LPSC Grenoble
Laboratoire de Physique Subatomique et de Cosmologie

UNIVERSITE JOSEPH FOURIER
SCIENCES. TECHNOLOGIE. MEDECINE
GRENOBLE 1

How are you doing Mr. PEPPo?

A new possible source of polarized positrons at JLab

Erica Fanchini
(PEPPo Collaboration)

08/17/2011
JLab Pizza Seminar

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Overview

- ✔ Nuclear studies and polarized positron beam

Ingredients

- ✔ JLab CEBAF facility and injector
- ✔ PEPPo scheme and E166 experiment
- ✔ PEPPo detector

Cooking

- ✔ Elementary polarized processes
- ✔ PEPPo simulation
- ✔ Polarization measurements
- ✔ Future

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History of pizza

From Wikipedia, the free encyclopedia

This article is **written like a personal reflection or essay and may require cleanup.** Please help improve it by rewriting it in an encyclopedic style. *(April 2009)*

Pizza is a type of bread and dish that has existed since time immemorial in Middle Eastern and Mediterranean cuisine. By 997 the term had appeared in Medieval Latin,[citation needed] and in 16th century Naples a Galette flatbread was referred to as a pizza.[citation needed] A dish of the poor people, it was sold in the street and was not considered a kitchen recipe for a long time.[citation needed] Before the 17th century, the pizza was covered with red sauce.[citation needed] This was later replaced by oil, tomatoes (after Europeans came into contact with the Americas) or fish. In 1843, Alexandre Dumas, père described the diversity of pizza toppings.[citation needed] In June 1889, to honor the Queen consort of Italy, Margherita of Savoy, the Neapolitan chef Raffaele Esposito created the "Pizza Margherita," a pizza garnished with tomatoes, mozzarella cheese, and basil, to represent the colors of the Italian flag. He was the first to add cheese.[1] The sequence through which flavored flatbreads of the ancient and medieval Mediterranean became the dish popularized in the 20th century is not fully understood.

This article is part of the series on
Pizza

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Origins

Foods similar to pizza have been prepared since the Neolithic age. Records of people adding other ingredients to bread to make it more flavorful can be found throughout ancient history.

- In Sardinia, French and Italian archeologists have found a kind of bread baked over 3,000 years ago. According to Professor Philippe Marinval, the local islanders leavened this bread.[2]
- The Tuscan tribes of Northern Italy believed Pizza to hold the spirits of deceased relatives.[3]
- The Ancient Greeks had a flat bread called *plakous* (πλακοῦς, gen. πλακοῦντος - *plakountos*)[4] which was flavored with toppings like herbs, onion, and garlic.
- In the 1st century BCE, the Latin poet Virgil refers to the ancient idea of bread as an edible plate or trencher for other foods in this extract from his Latin poem, the Aeneid:

Their homely fare dispatch'd, the hungry band
Invade their trenchers next, and soon devour,
To mend the scanty meal, their cakes of flour.
Ascanius this observ'd, and smiling said:
"See, we devour the plates on which we fed."

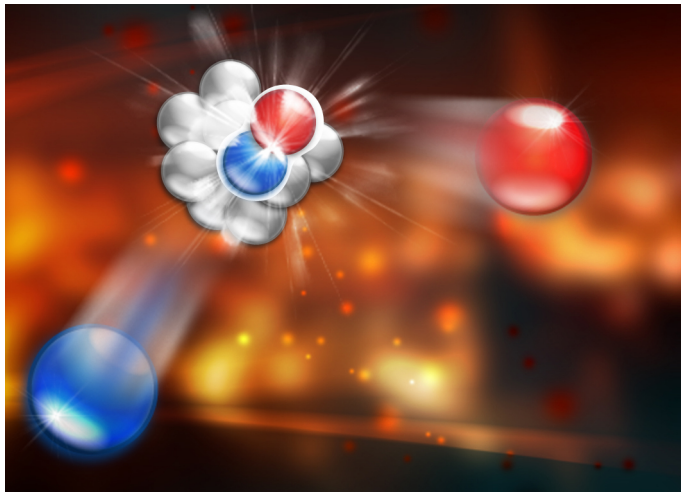
These flatbreads, like pizza, are from the Mediterranean area and other examples of flat breads that survive to this day from the ancient Mediterranean world are focaccia (which may date back as far as the Ancient Etruscans), coca (which has sweet and savory varieties) from Catalonia, Valencia and the Balearic Islands, the Greek Pita or Pide in Turkish. Lepinja or Somun in the Balkans or Piadina in the Romagna part of Emilia-Romagna in Italy.[5]

Similar flat breads in other parts of the world include the Indian Paratha, the South Asian Naan, the Sardinian Carasau, Spianata, Guttiau, Pistoccu and Finnish Rieska. Also worth note is that throughout Europe there are many similar pies based on idea of covering flat pastry with cheese, meat, vegetables and seasoning such as the Alsatian Flammkuchen, German Zwiebelkuchen, and French Quiche.

Nuclear study

The everyday life drive us to the understanding what is around us.
The fundamental questions "Why?", "What is it?", "How is it?" led to study the matter and its components.
The nuclear study become important.
Understanding of relations between quarks inside the nucleon.

A useful way to study nucleons is to interact with them.
Electrons and positrons at high energies are fundamental
Taking advantage to their polarization one can access on the spin information of the interacting parton



Polarized and unpolarized e-/ e+ beams become essential tools to further our understanding of nature at distance scales ranging from the frontiers of high energy physics to solid state physics.

Polarized e+ beam (1)

Polarized electron beams are easily produced and they are used in several facilities, but polarized positron production is more complex.

- ✔ γ produces $e^{\pm}$ pair. They are captured, stored in a ring and accelerated. The following "self" polarization is obtained via Sokolov-Ternov effect.
- ✔ Compton back-scattering of a beam laser of high energy electrons to make γ followed by $e^{\pm}$.
- ✔ Synchrotron radiation from very high energy electrons traveling through a helical undulator generate γ followed by $e^{\pm}$.

New Approach

Polarized e+ beam (2)

To provide polarized e+ beam by transferring polarization from an intense polarized e- beam to e+ in a single target.
The polarization transfer is obtained by bremsstrahlung of polarized e- followed by pair production processes.

PEPPo

Polarized Electrons for Polarized Positrons

It will investigate the possibility to provide polarized positron beams that could be used at JLab for the hadronic physics program of the JLab 12 GeV upgrade and/or in other future experiment (SuperB...)

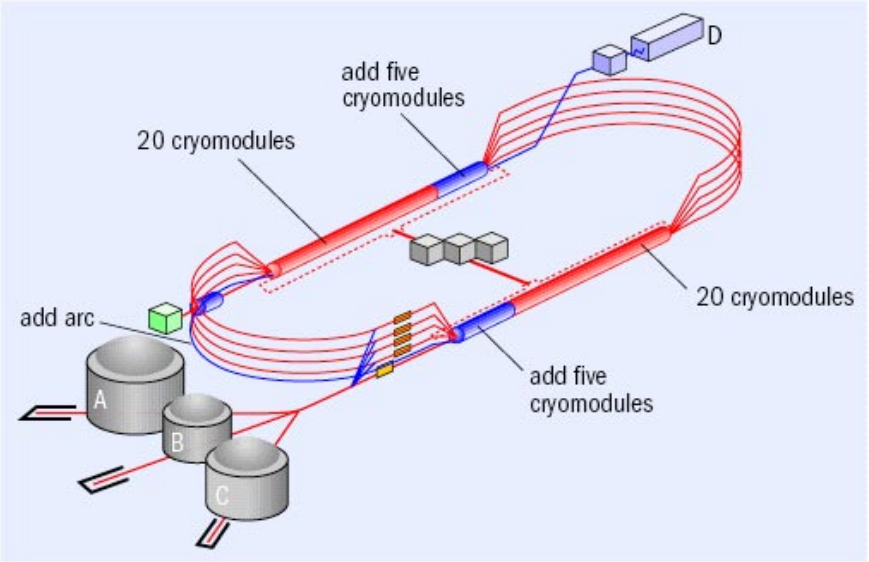
Ingredients

Italiano	English	Quantities
Farina	Wheat flour (type o or oo)	850 g
Acqua	Water	500 g
Lievito di birra	Brewer's yeast	3 g
Sale	Salt	Qb/as needed

Ingredients for the most Classical Italian pizza.
La Margherita

Italiano	English
Salsa di pomodori	Tomato sauce
Mozzarella	Mozzarella
Olio d'oliva	Olive oil
Basilico	Basil

JLab CEBAF facility



CEBAF will provide high polarized electrons for the experiments in the 3 + 1 halls

PEPPo requirement fixed the installation place in the injector area

	CEBAF	PEPPo
Polarization	85%	85%
Beam energy	6GeV	6.3MeV
Current	200μA	<4μA
Swapping helicity frequency	1kHz	1kHz

Injector

Bunching and acceleration

SRF acceleration

Beam polarization and energy measurement

e- source

Gun#2

Gun#3

V-Wien

Solenoids

Prebuncher

PCup

A1

H-Wien

A2

Chopper

Buncher

Capture

FC#1

Bunchlength Cavity

1/4 Cryo

500 keV Dump

5MeV Spectrometer

Mott

FC#2

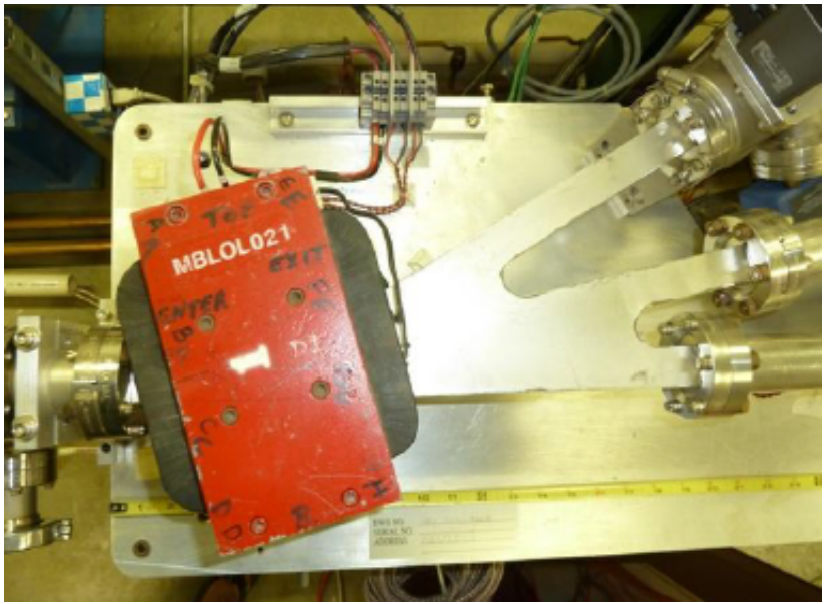
To the rest of the injector

$\vartheta \approx 25°$

Spin manipulation

Dipole

PEPPo

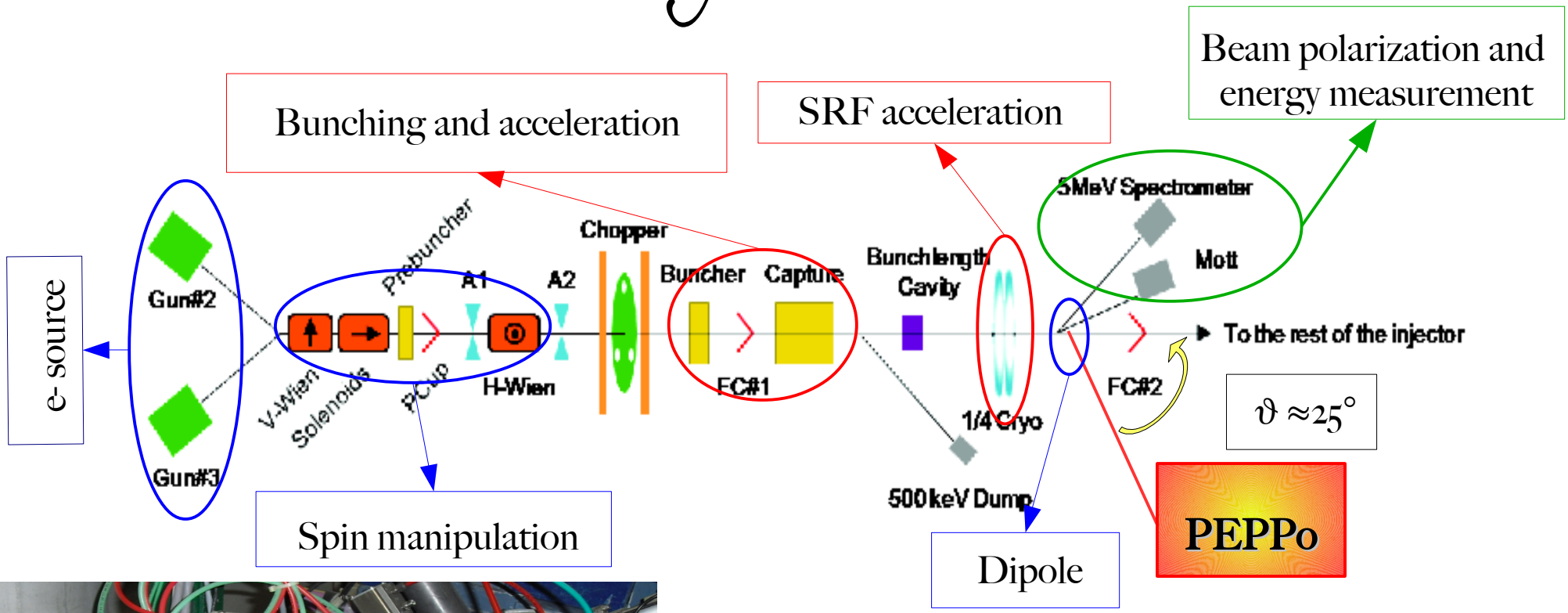


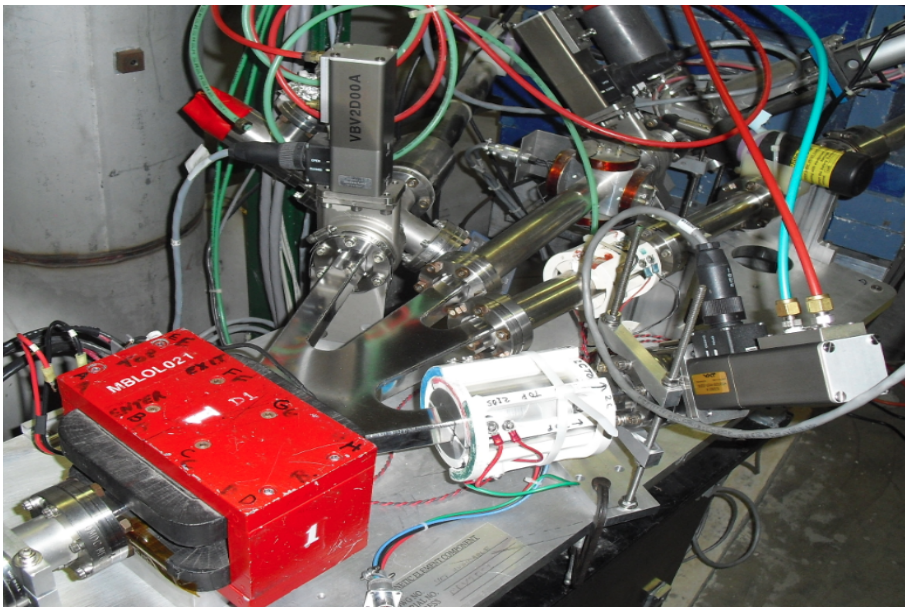
New beam line for PEPPo!

Small intervention in the injector line

new vacuum chamber

Injector



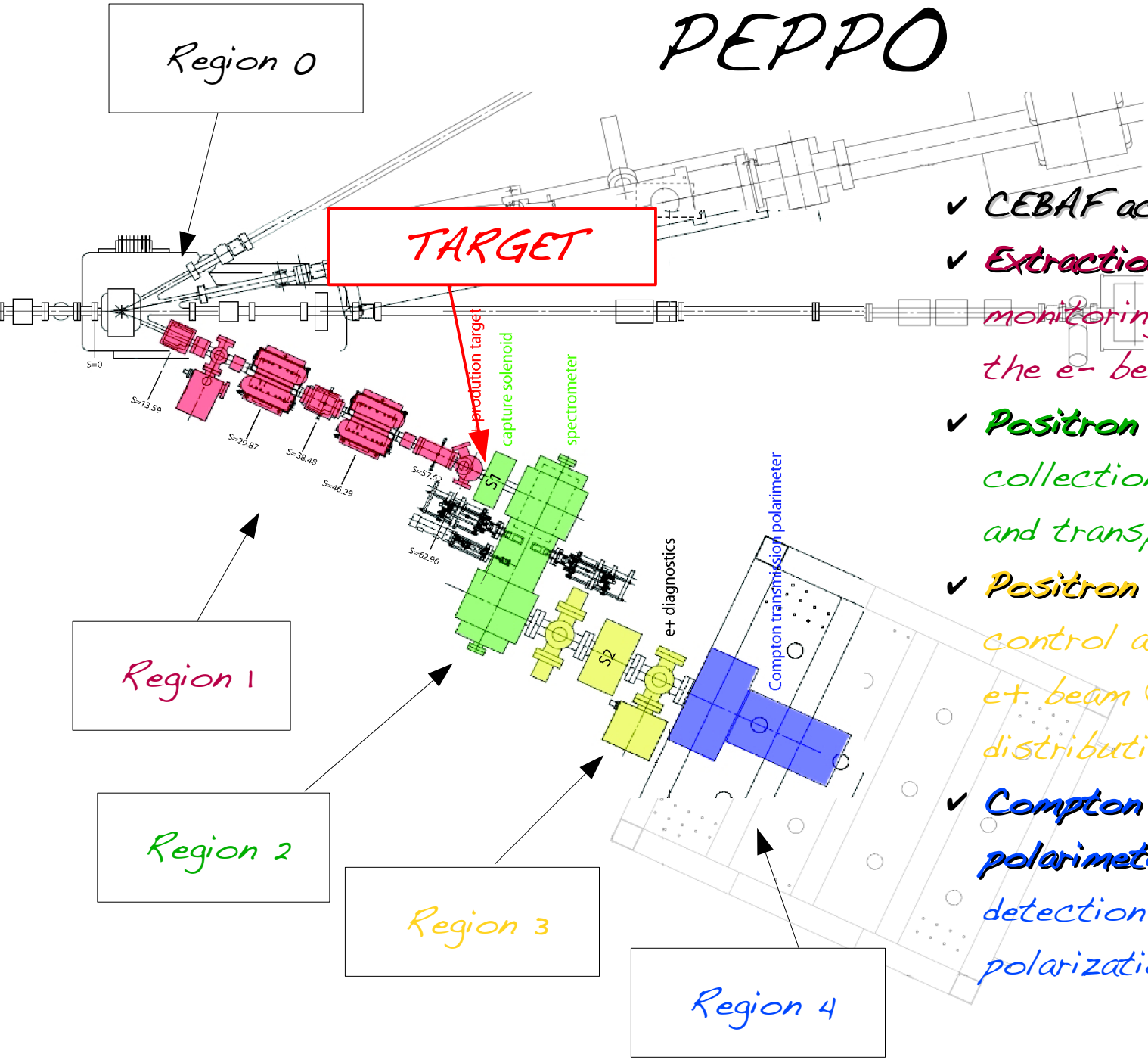


New beam line for PEPPo!

Small intervention in the injector line

new vacuum chamber

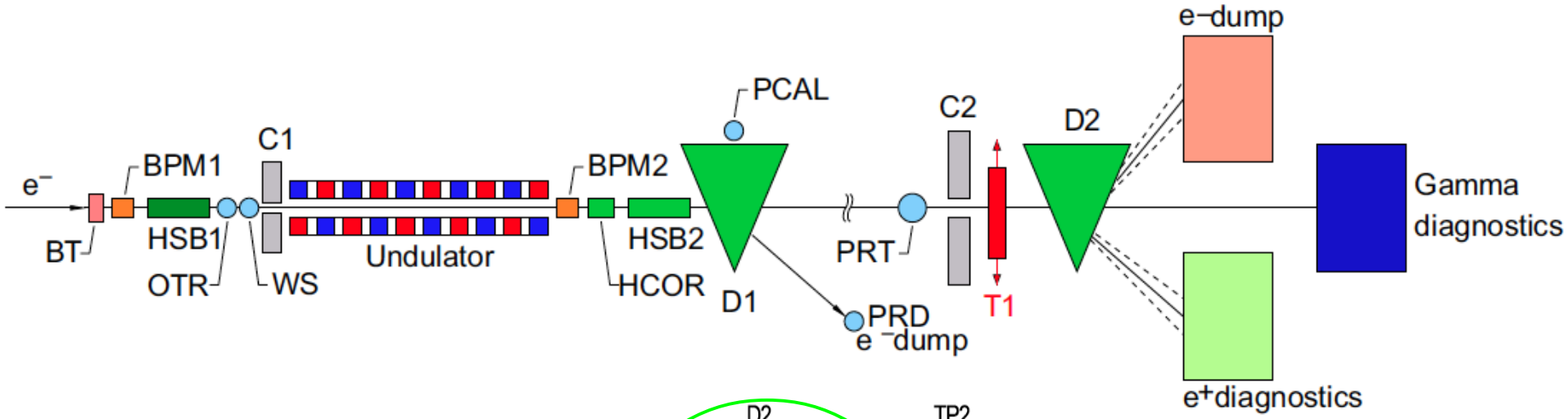
PEPPO



- ✔ CEBAF accelerator line
- ✔ **Extraction line**
  monitoring and diagnostic of the e- beam
- ✔ **Positron collection section**
  collection, momentum selection and transport of the e+
- ✔ **Positron diagnostic section**
  control and monitoring of the e+ beam (current and shape distributions)
- ✔ **Compton transmission polarimeter**
  detection of the e+ for polarization measurements

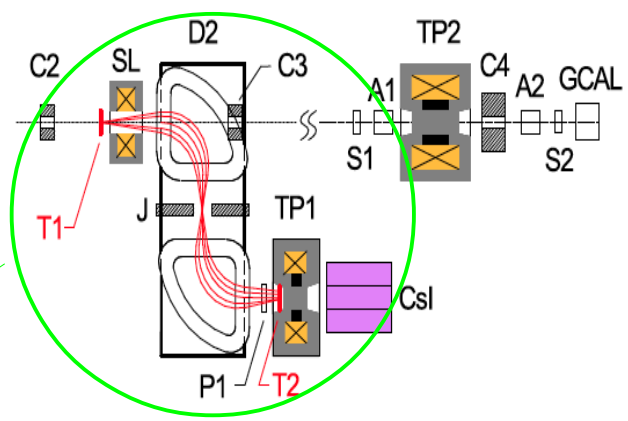
PEPPo and E166

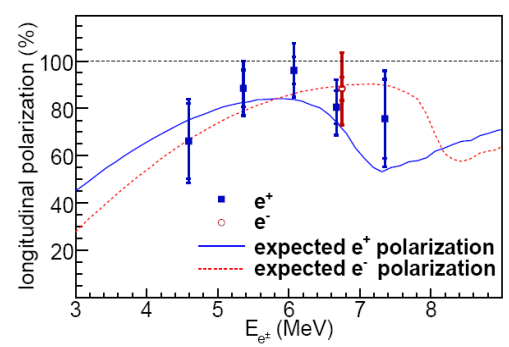
E166: SLAC experiment which measured the polarization of positrons created by 10 MeV circularly polarized photons generated in a helical undulator



The PEPPo architecture is influenced by the previous E166 experiment.

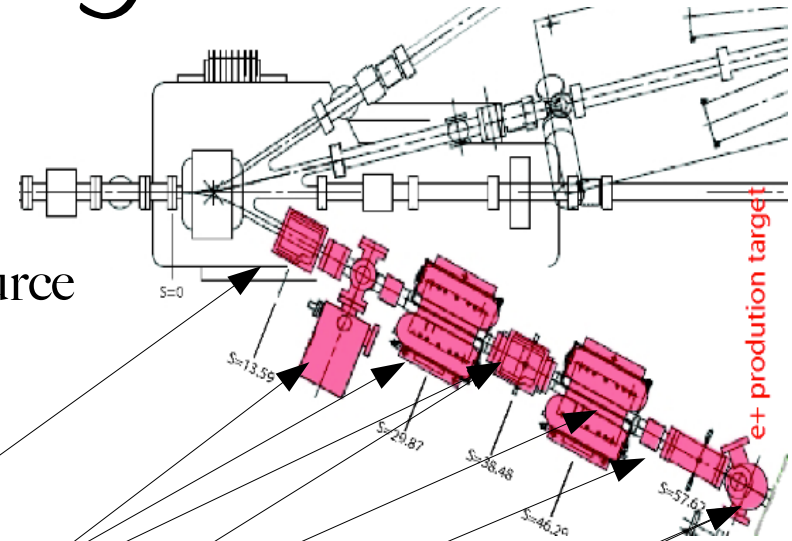
Some elements lent





Joseph Grames

Region 0 and Region 1



Region 0:

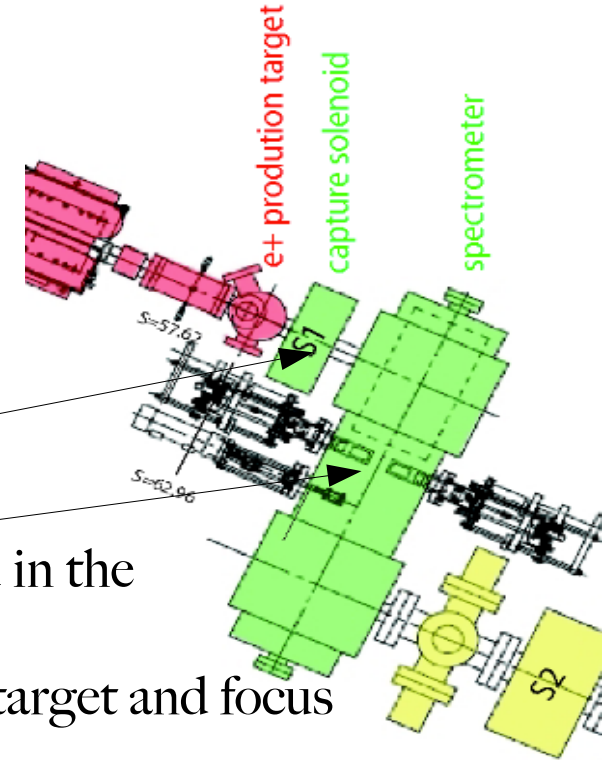
is the CEBAF accelerator line from the electron source up to the dipole (new vacuum pipe).

Region 1:

is the "red" region or electron beam diagnostic line connected the accelerator to the conversion target.
Its aim is the management and monitoring of the e- beam at the target entrance.
Beam position, angle and size are the variables monitored.

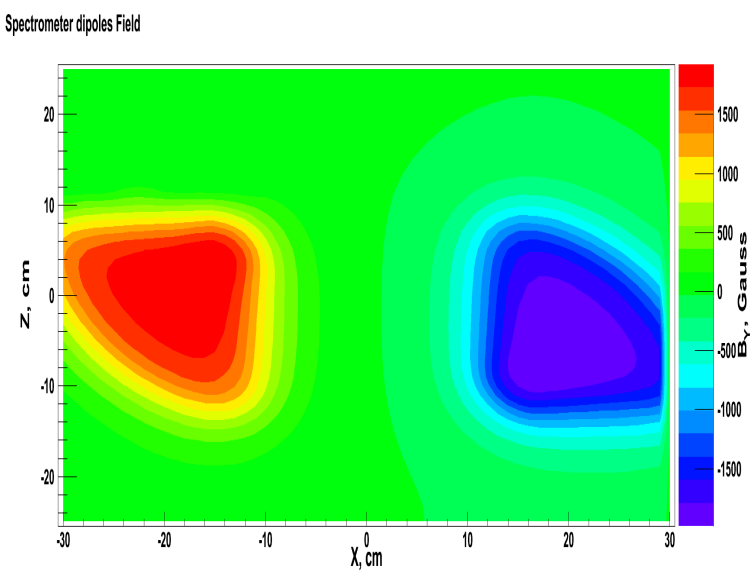
-) 2 Beam Position Monitors (BPM)
-) 2 steering magnets
-) 2 quadrupoles
-) Target ladder
-) 2 viewscreens

Region 2



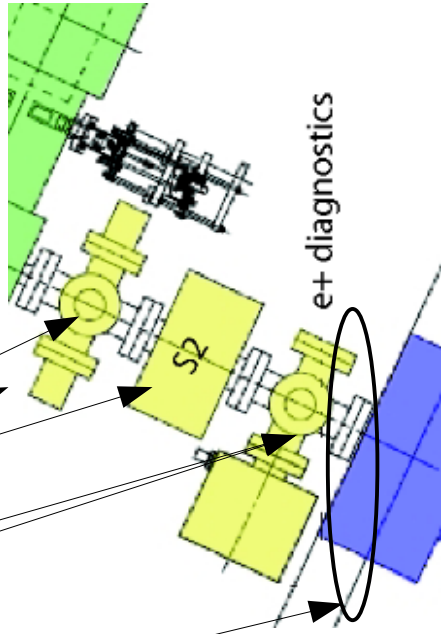
Region 2

Is the "green" region for collection and momentum selection of the e+ beam.
Both the collection solenoid and the spectrometer were used in the E166 exp.
The collection solenoid gathers the e+ coming out from the target and focus them into the spectrometer.
The spectrometer is a double dipole which select e+ momentum with a $\Delta p/p < 10\%$



The spectrometer structure was slightly modified for PEPPo purpose.
It has new vacuum chamber, new shielding structure and new momentum selection's jaws.

Region 3



Region 3

Is the e+ beam diagnostic region.
Spatial and rate measurements are done to optimize the positron transport to the analyzing magnet.

-) e+ annihilation counter
-) solenoid
-) Faraday cup
-) 2 viewers
-) Fiber array detector (not in the design) but it will be placed in front of the polarized iron target (blue box)

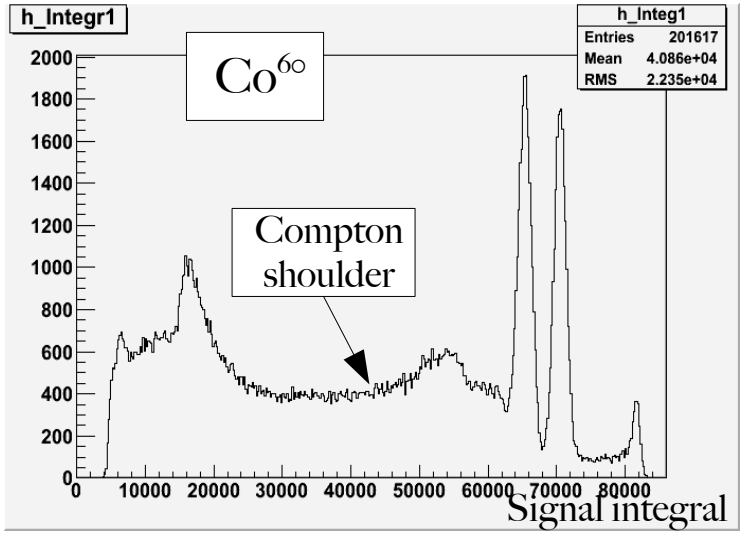
All these detectors are movable and they have to be retracted during the positron data taking

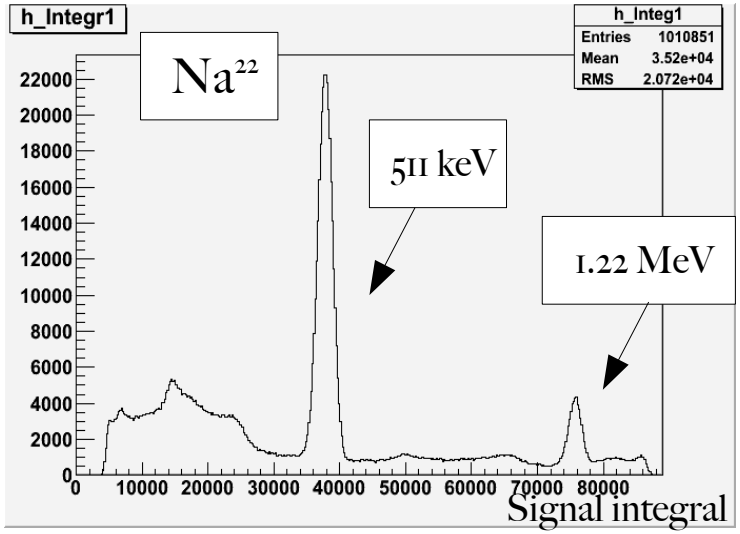
Arne Freyberger; Sadiq Setiniyaz; Tony Forest

Annihilation counter

2 NaI detectors used for the annihilation detection of positrons stopped in an insertable target.

The coincident detection of the 511 keV photons will be one of the first signals that positrons are transported through the spectrometer





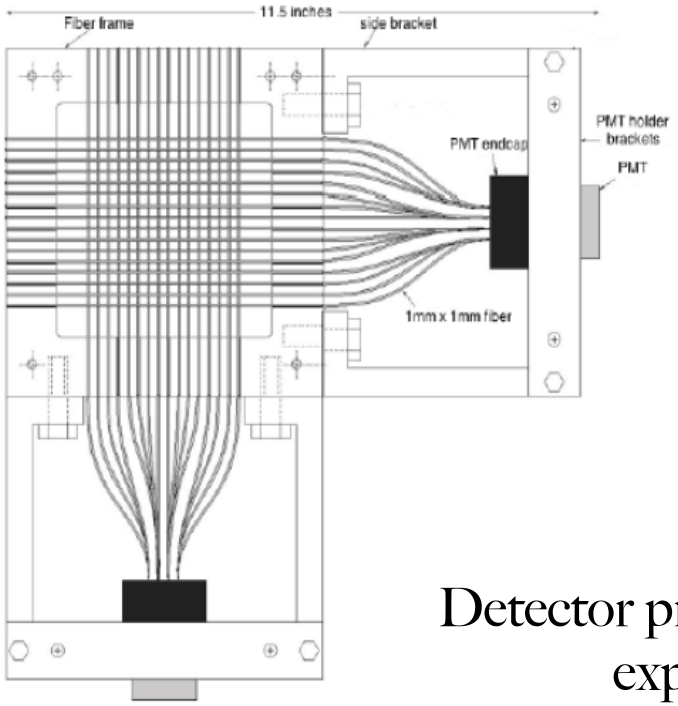
Calibration measurements to characterize and to obtain the optimal working condition.

Radioactive sources are used to calibrate voltage and to study the energy resolution.

Coincidence measurements are useful to establish time/amplitude window for the data taking mode

Eric Forman, Paul Guèye

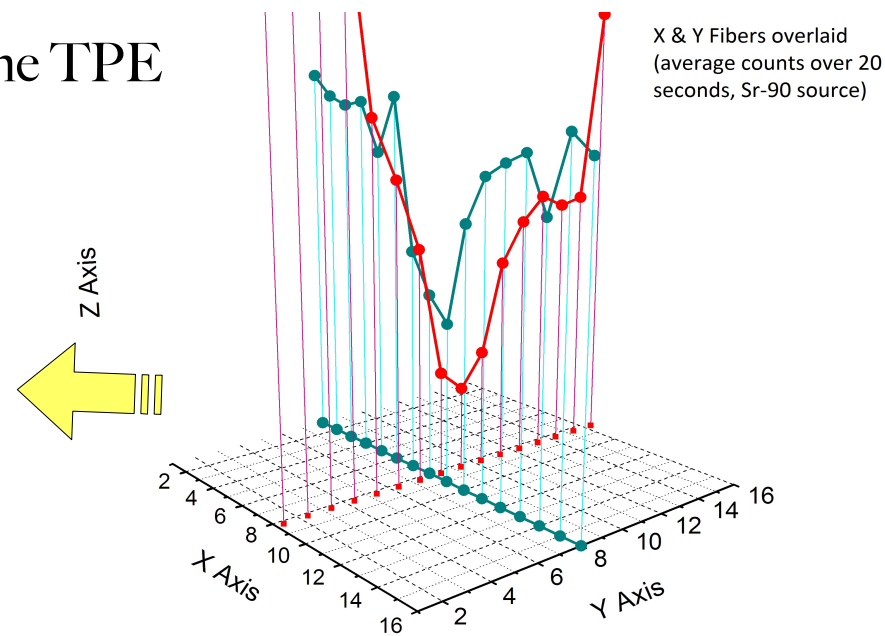
Fiber array detector (1)



It is used to measure beam profile and position in front of the Compton transmission polarimeter.

It is made by a 2D scintillating fiber array that can be easily inserted/removed.

Detector previously used in the TPE experiment in Hall B

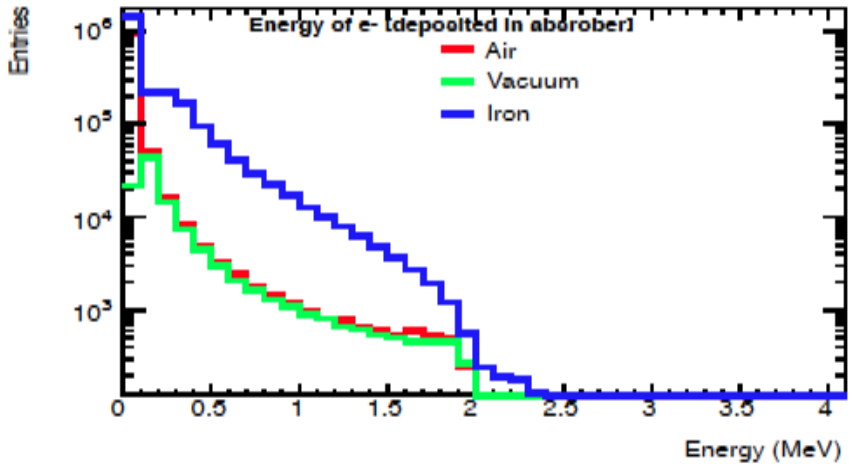


The response of the detector to a Sr^{90} source signal shows a radiation damage in the central zone

Adeleke Adeyemi; Paul Guèye

Fiber array detector (2)

Background simulation studies are ongoing!
Considering a 4 MeV e- beam in front of the fiber array:

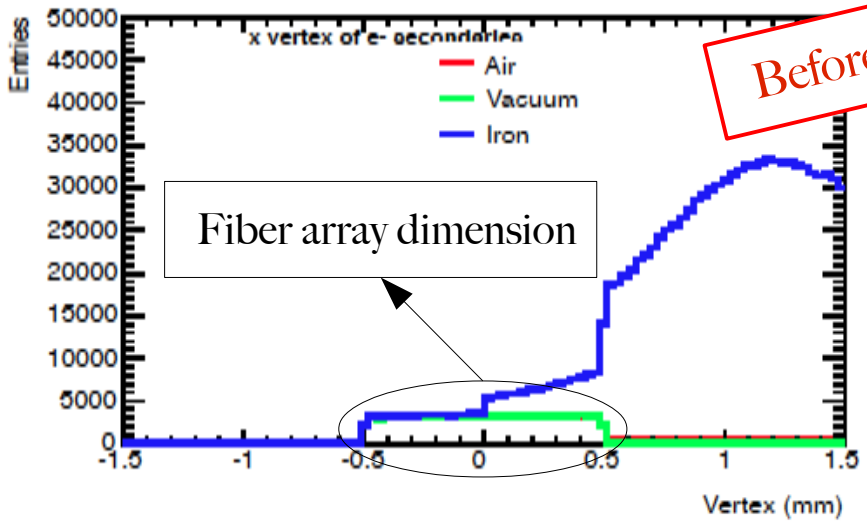


Energy deposit inside the fiber array with a vacuum, air or iron behind it.

Difference of the number of particle detected comparing vacuum/air with iron placed backward the fiber array larger than 1 order of magnitude.

Where they come from?

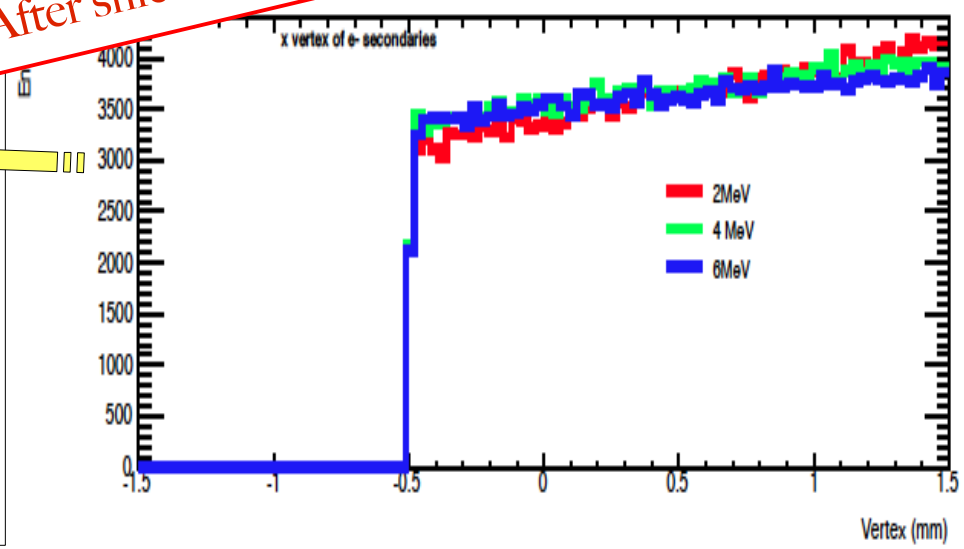
Fiber array detector (3)



Before shielding

Production vertexes of detected e-. Most of the e- are back-scattered from the iron block placed after the fiber array

After shielding



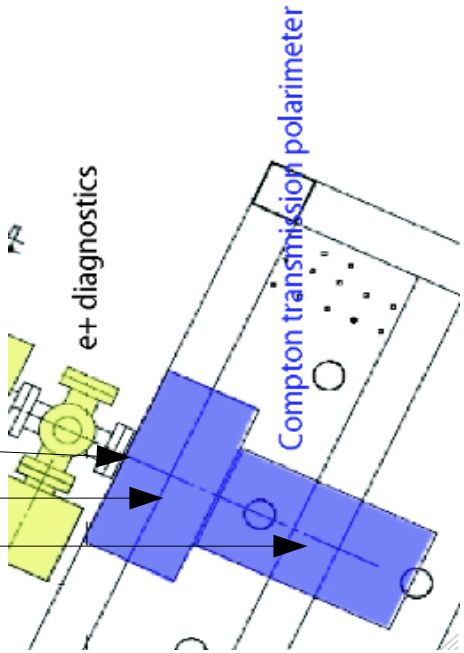
One evaluated shielding 1 mm plastic + 1 mm aluminium
e- beam of different energies (2, 4 and 6 MeV) Are shielded (look at the different scales)

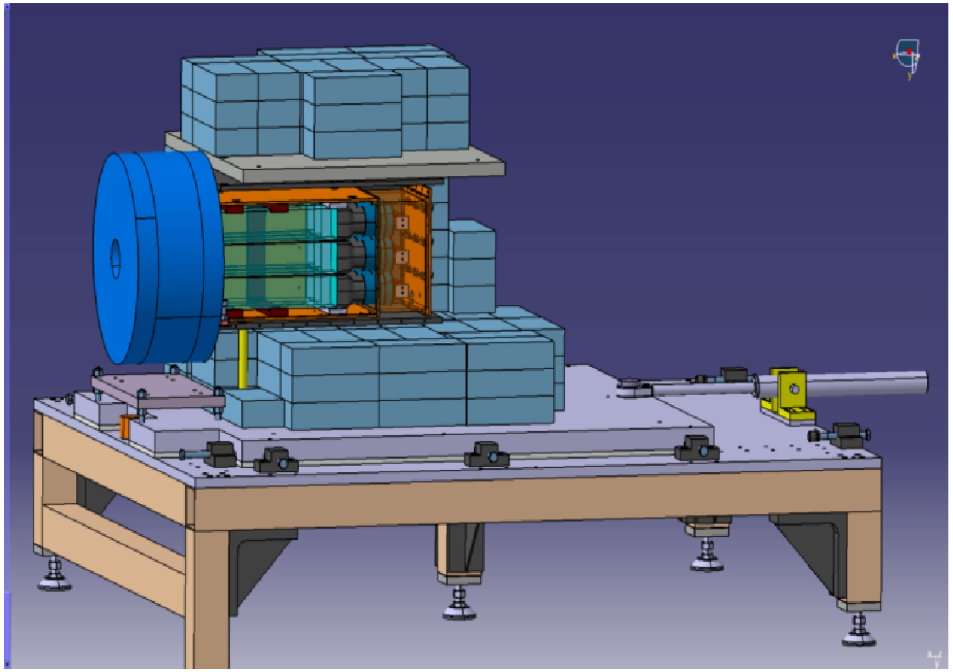
Same studies for e+ and γ and different shielding materials

Region 4

is the Compton transmission polarimeter measuring the e+ Polarization (and e- too).

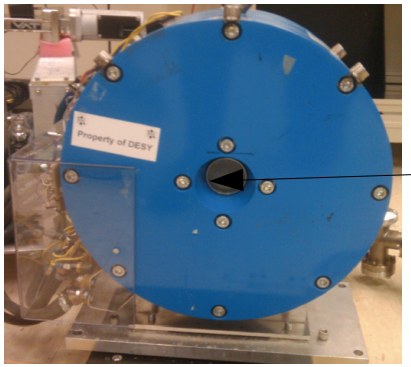
- ✔ Reconversion target
- ✔ Analyzing magnet
- ✔ Photon calorimeter





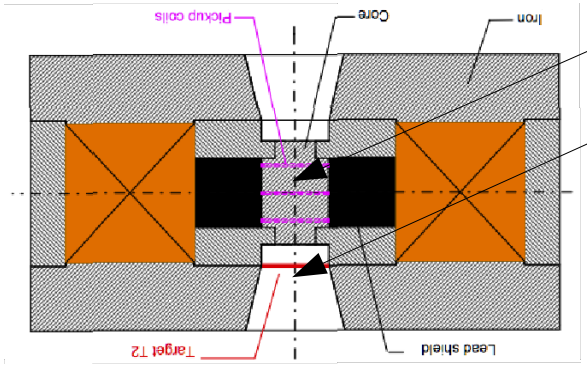
- ✔ e+ transfer their polarization to γ via Bremsstrahlung into the re-conversion target
- ✔ γ pass through the 7.5 cm of the polarized iron target
- ✔ Transmitted γ are detected in the photon calorimeter

Analyzing magnet (1)



The magnetic field is used to polarize the conversion target for the photon-production and the analyzing iron target.

Sensitivity to e+ polarization

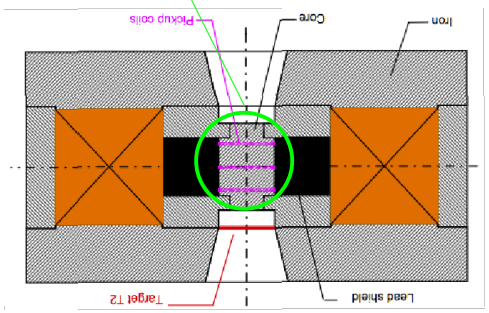


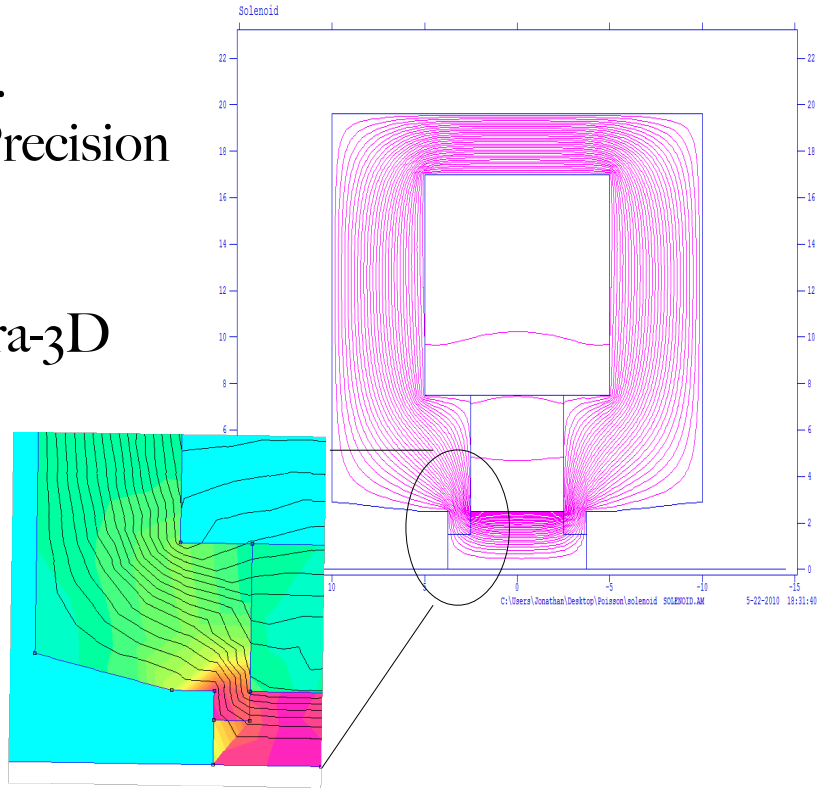
- ✔ 2 mm tungsten conversion target necessary to convert e+ into γ
- ✔ The core of a solenoid is a iron analyzing target of 7.5 cm
- ✔ The solenoid magnet provides a magnetic field saturating the target producing an overall longitudinal polarization of 7% => obtained with 60 A bipolar current supply
  => The averaged polarization value of the iron target is 0.069± 0.002, according to the E166 collaboration
- ✔ The magnetic field along the axis of the iron core is 2.3 T

Analyzing magnet (2)

Accurate knowledge of the target polarization => combination of a precise experimental field mapping and modeling, and the measurement of the magnetic field during data taking.

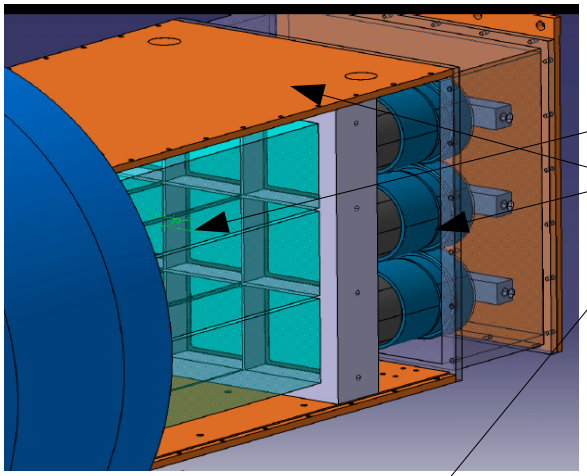
-) Pickup coils surrounding the core of the magnet.
-) The induced-voltage signal is measured with a Precision Digital Integrator (PDI).
-) The external magnetic field will be measured to determine the fringe field to compare with Opera-3D modeling



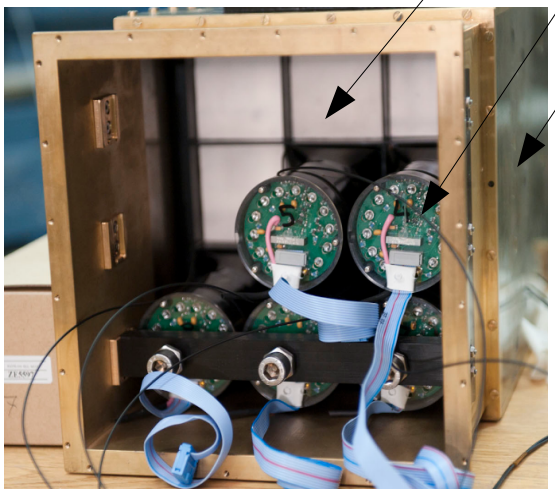


Jean-Francois Muraz, Marc Marton

Photon calorimeter



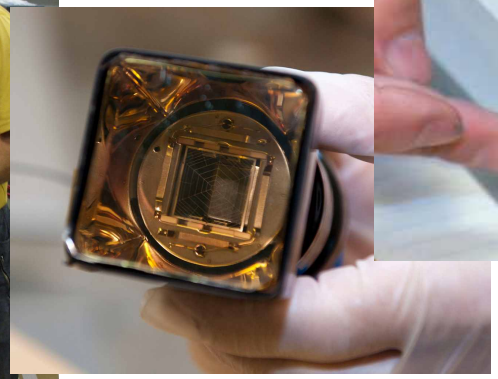
-) 9 CsI(Tl) crystals arranged in an 3x3 array
-) 9 PMTs
-) 1 brass box for light tightness
-) 1 external iron shielding

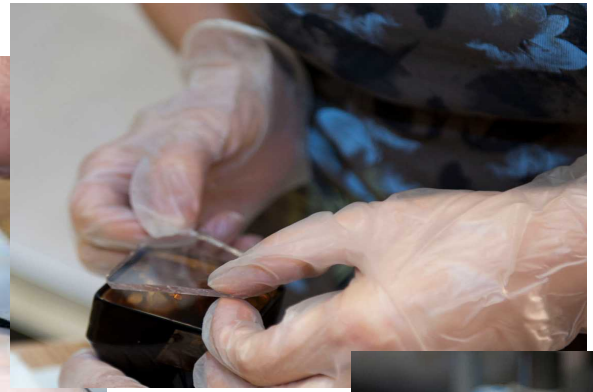


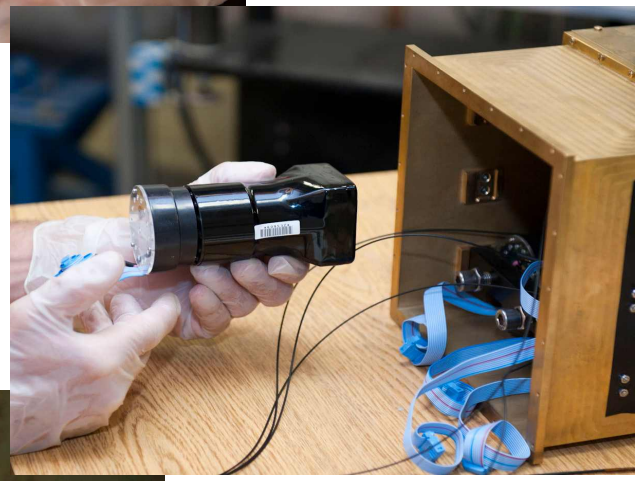
Photons transmitted by the iron target are detected in the crystals which measure the energy deposited

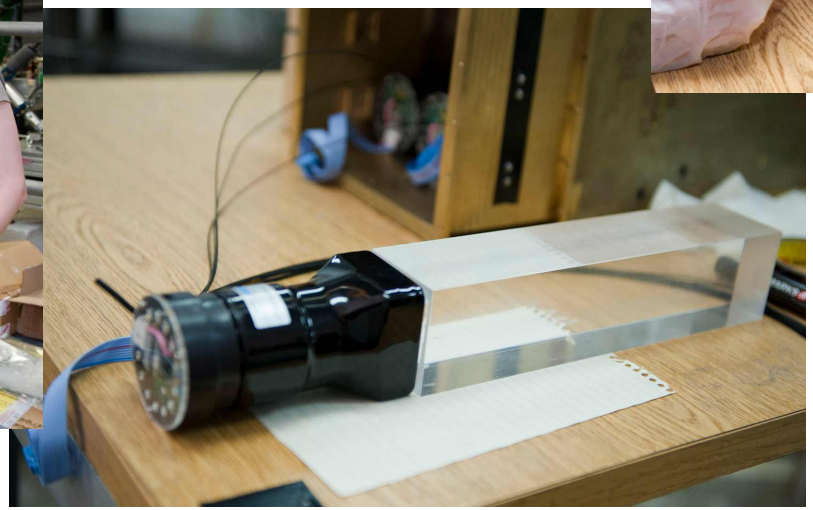
A LED monitoring system for each crystal is implemented to control of the evolution of the PMTs gain.

Photon calorimeter (2)







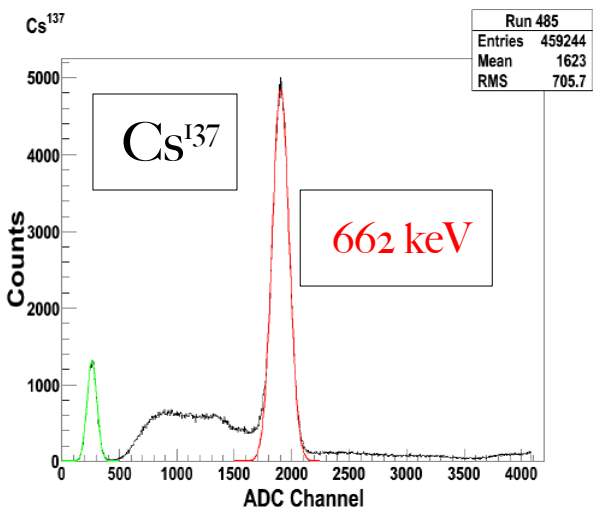


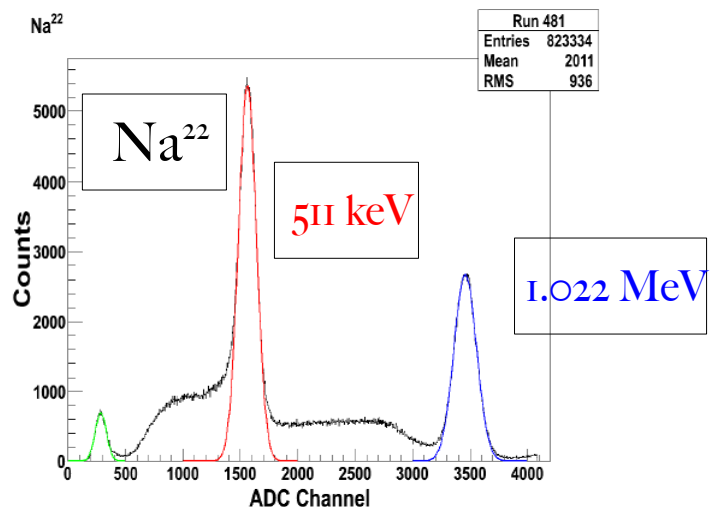
Polarimeter & sources (1)

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

$$\frac{\Delta E}{E} = \frac{Peak\,Width}{Peak\,Loc. - Pedestal\,Loc.}$$

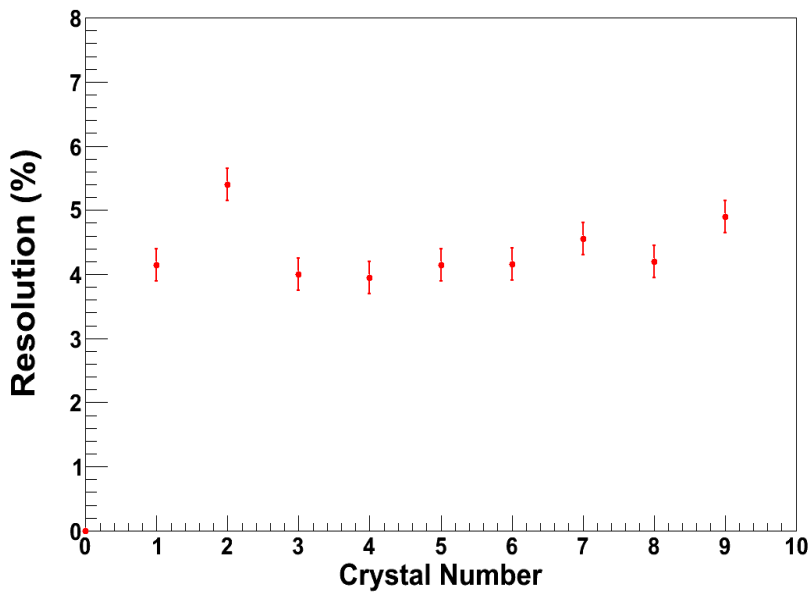
The difference between the pedestal and signal peak locations (red and blue) represents quantitatively the analyzed photon energy





Polarimeter & sources (2)

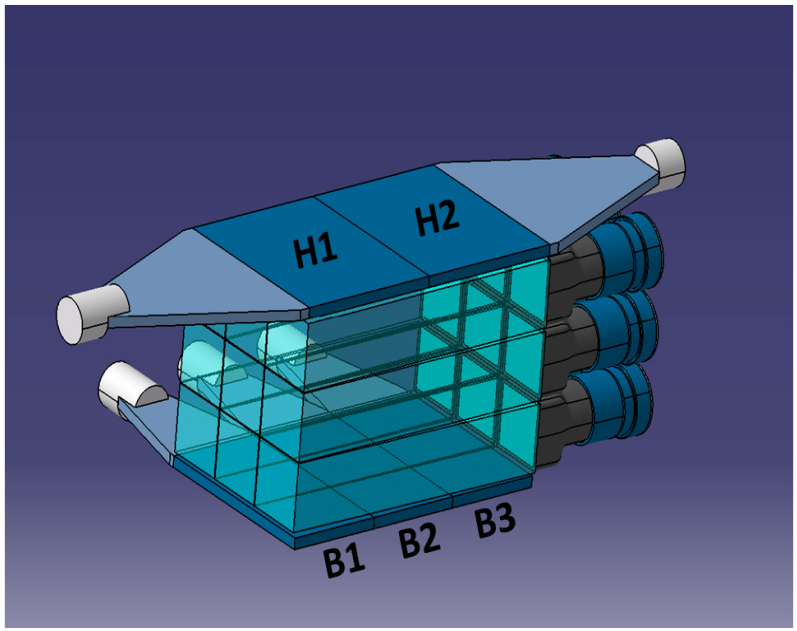
All the crystals have a comparable resolution (flatness).
resolution between 3.5% and 5.5%



With radioactive source is possible to establish the operational voltage of the PMTs
They are supplied with voltages in the range of -1 kV/-1.25 kV

Polarimeter & cosmic rays (1)

An absolute energy calibration of the PMTs can be obtained using cosmic rays.
The calorimeter can detect minimum ionizing particles (mip).
The energy loss for minimum ionizing muon (μ) is ~40 MeV giving an absolute energy calibration of each crystals



Measurement setup:
5 scintillator paddles
(2 on the top and 3 on the bottom of the crystal box)

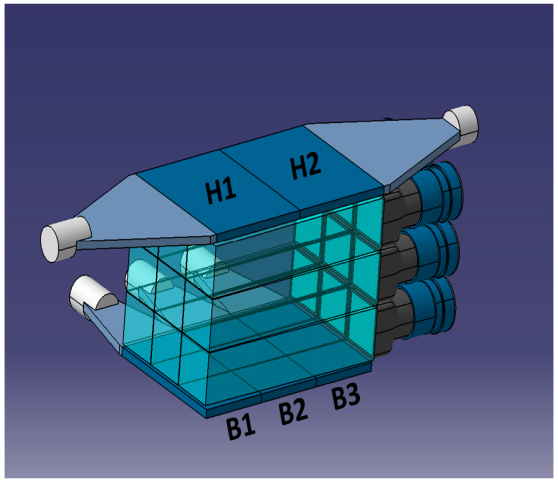
Coincidence signals generate the trigger for cosmics measurements.

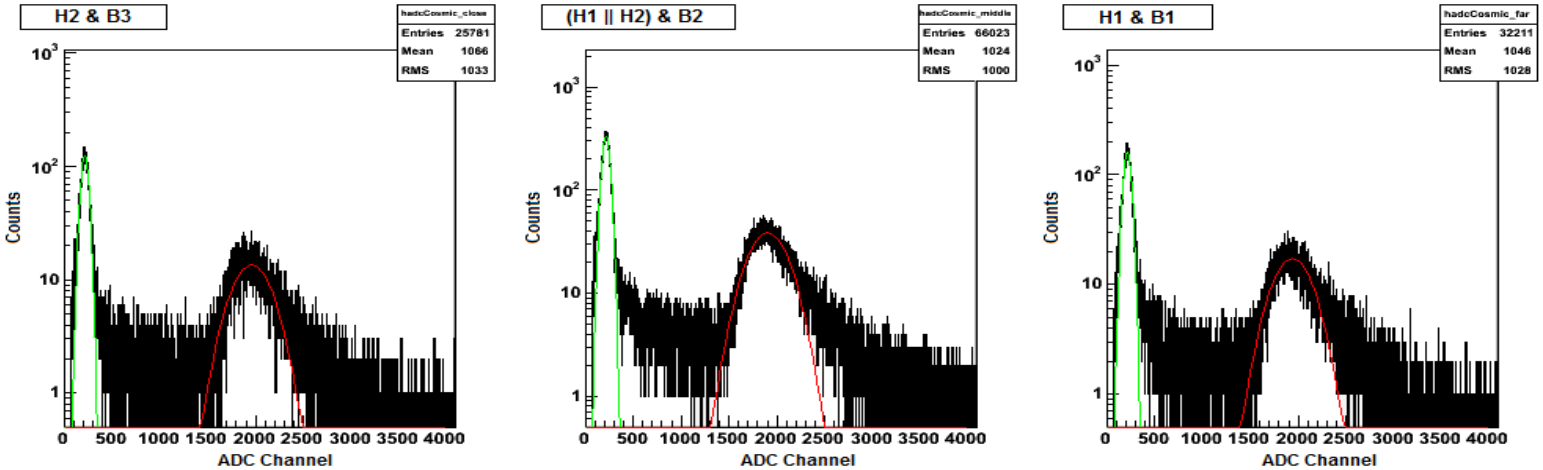
All the scintillators are easily removable

Polarimeter & cosmic rays

Minimum requirement: 2 signals in coincidence, 1 from one of the top and 1 from the bottom paddles

	Values
$E_{mip(\mu)}$	~40 MeV
Rate	1 Hz
Signal Amplitude	~140 mV





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

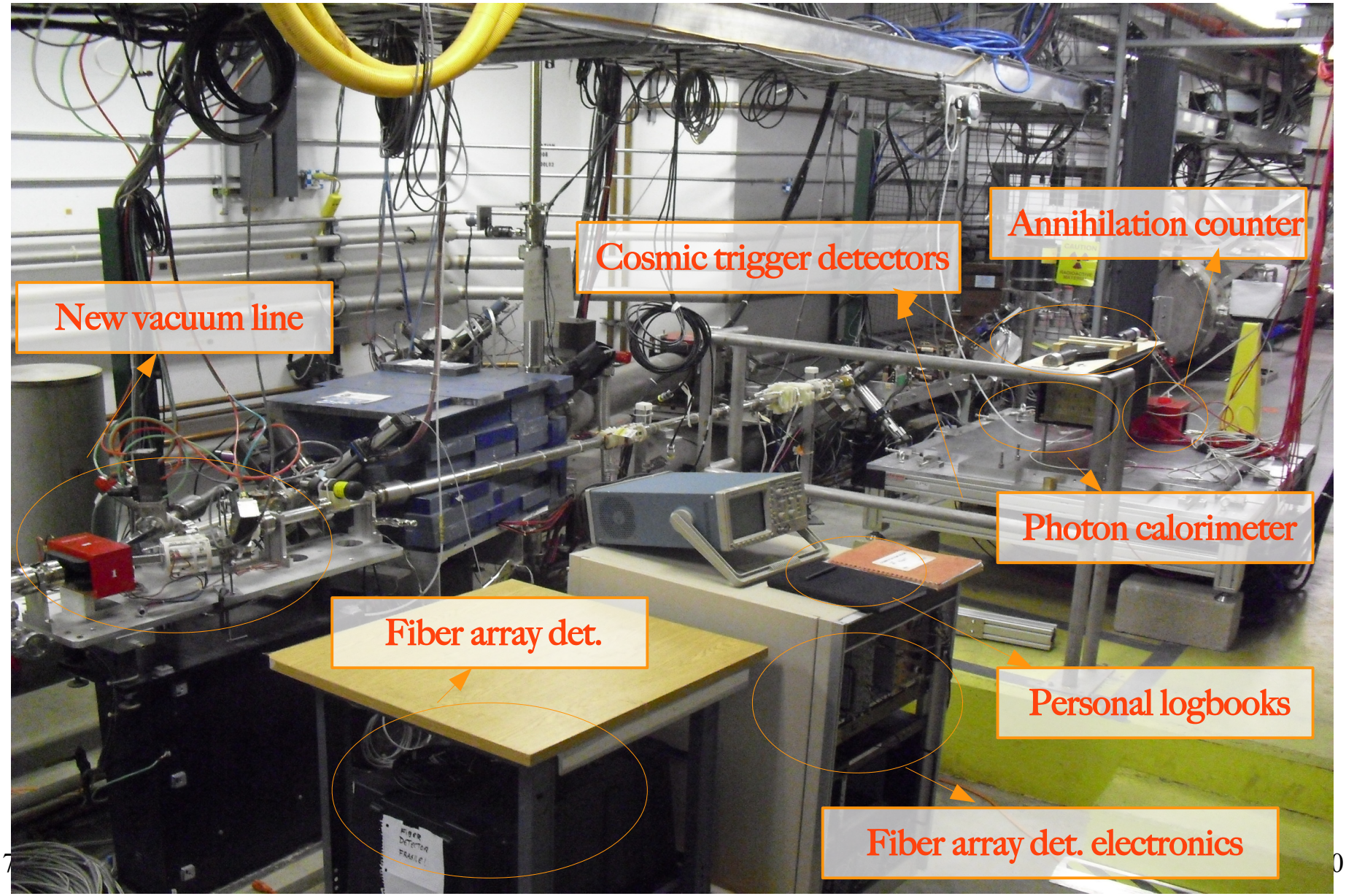
PEPPo's status (1)

PEPPo is not yet taking data! (PAC38)
PEPPo is an experiment under construction!!!
Installation, assembling and characterization of all subdetectors and of the DAQ are ongoing

In the experimental area there are:
-) New vacuum beam line
-) Annihilation counters
-) Fiber array detector
-) Polarimeter

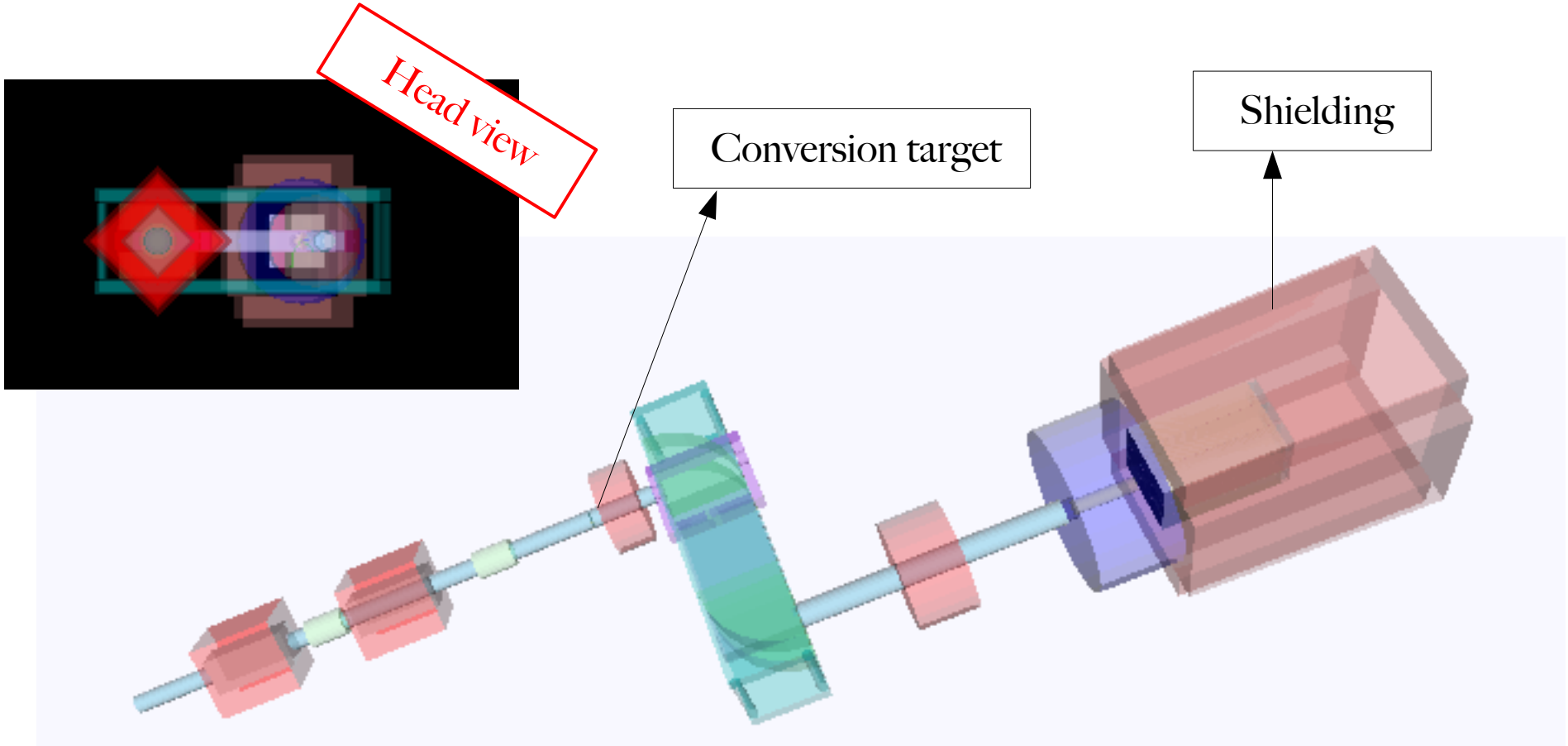
How PEPPo is and could be?

PEPPo's status (2)



Paula Aguilera; Olivier Dadoun; Jonathan Dumas; Paul Guèye

PEPPo's status (3)



Also model and simulation studies are progressing :)

Simulations

The necessity to optimize the experimental apparatus and to study physics performances => a simulation project was developed.
To study of the beam shape parameters => technical and physical requirements are taken into account to define the optimal data taking conditions

Region 0
Region 1

Elegant code was used to investigate the e- beam optics

Insertion of 2 quadrupoles to reduce the horizontal dispersion

Region 2
Region 3
Region 4

Geant 4 + SLAC E166 sim. tool adapted to PEPP0

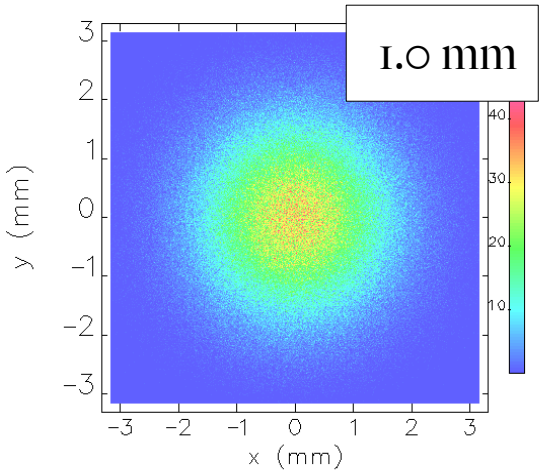
Hardware parameter optimization & physics studies

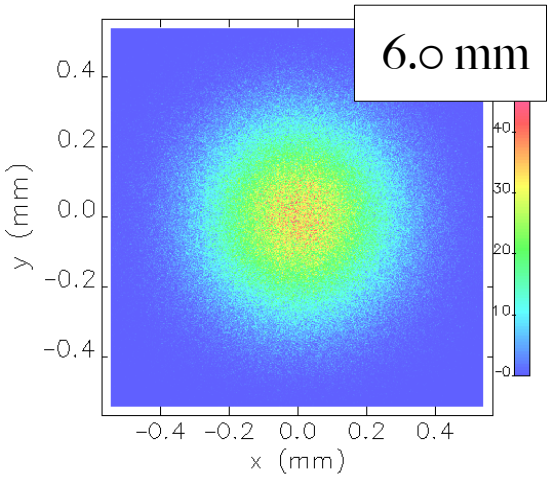
Yujong Kim

Beam diagnostic simulation

The Elegant simulation tool is used to study particle transport in an accelerator device => from Region 0 to Region 1 (up to the conversion target).
The obtained simulation showed a large spot size at the target level.

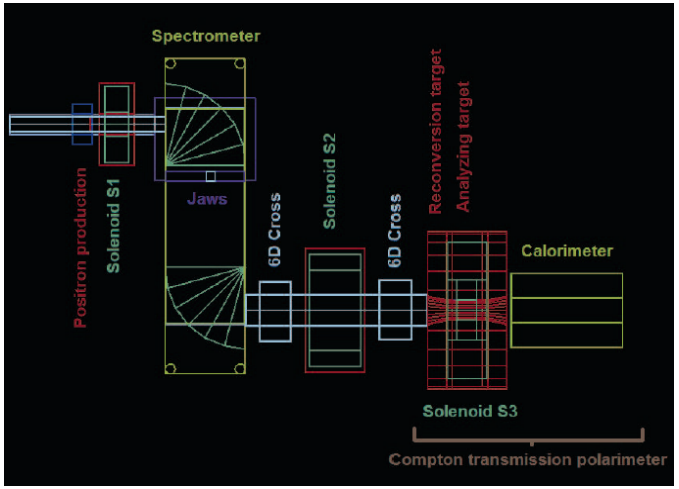
To reduce the horizontal dispersion 2 quadrupole were added in the previous design.
The optimization of the quadrupole => define a symmetrical gaussian profile at the target
=> possibility to adjust the beam diameter from 1.0 mm to 6.0 mm





Geant4 simulation

Geant 4 is a MonteCarlo simulation toolkit => Implementation of the PEPPo detector structure.
It is used for tracking charged particles traversing the modelled structure.



1) It was implemented from the already existing code of E166 experiment
2) It was modified with the new PEPPo design
3) It was attached to the injector beamline

1) Standard electromagnetic package => e- will have momentum lower that 8MeV/c

2) Polarization packages
3) Optical package

Cooking

Dissolve the brewer's yeast in the water and mix it with flour and salt.

After the rising (2h) process,the dough must be formed by hand without the help of a rolling pin or other machine.

It may be no more than 3 mm thick.

Put the tomato sauce on the dough, spread mozzarella cheese, olive oil and few levees of fresh basil!

The pizza must be baked for a couple of minutes in a wood oven.

When cooked, it should be crispy, tender and fragrant.

Eric Voutier; Johnatan Dumas

Polarization

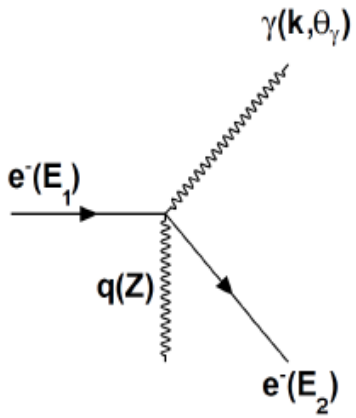
Bremsstrahlung and pair production are 2 electromagnetic processes that can occur when particles traverse matter.

- These phenomena are well described and known :)
- Polarization phenomena in these processes are not well known and described
  OM => H. Olsen, L. Maximon, PR114 (1959) 887
  KBST => E.AKuraev, Y.M. Bystritskiy, M. Shatnev, E.Tomasi-Gustafsson, PRC 81 (2010) 055208.
  :(

Practical reason

difficulty to access to high polarized and high current sources

Bremsstrahlung



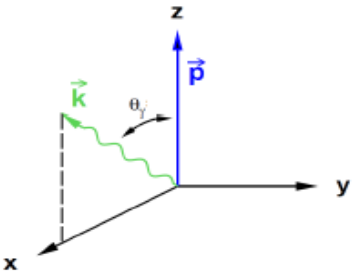
Electromagnetic radiation produced by charged particles (especially $e^{\pm}$) during a deceleration or deflection passing nearby the strong electric fields of atomic nuclei.

Considering the polarization transfer:

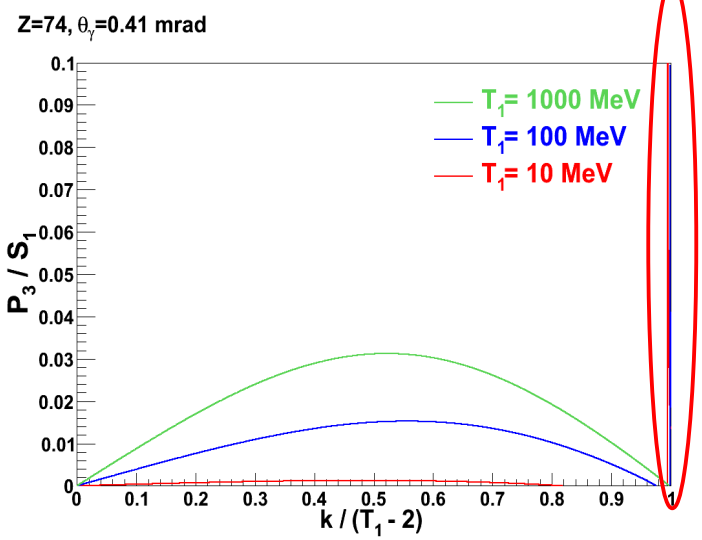
- ✔ Bremsstrahlung reaction yields a linearly polarized photon beam independently of the initial electron beam polarization.
- ✔ Circularly polarized photon beam can be obtained from a transversely or a longitudinally polarized electron beam.
- ✔ The process is insensitive to the perpendicular polarization.

Polar. Bremsstrahlung

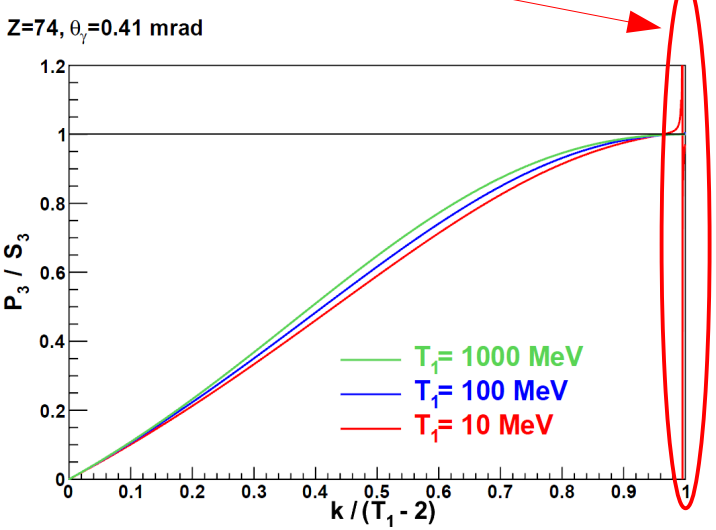
Considering the OM prediction in Born approximation for relativistic particles the photon circular polarization => The energy spectra shows singularities



Tip 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

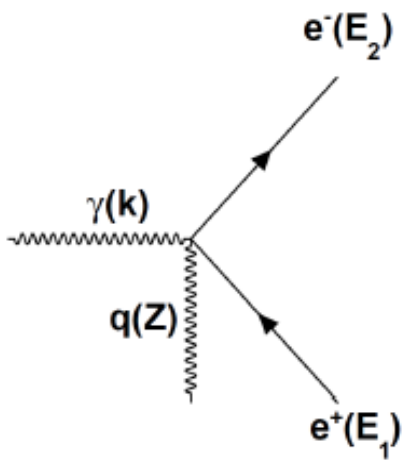


from transversely polarized electrons



from longitudinally polarized electrons

Pair production



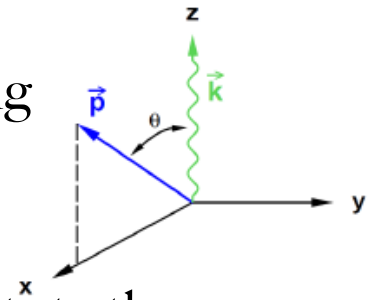
It is a threshold process. The photon energy must exceeds twice the rest-mass energy of an electron (1.02 MeV).
It is the interaction, in the coulomb field of a nucleus, of a photon which materializes by an electron-positron pair.

Pair creation and bremsstrahlung reactions are reciprocal processes => look at the Feymann diagrams

- Physics observables can be obtained from bremsstrahlung with simple substitutions :)
- Cross section suffers from the same singularities observed at low and high energy of the bremsstrahlung spectra :(

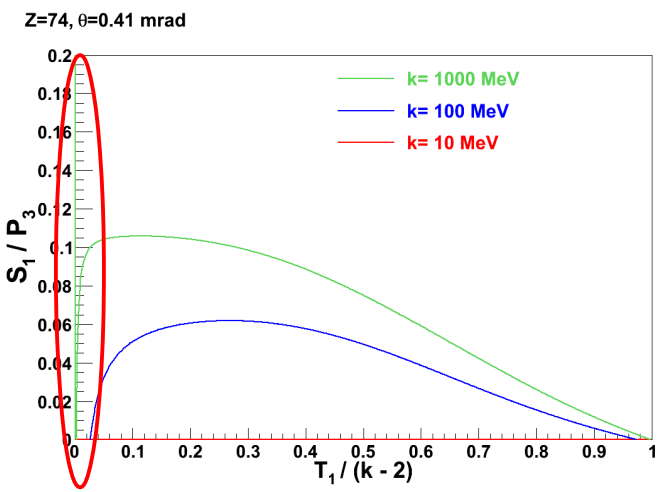
Pol. Pair production

Circularly polarized photons create a polarized $e^{\pm}$ pair. The resulting polarization has two components: transverse and longitudinal (the latter dominates in most of the cases).

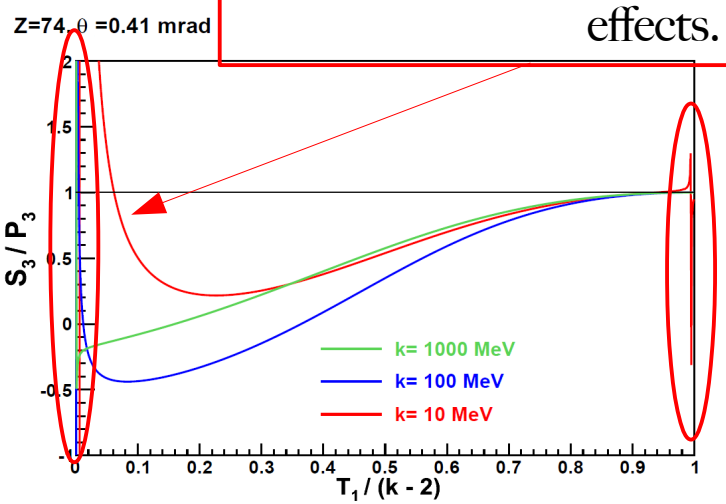


Considering the OM prediction the polarization transfer components to the $e^{\pm}$ from a circularly polarized photon:

Unphysical polarization transfers shown at small energy over the full kinematic range => independent of Coulomb correction effects.



transvers component



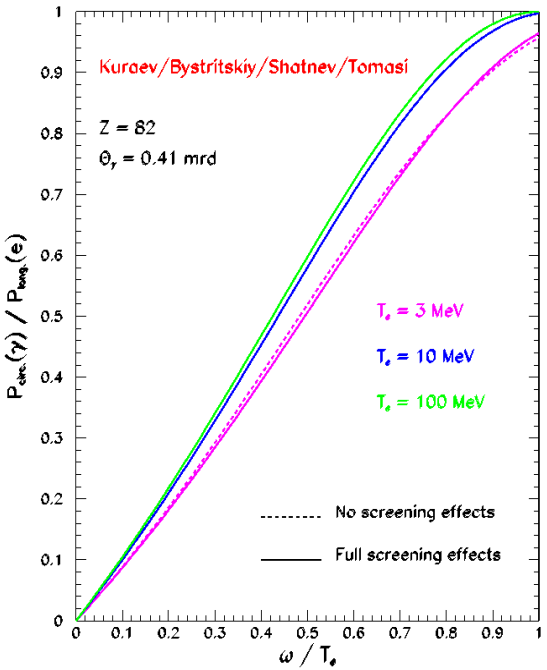
longitudinal component

KBST model

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

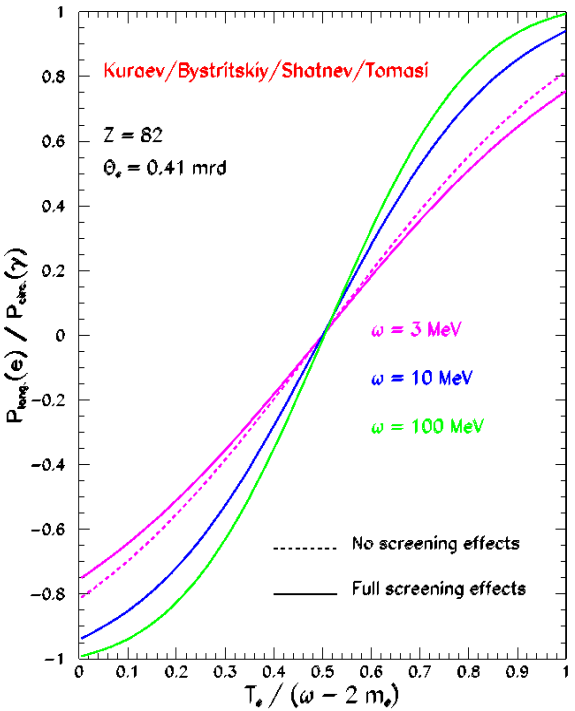
Considering the low energy case:

Bremsstrahlung



- ✔Kinematic symmetry
- ✔Singularities disappear
- ✔Significant effect also at high energies

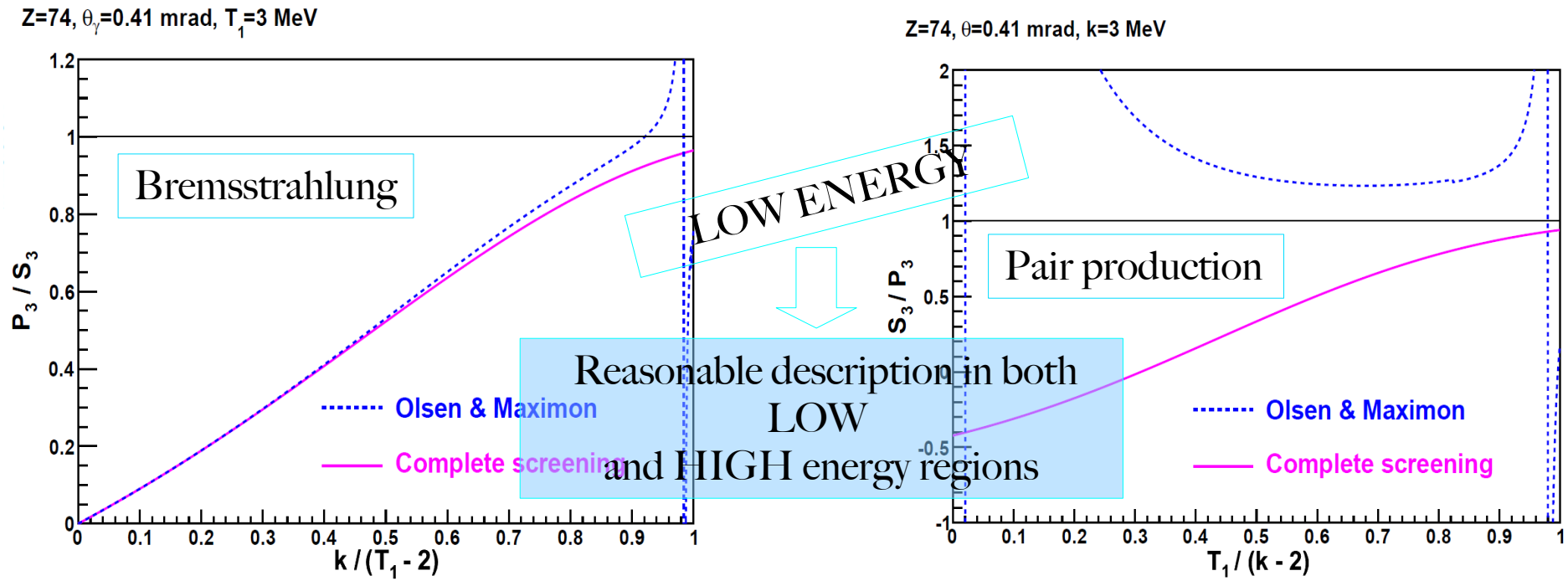
Pair production



Polarization in Geant4

Geant 4 polarization package includes only the regularized OM model.
The standard OM model was already included.

Coulomb screening => It is an empirical extrapolation of the experimental observables
=> Included in G4



Photon circular polarization from longitudinally polarized e-

$e^{\pm}$ longitudinal polarization from circularly polarized photons

Polarization in Geant4

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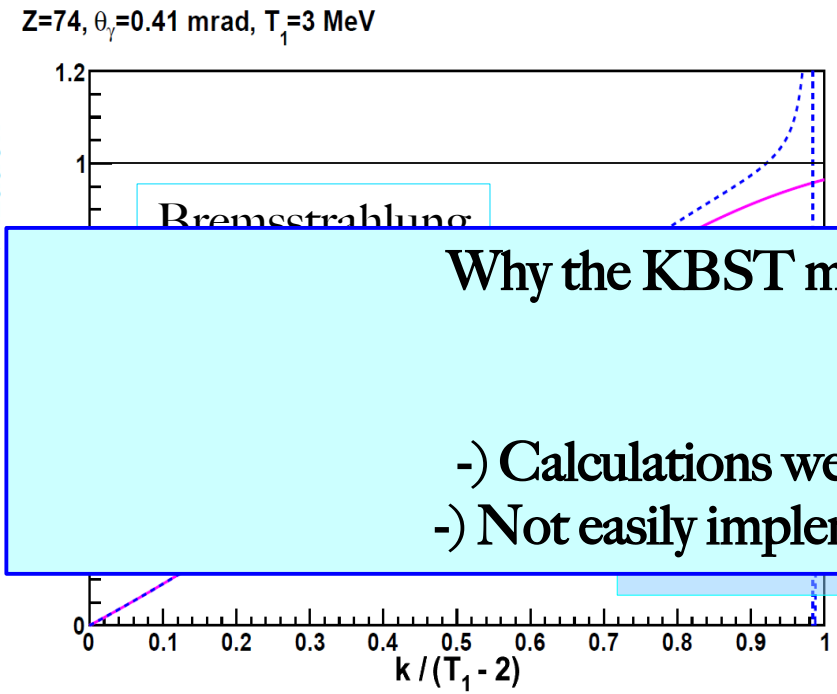
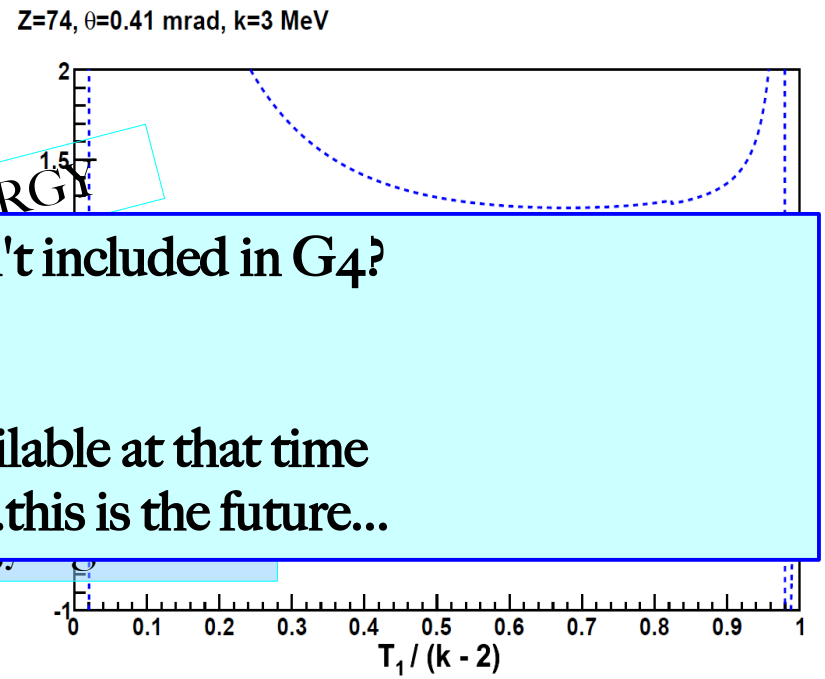


Photon circular polarization from longitudinally polarized e-



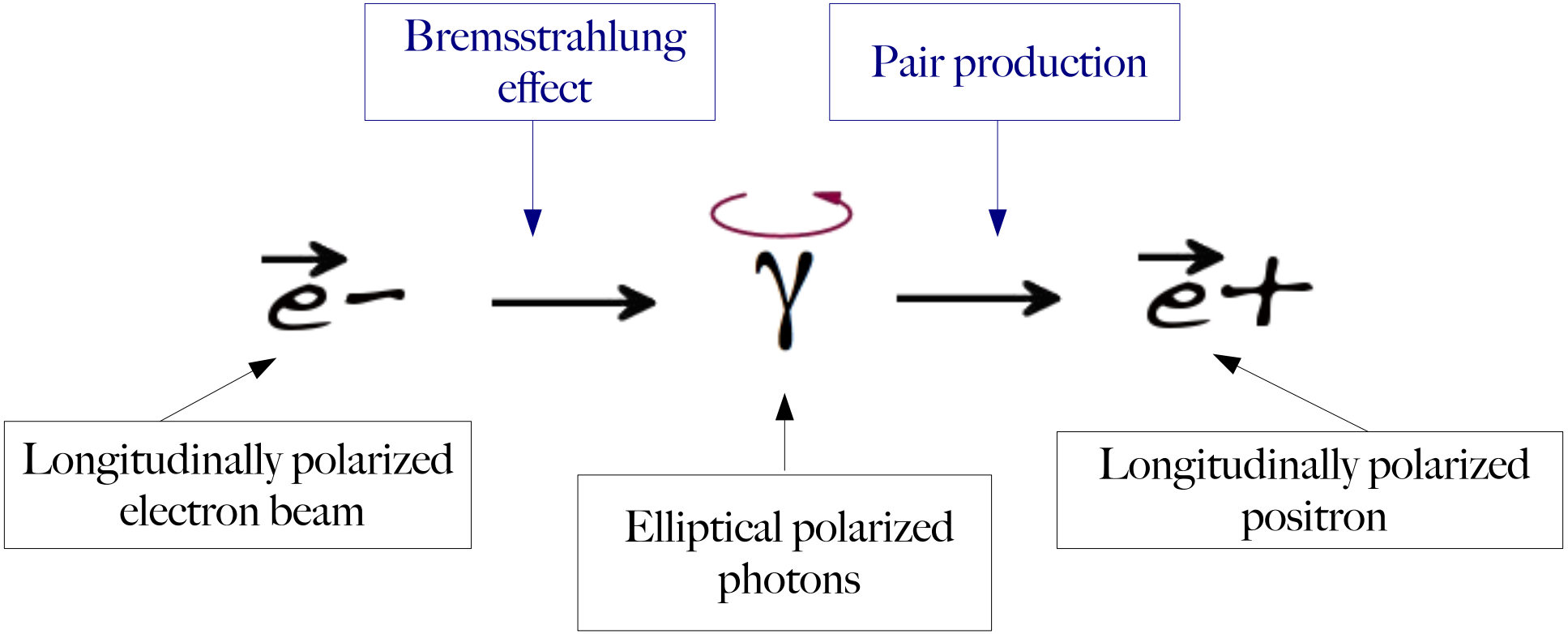
$e^{\pm}$ longitudinal polarization from circularly polarized photons

Why the KBST model wasn't included in G4?

Simple...
-) Calculations were not available at that time
-) Not easily implementable...this is the future...

PEPPo polarization

In the PEPPo conversion target:



The linear polarization component of the photons is independent of the initial polarization and does not transfer to positrons.

Physics measurements

The aim of the experiment is to measure polarization as a function of the positron energy

Precision measurements depend on the positron polarization and current

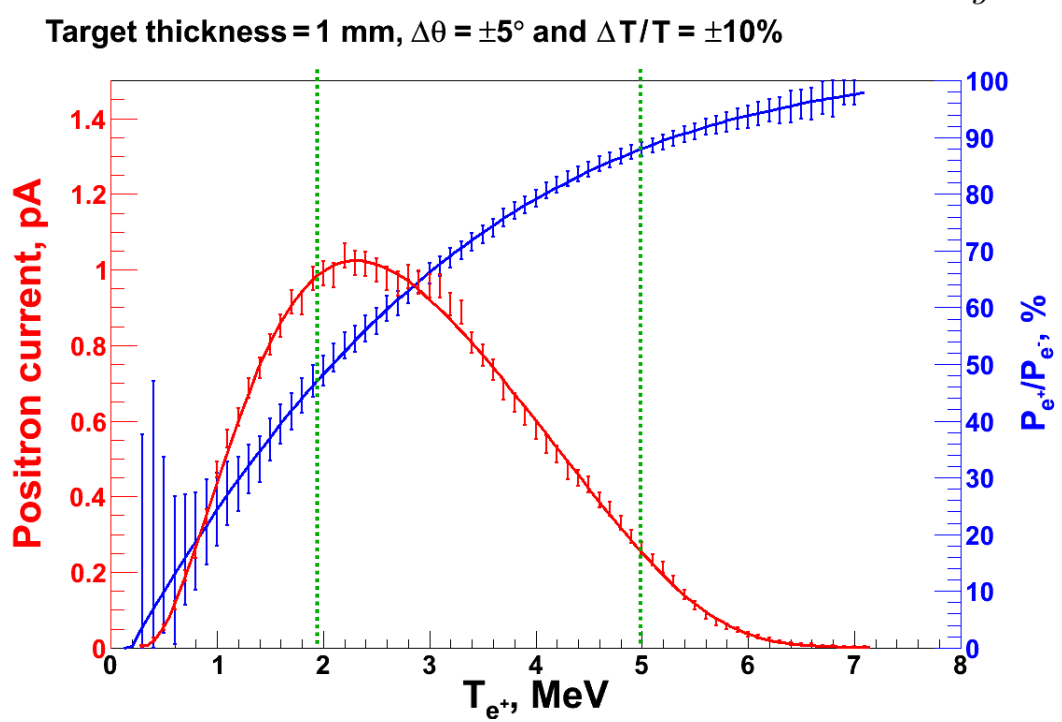
$TargetThikness = 1mm$

$T_{e^-} = 8MeV$

$I_e = 1\mu A$

$\Delta T/T = 10\%$

Energy region experimentally accessible



Polarization transfer (1)

A step back: existence of an analyzing magnet with a reconversion target.
Photons coming out of the reconversion target are transmitted by the polarized iron target and detected by the CsI

- ✔ Calculations made for a mono energetic photon beam
- ✔ In first approximation the linear polarization is considered negligible

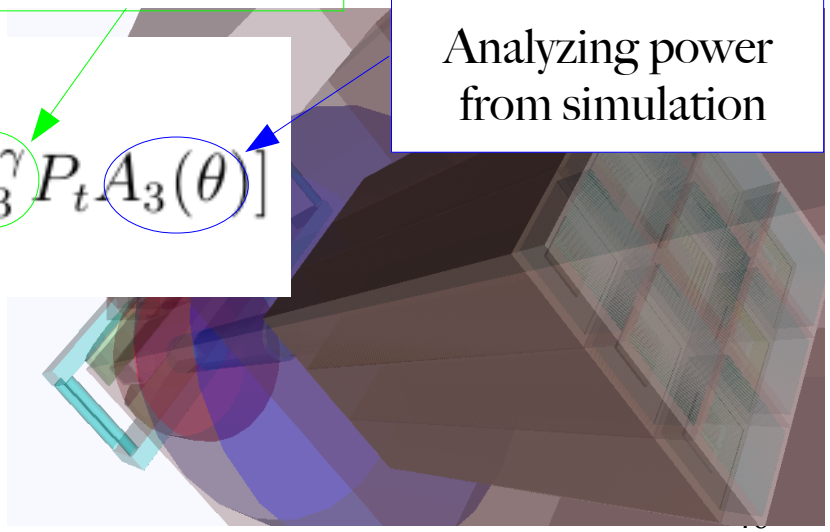
Unpolarized Compton cross section

Circular photon polarization component

Analyzing power from simulation

$$\frac{d^2\sigma}{d\theta d\phi} = \frac{d^2\sigma^0}{d\theta d\phi}\left[1 + P_3^{\gamma} P_t A_3(\theta)\right]$$

Compton differential cross section for a polarized γ (ω_o) on a longitudinally polarized (P_t) target



Polarization transfer (2)

Measurements of the photon asymmetry obtained reversing the beam polarization or/and the polarization of the target generate of an asymmetry proportional to **P3**

$$A_T = \frac{N^+ - N^-}{N^+ + N^-} = \tanh(-P_3^\gamma P_t \mu_1 L)$$

N+ and N- are the number of detected photons with opposite polarizations

Compton absorption coefficient

The experimentally asymmetry can be always seen as the product of the polarization of the electron (Pe) of the target (Pt) and the analyzing power of the polarimeter

$$A_T = P_e \, P_t \, A_e$$

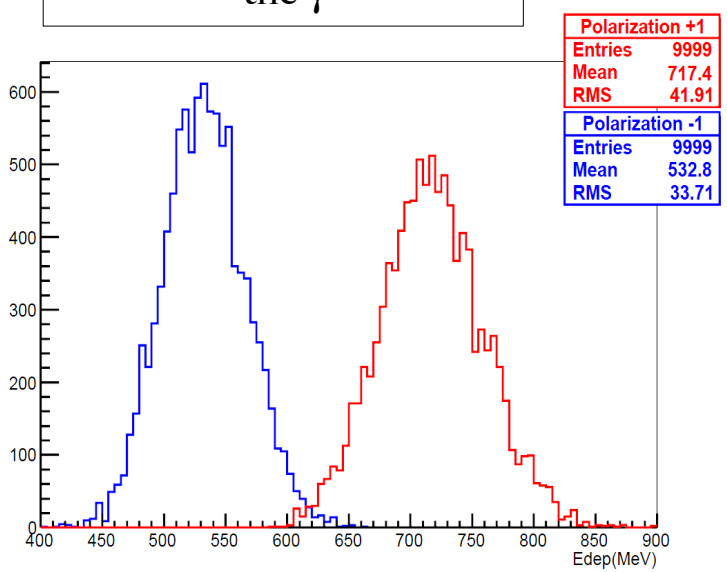
Integrated mode (1)

PEPPO has developed 2 data taking methods

Integrated method

Integration over all the energy deposited, in the iron target, between 2 spin flip of the electron beam

Experimental conditions => energy distribution of the γ



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

$$E_i^{\pm} = N_e^i \sum_j \varepsilon_j^{\pm} e_j$$

Number of e^- or e^+ per helicity event

Probability to produce and detect a photon of energy e_j

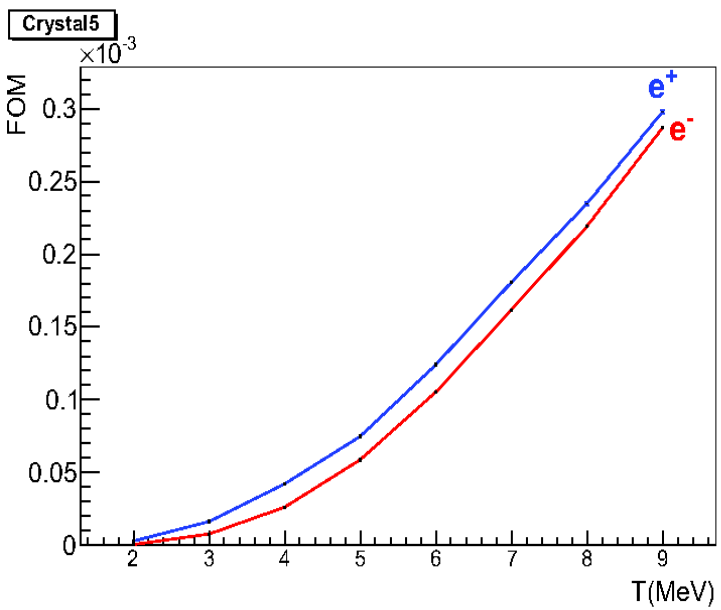
$$\varepsilon_j^{\pm} = \varepsilon_j^0 \pm P_e P_t \varepsilon_j^3$$

Integrated mode (2)

$$A_T = P_e\, P_t \left[\sum_j \varepsilon_j^3\, e_j \Big/ \sum_j \varepsilon_j^0\, e_j \right]$$

The asymmetry is proportional to the analysing power of the polarimeter A_e

$$A_T = P_e\, P_t\, A_e$$



And the statistical uncertainty:

$$\delta P_e = \left[2 N_e\, P_t^2 \sum_j \varepsilon_j^0\, A_e^2 \right]^{-1/2}$$

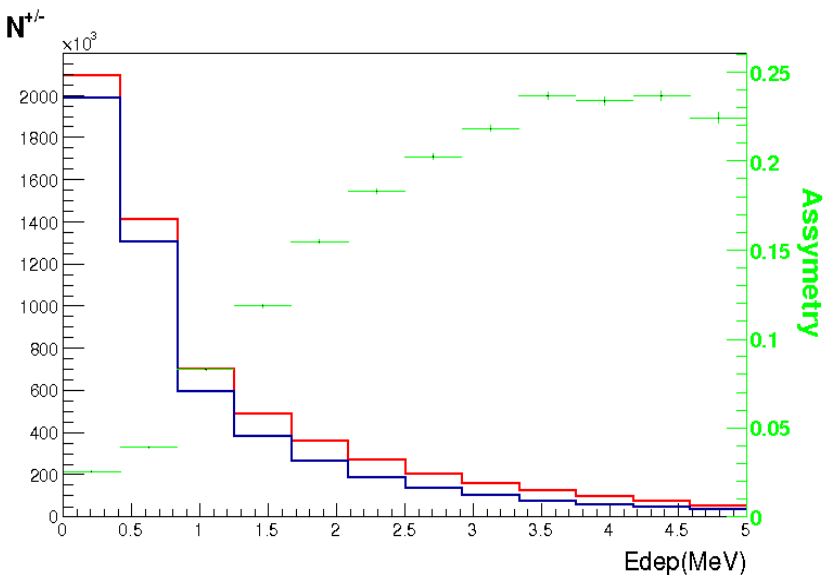
Figure of Merit (FoM) characterizes the performances of a polarized source

Semi-integrated mode

Recording the number of particle per energy bin during each helicity state of the e^- beam

$$A_T^j = \frac{n_j^+ - n_j^-}{n_j^+ + n_j^-} = \left[\sum_i n_{ij}^+ - \sum_i n_{ij}^-\right] \Big/ \left[\sum_i n_{ij}^+ - \sum_i n_{ij}^-\right]$$

$$A_T^j = P_e\, P_t\, A_e^j = P_e\, P_t \left[\frac{\varepsilon_j^3}{\varepsilon_j^0}\right]$$



And the statistical uncertainty:

$$\delta P_e = \left[2 N_e\, P_t^2 \sum_j \varepsilon_j^0 (A_e^j)^2\right]^{-1/2}$$

Energy spectra obtained with 5 MeV incident particles at the reconversion target

FoM_{SI}

Conclusions

PEPPo is an experiment to test the feasibility to produce highly spin polarized positrons from a polarized electron beam.

First simulations and calculations done to understand the feasibility of the technique are promising and motivate our progress

First tests and measurements of the already existing elements, a new design and more detailed simulations are ongoing

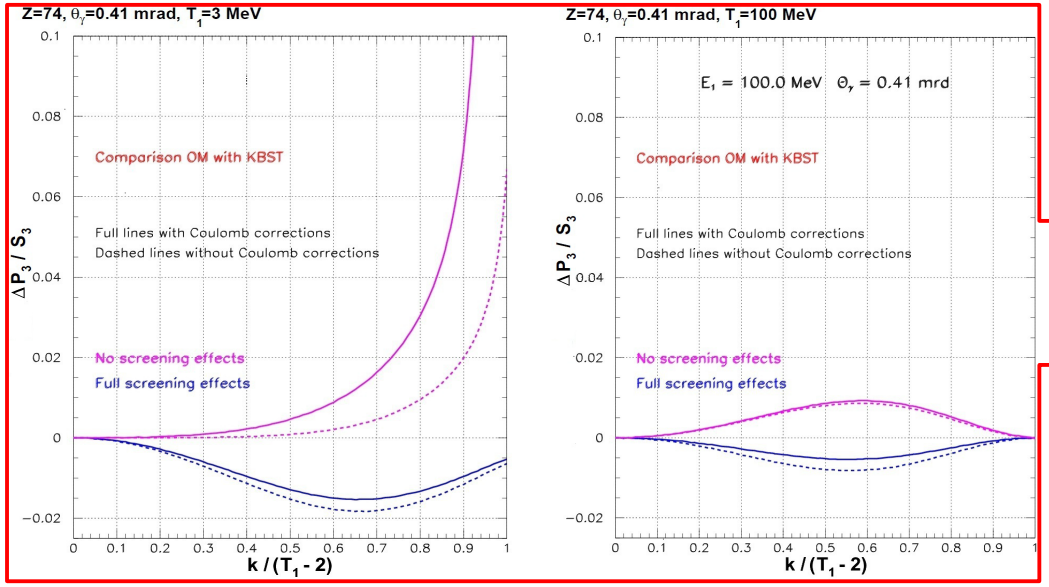
A lot of work has been done and remains to be done for data taking...
...but all the people involved are enthusiastic and are working well...
to be ready!

The idea is amazing as the future issues that can be explored (GPDs...)

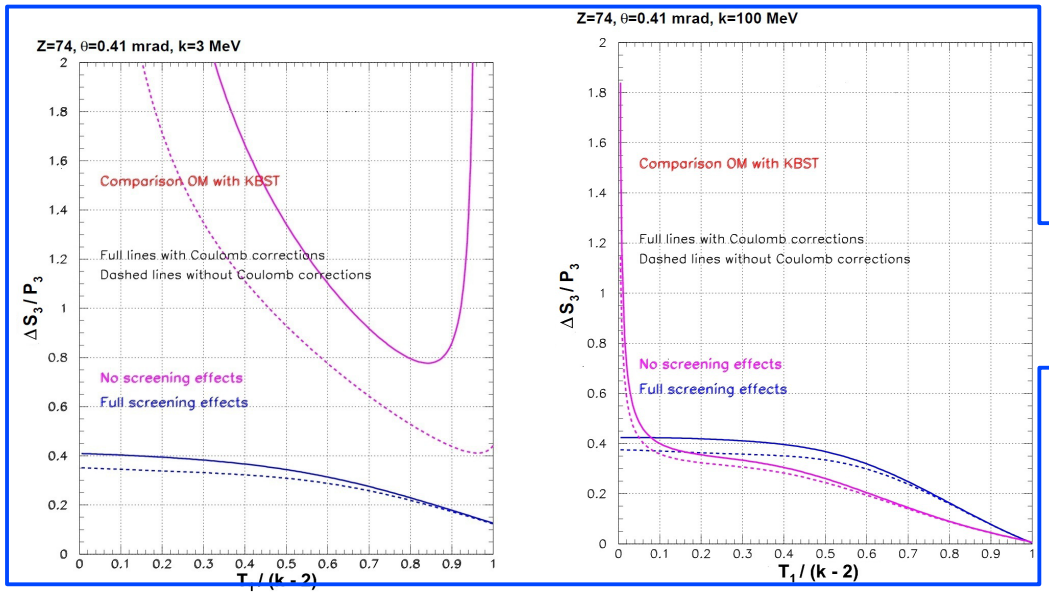
Enjoy!

Spare Slides

OM Vs KBST



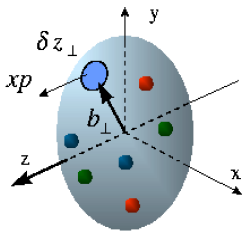
Bremsstrahlung

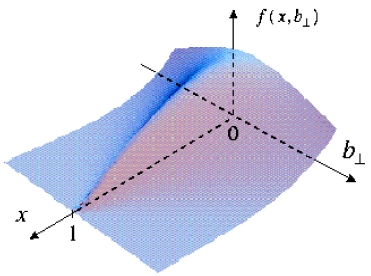


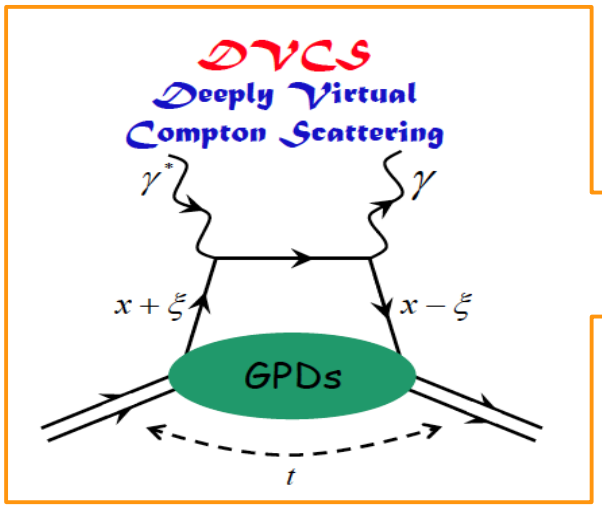
Pair Creation

Generalized Parton Distributions

GPDs are a framework describing the partonic structure of hadrons giving access to the spatial distribution of partons inside the nucleon.







The cross section of the DVCS can be expressed as a convolution of 2 term. One known hard scattering term and an unknown soft matrix element related to GPDs

Cross section term independent to the target polarization S

Polarized positron beam sensitivity

$$\sigma(ep \rightarrow ep\gamma) = \sigma_{P0} + S\,[P_l\,\Delta\sigma_{BH} + P_l\,\Delta\sigma_{DVCS} + \Delta\tilde{\sigma}_{DVCS} + P_l e_l\,\Delta\sigma_{INT} + e_l\,\Delta\tilde{\sigma}_{INT}]$$

8 variables to be determine => 8 independent observables => can be determined ***ONLY combining polarized e- and polarized e+ data!***