Multi-Particle Analysis for Jet Identification at PHENIX

JPS Autumn Meeting, Sep. 27, 2004

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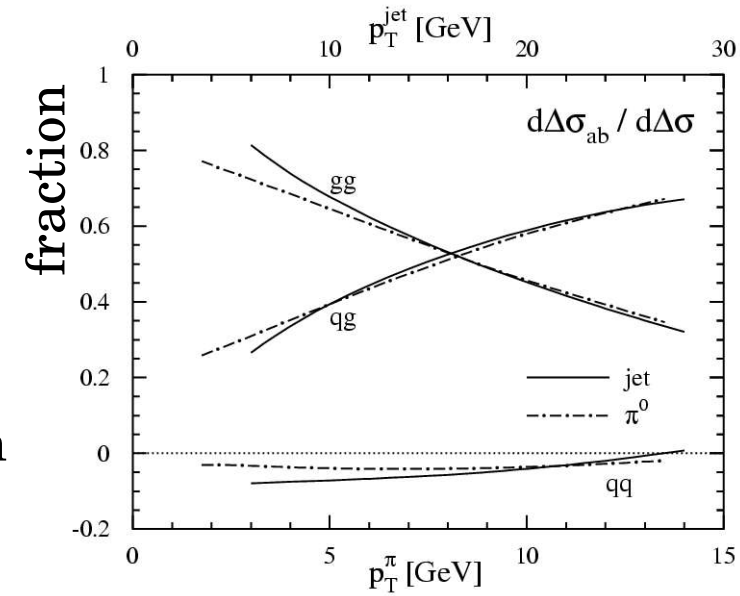
Motivation

- Gluon polarization in proton (spin puzzle)

$$\frac{1}{2}_{\text{proton}} = \frac{1}{2}\sum_q \Delta q + \Delta G + L_{q,g}$$

$\Delta q / \Delta G$: quark/gluon polarization,

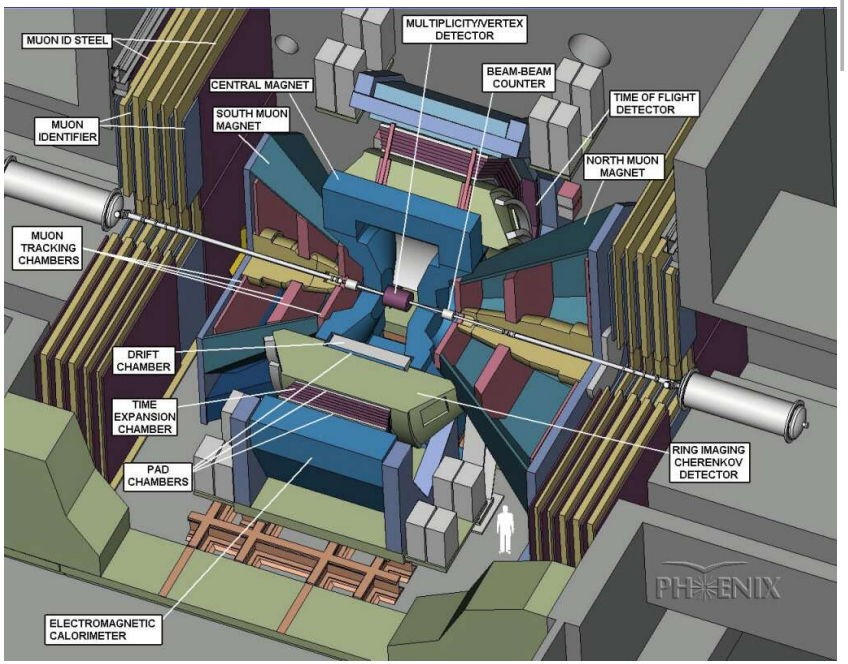
$L_{q,g}$: orbital angular momenta

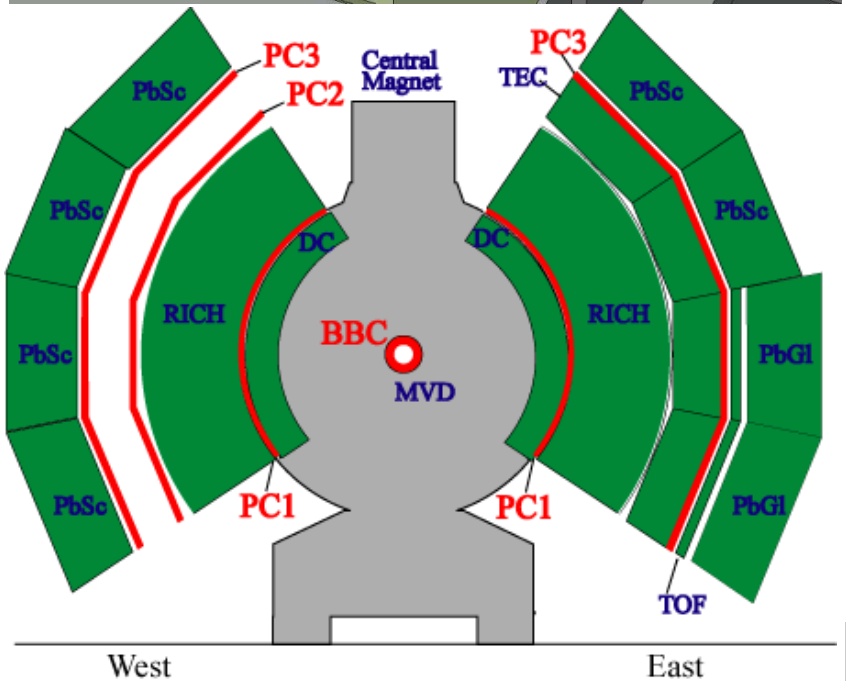


- Double helicity asymmetry (A_{LL}) of jet production
  - A_{LL} has an information on ΔG
    - g+g and q+g reaction are dominant in high-p_T jet productions
    - for g+g reaction, $A_{LL} \approx \int dx_1 dx_2 \frac{\Delta G(x_1)}{G(x_1)} \cdot \frac{\Delta G(x_2)}{G(x_2)} \cdot \hat{a}_{LL}^{gg\to gg}$
  - higher statistics can be achieved at particularly high-p_T region in comparison with single-particle measurements
    - A_{LL}^{pi0} with PHENIX Run3 data was submitted to PRL
  - A selection of jet-like event is needed because of the limited detector acceptance of PHENIX

PHENIX Detector and Data Set

- RHIC-PHENIX RUN3, longitudinally polarized proton-proton, $\sqrt{s}$ = 200 GeV, polarization 26%, luminosity 0.26 pb^{-1}
- Central Arms: $\Delta\phi = 90^{o} \times 2$, $|\eta| < 0.35$
  - A selection of jet-like event is needed
- Event selection
  - p_T(photon) > 2 GeV/c (offline trigger)
- Particle selection
  - photon: detected with EMCal
    - $p_T > 0.4$ GeV/c
    - track veto
    - shower shape cut
  - charged particle: detected with DC & PC
    - $0.4 < p_T < 5.0$ GeV/c
    - track quality cut



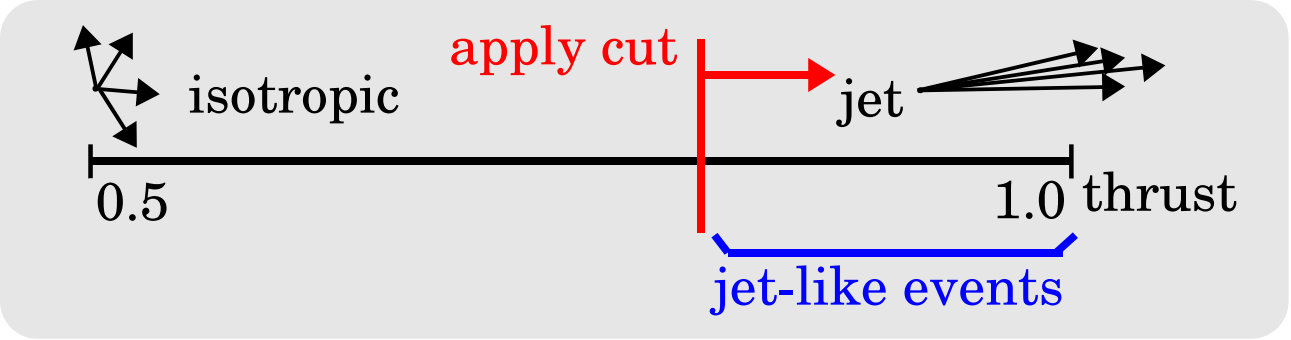


Strategy about Event Selection with Thrust

- Analysis is proceeded arm by arm (calculation of p_T^{sum} and thrust)
- $p_T^{\mathrm{sum}} \equiv \sum_i \boldsymbol{p}_{Ti}$ (vector sum) of all detected particles with one (East/West) arm
- p_T of a jet can be evaluated from p_T^{sum} with simulation
- Jet-like event is enhanced (soft scattering event is excluded) with a cut of thrust value
  - thrust ... topology variable about distribution of particles

$$T \equiv \max_{\boldsymbol{u}} \frac{\sum_i |\boldsymbol{p}_i \cdot \boldsymbol{u}|}{\sum_i |\boldsymbol{p}_i|} = \frac{\sum_i \boldsymbol{p}_i \cdot \hat{\boldsymbol{p}}}{\sum_i |\boldsymbol{p}_i|}$$

($\boldsymbol{u}$: thrust axis, $\hat{\boldsymbol{p}}$: unit of $\sum \boldsymbol{p}_i$)



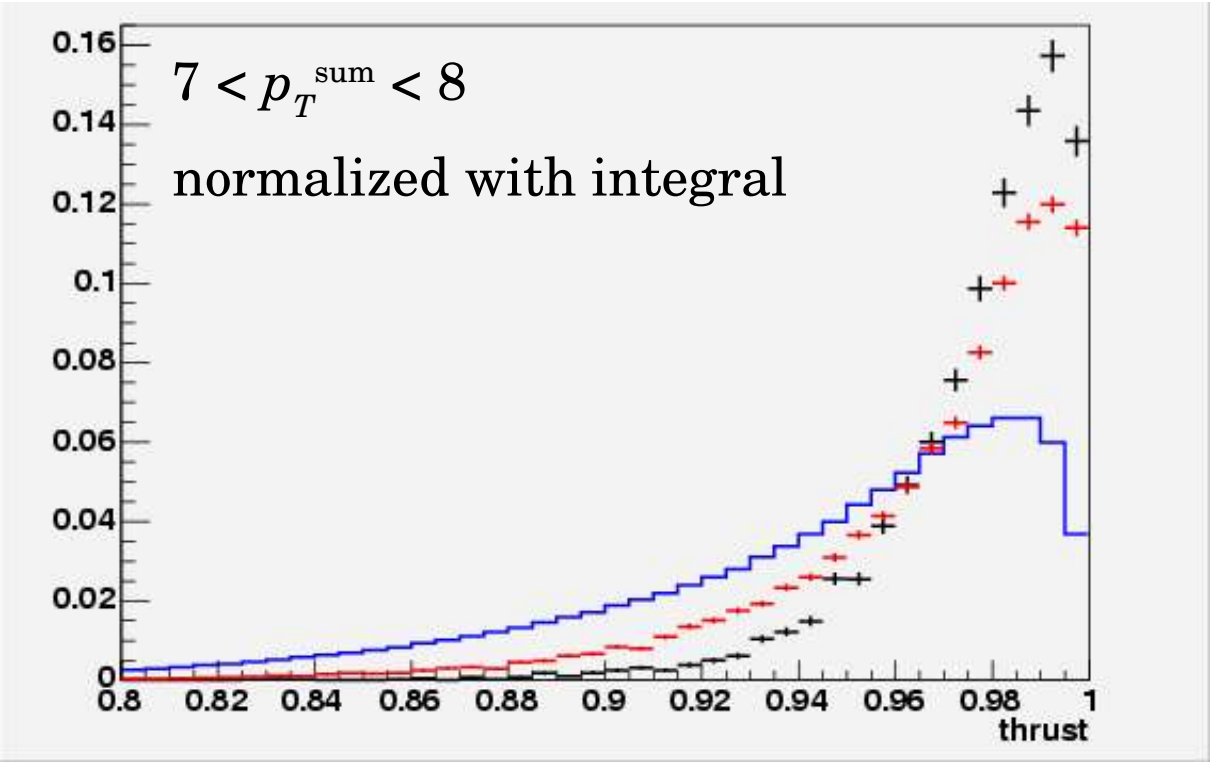
Strategy about Event Selection with Thrust

- We compared real data with Monte-Carlo to evaluate the event selection method
  - data are almost raw (no correction for trigger efficiency, detector resolution, detector mask...)
- Statistical error of A_{LL} was evaluated with cut-applied yield

- Simulation with PYTHIA
  - CTEQ5L PDF
  - high-p_T QCD (jet production) process (MSEL = (2))
  - hard process $\hat{p}_T$ minimum: CKIN(3) = 2 GeV/c
  - acceptance : $\Delta\phi = 90^{\circ} \times 2$, $|\eta| < 0.35$
  - detector resolution is not taken into account

Results - Study of Thrust Distributions

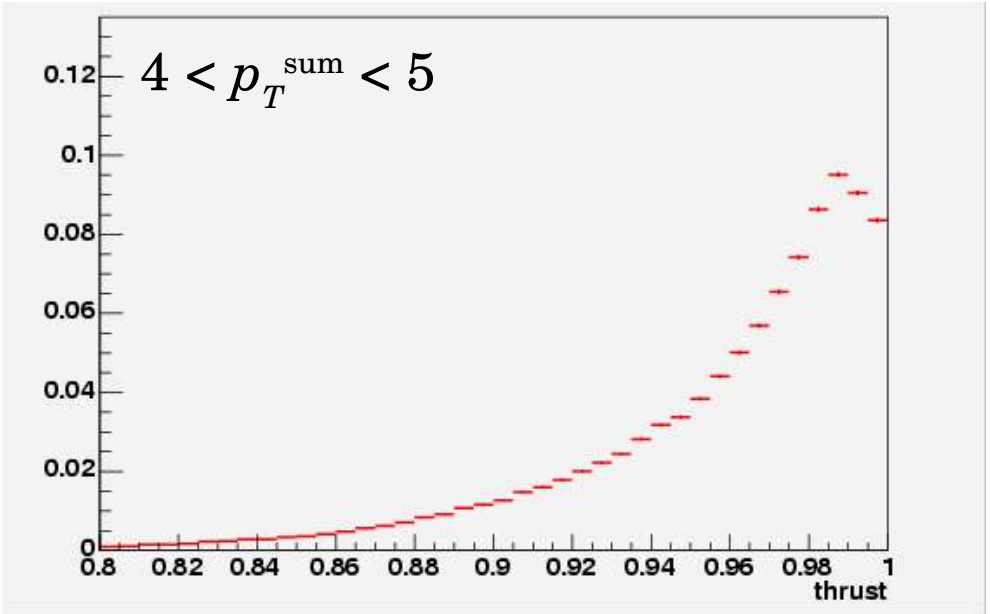
- Red: real data, black: PYTHIA, blue: isotropic event

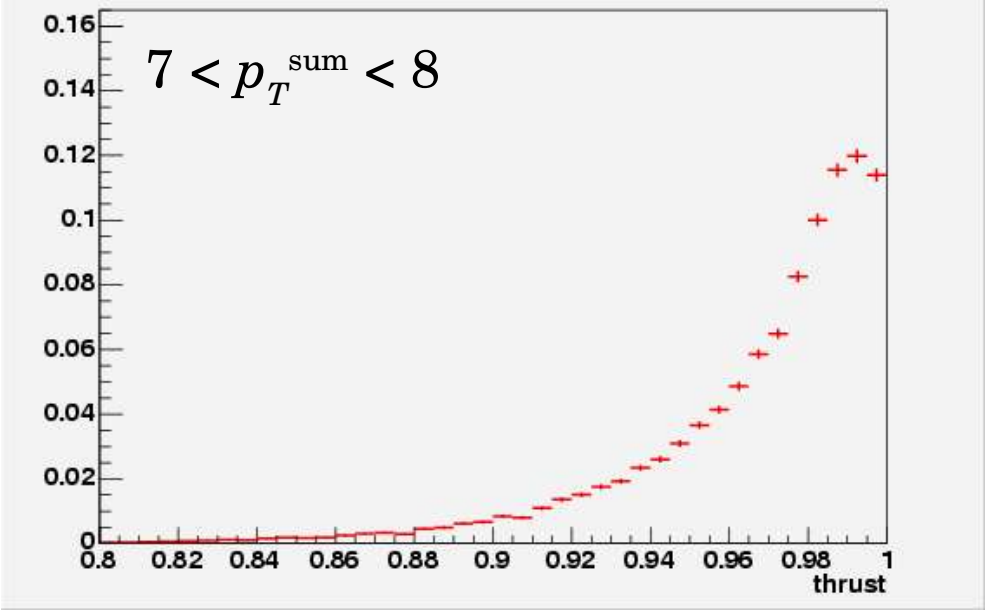


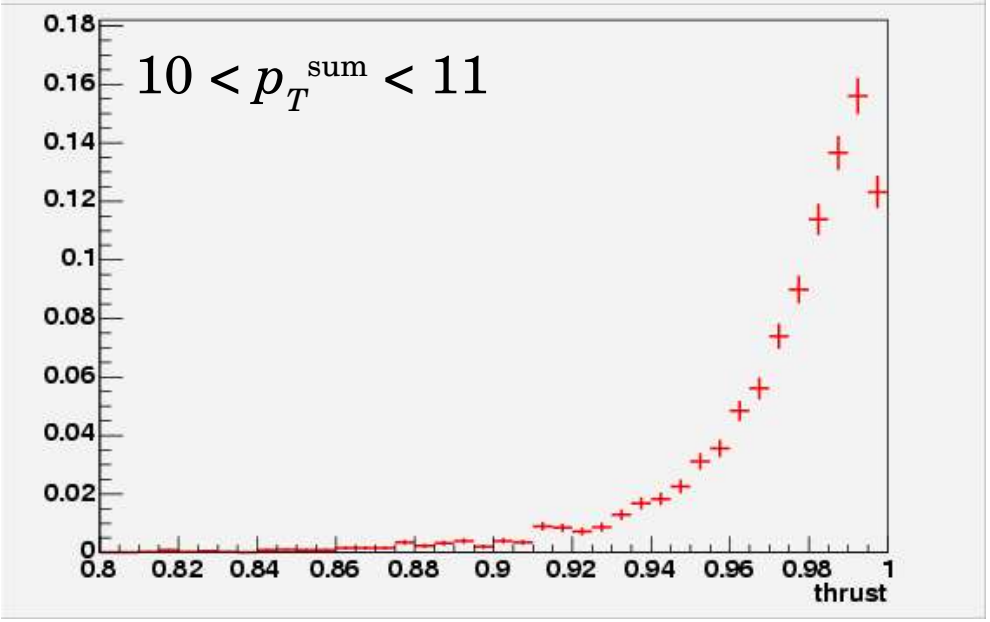
- isotropic event generation: $\mathcal{P}(p_T, \phi, \eta) \propto \exp(-p_T)$
- we used events with particles ≥ 3 (low-multiplicity event is not distinguishable)
- both real data and PYTHIA data have sharp distribution which differs from isotropic event = jet-like events exist and can be enhanced with thrust value

Results - Study of Thrust Distributions

- Red: real data



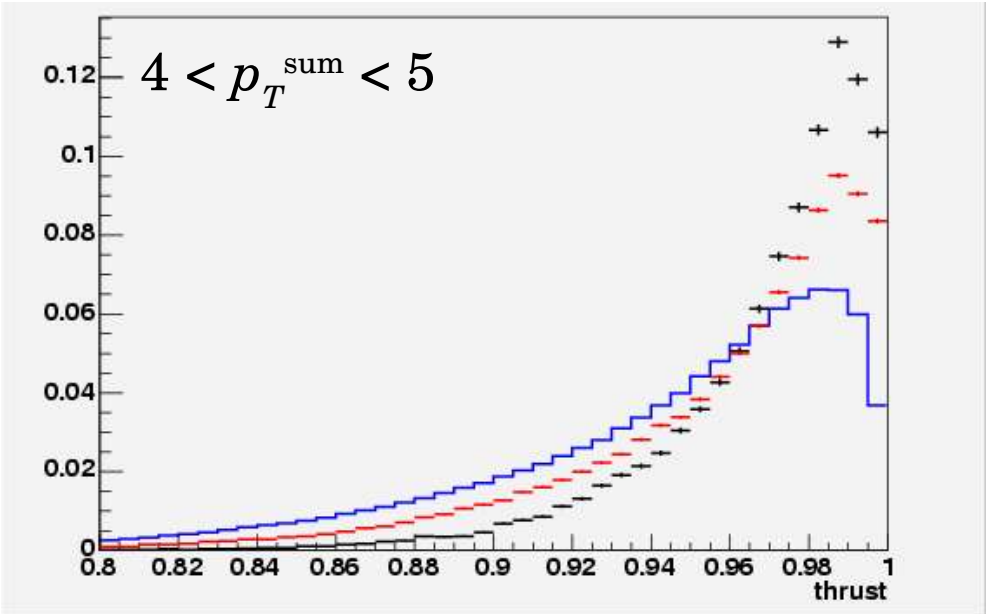


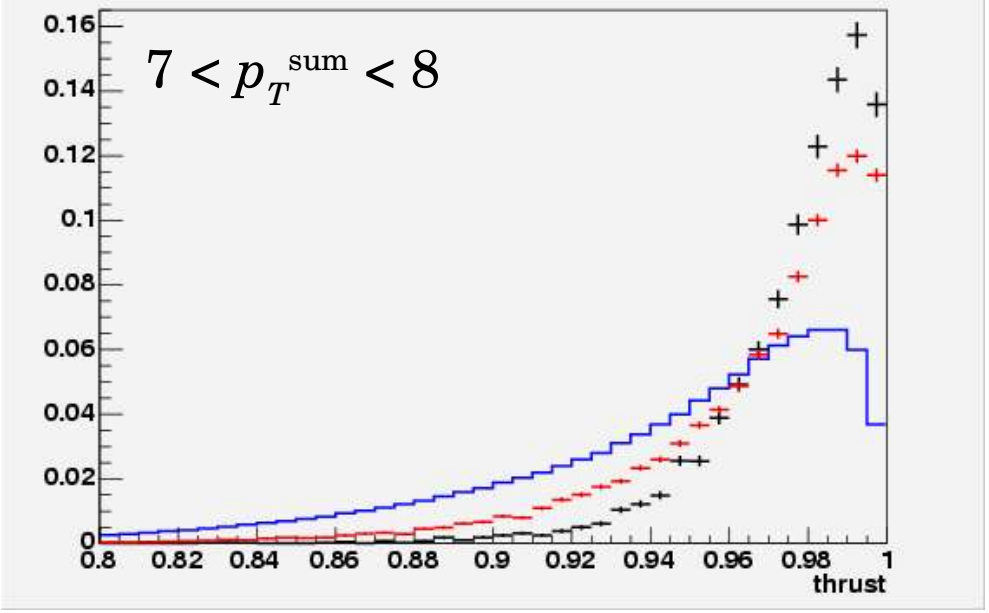


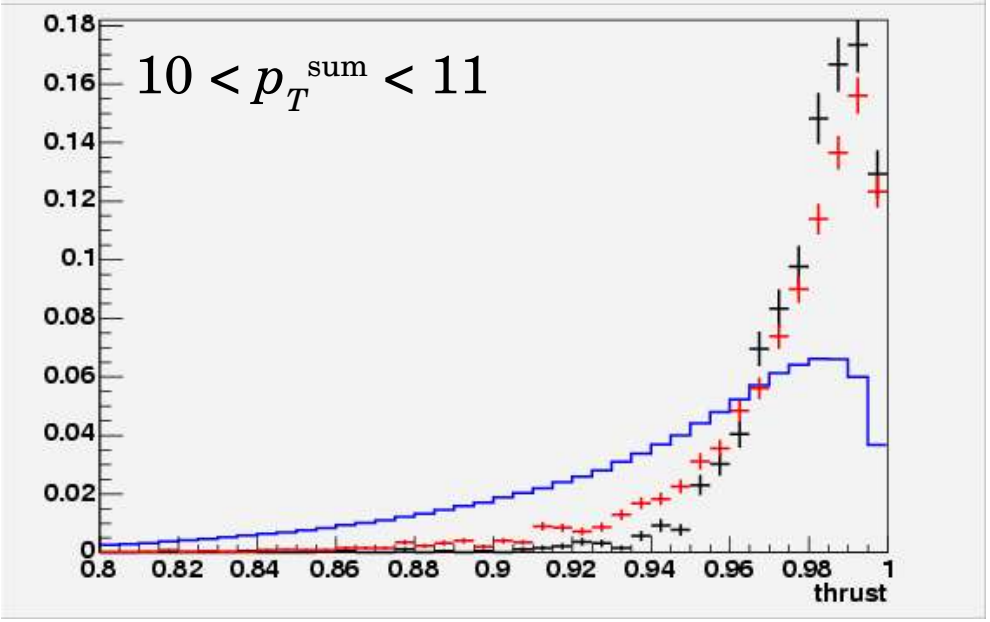
- distribution becomes sharp as p_T^{sum} increases (a characteristic of jet)

Results - Study of Thrust Distributions

- Red: real data, black: PYTHIA, blue: isotropic event







- distribution becomes sharp as p_T^{sum} increases (a characteristic of jet)
- real data might have soft scattering component at particularly low-p_T^{sum}

Results - Study of Thrust Distributions

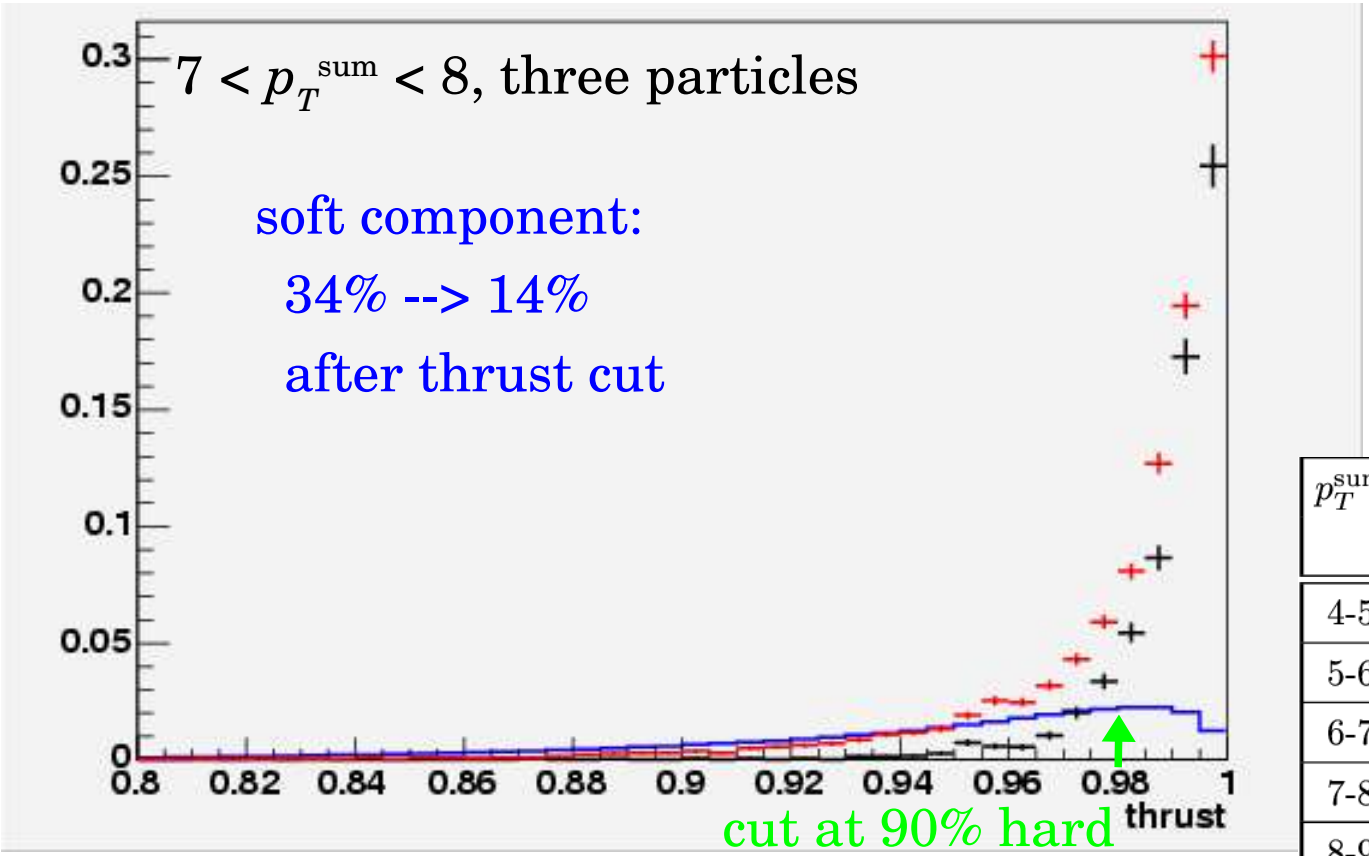
- Jet-like event is enhanced (soft scattering event is excluded) with the thrust cut
- A cut condition: 90% efficiency for PYTHIA (hard scattering component)

$$R(T_{\rm cut}) \equiv \frac{\int_{T_{\rm cut}}^{1} dT N(T)}{\int_{0.5}^{1} dT N(T)} = 0.9$$

- A fraction (α) of soft scattering component before/after the thrust cut can be evaluated
  - real data = (1 - α) (PYTHIA) + α (isotropic event)
  - $R(T_{\rm cut})$ for the three data are known
  - $R_{\rm real} = (1 - \alpha)\, R_{\rm PYTHIA} + \alpha\, R_{\rm isotropic}$

Results - Study of Thrust Distributions

- red: real data, black: PYTHIA, blue: isotropic event



p_T^{sum}	soft component		yield after cut
	before cut	after cut	$(N \geq 3)$
4-5	32%	24%	1.61×10^5
5-6	30%	18%	8.14×10^4
6-7	29%	14%	4.07×10^4
7-8	34%	14%	2.10×10^4
8-9	21%	6.3%	1.09×10^4
9-10	26%	5.8%	6.03×10^3

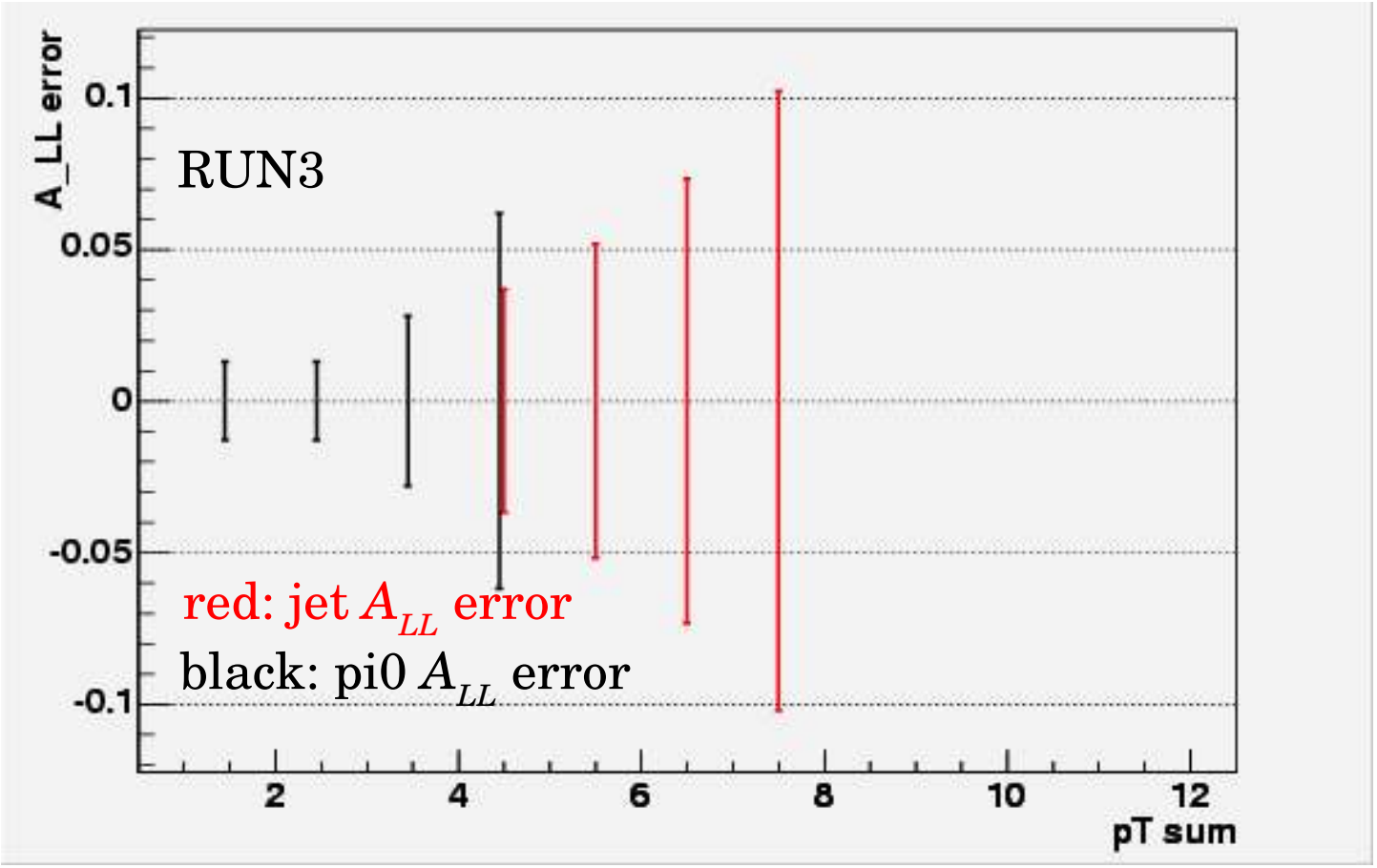
- the thrust cut excludes 40-80% of soft scattering component
- statistical error of A_{LL} was estimated for the “jet”-enhanced sample

Results - Estimation of A_{LL} Statistical Error

- Statistical error of A_{LL}

$$A_{LL} = \frac{1}{|P_B|\,|P_Y|}\frac{N_{++} - N_{+-}}{N_{++} + N_{+-}} \qquad \sigma_{A_{LL}} \approx \frac{1}{|P_B|\,|P_Y|}\frac{1}{\sqrt{N_{++} + N_{+-}}}$$

  - N_{++}, N_{+-}: the number of events for each helicity configuration
  - $|P_B|$, $|P_Y|$: beam polarization for each ring (= 26%)

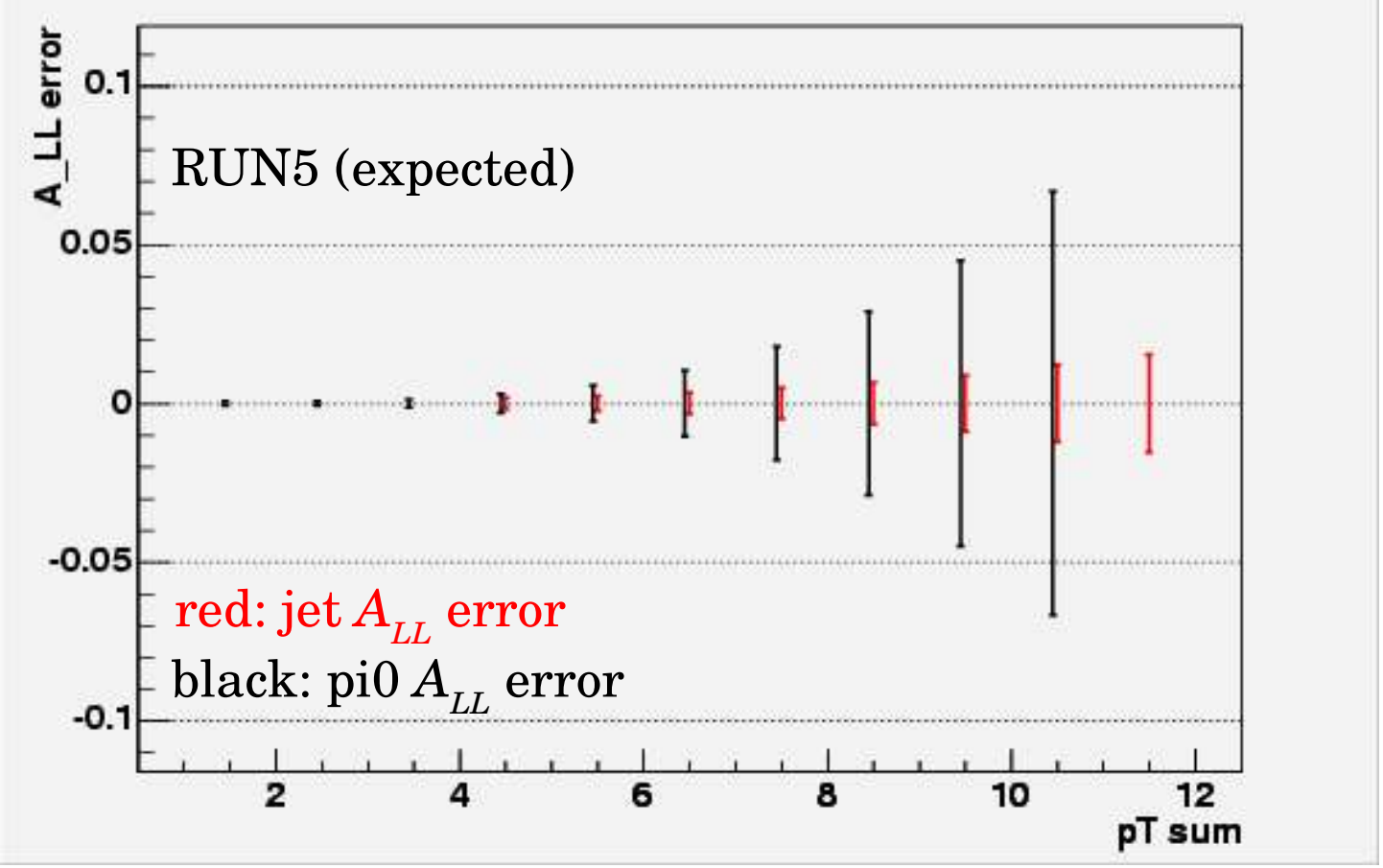


Results - Estimation of A_{LL} Statistical Error

- Statistical error of A_{LL} with RUN5 statistics

$$A_{LL} = \frac{1}{|P_B|\,|P_Y|}\frac{N_{++}-N_{+-}}{N_{++}+N_{+-}} \qquad \sigma_{A_{LL}} \approx \frac{1}{|P_B|\,|P_Y|}\frac{1}{\sqrt{N_{++}+N_{+-}}}$$

  - luminosity: 0.3 --> 10 pb^{-1}, beam polarization: 26 --> 50%



  - PHENIX RUN5 will provide more statistics

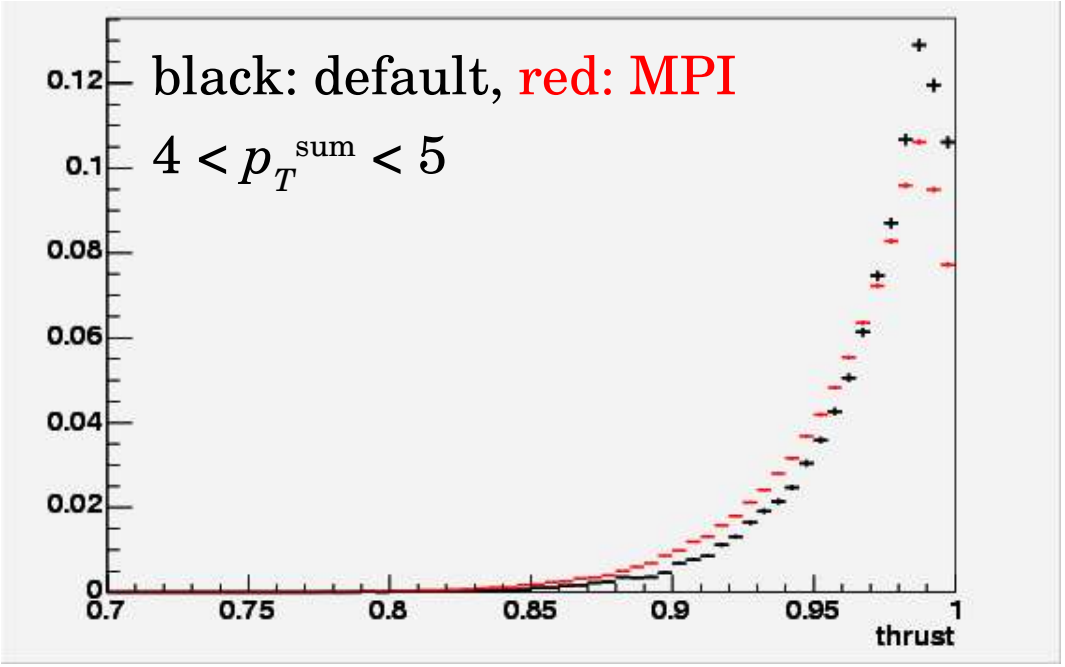
Summary

- The goal of this analysis is to obtain gluon polarization in proton (ΔG) from double helicity asymmetry (A_{LL}) of jet production
- RHIC-PHENIX RUN3, longitudinally polarized proton-proton, $\sqrt{s}$ = 200 GeV, polarization 26%, luminosity 0.26 pb^{-1}
- p_T of a jet can be obtained from the sum of p_T of particles ($p_T^{\mathrm{sum}} \equiv \sum_i \boldsymbol{p}_{Ti}$)
- Jet-like event and isotropic event can be distiguished with thrust distribution in the acceptance of PHENIX Central Arm ($\Delta\phi = 90^{\circ} \times 2$, $|\eta| < 0.35$)
- Jet-like event is enhanced with a cut of thrust value
  - a cut condition: 90% efficiency for PYTHIA thrust distribution
  - roughly 40-80% of soft scattering component was excluded
- A_{LL} will be measured with higher statistics at high-p_T region in comparison with single-particle measurements

Backup Slides...

Future Work

- Study about underlying event
  - “underlying event” means scatterings between beam remnants
  - PYTHIA models underlying event with color string fragmentation and Multi-Parton Interaction
  - but PYTHIA default does not reproduce real data very well
  - comparison between default and MPI tune studied by Rick Field
    - PYTHIA MPI makes broader thrust distribution

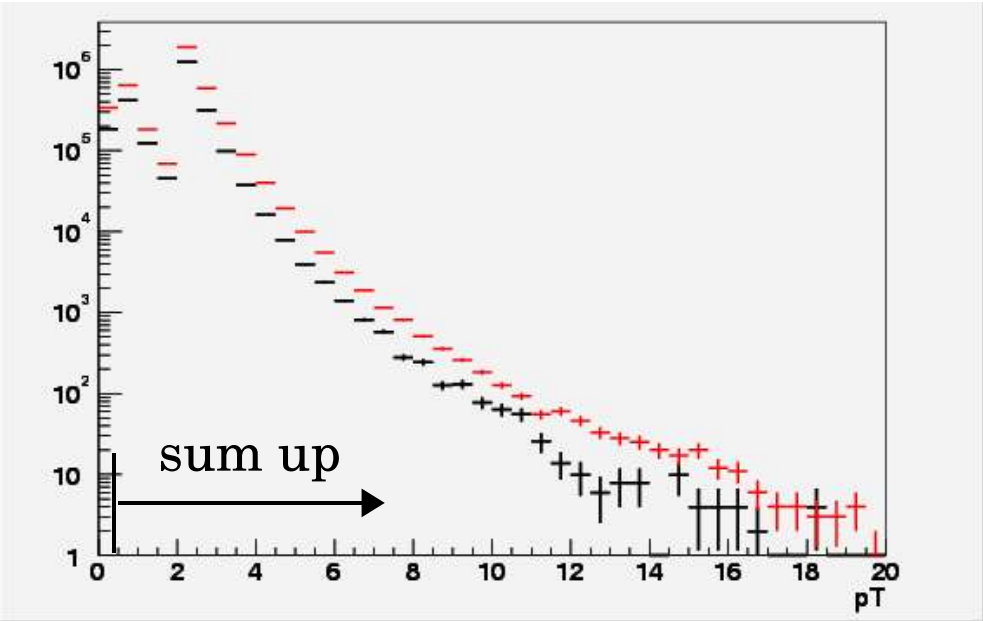


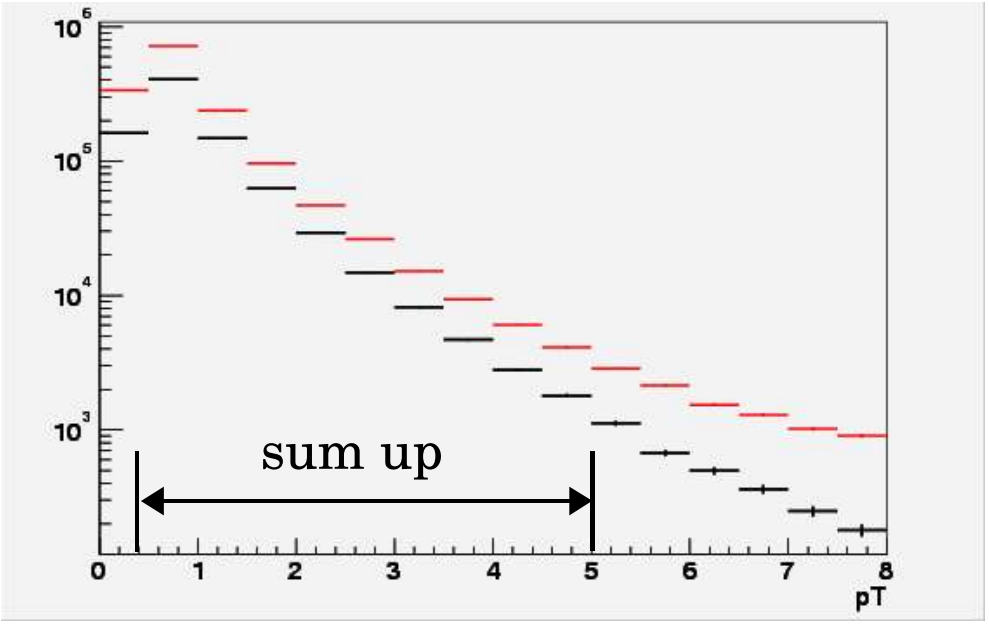
Analysis Condition

- Event selection
  - gamma3 trigger, L = 259 nb^{-1} (MB 5.56 x 10^{9} events)
  - off-line jet event trigger: E_T(cluster) > 2 GeV
  - 2.83 x 10^{6} triggered sample (West & East Arm)
- Particle selection
  - photon momentum: p_T > 0.4 GeV/c
  - photon probability > 0.01 (shower shape)
  - charged momentum: 0.4 < p_T < 5.0 GeV/c
  - DC track quality == 31 | | 63
  - cluster charged veto: DC matching (|emcsdphi|, |emcsdz| < 3.0)
- Yield correction (not yet)
  - trigger efficiency (~75%)
  - EMCal dead/warn tower mask (~89%) (also affects p_T sum)

p_T Distributions

- Inclusive (red: real data, black: PYTHIA data)

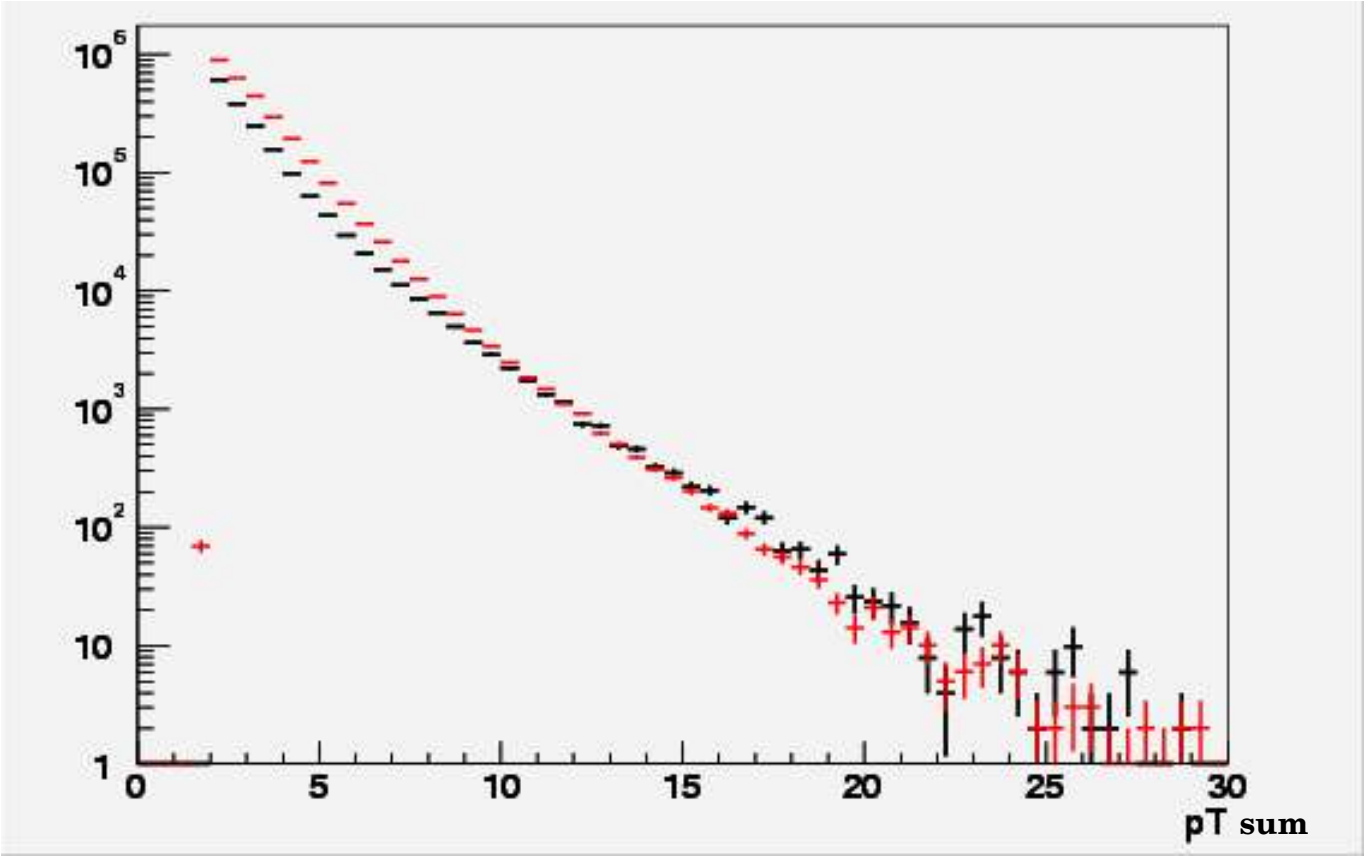




- PYTHIA is smaller with a factor of ~2 (because of LO calculation)

Results - p_T^{sum} Distribution

- $p_T^{\mathrm{sum}} \equiv \sum_i p_{Ti}$ (red: real data, black: PYTHIA data)



- agreement within factor ~2
  - PYTHIA LO calculation
  - trigger efficiency, detector resolution, detector mask ...