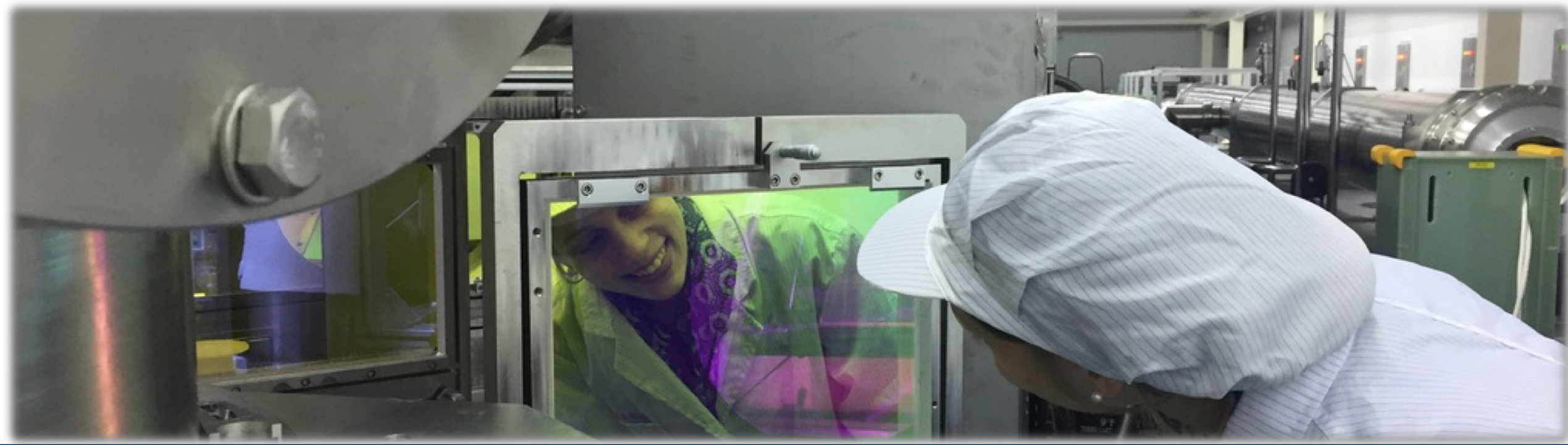




LASER-PLASMA ACCELERATION OF POLARIZED BEAMS

@ The Jülich Short-Pulse Particle and Radiation Center (*JuSPARC*)

06. MARCH 2019 | ANNA HÜTZEN

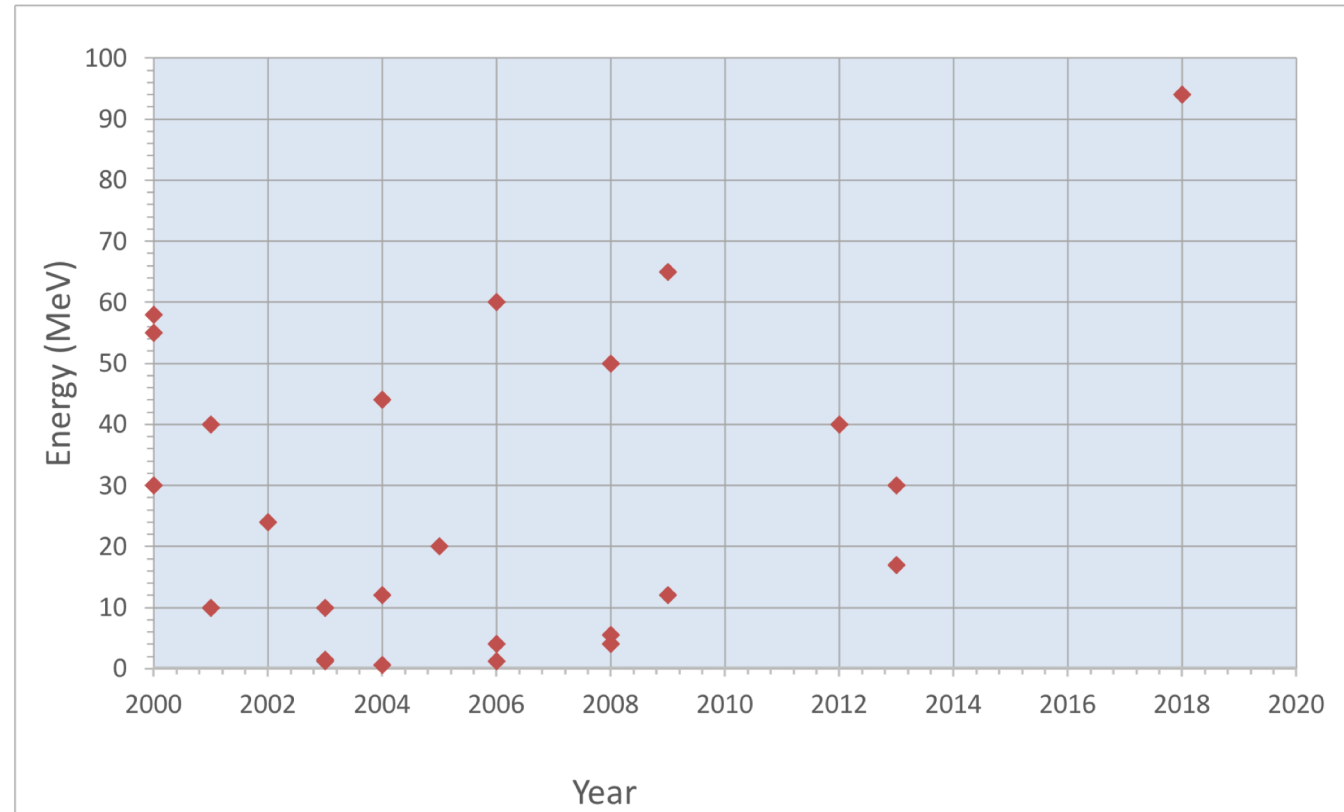


STATUS QUO OF LASER-INDUCED ION ACCELERATION

An overview of the worldwide activities

- Generation of multi-MeV proton beams already demonstrated
- Target geometry and laser parameter limit increase of proton energy

➔ Recent development of laser technology resulted in new table-top laser-based applications



HOW ARE POLARIZED BEAMS PRODUCED?

Conventional accelerators:
Cooler Synchrotron COSY-Jülich

Possible scenarios in laser-
induced plasmas

Spin-polarized ion beams from a plasma accelerator

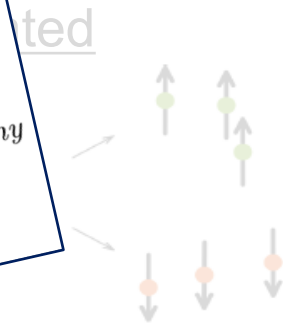
Johannes Thomas¹, Anna Hützen^{2,3}, Andreas Lehrach^{4,5}, Alexander Pukhov¹ and Markus Büscher^{2,3}

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Stern-Gerlach effect

Polarization is preserved

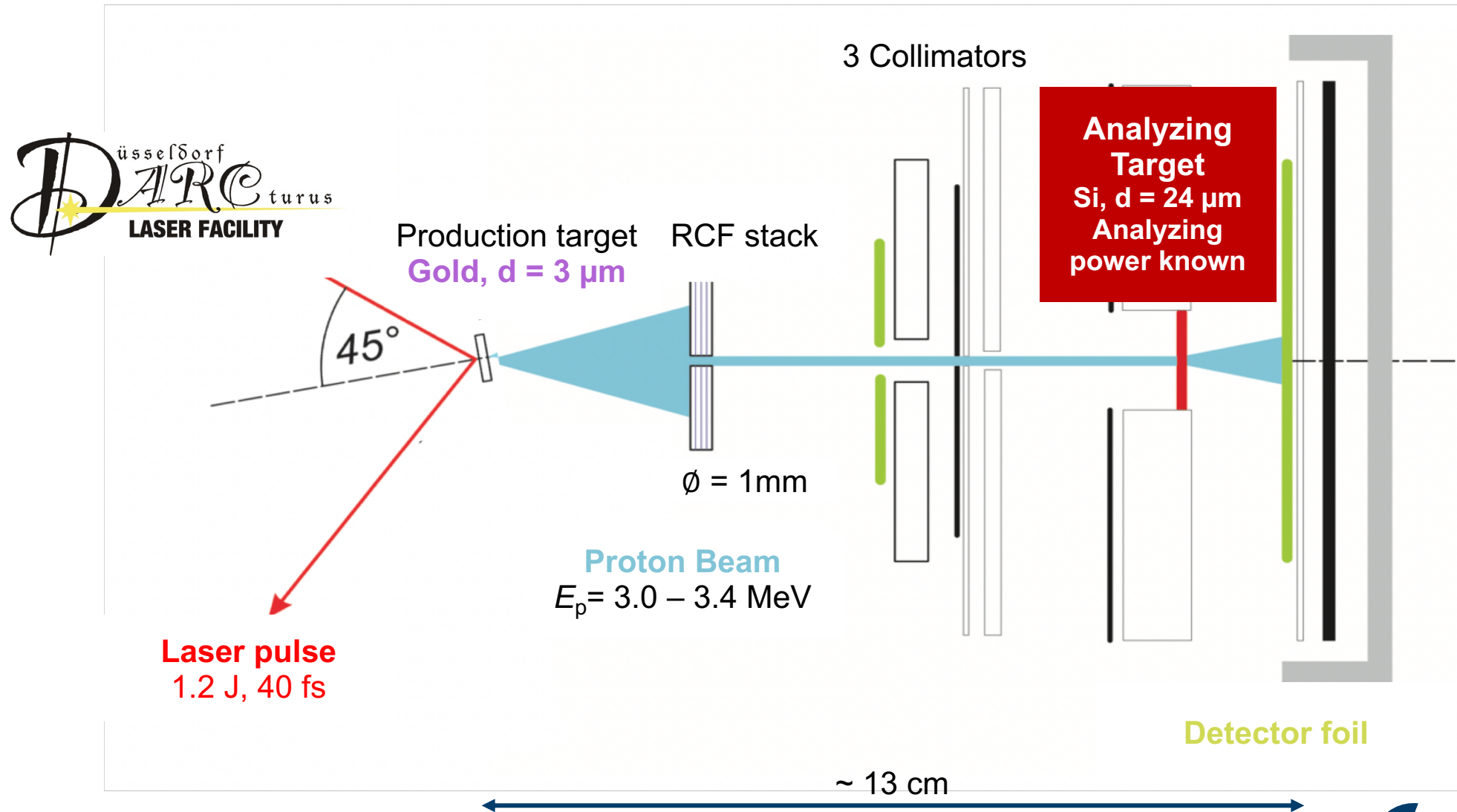


Thomas-BMT
equation

Reach fundamental & technological limits

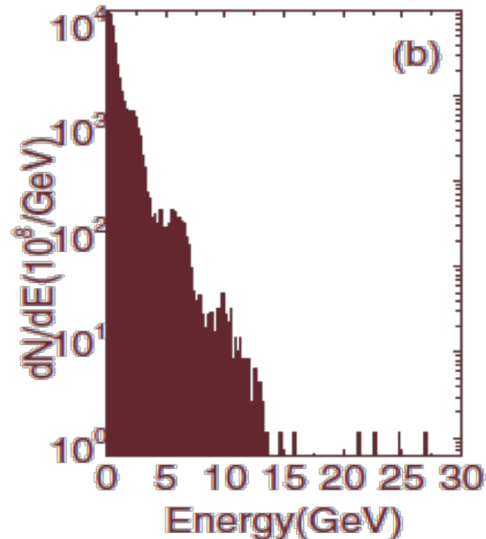
New applications for table-top experiments

FIRST PROTON POLARIZATION MEASUREMENT



PROTON ACCELERATION IN GAS TARGETS

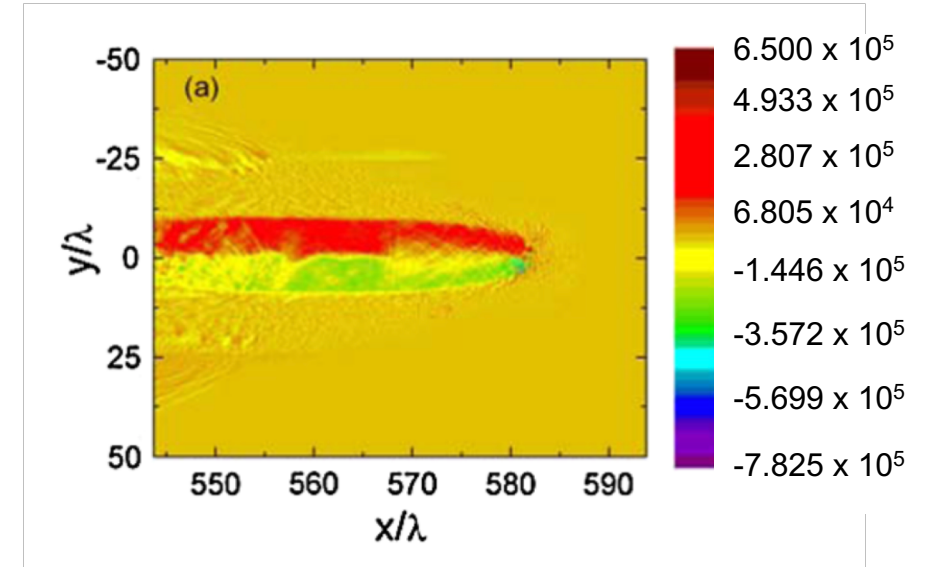
Proton acceleration into the GeV regime
(here: simulation for H/T gas mixture)



B. Shen et al., Phys. Rev. E **76**, 055402R (2007)

Requires Laser powers $\gtrsim 1$ PW!
➔ GeV proton energies predicted

Proton spin alignment for long
interaction time with huge B -field

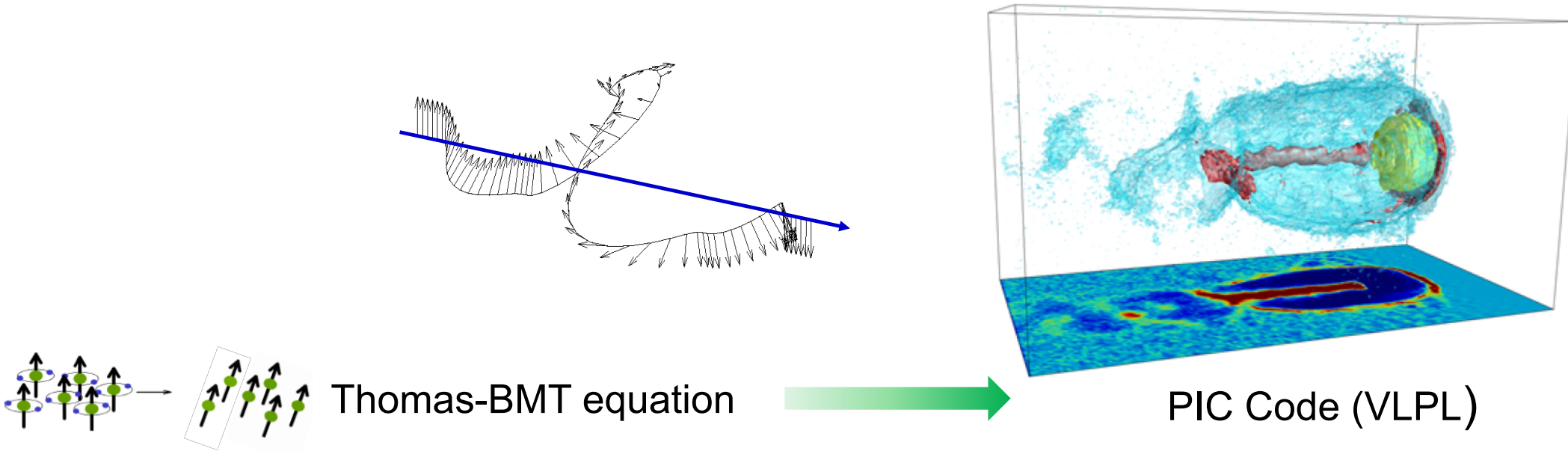


B. Shen et al., Phys. Rev. ST Accel. Beams **12**, 121301 (2009)

Long interaction time of protons with B-field
➔ Spin rotation very likely

MODELLING OF SPINS IN LASER-INDUCED PLASMAS

Implementation of particle spins into a simulation code (in collaboration with A. Pukhov,

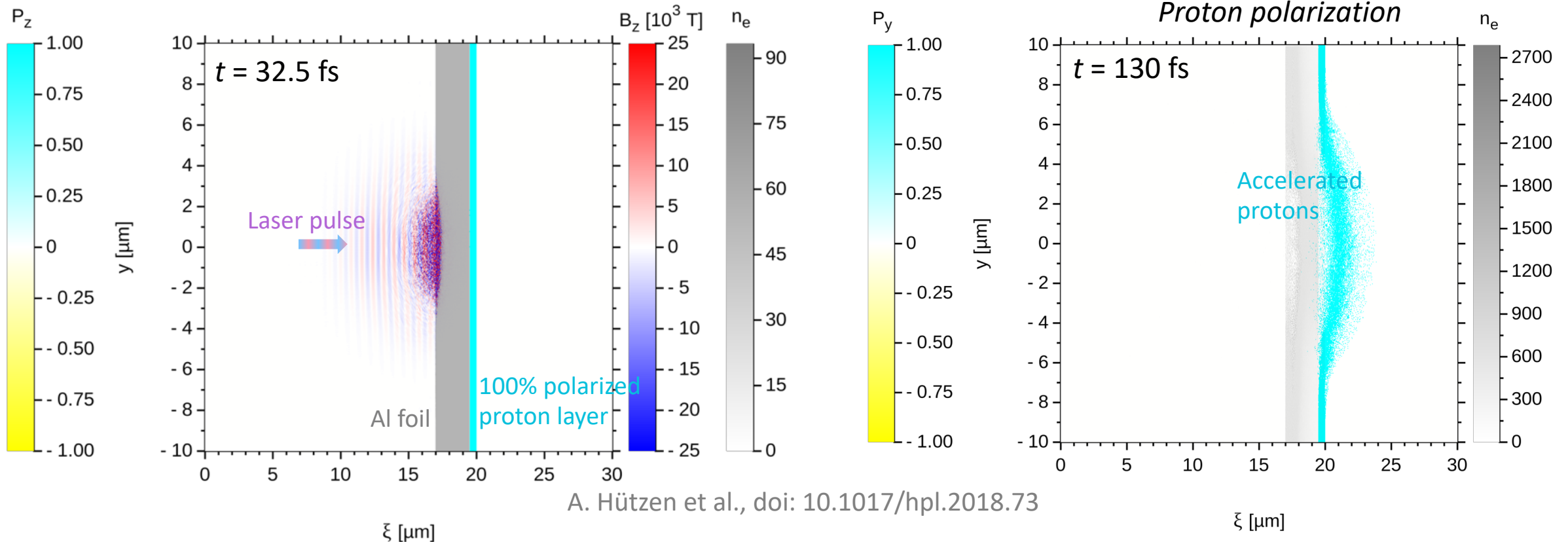


Description of spin motion in arbitrary electric and magnetic fields for the semi-classical approach

$$\frac{ds}{dt} = -\frac{e}{m_p c} \left[\left(a_p + \frac{1}{\gamma} \right) \mathbf{B}_\perp - \frac{a_p \gamma}{\gamma + 1} \left(\frac{\mathbf{v}}{c} \cdot \mathbf{B}_\parallel \right) \frac{\mathbf{v}}{c} - \left(a_p + \frac{1}{1 + \gamma} \right) \frac{\mathbf{v}}{c} \times \mathbf{E} \right] \times \mathbf{s}$$

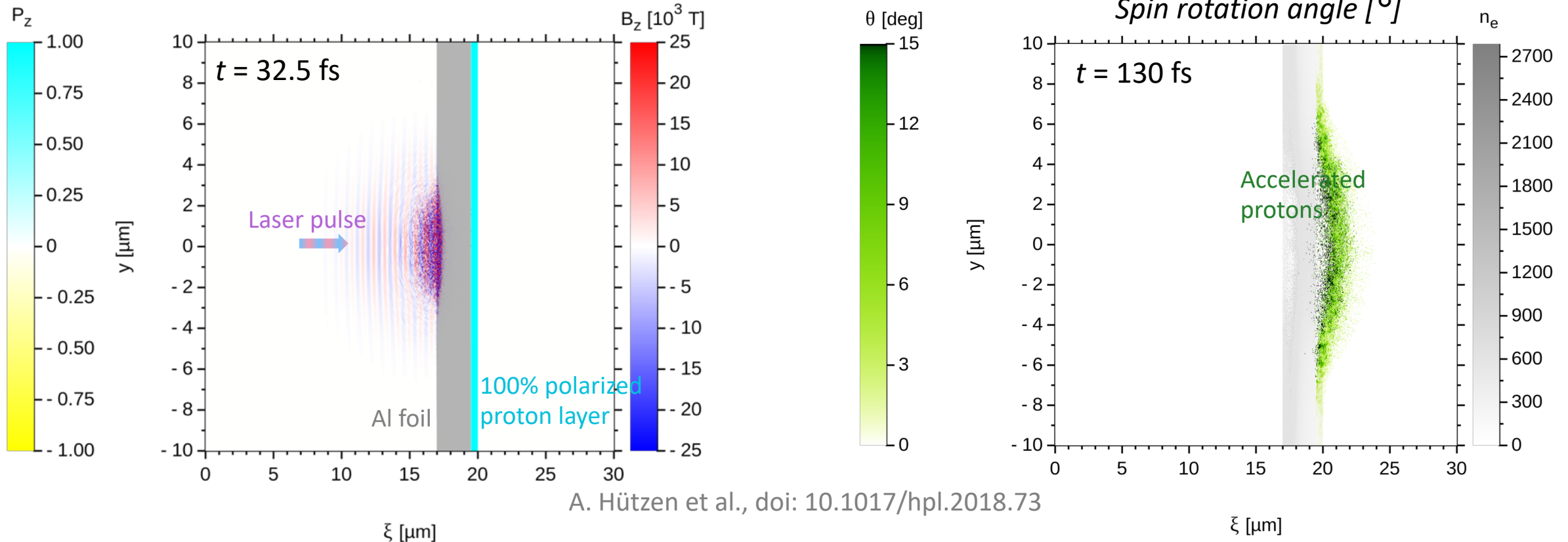
A FIRST PIC SIMULATION W/ PARTICLE SPINS

3D VLPL simulation ($\lambda = 800$ nm, normalized laser amplitude $a_0 = 12$, 25 fs duration, 5 μm focal spot size)



A FIRST PIC SIMULATION W/ PARTICLE SPINS

3D VLPL simulation ($\lambda = 800$ nm, normalized laser amplitude $a_0 = 12$, 25 fs duration, 5 μm focal spot size)

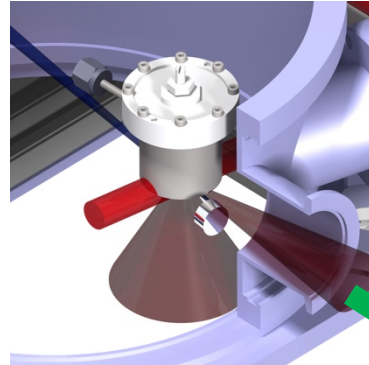


➡ Proton polarization is conserved during acceleration

POLARIZED HYDROGEN GAS TARGET @ FZJ

Nozzle

For HCl gas jet



Method described in:

T. P. Rakitzis,
Chem.Phys.Chem. 5, 1489 (2004)

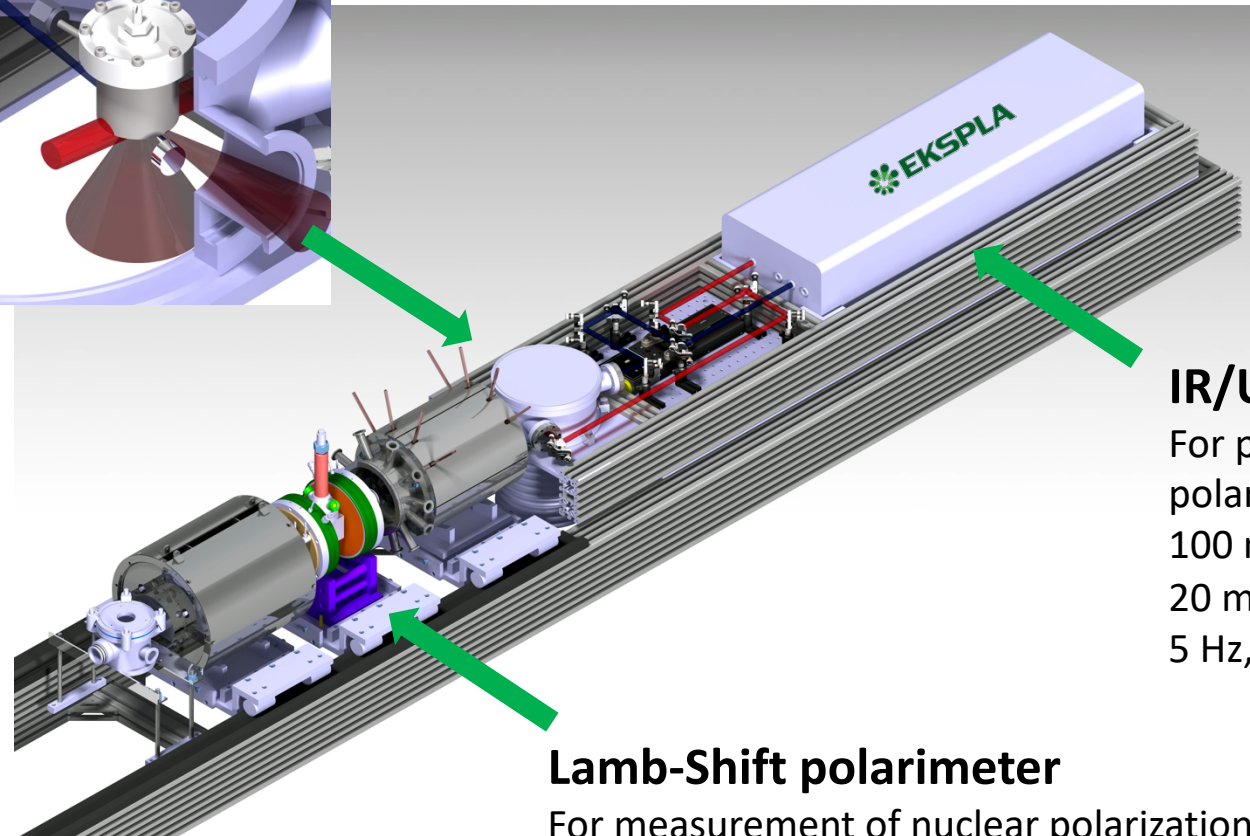


UNIVERSITY
OF CRETE



ATHENA

The Helmholtz-Project for
Laser-Plasma-Acceleration



IR/UV Laser

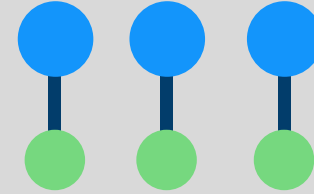
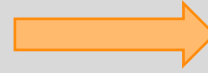
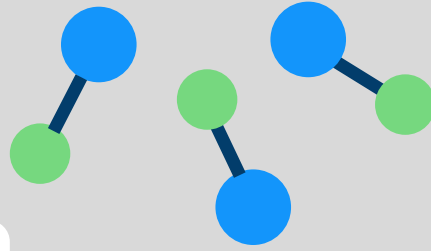
For photo-dissociation &
polarization of H atoms,
100 mJ @ 1064 nm,
20 mJ @ 213 nm,
5 Hz, 170 ps

Lamb-Shift polarimeter

For measurement of nuclear polarization
R. Engels et al., Rev.Sci.Instrum. 74, 4607 (2003)

PRODUCTION OF POLARIZED PROTON BEAMS

100 mJ @ 1064 nm



Alignment of
HCl bonds



20 mJ @ 213 nm

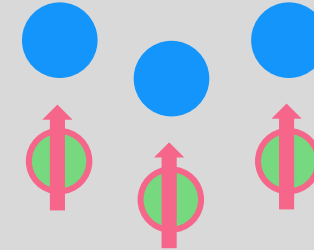
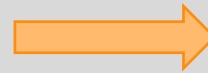
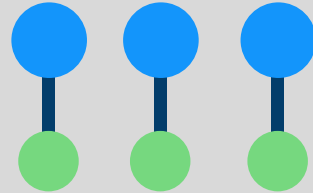
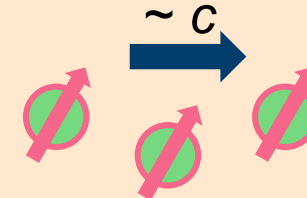
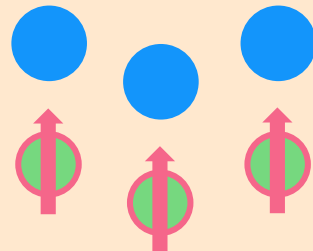


Photo-dissociation &
polarization transfer to
H nuclei (Dt = 350 ps)



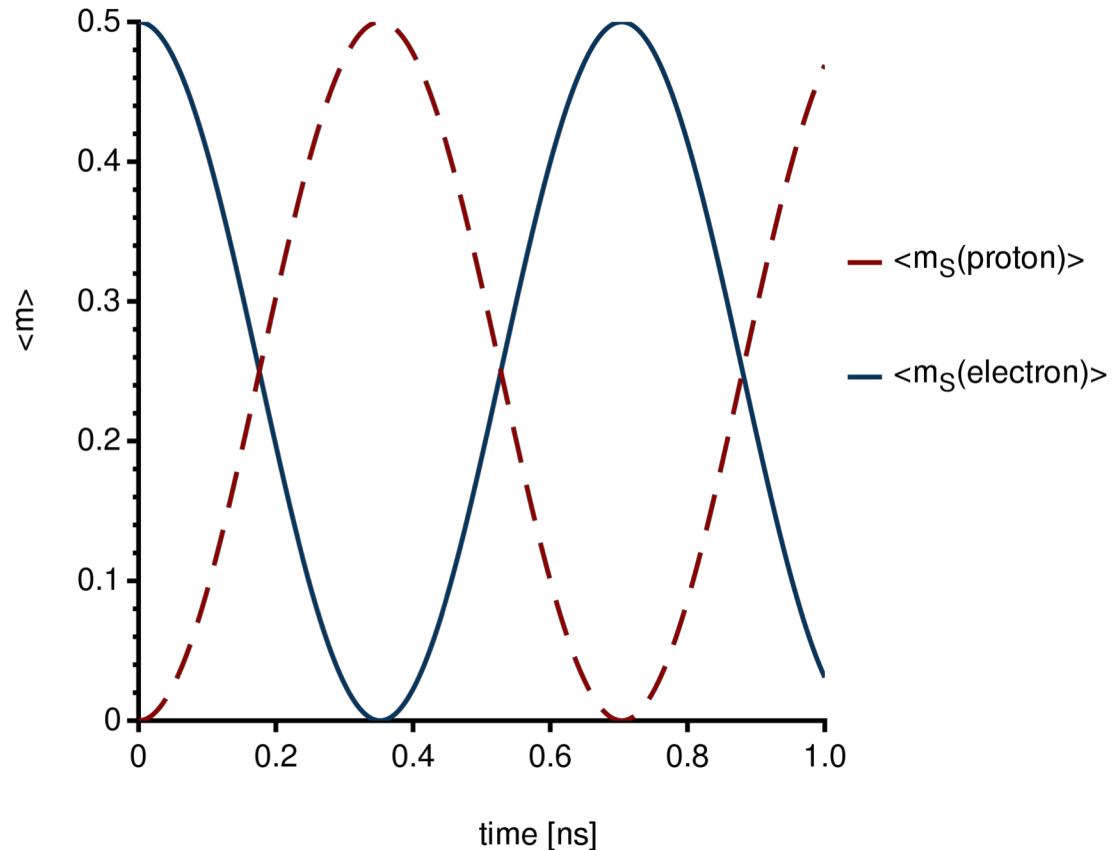
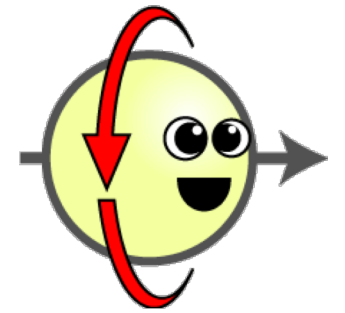
300 J @ 800 nm



Acceleration of the
protons in gas jet

A. Hützen et al., doi: 10.1017/hpl.2018.73

POLARIZATION OF THE H NUCLEUS



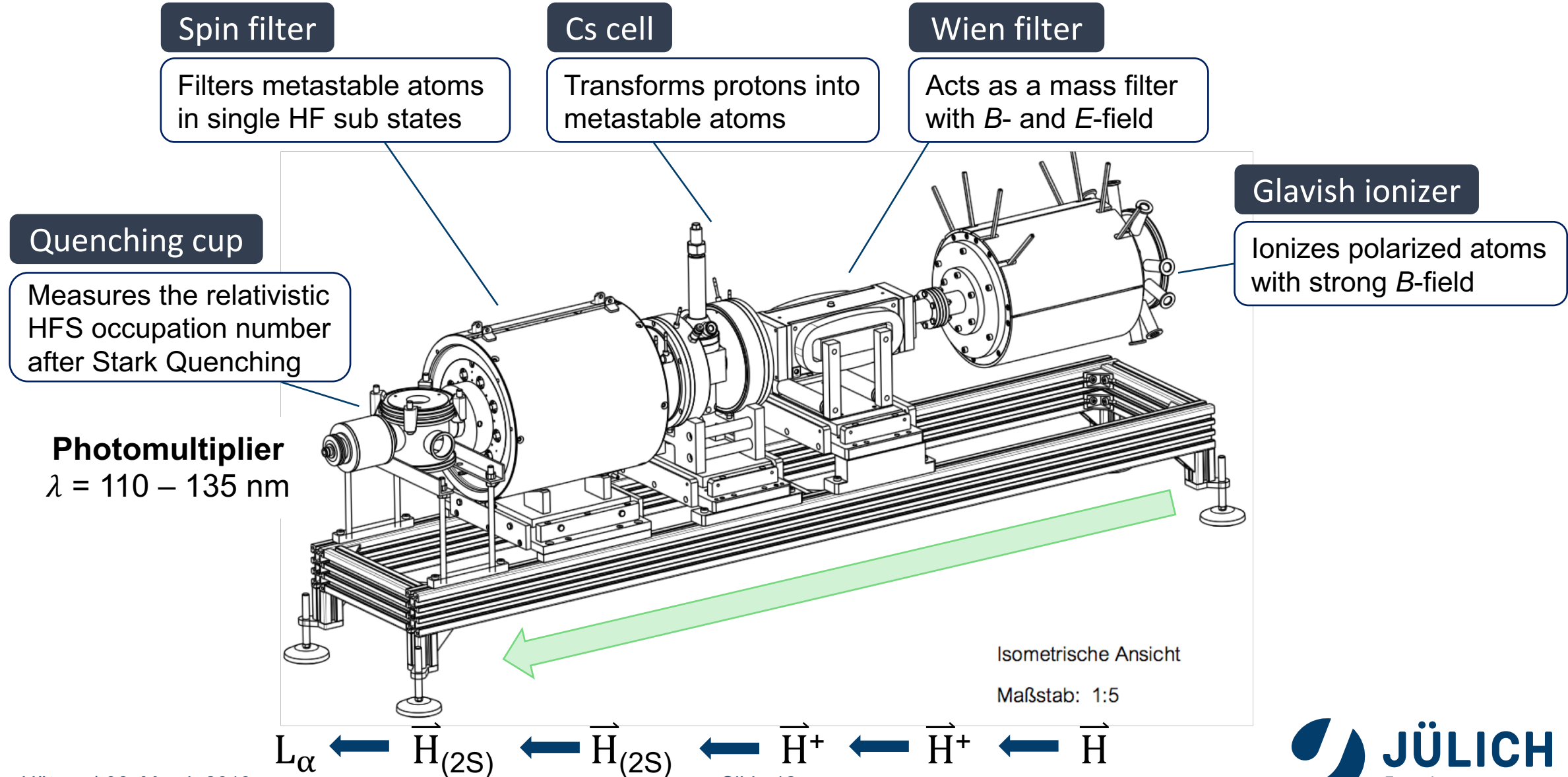
- Maximal theoretical polarization P

$$P = \frac{m}{m_{\max}} = 100\%, \text{ with } m_{\max} = 0.5$$

- After 0.35 ns the electron polarization of the H atoms is transferred into a nuclear polarization

➡ The out-coming protons will remain polarized, even if they undergo spin precessing (T-BMT)

THE LAMB-SHIFT POLARIMETER



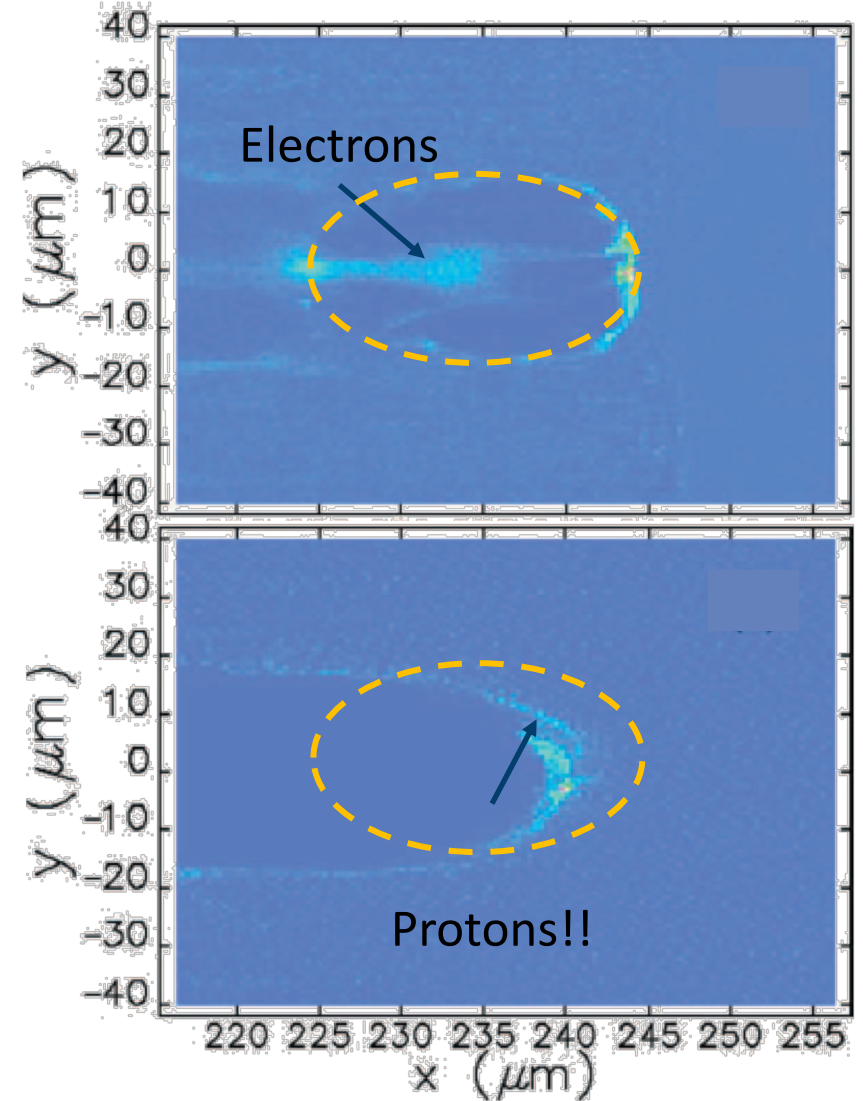
PROTON ACCELERATION @ 10 PW LASER

Predicted acceleration scheme for protons

- Acceleration in electron bubble-channel structure:
e⁻ at the rear of the bubble, ions at the front
- Gas mixtures (protons & heavier nuclei) &
high Laser powers required (≥ 10 PW)
- Trapped ions, are accelerated over a long
distance and achieve a very large energy gain

➡ Observation of a up to GeV polarized proton beam

$\lambda_L = 800$ nm, $a_0 = 316/\sqrt{2}$, $\Delta x = 10$ μm , $\rho_H = 10^{20}$ cm⁻³,
t = 320 fs; doi: 10.1103/PhysRevE.76.055402.



CURRENT STATUS @ SULF IN SHANGHAI

Commissioning of the 10 PW laser system - Visit in Nov. 2018



- Common simulation work on polarized particle beams
- First common experiments on proton acceleration in spring 2019

Laser parameter for SULF

- Central wavelength: ~ 800 nm
- Pulse energy: ~ 300 J
- Pulse duration: ~ 30 fs
- Contrast ratio: $\sim 10^{11}$
- Focused intensity: $> 10^{22}$ W/cm²





 JuSPARC Group at **JÜLICH**
Forschungszentrum

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- Andreas Lehrach
- Claus M. Schneider
- Paul Gibbon
- Jürgen Böker
- Ralf Engels
- Ilhan Engin

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and Fine Mechanics**

- Baifei Shen
- Jiancai Xu
- Liangliang Ji
- Lingang Zhang
- Yitong Wu
- Xuesong Geng

University of Crete

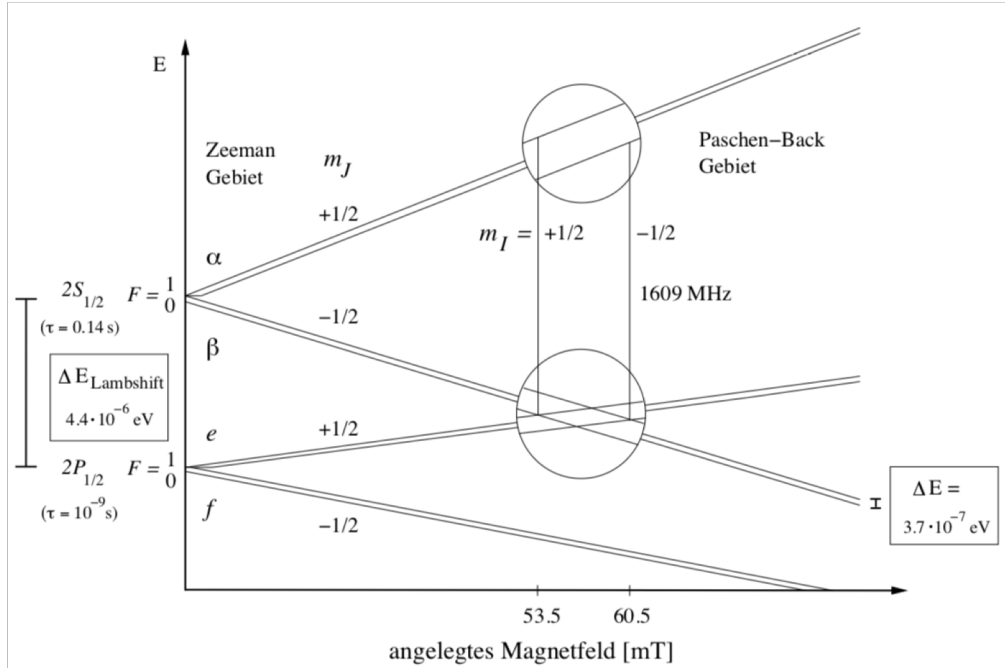
- T. Peter Rakitzis
- Dimitrios Sofikitis

Institut für Theoretische Physik I

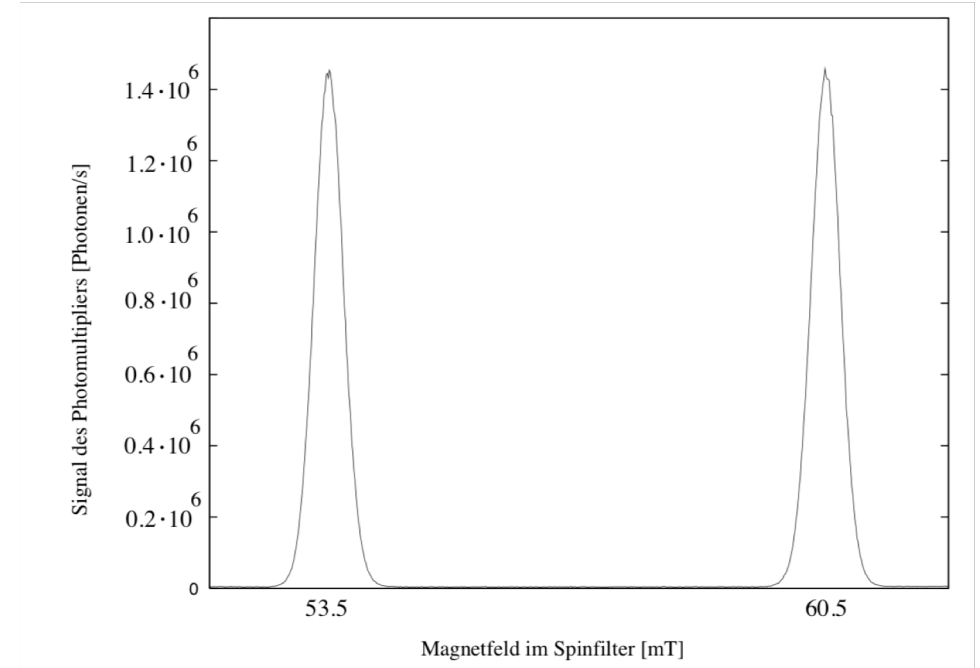
- Alexander Pukhov
- Johannes Thomas



HOW DOES THE LSP WORK?



Breit-Rabi diagram for the excited state with the quantum number $n = 2$ for hydrogen



Lyman spectrum of an unpolarized proton beam