A BACKGROUND ESTIMATOR FOR JET STUDIES IN P+P AND A+A COLLISIONS

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[Yacine Mehtar-Tani, ASO, Marta Verweij arXiv:1904.12815]

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BROOKHAVEN NATIONAL LABORATORY

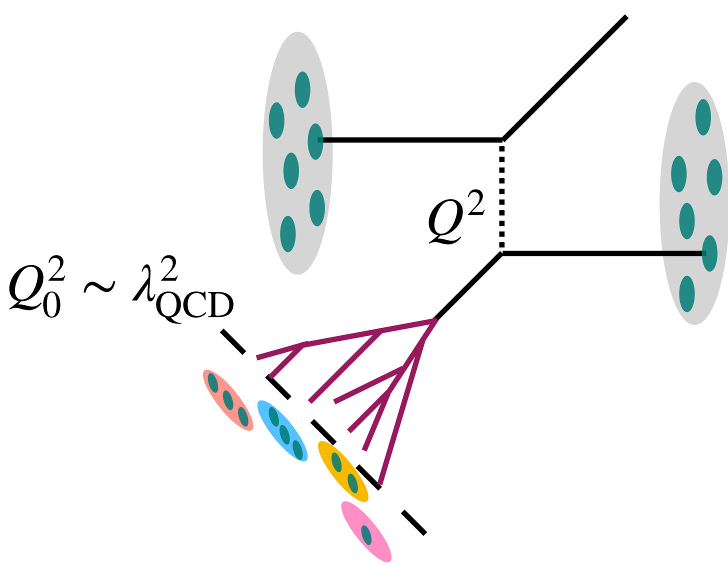
Center for Frontiers in Nuclear Science

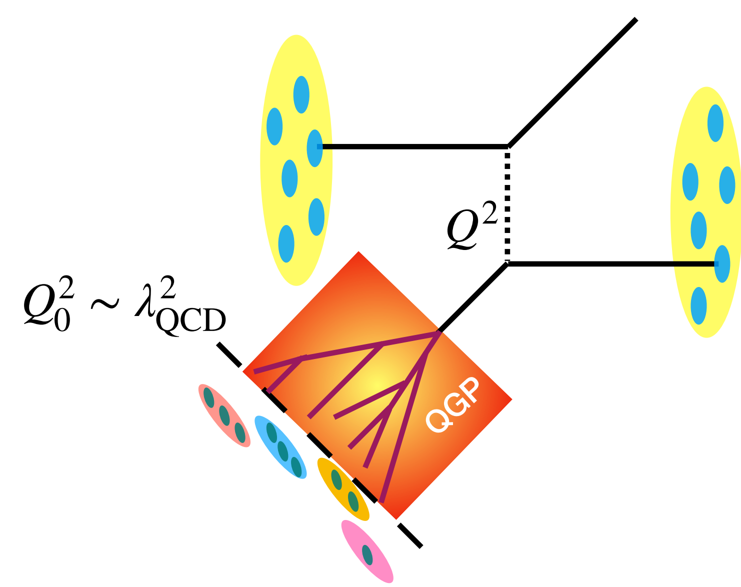
Jet reconstruction analyses [See talks by A.Bennecke and C. Wanotayaroj]

Cluster all particles in the event with k_T / anti-k_T / Cambridge-Aachen

p+p

A+A





+

$$X_{\text{jet}}^{\text{reco}} = X_{\text{jet}}^{\text{sig}} + X_{\text{jet}}^{\text{bkg}}$$

+

pileup interactions

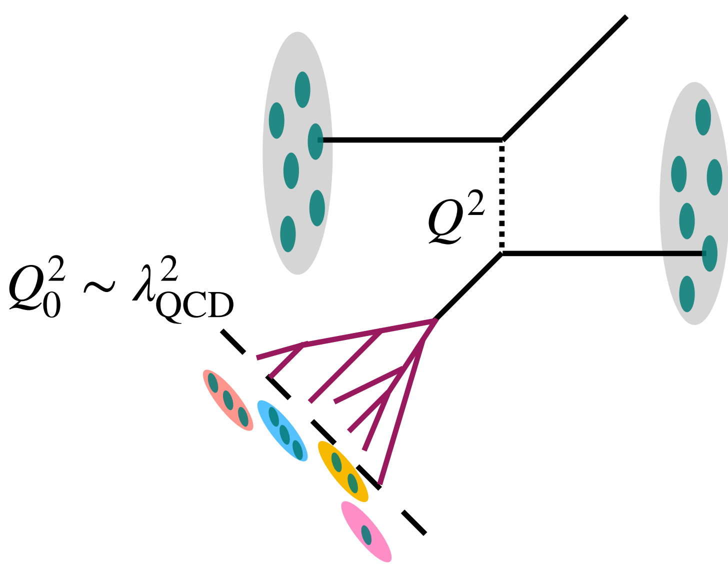
underlying event

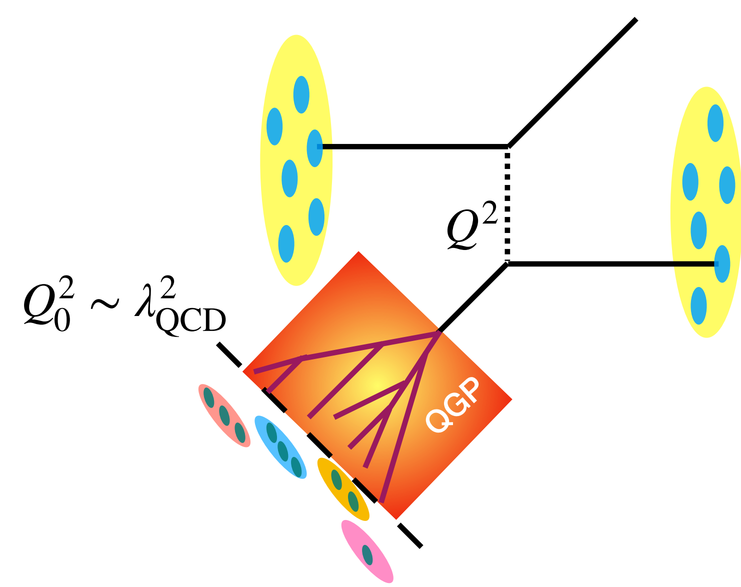
Jet reconstruction analyses

Cluster all particles in the event with k_T / anti-k_T / Cambridge-Aachen

p+p

A+A





+

pileup interactions

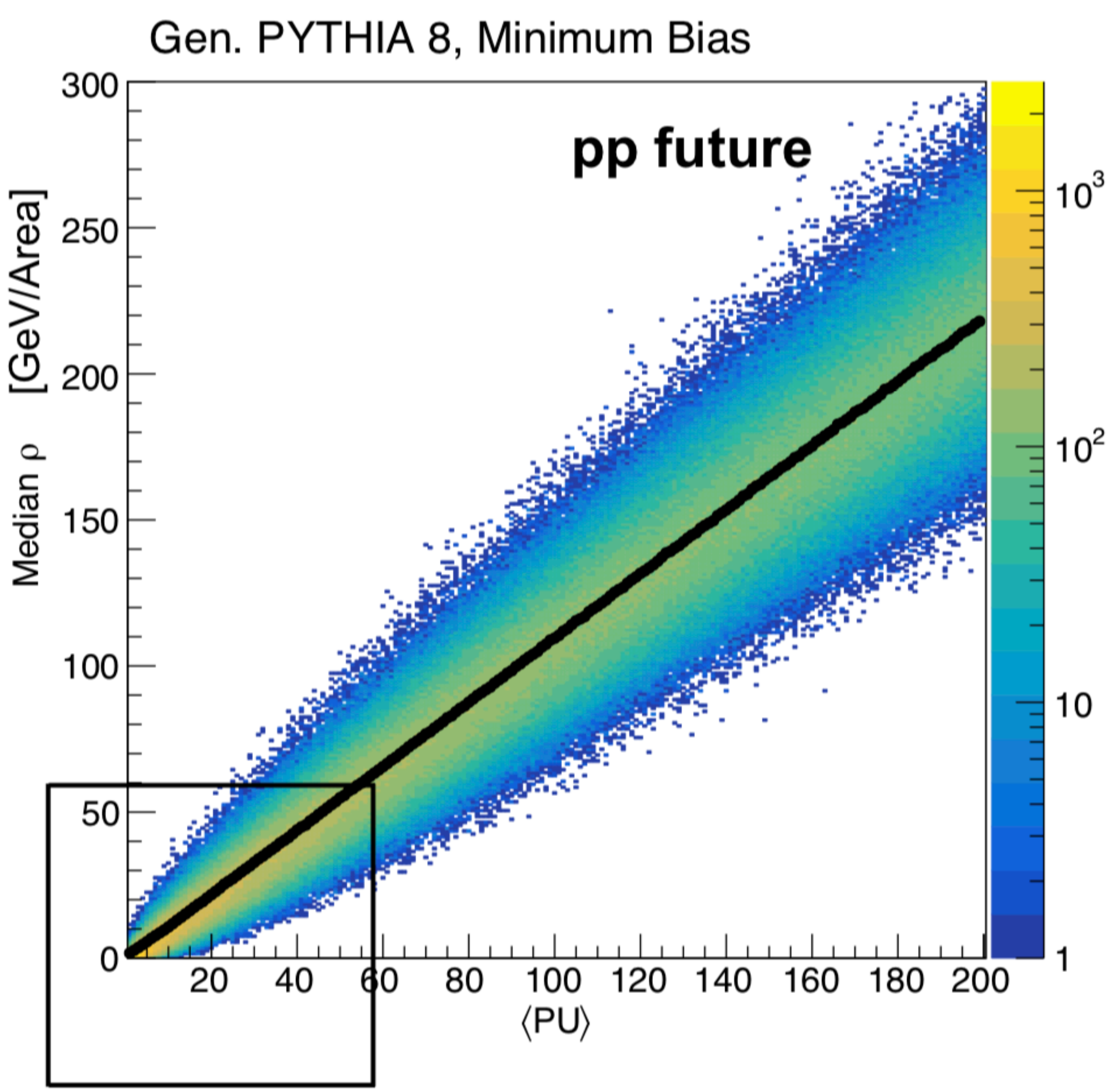
$$p_{T,\rm jet}^{\rm reco} = p_{T,\rm jet}^{\rm sig} + p_{T,\rm jet}^{\rm bkg}$$

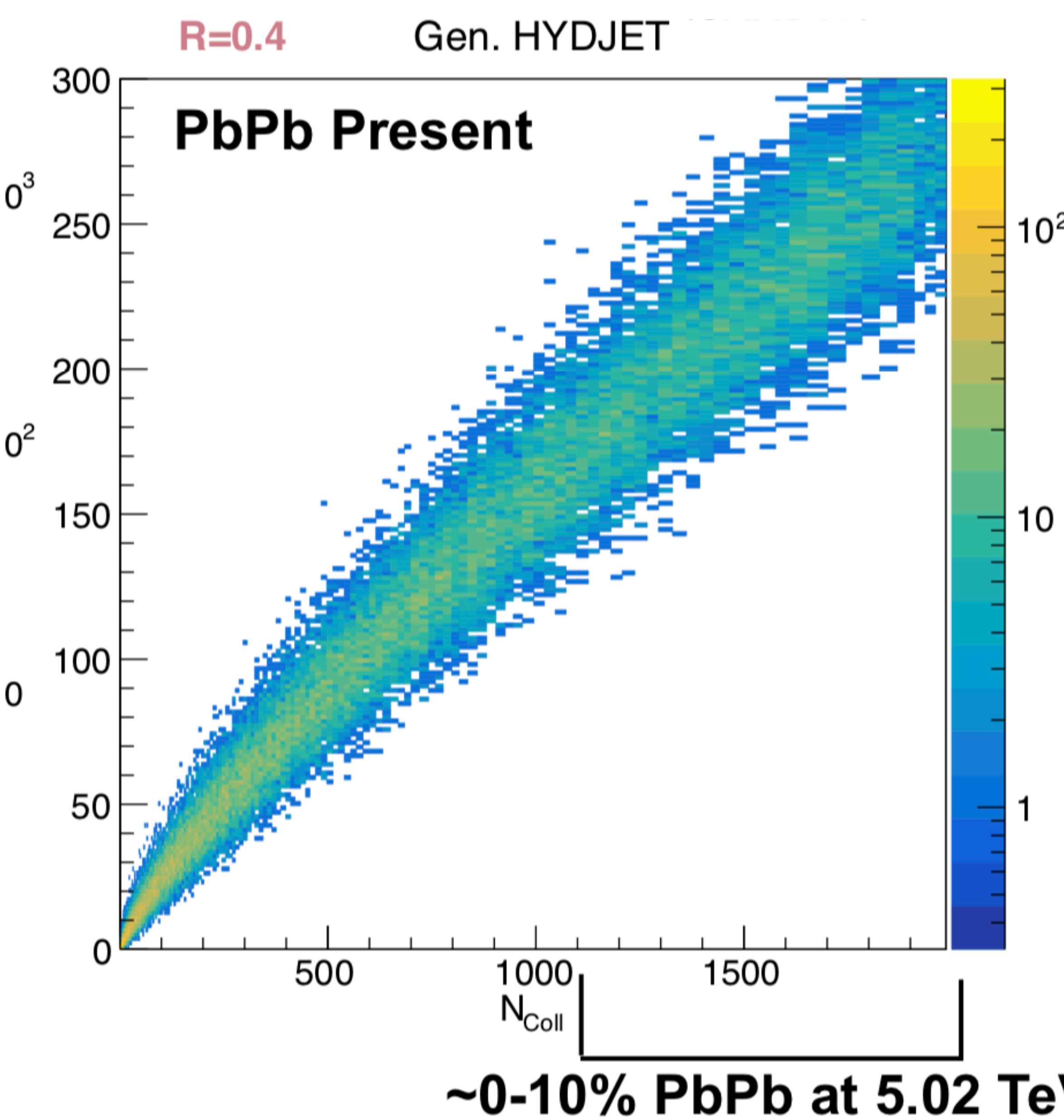
+

underlying event

HL-LHC and HIC background contamination

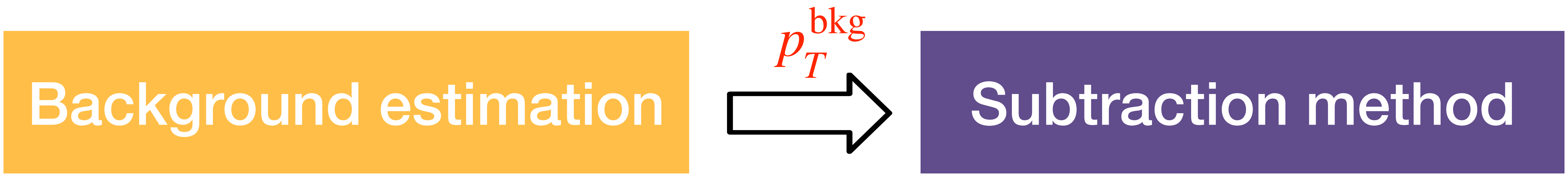
Background momentum density per unit area $\rho = \frac{p_T^{\text{bkg}}}{A}$

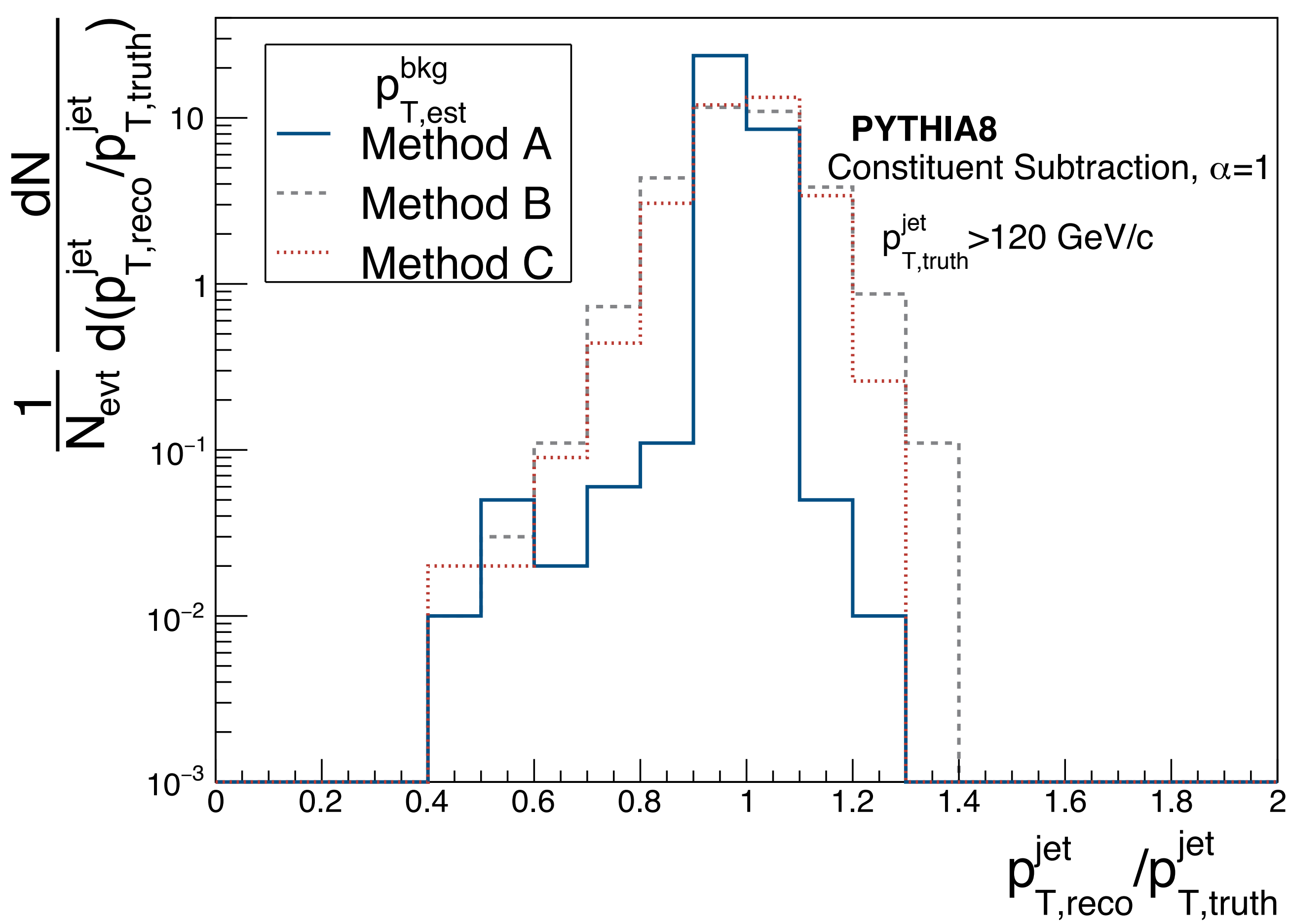


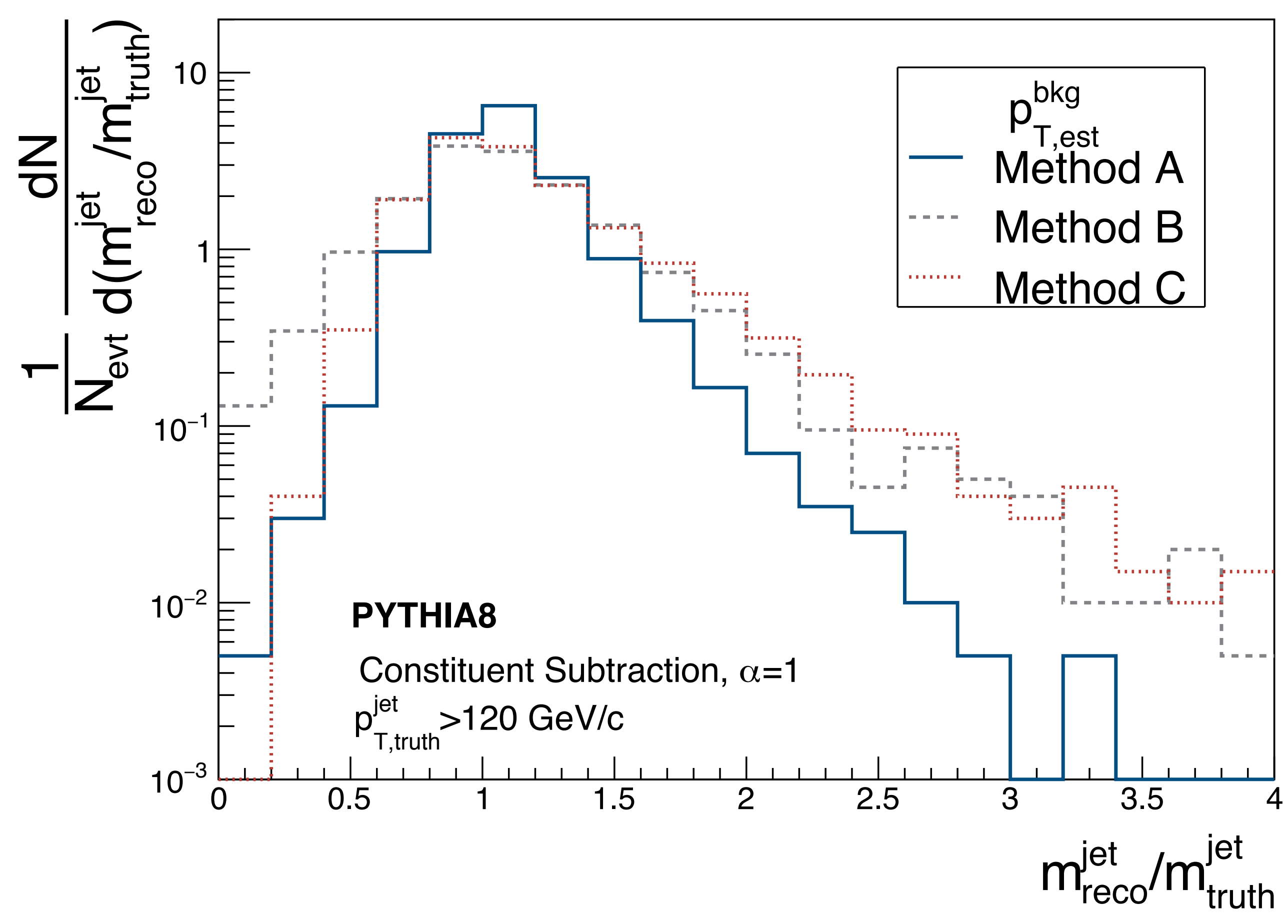


[C.McGinn Talk at "The Definition of Jets in Large Background"]

Background subtraction: two-step process







Method A: Truth Method B: Area median Method C: SoftKiller

Simulation setup [https://github.com/JetQuenchingTools/JetToyHI]

Background

- Randomly distributed in (η, ϕ)
- Thermal distribution with

This talk $\begin{cases} |\eta| < 3, \\ \langle N_{\text{part}} \rangle = 7000, 12000 \\ \mu \equiv \langle p_{\text{T}} \rangle = 1.2, 0.7\ \text{GeV/c} \end{cases}$

Signal

- Pythia8 dijet event

This talk: $\langle \hat{p}_{\text{T}} \rangle = 100\ \text{GeV}$

- JEWEL w/ and w/o energy loss (no recoil)

This talk: $\langle \hat{p}_{\text{T}} \rangle = 150\ \text{GeV}$

$\sqrt{s} = 5.02\ \text{TeV}$

PYTHIA8 + Thermal background == p+p collision @ HL-LHC

JEWEL w/ E-loss + Thermal background == Pb+Pb collision @LHC

A decade of progress

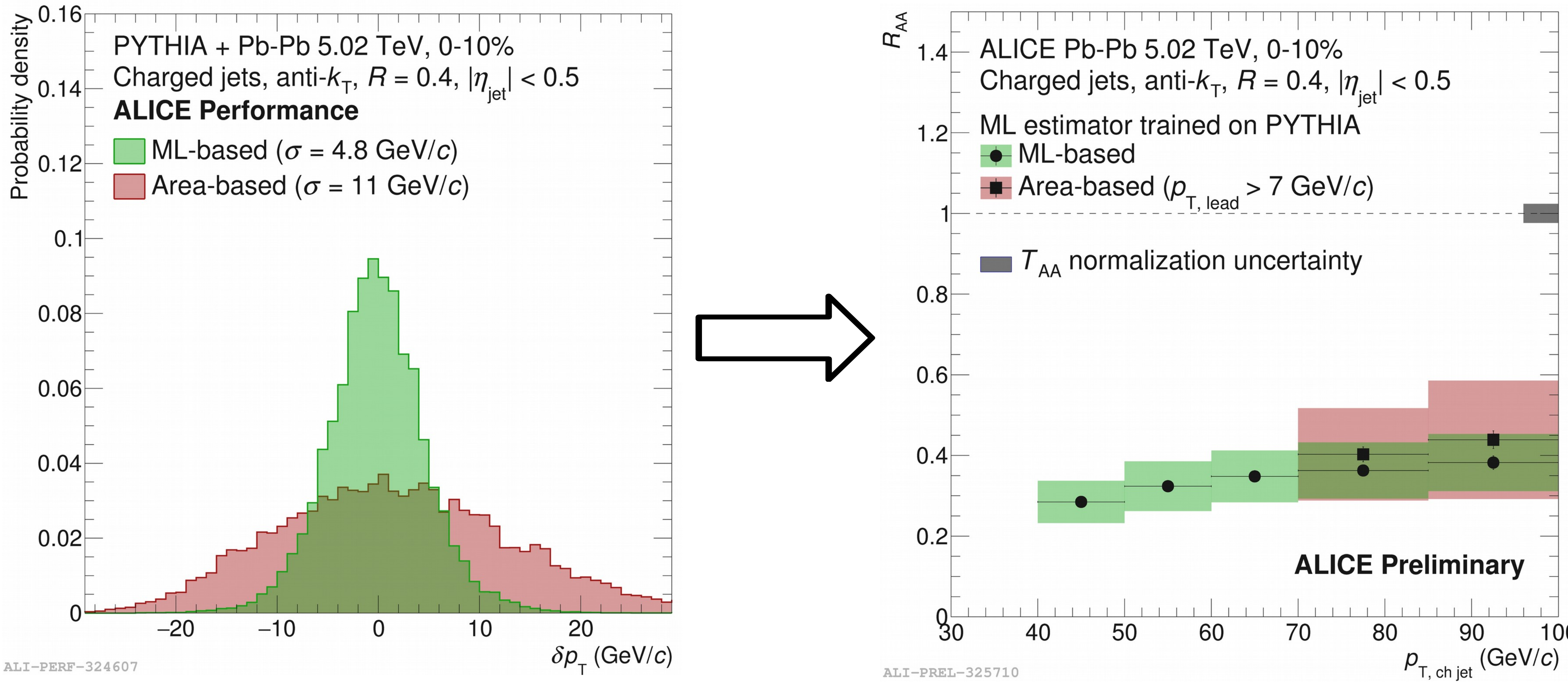
- **Area-median:** an unbiased method [M. Cacciari, G.Salam Phys. Lett. B659 (2008) 119–126]

$$p_{\mathrm{T,reco}}^{\mathrm{jet}} = p_{\mathrm{T,raw}}^{\mathrm{jet}} - \mathrm{med}(\rho) A_{\mathrm{raw}}^{\mathrm{jet}}$$

+ unfolding

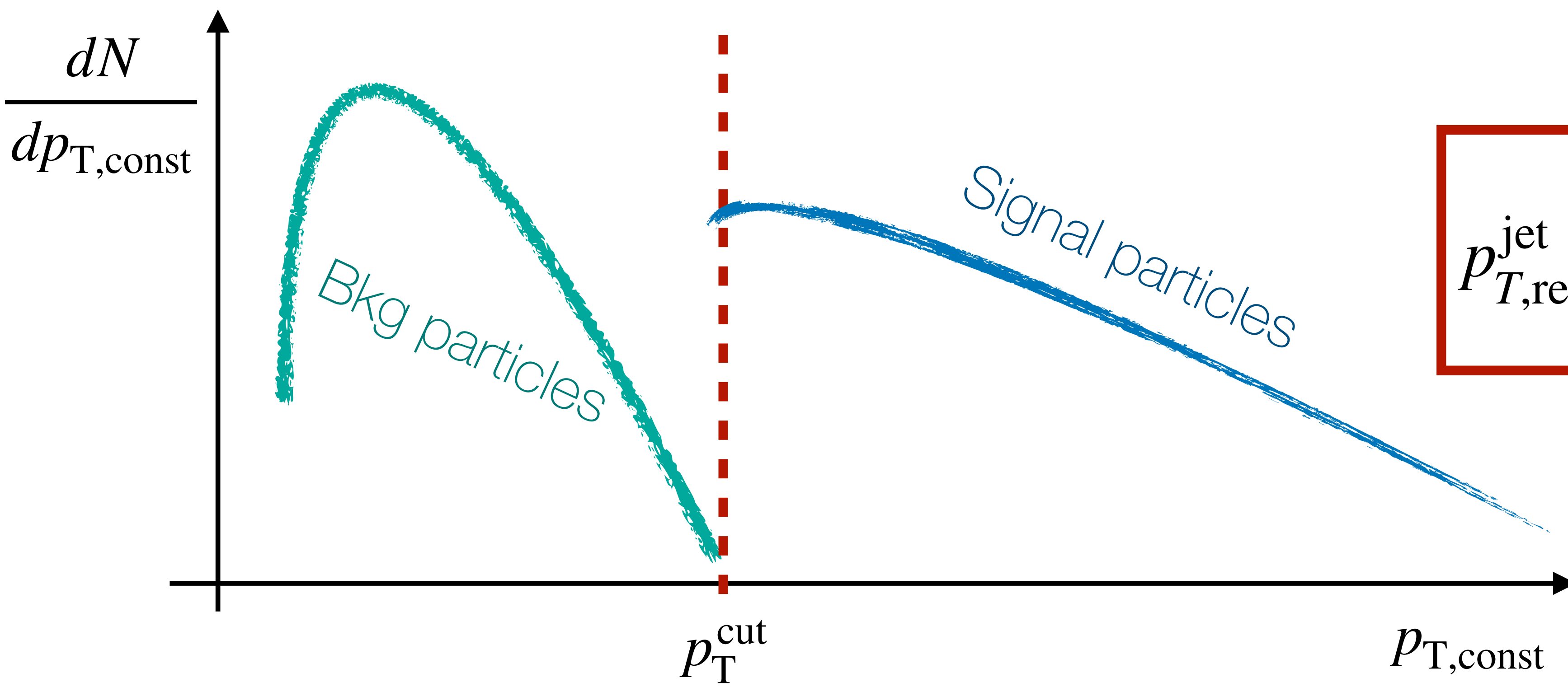
- **Supervised learning approach** [R. Haake, C.Loizides, PRC 99, 064904 (2019)]

$$p_{\mathrm{T,reco}}^{\mathrm{jet}} = p_{\mathrm{T,raw}}^{\mathrm{jet}} - p_{\mathrm{T,ML}}^{\mathrm{bkg}}$$



SoftKiller: introducing a soft p_T-cut

[M. Cacciari, G. Salam and G. Soyez Eur.Phys.J. C75 (2015) no.2, 59]



$$p_{T,\mathrm{reco}}^{\mathrm{jet}} = p_{T,\mathrm{raw}}^{\mathrm{jet}} - \sum_{i}^{p_{T,i}<p_T^{\mathrm{cut}}} p_{T,i}$$

If there is no signal below the p_T-cut, exact handle on background fluctuations

$$\langle p_{\mathrm{T,reco}}^{\mathrm{jet}} - p_{\mathrm{T,truth}}^{\mathrm{jet}} \rangle = 0$$

$$\sigma(p_{\mathrm{T,reco}}^{\mathrm{jet}} - p_{\mathrm{T,truth}}^{\mathrm{jet}}) = 0$$

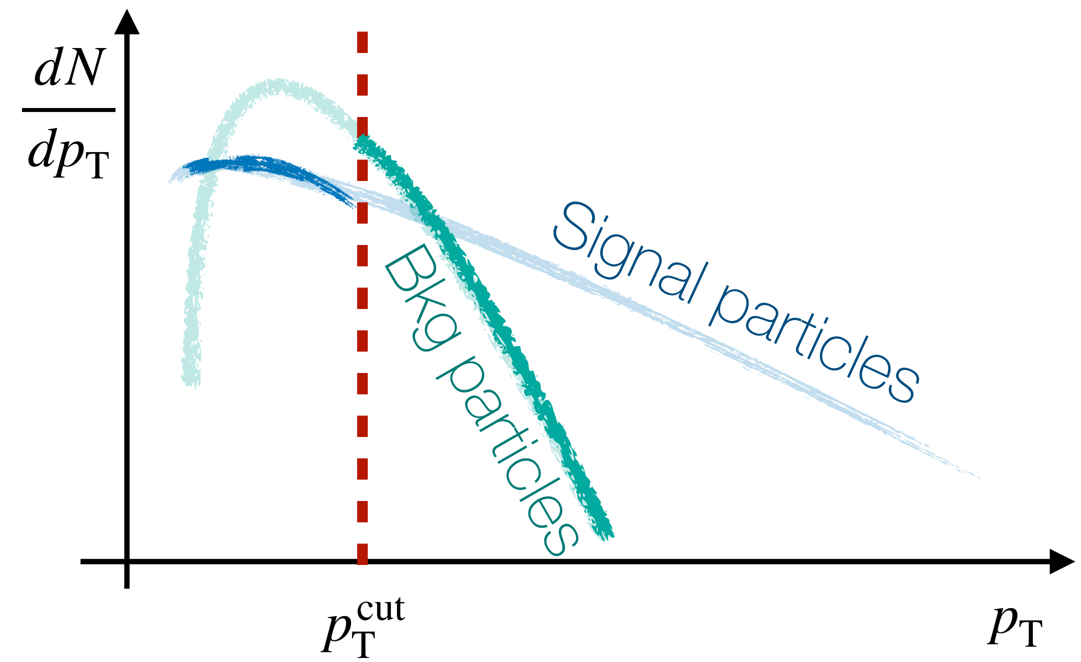
SoftKiller: introducing a soft p_T-cut

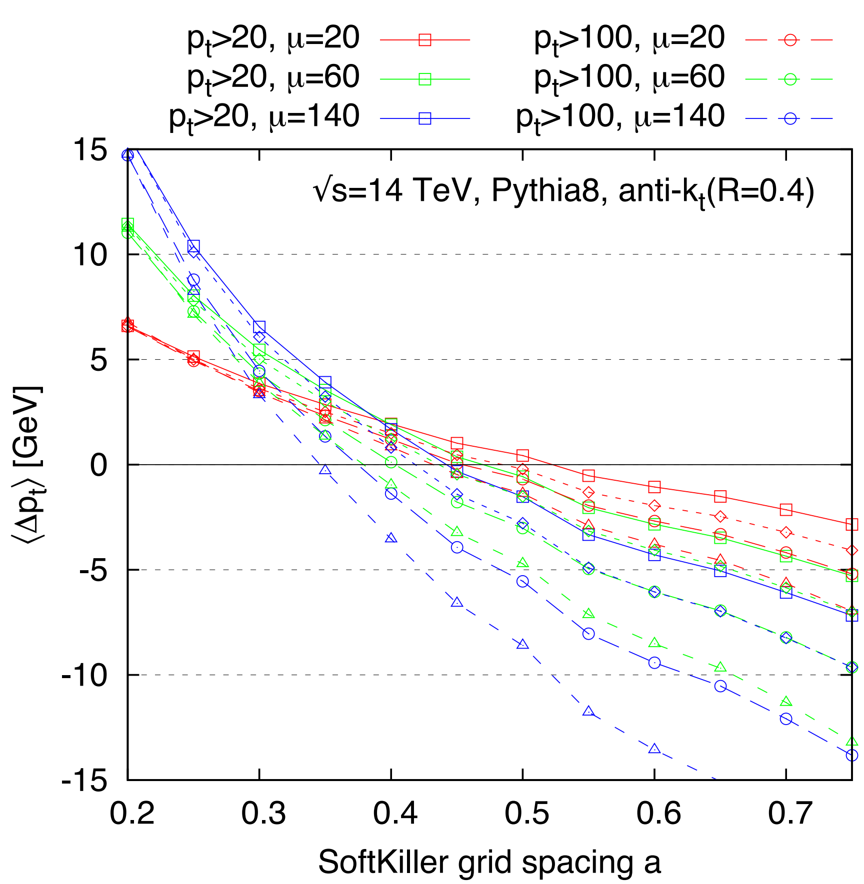
[M. Cacciari, G. Salam and G. Soyez Eur.Phys.J. C75 (2015) no.2, 59]

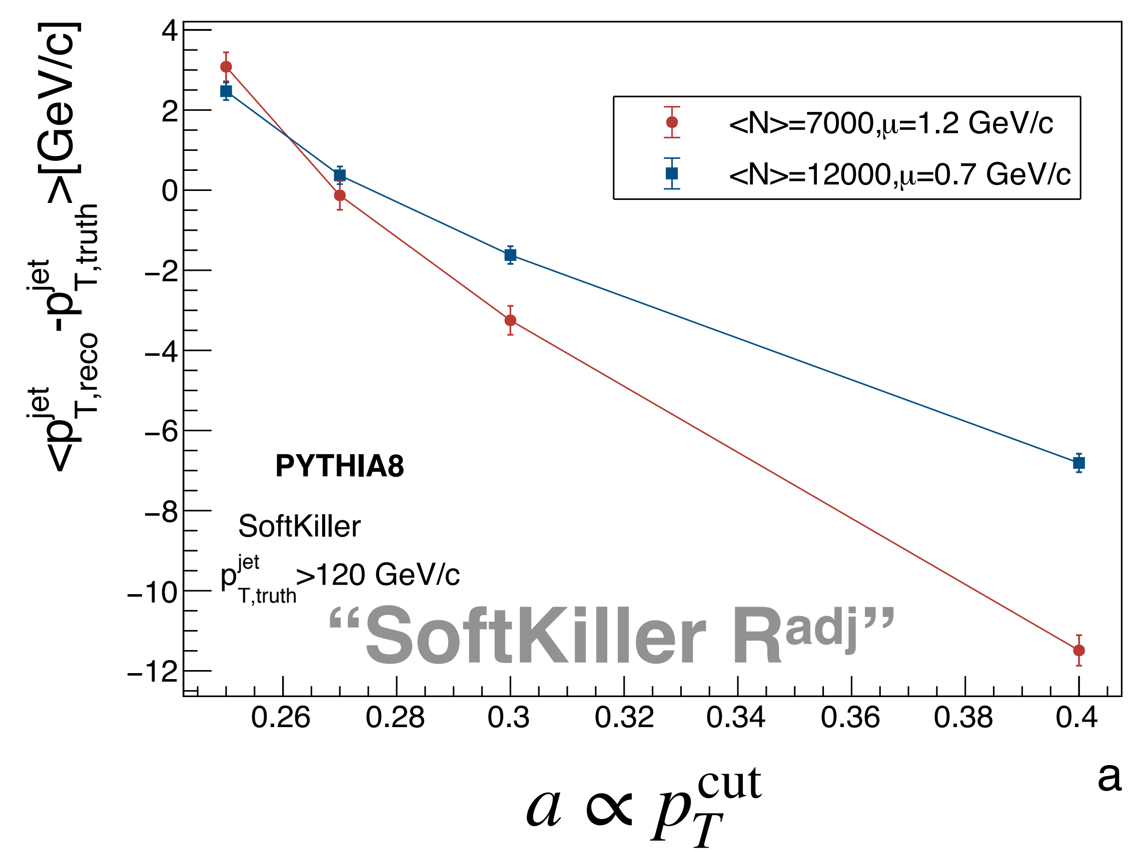
- Choose p_T-cut such that $p_{T,<}^{\mathrm{sig}}$ and $p_{T,>}^{\mathrm{bkg}}$ balance each other

$$\langle p_{T,\mathrm{reco}}^{\mathrm{jet}} - p_{T,\mathrm{truth}}^{\mathrm{jet}} \rangle \sim 0$$

- But…this actually requires a large degree of fine tuning



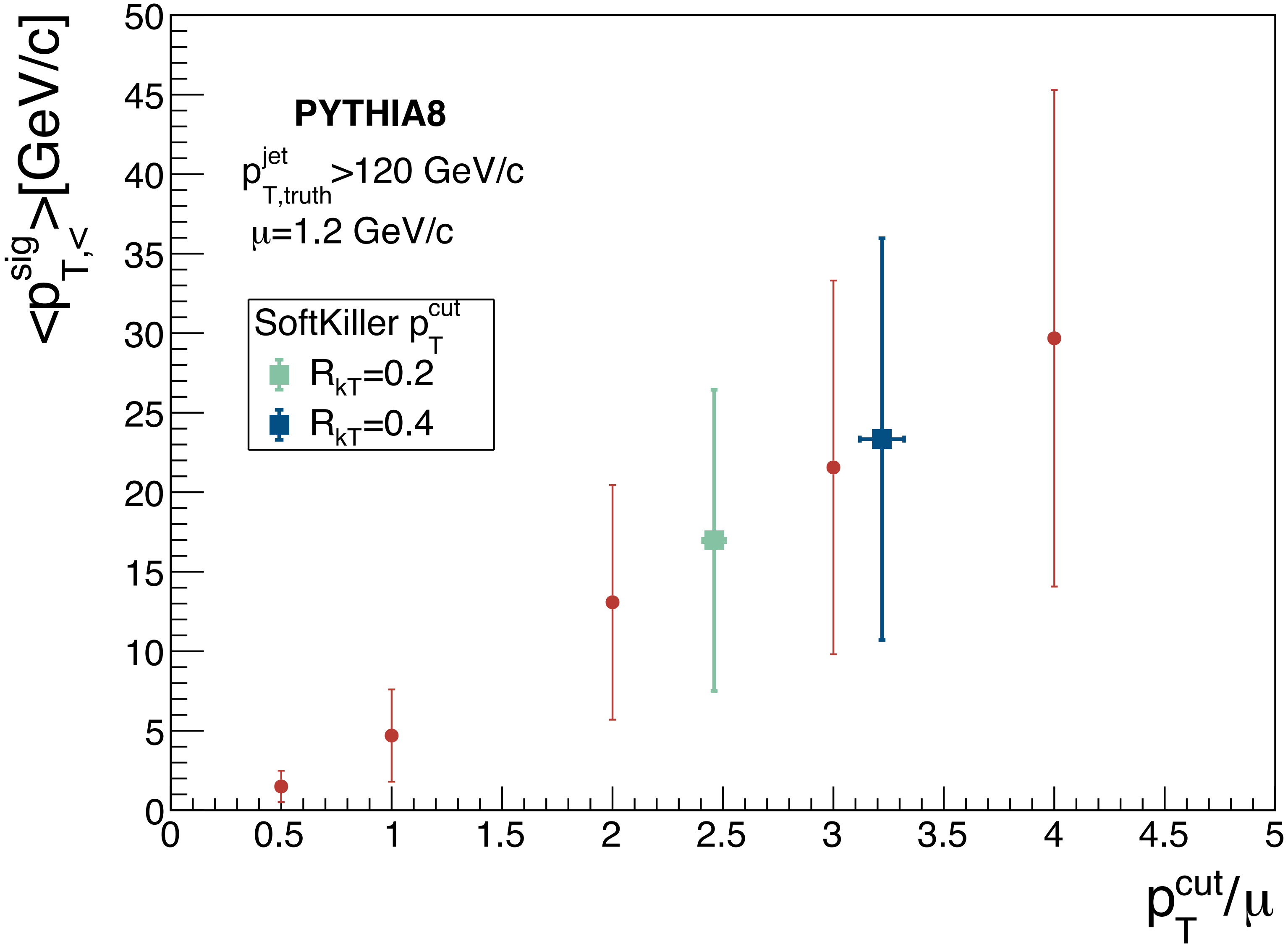




Impact of signal contamination

Any background estimator that relies on a soft pT-cut is sensitive to QCD radiation below this threshold

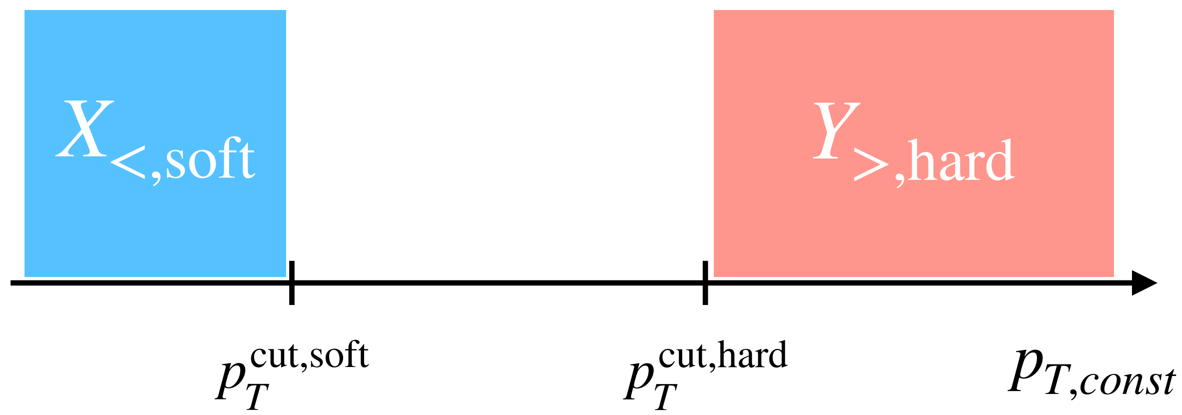
[Mehtar-Tani, ASO, Verweij arXiv:1904.12815]

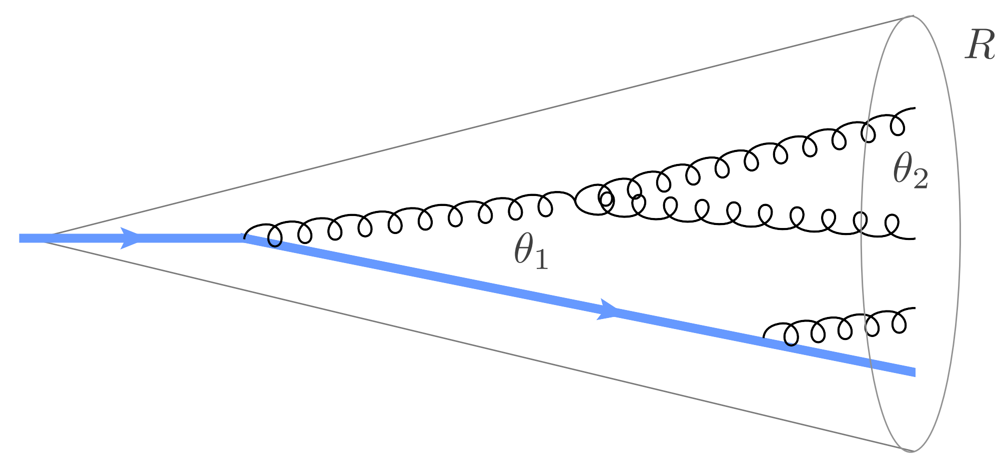


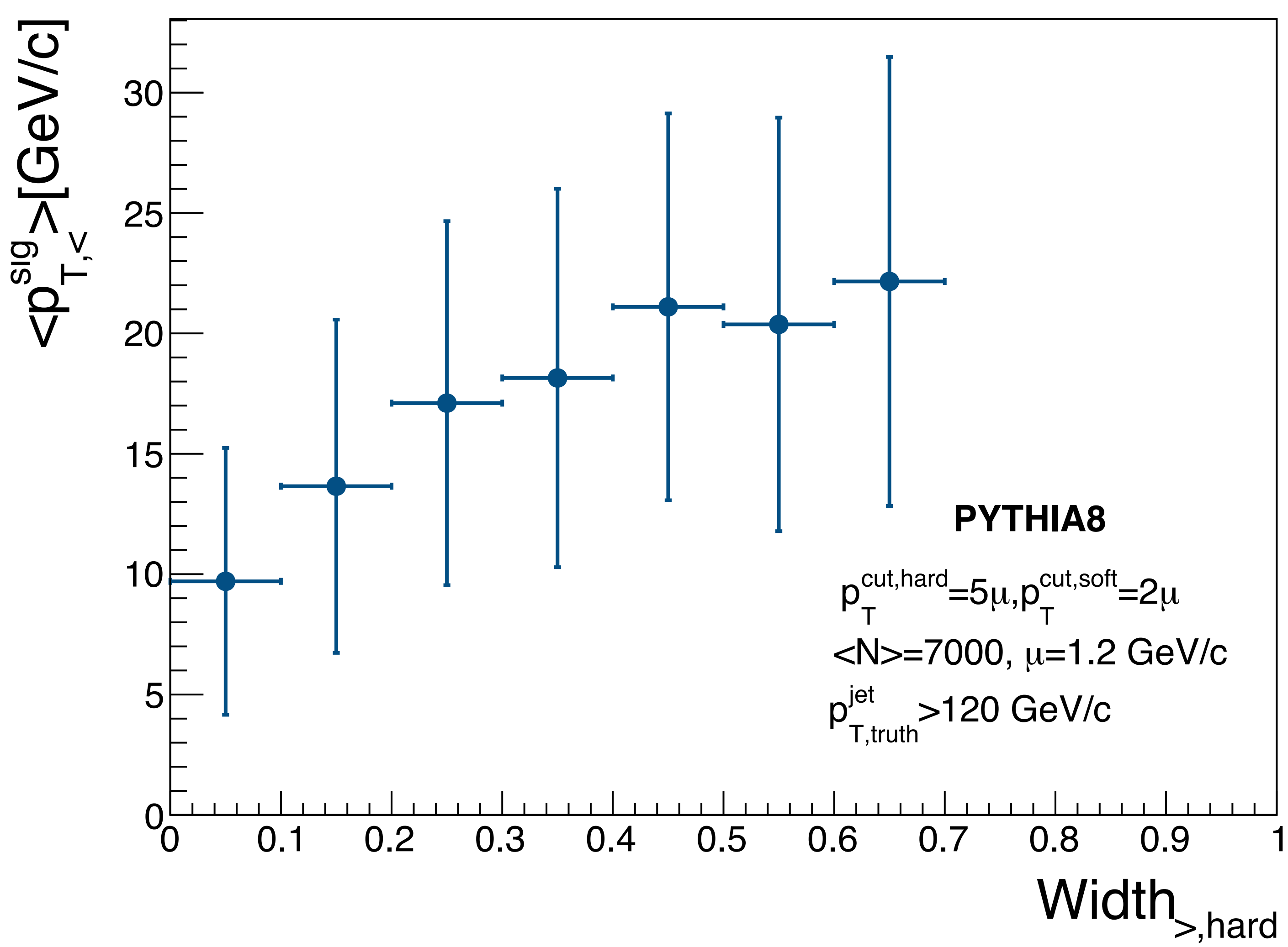
$$p^{sig}_{T,<} = \sum_{i \in sig}^{p_{T,i} < p_T^{cut}} p_{T,i}$$

$$\langle p^{jet}_{T,reco} - p^{jet}_{T,truth} \rangle \propto - \langle p^{sig}_{T,<} \rangle + \ldots \qquad \sigma(p^{jet}_{\mathrm{T,reco}} - p^{jet}_{\mathrm{T,truth}}) \propto \sigma(p^{sig}_{T,<})$$

Hard-soft correlations within a QCD jet







$\langle p_{T,<}^{\mathrm{sig}} \rangle$ and $\sigma(p_{T,<}^{\mathrm{sig}})$ can be mitigated by knowing/measuring jet properties in the hard sector i.e. a bkg free environment

The ρ-correction approach

[Mehtar-Tani, ASO, Verweij arXiv:1904.12815]

1

Cluster all particles (sig+bkg) in the event with **k_T algorithm, R=0.4**

⇨

Remove the **2 hardest** patches from the sample

For each patch, $\rho_> = \frac{1}{A} \sum_i^{p_T > p_T^{\text{cut,soft}}} p_{T,i}$ ⇨ $\text{med}(\rho_>)$

2

Re-cluster the whole event (sig+bkg) in the event with **anti-k_T algorithm, R=0.4**

For each jet, $p_{T,<} = \sum_i^{p_T < p_T^{\text{cut,soft}}} p_{T,i}$

3

For a given $p_T^{\text{cut,soft}}$ measure $\langle p_{T,<}^{\text{sig}} \rangle$ in low pileup proton-proton collisions

The ρ-correction approach

[Mehtar-Tani, ASO, Verweij arXiv:1904.12815]

$$p_{\mathrm{T,reco}}^{\mathrm{jet}} = p_{\mathrm{T,raw}}^{\mathrm{jet}} - \mathrm{med}(\rho_{>})A_{\mathrm{raw}}^{\mathrm{jet}} - p_{T,<} + \langle p_{T,<}^{\mathrm{sig}} \rangle$$

- Neglecting $\langle p_{T,<}^{\mathrm{sig}} \rangle$-term, $\begin{cases} p_{\mathrm{T}}^{\mathrm{cut,soft}} = 0 : \textbf{Area-median} \\ p_{\mathrm{T}}^{\mathrm{cut,soft}} = p_{\mathrm{T}}^{\mathrm{cut,SK}} : \textbf{SoftKiller R}_{\mathbf{kT}} \end{cases}$

- Role of $\langle p_{T,<}^{\mathrm{sig}} \rangle$: correct for the signal contamination below $p_{\mathrm{T}}^{\mathrm{cut,soft}}$
  - If measured inclusively, ρ-correction
  - If measured as a function of $\mathrm{width}_{>,\mathrm{hard}}$, ρ-correction $\mathrm{HS}_{\mathrm{corr}}$

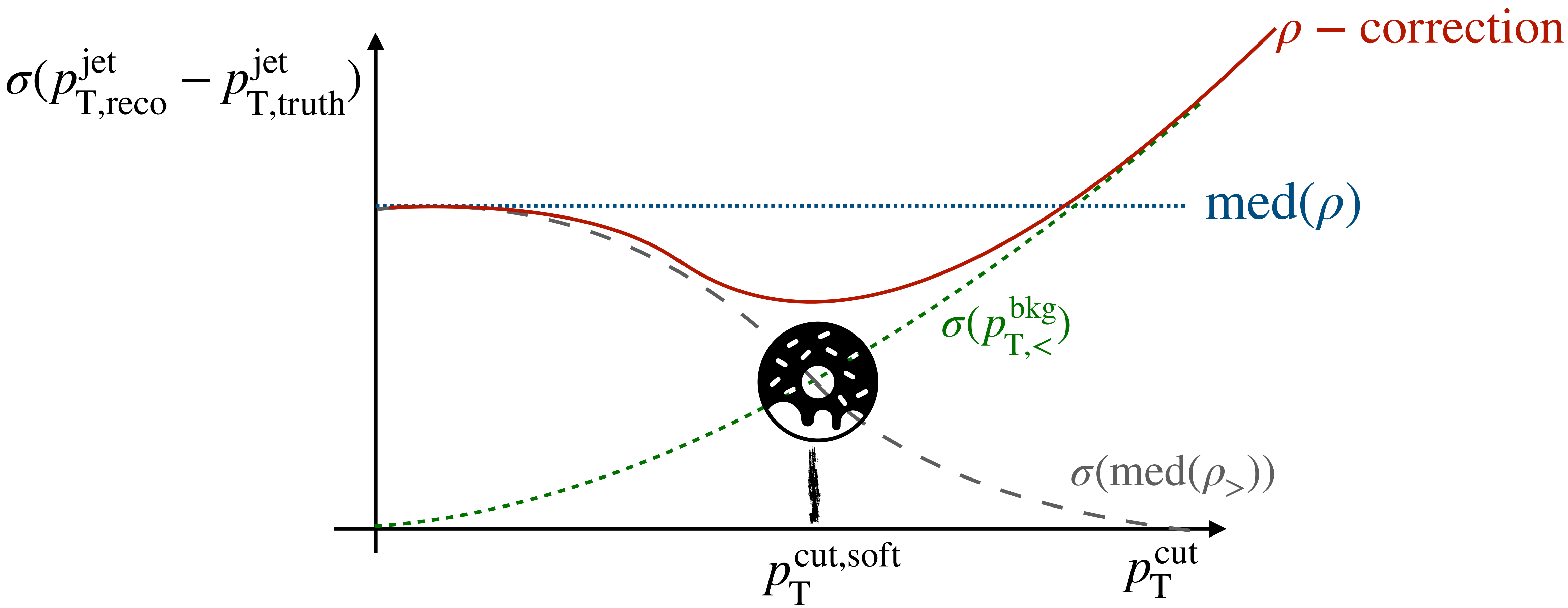
  Value of $p_T^{\mathrm{cut,hard}}$? Large enough to be in the background-free region

  $$p_T^{\mathrm{cut,hard}} = 5\mu \qquad (\mu : \text{average momentum of bkg constituents})$$

The ρ-correction approach

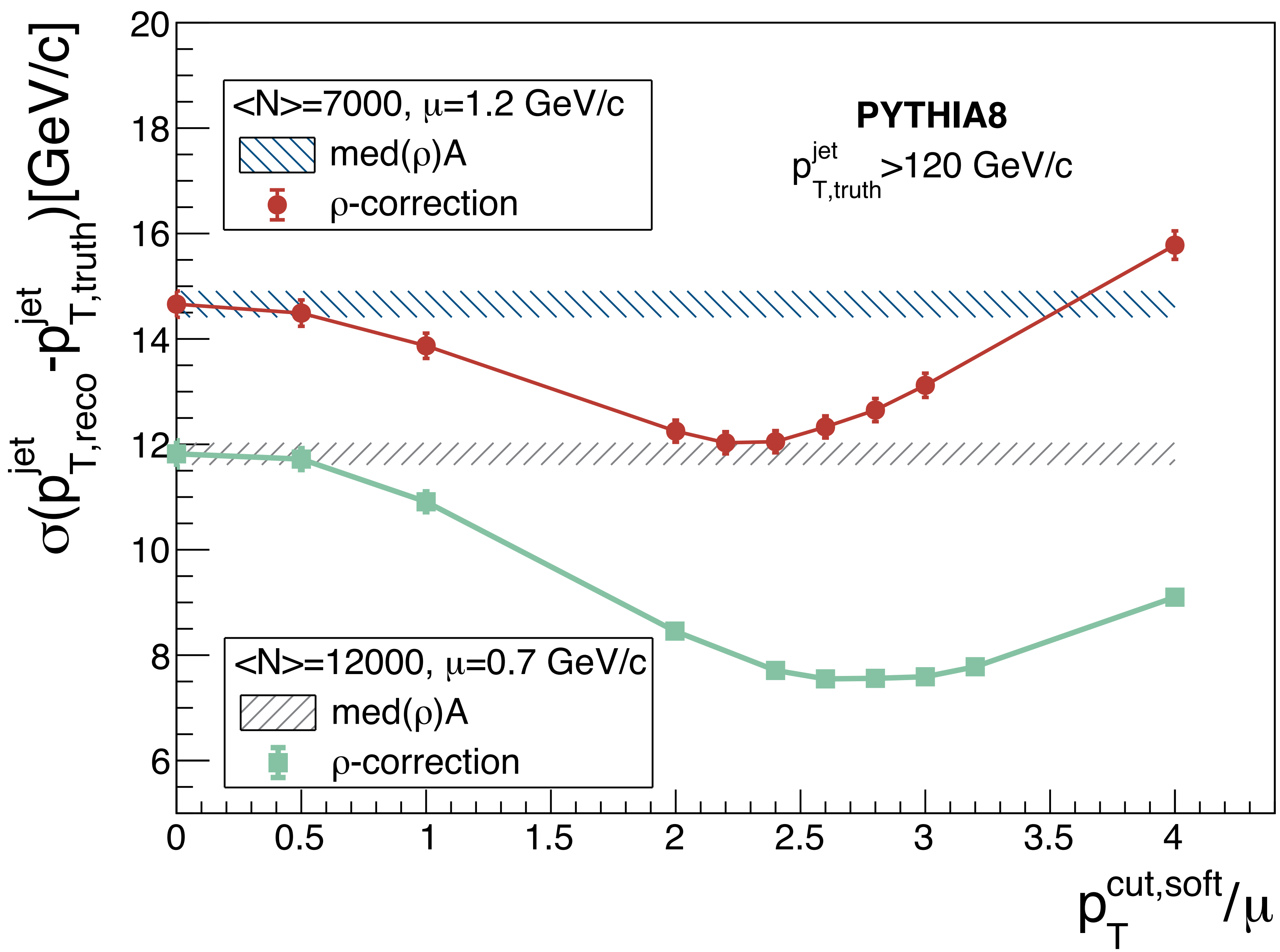
[Mehtar-Tani, ASO, Verweij arXiv:1904.12815]

- Prescription to choose $p_T^{\mathrm{cut,soft}}$: minimize $\sigma(p_{\mathrm{T,reco}}^{\mathrm{jet}} - p_{\mathrm{T,truth}}^{\mathrm{jet}})$



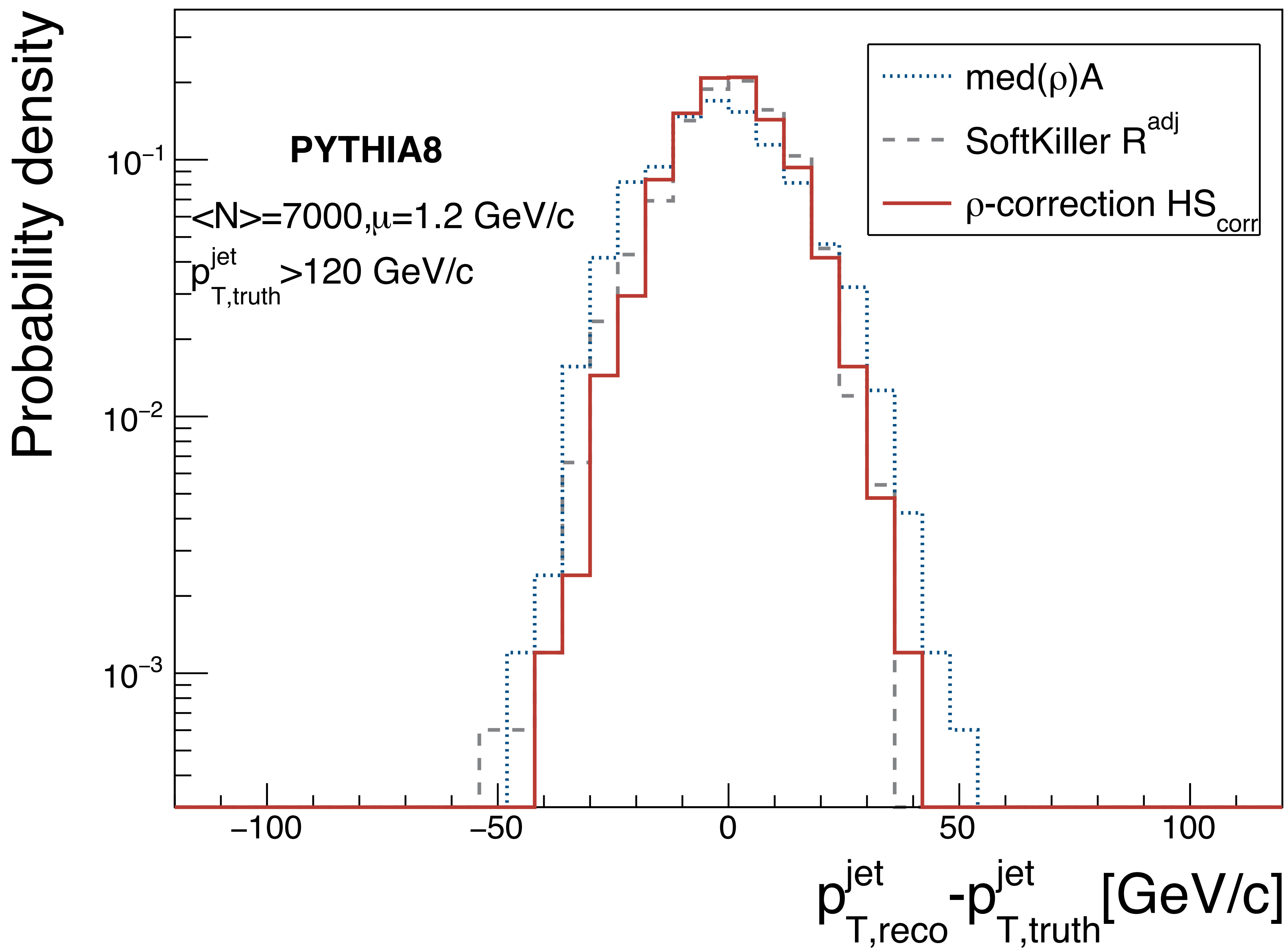
$$p_{\mathrm{T,reco}}^{\mathrm{jet}} = p_{\mathrm{T,raw}}^{\mathrm{jet}} - \mathrm{med}(\rho_>)A_{\mathrm{raw}}^{\mathrm{jet}} - p_{T,<} + \langle p_{T,<}^{\mathrm{sig}} \rangle$$

PYTHIA8 + Thermal background



Plateau-like region around the optimal $p_T^{cut,soft}$.
No need to fine-tune

PYTHIA8 + Thermal background



ρ-correction HS_{corr}

- **23% improvement w.r.t area-median**
- **6% improvement w.r.t SoftKiller R^{adj}**

[GeV/c]	Mean	Standard deviation
med(ρ)A	-1.51±0.36	14.66±0.25
SoftKiller R^{adj}	0.29±0.29	12.10±0.21
ρ-correction	0.37±0.31	12.03 ± 0.21
ρ-correction HS_{corr}	0.49±0.28	11.39 ±0.21

JEWEL w/ E-loss + Thermal background

Hard to know $p_{\mathrm{T,truth}}^{\mathrm{jet}}$ due to energy loss + cannot switch off the background

⇨ $p_{\mathrm{T}}^{\mathrm{cut,soft}}$ minimizes $\sigma(p_{\mathrm{T,reco}}^{\mathrm{jet}} - p_{\mathrm{T,truth}}^{\mathrm{jet}})$ in JEWEL w/o E-loss

⇨ Apply $\langle p_{T,<}^{\mathrm{sig}} \rangle$ as measured in low pileup p+p

[GeV/c]	Mean	Standard deviation	Δ_{truth}
med(ρ)A	-0.61±0.17	14.73±0.12	10.1
SoftKiller R^{adj}	2.90±0.12	10.91± 0.09	7.55
ρ-correction	2.96±0.12	10.92± 0.09	7.6
ρ-correction $\mathrm{HS_{corr}}$	2.04±0.12	10.34± 0.08	6.9

$[-\Delta_{\mathrm{truth}}, \Delta_{\mathrm{truth}}]$: interval in $p_{\mathrm{T,reco}}^{\mathrm{jet}} - p_{\mathrm{T,truth}}^{\mathrm{jet}}$ centered around 0 and containing 1/2 jets

Better resolution but not straightforward to control the bias due to in-medium modifications

Wrap-up

- Background subtraction essential for jet studies both in HL-LHC and heavy ions

- ρ-correction is a new method based on:
  - Choice of $p_T^{\mathrm{cut,soft}}$ to minimize $\sigma(p_{\mathrm{T,reco}}^{\mathrm{jet}} - p_{\mathrm{T,truth}}^{\mathrm{jet}})$
  - $\langle p_{\mathrm{T,reco}}^{\mathrm{jet}} - p_{\mathrm{T,truth}}^{\mathrm{jet}} \rangle$ under control via an experimentally accesible quantity $\langle p_{\mathrm{T},<}^{\mathrm{sig}} \rangle$
  - Introduce QCD hard-soft correlations as a tool to improve $\sigma(p_{\mathrm{T,reco}}^{\mathrm{jet}} - p_{\mathrm{T,truth}}^{\mathrm{jet}})$
  - To be combined with a subtraction method

    [Y.Mehtar-Tani, ASO, M. Verweij in preparation]

Keep tuned and find more on: https://github.com/aontoso/JetToyHI

Soon in FastJet/contrib