Upgrade and new Physics PHENIX

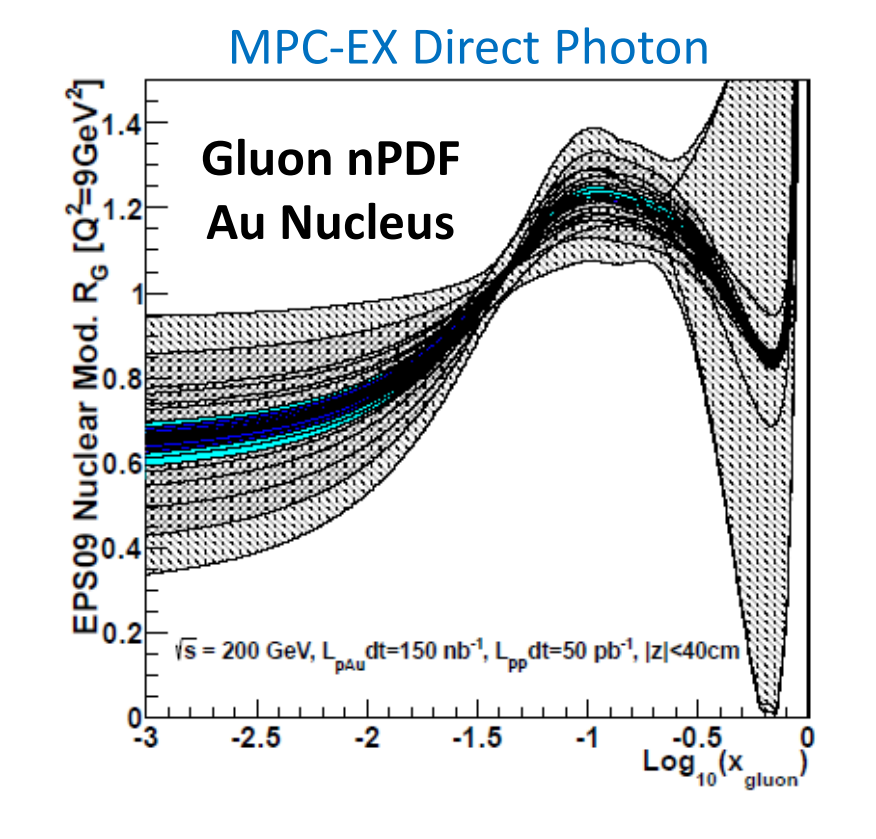
Chris Pinkenburg
for the
PHENIX collaboration

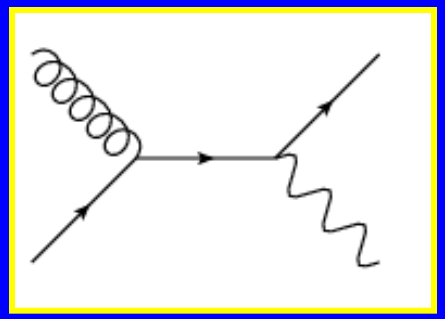
Constraining Gluon nPDFs

Strong indications of low-x shadowing/saturation physics with d+Au J/ψ, e-μ correlations, h-h correlations, single muons, electrons, …

And yet, all have final state interactions.

Golden channel direct photon





Using full statistical / systematic constraint method on EPS09 nPDFs, blue bands indicate projected measurement (**1, 2 σ** level)

p+Au with transversely polarized proton

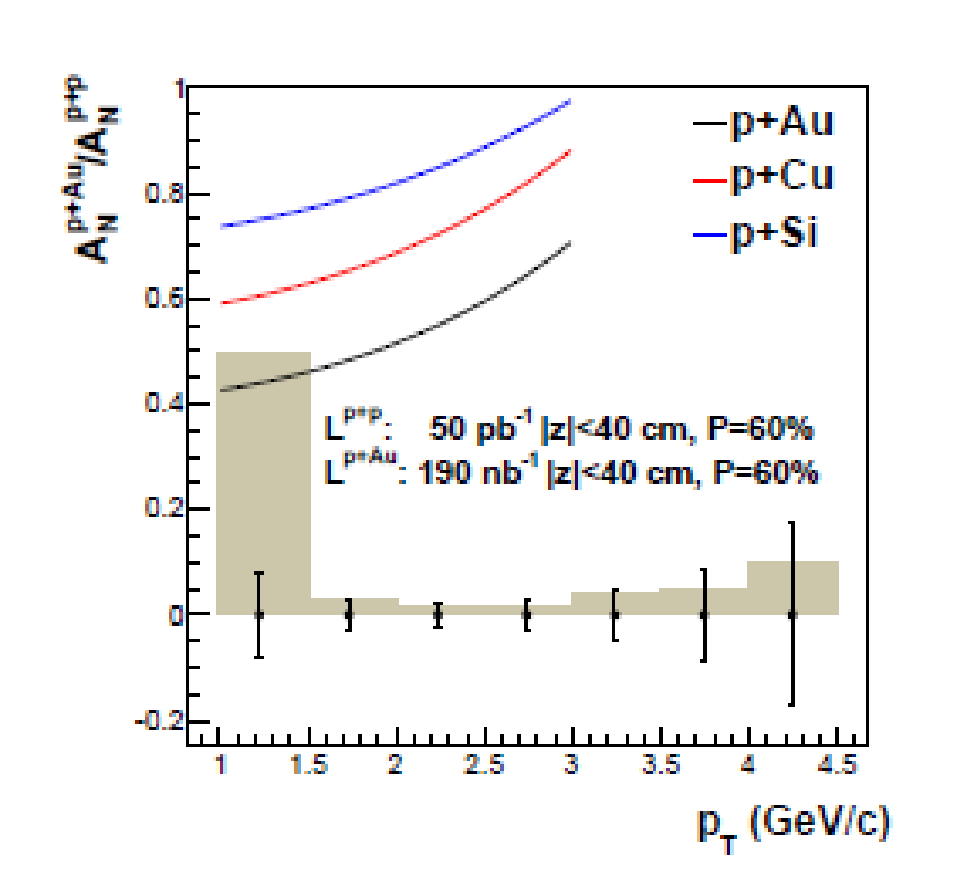
New theory developments… Transverse polarization A_N in $\vec{p}$+A scales with the saturation scale for $p_T < Q_s$

Completely unique RHIC access to saturation physics

$\vec{p}$+Au measurement with projected uncertainties in 190 nb^{-1} |z|<40cm

Testing geometric scaling with Si target nuclei

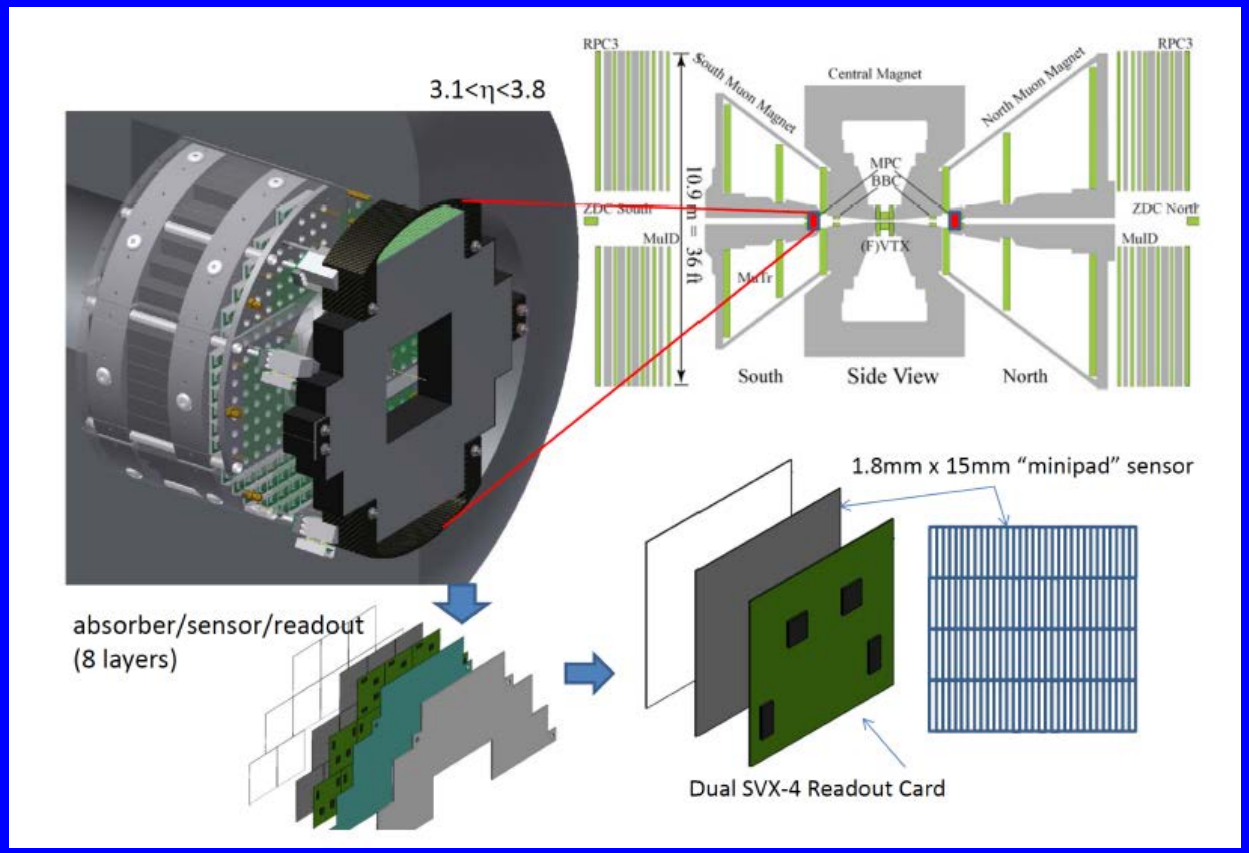
Comparable uncertainties with 2 week runs



MPC-EX Upgrade

The PHENIX MPC Crystal Calorimeter ($|\eta|$=3.1-3.8) has played a critical role in our forward (low-x) and transverse spin physics program

MPC-EX upgrade adds novel silicon tracking / preshower detector to enable *direct photon* identification and $\pi^0 \rightarrow \gamma\gamma$ to higher momentum



- π^0 rejection (prompt photons)
- Charged track identification
- π^0 reconstruction out to >80GeV

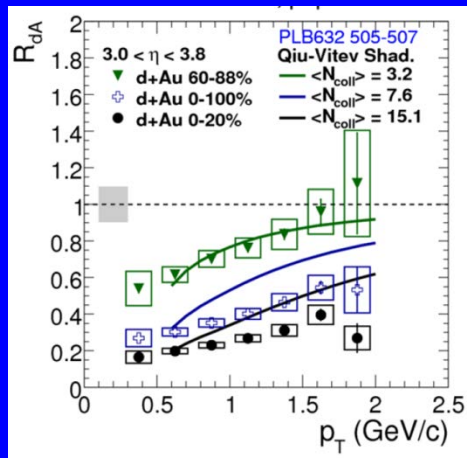
Beam test in fall, and section installed for integration tests in Run 14

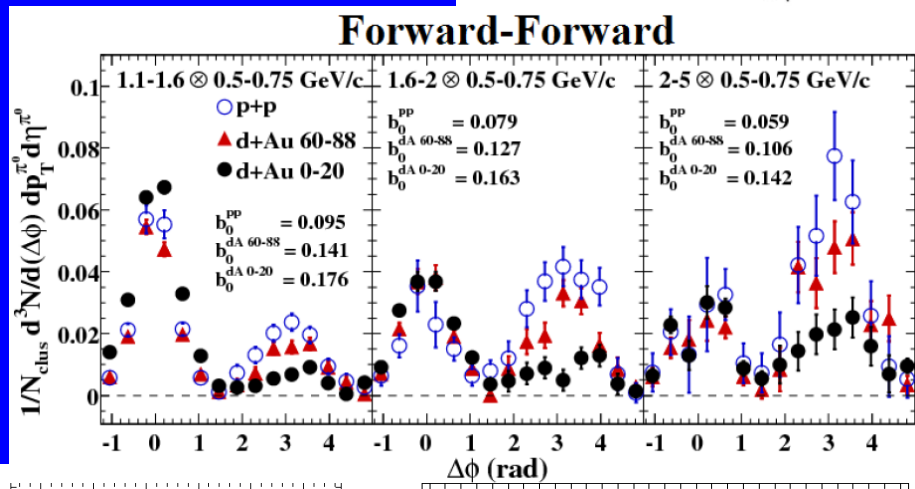
Full detector available for physics in Run-15

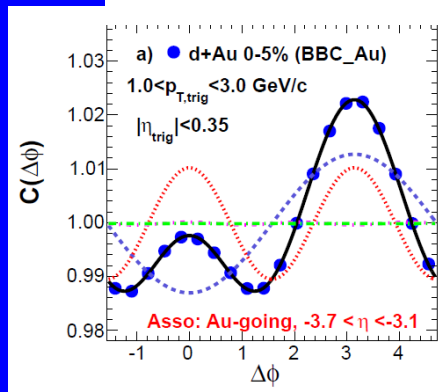
MPC-EX Section in Situ

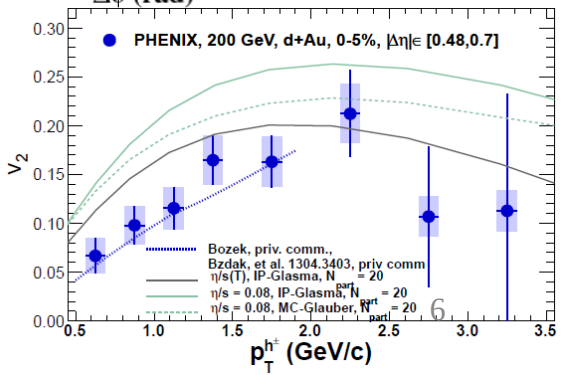
Other MPC-EX measurements

- Forward single-track π^0 out to higher p_T
- Correlations for forward-forward and mid-forward
  - with single-track π^0's, prompt photons?
- Jet cluster reconstruction using MPC-EX MIPs
  - Assume $p_{MIPs} \sim 1$ GeV/c
- Reaction plane determination with MPC and MIPs in MPC-EX

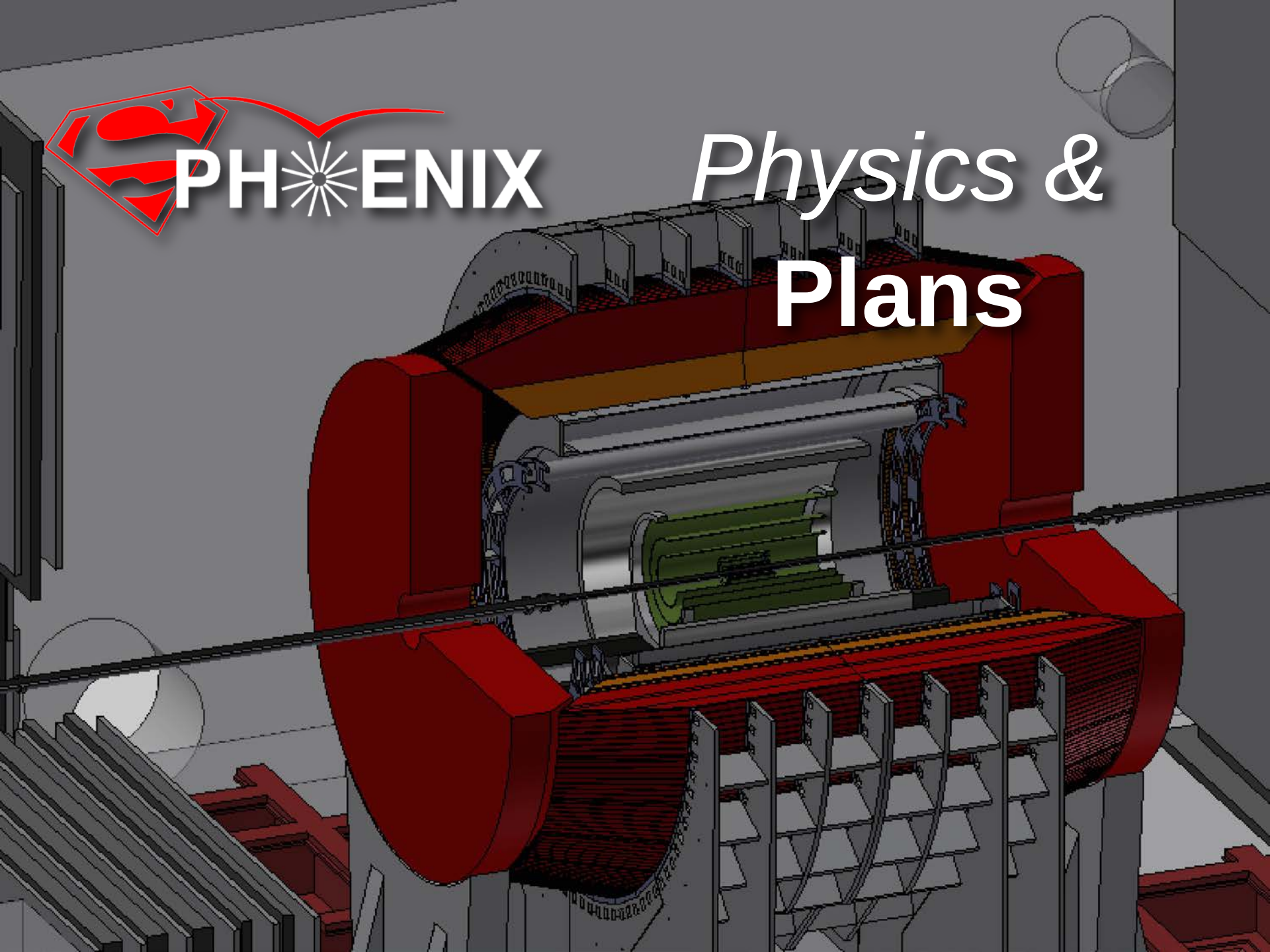




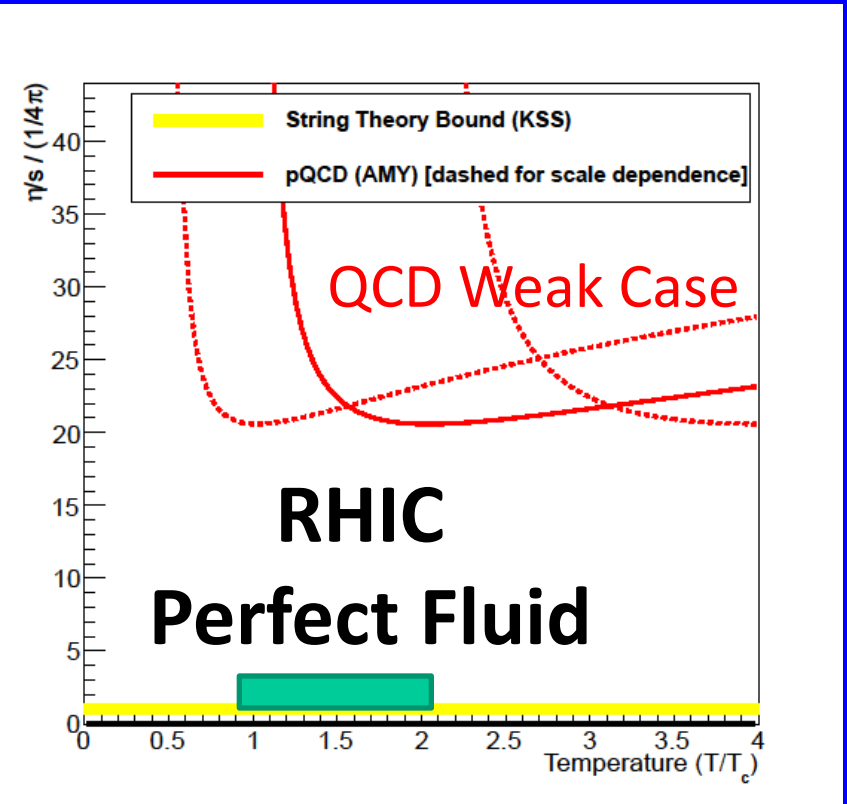




PHENIX *Physics &* **Plans**



The Perfect Fluid@RHIC



RHIC probes the QGP near 1-2 T_C

The expected weak coupling value for η/s is 1-2 orders of magnitude larger

Surprise: The Quark Gluon Plasma (QGP) created at RHIC is strongly coupled (sQGP) and behaves like a liquid close to the quantum mechanical limit, not like a gas

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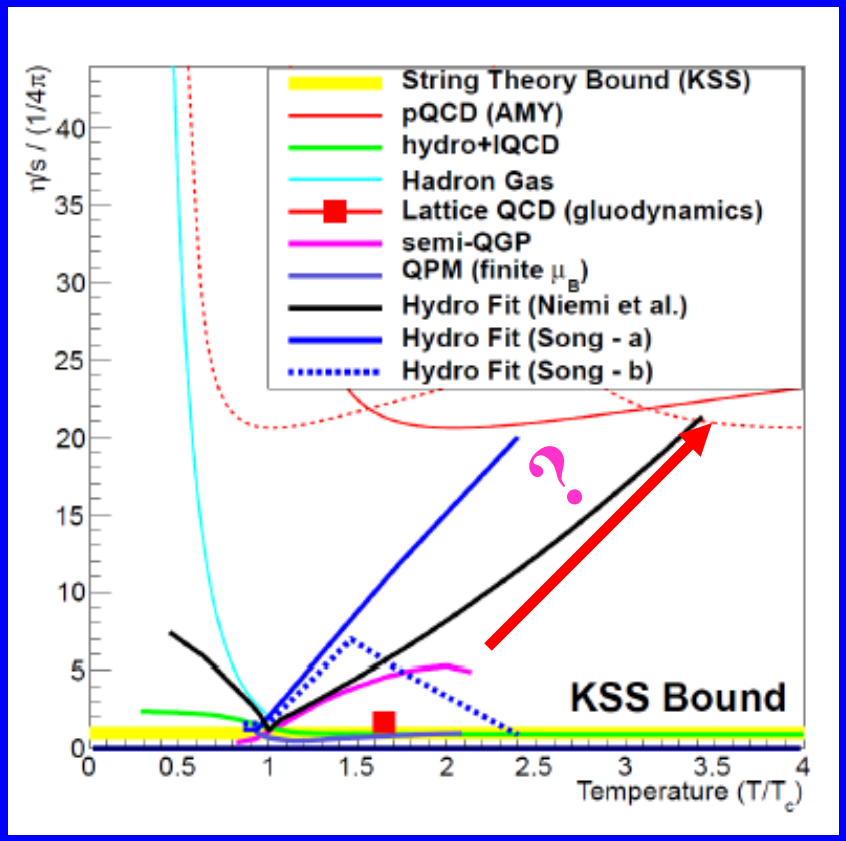

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The theory of the QGP is not well constrained but at high T we have to move to the weakly coupled regime

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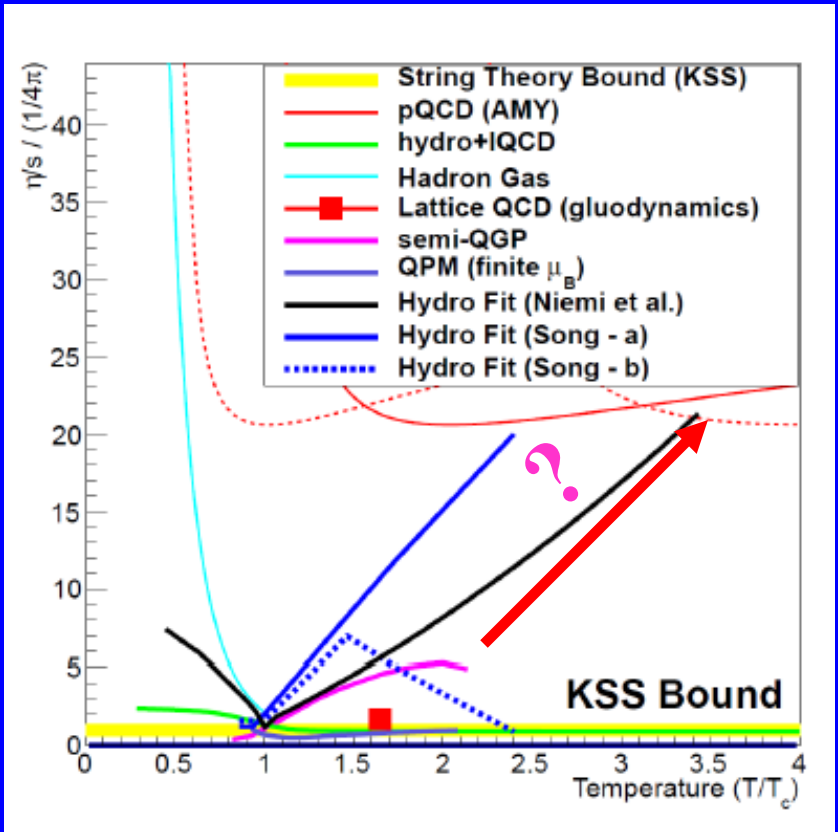

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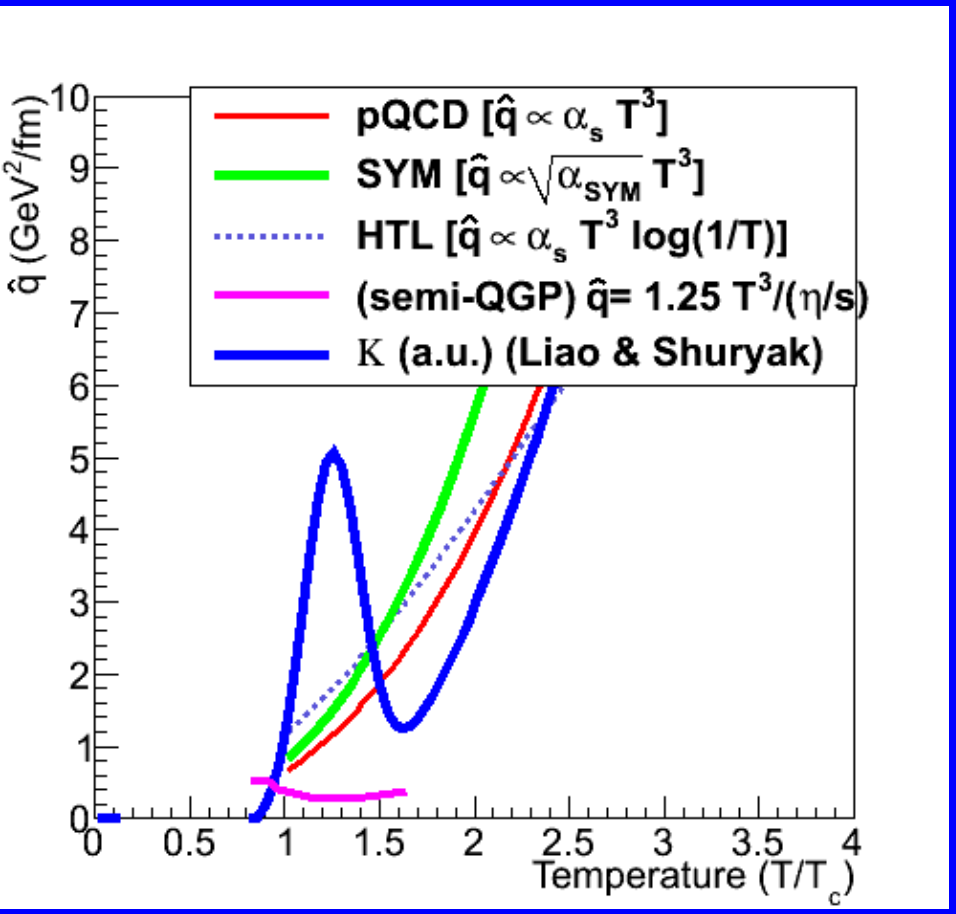
How does the Quark-Gluon Plasma transition from Strong to Weak?

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

Relating shear viscosity/entropy to the transport coefficient $\hat{q}$



"Small Shear Viscosity Implies Strong Jet Quenching"

A. Majumder, B. Muller, X.N. Wang, PRL (2007)

(derived for weak coupling)

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

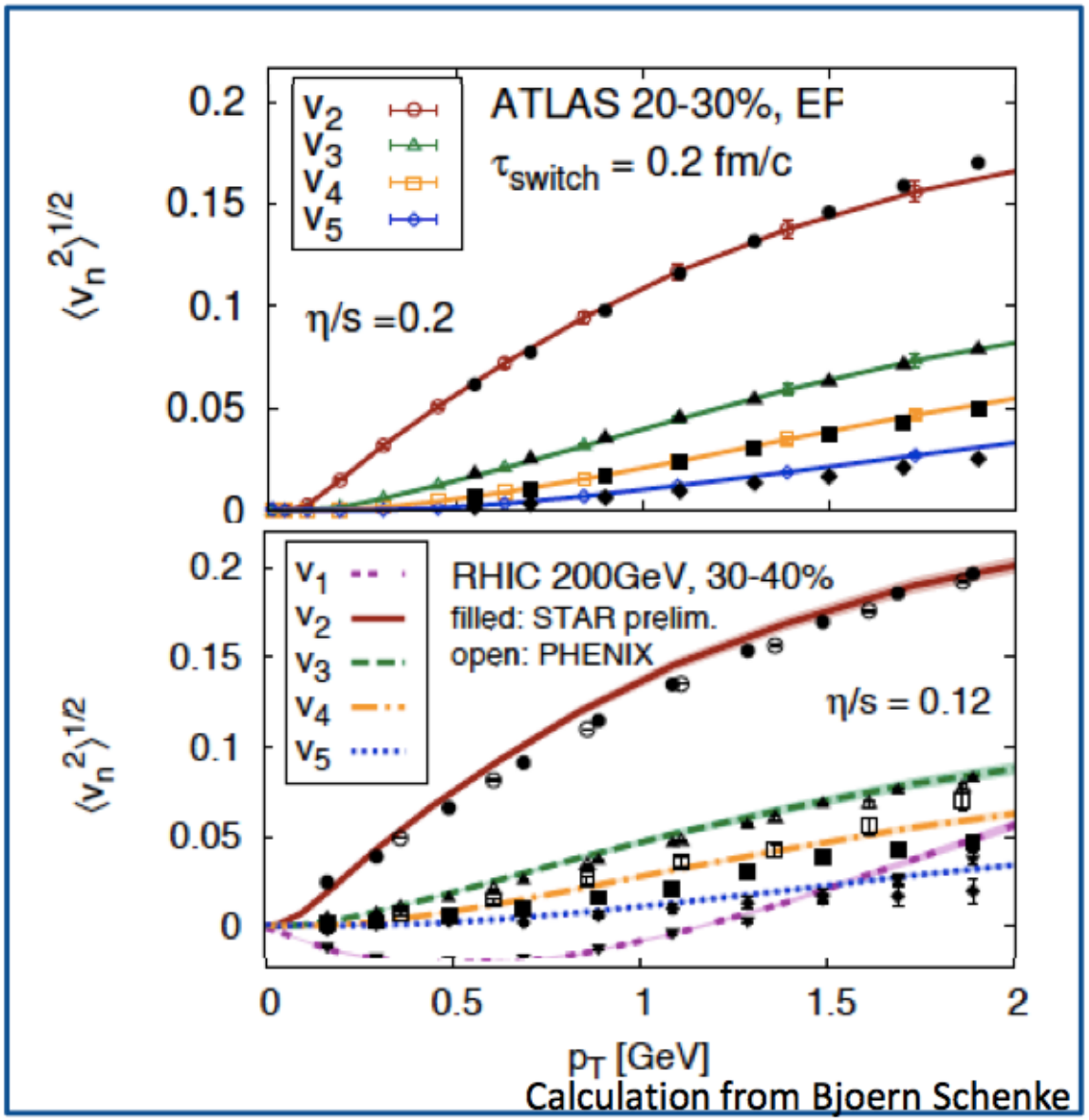
"Jet Quenching is a few times <u>stronger</u> near T_c relative to the QGP at $T > T_c$."

Liao and Shuryak, PRL (2009)

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

Horowitz and Gyulassy NPA(2011)

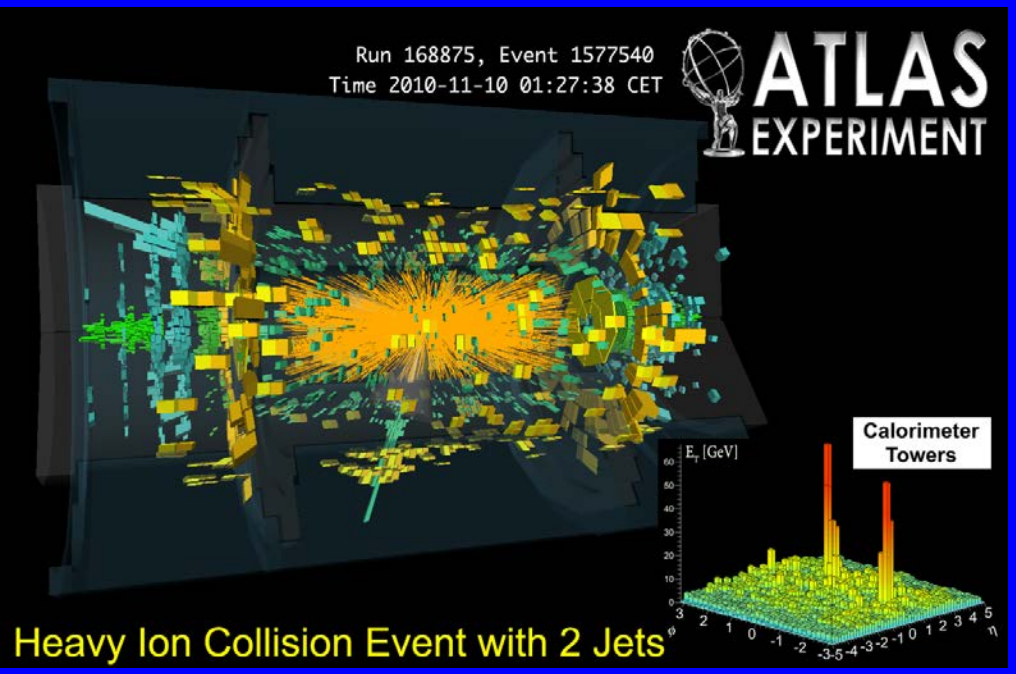
Stronger Coupling at RHIC?



Flow data indicate that η/s is smaller at RHIC
→The QGP created at RHIC is more strongly coupled

What are the underlying changes in QGP properties near the transition?

Advantage of Hadronic Calorimetry



ATLAS and CMS heavy ion jet observables come from calorimeter measurements

Ability to try different methods (using tracking information) is a big advantage

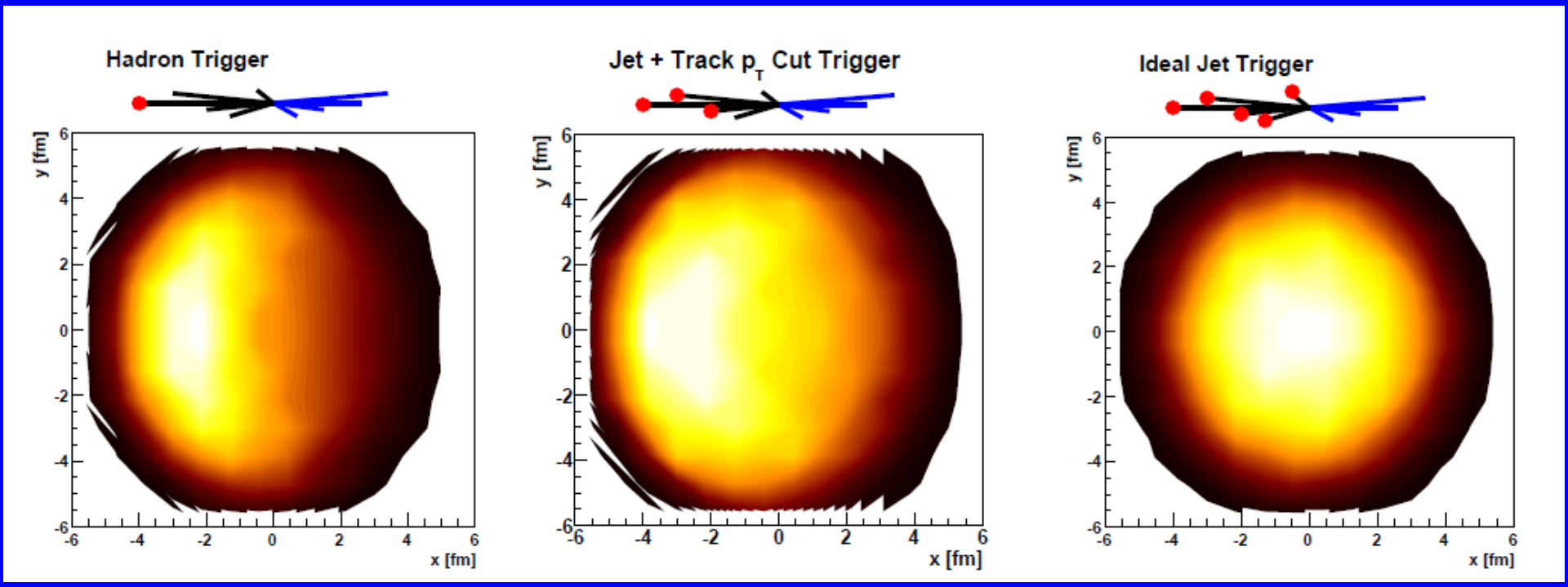
Critical to have large acceptance calorimetry with continuous coverage (no gaps,spokes, holes) to see both jets and γ-jet at very high rate. Tracking information provides key additional handle for systematic studies

For measurement of fragmentation functions: hadron p_T and jet energy measures are independent

Enables triggering in p+p, p+A without jet bias

Surface Bias Engineering

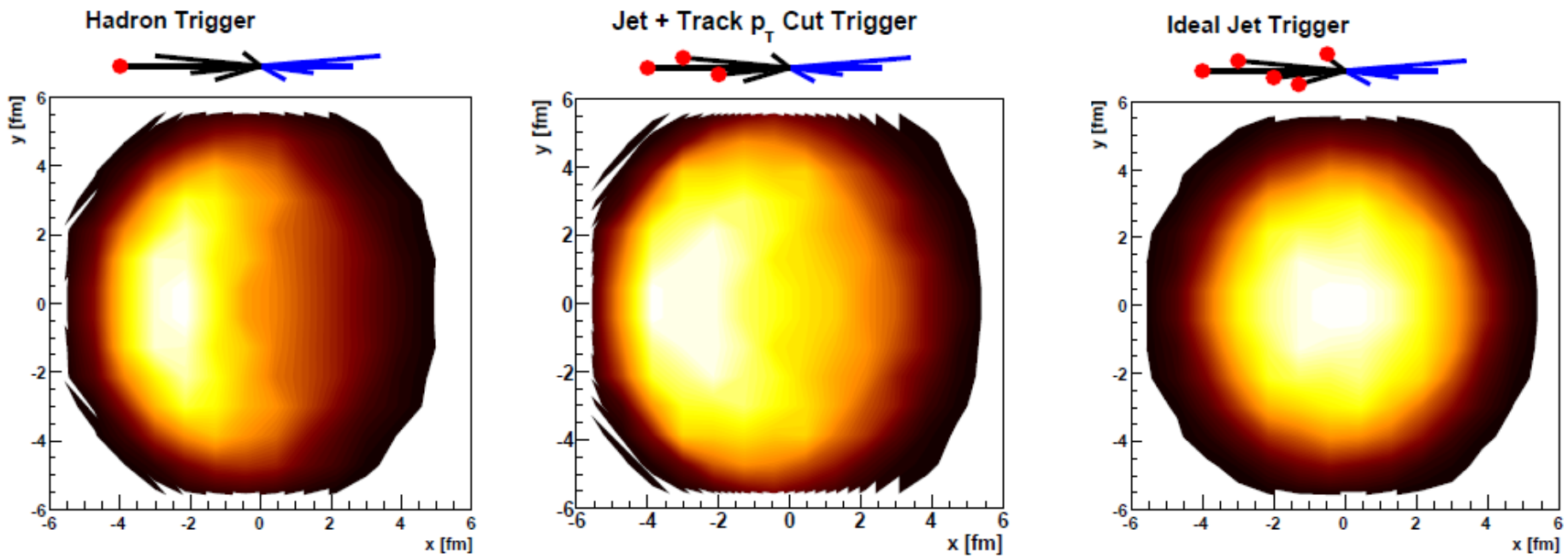
Thorsten Renk has explored the ability to engineer the surface and energy loss bias to gain more information



sPHENIX can measure these jets with no minimum p_T selection and no online trigger bias. Thus, one can explore the full range of engineered geometries. Systematic measurements enabled "tomography"

Surface Bias Engineering

sPHENIX



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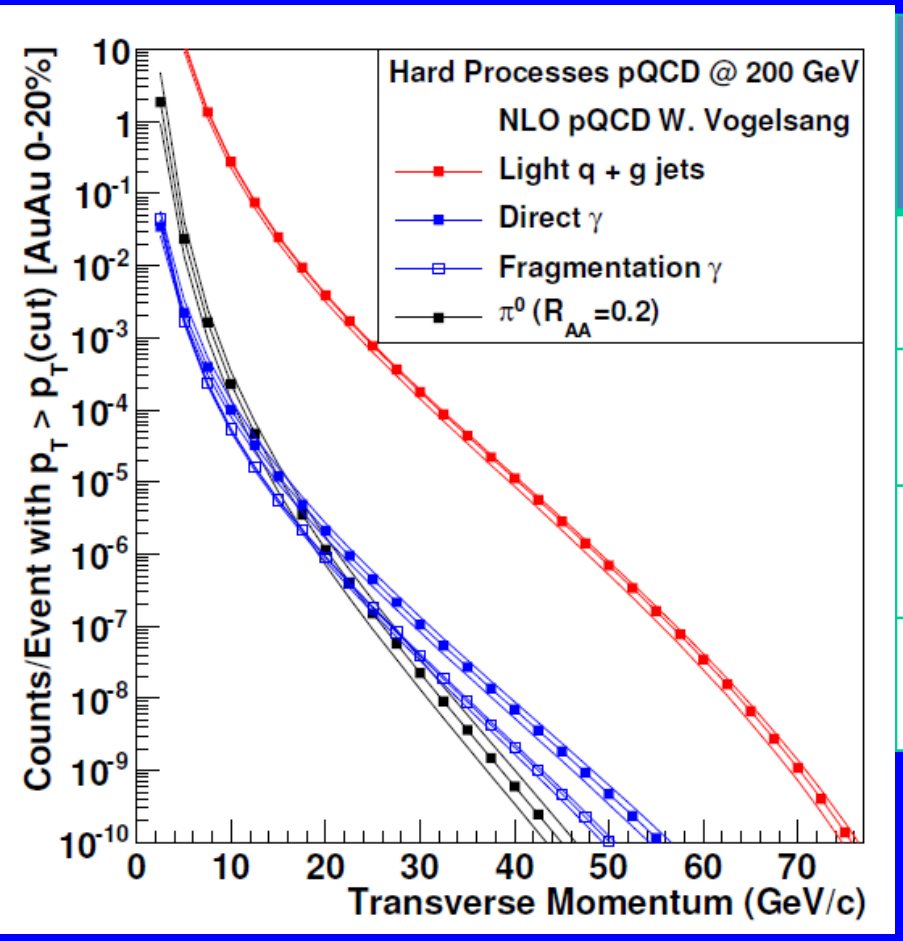
RHIC Jet Rates

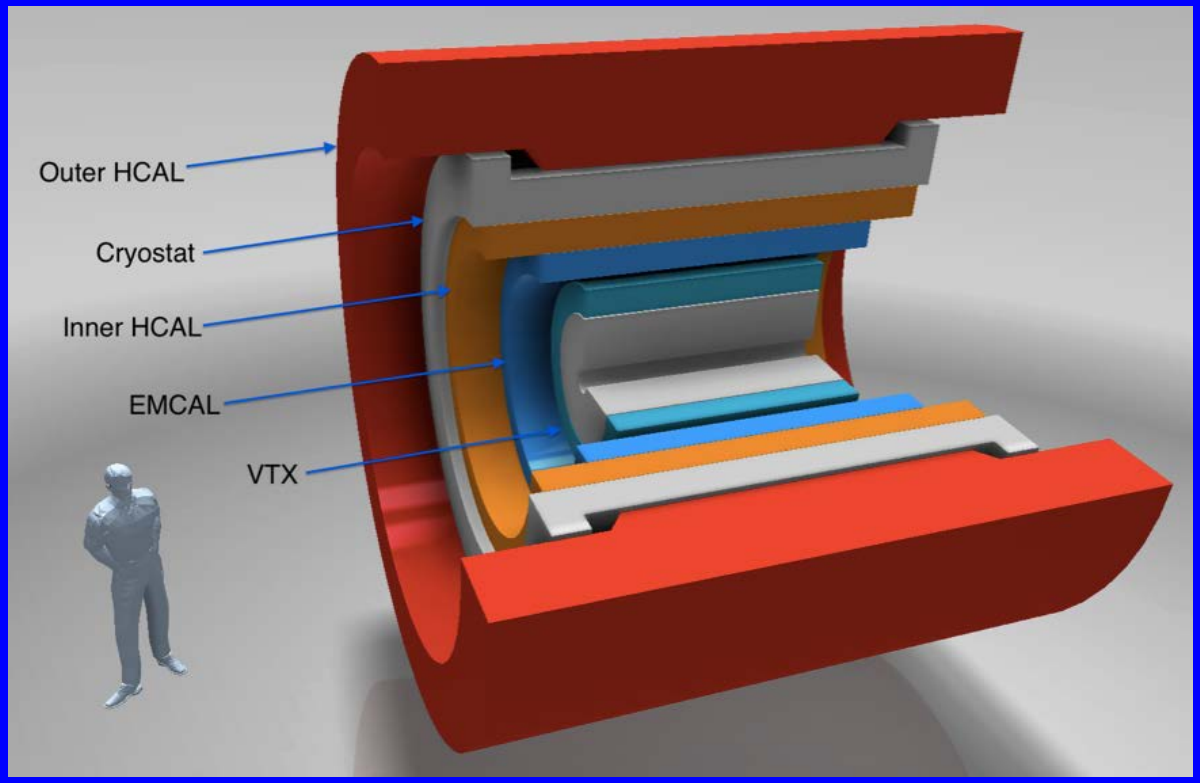


	Au+Au (central 20%)	p+p	d+Au
>20GeV	10^7 jets 10^4 photons	10^6 jets 10^3 photons	10^7 jets 10^4 photons
>30GeV	10^6 jets 10^3 photons	10^5 jets 10^2 photons	10^6 jets 10^3 photons
>40GeV	10^5 jets	10^4 jets	10^5 jets
>50GeV	10^4 jets	10^3 jets	10^4 jets

20 weeks of running would yield 50B events, high speed daq →on tape
80% of dijets within $|\eta| < 1$

NEWSFLASH: The above numbers assume Run 11 performance. Just repeating the RHIC performance of Run14 we can sample 200 B events

sPHENIX detector



Coverage $|\eta| < 1.1$

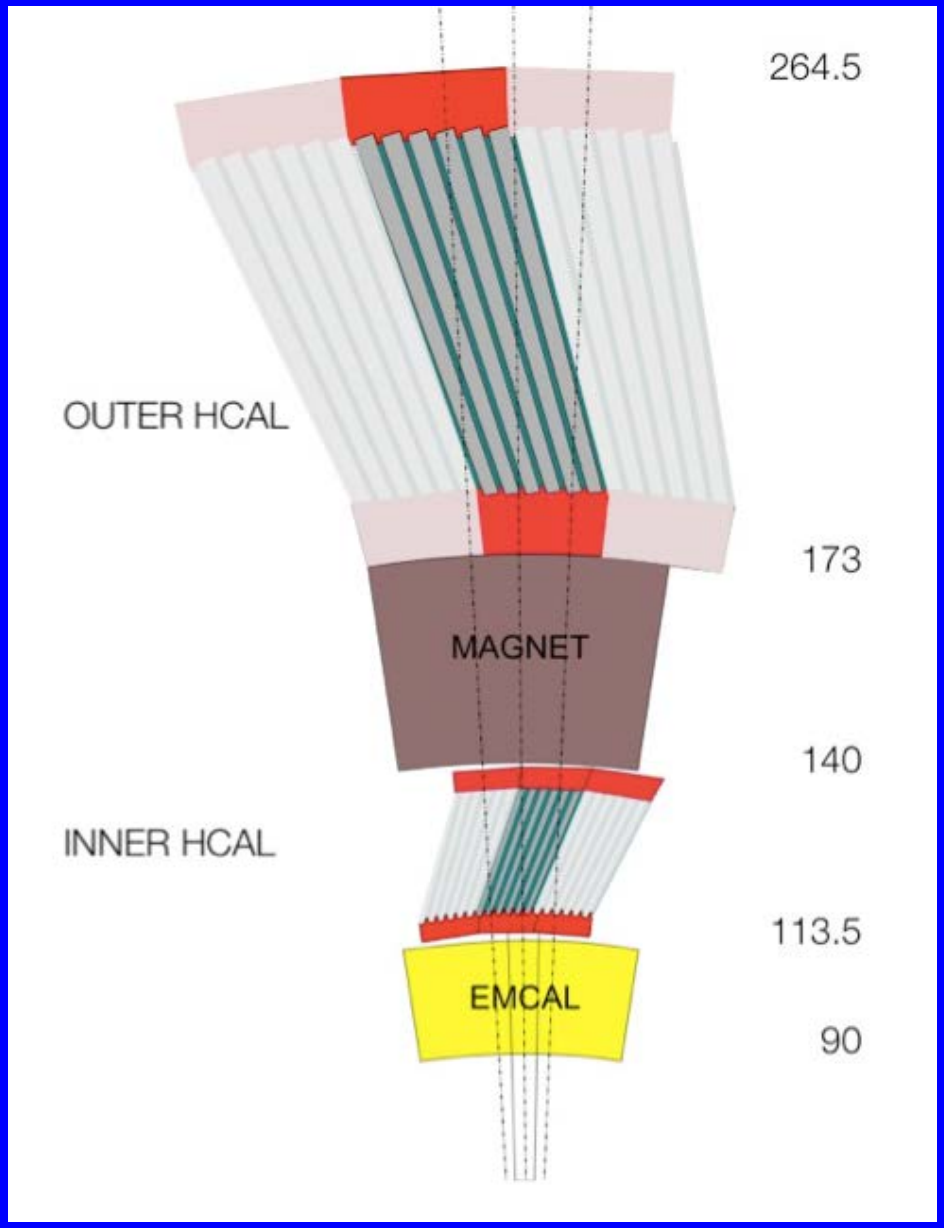
hermetic electromagnetic and hadron calorimetry

6 layer silicon tracking
3 layers refurbished from PHENIX vtx detector

BaBar magnet 1.5 T
outer HCAL provides flux return

Common Silicon Photomultiplier readout and electronics for Calorimeters
Full clock speed digitizers, digital information for triggering available
High data acquisition rate capability (~10kHz)

Calorimeter design

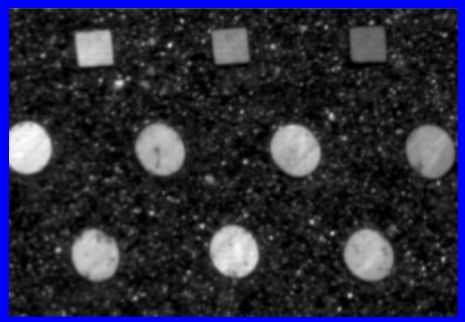


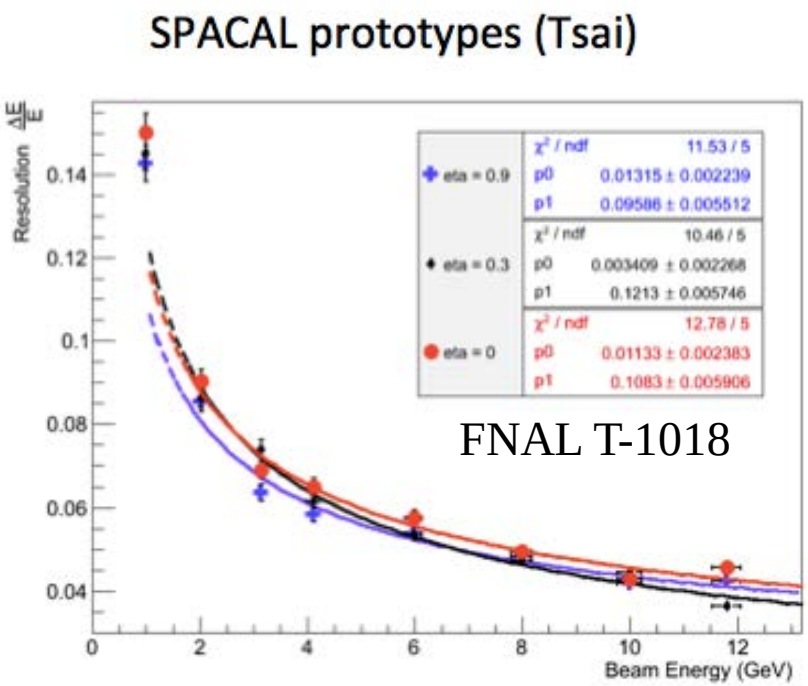
HCAL: Novel tilted plate design!

EMCAL $\approx 18X_0 \approx 1\lambda$
Inner HCAL $\approx 1\lambda$
Magnet $\approx 1X_0$
Outer HCAL $\approx 4\lambda$

Total HCal depth 5λ (plus EMCAL 1λ) leads to few percent energy leakage for hadrons above 50GeV comparable to other contributions to energy resolution constant term

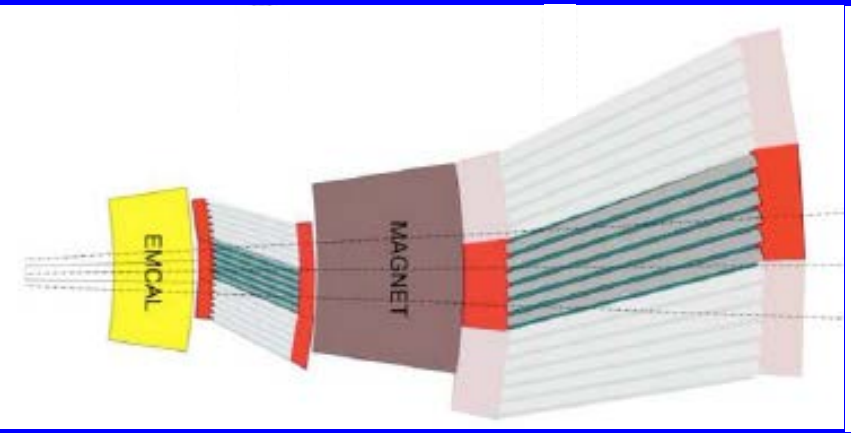
EMCAL SPACAL Option

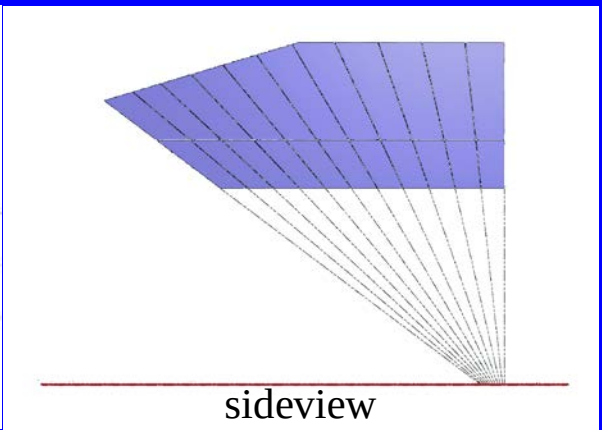


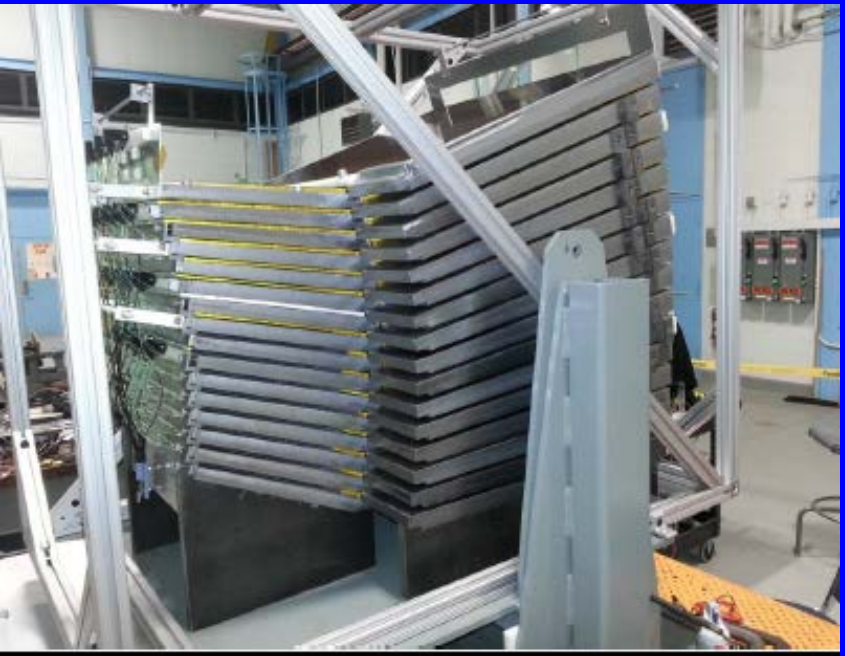


- Scintillating fiber embedded into tungsten epoxy
- 18 X_0 deep
- Moliere Radius 2.3cm ≈ cell size
- Sampling fraction ≈ 2%
- Resolution ≈ 12%/√E
- 256x96 = 24576 channels
- ≈ 500pe/GeV

HCal:Tilted plates

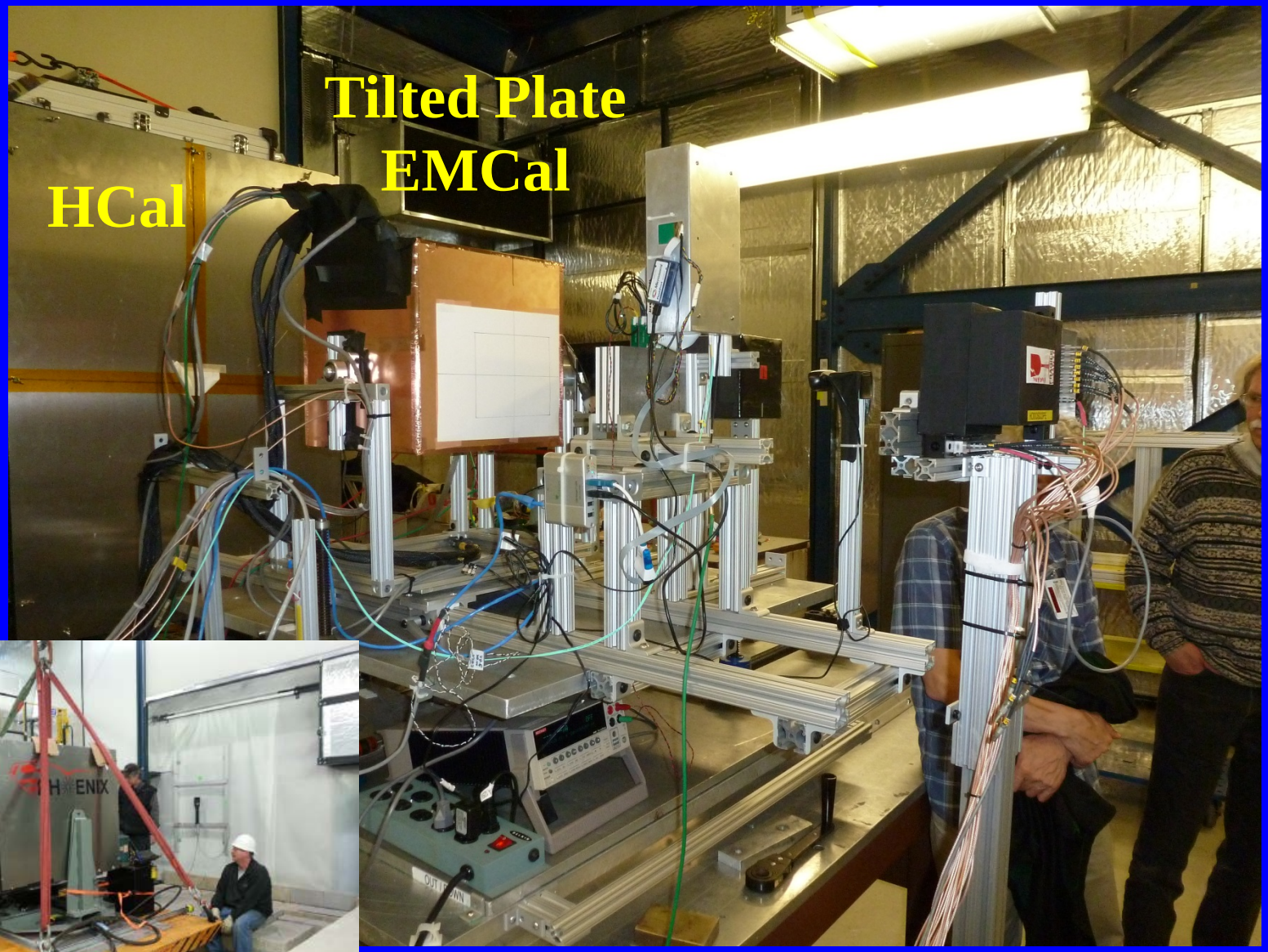






- HCal absorber serves as flux return for the BaBar magnet
- Straight line from vertex crosses 4 scintillators
- Towersize in $\eta/\varphi \approx 0.1 \times 0.1$
- Prototype build and tested at FNAL
- modest energy resolution requirement of $\leq 100\%/\sqrt{E}$

FNAL Test Beam Exp T-1044



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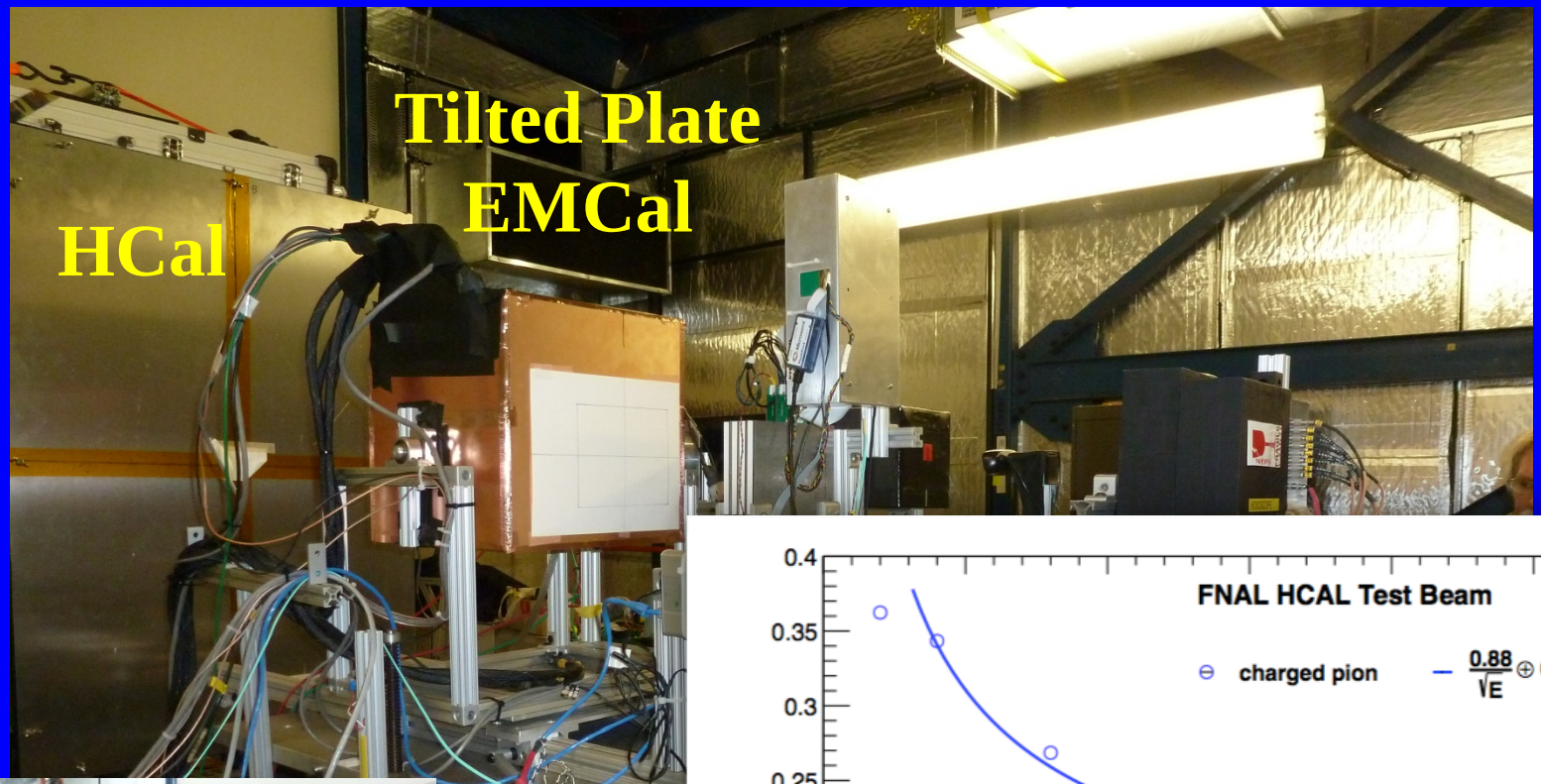
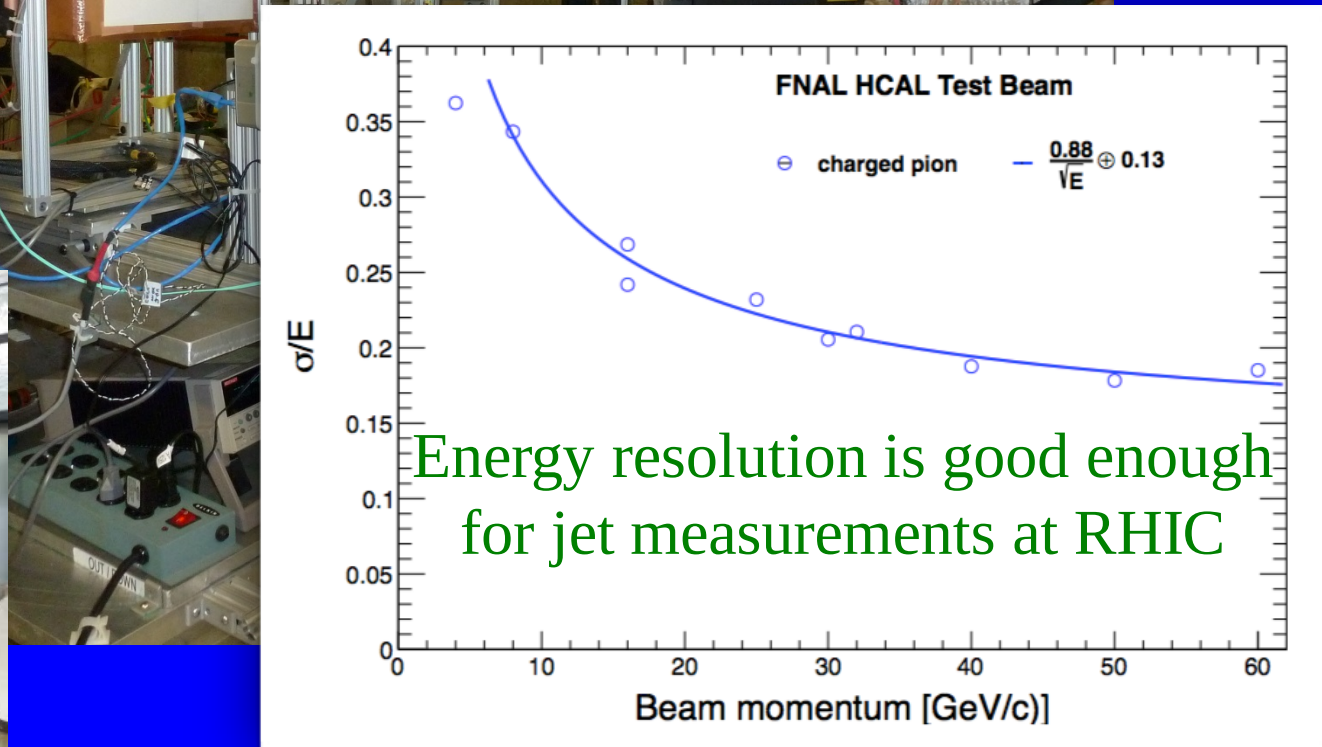
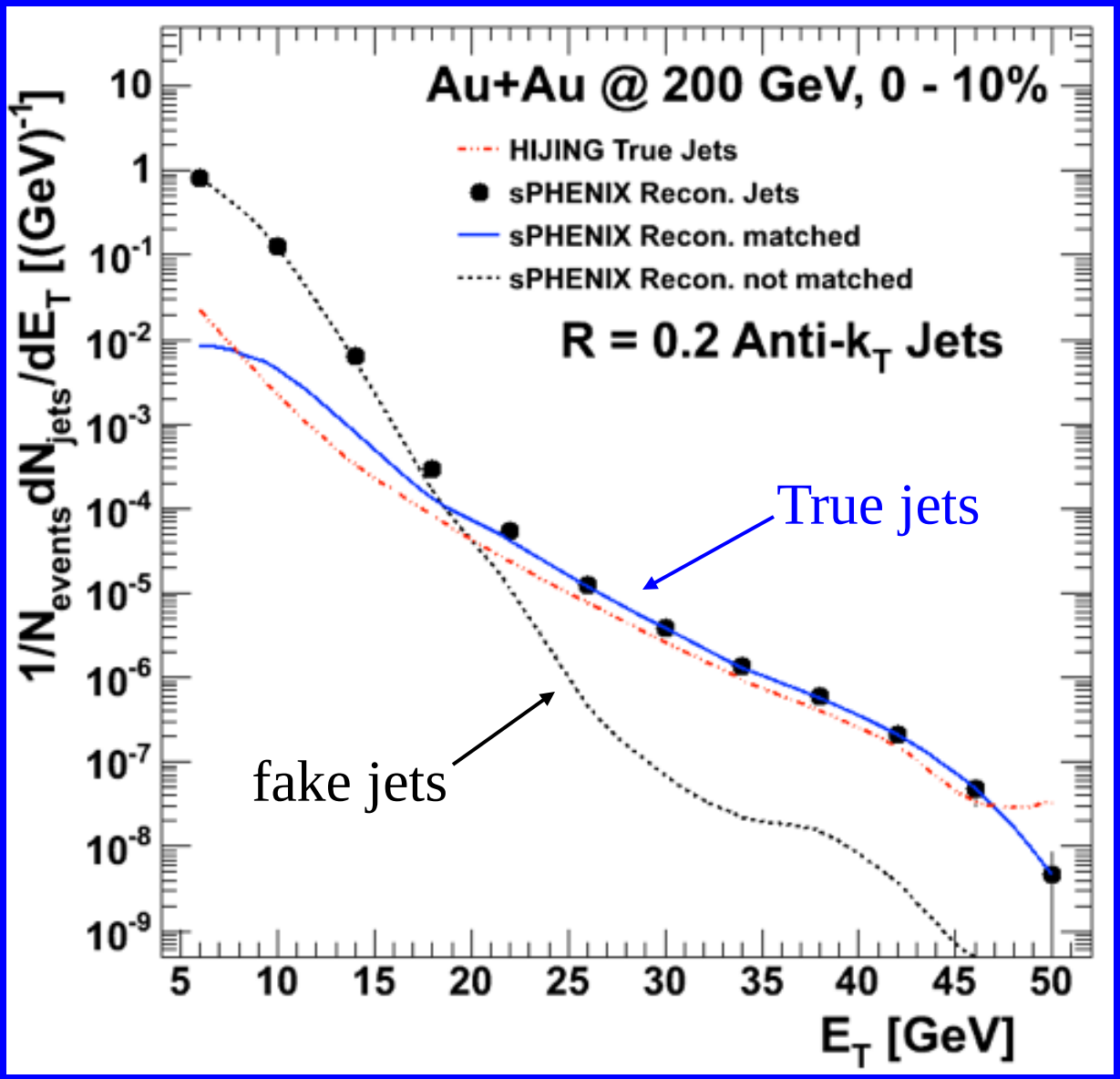




Energy resolution is good enough for jet measurements at RHIC

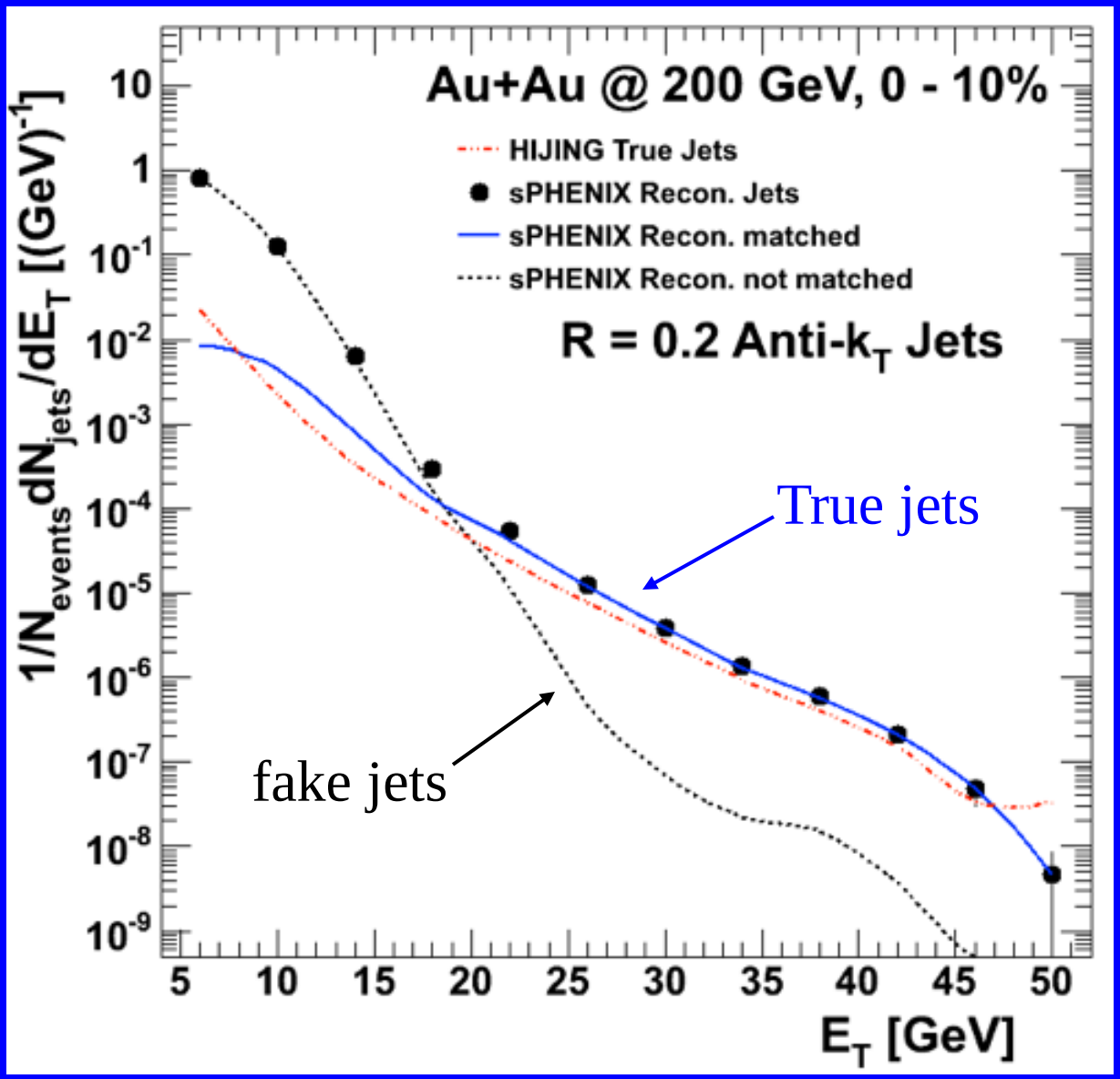
Jet studies: Fake Jet Rates



For R=0.2 jets
> 20 GeV real jets
dominate HIJING

Details in
PRC86 (2012) 024908

Jet studies: Fake Jet Rates



for R=0.2 jets
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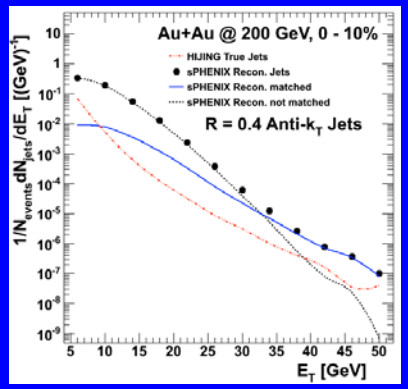
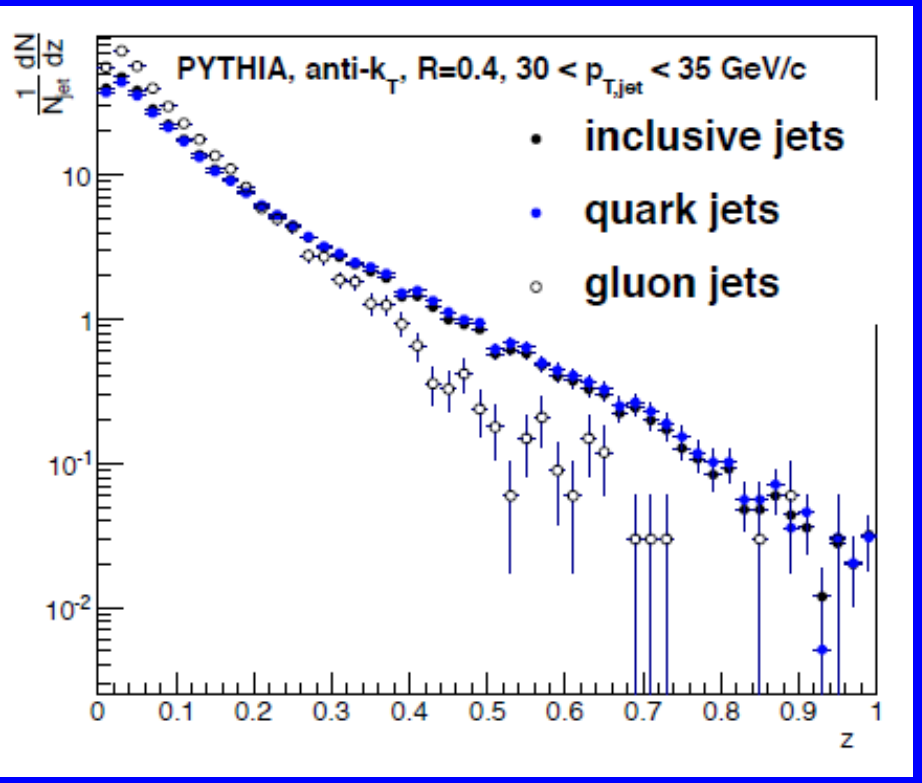
Details in
PRC86 (2012) 024908

for R=0.4 the lower
limit is > 35 GeV

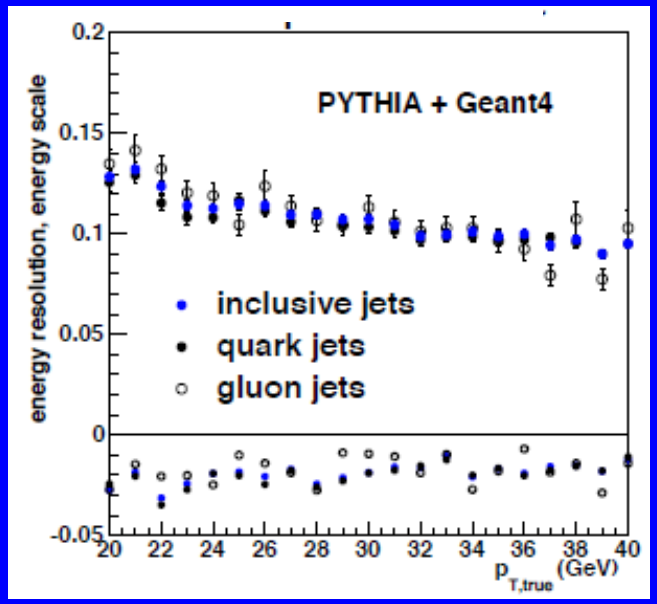


Different bias for quark or gluon jets?

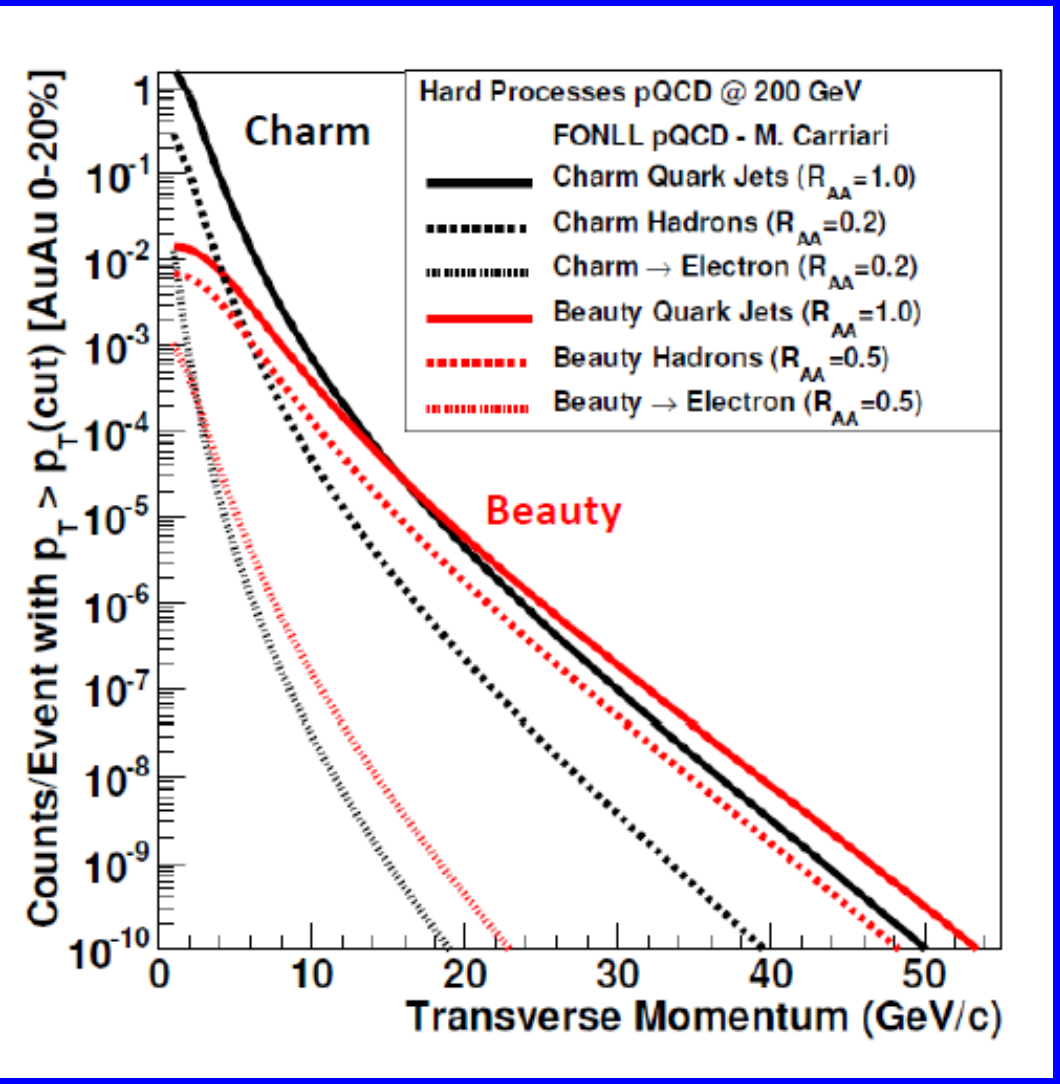


Quark and gluon jets have very different fragmentation functions
Introducing p_T cutoffs in the jet reconstruction (or trigger) will affect quark and gluon jets differently

sPHENIX calorimetric measurement gives the same energy scale and resolution for quark and gluon jets



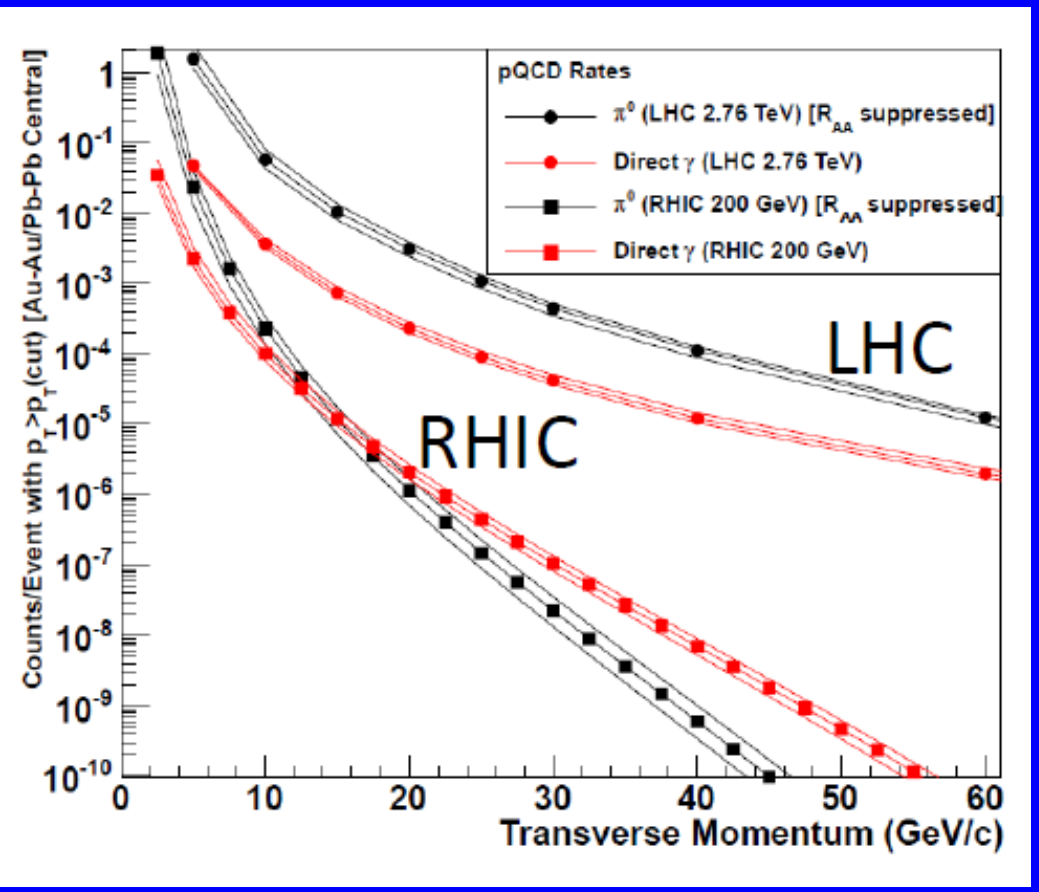
Beauty tagged jets



Substantial rate, tagged with large displaced vertex identified by inner silicon detector

Key tests of mass dependence of radiative energy loss

Direct photons

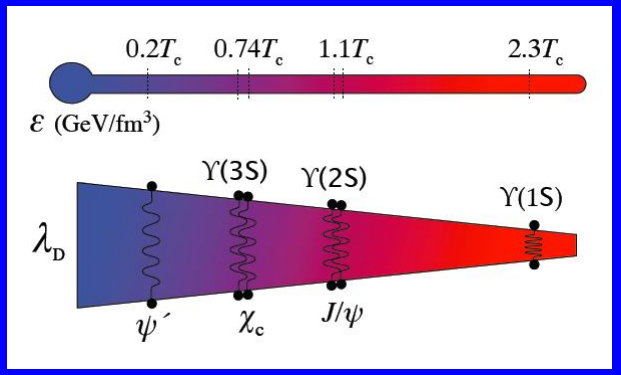


sPHENIX has excellent direct photon capabilities

Nature favors RHIC, in central Au+Au collisions direct photons dominate for p_T > 20GeV/c

Simple isolation cuts with full calorimetry give additional handle and enable p+p and p+A comparison measurements

Upsilons

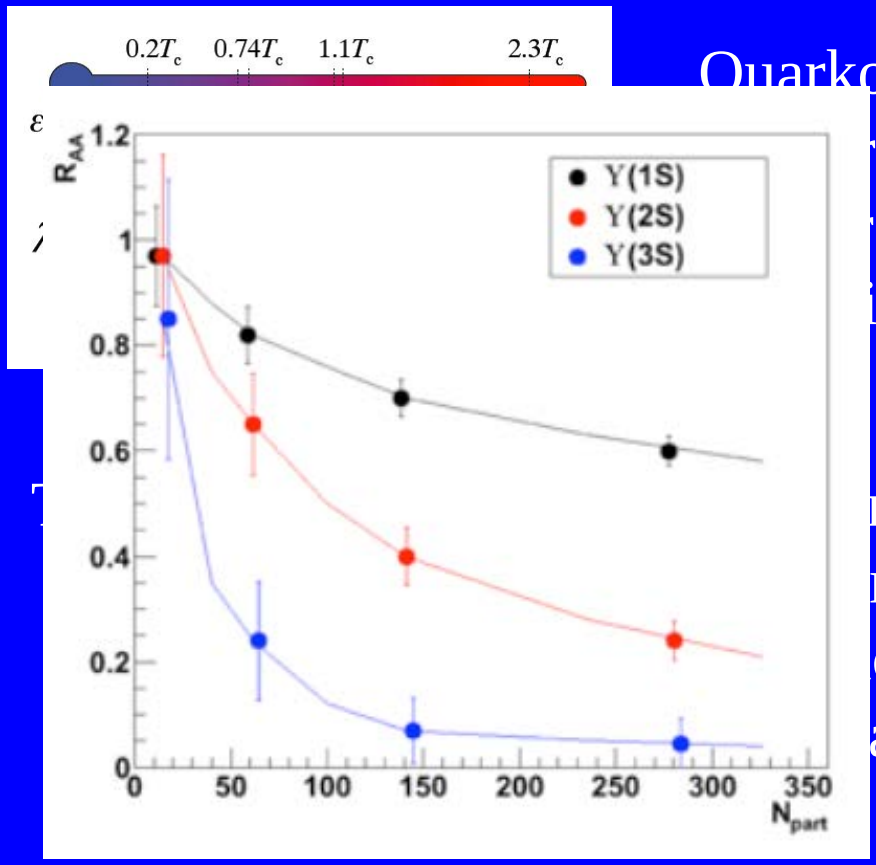


Quarkonia become unbound at different temperatures depending on their radius – they are sensitive to different color screening lengths

The Y(1S), Y(2S) and Y(3S) span a broad range of sizes, accessible via e^+e^- or $\mu^+ \mu^-$ and have similar cold nuclear matter effects. They Will not have a large coalescence contribution at RHIC or LHC. Underlying bottom production at LHC similar to charm at RHIC

Charmonium production becomes large at LHC, making direct RHIC/LHC comparisons problematic

Upsilons



Quarkonia become unbound at different
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The points show the projected statistical accuracy for sPHENIX

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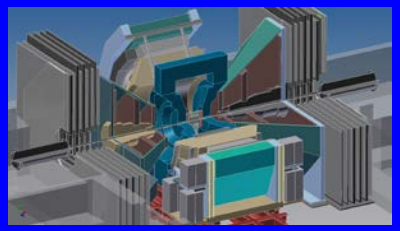
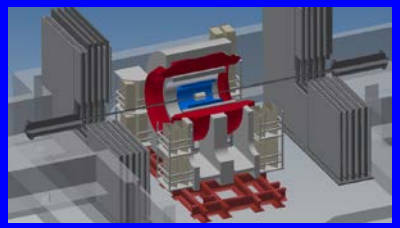
Summary

PHENIX



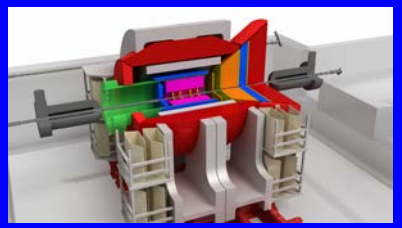
2021 →

sPHENIX



2025 →

TBN@EIC



- RHIC probes the QGP at T_C where the coupling is strongest
- sPHENIX will measure unbiased jets with full calorimetry, direct photons and upsilons
- We are on track to make this happen by 2021
- The acquisition of the BaBar magnet was a game changer – opening up the possibility to evolve into an EIC detector

Backup

The BaBar Solenoid Magnet

Dimensions:

- R_{inner} = 140 cm
- R_{outer} – 173 cm
- L = 385 cm

Field

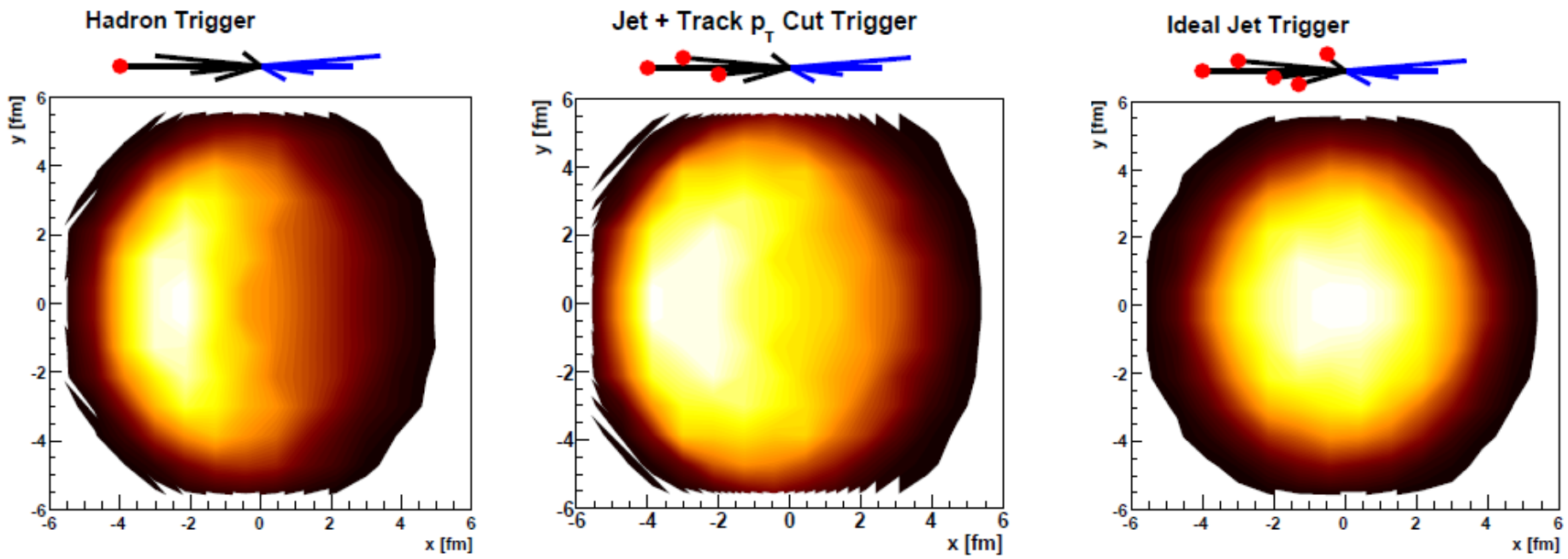
- 1.5 Tesla (Nominal)
- Homogeneous in center
- Higher field at ends → Better forward tracking

Ownership officially transferred to BNL
Being prepared for shipping

Surface Bias Engineering

STAR

sPHENIX



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