ST reconstruction studies

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Updates on studies of reconstruction of the SPD Straw Tracker in p–p and ion–ion collisions

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SPD Experiment

- **Spin Physics Detector (SPD)** is an experiment at the NICA facility designed to study the spin structure of the proton and deuteron using polarized beams, as well as other spin-related phenomena. It is being developed as a universal 4π detector equipped with tracking, particle identification systems, and high luminosity (up to $10^{32} cm^{-2} s^{-1}$)
- Expected energies for **Phase 1 is** $\sqrt{s} = 10\ GeV$ and for **Phase 2 is** $\sqrt{s} = 27\ GeV$
- **Straw Tracker (ST)** is a subsystem responsible for charged track reconstruction and their momentum determination. It plays a critical role in ion-ion collisions with high particle multiplicity, where signal overlap is likely. It is susceptible to occupancy issues, as the front-end electronics require time to process events, which may reduce accuracy under high load conditions. The Straw Tracker is planned to be used throughout all stages of the SPD experiment

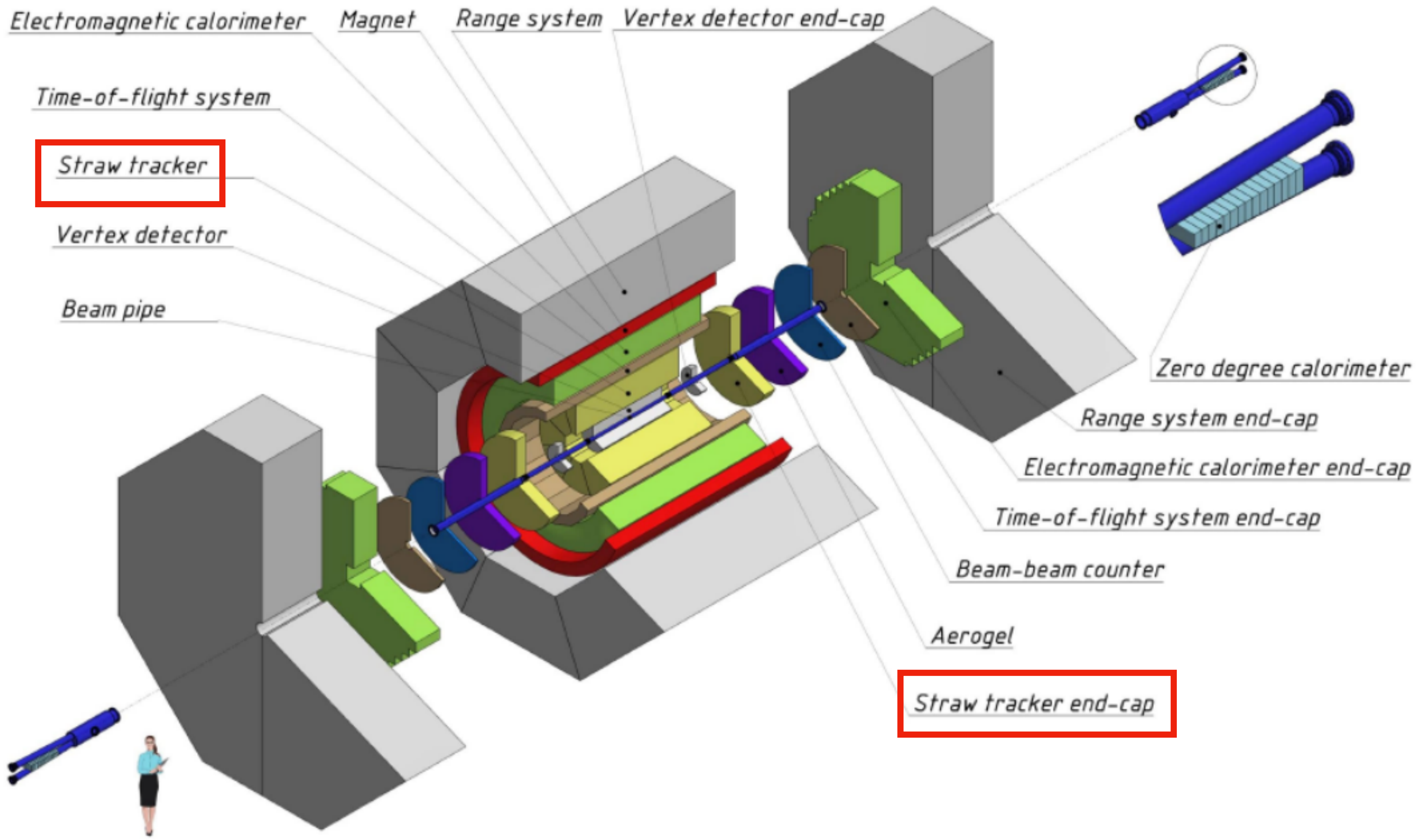


Fig. 1 - SPD Experiment

Straw Tracker (TS) & purpose of the study

- **Purpose:**
  To reconstruct charged particle tracks, measure their momenta based on trajectory curvature in a magnetic field, and perform particle identification via energy loss (dE/dx)

- **Design:**
  The detector consists of a barrel section (for tracking) and two end-caps (primarily for tracking and for identification)

1. **Barrel:** Comprises 8 modules, each containing approximately 3,300 straw tubes (both straight and inclined), totaling around 26,000 tubes
2. **End-caps:** Each contains 8 coordinate planes (disks) utilizing straw tubes with various orientations and lengths

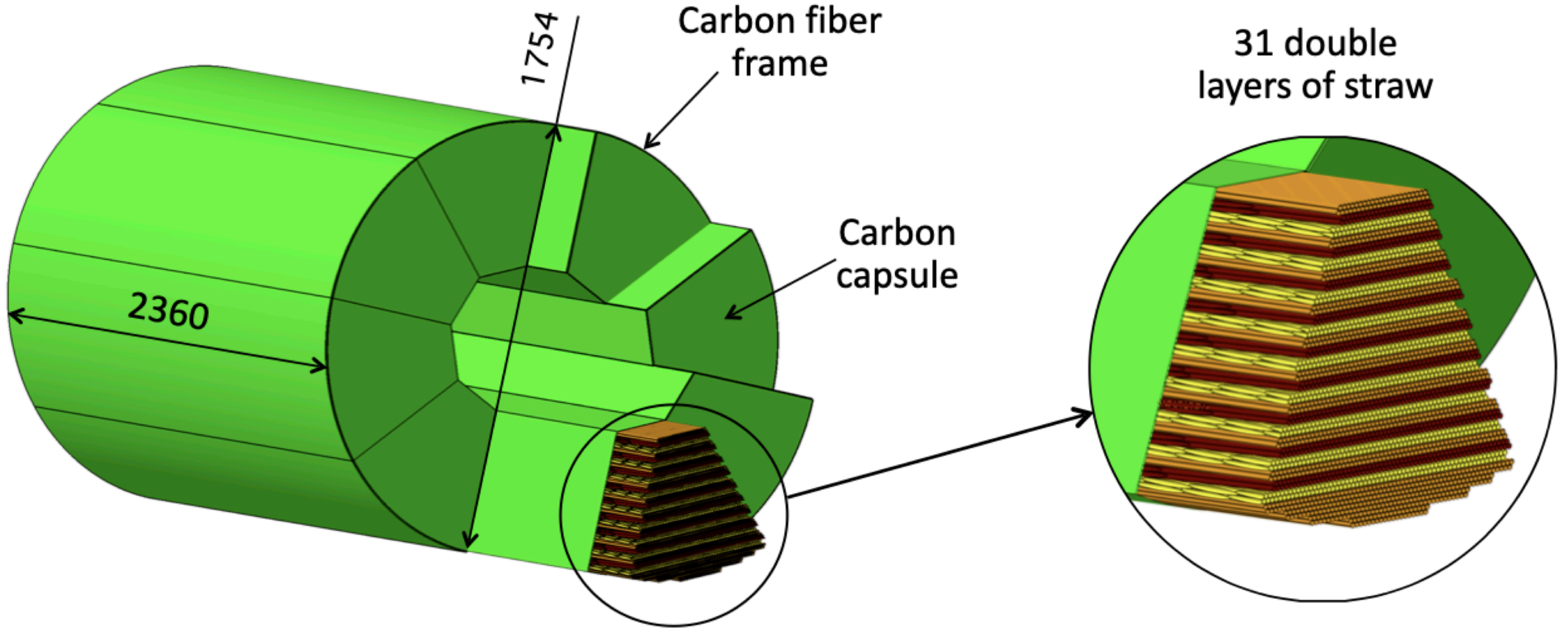


Fig. 2 - Straw Tracker (barrel)

Purpose of the study:

- Determine the hit-rate conditions (colliding system) under which the SPD straw tracker performance remains reliable, and where tracking starts to degrade

- Check the tracking updates on this study

- Use such the results to propose practical detector and reconstruction settings that would keep reconstruction stable at ion program

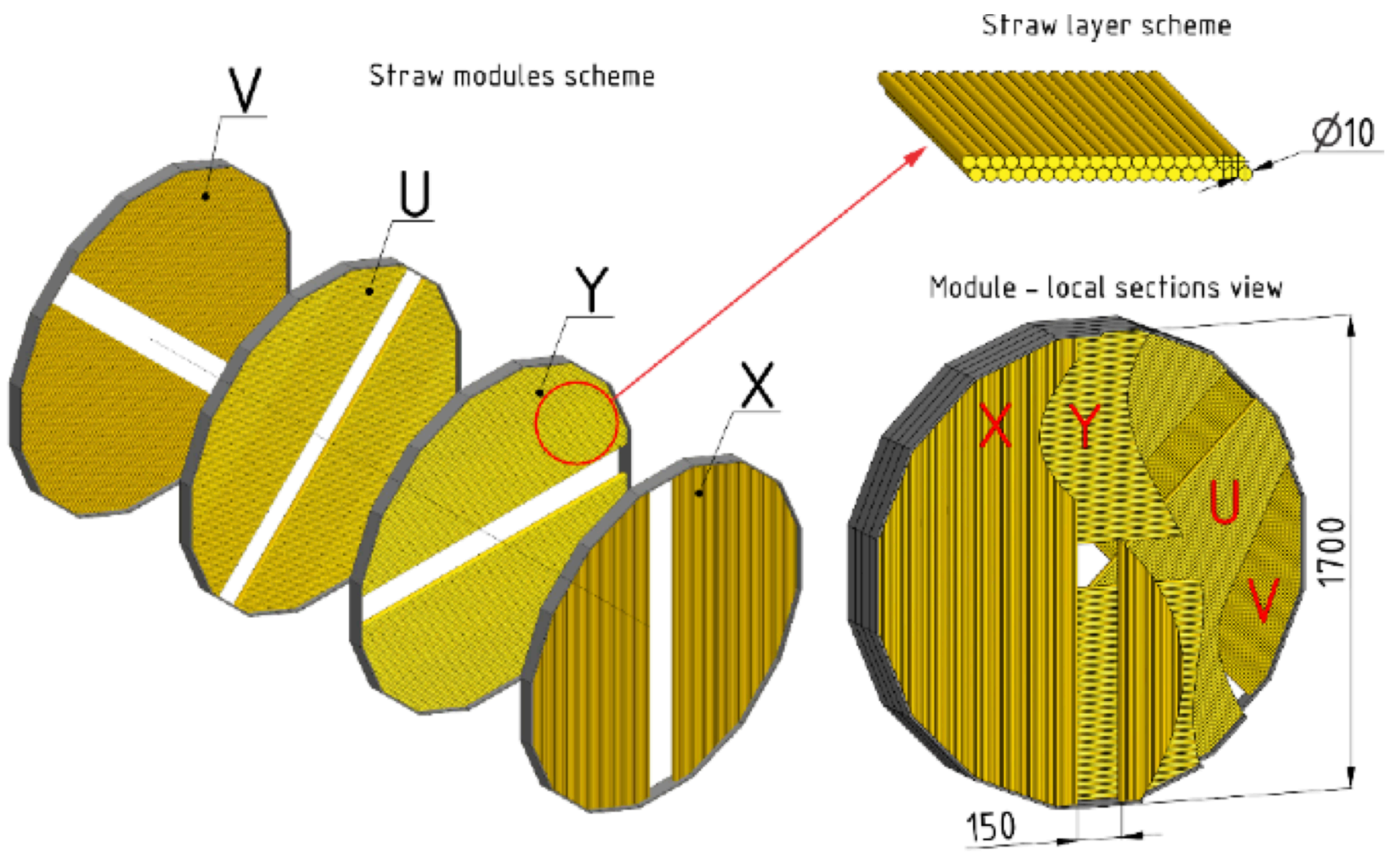


Fig. 3 - Straw Tracker (end-cap)

pT distributions (default SPDRoot reconstruction algorithms) in p-p collisions

Fig. 4 - pT^{MC} (default SPDRoot reconstruction algorithms)

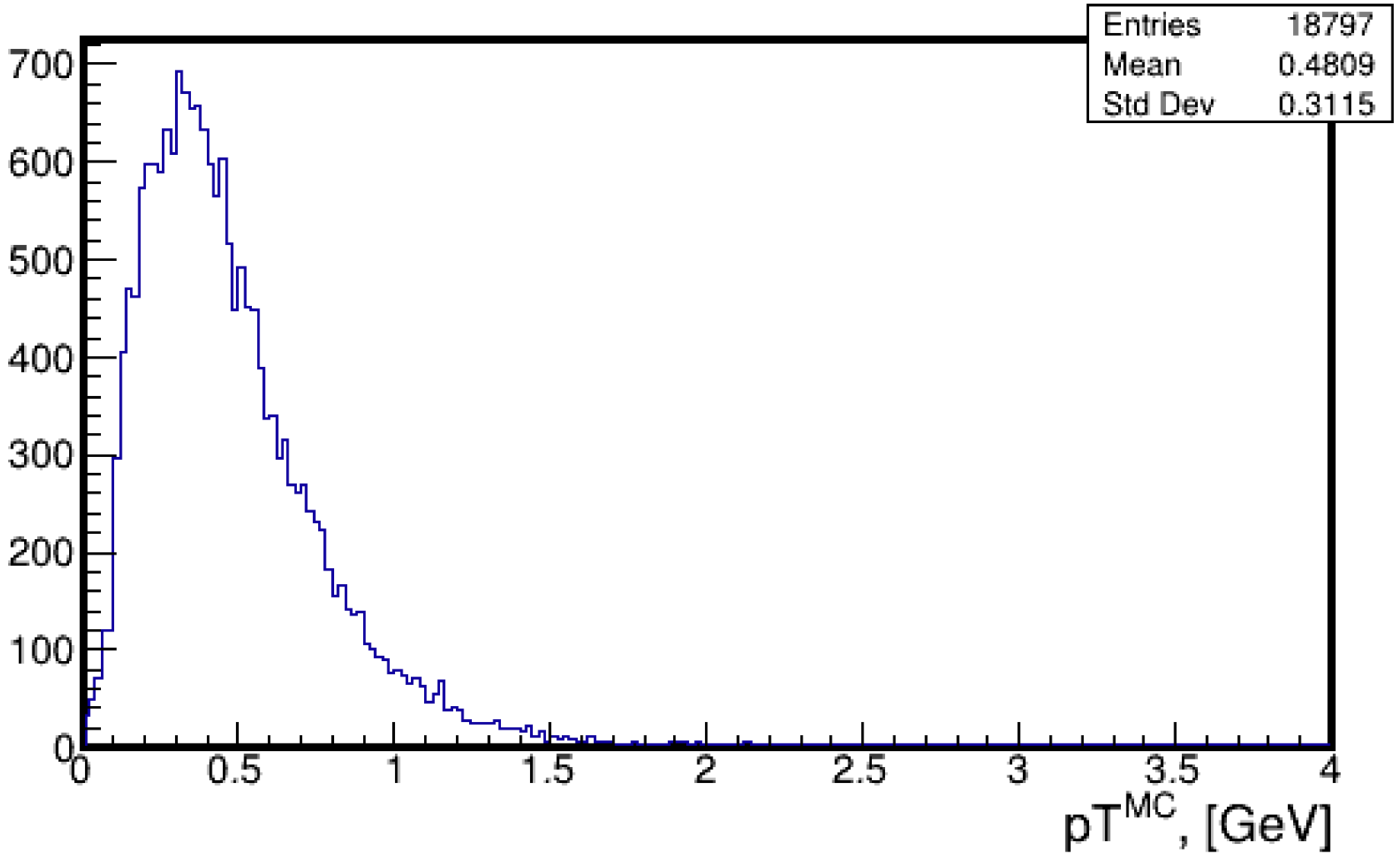
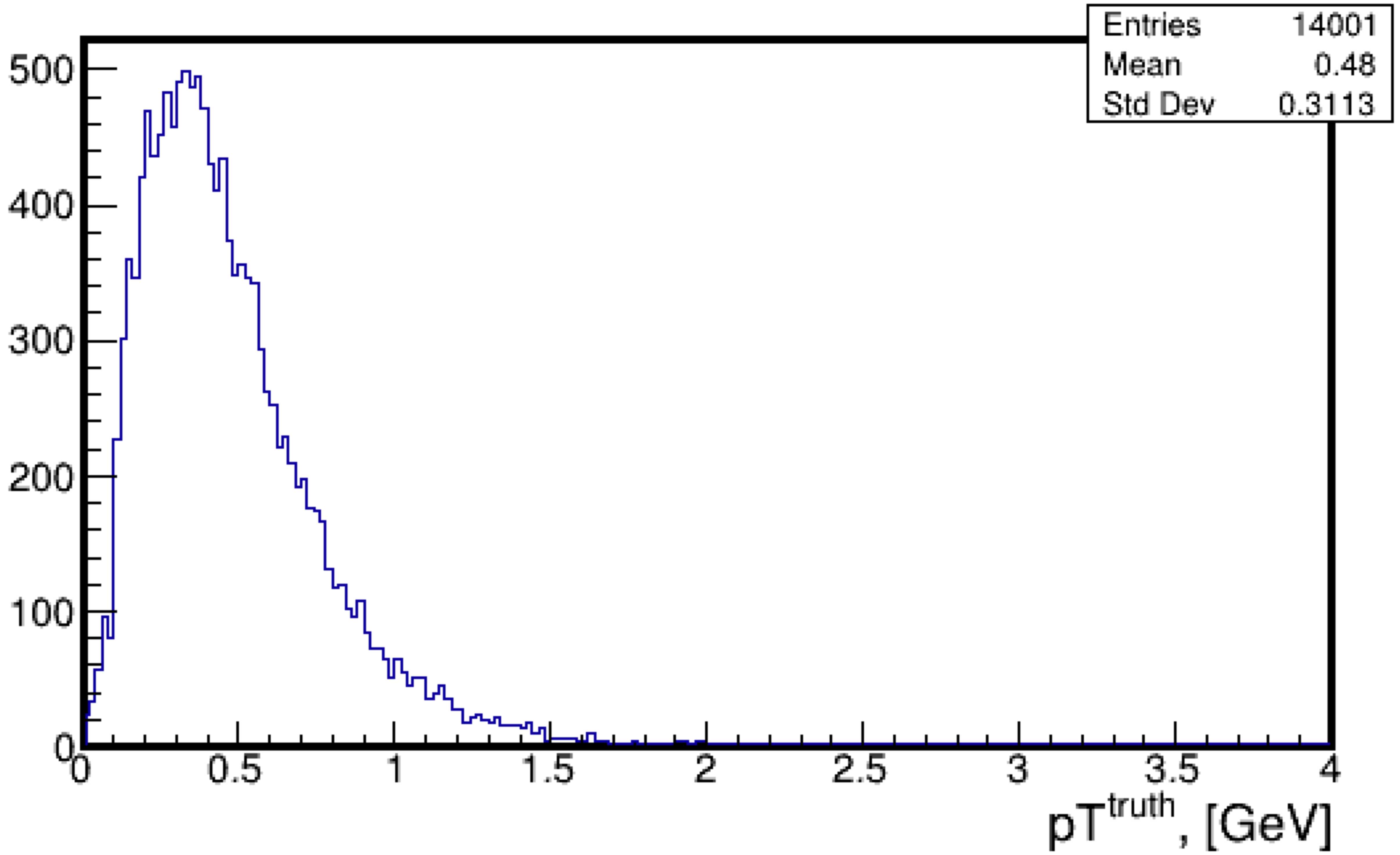


Fig. 5 - pT^{truth} (default SPDRoot reconstruction algorithms)

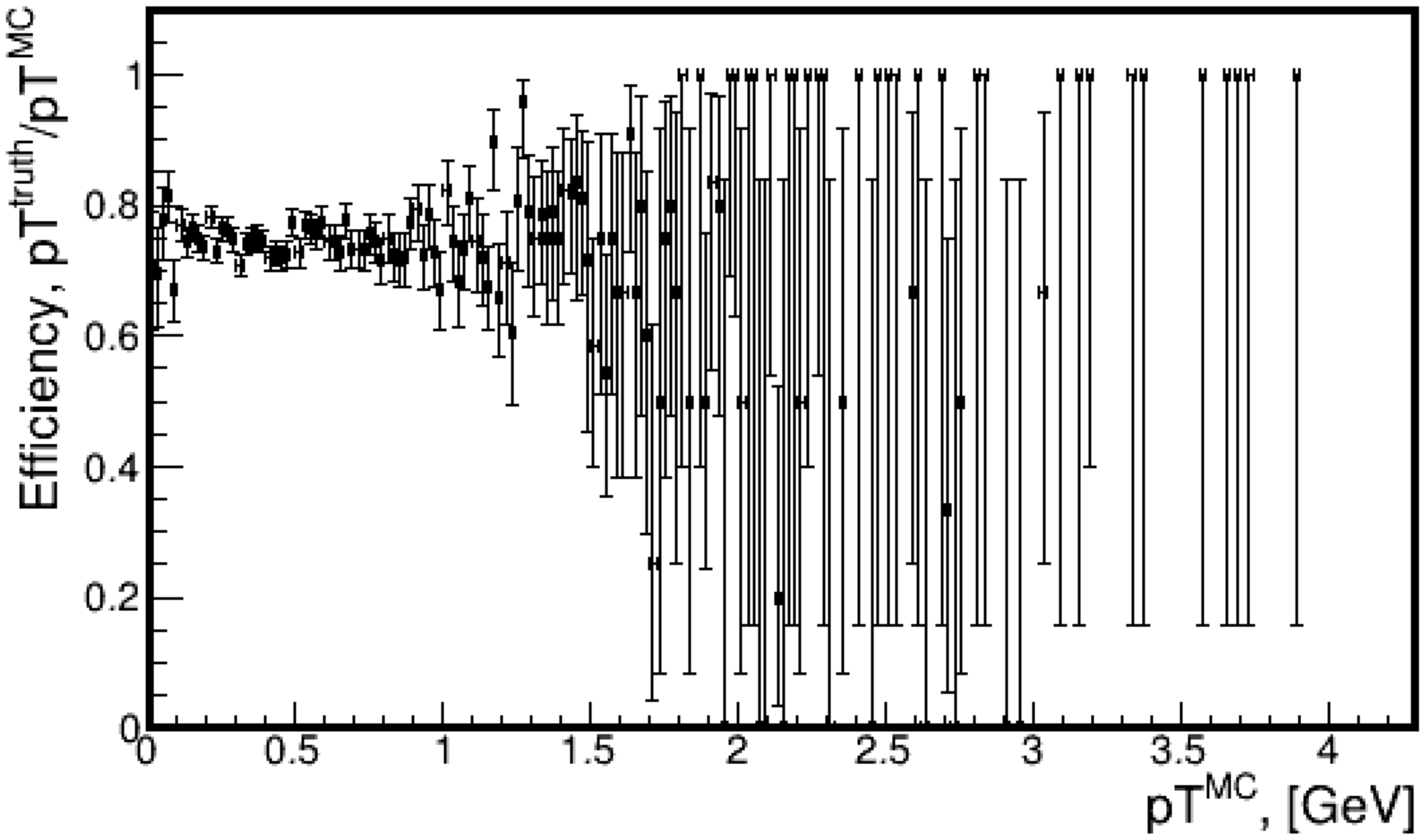


<u>Simulation parameters:</u>

- Event Generator: Pythia8
- Minimum bias
- Default SPDRoot reconstruction algorithms
- $\sqrt{s} = 10\ GeV$
- Only 1st generation
- Only charged particles
- Vertex detector (ITS) enabled
- 5 000 p-p collisions
- $-2 < \eta < 2$ pseudorapidity region (barrel part only)

Efficiency pT^{truth}/pT^{MC} (default SPDRoot reconstruction algorithms) in p-p collisions

Fig. 6 - Efficiency vs pT^{MC} (default SPDRoot reconstruction algorithms)



Efficiency (p-p) ~ 75%

Relative number of fired straws:
1.8% ~ 450 straws

<u>Simulation parameters:</u>

- Event Generator: Pythia8
- Minimum bias
- Default SPDRoot reconstruction algorithms
- $\sqrt{s} = 10\ GeV$
- Only 1st generation
- Only charged particles
- Vertex detector (ITS) enabled
- 5 000 p-p collisions
- $-2 < \eta < 2$ pseudorapidity region (barrel part only)

pT distributions (new reconstruction algorithms by Vladimir Andreev) in p-p collisions

Fig. 7 - pT^{MC} (new reconstruction algorithms by Vladimir Andreev)

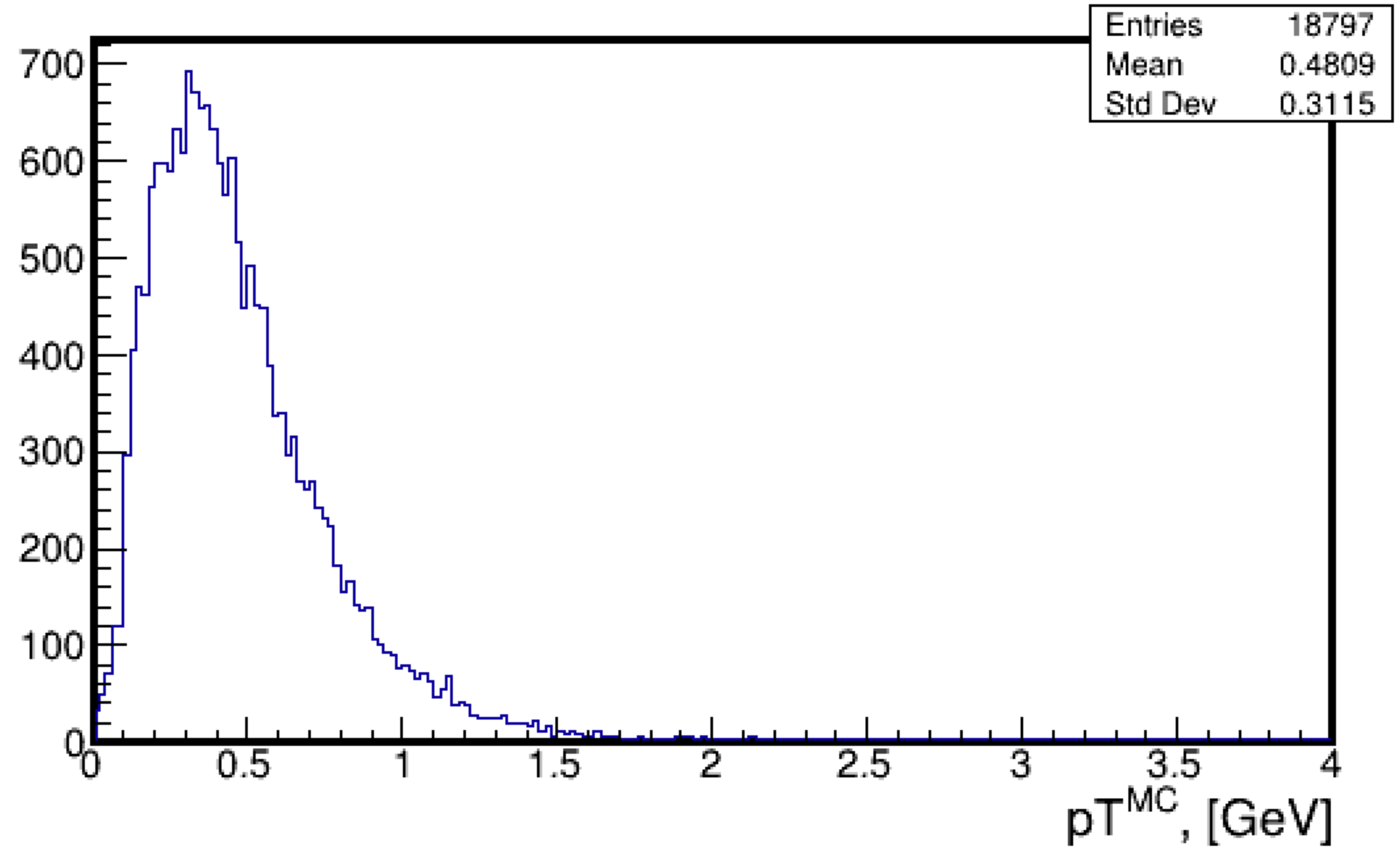
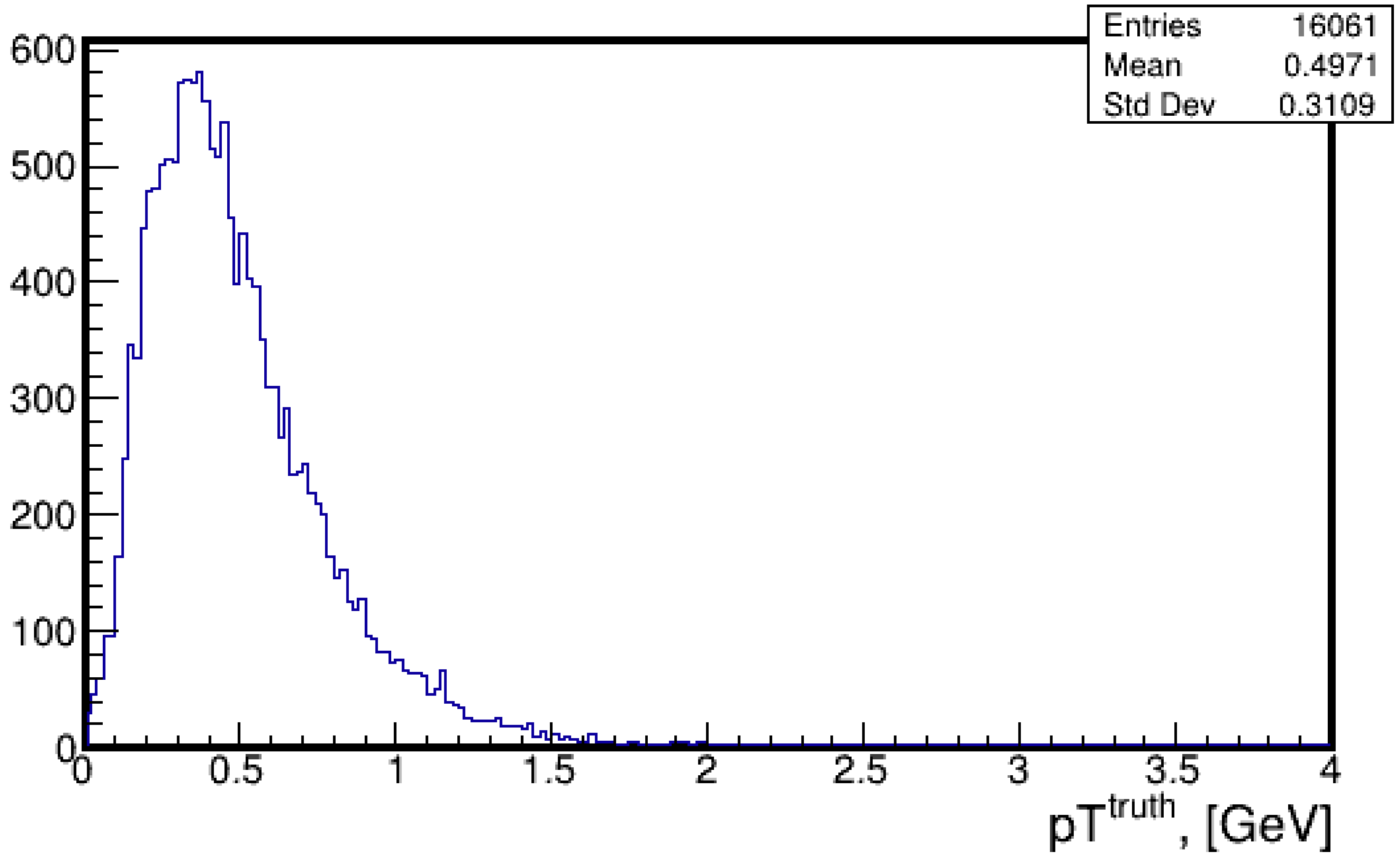


Fig. 8 - pT^{truth} (new reconstruction algorithms by Vladimir Andreev)

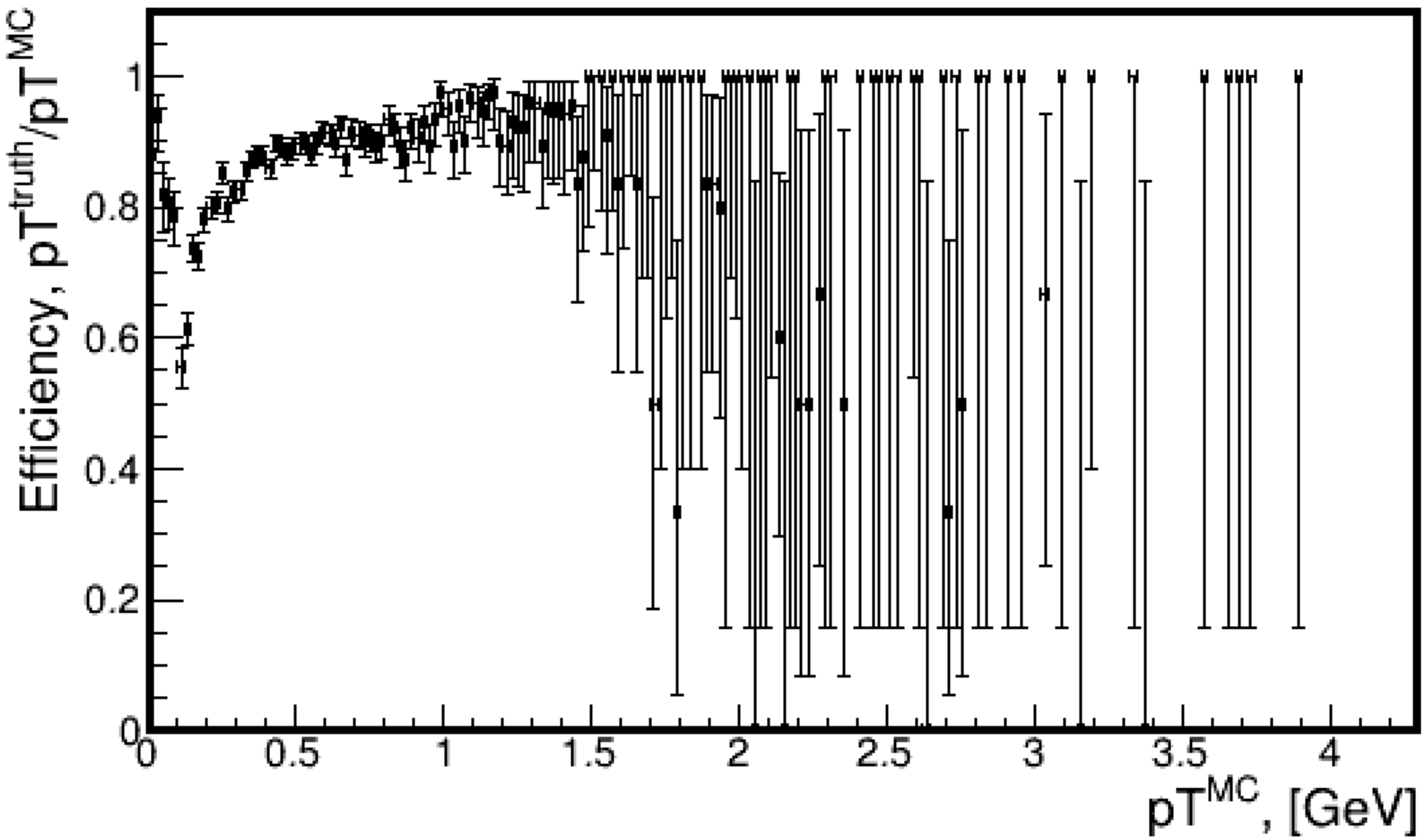


<u>Simulation parameters:</u>

- Event Generator: Pythia8
- Minimum bias
- New reconstruction algorithms
- $\sqrt{s} = 10\ GeV$
- Only 1st generation
- Only charged particles
- Vertex detector (ITS) enabled
- 5 000 p-p collisions
- $-2 < \eta < 2$ pseudorapidity region (barrel part only)

Efficiency pT^{truth}/pT^{MC} (new reconstruction algorithms by Vladimir Andreev) in p-p collisions

Fig. 9 - Efficiency vs pT^{MC} (new reconstruction algorithms by Vladimir Andreev)



Efficiency (p-p) ~ 90%

Relative number of fired straws: 1.8% ~ 450 straws

Simulation parameters:

- New reconstruction algorithms
- Vertex detector (ITS) enabled
- Event Generator: Pythia8
- $\sqrt{s} = 10\ GeV$
- 5 000 p-p collisions
- Minimum bias
- Only 1st generation
- $-2 < \eta < 2$ pseudorapidity region (barrel part only)
- Only charged particles

pT distributions (default SPDRoot reconstruction algorithms) in O-O collisions

Fig. 10 - pT^{MC} (default SPDRoot reconstruction algorithms)

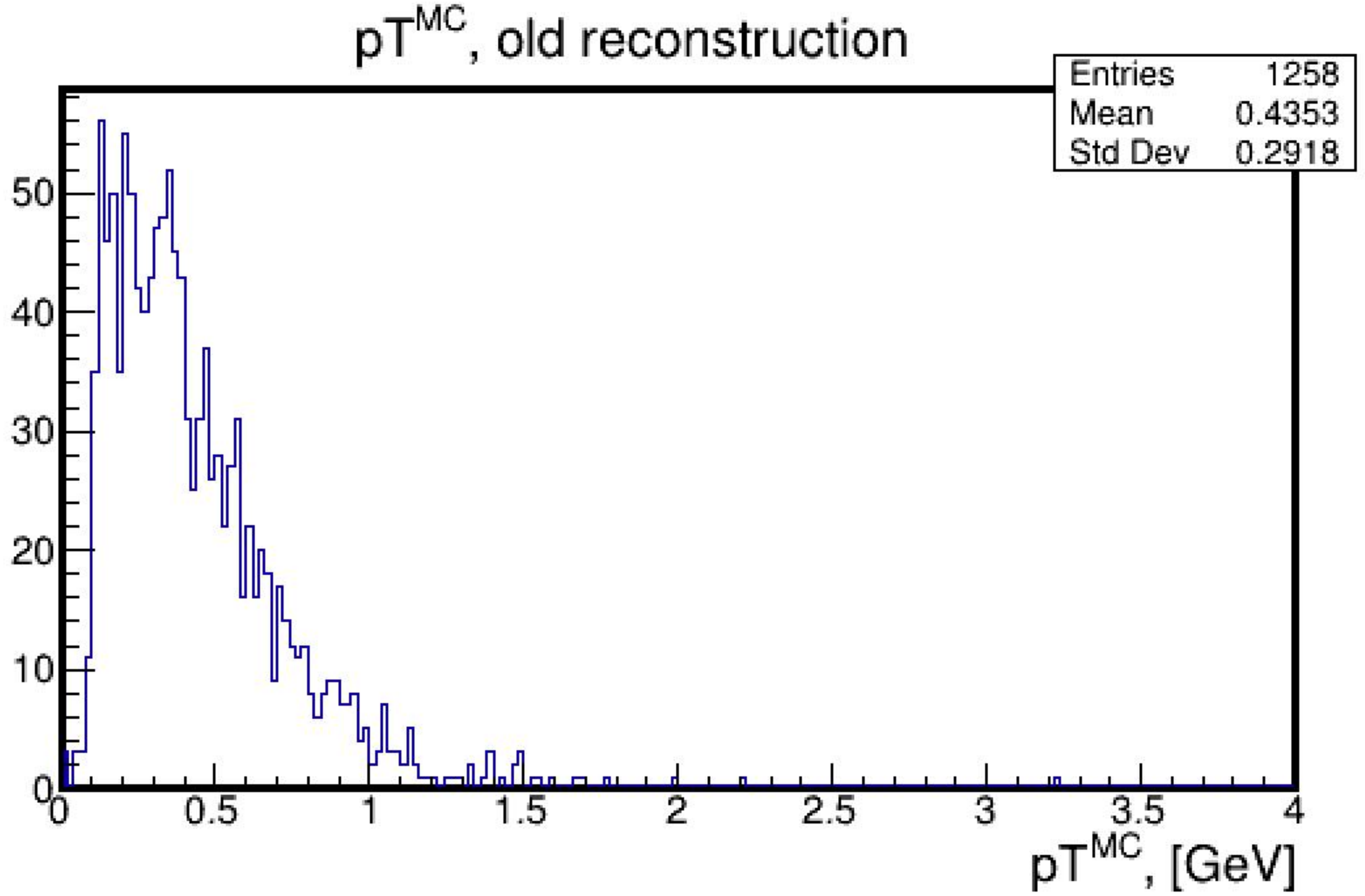
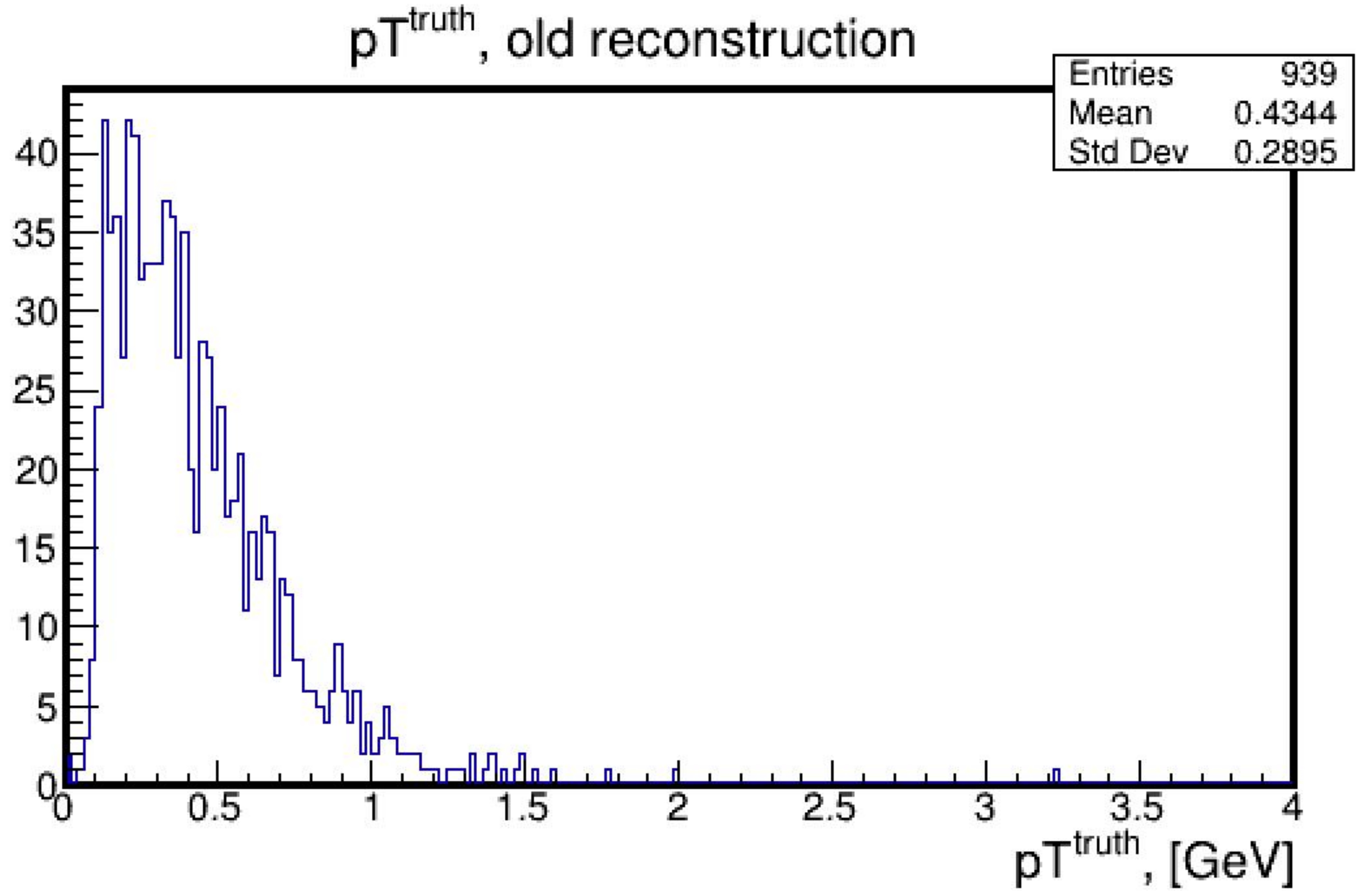


Fig. 11 - pT^{truth} (default SPDRoot reconstruction algorithms)

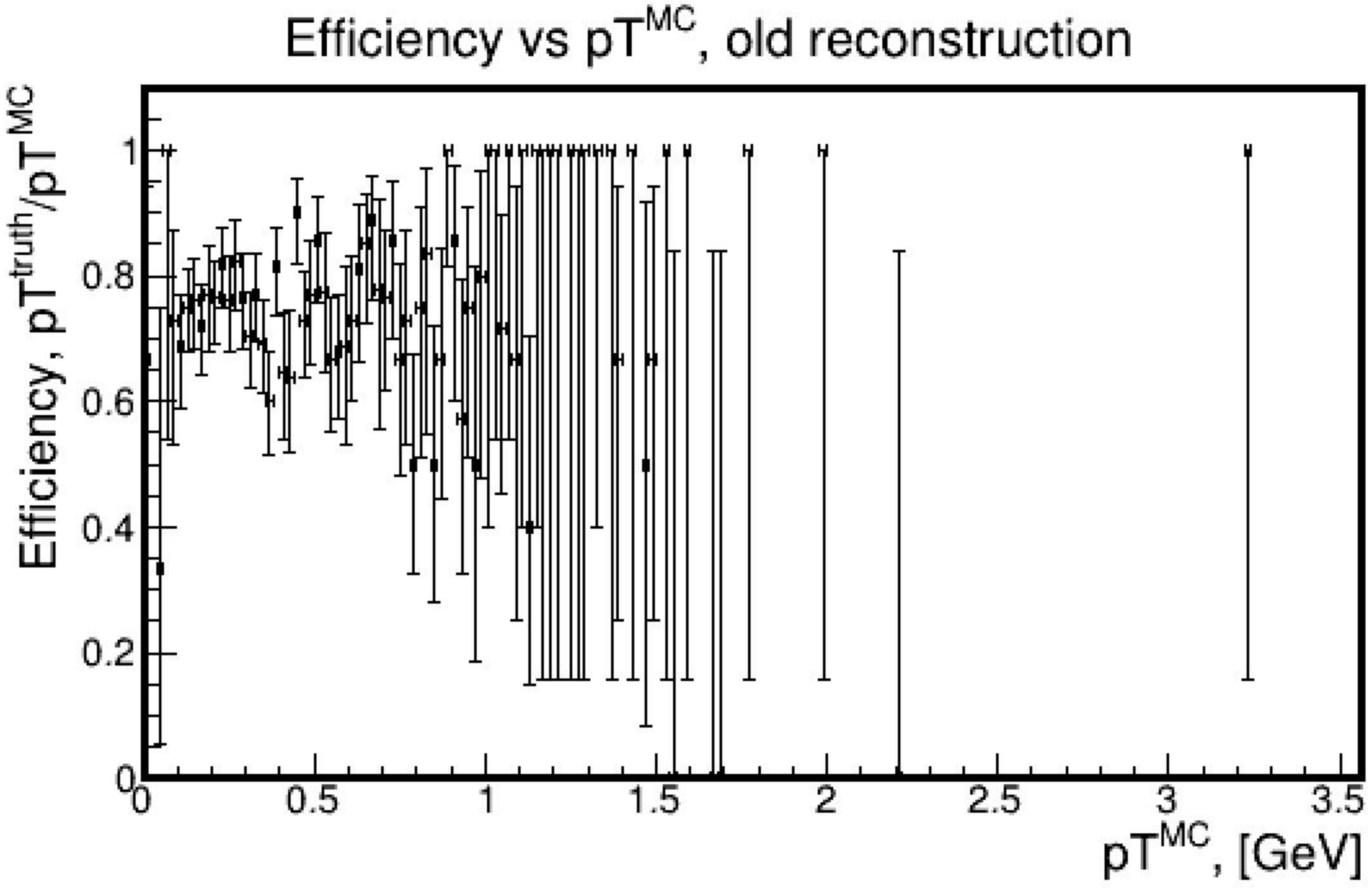


<u>Simulation parameters:</u>

- Event Generator: URQMD
- Minimum bias
- Default SPDRoot reconstruction algorithms
- $\sqrt{s} = 10\ GeV$
- Only 1st generation
- Only charged particles
- Vertex detector (ITS) enabled
- 100 O-O collisions (O_8^{16})
- $-2 < \eta < 2$ pseudorapidity region (barrel part only)

Efficiency pT^{truth}/pT^{MC} (default SPDRoot reconstruction algorithms) in O-O collisions

Fig. 12 - Efficiency vs pT^{MC} (default SPDRoot reconstruction algorithms)



Efficiency (p-p) ~ 80%

Relative number of fired straws: 6.2% ~ 1600 straws

<u>Simulation parameters:</u>

- Event Generator: URQMD
- Minimum bias
- Default SPDRoot reconstruction algorithms
- $\sqrt{s} = 10\ GeV$
- Only 1st generation
- Only charged particles
- Vertex detector (ITS) enabled
- 100 O-O collisions (O_8^{16})
- $-2 < \eta < 2$ pseudorapidity region (barrel part only)

pT distributions (new reconstruction algorithms by Vladimir Andreev) in O-O collisions

Fig. 13 - pT^{MC} (new reconstruction algorithms by Vladimir Andreev)

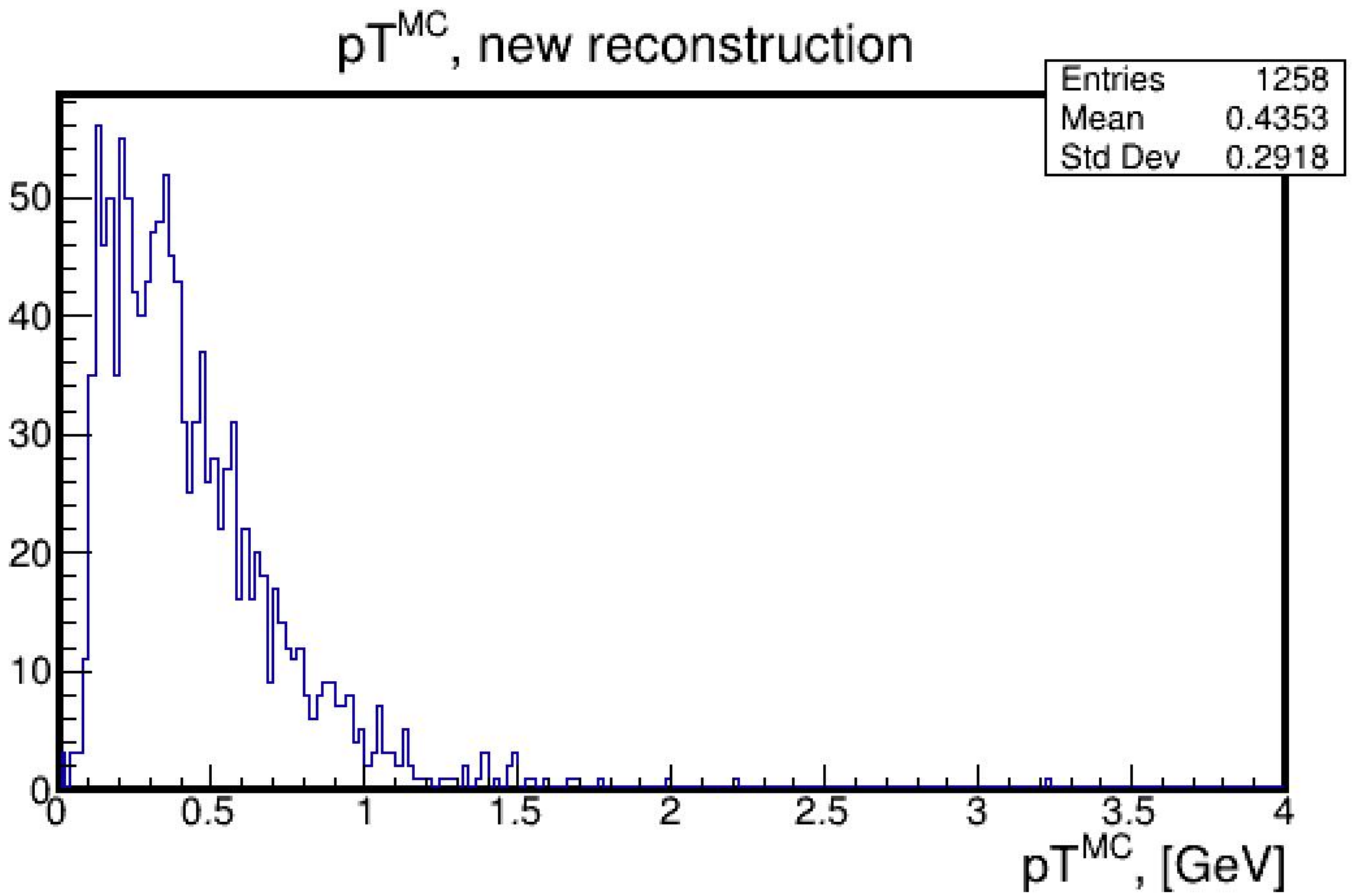
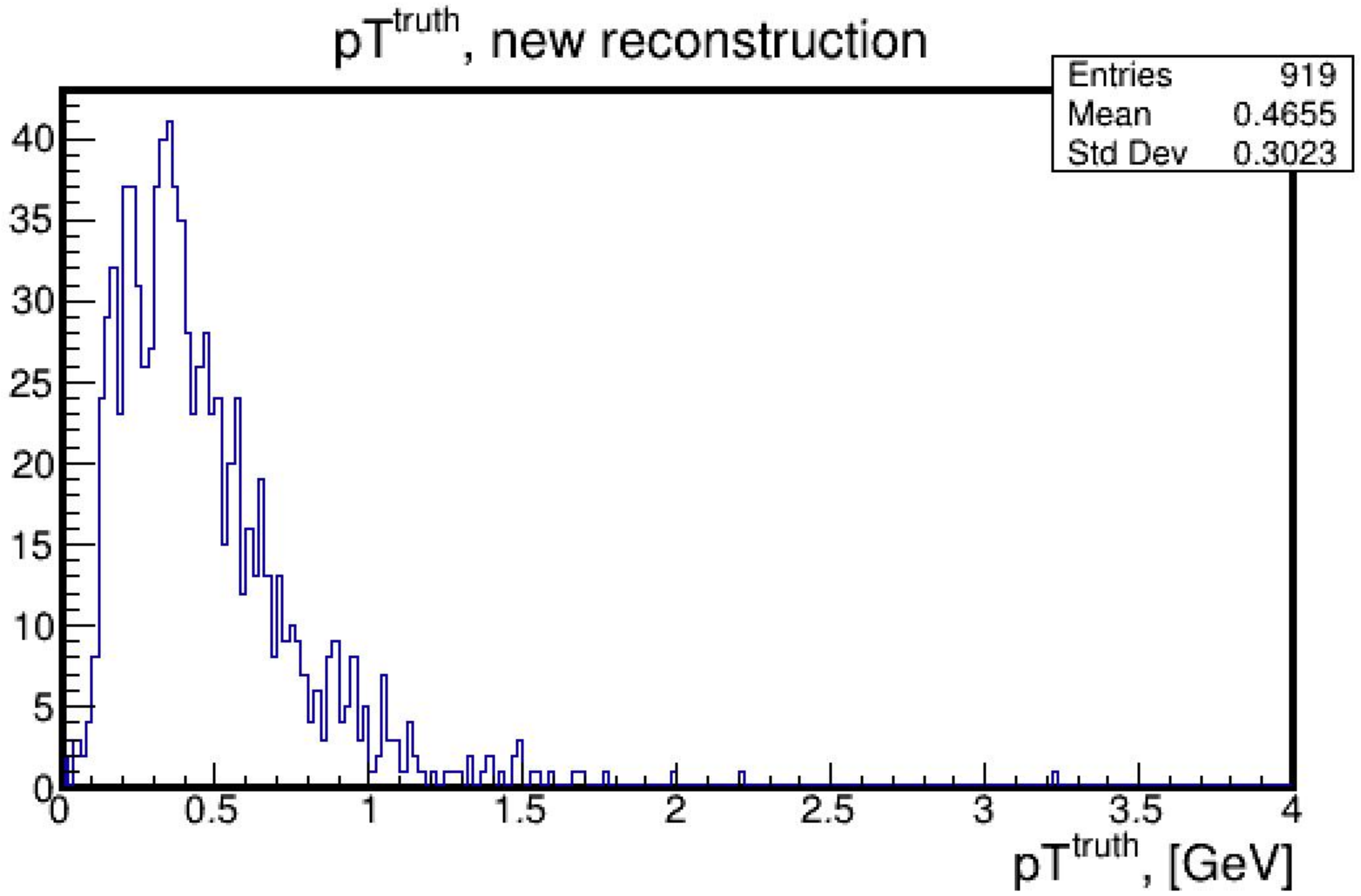


Fig. 14 - pT^{truth} (new reconstruction algorithms by Vladimir Andreev)

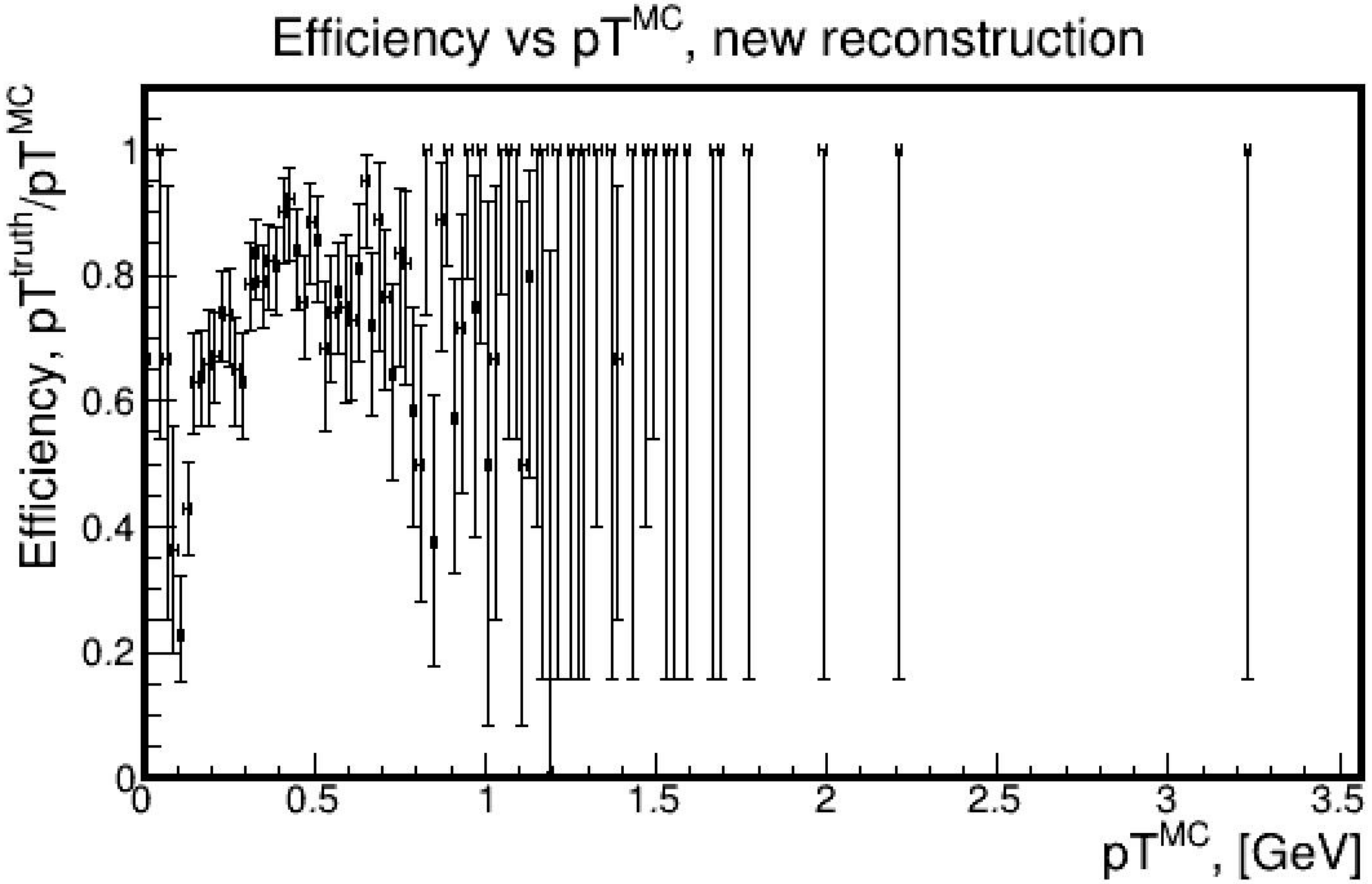


Simulation parameters:

- Event Generator: URQMD
- Minimum bias
- New reconstruction algorithms
- $\sqrt{s} = 10\ GeV$
- Only 1st generation
- Only charged particles
- Vertex detector (ITS) enabled
- 100 O-O collisions (O_8^{16})
- $-2 < \eta < 2$ pseudorapidity region (barrel part only)

Efficiency pT^{truth}/pT^{MC} (new reconstruction algorithms by Vladimir Andreev) in O-O collisions

Fig. 15 - Efficiency vs pT^{MC} (new reconstruction algorithms by Vladimir Andreev)



Efficiency (p-p) ~ 79%

Relative number of fired straws: 6.2% ~ 1600 straws

Simulation parameters:

- New reconstruction algorithms
- Vertex detector (ITS) enabled
- Event Generator: URQMD
- $\sqrt{s} = 10\ GeV$
- 100 O-O collisions (O_8^{16})
- Minimum bias
- Only 1st generation
- $-2 < \eta < 2$ pseudorapidity region (barrel part only)
- Only charged particles

pT distributions (default SPDRoot reconstruction algorithms) in Kr-Kr collisions

Fig. 16 - pT^{MC} (default SPDRoot reconstruction algorithms)

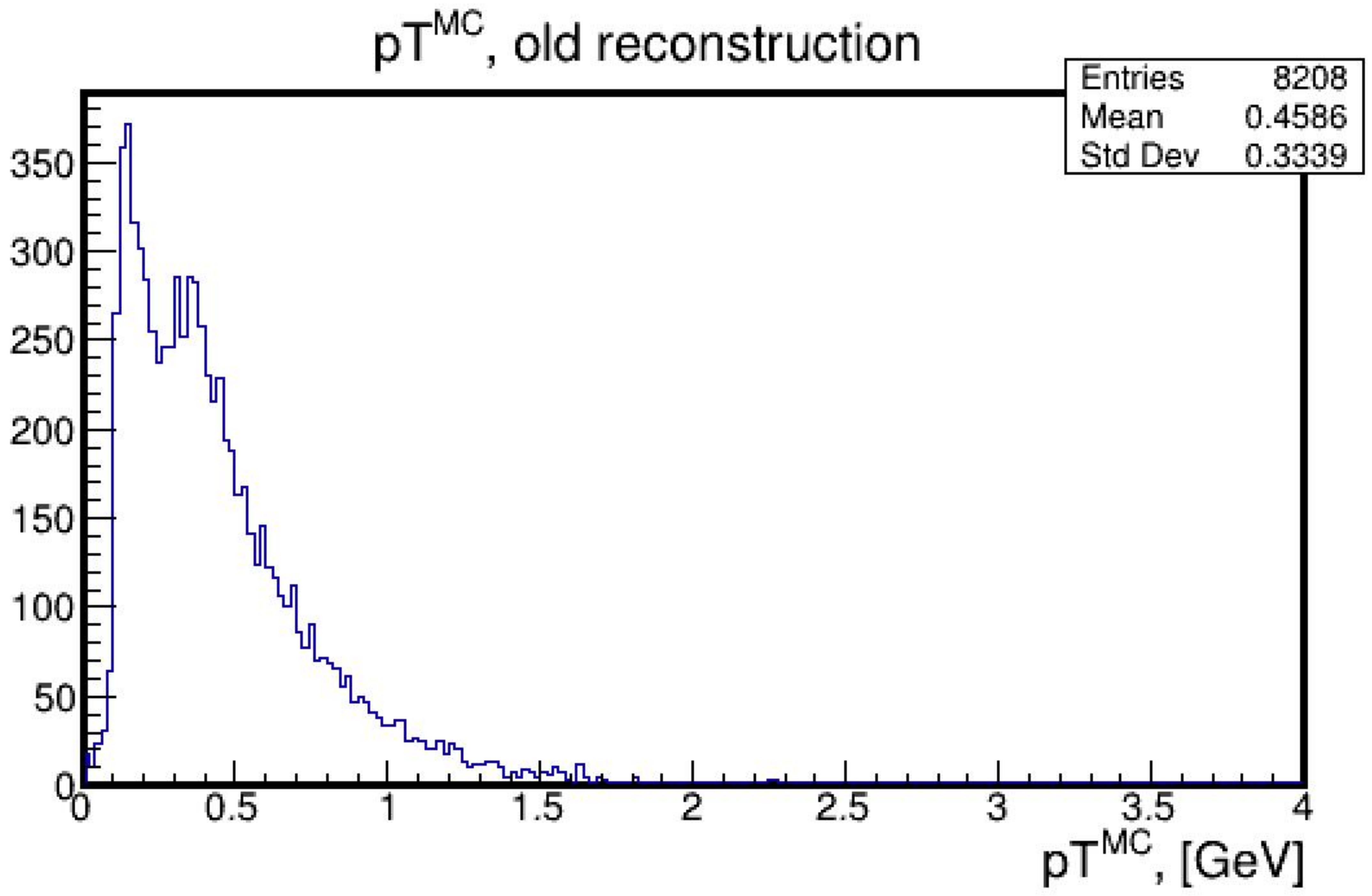
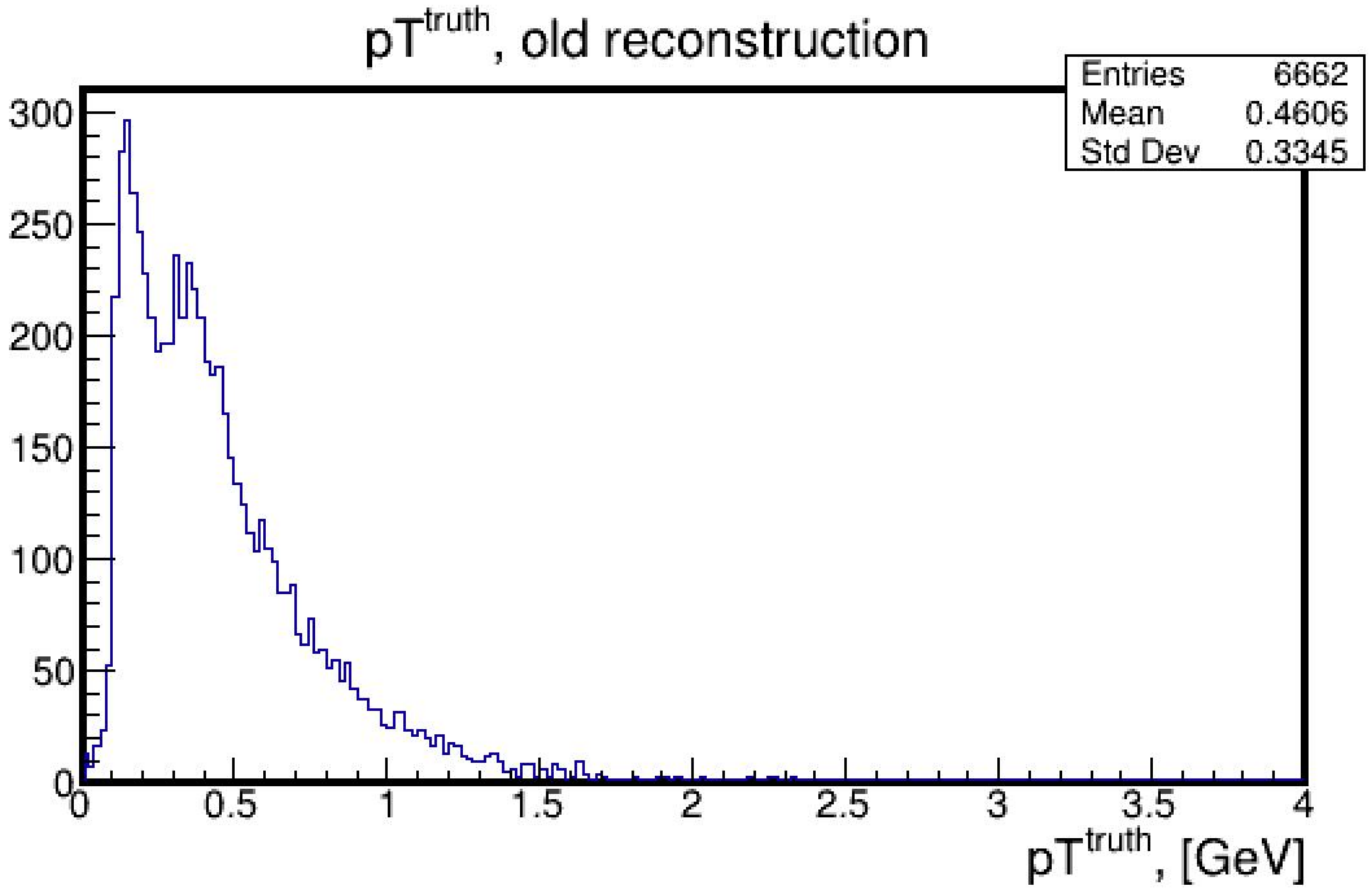


Fig. 17 - pT^{truth} (default SPDRoot reconstruction algorithms)

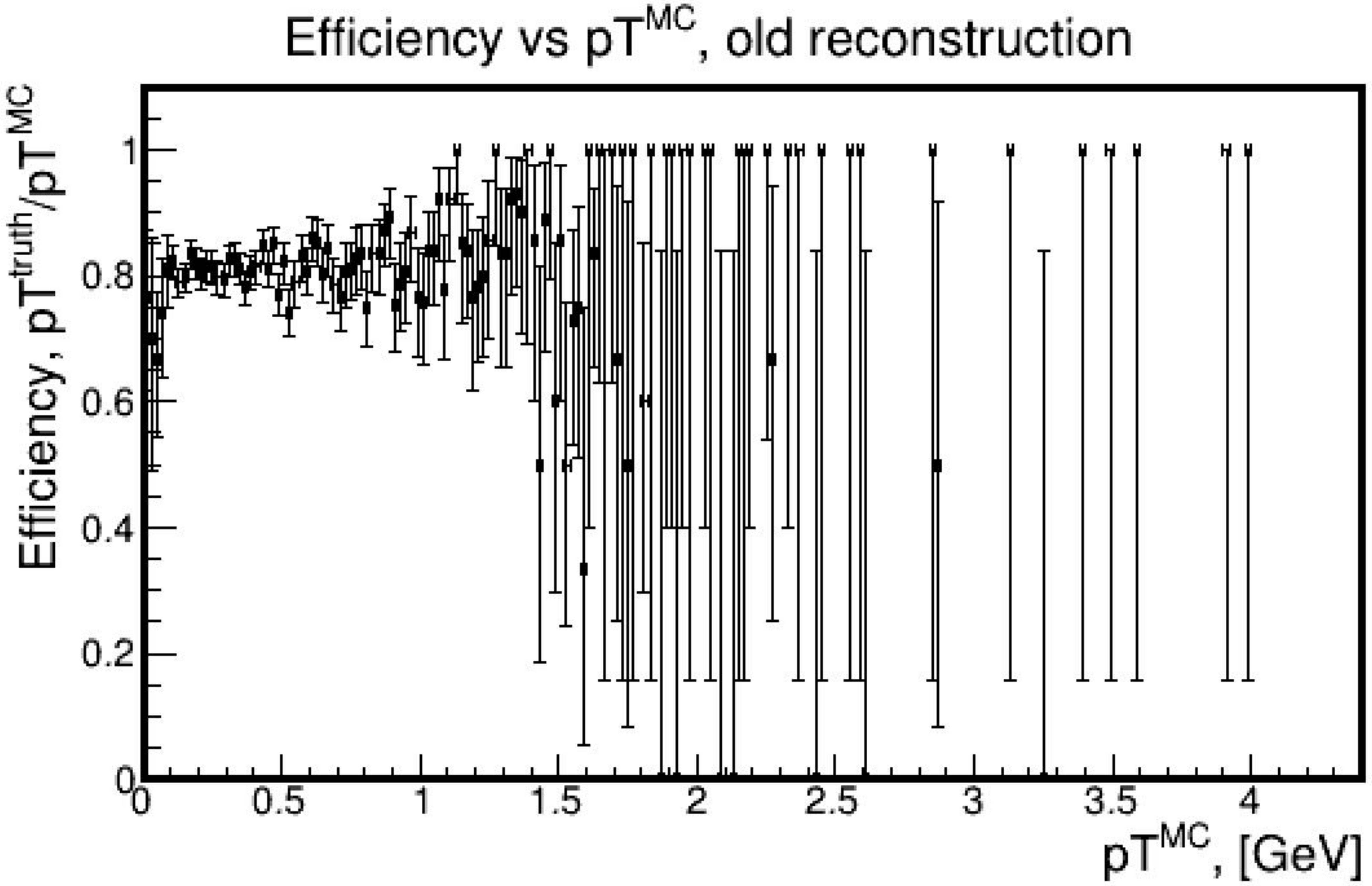


Simulation parameters:

- Event Generator: URQMD
- Minimum bias
- Default SPDRoot reconstruction algorithms
- $\sqrt{s} = 10\ GeV$
- Only 1st generation
- Only charged particles
- Vertex detector (ITS) enabled
- 100 Kr-Kr collisions (Kr^{84}_{36})
- $-2 < \eta < 2$ pseudorapidity region (barrel part only)

Efficiency pT^{truth}/pT^{MC} (default SPDRoot reconstruction algorithms) in Kr-Kr collisions

Fig. 18 - Efficiency vs pT^{MC} (default SPDRoot reconstruction algorithms)



Efficiency (p-p) ~ 82%

Relative number of fired straws: 26.2% ~ 6800 straws

Simulation parameters:

- Event Generator: URQMD
- Minimum bias
- Default SPDRoot reconstruction algorithms
- $\sqrt{s} = 10\ GeV$
- Only 1st generation
- Only charged particles
- Vertex detector (ITS) enabled
- 100 Kr-Kr collisions (Kr^{84}_{36})
- $-2 < \eta < 2$ pseudorapidity region (barrel part only)

pT distributions (new reconstruction algorithms by Vladimir Andreev) in Kr-Kr collisions

Fig. 19 - pT^{MC} (new reconstruction algorithms by Vladimir Andreev)

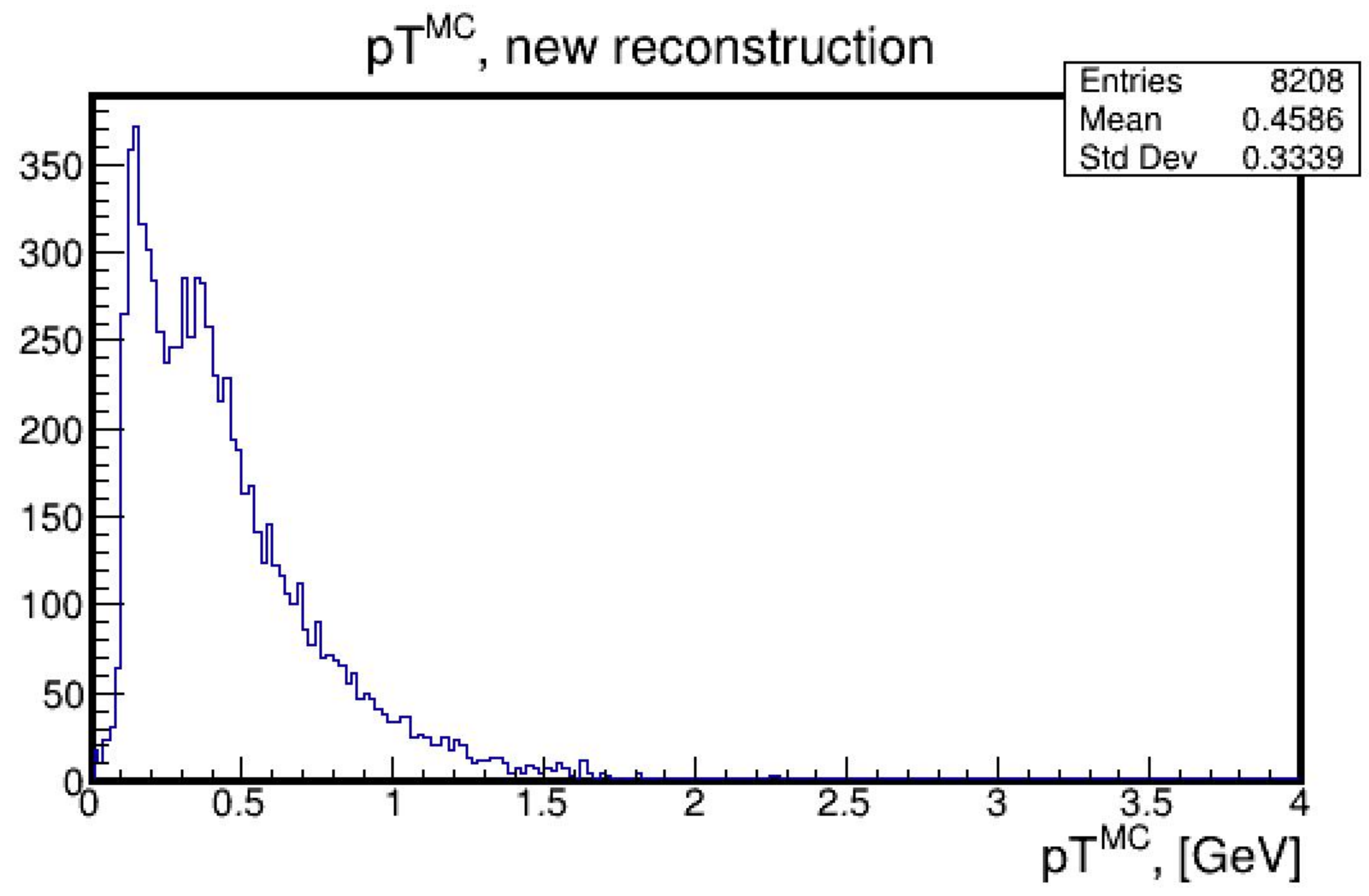
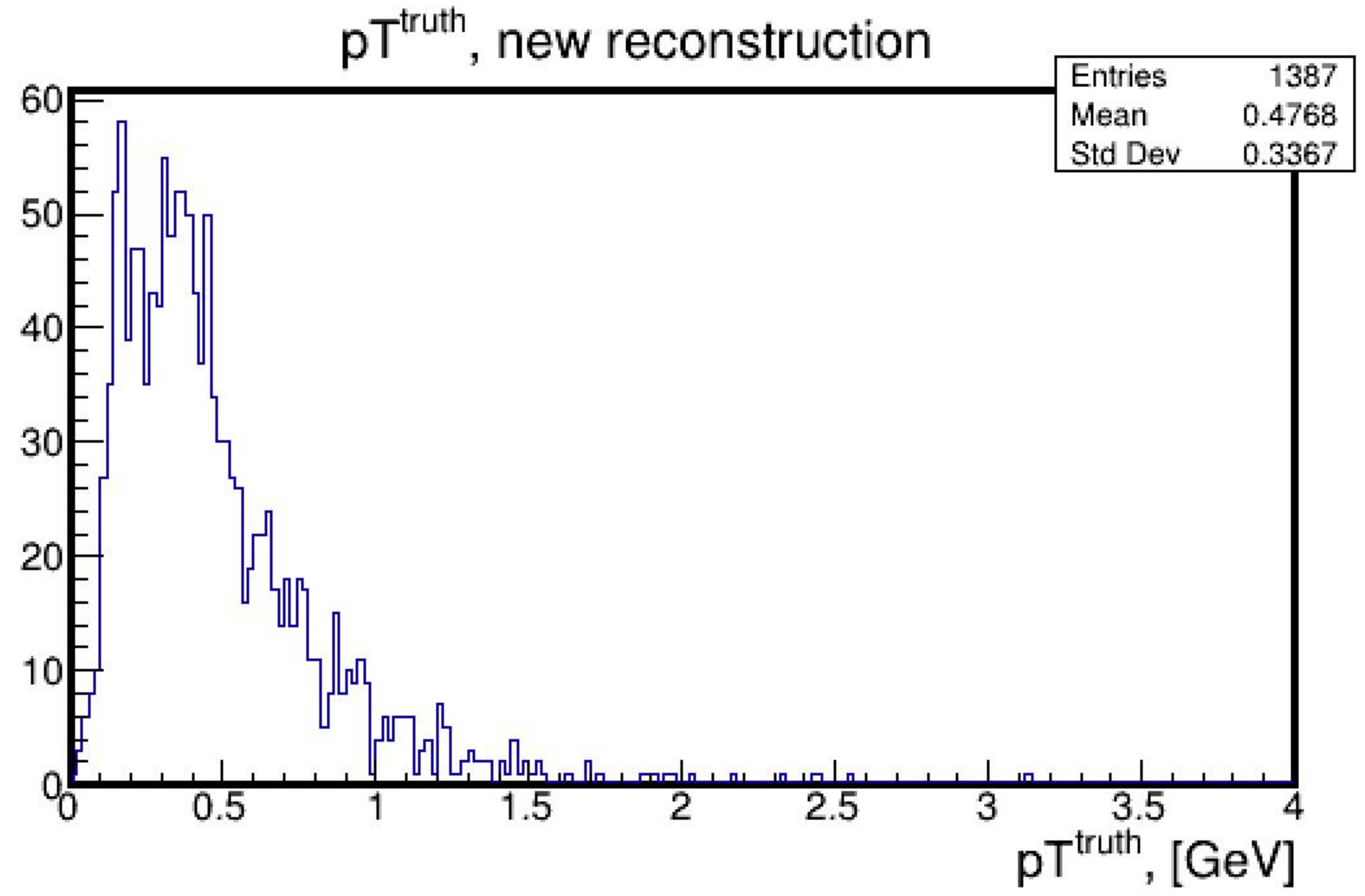


Fig. 20 - pT^{truth} (new reconstruction algorithms by Vladimir Andreev)

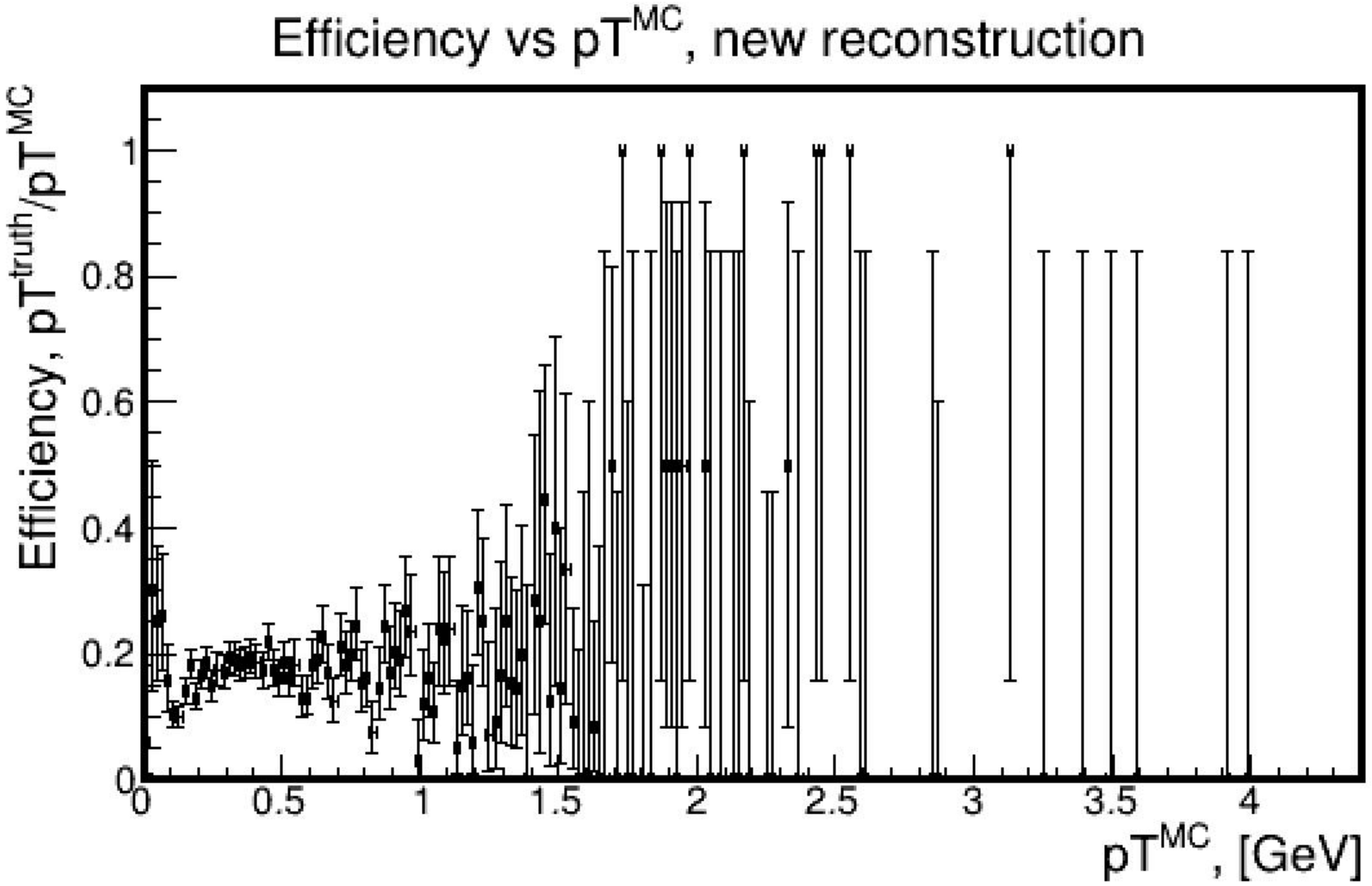


Simulation parameters:

- Event Generator: URQMD
- Minimum bias
- New reconstruction algorithms
- $\sqrt{s} = 10\ GeV$
- Only 1st generation
- Only charged particles
- Vertex detector (ITS) enabled
- 100 Kr-Kr collisions (Kr^{84}_{36})
- $-2 < \eta < 2$ pseudorapidity region (barrel part only)

Efficiency pT^{truth}/pT^{MC} (new reconstruction algorithms by Vladimir Andreev) in Kr-Kr collisions

Fig. 21 - Efficiency vs pT^{MC} (new reconstruction algorithms by Vladimir Andreev)



Efficiency (p-p) ~ 20%

Relative number of fired straws: 26.2% ~ 6800 straws

<u>Simulation parameters:</u>

- New reconstruction algorithms
- Vertex detector (ITS) enabled
- Event Generator: URQMD
- $\sqrt{s} = 10\ GeV$
- 100 Kr-Kr collisions (Kr^{84}_{36})
- Minimum bias
- Only 1st generation
- $-2 < \eta < 2$ pseudorapidity region (barrel part only)
- Only charged particles

pT distributions (default SPDRoot reconstruction algorithms) in Xe-Xe collisions

Fig. 22 - pT^{MC} (default SPDRoot reconstruction algorithms)

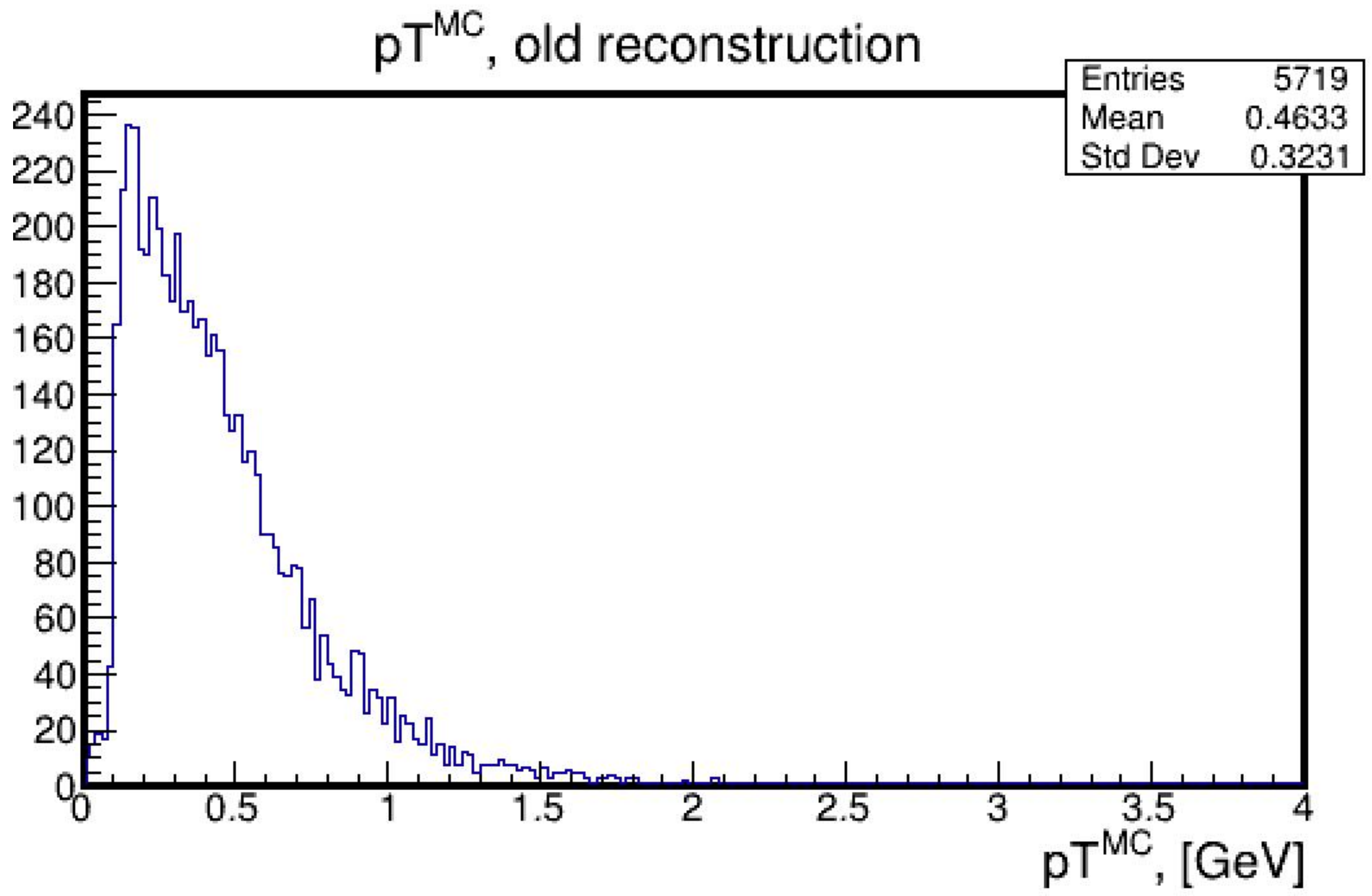
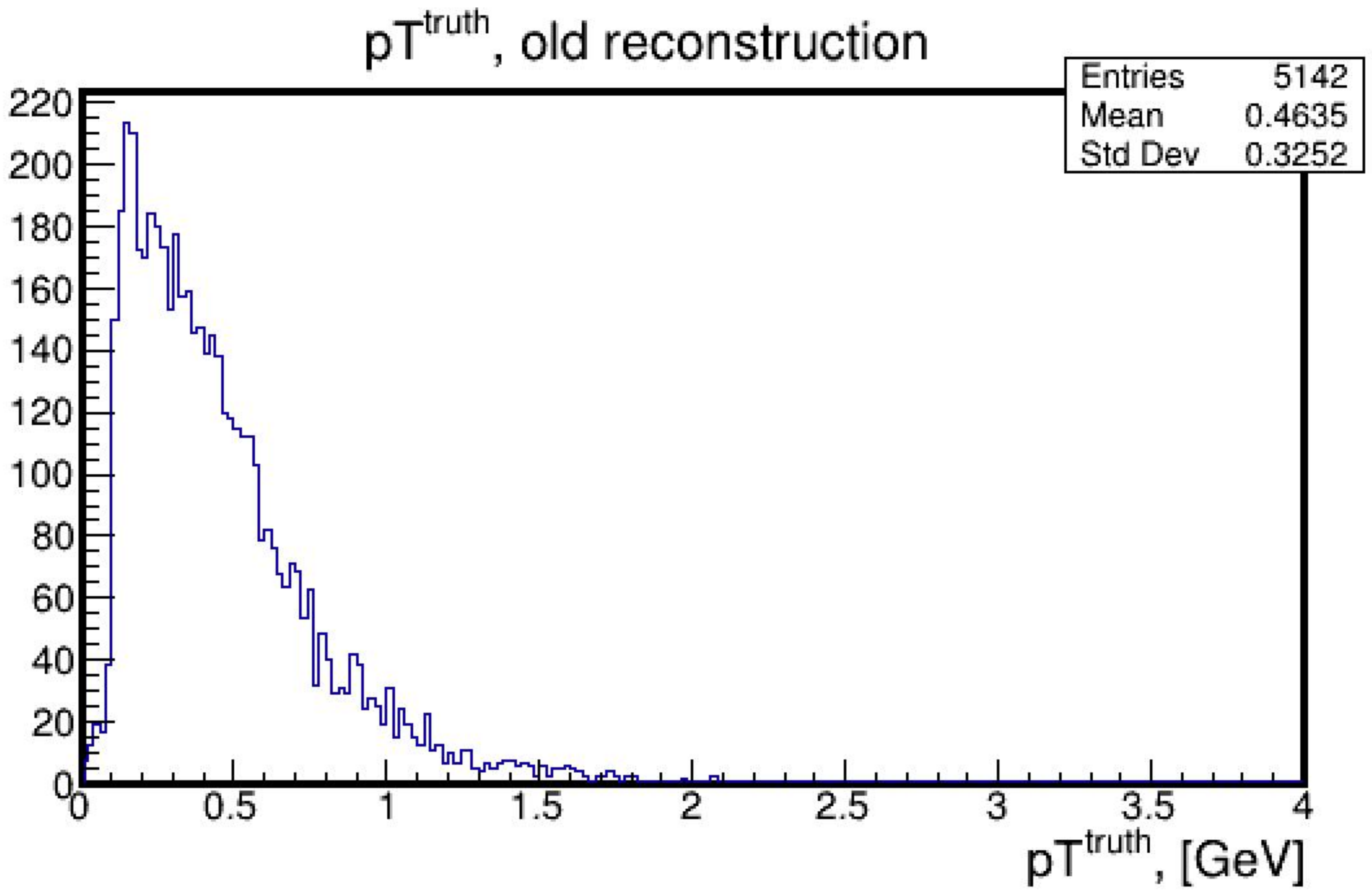


Fig. 23 - pT^{truth} (default SPDRoot reconstruction algorithms)

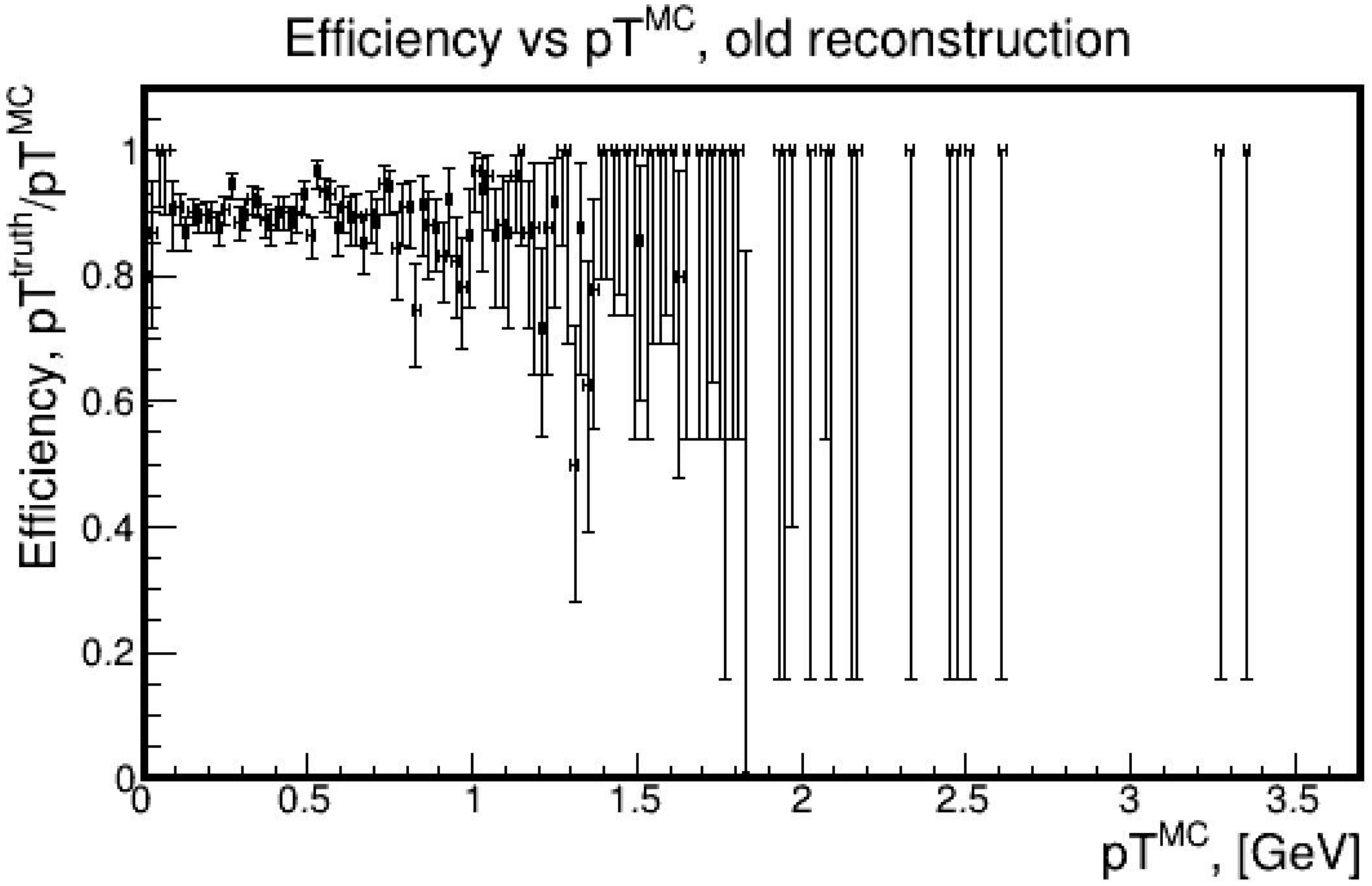


Simulation parameters:

- Event Generator: URQMD
- Minimum bias
- Default SPDRoot reconstruction algorithms
- $\sqrt{s} = 10\ GeV$
- Only 1st generation
- Only charged particles
- <100 Xe-Xe collisions (Xe_{54}^{131})
- $-2 < \eta < 2$ pseudorapidity region (barrel part only)
- Vertex detector (ITS) enabled

Efficiency pT^{truth}/pT^{MC} (default SPDRoot reconstruction algorithms) in Xe-Xe collisions

Fig. 24 - Efficiency vs pT^{MC} (default SPDRoot reconstruction algorithms)



Efficiency (Xe-Xe) ~ 90%

Relative number of fired straws: 33.6% ~ 8700 straws

Simulation parameters:

- Event Generator: URQMD
- Minimum bias
- Default SPDRoot reconstruction algorithms
- $\sqrt{s} = 10\ GeV$
- Only 1st generation
- Only charged particles
- Vertex detector (ITS) enabled
- <100 Xe-Xe collisions (Xe^{131}_{54})
- $-2 < \eta < 2$ pseudorapidity region (barrel part only)

pT distributions (new reconstruction algorithms by Vladimir Andreev) in Xe-Xe collisions

Fig. 25 - pT^{MC} (new reconstruction algorithms by Vladimir Andreev)

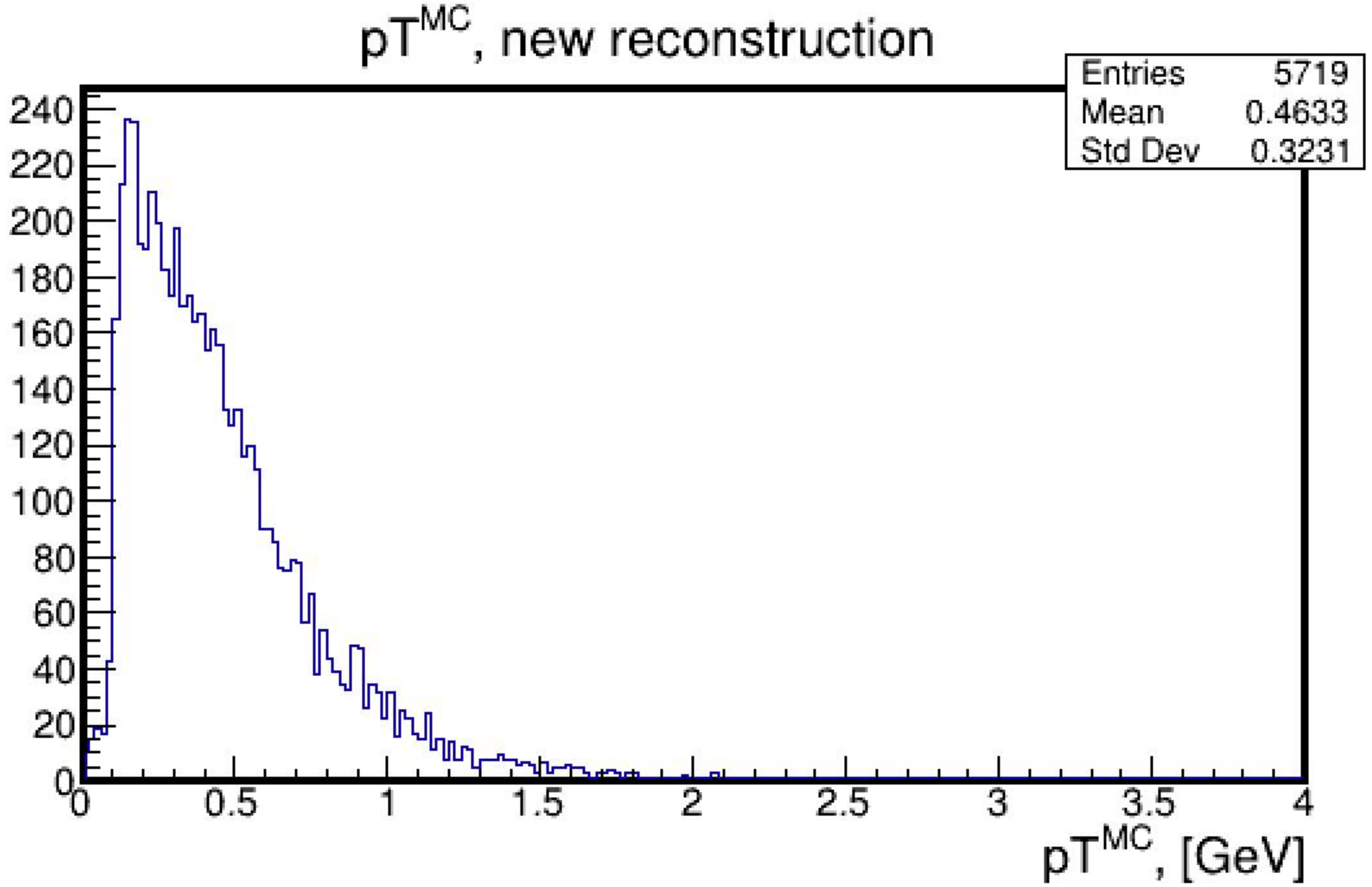
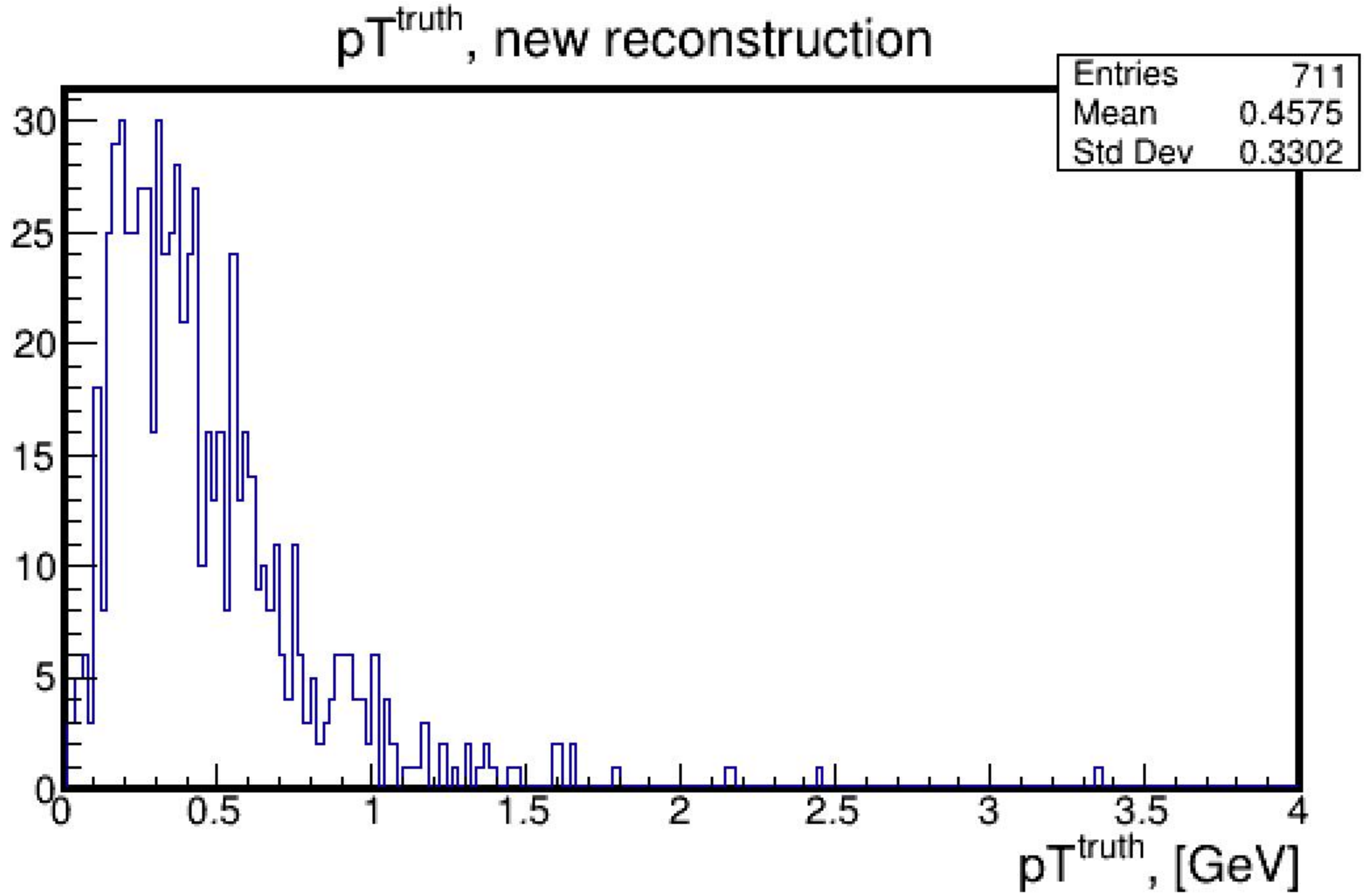


Fig. 26 - pT^{truth} (new reconstruction algorithms by Vladimir Andreev)

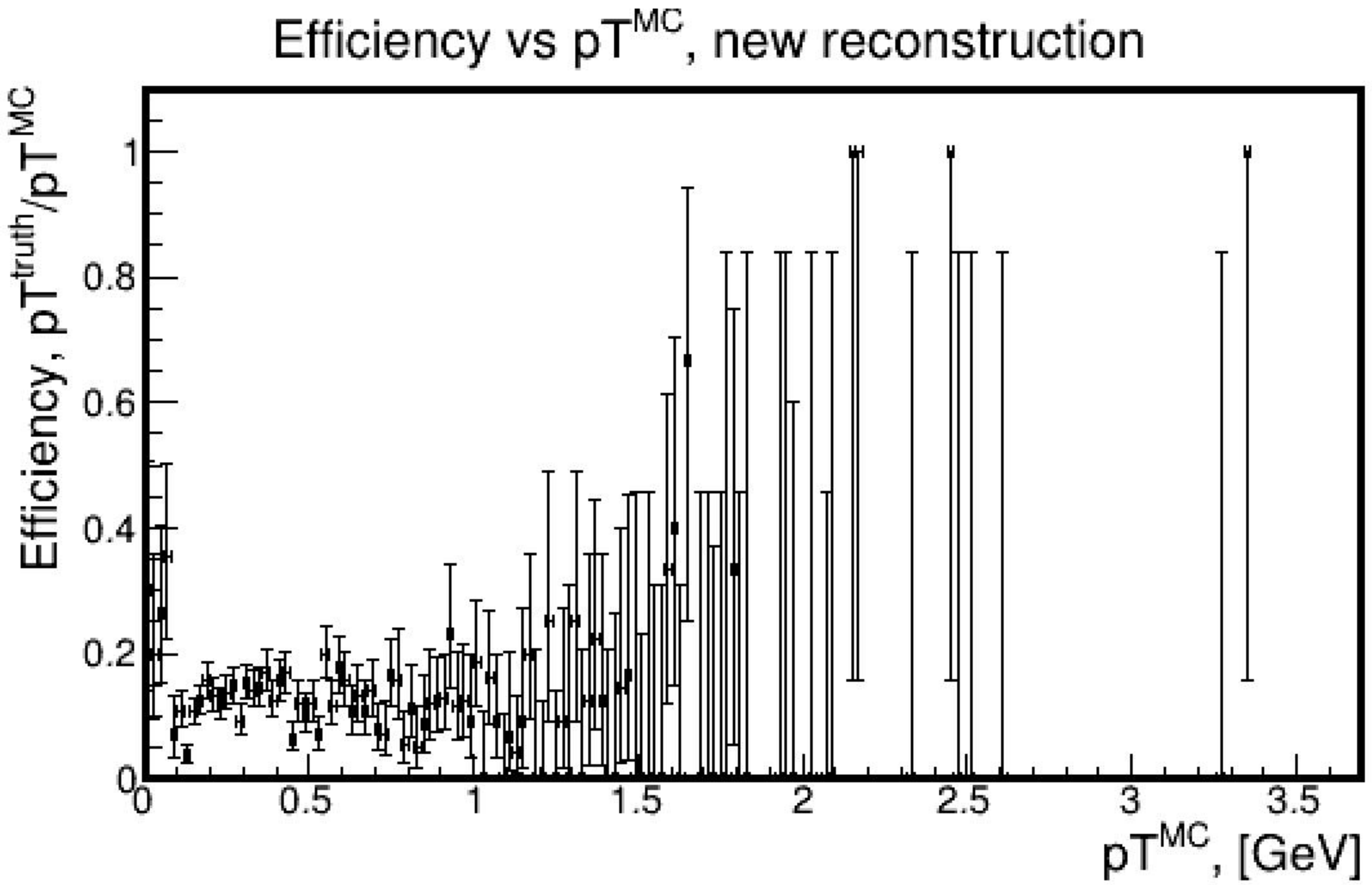


Simulation parameters:

- Event Generator: URQMD
- Minimum bias
- New reconstruction algorithms
- $\sqrt{s} = 10\ GeV$
- Only 1st generation
- Only charged particles
- Vertex detector (ITS) enabled
- <100 Xe-Xe collisions (Xe^{131}_{54})
- $-2 < \eta < 2$ pseudorapidity region (barrel part only)

Efficiency pT^{truth}/pT^{MC} (new reconstruction algorithms by Vladimir Andreev) in Xe-Xe collisions

Fig. 27 - Efficiency vs pT^{MC} (new reconstruction algorithms by Vladimir Andreev)



Efficiency (p-p) ~ 15%

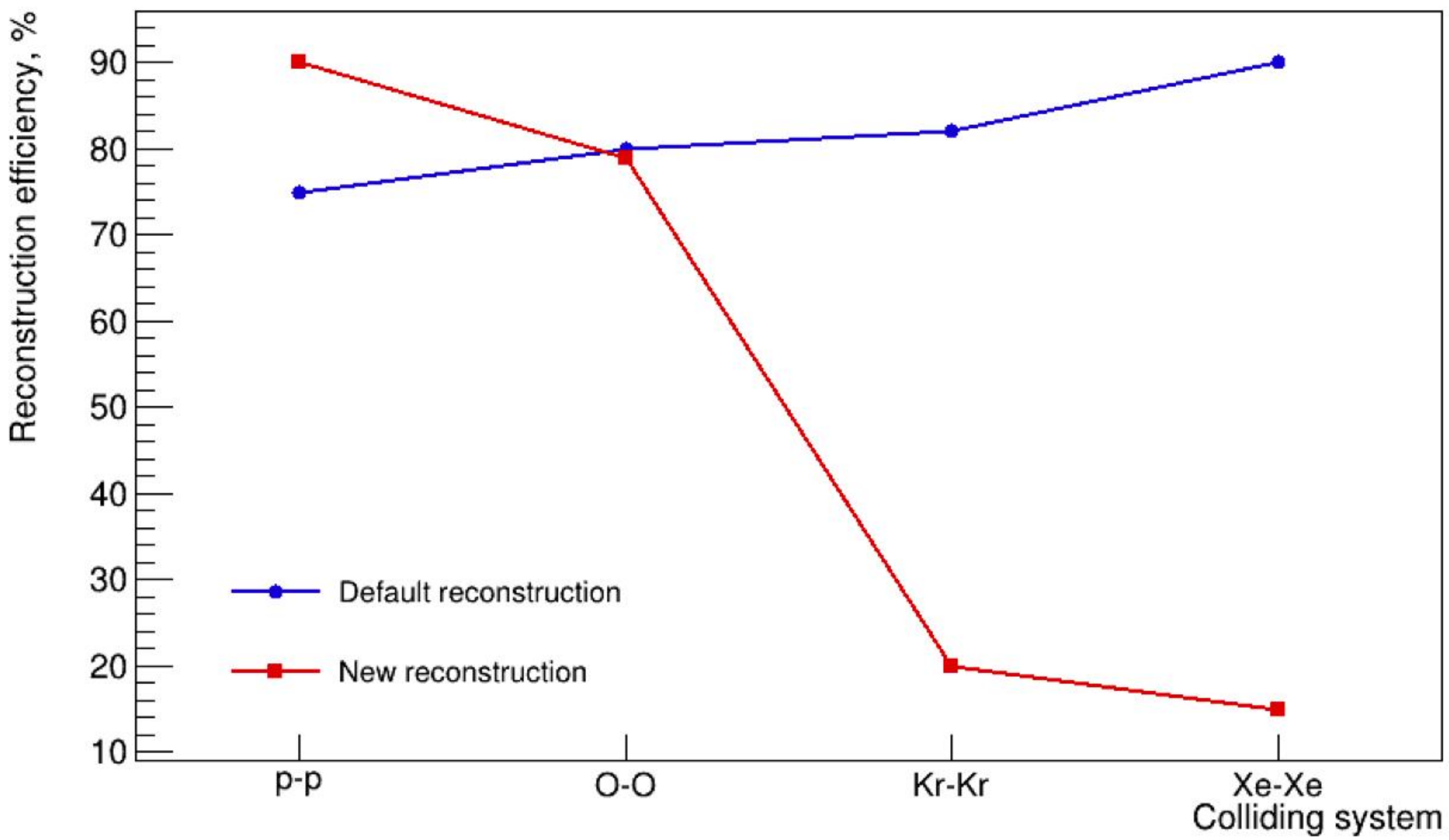
Relative number of fired straws: 33.6% ~ 8700 straws

Simulation parameters:

- Event Generator: URQMD
- Minimum bias
- New reconstruction algorithms
- $\sqrt{s} = 10\ GeV$
- Only 1st generation
- Only charged particles
- Vertex detector (ITS) enabled
- <100 Xe-Xe collisions (Xe^{131}_{54})
- $-2 < \eta < 2$ pseudorapidity region (barrel part only)

Reconstruction efficiencies comparison

Fig. 28 - Reconstruction efficiencies comparison



Simulation parameters:

- Event Generators: Pythia8 & URQMD
- Minimum bias
- Only charged particles
- Default and new reconstruction algorithms
- $\sqrt{s} = 10\ GeV$
- Only 1st generation
- Vertex detector (ITS) enabled
- p-p, O-O, Kr-Kr and Xe-Xe collisions
- $-2 < \eta < 2$ pseudorapidity region (barrel part only)

Questions

1. Среднее число загорающихся straw в p-p столкновениях меньше 500, а вот в ионах, уже начиная с O-O, аж 1600 и больше. Если в новой реконструкции делается кат на 500 загорающихся straw (тк для таких больших загрузок трекинг начинает вести себя непредсказуемо), то как быть в таких случаях? Можно ли «двигать» этот кат в большую сторону - насколько ухудшается трекинг от этого?

2. Есть ли еще какие-то каты или особенности новой реконструкции, сильно зависящие от большой загруженности на одно столкновение?

3. Есть ли уже реализованный запуск новой реконструкции отдельным скриптом от остального финального анализа или даже имплементированная новая реконструкция вместо старой реконструкции, а не после нее? Вопрос связан с тем, что сейчас workflow состоит так, что нужно два раза выполнять реконструкцию (старую, а потом новую), плюс новая реконструкция выполняется непосредственно в коде анализа - то есть если что-то нужно менять в анализе, приходится каждый раз заново запускать новую реконструкцию

4. Чем могут быть вызваны резкие «просадки» эффективности в начальном диапазоне по pt именно в новой реконструкции?

Conclusions

- Total occupancy maps of the Straw Tracker were obtained for both proton-proton and different ion-ion collisions (O-O, Kr-Kr, Xe-Xe)

- The relative fraction of active straws increased with increasing atomic number of the colliding nuclei

- According to the average straw occupancies and hit rates maps we can make a conclusion that **light ion collisions like O can be studied with high accuracies** but it **seems unlikely to study heavier ions like Xe** at the SPD because it would be rather difficult to separate different tracks via one ion collision

- All colliding systems show the common low-p_T degradation, a shallow minimum at intermediate p_T and a rise at high p_T

- A preliminary implementation of new reconstruction algorithms was performed by studying the efficiency of reconstruction

Thank you for your attention!

BACK-UP SLIDES

TS full hit rate and straw occupancy in p-p collisions

Fig. 29 - TS full hit rate (barrel и end-caps parts) in p-p collisions

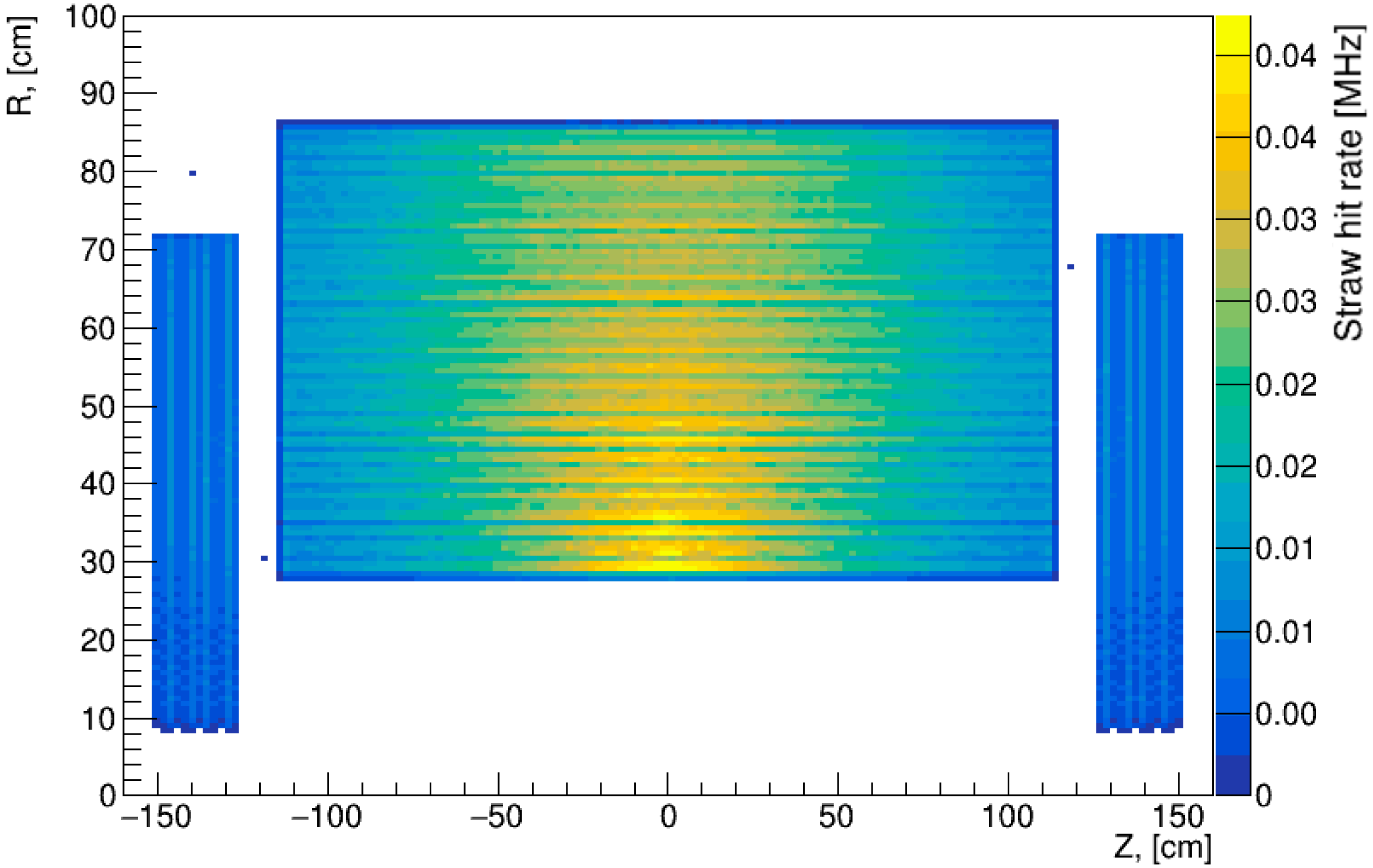
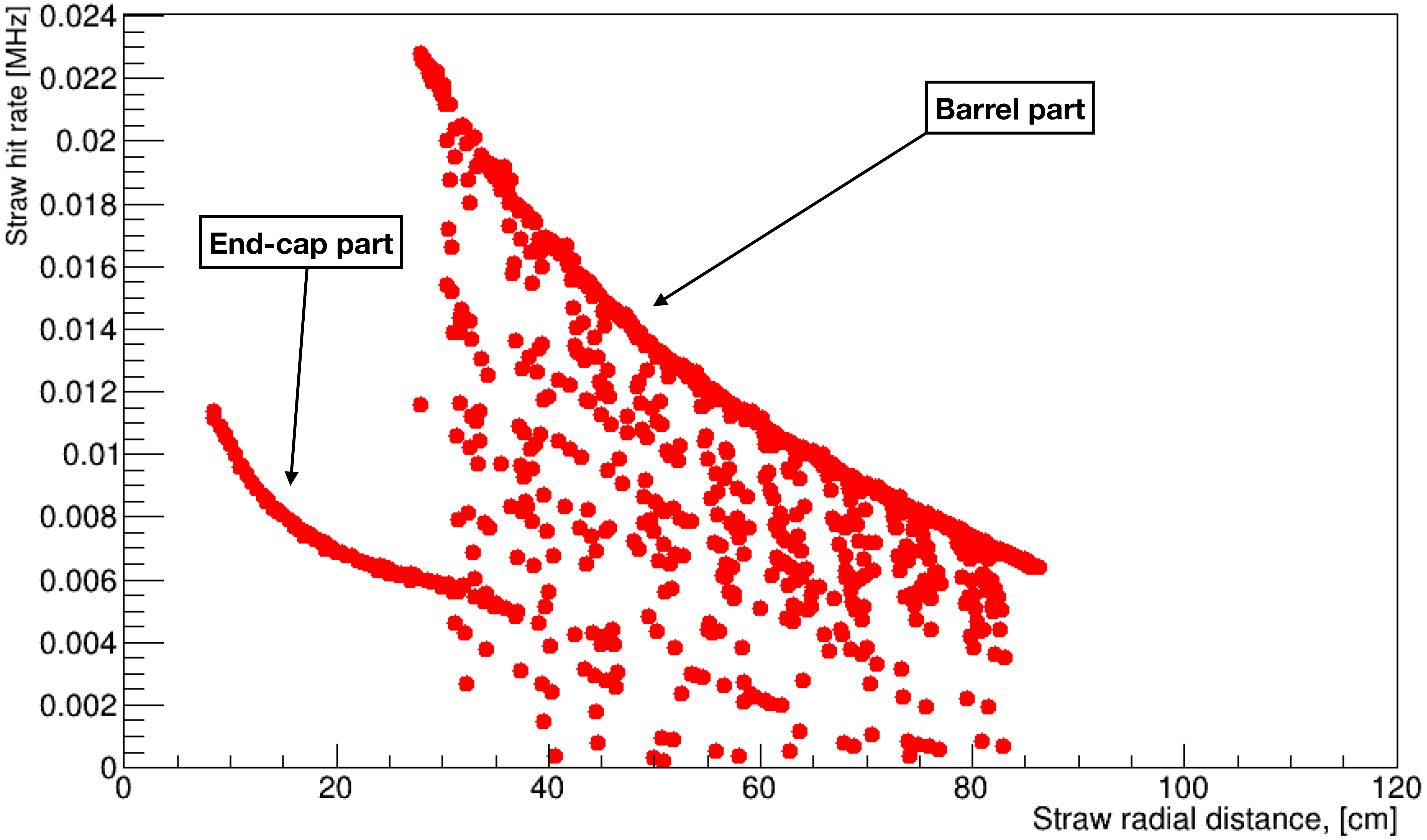


Fig. 30 - Average number of hits per straw in the TS in p-p collisions



Simulation parameters:

- Event Generator: Pythia8
- $\sqrt{s} = 10\ GeV$
- 100 000 p-p collisions
- Minimum bias
- Interaction rate (for colored Z-axis) = 0.4 MHz

The relative fraction of active straws (straws with at least 1 hit): 1.8%

Interaction rates are obtained from SPD TDR: https://arxiv.org/pdf/2404.08317

Momentum resolution of the Straw Tracker in p-p collisions

A region of particular interest for event reconstruction in the Straw Tracker is that of mid-range pseudorapidity ($-1.1 < \eta < 1.1$), where the highest particle registration accuracy is expected. Figure 6 presents a total occupancy map of the entire Straw Tracker in this pseudorapidity region. To evaluate the momentum resolution, distributions of the relative momentum reconstruction accuracy $(Pt_{reco} - Pt_{truth})/Pt_{truth}$ were obtained for different MC Pt intervals. These distributions were then fitted with Gaussian functions, and the standard deviations of the fits were taken as the measure of momentum resolution.

<u>Simulation parameters:</u>

- Event Generator: Pythia8
- $\sqrt{s} = 10\ GeV$
- 5 000 p-p collisions
- Minimum bias
- Interaction rate (for colored Z-axis) = 0.4 MHz

Interaction rates are obtained from SPD TDR: https://arxiv.org/pdf/2404.08317

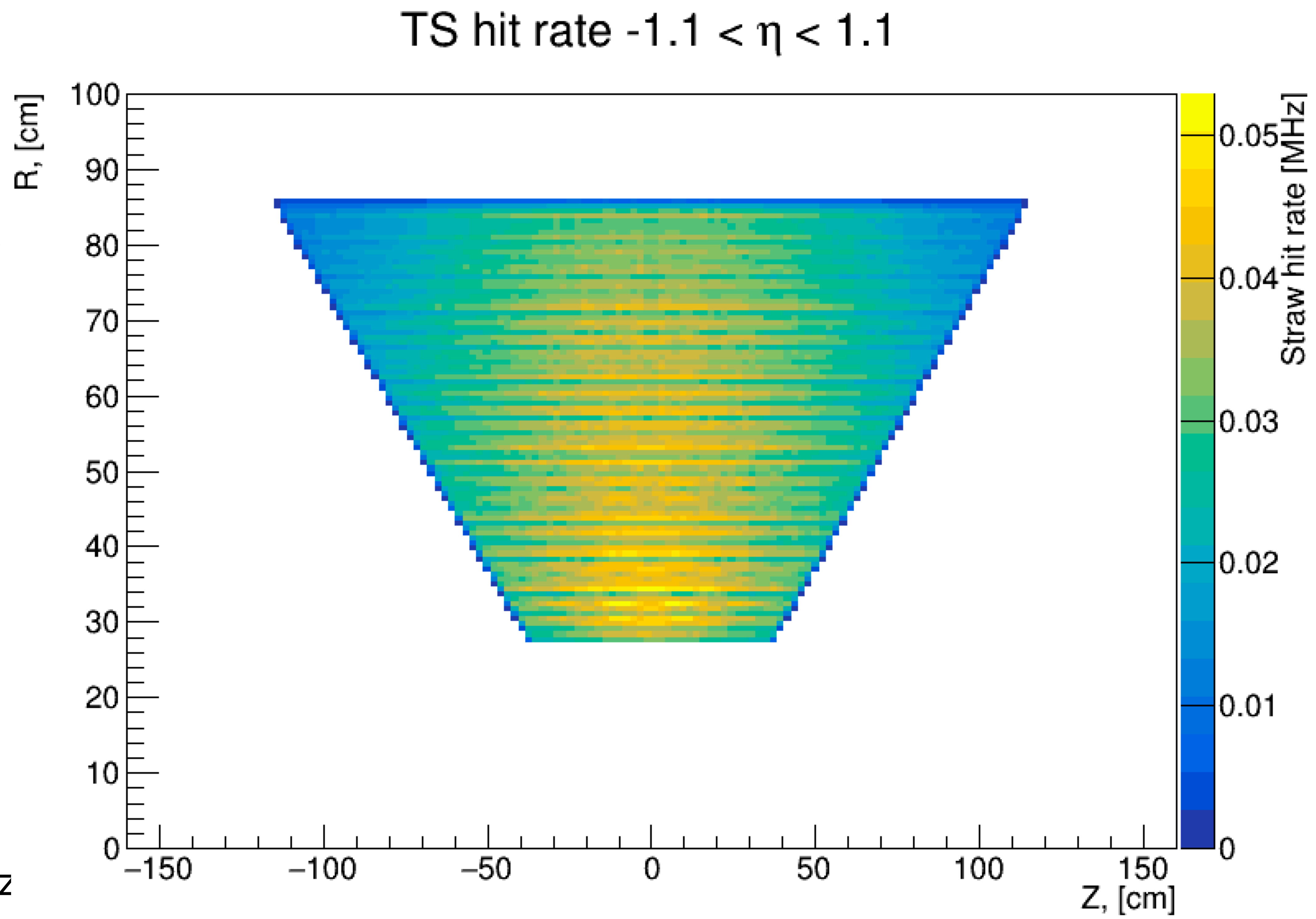


Fig. 31 - TS full hit rate in the central pseudorapidity region

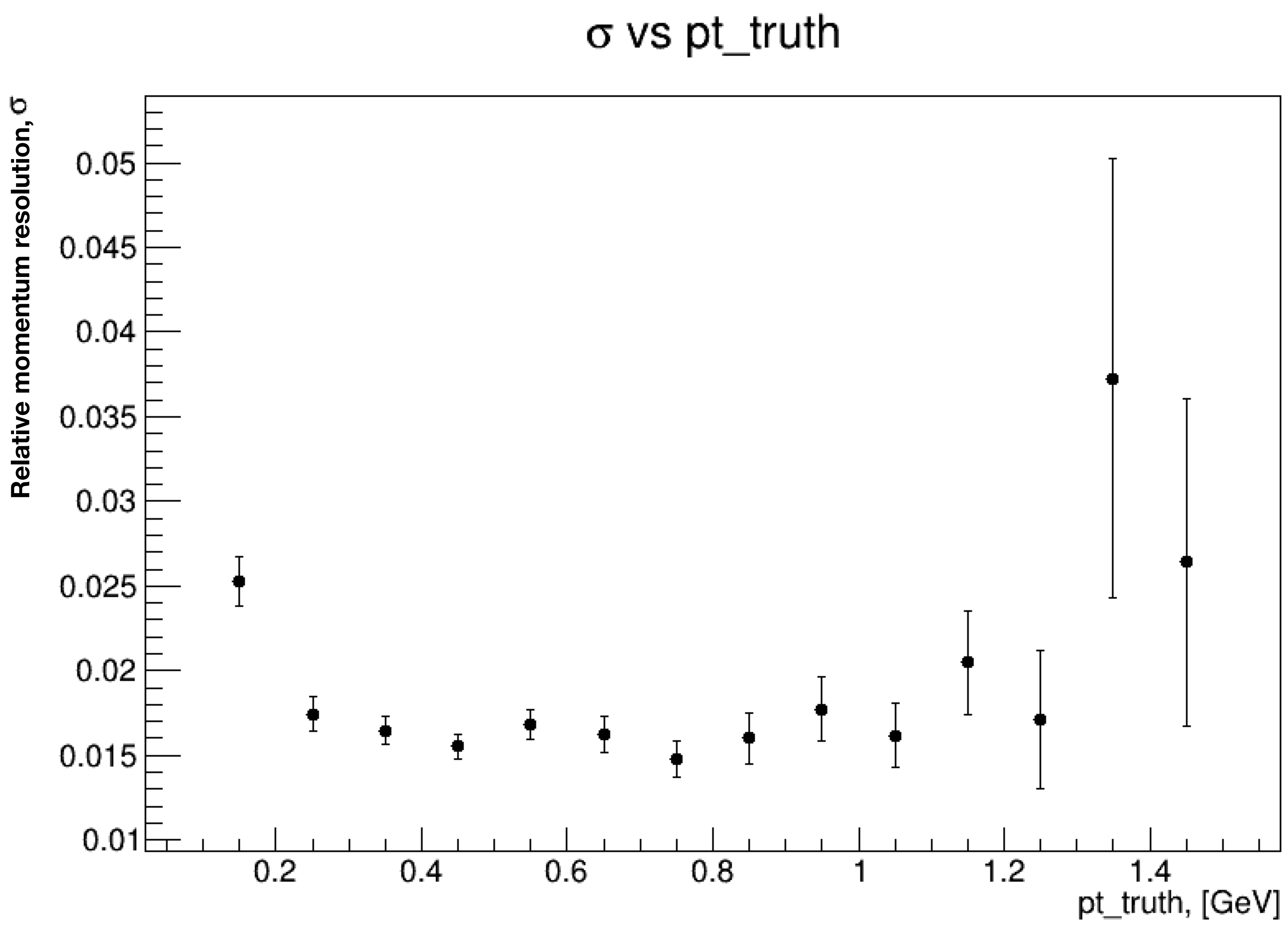


Fig. 32 - Momentum resolution of the Straw Tracker for MC Pt within the central pseudorapidity interval

TS full hit rate and straw occupancy in Xe-Xe collisions

Fig. 33 - TS full hit rate (barrel и end-caps parts) in Xe-Xe collisions

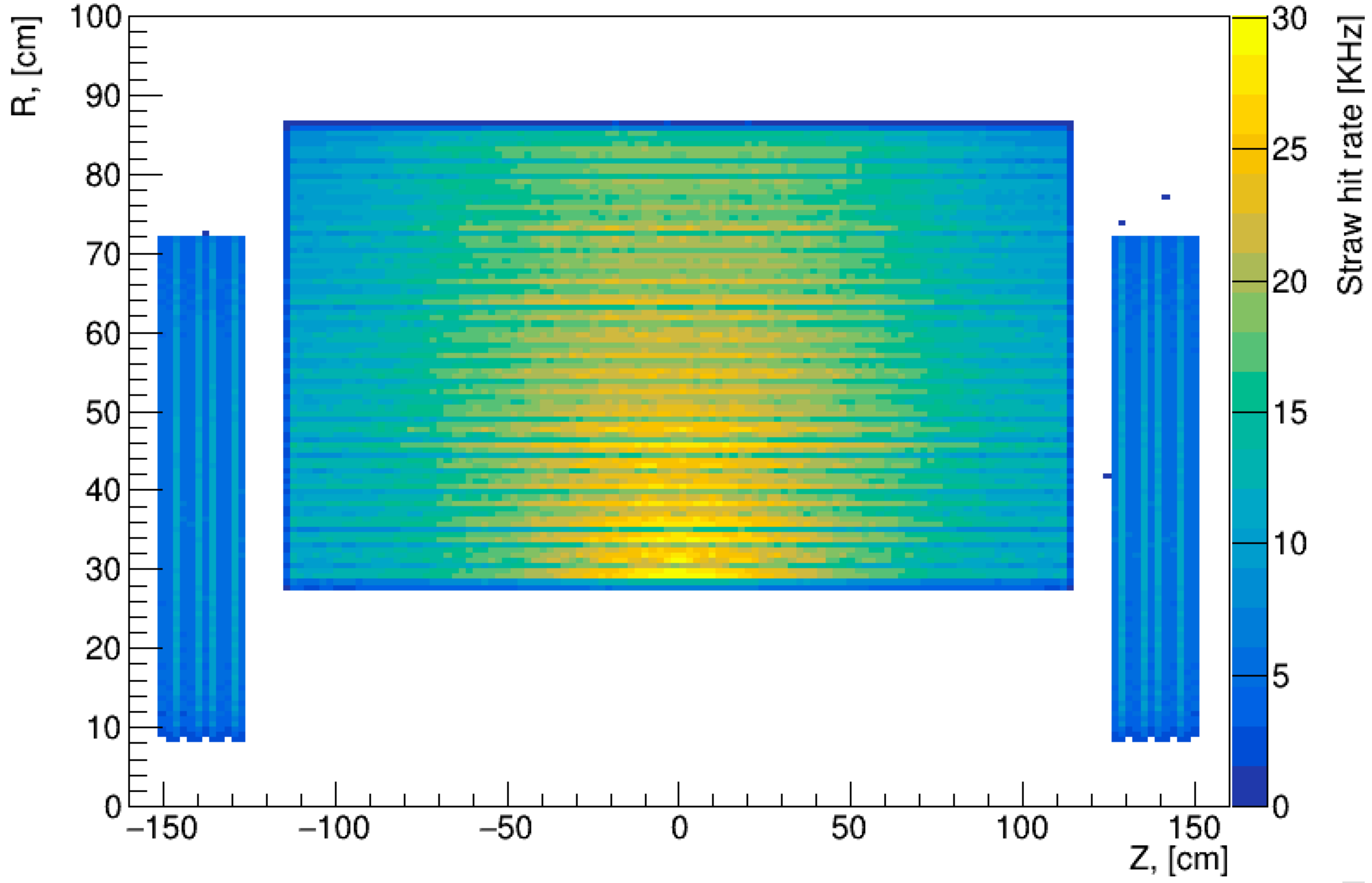
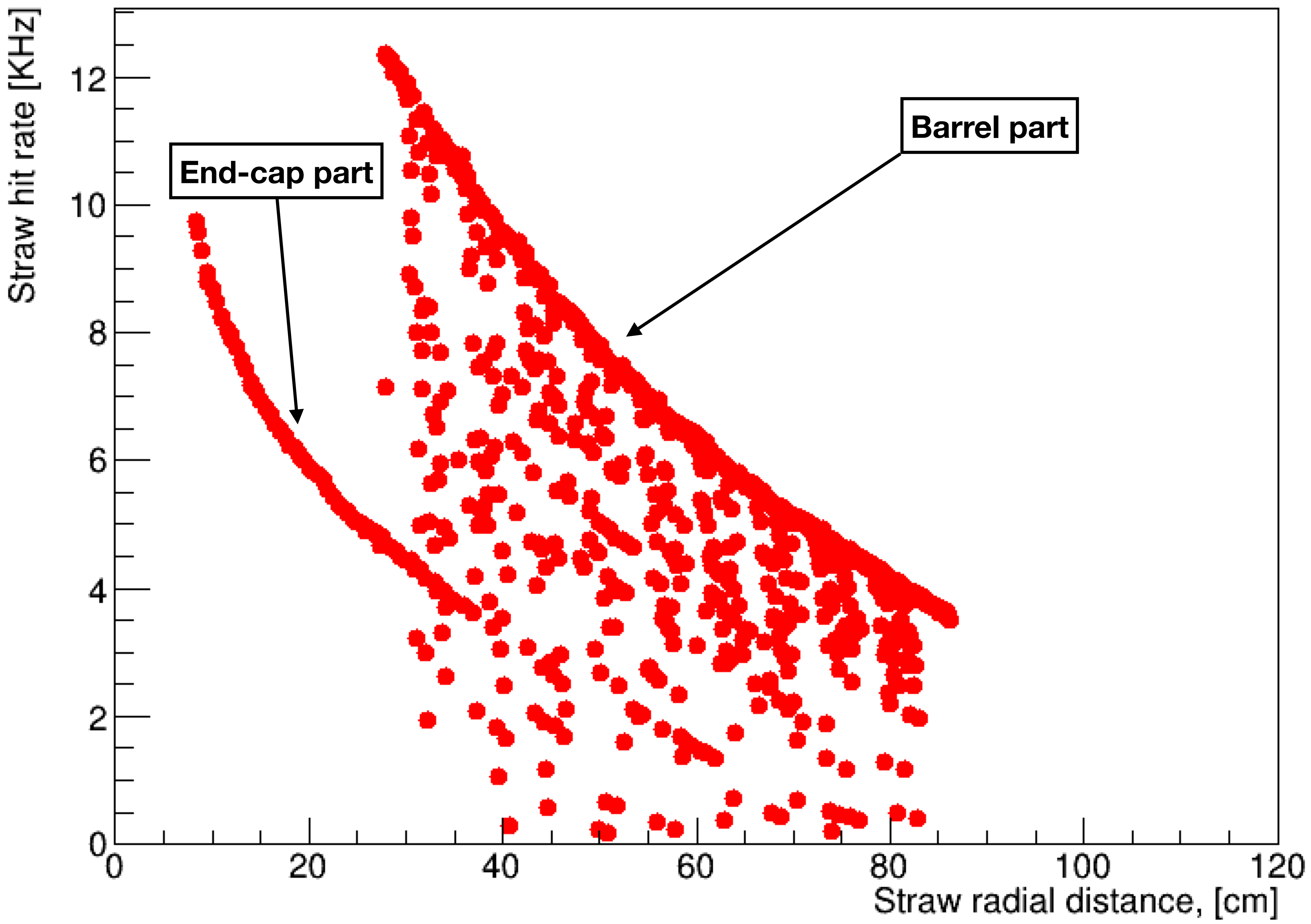


Fig. 34 - Average number of hits per straw in the TS in Xe-Xe collisions



The relative fraction of active straws (straws with at least 1 hit): 33.6%

Simulation parameters:

- Event Generator: URQMD 3.4
- $\sqrt{s} = 10\ GeV$
- 10 000 Xe-Xe collisions (Xe^{131}_{54})
- Minimum bias
- Interaction rate (for colored Z-axis) = 7 kHz

Interaction rates are obtained from MPD CDR: https://mpd.jinr.ru/wp-content/uploads/2023/11/MPD_CDR_en.pdf

Momentum resolution of the Straw Tracker in Xe-Xe collisions

The momentum resolution was similarly evaluated for ion-ion collisions.
In particular, Figure 35 presents the total occupancy map of the entire Straw Tracker in the central pseudorapidity region ($-1.1 < \eta < 1.1$) for oxygen-oxygen Xe-Xe) collisions.
Figure 36 shows the momentum resolution (Pt) across the full momentum spectrum for Xe-Xe collisions in the same central pseudorapidity region.

<u>Simulation parameters:</u>

- Event Generator: URQMD 3.4
- $\sqrt{s} = 10\ GeV$
- 1 000 Xe-Xe collisions (Xe^{131}_{54})
- Minimum bias
- Interaction rate (for colored Z-axis) = 7 kHz

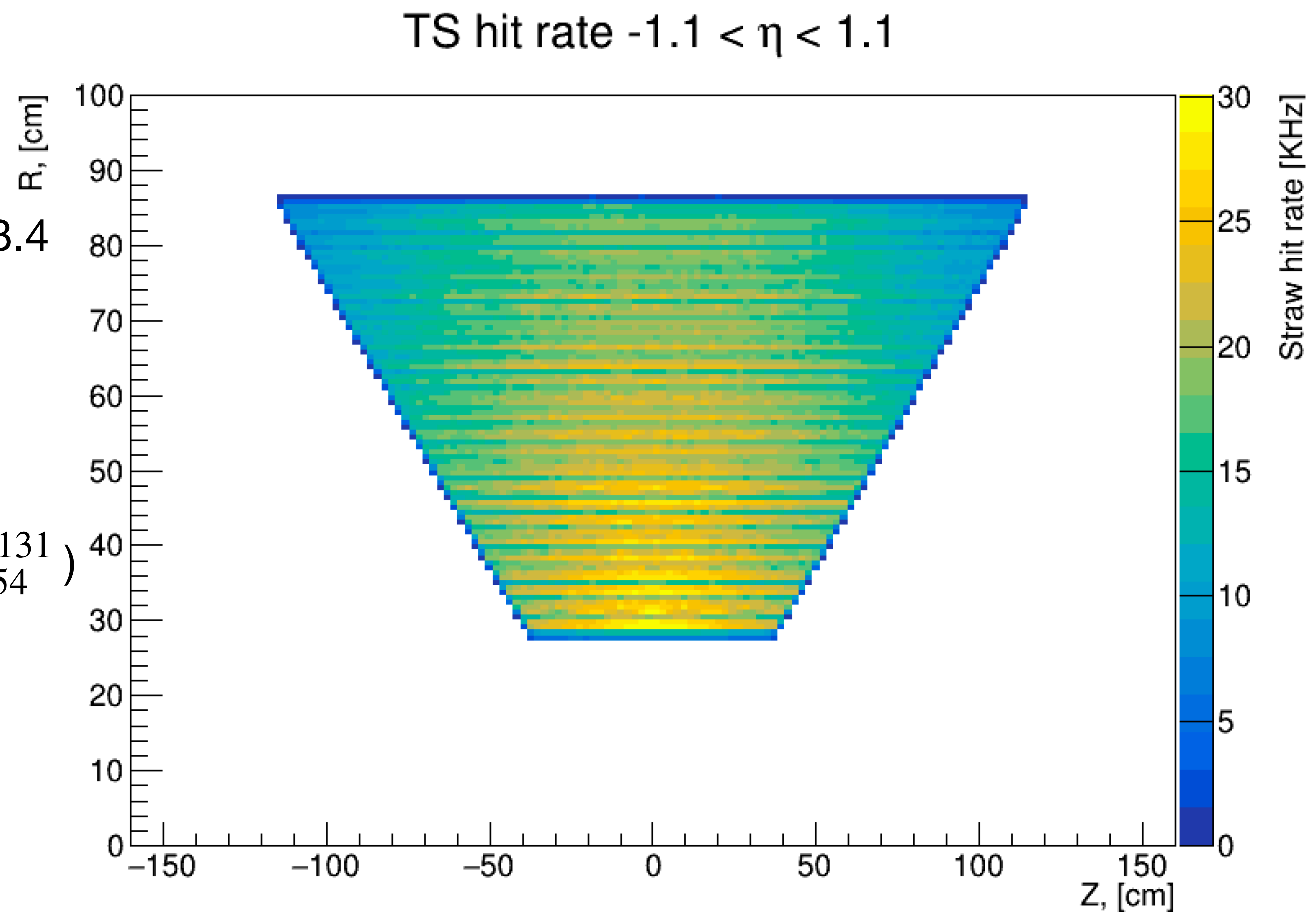


Fig. 35 - TS full hit rate in the central pseudorapidity region for the Xe-Xe collisions

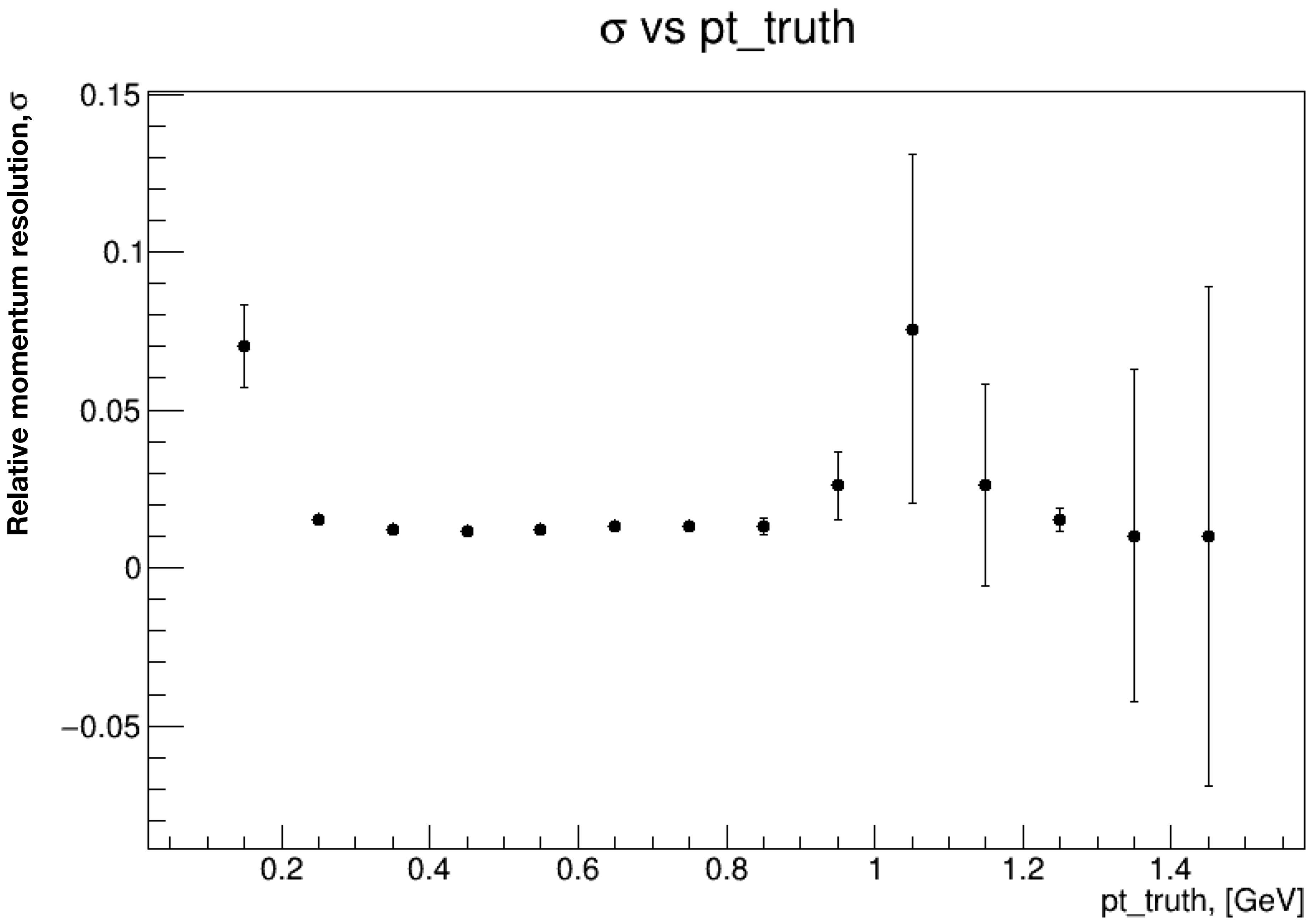


Fig. 36 - Momentum resolution of the Straw Tracker for MC Pt within the central pseudorapidity interval for the Xe-Xe collisions

Interaction rates are obtained from MPD CDR:
https://mpd.jinr.ru/wp-content/uploads/2023/11/MPD_CDR_en.pdf

Compared relative fraction of active straws in the TS

Fig. 37 shows the relative fraction of active straws in the TS, compared between p-p, O-O, Kr-Kr and Xe-Xe collisions

<u>Simulation parameters:</u>

- Event Generator: URQMD
- $\sqrt{s} = 10\ GeV$
- 100 000 p-p and 10 000 ion-ion collisions
- Minimum bias

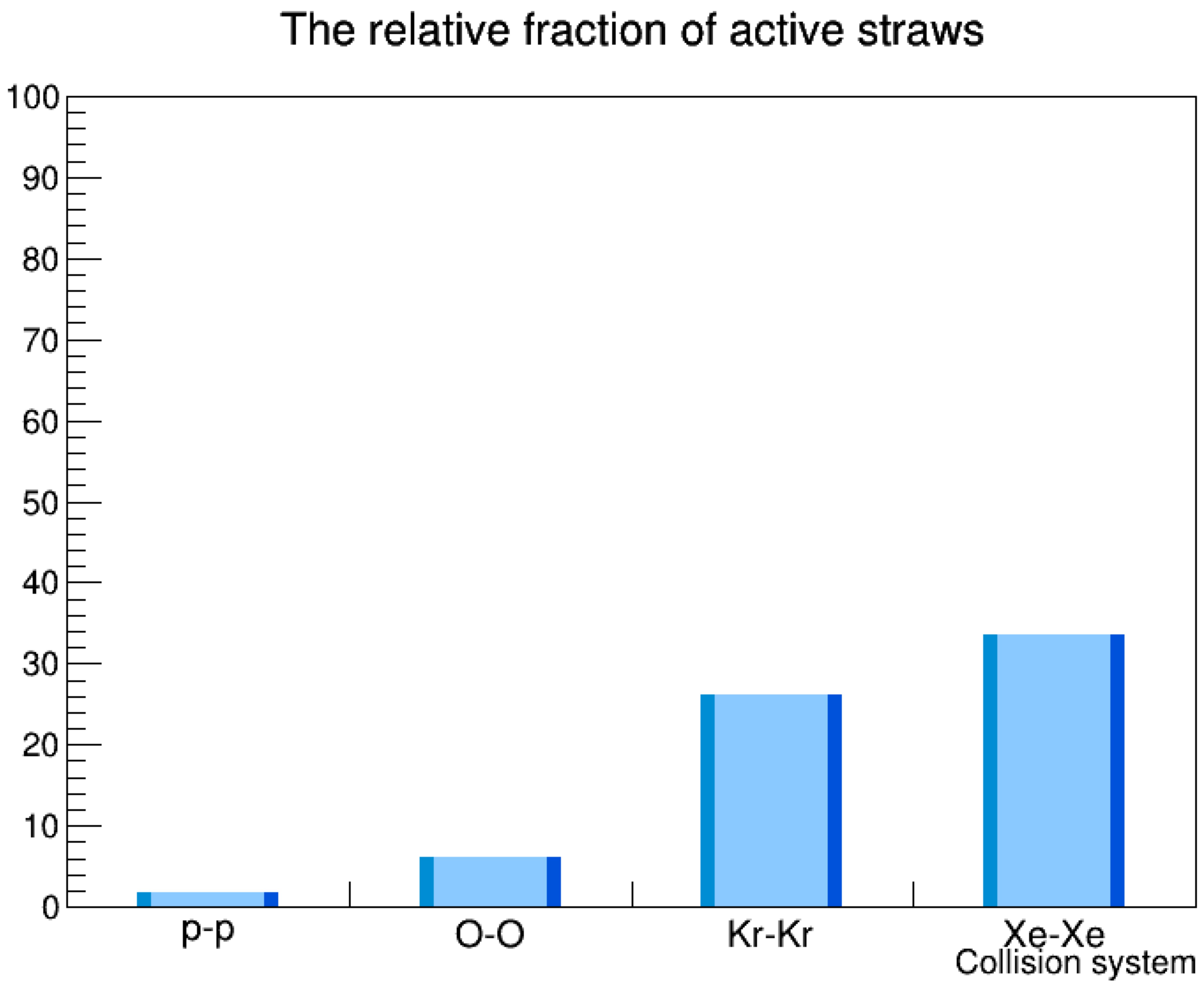


Fig. 37 - Compared relative fraction of active straws in the TS

Comparison of momentum resolution in the Straw Tracker in p-p and ion-ion collisions

By comparing the momentum resolution distributions between proton-proton and various ion-ion collision systems, a combined distribution was obtained.

Simulation parameters:

- Event Generator: URQMD
- $\sqrt{s} = 10\ GeV$
- 10 000 p-p and 1000 ion-ion collisions
- Minimum bias

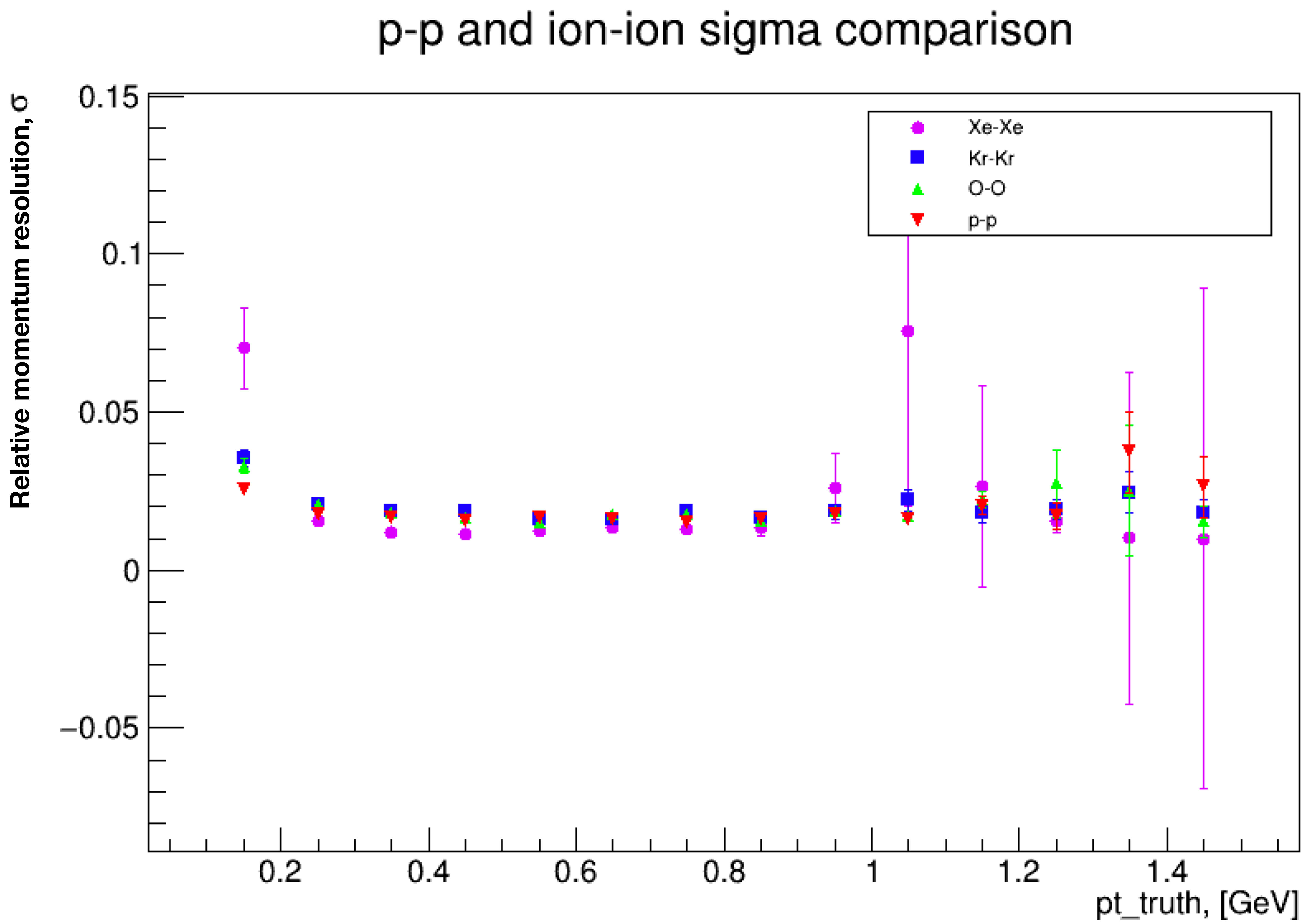


Fig. 38 - Comparison of momentum resolution in the Straw Tracker in p-p and ion-ion collisions

TS full hit rate and straw occupancy in O-O collisions

Fig. 39 - TS full hit rate (barrel и end-caps parts) in O-O collisions

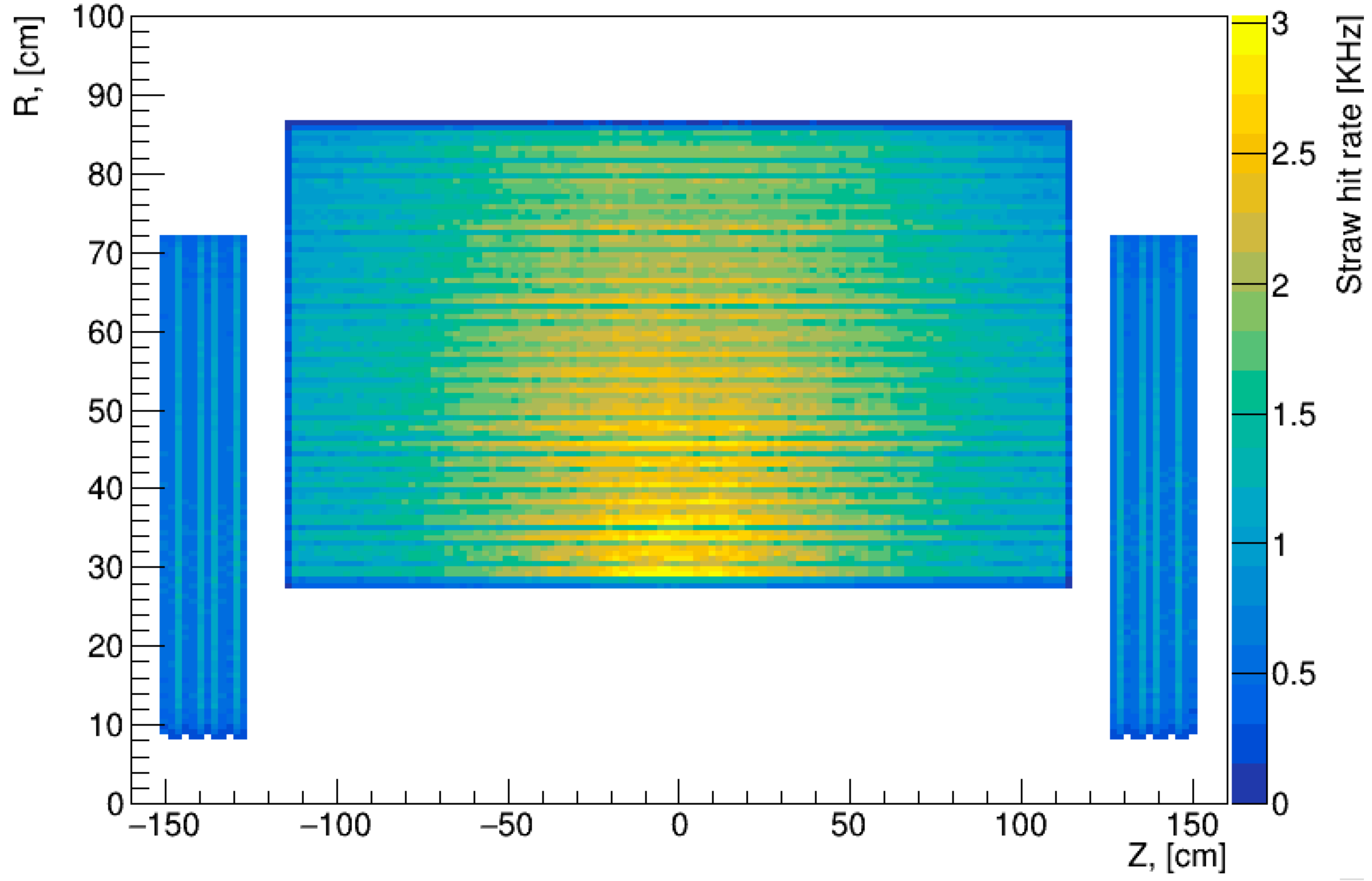
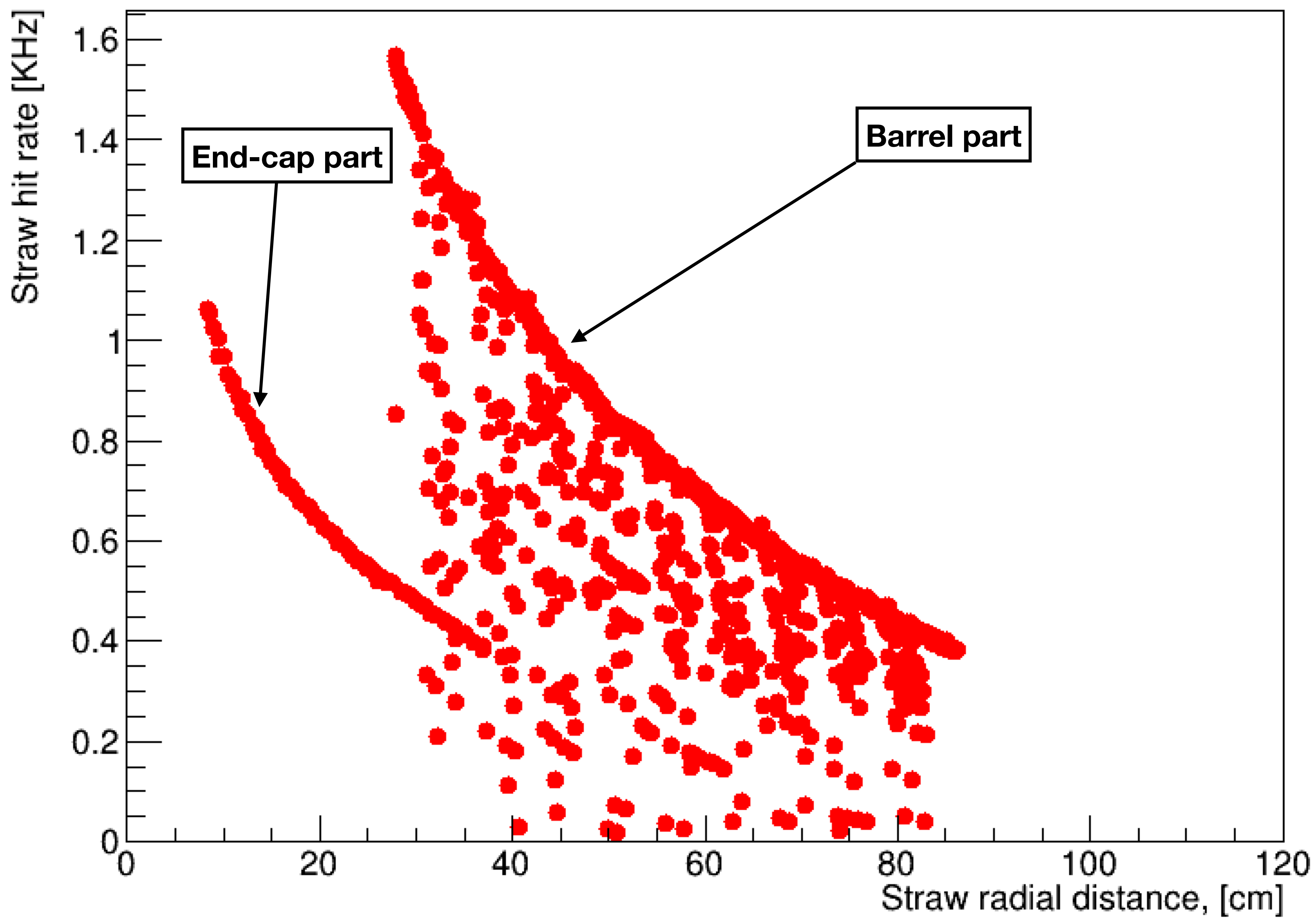


Fig. 40- Average number of hits per straw in the TS in O-O collisions



Simulation parameters:

- Event Generator: URQMD 3.4
- $\sqrt{s} = 10\ GeV$
- 10 000 O-O collisions (O_8^{16})
- Minimum bias
- Interaction rate (for colored Z-axis) = 7 kHz

The relative fraction of active straws (straws with at least 1 hit): 6.2%

Interaction rates are obtained from MPD CDR: https://mpd.jinr.ru/wp-content/uploads/2023/11/MPD_CDR_en.pdf

Momentum resolution of the Straw Tracker in O-O collisions

The momentum resolution was similarly evaluated for ion-ion collisions.
In particular, Figure 41 presents the total occupancy map of the entire Straw Tracker in the central pseudorapidity region ($-1.1 < \eta < 1.1$) for oxygen-oxygen (O–O) collisions.
Figure 42 shows the momentum resolution (Pt) across the full momentum spectrum for O–O collisions in the same central pseudorapidity region.

<u>Simulation parameters:</u>

- Event Generator: URQMD 3.4
- $\sqrt{s} = 10\ GeV$
- 1 000 O-O collisions (O_8^{16})
- Minimum bias
- Interaction rate (for colored Z-axis) = 7 kHz

Interaction rates are obtained from MPD CDR:
https://mpd.jinr.ru/wp-content/uploads/2023/11/MPD_CDR_en.pdf

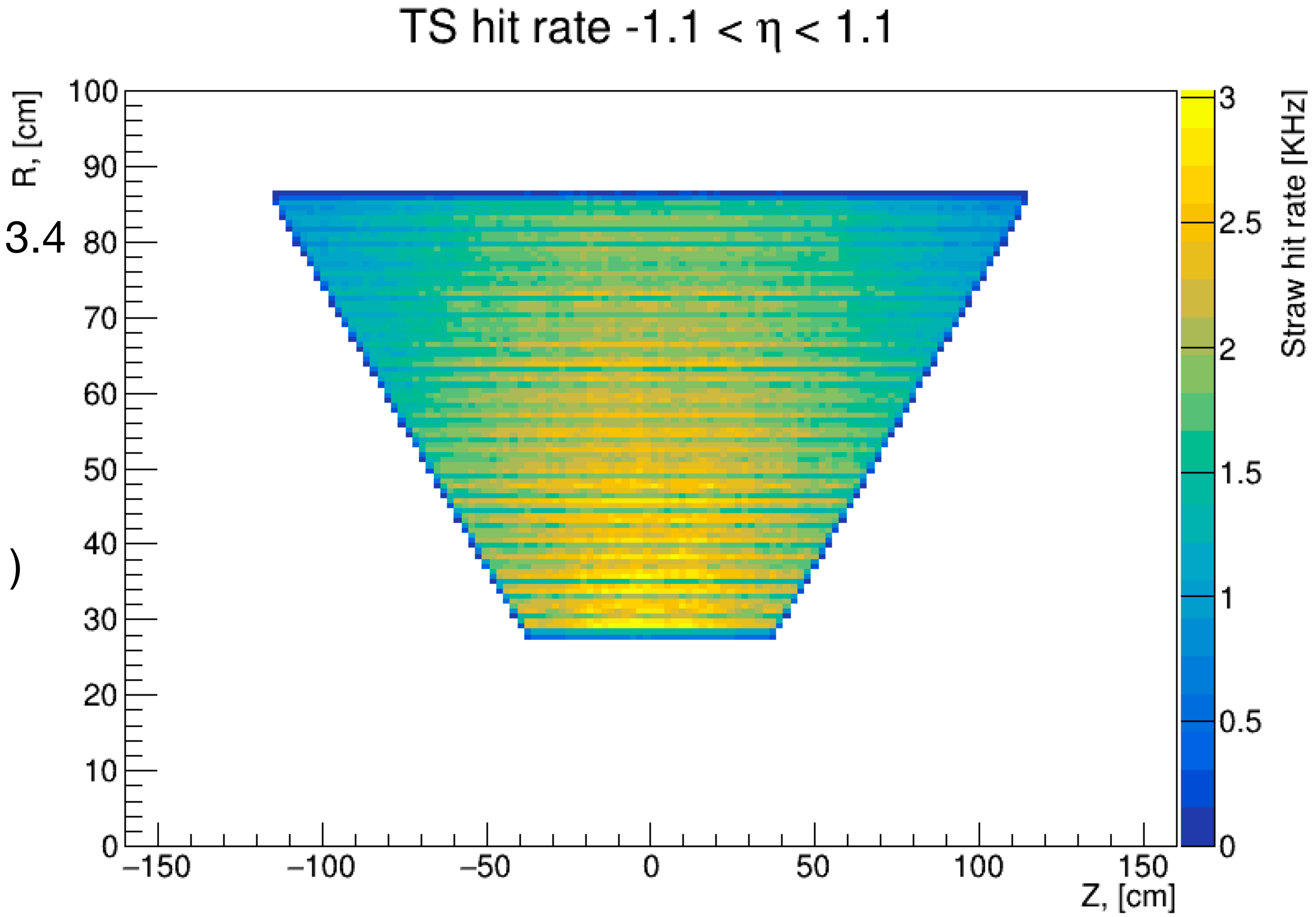


Fig. 41 - TS full hit rate in the central pseudorapidity region for the O-O collisions

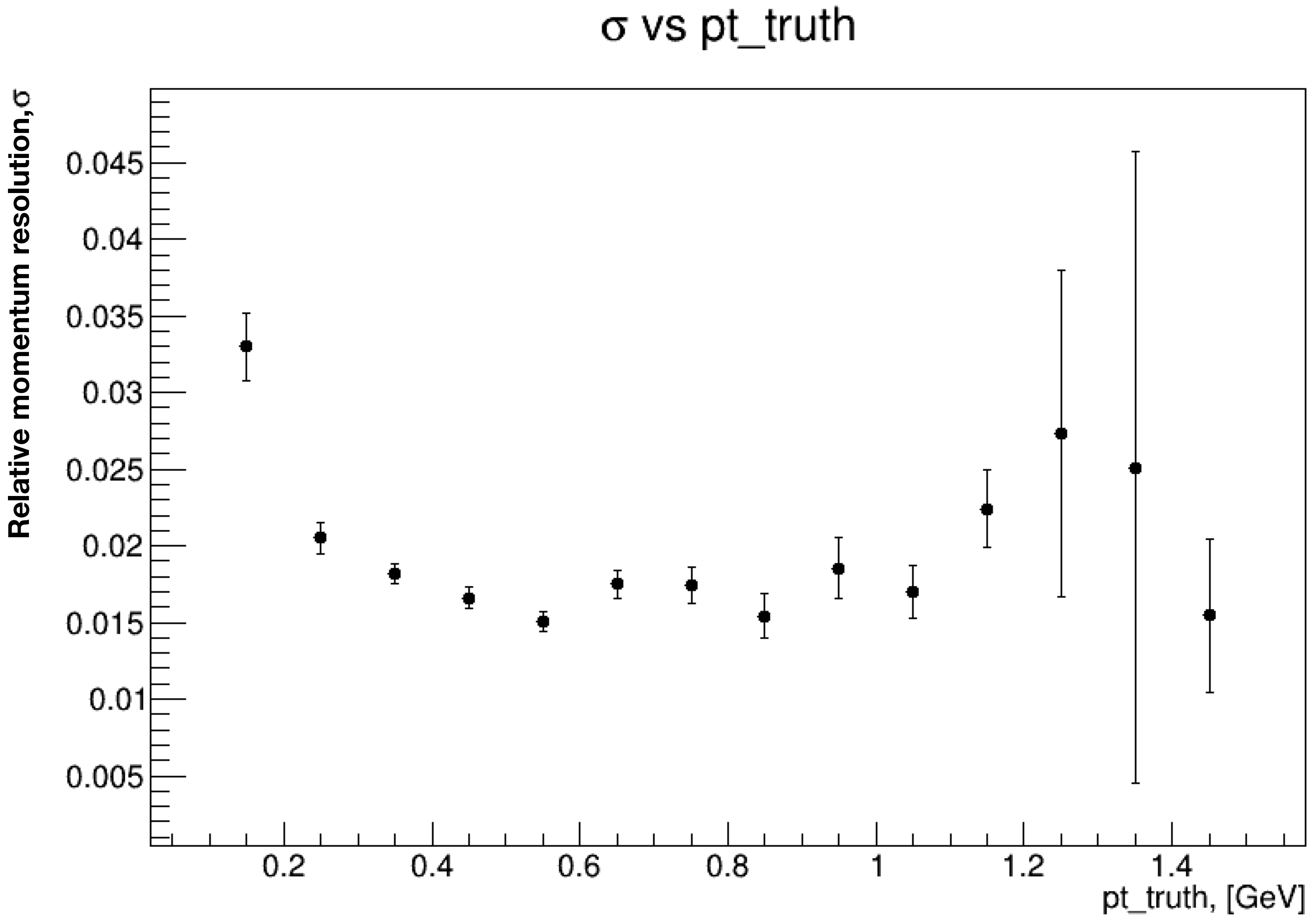


Fig. 42 - Momentum resolution of the Straw Tracker for MC Pt within the central pseudorapidity interval for the O-O collisions

TS full hit rate and straw occupancy in Kr-Kr collisions

Fig. 43 - TS full hit rate (barrel и end-caps parts) in Kr-Kr collisions

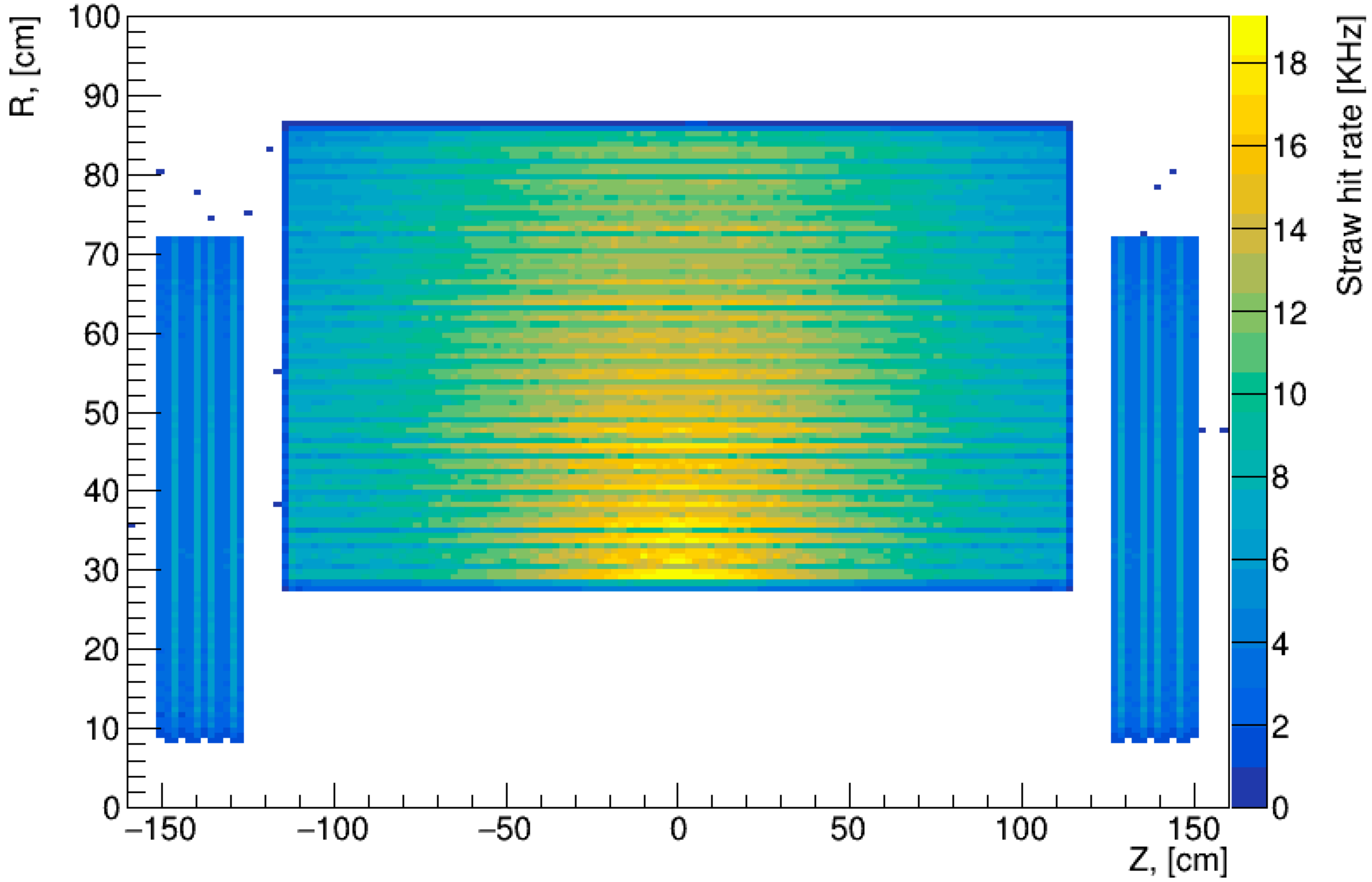
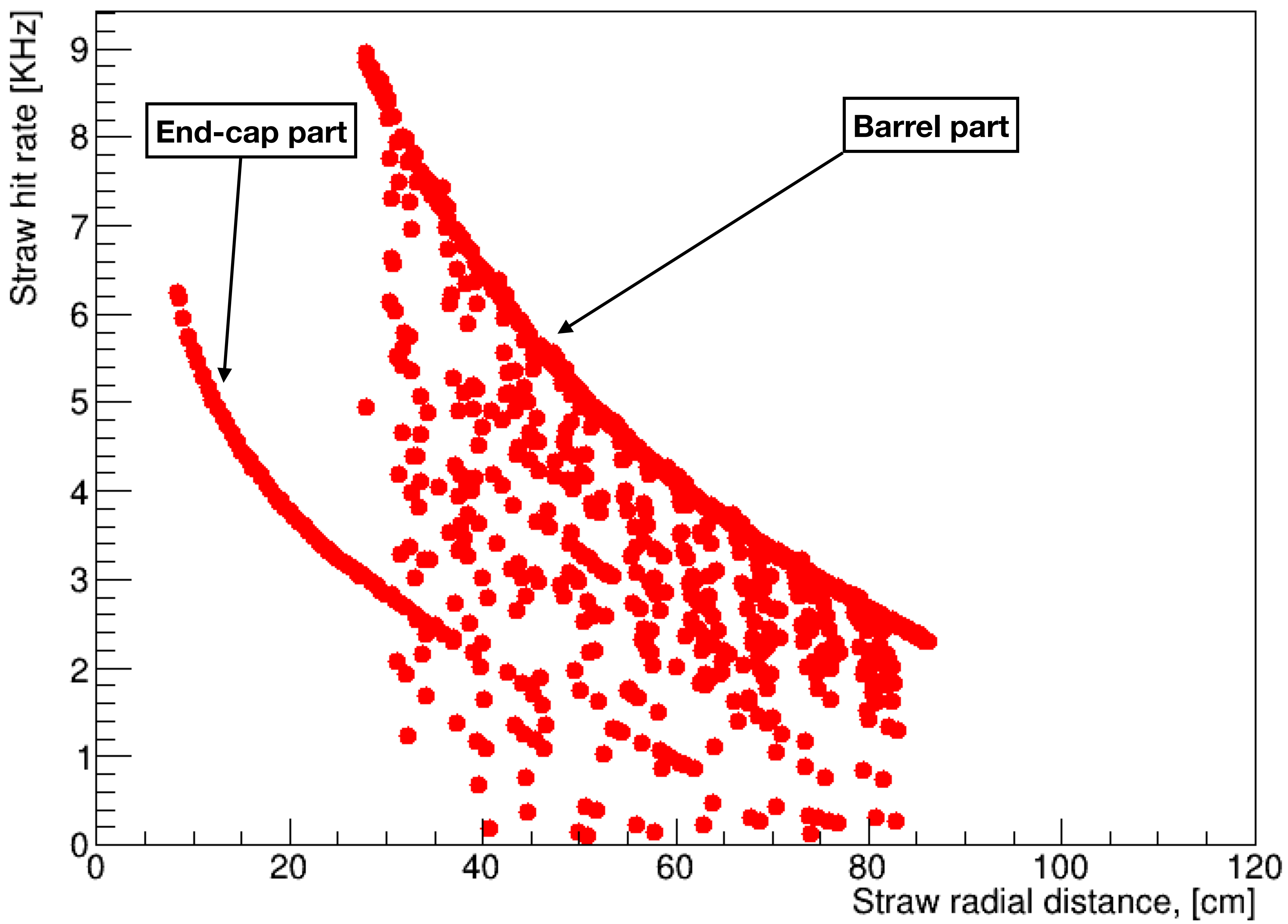


Fig. 44 - Average number of hits per straw in the TS in Kr-Kr collisions



Simulation parameters:

- Event Generator: URQMD 3.4
- $\sqrt{s} = 10\ GeV$
- 10 000 Kr-Kr collisions (Kr^{84}_{36})
- Minimum bias
- Interaction rate (for colored Z-axis) = 7 kHz

The relative fraction of active straws (straws with at least 1 hit): 26.2%

Interaction rates are obtained from MPD CDR: https://mpd.jinr.ru/wp-content/uploads/2023/11/MPD_CDR_en.pdf

Momentum resolution of the Straw Tracker in Kr-Kr collisions

The momentum resolution was similarly evaluated for ion-ion collisions.
In particular, Figure 45 presents the total occupancy map of the entire Straw Tracker in the central pseudorapidity region ($-1.1 < \eta < 1.1$) for oxygen-oxygen Kr-Kr) collisions.
Figure 46 shows the momentum resolution (Pt) across the full momentum spectrum for Kr-Kr collisions in the same central pseudorapidity region.

<u>Simulation parameters:</u>

- Event Generator: URQMD 3.4
- $\sqrt{s} = 10\ GeV$
- 1 000 Kr-Kr collisions (Kr^{84}_{36})
- Minimum bias
- Interaction rate (for colored Z-axis) = 7 kHz

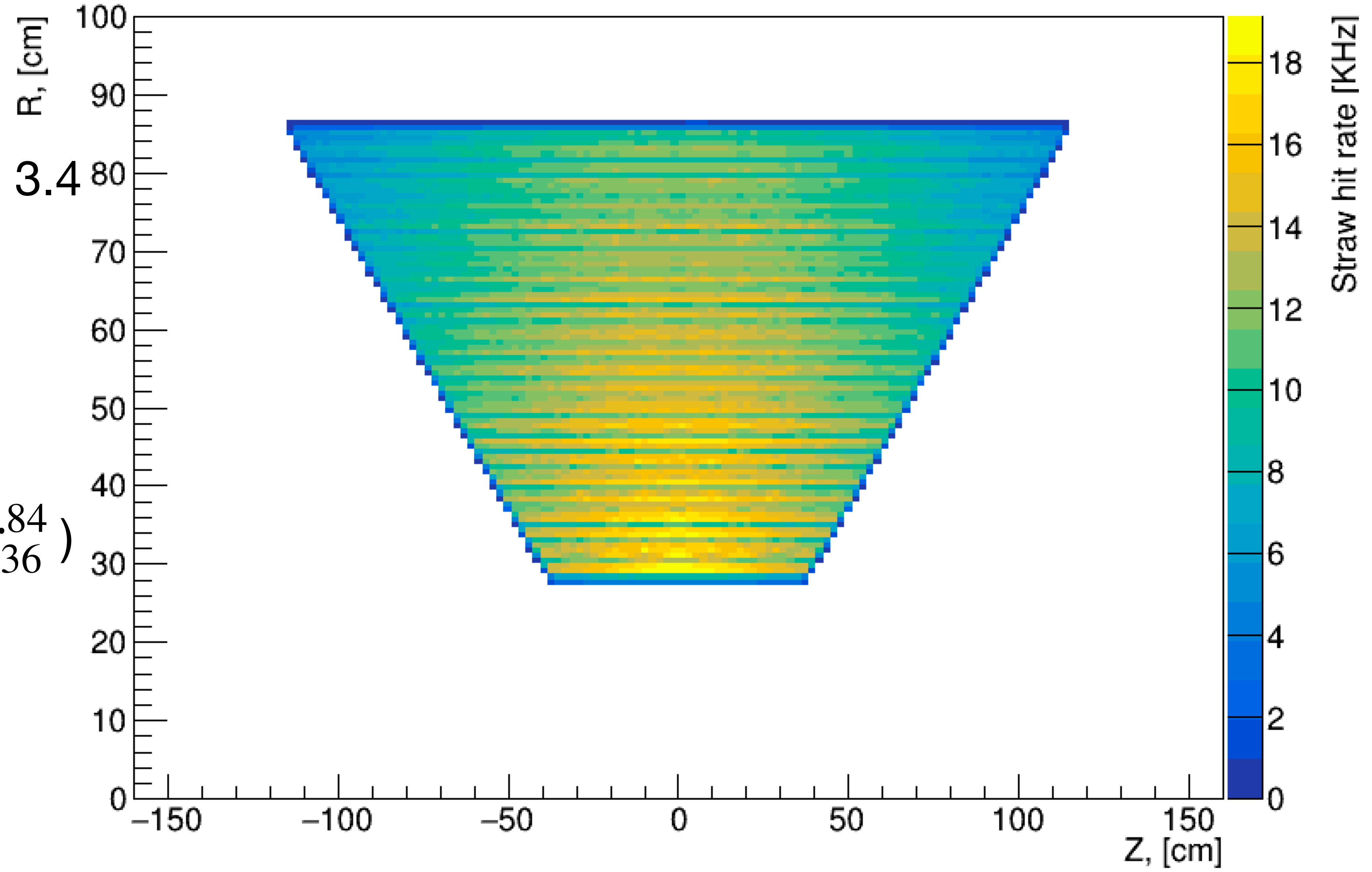


Fig. 45 - TS full hit rate in the central pseudorapidity region for the Kr-Kr collisions

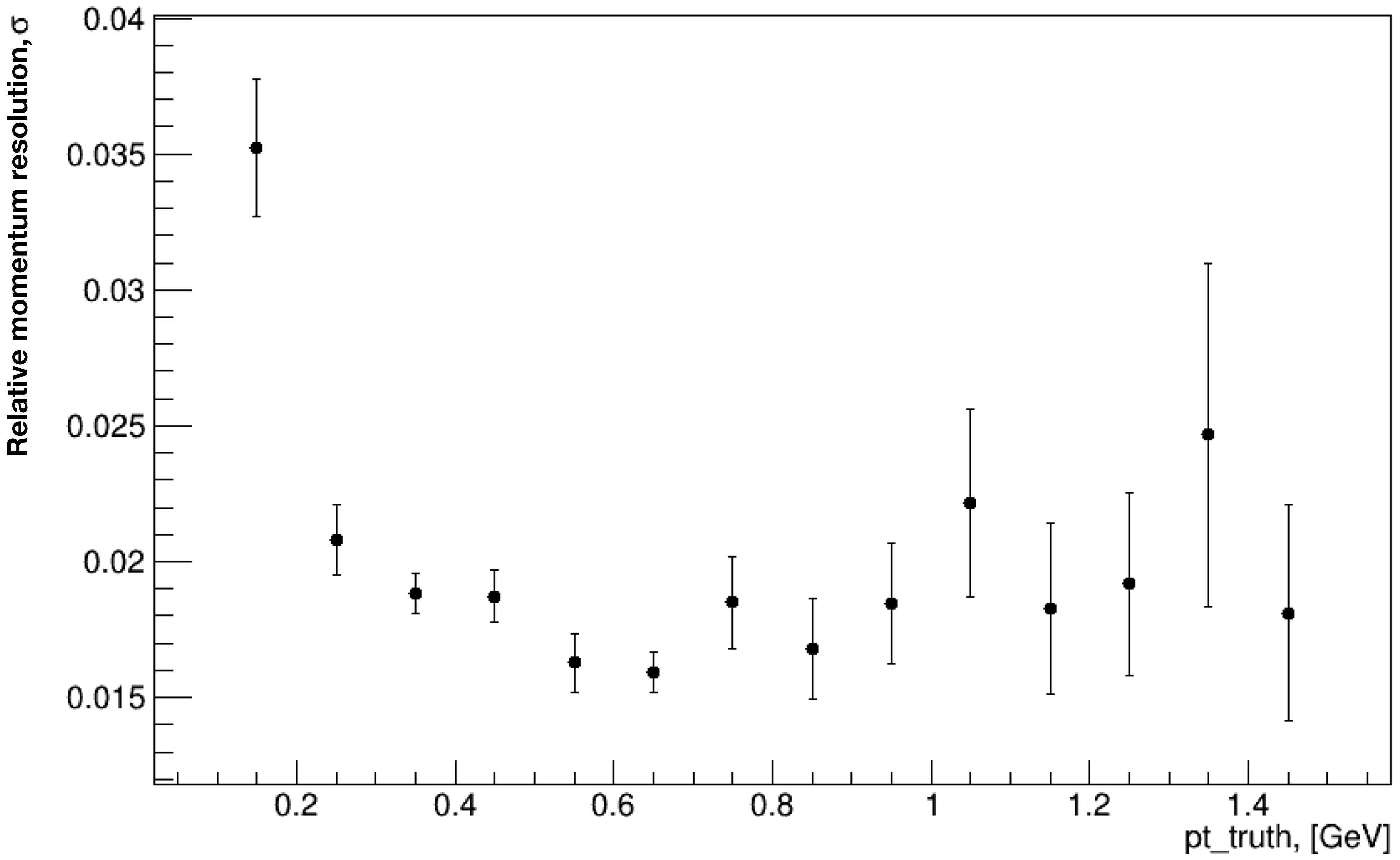


Fig. 46 - Momentum resolution of the Straw Tracker for MC Pt within the central pseudorapidity interval for the Kr-Kr collisions

Interaction rates are obtained from MPD CDR: https://mpd.jinr.ru/wp-content/uploads/2023/11/MPD_CDR_en.pdf