Semi-inclsuive jet mass measurement in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV with STAR

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(Sejong University)

2025 Hot-Quarks

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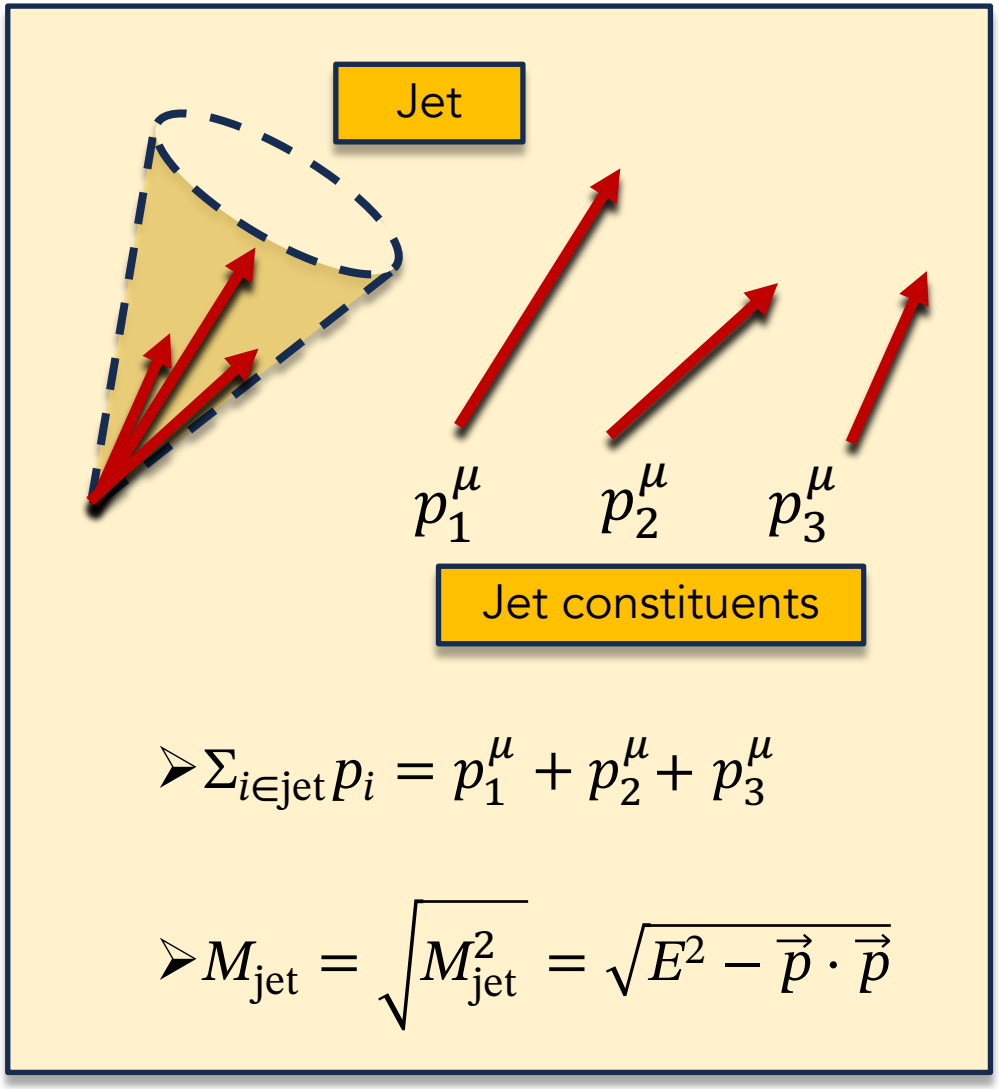
Zipeng Mountain Guangyuan International Conference Center

Jet and jet mass (M_{jet})

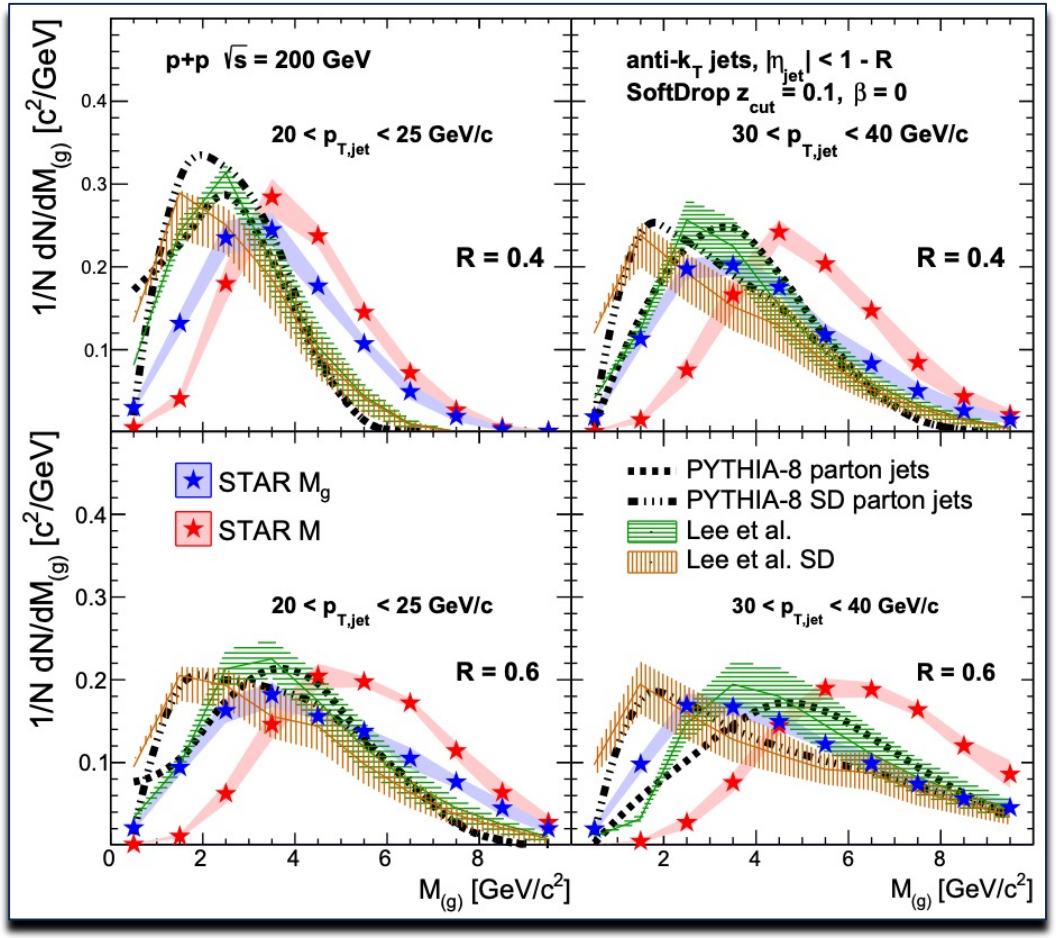
- Jet
  - Algorithmically clustered final state particles (bunch of stable hadrons)
  - Useful tool to study pQCD in *pp* collisions and properties of QGP in AA collisions
- How to calculate the Jet mass (M_{jet})?
  - $M_{\mathrm{jet}} = |\Sigma_{i\in\mathrm{jet}} p_i| = \sqrt{E^2 - \vec{p}\cdot\vec{p}}$



Jet and jet mass (M_{jet})

- Why do we measure M_{jet}?
  - Jet substructure
  - Largely correlated with parton virtuality evolution in both *pp* and AA (Sudakov peak in *pp*)
- Final goal of this study
  - Modification of parton virtuality evolution in AA
  - Measuring M_{jet} in wide $p_{\mathrm{T,jet}}$ range

STAR, Phys. Rev. D 104, 052007 (2021)



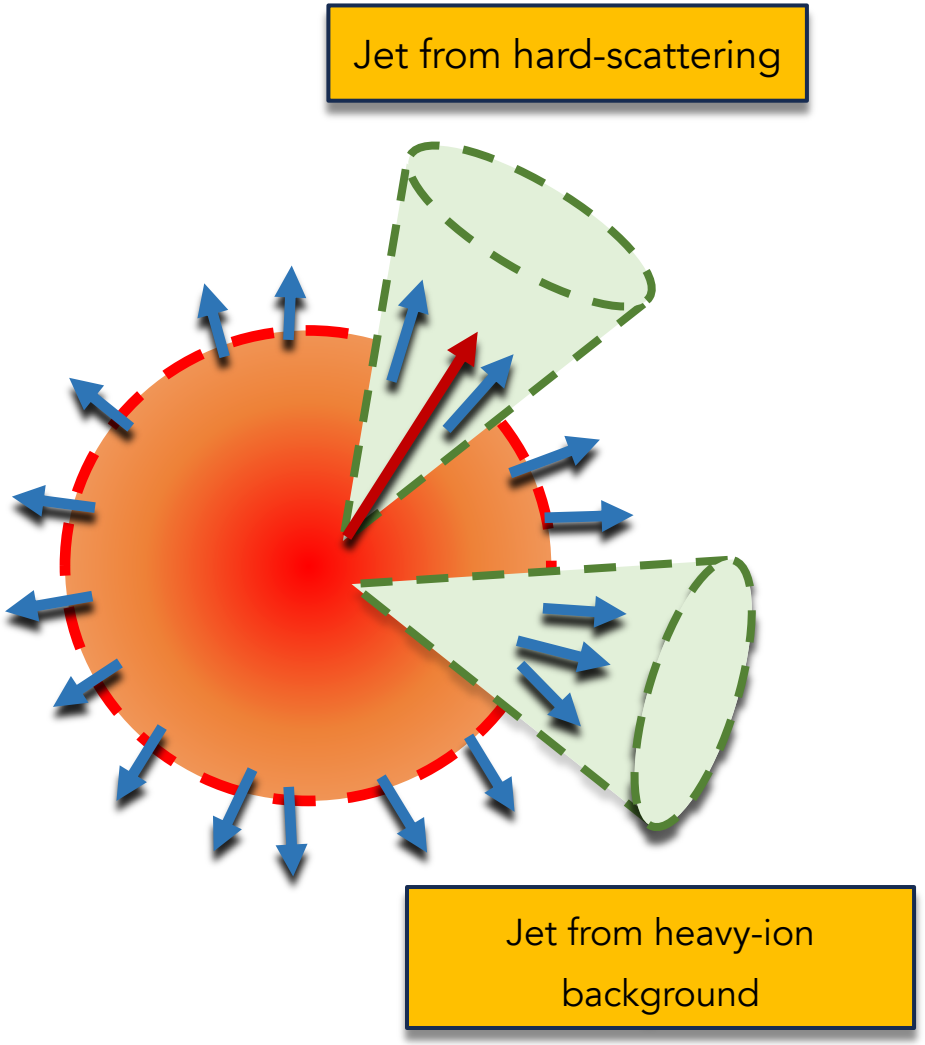
Difficulties of jet measurements in AA

➢ Combinatorial background

- Lage background particles uncorrelated with hard scattering are created in AA collisions
- We can't distinguish signal jets and background jets
- M_{jet} and $p_{T,jet}$ of signal jets are distorted due to the background particles

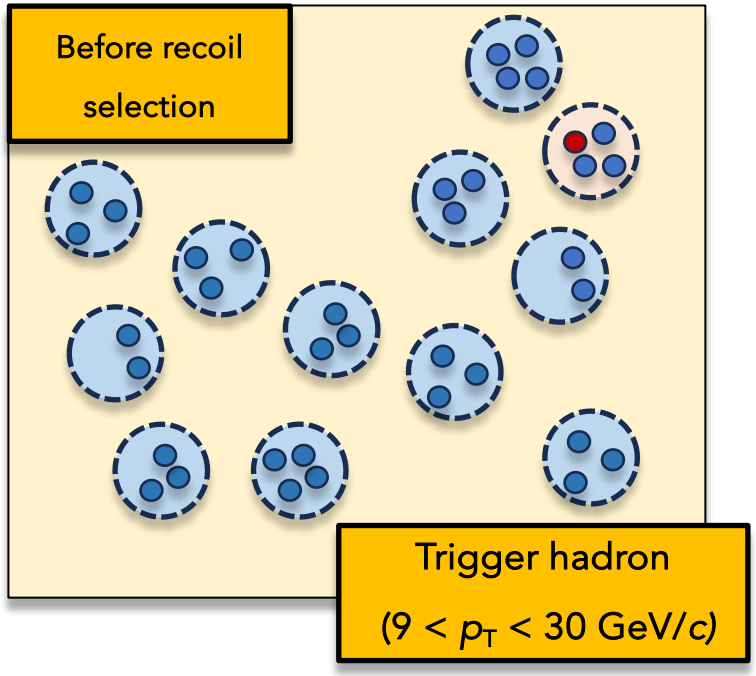
➢ Challenges

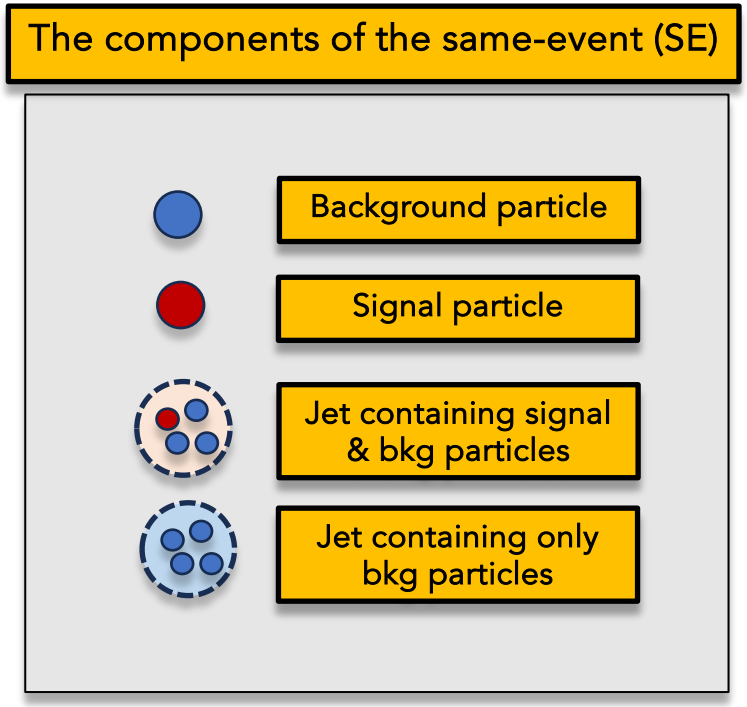
- **How do we subtract the contribution from background jets?**
- **How do we correct the distorted signal jets?**



Semi-inclusive recoil jets measurement

➢How do we subtract the contribution from background jets?

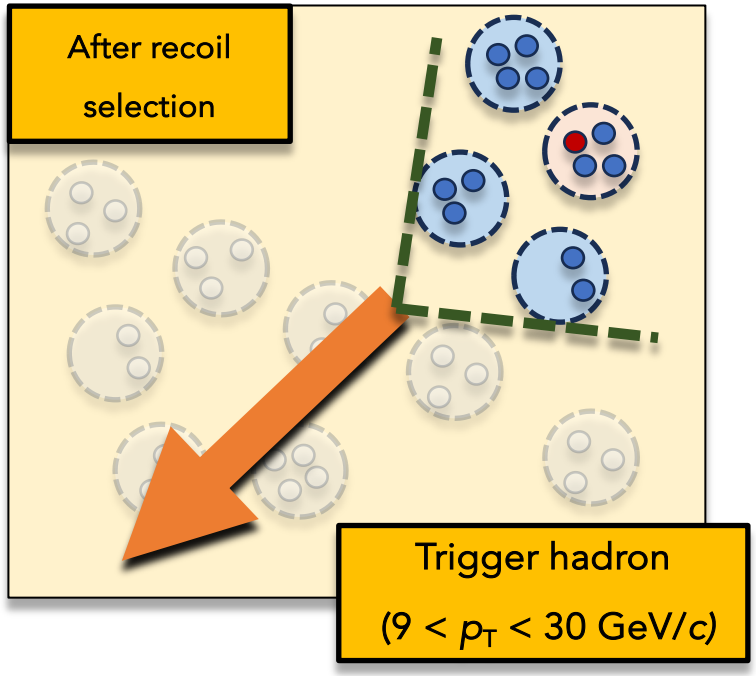


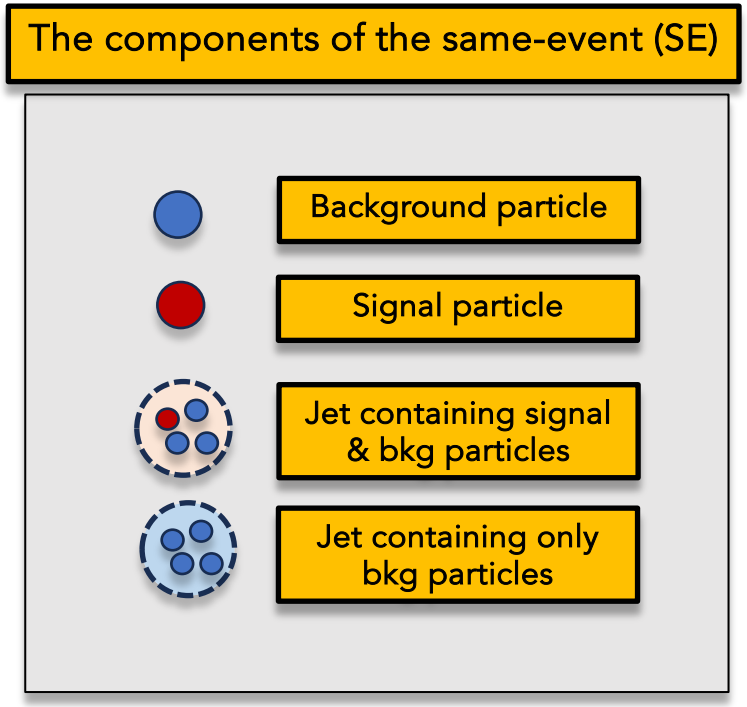


➢ We can't distinguish signal jets and background jets in experiment data

Semi-inclusive recoil jets measurement

➢How do we subtract the contribution from background jets?

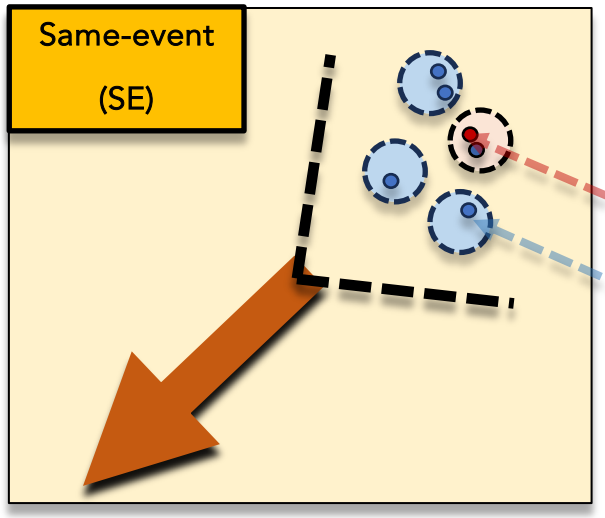




➢ Many of background jets can be easily discarded by selecting recoil-side jets from the hard trigger particle

Mixed-event technique

- Mixed-event technique can further remove the background jets
- Example :
  - A single high p_T (15 GeV/c) particle in each event
  - Then, ($p^{reco}_{T,jet}$) = 15$\pm\sigma$ GeV/c



- SE can be decomposed by two parts
  - SE = Smeared signal + bkg
  - We need to subtract bkg in SE

$p^{reco}_{T,jet}$ for example,

- SE = (Smeared signal) + (bkg in SE)
- SE – (bkg in SE) = (Smeared signal)
- But we don't know (bkg in SE)
- Can we make a proxy of (bkg in SE)?
  - Mixed-event (ME) technique

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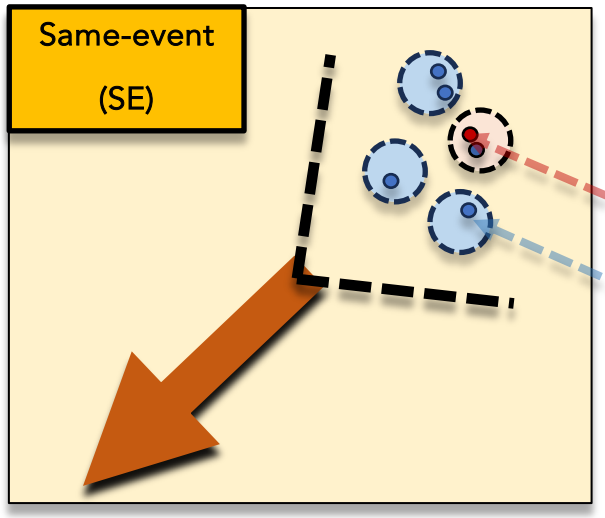

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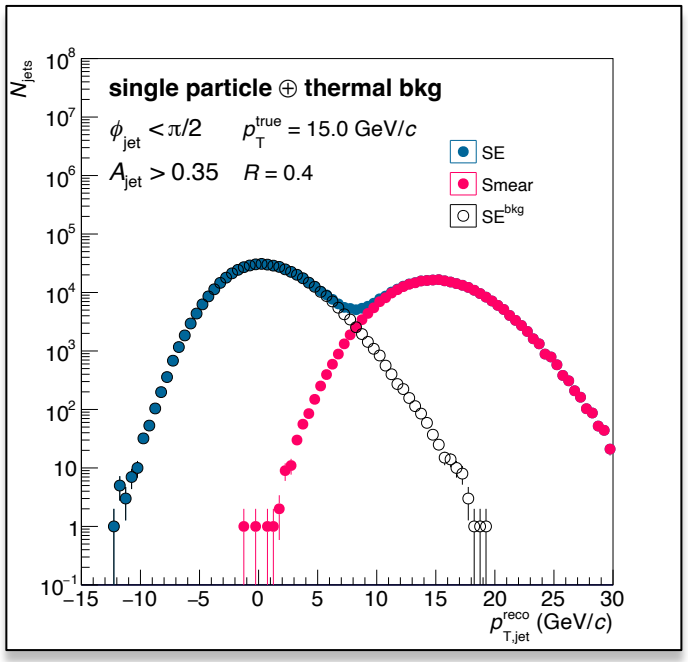

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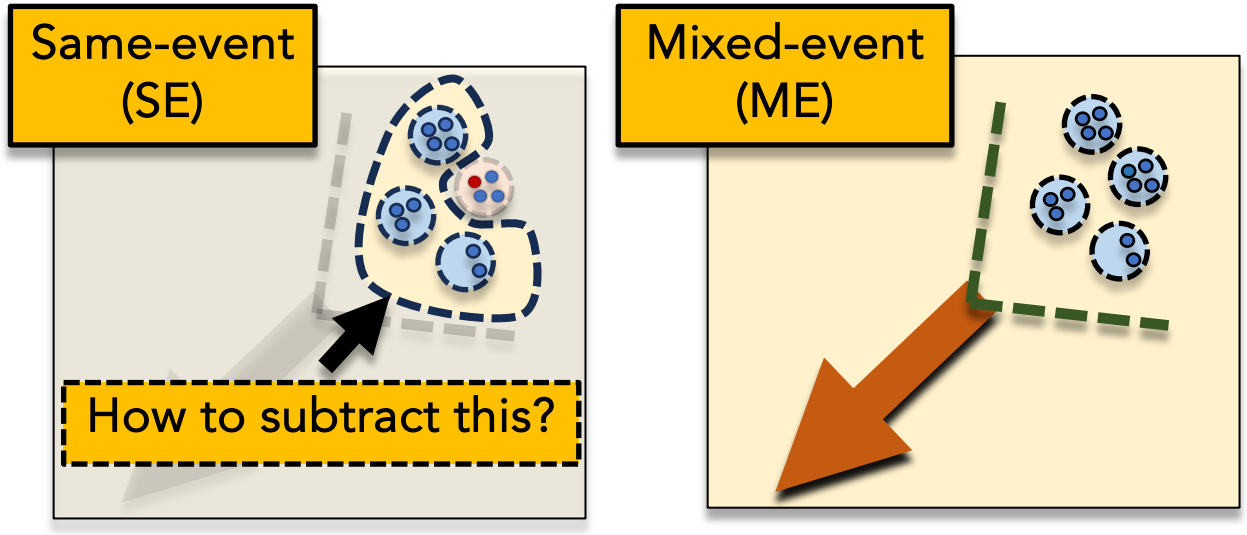
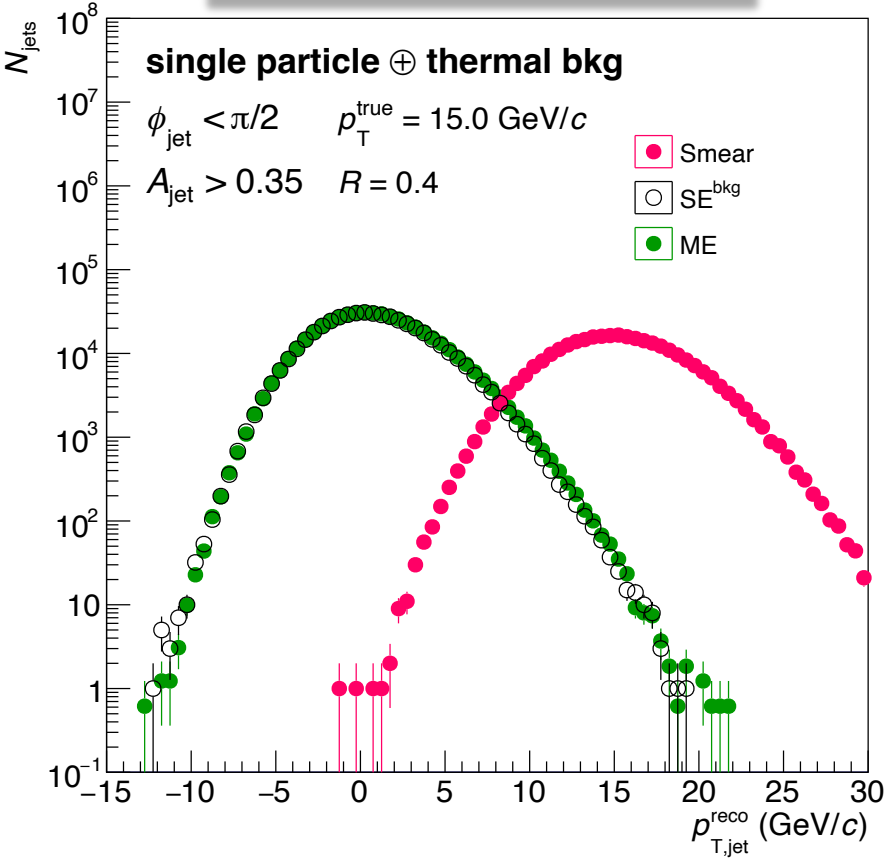
Mixed-event technique

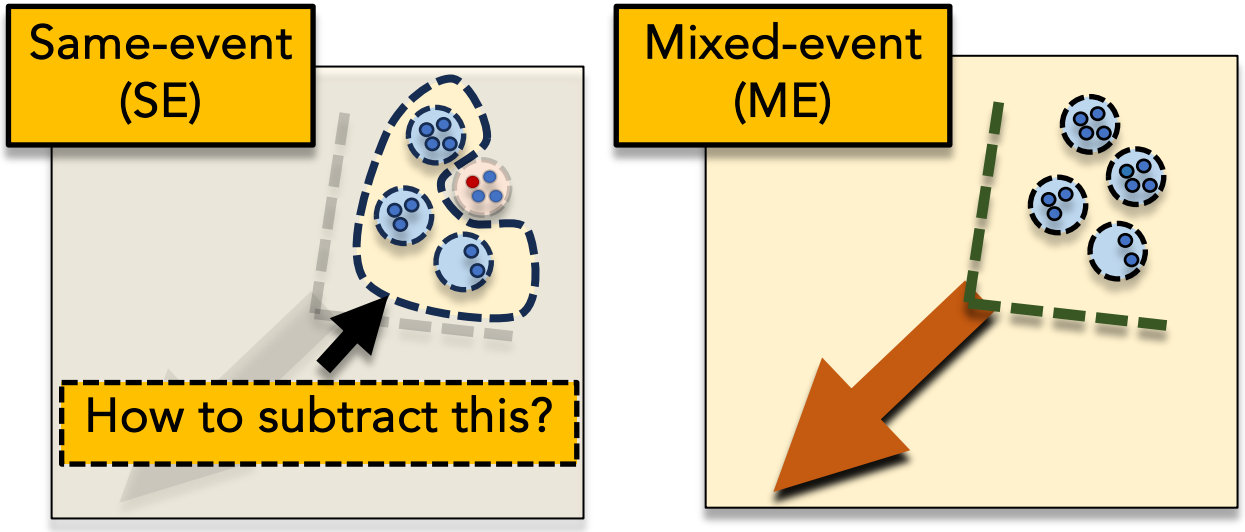


- Mixed-event
  - Data-driven method systematically combining events in the same class
  - ME ~ bkg in SE
- Yield corrected spectra (SE-ME)
  - Subtract ME instead of (bkg in SE) in ensembel level
  - SE-ME = (Smeared true) – (bkg in SE) – ME ~ (Smeared true)

(Bkg in SE) vs ME



Mixed-event technique



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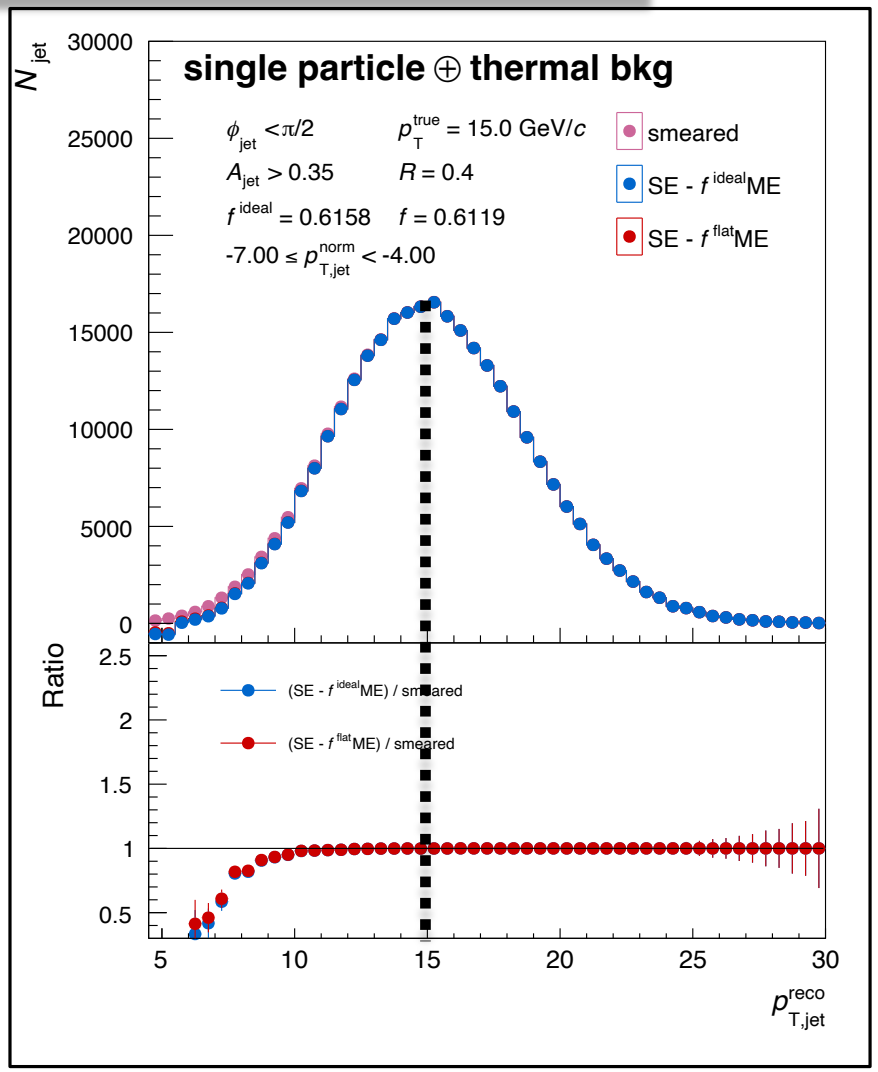
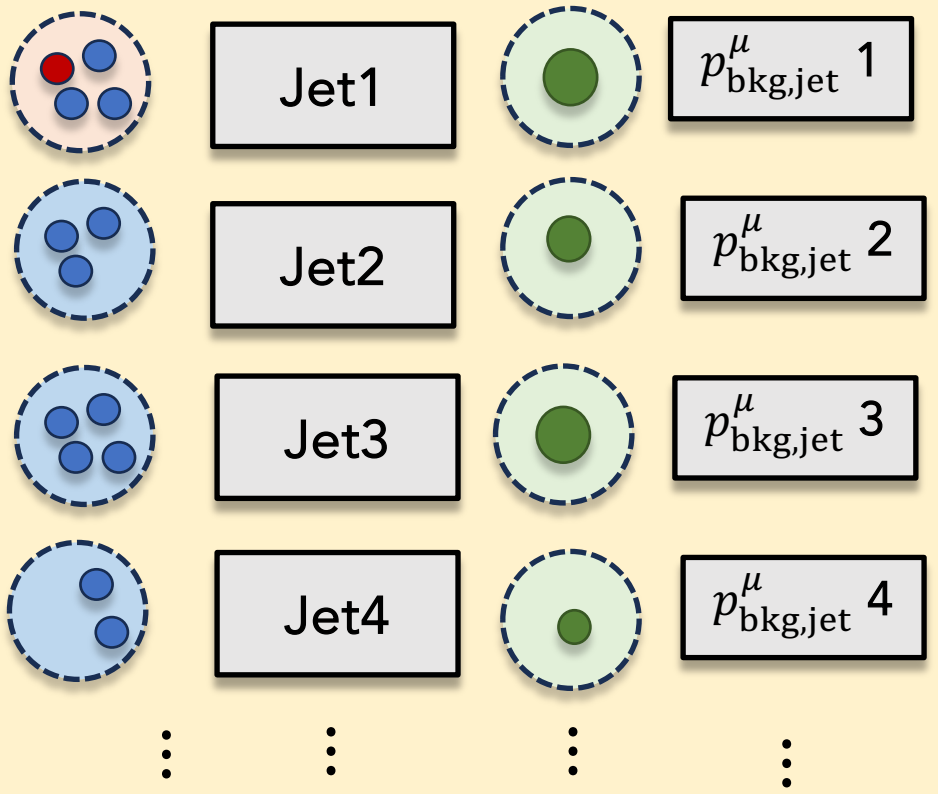
(SE-ME) vs Smeared true



Uncorrelated background effect

➢How do we correct the distorted signal jets?

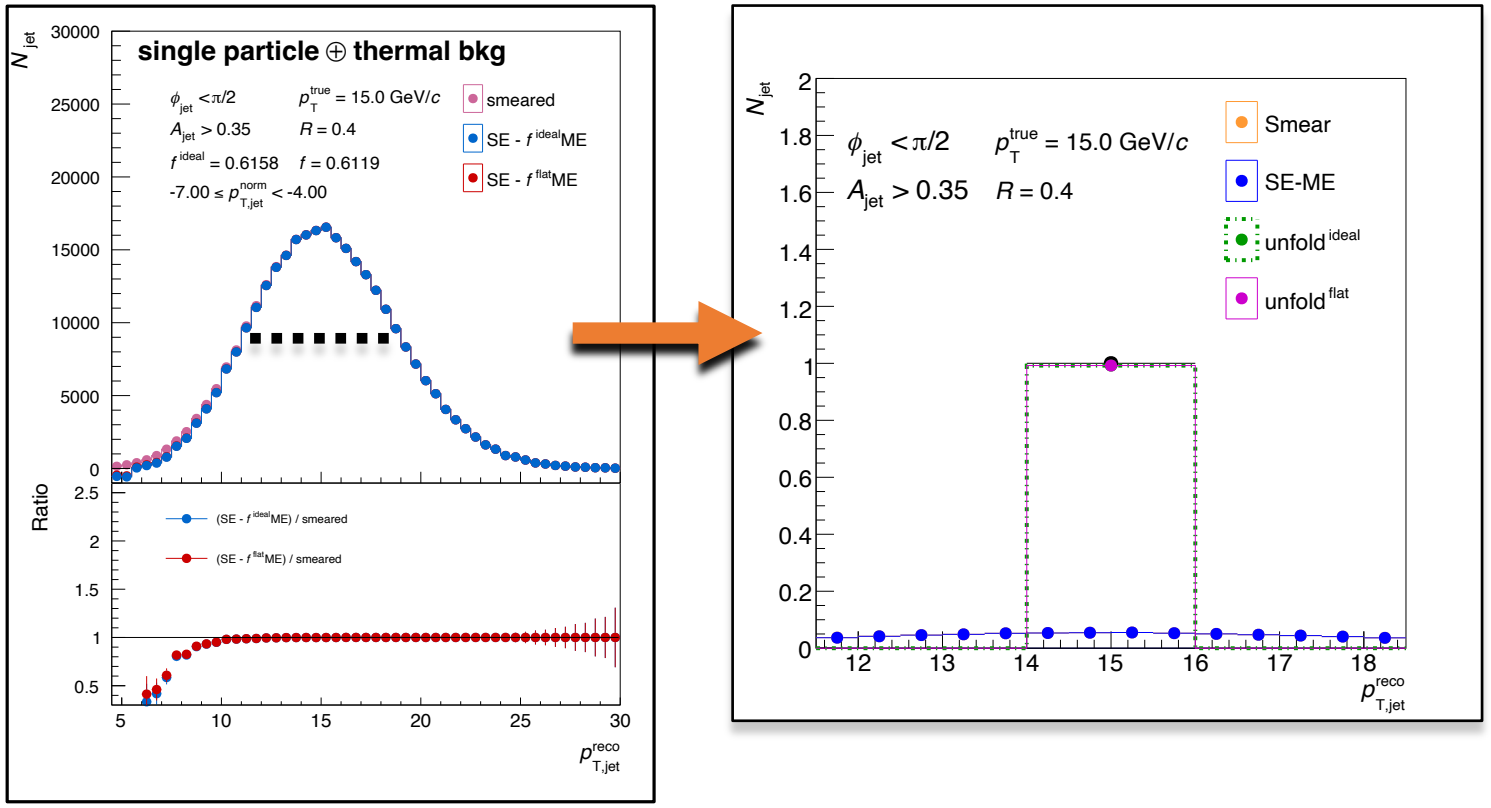
Each jet has it's own background jet 4-vector



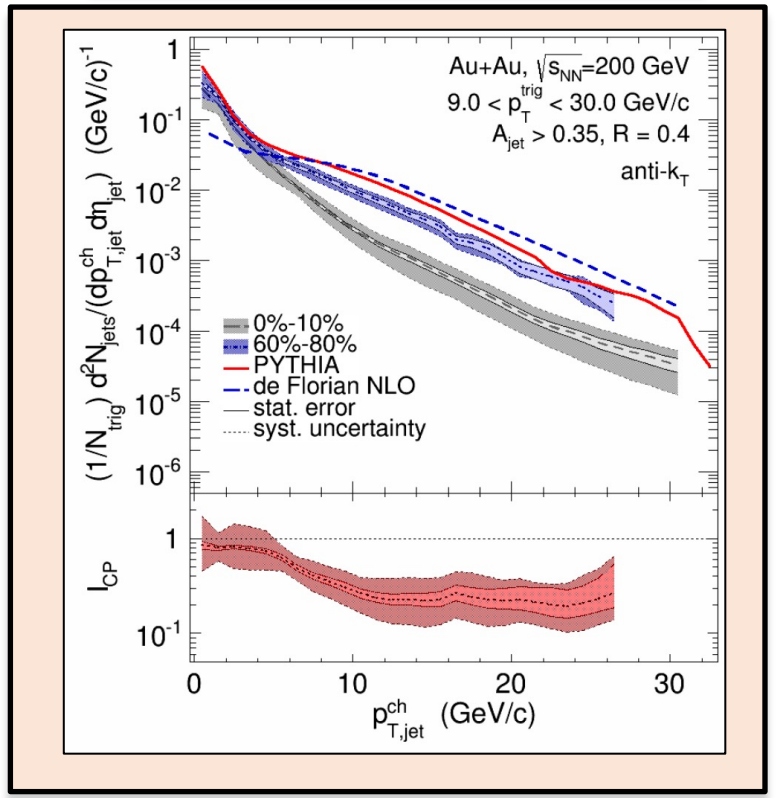
- Jet reconstruction has been applied in event-by-event
- Proxy of background jet four-vector $(p^{\mu}_{\mathrm{bkg,jet}})$
  - Calculated by $p_{\mathrm{T,jet}}$ and $m_{\mathrm{T,jet}}$ density (ρ, ρ_m) based on median value estimation
- Reconstructed $p_{\mathrm{T,jet}}$ and M_{jet} $(p^{\mathrm{reco}}_{\mathrm{T,jet}}, M^{\mathrm{reco}}_{\mathrm{jet}})$
  - $p^{\mathrm{reco}}_{\mathrm{T,jet}} = p^{\mathrm{raw}}_{\mathrm{T,jet}}$ - ($p_{\mathrm{T,jet}}$ of $p^{\mu}_{\mathrm{bkg,jet}}$) $= p^{\mathrm{raw}}_{\mathrm{T,jet}} - \rho A_{\mathrm{jet}}$
  - $M^{\mathrm{reco}}_{\mathrm{jet}} = M^{\mathrm{raw}}_{\mathrm{jet}}$ - (M_{jet} of $p^{\mu}_{\mathrm{bkg,jet}}$) $= M^{\mathrm{raw}}_{\mathrm{jet}} - M_{\mathrm{c}}$ (?)
- Smearing effect (uncorrelated background effect)
  - $M^{\mathrm{reco}}_{\mathrm{jet}} = M^{\mathrm{signal}}_{\mathrm{jet}} \pm \sigma_{M_{\mathrm{jet}}}$
  - $p^{\mathrm{reco}}_{\mathrm{T,jet}} = p^{\mathrm{signal}}_{\mathrm{T,jet}} \pm \sigma_{p_{\mathrm{T}}}$

Unfolding

➢How do we correct the distorted signal jets?



Previous $p_{T,jet}$ measurement with this analysis chain



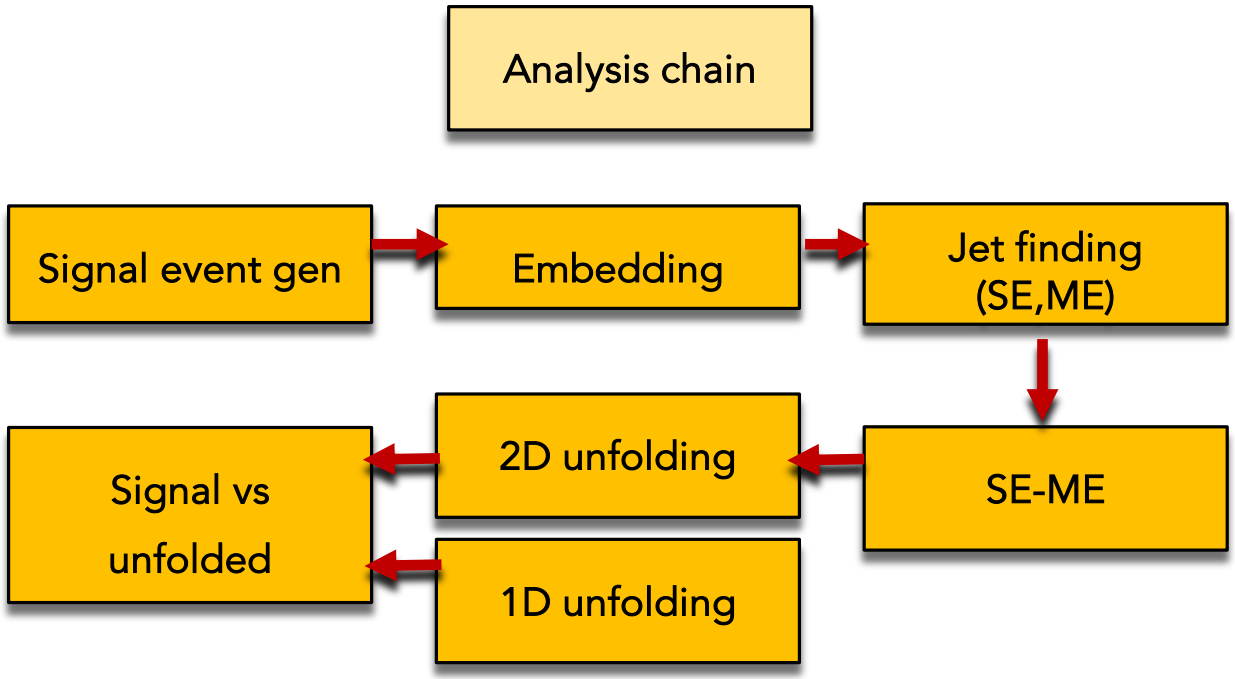
➢ Correction of uncorrelated background effect using RooUnfold package

➢ Response matrix $R^{\mathrm{bkg}}(p_{\mathrm{T,jet}}^{\mathrm{reco}}, p_{\mathrm{T,jet}}^{\mathrm{signal}}) = R^{\mathrm{bkg}}(p_{\mathrm{T,jet}}^{\mathrm{reco}}, 15\ \mathrm{GeV}/c)$

➢ STAR, Phys. Rev. C 96, 024905 (2017)

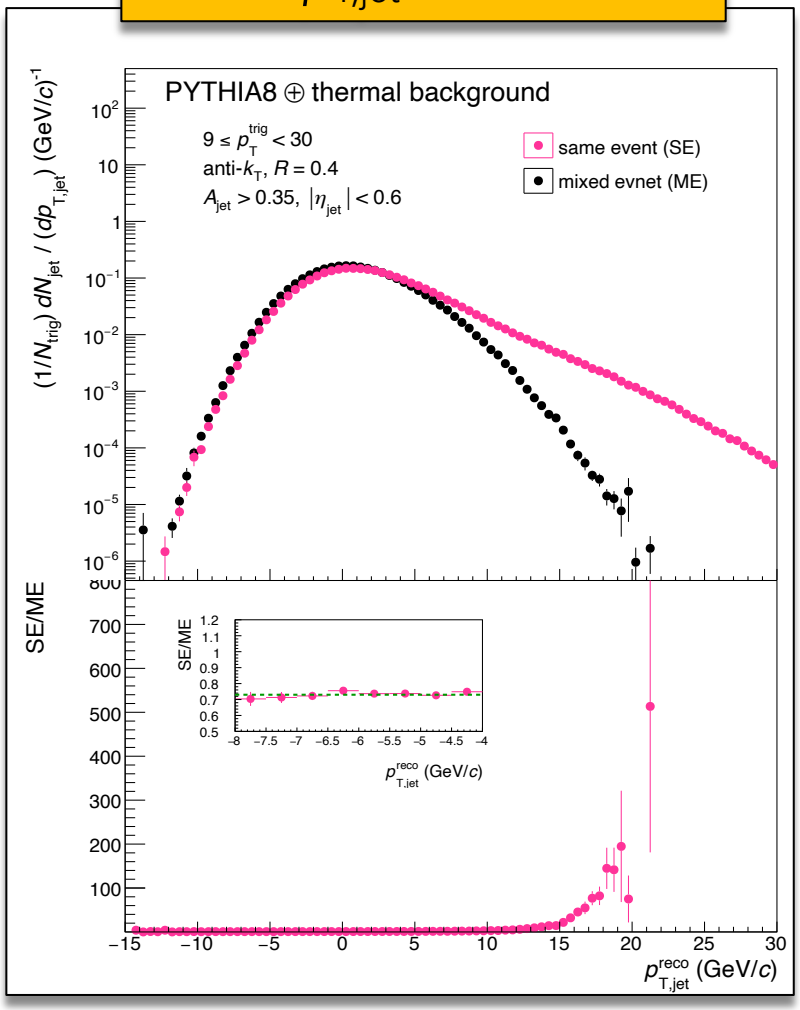
Closure test for ($p_{T,jet}$,M_{jet}) measurement

- Semi-inclusive jet mass measurement with ME technique
  - Extension of previous $p_{T,jet}$ measurement
  - $p_{T,jet}$ to ($p_{T,jet}$, M_{jet}) measurement
- MC closure test
  - PYTHIA events are embedded to thermal background model and tested

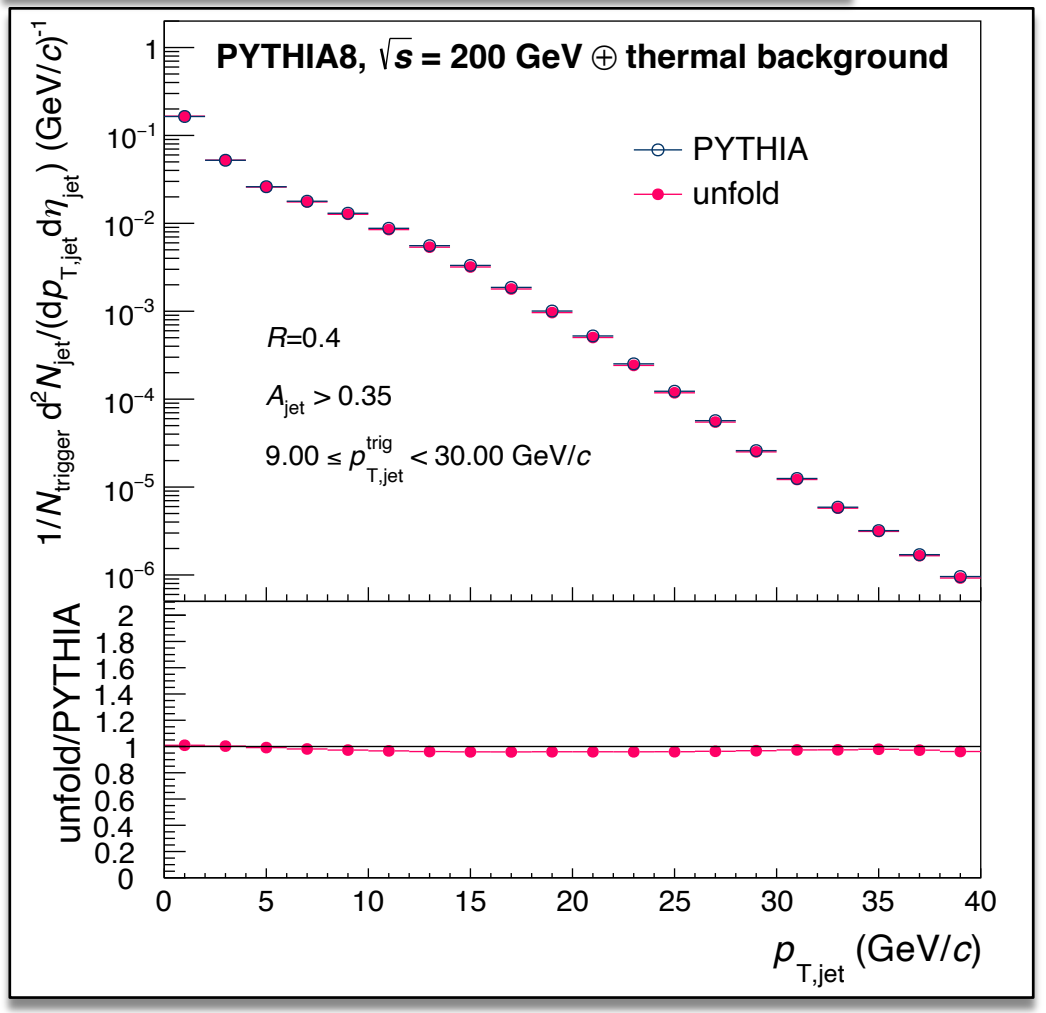


$p_{T,jet}$ closure test result

➢ Raw $p_{T,jet}$ distribution



➢ Fully corrected $p_{T,jet}$ distribution



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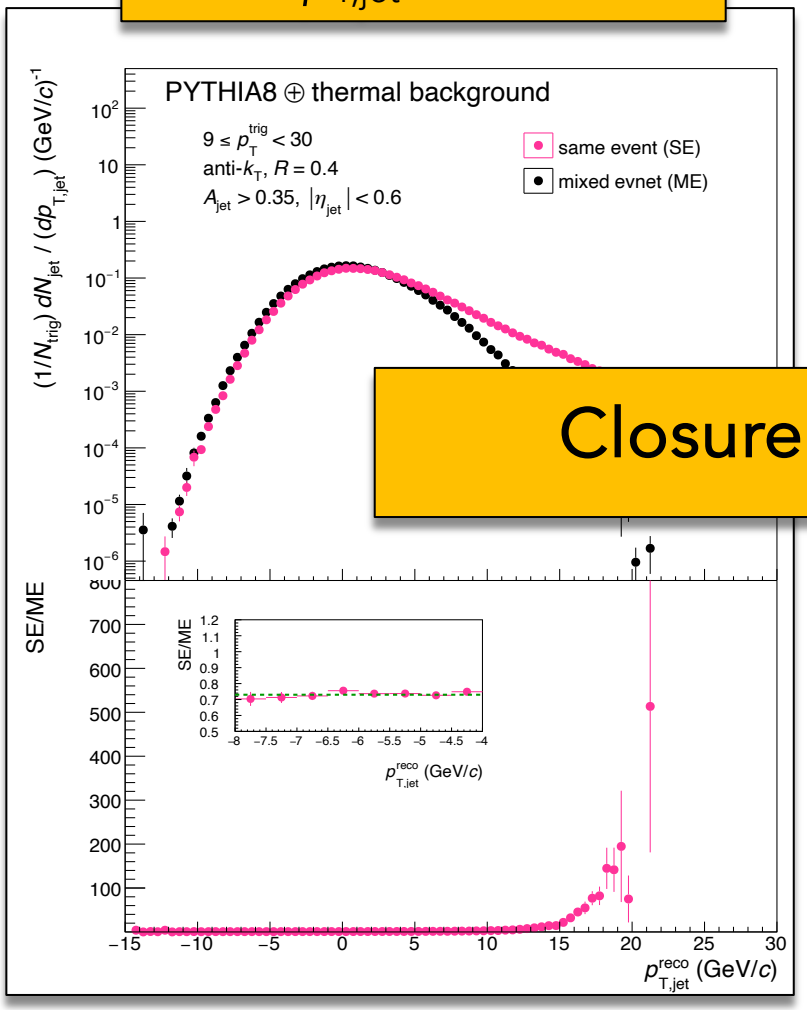

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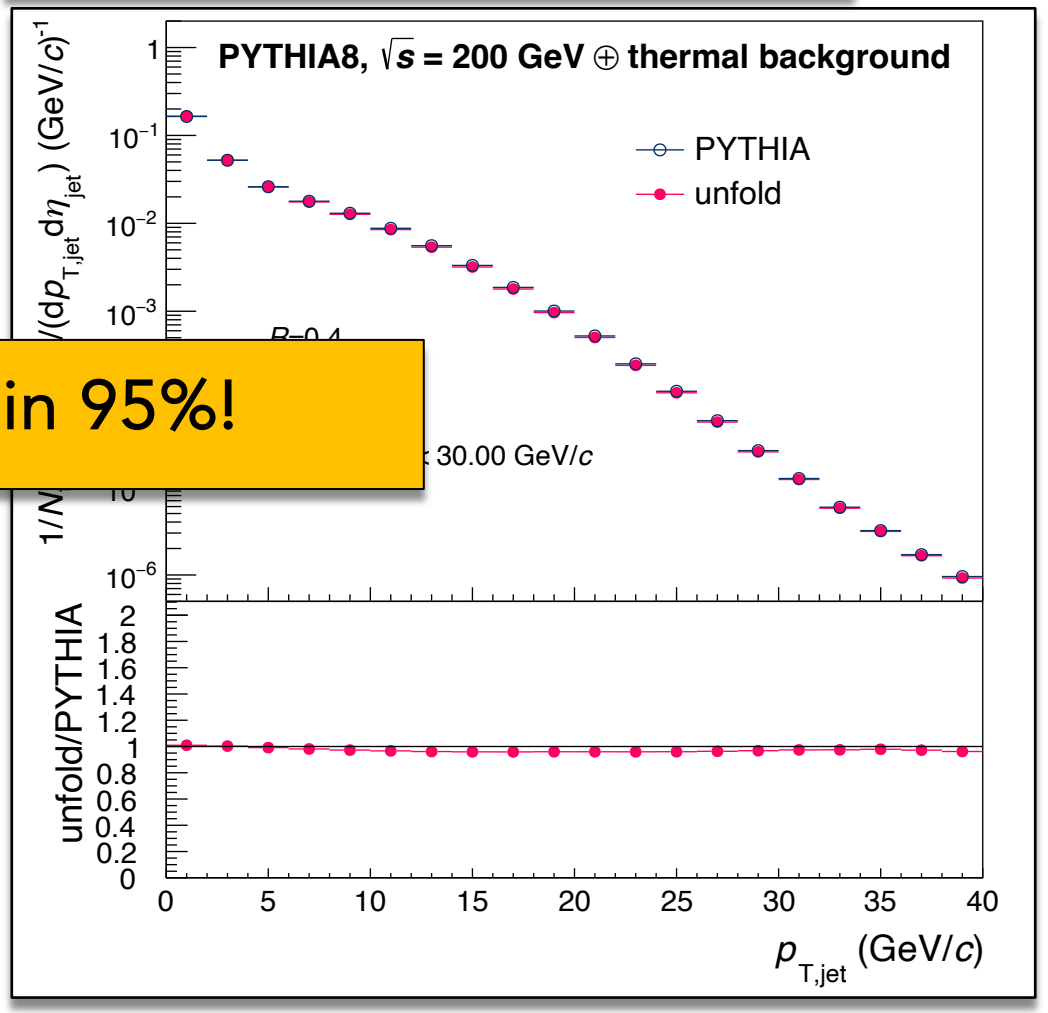
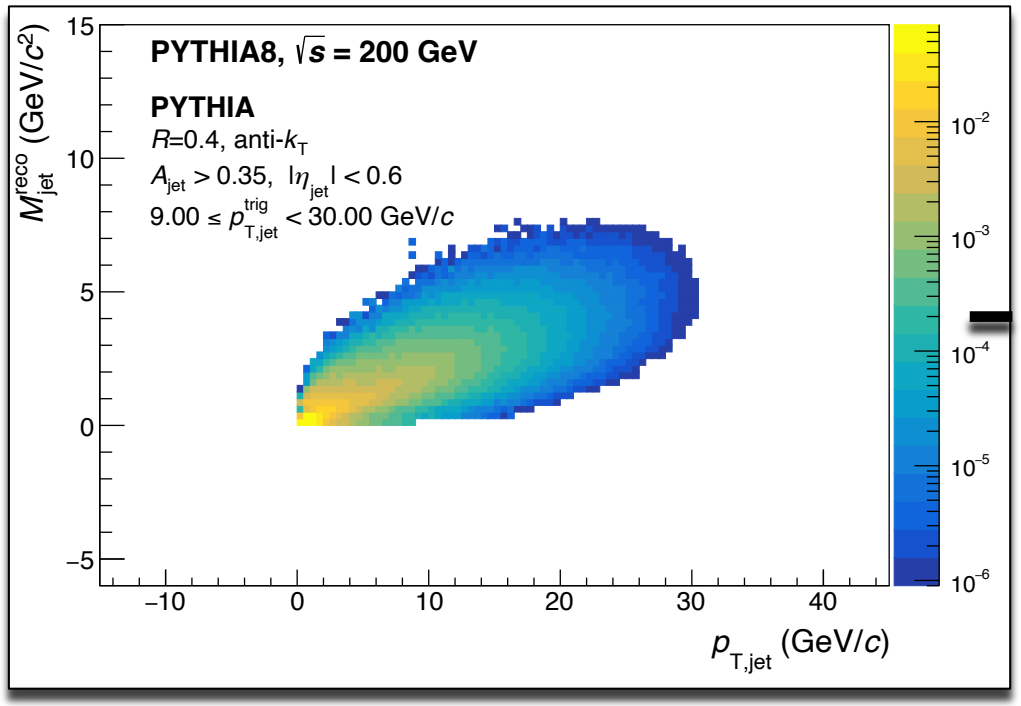


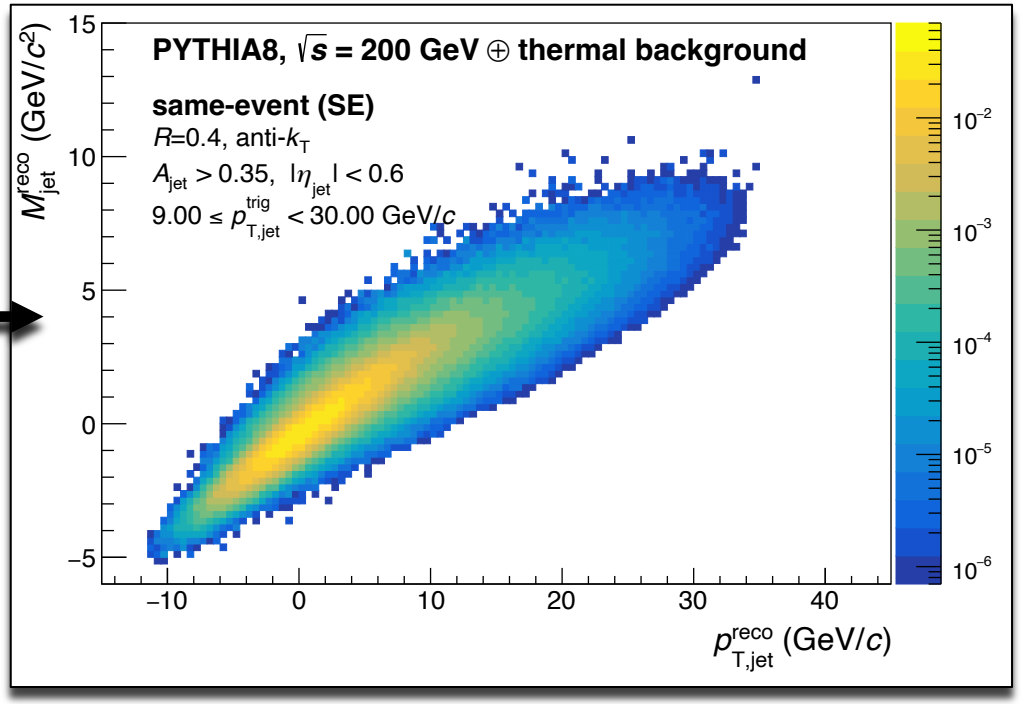
Closure within 95%!

M_{jet} Closure test result (PYTHIA and SE)

Signal (PYTHIA)



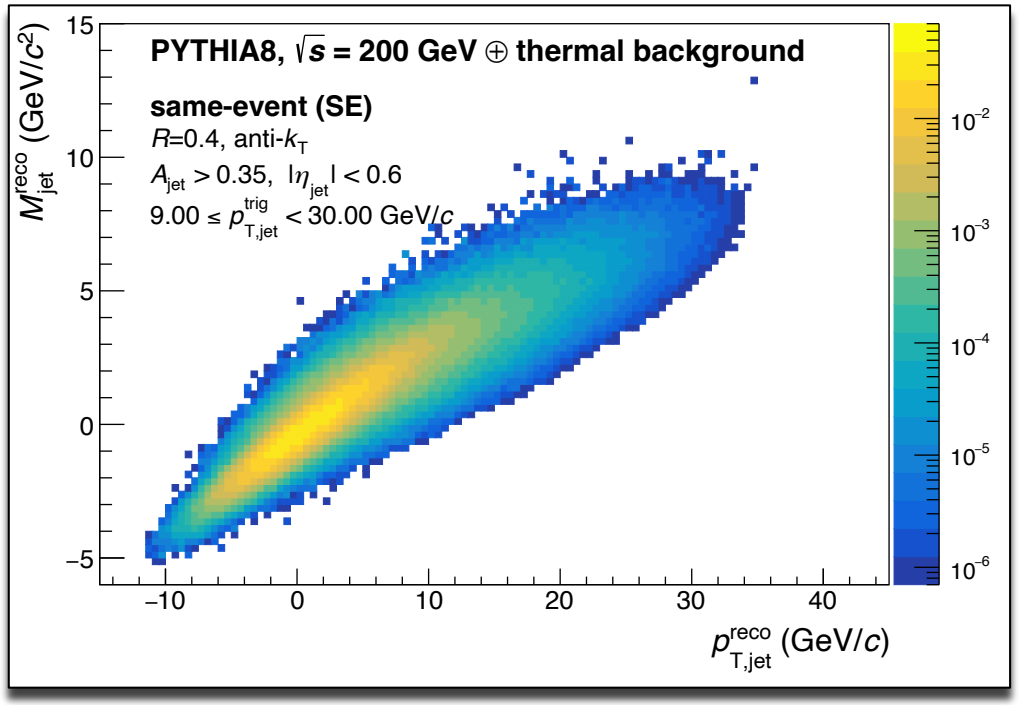
Smeared signal + bkg



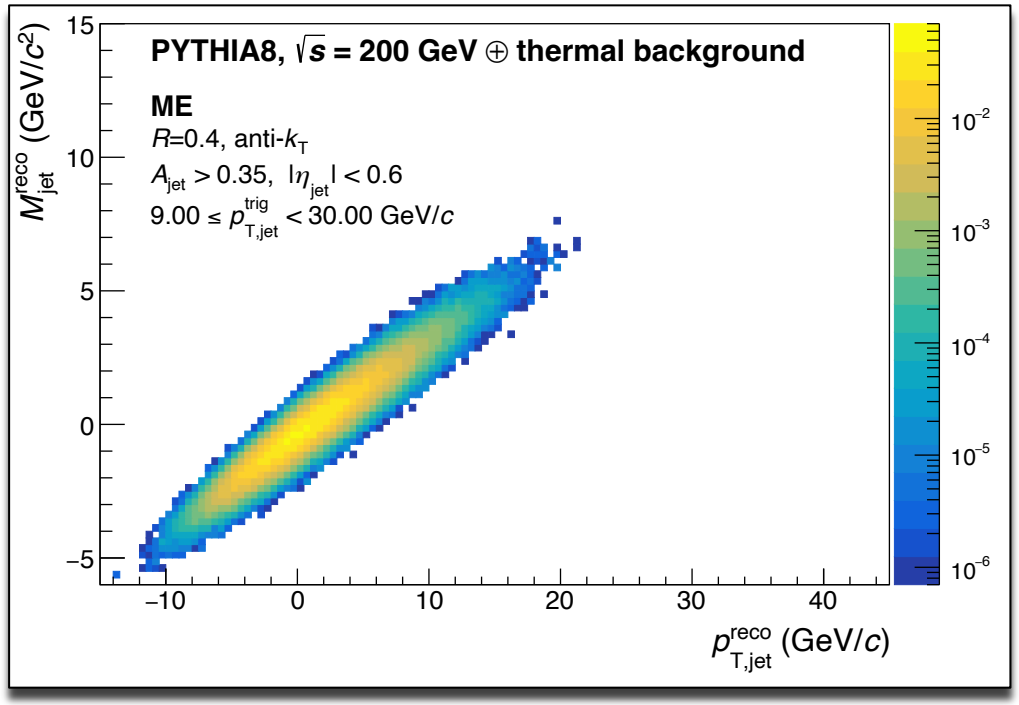
1. Signal distribution (PYTHIA) was distorted by bkg
2. Distorted PYTHIA was hidden in SE
3. SE-ME (subtract bkg in SE)
4. (SE-ME) -> Unfolding -> PYTHIA

M_{jet} Closure test result (SE and ME)

Same-event (Smeared signal + bkg)



Mixed-event (bkg)



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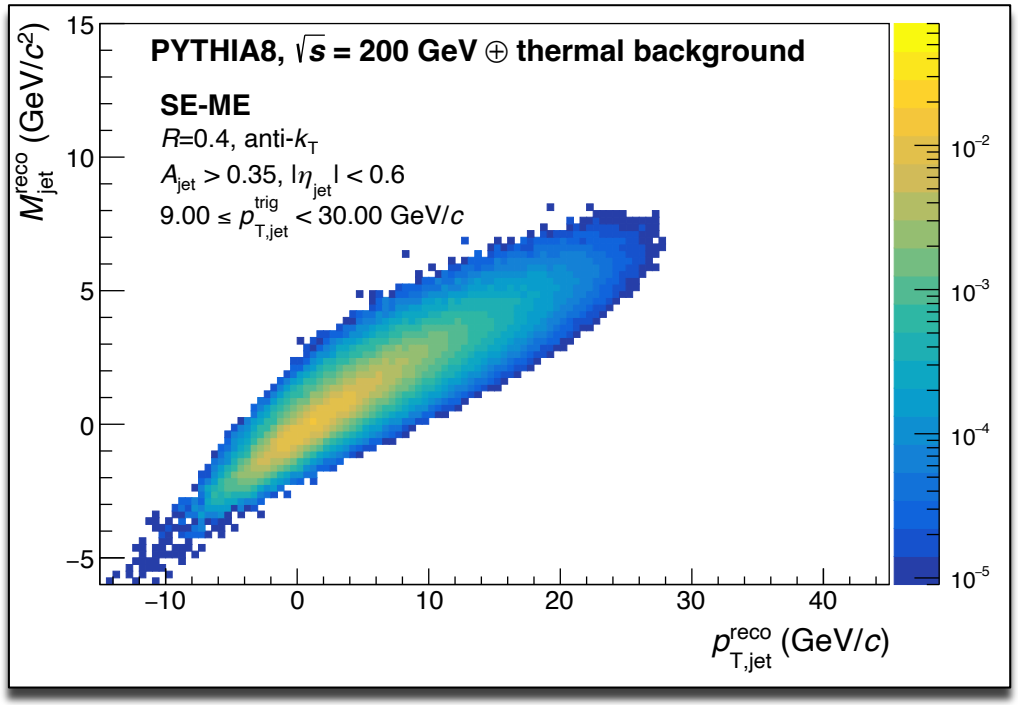
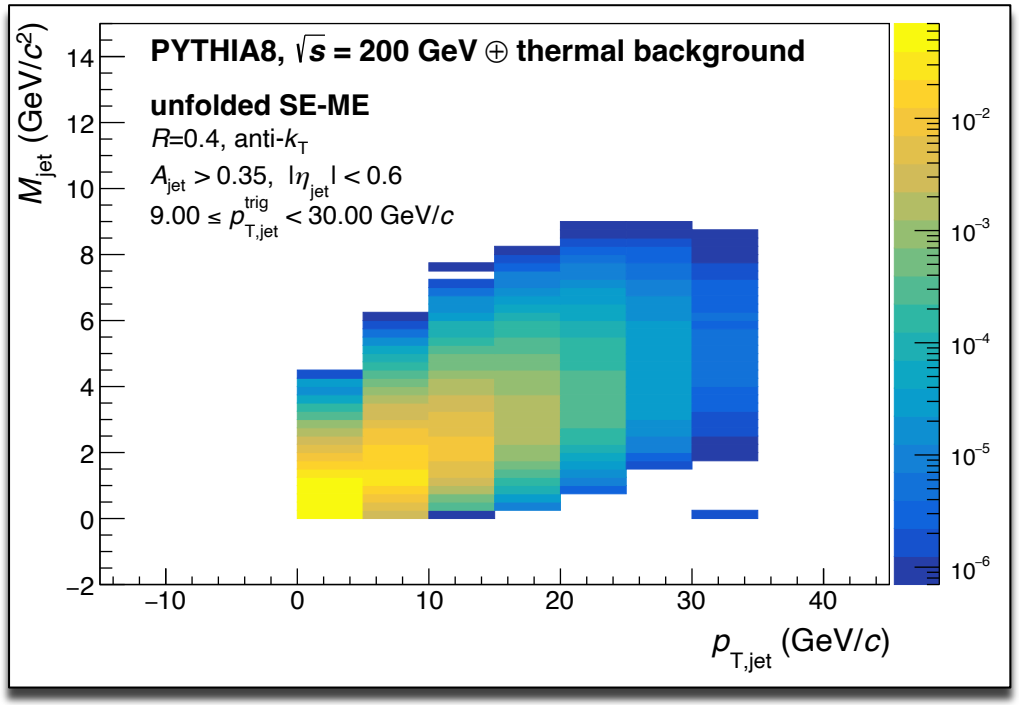
M_{jet} Closure test result (SE-ME and unfolded)

(SE-ME)~Smeared signal



Unfolded



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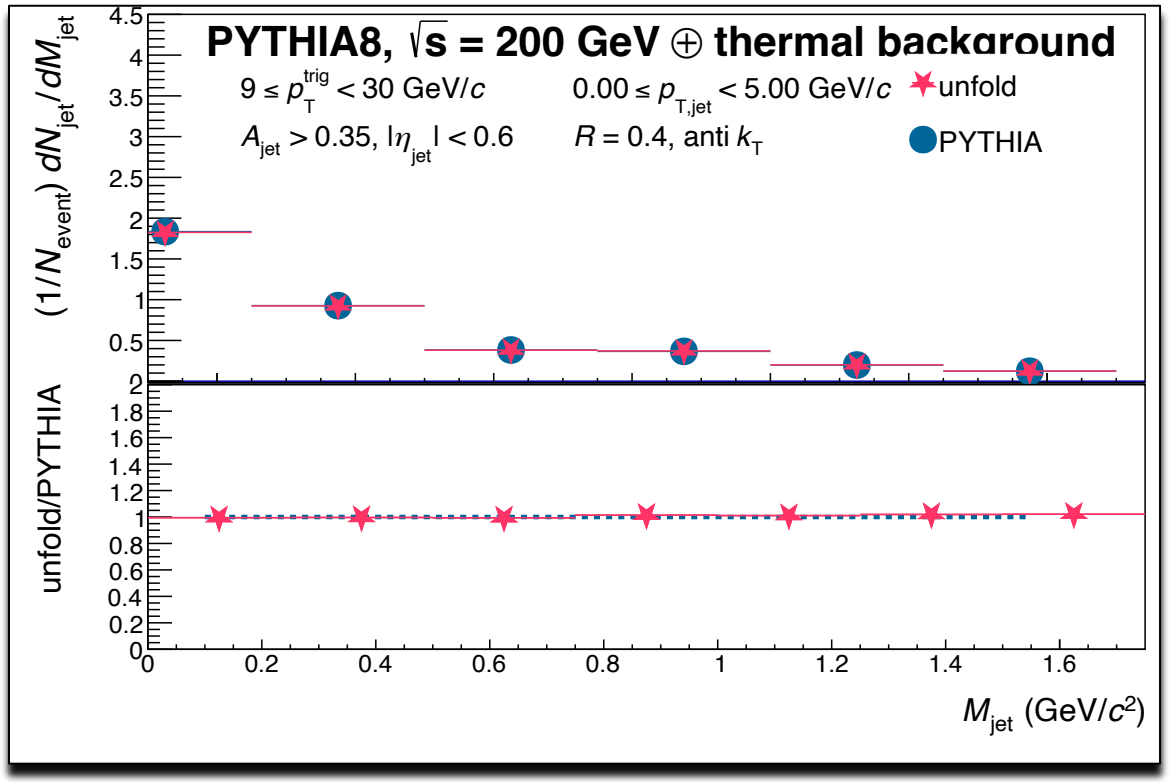
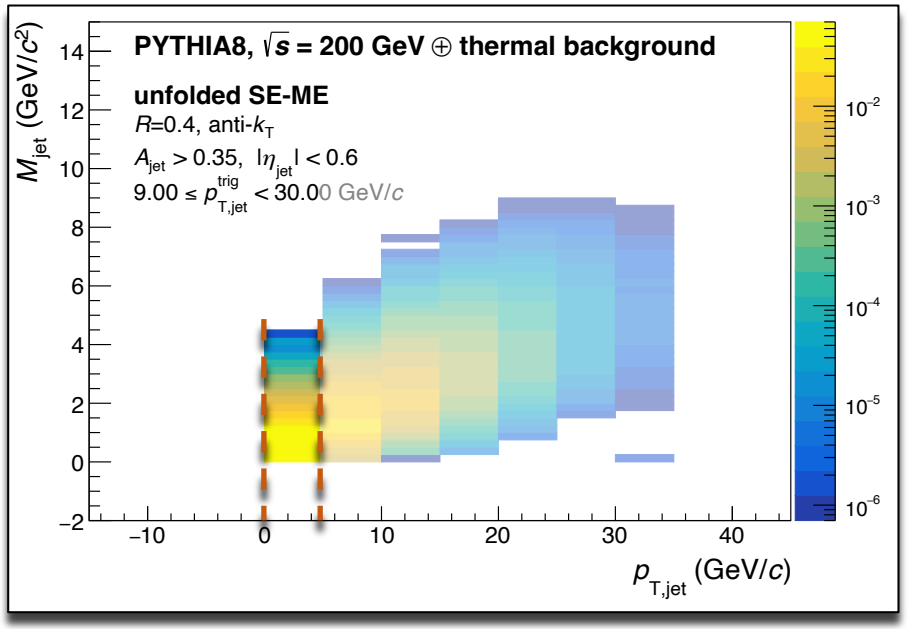
M_{jet} closure test result (PYTHIA vs unfold)

➢ Fully corrected M_{jet} spectra





Closure within 95%!

➢ Projection into M_{jet} integrate several $p_{\text{T,jet}}$ bin

- [0,5] GeV/c (PYTHIA ~ unfold)
- [5,10] GeV/c (PYTHIA ~ unfold)
- [10,30] GeVc (PYTHIA ~ unfold)

M_{jet} closure test result (PYTHIA vs unfold)

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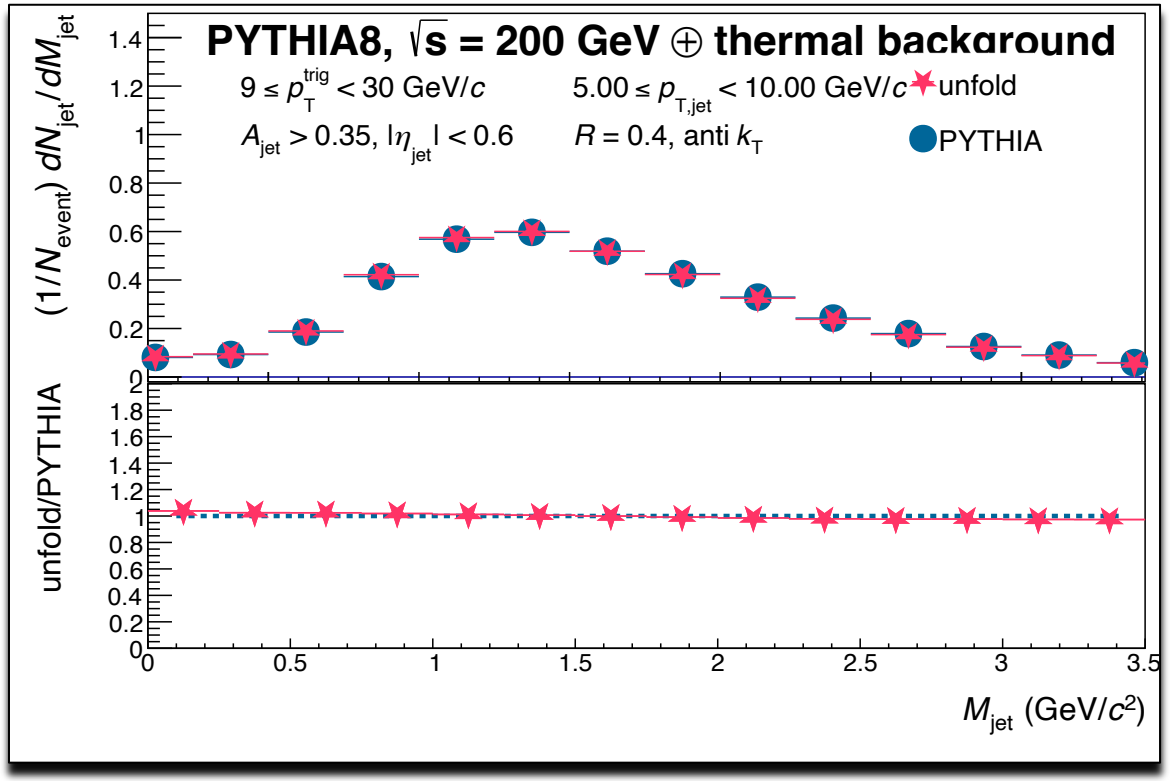

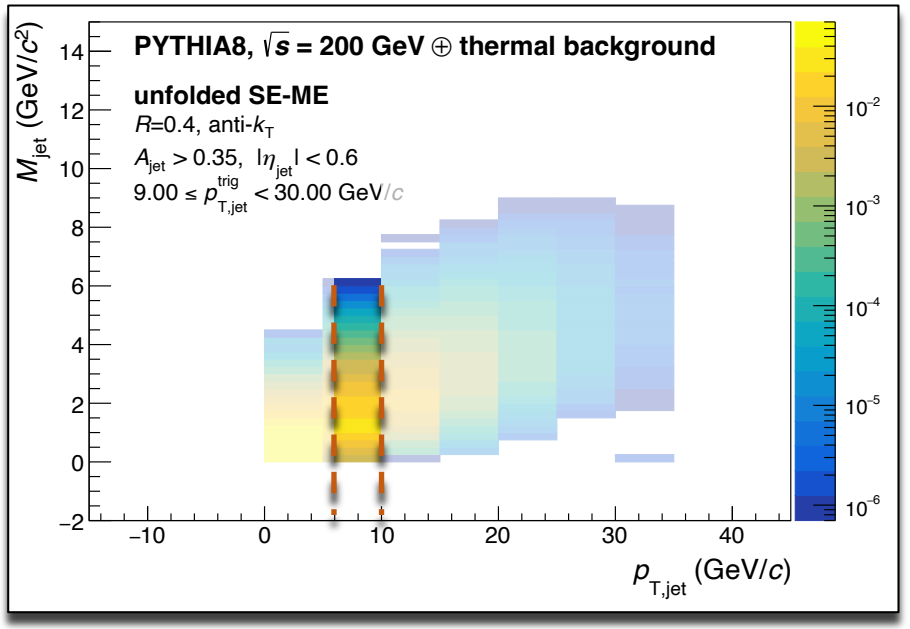

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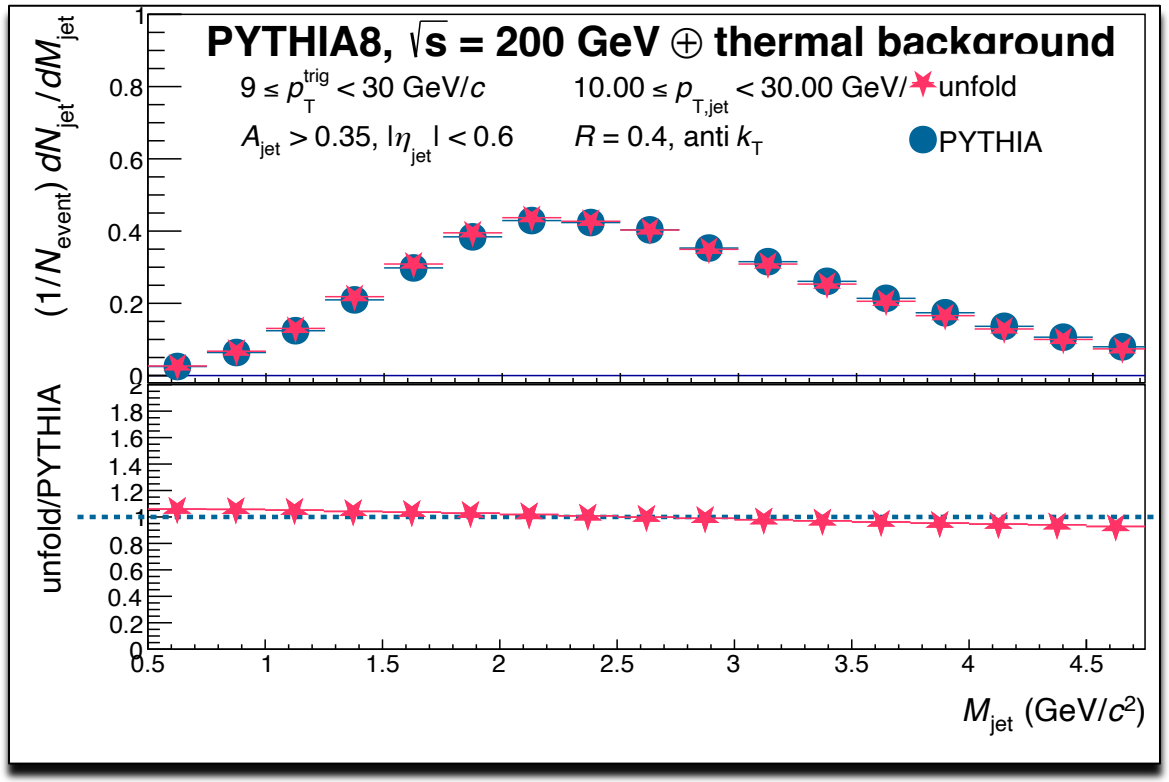

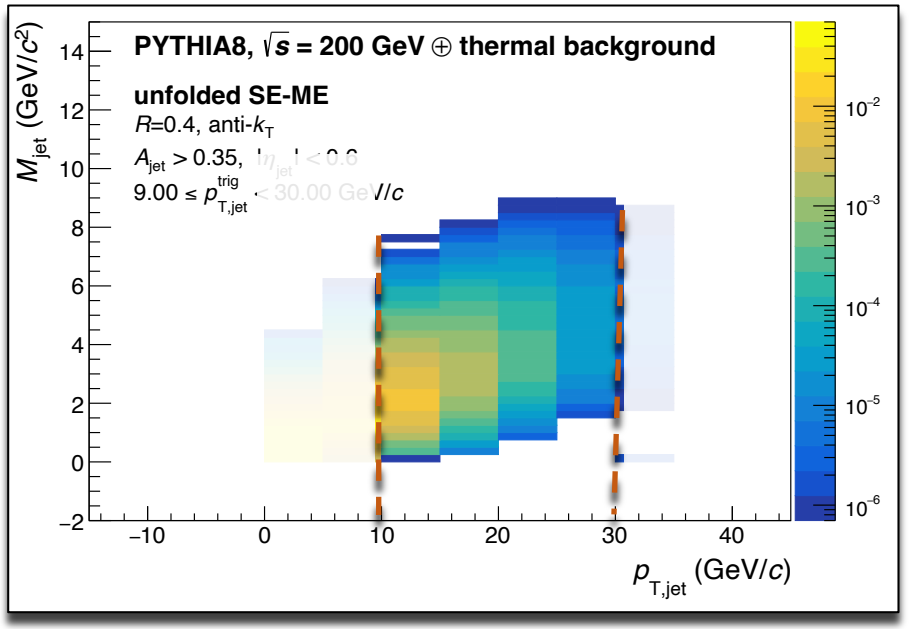

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Summary

- Jet is a useful tool to study QGP and we can access to the parton virtuality evolution in AA by measuring precise jet mass in heavy-ion collisions
- As a correction of combinatorial background for jet mass measurement, framewrok of semi-inclusive measurement as a function of ($p_{T,jet}$, M_{jet}) is developed and tested via PYTHIA embedding
- Both $p_{T,jet}$, M_{jet} closure tests are showing reasonable closure result
- Next step
  - Apply to the data (200 GeV Au+Au collisions with STAR collaboration)

감사 합니다

thank you