sPHENIX Future

30 minutes for this presentation is an impossibly short duration to discuss everything in sufficient (any) detail. Plan to give overview of key points and then afterwards you can ask for more information….

Experiments charged in December 2009 with producing Decadal Plans

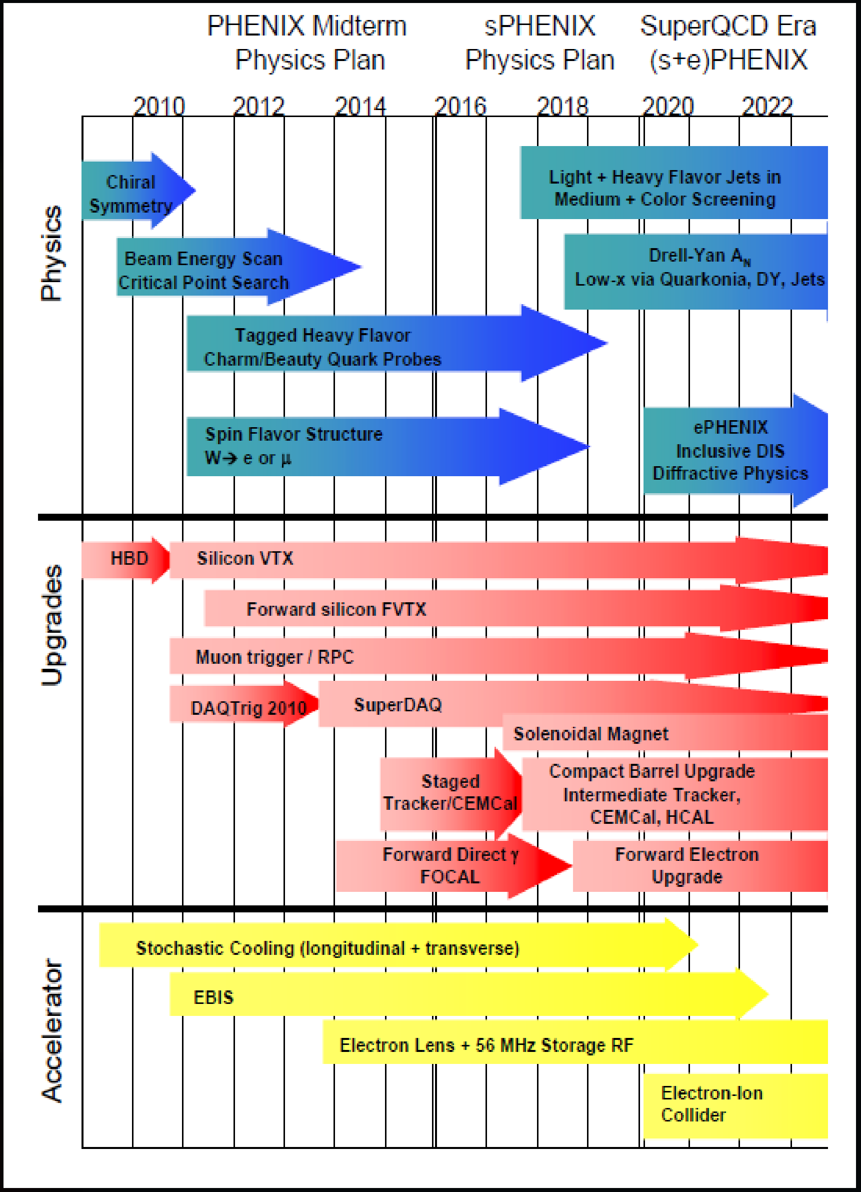
The PHENIX Experiment at RHIC

Decadal Plan 2011–2020

Brookhaven National Laboratory

Relativistic Heavy Ion Collider

October, 2010



PHENIX handed in Plan on October 1, 2010

and then it was reviewed by PAC in June 7, 2011.

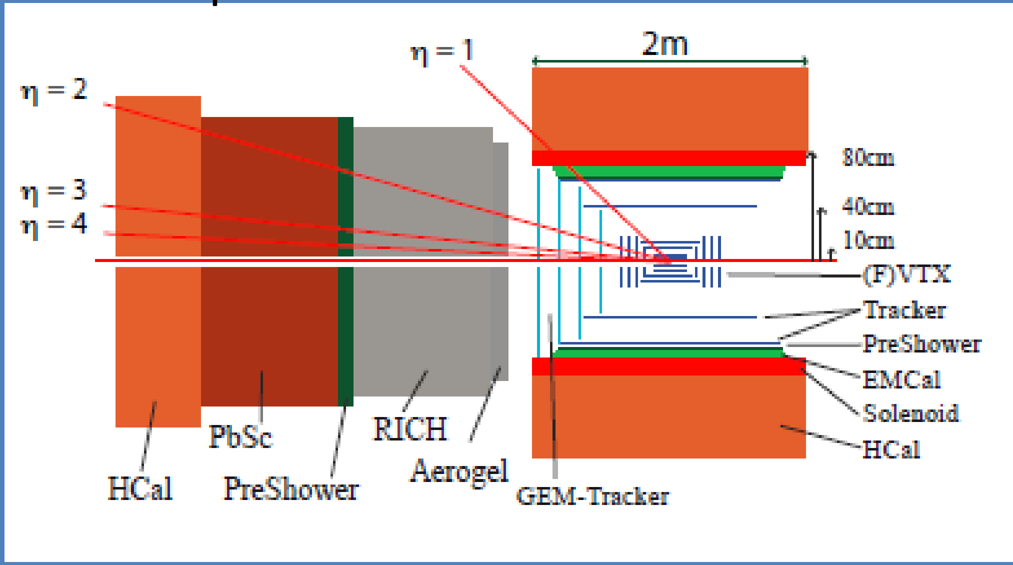
http://www.phenix.bnl.gov/phenix/WWW/docs/decadal/2010/phenix_decadal10_full_refs.pdf

PHENIX Decadal Plan

(beyond the midterm upgrades, that are now in place)

entailed an ambitious upgrade to study the sQGP with a new compact, large acceptance and high rate detector (*sPHENIX*).

As presented in the Decadal Plan



As the PAC noted last year, the entire upgrade package is expensive.

Broad program including high statistics **Upsilons** , large **Dijet** and **γ-jet** rates with full calorimetry, **charm/beauty** tagging of jets, γ/π^0 separation to 40 GeV/c, fragmentation functions,

forward p+A low-x jet, γ, quarkonia, forward transverse spin probes,

staged into ePHENIX detector for 5-10 GeV electron beam at EIC.

PAC recommendations (2011)

"With most of the observables underpinning the RHIC program being accessible also to the LHC, it is crucial that the decadal plans document how the measurements at RHIC can uniquely advance the field. This implies, in particular, that the decadal plans should build more prominently on the fact that RHIC operates in a particularly interesting energy regime, closer than the LHC to the phase boundary, where precision measurements will constrain key quantities in what is arguably the more interesting regime."

"Theoretical physicists, including in particular existing coordinated phenomenological efforts like the JET topical collaboration, should be more actively engaged in the decadal planning process."

"The PAC expects to see a near-complete decadal plan from each collaboration prior to a potential meeting in early 2012." [no charge was given on this front – i.e. a RHIC Decadal Plan]

"PHENIX correctly recognizes that despite its superb track record of delivering timely and interesting physics with a small aperture device, all their physics goals will require large aperture measurements with highly selective triggers which are fully efficient for the top RHIC-II luminosity. The PHENIX decadal upgrade plan is thus appropriately ambitious."

Tim Hallman and DoE in late June 2011 said any such project must be staged and that we should aggressively pursue a first stage ~ $20M MIE proposal to be handed in July 1, 2012.

Lots of Excitement and Hard Work!

September 2011 – Brookhaven workfest

December 2011 – Boulder workfest

January 2012 – Tennessee workfest

February 2012 – Columbia workfest

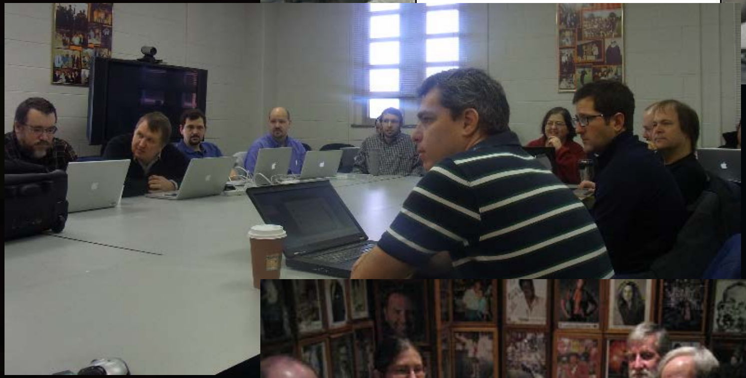
March 2012 – Florida State collab. meeting

April 2012 – Boulder workfest

May 2012 – Brookhaven/Boulder writing

30+ people working with sPHENIX
focus for 5 days at each workfest

And a lot of food
was involved…



1. Write a $20M MIE proposal by July 2012 for a first stage of sPHENIX
   → The MIE funded portion ***must*** provide compelling and unique world class physics ***by itself*** (or with projects with funding in-hand)
2. Enable further staged upgrades to sPHENIX for more capabilities including forward physics for spin and cold nuclear matter
3. Lay the foundation for further staged upgrades to evolve into a compelling EIC (ePHENIX) detector

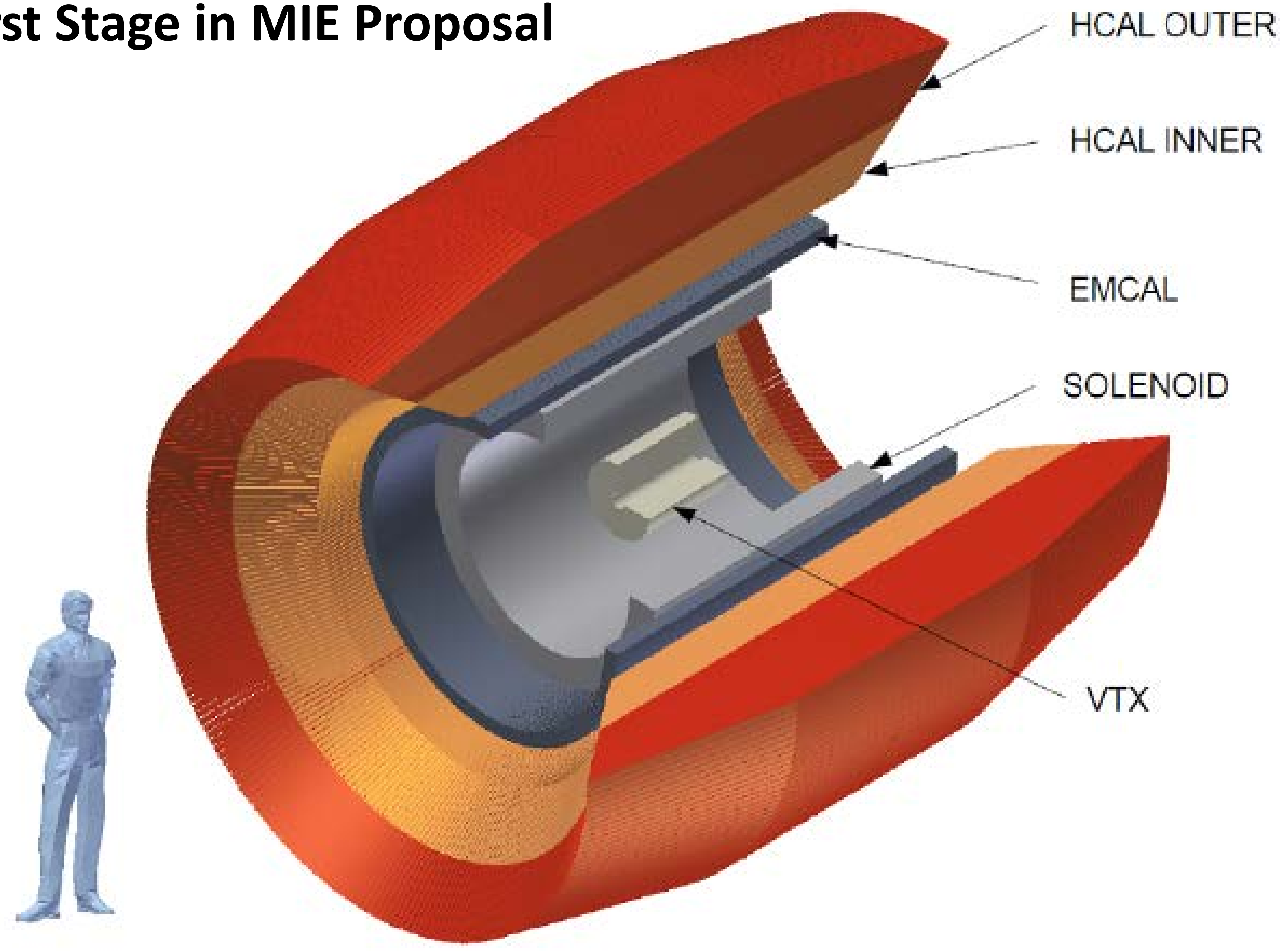
---

After considering many options based on physics, detector costs and integration, ... we are pursuing a first stage with a
2 Tesla Magnetic Solenoid (70 cm inner radius), full coverage ($|\eta|<1.0$) Electromagnetic and Hadronic calorimetry.

This enables a world-class jet physics program, and also with incremental upgrades recovers the other Decadal Plan physics including a world-class ePHENIX program.

MIE Proposal is for the first stage (focused on jet program).
The design from the very start is to enable the broader program.
Start with MIE justification!

sPHENIX
First Stage in MIE Proposal



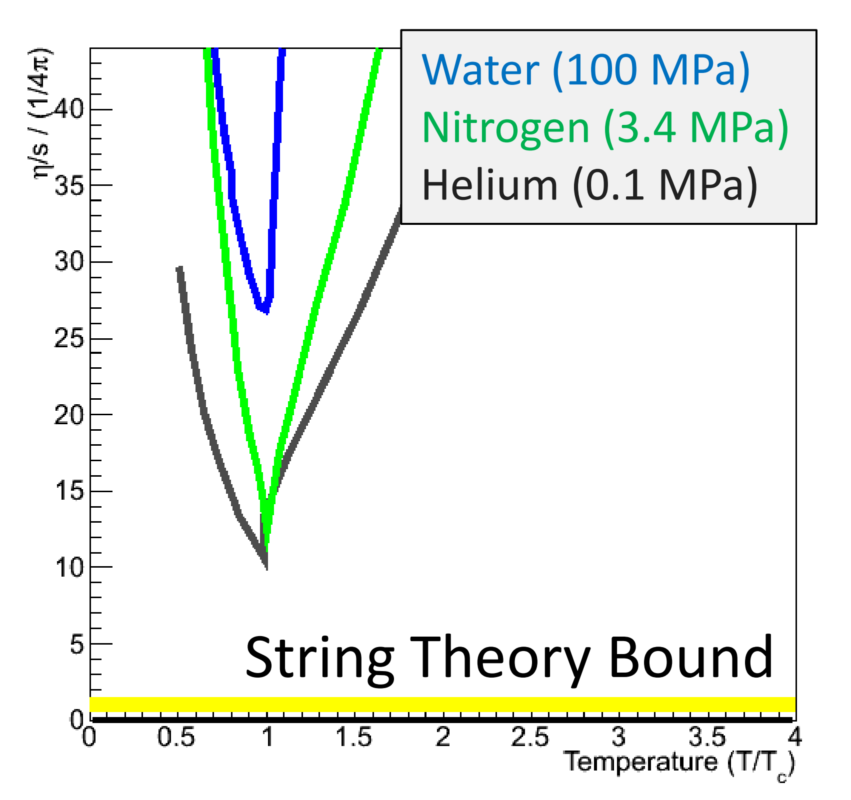
The textbook (or Wiki entry) on the Quark-Gluon Plasma will be incomplete without

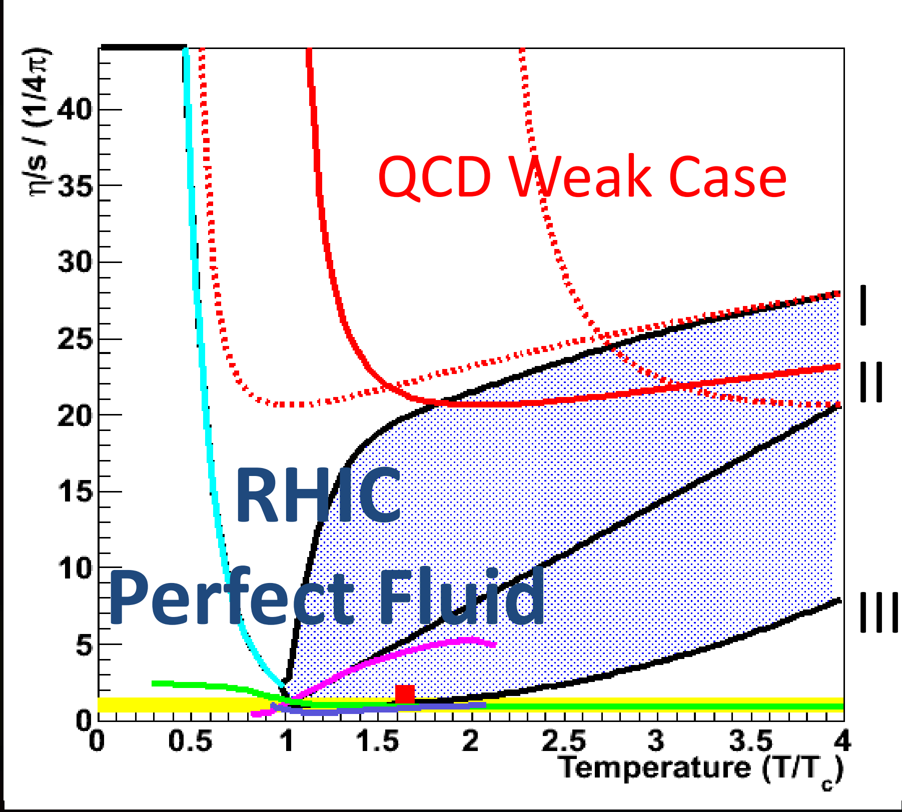
a fundamental explanation for how the perfect fluid emerges at strong coupling near T_c from an asymptotically free theory of quarks and gluons.

Jet observables at RHIC enabled by the sPHENIX upgrade are critical to providing this explanation by probing the QGP near 1-2 T_c and at distances comparable to the thermal scale.

Measurements of jets only at the LHC will leave these questions with an incomplete answer (particularly right where the coupling <u>may</u> be strongest).

Strong versus Weak Coupling





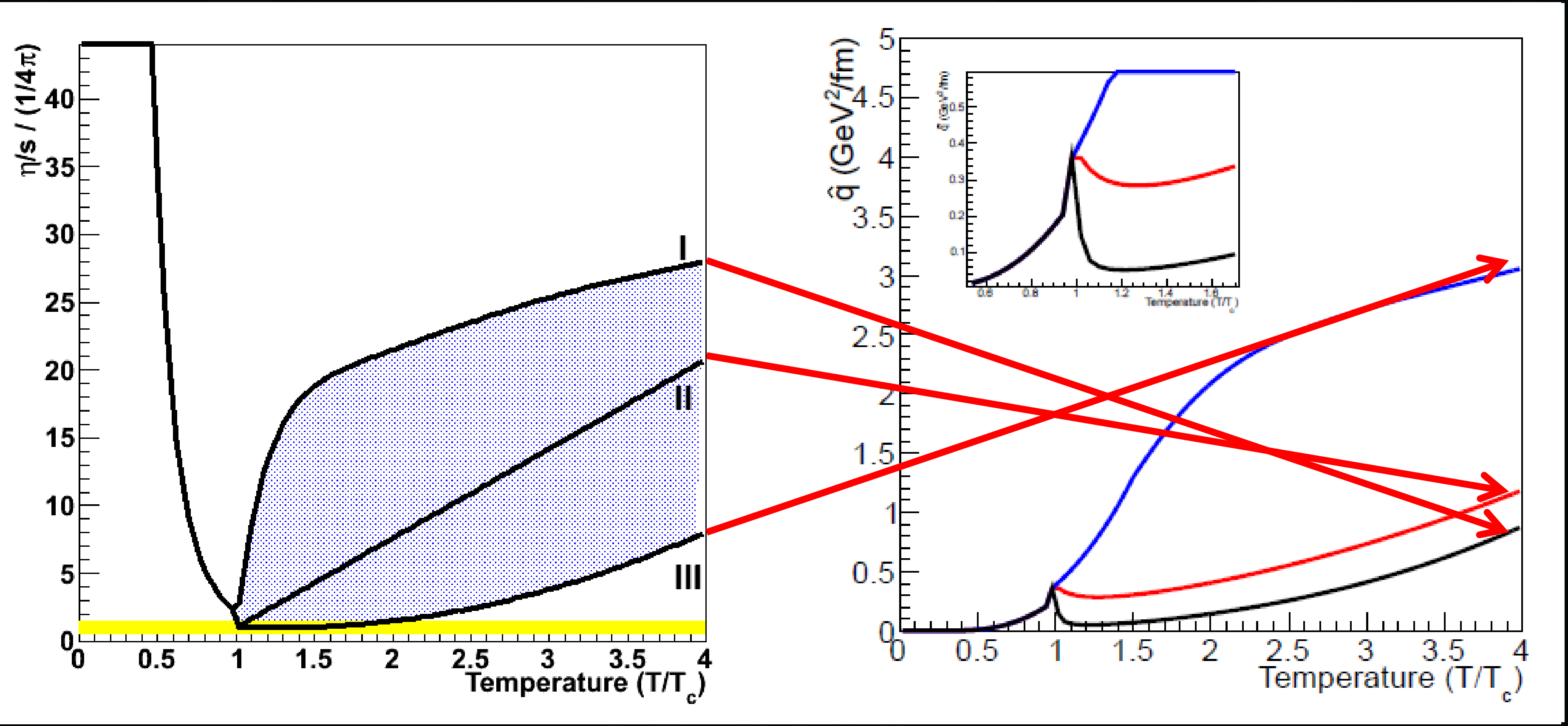
How does the Quark-Gluon Plasma transition from Strong to Weak?

Is this transition associated with changes in quasi-particles, excitations, strong fields?

Mapping Out Strong Coupling with Jet Probes

"Small Shear Viscosity Implies Strong Jet Quenching"
A. Majumder, B. Muller, X.N. Wang, PRL (2007).

$$\hat{q} = \frac{1.25T^3}{\eta / s}$$

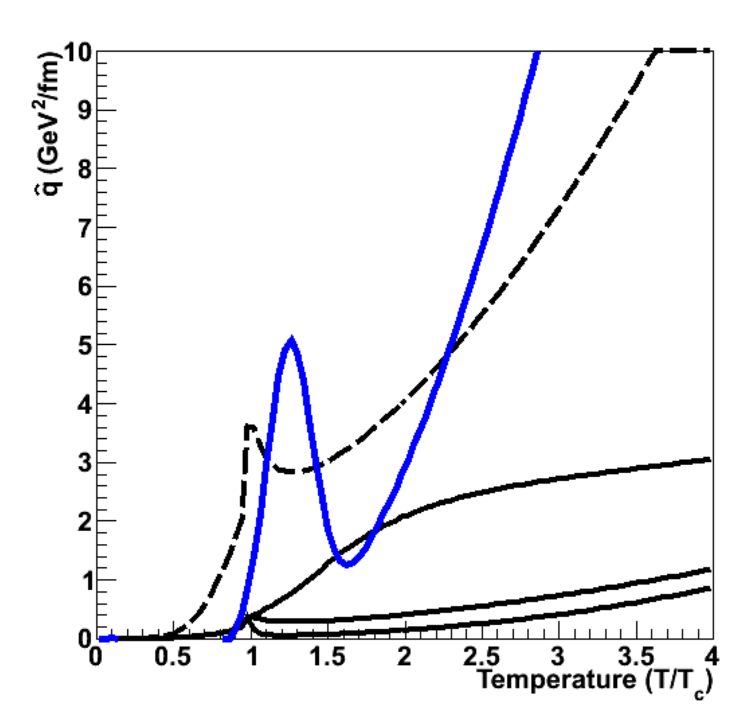


Key is independently measuring both sides of this equation!

Super-Strong Coupling near Transition Temperature?

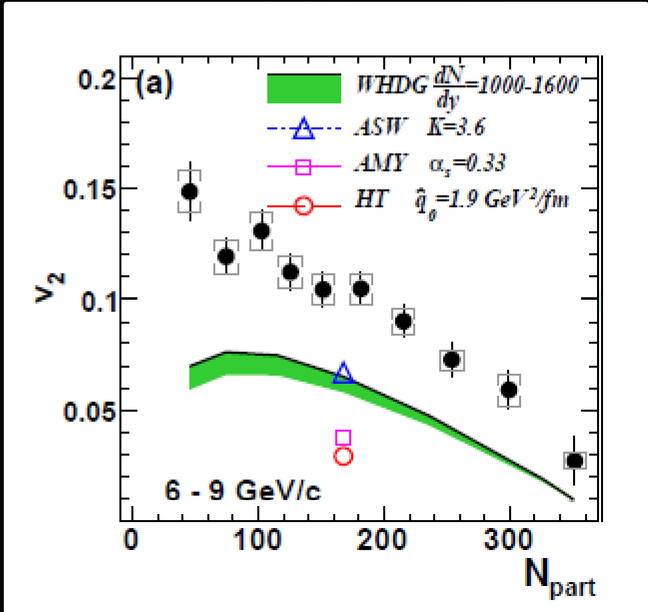
“Jet Quenching is a few times <u>stronger</u> near T_c relative to the QGP at $T > T_c$.”

Liao and Shuryak, PRL (2009)



“The surprisingly transparent sQGP at the LHC [compared to RHIC]”

Horowitz and Gyulassy, NPA (2011)

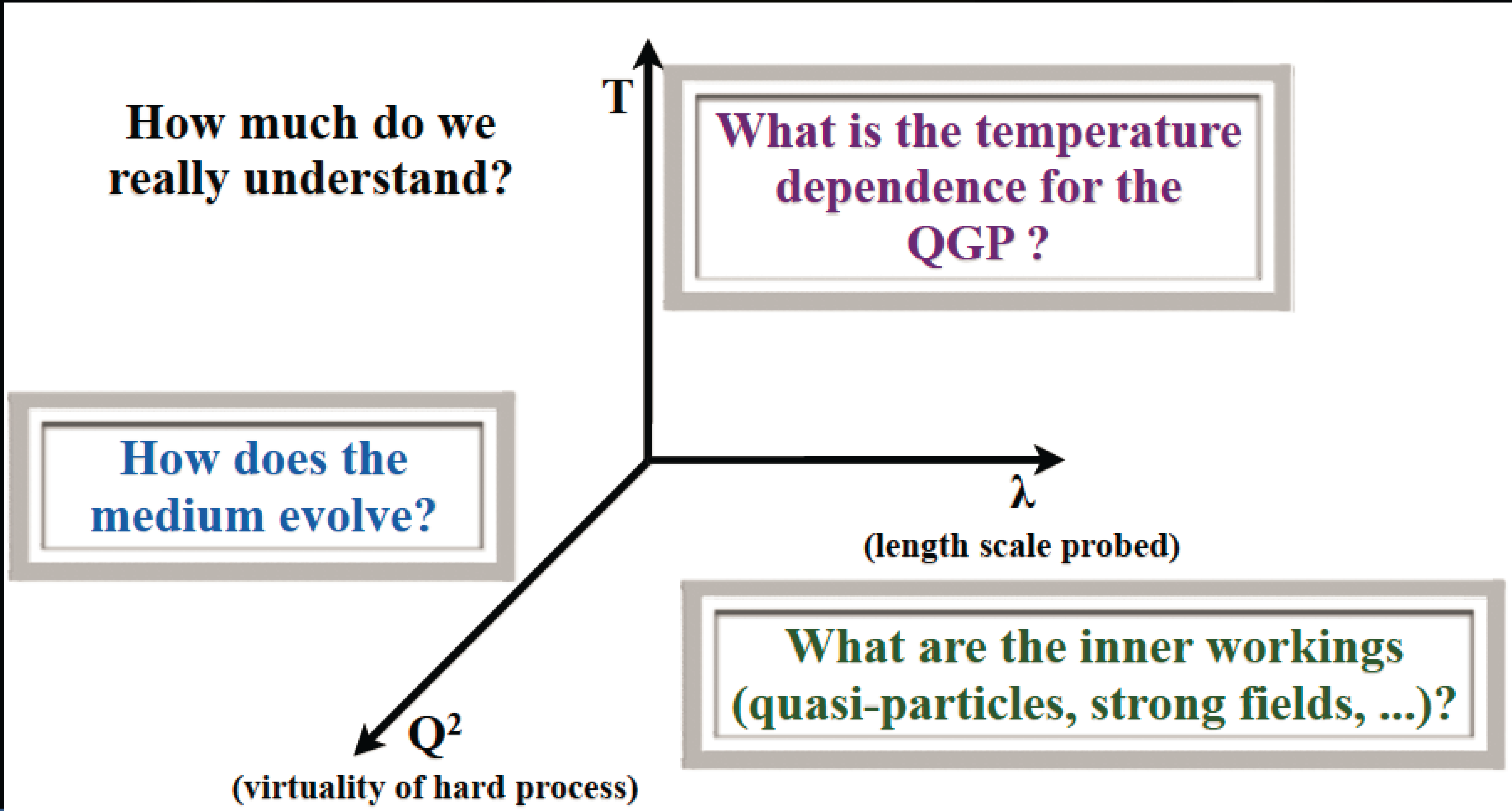


“Large v_2 is striking in that it exceeds expectations of pQCD models even at 10 GeV/c.”

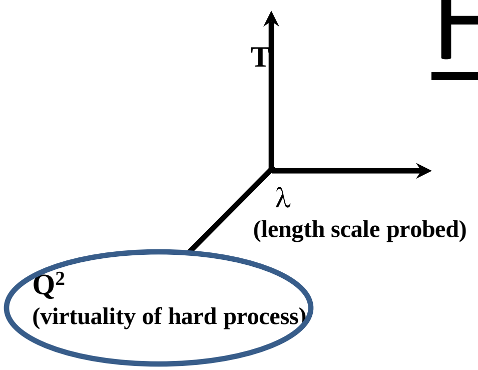
PHENIX, PRL (2010)

RHIC jet physics measurements are critical to exploring along the **temperature axis** (in concert with LHC measurements).

Also, pushing / probing the medium along two other axes.

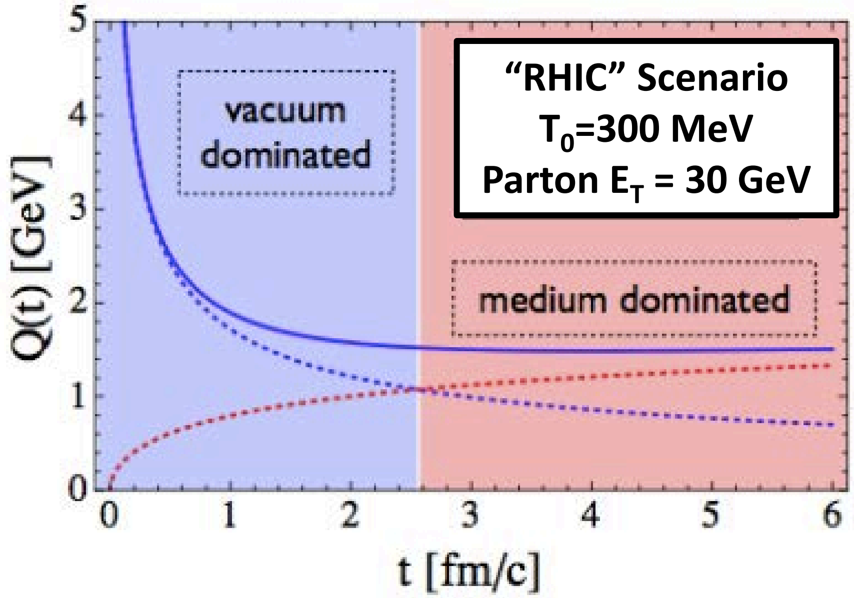


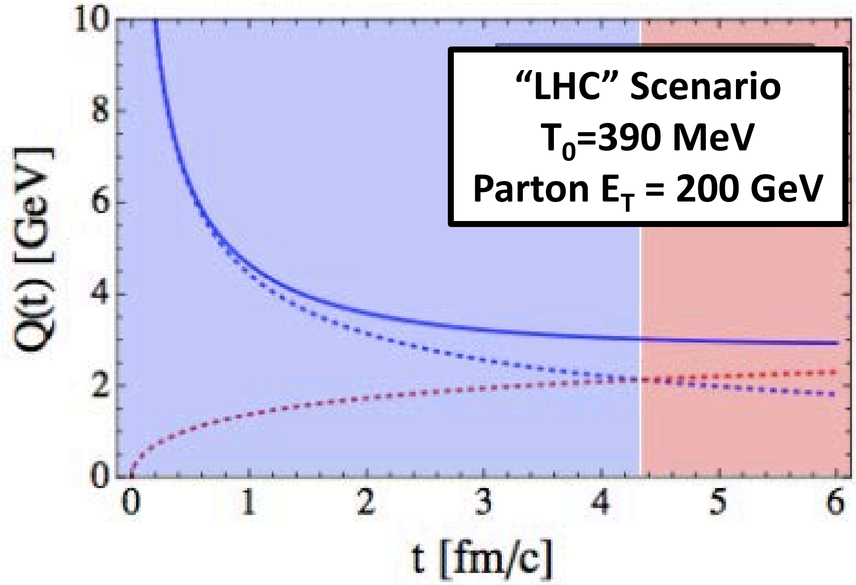
Hard Parton Virtuality



$$Q^2_{vac}(t) = \frac{E}{2t} \qquad Q^2_{med}(t) = \int \hat{q}(t)\,dt$$

$$Q^2(t) = Q^2_{vac}(t) + Q^2_{med}(t)$$



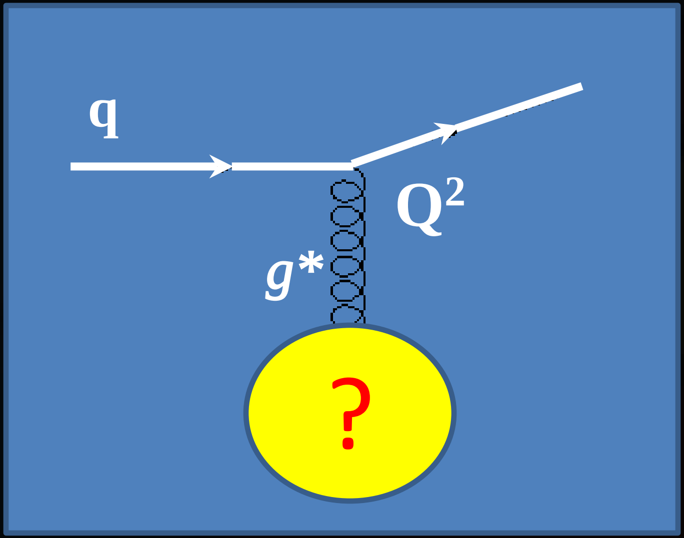


LHC Scenario

the vacuum contribution to the parton virtuality to fall below the in-medium contribution in the pQCD scenario. This effect is due to the collinear splitting in pQCD, which reduces the parton energy only gradually and thus leads to an increase in time dilation as the virtuality drops. This means that the very energetic parton hardly notices the medium for the first 3 – 4 fm of its path length. On the other hand, in the AdS/CFT scenario, parton energy and virtuality

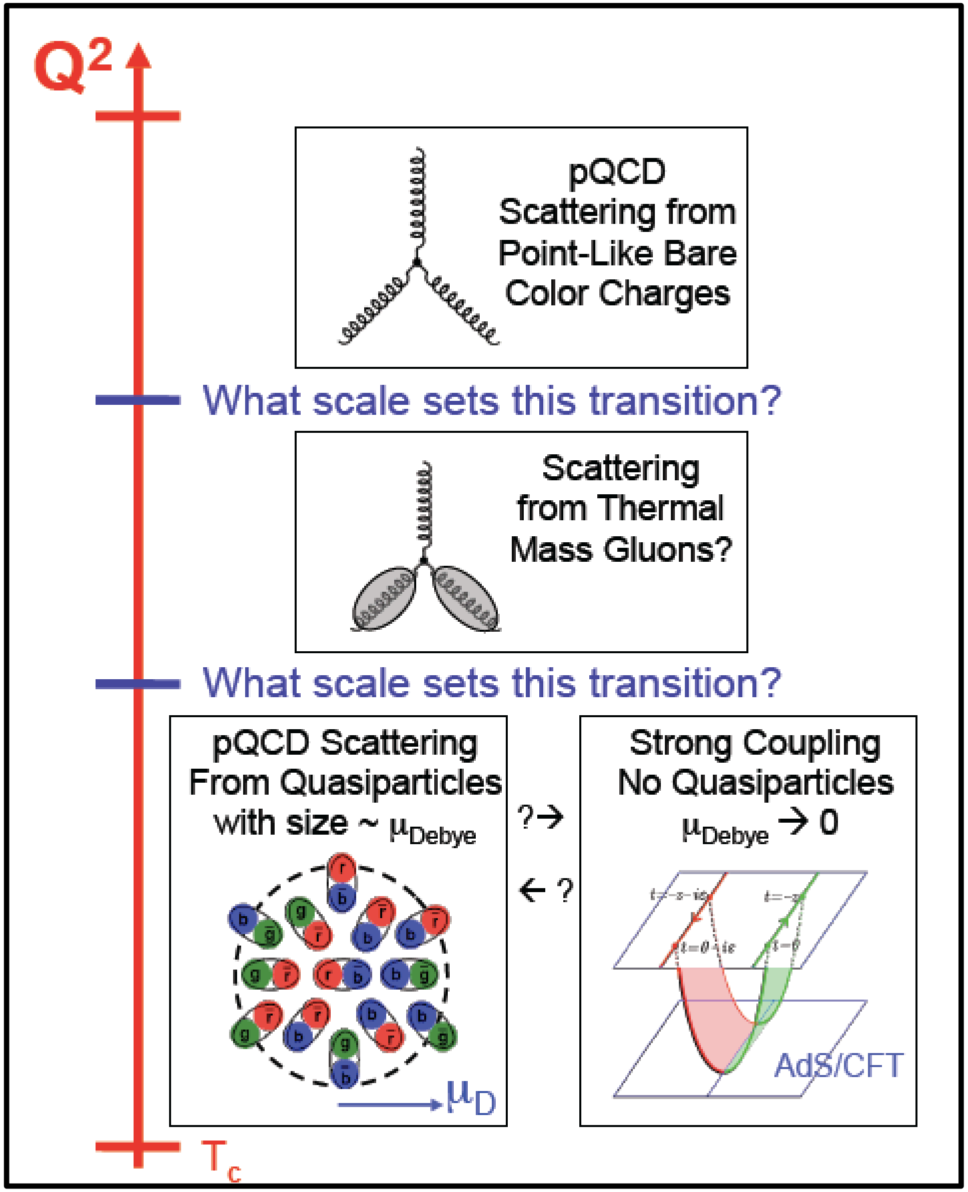
B. Muller. Nucl.Phys., A855:74–82, 2011, RHIC/AGS Users Meeting 2011

At which length scale is the medium probed?



What sets this scale?

- the exchange gluon momentum?
- total coherent energy loss?
- impact of deconfinement?



W. Horowitz

Theoretical Guidance on Observables/Sensitivity

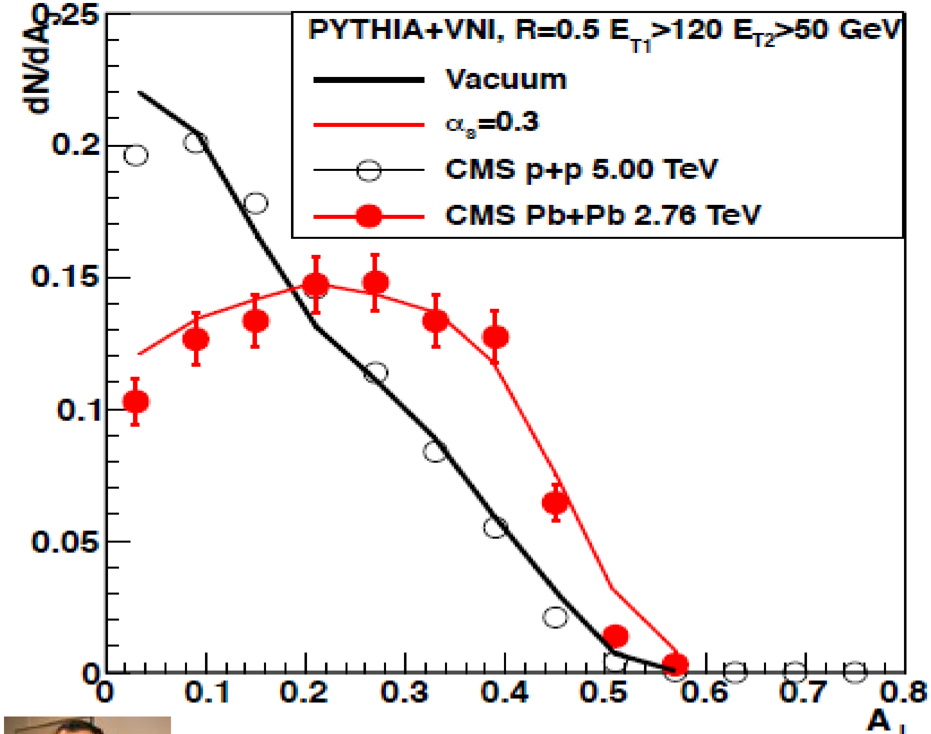
The theoretical bridgework needed to connect measurement to the interesting and unknown medium properties of deconfined color charges is under active construction by many theorists

JET Collaboration

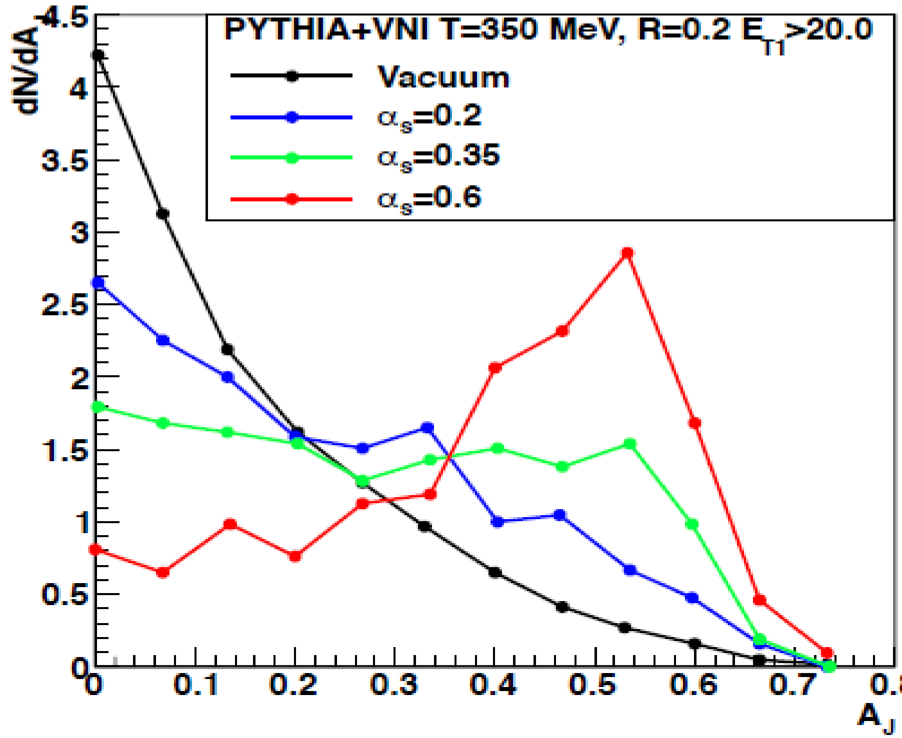
March 3-4, 2012 at Duke University
lots of interest from theoretical community.

Follow up EVO meetings.

Comparison to LHC data



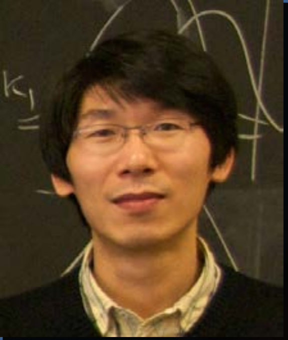
Sensitivity to α_s at RHIC energies



symmetric ⟷ asymmetric

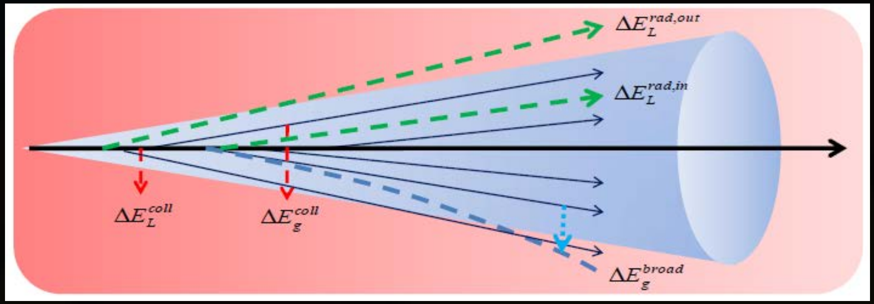
Chris Coleman-Smith (Duke)

Dijets at RHIC scales are likely to be strongly modified by the presence of the deconfined QGP medium. The observables we have discussed are sensitive to many aspects of this modification and suggest that further jet measurements at RHIC will provide valuable insights into the nature of the QGP and into the applicability of pQCD jet suppression models .

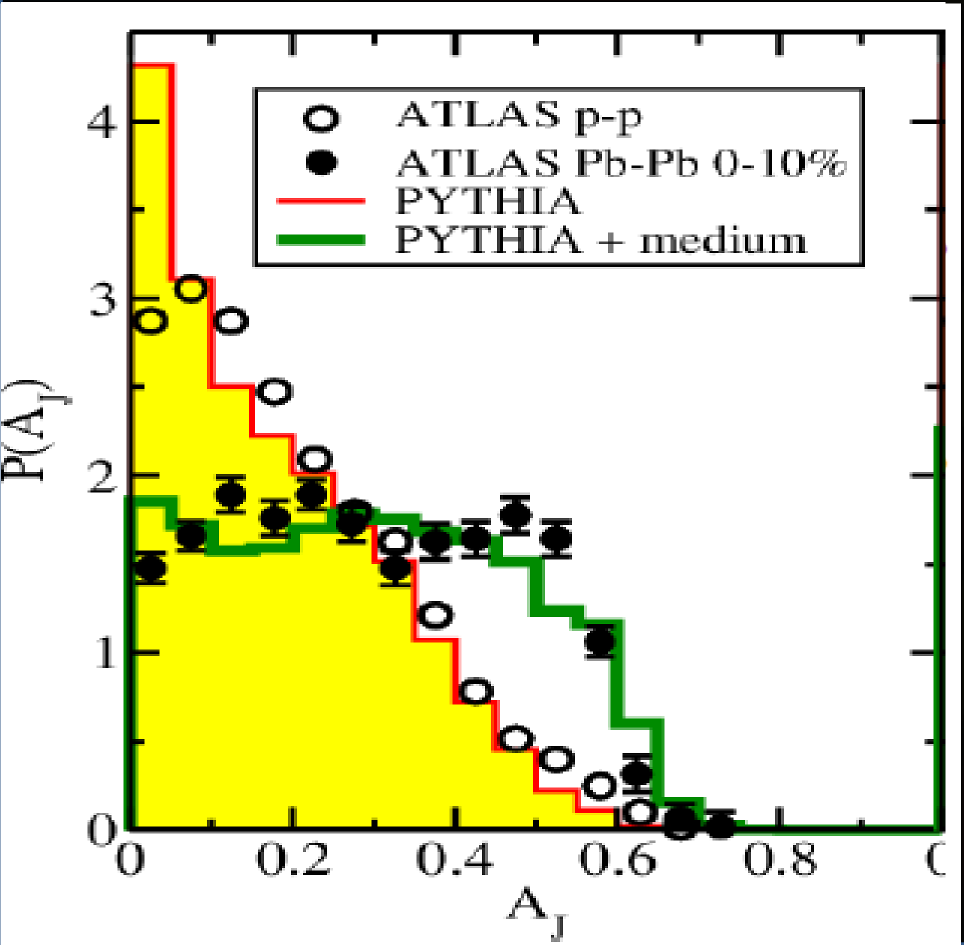


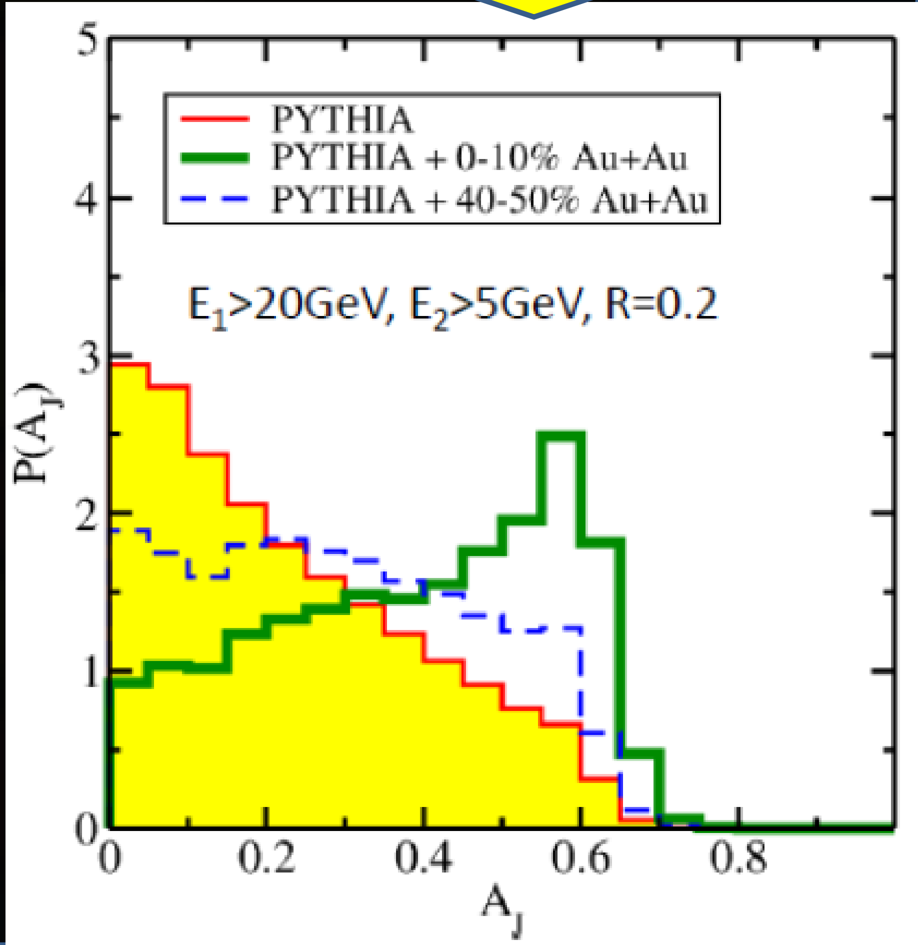
PRL 2011

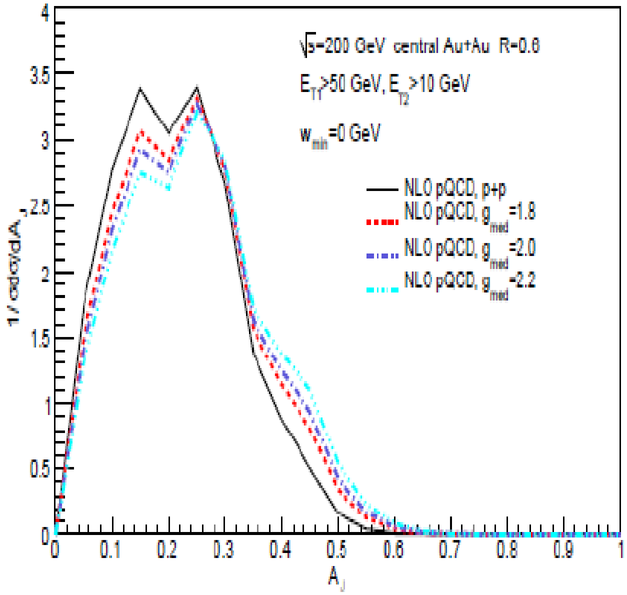
Guangyou Qin, Berndt Muller



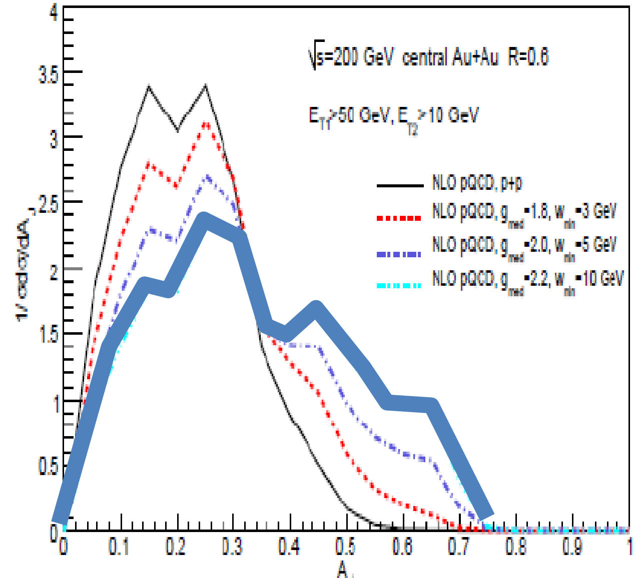
Larger modification at RHIC
More of parton shower equilibrated into medium.







Radiative E-loss only

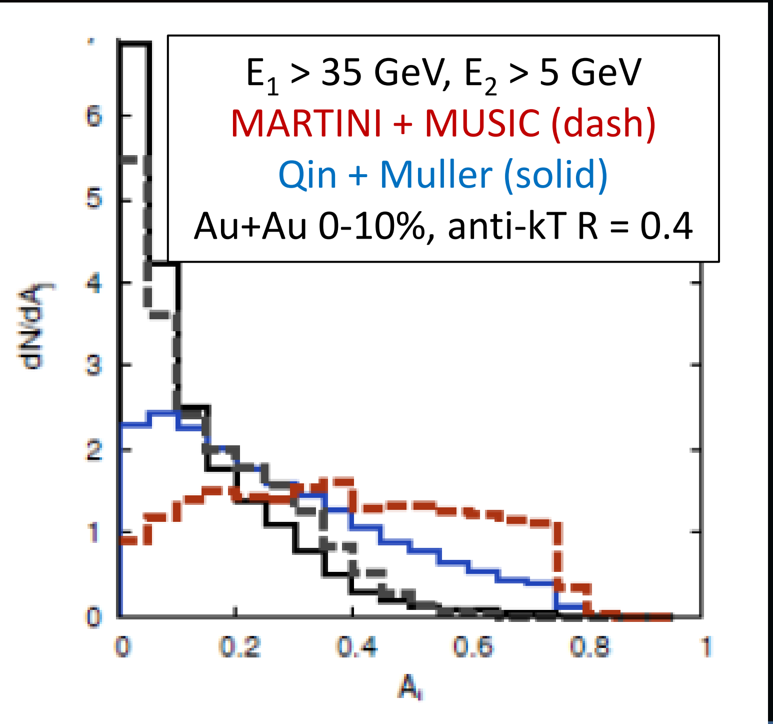


Radiative + Collisional E-loss
±10% changes in coupling strength

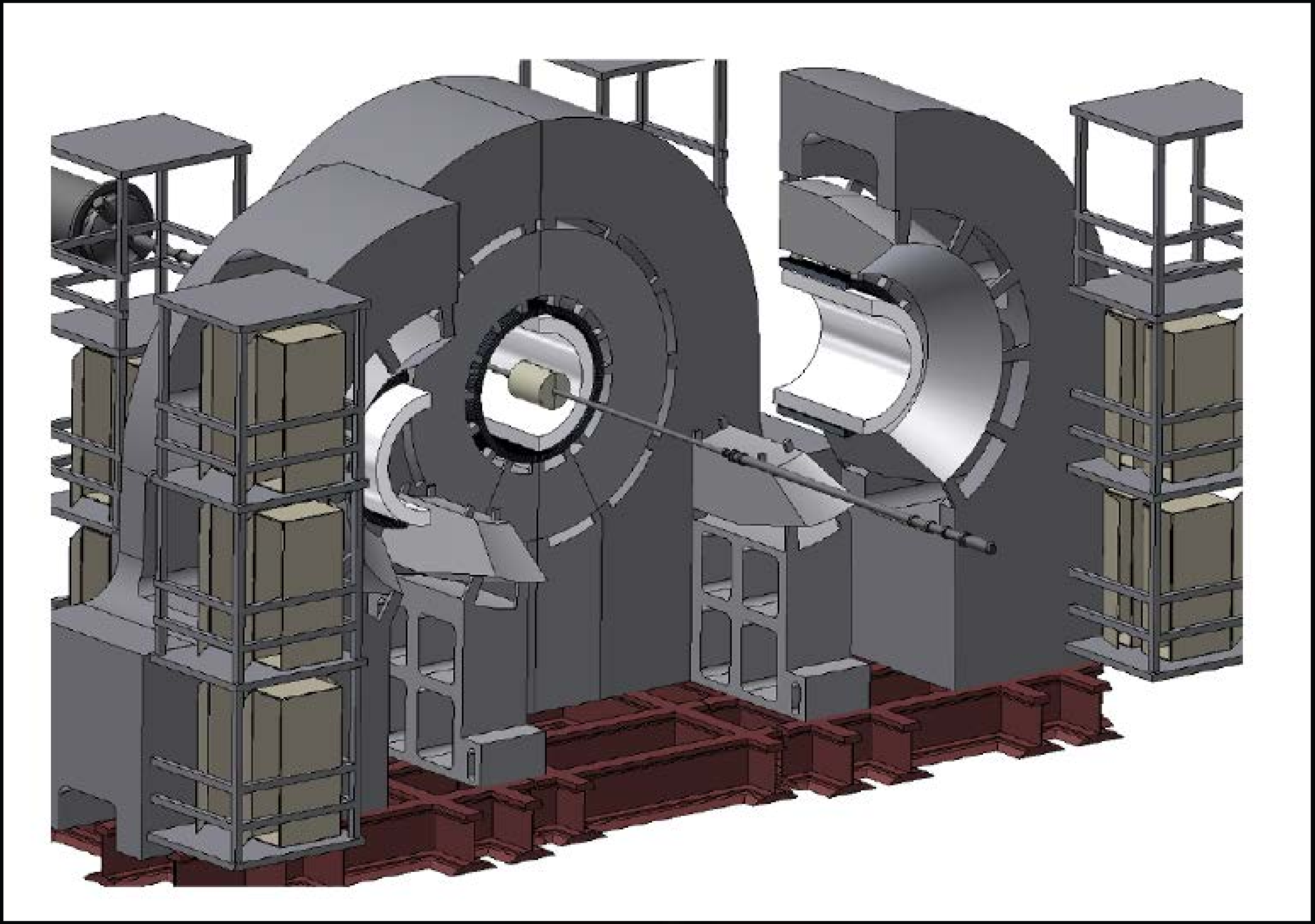
Ivan Vitev et al.

Bjorn Schenke, Clint Young et al.

Large effects!
Different models matching LHC data disagree on RHIC predictions.



sPHENIX MIE Proposal



Major change to the PHENIX detector.
Removal of outer PHENIX central arms, keep VTX inner tracking.

Magnet

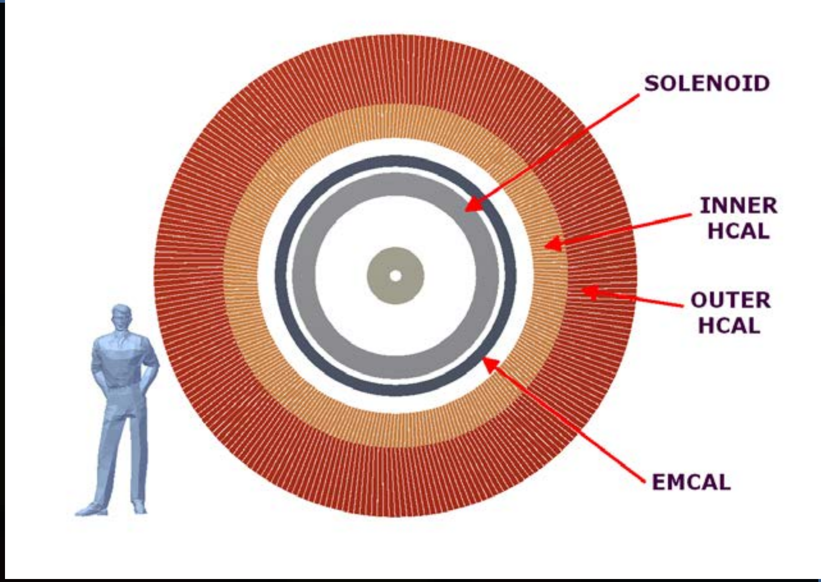
- Solenoid 2 Tesla, R_{inner} = 70 cm

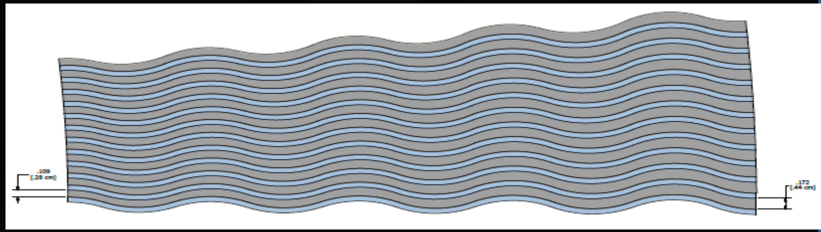
Accordion Tungsten-Fiber EMCal

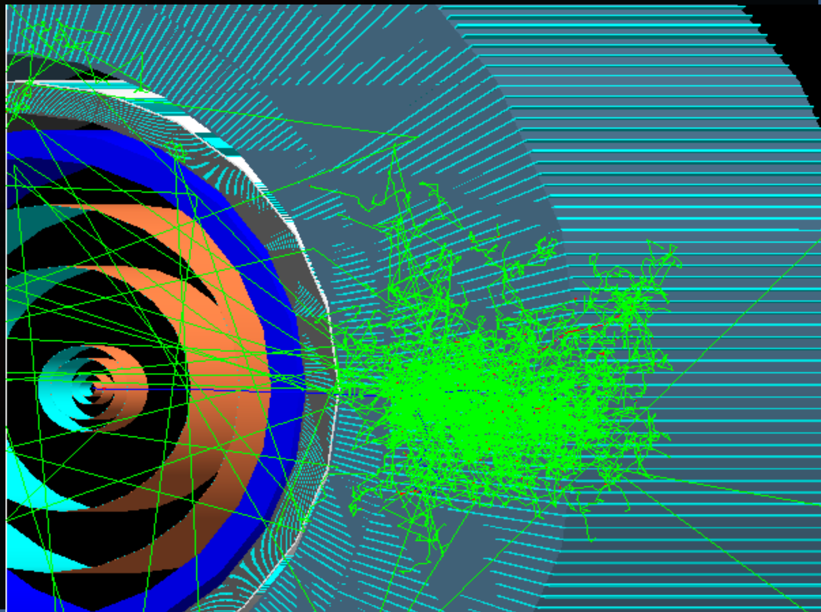
- SBIR with Tungsten Heavy Powder
- Prototype being constructed, EIC R&D
- 10 cm total thickness
- 14%/sqrt(E) resolution
- Full GEANT-4 simulation results
- Silicon Photomultiplier (SiPM) readout

Fe-Scintillator HCal

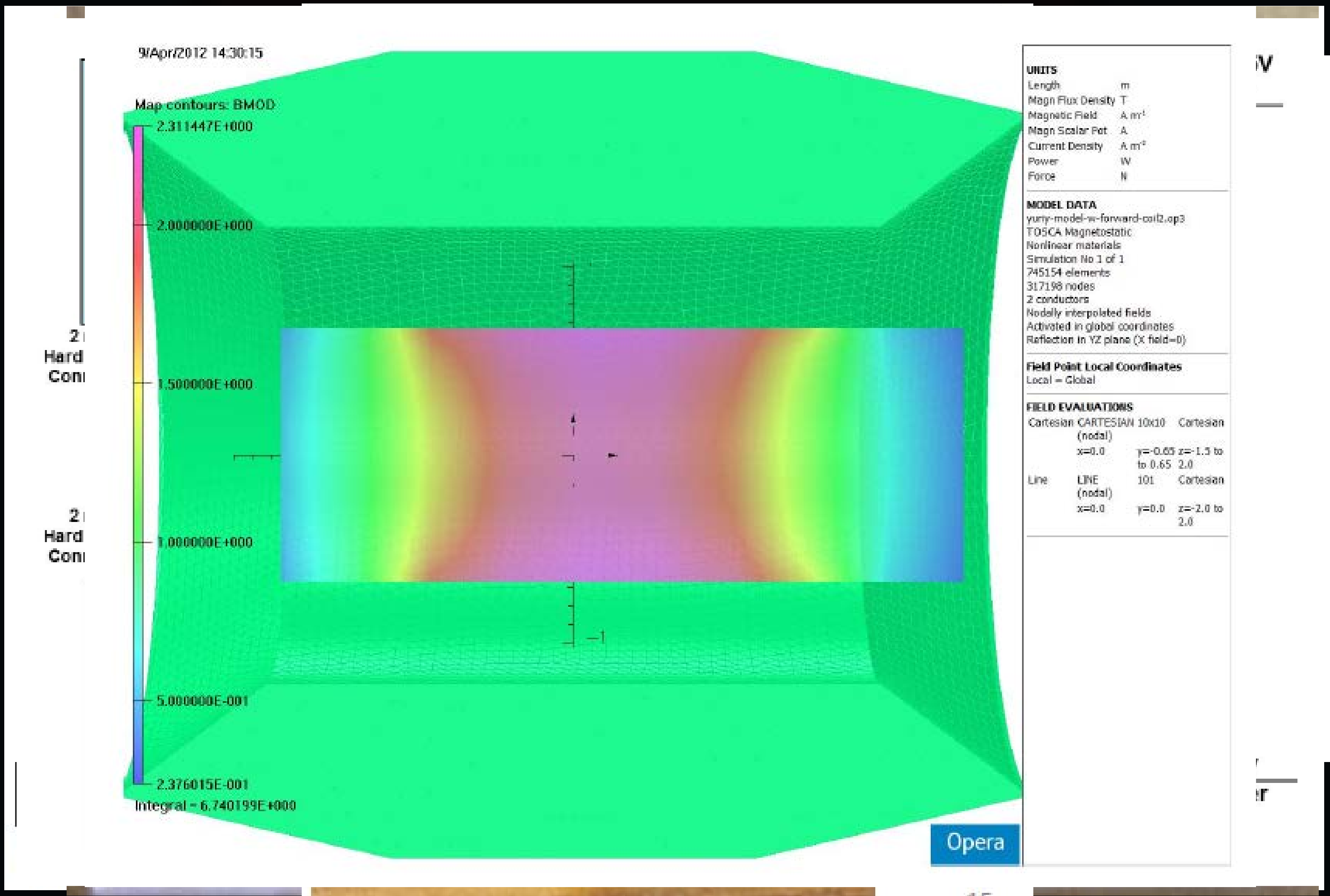
- Acts as flux return for magnetic field
- Prototype being constructed
- 1 meter total thickness
- 75%/sqrt(E) resolution
- Full GEANT-4 simulation results
- Common SiPM/electronics to EMCal







Flash Examples



Detailed Costing for MIE

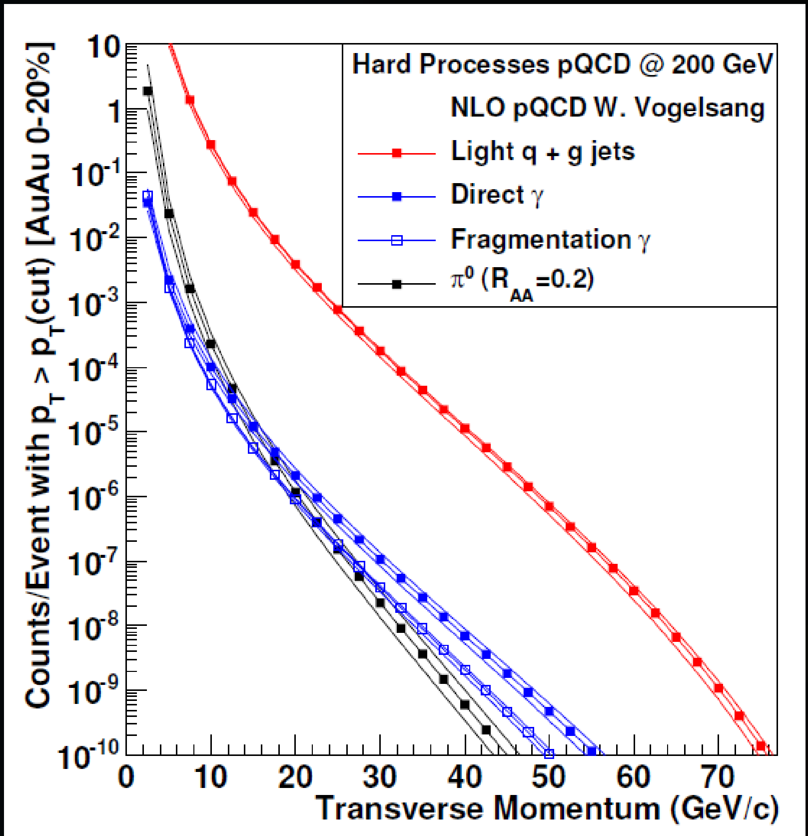
- Magnet quote from CMS Magnet Vendor
- Specific SiPM quotes
- Full electronics costing
- Hcal steel, scintillator, fiber, and assembly costing
- Tungsten Heavy Powder company detailed quote including assembly

With full overhead, project averaged contingency of 40%, management, engineering, labor, … the total is ~ $24M in new funds and another $6M of existing BNL labor re-direct.

Working closely with BNL Project Specialists for detailed WBS.

Very far advanced for CD-0, in part since we want to move forward on an aggressive time scale (as recommended by the PAC).

Can we measure these key observables?



	Au+Au (central 20%)	p+p	d+Au
>20GeV	10^7 jets 10^4 photons	10^6 jets 10^3 photons	10^7 jets 10^4 photons
>30GeV	10^6 jets 10^3 photons	10^5 jets 10^2 photons	10^6 jets 10^3 photons
>40GeV	10^5 jets	10^4 jets	10^5 jets
>50GeV	10^4 jets	10^3 jets	10^4 jets

Rates based on full stochastic cooling, but no additional accelerator upgrades.

Note, first ATLAS dijet paper based on ~ 1k pairs.

Huge rates allow differential measurements with geometry (v_2, v_3, A+B, U+U, …) & precise control measurements (d+Au & p+p).

Over 80% as dijets into $|\eta|<1.0$

Are jet measurements at RHIC dominated by "fake jets"?

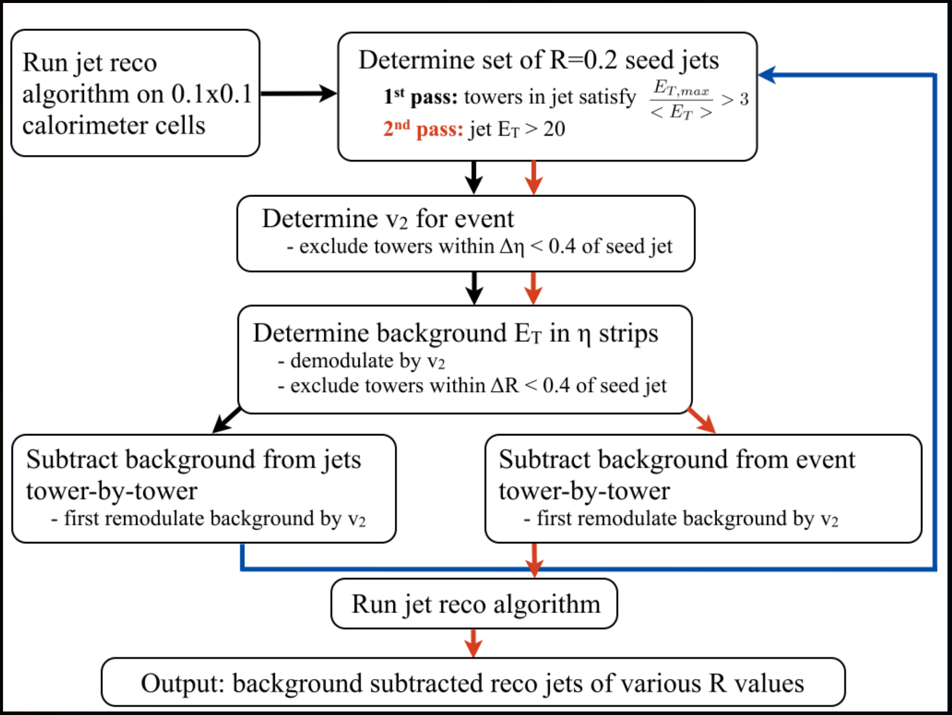
Jet - Underlying Event Separation Method for Heavy Ion Collisions at the Relativistic Heavy Ion Collider

J. A. Hanks[1], A. M. Sickles[2], B. A. Cole[3], A. Franz[2], M. P. McCumber[4], D. P. Morrison[2], J. L. Nagle[4], C. H. Pinkenburg[2], B. Sahlmueller[1], P. Steinberg[2], M. von Steinkirch[1], M. Stone[4]
[1] *Department of Physics and Astronomy, Stony Brook University, SUNY, Stony Brook, New York 11794-3400, USA*
[2] *Physics Department, Brookhaven National Laboratory, Upton, New York, 11973-5000*
[3] *Columbia University, New York, New York 10027 and Nevis Laboratories, Irvington, New York 10533, USA and*
[4] *University of Colorado, Boulder, Colorado 80309, USA*
(Dated: March 8, 2012)

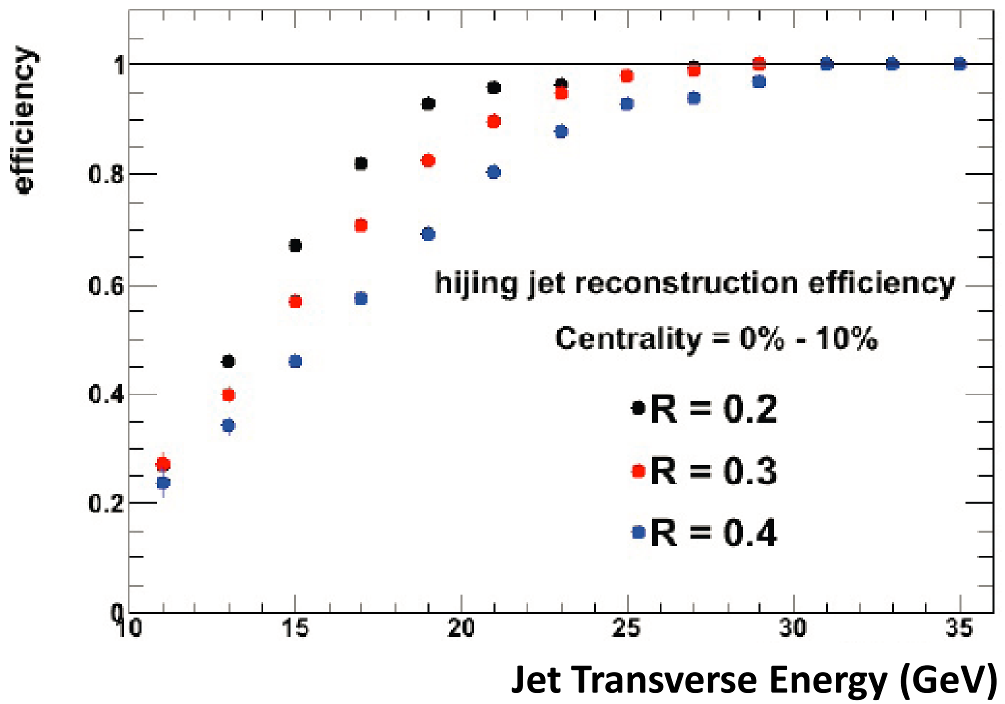
arXiv:1203.1353

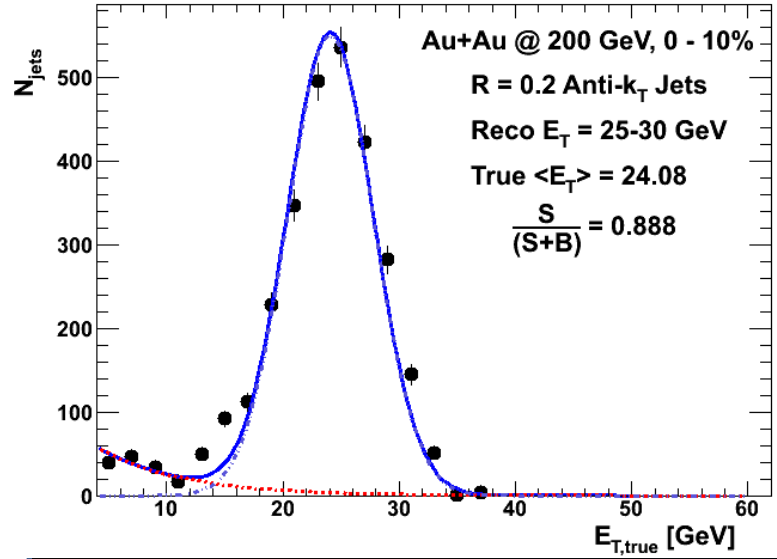
Positive referee report:
"very useful study regarding the practicality and efficiency of jet reconstruction at RHIC energies. The paper is scientifically sound, well written, and suitable for publication."

Over <u>1 billion</u> HIJING events run, tagging of fragmentation call jets, full ATLAS-type background subtraction method.



Full HIJING Event Analysis





Very good jet finding efficiency even in the most central Au+Au events for $E_T > 20$ GeV

Jets reconstructed 25-30 GeV dominated by real jets (known from HIJING truth) at 24 GeV (shift from resolution).

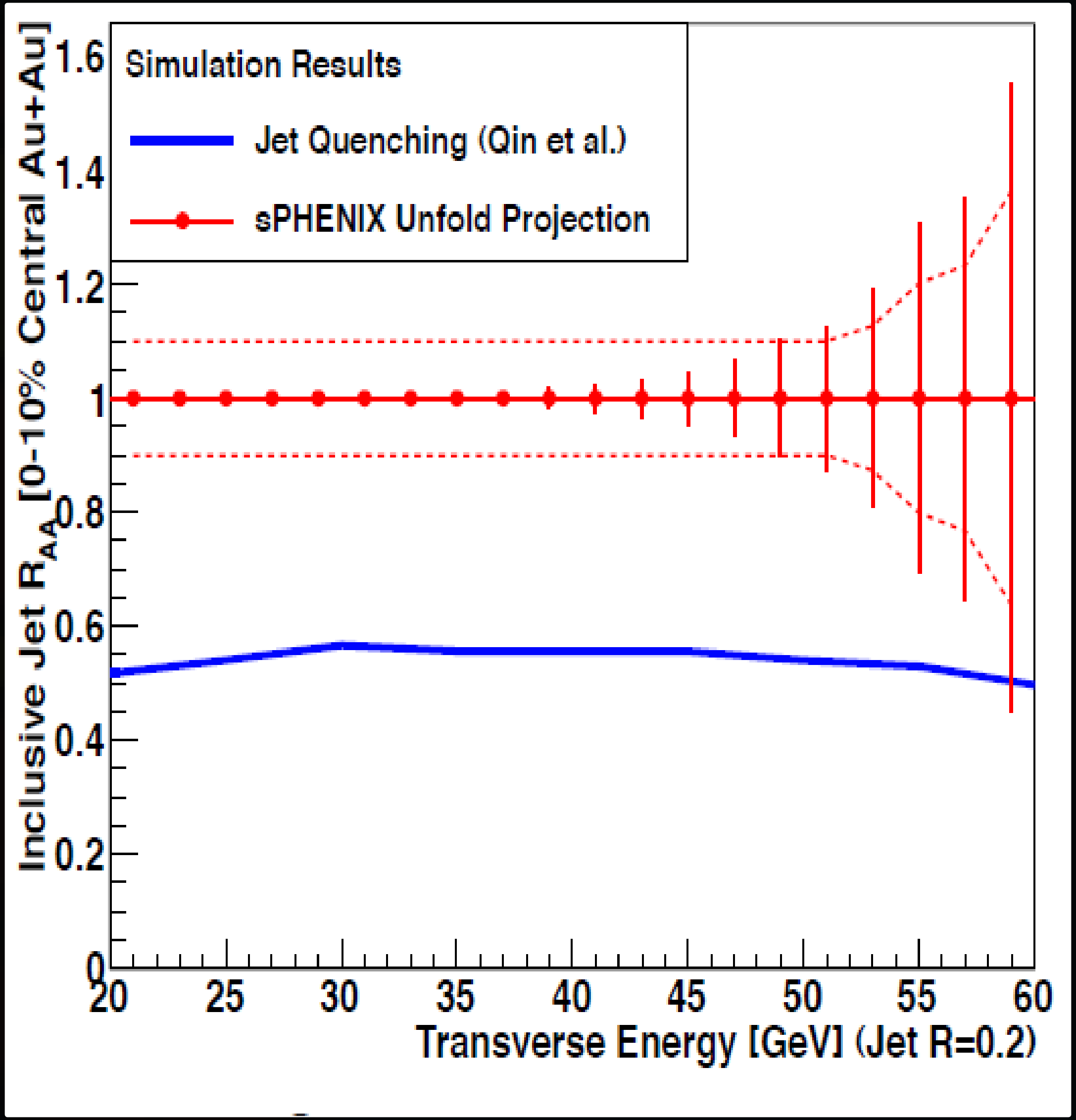
And this is with no fake rejection (expected to give X10 more suppression).

Jet Spectra

In region above fake jet contributions, we can measure the inclusive jet spectra.

Example ROOUNFOLD Iterative Bayes Method shows very good result.

Full GEANT-4 simulation with FastJet Reconstruction gives good resolution.



Jet R_{AA} measurable with high stats

• PYTHIA (vacuum case)

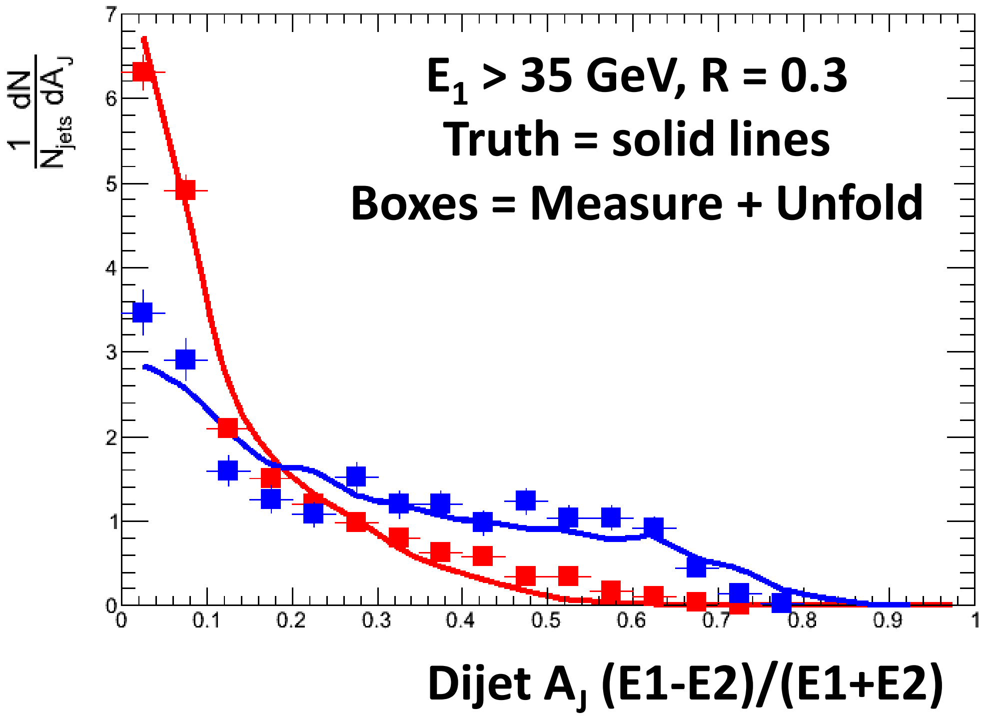
• PYQUEN (quenched case)

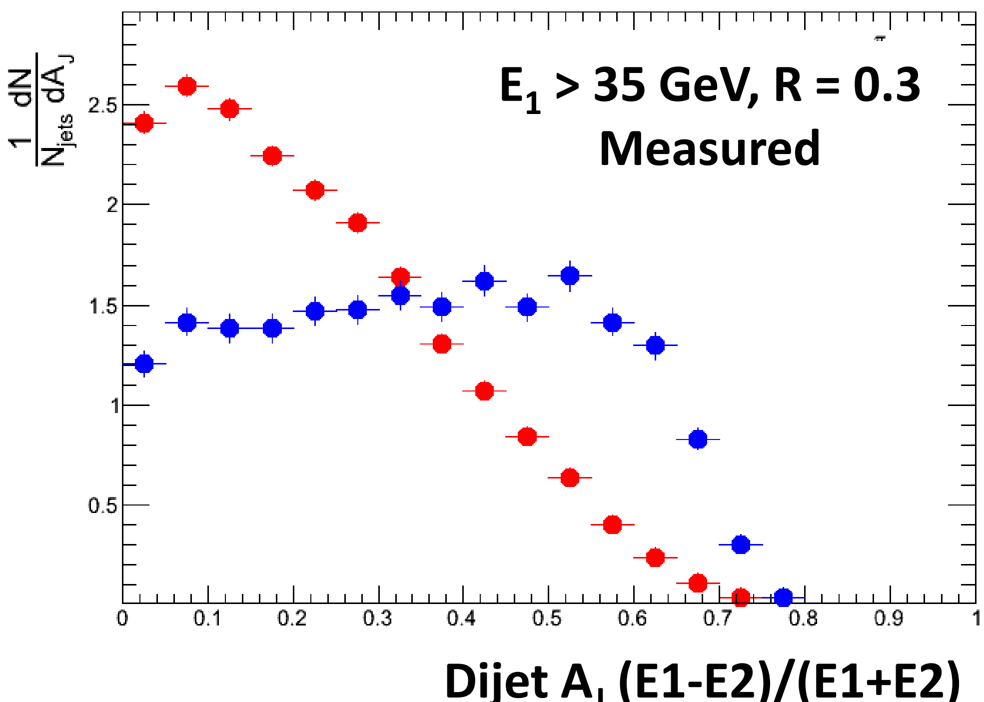
Full jets + HIJING background + detector resolution + FastJet + underlying event subtraction

Very easily discriminated (large effect)

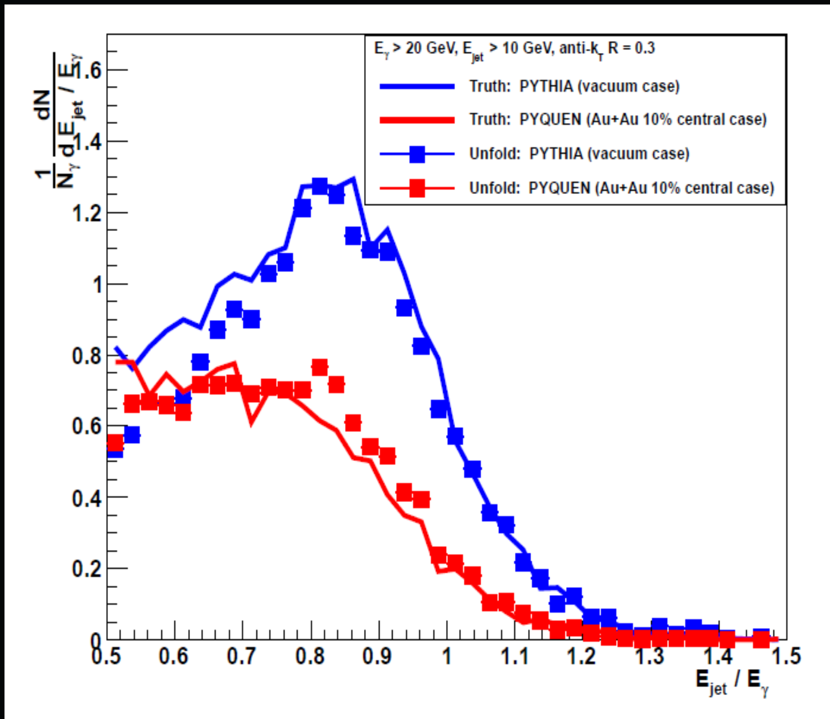
Full 2-d unfold in progress, and example trigger unfold gets most of the way there.

<u>*Excellent ability to constrain coupling to medium and check parton shower modification.*</u>





Gamma-Jet



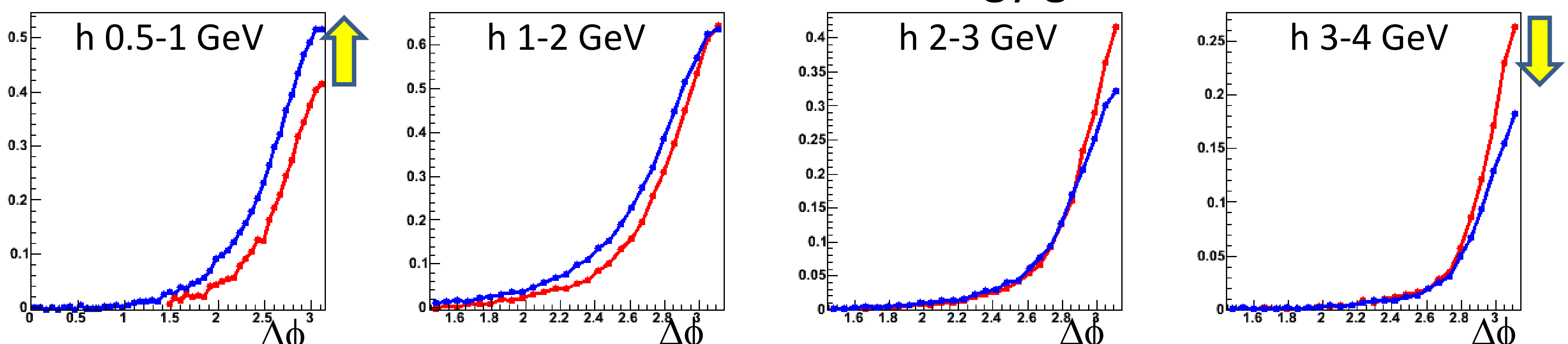
For p_T > 15 GeV, direct photons dominate at RHIC

Direct γ – jet correlations

- PYTHIA (vacuum)
- PYQUEN (quenching)

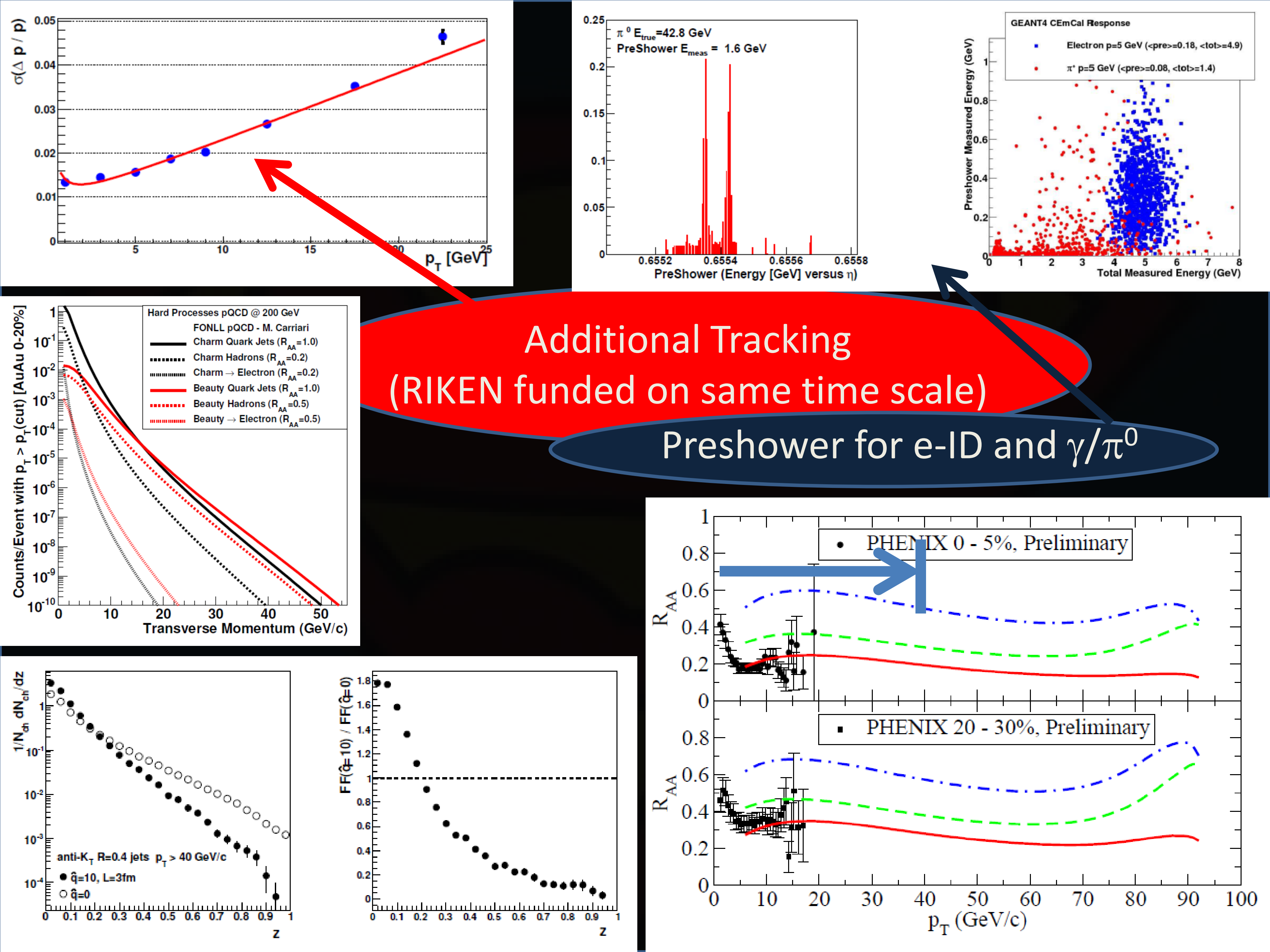
γ– hadron correlations

Track with VTX where the energy goes!



Evolution

- *All jet and γ-jet physics results in this talk can be measured with this first stage MIE …*
-
- *Evolution with **additional tracking layers** (RIKEN funded) adds capability for high-z fragmentation functions*
- *Evolution with **additional pre-shower** on EMCal allows for π^0 R_{AA} measurement up to p_T = 40 GeV/c and electron-ID for Upsilon measurements (with resolution to separate 3 states) and tagging of charm/beauty jets*
- *Evolution with forward detector allows for key transverse spin and cold nuclear matter p+A measurements*
- *Evolution into Electron-Ion Collider detector (ePHENIX) with world class capabilities for electron beam 5-10 GeV*



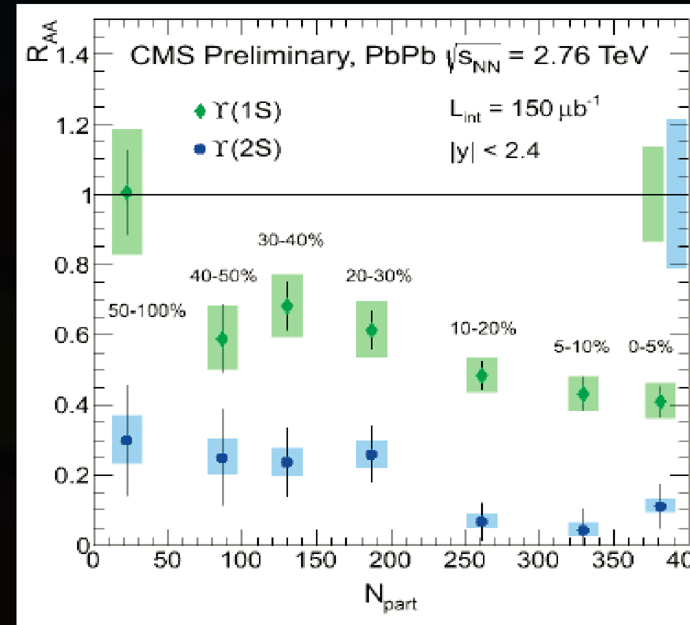
Additional Tracking
(RIKEN funded on same time scale)
Preshower for e-ID and γ/π0
σ(Δ p / p)
p_T [GeV]
π0 E_true=42.8 GeV
PreShower E_meas = 1.6 GeV
PreShower (Energy [GeV] versus η)
GEANT4 CEmCal Response
Electron p=5 GeV (<pre>=0.18, <tot>=4.9)
π+ p=5 GeV (<pre>=0.08, <tot>=1.4)
Preshower Measured Energy (GeV)
Total Measured Energy (GeV)
Hard Processes pQCD @ 200 GeV
FONLL pQCD - M. Carriari
Charm Quark Jets (R_AA=1.0)
Charm Hadrons (R_AA=0.2)
Charm → Electron (R_AA=0.2)
Beauty Quark Jets (R_AA=1.0)
Beauty Hadrons (R_AA=0.5)
Beauty → Electron (R_AA=0.5)
Counts/Event with p_T > p_T(cut) [AuAu 0-20%]
Transverse Momentum (GeV/c)
PHENIX 0 - 5%, Preliminary
PHENIX 20 - 30%, Preliminary
R_AA
p_T (GeV/c)
1/N_ch dN_ch/dz
anti-K_T R=0.4 jets p_T > 40 GeV/c
q̂=10, L=3fm
q̂=0
z
FF(q̂=10) / FF(q̂=0)
z

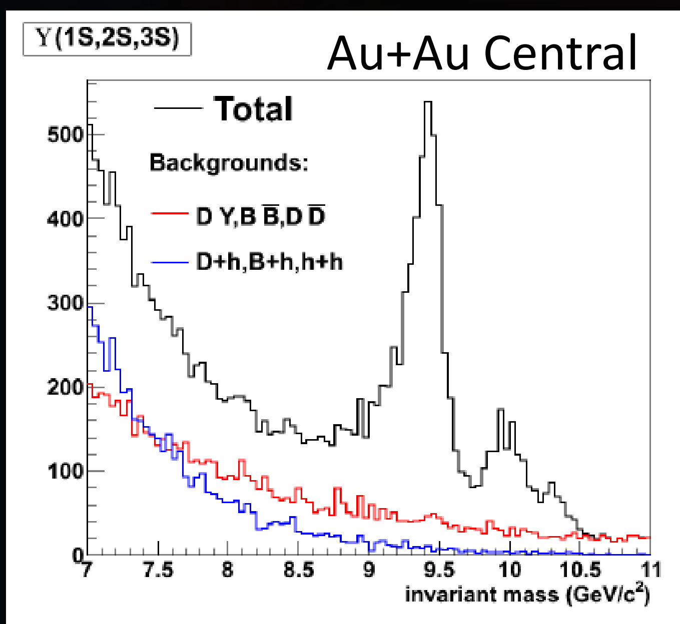
Extremely exciting LHC Upsilon results

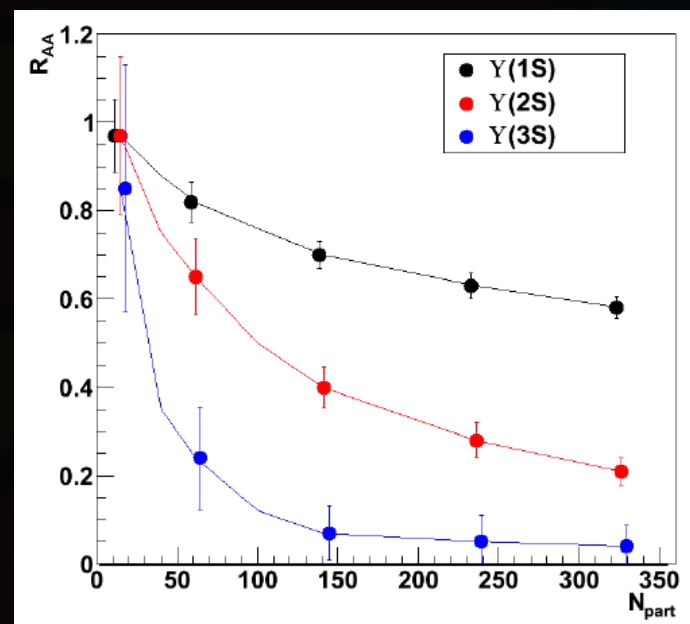
Key to map out temperature dependence

sPHENIX will have similar statistics to LHC and > 7x STAR MTD measurement

Needs additional tracking + preshower







Forward sPHENIX and Evolution to ePHENIX

Next stage forward spectrometer under design – enabled by open geometry of central solenoid. p+A and transversely polarized p+p is the focus. Task force writing detailed physics and design report (somewhat longer time scale).

ePHENIX task force.... Lots of real work, very engaged...

Abhay Deshpande (chair), Christine Aidala, Ken Barish, Sasha Bazilevsky, Kieran Boyle, Tom Hemmick, Dave Morrison, Itaru Nakagawa, Joe Seele, Ralf Seidl and Craig Woody.

Really investigating the barrel first stage requirements for enabling a world class EIC program for 5-10 GeV electron beam. Direct coupling with EIC task forces (Tom Hemmick can tell you much more) and with EIC R&D projects. Included details in MIE Appendix, and world-class program builds on sPHENIX foundation.

We had a 2 hour meeting with DoE in Washington DC (including ALD) on May 15, 2012 (Tim Hallman, Jehanne Gillo, Jim Sowinski)

Tim's reaction to the sPHENIX presentations was positive:

“Entirely timely to be thinking about these important questions.”
“Important topic to be pursued at RHIC.”
“[sPHENIX] has landed on a key topic [jet measurements] and it would be very disappointing, even tragic, to not answer these questions.”
“Excited and alarmed at how far you are in thinking about the detector“
“CD-0 is a demonstration of mission need... don't want to go forward until ONP understands how to fund it” [i.e. decision from Tribble II]

Jehanne remarked:

“Looks like an exciting approach to the detector design. I appreciate the technical design and the conservative approach.”
“The project looks really cool.”

What do we want from you?

Time of great uncertainty and doubt… Best plan is to push forward with what physics gets you the most excited and motivated. Is that right?

The MIE proposal is essentially done and undergoing internal PHENIX review. Will be handed in to BNL management on July 1, 2012. Glad to distribute the document to the PAC members.

We believe it is crucial to have a detailed outside review by BNL on a short time scale (and not tied to resolving the Tribble II panel decision which could take quite some time). This can serve as important input into the RHIC future plan to be presented. Also, it is critical to keep the collaboration energized at a time when doubt rules the world (Drachma or Euro, paper or plastic, RHIC or FRIB or neither).

PAC review of Decadal Plan in 2011 (1 hour presentation) and this MIE (30 minute presentation) is simply insufficient.

Need sPHENIX plans to be integral part of RHIC decade plan. If not ?

Extras

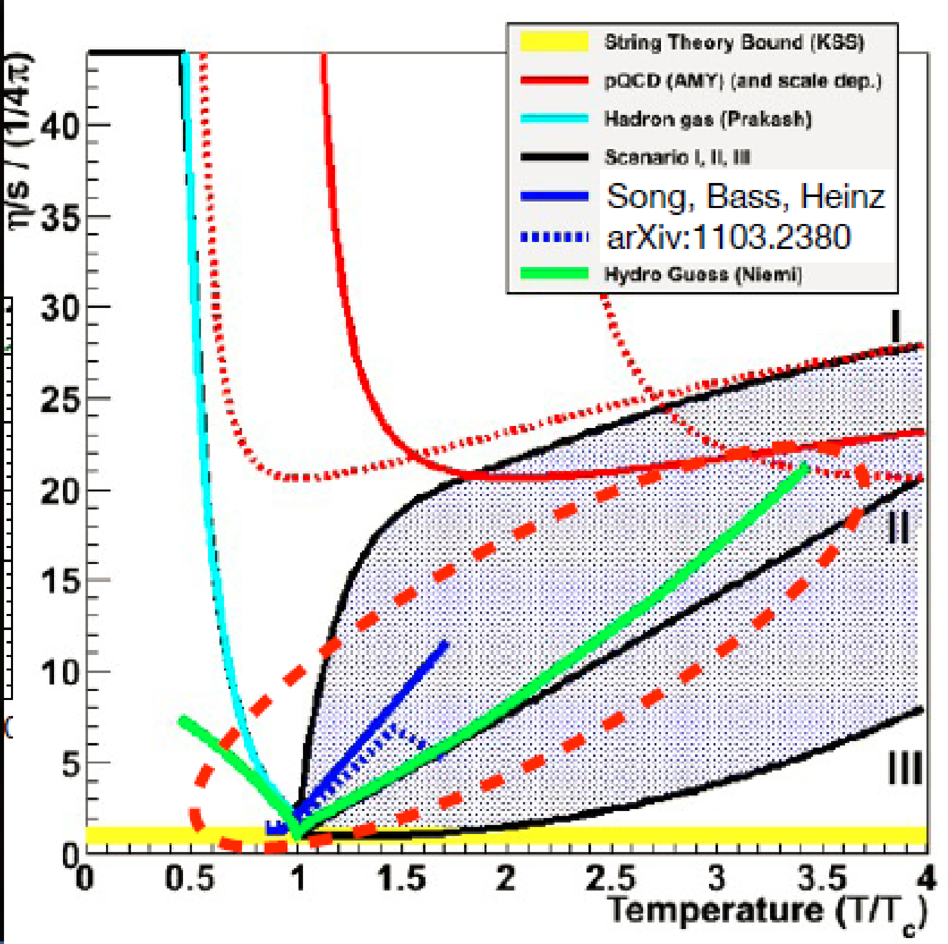
Complementarity of Hydrodynamics and Jets

Recent studies of η/s (T) in the literature

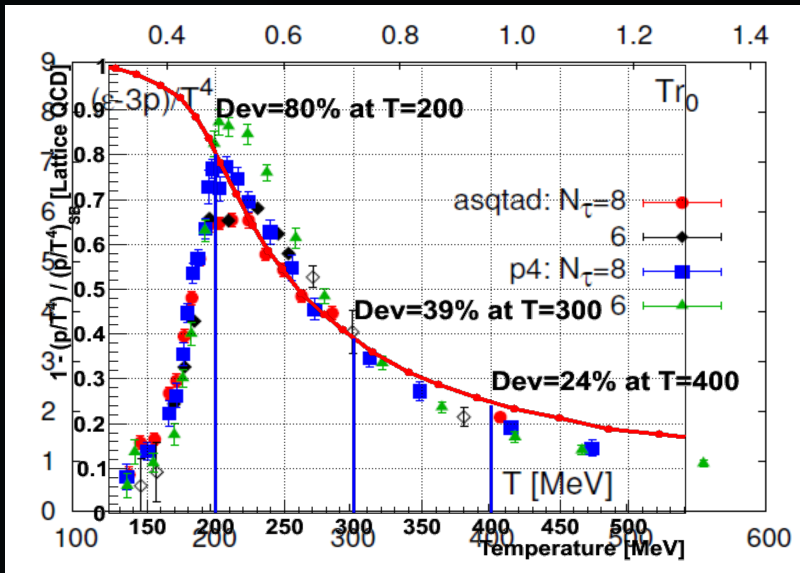
arXiv:1101.2442 (Niemi, Denicol, Huovinen, Molnar, Rischke)
arXiv:1103.2380 (Song, Bass, heinz)
arXiv: 1102.0680 (Nagle, Bearden, Zajc)

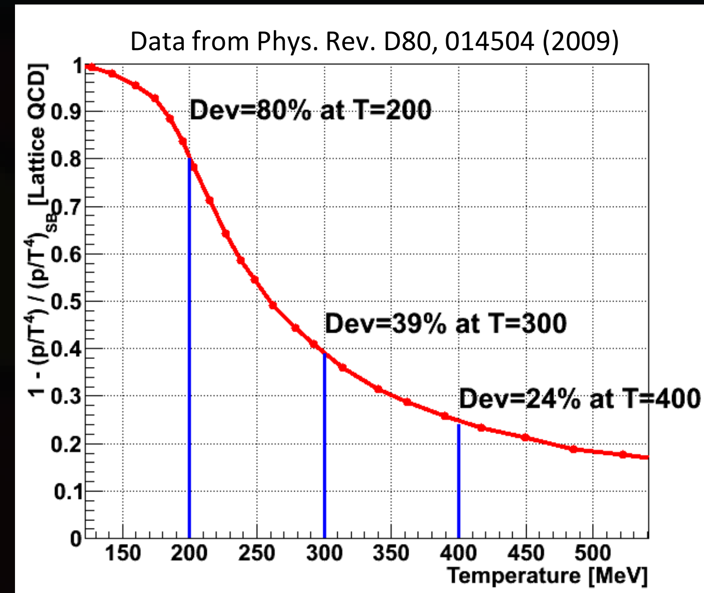
Models favor increase of η/s (less strongly coupled) above T_c. Exact constraints unclear until fluctuating initial conditions, initialization of stress-energy tensor, and relaxation time systematics included.

Interesting that change $\eta/s = 1/4\pi$ to $2/4\pi$ for $T > 2\,T_c$ does not change the flow at all.



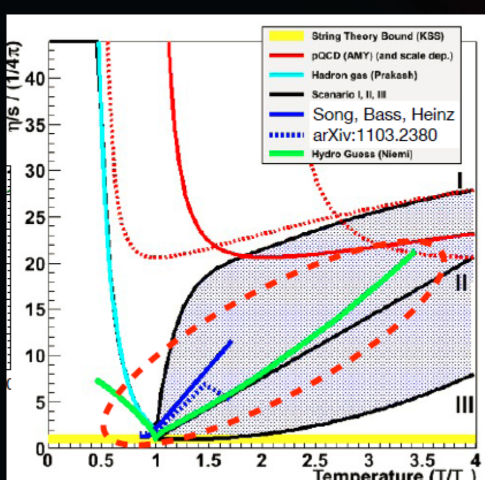
Is the medium coupling strongest near 1-2 T_c?





Trace anomaly – mixed information.
Perturbatively ~ g dg/dΛ ~ $d\alpha_s/d\Lambda$
Deviation from conformal

Some suggested deviation of P/T^4 from SB.
Of course, AdS/CFT gives result within ~25% of SB and still very strongly coupled.



η/s is another measure, but without reliable lattice guidance. Hydro models need significant rise

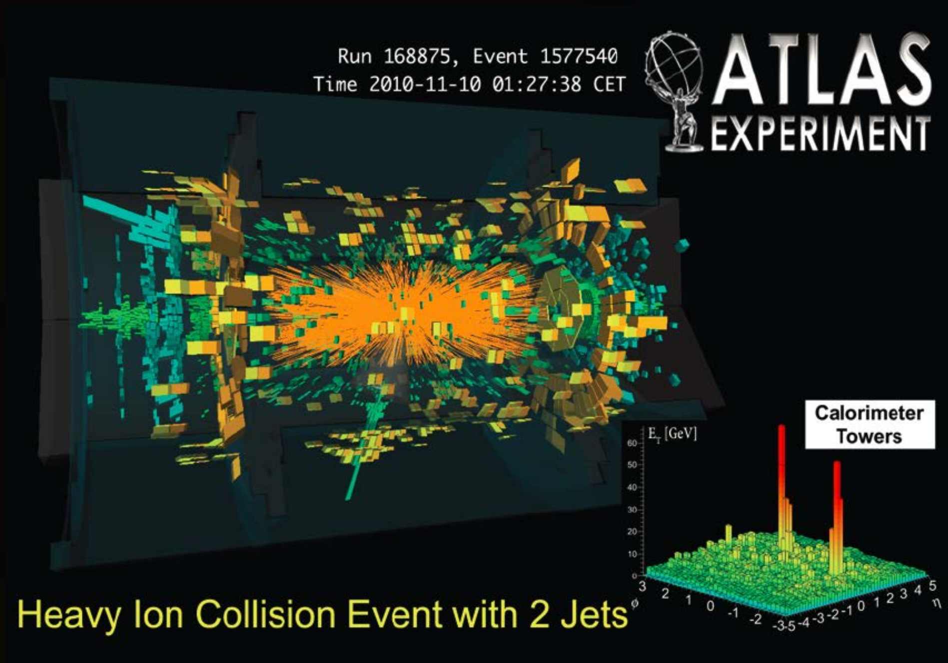
Lots of discussion of this topic at Hard Probes '12 in Sardinia…

Seems like a good thing to measure experimentally

Why Hadronic Calorimetry?

<u>All</u> heavy ion jet publications to date (i.e. ATLAS and CMS) come from calorimeter measurements !

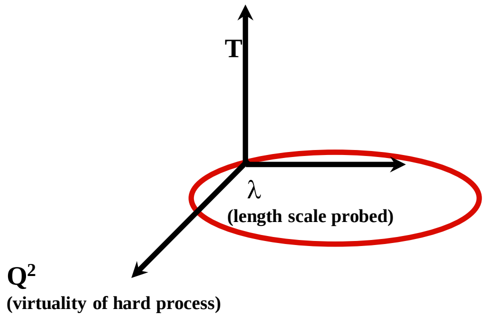
Ability to try different methods (supplementing with tracking) is also a big advantage.



Critical to have EMCal + HCAL with continuous coverage (no gaps, spokes, holes) with large acceptance to see both jets and γ-jet and at very high rate. Then add in tracking information as key additional handle for systematic studies.

Also, when measuring fragmentation functions, hadron p_T and jet energy measures are independent.

At which length scale is the medium probed?



Related to virtuality of exchange particle with medium.

Electron Scattering Example