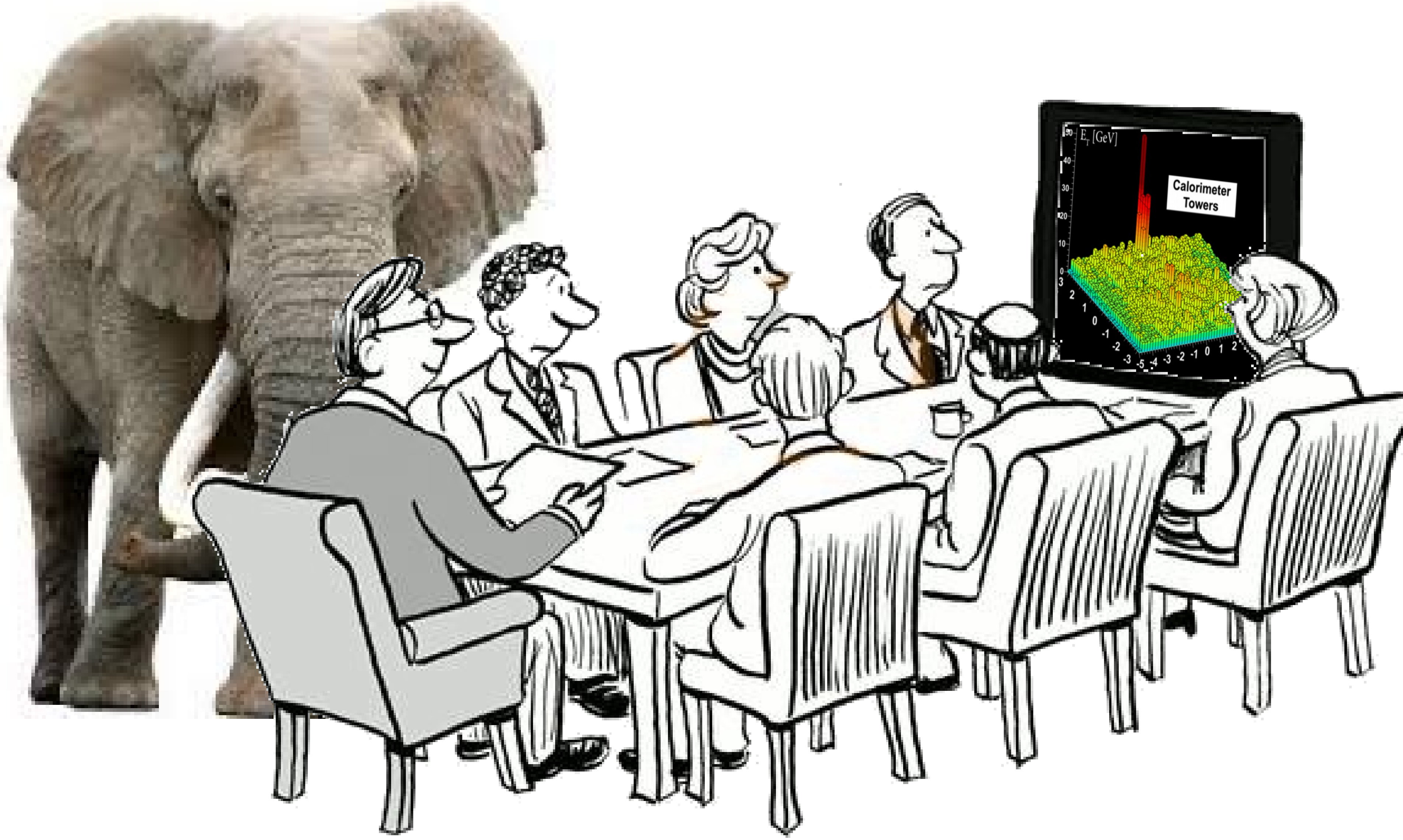
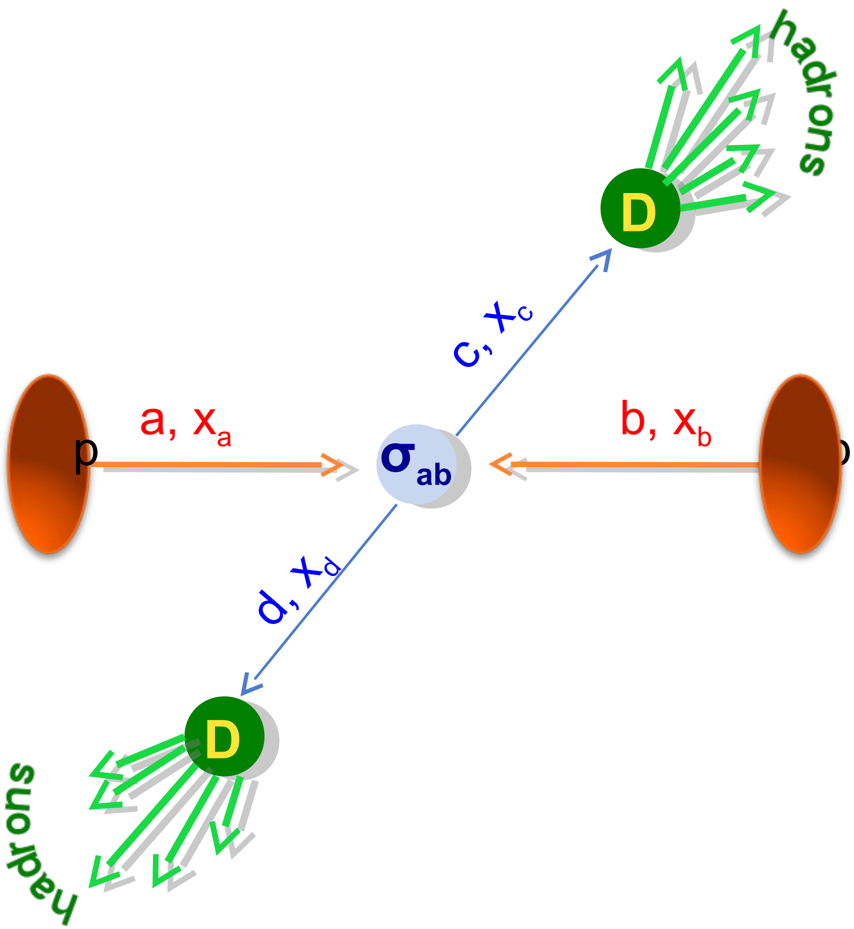


Bias and background

Christine Nattrass

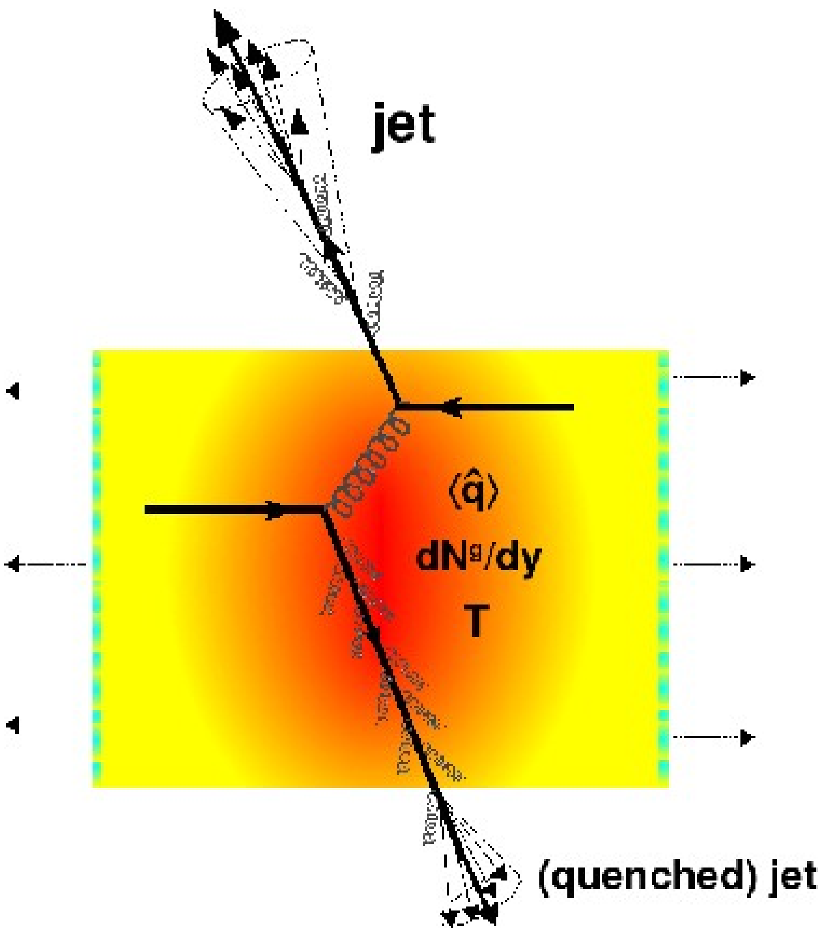
RHIC/AGS User's Meeting 2016

Jets in principle



- Jet measures **partons**
- Hadronic degrees of freedom are integrated out
- Algorithms are **infrared and colinear safe**

Quenched jets: what we're trying to study



- Quenched jet
  - Softer constituents
  - Broader radius
- →Looks more like background

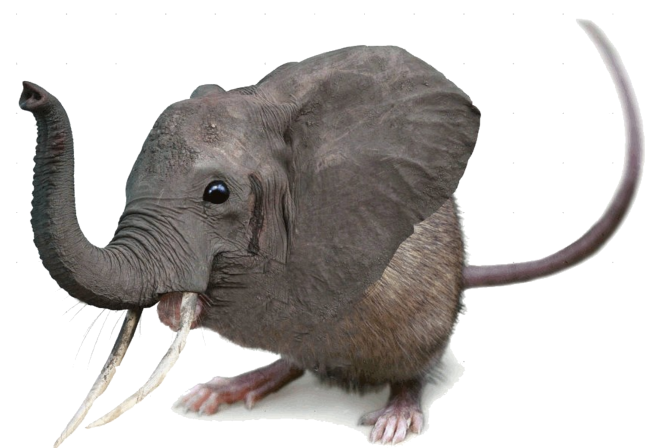


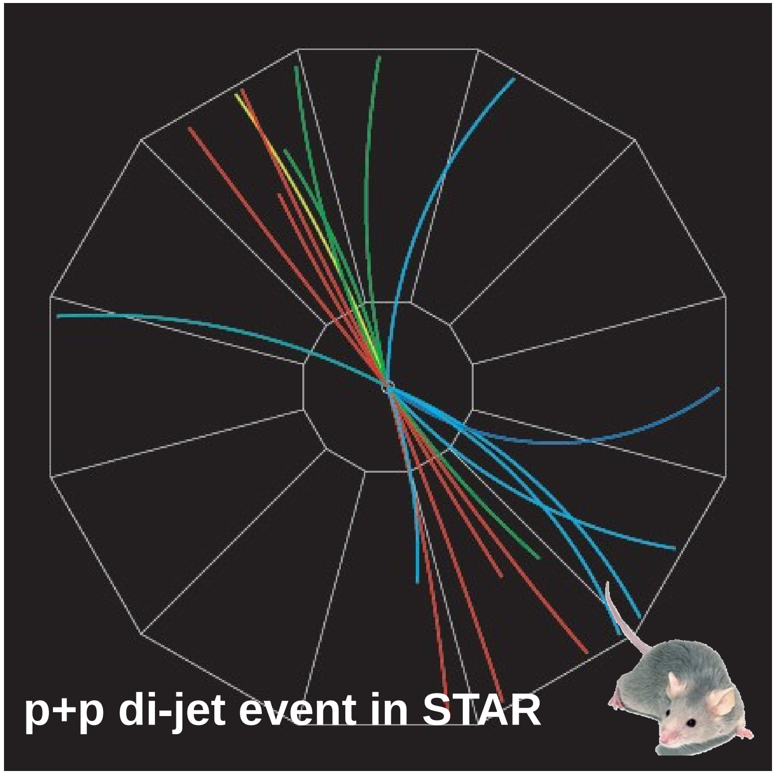
Figure from Nucl.Phys. A827 (2009) 356C-364C arXiv:0902.2488 [nucl-ex]

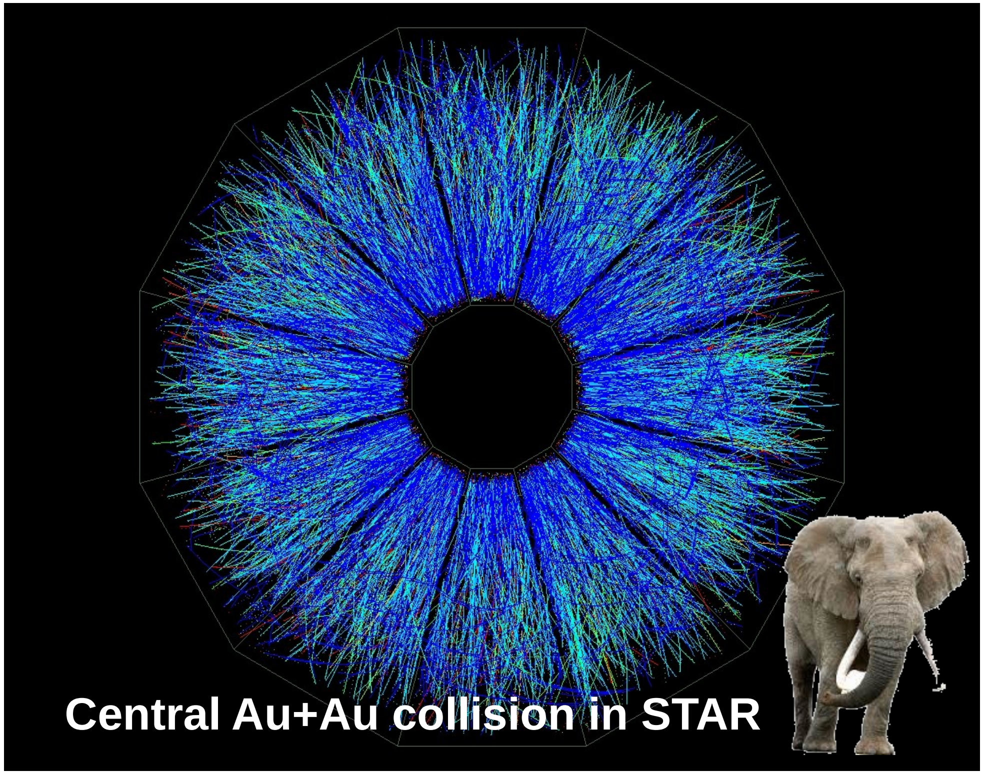
Background: our white elephant

Wiki: “A **white elephant** is a possession which its owner cannot dispose of and whose cost, particularly that of maintenance, is out of proportion to its usefulness. The term derives from the story that the kings of Siam, now Thailand, were accustomed to make a present of one of these animals to courtiers who had rendered themselves obnoxious, in order to ruin the recipient by the cost of its maintenance.”

- Background properties
- Impact of background subtraction/suppression on reconstructed jets
- Background subtraction in jet-h and h-h correlations

Properties of the background





Signal

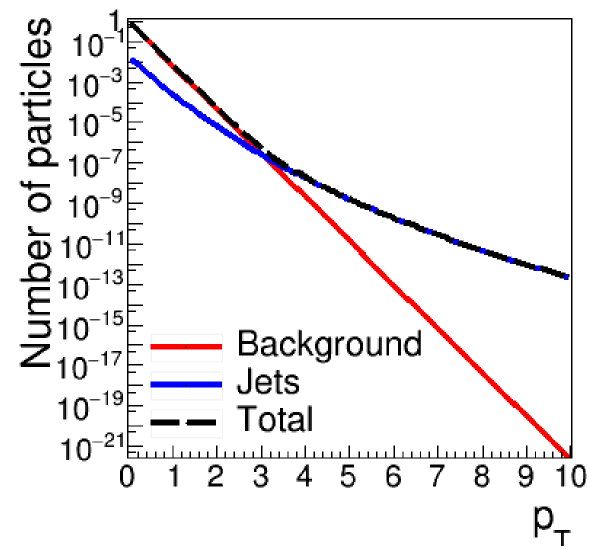
- Harder
- Correlated with rxn plane
- Low p_T modifications
- Flavor modifications?

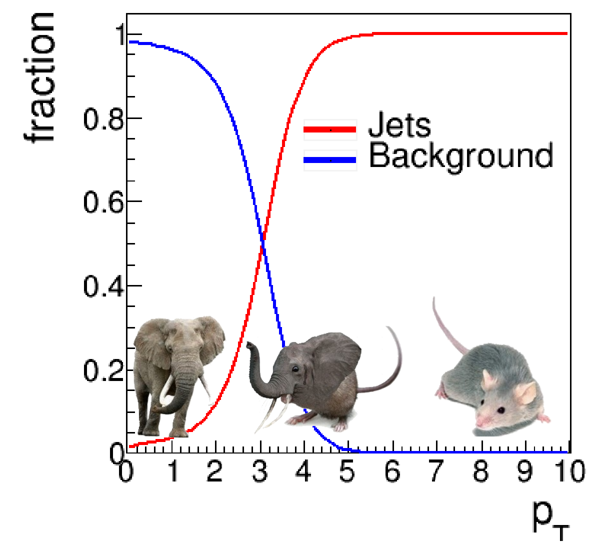
Background

- Softer
- Correlated with rxn plane
- Large fluctuations/hot spots
- Combinatorial background
- Degraded energy resolution

Focus on high p_T

- Pros:
  - Reduces combinatorial background
- Cons:
  - Cuts signal where we expect modifications
  - Could impose a bias

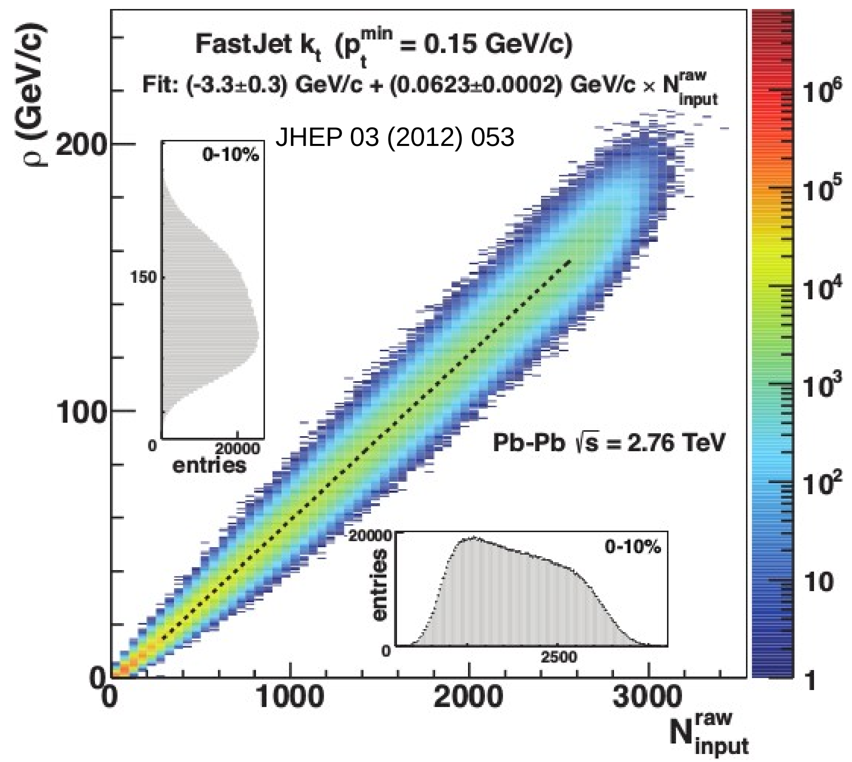




Schematic only!

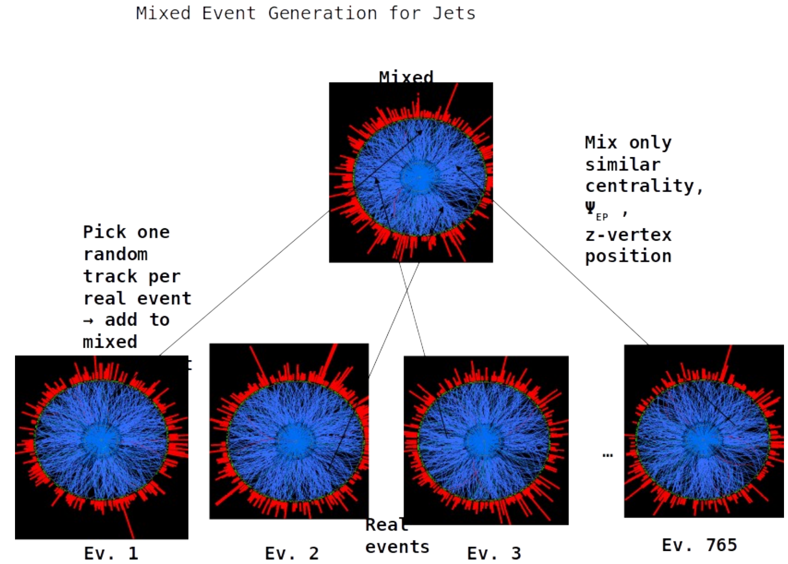
Focus on smaller angles

- Pros
  - Background is smaller
  - Background fluctuations smaller
- Cons:
  - Modifications expected at higher R

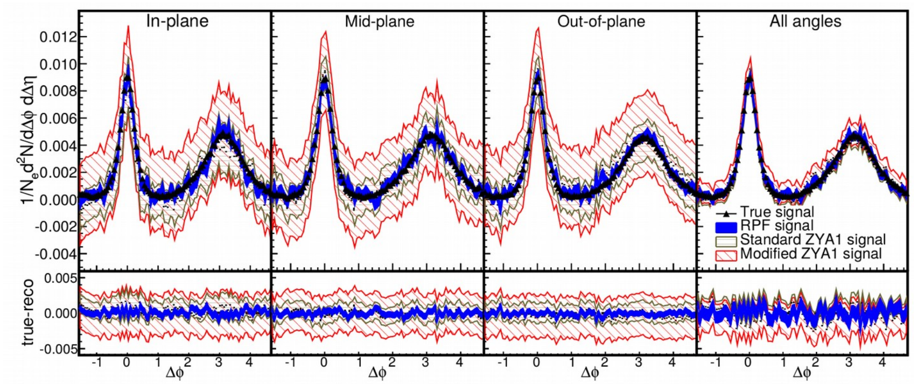


Carefully quantify background

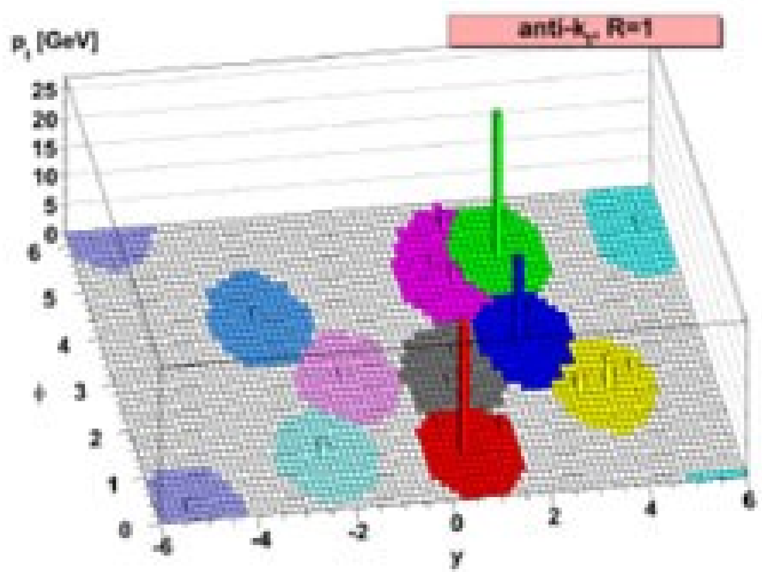
- Jet reconstruction: mixed events



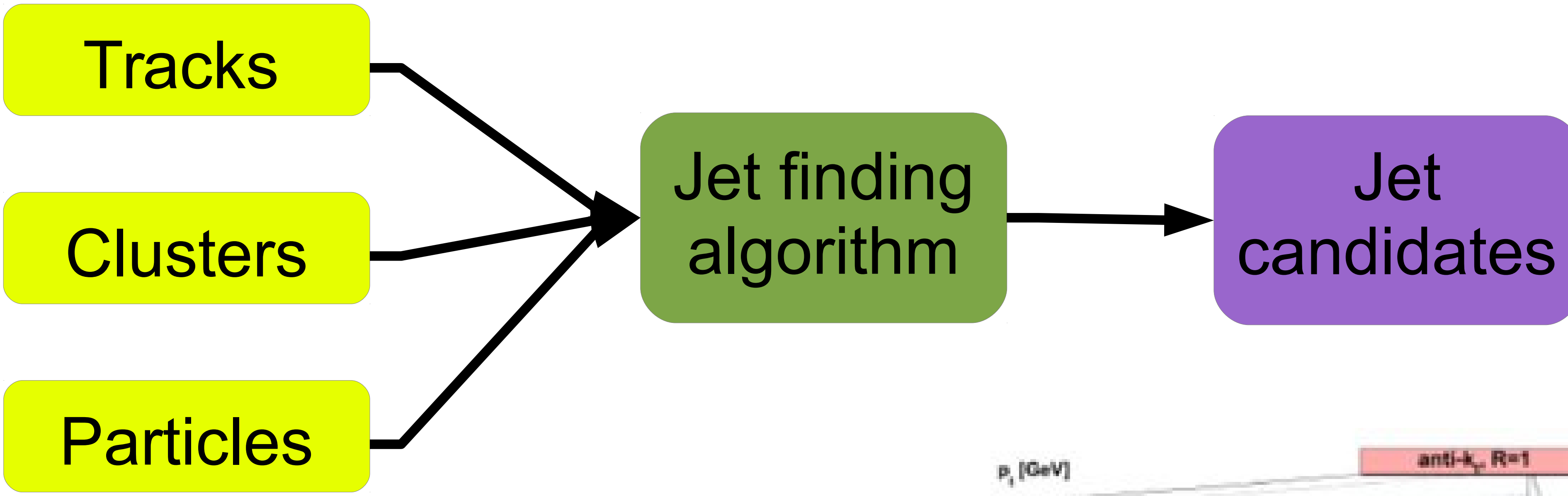
- Correlations: go beyond ZYAM



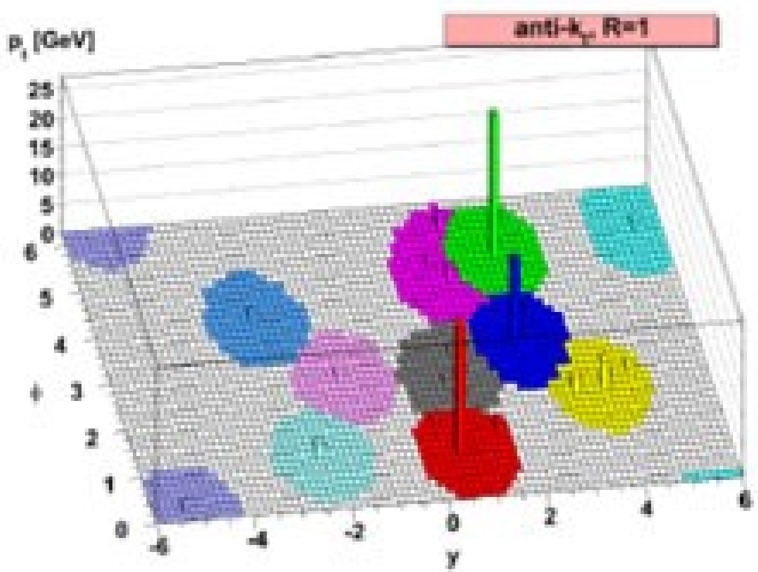
Reconstructed jets



Jet finding algorithms



- Any list of objects works as input
- Output only as good as input
- ~~IR Safe~~
- ~~Colinear safe~~



M. Cacciari, G. P. Salam, G.Soyez, JHEP 0804:063,2008

ALICE/STAR

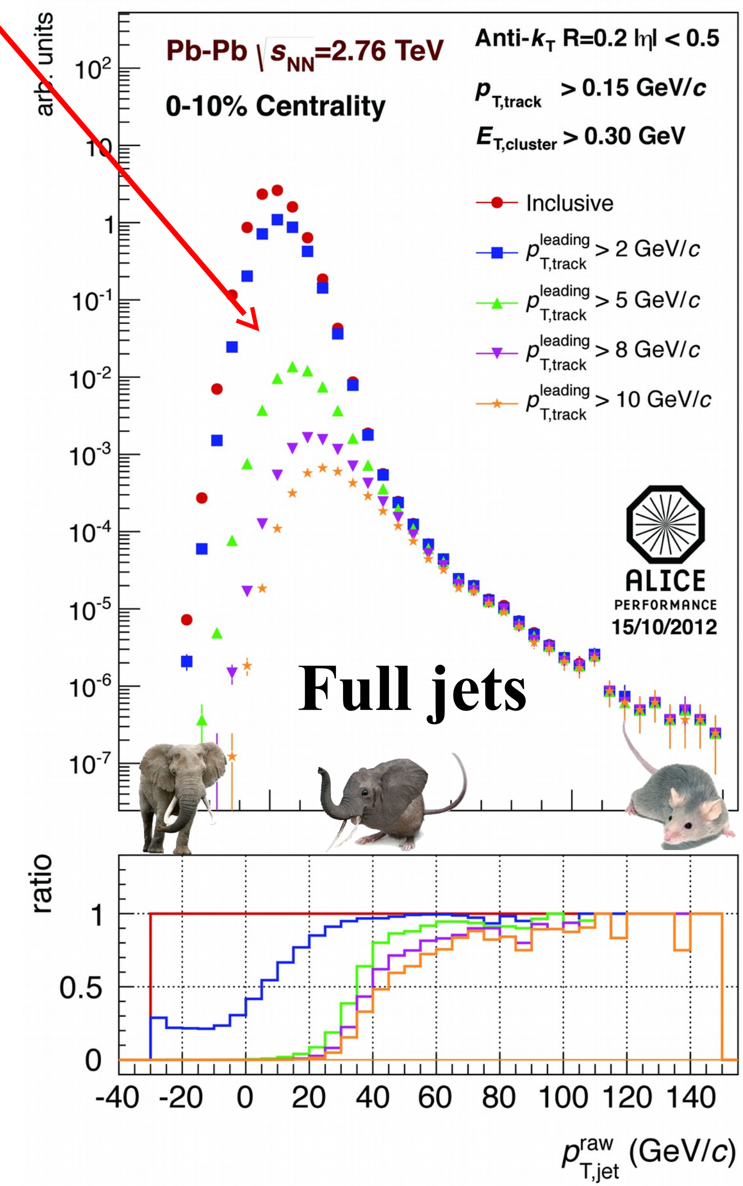
Combinatorial “jets”

- Estimate combinatorial jet contributions and its fluctuations from data
- Require leading track p_T > 5 GeV/c
  - Suppresses combinatorial “jets”
  - Biases fragmentation
- No threshold on constituents
- Limited to small R

Measured spectra:

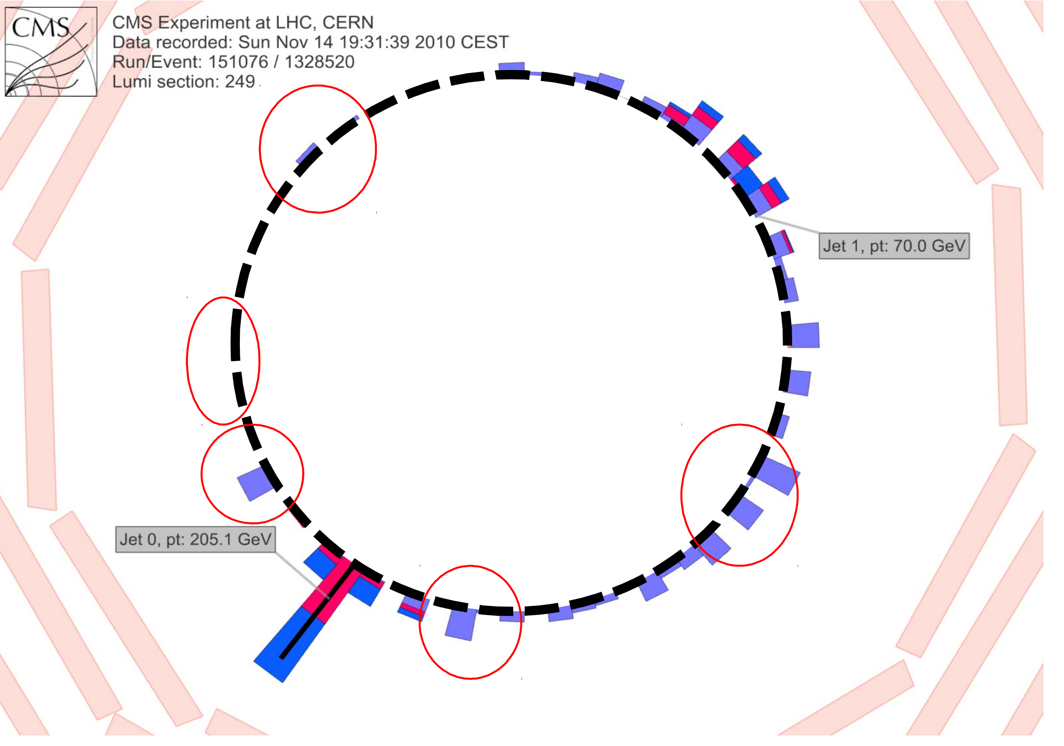
$$p_{T,jet}^{unc} = p_{\mathrm{T,jet}}^{rec} - \rho\, A$$

Where $p_{\mathrm{T,jet}}^{rec}, A$ comes from FastJet anti-k_T algorithm



CMS: Iterative Pile-Up Event Background Subtraction

Background is estimated
- for each calorimeter ring of constant η
- subtracted before jet finding
- re-iterated after excluding the jets found in the first iteration



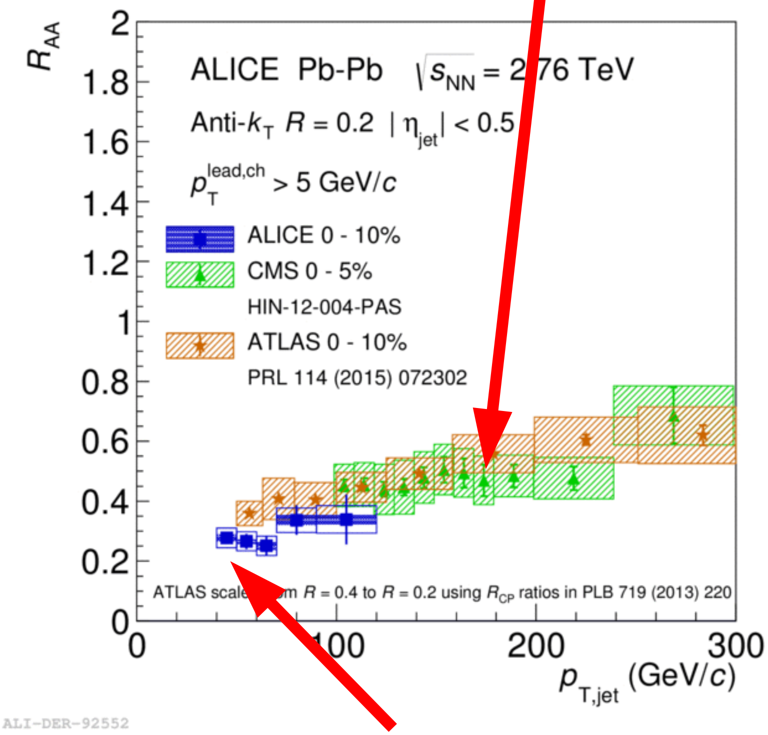
Fake Jets: After the background subtraction, some local fluctuations remain!
Fluctuations will deteriorate the jet resolution in central events.

Sevil Salur 13

ATLAS

- Iterative procedure
  - **Calorimeter jets:** Reconstruct jets with R=0.2. v_2 modulated <Bkgd> estimated by energy in calorimeters excluding jets with at least one tower with
    $E_{tower} > \langle E_{tower} \rangle$
    Track jets: Use tracks with p_T>4 GeV/c
  - Calorimeter jets from above with E>25 GeV and track jets with p_T>10 GeV/c used to estimate background again.
- Calorimeter tracks matching one track with p_T>7 GeV/c or containing a high energy cluster E >7 GeV are used for analysis down to E_{jet} = 20 GeV

Constituent biases don't matter that much up here



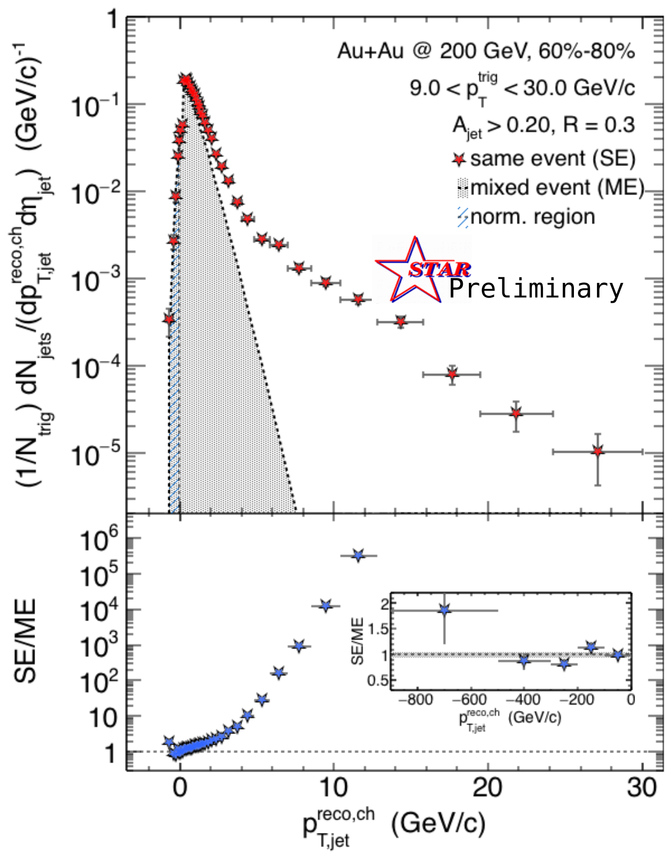
But they do matter down here!

Definitely imposes a bias, especially at 20 GeV!
We should treat that bias as a tool, not a handicap

Phys. Lett. B 719 (2013) 220-241

Event mixing

Peripheral

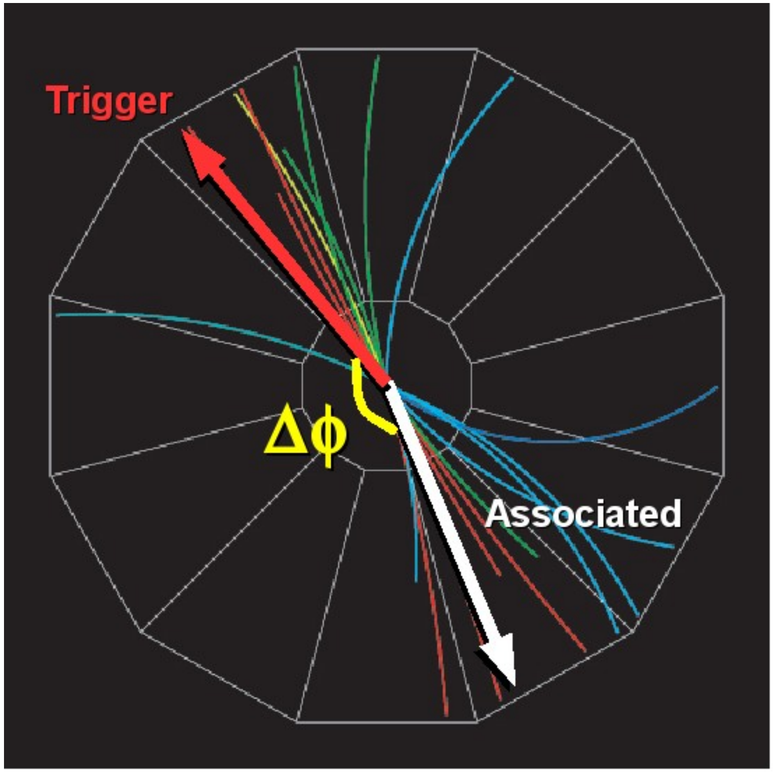


Alex Schmah, Hard Probes 2015

- Reference spectrum: peripheral collisions
- Much less combinatorial background compared to most central data
- Excellent signal/background ratio down to 3 GeV/c

- Requires normalization at low p_T
- All physical correlations treated like jets

h-h and jet-h correlations

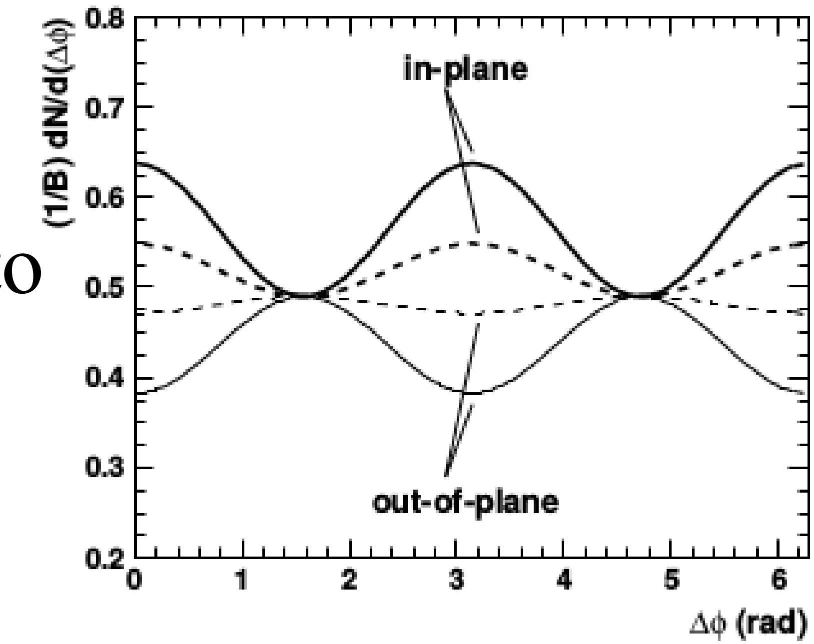


Based largely on:

Sharma, Mazer, Stuart, Nattrass Phys. Rev. C 93, 044915

Nattrass, Sharma, Mazer, Stuart,Bejnood arXiv:1606.00677

Correlation with reaction plane



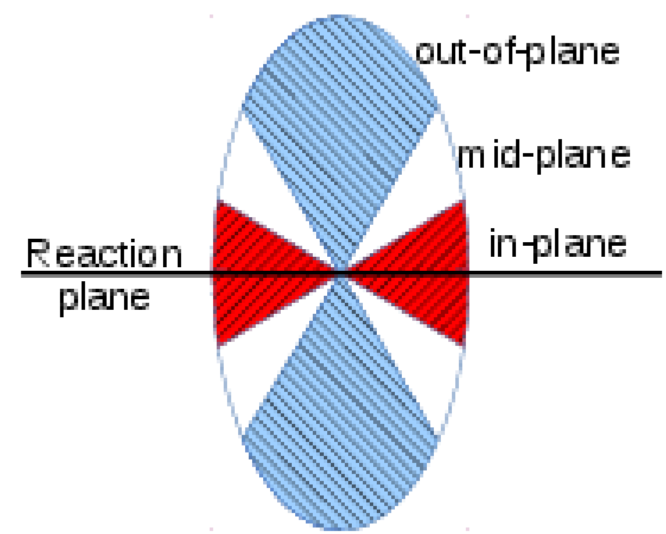
- All reaction plane angles

$$B\left(1+\sum_{n=2}^{\infty} v_n^t v_n^a \cos(n\Delta\phi)\right)$$

- When trigger is restricted relative to reaction plane
  - Background level modified

$$B=1+\sum_{k=2}^{\infty} 2 v_k^a v_k^{R,t} \cos(k\phi_S)\frac{\sin(kc)}{kc}R_n$$

  - Effective v_n modified



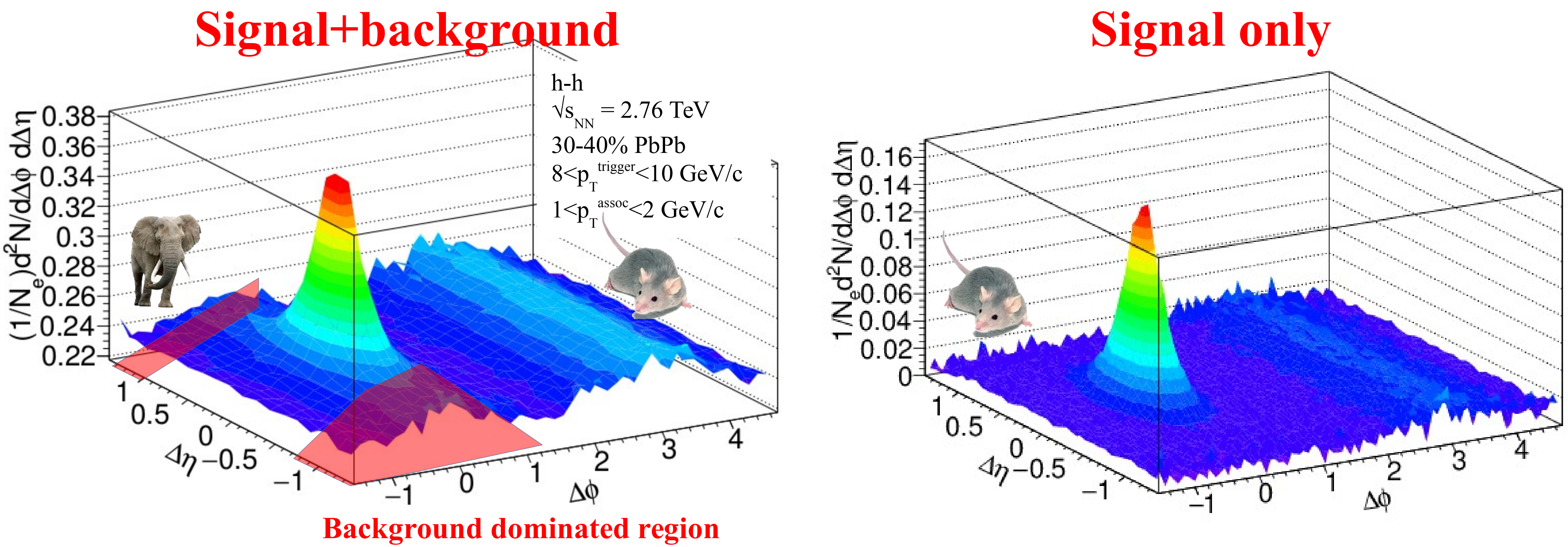
$$v_n^{R,t}=\frac{v_n+\cos(n\,8_S)\frac{\sin(nc)}{nc}R_n+\sum_{k=2,4,6...}^{\infty}(v_{k+n}+v_{k-n})\cos(k\phi_S)\frac{\sin(kc)}{kc}R_n}{1+\sum_{k=2,4,6...}^{\infty}2v_k\cos(k\phi_S)\frac{\sin(kc)}{kc}R_n}, n=even$$

φ_S is the angular threshold

$$R_n=\langle\cos(n(\psi_{true}-\psi_{reco}))\rangle$$

Phys.Rev. C69 (2004) 021901 arXiv:nucl-ex/0311007

Separating signal+background

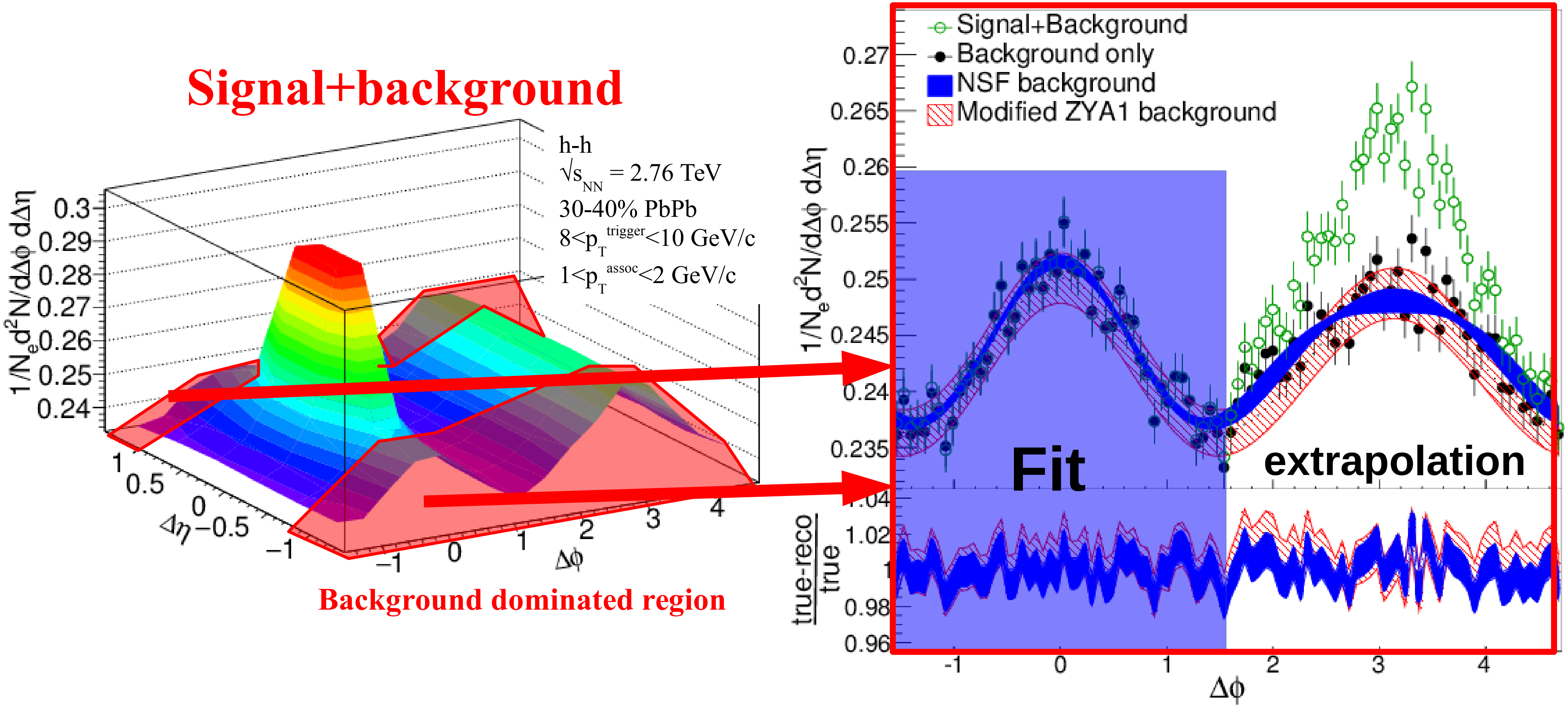


Using toy model

described in Sharma, Mazer, Stuart, Nattrass Phys. Rev. C 93, 044915

Near-Side Fit (NSF) method

No reaction plane dependence



- Project signal+background over $1.0<|\Delta\eta|<1.4$
- Fit background in $|\Delta\varphi|<\pi/2$ with v_n up to n=4

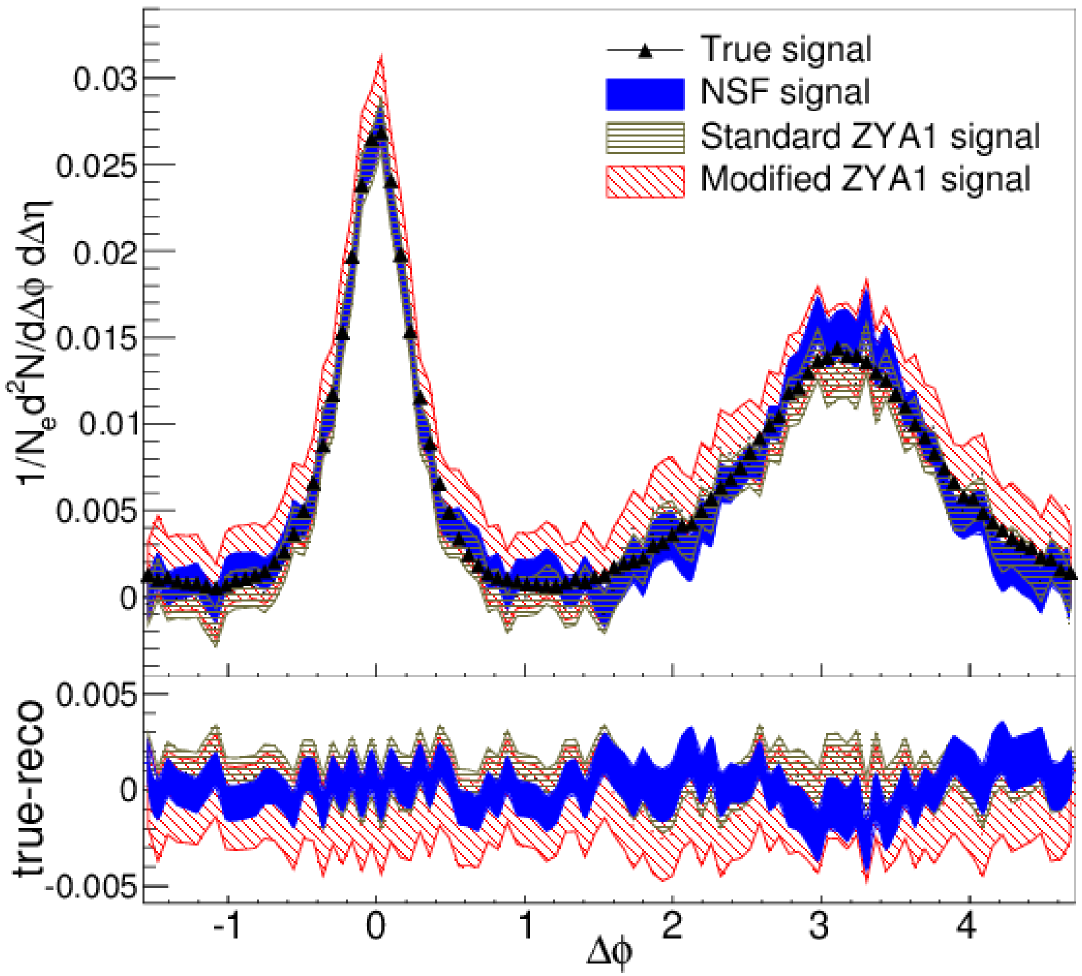
Near-Side Fit (NSF) method

No reaction plane dependence

- Reconstructs signal with less bias and smaller errors than ZYA1 method
- Extract v_n consistent with input

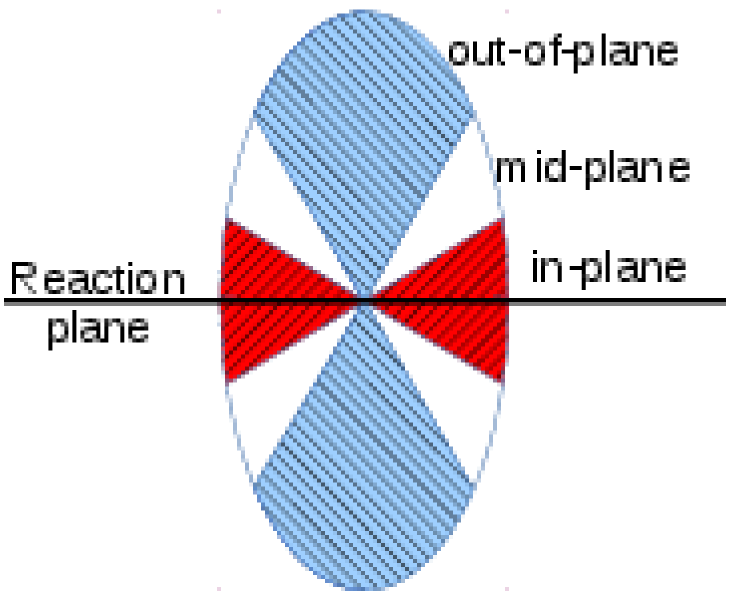
Sample		Yield ($Y \times 10^{-3}$) near-side	Yield ($Y \times 10^{-3}$) away-side
30-40% h-h	True	$17.1 \pm 0.1 \pm 0.2$	$19.9 \pm 0.1 \pm 0.2$
	Mod. ZYA1	$18.9 \pm 4.2 \pm 1.2$	$21.9 \pm 4.2 \pm 1.2$
	Std. ZYA1	$15.7 \pm 1.6 \pm 1.2$	$18.7 \pm 1.6 \pm 1.2$
	NSF	17.14 ± 1.1	20.14 ± 1.11

h-h
$\sqrt{s_{NN}} = 2.76$ TeV
30-40% PbPb
$8 < p_T^{trigger} < 10$ GeV/c
$1 < p_T^{assoc} < 2$ GeV/c

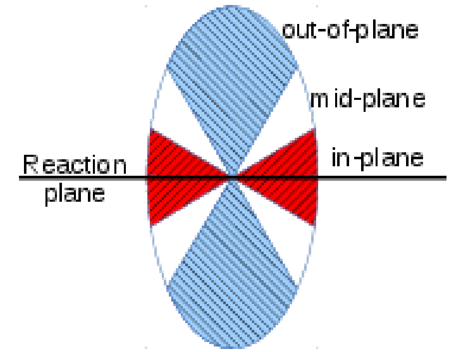


Standard ZYA1 = Zero Yield at $\Delta\Phi$=1
Modified ZYA1 = Zero Yield at $\Delta\Phi$=1 for $1.0<|\Delta\eta|<1.4$

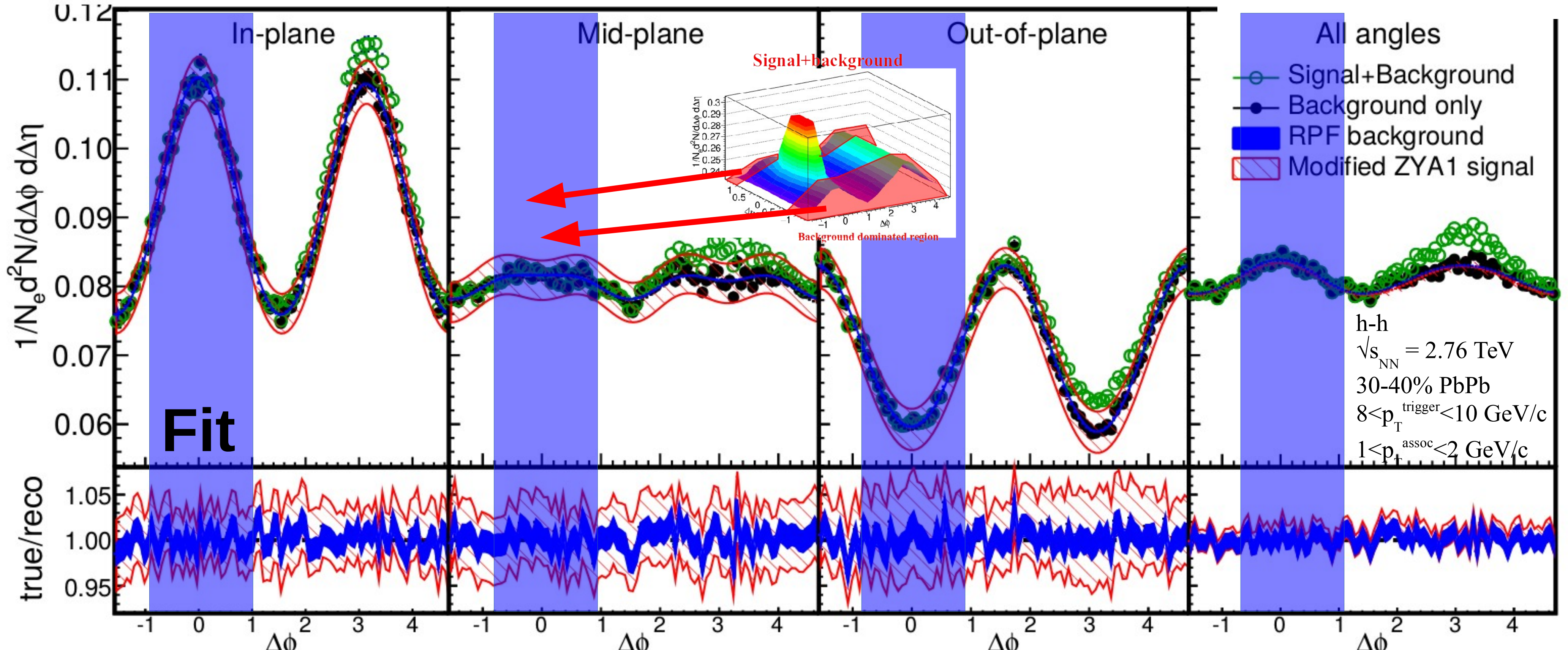
Adding reaction plane dependence



Reaction Plane Fit (RPF) method



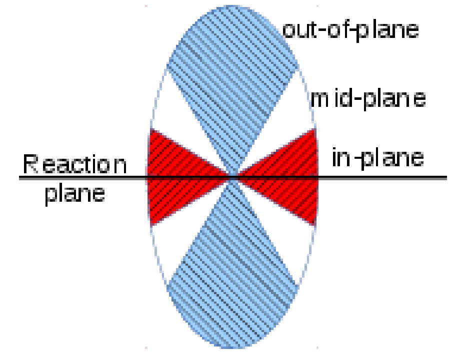
30-40% central

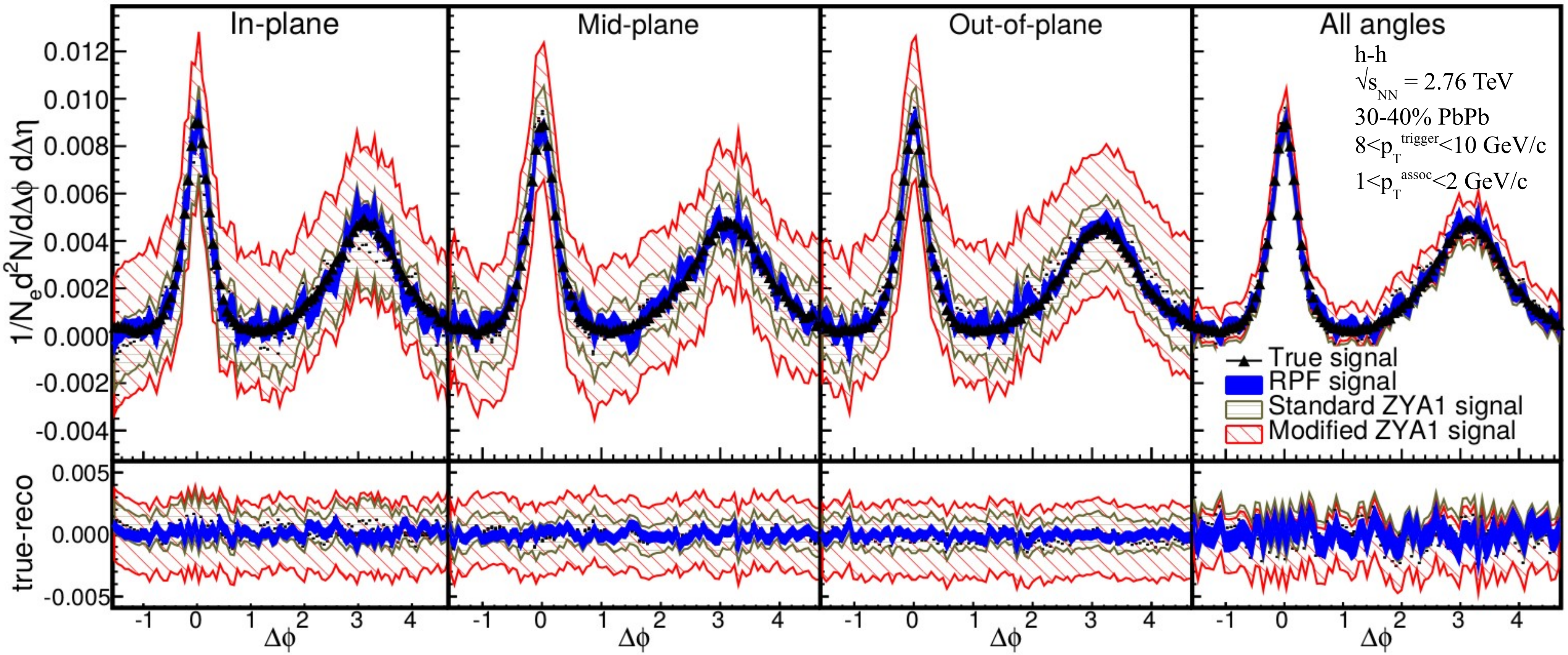


- Project signal+background over $1.0<|\Delta\eta|<1.4$
- Fit background in $|\Delta\varphi|<1$ including reaction plane dependence
- v_n and B extracted with v_n up to n=4

Reaction Plane Fit (RPF) method

30-40% central

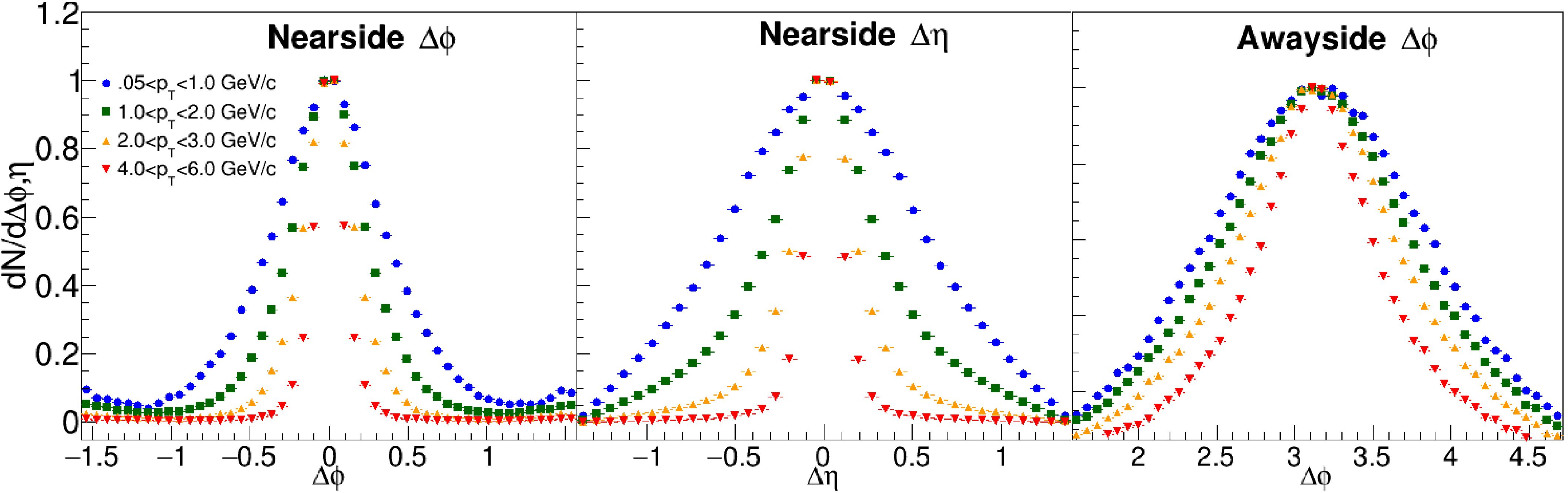




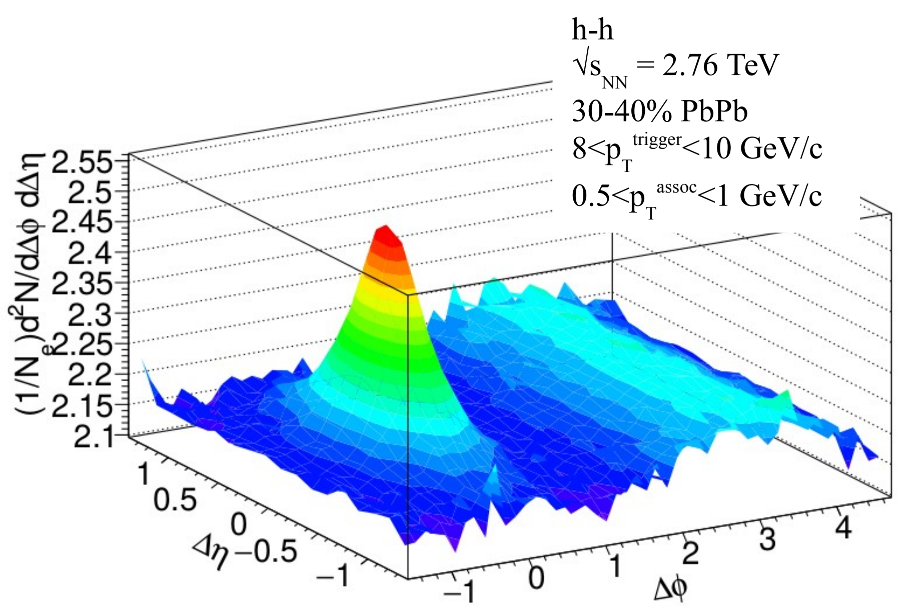
	near-side $Y \times 10^{-3}$				away-side $Y \times 10^{-3}$			
	in-plane	mid-plane	out-of-plane	All	in-plane	mid-plane	out-of-plane	All
True	$5.78 \pm 0.03 \pm 0.13$	$5.77 \pm 0.03 \pm 0.14$	$5.65 \pm 0.03 \pm 0.13$	$17.1 \pm 0.1 \pm 0.2$	$6.74 \pm 0.03 \pm 0.13$	$6.72 \pm 0.03 \pm 0.14$	$6.52 \pm 0.03 \pm 0.13$	$19.9 \pm 0.1 \pm 0.2$
Mod. ZYA1	$6.3 \pm 5.9 \pm 1.7$	$5.7 \pm 6.0 \pm 0.3$	$6.8 \pm 6.1 \pm 0.9$	$18.9 \pm 4.2 \pm 1.2$	$7.3 \pm 5.9 \pm 1.7$	$6.8 \pm 6.0 \pm 0.3$	$7.7 \pm 6.1 \pm 0.9$	$21.9 \pm 4.2 \pm 1.2$
Std. ZYA1	$4.5 \pm 2.3 \pm 1.7$	$5.5 \pm 2.3 \pm 0.3$	$5.6 \pm 2.3 \pm 0.9$	$15.7 \pm 1.6 \pm 1.2$	$5.5 \pm 2.3 \pm 1.7$	$6.5 \pm 2.3 \pm 0.3$	$6.5 \pm 2.3 \pm 0.9$	$18.7 \pm 1.6 \pm 1.2$
RPF ($\|\Delta\phi\| < \pi/2$)	5.5 ± 0.4	5.7 ± 0.3	5.9 ± 0.3	17.0 ± 0.7	6.6 ± 0.4	6.8 ± 0.3	6.8 ± 0.3	20.1 ± 0.7
RPF ($\|\Delta\phi\| < 1$)	5.7 ± 0.4	5.8 ± 0.4	5.9 ± 0.3	17.4 ± 0.7	6.8 ± 0.4	6.8 ± 0.4	6.8 ± 0.3	20.4 ± 0.7

Going to lower momenta

Low momenta

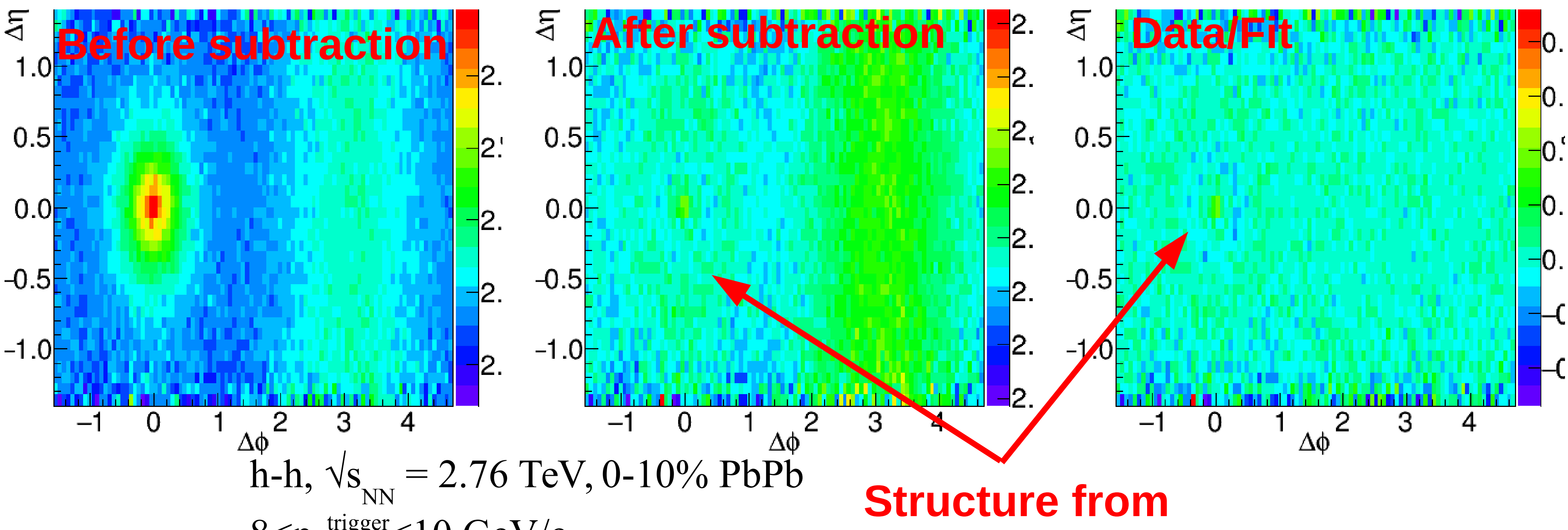


- ZYAM assumptions break down at low p_T
- If method doesn't work on PYTHIA, it can't be trusted on data!
- But low p_T is interesting!



Going to lower momenta, medium modifications

- Peak gets broader
- Fit near-side peak and subtract it
- Increase Δη range available for background subtraction



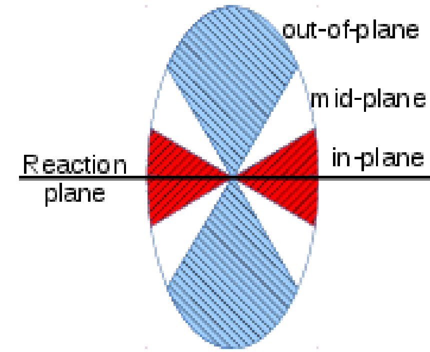
h-h, $\sqrt{s_{NN}}$ = 2.76 TeV, 0-10% PbPb

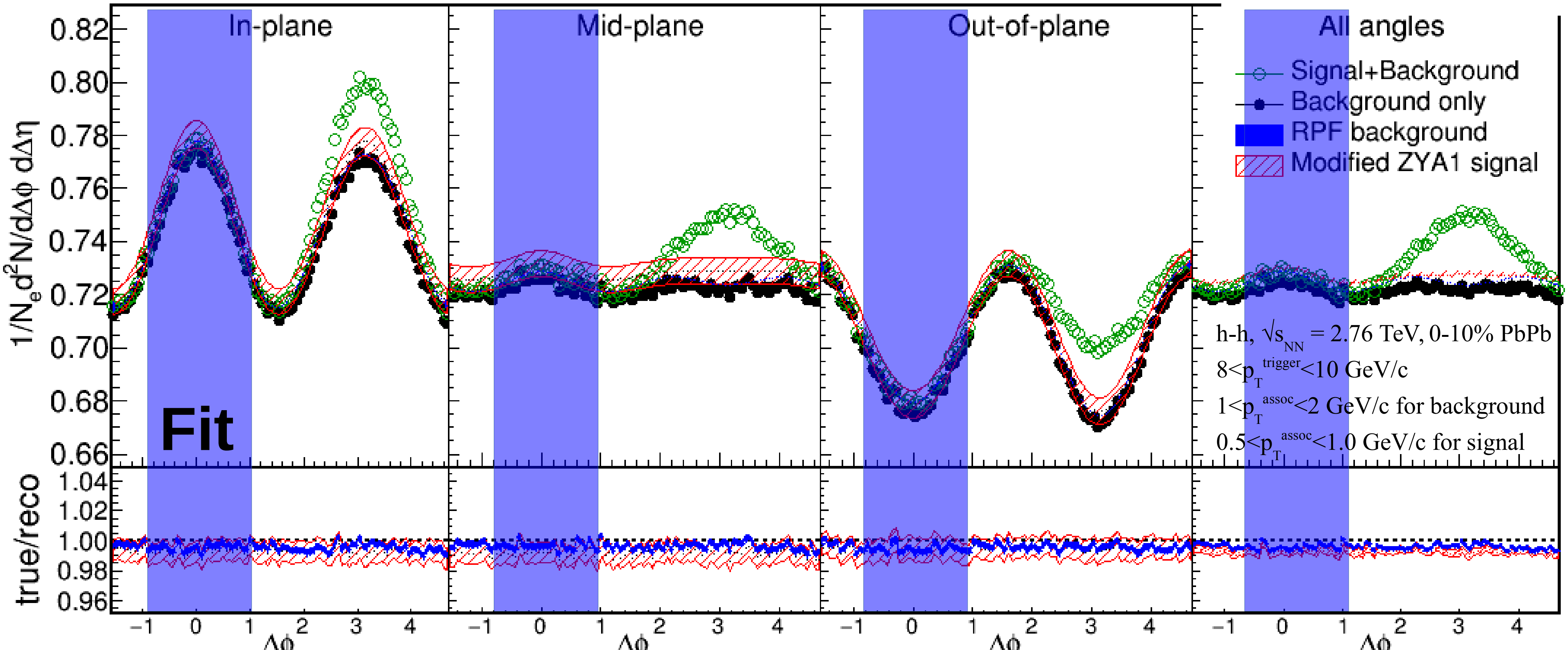
$8 < p_T^{trigger} < 10$ GeV/c

$1 < p_T^{assoc} < 2$ GeV/c for background, $0.5 < p_T^{assoc} < 1.0$ GeV/c for signal

Near-Side Subtracted RPF method

30-40% central

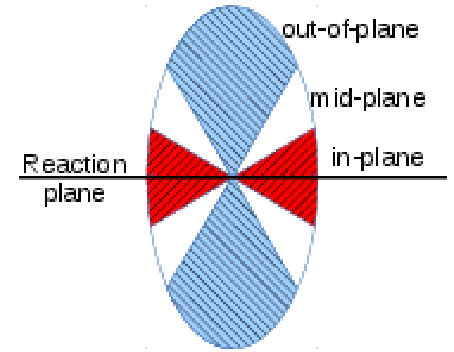


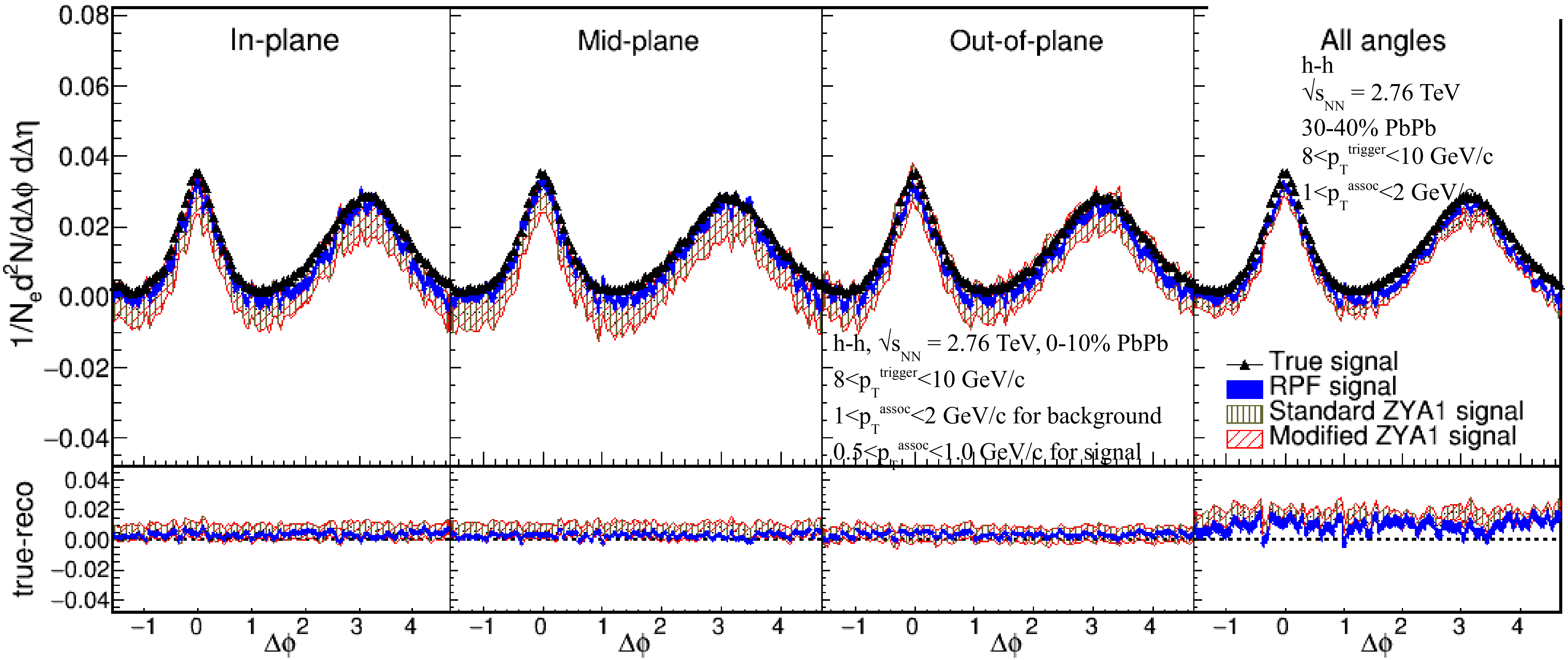


- Project signal+background over **0.0**<|Δη|<1.4
- Fit background in |Δφ|<1 including reaction plane dependence
- v_n and B extracted with v_n up to n=4

Reaction Plane Fit (RPF) method

30-40% central



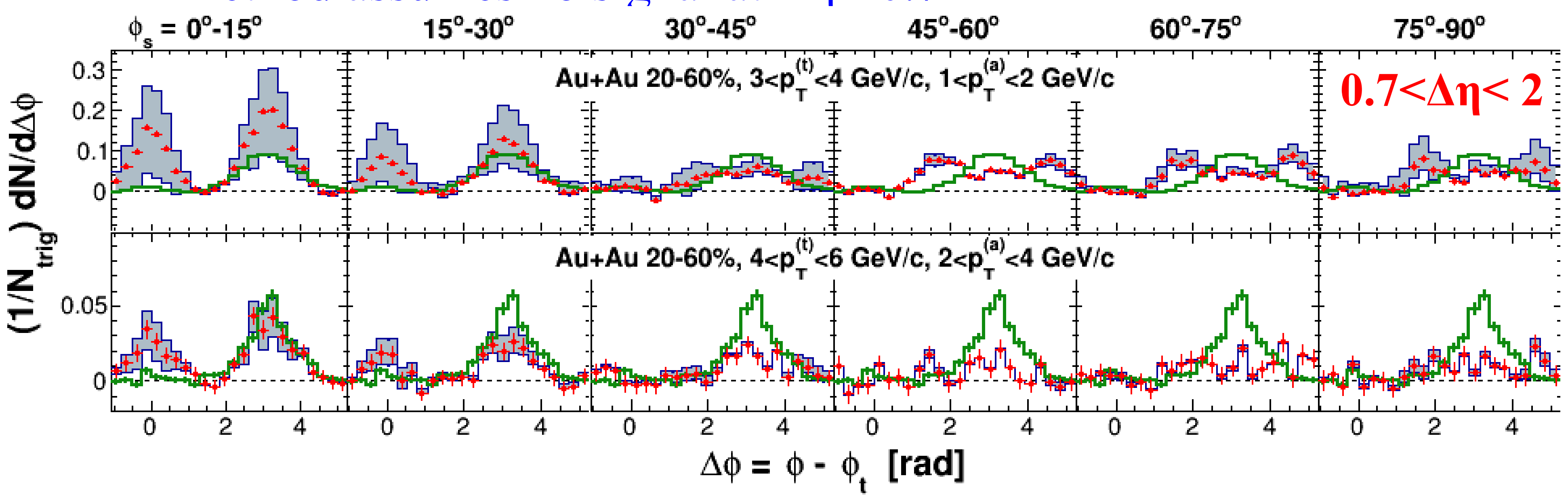


- **Works beautifully!**

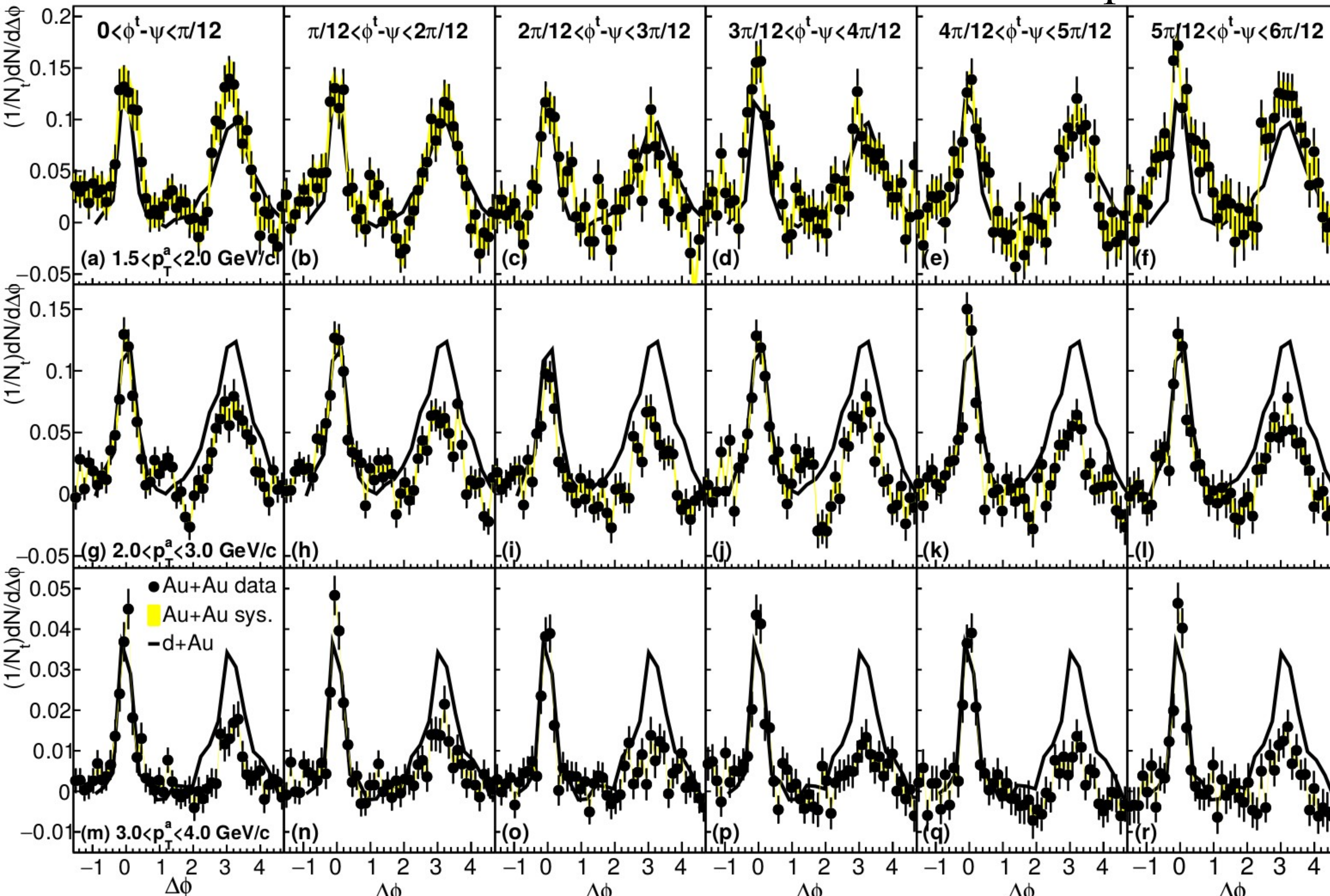
Revisiting dihadron correlations

STAR measurements of dihadron correlations relative to reaction plane

- Correlations on arxiv (nucl-ex/1010.0690 v2)
  - Published article (Phys. Rev. C 89 (2014) 41901) does not include raw correlations
- ZYAM background subtraction
  - Reports ridge at $\Delta\eta > 0.7$
  - RPF method assumes no signal at $\Delta\eta > 0.7$



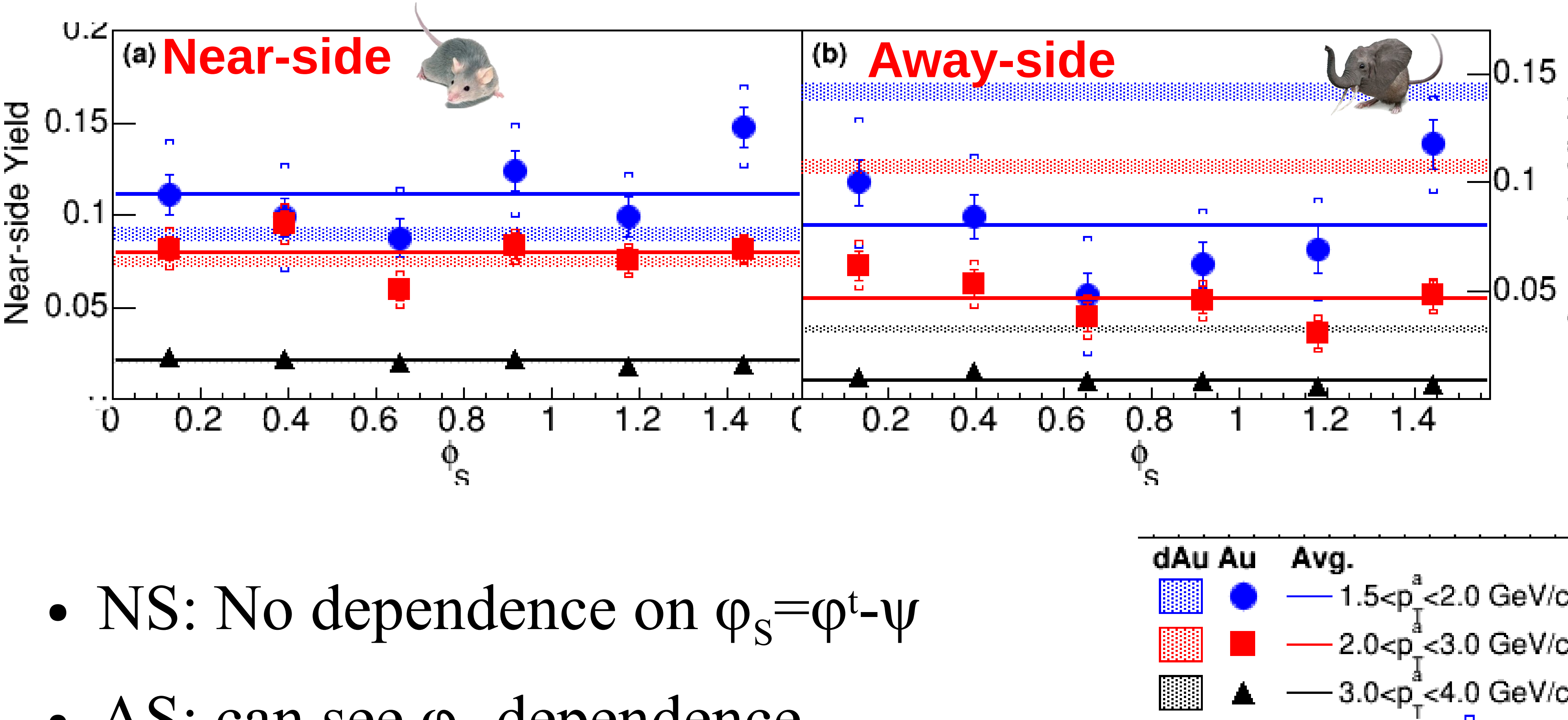
Background subtracted correlations $4<p_T^t<6$ GeV/c



No "Mach Cone", up to 10x higher precision

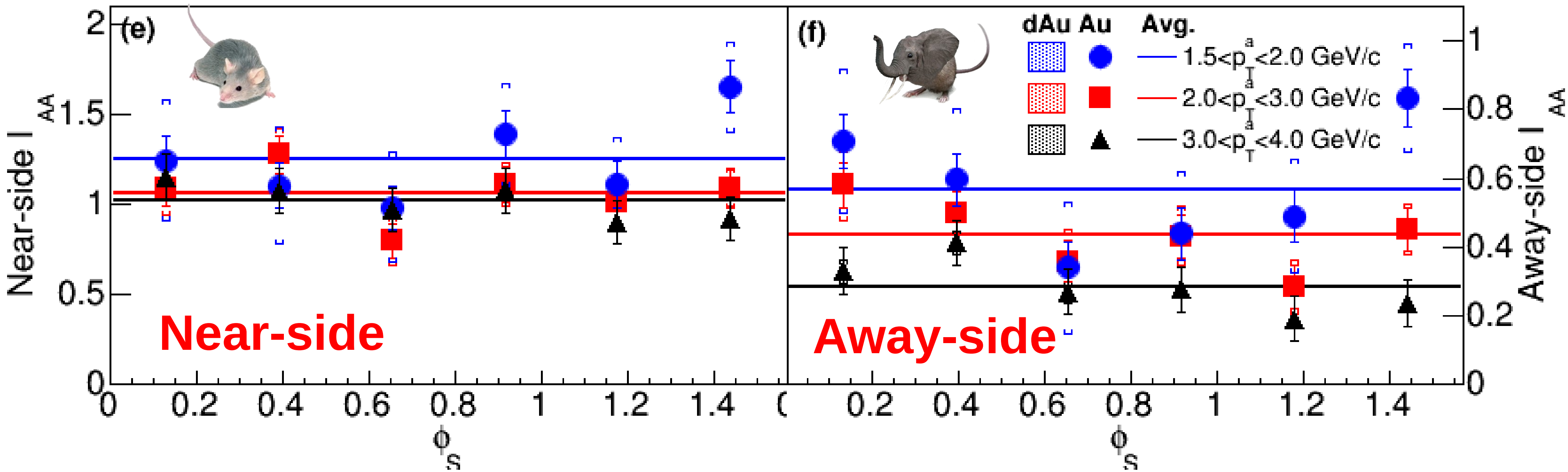
Statistical error bars include correlated statistical error on background

Yields $4<p_T^t<6$ GeV/c



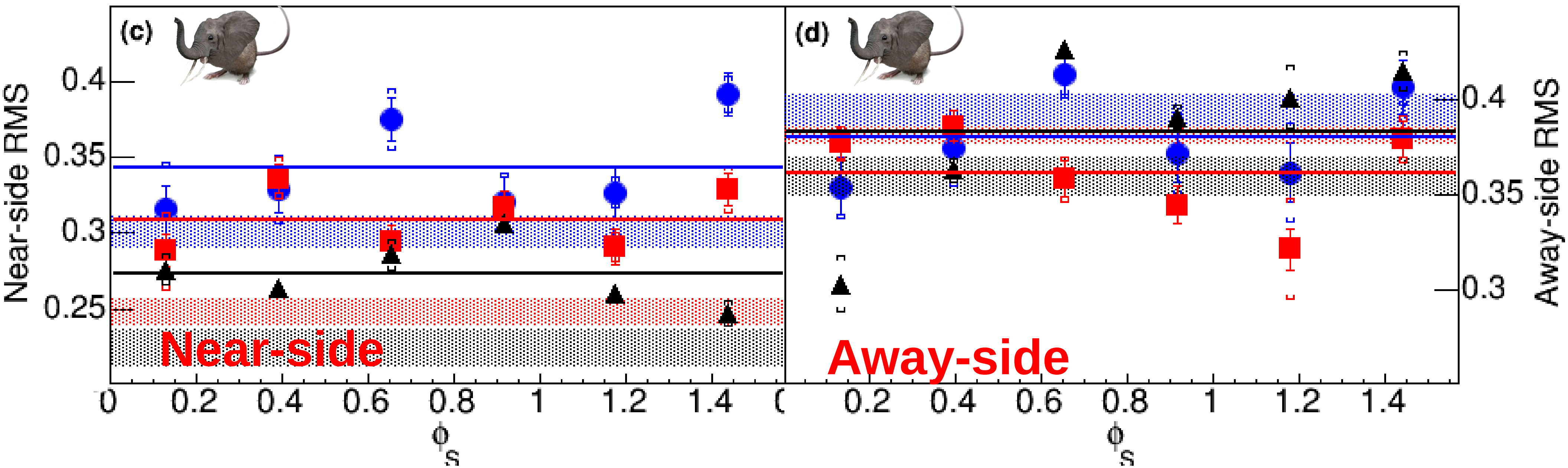
- NS: No dependence on $\varphi_S=\varphi^t-\psi$
- AS: can see φ_S dependence
- Higher precision than previous analyses

$$I_{AA} = Y_{AuAu}/Y_{dAu}$$



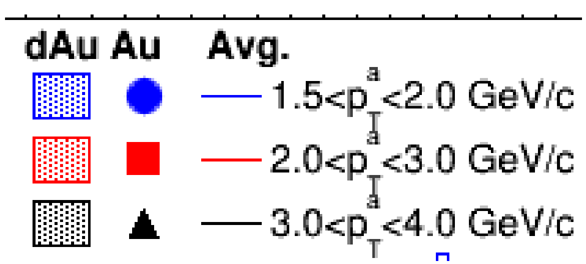
- NS: No dependence on $\varphi_S=\varphi^t-\psi$
- AS: can see φ_S dependence
- Higher precision than previous analyses

Truncated RMS $4<p_T^t<6$ GeV/c



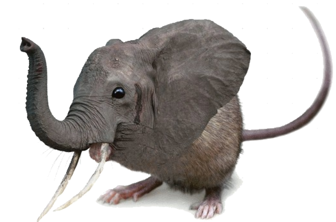
$$RMS_{trunc}^{NS}=\sqrt{\int_{-0.8}^{0.8}\Delta\phi^2 C(\Delta\phi)\,d\Delta\phi}\qquad RMS_{trunc}^{AS}=\sqrt{\int_{\pi-0.8}^{\pi+0.8}(\Delta\phi-\pi)^2 C(\Delta\phi)\,d\Delta\phi}$$

- Lines show averages
- Higher precision than public analysis (different p_T)



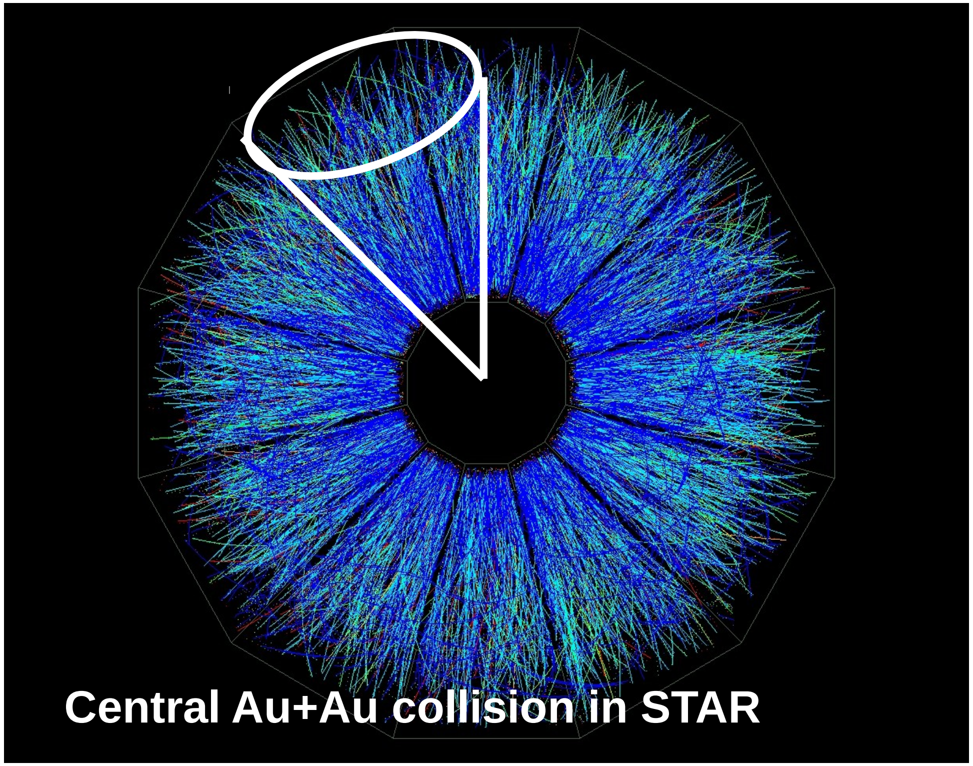
Conclusions

Conclusions



- With right background subtraction, we can see low p_T modifications!
- Dihadron correlations:
  - now consistent with fully reconstructed jets
  - Broadening and softening of jet
- Need to continue to work to understand background better!
- Need to treat bias as a toolls

Background for jet studies



- New method for subtracting combinatorial background from flow (nucl-ex/1509.04732 accepted to PRC)
- Improvements on new method
- Reanalysis of published STAR data (nucl-ex/1010.0690)

Conclusions

- NSF, RPF, NSS(NSF/RPF) methods work!
  - Much higher precision than ZYAM
  - NSS works to extend analyses to low p_T
- Qualitatively different results from public STAR analysis
  - Little/no reaction plane dependence in yield, RMS at these momenta
  - Away-side does not disappear completely, comparable to d+Au
  - More subtle effects than with ZYAM

Background Subtraction Methods

- **Zero-Yield at Minimum (ZYAM):** Assumes v_n from other studies, assumes region around $\Delta\varphi\approx1$ is background dominated
- **Near-Side Fit (NSF):** assumes small $\Delta\varphi$/large $\Delta\eta$ region background dominated, fits v_n and B
- **Reaction Plane Fit (RPF):** assumes small $\Delta\varphi$/large $\Delta\eta$ region background dominated, fits v_n and B using reaction plane dependence
- **Near-Side Subtracted NSF/RPF (NSS NSF/RPF):** fits v_n and B at small small $\Delta\varphi$ using reaction plane dependence after subtracting the near-side with a fit

RPF Method as applied to STAR data

- 6 bins relative to reaction plane
- Background level
  - Normalized per trigger → B same in all bins if v_2^t is the only effect → reduces info for RPF
  - "The background levels can be different for the different φ_s slices because of the net effect of the variations in jet-quenching with φ_s and the centrality cuts in total charged particle multiplicity in the TPC within $|\eta| < 0.5$." (Pg. 10, arxiv version) → **Not consistent with ZYAM assumptions!**
- Used reaction plane resolution values from paper and their uncertainties
  - Used TPC for reaction plane and analysis – potential autocorrelations
- Data available for $\Delta\eta < 0.7$ (signal+background) and $0.7 < \Delta\eta < 2$ (background dominated)
  - Acceptance correction in not applied → background must be scaled → uncertainty
  - Jet-like correlation not eliminated in $0.7 < \Delta\eta < 2$ for all p_T^t, p_T^a given in paper → **focus on high p_T**

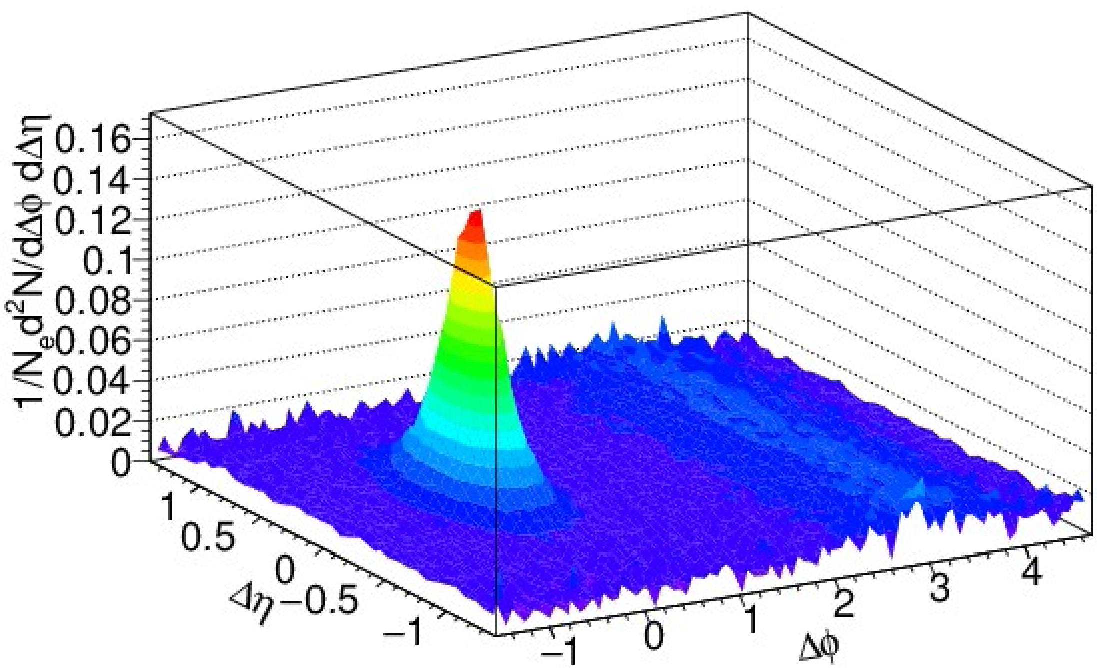
Toy model

Model for background

- True reaction plane angle is always at $\varphi=0$ in detector coordinates
- Throw random reconstructed reaction plane angle
  - Assume Gaussian reaction plane resolution
  - Selected to approximate data
- Use measured particle yields to calculate how many associated particles would be measured
- Use measured v_n to determine their anisotropy relative to the reaction plane
- Throw associated particles matching distribution observed in data using v_n up to n=10

Model for signal

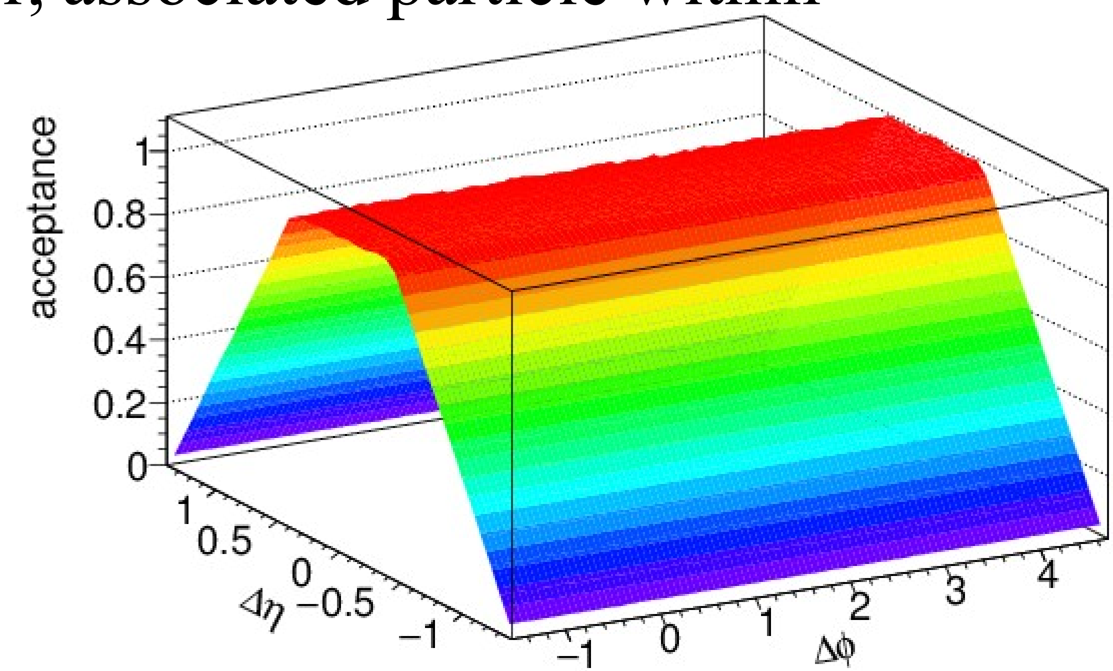
- Use PYTHIA Perugia 2011
- $\pi^{\pm}$, $K^{\pm}$, $\bar{p}$, p for unidentified hadrons
- Quarks and gluons as proxy for reconstructed jets



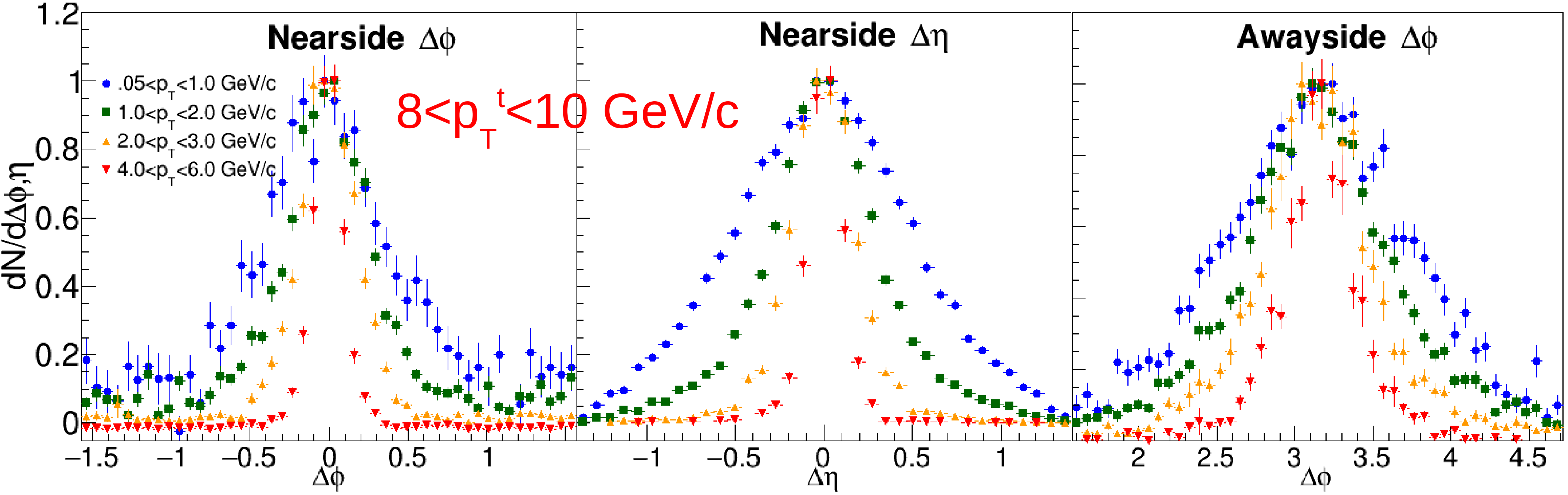
h-h
$\sqrt{s}$ = 2.76 TeV
pp collisions
$8<p_T^{trigger}<10$ GeV/c
$1<p_T^{assoc}<2$ GeV/c

Acceptance correction

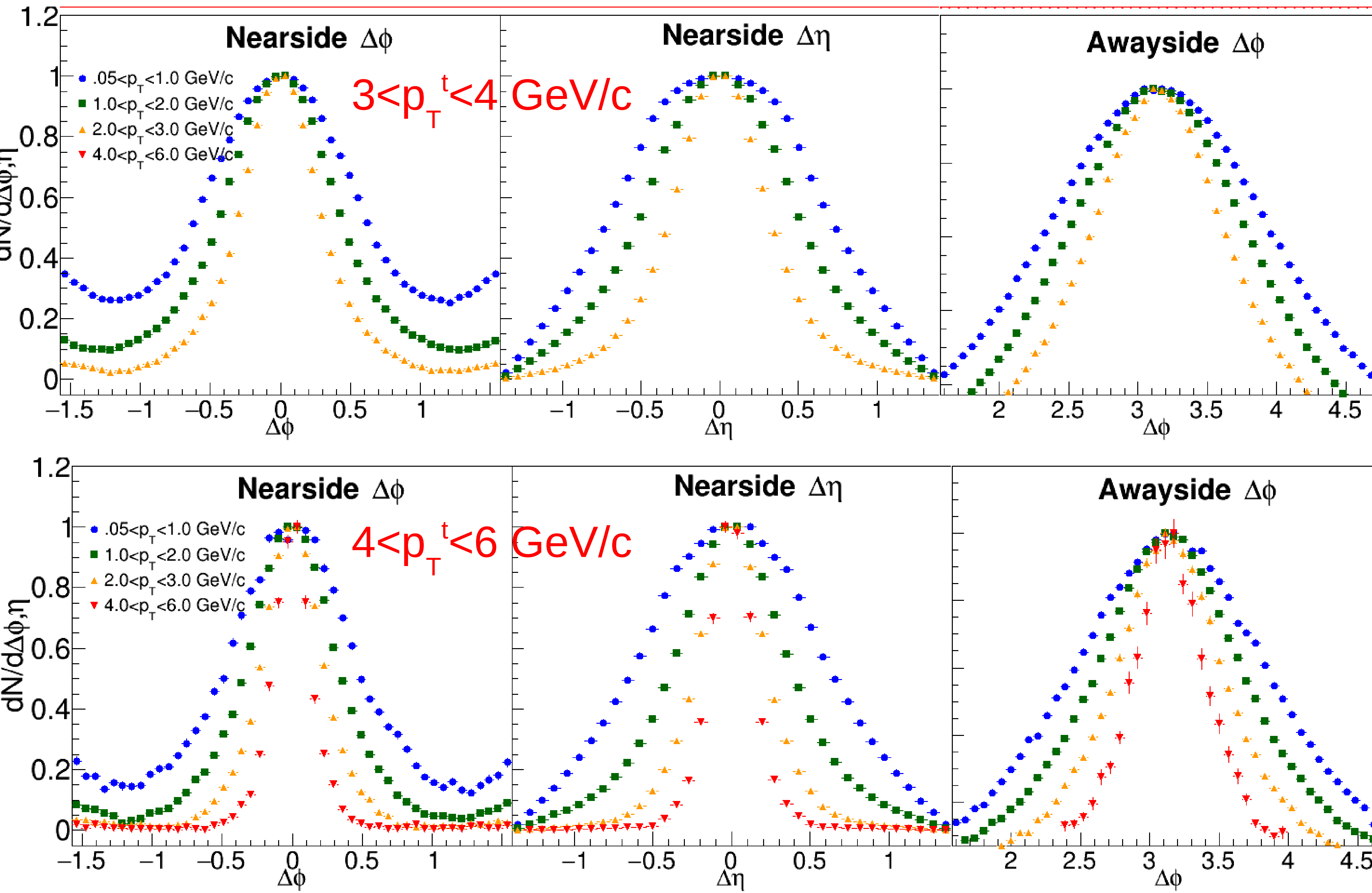
- Fixed acceptance cuts leads to a trivial structure due to acceptance
- This is fixed with a “mixed event” correction
  - Throw random trigger, associated particle within acceptance
  - Calculate $\Delta\varphi$, $\Delta\eta$
  - Use this distribution to correct for acceptance



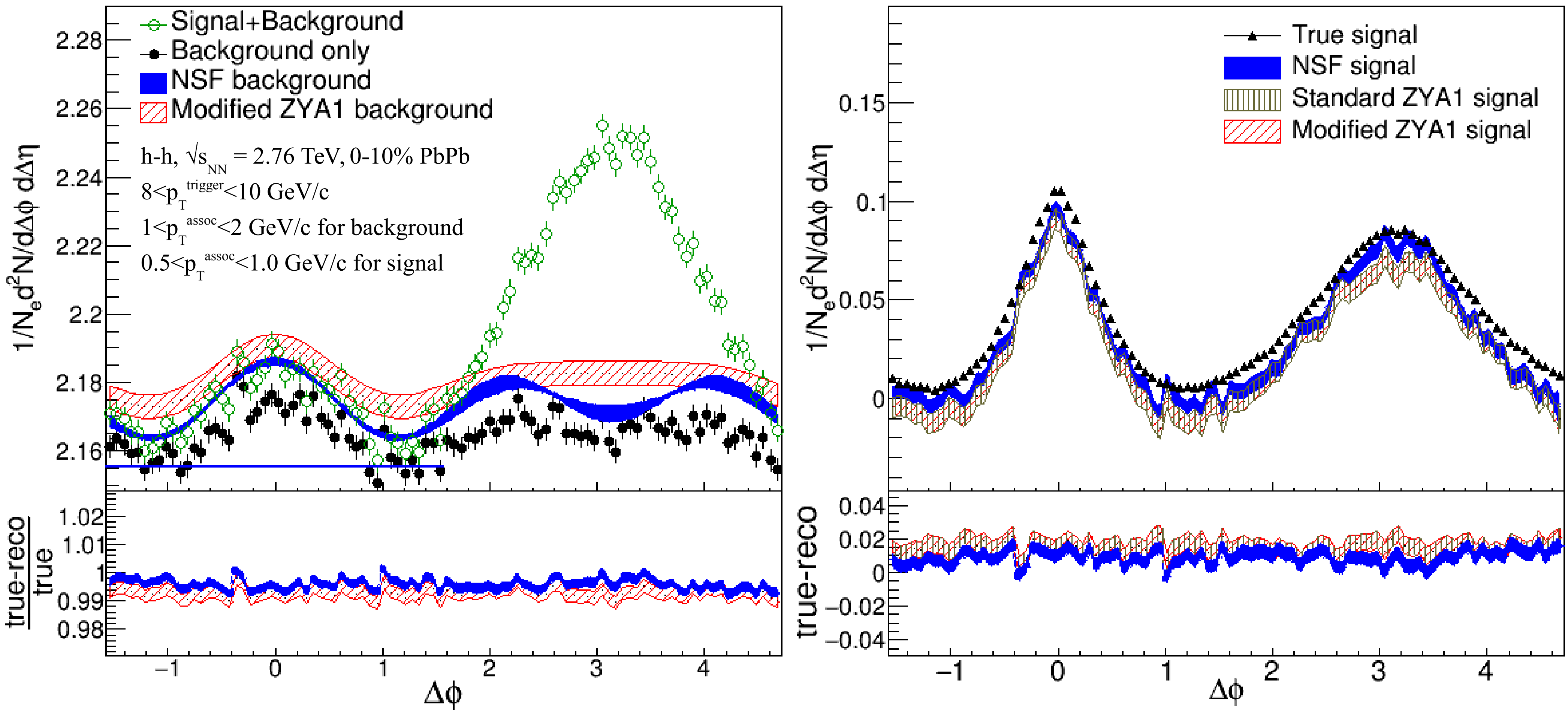
PYTHIA at 200 GeV



PYTHIA at 200 GeV



Near-Side Subtracted NSF method



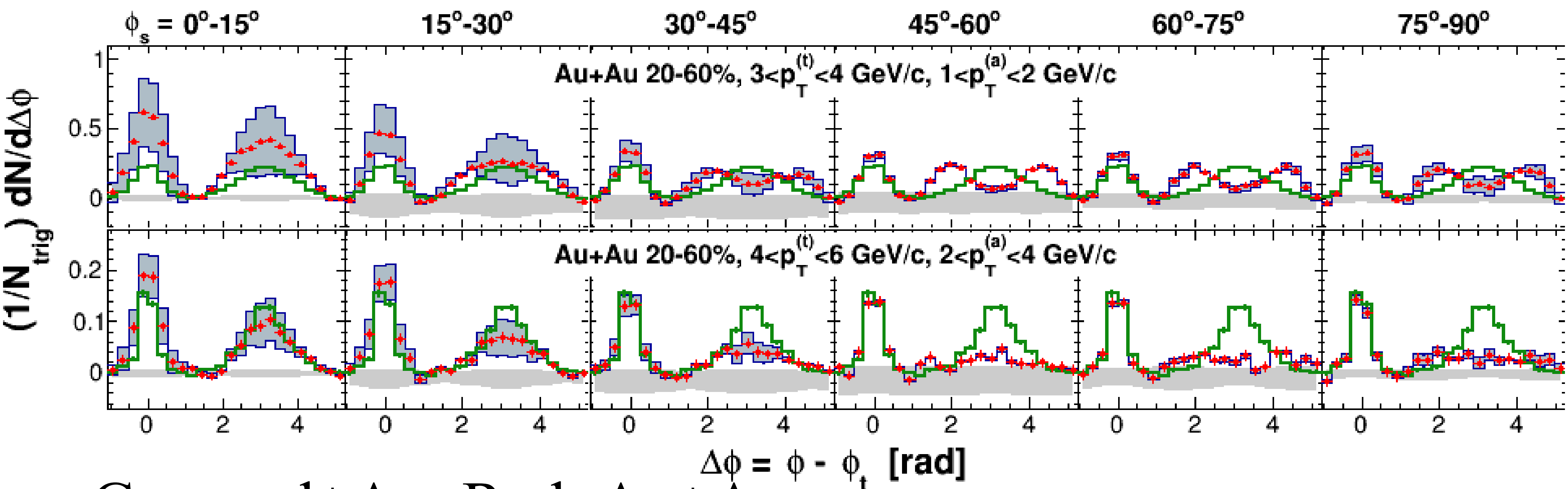
- Project signal+background over **0.0**<|Δη|<1.4
- Fit background in |Δφ|<1 including reaction plane dependence
- Bias from residual contamination by near-side

v_2 STAR vs Fit

	v_2 STAR (Table I)	v_2 Fit (stat. errors only)
$1.5<p_T<2.0$ GeV/c	0.164 ± 0.011	0.194 ± 0.008
$2.0<p_T<3.0$ GeV/c	0.189 ± 0.012	0.237 ± 0.010
$3.0<p_T<4.0$ GeV/c	0.194 ± 0.013	0.293 ± 0.058
$4.0<p_T<6.0$ GeV/c	0.163 ± 0.020	0.073 ± 0.025 0.036 ± 0.033 0.033 ± 0.068

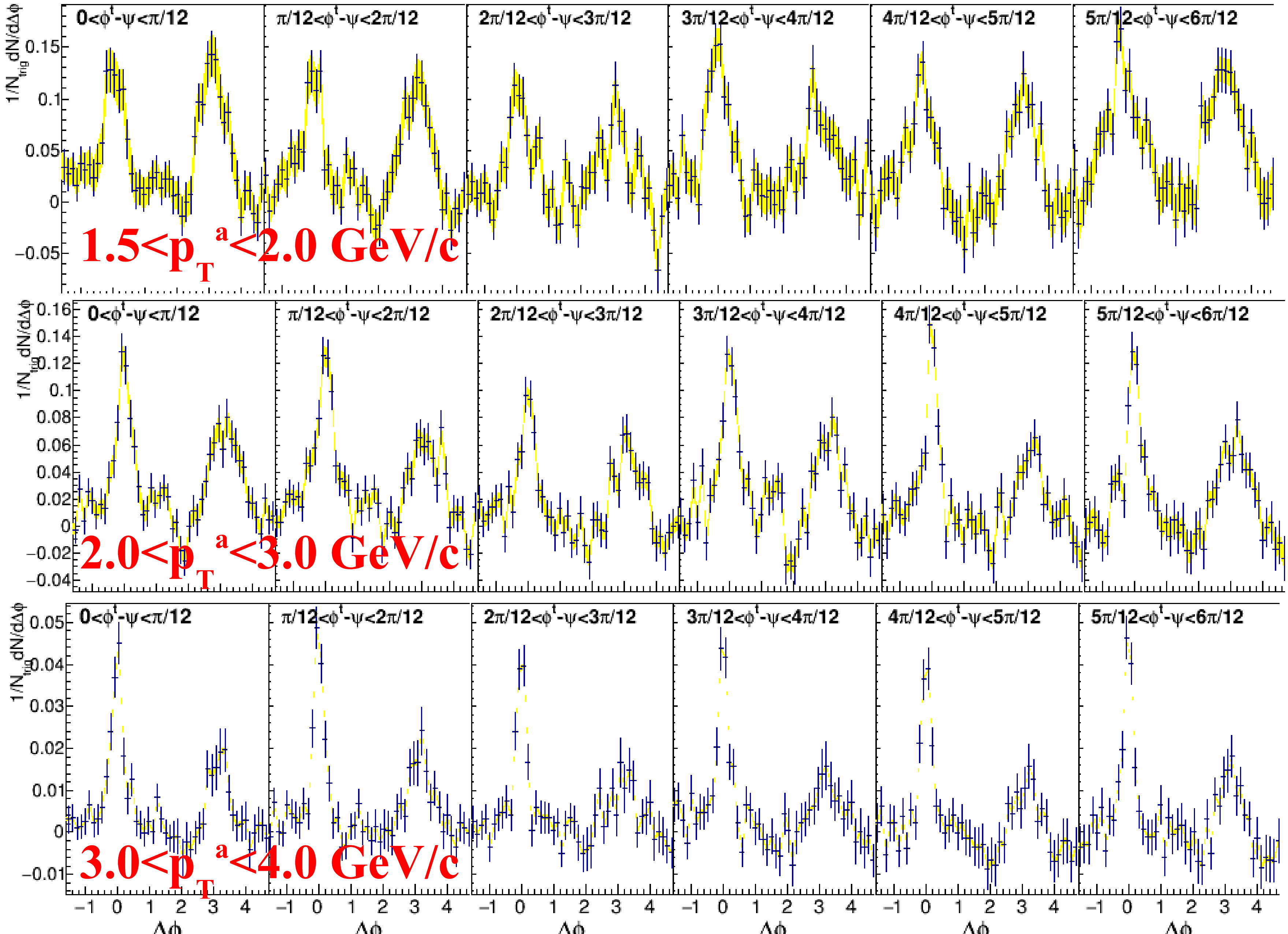
- Centrality bin is 20-60% - proper weighting of average?
- Bias in event selection with high p_T trigger?
- Bias in reconstructed reaction plane in the presence of a jet?
- Residual jet-like signal in background dominated region?
- Less information in fit due to normalization by $N_{trigger}$?

Correlations - STAR



- Green: d+Au, Red: Au+Au
- Large error bars
- "Mach Cone" evident, even decrease in amplitude for higher p_T^t

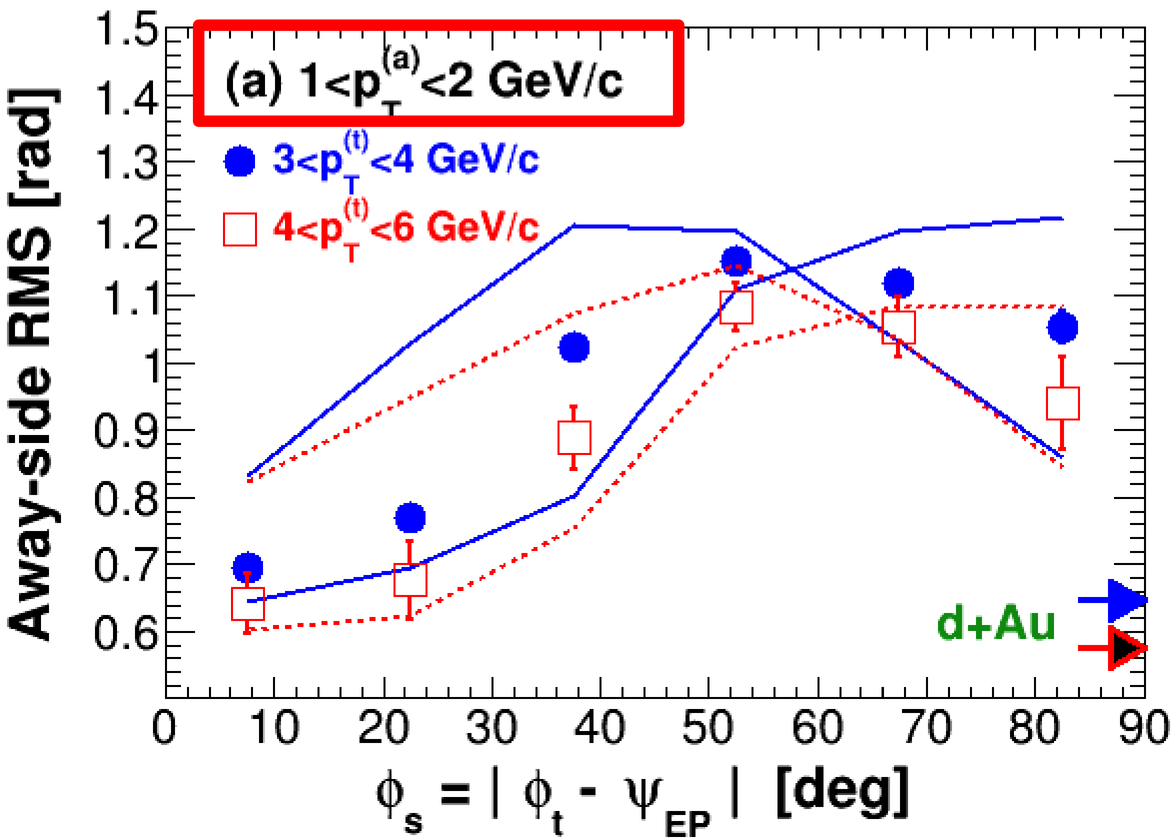
Background subtracted correlations $4<p_T^t<6$ GeV/c



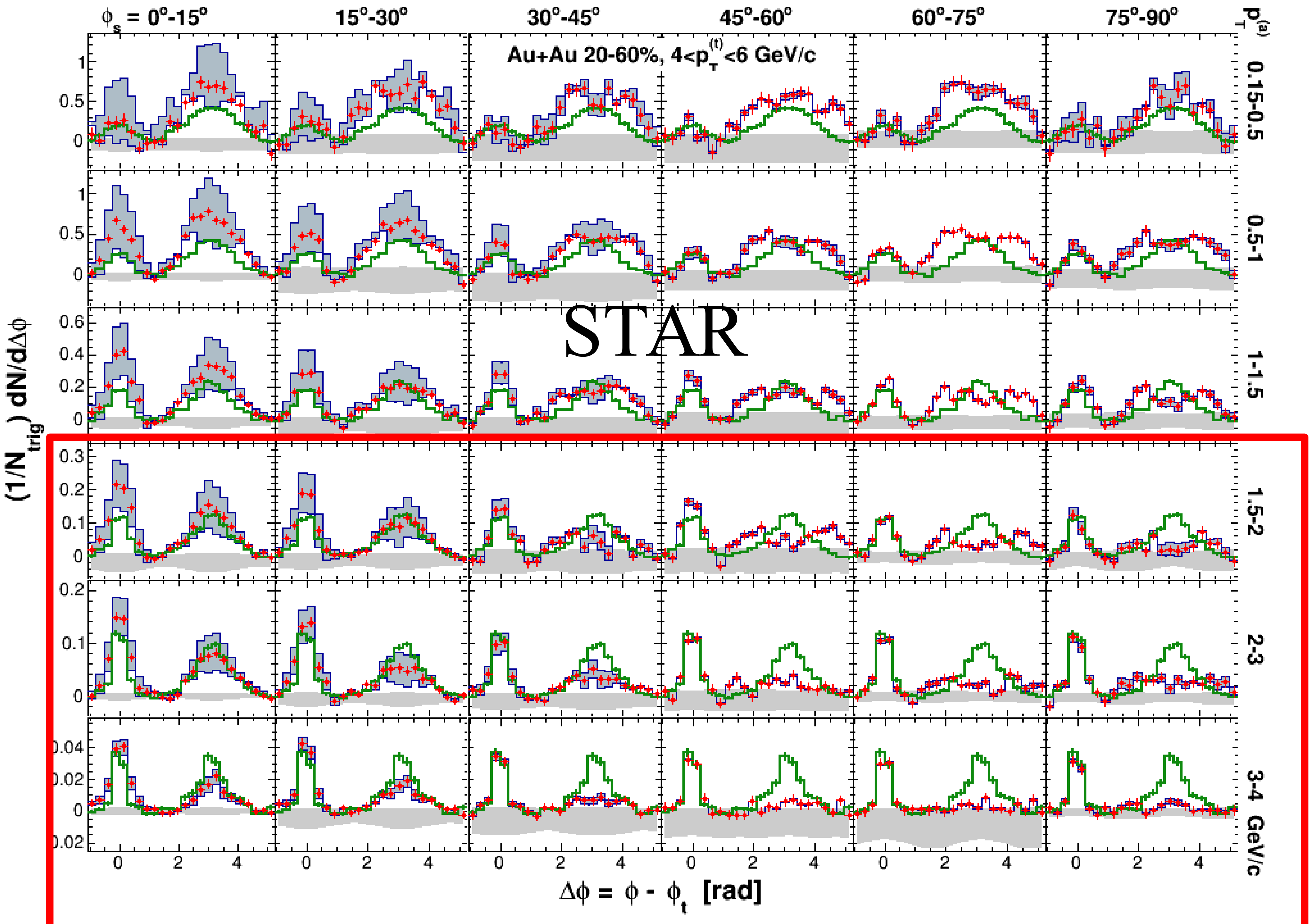
Yellow bands: uncertainty in rescaling of background
Statistical error bars include correlated statistical error on background

No "Mach Cone"

RMS - STAR

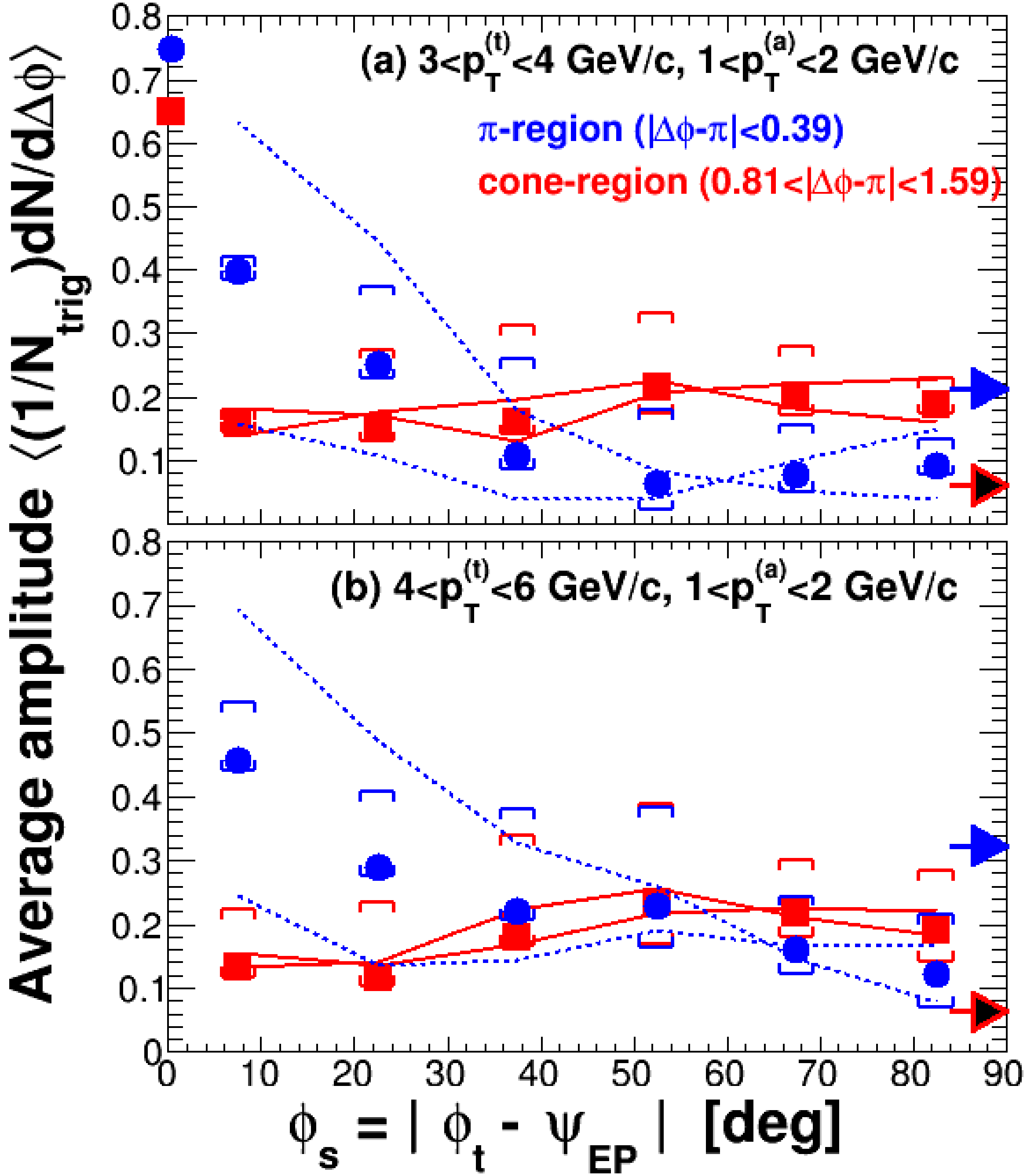


- Large error bars (shown as lines)
- Strong reaction plane dependence



ϕ_s = 0°-15°
15°-30°
30°-45°
45°-60°
60°-75°
75°-90°
$p_T^{(a)}$
Au+Au 20-60%, 4<$p_T^{(t)}$<6 GeV/c
0.15-0.5
0.5-1
1-1.5
1.5-2
2-3
3-4 GeV/c
STAR
$(1/N_{trig})$ dN/d$\Delta\phi$
$\Delta\phi = \phi - \phi_t$ [rad]

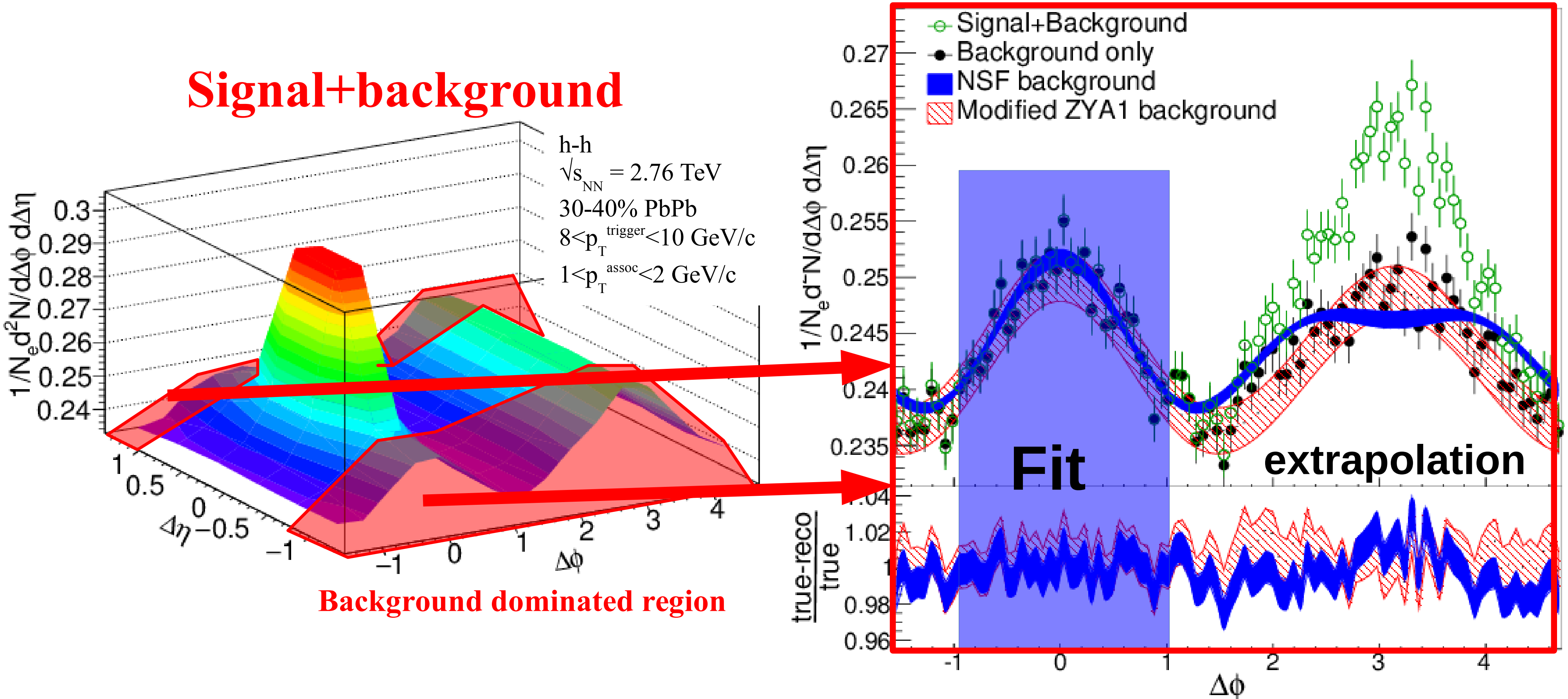
Yields – STAR



- Large error bars (shown as lines)
- Indications of reaction plane dependence?

Near-Side Fit (NSF) method

No reaction plane dependence



- Project signal+background over 1.0<|Δη|<1.4
- Fit background in **|Δφ|<1**
- **Not reliable over narrower Δφ region**