EUROPEAN WORKSHOP ON PHOTOCATHODES FOR ACCELERATOR APPLICATIONS (EWPAA) –ELECTRON SPIN POLARIZATION RELATED ACTIVITIES IN EUROPE

Polarized Sources and Targets Workshop

PSTP-24

Wednesday, SEP 25. 2024

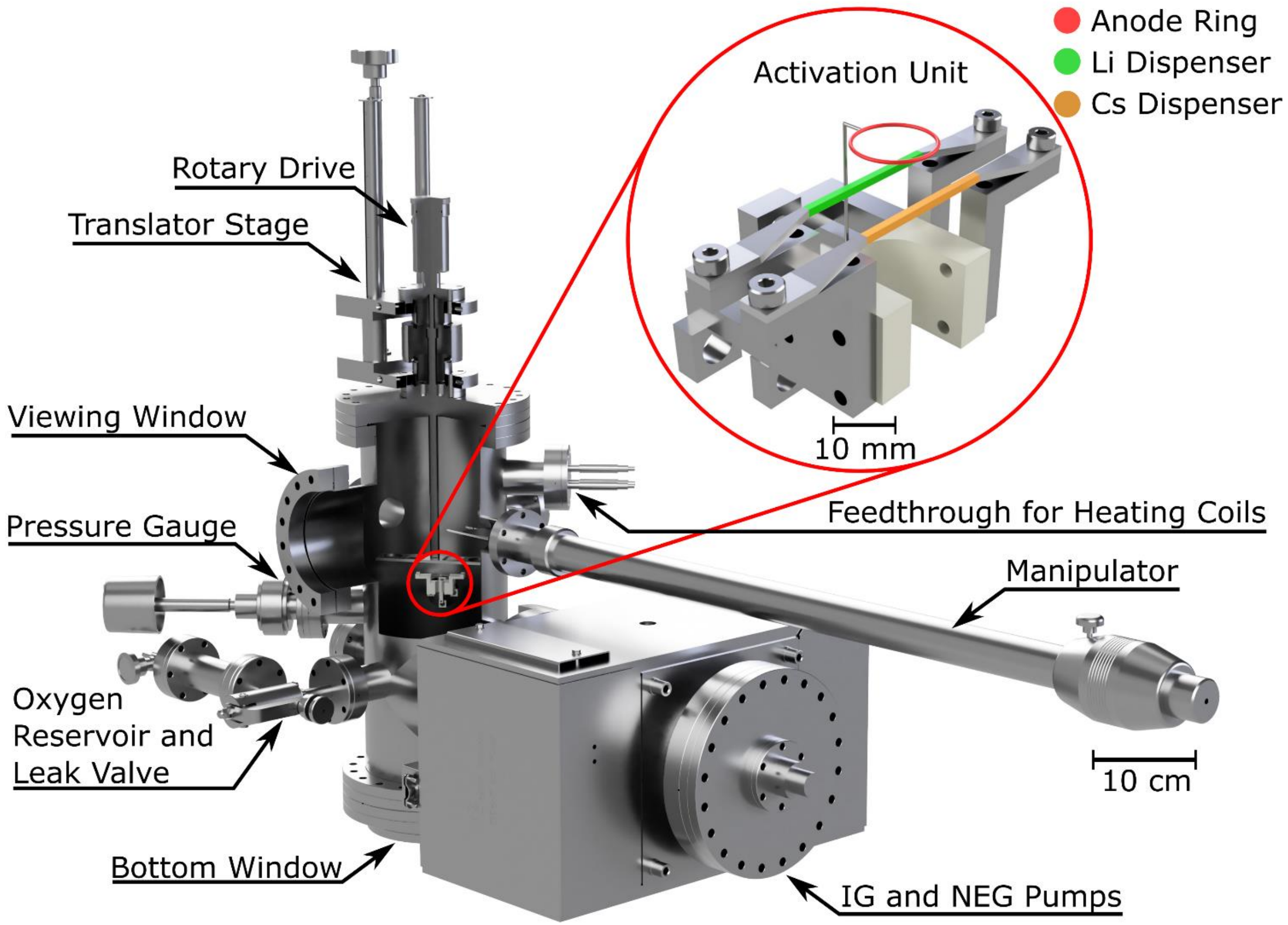
Kurt Aulenbacher

Institut für Kernphysik der Universität Mainz

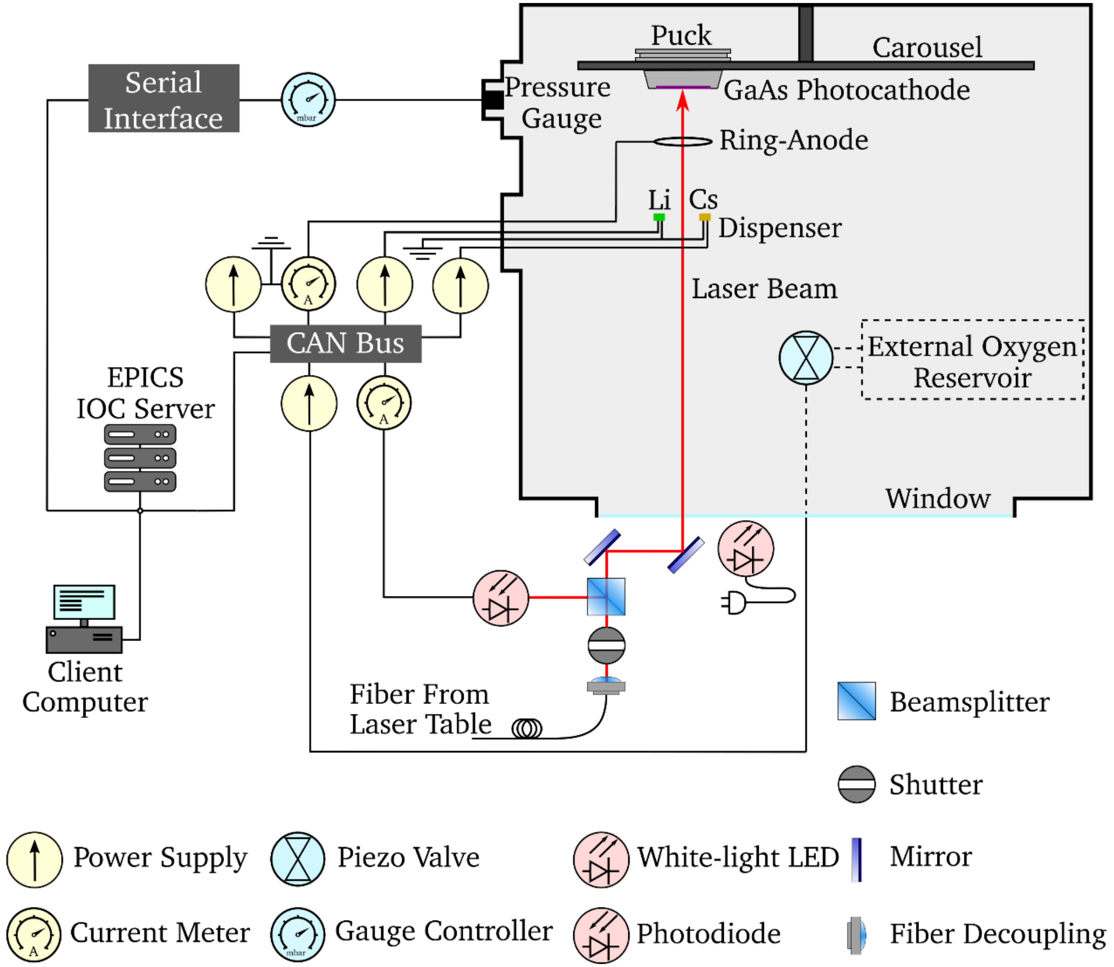
Outline-

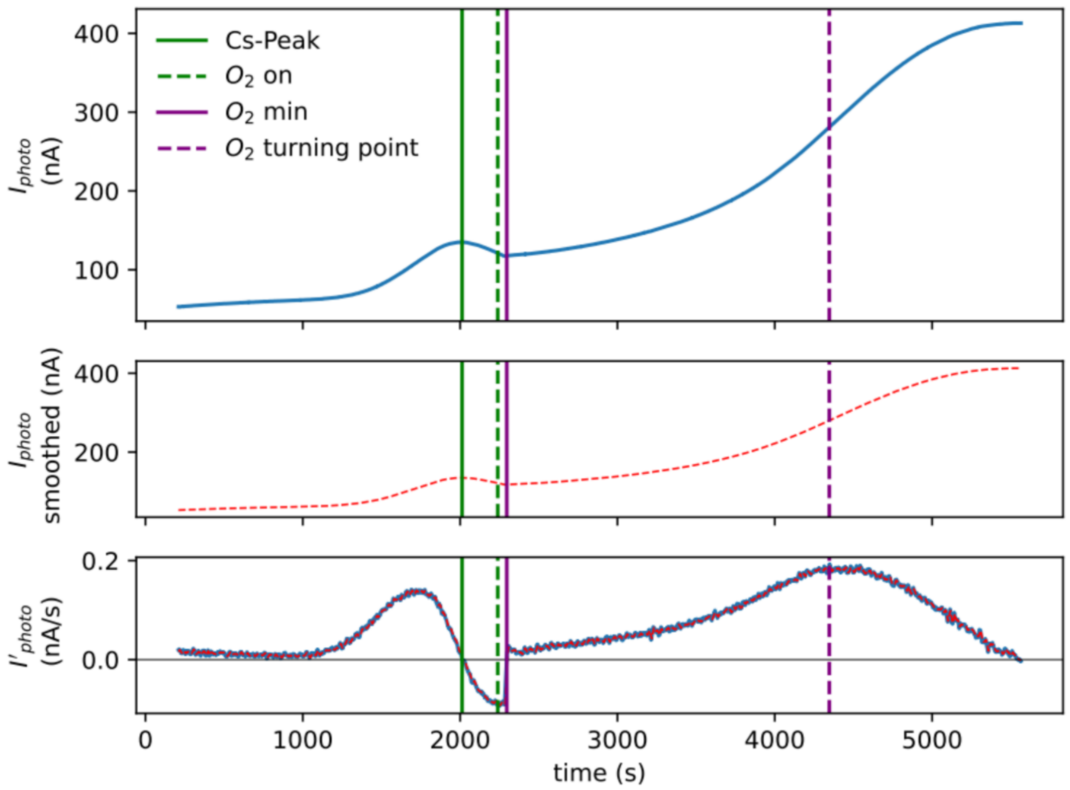
- NEA-GaAs lifetime work at Darmstadt
- Spin polarization drift of NEA cathodes
- Sustainable photocathode supply
- Low intensity spin polarized positron sources: Mainz/Dresden/Munich
- A new polarimeter idea - the „Colliding beam Möller polarimeter“

TU-Darmstadt Activities



M. Herbert, TU-Darmstadt- Automatic activation



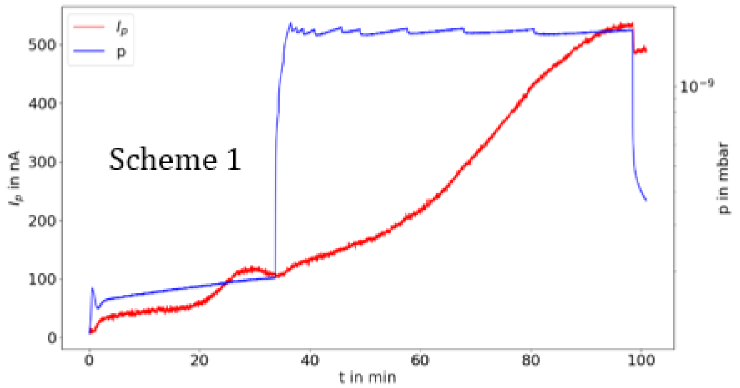


first tests successful!

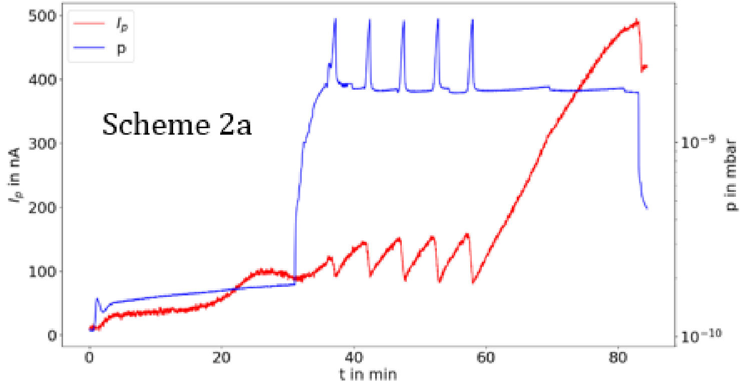
TU-Darmstadt: Lithium „assisted“ activation

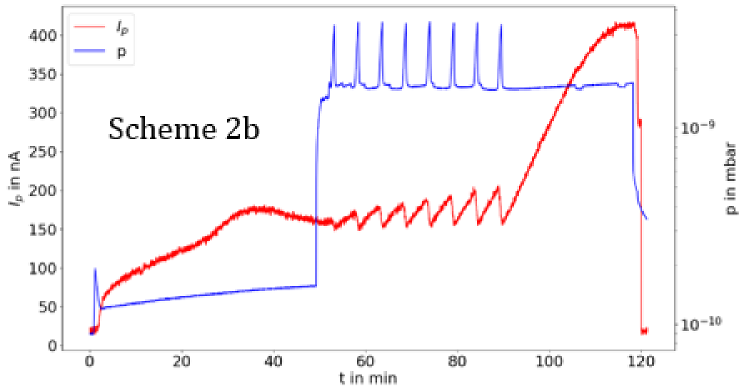
TECHNISCHE UNIVERSITÄT DARMSTADT

Li-enhanced activation



- Goal: enhanced lifetime
- Co-De with pulsed Li, based on previous study
- Scheme 1: Cs + O_2
- Scheme 2a: Cs + O_2 + Li, 5 pulses
- Scheme 2b: Cs + O_2 + Li, 8 pulses



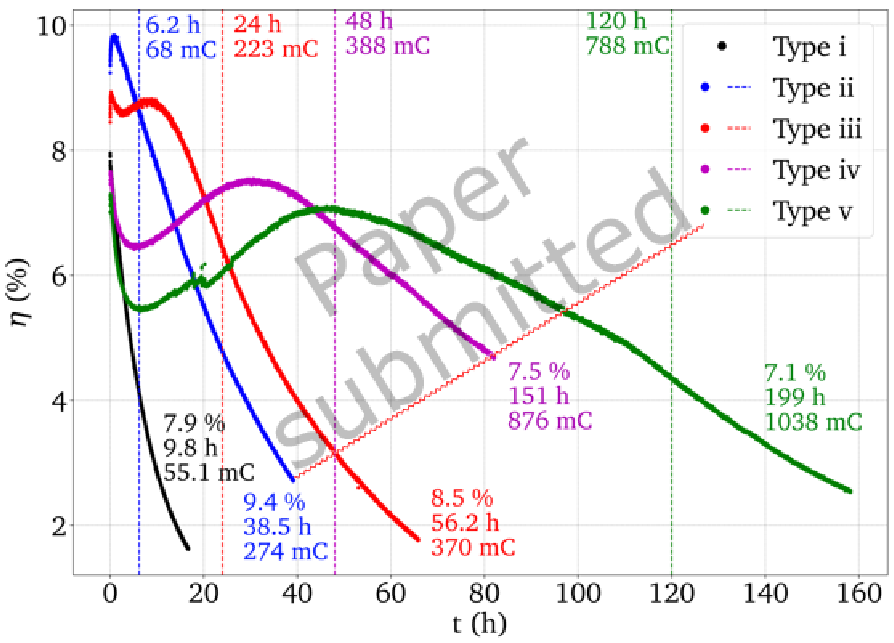


TU-Dar

TU-Da: Lifetime improvement

TECHNISCHE UNIVERSITÄT DARMSTADT

Li-enhanced activation

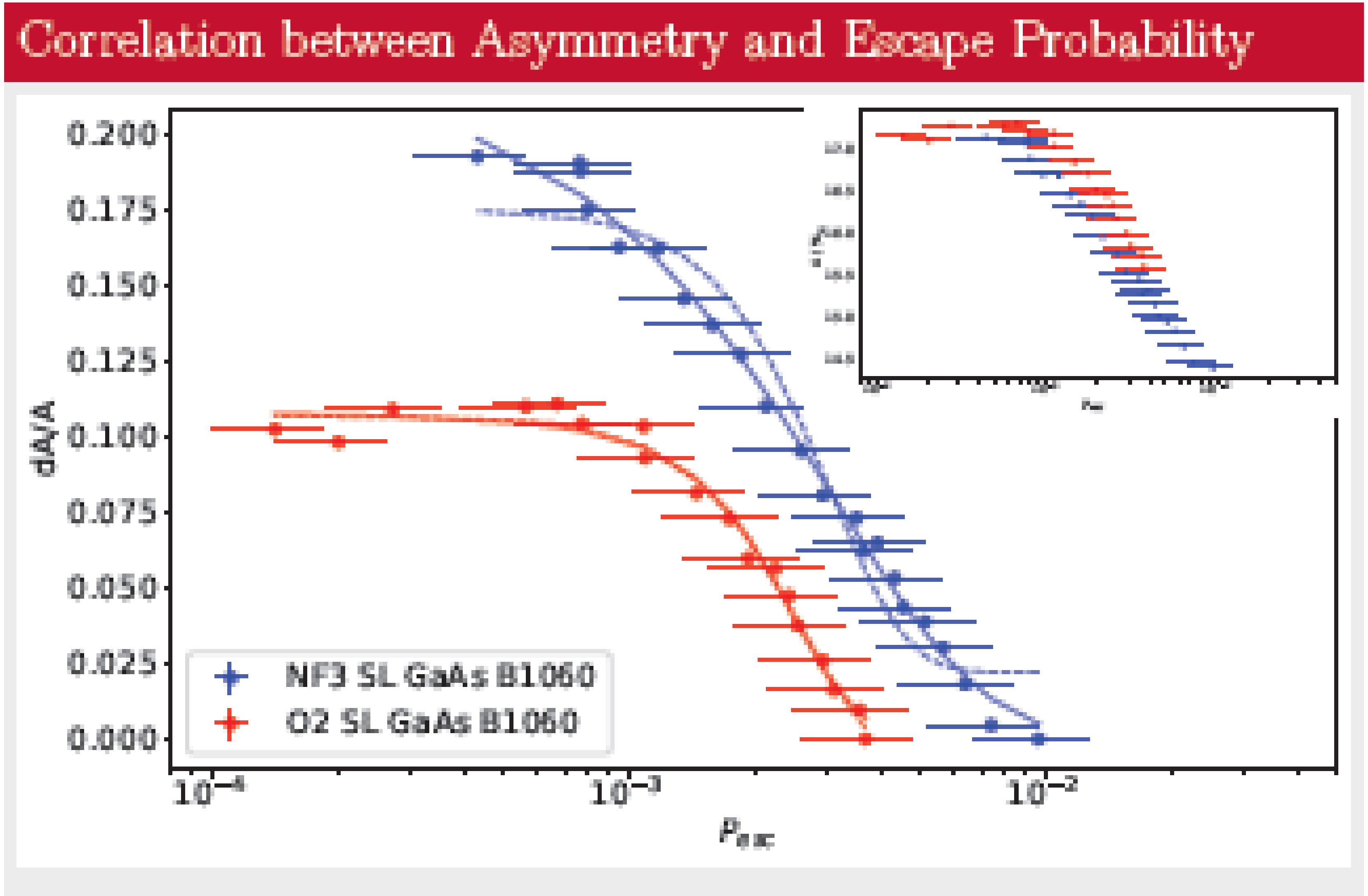


- QE & Lifetime measurements in activation chamber
- P_{laser} = (50 ± 5) μW, λ = (785 ± 2) nm, U_{bias} = 100 V
- 5 types of activations:
  - i. Scheme 1, no prior scheme 2
  - ii. Scheme 1, subsequent to scheme 2a
  - iii. Scheme 2a, subsequent to scheme 1
  - iv. Scheme 2b, subsequent to scheme 1
  - v. Scheme 2b, subsequent to scheme 2b
- Effect of Li on subsequent activations observed

Significat increase in τ (up to factor 19) and Q(τ) (up to factor 16.5) observed!

Tests in DC-HV-gun upcoming!

JGU: Drift of polarization



See also
Talk by J. Trieb
This conference

Positrons in Europe

1. Mainz: Channeling of 600 MeV positrons (polarization on demand)
2. Dresden HZDR: Thermal polarized positron source desired
3. Munich/FRM-2: Acceleration of thermalized (polarized) positrons at NEPOMUK to 1 MeV (MAMI technology, using 3d Printing of acclerator structures)
4. Mainz – target tests for CEBAF-polarized positron source

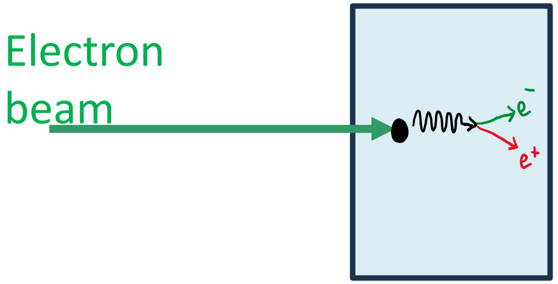
Spin polarized positrons can make use of the electron→photon→ pair production process

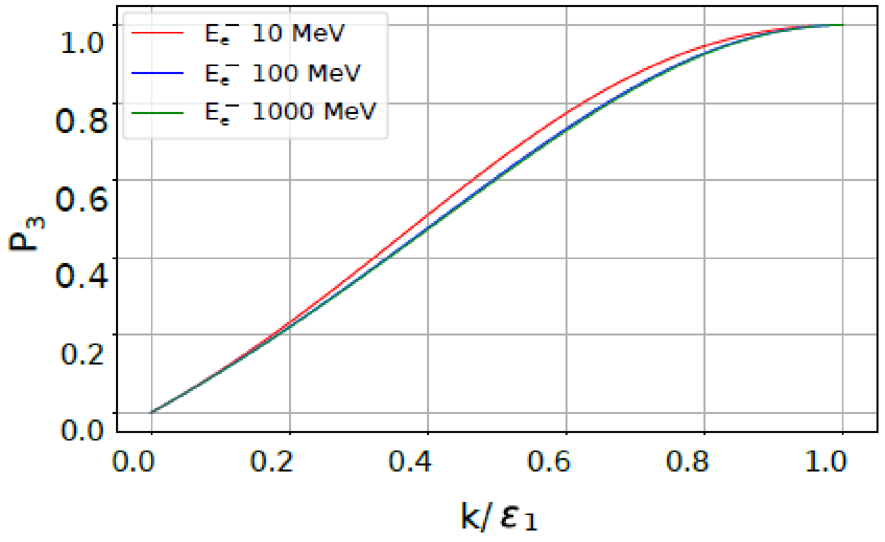
This also generates spin polarized positrons by spin transfer

But will the positrons be polarized too –yes!

Principle demostrated by the PEPPO experiment at JLAB!
 (D. Abbot et al.:
https://link.aps.org/doi/10.1103/PhysRevLett.116.214801})
Thick-targets:
Cross sections and multiple scattering must be taken into
Account→ PhD work by S. Habet at ORSAY for JLAB

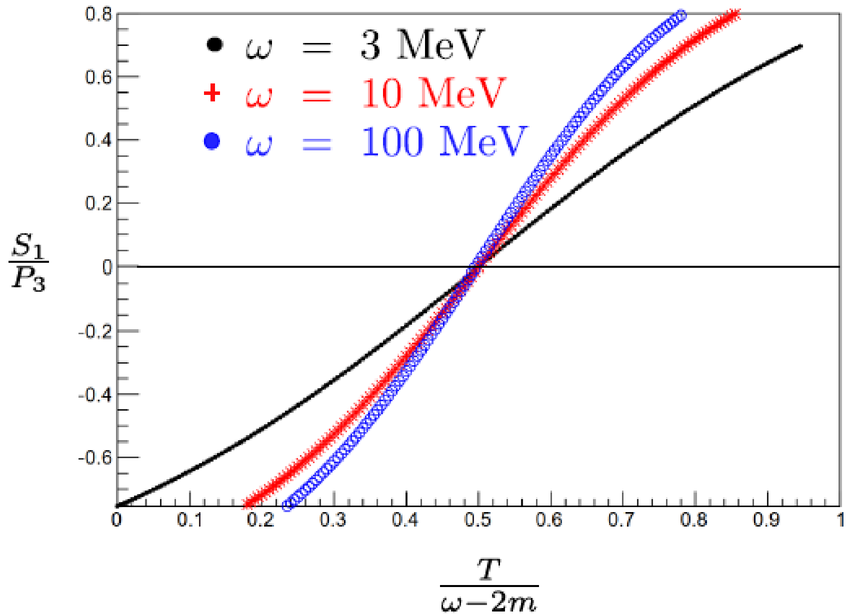
Doube conversion in thin target





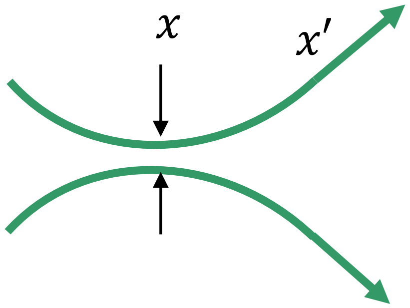
Transfer of electron polarization to photon circ. pol.

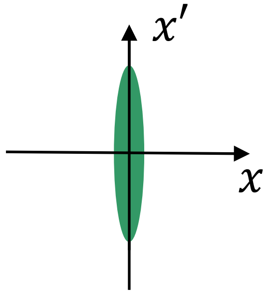
Figures after QED calculations by Olsen et al, taken from:
S. Habet: Concept of a polarized electron source for CEBAF, PhD Thesis, Université Paris-Saclay, CNRS, IJCLab, 91405, Orsay, France. (2023)



Transfer of photon circ. pol. To positron pol

Thin target: „Good“ geometrical emittance of e+ beam….





vertical

MAMI: $\varepsilon_x = x \cdot x'$

$= 1\, mm \cdot \mu rad$

$= 10\ \mu m \cdot 0.1 mrad = 1 nm$

Emittance $\varepsilon_x = x \cdot x' = \frac{F}{\pi} = const$

Thin target for Positron production

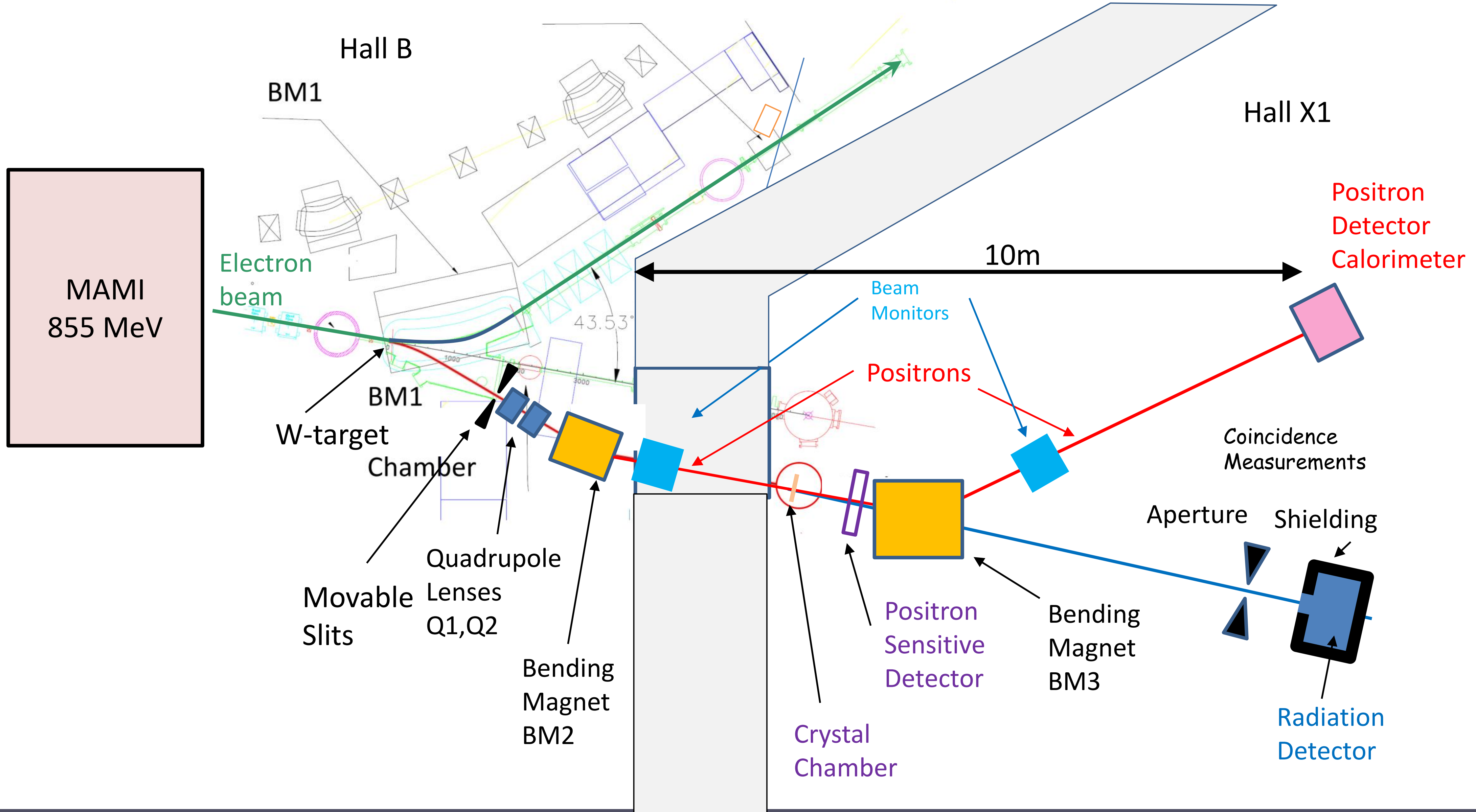
$10\ \mu m\ \ W\ \ \rightarrow Scattering\ \sigma_S = 0.94\ \mathrm{mrad}$

$\sigma_p = \cong \frac{1}{\gamma} = 1\ \mathrm{mrad}\ @500\mathrm{MeV}$

$\varepsilon_{e+} = 10\ \mu m\ \cdot\ 1.4\ mrad$

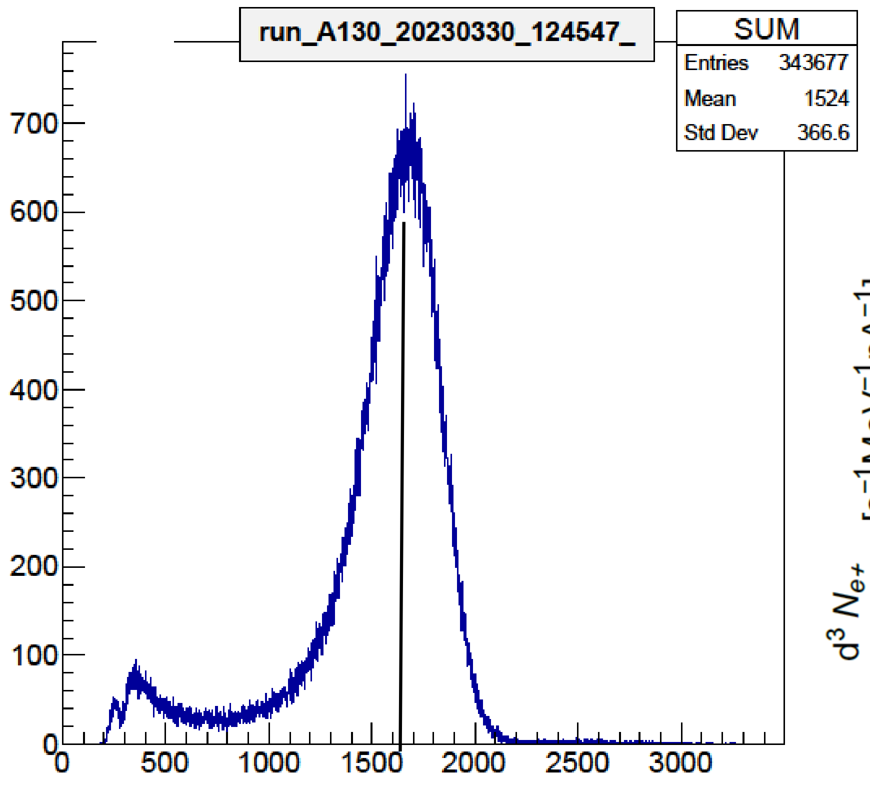
Emittance of Positrons: $= 1 mm \cdot 0.014\ mrad = 14 nm$

Overview Positron beam line

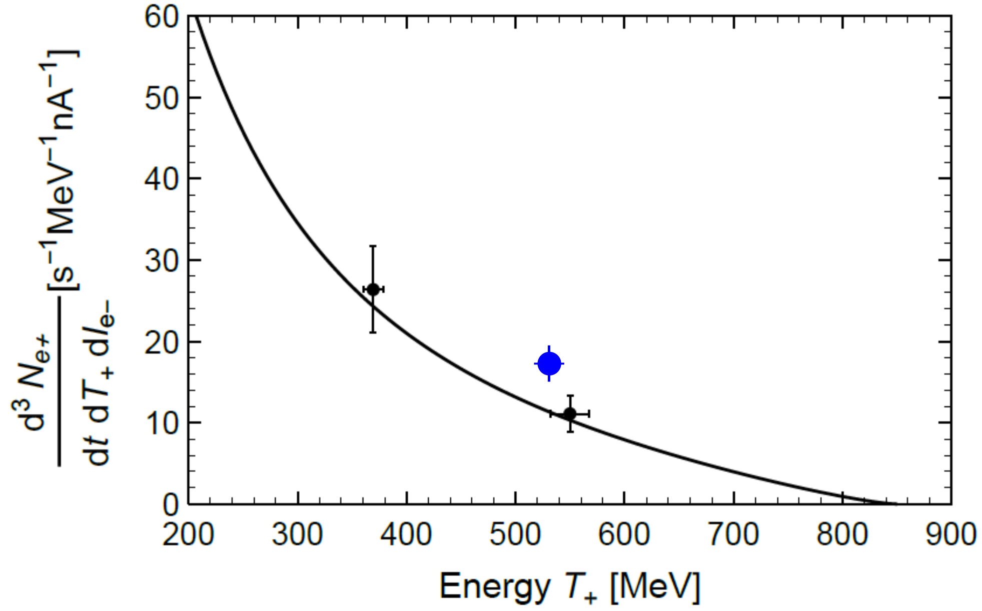


Production Rate

10 μm W Target
Slit width 3mm
~4.5 MeV



530 MeV



$$17.3 \frac{1}{s \cdot nA \cdot MeV}$$

Max. e-current (without shielding) ~1 µA ->
Max. positron rate **20 kHz**

Positrons in Europe

1. Mainz: 600 MeV positron beam with high bema quality – setup completed and running
   (no polarization experiment planned so far…)

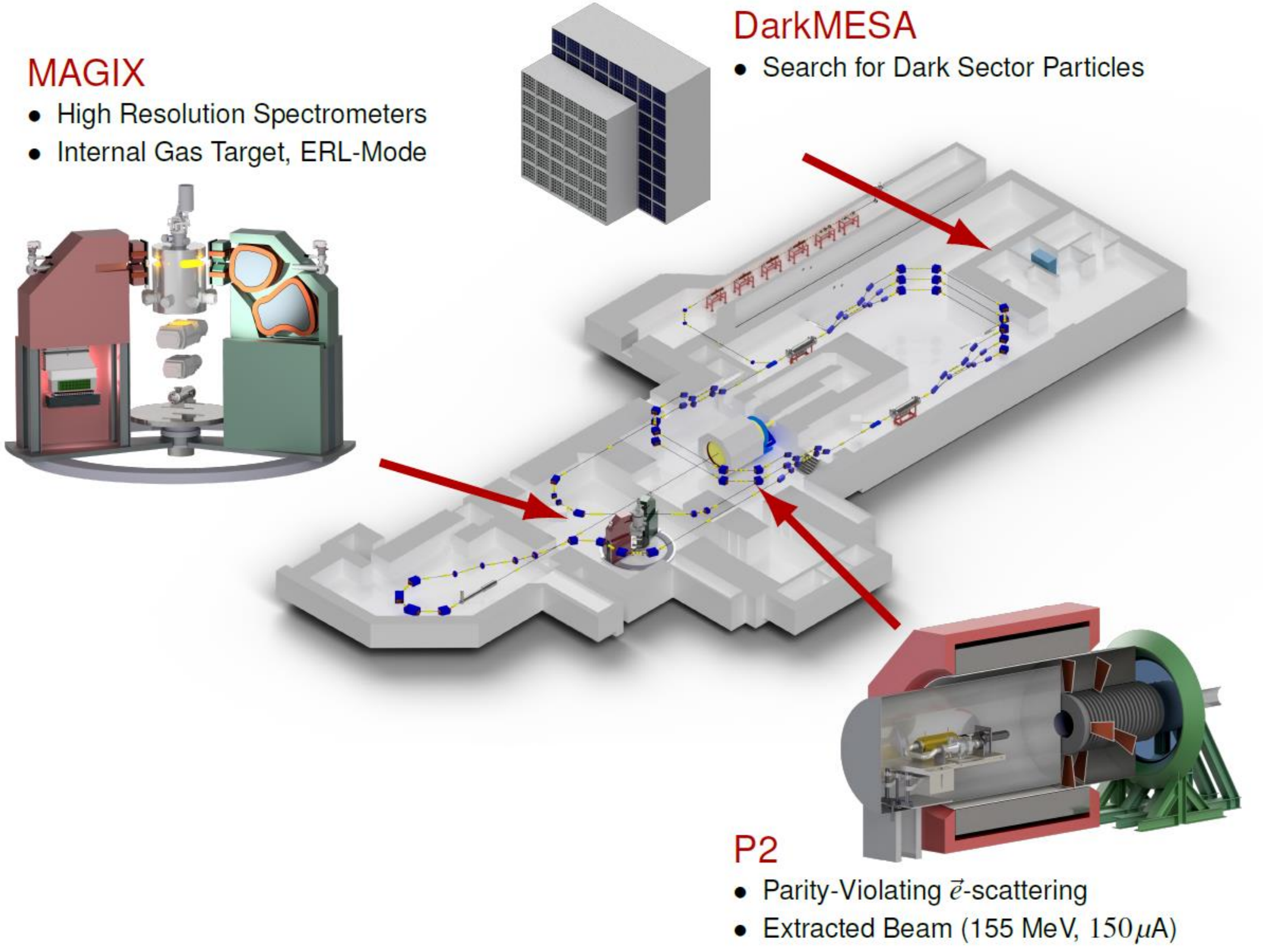
2. Dresden HZDR: 250keV polarized positron source desired , Conversion at ~30 MeV
3. Munich/FRM-2: Acceleration of thermalized (polarized) positrons at NEPOMUK to 1 MeV (MAMI technology, using 3d Printing of accelerator structures)
4. Mainz – target tests for CEBAF-polarized positron source

Applied Research activities ask for <100kHz polarized positrons (3 Attoampere) → good beam could possibly be delivered with moderate effort (10μA beam) polarized current on 10 μm W-Target

Open questions: Depolarisation by Moderator/decelleration ?

→ Mainz will support HZDR integrating polarized source into the ELBE accelerator

Establishing a sustainable supply for SL-cathodes

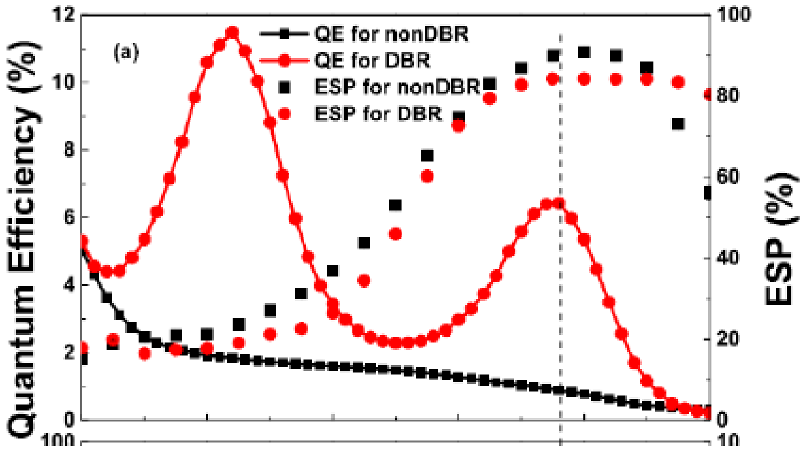


The MESA Project at JGU needs reliable supply of photcathodes achieving >85% polarization with QE >1% for the next decades!

State of the art Superlattice cathodes

GaAs	5 nm	p=5 × 10^{19} cm^{-3}
GaAs/GaAsP SL	(3.8/2.8 nm) ×14	p=5 × 10^{17} cm^{-3}
$GaAsP_{0.35}$	2750 nm	p=5 × 10^{18} cm^{-3}
Graded $GaAsP_x$ (x = 0~0.35)	5000 nm	p=5 × 10^{18} cm^{-3}
GaAs buffer	200 nm	p=2 × 10^{18} cm^{-3}
p-GaAs substrate (p>10^{18} cm^{-3})		

GaAs	5 nm	p=5 × 10^{19} cm^{-3}
GaAs/GaAsP SL	(3.8/2.8 nm) ×14	p=5 · 10^{17} cm^{-3}
$GaAsP_{0.35}$	750 nm	p=5 × 10^{18} cm^{-3}
$GaAsP_{0.35}$/ $AlAsP_{0.4}$ DBR	(54/64 nm) ×12	p=5 × 10^{18} cm^{-3}
$GaAsP_{0.35}$	2000 nm	p=5 × 10^{18} cm^{-3}
Graded $GaAsP_x$ (x = 0~0.35)	5000 nm	p=5 × 10^{18} cm^{-3}
GaAs buffer	200 nm	p=2 × 10^{18} cm^{-3}
p-GaAs substrate (p>10^{18} cm^{-3})		



JLAB/SVT cooperation

Table and plot takenfrom: Liu et al. Appl. Phys. Lett. **109**, 252104 (2016); doi: 10.1063/1.4972180

1%QE at 780nm = 6mA/Watt!

Prepare for lifetimes effects → Present (upper) limit of charge lifetime ~200 Coulombs at MAMI correponds to 60hours at 1mA

For currents at multi-milliampere scale DBR based superlattices are mandatory!

The issue with vendors….

1. The old vendor does not want to deliver samples any more.
2. GaAsP not very attractive for mass fabrication (contrast to the 1990 „epitaxy“ peak)
3. Handling Phosphorus diffcult and blocks production
4. → an issue of „world wide“ interest. Stakeholders: Particle physicists (EIC, EICC, LHEC,..), e+ source developers …and MAMI/MESA at Mainz.

Mainz/MESA has contacts to several national semiconductor research institutes (from the Fraunhofer and Leibnizinstitutes).

Production offer & services by federal lab:

Teil A - Fertigung des Puffers

Detailliertes Verfahren (Ausschreibung 3.2 a)

1. Epitaxieentwicklung auf p-leitenden GaAs-Substraten eines 5000 nm dicken Stufenpuffers (graded buffer) von GaAs hin zu $GaAs_{0.65}P_{0.35}$
2. inklusive Kalibrierung der Gasquellen-Regelparameter für As und P
3. inklusive Charakterisierung der Schichten mittels optischer Mikroskopie, hochauflösender Röntgenbeugung (HRXRD) und reciprocal space maps (RSM) sowie Sekundärionen-Massenspektroskopie (SIMS)
4. inklusive der Entwicklung und Analyse der in-situ-Messung der Substratkrümmung und Schichtverspannung (EZcurve) für den graded buffer
5. Epitaxieentwicklung metamorpher $GaAs_{0.65}P_{0.35}$-Puffer auf vorher entwickelten Stufenpuffer mit Variation der Wachstumstemperaturen für reduzierte AFM- (atomic force microscopy) Rauigkeit
6. inklusive Charakterisierung mittels Mikroskopie, AFM, EZcurve, HRXRD mit RSM
7. inklusive der Entwicklung und Analyse der in-situ-Messung der Substratkrümmung und Schichtverspannung (EZcurve) für den graded buffer
8. inklusive Charakterisierung mittels Transmissionselektronenmikroskopie (TEM) zur Bestimmung von Versetzungsdichten

The text on the left is only the number of steps required
to make the buffer layer!

GaAs	5 nm	p=5 × 10^{19} cm^{-3}
GaAs/GaAsP SL	(3.8/2.8 nm) ×14	p=5 × 10^{17} cm^{-3}
$GaAsP_{0.35}$	2750 nm	p=5 × 10^{18} cm^{-3}
Graded $GaAsP_x$ ($x = 0–0.35$)	5000 nm	p=5 × 10^{18} cm^{-3}
GaAs buffer	200 nm	p=2 × 10^{18} cm^{-3}
p-GaAs substrate (p>10^{18} cm^{-3})		

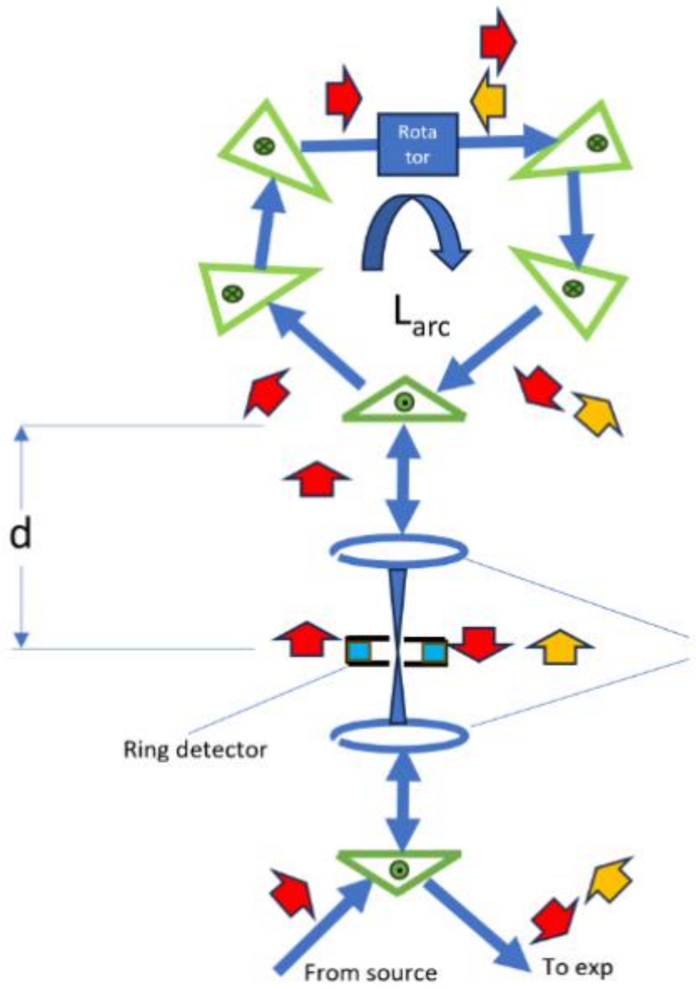
Even if the production produces non-optimal results, the information about the growth will be transferred to us!

The colliding beam online-polarimeter

Spoiler:

- Works only at source energies
- Requires very high average currents of at least 100μA

The colliding beam Moller polarimeter



Since all the bunches produced by the cathode have the same polarization, the resulting experimental asymmetry of coliding bunches is:

$$A = S_{Moller} P_e^2$$

Since we have free electrons scattering and colliding head on we can calculate S_{Moller} extremely accurately, pointing at an accuracy of the extraction

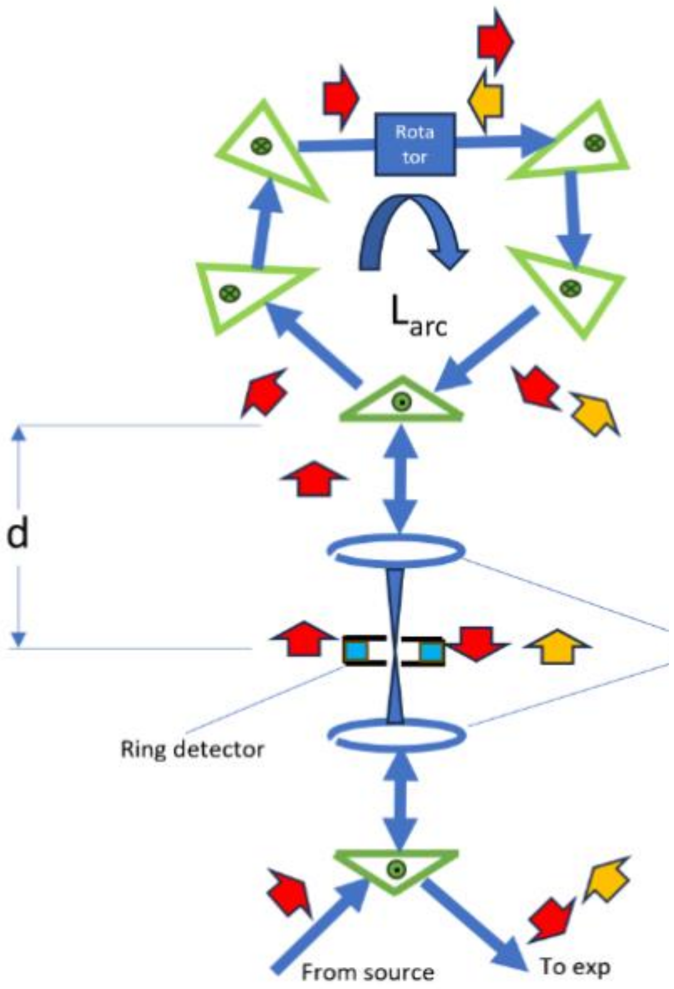
$$P_e = \sqrt{\frac{A}{S_{Moller}}}$$

in the low 10^{-3} region or even lower…
The cross section is depending on the total energy squares s (Lab frame and CM-frame are identical here)

$$\sqrt{s} = 2(E_{kin} + m_e c^2)$$

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{s} \frac{(3 + cos^2\theta)^2}{sin^4\theta}$$

The colliding beam Moller polarimeter



Luminosity:

$$L = f_{coll}\frac{N_B^2}{k * \pi r_{IP}^2} = I_{beam}\frac{N_B}{ek\pi r_{IP}^2}$$

Limited by „hourglas“ effect i.e. $\beta > l_{bunch}$
and $\beta_{IP}\varepsilon = r_{IP}^2$

TABLE 1. Rates and statistical accuracies with source beam parameters for MESA stage-2 assuming two steradian detector acceptance. The second parameter set represents online operation which requires reduction of average beam current towards a typical value for P2 by reducing the bunch collision rate.

beam energy (kinetic) [MeV]	average current [mA]	collision rate [MHz]	beta function β_{IP} [m]	rate [Hz]	stat. accuracy after one hour [%]
0.3	10	1300	0.01	412	0.06
0.3	0.15	20.3	0.01	5.9	0.57

Caveat: Spin flip and luminosity control !
Advantage: Lab-scale experiment!

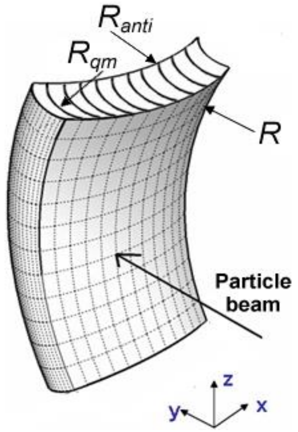
Conclusion

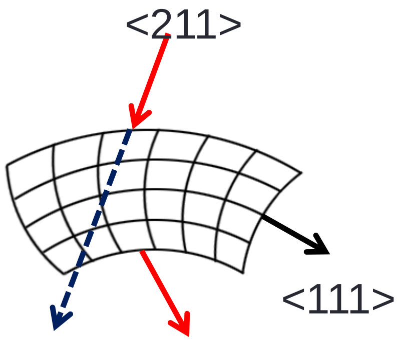
- Only small number of players in Europe remain
- Pol. Positrons will revive the activities
- We try to organize the sustainable delivery of cathodes for MESA
- New online-polarimeter aproach is discussed at Mainz

Thank you!

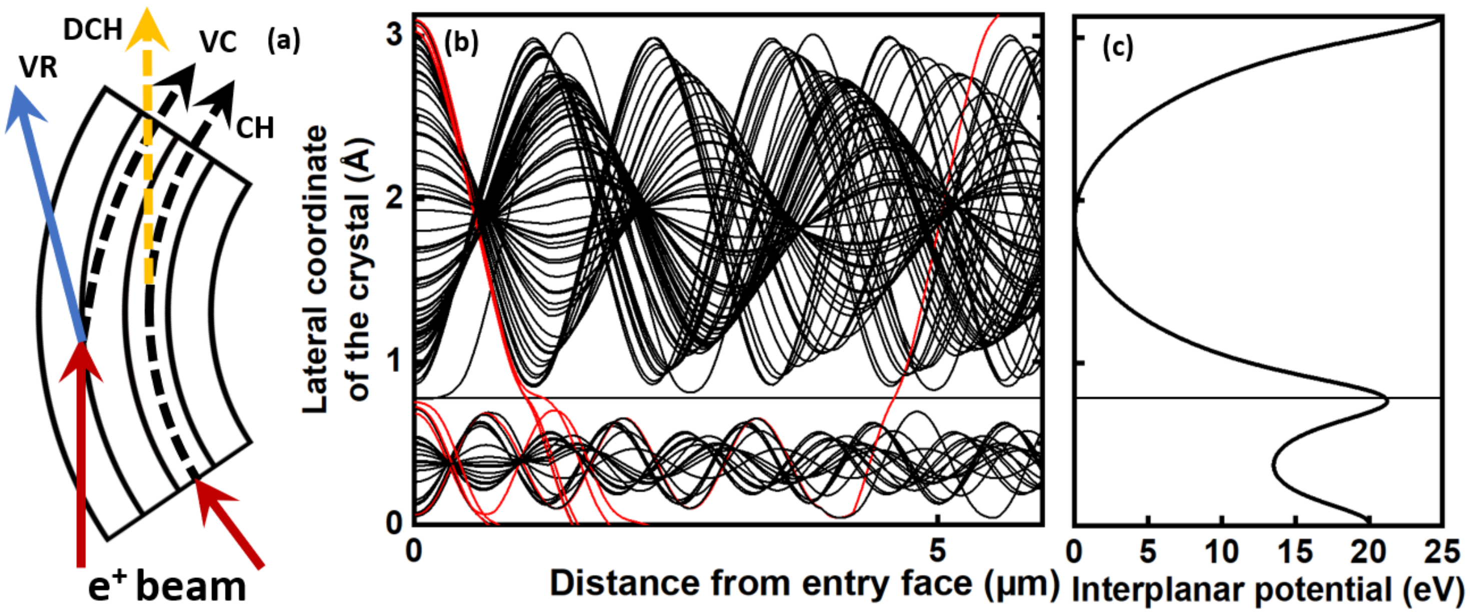
Spares

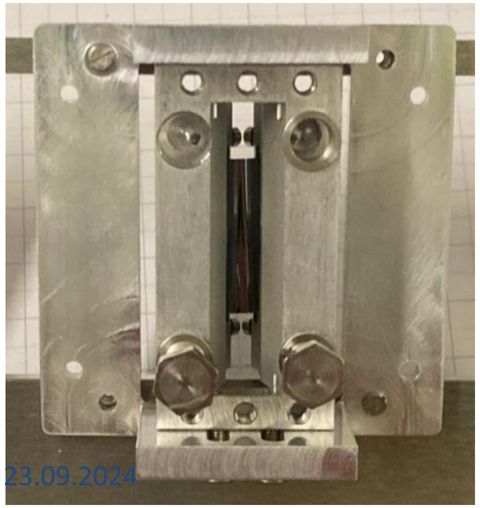
Beam deflection of 530 MeV positrons with mechanically bent Si crystal





Guidi, V., et al.,, 2009. Journal of Physics D Applied Physics42(18).
Germogli, G.,NIM B, 2015. 355: p. 81-85

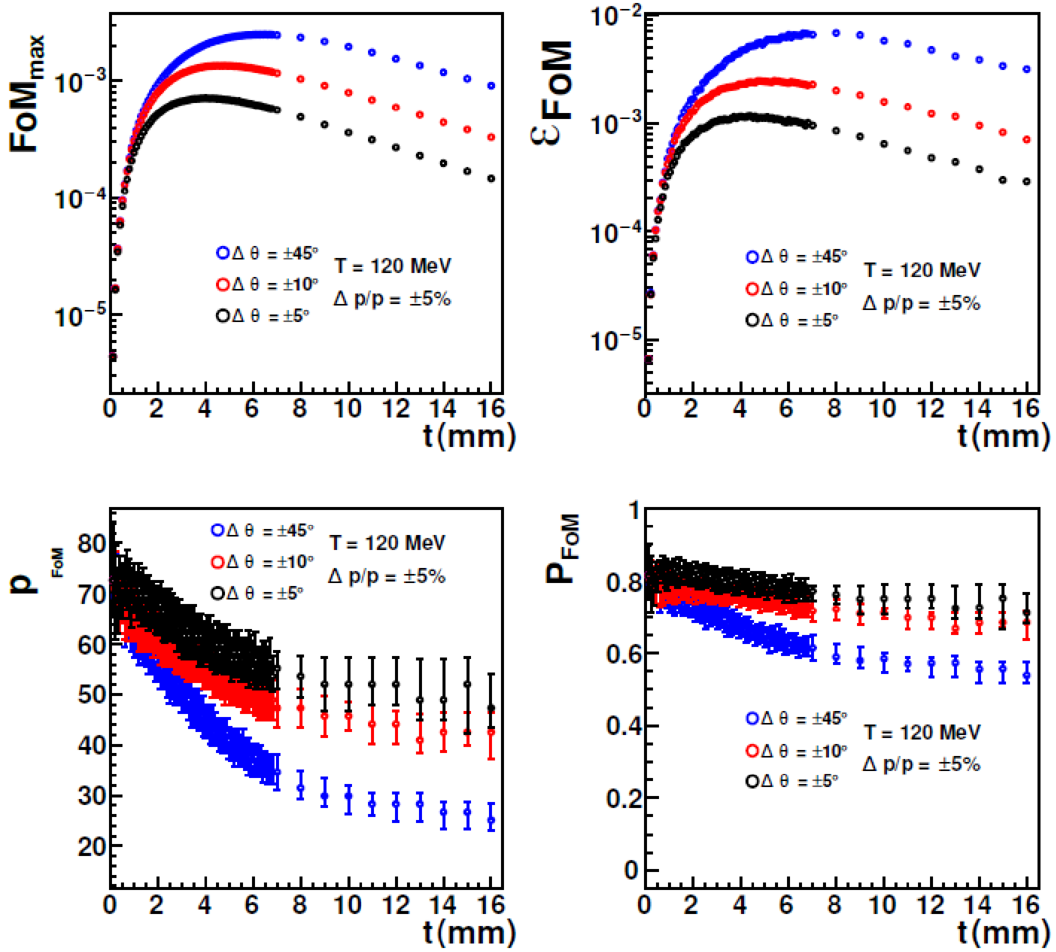




Thickness along the beam: 29.9±0.1 μm Bent planes, exploiting quasimosaic effect (111)
Bending angle: 970±10 μrad

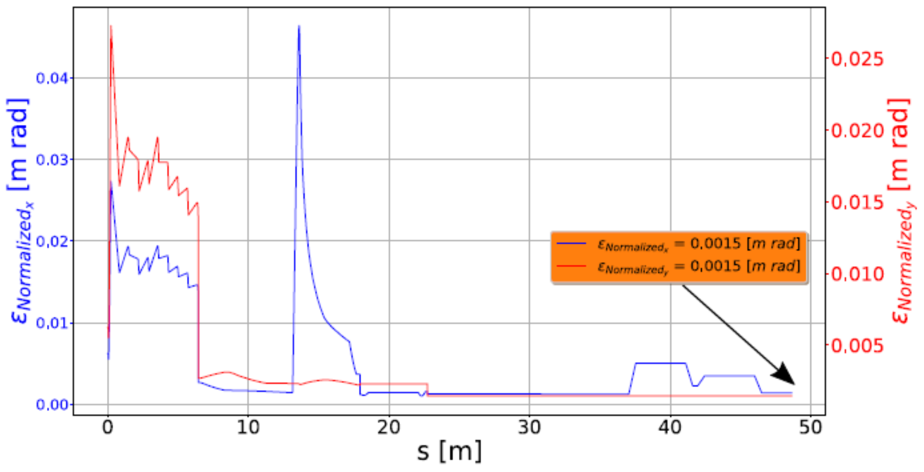
Crystal available from a previous project @

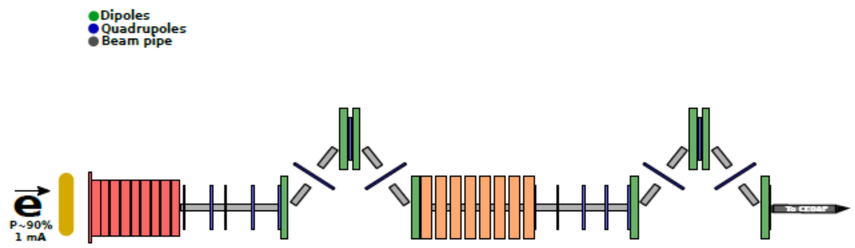
Simulations for $CE^{+}BAF$ with 126 MeV pol drive beam



Figures/Data taken from:
S. Habet: Concept of a polarized electron source for CEBAF, PhD Thesis, Université Paris-Saclay, CNRS, IJCLab, 91405, Orsay, France. (2023)

Simulations for CE$^+$BAF with 126 MeV pol drive beam



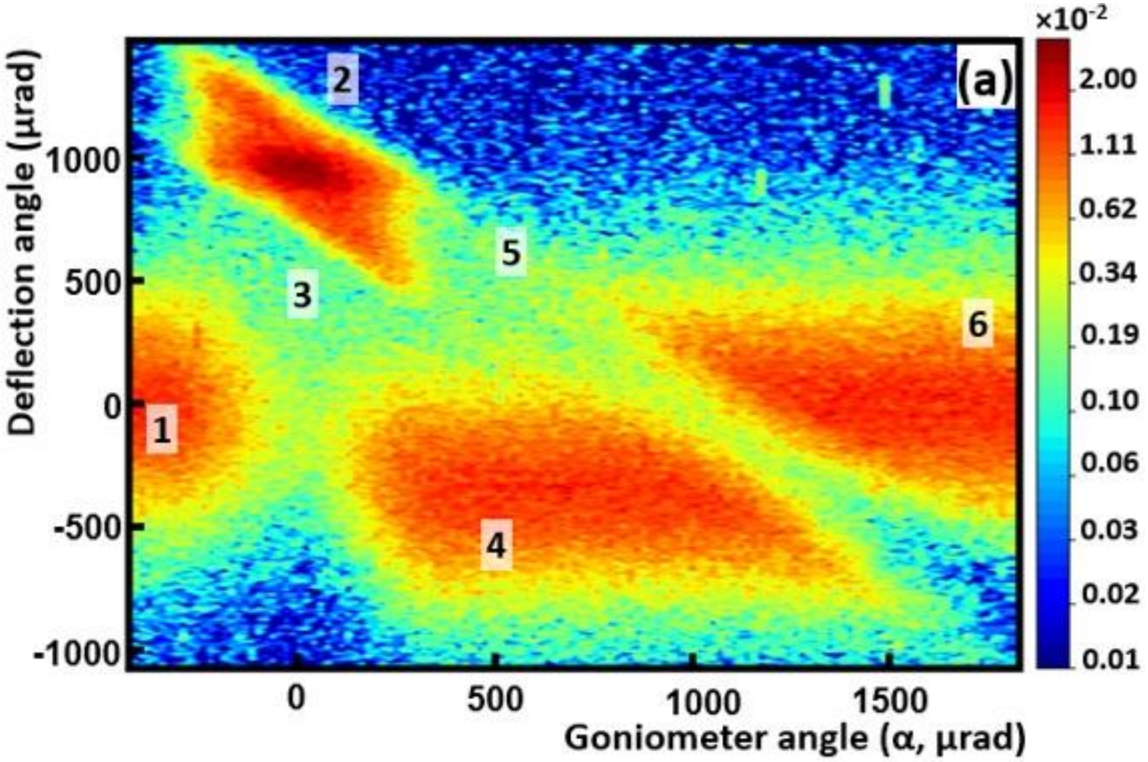


Predicted parameters:

Predicted Parameters	
E- beam current/Energy/Polarization	1mA/120 MeV/0.9
Positron beam current	0.17 μA
Positron Polarization	0.65
Energy width /bunch length	0.6%/ 2ps
Positron normalized emittance	1500 μm

Figures/Data taken from:
S. Habet: Concept of a polarized electron source for CEBAF, PhD Thesis, Université Paris-Saclay, CNRS, IJCLab, 91405, Orsay, France. (2023)

First results from e+ beam



Mazzolari, A., Backe, H., Bandiera, L., et al., (2024)
arXiv:2404.08459

First high-efficient deflection of sub-GeV positron worldwide !!!

Fallout in :

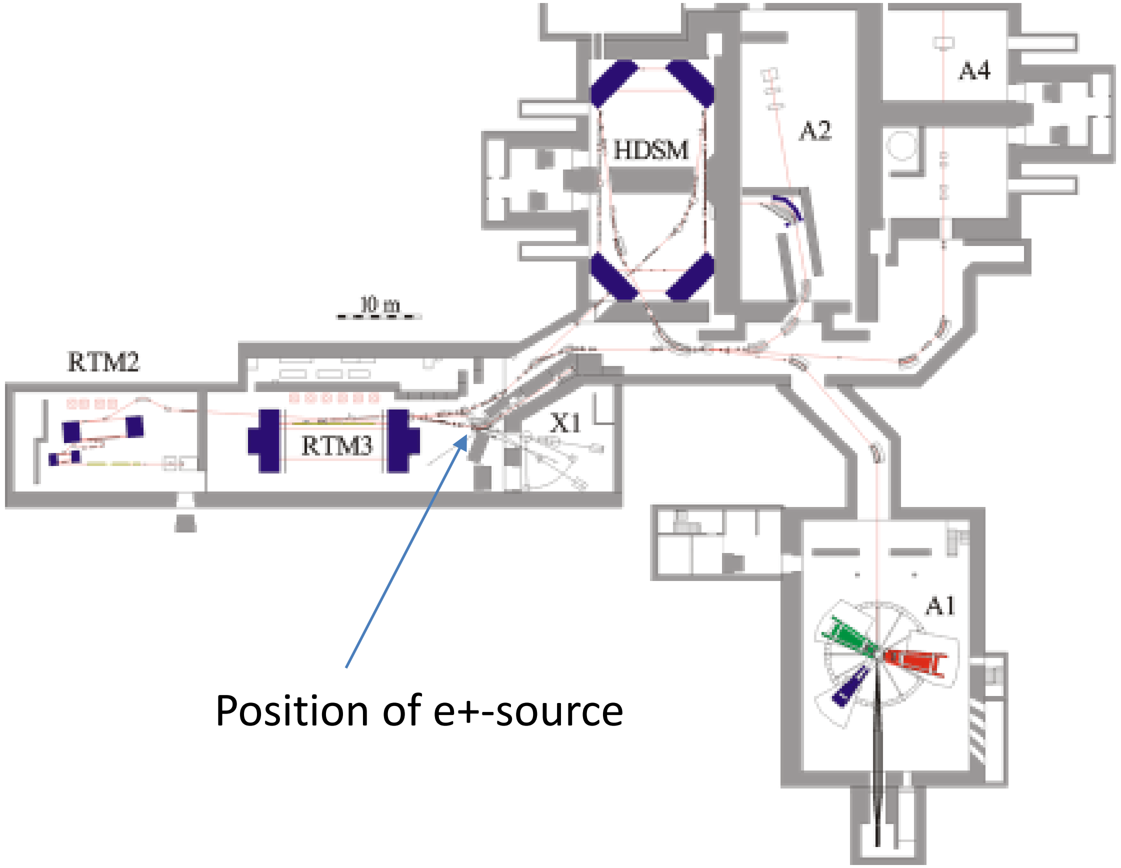
- ❑ Crystal-Light-Source
- ❑ Channeling based technologies
- ❑ Accelerator technologies: for beam steering, extraction, focusing..

Open access paper on arXiv
Submitted to Phys. Rev. Lett.

Positron Production with high power recirculating linear accelerator MAMI

MAMI: MAINZER MIKROTRON
MAMI-C –three RTM stages + „HDSM"
CW-machine
Energies: 180-1600 MeV
Beam current: few electrons/s – 100µA (150kW)
Applications:
- Electron scattering (A1)
- Tagged Photon scattering (A2)
- PV-electron scattering (A4, until 2012→MESA)
- Detector/materials testing
- Secondary positron beams
- Spin polarized electron beams (A1,A2,A4)

GSI-related Collaborations:
- Detector/target testing (e.g. PANDA)
- FAIR phase-0 experiment PRIMA in hall A1

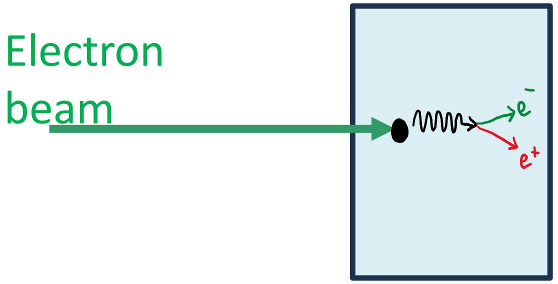


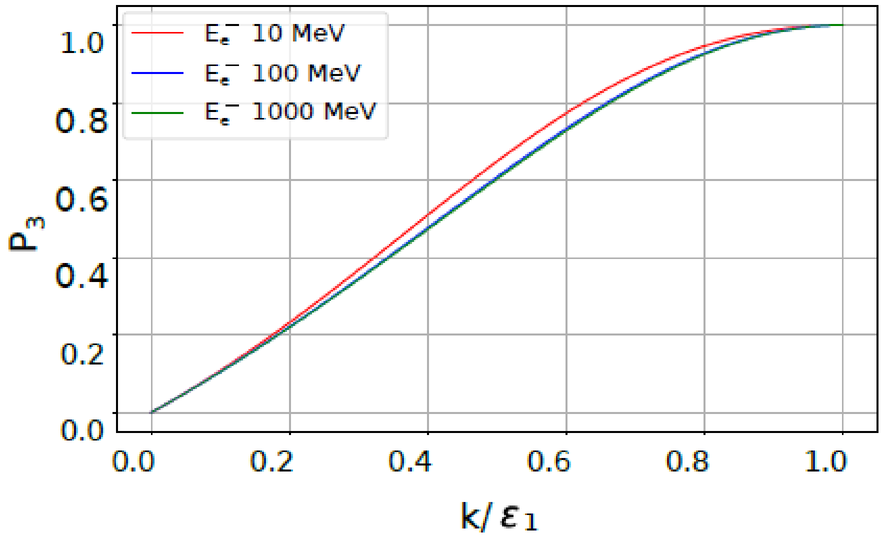
1. Why polarized positrons?

1. Particle physics: e-/e+ colliders (especially, but not only, linear colliders) (100 GeV scale)
2. Hadron Physics: 2 photon processes „deeply virtual Compton scattering“ (GeV scale)
3. Applied science: in particular magnetic nanostructures (eV –MEV scale)

But will the positrons be polarized too –yes!

Doube conversion in thin target

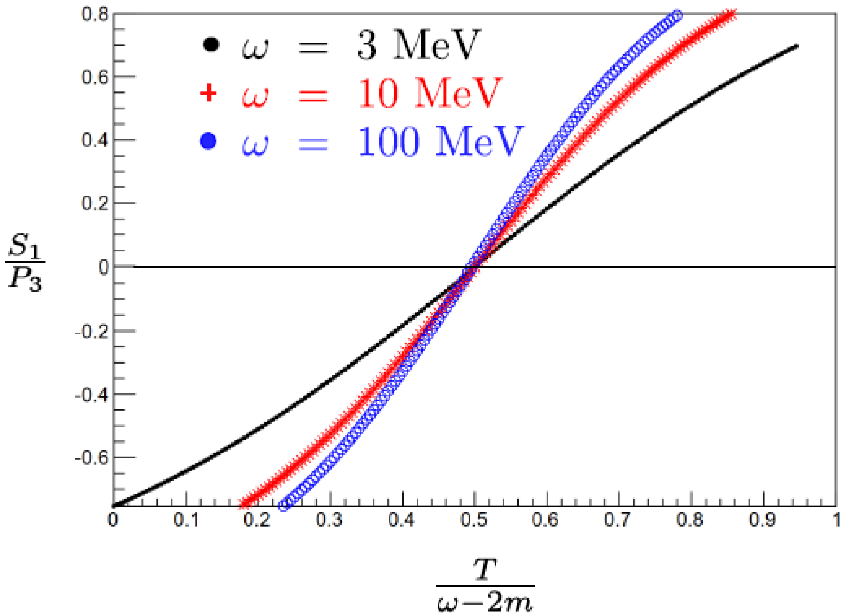




Transfer of electron polarization to photon circ. pol.

Principle first tested by SLAC/DESY collaboration for ILC in 2006.
Cross sections and multiple scattering must be taken into Account→ PhD work by S. Habet at ORSAY for JLAB

Figures after QED calculations by Olsen et al, taken from:
S. Habet: Concept of a polarized electron source for CEBAF, PhD Thesis, Université Paris-Saclay, CNRS, IJCLab, 91405, Orsay, France. (2023)



Transfer of photon circ. pol. To positron pol

Low efficiency!

Based on the simulations by Habet we could assume the following requirement for the palarized electron beam with 90% Polarization at 120 MeV:

$$I_{\vec{e}^-}[mA] = 6 I_{\vec{e}^+}[\mu A] \frac{1500}{\varepsilon_{norm}[\mu m]}$$

Note that 1mA means 120 kW beam power on the target.

For the „rotating rim technology“ for cooling, MAMI experiments (*) at 3.5 MeV may suggest that materials can withstand such loads regarding radiation damage for very long time :
→ lower energies may be better, at least to handle high beam currents….
→ But high QE cathodes required because of cathode heating!

T. Lengler et al., "Characterization of radiation damages to positron source materials",
in Proc. IPAC'24, Nashville, TN, May 2024, pp. 1206-1209. doi:10.18429/JACoW-IPAC2024-TUPC81

Principle of the Positron source at MAMI