RICH status
pass2 cooking

Introduction
- basic of the RICH reconstruction and PID
- pass2 cooking release

Present performance and comparison with EB PID
- RICH vs EB information
- EB ID efficiency
- EB ID contamination

Plans for a next RICH reconstruction pass
- improving the calibration and alignment

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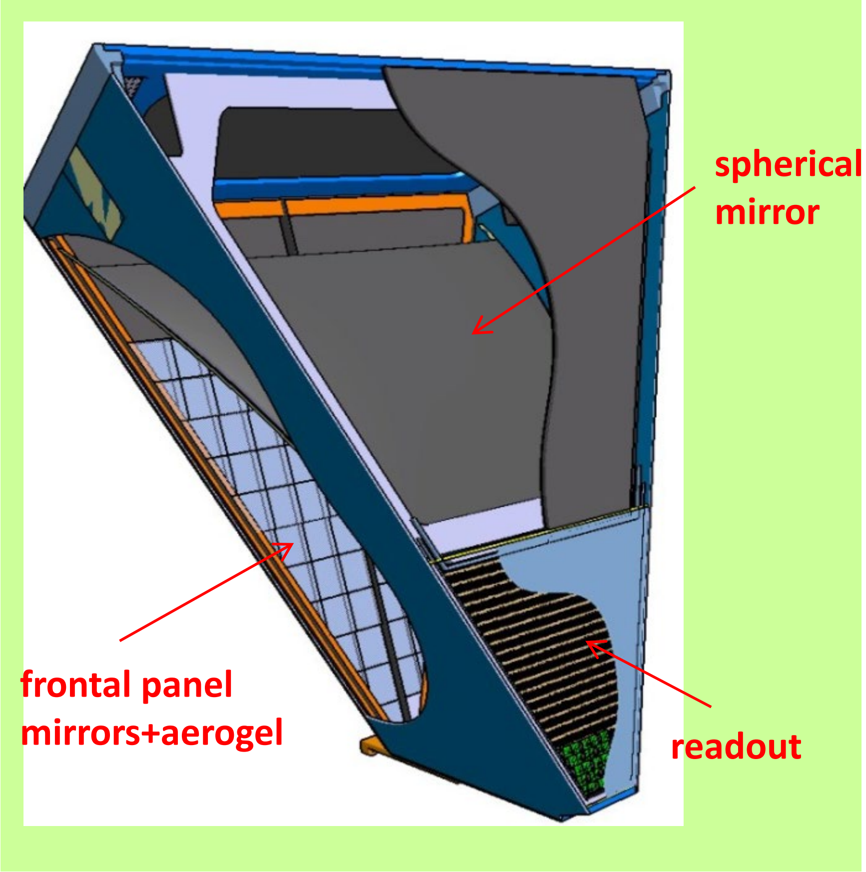
CLAS12 RG-A retreat – CNU, October 18, 2023

The RICH detector

Clean identification of kaons with respect to pions and protons in the momentum range from 3 to 8 GeV/c
- time resolution better than 1 ns
- Cherenkov angle resolution 5 mrad
- pi/K rejection factor larger than 500
- p/K rejection factor larger than 100



- Cherenkov radiator composed by 102 tiles with nominal refractive index ~1.05
- 7 planar mirrors
- 10 spherical mirrors
- 391 Multi-Anode PMTs, total of 25024 readout channel

Chrenkov emission thresholds

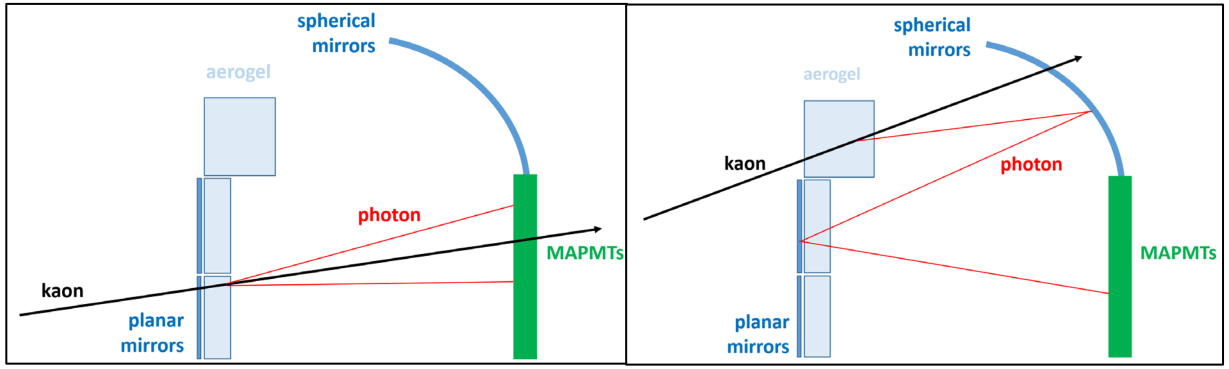
$\beta > 1 / n \approx 0.952$ with n=1.05

$P_{\pi} > 0.45$ GeV/c

$P_{K} > 1.5$ GeV/c

$P_{p} > 3.0$ GeV/c

Approximately P > 3 M



Reconstruction and PID

1. calculate the Cherenkov angle for all the hits in the MAPMT plane
   → Ray tracing of Cherenkov photons inside the RICH, based on:
   - the charged particle trajectory from CLAS12
   - the geometry of the detector
     - nominal geometry plus misalignments

2. perform the particle ID of each charged track in the detector (likelihood approach)
   - prior knowledge of the refractive index
     - from alignment, stored in the CCDB
   - expected time of the hits, number of photons, Cherenkov angle and resolution
     - from the calibration suites, stored in the CCDB

Particle ID

Based on a binned likelihood approach as described in the PDG (Section 40 Statistics), where the **bin** is the **MAPMT pixel**

$$-2\ln\lambda(\boldsymbol{\theta}) = 2\sum_{i=1}^{N}\left[\mu_i(\boldsymbol{\theta}) - n_i + n_i \ln\frac{n_i}{\mu_i(\boldsymbol{\theta})}\right]$$

$\boldsymbol{n_i}$ = number of hits in the pixel i (= 0,1)

$$\boldsymbol{\mu_i(\theta)} = \boldsymbol{\varepsilon_i}\underbrace{\frac{\boldsymbol{\Delta\phi}}{\boldsymbol{2\pi}}}_{\text{flat } \phi}\underbrace{\boldsymbol{e}^{-\frac{(\boldsymbol{\theta_i}-\langle\boldsymbol{\theta}\rangle)^2}{2\sigma^2}}\frac{\boldsymbol{\Delta\theta}}{\boldsymbol{\sigma\sqrt{2\pi}}}}_{\text{gauss } \theta}\underbrace{\boldsymbol{e}^{-\frac{(\boldsymbol{t_i}-\langle\boldsymbol{t}\rangle)^2}{2\sigma_t^2}}\frac{\boldsymbol{\Delta t}}{\boldsymbol{\sigma_t\sqrt{2\pi}}}}_{\text{gauss } t} + \boldsymbol{B_i}$$

$\boldsymbol{\theta_i}$ and $\boldsymbol{t_i}$ measured quantities for the hit

ε_i = efficiency of the pixel i (=0 dead, =1 ok)

B_i = expected background of the pixel i (typical few hertz from calibration data)

A smaller log-likelihood corresponds to a better agreement with the hypothesis

Output banks (DST format)

1. **RICH::Ring → reconstructed Cherenkov angles: for experts**
   - **pointer to REC::Particle**
   - **all hits in the fiducial region**
   - **reconstructed info for all the particle hypothesis**
     - **verification and improvement of calibration, alignments, etc**
     - **redo the PID with alternative user-defined algorithms**

2. **RICH::Particle → PID information from the RICH: for users**
   - **list all the particles crossing the aerogel, wether they generated photons or not**
   - **pointer to REC::Particle**
   - **best particle ID**
   - **ID quality parameter**

RICH::Particle bank

```
"name": "RICH::Particle",
"group": 21800,
"item" : 37,
"info": "Reconstructed Cherenov information per track",
"entries": [
        {"name":"id",          "type":"B", "info":"id"},
        {"name":"hindex",      "type":"S", "info":"related row in the RICH::clusters bank (if any)"},
        {"name":"pindex",      "type":"B", "info":"related row in the REC::Particle bank"},

        {"name":"emilay",      "type":"B", "info":"aerogel layer of photon emission"},
        {"name":"emico",       "type":"B", "info":"aerogel component of photon emission"},
        {"name":"enico",       "type":"B", "info":"aerogel component of photon entrance point"},
        {"name":"emqua",       "type":"S", "info":"aerogel quadrant of photon emission"},
        {"name":"mchi2",       "type":"F", "info":"track-cluster matching chi2 (if any)"},
        {"name":"mass",        "type":"F", "info":"reconstructed mass for best hypo"},

        {"name":"best_PID",    "type":"S", "info":"most probable PID choice"},
        {"name":"RQ",          "type":"F", "info":"goodness of hadron choice parameter (1=anambiguos, 0=random)"},
        {"name":"ReQ",         "type":"F", "info":"goodness of electron choice parameter (1=anambiguos, 0=random)"},
        {"name":"el_logl",     "type":"F", "info":"log-likelihood to be an electron"},
        {"name":"pi_logl",     "type":"F", "info":"log-likelihood to be an pion"},
        {"name":"k_logl",      "type":"F", "info":"log-likelihood to be an kaon"},
        {"name":"pr_logl",     "type":"F", "info":"log-likelihood to be an proton"},

        {"name":"best_ch",     "type":"F", "info":"Average etaC for best hypothesis"},
        {"name":"best_c2",     "type":"F", "info":"chi2 for best hypothesis"},
        {"name":"best_RL",     "type":"F", "info":"Likelihood ratio for best hypothesis"},
        {"name":"best_ntot",   "type":"F", "info":"Number of photon used for likelihood"},
        {"name":"best_mass",   "type":"F", "info":"Reconstructed mass for best hypothesis"}
    ]
  }
]
```

PID quality parameters

RICH reconstruction in pass2 cooking

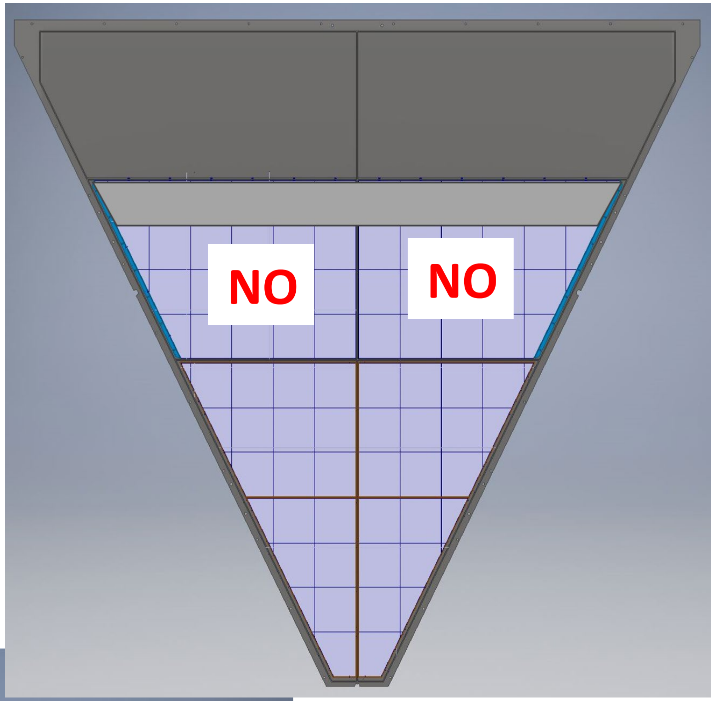
The RICH PID is controlled by a number of status flags stored in the CCDB.

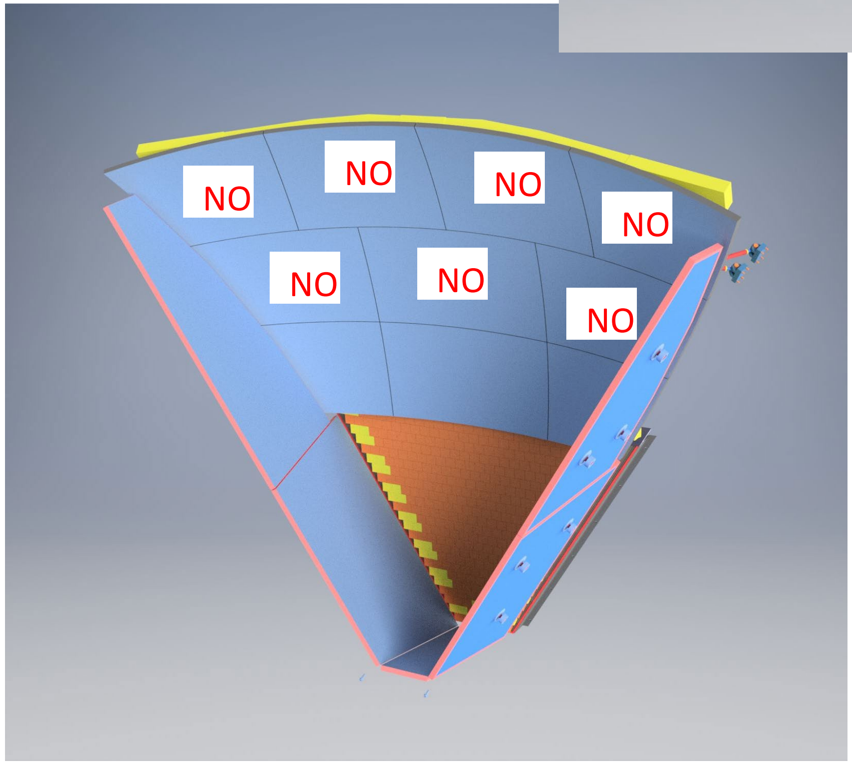
Only photons hitting elements with status flag set to OK are used for the PID.

In preparation for the pass2 cooking, good alignment has been obtained for

- **2 cm thickness aerogel**
- **all planar mirrors**
- **3 out of 10 spherical mirrors**

Therefore, the pass2 cooking RICH PID utilizes only photons hitting these components, limiting the coverage in angle (see later)





How to use the RICH ID information

1. loop over the rows in RICH::Particle
2. get the pointer to REC::Particle, read the momentum and PID from the Event Builder
3. check that the PID from the Event Builder is not an electron or positron
4. get the best ID from the RICH
5. apply quality cuts: number of photons, RQ, chisquare

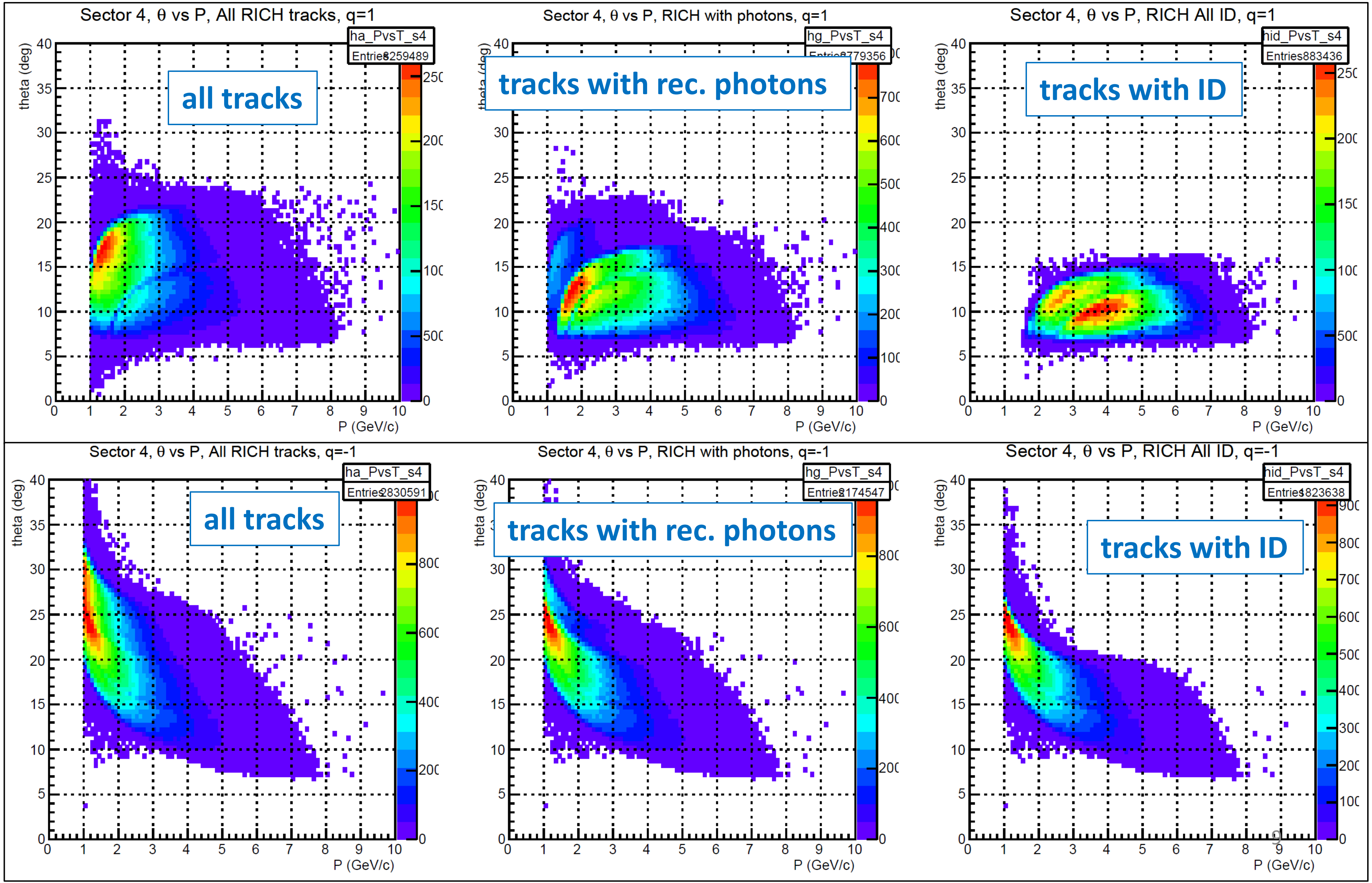
Cuts on the PID quality parameters should be optimized based on the final state of interest.
Minimal recommended cut: at least 3 photons

> **Analysis of the RICH data**
>
> Marco Mirazita
> INFN Laboratori Nazionali di Frascati
>
> March 14, 2023
>
> **Abstract**
>
> This document describes how to use RICH particle identification information. It is valid for data processed with the RICH reconstruction software released in March 2023 for the pass2 cooking or later distributions.

Kinematic coverage

Outbending particles

Inbending particles



RICH vs EB performance

Plots of PID quantities from the RICH and from the EB as a function of the momentum (next slides) or theta (not shown here)

- **For the RICH reconstruction**

  $\Delta\theta_c = \theta_{meas} - ACos(1/\beta n)$

- **For the Event Builder**

  chi2pid

- **For the FTOF reconstruction (panel 1a and 1b)**

  $\Delta T = T_{meas} - L_{path} / \beta$

- **For the HTCC reconstruction**

  number of photons

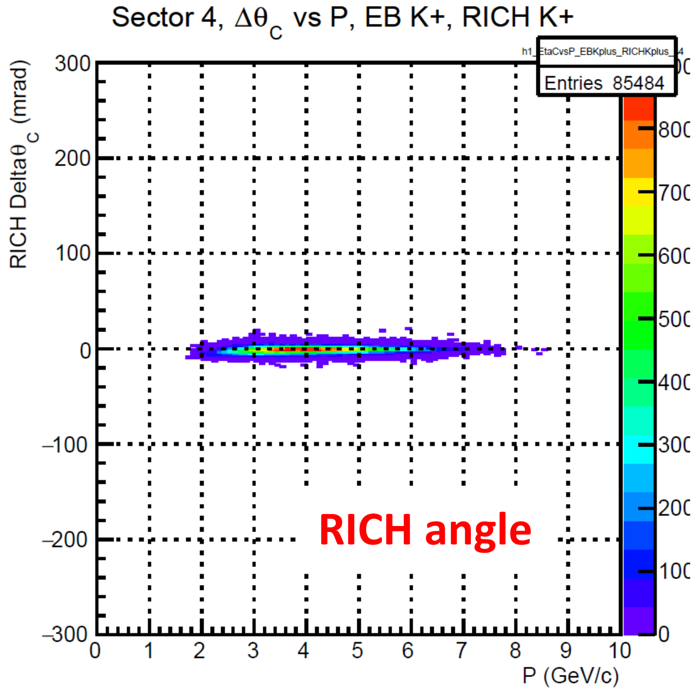
DATA set

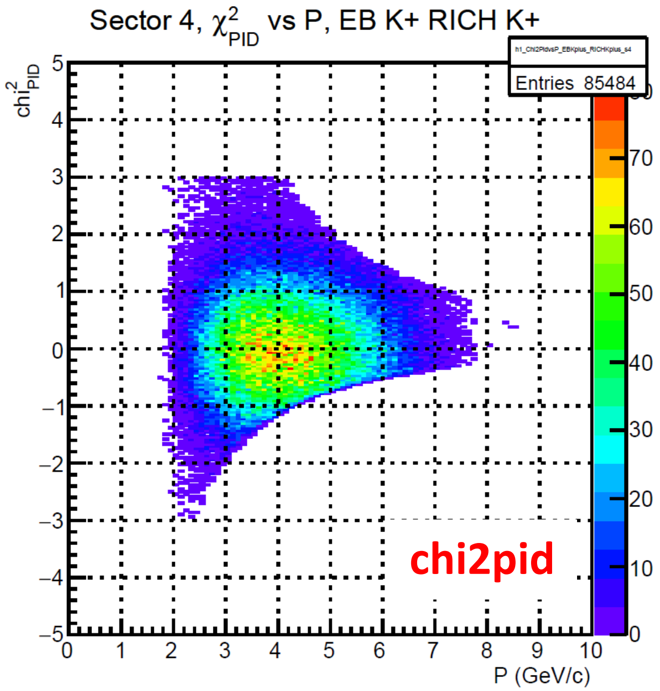
- **RG-A spring 2019 data (10.2 GeV beam energy, inbending torus field), full statistics**

Data analysis:

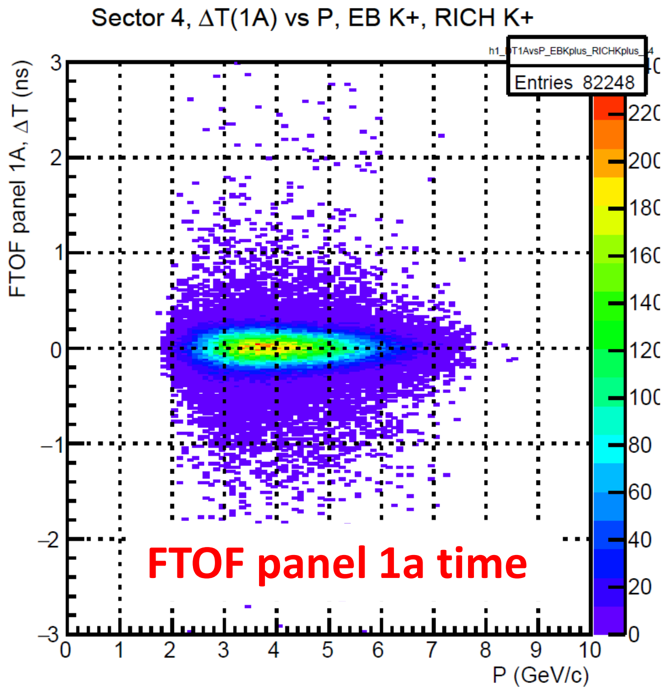
event selection, fiducial cuts, etc. as in the kaon SIDIS BSA analysis from A. Kripko (but pass1 cooking)

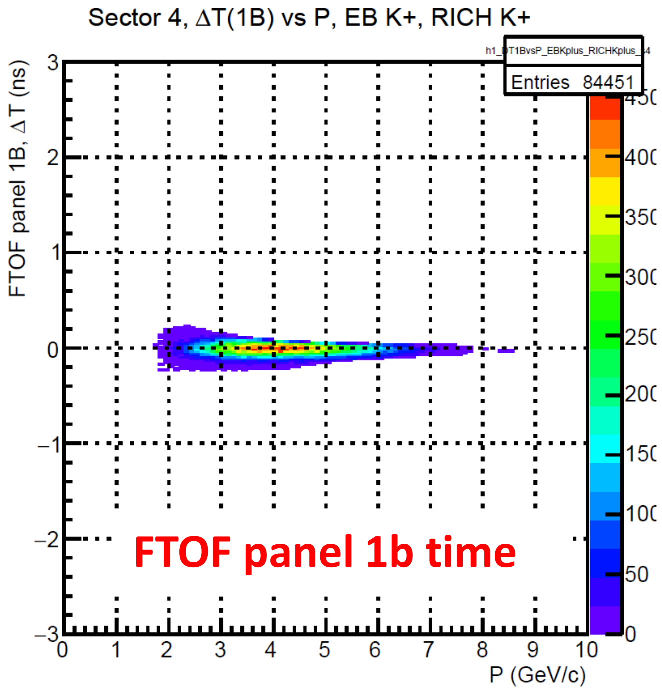
K+ ID

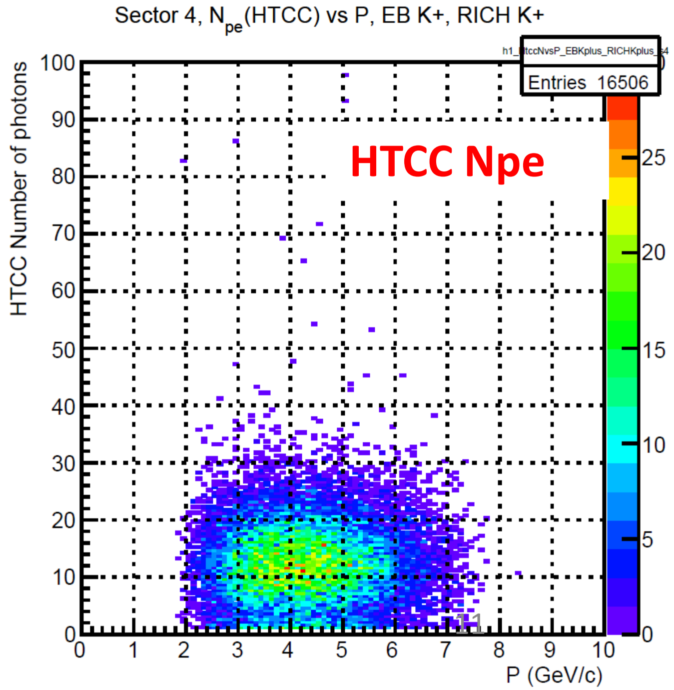




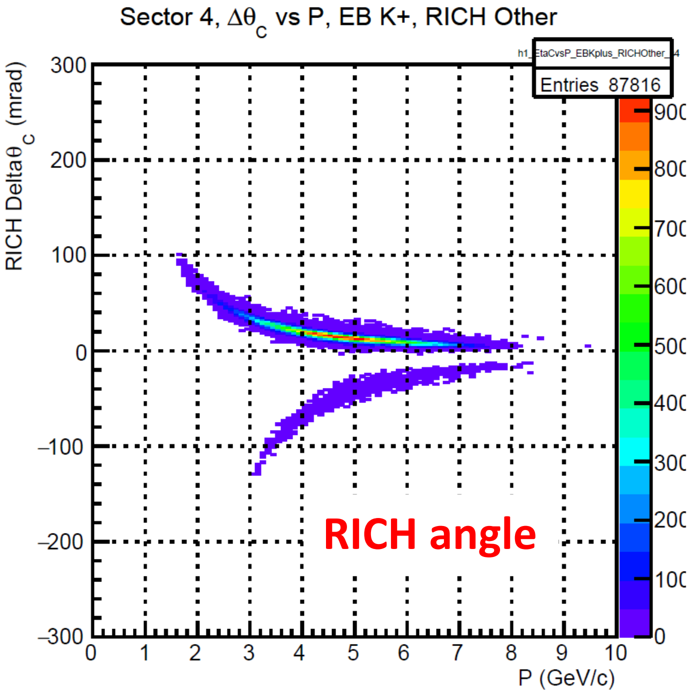
Particles that are K+ in both EB and RICH

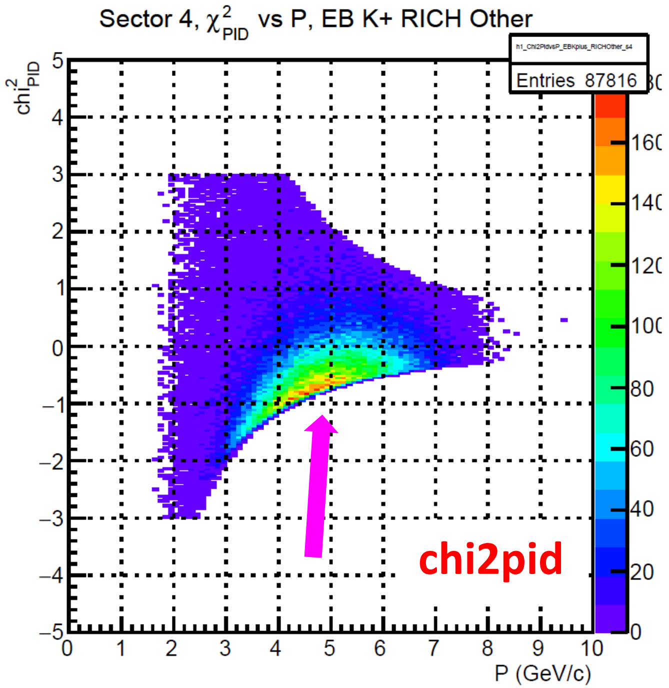






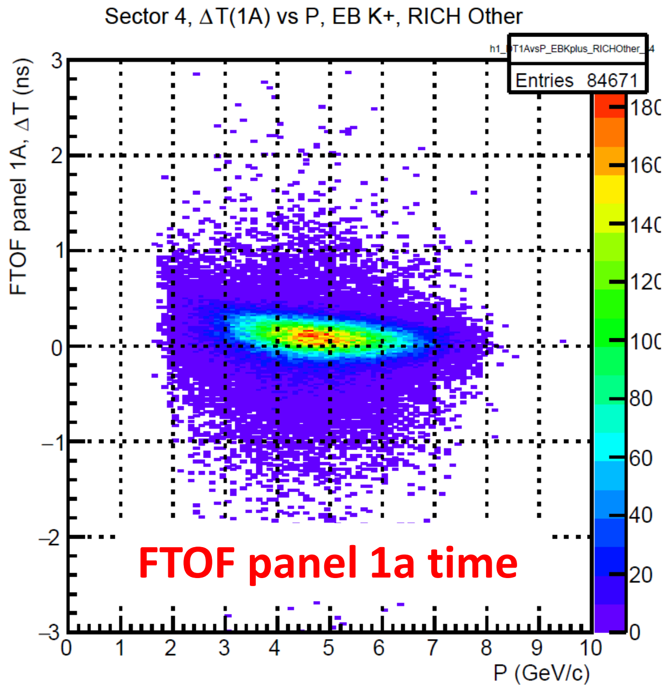
K+ ID

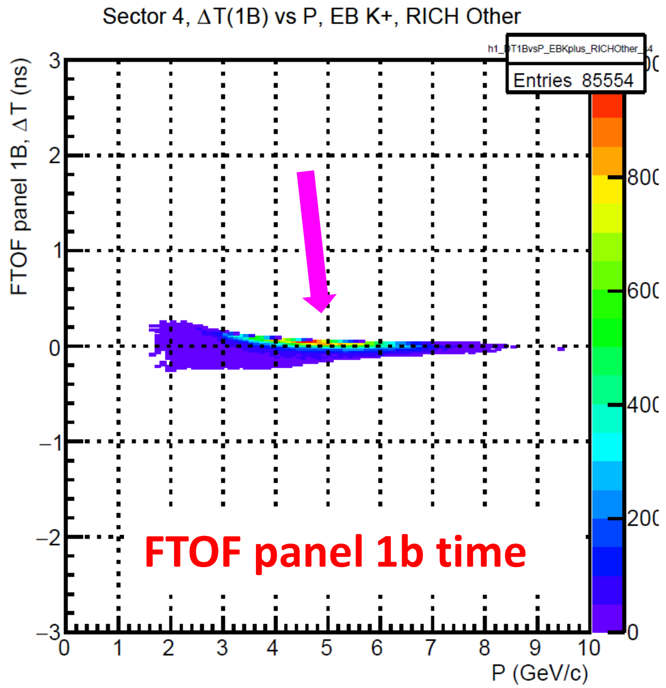


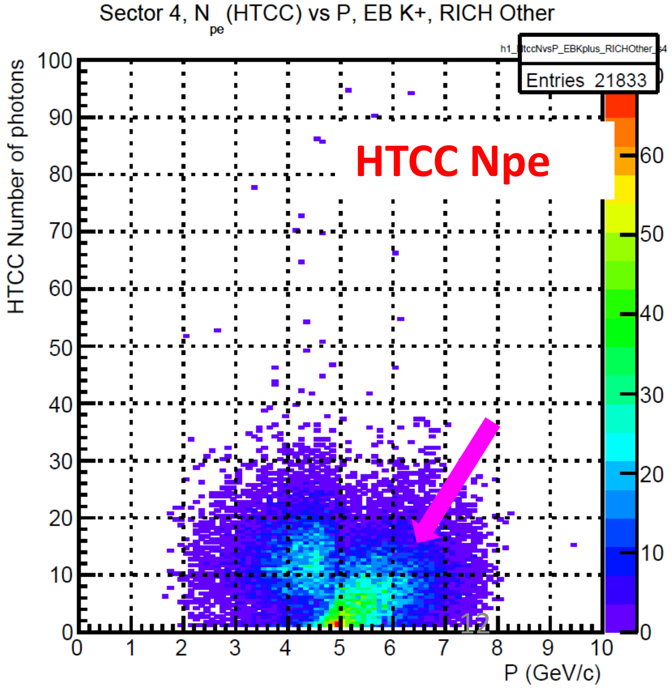


Particles that are K+ in the EB but something else in the RICH

pions







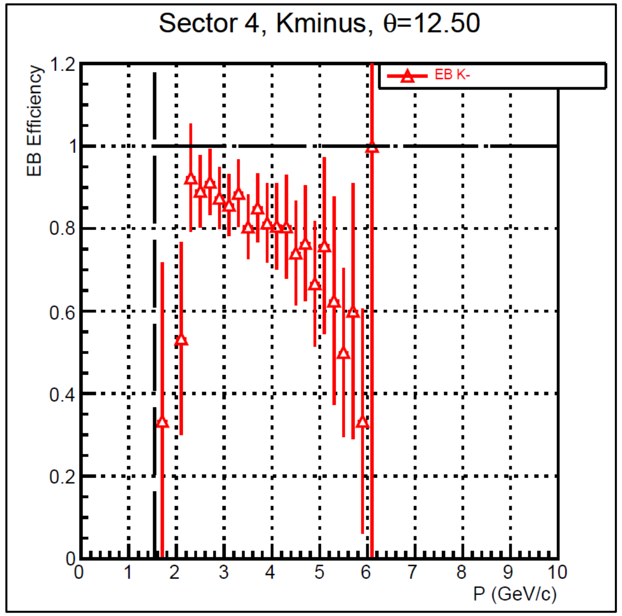
EB identification efficiency

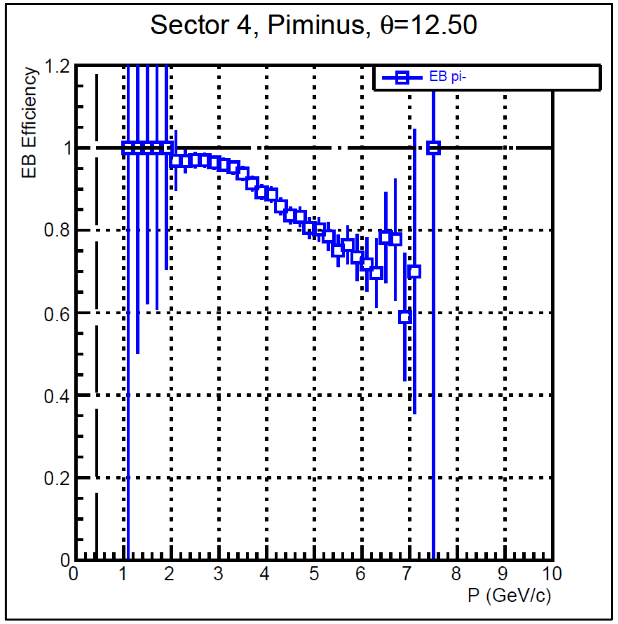
Plots for one angular bin (Δθ=1 deg) as a function of P

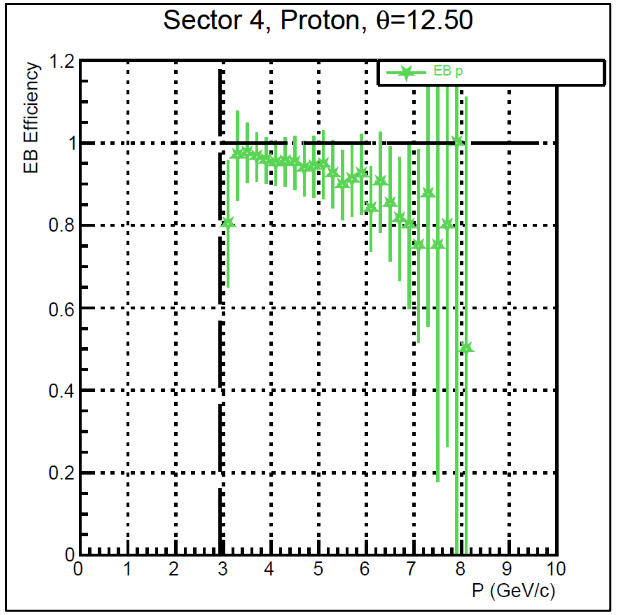
Given one track in CLAS12, what is the probability that it is correctly identified in the EB?

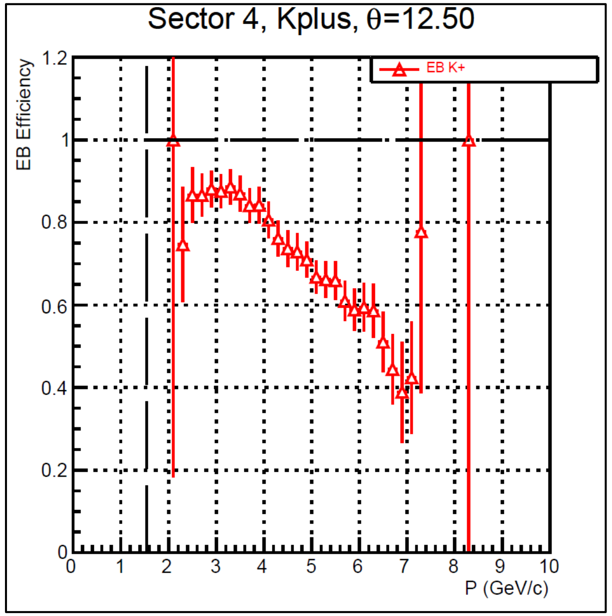
Let's assume that the RICH is 100% accurate, then:

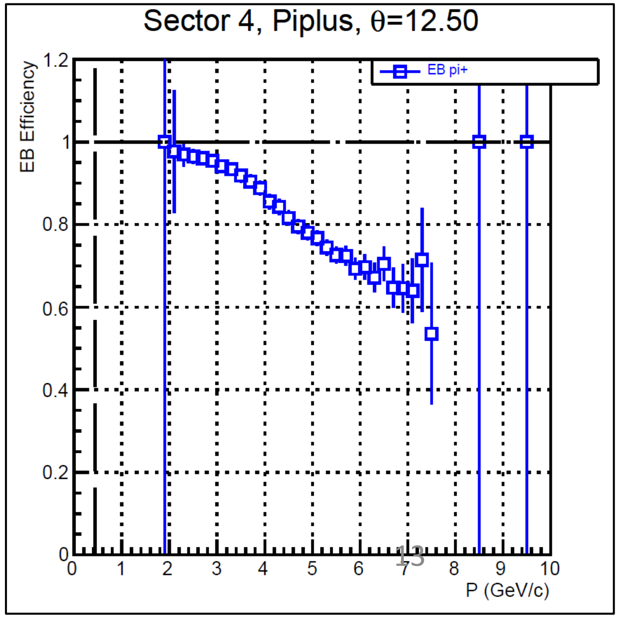
$$\epsilon_{EB} = \frac{N(RICH=id, EB=id)}{N(RICH=id)}$$











EB misidentification

Plots for one angular bin ($\Delta\theta$=1 deg) as a function of P

Given one track ID (kaon) in the EB, what is the probability that the ID is correct? And that is wrong?

Let's assume again that the RICH is 100% accurate, then:

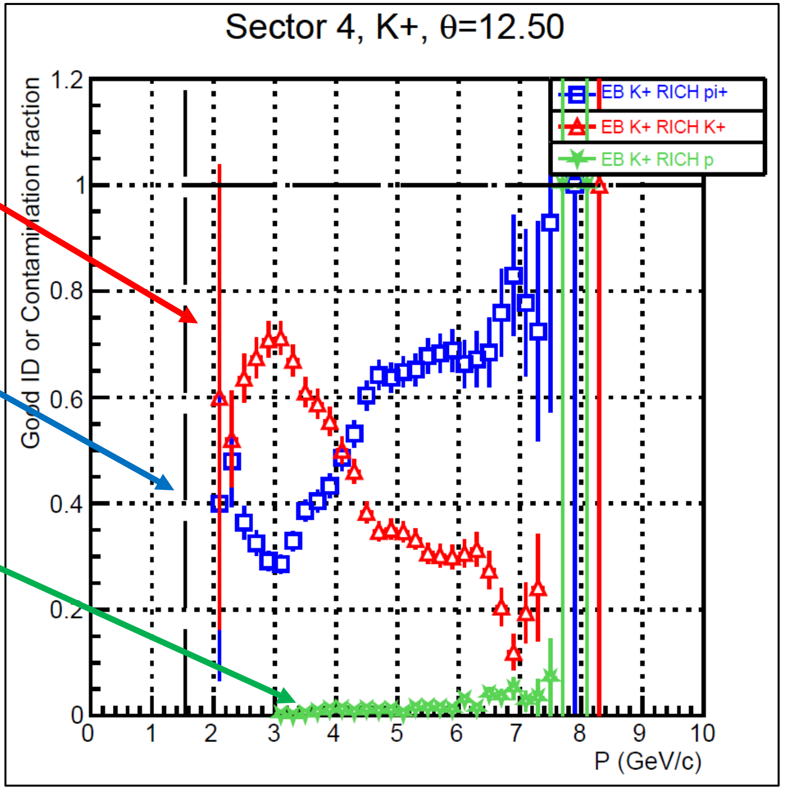
$$P_{EB} = \frac{N(EB=id, RICH=id)}{N(EB=id)}$$

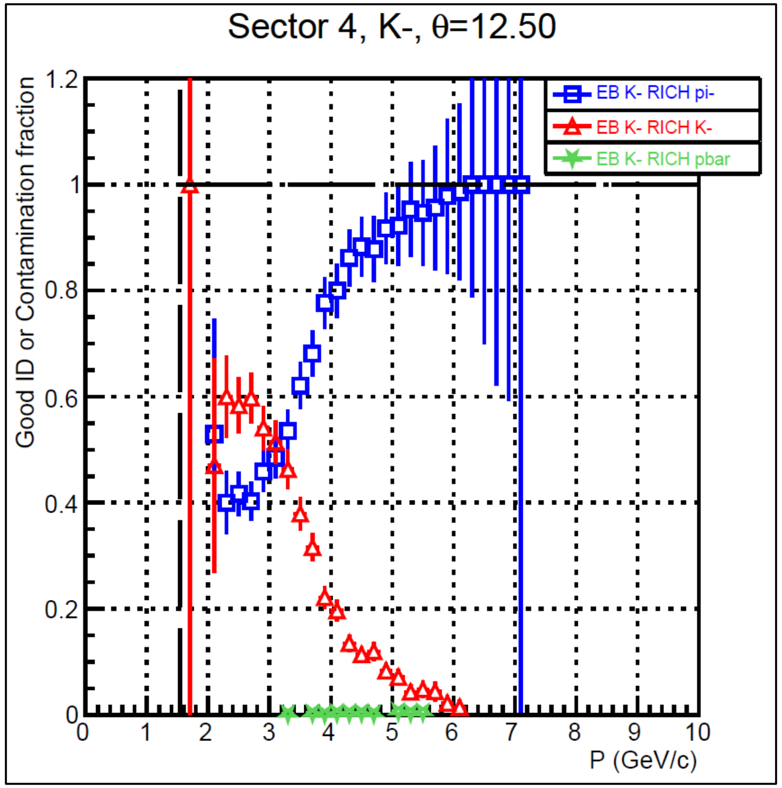
$$C_{EB} = \frac{N(EB=id1, RICH=id2)}{N(EB=id1)}$$

EB K and RICH K: purity

EB K and RICH π: pion containation

EB K and RICH p: proton containation



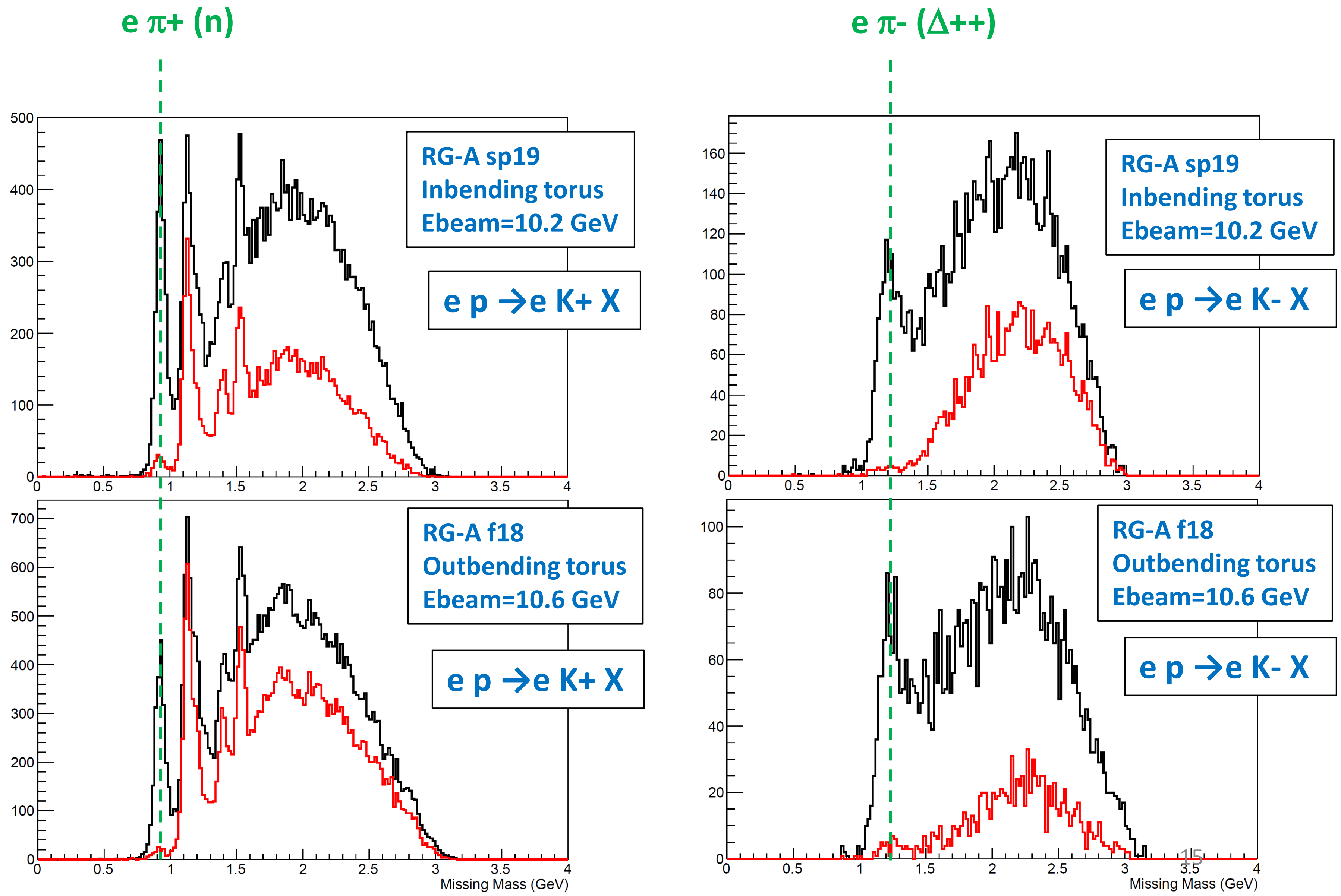


Physics quantities: missing masses

MM(e p → e K X)

black: EB Kaons restricted in the RICH acceptance

red: RICH Kaons



Plans for improvements

1. **Improving calibrations**
   - **run the calibration suites on the full statistics of each data set, update the CCDB and rerun the RICH reconstruction**
   - **expected slightly better performance, might be relevant at lower momentum where the number of photons is low**

2. **Improving the alignment**
   - **the algorithm used so far (i.e. align one element at a time) failed for photons with many reflections and tiles with no direct photons**
   - **possible improvements:**
     - **better selection of the tracks/photons**
     - **simultaneous extraction of the alignment parameters of many elements**

3. **Alternative approach: use Machine Learning technique to obtain pi/K/p separation by hit pattern recognition**
   - **advantage: PID does not depend on the alignment any more, no need of huge CCDB tables, etc**
   - **problems: how to train the ML algorithm?**
   - **project started few months ago with Gagik and one Post-Doc student in Frascati (Armen Gyurjinyan)**

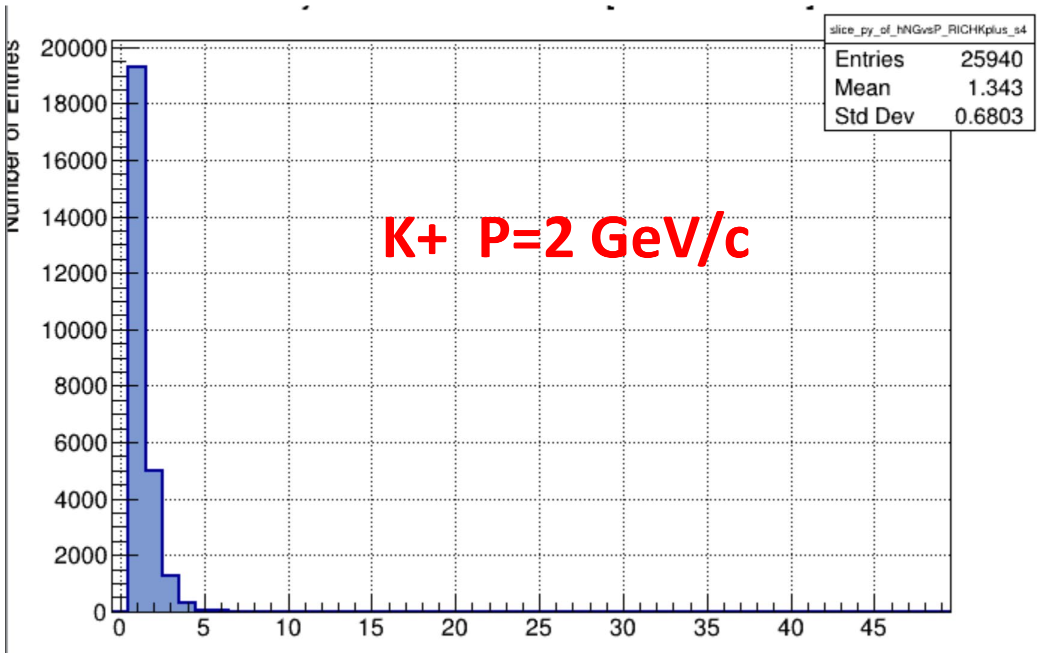
Additional slides

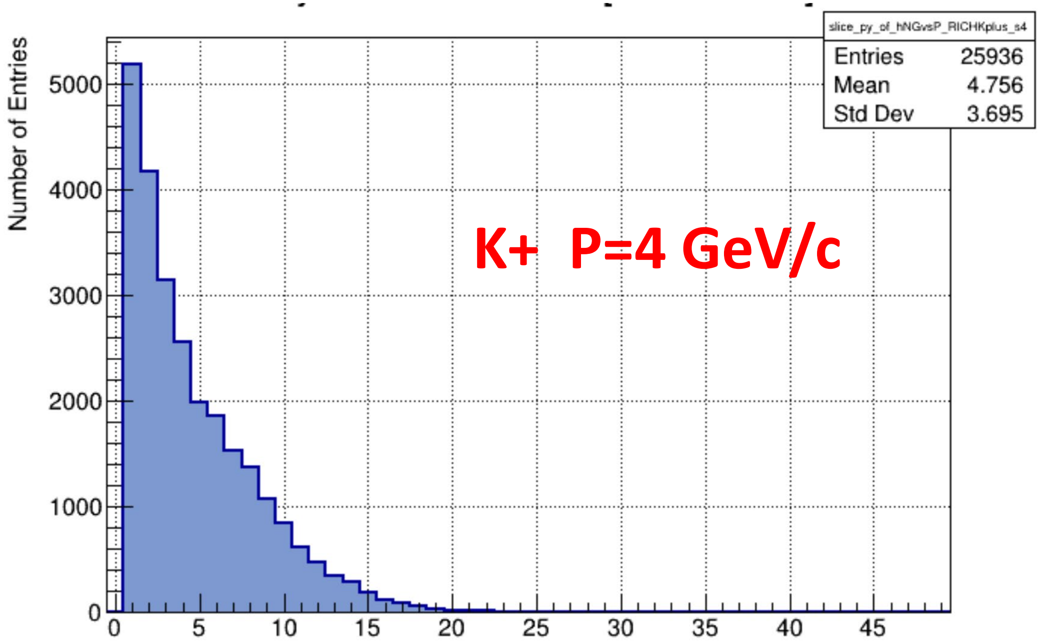
Kinematic coverage vs momentum threshold

The number of photons per track close to threshold is small and can be too low for a good ID

- **but separation between a particle close to threshold (K) and a beta=1 particle (pion) is relatively easy**

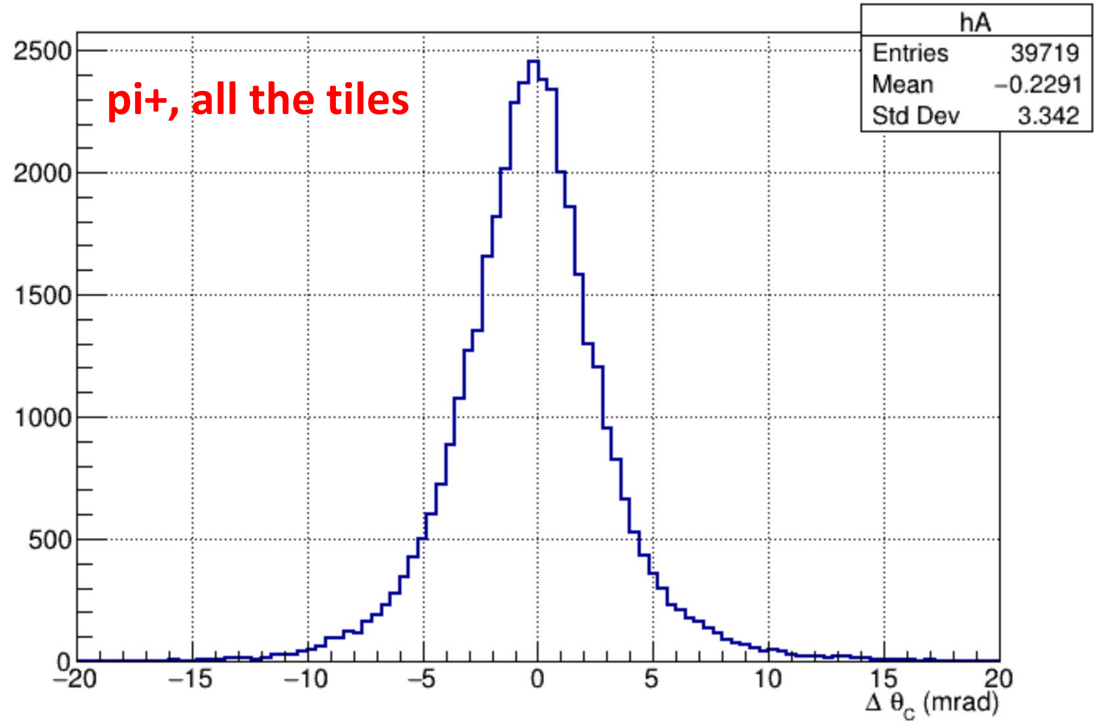
→RICH efficiency at threshold not well defined
→ pions are always in saturation regime

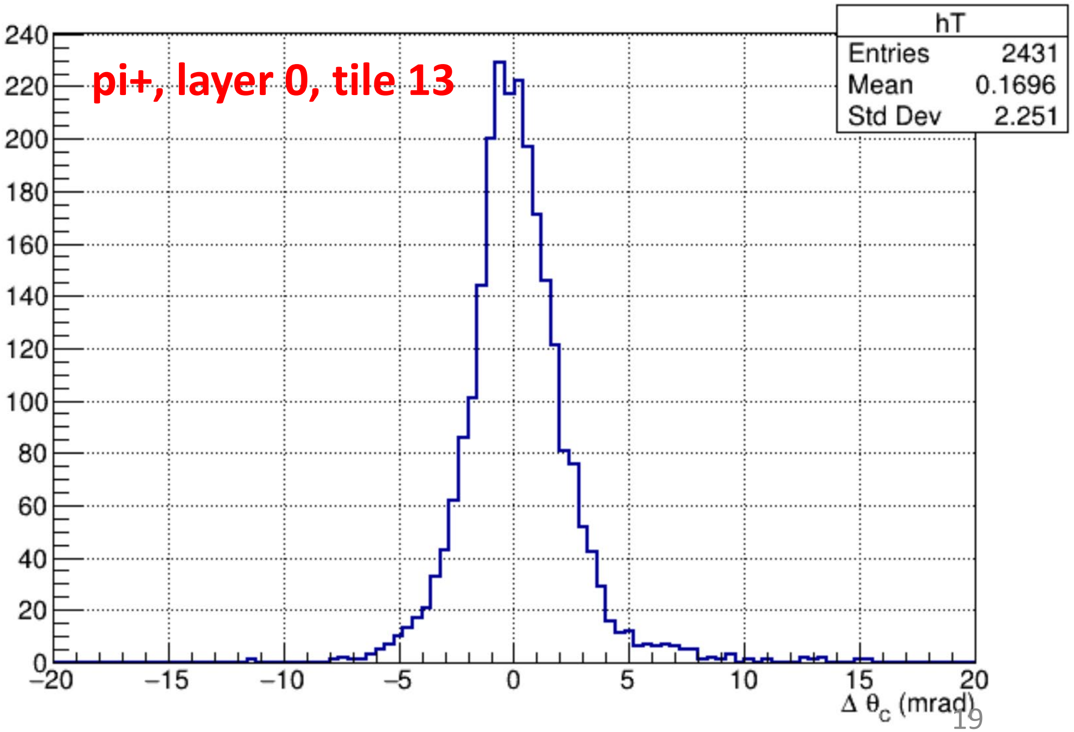




RICH: tile vs integrated plots

The plots showed for the RICH in the next slides are integrated over all the tiles.
However, the tile (and photon detection topology) dependence is relevant, and is correctly taken into account in the RICH reconstruction software, provided that the alignment and calibration are good enough.
→ the pi/K/p separation looks a bit worse in the plots than they are in reality
→ the same should be true for the FTOF plots too

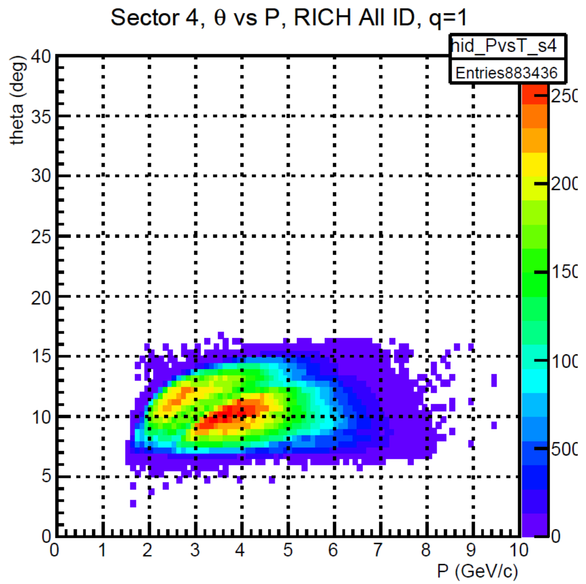


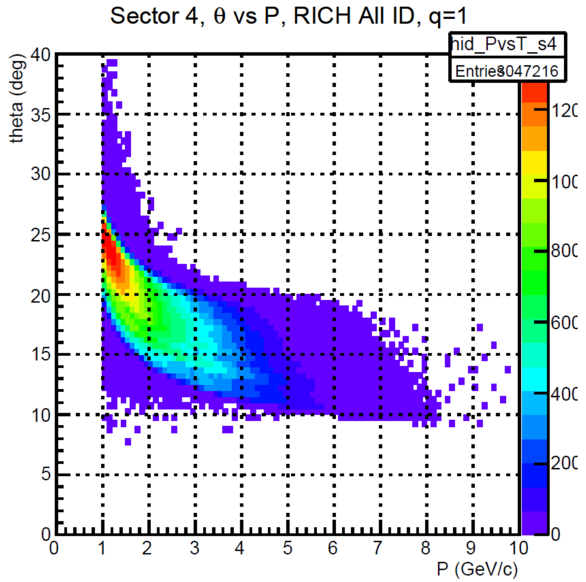


Kinematic coverage: Outbending vs inbending data

Reversing the torus field and the charge of the particles, the RICH acceptance doesn't change

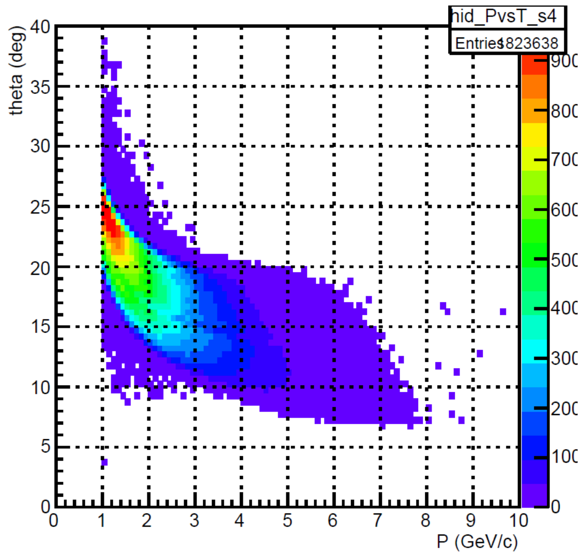
RG-A spring 19
inbending field
positive charge

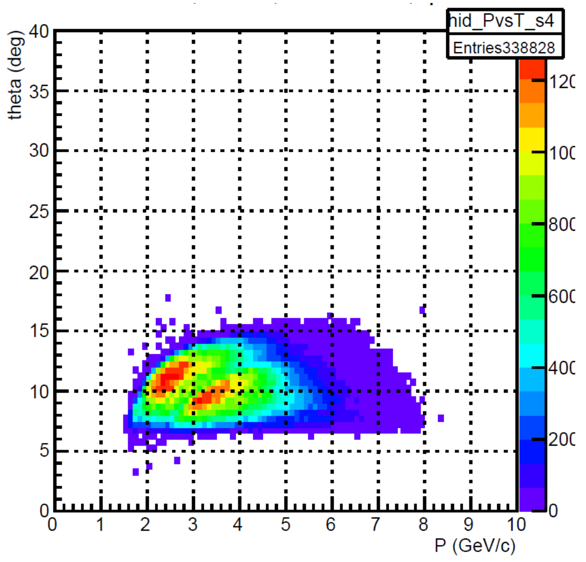




RG-A fall 18
outbending field
positive charge

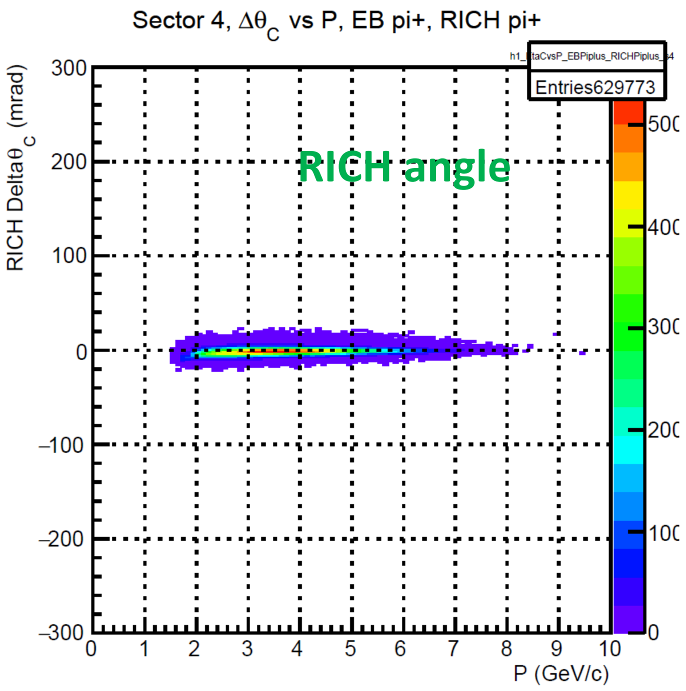
RG-A spring 19
inbending field
negative charge

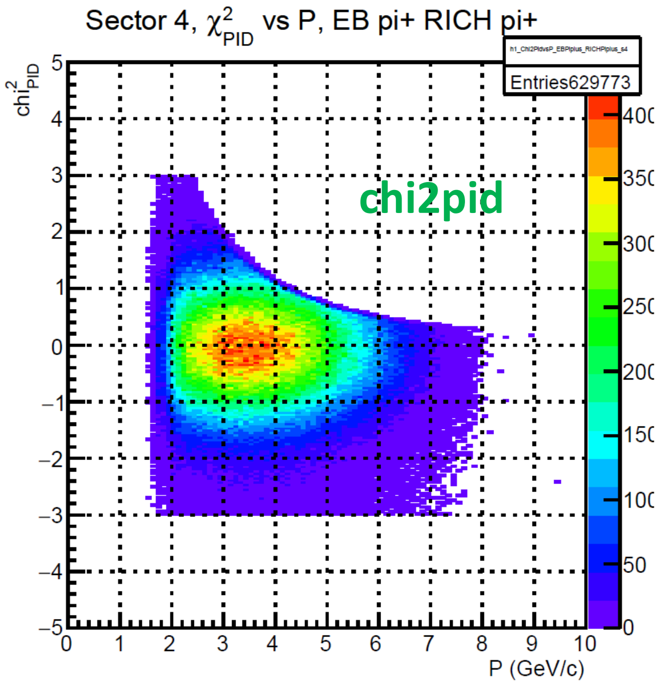




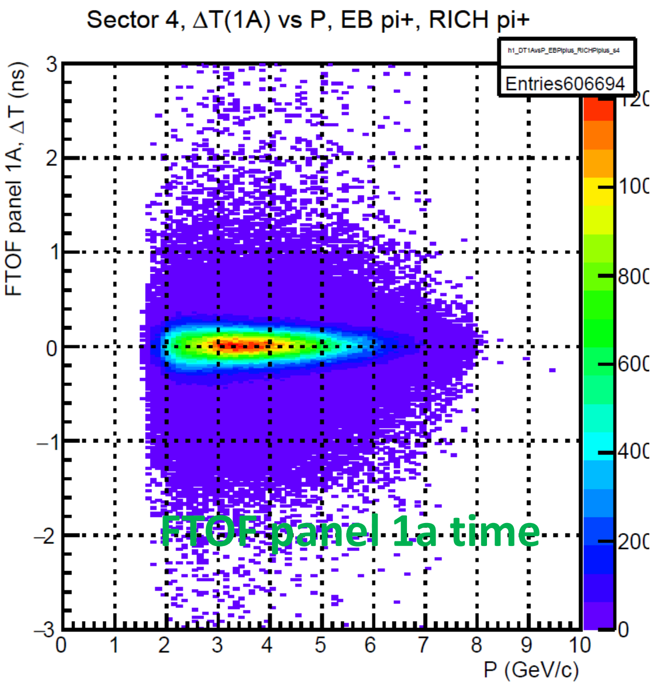
RG-A fall 18
outbending field
negative charge

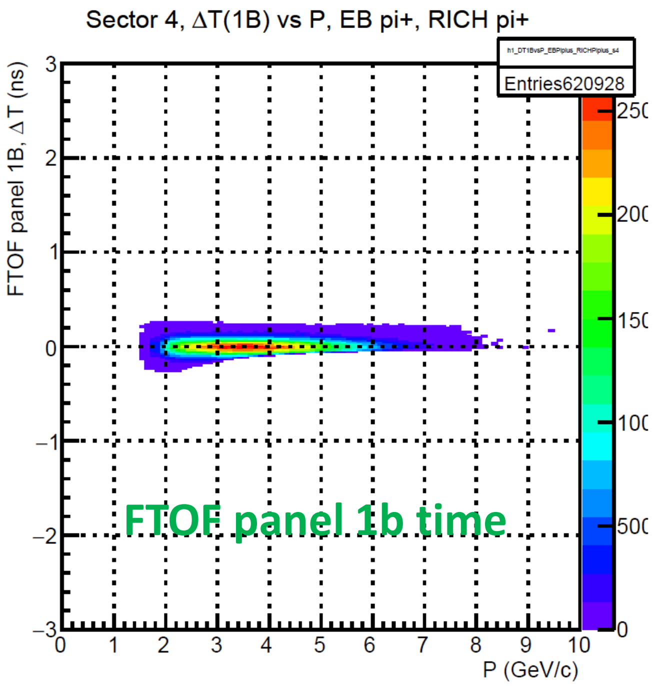
pi+ ID

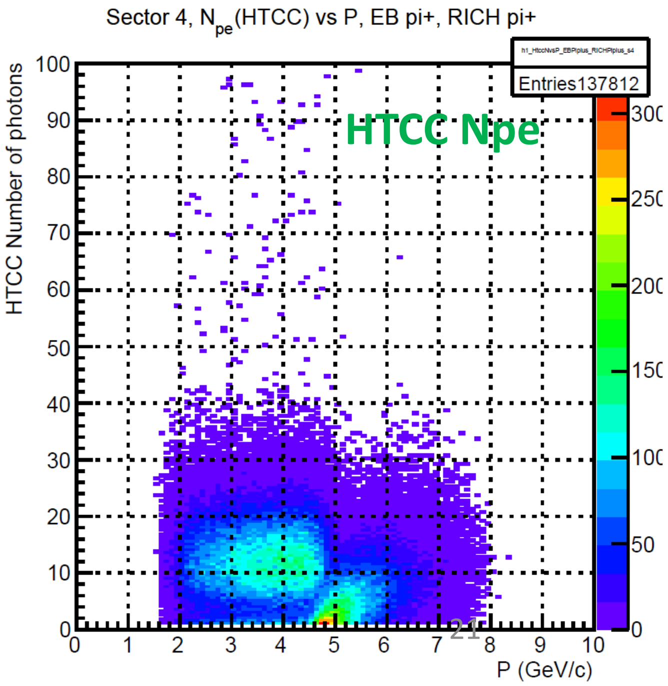




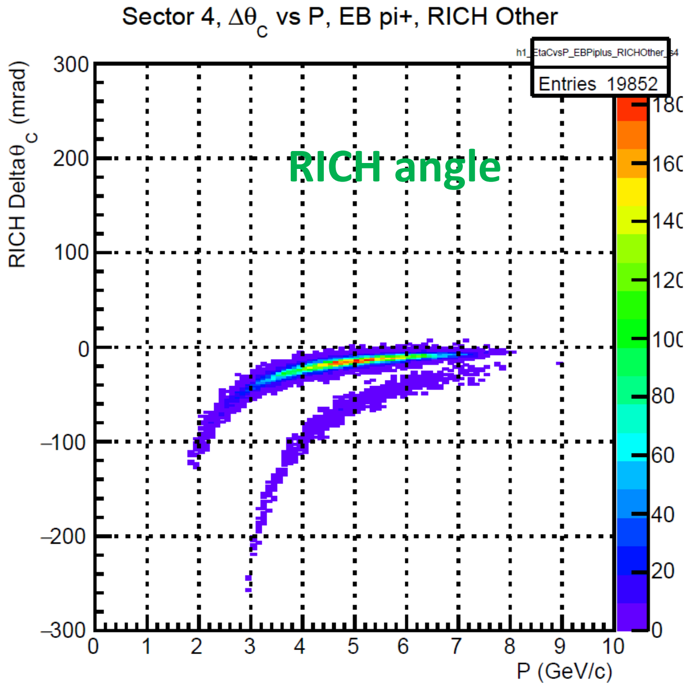
Particles that are pi+ in both EB and RICH

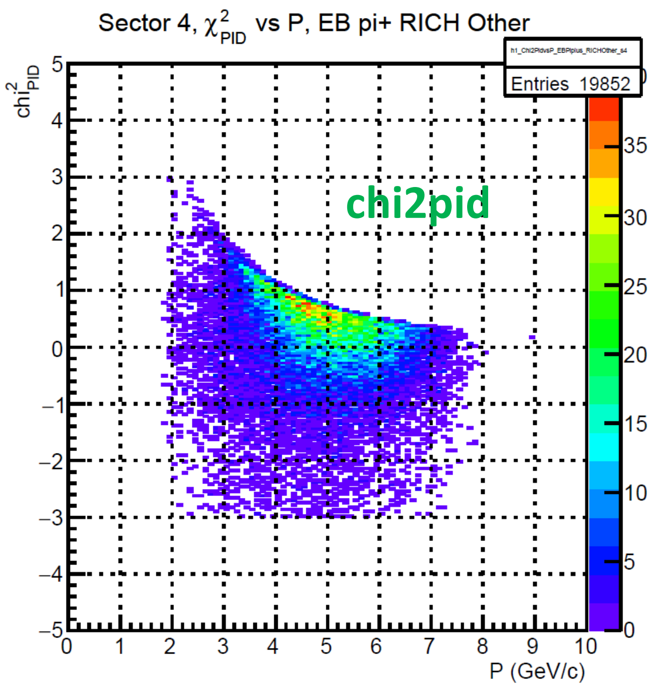




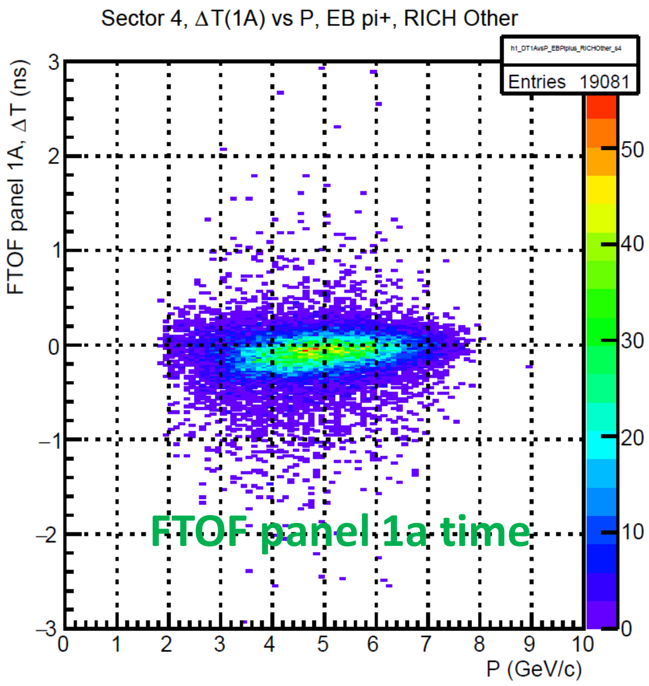


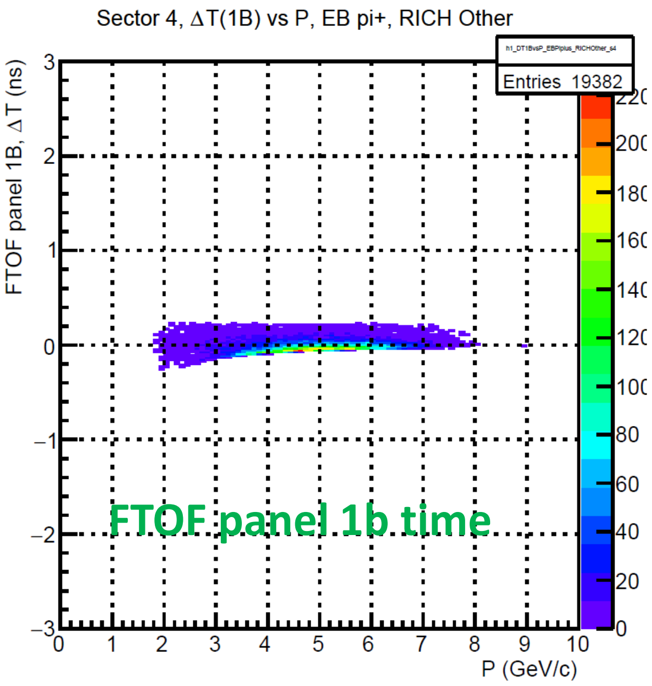
pi+ ID

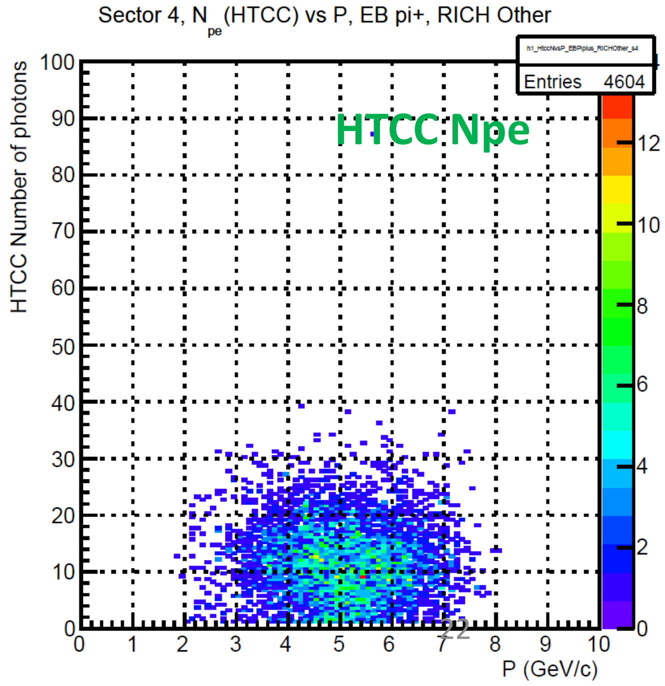




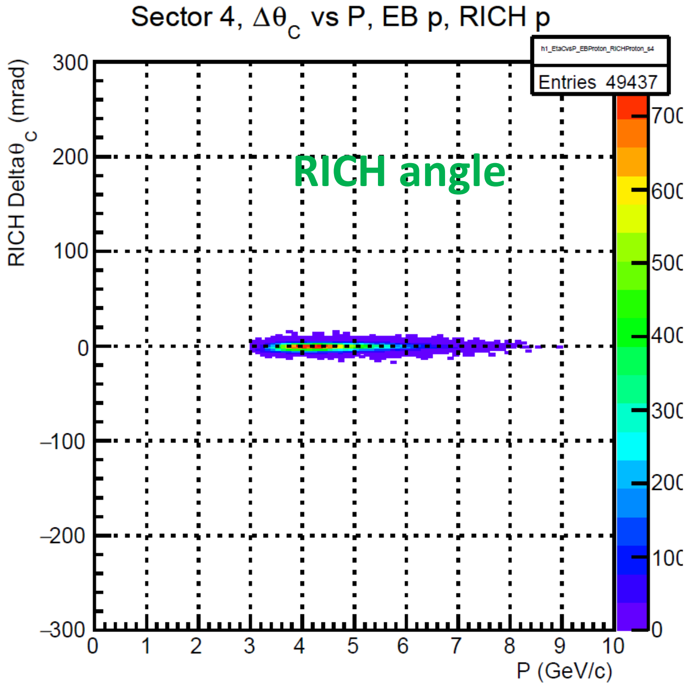
Particles that are pi+ in the EB but <u>something else in the RICH</u>

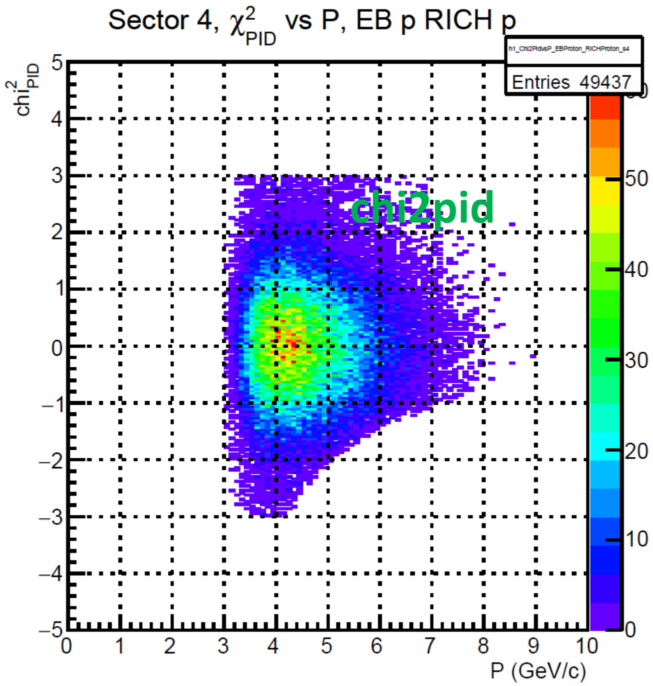




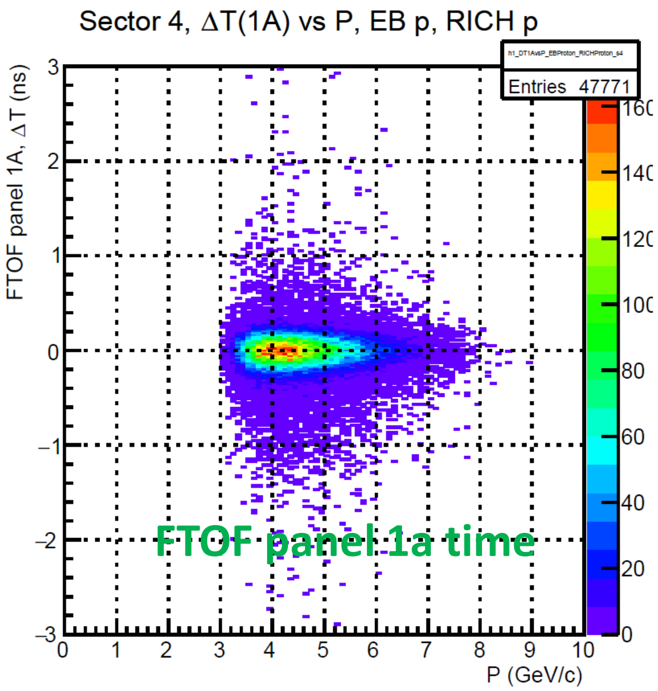


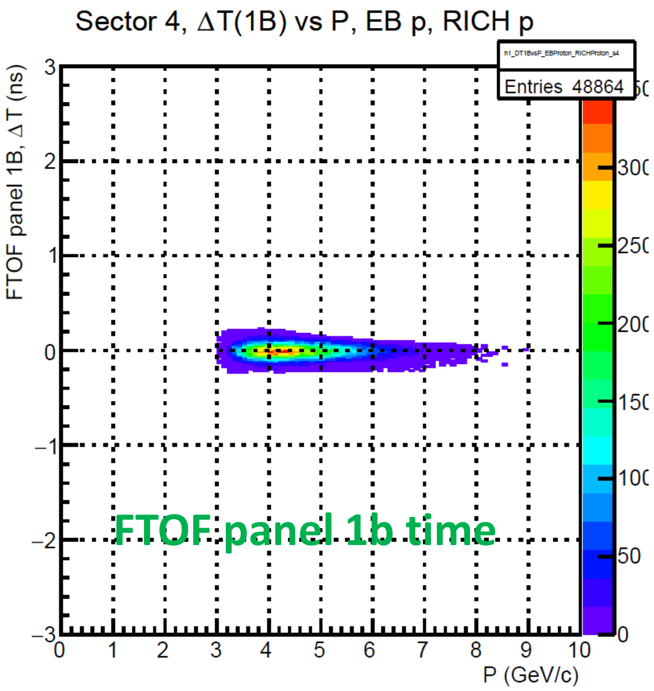
proton ID

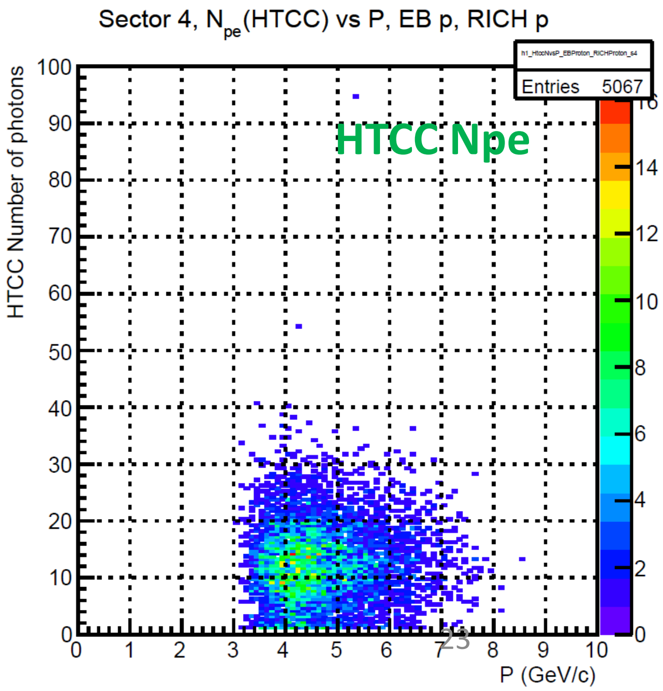




Particles that are protons in both EB and RICH

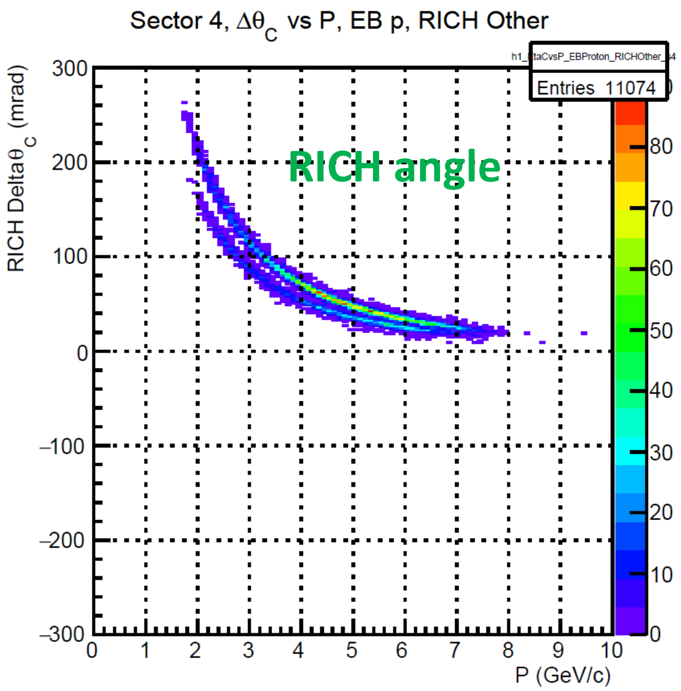


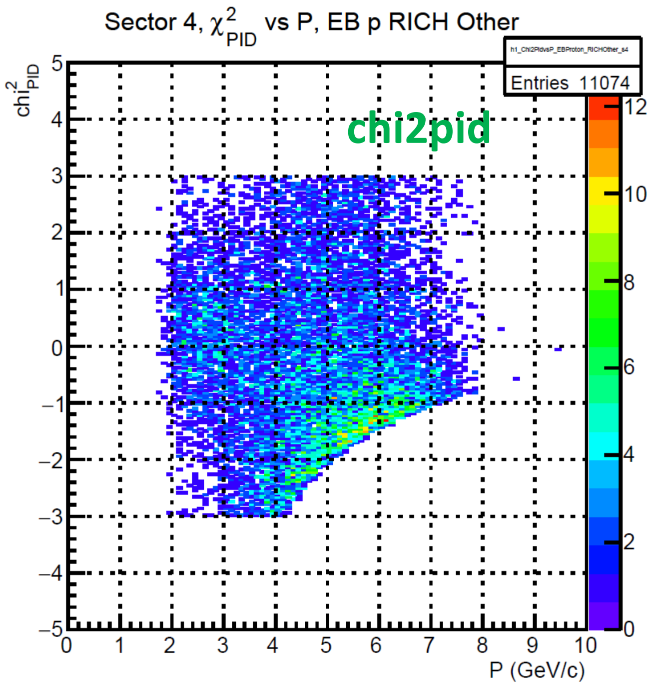


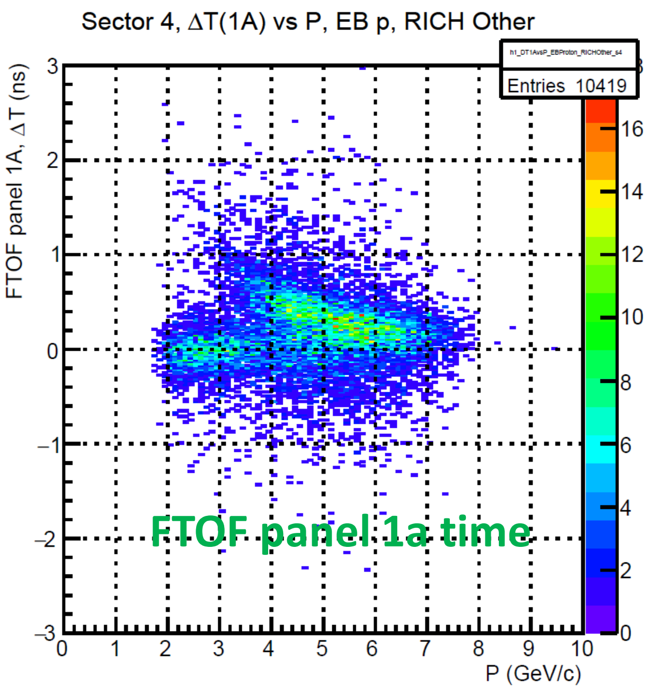


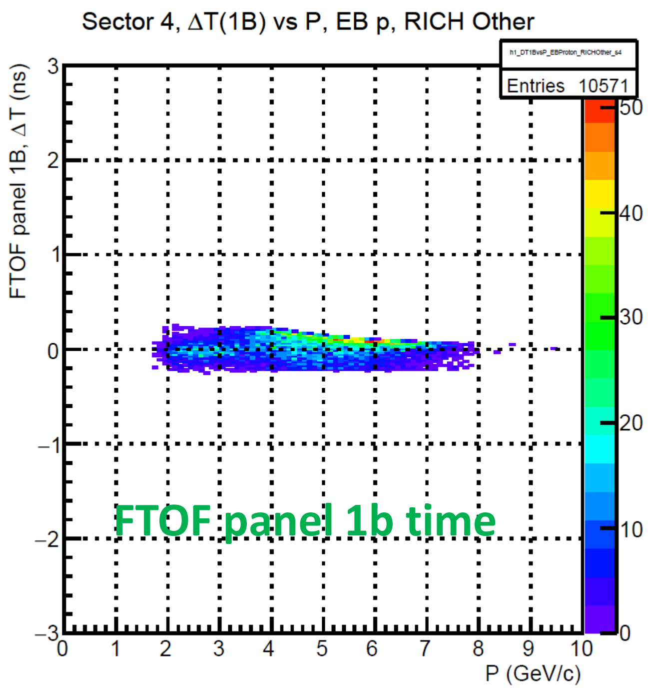
proton ID

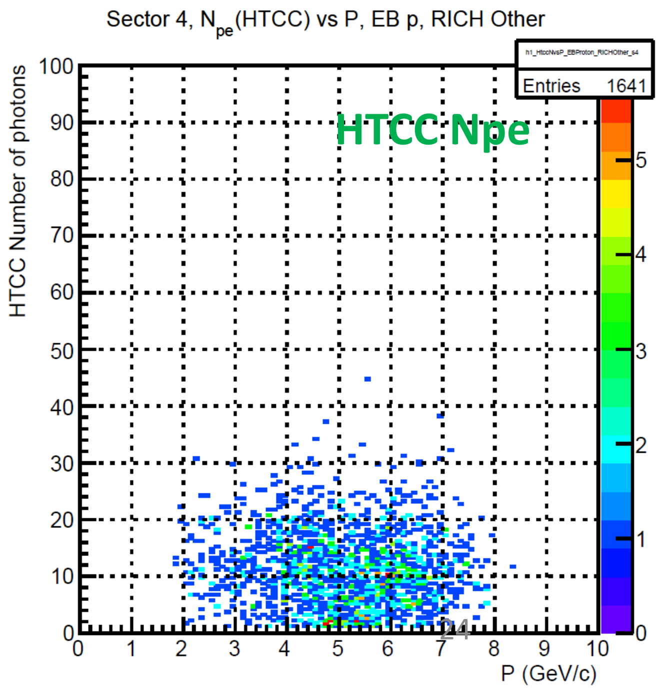
Particles that are protons in the EB but <u>something else</u> in the RICH



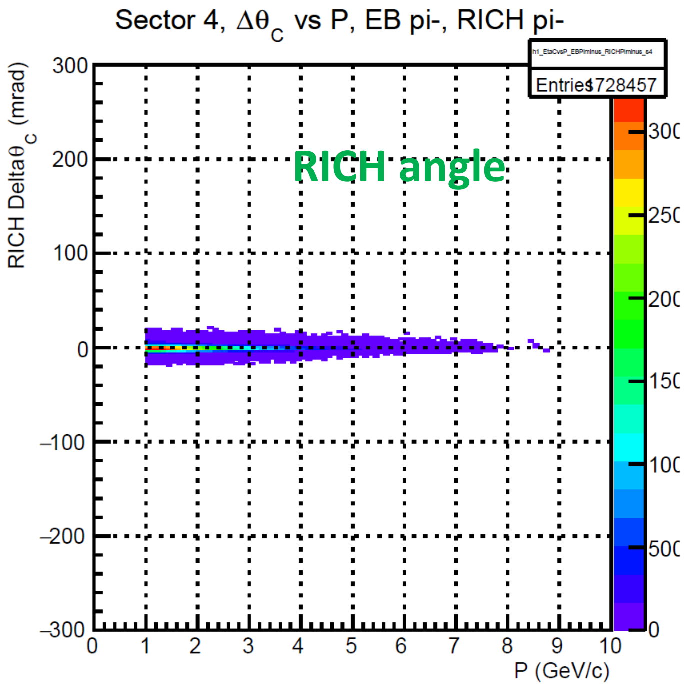


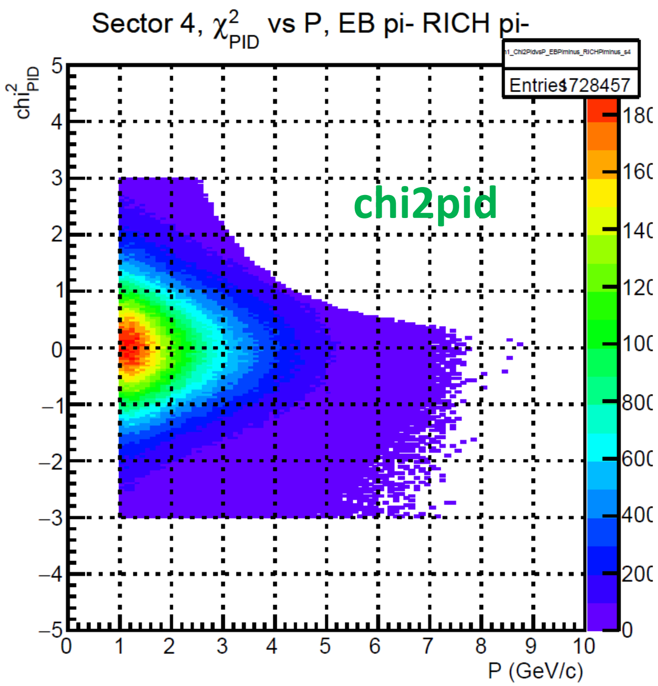




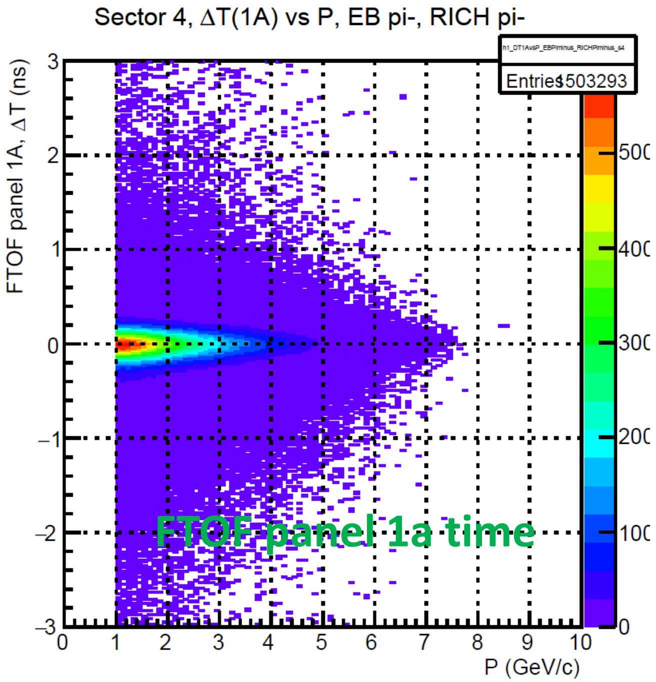


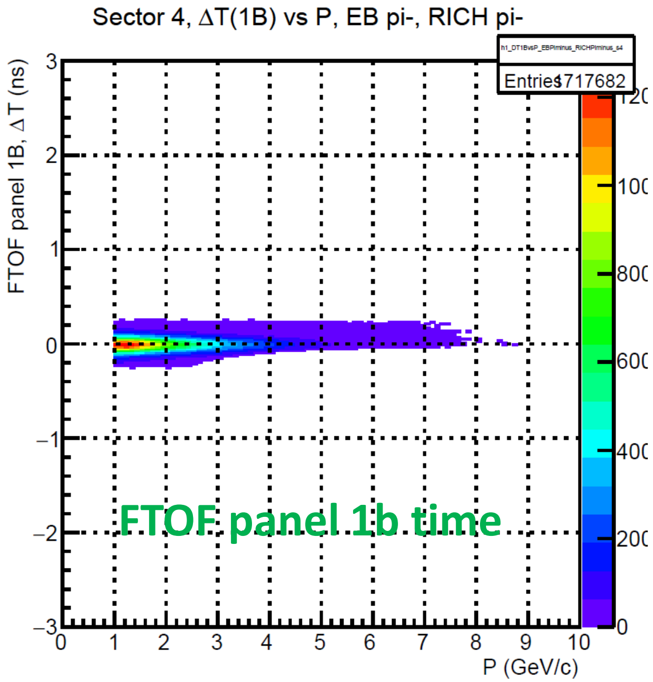
pi- ID

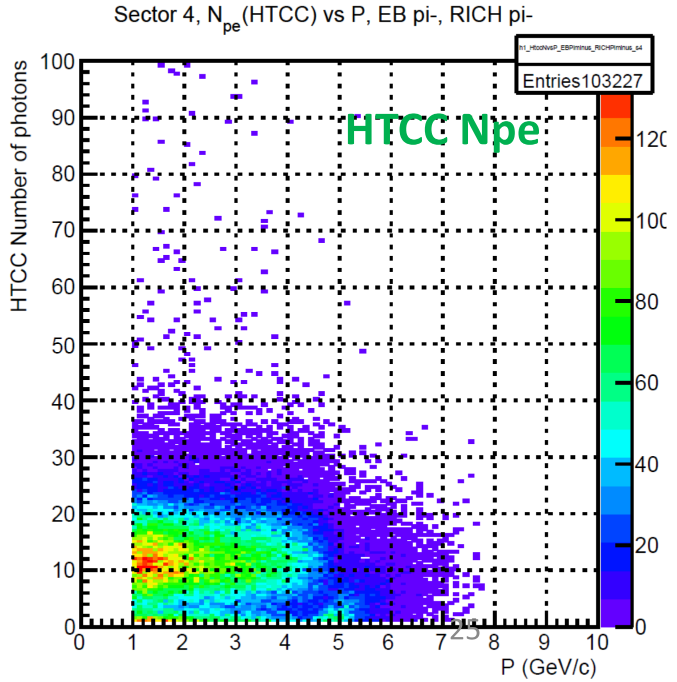




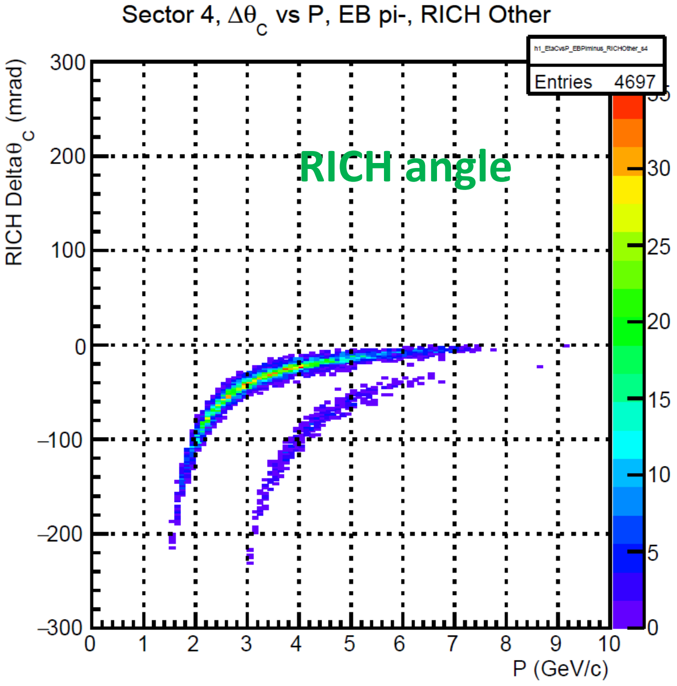
Particles that are pi- in both EB and RICH

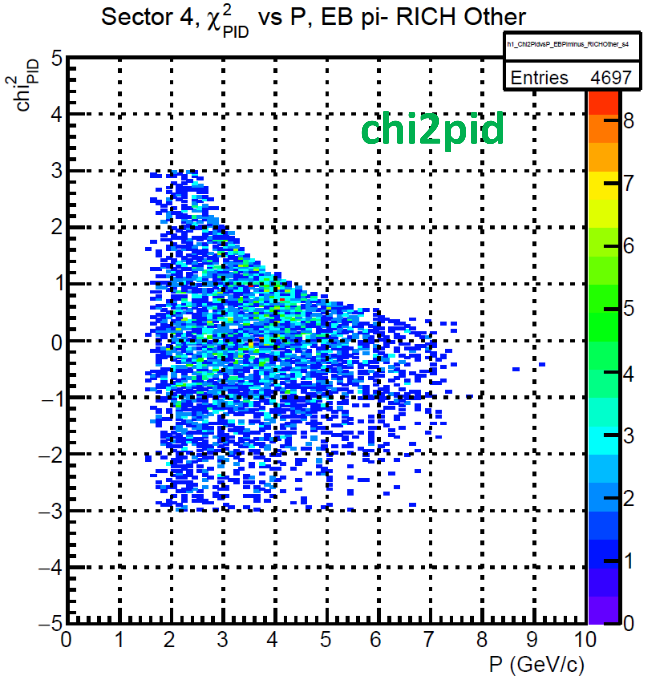




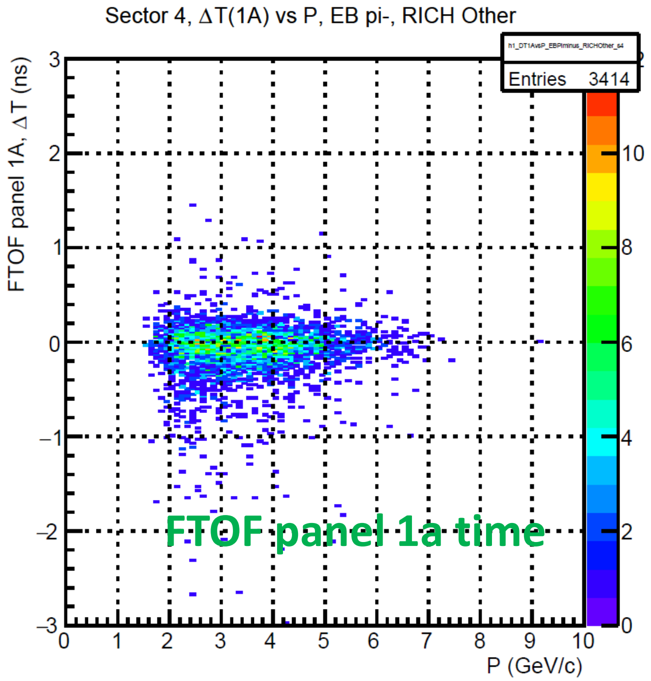


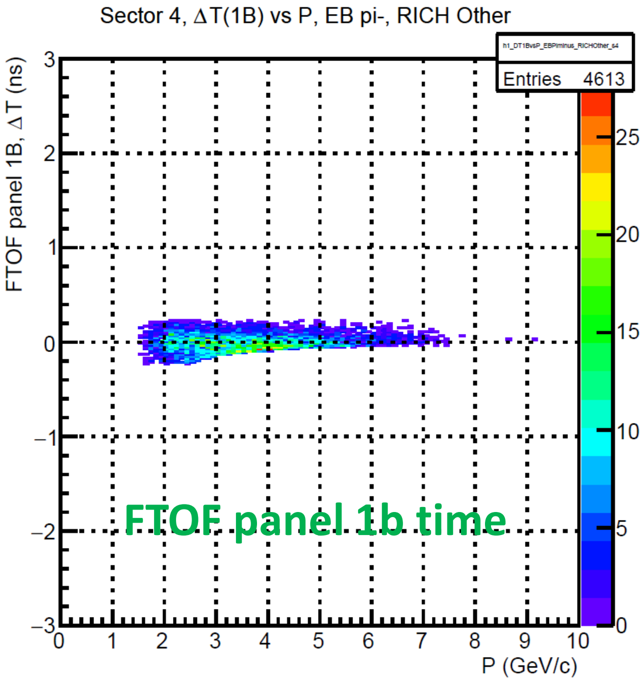
proton ID

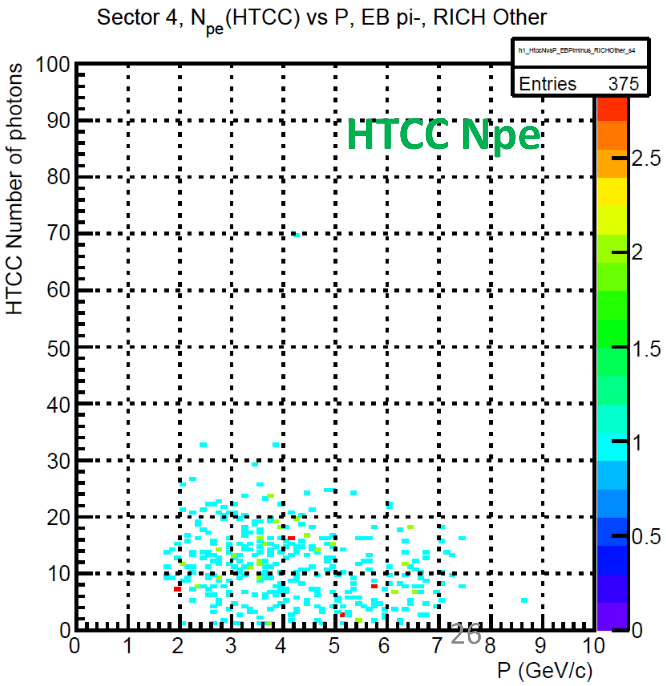




Particles that are pi- in the EB but <u>something else in the RICH</u>

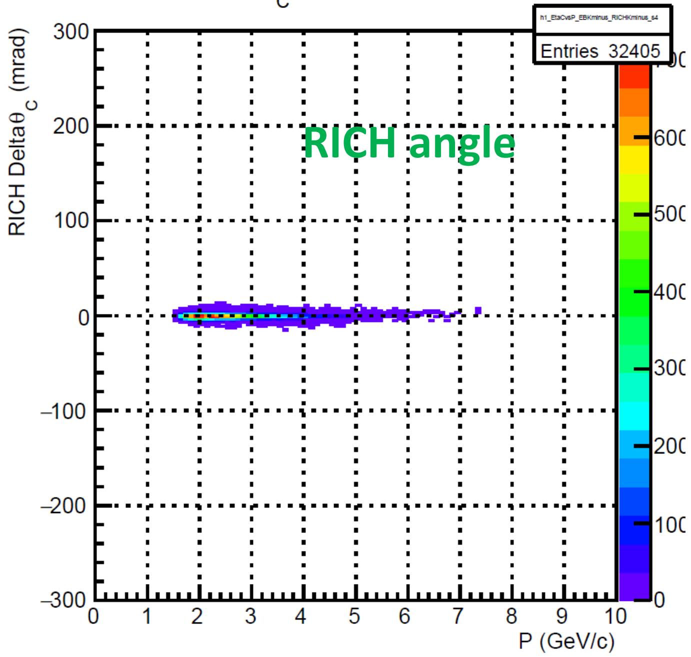




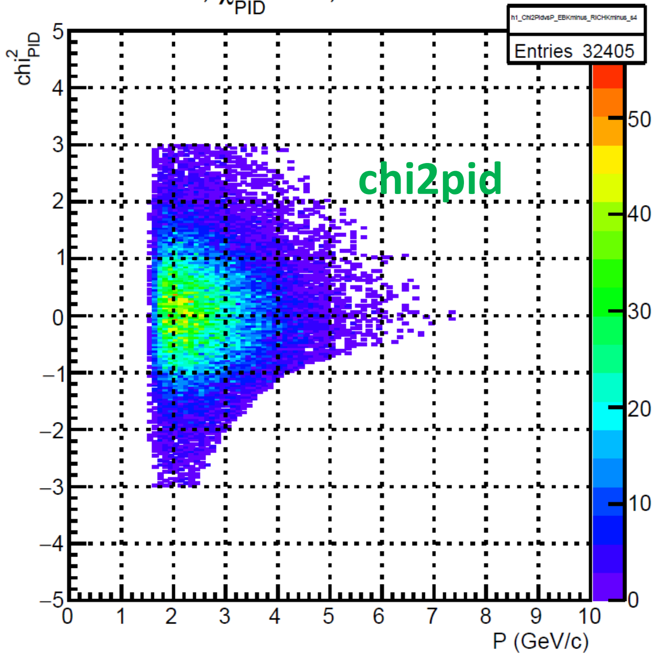


K- ID

Sector 4, $\Delta\theta_C$ vs P, EB K-, RICH K-

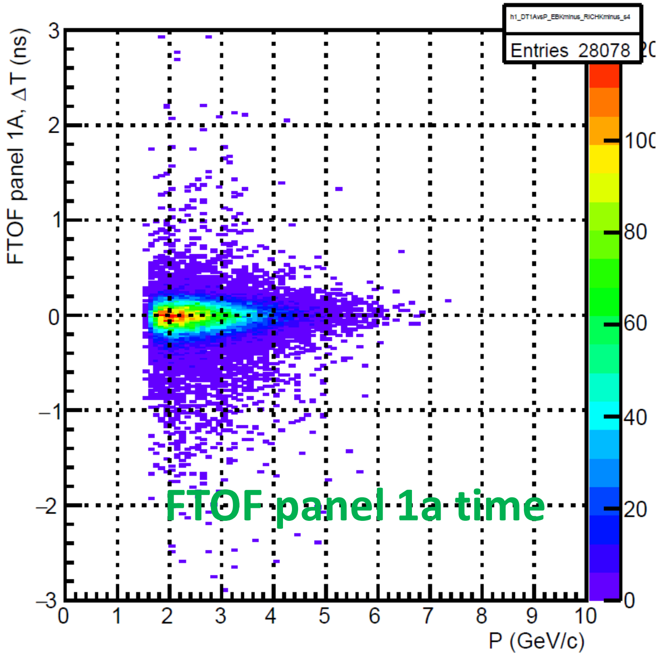


Sector 4, χ^2_{PID} vs P, EB K- RICH K-

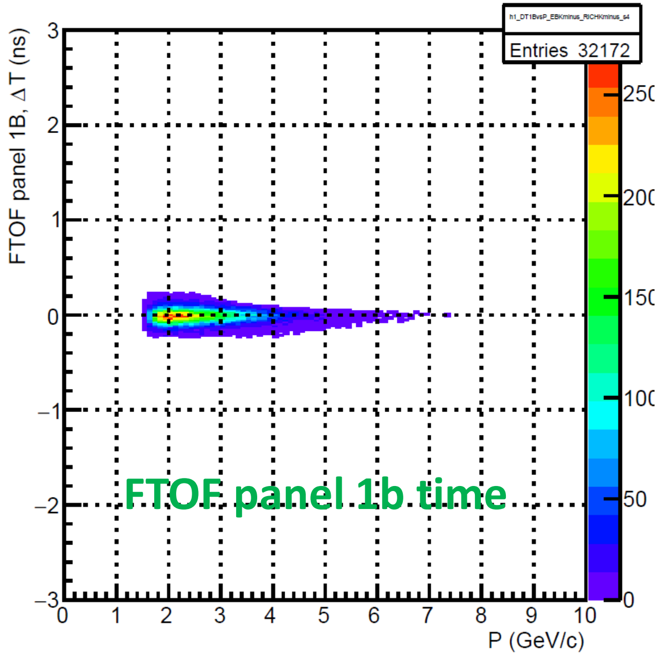


Particles that are K- in both EB and RICH

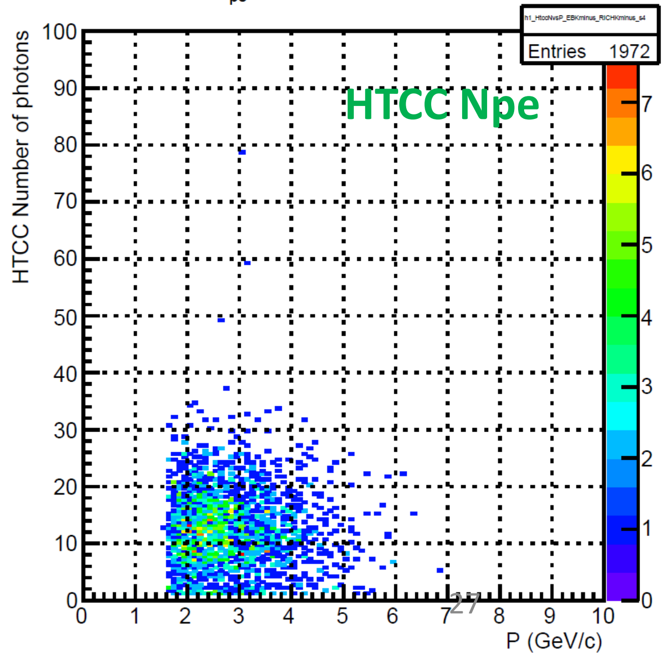
Sector 4, ΔT(1A) vs P, EB K-, RICH K-



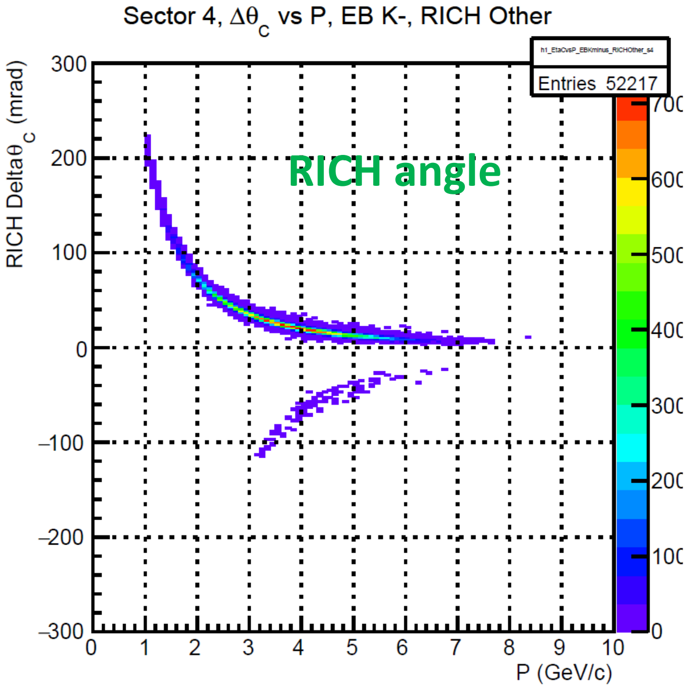
Sector 4, ΔT(1B) vs P, EB K-, RICH K-

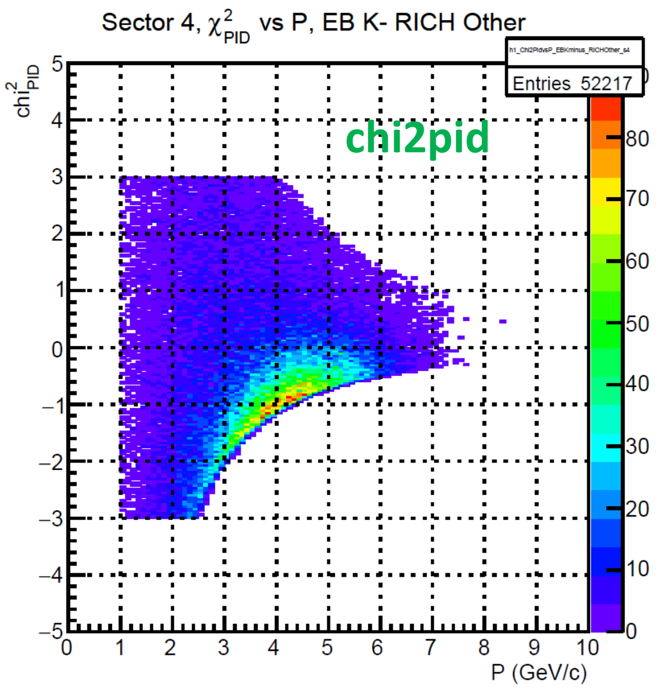


Sector 4, N_{pe}(HTCC) vs P, EB K-, RICH K-

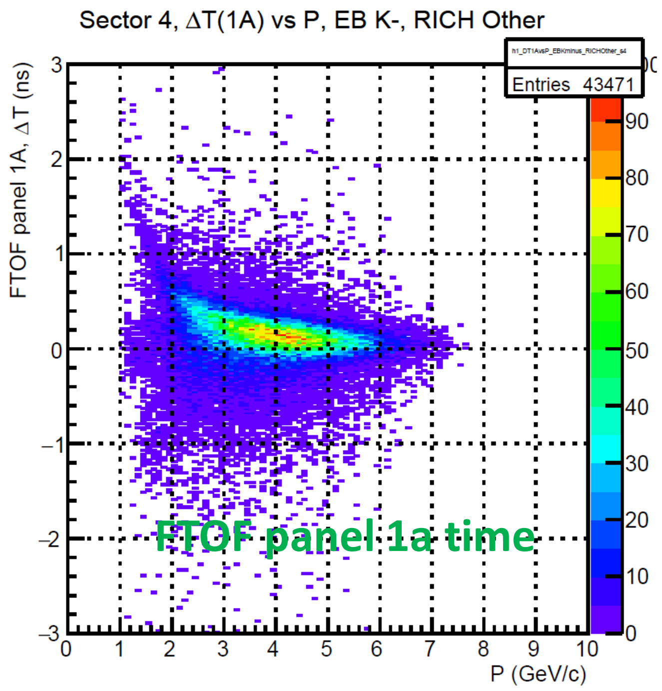


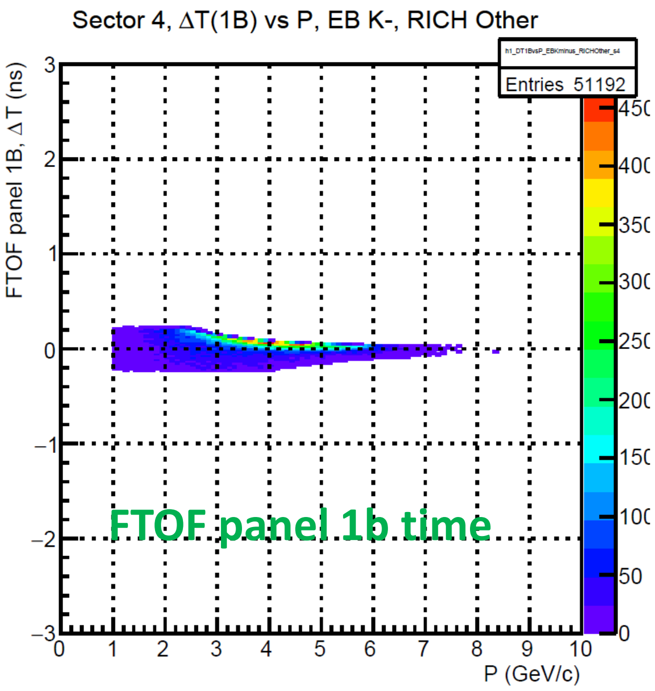
proton ID

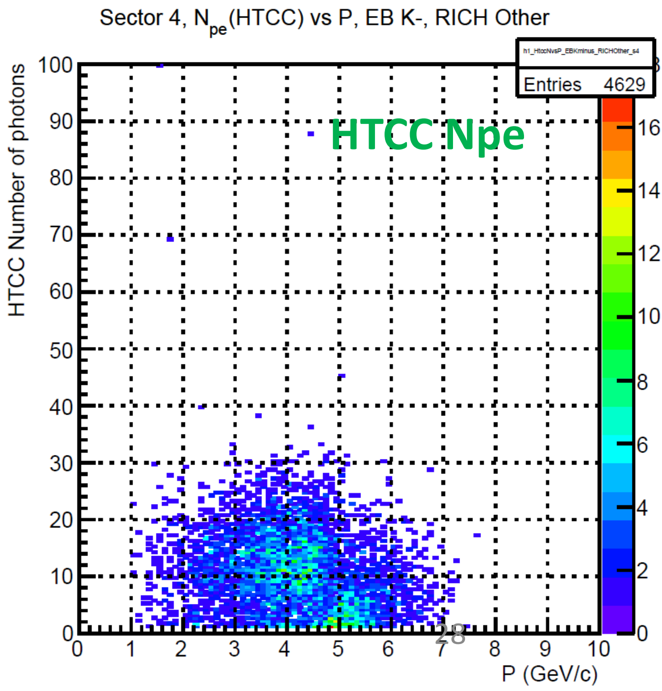




Particles that are K- in the EB but <u>something else in the RICH</u>

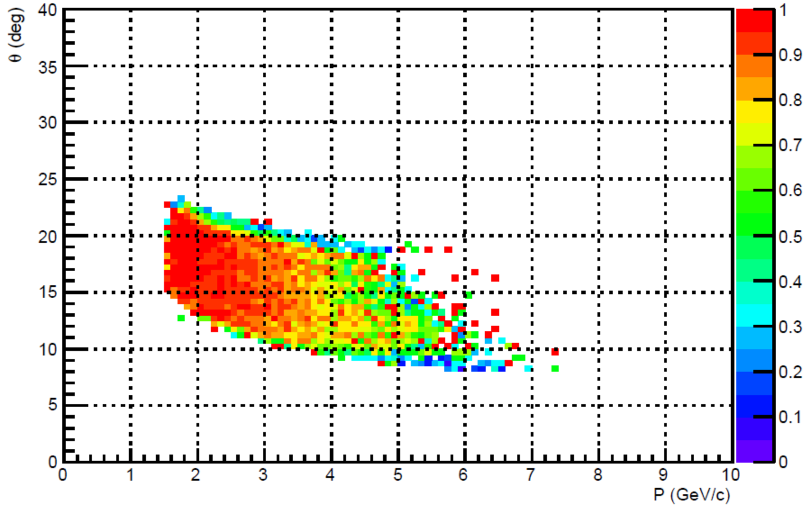




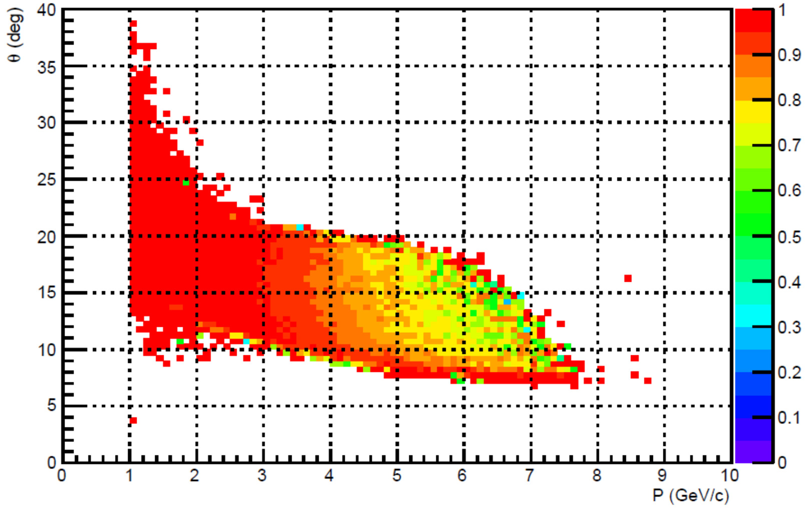


EB identification efficiency

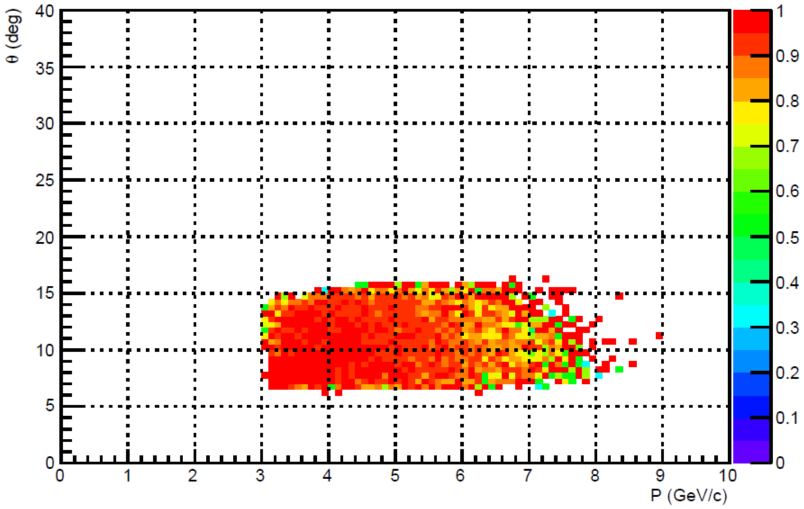
Sector 4, θ vs P, EB Efficiency K-



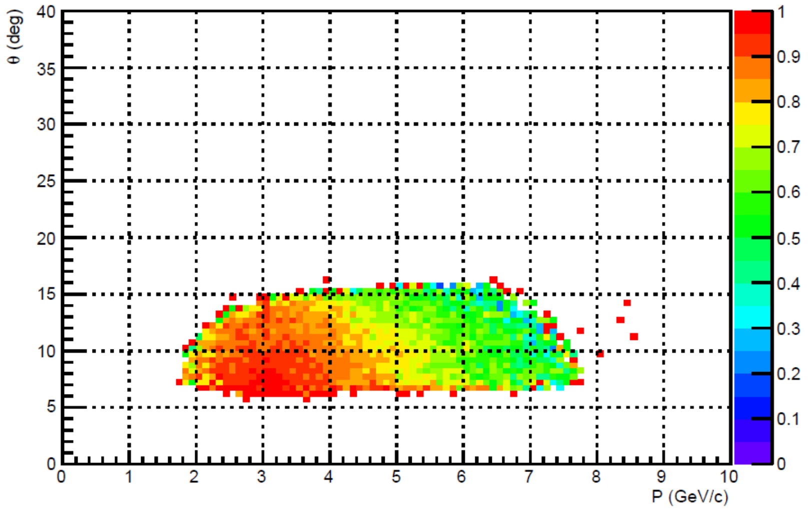
Sector 4, θ vs P, EB Efficiency pi-



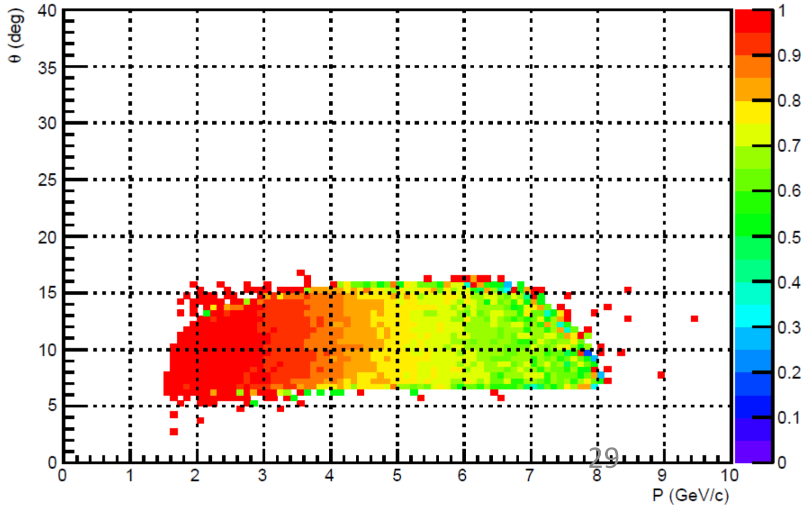
Sector 4, θ vs P, EB Efficiency p



Sector 4, θ vs P, EB Efficiency K+



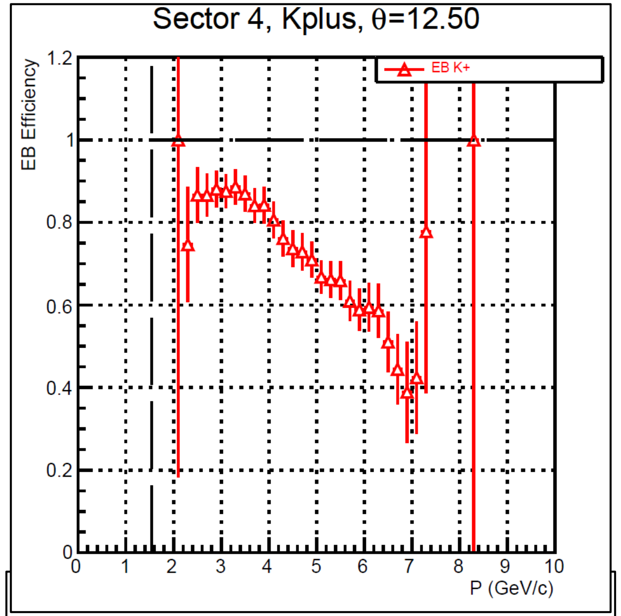
Sector 4, θ vs P, EB Efficiency pi+



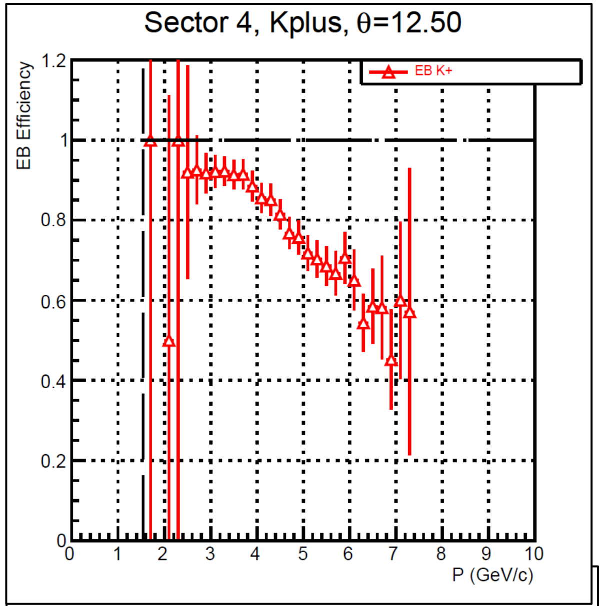
EB efficiency: Outbending vs inbending data

No significant differences reversing the torus and/or the charge

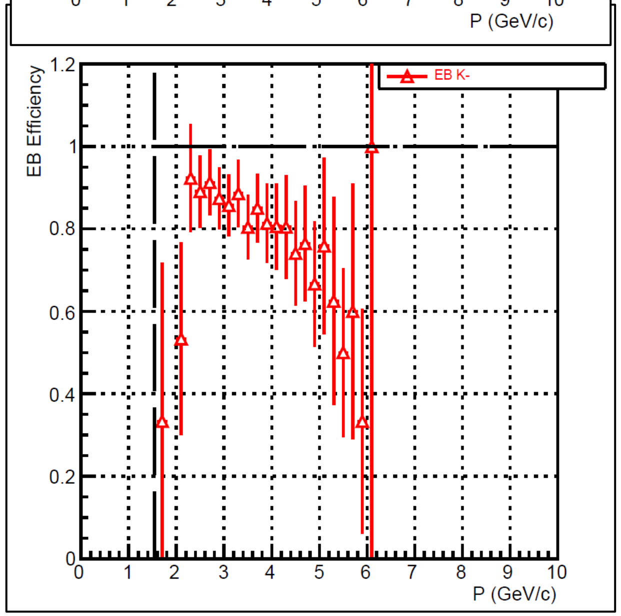
RG-A spring 19 inbending field K+



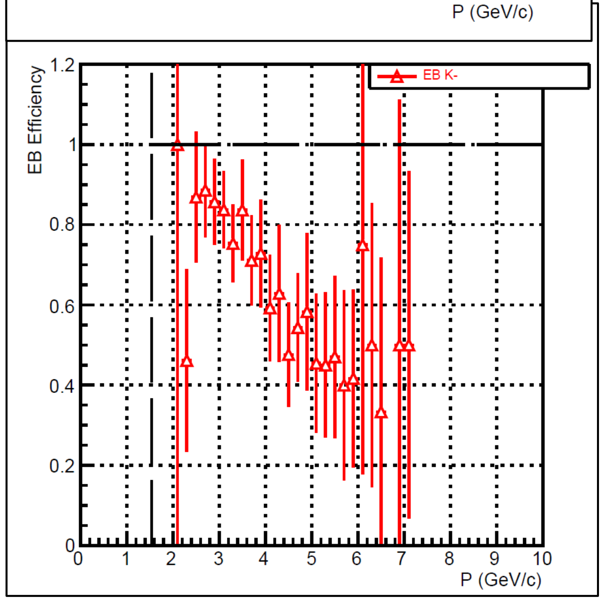
RG-A fall 18 outbending field K+



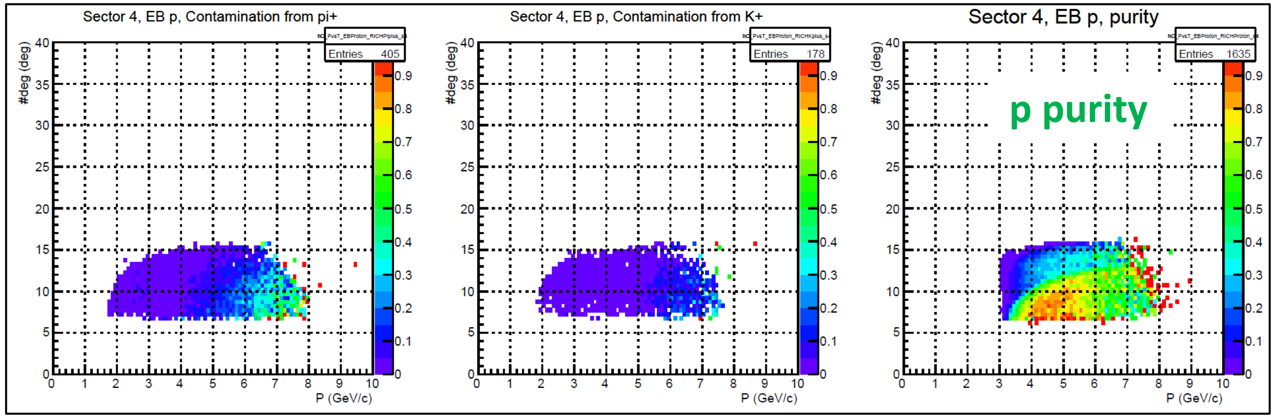
RG-A spring 19 inbending field K-

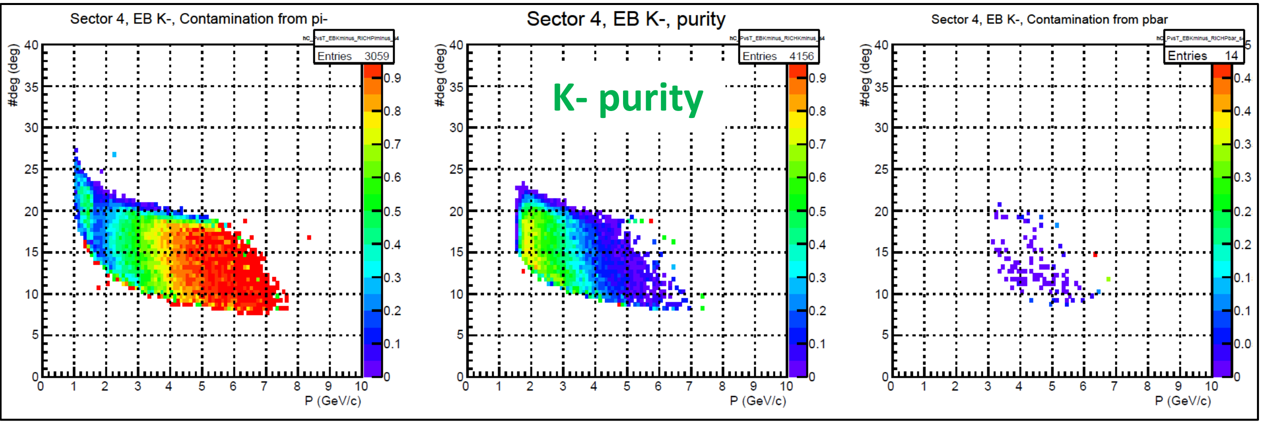


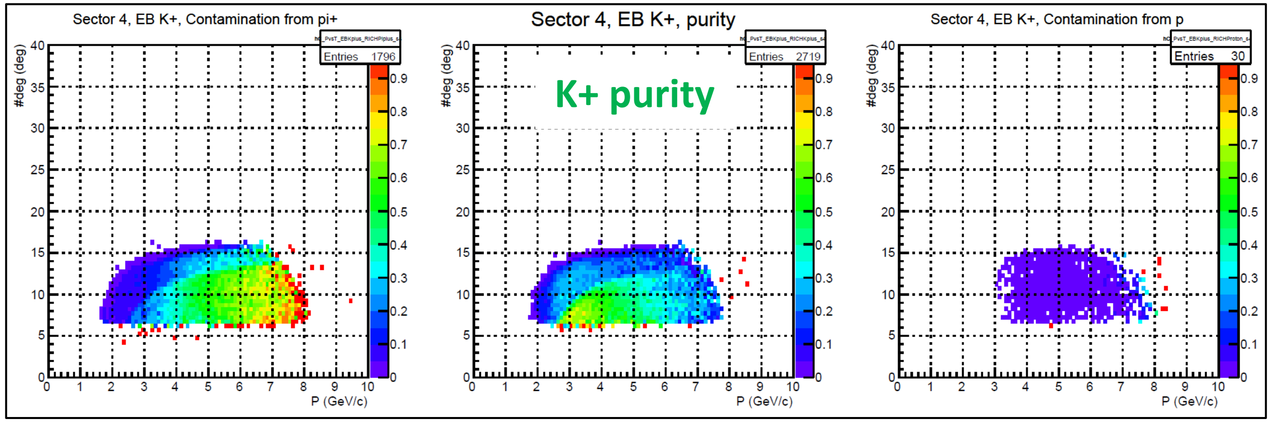
RG-A fall 18 outbending field K-

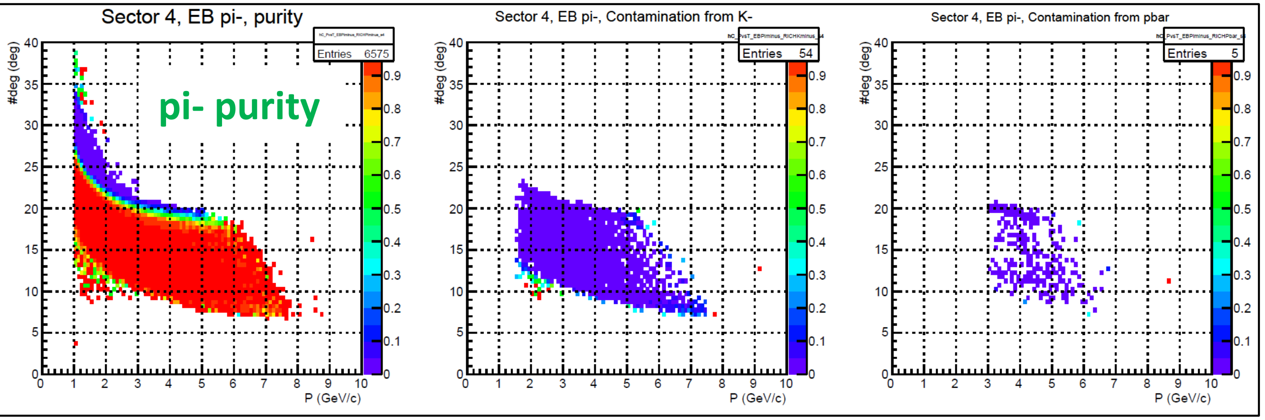


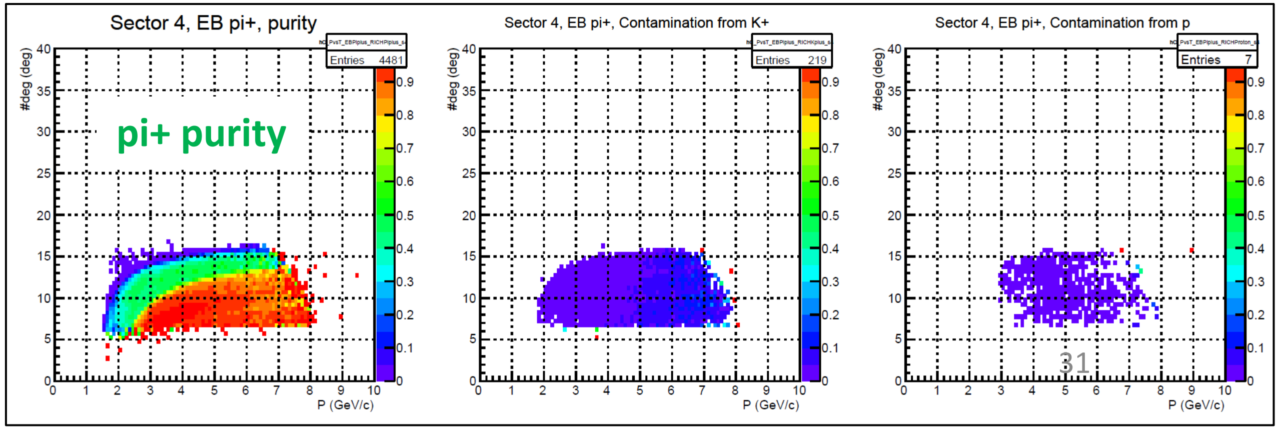
EB misidentification







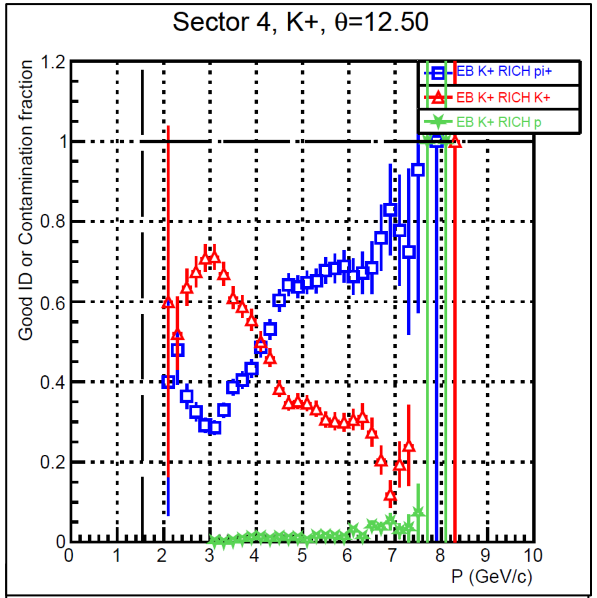




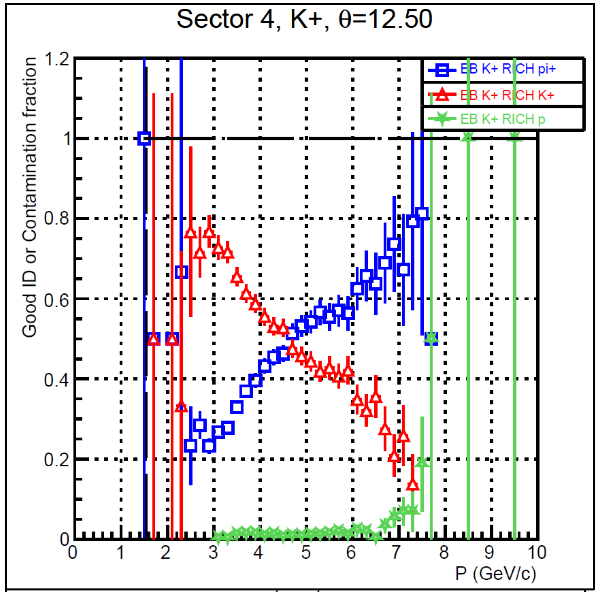
EB misedintification: Outbending vs inbending data

The purities and contaminations are mainly driven by the physical K/pi production ratio

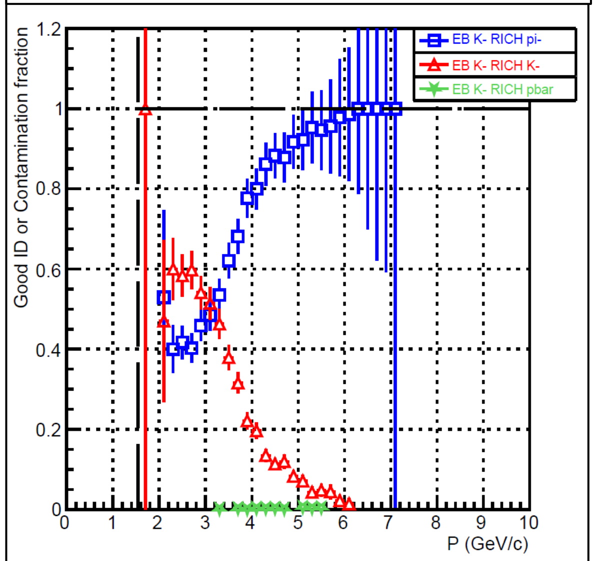
RG-A spring 19 inbending field K+



RG-A fall 18 outbending field K+



RG-A spring 19 inbending field K-



RG-A fall 18 outbending field K-