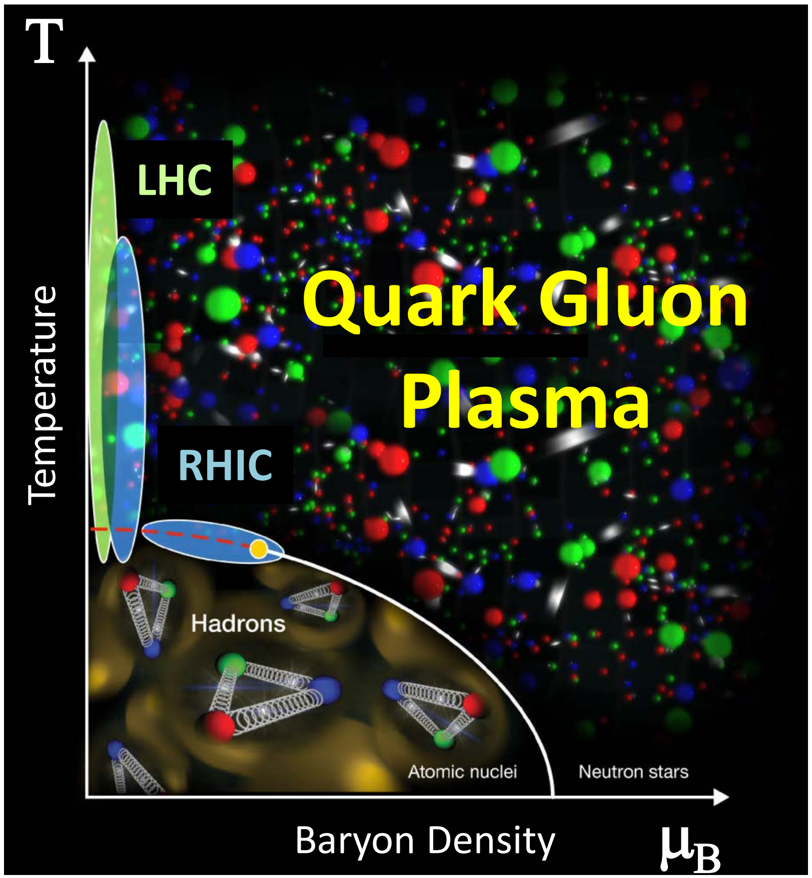
RHIC physics with Hard Probes

Y. Akiba (RIKEN/RBRC)

NSAC Sub-committee presentation

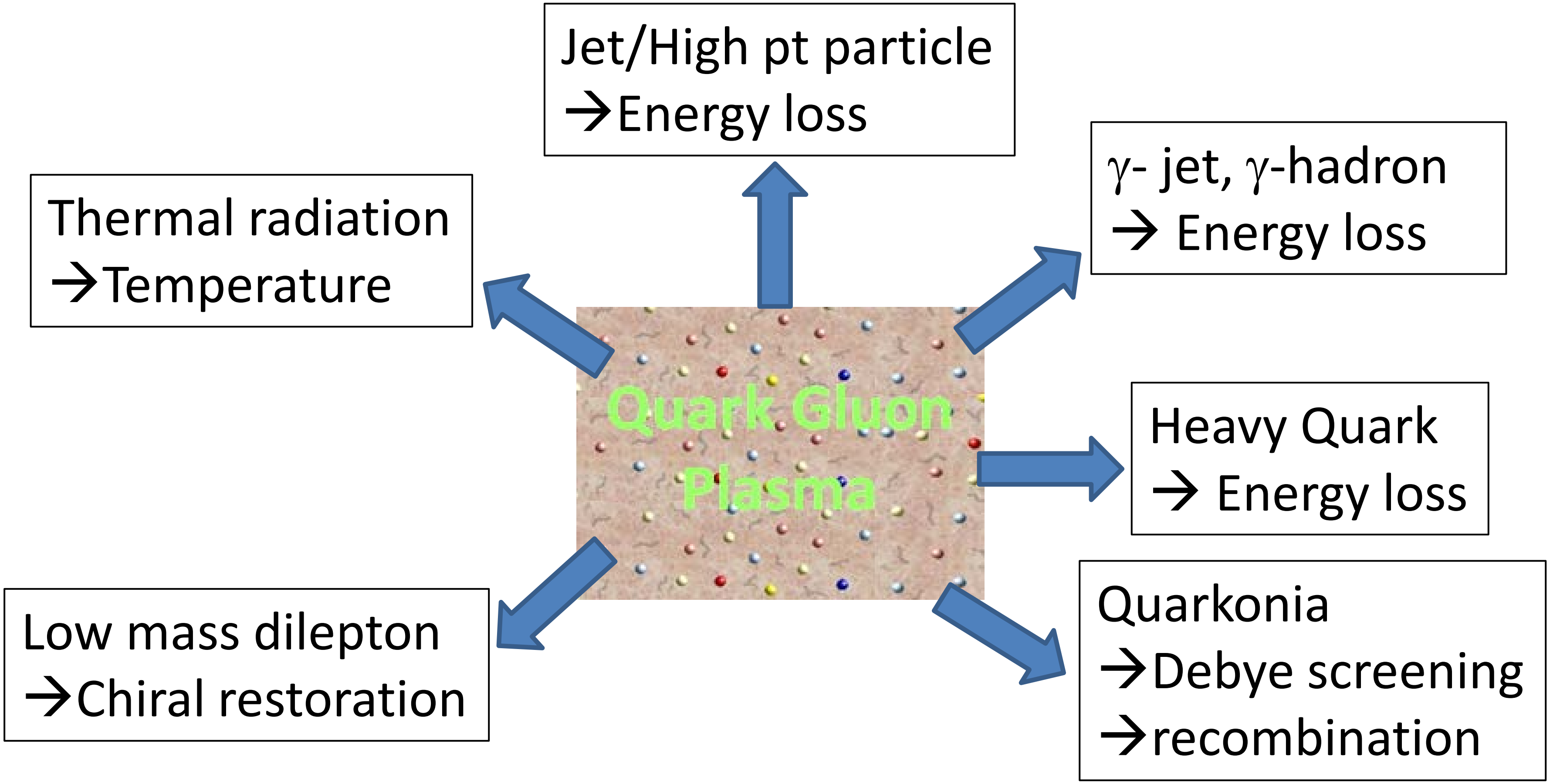
September 7, 2012

Study of QCD matter at RHIC and LHC



- New phase of matter, QGP, is discovered at RHIC and is confirmed at LHC
- QGP at LHC should be ~30% higher temperature than RHIC
- QGP is characterized by
  - Near perfect fluidity
  - Strong energy loss of parton
- This is the only “Phase transition” of quantum field realized at laboratory
- It is our Scientific Obligation to quantify the property of QGP.
- Quantitative study of QGP property is underway at RHIC and LHC

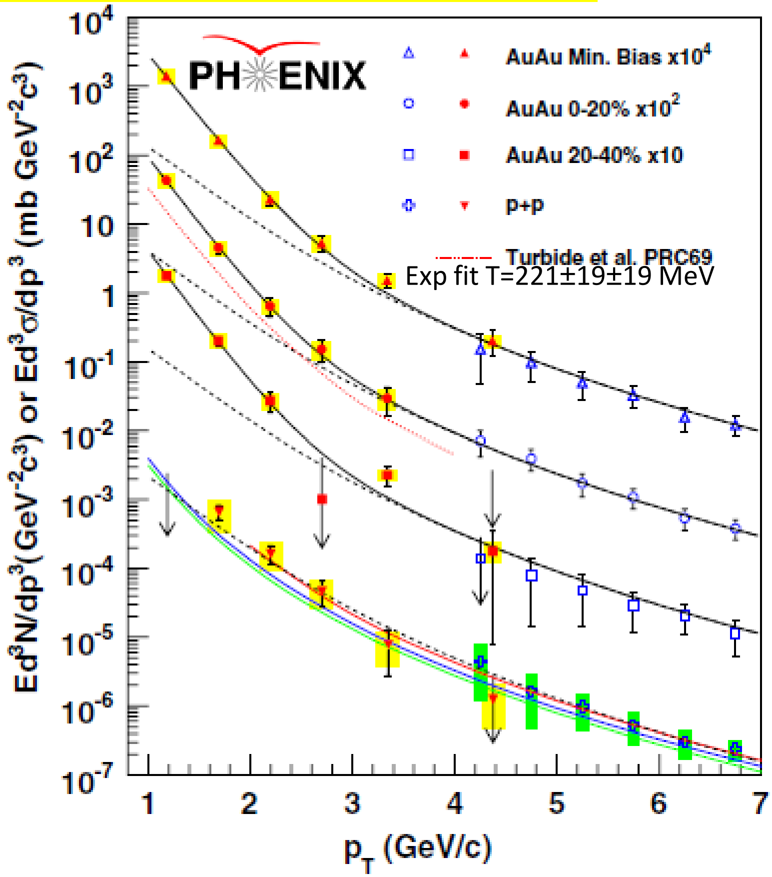
Probing QGP with Hard Probes



- Systematic study with different condition (T, μ) with various probe is required to *quantitatively understand properties of QGP*
- Both RHIC and LHC is needed to provide *sufficient leverage* in conditions and dynamic range of hard probes (p_T, mass, etc).
- RHIC, being flexible and dedicated machine, is essential for study of QGP

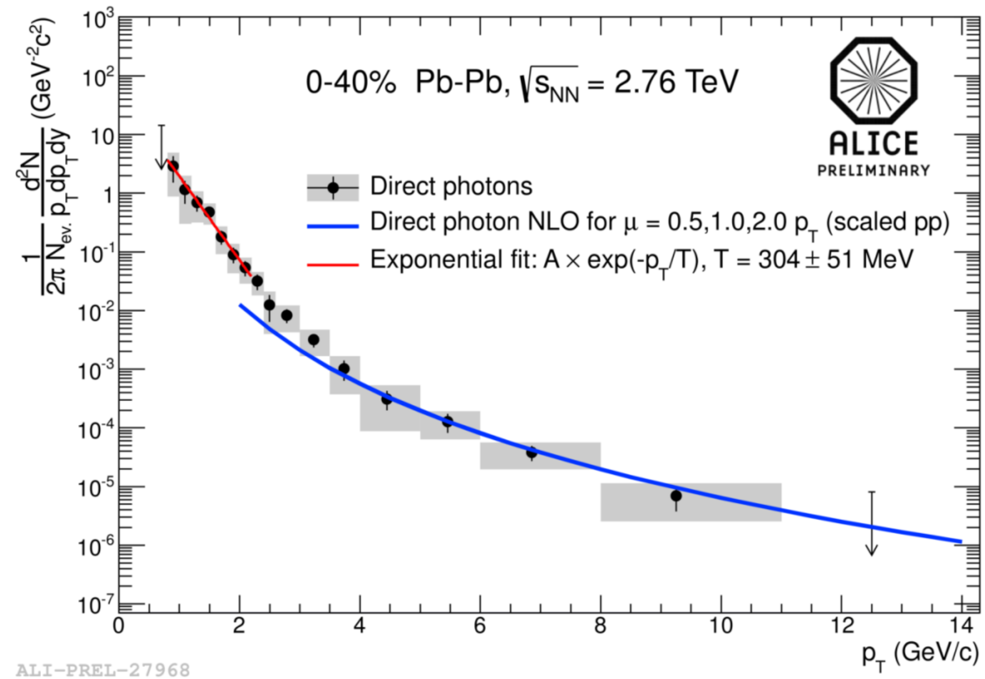
Thermal photons at RHIC and LHC

PHENIX PRC81, 034911 (2010)



- Strong enhancement of direct photons at low p_T at RHIC.
- Consistent with thermal radiation with initial temperature of 300-600 MeV

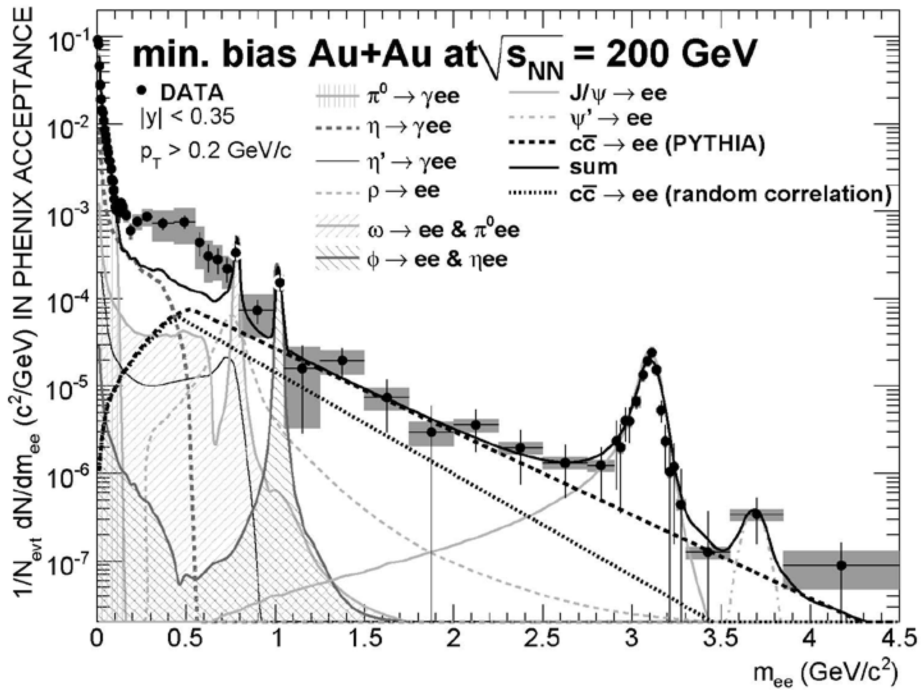
ALICE QM2012 preliminary



- Recently large enhancement of direct photons at LHC reported, consistent with higher initial temperature at LHC
- RHIC measurement has a factor of 2 to 3 better precision

Low mass dilepton enhancement

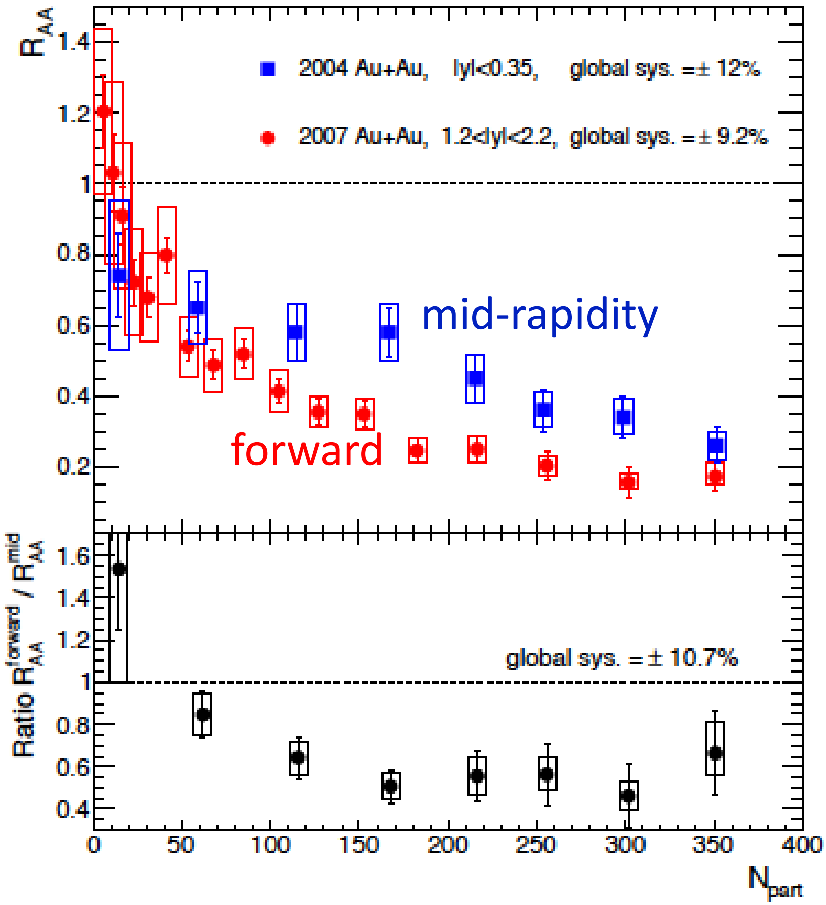
PHENIX PRC81, 034911 (2010)



- Strong enhancement of low mass dilepton seen by PHENIX
- STAR reported similar measurement at QM2012
- Related to chiral symmetry restoration (modified ρ)
- Unique measurement at RHIC
  - LM is one of the main physics goals of ALICE upgrade after 2018

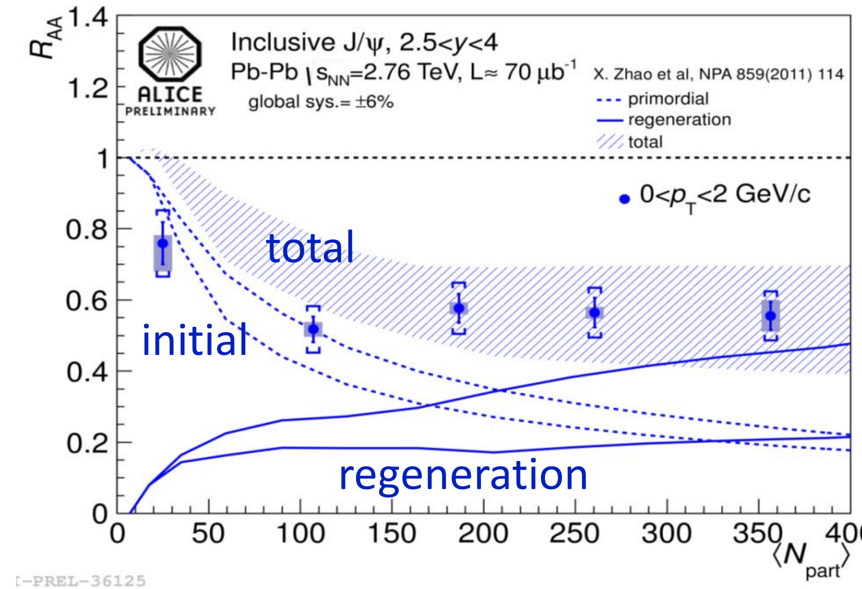
J/ψ measurements at RHIC and LHC

PHENIX PRL98,232301(2007),PRC84,054912 (2011)



- Strong suppression of J/ψ at RHIC seen by PHENIX
- Forward J/ψ more suppressed than mid-rapidity, challenging theory

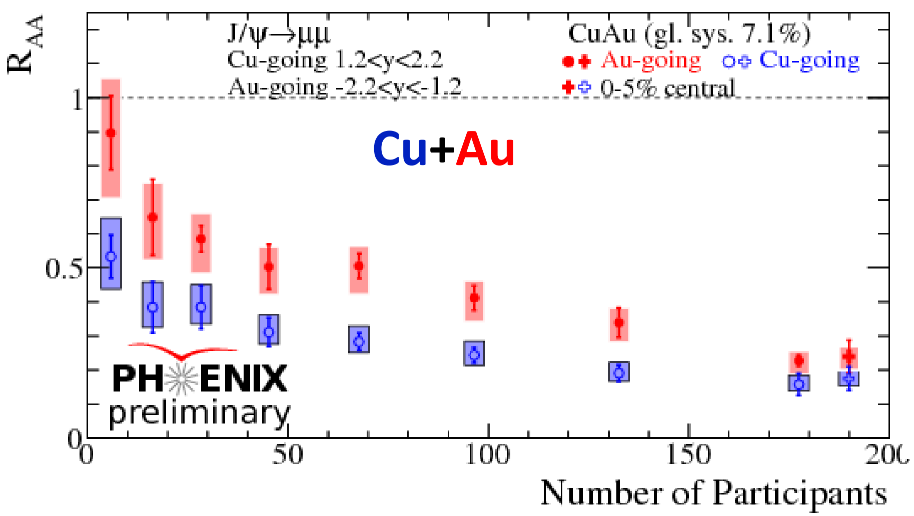
ALICE QM2012 preliminary



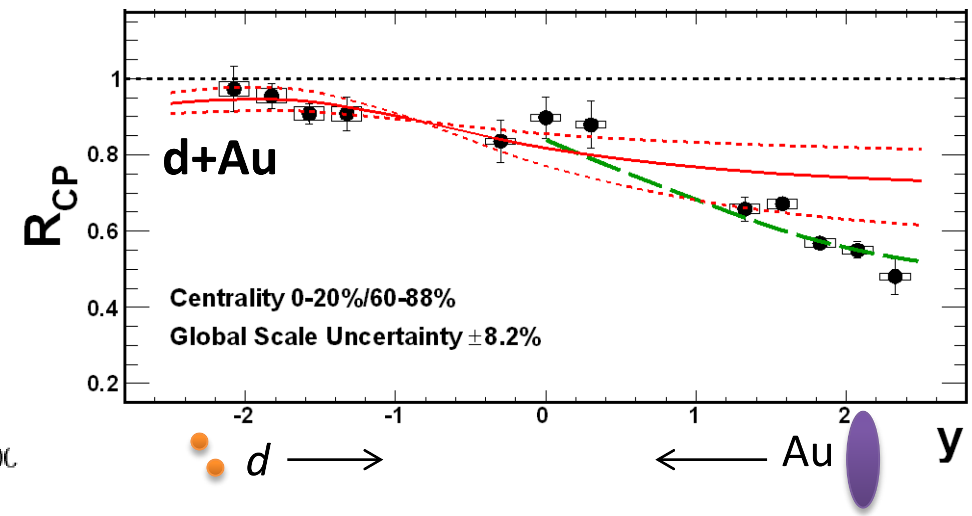
- J/ψ at LHC is less suppressed than RHIC in both mid- and forward rapidity
- In forward rapidity, high p_T J/ψ is more suppressed
- These features consistent with large contribution from re-generation of J/ψ via cc→ J/ψ

J/ψ in d+Au, Cu+Au, and low E at RHIC

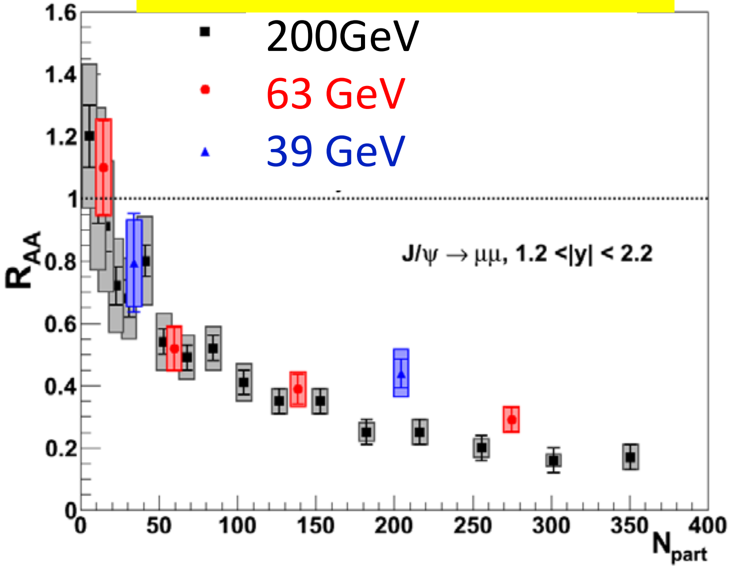
PHENIX QM2012 preliminary



PHENIX PRL107,142301(2011)



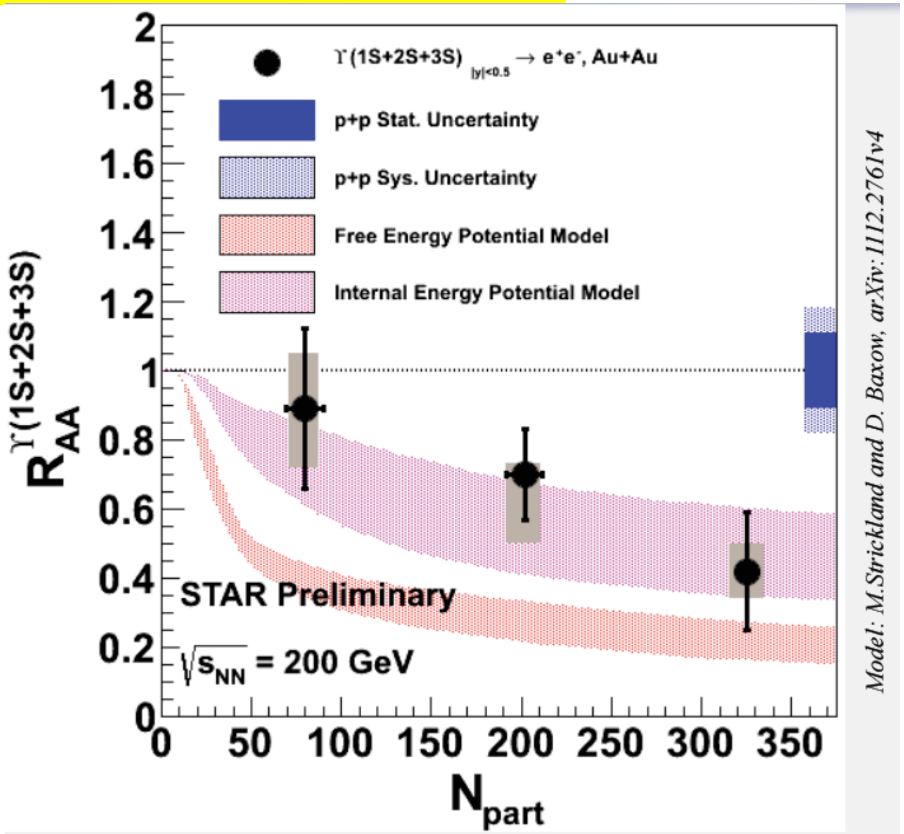
PHENIX arXiv:1208.2251



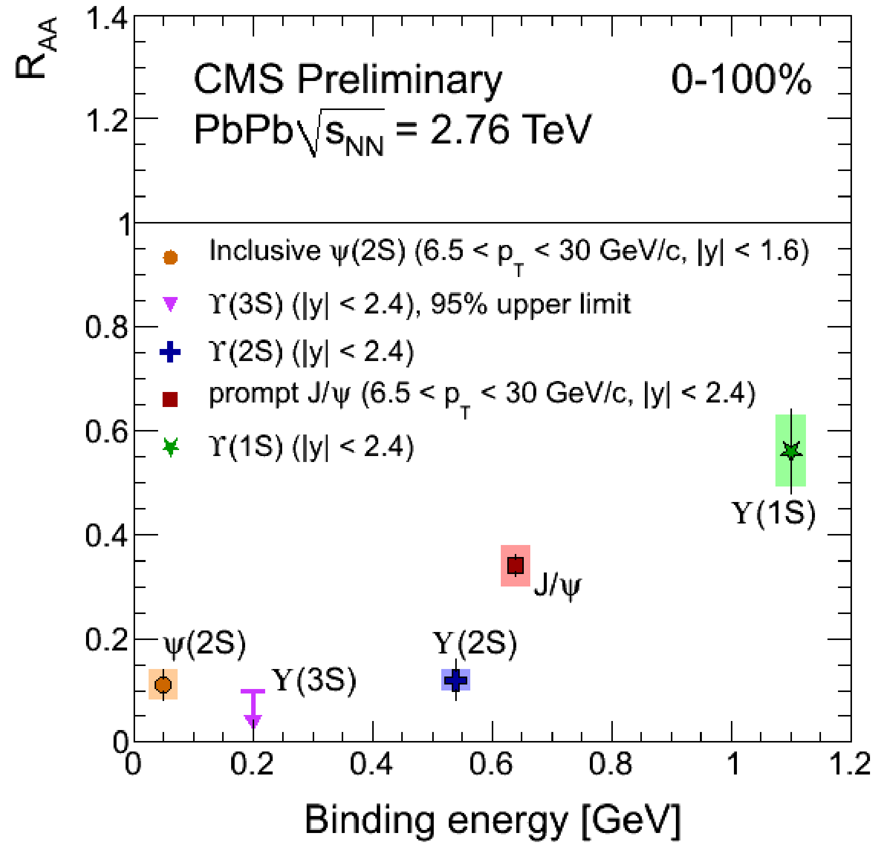
- Many competing effects (QGP suppression, Cold nuclear matter, regeneration , etc) contribute to J/ψ suppression
- It is important to make systematic study with various collision system and beam energy
- RHIC, being a very flexible and dedicated machine with high luminosity, allows systematic study of J/ψ suppression.

Upsilon suppression at RHIC and LHC

STAR QM2012 preliminary



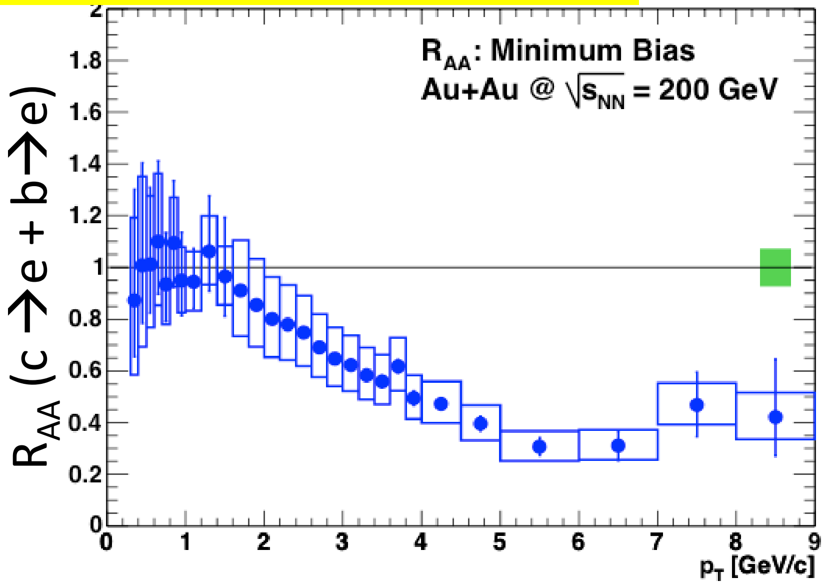
CMS QM2012 preliminary

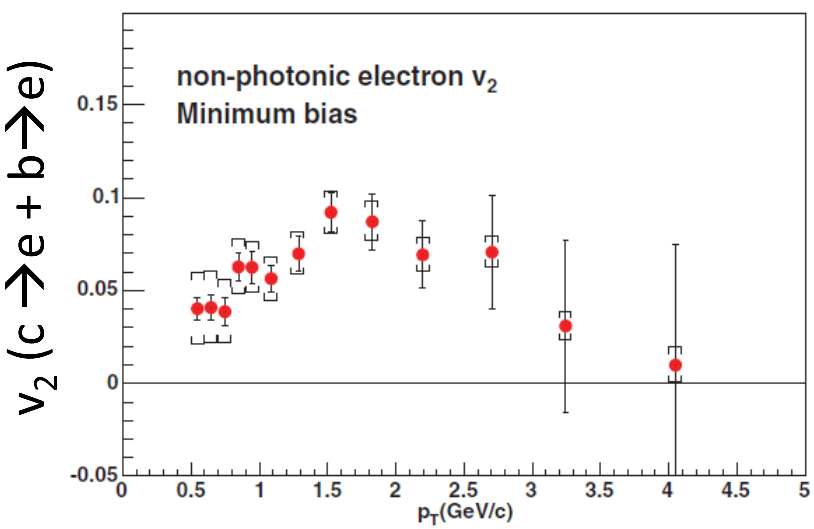


- Superior data of Upsilon from LHC
- The suppression pattern consistent with Binding energy.
- Similar data can be achieved at RHIC with sPHENIX upgrade and MTD upgrade of STAR

Heavy quark suppression and flow: Discovery

PHENIX PRL98,172301 (2007)
PRC84,044905(2011)



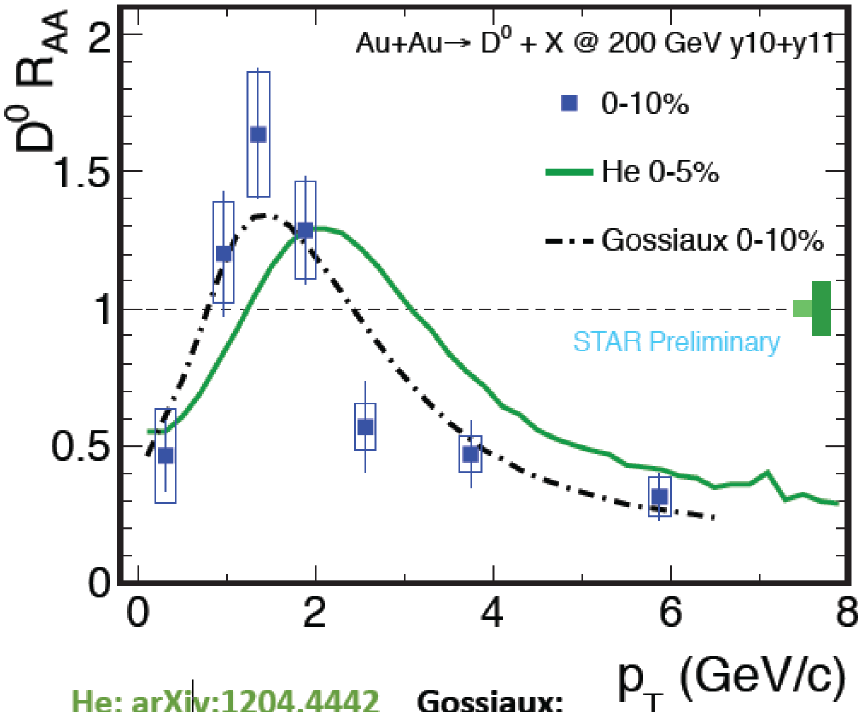


- Single electrons from heavy quark decay are suppressed and flow.
- Highest cited RHIC paper after 2006, ~400 cites
- Before the data, it was believed that suppression is small for heavy quark
- The data provide mass dependence of the interaction of quark with the QGP medium
- Charm and bottom were not separated in these measurement

→ Need of Silicon trackers

Charm Suppression at RHIC and LHC

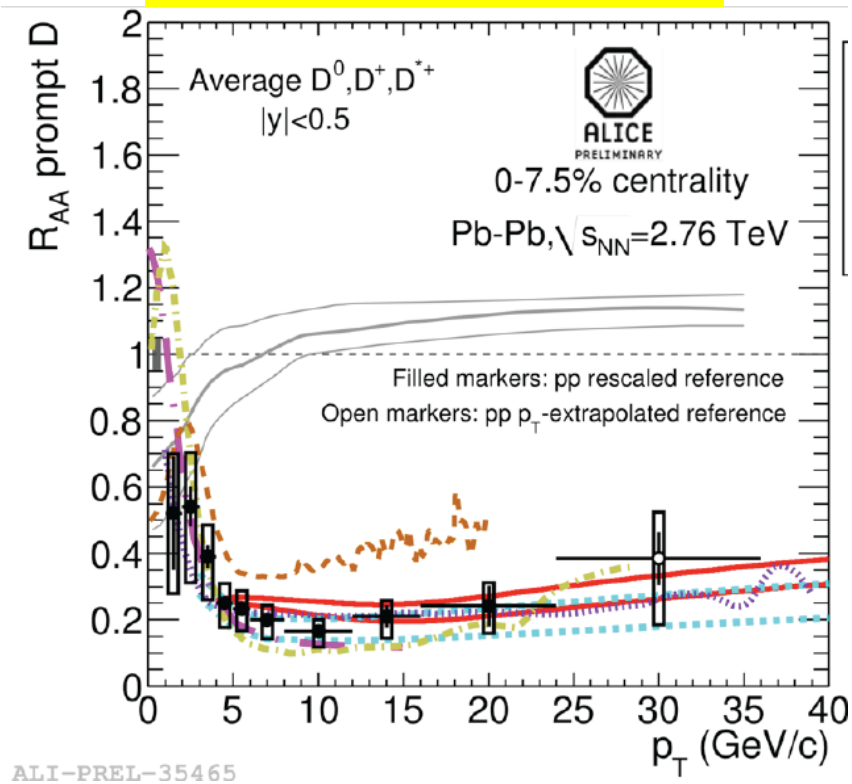
STAR QM2012 preliminary



He: arXiv:1204.4442
Focker-Planck

Gossiaux:
arXiv:1207.5445

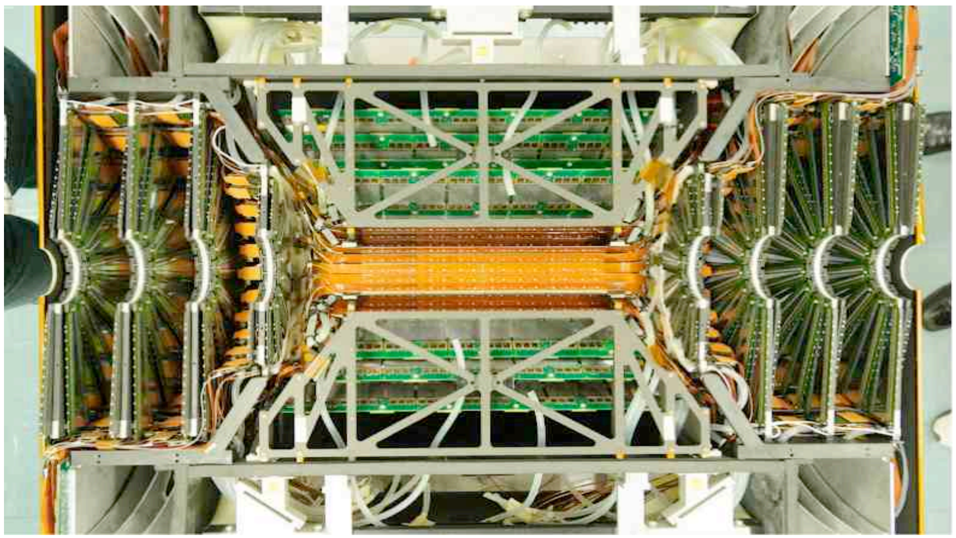
ALICE QM2012 preliminary



- Heavy quark is hot topic. Many presentations in QM2012 from RHIC/LHC
- Strong charm suppression and flow in QGP are confirmed at LHC
- RHIC and LHC measurements are complementary
- At low p_T, R_{AA}(D @RHIC) > R_{AA}(D @ LHC).
- RHIC measurement covers low pT where QGP properties are concentrated

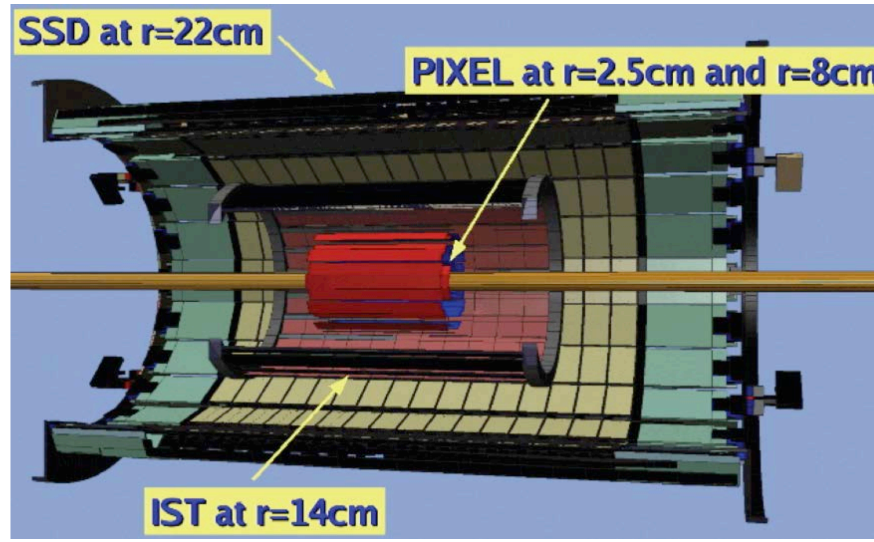
Precise Heavy quark measurement with silicon tracker upgrades at RHIC

PHENIX VTX + FVTX



- VTX (DOE $4.7M + RIKEN(~$4-5M))
  - Completed under budget in 2010
  - Taking data since RUN11
  - First results in QM2012
- FVTX (DOE $4.9M)
  - Completed in 2011
  - Started taking data in RUN12

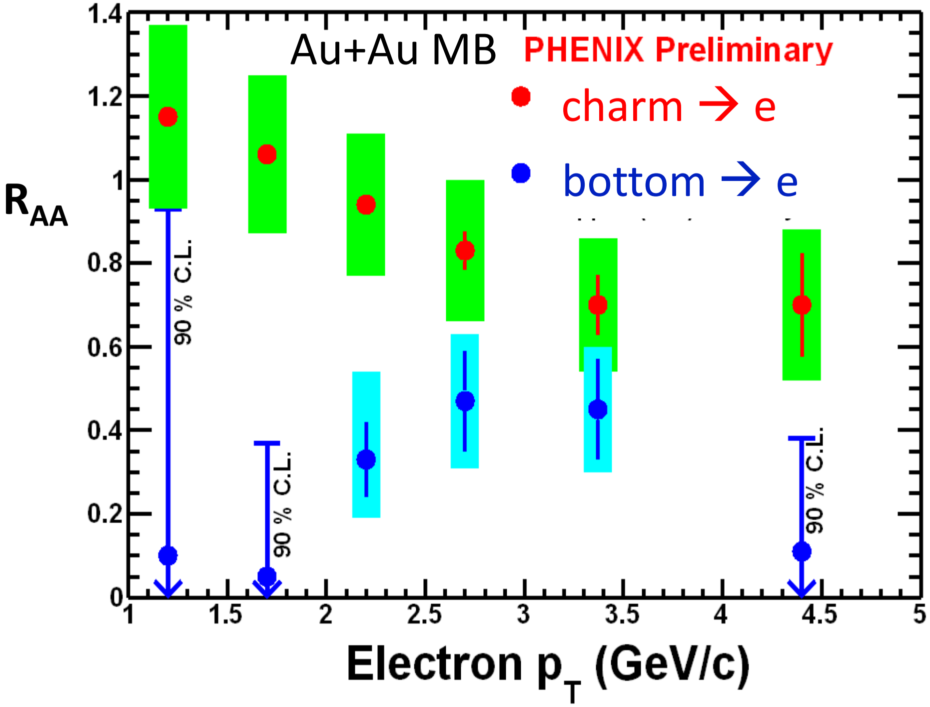
STAR HFT



- HFT (DOE $16M)
  - Construction well underway
  - Engineering run with partial installation in RUN13
  - Start taking data with full detector in RUN14

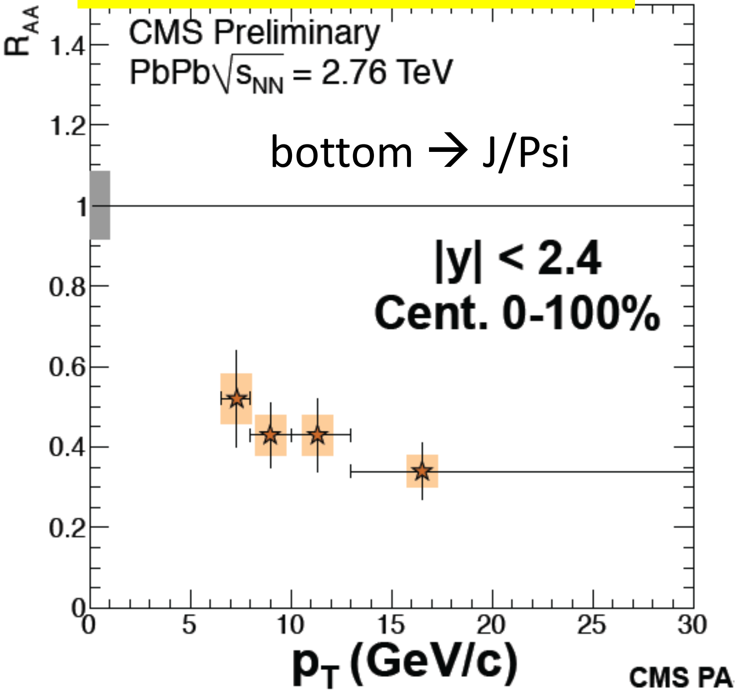
Bottom measurements at RHIC and LHC

PHENIX QM2012 preliminary



First result of R_{AA} of b→e and c→e with VTX

CMS QM2012 preliminary



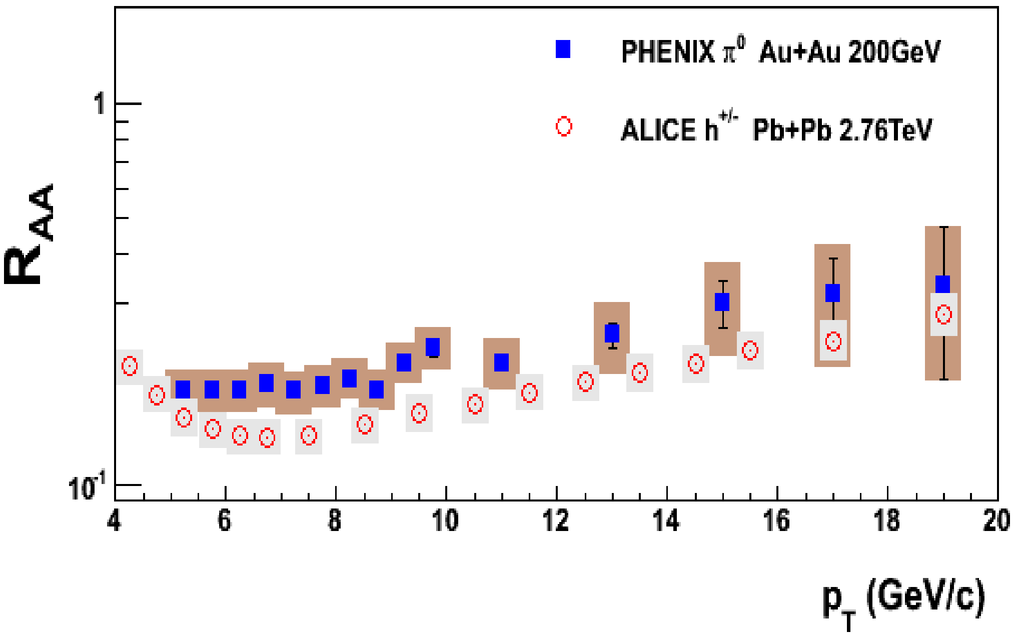
R_{AA} of J/Psi from b decay

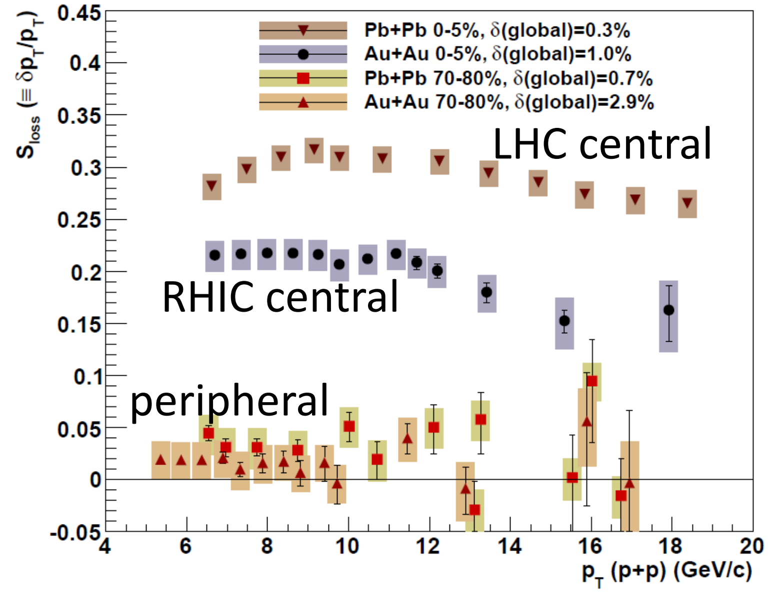
- Suppression of bottom by factor of ~2 seen both at RHIC and LHC
- These measurements are possible only with silicon trackers
- RHIC data covers low p_T region where QGP effects are concentrated
- RHIC results show $R_{AA}(b)<R_{AA}(c)$, doesn't follow simple mass hierarchy
- This is a main physics topic in the coming years. More data are coming

Energy loss at RHIC and LHC

PHENIX arXiv:1208.2254

ALICE PLB696,301(2011)





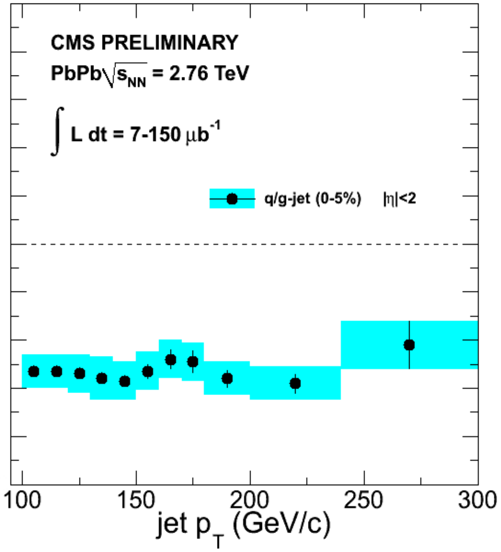
Fractional energy loss deduced from R_{AA}

- R_{AA} increase at high p_T at RHIC and LHC
- R_{AA}(LHC)<R_{AA}(RHIC) at the same p_T, indicating stronger energy loss
- Fractional energy loss deduced from R_{AA} is higher at LHC

→ Hard probes see difference in medium property at RHIC and LHC

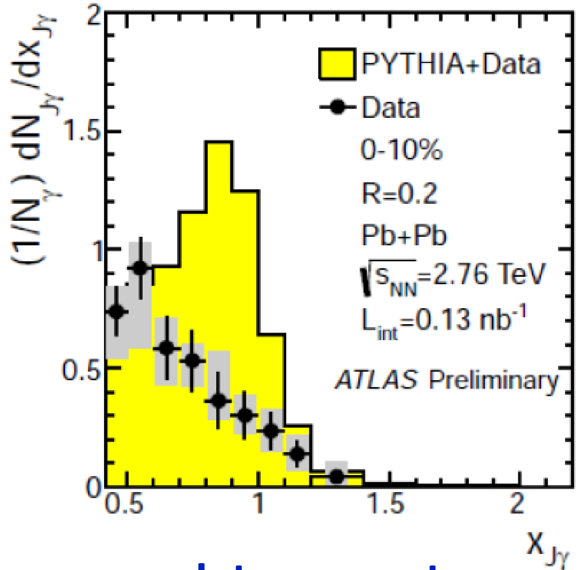
Direct measurements of Jets at LHC

CMS QM2012



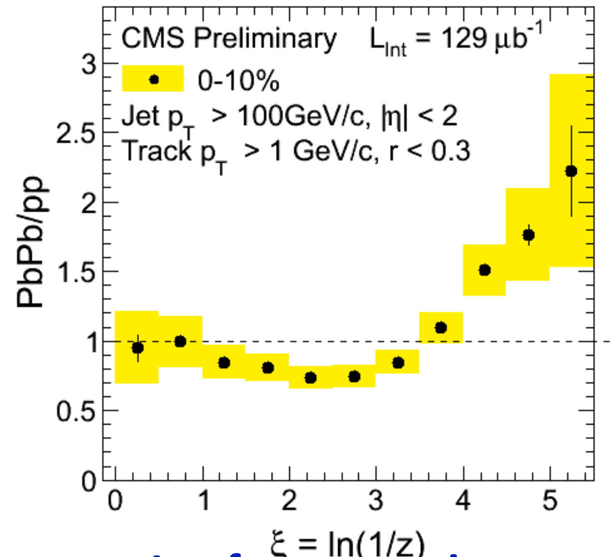
Jet R_{AA}

ATLAS QM2012



γ-Jet asymmetry

CMS QM2012



Jet fragmentation

- LHC demonstrated that direct jet measurement in heavy ion collision is possible.
- Rich data on reconstructed jets at LHC from ATLAS and CMS
  - R_{AA}, v_2, Jet-Jet, γ-Jet, Z/W-jet, Jet fragmentation, etc
- Similar measurement at RHIC requires a new capability

Why measure jets at RHIC

- The textbook 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

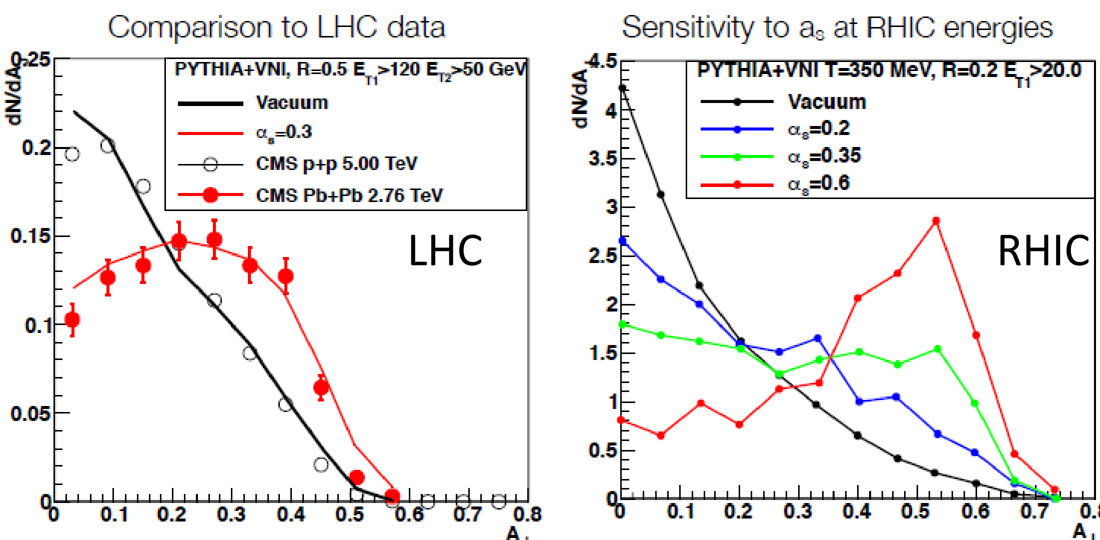
- Jet measurements at RHIC are essential to answer this question
  - Probe QGP near 1-2 T_c where the coupling is the strongest
  - Cover lower p_T range of parton where QGP effects are concentrated
- Measurements of jets only at LHC leave this question with an incomplete answer.

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

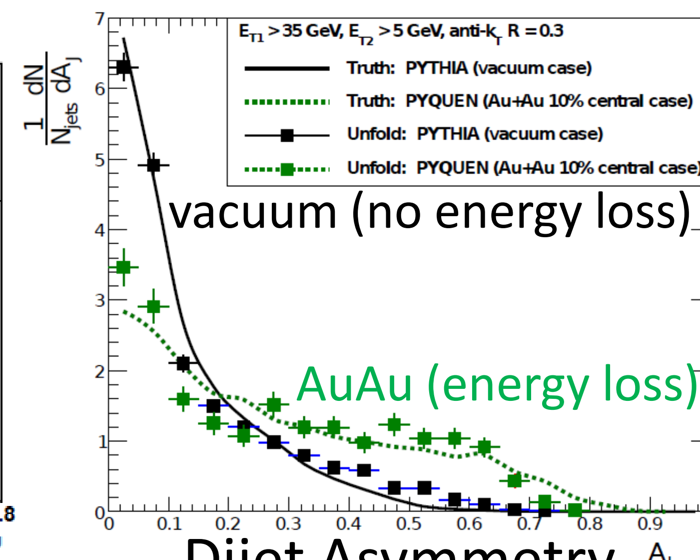
X.N. Wang taking the photo

Coleman-Smith Calculation



Dijet Asymmetry

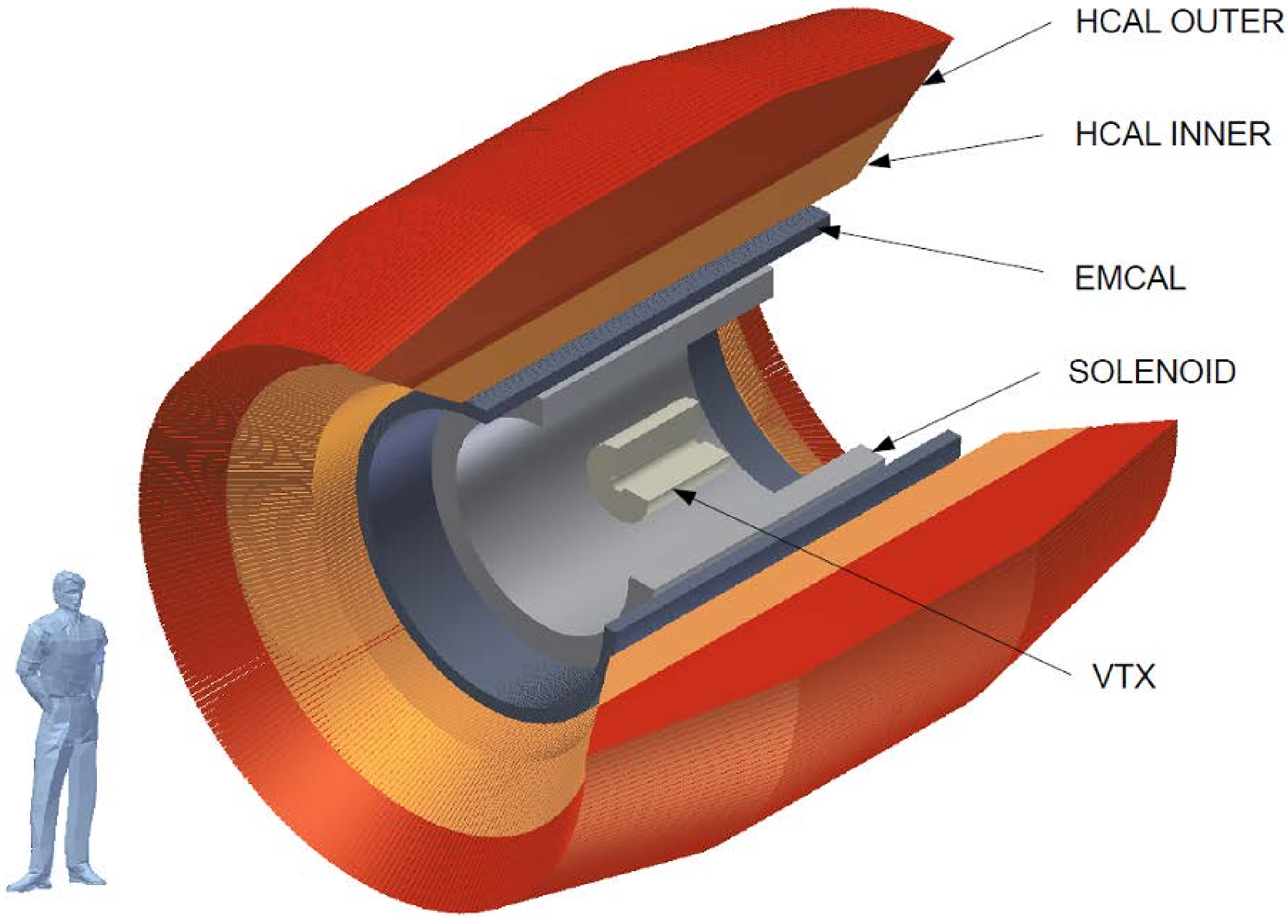
sPHENIX Simulation



Dijet Asymmetry

Larger jet asymmetry expected at RHIC than LHC and can be measured at RHIC

sPHENIX: jet detector at RHIC



- Proposal submitted to BNL (~$25M) for sPHENIX July 1, 2012
- Details available at http://arxiv.org/abs/arXiv:1207.6378
- BNL internal review scheduled on October 5-6, 2012

The sPHENIX concept

Design a major upgrade to PHENIX to address fundamental questions about the nature of the strongly coupled QGP near T_c at RHIC

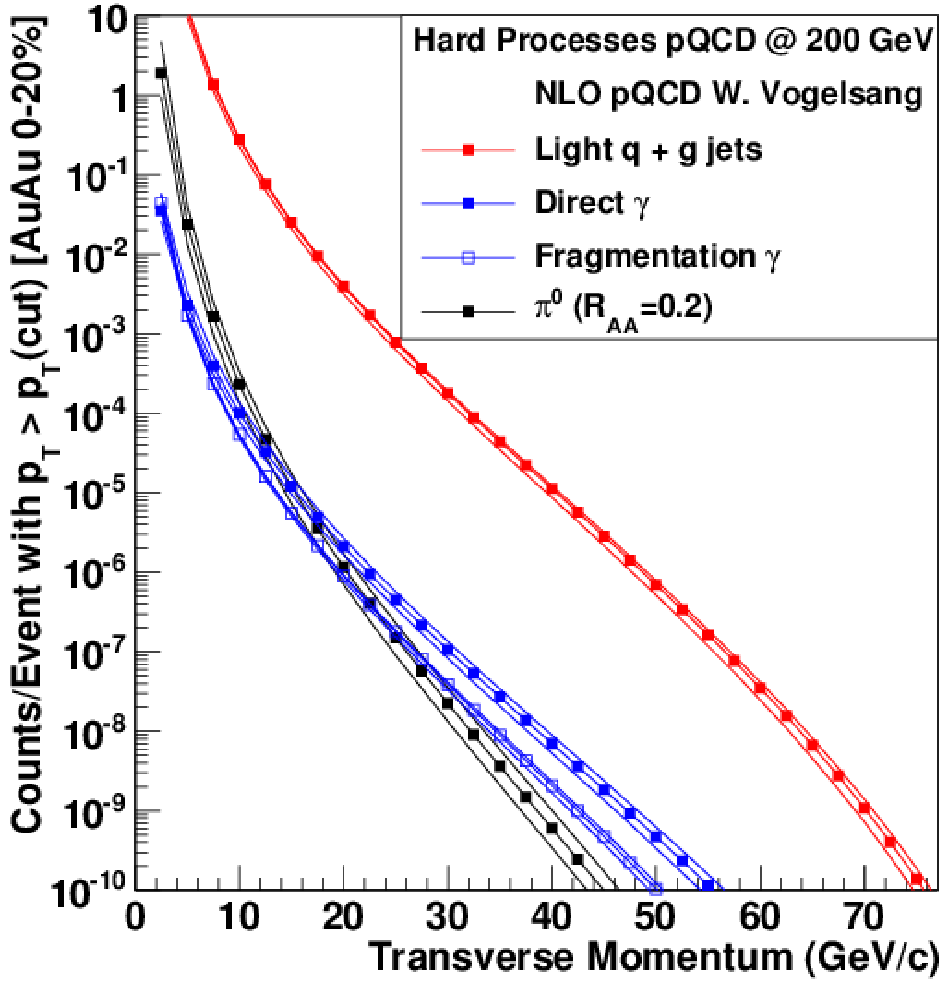
- Emphasizes jet physics observables with calorimetry initially
- Provides a solid platform for future upgrades and enhancements
- Takes advantage of the luminosity improvements due to stochastic cooling and the wide range of species and energies available at RHIC
- Designed around new technologies that enable a more compact detector, and reuses as much of the PHENIX infrastructure as possible, both helping to keep costs down

Jet rates at RHIC

- Even at present RHIC luminosity, we would have
  10^6 jets(p_T>30 GeV)/year
  in 0-20% central Au+Au
- 80 % of them are di-jet in sPHENIX acceptance

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

Per year (20 weeks DAQ) jet and γ rate)

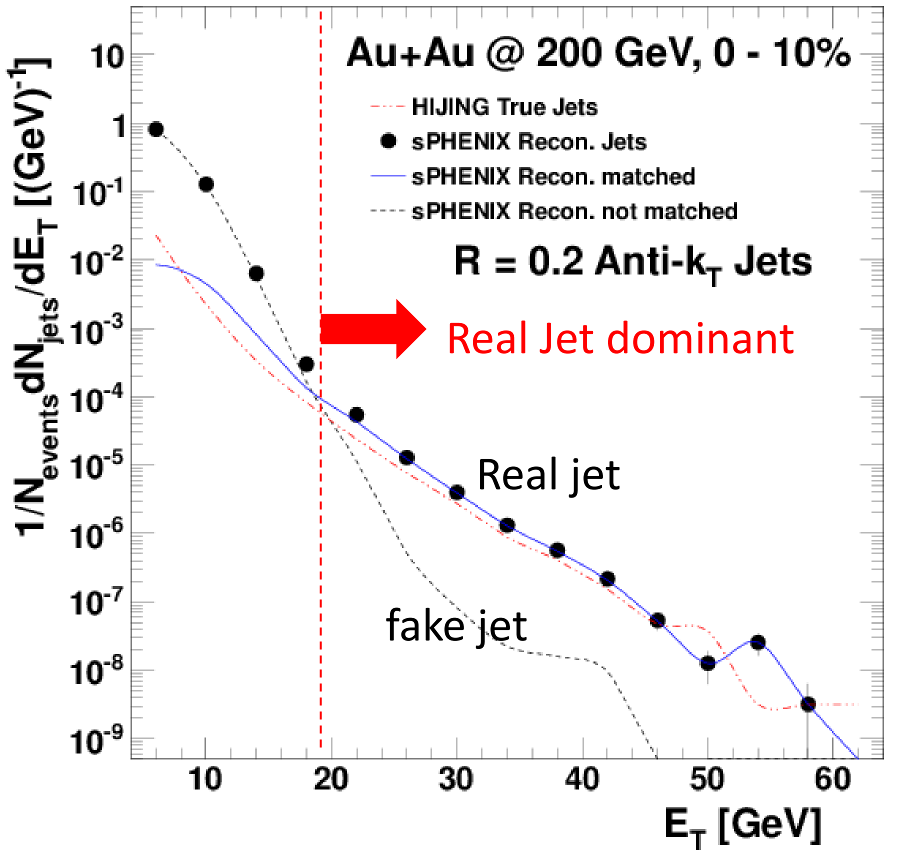


Fake jets

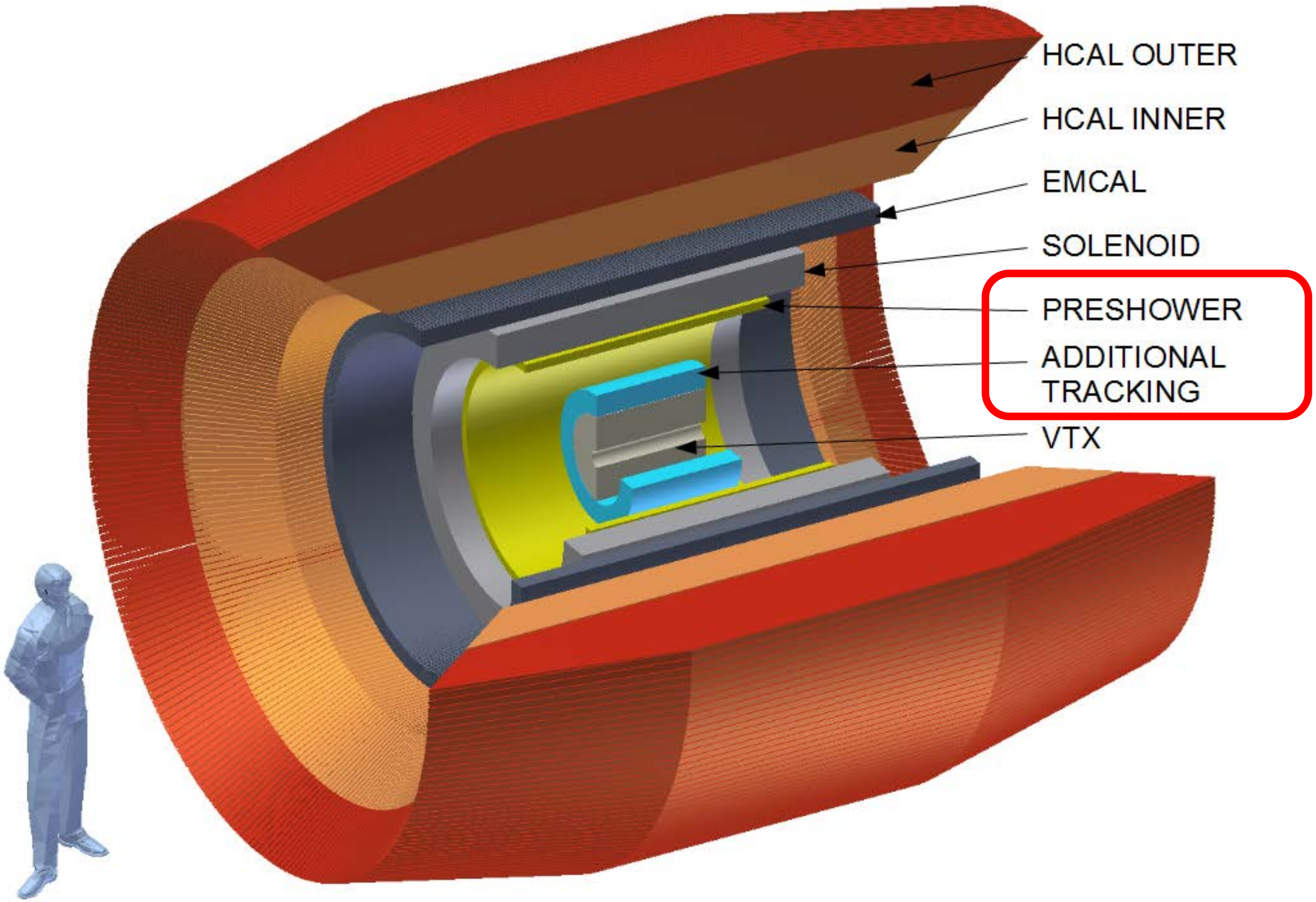
- Using 750M minimum bias HIJING events
- S/B ratio of true jets becomes greater than 1 for p_T > 20 GeV/c
- Details published on August 10 as

Hanks et al.,

PRC86,024908 (2012)



sPHENIX upgrade path



- Additional Tracking → heavy quark jets, modification of jets
- Preshower → γ-jet, upsilon

Strong interest from Japan to add these additional subsystems

International interest in hard probe measurements at RHIC

- Original PHENIX detector

EMCal: Russia, Germany	pi0, direct photon, W
RICH: Japan	e, J/ψ, ee pair
Muon arm: Japan, France, Korea	muon, J/Psi

- PHENIX upgrades (completed)

Muon trigger: Japan	W
VTX: Japan	heavy quark

- STAR upgrades (completed)

Barrel EMCal: Russia	e, J/ψ, pi0
FMS: Croatia, Russia	forward pi0
TOF: China	e, ee pair

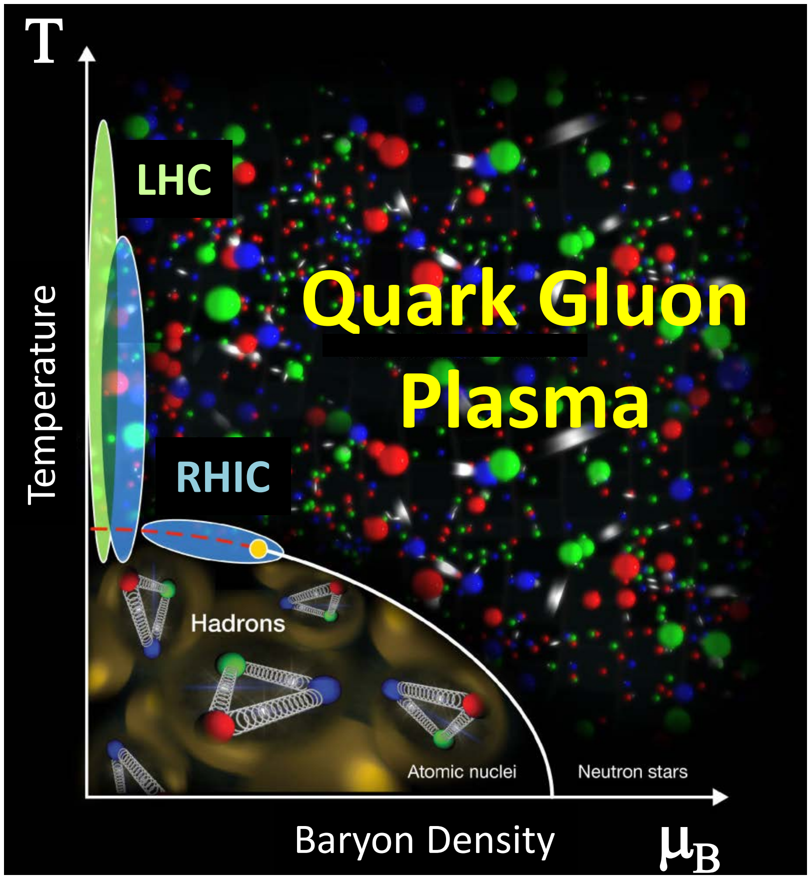
- sPHENIX (upgrade)

additional tracker: Japan	heavy quark, jet fragmentation
additional preshower: Japan	Upsilon, direct photon, pi0

- STAR upgrades

HFT: China, France	heavy quark
MTD: China, India	Upsilon

Summary



- Hard Probes (EM radiation, Quarkonia, Heavy Quarks, and Jets) are important for quantitative study of QGP propeties
- Both RHIC and LHC are needed to quantitatively understand the property of QGP
- In coming years RHIC measurements with Hard probes, in particular Heavy Quark and Low P_T EM probes are competitive with and complementary to LHC
- sPHENIX upgrade will provide good jet measurement capability to RHIC. This is complementary to LHC and essential for further study of properties of QGP