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High-intensity Lasers for particle physics

5th Georgian - German School and Workshop in Basic Science

August 9th, 2012 | Ilhan Engin - IKP *i.engin@fz-juelich.de*

HEINRICH HEINE
UNIVERSITÄT DÜSSELDORF

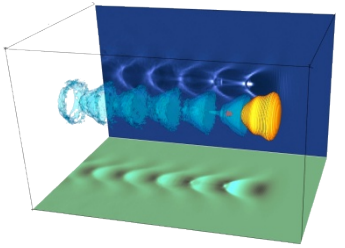
Working group

- Institute for Nuclear Physics *(FZJ)* → M. Büscher *)
- Jülich Supercomputing Centre *(FZJ)* → P. Gibbon *)
- Zentralinstitut für Technologie ZAT *(FZJ)* → H. Soltner
- Institute for Laser and Plasma Physics,
  Heinrich Heine University Düsseldorf *(HHUD)* → Prof. O. Willi *)
- Institute for Nuclear Physics,
  University of Münster *(WWUM)* → Prof. A. Khoukaz *)
- in cooperation with *RWTH Aachen University*, *University of Cologne*

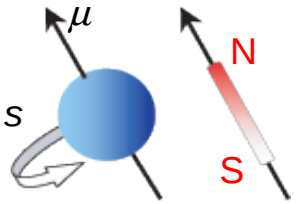
*) group leaders

Outline

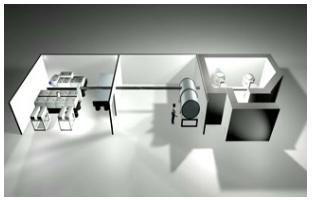
- Laser: New Generation of Particle Accelerators



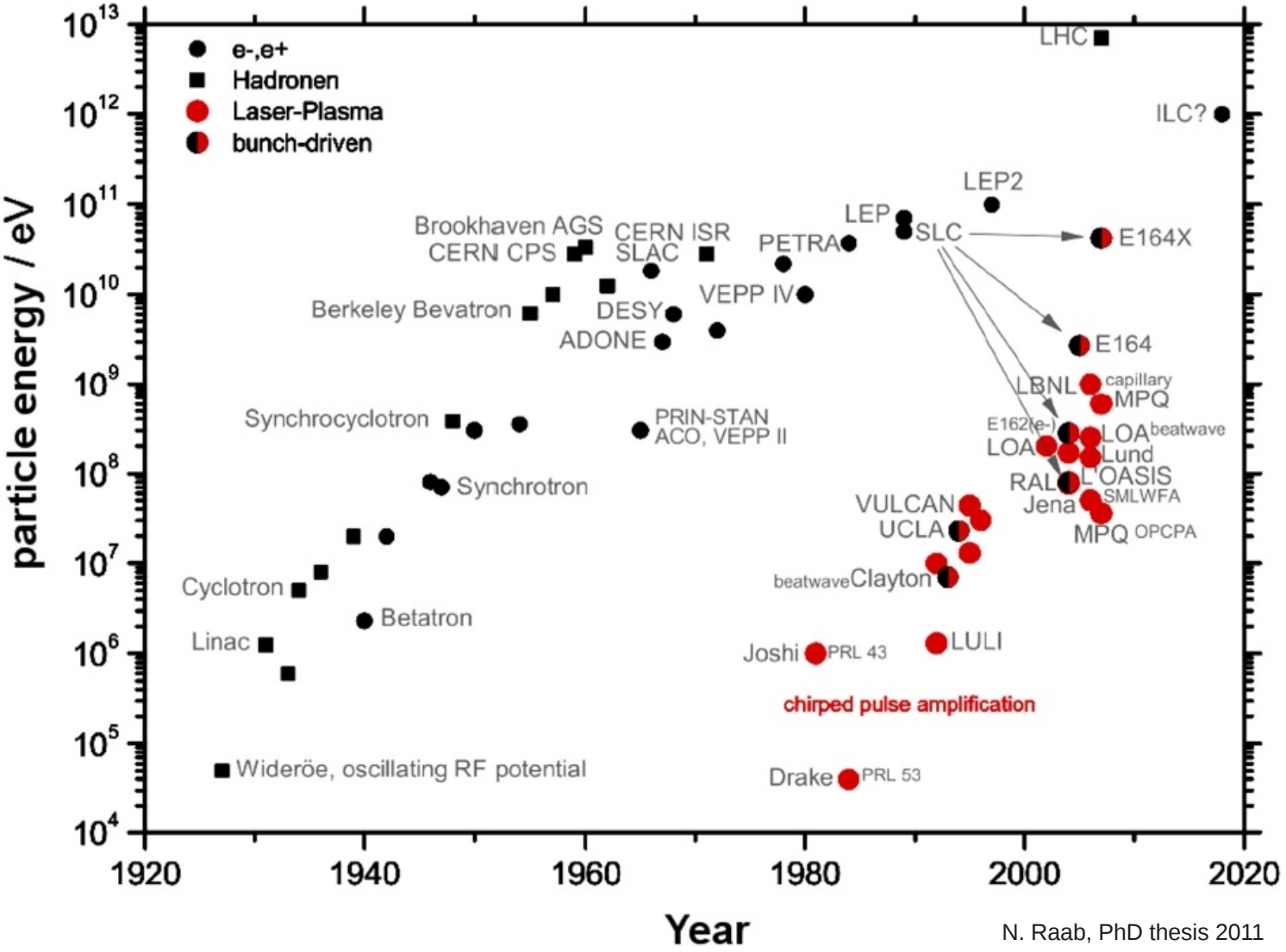
- Polarized Beams



- Current Experiments at HHUD

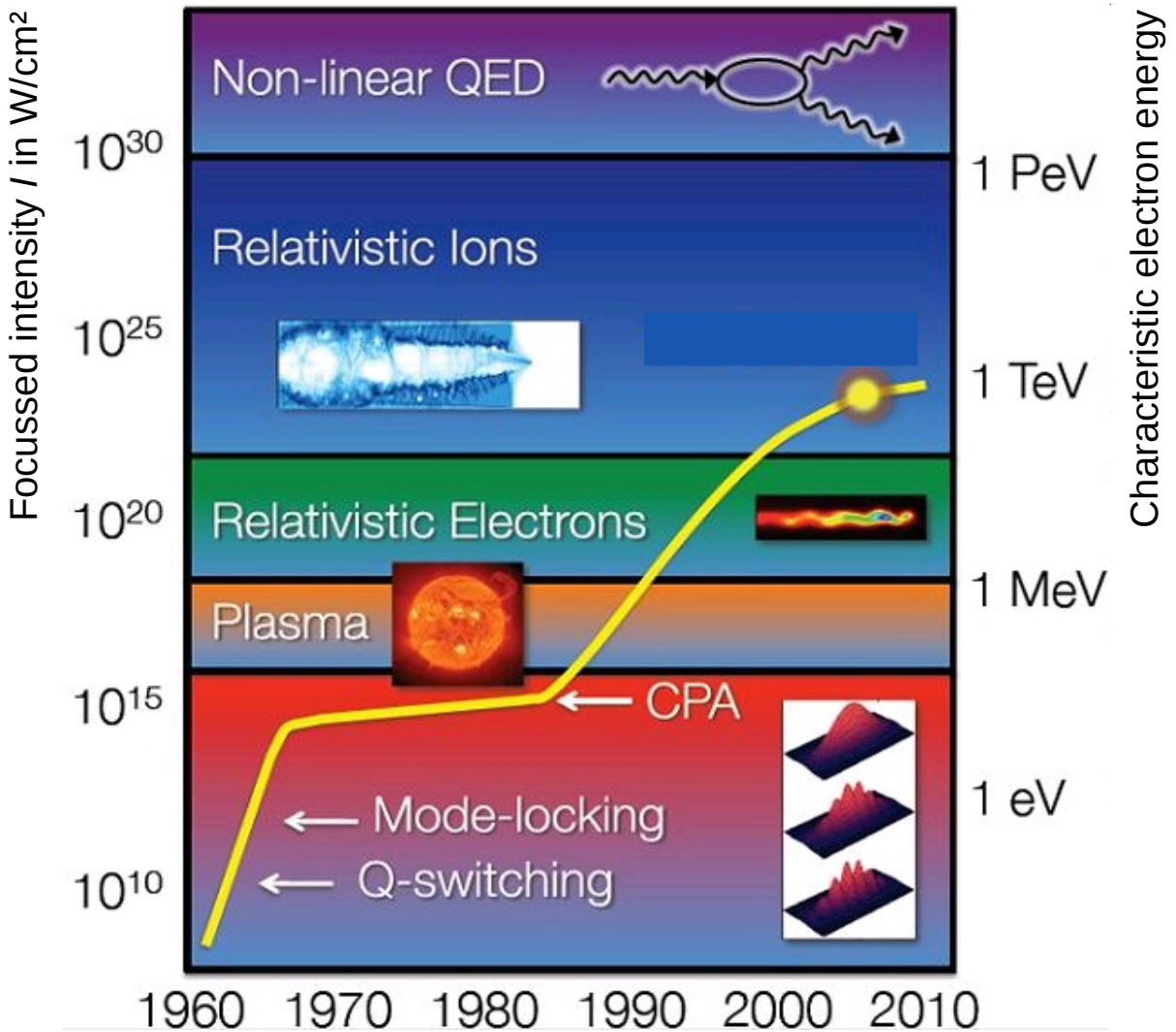


Development of conventional accelerators and plasma driven particle sources



N. Raab, PhD thesis 2011

Development of Laser intensities



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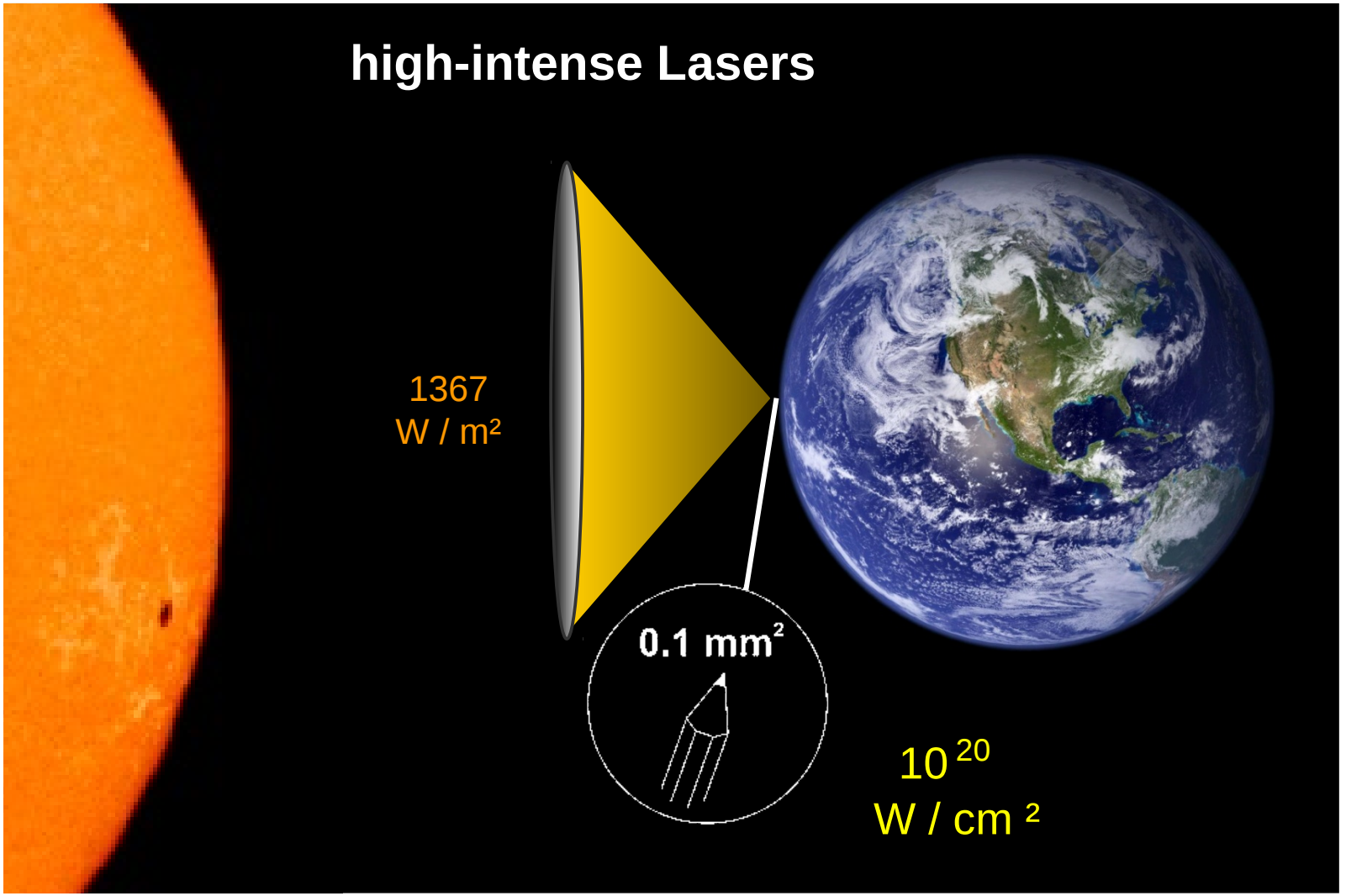
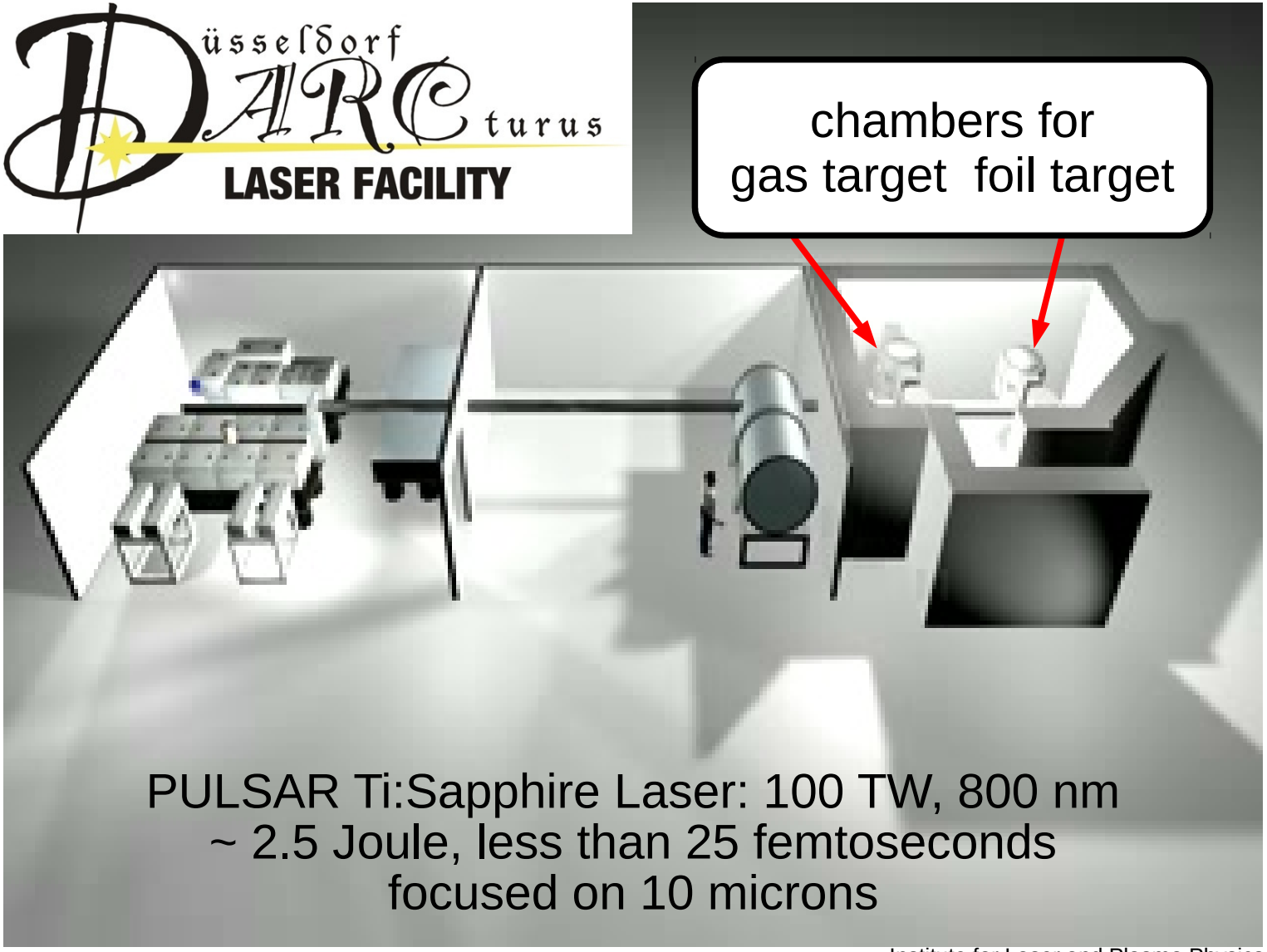
Current Laser intensities



Düsseldorf ARCturus Laser facility



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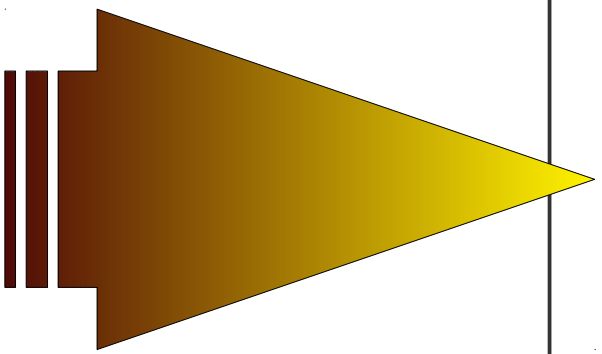
Institute for Laser and Plasma Physics
Prof. O.Willi - *HHUD*

Laser-induced particle acceleration

ultra-short high-intense Laser pulse

$I \sim 10^{20}$ W/cm^2 *)



mass limited target

gas jets

underdense plasma

solid targets

overdense plasma

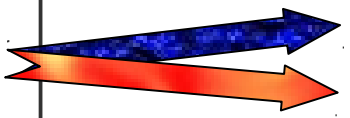
new approach:

cluster jets

future plans:

H_2 pellets

charged particles



electrons
~ 100 MeV *)

protons / ions
~ 10 MeV *)

*) typical values at *HHUD*

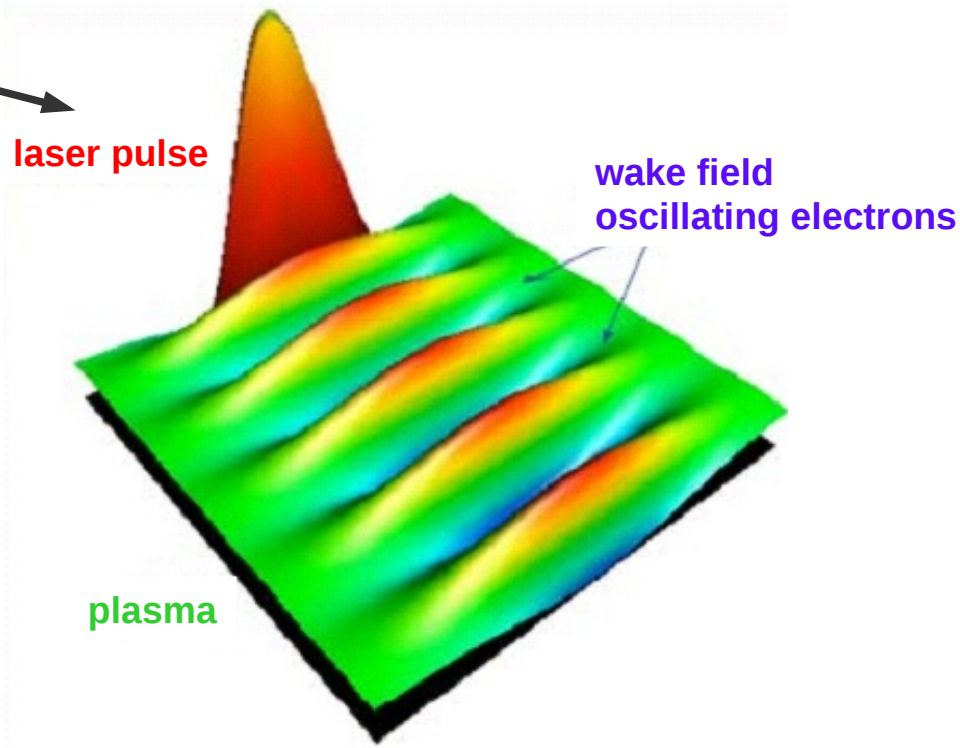
Laser-induced acceleration mechanisms

Wake fields / bubbles

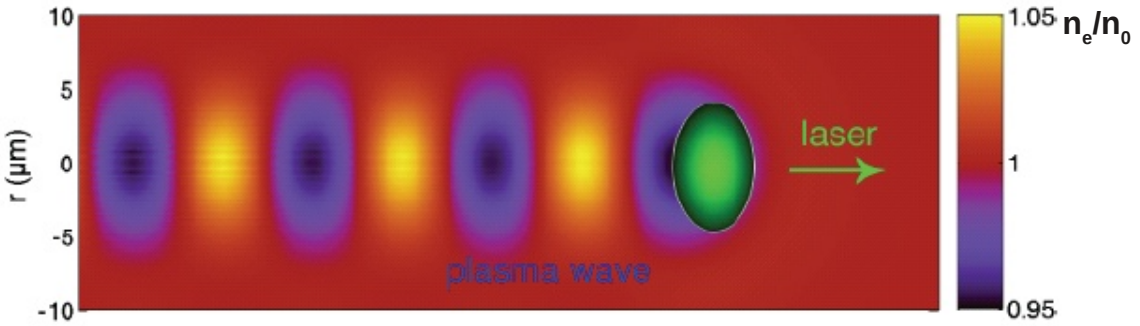
ponderomotive force $\boldsymbol{F}_{pon} \propto -\nabla I$

→ some electrons expel out of regions with higher intensity

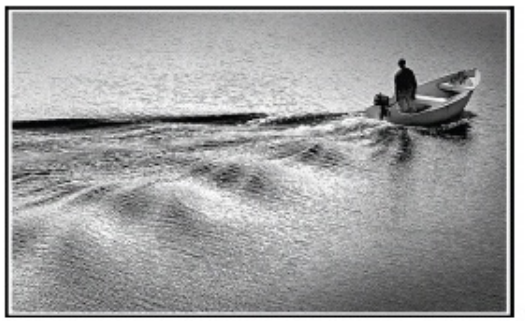
→ some electrons **oscillate**



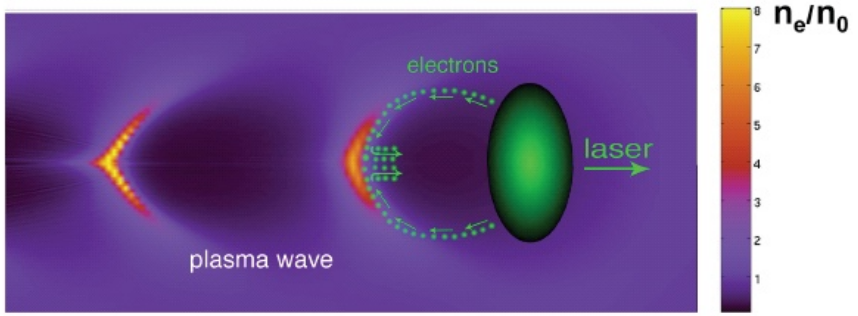
- lower intensities: wake fields



V.Malka et al., Nature Physics 4, 447–452 (2008)



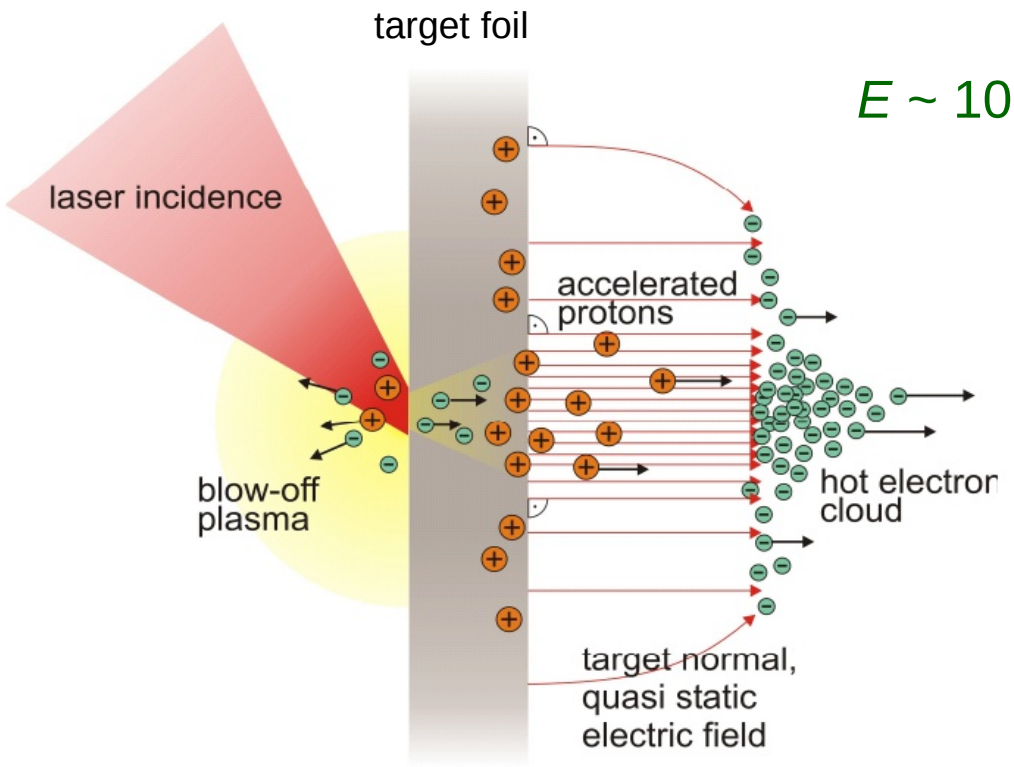
- high intensities: wake fields & bubble regime



A.Pukhov & J.Meyer-ter-Vehn, Appl. Phys. B 74, 355–361 (2002)

→ *acceleration of electrons*

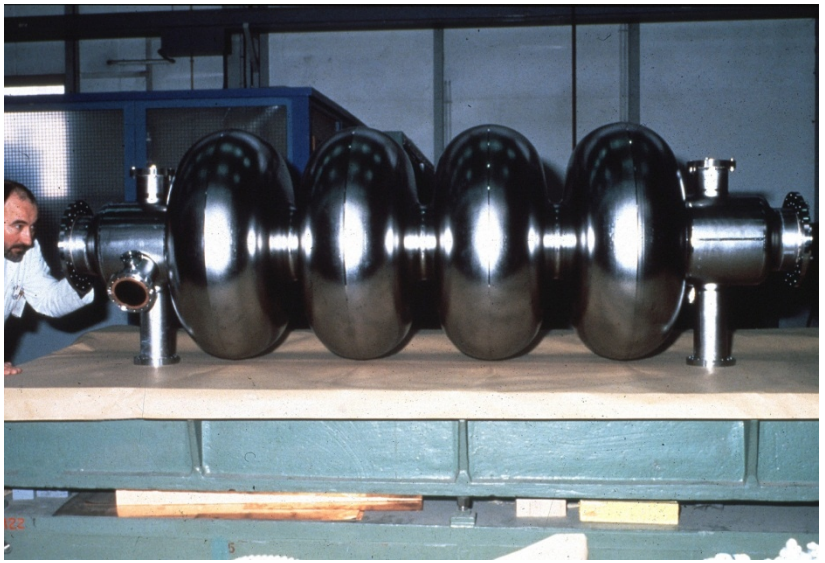
Target Normal Sheath Acceleration TNSA



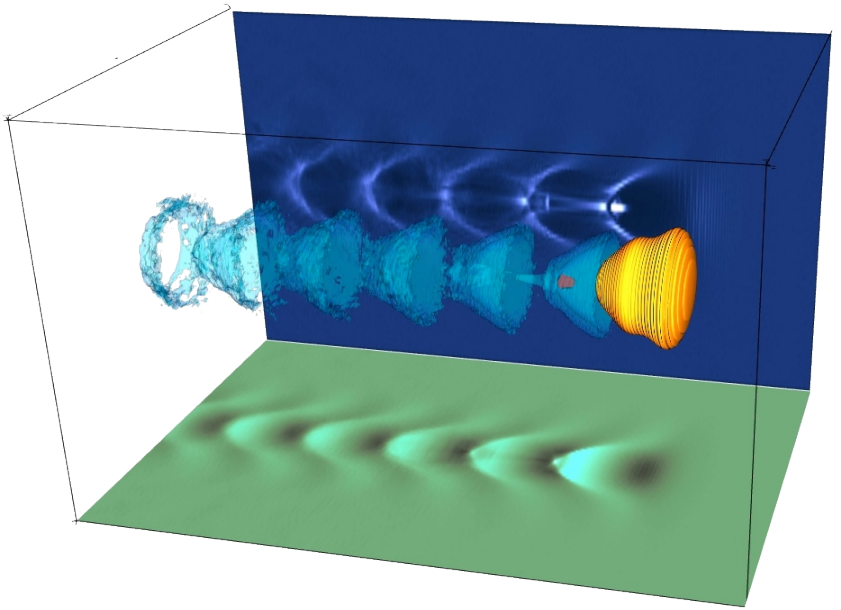
E ~ 100 GV/m

→ *proton acceleration from surface of thin foils (solid targets)*

Conventional vs. Laser-induced acceleration



1 m
1 MV/m } 1 MeV



100 µm
100 GV/m } 10 MeV

Outline

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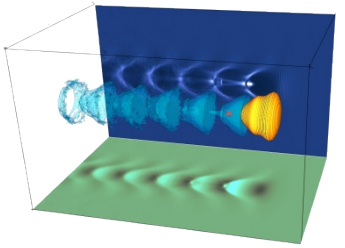

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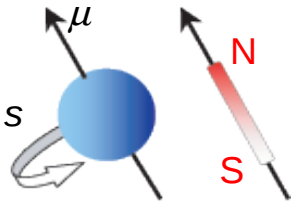
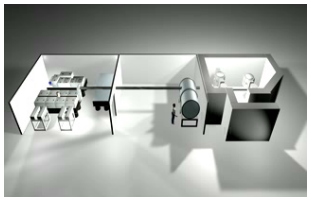
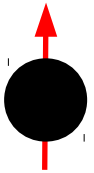


- Current Experiments at HHUD



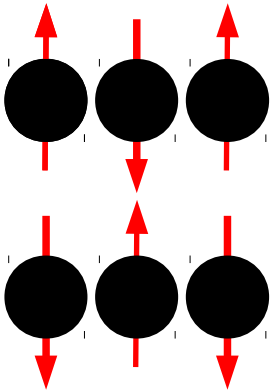
Spin-polarization (spin ≠ 0, e.g. protons)

- 1 particle → spin

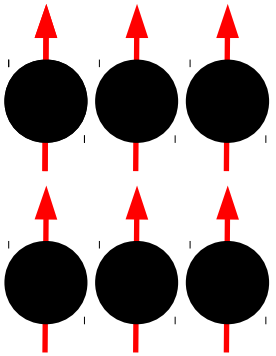


- Ensemble of particles

random spin-orientation
here: disordered spins
P = 0% = 0
no polarization



all spins ordered in same direction
here: P = 100% = 1
polarized particle beam



polarization

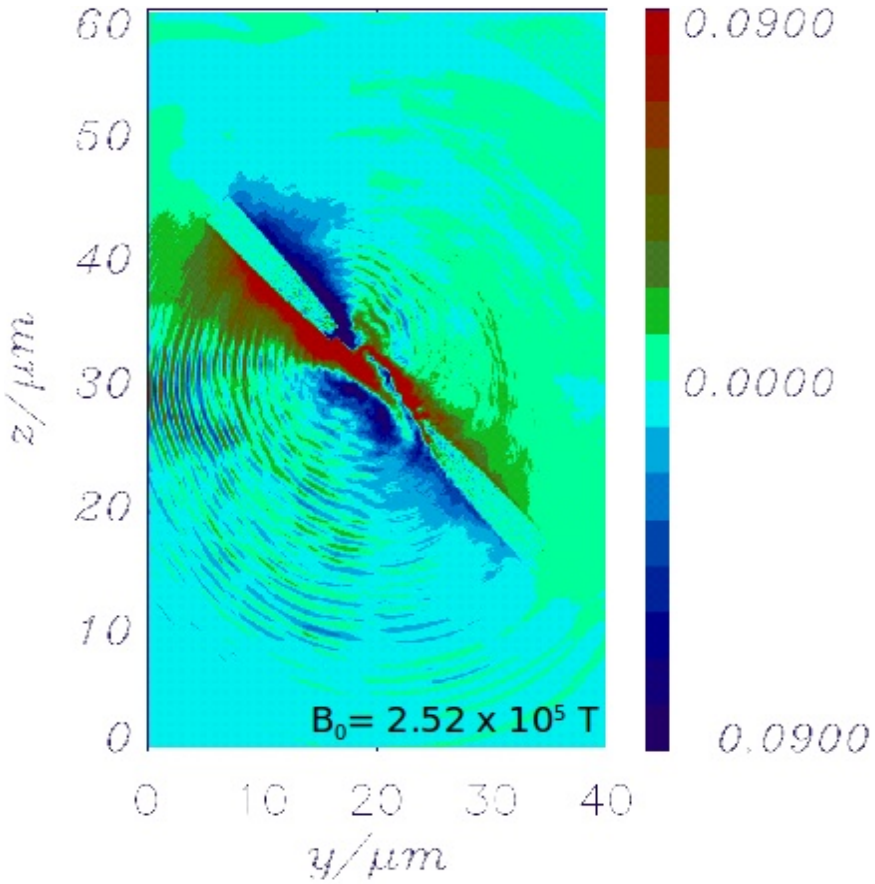
$$P = \frac{N^{up} - N^{down}}{N^{up} + N^{down}}$$

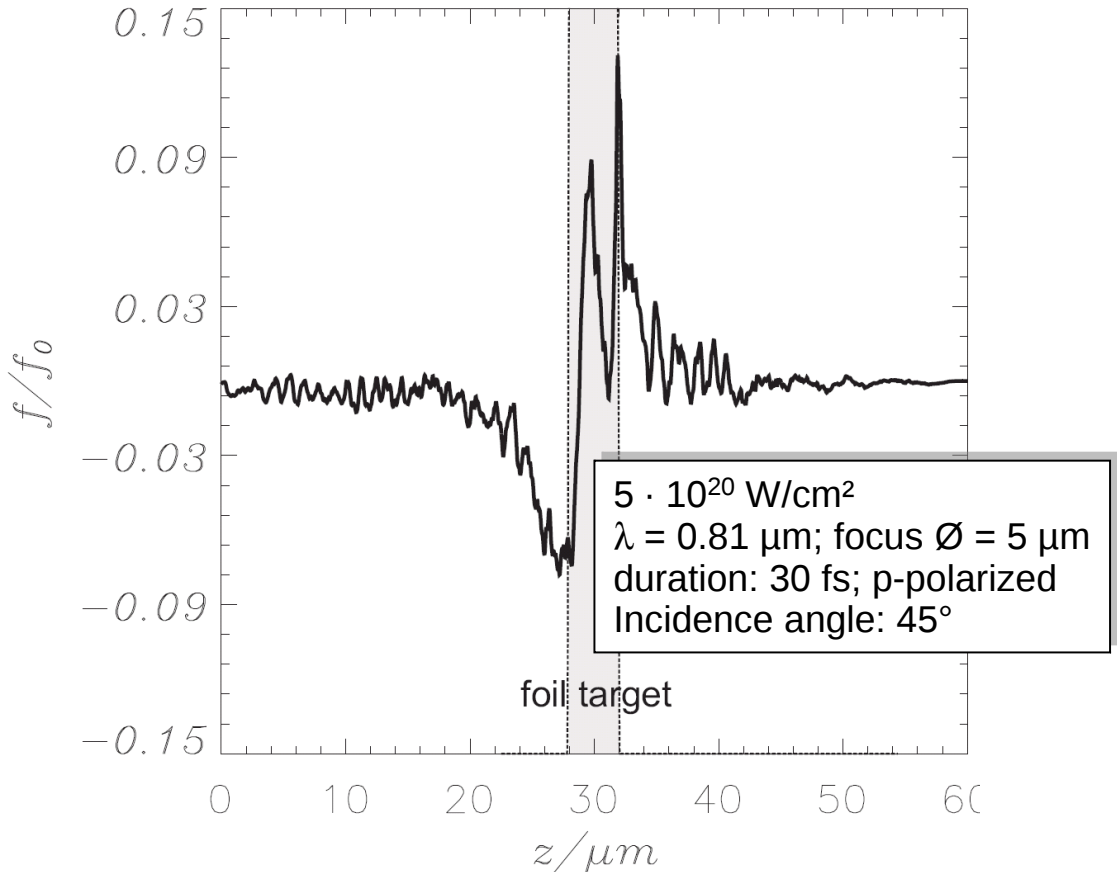
N = occupation number of u/d - state

Strong electro-magnetic fields (simulation)

B - field distribution 140 fs after laser hits target

Simulations: A.Karmakar, P.Gibbon (IAS, FZJ)





field strength / gradient: ~ 10^4 T / 10^{10} T/m

Polarized beams from Laser plasmas

2 possible scenarios for creating **polarized particle beams**

- *Polarization is **generated***

  Laser-acceleration process polarizes

  particles from unpolarized targets (plasmas)

  due to large magnetic fields and / or gradients

foil targets

gases / gas mixtures

(H_2 He ^{3}He)

cluster jets

- *Polarization is **conserved***

  Spin direction is invariant in

  strong laser & plasma fields

polarized

^{3}He gas

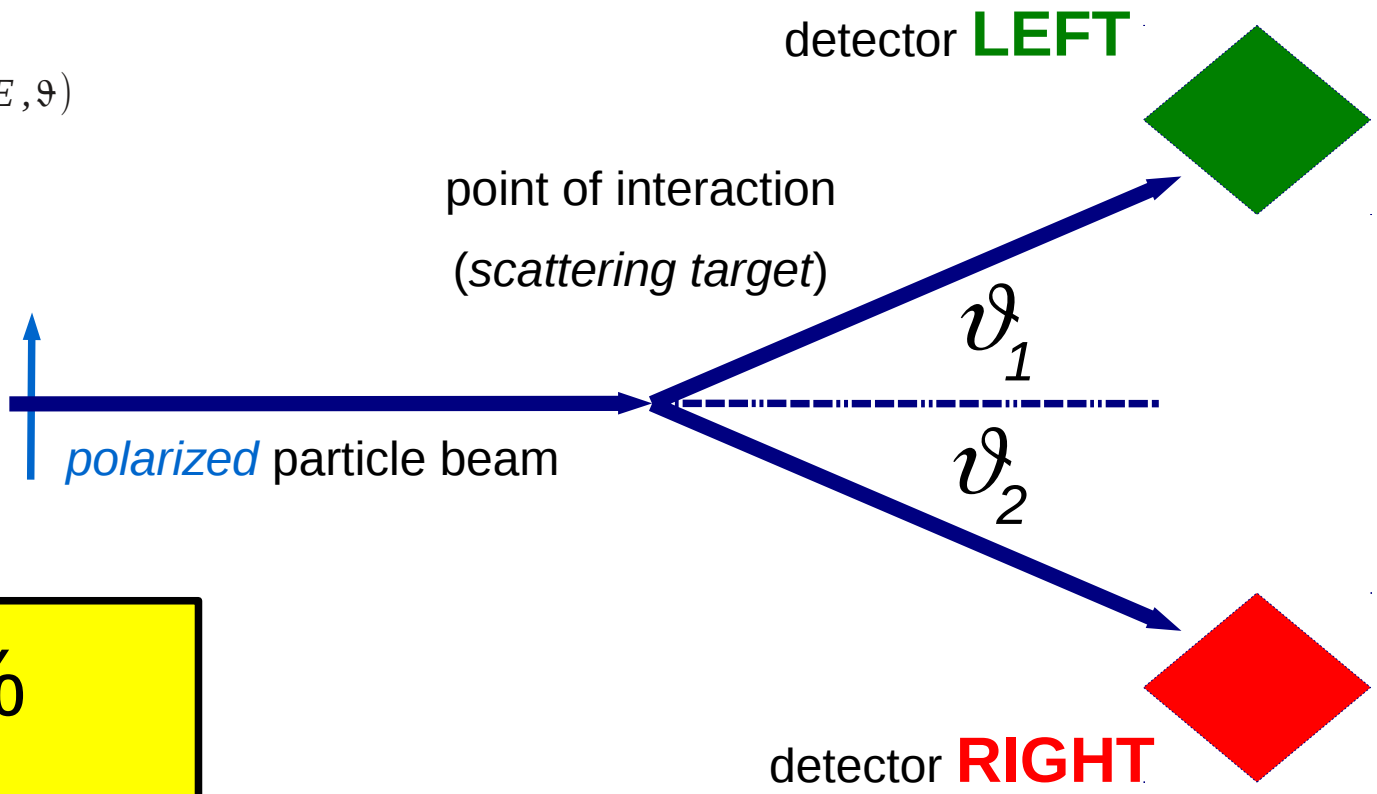
Scattering of a polarized particle beam

Observables, e.g.

diff. cross section $\frac{d\sigma}{d\Omega}(E,\vartheta)$

beam polarization P

analyzing power A

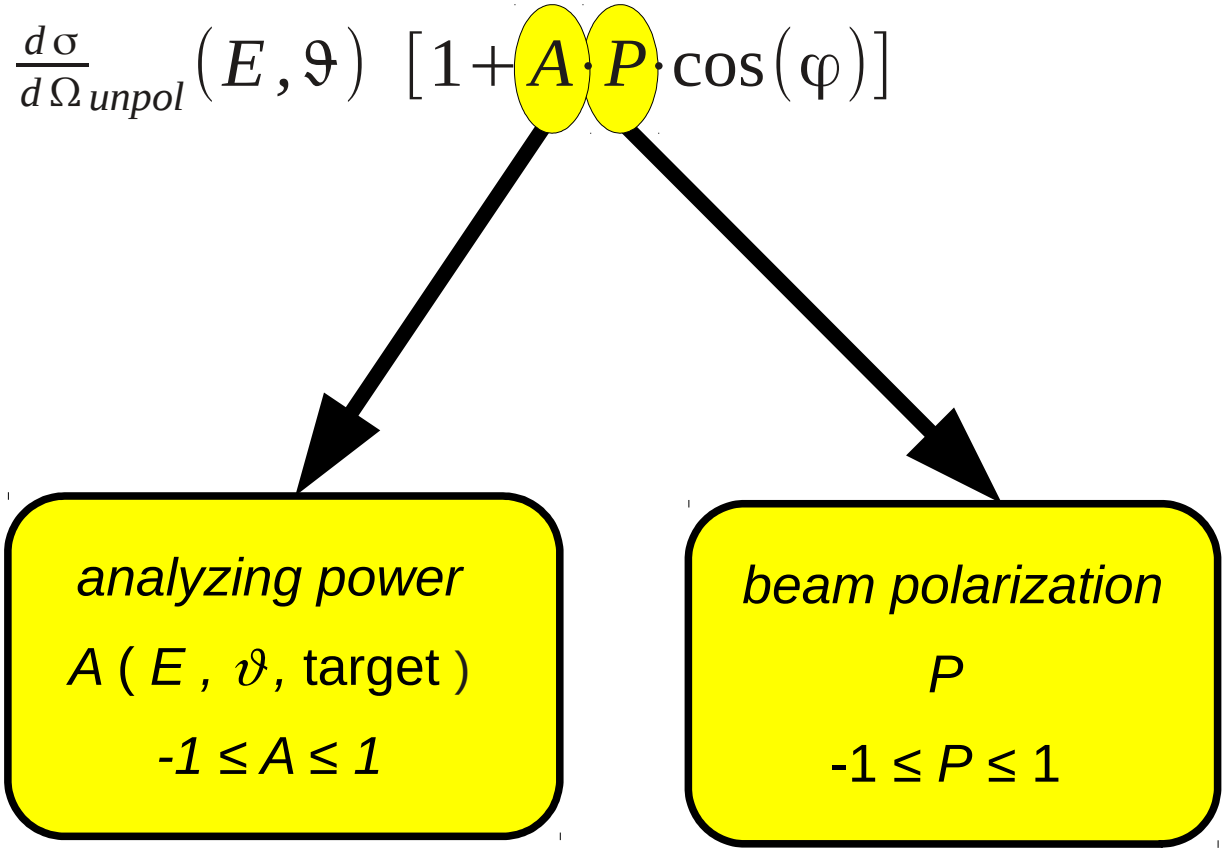


if $P > 0$ %

$N_{LEFT} \neq N_{RIGHT}$

simplest case: particle (**spin-½**) on **unpolarized** particle

$$\frac{d\sigma}{d\Omega}_{pol}(E,\vartheta,\varphi) = \frac{d\sigma}{d\Omega}_{unpol}(E,\vartheta)\ [1 + A \cdot P \cdot \cos(\varphi)]$$



$$\frac{d\sigma}{d\Omega}_{pol}(E,\vartheta,\varphi) = \frac{d\sigma}{d\Omega}_{unpol}(E,\vartheta)\ [1+A\cdot P\cdot\cos(\varphi)]$$

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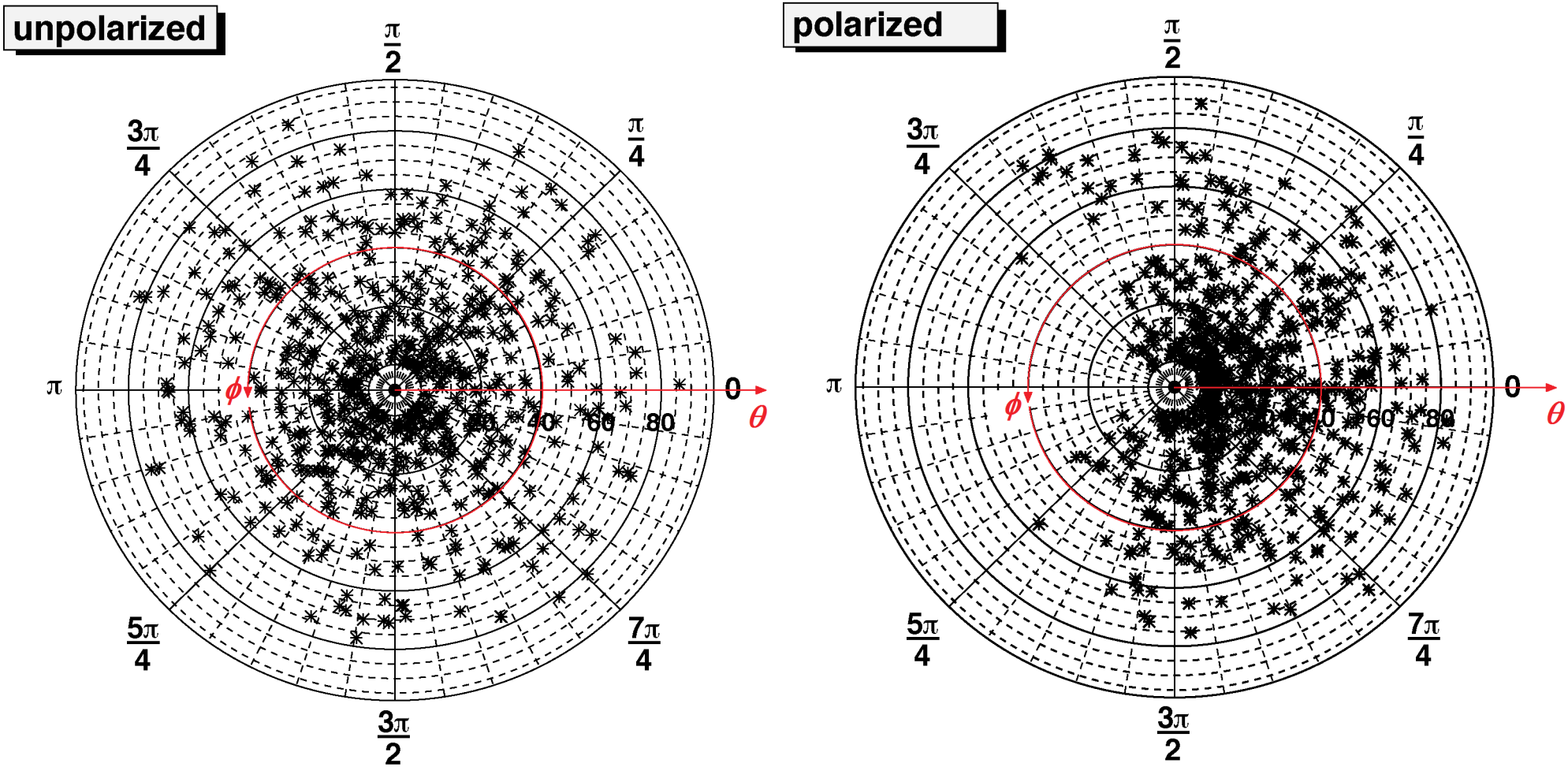
$P = 0$ or $A = 0$
symmetric distribution

$P = 1$, $A = 1$
asymmetric distribution



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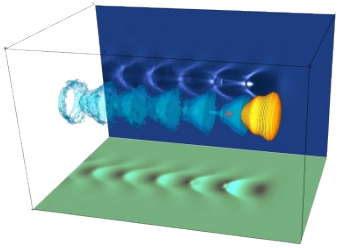

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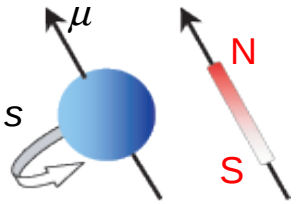

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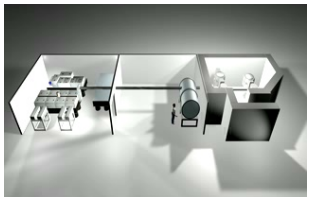
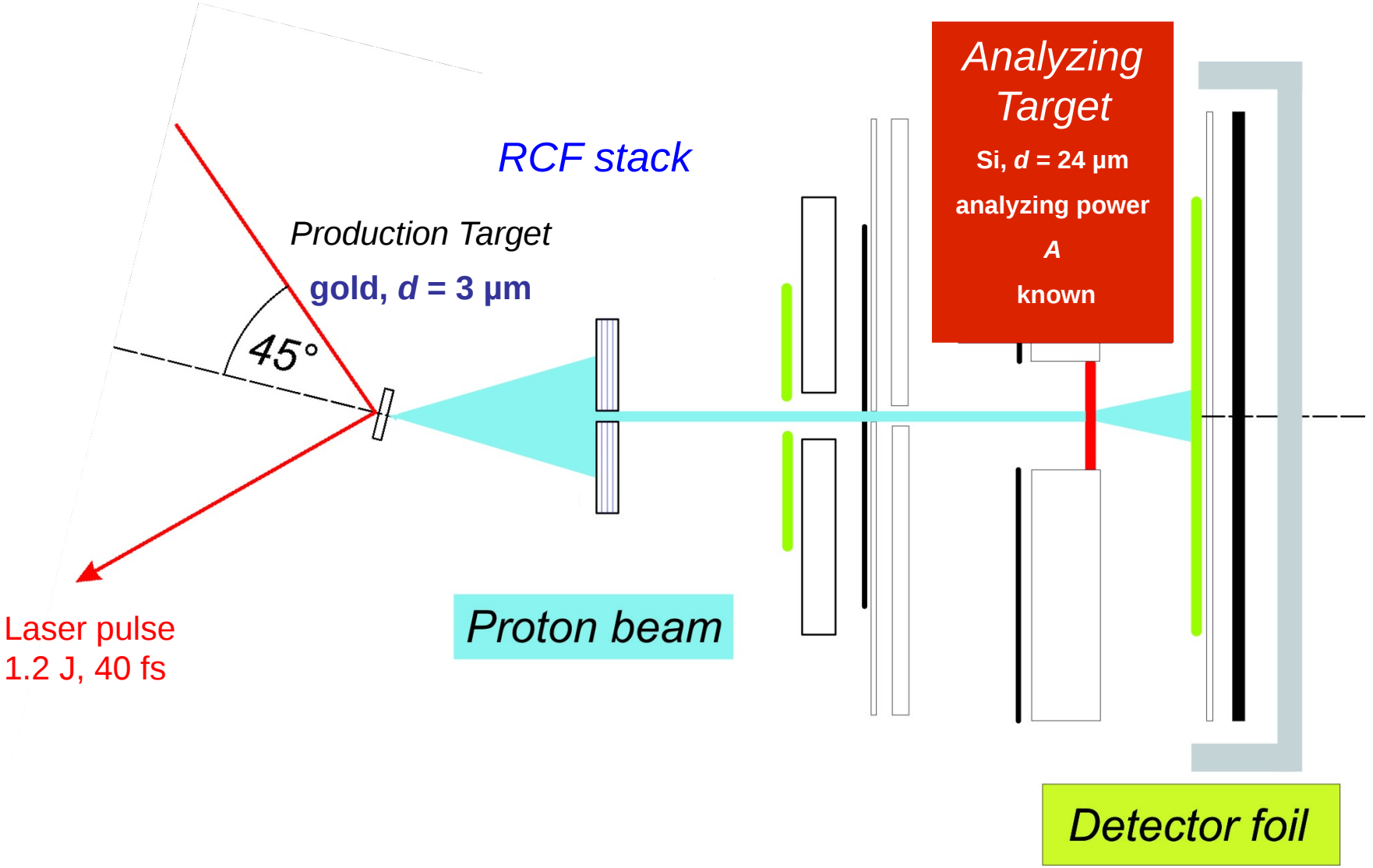


Polarization measurement: setup



Appertures Ø = 1mm
for angular selection

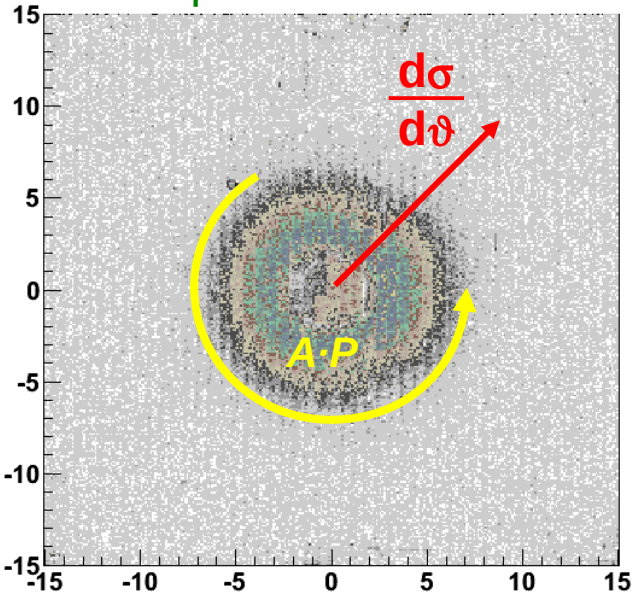
Secondary scattering target
Si, *d* = 24 µm

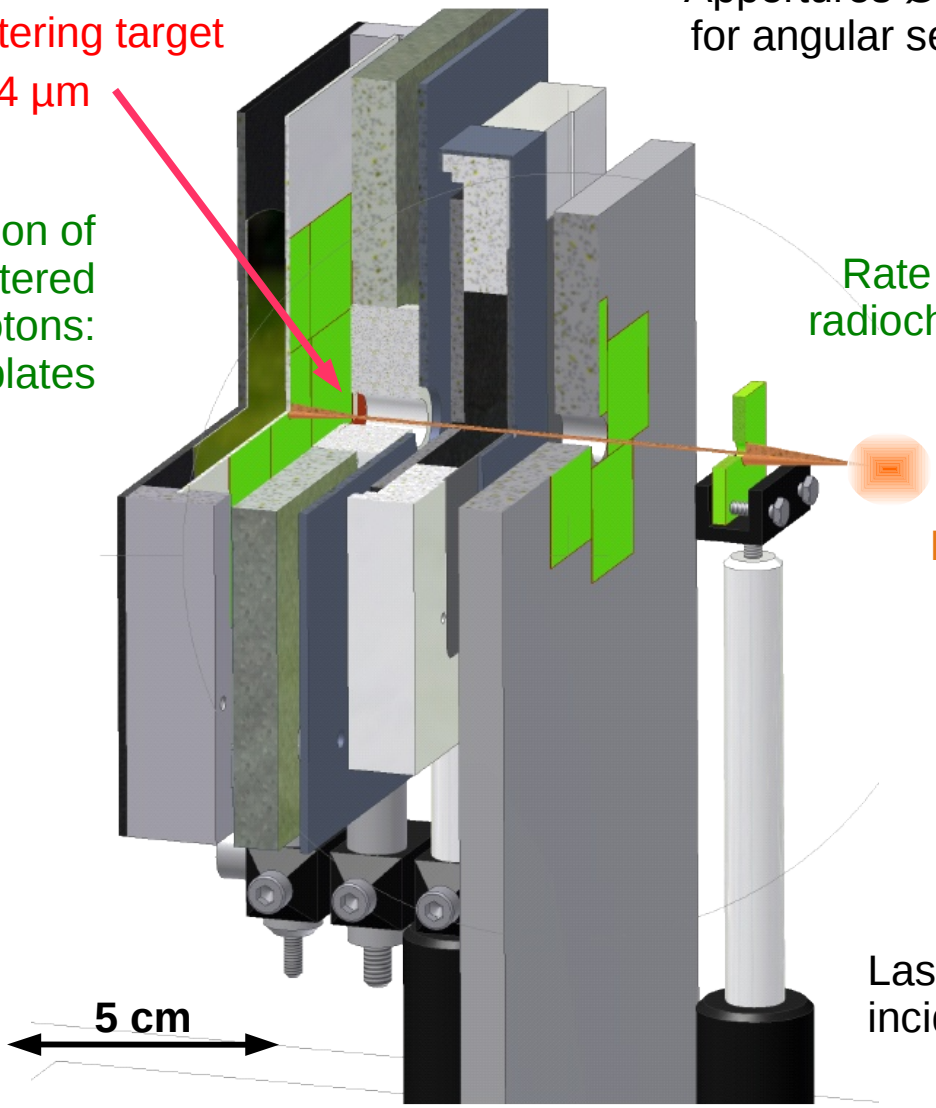
Detection of
scattered
protons:
CR-39 plates

Rate monitor:
radiochromic film

Production target:
gold, *d* = 3 µm

CR-39 plates





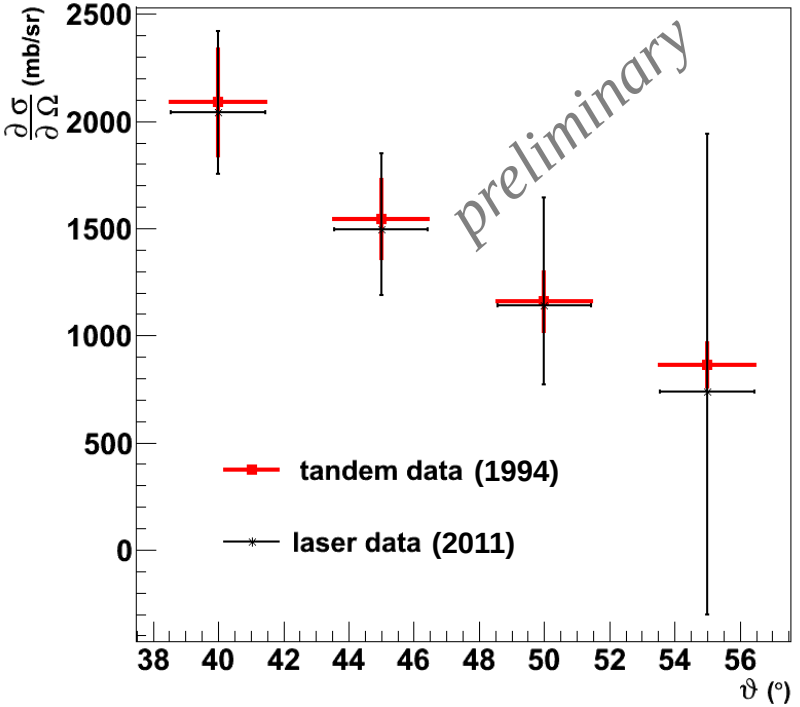
Laser pulse: 1.2 J, 40 fs
incidence angle: 45°

Scattering-angle distribution

Si(p, p')Si, T_p = (3.2±0.2) MeV

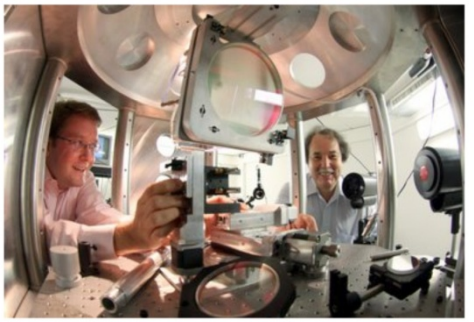
Cologne Tandem

beam time ~ days



N.Raab, Ph.D. thesis 2011

ARCturus Laser

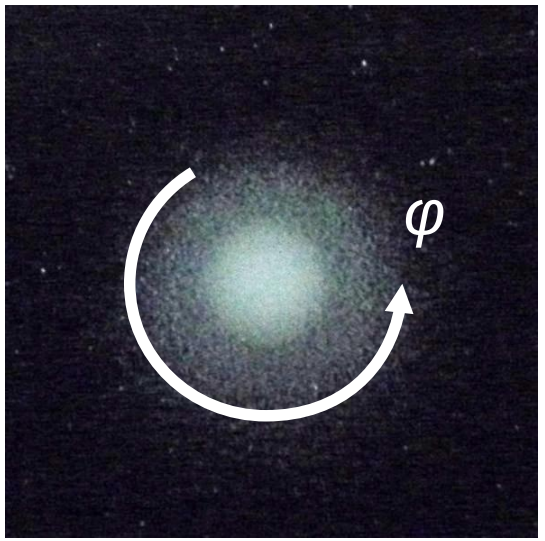


beam time ~ 100 fs *)

*) average over 10 shots

Angular distribution of the proton polarization

$$\frac{d\sigma}{d\Omega}(E,\vartheta,\varphi) \propto [1 + A \cdot P \cdot \cos(\varphi - \varphi_0)]$$

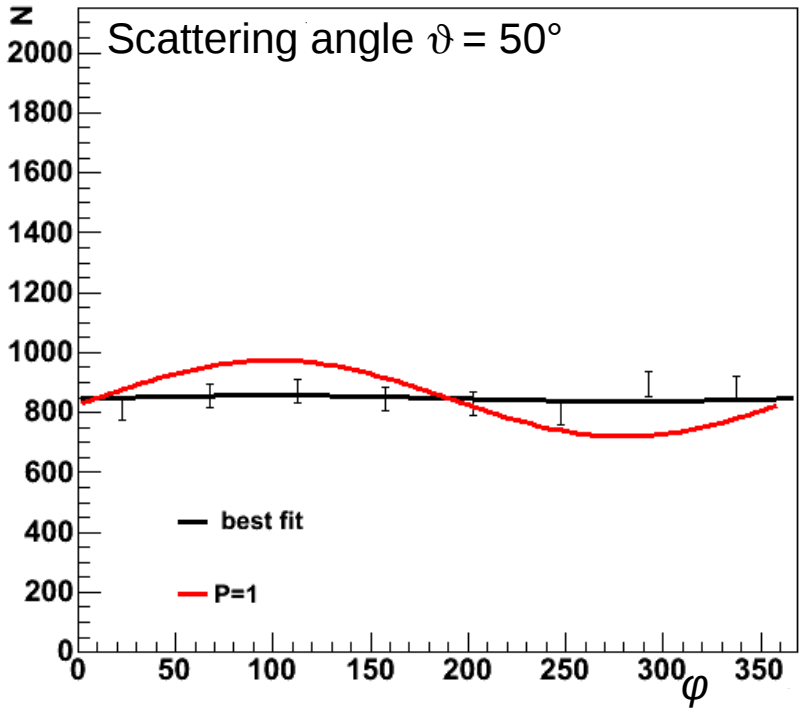


Laser incidence angle:
φ = 90°, ϑ = 45°

Proton emission angle:
φ = 180°, ϑ = 8°

Relative to production target normal

Fit

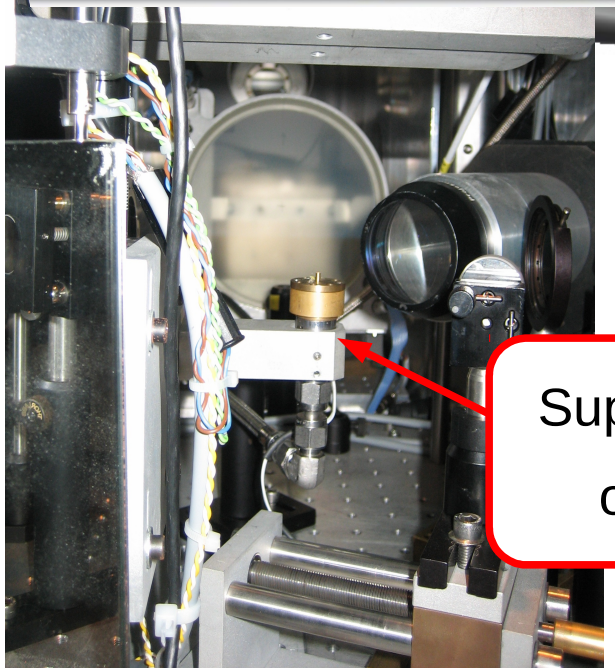


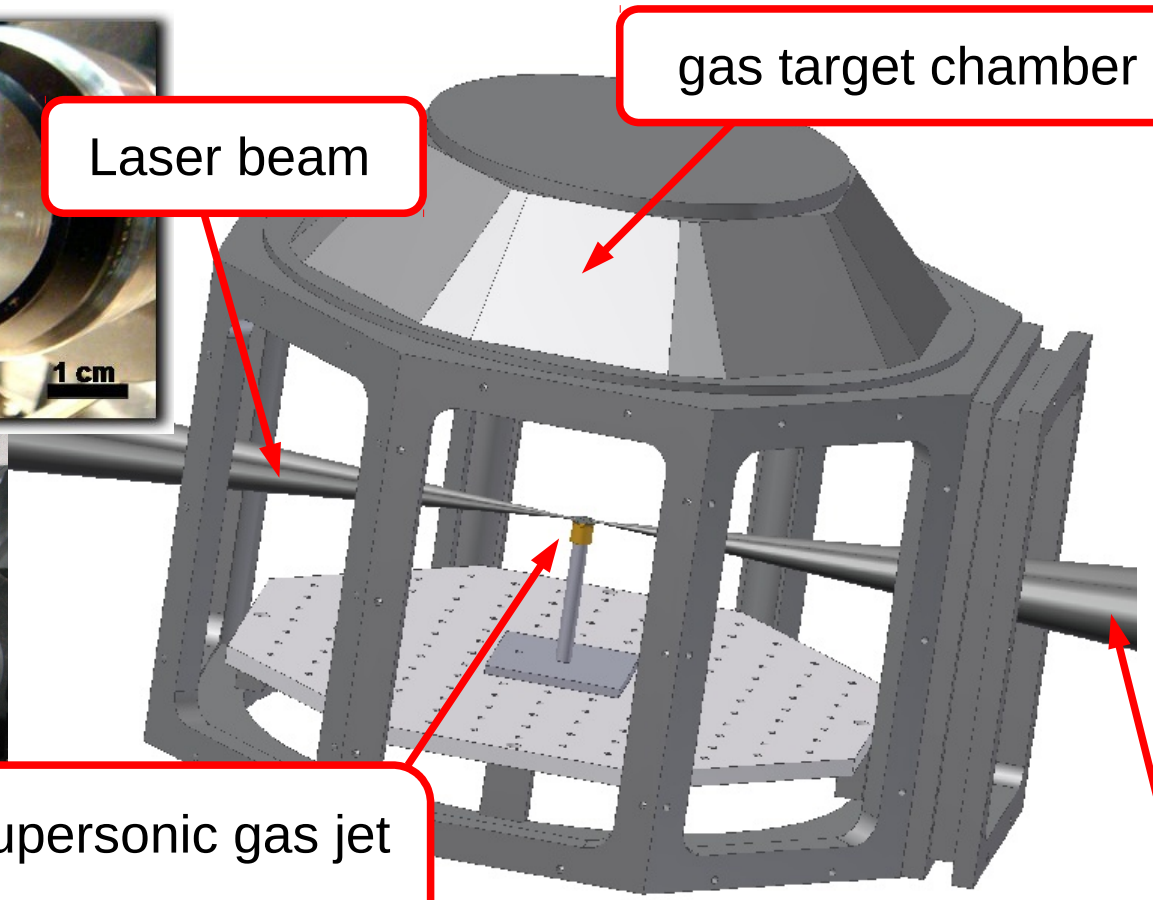
→ Averaging scattering angle
ϑ = 37.5°– 57.5°

→ $P \approx 0.08 \pm 0.08_{stat,2\sigma} \pm 0.08_{syst}$

Gas target experiments:

H_2 ^4He $^3He_{pol\text{-}unpol}$ H_2 clusters





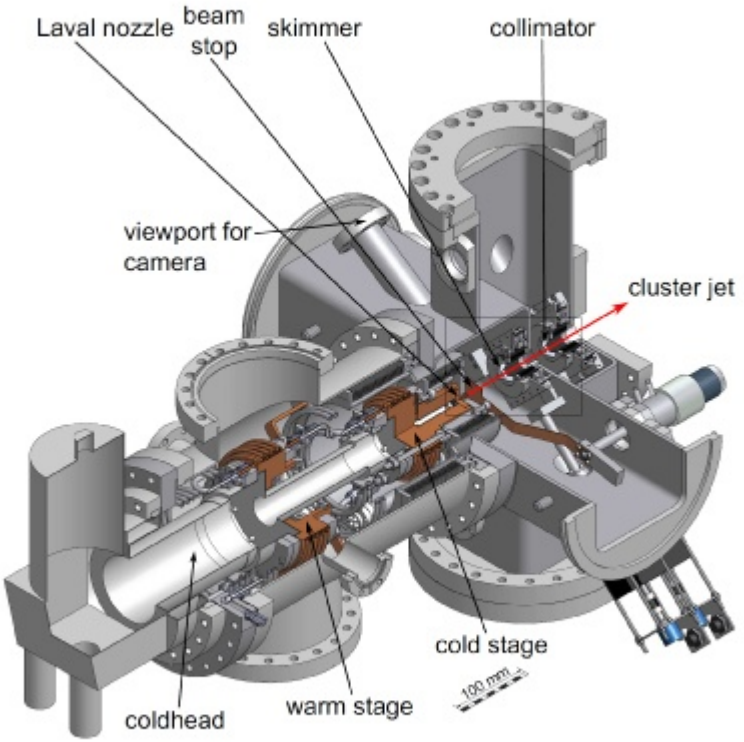
gas target chamber

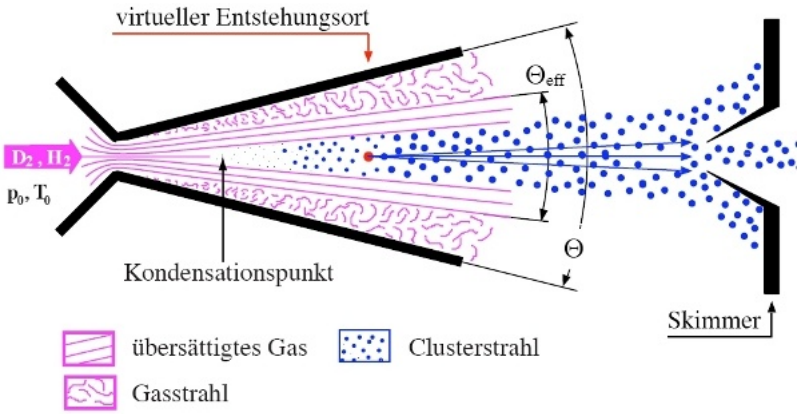
Laser beam

Supersonic gas jet out of nozzle

accelerated protons / **ions**

H_2 cluster source



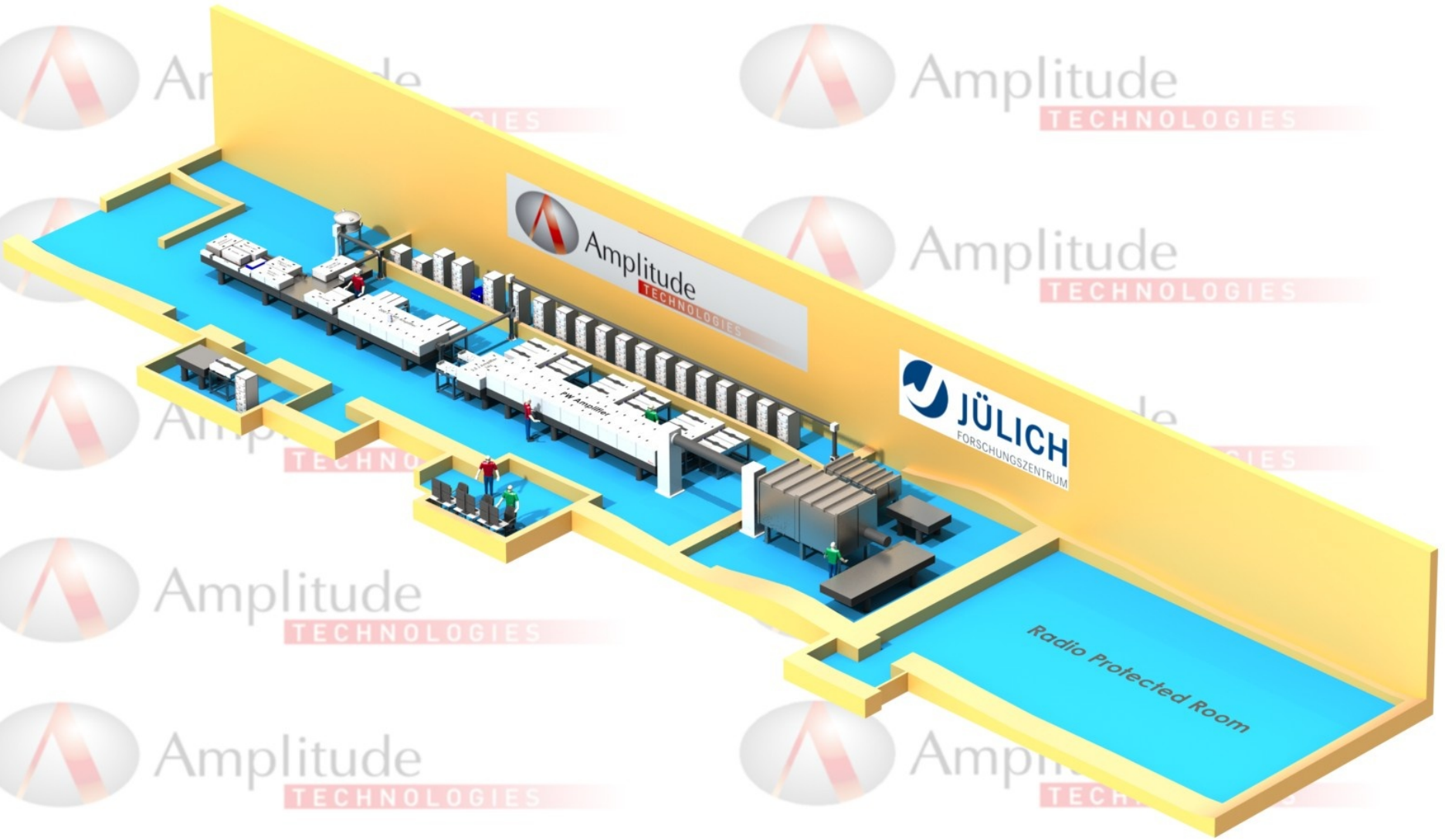


A. Täschner, http://arxiv.org/abs/1108.2653

Outlook

- fundamental research
  - comprehension of Laser-acceleration mechanisms
  - advantages of Laser-accelerated high-energy particles
- possible applicability, *e.g.* in future accelerator physics, synchrotron radiaton, etc.
- integration in existing or planned infrastructure, *e.g.* the planned *Ju-SPARC* *) at FZJ

*) Short-Pulsed Particle and Radiation Center


Amplitude
TECHNOLOGIES
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FORSCHUNGSZENTRUM
Radio Protected Room