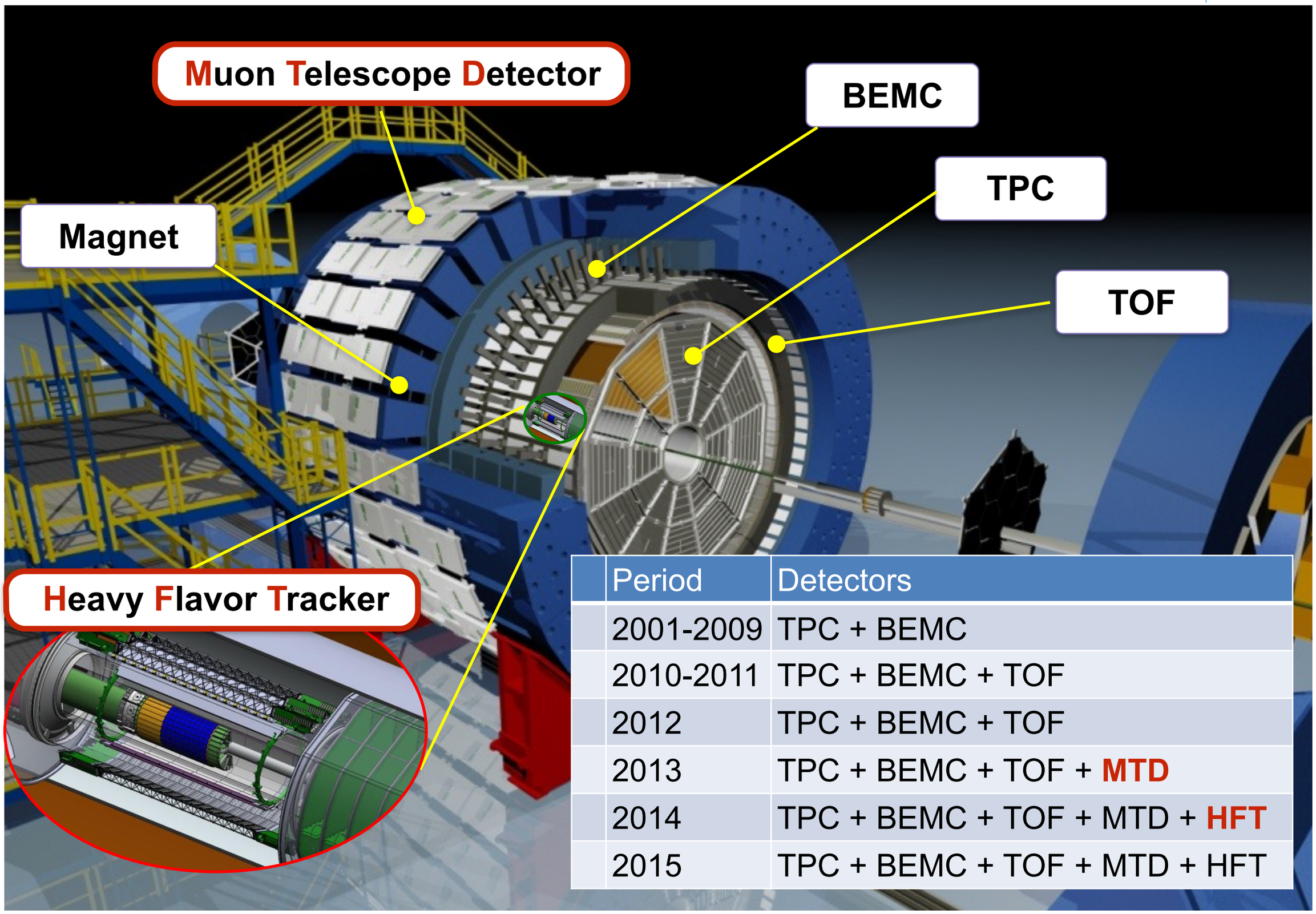
STAR Overview

Li Yi (for the STAR Collaboration)
Yale University

STAR Detector System



	Period	Detectors
	2001-2009	TPC + BEMC
	2010-2011	TPC + BEMC + TOF
	2012	TPC + BEMC + TOF
	2013	TPC + BEMC + TOF + **MTD**
	2014	TPC + BEMC + TOF + MTD + **HFT**
	2015	TPC + BEMC + TOF + MTD + HFT

Heavy Flavor Probes

- Heavy flavor quark, primarily produced in initial hard scattering, is exposed to the medium evolution

  - Charm-medium interaction D^0 ($c\bar{u}$) ..
    light vs heavy quark: mass hierarchy of parton energy loss

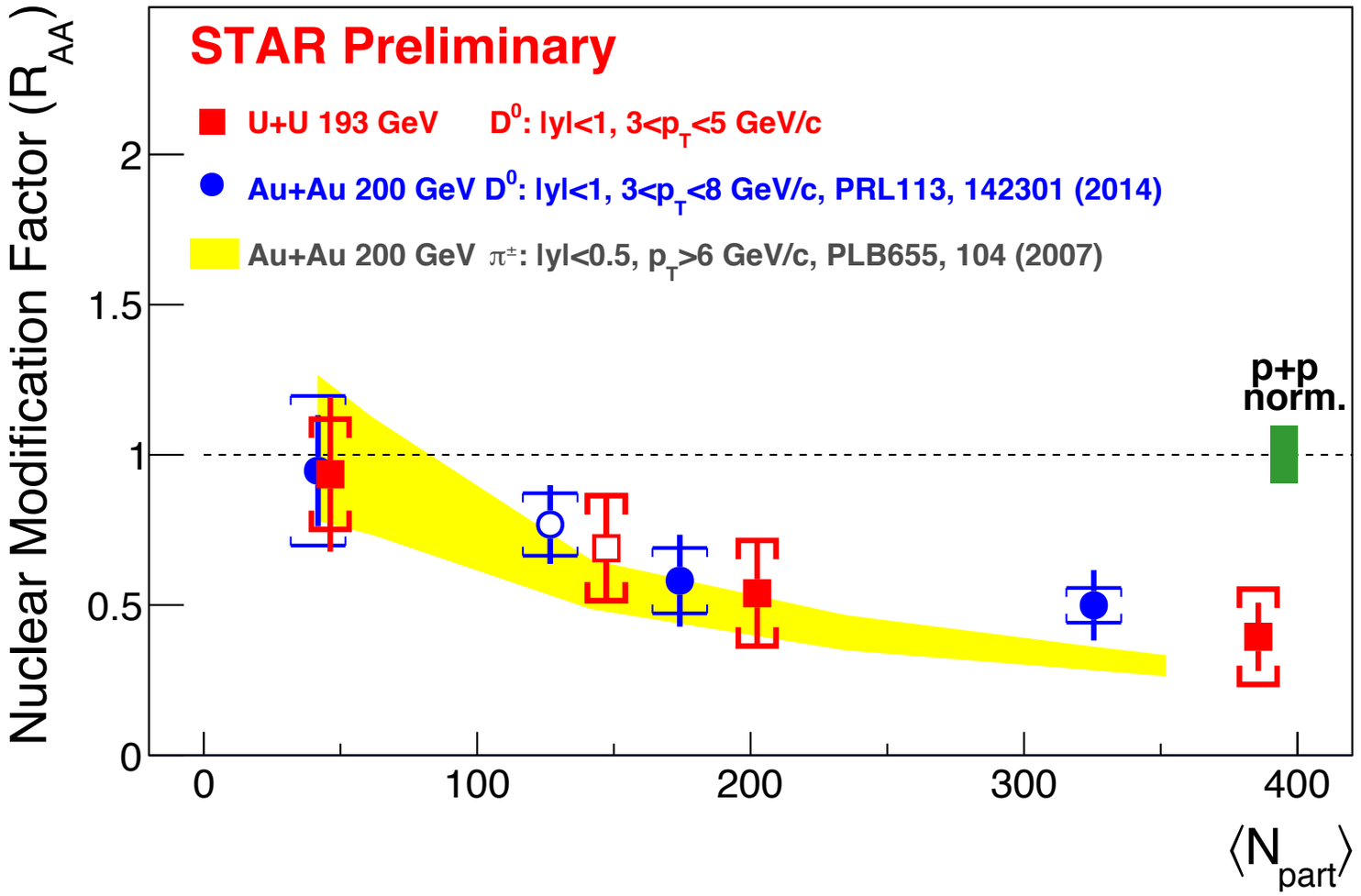
  - Quarkonia J/ψ ($c\bar{c}$), Υ($b\bar{b}$) expected to be QGP thermometer
    direct production - thermal dissociation + recombination

- Cu+Cu, Au+Au, U+U: system size, energy dependence

- p+p: pQCD test, heavy ion reference

- p+Au, d+Au: Cold Nuclear Matter effect

Heavy vs Light Flavor Suppression

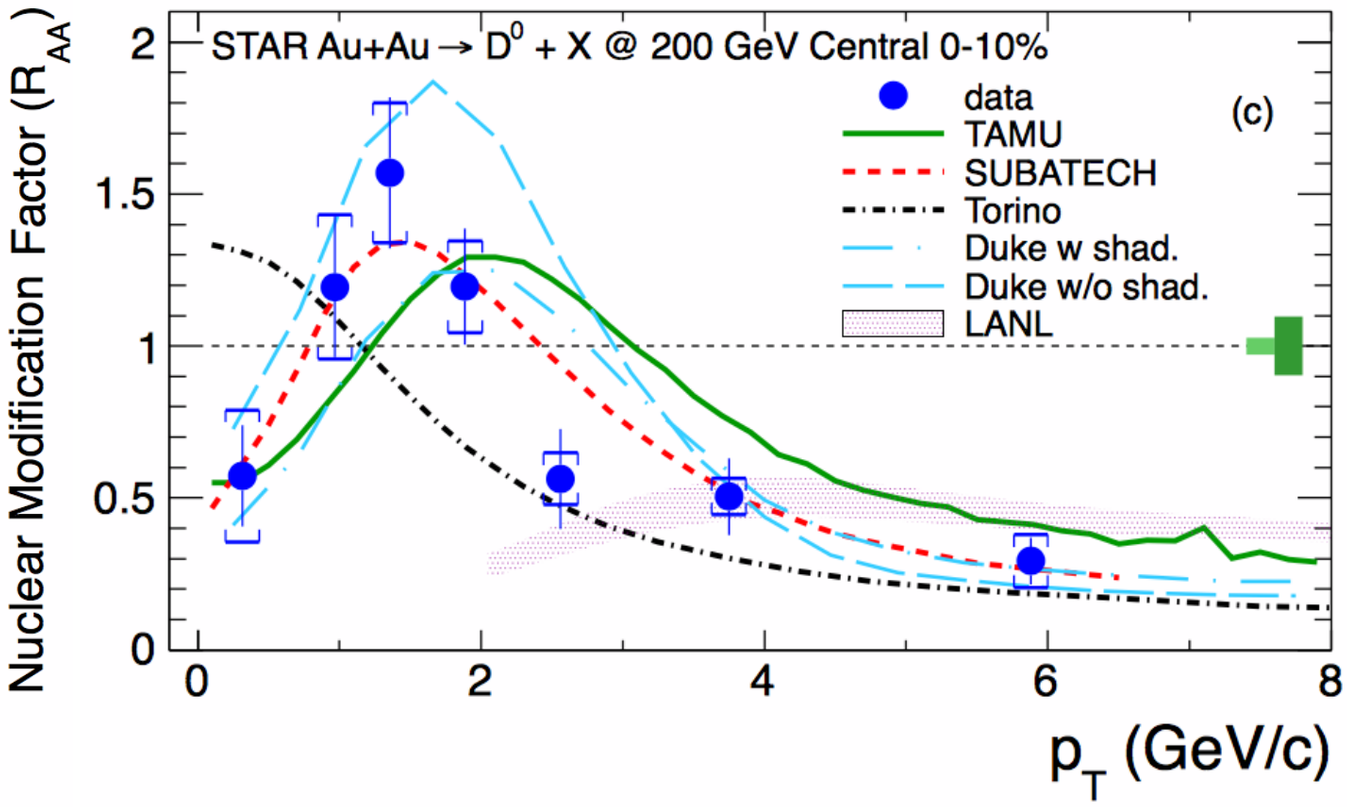


- Suppression of **open charm** at high p_T in U+U collisions follows the density dependence trend of **open charm** and **pions** in Au+Au collisions.

D^0 Nuclear Modification p_T Dependence

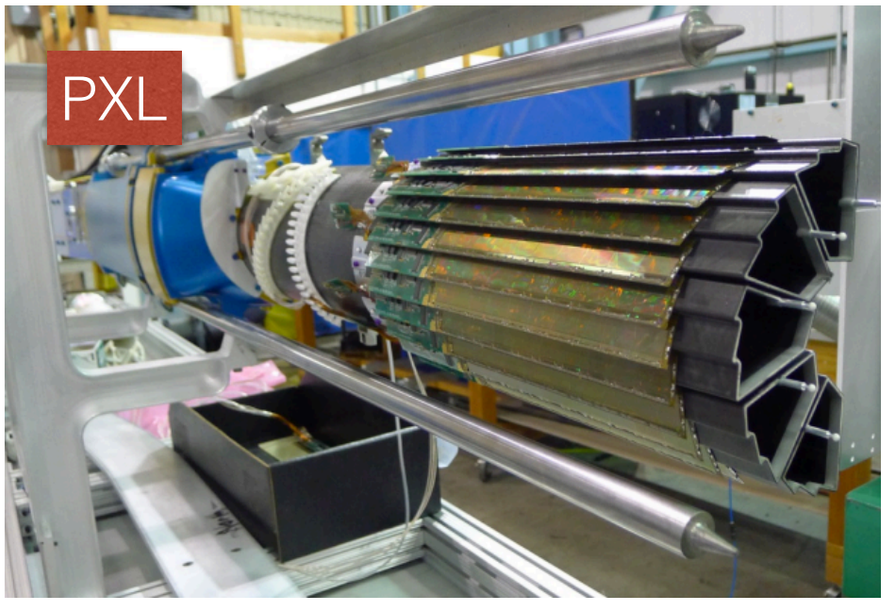
STAR, PRL 113, 142301 (2014)

Year 2010 + 2011 Au+Au @ 200 GeV data

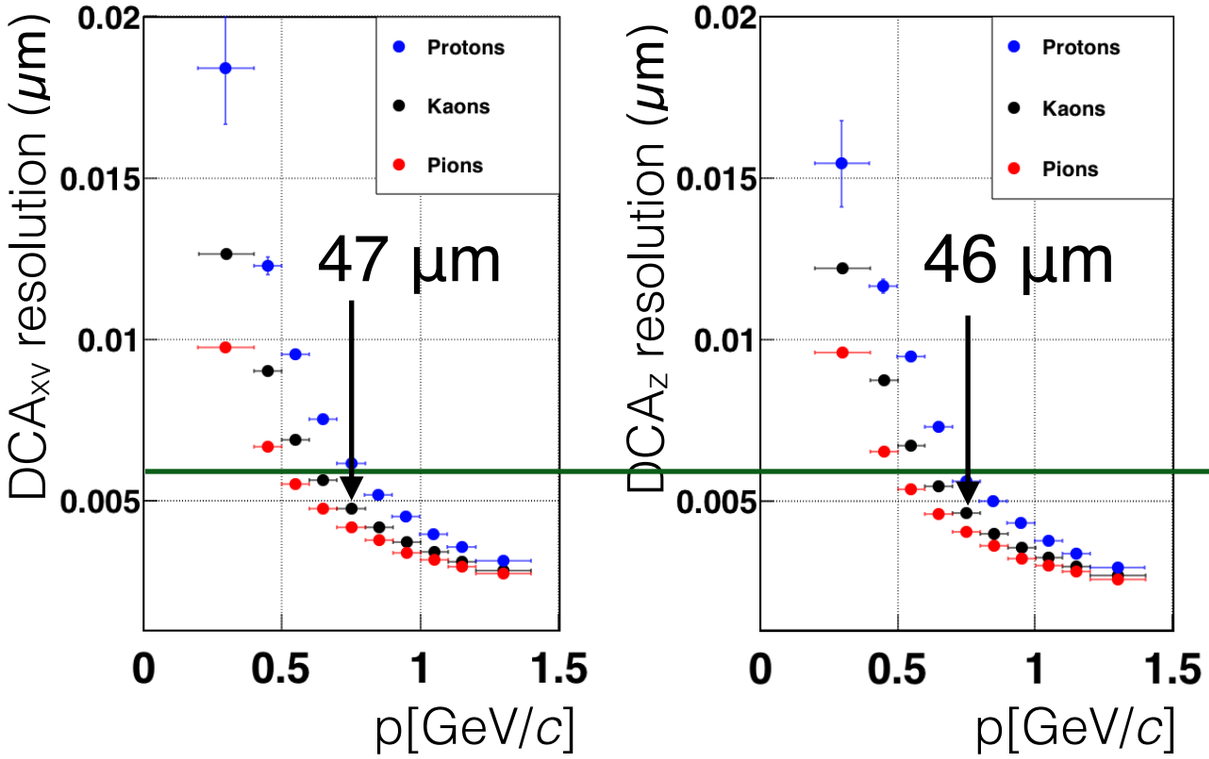


- Large suppression for $p_T > 4$ GeV/*c*
  Strong charm-medium interaction
- Indication of enhancement at p_T~0.7-2GeV/*c*
  Described by recombination models
- More precise measurement needed

Heavy Flavor Tracker



- 3 kinds of silicon detectors (PXL, IST, SSD)
  - **PXL**: **First** application of the Monolithic Active Pixel Sensors (**MAPS**) technology in a collider experiment
  - Decay vertex reconstruction with high resolution



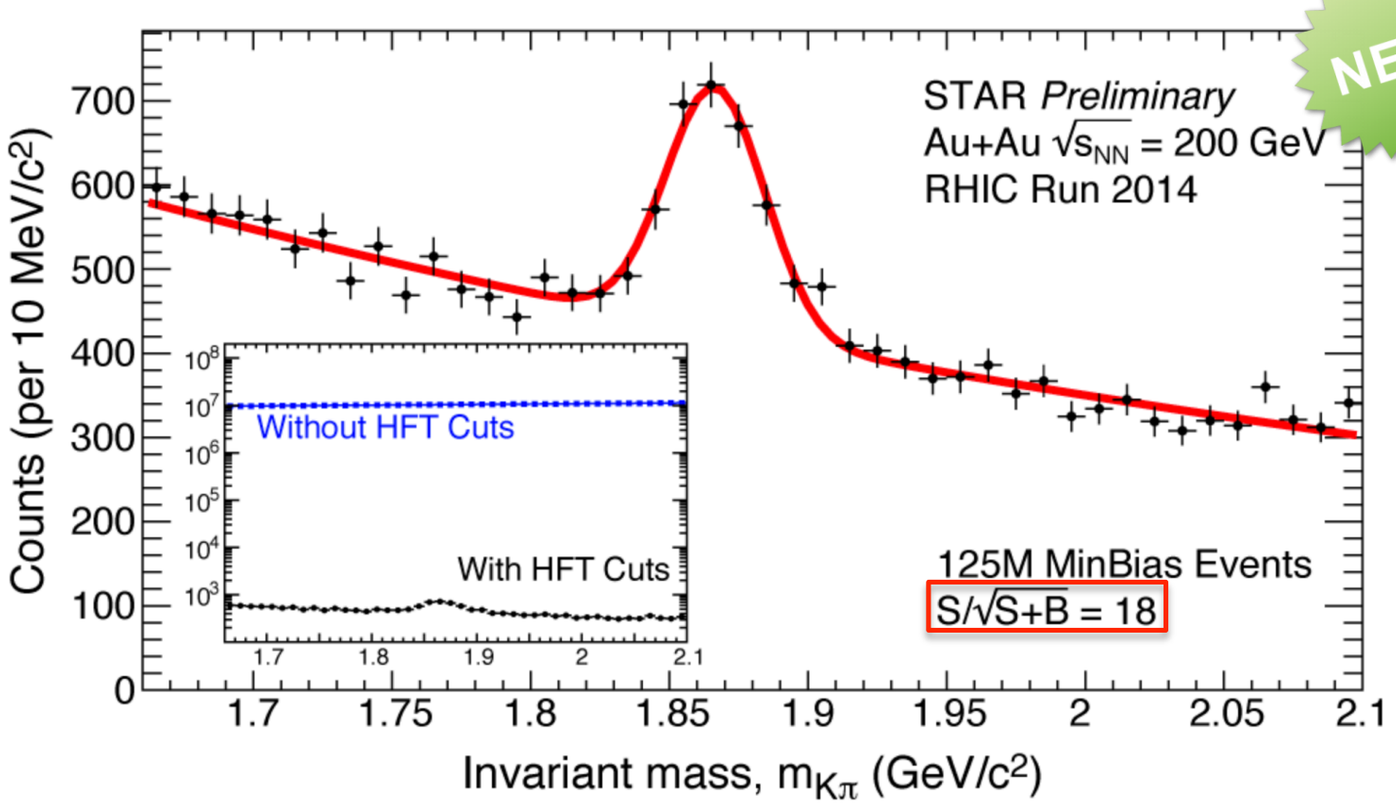
Excellent resolution even at low p

Exceeded DCA Resolution Design Goal
60μm for Kaon at p= 0.75 GeV/c

H. Qiu, Tue 13:30
HF and Quarkonium

D^0 signal with HFT

~10% statistics of year 2014 Au+Au



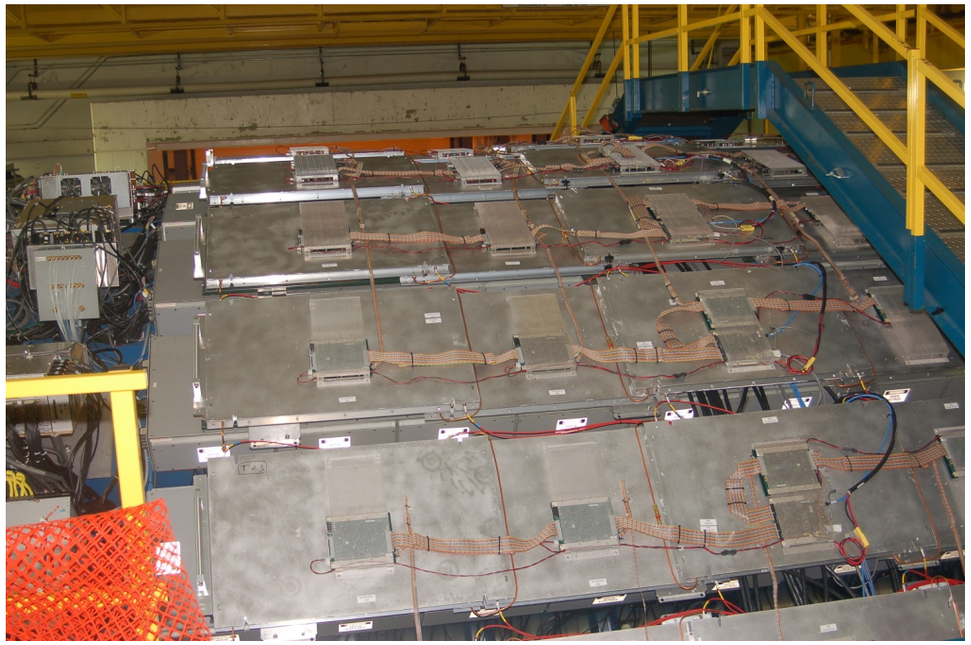
	Without HFT	With HFT
Year	2010+2011	2014
N_{events}	1.1 B	10%*1.2B
significance	13.9	18

- Background greatly suppressed by topology cuts with HFT
- Physics results with HFT will come soon.

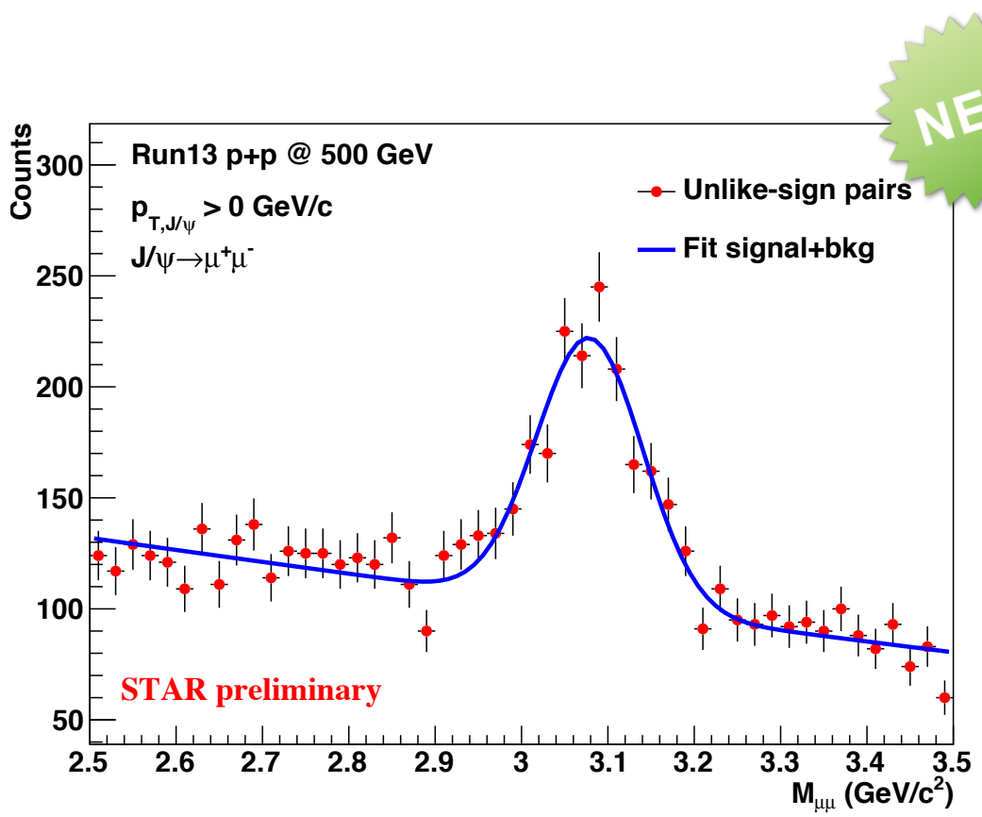
A. Quintero, Poster for Optimize D^0 signal

H. Qiu, Tue 13:30 HF and Quarkonium

J/ψ with Muon Telescope Detector



- Multi-gap Resistive Plate Chamber (MRPC) technology
  - Precise timing ~ 95 ps
  - Accurate hit position ~ 1 cm
- Muon identification
  - TPC track and MTD hit match



- Dimuon trigger increases low p_T accuracy

p+p @ 500 GeV

7.7 pb^{-1} taken in 2013

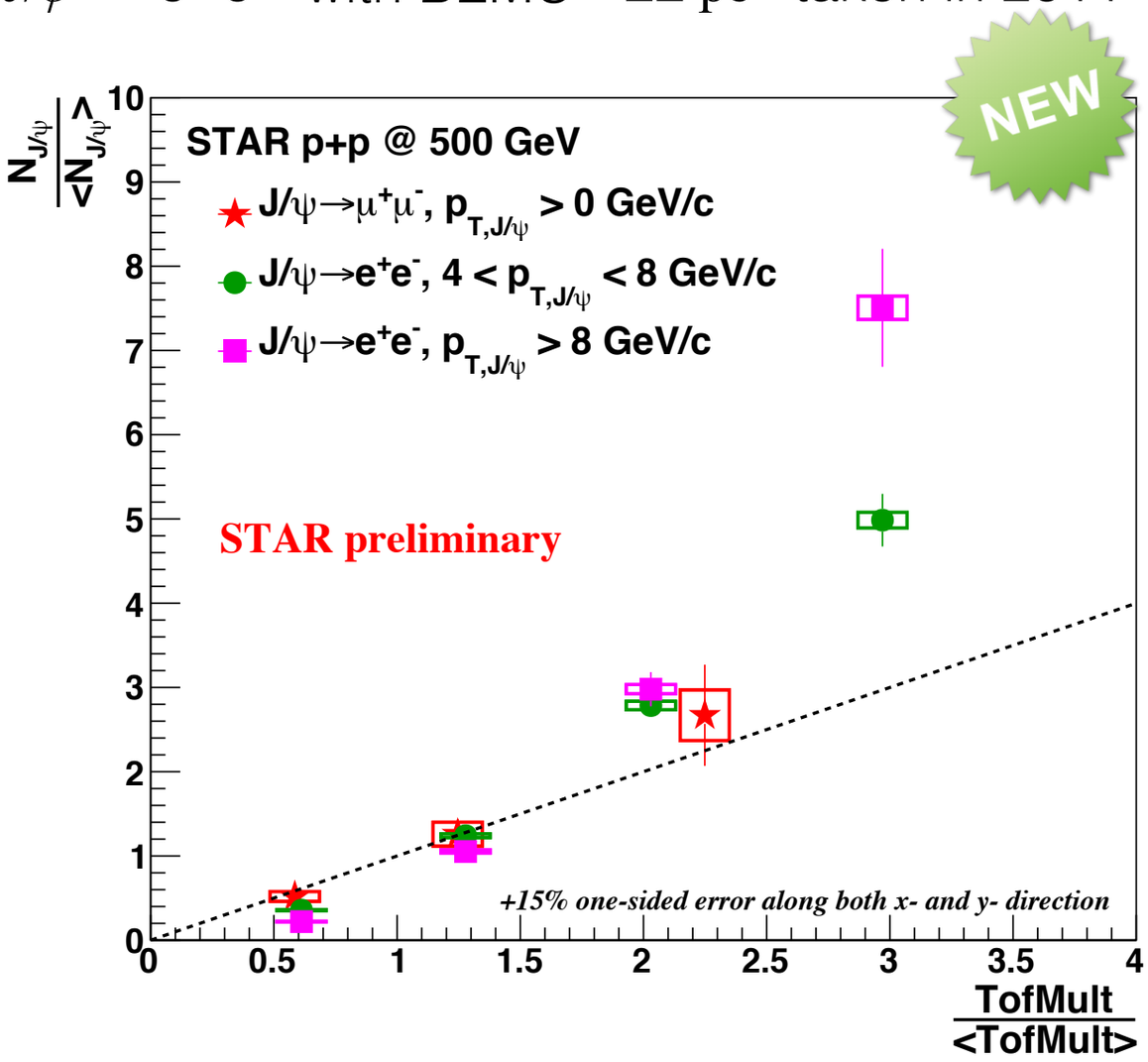
$J/\psi \rightarrow \mu^+ \mu^-$

R. Ma, Tue 15:20
HF and Quarkonium

J/ψ Yield vs Multiplicity in p+p 500 GeV

$J/\psi \rightarrow \mu^+ \mu^-$ with MTD 7.7 pb^{-1} taken in 2013

$J/\psi \rightarrow e^+ e^-$ with BEMC 22 pb^{-1} taken in 2011



- Clear correlation between quarkonia yields and multiplicity in pp
- Faster rise for higher p_T

R. Ma, Tue 15:20
HF and Quarkonium

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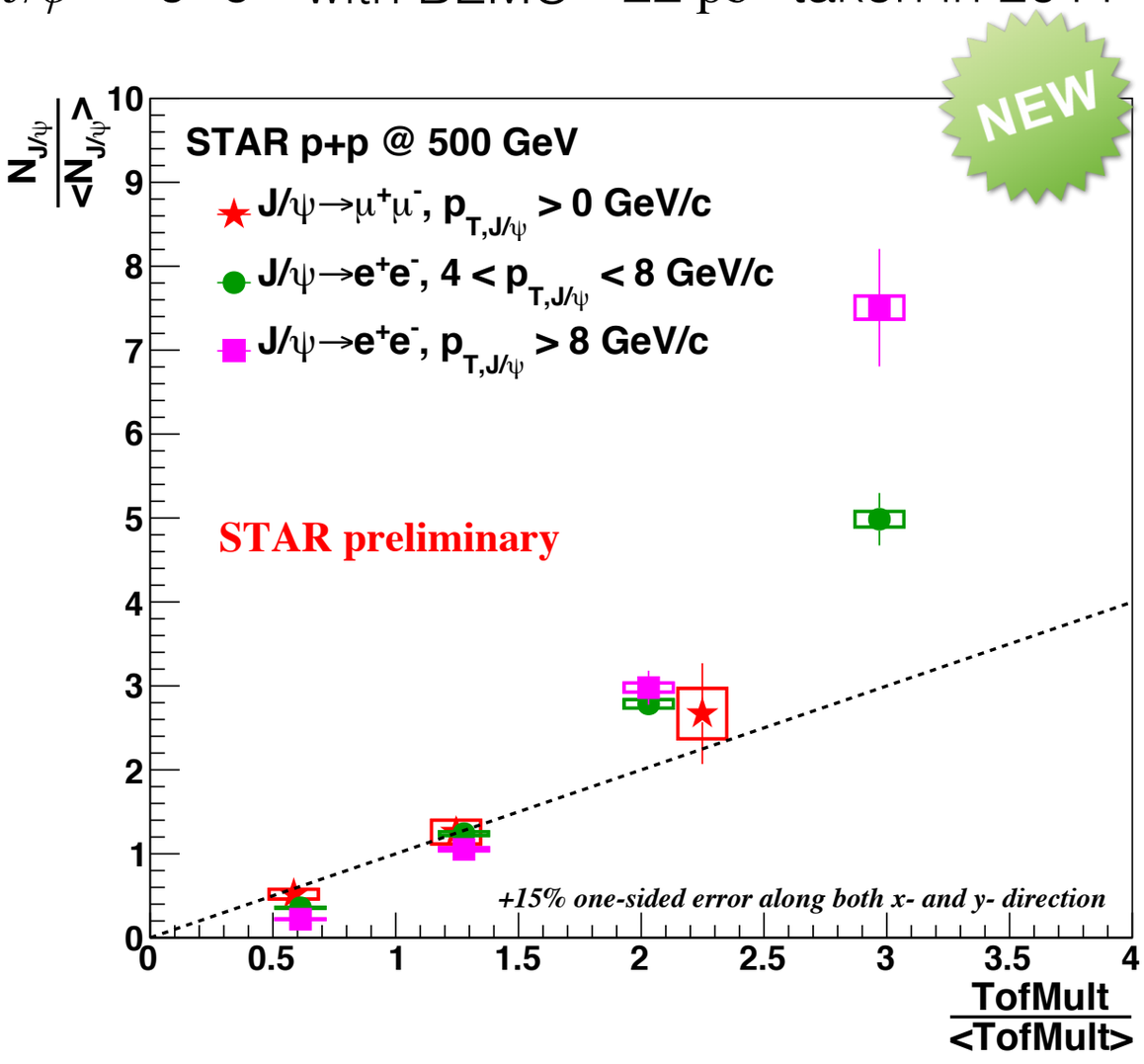
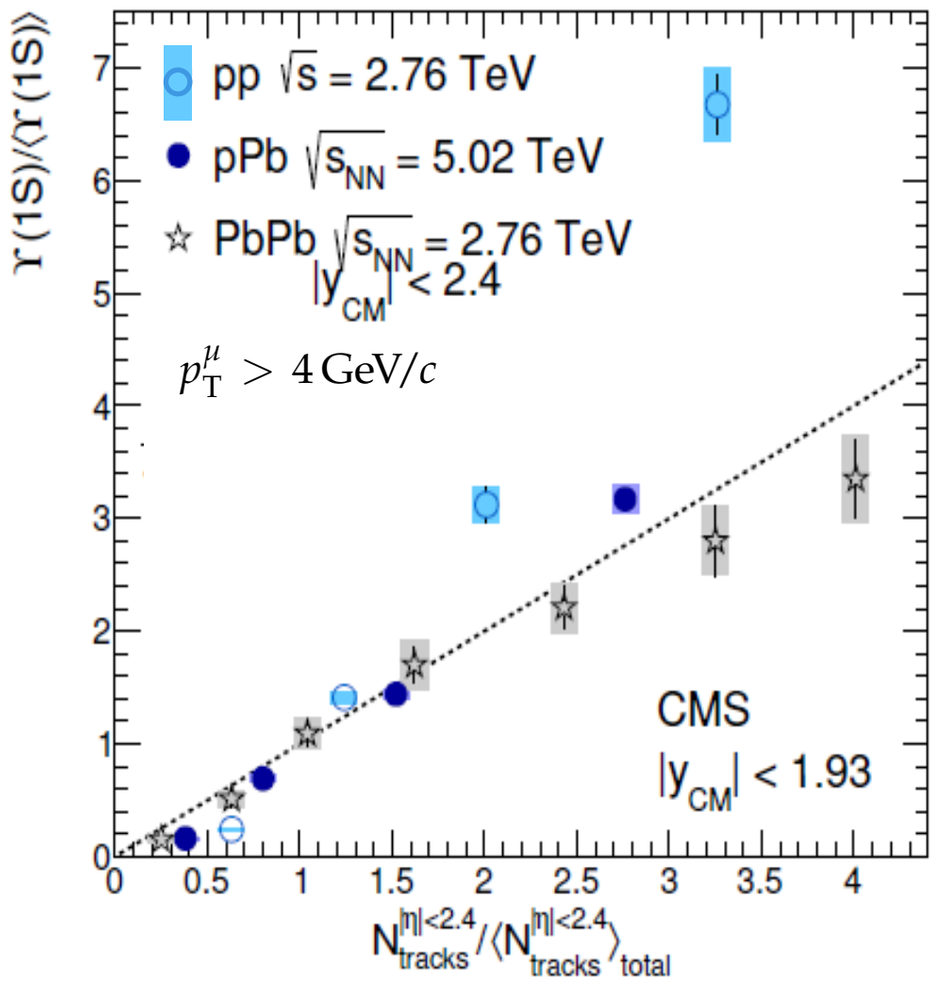


CMS, JHEP 04 (2014)103



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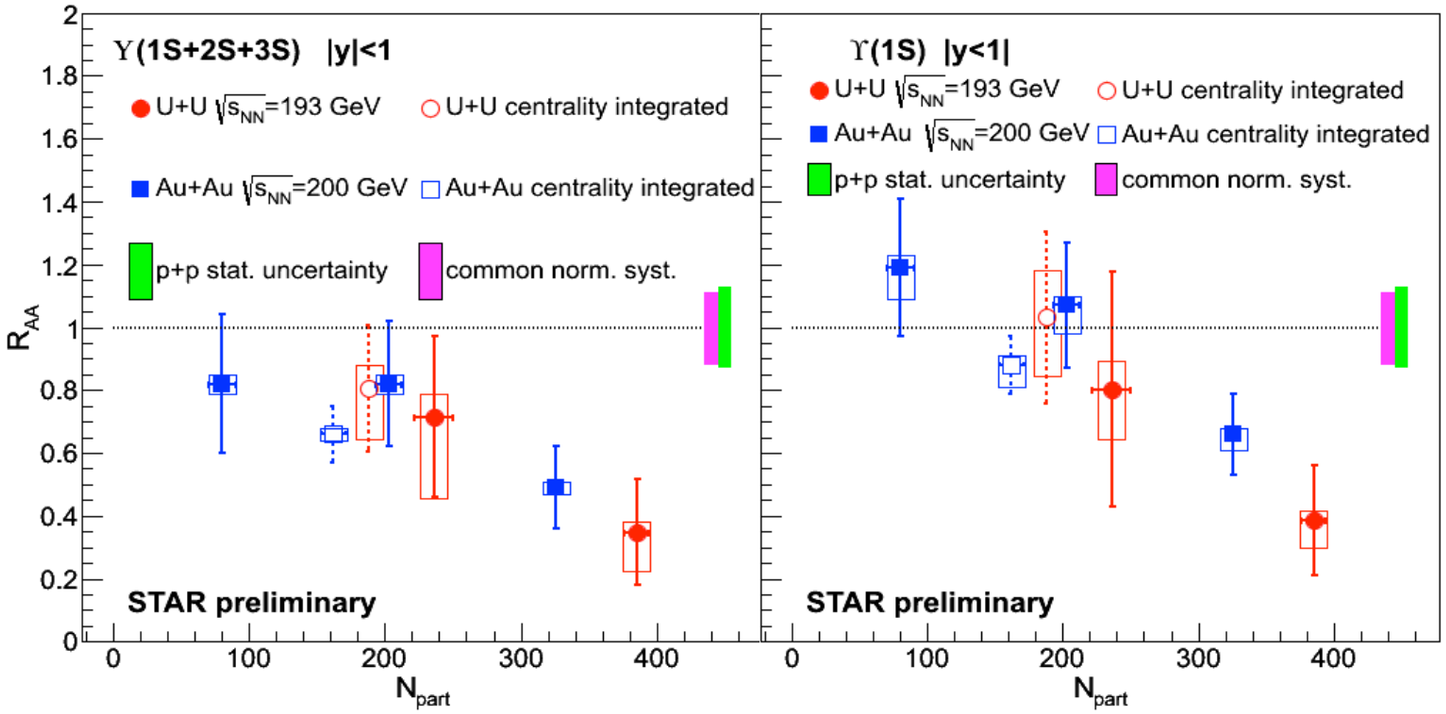
R. Ma, Tue 15:20
HF and Quarkonium

ϒ Suppression

- ϒ → e^+e^- with BEMC

  ϒ suppression consistent with sequential melting



ϒ(1S) and ϒ(1S+2S+3S):

- Peripheral: consistent with no suppression
- 0-10% central: significant suppression
- New U+U data extend Au+Au trends to higher Npart

R. Vertesi, Tue 16:20
HF and Quarkonium

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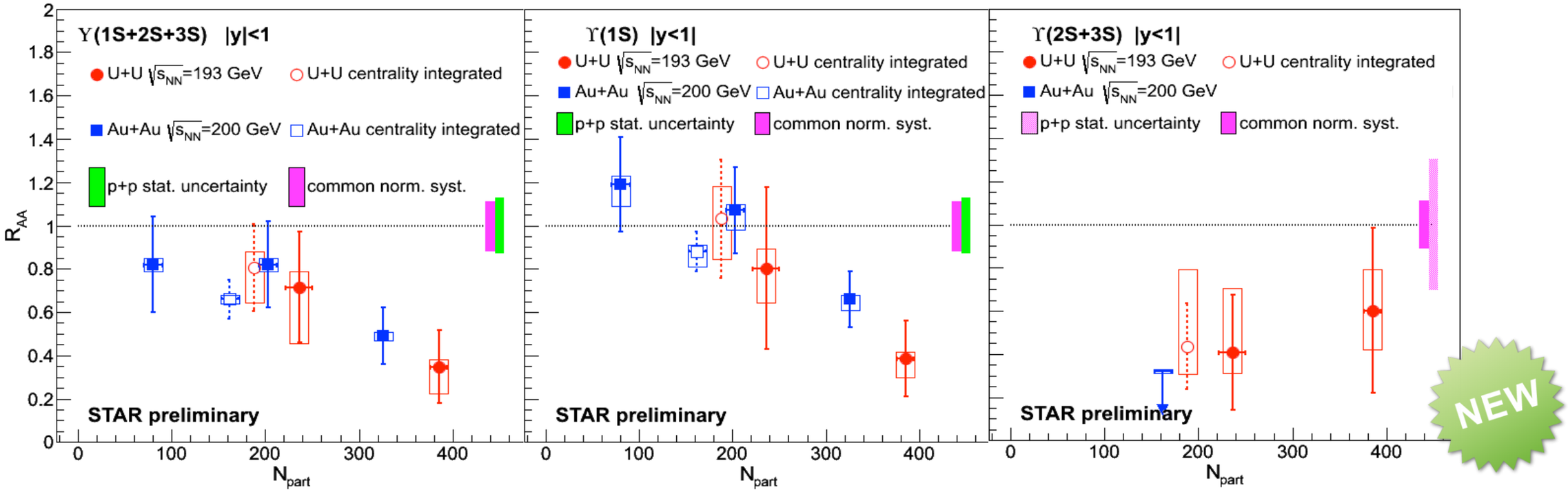


ϒ(1S) and ϒ(1S+2S+3S):

- Peripheral: consistent with no suppression
- 0-10% central: significant suppression
- New U+U data extend Au+Au trends to higher Npart

ϒ(2S+3S):

- No evidence in 0-60% Au+Au
- Hint of presence in 0-60% U+U data

- Stay tuned for dimuon ϒ with MTD

R. Vertesi, Tue 16:20
HF and Quarkonium

Jet Probes in Au+Au 200 GeV

- Jet yield suppression

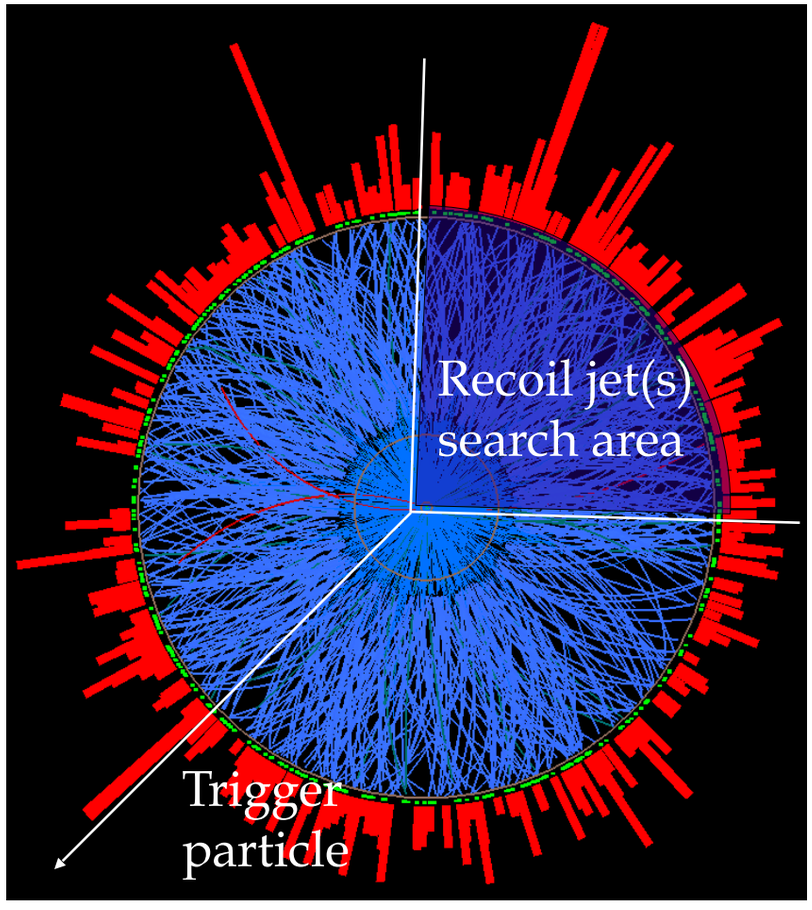
Semi-inclusive jet
A. Schmah, Mon 15:30
Jets

- Jet angle diffraction in medium
- Where does jet energy go?

Dijet imbalance
K. Kauder, Tue 13:30
Jets

Semi-Inclusive Recoil Jets

Semi-inclusive yield of recoil jets with a high p_T hadron trigger

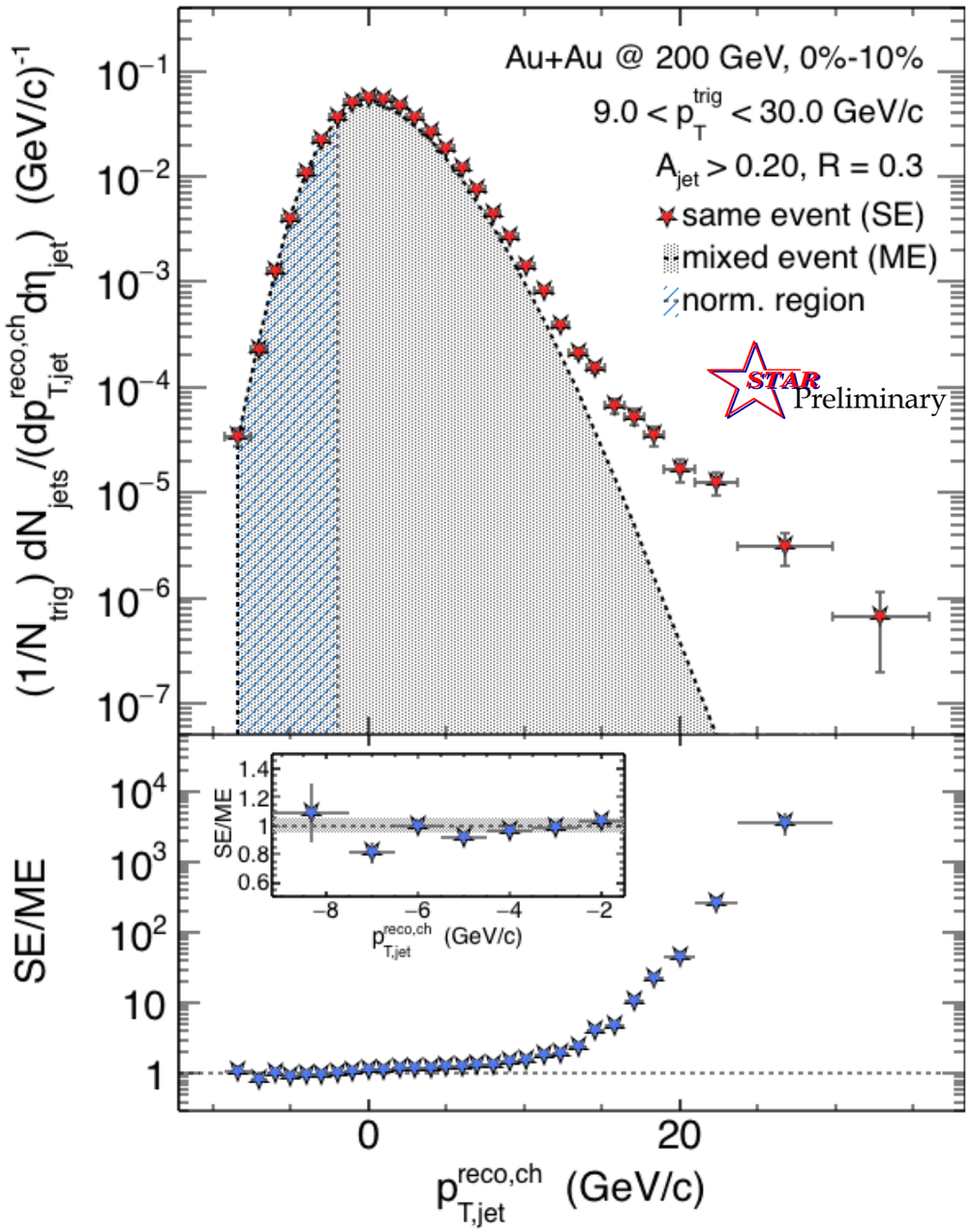


- Trigger on high p_T hadron → Select hard process with surface bias
- Measure the recoil jets → **No fragmentation bias on recoil side!**
- Combinatorial jet-finding background?

A. Schmah, Mon 15:30
Jets

Mixed Event for Jet-finding Background

Central



Mixed event

Same event

Pick one random track per real event → add to mixed event

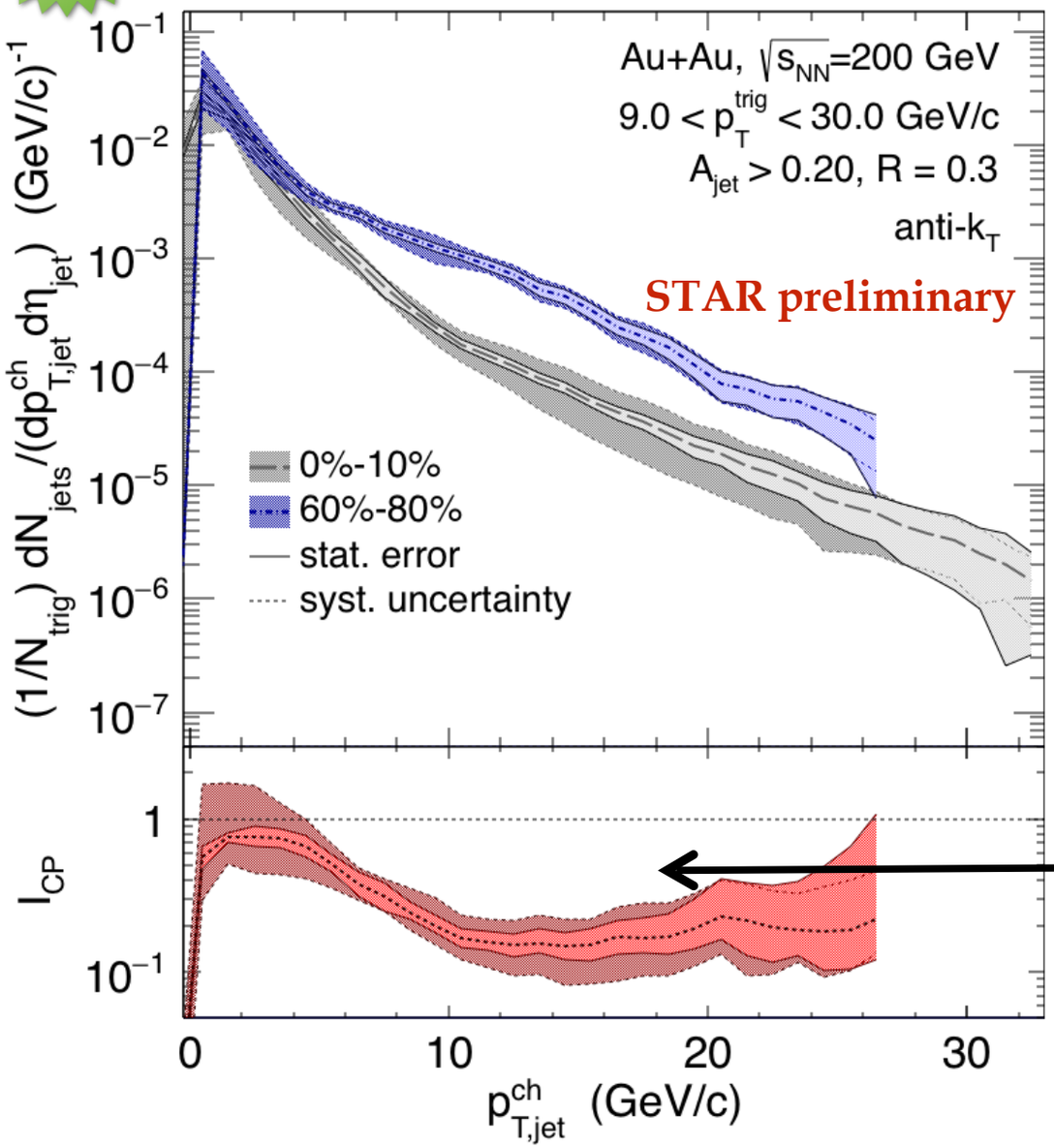
- Combinatorial jet background → statistically described by mixed event
  - Excellent description of low p_T spectrum with mixed event
  - Significant jet signal at p_T-ρA > 10 GeV/*c*

A. Schmah, Mon 15:30 Jets

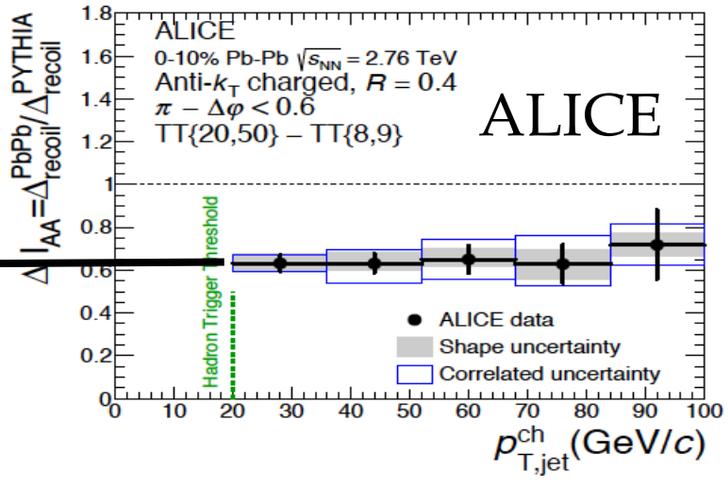
Comparison Central-Peripheral: I_{CP}

NEW

After fluctuation unfolding procedure:



- I_{CP} close to 1 at low p_T
- Significant suppression (~0.2) at p_T > 10 GeV/c
- Larger suppression compared to LHC energies
  - similar Δp_T shift with steep spectra
  - different surface bias?
  - caveat: different measurement techniques



arXiv:1506.03984

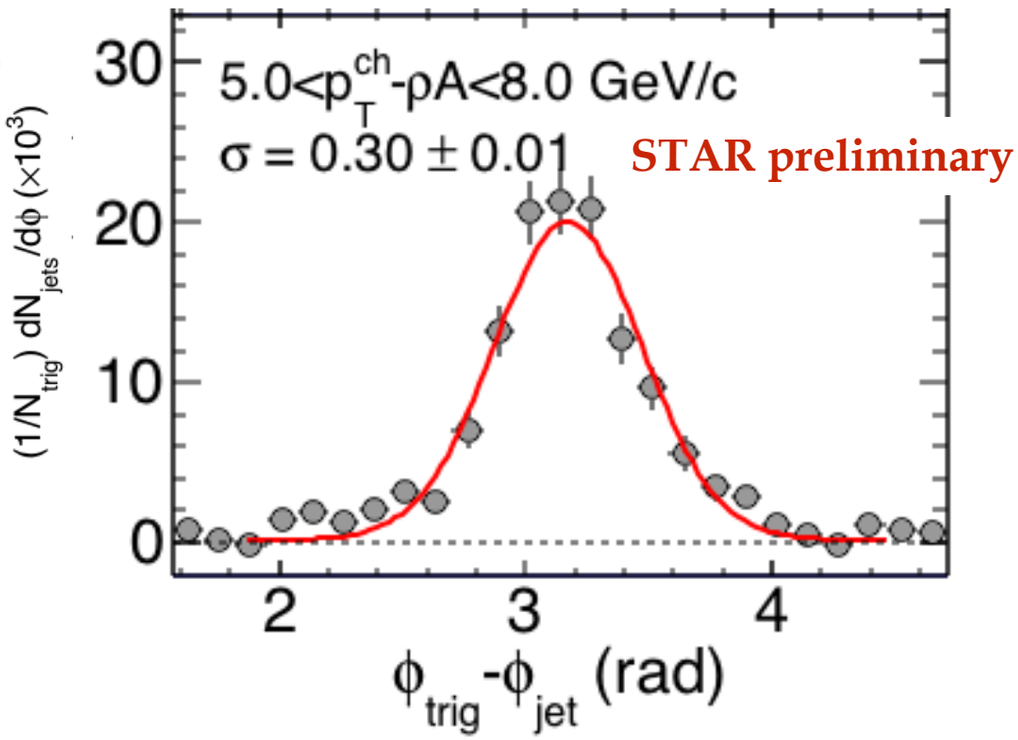
A. Schmah, Mon 15:30 Jets

Large Angle Jet Scattering?

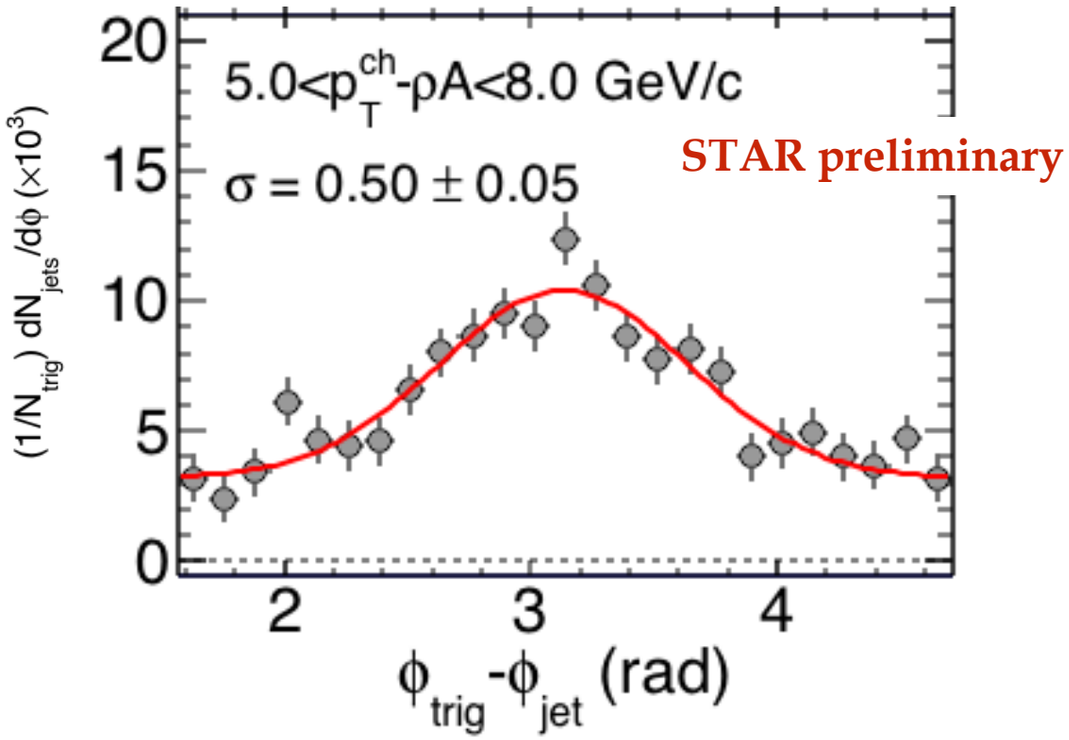
9 < trigger p_T < 30 GeV/*c*

NEW

Peripheral



Central



- Jet angle changes significantly in central for $5 < p_T - \rho A < 8$ GeV/*c*
  - Flow?
  - Φ dependent normalization needed?
  - Background from multiple interactions? *ALICE, arXiv:1506.03984*
  - More studies needed!

A. Schmah, Mon 15:30 Jets

Dijet Imbalance A_J Measurement

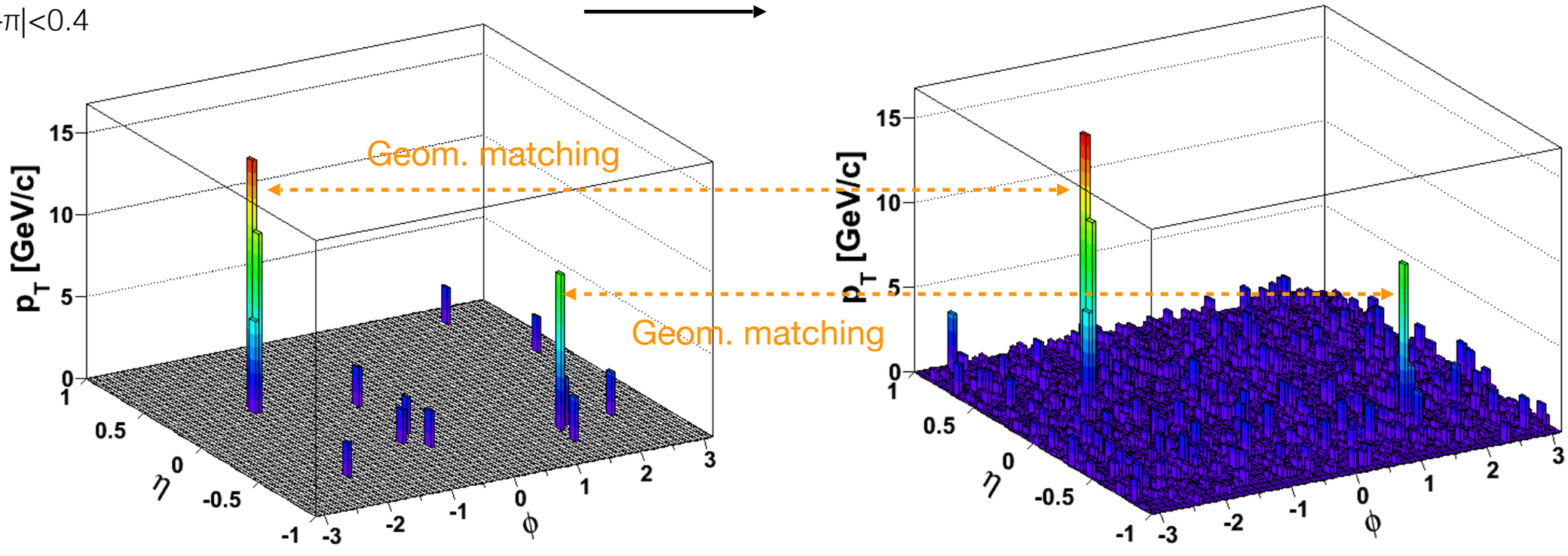
$$A_J = \frac{p_T^{\mathrm{Lead}} - p_T^{\mathrm{SubLead}}}{p_T^{\mathrm{Lead}} + p_T^{\mathrm{SubLead}}}$$

K. Kauder, Tue 13:30
Jets

$p_{T,cut}$=2 GeV/c
p_T^{Lead}>20 GeV/c
$p_T^{SubLead}$>10 GeV/c
$|\Delta\phi-\pi|<0.4$

Rerun jet-finding algorithm anti-k_T for **these dijets**

$p_{T,cut}$=0.2 GeV/c
p_T^{Lead}>20 GeV/c ($p_{T,cut}$=2 GeV/c)
$p_T^{SubLead}$>10 GeV/c ($p_{T,cut}$=2 GeV/c)

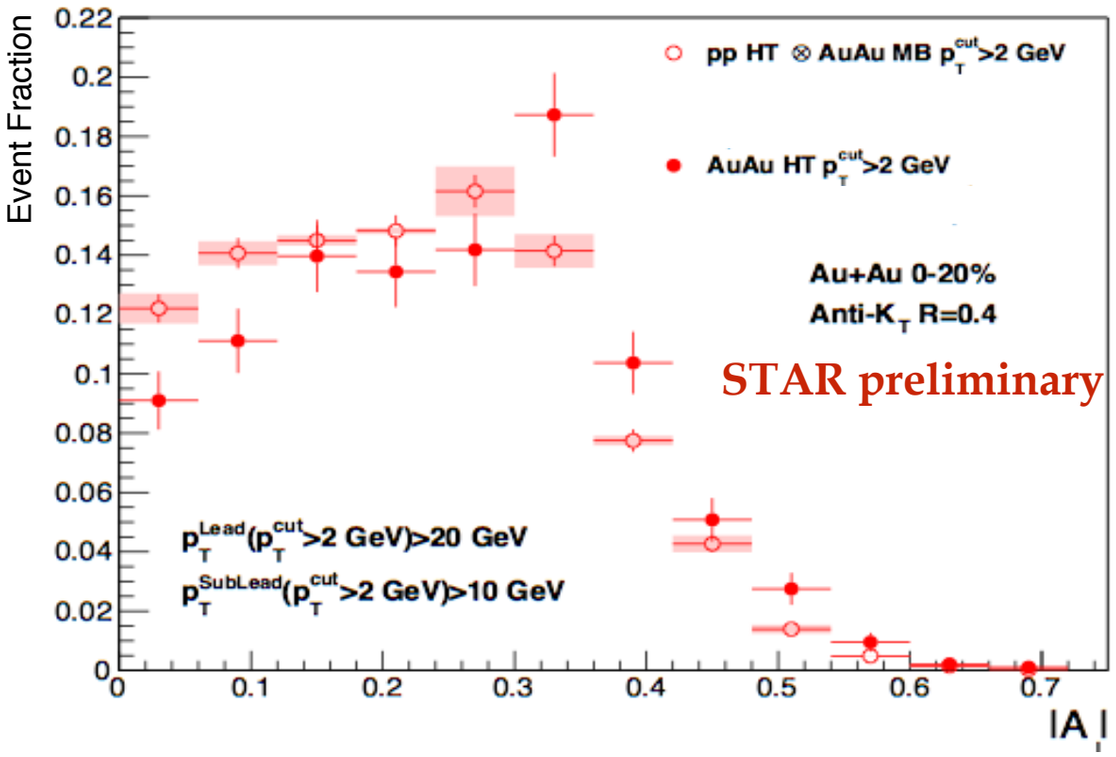


Locate dijet with high p_T particle cuts

Reconstruct jets with low p_T particle cuts

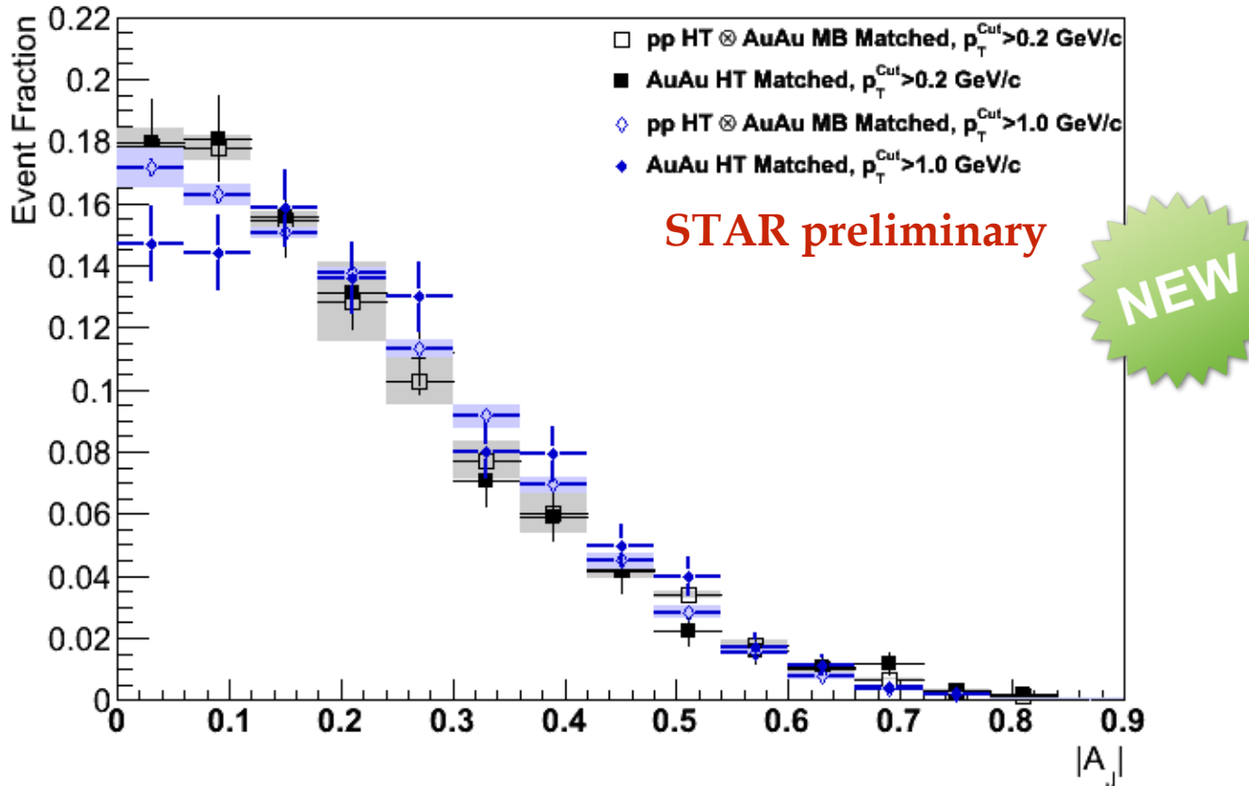
Dijet Imbalance: p_T Softening

R=0.4



p_T>2 GeV/*c* p-value < 10^{-4}

K. Kauder, Tue 13:30
Jets



p_T>1 GeV/*c* p-value = 0.05 - 0.2

p_T>0.2 GeV/*c* p-value = 0.8

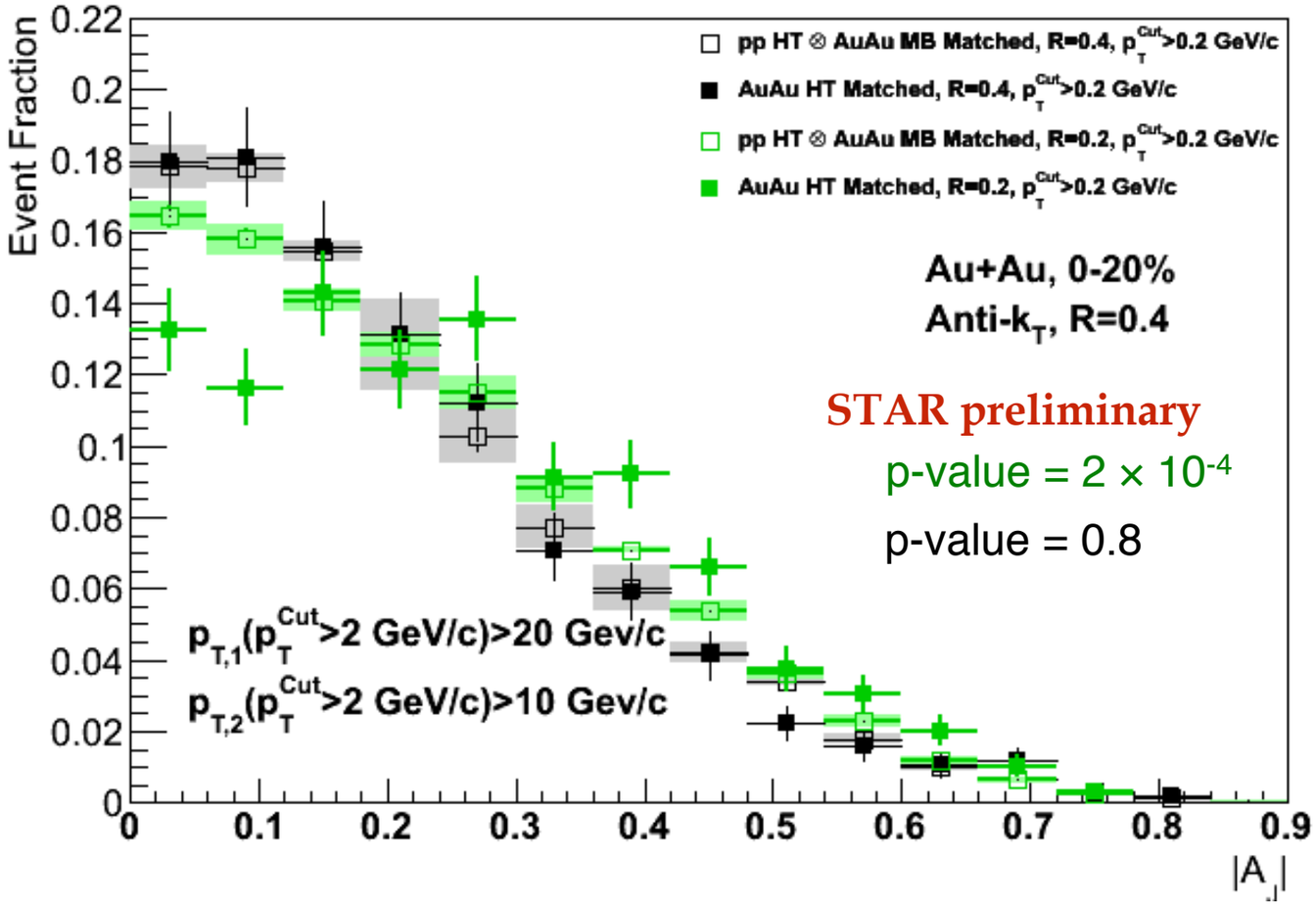
- If AuAu dijet == pp dijet with AuAu background: Aj balanced
- If AuAu dijet != pp dijet with AuAu background: Aj imbalanced

- From p_T = 2 → 1 → 0.2 GeV/*c*, dijet gradually regains balance.
- Lost energy remerges to low p_T particles.

Dijet Imbalance: Jet Traverse Profile

p_T>0.2 GeV/c

K. Kauder, Tue 13:30
Jets



R=0.2 Dijet imbalanced

↓

R=0.4 Dijet balanced

Sub-leading jet gets broadened.

Beam Energy Scan Program

Observables:

1st order phase transition

(1) Azimuthally sensitive HBT

(2) Directed flow v_1

Partonic vs. hadronic dof

(3) R_{AA}: Nucl. Mod. Fact.

(4) Charge separation

(5) v_2 - NCQ scaling

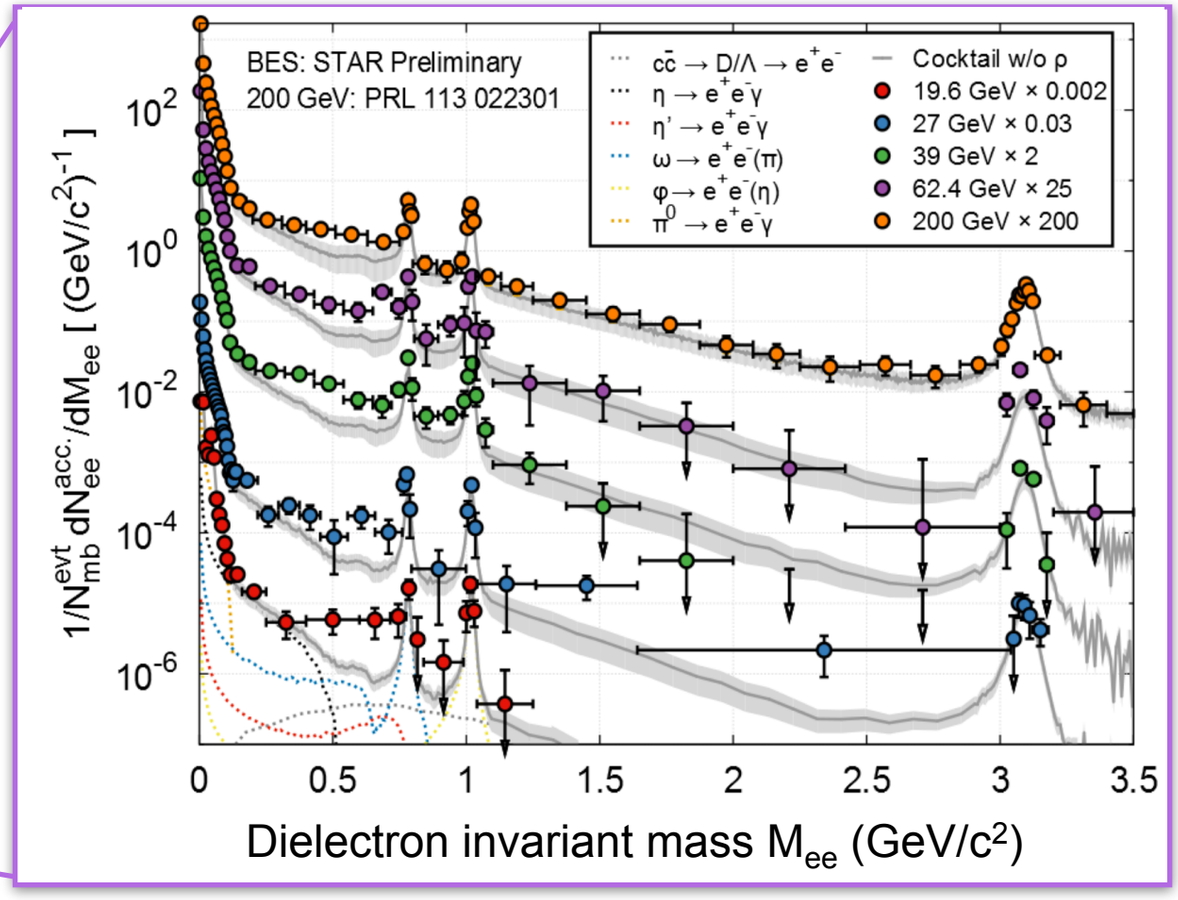
Critical point, correl. length

(6) Fluctuations

Chiral symmetry restoration

(7) Di-lepton production

BES-I: $\sqrt{s_{NN}}$ = 7.7, 11.5, 14.5, 19.6, 27, 39, 62.4GeV



- BES-II and lower energy d+Au and p+p collisions needed

B. Huang Wed 09:00
EW and Associated Topics

Summary and Outlook

- **MTD** and **HFT** detectors running successfully
  - J/ψ yield
  - D^0 signal
- Υ and D^0 in higher energy density **U+U** collisions confirm suppression trend seen in Au+Au
- Jet probes at RHIC
  - Larger jet suppression measured at RHIC energy than LHC
  - Large jet angle diffraction
  - Jet substructure broadening and softening
- BES-II in 2019-2020

Enjoy the exciting STAR Results!

A. Schmah	Semi-inclusive Jets	Mon 15:30
K. Kauder	Dijet imbalance	Tue 13:30
H. Qiu	D^0 in Au+Au	Tue 13:30
R. Ma	J/ψ in p+p	Tue 15:20
R. Vertesi	Υ in U+U	Tue 16:20
B. Huang	Dilepton in BES	Wed 09:00
A. Quintero	D^0 Finding in Au+Au	Poster session

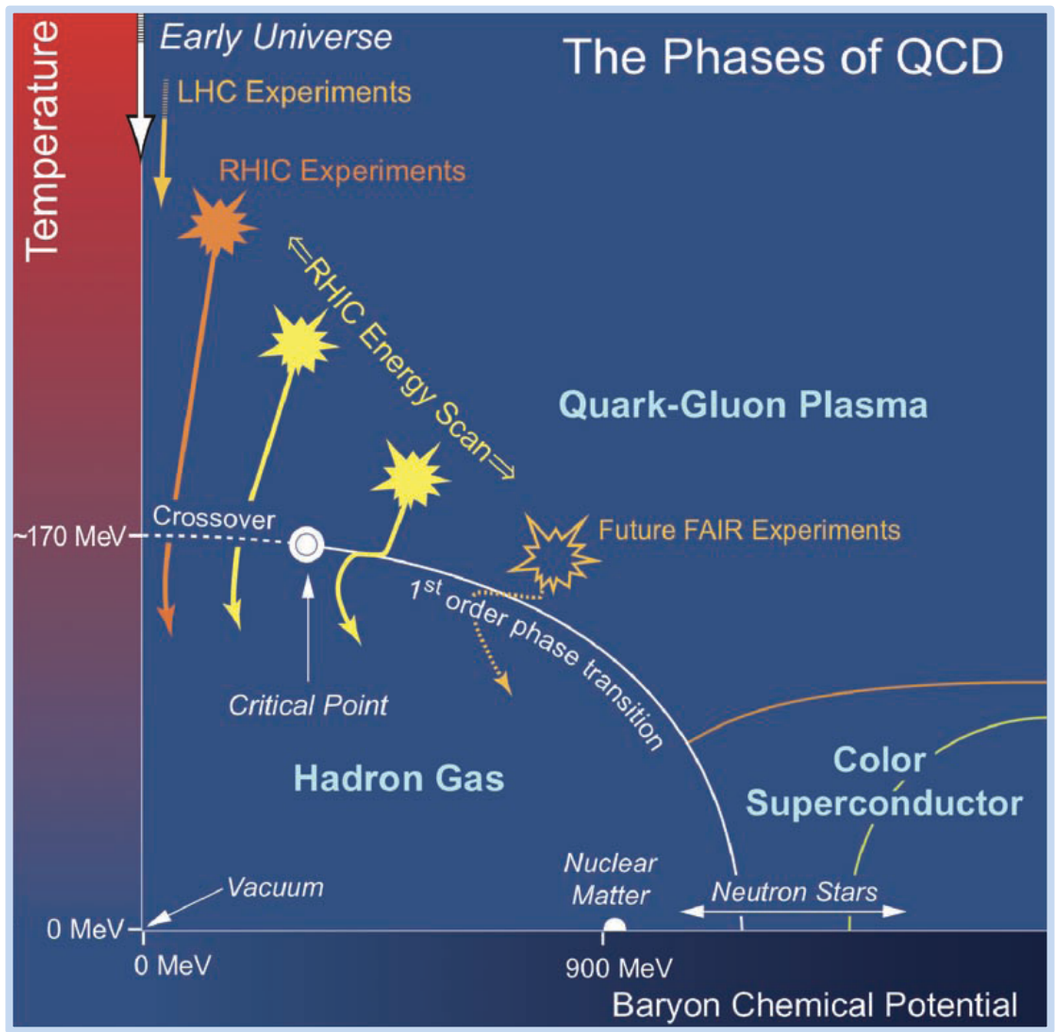
STAR Physics Programs

	Period	Detectors	Collisions
	2001-2009	TPC + BEMC	AuAu, dAu, CuCu, pp
	2010-2011 **(BES-I)**	TPC + BEMC + TOF	AuAu, pp
	2012	TPC + BEMC + TOF	**UU**, CuAu, pp
	2013	TPC + BEMC + TOF + **MTD**	**pp**
	2014 **(BES-I)**	TPC + BEMC + TOF + MTD + **HFT**	**AuAu**, He^3Au
	2015	TPC + BEMC + TOF + MTD + HFT	pp, pAu, pAl

Heavy flavor, jet quenching, beam energy scan..

Beam Energy Scan Program

BES-I: $\sqrt{s_{NN}}$ = 7.7, 11.5, 14.5, 19.6, 27, 39, 62.4GeV



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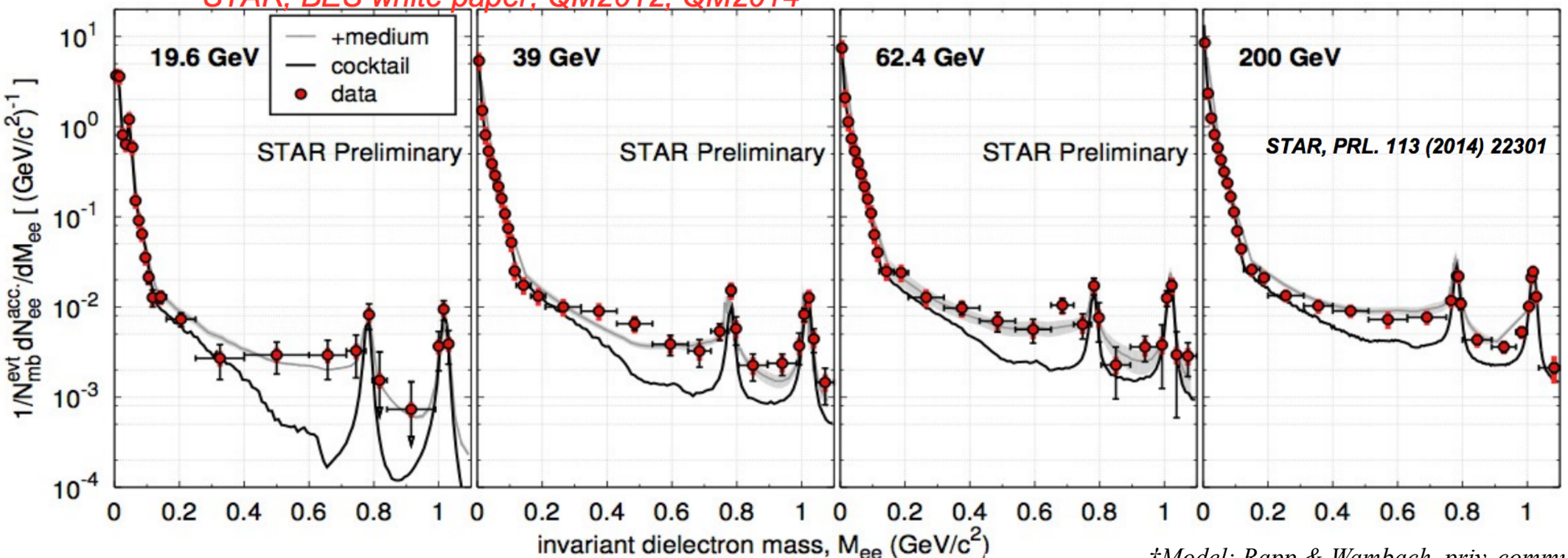
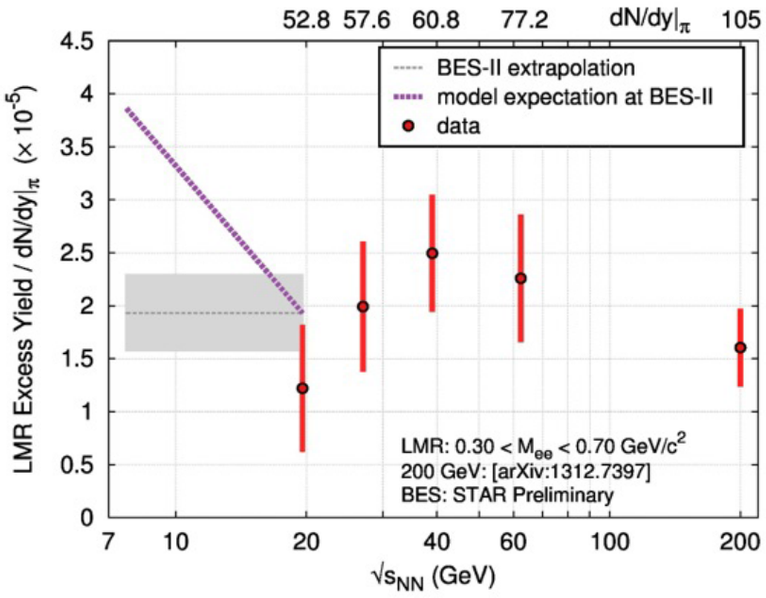
B. Huang Wed 09:00
EW and Associated Topics

Dielectron in Beam Energy Scan-I

STAR, BES white paper, QM2012, QM2014



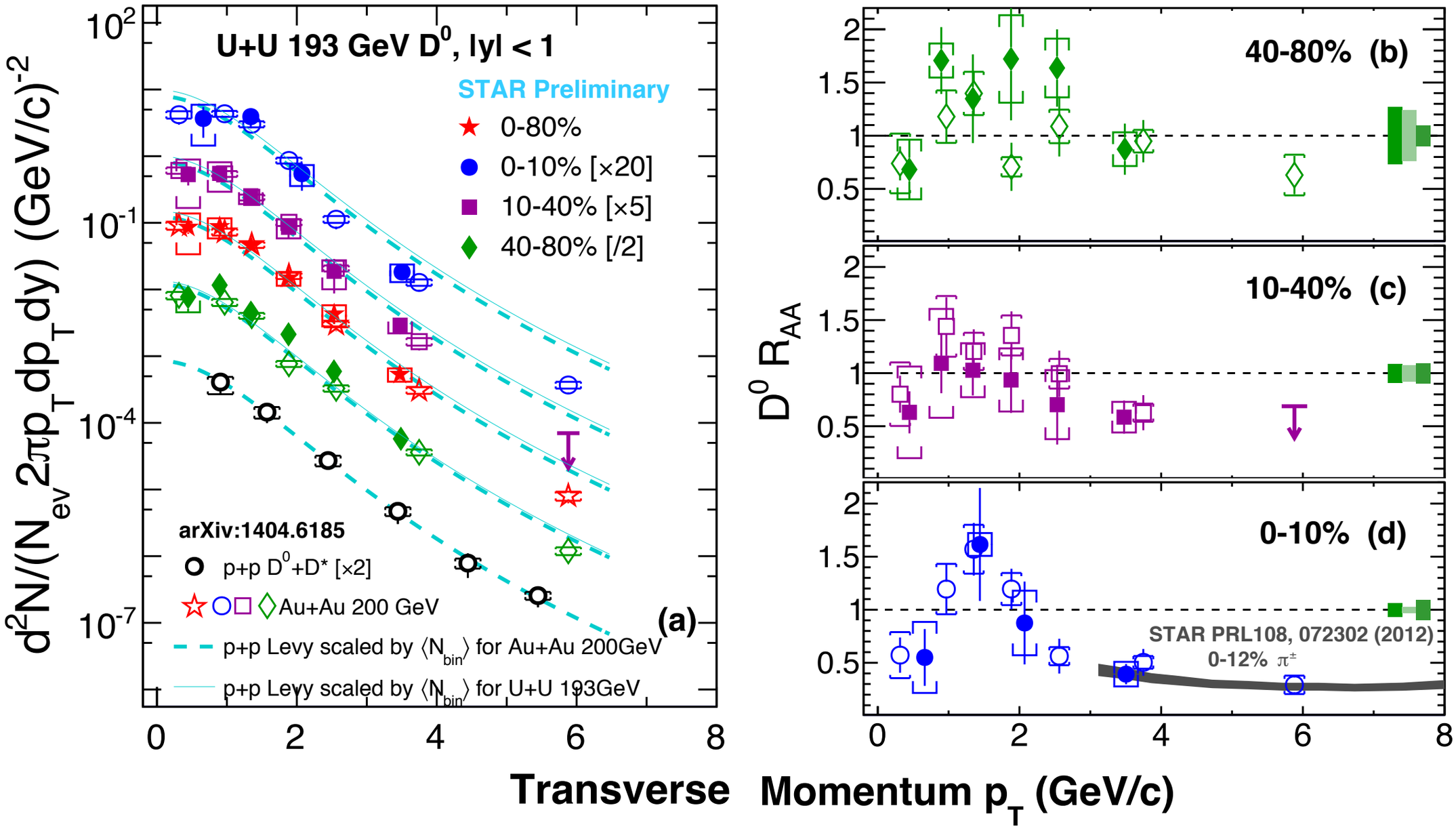
†Model: Rapp & Wambach, priv. communication; Adv. Nucl.Phys. 25, 1 (2000) Phys. Rept. 363, 85 (2002)



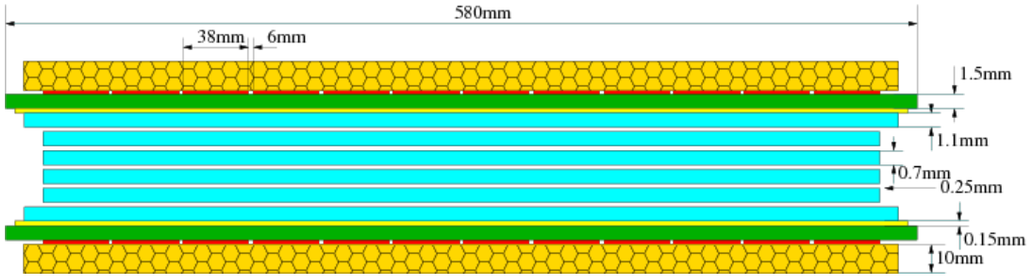
- 200 GeV to 19.6 GeV excess at M_{ee}<1.1 GeV/c^2 described by ρ meson in-media broadening
- More excess expected from model due to total baryon density increase at lower energy (< 20 GeV)
- BES-II needed for more statistics below 20 GeV

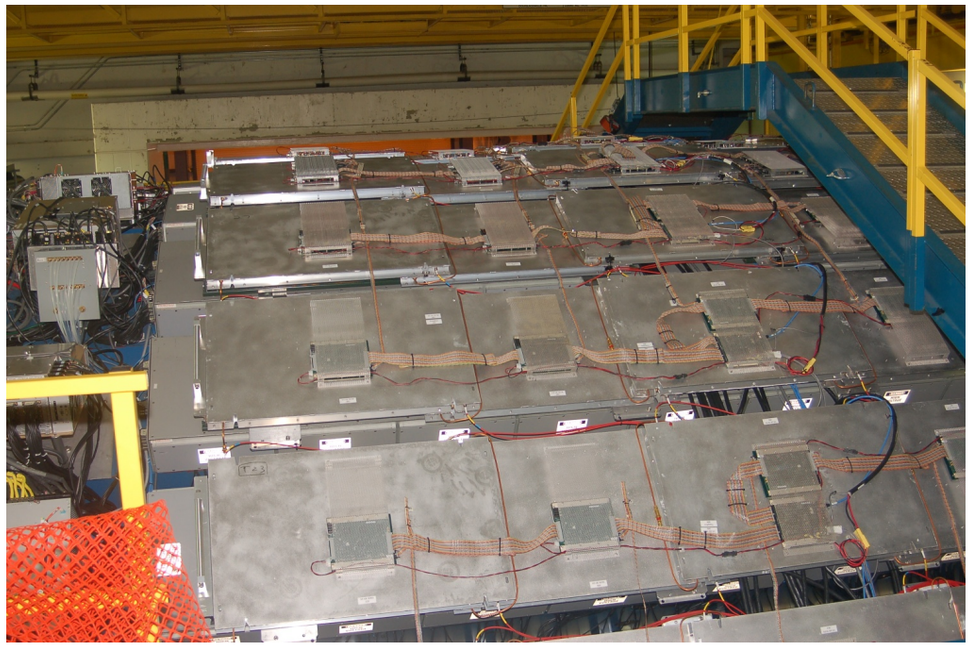
B. Huang Wed 09:00
EW and Associated Topics

Heavy vs Light Flavor Suppression p_T Dependence



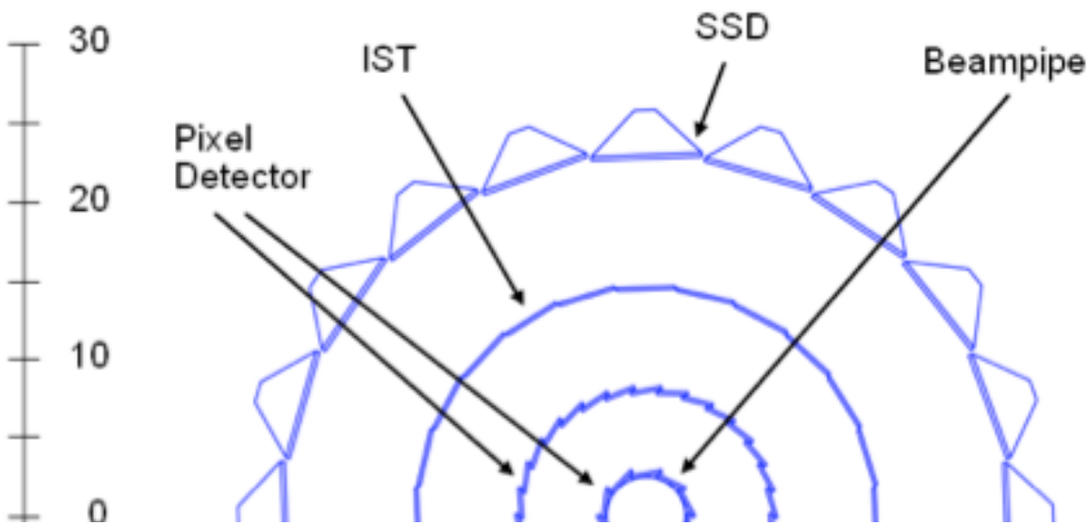
Muon Telescope Detector

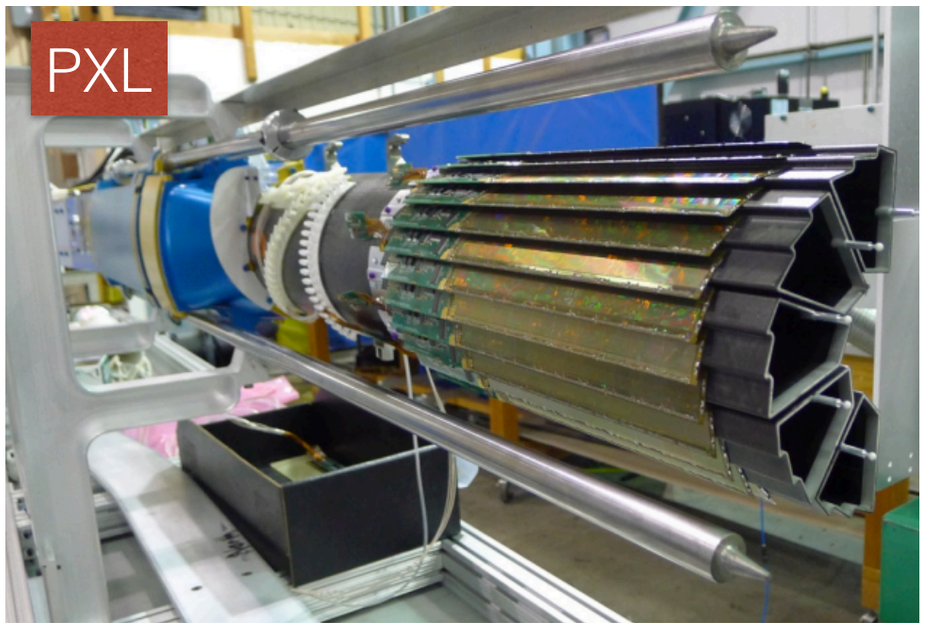




- Multi-gap Resistive Plate Chamber (MRPC) technology
  - Precise timing ~ 95 ps
  - Accurate hit position ~ 1 cm
- Muon identification
  - TPC track and MTD hit match

Open Charm with HFT





- Heavy Flavor Tracker
  3 silicon detectors (PXL, IST, SSD)
  - Direct reconstruction of heavy flavor hadron decay vertex with high resolution

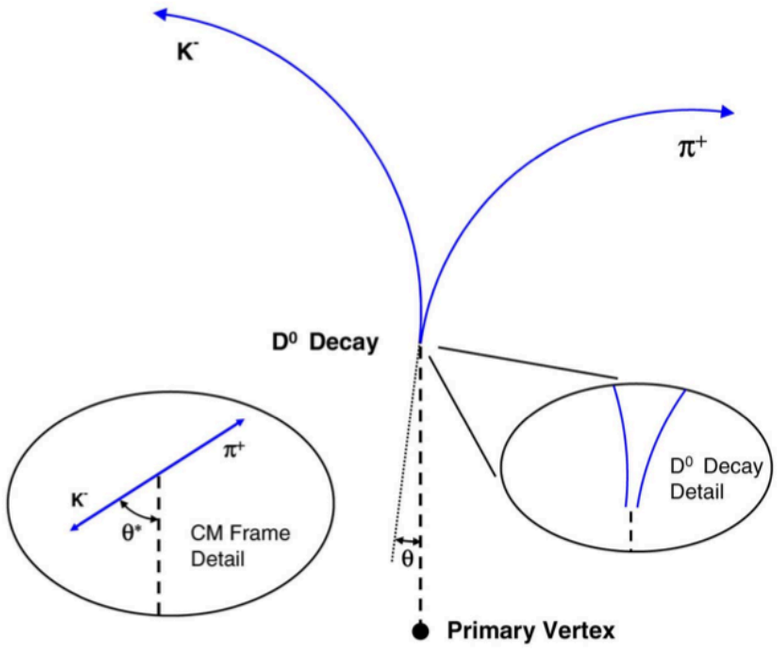
    σ = 6.2 μm (PXL)

H. Qiu, Tue 13:30
HF and Quarkonium

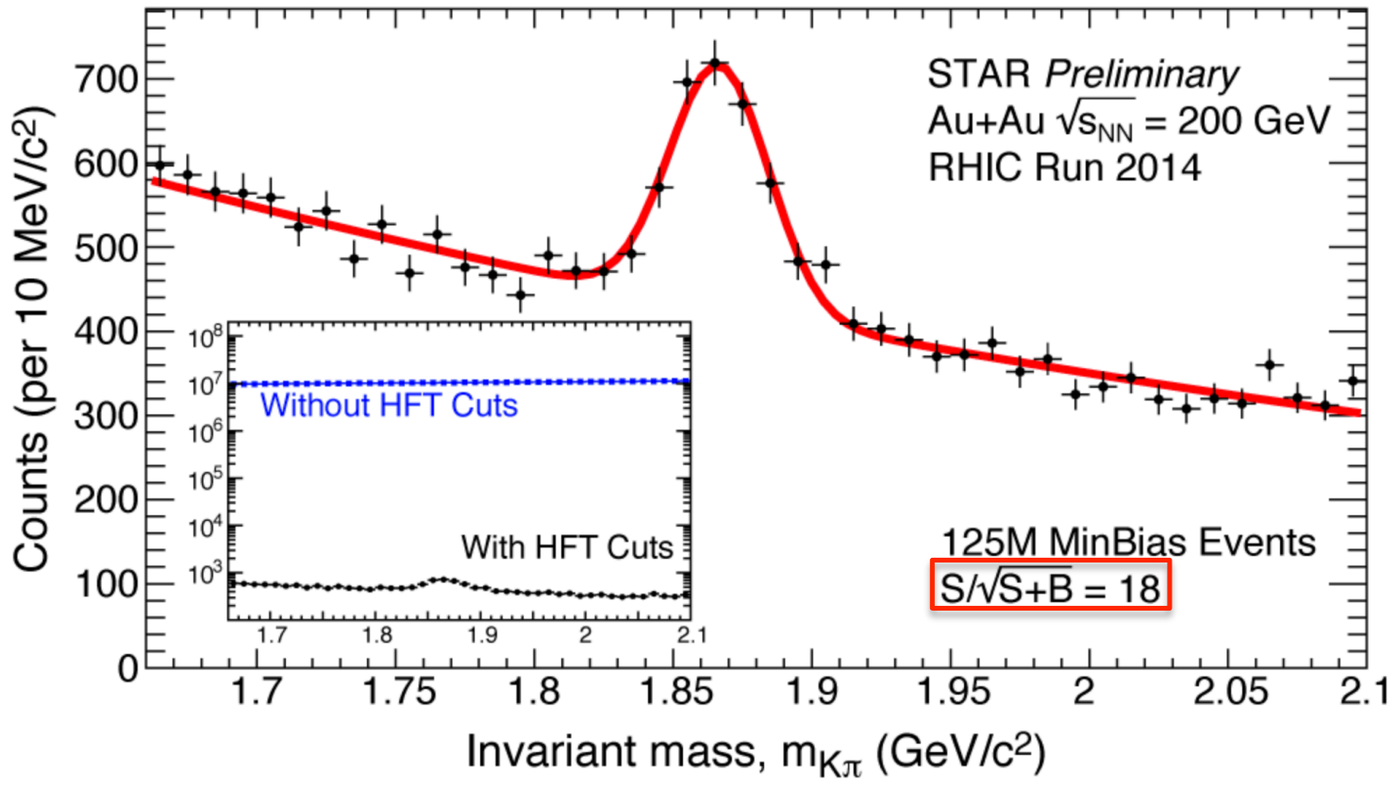
- **D^0 (cū)→ K^- π^+**
  rest frame life time ~120 μm
- Λ_c^+ (udc)→ p K^- π^+
  rest frame life time ~60 μm

D^0 signal with HFT

$D^0 \rightarrow K^- \pi^+$



~10% statistics of year 2014 Au+Au



- Background greatly suppressed by topology cuts with HFT
- Physics results with HFT will come soon.

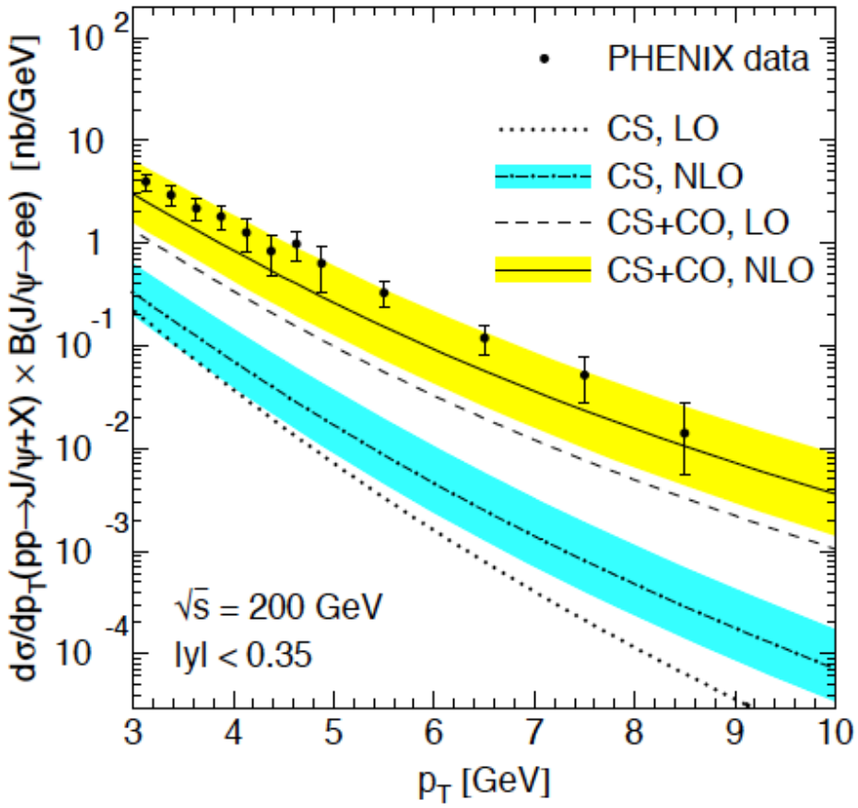
A. Quintero, Poster for Optimize D^0 signal

H. Qiu, Tue 13:30 HF and Quarkonium

Do we understand J/ψ in pp?

- NRQCD long-distance matrix at Next-to-Leading Order from world-data fitting.

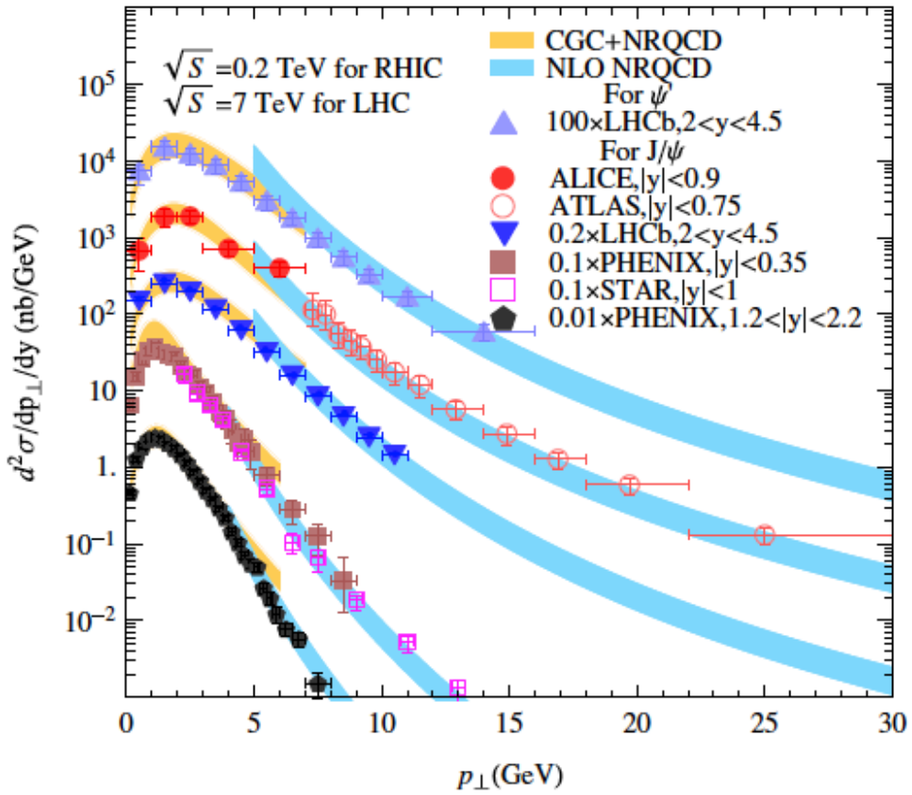
Phys. Rev. D84 (2011) 051501



Low p_T

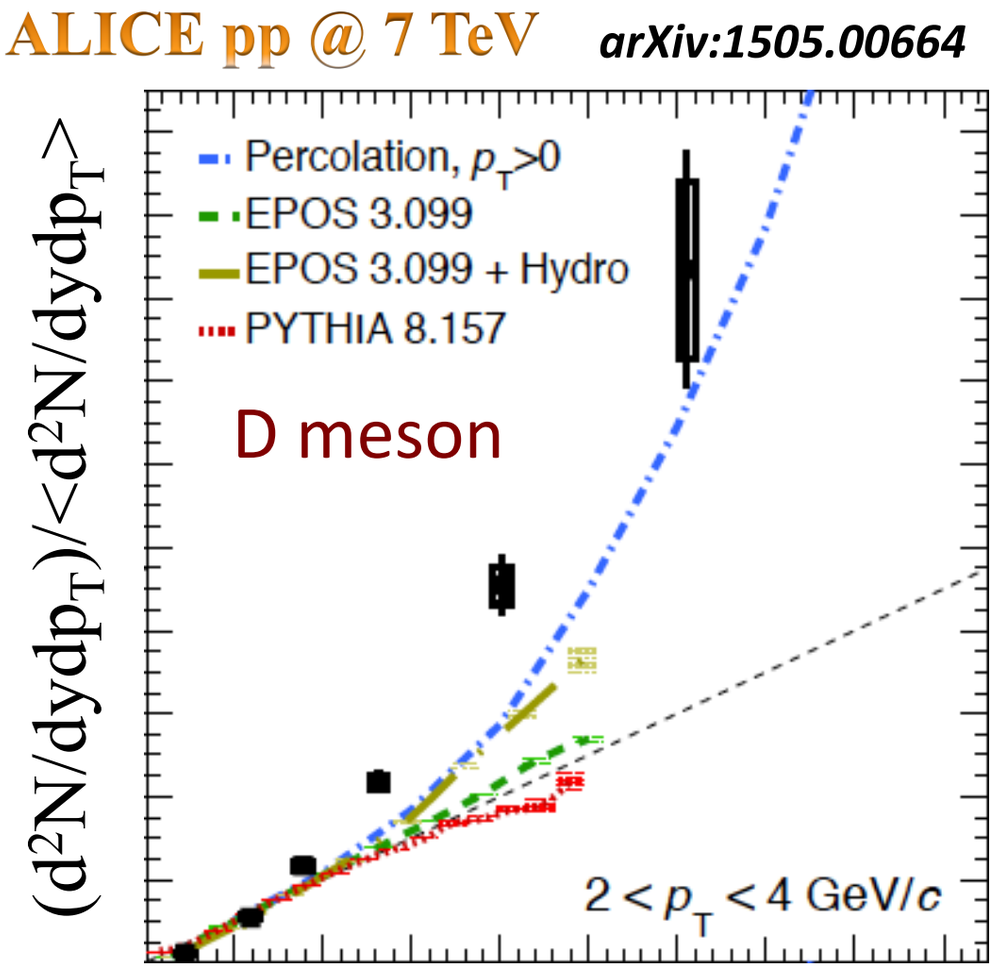
- Color Glass Condensate effective theory to calculate cross section at low p_T

Phys.Rev.Lett. 113 (2014) 192301



- **Good data-theory agreement over $0 < p_T < 30$ GeV/**
  - Caveat: direct J/ψ in model, but inclusive J/ψ for data. ~40% feed-down contribution from excited $c\bar{c}$ states and B hadrons. ***PRD64 (2001) 094015***

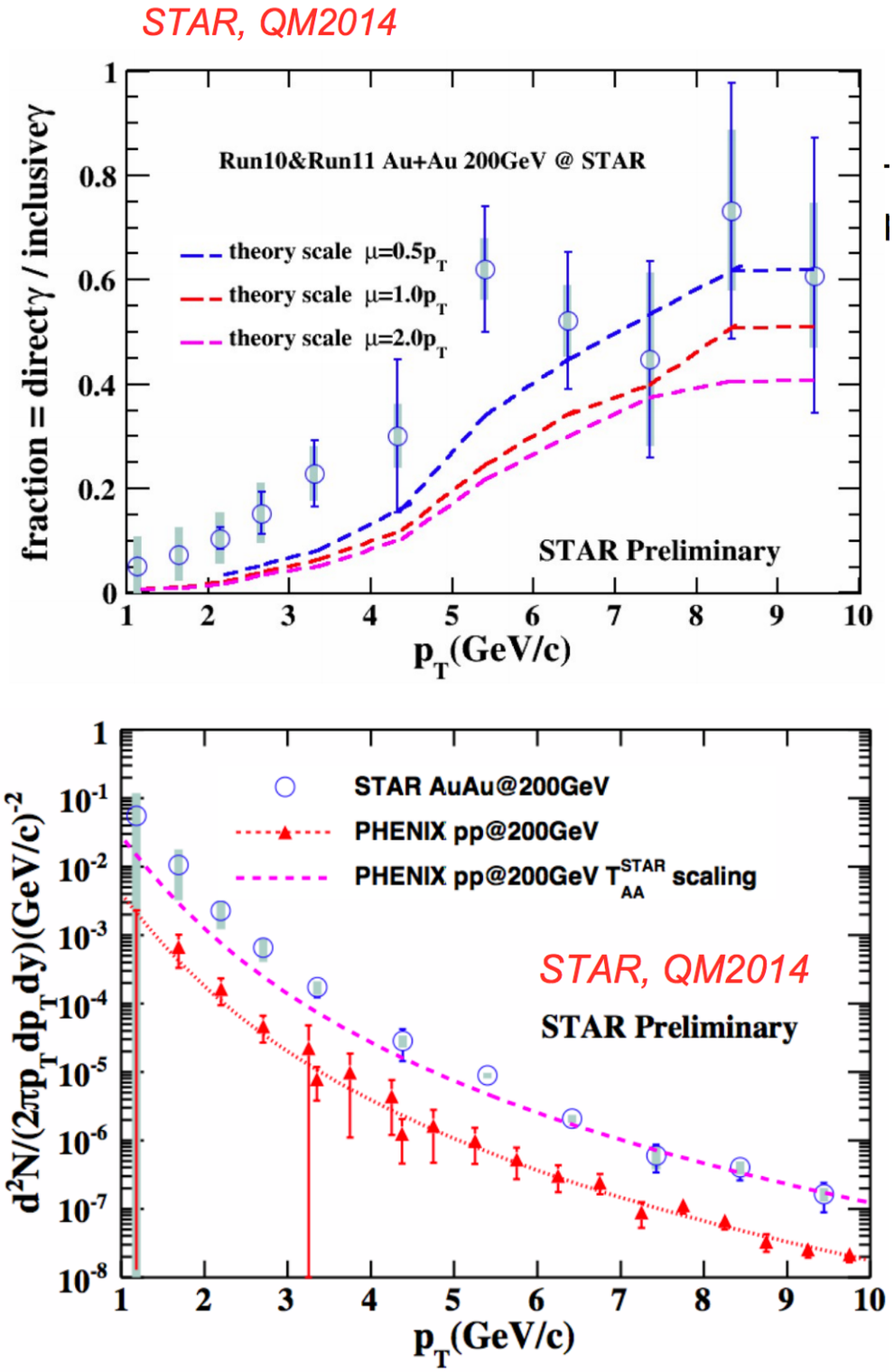
A closer look: Event Multiplicity Dependence

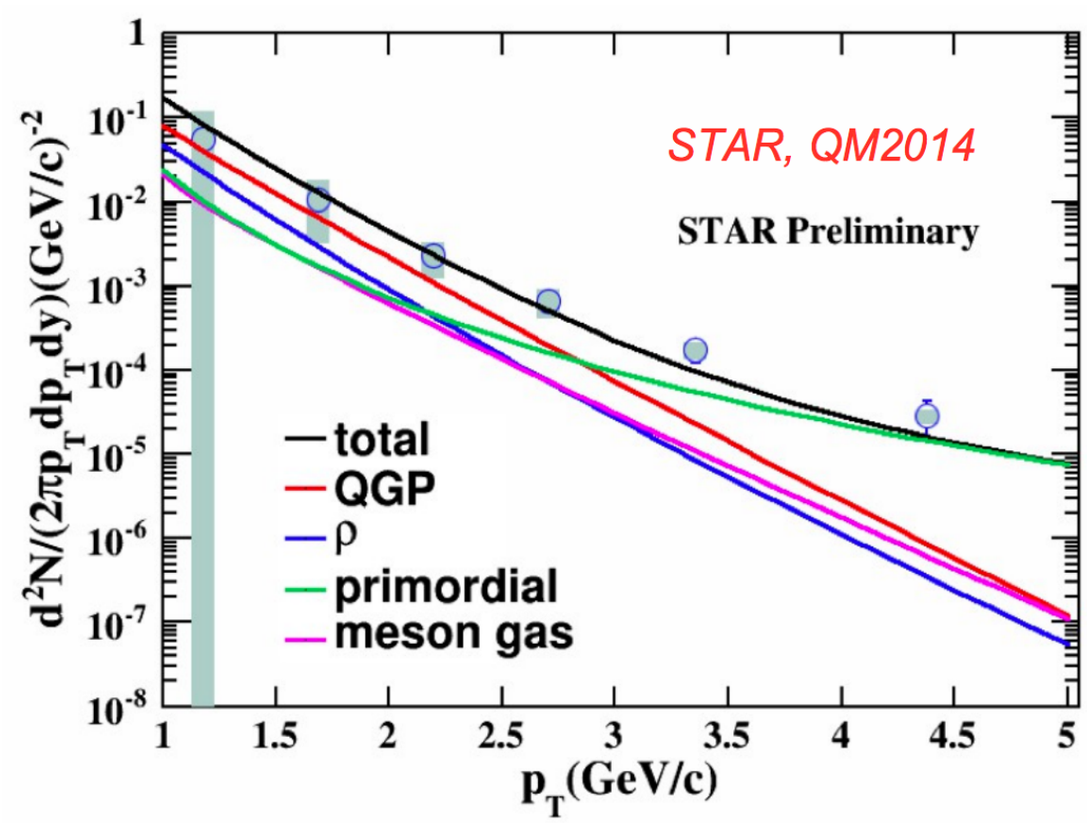


- Stronger-than-linear rise of open charm production vs event activity.
- Similar behavior seen for inclusive J/ψ at both mid- and forward-rapidity.
- Several ideas on the market:
  - PYTHIA 8: c and b quarks produced in Multi-Parton-Interaction -> **underestimate yield at large multiplicity**
  - Percolation model: string screening -> **quadratic rise at high multiplicity**
  - Hard process is associated with larger gluon radiation

- Collective effects in high-multiplicity pp collisions?
- Do we see similar or different behavior at RHIC?

Direct virtual photon yield





In high p_T region (5~10 GeV/c):

– consistent with T_{AA} scaled function fit to PHENIX p+p data.

In low p_T region:

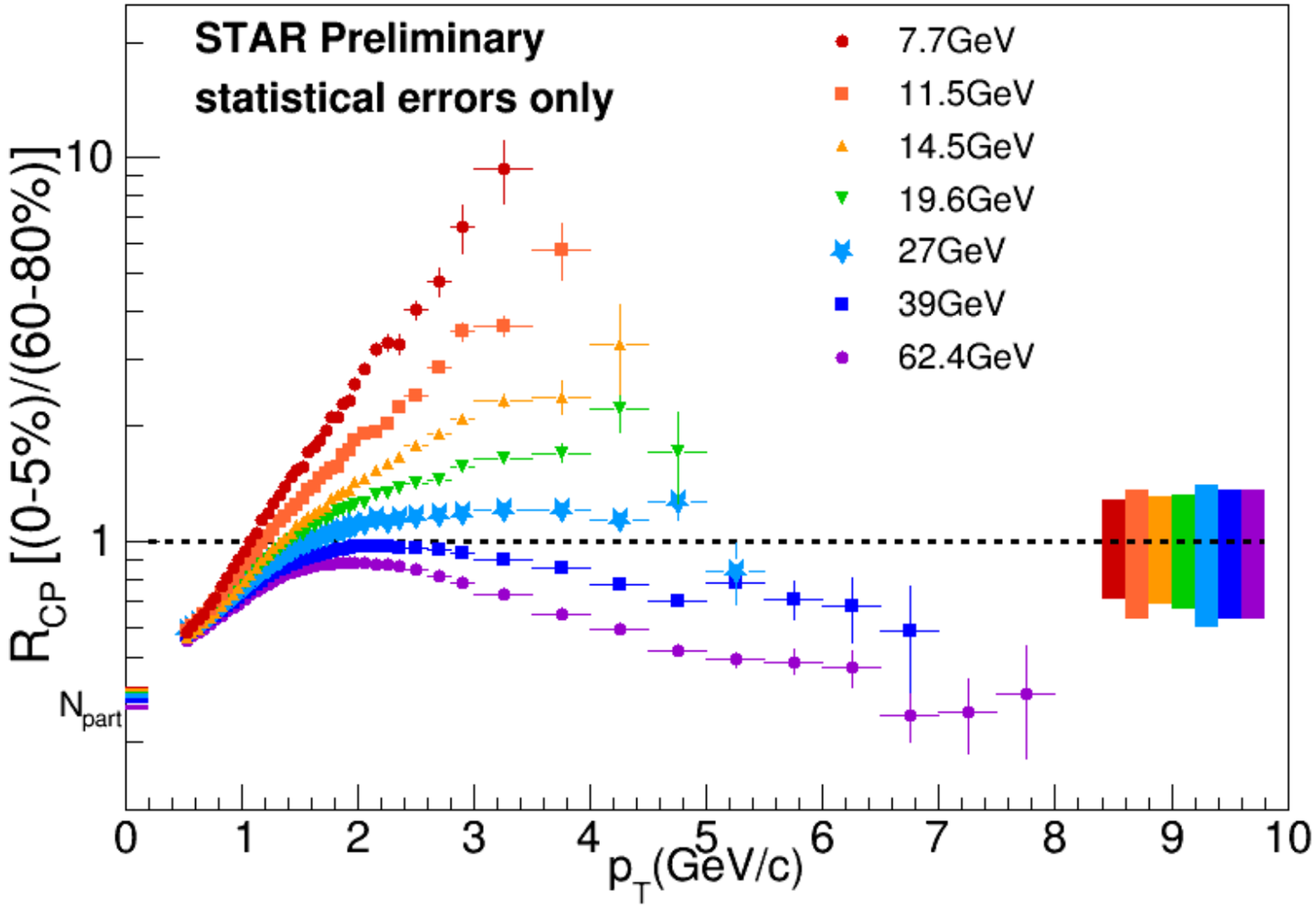
– an excess is observed in p_T range 2~4 GeV/c.

Rapp's model prediction:

➔ Including QGP, ρ, meson gas, and primordial production contributions.

➔ Well describing the low p_T excess in our data within uncertainty.

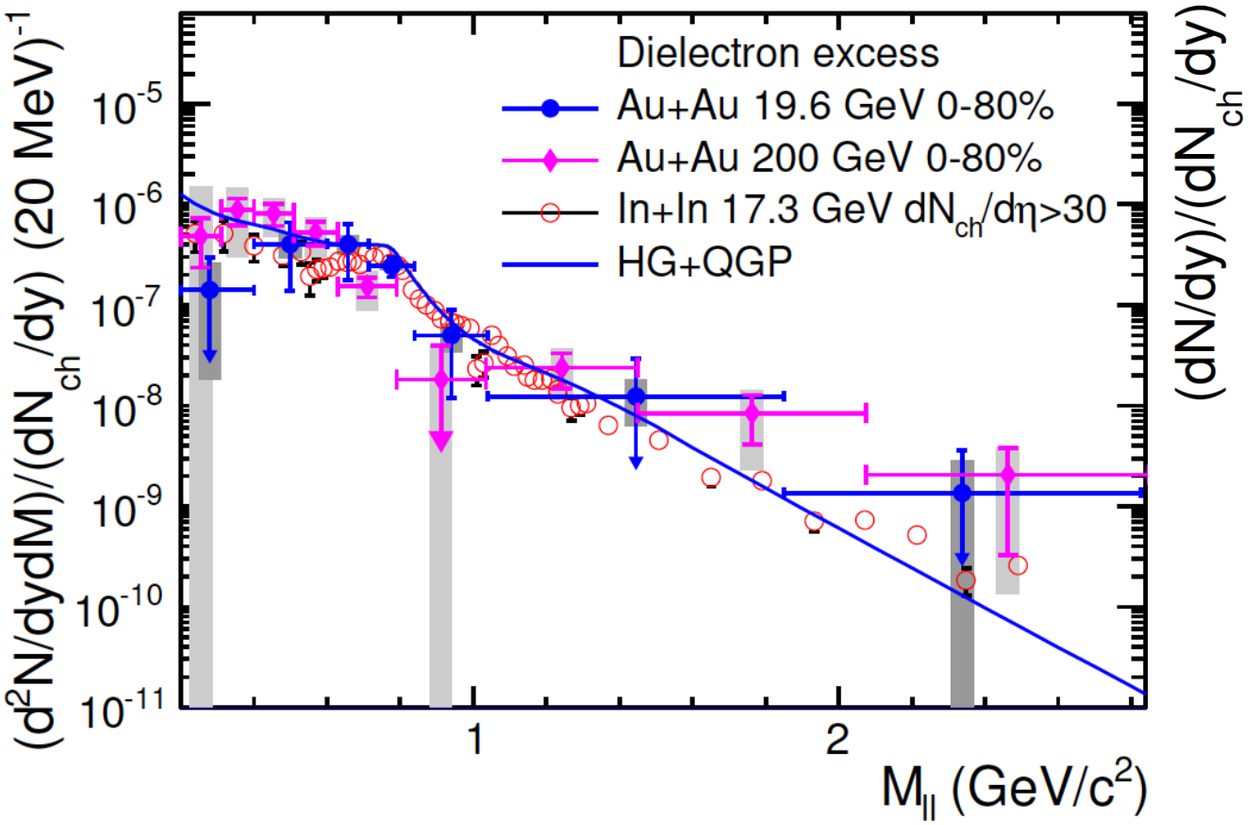
Nuclear Modification Factor in BES-I

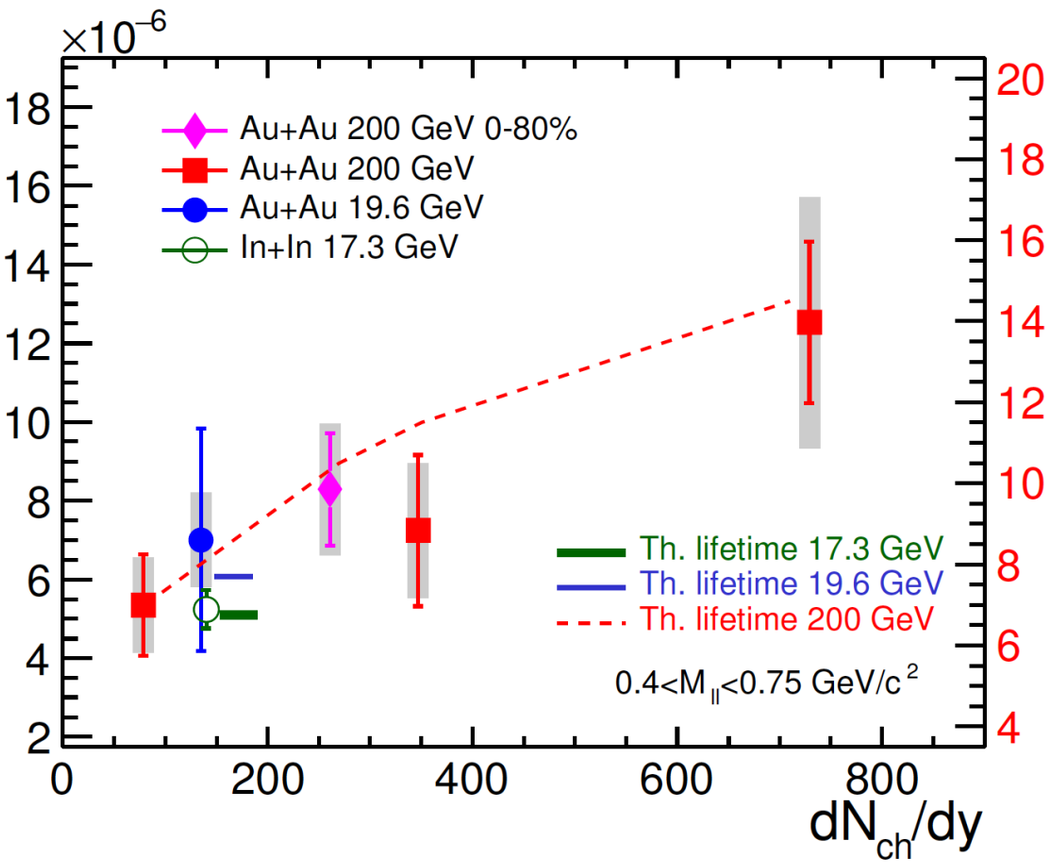


- Jet quenching disappear?
- Cold nuclear effect?
- BES-II and lower energy d+Au and p+p collisions

Energy dependence of dilepton excess

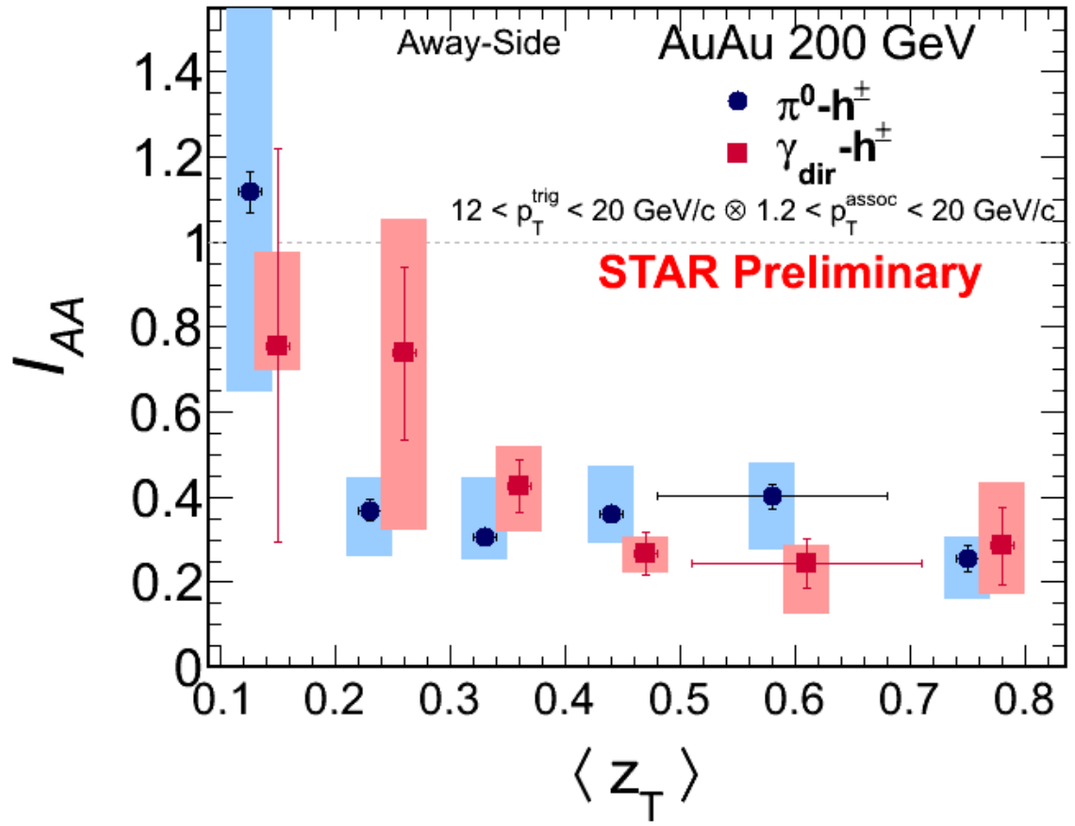
arXiv:1501.05341





- 19.6 GeV consistent with SPS results.
- Excess shape at low mass well described by rho in-medium broadening.
- Excess yields (after detector acceptance correction) are sensitive to early system lifetime: integrated over duration at the high temperature.

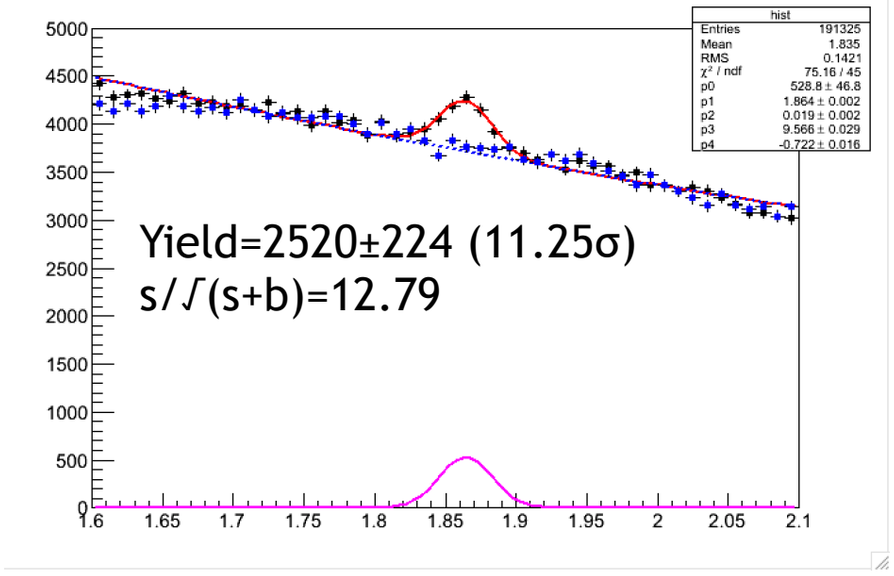
r-jet



- $I_{AA}^{\pi 0\text{-}h}$ and $I_{AA}^{\gamma dir\text{-}h}$ show similar and strong suppression
- At low z_T, data suggests lost energy may start to be recovered (with large uncertainty)

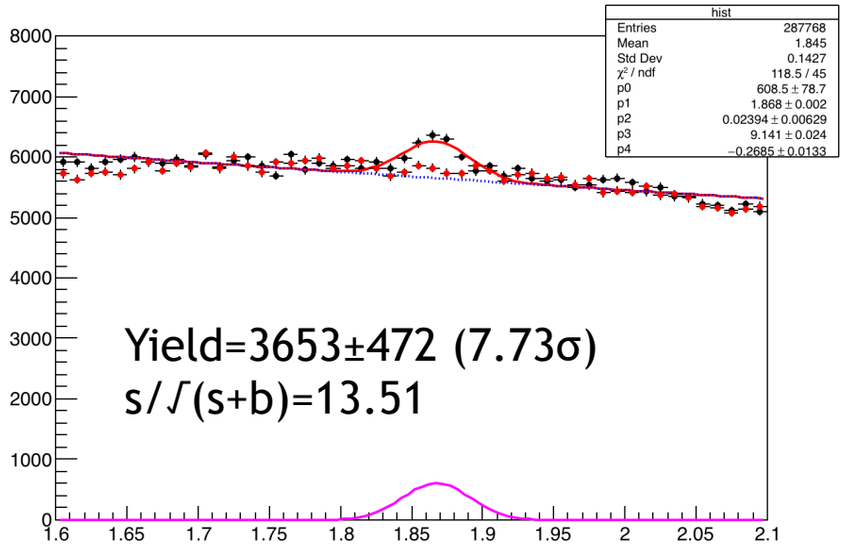
KFParticle: reconstruction of decay particles using Kalman Filter algorithm

D^0 -> K p
100 million minimum bias events

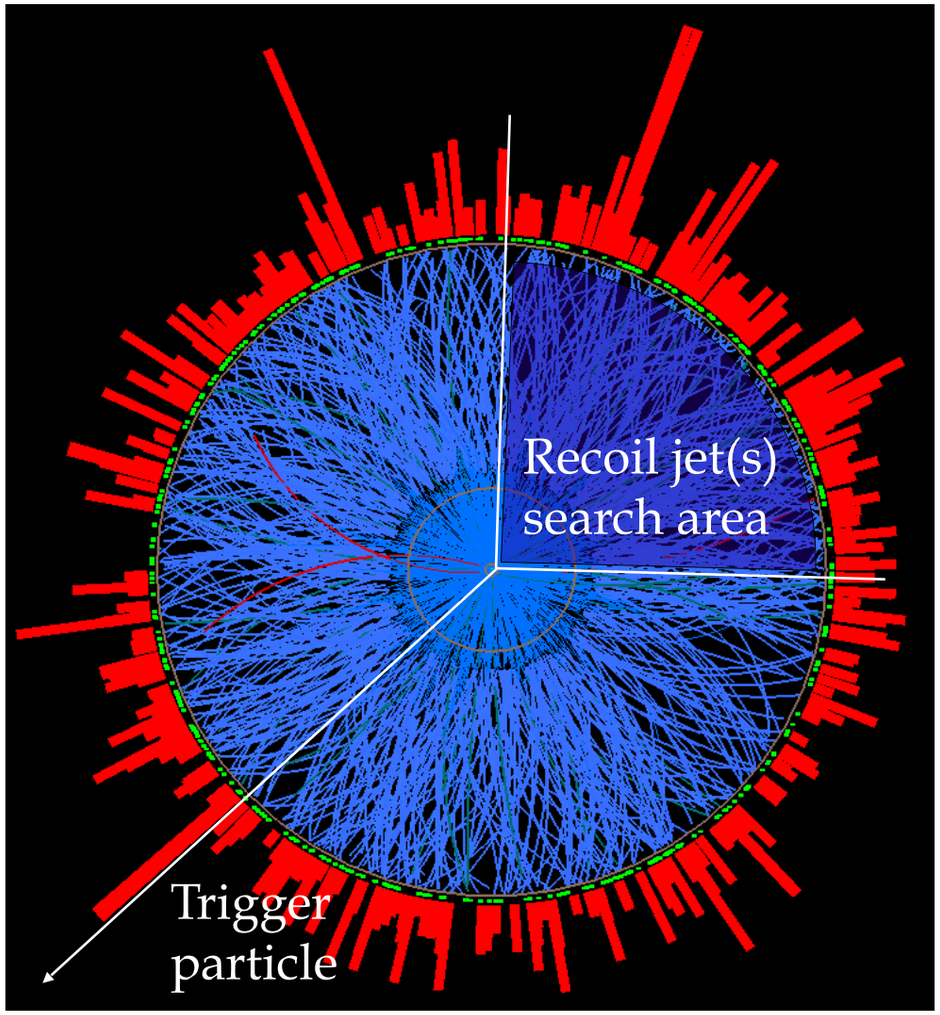


Optimize D^0 signal

TMVA for signal optimization



Semi-Inclusive Recoil Jets



Semi-inclusive yield of jets recoiling from a high p_T hadron trigger

$$\frac{1}{N^h_{trig}}\frac{dN_{jet}}{dp_{T,jet}} = \frac{1}{\sigma^{pp\to h+X}}\frac{d\sigma^{pp\to h+jet+X}}{dp_{T,jet}}$$

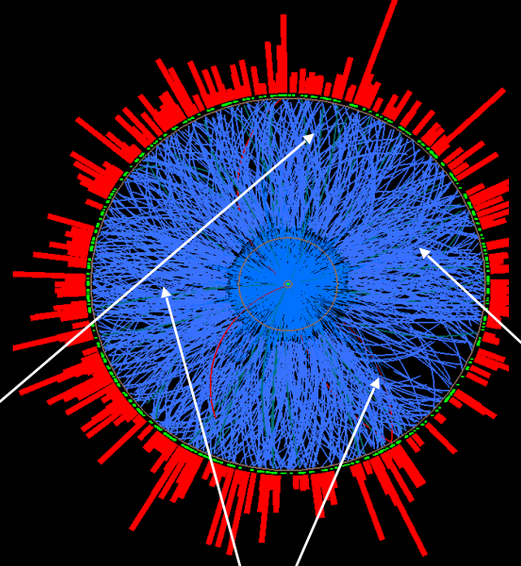
Measured — Calculable in fixed-order pQCD

- Trigger on high p_T hadron → Select hard process with surface bias
- Measure the recoil jets → **No fragmentation bias on recoil side!**
- How to deal with combinatorial jet-finding background?

A. Schmah, Mon 15:30
Jets

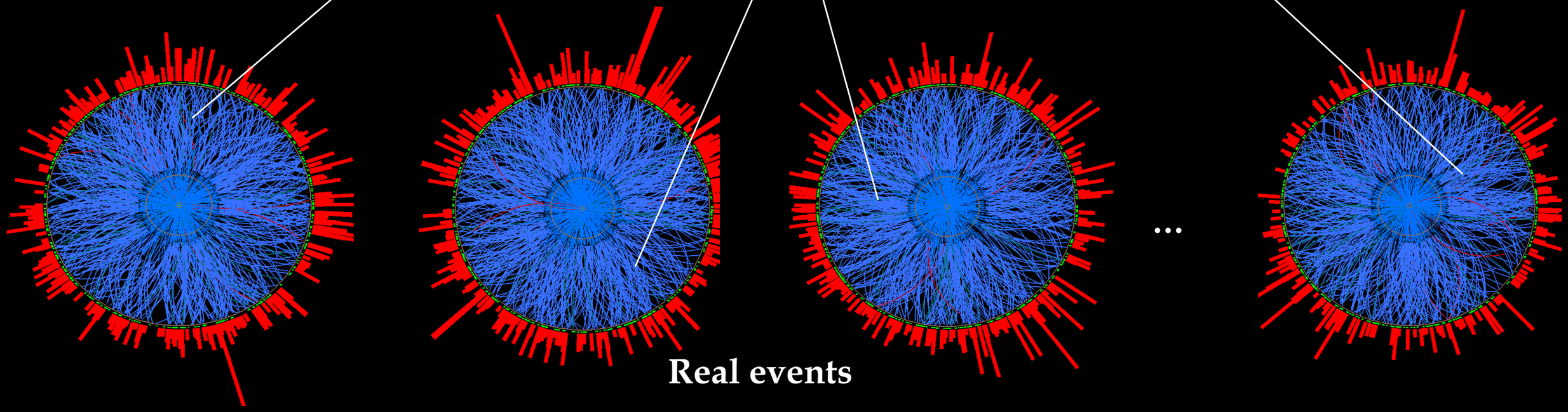
Mixed Event Generation for Jets

Mixed event



Mix only similar centrality, Ψ_{EP}, z-vertex position

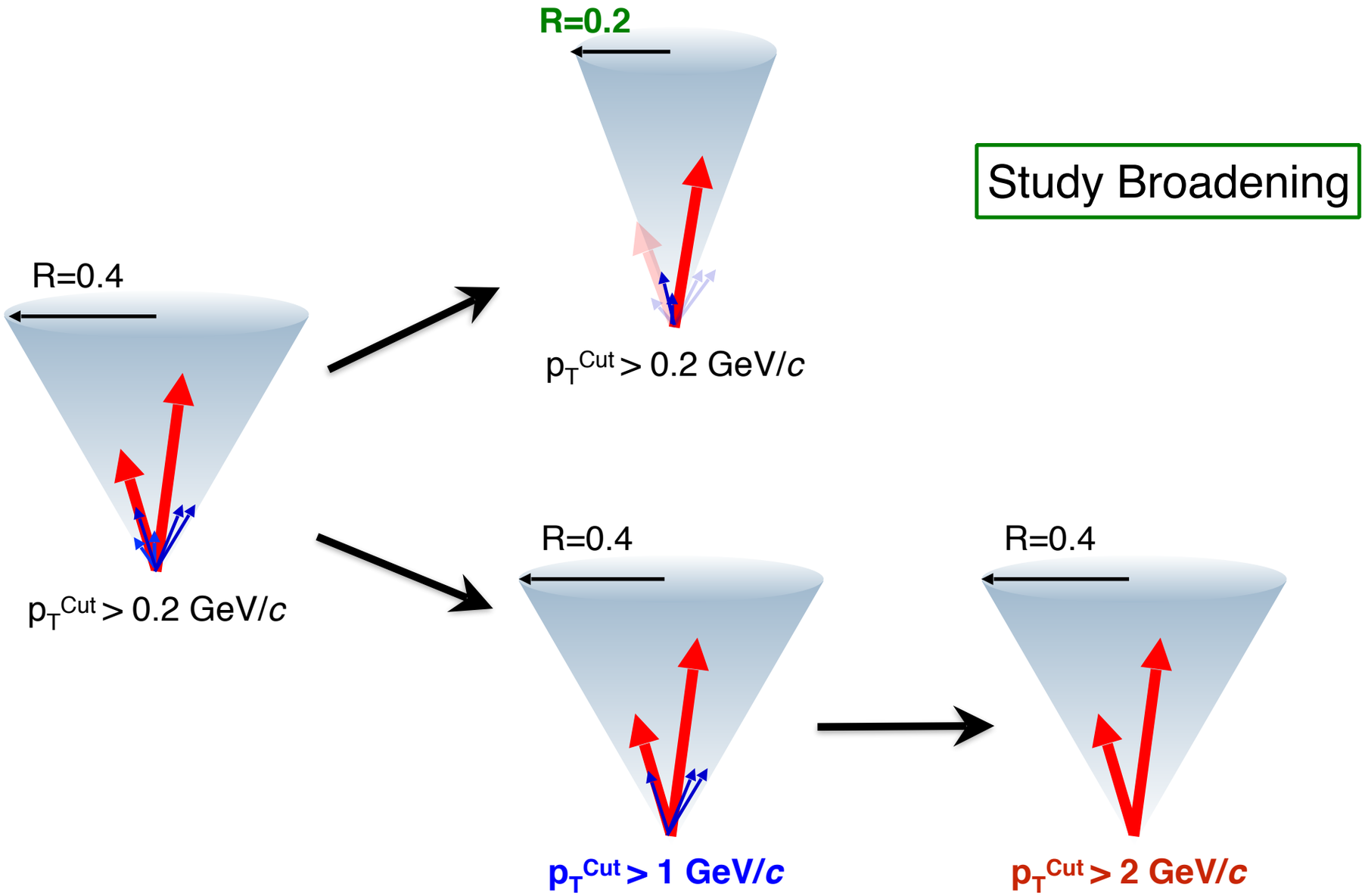
Pick one random track per real event → add to mixed event



Real events

Ev. 1 **Ev. 2** **Ev. 3** ... **Ev. 765**

Jet Substructure



Study Broadening

Study Softening