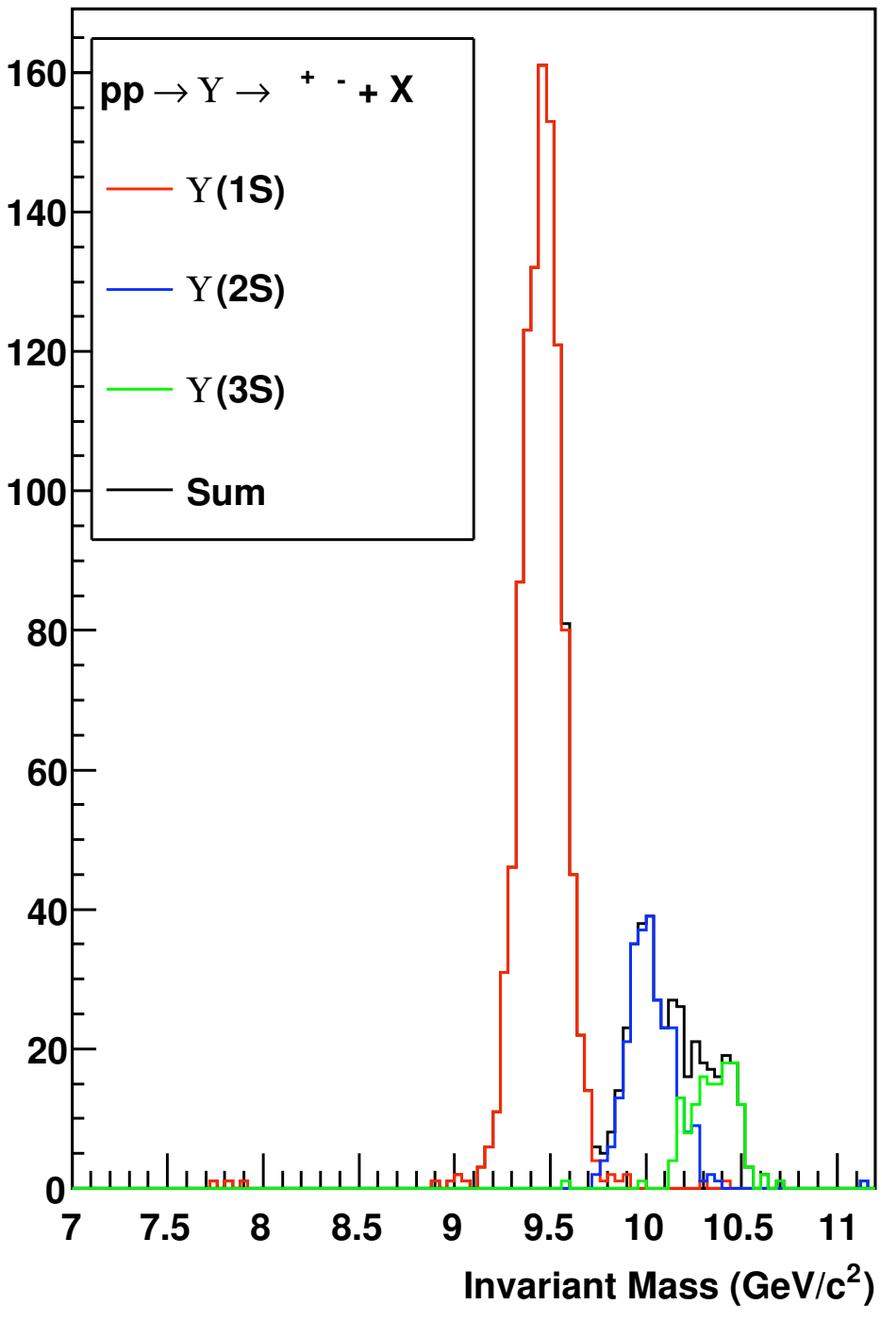


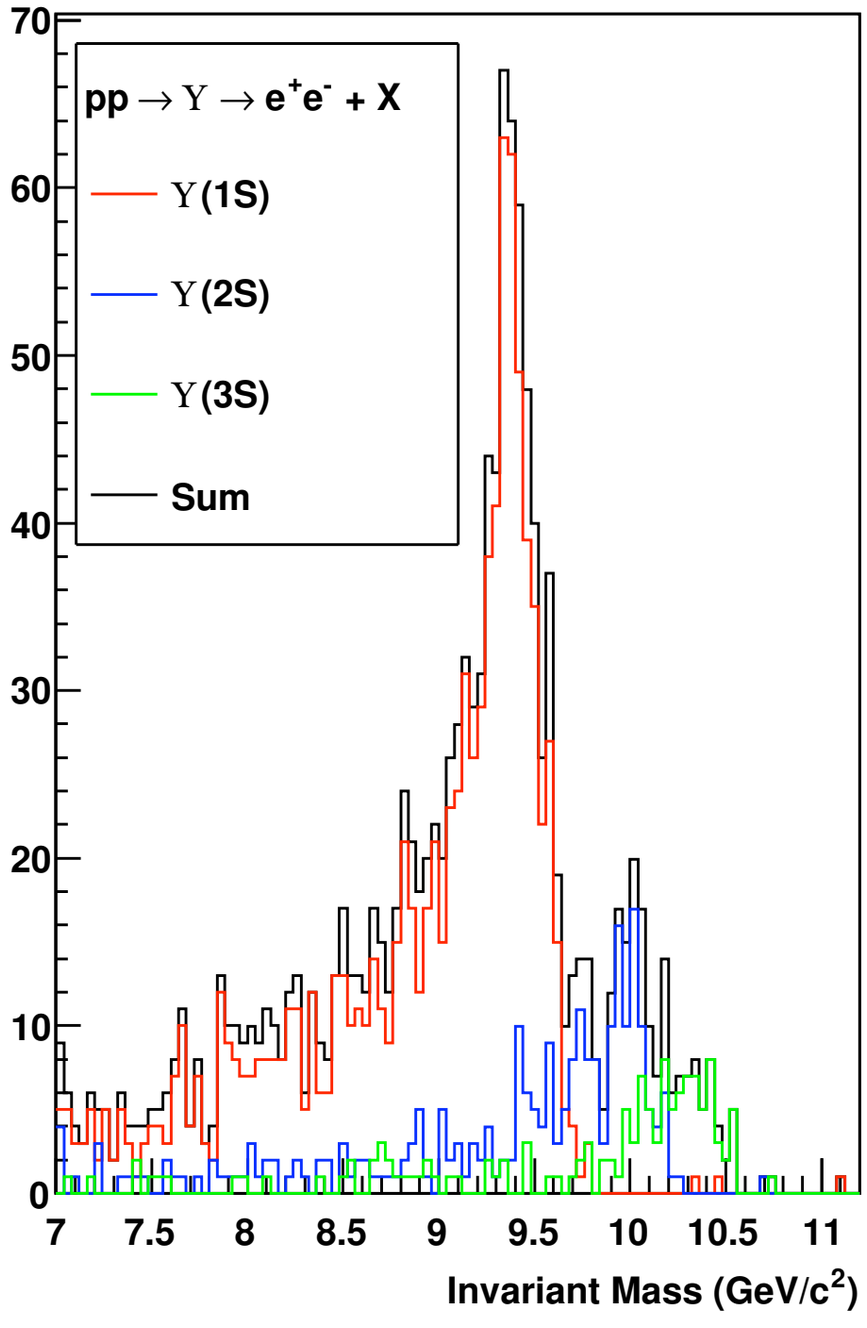
$$\frac{\Upsilon(2S+3S)/\Upsilon(1S)\big|_{PbPb}}{\Upsilon(2S+3S)/\Upsilon(1S)\big|_{pp}} = 0.31^{+0.19}_{-0.15} \pm 0.03$$



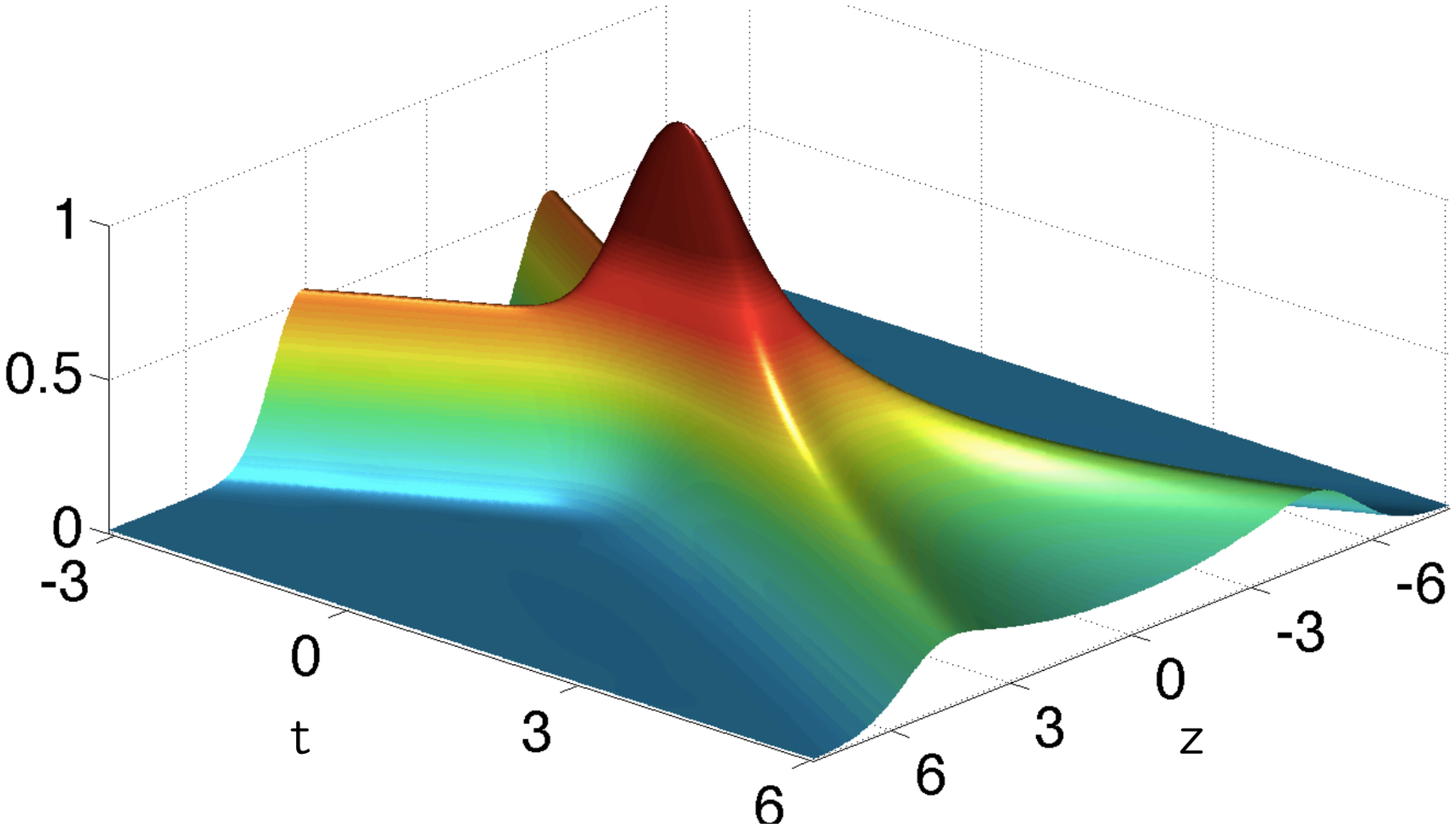
B. Wyslouch, QM'11

Resolving upsilon states





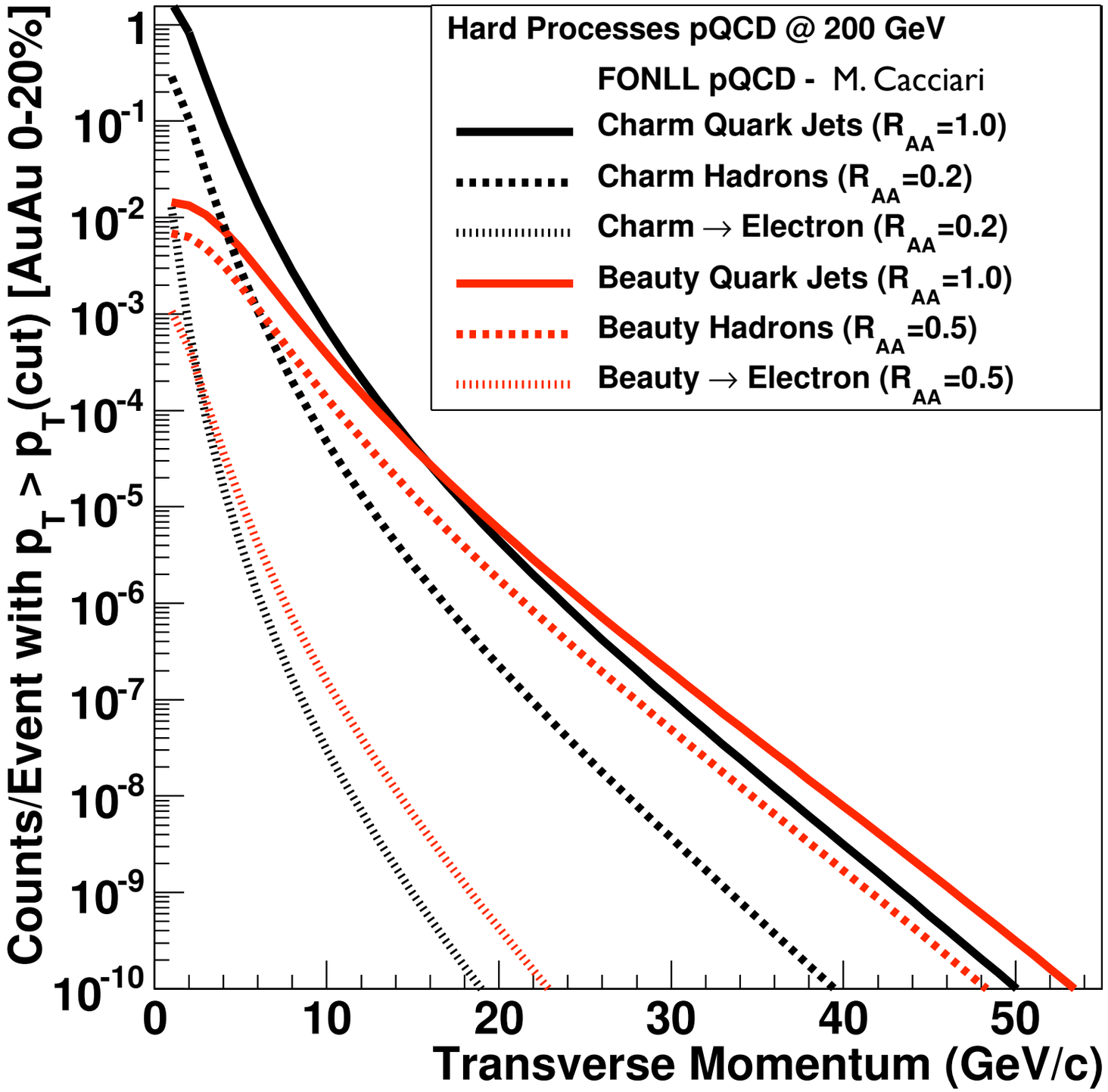
Colliding Sheets of Energy in a Strongly Coupled Theory



Hydrodynamics valid ~ 3 sheet thicknesses after the collision, i.e. ~ 0.35 fm after a RHIC collision. Equilibration after ~ 1 fm need not be thought of as rapid. Chesler, Yaffe arXiv:1011.3562

K. Rajagopal, QM'11

significant rates for heavy flavor tagged jets



M. Cacciari, private comm.

The only period when charm quarks can be easily produced is during the early stage of the parton evolution when the effective temperature is still high. At this stage, the parton gas is still not fully equilibrated yet so that the temperature is only an effective parameter describing the average momentum scale. By measuring this pre-equilibrium charm production, one can thus probe the initial parton density in phase space and shed light on the equilibration time.

P. Lévai, B. Müller, and X-N Wang

Phys. Rev. C 51, 3326–3335 (1995)

Questions

Observables

Needs

Quarks strongly coupled
Interaction mechanisms

Jets, Dijets,
γ - Jet (FF, radiation)

Quasiparticles in medium

Charm/Beauty Jets

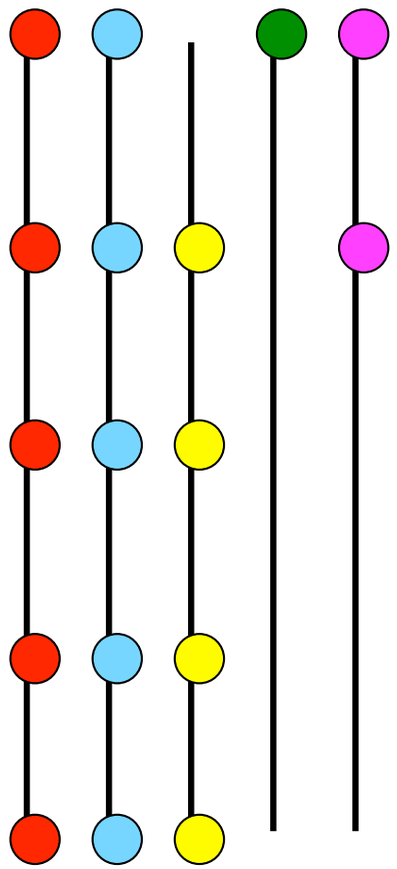
Screening Length

J/ψ at multiple energies

Upsilons (all states)

Thermal Behavior
Thermalization time

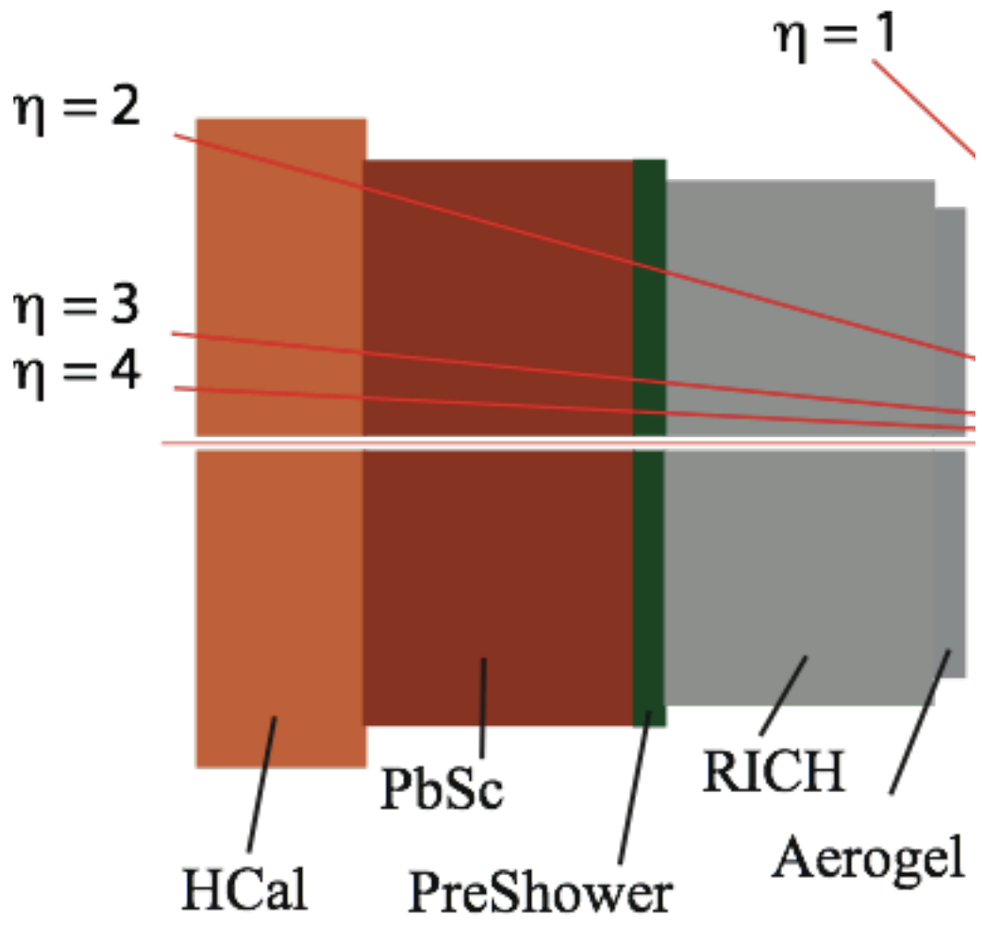
Direct γ^* flow



- Large Acceptance
- High Rate
- Electron ID
- Photon ID
- Excellent Jet Capabilities (HCAL)

Forward Physics

- tracking, PID, calorimetry to η = 4
- characterize initial state
- move in and out of saturation region
- gluon distribution in a nucleus
- comparison with hydro. including longitudinal d.o.f.



Complementarity

- Lever arm in $\sqrt{s}$
- "Sweet spot" in $\sqrt{s}$?
- Move in and out of saturation region?
- Manipulate charm, bottom cross sections
- Luminosity, running time, DAQ rate
- Probe medium over wide range of Q^2
- Manipulate geometry of collision
- Systematic, differential, comprehensive

"Holy cow. It's a 200 million dollar detector."

– *Anonymous*

“Holy cow. It’s a 2[illegible] dollar detector.”

– *Anonymous*

"Holy cow. It's a 2[MYTHBUSTED]? dollar detector."

– *Anonymous*

It's a 60–80 million dollar detector.
It can sensibly be built in stages.
Planning for multiple funding sources.

Technology

- Active R&D for upgrades
  - low mass tracking
  - compact calorimetry
  - very fast time-of-flight
- Coupling between RHIC and EIC R&D
- Compactness of sPHENIX possible due to technological advances

One possible way to stage sPHENIX

- 2017 Shutdown
  - New solenoid
  - Barrel Preshower
  - Barrel EMCal (Partially reconfigured existing EMCal)
  - Barrel HCal
  - Additional Barrel Tracking Layers

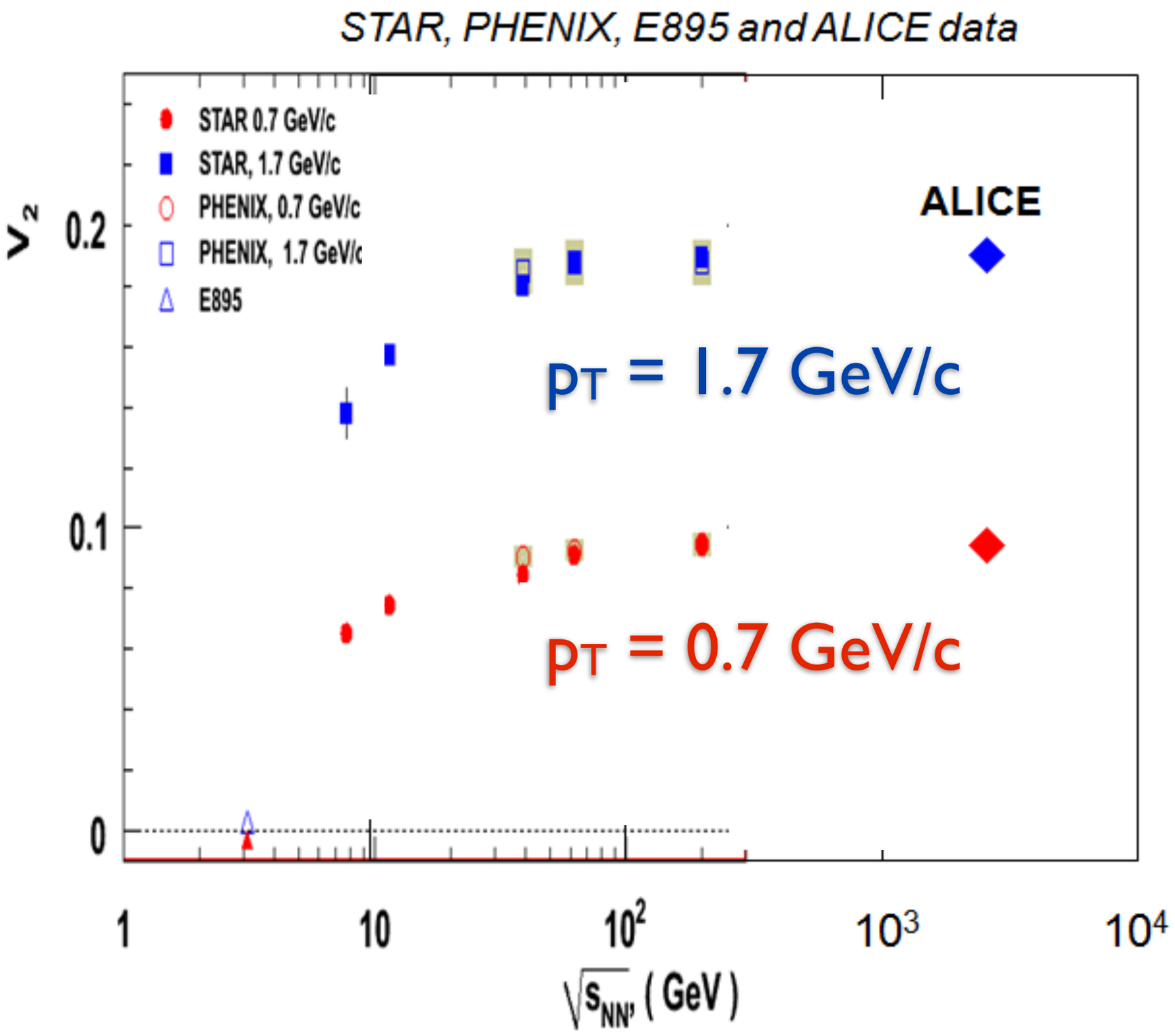
jets, heavy flavor

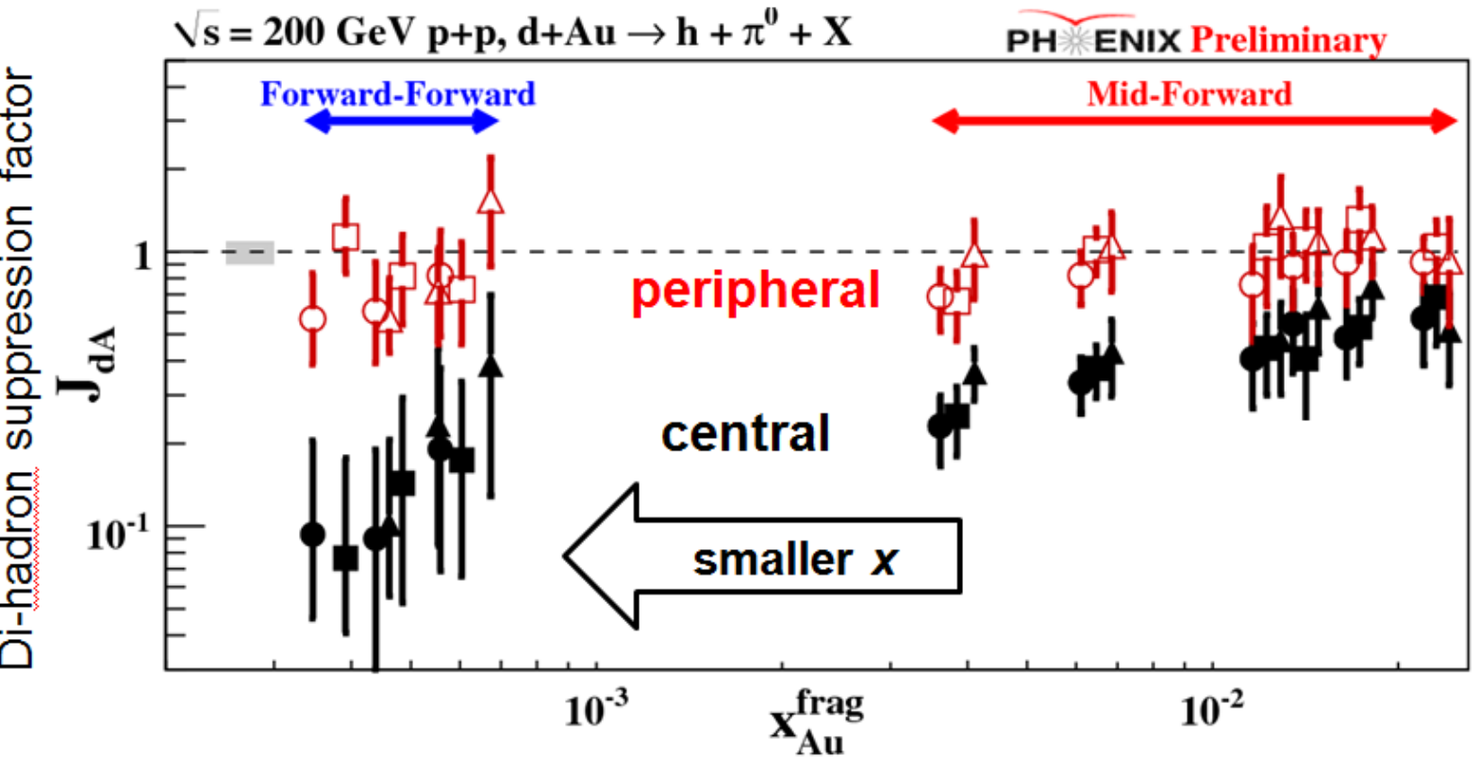
- 2018 Shutdown
  - Forward Preshower
  - Forward EMCal (Reconfigured existing EMCal)
  - Forward HCal

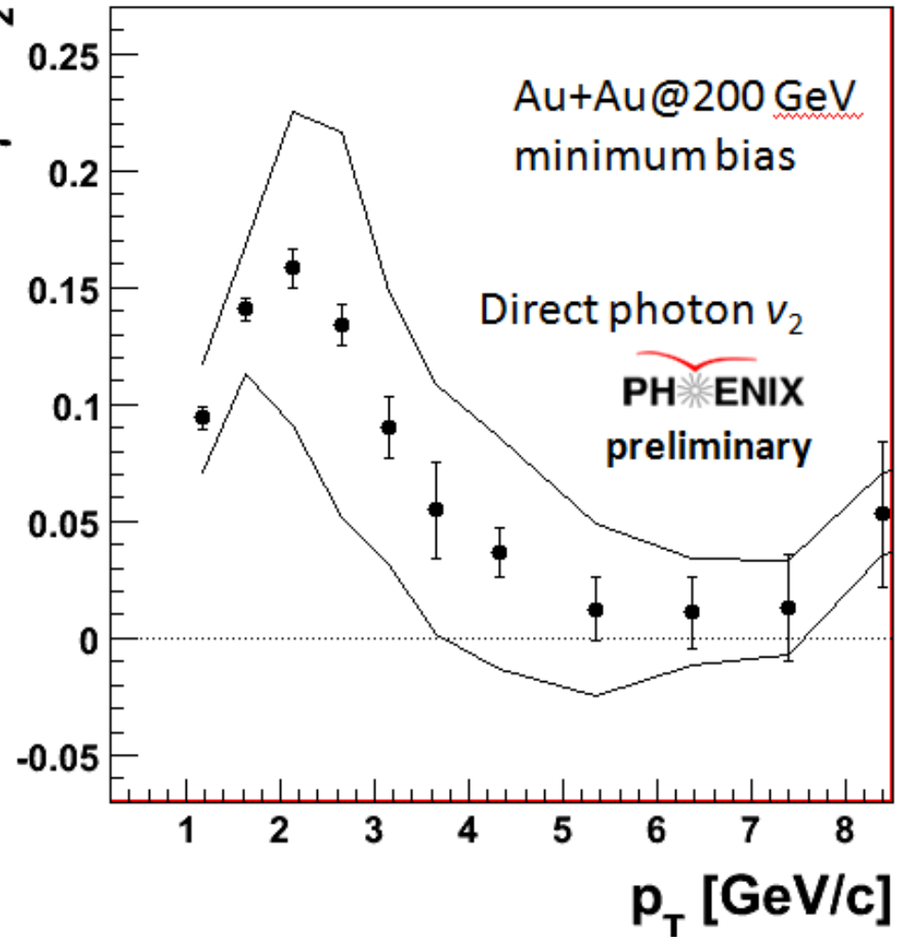
CNM, saturation
π^0, photons

- 2019 Shutdown
  - Forward Magnet
  - Forward PID (RICH)
  - Forward Tracking (GEMs)

CNM, saturation
J/ψ, DY, electrons


STAR, PHENIX, E895 and ALICE data
STAR 0.7 GeV/c
STAR, 1.7 GeV/c
PHENIX, 0.7 GeV/c
PHENIX, 1.7 GeV/c
E895
ALICE
v_2
0.2
0.1
0
p_T = 1.7 GeV/c
p_T = 0.7 GeV/c
1
10
10^2
10^3
10^4
$\sqrt{s_{NN}}$ (GeV)


$\sqrt{s}$ = 200 GeV p+p, d+Au → h + π^0 + X
PHENIX Preliminary
Forward-Forward
Mid-Forward
peripheral
central
smaller x
J_{dA}
x_{Au}^{frag}
10^{-3}
10^{-2}
1
10^{-1}
Di-hadron suppression factor


$\gamma^{dir.}$ v_2
Au+Au@200 GeV
minimum bias
Direct photon v_2
PHENIX
preliminary
0.25
0.2
0.15
0.1
0.05
0
-0.05
1
2
3
4
5
6
7
8
p_T [GeV/c]

J/Ψ suppression
Debye screening? Puzzle remains