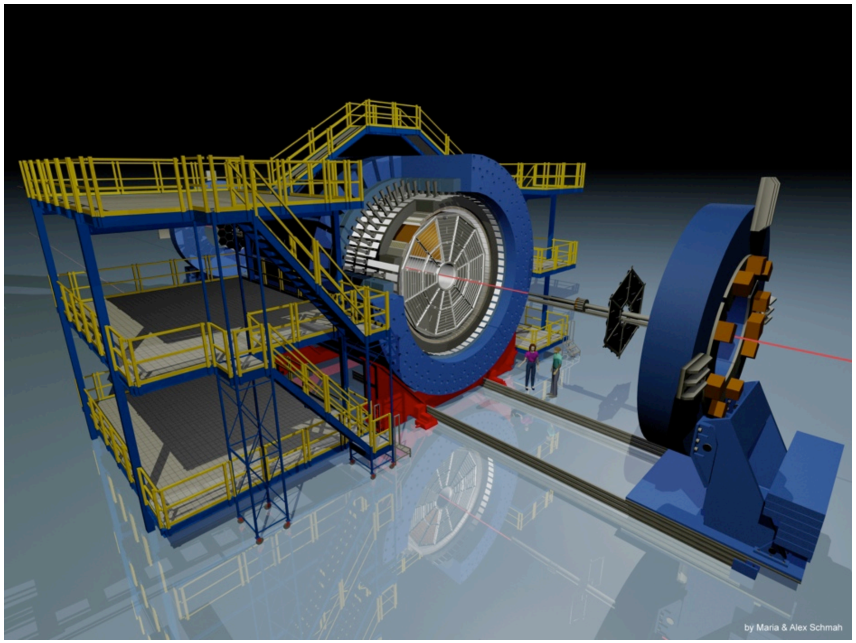
Future Dilepton Measurements at STAR

Frank Geurts
Rice University

Outline

- STAR dielectron results: a brief summary
- Immediate Future: 2014-2016
  - STAR detector upgrades
  - dilepton physics
- Beam Energy Scan, 2nd Phase: 2018-2019
  - dilepton measurements
  - proposed detector upgrades
- Outlook

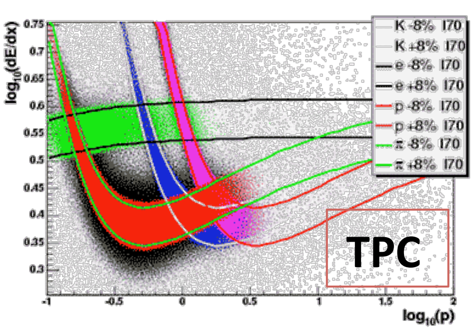
The STAR experiment

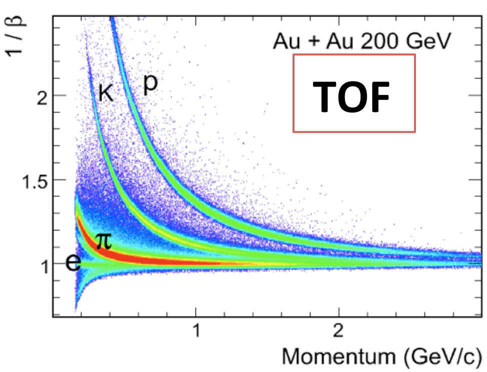


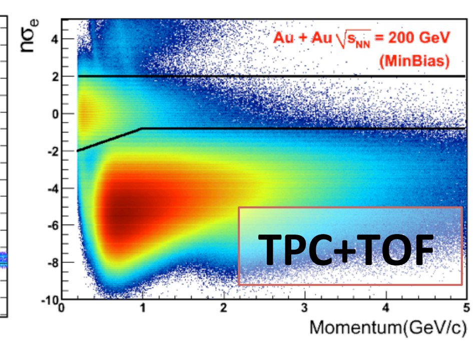
Large & uniform acceptance electron ID

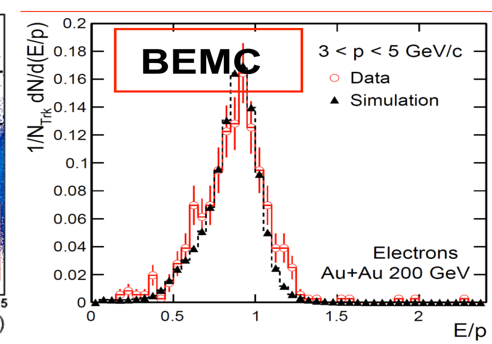
$|\eta| < 1$ and $0 < \phi < 2\pi$

- Time Projection Chamber
  - tracking, dE/dx PID
- Time-of-Flight detector
  - removal of “slow” hadrons
  - improves electron purity
- Electromagnetic Calorimeter
  - high-p_T trigger
- Fast data acquisition









Brief Summary

Current state of dielectron measurements at STAR

- At this workshop

  - dielectron production and elliptic flow at 200 GeV (Xin Dong)
  - direct virtual photon production at 200 GeV (Bingchu Huang)
  - dielectron production from RHIC BES (Joey Butterworth)

- At QM'14

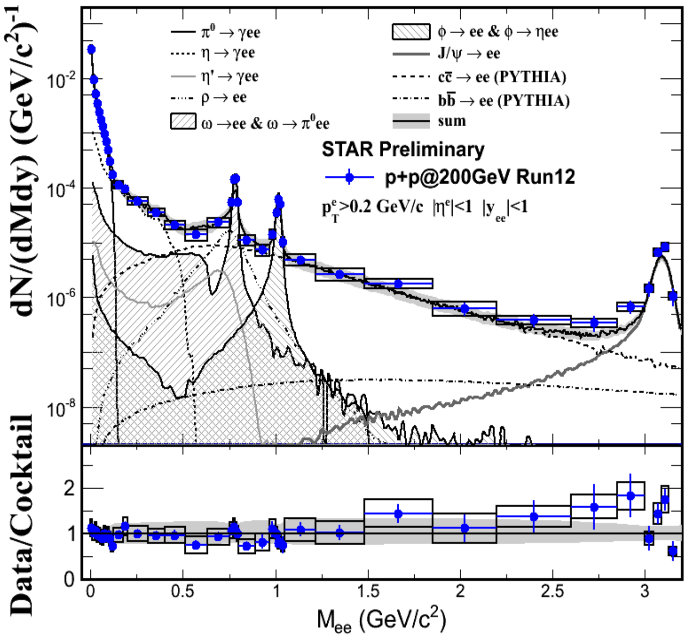
XXIV QUARK MATTER DARMSTADT 2014

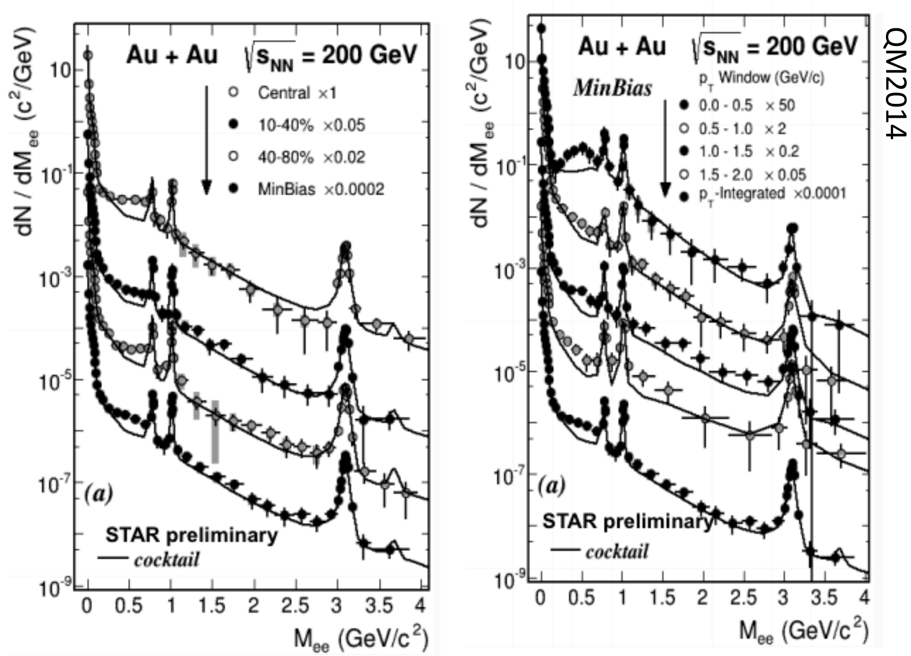
  - 3 parallel talks (Patrick Huck, Chi Yang, *Wangmei Zha*)
  - 8 posters (Joey Butterworth, Yi Guo, Kefeng Xin, *Ota Kukral, Barbara Trzeciak, Robert Vertesi*, *Qian Yang*, *Guannan Xie*,)
    - incl. low-mass dimuons based on TPC+TOF!

Dielectron Production at 200GeV

p+p baseline: 2012 - much improved statistics

Au+Au: 2010+2011 combined statistics





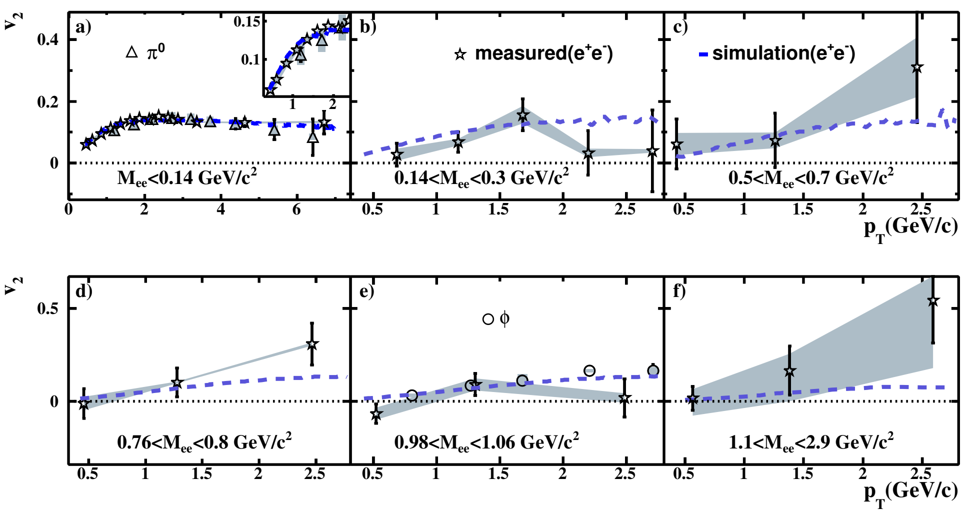
- good description by hadron cocktails
- no strong p_T or centrality dependence of the low-mass enhancement
- indications of modified charm in intermediate mass range

Dielectron Elliptic Flow at 200GeV

Combined statistics of Au+Au runs in 2010 and 2011 (760M)

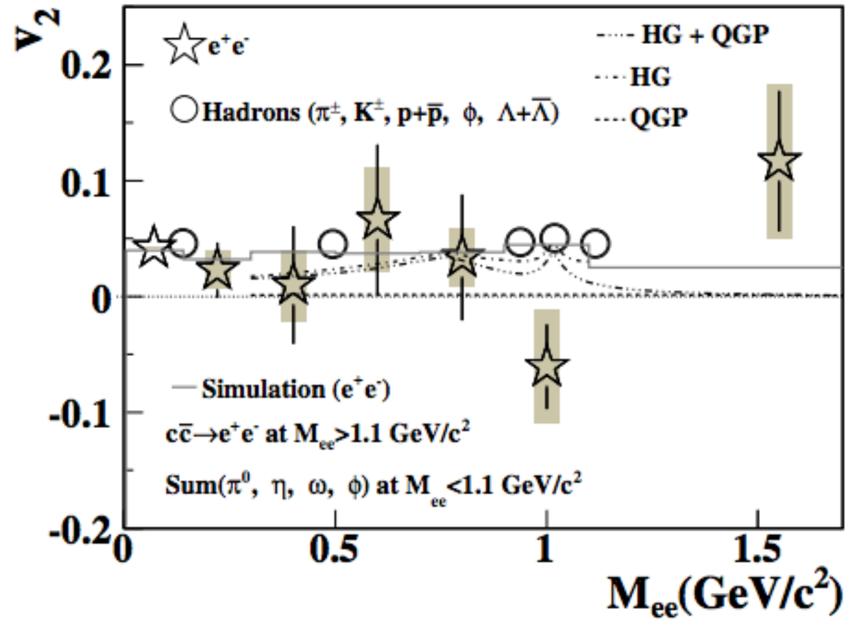
- precision still limited

STAR arXiv:1402.1791



- ➢ $v_2(p_T)$ consistent with simulations & measurements

STAR arXiv:1402.1791



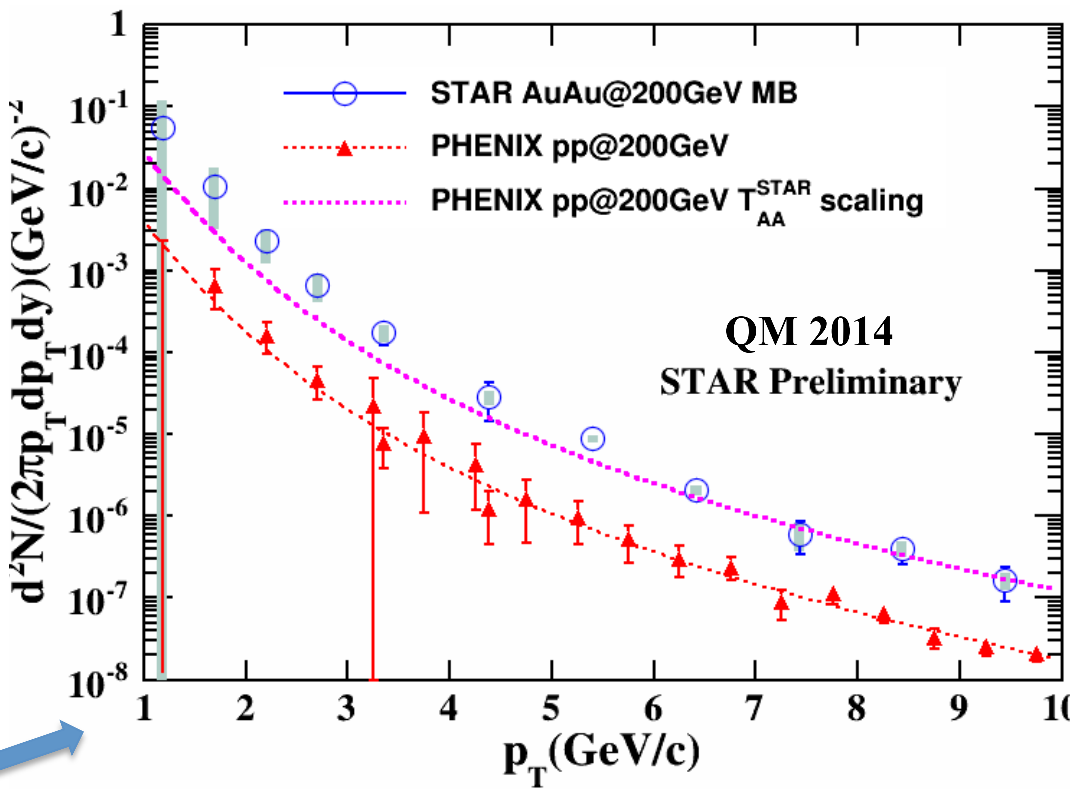
- ➢ $v_2(M_{ee})$ is consistent with cocktail simulations
  - Increase statistics
  - Disentangle charm contributions

Direct Virtual Photon at 200GeV

STAR measurements compared to PHENIX p+p T_{AA}-scaled fit:

- Consistent with high-p_T p+p reference
  - dominated by initial hard scattering

- Excess for $1 < p_T < 5$ GeV/c
  - dominated by QGP



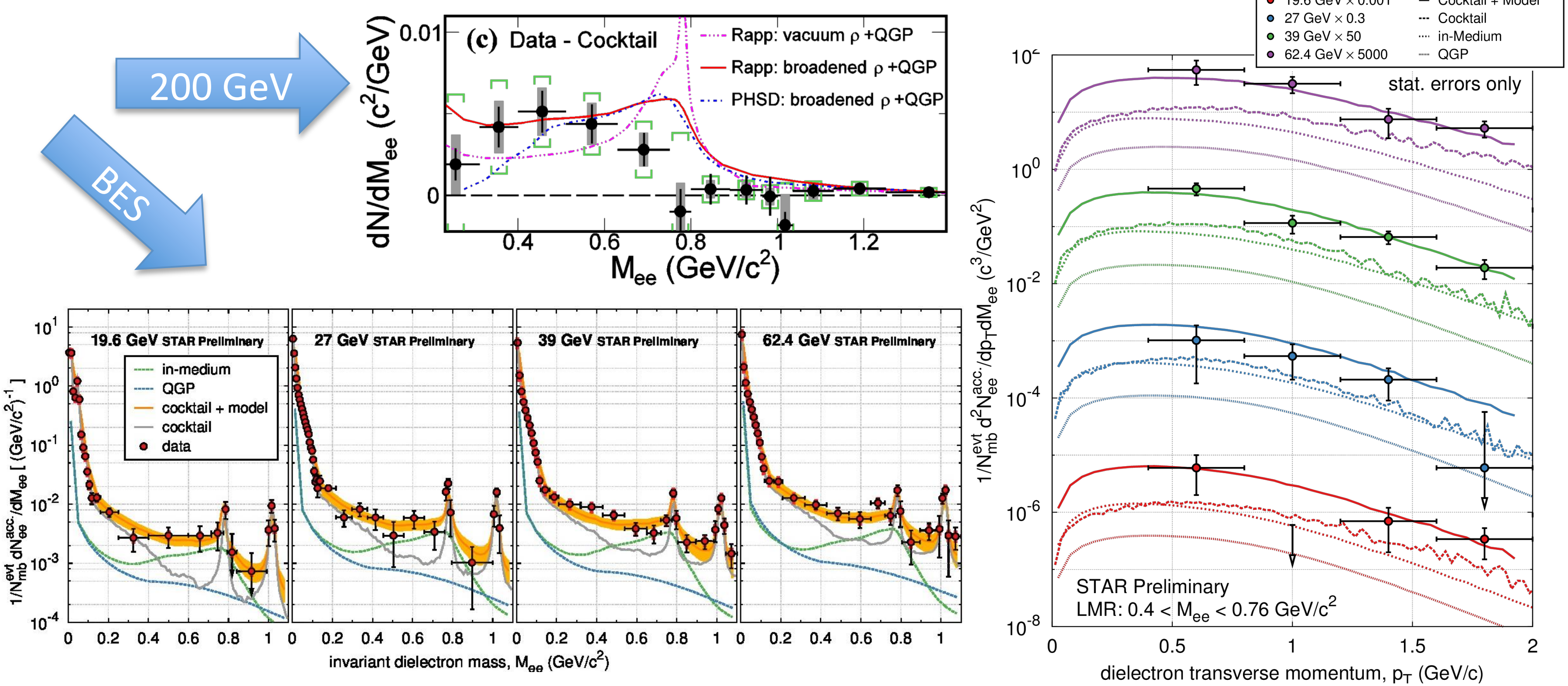
- Large uncertainties for $p_T < 2$GeV/c
  - Lack of η measurements at low p_T

BES Dielectron Production

Systematic measurement of dielectron production from top RHIC energies down to SPS energies

QM2014

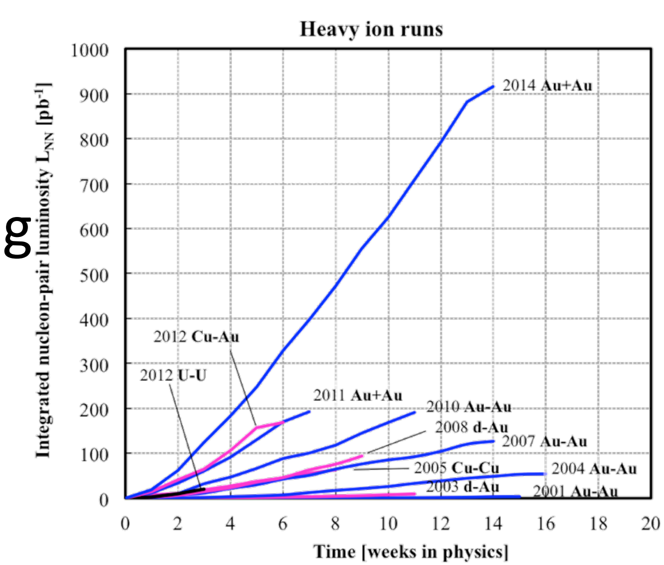
PRL 113 022301

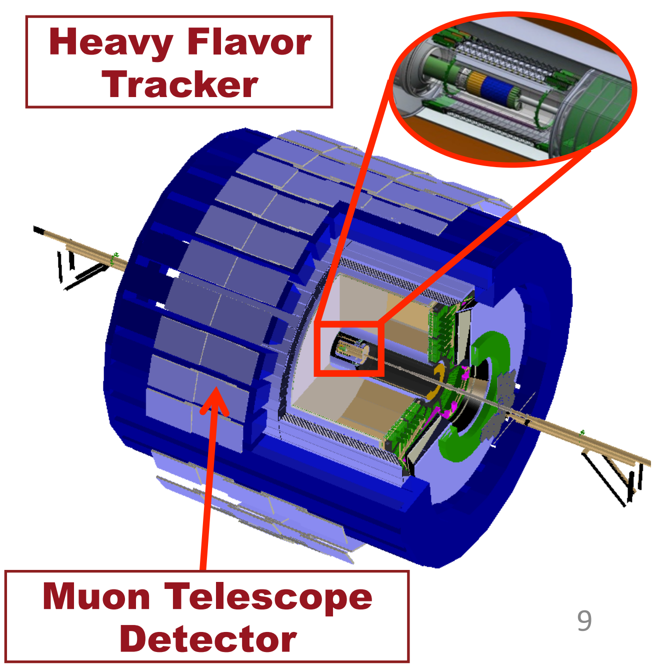


➢ Cocktail + Model contributions consistent with measurements (M_{ee} and p_T)

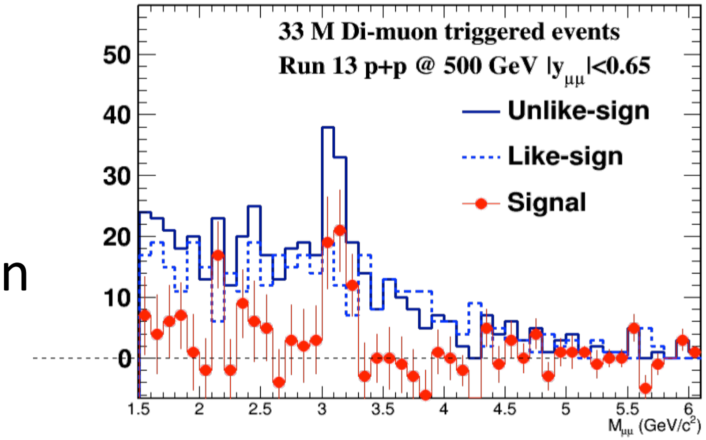
Immediate Future: 2014-2016

- RHIC upgrades
  - fully implemented stochastic cooling
- STAR upgrades
  - Heavy Flavor Tracker
  - Muon Telescope Detector
    dedicated muon triggers: e.g. *e*-muon
- 2014: Au+Au statistics
  - 200 GeV: 1.2B events
  - 14.6 GeV: 20M events
- 2015: p+p (9wks), p+Au,Si (5+2wks)
- 2016: Au+Au (10wks)





Heavy Flavor Physics

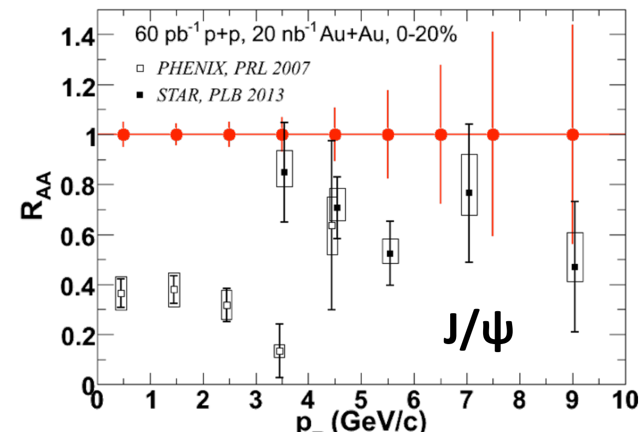


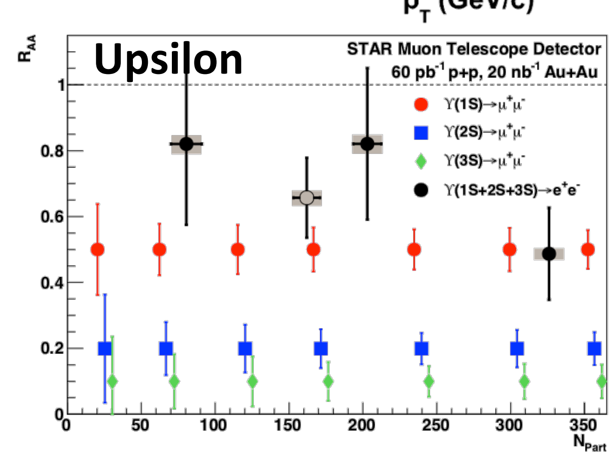
<u>Open Heavy Flavor</u>

- HFT optimized for D^0 reconstruction in the p_T range where hydro flow is dominant
  - R_{AA} for D^0 from fully topological reconstruction (cτ≈120μm)

<u>Charmonium</u>

- MTD Dimuon trigger
- Combination of HFT and MTD significantly improves direct J/ψ measurements
  - measure B→J/ψ→μμ by combining HFT, TPC, and MTD (cτ≈500μm)
- MTD Υ(1S, 2S, 3S) measurements
  - Υ->e$^+$e$^-$ significant bremsstrahlung losses → large tail
  - Υ->μ$^+$μ$^-$ channel less affected





Kesich@AUM'14

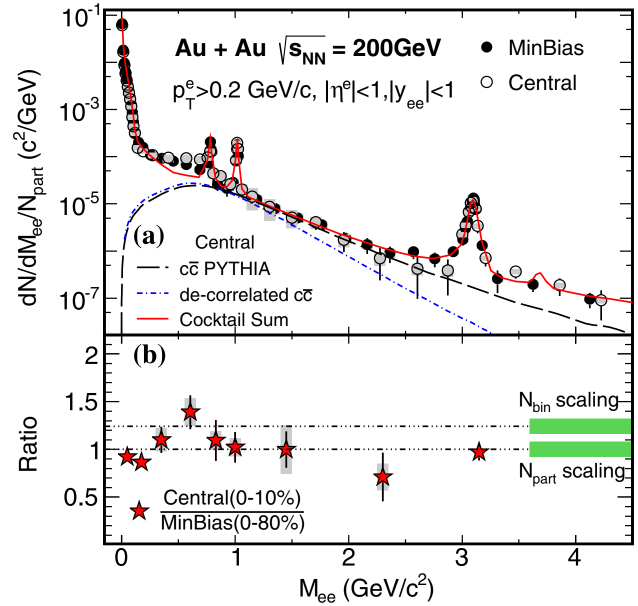
MTD Dilepton Physics

Significant charm contribution spanning both intermediate and low mass range

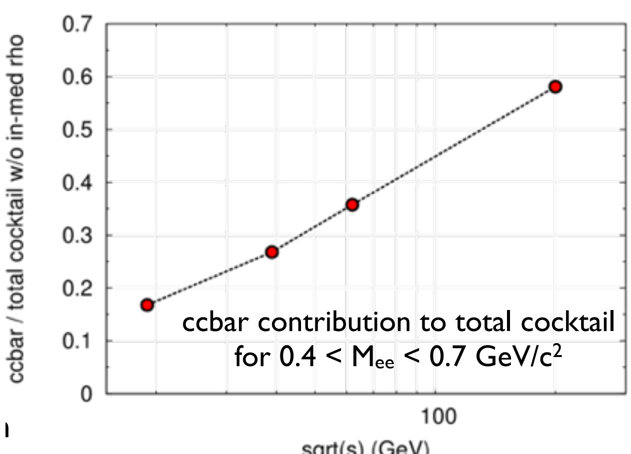
- especially relevant in LMR at high energies
- Distinguish thermal and charm production
- ➢ use e-μ correlation to get a handle on charm contributions

Dimuon continuum:

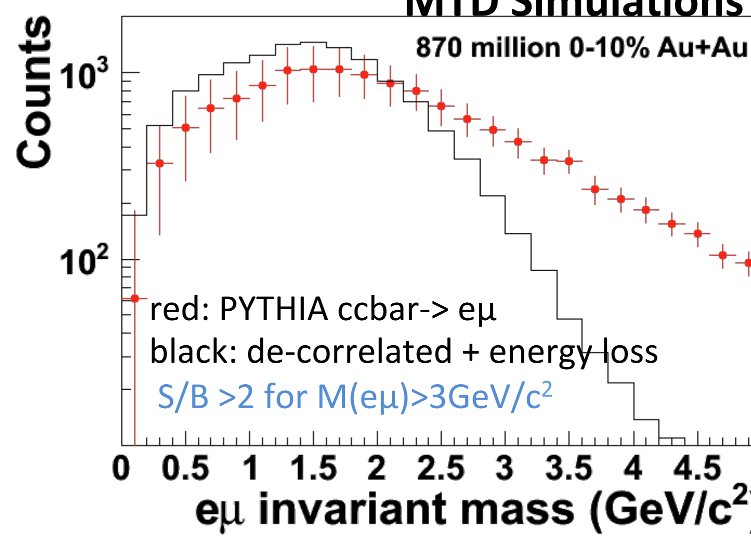
- ➢ LMR: vector meson in-medium modifications
- ➢ IMR: radiation from QGP
- ➢ Dimuon elliptic flow



PRL 113 022301



MTD Simulations



STAR Beam Energy Scan Program

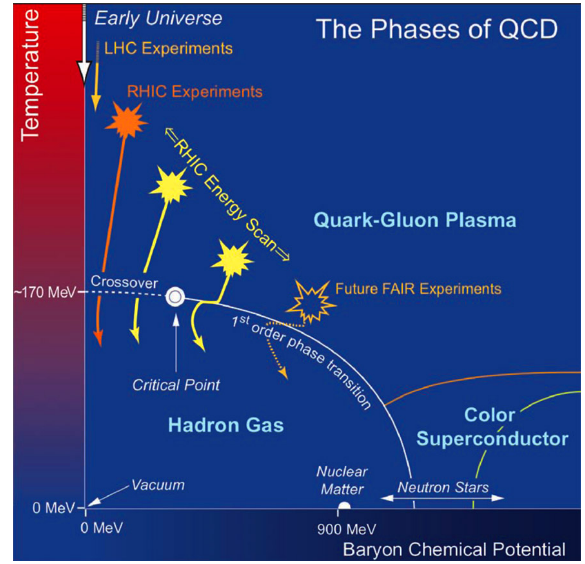
Objectives:

- search for threshold energies for QGP signatures
- search for signatures of 1st order phase transitions
- search for a Critical Point

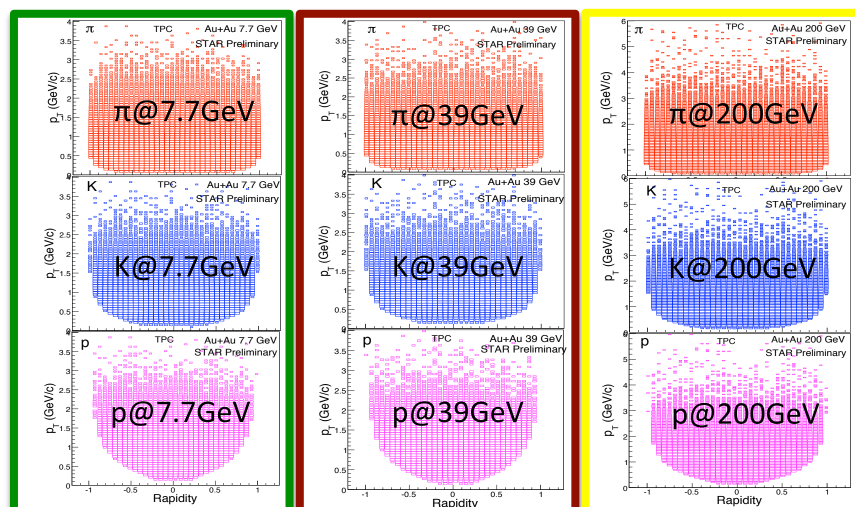
Vary beam energy ⟹ vary (T, μ_B)

STAR: a mid-rapidity collider experiment

- uniform acceptance
- uniform particle ID



BES-II White Paper



Nu Xu @QM14

BES Phase 1: 2010-2011, 2014

Table 1. An overview of Beam Energy Scan Phase-I. The μ_B values are estimated from the systematics of central collisions in Ref. [19]. The 200 GeV is also listed in the table as a reference.

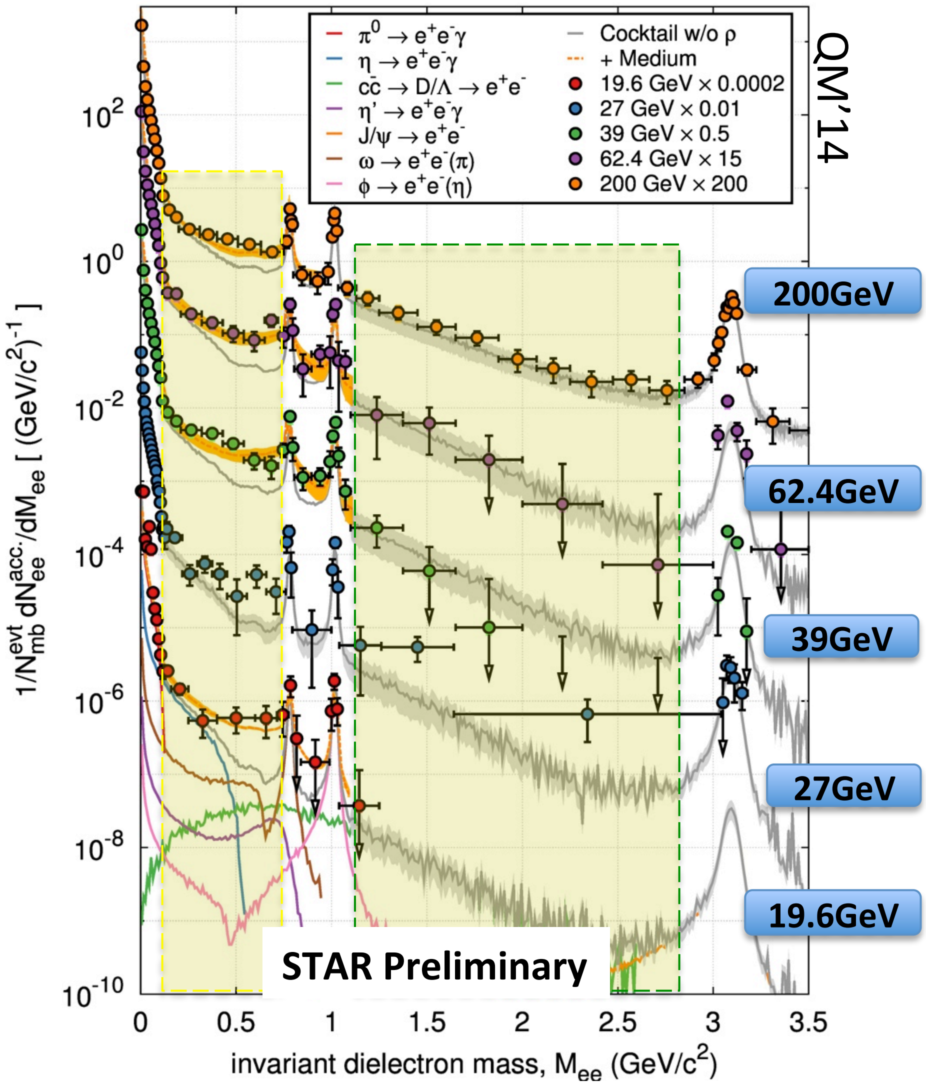
Beam Energy (in GeV)	Baryon Chemical Potential (in MeV)	Year of Data Taking	Event Statistics (Millions)	Beam Time (Weeks)
200	20	2010	350	11
62.4	70	2010	67	1.5
39	115	2010	130	2.0
27	155	2011	70	1.0
19.6	205	2011	36	1.5
14.5	260	2014	20	3.0
11.5	315	2010	12	2.0
7.7	420	2010	4	4.0

Many BES Phase-1 results published or shown at QM'14

cf. Nu Xu's plenary presentation

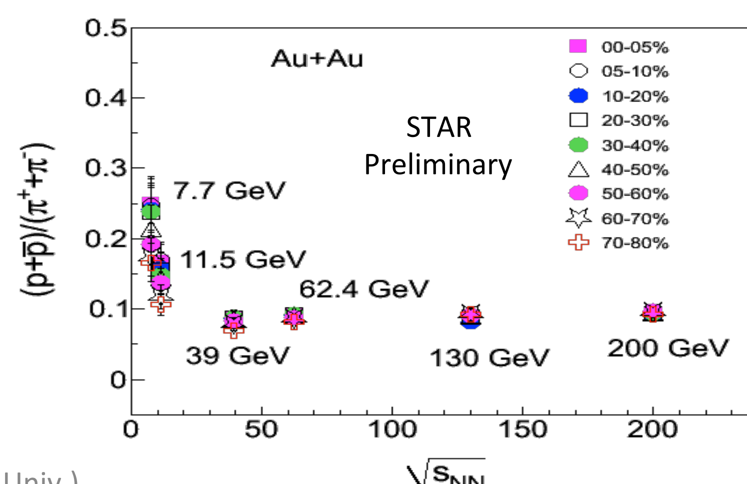
- Large μ_B gap between 7.7 and 11.5GeV
- For some results, however, strength of conclusions limited to uncertainty in measurements
  - R_{CP}, ϕ-meson v_2, proton v_1, net-proton kurtosis, CME, asHBT
  - LMR and IMR dielectrons

BES Phase 1: Dielectrons



- LMR (M_{ee}<1GeV/c^2): in-medium broadened ρ, model results consistent with data
  - driven by the baryon density
- IMR (1 <M_{ee}<3 GeV/c^2): thermal radiation
  - not enough statistics for meaningful results

➢ Need more statistics!



BES Phase 2 Proposal

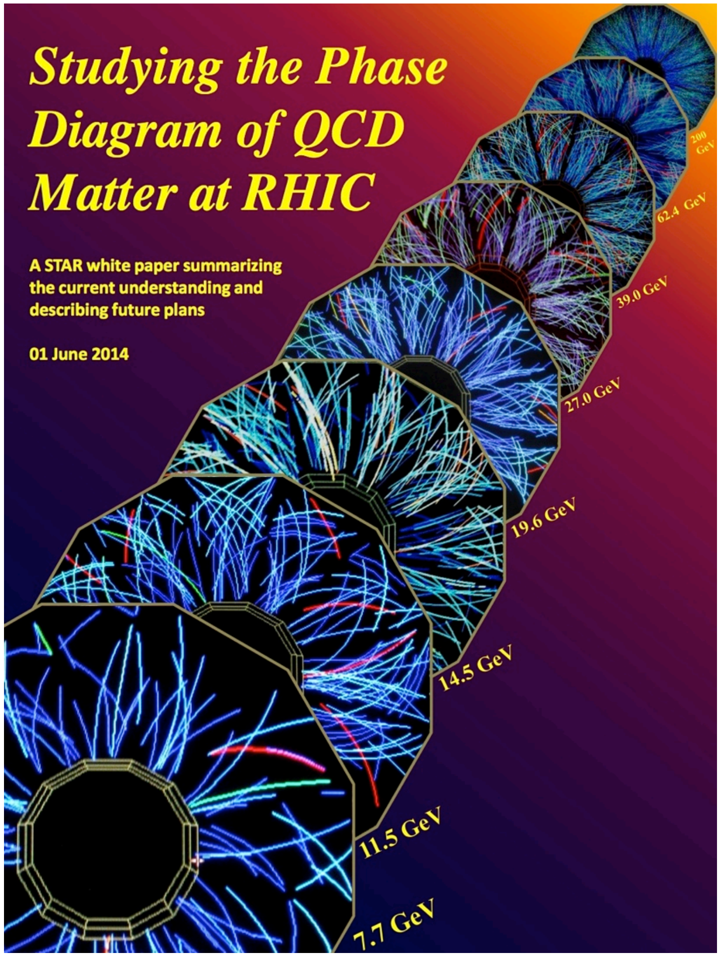


Table 2. Event statistics (in millions) needed for Beam Energy Scan Phase-II for various observables.

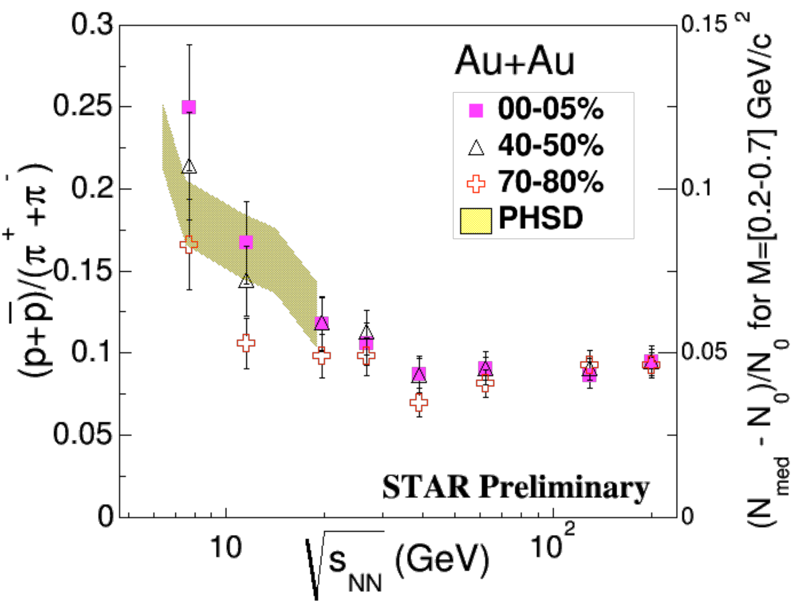
Collision Energy (GeV)	7.7	9.1	11.5	14.5	19.6
μ_B (MeV) in 0-5% central collisions	420	370	315	260	205
Observables					
R_{CP} up to p_T = 5 GeV/c	–		160	125	92
Elliptic Flow (ϕ mesons)	100	150	200	200	400
Chiral Magnetic Effect	50	50	50	50	50
Directed Flow (protons)	50	75	100	100	200
Azimuthal Femtoscopy (protons)	35	40	50	65	80
Net-Proton Kurtosis	80	100	120	200	400
Dileptons	100	160	230	300	400
Required Number of Events	**100**	**160**	**230**	**300**	**400**

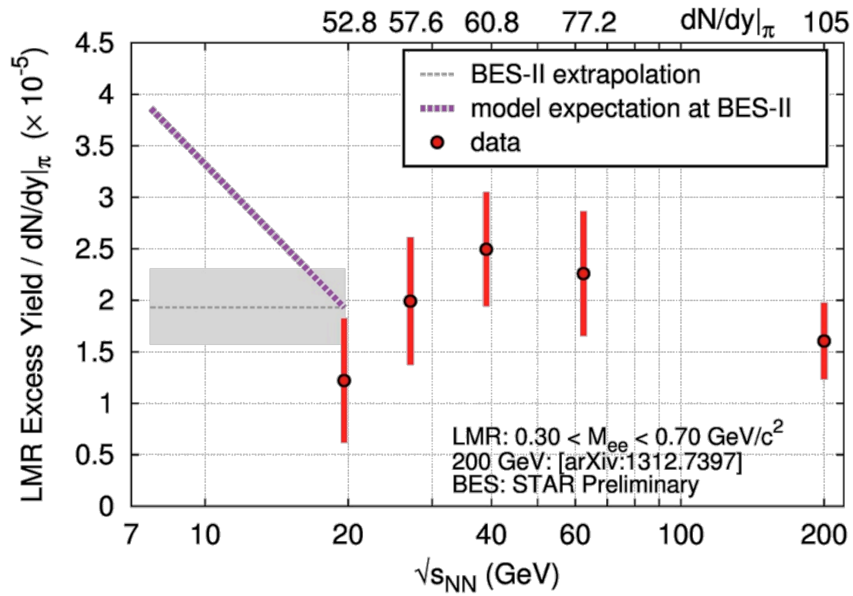
- Proposed statistics mainly driven by ϕ-meson v_2 and dilepton measurements
  - ➢ Dilepton statistics should reach similar uncertainties as at $\sqrt{s_{NN}}$=200 GeV

https://drupal.star.bnl.gov/STAR/starnotes/public/sn0598

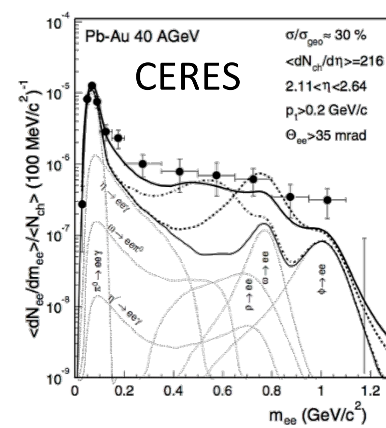
BES Phase 2: Dileptons

Precision Measurements for $\sqrt{s_{NN}}$<20GeV





- LMR :: study total baryon density dependence
  - CERES: Pb+Au @ 40 AGeV
- IMR :: determine how this range may transition and match to the LMR p_T slopes

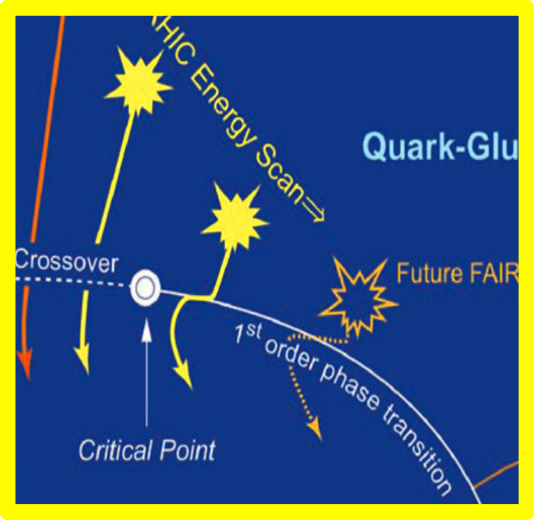


PRL 91 (2003) 042301

BES: Critical Point?

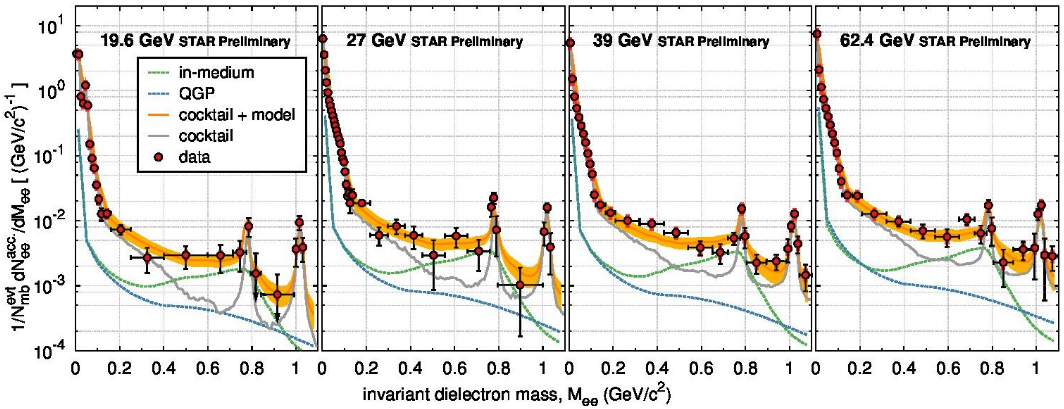
- Dilepton yields sensitive to life time of the system
  - close to Critical Point, expect increase in correlation lengths
  - critical slowing down? *anomalous* increase in the lifetime of the fireball?

➢ Can we observe this in an increase of the rates?



Rapp, Adv. High Energy Phys. 2013 148253

NA60 life time measurement with uncertainty ±1 fm/c (ρ clock)

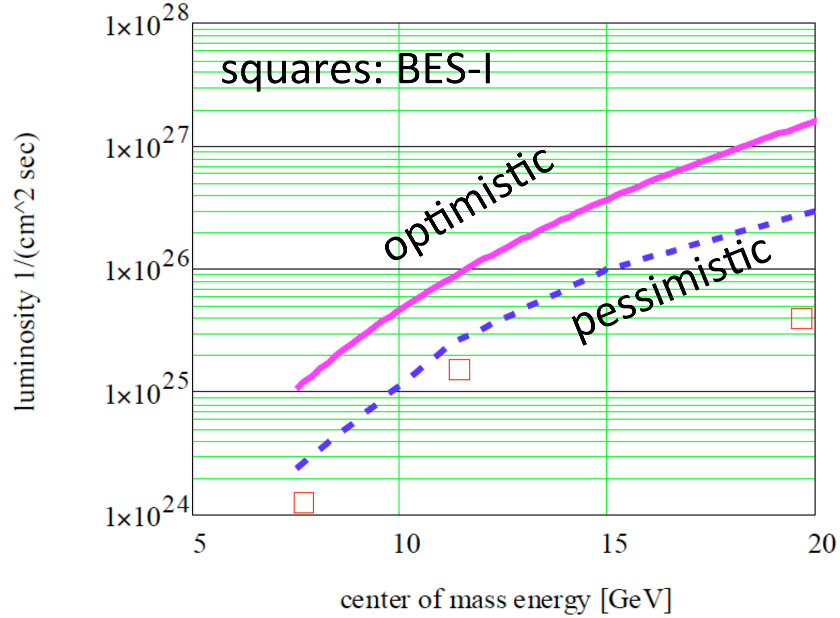


➢ STAR BES (19.6 – 200 GeV)
  - no critical slowing-down in calculations
  - smooth increase from 8–10 fm/c

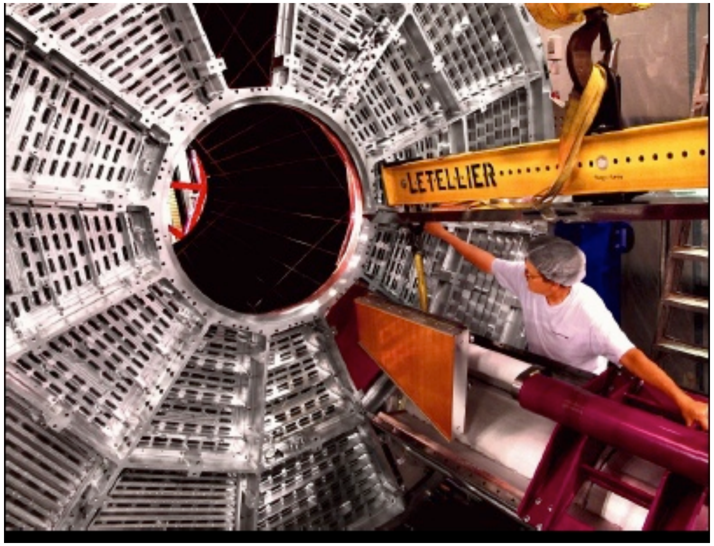
BES Phase 2: Upgrades

- RHIC e-cooling for low energy operation

⇛ higher luminosity
  - at 7 GeV : 2-5x
  - at 20 GeV: 8-20x



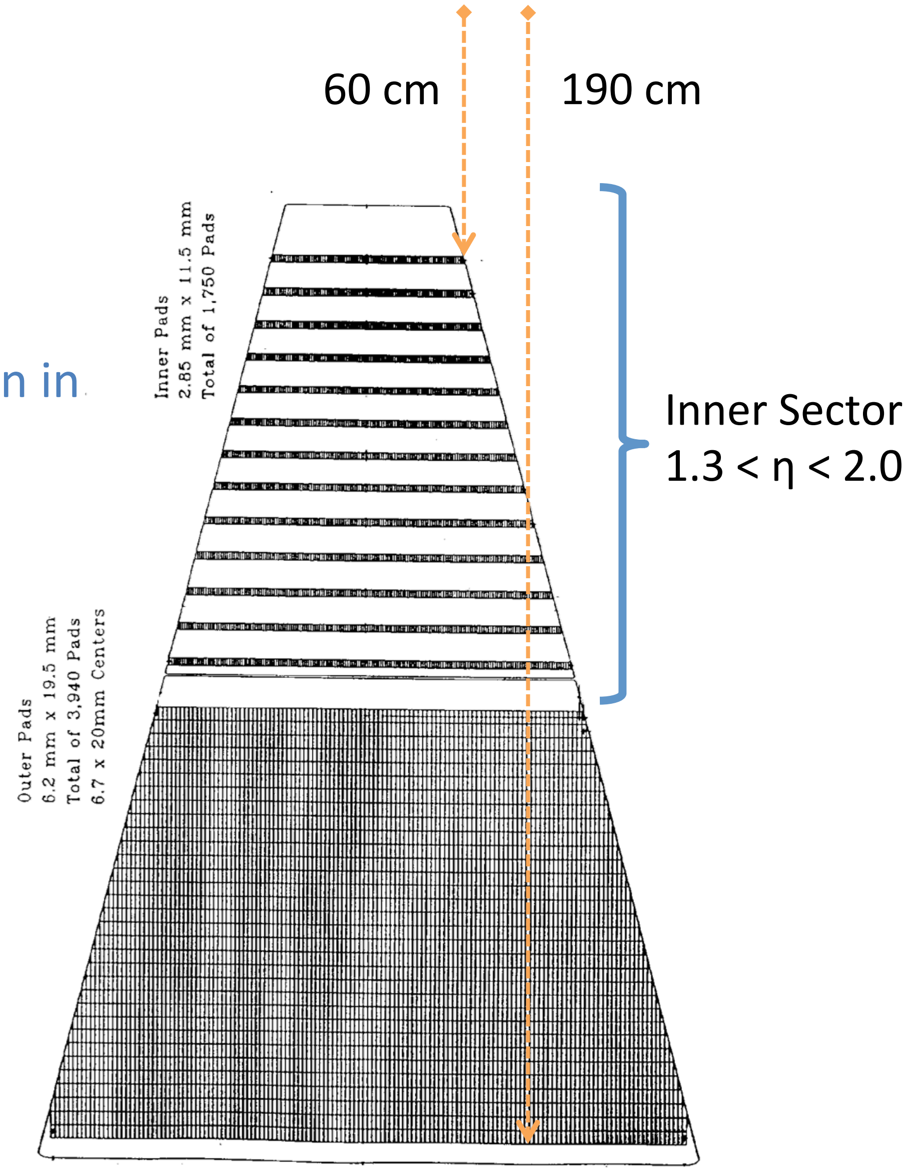
- Proposed STAR detector upgrades
  - Event Plane Detector
  - ➢ iTPC



iTPC Upgrade

- STAR TPC:
  - 24 sectors (12 on each side)
  - design choice (1990s):
    - small pads for good 2-track resolution in Inner Sector
    - large pads for good dE/dx in Outer Sector

- Proposed Inner Sector upgrade:
  - more pad rows
  - larger pads



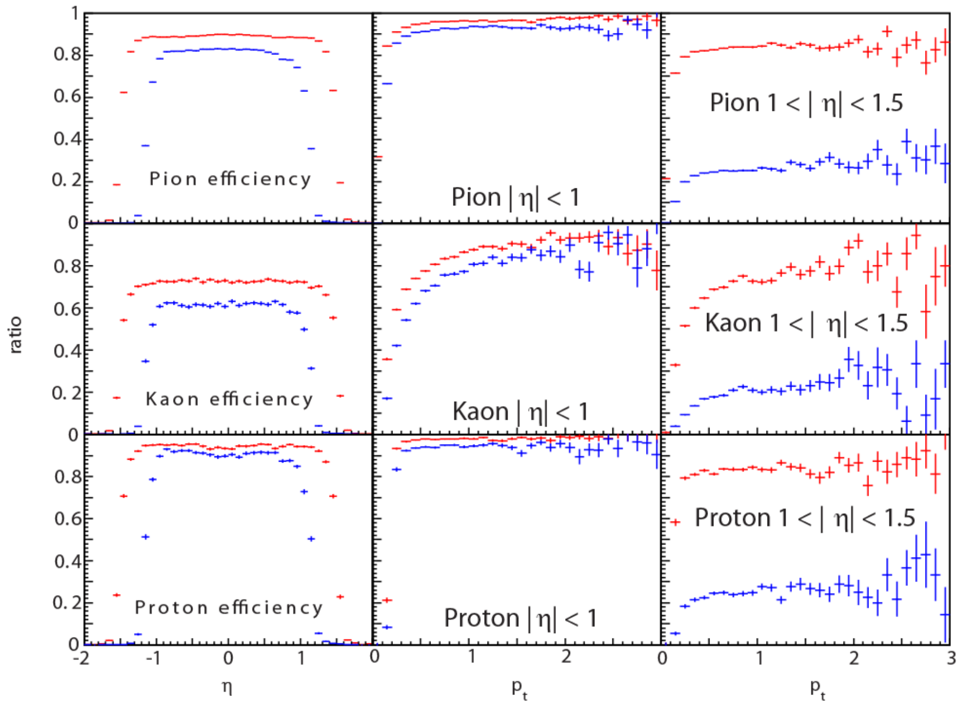
Physics Motivation

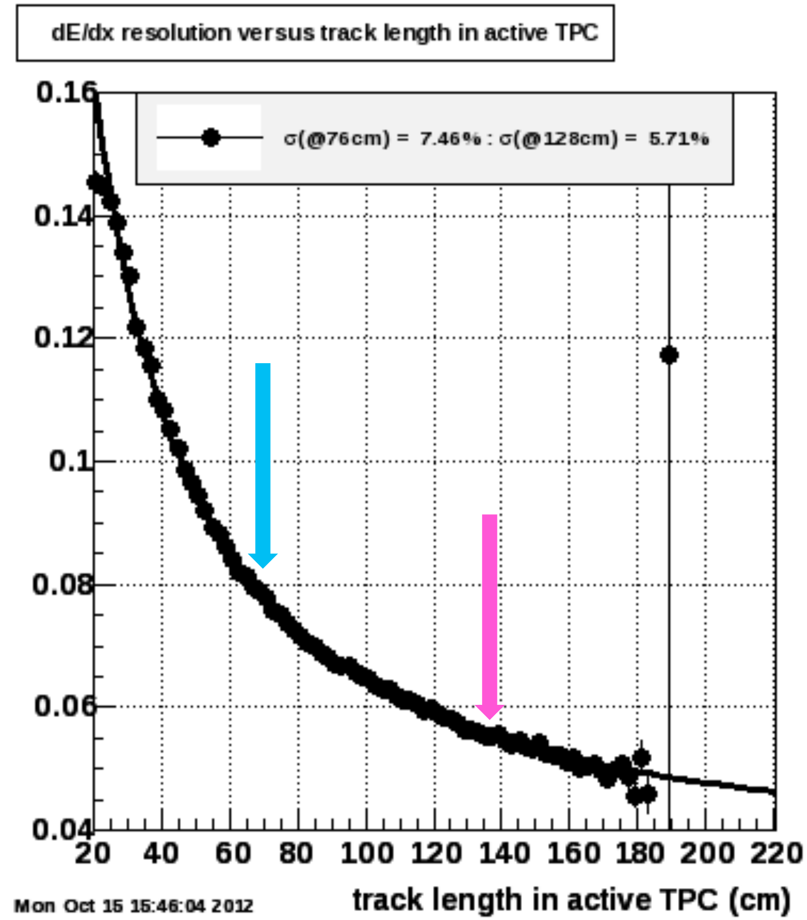
- Increase η coverage for hadron acceptance and correlations
  - high-η coverage for fixed-target datasets
- Improve low-p_T coverage for hyperon reconstruction and weak-decay reconstruction
- Improve dE/dx resolution for particle identification
  - improve high-p_T identified hadron spectra and correlations (jet studies)
- Spin structure measurements in polarized p+p
  - improve forward tracking with FGT/EEMC
  - interference fragmentation functions at high x
  - y-dependence of Λ hyperon polarization

- But also
  - reduce space-charge distortion (induced by charge leak from Gating Grid)
  - eliminate concerns about wire-aging issues

iTPC & Dilepton Measurements (1)

- Increase acceptance
- Improve dE/dx resolution

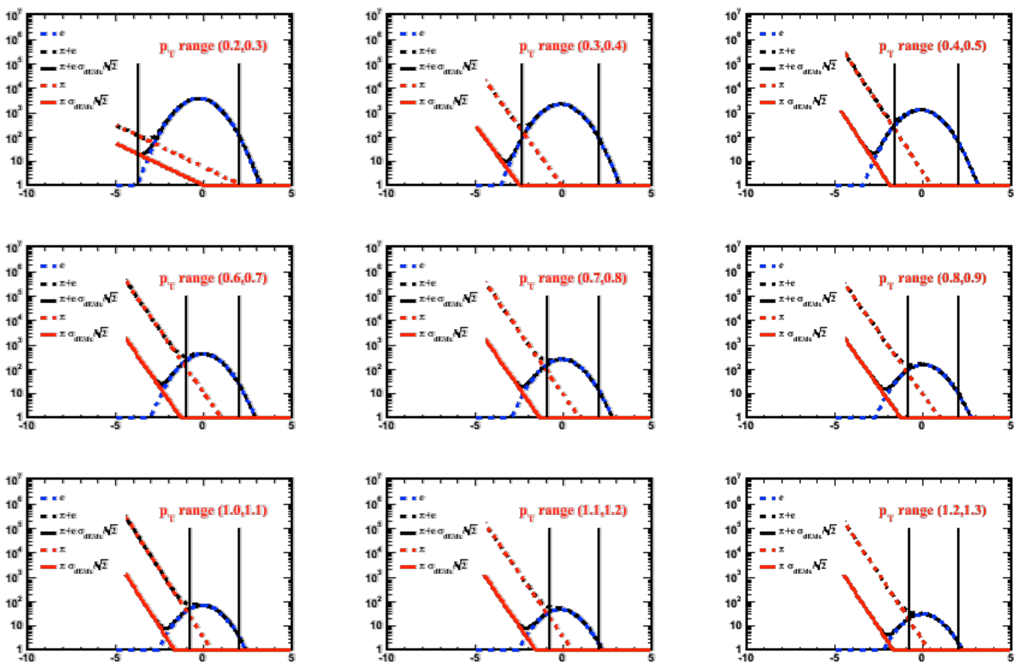


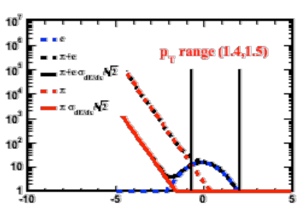


iTPC & Dilepton Measurements (2)

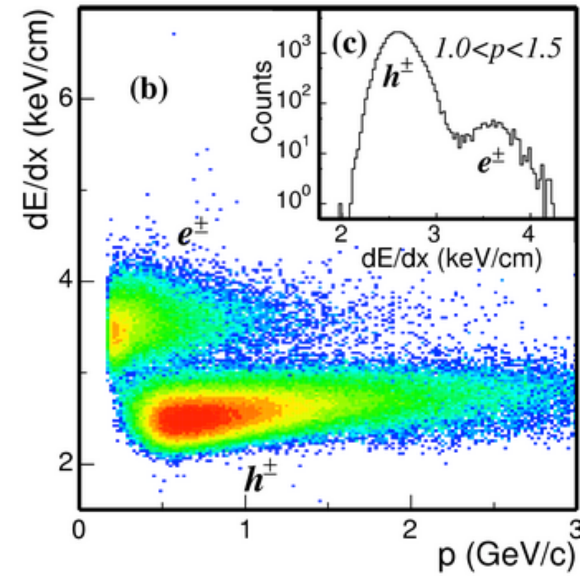
- Improve purity, efficiency
  - $n\sigma_e$ distributions for increasing p_T windows [0.2-0.3] – [1.4-1.5] GeV/c

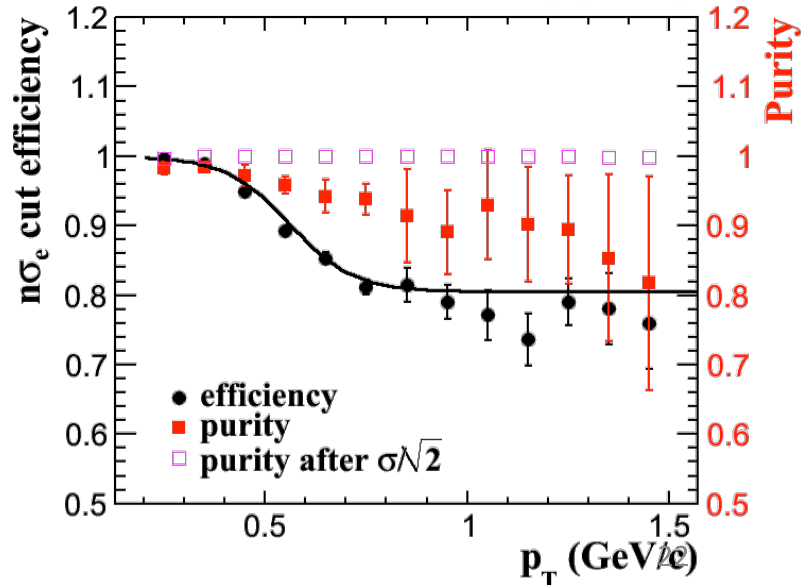
Bingchu Huang





blue = electrons
red = pions
dashed = typical dE/dx
solid = typical iTPC improvement





Outlook

- The TOF detector, 2010, kicked off STAR's dielectron program
  - e^+e^- top energy spectra, e^+e^- v_2, direct virtual photon, systematic measurements of LMR excess
  - Beam Energy Scan Phase 1 allowed for a systematic measurement of the LMR excess from top RHIC down to top SPS energies
- The MTD, now, marks the start of STAR's muon detection capabilities
  - 2014 – 2016: high statistics Au+Au, p+p, and p+A
  - dilepton program: revisit top energies, disentangle charm, dimuon continuum, charmonium
- BES Phase 2 (2018-2019): systematic dilepton measurements down to $\sqrt{s_{NN}}$=7.7 GeV
  - measure baryon density dependence
  - measure p_T slopes both in LMR and IMR
  - look for anomalous increases in yield, suggestive of a critical point