Measurements of semi-inclusive recoil jet production in pp and Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

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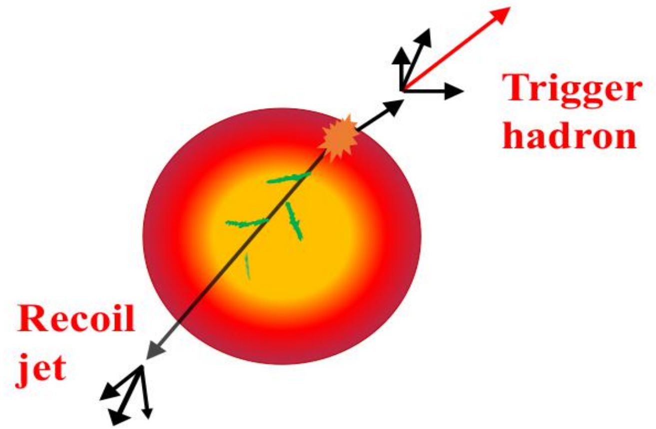
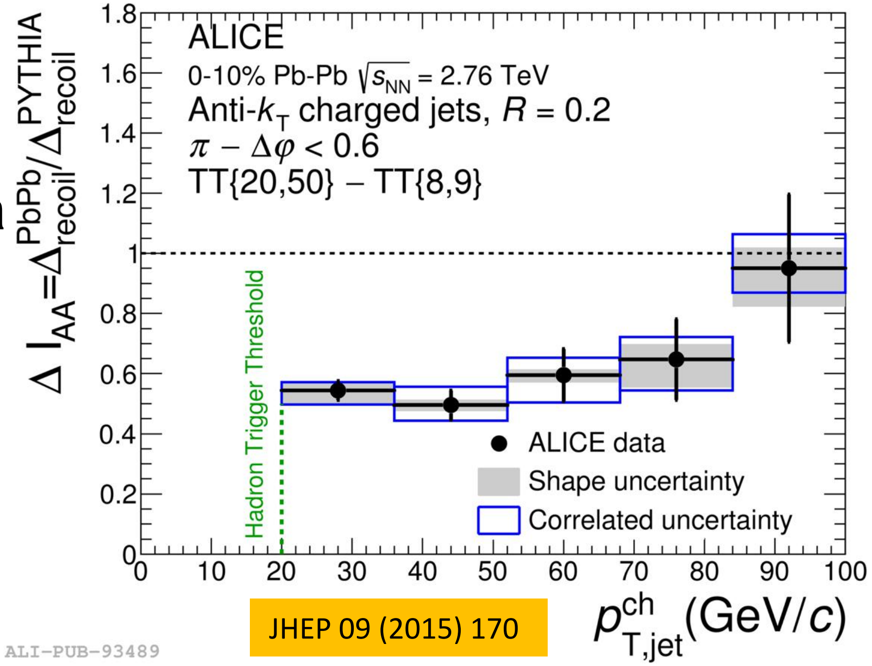
Motivation

➢ Why hadron-jet ?

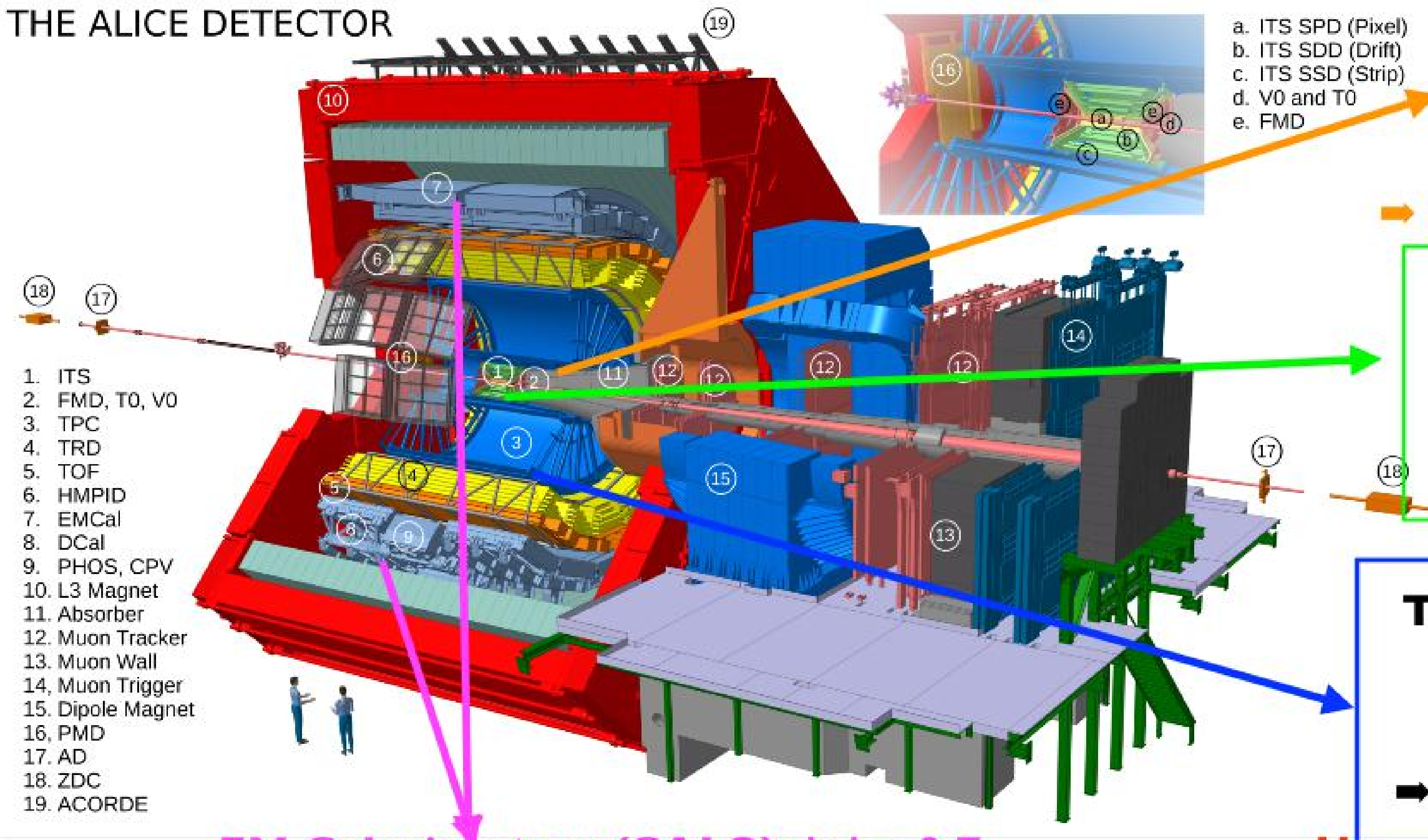
- Observable can be calculated by pQCD
- Trigger track close to surface, but no bias on recoil jets
- Provide a good handle on the combinatorial background by varying trigger track intervals → possible low pT, large R jet
- The measurement in pp collisions provide a reference study in nucleus-nucleus collisions
- A probe to study medium effect in nucleus-nucleus collisions





JHEP 09 (2015) 170

ALICE detector



VZERO Detector (V0)

$2.8 < \eta_{V0A} < 5.1$, $-3.7 < \eta_{V0C} < -1.7$

➡ Event selection, centrality determination

Inner Tracking System (ITS)

$|\eta| < 0.9$, $0 \leq \varphi < 2\pi$

➡ Tracking, vertex reconstruction

+

Time Projection Chamber (TPC)

$|\eta| < 0.9$, $0 \leq \varphi < 2\pi$

➡ Tracking, particle identification

||

EM Calorimeters (CALO): $|\eta| < 0.7$

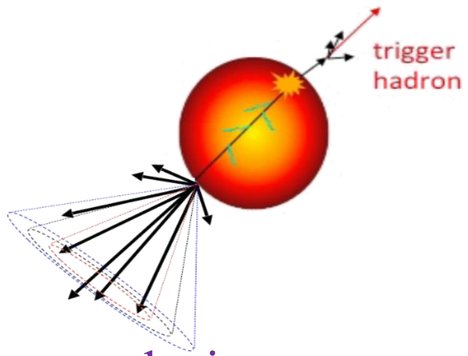
Neutral constituents

Charged constituents $p_T^{trk} > 0.15$ GeV/c

Full jets

Charged jets

Analysis Strategy



- Measure trigger-normalized charged jet recoiling from trigger hadron

$$\frac{1}{N_{trig}}\frac{d^2N_{jet}}{dp^{ch}_{T,jet}d\eta_{jet}}\bigg|_{p_{T,trig}\in TT} = \left(\frac{1}{\sigma^{PP\to h+X}}\cdot\frac{d^2\sigma^{pp\to h+jet+X}}{dp^{ch}_{T,jet}d\eta_{jet}}\right)_{p_{T,h}\in TT}$$

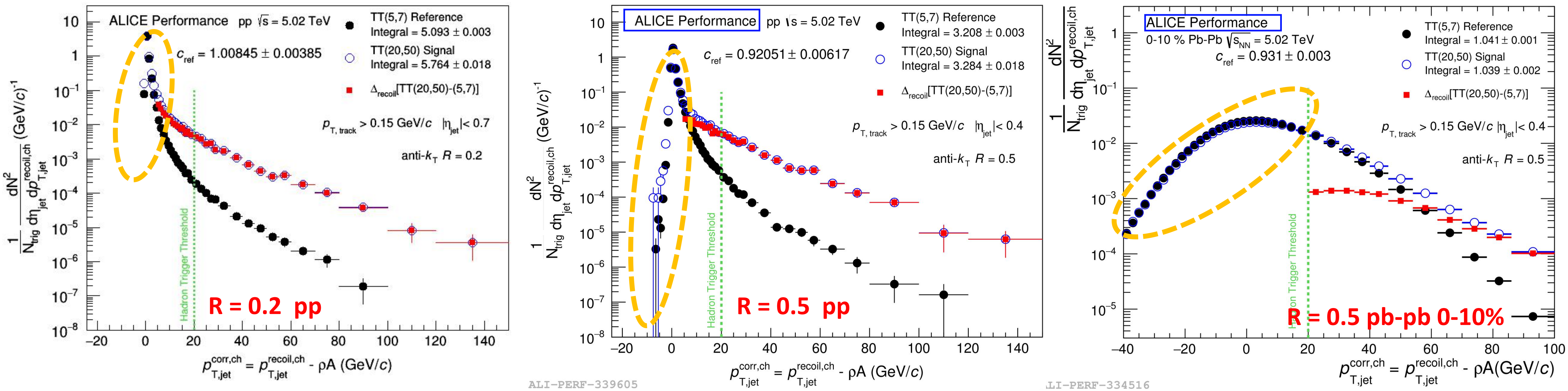
- Observables defined as the difference between trigger-normalized recoil jet distributions in two exclusive trigger track intervals in order to subtract all uncorrelated background jets

$$\Delta_{\mathrm{recoil}} = \frac{1}{\mathrm{N^{AA}_{trig}}}\frac{\mathrm{d^2N^{AA}_{jet}}}{\mathrm{d}p^{\mathrm{ch}}_{\mathrm{T,jet}}\mathrm{d}\eta_{\mathrm{jet}}}\bigg|_{p_{\mathrm{T,trig}}\in\mathrm{TT_{Sig}}} - c_{\mathrm{Ref}}\cdot\frac{1}{\mathrm{N^{AA}_{trig}}}\frac{\mathrm{d^2N^{AA}_{jet}}}{\mathrm{d}p^{\mathrm{ch}}_{\mathrm{T,jet}}\mathrm{d}\eta_{\mathrm{jet}}}\bigg|_{p_{\mathrm{T,trig}}\in\mathrm{TT_{Ref}}}$$

c_{Ref} = scaling factor to account for conserved jet density

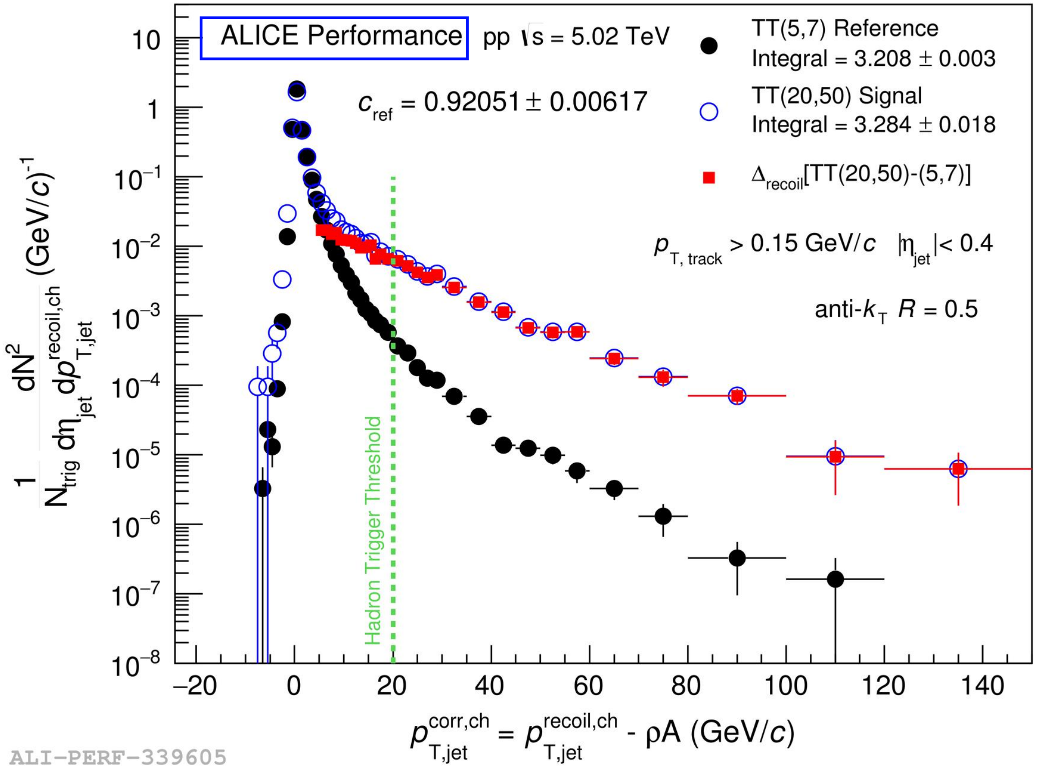
- Trigger track selection: $20 < TT_{sig} < 50$ GeV/c, $5 < TT_{ref} < 7$ GeV/c
- recoil jet reconstruction: anti-k_T, $p_T^{trk} > 0.15$ GeV/c, $|\eta_{jet}| < 0.9 - R$, R = 0.2, 0.4, 0.5
- Background subtraction: $p^{corr}_{T,jet} = p^{raw}_{T,jet} - \rho * A_{jet}$ $\quad \rho = median\left\{\frac{p^{k_T}_{T,jet}}{A_{jet}}\right\}$ $\quad A_{jet}$: Jet area

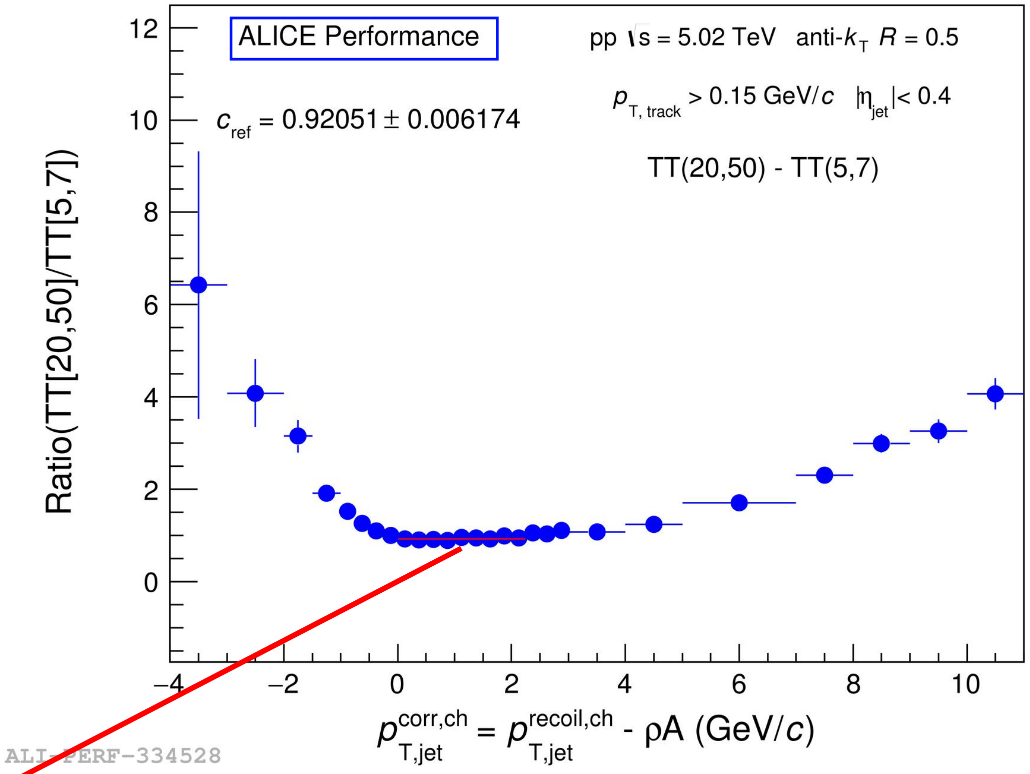
Semi-inclusive recoil jet distributions



- Recoil jets measured for two p_T different trigger track(TT) intervals
- Combinational background uncorrelated with the trigger p_T
  - ✓ Small background contribution in pp, much larger in Pb-Pb
  - ✓ Combinational background can be removed by taking the difference of the recoil jet distributions in two TT intervals

Scaling factor c_{Ref} determination



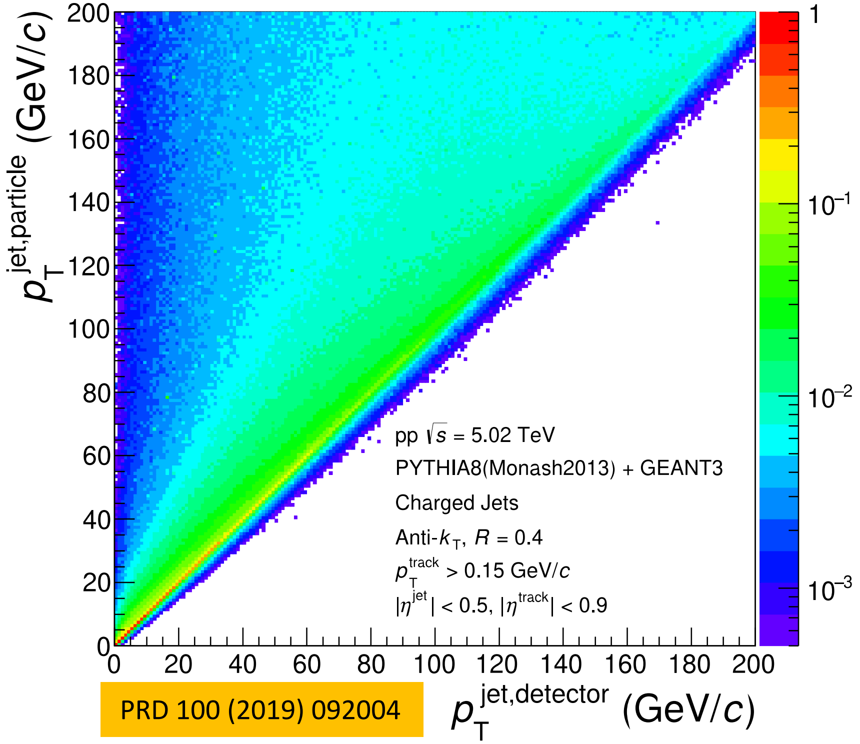


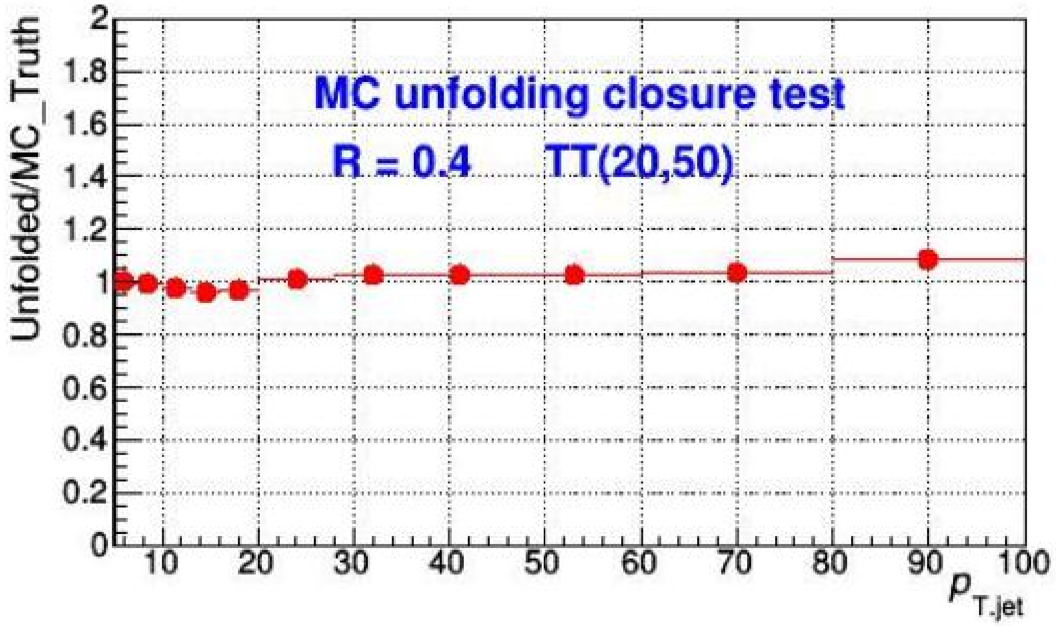
$$\Delta_{\mathrm{recoil}} = \frac{1}{\mathrm{N}^{\mathrm{AA}}_{\mathrm{trig}}} \frac{\mathrm{d}^2\mathrm{N}^{\mathrm{AA}}_{\mathrm{jet}}}{\mathrm{d}p^{\mathrm{ch}}_{\mathrm{T,jet}}\mathrm{d}\eta_{\mathrm{jet}}}\Bigg|_{p_{\mathrm{T,trig}}\in\mathrm{TT_{Sig}}} - c_{\mathrm{Ref}} \cdot \frac{1}{\mathrm{N}^{\mathrm{AA}}_{\mathrm{trig}}} \frac{\mathrm{d}^2\mathrm{N}^{\mathrm{AA}}_{\mathrm{jet}}}{\mathrm{d}p^{\mathrm{ch}}_{\mathrm{T,jet}}\mathrm{d}\eta_{\mathrm{jet}}}\Bigg|_{p_{\mathrm{T,trig}}\in\mathrm{TT_{Ref}}}$$

$c_{Ref} = 0.92051$

- Fitting by pol0, using the value of the parameter as the scale factor when calculate Δ_{recoil}
- Δ_{recoil} is clean of combinatorial background and corrected for detector effects using unfolding

Detector response and MC unfolding closure test





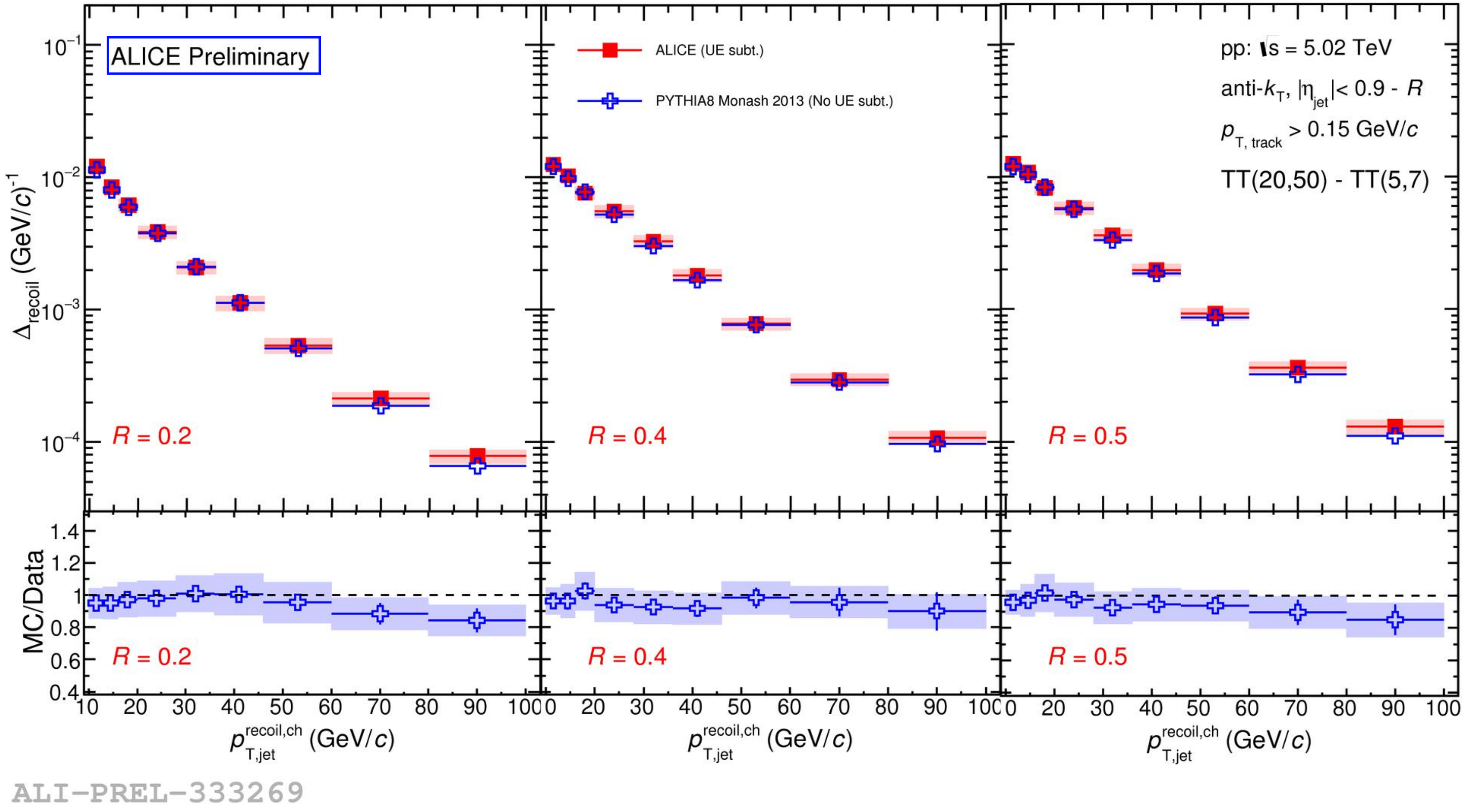
- Detector response matrix is obtained with MC simulation for jet energy scale and resolution correction
- Validate the procedure through the MC unfolding closure
- Using this response matrix to perform unfolding correction

Systematic uncertainty estimate

Resource	How to estimate	Value (%)
Track efficiency	varying tracking efficiency by 4%	4-8
Unfolding	closure test regularization iteration methods(Svd/Bayes)	1-4
Prior	Different generator level as prior	1-3
UE subtraction	background fluctuation	2-6
Binning truncation	different bin boundary in analysis	1-6
C_{ref} determimation	different methods of getting C_{ref} & fitting error	< 1
Total	added in quadrature when uncorrelated	5-13

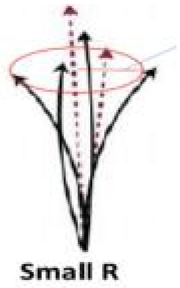
- Systematical uncertainties for different R analysis are similar

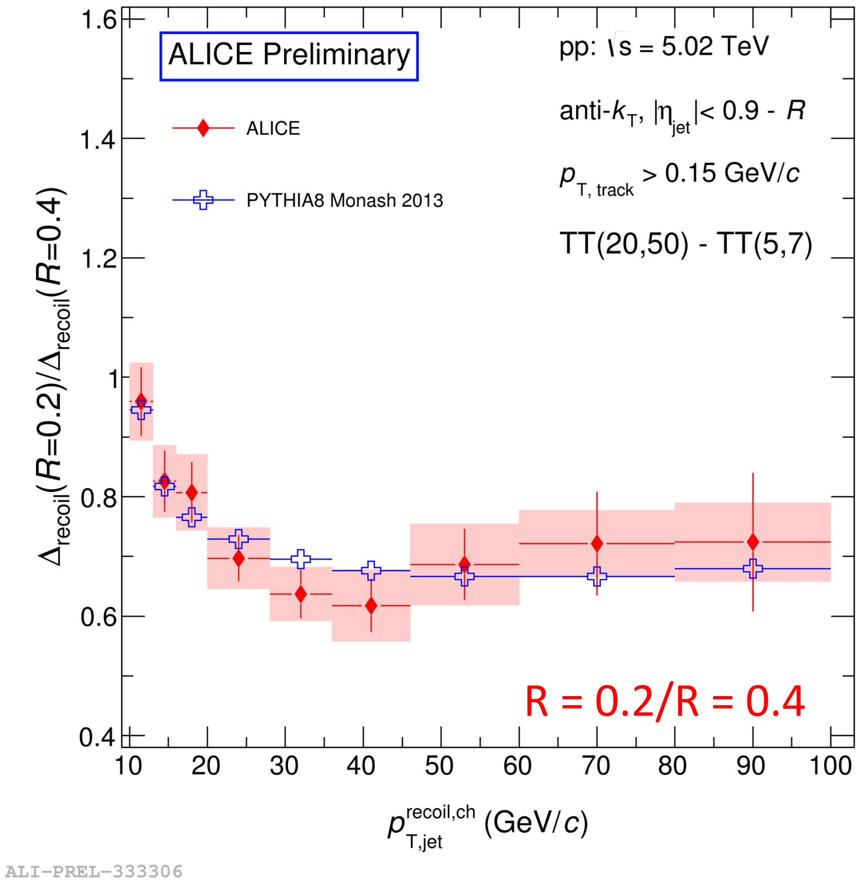
Results (Spectra: △recoil)

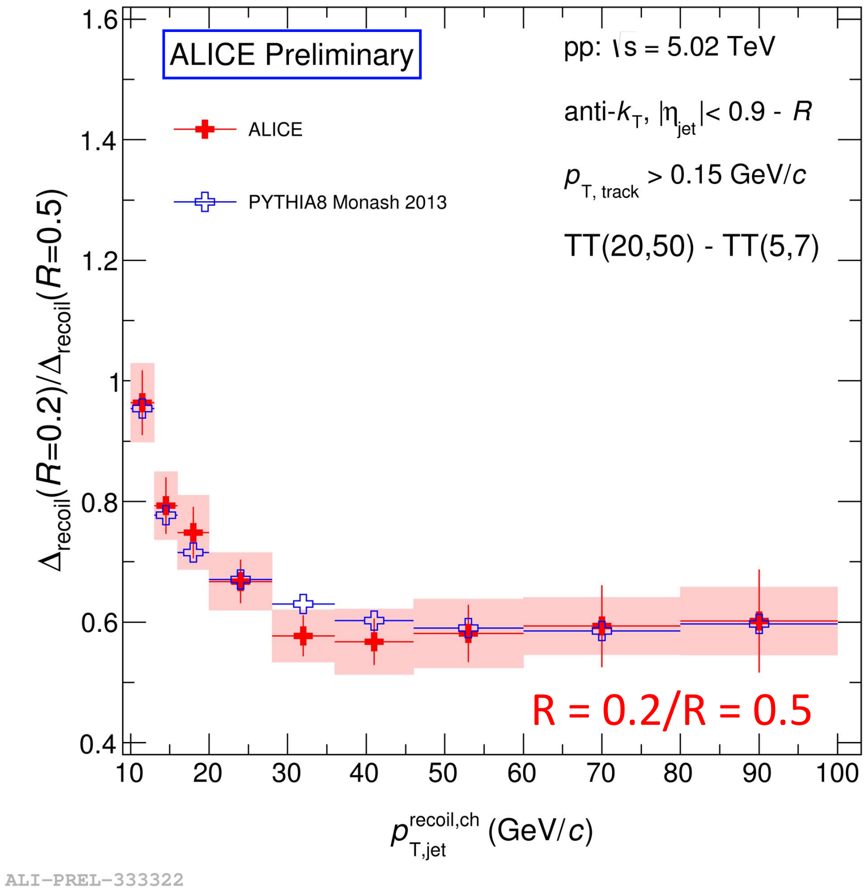


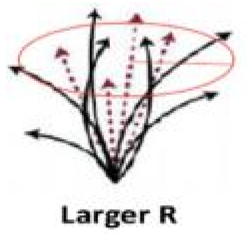
- Corrected Δrecoil distributions for different resolution parameters R = 0.2, 0.4 and 0.5
- PYTHIA8 simulation describes our data well

Results (Spectra: ratio for different radii)



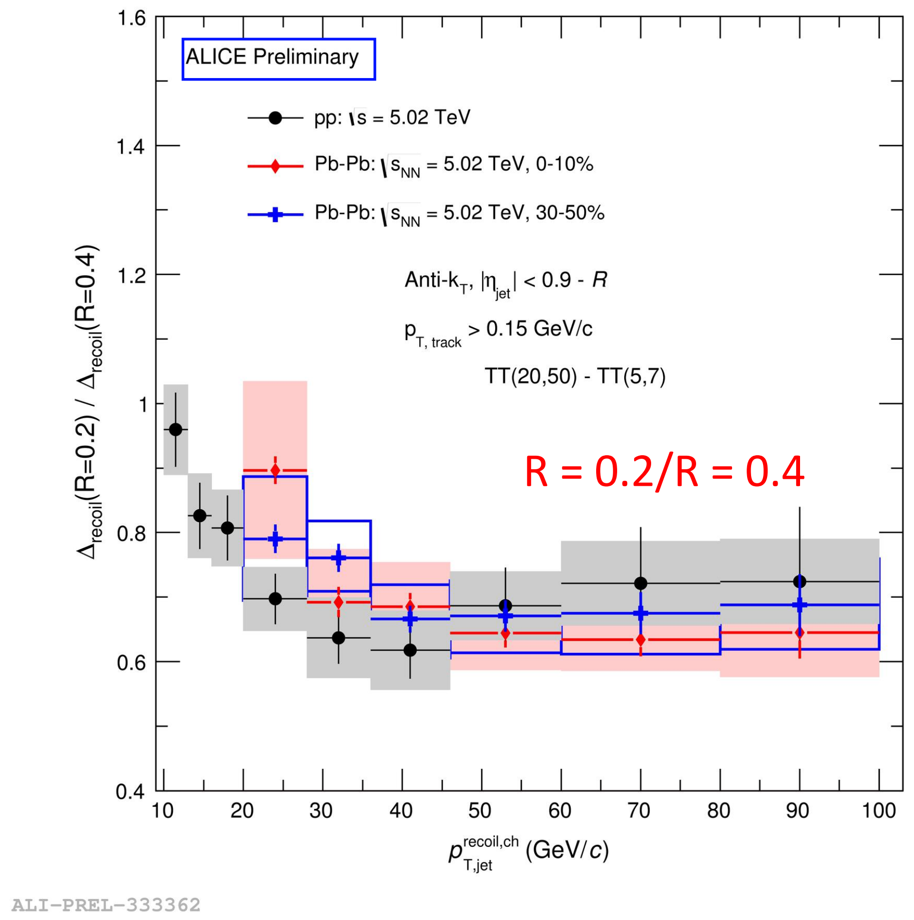


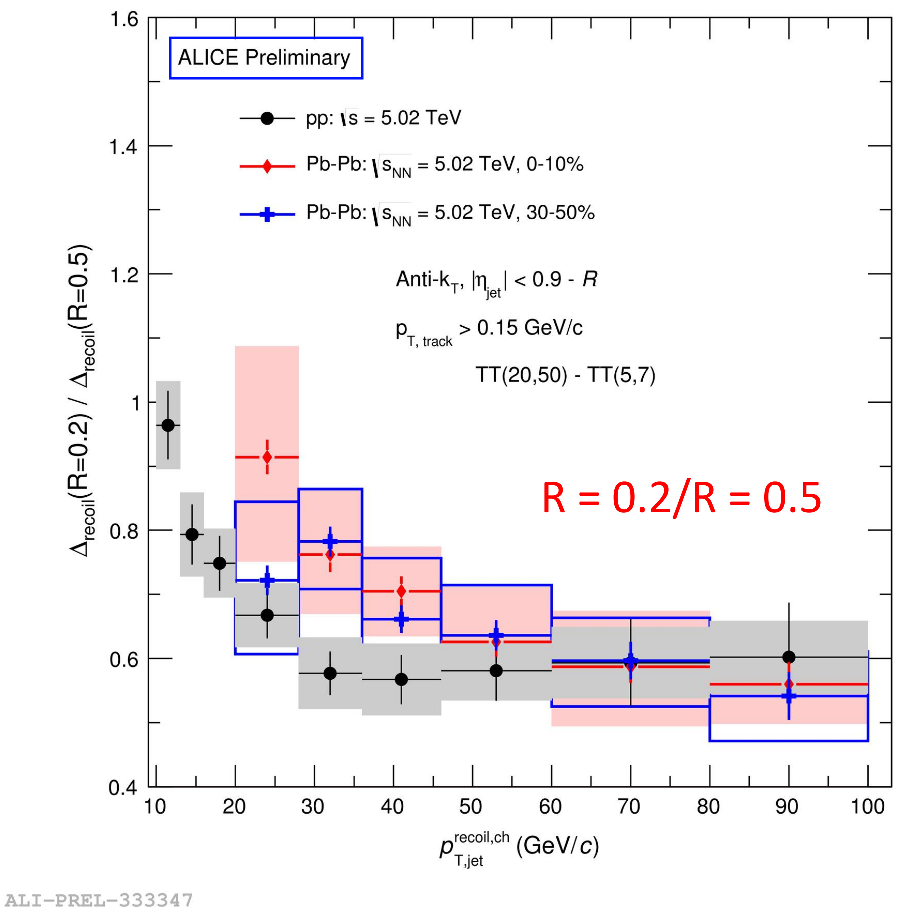




- Jet cross section ratio measures the jet collimation
- Ratios R=0.2/R=0.4 and R=0.2/R=0.5 is slightly increasing with jet p_T
- Consistent with Monte Carlo simulation

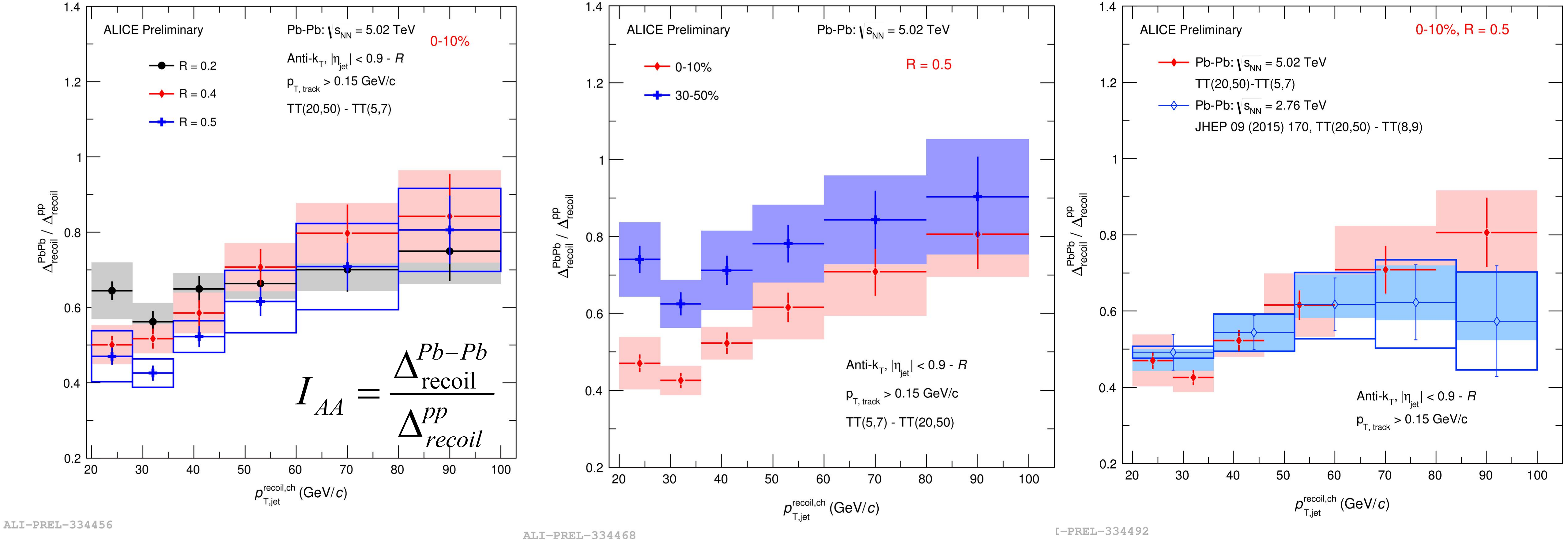
Results (compared with Pb-Pb results)





- Ratios R=0.2/R=0.4 and R=0.2/R=0.5 consistent in different centralities and in pp collisions
- Hint of energy redistribution to large R for low p_T jets in central Pb-Pb collisions

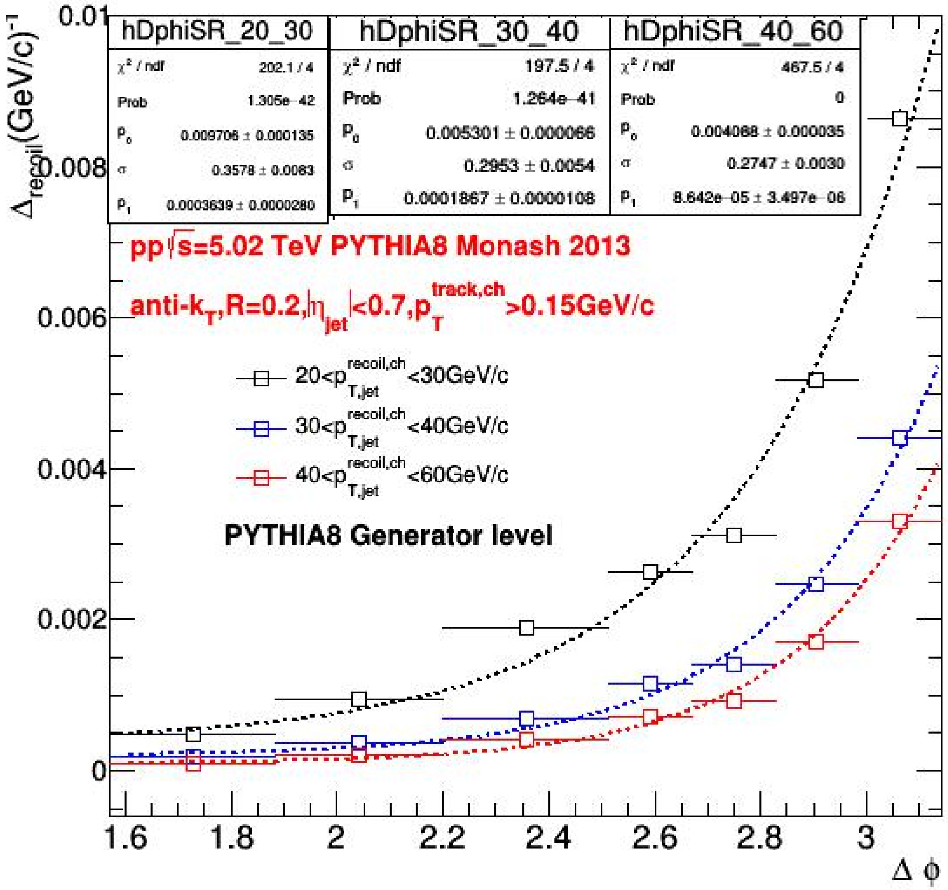
Results (I_{AA})

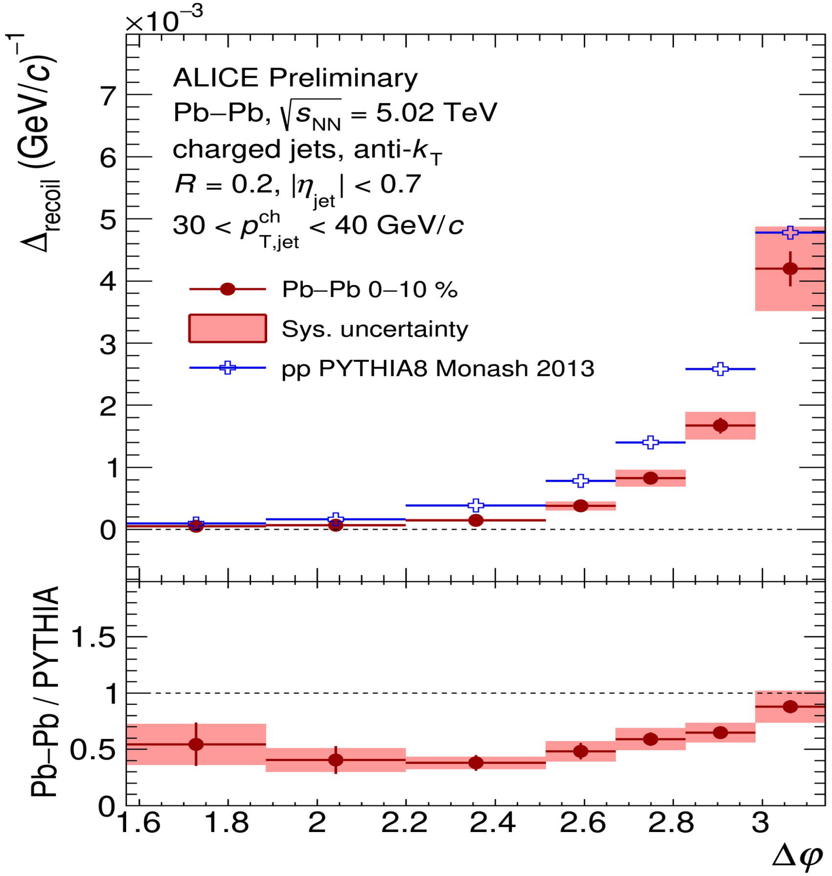


- Recoil jet yield suppression with respect to pp and I_{AA} consistent for different jet radius within uncertainties
- Larger suppression in most central collisions
- Consistent results between 2.76 TeV and 5.02 TeV energy, even with different TT intervals and different references

Hadron-jet azimuthal correlations

- ➢ Azimuthal distribution of recoil jets provides additional insight into QGP properties
- ➢ Broadening of away side jet peak gives direct access to transport coefficient





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Summary and outlook

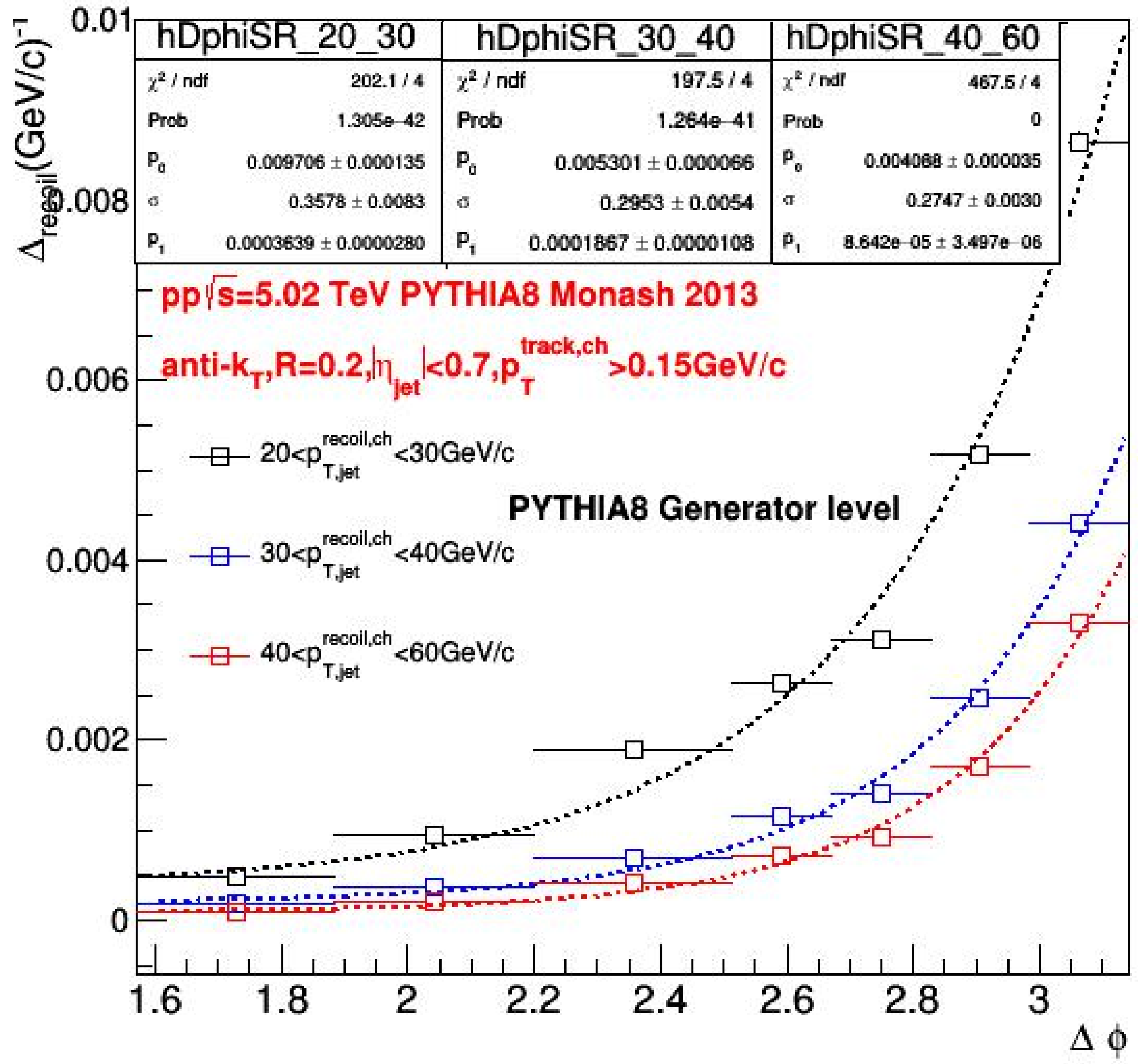
- Semi-inclusive recoil jet yields have been measured in pp and Pb-Pb collisions at 5.02 TeV using RUN2 data at LHC
  - Recoil jet yields can be well described by PYTHIA MC in pp
  - Suppression observed in most and semi-central Pb-Pb collisions, a rising trend with p_{T}
  - Ratios for different Rs have been calculated and are similar between pp and Pb-Pb collisions, hint of energy redistribution to large R for low p_{T} jets in central Pb-Pb collisions

- Next steps
  - pp reference:large-statistics 2017 pp sample at $\sqrt{s} = 5.02$ TeV
  - Push the measurement to low p_{T} and large R

Thank you !

Back up

Hadron-jet azimuthal correlations



p_T^{rec} Range(GeV/c)	σ_{gen}^{MC}	$\varepsilon_{\sigma,error}^{MC,gen}$
20-30	0.3578	± 0.0083
30-40	0.2953	±0.0054
40-60	0.2747	±0.0030

Data and MC samples

- Data: pp @5.02 TeV

Period	N event (FAST)	N event (CENT)	N event (All)	Percentile of total events
LHC15n	90M		90M	9%
LHC17p	573M	316M	889M	86%
LHC17q	29M	25M	54M	5%

For the preliminary results: only 17p FAST+CENT was used (~86%)
(full list of run numbers in backup)

- Mote Carlo(anchored to 17p data) : only JJ MC used for the moment

LHC18b8_FAST (Jet-Jet): PYTHIA8, ~4.7M events/bin 20bins in total

LHC18b8_CENT(Jet-Jet): PYTHIA8, ~2.6M events/bin 20bins in total

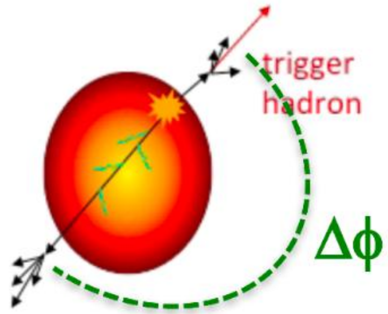
Selection

Selection for events and tracks:

- **Evet Selection:** kINT7, $|V_z| < 10cm$, $|V_{z(TPCtracks)} - V_{z(SPDtracks)}| < 0.5cm$
- **Track Selection:** $\mathrm{P}_T^{\mathrm{track}} > 0.15GeV/c$ $|\eta_{\mathrm{track}}| < 0.9$

Selection for hadron-jet analysis:

- **Jet Reconstruction:** Anti-KT algorithm,R=0.2, 0.4,0.5 $P_T^{Jet} > 1.0GeV/c$ $|\eta_{\mathrm{jet}}| < 0.9 - R$
- **Trigger Tracks pt Interval :** Signal: (5, 7)GeV/c Reference:(20, 50)GeV/c



Analysis Strategy

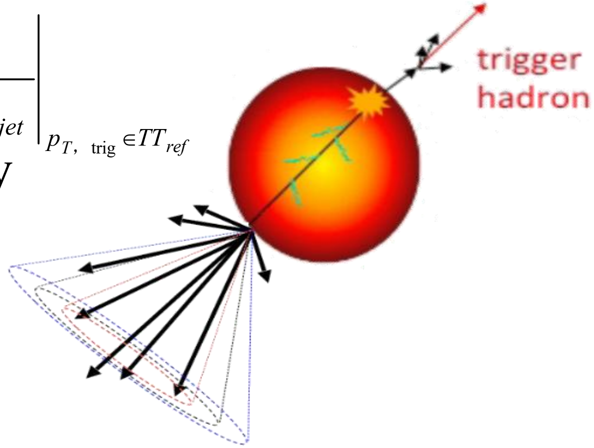
- Measure trigger-normalized charged jet recoiling from trigger hadron

$$\frac{1}{N_{trig}}\frac{d^2N_{jet}}{dp^{ch}_{T,jet}d\eta_{jet}}\bigg|_{p_{T,trig}\in TT}=\left(\frac{1}{\sigma^{PP\to h+X}}\cdot\frac{d^2\sigma^{pp\to h+jet+X}}{dp^{ch}_{T,jet}d\eta_{jet}}\right)\bigg|_{p_{T,h}\in TT}$$

- Observables defined as the difference between trigger-normalised recoil jet distributions in two exclusive trigger track intervals in order to subtract all uncorrelated background jets
  - Signal: (20,50) GeV/c Reference:(5,7) GeV/c
    Cross checks: Signal: TT[15,20] ,[20-25], [25-30], [30-45] GeV/c Reference: TT[5-6], [6-7], [7-8], [8-9] GeV/c
  - Divide data into two subsets for statistical independent signal & reference sample
  - Loop over events:
    - ✓ Select event if there is a trigger track within the defined p_{T} interval
    - ✓ Select all jet candidates with R = 0.2, 0.4, 0.5
  - Observable Δ recoil is defined:

$$\Delta recoil=\frac{1}{N_{\mathrm{trig}}}\frac{d^2N_{jet}}{dp^{ch}_{T,jet}d\Delta\eta_{jet}}\bigg|_{p_{T,\ \mathrm{trig}}\in TT_{sig}}-c.\frac{1}{N_{\mathrm{trig}}}\frac{d^2N_{jet}}{dp^{ch}_{T,jet}d\Delta\eta_{jet}}\bigg|_{p_{T,\ \mathrm{trig}}\in TT_{ref}}$$

c = scaling factor to account for conserved jet density

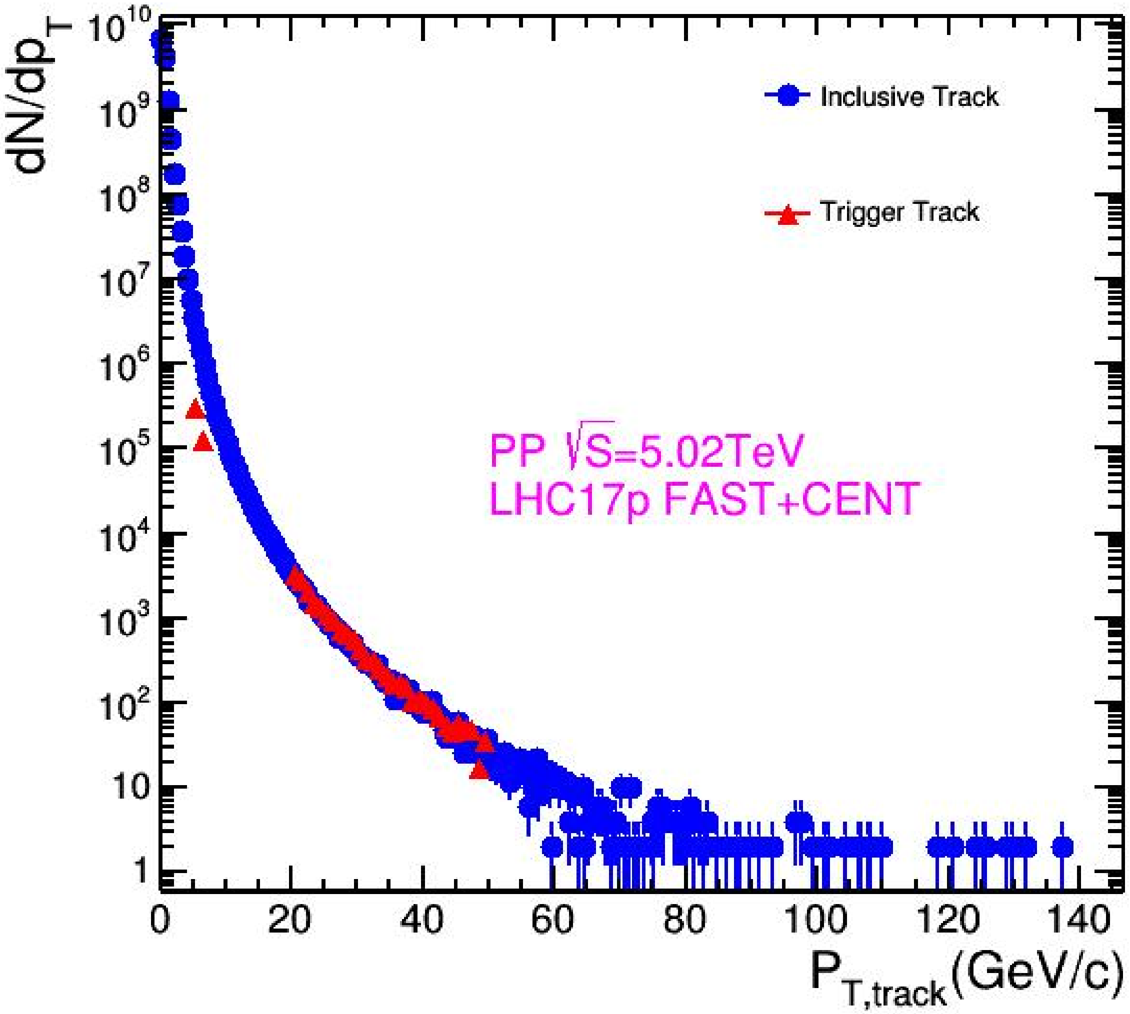


  - Azimuthal correlation observable Φ(Δφ) :

$$\Phi(\Delta\phi)=\frac{1}{N_{\mathrm{trig}}}\frac{d^2N_{jet}}{dp^{ch}_{T,jet}d\Delta\phi_{jet}}\bigg|_{p_{T,\ \mathrm{trig}}\in TT_{sig}}-c.\frac{1}{N_{\mathrm{trig}}}\frac{d^2N_{jet}}{dp^{ch}_{T,jet}d\Delta\phi_{jet}}\bigg|_{p_{T,\ \mathrm{trig}}\in TT_{ref}}$$

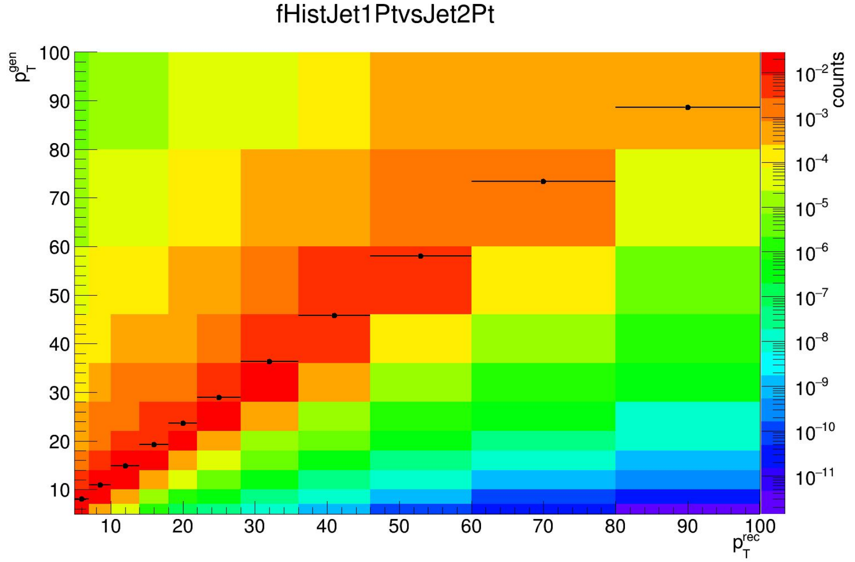
Trigger track distribution

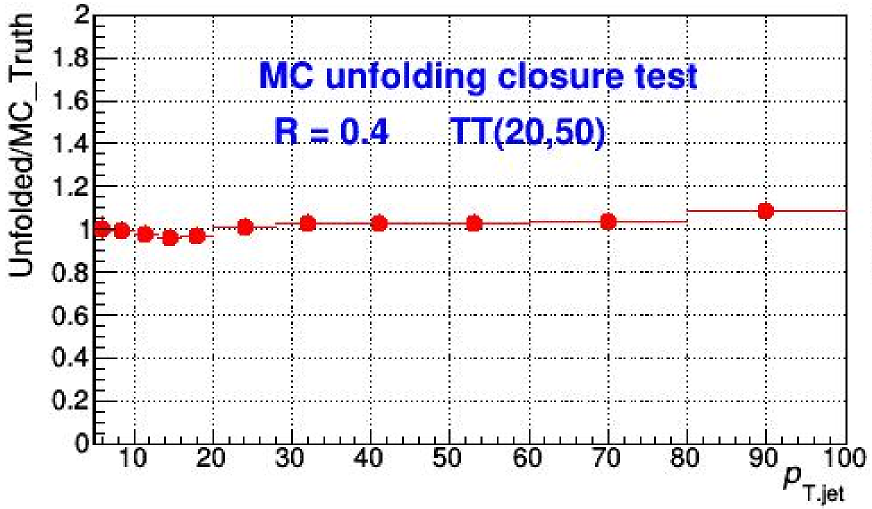
➢ Trigger track p_T distribution

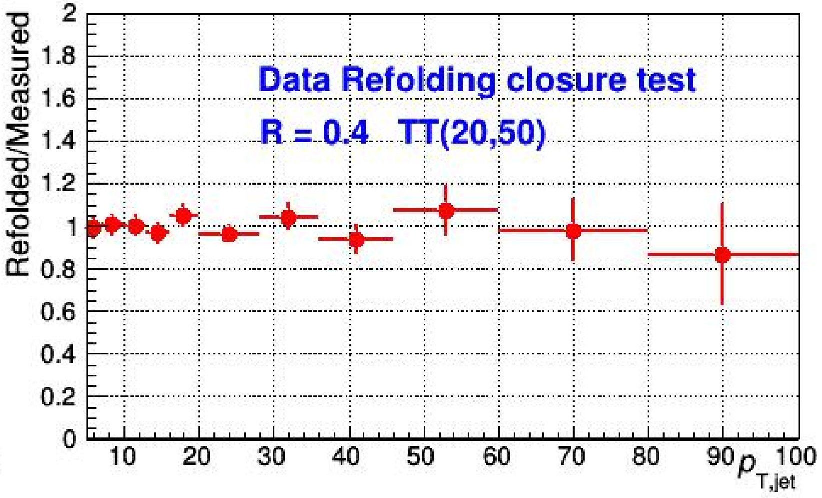


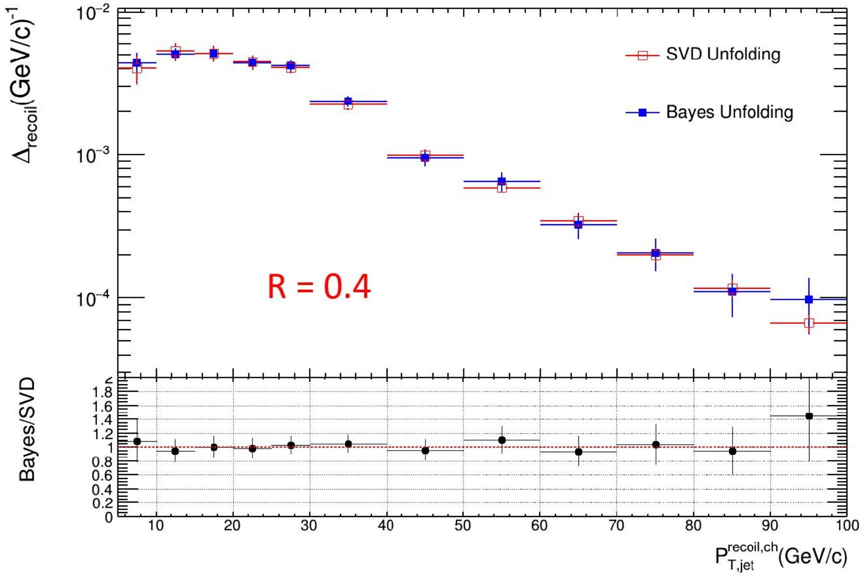
- Signal trigger particle p_T interval (20, 50) GeV/c
- Reference trigger particle p_T interval (5, 7) GeV/c

Unfolding corrections



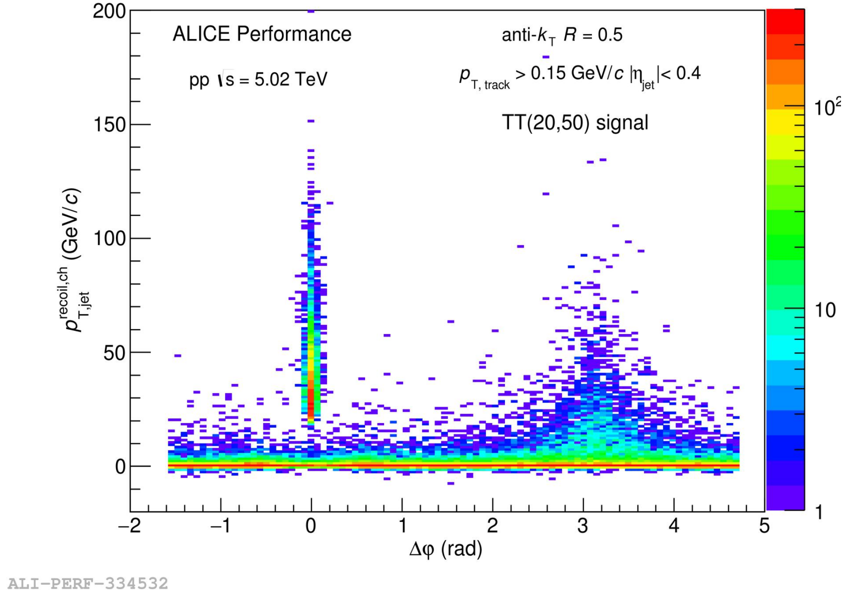




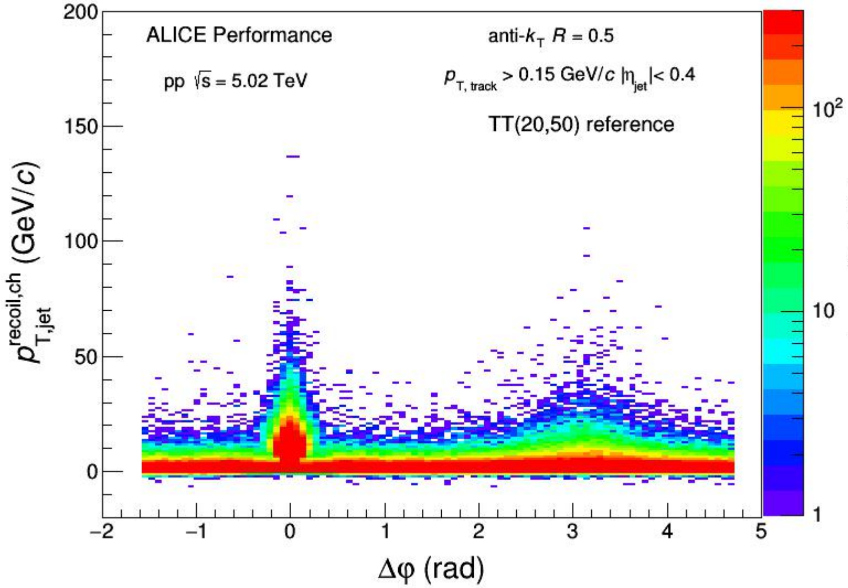


- The black point on the response show the mean value between x and y
- Validate the procedure through the MC unfolding closure and refolding test
- Different unfolding methods are consistent

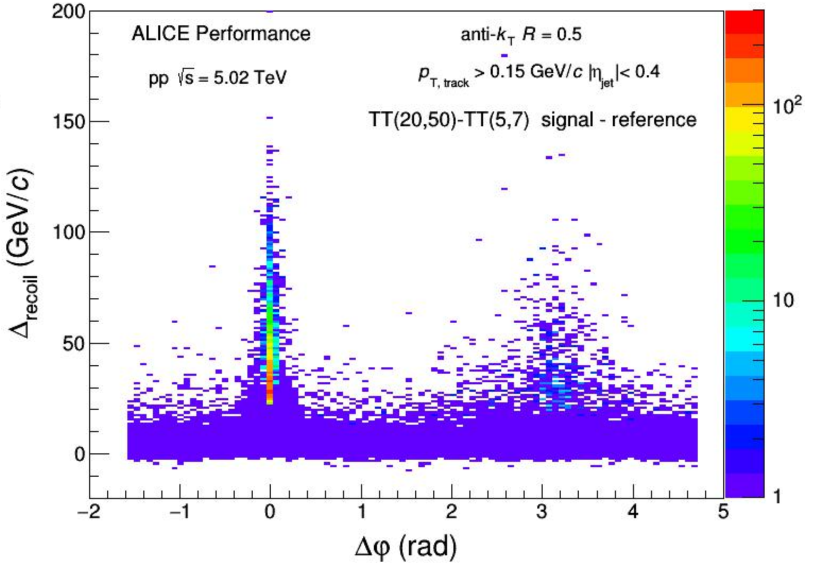
Δφ analysis status



TT(20,50) signal

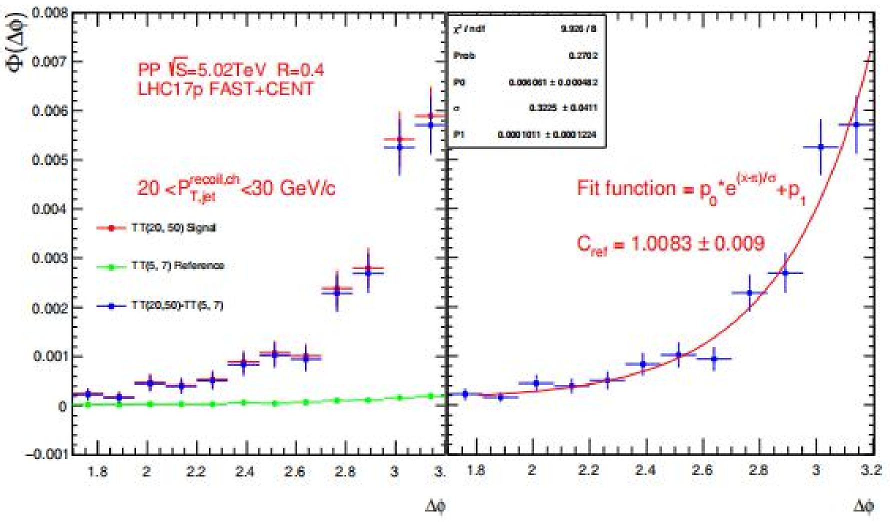


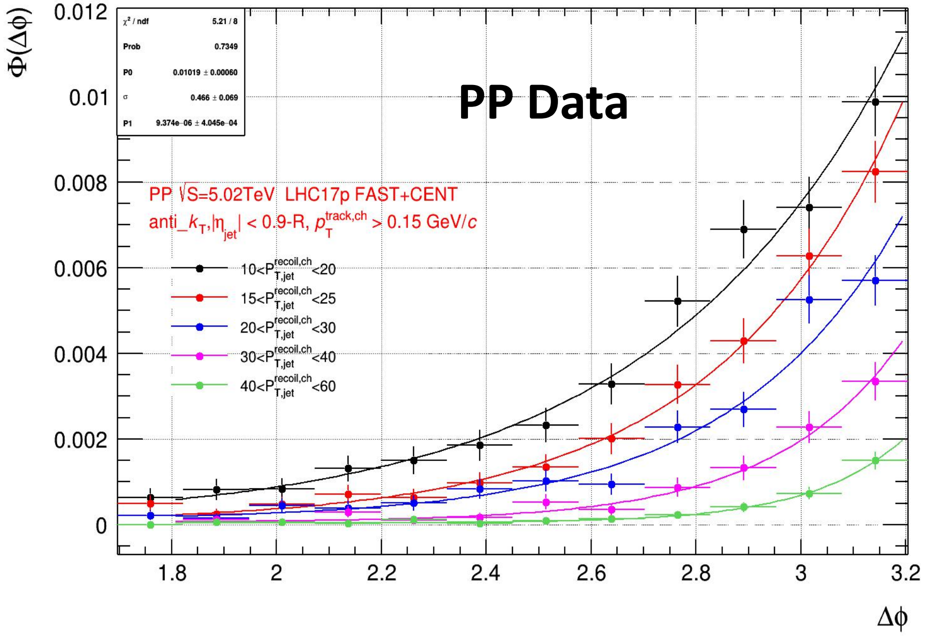
TT(5,7) reference

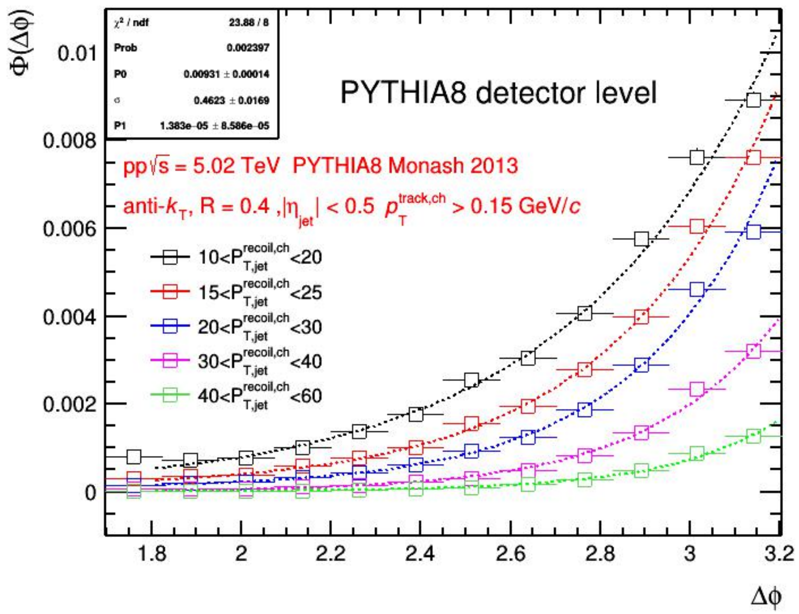


signal - reference

Δφ analysis status



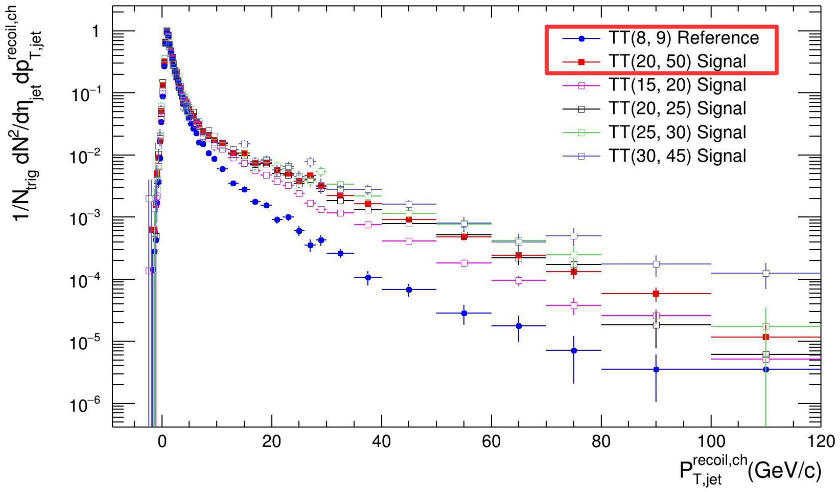


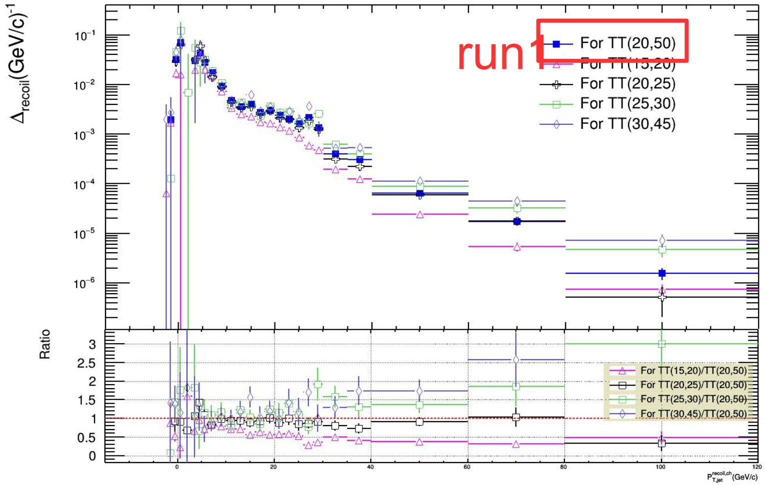


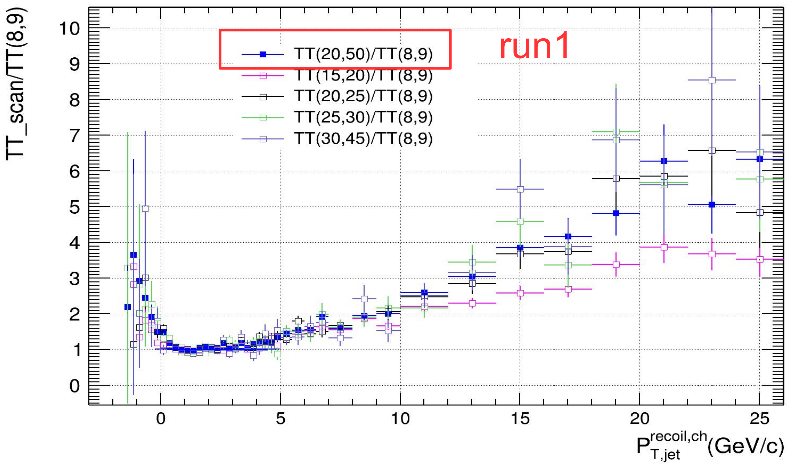
p_T^{rec} Range(GeV/c)	σ^{data}	$\varepsilon^{data}_{\sigma.error}$	$\sigma^{MC}_{det.}$	$\varepsilon^{MC,det}_{\sigma.error}$
10 - 20	0.4659	±0.0685	0.4514	±0.0156
15 - 25	0.3543	±0.0407	0.3619	±0.0083
20 - 30	0.3225	±0.0411	0.3086	±0.0061
30 - 40	0.2438	±0.0346	0.2539	±0.0931
40 - 60	0.1782	±0.0284	0.2469	±0.0020

TT signal interval scan for recoil jet P_T

- TT_reference: 8-9 GeV/c (run1), TT_signal scan: 15-20, 20-25, 25-30, 30-45 GeV/c





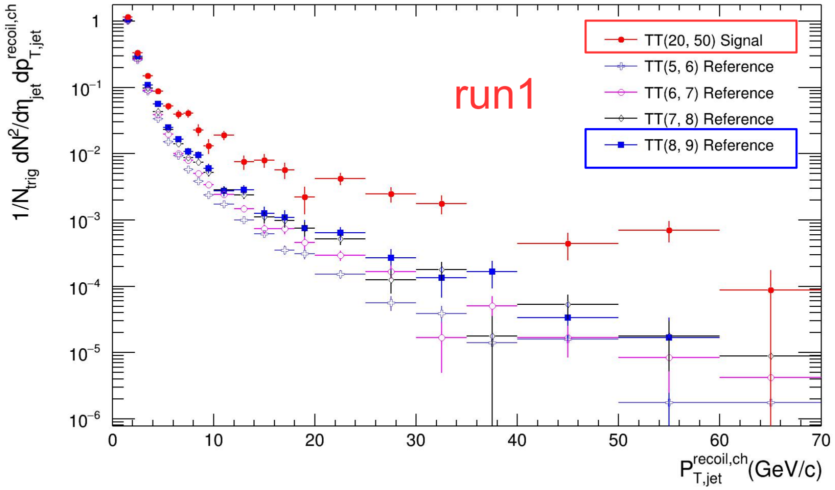


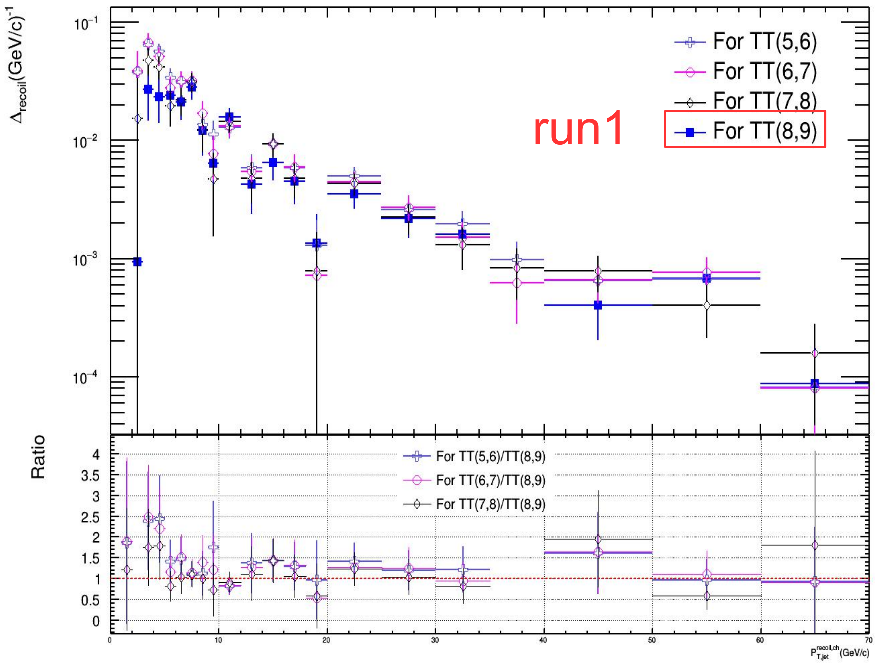
p_T low	p_T high	R	N Trigger Tracks	N jet > 40 GeV/c
15	20	0.4	29083	232
20	25	0.4	8183	145
25	30	0.4	2857	87
30	35	0.4	1176	35
35	45	0.4	821	44
20	50	0.4	12809	247

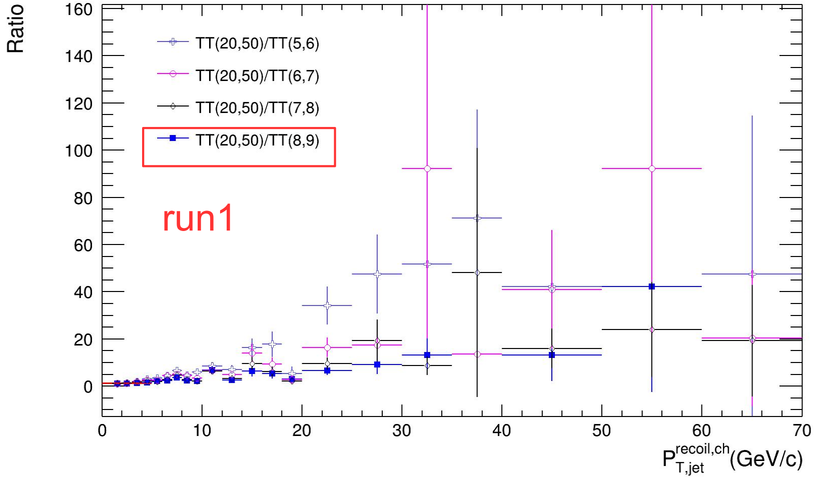
- Increasing statistic fluctuation with smaller TT signal intervals

TT reference interval scan for recoil jet P_T

➢ TT_signal: 20-50 GeV/c (run1) TT_reference scan: 5-6, 6-7, 7-8, 8-9 GeV/c







p_T low	p_T high	R	N Trigger Tracks	N jet > 40 GeV/c
5	6	0.4	526708	143
6	7	0.4	221962	104
7	8	0.4	104793	143
8	9	0.4	55458	52