Apr/15/2025, RBRC exp. group meeting

Status of jet asymmetry study

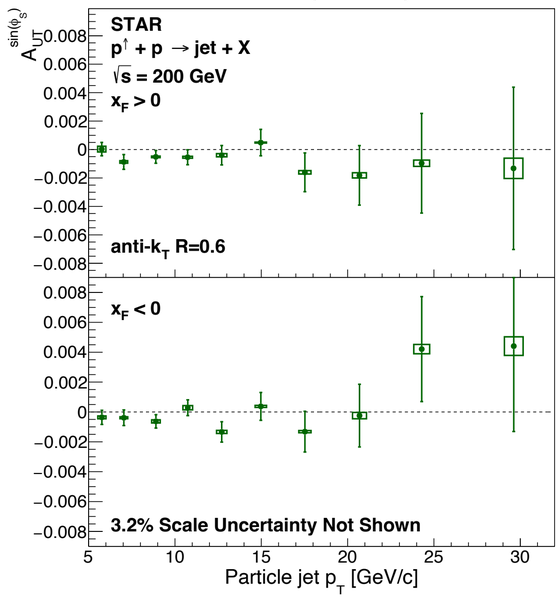
Genki Nukazuka (RIKEN)

Jet asymmetries

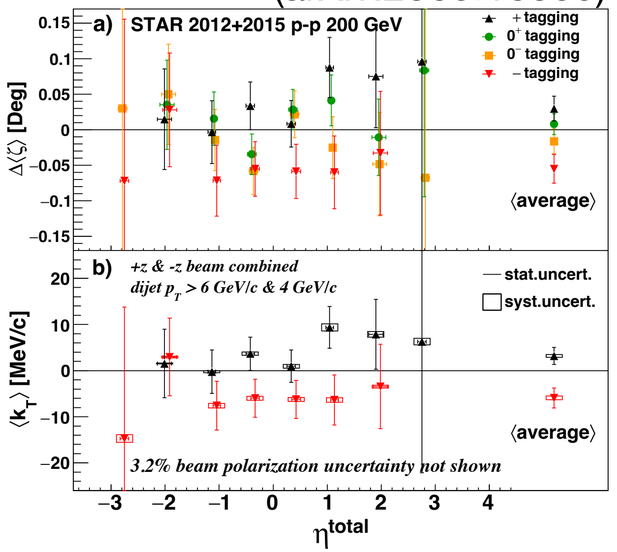
sPHENIX is a jet detector. Jet asymmetries are good choices.
Possible observables are, for example,

- inclusive jet ← I'm working on it.
  - Theory: PRD83(2001)034021
  - STAR: PRD106(2022)072010
- di-jet
  - Theory: PRD69(2004)094025
  - STAR:
- photon-jet ← This is my interest.
  - Theory AN: PRD72(2005)054028
  - Theory azimuthal moment: PRL99(2007)212002
  - no measurement
- π in jet
  - Theory: PRD83(2001)034021
  - STAR: JPS Conf. Proc. 37(2022)020118

PRD106(2022)072010

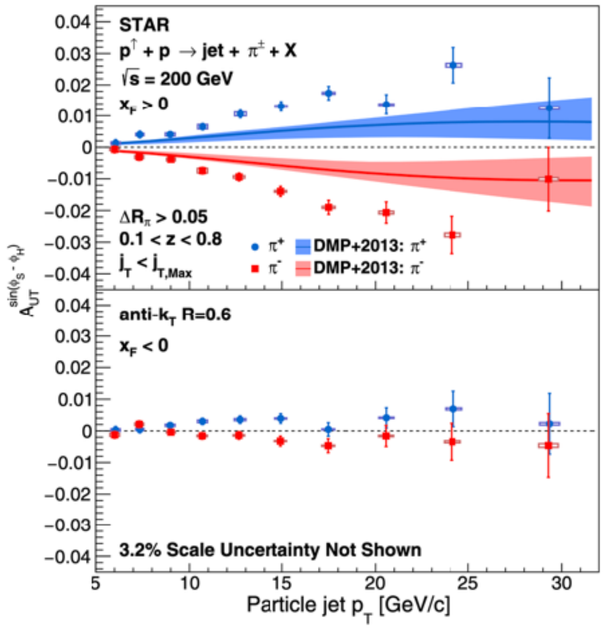


(arXiv:2305.10359)



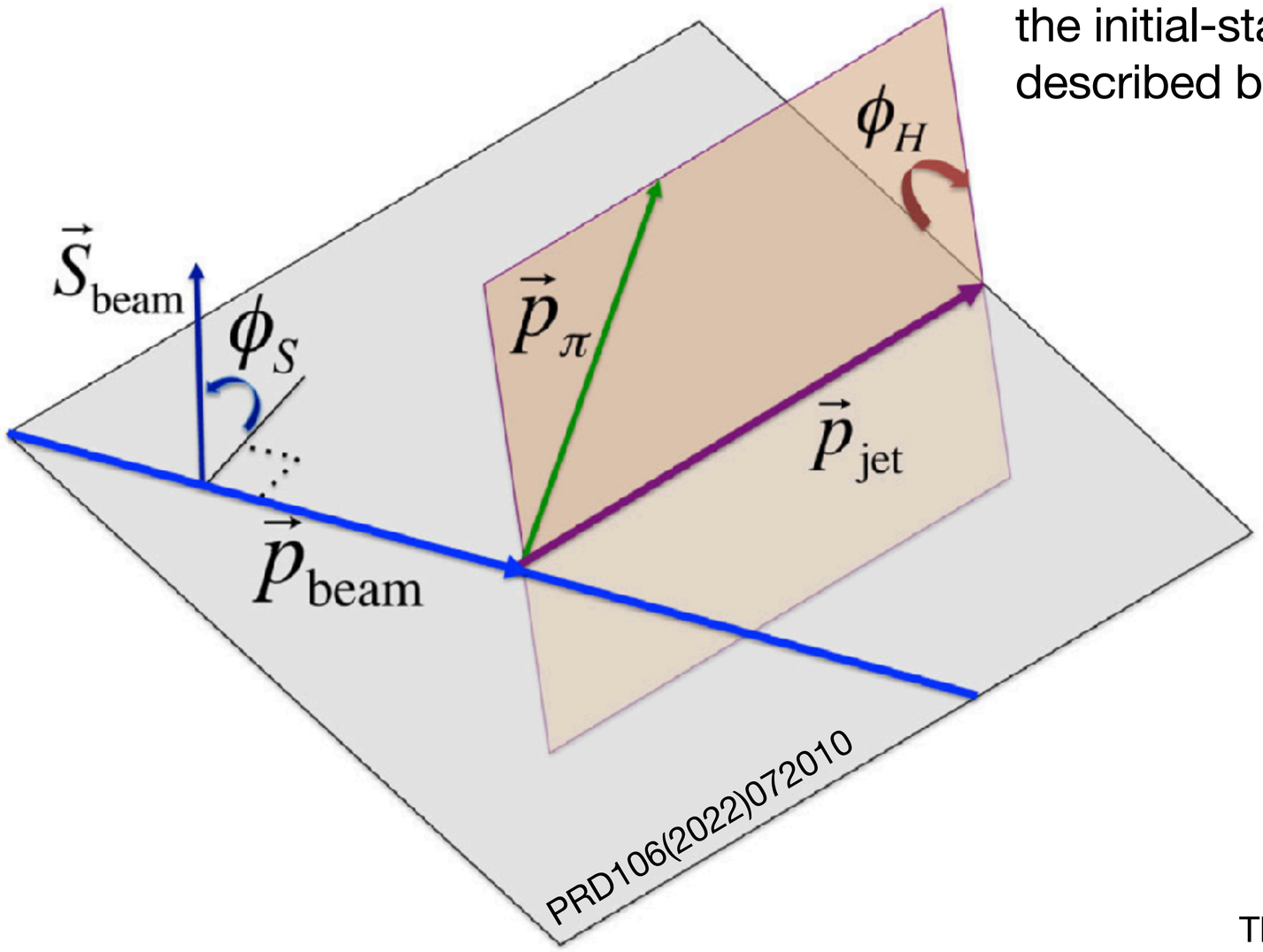
Dijet TSSA by STAR

PRD106(2022)072010



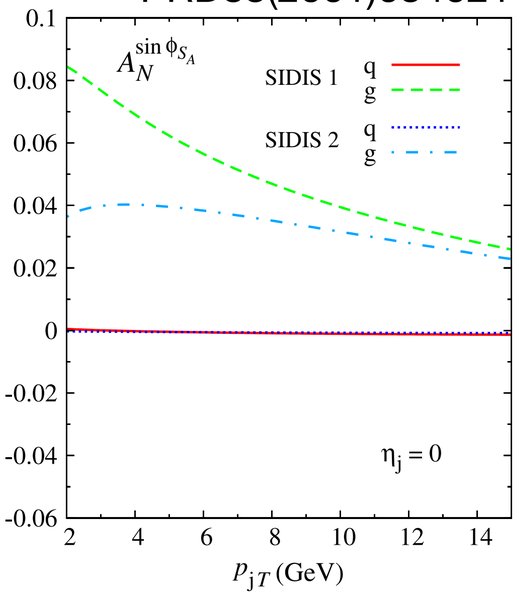
Inclusive Jet A_N

Inclusive jet A_N (sometimes written as $A_{\mathrm{UT}}^{\sin(\phi_S)}$) is sensitive to the initial-state twist-3 quark-gluon correlators, which are described by the Efremov-Teryaev-Qiu-Sterman function.



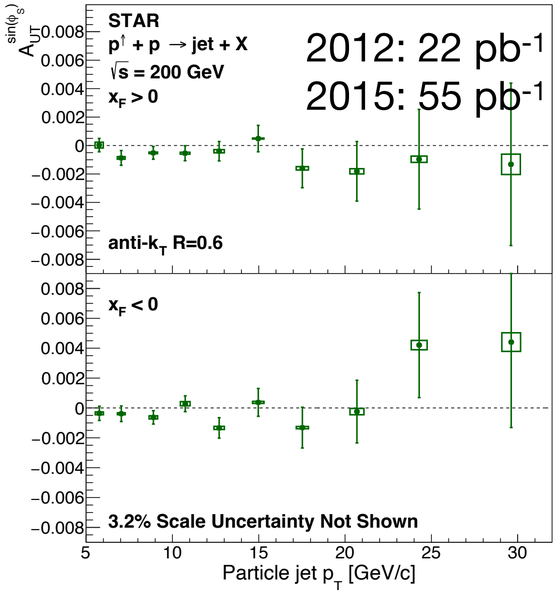
$$A_N \sin(\phi) = \frac{1}{P} \cdot \frac{\sqrt{N^{\uparrow}(\phi)N^{\downarrow}(\phi+\pi)} - \sqrt{N^{\downarrow}(\phi)N^{\uparrow}(\phi+\pi)}}{\sqrt{N^{\uparrow}(\phi)N^{\downarrow}(\phi+\pi)} + \sqrt{N^{\downarrow}(\phi)N^{\uparrow}(\phi+\pi)}}$$

PRD83(2001)034021



Theoretical prediction for inclusive jet A_N at RHIC kinematics in the mid-rapidity.

PRD106(2022)072010

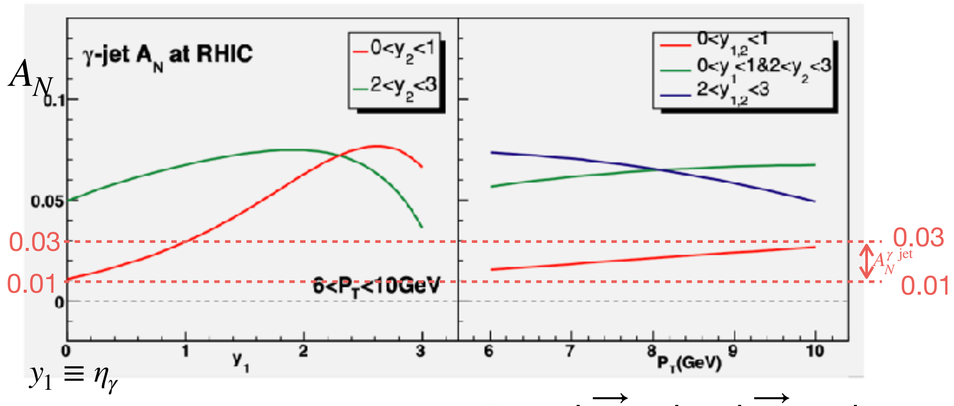


Inclusive jet A_N measurement by STAR.

Photon-Jet asymmetries

A_N measurement (PRD72(2005)054028)

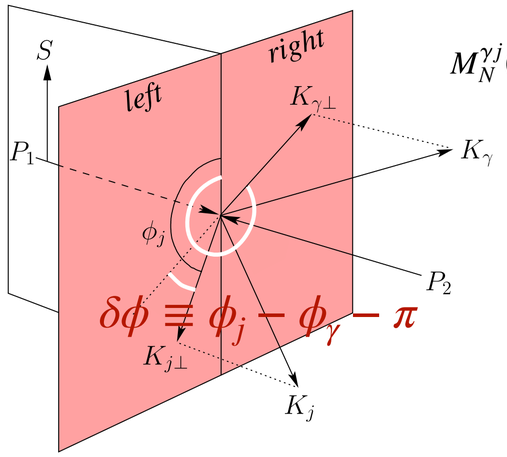
$$A_N \equiv \frac{d\sigma_{TU}}{d\sigma_{UU}}$$



$y_1 \equiv \eta_\gamma$

$$P_\perp \equiv |\vec{P}_{\gamma\perp}| = |\vec{P}_{jet\perp}|$$

Azimuthal moment (PRL99(2007)212002)



$$M_N^{\gamma j}(\eta_\gamma, \eta_j, x_\perp) = \frac{\int d\phi_j d\phi_\gamma \frac{2|\boldsymbol{K}_{\gamma\perp}|}{M} \sin(\delta\phi)\cos(\phi_\gamma)\frac{d\sigma}{d\phi_j d\phi_\gamma}}{\int d\phi_j d\phi_\gamma \frac{d\sigma}{d\phi_j d\phi_\gamma}}$$

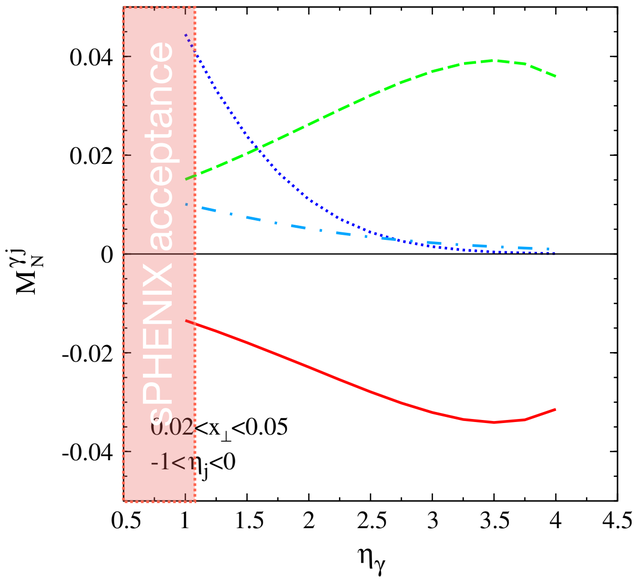
$$\equiv -\frac{A+B}{C}. \quad \begin{matrix} \leftarrow \text{pol} \\ \leftarrow \text{unpol} \end{matrix} \qquad (3)$$

$$A = x_\perp x_1 x_2 \sum_q [f_{1T}^{\perp(1)g_a}(x_1) f_1^q(x_2) d\hat{\sigma}_{[g]q\to\gamma q}^{(d)}$$

$$+ f_{1T}^{\perp(1)g_f}(x_1) f_1^q(x_2) d\hat{\sigma}_{[g]q\to\gamma q}^{(f)} + f_{1T}^{\perp(1)q}(x_1)$$

$$\times (f_1^{\bar{q}}(x_2) d\hat{\sigma}_{[q]\bar{q}\to\gamma g} + f_1^g(x_2) d\hat{\sigma}_{[q]g\to\gamma q})],$$

$$B = x_\perp x_1 x_2 \sum_q h_1^q(x_1) h_1^{\perp(1)\bar{q}}(x_2) d\delta\hat{\sigma}_{q[\bar{q}]\to\gamma g},$$



using gluonic pole cross-section

using standard partonic cross-sections

Maximum contribution from the gluon Sivers

Maximum contribution from the Boer-Mulders

Inclusive jet A_N analysis

1. Learning calorimeter data and jet with MC data
2. Real data analysis
3. Comparison with MC data

Exercise with MC data

MC Truth Jet

- These are in my understanding. Please correct me.
- MC truth jet objects can be accessed through JetContainerv1.
- It looks that there are 7 types with different jet cone radius from 0.2 to 0.7 for anti-k_T algorithm.

```
List of Nodes in Fun4AllServer:
Node Tree under TopNode TOP
TOP (PHCompositeNode)/
  DST (PHCompositeNode)/
    Sync (IO,SyncObjectv1)
    EventHeader (IO,EventHeaderv1)
    ANTIKT (PHCompositeNode)/
      TRUTH (PHCompositeNode)/
        AntiKt_Truth_r02 (IO,JetContainerv1)
        AntiKt_Truth_r03 (IO,JetContainerv1)
        AntiKt_Truth_r04 (IO,JetContainerv1)
        AntiKt_Truth_r05 (IO,JetContainerv1)
        AntiKt_Truth_r06 (IO,JetContainerv1)
        AntiKt_Truth_r07 (IO,JetContainerv1)
        AntiKt_Truth_r08 (IO,JetContainerv1)
```

JetContainerv1 class

#jet
Jet objects

used algorithm
jet cone radius

Doxygen

Jet class Doxygen

#components of a jet

9

Pythia configuration for type12 (Jet10)

flag HardQCD:all (default = off) **on**
Common switch for the group of all hard QCD 2→2 processes, as listed separately in the following.

Cuts in $2 \to 2$ processes

parm PhaseSpace:pTHatMin (default = 0.; minimum = 0.) **7 GeV/c**
The minimum invariant p_T.

Why 7 GeV/c?

flag ParticleDecays:limitCylinder (default = off) **on**
When on, only particles with a decay within a volume limited by $rho = sqrt(x^2 + y^2) < xyMax$ and $|z| < zMax$ are decayed. There is assumed to be no magnetic field or other detector effects.

parm ParticleDecays:xyMax (default = 10.; minimum = 0.)
The above *xyMax*, expressed in mm. **10 μm**

parm ParticleDecays:zMax (default = 10.; minimum = 0.)
The above *zMax*, expressed in mm. **10 μm**

$xyMax = 10\mu m$

$zMax = 10\mu m$

$\rho \equiv \sqrt{x^2 + y^2} < xyMax$

$|z| < zMax$

Any decay make a jet in my understanding.

mode ColourReconnection:mode (default = 0; minimum = 0; maximum = 4) **2**
Determine which model is used for colour reconnection. Beware that some settings may need to be changed to match the hadronization model selected.
option 0 : The MPI-based original Pythia 8 scheme.
option 1 : The new more QCD based scheme. Should be combined with BeamRemnants:remnantMode = 1.
option 2 : The new gluon-move model.
option 3 : The SK I of the SK II annihilation-like CR model. Requires ColourReconnection:forceResonance = on (and default PartonLevel:earlyResDec = off) to give any CR.
option 4 : The SK II annihilation-like CR model. Requires ColourReconnection:forceResonance = on (and default PartonLevel:earlyResDec = off) to give any CR.

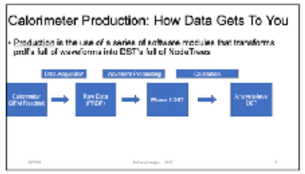
parm TimeShower:alphaSvalue (default = 0.1365; minimum = 0.06; maximum = 0.25) **0.18**
The *alpha_strong* value at scale *M_Z^2*. The default value corresponds to a crude tuning to LEP data, to be improved.

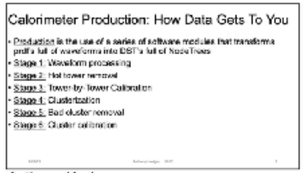
The actual value is then regulated by the running to the scale *pT^2*, at which the shower evaluates *alpha_strong*.

21

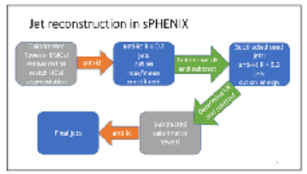
Reconstructed jet object in MC data

```
DST: DST_CALO_CLUSTER_pythia8_Jet10-0000000021-000000.root
List of Nodes in Fun4AllServer:
Node Tree under TopNode TOP
TOP (PHCompositeNode)/
  DST (PHCompositeNode)/
    HCALOUT (PHCompositeNode)/
      WAVEFORM_HCALOUT (IO,PHObject)
      TOWERS_HCALOUT (IO,PHObject)
      TOWERINFO_CALIB_HCALOUT (IO,PHObject)
    HCALIN (PHCompositeNode)/
      WAVEFORM_HCALIN (IO,PHObject)
      TOWERS_HCALIN (IO,PHObject)
      TOWERINFO_CALIB_HCALIN (IO,PHObject)
    CEMC (PHCompositeNode)/
      WAVEFORM_CEMC (IO,PHObject)
      TOWERS_CEMC (IO,PHObject)
      TOWERINFO_CALIB_CEMC (IO,PHObject)
      CLUSTERGMPG_CEMC (IO,PHObject)
    Sync (IO,SyncObjectv1)
    EventHeader (IO,EventHeaderv1)
```





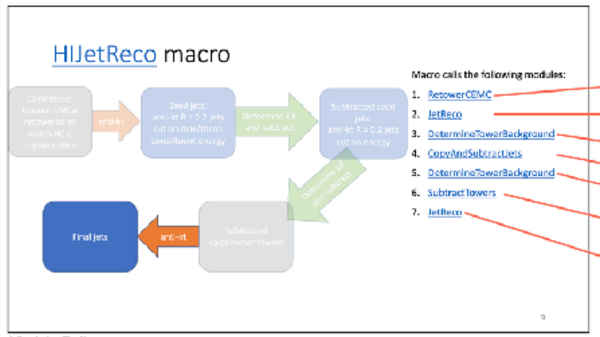
Anthony Hodges,
sPHENIX Analysis Software Tutorial, Oct. 2023.



Virginia Bailey,
sPHENIX Analysis Software Tutorial, Oct. 2023.

Reconstructed jet object in MC data

https://github.com/sPHENIX-Collaboration/macros/blob/master/common/HIJetReco.C



for truth jet if available

confirmed

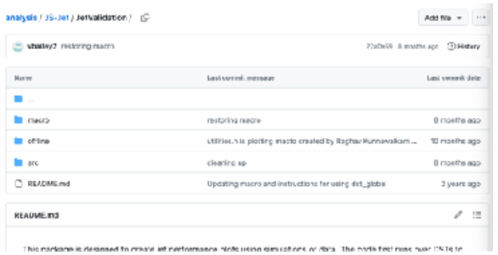
Virginia Bailey,
sPHENIX Analysis Software Tutorial, Oct. 2023.

As sPHENIX documentation is terrible, just collecting information is quite important.
Catching up what has been done in the Jet topical group is also a good starting point.

Jet validation and Jet_reso.C in analysis repository

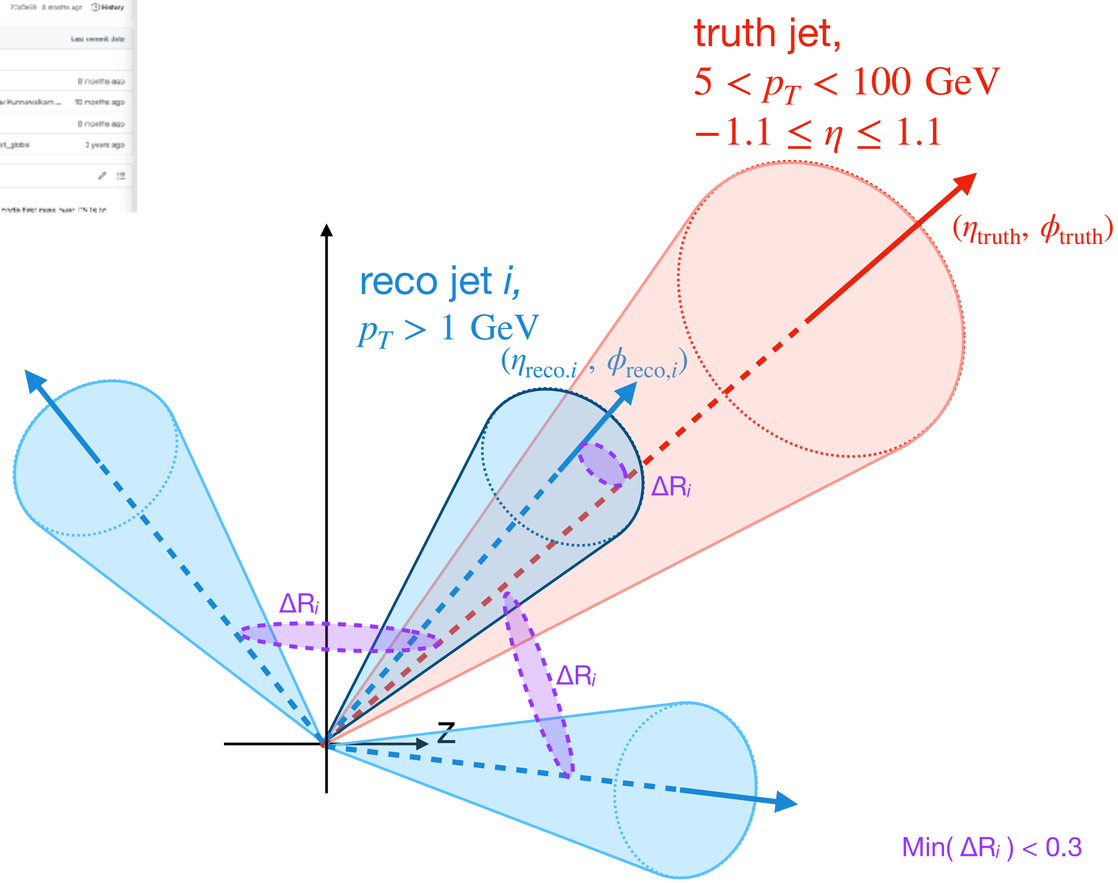
Input:
- DST_TRUTH_JET_…
- DST_CALO_CLUSTER_…
- DST_GLOBAL_…

100k events



JetValidation module in Fun4All_JetVal.C
- writes information to event-base TTree
- Reconstructed jets:
  - $p_T > 1$ GeV required
  - ID, component info, η, ϕ, E, p_T are saved
- Truth jets:
  - $-1.1 \leq \eta \leq 1.1$ and $5 \leq p_T \leq 100$ GeV are required
  - ID, component info, η, ϕ, E, p_T are saved

Jet_reso.C
- loops over truth jets in an event,
  - a reconstructed jet with the smallest $dR \equiv \sqrt{\Delta\eta^2 + \Delta\phi^2}$ is assigned as a matched one.
    - $\Delta\eta_i \equiv \eta_{\text{truth}} - \eta_{i,\text{reco}}$, and $\Delta\phi_i \equiv \phi_{\text{truth}} - \phi_{i,\text{reco}}$
    - If dR > 0.3, no matching is done



Truth jet — Reconstructed jet matching

The same analysis was done by myself as an exercise.

https://github.com/sPHENIX-Collaboration/analysis/tree/master/JS-Jet/JetValidation

Jet validation and Jet_reso.C in analysis repository

Input:
- DST_TRUTH_JET_…
- DST_CALO_CLUSTER_…
- DST_GLOBAL_…

100k events

JetValidation module in Fun4All_JetVal.C
- writes information to event-base TTree
- Reconstructed jets:
  - $p_T > 1$ GeV required
  - ID, component info, η, ϕ, E, p_T are saved
- Truth jets:
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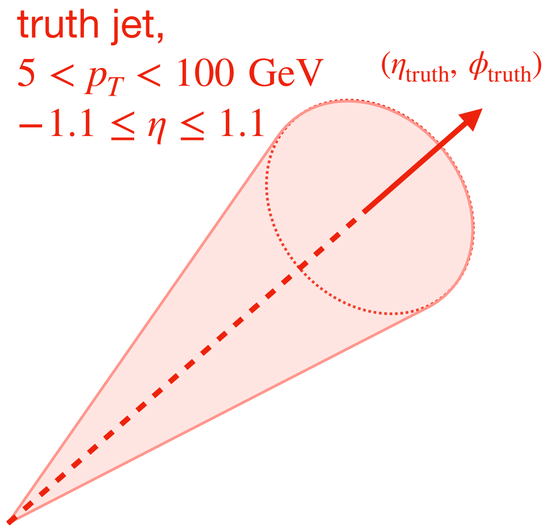
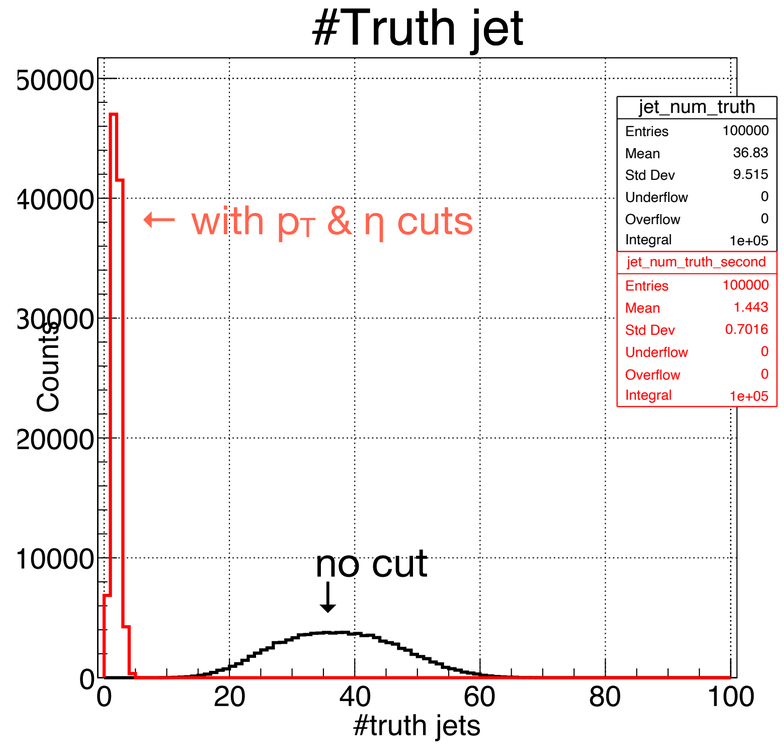
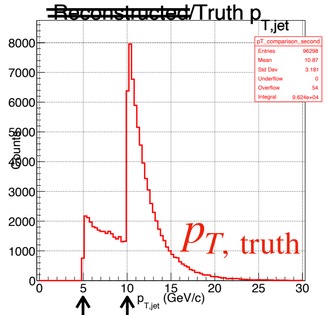
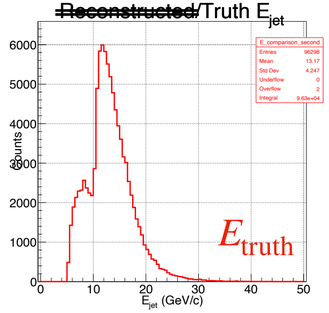
Jet_reso.C
- loops over truth jets in an event,
  - a reconstructed jet with the smallest $dR \equiv \sqrt{\Delta\eta^2 + \Delta\phi^2}$ is assigned as a matched one.
    - $\Delta\eta_i \equiv \eta_{\text{truth}} - \eta_{i,\text{reco}}$, and $\Delta\phi_i \equiv \phi_{\text{truth}} - \phi_{i,\text{reco}}$
    - If dR > 0.3, no matching is done

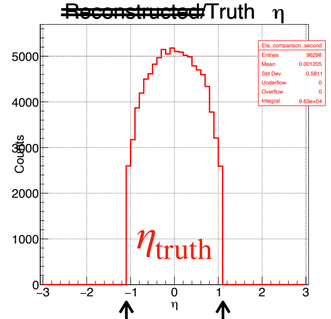
https://github.com/sPHENIX-Collaboration/analysis/tree/master/JS-Jet/JetValidation

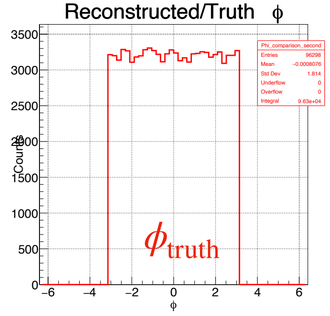












Generation threshold at 10 GeV/c
The minimum p_T 5 GeV/c

η boundaries
-1.1 — +1.1

Jet validation and Jet_reso.C in analysis repository

Input:
- DST_TRUTH_JET_…
- DST_CALO_CLUSTER_…
- DST_GLOBAL_…

100k events

JetValidation module in Fun4All_JetVal.C
- writes information to event-base TTree
- Reconstructed jets:
  - $p_T > 1$ GeV required
  - ID, component info, η, ϕ, E, p_T are saved
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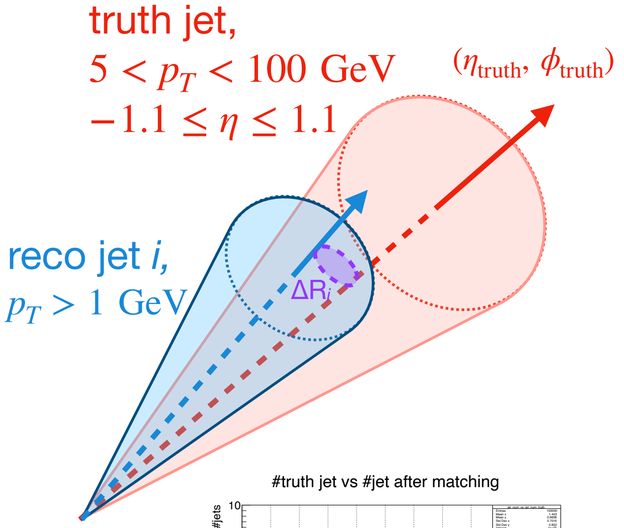
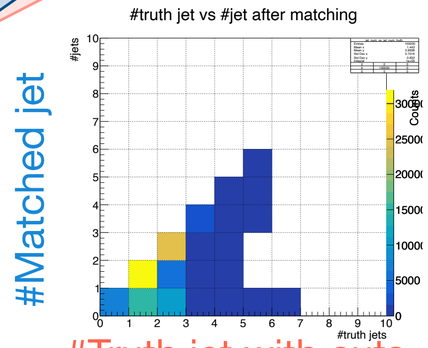
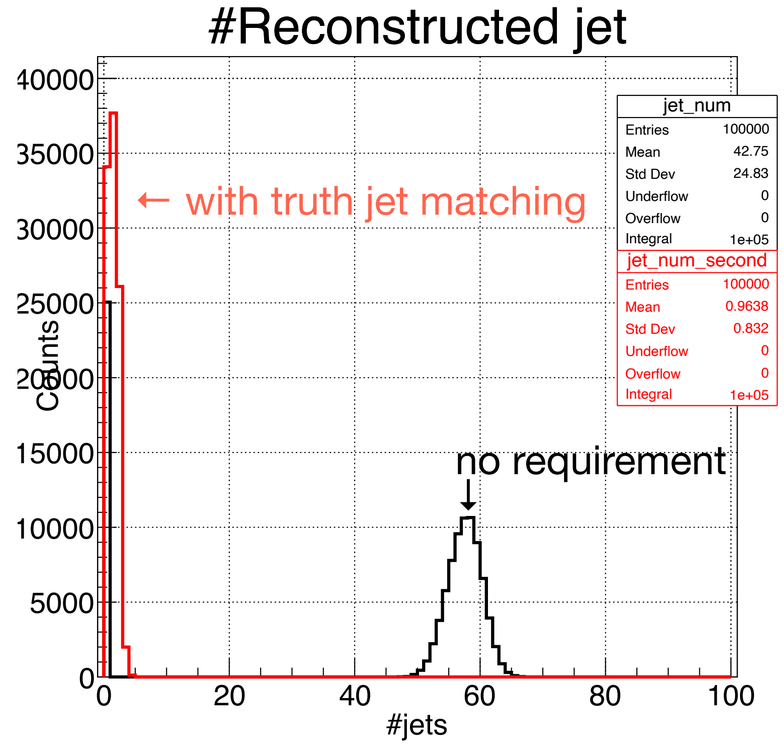
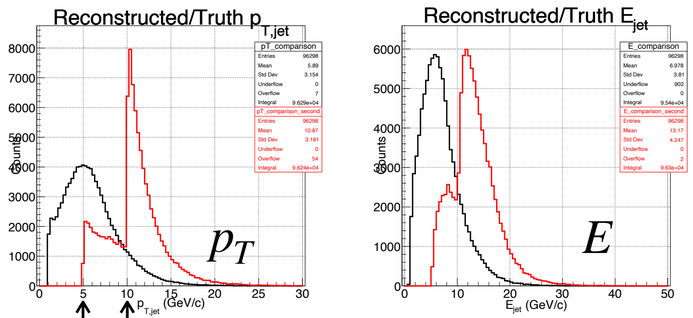
Jet_reso.C
- loops over truth jets in an event,
  - a reconstructed jet with the smallest $dR \equiv \sqrt{\Delta\eta^2 + \Delta\phi^2}$ is assigned as a matched one.
    - $\Delta\eta_i \equiv \eta_{\text{truth}} - \eta_{i,\text{reco}}$, and $\Delta\phi_i \equiv \phi_{\text{truth}} - \phi_{i,\text{reco}}$
    - If dR > 0.3, no matching is done

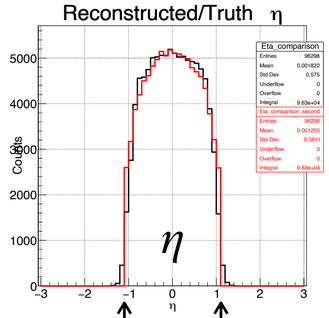
https://github.com/sPHENIX-Collaboration/analysis/tree/master/JS-Jet/JetValidation

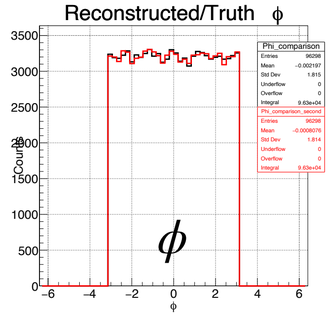






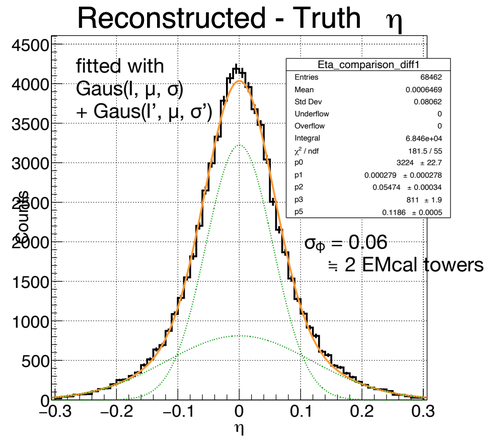


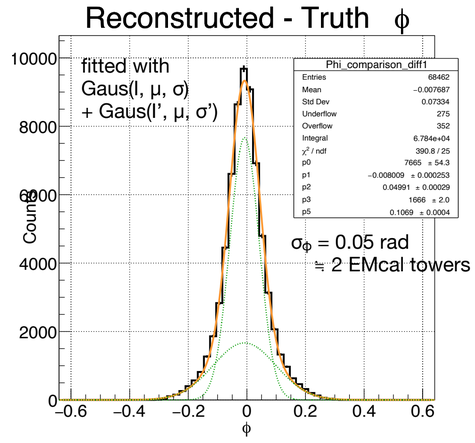


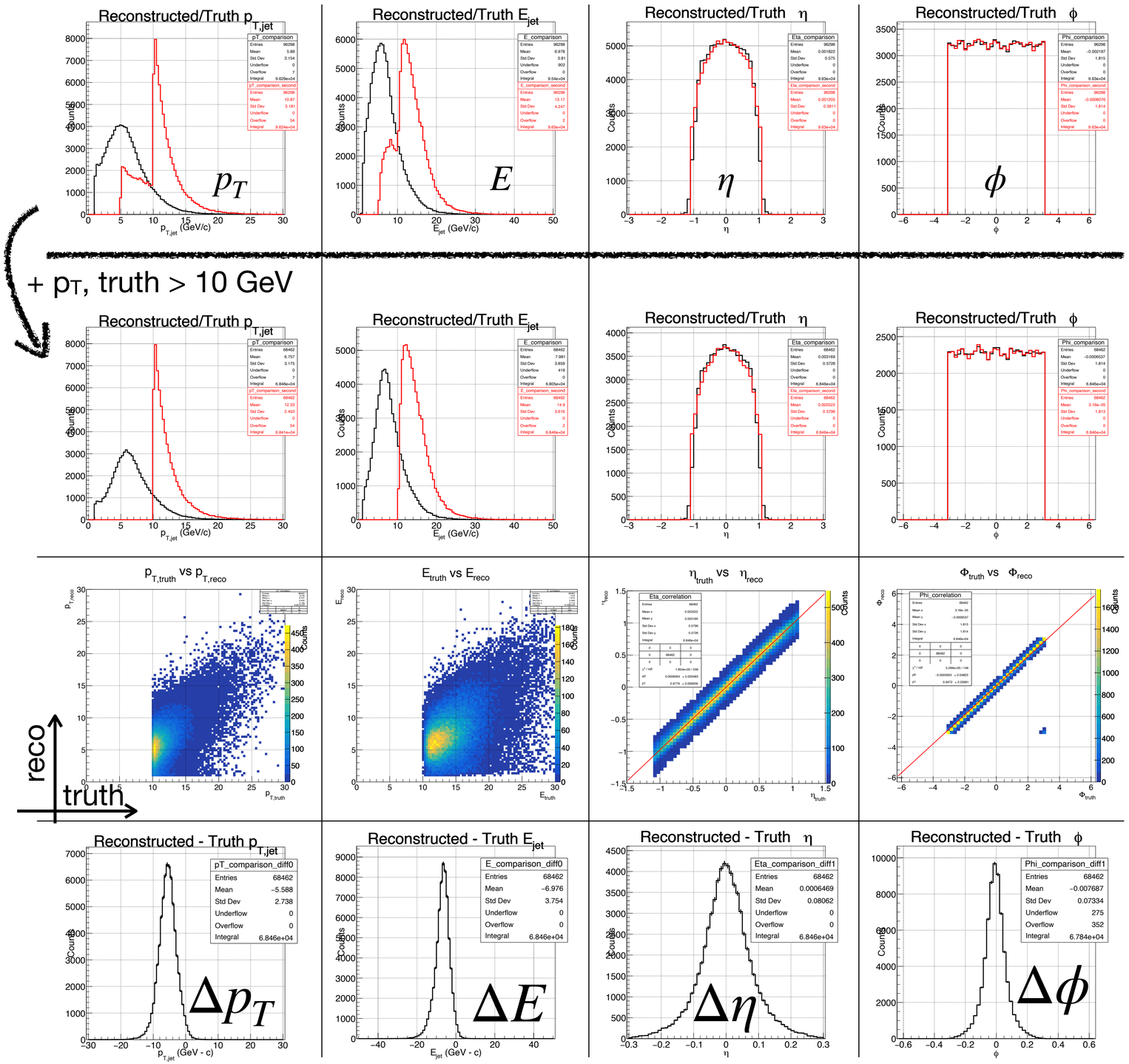


Comparison of truth/reconstructed kinematics

- In addition to the cuts in JetValidation, pT, truth > 10 GeV was required to make the situation simpler.
- p_T, E, η, and ϕ are compared.
  - Jets were well reconstructed.
  - Good agreement and linear correlation could be seen in η and ϕ.

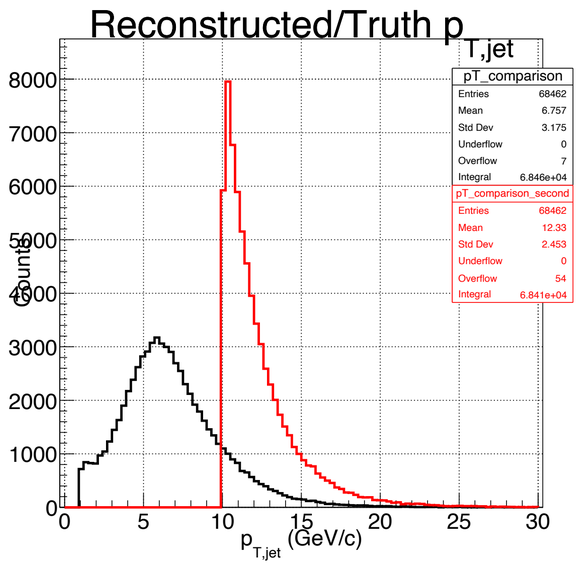


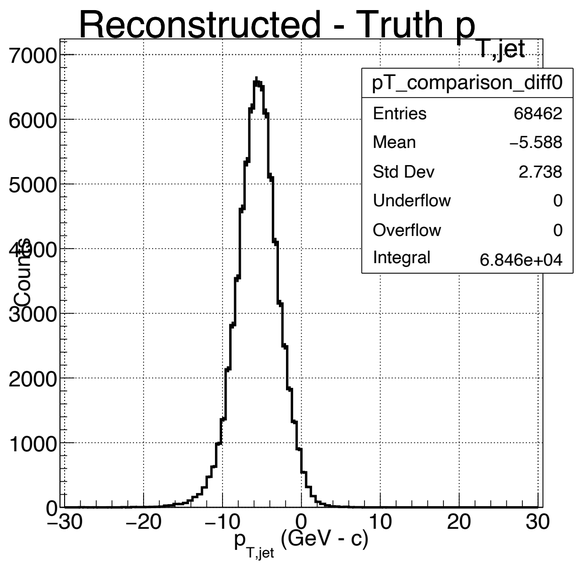


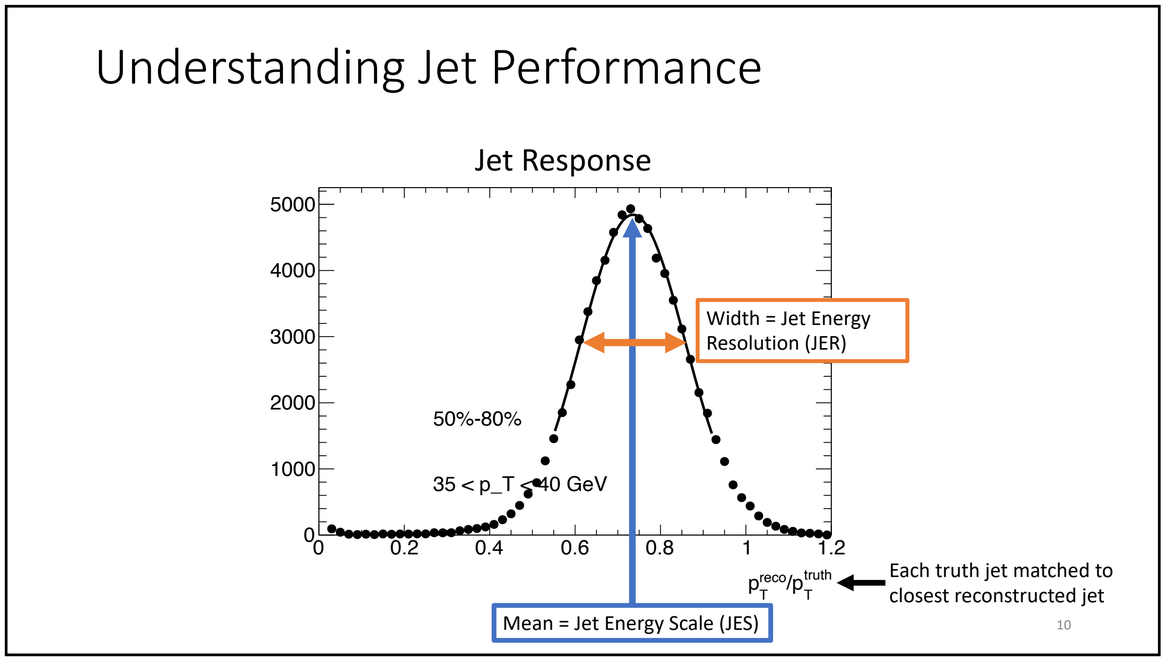


What was done in the last 2 weeks…

- The difference of truth/reconstructed jet energy shown in the last meeting was not small.
  I should understand it.





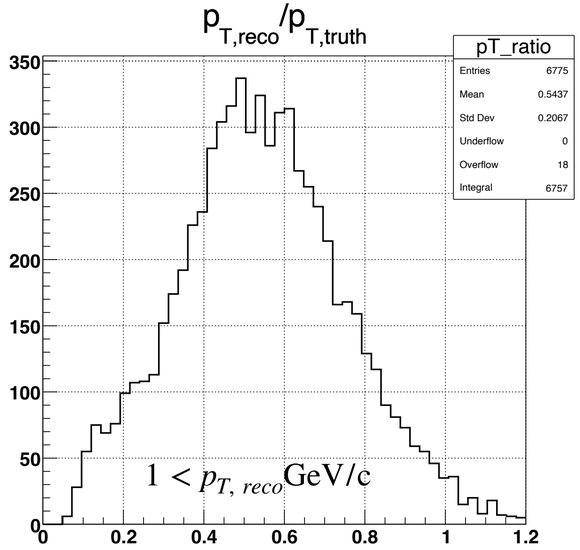


Virginia Bailey,
sPHENIX Analysis Software Tutorial, Oct. 2023.

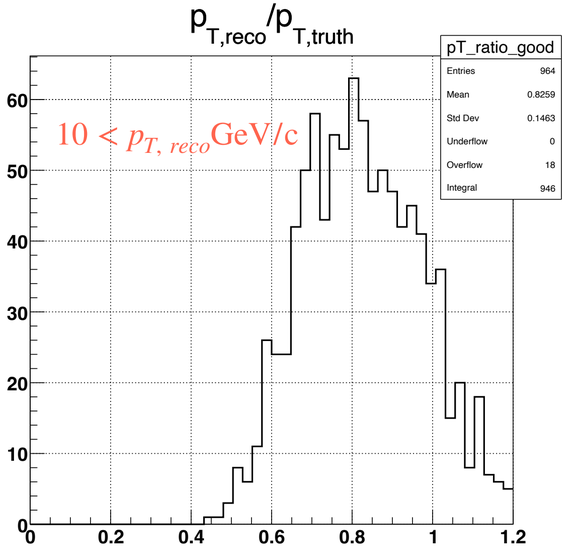
Comparisons b/w HIJetReco and JetReco macros

- Data: MDC2 run21 type 12, no pileup
  - i.e. p+p with 0 mrad crossing angle for jets with p_T with 10 GeV/c
  - ~~100k~~ 10k events ← If I had time…
- The same cuts as last meeting's were applied:
  - p_T, reco > 1 GeV
  - $|\eta_{truth}| < 1.1$
  - $10 \leqq p_{T,\,truth} \leqq 100$ GeV/c

HIJetReco

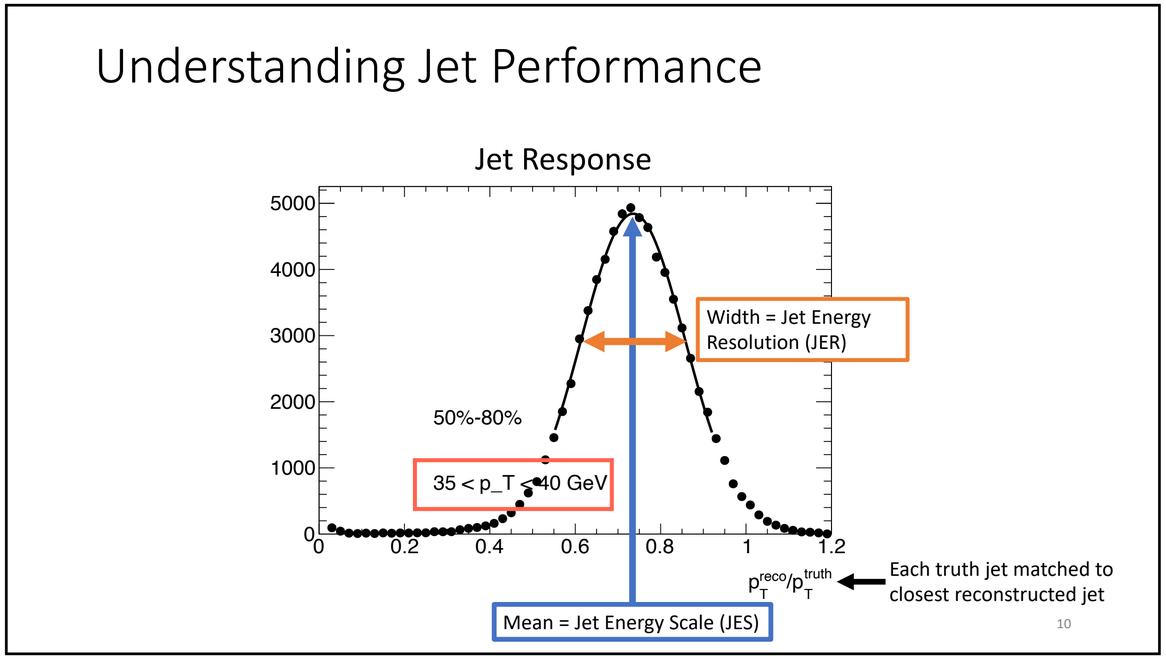


Δp_T



Δp_T

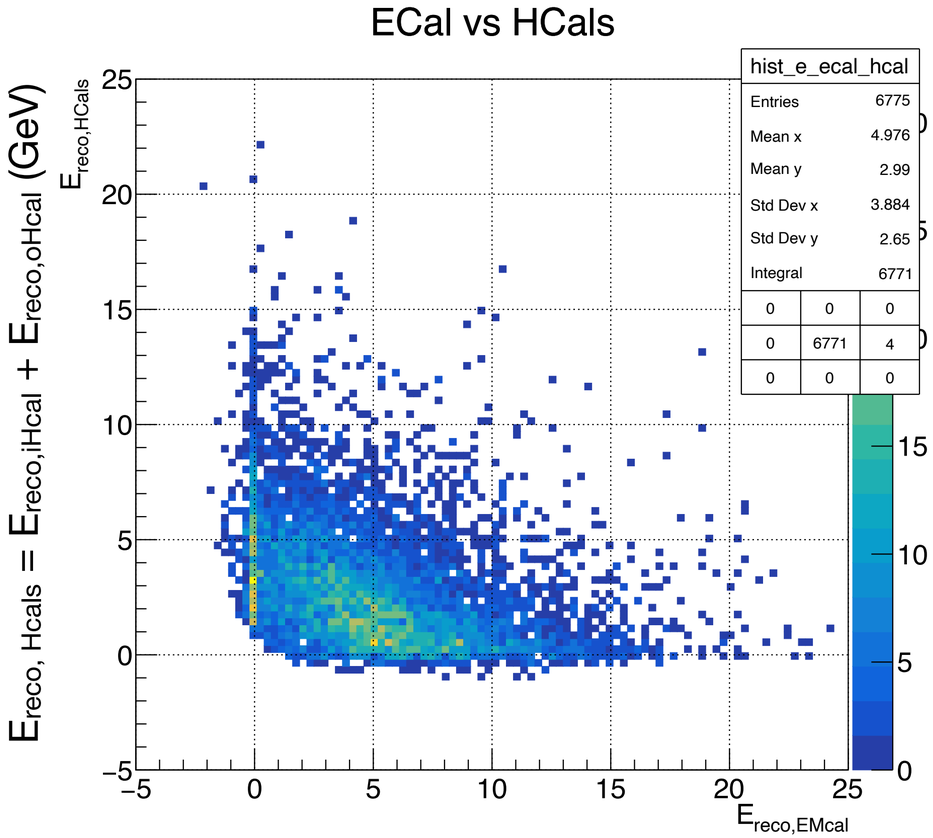
The worse agreement is probably due to the pT selection.

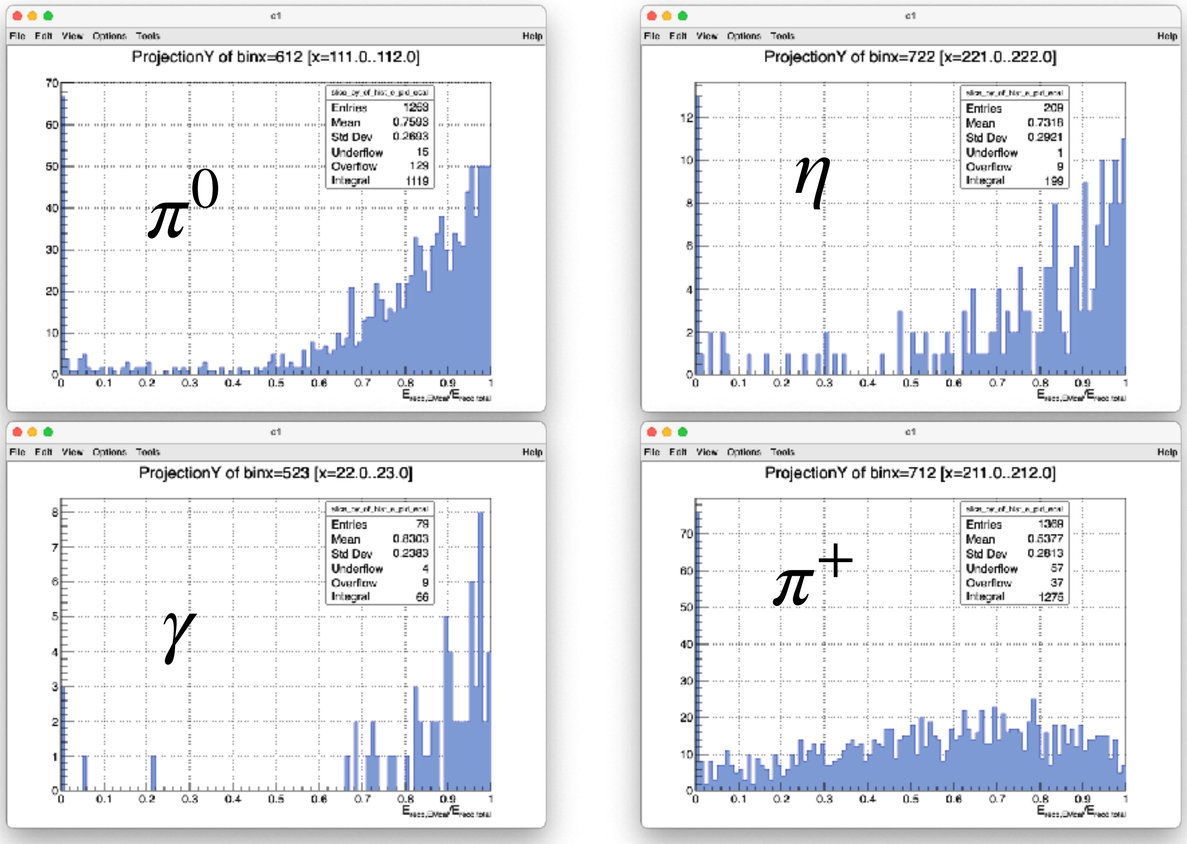


Virginia Bailey,
sPHENIX Analysis Software Tutorial, Oct. 2023.

Jet/TowerInfo/G4Hit
towards the discrepancy of truth/reconstructed energy of jet

- Data: MDC2 run21 type 12, no pileup
  - i.e. p+p with 0 mrad crossing angle for jets with p_T with 10 GeV/c
  - ~~100k~~ 10k events ← If I had time…
- The same cuts as last meeting's were applied:
  - p_T, reco > 1 GeV
  - $|\eta_{truth}| < 1.1$
  - $10 \leqq p_{T,\,truth} \leqq 100$ GeV/c



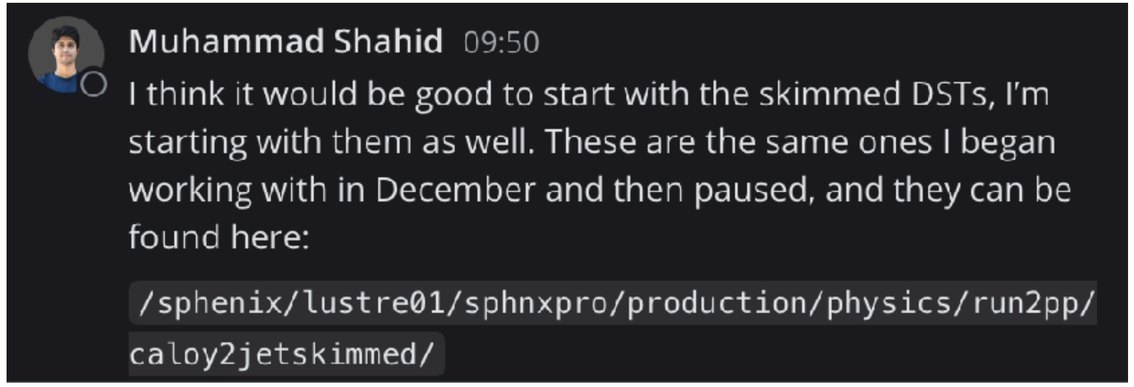


Fraction of EMcal energy to total reconstructed jet energy if truth leading particle is selected

It's maybe too much detailed for inclusive jet An analysis, but we use such information eventually…

Real data analysis

- Official DST productions
  - I made list of nodes in the official DSTs in the sPHENIX wiki
  - Root dir: /sphenix/lustre01/sphnxpro/physics/slurp
  - Which one should I use?
    - calobeam
    - calophysics
    - *caloy2fitting* ← maybe this one as TowerInfo is available
- Another DST productions
  - Root dir: /sphenix/lustre01/sphnxpro/production
  - sub directory: run2pp/physics/
    - ana462_2024p010_v001
    - ana468_2024p012_v001



Great starting point!

Build ana430_2024p007 [edit | edit source]

DST_CALO_run2pp_ana430_2024p007 [edit | edit source]

```
DST: /sphenix/lustre01/sphnxpro/physics/slurp/caloy2fitting/ana430_2024p007/run_00045100_00045200/
DST_CALO_run2pp_ana430_2024p007-00045142-00033.root
List of Nodes in Fun4AllServer:
Node Tree under TopNode TOP
TOP (PHCompositeNode)/
   DST (PHCompositeNode)/
      MBD (PHCompositeNode)/
         MbdOut (IO,PHObject)
         MbdPmtContainer (IO,PHObject)
      GLOBAL (PHCompositeNode)/
         MbdVertexMap (IO,PHObject)
         GlobalVertexMap (IO,PHObject)
      GL1 (PHCompositeNode)/
         GL1Packet (IO,Gl1Packetv2)
      ZDC (PHCompositeNode)/
         Zdcinfo (IO,PHObject)
         TOWERINFO_CALIB_ZDC (IO,PHObject)
      CEMC (PHCompositeNode)/
         TOWERINFO_CALIB_CEMC (IO,PHObject)
         CLUSTERINFO_CEMC (IO,PHObject)
      Sync (IO,SyncObjectv1)
      EventHeader (IO,EventHeaderv1)
      HCALIN (PHCompositeNode)/
         TOWERINFO_CALIB_HCALIN (IO,PHObject)
      HCALOUT (PHCompositeNode)/
         TOWERINFO_CALIB_HCALOUT (IO,PHObject)
   RUN (PHCompositeNode)/
      MBD (PHCompositeNode)/
         MbdGeom (IO,PHObject)
      CEMC (PHCompositeNode)/
         TOWERGEOM_CEMC (IO,PHObject)
      HCALIN (PHCompositeNode)/
         TOWERGEOM_HCALIN (IO,PHObject)
      HCALOUT (PHCompositeNode)/
         TOWERGEOM_HCALOUT (IO,PHObject)
      RunHeader (IO,RunHeaderv1)
      Flags (IO,FlagSavev1)
      CdbUrl (IO,CdbUrlSavev1)
   PAR (PHCompositeNode)/
```

Runs

- A good(-looking) RHIC fill was randomly picked.
- Runs:
  - 50031
  - 50032
  - 50033
  - 50034
  - 50036
  - 50045
  - 50046
  - 50047
  - Condition: stable data taking. INTT was in the streaming mode only run 50032. 50045 was very successful long run, which was for 1 hour.

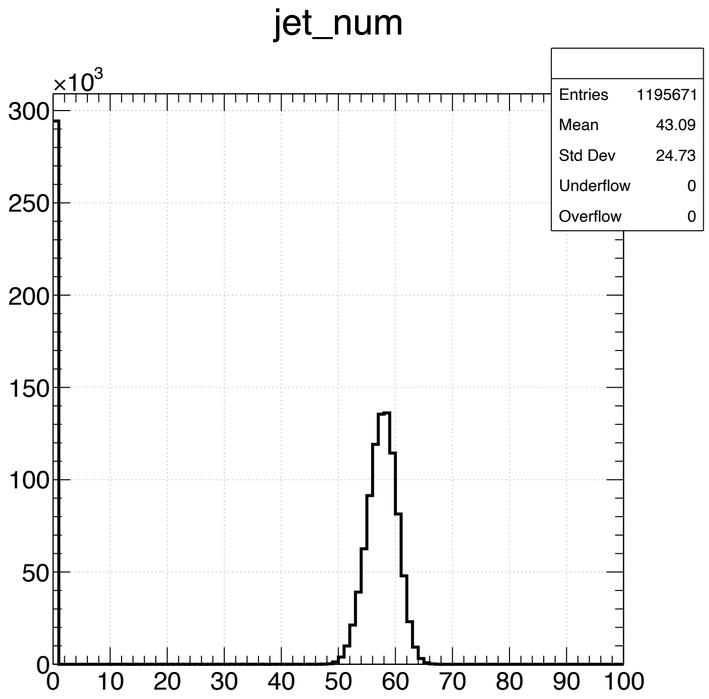
Quick look

Run: 50036

Cut:

- nothing or #jet ≠ 0

- All jets in events, taken everything even if they look junk, were checked.



#jet/event
No cut applied

Quick look

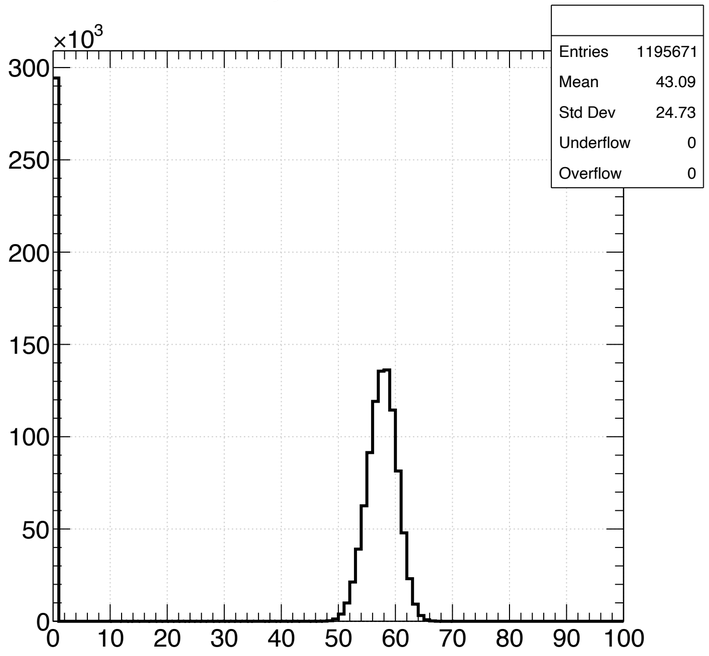
Run: 50036

Cut:

- nothing or #jet ≠ 0

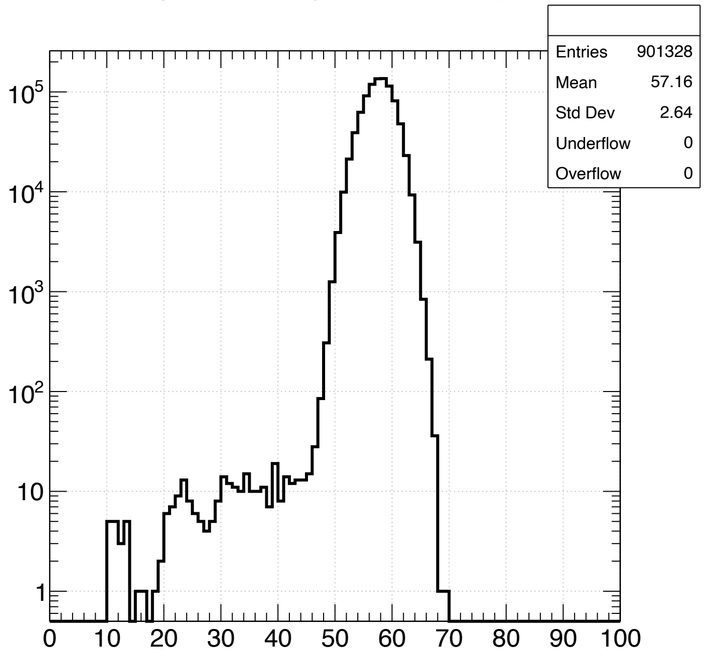
- All jets in events, taken everything even if they look junk, were checked.

jet_num



#jet/event
No cut applied

jet_num {jet_num!=0}



#jet/event
Events with #jet/event = 0 are removed.

Quick look

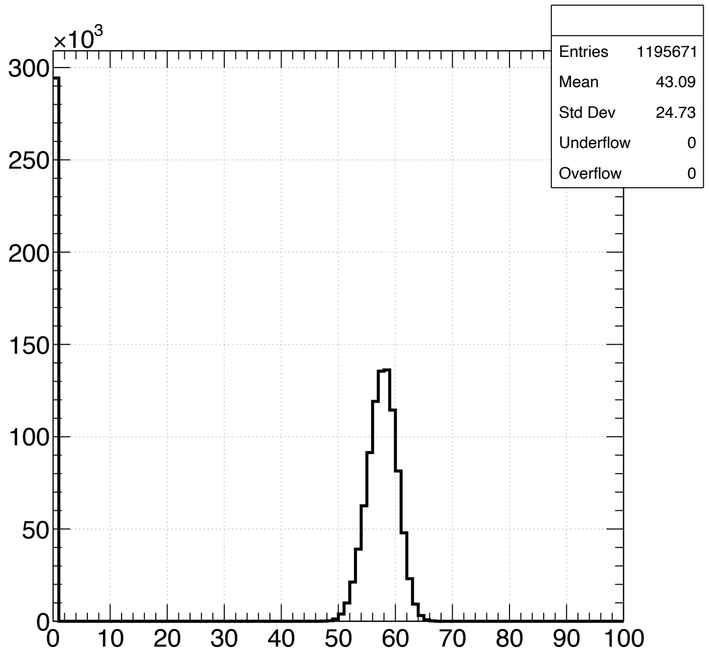
- All jets in events, taken everything even if they look junk, were checked.

Run: 50036

Cut:

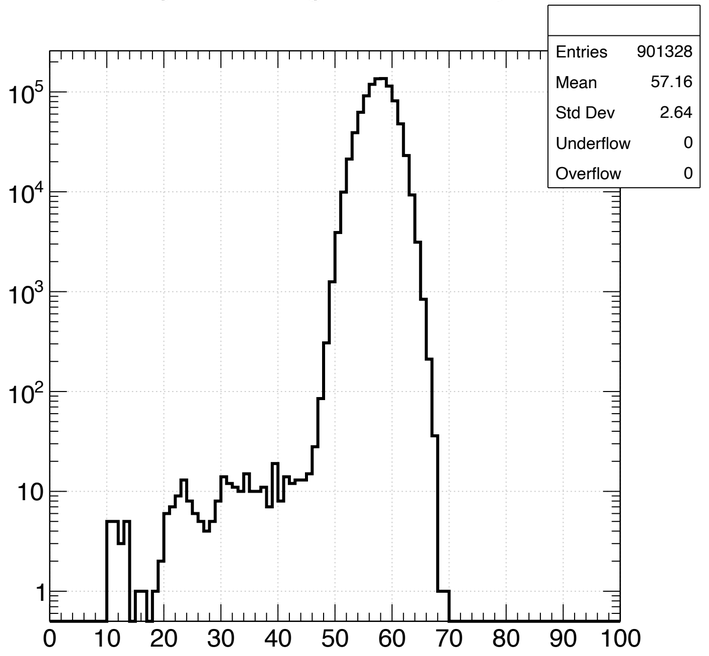
- nothing or #jet ≠ 0

jet_num



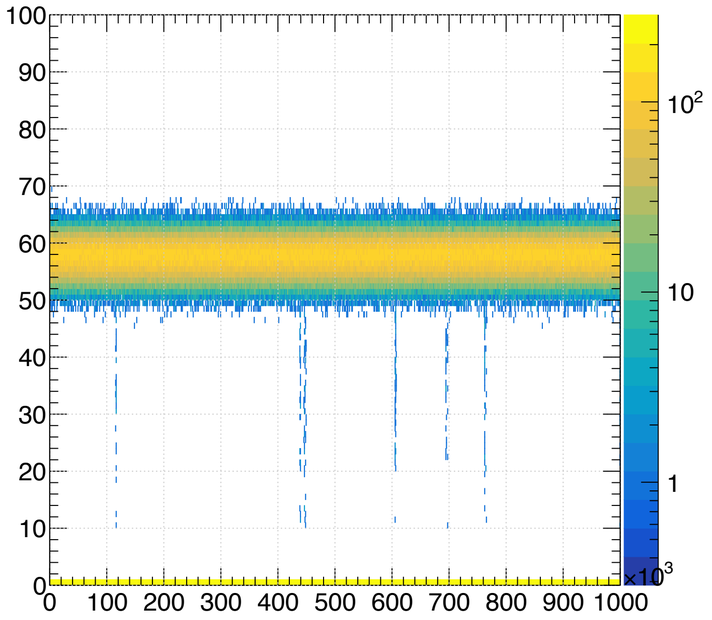
#jet/event
No cut applied

jet_num {jet_num!=0}



#jet/event
Events with #jet/event = 0 are removed.

jet_num:event



#jet/event as a function of event counter.

Quick look

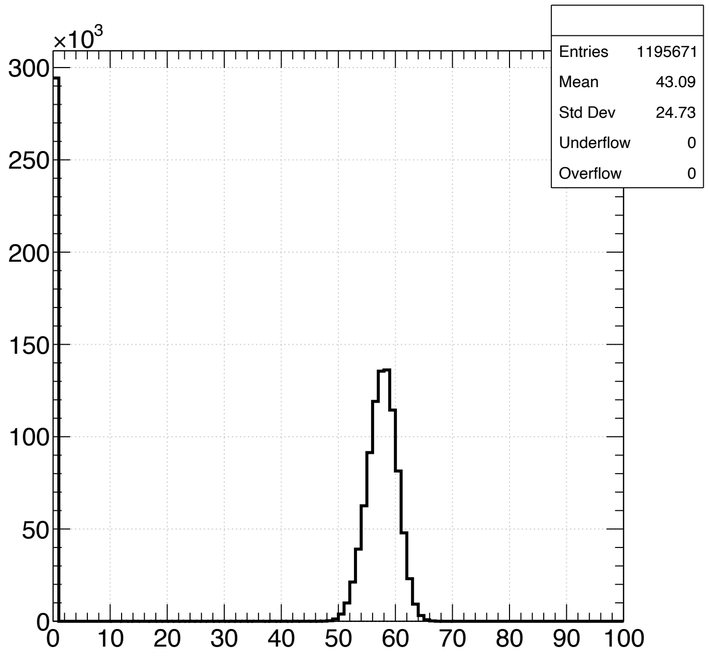
Run: 50036

Cut:

- nothing or #jet ≠ 0

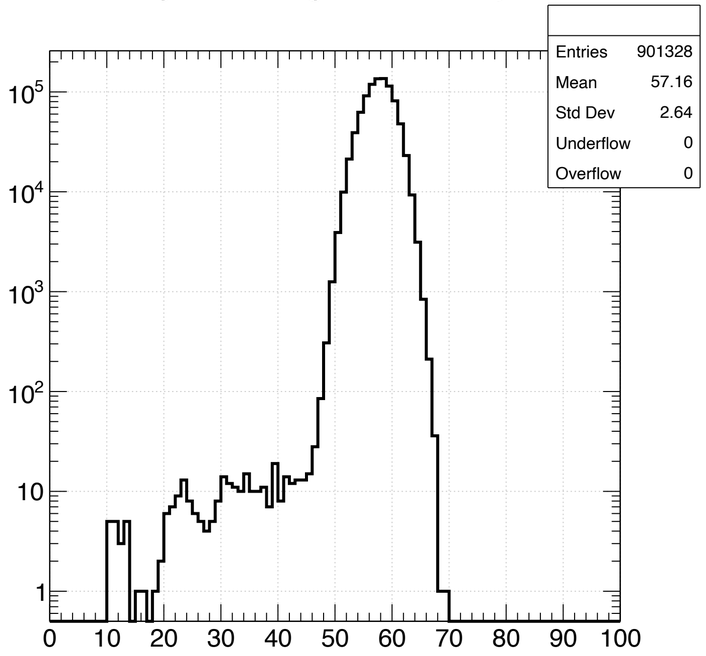
- All jets in events, taken everything even if they look junk, were checked.

jet_num



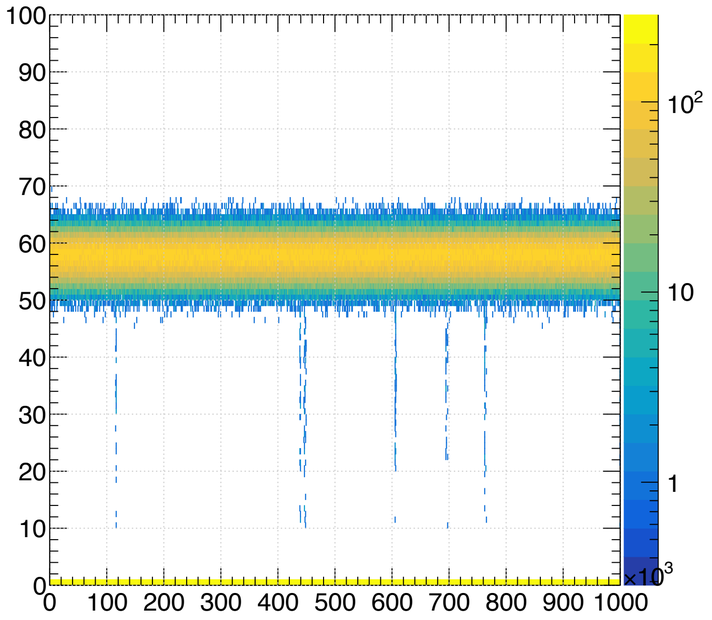
#jet/event
No cut applied

jet_num {jet_num!=0}



#jet/event
Events with #jet/event = 0 are removed.

jet_num:event



#jet/event as a function of event counter.

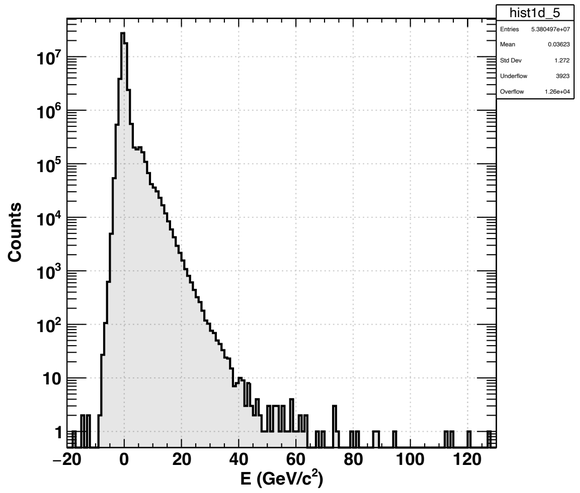
Quick look

Run: 50036

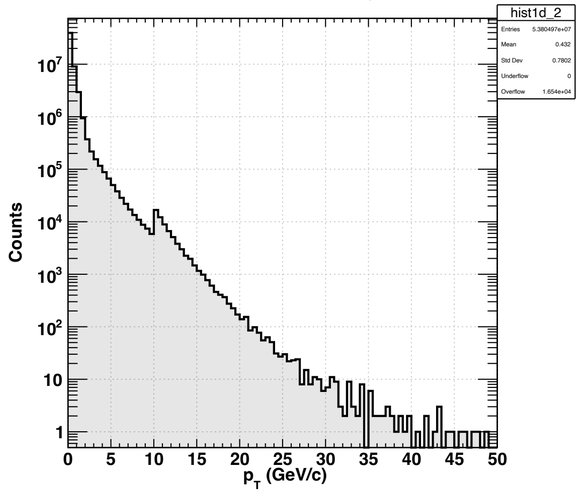
Cut:
- nothing

- All jets in events, taken everything even if they look junk, were checked.
- Kinematics of all jets

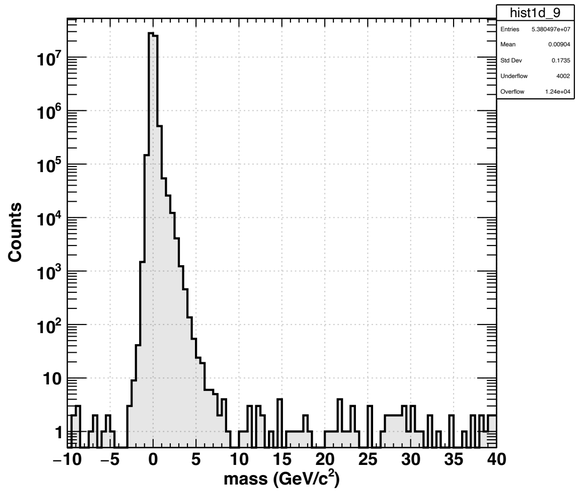
E



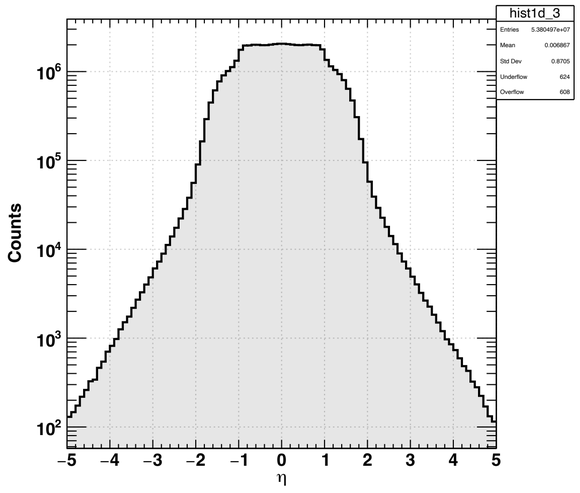
p_T



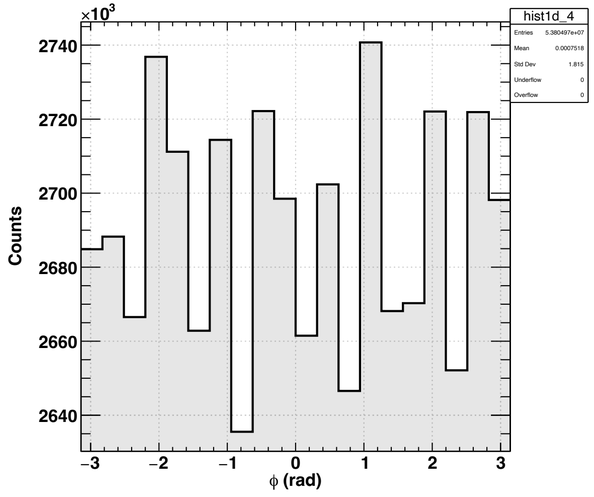
mass



η



ϕ



#jet: 5e7

Quick look

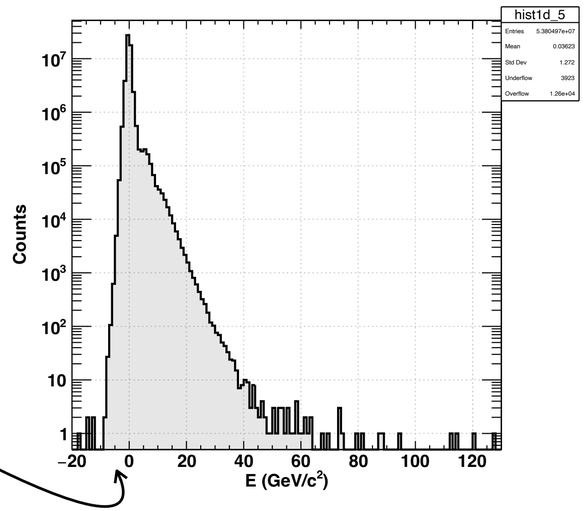
- All jets in events, taken everything even if they look junk, were checked.
- Kinematics of all jets

Run: 50036

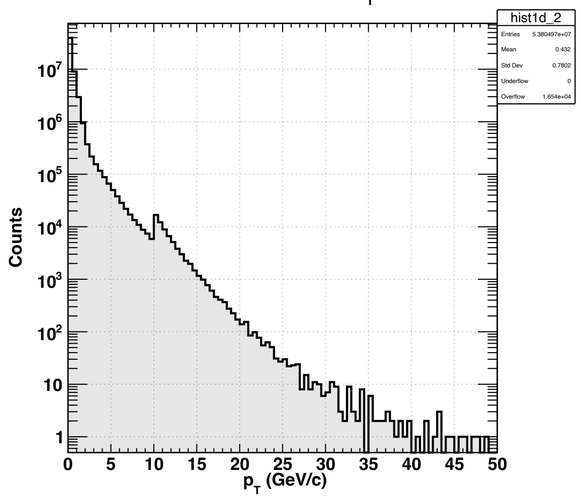
Cut:
- nothing

Jets with negative energy are known. They are due to pedestal subtraction in my understanding.

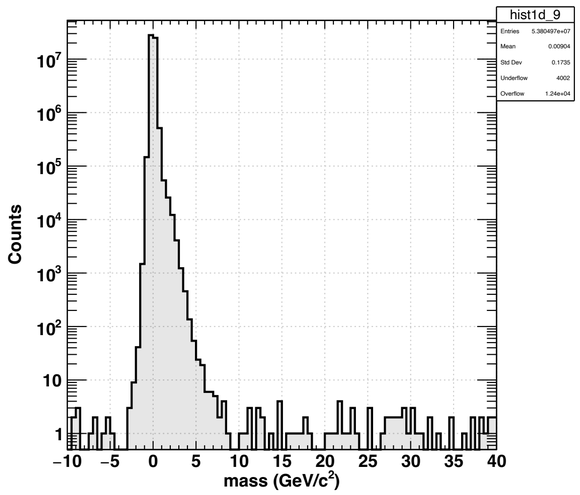
E



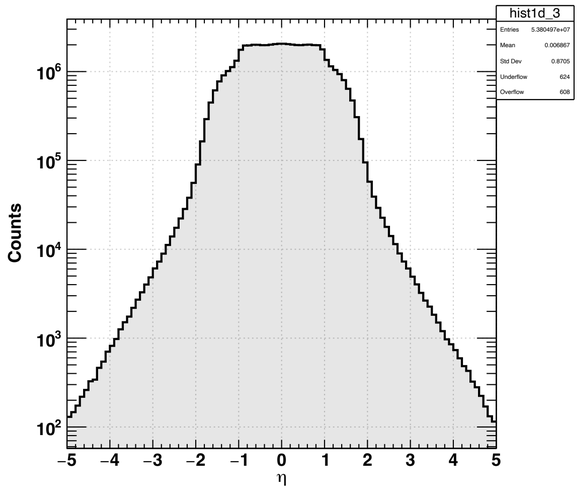
p_T



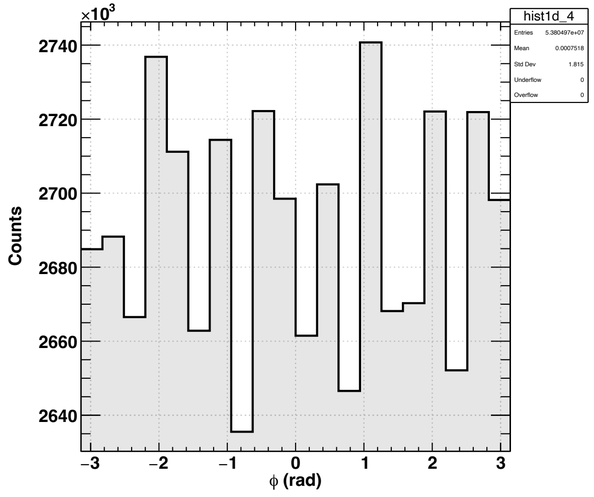
mass



η



ϕ



#jet: 5e7

Quick look

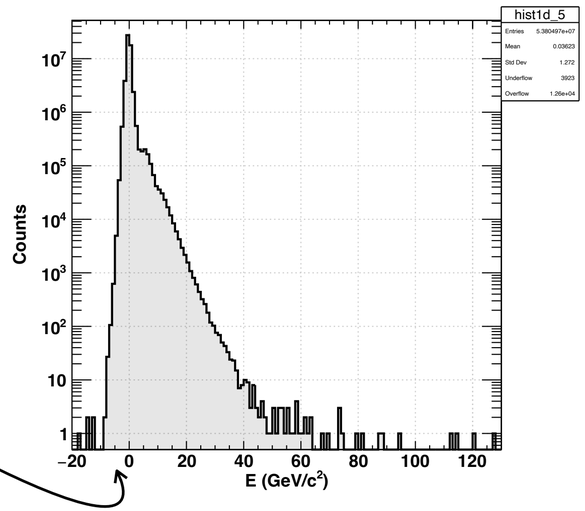
- All jets in events, taken everything even if they look junk, were checked.
- Kinematics of all jets

Run: 50036

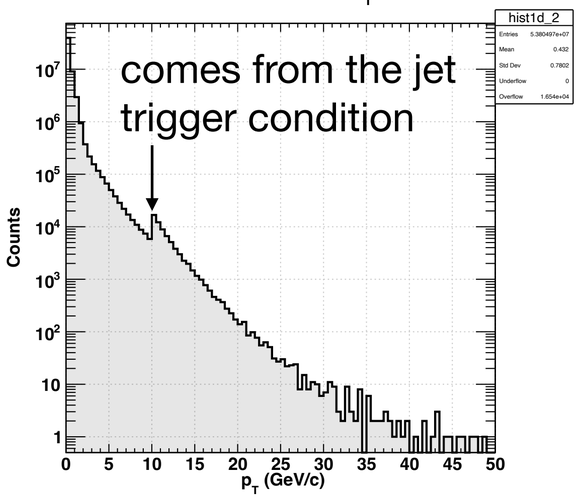
Cut:
- nothing

Jets with negative energy are known. They are due to pedestal subtraction in my understanding.

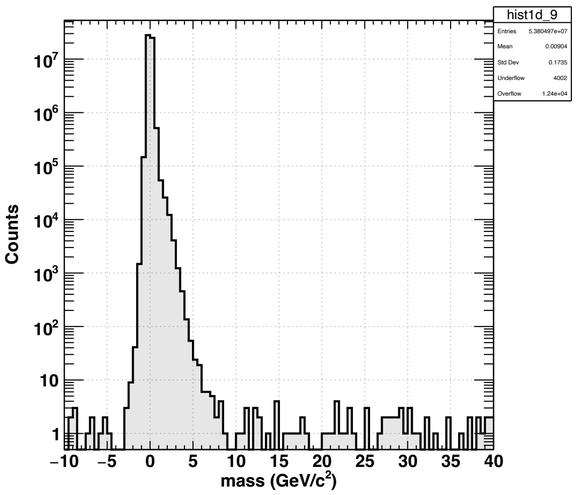
E



p_T



mass



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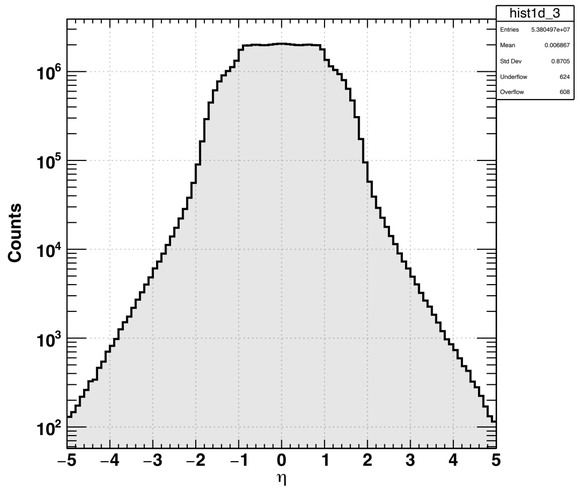
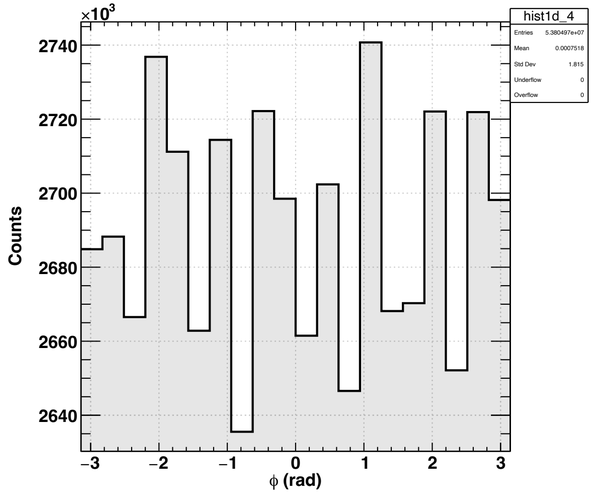


ϕ



#jet: 5e7

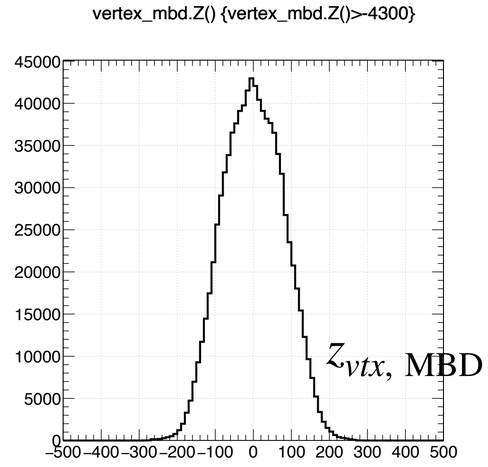
Quick look

Run: 50036

Cut:
- nothing

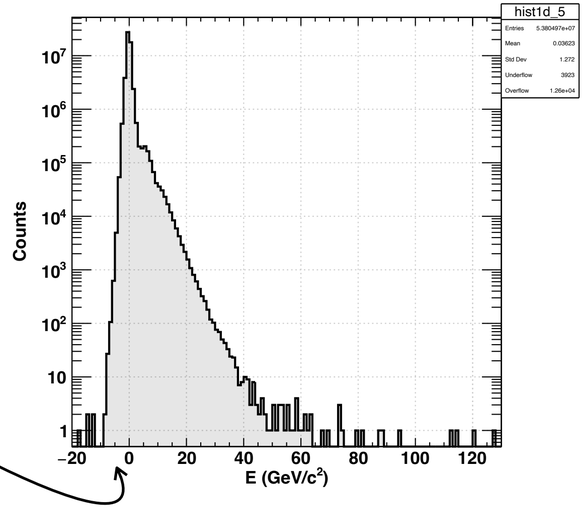
- All jets in events, taken everything even if they look junk, were checked.
- Kinematics of all jets

Jets with negative energy are known. They are due to pedestal subtraction in my understanding.

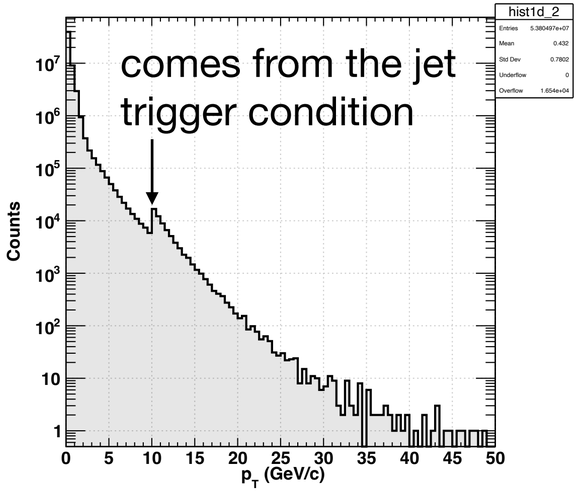


$|\eta| > 1.1$ is possible depending on the vertex position.

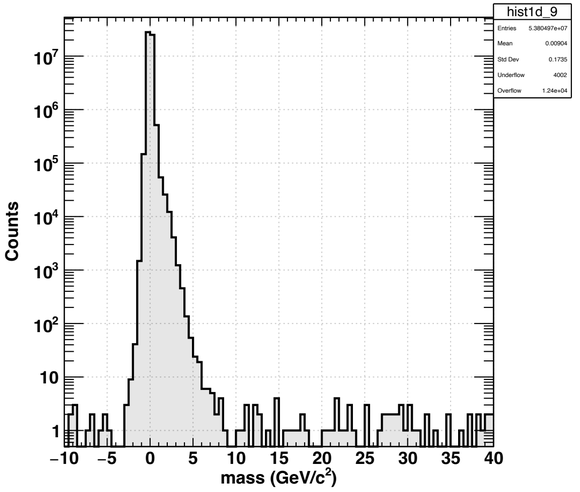
E



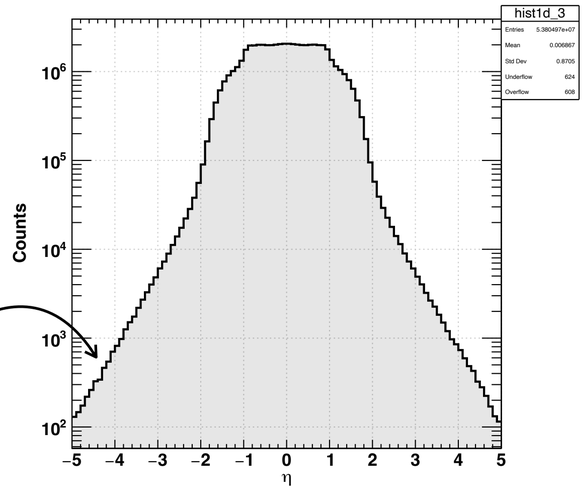
p_T



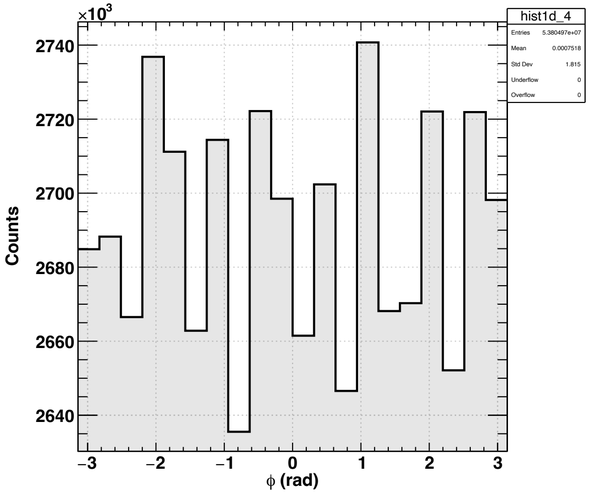
mass



η



ϕ



#jet: 5e7

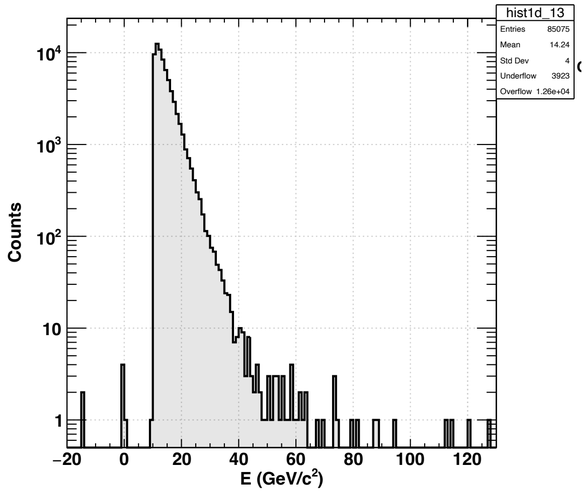
Quick look

- All jets in events, taken everything even if they look junk, were checked.
- Kinematics of all jets

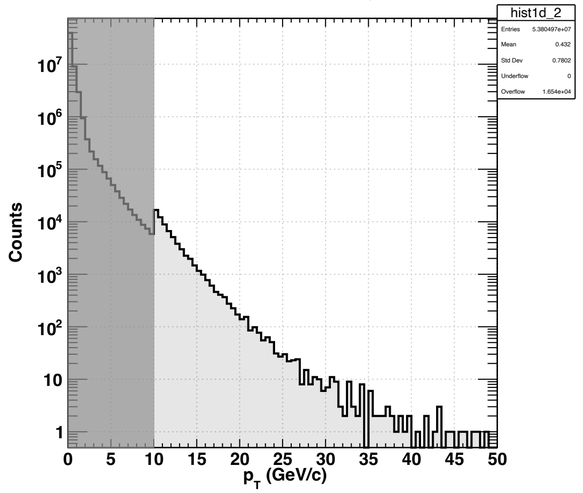
Run: 50036

Cut:
- p_T > 10 GeV/c

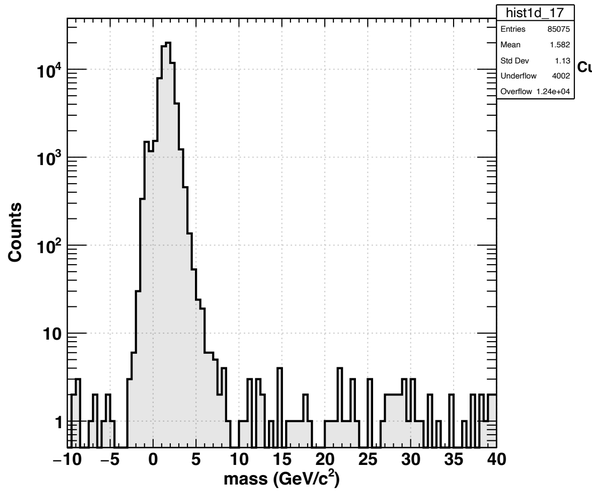
E



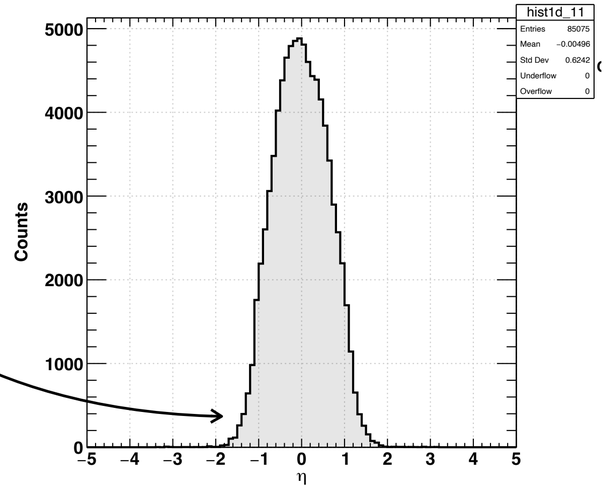
p_T



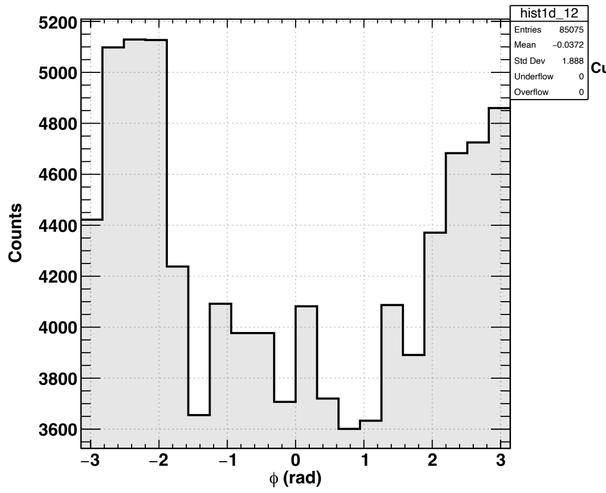
mass



η



ϕ



#jet: 5.4e7 → 8.5e4

η distribution became similar to the sPHENIX acceptance.

Quick look: Leading/Subleading jets

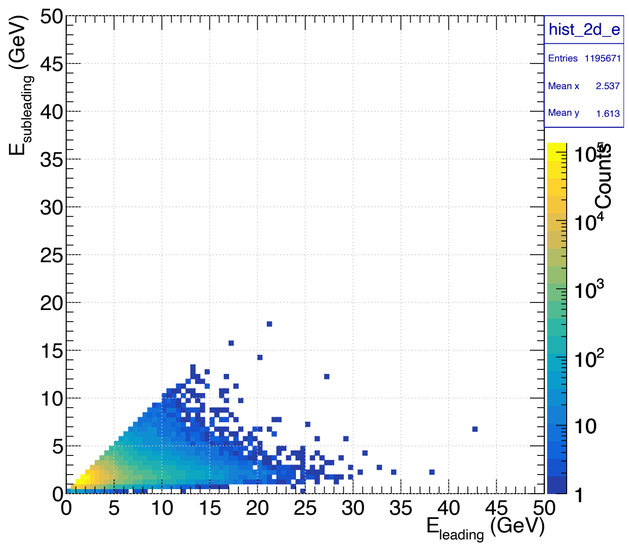
- >50 jets/event is too many. It's good to see the kinematics of leading/ subleading jets (jet with the (2nd) highest energy).

Run: 50036

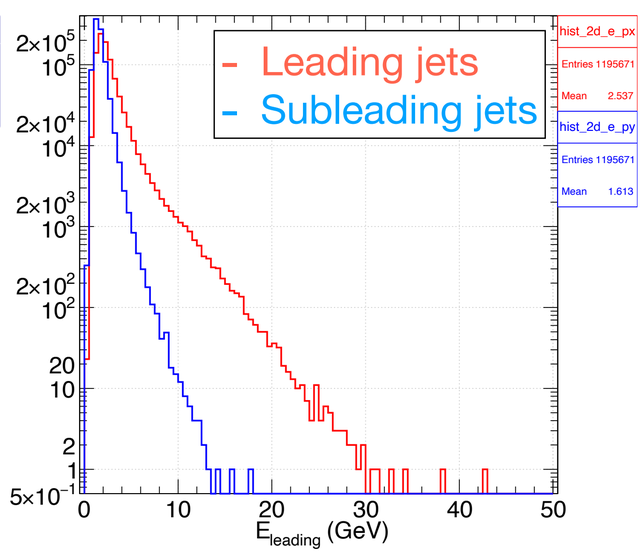
Cut:

- Leading or subleading jet

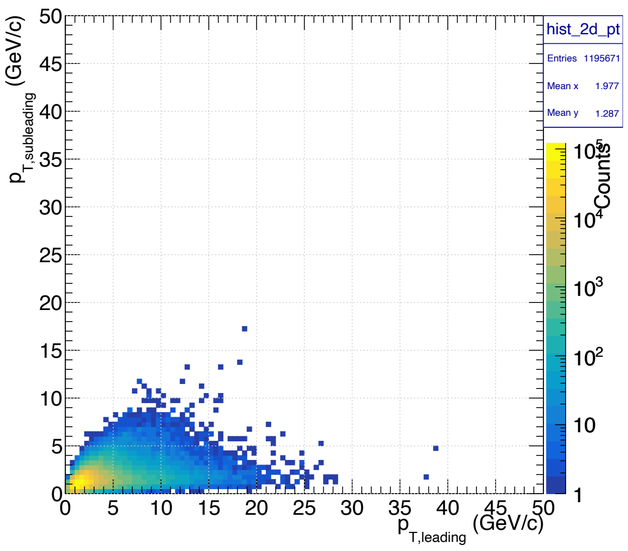
E



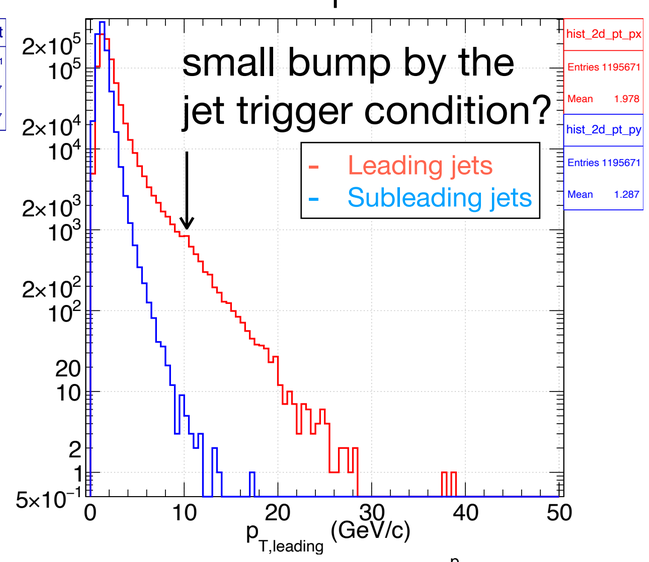
E



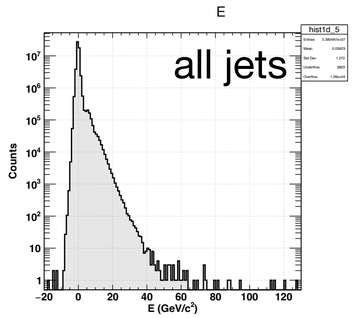
p_T



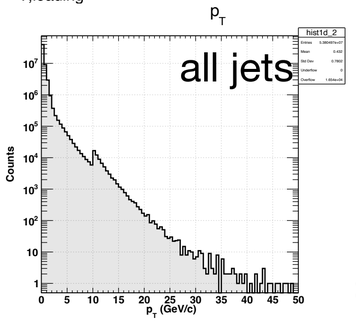
p_T



E

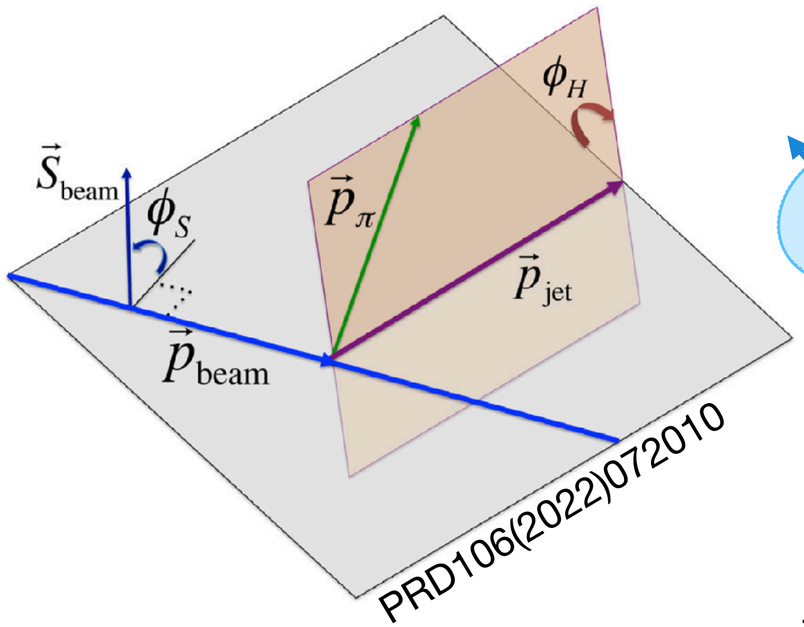


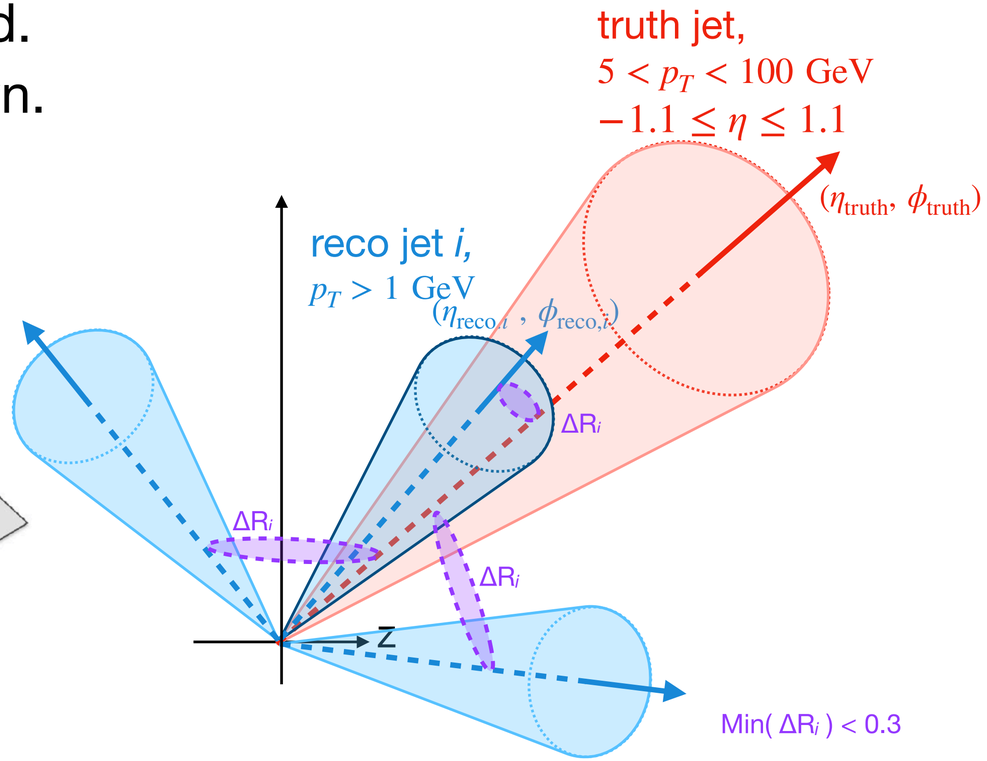
p_T



Summary

- Jets are useful tool for the study of proton structure.
- I'm currently working on inclusive jet AN analysis. My goal is γ-Jet asymmetry.
- The analysis was started from looking into MC data. Some analysis has been done.
- I moved to the real data analysis. Currently, the skimmed DSTs prepared by the Jet topical group, which contain calorimeter data, reconstructed jets with pT cut of >10 GeV/c, MBD vertex, and trigger information, are used.
- Some quick looks are shown.





Truth jet — Reconstructed jet matching