# Dielectron Production in Au+Au Collisions at BES Energies

## and its energy dependence from SPS to top RHIC energies

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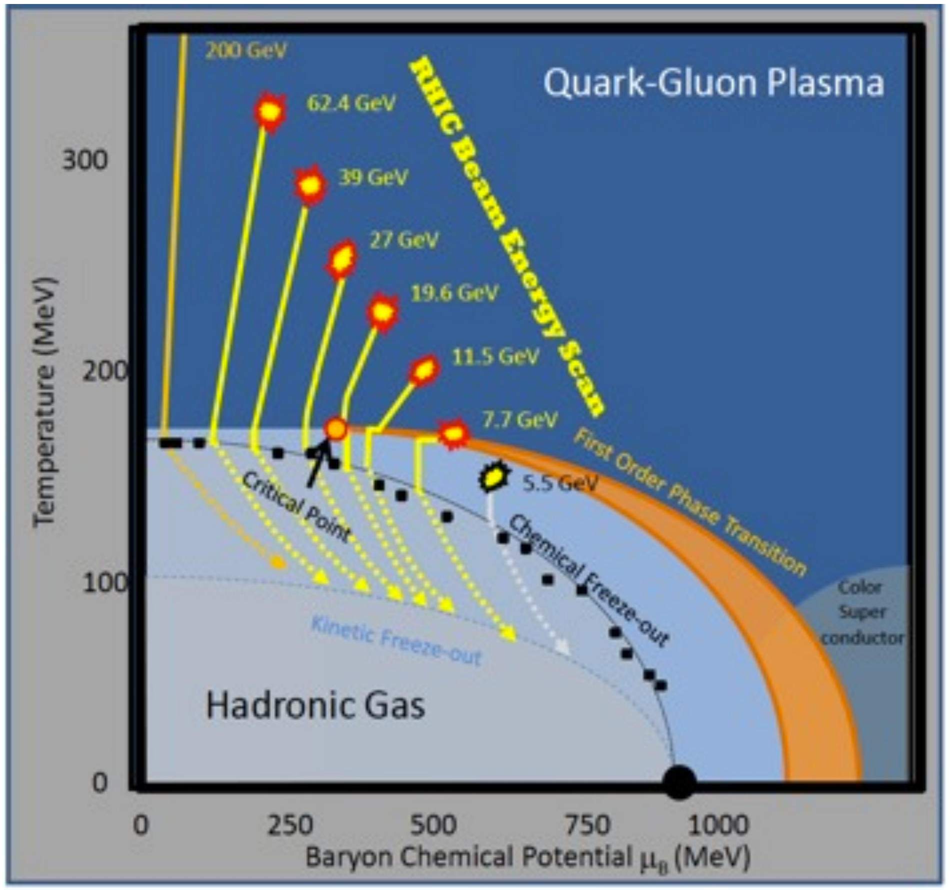
# STAR ☆ Study the QCD Phase Diagram

## Fundamental Questions for HIC's

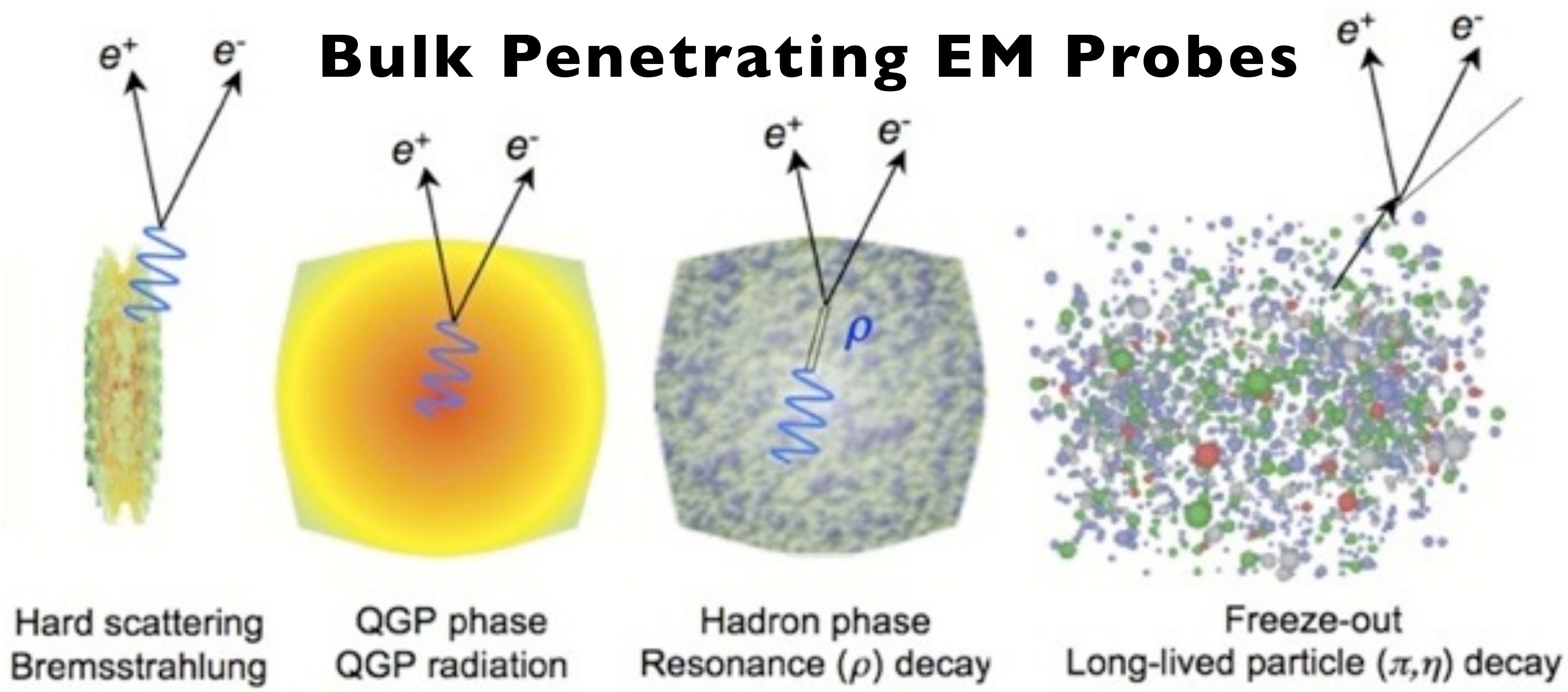
1) thermally equilibrated matter produced through sufficient rescattering?
   magnitude of collective expansion indicates $\tau < 1$-$2$ fm/c
   characterize medium by bulk thermodynamic variables

2) distinctive footprint of individual partons?
   $v_2$ NCQ scaling: collectively expanding partonic source

3) deconfinement? chiral restoration?
   spectroscopy via short-lived resonances due to inaccessible order parameter




## Bulk Penetrating EM Probes




## Beam Energy Scan Program

consistently combine various signatures over a wide range of beam energies

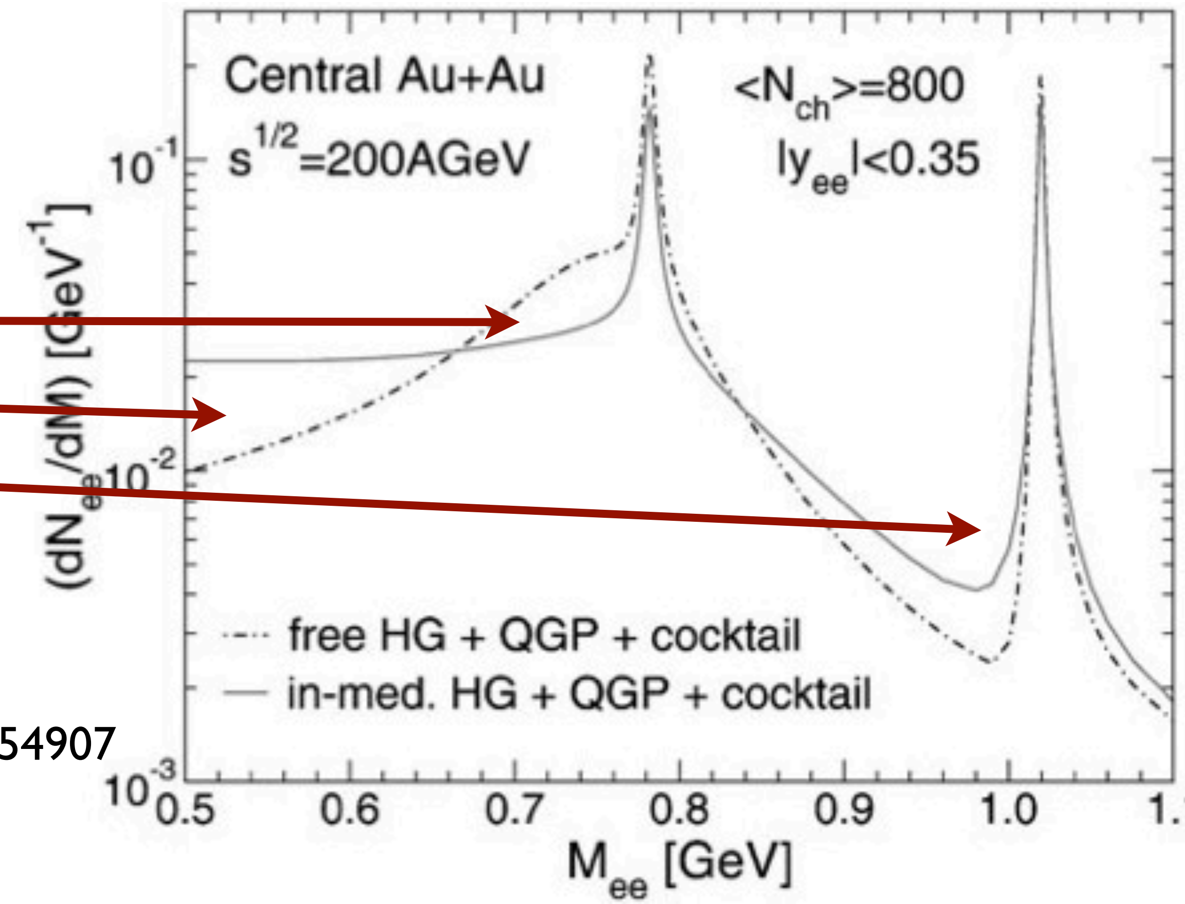
- access hadronic spectral functions via EM probes ($\gamma$ / $l^+l^-$)
  negligible FS interactions due to $\lambda_{mfp} >> \tau_{FB}$
- additional dynamic information about HIC stages encoded in invariant mass

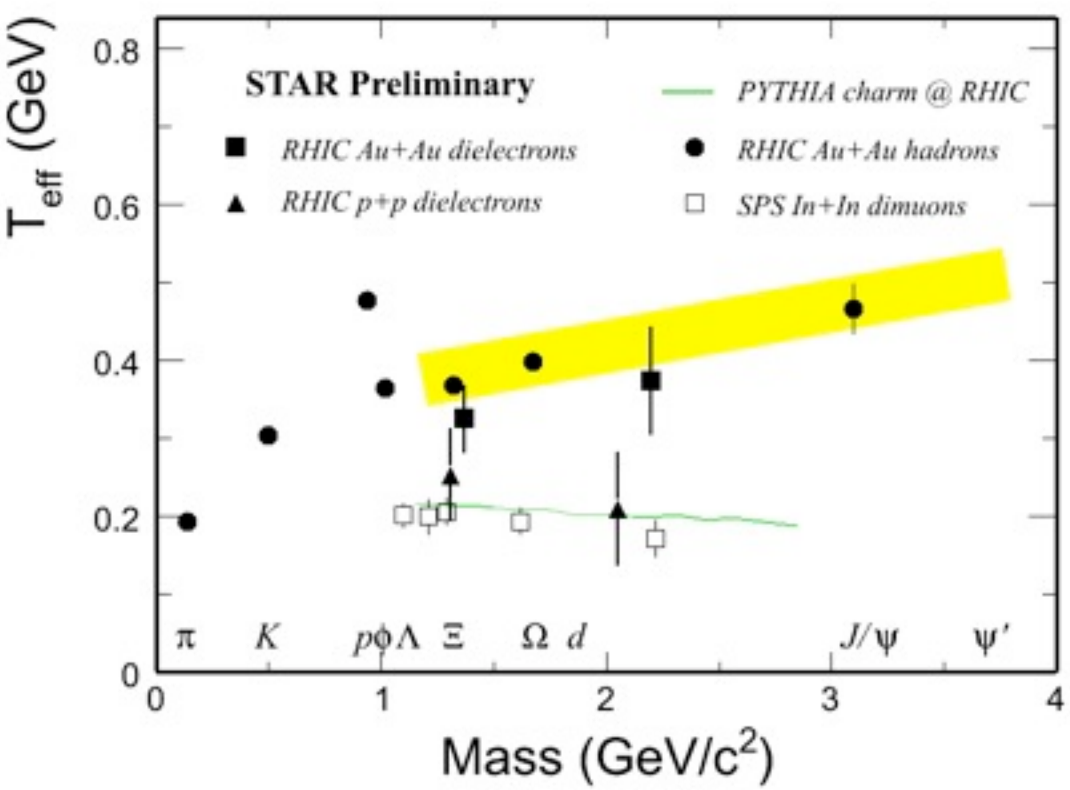
# Dielectron Physics @ STAR

## Low-Mass-Region ($M_{ee}$ < 1.1 GeV/$c^2$)

- distinct features of fireball radiation from hadronic phase hidden by direct decays
- ~50% reduction in $\rho/\omega$ region
- factor 2 enhancement at ~0.5 GeV/$c^2$
- $\omega/\phi$ less susceptible to in-med. modifications
- possibly connected to $\chi$SR through analogy with reduced duality threshold

R. Rapp, arXiV:0901.3289 & PRC 63 054907



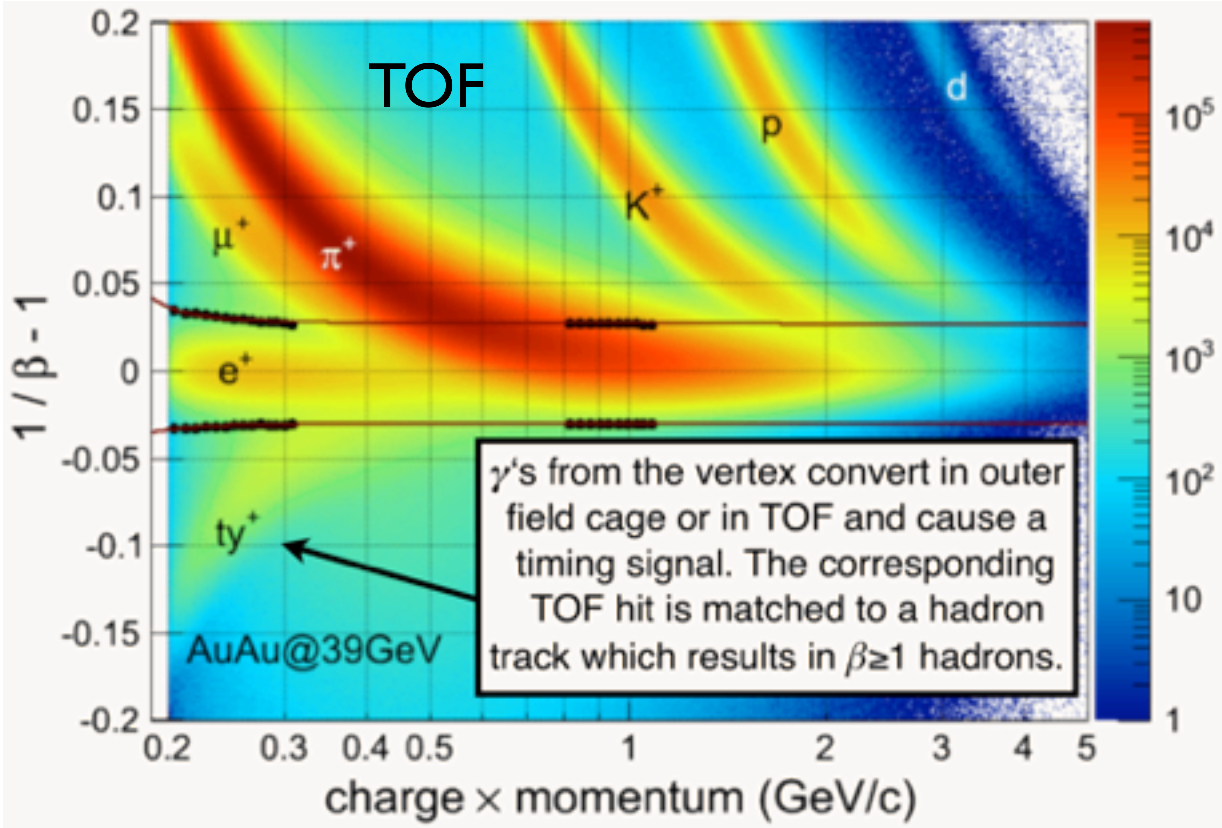



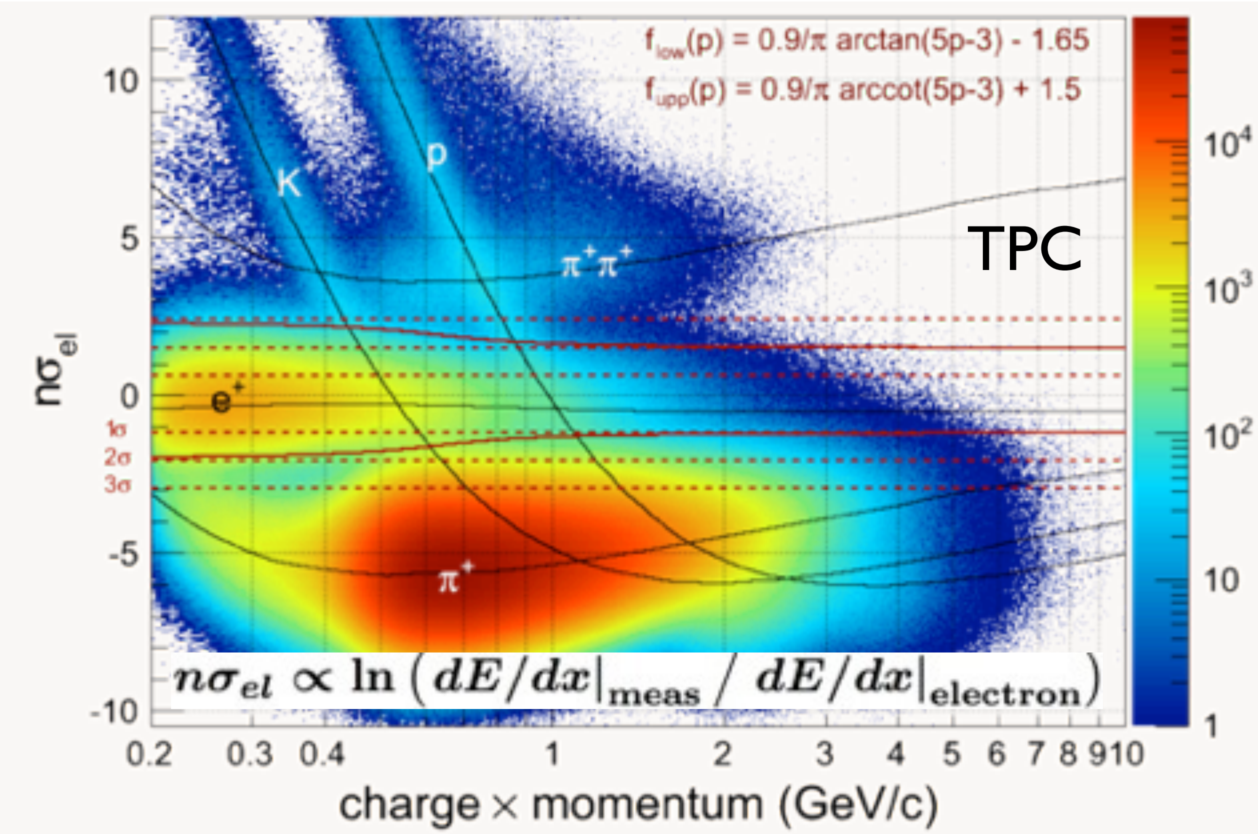

## Intermediate-Mass-Region (1.1 < $M_{ee}$ < 3 GeV/$c^2$)

- measure initial QGP temperature from IMR $m_T$ spectra
  - however, with contributions from correlated charmed decays unknown, large systematic uncertainties arise even at 200 GeV.
  - thus, BES analyses presented here concentrate on LMR physics

STAR in unique position to study energy dependent dielectron production and study/confirm medium consequences on spectra w.r.t to their energy dependence

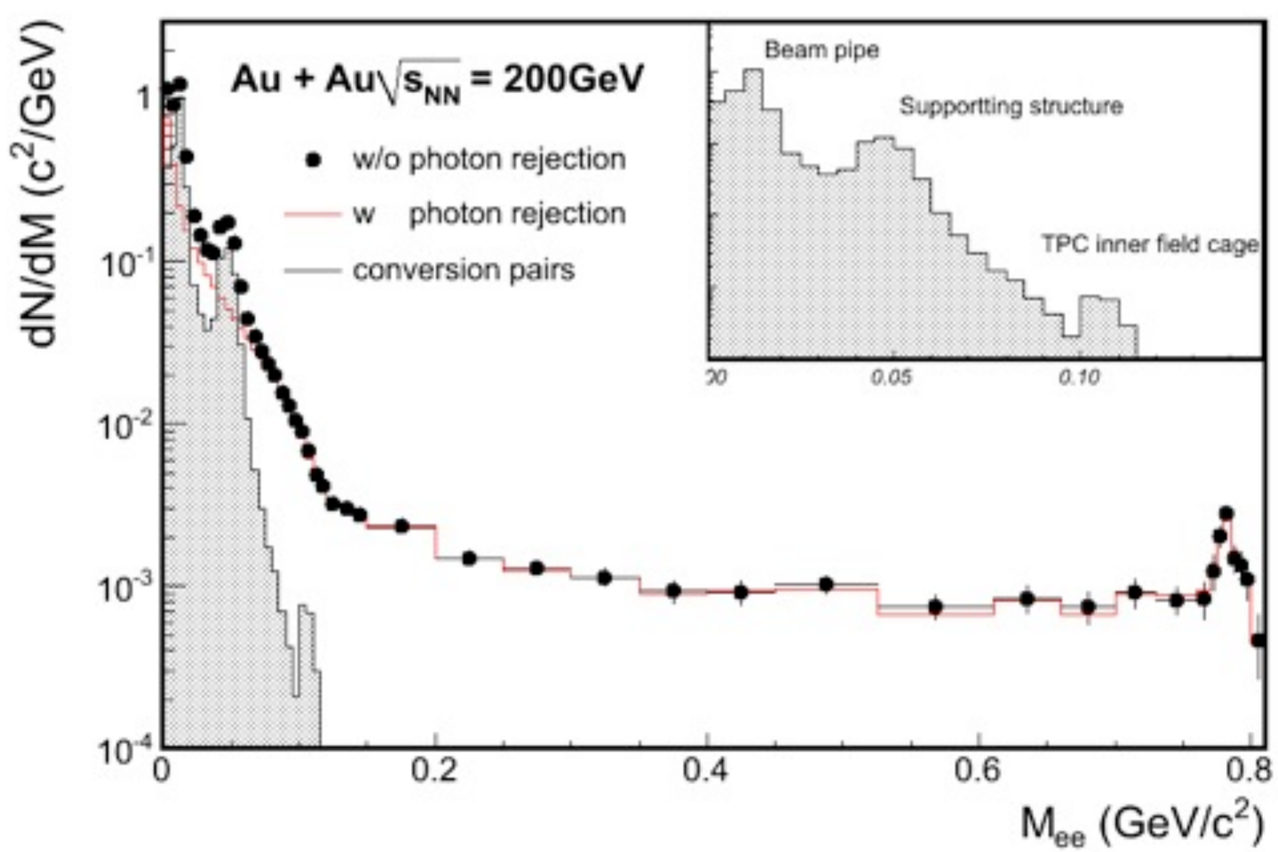
# Datasets, Electron-ID & Conversion Rejection




| Energy | 19.6 GeV | 39 GeV | 62.4 GeV | 200 GeV |
|---|---|---|---|---|
| used MB Evts | 35.8 M | 99.4 M | 54.6 M | 240 M |

- installation of TOF completed in 2010 enables pure eID combined with energy loss in TPC
- photon conversion sources: beam pipe, SVT support cones and inner TPC field cage
- >98% conversion rejection via $\phi_V$ cut



# Background Subtraction Methods

$e^+/e^-$ *created in pairs*
⇒ unlike-sign BG is *geometric mean* of the like-sign BGs independent of primary probability/multiplicity distribution

$$\langle \mathrm{BG}_{+-} \rangle = 2\sqrt{\langle \mathrm{BG}_{++} \rangle \langle \mathrm{BG}_{--} \rangle}$$

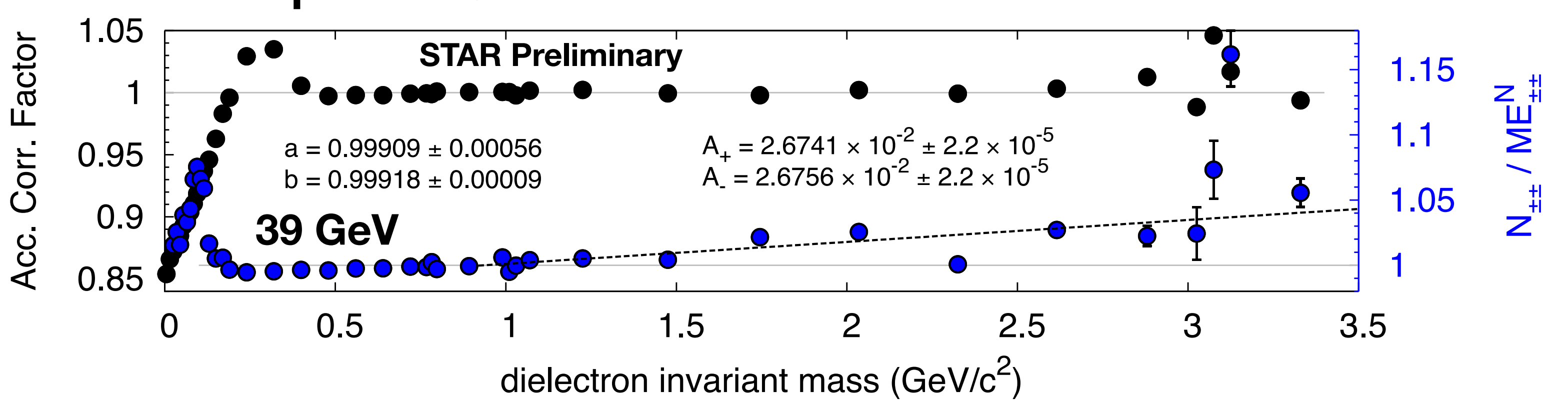
## 1) Like-Sign Same Event Method

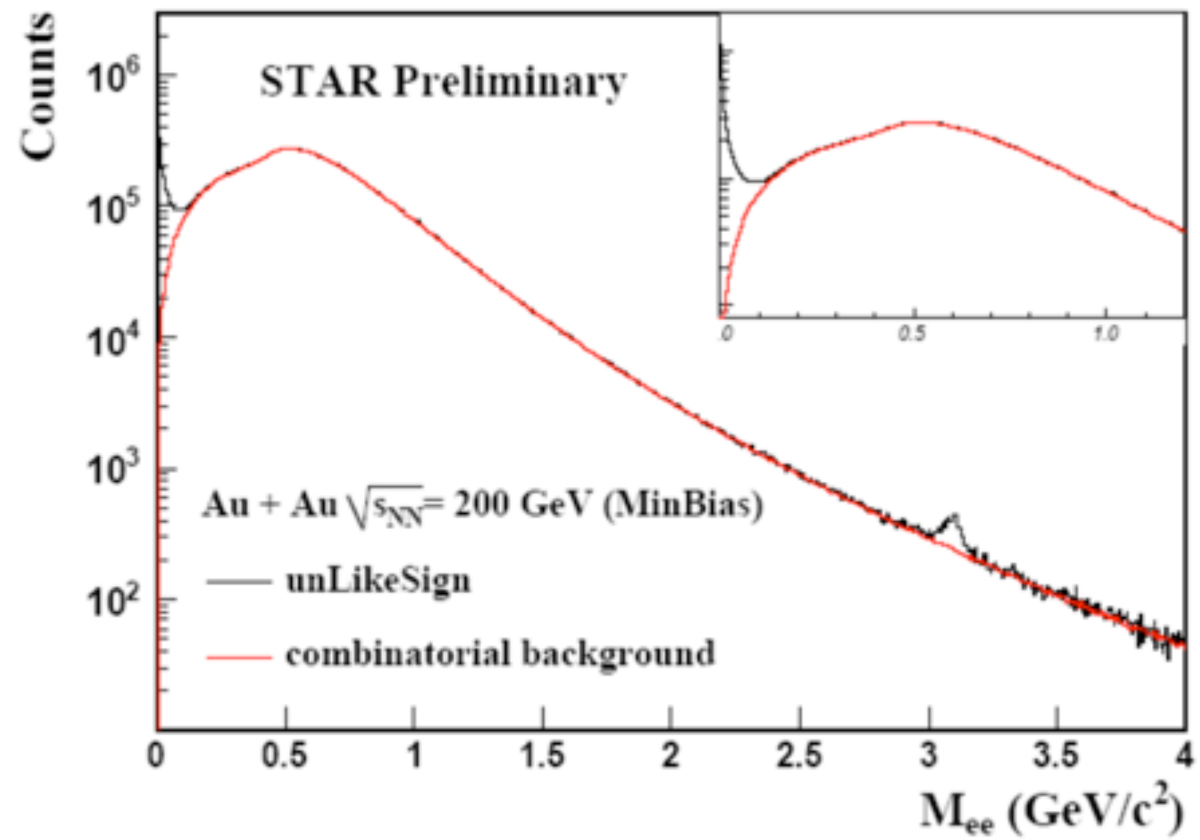
- All like-sign pairs of one event are combined and averaged.
- Method reproduces the background from all correlated sources.
- Acceptance difference of like-sign to unlike-sign pairs is corrected using the ME Technique.

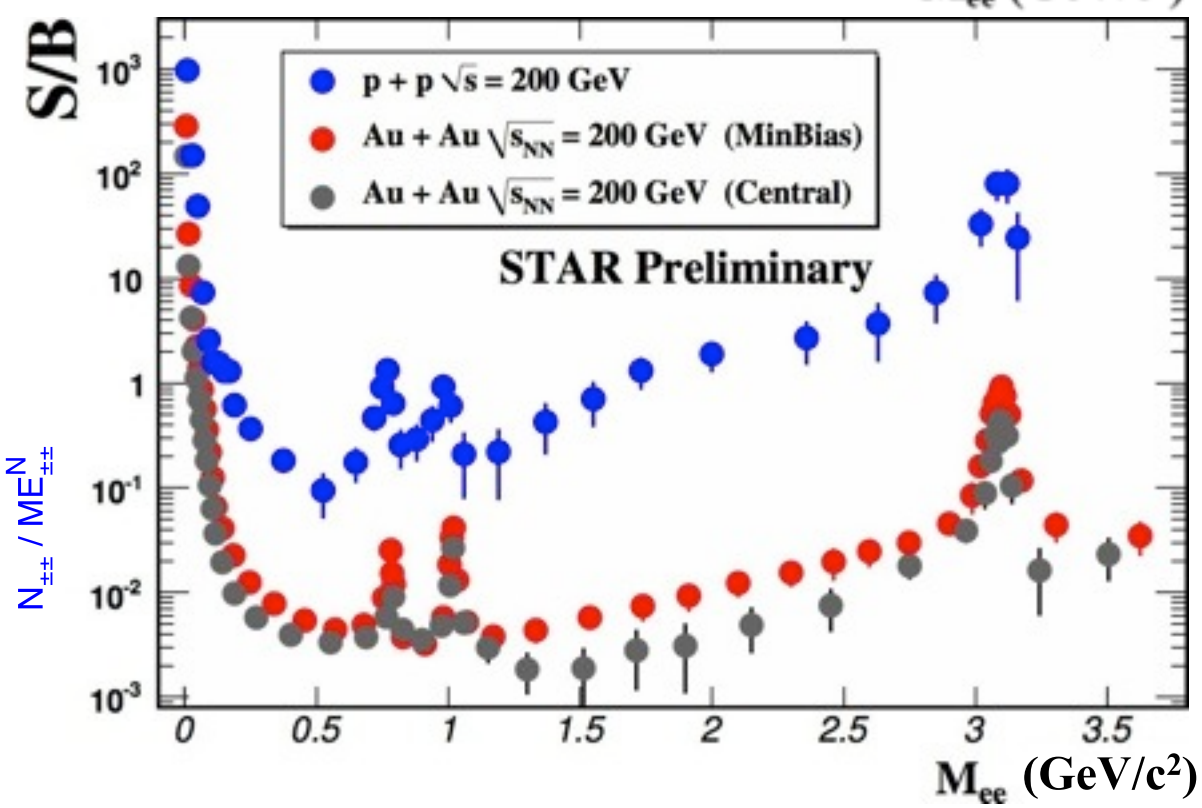
## 2) Unlike-Sign Mixed Event Method

- Charges from two different events within same event class are combined (event vertex, reference multiplicity & event plane).
- Method describes uncorrelated BG only.

**Pair-Acceptance Correction & Mixed Event Normalization**

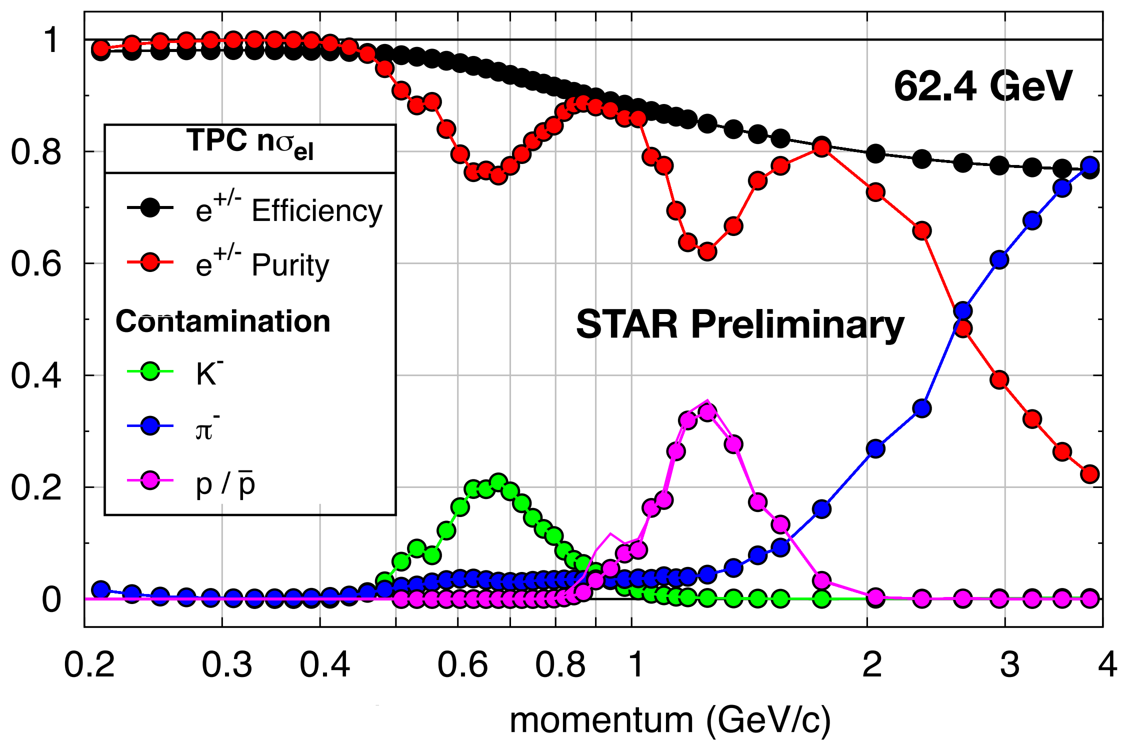


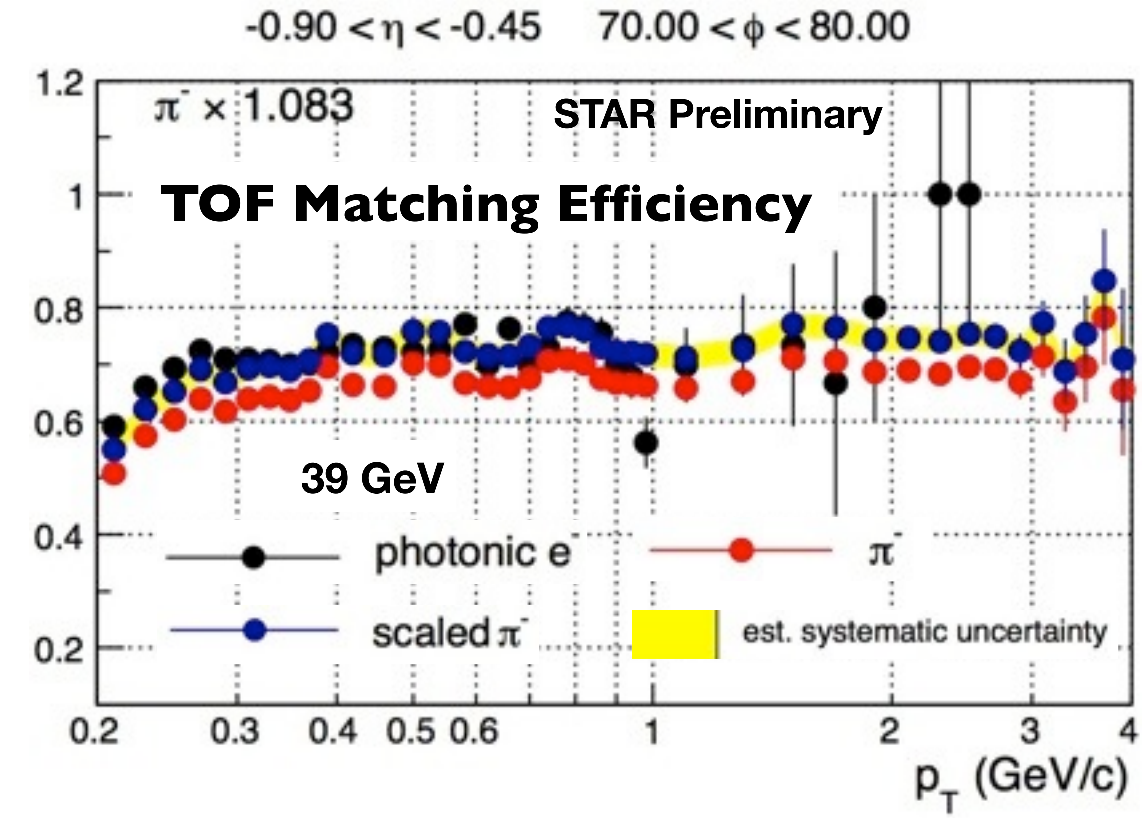



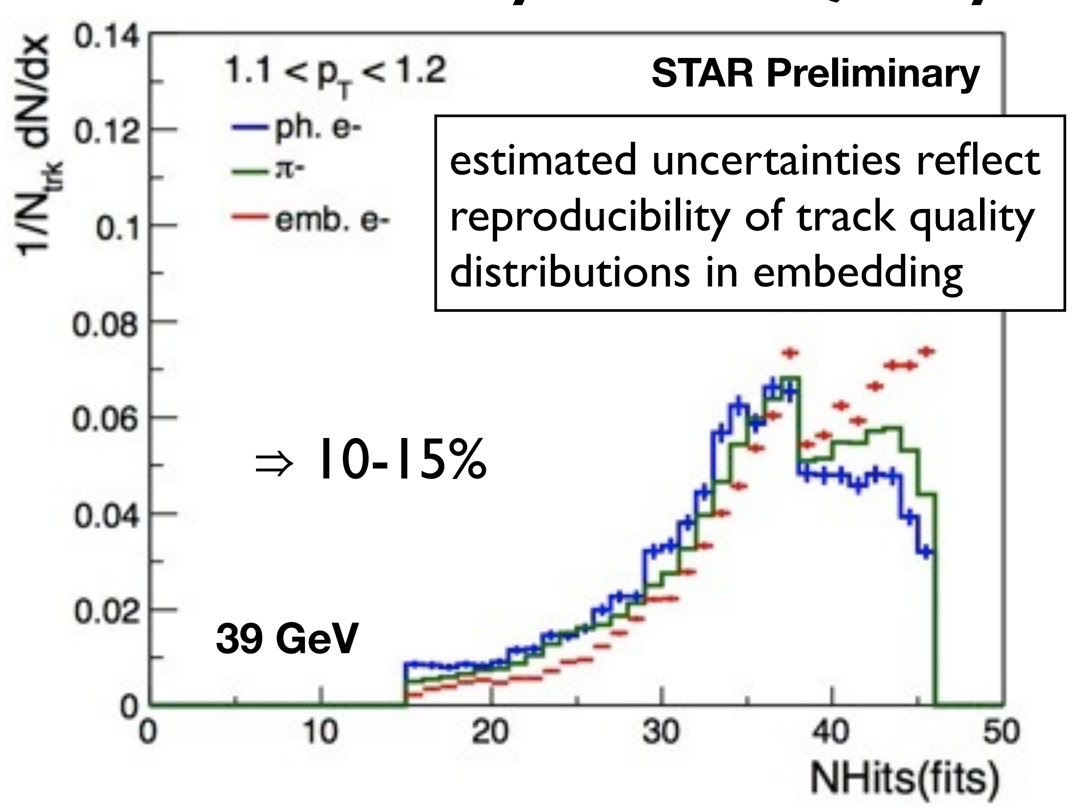
# Efficiency Correction

## TPC Selection Efficiency & Purity



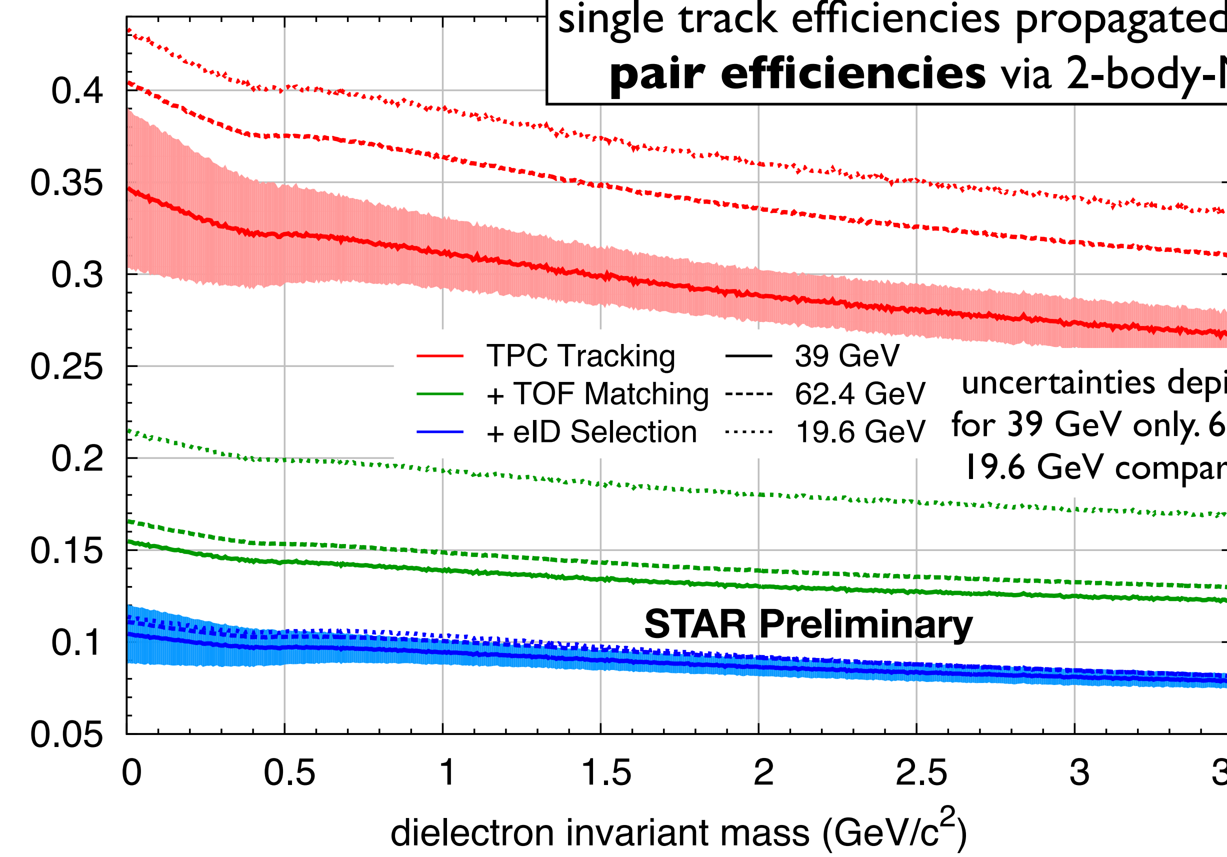

## Systematic Uncertainty of Track Quality Cuts




estimated uncertainties reflect reproducibility of track quality distributions in embedding

⇒ 10-15%

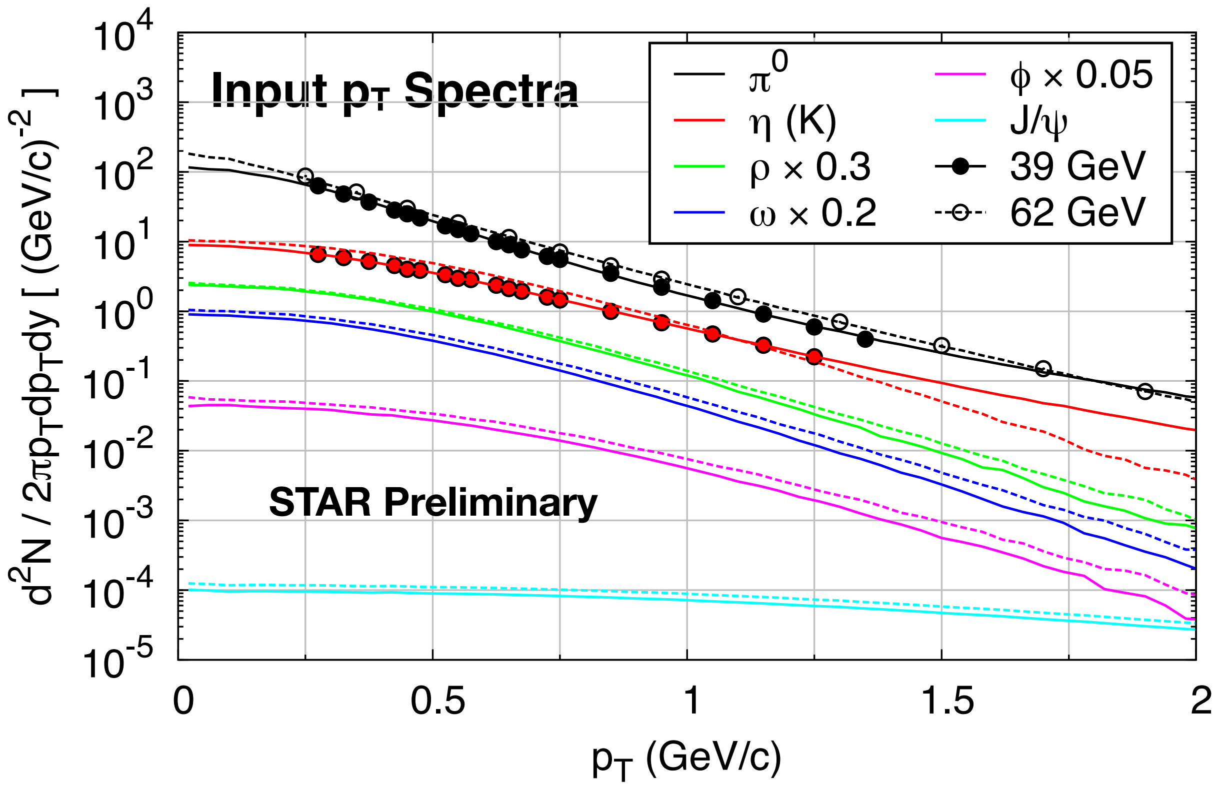
single track efficiencies propagated to **pair efficiencies** via 2-body-MC

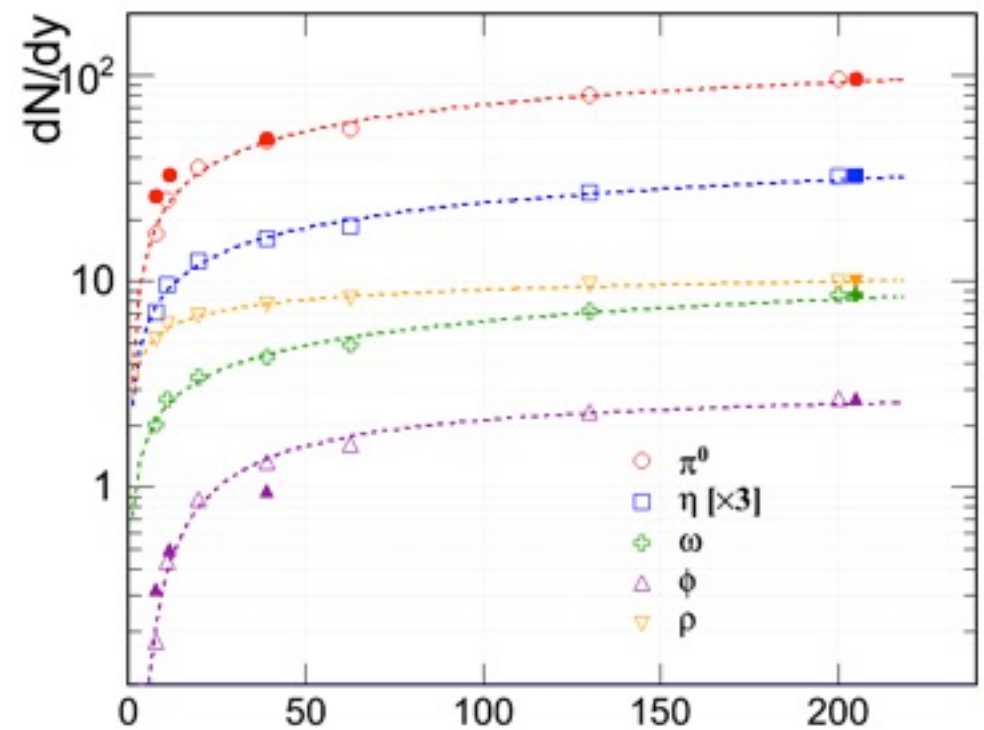


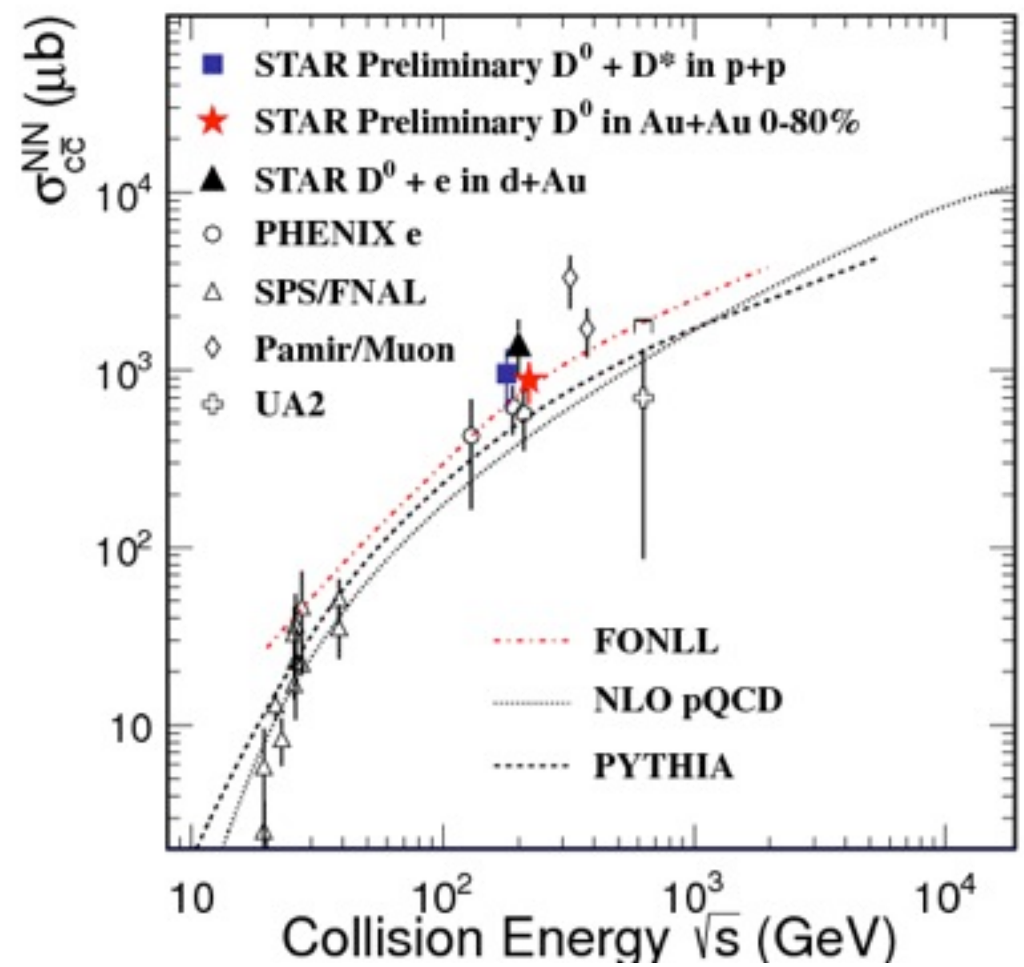

uncertainties depicted for 39 GeV only. 62.4 & 19.6 GeV comparable.

# Cocktail Simulation

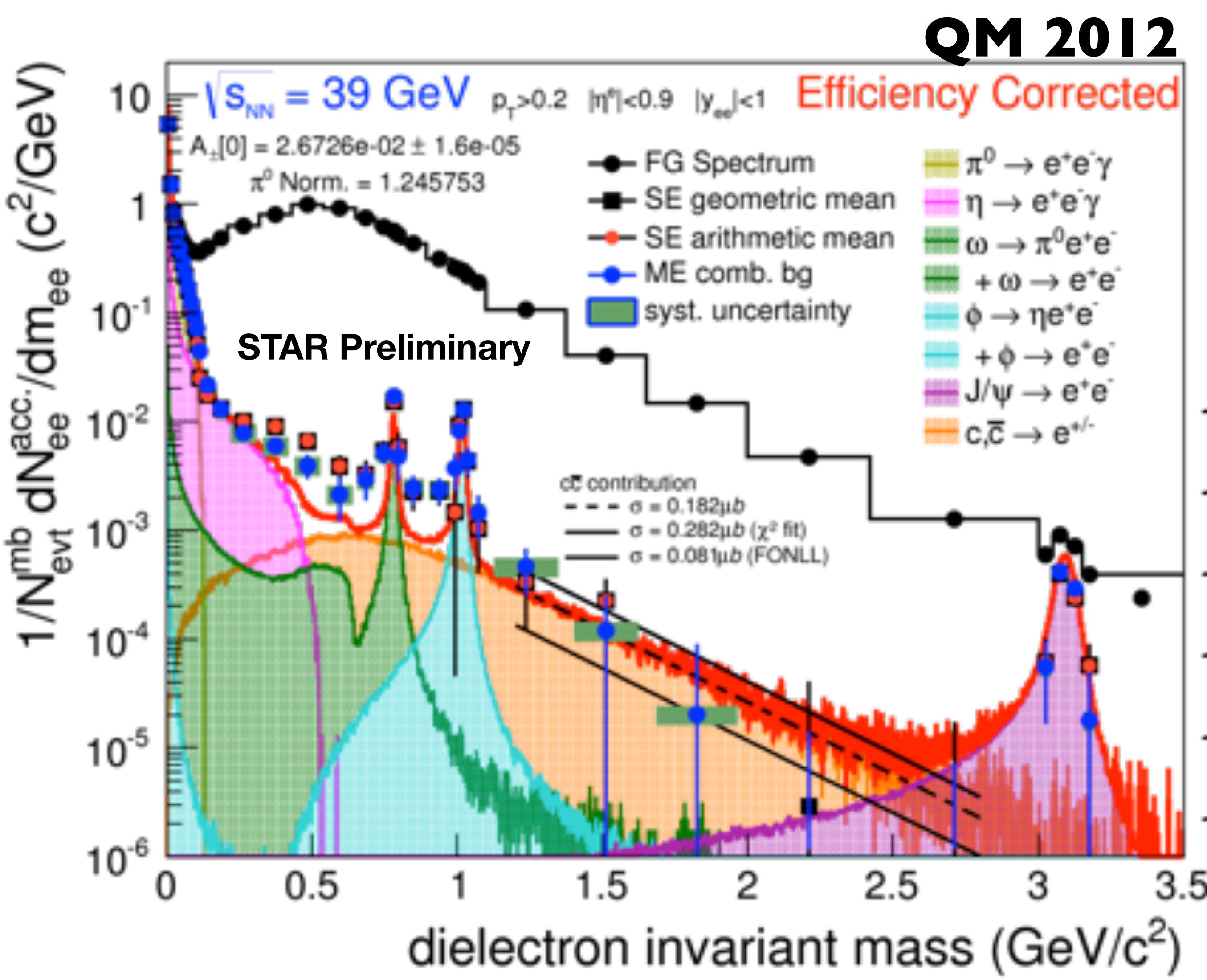
- flat $\eta$ [-1,1] & $\phi$ [0,2$\pi$], Kroll-Wada for Dalitz decays & according form-factors from measurements (PDG)
- *AuAu@19.6 GeV:*
  - Tsallis fits to meson spectra from SPS PbPb@17.3GeV
  - meson/$\pi^0$ ratio from SPS & $\pi^0$ yield from STAR
  - Conversion included via full STAR GEANT simulation
- *AuAu@39 & 62.4 GeV:*
  - $\pi^0$ $p_T$ spectra from $\pi^{+/-}$ @STAR, K spectra used for $\eta$
  - Unknown $p_T$ distributions taken from AMPT
  - According yields extrapolated from 200 GeV based on AMPT's √s-dependence
  - conversion rejected via $\phi_V$ cut
- Contributions due to correlated charmed decays simulated using PYTHIA and scaled to Au+Au by $N_{bin}$

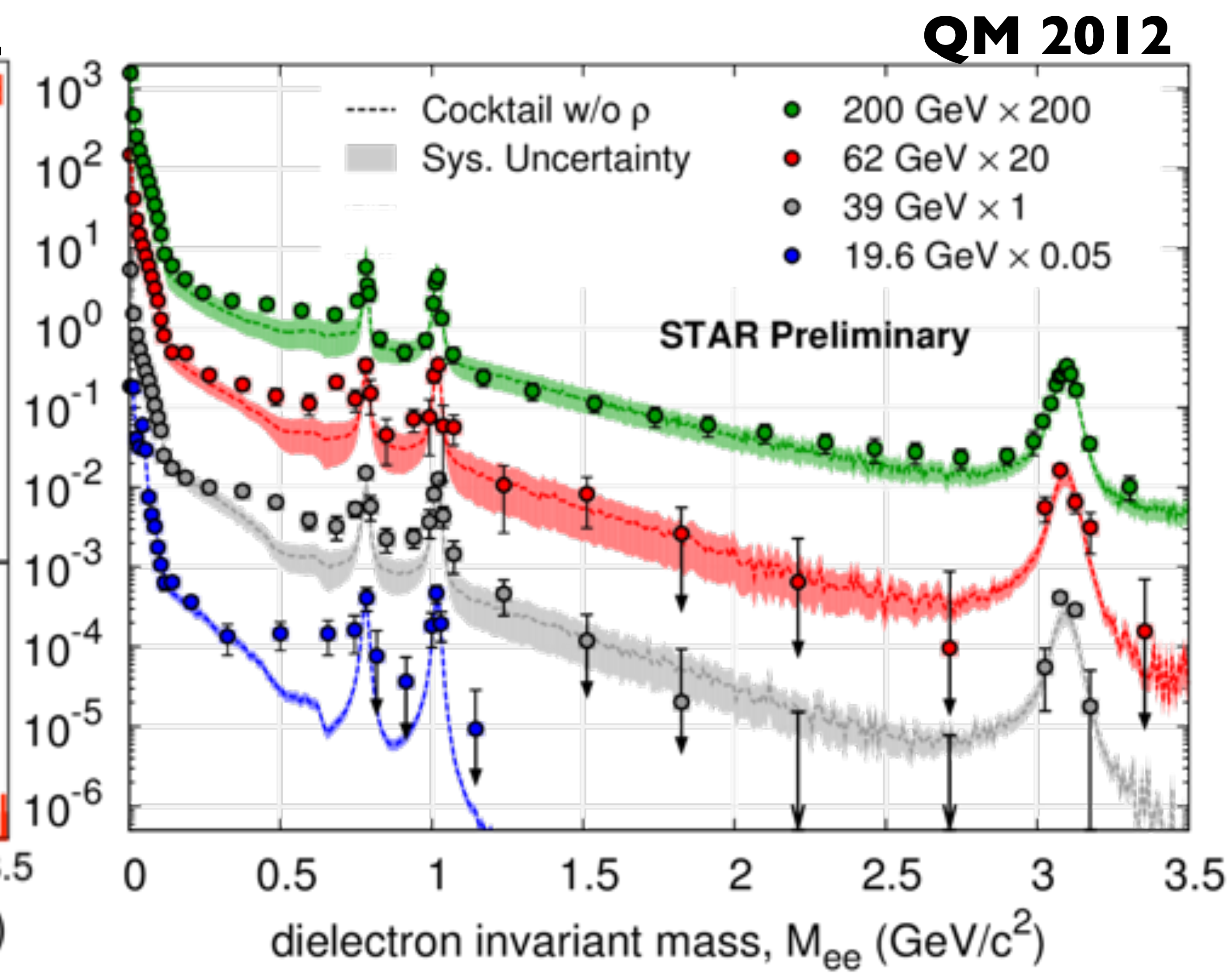


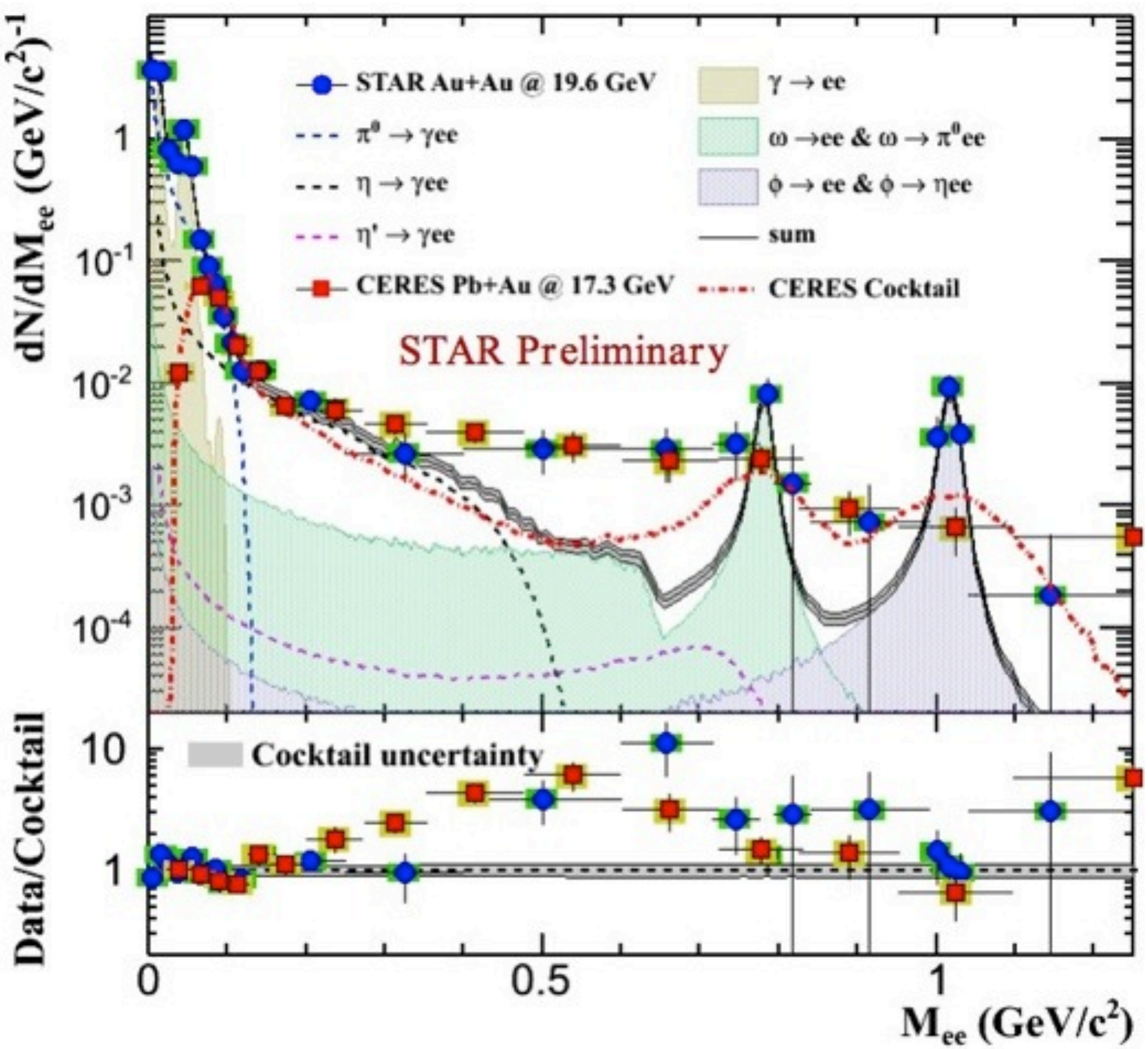
# BES Dielectron Spectra

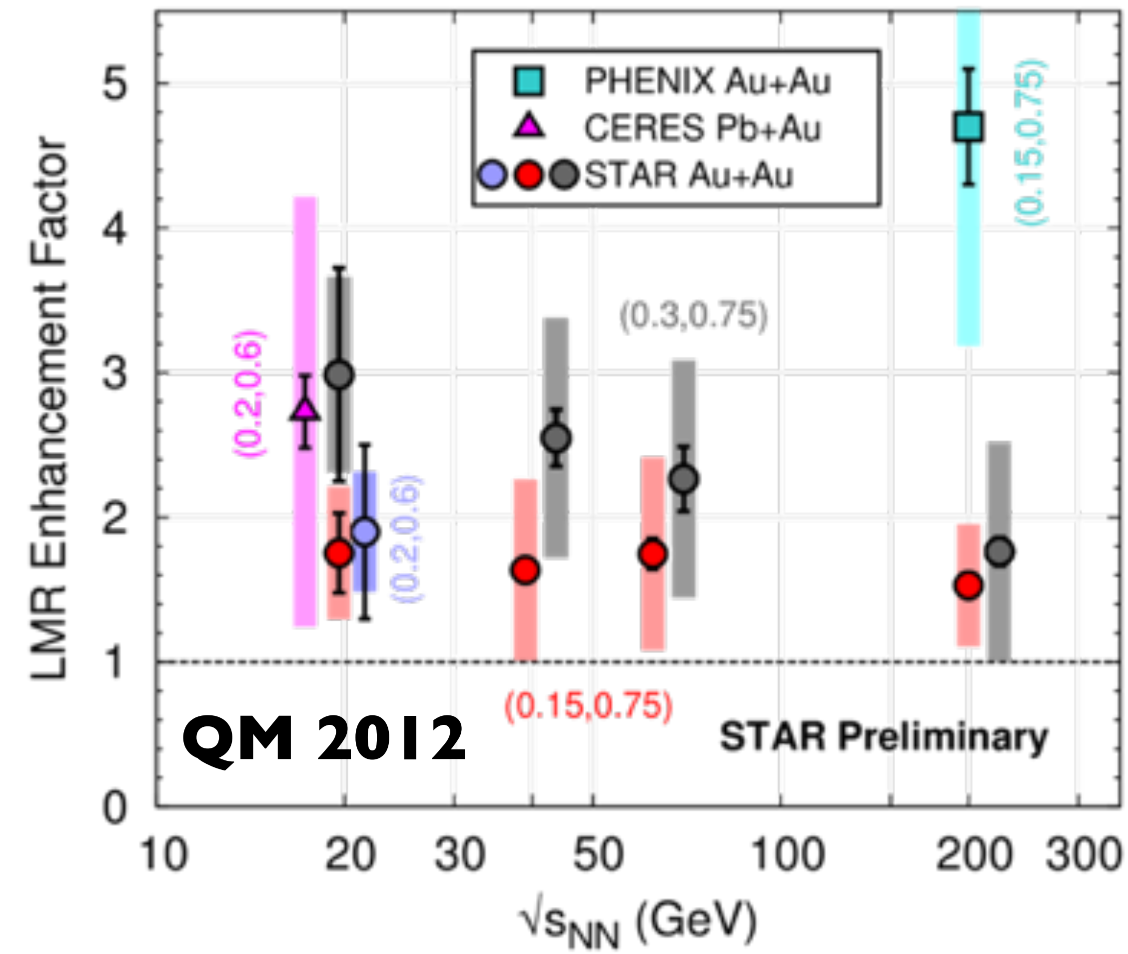



- $e^+e^-$ production below 3.5 GeV/$c^2$ systematically studied in STAR from $\sqrt{s_{NN}}$ = 19.6 GeV up to top RHIC energy.
- correlated charm adjusted to observed dielectron yield
  FONLL predictions are used as lower and
  $\chi^2$ fits to the IMR data as upper limits
- vacuum-ρ does not account for the excess yield in the LMR

# LMR Enhancement



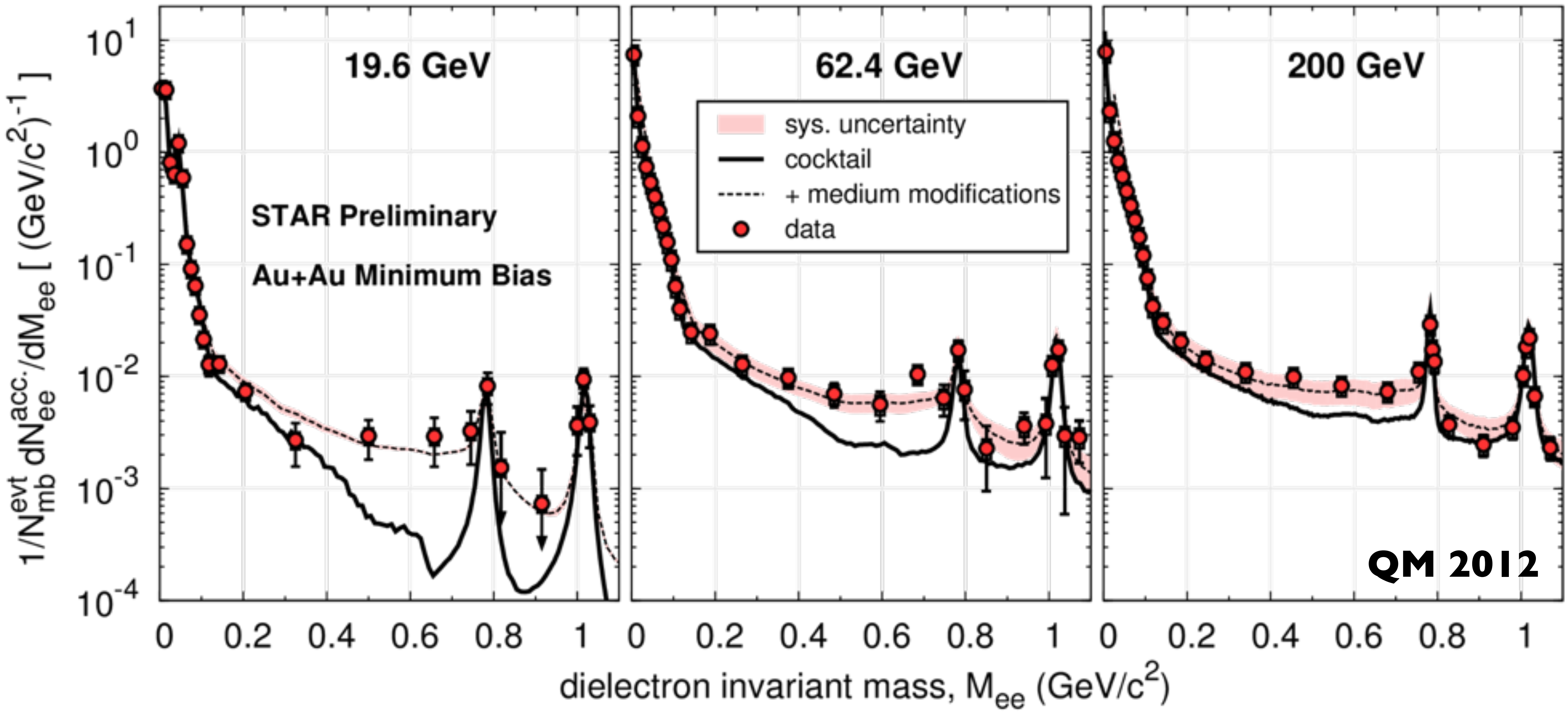




- visible LMR excess over hadronic cocktail observed for all energies. (excl. $\rho \to e^+e^-$)
- systematic measurement of the LMR enhancement factor (agreement with CERES result) [ $M_{ee}$-dep. energy overlay see backup ]

- LMR enhancement at 19.6 GeV comparable with CERES at 17.3 GeV (note: different experimental acceptances)
- increasing enhancement with decreasing energy w.r.t. the cocktail? "any energy dep. in X-Factor might be physics directly related to dielectrons from earlier creation times due to $\rho_B^{tot}$~const" Z. Xu

# Energy Dependence of In-Medium Mods

Rapp & Wambach, Adv. Nucl.Phys. 25, 1 (2000) Phys. Rept. 363, 85 (2002) displayed energies through priv. comm.




- Within systematic uncertainties, in-medium modifications of the ρ spectral function consistently describe the LMR enhancement from SPS to top RHIC energies.

# Summary , Outlook & Work in Progress

- Dielectron spectra from Au+Au collisions measured in STAR at $\sqrt{s_{NN}}$ = 19.6, 39, 62.4 & 200 GeV and compared to cocktail calculations.
- LMR excess yield can be accounted for by in-medium modifications to the ρ spectral function across a wide range of energies.
- enhancement increasing with decreasing energy w.r.t. the cocktail?
- measurements will provide comprehensive data for the better understanding of the LMR enhancement ($p_T$, centrality and energy dependence)

**work in progress**

- complete BES data set
- $p_T$ spectra for $M_{ee}$ regions
- detailed systematic uncertainty studies
- cocktail improvements

**outlook**

- IMR: Charm continuum contribution and its possible in-medium modification need better understanding in Au+Au to possibly access QGP radiation in the future
  ⇒ study energy dependence of initial temperature
  ⇒ STAR HFT & MTD upgrades

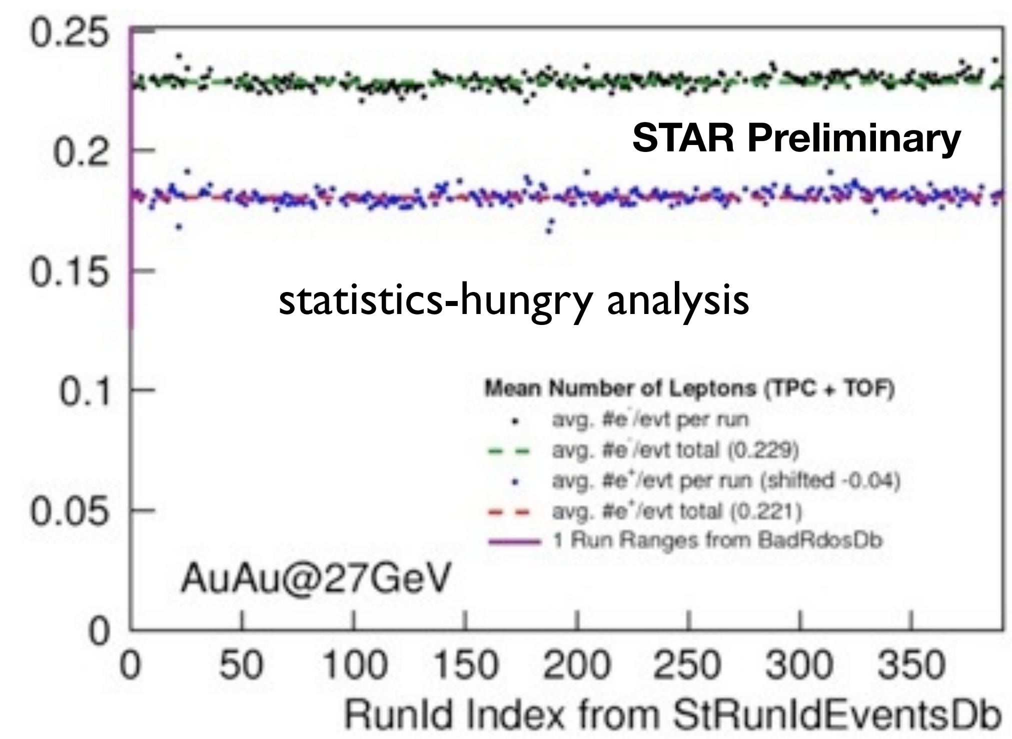
## Thank you for your attention

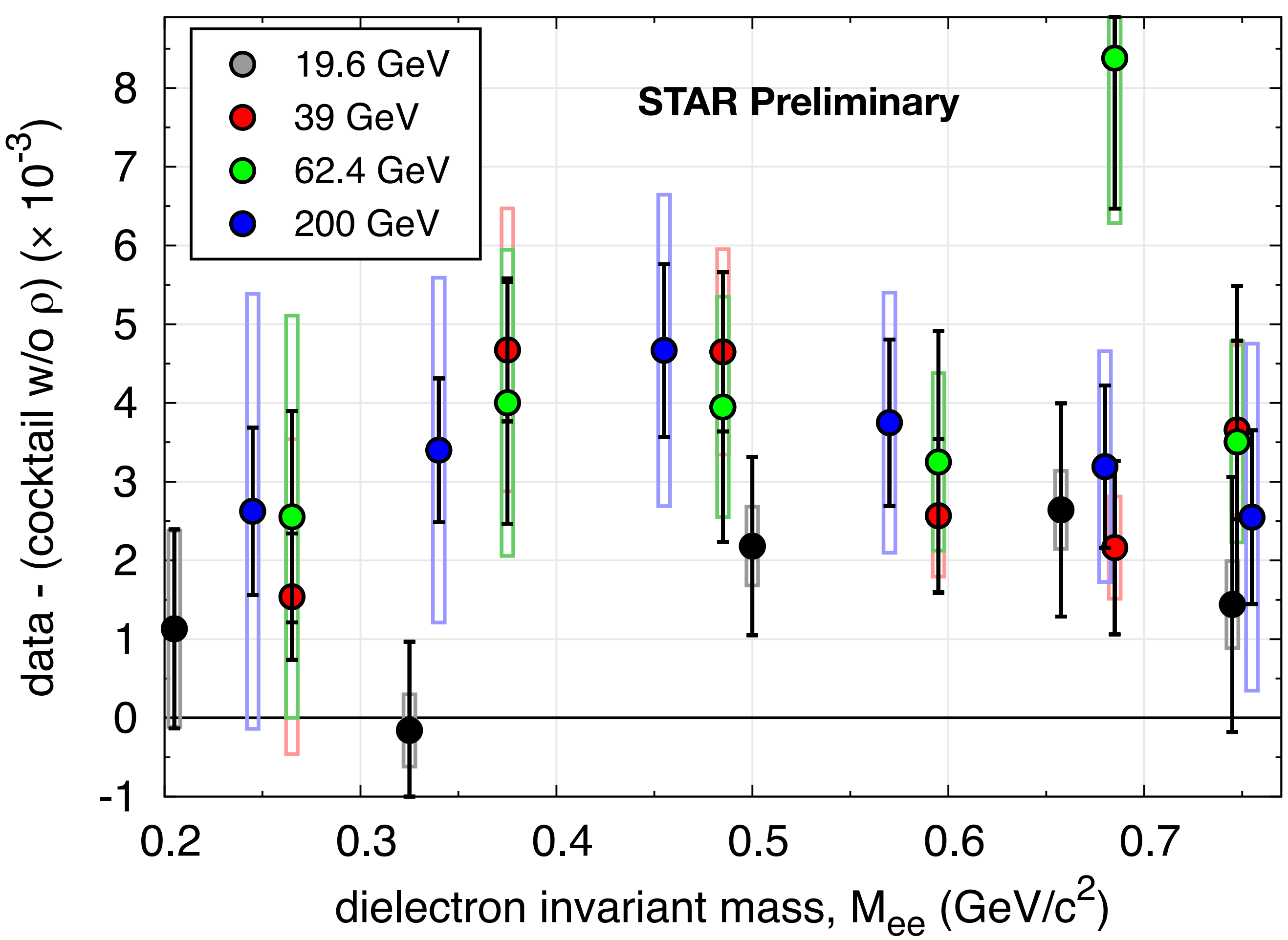
# BACKUP SLIDES

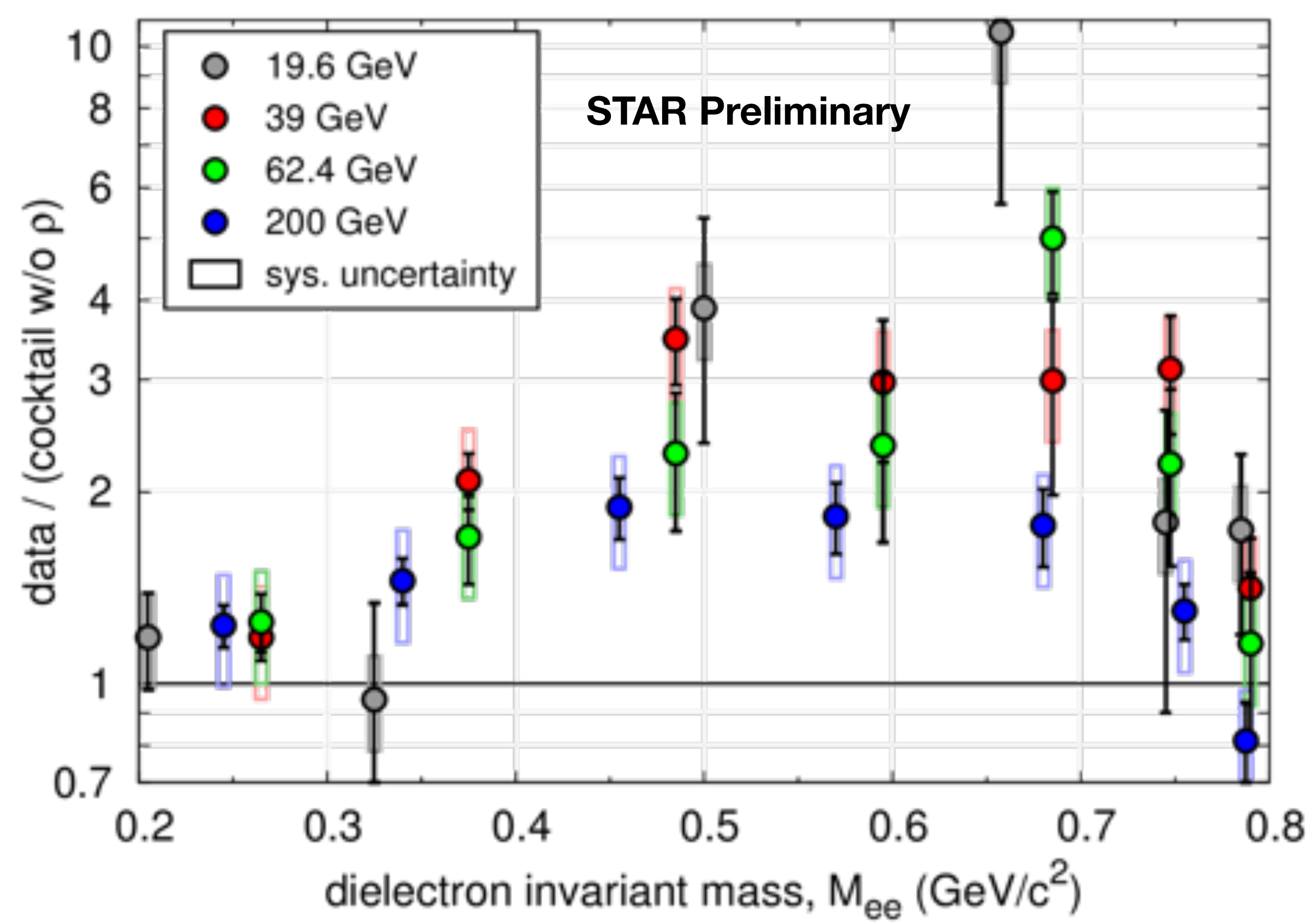
- absence of baryonic resonances with $\phi$N decay channels due to OZI-rule *

*$\bar{s}$ annihilation into excitation energy strongly suppressed

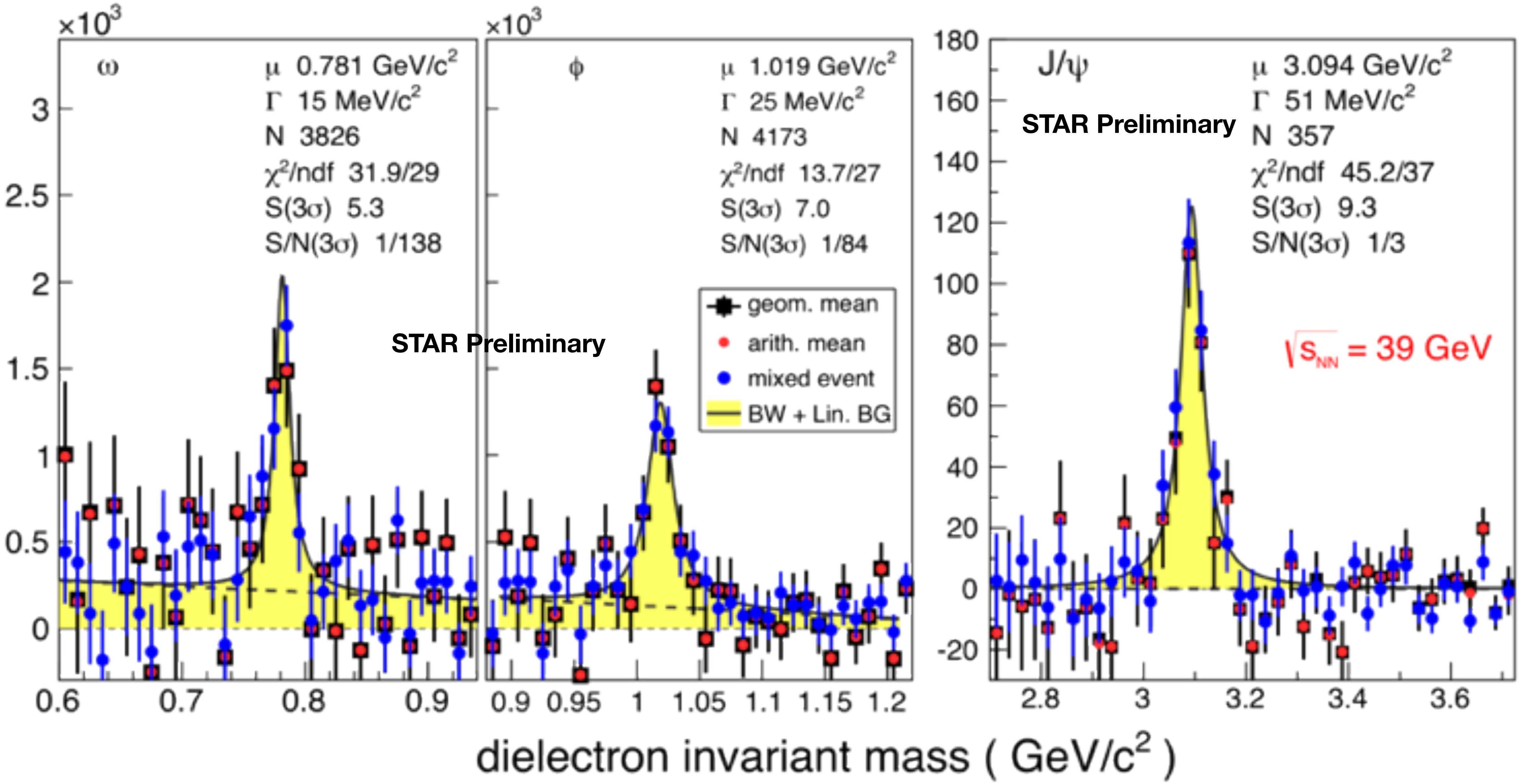
| $\sqrt{s_{NN}}$ (GeV) | Vector Meson Yields (30% uncertainty assigned) | | | | | $\sigma_{pp}^{c\bar{c}}$ (mb) ± sys. | $N_{bin}^{coll}$ |
|---|---|---|---|---|---|---|---|
| | $\pi^0$ † | $\eta$ † | $\omega$ | $\phi$ | J/$\psi$ | | |
| 39 | 57 | 9.37 | 4.42 | 1.39 | $4.8 \times 10^{-4}$ | 0.19 ± 0.11 | 243 |
| 62.4 | 72.9 | 11.4 | 5.38 | 1.79 | $1.2 \times 10^{-3}$ | 0.40 ± 0.25 | 253 |



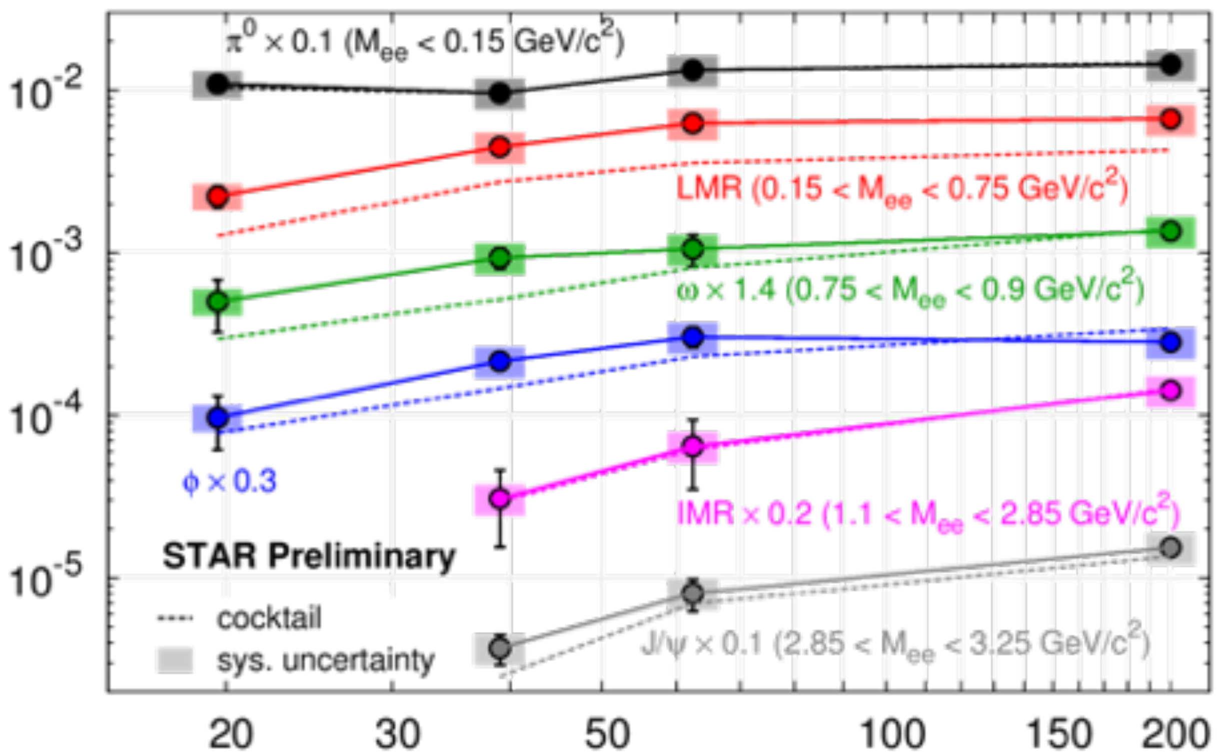



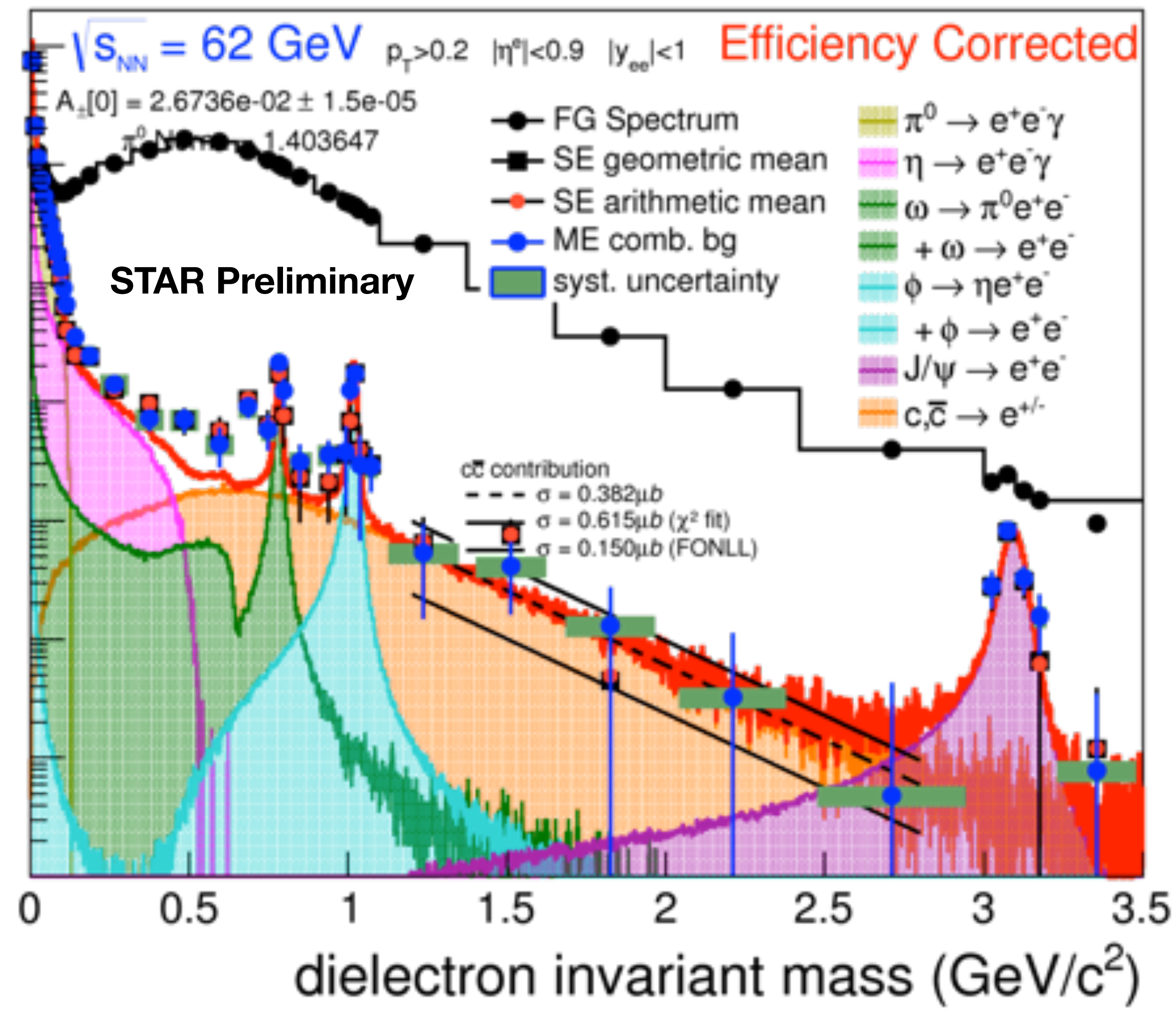



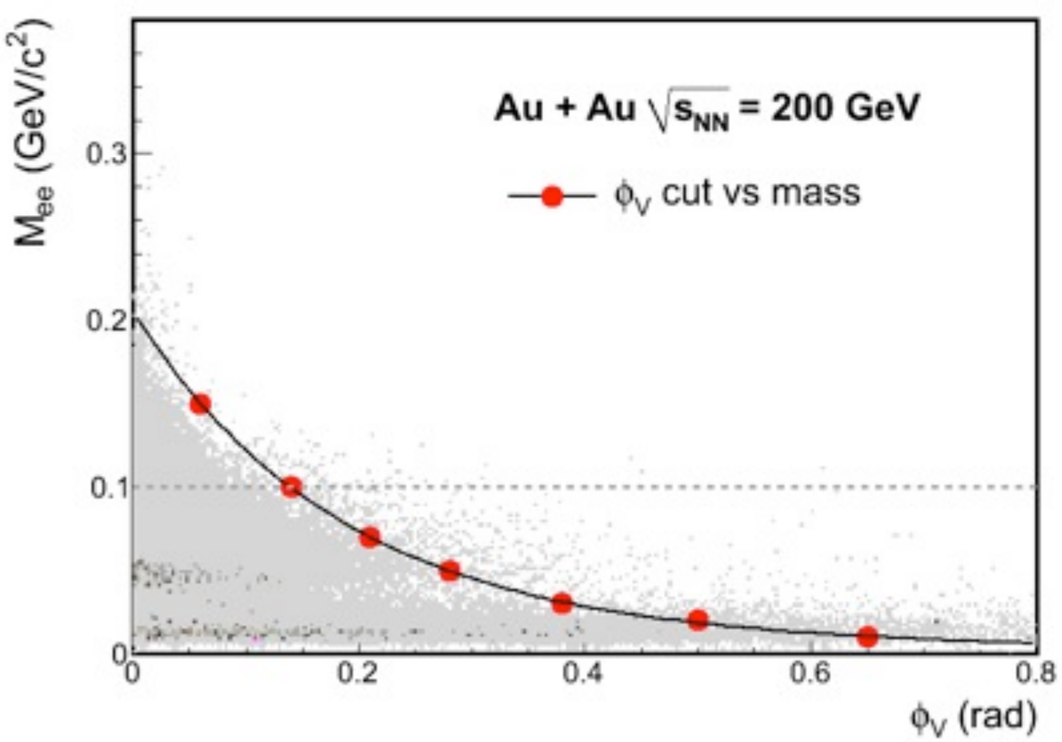
# STAR ☆ Vector Meson Signals & S/N

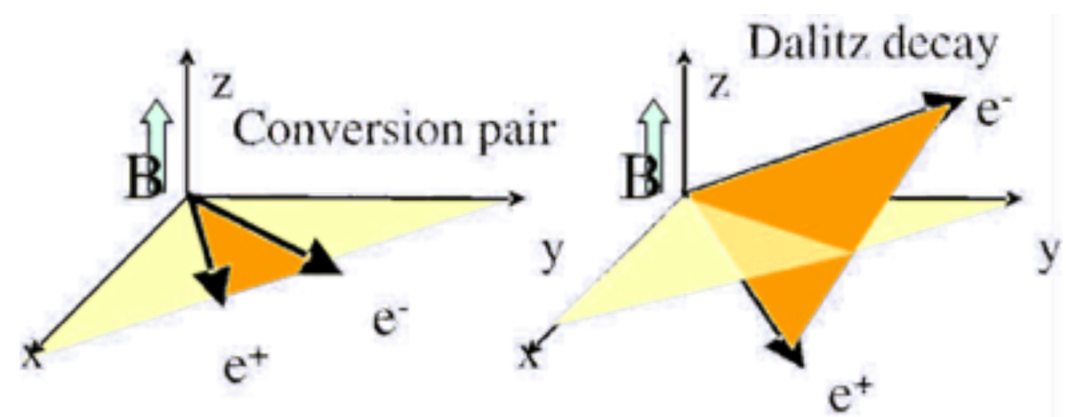



- $\rho/\omega$ region exhibiting a S/N ratio of ~1/100 - 1/250
- background subtraction crucial
- prominent vector meson signals after background subtraction




define phiV as the orientation of the dilepton plane w.r.t the magnetic field

# Cocktail w/ Vacuum-Rho