Feasibility studies of a polarized positron source based on the bremsstrahlung of polarized electrons

Jonathan DUMAS

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September 22, 2011

Plan

1) Why?
- **-CEBAF Accelerator**
- **-Physics motivations (DVCS, Two γ exchange…)**

2) How?
- **- Positron source polarization**
- **- Proposed source for CEBAF**

3) Elementary processes
- **- Olsen & Maximon (OM) model**
- **- Singularities**
- **- Kuraev, Bystritskiy, Shatnev, Tomasi-Gustafsson (KBST) model**

4) Source Optimization
- **- Source characterization**
- **- Optimal target thickness**
- **- Electron beam energy parameter**

5) Polarized Electrons for Polarized Positrons (PEPPo)
- **-Equipment**
- **-Modifications**
- **-Diagnostics**

6) PEPPo Polarimetry
- **- Apparatus**
- **- Data taking methods**
- **- Calorimeter test**

7) Conclusion

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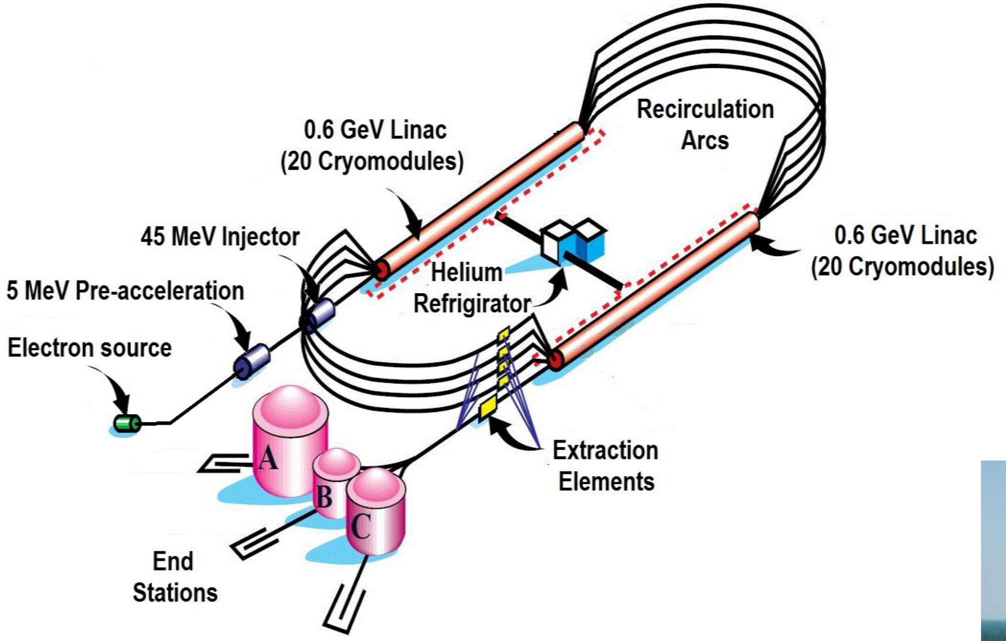
Continuous Electron Beam Accelerator Facility



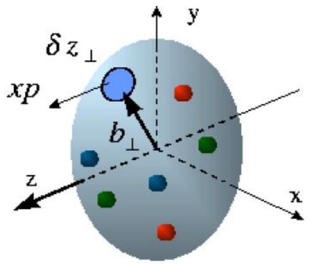
CW Electron beam in Halls
Polarization: 85-90 %
Beam Energy: 6 GeV
Max. Current: 180 μA

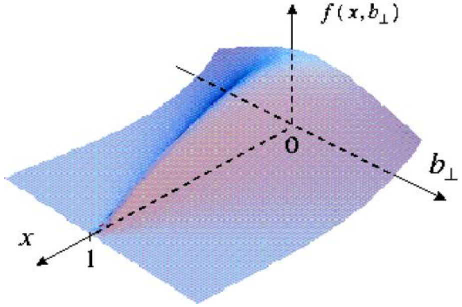
3 end stations for nuclear physics experiments would benefit from polarized positrons

Generalized Parton Distributions
Nucleon Form Factors

Generalized Parton Distributions (1/2)

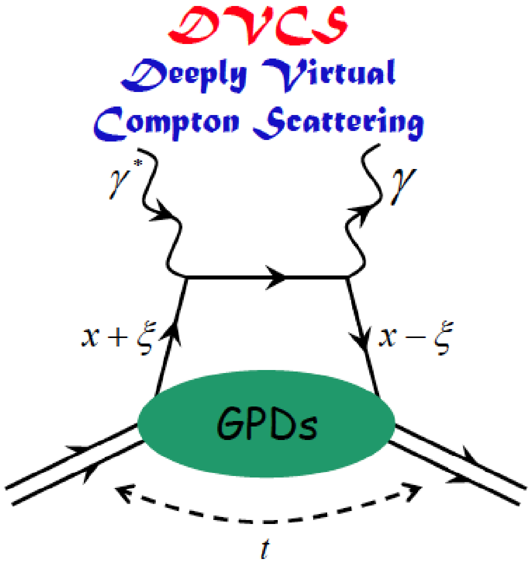
One of the JLab nuclear physics program aims at the investigation of the spatial distribution of partons in the nucleons via **GPDs**.



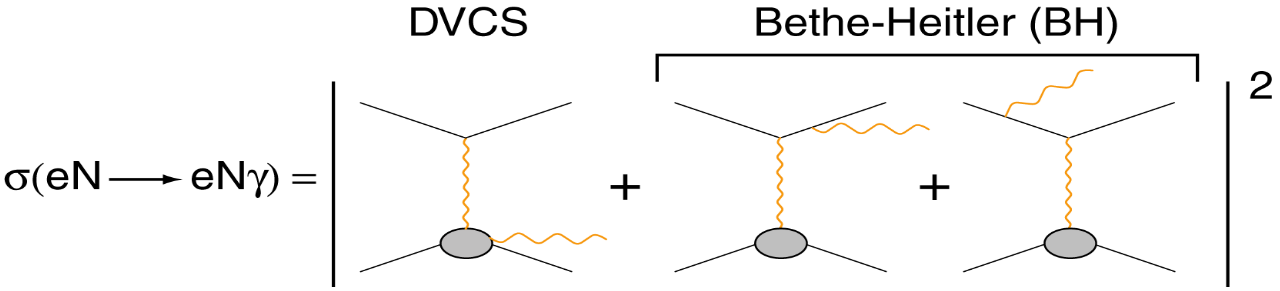


GPDs are extracted from the ***Deeply Virtual Compton Scattering*** reaction off proton or neutron targets

$eN \rightarrow eN\gamma$



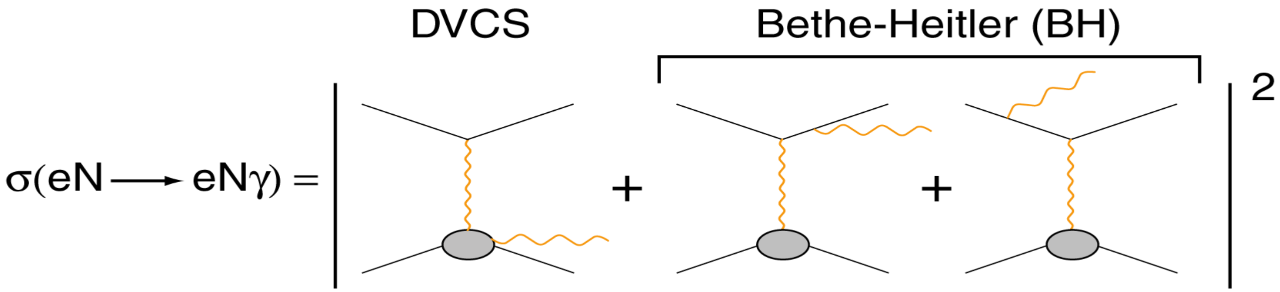
Generalized Parton Distributions (2/2)



Different observables from beam **charge** and **polarization**, are required **to extract** the different linear and bilinear combinations of Compton form factors. Their real and imaginary parts are related to **GPDs**.

$$\sigma_P^q = \sigma_{BH} + \sigma_{DVCS} + P\,\tilde{\sigma}_{DVCS} + q\left(\sigma_{INT} + P\,\tilde{\sigma}_{INT}\right)$$

Generalized Parton Distributions (2/2)



Different observables from beam **charge** and **polarization**, are required **to extract** the different linear and bilinear combinations of Compton form factors. Their real and imaginary parts are related to **GPDs**.

$$\sigma_{P}^{q} = \sigma_{BH} + \sigma_{DVCS} + P\tilde{\sigma}_{DVCS} + q\left(\sigma_{INT} + P\tilde{\sigma}_{INT}\right)$$

P: beam polarization

q: beam charge

$$\sigma_{0}^{-} = \sigma_{BH} + \sigma_{DVCS} - \sigma_{INT}$$

$$\sigma_{+}^{-} - \sigma_{-}^{-} = 2\tilde{\sigma}_{DVCS} - 2\tilde{\sigma}_{INT}$$

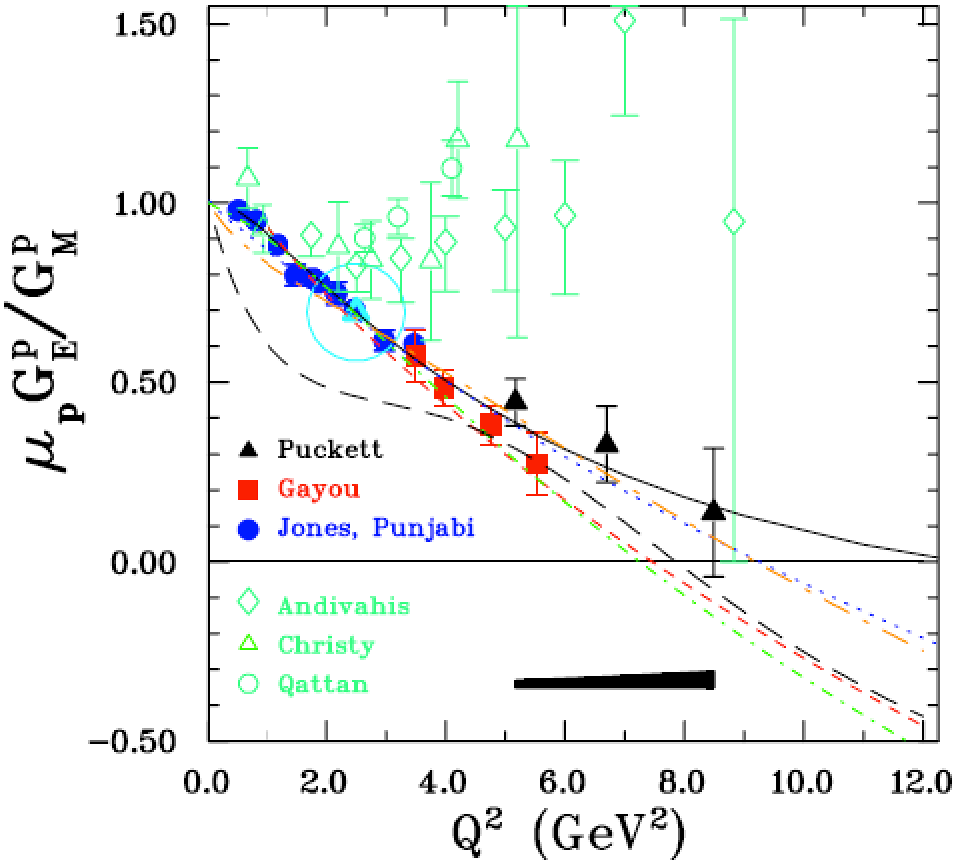
$$\sigma_{0}^{+} - \sigma_{0}^{-} = 2\sigma_{INT}$$

$$\left[\sigma_{+}^{+} - \sigma_{-}^{+}\right] - \left[\sigma_{+}^{-} - \sigma_{-}^{-}\right] = 4\tilde{\sigma}_{INT}$$

Complete determination of the 4 unknown amplitudes

Proton Form Factors (1/2)

The electric **G_E** and magnetic **G_M** form factors of the proton measured via **Rosenbluth** or **Polarization Transfer** techniques in the **1** γ exchange approximation present a **discrepancy**.



Rosenbluth:

$$\sigma_R = f\left(G_M^2, G_E^2\right)$$

Polarization transfers: $\vec{e}\,N \rightarrow e\,\vec{N}$

$$P_l = f(G_M^2)$$

$$P_t = f(G_E G_M)$$

Possible explanation proposed: **2** γ exchange

Proton Form Factors (2/2)

The **2 γ** exchange mechanism introduces **corrections** to the form factors that can be separated with **beam charges**

$$\tilde{G}_E = -qG_E + \delta\tilde{G}_E \qquad \tilde{G}_M = -qG_M + \delta\tilde{G}_M \qquad \tilde{F}_3 = \delta\tilde{F}_3$$

q: beam charge

3 additional terms are introduced in the observables with the form factor corrections accounted for the 2 γ exchange

$$\sigma_R = f\left(G_M, G_E, \delta\tilde{G}_E, \delta\tilde{G}_M, \delta\tilde{F}_3\right)$$

$$P_l = f\left(G_M, \delta\tilde{G}_M, \delta\tilde{G}_E, \delta\tilde{F}_3\right)$$

$$P_t = f\left(G_E G_M, \delta\tilde{G}_M, \delta\tilde{F}_3\right)$$

5 Form Factors terms that can be separated with **3** observables with polarized **electrons** and **3** more with polarized **positrons**

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Polarized Sources (1/2)

β^+ decay:

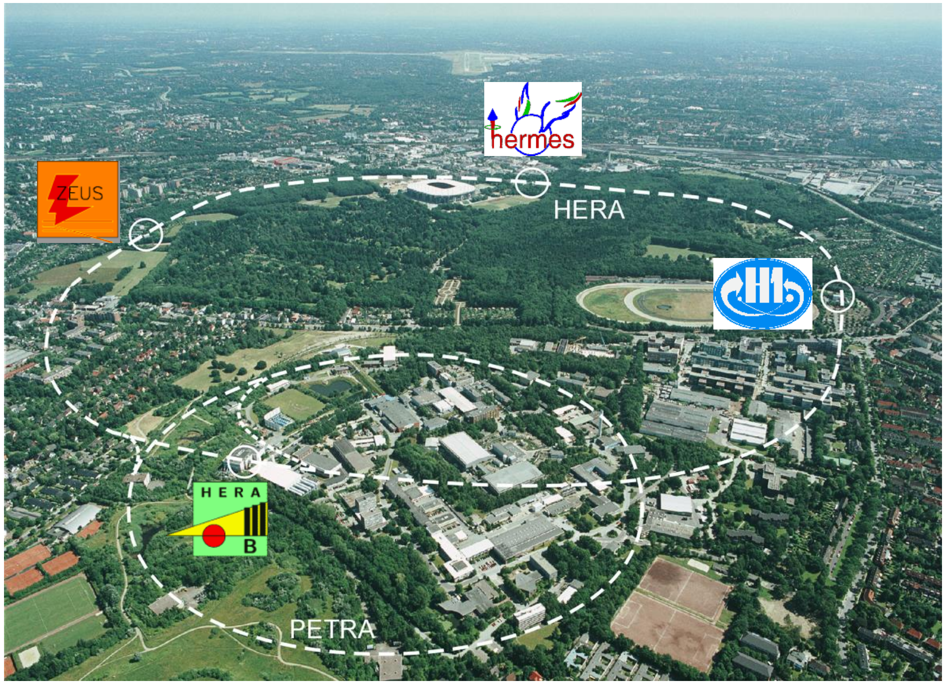
$${}^{22}\mathrm{Na} \longrightarrow {}^{22}\mathrm{Ne} + \overrightarrow{e^+} + \nu_e$$

$$P_{e+} = 40\%$$

L.A. Page & M. Heinberg. Phys. Rev., 106(6):1220-1224, 1957.

Not used in accelerators because of **low currents, time structure.**

Pair creation: gamma rays produce **e^-e^+** pairs



Polarization can be obtained in storage rings via **Sokolov-Ternov** effect. Precession of the spin parallel to the dipole magnetic fields.

$$\tau = \frac{8}{5\sqrt{3}} \frac{m_e^2 c^2}{\hbar e^2} \frac{\rho^3}{\gamma^5}$$

High polarization, but long build-up time:

HERA: $E = 27.5$ GeV ; $\tau = 23$ minutes

Polarized Sources (2/2)

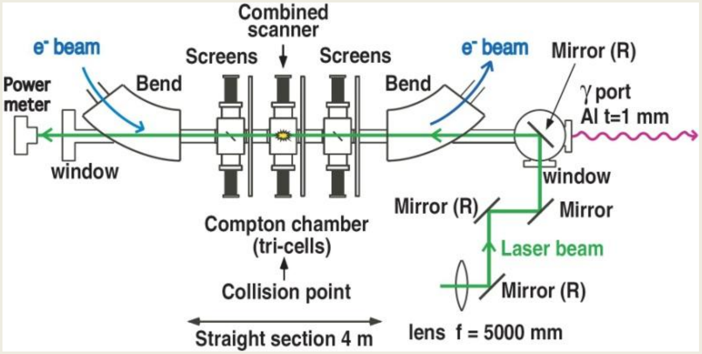
Polarization transfer from **photons** to **positrons**

The **challenge** is creating **polarized photons energetic enough** for pair production

Compton back scattering

Demonstration at KEK:

Circularly polarized laser photons scatter from a 1.22 GeV electron beam



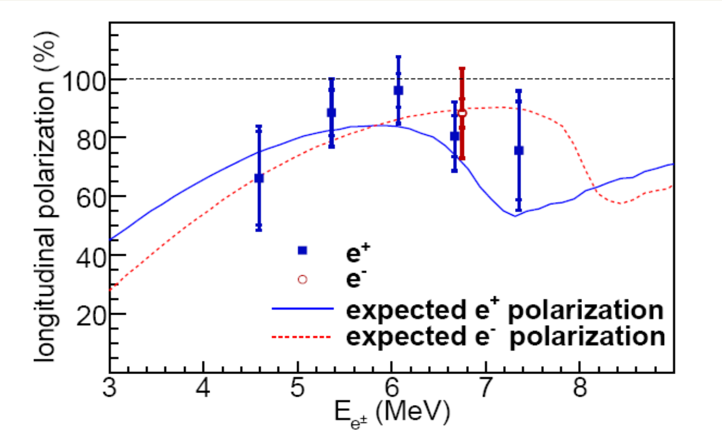
$P_{e+} = 75 + 15 + 19\ \%$ for $\overline{T}_{e+} = 36$ MeV

T. Omori et al, PRL 96 (2006) 114801

Helical Undulator

Demonstration at SLAC (E166):

46.6 GeV electron beam in helical undulator producing 8MeV photons at main harmonic



G. Alexander et al, PRL 100 (2008) 210801

Requires independent electron accelerator

Polarized Bremsstrahlung

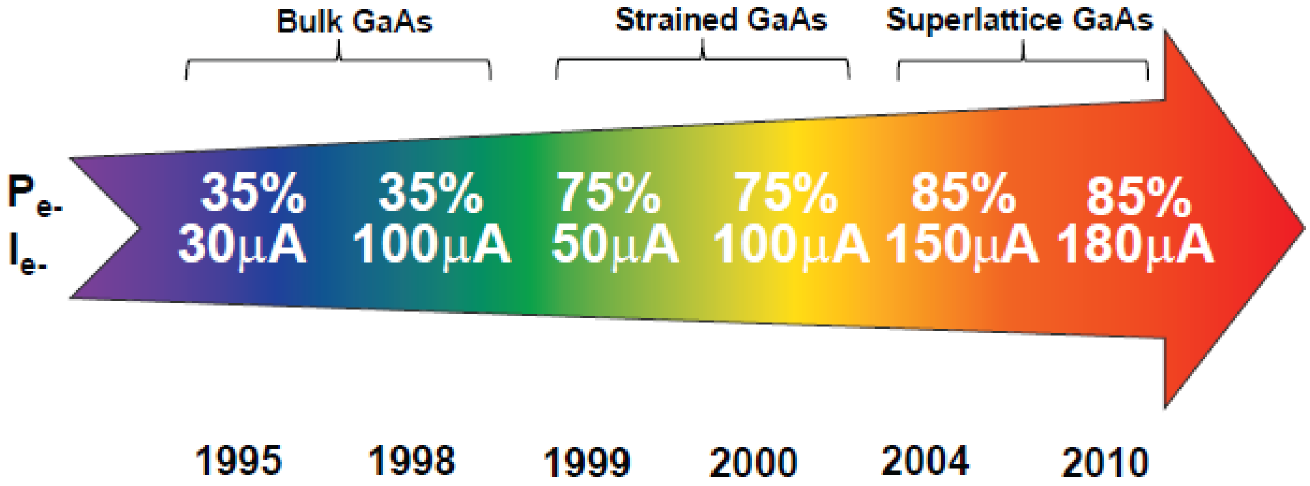
For **CEBAF**, a **new** approach is proposed.
Polarized electrons radiate **Bremsstrahlung photons** followed by **pair creation**.
The electron **polarization** is successively **transferred** to the photons and the positrons

E.G. Bessonov, A.A Mikhailichenko, EPAC (1996)

A.P. Potylitsin NIM A398 (1997) 395

$$\vec{e}^{\,-} \longrightarrow \vec{\gamma} \longrightarrow \vec{e}^{\,+}$$

Not measured



Interesting to investigate due to technological advances of polarized electron sources at JLAB

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Elementary Processes

❖The cross sections for Bremsstrahlung and pair creation are **well known** and **documented** :

Relativistic or non-relativistic regimes? **Small or large emission angles?**

Coulomb corrections? **Screening effects?**

❖Polarization transfers were calculated for a single interaction by:

OM:

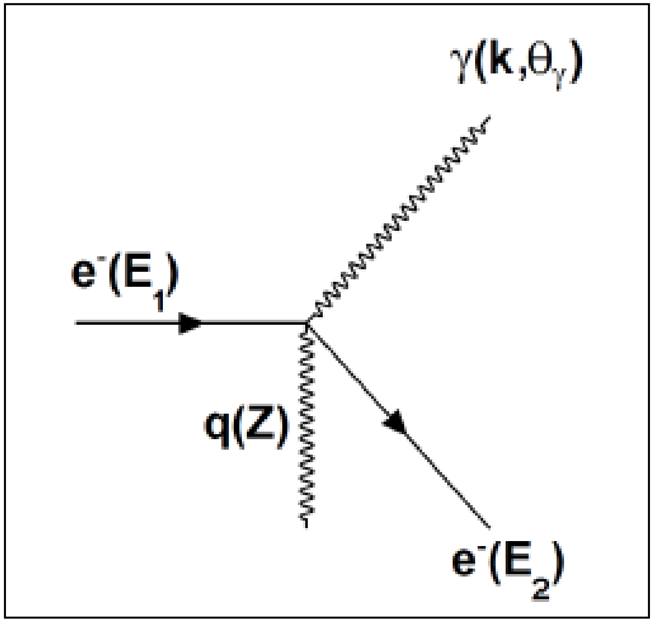
H. Olsen, L. Maximon, PR114 (1959) 887

→ Model implemented in simulation tools such as Geant4

KBST:

E.A. Kuraev, Y.M. Bystritskiy, M. Shatnev, E.Tomasi-Gustafsson, PRC 81 (2010) 055208

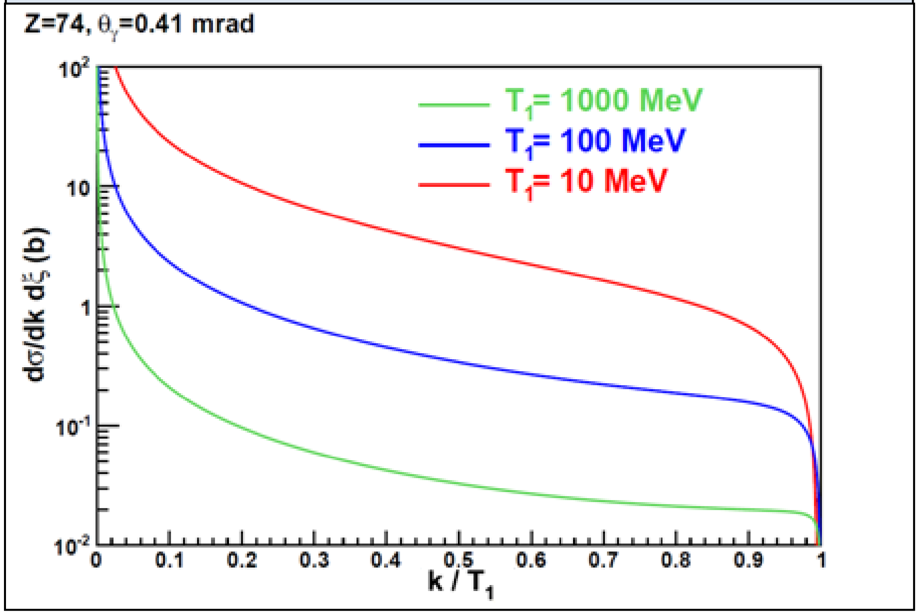
Bremssthrahlung



- Photon energy **k** up to the electron energy **T_1**
- Preferably low energy photons
- Cross section decreases as 1/k

Electromagnetic radiation produced by **charged particles** during a **deceleration** or **deflection** passing nearby the strong **electric fields** of atomic nuclei.

Cross section



Photon energy normalized by electron energy

Bremssthrahlung Polarization

In the **Stokes** formalism, the components of the **photon** polarization **P** is a function of the **lepton** polarization **S** as calculated by OM:

$$\begin{pmatrix} I \\ P_1 \\ P_2 \\ P_3 \end{pmatrix} = T^{\gamma}_{Brem.} \begin{pmatrix} 1 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix} \quad \text{with} \quad T^{\gamma}_{Brem.} = \begin{pmatrix} I_0 & 0 & 0 & 0 \\ D & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & T & 0 & L \end{pmatrix}$$

Transfer matrix depends of kinematical variables, screening and Coulomb corrections:

Photon **linear** polarization → P_1

Photon **circular** polarization → P_3

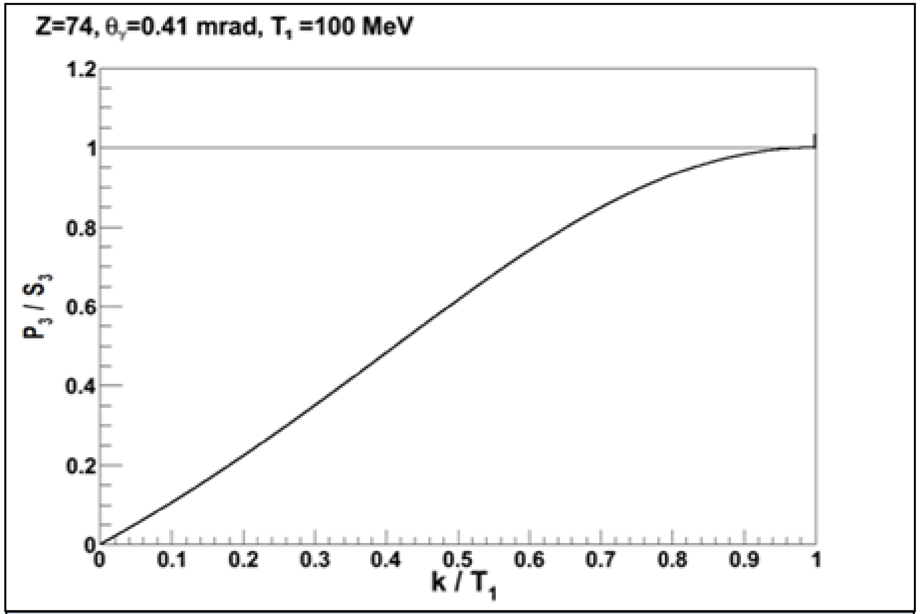
$$\begin{pmatrix} P_1 \\ P_2 \\ P_3 \end{pmatrix} = \begin{pmatrix} D \\ 0 \\ \bigcirc\!\!\!\!\!S_1 T + \bigcirc\!\!\!\!\!S_3 L \end{pmatrix}$$

Transverse and longitudinal polarization of the leptons

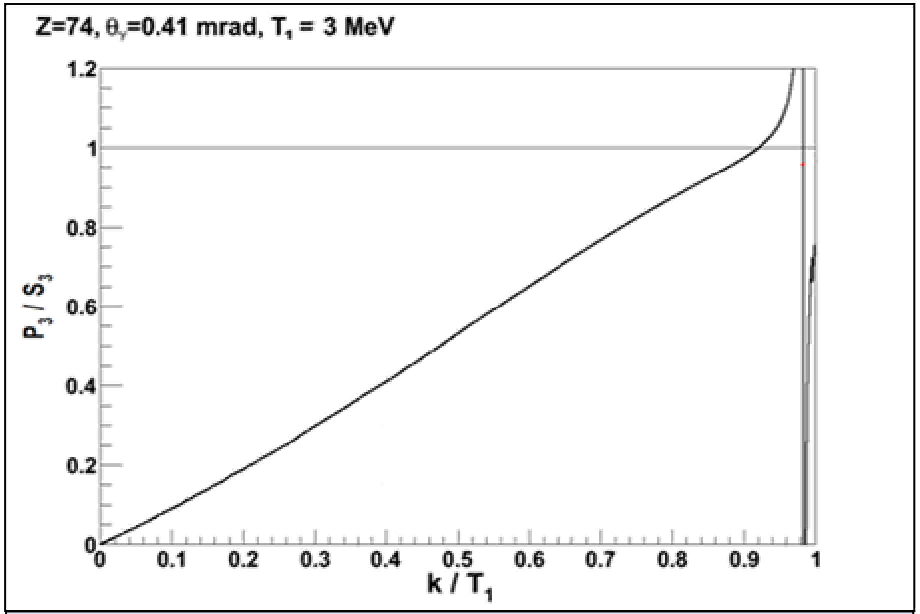
Bremssthrahlung Polarization

Considering the OM model for different electron energies.

Problem: Singularities originate mathematically from the zero crossing of the differential cross section. Too strong Coulomb corrections for heavy nuclei which leads to negative cross sections



100 MeV longitudinaly polarized electrons



3 MeV longitudinaly polarized electrons

The energy spectra shows **singularities** for **high energy photons**.

The singularities increase for **lower energy electrons**.

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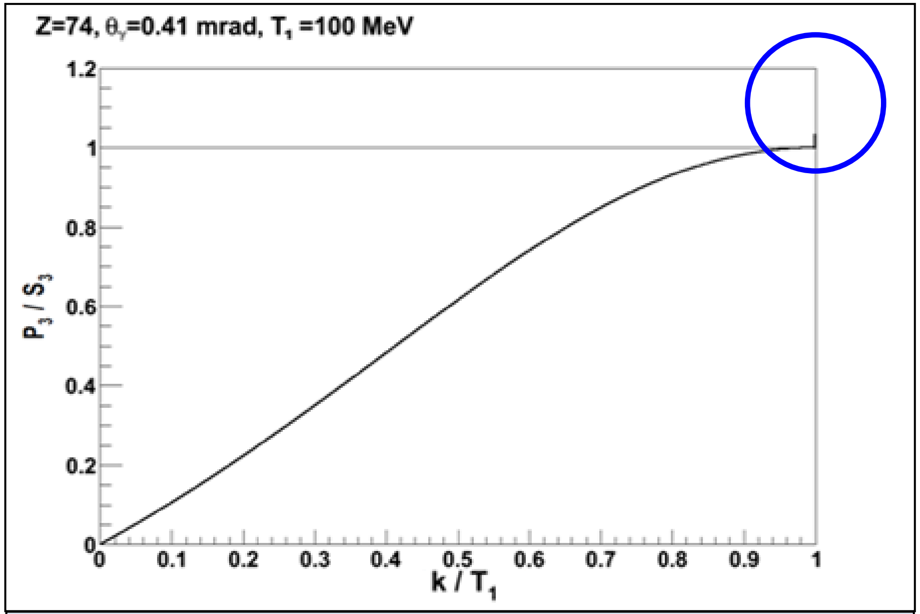

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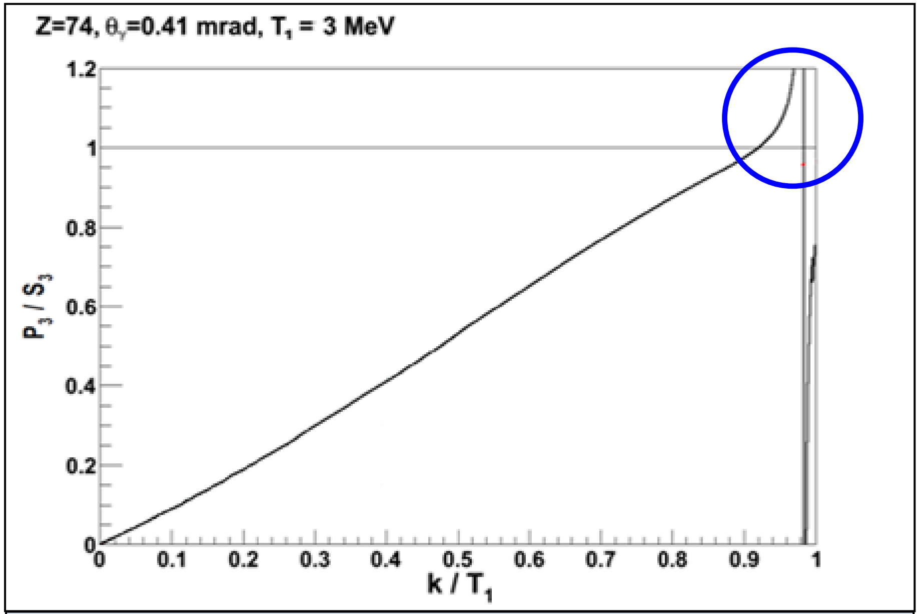

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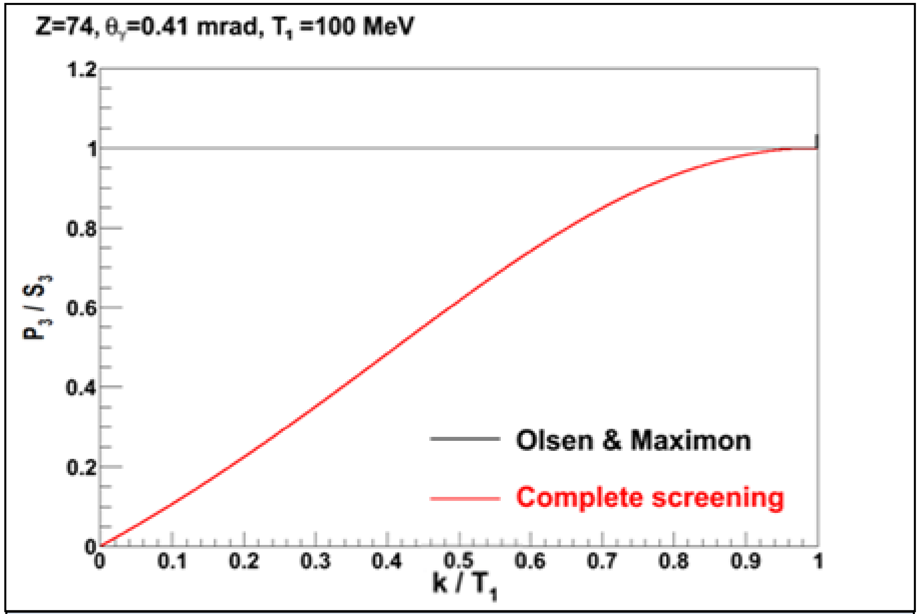

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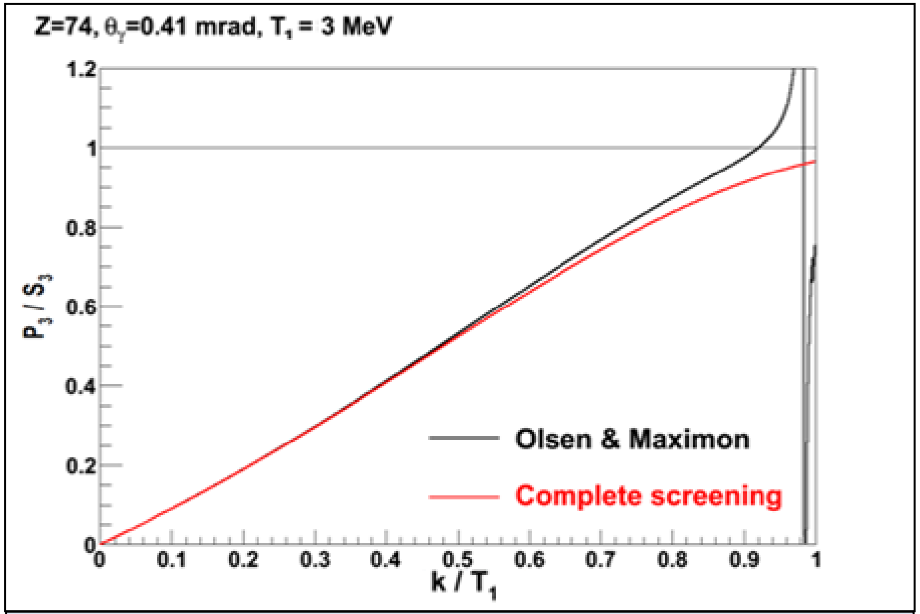
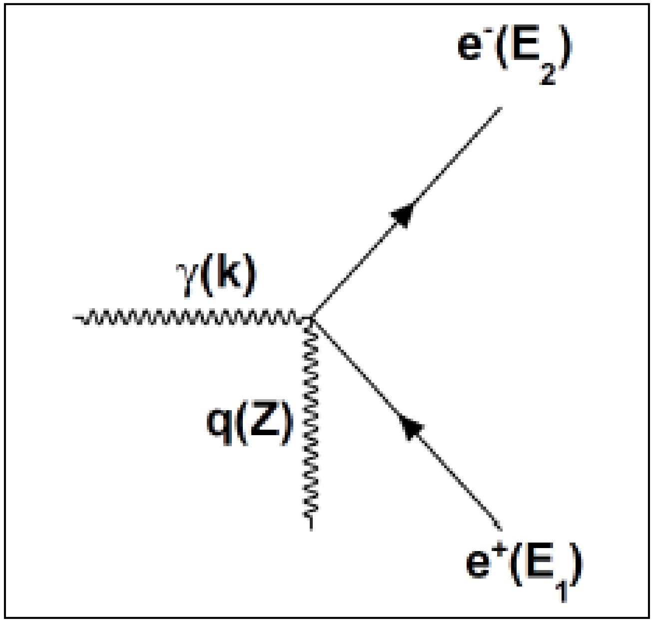


3 MeV longitudinaly polarized electrons

Resolution of the singularities when considering only a **screening regime** that can be applied for some very specific kinematical regions.

Pair Production

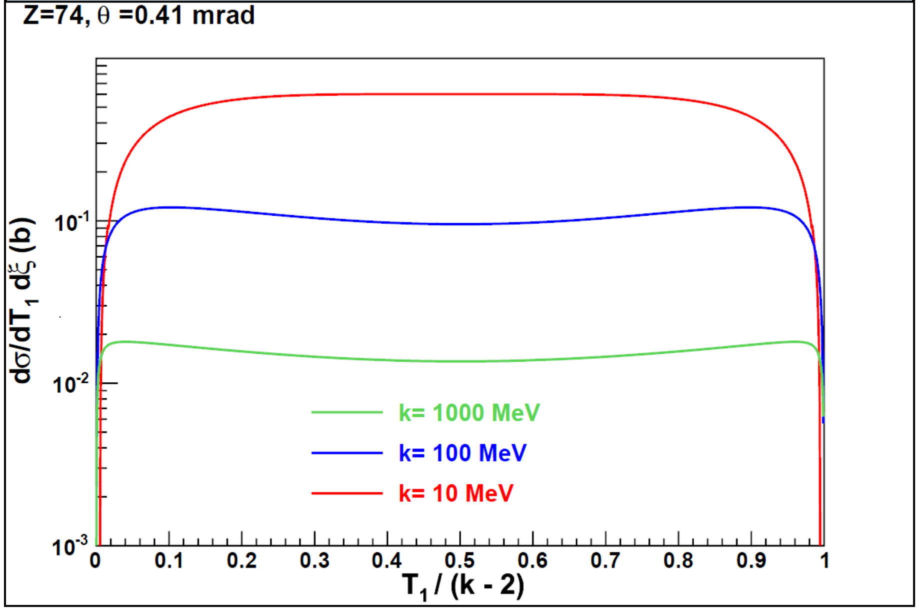


- Positron energy T_1 up to the photon energy $k-2\ mc^2$
- Flat distribution of the cross section

Pair creation and bremsstrahlung reactions are **reciprocal** processes.

Physics observables can be obtained from bremsstrahlung with **simple substitutions**.

Cross section



Positron energy normalized by photon energy

Pair Production Polarization

In the **Stokes** formalism, the transfer matrix of the **lepton** polarization **S** is a function of the **photon** polarization **S** as calculated by OM:

$$T^{e}_{Pair.} = \begin{pmatrix} 1 & D & 0 & 0 \\ 0 & 0 & 0 & T \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & L \end{pmatrix}$$

Transfer matrix depends of kinematical variables, screening and Coulomb corrections

Lepton **transverse** polarization

Lepton **longitudinal** polarization

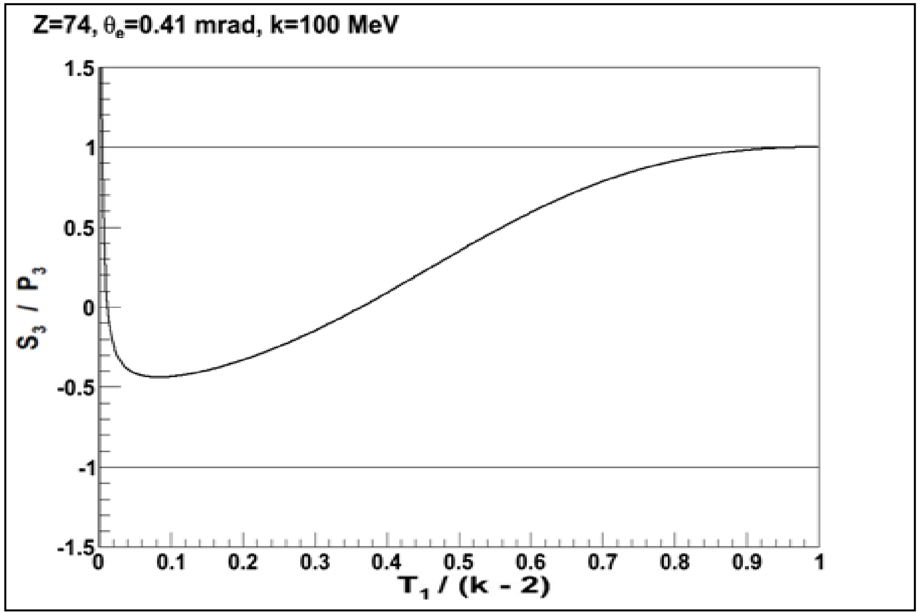
$$\begin{pmatrix} S_1 \\ S_2 \\ S_3 \end{pmatrix} = \begin{pmatrix} P_3 T \\ 0 \\ P_3 L \end{pmatrix}$$

Only function of the photon **circular** polarization **P$_3$**

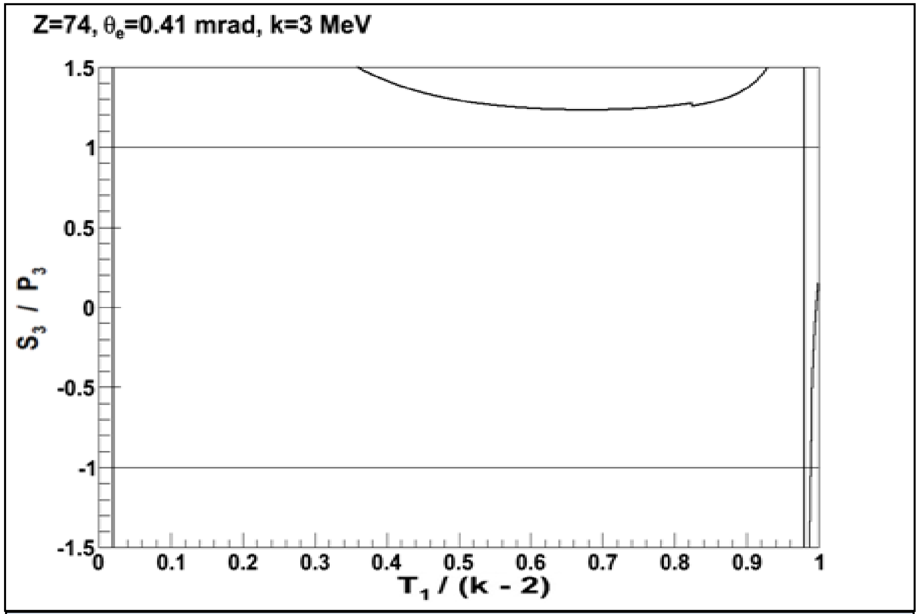
Pair Production Polarization

Polarization transfers suffer from the **same singularities** observed at **low** and **high** energy of the bremsstrahlung spectra.

Effects are much more dramatic at low energy: **Polarization always > 100 %**



100 MeV circularly polarized photons



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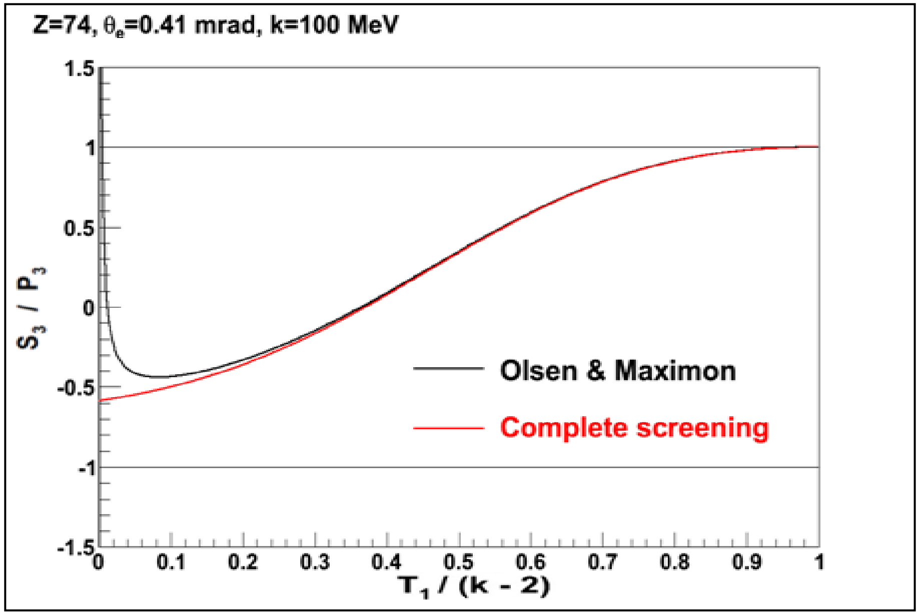

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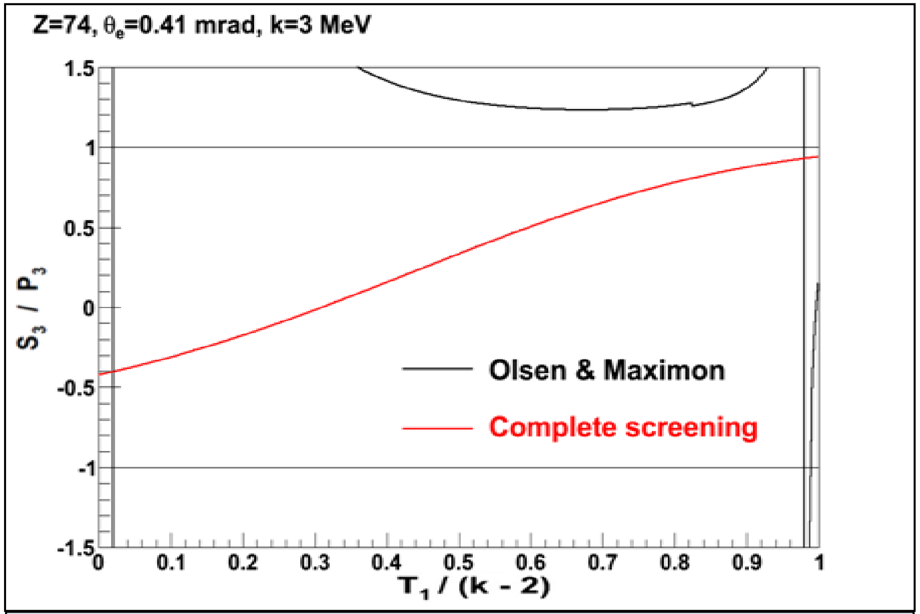


3 MeV circularly polarized photons

Complete screening approximation gives a reasonable description at high and low energies

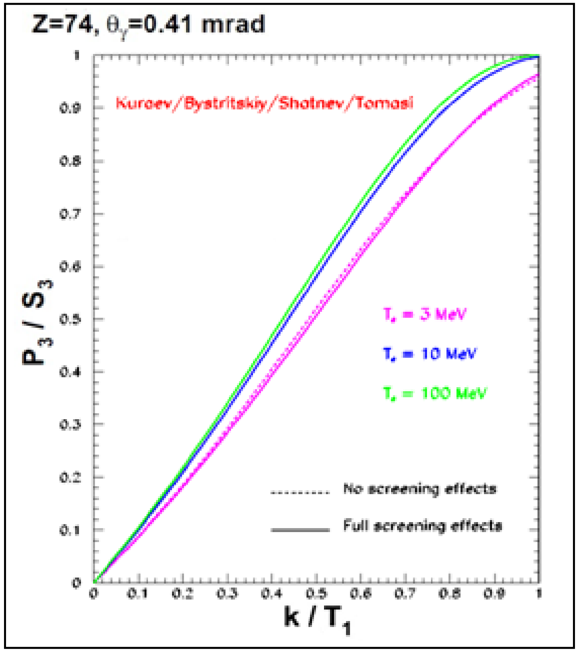
$-100\% < S < 100\%$

KBST Calculations

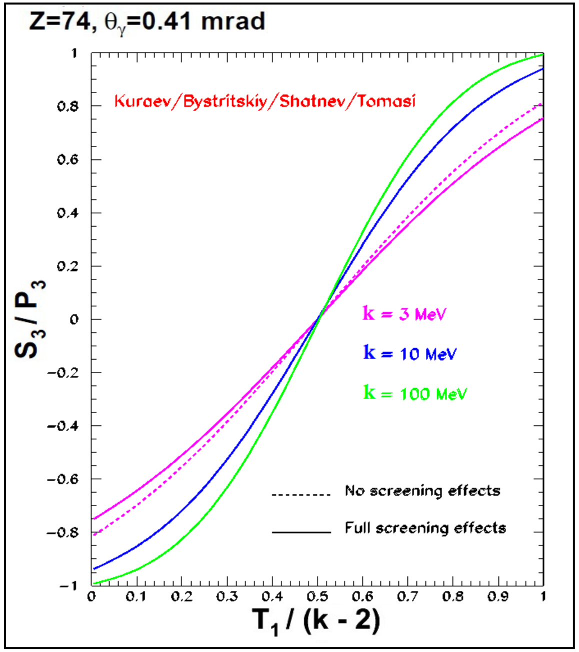
E.A. Kuraev, Y.M. Bystritskiy, M. Shatnev, E.Tomasi-Gustafsson, PRC 81 (2010) 055208

The **KBST** model takes into account **the screening effects** of the Coulomb field and specially the effects of the **finite electron mass**.

Bremsstrahlung



Pair Creation



- No singularities
- Kinematical symmetry

Not implemented in simulation tools (calculations in 2010)

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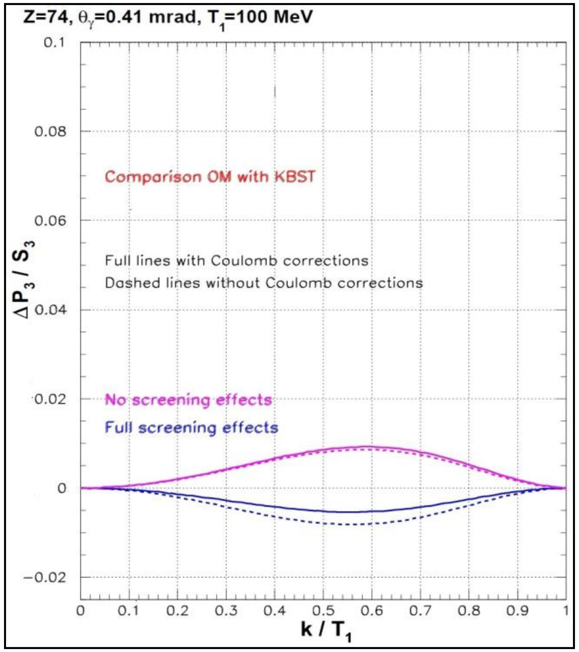

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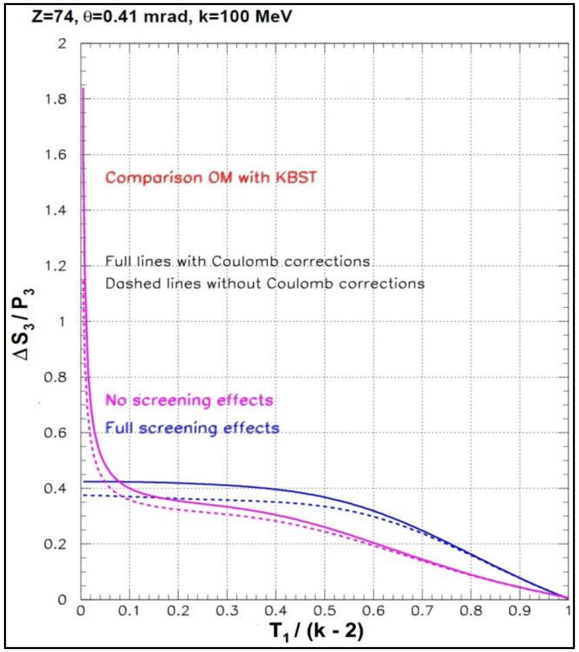
OM vs KBST
Significant effects even
at 100 MeV

Pair Creation



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Source Optimization

Analytical calculations were made for **one atom** interaction
Geant4 simulations are needed for thicker targets, include OM models
Geant4 modifications to contain polarization transfers within realistic boundaries

Considering:

1) Energy: A **polarized electron beam** comparable to **CEBAF injector** (**5-100 MeV)**
2) Material: Tungsten targets (high Z: **74**, high melting point: **3400°C**)
3) Thickess: Different target thicknesses

Studying the positron parameters that are essential for physics experiments:

1) Yield ε (ppm; per 10^6 electrons)
2) Longitudinal Polarization $\mathbf{S_3}$ (normalized by the electron polarization)
3) Figure of Merit **FoM**
4) Momentum of positrons $\mathbf{p_{positrons}}$

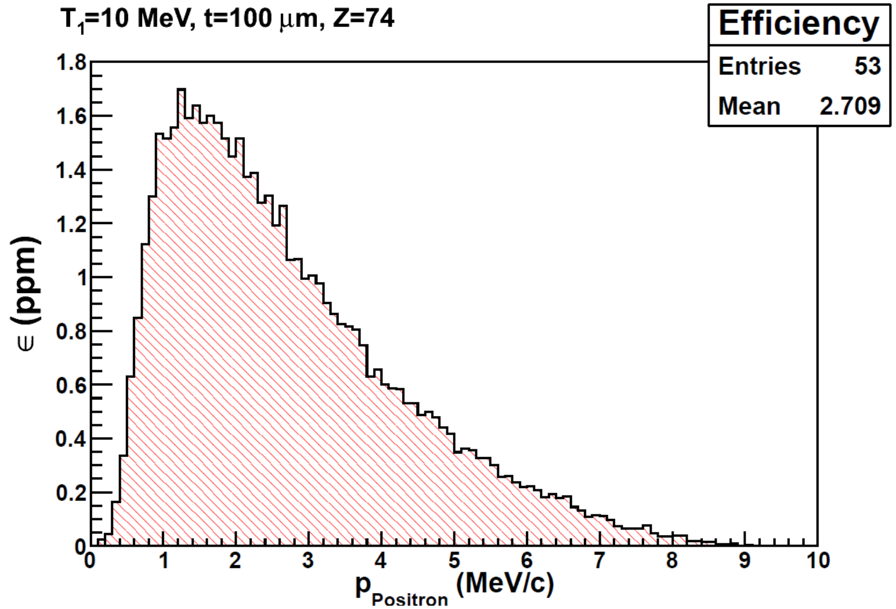
Example with an electron beam 10 MeV, t=100 μm, Z=74

Source Optimization Parameters

The positron yield is a **convolution** of the **bremsstrahlung** and **pair creation** cross sections.

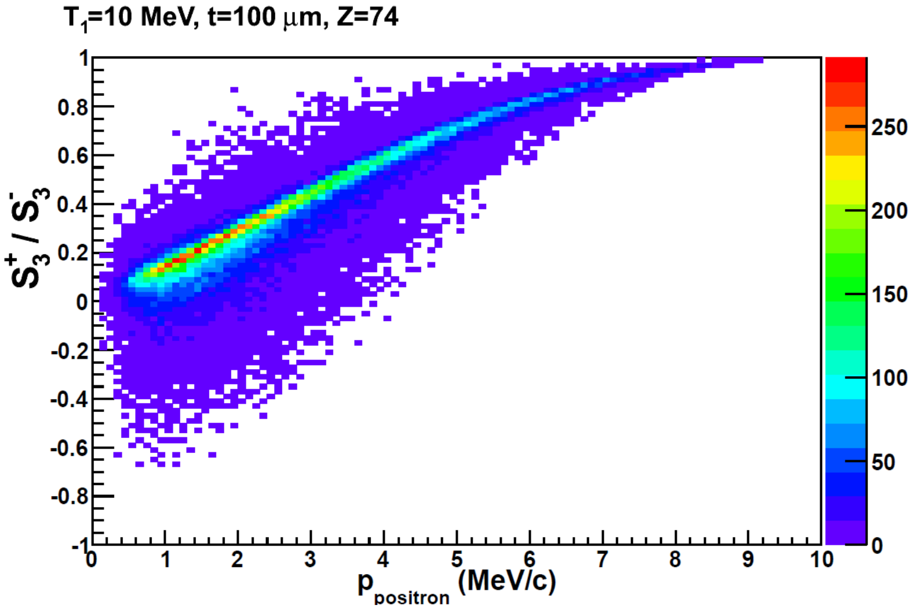
The polarization is calculated for positrons in terms of the Stokes parameters

Positron efficiency



More positrons produced at **low momentum**.

Positron polarization



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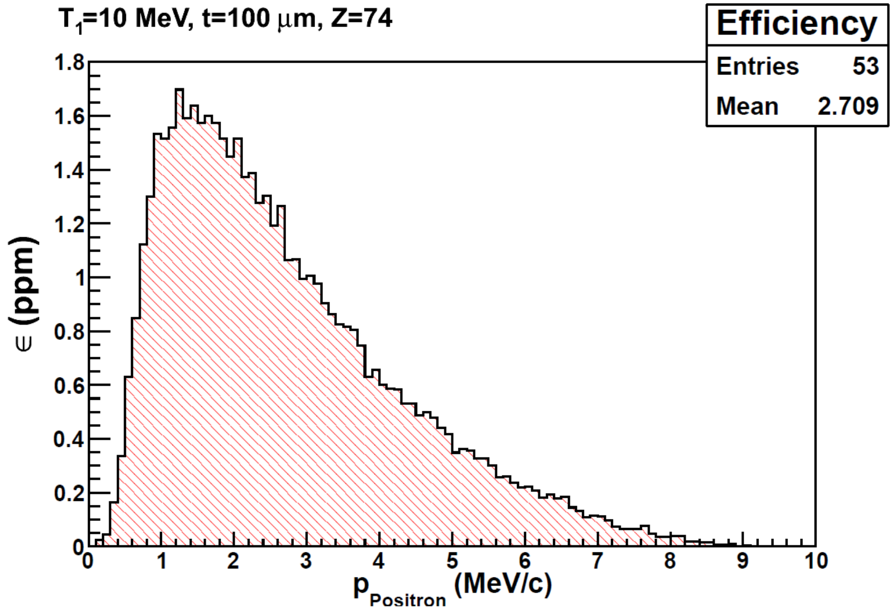
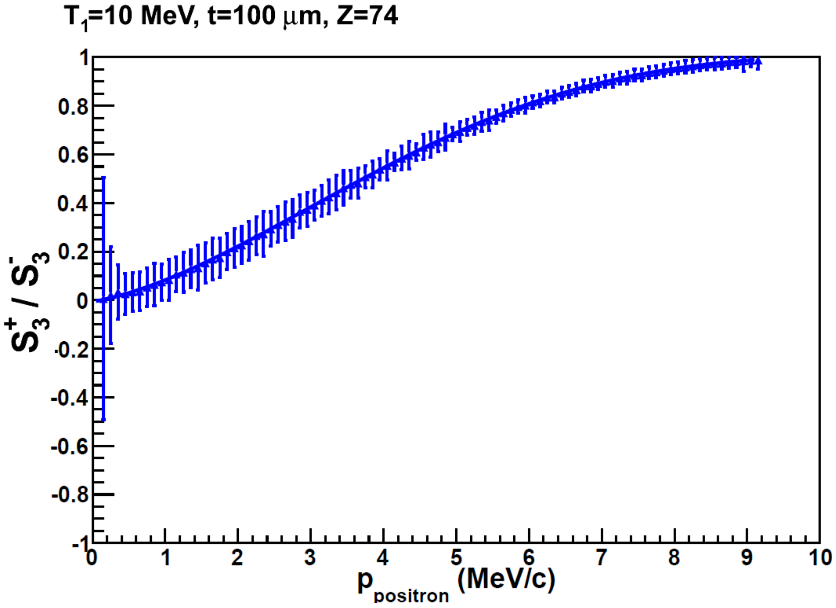


More positrons produced at **low momentum**.

Positron polarization



The polarization of the positron beam is the **mean value** for slices of energies

Source Optimization Parameters

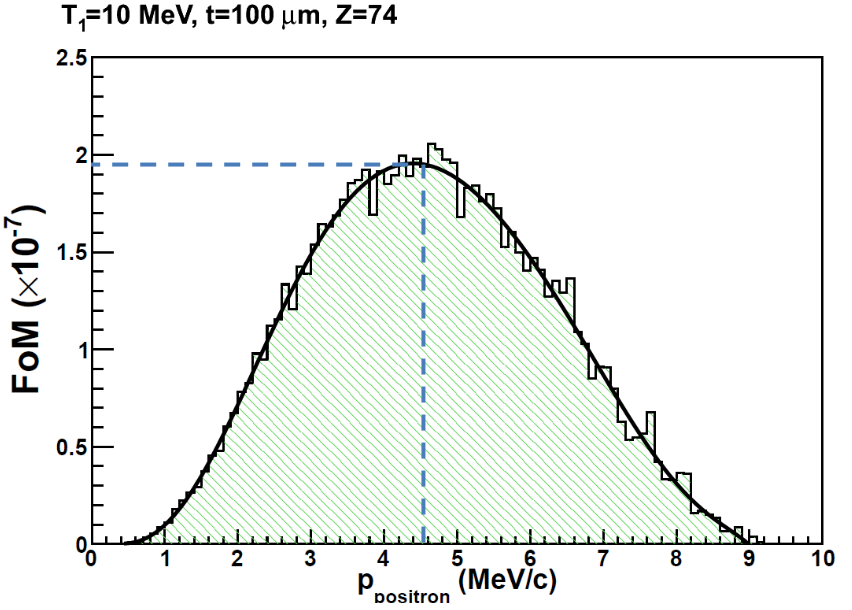
The **precision** of measurements in polarized physics experiments depends on the positron **polarization AND current**.

It can be characterized by the ***figure of merit (FoM)***

$$\frac{d\sigma^{\pm}}{d\Omega} = \frac{d\sigma^{0}}{d\Omega}\left(1 \pm P_e A\right)$$

$$[\delta A]^2 \propto \left[\underbrace{N_e P_e^2}_{\text{FoM}}\right]^{-1}$$

$\boxed{\text{FoM} = \varepsilon \text{ x } P^2}$



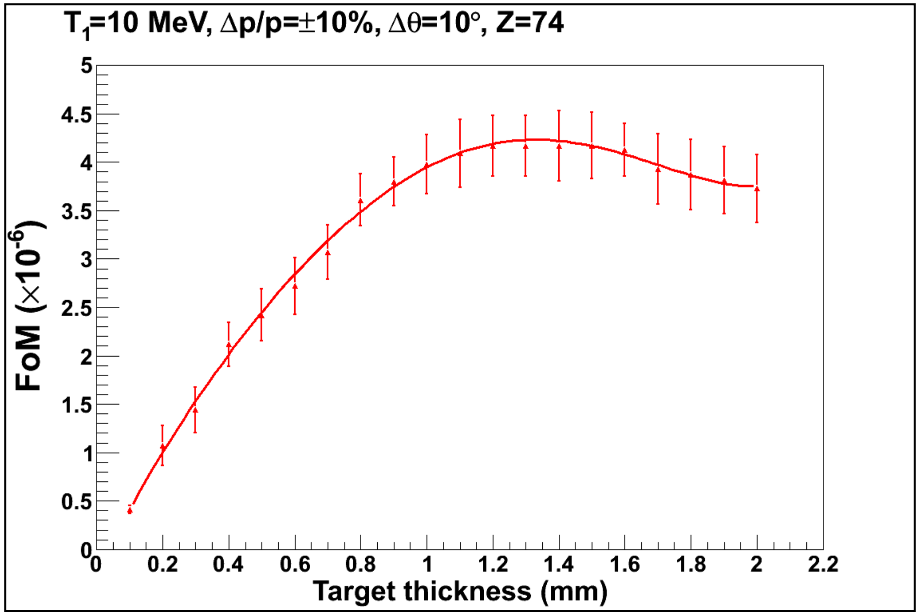
The **momentum** of polarized positrons for which the FoM is <u>maximized</u>, is the 4th parameter of interest in this study.

Target Thickness Optimization

Simplistic **cuts** have been applied to account for the **angular and momentum acceptances** of a possible collection device after the e^+ source.

The acceptances **change values** but do **not** change **the optimization**.

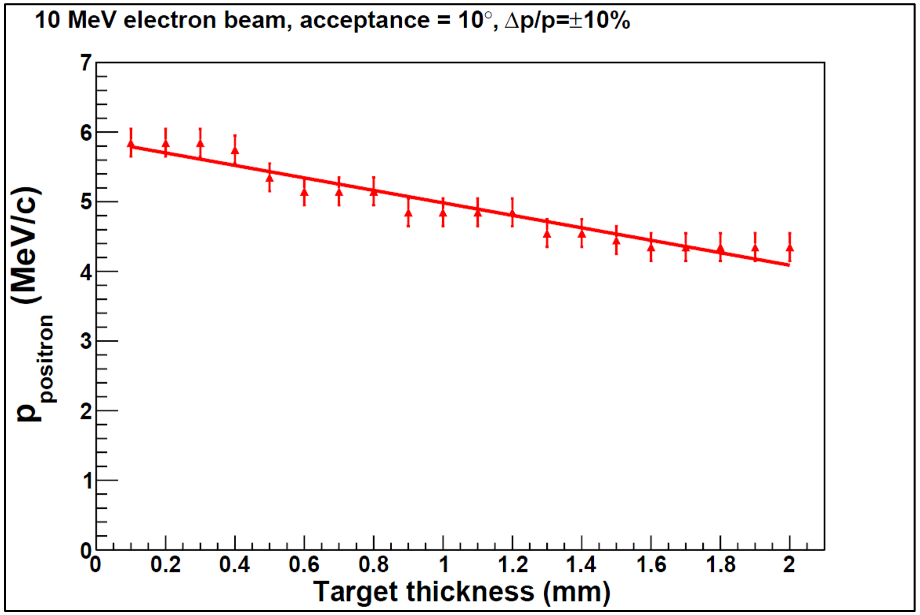
FoM



For a 10 MeV electron beam in a

The FoM is maximized for a **1.3 mm** target

Momentum



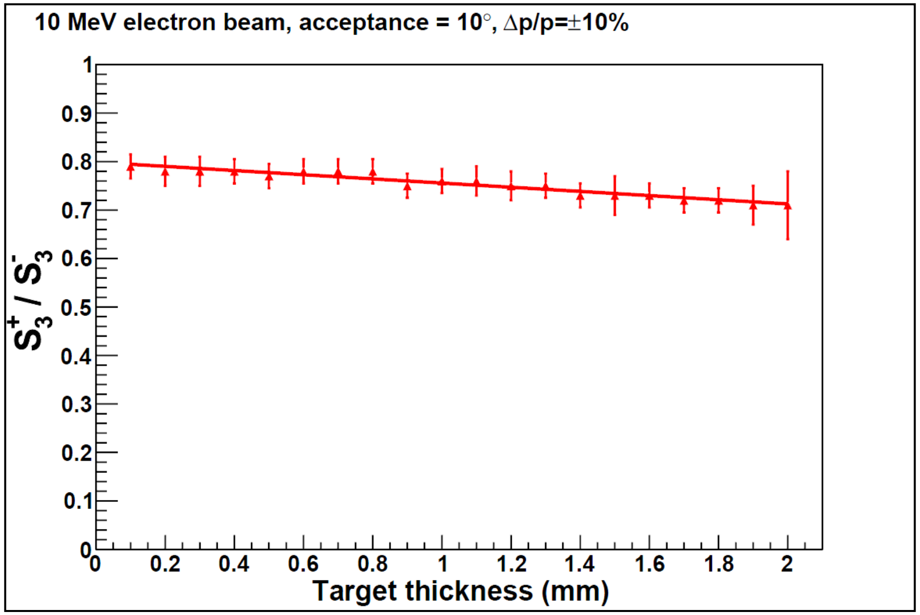
e^+ corresponding to the maximized FoM have a momentum of **4.5 MeV/c**

Target Thickness Optimization

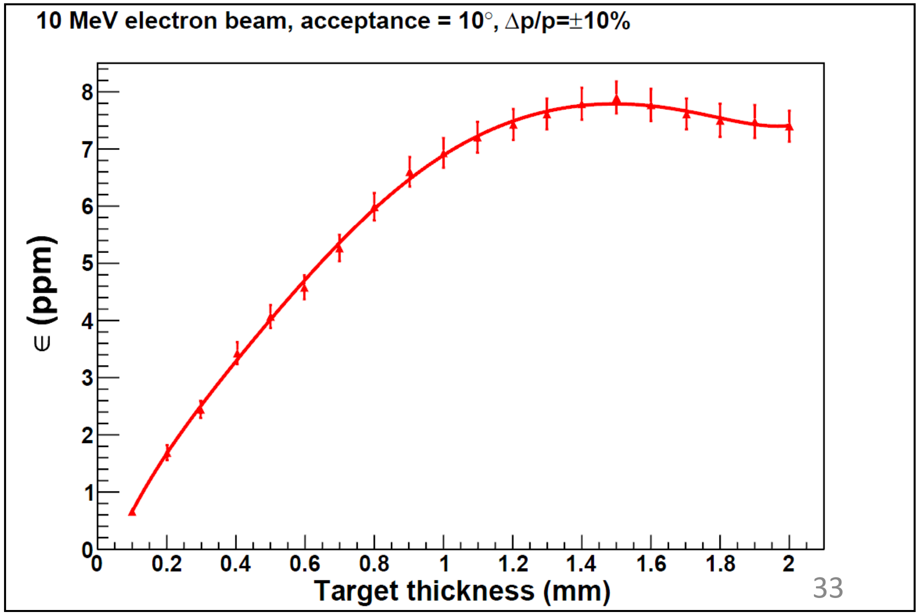
The **polarization** at the maximized FoM is **decreasing** with the target thickness (70-80%)

The **efficiency** reaches an **optimum** as the target has to be **thick** enough to let the EM shower to propagate however it has to be **thin** so that the positrons can escape the target

Polarization

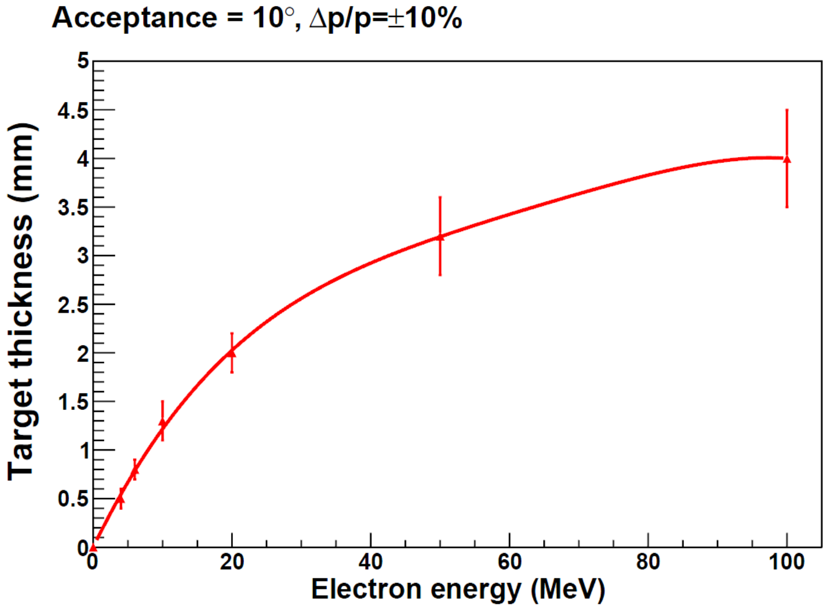


Efficiency



Beam Energy Dependency

The target thickness maximizing the **FoM** can be calculated for **any** electron **energy** available in the injector of CEBAF.



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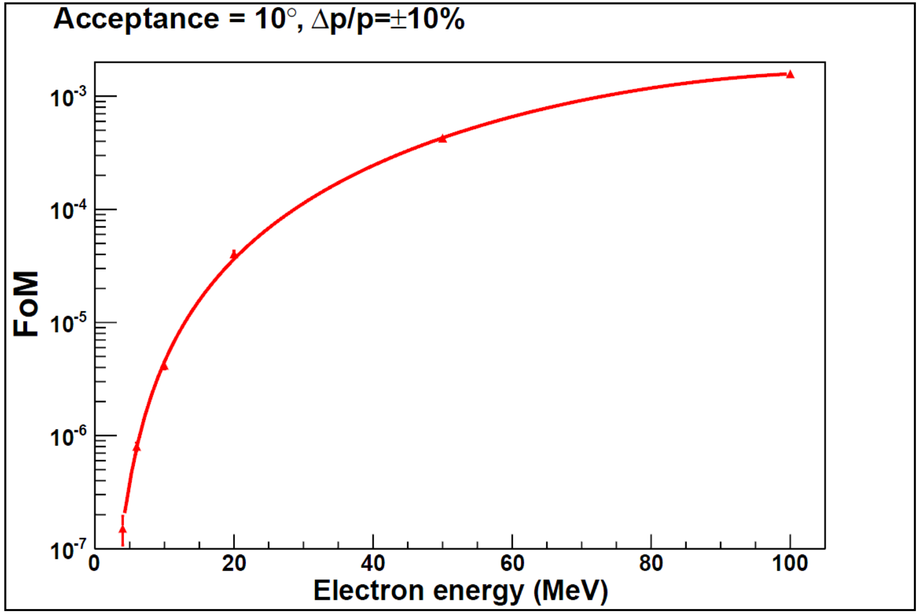
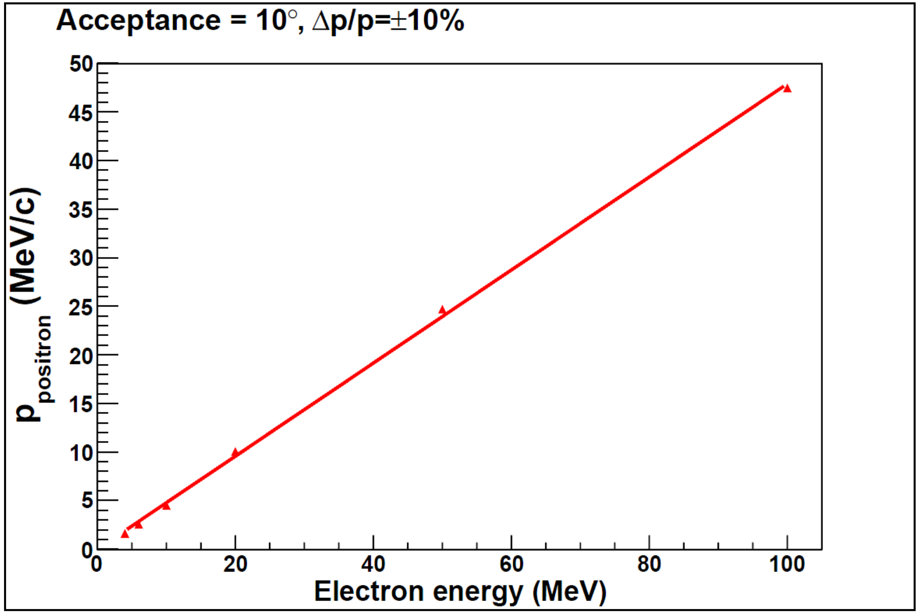
FoM



Momentum



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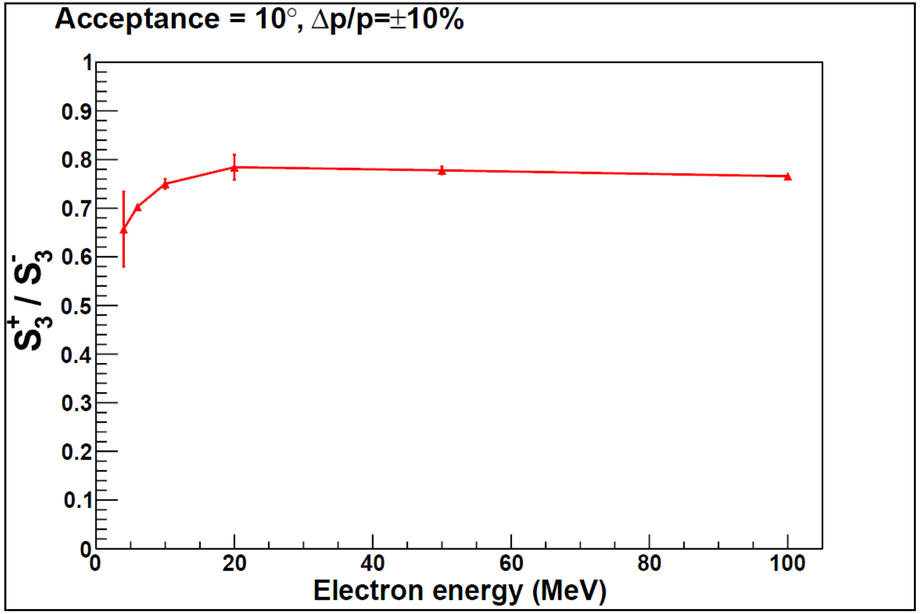
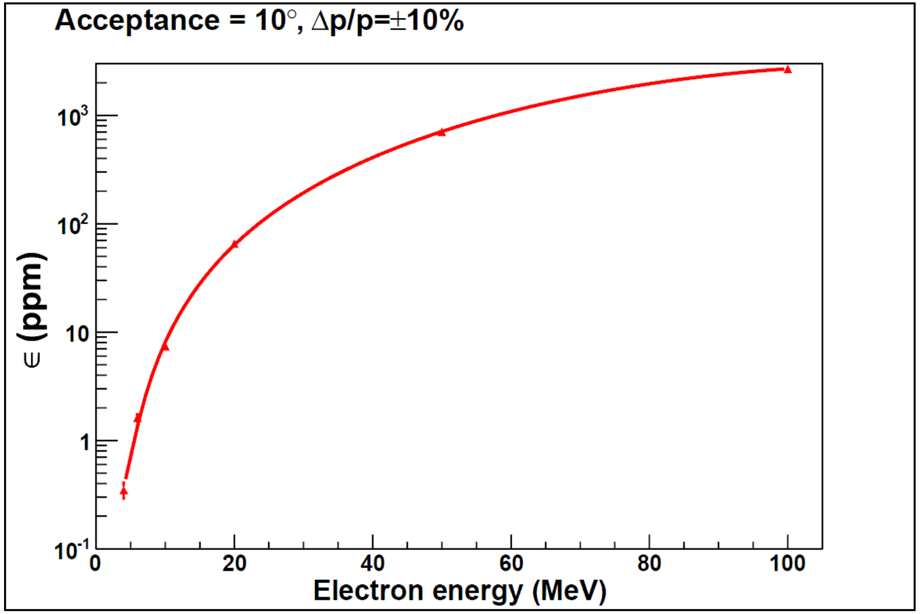


Yield



Conclusion:

Electron beam of 100 MeV, current of 180 μA, polarization of 85%, in a 4 mm W target

Positron beam of 50 MeV, current of 360 nA, polarization of 65%

Plan

1) Why?
  - CEBAF Accelerator
  - Physics motivations (DVCS, Two γ exchange…)

2) How?
  - Positron source polarization
  - Proposed source for CEBAF

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  - **Equipment**
  - **Modifications**
  - **Diagnostics**

6) PEPPo Polarimetry
  - Apparatus
  - Data taking methods
  - Calorimeter test

7) Conclusion

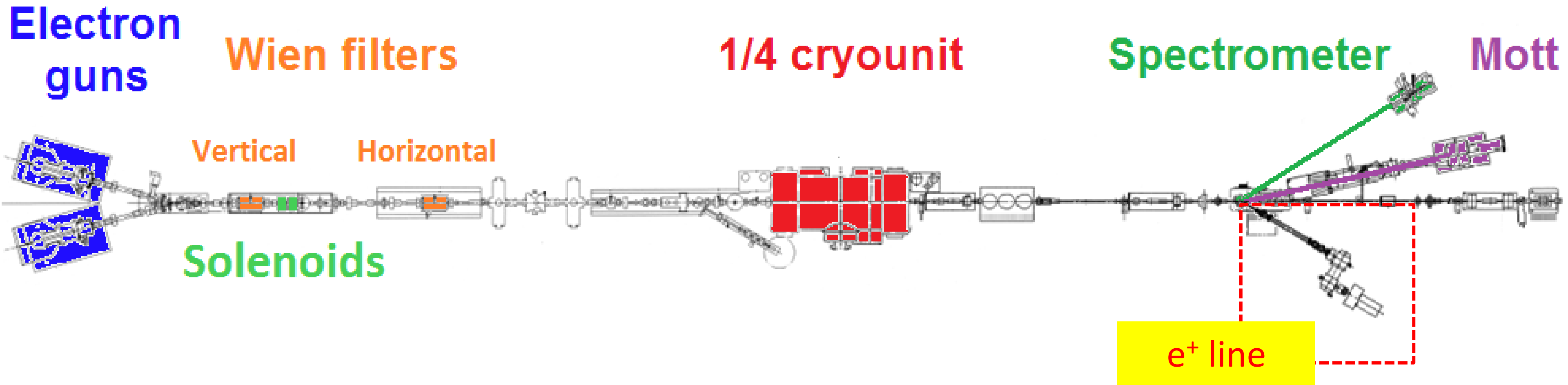
Polarized Electrons for Polarized Positrons

Goal:
Polarization measurement for **demonstration** of principle of $\vec{e}^+$ with $\vec{e}^-$ in a single target.

Electron beam in the injector
Current: 180 μA
Max. kinetic energy: 8 MeV
Polarization: 85%

Advantages:

- ✓ Mott Polarimeter ($\Delta P/P<2\%$)
- ✓ e^- spectrometer ($\Delta p/p<1\%$)
- ✓ Adjustable e^- energy (2-8 MeV)
- ✓ e^- for calibration of e^+ line
- ✓ Same e^+ energy range as E166 experiment $\longrightarrow$ expertise & equipment for e^+ line



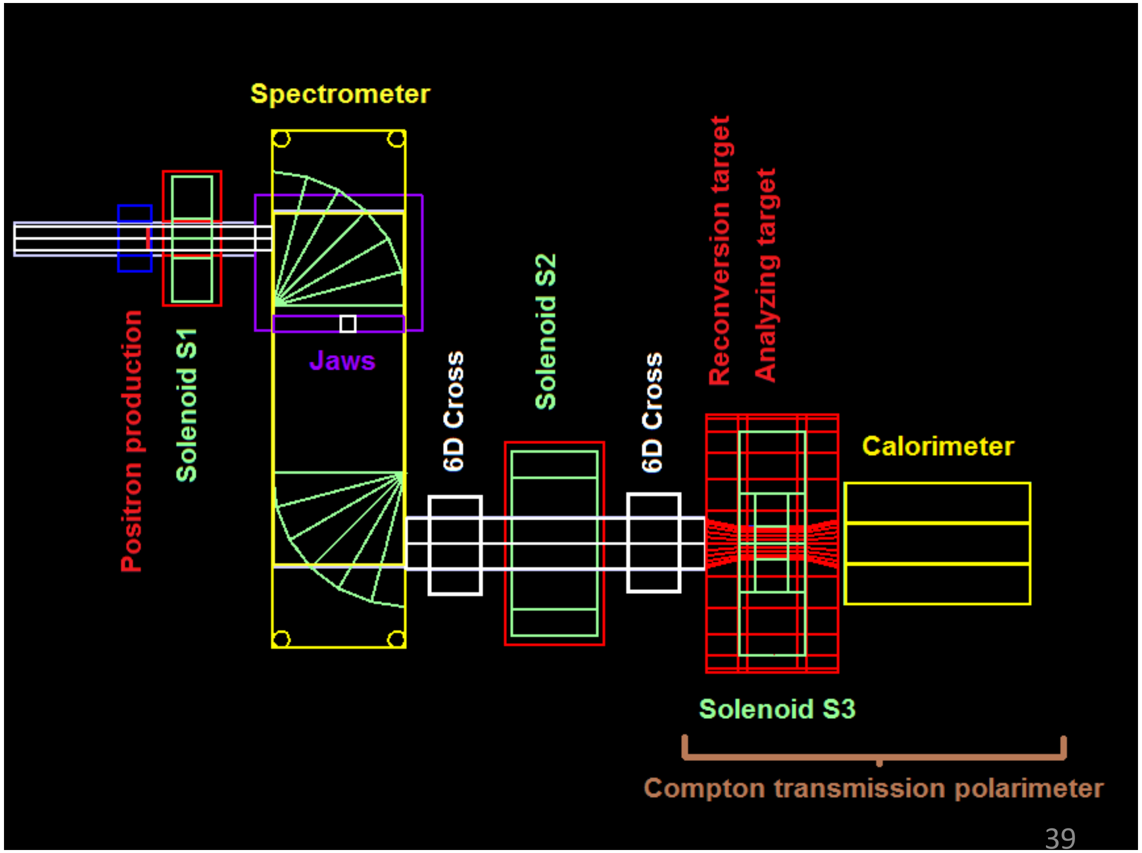
PEPPo Line

Based on E166 positron line, but with modifications at every step

Borrowed critical elements used by the E166 collaboration

Geant4 simulation for tracking through the new beamline

1) Production target
2) Collection solenoid
3) 2 dipole spectrometer-jaws
4) New implemented line for optical analysis.
5) Compton transmission polarimeter

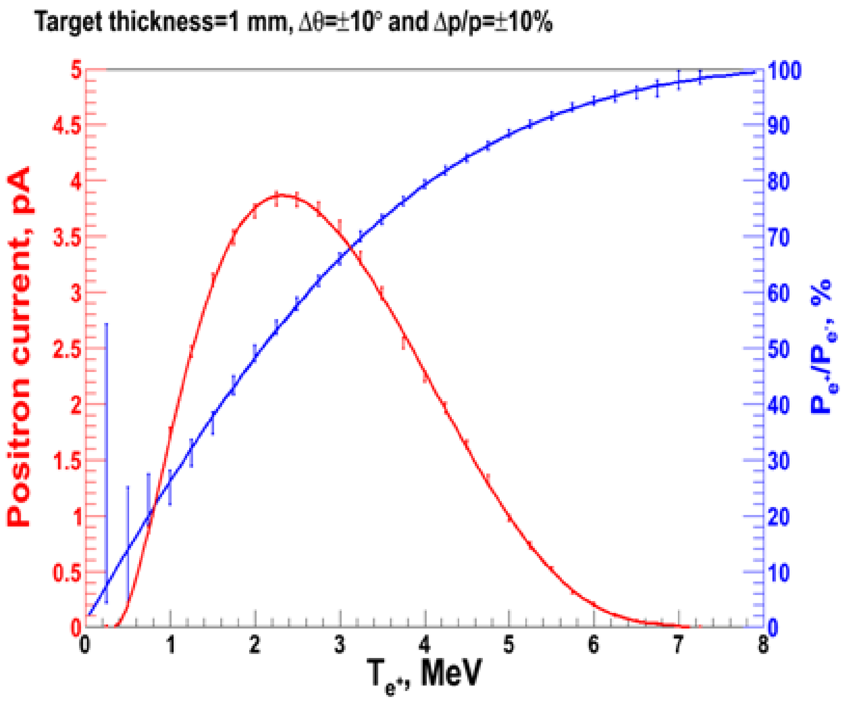


Positron Production

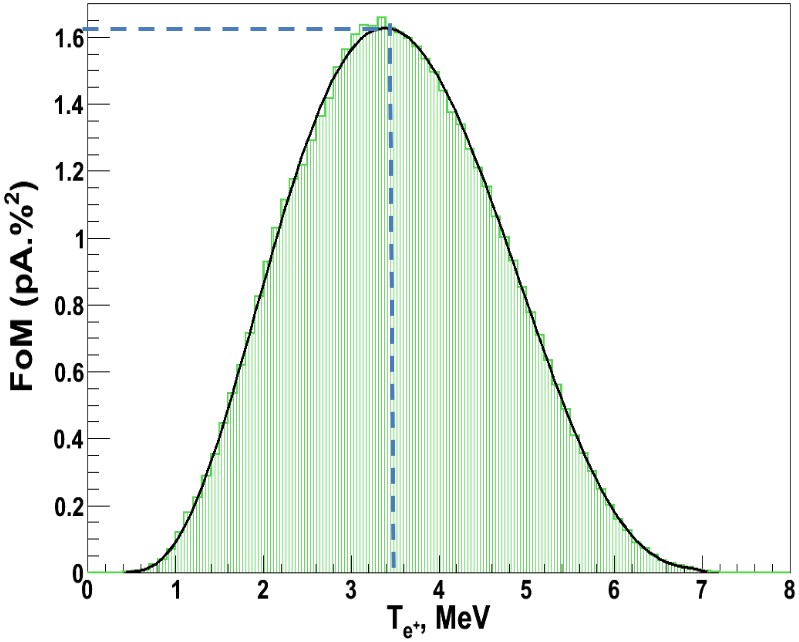
e$^-$ beam:
1 μA, P=85%, 8 MeV

Tungsten target:
1 mm as advised

Experiment: measurement of polarization as a function of the positron energy



FoM suggests that the measurement is more convenient for energies between **2 and 5 MeV**



E166 Spectrometer

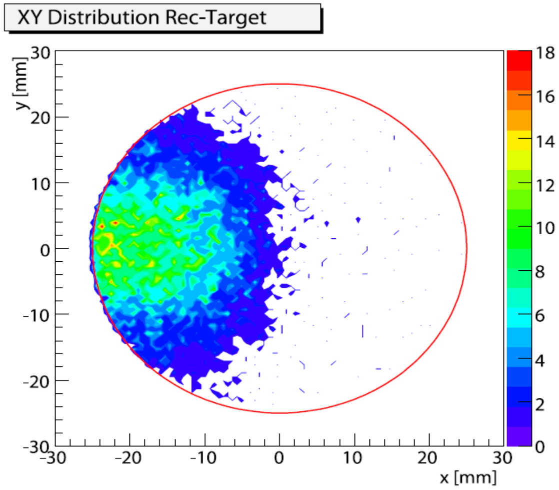
E166: Illustration of positron tracking in the spectrometer

Particles are **lost** in beam pipe at the exit of the spectrometer

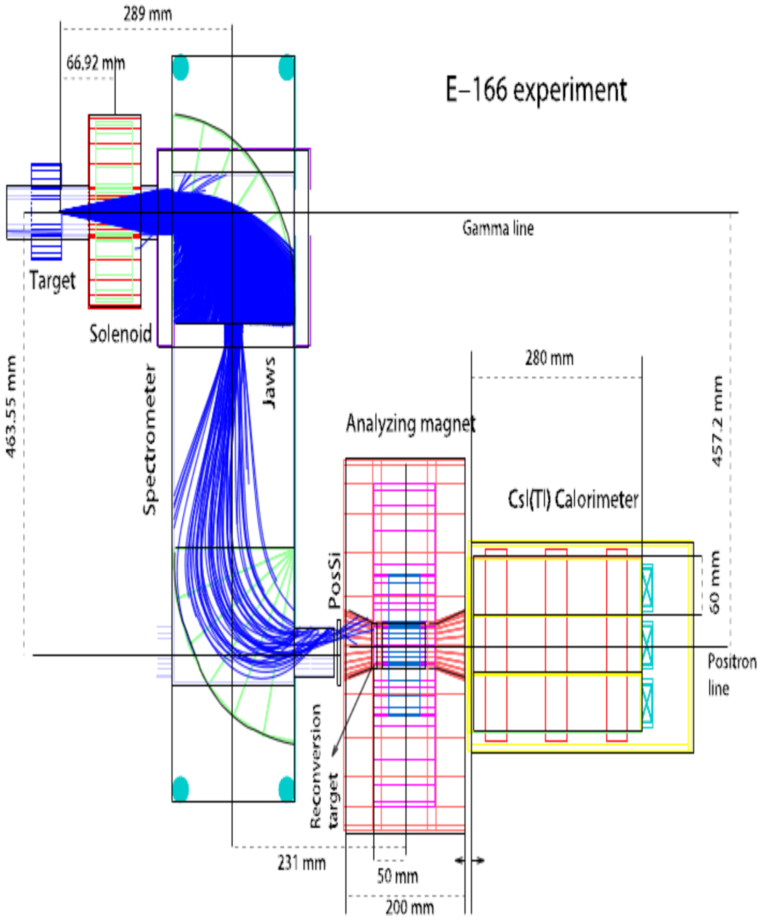
Possible explanation proposed:

- Unknown permeability of tungsten alloy in dipoles (**removed for PEPPo**)
- Wrong position of exit aperture

(**corrected now and with larger aperture**)



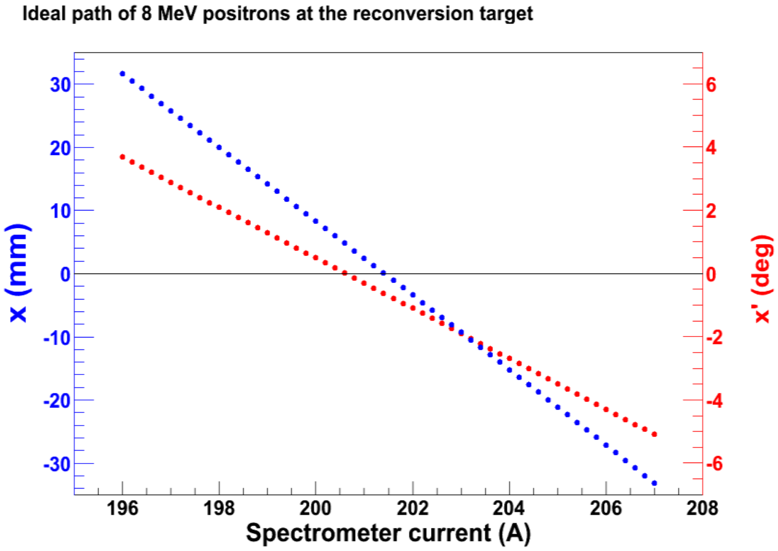
K. Laihem, Thesis



K. Laihem, Thesis

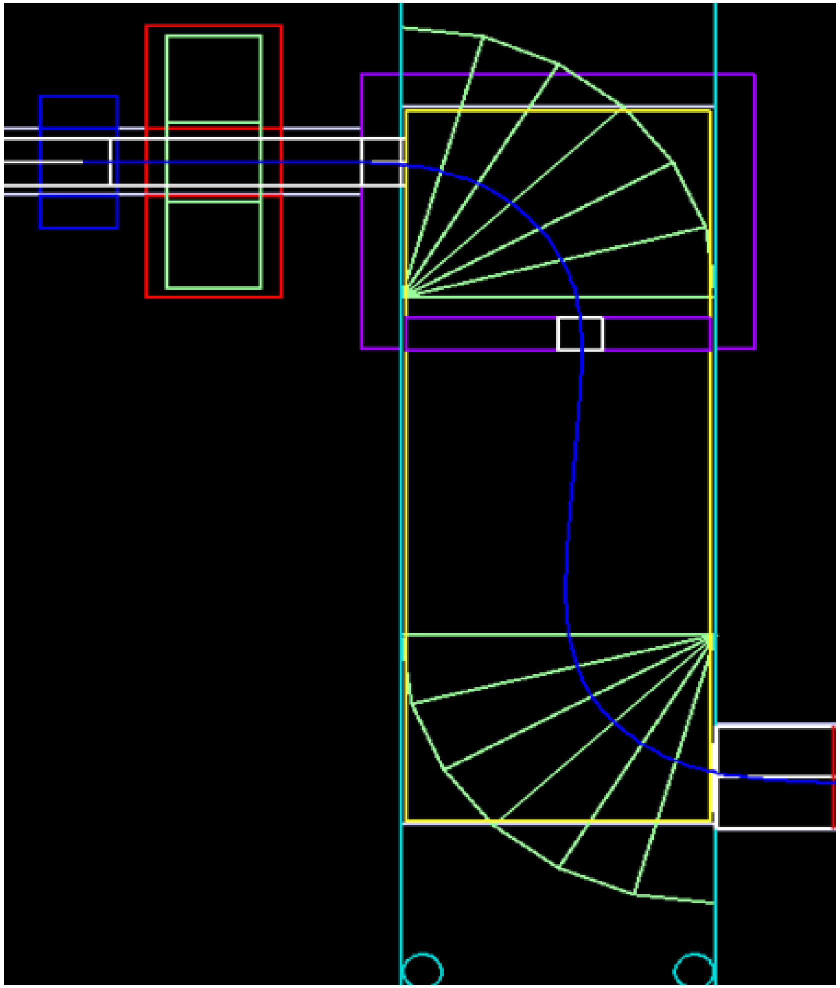
Spectrometer

For an **ideal** electron beam going through the spectrometer and exiting with the same angle as it is coming in.



At the location of the jaws, the beam is **not centered** on the vacuum chamber.

Jaws **not centered**



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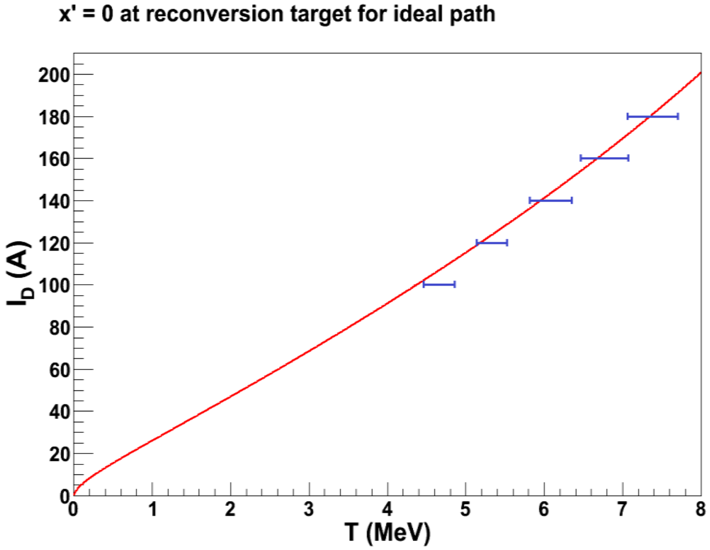

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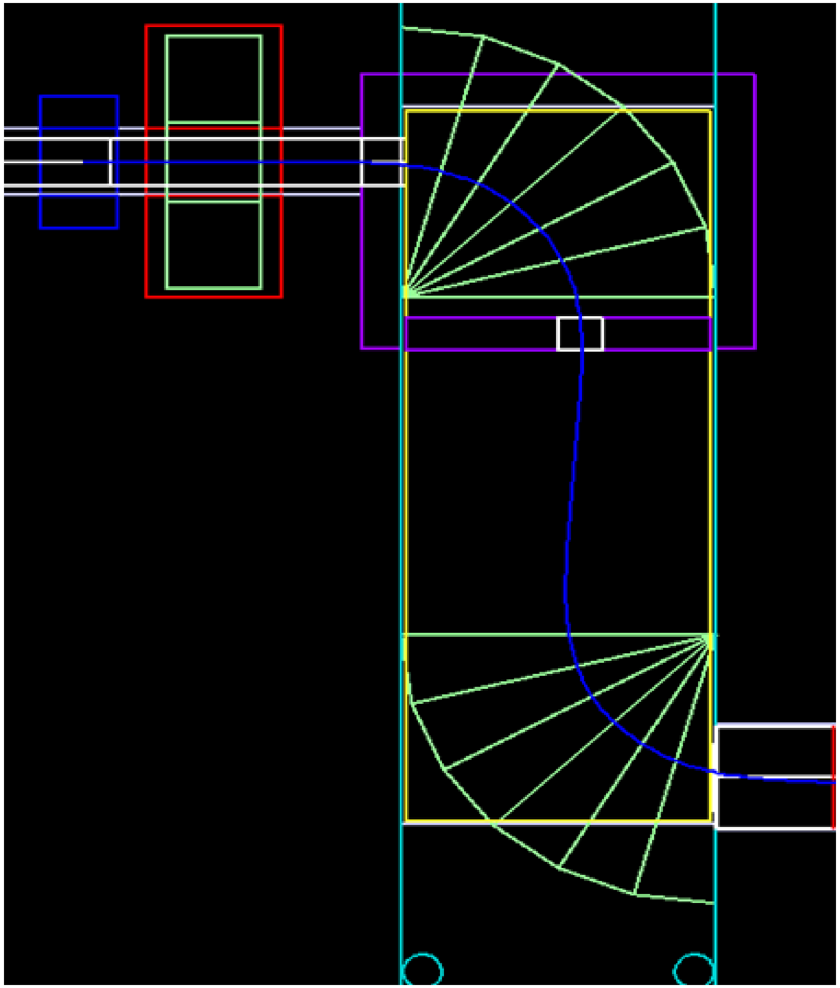

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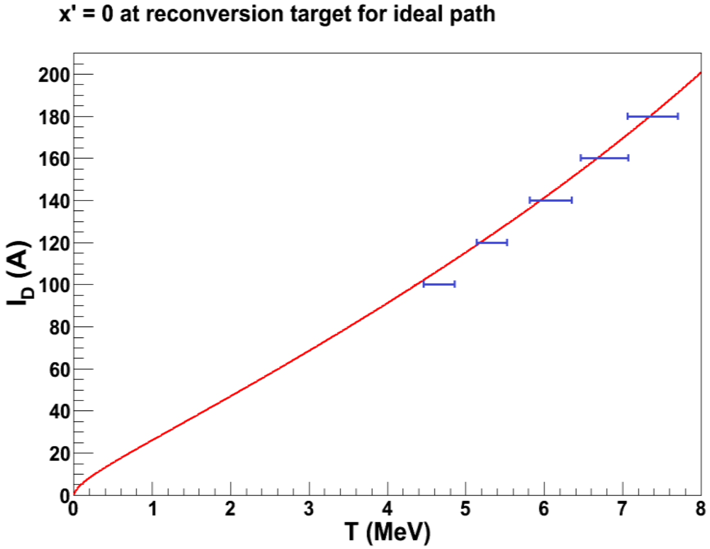

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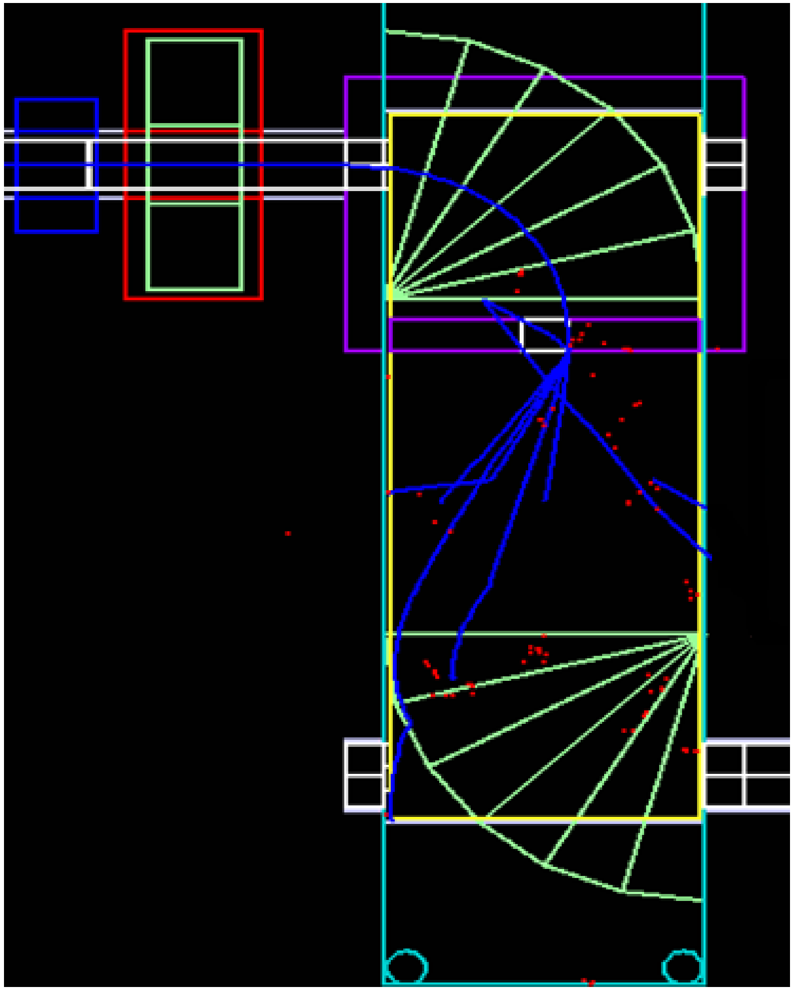

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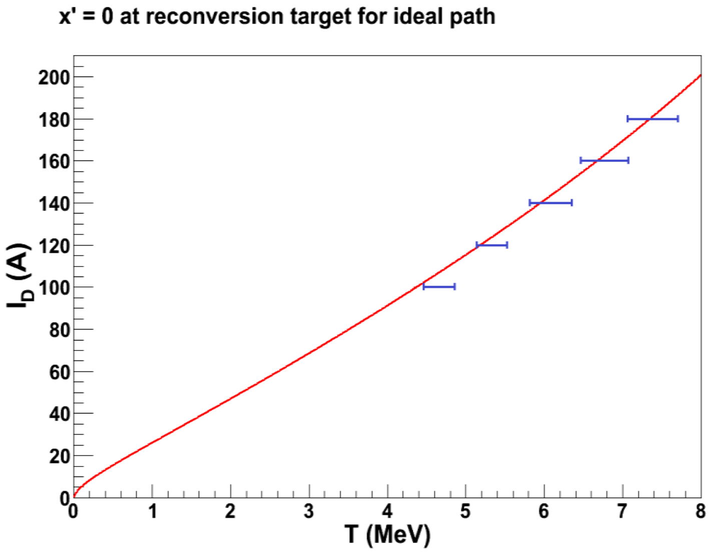
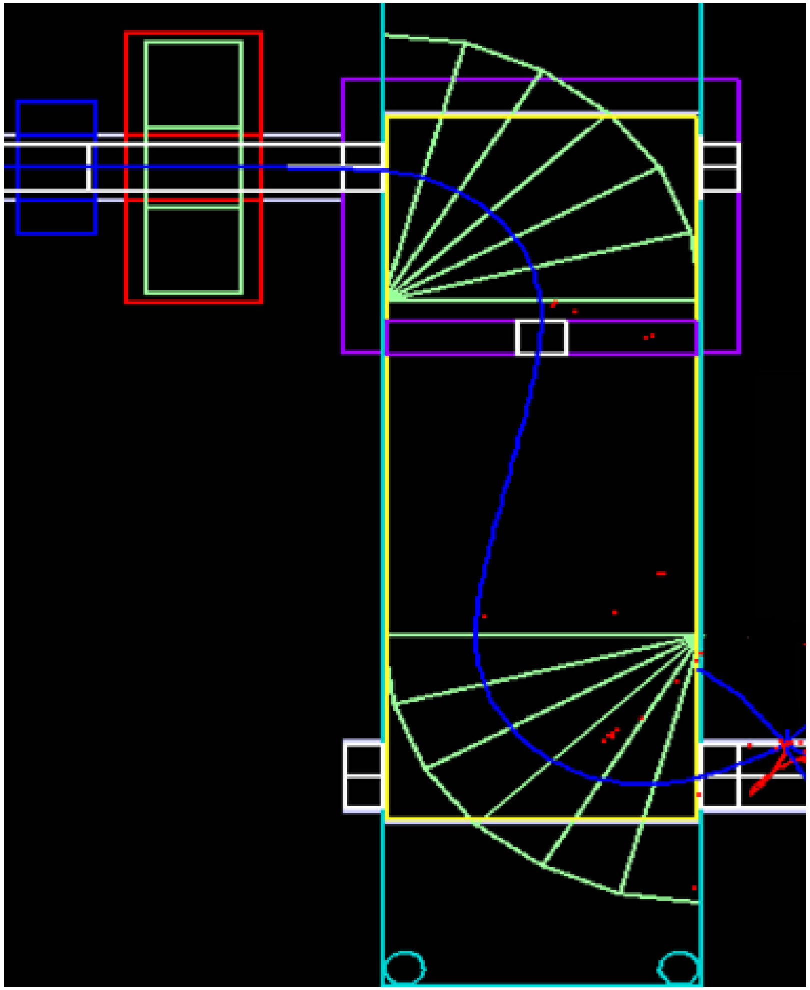


Jaws **centered**



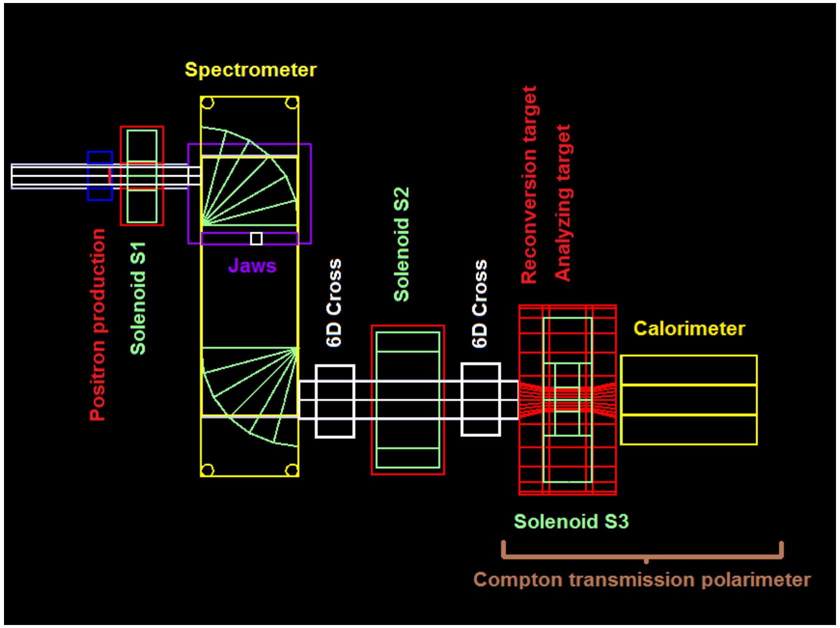
At the location of the jaws, the beam is **not centered** on the vacuum chamber.

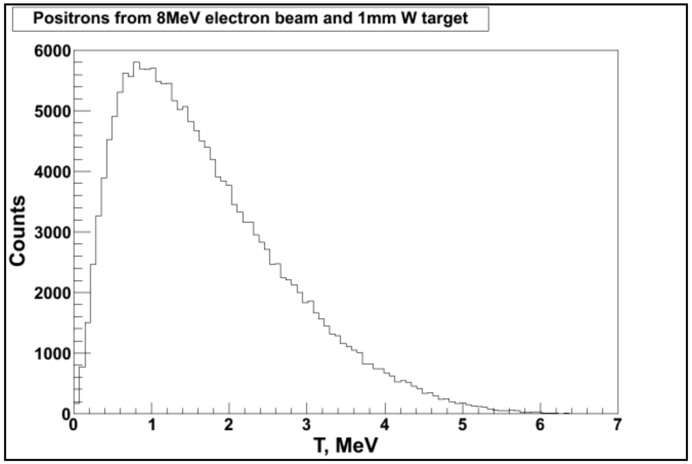
Need **independent** motion of the jaws ⟶ Not possible for E166 ⟶ **Modifications**

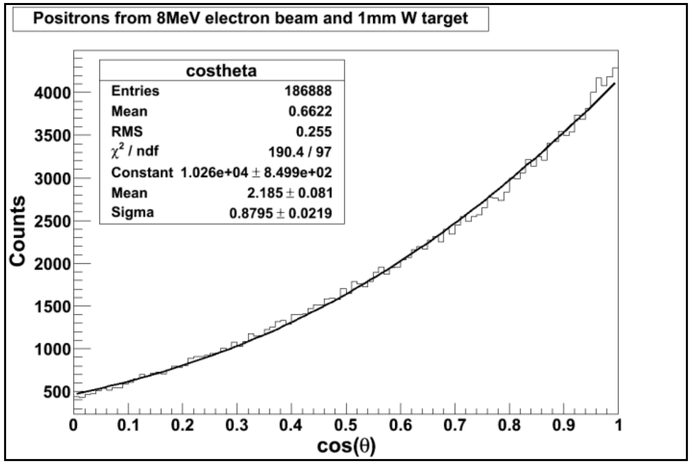
Transmission

Rule of thumb: 1 e^+ for 10^4 e^-

Realistic distribution of positrons from a 8 MeV electron impinging a 1 mm W target







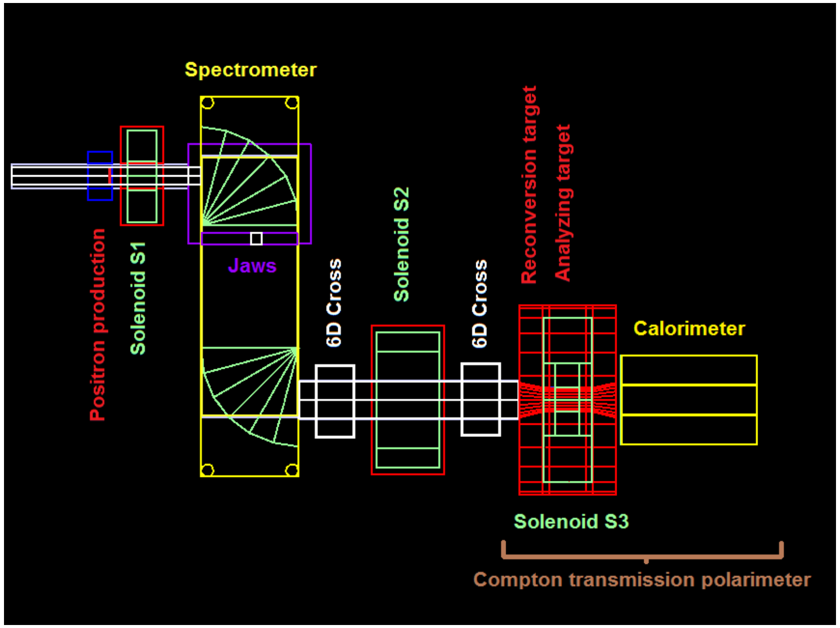
For S1 optimization of the **transmission** to the polarimeter:

Transmission = # positrons at the Polarimeter / # positrons produced at the W target

S1 Solenoid Optimization

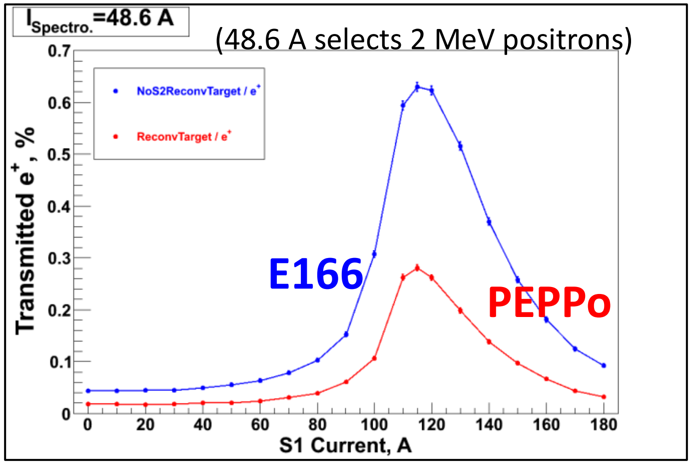
Optimization of the **transmission** for a given spectrometer current

Polarimeter position for **E166** or **PEPPo**

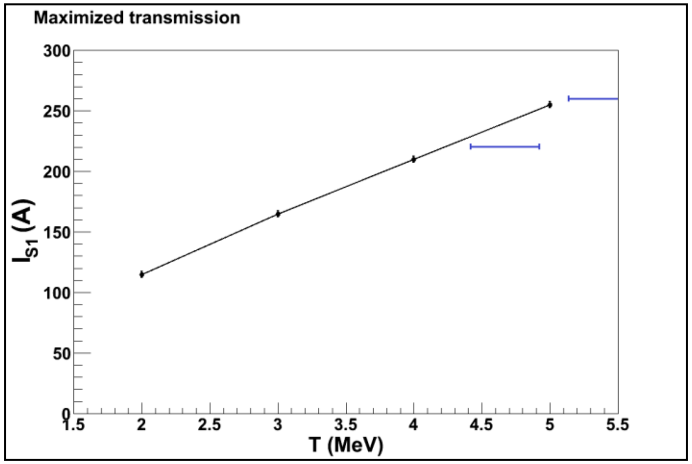


The solenoid S1 current for any selection positron energy (**110 A- 250 A**)

S2 is turned off

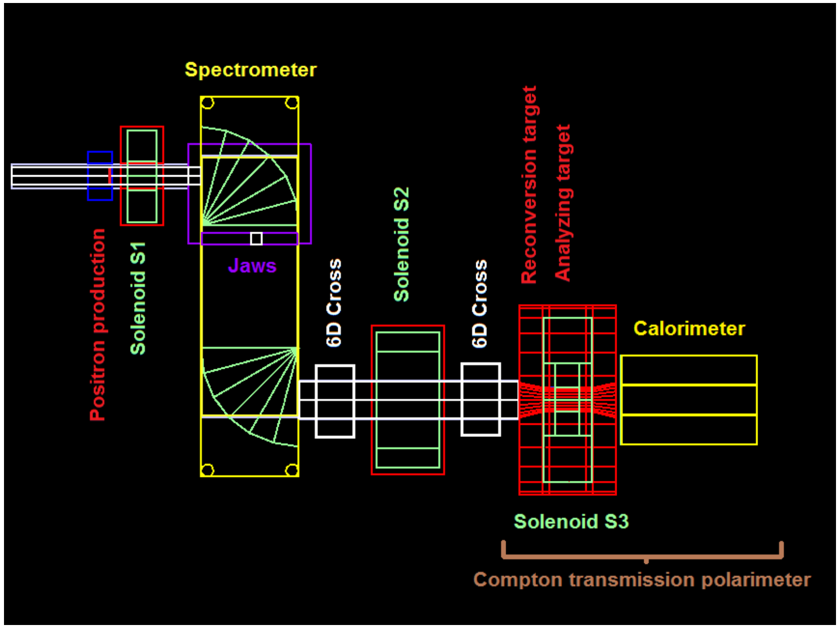


(48.6 A selects 2 MeV positrons)



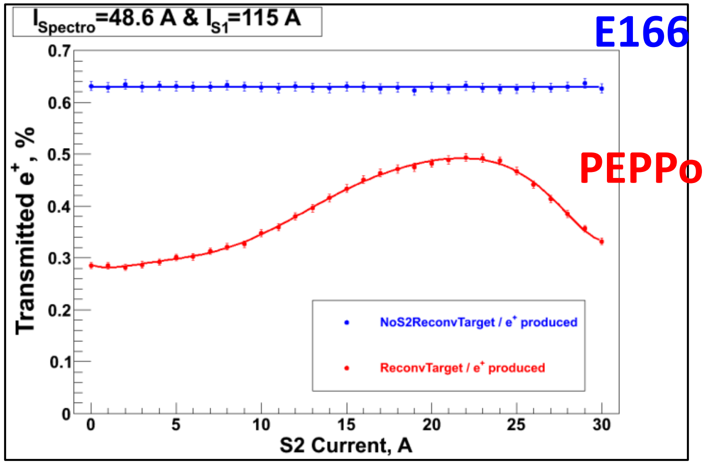
S2 Solenoid Optimization

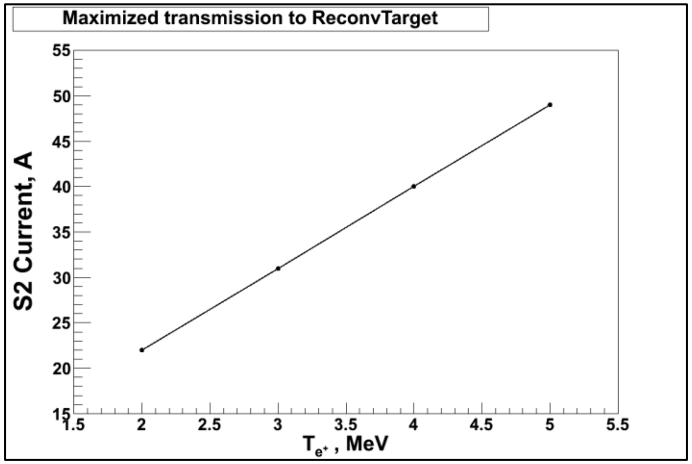
Poisson calculations on basis of a mechanical design of a **Jlab solenoid** for **S2**. Implemented in Geant4



The current needed for the second solenoid (22 A -50 A)

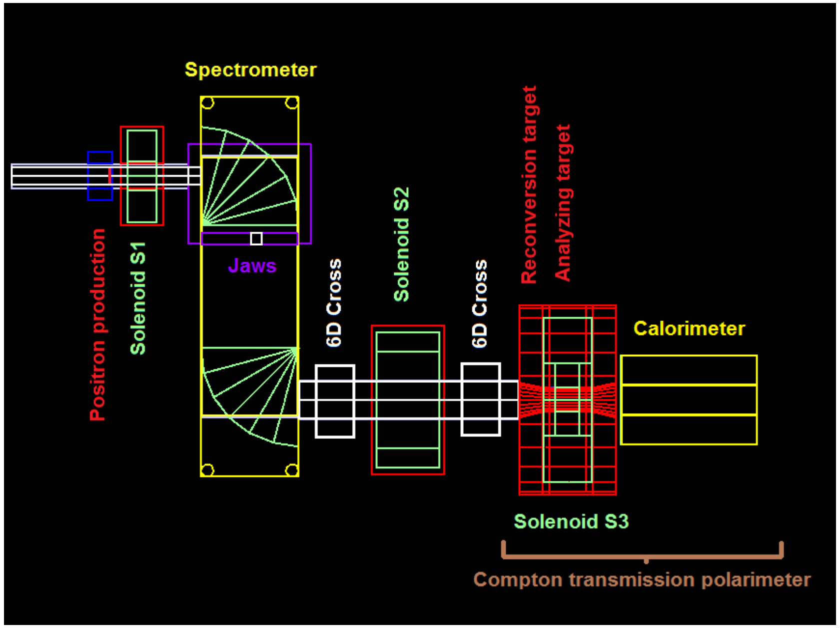
For S1 optimized

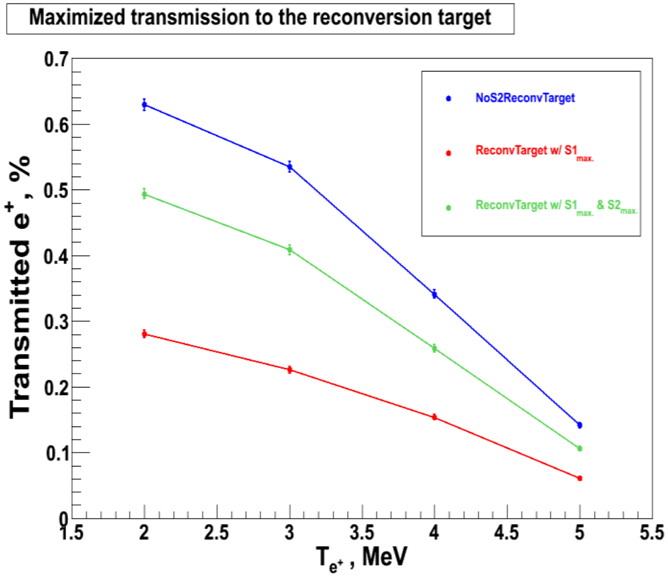




Transmission Rates

Transmission rates for any positron energy (**0.15 – 0.5 %**) from production to the polarimeter.





E166 PEPPo with S1 PEPPo with S1 & S2

The addition of the second solenoid is useful for beam control

The positron **production**: **1 e^+ for 10^4 e^-**

Transmission: pA of e^+/ μA of e^-

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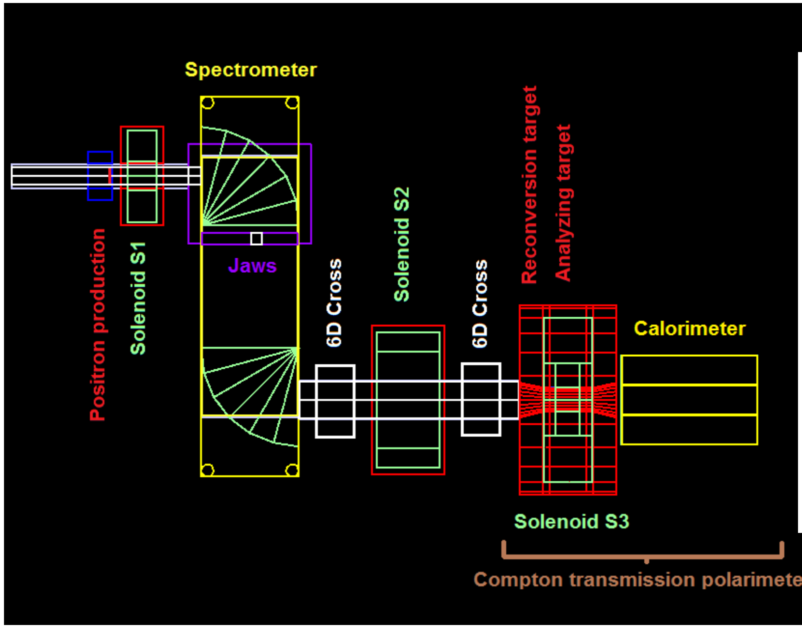
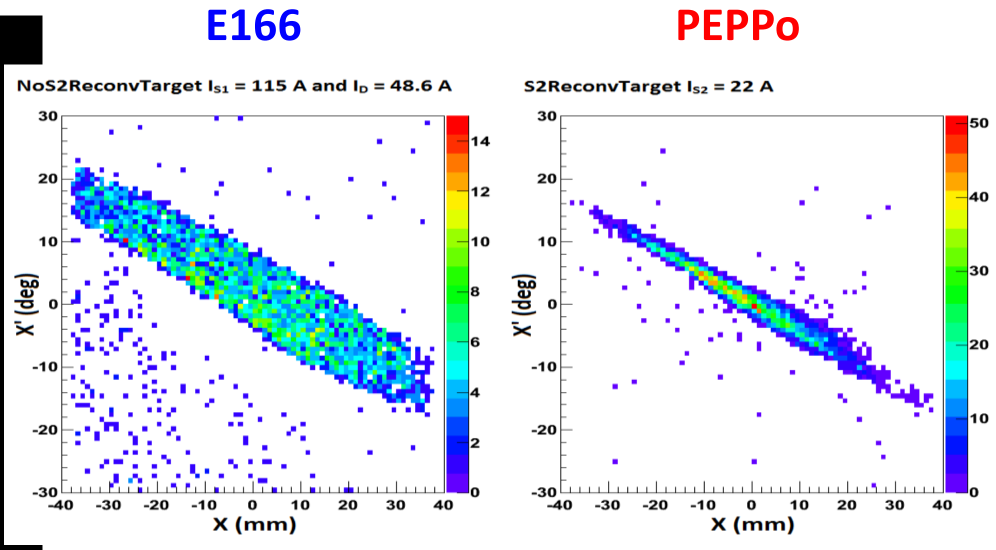
Transmission rates for any positron energy (**0.15 – 0.5 %**) from production to the polarimeter.




E166

PEPPo

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    - **Apparatus**
    - **Data taking methods**
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7) Conclusion

Polarimetry

Compton Transmission polarimeter

used for E166, loan for PEPPo

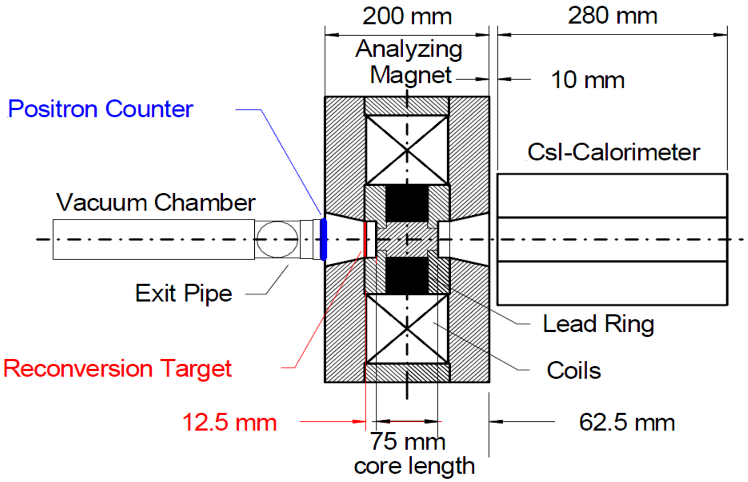
Reconversion target ($\vec{e}^{+} \longrightarrow \vec{\gamma}$)

The **asymmetry** δ of **the photon transmission** through an analyzing target (P_t), when **flipping e$^+$ helicity**, gives the positron polarization

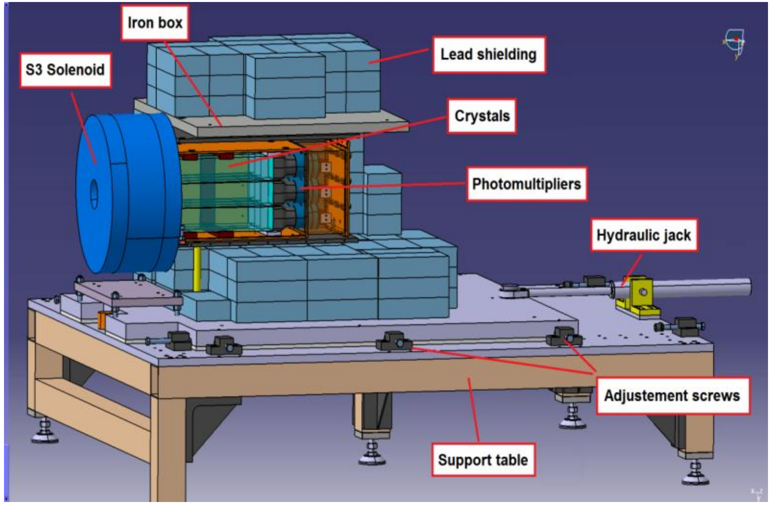
$$P_e = \frac{\delta}{P_t . A_e}$$

A_e is the analyzing power determined by **simulation** or **cross calibration** of electron polarization with **Mott electron polarimeter**

G. Alexander et al, PRL 100 (2008) 210801



M. Marton J.F. Muraz



Signal Integration

Two data taking methods for PEPPo

For +/- helicty states, asymmetry can be measured

Integrated Method

Integration over all the photon energy deposited in the crystals

$$A_T = \frac{E^+ - E^-}{E^+ + E^-}$$

Discretized Method

Integration over **discretized energy bins j** in the crystals

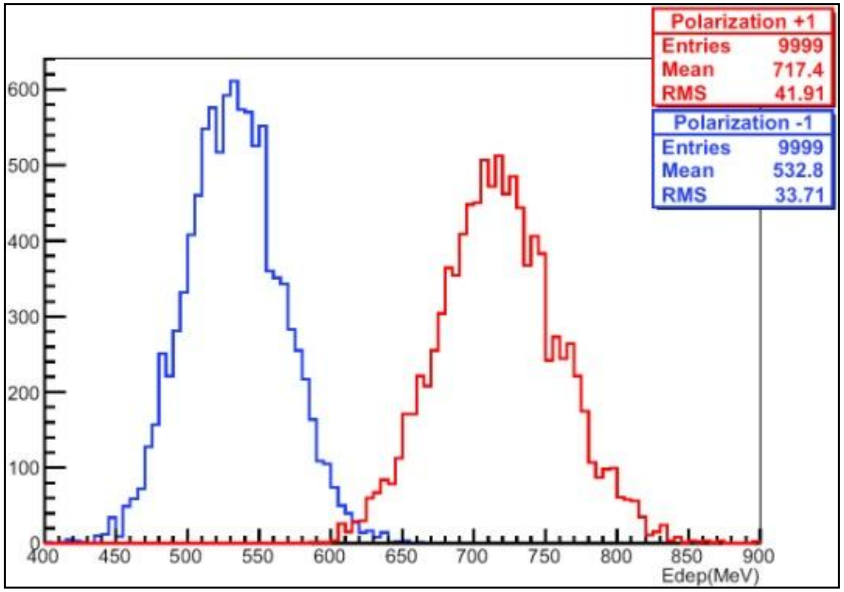
$$A_T^j = \frac{N_j^+ - N_j^-}{N_j^+ + N_j^-}$$

Signal Integration

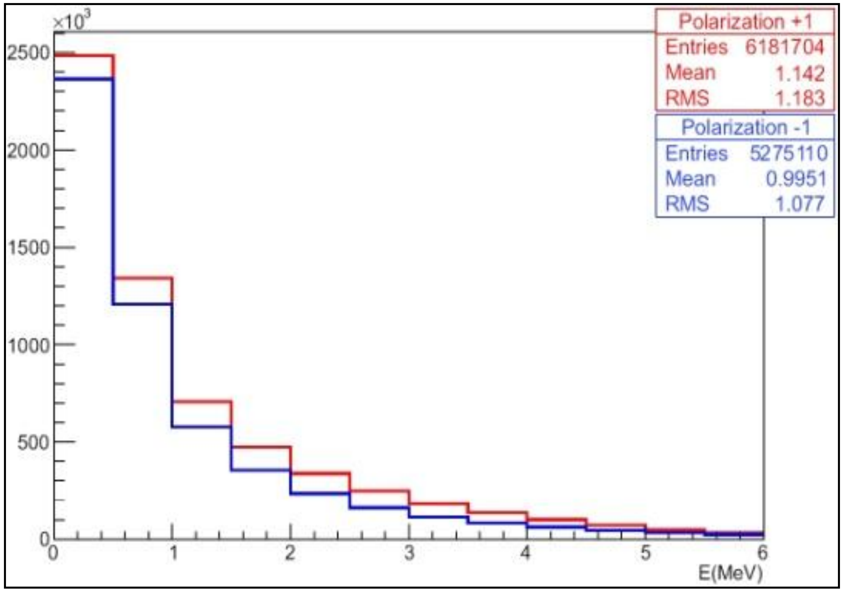
Two data taking methods for PEPPo

5 MeV positrons, polarization of 100% (Pt, Pe)

Integrated Method



Discretized Method



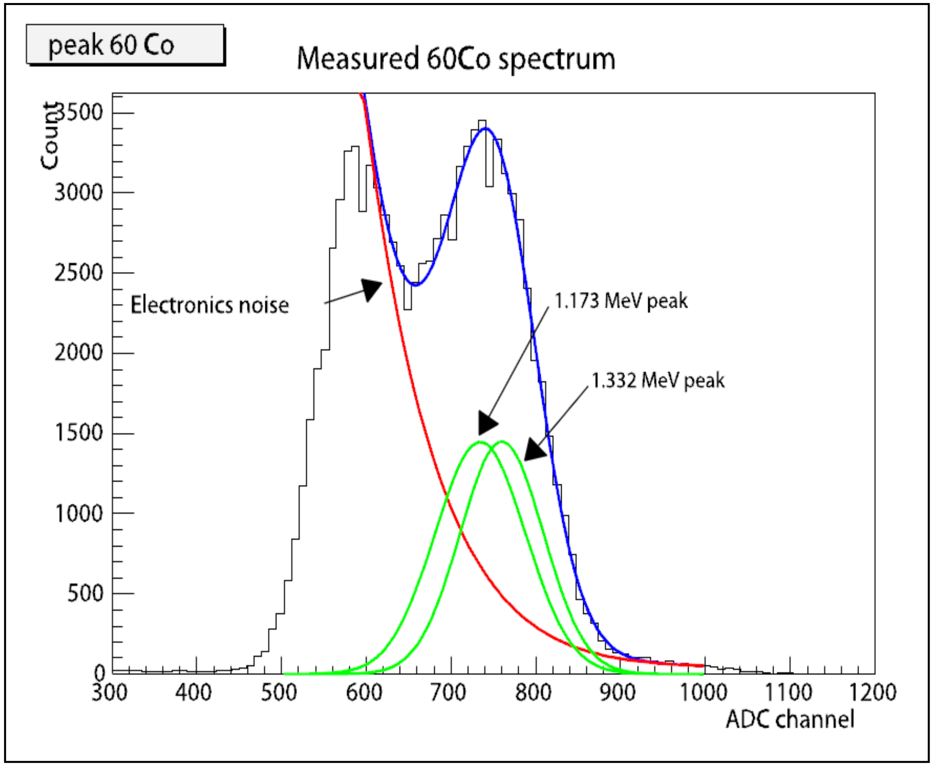
Expected experimental **asymmetries** are small (**1-8x10^{-3}**)
Hours of data taking for a 5% polarization precision

Calorimeter Test

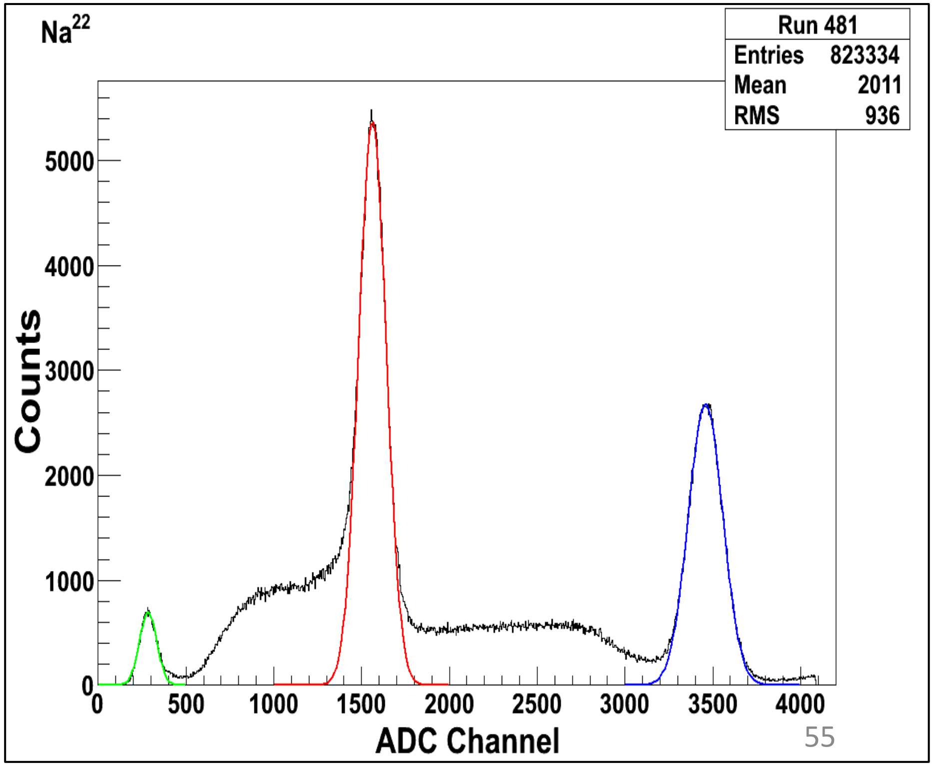
Part of the polarimeter, test with the crystals and DAQ

Modification (LPSC): PMTs instead of **pin diodes** (E166) to reduce electronic noise

Pin Diode



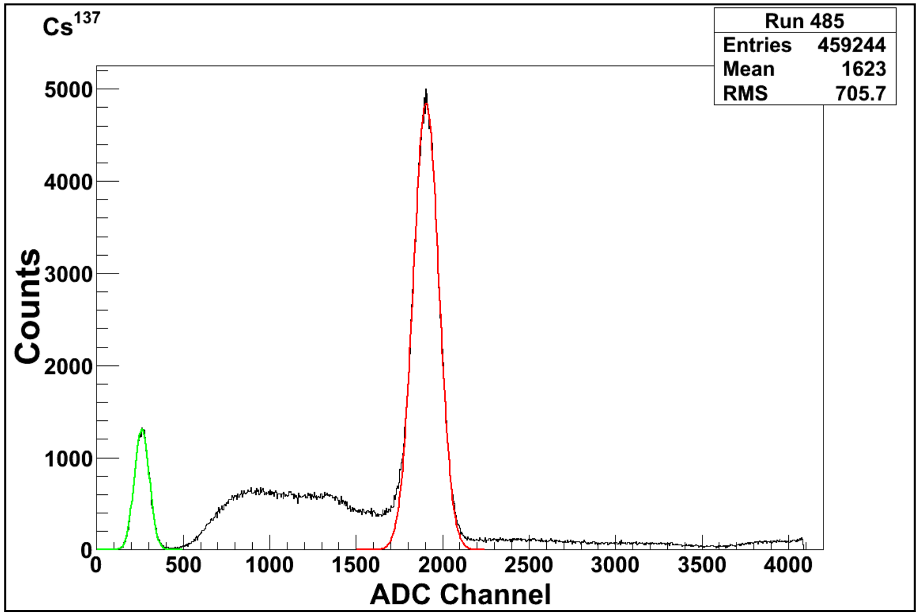
PMT

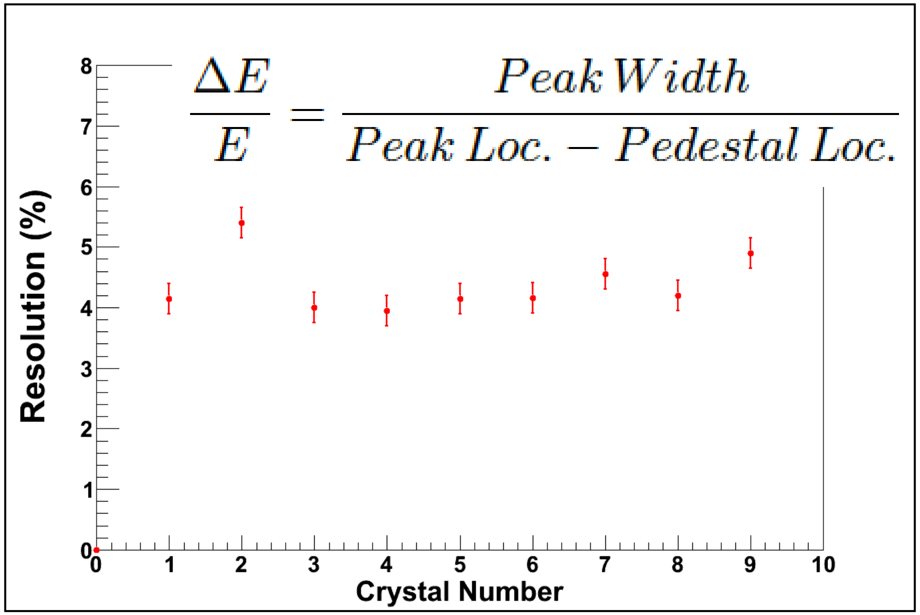


Crystal Resolution

Radioactive source measurements are used for the energy calibration of the PMTs

The difference between the **pedestal** and **signal peak** locations represents quantitatively the analyzed photon energy





All the crystals have a comparable energy resolution (between **3.5%** and **5.5%**)

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  - -Physics motivations (DVCS, Two γ exchange…)

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7) Conclusion

Conclusion

Strong interest in polarized positrons especially at Jlab

Polarized positrons via bremsstrahlung **not yet measured**

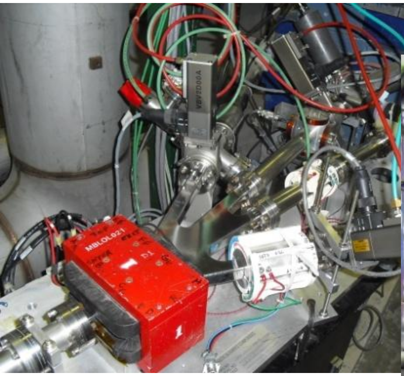
KBST to address OM inadequacies
for polarization transfers even at high energy

First simulations, promising results, **e^+ I=360 nA, P=65%, T=50 MeV**
with **e^- I=180mA, P=85%, T=100 MeV**

Motivating for a **demonstration experiment**

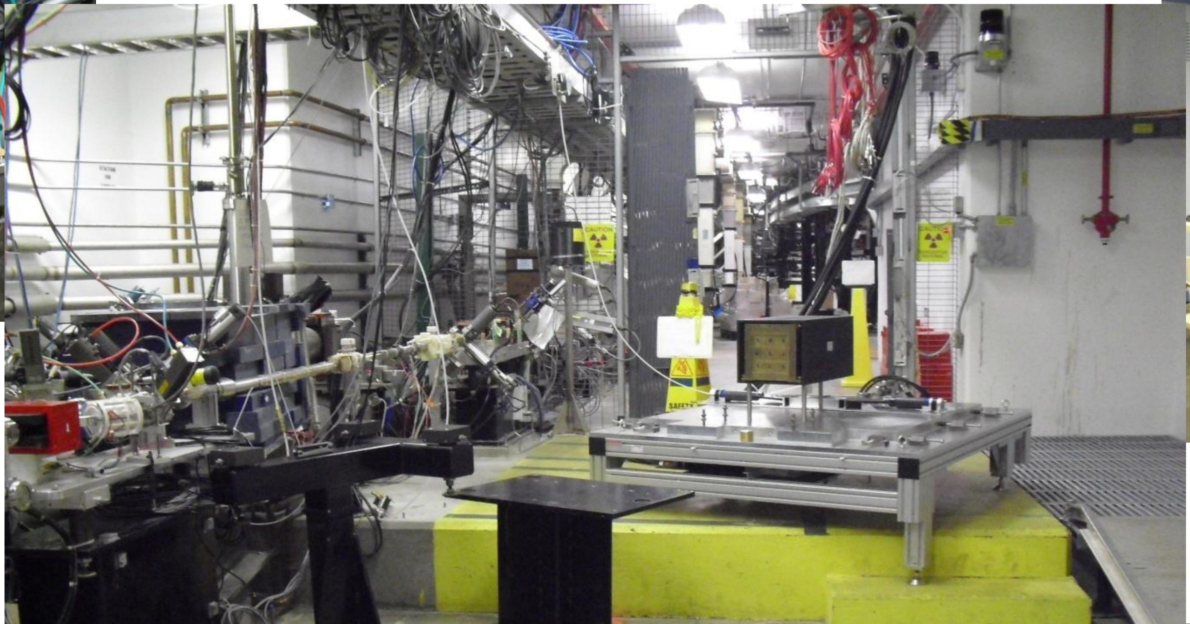
In August 2010, JLAB Program advisory commitee
approved PEPPo with A rating and awarded 14 weeks.

September 22, 2011

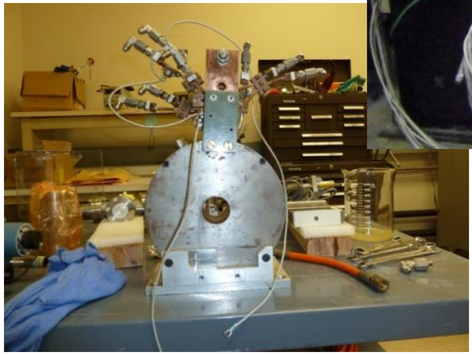


PEPPo branch

Polarimeter calorimeter and table

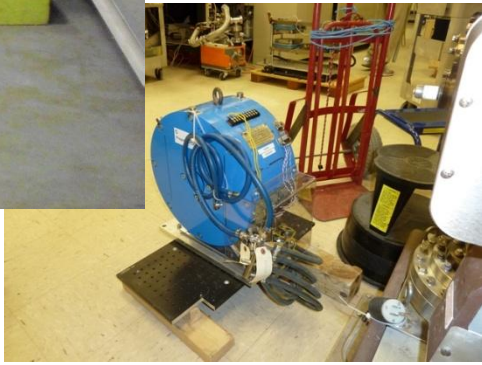


DAQ, Power Supplies....



S_1 Solenoid

DD Spectrometer



Analyzing magnet

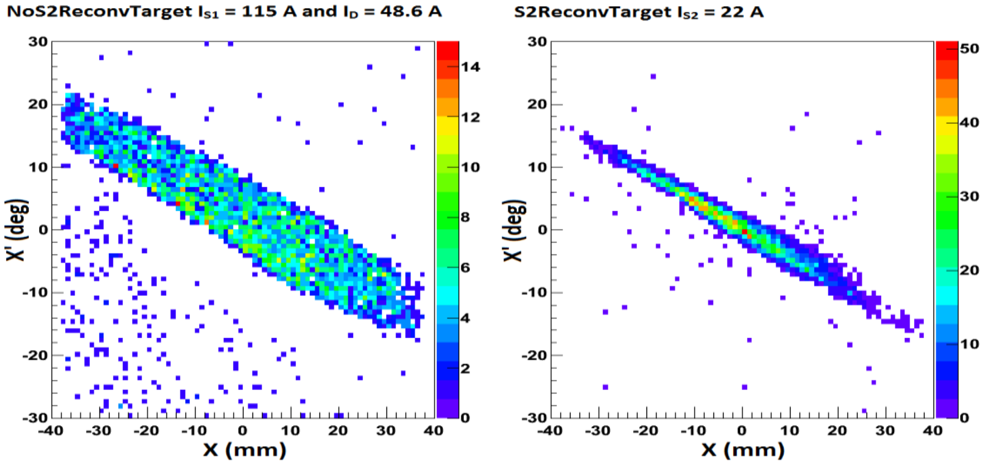
Backup slides

Transmission Rates

The positron beam **waist** can be **controlled** with S2 to enter the polarimeter.

Phase spaces

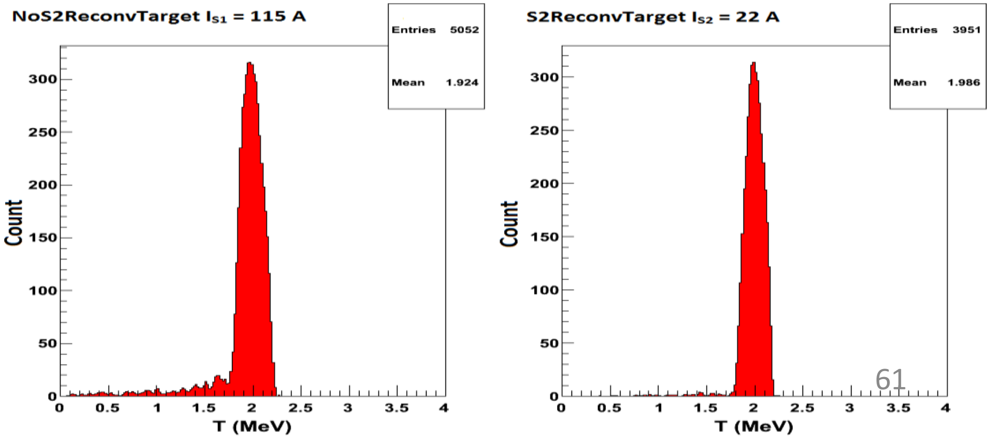
E166 PEPPo



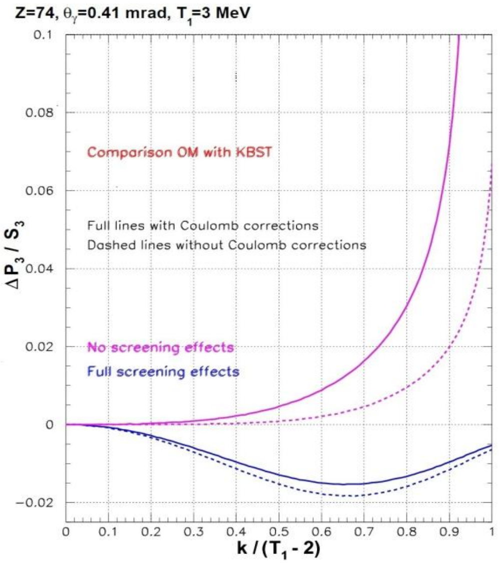
Cleaner **energy selection**

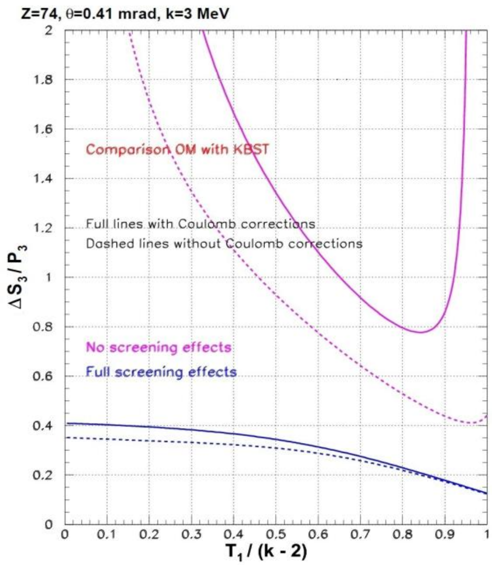
Energy distributions

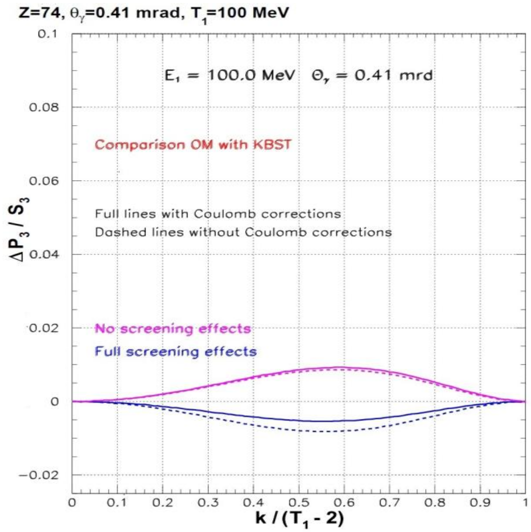
E166 PEPPo

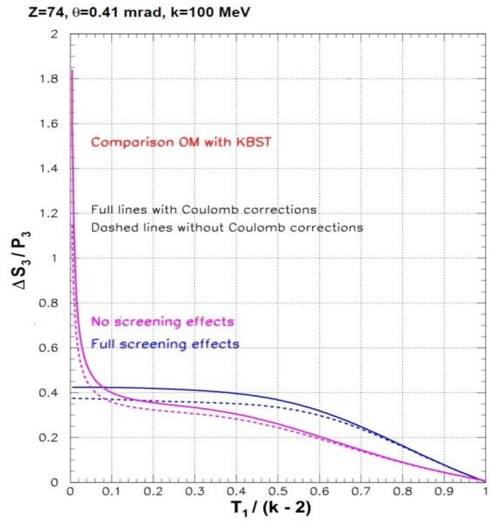


KBST vs OM


Z=74, θγ=0.41 mrad, T1=3 MeV
Comparison OM with KBST
Full lines with Coulomb corrections
Dashed lines without Coulomb corrections
No screening effects
Full screening effects
ΔP3 / S3
k / (T1 - 2)
0.1
0.08
0.06
0.04
0.02
0
−0.02
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


Z=74, θ=0.41 mrad, k=3 MeV
Comparison OM with KBST
Full lines with Coulomb corrections
Dashed lines without Coulomb corrections
No screening effects
Full screening effects
ΔS3 / P3
T1 / (k - 2)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

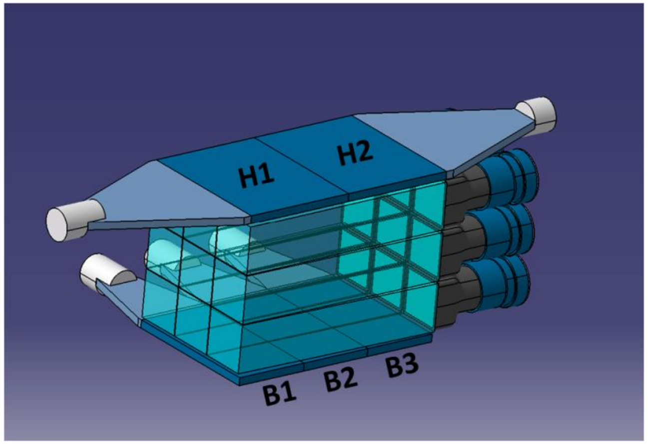

Z=74, θγ=0.41 mrad, T1=100 MeV
E1 = 100.0 MeV Θγ = 0.41 mrd
Comparison OM with KBST
Full lines with Coulomb corrections
Dashed lines without Coulomb corrections
No screening effects
Full screening effects
ΔP3 / S3
k / (T1 - 2)
0.1
0.08
0.06
0.04
0.02
0
−0.02
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

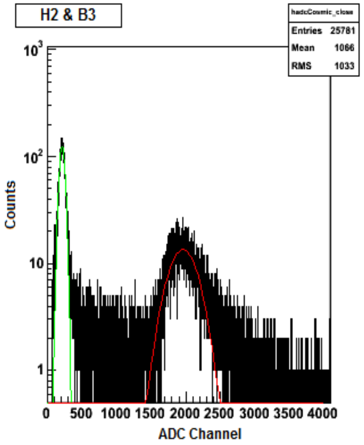

Z=74, θ=0.41 mrad, k=100 MeV
Comparison OM with KBST
Full lines with Coulomb corrections
Dashed lines without Coulomb corrections
No screening effects
Full screening effects
ΔS3 / P3
T1 / (k - 2)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

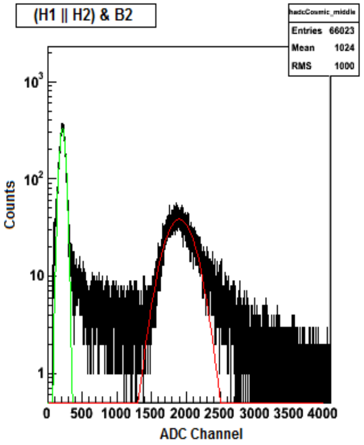
Cosmic Measurement

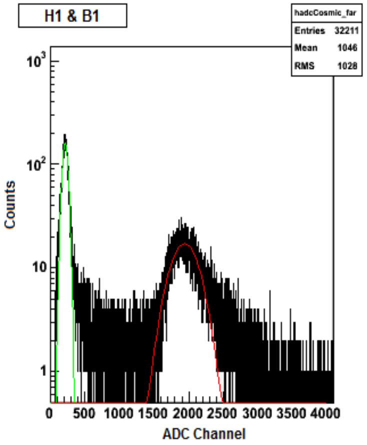
2 signals in coicidence for cosmics

The ADC channel correspondent to the 40 MeV is **independent** of the cosmic ray position relative to the PMT





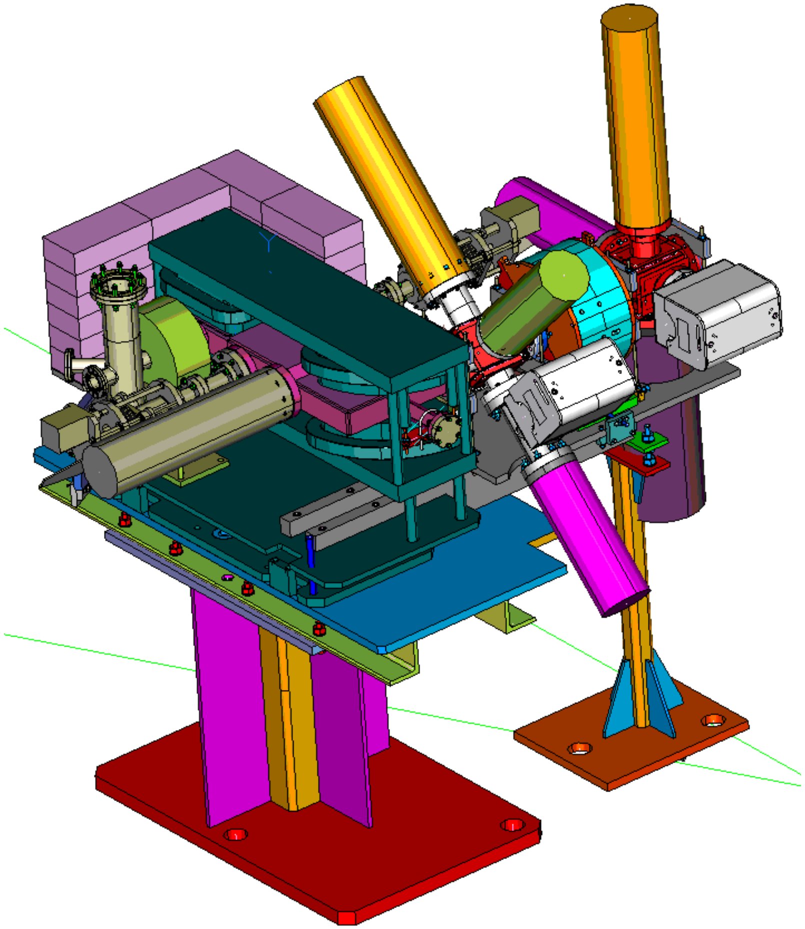




Amplifiers modified for higher energy signal to be in the ADC channel range.

For on-site tests of the signal integration.

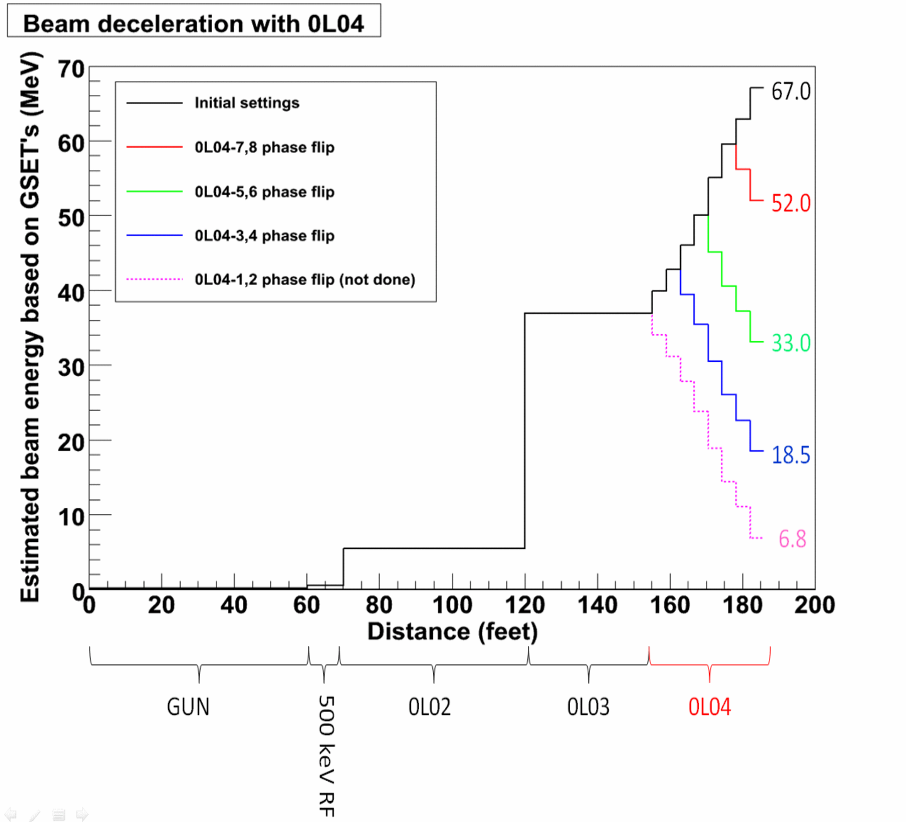
PEPPo Line

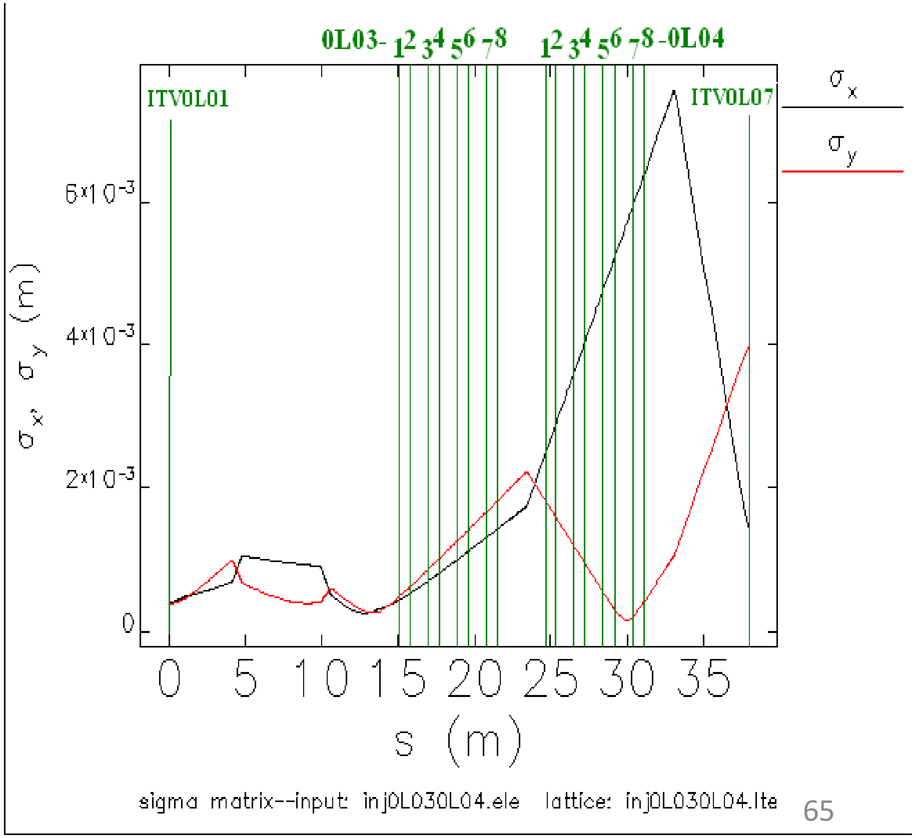


Electron beam

Energy range:

67 MeV after cryomodules -> down to 5 MeV beam.

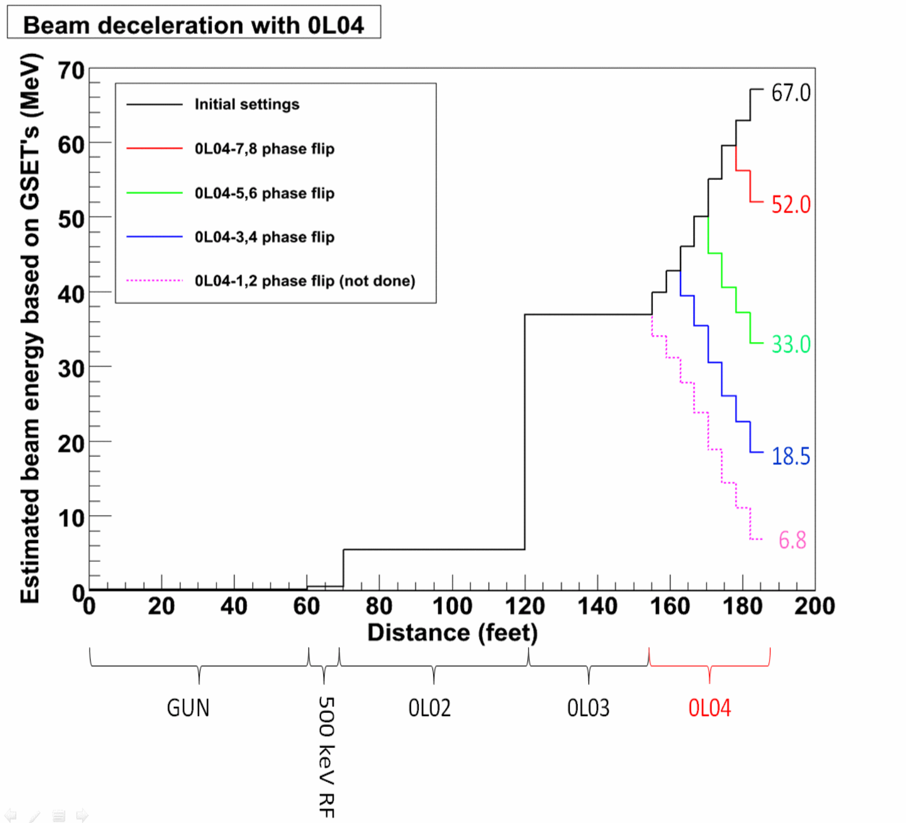


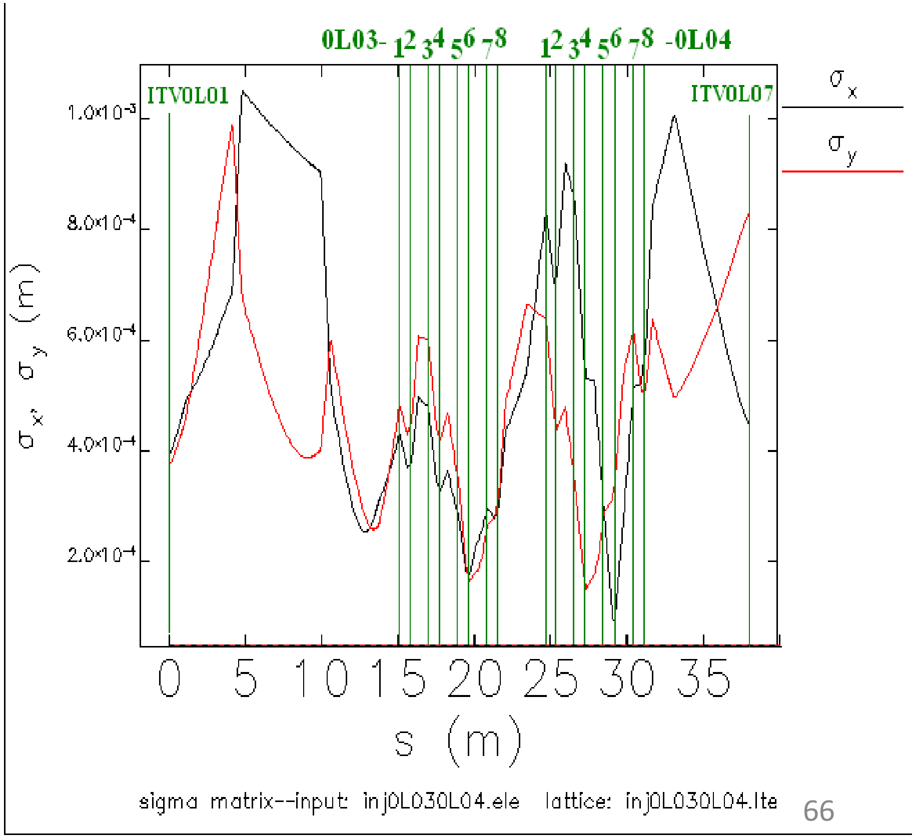


Electron beam

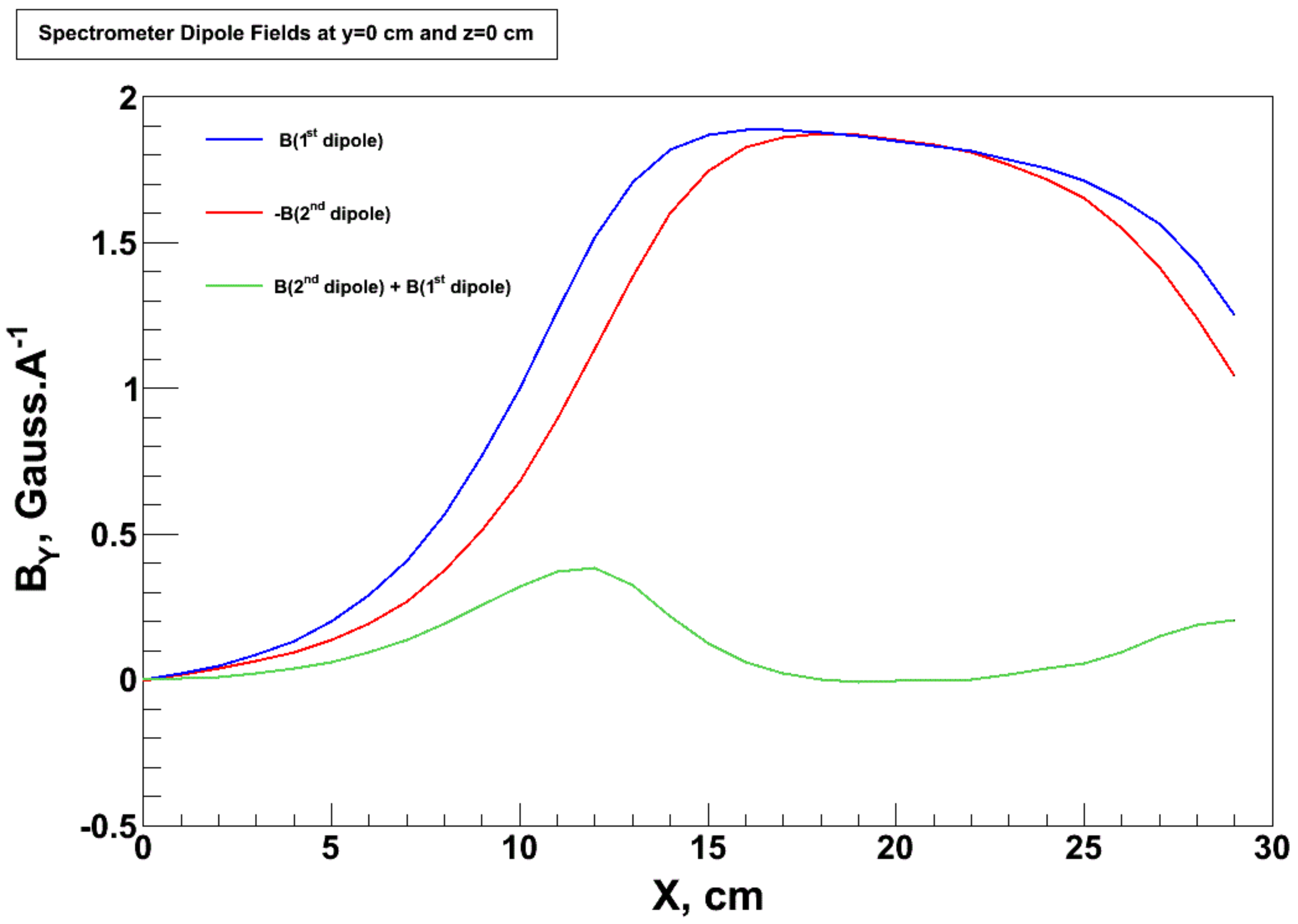
Energy range:

67 MeV after cryomodules -> down to 5 MeV beam.

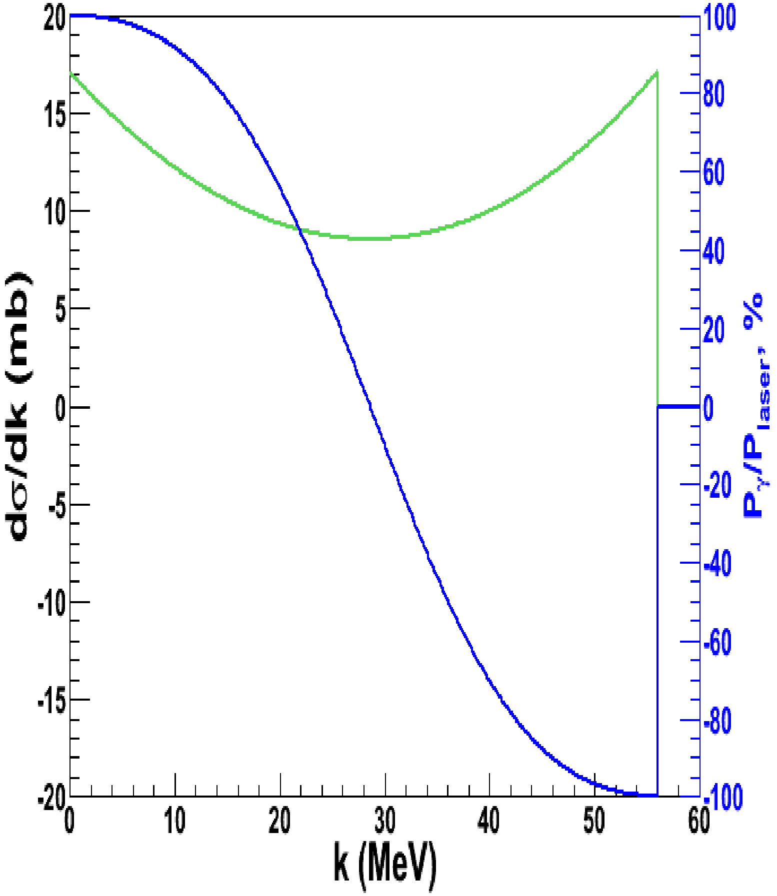


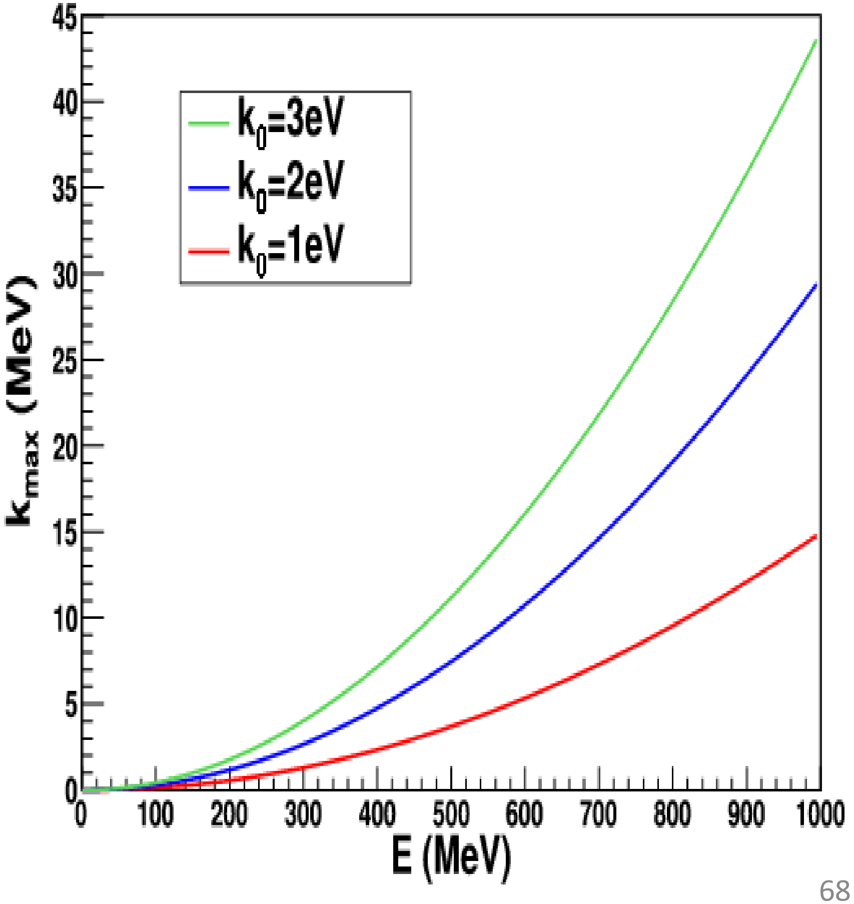


Spectrometer field

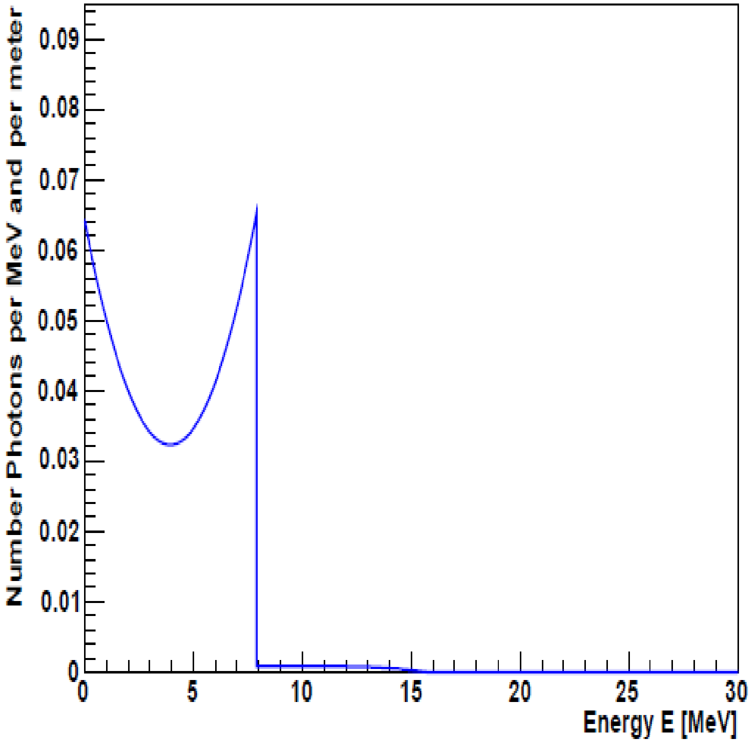


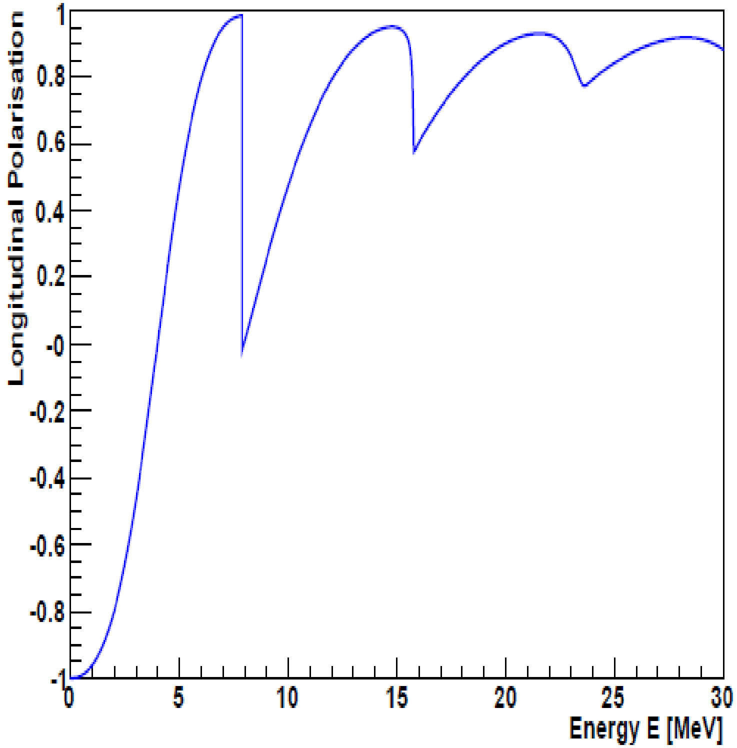
Compton back scattering



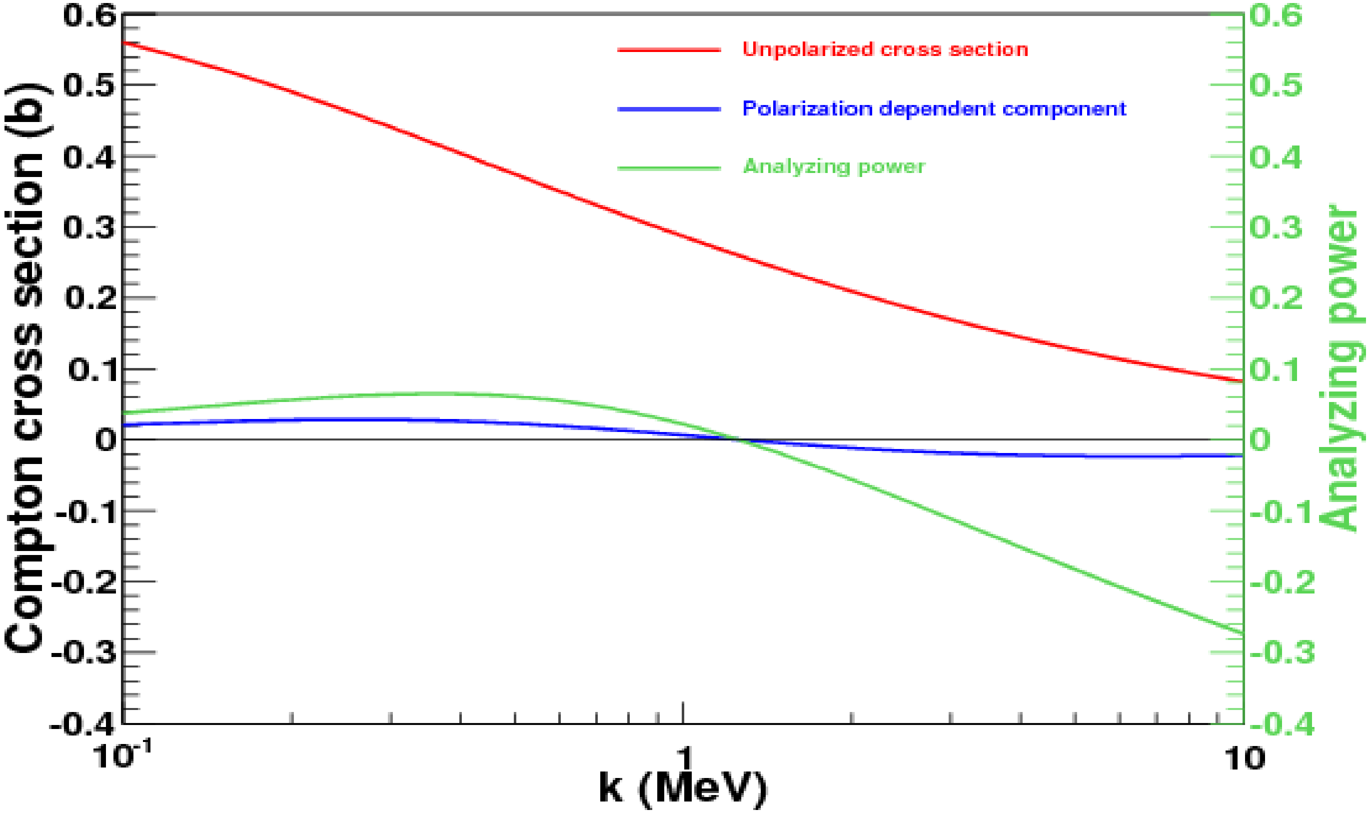


Undulator





G. Alexander et al, PRL 100 (2008) 210801



Unpolarized cross section
Polarization dependent component
Analyzing power
Compton cross section (b)
Analyzing power
k (MeV)
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
10^{-1}
1
10