The HERMES Recoil Detector

Commissioning Status and Analysis Prospects

Alberto Martínez de la Ossa

University Of Colorado

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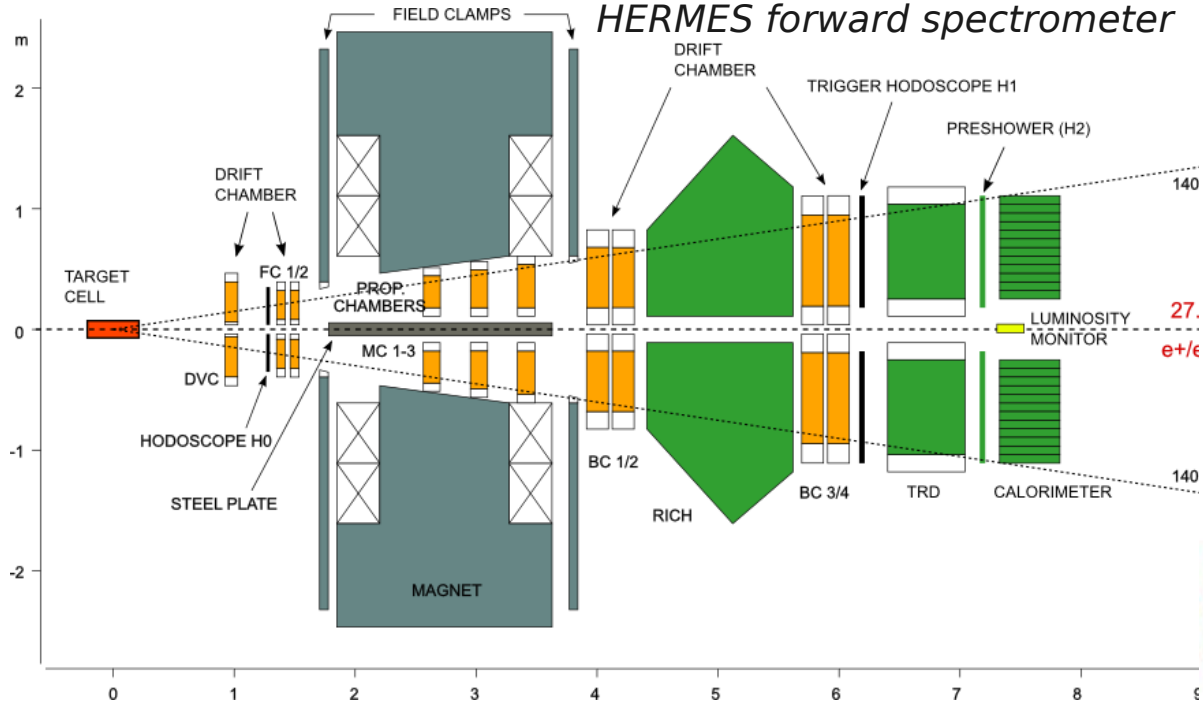
Outline

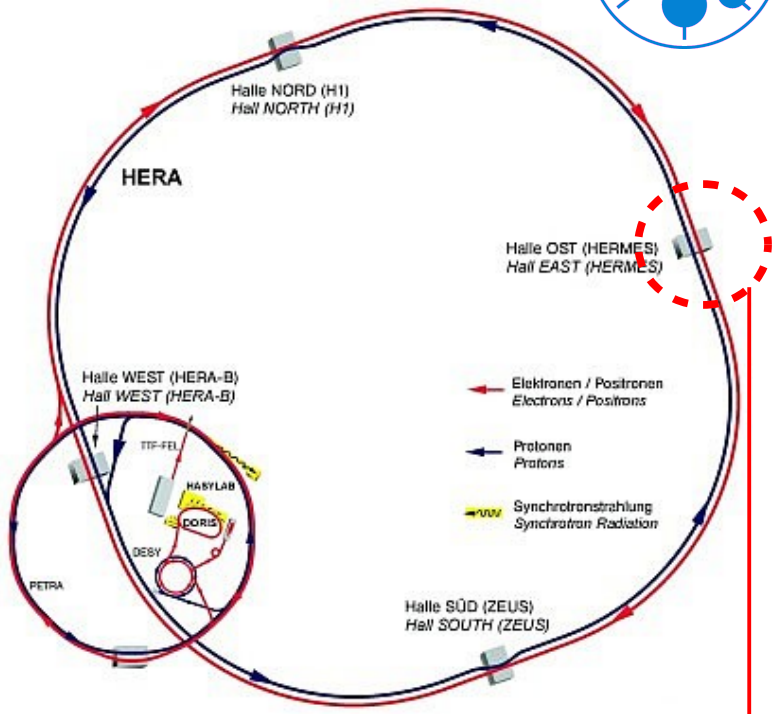
1. *Introduction:*
   - *1.1. The HERMES experiment.*
   - *1.2. The HERMES analyses.*
   - *1.3. HERMES with Recoil and Exclusivity.*
2. *HERMES Recoil Detector:*
   - *2.1. Description.*
   - *2.2. Status of commissioning.*
   - *2.3. Track reconstruction and PID.*
3. *Exclusive reactions with Recoil:*
   - *3.1. Deeply Virtual Compton Scattering.*
   - *3.2. Deeply Virtual Meson Production.*
4. *'Tagged' Structure Functions:*
   - *4.1. Motivation and analysis description*
   - *4,2. Spectator protons with Recoil.*
   - *4.3. Kinematic selection and prospects.*
5. *Conclusions*

The HERMES experiment

schematic side view of the HERMES forward spectrometer



HERA *accelerator at* DESY



* *Polarized Lepton beam at **27.5 GeV**.*
* *Polarized target (reversed every 1-3min):*
  - *Longitudinally H,De,He*
  - *Transversely H*
  - *Unpolarized H, De, Ne, Kr, etc*
* *Particle ID (RICH + TRD + Pre-Shower + CALO)*
  Provide superb lepton/hadron separation.
* *Tracking system: Resolution on kinematics ~ 1%*

The HERMES analyses

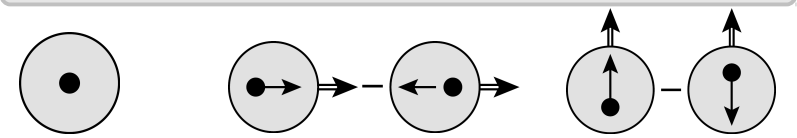
Pioneer in the understanding of nucleons structure:

Inclusive DIS
Structure of the nucleon

$$F_1(x),\ F_2(x),\ g_1(x),\ g_2(x)$$

Unpolarized structure functions — *Spin-dependent structure functions*

Semi-Inclusive DIS
Quark structure of the nucleon



$q(x)$ *Unpolarized* — $\Delta q(x)$ *Helicity* — $\delta q(x)$ *Transversity*

in quark parton model..

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + \Delta g + L_g$$

..Spin of Quarks: $\Delta\Sigma \approx \frac{1}{3}$

Hermes: Phys. Rev. D75 (2007) 012007

Quark orbital momentum?

$$J^q = \lim_{t\to 0}\int_0^1 dx x[H^q + E^q]$$

Exclusive DIS
General structure of the nucleon

- ***D**eeply **V**irtual **C**ompton **S**cattering*
- ***E**xclusive **M**esons **P**roduction*

described in terms of..

Generalized Parton Distributions.

The HERMES analyses

Pioneer in the understanding of nucleons structure:

Inclusive DIS
Structure of the nucleon

$F_1(x),\ F_2(x),\ g_1(x),\ g_2(x)$

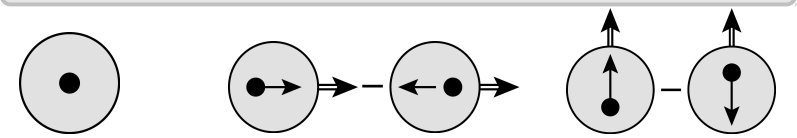
Unpolarized structure functions — *Spin-dependent structure functions*

Structure function of the Neutron?

$F_2^n(x)$ can be accesible via tagging spectator protons in DIS off Deuterium.

Determination of $F_2^n(x)/F_2^p(x)$ *would lead to important insights on quark dinamics on nuclei.*

Semi-Inclusive DIS
Quark structure of the nucleon



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General structure of the nucleon

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described in terms of..

Generalized Parton Distributions.

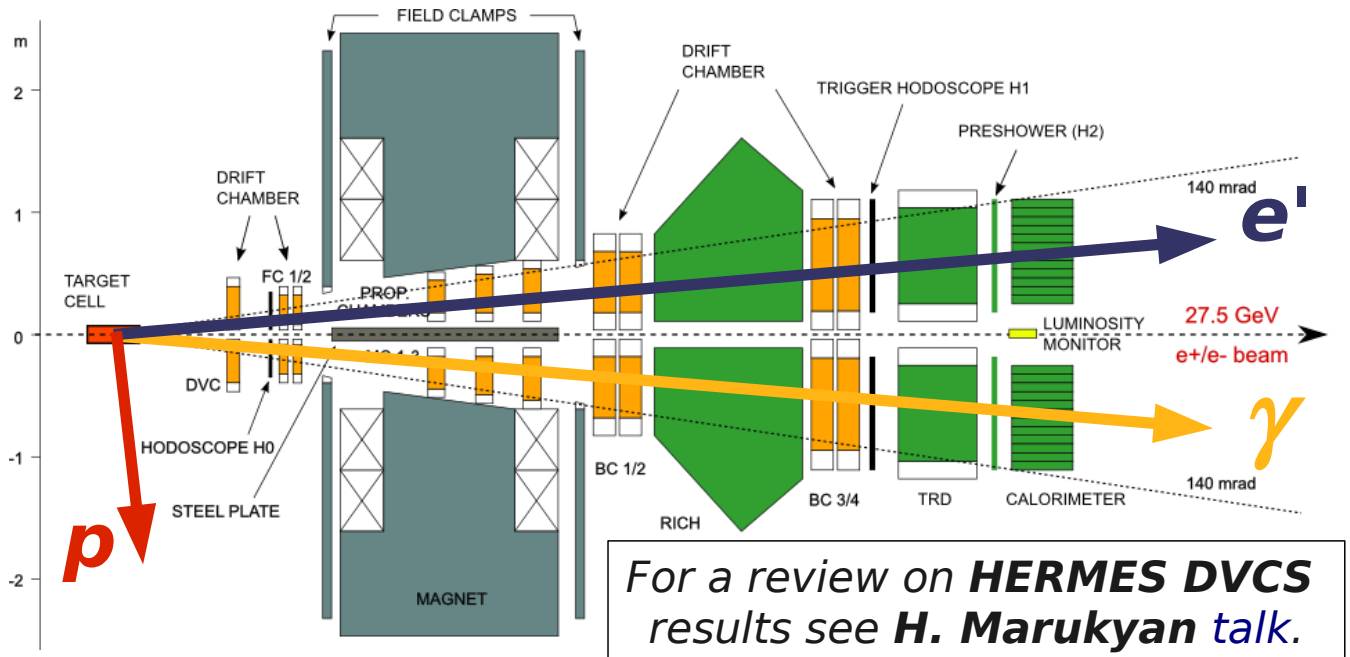
Exclusivity at HERMES (96-05)

Detected Particles:
* *DIS* ***electron***
* ***photon*** *(DVCS)*
  or leading ***meson*** *(DVMP).*

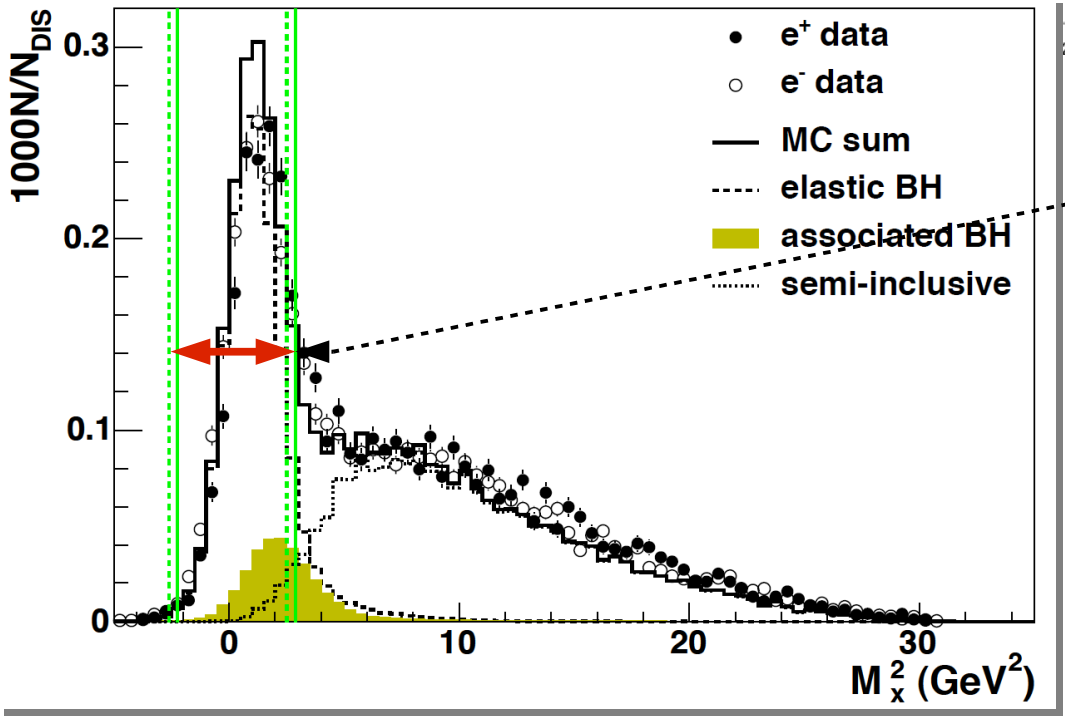
recoiling ***proton*** *undetected*

Exclusivity by means of ***Missing mass*** technique

$$M_X^2 = (p + q - p_\gamma)^2$$



For a review on ***HERMES DVCS*** *results see* ***H. Marukyan*** *talk.*



Exclusive Region

$$(-1.5)^2 < M_X^2 < (1.7)^2 GeV^2$$

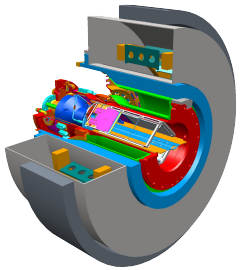
Elastic BH $ep \to ep\gamma$

associated BH	$ep \to e\Delta^+\gamma$	*12%*
Semi-Inclusive	$ep \to e\pi^0 X$	*3%*

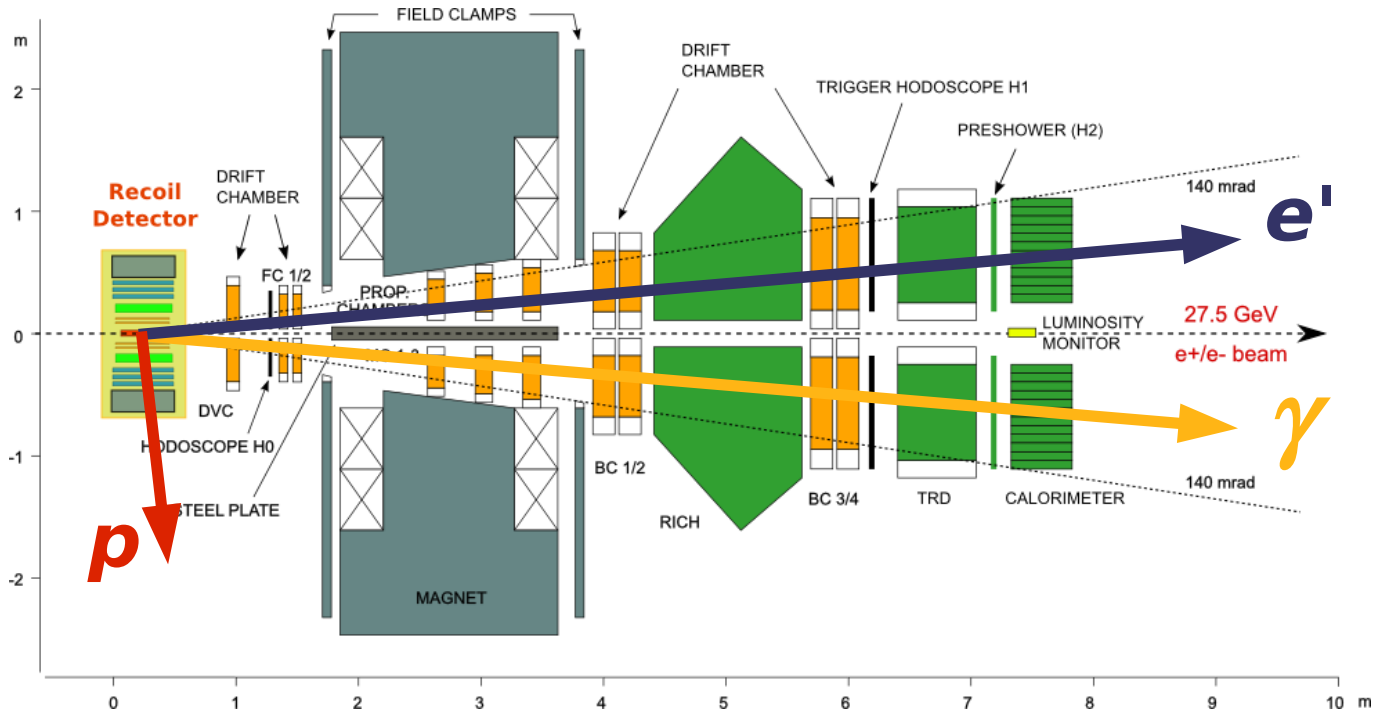
15% background contribution

Exclusivity at HERMES (06-07)

Recoil Detector



Improves exclusivity:
* *Detecting the proton.*
* *Pions and photons.*



Substantially reduce associated BH contributions:

$$\Delta^+ \rightarrow p\pi^0 \rightarrow p\gamma\gamma$$
$$\rightarrow \pi^+ n$$

Background contribution below ***1%***

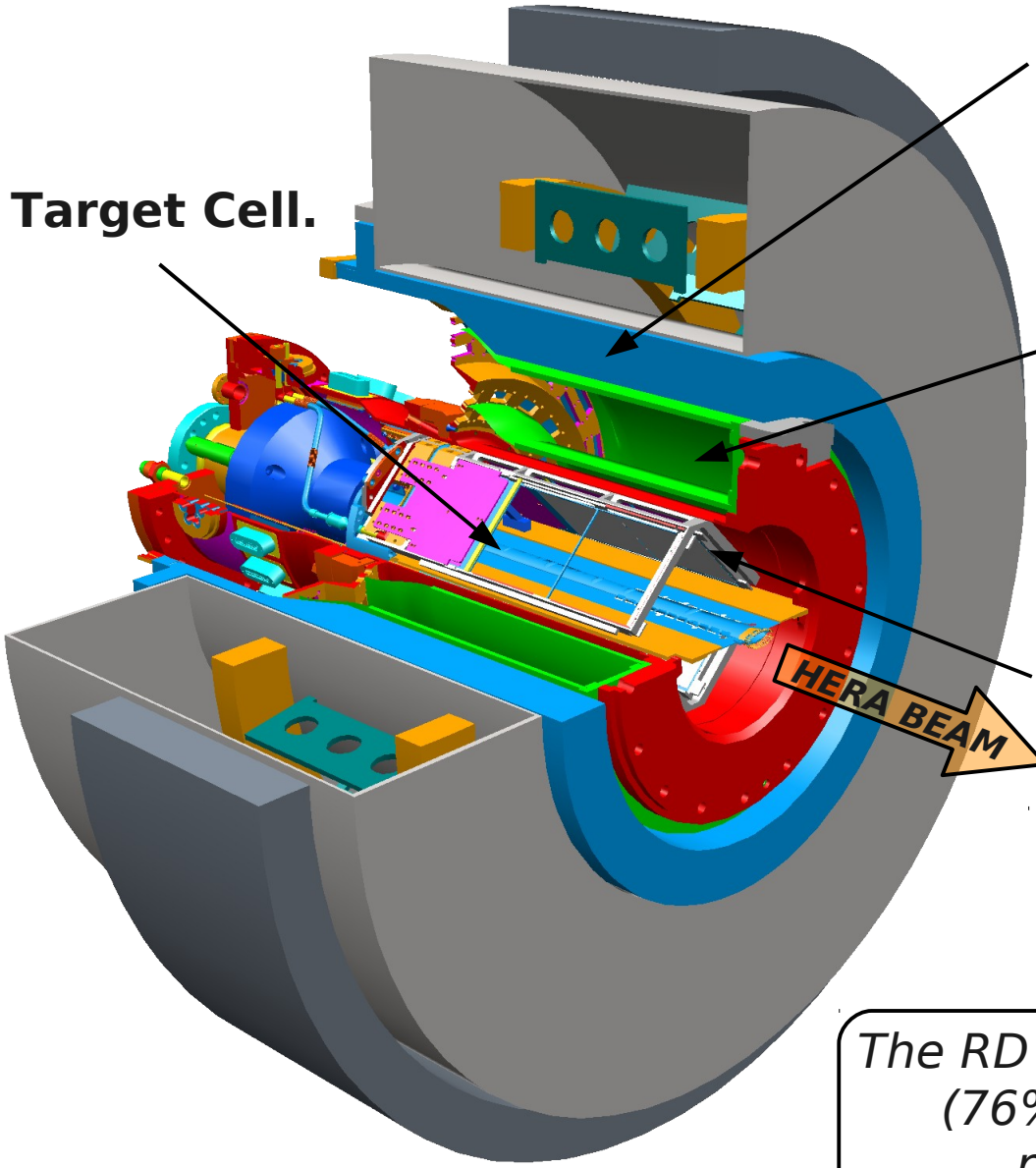
Experimental setup:
* *Unpolarized H and De targets.*
* *Polarized e^+ and e^- beam.*

Available Statistics:

DIS events	**Hydrogen**	**Deuterium**
2006	32 M	7.6 M
2007	25 M	6.6 M
Total	**57 M**	**14.2 M**

Recoil Detector (RD)

Superconducting Solenoid (1T)



Photon Detector (PD):

* 3 layers of Tungsten/scintillator sandwich

*PID for proton tracks **P>0.6 GeV**.*
Detects Photons!

Fiber Detector (SFT):

* 2 barrel with 4 layers of scintillating fibers.
* 2 parallel and 2 stereo layers per barrel.

*Track reconstruction and PID for proton tracks **P>0.25 GeV***

Silicon Strip Detector (SSD):

* 16 sensors
* **Inside HERA vacuum**
* **5 cm. close to beam.**

*Track reconstruction and PID for proton tracks **P>0.09 GeV***

*The RD offers a large azimuthal acceptance (76%) and minimum reconstructible proton momentum of **90 MeV***

Status of Commissioning

RAW data processing algorithms:

- Pedestal and noise studies.
- Crosstalk corrections.
- Signal processing algorithms to hit detection.

Alignment and Calibration:

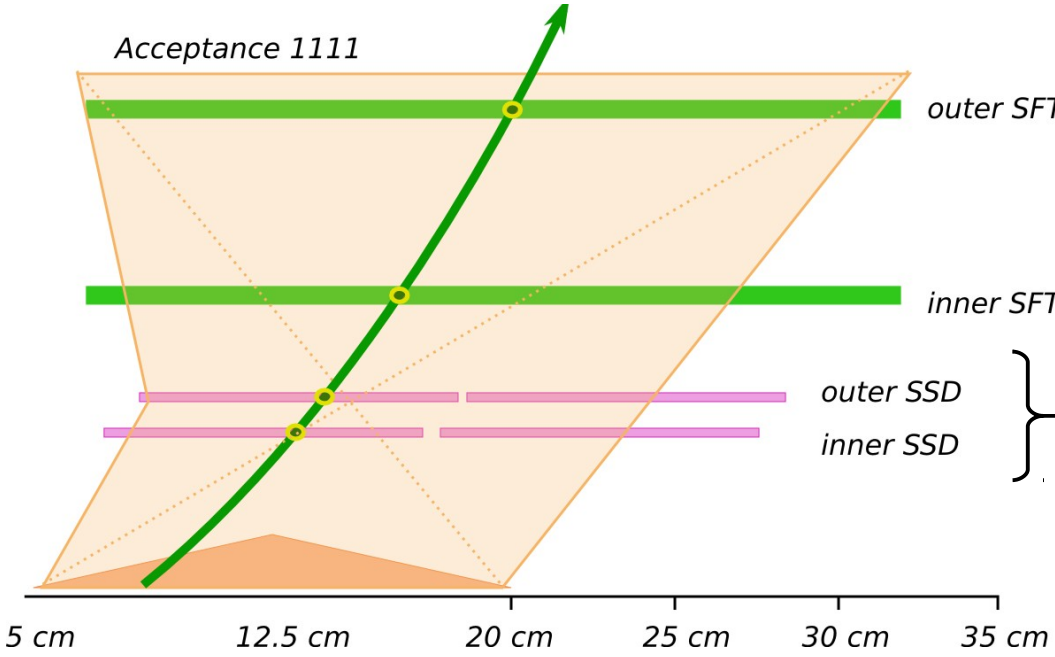
- Alignment and Calibration of each sub-detector
- Efficiencies studies.

Event Reconstruction:

- Tracking algorithms.
- Particle Identification.
- Pasive material corrections.
- Mapping of detector acceptance.

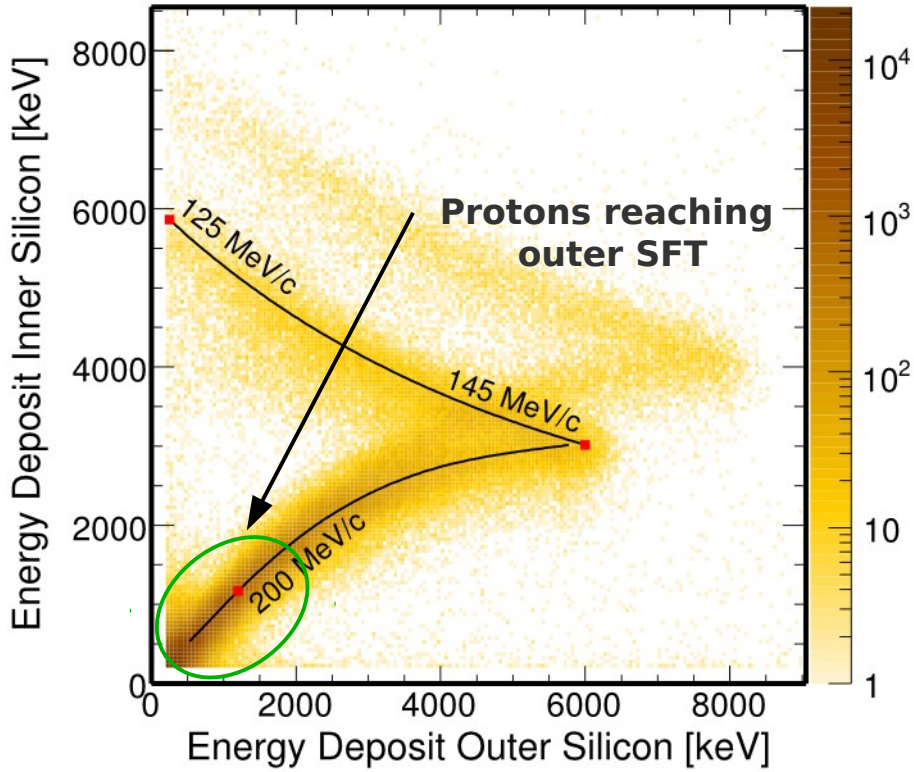
Ready for physics analyses

Track reconstruction



Schematic side View of RD showing zenithal acceptance vs. Z vertex

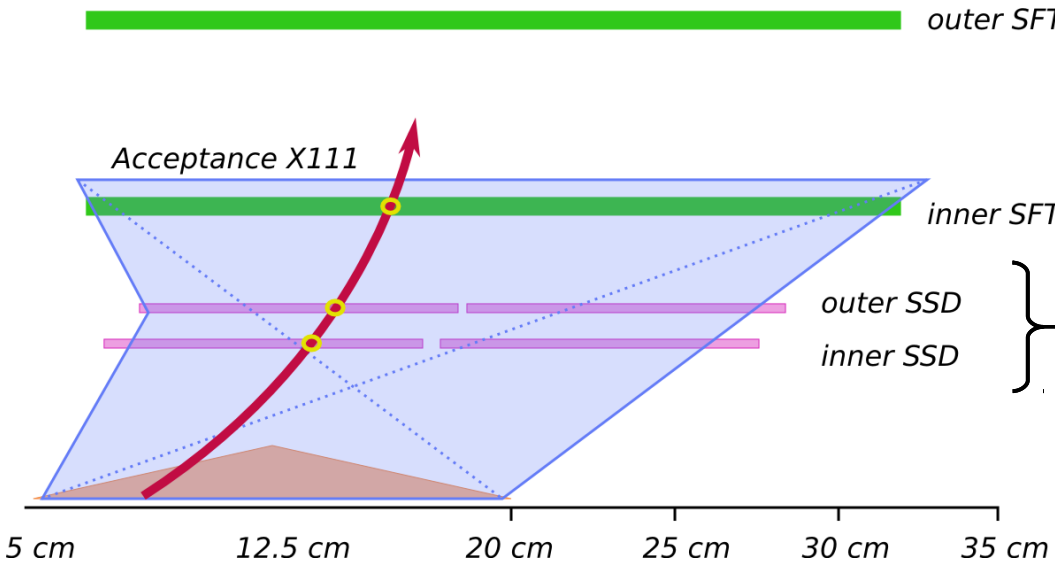
Energy deposition in SSD



High-Energy Protons (1111): *p>200 MeV/c*

* *Momentum via bending in Magnetic field*

Track reconstruction



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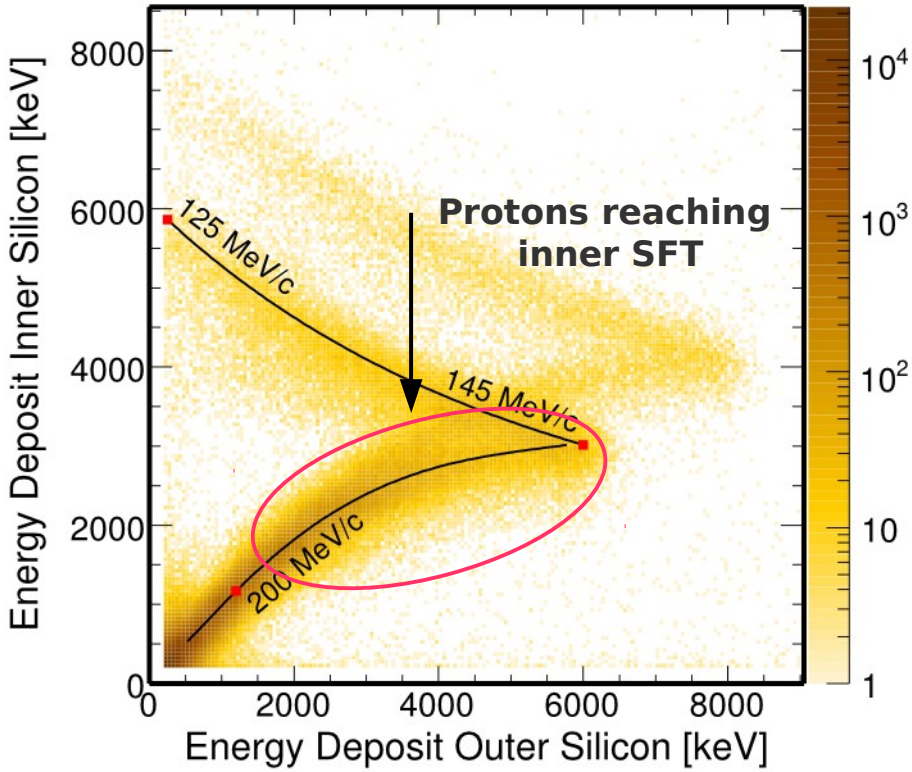
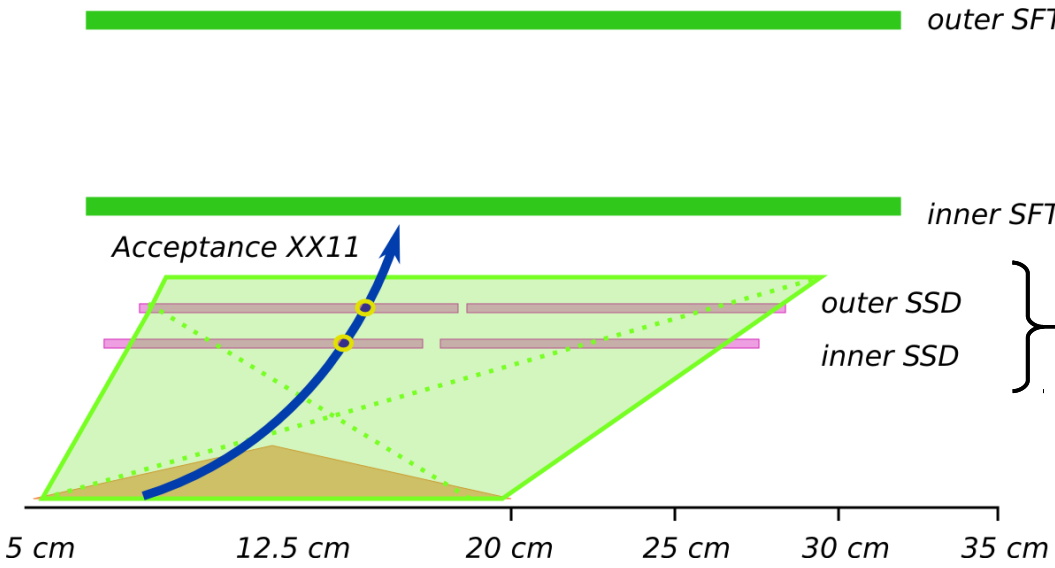


Medium-Energy Protons (X111): ***145 MeV/c < p < 250 MeV/c***

* *Momentum via dE/dx*

Track reconstruction



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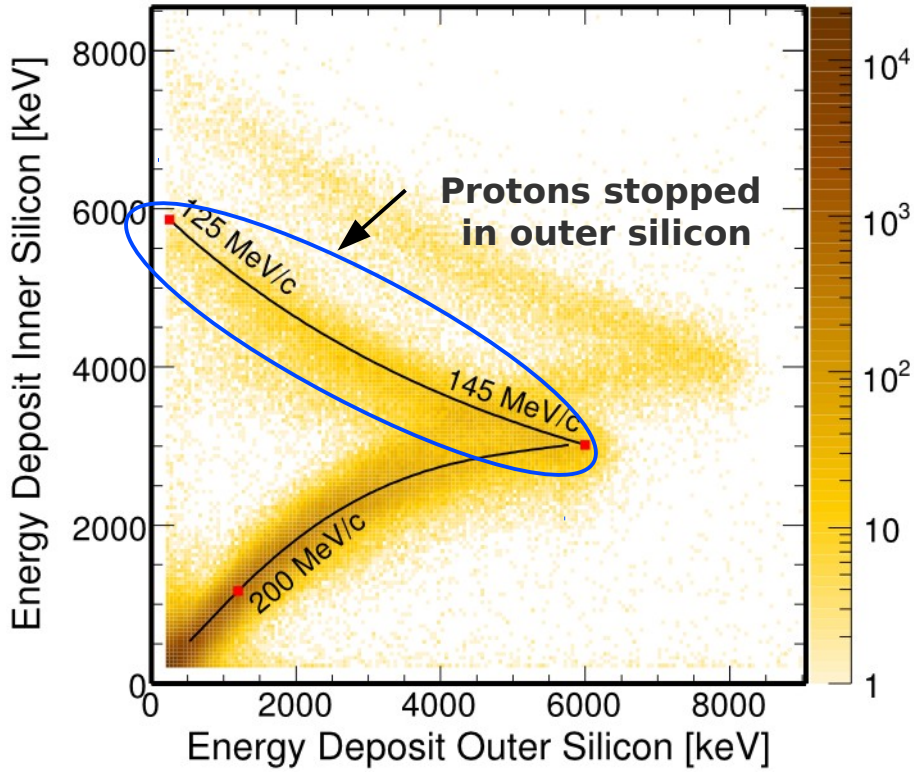
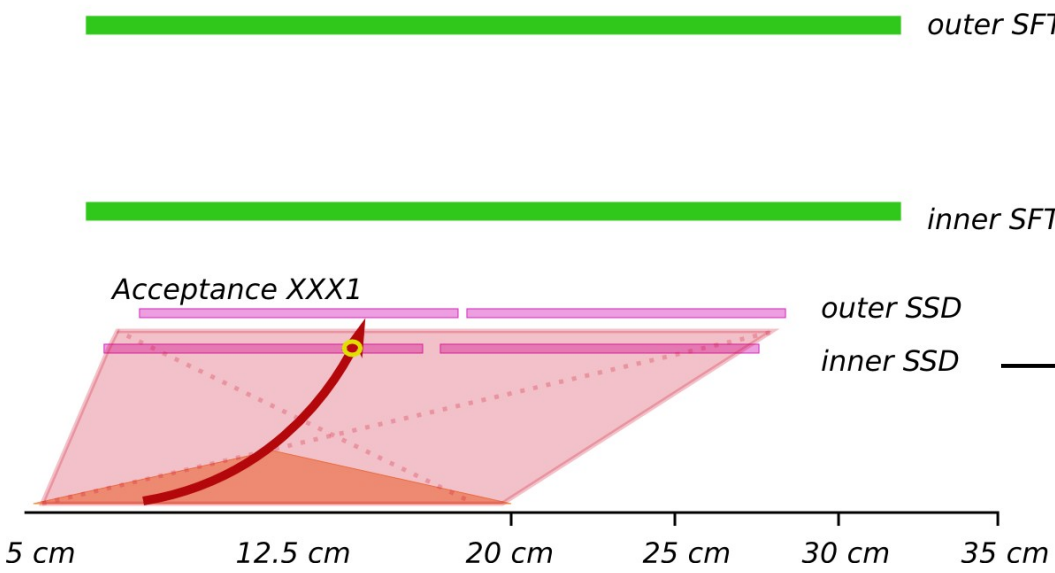


Low Energy Protons (XX11): ***125 MeV/c < p < 145 MeV/c***

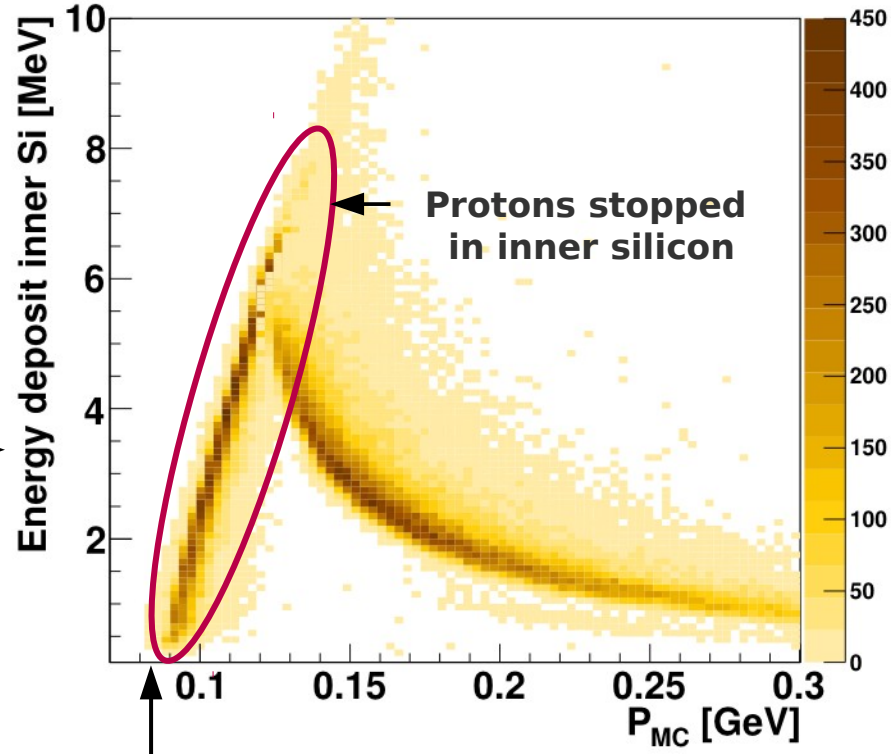
* *Momentum via sum of energy deposits*

Track reconstruction



Schematic side View of RD showing zenithal acceptance vs. Z vertex

Energy deposition in inner SSD



minimum reconstrutible momentum

Lowest Energy Protons (XXX1): ***90 MeV/c < p < 125 MeV/c***

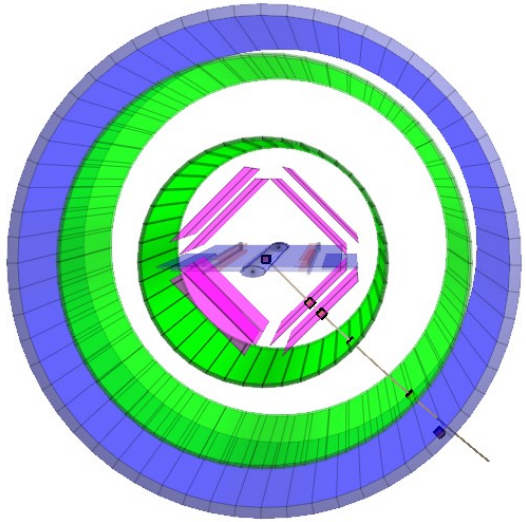
* *Momentum via energy deposit*
* *Production vertex from DIS lepton.*

Track reconstruction

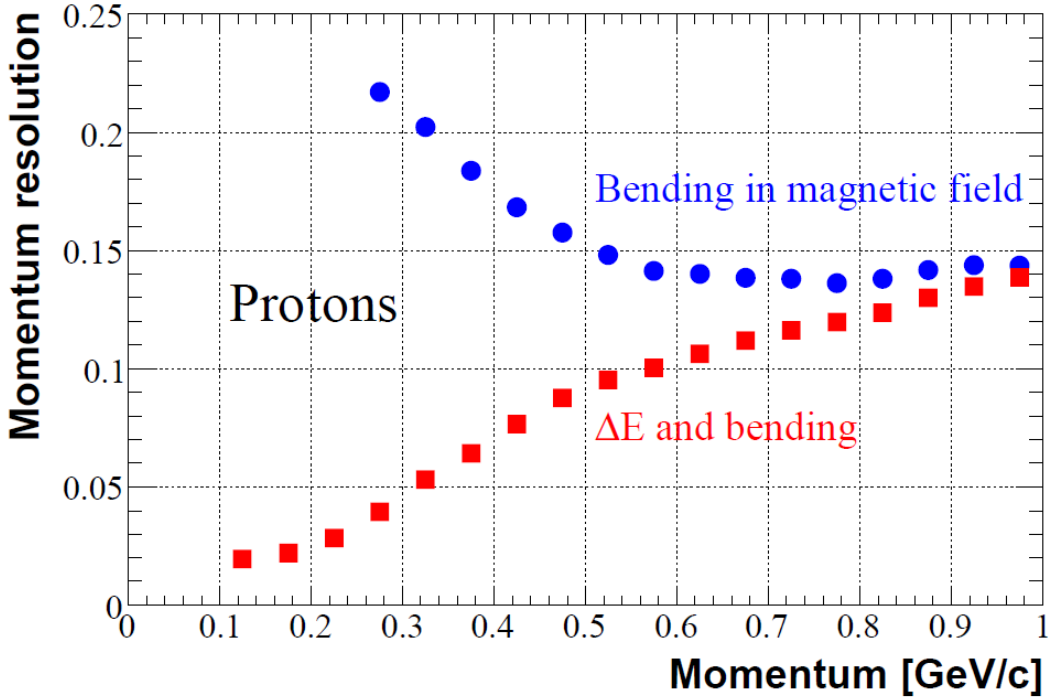
Outlook in Track reconstruction

1. *Geometric track finder.*
   Find helices compatibles with beam.
2. Every possible track reconstructed under *different hypothesis*.
   - Particle hypothesis.
   - Track topology (Stopped or through going).
3. Geometrical information (*bending*) used in conjunction with *energy depositions* to improve reconstruction.
4. Quality of tracking estimated (χ^2).

Momentum resolution
Below 15%
in whole kinematic range

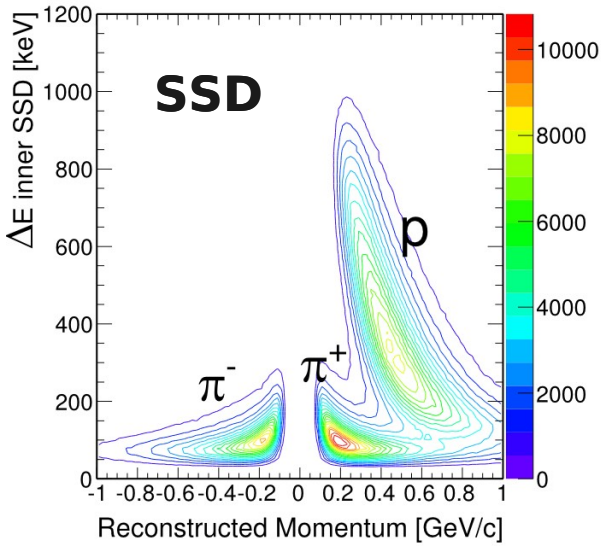


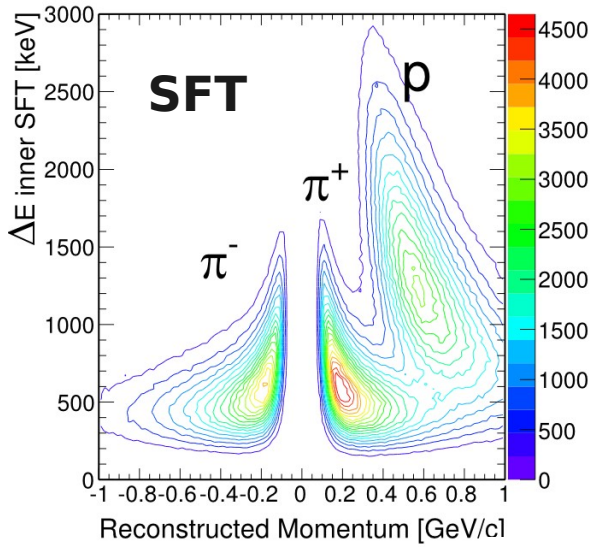
A 3D view of the reconstruction of a 4 space points proton.

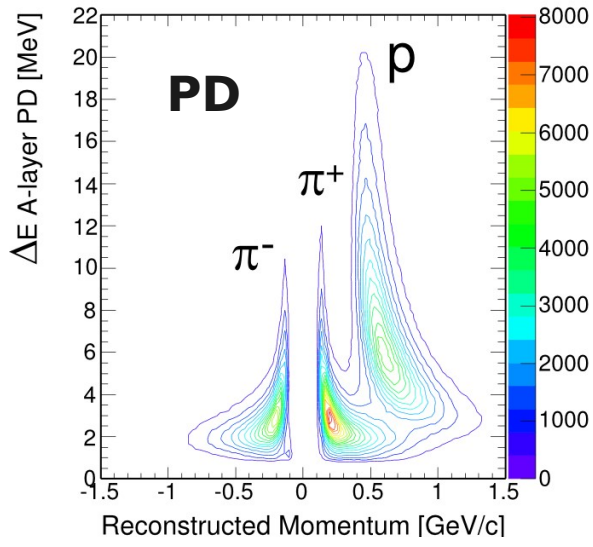


Particle identification

proton/pion separation from energy deposits in each subdetector:





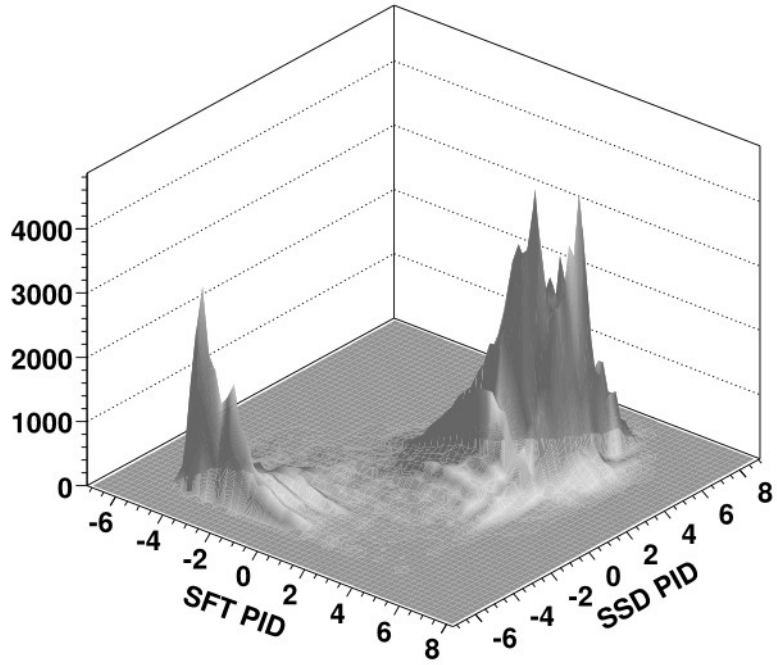


P<600 MeV/c SSD + SFT (6 layers)
P>600 MeV/c + PD

Likelihood formalism to combine all PIDs

$$PID_i \equiv \log \frac{\mathcal{P}_p(\Delta E_i, p)}{\mathcal{P}_{\pi^+}(\Delta E_i, p)}$$

`i denotes different sub-detectors`

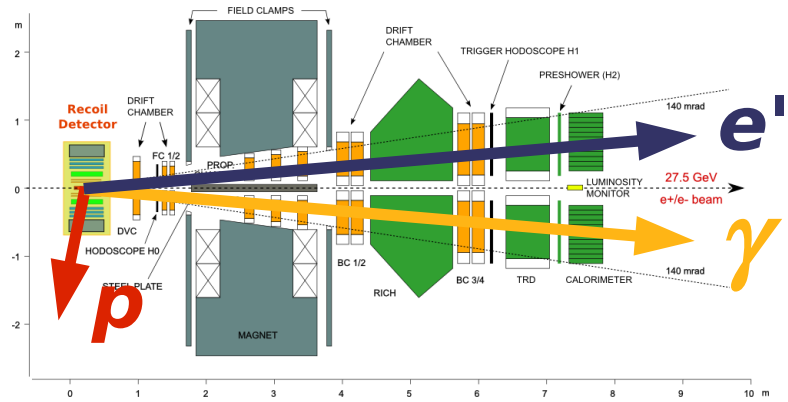


DVCS with Recoil

DVCS analysis with Recoil:

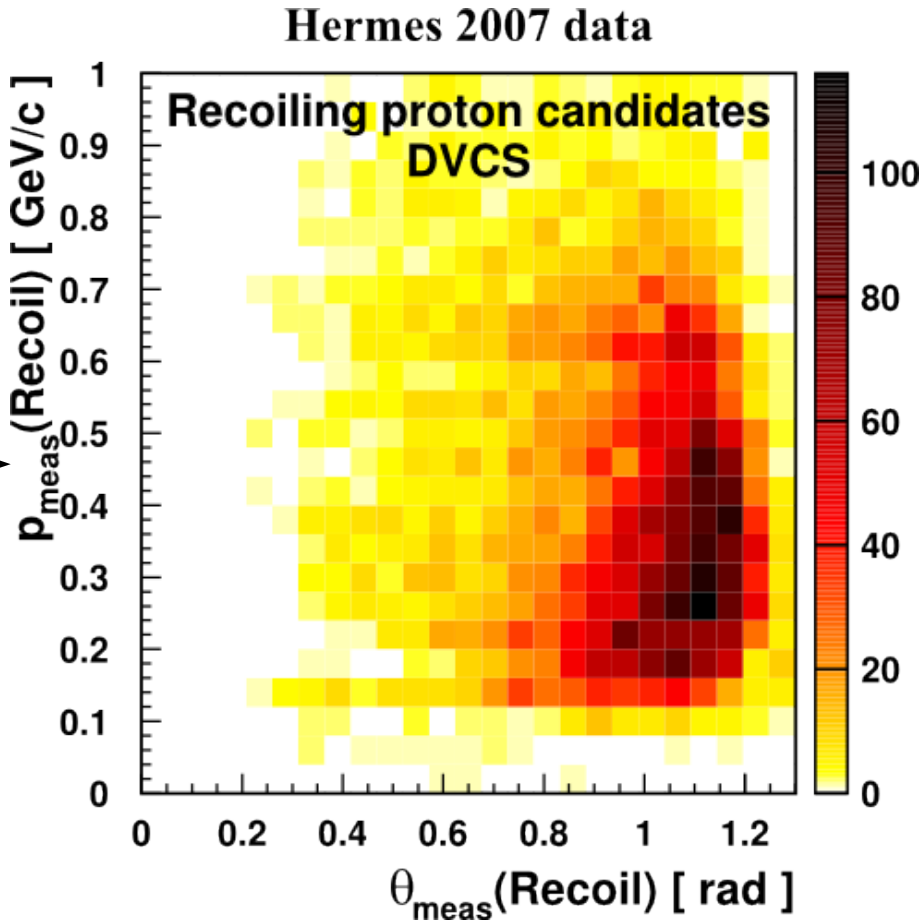
1. Forward Spectrometer:

* Selection of $e\gamma$ topologies.
* Calculate 'missing' p and ϕ .



2. Recoil Detector:

* Select proton track candidate.



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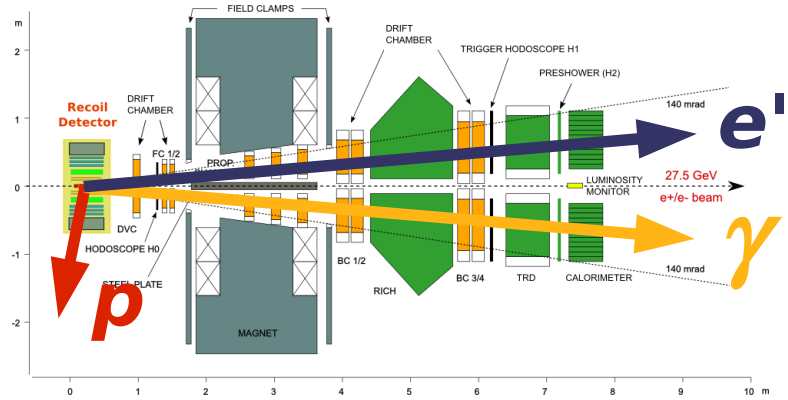
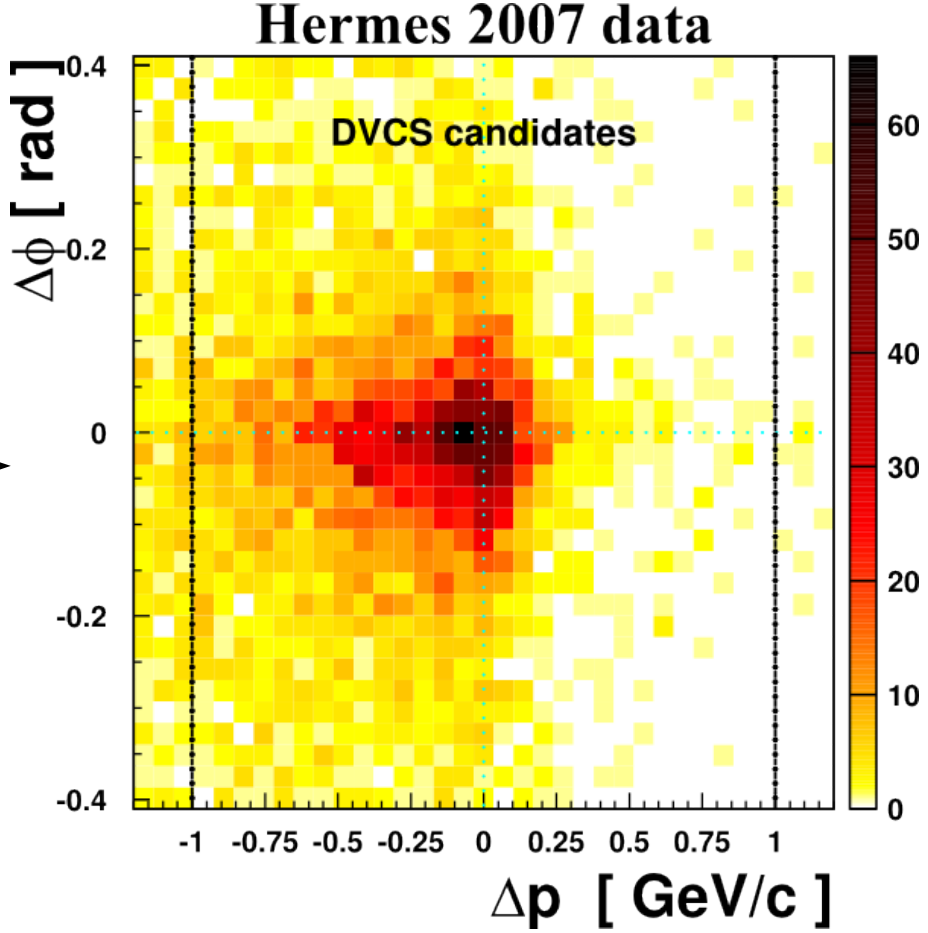


2. Recoil Detector:

* Select proton track candidate.
* Look for “DVCS” correlations:

$$\Delta\phi = \phi_{meas} - \phi_{calc}$$
$$\Delta p = p_{meas} - p_{calc}$$



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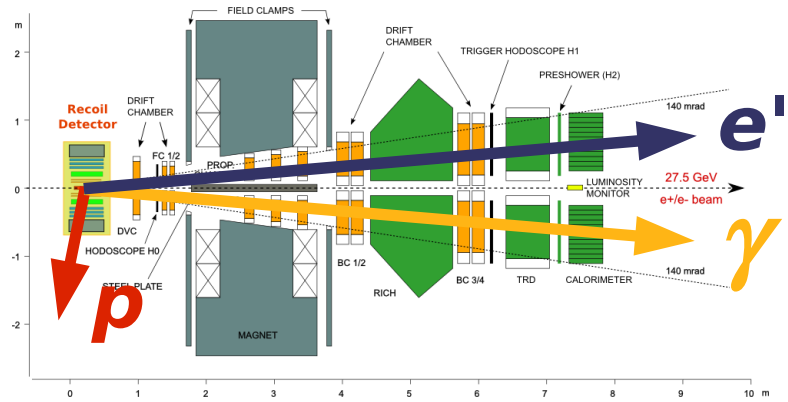

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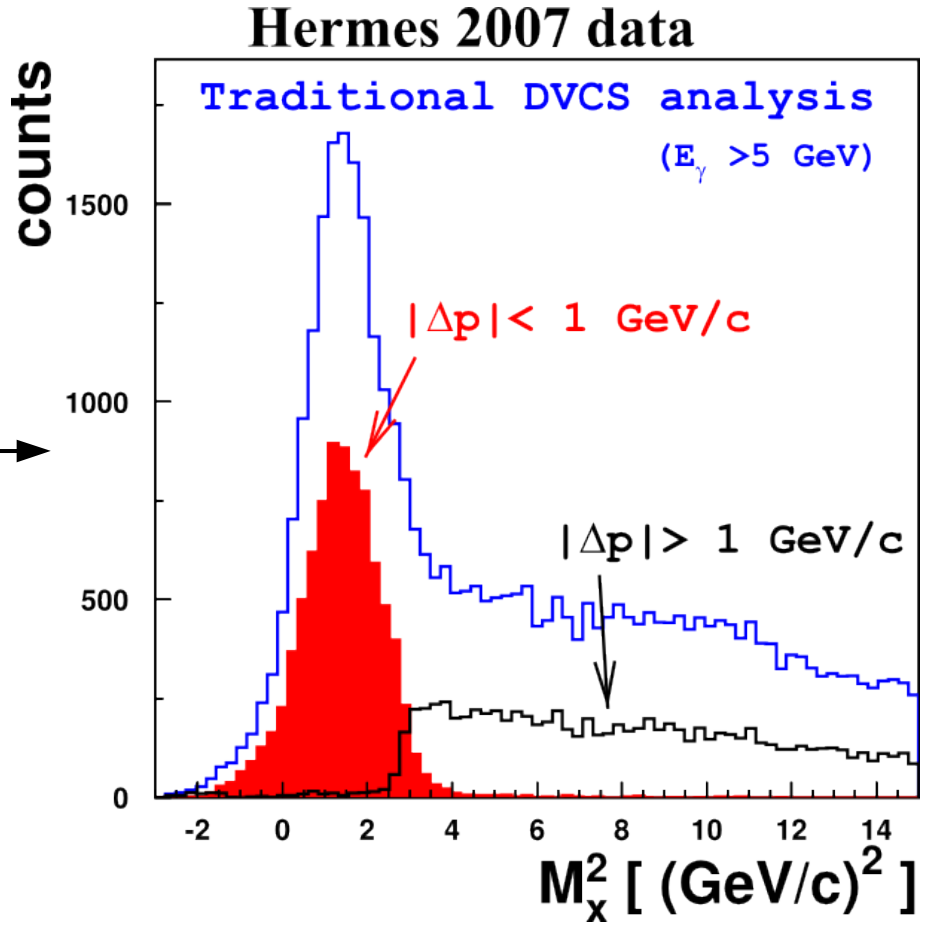


* **Apply exclusivity cut:**

$$|\Delta p| < 1 GeV/c$$

Background levels ***< 1%***

DVCS with Recoil

..Event Selection refinements:

Kinematic fitting:

* *Tracks in Recoil are re-fitted under a certain global kinematic hypothesis: DVCS*
* *Validity of hypothesis is checked in terms of the χ^2 of the fit.*
* *Selection of DVCS proton candidate with smallest χ^2.*

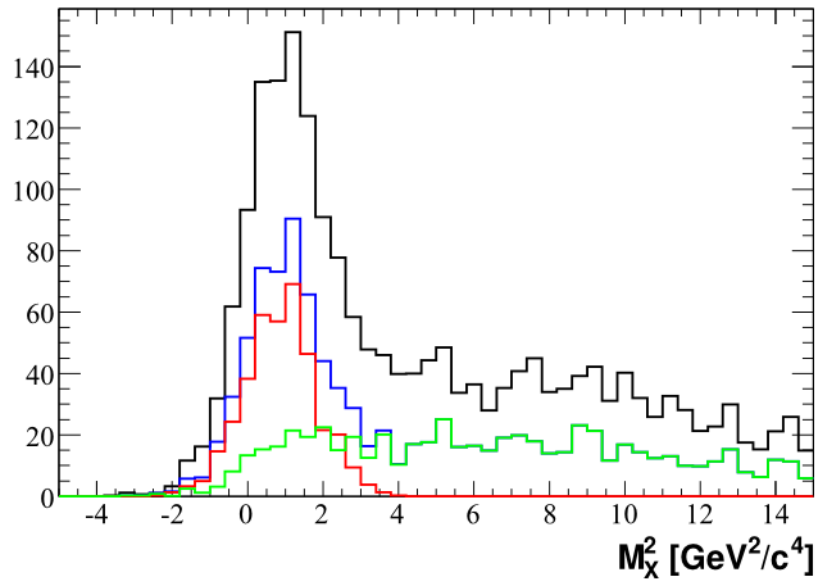
Missing mass distribution:

* **No requirement for Recoil**
* **Positively charged track in Recoil**
* **Kinematic fit probability <1%**
* **Kinematic fit probability >1%**

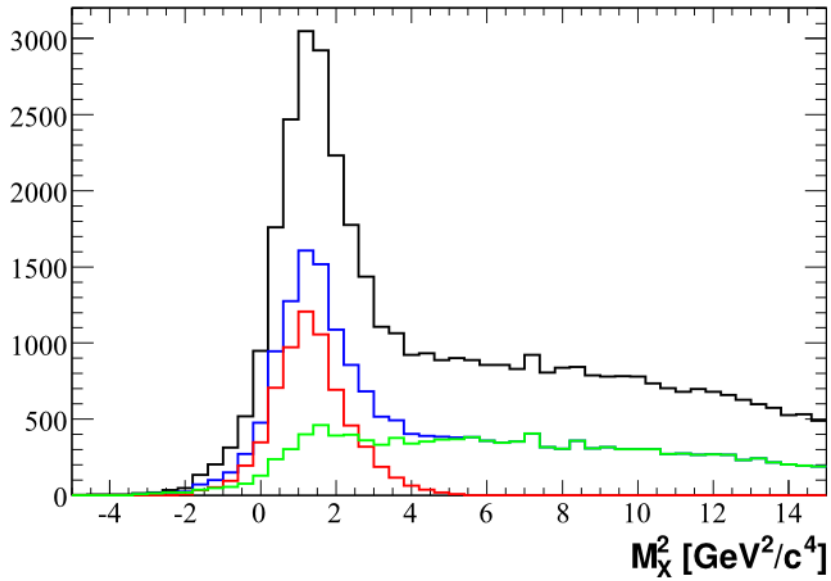
Results and status for DVCS:

* Excellent performance in Monte Carlo.
* Data behaves as expected.
* Systematics studies are in progress.

MONTE CARLO



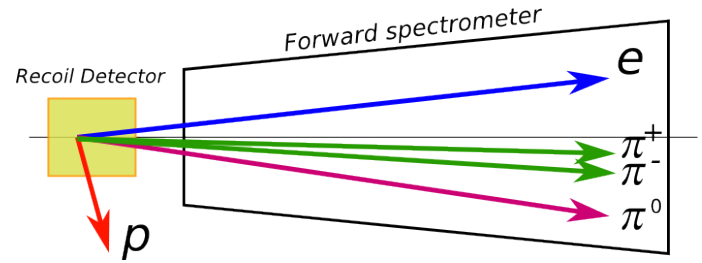
DATA

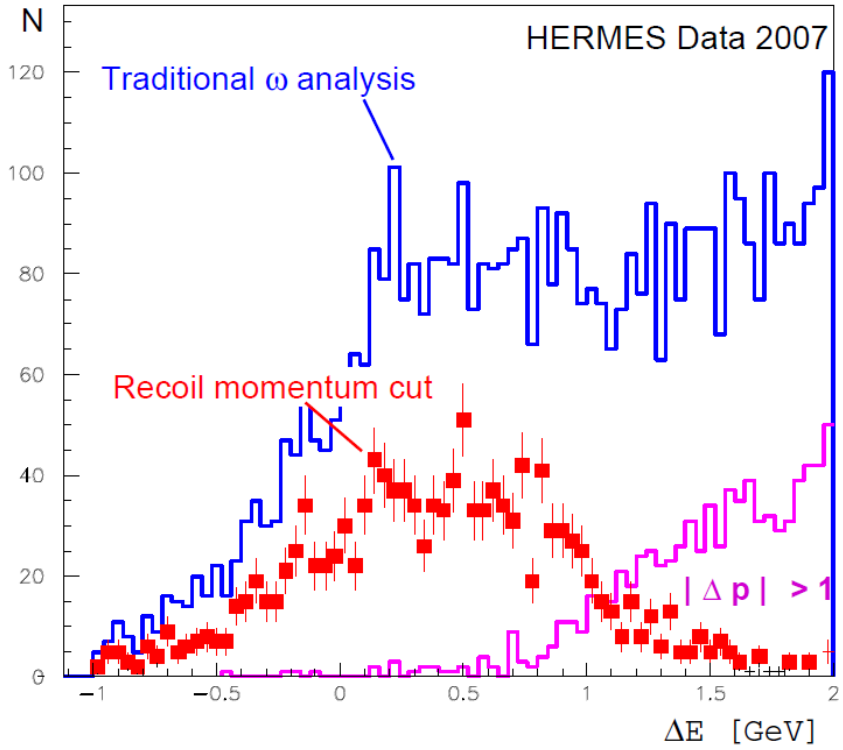


Exclusive Mesons with Recoil

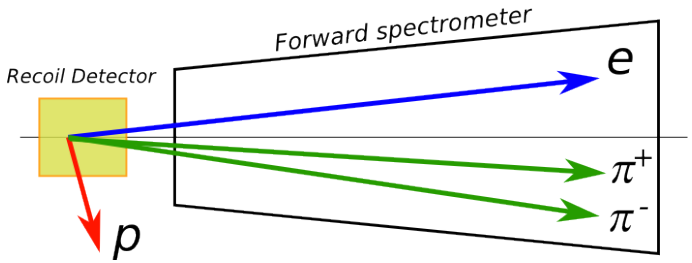
..Using same techniques for EMP:

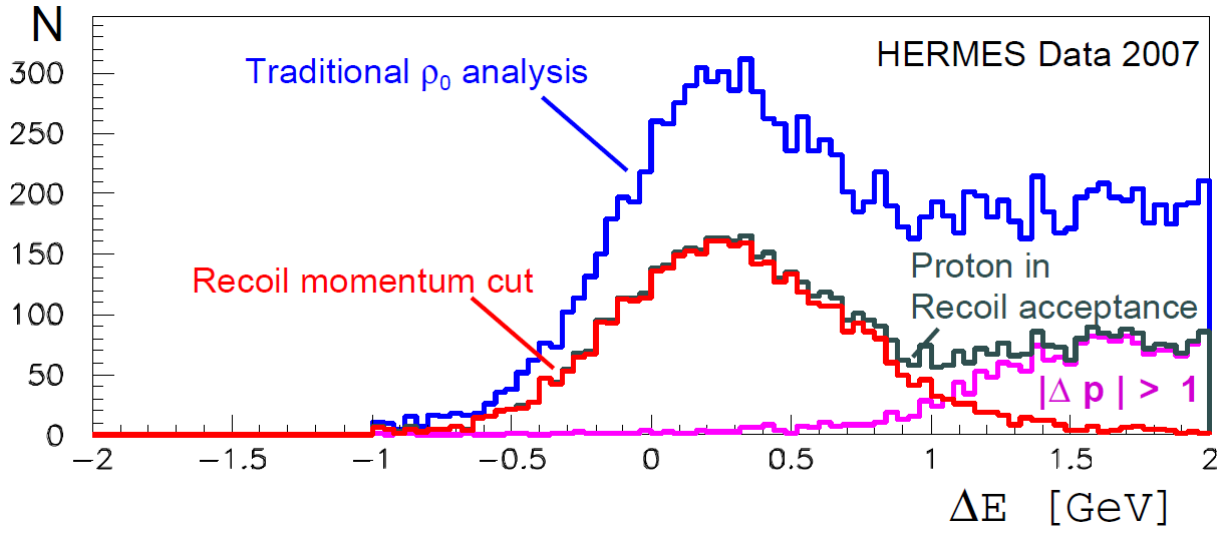
$$ep \rightarrow ep\omega^0$$





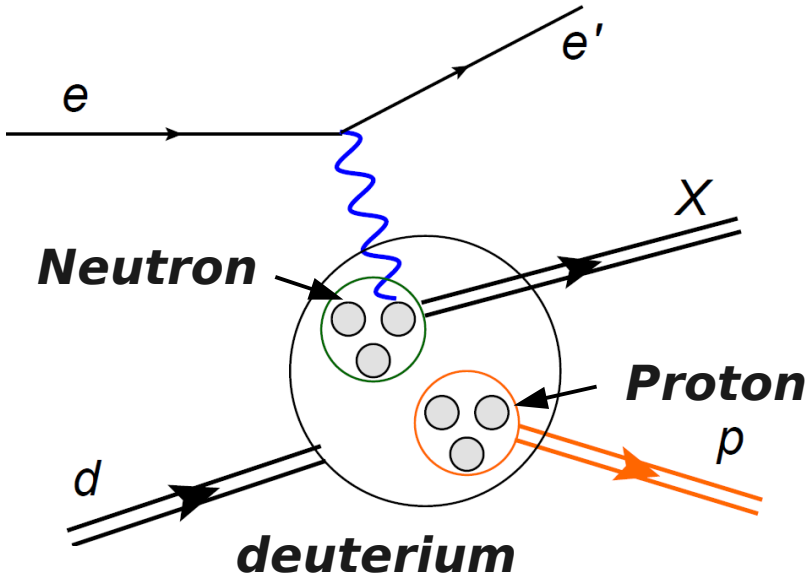
$$ep \rightarrow ep\rho^0$$





'Tagged' Neutron Structure Function

Measuring the effective Structure Function of the Neutron
by means of 'tagging' spectator protons of electron DIS off Deuterium



$$e + d \rightarrow e + X + p_{spec}$$

Scheme of **electron DIS off Deuterium**:
The detection of the spectator proton allows to 'tag' the initial nuclear state of the neutron

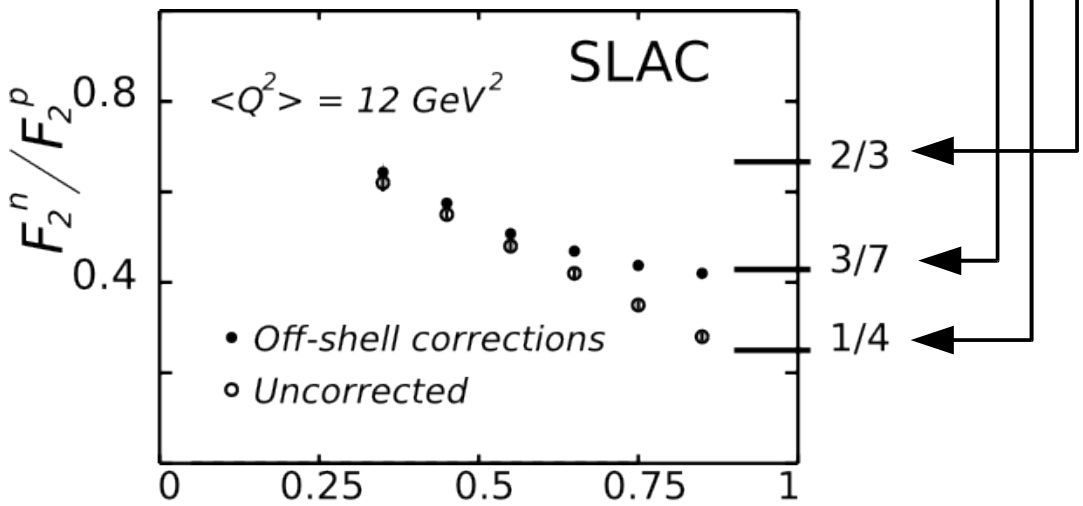
Structure functions at x → 1 limit?:

* *Structure functions are dominated by valence quarks.*

$$\frac{F_2^n}{F_2^p} \approx \frac{1+4d/u}{4+d/u}$$

The Study of this ratio allow to discriminate between different models:

* *Simplest SU(6) → ½*
* *1-gluon exchange among spectator quarks → 0*
* *Quark spin collinear with the nucleon → 1/5*



W. Melnitchouk *et al*, Phys. Lett. B377, 11 (1996).

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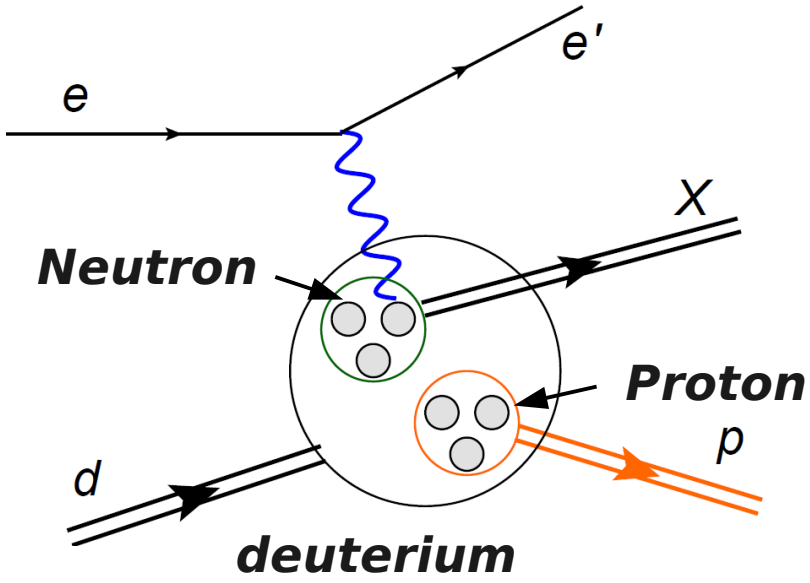
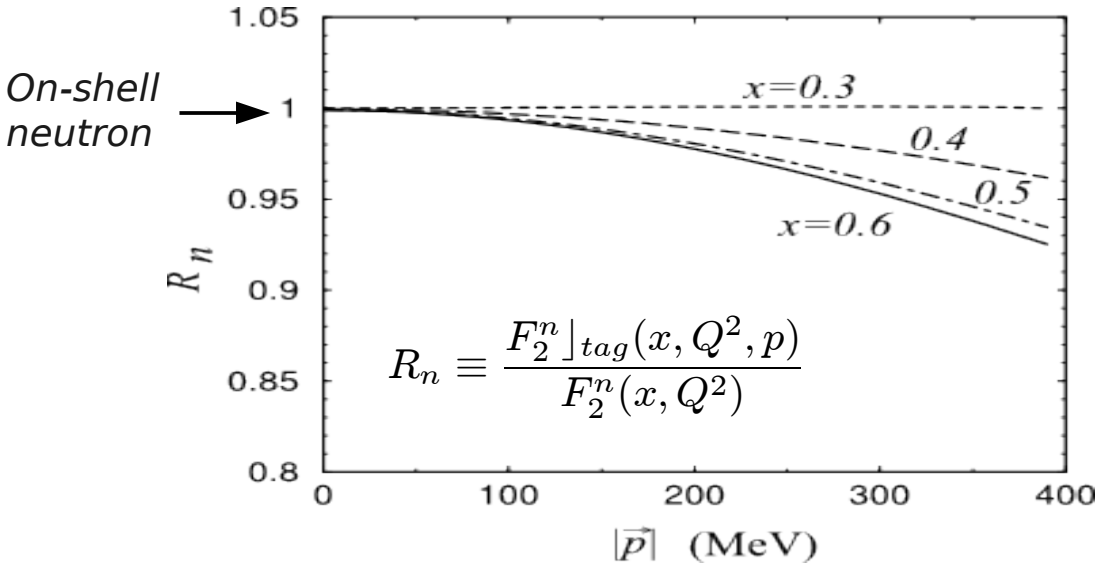


$$e + d \rightarrow e + X + p_{spec}$$

EMC Effect: *Structure functions of free nucleons are altered when in a nuclear environment.*



W. Melnitchouk *et al.* Phys. Lett. B335, 11 (1994)

Differential cross section:

Deuteron spectral function

$$\frac{\mathrm{d}^5\sigma}{\mathrm{d}x\ \mathrm{d}Q^2\ \mathrm{d}\vec{p}} = \frac{2\pi\alpha^2}{Q^4}\frac{1+(1-y)^2}{x} F_2^n\rfloor_{tag}(x,Q^2,p)\cdot n(p)$$

'Tagged' Structure Function

W. Melnitchouk *et al.* Z. Phys. A359, 99 (1997).

'Tagged' Neutron Structure Function

How to access the structure function ratio?

$$\frac{F_2^n\rfloor_{tag}(x,Q^2,p)}{F_2^p(x,Q^2)} = \frac{N_{RD}^d(x,Q^2,\vec{p})/\mathcal{L}_{RD}}{N_{incl}^p(x,Q^2)/\mathcal{L}_{incl}} \cdot \frac{1}{V_{RD}(\vec{p})} \cdot \frac{1}{n(p)}$$

via its relation with inclusive DIS off Hydrogen.

Needs to know spectator protons spectrum

How to measure $n(p)$?

1. **Combined measurements** of Deuterium and Hydrogen:

$$n(p) = \frac{N_{RD}^d(p) - \frac{\mathcal{L}_{RD}^d}{\mathcal{L}_{RD}^p} \cdot N_{RD}^p(p)}{\mathcal{L}_{RD}^d V_{RD}(\vec{p})}$$

Assuming background protons from fragmentation are the same for H and De.

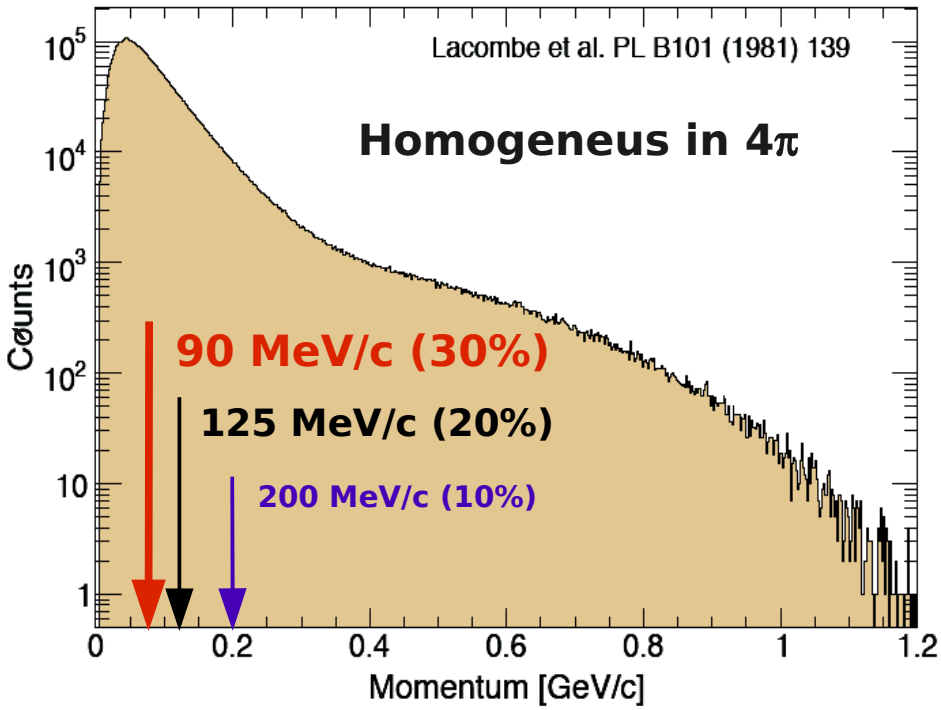
2. ***Direct approach***: Use region without non-spectator protons.

Hadrons coming from fragmentation and DIS related process are mostly in forward direction: ***Select protons on backward hemisphere***

Spectator protons and Recoil

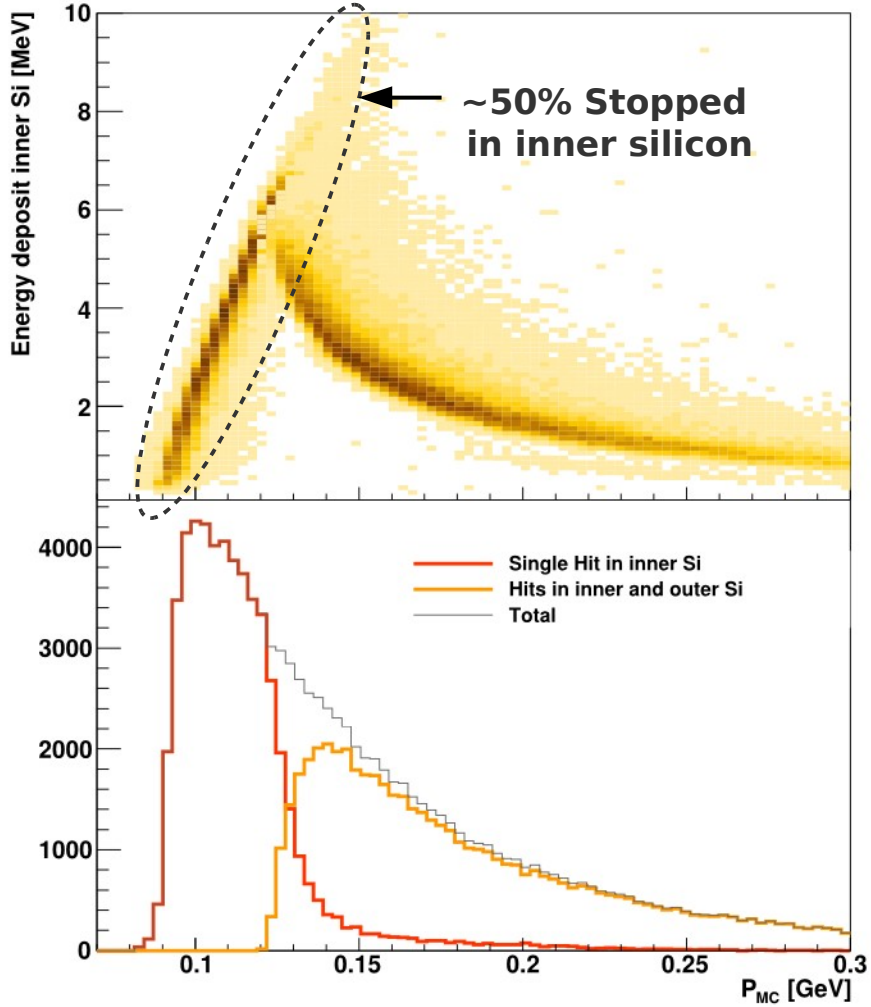
Simple spectator model:
Lacombe et al. PL B101 (1981) 139

Spectator spectrum is at low momentum and Isotropically distributed



Minimum momentum **90 MeV/c*
Energy acceptance **30%*
Geometrical acceptance **57%*

Spectator protons in Recoil Detector



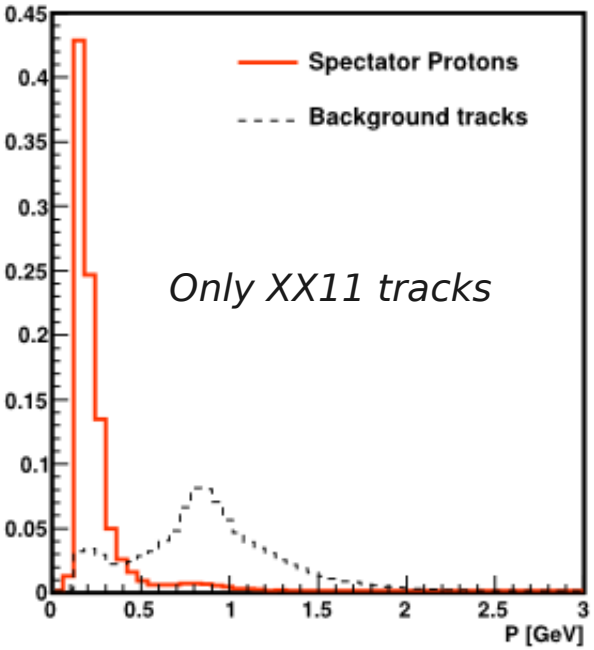
Accessible spectator spectrum with Recoil Detector: 30 %

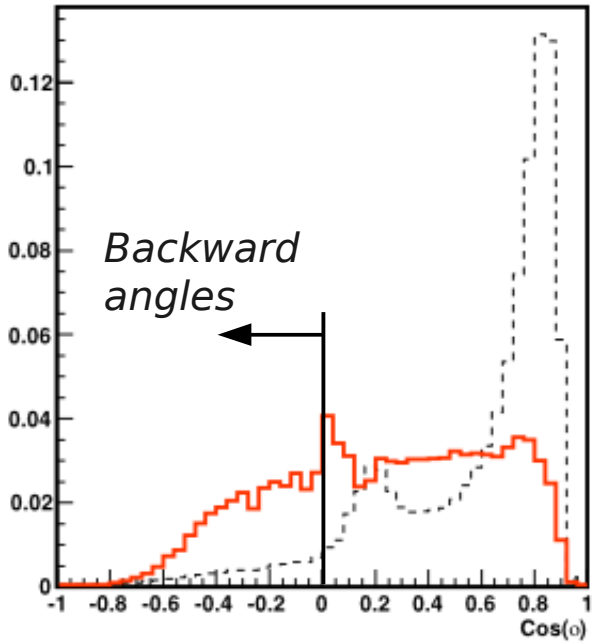
Spectator protons and Recoil

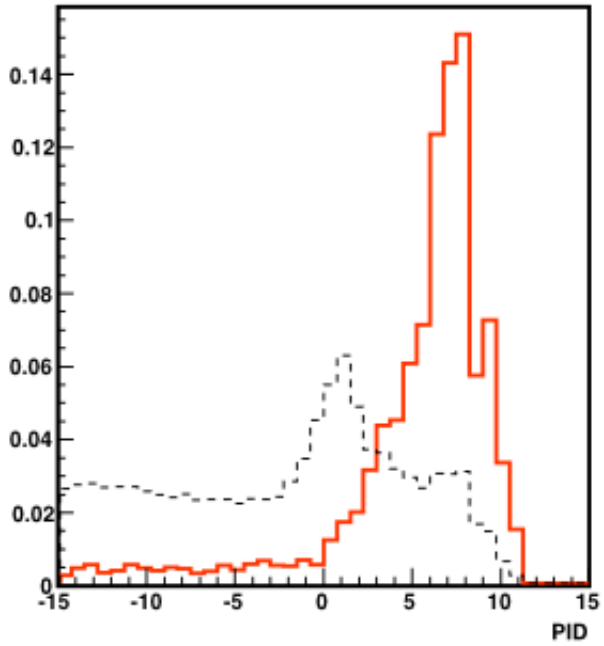
Full HERMES MonteCarlo Simulation:

* *Electron DIS interactions off Deuterium.*
* *Spectator proton added to electron-neutron processes.*
* *Full simulation of detectors effects.*

Explore spectators and background kinematics to maximize tagging efficiency and minimize background contributions







Exploit different kinematics of spectators:

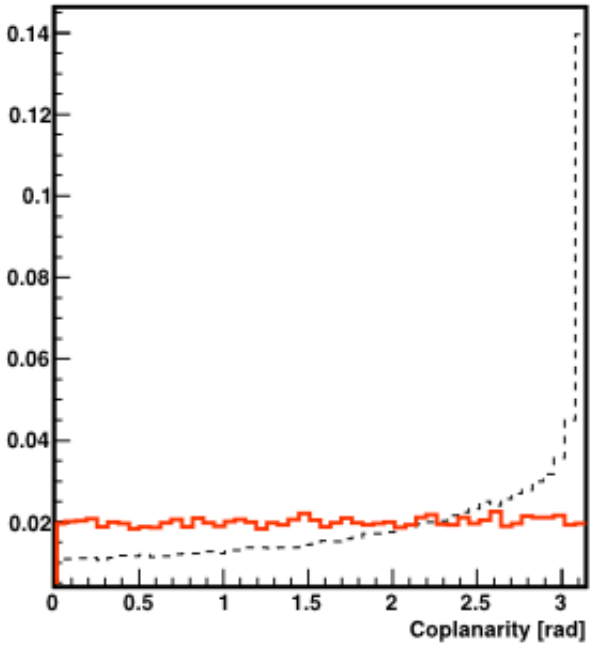
* *Spectators are shifted to low momentum values*
* *Background protons are mainly in forward hemisphere*

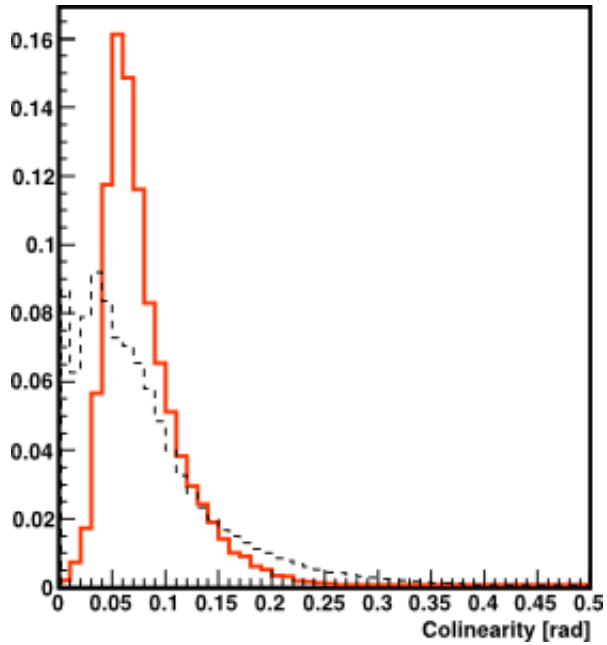
Spectator protons and Recoil

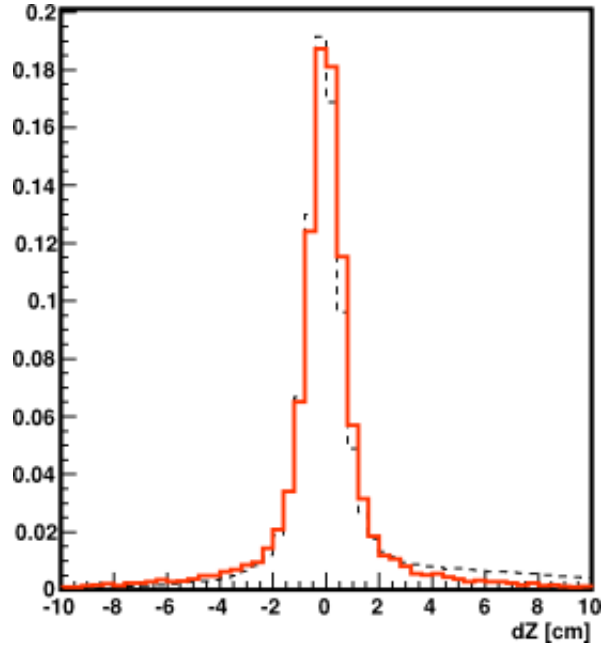
Full HERMES MonteCarlo Simulation:

* *Electron DIS interactions off Deuterium.*
* *Spectator proton added to electron-neutron processes.*
* *Full simulation of detectors effects.*

Explore spectators
and background kinematics to
maximize tagging efficiency and
minimize background contributions







Exploit correlation with DIS electron:

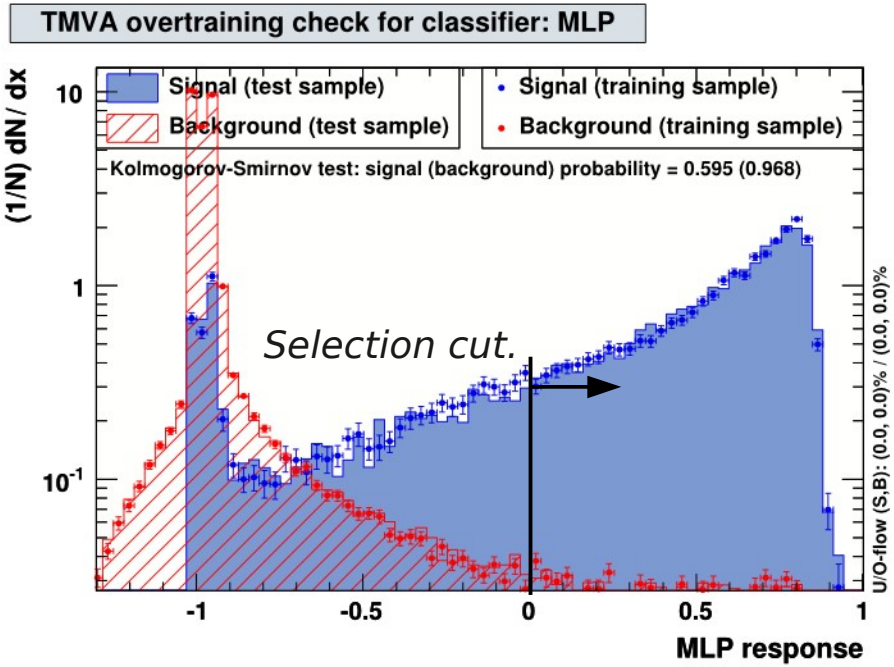
* *Spectators are uncorrelated with DIS*
* *Hadrons from fragmentation collinear with virtual photon*
* *Hadrons from decays are shifted from main interaction vertex*

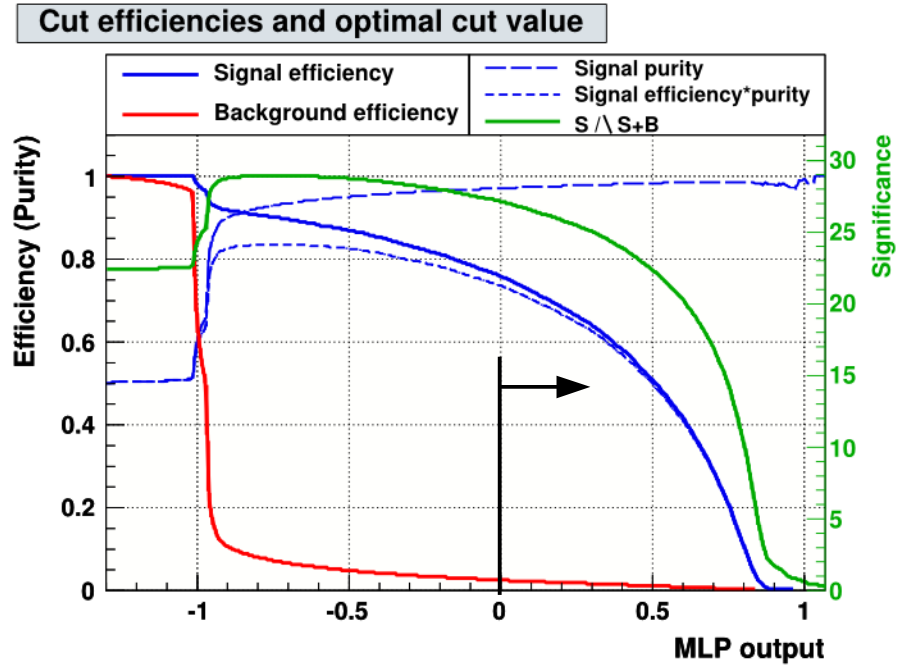
Spectator protons and Recoil

The potential discriminating power of all kinematic variables is combined together using advanced pattern recognition tools:

Likelihood, neural net, boosting methods, etc. efficiently find regions in kinematic space quasi-free of non-spectators.

Spectator proton tagging performance for a Multi-Layer Perceptron (MLP):





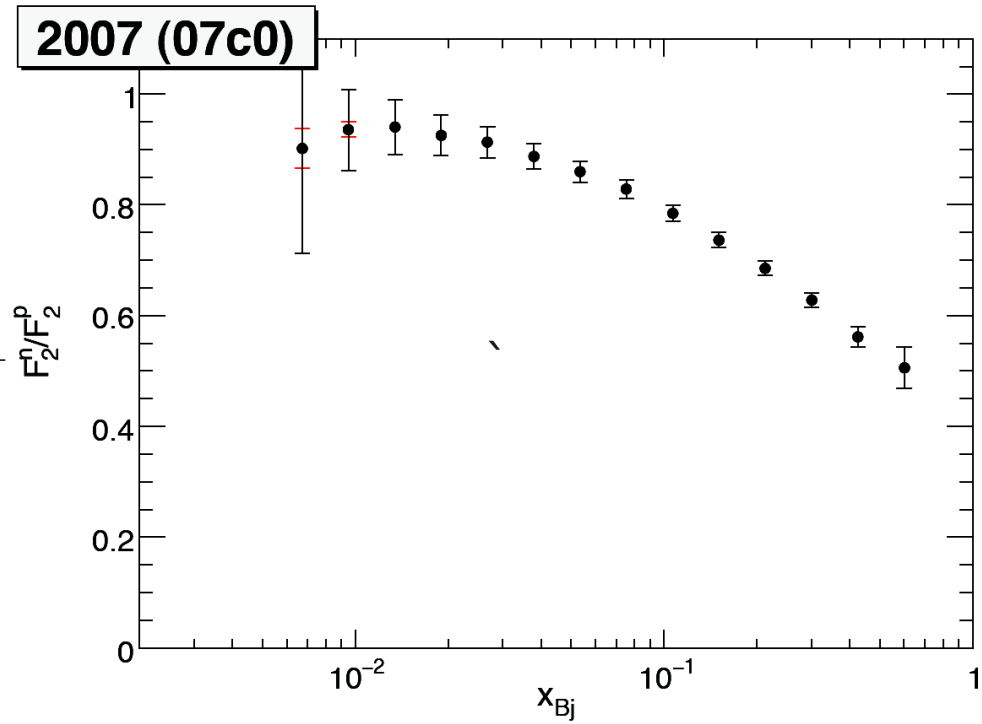
A selection cut of **MLP>0.** reduce background levels below **3%** while keeping signal efficiency around **75%**.

'Tagged' Structure Function: Expectations

A fast estimation of expected precision:

in absence of nuclear effects:

$$\frac{F_2^n}{F_2^p} = 2\frac{\sigma^d}{\sigma^p} - 1$$



Error calculations via cross section ratio:

* Full Hydrogen statistics
* **2.5%** of Deuterium statistics:
  * **5%** total acceptance for spectators (at backward angles)
  * **50%** for DIS on Neutron.

Incoming improvements

* ***The inclusion of 2006 data will provide approx. double statistics.***
* ***Sophisticated signal selection techniques offer three times larger signal selection efficiency***

Conclusions

HERMES Recoil Detector is ready for first physics analyses:

- *Tracking and PID capabilities exhibit optimal performance.*

First approach to physics analyses looks promising:

- *Exclusive reactions (DVCS and EMP) can be measured with negligible background levels.*
- *Neutron structure function can be accessed via spectator proton tagging.*