Analysis of Semi-Inclusive Deep-Inelastic Scattering data from HERMES experiment

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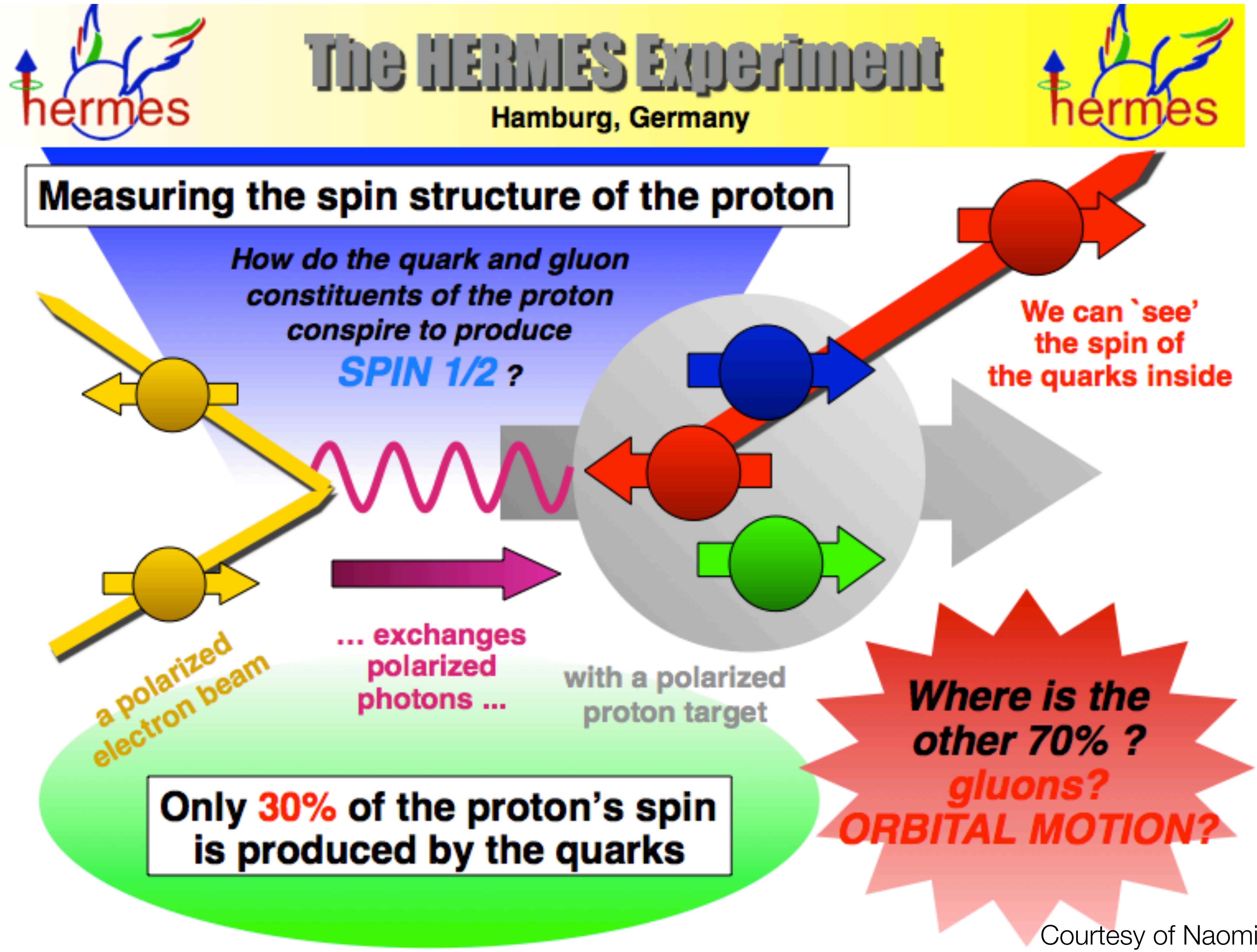
Index

- **The HERMES experiment**: target, beam, spectrometer, experiments...
- **Semi-Inclusive DIS**: small review of basic concepts
- Experimental Data Selection:
    - Data Quality
    - Burst Selection
    - Fiducial-Volume Cuts
    - Kinematic Cuts
    - Event Selection
    - Charged Hadron Identification
- **My Master Thesis Project:** Main ideas and some results

The HERMES Experiment

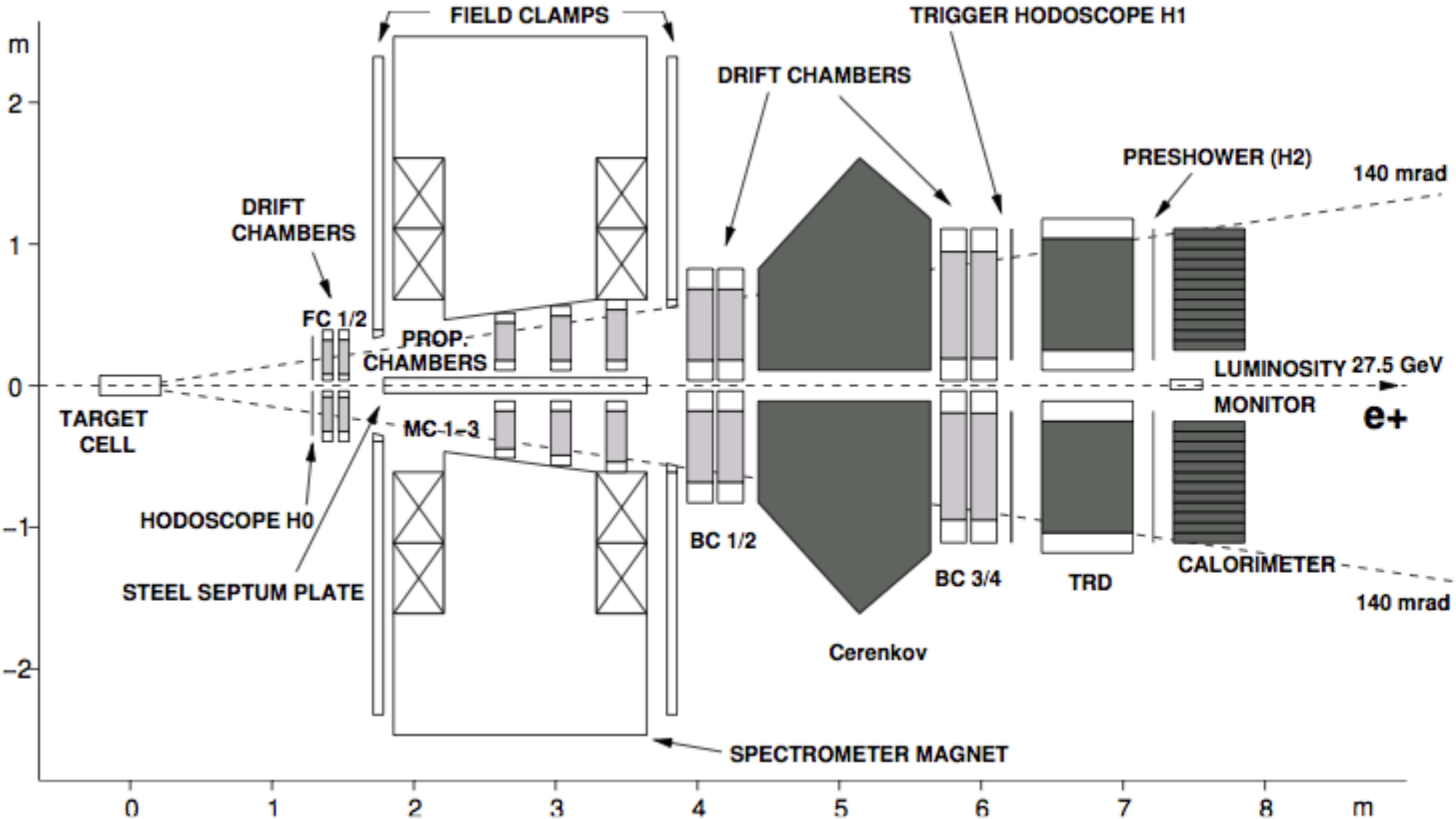
- HERMES is a fixed target experiment.
- It can be operated with polarized gas targets as well as with high-density unpolarized gas targets.
- Uses the 27.5 GeV electron or positron beam of HERA.
- Initially unpolarized positron beam becomes transversely polarized due to the Sokolov-Ternov effect.
- Beam polarization direction is changed from transverse to longitudinal and back again. This is accomplished by two spin rotators.

- HERa MEasurement of Spin (HERMES) proposed in 1990 to study the spin structure of nucleons: proton spin puzzle.



Courtesy of Naomi Makins

- Side view of the HERMES spectrometer.



- Not only the nucleon structure functions, but also distribution functions of quarks of a specific flavor and gluons inside the nucleons:

  - Obtain precise information on the helicity distribution of u, $\bar{u}$, d, $\bar{d}$ and s quarks in the nucleon.

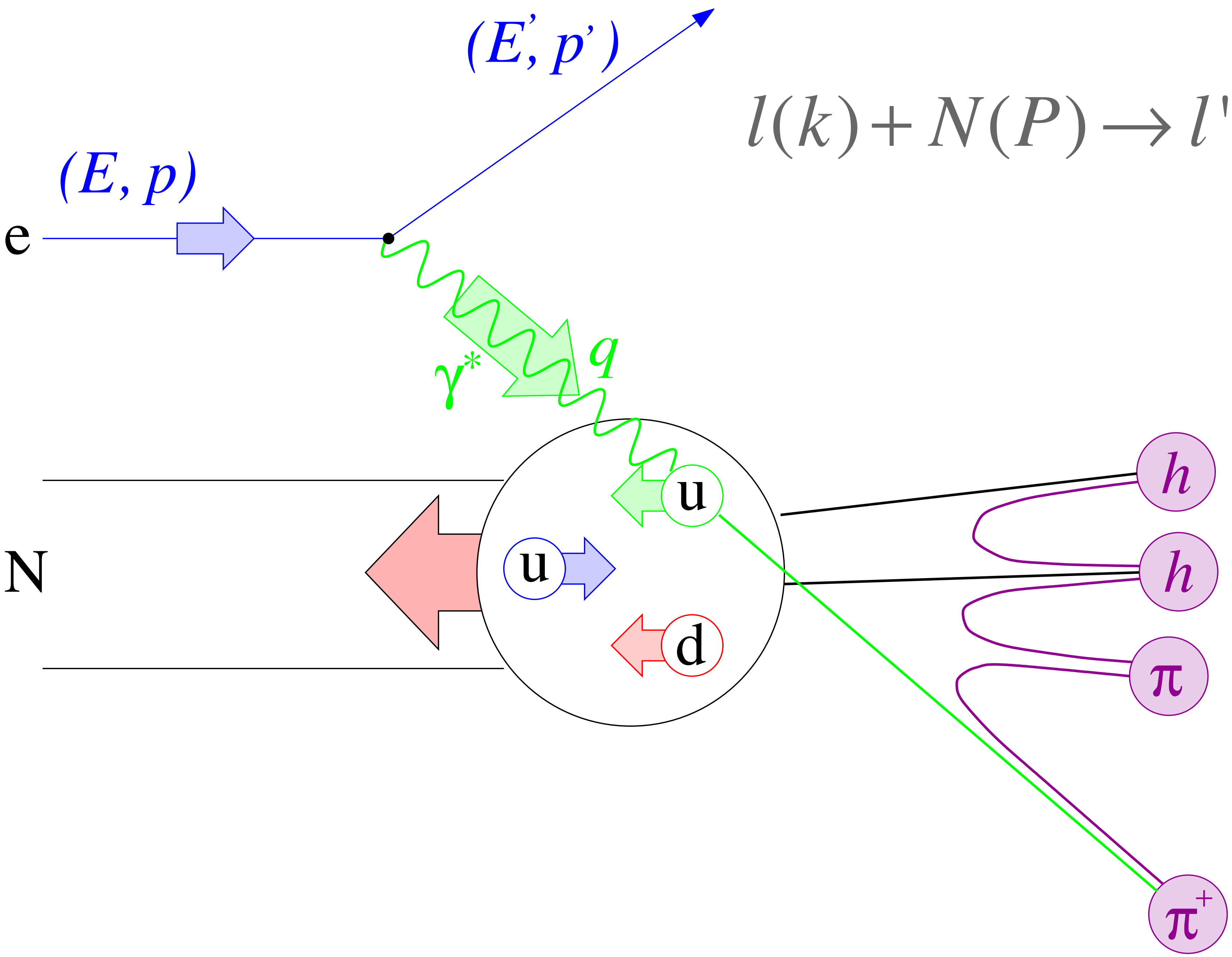
  - Measurement of a double-spin asymmetry related to the gluon helicity distribution.

  - Single-spin asymmetries related to transversity.

  - Use unpolarized gas targets: investigation of hadron formation and the search for exotic baryons like the pentaquark.

Semi-Inclusive Deep Inelastic Scattering: SIDIS

- A deep-inelastic scattering process is called semi-inclusive if besides the scattered lepton, at least one final hadron (h) is also detected.



$$l(k) + N(P) \rightarrow l'(k') + h(P_h) + X(P_X)$$

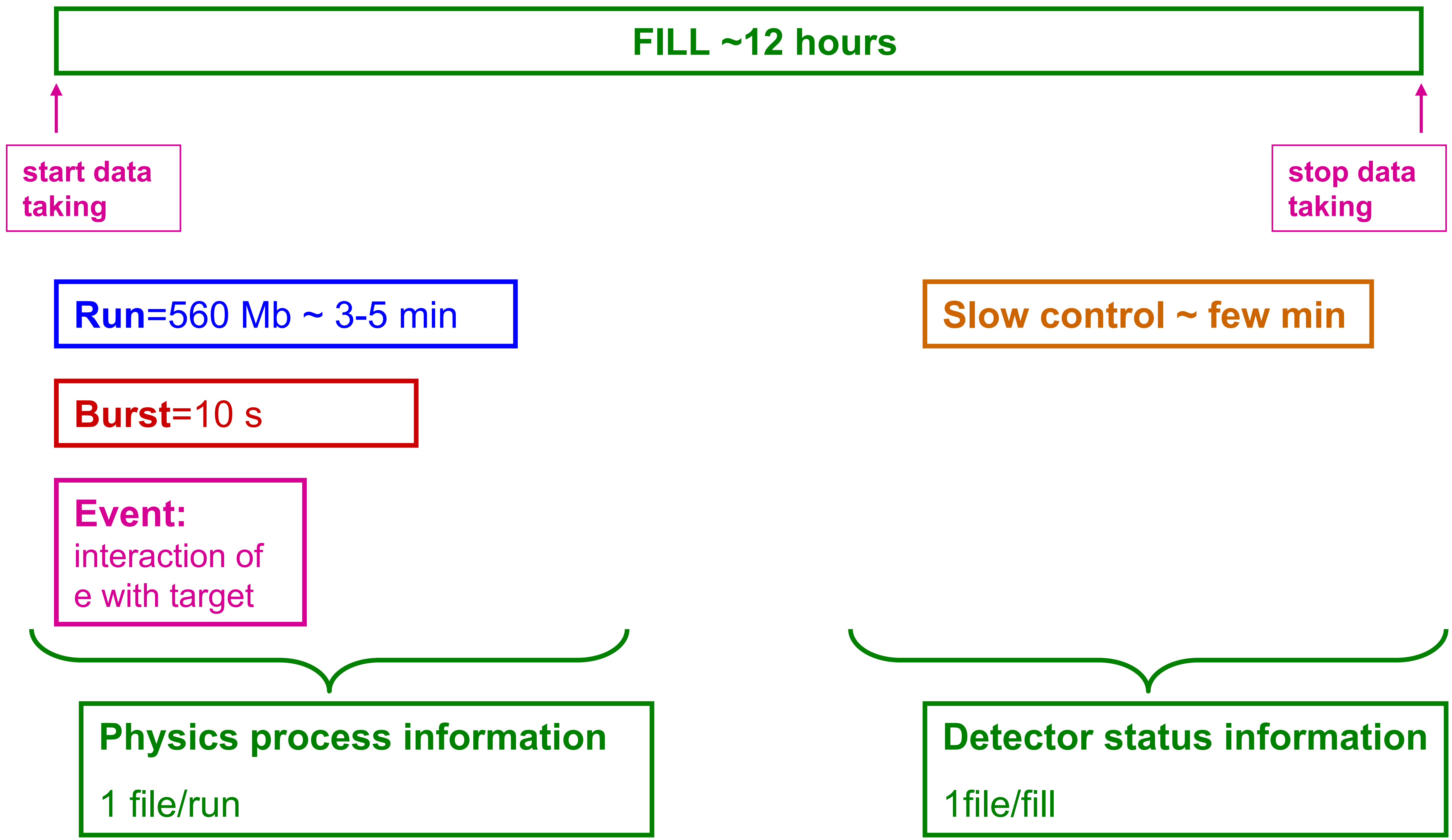
N represents the target nucleon, h the produced hadron, X the target remnant and the quantities in parentheses their four-momenta.

Experimental data selection

- **DATA QUALITY:** To ensure a high data quality in each recorded burst, several measured quantities are checked for consistency:

  - The rate of the luminosity monitor
  - The beam current (and the beam polarisation)
  - The status of the target and of the data acquisition system
  - Malfunctioning PID detectors
  - High voltage trips in the wire chambers

- Before we go on, let's see a bit of typical experimental slang:



Courtesy of Charlotte Van Hulse

- **BURST SELECTION:** Badbits. The burst list contains the condensed data quality information in two bit patterns for the top and bottom detector halves. We have for example, the following examples:

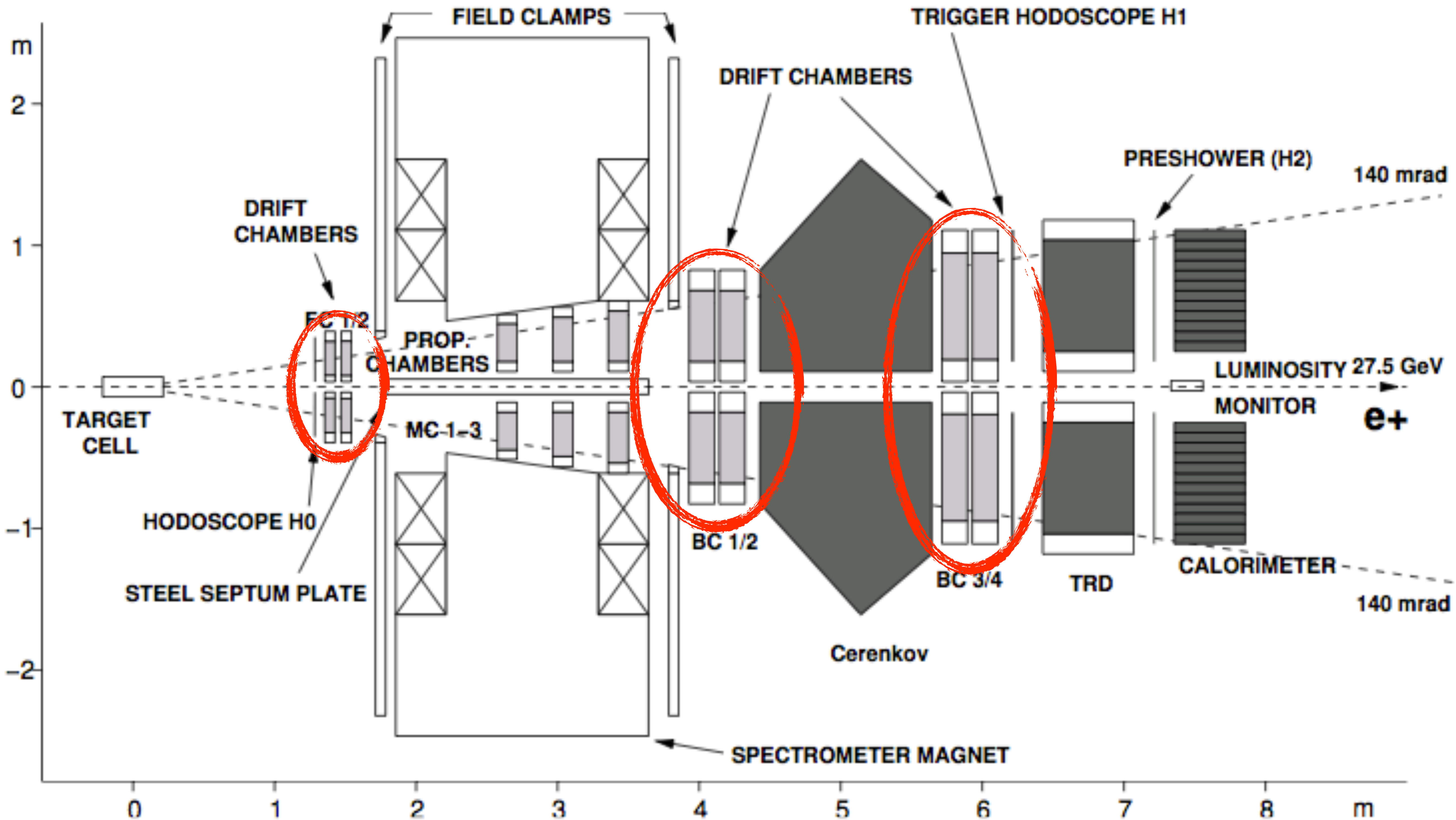
    - **bit 8**: there is no particle identification (PID) available due to initialization problems or an unknown calorimeter threshold

    - **bit 11**: the target is unpolarized

    - **bit 17**: there are dead blocks in the calorimeter

    - **bit 20**: bursts, during which one or more planes of the FC or BC tripped, are discarded.

    - **bit 25**: the RICH is in a bad state


FIELD CLAMPS
TRIGGER HODOSCOPE H1
DRIFT CHAMBERS
PRESHOWER (H2)
140 mrad
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FC 1/2
PROP.
CHAMBERS
LUMINOSITY
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27.5 GeV
e+
TARGET
CELL
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HODOSCOPE H0
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BC 3/4
TRD
CALORIMETER
140 mrad
STEEL SEPTUM PLATE
Cerenkov
SPECTROMETER MAGNET
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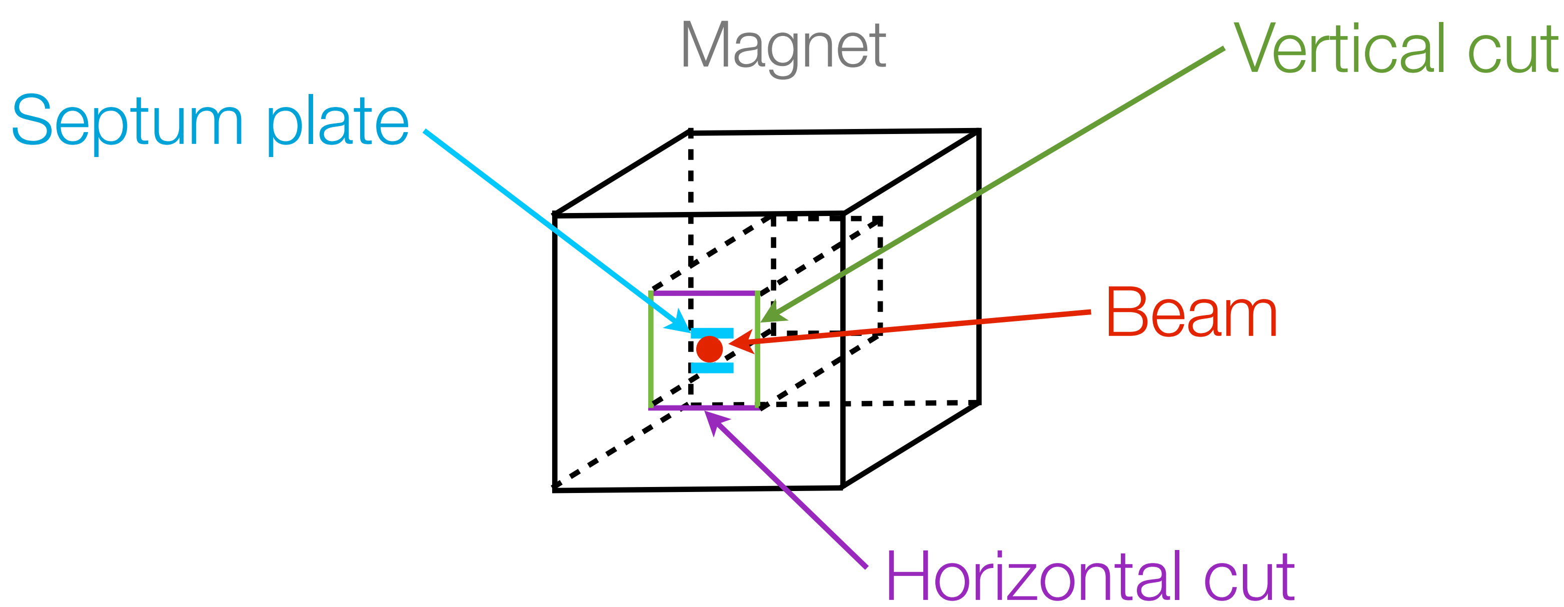
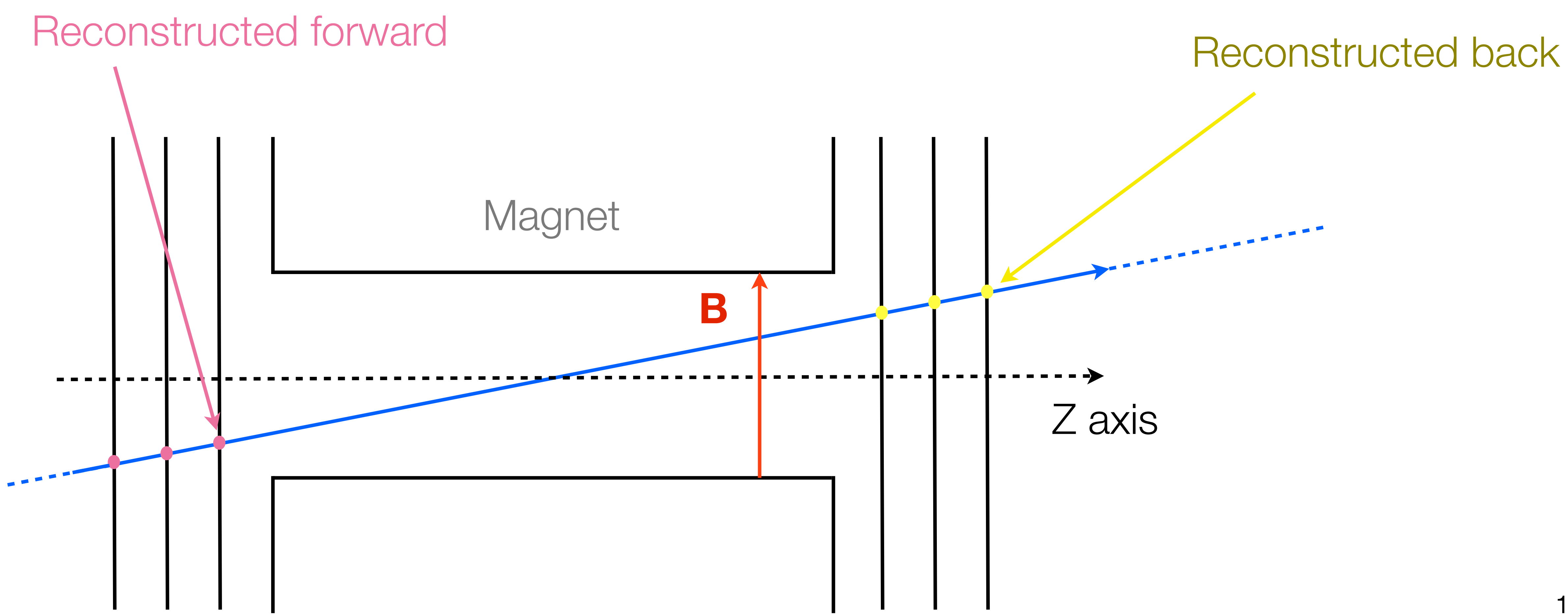
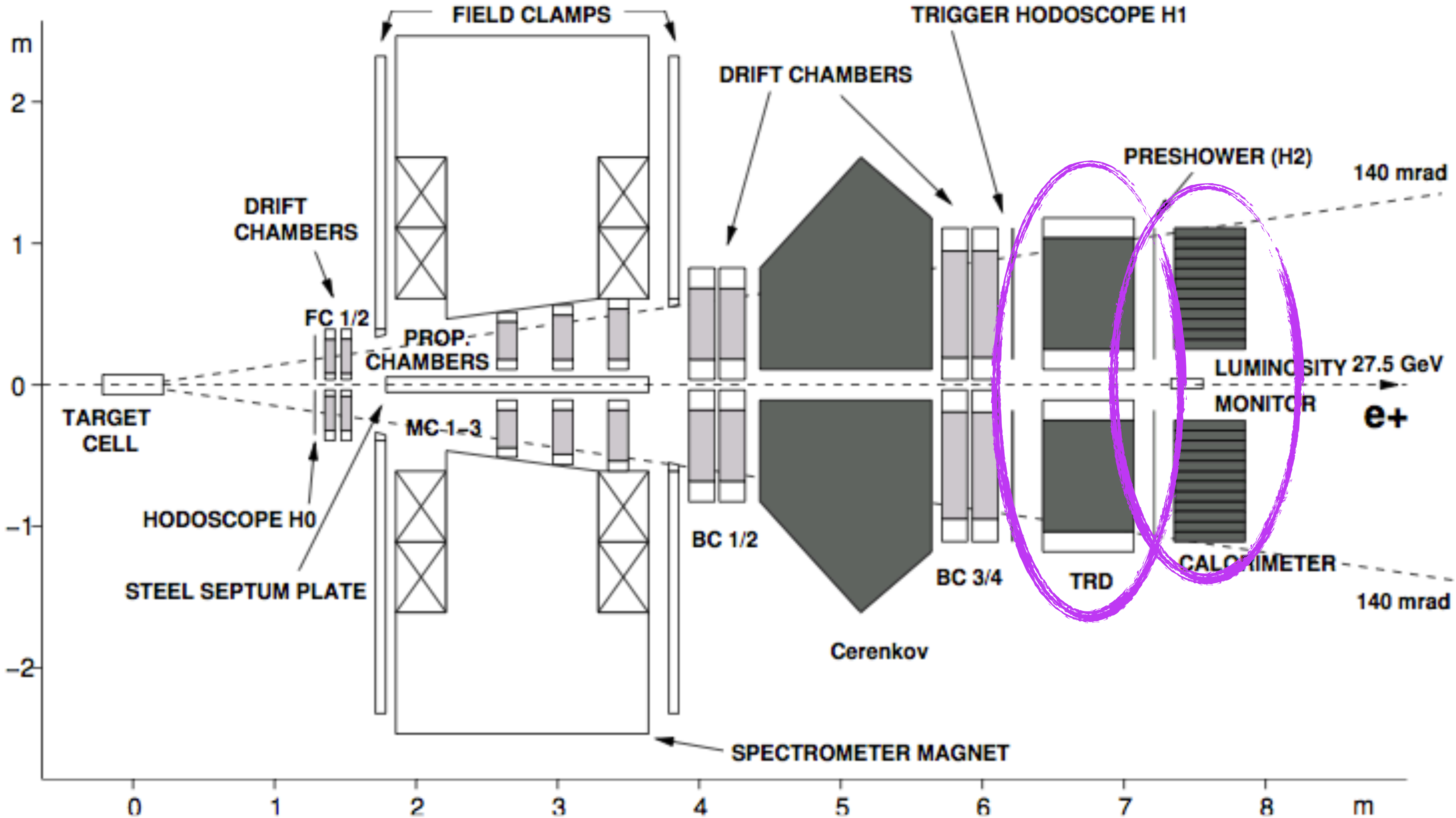
- **FIDUCIAL-VOLUME CUTS:** we have to make sure that our track does not hit any detector. As well, border effects must also be taken in account.



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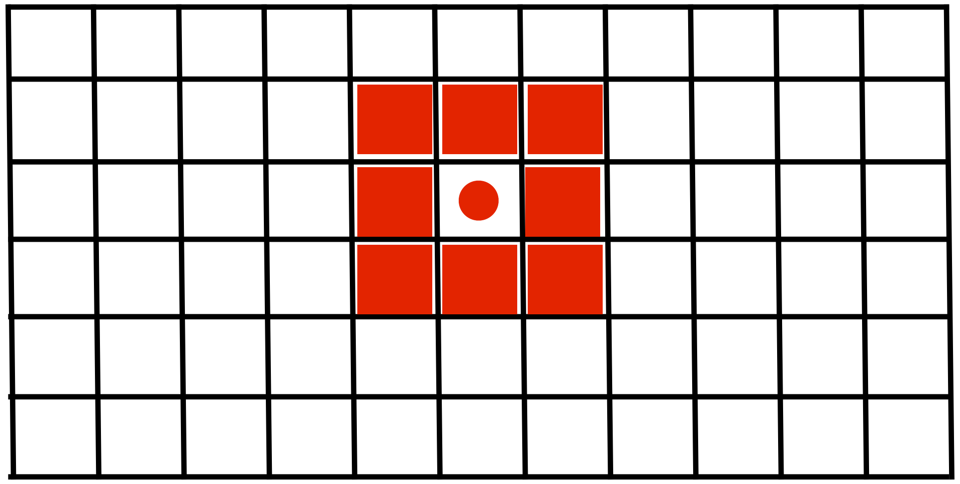

- To determine more precisely the point of impact, we take into account the energy deposition on the calorimeter:

$$x = \frac{\sum_{i=1}^{9} x_i E_i}{\sum_{i=1}^{9} E_i} \rightarrow x = \frac{\sum_{i=1}^{9} x_i \ln(E_i)}{\sum_{i=1}^{9} E_i}$$

- On the calorimeter we also reconstruct the photons. They leave no signal in any other detector (except for the preshower).

- Hadrons also leave some signal on the calorimeter, but it is usually quite weak.

- Leptons leave a big shower and they deposit all their energy in the calorimeter. Only muons and hadrons can cross the whole calorimeter.

- Summarizing, the steps we have to take to validate a measure are the following:
    - Position of the front track at z=0
    - Position of the back track at z=‘middle of the magnet’
    - Energy divided on the different cells on the calorimeter

- **KINEMATIC CUTS:** we also have to choose SIDIS events. This is achieved imposing the following conditions in our kinematics:

	semi–inclusive DIS	
four momentum transfer	$Q^2 > 1\,\text{GeV}^2$	
squared mass of the final state	$W^2 > 10\,\text{GeV}^2$	($W^2 > 4\text{GeV}^2$)
fractional energy transfer	$y < 0.85$	
Bjorken scaling variable	$0.023 < x < 0.4$	
virtual photon – hadron angle	$\theta_{\gamma^* h} > 0.02\,\text{rad}$	
hadron momentum	$2\,\text{GeV} < P_h < 15\,\text{GeV}$	
energy fraction (extended range)	$0.2 < z < 0.7$ $(0.7 < z < 1.2)$	

- A four–momentum transfer of more than 1GeV^2, i.e., larger than the squared proton mass, is required for scattering processes in the deep–inelastic region

- The upper limit on the fractional energy transfer y eliminates DIS events from a region with a large contribution of higher order QED effects (ex. Bremsstrahlung)

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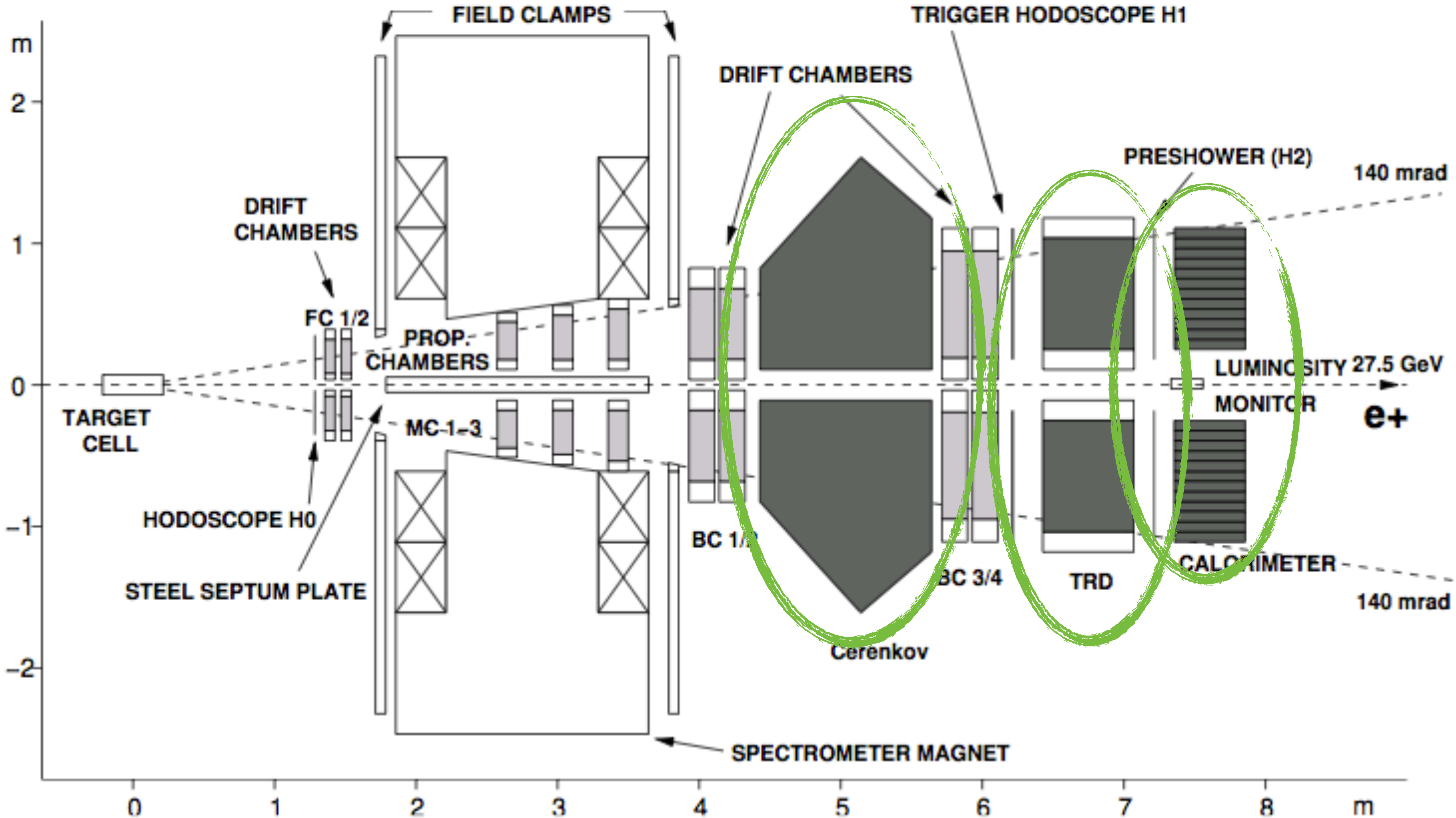
- Due to the restrictions on W^2 and Q^2, the lowest possible value of the fractional energy transfer in semi–inclusive events is around 0.18

- The upper limit of the energy fraction $z < 0.7$ rejects scattering events in a region which is dominated by exclusively produced vector mesons.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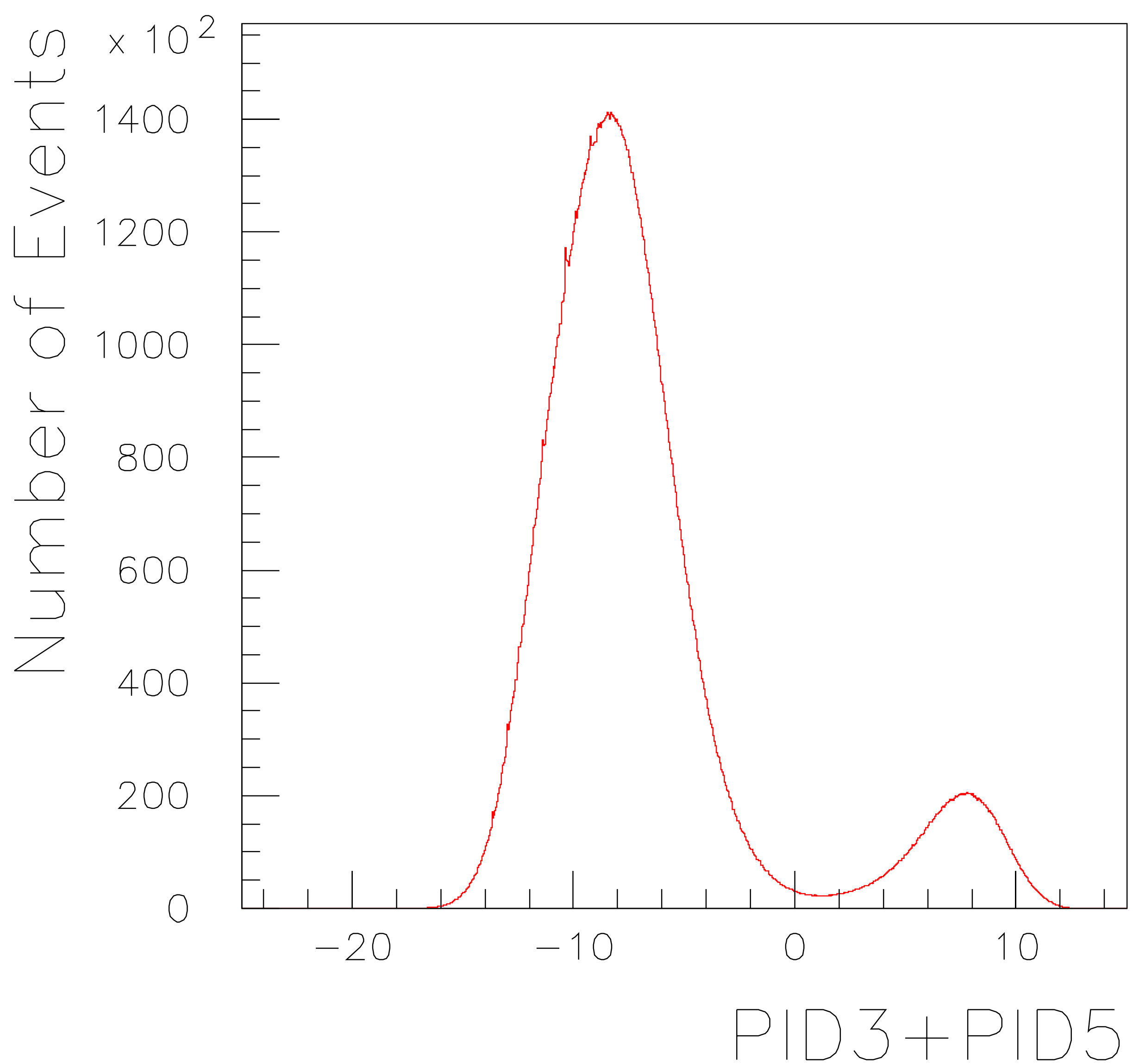
- **EVENT SELECTION:**

  - Leading leptons are identified using the PID values: PID3 + PID5 <k

  - Hadrons are identified using the PID values: PID3 + PID5 >k



- PID3: RICH, Preshower and Calorimeter.

- PID5: TRD ratio

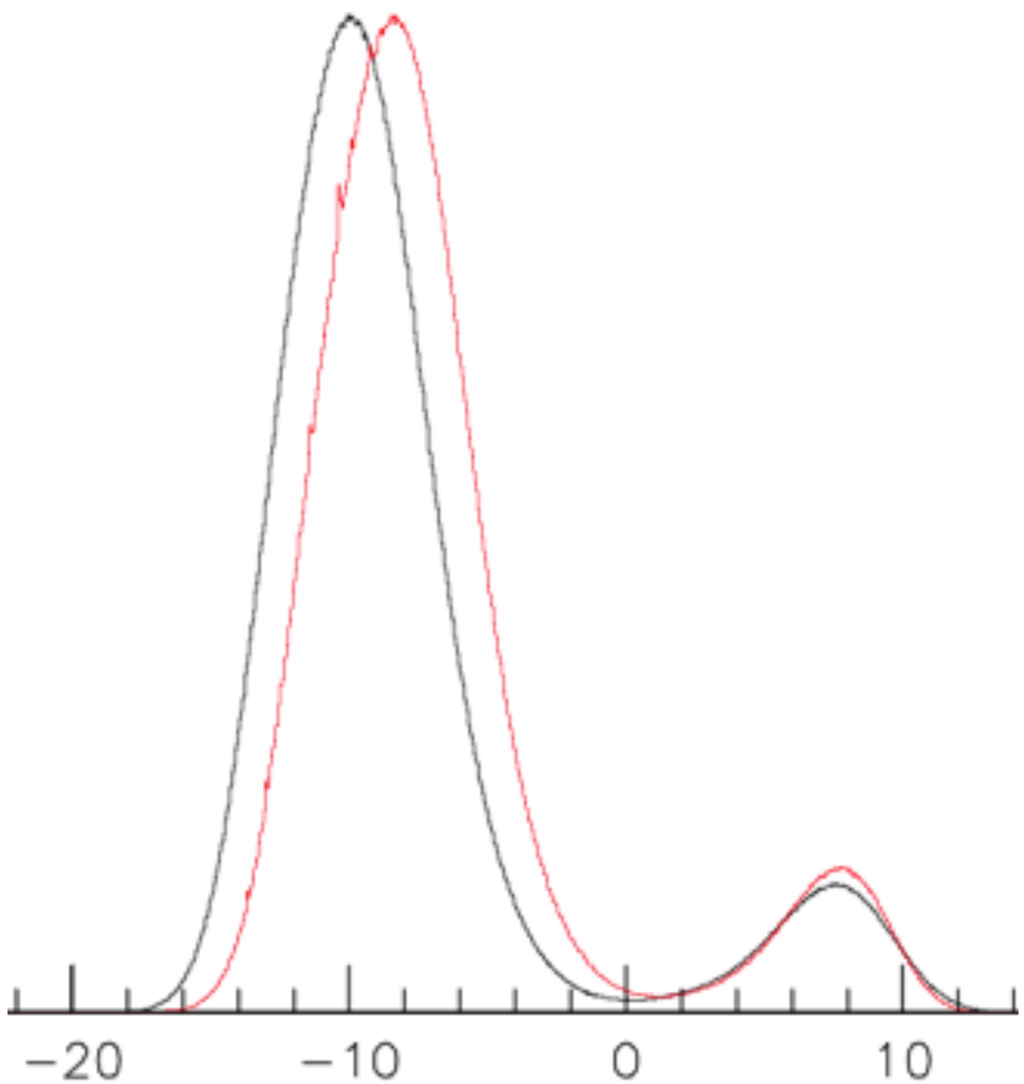
- How accurate is this measure? How can we sure about the choice we make to separate leptons and hadrons? Let’s try to answer these questions.

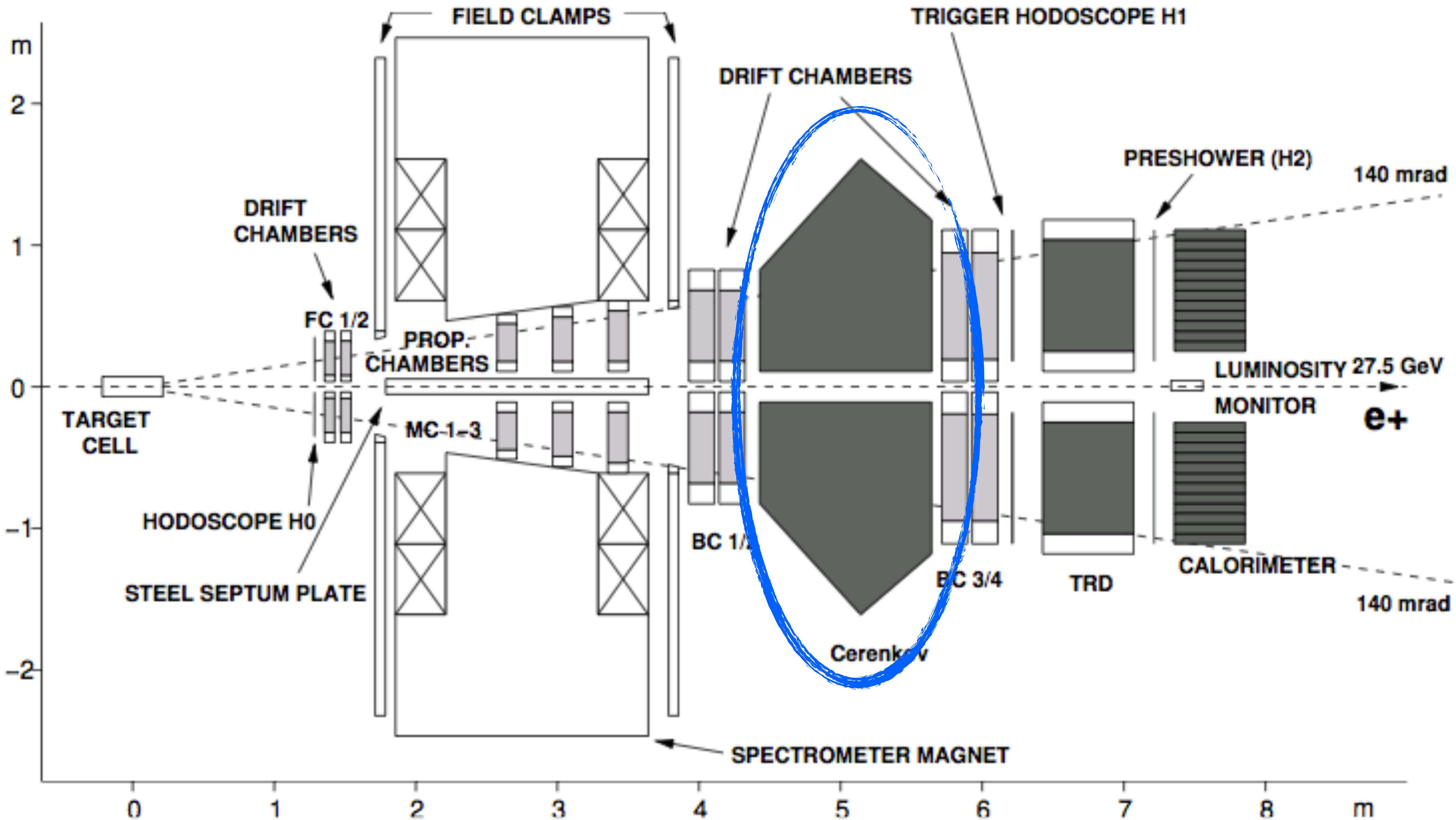
- In order to be more accurate, the following correction is usually done:

$$PID_3 + PID_5 - \log_{10}\frac{\Phi^h}{\Phi^l} = \log_{10}\frac{P^l}{P^h}$$

- This correction simply tries to calibrate the displacement of the minimum of the function due to different amounts of leptons and hadrons we have. Let's see the effect:

- In this case, a clean cut would be choosing :
  - Leptons: PID3+PID5 < -2
  - Hadrons: PID3+PID5 > 1

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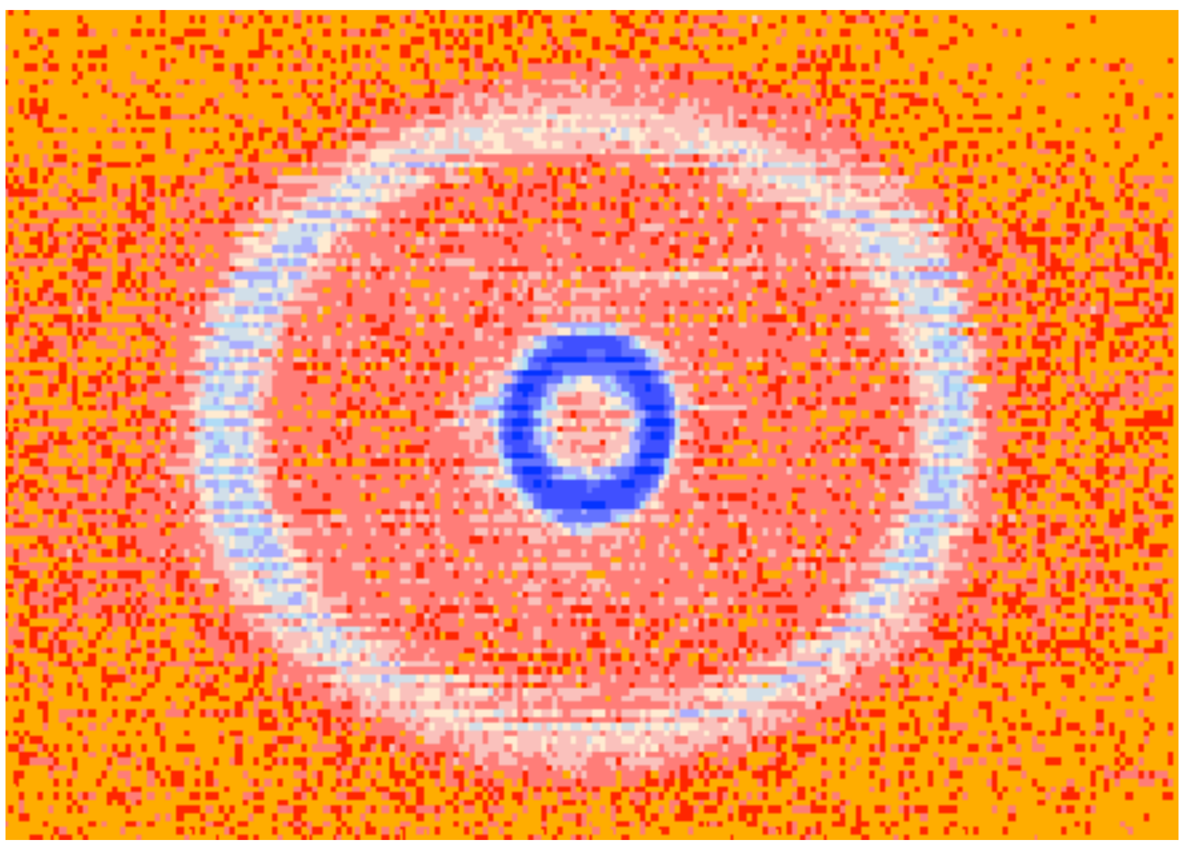
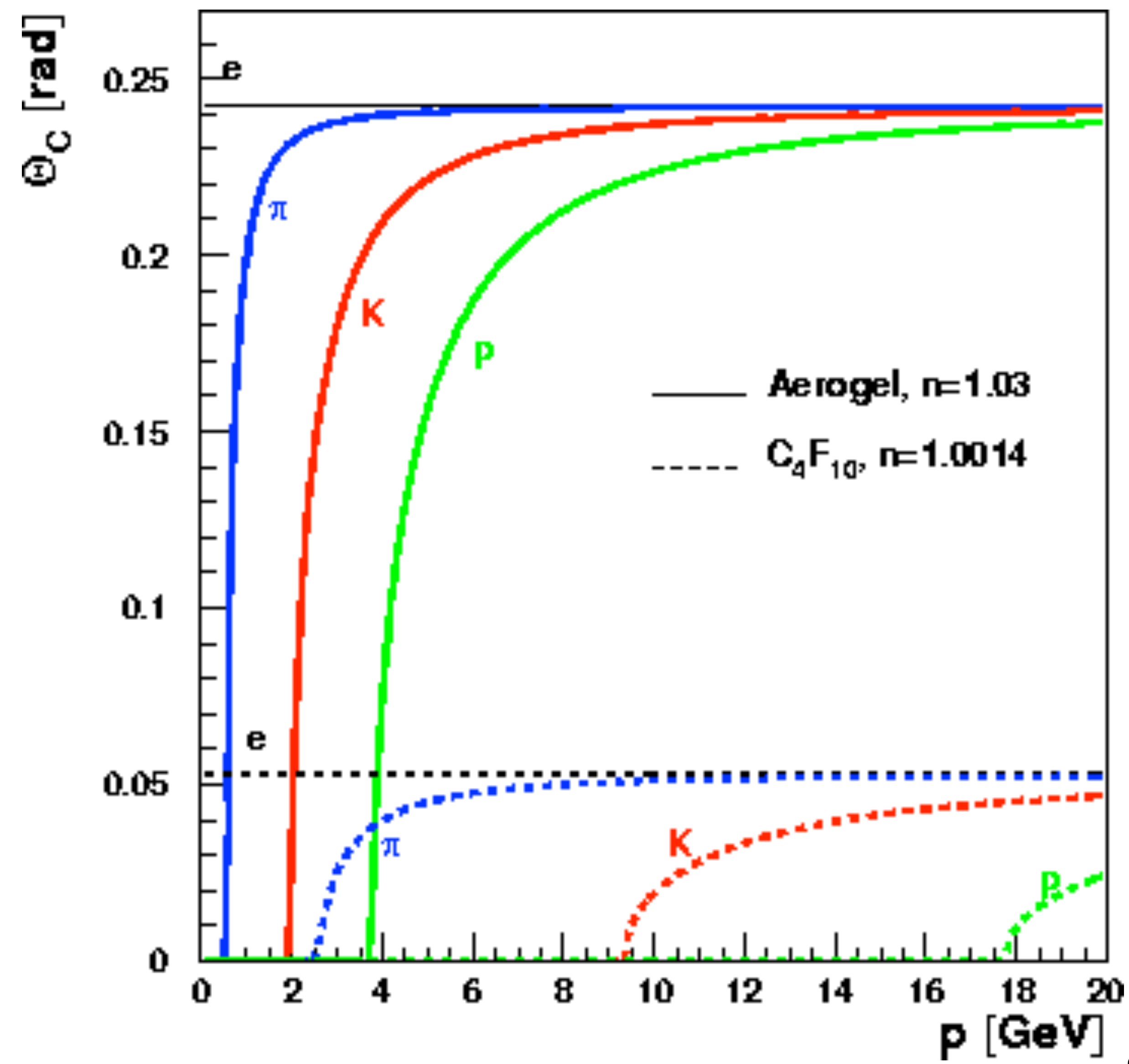
- **<u>CHARGED HADRON IDENTIFICATION</u>:** The next step is trying to distinguish the different hadrons we have: protons, pions and kaons.

- For that, we use the information provided by the RICH (Ring Imaging CHerenkov) detector. Here, ring imaging is used in order to obtain information about the mass of the particle.





- The success of the identification is assured by requiring a positive value of the quality parameter Qp which is defined as the logarithm of the likelihood ratio of the most and the second most likely hadron types, h1 and h2

$$Q_p = \log_{10} \frac{\varsigma_{h_1}^{tot}}{\varsigma_{h_2}^{tot}} > 0$$

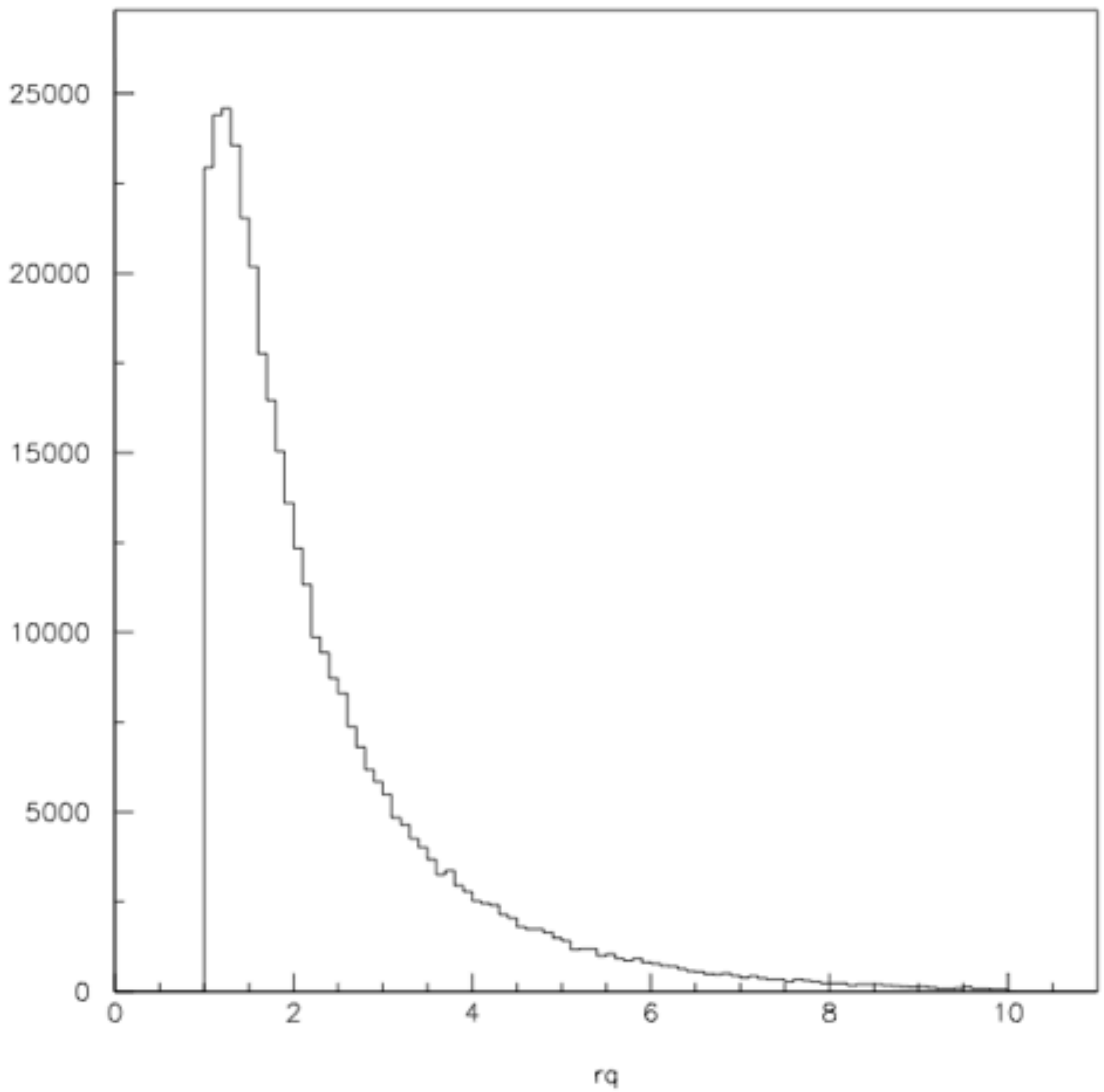
- Through a Monte Carlo simulation for the RICH, we can estimate the contamination and efficiency of the hadron identification:

$$\mathrm{P} = \begin{pmatrix} P(\pi_{id} \mid \pi_{true}) & P(\pi_{id} \mid K_{true}) & P(\pi_{id} \mid p_{true}) \\ P(K_{id} \mid \pi_{true}) & P(K_{id} \mid K_{true}) & P(K_{id} \mid p_{true}) \\ P(p_{id} \mid \pi_{true}) & P(p_{id} \mid K_{true}) & P(p_{id} \mid p_{true}) \end{pmatrix}$$

My Master Thesis Project

- Unpolarized data from year 2000 + Monte Carlo simulations.
- The main aim of the project is trying to learn more about the intrinsic transverse momentum of the quarks inside the nucleon.
- Once the whole analysis of the real data is done, we will compare it to Monte Carlo data and we will try to see which assumptions fit better to reality.

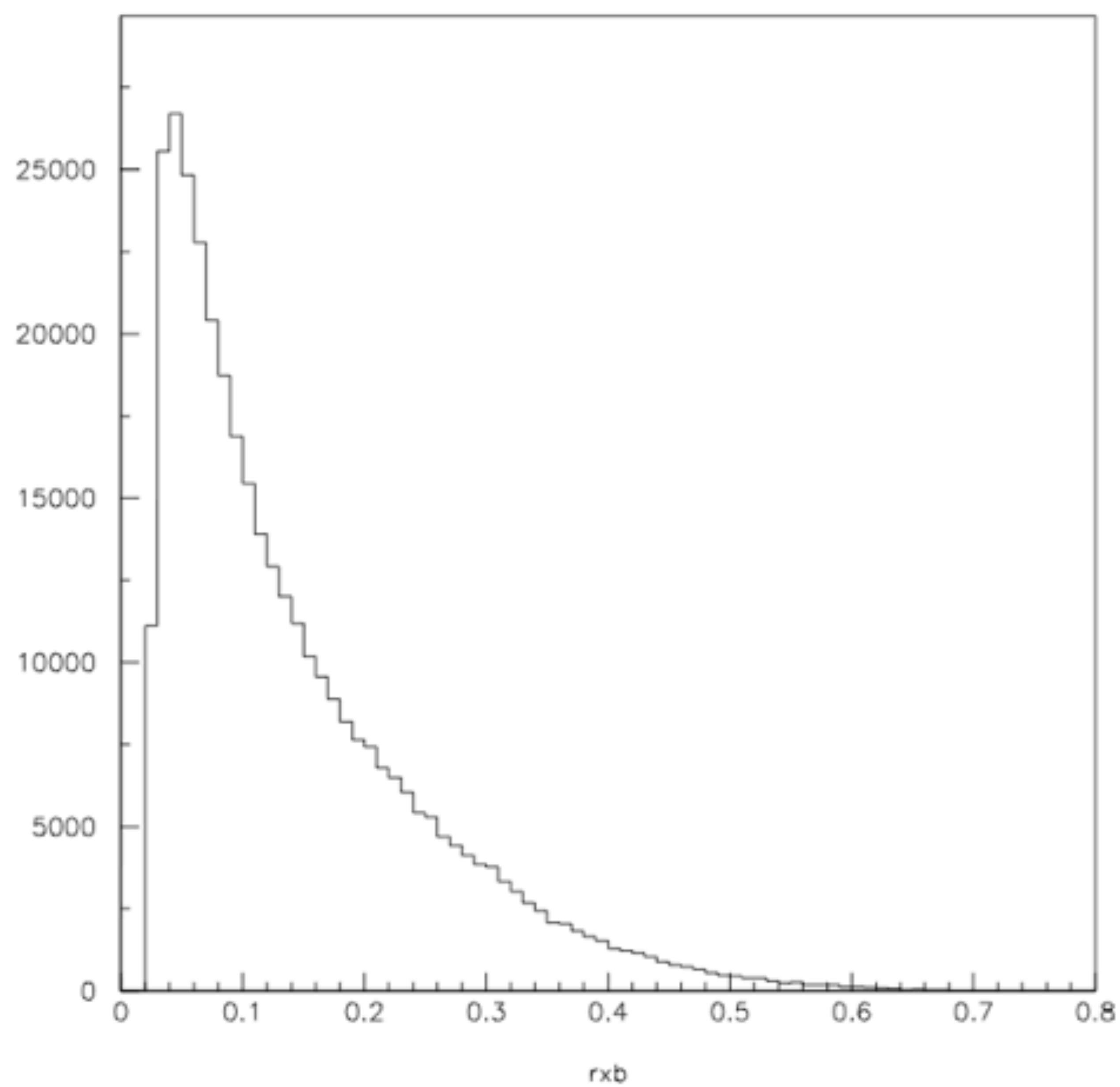
Q^2



$$Q^2 = -q^2 \overset{Lab.}{\approx} 4E_B E' \sin^2(\theta/2)$$

Real data, HERMES 2000

x_B



$$x_B = \frac{Q^2}{2P_q} = \frac{Q^2}{2M\nu}$$

Real data, HERMES 2000

Summary

- First, some *quality requirements* must be imposed, not only *for the detectors*, but also *for the data*.

- Then, *fidutial-volume cut* is required, in order to avoid border effects and discard leptons that may be ambiguous. Besides, *kinematic cuts* are also applied to select the SIDIS events.

- Finally, an *exhaustive analysis of the particles* is necessary, in order to know what we are detecting. For that, we use the data collected by the *forward and back drift chambers* (select the *leading lepton*), by the *PID* (*separate leptons and hadrons*), by the *RICH* (*distinguish* the different *hadrons*) and the *calorimeter* (detect *photons*, and have more information about *leptons and hadrons*).

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Thank you very much for you attention!