CLAS collaboration meeting - JLAB

30.03.2017

Simulation of e p → e p π^0 with the CLAS12 simulation and reconstruction / analysis framework

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

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The work has been done during a stay at INFN Genova in cooperation with Marco Battaglieri, Andrea Cenlentano, Derek Glazier and Raffaella de Vita

Outline

<u>Aim:</u> Simulation of the channel e p → e p π^0

<u>Secondary aim:</u> Get the complete simulation and analysis chain working

<u>Steps of the simulation/analysis chain</u>:

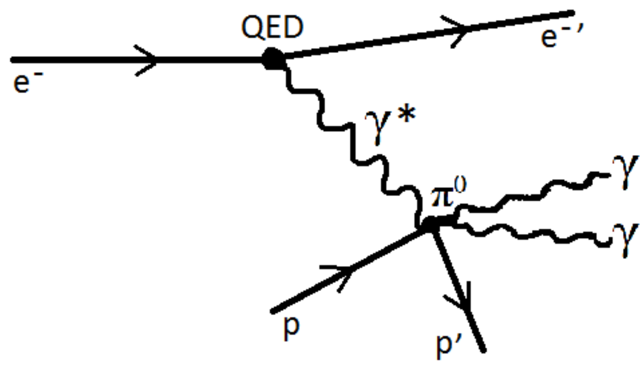
- Generate physics data with AmpTools
- Simulate the response of the CLAS detector and the forward tagger with gemc
- Reconstruct the data with CLARA
- Convert the output to the HASPECT format (root)
- Do physics analysis with the HASPECT framework

Step 1: Physics data generation with AmpTools

- Andrea has provided a macro, which uses AmpTools to generate physics events for the channel e p → e p π^0 based on amplitudes from Vincent
- The beam energy has been set to 11 GeV
- The macro contains the condition that electrons are only generated under a forward angle between 2.5° and 4.5° and with energies between 0.5 GeV and 4.5 GeV

→ Only these electrons will be detected by the FT and act as part of the trigger for the MesonEx experiment

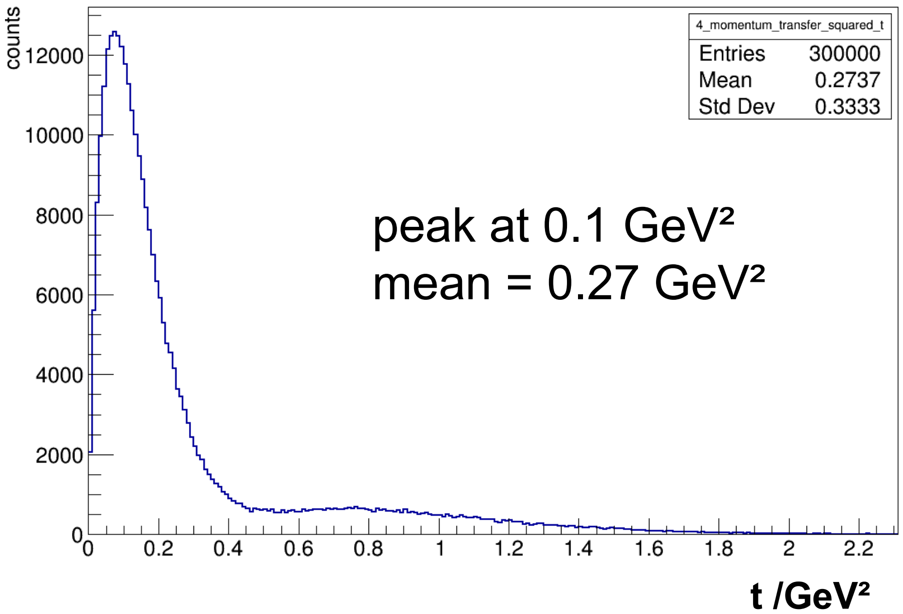
→ The quasi real photons produced by the electrons scattered under a very small angle (low Q^2) are used for the photoproduction of the neutral pion.



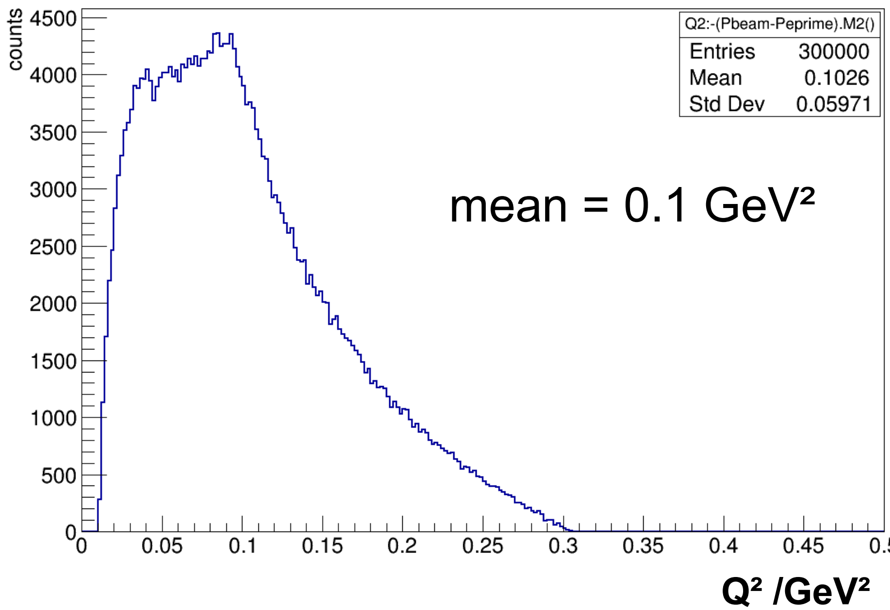
Reaction kinematics of the generated data

- The generated events have been analyzed to get a first impression how the reaction kinematics will look like

t-distribution



Q²-distribution of the virtual photon

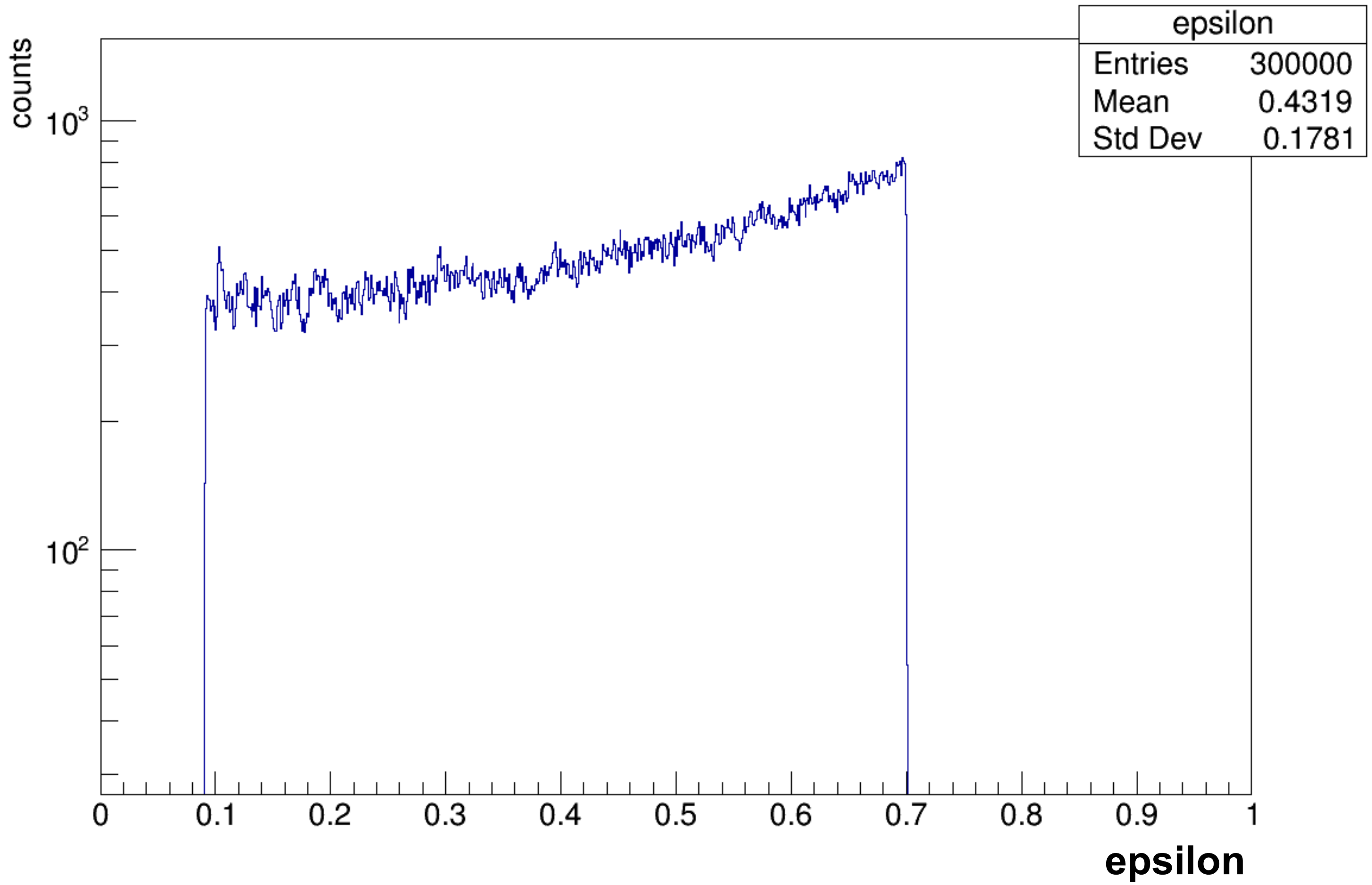


Q^2 distribution is not exactly 0 like for a real photoproduction experiment

→ Has to be considered by small corrections in the amplitude model

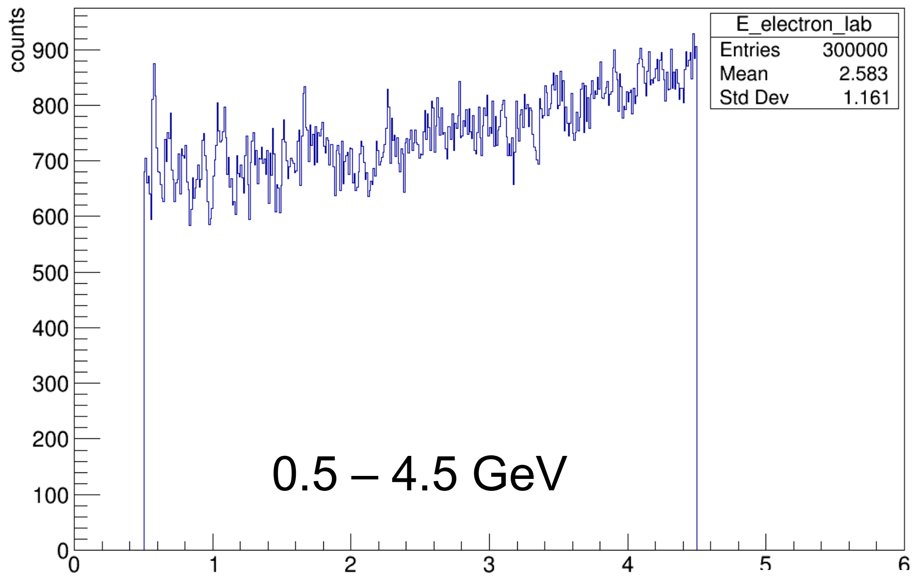
Reaction kinematics of the generated data

degree of transverse polarization of the virtual photon (epsilon):



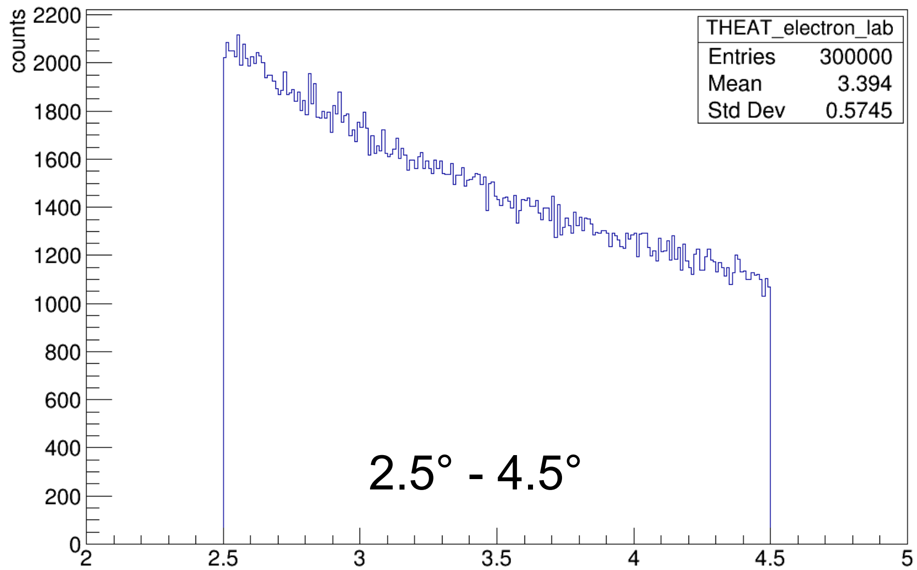
Kinematics of the scattered electron

electron energy



energy /GeV

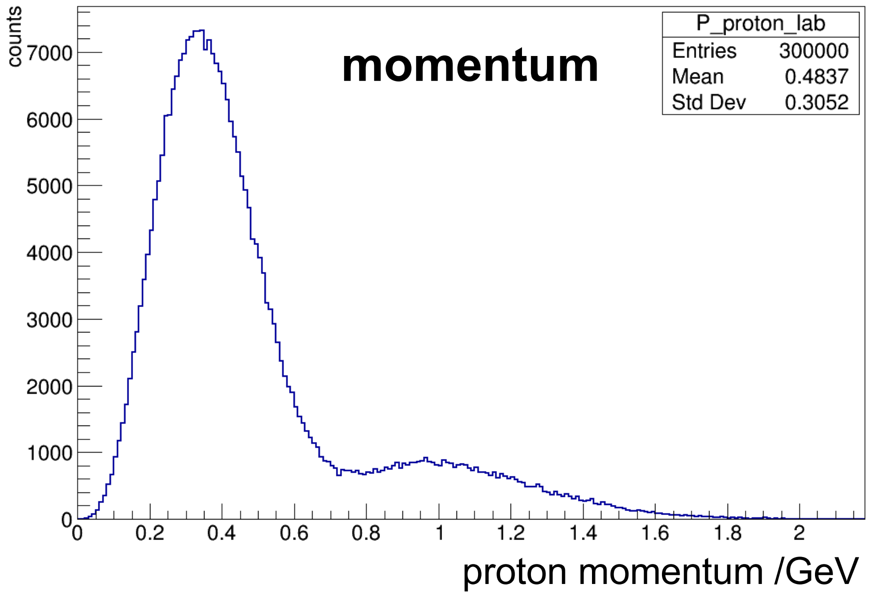
electron theta distribution

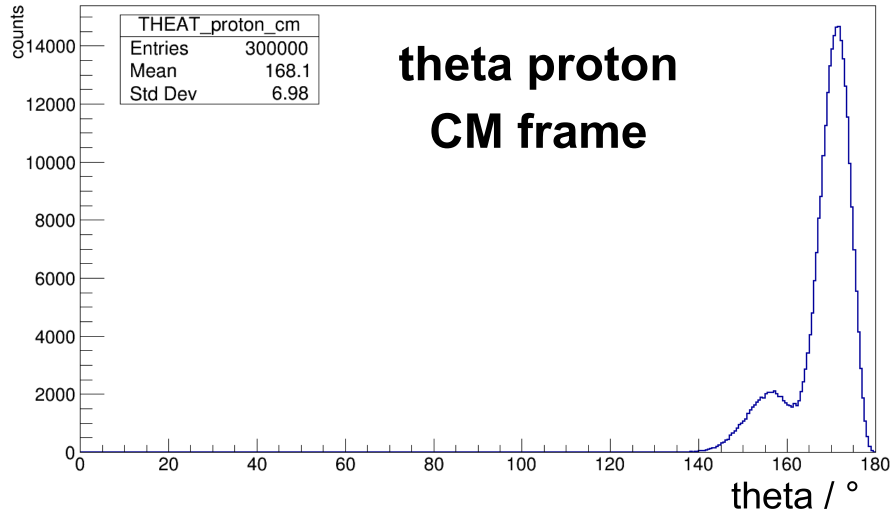


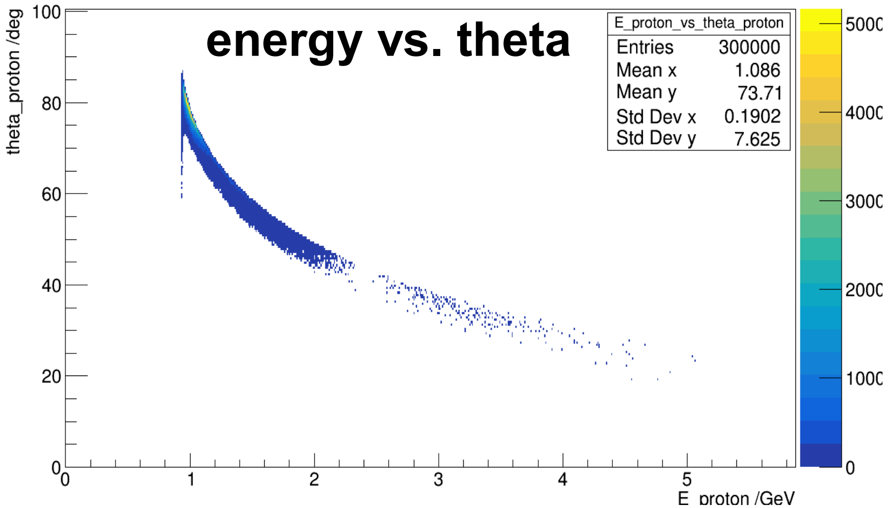
theta / °

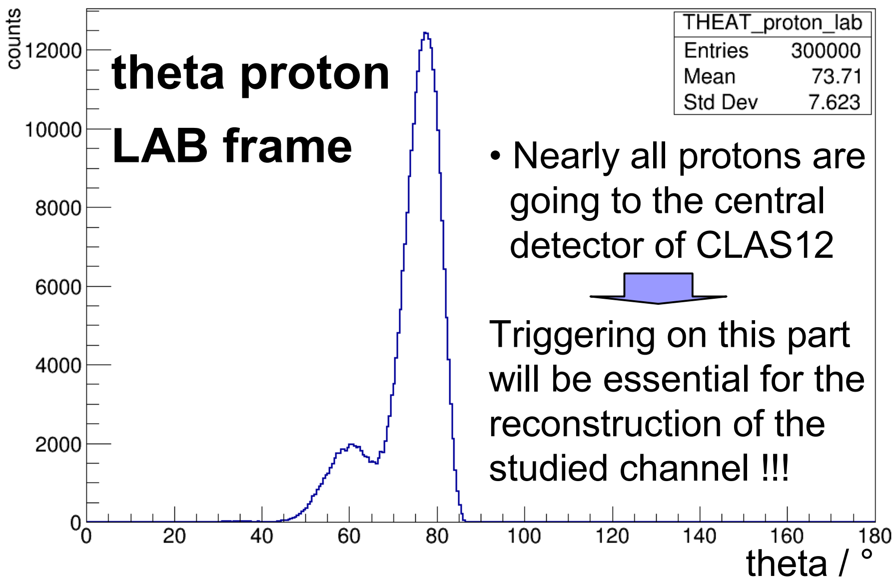
- The energy and the angle theta of the electron are only simulated within the acceptance range of the forward tagger (trigger condition)

Kinematics of the proton







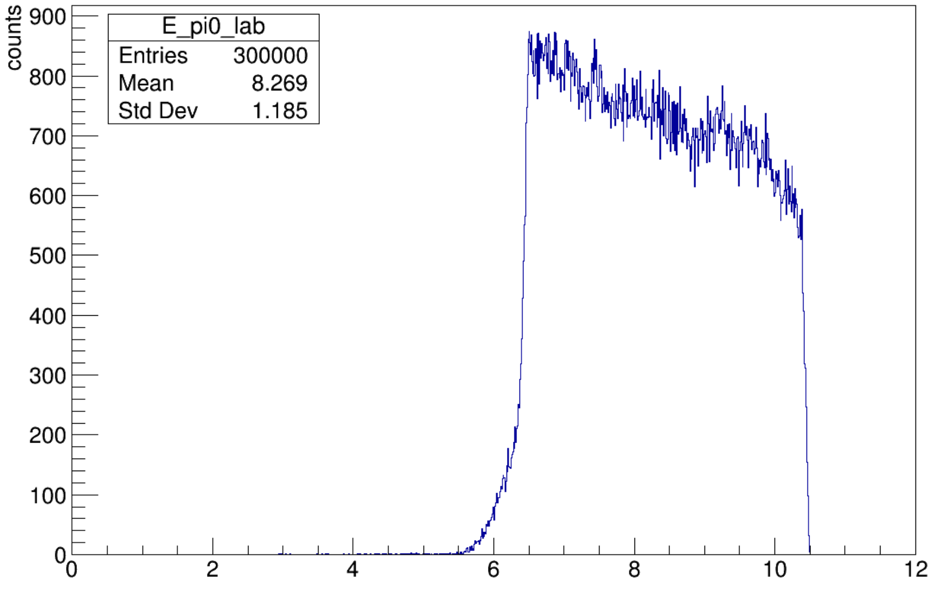


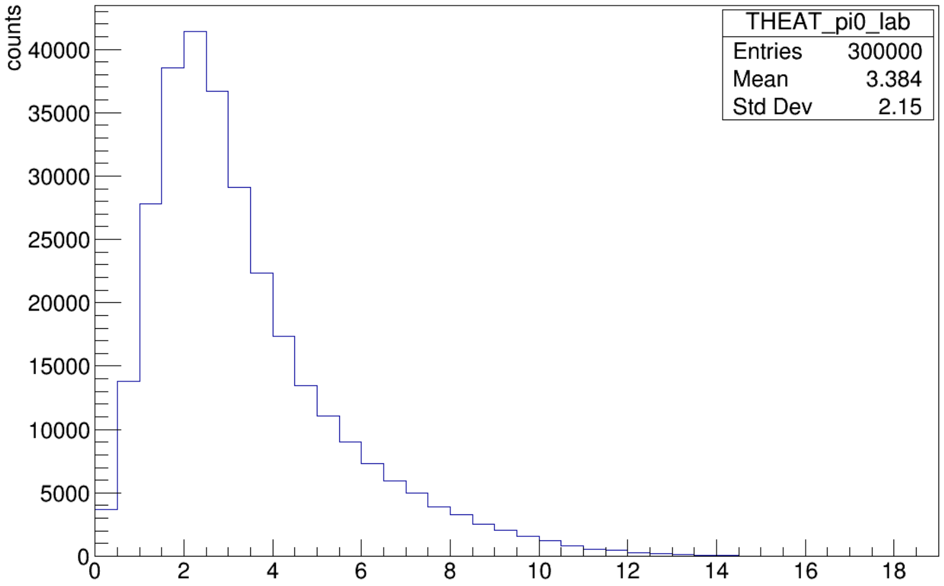
- Nearly all protons are going to the central detector of CLAS12

Triggering on this part will be essential for the reconstruction of the studied channel !!!

Kinematics of the neutral pion

energy distribution of the pion | **theta distribution of the pion**

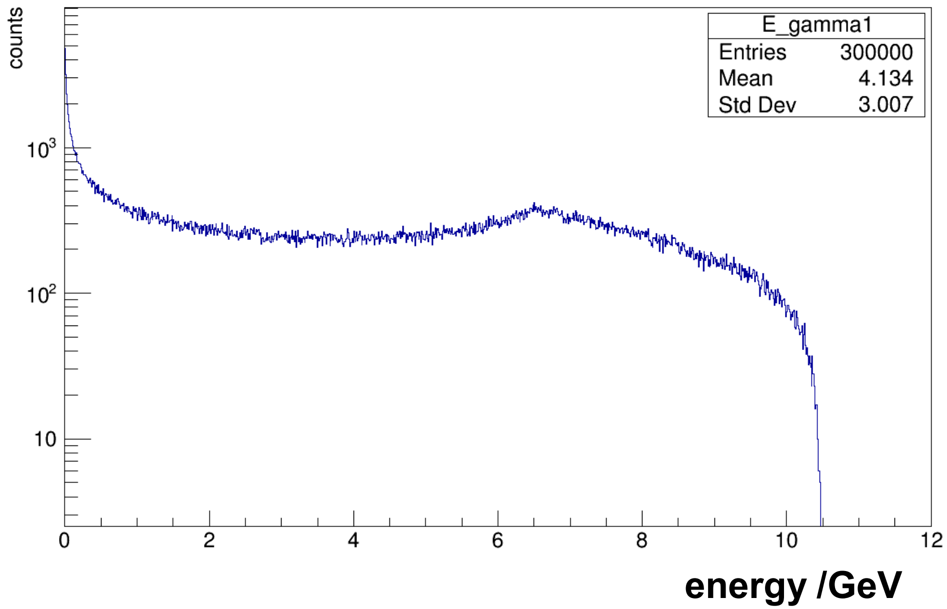




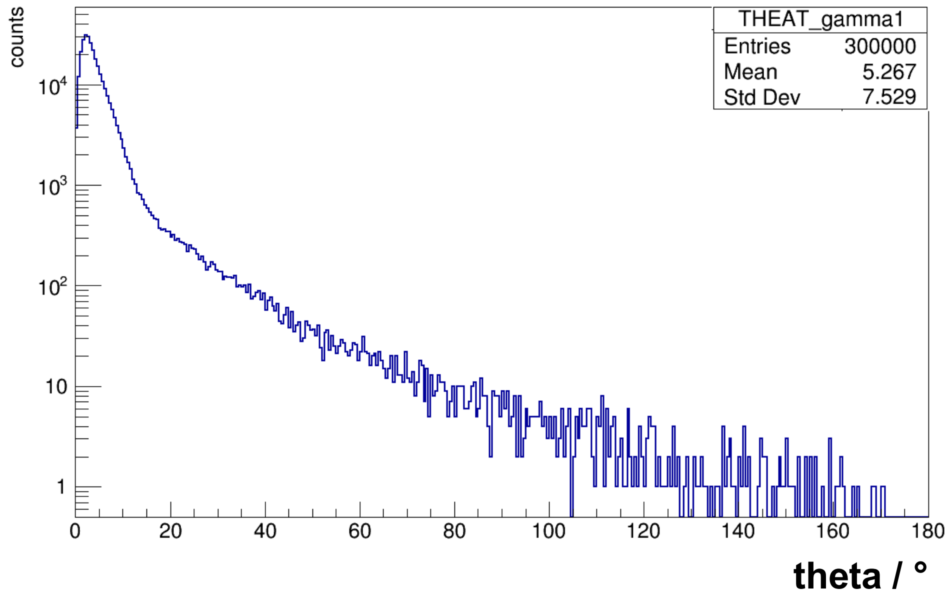
- π^0 has a quite high energy and is emitted in forward directions
- Information for π^0 can be used to calculate the gammas
  - → Random back to back distribution in the CM frame
  - → Boost to the LAB frame

Calculated kinematics of the two gammas

energy distribution of the gammas



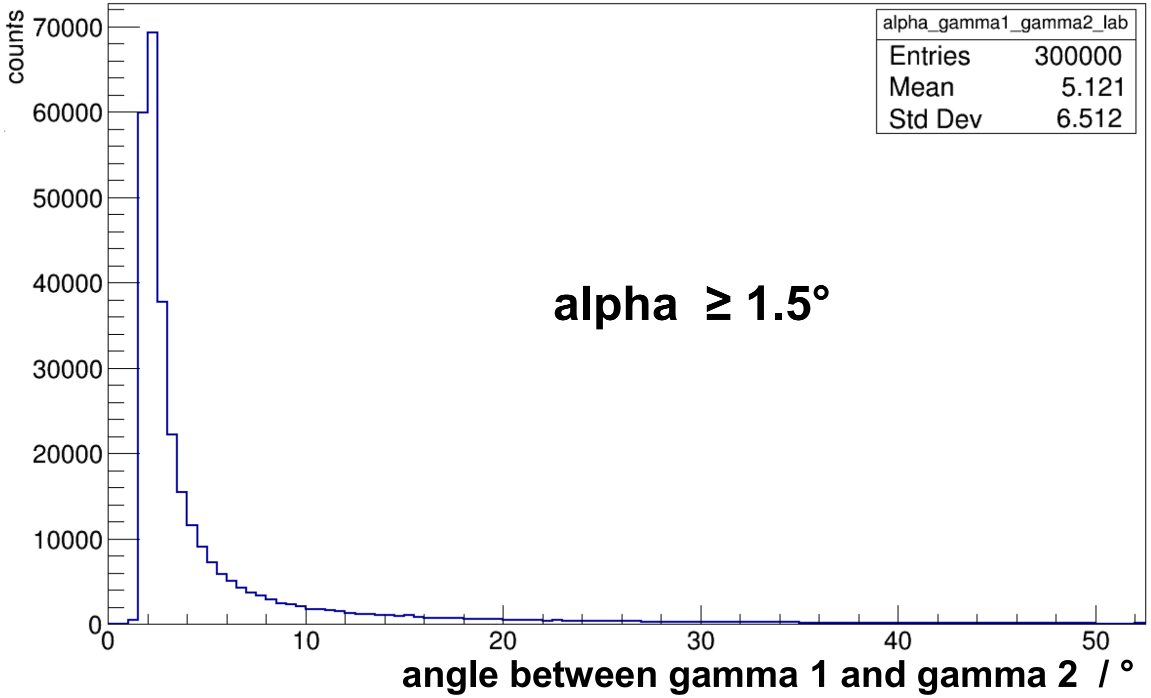
theta distribution of the gammas

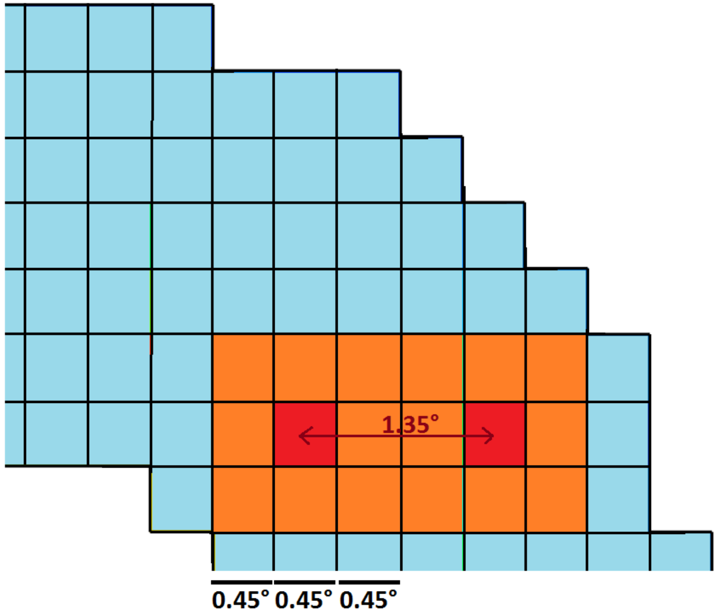


- Many low energetic gammas
- Most gammas are detected by the forward tagger and the forward detector of CLAS12

Angle between the two gammas of the π^0 decay

Angle between the two gammas





- Narrow angle between the gammas for most of the pairs, but gamma clusters can be separated in most cases

Step 2: Simulation of the detector response with gemc

- AmpTools provides the generated events in the **lund format** (text file) which is used as **input for gemc**

- Simulation has been performed with a realistic resolution (RUNNO = 11)

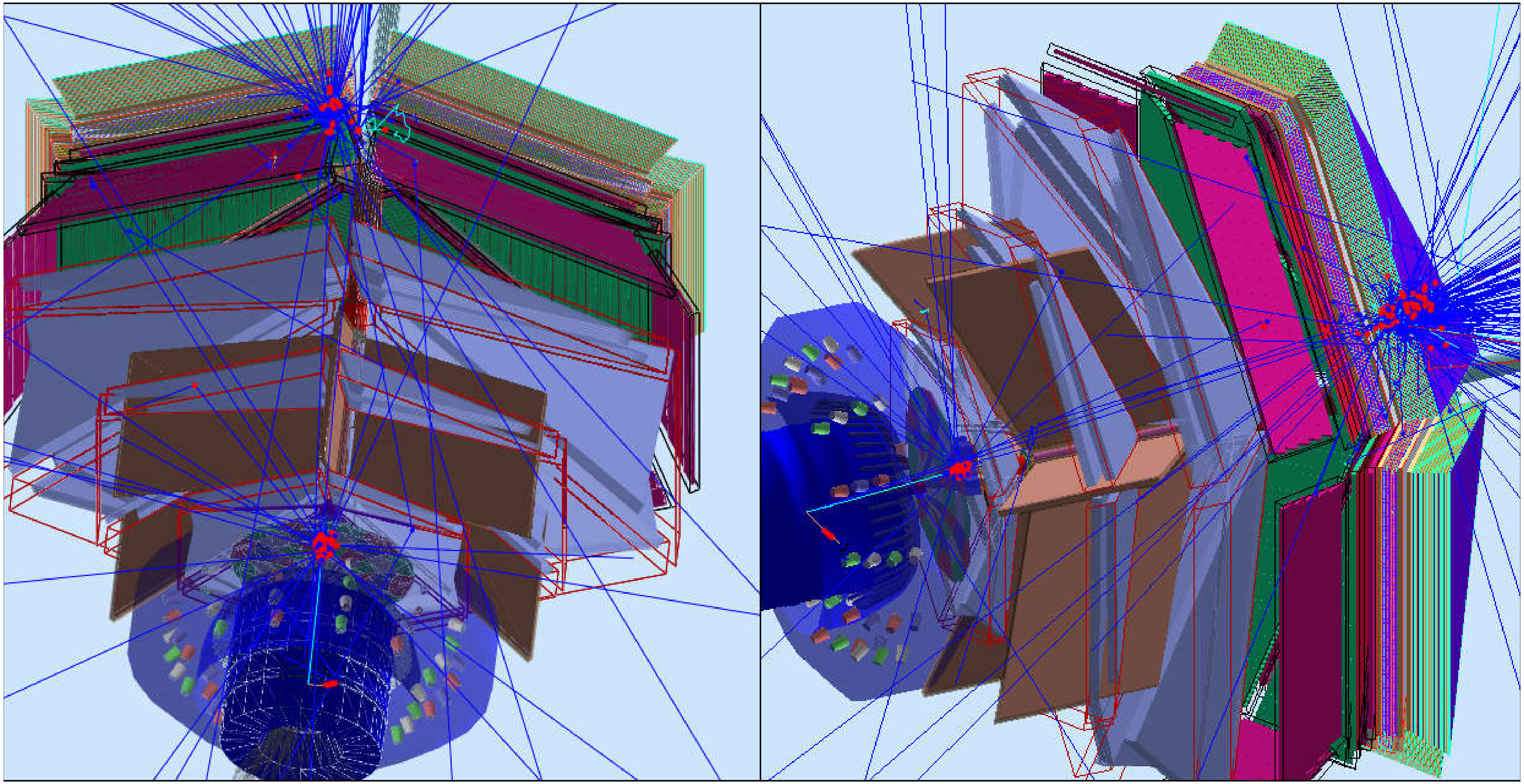
- Simulation takes 1.2 - 1.5 s per event with 2 Intel i5 650 (3.2 GHz) cores (approx. 55000 events are simulated in 24 h)

  → Move to a cluster for larger event numbers

Output of the simulation: evio file

→ Has to be converted to the hipo format to pass it through the reconstruction

gemc GUI for the visualization of the simulation



Step 3: Reconstruction of the events with CLARA

- CLARA is based on COATJAVA
- CLARA stores the reconstructed particles in a hipo database in which also the generated particles are kept
- In addition all information about the output of the detectors which contributed to the reconstructed events can be looked up in this database

To consider: In the used version of CLARA tracking in the CD had been deactivated to fix an issue

→ Protons in the CD are not reconstructed!

➔ Issue is fixed in the recent version of CLARA

- The database can be directly accessed to view the events
- For further analysis the contained information have to be read out from the databse and converted to the HASPECT format (root)

HIPO database provided by CLARA

Overview for one event:

- The single banks can be selected for more information

```
[hipo-reader] ---> header record is read successfully : # events = 1
Number of records recovered = 31


*********************** EVENT # 0  ***********************
        +----+------------------------------------+------------+---------+---------+
        |  id|                                name|     entries|    group|    items|
        +----+------------------------------------+------------+---------+---------+
        |   0|                             RUN::rf|           3|       11|        2|
        |   1|                           FTOF::adc|          84|      101|        7|
        |   2|                           FTOF::tdc|          84|      102|        5|
        |   3|                          FTCAL::adc|          76|      401|        7|
        |   4|                         FTHODO::adc|           2|      402|        7|
        |   5|                             DC::tdc|         442|      302|        5|
        |   6|                            DC::doca|         442|      303|        5|
        |   7|                           CTOF::adc|           4|      501|        7|
        |   8|                           CTOF::tdc|           4|      502|        5|
        |   9|                           ECAL::adc|          68|      201|        7|
        |  10|                           ECAL::tdc|          68|      202|        5|
        |  11|                        MC::Particle|           3|       20|        7|
        |  12|                         RUN::config|           1|       10|        9|
        |  13|                     FTCAL::clusters|           1|      912|       12|
        |  14|                    FTHODO::clusters|           1|      812|       10|
        |  15|                       FT::particles|           1|     1711|       10|
        |  16|                HitBasedTrkg::HBHits|         335|     1311|       17|
        |  17|            HitBasedTrkg::HBClusters|          25|     1312|       23|
        |  18|            HitBasedTrkg::HBSegments|          23|     1313|       28|
        |  19|             HitBasedTrkg::HBCrosses|          10|     1314|       18|
        |  20|                       FTOF::rawhits|          35|     1211|       13|
        |  21|                          FTOF::hits|          35|     1212|       23|
        |  22|                      FTOF::clusters|          18|     1213|       16|
        |  23|               FTOF::matchedclusters|          22|     1214|       10|
        |  24|                      ECAL::clusters|           3|     1613|       18|
        |  25|                     RECHB::Particle|           1|       22|       12|
        |  26|                     RECHB::Detector|           2|       23|       15|
        |  27|              TimeBasedTrkg::TBHits|         155|     1321|       17|
        |  28|          TimeBasedTrkg::TBClusters|          27|     1322|       23|
        |  29|          TimeBasedTrkg::TBSegments|          26|     1323|       28|
        |  30|           TimeBasedTrkg::TBCrosses|          12|     1324|       18|
        |  31|                       REC::Particle|           1|       24|       12|
        |  32|                       REC::Detector|           2|       25|       15|
        +----+------------------------------------+------------+---------+---------+


Choose (n=next,p=previous, q=quit), Type Bank Name or id : REC::Particle
 SHOWING BANK
```

HIPO database provided by CLARA

Reconstructed particles in CLAS12:

```
Choose (n=next,p=previous, q=quit), Type Bank Name or id : REC::Particle
 SHOWING BANK
------------------------+--------------------------+
>>>> GROUP (group=     1) (name=REC::Particle):
------------------------+--------------------------+
         pid (      INT) :         22
          px (    FLOAT) :     -0.453
          py (    FLOAT) :      0.071
          pz (    FLOAT) :      4.786
          vx (    FLOAT) :      0.000
          vy (    FLOAT) :      0.000
          vz (    FLOAT) :      0.000
      charge (     BYTE) :          0
        mass (    FLOAT) :      0.000
        beta (    FLOAT) :      0.000
     chi2pid (    FLOAT) :      0.000
      status (     BYTE) :          1
------------------------+--------------------------+
```

Reconstructed particles in the forward tagger:

→ FT particles are not included in the REC database so far

```
Choose (n=next,p=previous, q=quit), Type Bank Name or id : FT::particles
 SHOWING BANK
------------------------+--------------------------+
>>>> GROUP (group=     1) (name=FT::particles):
------------------------+--------------------------+
          id (    SHORT) :          0
      charge (     BYTE) :         -1
      energy (    FLOAT) :      3.015
          cx (    FLOAT) :      0.035
          cy (    FLOAT) :      0.035
          cz (    FLOAT) :      0.999
        time (    FLOAT) :    125.256
       calID (    SHORT) :          0
      hodoID (    SHORT) :          1
       trkID (    SHORT) :         -1
------------------------+--------------------------+

Choose (n=next,p=previous, q=quit), Type Bank Name or id :
```

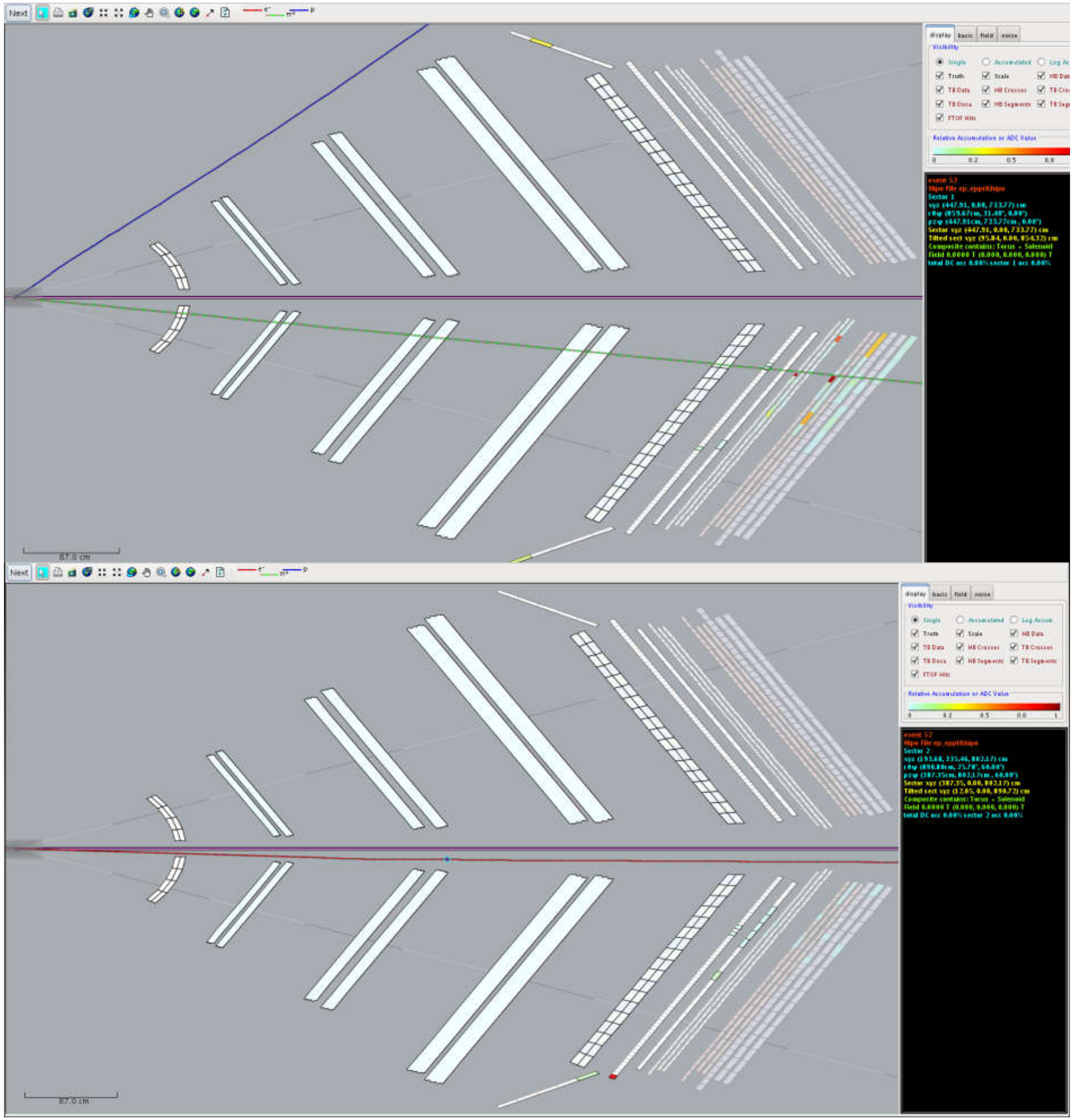
Event monitor for the visualization of the hipo database

sector 1 and 4:

pion is passing
(green line)
proton is going
to CD (blue line)

sector 2 and 5:

electron is passing
(red line)



Step 4: Extraction of the content of the hipo database and conversion to the HASPECT format (root)

- **Plan for the future**: Get a direct root output from CLARA
  → The present conversion is only an intermediate solution

a) Conversion from hipo to the lund format (txt)

I have written a groovy script which reads all generated and reconstructed particles from CLAS12 and the Forward Tagger and writes it as lists in a modified lund format to a text file.

b) Conversion from lund (txt) to root (HASPECT format)

Derek provides a macro to convert the produced list of particles to the HAPECT format (root)

➔ Conversion is working now

Step 5: Analysis of the reconstructed data

Aim for the current reaction:

- Reconstruct π^0 from two detected gammas
- Compare the reconstructed electron with the generated to check if the reconstruction in the FT is working correctly
- Do first physics analyses

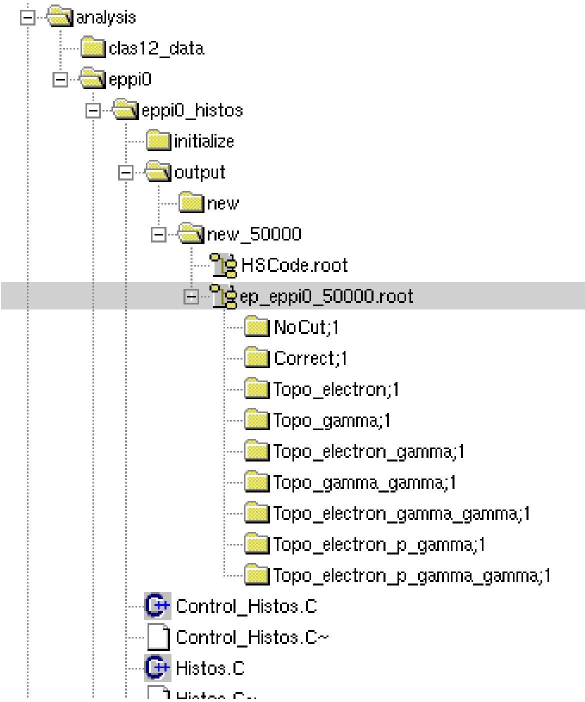
→In the used (not recent) version fo CLARA protons are not reconstructed in the CD

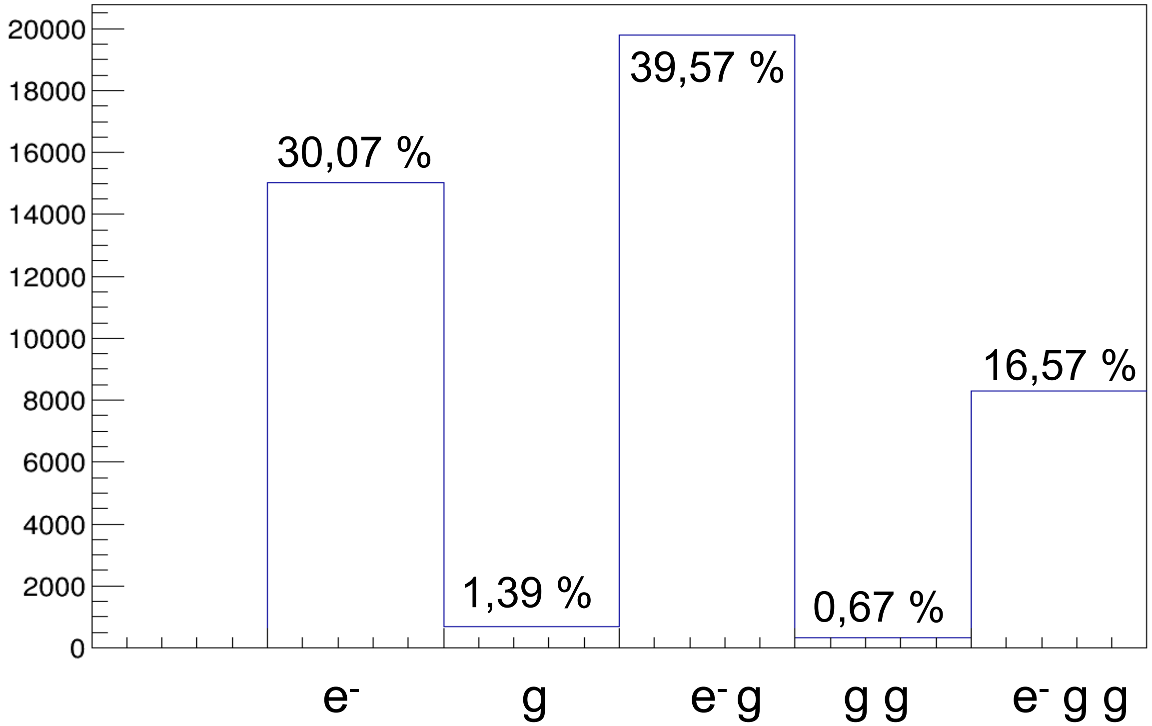
→ It is not clear if triggering on the CD will be possible at all in the experiment

→ This is mandatory to study this reaction

→ Reconstruction of π^0 can be used for calibration of the FT

Analysis: Topologies and distribution of gammas





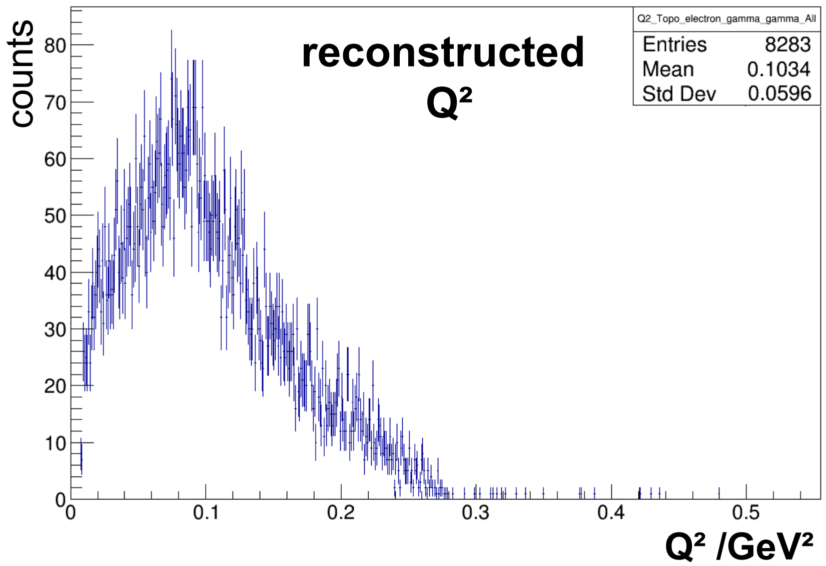
- Events with a proton in the FD are in the order of 0.44 % → Most protons go to the CD!

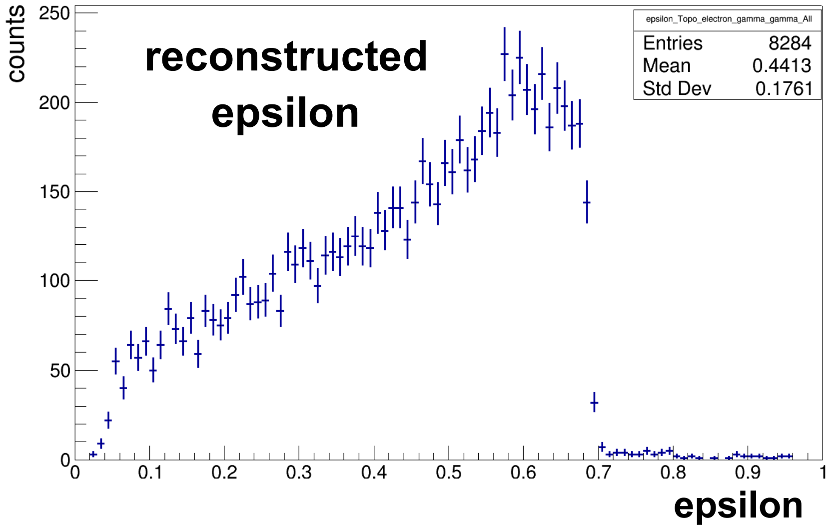
Distribution of the gammas on the detectors:

a) Both gammas detected in the FT: 55.7 %
b) One gamma detected in the FT: 30.6 %
c) Both gammas detected in the forward calorimeter (FD): 6.7 %
d) One gamma detected in the forward calorimeter (FD): 14.2 %

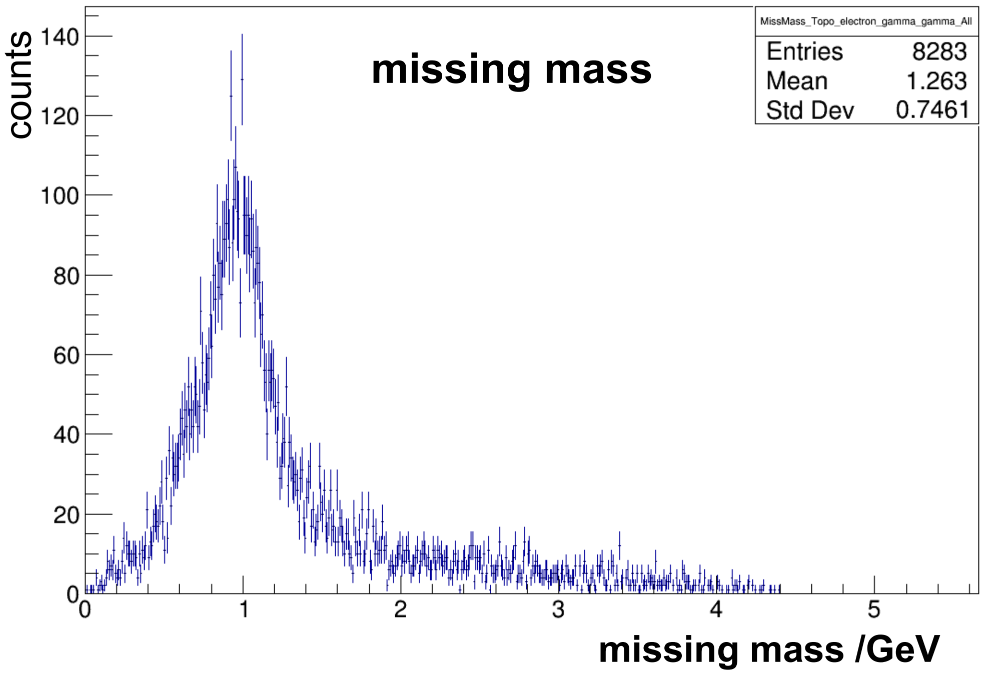
Analysis: Reconstructed reaction kinematics

From now on: Take the topology with e^- gamma gamma detected



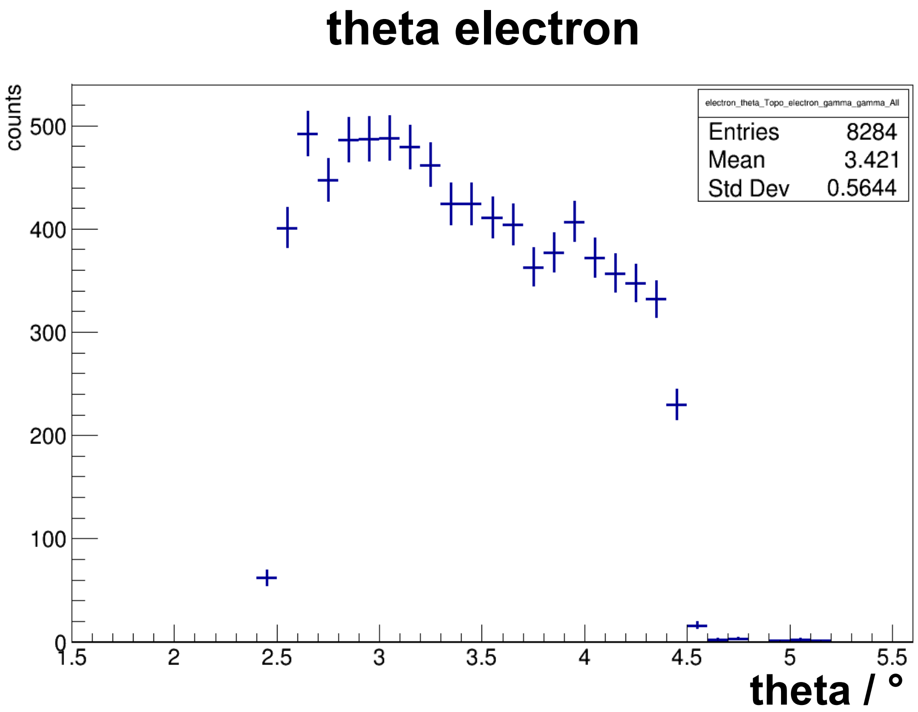


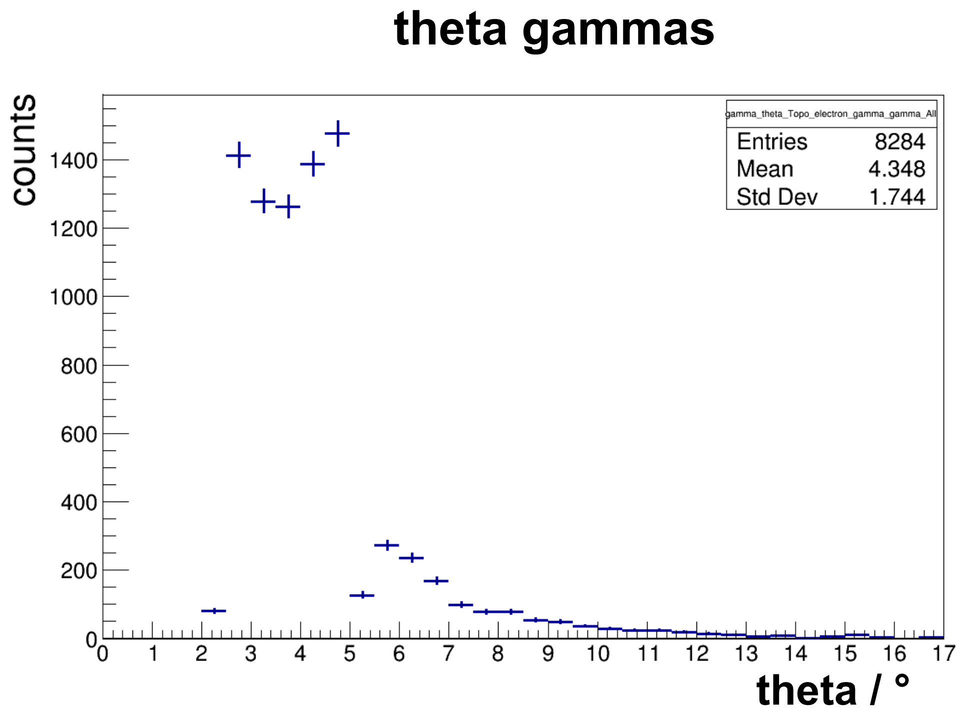
- Q^2 and epsilon show the same range and a similar shape as for the generated data



- Expected is a single missing proton at 0.938 GeV/c²

Analysis: Reconstructed particle angles

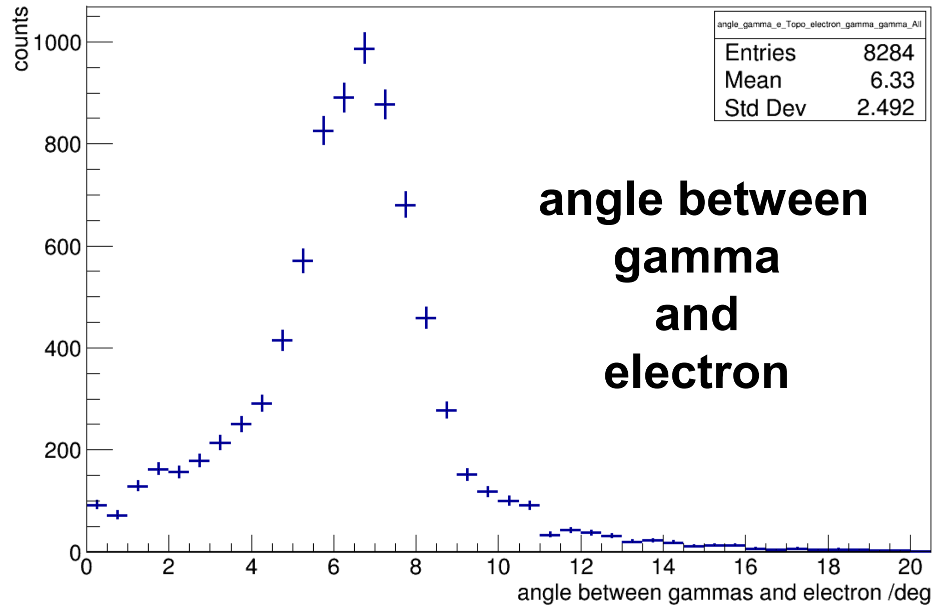


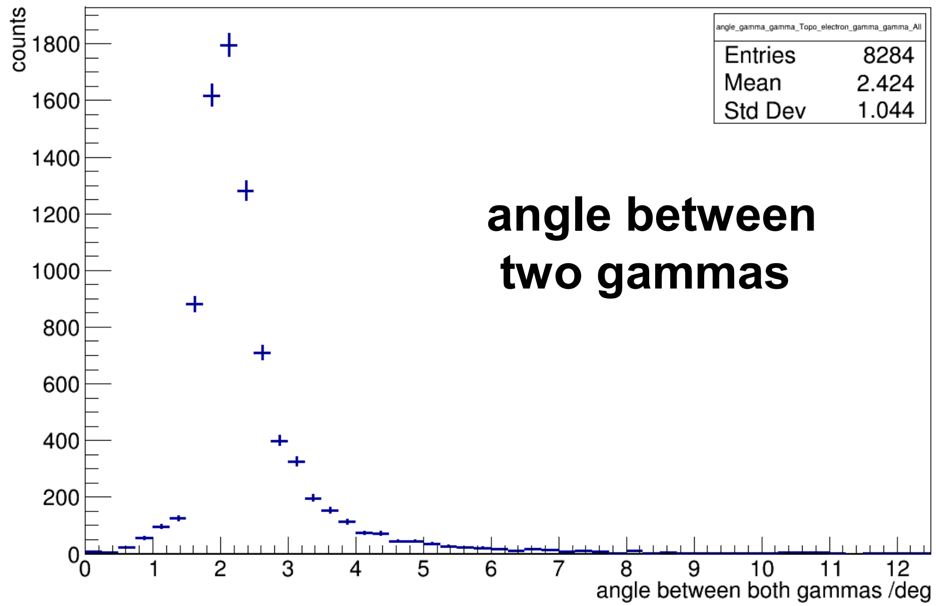


- Electrons only detected in FT
  → Same as generated

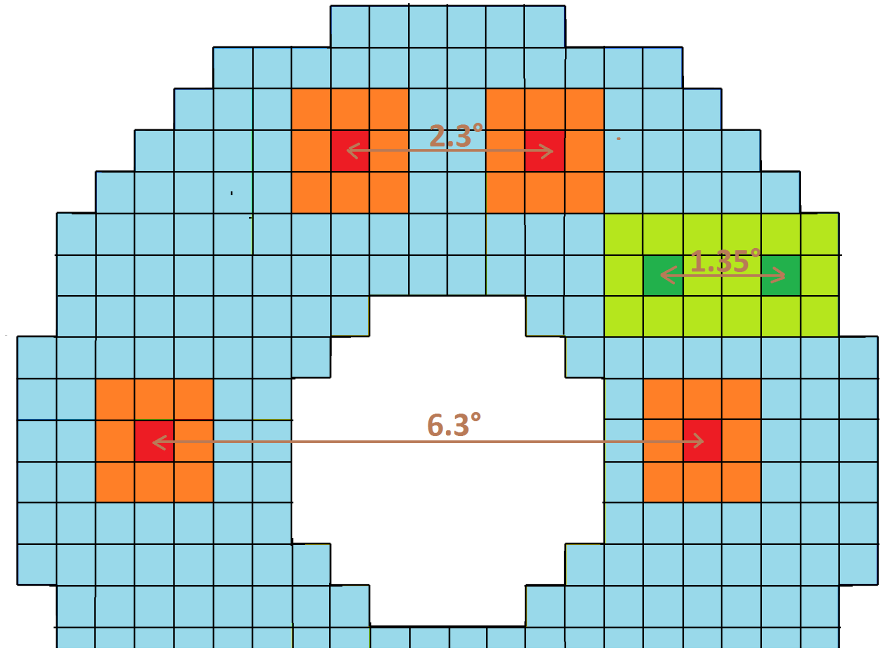
- Most gammas detected in FT
- Some also in FD (tail for > 5°)

Analysis: angle between electron and gammas (lab frame)





- average angle = 6.3°
  → ~ 20 cm at FT position
- for most events > 4 °

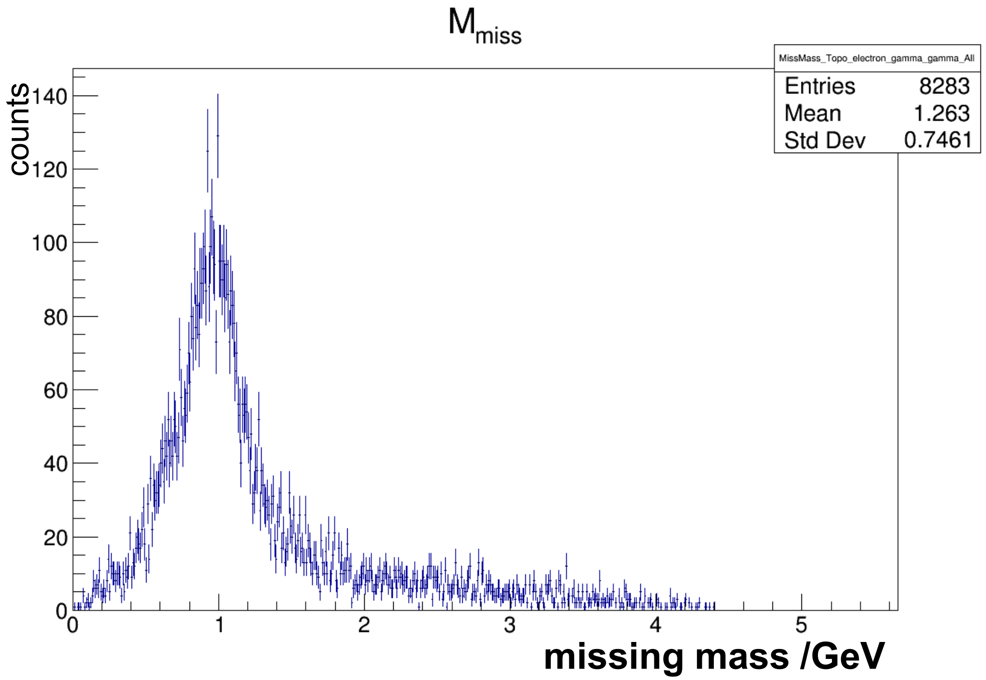


- average angle = 2.4°
  → ~ 8 cm at FT position (5 crystals)
- for most events > 1.5°

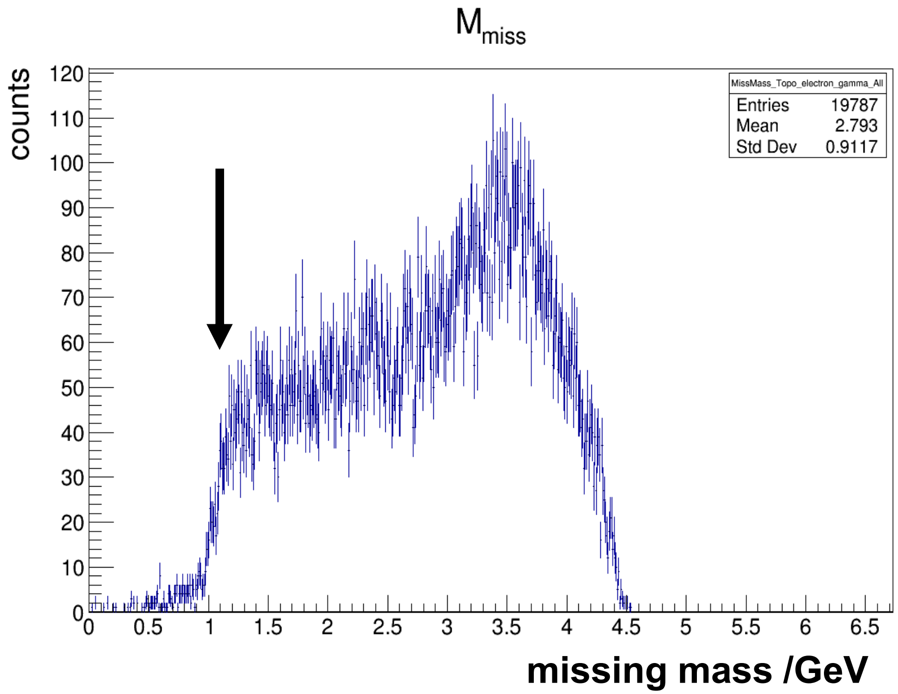
Analysis: Check for overlapping gamms

Compare **missing mass**, if both gammas are reconstructed
and if only one gamma is reconstructed

both gammas reconstructed:



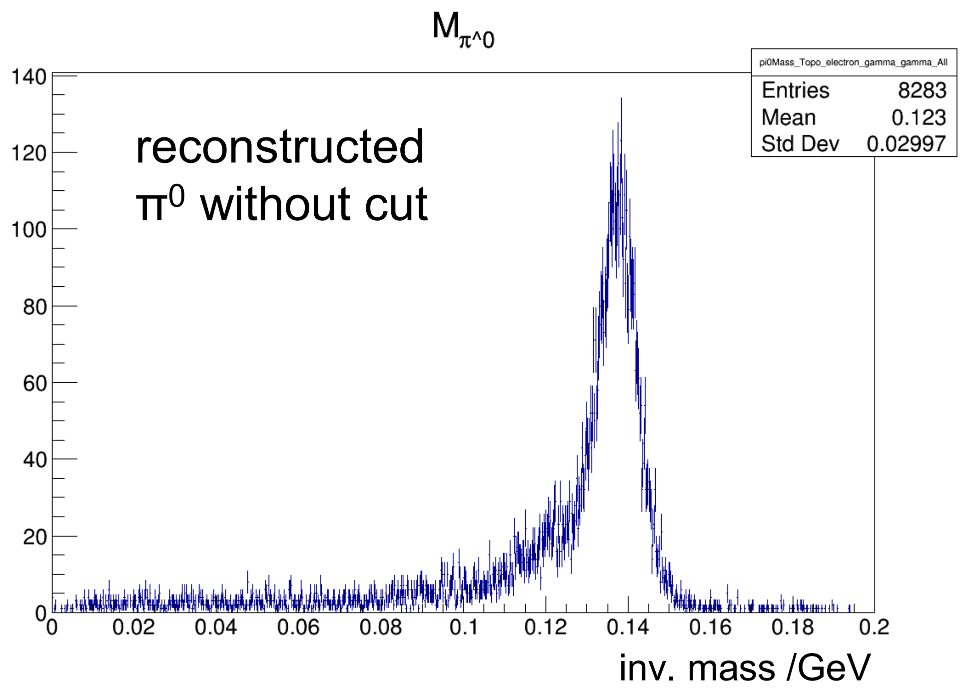
only one gamma reconstructed:

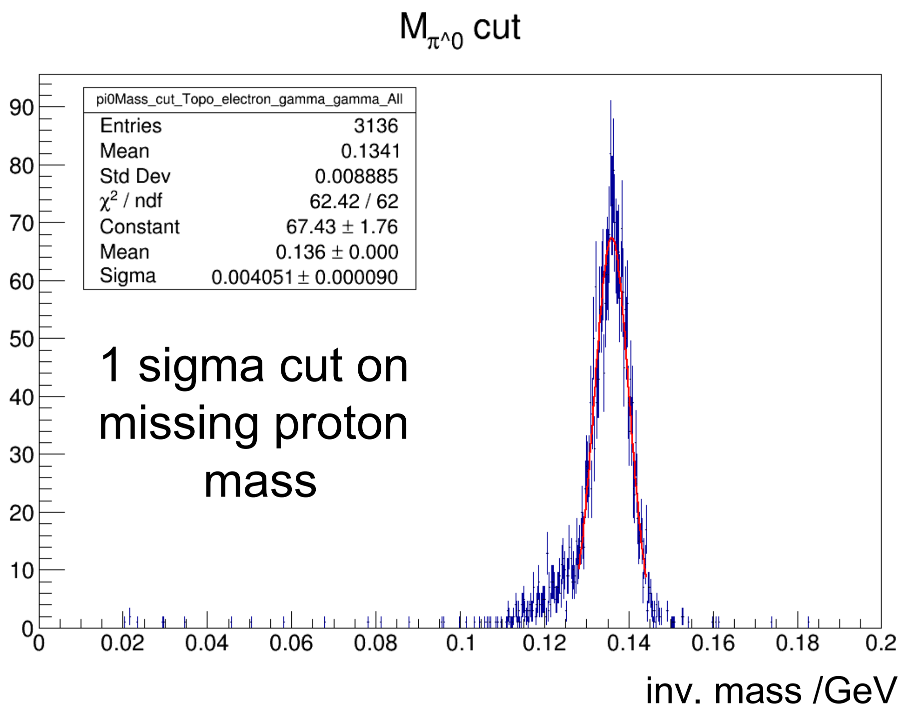


misidentified overlapping gammas would lead to a peak at ~ 1 GeV
which is not observable in the left distribution

Analysis: π^0 invariant mass reconstruction

- **Topology with e^- gamma gamma detected**





136 MeV/c² reconstructed (*lit.*: 134,98 MeV/c²)

Resolution: 4.1 MeV/c²

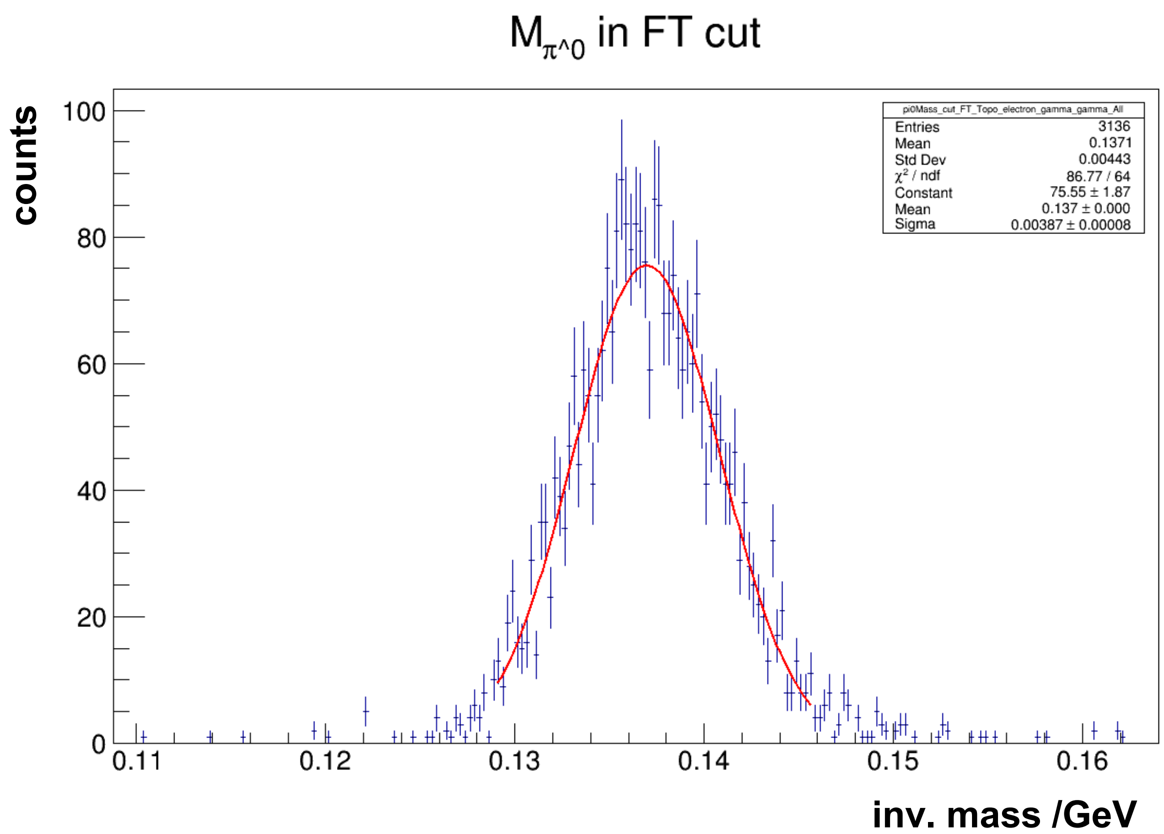
Analysis: π^0 invariant mass reconstruction

Now:

both gammas have to be detected by the Forward Tagger (most of the pairs fulfill this condition)

in addition:

1 sigma cut on missing proton mass

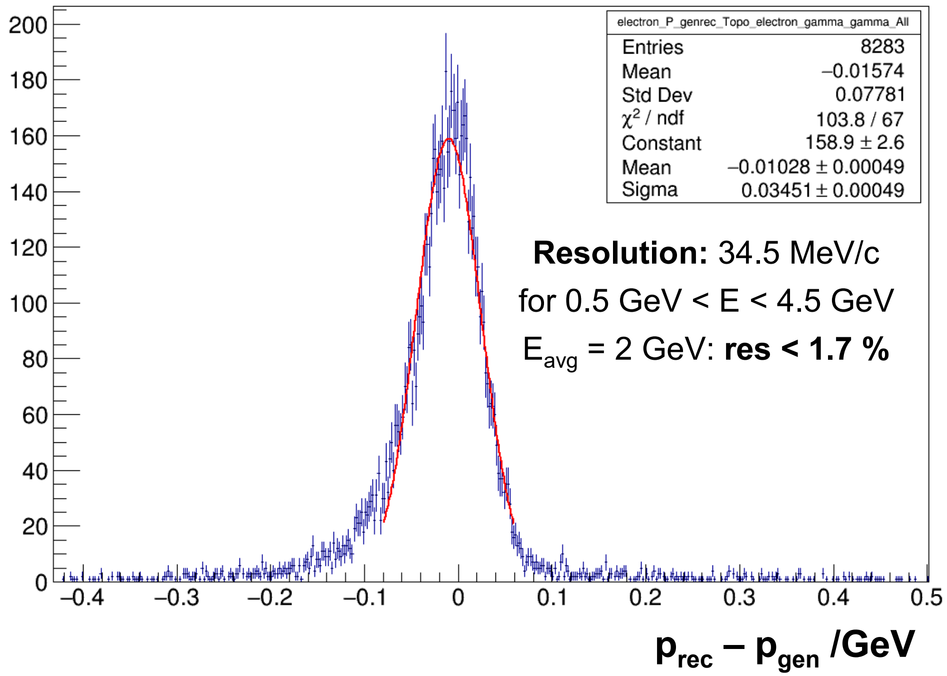


137 MeV/c² reconstructed (*lit.:* 134,98 MeV/c²)

Resolution: 3.9 MeV/c²

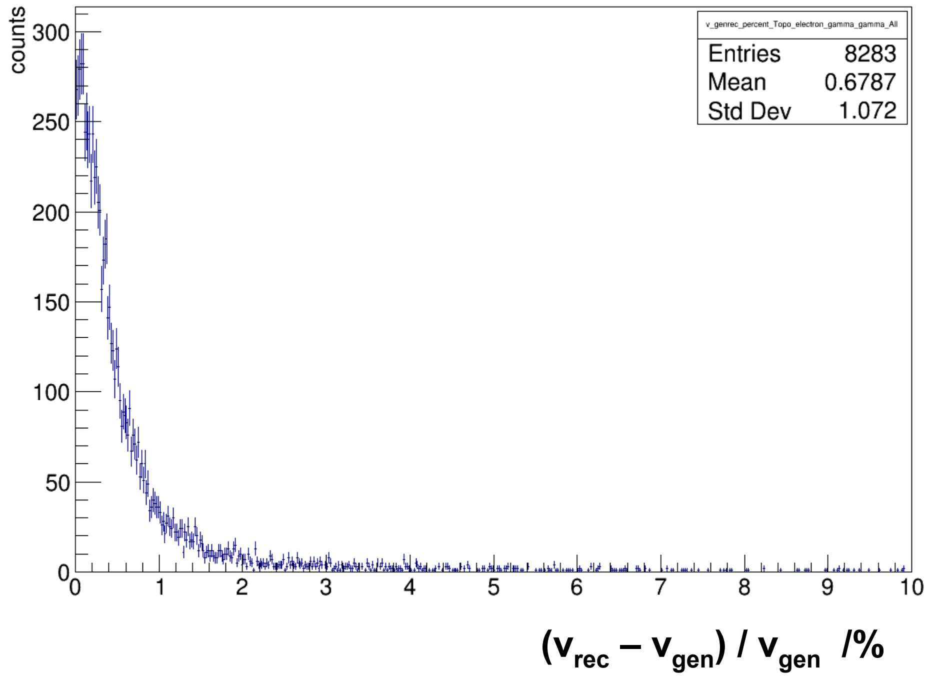
Analysis:
Comparison of generated and reconstructed values

e^- in the FT
reconstructed – generated
momentum



Resolution of the reconstructed virtual photon energy (*ν*):

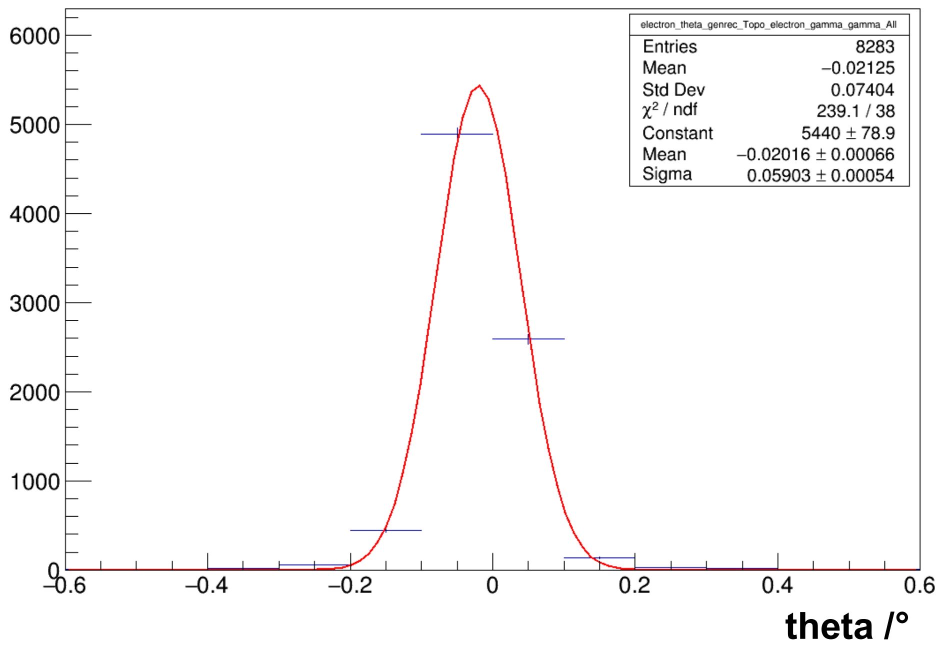
→ Energy of the scattered electron minus energy of the initial electron



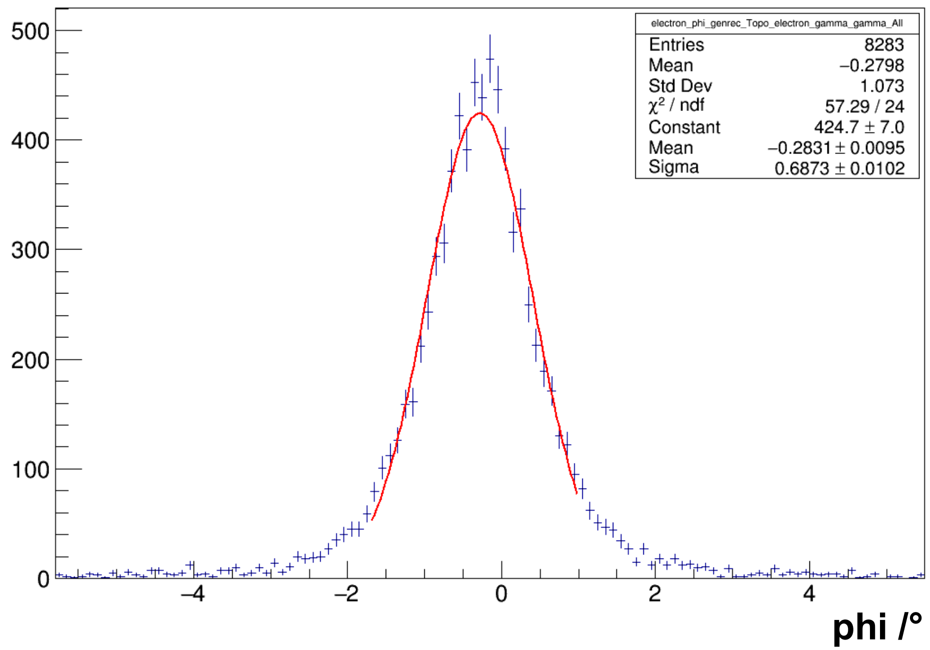
Analysis:
Comparison of generated and reconstructed values

Reconstruction of the **electron angle in the FT**
reconstructed - generated

electron_theta_gen-rec



electron_phi_gen-rec



res(theta) = 0.06°

res(phi) = 0.69°

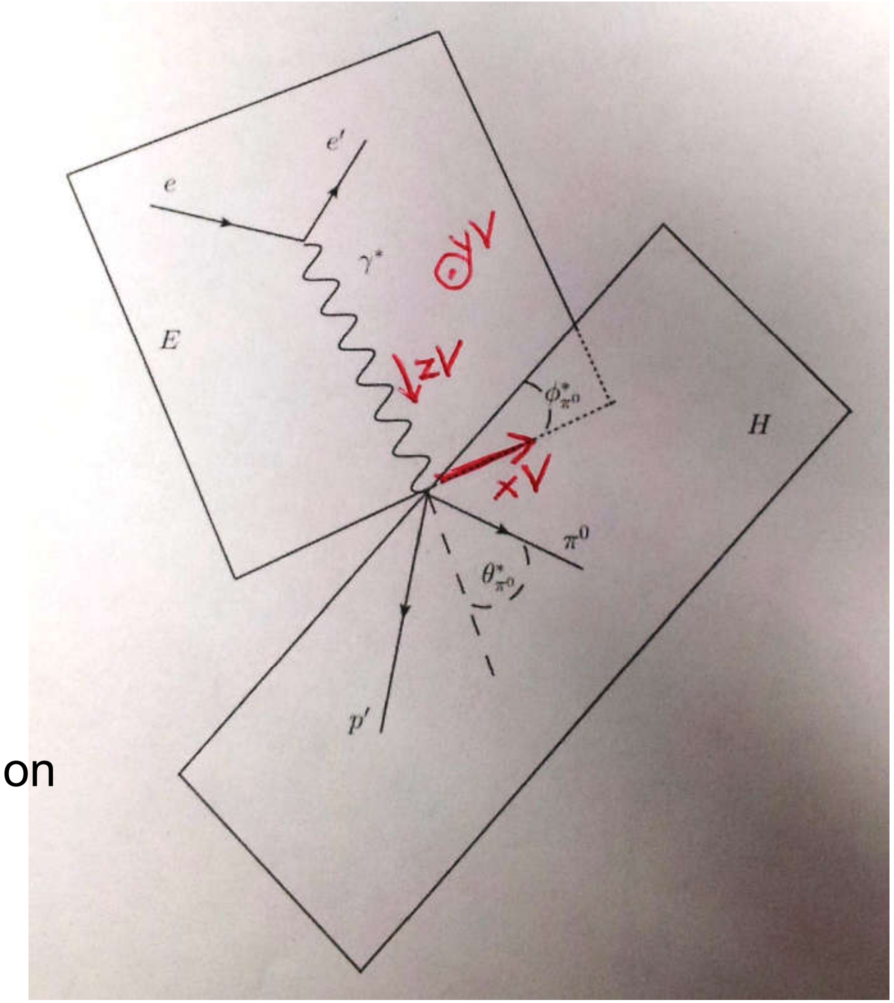
Analysis:
Determination of the angular dependence of the cross section

- Reaction is defined by a leptonic and a hadronic plane

  Leptonic plane is defined by the ingoing and outgoing electron

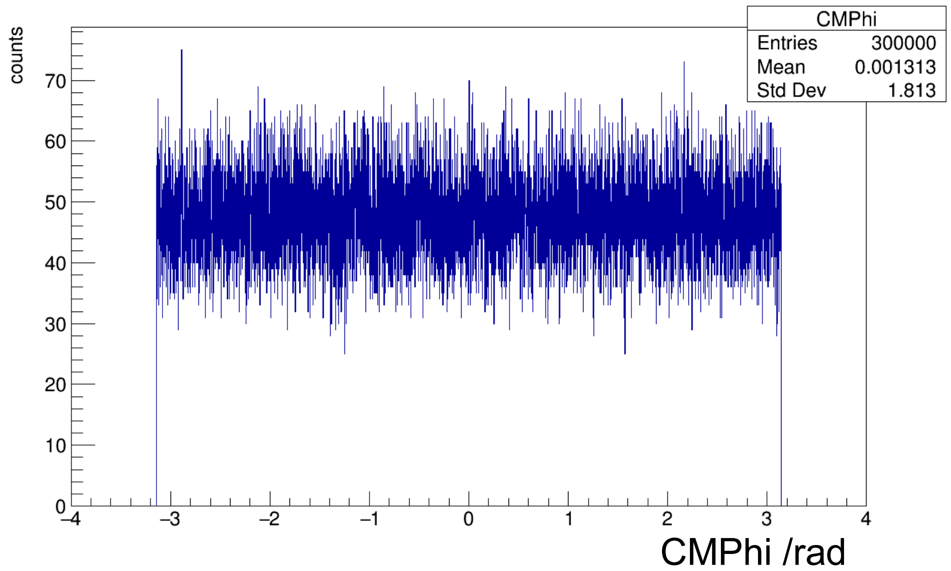
  Hadronic plane is defined by the π^0 and the outgoing proton

- Determine the phi angle of the π^0 in the CM frame of the photo production

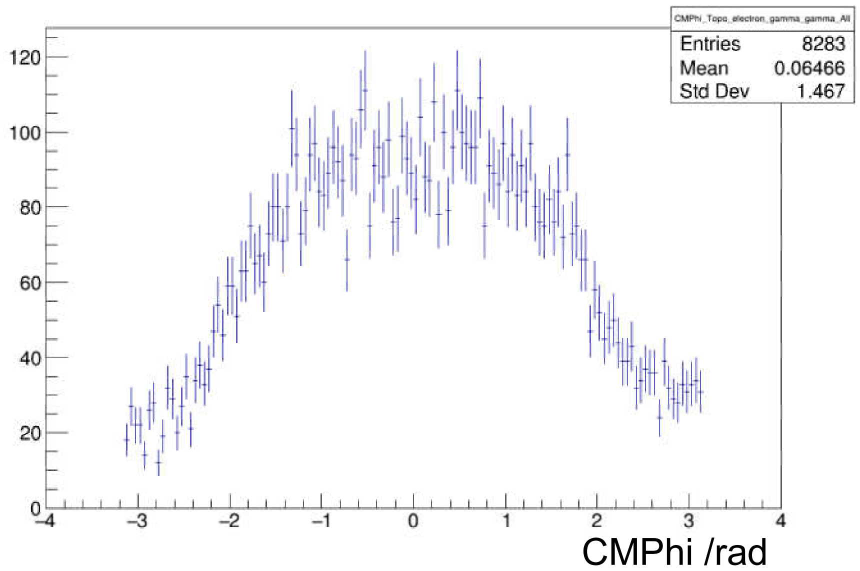


Analysis:
Determination of the angular dependence of the cross section

CMPhi for generated events



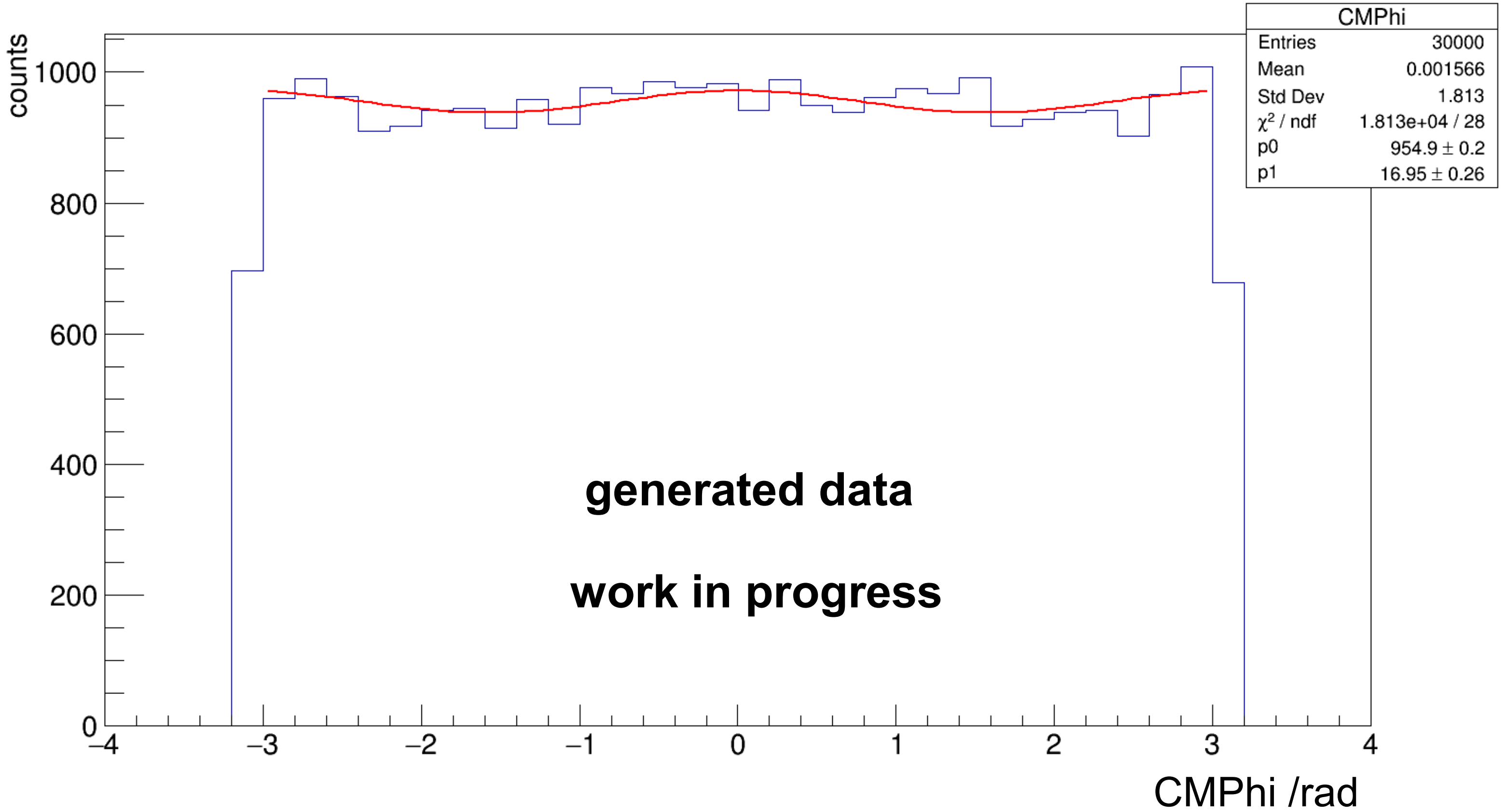
CMPhi for reconstructed events



- The cross section should show a constant offset and a cos(2 phi) modulation
- **But:** For our kinematic region (low Q^2) the modulation seems to be completely suppressed → Only constant offset is visible
- The <u>reconstructed data</u> is dominated by the acceptance, which causes the fall of the cross section to both sides.

Analysis:
Determination of the angular dependence of the cross section

- A very small modulation can be obtained by increasing the value of the residuum g2 in the amplitude model

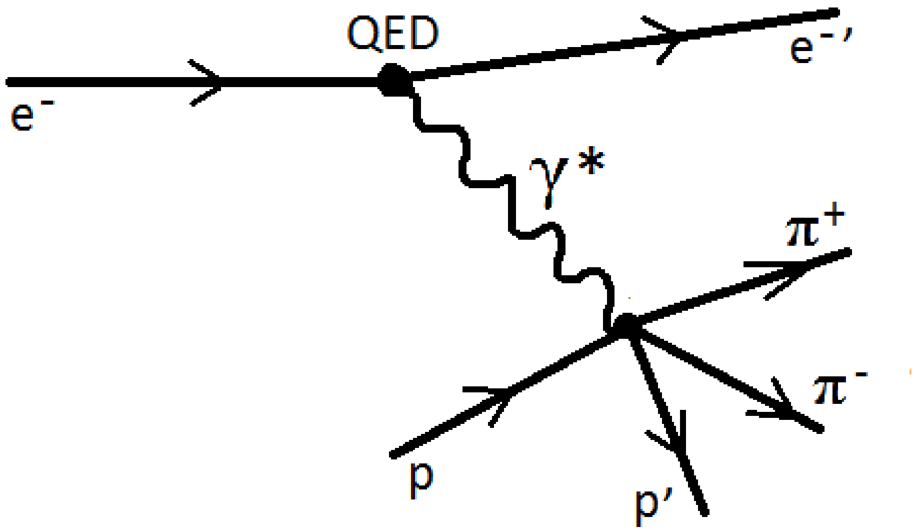


Simulation of

$e\, p \rightarrow e\, p\, \pi^+ \pi^-$

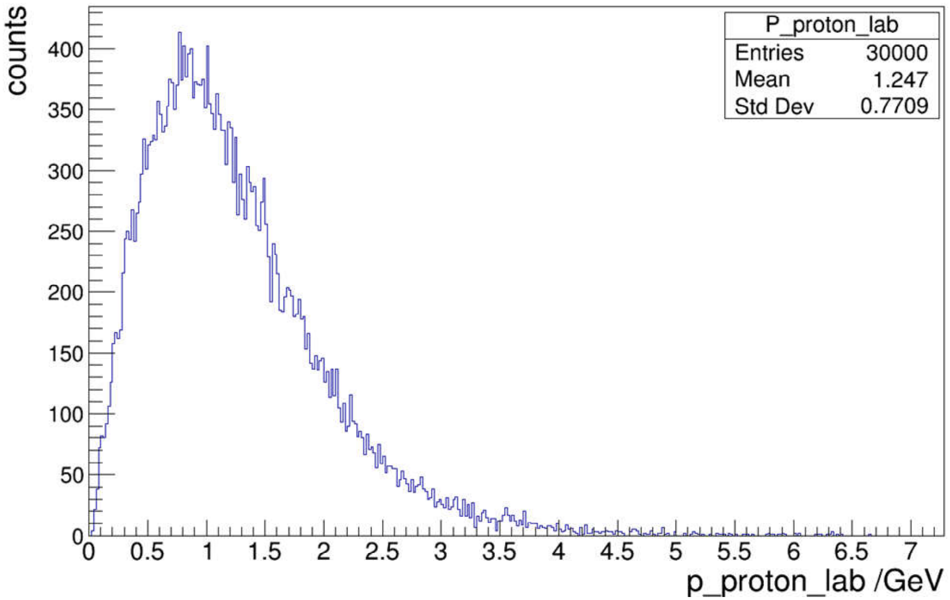
Event generation

- Amplitudes for the reaction provided by Vincent
- Calculate generated events with AmpTools like for the first reaction

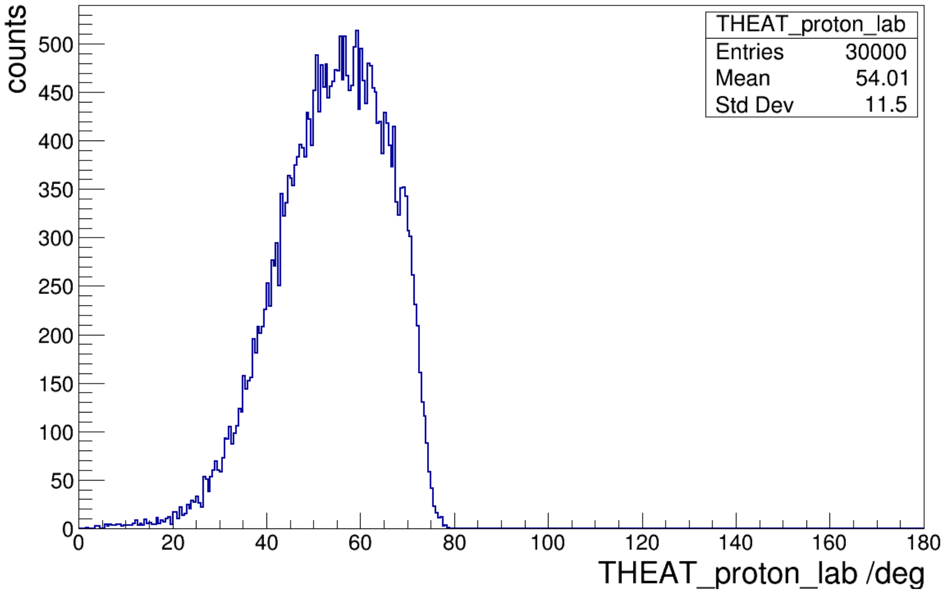


Momentum and angular distributions of the proton

proton momentum



proton theta

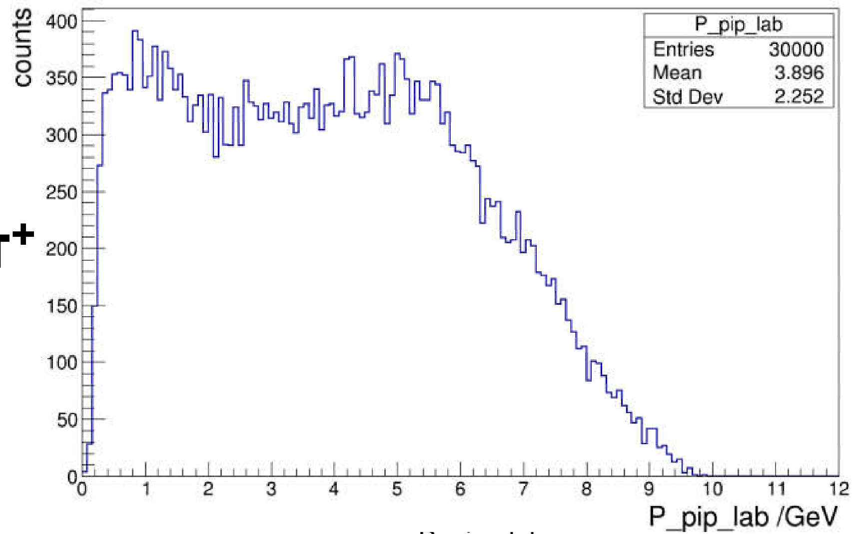


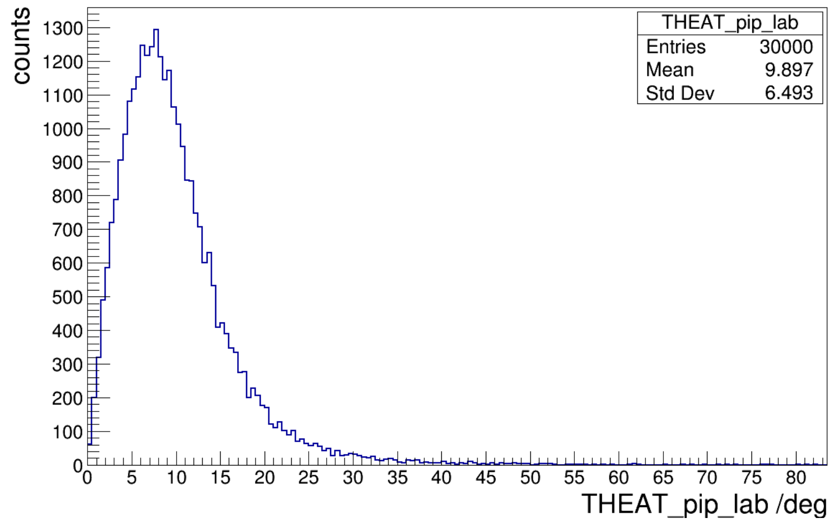
- Protons mainly hit the central detector (> 35°)
- Only a small fraction will be detected by the forward detector (5° – 35°)
- Triggering on protons in the CT will be mandatory for this reaction

Momentum and angular distributions of the charged pions

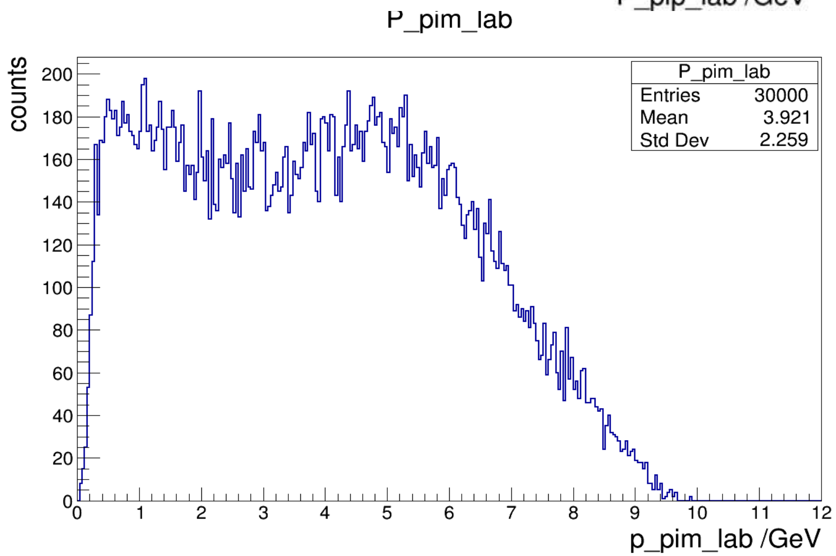
momentum | **theta**

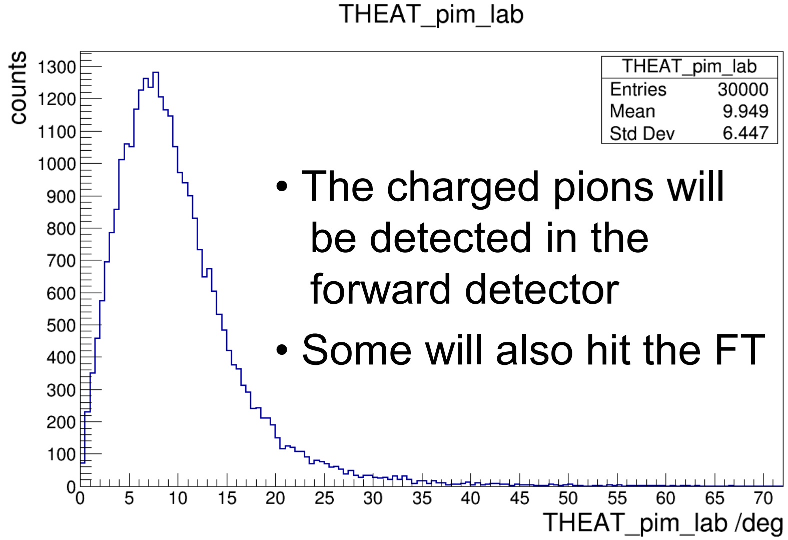
π⁺





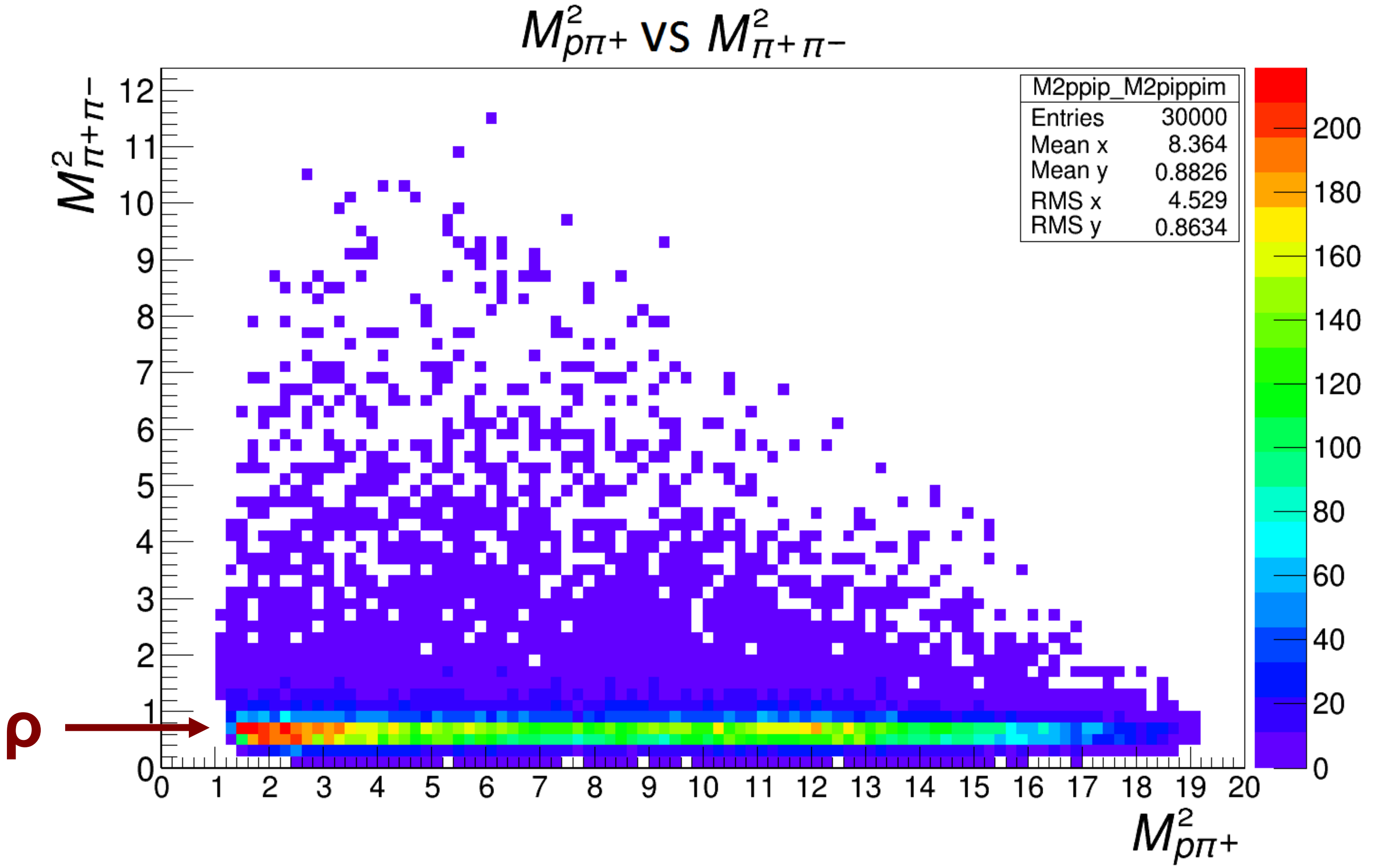
π⁻





- The charged pions will be detected in the forward detector
- Some will also hit the FT

Dalitz plot for the generated particles



Simulation and reconstruction

• Simulate the detector response with gemc √

• Reconstruct the events with CLARA √

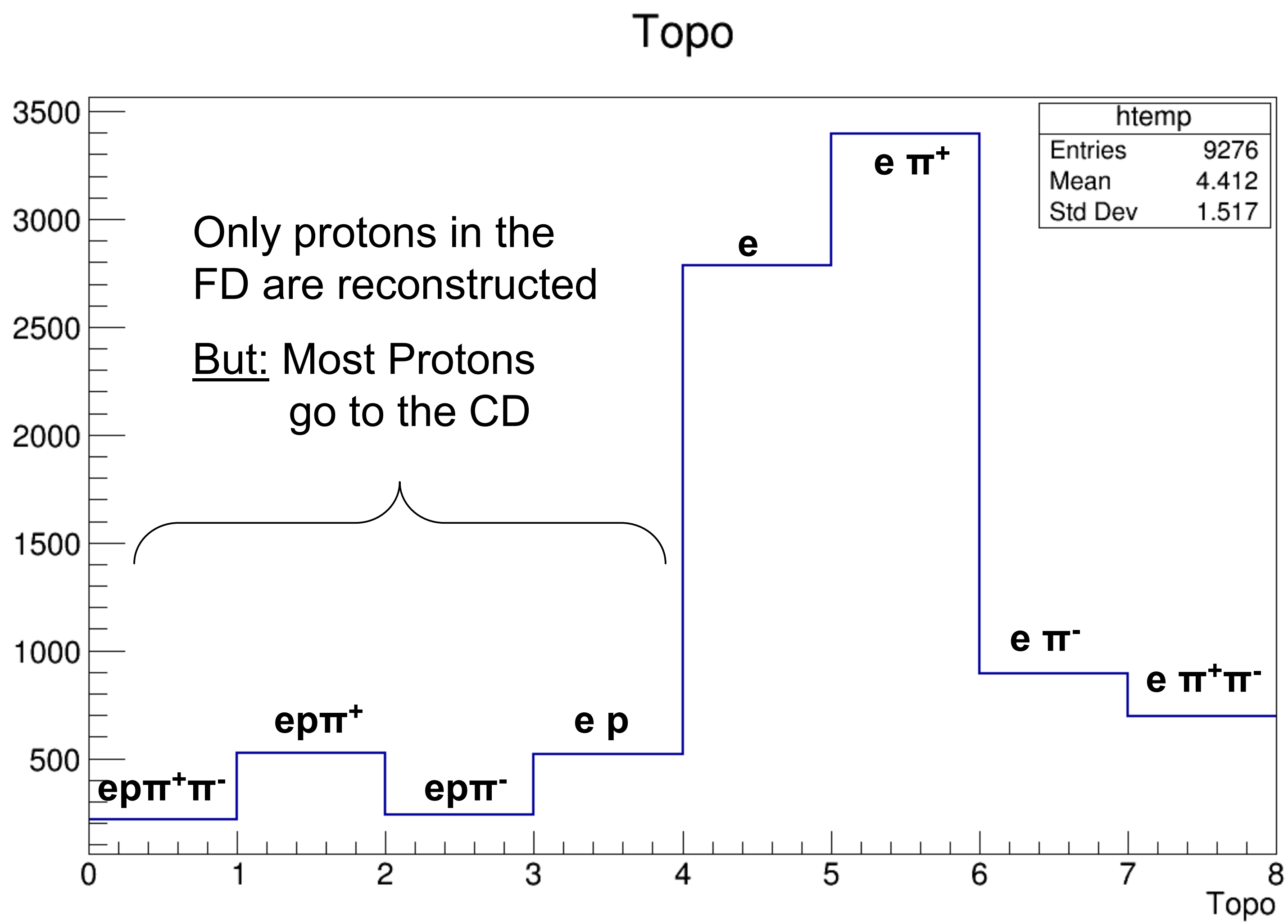
• Convert the output to the HASPECT format (root) √

→ Particle ID has been done maually for charged particles, since it is not implemented in CLARA yet

• Use the analysis framework to analyze the data √

➔ Details are the same as for the first reaction

Analysis

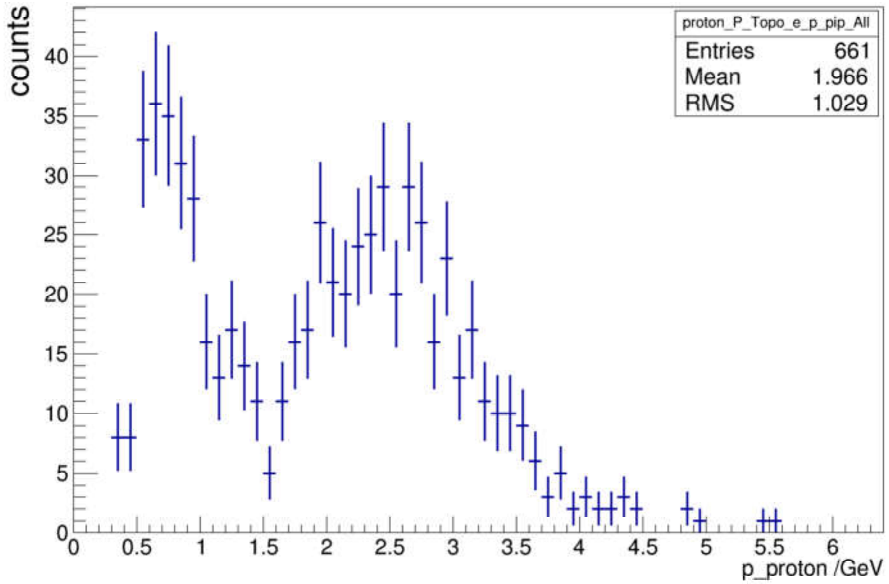


Topo
htemp
Entries 9276
Mean 4.412
Std Dev 1.517
Only protons in the FD are reconstructed
But: Most Protons go to the CD
epπ+π-
epπ+
epπ-
e p
e
e π+
e π-
e π+π-
3500
3000
2500
2000
1500
1000
500
0
1
2
3
4
5
6
7
8
Topo

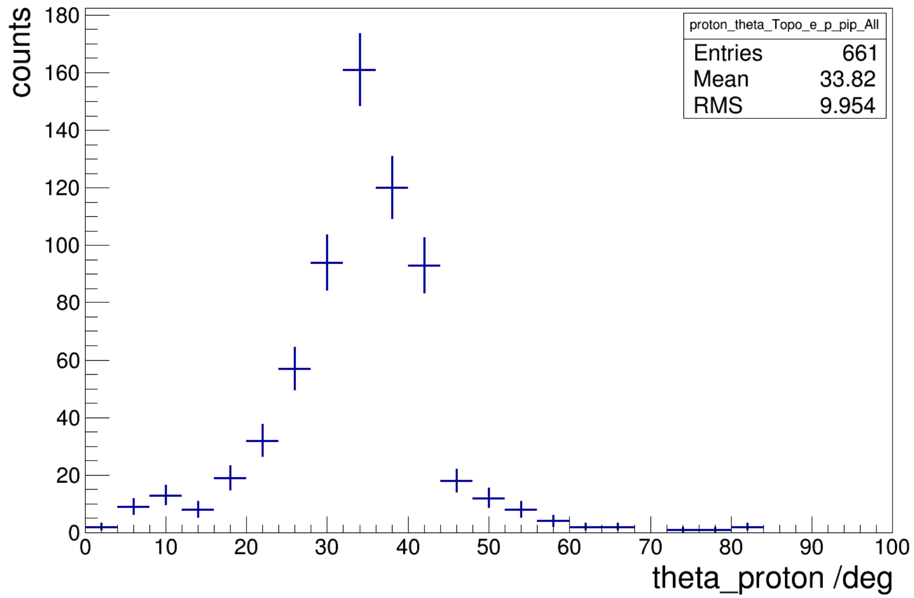
a) Proton: Reconstructed momentum and theta

For the following plots, the e p π^+ (π^-) topology has been selected

proton momentum



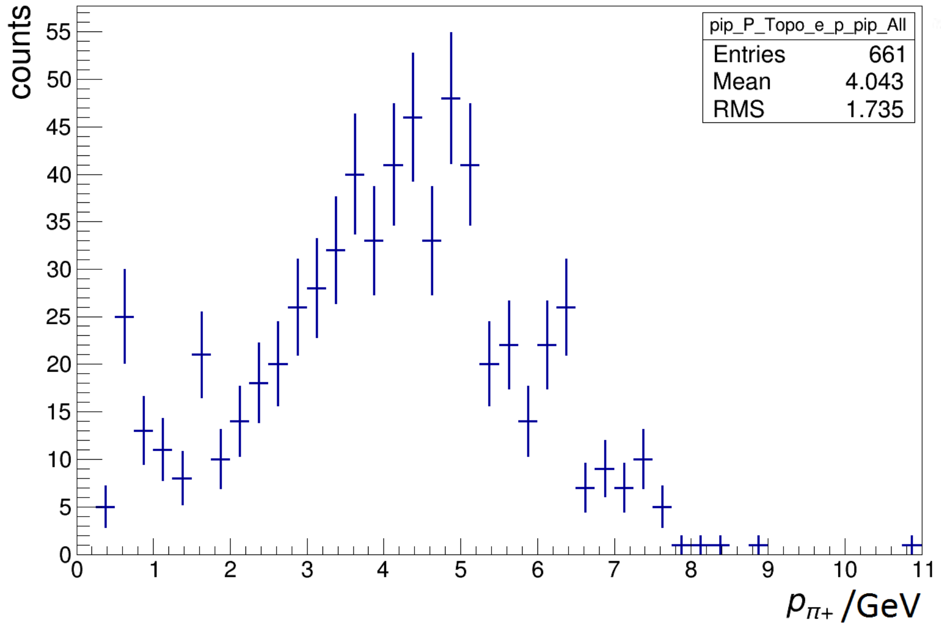
proton theta



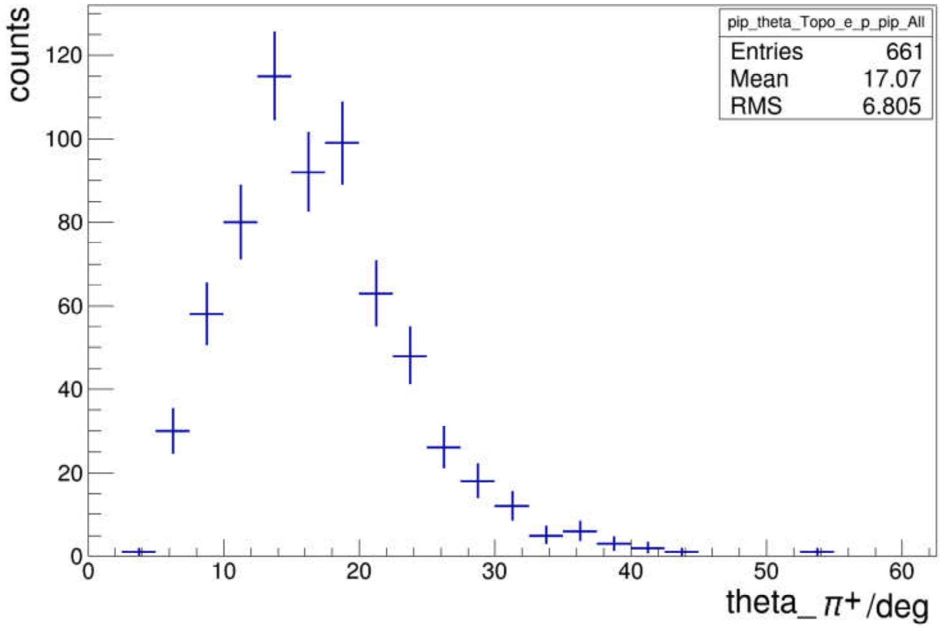
- Typical proton momentum: 0.5 – 4 GeV
- Protons are only detected in FD (< 35°)
- Tracking in CD (> 35°) was not available in the used CLARA version

b) π^+ reconstructed momentum and theta

π^+ momentum



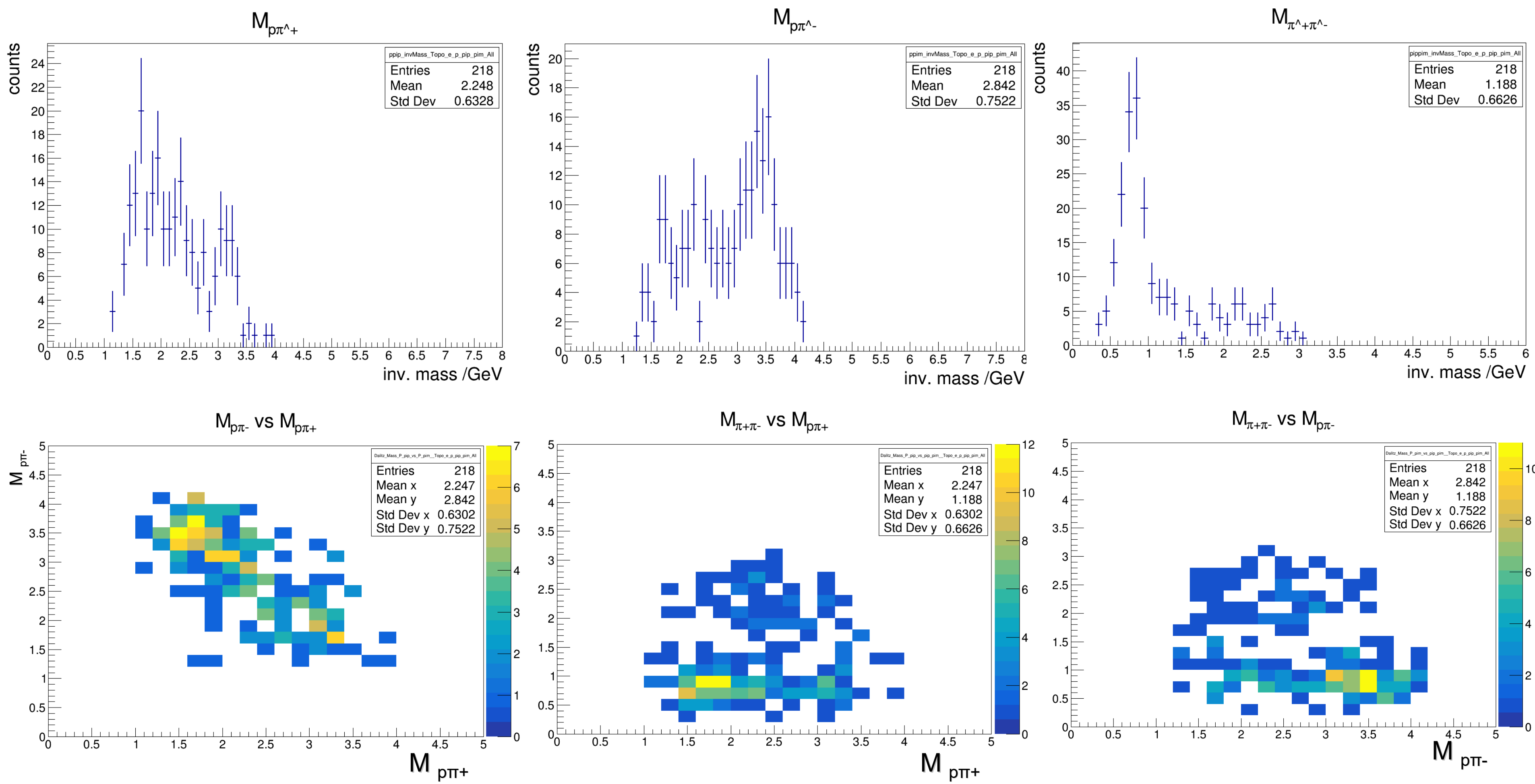
π^+ theta



- Pion momentum goes up to 8 GeV
- Most Pions are detected in the FD
- Results for π^- are similar, but acceptance difference due to the magnetic field causes a slightly different behavior, especially at small momenta.

Invariant mass of $p\pi^+$ and $p\pi^-$ and $\pi^+\pi^-$ and Dalitz plots

For the following plots, the $e\,p\,\pi^+\,\pi^-$ topology has been selected



- **More statistics is needed to identifiy resonances**

Outlook

- Complete simulation – reconstruction – analysis chain is working
- Two channels have been passed through the complete chain

Next steps:

- Increase the statistics of p $\pi^+ \pi^-$
- Do physics analyses for p $\pi^+ \pi^-$
- Define trigger conditions for the mesonEx experiment
- Simulate / analyze additional channels

A documentation of the single steps is available
on the HASPECT wiki under the following link:

https://wiki.ge.infn.it/haspect/index.php/Ppi0