Implementation of jet analyses in Rivet

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Outline

- Rivet projections for jets
- Jets in pp or modified pp (ex. Jewel) simulations
- Jets in heavy-ion simulations
  - Centrality determination
  - Jet background
  - Examples of implementations
    - ALICE jet background paper
    - ALICE jet suppression in central Pb-Pb collisions
- Unfolding?

Projection: FastJets

FastJets

- Rivet projection to cluterize jets using the FASTJET package
- Can calculate jet area if some parameters are set
- Ready to analyze jets in pp collisions

Heavy-ion collisions

- Modified pp collisions (ex. PYTHIA+JEWEL)
  - Standard pp collisions analysis

- Heavy-ion simulation (ex. Angantyr, HIJING)
  - Centrality has to be determined
  - Jet background needs to be subtracted
  - Rivet standard code can not fully handle it

Jets in simulations of pp collisions

Projection: FastJets

Standard Rivet Analysis

- init() -> Declarations
- analyze() -> Main analysis. Loop over all events
- finalize() -> Normalizations and ratios

Defining particles and jets

- Define FinalState particles inside init()

```
const FinalState fs(Cuts::pT > 150*MeV && Cuts::abseta < 0.9);
declare(fs,"fs");
```

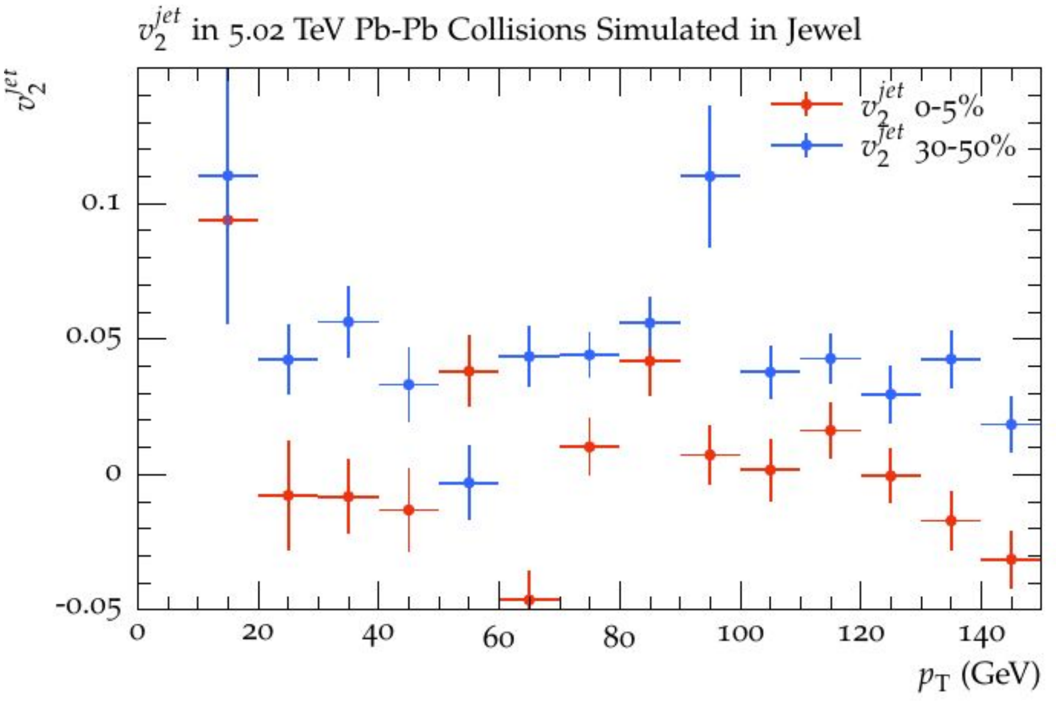
- Define FastJets inside init()

```
FastJets jetfs(fs, FastJets::ANTIKT, 0.4, JetAlg::Muons::NONE, JetAlg::Invisibles::NONE);
declare(jetfs, "jets");
```

- During analyze()

```
Jets jets = apply<FastJets>(event, "jets").jetsByPt(Cuts::pT > 30*GeV);
```

Jet v_2 with Rivet



William Witt, UT Knoxville

Jewel was used to simulate heavy-ion collisions (Pb-Pb at 5.02 TeV)

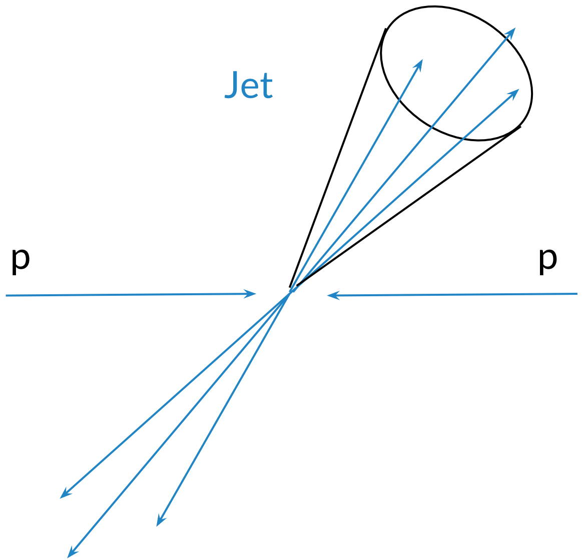
- Jet v_2 in two centralities set in Jewel
- Data is not displayed because it is not publish yet
- With a few changes it will work for different collision systems and energies
- **Rivet is ready for pp or pp modified (ex. Jewel) analyses**

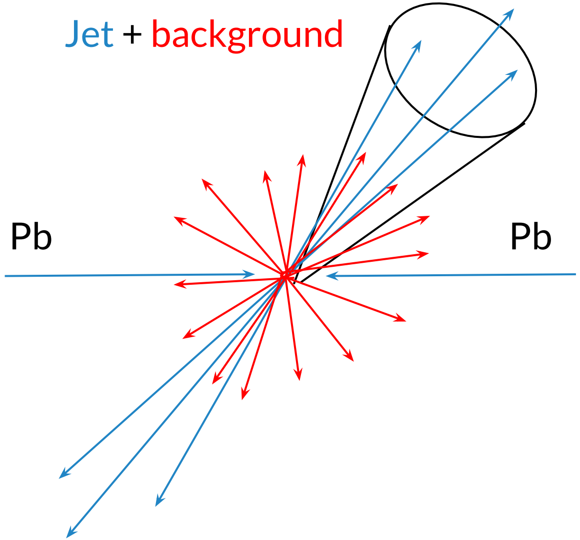
Jets in heavy-ion simulations

Rivet: Jet background in heavy-ions

Heavy-ion simulation

- Simulations like Angantyr and HIJING will generate not only jets, but also a large amount of soft particles created in a heavy-ion collision
- Centrality needs to be determined using the particles created in the event
- The average background in the event needs to be subtracted from the jet





Rivet: Centrality determination

Centrality determination

- In experiments the impact parameter is not accessible, so one must calculate the centrality
- Before running the physics analysis, the centrality has to be calibrated
- ALICE centrality is presented here as an example

ALICE Centrality determination

- Run the analysis ALICE_2015_PBPBCentrality.cc (centrality calibration)

```
rivet --pwd -a ALICE_2015_PBPBCentrality -o calibration.yoda /path_to_hepMC_files/file.hepMC
```

calibration.yoda → Centrality calibration file

/path_to_hepMC_files/file.hepMC → Minimum bias heavy-ion collisions events

Rivet: Centrality determination

Running the physics analysis

- After having the calibration.yoda file, you can use it to determine centrality in your analysis

rivet --pwd -p calibration.yoda -a ALICE_2020_I1234567:cent=GEN /path_to_hepMC_files/file.hepMC

Centrality calibration file

Use generated centrality

Attention: the file ALICE_2020_I1234567.info has to contain the following lines

Options:

- cent=REF,GEN,IMP,USR

Otherwise Rivet will not be able to identify that “cent” is being set to “GEN”

Rivet: Centrality determination

Declaring centrality in the analysis

- The centrality is a projection in Rivet and has to be declared inside init()

```
declareCentrality(ALICE::V0MMultiplicity(), "ALICE_2015_PBPBCentrality", "V0M","V0M");
```

- Then it can be used during the event loop in analyze(const Event& event)

```
const CentralityProjection& centProj = apply<CentralityProjection>(event,"V0M");
const double cent = centProj();
```

Once the centrality is obtained, any selection between 0. to 100. can be applied accordingly to the analysis

Projection: BackgroundRho

BackgroundRho

- Created a new class (projection) in Rivet to handle the jet background subtraction.
- Jet area is necessary

Ghost Area

```
fastjet::AreaDefinition *fjAreaDef;
fastjet::GhostedAreaSpec fjGhostAreaSpec = fastjet::GhostedAreaSpec(1., 1, 0.005, 1., 0.1, 1e-100);
fastjet::AreaType fjAreaType = fastjet::active_area_explicit_ghosts;
fjAreaDef = new fastjet::AreaDefinition(fjGhostAreaSpec, fjAreaType);
```

Ghost area (0.005)

Ghost mean p_T (1e-100)

FastJets definition

```
const FastJets jetsFJ(fs, fastjet::JetAlgorithm::antikt_algorithm, fastjet::RecombinationScheme::pt_scheme,
jetR, fjAreaDef, JetAlg::Muons::NONE, JetAlg::Invisibles::NONE);
declare(jetsFJ, "jets");
```

Parameters may depend on the experiment!

Projection: BackgroundRho

Jet Background Subtraction

- Possibility of removing leading jets
- Selections on jets used in the calculation of rho
    - Jet p_T, acceptance, area

$$\rho = median\left\{\frac{p_{\mathrm{T}}^{jet}}{A_{jet}}\right\} \qquad p_{\mathrm{T}}^{corr} = p_{\mathrm{T}}^{raw} - \rho A_{jet}$$

Typically this is performed using k_T jets

Projection: BackgroundRho

Declaring BackgroundRho in the analysis

- Declared inside the init()

```
BackgroundRho projRho(removeNLeadJets, jetAreaCut);
declare(projRho,"projRho");
```

Number of leading jets to be removed

Accept jet if A_{jet} > jetAreaCut

- During the analyze()

```
BackgroundRho projRho = applyProjection<BackgroundRho>(event, "projRho");
double rho = projRho.getRho(jetsKT);
```

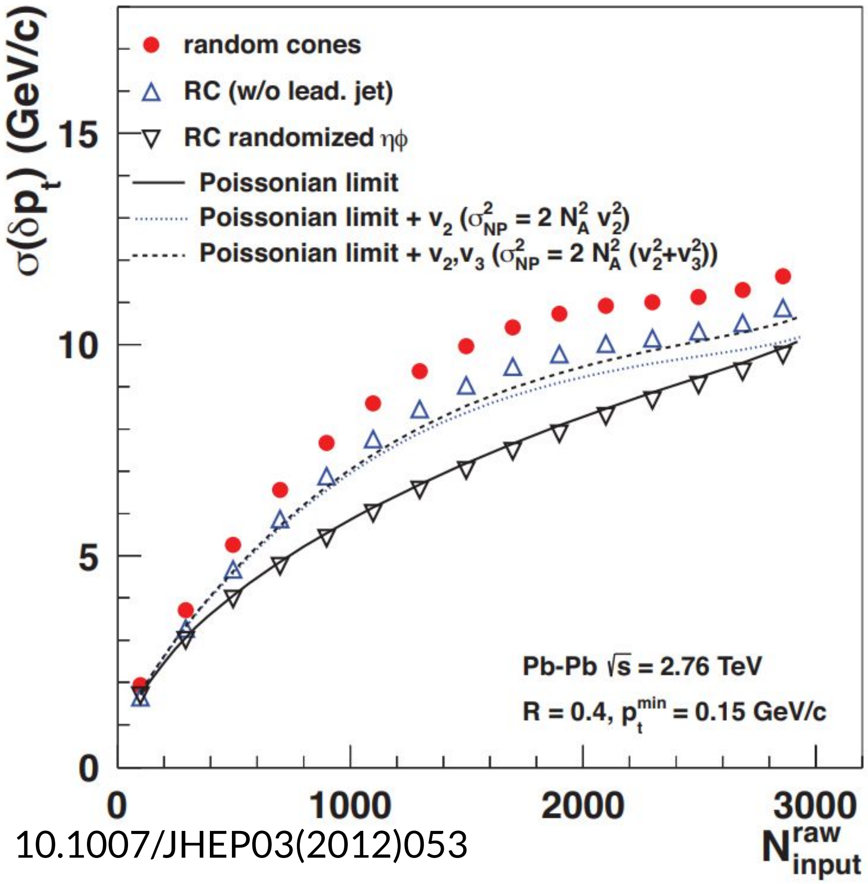
FastJets object

ALICE jet background paper

Measurement of event background fluctuations for charged particle jet reconstruction in Pb–Pb collisions at = 2.76TeV

- Published in 2012, 10.1007/JHEP03(2012)053
- Calculated δp_T distribution using random cones, where $\delta p_T = p_{T,cone} - \rho A_{cone}$
- Angantyr was used to generate Pb-Pb collisions events at 2.76 TeV
- The paper presents a study of the jet background fluctuation in Pb-Pb collisions

ALICE jet background paper



10.1007/JHEP03(2012)053

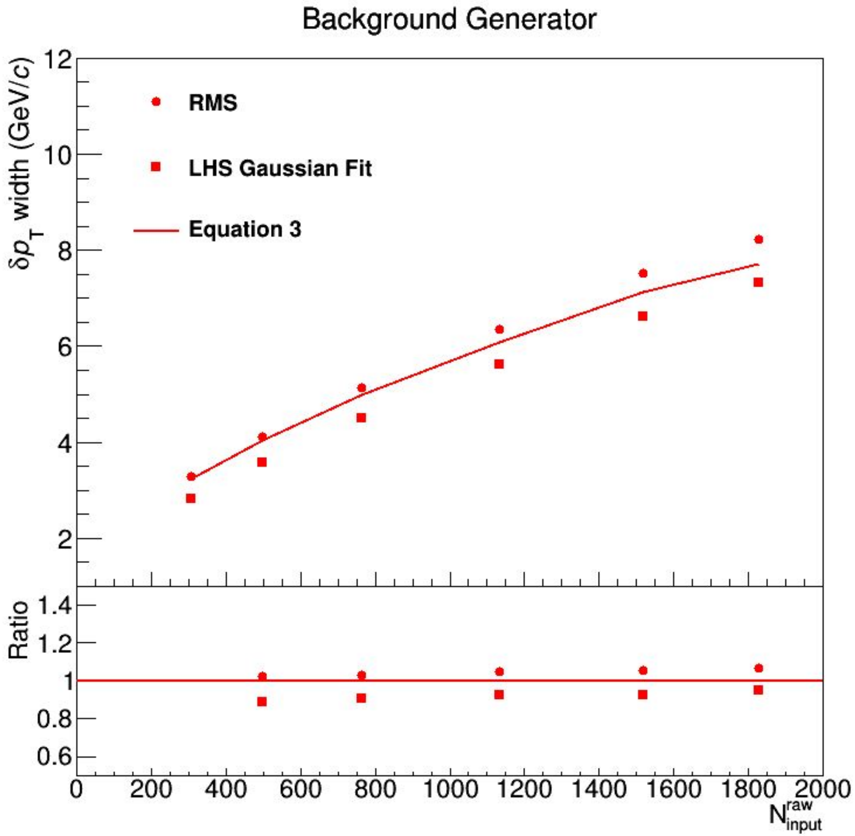
Jet background studies

- ALICE compared Pb-Pb data to the prediction for the standard deviation of the δp_T distribution
- The distribution for randomized η-ϕ particles is in agreement with the prediction
- The non randomized distribution agrees with a modified version of the prediction, where flow is added to the equation

$$\sigma(\delta p_T) = \sqrt{N_A \sigma^2(p_T) + (N_A + \sigma^2_{NP})\langle p_T \rangle^2}$$

- N_A is the expected number of particles in the cone area A

ALICE jet background paper



Jet background studies

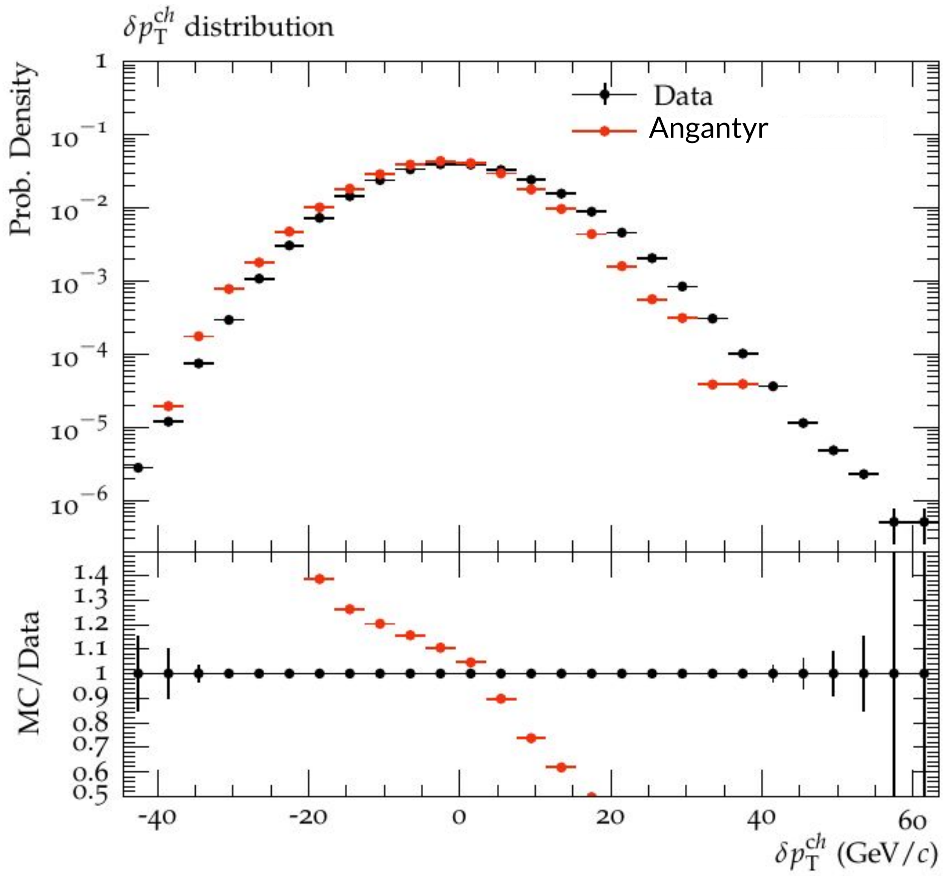
- The standard deviation of the δp_T distribution for a purely random η-ϕ particle distribution follows the equation

$$\sigma(\delta p_T) = \sqrt{N_A \sigma^2(p_T) + N_A \langle p_T \rangle^2}$$

- The background generator creates a random η-ϕ distributions of particles that are direct compared to the equation

Charles Hughes background generator

ALICE jet background paper



The BackgroundRho projection was used for this comparison

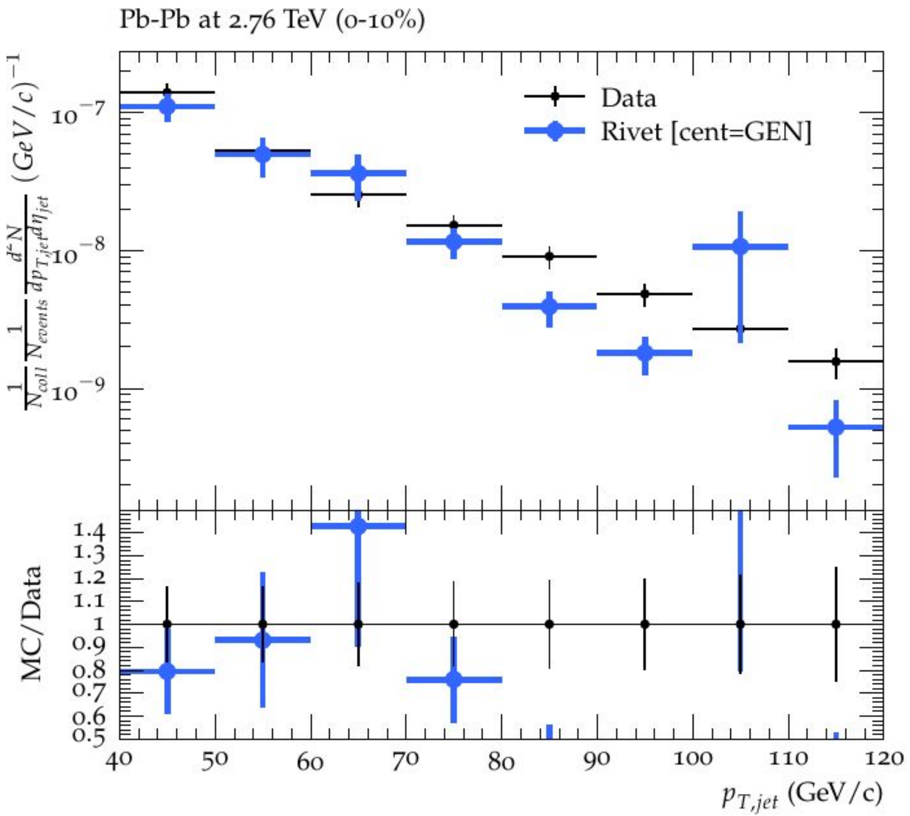
- Pb-Pb at 2.76 TeV, 0-10% most central
- The two leading jets in the event were removed
- The standard ALICE parameters were used
- R_{jet} = 0.4, anti-k_T algorithm

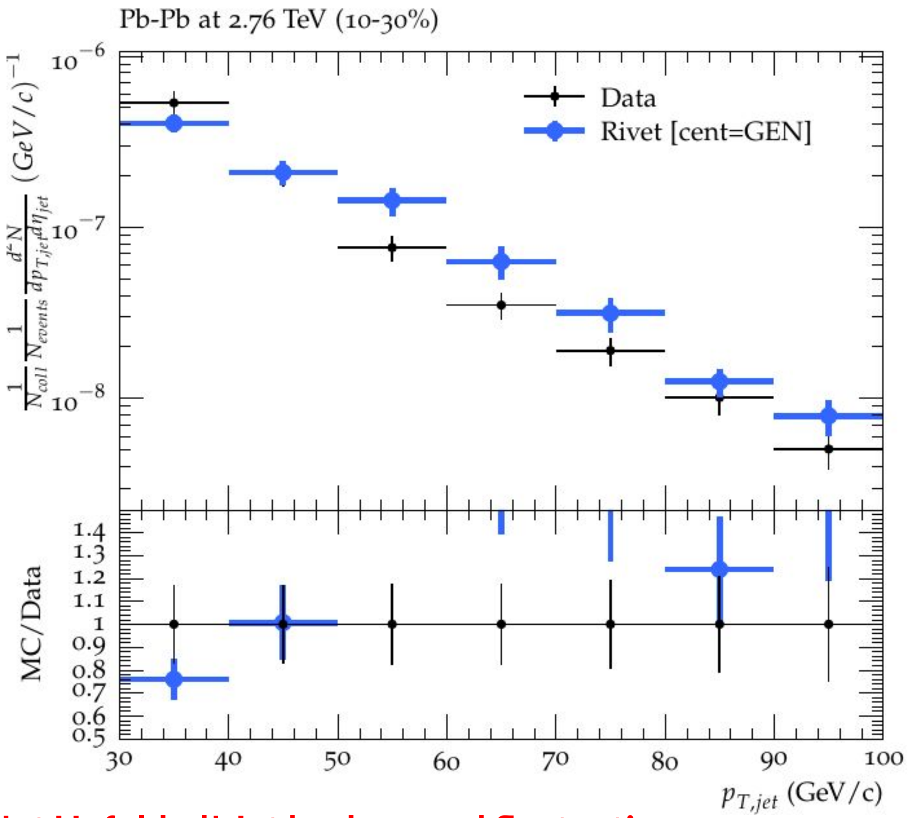
Jet suppression in central collisions

ALICE paper: Measurement of jet suppression in central Pb–Pb collisions at 2.76 TeV

- Published in 10.1016/j.physletb.2015.04.039
- Angantyr was used to generate Pb-Pb collisions events at 2.76 TeV
- The standard ALICE parameters were used
- R_{jet} = 0.2, anti-k_T algorithm

Jet suppression in central collisions





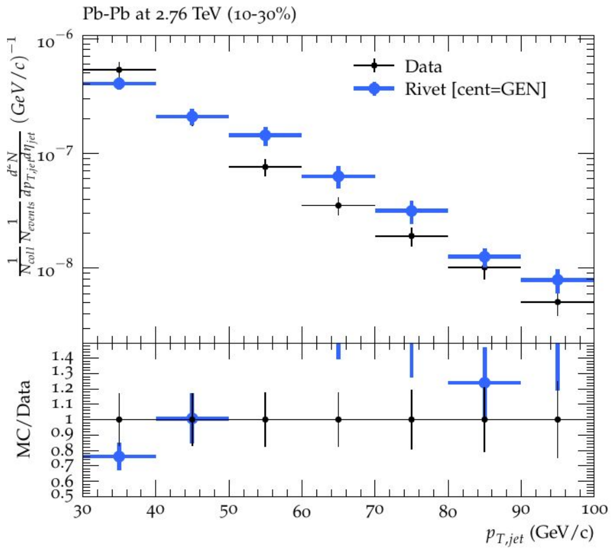
Not Unfolded! Jet background fluctuation is still affecting the comparison

Unfolding is still missing

Rivet standard code do not support Unfolding at the moment

- Jet background fluctuation still needs to be corrected

- Not an easy implementation, but necessary to make comparisons with jets in heavy-ion collisions



Conclusions

- Presented instructions of how to proceed with a jet analysis in Rivet
  - FastJets declaration and usage

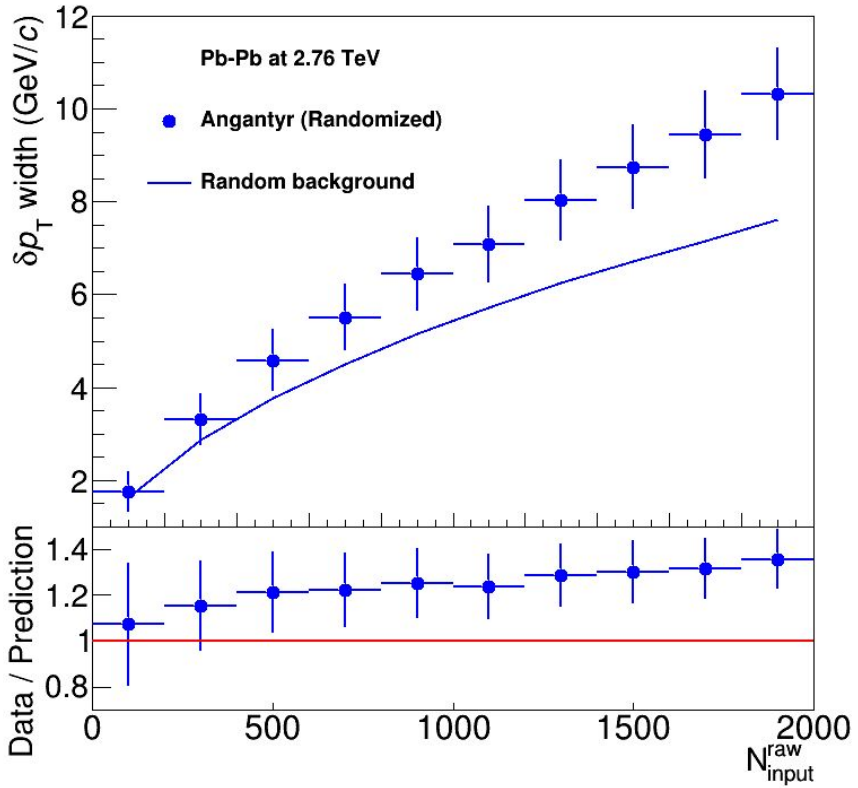
- Simulations of heavy-ion collisions **without the jet background**: Rivet is ready to analyse it
  - Ex. Jewel

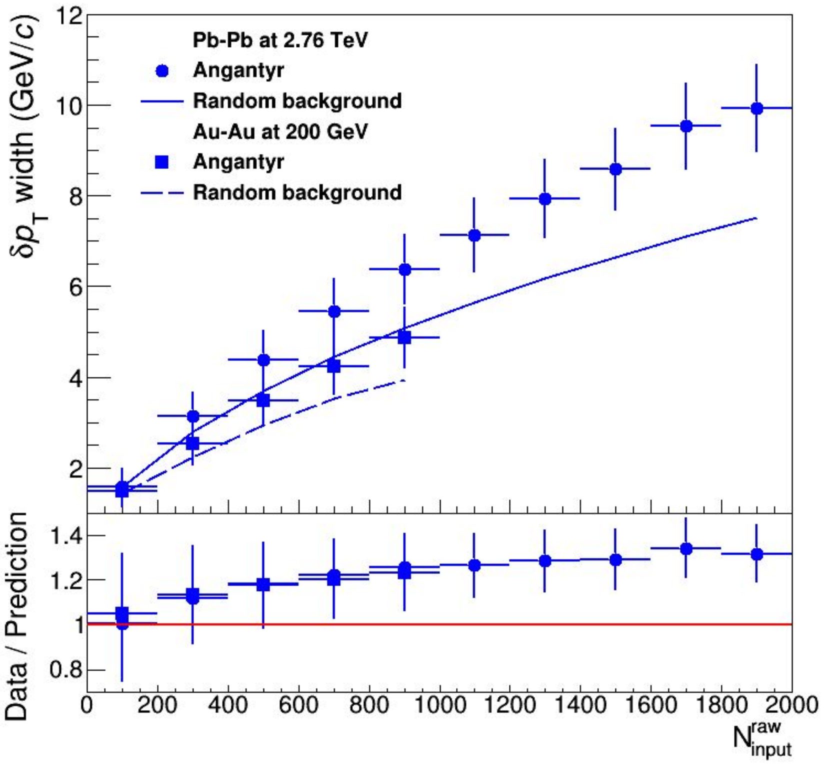
- Simulations with the jet background: Rivet needs unfolding
  - BrackgroundRho projection can subtract the median of the jet background
  - Fluctuations still present
  - Centrality determination works

Thank you!

Backup

Backup


Pb-Pb at 2.76 TeV
Angantyr (Randomized)
Random background
δp_T width (GeV/c)
Data / Prediction
N_{input}^{raw}


Pb-Pb at 2.76 TeV
Angantyr
Random background
Au-Au at 200 GeV
Angantyr
Random background
δp_T width (GeV/c)
Data / Prediction
N_{input}^{raw}