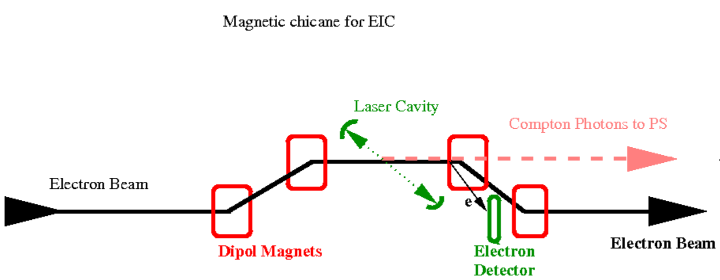
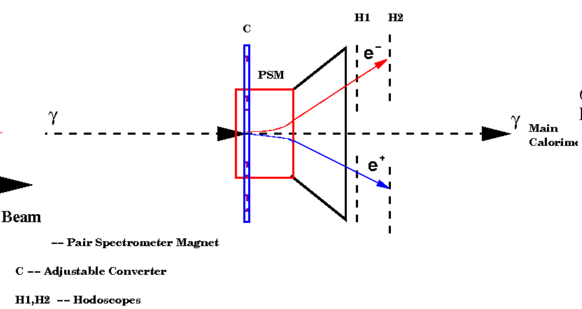
Hybrid Electron Compton Polarimeter with online self-calibration

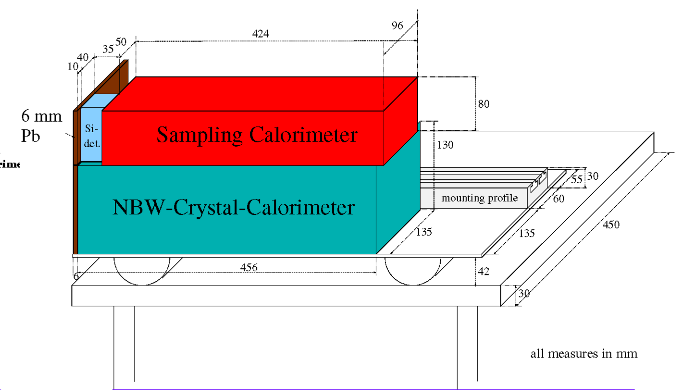
August 24, 2007

W. Deconinck, A. Airapetian, W. Lorenzon

UNIVERSITY OF MICHIGAN







single electron

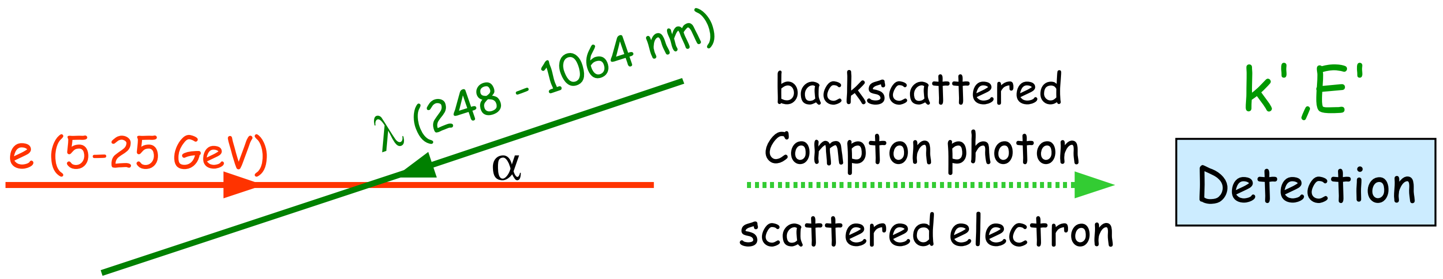
single photon

multi photon

Outline

- Physics behind Compton polarization measurements
  - single photon mode (differential asymmetry)
  - multi photon mode (energy weighted asymmetry)
- Hybrid design using:
  - chicane
  - scattered electron
  - pair spectrometer
  - sampling calorimeter
- Advantages multiple detection scheme
- First Monte Carlo studies
- Conclusions

Physics behind P_e measurement using Compton scattering



Compton scattering:

$e(E) + \lambda(k) \rightarrow e'(E') + \gamma(k')$ (~ zero crossing angle)

Cross section:

- Transverse polarization → position asymmetry (HERA TPOL)
- Longitudinal polarization → energy asymmetry (HERA LPOL)

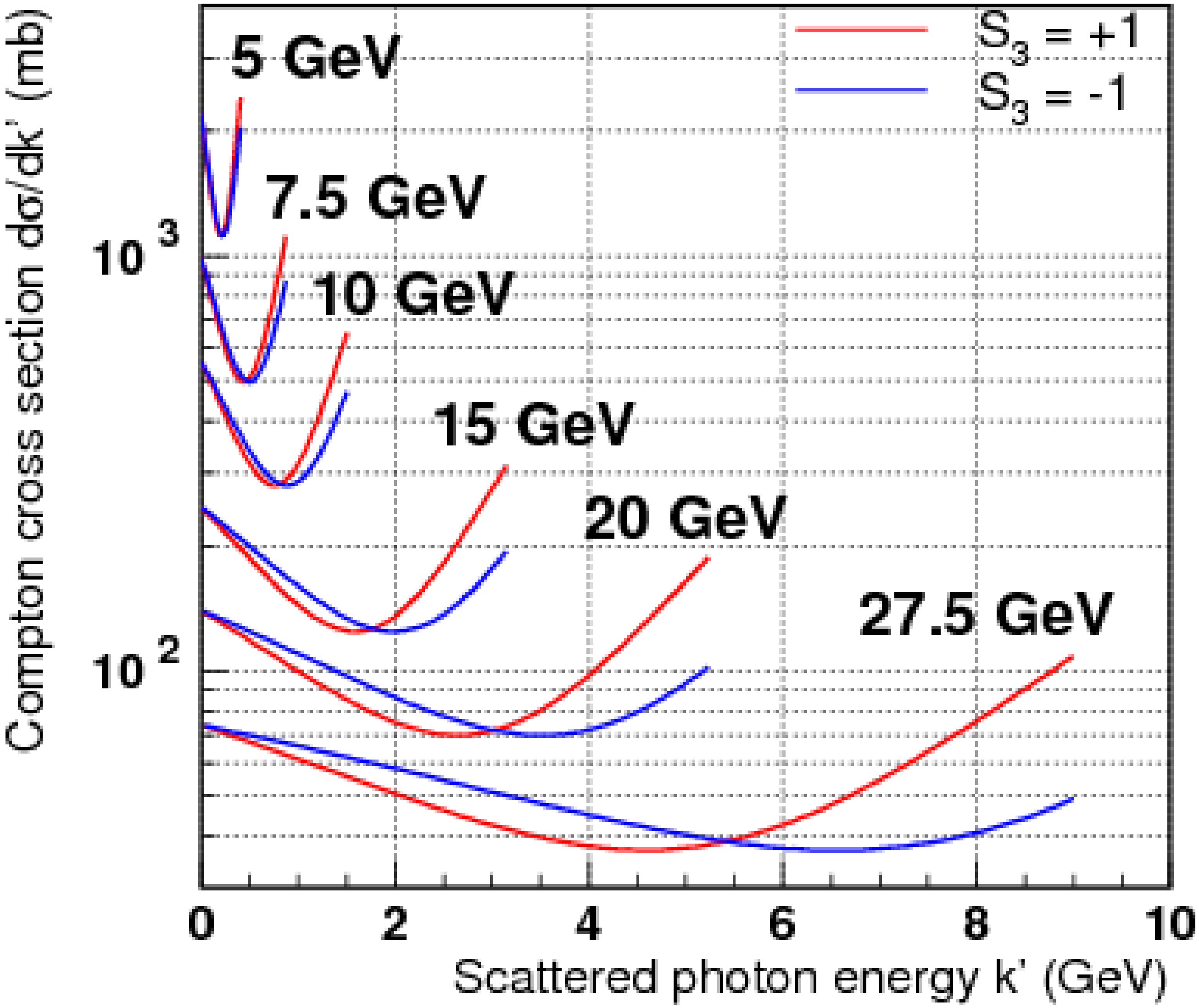
  Due to experience: LPOL-like polarimeter described here

$\mathbf{d\sigma/dk'} = d\sigma_0/dk' \, [1 + P_e P_\lambda A_z(k')]$ $d\sigma_0$, A_z: known (QED)

P_λ: circular polarization (±1) of **laser beam** (measured after IP)

P_e: longitudinal polarization of **electron beam**

Physics behind P_e measurement using Compton scattering



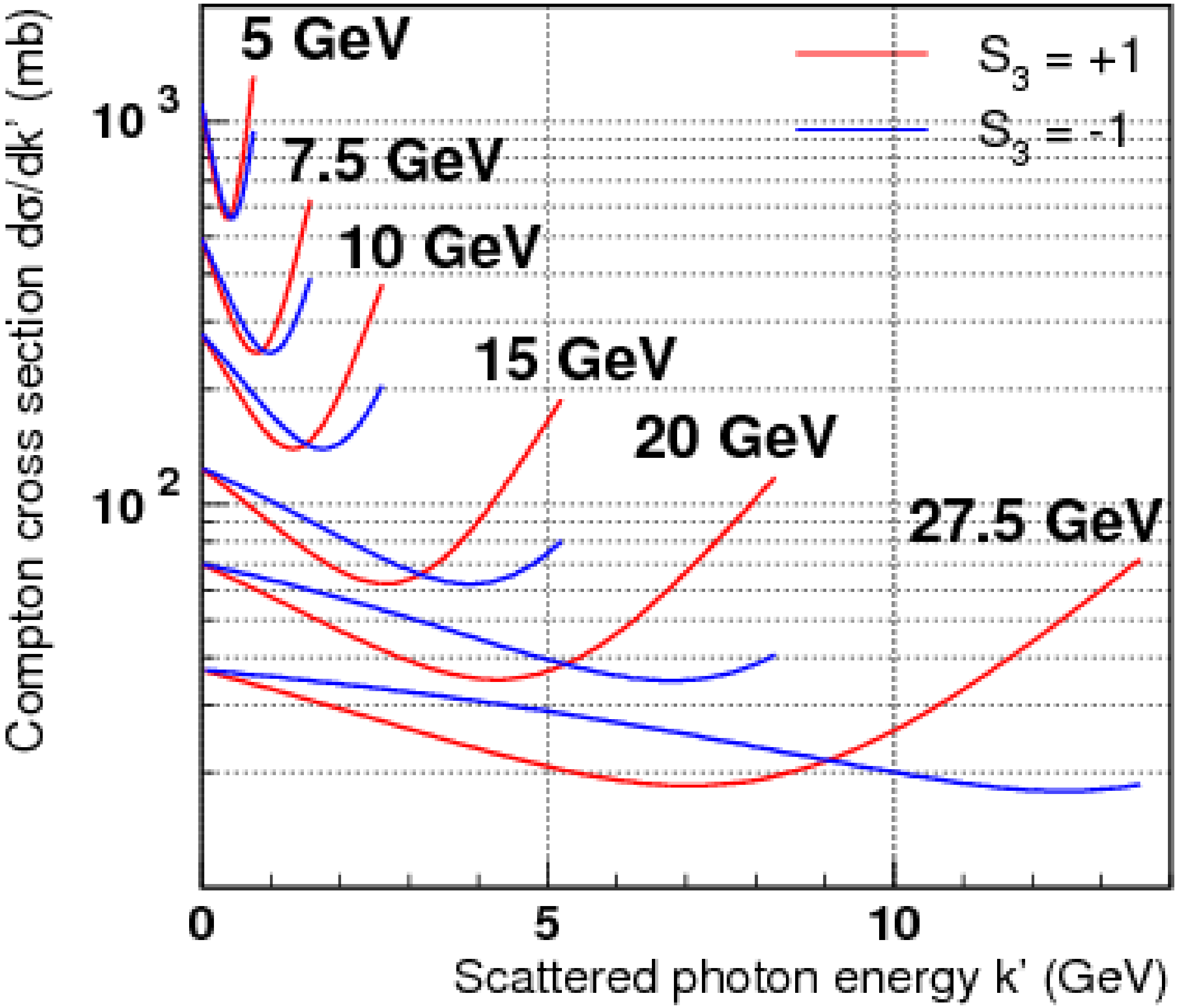
Different cross section for positive and negative photon helicity S_3.

Difference largest at higher electron beam energy. (HERA = 27.5 GeV)

Laser energy:

- 1064 nm (1.17 eV)

Physics behind P_e measurement using Compton scattering



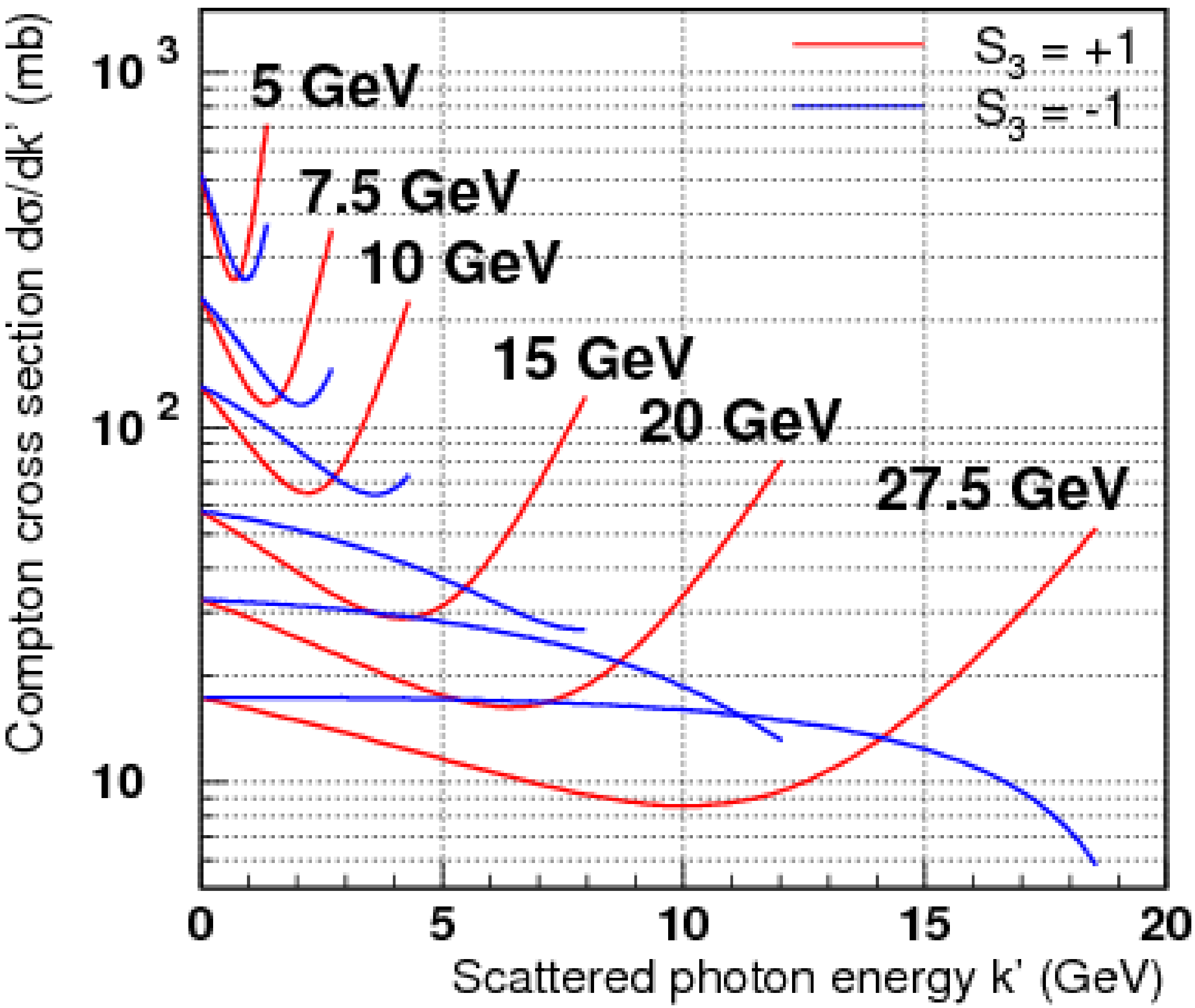
Different cross section for positive and negative photon helicity S_3.

Difference largest at higher electron beam energy. (HERA = 27.5 GeV)

Laser energy:

- 1064 nm (1.17 eV)
- 532 nm (2.33 eV)

Physics behind P_e measurement using Compton scattering



Different cross section for positive and negative photon helicity S_3.

Difference largest at higher electron beam energy. (HERA = 27.5 GeV)

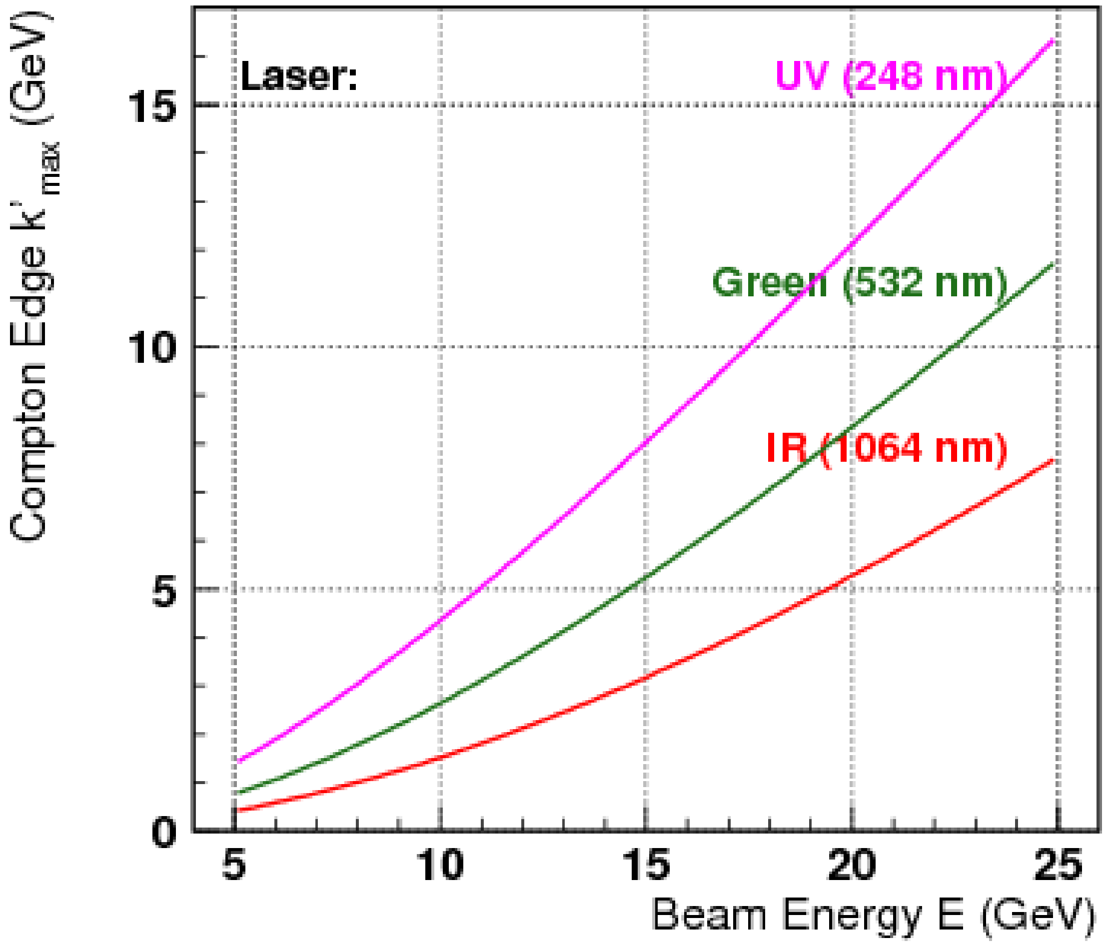
Laser energy:

- 1064 nm (1.17 eV)
- 532 nm (2.33 eV)
- 248 nm (5.0 eV)

Physics behind single photon mode

Single photon mode:
measure energy of
every Compton photon.

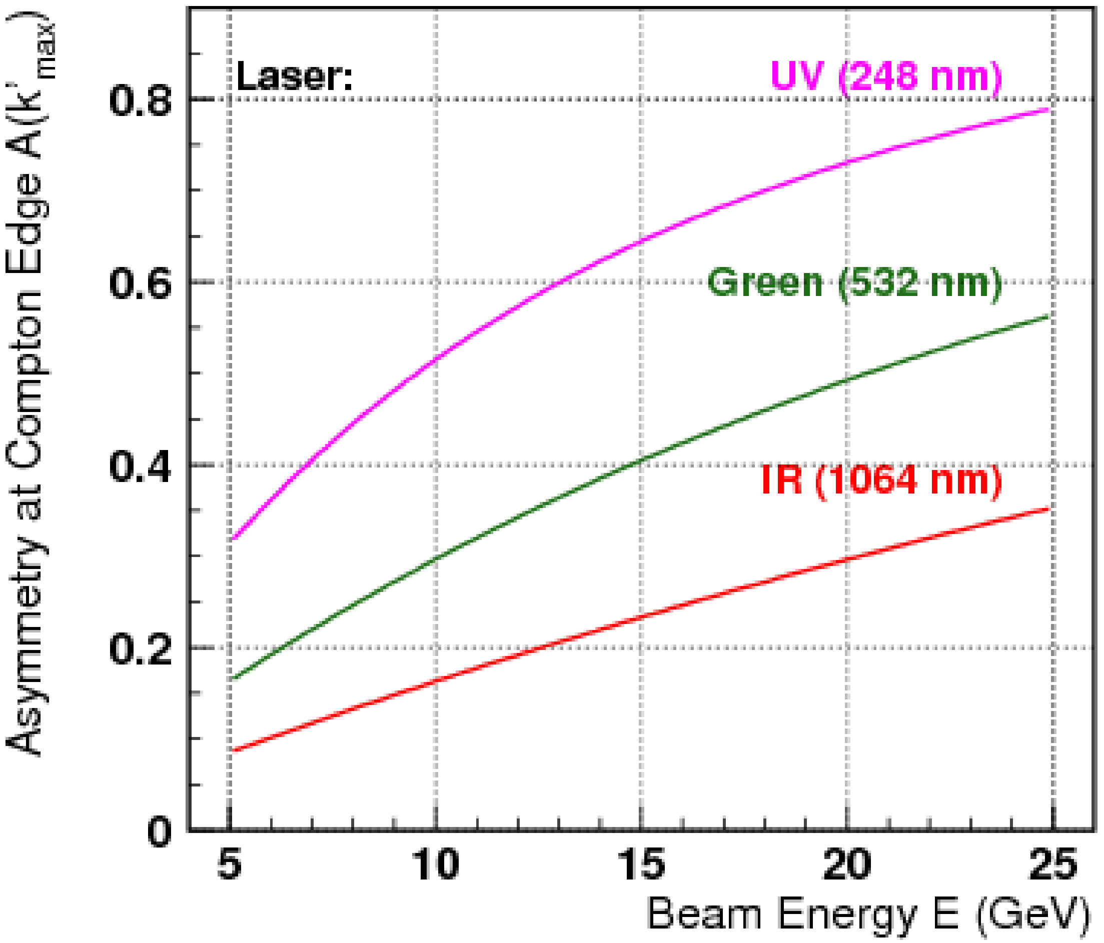
- Highest photon energy: Compton edge $k'_{max} \sim k \cdot E^2$



Physics behind single photon mode

Single photon mode: measure energy of **every Compton photon**.

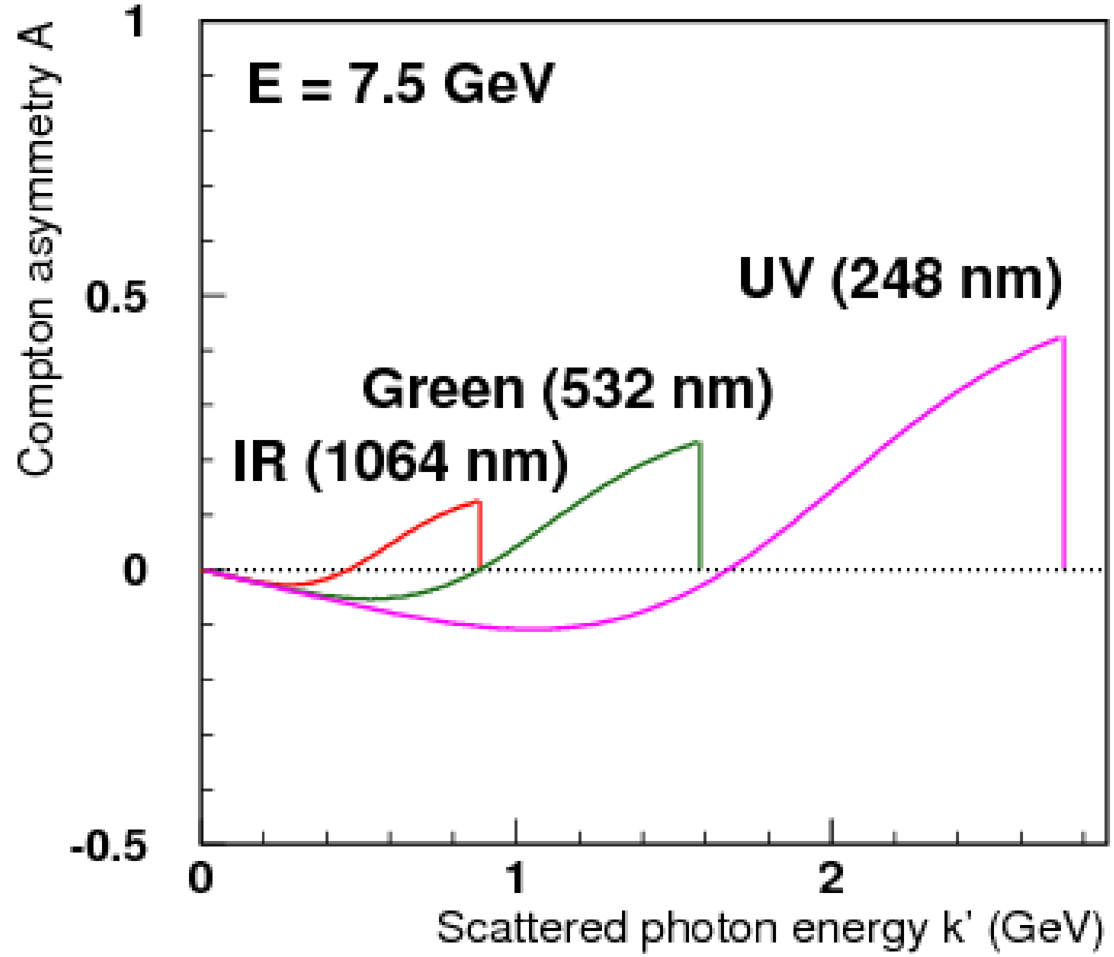
- Highest photon energy: Compton edge $k'_{max} \sim k \cdot E^2$
- Highest asymmetry at Compton edge: $A(k'_{max}) \sim k \cdot E$



Physics behind single photon mode

Single photon mode: measure energy of **every Compton photon.**

- Highest photon energy: Compton edge $k'_{max} \sim k \cdot E^2$
- Highest asymmetry at Compton edge: $A(k'_{max}) \sim k \cdot E$
- Cross check at zero asymmetry crossing
- Calibration at sharp Compton edge



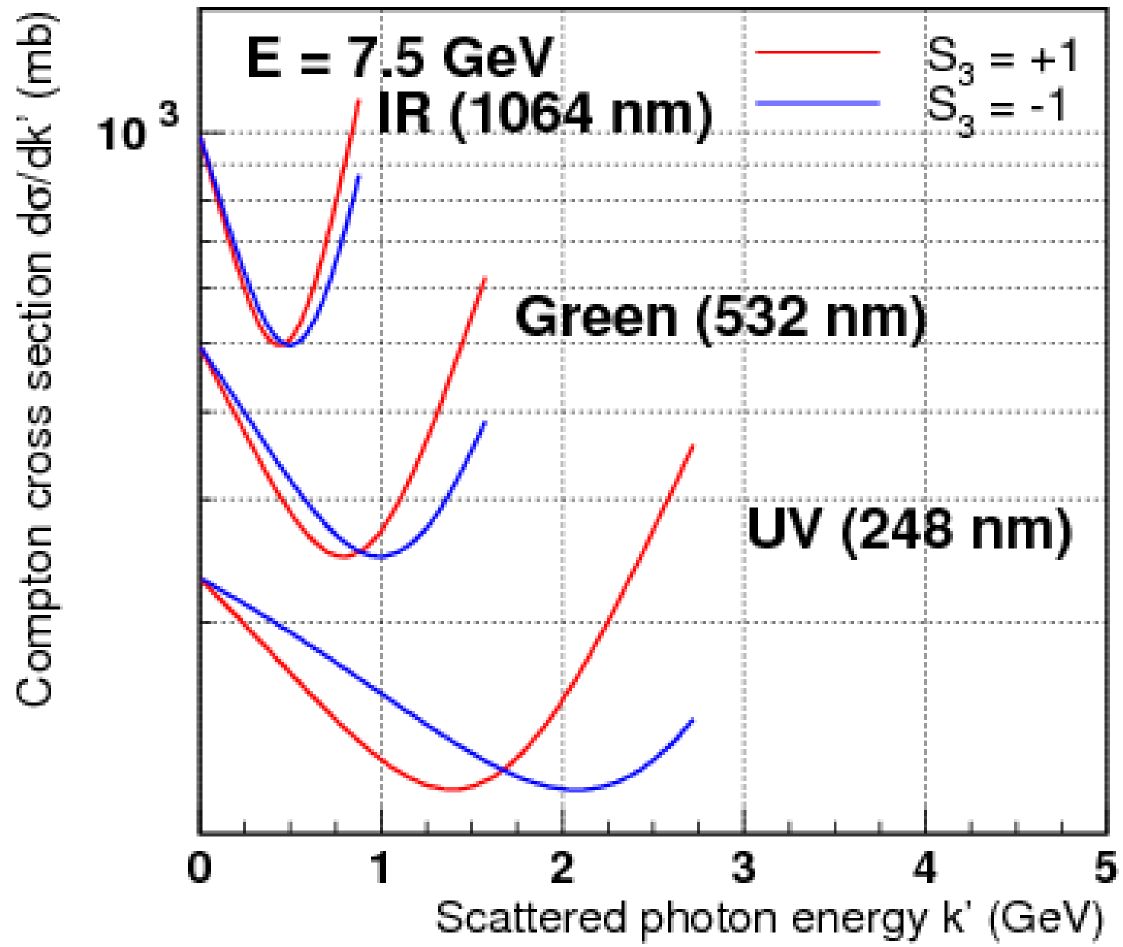
Two points with known energy (QED)

Physics behind single photon mode

Single photon mode: measure energy of **every Compton photon.**

→ Higher laser energy has some advantages (higher asymmetry)

→ Variable laser energy: move zero-crossing and Compton edge around



But...

Everything has its price: **differential cross section smaller**!

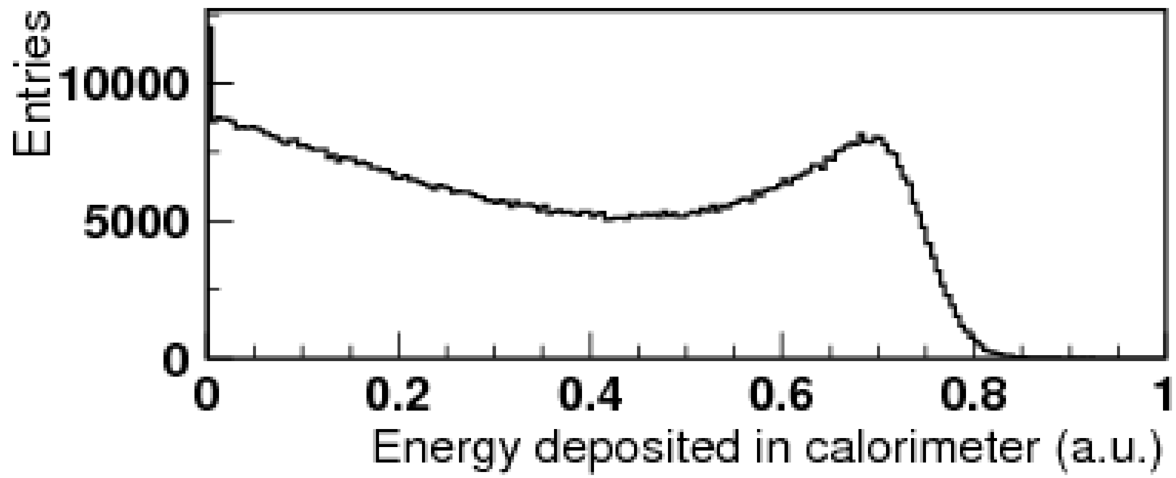
Physics behind single photon mode

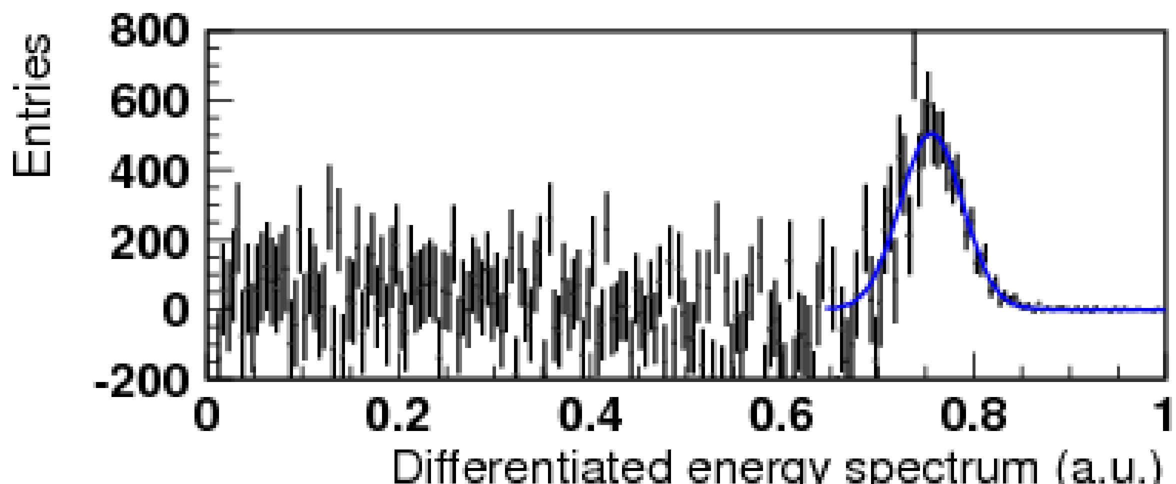
Advantages:

- Uses all information in photons
- Calibration using Compton edge

Disadvantages:

- Sensitive to absolute calorimeter calibration
- Background from Bremsstrahlung





Physics behind multi photon mode

Energy weighted asymmetry:

$A_m = (I_{3/2} - I_{1/2}) / (I_{3/2} + I_{1/2}) = P_e P_\lambda A_p$

Analyzing power

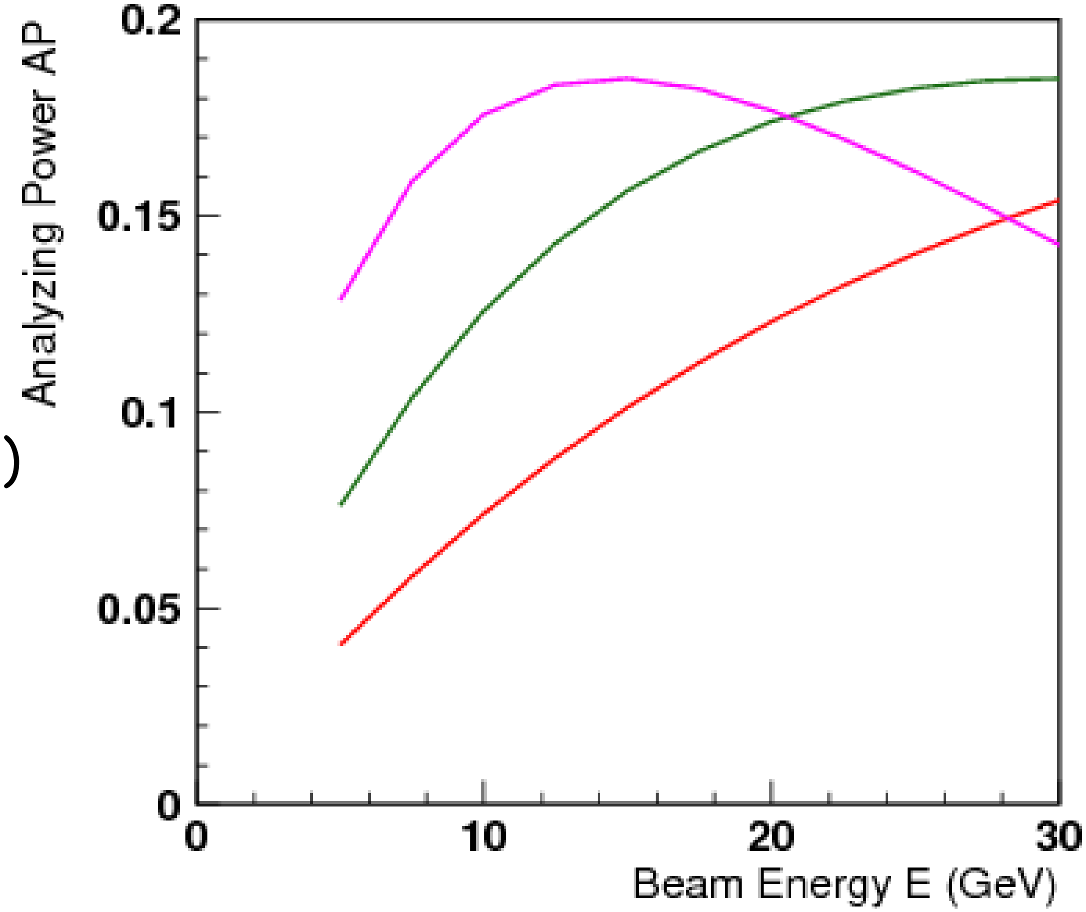
$A_p = (\Sigma_{3/2} - \Sigma_{1/2}) / (\Sigma_{3/2} + \Sigma_{1/2})$

Advantages:

- Effectively independent of bremsstrahlung background
- dP/P = 1%/min now already
- Independent from absolute energy calibration (first order)

Disadvantages:

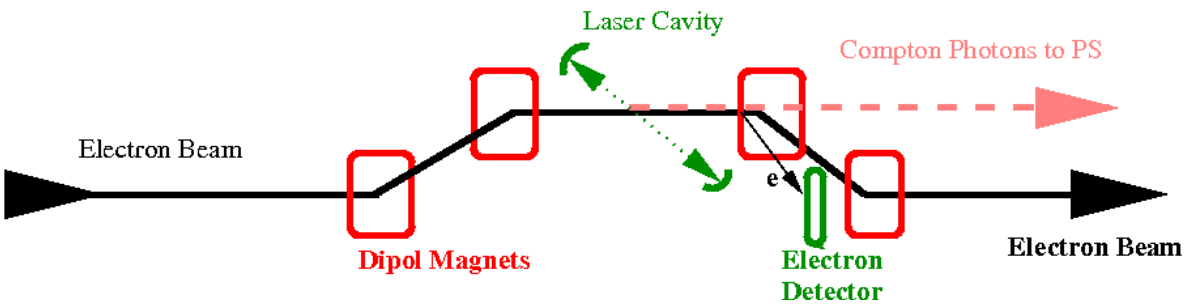
- No monitoring of calorimeter performance and linearity



Combine both photon methods and measure simultaneously

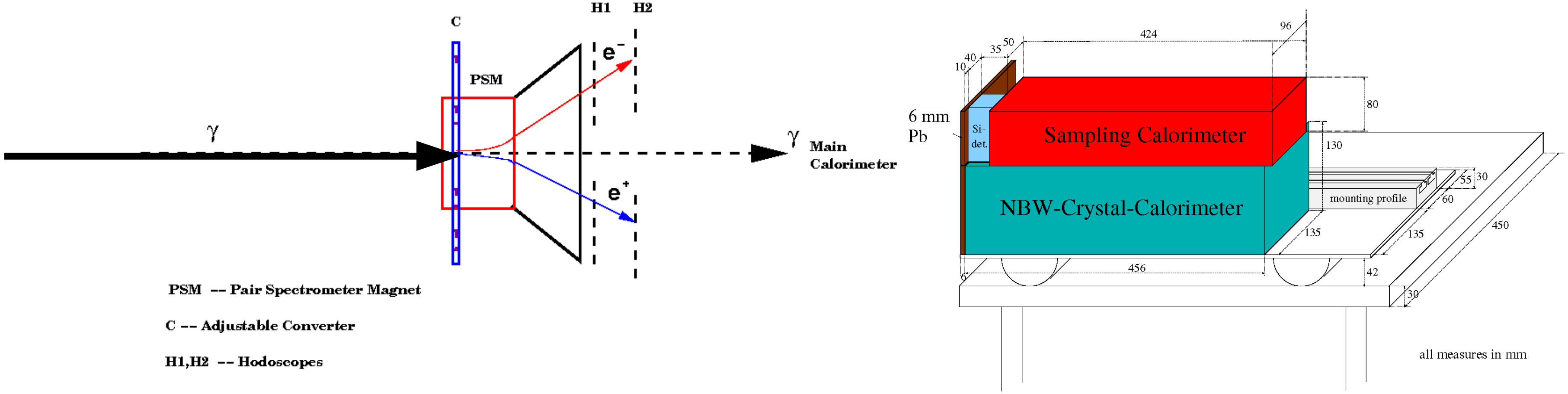
chicane

scattered electron



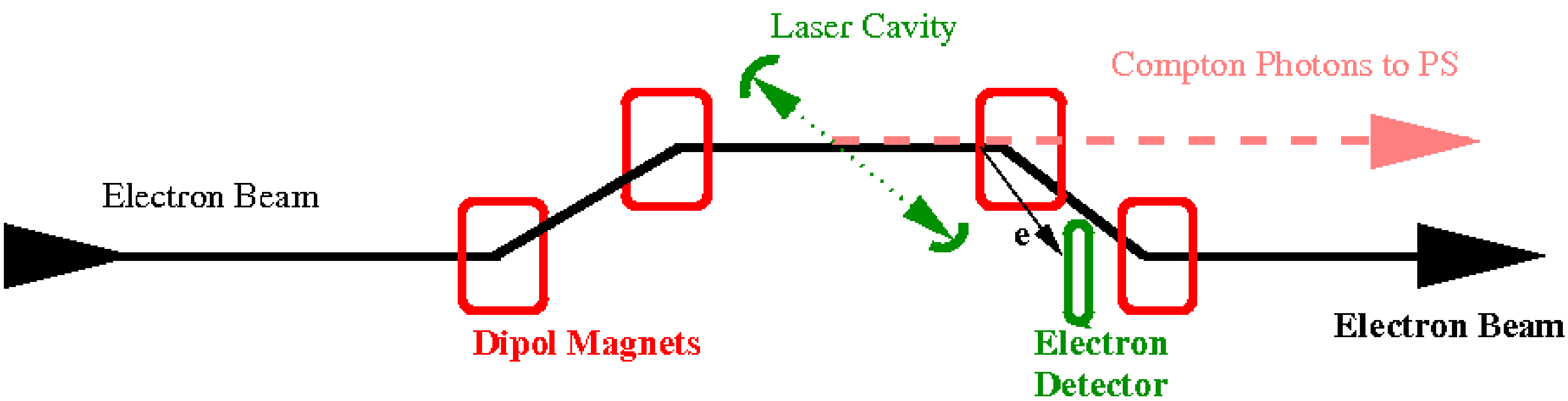
single photon

single/multi photon



Advantages of chicane setup

- Moves Compton cone away from electron beam
- Reduces bremsstrahlung background (maybe less at EIC)
- (Possibly) compensation of focusing magnets around experiment IR

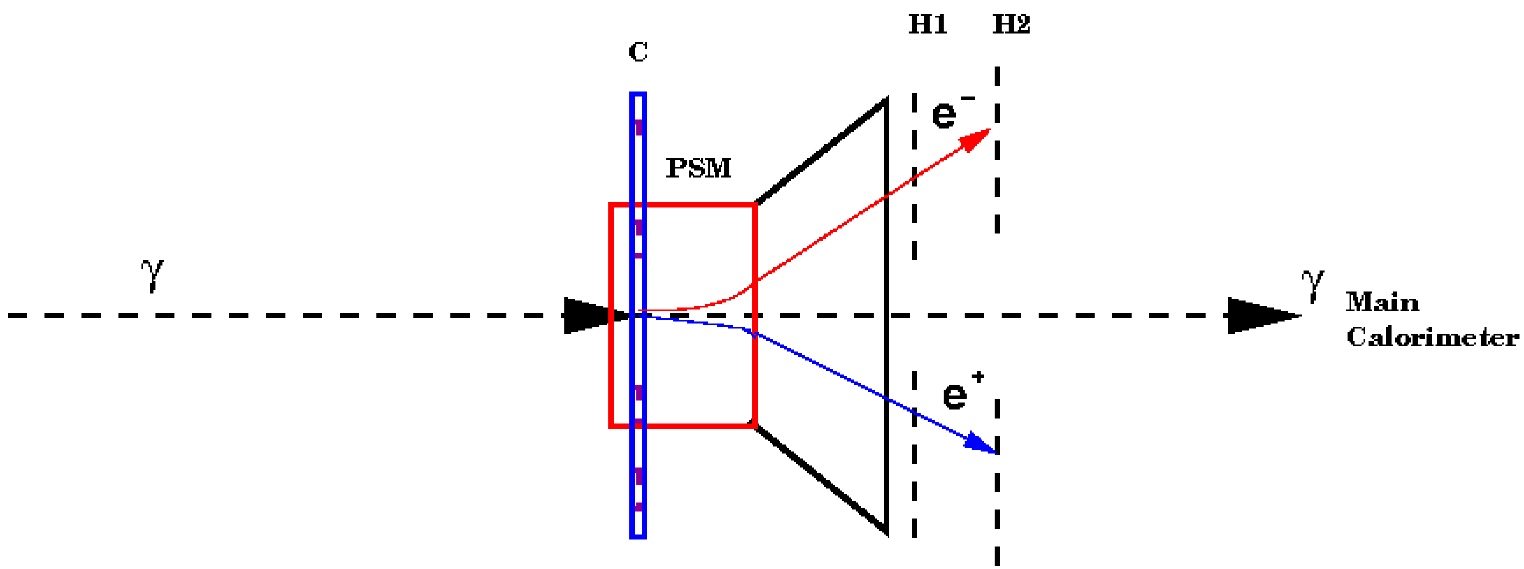


Scattered electron

We have not yet put a great deal of thought into this...

Pair spectrometer magnet with e^+e^- pair production

- Convertor material (movable, with variable thickness) produces e^+e^- pairs of fraction of the Compton photons
- Dipole magnet separates electrons and positrons
- Detection in Si, SciFi, scintillator detectors



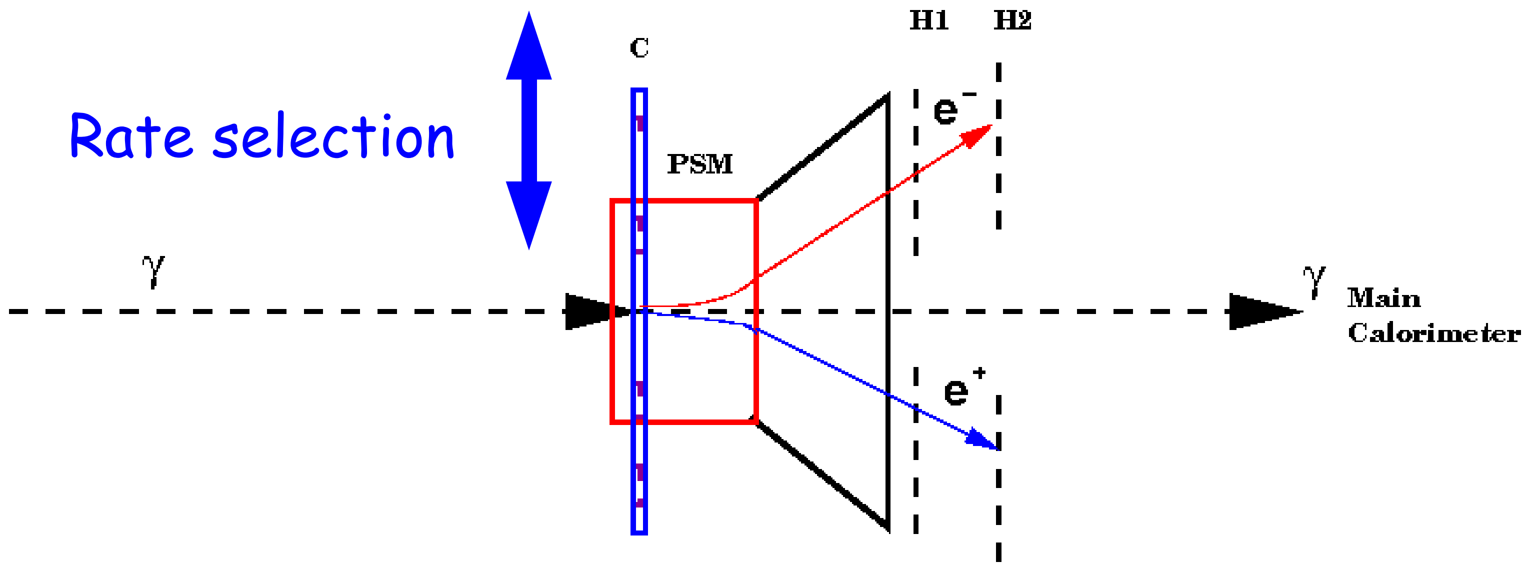
PSM -- Pair Spectrometer Magnet

C -- Adjustable Converter

H1,H2 -- Hodoscopes

Pair spectrometer magnet with e^+e^- pair production

- Convertor material (movable, with variable thickness) produces e^+e^- pairs of fraction of the Compton photons
- Dipole magnet separates electrons and positrons
- Detection in Si, SciFi, scintillator detectors



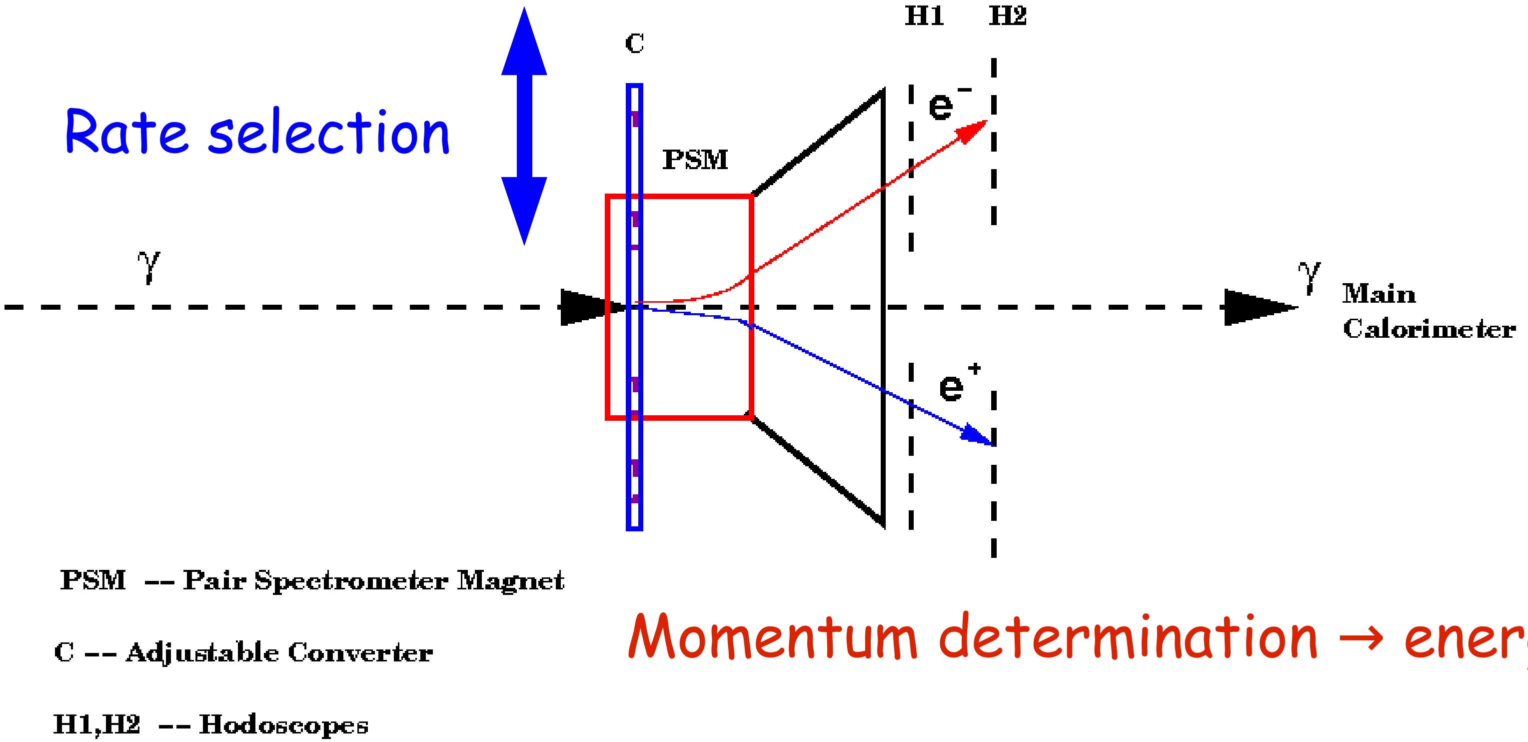
PSM -- Pair Spectrometer Magnet

C -- Adjustable Converter

H1,H2 -- Hodoscopes

Pair spectrometer magnet with e^+e^- pair production

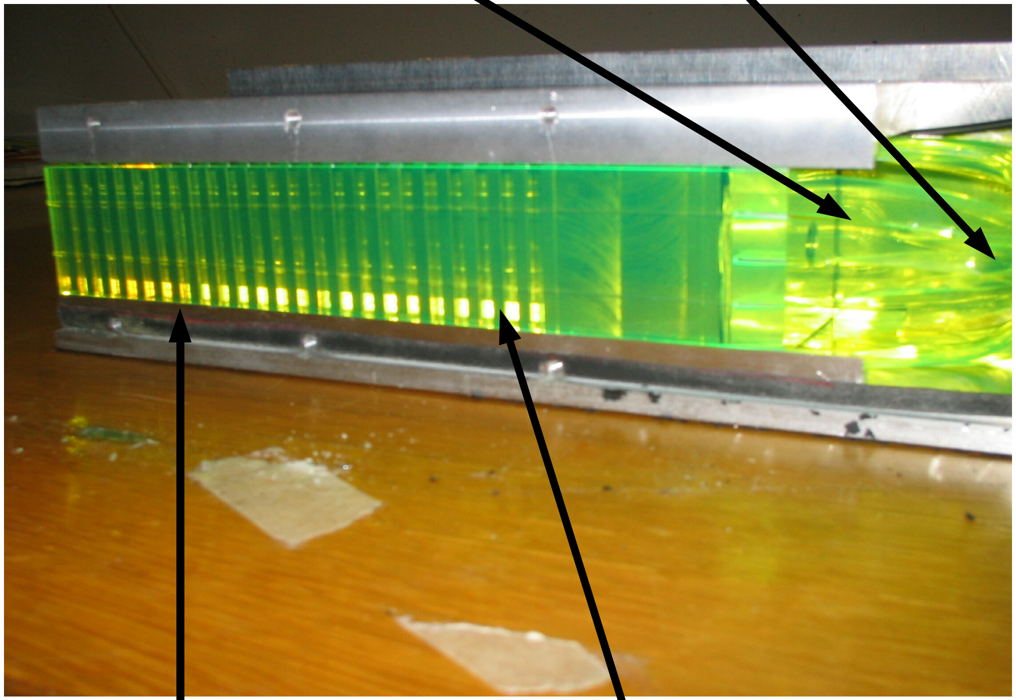
- Convertor material (movable, with variable thickness) produces e^+e^- pairs of fraction of the Compton photons
- Dipole magnet separates electrons and positrons
- Detection in Si, SciFi, scintillator detectors



Momentum determination → energy k'

Sampling calorimeter with spatial resolution

Use experience gained at HERA LPOL:
sampling calorimeter with W convertor plates and scintillator



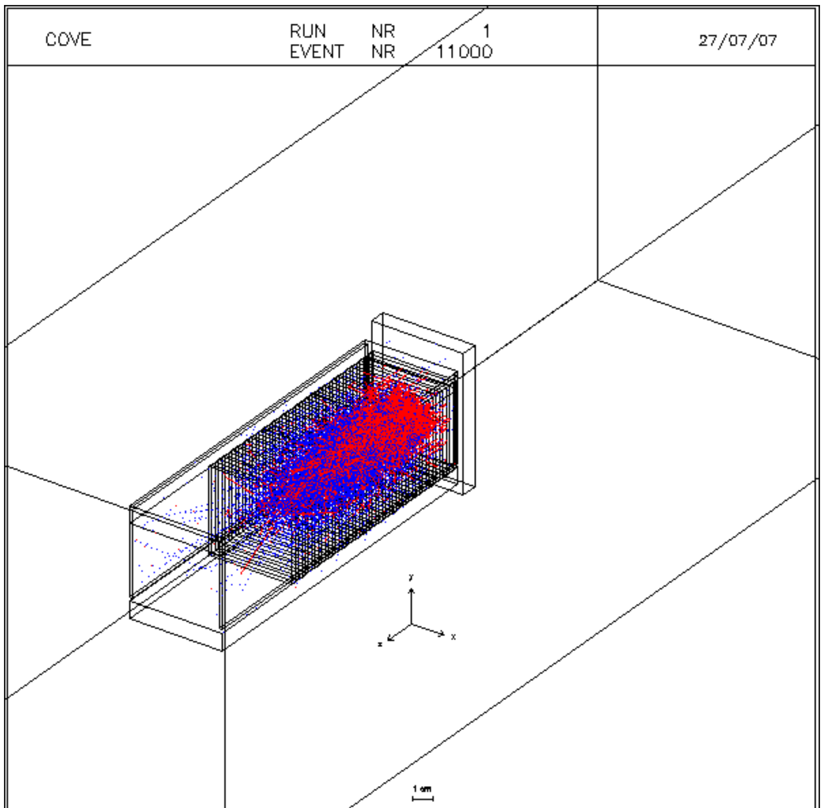
Operated in

- **single photon mode** at high PMT voltage (lower laser power)
- **multi photon mode** at lower PMT voltage (higher laser power)

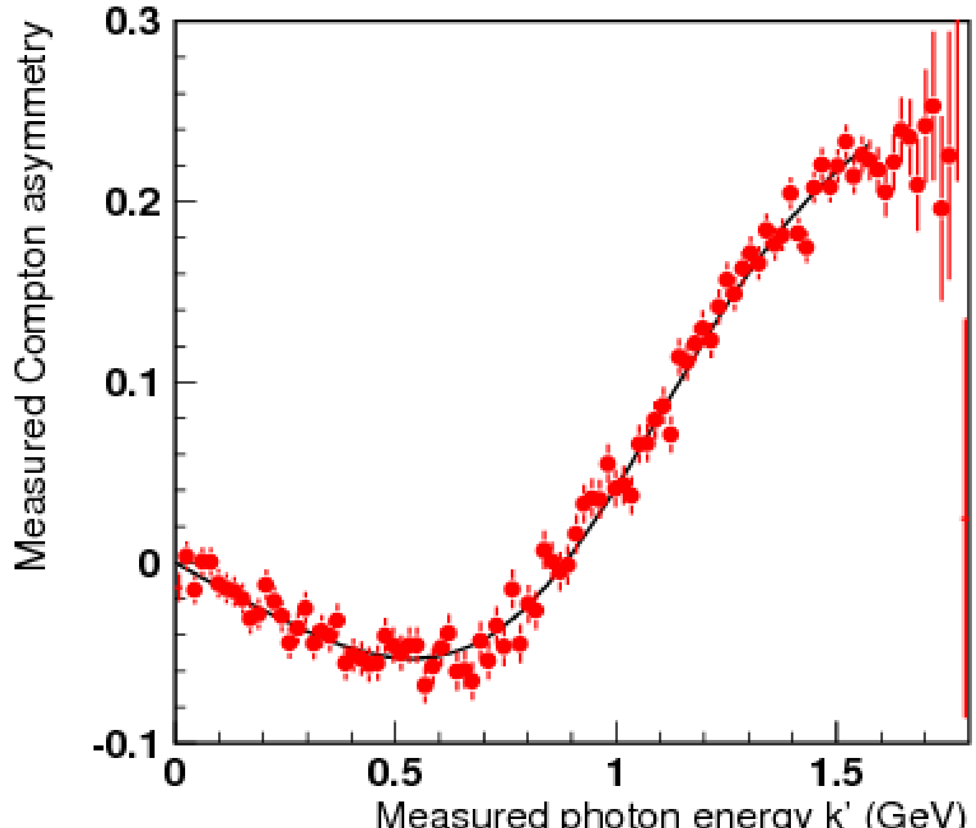
Good energy resolution and linearity in test beams (DESY and CERN)

Sampling calorimeter with spatial resolution

Monte Carlo in Geant:
- model detector
- Compton cross section
- shower simulation

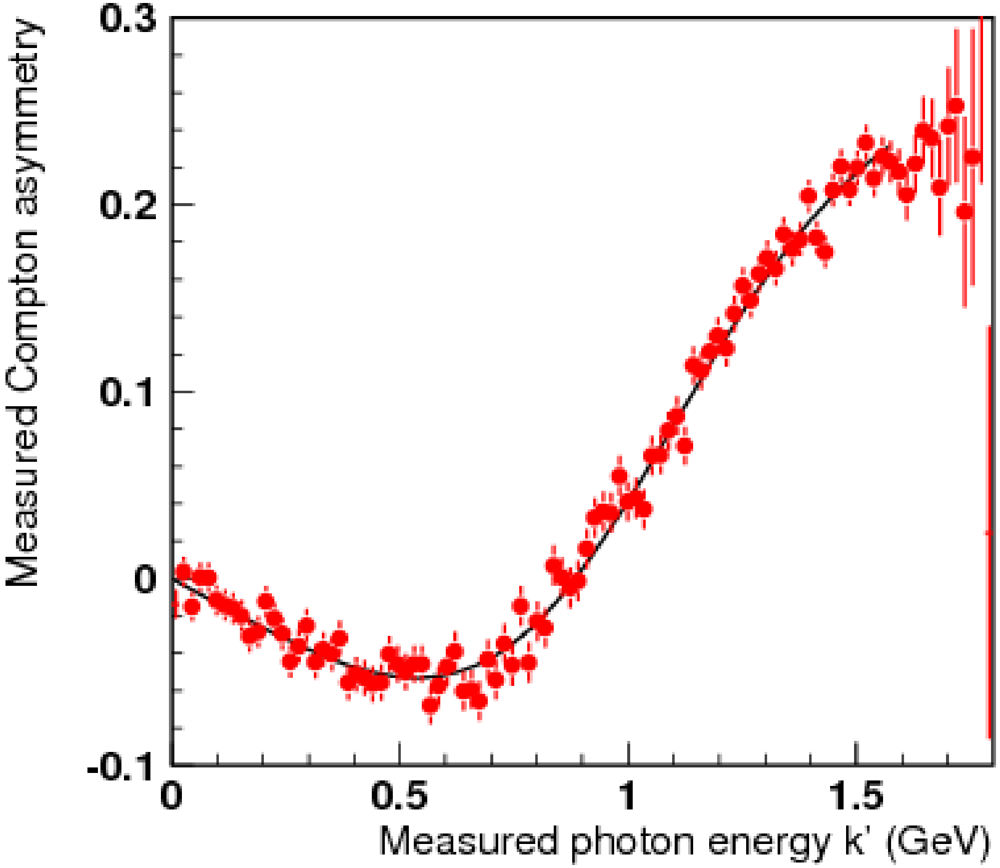


Simulated asymmetry agrees with theoretical curve, at E = 7.5 GeV



Sampling calorimeter with spatial resolution

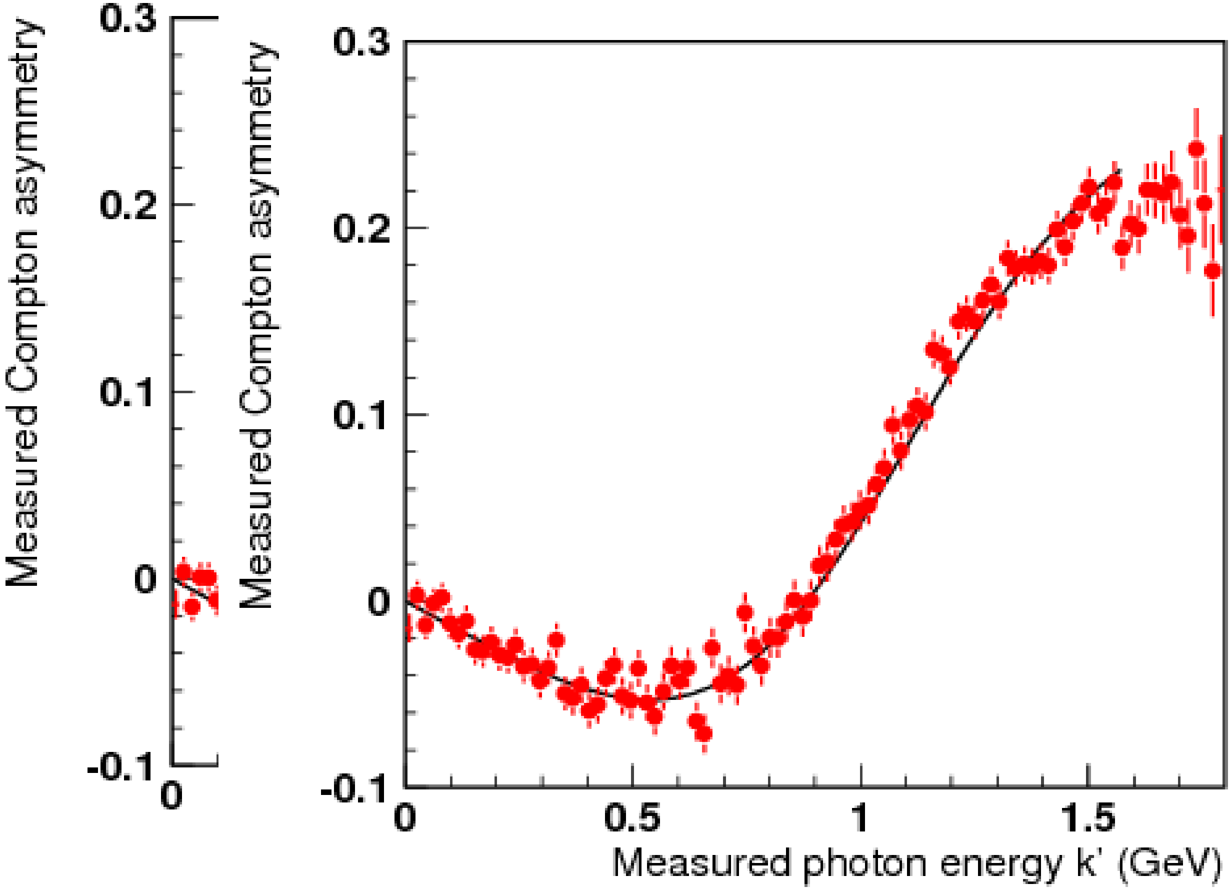
Additional energy smearing could complicate things:



No additional smearing

Sampling calorimeter with spatial resolution

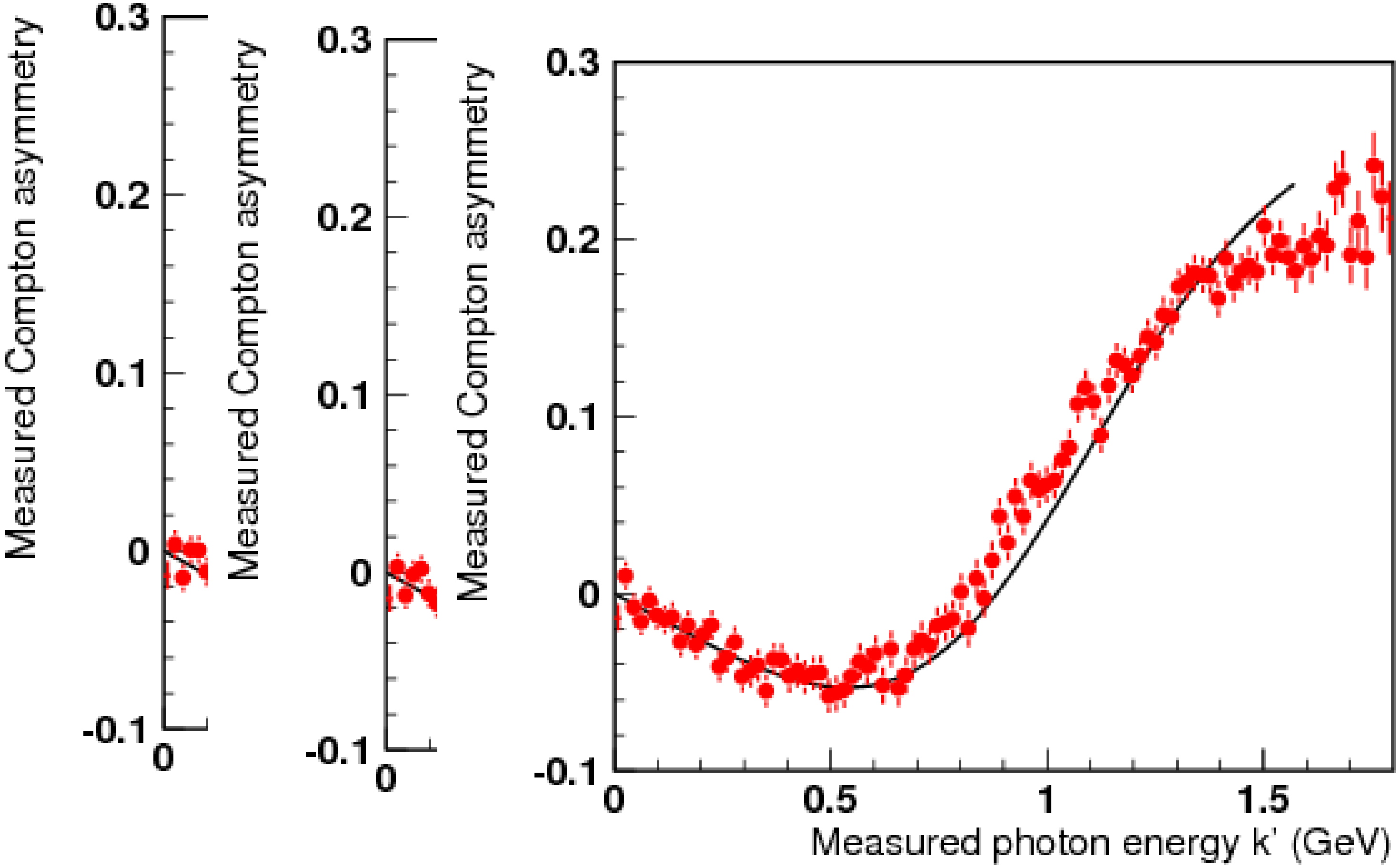
Additional energy smearing could complicate things:



Additional smearing: 5%

Sampling calorimeter with spatial resolution

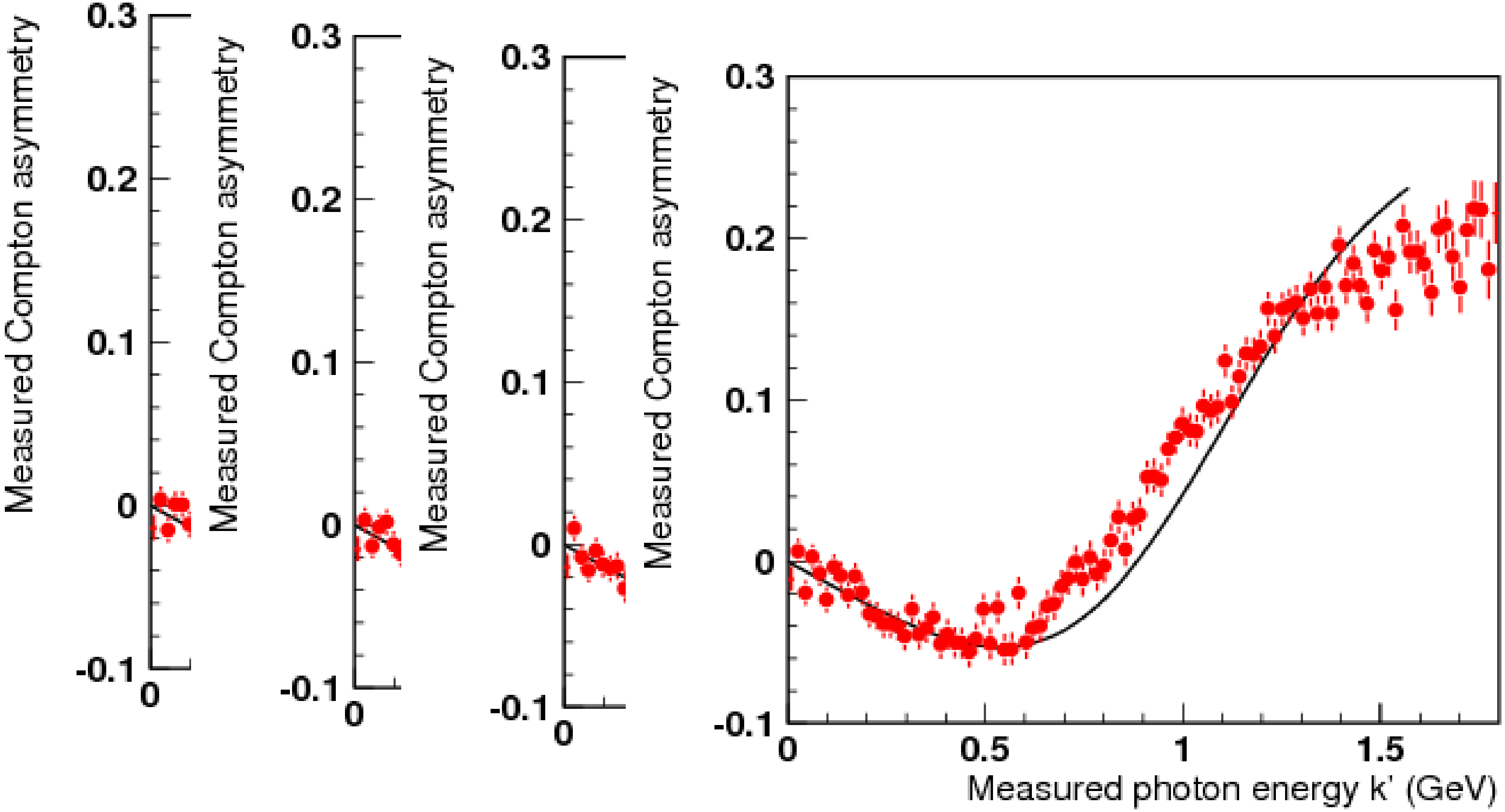
Additional energy smearing could complicate things:



Additional smearing: 10%

Sampling calorimeter with spatial resolution

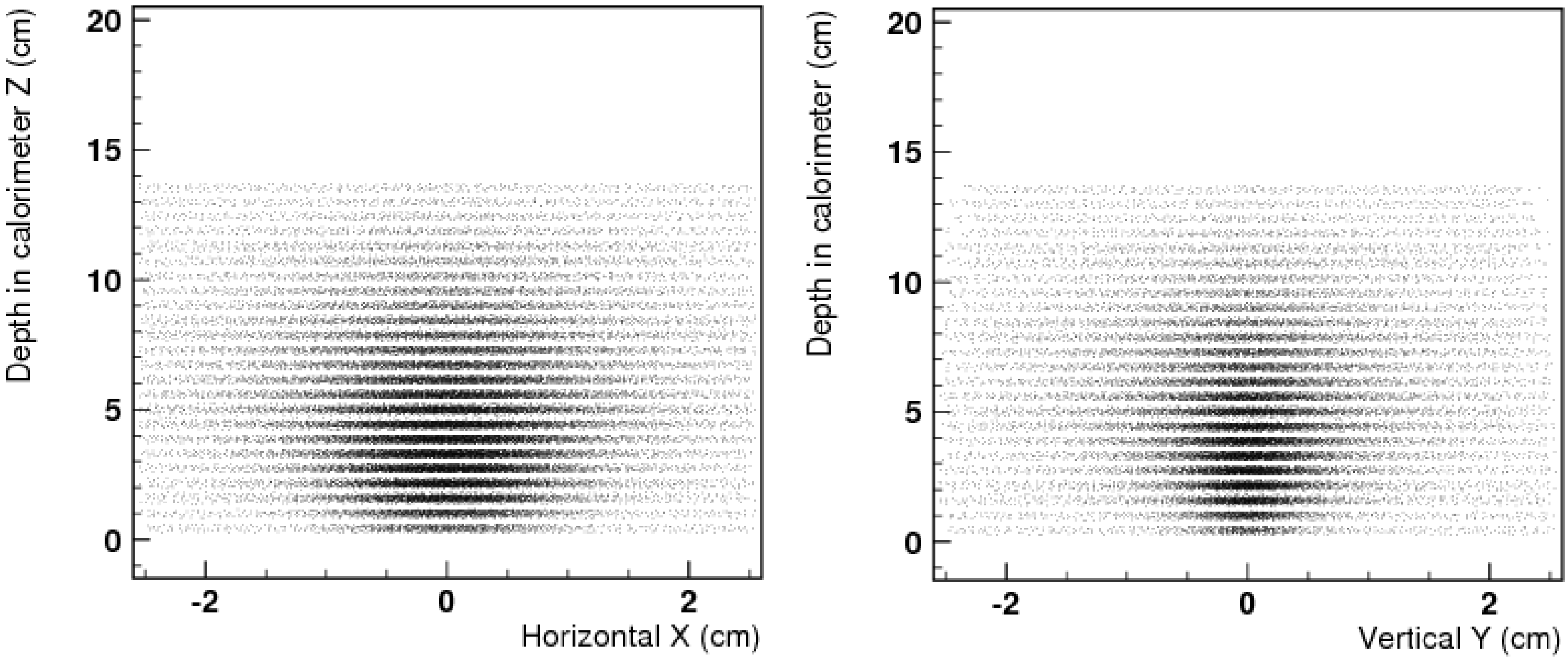
Additional energy smearing could complicate things:



Additional smearing: 15%

Sampling calorimeter with spatial resolution

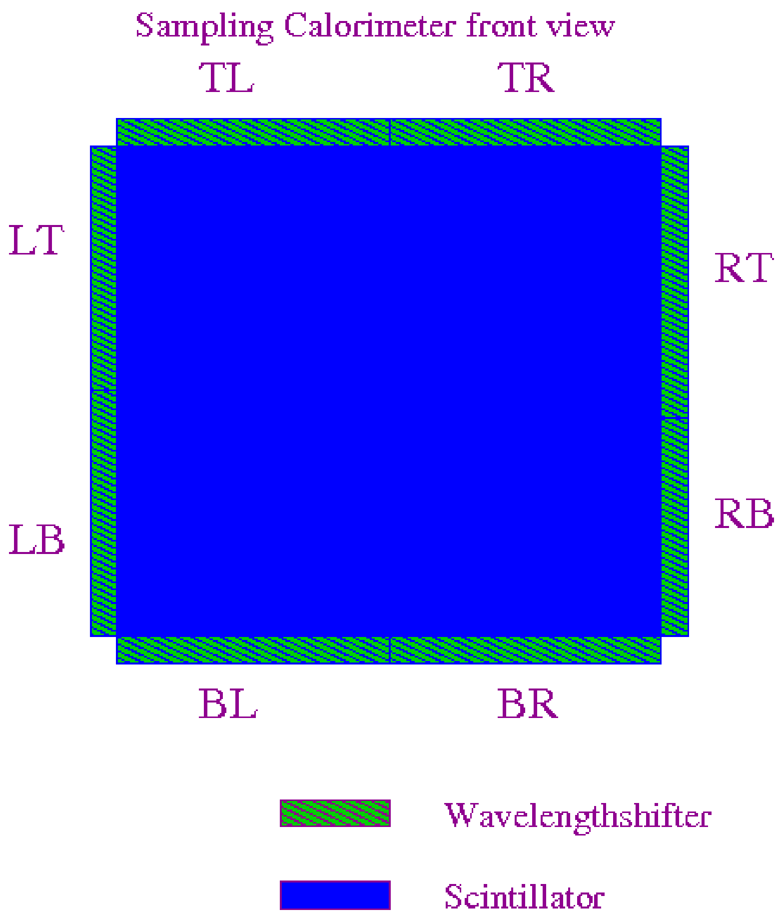
Shower development in calorimeter



- Compton centering important, to avoid losing part of the shower (beam sizes from HERA used in this Monte Carlo simulation)

Sampling calorimeter with spatial resolution

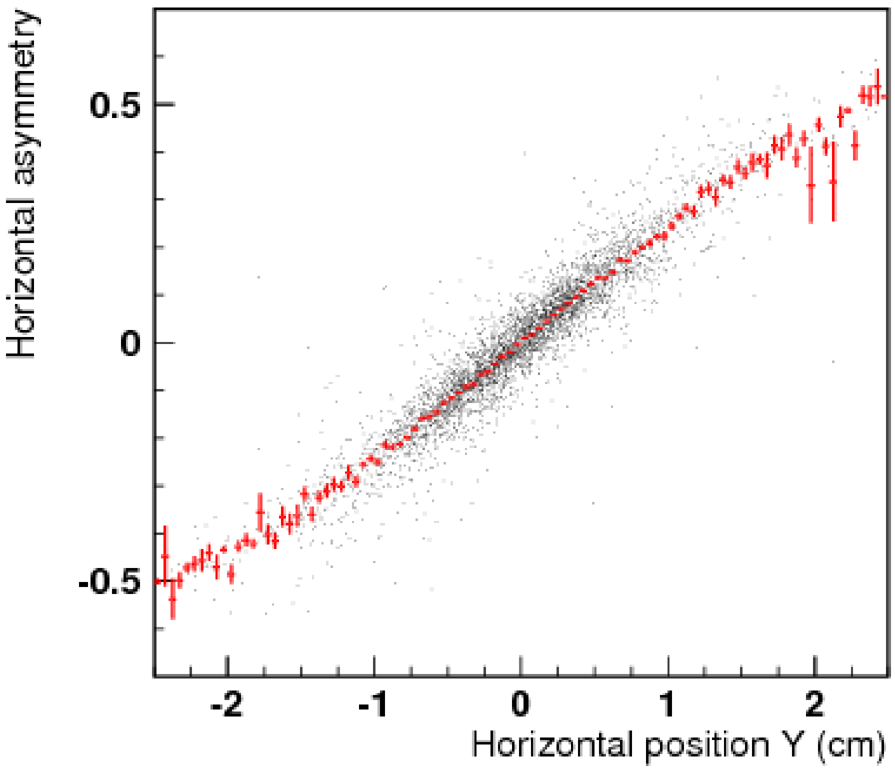
Shower development in calorimeter → add spatial resolution

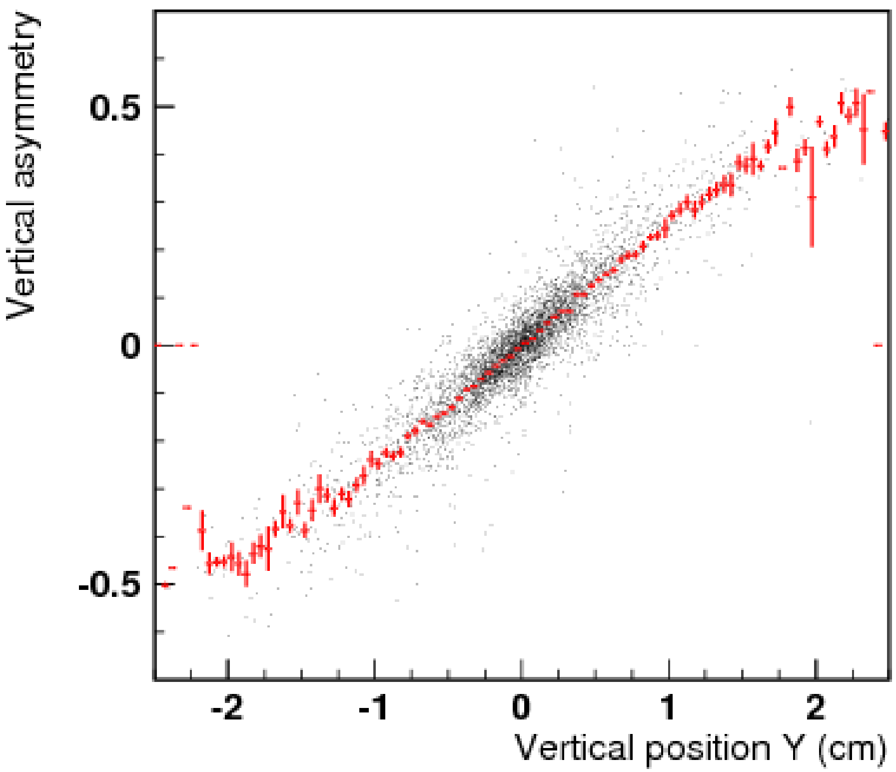


- Optically separate sides of detector with separate PMTs
- Four PMTs enough to determine position of Compton cone
- Eight PMTs in simulation

Sampling calorimeter with spatial resolution

Position of Compton photons:



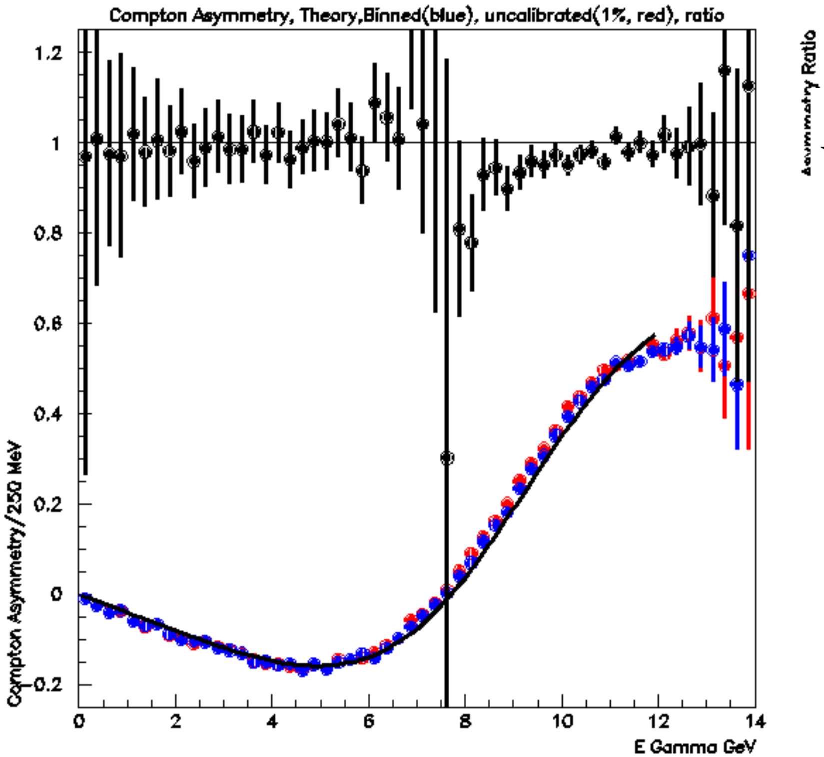


Asymmetry η in PMT signal correlated to position on calorimeter

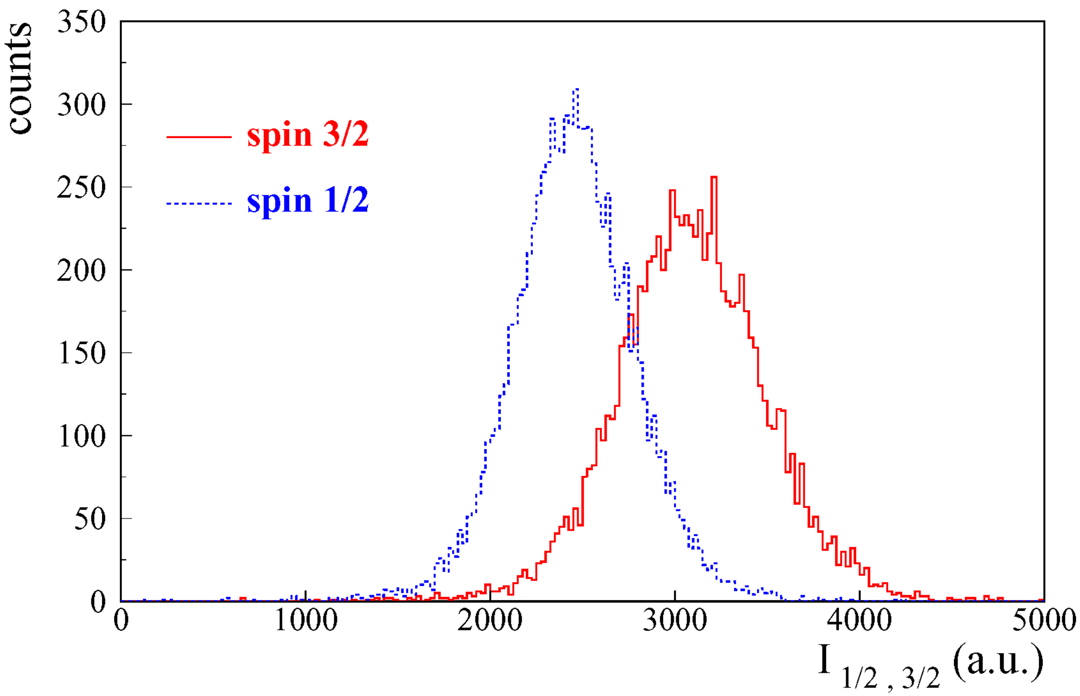
Sampling calorimeter with spatial resolution

Comparison Monte Carlo and theory

In single photon mode

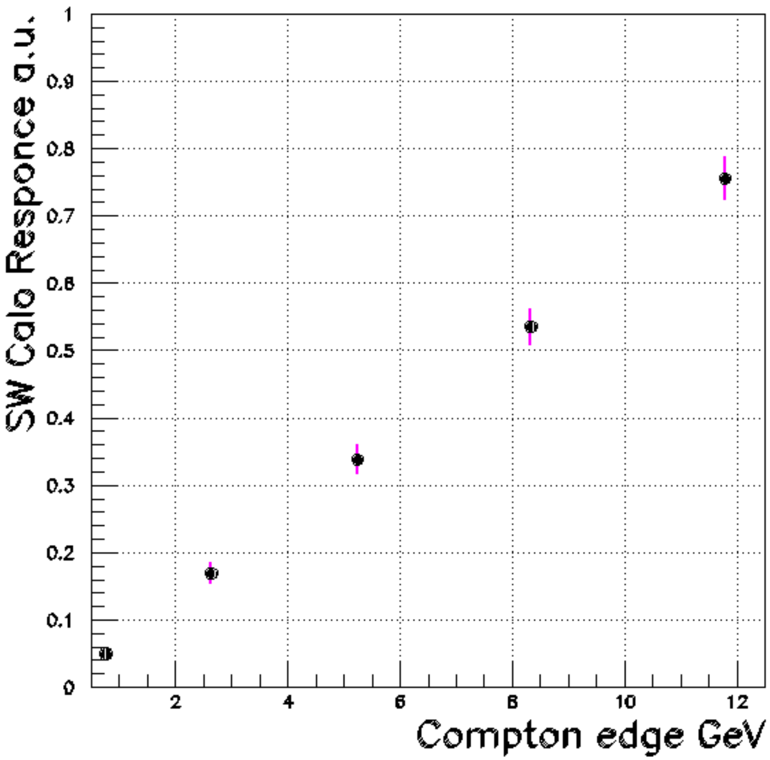


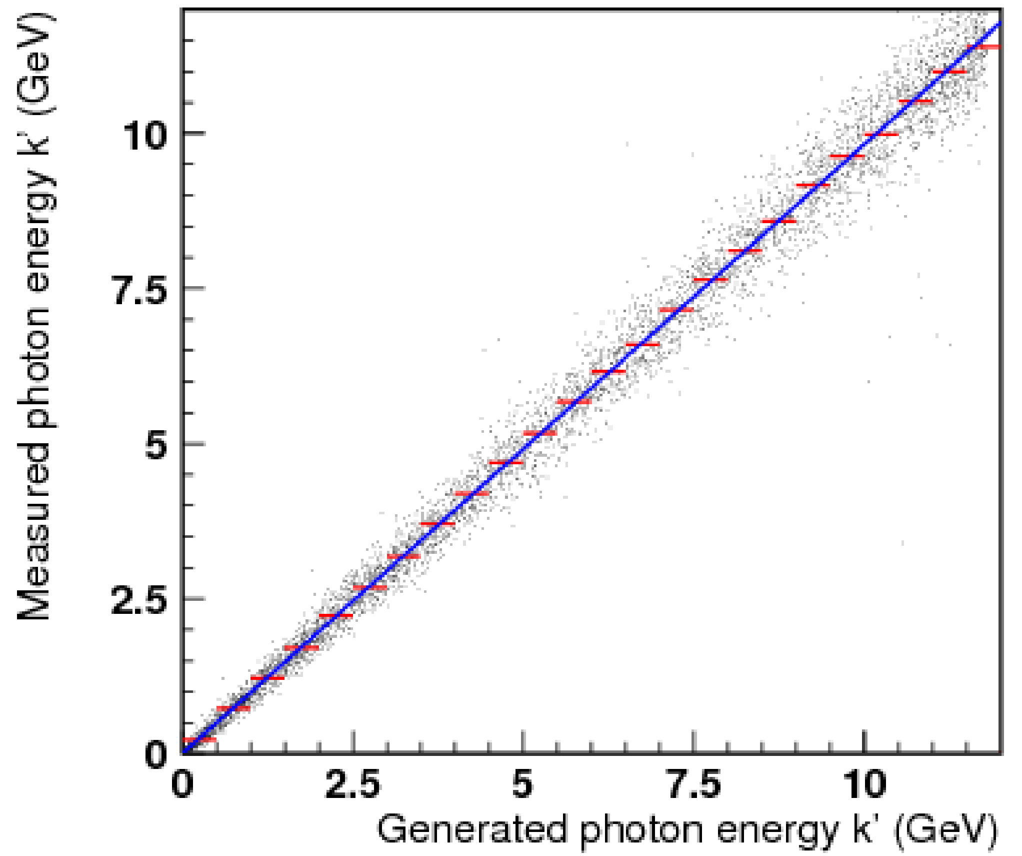
Energy weighted asymmetry multi photon mode



Sampling calorimeter with spatial resolution

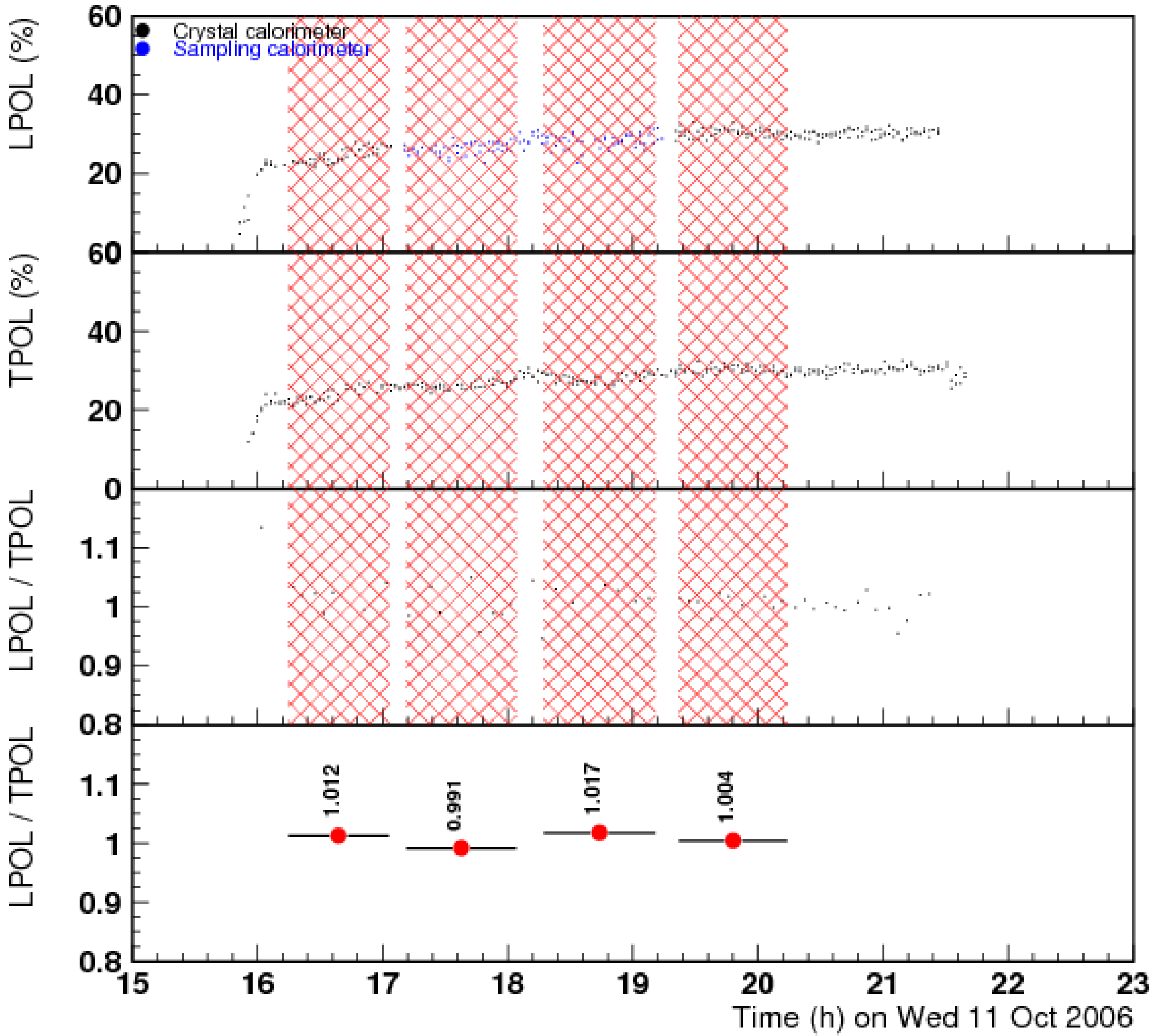
Linearity of the calorimeter:





Use Compton edge to calibrate calorimeter → Change beam energy to access different Compton edge values

Advantage of two polarimeters



Systematics:

- simultaneous or interleaved measurements with two devices
- disentangle effects of machine and polarimeter

Efficiency:

- redundancy leads to high efficiency, in cases of failure

Summary

chicane

Dedicated beam component and space for a polarimeter

scattered electron

Scattered electron measurement (with Si,...)

pair spectrometer

Single photon mode by e^+e^- pair production in variable convertor

single/multi photon

Single photon mode:

- calibration at zero-crossing and Compton edge

Multi photon mode

- independent of calorimeter response

Sampling calorimeter with W and plastic scintillator plates