Physics with Hard/Heavy Probes at sPHENIX/RHIC
and Non-MIE Pre-Shower Detector

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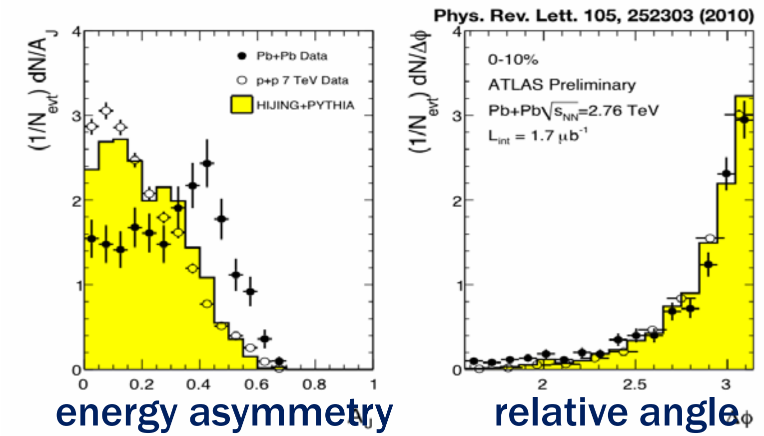
s/ePHENIX Workfest at RIKEN

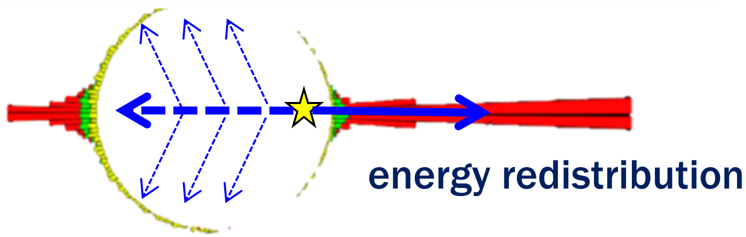
Presentation Outline

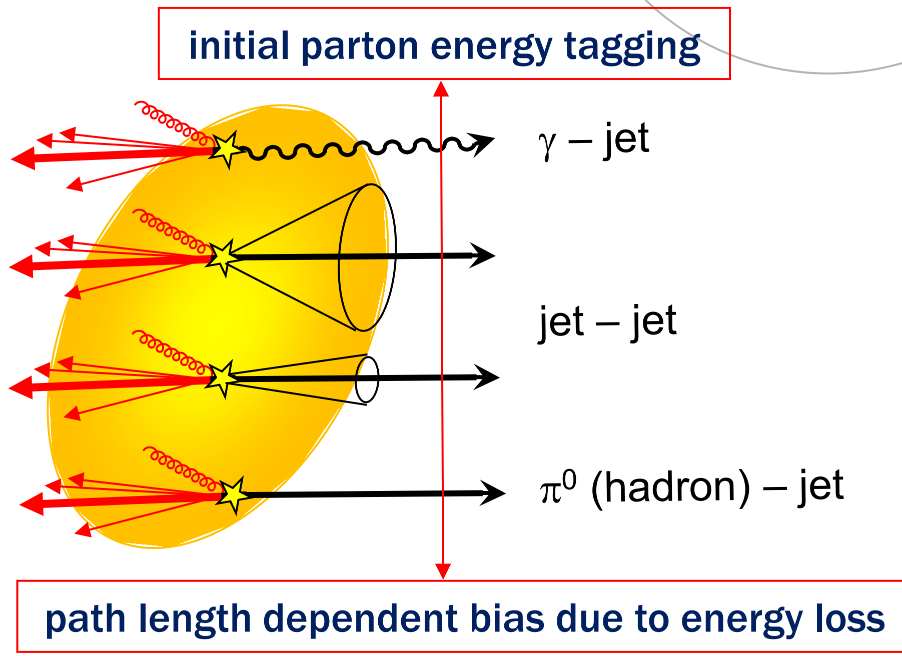
- highlights via hard/heavy probes (mostly) at LHC
  - *e.g.* parton energy loss and redistribution
    - parton initial energy tagging
- hard/heavy probes at RHIC: sPHENIX
- physics prospects of sPHENIX with inner detectors
  - *e.g.* flavor differential energy loss and redistribution
  - *e.g.* QCD Debye screening
- pre-shower detector
- sPHENIX-J activities and prospects
- summary

Insight into Quark-Gluon Plasma

- via high p_T probes, *e.g.* jets, photon–jet correlation



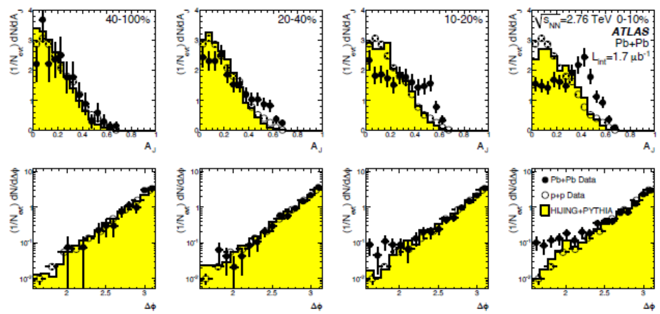




- recent highlights include:
  - energy loss/redistribution of hard scattered parton
  - photon–jet correlation: parton initial energy tagging

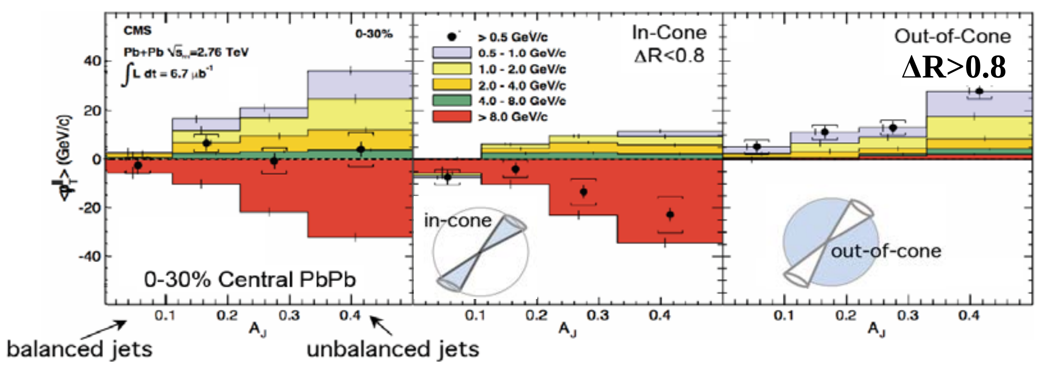
Jets at the LHC

- asymmetric di-jets and even mono-jets



ATLAS

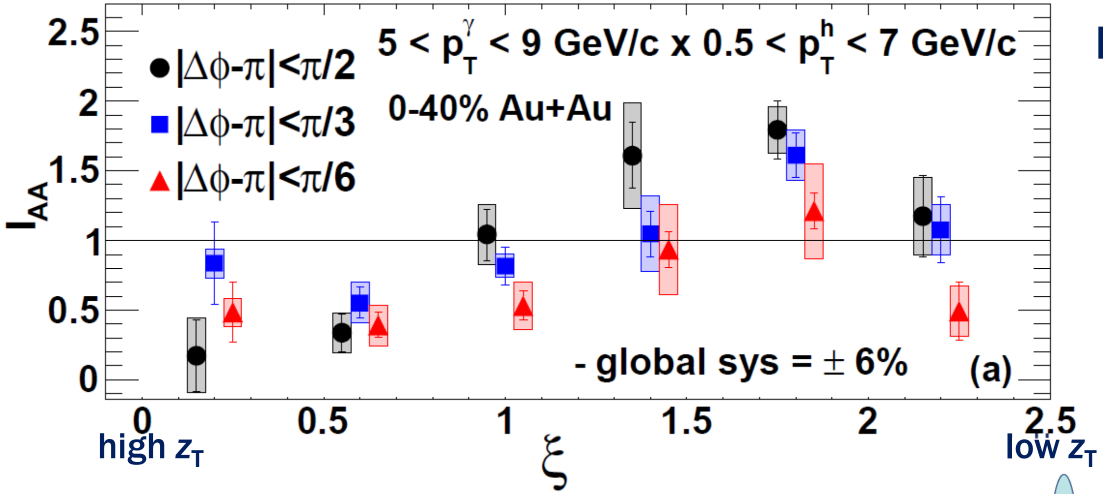
- lost jet energy distributed very widely



CMS

  - $\Delta R > 0.8 \sim \pi/4$
  - enhancement at low p_T

Jet Energy Loss and Redistribution

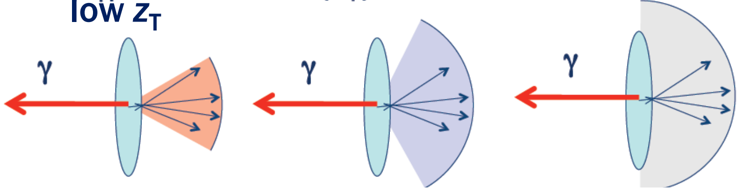


PHENIX

$$I_{AA} = \frac{\text{yield in Au+Au}}{\text{yield in p+p}}$$

$$\xi = \ln(1/z_T)$$

$$z_T = p_T^{hadron}/p_T^{photon}$$

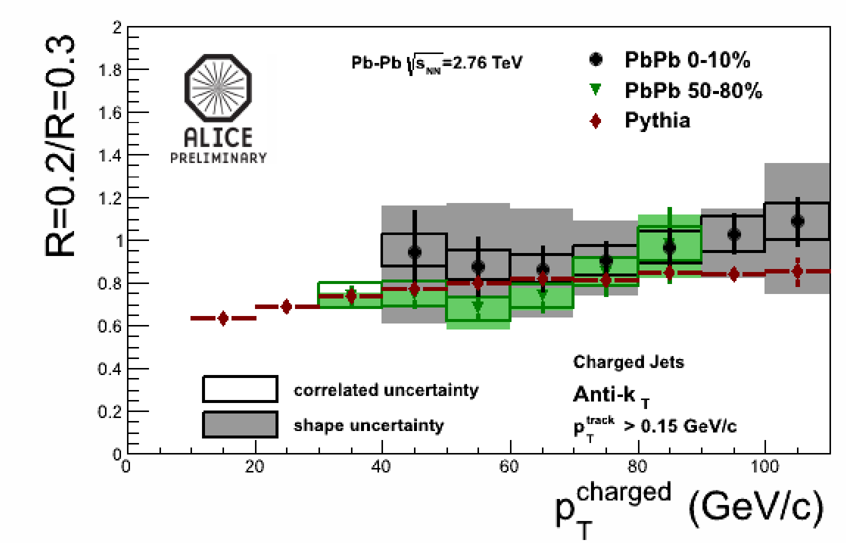


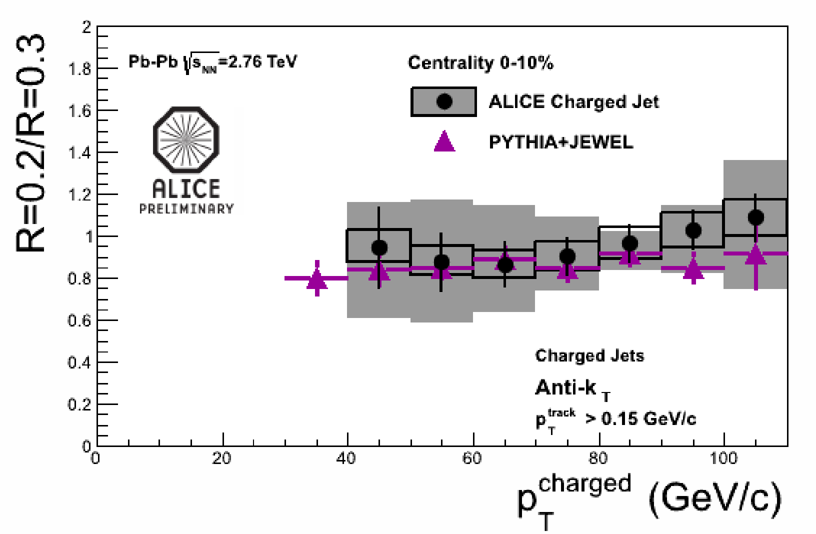
$|\Delta\varphi-\pi| < \pi/6$ $|\Delta\varphi-\pi| < \pi/3$ $|\Delta\varphi-\pi| < \pi/2$

- high z_T suppression in narrow cone
  - no corresponding enhancement at low z_T
- low z_T enhancement in wider cone

Survived Jets

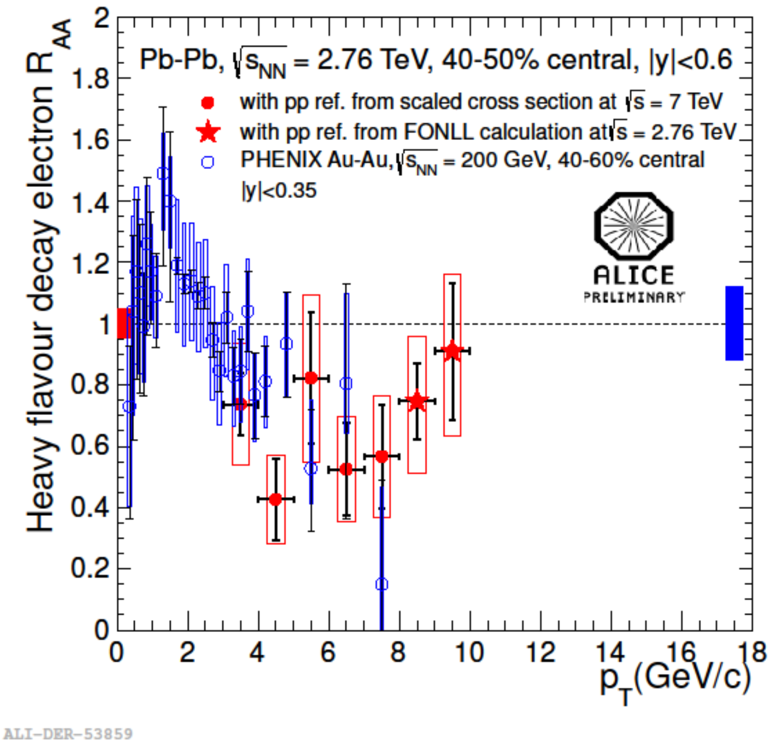
- $\sigma(R=0.2)/\sigma(R=0.3)$ consistent with vacuum jets
  - both for peripheral and central collisions
- no sign of jet broadening
- good agreement with a model with energy loss





PID'ed Singles for Flavor Differential

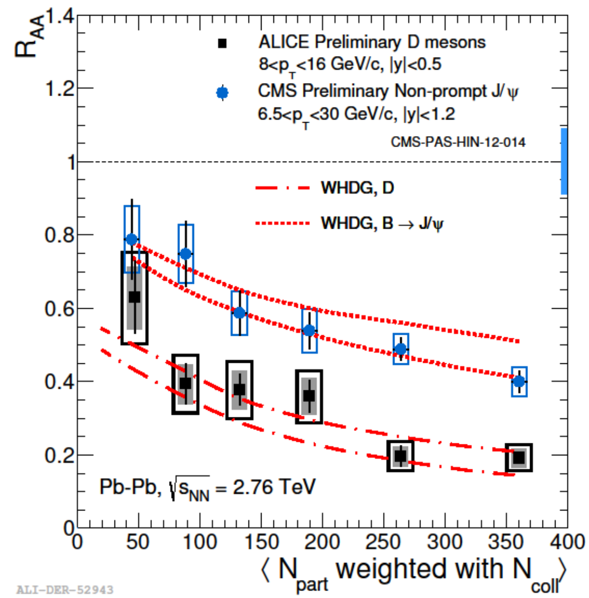
- PHENIX and ALICE heavy flavor results consistent
  - charm+beauty decay electrons in semi-central collisions



- next step: charm/beauty separation

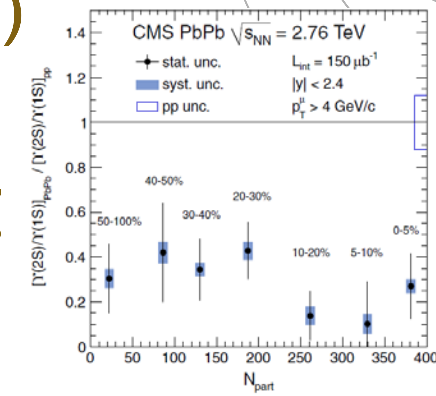
Possible Mass Hierarchy

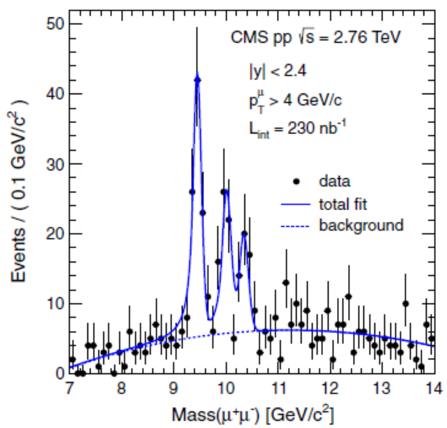
- charm and beauty mesons with compatible $<p_T>$
  - open charm (average of D^0, D^+, D^{*+}), ALICE
  - non-prompt J/Ψ ($\leftarrow$ B), CMS
- indication of lower suppression of beauty
  - *cf.* PHENIX VTX result?

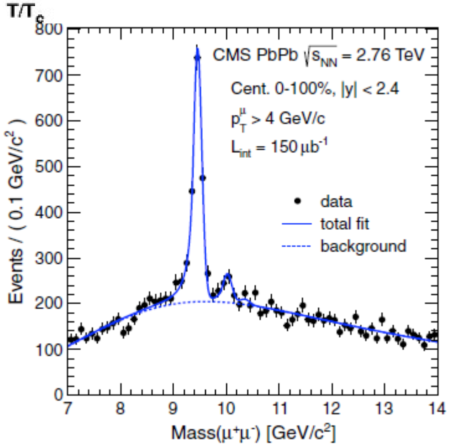


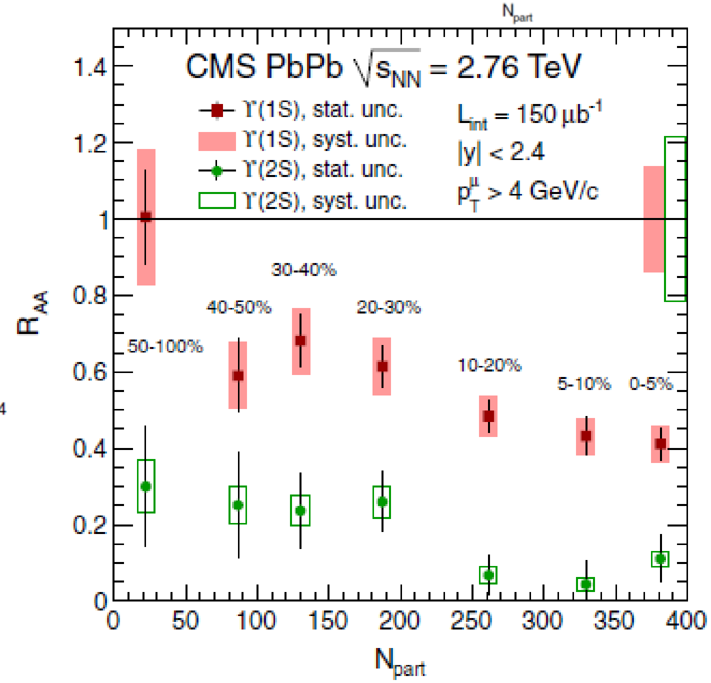
Quarkonia – Sequentially Melting?

- Υ(2S) more suppressed than Υ(1S)
  - – Υ(3S) even more suppressed
- no signature of sequential melting
- (feed down uncorrected)





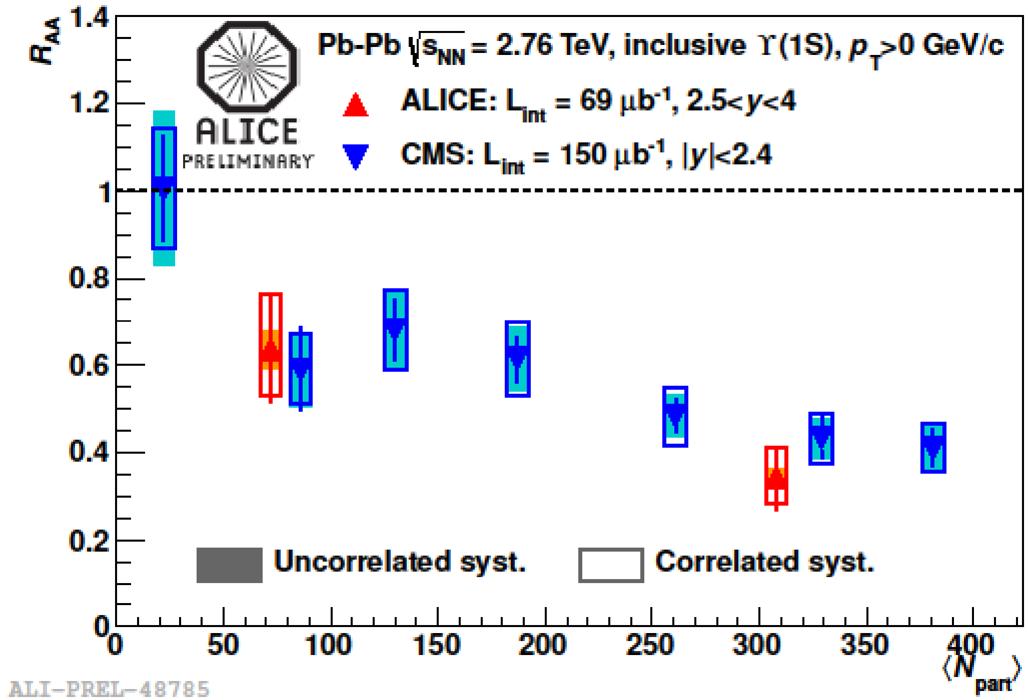




CMS, PRL 109, 222301 (2012)

Forward Upsilons at ALICE

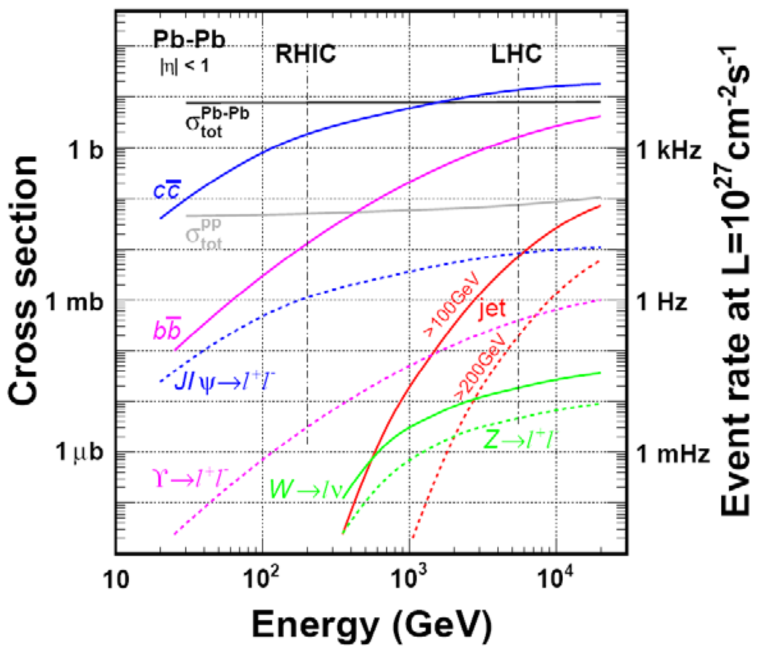
- forward Υ at ALICE ~ mid-rapidity Υ at CMS
  - for both central and semi-peripheral collisions



- further systematic ALICE results awaited

Hard/Heavy Probes at LHC vs. RHIC

- original sales points at higher energies
  - demonstrated very powerful at ALICE/ATLAS/CMS



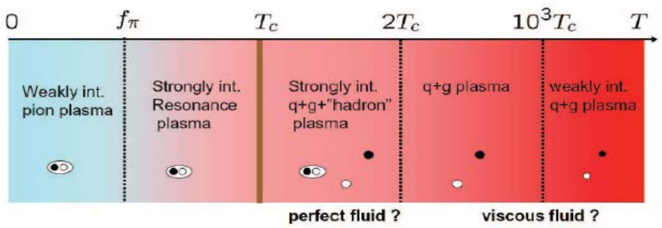
parameter	unit	enhanced design	achieved 2010	next upgrade $\geq$2012
			Au-Au operation	
particle energy E	GeV/n		— 100 —	
no of bunches N	...		— 111 —	
bunch intensity N_b	...	1.1	1.1	1.0×10^9
IP envelope function β^*	m	1.0	0.75	0.5
norm. rms emittance ϵ_n	mm·mrad	2.5	2.8	2.5
rms bunch length σ_s	m	0.3	0.3	0.3
hourglass factor h	...	0.96	0.93	0.88
beam-beam parameter ξ/IP	10^{-3}	1.6	1.5	1.5
peak luminosity L_{peak}	$cm^{-2}s^{-1}$	36	40	55×10^{26}
average luminosity L_{avg}	$cm^{-2}s^{-1}$	8	20	40×10^{26}
average polarization P	%		———	
calendar time in store	%	60	53	55
integrated L per week	...	300	650	1300 μb

W.Fischer, IPAC'10

- RHIC luminosity upgrade to give new opportunities
- more flexibility with EBIS and beam cooling

RHIC/LHC from Heavy Ion Viewpoint

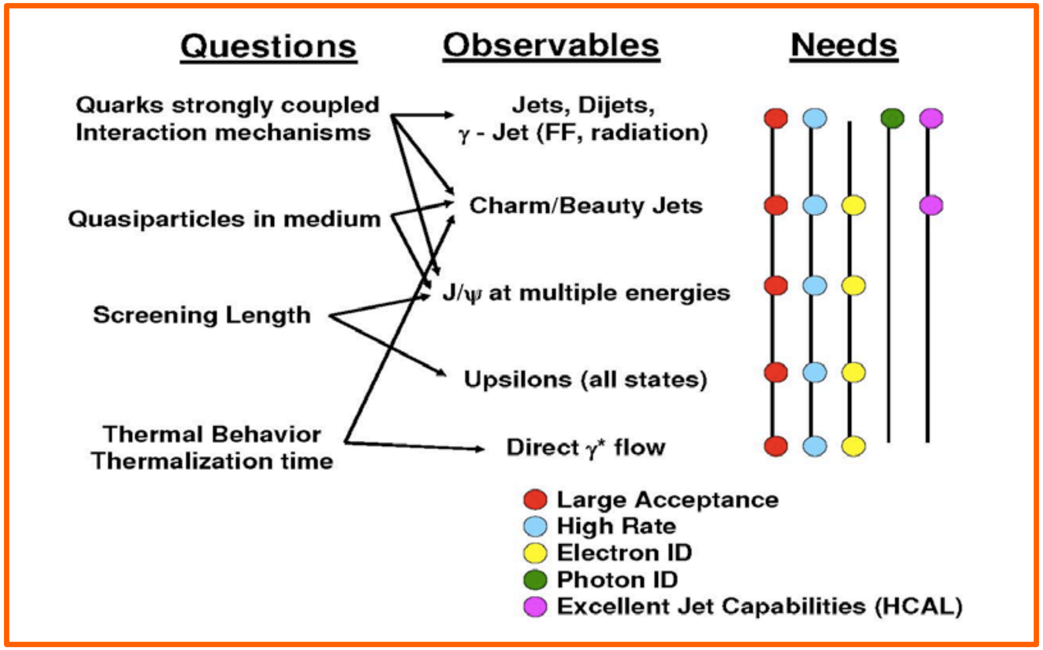
- highest energy ≠ optimum physics condition
- RHIC： dedicated to heavy ion (and spin) programs
  - wide collision energy range
    - ~10 < $\sqrt{s_{NN}}$ < 200 GeV
    - phase boundary; transition regime



  - variety of collision systems including asymmetric
    - Au+Au, Cu+Cu, U+U, Cu+Au, *d*+Au, *p*+*p*（, *p*+Au, ...）
  - high luminosity
    - average 30 × 10^{26} cm^{-2}s^{-1}（2011, Au+Au 200 GeV）
    - *cf.* LHC peak 5 × 10^{26} cm^{-2}s^{-1}（2011, Pb+Pb 2.76 TeV）
  - good time allocation for heavy ion program
    - ave. 9.6 weeks (+ ave. 7.0 weeks of *p*+*p*) /year (runs 1–13)

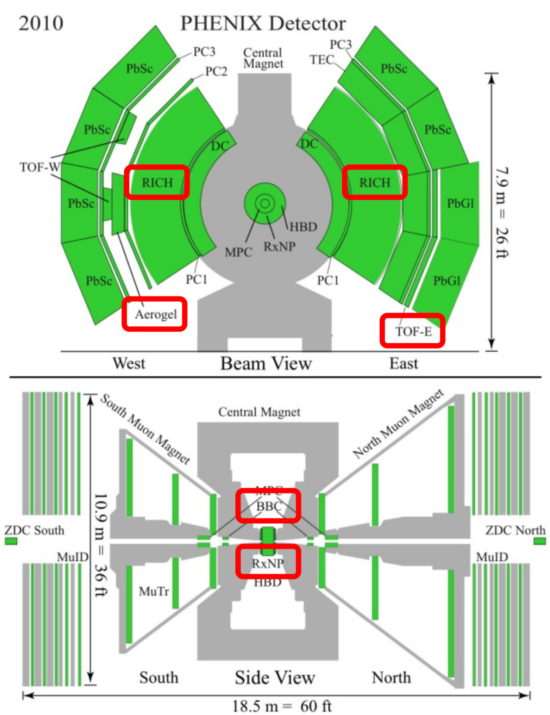
Strategy Feedback from LHC to RHIC

- high p_T probes
- large acceptance
- high luminosity
- full jet reconstruction
  - electro-magnetic + hadronic calorimeters
- fast data collection
- $e^{\pm}$ and γ ID

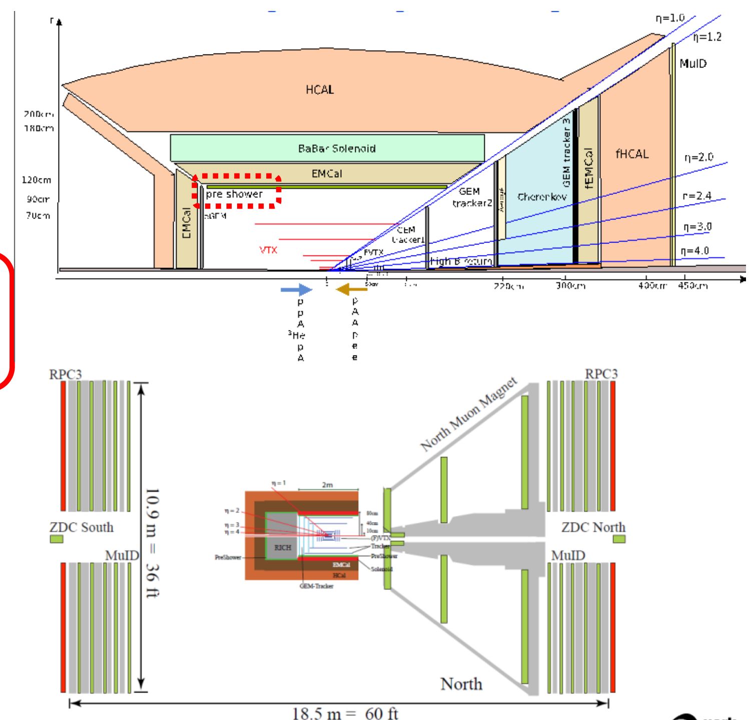


sPHENIX Basic Strategies

- **PHENIX**
  - fast, selective, precise
  - mid/low p_T
  - limited acceptance
- **sPHENIX**
  - fast, (selective,) precise
  - high/mid p_T
  - large acceptance



Detectors by US-Japan



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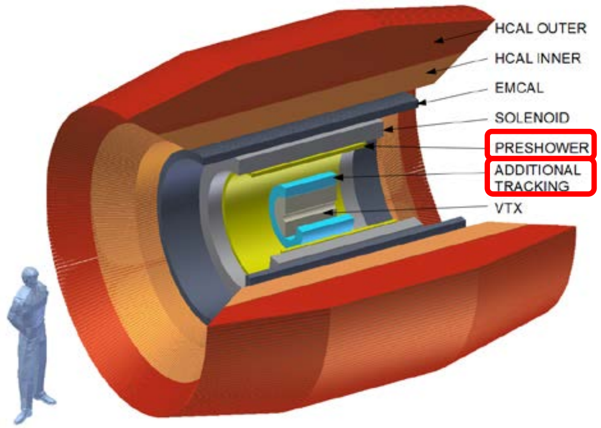
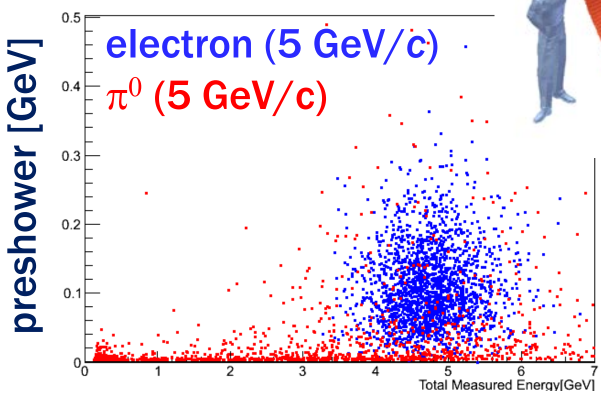
Hiroshima University, Japan

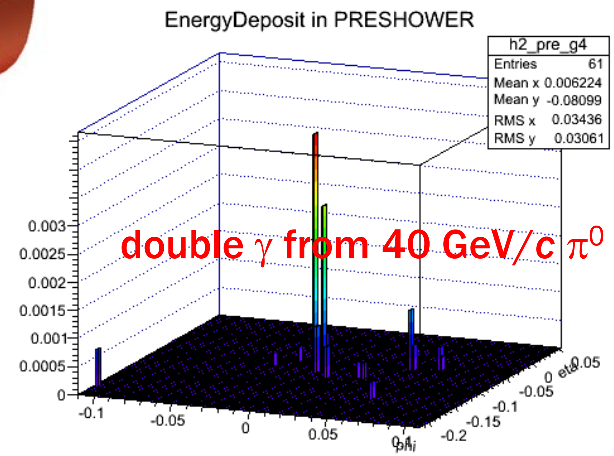
Non-MIE Inner Detectors

- precise measurement of charged particles
  - inside magnet/calorimeters
  - tracking
  - particle ID





preshower + EM calorimater [GeV]



preshower position [h]

- electron/hadron ID
- single/double photon ID

Tracking → Jet Modification

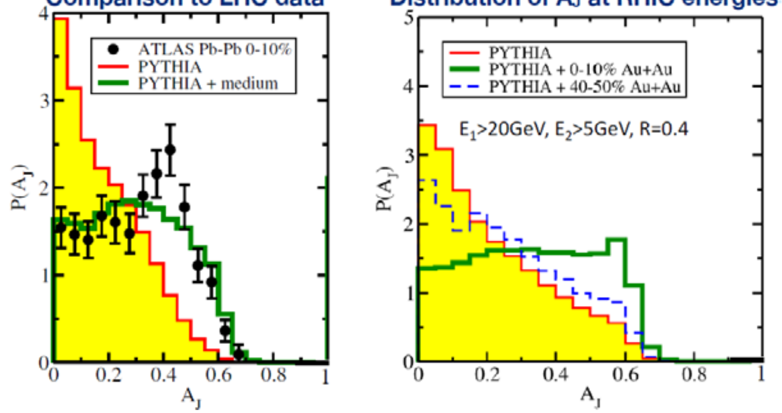
- transverse and longitudinal jet modifications

→ energy loss and fragmentation

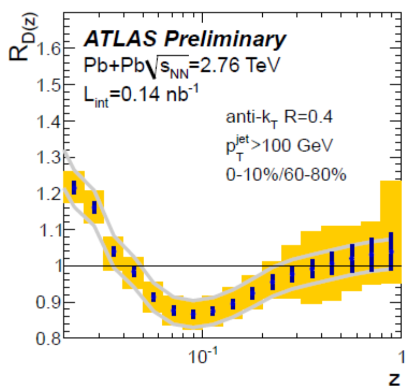
  – comparison between RHIC and LHC
    - model prediction of stronger effects at RHIC

Comparison to LHC data

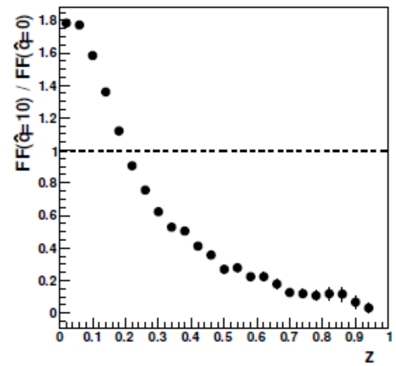
Distribution of A_J at RHIC energies



G.-Y.Qin and B.Muller,
PRL106, 162302 (2011)



Q-PYTHIA, RHIC



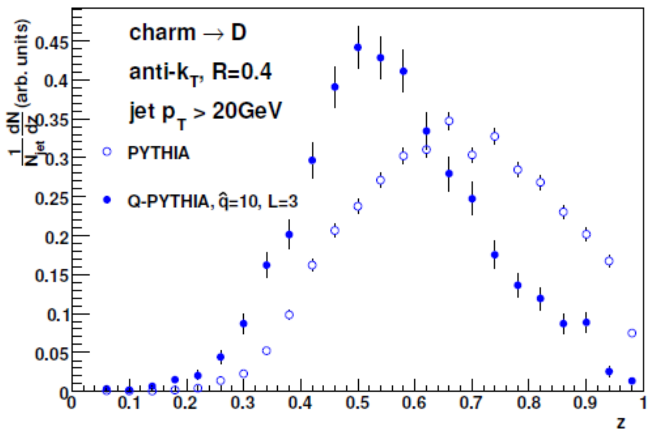
  – measurement in wide p_T range

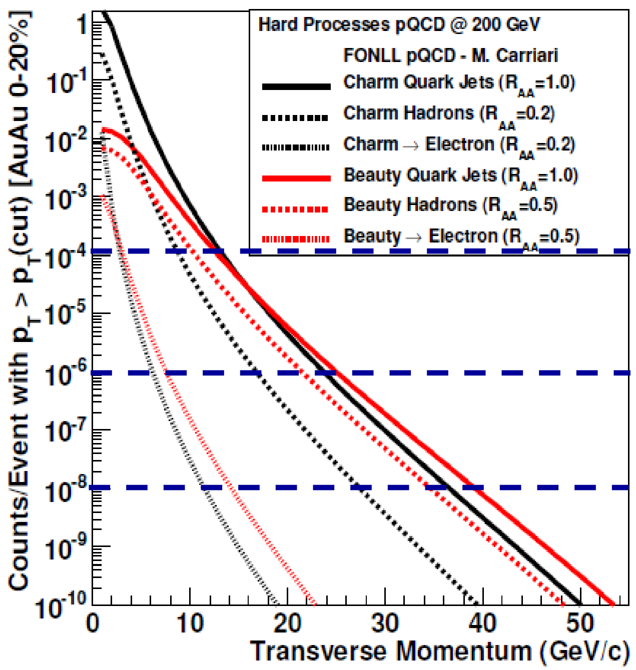
Tracking → Heavy Flavor Jets

- charm/beauty hadron and tagged jet

→ energy loss and fragmentation of heavy flavor

  – additional exams to models

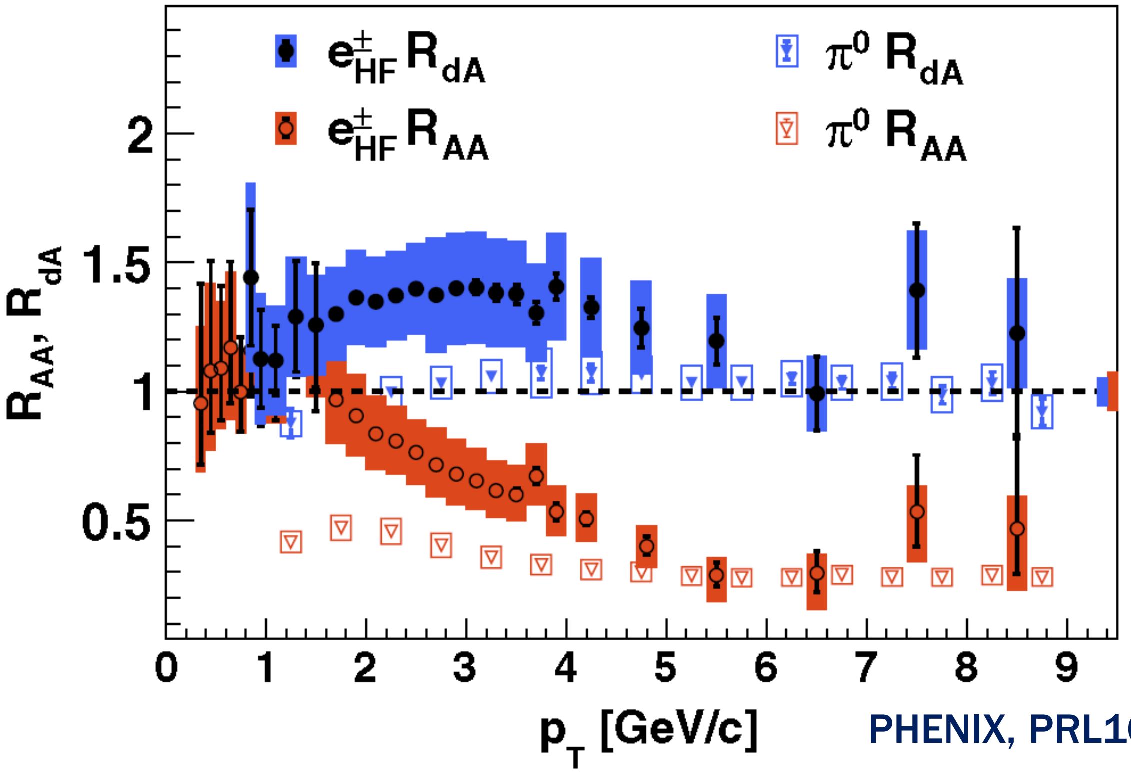




Electron ID → Open Heavy Flavor

- light (u, d, s), charm, and beauty quarks
  - vertex + tracking + electron ID

→ mass hierarchy question



PHENIX, PRL109, 242301 (2012)

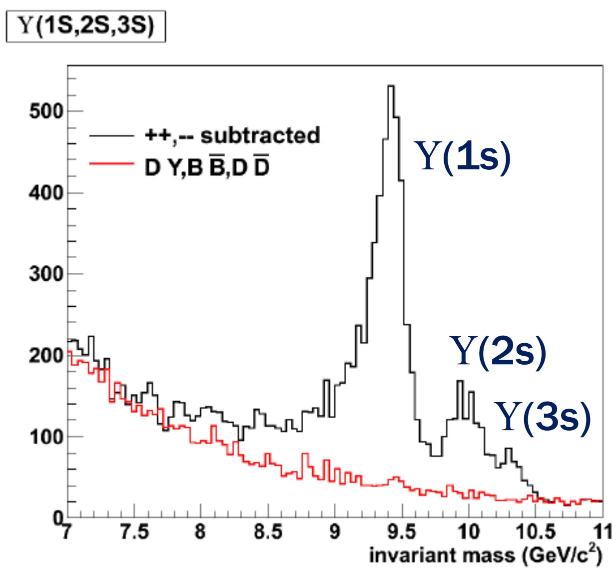
Electron ID → QCD Debye Screening

- precise Υ measurement separating excited states

→ binding energy (average radius) dependence

→ function of temperature (color Debye length) ?

  – comparison between RHIC and LHC



Species	$\int$ L dt	Events	$\langle N_{coll} \rangle$	Υ(1S)	Υ(2S)	Υ(3S)
$p+p$	18 pb^{-1}	756 B	1	805	202	106
Au+Au (MB)		50 B	240.4	12794	3217	1687
Au+Au (0–10%)		5 B	962	5121	1288	675

- *ref.* X.He, this afternoon

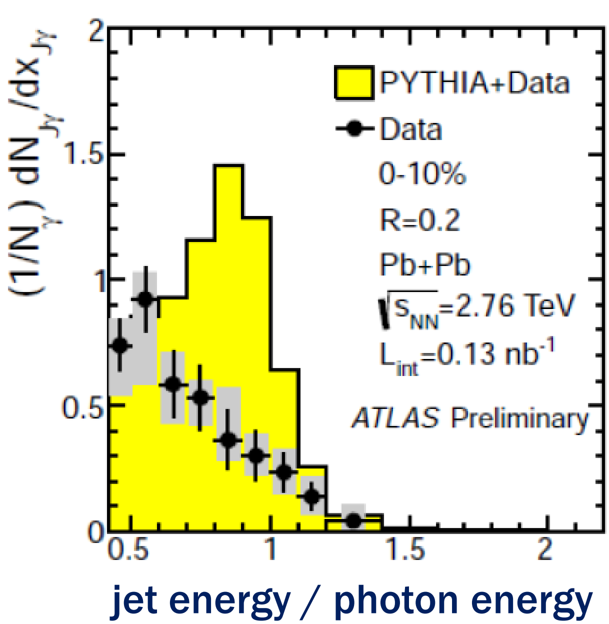
Single γ ID → Direct γ–Jet Correlation

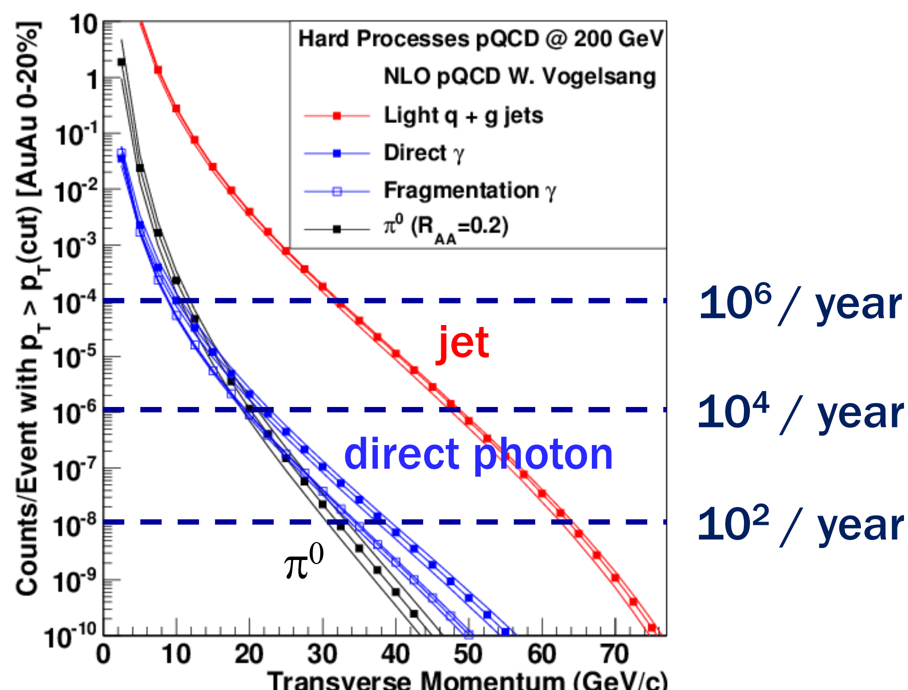
- rejection of double γ from hadron decay

→ direct γ tagged jet: ultimate jet measurement

→ direct γ : QCD reference process

- – wide p_T range from below 15 GeV/*c* to above 30 GeV/*c*





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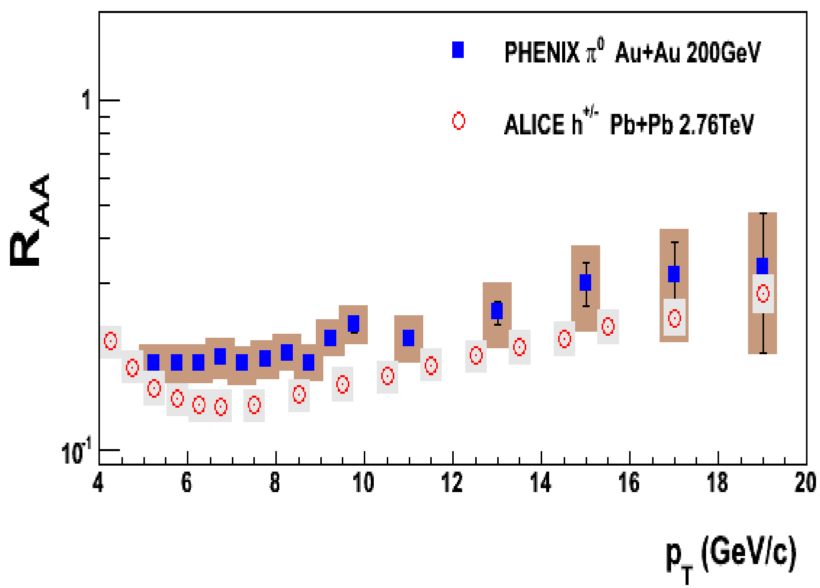
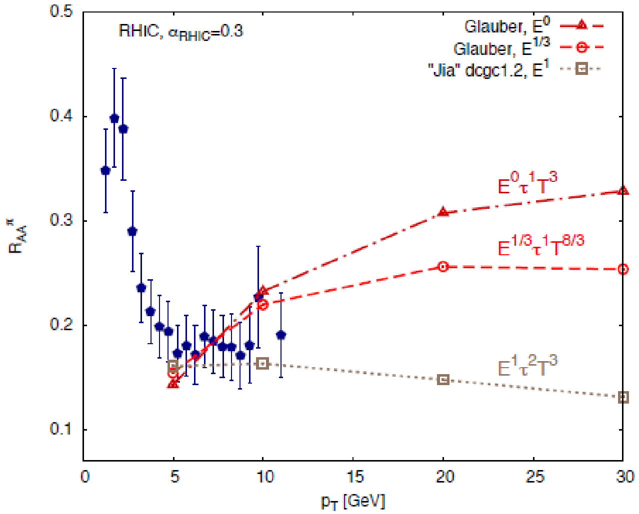
Double γ ID → High p_T Neutral Mesons

- **very high p_T π^0 suppression**
  - present RHIC data up to 20 GeV/*c* → ~ 40 GeV/*c*

→ constraints on energy loss models

→ check if different behavior at RHIC and LHC





sPHENIX Pre-Shower Detector

- design/simulation/R&D/prototyping
  - ongoing/planned activities in Japan, as well as in US
    - *ref.* Y.Akiba 7/29; K.Nagashima, E.Kistenev, this afternoon
  - *cf.* PHENIX MPC-EX
    - *ref.* J.Lajoie, 7/31
  - *cf.* sPHENIX internal Si tracker
    - *ref.* Y.Kwon, E.Mannel, this afternoon; A.Taketani, 7/31
- especially simulation studies in Japan
  - K.Nagashima (Hiroshima U.), this afternnon
    - "*naga*" = long, "*shima*" = island
    - many thanks to C.Pinkenburg
  - GEANT4 based simulation studies of pre-shower

Pre-Shower Design Parameters

- full azimuth, $|\eta| < 1$, radius ~ 65 cm (?)
  - between inner trackers and EM calorimeter
  - area ~ 6.2 m^2
- tungsten absorber (~ 2 X_0)
- 1 (or 2?) layer(s) of Si pad/pixel
- *in case of* 1 layer of 2 (ϕ) × 50 (z) mm^2 at 65 cm
  - $\Delta\phi = 0.003$, $\Delta\eta = 0.08$ (at $\eta = 0$) – 0.05 (at $|\eta| = 1$)
  - ~ 62 k readout channels
- all parameters are very preliminary
- performance study and optimization needed

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sPHENIX-J Activities/Prospects

- most of current PHENIX-J group
  - Hiroshima U. (Shigaki *et al.*), U. Tsukuba (Esumi *et al.*)
  - CNS Tokyo (Gunji *et al.*), Tsukuba U. of Tech. (Inaba), ...
- open minded technical collaborations
  - RIKEN Nishina Center (PHENIX VTX, sPHENIX tracker)
  - T.Ohsugi (spec. appoint. prof., Hiroshima U.)
    - world-class silicon detector expert
- funding efforts
  - (continuing)
  - US-DoE CD0 would be very helpful

Summary

- hard/heavy probes demonstrated more and more
- sPHENIX: strategy feedback from LHC to RHIC
  - RHIC: optimum facility to explore heavy ion physics
  - keeping basic PHENIX strategies: fast, (selective,) precise
  - *plus:* higher p_T, larger acceptance
- strong physics case via high p_T electron/photon
  - to attack most interesting topics now at LHC/RHIC
  - highly regarded; aimed at sPHENIX day-1
- pre-shower detector for $e^{\pm}$ / $h^{\pm}$ / γ / π^0 identification
  - activities in Japan toward design/R&D/prototyping
  - *ref.* K.Nagashima, GEANT4 simulation, this afternoon