

Simulation Studies for the Polarimetry of a LPA Electron Beam

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DPG Spring Meeting, 22.03.2022

Why polarized electron beams from plasma acceleration?

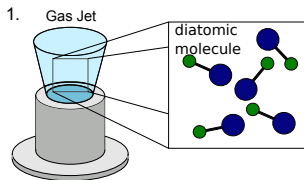
The advantages of plasma acceleration

- > 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)

Polarized electrons from laser plasma acceleration



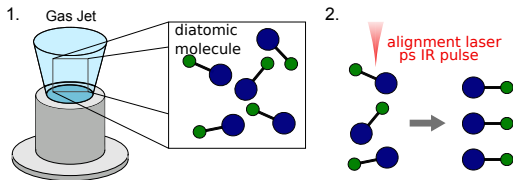
- > Polarized beams from a pre-polarized gas jet target [2,3]
- > Alignment of diatomic molecules with ps IR pulse
- > Photodissociation into molecular states with polarized valence electrons using UV pulse.
- > LPA laser drives plasma wave and injected electrons are accelerated
- > Beam polarization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

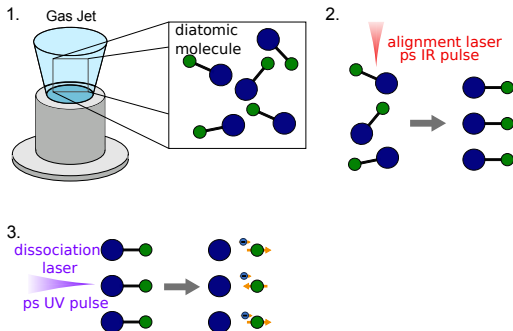
Polarized electrons from laser plasma acceleration



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Polarized electrons from laser plasma acceleration



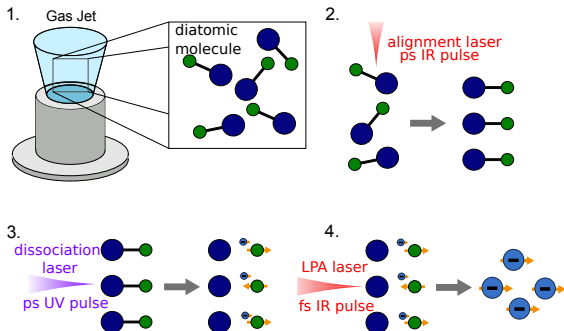
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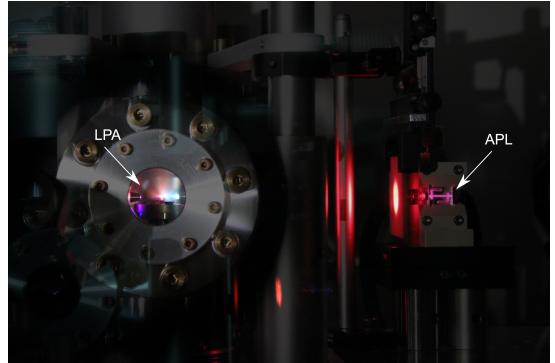
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[4] J. Viera et al., Phys Rev. ST Acell. Beams 14, 071303 (2011)

Electron Beam Parameters [5]

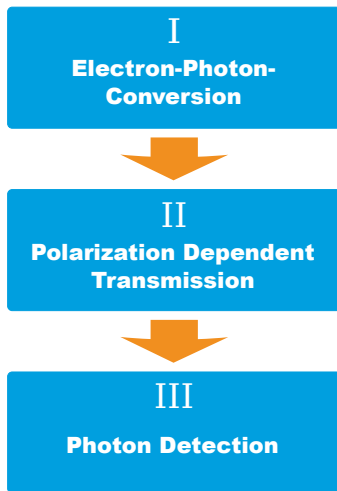
- > central energy: tunable from 10 to 100 MeV
- > FWHM energy spread: 10 %
- > electron spot size: 1 μm
- > divergence: 3 mrad
- > electron beam charge: 2 pC



[5] Bohlen, S et al., arXiv:2203.00561 [physics.acc-ph]

How to measure the polarization?

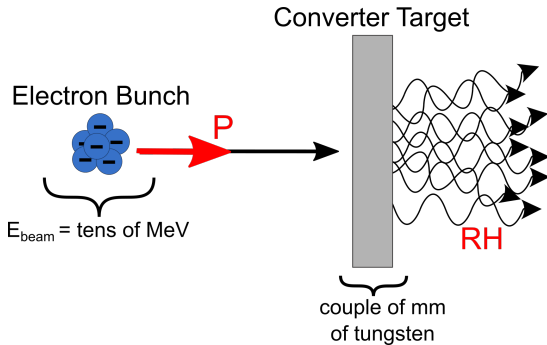
- > at expected energy range **transmission polarimetry** is ideal
- > demonstrated for positron polarimetry at the E166 Experiment [6]
 - positron energy between 4-8 MeV
 - polarization about 80 %
 - relative measurement error about 10-15 %



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

I. Electron-Photon-Conversion

Polarized Bremsstrahlung

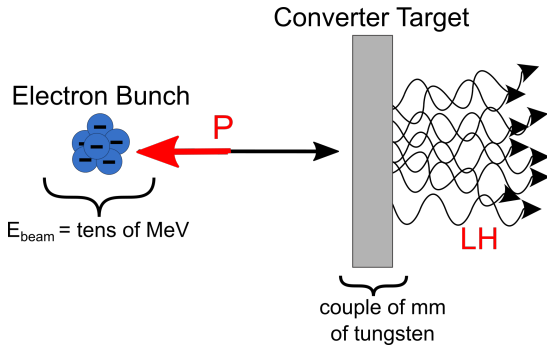


> creation of circularly polarized photons via **Bremsstrahlung** [7]

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

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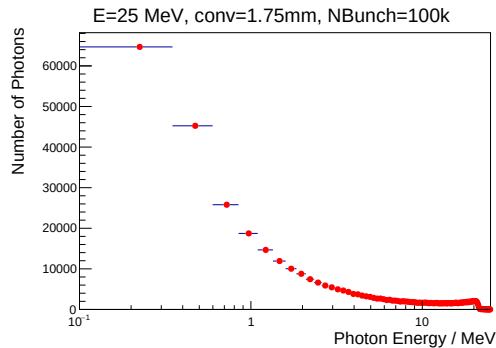
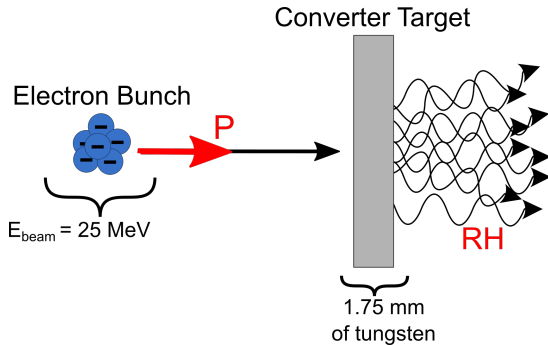


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I. Electron-Photon-Conversion

Polarized Bremsstrahlung

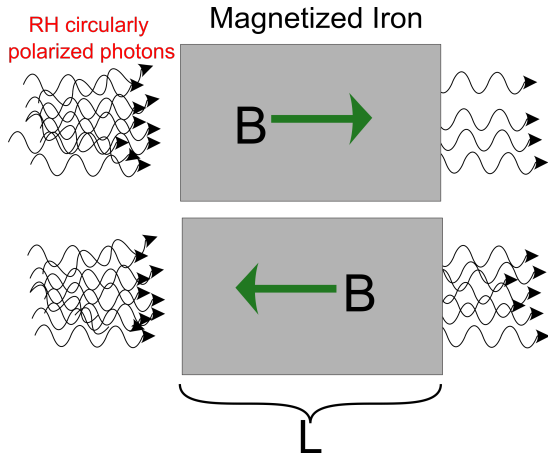


simulated spectrum

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

II. Photon Transmission

Depending on Polarization



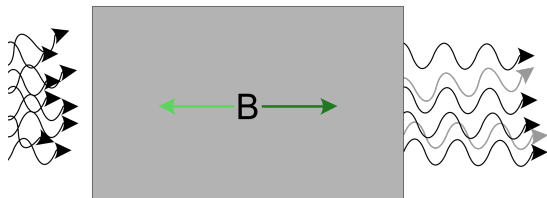
- > the transmission of the photons through the iron, depends on polarization direction of both

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

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

Transmission Asymmetry

With Respect to Magnetization Direction



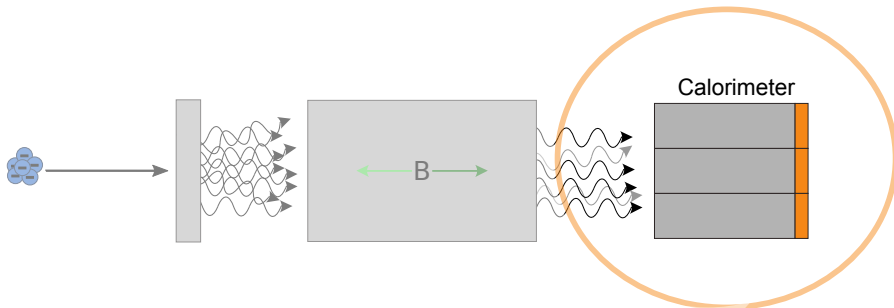
$$\delta = \frac{T_{AP} - T_P}{T_{AP} + T_P}$$

AP: Anti-Parallel
P: Parallel

III. Photon Detection

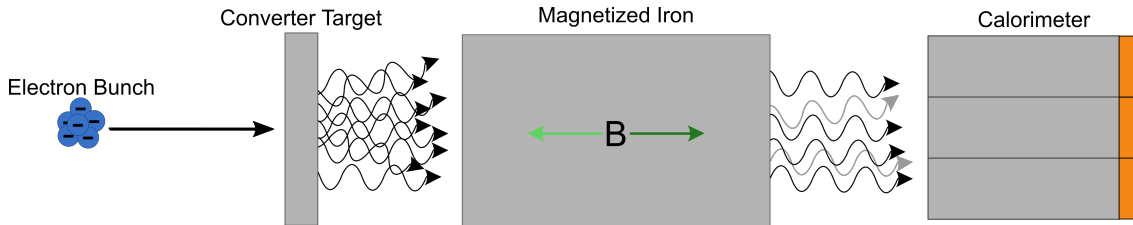
Calorimeter

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



Photon Transmission Polarimetry

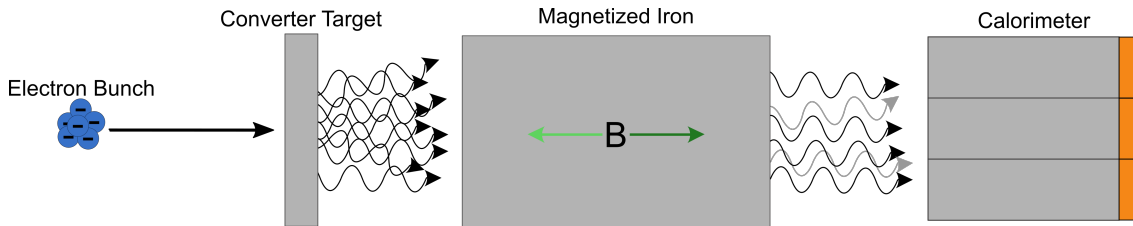
Summary



- > 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

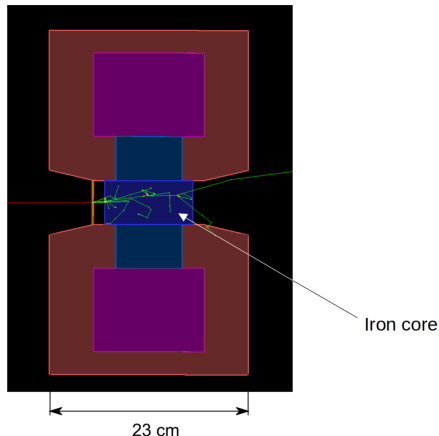
Photon Transmission Polarimetry

Summary



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

Set Up and Specifics of GEANT4 Simulations

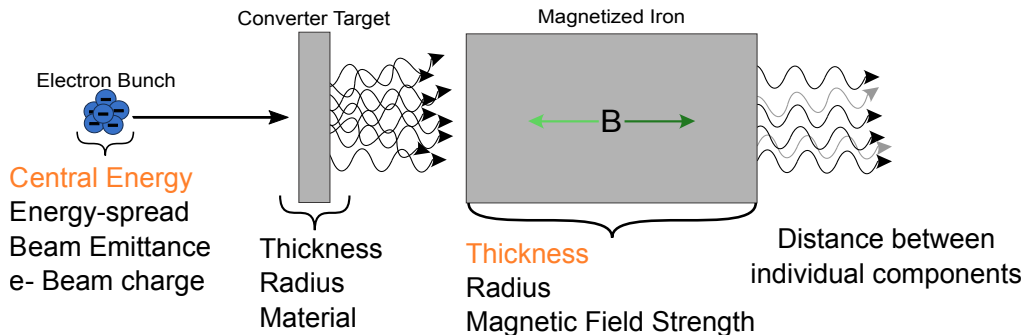


- > simplified idealistic beam
- > e-/iron core polarization of ± 1
- > GEANT4[8] physicslist including **polarized** Compton scattering, γ -conversion, ionization, Bremsstrahlung, e^+ annihilation and photoelectric effect [9]

[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

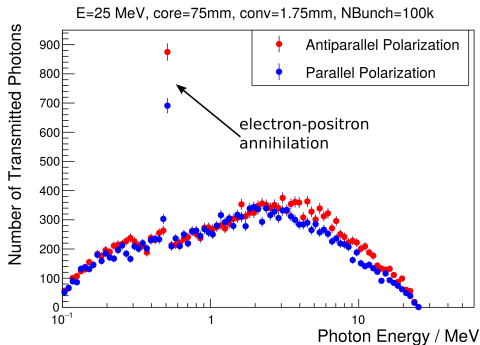


GOAL:

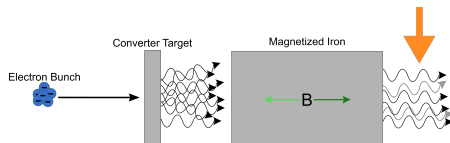
- > Asymmetry as large as possible
- > Asymmetry robust against beam parameter fluctuations

Photon Energy Spectrum Single e- Bunch

After transmission through magnet

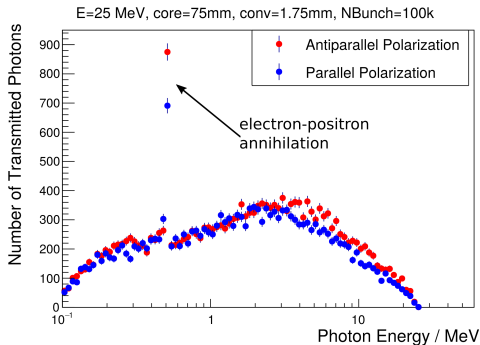


- > Transmission is **higher** when polarization of incident e- and iron is **antiparallel**



Photon Energy Spectrum Single e- Bunch

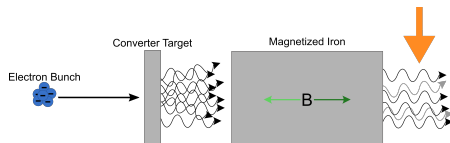
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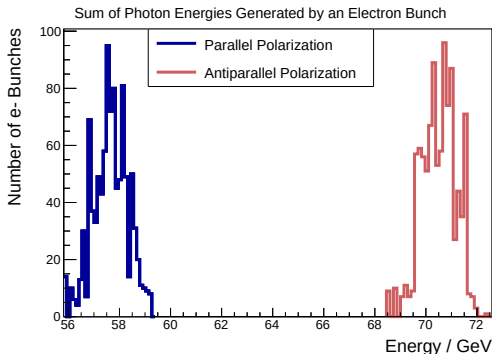
Next:

- > 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-

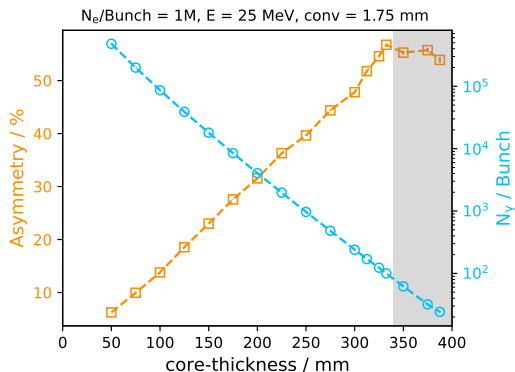
Transmission Asymmetry

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

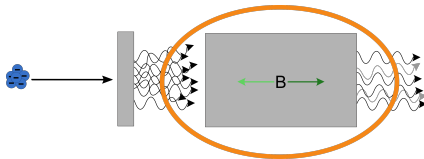
- > $E_{AP/P}$ is the average photon energy sum per electron bunch
- > simulate δ ($P_e = 100\%$) to get analyzing power A_e
- > Later: $\delta_{measured}/A_e$ yields electron polarization

Transmission Asymmetry

Asymmetry increases with increasing core thickness

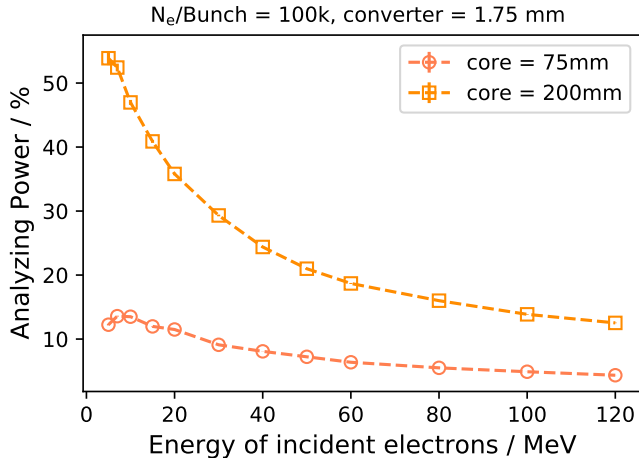


- > Asymmetry increases from $\approx 6\%$ at 50 mm to $\approx 57\%$ at 333 mm
- > Rate decreases



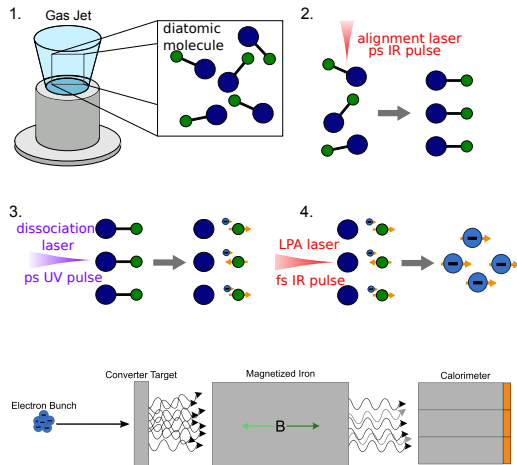
Transmission Asymmetry

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. asymmetries up to 50 % possible



Thank you!

Contact

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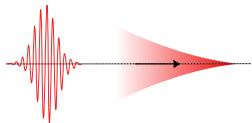
Polarized LPA

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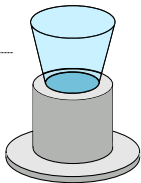
Polarimetry

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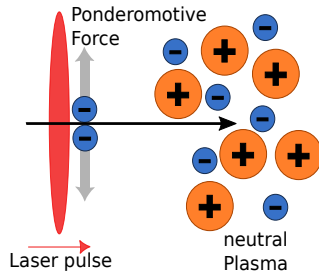
a)

Laser pulse: $I \sim 10^{18} \text{ W/cm}^2$ 

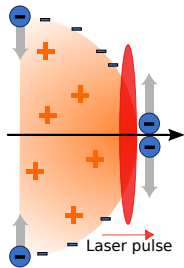
Gas target



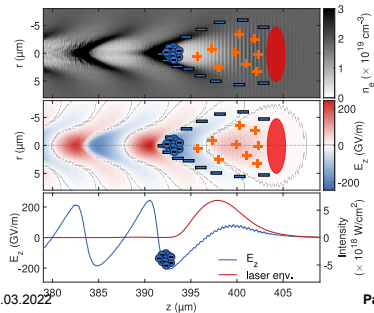
b)



c)

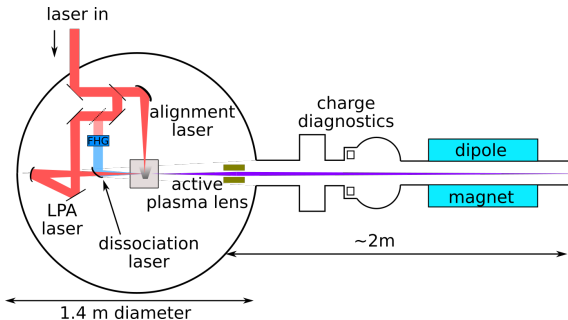


d)



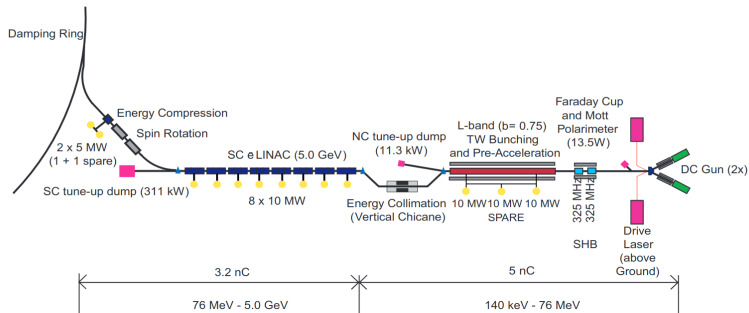
SETUP

Overview over experimental components



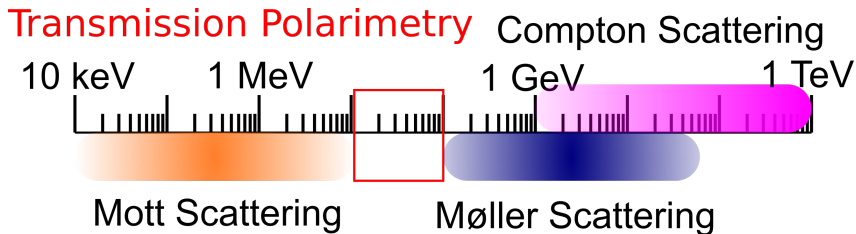
- > fs, linearly polarized, IR laser pulse is split
- > stretched ps IR pulse for bond alignment
- > other pulse further split
- > cascaded 2nd harmonic generation and quarter-wave plate to get ps, circularly polarized UV pulse for photo dissociation
- > laser plasma acceleration with the 3rd pulse
-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

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