Electron production from the open-heavy flavor decay in relativistic heavy-ion collision at STAR

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Overview

- Introduction
- Theory
- The STAR experiment
- Data analysis
- Previous works
- Results
- Outlook

I. Introduction

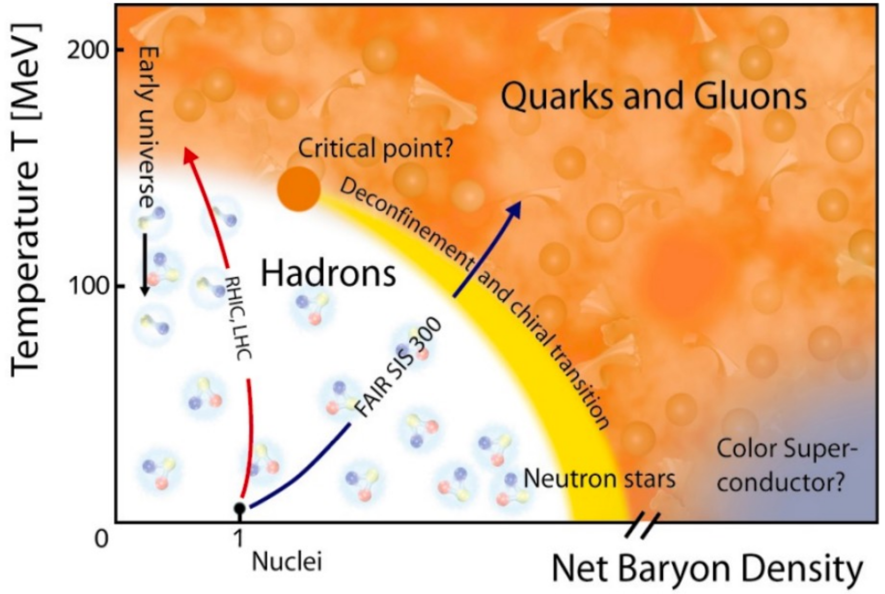
Theoretical vision

Theoretical vision

- Heavy-Ion collision: Formation of Quark-Gluon Plasma (QGP)

Soft probes
- Small momentum transfer
- Particles created during QGP

Hard probes
- Large momentum transfer
- Particle created during initial hard scattering



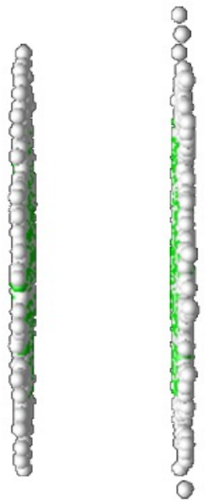
To investigate the properies of QGP, the probes needs to be produced in the stage of early collision process and to interact with the medium

2. Theory

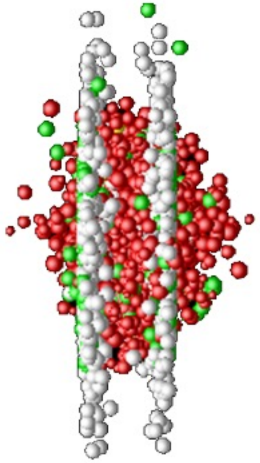
- Heavy-ion collision
- From the prespective of hard probes
- Heavy flavors
- Non-photonic electron measurements

Heavy-ion collisions

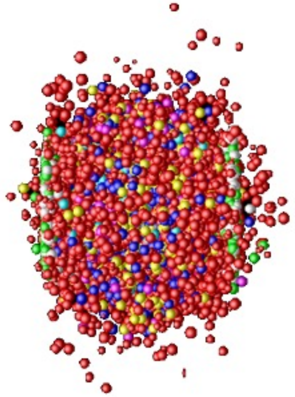
Creation of strongly interacting quark-gluon plasma



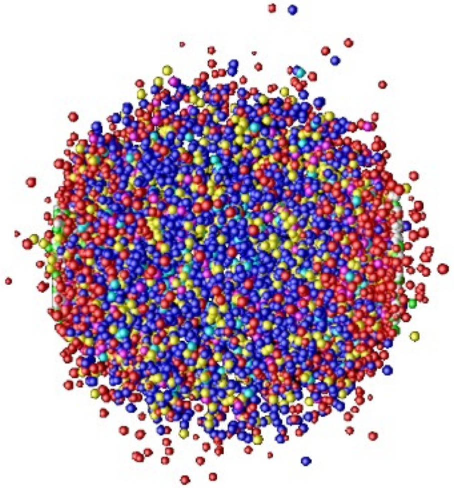
Colliding beams



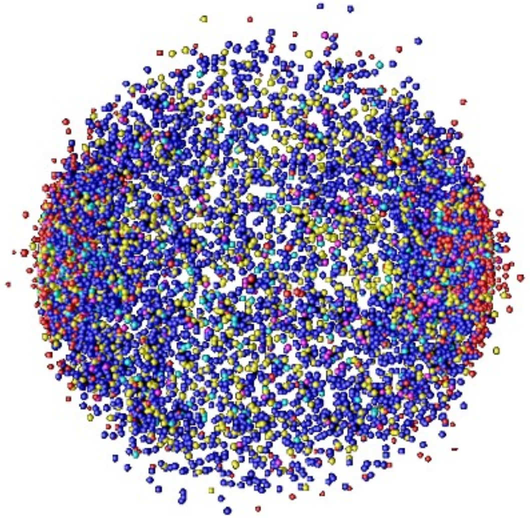
Collision overlap zones



Formation of QGP



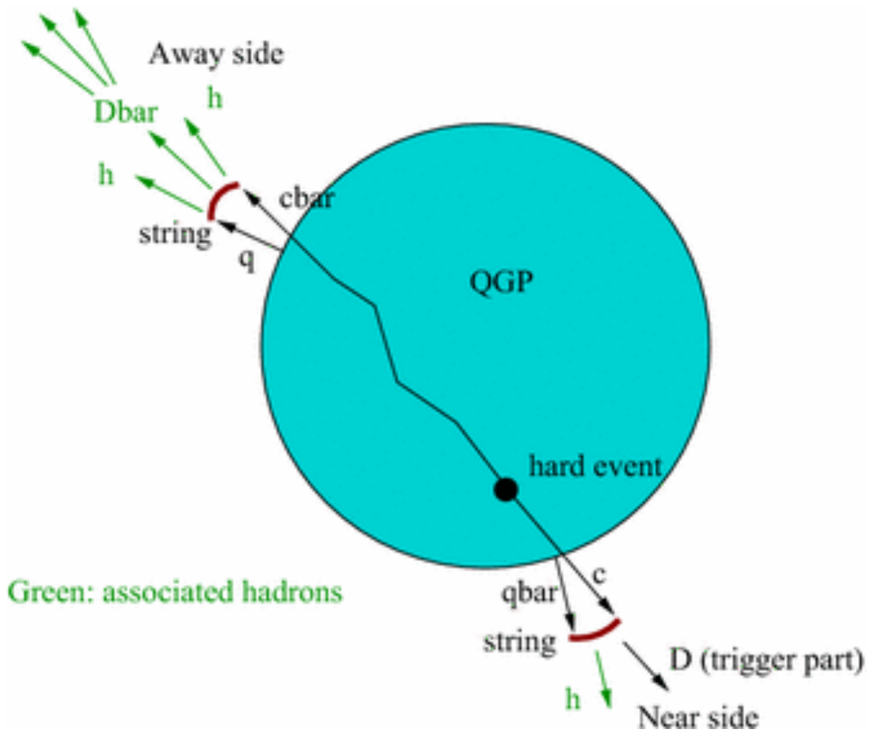
Chemical freeze-out (hadronisation)



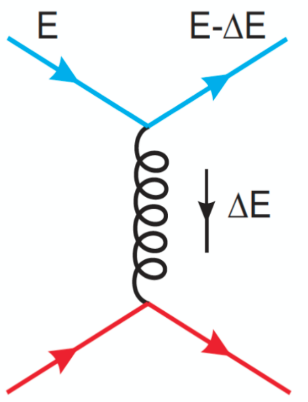
Kinetic freeze-out (particle detection)

From the prespective of hard probes

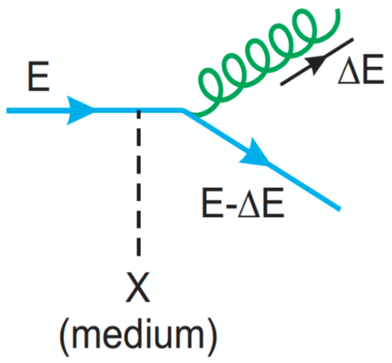
- Hard probes: large masses, generally with $p_T > 2$ GeV/c
- Unique probes for studying QGP properties
  1. produced at the early stage of collision
  2. Interact differently with QGP in comparison with other quarks



Energy loss mechanisms



(a)



(b)

a) Collisional processes: elastic scatterings
b) Radiative processes: gluon radiation due to exchange of color forces between heavy quarks and medium

Heavy flavors

D and B Mesons

Particle	Mass MeV/c^2	Composition	$I(J^P)$	Antiparticle
D^0	1864.84 ± 0.05	$c\bar{u}$	$1/2(0^-)$	$\overline{D}^0$
D^+	1869.66 ± 0.05	$c\bar{d}$	$1/2(0^-)$	D^-
B^0	5279.65 ± 0.12	$u\bar{b}$	$1/2(0^-)$	$\overline{B}^0$
B^+	5279.34 ± 0.12	$d\bar{b}$	$1/2(0^-)$	B^-

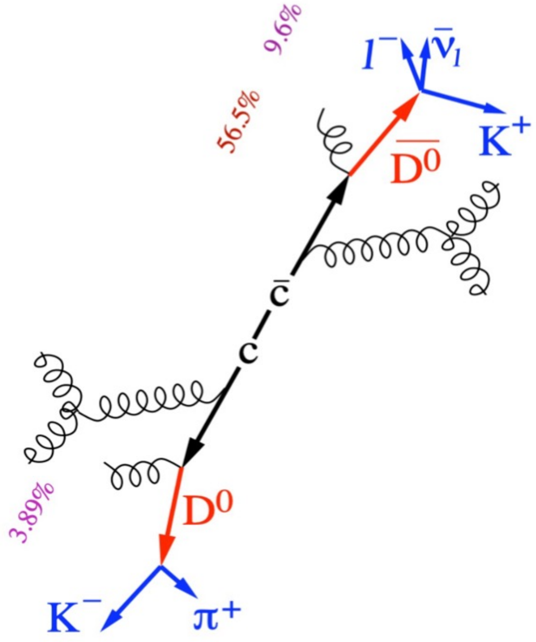
Measurements of heavy quark decays:

Hadronic decay channel

- direct reconstruction
- smaller branching ratio

Semi-leptonic decay channel

- heavy flavor electron measurement
- larger branching ratio



Non-photonic electrons measurements

Inclusive electrons (INCL) = Photonic electrons (PE) + Nonphotonic electrons (NPE)

$$N_{NPE} = \frac{N_{incl} \cdot \epsilon_{purity} - \frac{N_{PE}}{\epsilon_{PE}}}{\epsilon_{total}}$$

(a) Dalitz decays
- $\pi^0 \to e^+e^-\gamma$ B.R. $(1.1.74 \pm 0.035)\%$
- $\eta \to e^+e^-$ B.R. $(0.69 \pm 0.04)\%$

(b) Gamma conversions from di-gamma decays
- $\pi^0 \to \gamma\gamma$ B.R. $(98.823 \pm 0.034)\%$
- $\eta \to \gamma\gamma$ B.R. $(39.41 \pm 0.20)\%$

Heavy flavor electrons (HFE) = Nonphotonic electrons (NPE) – Hadron decay electrons

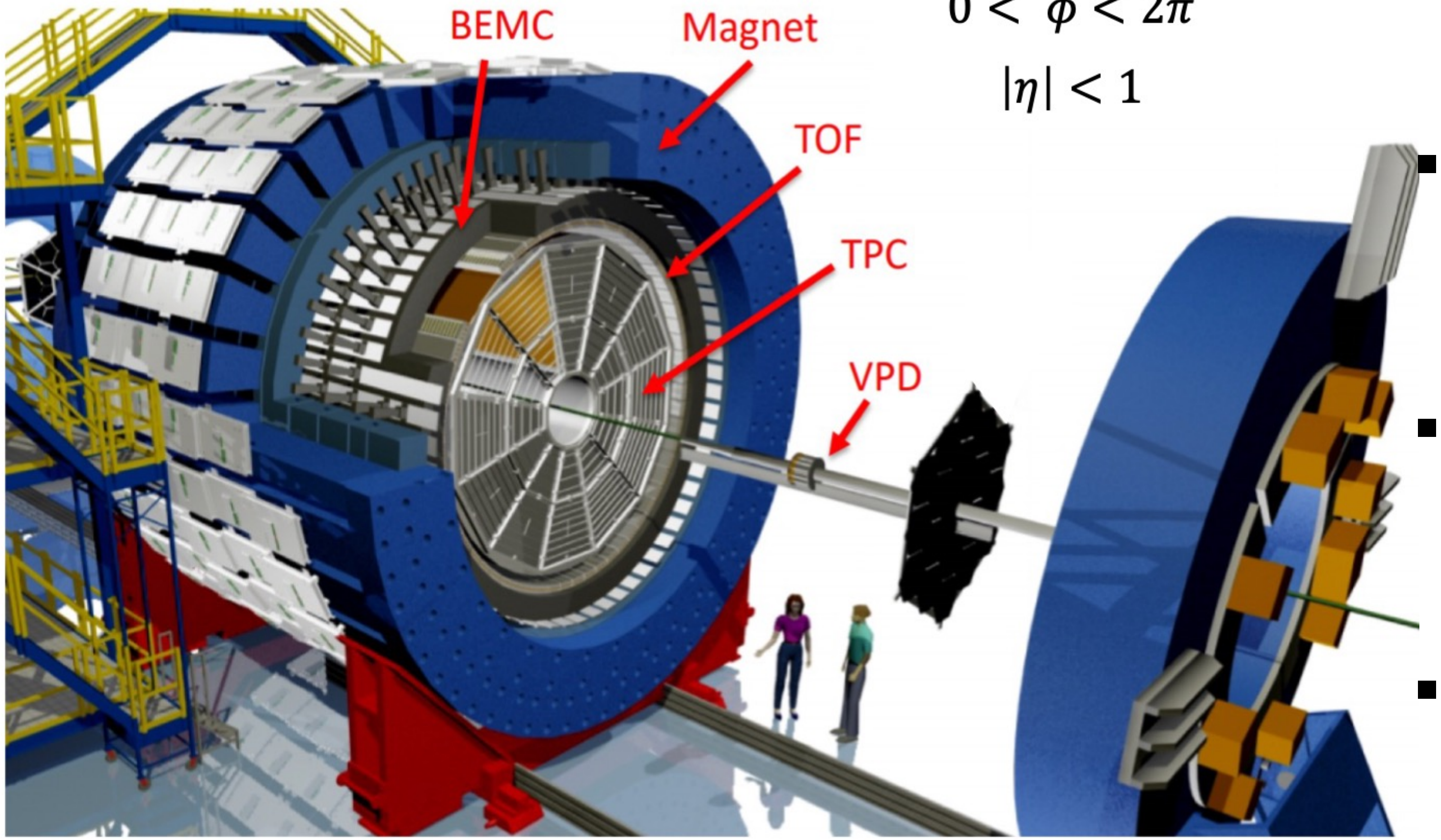
- $D^+ \to e^+$ semileptonic B.R. $(16.07 \pm 0.30)\%$
- $D^0 \to e^+X$ B.R. $(6.49 \pm 0.11)\%$
- $B^+ \to e^+$ semileptonic B.R. $(10.8 \pm 0.4)\%$
- $B^0 \to e^+X$ B.R. $(10.1 \pm 0.4)\%$

(a) Heavy quarkonia contributions
(b) Vector meson decays
(c) Drell-Yan contributions

3. The STAR experiment

- Detector systems
- Physics motivation
- Current goals and past results

Detector systems



$0 < \phi < 2\pi$

$|\eta| < 1$

Adapted from Yang, Yi. The STAR Detector Upgrades for the BES-II and Beyond Physics Program.

- Vertex Position Detector (VPD):

  Lead converters and plastic scintillators measure the position of the primary vertex and also to serve as a Minimum Bias trigger

- Time Projection Chamber (TPC):

  Gas chamber for momentum measurement, charged particle identification via energy loss

- Time of Flight (TOF):

  Timing information of VPD and number of hits in resistive plate chambers to calculate the time of flight of particles

- Barrel Electromagnetic Calorimeter (BEMC):

  Measurement of deposited energy of particles to distinguish electrons from hadrons

Physics motivation

Study of medium properties:

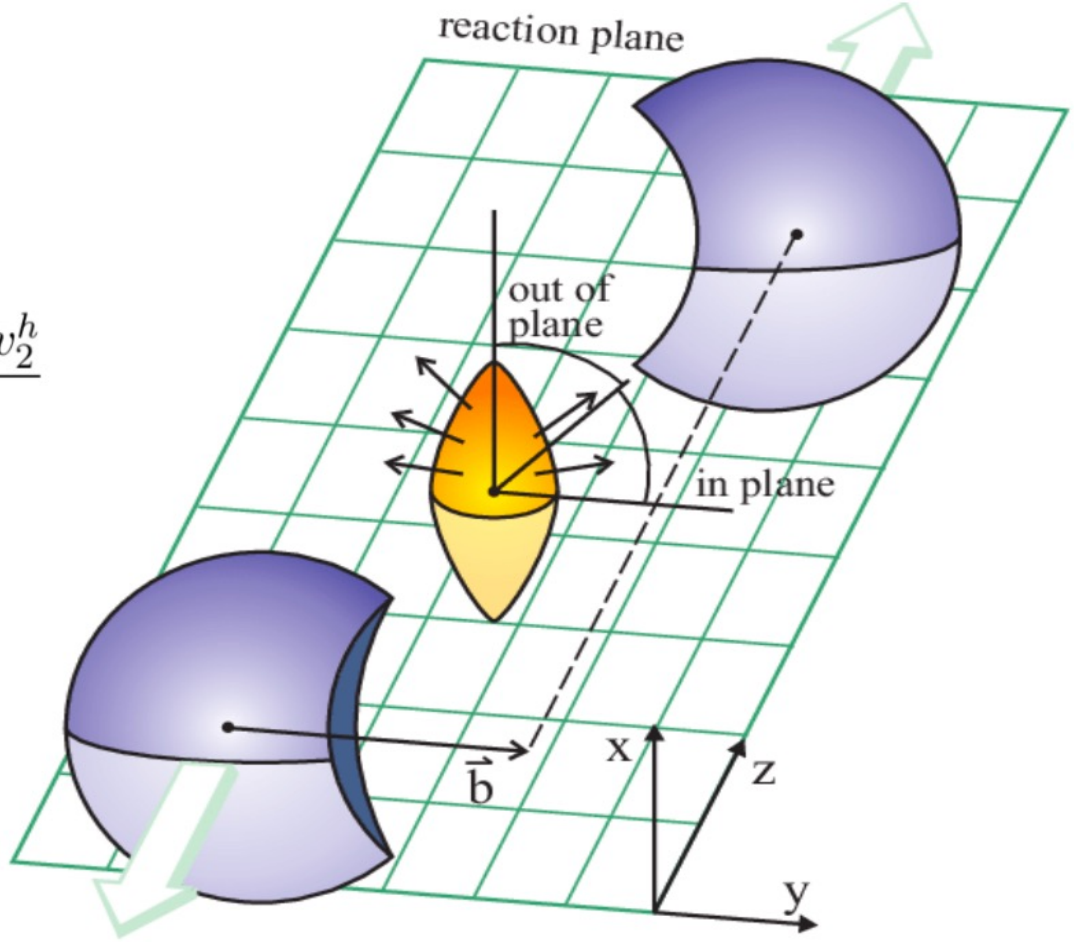
1. Elliptic flow (v_2)

$$v_2^{HF} = \frac{N^{inc} v_2^{inc} - N^{pho} v_2^{pho} - \sum ratio \cdot N^{inc} v_2^{h}}{p \cdot N^{inc} - N^{pho}}$$

2. Nuclear modification factors

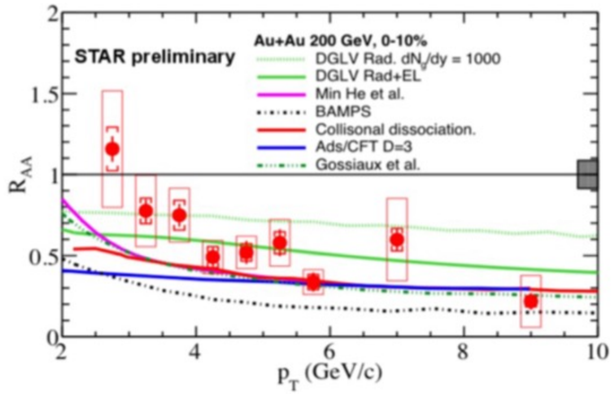
$$R_{AA} = \frac{1}{< N_{coll} >} \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}$$

$$R_{CP} = \frac{1}{< N_{coll} >} \frac{dN_{central}/dp_T}{dN_{peripheral}/dp_T}$$



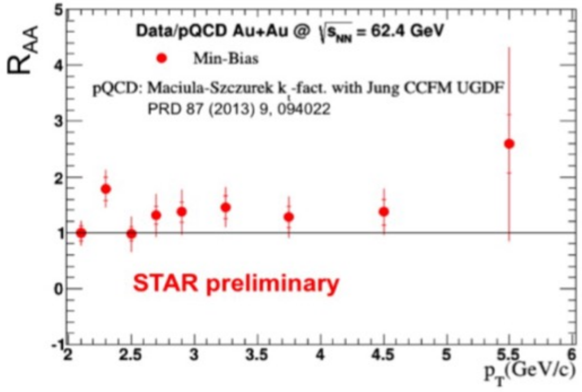
Current goals and past results

- identification of photonic electrons out of our inclusive electron sample
- purity estimation (inclusive electrons)
- addition of BEMC information to optimize electron identification (high p_T)



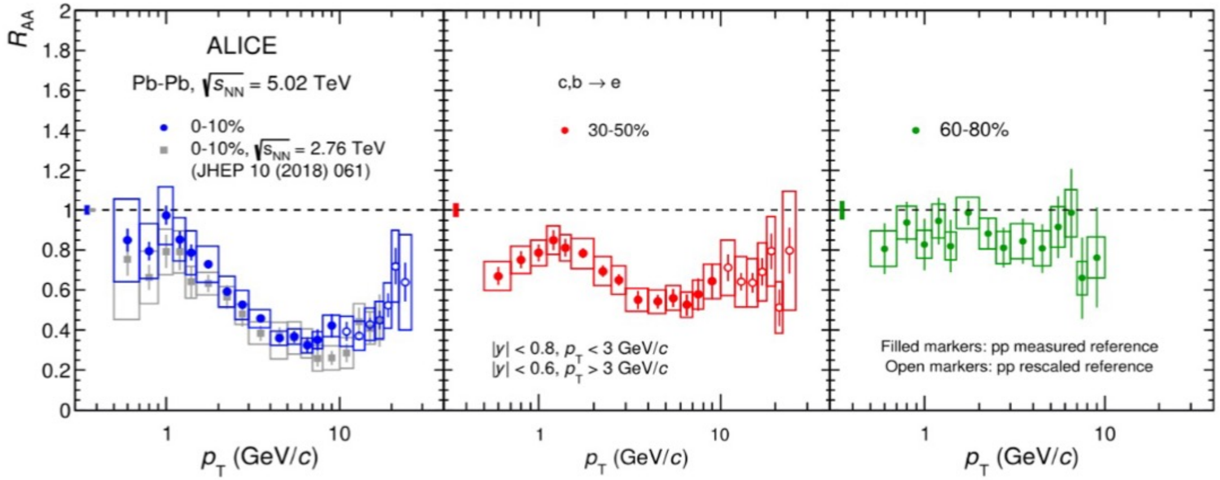
(a) R_{AA} vs p_T for STAR $Au + Au$ collisions at $\sqrt{s} = 200$ GeV showing strong yield suppression at high p_T

DOI: 10. 1016/j.nuclphysbps.2015.09.257.



(b) R_{AA} vs p_T for STAR $Au+Au$ collisions at $\sqrt{s} = 62.4$ GeV showing no meaningful yield suppression

DOI: 10. 1016/j.nuclphysbps.2015.09.257.



(c) R_{AA} vs p_T for ALICE $Pb+Pb$ collisions at $\sqrt{s} = 5.02$ TeV showing strong yield suppression at high p_T [

DOI: 10.1016/j.physletb.2020. 135377.

4. Data analysis

- Event and track selection
- Data sample
- Distribution of primary vertex
- Electron identification
- Histograms before and after electron identification

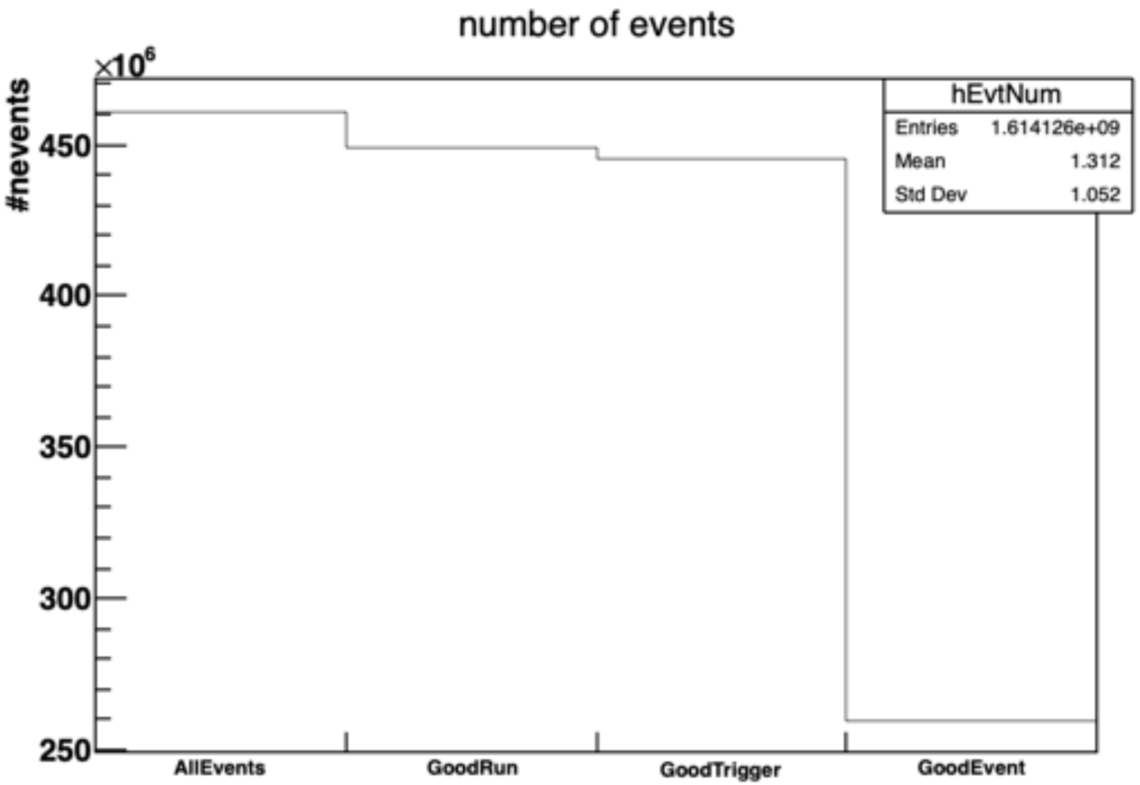
Event and track selection

- Minimum bias trigger data ⟶ coincidence signals in VPD
- Collision type: Au+Au
- Center-of-mass energy: $\sqrt{S_{NN}}$ = 54 GeV
- Production: P18ic ; picoDst production: SL20c
- Centrality bin = 0 – 60 %
- Trgsetupname: AuAu54production2017
- TriggerID: 580001, 580021

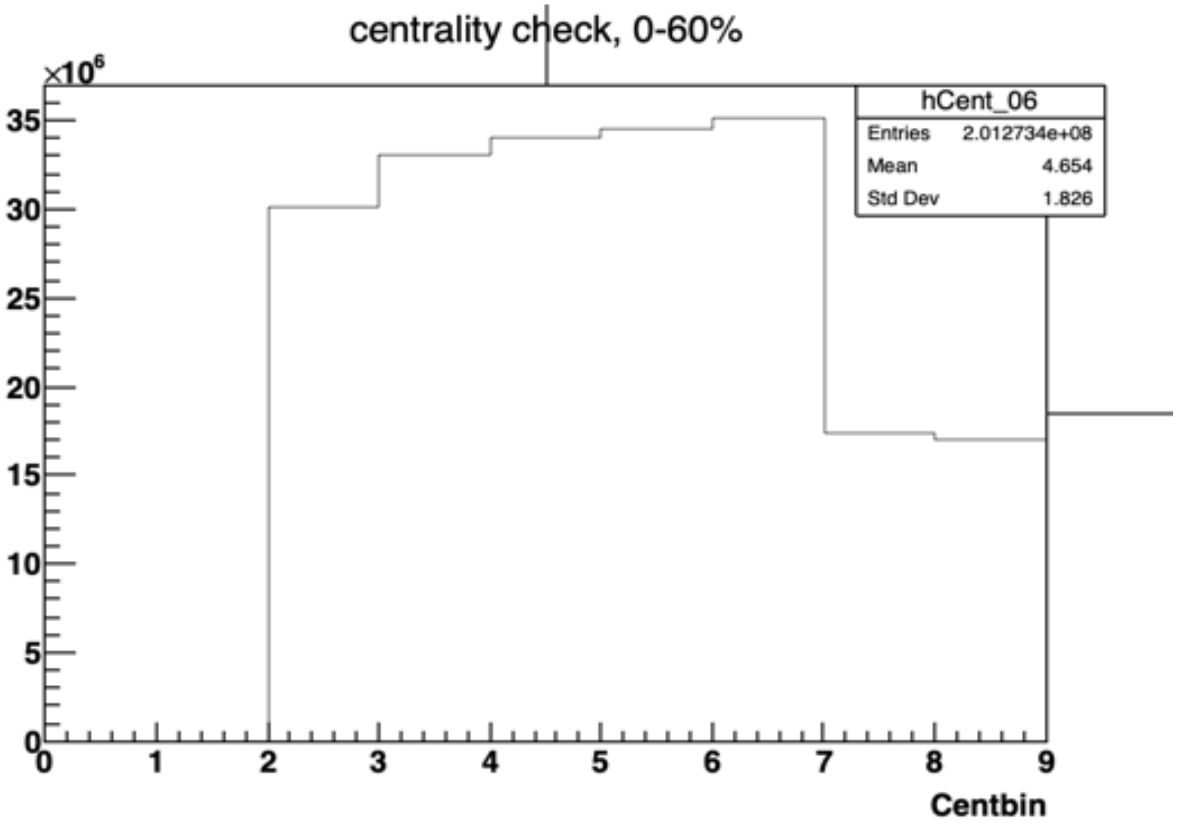
Event cuts	
$\|V_r\|$	< 2 cm
$\|V_z\|$	< 35 cm
$\|V_{z,vpd} - V_z\|$	< 3 cm
$\|V_x, V_y, V_z\|$	$> 10^{-5}$ cm

Track cuts	
p_T	> 0.2 GeV/c
nHitsFit	> 20
nHitsDedx	> 15
nHitsFit2Poss	> 0.52
$\|\eta\|$	< 0.8
|gDCA|	< 1.5 cm

Data sample

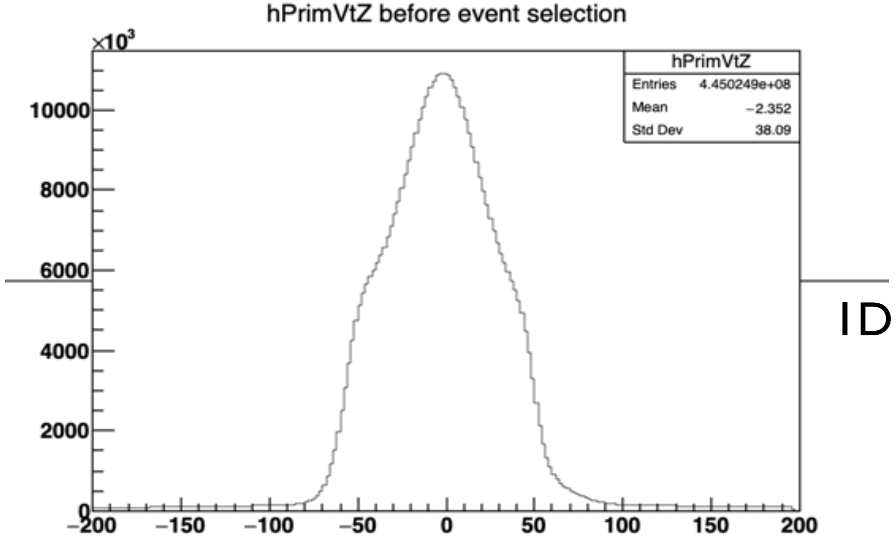


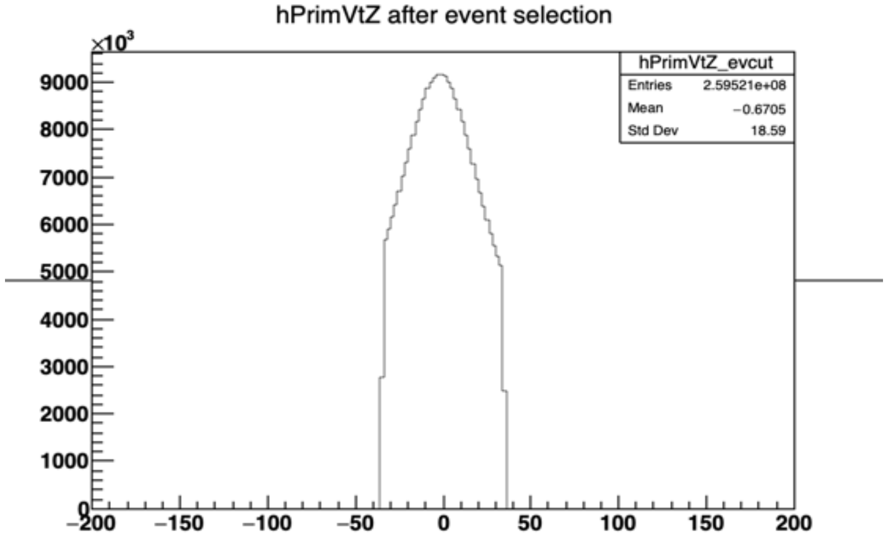
number of events
hEvtNum
Entries 1.614126e+09
Mean 1.312
Std Dev 1.052
#nevents
×10^6
450
400
350
300
250
AllEvents
GoodRun
GoodTrigger
GoodEvent



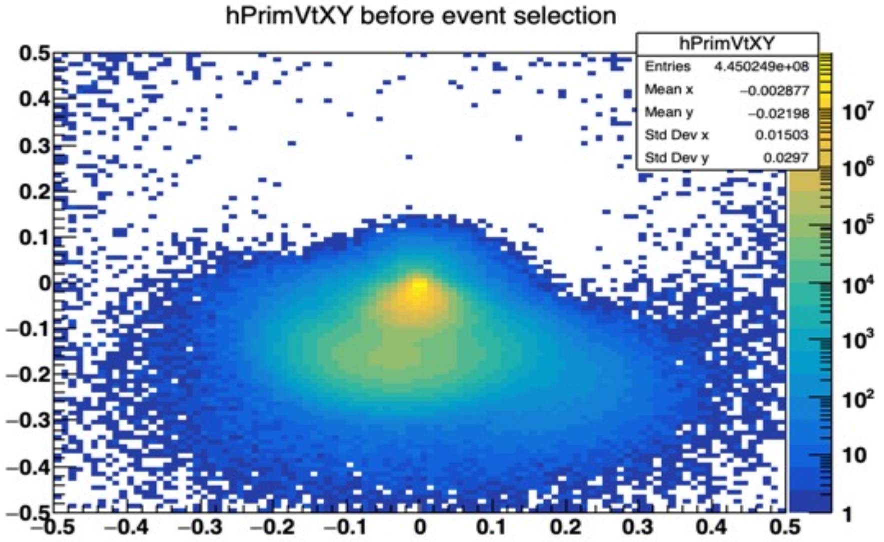
centrality check, 0-60%
hCent_06
Entries 2.012734e+08
Mean 4.654
Std Dev 1.826
×10^6
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9
Centbin

Distribution of primary vertex

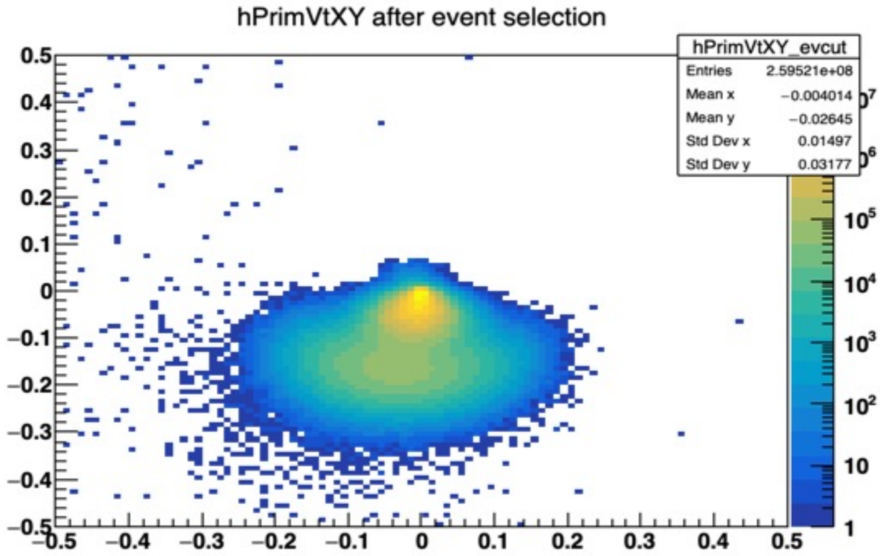




1D histogram in Z-direction



2D histogram in XY-plane



Electron identification

1. TPC –
   - cuts on particle energy loss
   - to identify the electrons and reduce hadron contamination (mainly pions)

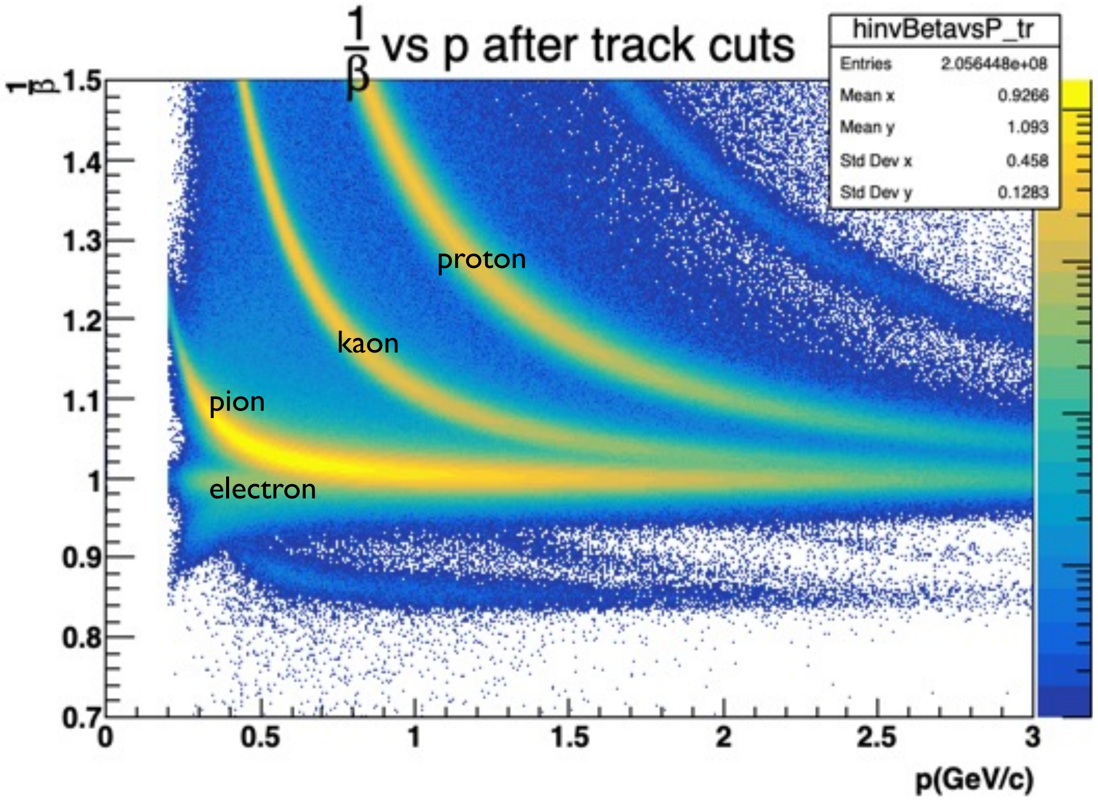
$$n\sigma_x = \frac{1}{\sigma_{dE/dx}} \ln \frac{\langle dE/dx \rangle_{measured,x}}{\langle dE/dx \rangle_x}$$

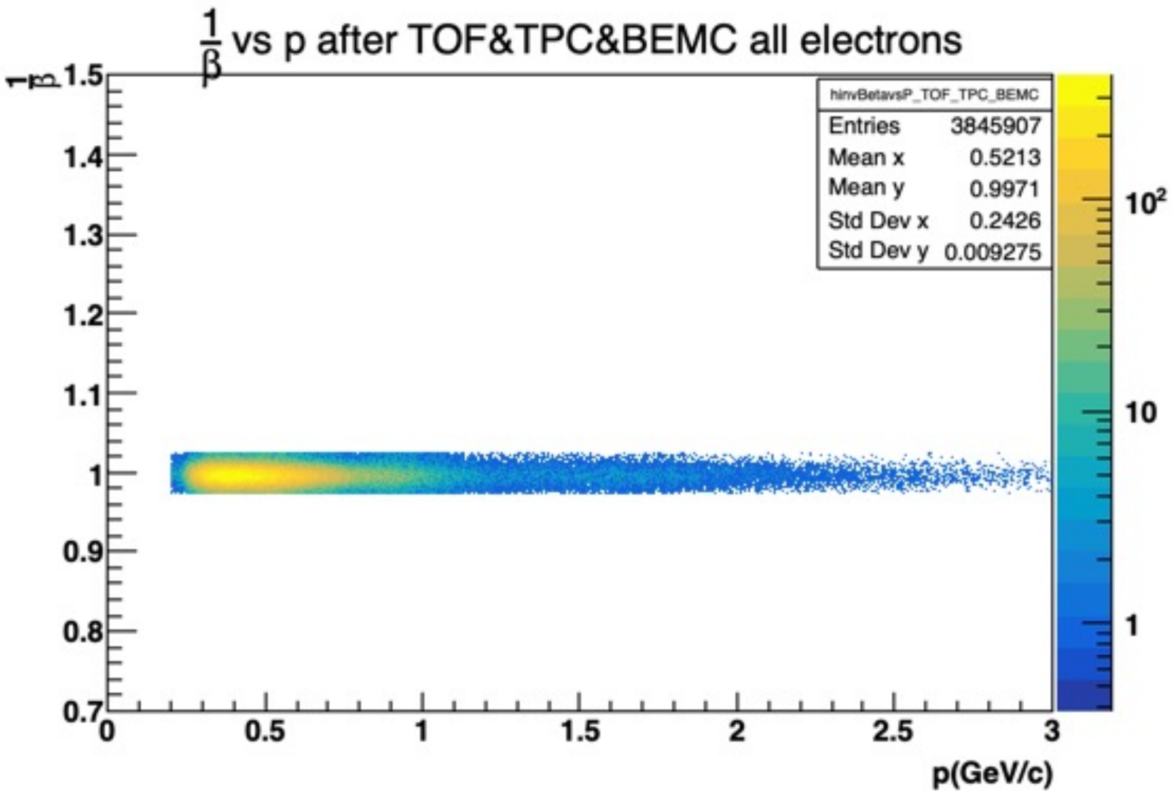
2. TOF –
   - cuts on particle velocity ($\beta = v/c \simeq 1$)
   - distinguish electrons from hadrons until the point which all the particles have a velocity close to c

3. BEMC –
   - cuts on energy-to-momentum ratio, E/p
   - provides a larger amount of statistics at the beginning to improve the purity

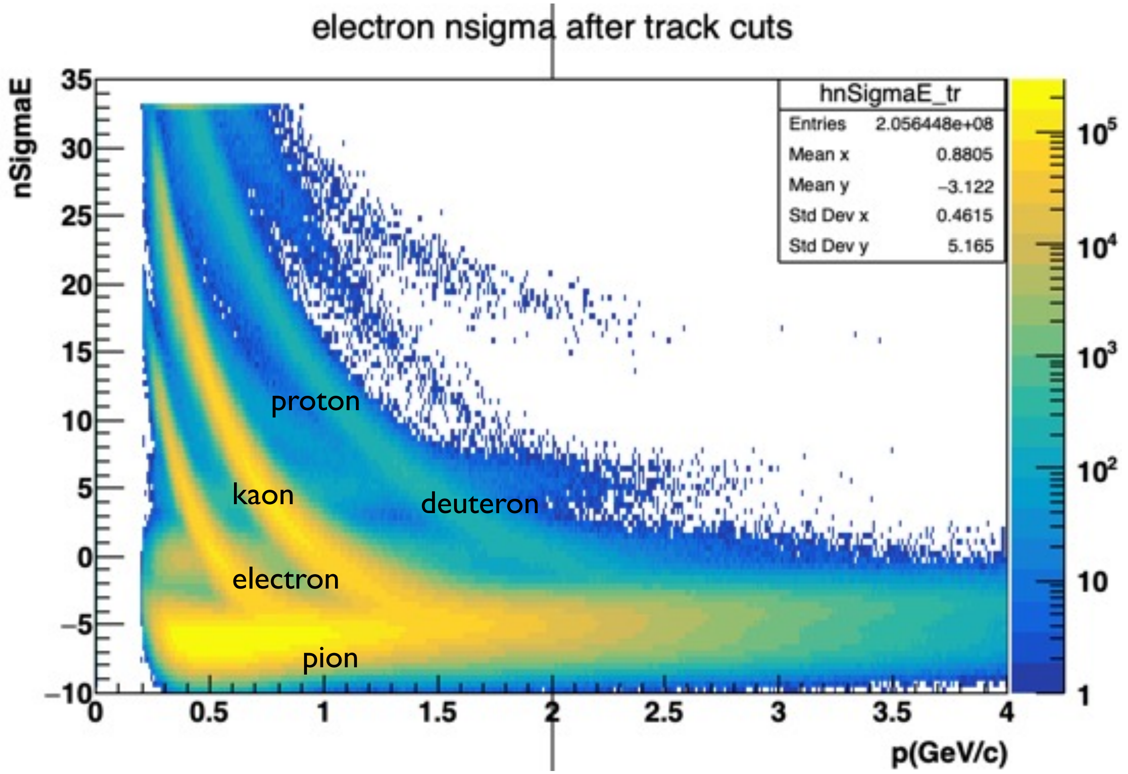
```
if (pT < 1.25 || only TPC){

      p < 0.8, 3.5 * p - 2.8 < nSigma(e) < 2;
      p > 0.8, 0 < nSigma(e) < 2;

      ifTOF: |1 - 1/beta | < 0.025;

} else {

      if ( ifTOF, no BEMC){

            p < 0.8, 3.5 * p - 2.8 < nSigma(e) < 2;
            p > 0.8, 0 < nSigma(e) < 2;

            ifTOF: |1 - 1/beta | < 0.025;

      } else if ( ifBEMC, no TOF){

            0.6 < E0/p < 1.5;
            0.5 < nSigma(e) < 2;

      } else if (ifTOF & ifBEMC){

            |1 - 1/beta | < 0.025;
            0.6 < E0/p < 1.5;

            -0.5 < nSigma(e) < 2;
      };
}
```

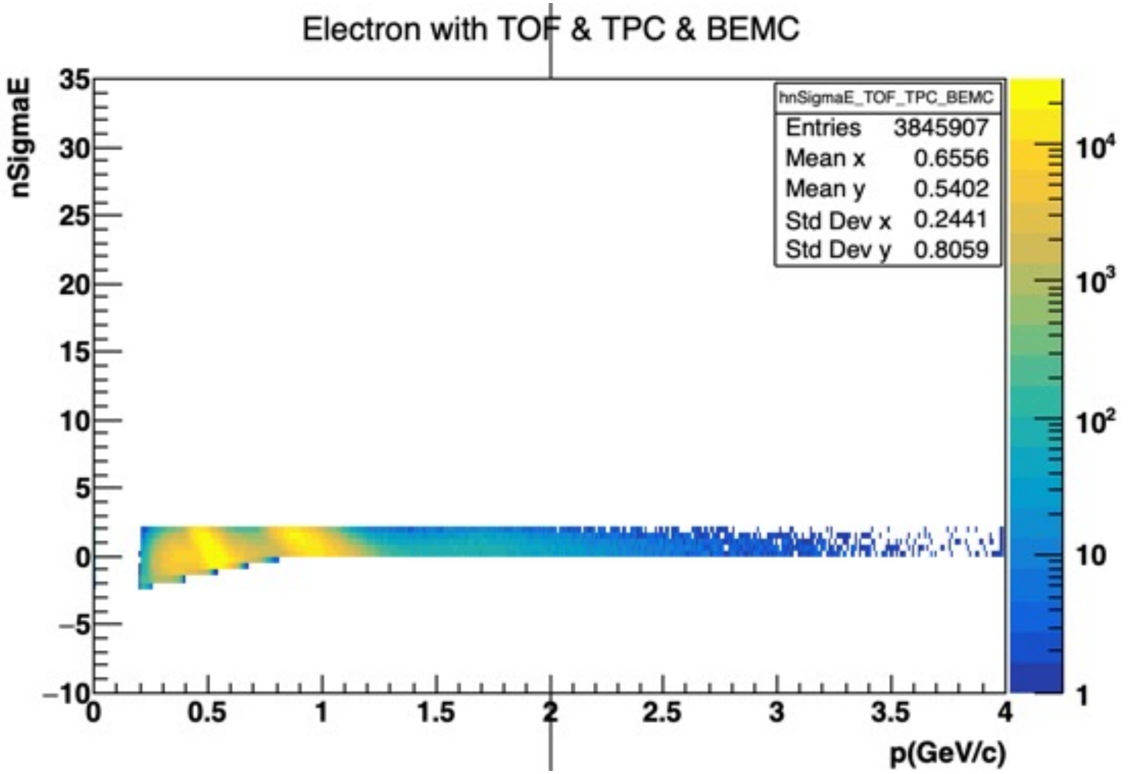
1/β vs p before and after electron identification



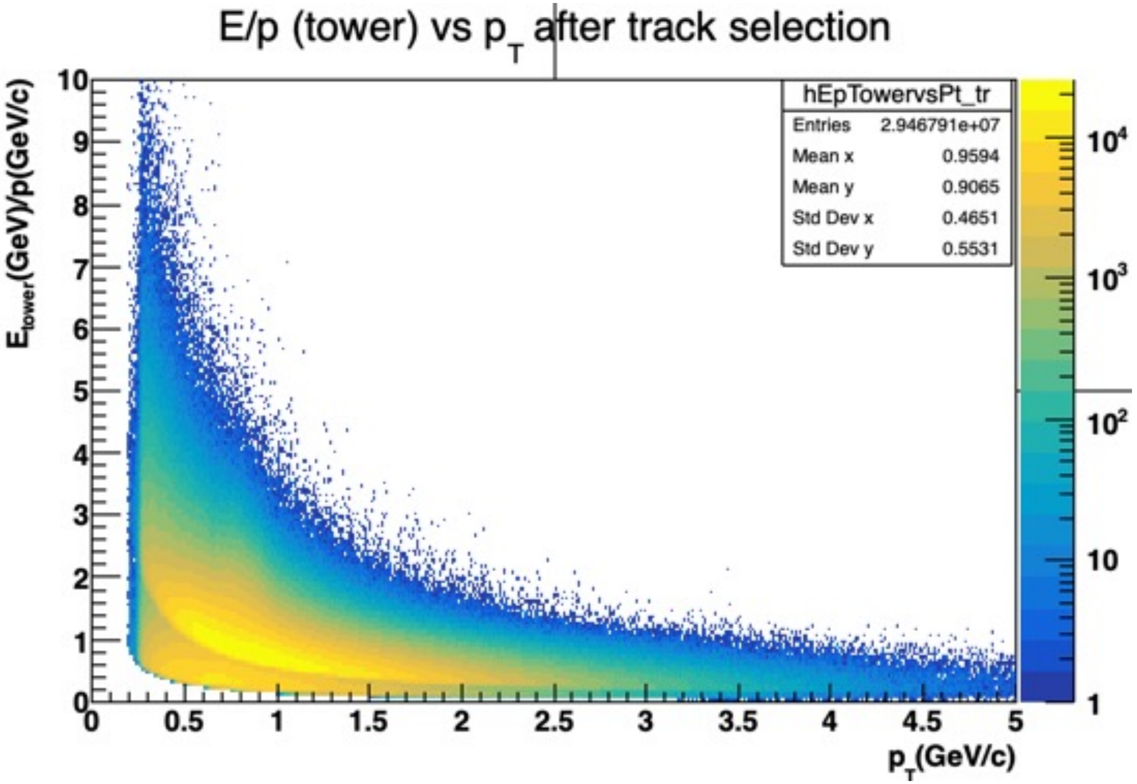


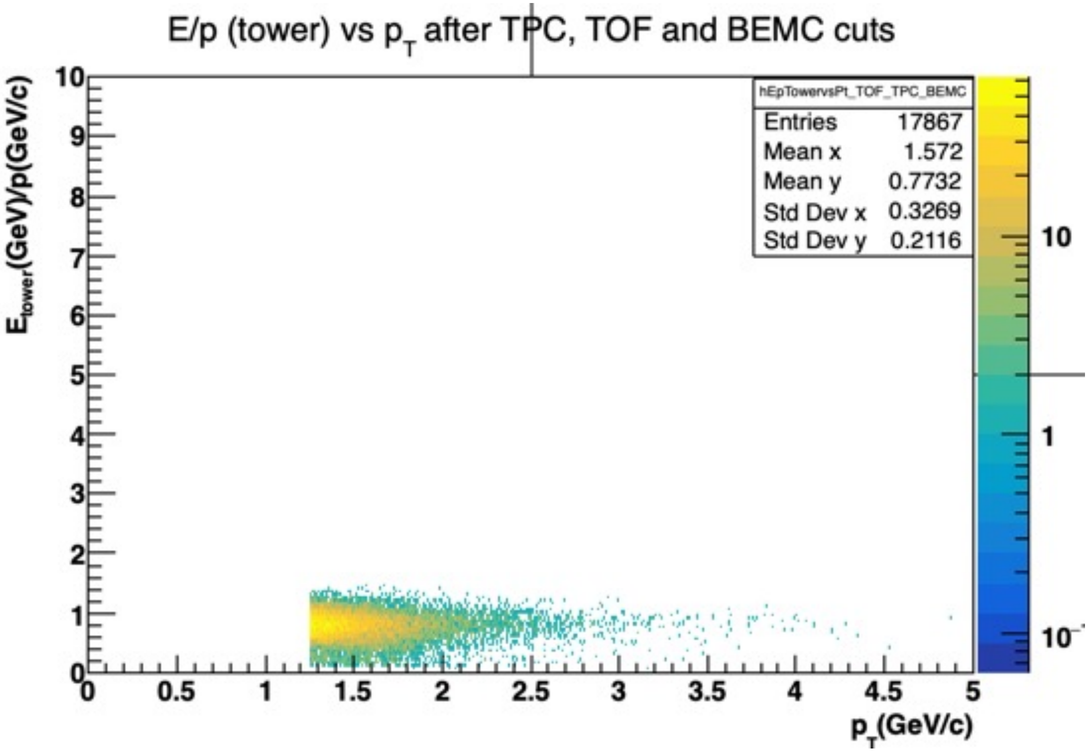
$n\sigma_e$ vs p before and after electron identification





E/p vs p before and after electron identification





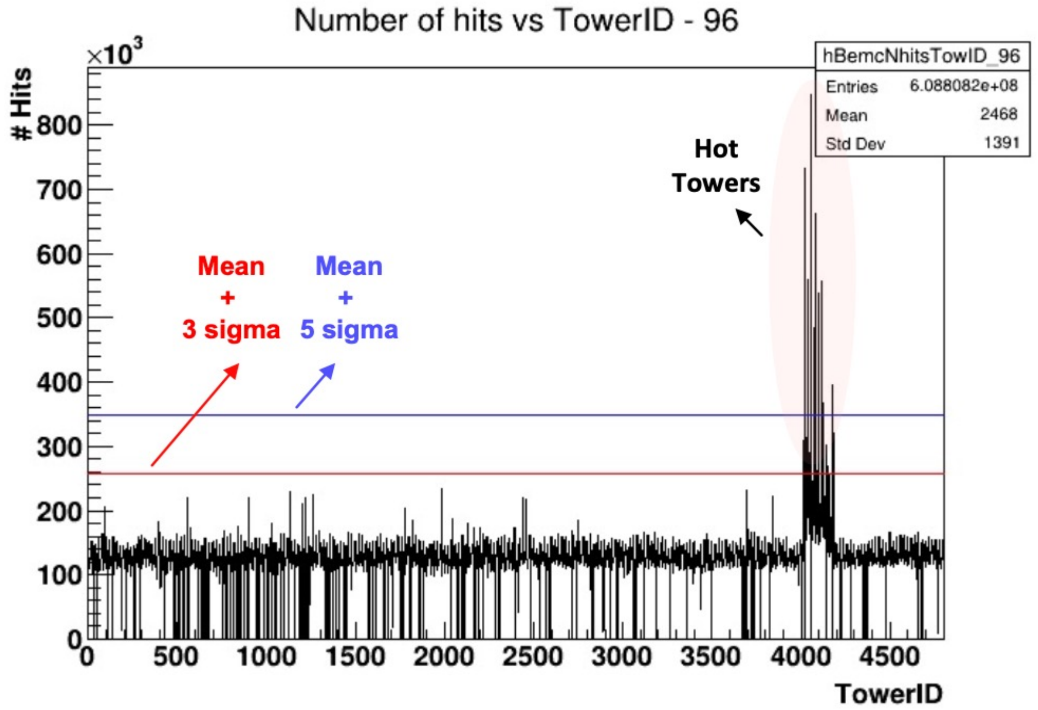
5. Previous works

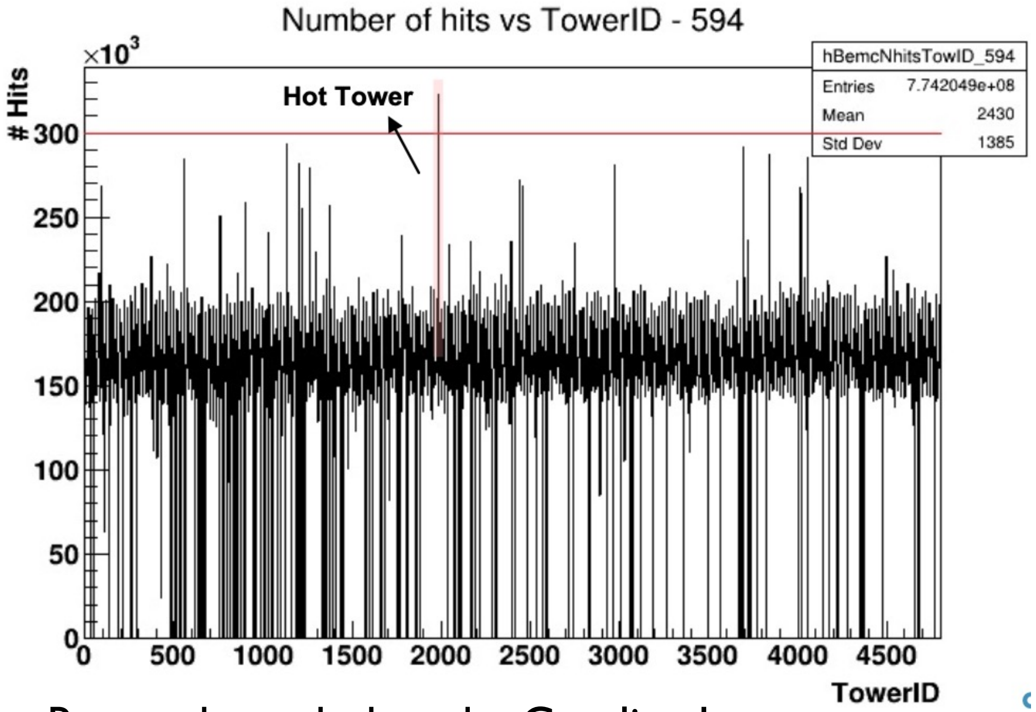
(Carolina Sergi Lopes)

- BEMC hot towers
- Photonic electron tagging

BEMC hot towers

- Check if BEMC information is reliable and if some towers fire more often than the average
- For each of the 614 runs, a tower is marked as hot if the number of hits is 3σ above the average
- Hit will be rejected if it corresponds to a hot tower during a certain run





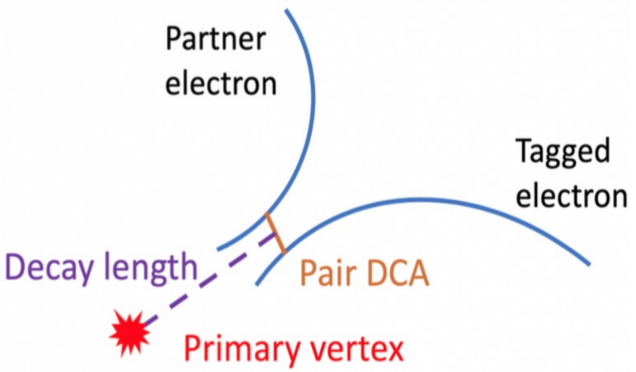
Research work done by Carolina Lopes

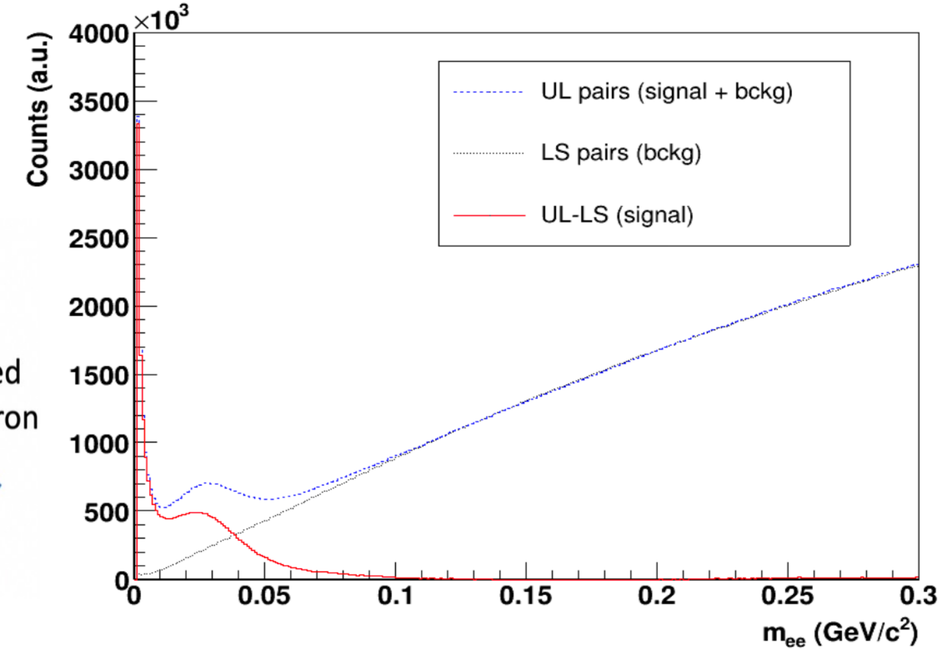
Photonic electron tagging

Partner electron cut	
gp_T	> 0.25 GeV/c
nHitsFit	> 15
$\|\eta\|$	< 1.0
$n\sigma_{el}$	< 3.0

- Statistical method to obtain number of PE
- Inclusive target electron candidate is associated to partner electron candidate
- Invariant mass spectra of e+e- pairs: peak at low invariant mass indicates the photonic electrons from conversions (dominant)
- To extract the background, the UL – LS pairs technique is employed

Di-electron Pair cut	
Pair DCA	< 1 cm
Inv mass (e^+e^-)	< 0.1 GeV/c^2





6. Current results

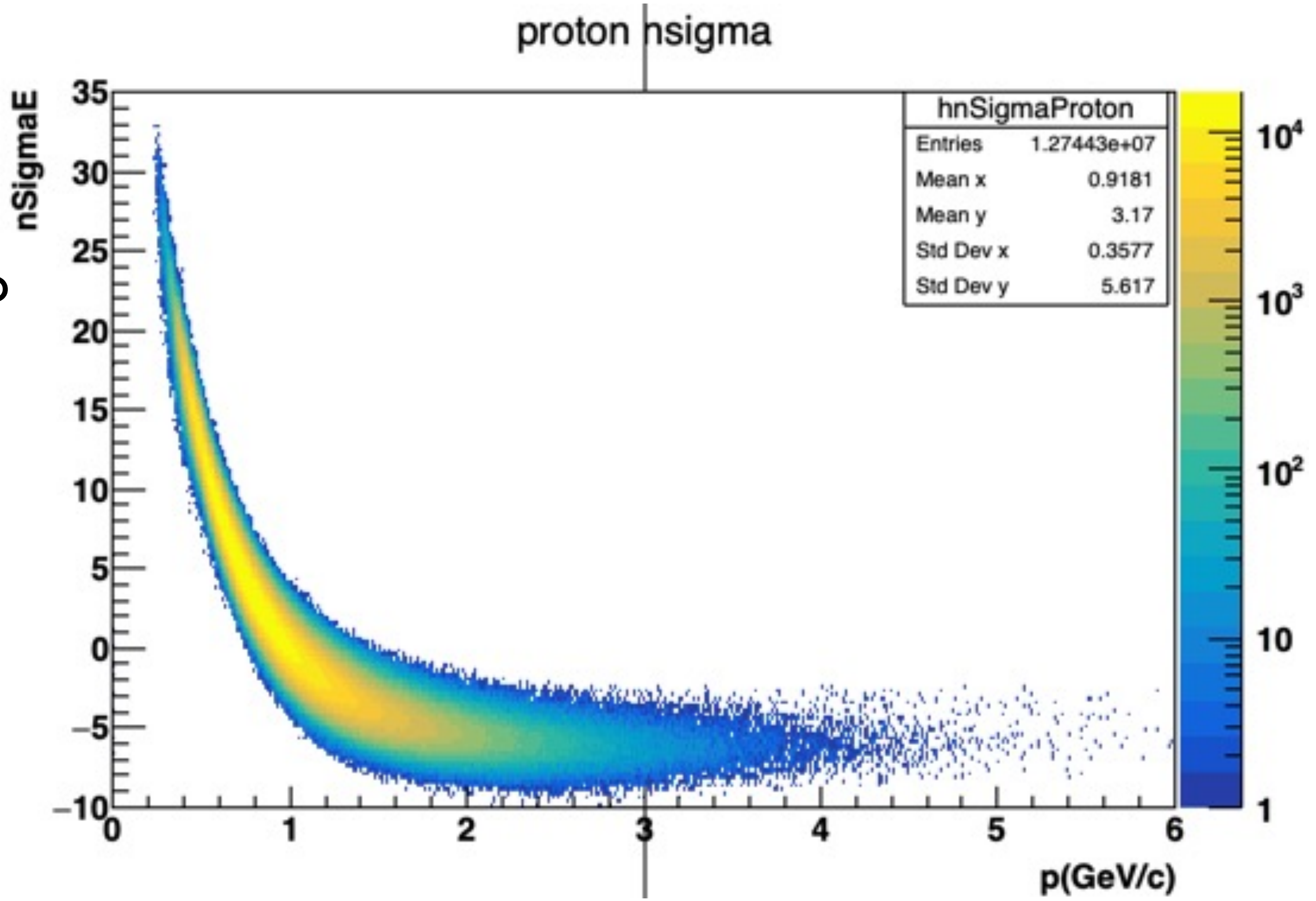
- Fitting of pure samples
- Multigaussian fit
- Purity estimation

Fitting of pure samples: protons

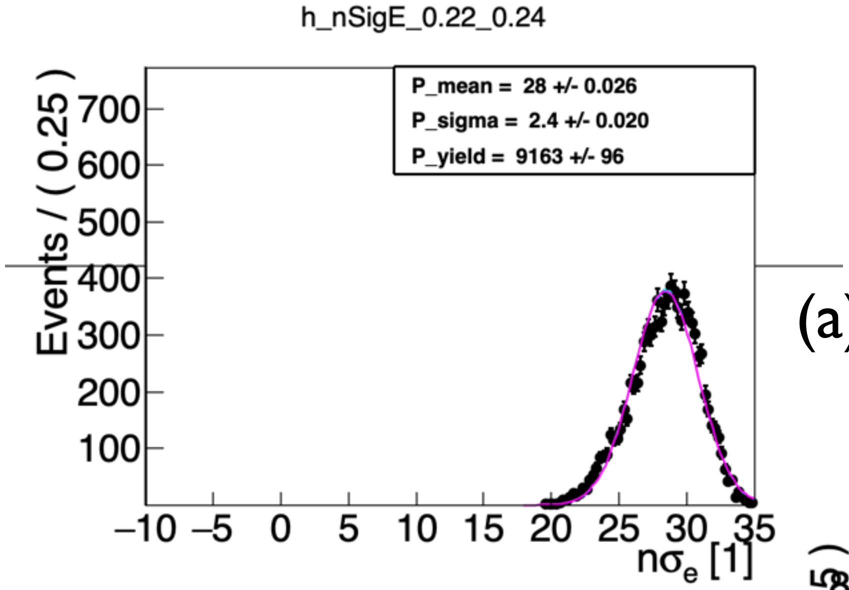
- Use of TOF information to select proton candidates:

$|n\sigma_p| < 4$

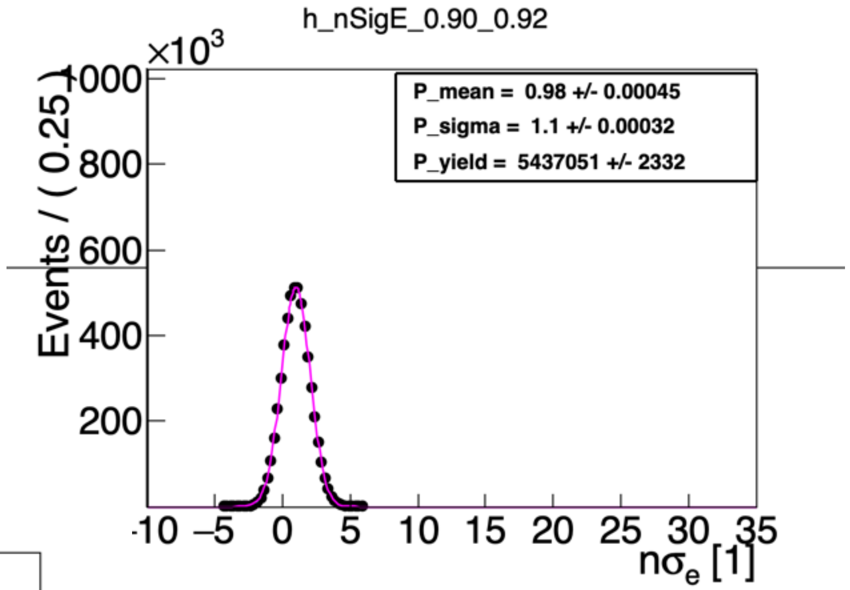
$|M^2 - 0.879| < 0.02$



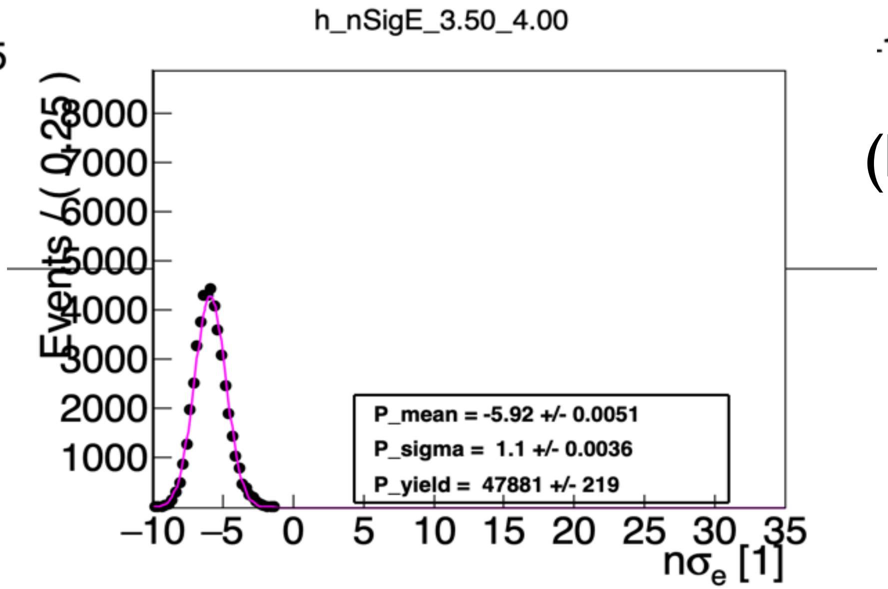
Fitting of pure samples: protons



(a) 0.22 < pT < 0.24 GeV/c



(b) 0.90 < pT < 0.92 GeV/c



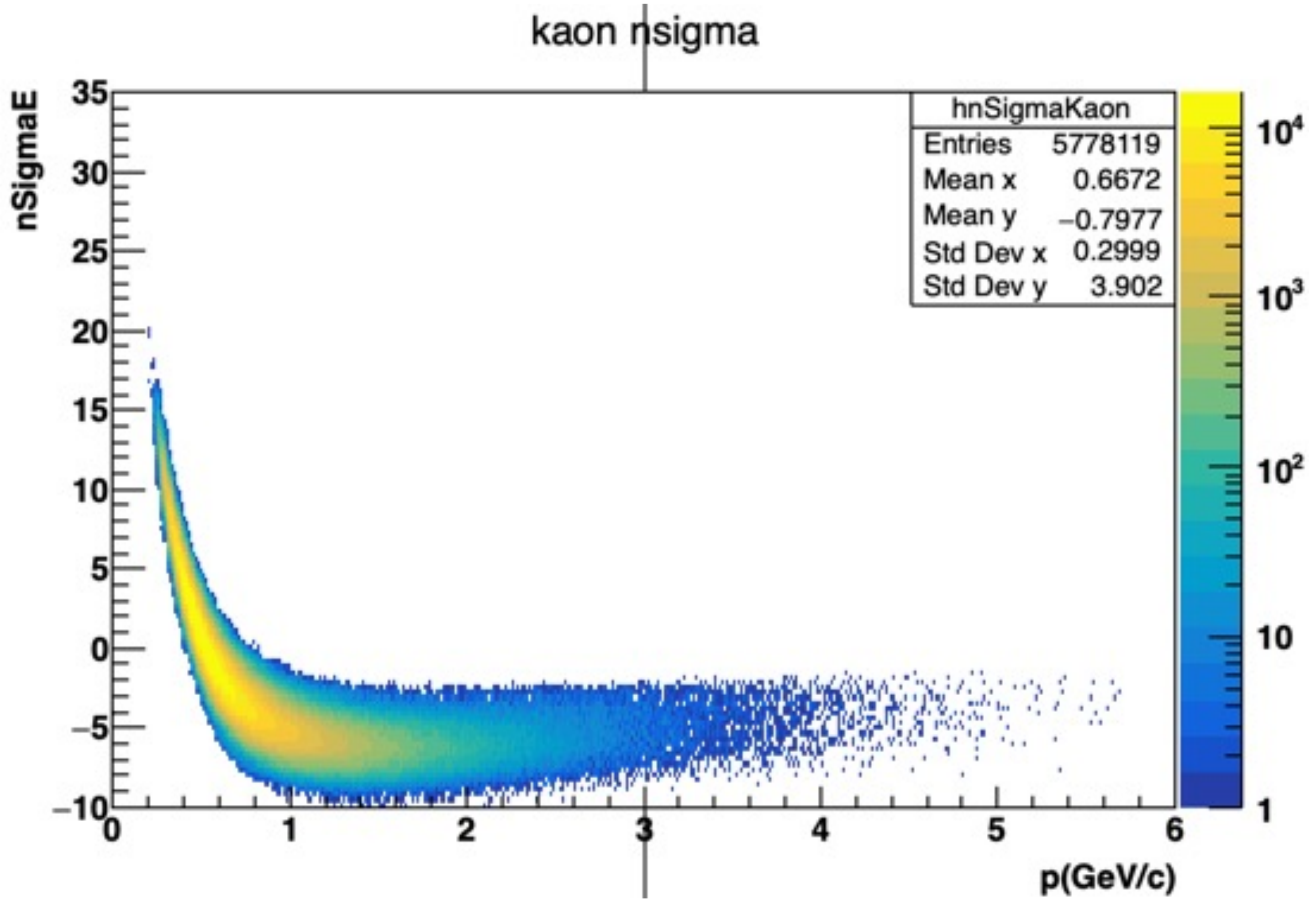
(c) 3.50 < pT < 4.00 GeV/c

Fitting of pure samples: Kaons

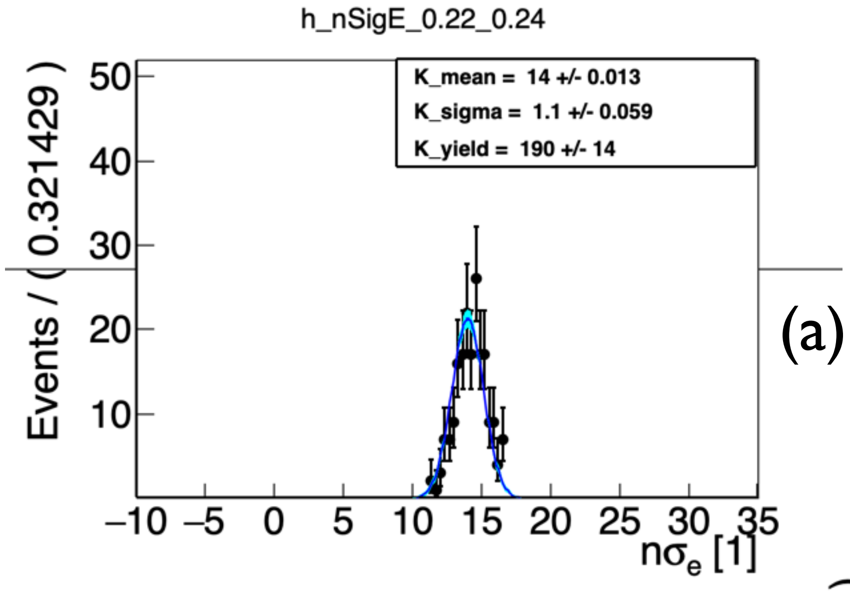
- Use of TOF information to select kaon candidates:

  $|n\sigma_K| < 4$

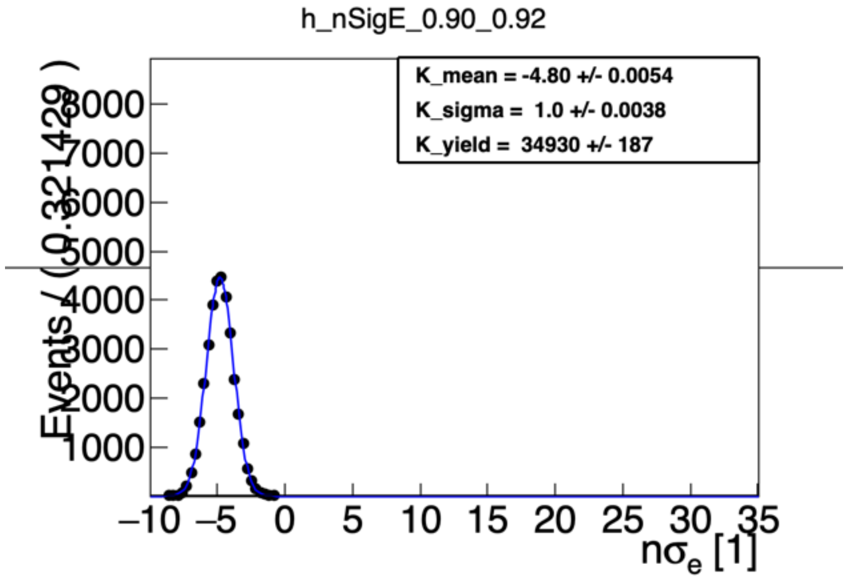
  $|M^2 - 0.243| < 0.005$



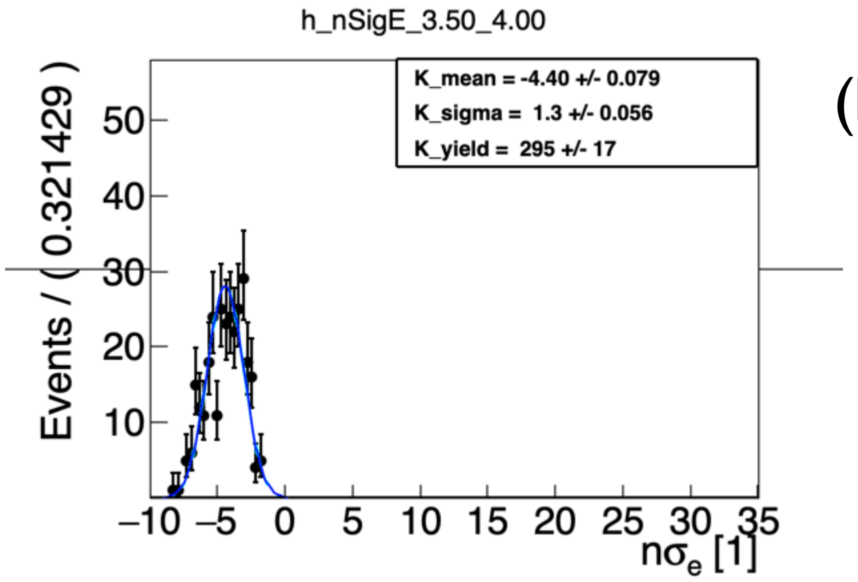
Fitting of pure samples: Kaons



(a) 0.22 < pT < 0.24 GeV/c



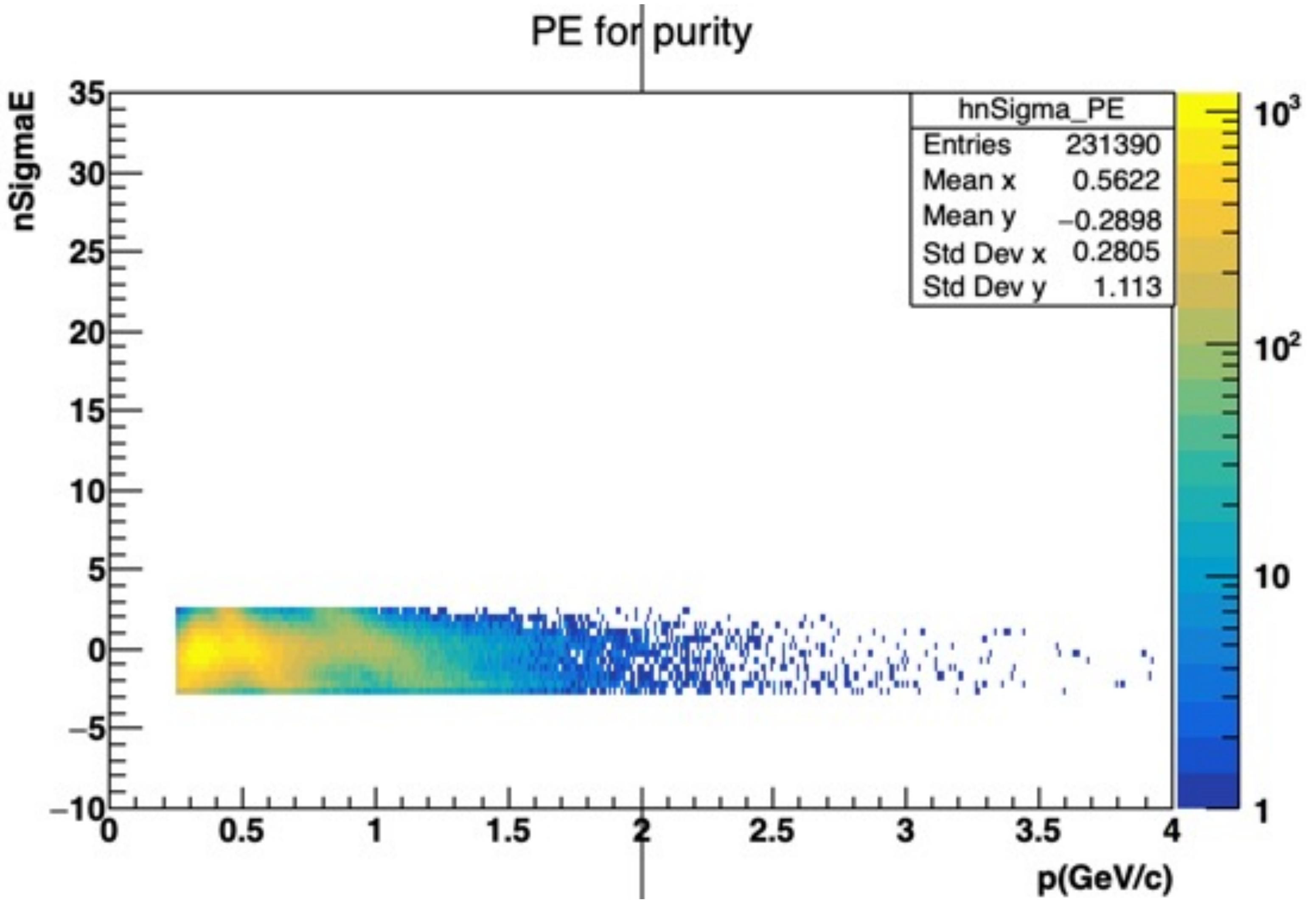
(b) 0.90 < pT < 0.92 GeV/c



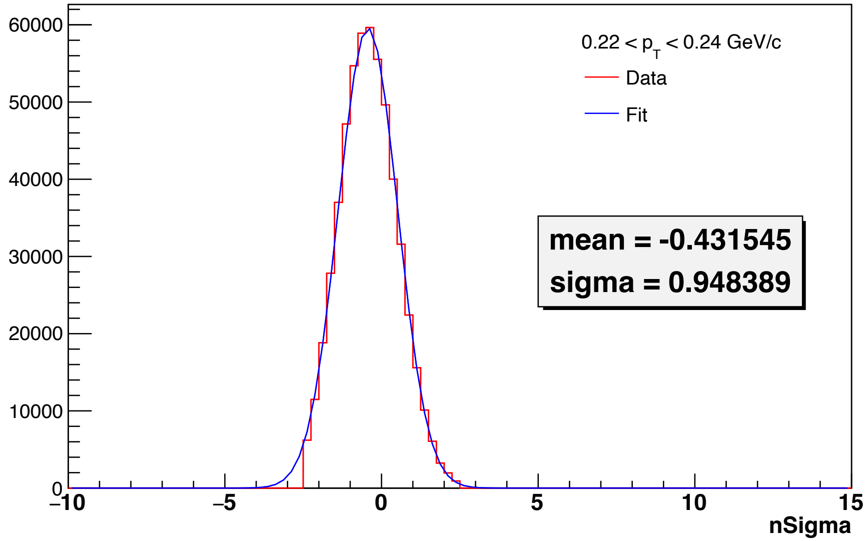
(c) 3.50 < pT < 4.00 GeV/c

Fitting of pure samples: photonic electrons

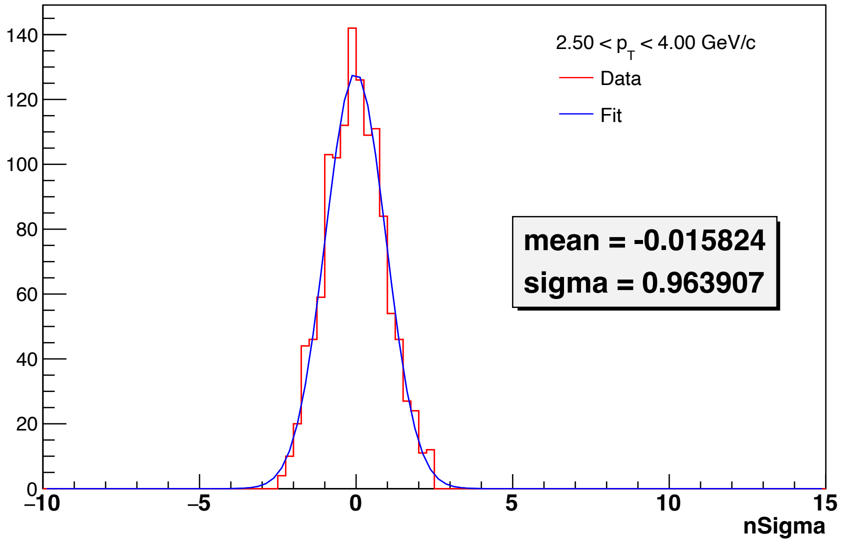
- Choose photonic electron at $M_{ee} < 0.04$GeV
- Tagged electron require |nsigmaE| < 2.5
- Use partner electron as the electron candidates



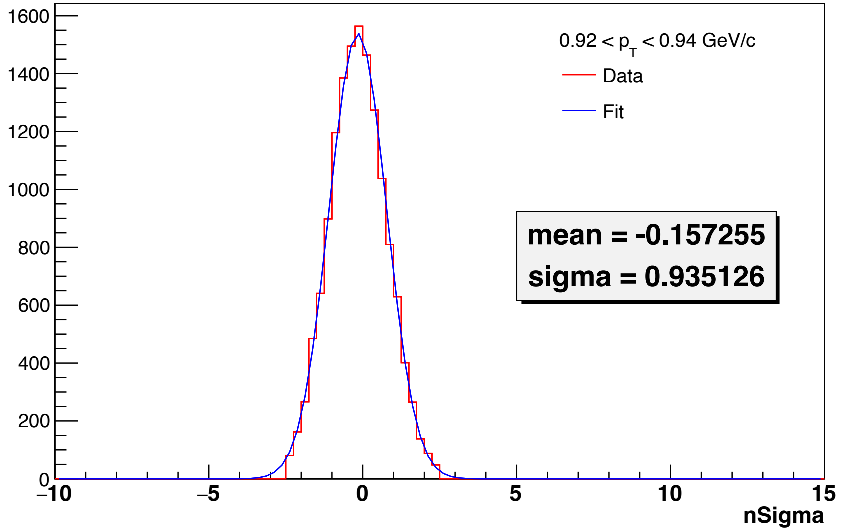
Fitting of pure samples: photonic electrons



(a)



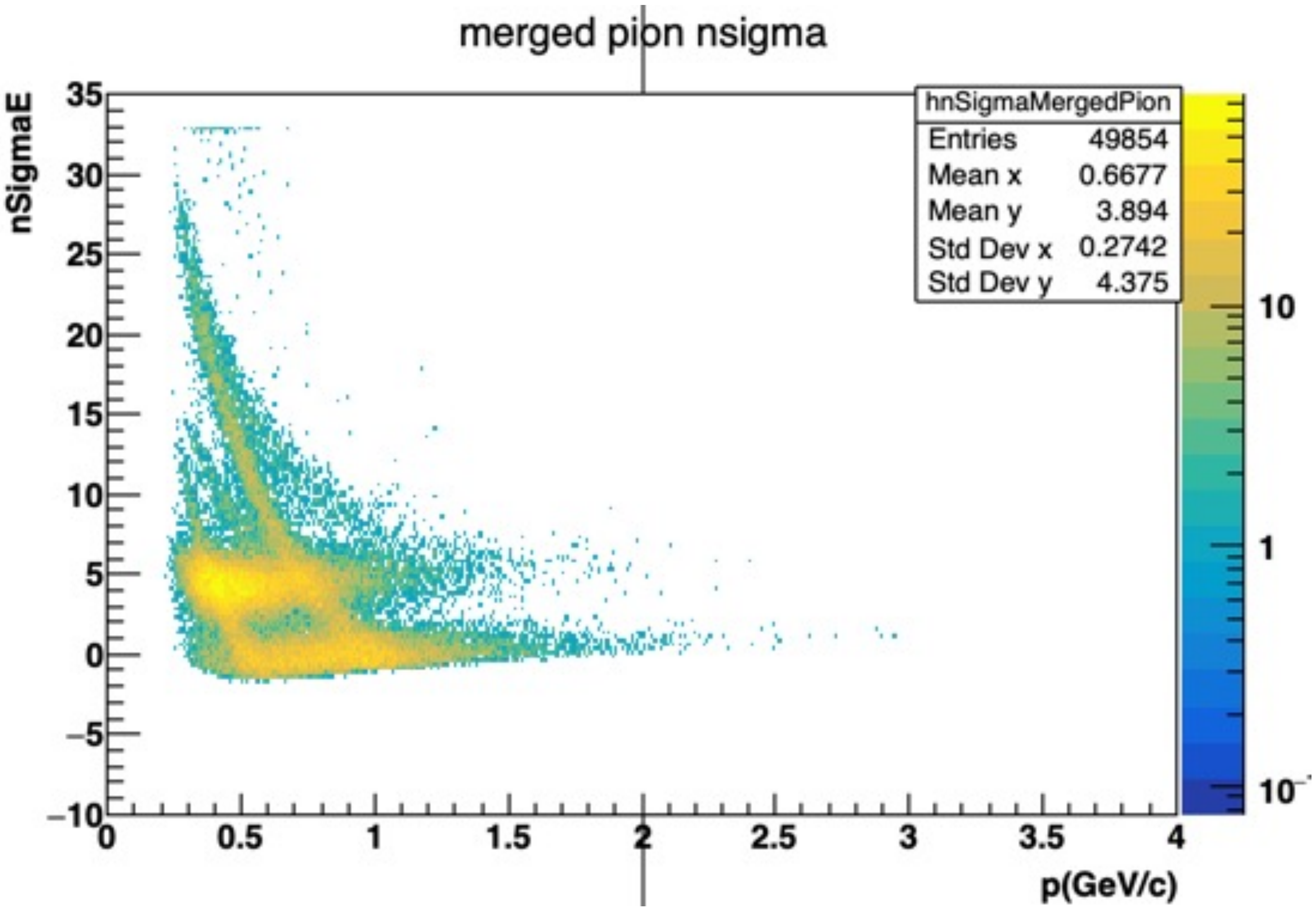
(c)



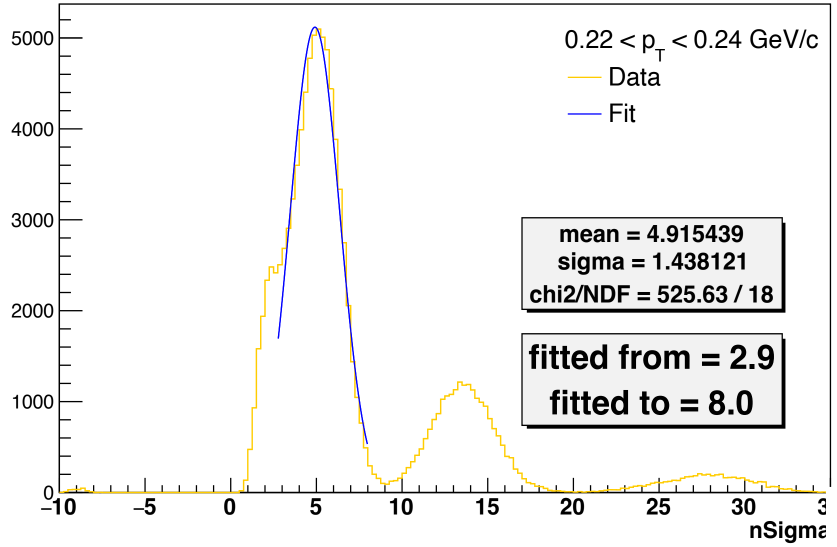
(b)

Fitting of pure samples: merged pions

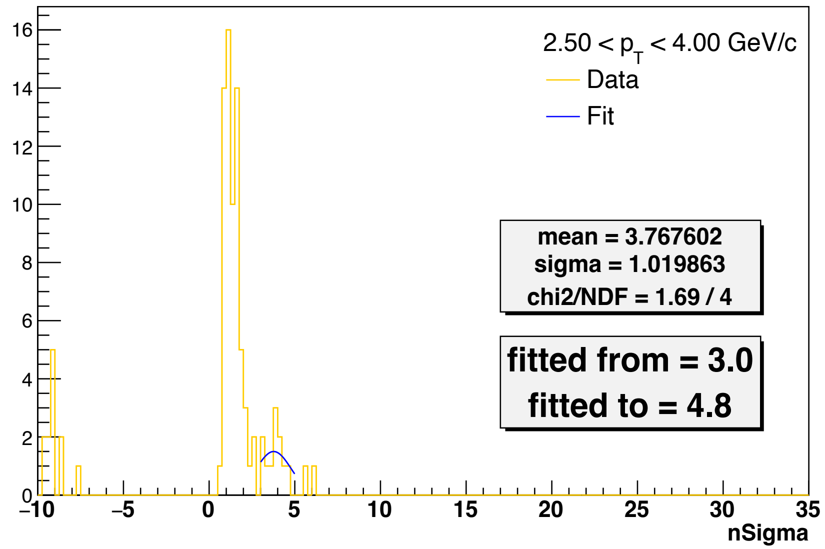
- $|n\sigma_{Pi}| > 5$
- $|M^2 - 0.019| < 0.003$



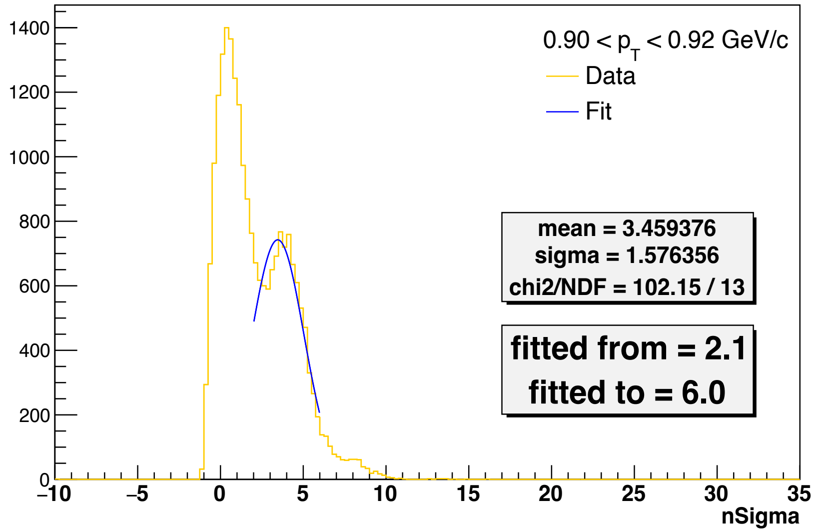
Fitting of pure samples: merged pions



(a)



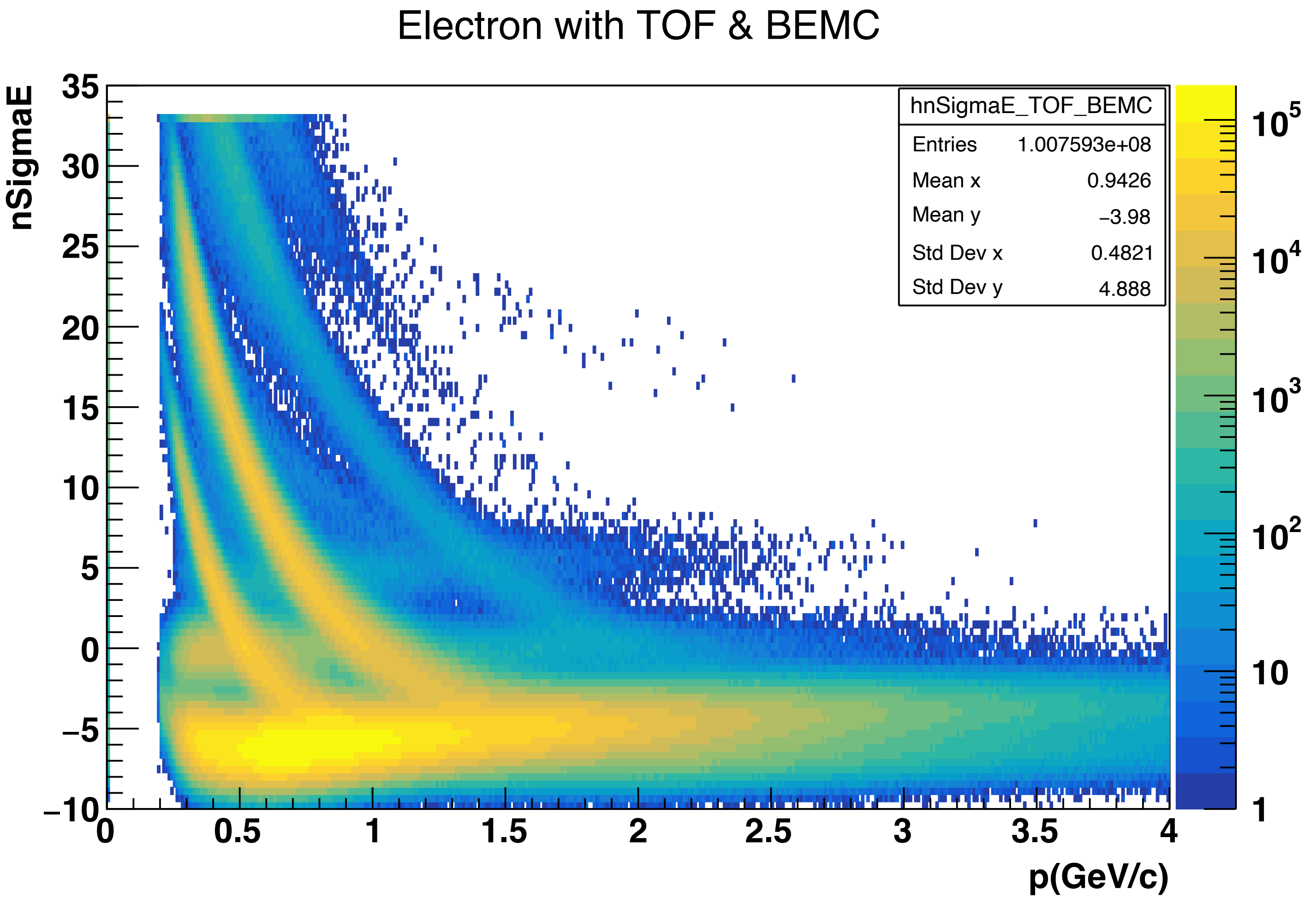
(c)



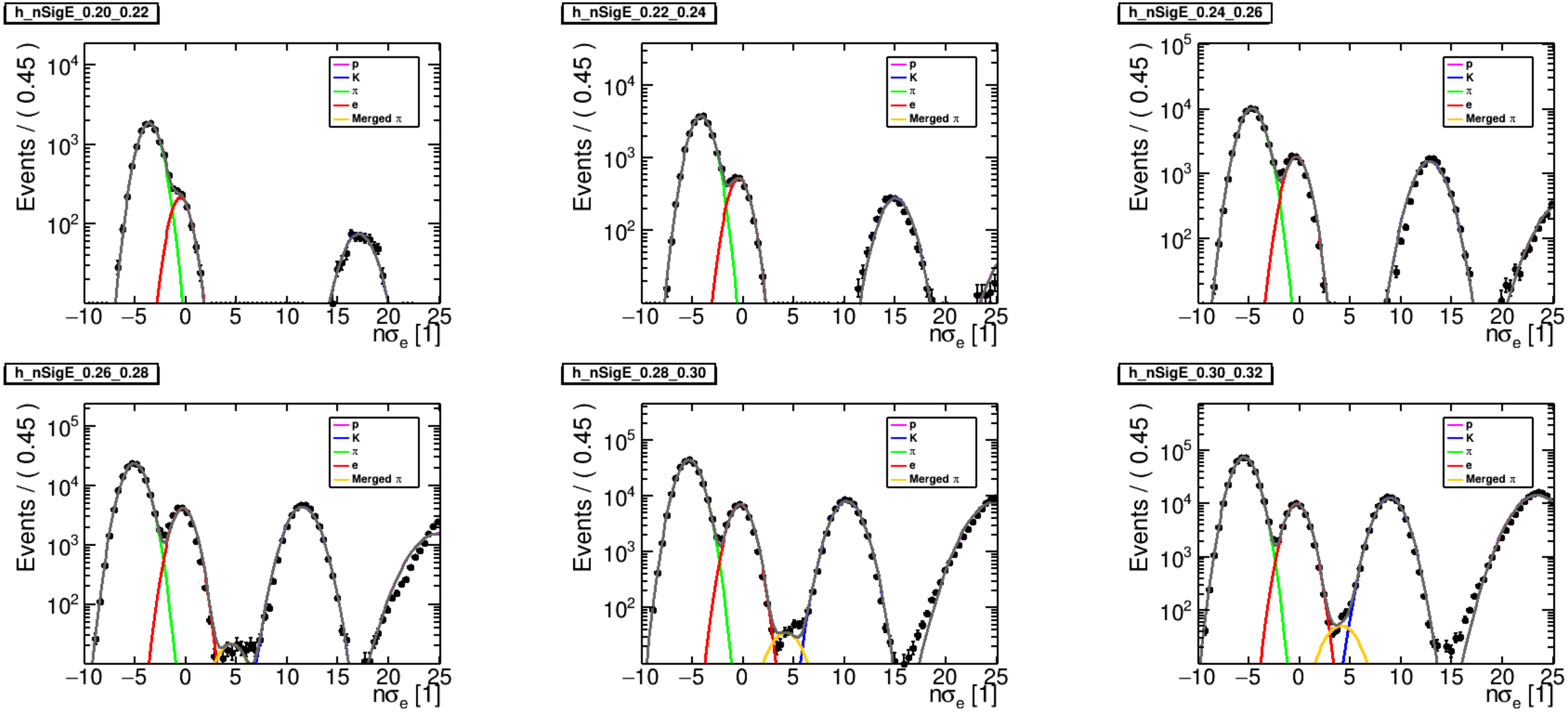
(b)

Multigaussian fit

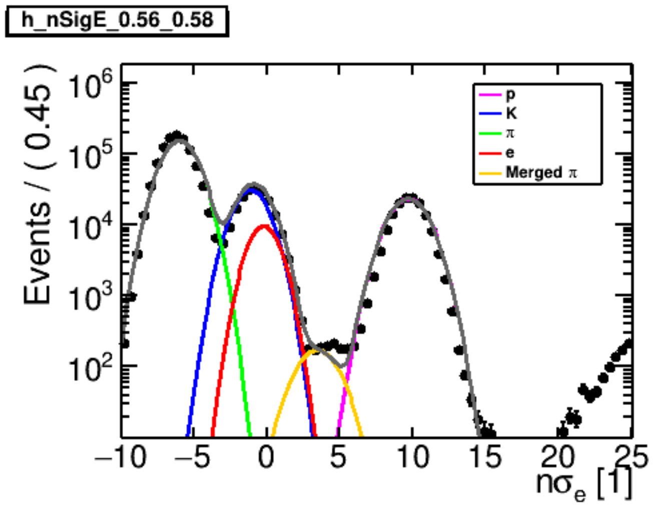
- The nSigma histogram is used after implementing TOF and BEMC cut value
- Total range is divided into smaller momentum bins with an increase of 0.02 GeV/c
- Each bins are being fitted with multigaussian function to constrain the yield for different particle

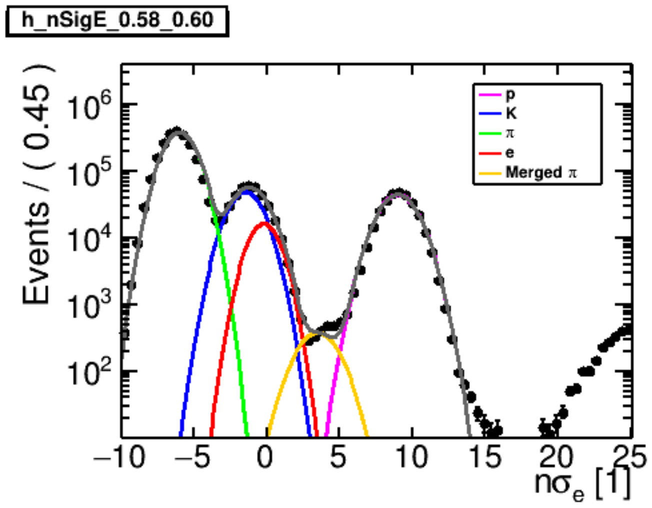


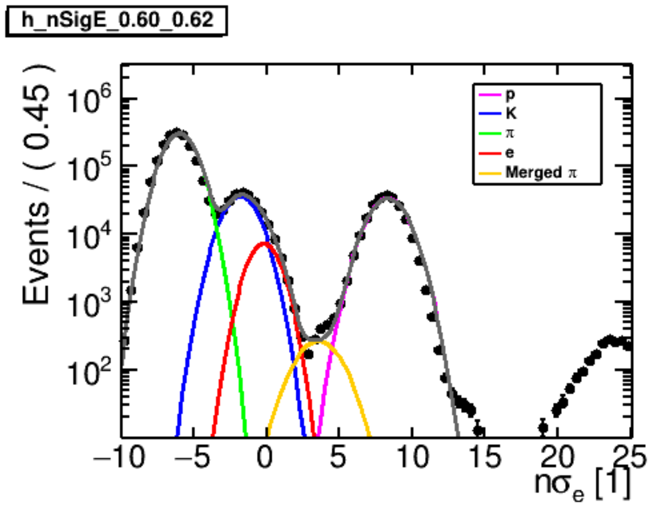
Multigaussian fit

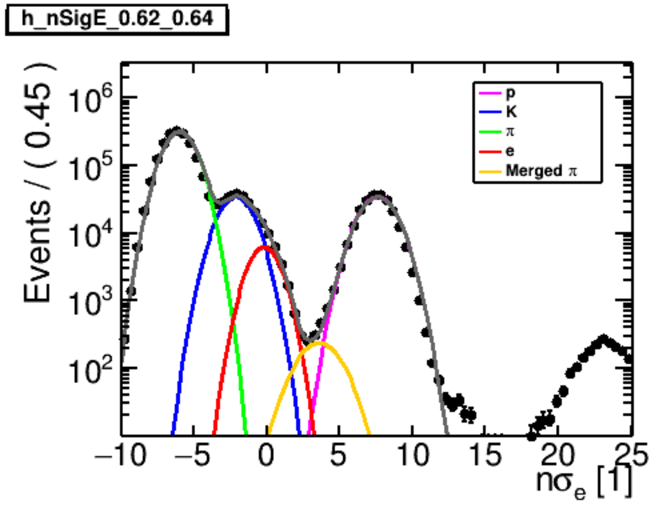


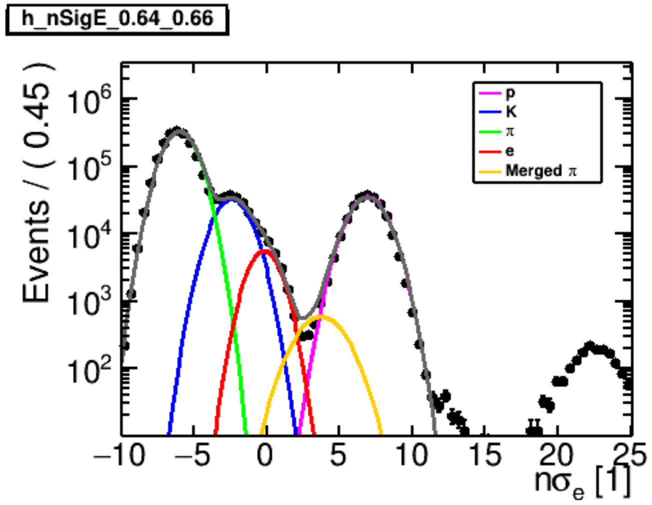
Multigaussian fit

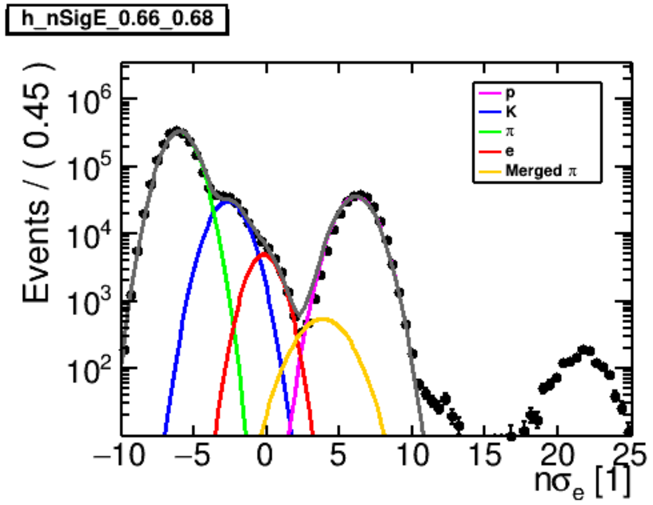




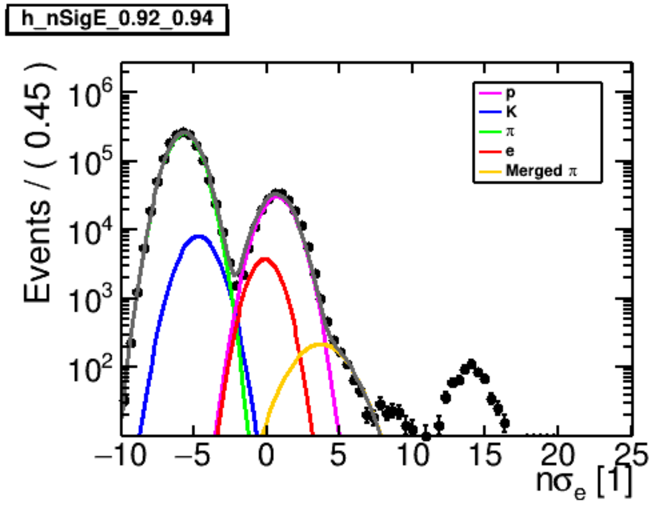


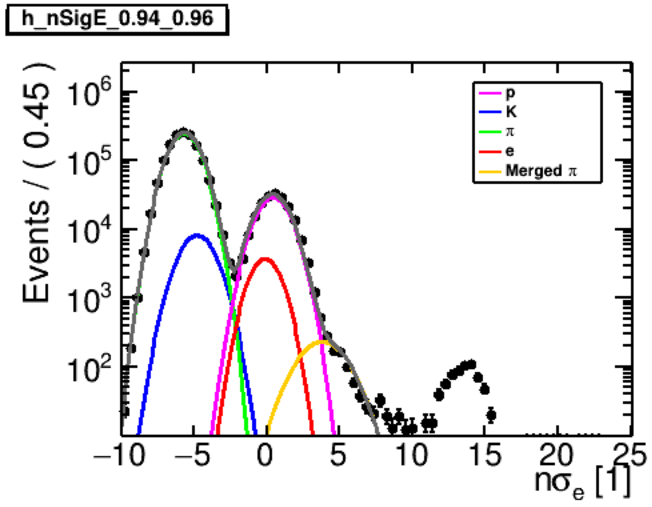


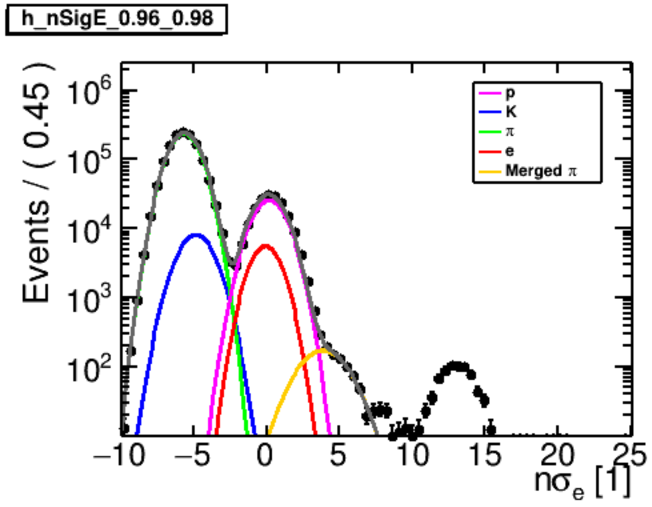


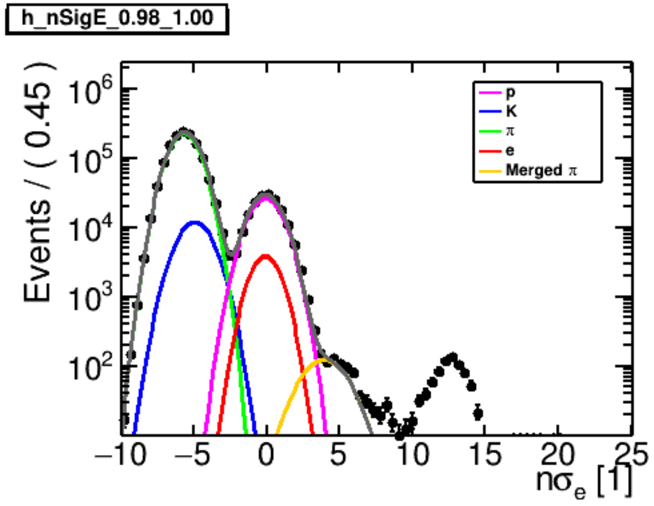


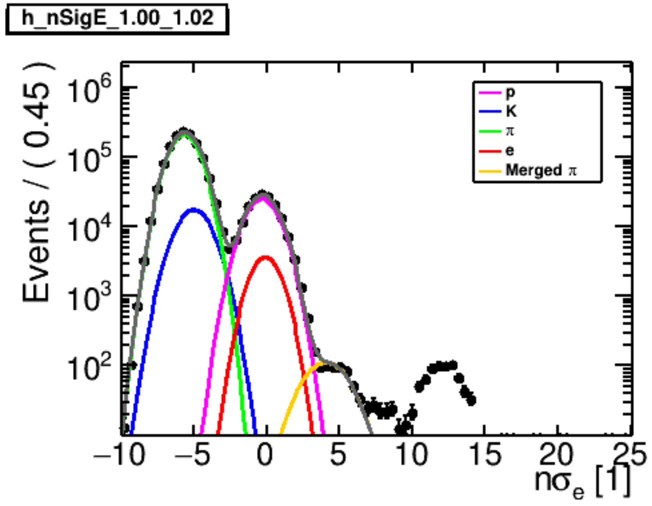
Multigaussian fit

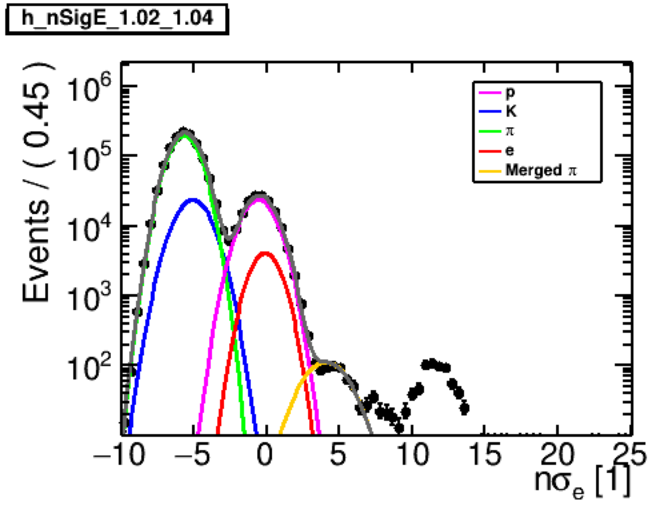




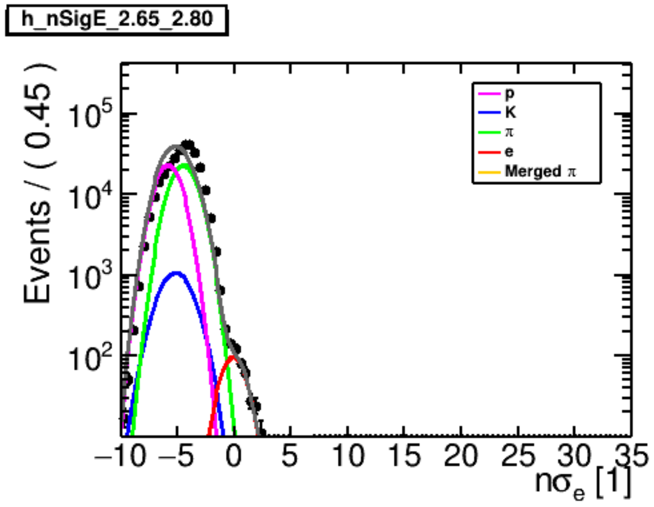


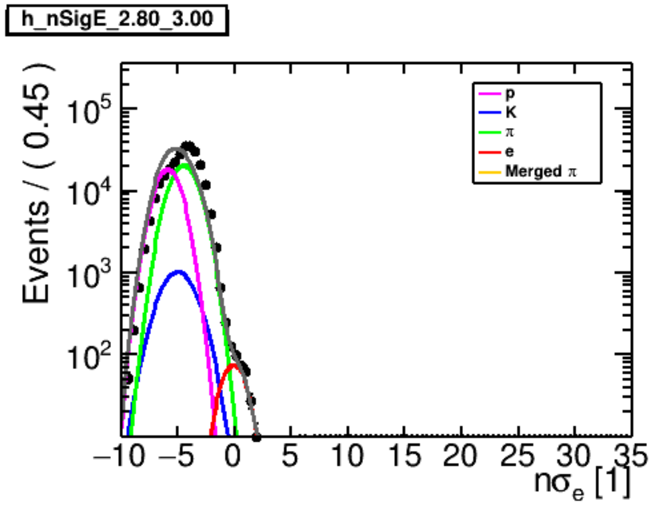


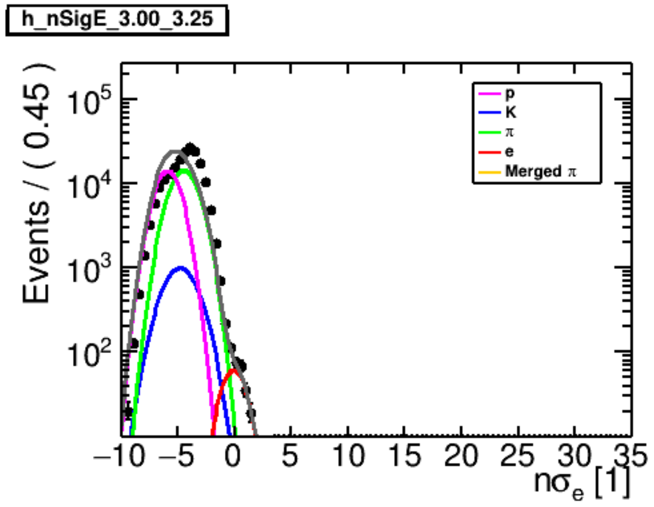


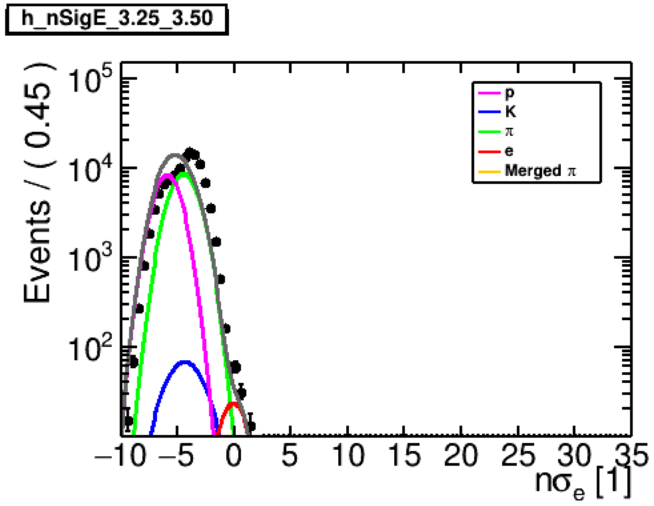


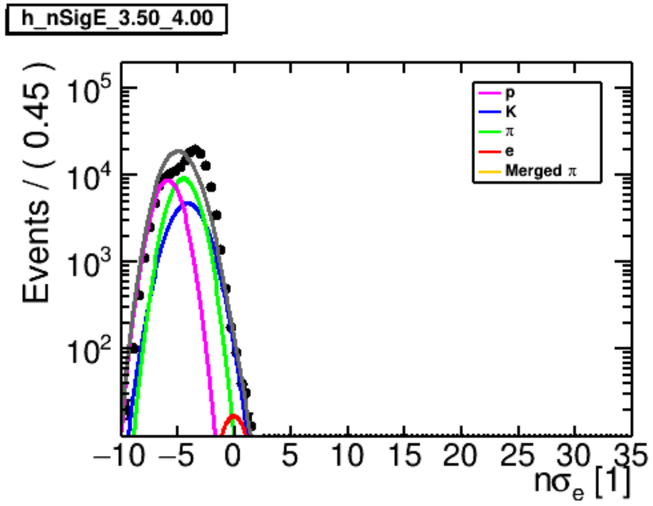
Multigaussian fit



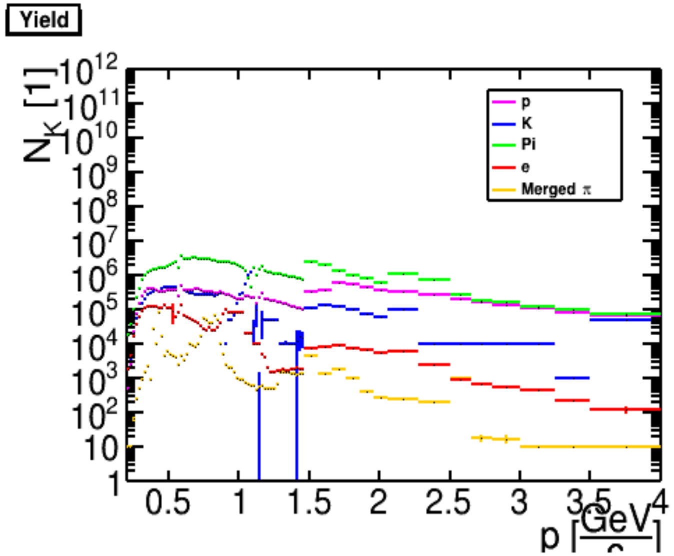


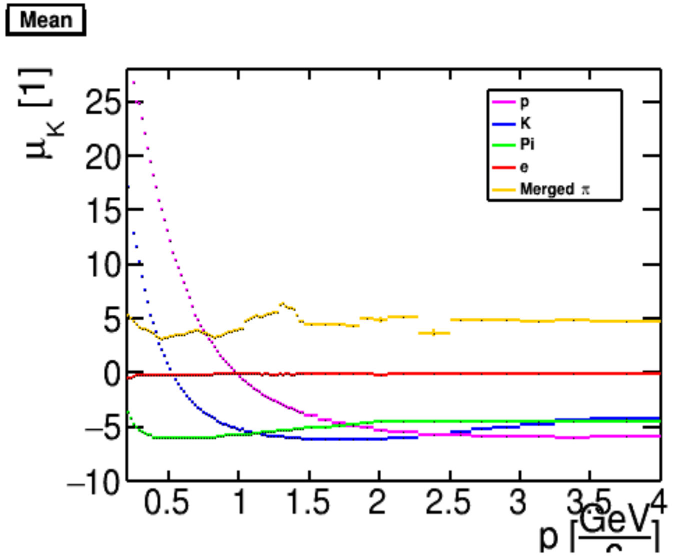


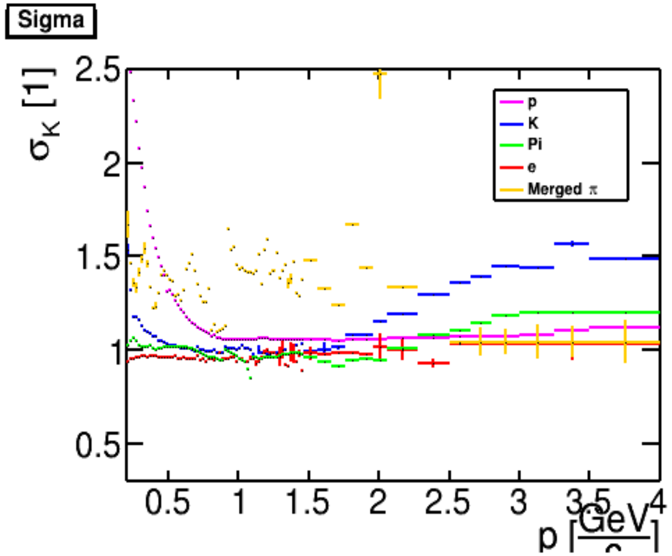




Parameters from multigaussian fit







- Parameters from multigaussian fittings are presenting large uncertainties
- requirements of further analysis

Purity estimation

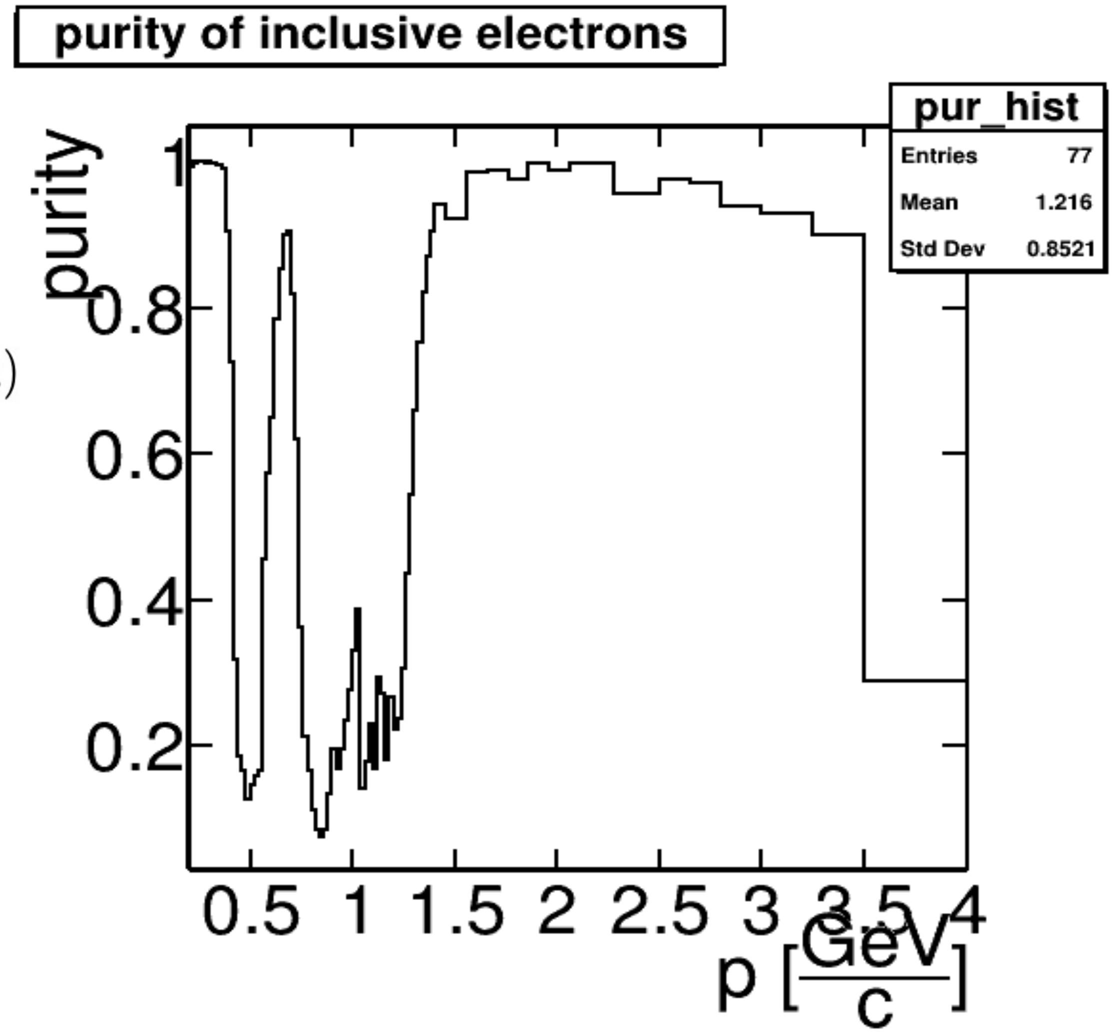
- Total fitting function

$$f^{total} = C_e \cdot Gaus(\mu_e, \sigma_e) + C_\pi \cdot Gaus(\mu_\pi, \sigma_\pi) + C_K \cdot Gaus(\mu_K, \sigma_K) + C_{merged\ \pi} \cdot Gaus(\mu_{merged\ \pi}, \sigma_{merged\ \pi}) + C_p \cdot Gaus(\mu_p, \sigma_p)$$

- Calculation of purity for inclusive electrons:

$$\text{purity} = \frac{\int_{n\sigma\ cut} f^e}{\int_{n\sigma\ cut} f^{total}}$$

$$f^e = C_e \cdot Gaus(\mu_e, \sigma_e)$$



7. Outlook

Future steps

Future steps

- Obtain an accurate purity of the inclusive electron sample
- Perform simulations to obtain the reconstruction efficiency
- Optimization of electron identification cuts using BEMC
- Efficiency of electron reconstruction to be analyzed via simulations
- Calculation of yields of nonphotonic electrons in different centrality classes to obtain R_{AA} and R_{CP}; comparison with other collision energies
- Inclusion of other NPE contributions to obtain more accurate information of electrons from heavy-flavor hadron decays

THANK YOU