PPG04 IRC Meeting

Tanner Mengel, Virginia Bailey

sPHENIX PCM

March 3, 2025

PPG04 Physics Goals

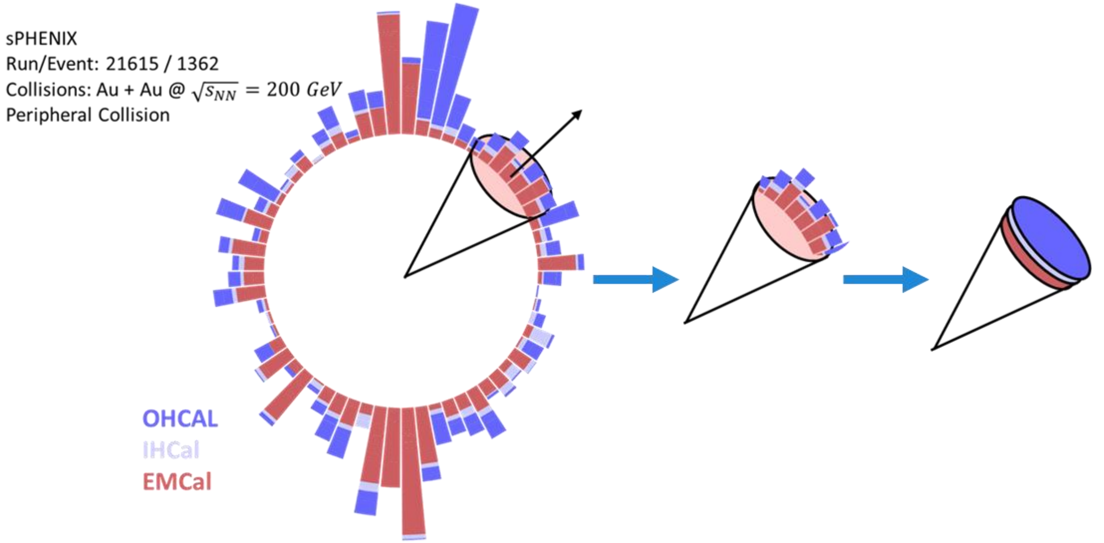
- Characterize UE and its fluctuations in Au+Au 200 GeV data
- Quantify sources and determine spatial correlations of UE fluctuations
- Characterize performance of 3 background subtraction methods in data. Investigate their ability to suppresses UE fluctuations from different sources and inform unfolding of future jet measurements
    - Multiplicity method: *T. Mengel et. al. Phys. Rev. C 108, Letter 021901*
    - Area method (STAR, ALICE): Phys. Lett. B 659 (2008) 119-126
    - Iterative subtraction (ATLAS, CMS): Phys. Rev. C 86, 024908

Current Priority Items

- Embedding pythia into MB data (Ben Kimelman)
  - Currently running embedding jobs for run 54912
  - ~20% of jobs failed in first pass have been resubmitted
- In-plane/out-plane random cones analysis (Tanner Mengel)
  - Investigate sources to UE fluctuations for cones placed in and out of plane. The negative and positive δE_T tails will be affected by different sources- this will tell us the sensitivity to a given source for to each method
- Implement flow estimation into iterative subtraction (Virginia Bailey)
  - Event plane angle reconstruction from sEPD available (s/o Ejiro!), this needs to be integrated with *DetermineTowerBackground* module on *jetbackground*
  - Use v2 from this to cross-check with STAR measurement

UE Characterization Objects

- **Calorimeter windows:** Sliding window within acceptance with different area sized
- **Random cones**: R = 0.4 rigid cones placed in calo acceptance
  - Not biased by jet clustering algorithm
  - Allows for determination of sources of background fluctuations
  - Two types of cones: basic, randomized $\eta\phi$
- **High energy probes:** E_T^{probe} = 30 GeV added to event and found in reconstructed R = 0.4 jet candidates
  - Not biased by fragmentation but is constructed using anti-kT
  - Matched geometrical to probe $\eta\phi$
- **Embedded PYTHIA Jets:** Fully embedded pythia dijet events into data
  - Full interplay between UE fluctuations and jet finding algorithm,



Analysis Details

- Using initial calo calibrations provided by PPG03 for run 2024 Au+Au calo data
  - Just updated on Friday
- Tower reconstruction info:
  - EMCAL and HCAL calibrated to EM Scale
  - Standard software ZS by ADC threshold used in central prod. (60,30,30)
  - Excluding event-by-event masked towers from all analysis inputs

Event selection cuts:

  - sPHENIX min. bias definition
  - $|z_{vrtx}| < 20$ cm
  - Centrality 0-80%

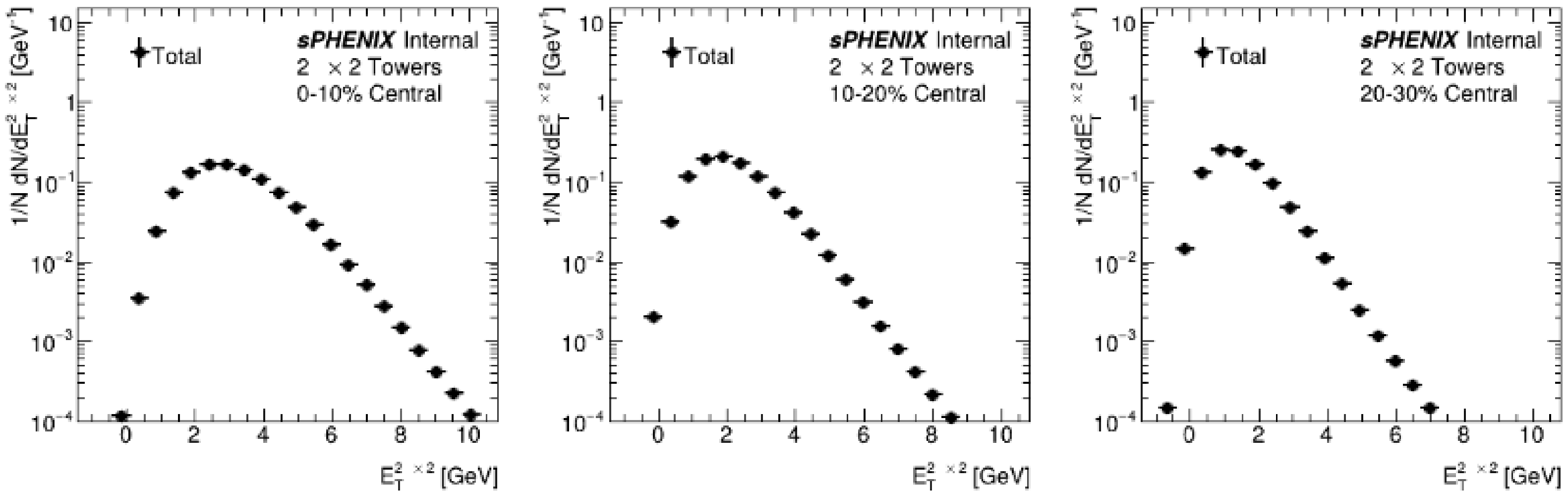
Run Number	Production Tag	CDB Tag	Number of Events [millions]
54912	Ana.450	2024p009	1

- 1e6 events are found in run 54912 with this selection criteria

Calo Windows

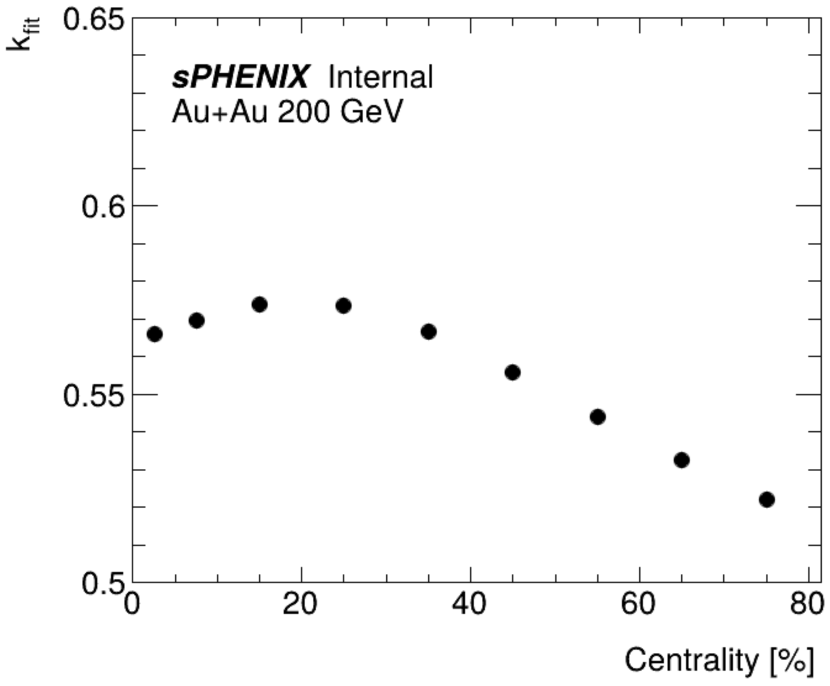
- Using sliding windows with different area sizes
  - Re-towered EMCAL, and HCALS. $|\eta| < 1.1$
  - Any window with masked tower is excluded
- No pedestal subtraction

R	A_{cone}	Window Size	A_{window}
0.2	0.13	3×4	0.11
0.3	0.28	5×6	0.27
0.4	0.5	7×8	0.5
0.5	0.79	9×10	0.81
0.6	1.13	11×12	1.19
0.7	1.54	13×13	1.52
0.8	2.01	15×15	2.02

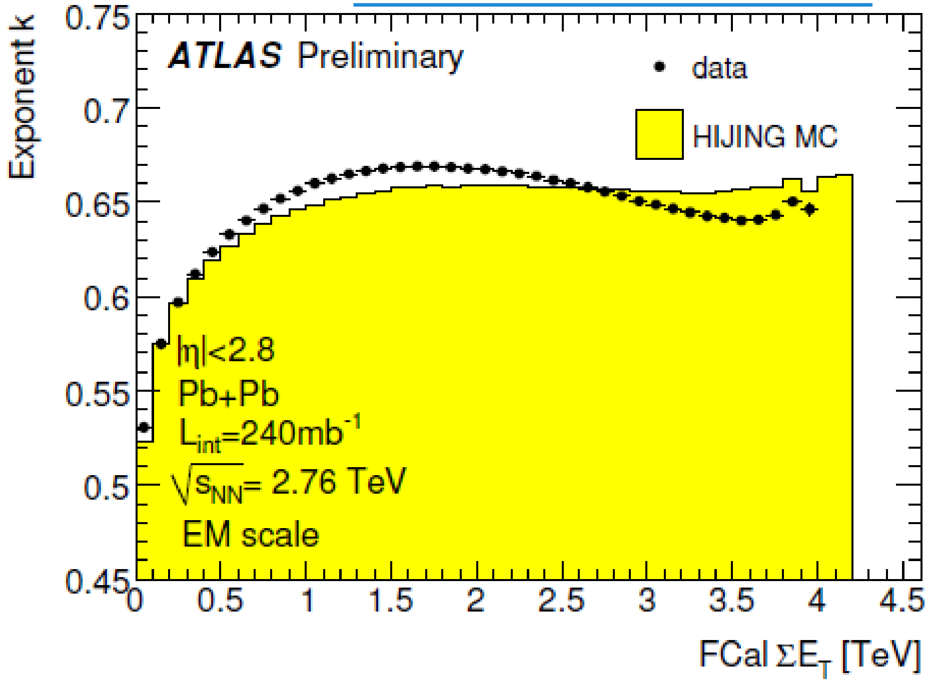


UE fluctuations spatial correlations

- Spatial correlations of UE fluctuations extracted by fit
  - $\bar{\sigma}^{nxm}/\bar{\sigma}^{1x1} = (nxm)^k$
  - $k > 1/2$ for all centralities
- Correlation peaks at 20-30% then begins to approach $\sqrt{A}$ scaling

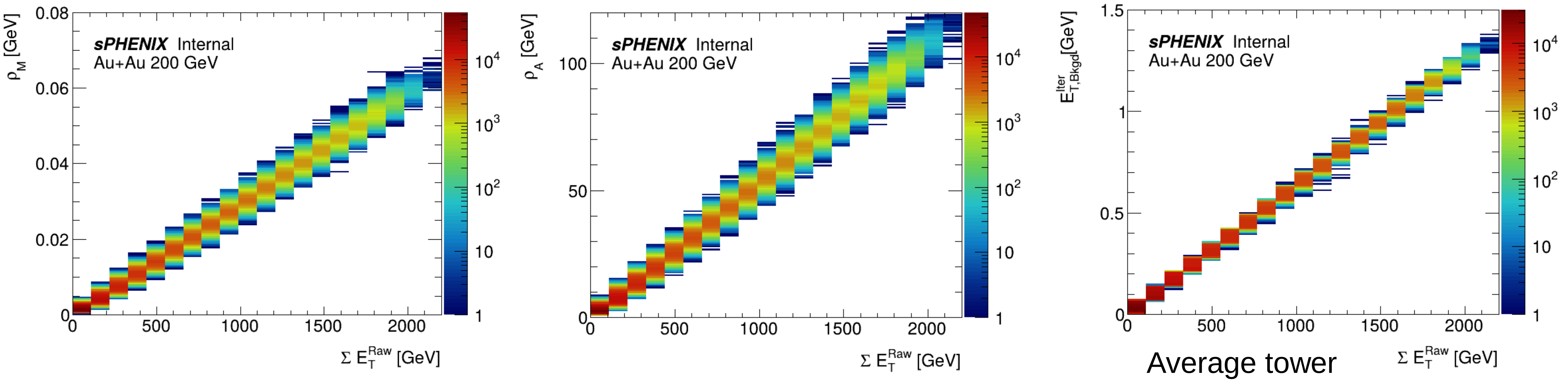


ATLAS-CONF-2012-045



Background estimations

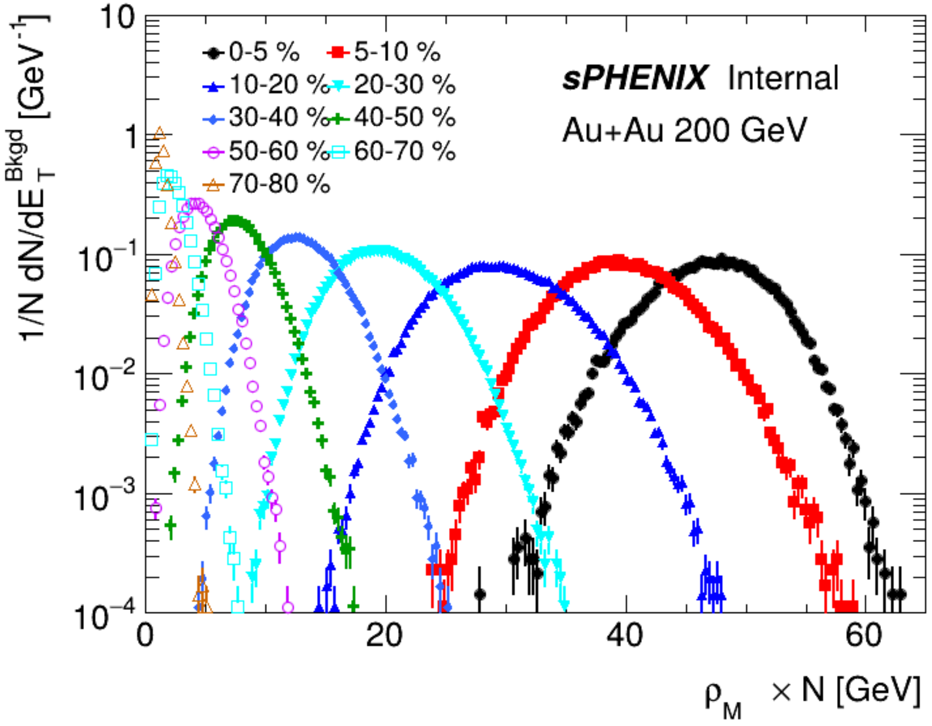
- Event background densities are estimated with iterative method, multiplicity method, area method
- All background estimations have linear dependence with $\sum E_T^{raw}$ and intersect at origin

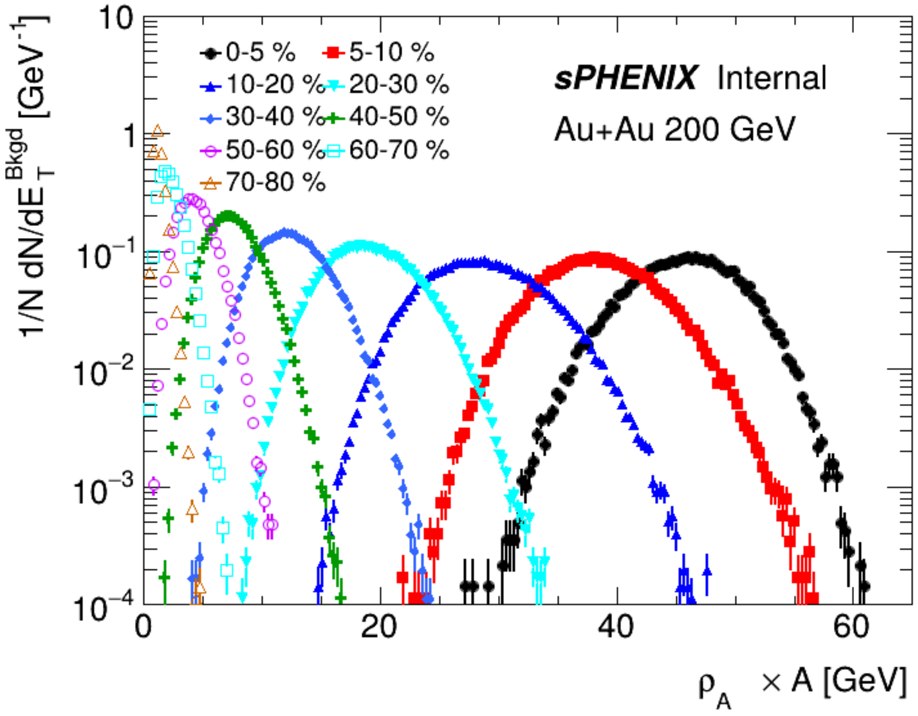


Average tower background from iterative subtraction

Background estimations

- Good agreement between background contribution estimates between both ρ methods
- UE is significant in most central events and is well behaved





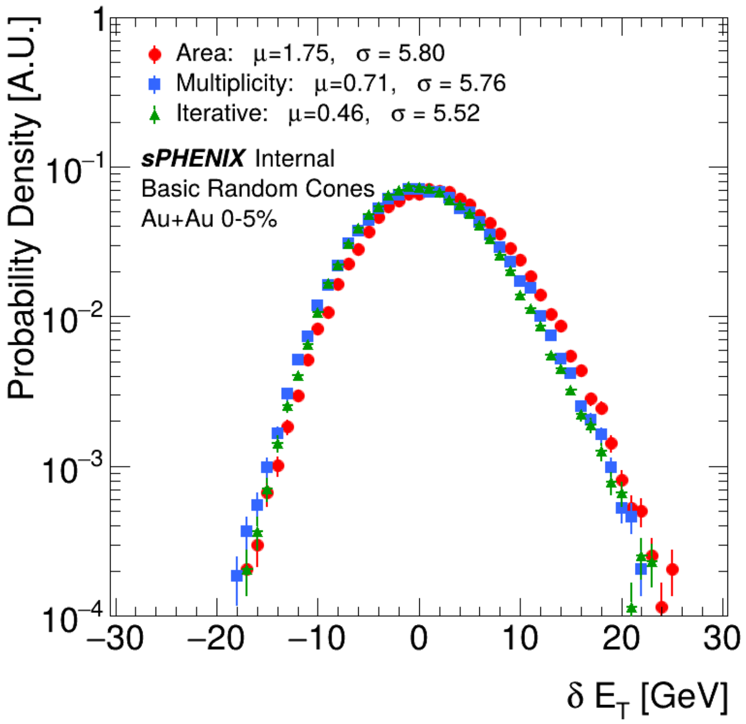
Random Cones

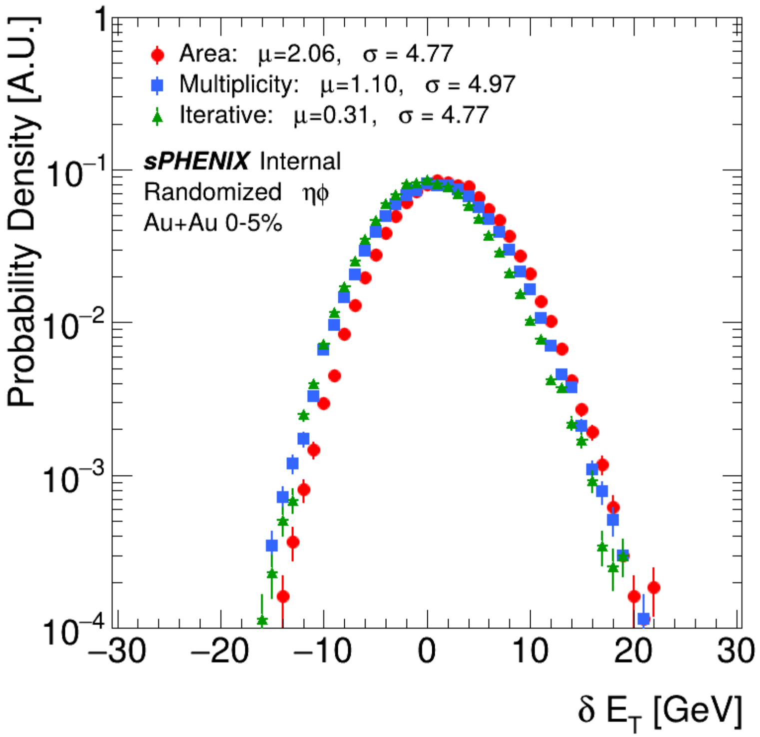
- R = 0.4 rigid cones placed within calo acceptance $|\eta| < 0.6$
  - Must contain 0 masked towers
- Randomized tower η, ϕ suppressed event correlations

$$\delta E_T^{\text{Area}} = \sum_{i=0}^{N} E_{T,i} - \rho_A \cdot A_{cone},$$

$$\delta E_T^{\text{Mult}} = \sum_{i=0}^{N} E_{T,i} - \rho_M \cdot N,$$

$$\delta E_T^{\text{iter}} = \sum_{i=0}^{N} E_{T,i}^{Sub},$$





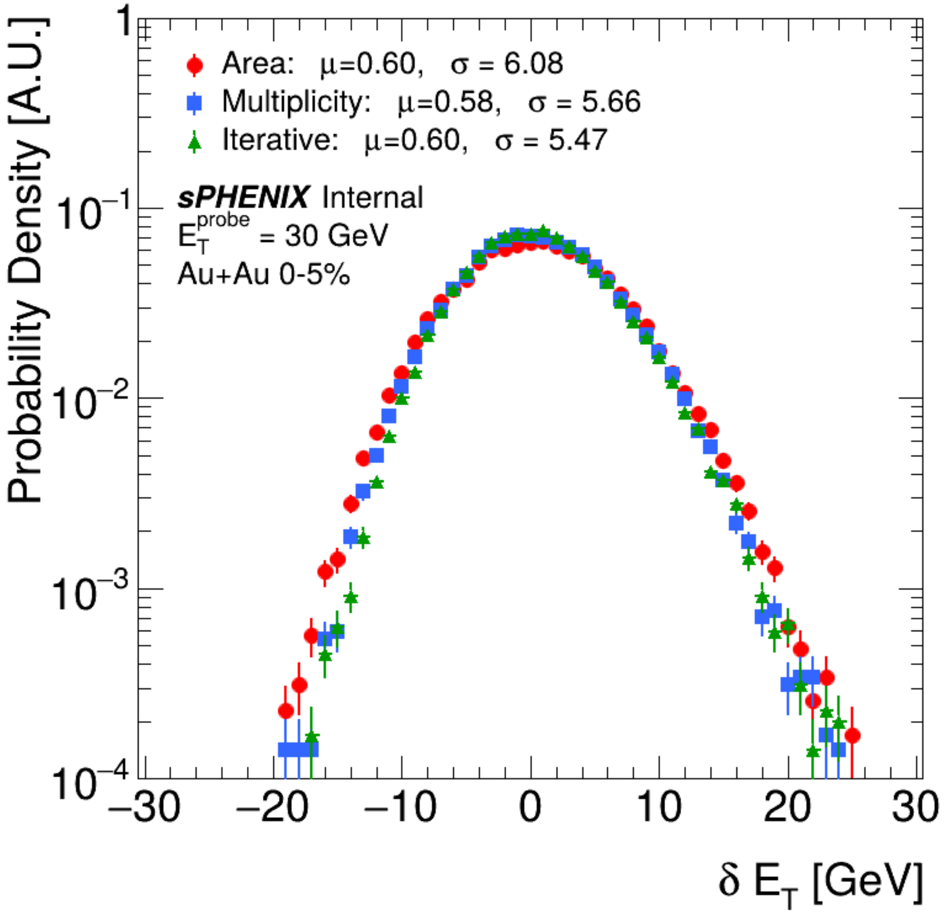
High energy probes

- E_T^{probe} = 30 GeV, $\eta < 0.6$
- Probe is added on top of data (not embedded) and results in a circular R =0.4 anti-kT jet
- Geometrically matched back to probe $\eta\phi$

$$\delta E_{\mathrm{T,Area}} = E_{T,jet}^{Uncorr.} - \rho_A \cdot A_{jet} - E_{T,truth}$$

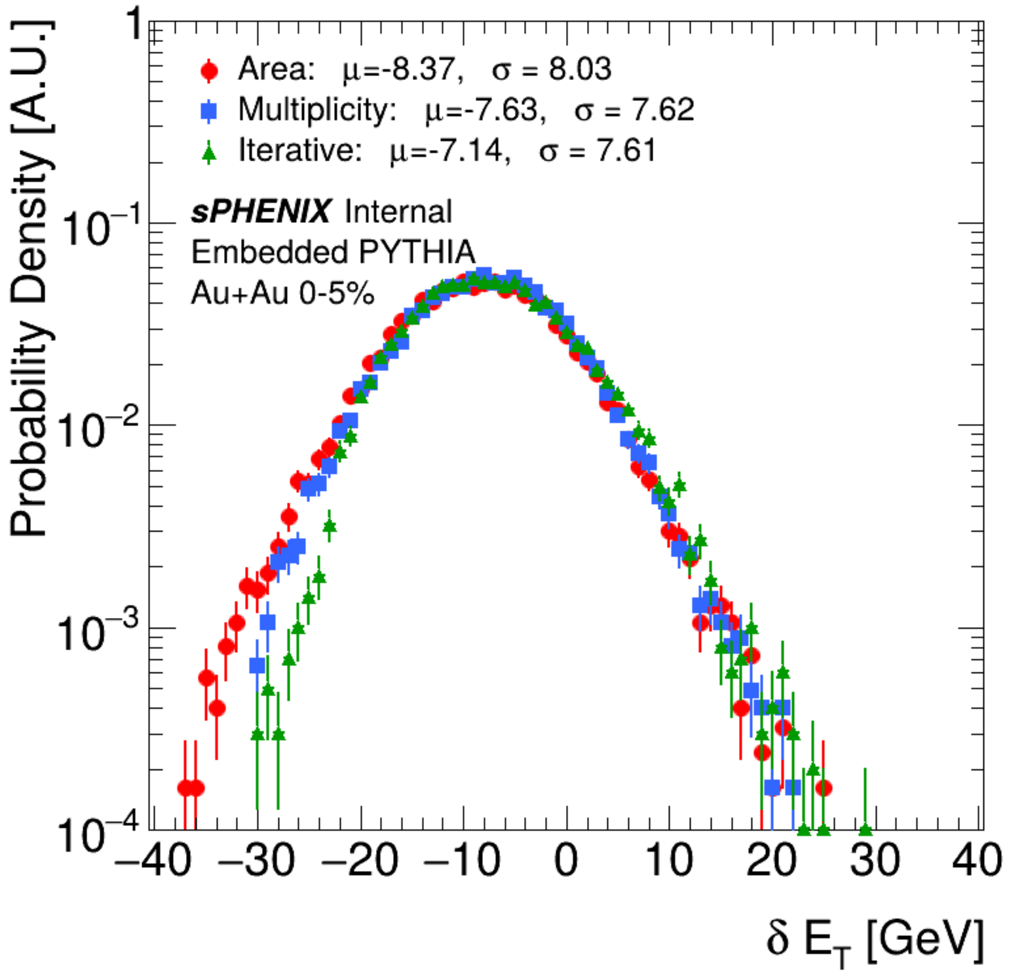
$$\delta E_{\mathrm{T,Mult}} = E_{T,jet}^{Uncorr.} - \rho_M \cdot (N_{\mathrm{const}} - \langle N_{signal} \rangle) - E_{T,truth}$$

$$\delta E_{\mathrm{T,Iter}} = E_{T,jet}^{sub.} - E_{T,truth}$$



Embedded Jets

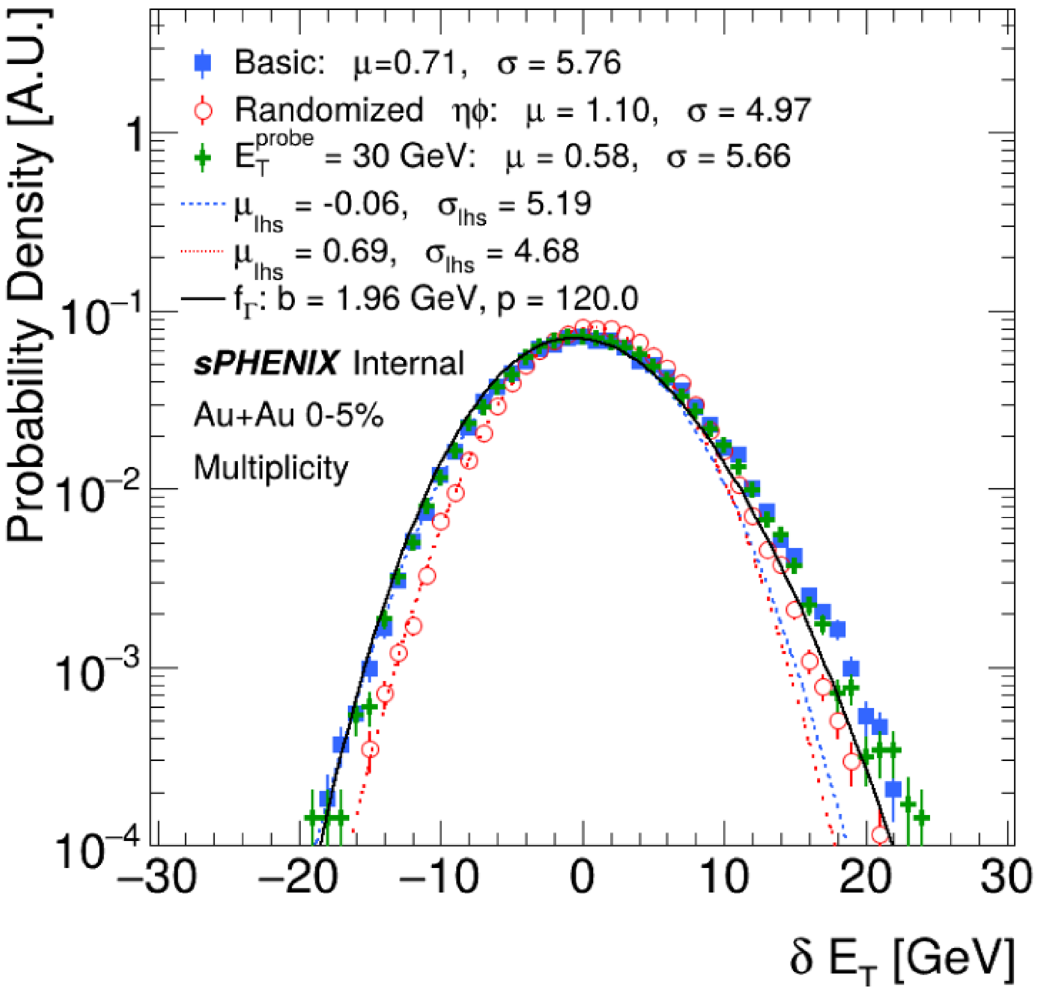
- Pythia8 embedded into MB Au+Au
- **Plots are currently WRONG**
  - Vertex between data and PYTHIA events are not aligned
  - Ben is running full embedding simulation now- plots in note will be updated when complete
- Reco jets are matched back to truth particle level jets
- $E_{T,jet}^{reco} > 5$ GeV, $E_{T,jet}^{truth} > 10$ GeV



Residual Distributions

- $\sigma_{l.h.s}$ is lower bound for magnitude of fluctuations (statistical)
- Gaussian can be extrapolated to positive δE_T to show difference in tails
- Shapes are not gaussian (even without non-statistical fluctuations)
- Better described by single tower E_T spectra

$$f_\Gamma(\delta E_T) = A \cdot \frac{b}{\Gamma(p)} \cdot (b \cdot \delta E_T + p)^{p-1} \cdot e^{-(b \cdot \delta E_T + p)}$$



Most Central Events

- The standard deviation for central events using unbiased sampling is found to be σ = 5.5 ± 0.5 GeV.
- Similar proportionality between UE fluctuations and left-hand side extrapolation seen at ALICE

	σ (GeV/c)	$\sigma^{\text{l.h.s.}}$ (GeV/c)	$\mu^{\text{l.h.s.}}$ (GeV/c)
$p_t^{\text{min}} = 0.15$ GeV/c			
random cones	10.98 ± 0.01	9.65 ± 0.02	-0.04 ± 0.03
track emb.	11.19 ± 0.01	9.80 ± 0.02	0.00 ± 0.03
jet emb.	11.34 ± 0.02	9.93 ± 0.06	0.06 ± 0.09

ALICE JHEP 03 (2012) 053

	μ [GeV]	σ [GeV]	$\sigma^{l.h.s.}$ [GeV]	$\mu^{l.h.s.}$ [GeV]
Area Method				
Basic Cone	1.75	5.8	5.15	0.83
Randomized $\eta\phi$	2.1	4.8	4.4	1.5
High Energy Probe	0.6	6.1		
Multiplicity Method				
Basic Cone	0.71	5.8	5.2	-0.057
Randomized $\eta\phi$	1.1	5	4.7	0.69
High Energy Probe	0.58	5.7		
Iterative Method				
Basic Cone	0.46	5.5	4.8	-0.48
Randomized $\eta\phi$	0.31	4.8	4.3	-0.34
High Energy Probe	0.6	5.5		

Sources of UE fluctuations

- UE fluctuations are well described by statistical and non-Poissonian multiplicity fluctuations

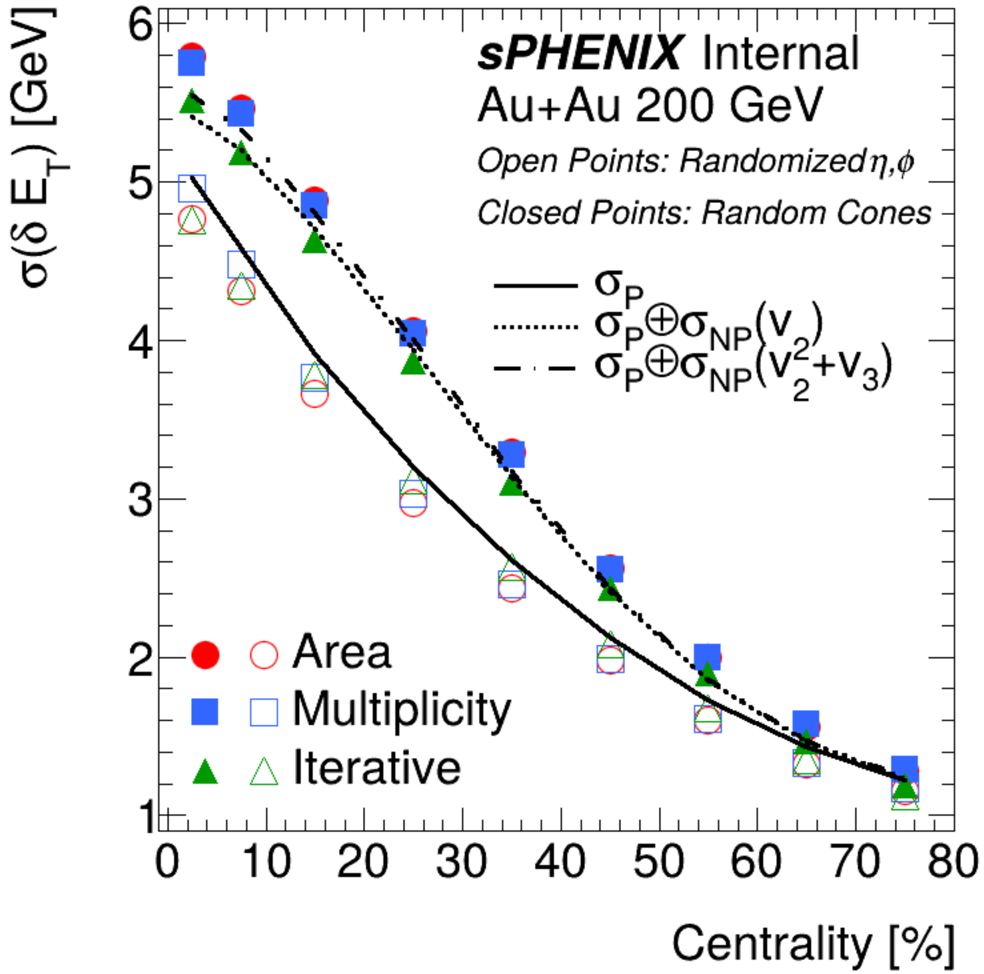
$$\sigma_P(\delta E_T) = \sqrt{\langle N\rangle(\sigma_{E_T}^2 + \langle E_T\rangle^2)}$$

- Estimate non-Poissonian contribution with STAR flow measurements

$$\sigma_{NP}^2\,(\delta E_T) \approx 2\langle N\rangle^2\langle E_T\rangle^2(v_2^2 + v_3^2)$$

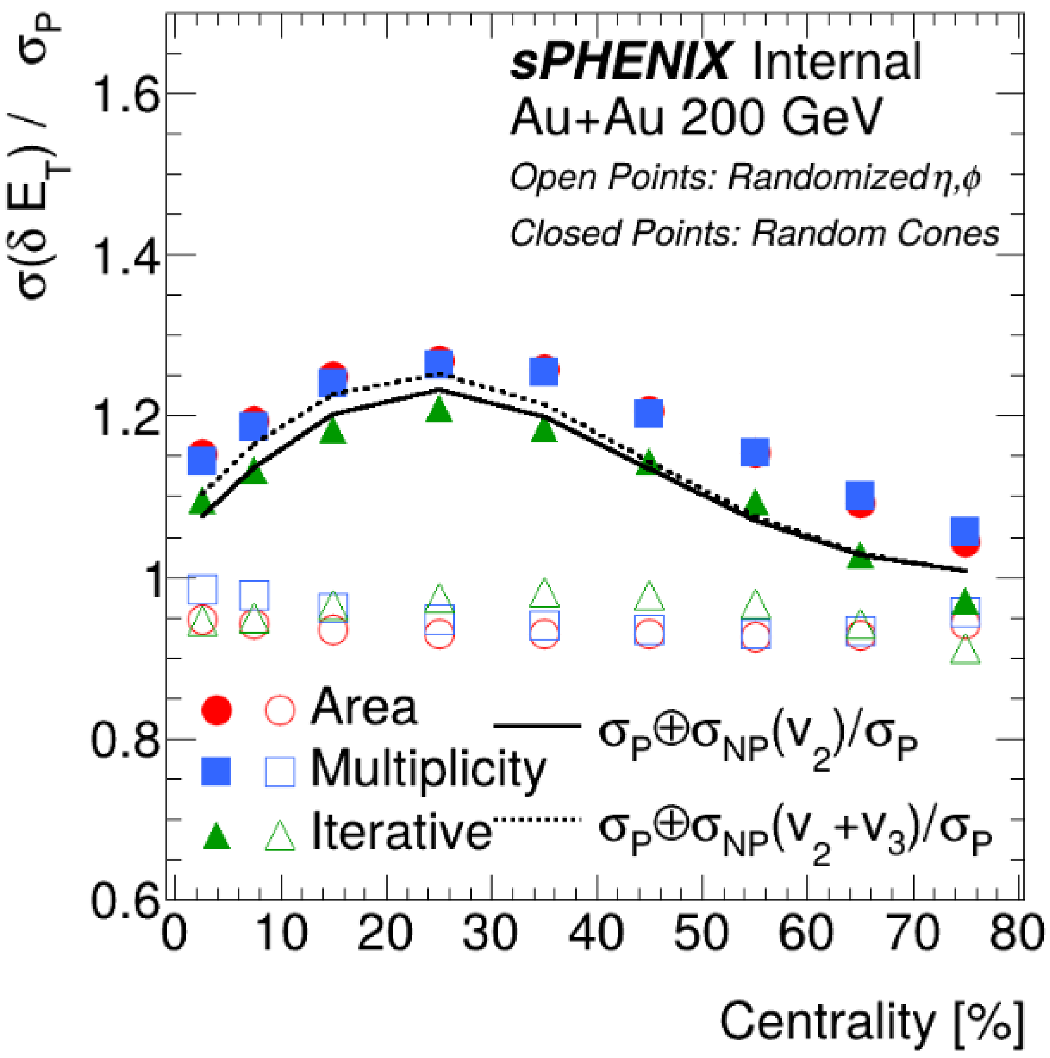
- Hydro contributes to UE fluctuations depending on centrality
  - v_2: ~20% in 20-30%
  - v_3: ~5% in 20-30%

[STAR v2 measurement]
[STAR v3 measurement]



Suppression of UE fluctuations

- Flow contributes 0-25% to UE fluctuations depending on centrality
- Iterative method is less dependent on flow contributions
- Multiplicity method is closest to Poissonian limit most central events
- Area and multiplicity method have similar flow sensitivity



Current Conclusions

- We have characterized the UE pedestal and fluctuations in data. We have determined the relative contributions for UE fluctuations at sPHENIX
- Our results indicate that the iterative method mitigates fluctuations from odd-order flow coefficients (regional fluctuations) ~5% effect in 20-30% central
- UE fluctuations are spatially correlated approaching $\sqrt{A}$ scaling in very peripheral events

Useful info

- Ana note overleaf: https://www.overleaf.com/8881559755wwffmkddgvzw#f407ff
- Ana note invenio (static): https://sphenix-invenio.sdcc.bnl.gov/communities/sphenixcommunity/requests/4d3db087-9c2c-438b-b83b-9042750abdbc
- Code repo: https://github.com/tmengel/UE-AuAu-PPG04/
- Conference note:

BACKUP

Multiplicity driven fluctuations

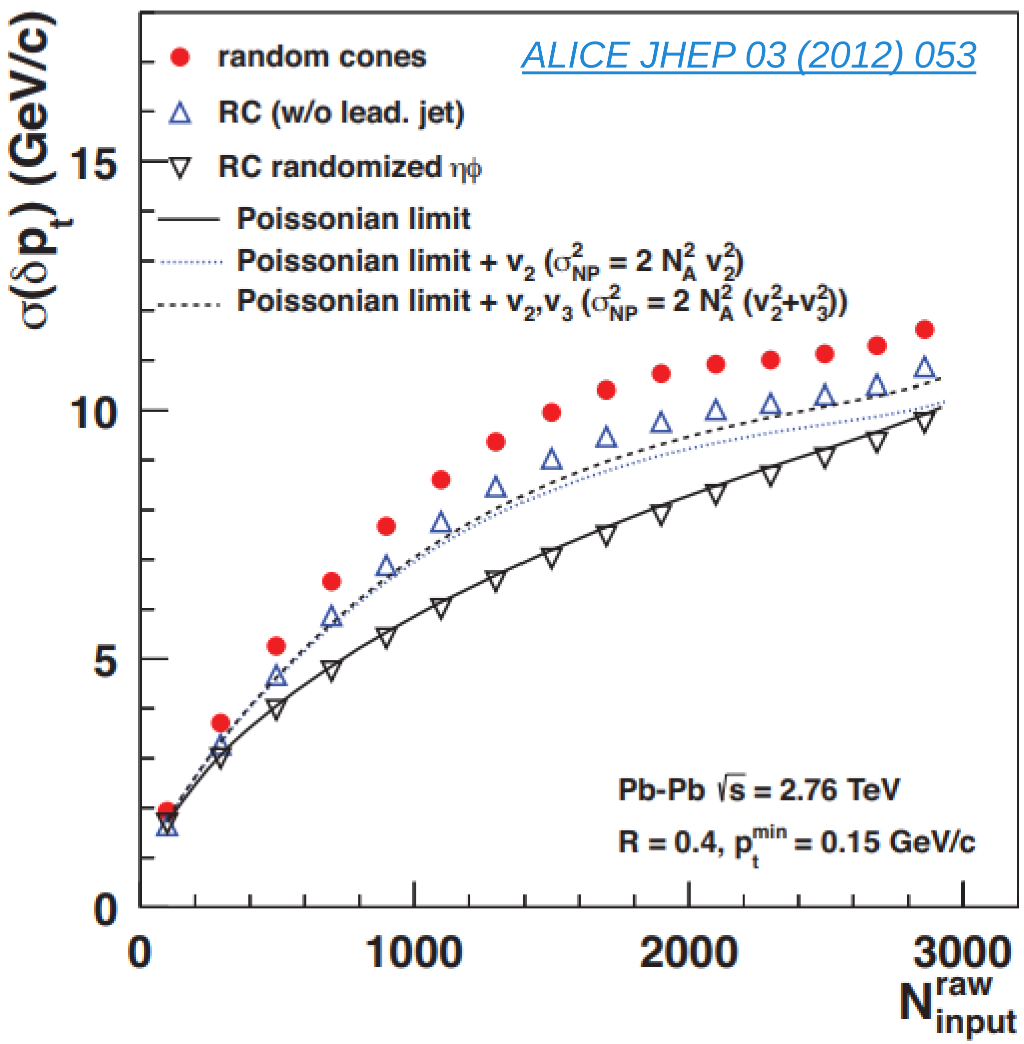
- UE fluctuations are well described by statistical and non-Poissonian multiplicity fluctuations

$$\sigma(\delta p_T) = \sqrt{N\sigma_{p_T}^2 + N\mu_{p_T}^2 + \sigma_{NP}^2}$$

- Background p_T in jets is multiplicity dependent

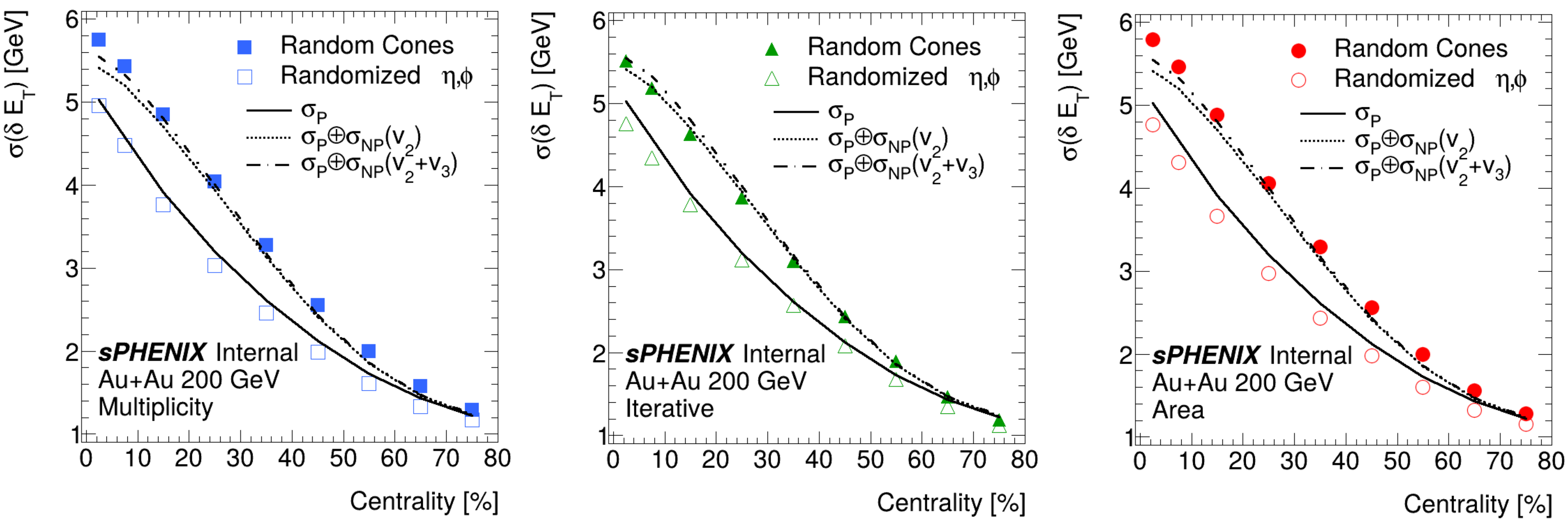
$$p_T^{UE} = \mu_{p_T} \cdot N \pm \mu_{p_T}\sqrt{2N}$$

$$p_T^{corr.} = p_T^{reco} - \langle p_T^{bkgd} \rangle \cdot N_{bkgd}$$



Comparisons between methods

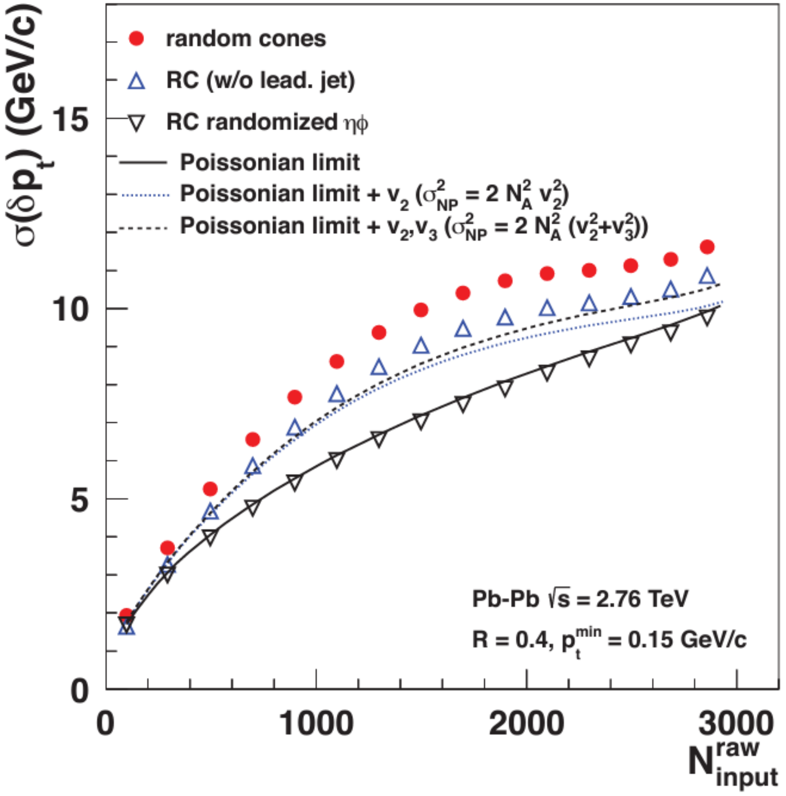
- All methods perform approximately the same, have similar pedestal value
- Iterative method is less dependent on flow contributions

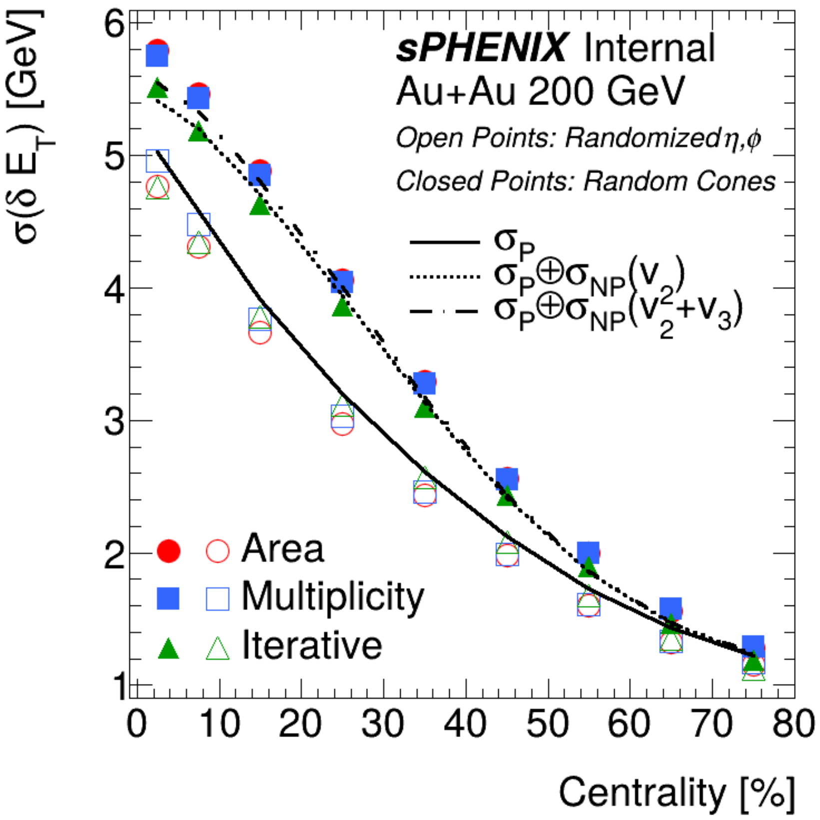


Fluctuations compared to LHC

- Similar increase due to flow contributions
- Same hierarchy between predicted standard deviation

ALICE JHEP 03 (2012) 053





Calo Windows

- Distributions of E_T^{nxm} for different window sizes
- E_T^{nxm} - Average is centered around zero
- EMCAL is the bulk of E_T^{nxm} - ZS is extremely important