

Polarized Electron Beams from LPA and their Polarimetry

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SPIN2021, 18.10.2021

The Importance of Polarized Electron Beams

and how they are generated classically

- > Polarized beams are indispensable for many experiments in particle, atomic and nuclear physics
- > For applications at e+e- colliders see:

5. The Central Role of Beam Polarization at Future e+e- Linear Colliders

Prof. Gudrid Moortgat-Pick (University of Hamb...

🕒 18/10/2021, 11:50

Future facilities and exp...

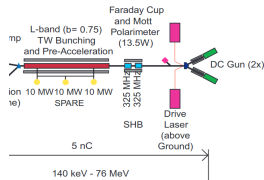
Parallel Session Present...

Future facilities and exp...

Example: Photoemission from GaAs

The ILC's polarized electron source [1]

- > 3×10^{10} electrons per bunch
- > 90% polarization
- > at source: 1 ns bunch length, 140 keV central energy
- > after buncher/preaccelerator: ≈ 20 ps and 76 MeV



[1] ILC TDR Volume 3.II, Accelerator Baseline Design (2013)

Why Polarized e- Beams from PA?

The advantages of plasma acceleration

- > plasma accelerators attractive because of their compactness
 - > acceleration gradients can be more than 3 orders of magnitude greater than from conventional linacs [2]
 - > short bunch length (a few fs) advantageous for imaging applications
 - > inherent synchronization to laser driver for pump and probe experiments
 - > how does the plasma acceleration affect the polarization ?
- ⇒ LEAP: proof-of-principle experiment for a polarized electron beam from laser plasma acceleration
- > as first step work with internally created electron beam

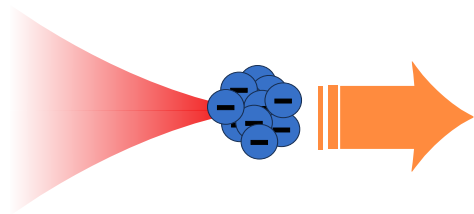
[2] E. Esaray, C. Schroeder and W. Leemans, Rev. Mod. Phys.81(3),1229-1285(2009)



Overview

I

II

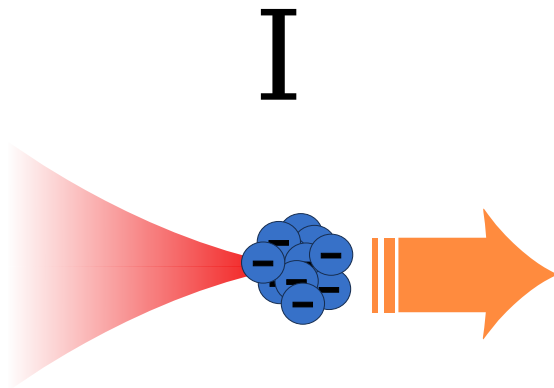


Electron Acceleration



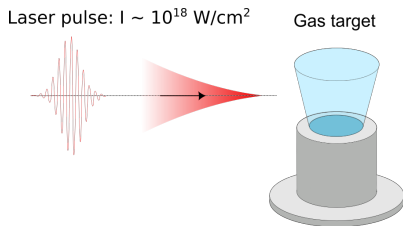
Polarimetry

Laser Plasma Acceleration of Polarized Electron Beams



Principle of Laser Plasma Acceleration (LPA) [3]

Acceleration of electrons using high gradients



- > Laser Pulse ionizes the gas to create a plasma
- > Ponderomotive force pushes electrons away

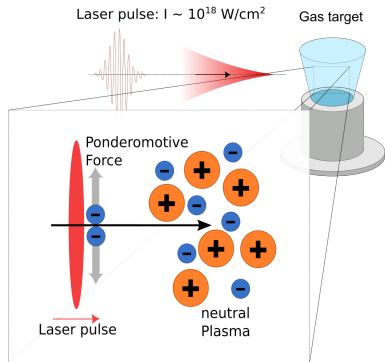
$$F_p \propto \frac{Q}{m} \nabla I$$

- > Ions mostly immobile due to higher mass
- > Resulting longitudinal fields reach more than 100 GV/m
- > e- injected at the back of the cavity can be accelerated in the wakefield

[3] T. Tajima and J. M. Dawson, Phys. Rev. Lett. 43, 267 (1979).

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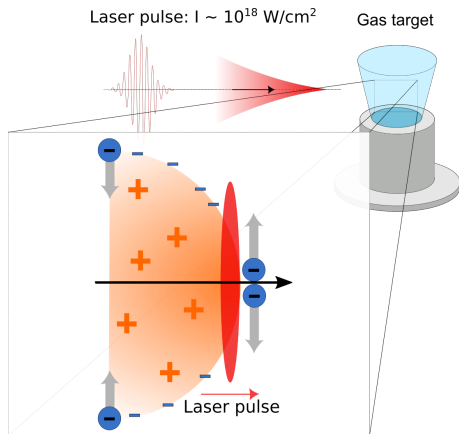
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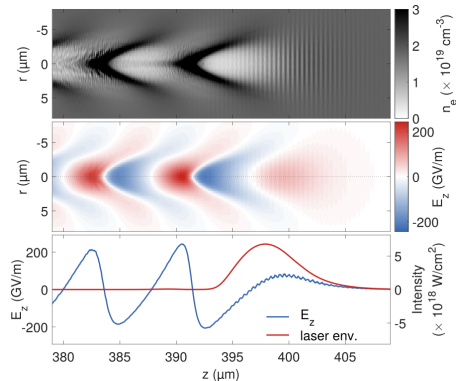


Figure: Simulation using FBPIC [4]

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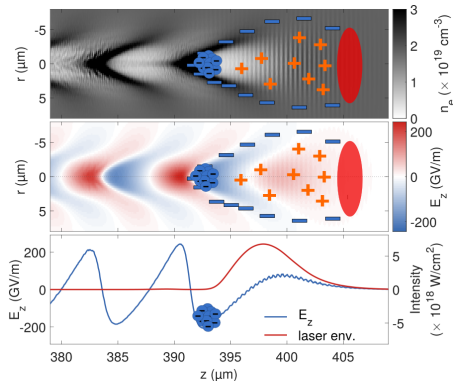


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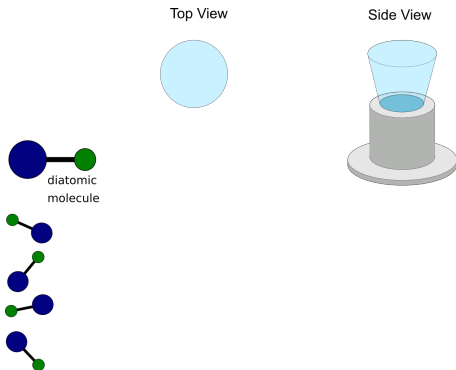
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How to get polarized electron beams from LPA?

Polarized beams from a pre-polarized gas jet target [5,6]



- > Alignment of diatomic molecules with ps IR pulse
- > Photodissociation of the molecules with UV pulse. Spin-orbit coupling results in polarized valence electron
- > LPA laser drives plasma wave and injected electrons are accelerated
- > Beam polarization maintained during further acceleration [7]

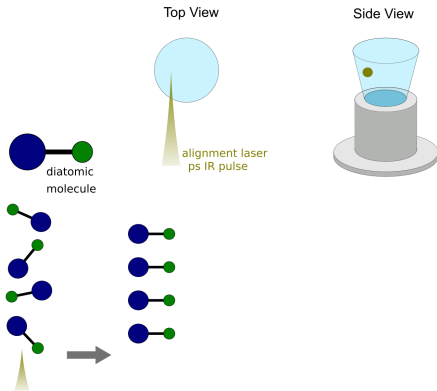
[5] A. Spiliotis et al., Light Sci. Appl. 10, no 35 (2021)

[6] M. Wen, M. Tamburini and H. Keitel, Phys. Rev. Lett. 122,214801 (2019)

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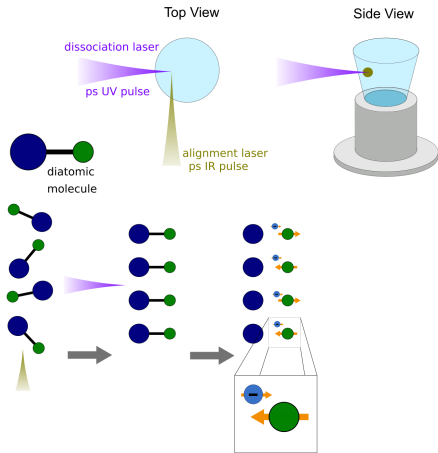
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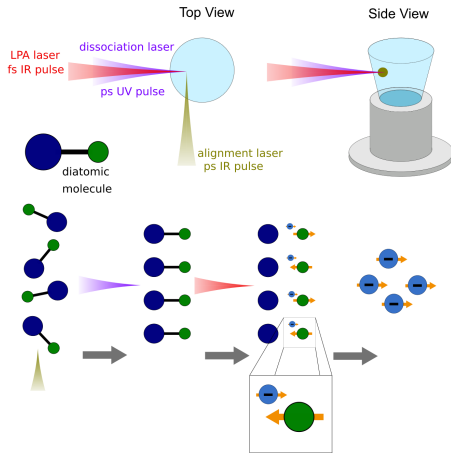
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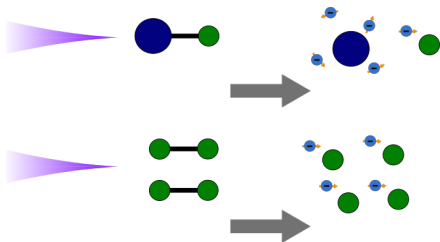
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[7] J. Viera et al., Phys Rev. ST Acell. Beams 14, 071303 (2011)

Which gas?

Laser wavelength, gas species and polarization are interdependent

Gas	Polarized e-	Total e-	Percentage	Laser Wavelength
H ₂	2	2	100%	< 100 nm
HF	2	8 (10)	25%	< 150 nm
HCl	2	8...16 (18)	25%...12.5%	< 220 nm



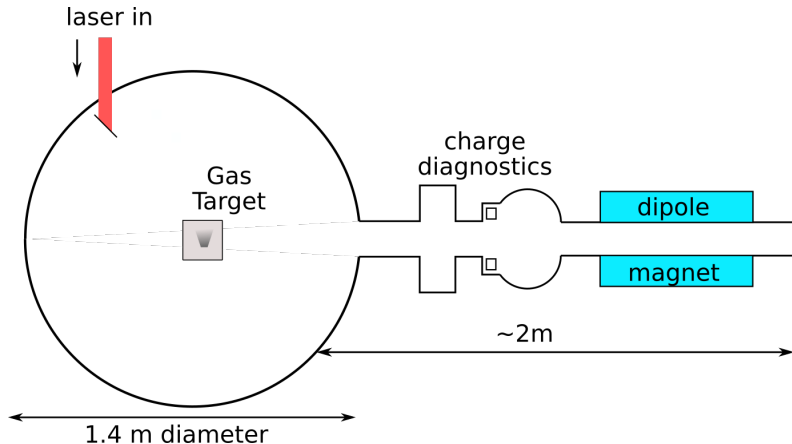
- > H₂: challenging wavelength
- > HF: "chemical weapon" → no option !
- > HCl: many electron levels

Now HCl, but H₂ future option! [8,9]

[8] Drescher, L. et al, Nat. Photonics 1, 263-266 (2021), [9] Travers, J.C. et al., Nat Photonics 13 547-554 (2019)

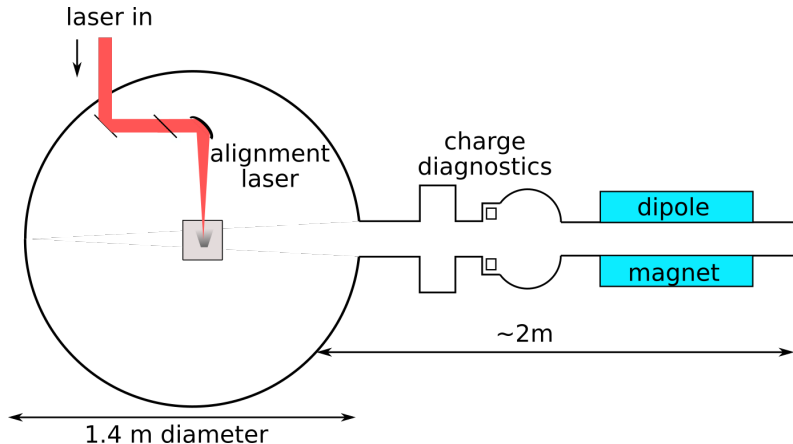
Setup

Overview of experimental components



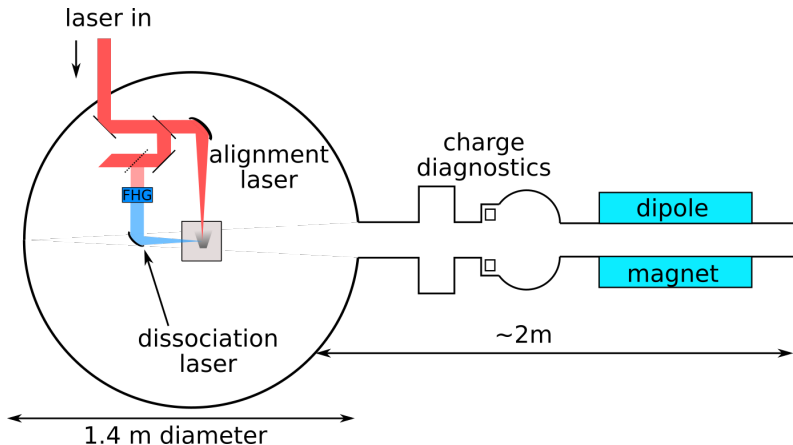
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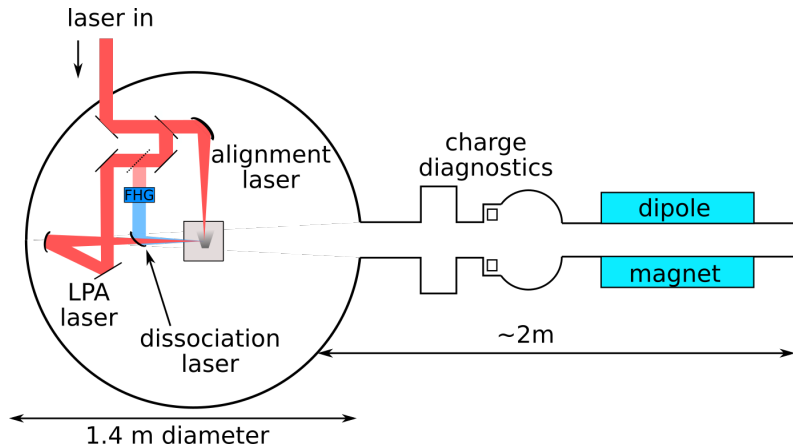
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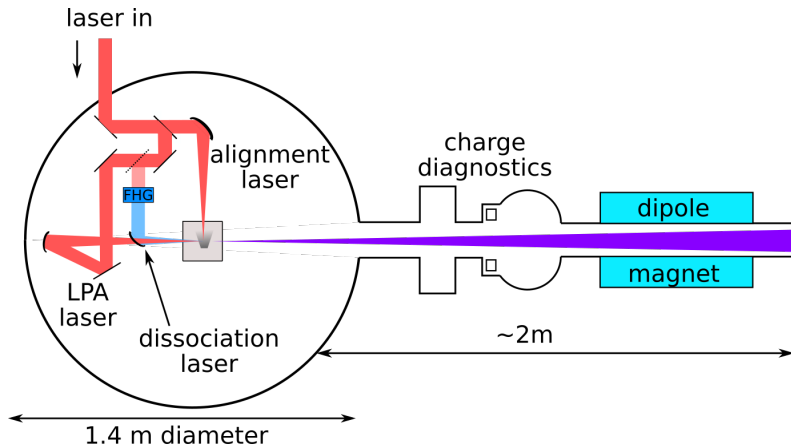
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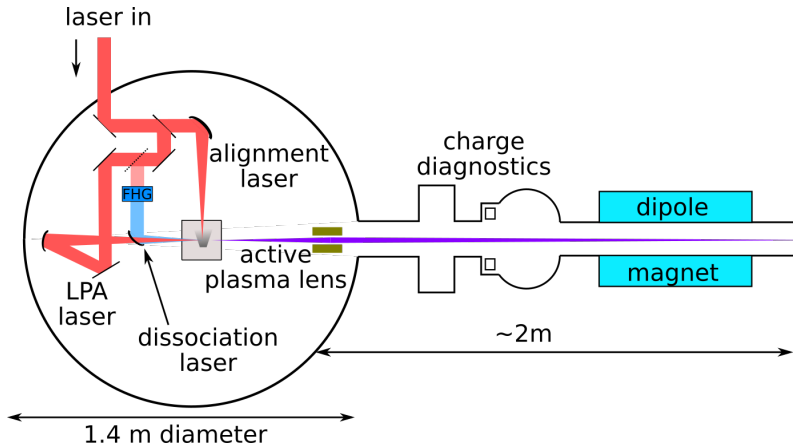
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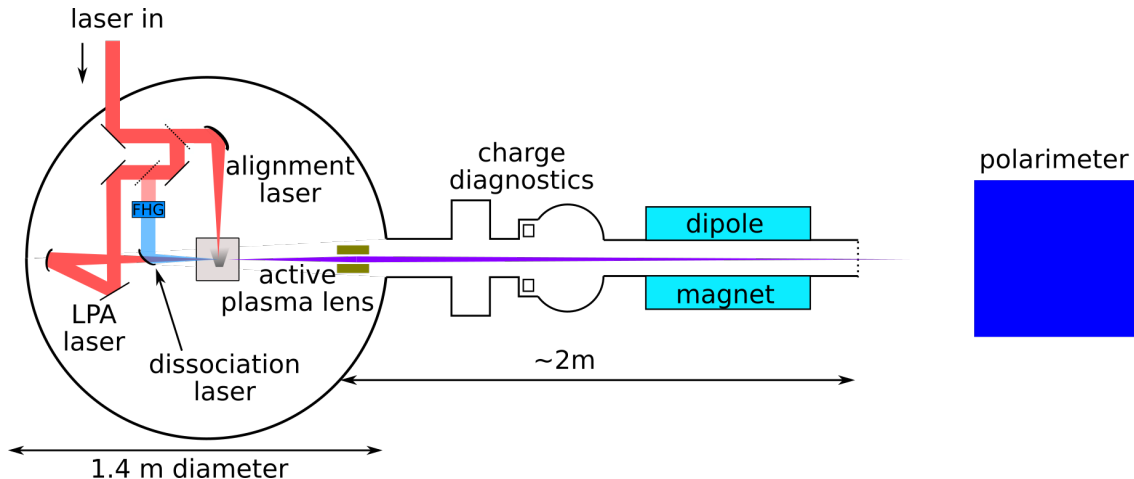
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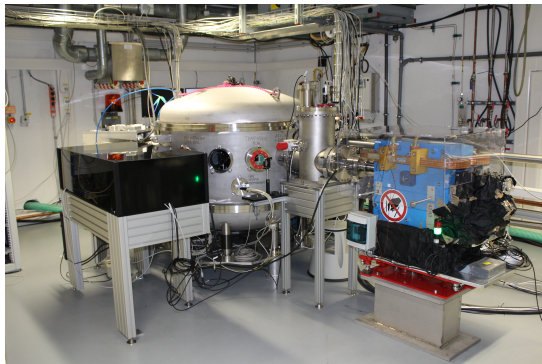
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Overview of experimental components



Electron Beam Parameters [10]

- > central energy: tunable from 10 to 100 MeV
- > FWHM energy spread: 10 %
- > electron spot size: 1 μm
- > divergence: 3 mrad
- > electron beam charge: 2 pC

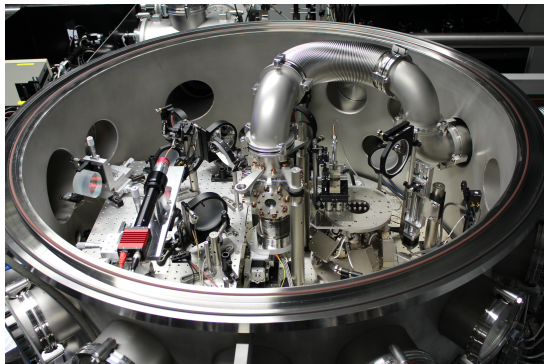


[10] Bohlen, S et al., in preparation

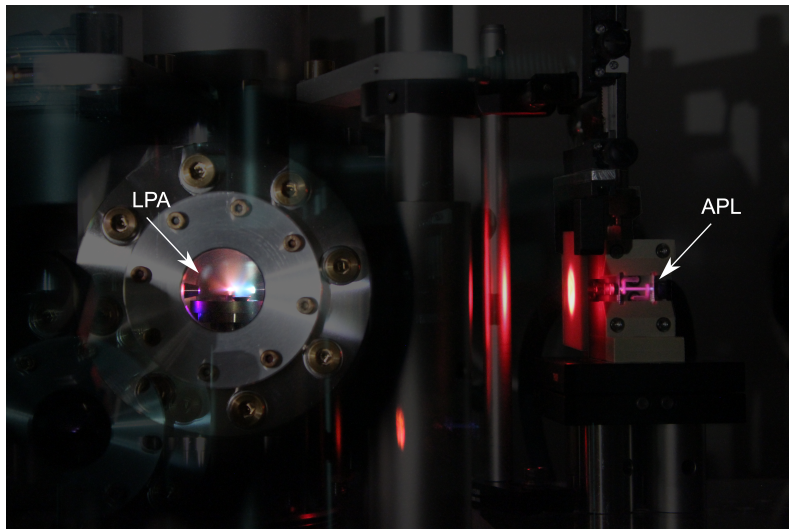
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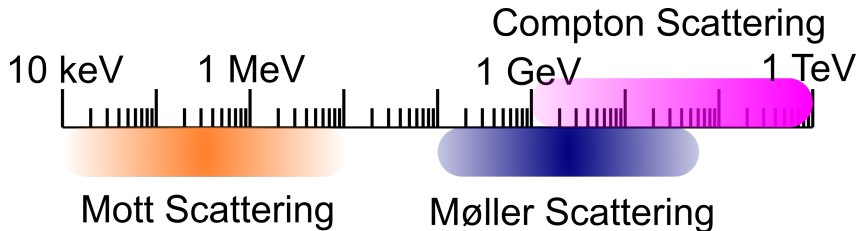


Polarimetry of LPA Electron Beams

II



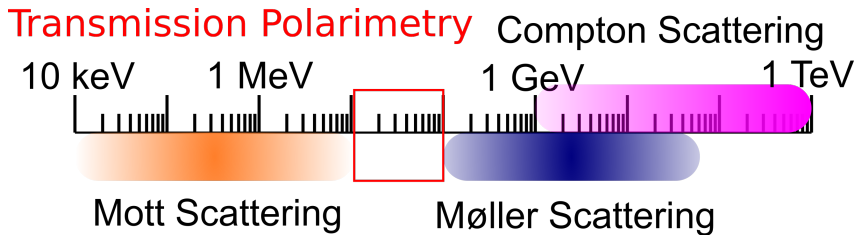
How to measure the polarization?



- > **Mott Scattering:** above about 10 MeV scatter probability very small and impractical scatter angles
- > **Møller Scattering:** > 200 MeV to suppress bremsstrahlung background
- > **Compton Scattering:** at few GeV and below the asymmetry is too small

[11] A.Schälicke et al., Pramana - J. Phys. 69, 1171-1175 (2007)

How to measure the polarization?



- > at expected energy range transmission polarimetry is ideal
- > demonstrated for positron polarimetry at the E166 Experiment [9]
 - positron energy between 4-8 MeV
 - polarization about 80 %
 - relative measurement error about 10-15 %

[12] G. Alexander et al., Nucl. Instrum. Methods Phys. Res. A, vol 610, no 2, 451-487 (2009)

Photon Transmission Polarimetry

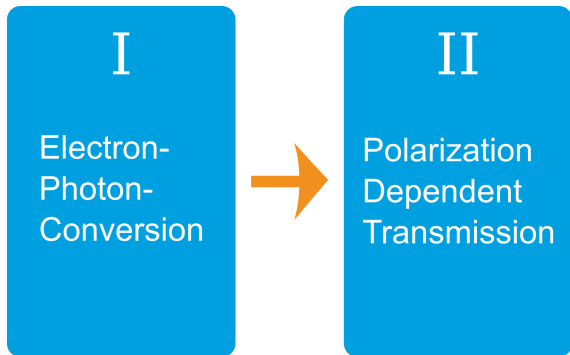
An Overview

I

Electron-
Photon-
Conversion

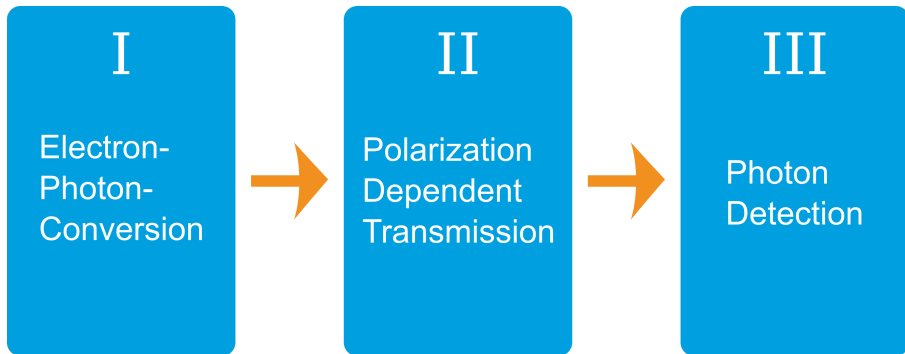
Photon Transmission Polarimetry

An Overview



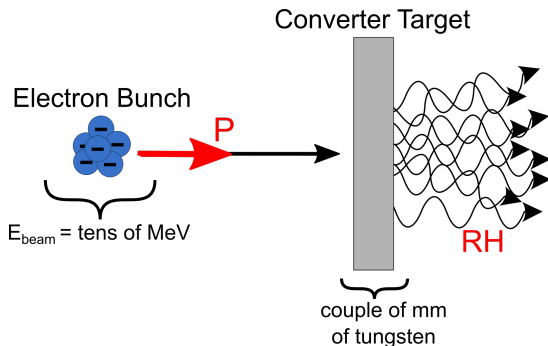
Photon Transmission Polarimetry

An Overview



I. Electron-Photon-Conversion

Polarized Bremsstrahlung

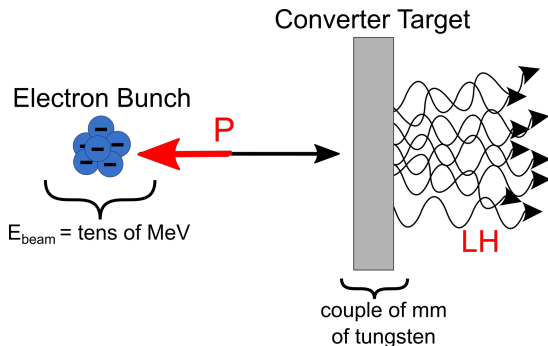


- > creation of circularly polarized photons via **Bremsstrahlung** [13]

[13] Likhachev et al., Nucl. Instrum. Methods Phys. Res. A, vol. 495, no. 2, pp. 139-17 (2002)

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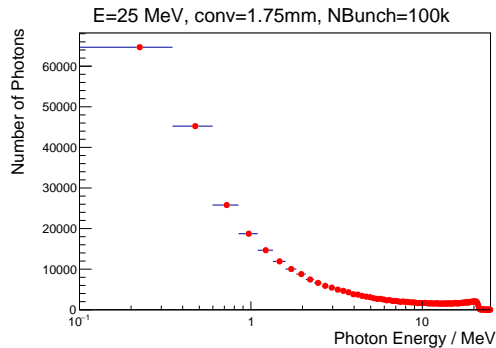
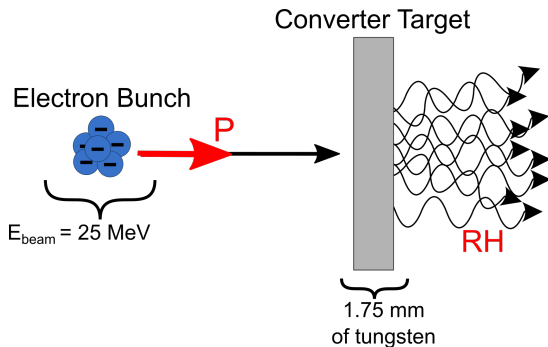


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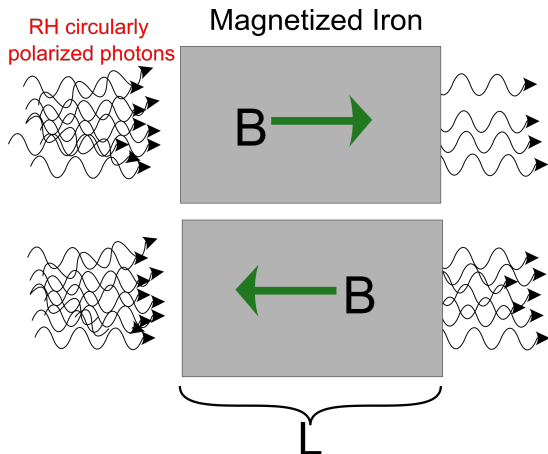


simulated spectrum

[13] Likhachev et al., Nucl. Instrum. Methods Phys. Res. A, vol. 495, no. 2, pp. 139-17 (2002)

II. Photon Transmission

Depending on Polarization



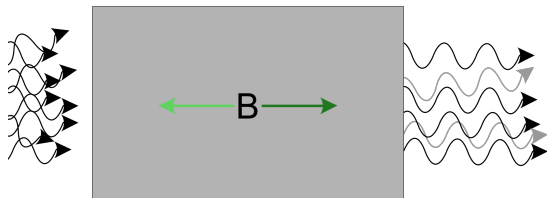
- > the transmission of the photons through the iron, depends on polarization direction of both

$$T = N e^{-nL(\sigma_{pair} + \sigma_{photo} + \sigma_{compton})} \cdot e^{-nL\sigma_{pot}P_{\gamma}P_e}$$

- > transmission is **higher** when polarization of incident e- and iron is **antiparallel**

Transmission Asymmetry

With Respect to Magnetization Direction



$$\delta = \frac{T_{AP} - T_P}{T_{AP} + T_P}$$

AP: Anti-Parallel
P: Parallel

III. Photon Detection

Calorimeter Made of Lead Glass



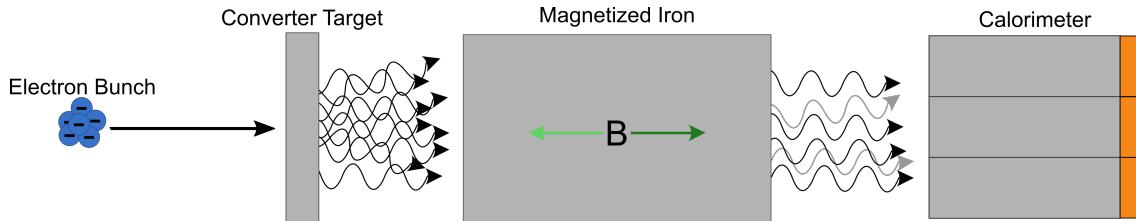
- > 9 crystals attached to PMTs
- > stacked in 3×3 grid
- > wrapped with aluminium

From the measured intensity of the visible photons the deposited energy can be inferred.

E_{dep} can be used to compute the transmission asymmetry.

Photon Transmission Polarimetry

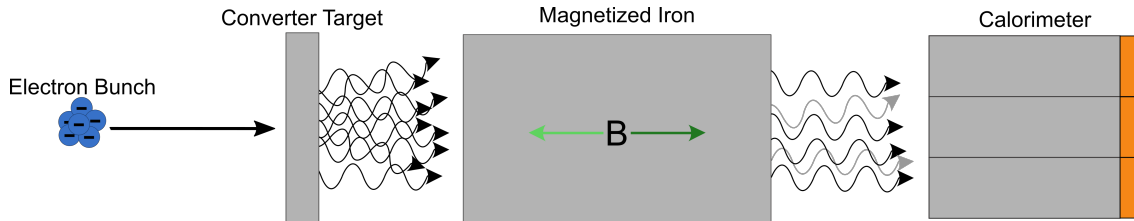
Summary



- > Transmission of circularly polarized photons through the iron depends on energy of photons and polarization direction
- > Magnitude of asymmetry wrt. magnetization direction is proportional to photon polarization

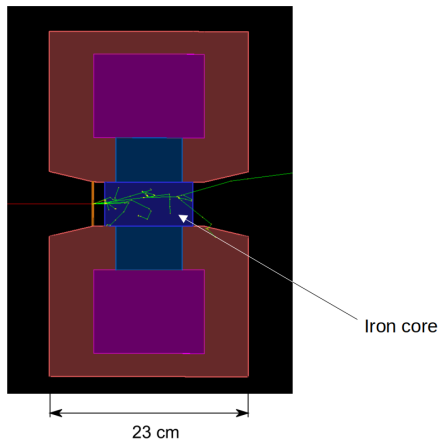
Photon Transmission Polarimetry

Summary



- > Transmission of circularly polarized photons through the iron depends on energy of photons and polarization direction
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- > **Next step: Computer simulations for setup optimization**

Set Up and Specifics of GEANT4 Simulations

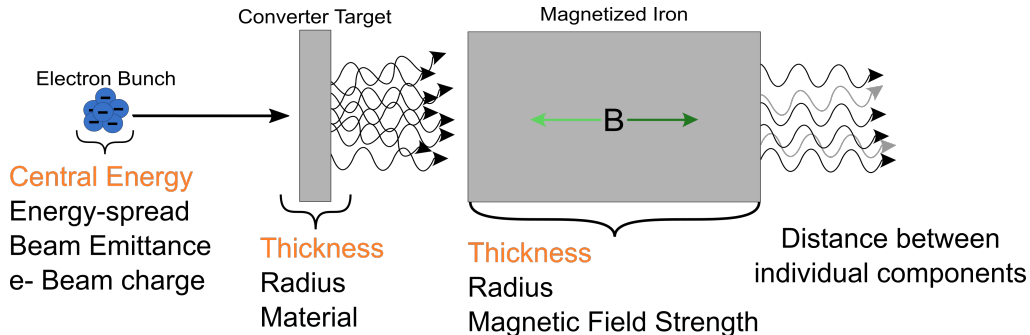


- > simplified idealistic beam
- > e-/iron core polarization of ± 1
- > GEANT4[14] physicslist including **polarized** Compton scattering, γ -conversion, ionization, Bremsstrahlung, e⁺ annihilation and photoelectric effect [15]

[14] S. Agostinelli et al., Nucl. Instrum. Meth. A 506 (2003) 250-303

[15] A.Schälicke, K. Laihem, P. Starovolotov, arXiv:0712.2336 (2007)

Parameters adjusted for Asymmetry Studies

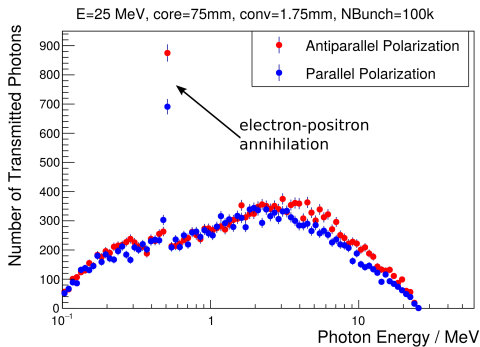


GOAL:

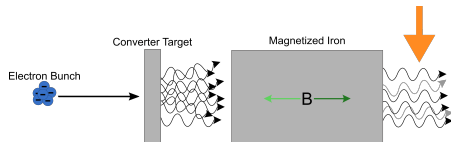
- > Asymmetry as large as possible
- > Asymmetry robust against beam parameter fluctuations

Photon Energy Spectrum Single e- Bunch

After transmission through magnet

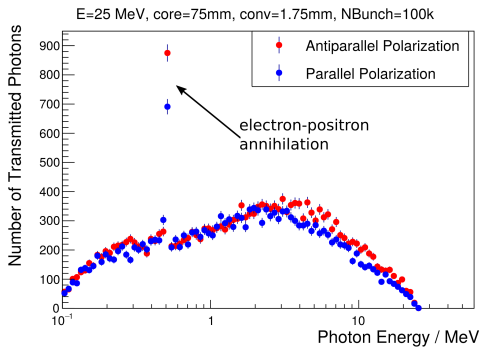


- > Transmission is **higher** when polarization of incident e- and iron is **antiparallel**



Photon Energy Spectrum Single e- Bunch

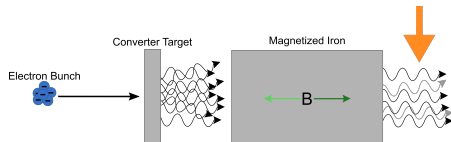
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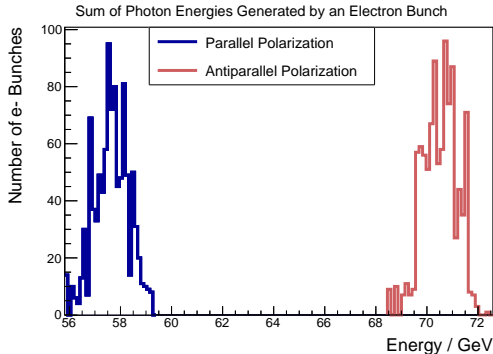
Next:

- > Sum up the photon energies
- > Repeat for statistics



Sum of Photon Energies

And computation of transmission asymmetry



Simulation Bunch: 100k e-, LPA Bunch: 1.2×10^8 e-

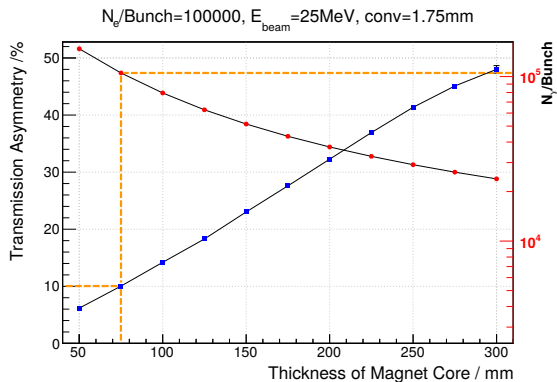
Transmission Asymmetry

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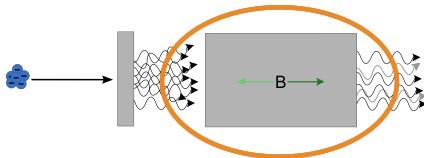
- > $E_{AP/P}$ is the average photon energy sum per electron bunch
- > simulate δ ($P_e = 100\%$) to get analyzing power A_e
- > Later: $\delta_{measured}/A_e$ yields electron polarization

Transmission Asymmetry

Asymmetry increases with increasing core thickness



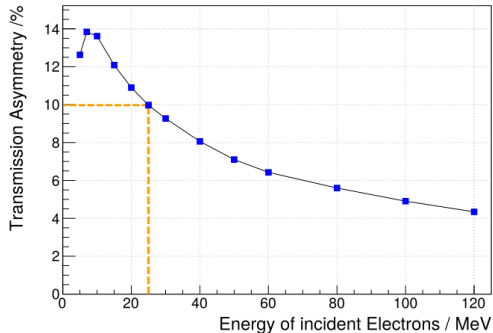
- > Asymmetry increases from $\approx 6\%$ at 50 mm to $\approx 48\%$ at 300 mm
- > Rate decreases
- > Use at least 300 mm of Iron



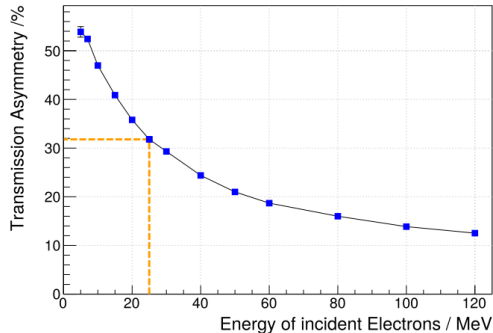
Transmission Asymmetry

Asymmetry decreases with increasing Energy of incident electrons

$N_e/\text{Bunch}=100000$, conv=1.75mm, core=75mm



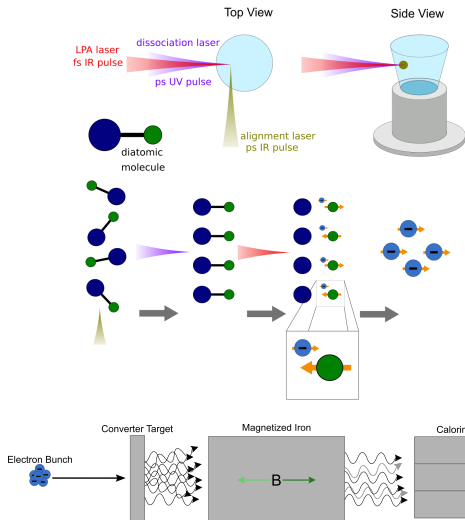
$N_e/\text{Bunch}=100000$, conv=1.75mm, core=200mm



> Lower energies more promising for polarimetry

Conclusion

- > Polarised beams are important, plasma accelerators are the future
 - Can we get both together ?
- > LEAP: Proof-of-principle experiment under construction at DESY
 - LPA with prepolarized plasma source
 - Photon transmission polarimetry
- > Ongoing work:
 - Design studies for setup optimization
 - Tests of calorimeter



Thank you!

Contact

DESY. Deutsches
Elektronen-Synchrotron
www.desy.de

Speaker

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Polarized LPA

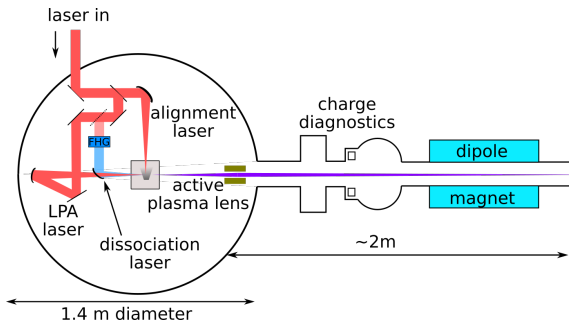
Kristjan Pöder
MPA
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Polarimetry

Jenny List
FTX-SLB
jenny.list@desy.de
+49-40-8998-3681

SETUP

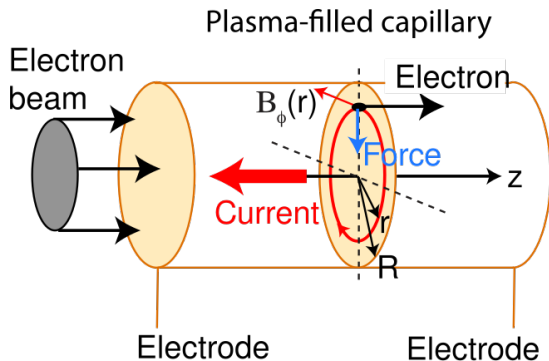
Overview over experimental components



- > fs, linearly polarized, IR laser pulse is split
- > stretched ps IR pulse for bond alignment
- > other pulse further split
- > cascaded 2nd harmonic generation and quarter-wave plate to get ps, circularly polarized UV pulse for photo dissociation
- > laser plasma acceleration with the 3rd pulse
- > active plasma lens for focusing

Plasma Lenses [7]

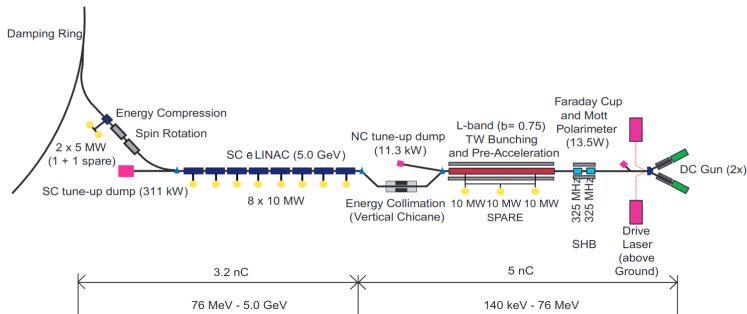
Makes an even more compact setup possible



- > thin gas capillary
- > HV electrodes on either end
- > longitudinal discharge current
- > radially symmetric focusing of particle beam
- > high focusing gradients of kT/m and upwards
- > conserve emittance

[7] van Tilborg et al., Phys Rev Lett. 115, 184802 (2015), figure taken from there

The ILC polarized electron source



[1] ILC TDR, Volume 3.II, Accelerator Baseline Design (2013)