Dielectrons in d + Au *collisions at* $\sqrt{s} = 200$ *GeV measured by PHENIX and its implications on heavy flavor*

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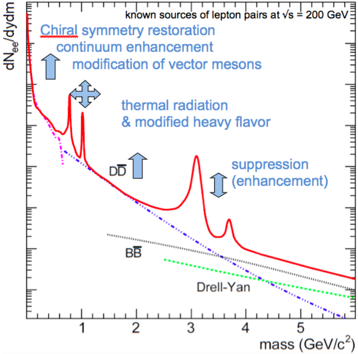
5th November, 2013

Dilpeton mass spectrum is a unique probe → allows access to diverse physics signal

Modifications to the dilepton spectrum due to the QCD phase transition



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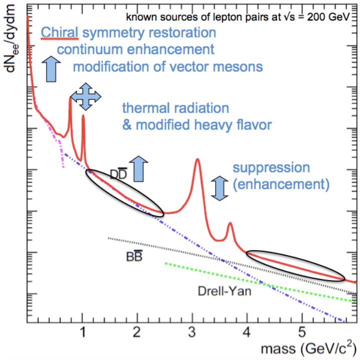
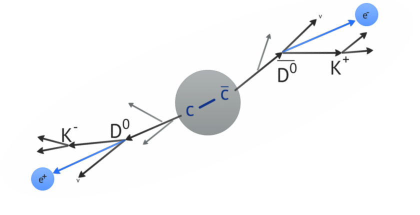




- 10% of c (or b) decay semileptonically to electrons.
- Looking simultaneously in the mass and p_T space allows the separation between charm and bottom.

- This talk is focussed on the heavy flavor (charm and bottom), that dominates the mass spectrum above 1 GeV/c^2.

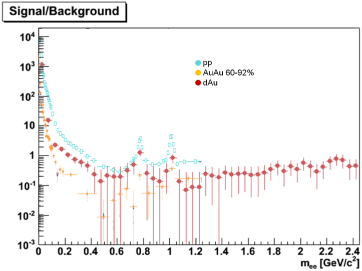
Why look into d + Au *collisions*

- Recent RHIC results have shown modification of heavy quark production rates and kinematics in d + Au collisions.
- Any intial state effects such as gluon shadowing, anti-shadowing etc will affect the heavy quark production.
- The shape of the mass and p_T distributions should additionally be sensitive to other effects, such as parton energy loss and rescattering in cold nuclear matter.

- Background Estimation
  - Like-sign technique is used for the signal extraction, after the like-sign pairs are corrected for the acceptance difference for $++$ and $--$ pairs. This method takes care of both the *combinatorial background* and *correlated background*. The relative accceptance correction α is derived from the mixed events and is defined as follows:

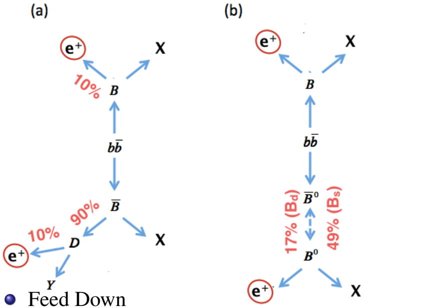
$$\alpha = \frac{BG_{+-}}{BG_{++} + BG_{--}}$$

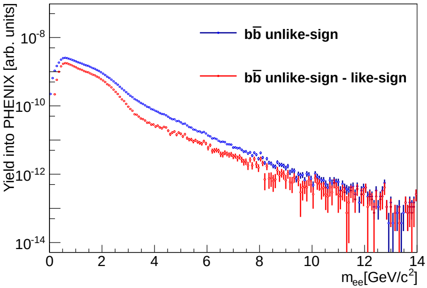
- Signal to Background in d + Au;



- One should take into account the signal from the like-sign heavy quark correlations (explained in the following slide).

Origin of Like-sign correlated pairs

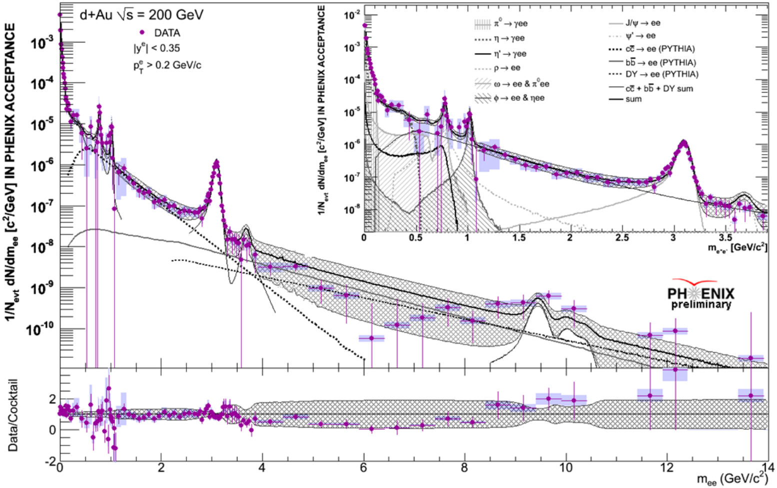




- Feed Down
  - BR for $B \to e \sim 10\%$, BR for $B \to D \sim 10\%$,
- Oscillations
  - $B^0 \bar{B}^0$ mixing. This leads to $\sim 60\%$ unlike-sign pairs and $\sim 40\%$ like-sign pairs.
- Nearly half the bottom yield is like-sign!.

- Because we use like-sign subtraction in data, we account for this effect in simulations too.
- This effect is less extreme for charm ($<1\%$ within PHENIX acceptance).

Minimum Bias d + Au *dielectrons*



- Consistent with the expected cocktail of known sources
- Large mass range coverage $0 - 14\ GeV/c^2$.

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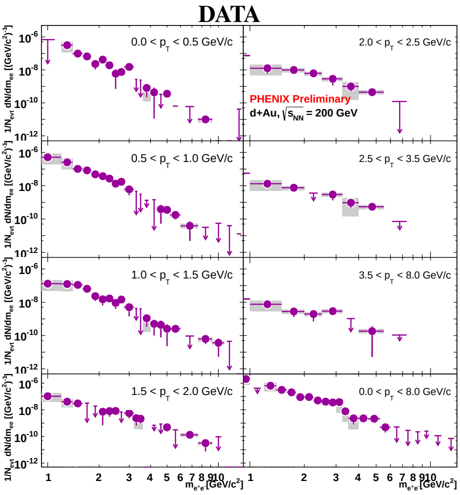

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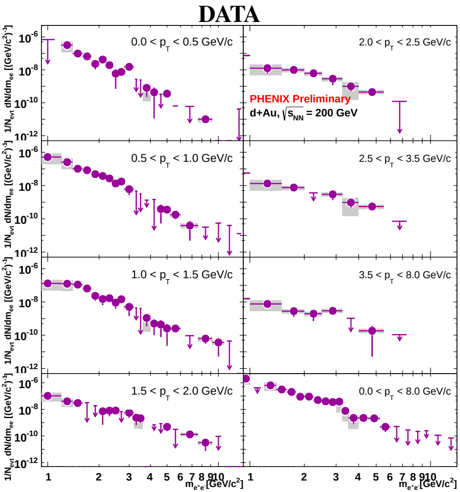
- Preliminary cross-sections extracted from this data set used earlier MC@NLO simulations.
- Studies shown in the following slides use new PYTHIA and higher statistics MC@NLO simulations so as to explore the model dependence on cross-section extrapolations.



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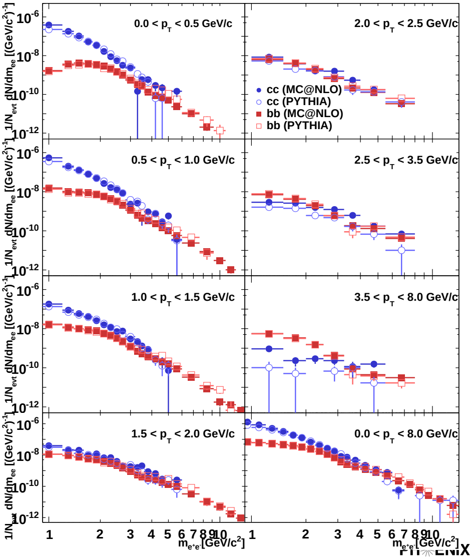
SIMULATIONS



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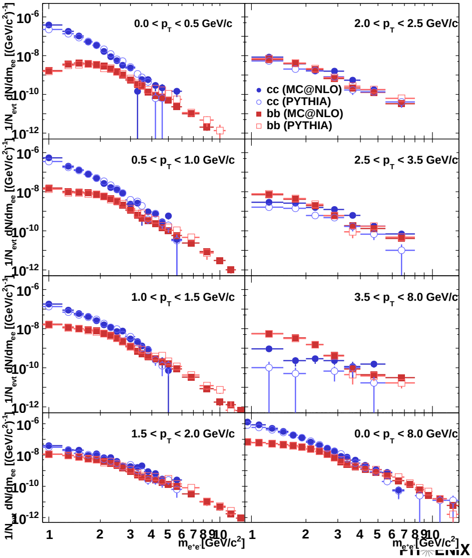

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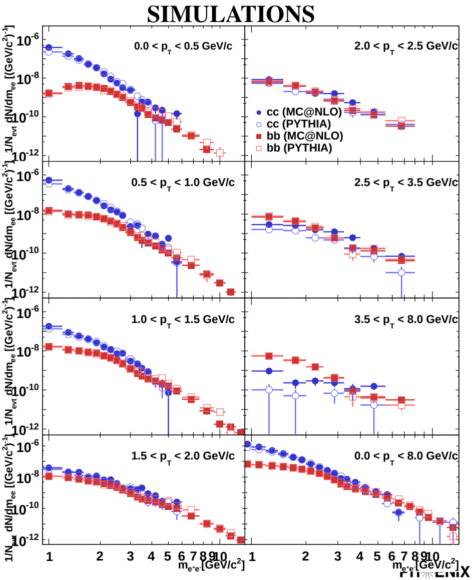
- Simulate the e^+e^- pair yield from heavy flavor
- Done using two event generators PYTHIA (which is a *leading-order* simulation) and MC@NLO (a *next-to-leading* order simulation).
- Evident here is the separation of e^+e^- pairs from charm and bottom in mass and p_T.
  - charm dominates at low mass and low p_T for pairs below 3 GeV/c^2 mass.
  - at p_T =2 GeV/c the low mass dominance of charm vanishes.
  - bottom starts to dominate at all masses for $p_T > 2.5$ GeV/c



Model dependence for the e^+e^- pair acceptance from heavy flavor

- e^+e^- pair acceptance governed by the correlation between the e^- and e^+, which depends on the production process
- For e^+e^- pairs from heavy flavor decays, the correlation is an interplay of two contributions:
  - the QCD production of the $q\bar{q}$ pair
  - the decay kinematics of the two independent semi-leptonic decays.

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Acceptance	PYTHIA $c\bar{c}$ pairs	MC@NLO $c\bar{c}$ pairs
4π	1	1
$\lvert\Delta y_{c\bar{c}}\rvert < 0.5$	0.275	0.297
$\lvert\Delta y_{c\bar{c}}\rvert < 0.35$	0.2	0.215

Acceptance	PYTHIA e^+e^- pairs from $c\bar{c}$ $[F_{BR}^{c\bar{c}}{}^{-1}]$	MC@NLO e^+e^- pairs from $c\bar{c}$ $[F_{BR}^{c\bar{c}}{}^{-1}]$
4π	1	1
$\lvert y_{e^+} \& y_{e^-}\rvert < 0.5$	0.042	0.035
$\lvert y_{e^+} \& y_{e^-}\rvert < 0.5$ $m_{e^+e^-} > 1.16 \mathrm{GeV}/c^2$	0.0047	0.00022
$\lvert y_{e^+} \& y_{e^-}\rvert_{PHENIX}$	0.0023	0.0016

$F_{BR}^{c\bar{c}} = (B.R.(c \to e))^2$, where B.R. is the effective branching ratio of 9.4%

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4π	1	1
$\|\Delta y_{b\bar{b}}\| < 0.5$	0.39	0.40
$\|\Delta y_{b\bar{b}}\| < 0.35$	0.28	0.29

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4π	1	1
$\|y_{e^+} \& y_{e^-}\| < 0.5$	0.095	0.091
$\|y_{e^+} \& y_{e^-}\| < 0.5$ $m_{e^+e^-} > 1.16 GeV/c^2$	0.0425	0.0395
$\|y_{e^+} \& y_{e^-}\|_{PHENIX}$	0.0084	0.0080

$F_{BR}^{b\bar{b}} = (B.R.(b \to e))^2$, B.R. is the effective branching ratio of 15.8% using a likesign pair subtraction, or 22% not considering like sign pairs.

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[illegible]	[illegible]	[illegible]
$m_{e^+e^-} > 1.16 GeV/c^2$		
$\lvert y_{e^+} \& y_{e^-}\rvert_{PHENIX}$	0.0084	0.0080

- The number of e^+e^- pairs from $c\bar{c}$ in 1 unit of rapidity differ by 1.2, that increases to 2.2 if one restricts the mass range above 1 GeVc^2.
- For $b\bar{b}$, the two simulations yield similar results within 5%.
- Is this a coincidence ? may be not!

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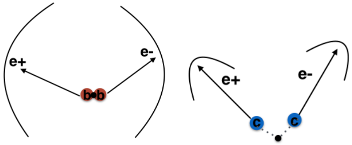
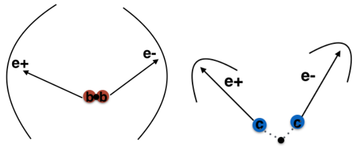
PHENIX



- If $m_q >> p$, the e^+e^- decay pair randomizes the correlation of $q\bar{q}$ pair.
- For a very heavy quark, the decay electron has no directional preference.

- $\approx$ 1 out of 80 pairs will fall into the phenix acceptance.
- the number of e^+e^- pairs from $b\bar{b}$ differ only by 30%
- For $c\bar{c}$, the deviation is by more than a factor of 5.
- implies a large model dependence for $c\bar{c}$ and small from $b\bar{b}$, as evident from the previous tables.
- consequently extrapolated cross-sections for $c\bar{c}$ will be different from PYTHIA and MC@NLO , but very similar for $b\bar{b}$.

Model dependence explained...



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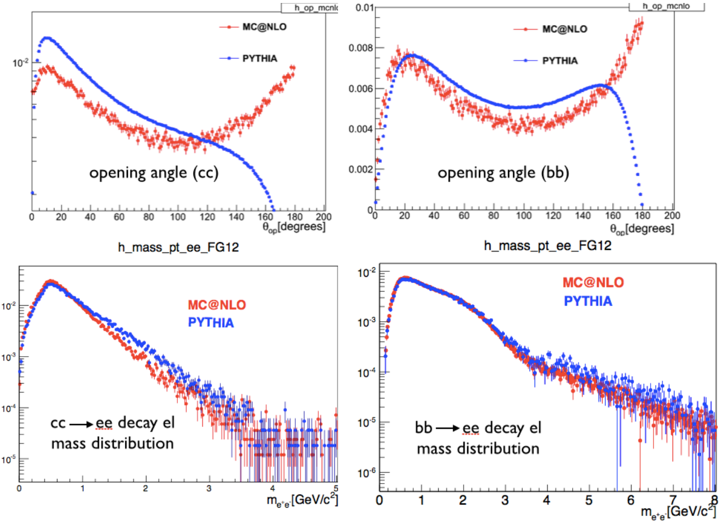
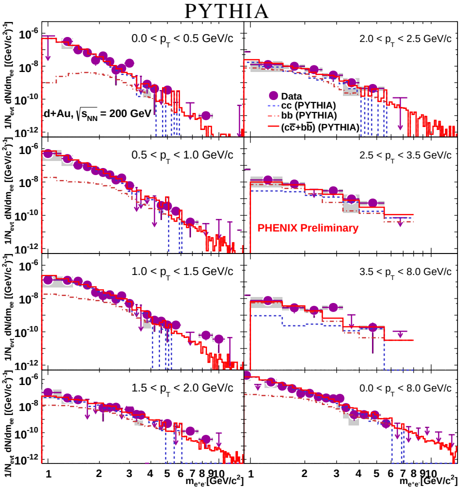
This is a physics issue, not an acceptance issue

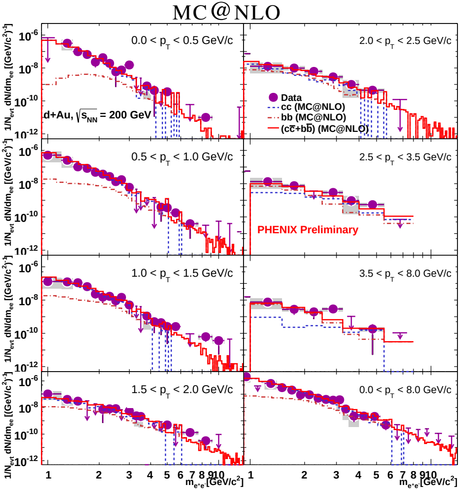
Some model distributions



- Different input correlations between the quarks in the two models.
- Final e^+e^- distribution for $c\bar{c}$ is different, while very similar for $b\bar{b}$.

Results of fitting the simulations to the data





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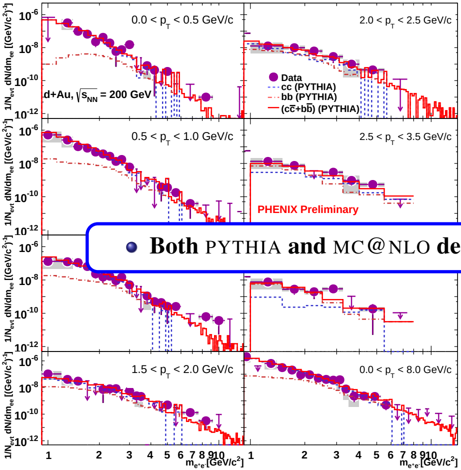
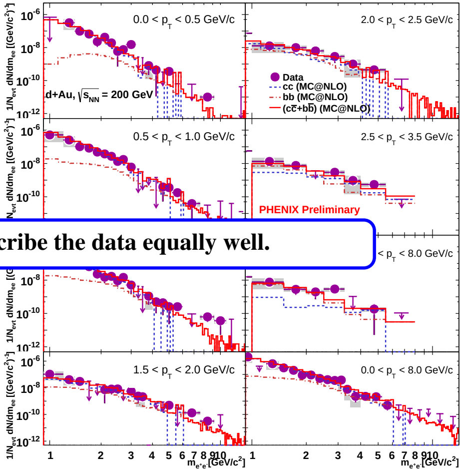
PYTHIA

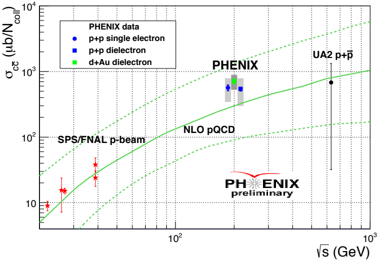


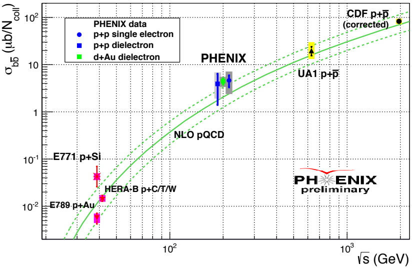
MC@NLO



- **Both PYTHIA and MC@NLO describe the data equally well.**

Extracted heavy flavor cross-section from MC@NLO





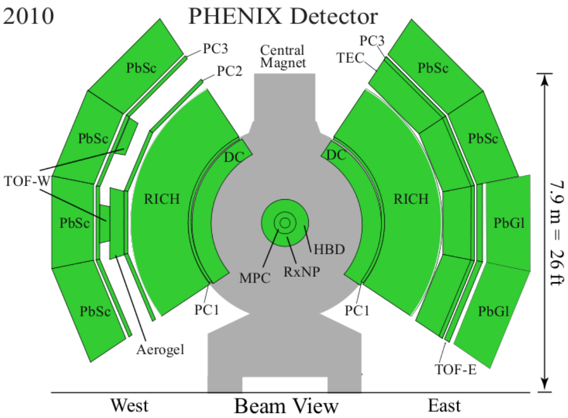
- **Preliminary** p + p equivalent extrapolated heavy flavor cross-sections using the MC@NLO simulations are :
- σ_{cc}^{pp} = 704 ± 47 (stat) ± 183 (syst) ± 40 (model) μb.
- σ_{bb}^{pp} = 4.29 ± 0.39 (stat) ± 1.08 (syst) ± 0.11 (model) μb.
- Results are consistent to the previously published PHENIX measurements of heavy flavor cross-section from singles and dielectrons in p + p (assuming small CNM effects on dielectrons).
- **Final** cross-section from the fits shown in the earlier slide to be published soon.
- Similar analysis in p + p is underway.

Summary

- The d+Au data dielectron spectrum is consistent with the expected cocktail of known sources and, to the scaled $p + p$ results.
- Any dielectron enhancement seen in the HI collisions is not due to any cold nuclear matter effects.
- The $d + Au$ dielectrons data provides a new independent measurement for the heavy flavor that are consistent with the already published results.
- Both the leading-order (PYTHIA) and next-to-leading order calculations (MC@NLO) describe the data nicely.
- The extrapolation for charm cross-section using the two models are different.
- The extrapolation for bottom cross-section is model independent.

Back-ups

PHENIX Central arms Acceptance: -0.35$< \eta <$0.35, 2$\times$90° in φ



Measure rare probes in different collision systems: **p+p, d+Au, Cu+Cu, Au+Au**

- Vertex: **BBC**
- Tracking: **DC/PC1**
- p_e $>$ 0.2 GeV/c;

Electron identification based on:

- **RICH** (Ring Imaging Čerenkov detector) (e/π rejection >1000)
- **EMCal** (Electromagnetic Calorimeter) (E-p matching, e/π rejection $\sim$ 10)

Extraction of cross-section of charm and bottom -II

- Fit the simulated charm and bottom distributions to the data with two free parameters $N_{c\bar{c}}$ and $N_{b\bar{b}}$.

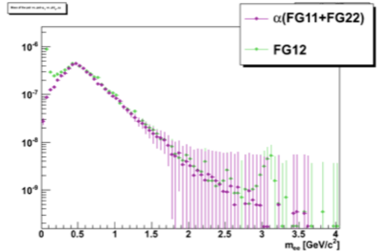
$$\frac{1}{N_{\rm evt}^{\rm MB}} \frac{dN_{ee}^{hf}}{dmdp_T}\bigg|_{PHENIX} = N_{c\bar{c}} \frac{dn_{ee}^{c\bar{c}}}{dmdp_T} + N_{b\bar{b}} \frac{dn_{ee}^{b\bar{b}}}{dmdp_T},$$

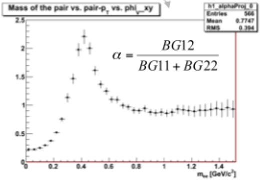
Like-sign pair subtraction

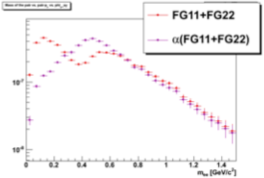
Backup Slide

like-sign pair subtraction

$$Signal = FG12 - \alpha \cdot (FG11 + FG22)$$







- Like-sign FG is used for the background subtraction.
- At high m,p_T this is fine, but at lower m,p_T must correct for the difference in PHENIX's acceptance for *like-sign* and *unlike-sign* pairs.
  - α = Relative Acceptance Correction.
- use *like-sign* FG because it contains "correlated background" of cross/jet pairs.

note:
All manipulation is done differentially in mass and pT (of the pair).
Low-stats mass projections are shown for illustration purposes.

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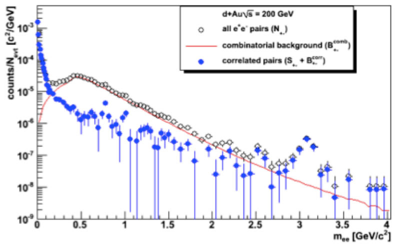
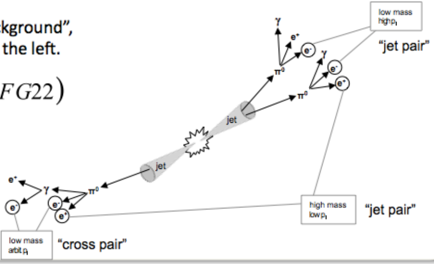
Backup Slide

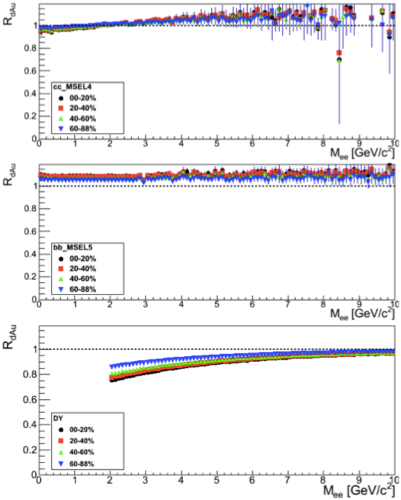
"correlated background"



- To see the significance of the "correlated background", compare the blue on the right to the blue on the left.
- We use: $Signal = FG12 - \alpha \cdot (FG11 + FG22)$



EPS09s Mass Dependent Modification



Calculate the mass dependent R_{dAu} from EPS09s using the PHENIX r_T distributions for each centrality bin.

Use the sea quark modification for up & down quarks.

For heavier quarks assume gluon fusion and use gluon modification.

No PHENIX Geometry cut!