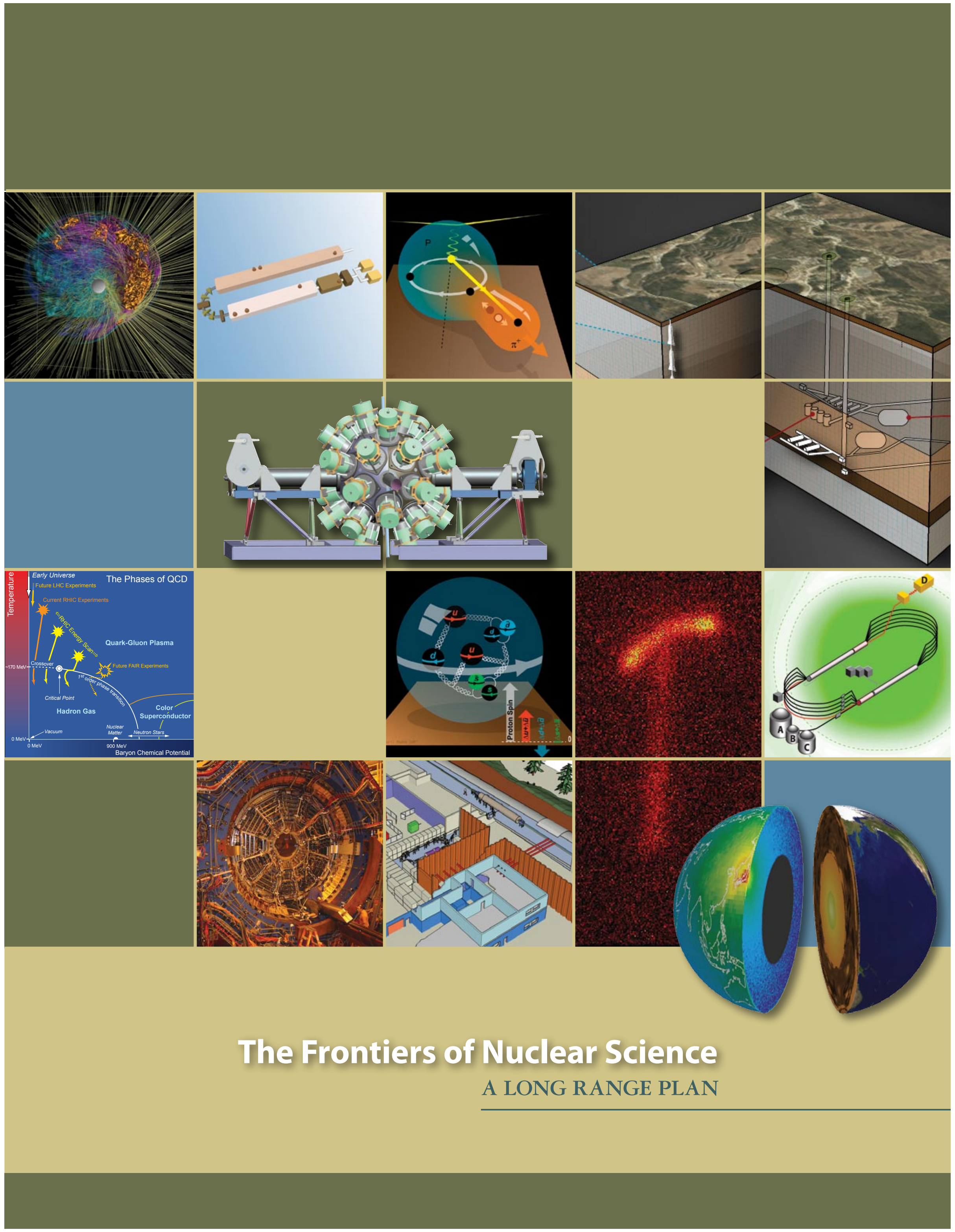
Future of Hard Probes at RHIC

Anne Sickles

2007 Long Range Plan



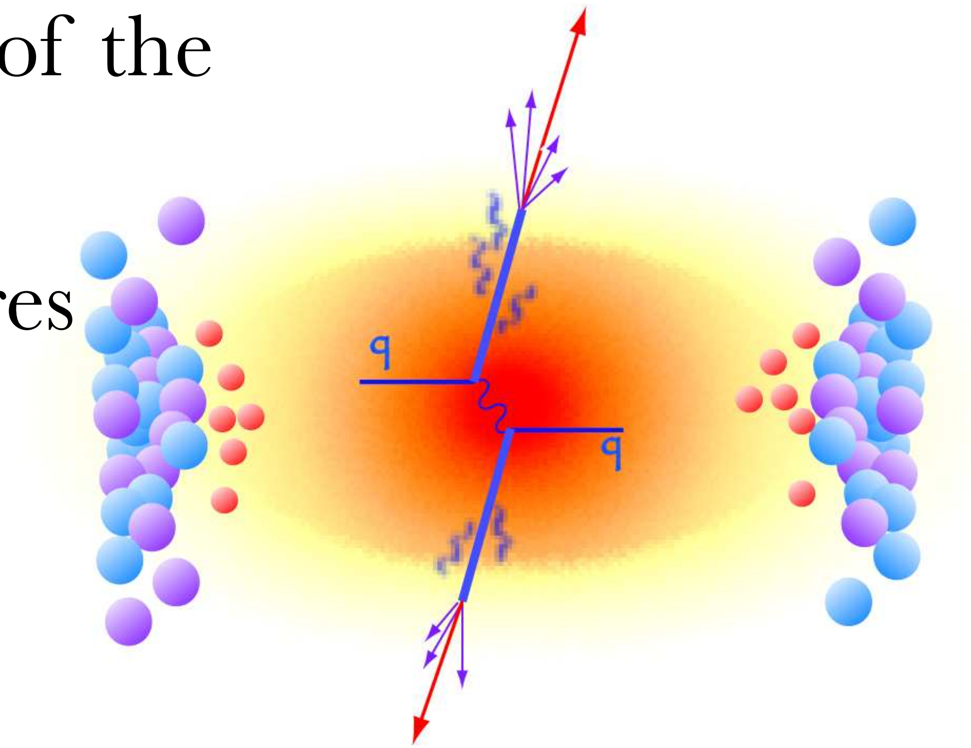
RECOMMENDATION IV

The experiments at the Relativistic Heavy Ion Collider have discovered a new state of matter at extreme temperature and density—a quark-gluon plasma that exhibits unexpected, almost perfect liquid dynamical behavior. We recommend implementation of the RHIC II luminosity upgrade, together with detector improvements, to determine the properties of this new state of matter.

The major discoveries in the first five years at RHIC must be followed by a broad, quantitative study of the fundamental properties of the quark-gluon plasma. This can be accomplished through a 10-fold increase in collision rate, detector upgrades, and advances in theory. The RHIC II luminosity upgrade, using beam cooling, enables measurements using uniquely sensitive probes of the plasma such as energetic jets and rare bound states of heavy quarks. The detector upgrades make important new types of measurements possible while extending significantly the physics reach of the experiments. Achieving a quantitative understanding of the quark-gluon plasma also requires new investments in modeling of heavy-ion collisions, in analytic approaches, and in large-scale computing.

Hard Probes at RHIC: quantify properties of QGP as a function of temperature

- hard probes created at the earliest stages of the collision
  - sensitive to highest collision temperatures
  - sensitive to entire lifetime of collision
  - calculable

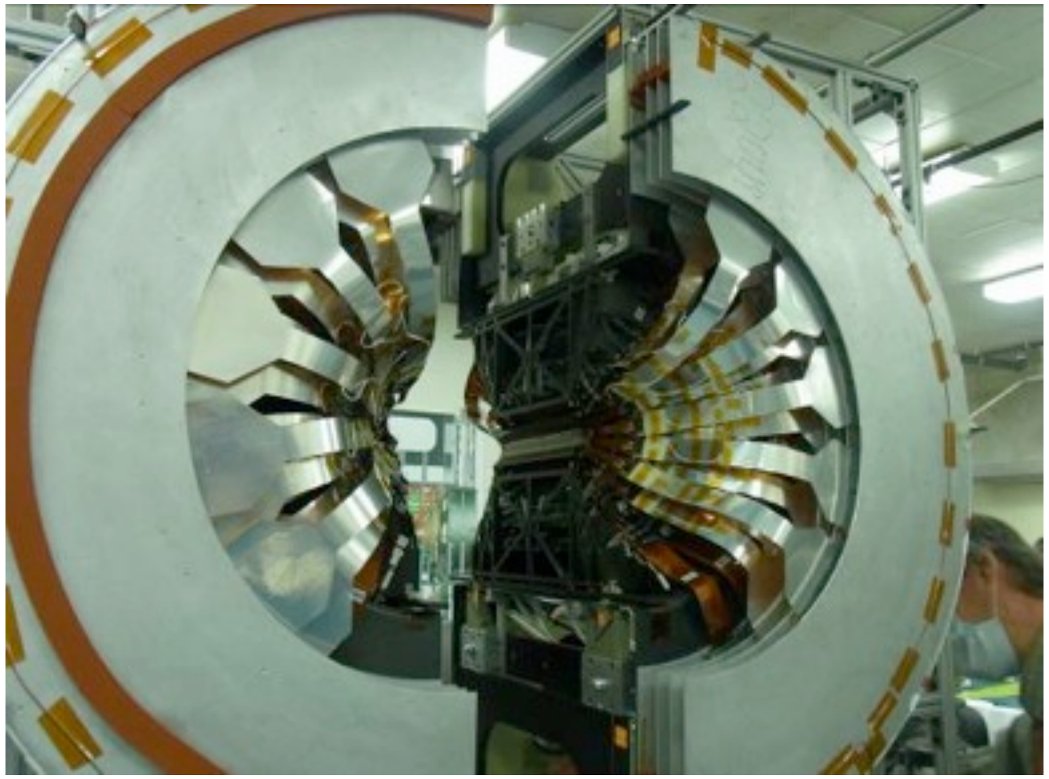


- d/pA collisions essential to quantify baseline expectations

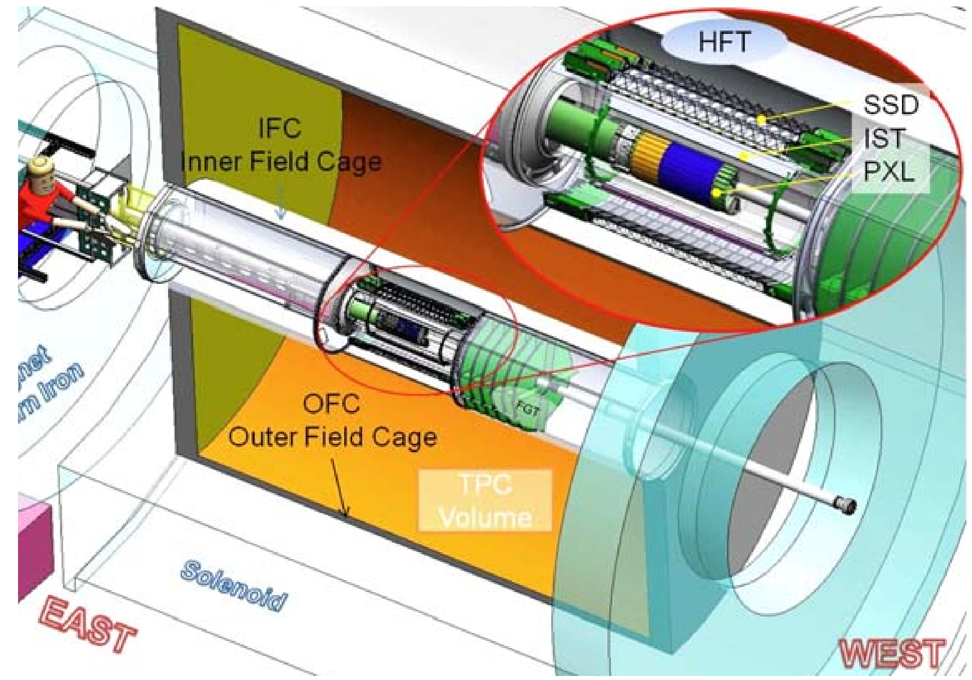
Timeline for RHIC's Next Decade

Years	Beam Species and Energies	Science Goals	New Systems Commissioned
2013	• 500 GeV $\vec{p}+\vec{p}$ • 15 GeV Au+Au	• Sea antiquark and gluon polarization • QCD critical point search	• Electron lenses • upgraded pol'd source • STAR HFT
2014	• 200 GeV Au+Au and baseline data via 200 GeV p+p (needed for new det. subsystems)	• Heavy flavor flow, energy loss, thermalization, etc. • quarkonium studies	• 56 MHz SRF • full HFT • STAR Muon Telescope Detector • PHENIX Muon Piston Calorimeter Extension (MPC-EX)
2015-2017	• High stat. Au+Au at 200 and ~40 GeV • U+U/Cu+Au at 1-2 energies • 200 GeV p+A • 500 GeV $\vec{p}+\vec{p}$	• Extract $\eta/s(T_{min})$ + constrain initial quantum fluctuations • further heavy flavor studies • sphaleron tests @ $\mu_B \neq 0$ • gluon densities & saturation • finish p+p W prod'n	• Coherent Electron Cooling (CeC) test • Low-energy electron cooling • STAR inner TPC pad row upgrade
2018-2021	• 5-20 GeV Au+Au (E scan phase 2) • long 200 GeV + 1-2 lower $\sqrt{s}$ Au+Au w/ upgraded dets. • baseline data @ 200 GeV and lower $\sqrt{s}$ • 500 GeV $\vec{p}+\vec{p}$ • 200 GeV $\vec{p}+A$	• x10 sens. increase to QCD critical point and deconfinement onset • jet, di-jet, γ-jet quenching probes of E-loss mechanism • color screening for different $q\bar{q}$ states • transverse spin asyms. Drell-Yan & gluon saturation	• sPHENIX • forward physics upgrades

Investment in New Detectors

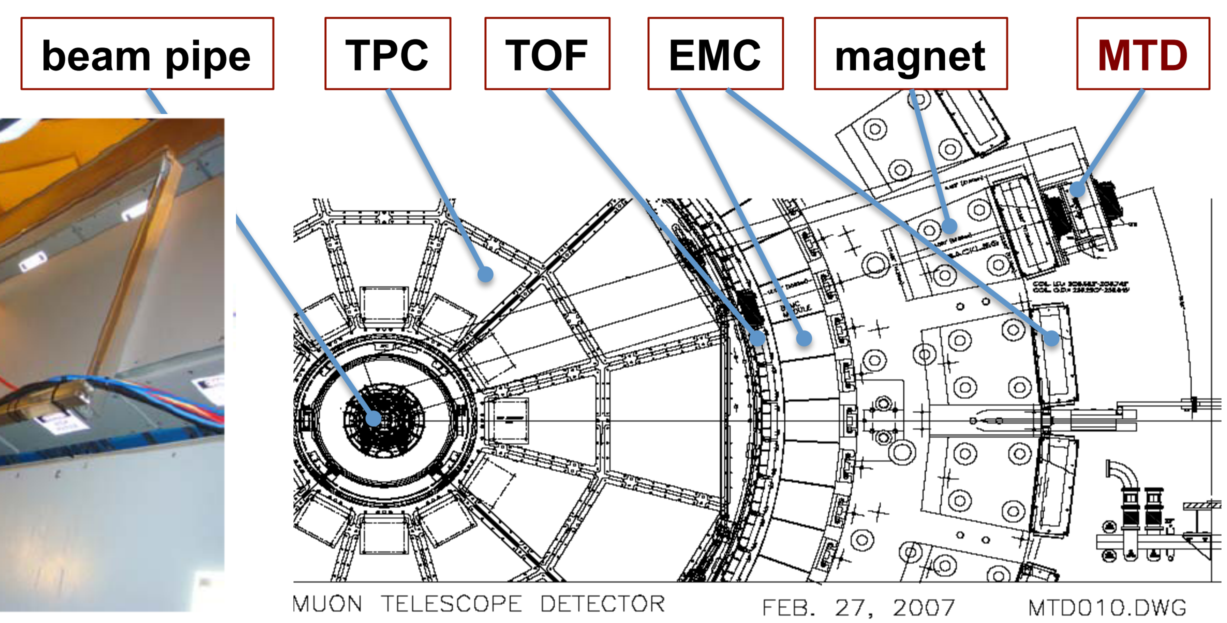


PHENIX (F)VTX
first data Run11



STAR HFT
projected
first data Run14

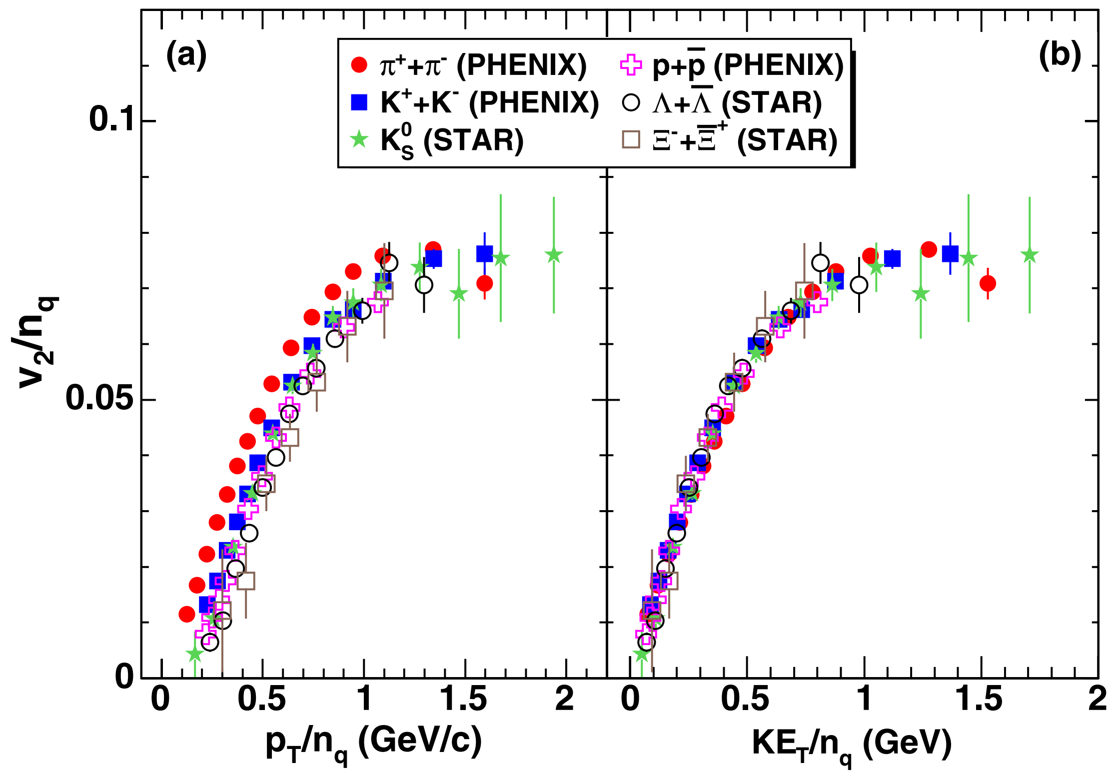
STAR MTD
partially installed Run13
fully installed Run14

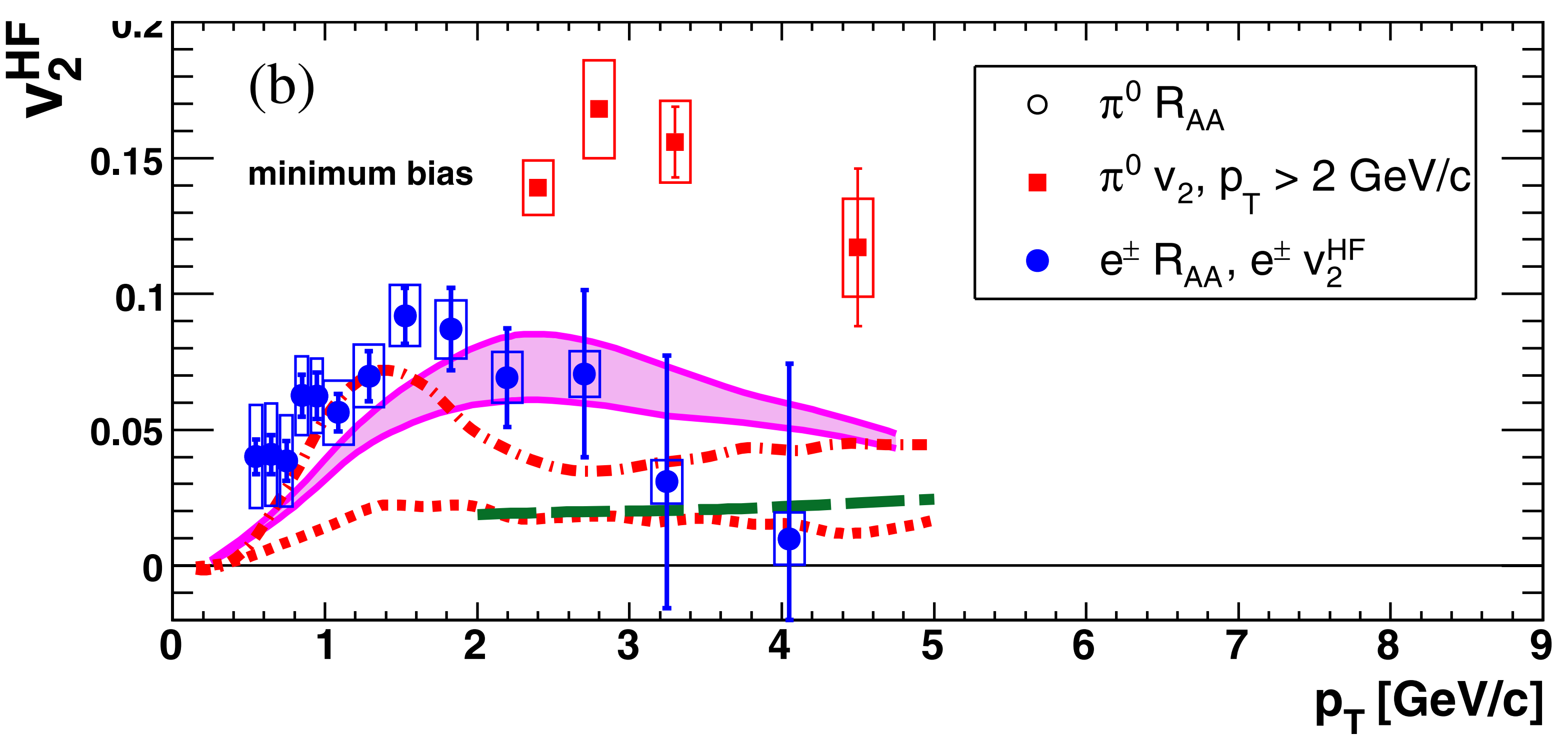


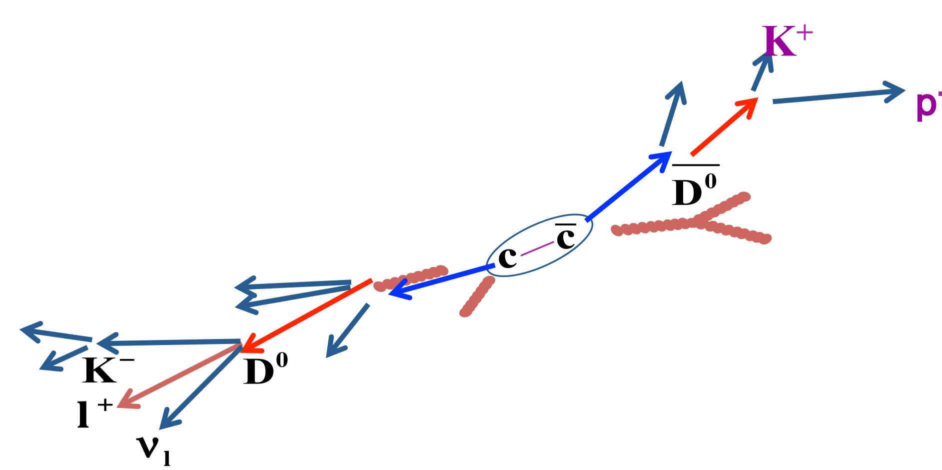
is charm part of the bulk matter?

picture!

light & strange hadron v2 scales with the number of constituent quarks
→hadron formation via recombination

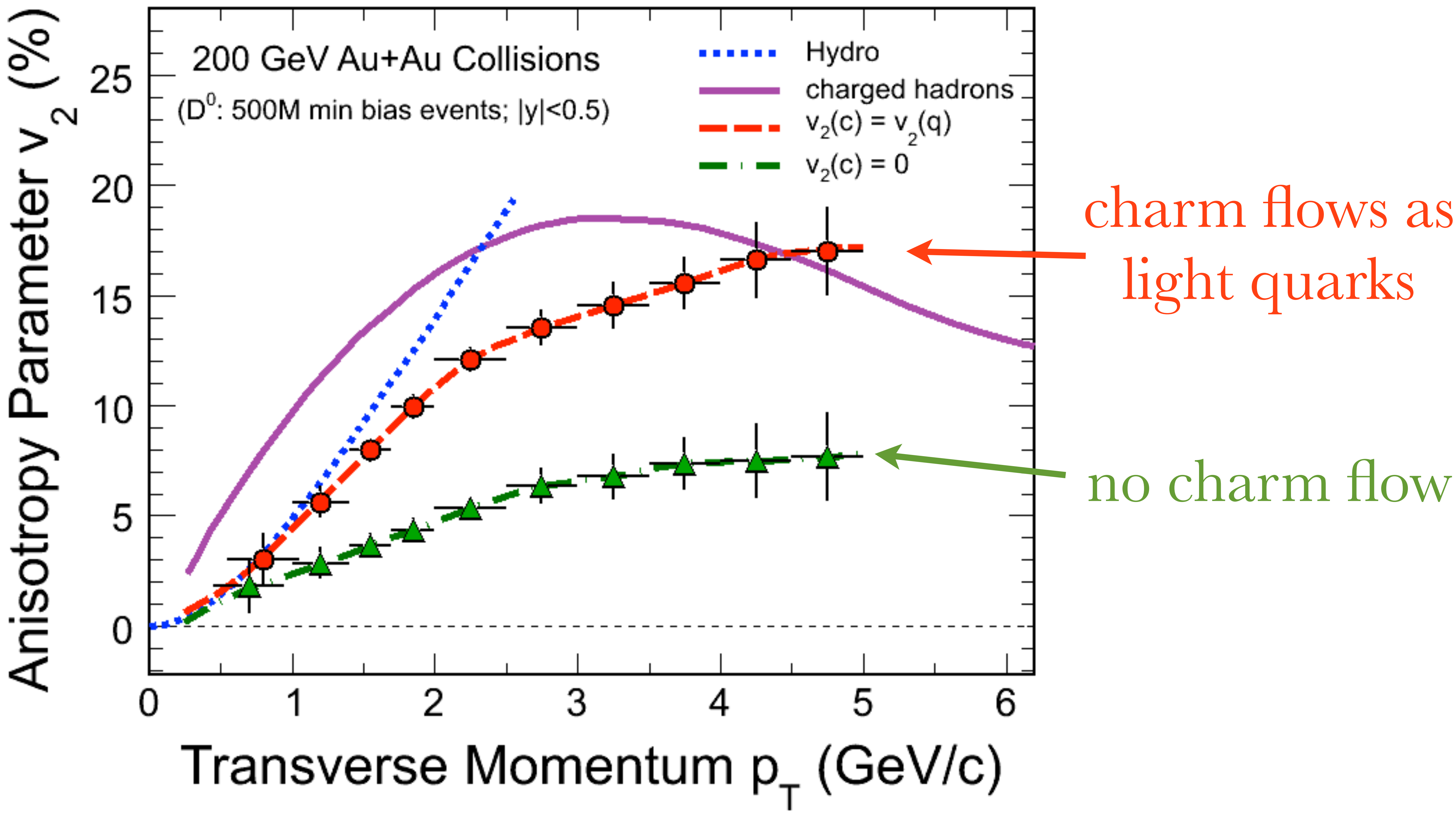






do D mesons follow with the light quarks?

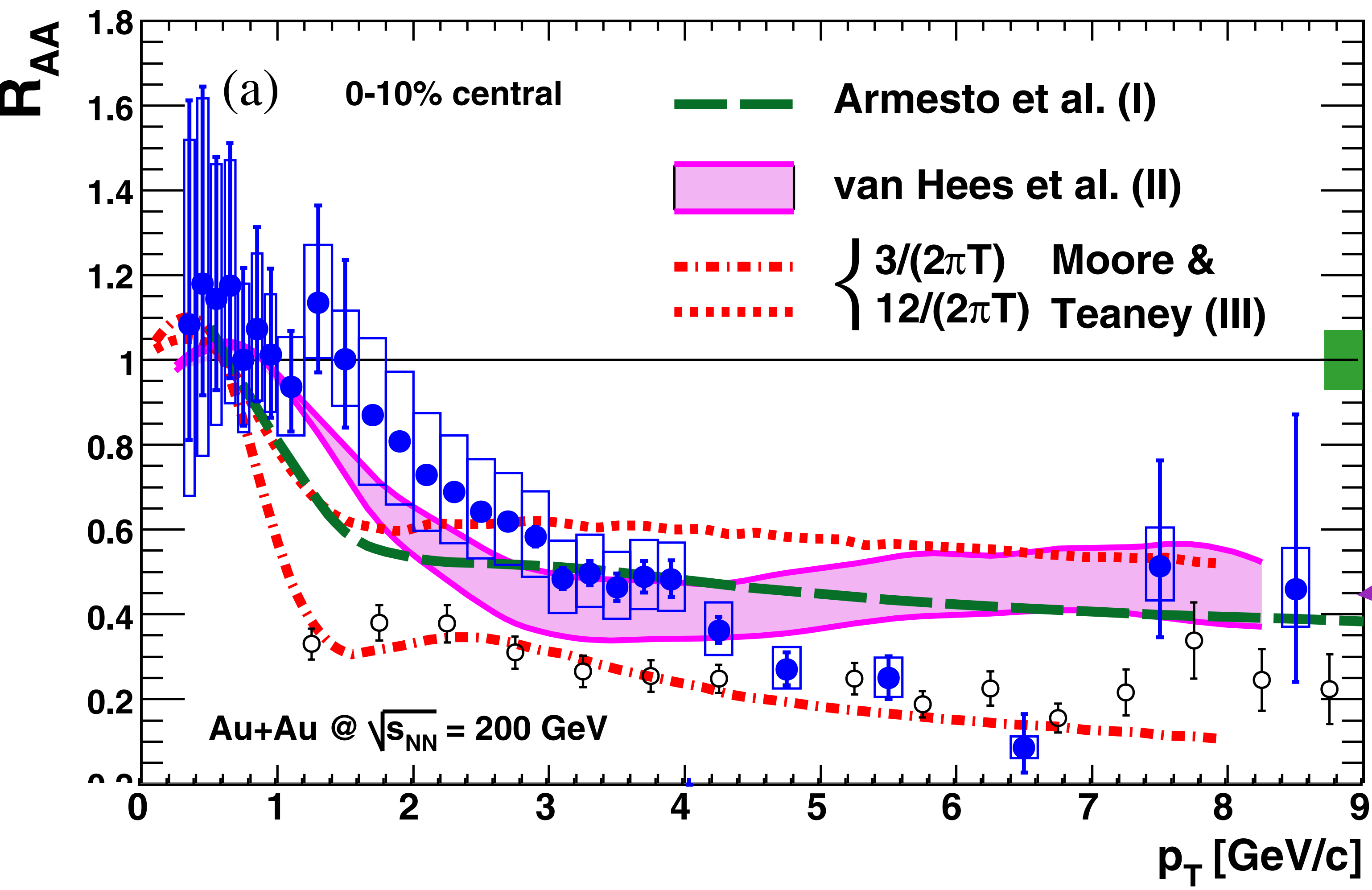
D mesons with HFT



- Run 14, 10 weeks AuAu

Diffusion of Heavy Quarks

Langevin-based models: heavy quarks undergo uncorrelated momentum kicks in thermal medium related to eta/s

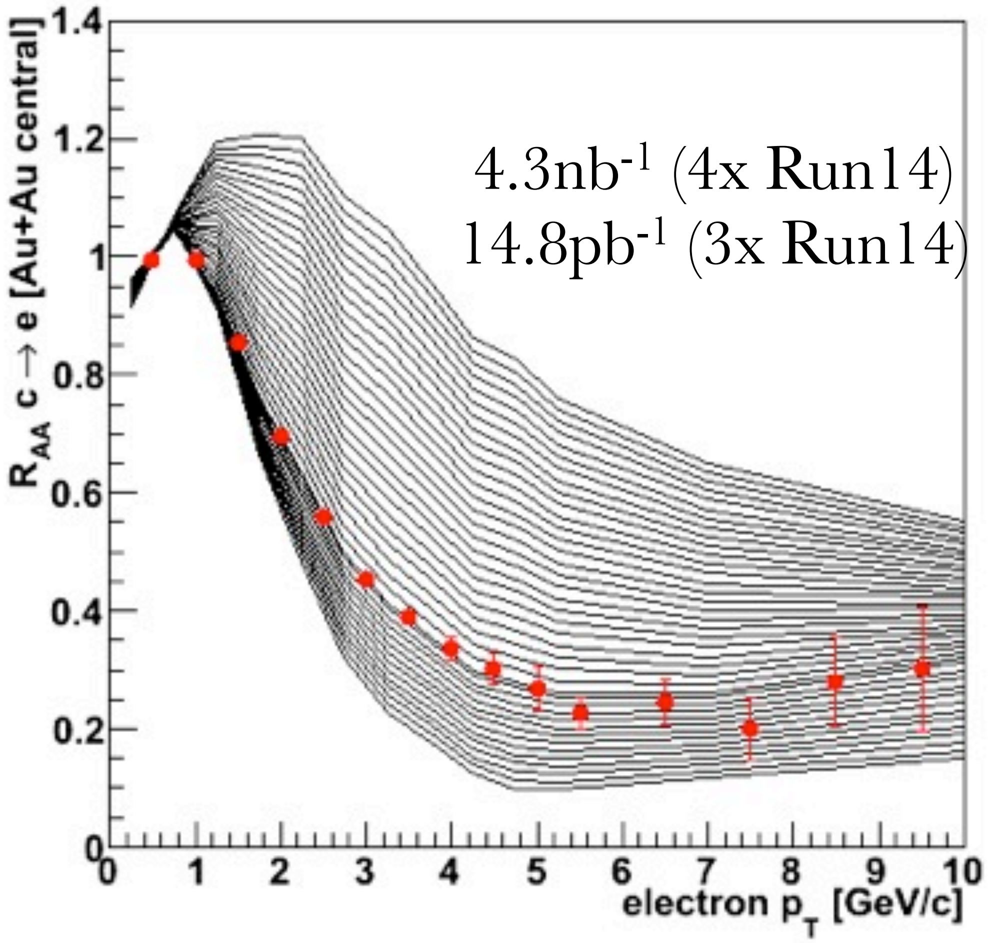


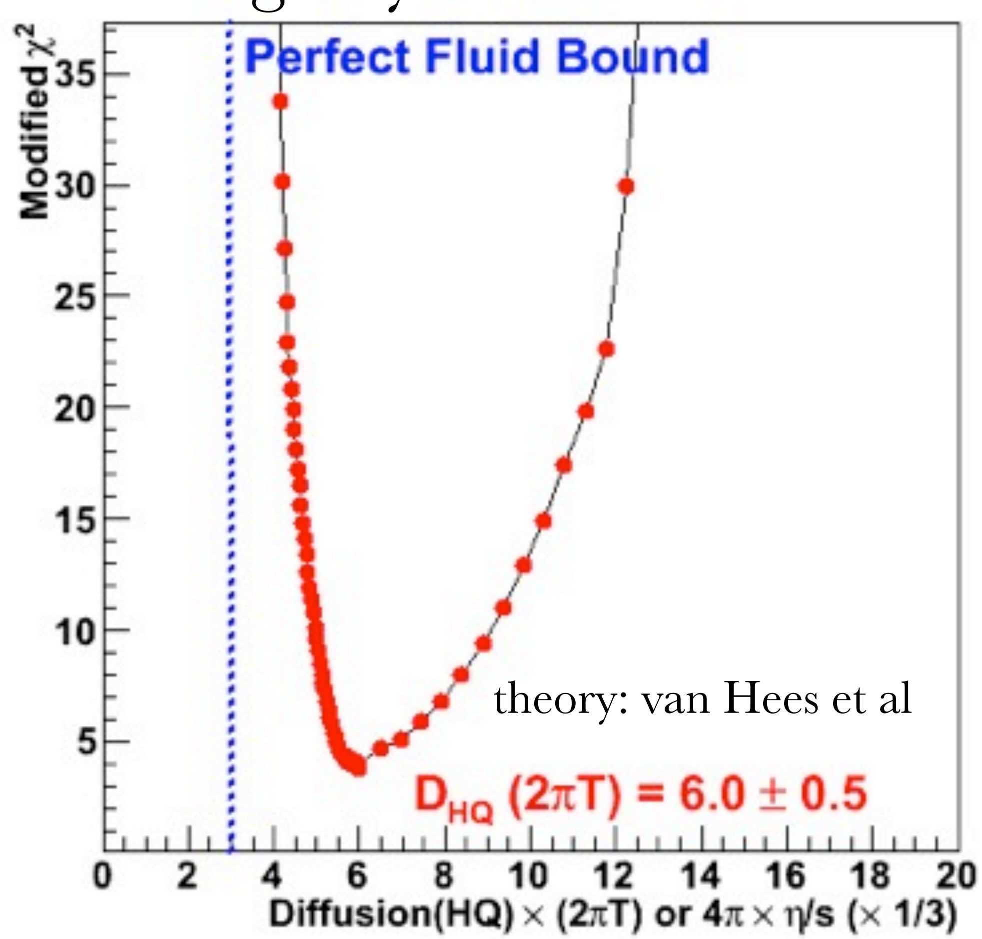
$D_{HQ} \sim 4\text{-}6\ (2\pi T)$

Diffusion of Charm

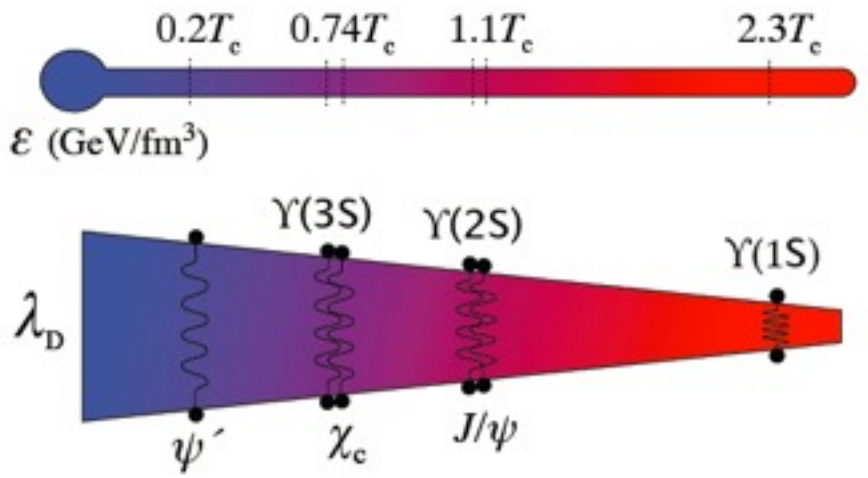
- D_{HQ} is related to η/s: **$D_{HQ} \cdot 2\pi T = 3\ (4\pi\eta/s)$**
- very different systematics & measurement
- is there consistency with flow measurements?
  - if not, why not?

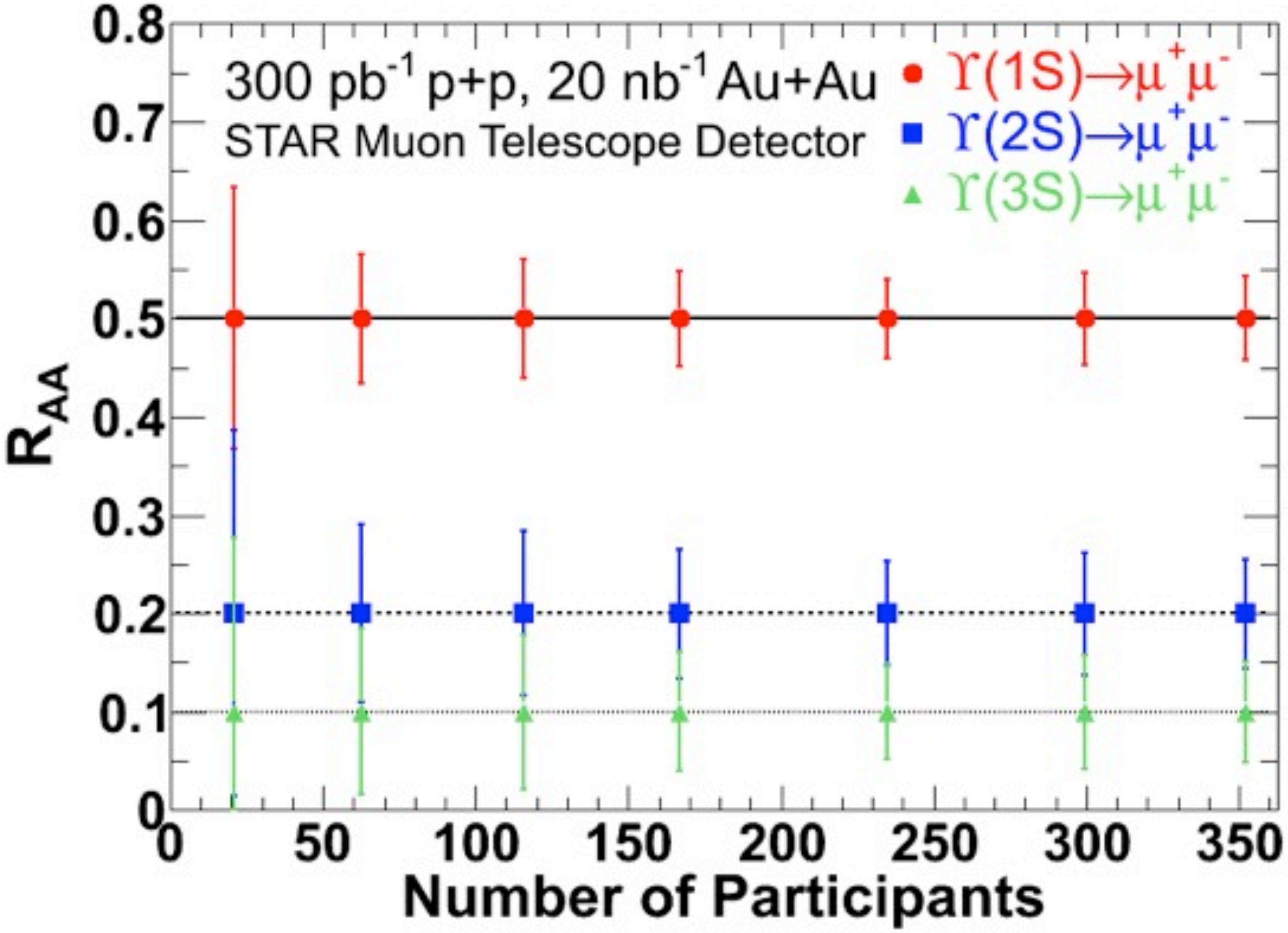
FY15: additional AuAu & pp running beyond FY14

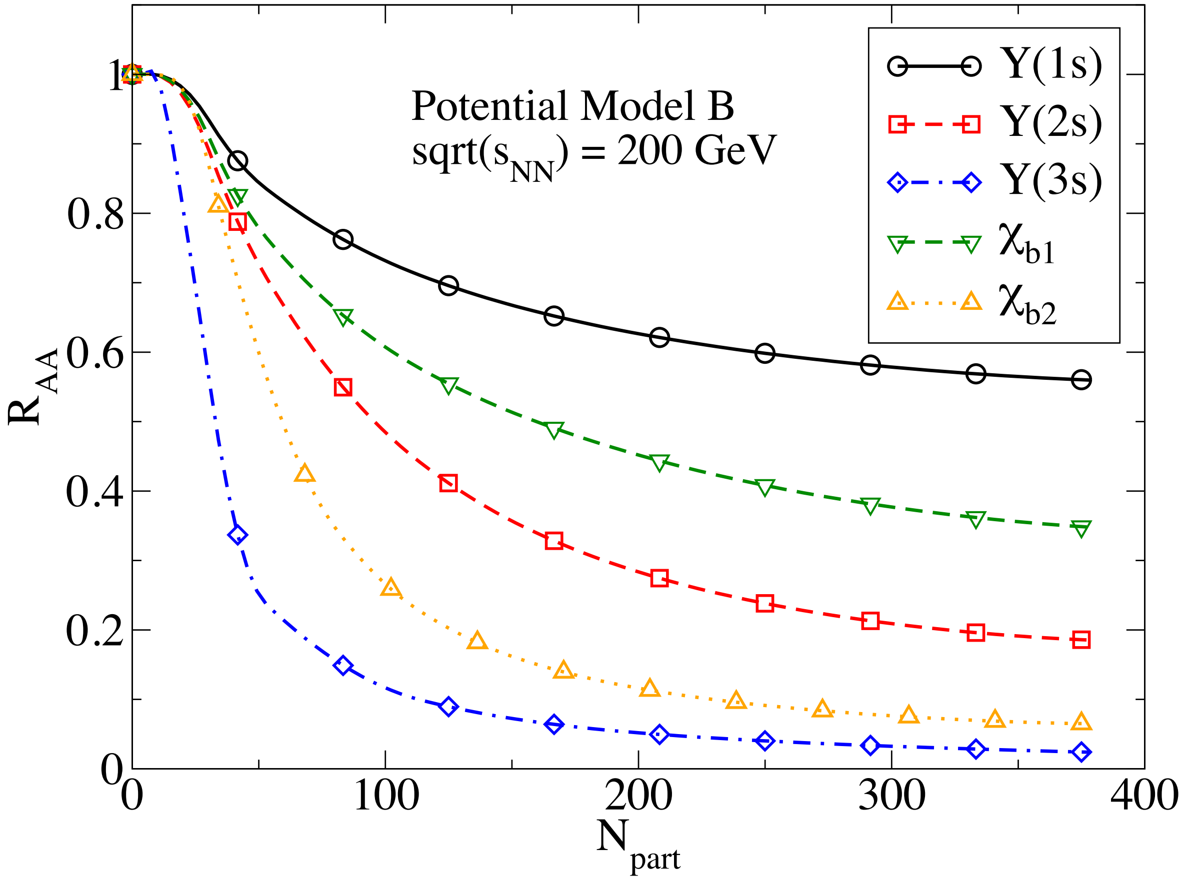




Upsilons

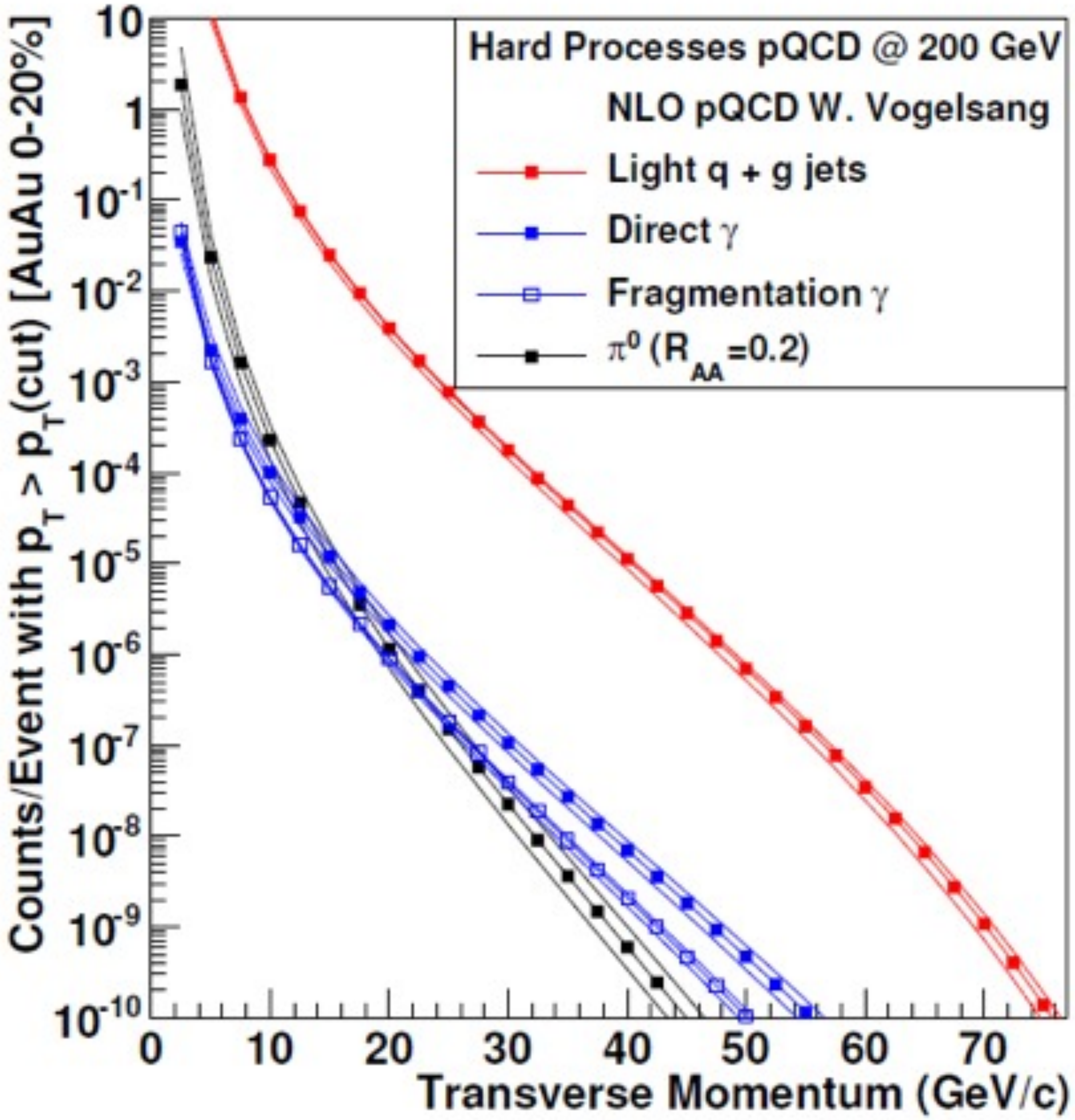


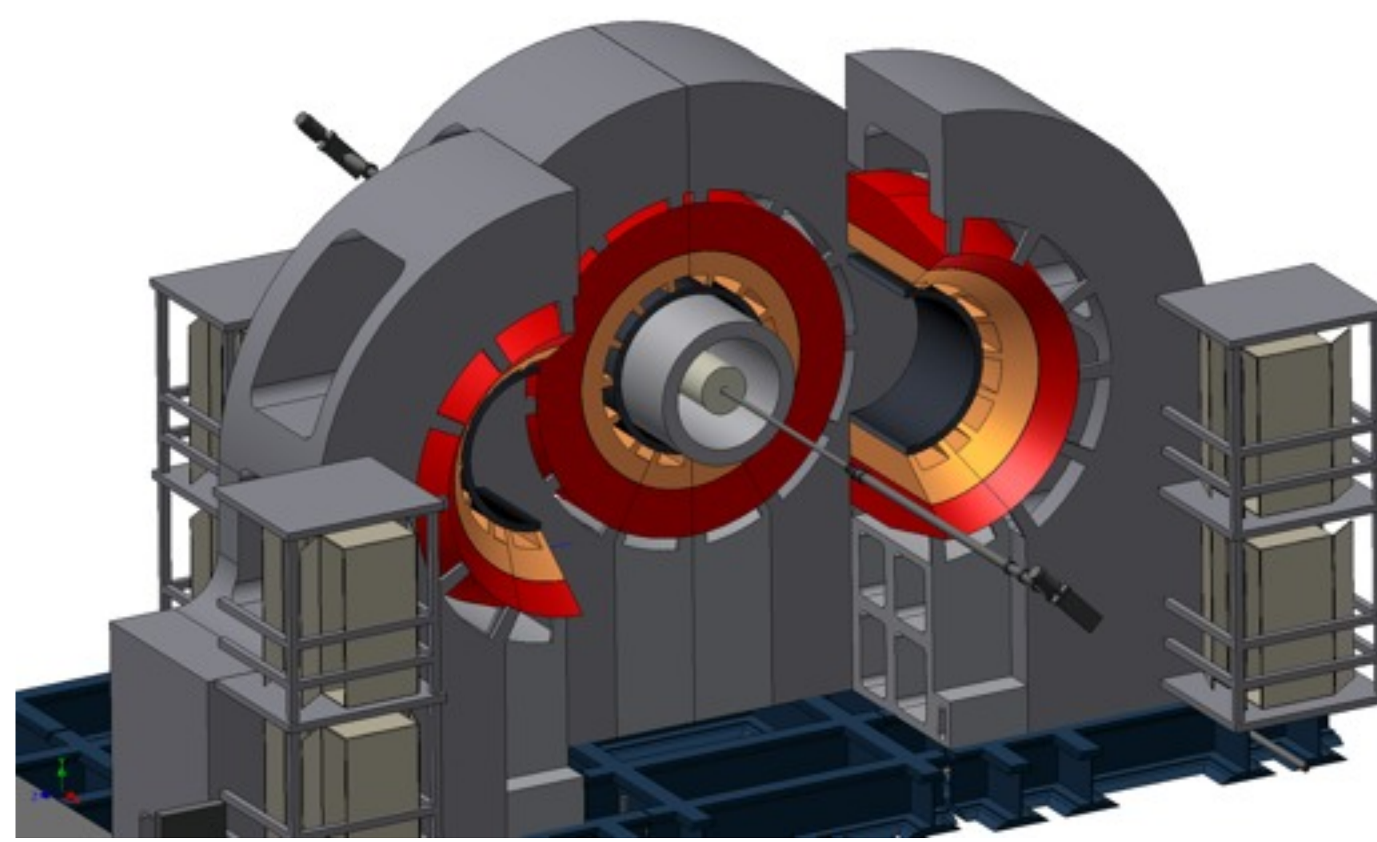




FY16: substantial pp running time required for reference data

sPHENIX FY19 Commisioning





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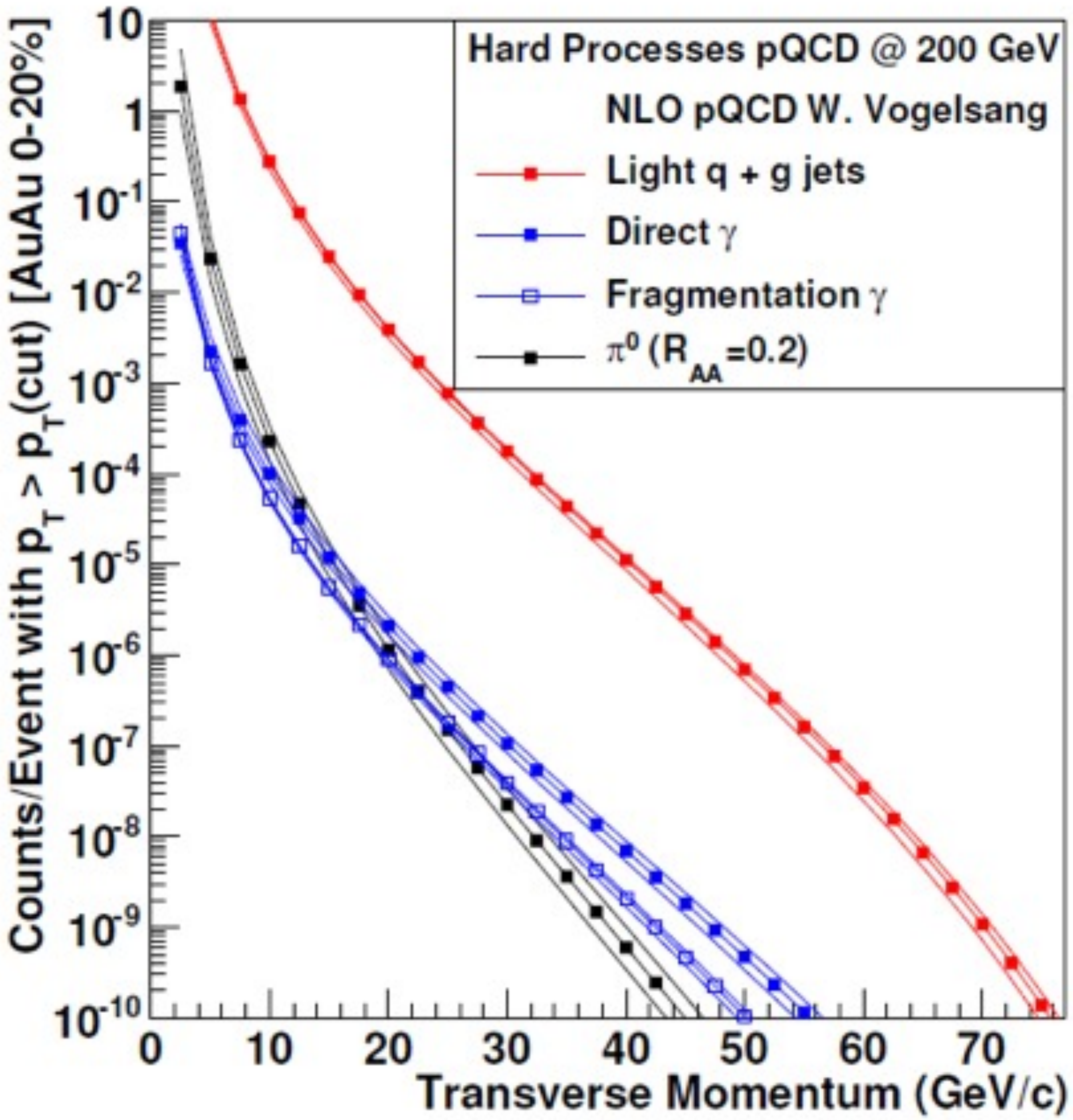
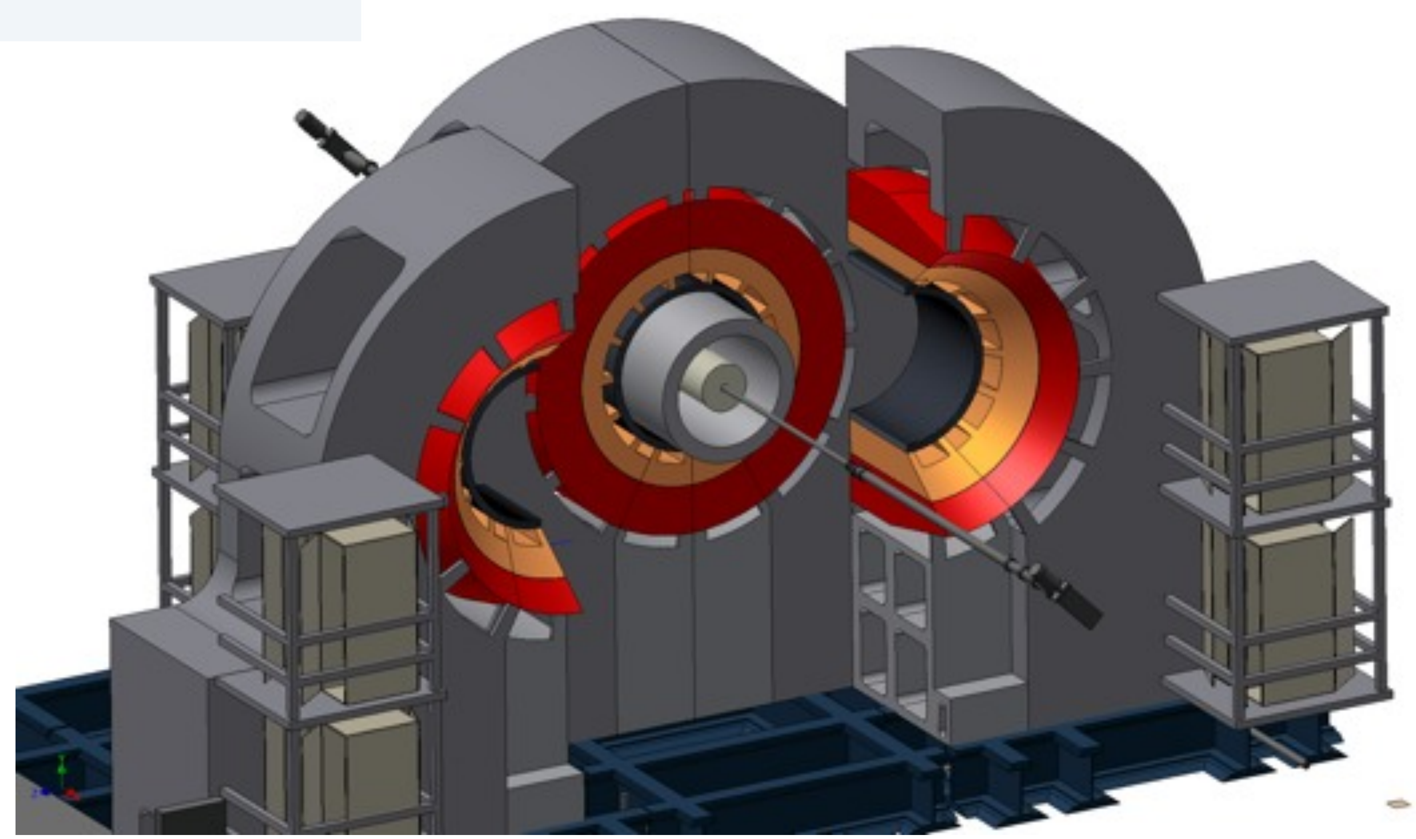


>20GeV
>30GeV
>40GeV
>50GeV



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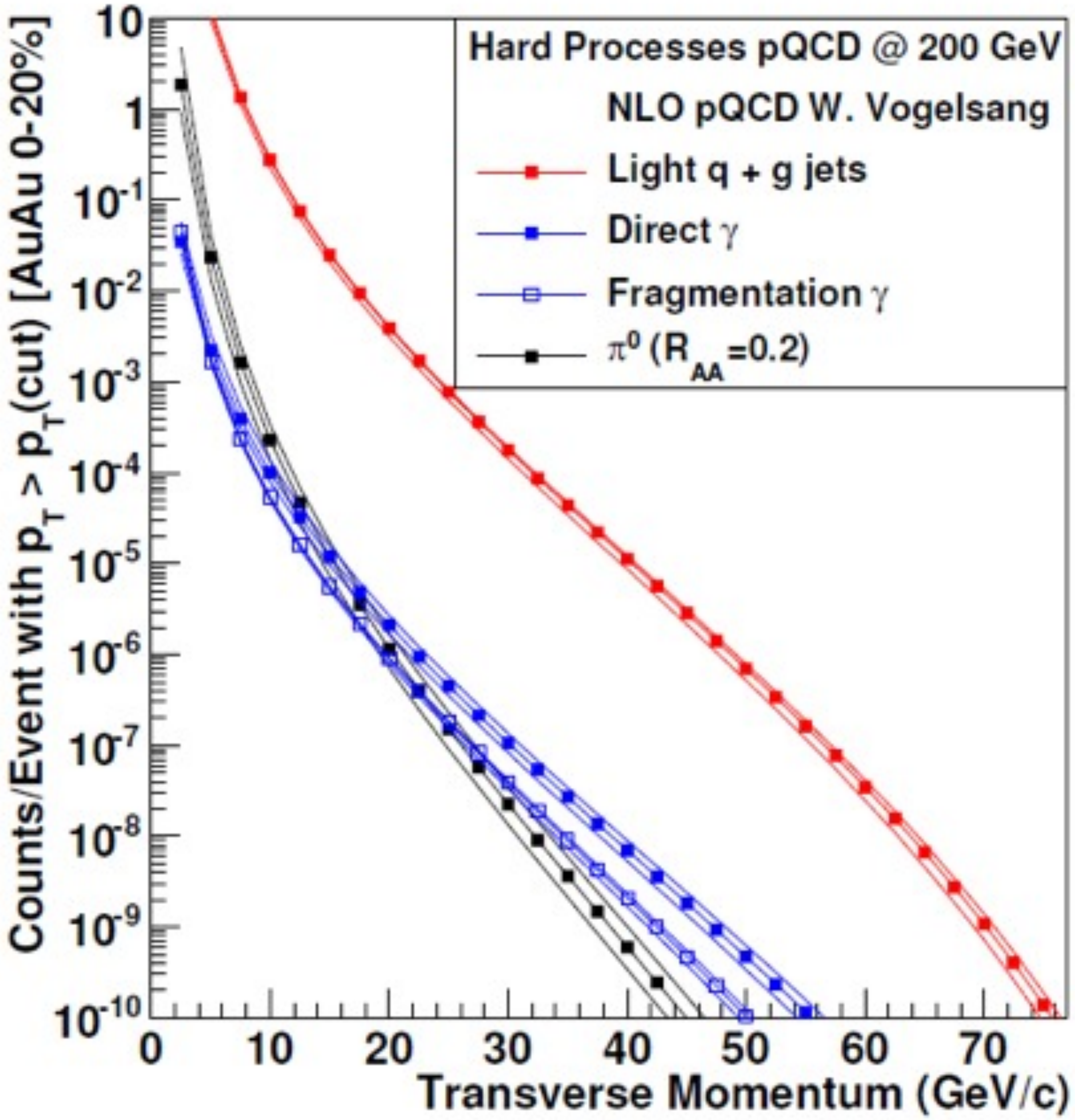
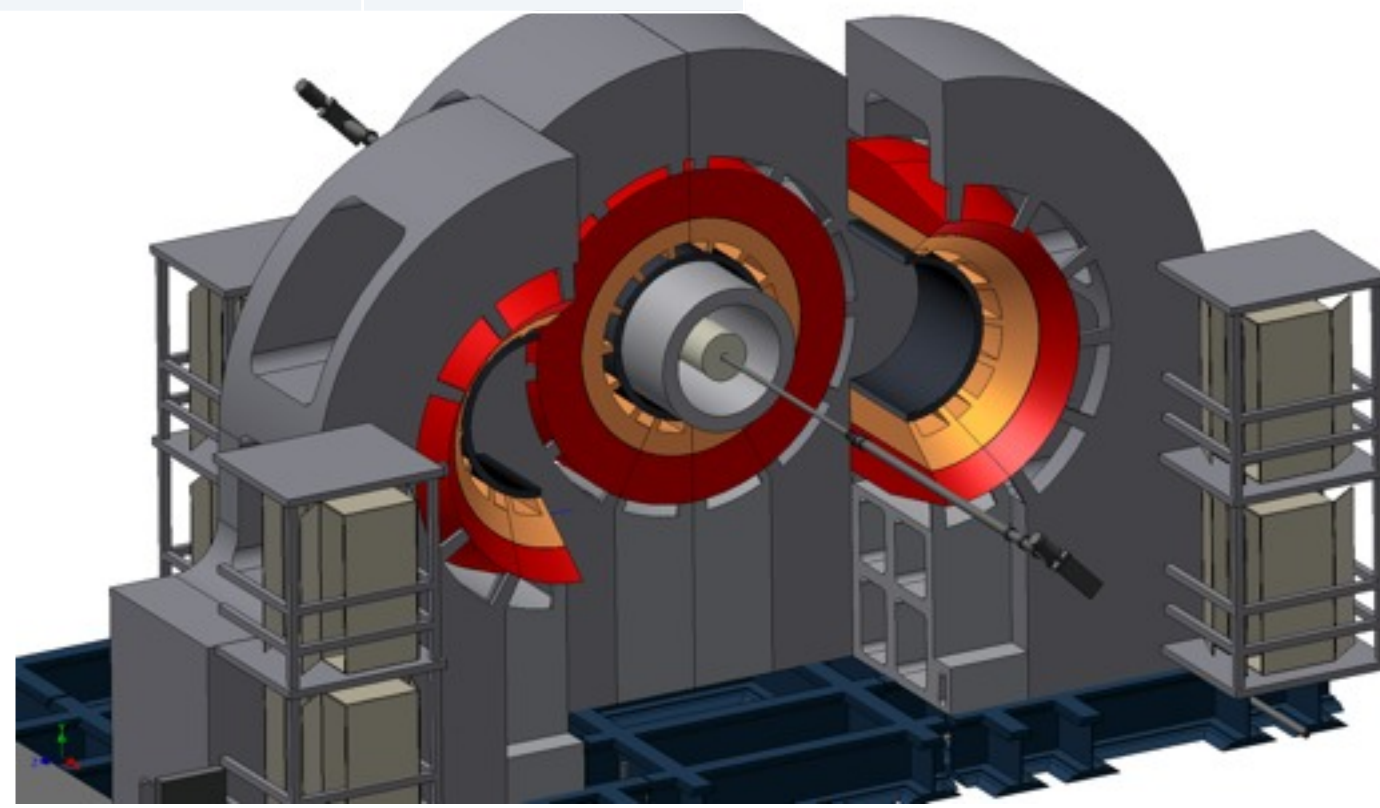


	Au+Au (central 20%)
>20GeV	10^7 jets 10^4 photons
>30GeV	10^6 jets 10^3 photons
>40GeV	10^5 jets
>50GeV	10^4 jets



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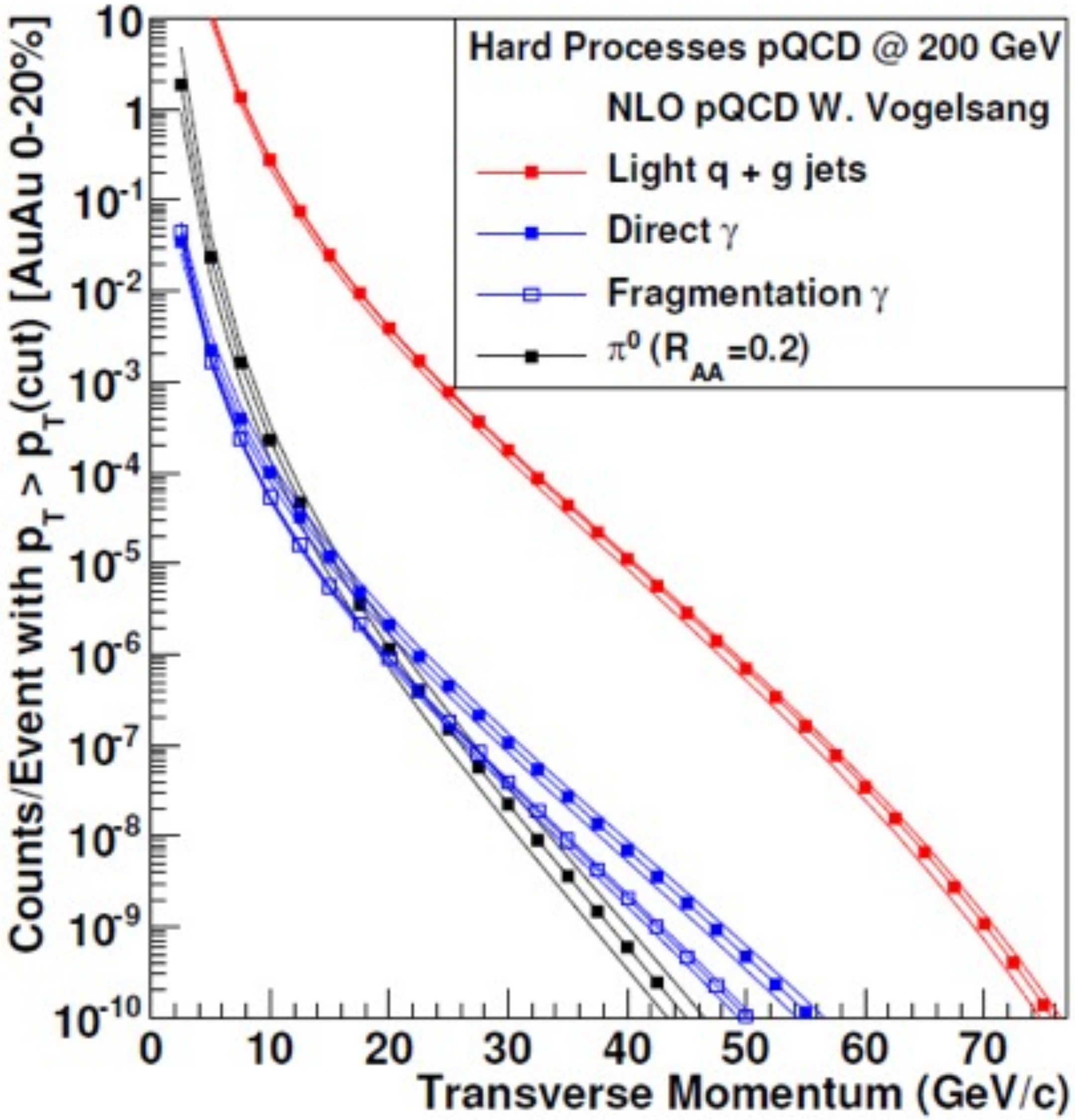

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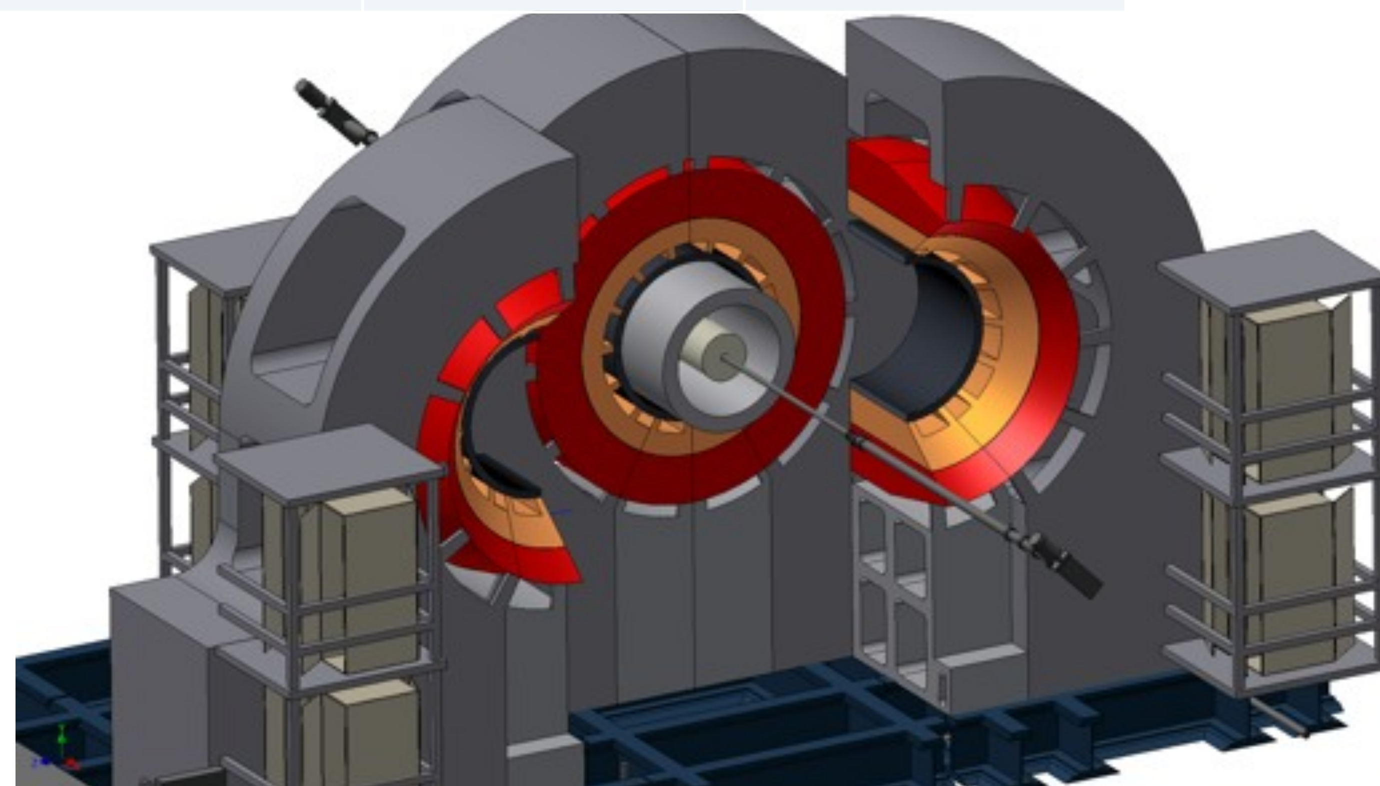

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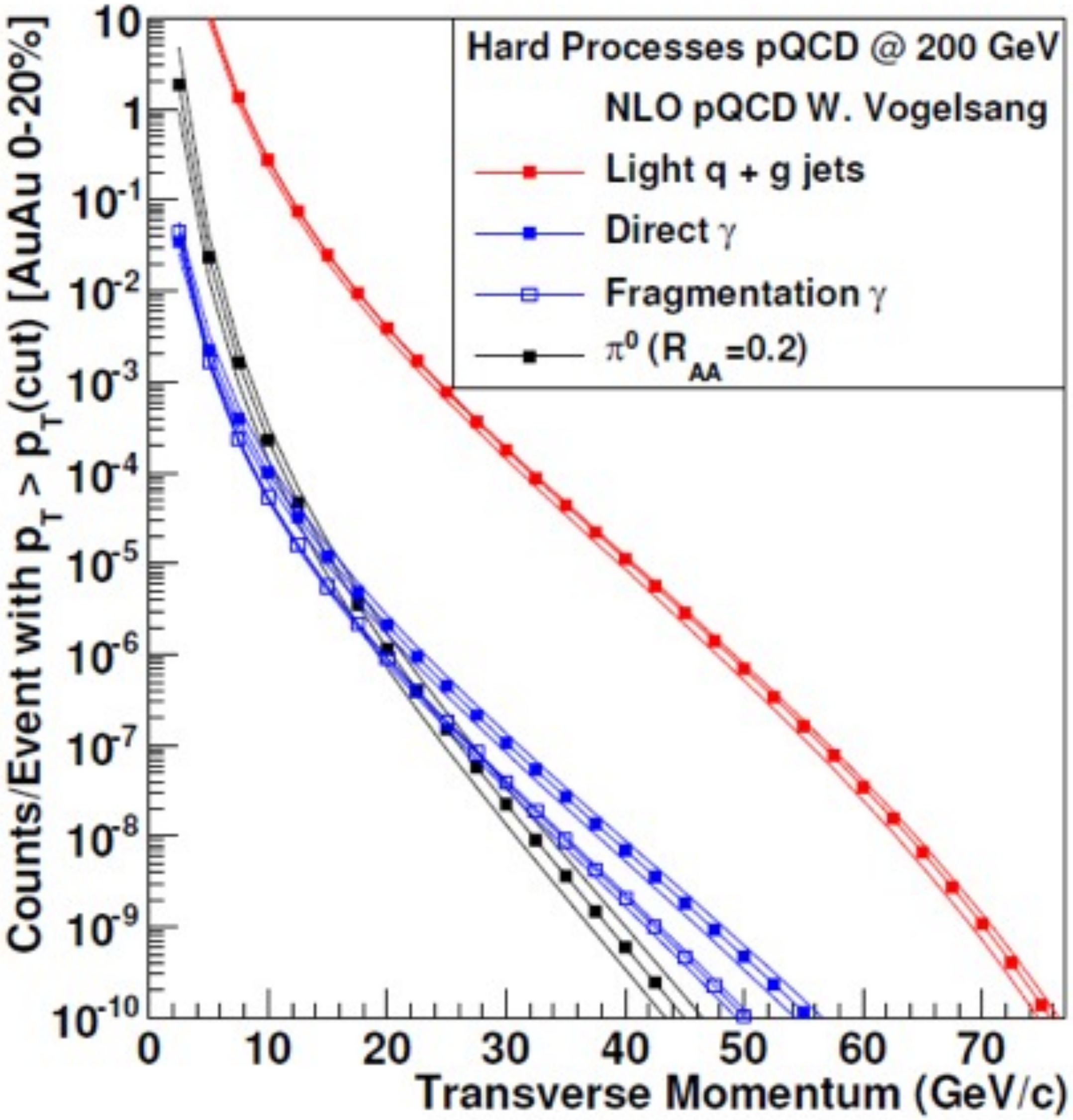
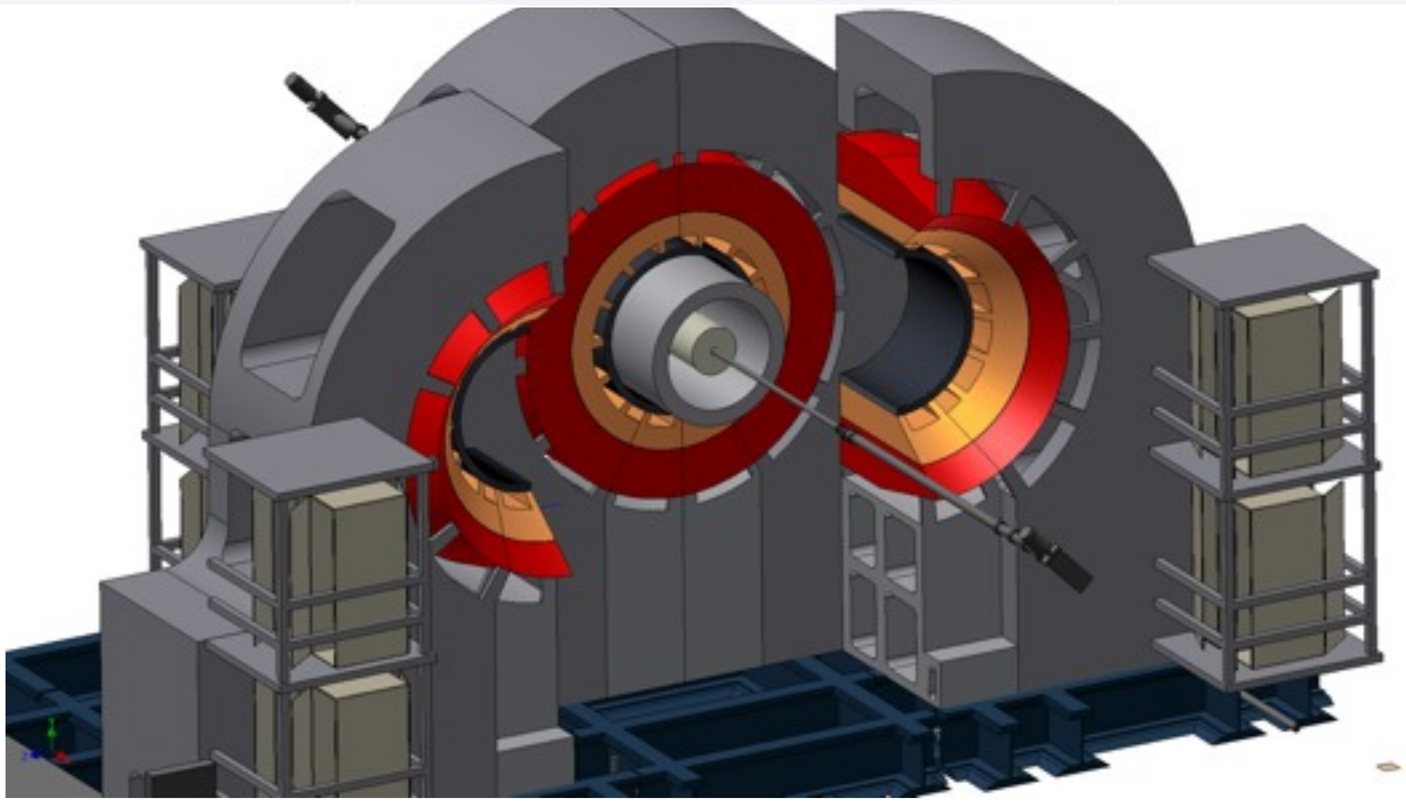
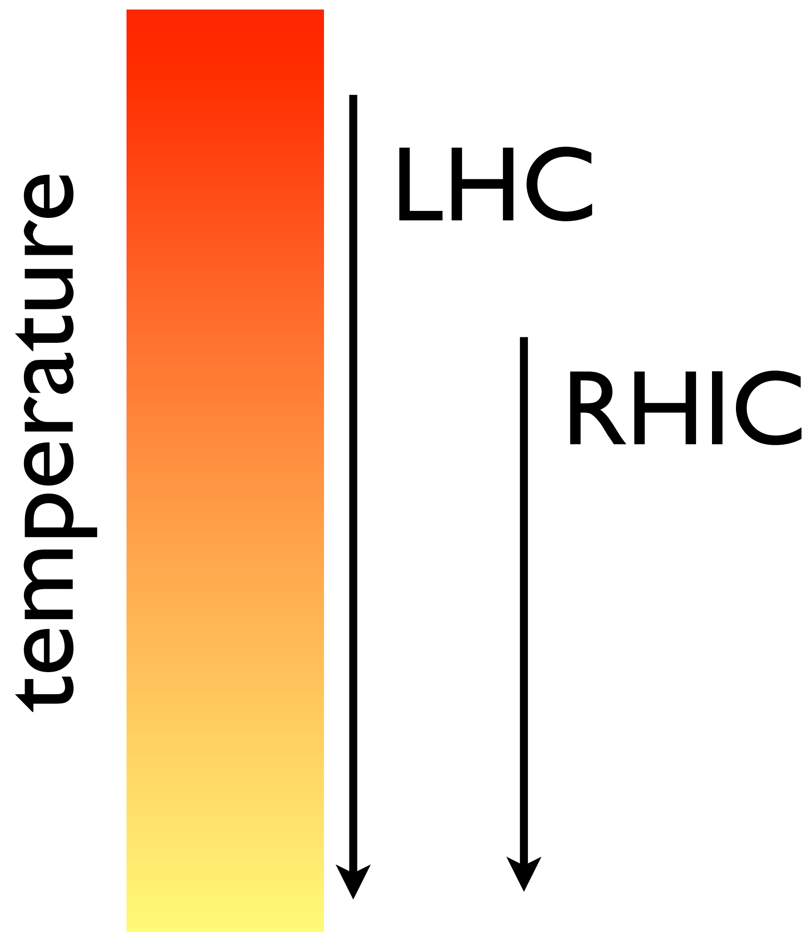


	Au+Au (central 20%)	p+p	d+Au
>20GeV	10^7 jets 10^4 photons	10^6 jets 10^3 photons	10^7 jets 10^4 photons
>30GeV	10^6 jets 10^3 photons	10^5 jets 10^2 photons	10^6 jets 10^3 photons
>40GeV	10^5 jets	10^4 jets	10^5 jets
>50GeV	10^4 jets	10^3 jets	10^4 jets



jet measurements

- jet quenching strongest at highest collision temperatures
  - to measure the temperature dependence of jet quenching, measure jet quenching at different collision energies



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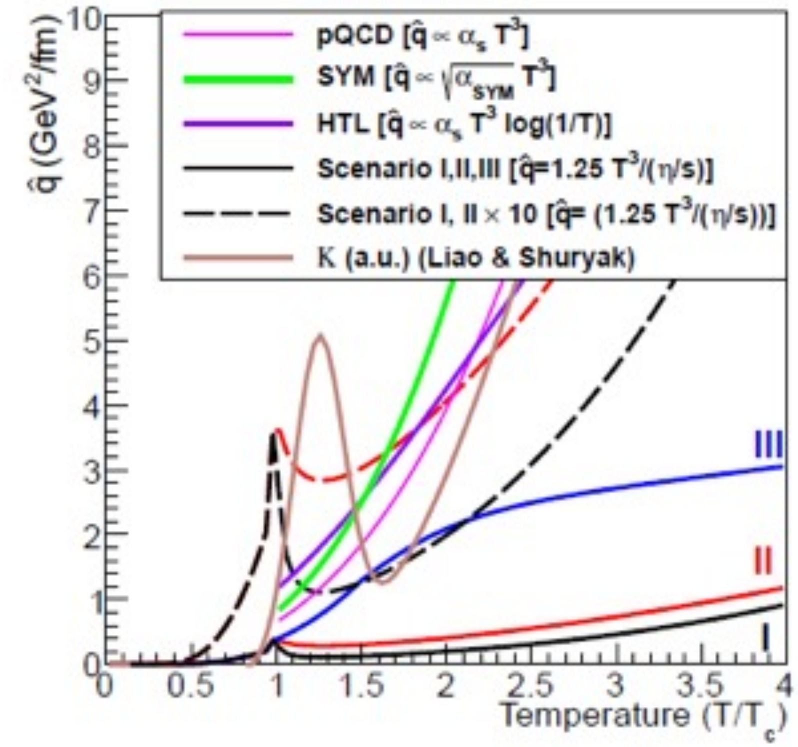
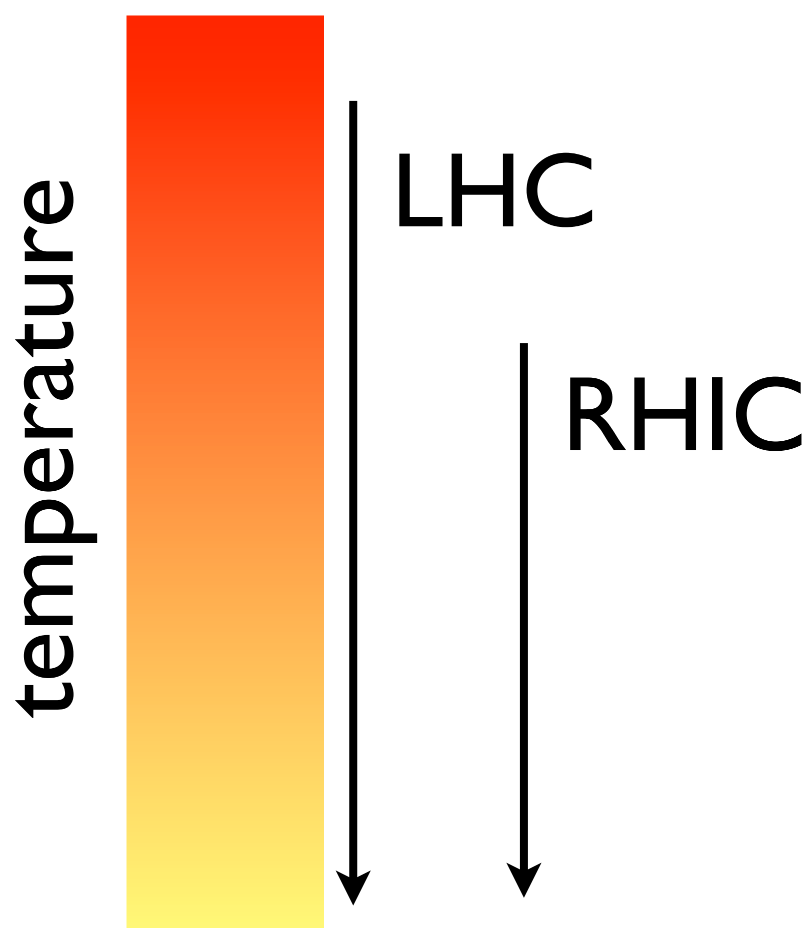




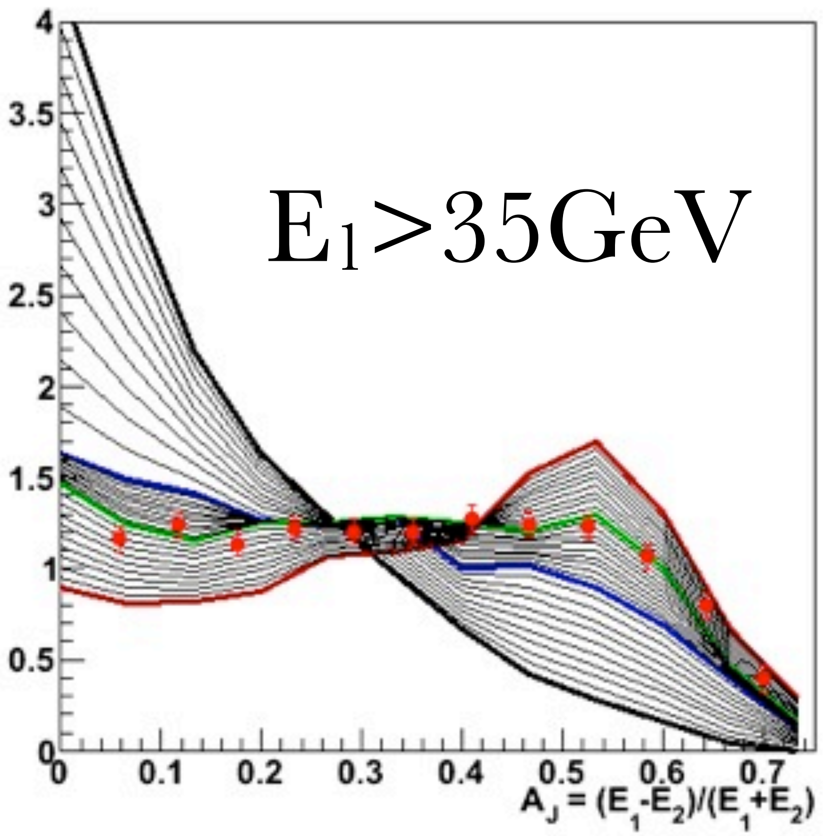
Constraining Effective Coupling

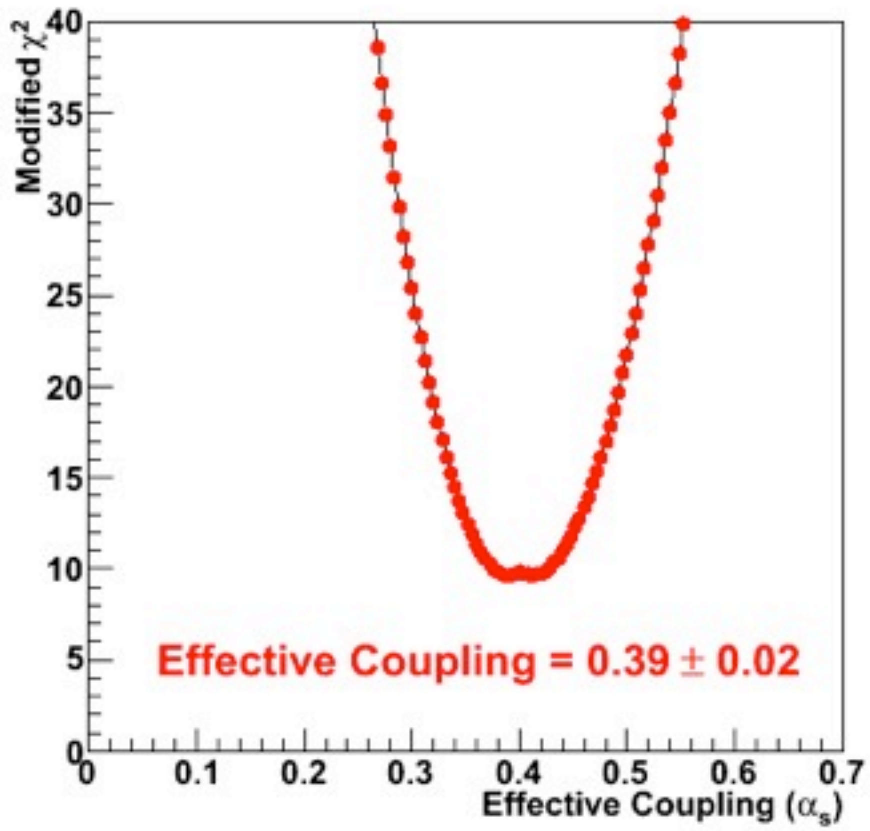
PRL **102,** 202302 (2009) PHYSICAL REVIEW LETTERS week ending 22 MAY 2009

Angular Dependence of Jet Quenching Indicates Its Strong Enhancement near the QCD Phase Transition

Jinfeng Liao[1,2,*] and Edward Shuryak[1,†]

FY19, 20 weeks AuAu





calculation: Coleman-Smith

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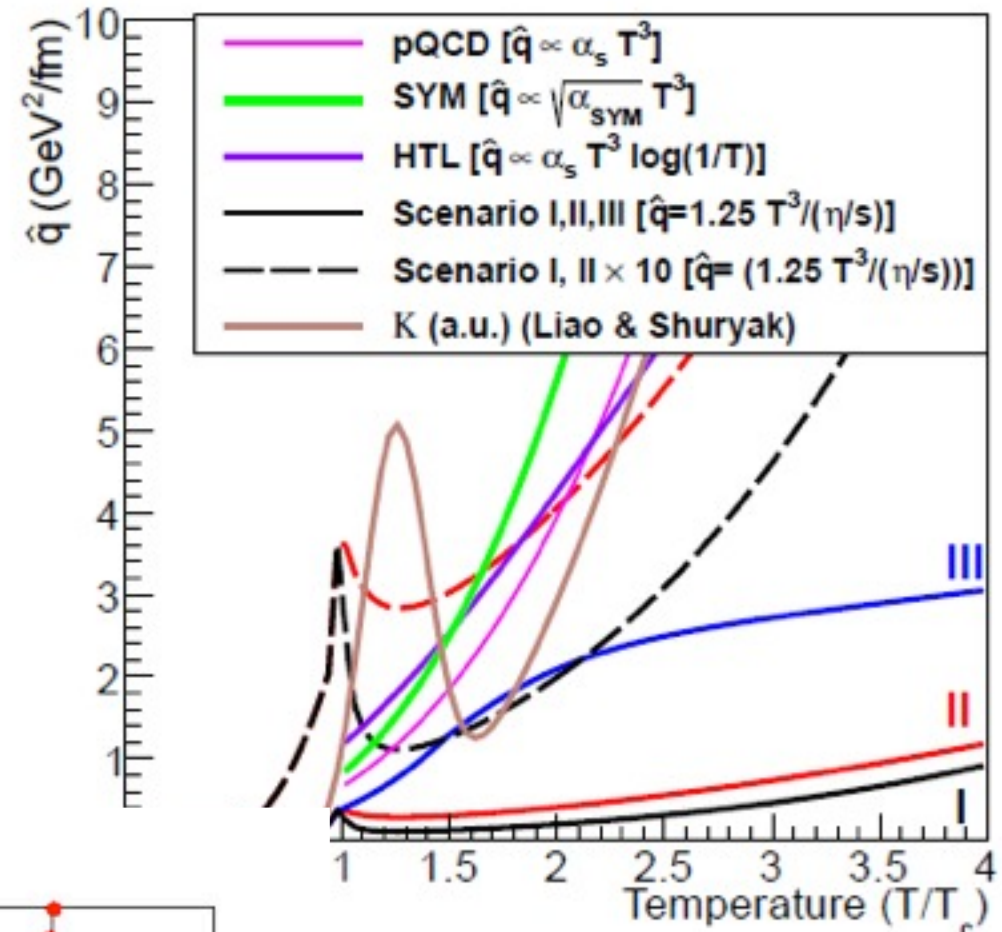

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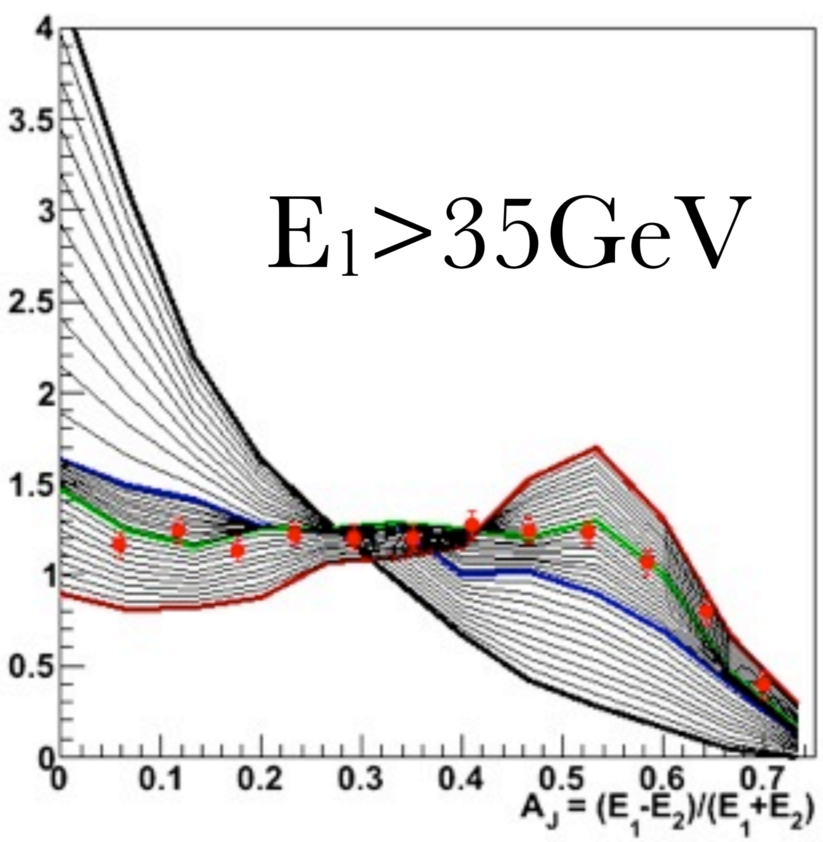
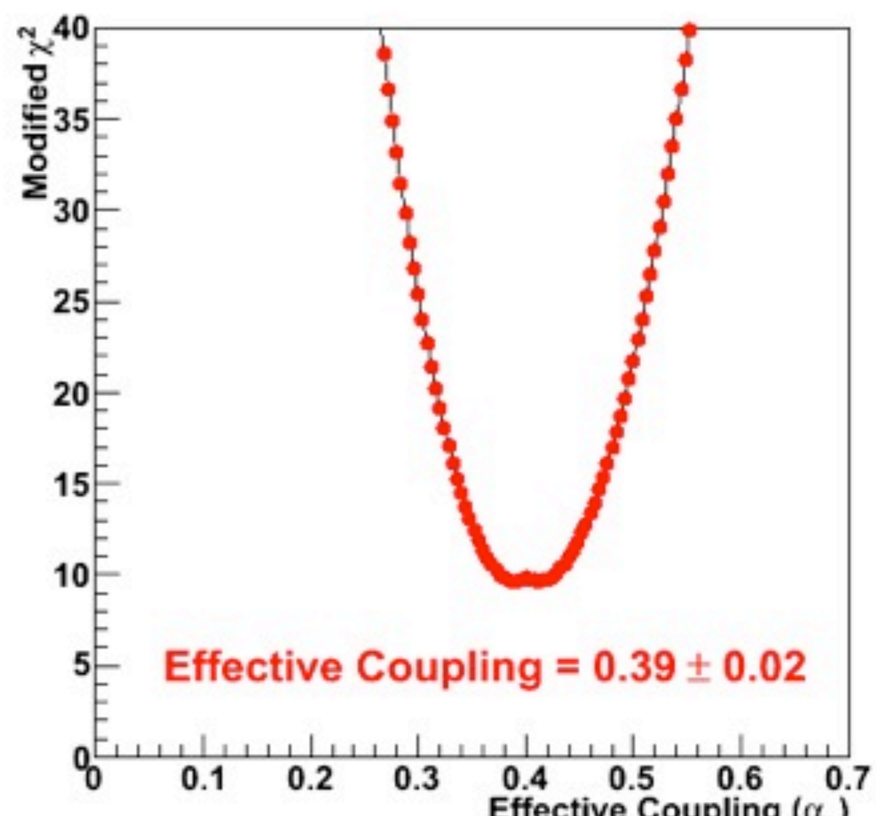
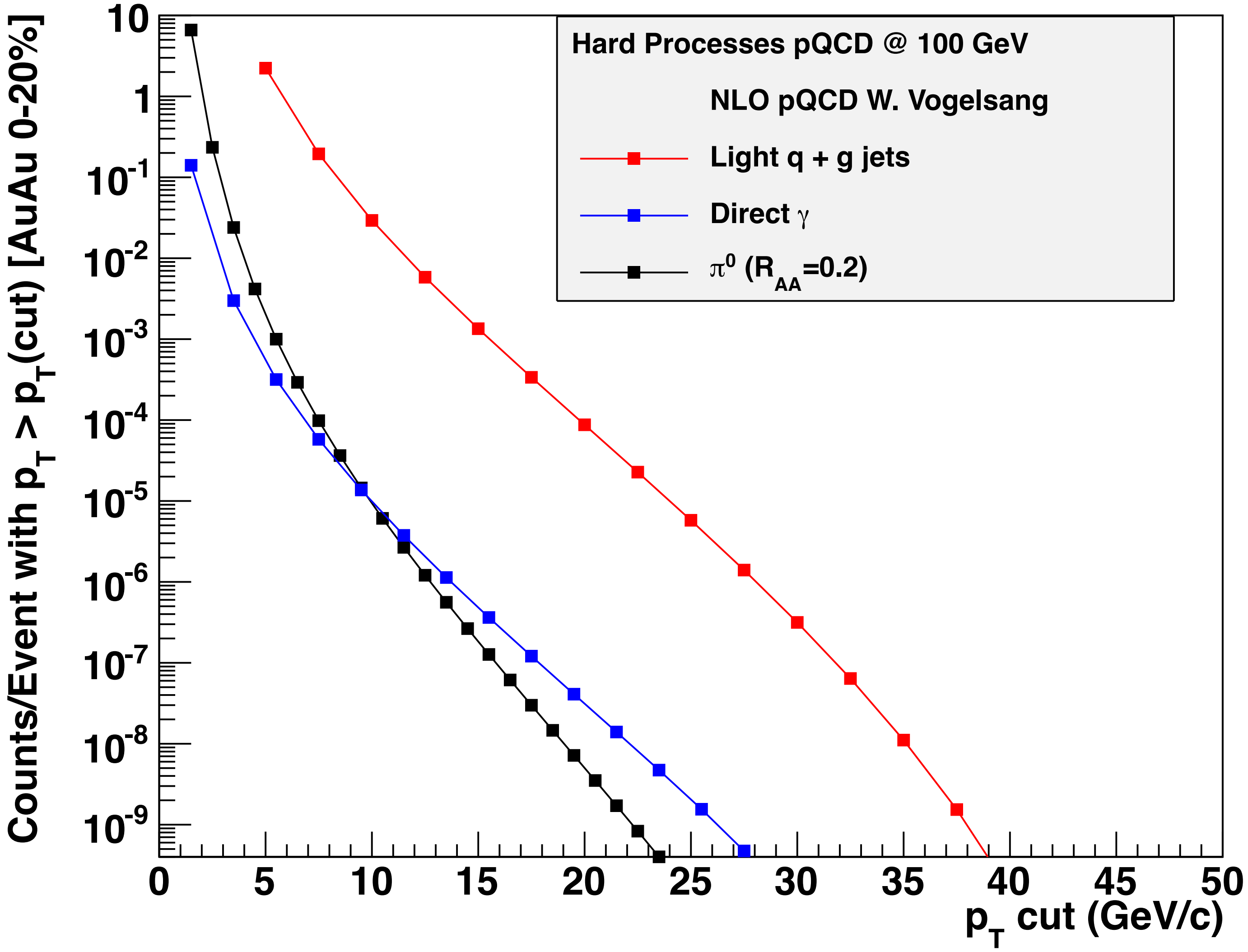




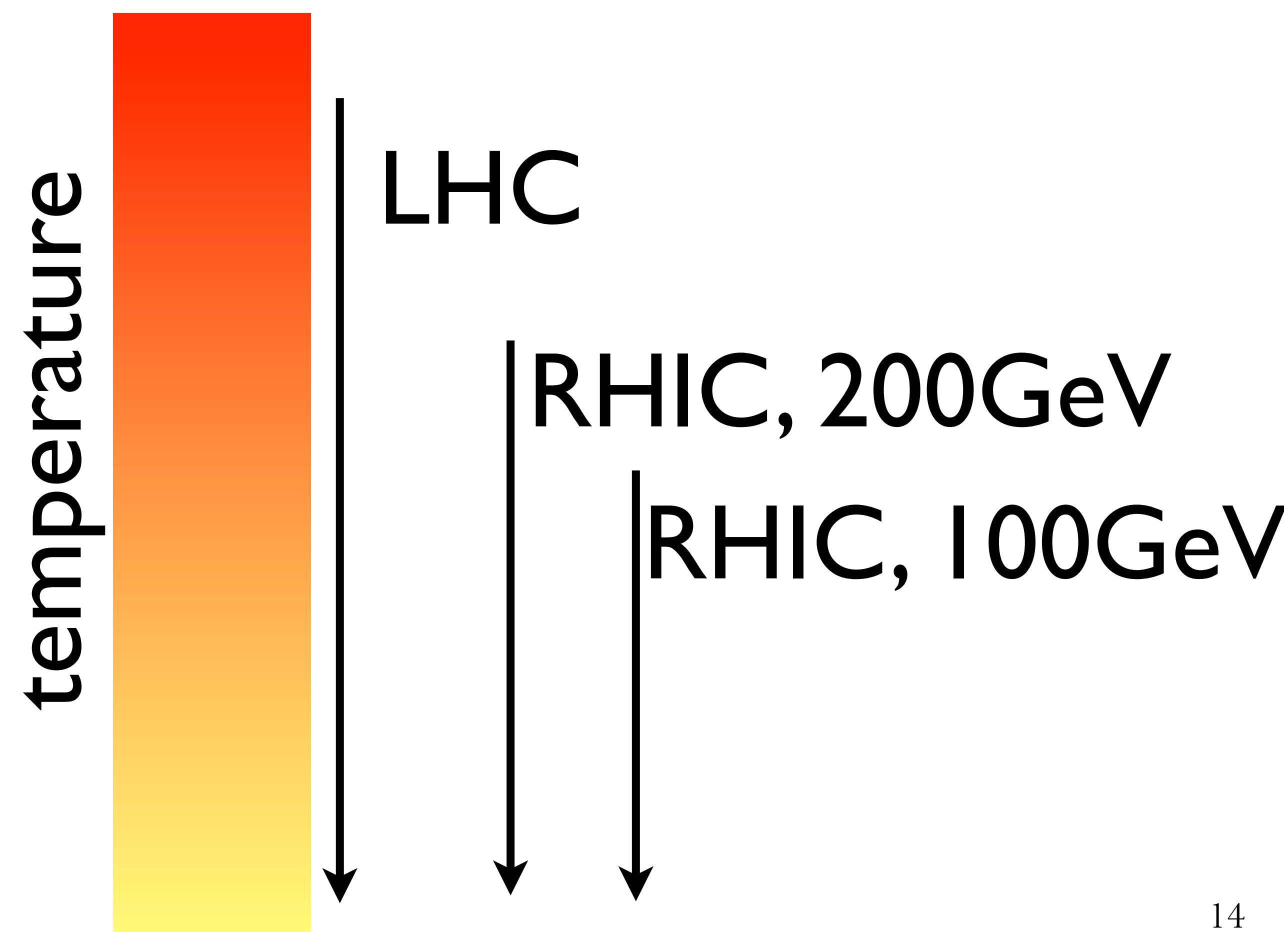
calculation: Coleman-Smith

further explore T dep. of QGP properties

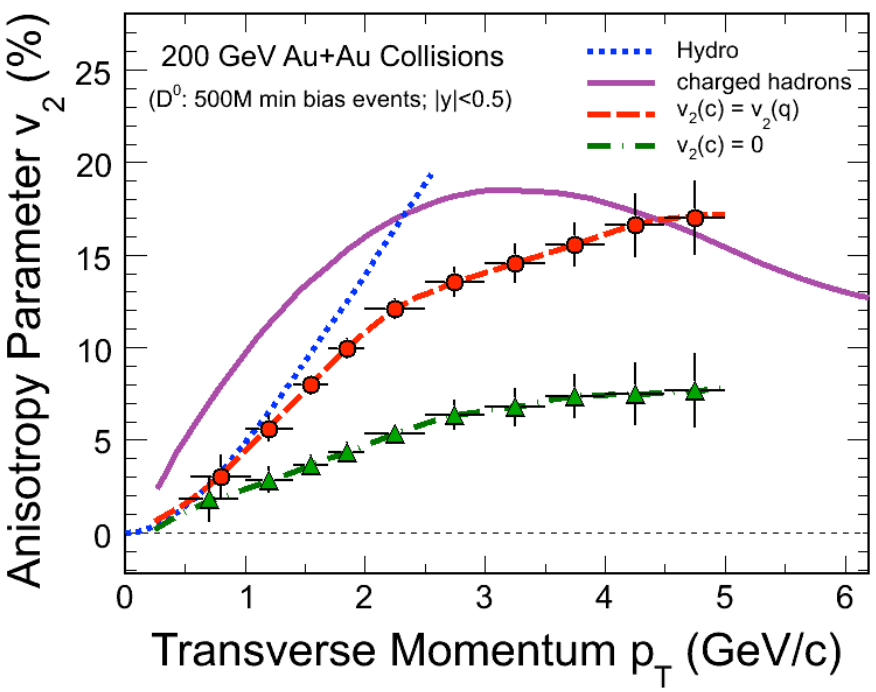
jet measurements @ $\sqrt{s_{NN}}$ = 100GeV



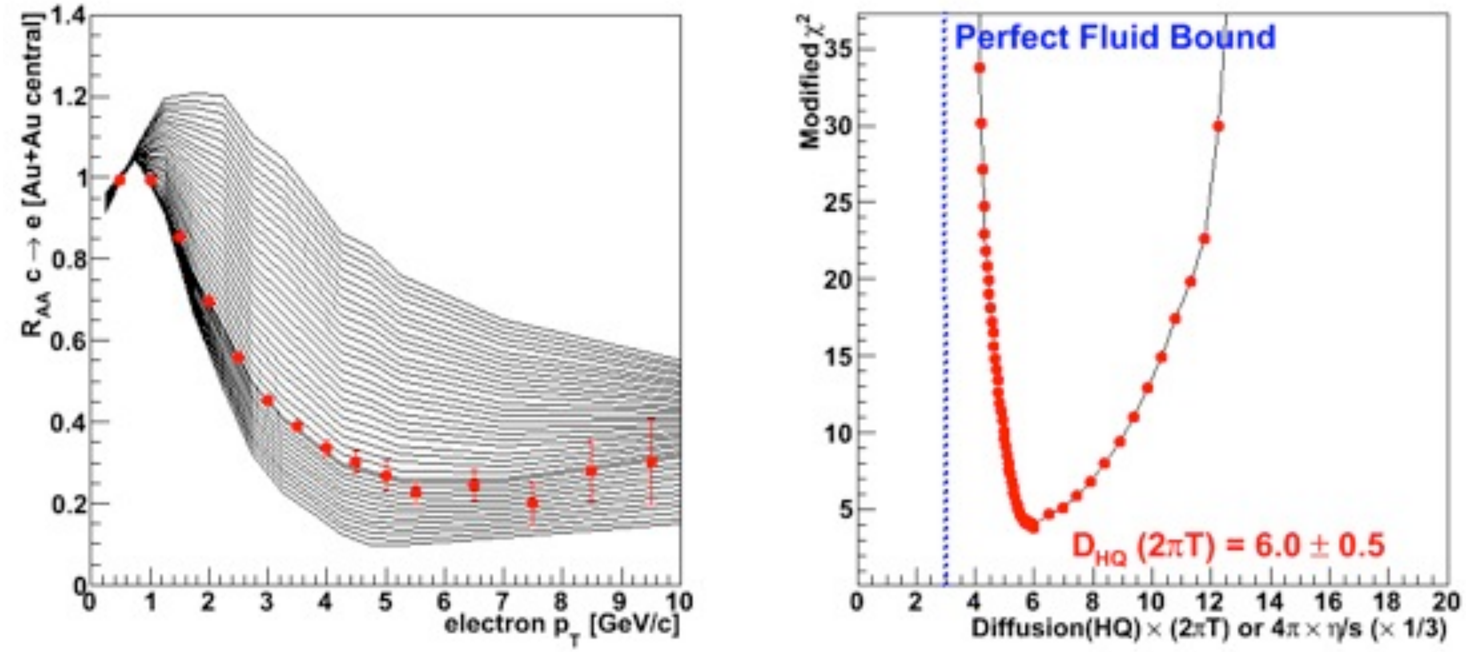
- 10^4 jets > 25GeV
- rates include RHIC luminosity scaling with beam energy



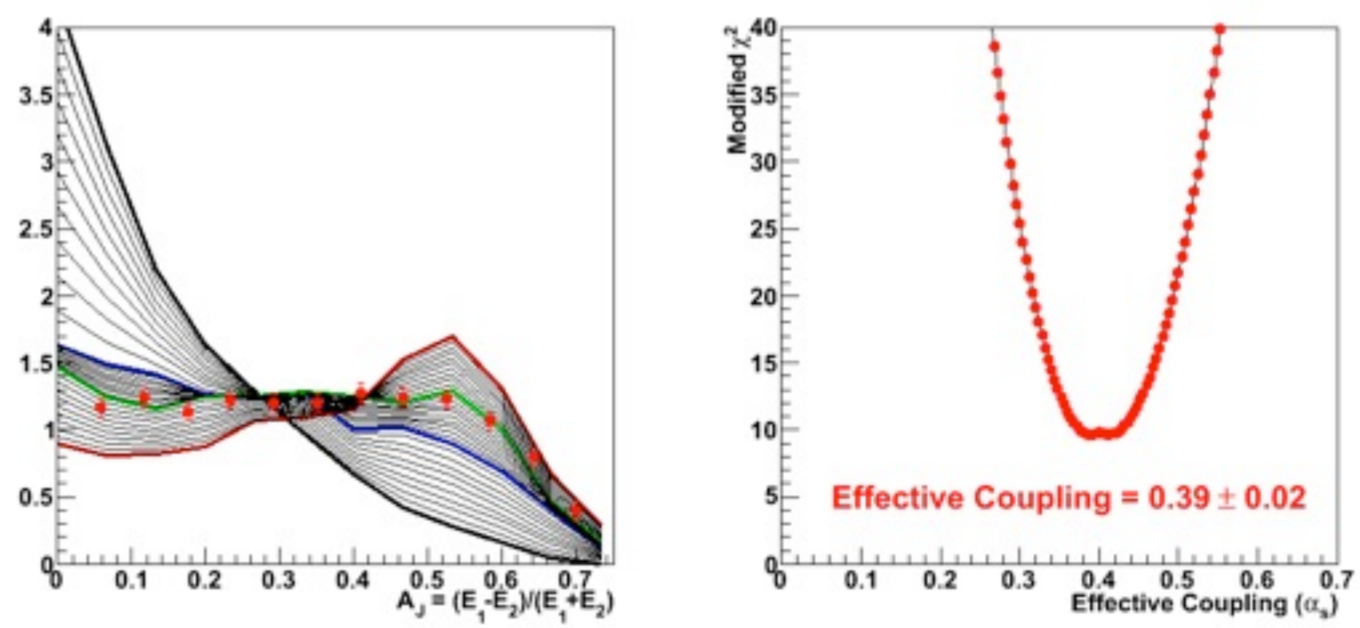
FY14



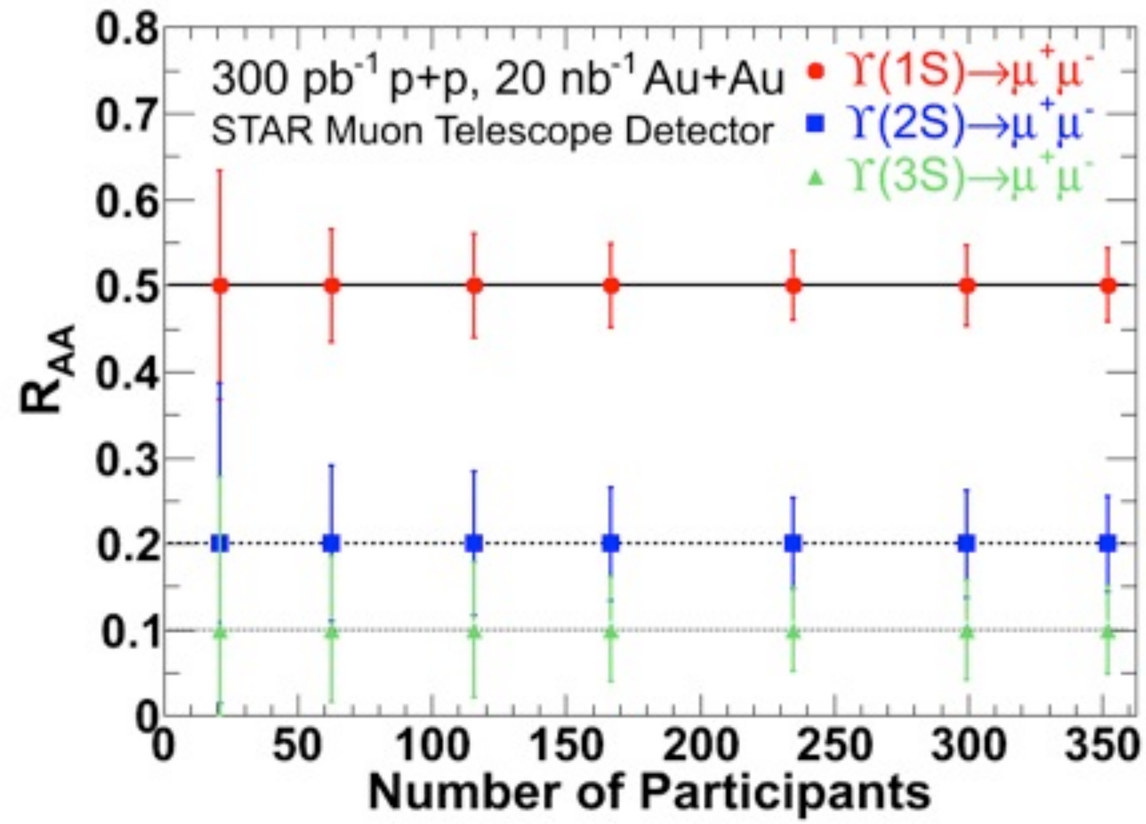
FY15



FY19



FY16



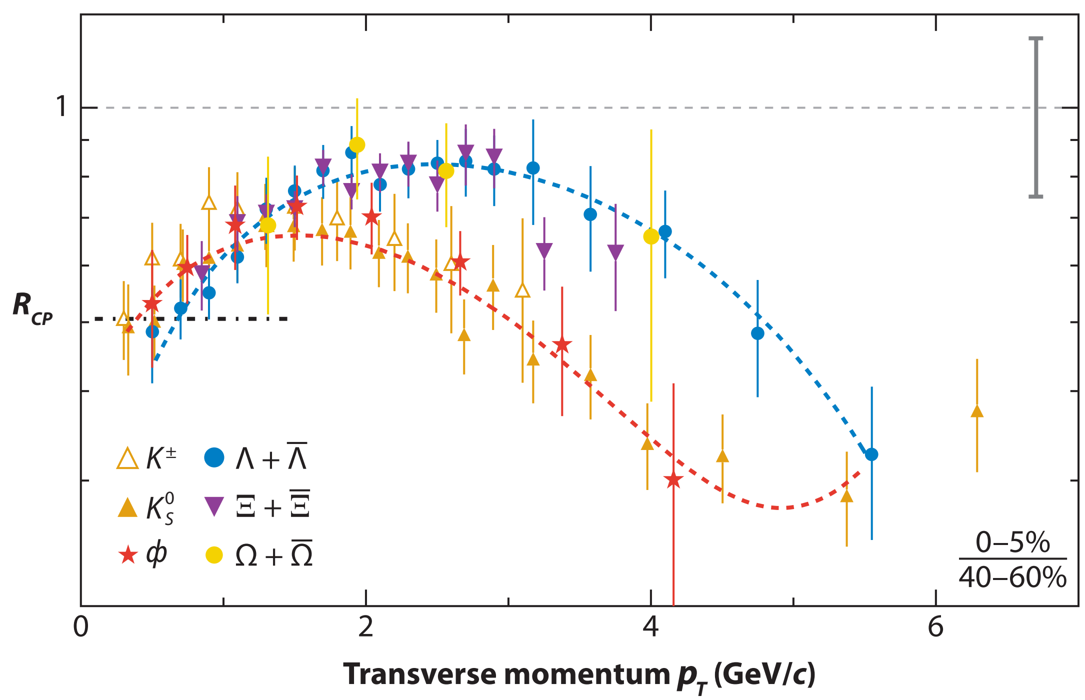
LHC timeline

LHC Heavy-Ion Programme to 2022

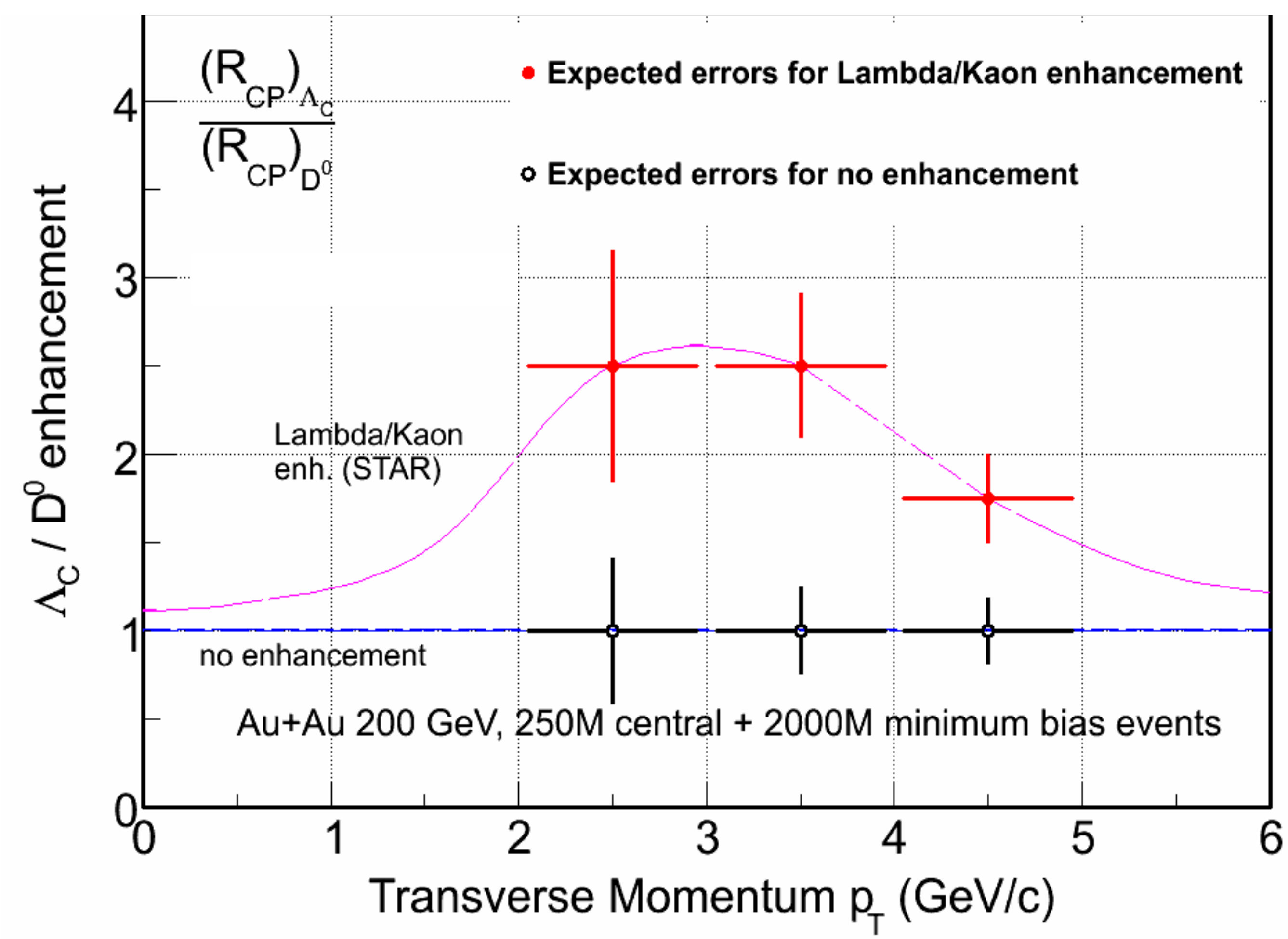
2013-14		Long shutdown LS1, increase *E*
2015-16	**Pb-Pb**	Design luminosity+, ~ 250 μb^{-1}/year
2017	**p-Pb *or* Pb-Pb**	P-Pb to enhance 2015-16 data. Energy? Pb-Pb if μb^{-1} still needed
2018		LS2: install DS collimators around ALICE to protect magnets (ALICE upgrade for 6 × design luminosity)
2019	**Pb-Pb**	Beyond design luminosity … as far as we can. Reduce bunch spacing?
2020	**p-Pb**	
2021	**Ar-Ar**	Intensity to be seen from injector commissioning for SPS fixed target. Demanding collimation requirements.
2022		LS3, upgrades ?? Stochastic cooling ??

does charm coalesce?

FY16, additional AuAu running 25 weeks



HFT Projections



- similar measurement at LHC doesn't come until ALICE ITS Upgrade

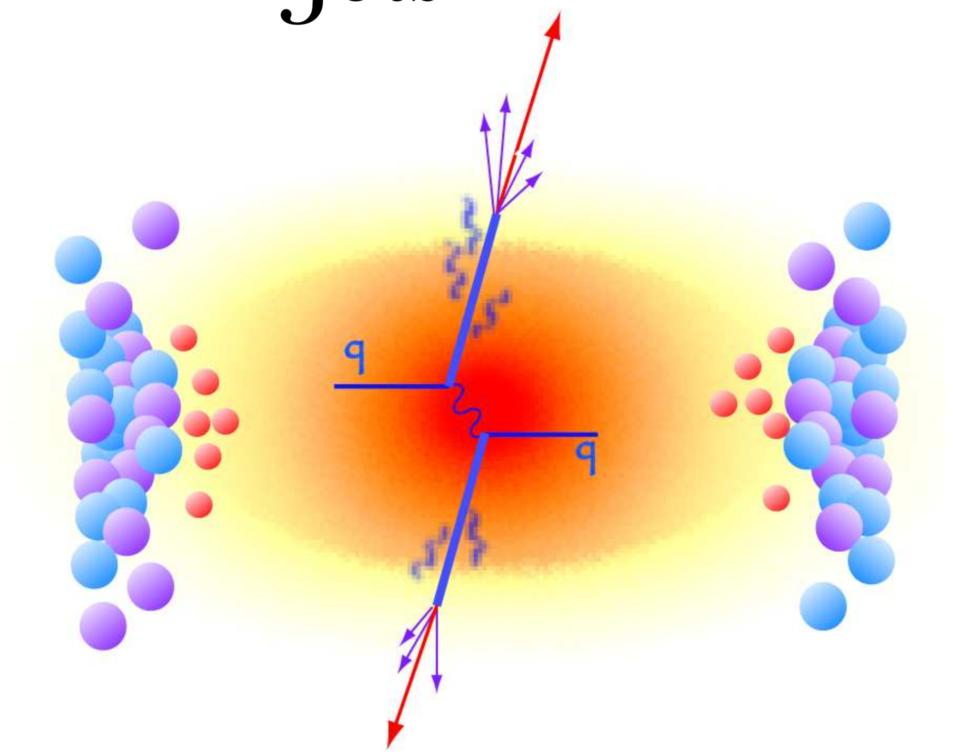
sPHENIX Physics

- what can be learned from jets near Tc?

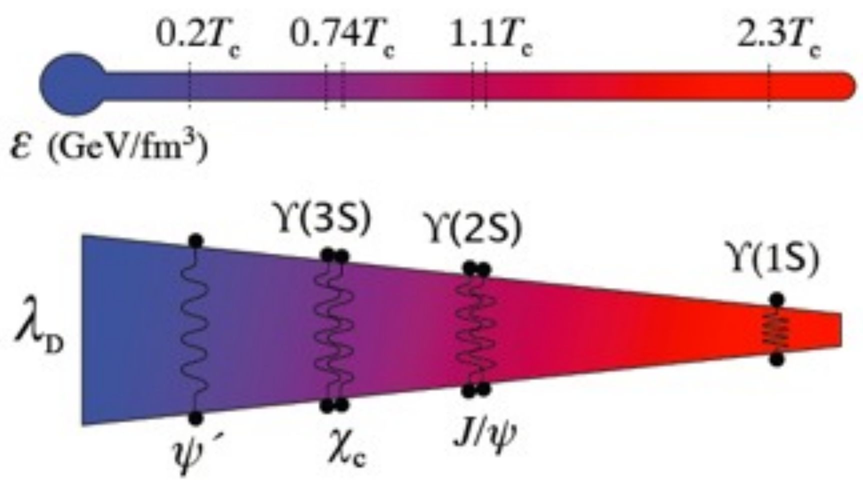
JET Collaboration

Penetrating Probes

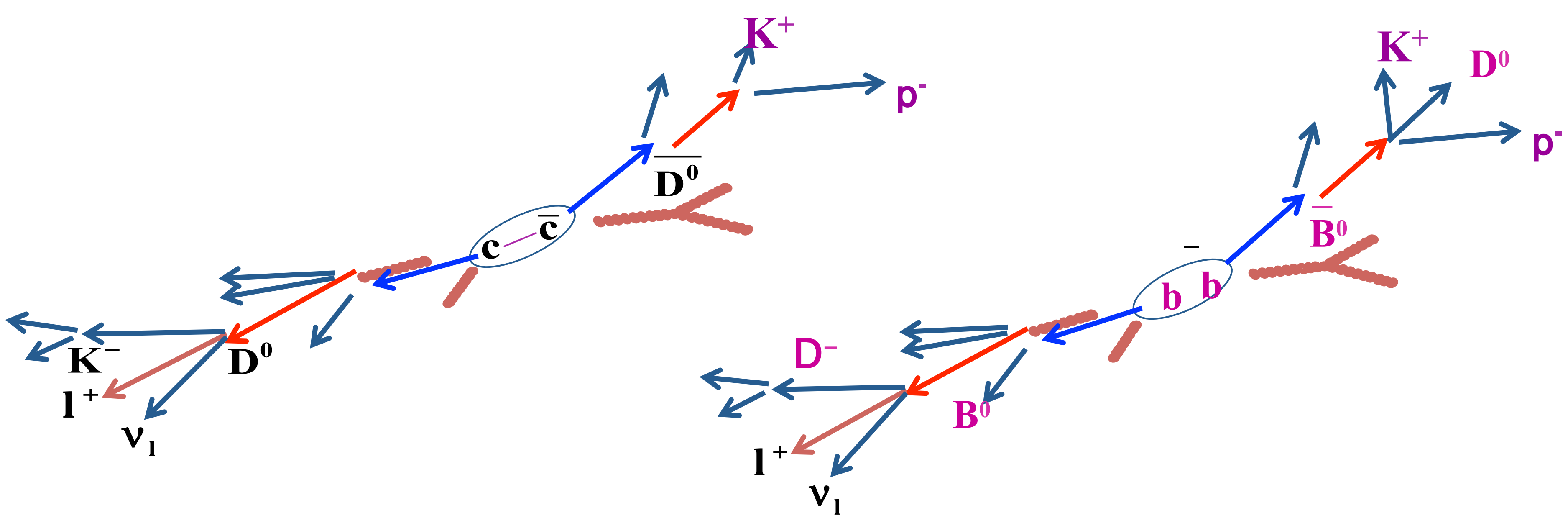
Jets



Quarkonia



Open Heavy Flavor



2013 & 2014 RHIC Running

PAC Reommendations: June 2012

For Run 13 the PAC recommends the following (*in order of priority*):

1. Running with polarized proton collisions at 500 GeV to provide an integrated luminosity of 750 pb^{-1} at an average polarization of 55%.
2. Depending on the amount of running time remaining after priority #1
   a. If less than 3 weeks remain, a week of 200 GeV Au+Au collisions.
   b. If at least 3 weeks of running time remain, 3 weeks of 15 GeV Au+Au collisions.
3. 8 days of 62 GeV p+p collisions.
4. At the discretion of the ALD, 4 days of low-luminosity running to accomplish the pp2pp goals.

For Run 14 the PAC recommends the following (*in order of priority*)

1. 8-10 weeks of 200 GeV Au+Au collisions.
2. 4-5 weeks of 200 GeV polarized proton collisions.
3. For any remaining time, 200 GeV d+Au collisions.