Simulation Studies for the Polarimetry of a LPA Electron Beam

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FTX

DESY.

Why polarized electron beams from plasma acceleration?

The advantages of plasma acceleration

- Polarized beams are indispensable for many experiments in particle, atomic and nuclear physics

- acceleration gradients can be more than 3 orders of magnitude greater than from conventional linacs [1]
- a few fs bunch length advantageous for imaging applications
- how does the plasma acceleration affect the polarization ?

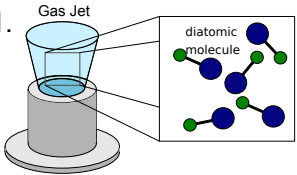
⇒ LEAP: proof-of-principle experiment for a polarized electron beam from laser plasma acceleration

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

LEAP

Polarized electrons from laser plasma acceleration

1.



- Polarized beams from a pre-polarized gas jet target [2,3]
- Alignment of diatomic molecules with ps IR pulse
- Photodissociation into molecular states with polarized valence electrons using UV pulse.
- LPA laser drives plasma wave and injected electrons are accelerated
- Beam polarization maintained during further acceleration [4]

[2] A. Spiliotis et al., Light Sci. Appl. 10, no 35 (2021)
[3] M. Wen, M. Tamburini and H. Keitel, Phys. Rev. Lett. 122,214801 (2019)
[4] J. Viera et al., Phys Rev. ST Acell. Beams 14, 071303 (2011)

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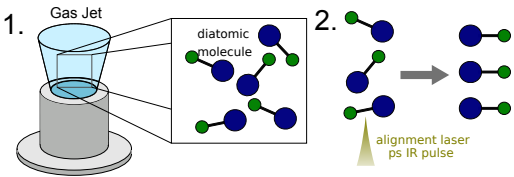

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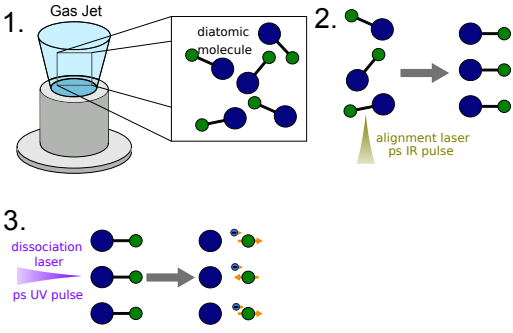

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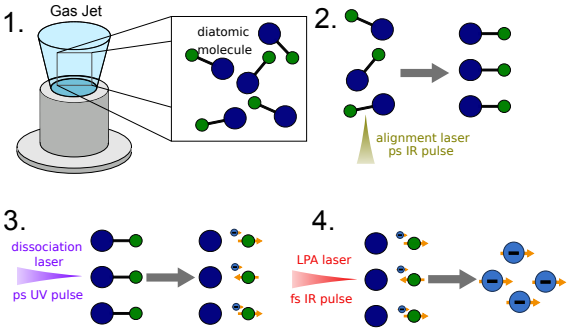

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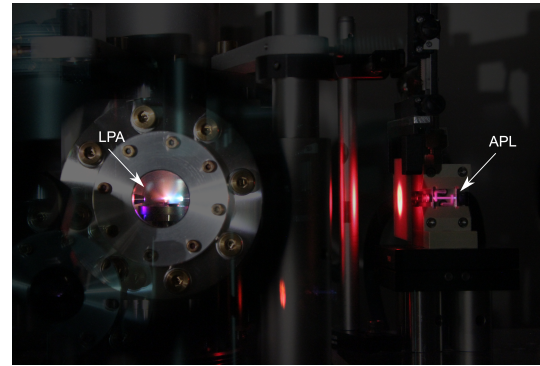
Electron Beam Parameters [5]

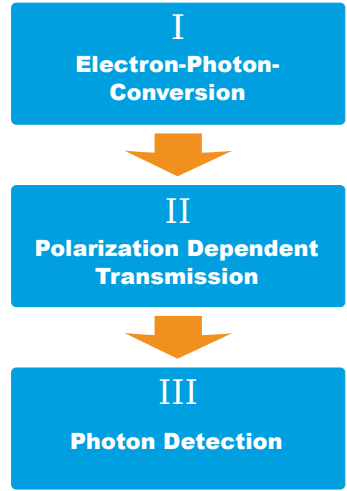
- central energy: tunable from 10 to 100 MeV
- FWHM energy spread: 10 %
- electron spot size: 1 μm
- divergence: 3 mrad
- electron beam charge: 2 pC



[5] Bohlen, S et al., Phys. Rev. Accel. Beams 25, 031301 (2022)

How to measure the polarization?

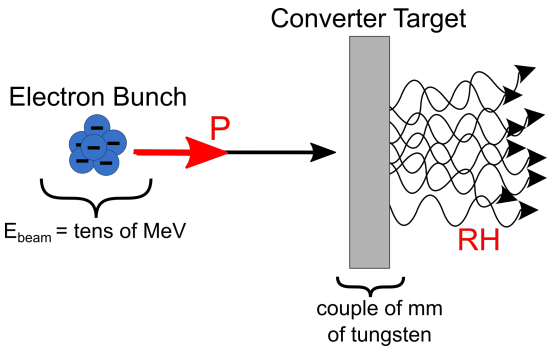
- at expected energy range **transmission polarimetry** is ideal
- demonstrated for positron polarimetry at the E166 Experiment [6]
  - positron energy between 4-8 MeV
  - polarization about 80 %
  - relative measurement error about 10-15 %



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

I. Electron-Photon-Conversion

Polarized Bremsstrahlung



> creation of circularly polarized photons via Bremsstrahlung [7]

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

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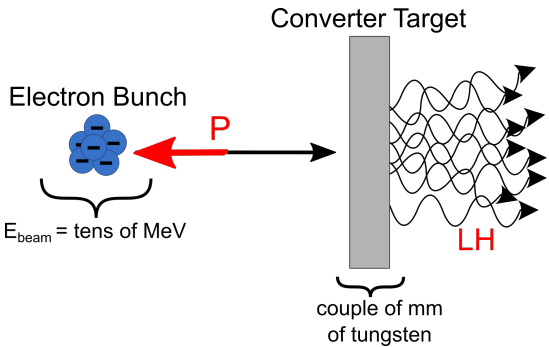

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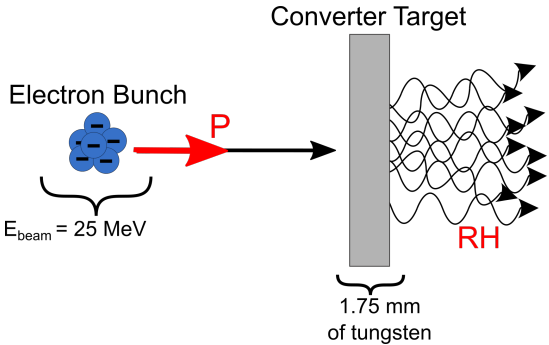
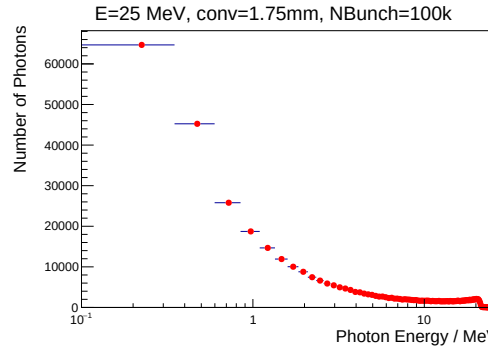


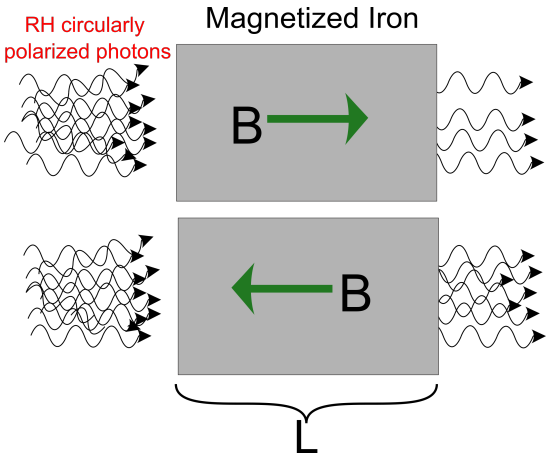


simulated spectrum

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

II. Photon Transmission

Depending on Polarization



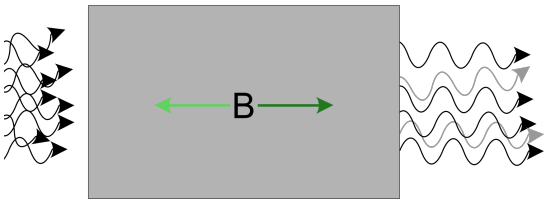
> the transmission of the photons through the iron, depends on polarization direction of both

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

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

Transmission Asymmetry

With Respect to Magnetization Direction



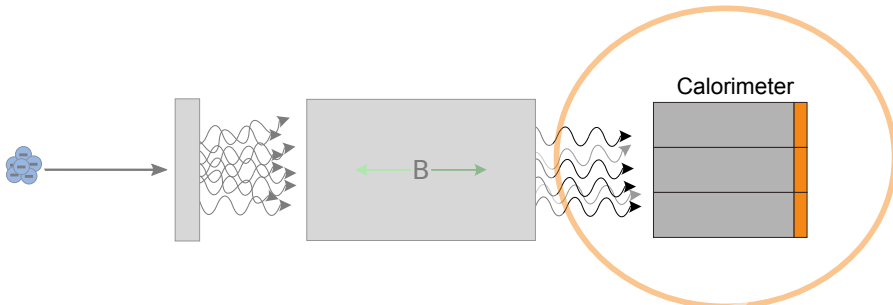
$$\delta = \frac{T_{AP} - T_P}{T_{AP} + T_P}$$

AP: Anti-Parallel
P: Parallel

III. Photon Detection

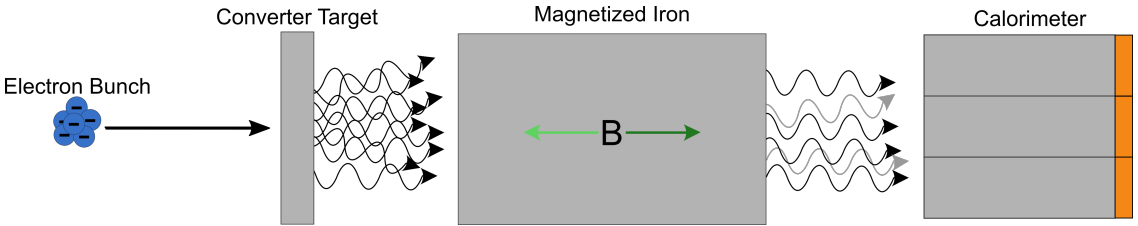
Calorimeter

T44.6 ”Calorimeter R&D for LPA Polarimetry” by Felix Stehr



Photon Transmission Polarimetry

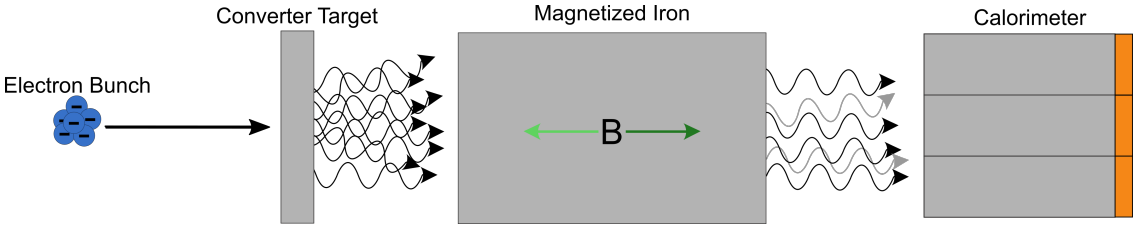
Summary



- 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



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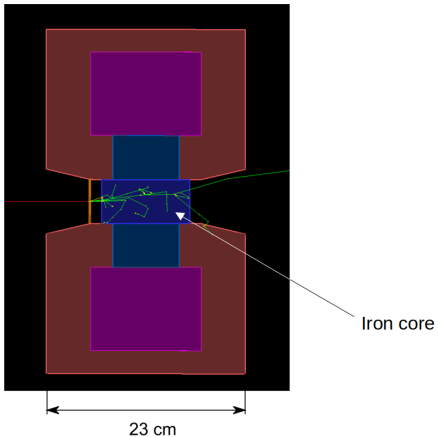
> **Next step: Computer simulations for setup optimization**

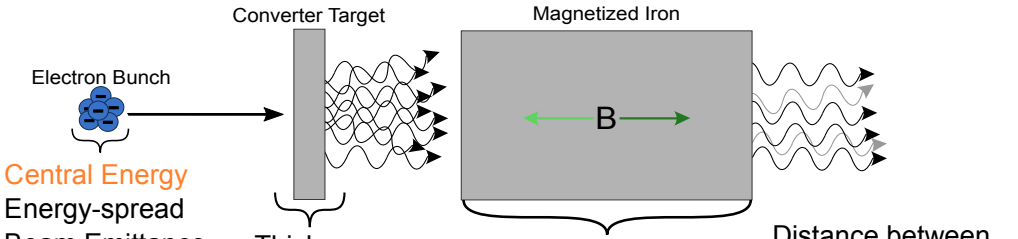
Set Up and Specifics of GEANT4 Simulations



- simplified idealistic beam
- e-/iron core polarization of +/- 1
- GEANT4[8] physicslist including polarized Compton scattering, γ-conversion, ionization, Bremsstrahlung, e+ annihilation and photoelectric effect [9]

[8] S. Agostinelli et al., Nucl. Instrum. Meth. A 506 (2003) 250-303
[9] A.Schälicke,K. Laihem,P. Starovoltov, arXiv:0712.2336 (2007)

Parameters adjusted for Asymmetry Studies

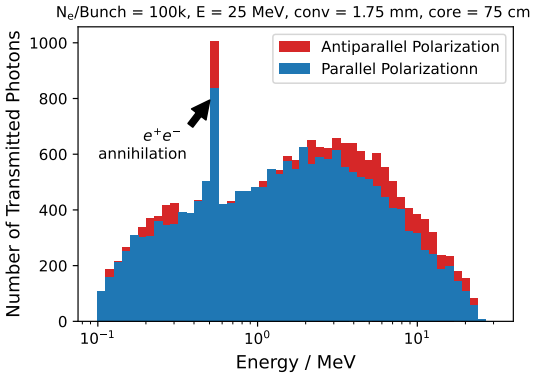


GOAL:

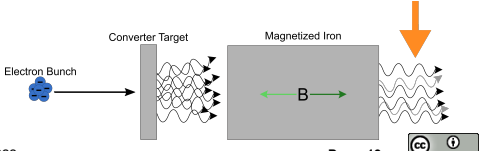
- Asymmetry as large as possible
- Asymmetry robust against beam parameter fluctuations

Photon Energy Spectrum Single e- Bunch

After transmission through magnet



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



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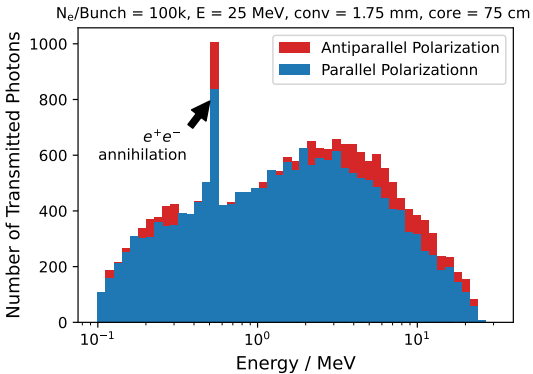

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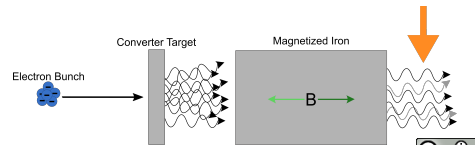
Next:

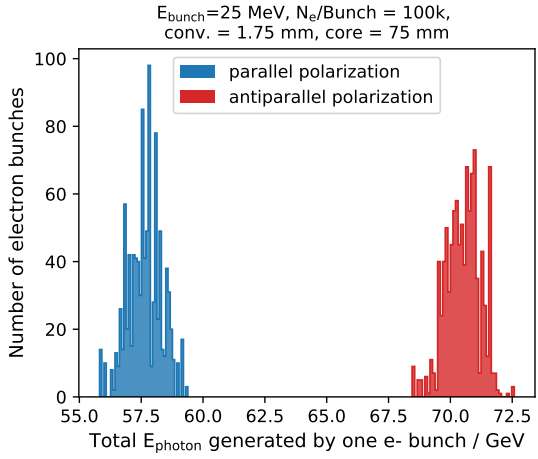
> Sum up the photon energies

> Repeat for statistics



Sum of Photon Energies

And computation of transmission asymmetry



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

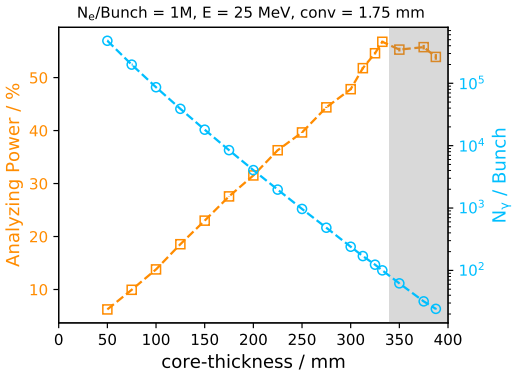
Transmission Asymmetry

$$\delta = \frac{E_{AP} - E_P}{E_{AP} + E_P}$$

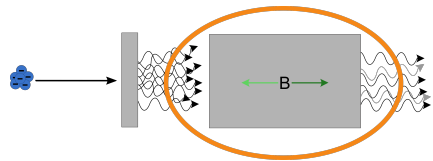
- $E_{AP/P}$ is the average photon energy sum per electron bunch
- simulate δ (P_e = 100%) to get analyzing power A_e
- Later: $\delta_{measured}/A_e$ yields electron polarization

Transmission Asymmetry

Asymmetry increases with increasing core thickness

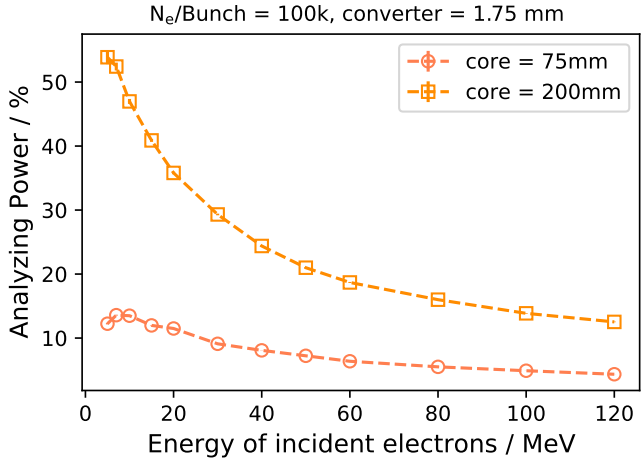


- Asymmetry increases from $\approx 6\%$ at 50 mm to $\approx 57\%$ at 333 mm
- Rate decreases



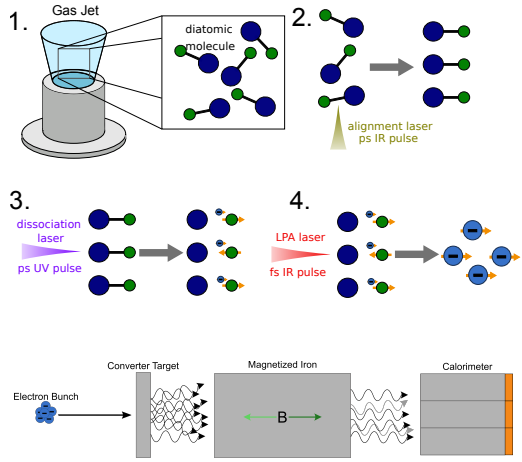
Transmission Asymmetry

Asymmetry decreases with increasing Energy of incident electrons



Conclusion

- LEAP aims to demonstrate creation of polarized electron beams from LPA
- best method to measure polarization: photon transmission polarimetry
  - polarized Bremsstrahlung
  - spin-dependent transmission through magnetized iron
- challenge here: wide range of expected electron beam parameters
- optimization of setup via GEANT4 simulations shows promising results, e.g. Analizing Power up to 50 % possible



Thank you!

Contact

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Polarized LPA

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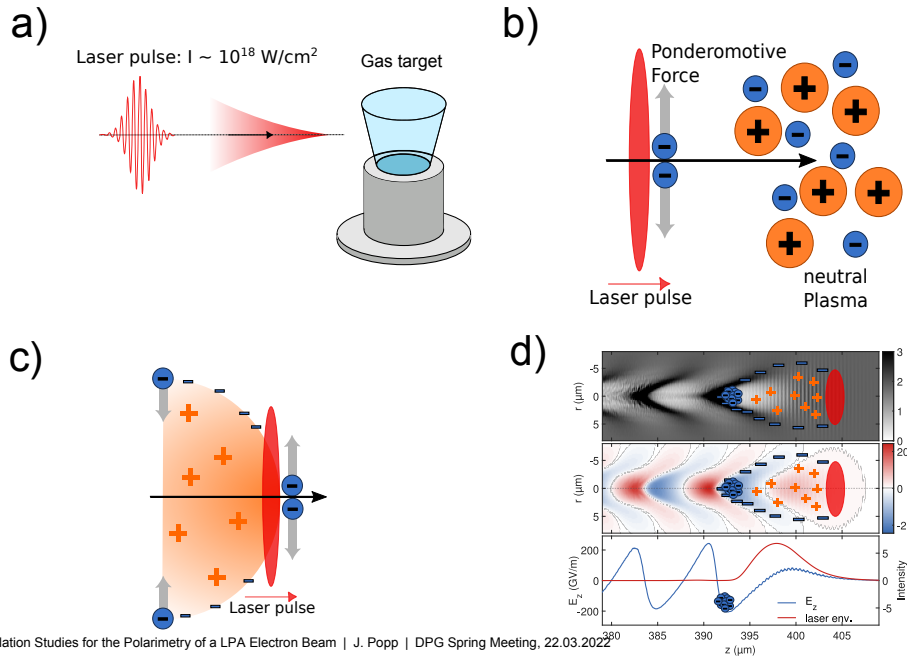
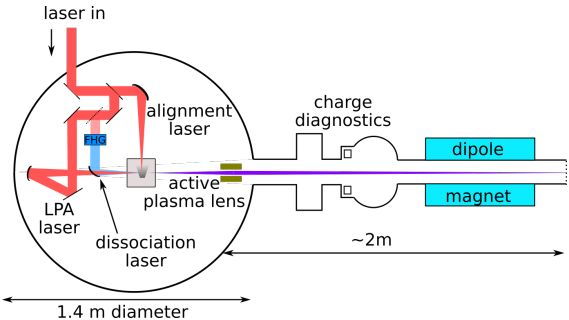

a)
Laser pulse: I ~ 10^18 W/cm^2
Gas target
b)
Ponderomotive Force
Laser pulse
neutral Plasma
c)
Laser pulse
d)
r (μm)
n_e (× 10^19 cm^-3)
E_z (GV/m)
Intensity (× 10^18 W/cm^2)
E_z
laser env.
z (μm)

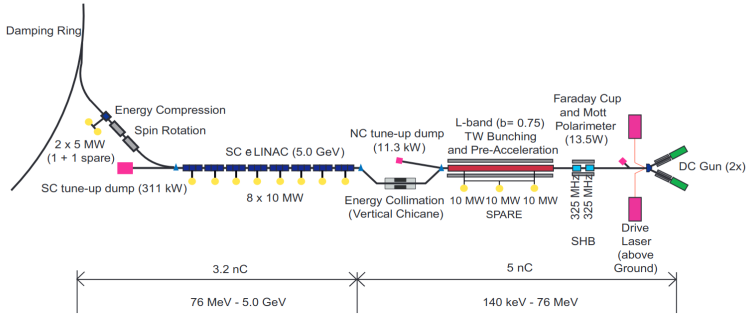
SETUP

Overview over experimental components



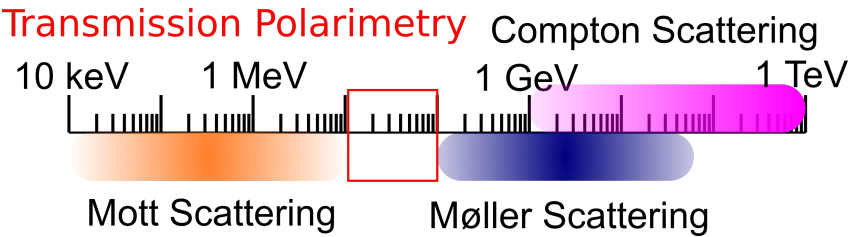
- fs, linearly polarized, IR laser pulse is split
- stretched ps IR pulse for bond alignment
- other pulse further split
- cascaded 2nd harmonic generation and quarter-wave plate to get ps, circularly polarized UV pulse for photo dissociation
- laser plasma acceleration with the 3rd pulse
- active plasma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

The ILC polarized electron source



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

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 to small

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