LATEST ANALYSIS WITH THE PHENIX HBD

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for the PHENIX Collaboration

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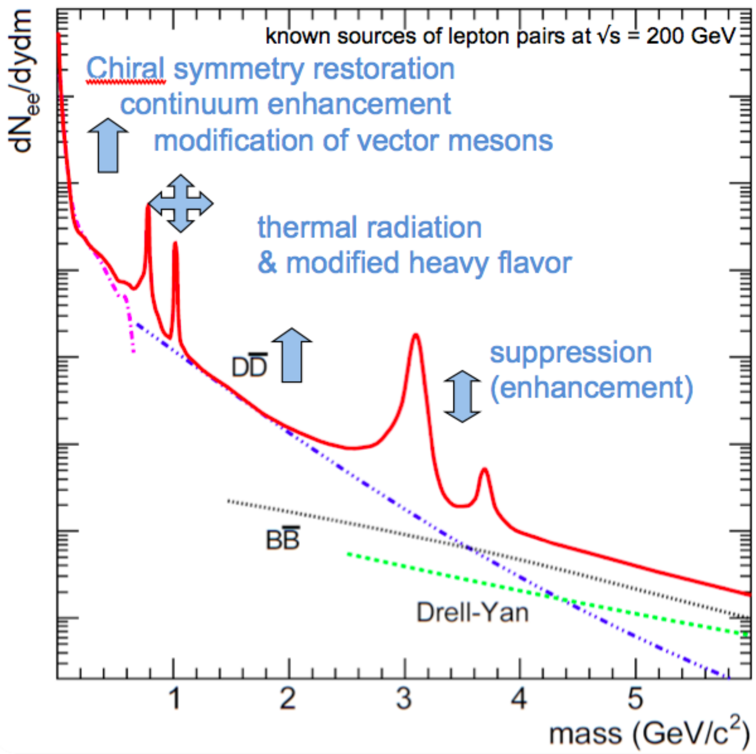
Outline

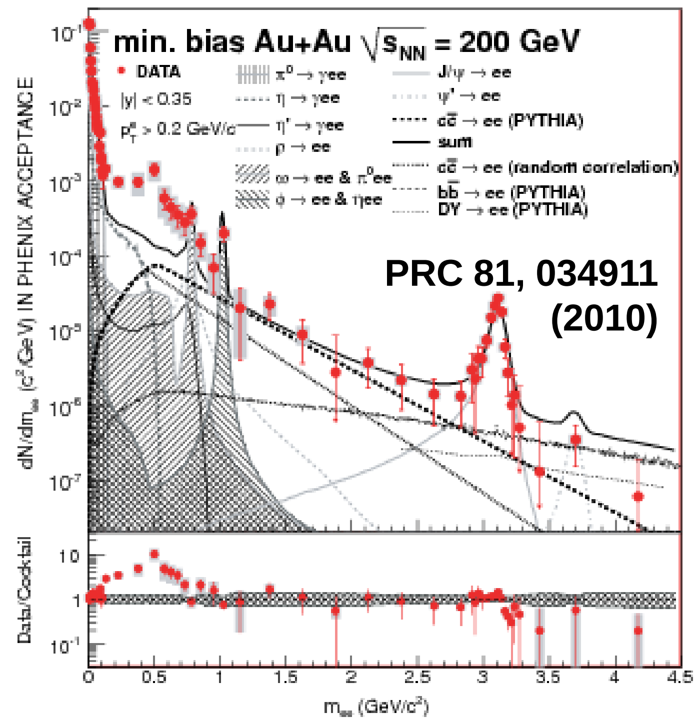
- Introduction
- PHENIX with the HBD
  - The Hadron Blind Detector
  - Run-10 preliminary result
- Recent progress
  - Statistics
  - Electron identification
  - Background subtraction
  - Quantitative understanding of the background
- Summary

Introduction

Dielectron mass spectrum

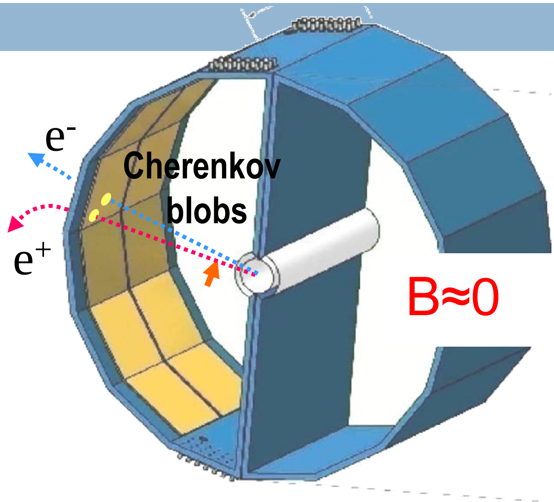


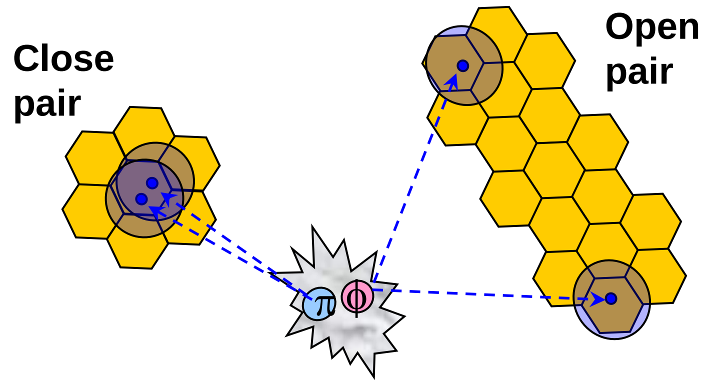
2004 Run (Au+Au) $\sqrt{s_{NN}}$=200 GeV



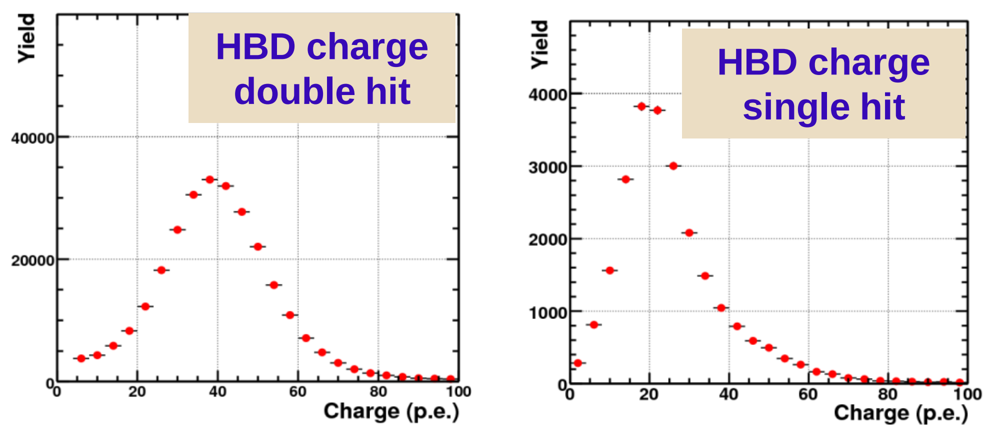
Large backgrounds due to π^0 Dalitz and conversions → improve with the **HBD**

The Hadron Blind Detector





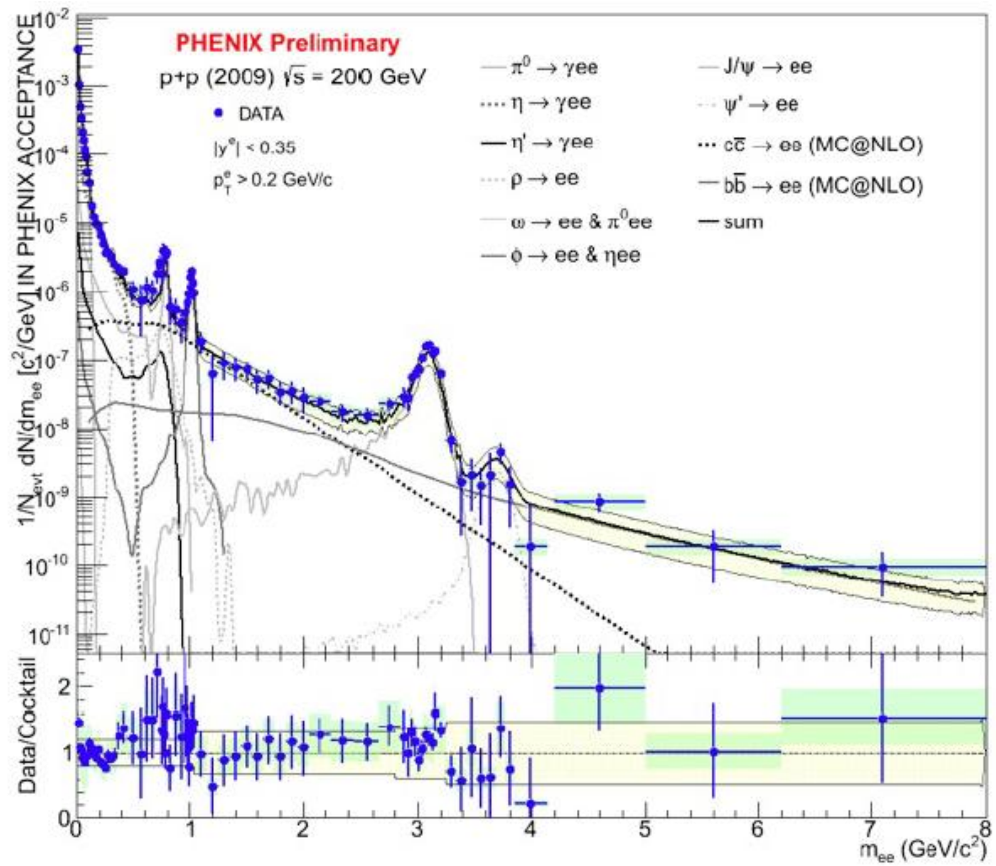
- Cherenkov detector
- GEMs with CF_4
- Distinguishes pair opening angle
- Can veto background e^+e^- pairs from π^0 Dalitz and γ conversions



NIM A646, 35-58 (2011)

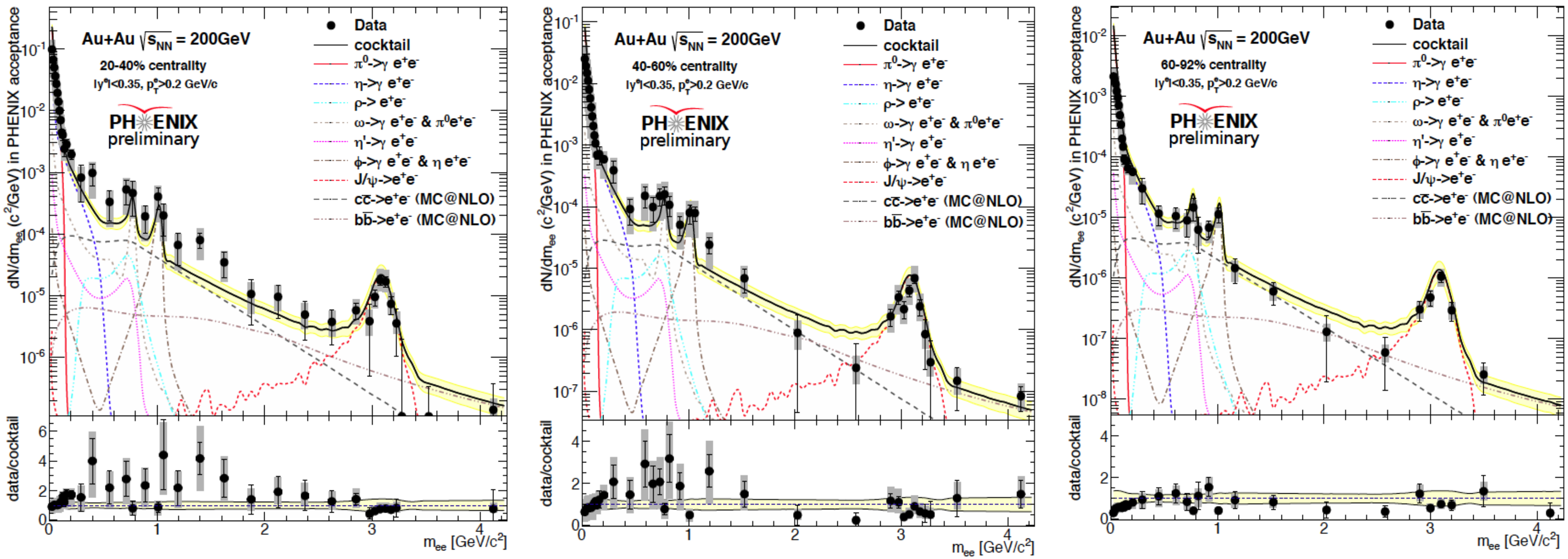
The preliminary result
2009 p+p Run, sqrt(s)=200 GeV

- Data consistent with the cocktail
- Fully consistent with the published result
- Provide the crucial proof of principle for understanding the HBD



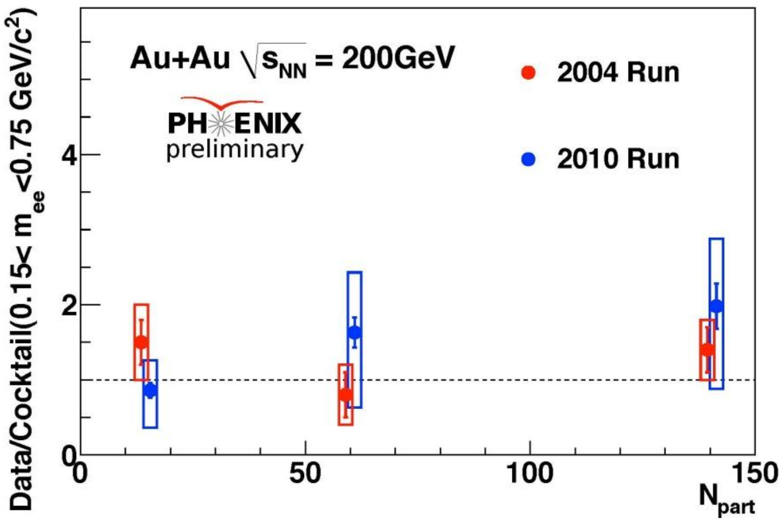
The preliminary result
2010 Au+Au Run, sqrt(s_{NN})=200 GeV

20-40% **40-60%** **60-92%**

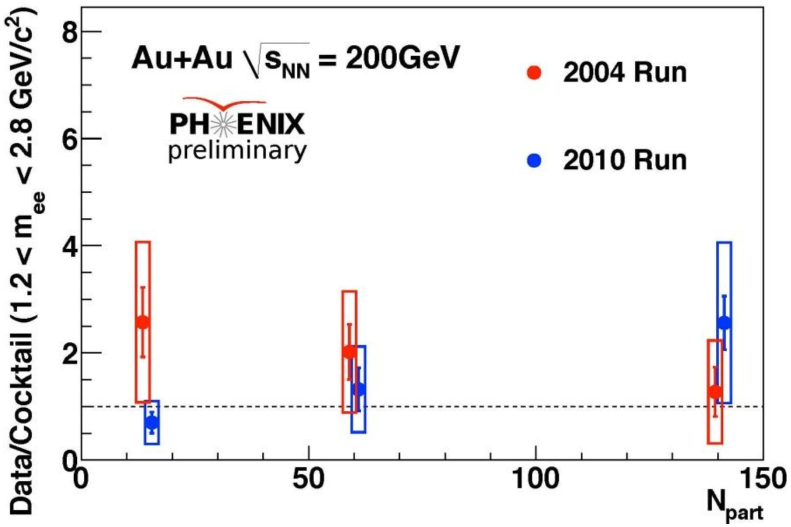


Data over cocktail

LMR (m = 0.15 – 0.75 GeV/c²)



IMR (m = 1.2 – 2.8 GeV/c²)



- 2004 and 2010 Run results consistent
- Large errors

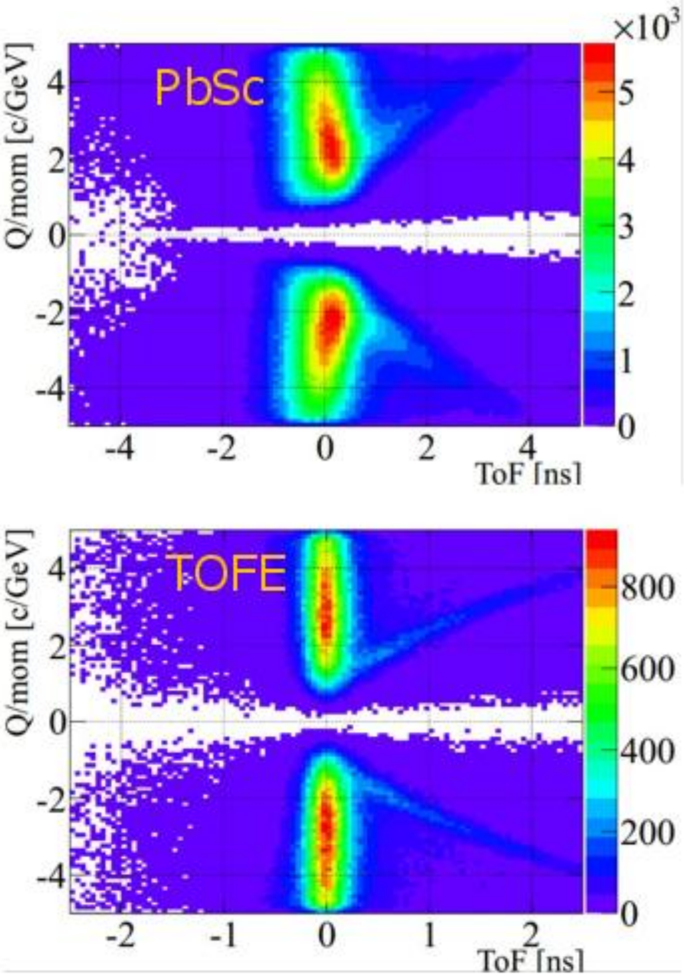
(Run-10 errors driven by strong fiducial cuts and conservative estimate of systematics)

Recent progress

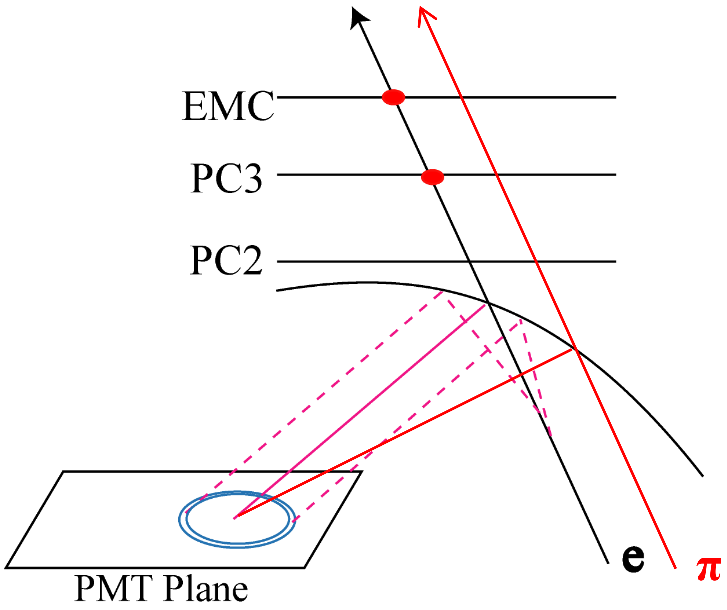
- Statistics:
  - 4.6B→5.6B events, by relaxing the vertex cut
- Electron identification
- Background subtraction

PHENIX Time-of-flight

- Time-of-flight information implemented for improved hadron rejection
  - EMCal (PbSc)
    - 3/4 of acceptance
    - σ=450 ps
  - ToF East
    - ~ 1/8 of acceptance
    - σ=150 ps



Revised RICH reconstruction algorithm



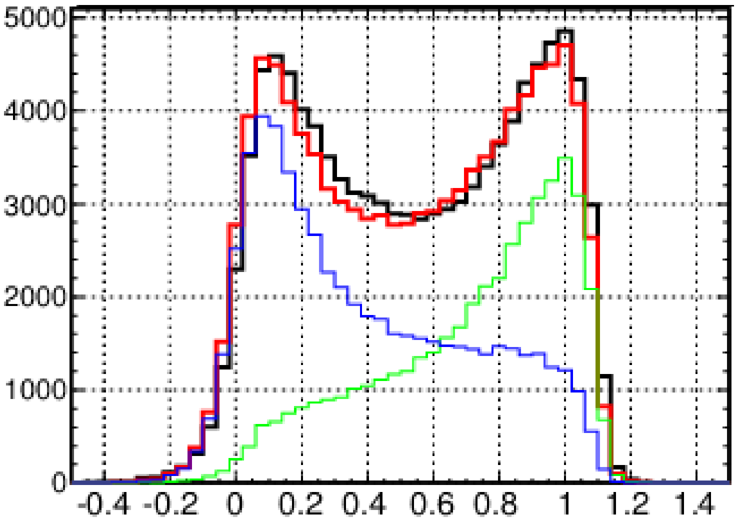
- Ring reconstruction in the Ring Imaging Cherenkov Detector (RICH)
  - Parallel tracks point to the same ring in RICH
  - Hadrons can leak in
  - New algorithm forbids a ring to be associated with multiple tracks
  - Associate only with signal electron candidate tracks

Optimized electron identification

- Use neural networks for:
  - Hadron rejection
  - Conversion rejection
  - HBD double hit rejection
- Input for NNs: EmCal, HBD, ToF, modifed RICH
- Hadron contamination factor of ~1/3 as with 1D cuts, keeping similar efficiency
- Electron sample purity in 0-10% central events is ~95% (was ~70% in 2004 Run)

NN trained and monitored on HIJING simulation:

DATA – black **HIJING – red**
HIJING signal **HIJING bckg**

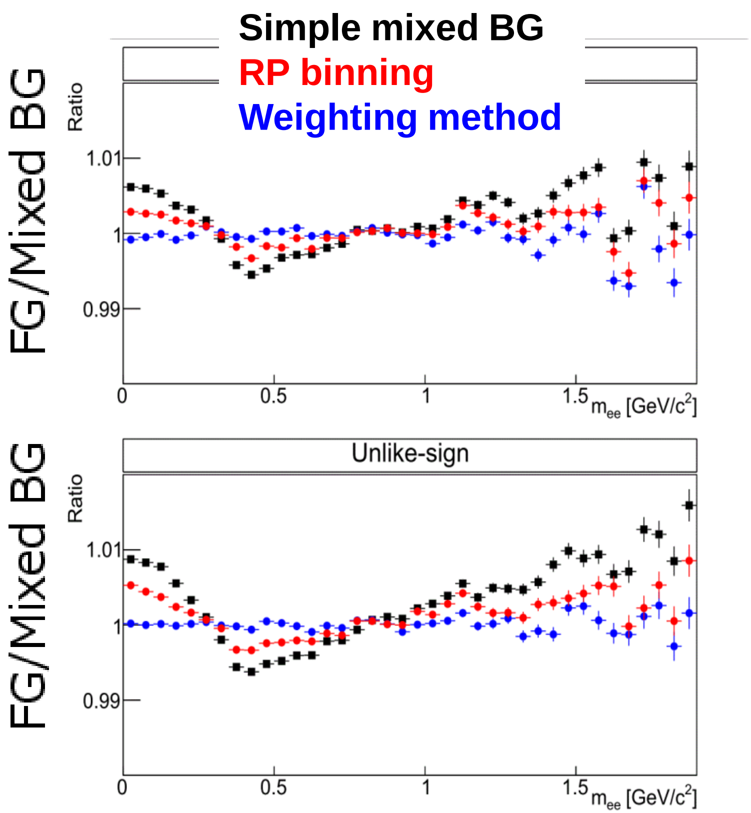


Neural network output

Background subtraction

- Run-10 preliminary result - hybrid background subtraction
  - Subtract the mixed BG
  - Subtract the acceptance corrected residual like-sign spectra
  - Not enough precision for the central bins
- Run-10 current effort - component-by-component subtraction:
  - Traditional approach: FG = mixed BG + jet + cross-pair
    → could not reproduce the like-sign data
  - New approach: **FG = mixed BG with flow + jet + cross-pair + e-h hidden correlation**

Mixed background with flow

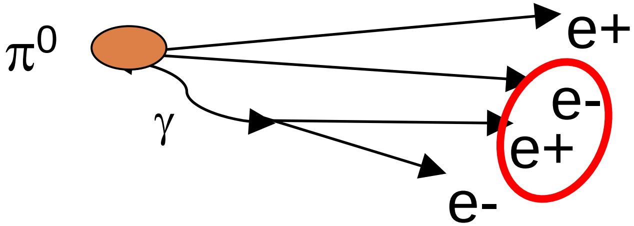


E.g. simulation using single electron v_2 from 20-40% data

- Flow distorts the shape of the combinatorial background
- RP binning does not correct the effect completely
- To correct for the flow effect, each mixed background pair is weighted by an analytic factor:

  $w(\Delta\varphi) = 1 + 2\, v_2(p_{T,1})\, v_2(p_{T,2}) \cos(2\Delta\varphi)$
- Single electron v_2 derived from the data
- The approach is verified by the simulation (plots on the left)
- The weighting method reproduces correctly the combinatorial background shape

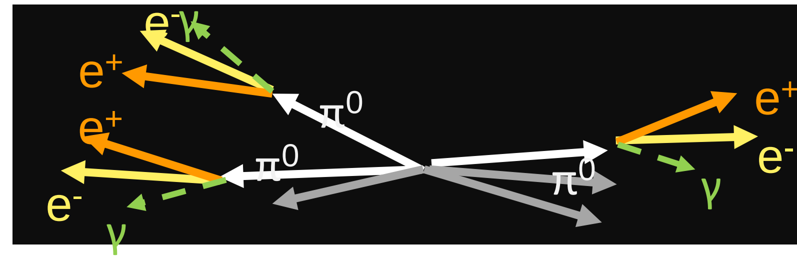
Cross-pairs



- e^+e^- pairs from the same primary particle, but different parent → correlated background
- $\pi^0 \rightarrow e^+e^-\gamma$, $\pi^0 \rightarrow \gamma\gamma$ and $\eta \rightarrow e^+e^-\gamma$, $\eta \rightarrow \gamma\gamma$ simulated with EXODUS generator
- Passed through PHENIX acceptance and reconstruction
- Normalization: **absolute**
  - π^0 and η contributions scaled by dN/dy measured by PHENIX

Jet contributions

- Correlated e^+e^- pairs from jets
- Simulated using PYTHIA generator (p+p jets)

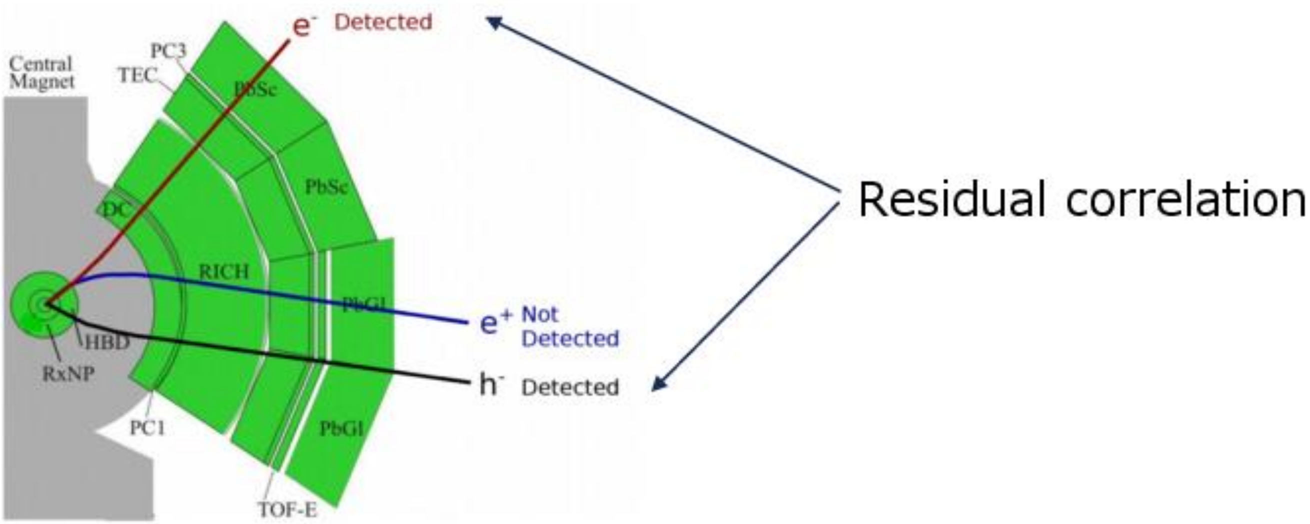


- Passed though PHENIX acceptance and reconstruction
- Normalization: **absolute**
  - Each *ee* pair scaled by:

$$\mathbf{N_{coll} * R_{AA}\,(p_T^{a}) * I_{AA}\,(p_T^{b},\Delta\phi)}$$

- p_T and $\Delta\phi$ refer to primary particles
- a – the particle with the higher p_T, b – the particle with the lower p_T
- R_{AA} is from PHENIX data for pions
- I_{AA} from PHENIX data from PRC 78,014901 (2008)

e-h hidden correlation



- Hadron (h^-) parallel to e^+ in RICH → h^- is misidentified as electron
  - If e^+ and h^- are reconstructed, the RICH ring sharing cut will reject the event
  - If e^+ is not reconstructed (efficiency or dead area), the ring sharing is not recognized, and the e^-h^- pair enters the event
- The e^-h^- pair is correlated, so cannot be removed by the mixed background
- Simulate this contribution and subtract

Mixed background normalization

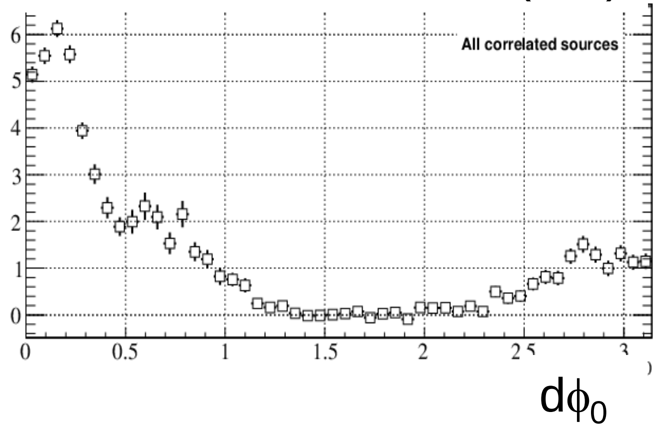
- Mixed BG normalization (weighted with flow):
  - FG_{++} = $Cross_{++}$ + Jet_{++} + $e\text{-}h_{++}$ + $\mathbf{nf_{++}}$ * $mixBG_{++}$
  - FG_{--} = $Cross_{--}$ + Jet_{--} + $e\text{-}h_{--}$ + $\mathbf{nf_{--}}$ * $mixBG_{--}$

  Fit with $\mathbf{nf_{++}}$ and $\mathbf{nf_{--}}$ being the only free parameters

A. Normalization using pair opening angle ($d\phi_0$)

Centrality	Norm region
0-10%	0.7<dphi0<3.14
10-20%	0.7<dphi0<2.3

All correlated sources (MC)

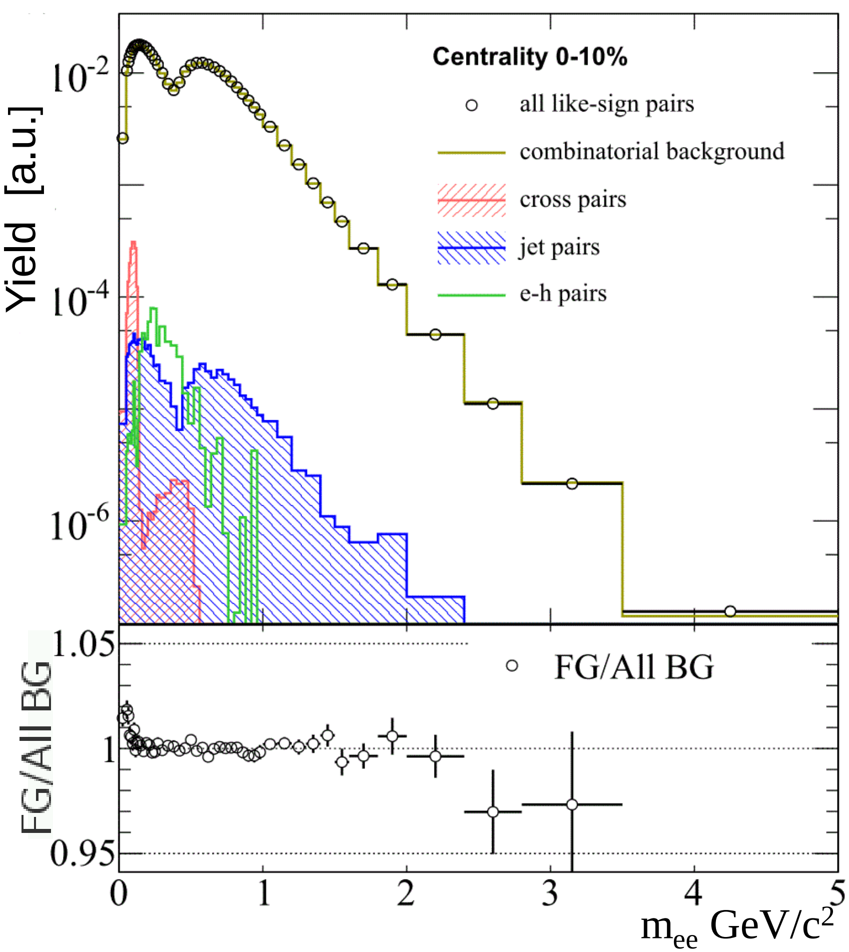


B. Normalization using pair mass $m_{ee} > 0.2\ GeV/c^2$

→ A and B are consistent

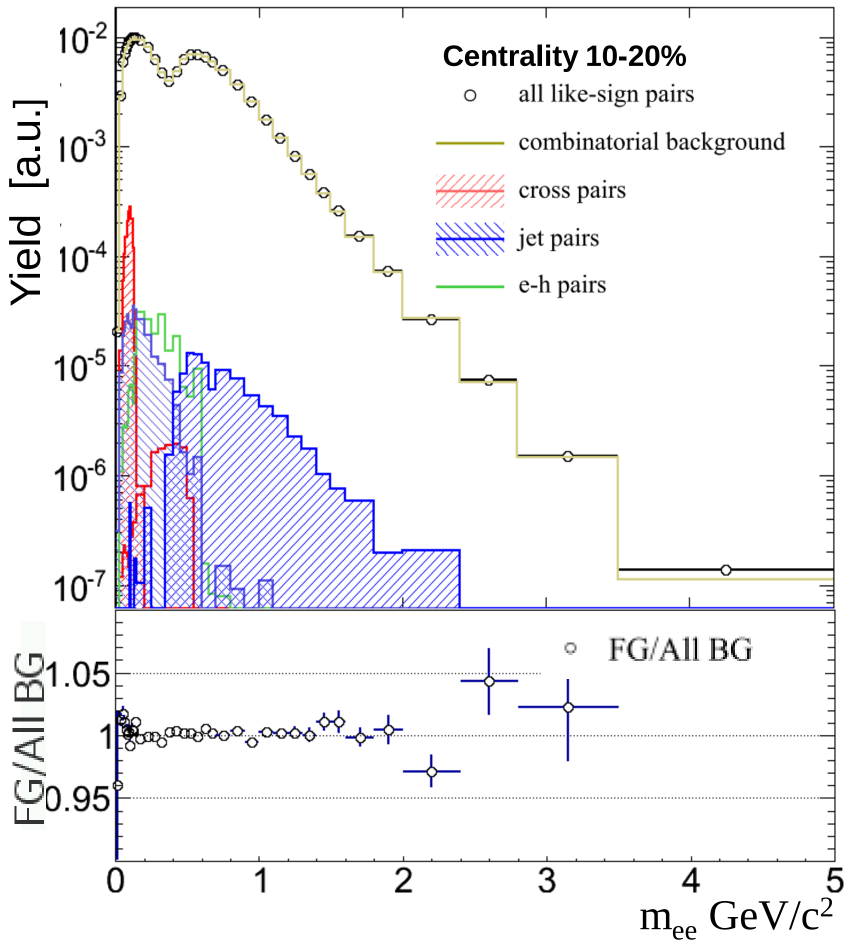
Like-sign spectrum, 0-10% centrality

- Understanding of the background verified by the **like-sign** spectra
- Correlated components absolutely normalized
- Combinatorial background - mixed background with flow
- The ratio of the like-sign foreground to total background, for m_{ee}>0.15 is **flat at 1**
- **Very good qualitative and quantitative understanding of all background components**



Like-sign spectrum, 10-20% centrality

- Understanding of the background verified by the **like-sign** spectra
- Correlated components absolutely normalized
- Combinatorial background - mixed background with flow
- The ratio of the like-sign foreground to total background, for $m_{ee}>0.15$ is **flat at 1**
- **Very good qualitative and quantitative understanding of all background components**



Summary

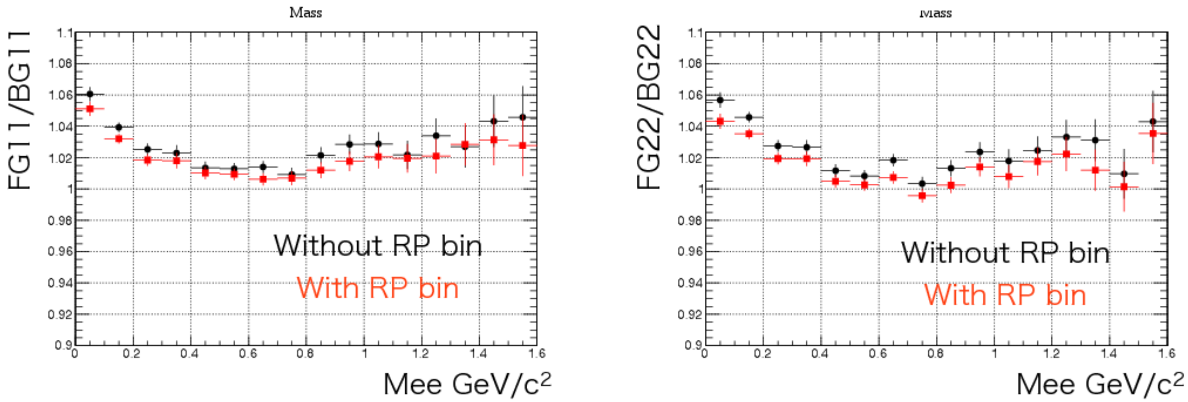
- Since QM2012
  - Significant progress on electron identification - 95% sample purity achieved
  - Good qualitative and quantitative understanding of the background component-by-component
- Analysis closing completion

BACKUP

Effect of flow on the combinatorial background (I)

- <u>Motivation</u>:
  - Residual correlated yield in the FG/mixedBG like-sign ratio
  - This yield could not be explained by know sources (e.g. jets)

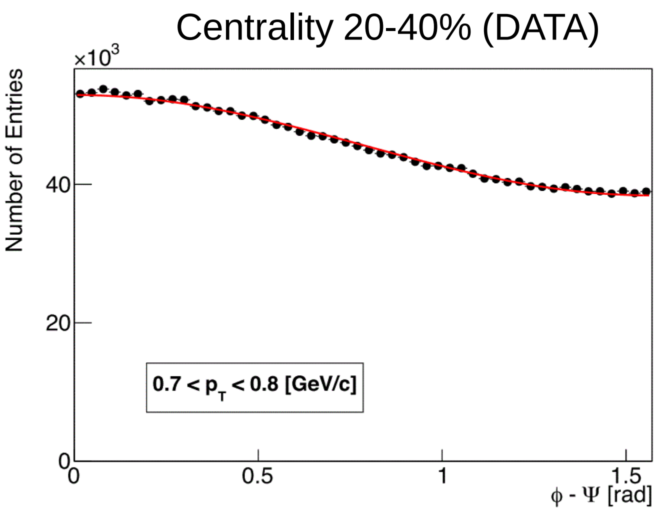
Centrality 20-40% (DATA)



- Suspect flow correlations
  - Only partially removed by the reaction plane binning
  - Cannot be completely eliminated due to finite RP resolution

Effect of flow on the combinatorial background (II)

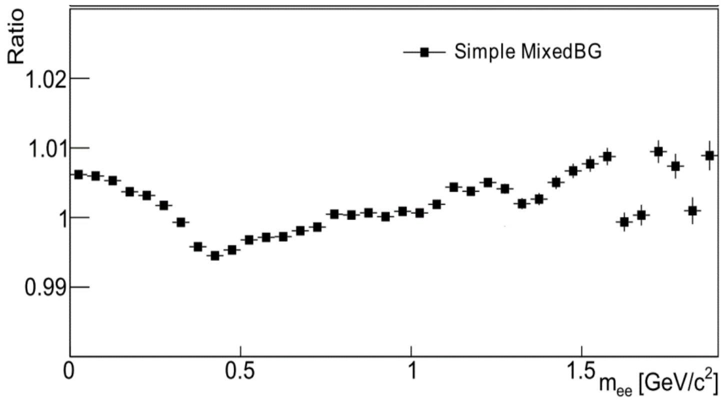
- Explanation:
  - Due to flow, particle emission angles (φ) are not uniformely distributed relative to the reaction plane (Ψ)
  - If single particles are generated according to the distribution function:
    $1+2v_2\cos(2(\varphi-\Psi))$
  - It can be shown that random pairs are distributed according to:
    $w(\Delta\varphi) = 1 + 2v_2(p_{T,1})v_2(p_{T,2})\cos(2\Delta\varphi)$



Effect of flow on the combinatorial background (III)

- <u>Study the effect with realistic MC</u>:
  - Generate e^+ and e^-
    - p_T distribution from data
    - Uniform in rapidity
    - Reaction plane (Ψ) uniformely from $[-\pi/2,\pi/2]$
    - Determine azimuth angle (j) by: $1+2v_2\cos(2(\varphi-\Psi))$
    - v_2 extracted from from 20-40% data
  - Pass PHENIX acceptance filter
  - Standard pair analysis
  - MC reproduced the residual shape compatible with the one seen in data

Like-sign FG/mixed BG (MC)



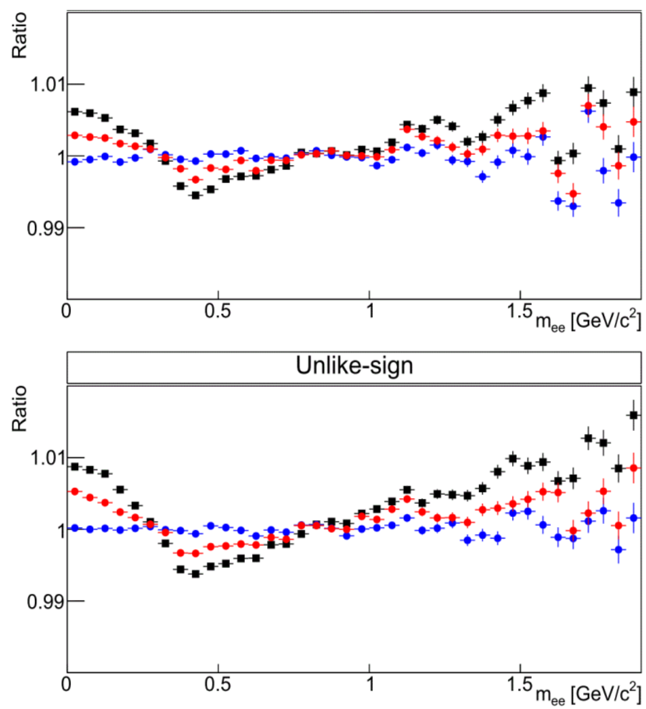
Effect of flow on the combinatorial background (IV)

- <u>Study the weighting method with realistic MC</u>:
  - Apply the weight for each pair in the generated mixed background:

    $w(\Delta\varphi) = 1 + 2v_2(p_{T,1})v_2(p_{T,2})\cos(2\Delta\varphi)$
  - Electron v_2 extracted from the analyzed data
  - Reproduces the combinatorial background perfectly
- Cross-check the reaction plane binning method with the same MC setup
  - Fails to reproduce the combinatorial background

Simple mixed BG
RP binning
Weighting method

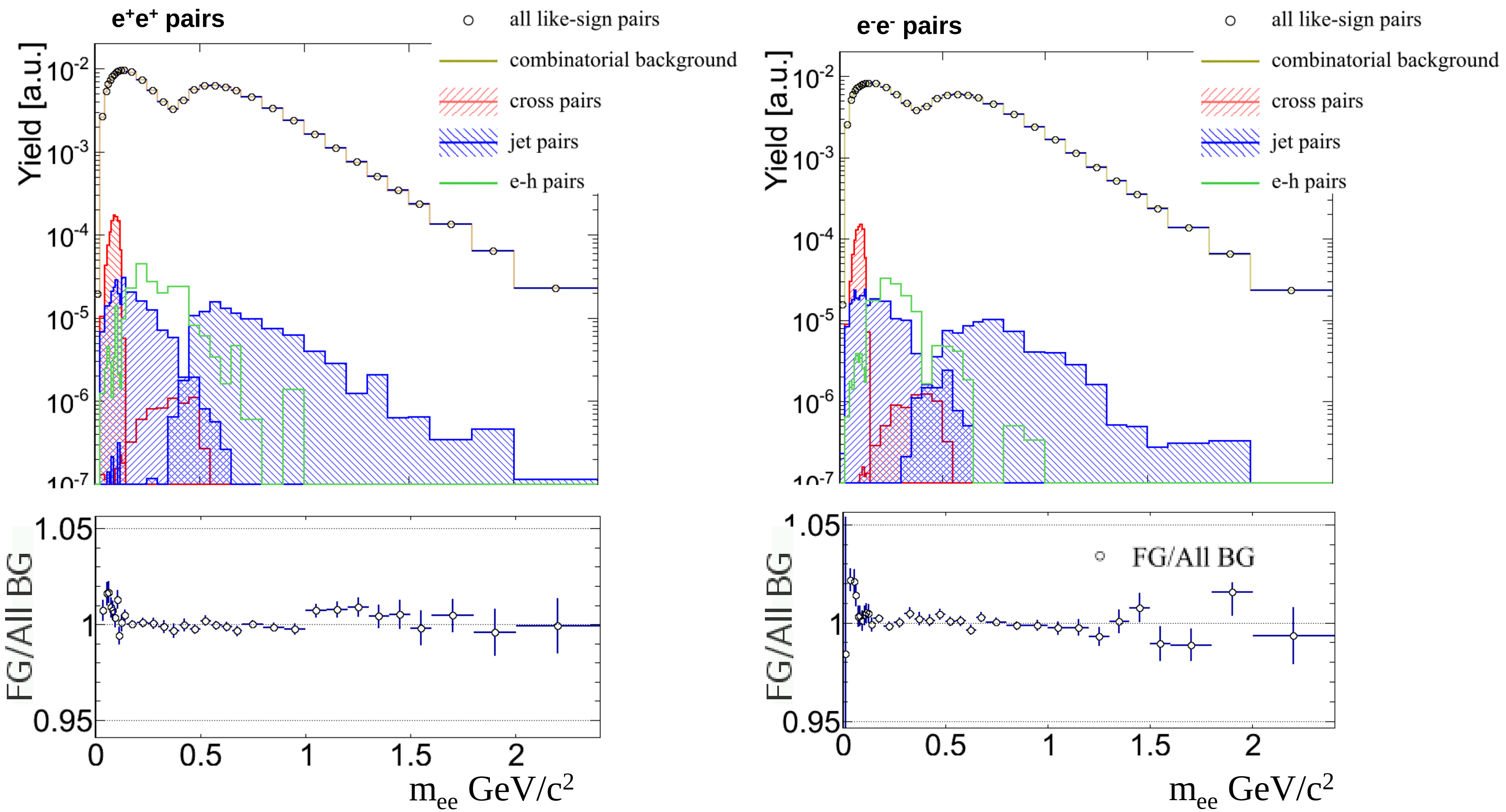
Like-sign FG/mixed BG (MC)



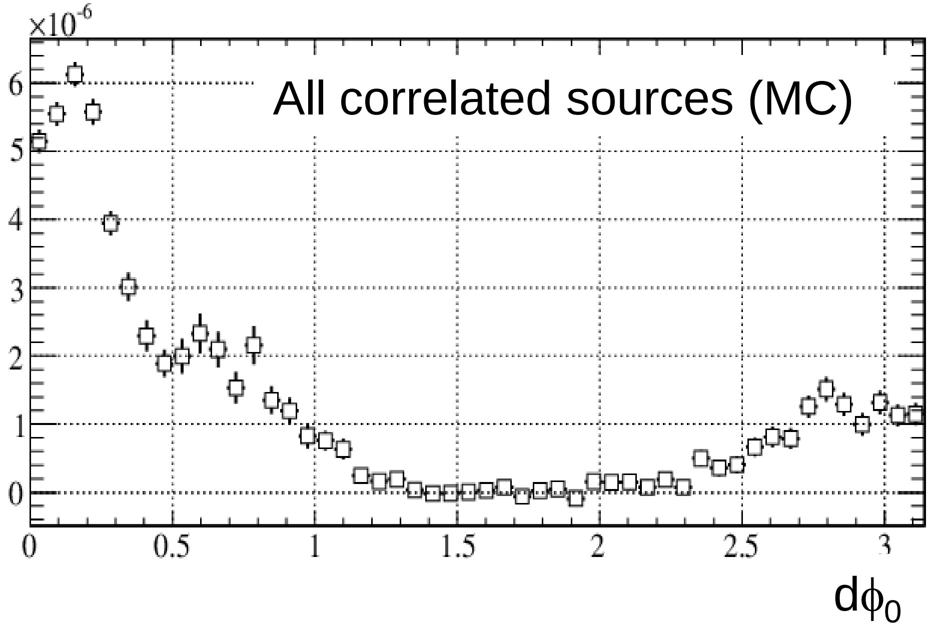
e-h contribution simulation

- Use π^0 and η cross-pair simulation
  - Add MC tracks to DATA events
  - Merge MC and DATA hits in RICH
- Filter only DATA tracks which used to fail eID cuts before merging, but pass eID cuts after merging (promoted hadrons)
- Apply all the analysis cuts
- Select the remaining MC-data pairs
- Normalization of e-h contribution: **absolute**
  - Comes automatically since the cross-pairs are absolutely normalized

Like-sign spectra, 0-10% centrality (++, -- separately)

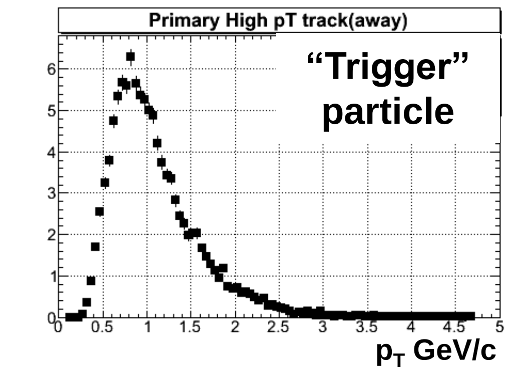


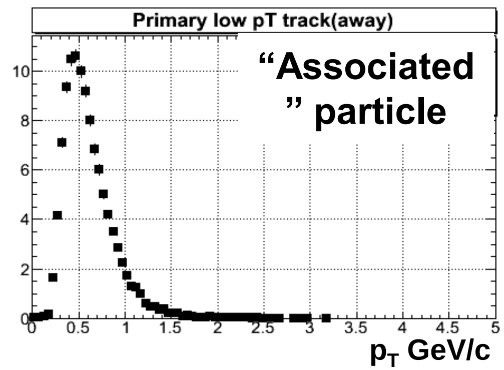
Background normalization using the opening angle

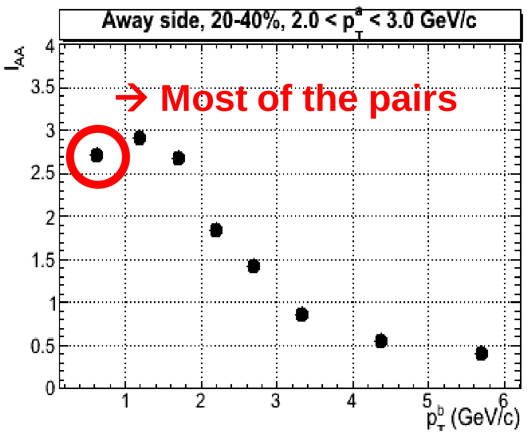


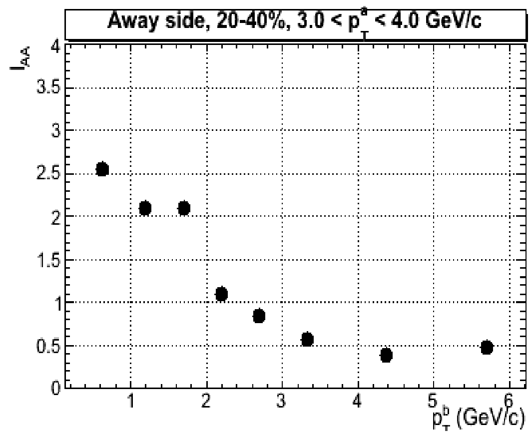
- Idea: normalize the combinatorial background in the region where the correlated components are minimal
- Avoid the systematic error of the correlated components (MC)
- Opening angle distribution of all correlated sources
- Clear minium around $d\phi_0 \sim 90°$

Jet normalization – I_{aa} extraction









example for 20-40%, away side

1. Select the centrality bin:
   - 0-20%
   - 20-40%
   - 40-60%
   - 60-92%
2. Op. angle <90° or >90° ?
3. Select p_T range of the “trigger particle” → for p_T<2.0, use the lowest p_T bin (2-3 GeV/c)
4. Select p_T of the “associated particle” → take the closest point
5. Get the corresponding I_{aa}

eID flow

STEP0

- **Reject obvious hadrons – NN0 (DCPC+EMCal+RICH+ToF)**

STEP1

- **Erase RICH PMTs** of uninteresting electrons:
  - identified conversions,
  - electrons with p_t<0.2,
  - HBD double hits - **NN SD (HBD)**

STEP2

- **Reject remaining hadrons – NN1 (DCPC+EMCal+RICH+ToF+HBD)**
- **Reject remaining backplane conversions – NN2 (HBD)**

Combinatorial background in PHENIX

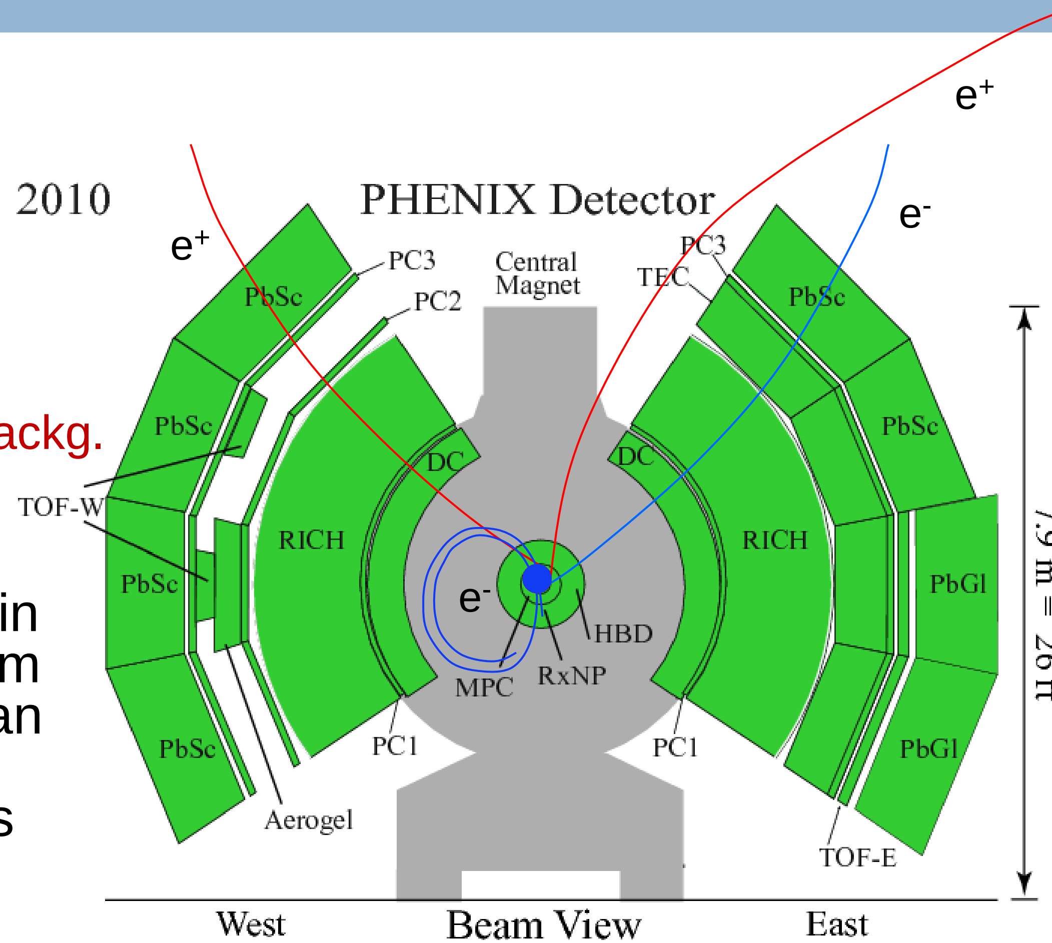
- The main sources of the <u>combinatorinal background</u>:

$\pi^0 \rightarrow \gamma\, \gamma \rightarrow \gamma\, e^+\, e^-$

$\pi^0 \rightarrow \gamma\, e^+\, e^-$

comb. backg. pair

- The magnetic field bends e⁺e⁻ in opposite directions, one of them can go out of acceptance or can spiral in the magnetic field not reaching the tracking detectors



The Cocktail (QM2012)

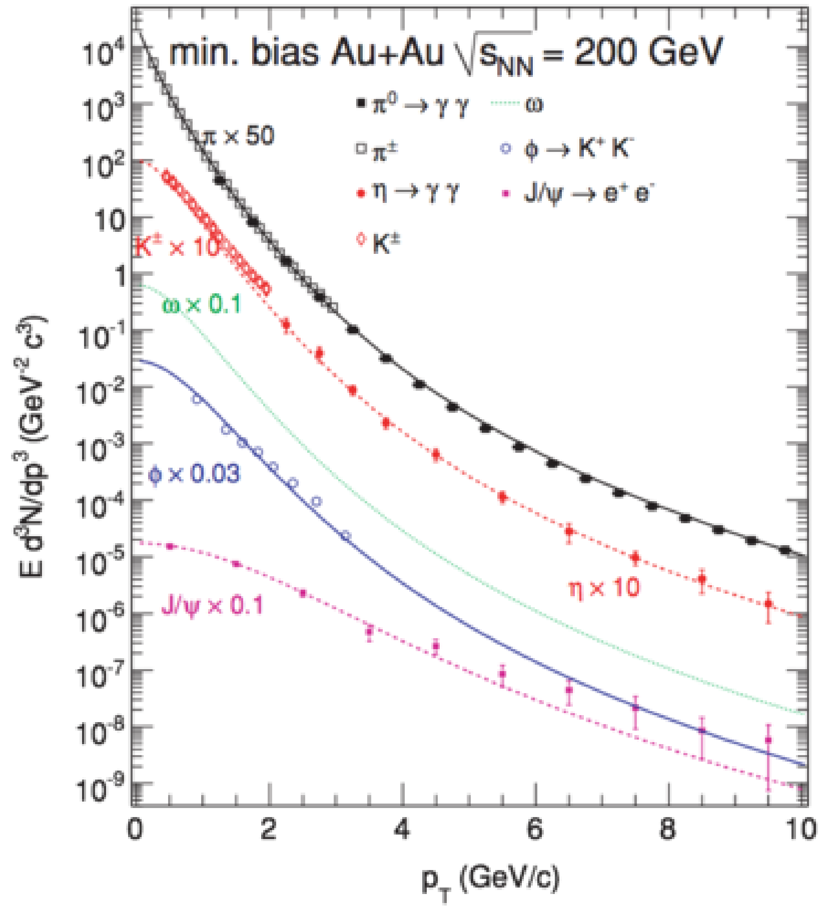
- Hadron decays simulated in EXODUS
- Fit π^0 and $\pi^\pm$ data p+p or Au+Au to modified Haggedorn function:

$$E\frac{d^3}{dp^3} = \frac{A}{\left(e^{-(ap_T + bp_T^2)} + p_T/p_0\right)^n}$$

- for other mesons η, ω, ρ, ϕ, J/Ψ etc. use pion parametrization and replace:

$$p_T \to \sqrt{p_T^2 + m^2 - m_{\pi^0}^2}$$

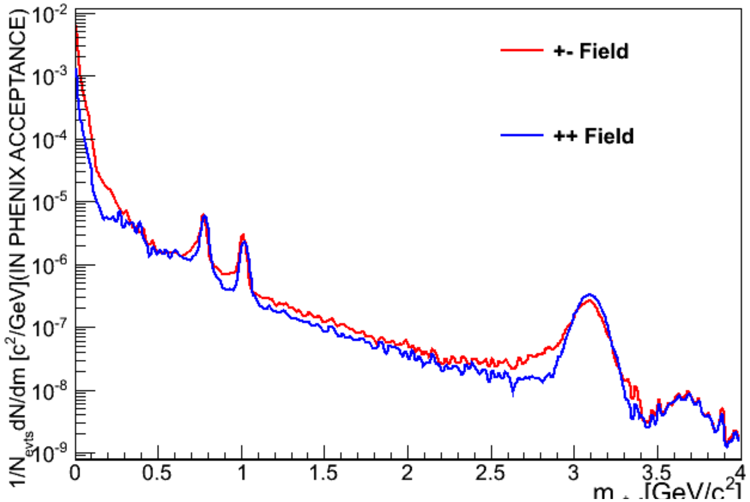
- The absolute normalization of each meson provided by meson to π^0 ratio at high p_T
- Open heavy flavor (c,b) simulated with MC@NLO
- The cocktail filtered through the PHENIX acceptance and smeared with detector resolution
- J/Ψ from full detector MC, normalization: pp yield scaled by N_{coll} * R_{aa}



Differences in runs with and without HBD

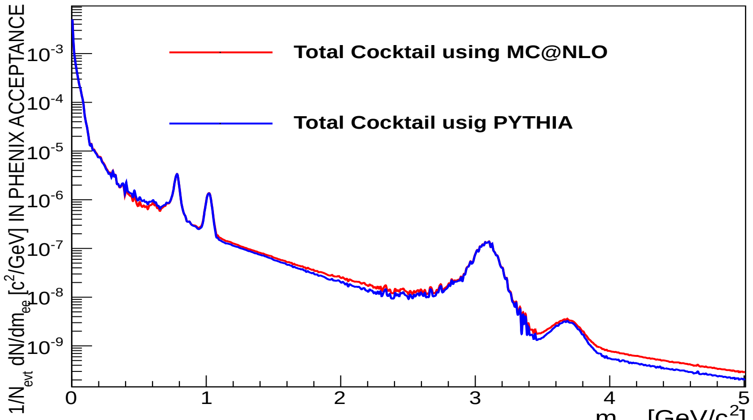
<u>Data:</u>

- Different magnetic field configuration:
  - Run-9 (p+p) and Run-10 (Au+Au) with HBD: **+-** field configuration
  - all other runs: **++** field configuration
  - larger acceptance of low p_T tracks in **+-** field
- More material due to HBD:
  - more J/Ψ radiative tail



<u>Cocktail:</u>

- MC@NLO for open heavy flavor (c,b) contribution instead of PYTHIA



Parallel analysis efforts

- Two parallel and independent analysis streams: provide crucial consistency check
  A. Weizmann + Tokyo + Zagreb group
  B. Stony Brook group

Stream A	Stream B
HBD: reconstruction based on **MinPad clusterizer**	HBD: reconstruction based on **LBS clusterizer**
Neural network for eID and for single/double electron separation	**Standard 1D cuts** for eID and for single/double electron separation
Correlated background from e-h contributions by **cross-pair simulation embedded into RICH data**	Correlated background from e-h contributions by **full Central Arm embedding**

Statistics

- Relaxed vertex cut:
  - Preliminary:

    -20 cm < z < 20 cm

    4.6B Min. Bias events
  - Current:

    -30 cm < z < 25 cm

    5.6B Min. Bias events