



# LASER-DRIVEN POLARIZED PROTON ACCELERATION

4<sup>th</sup> European Advanced Accelerator Concepts Workshop (EAAC2019)

ANDREAS LEHRACH | 18 SEPTEMBER 2019



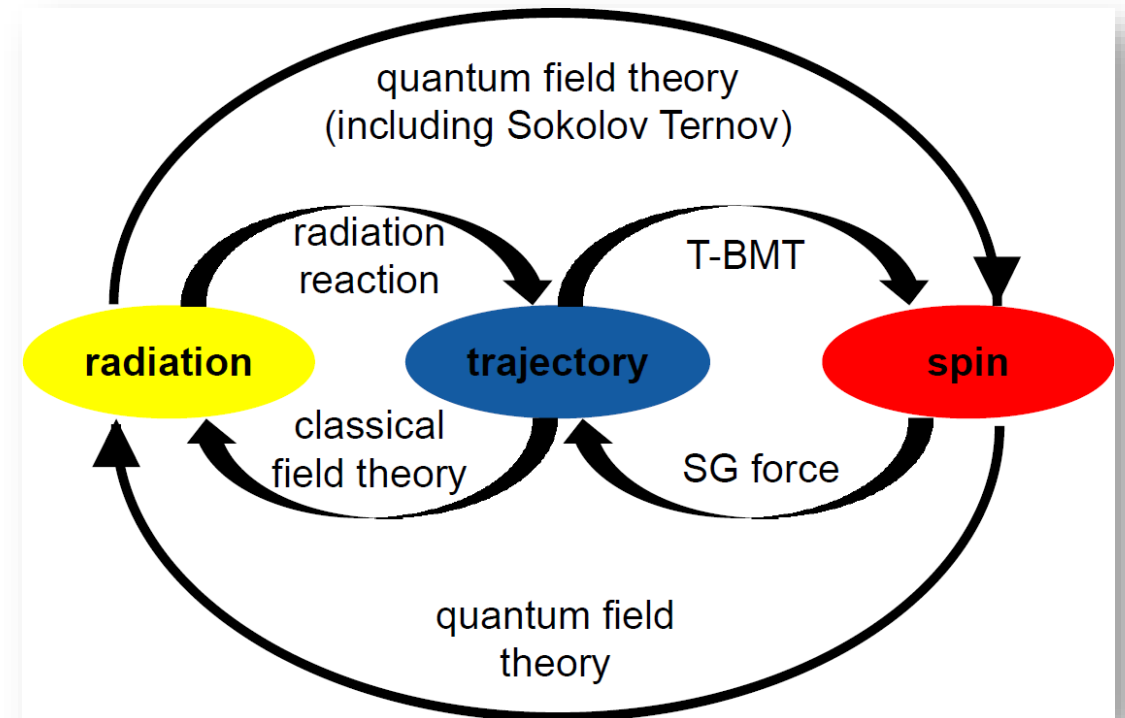
# HOW ARE POLARIZED BEAMS PRODUCED?

## Conventional accelerators: Cooler Synchrotron COSY-Jülich



Reach fundamental & technological limits

## Laser-plasmas Acceleration



Identify relevant processes!

# HOW ARE POLARIZED BEAMS PRODUCED?

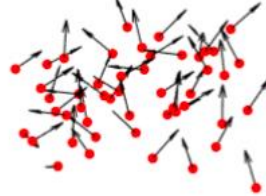
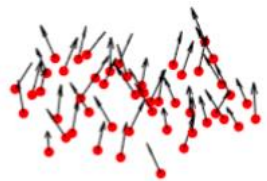
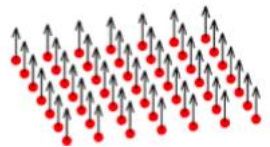
$T_0$

$T_1$

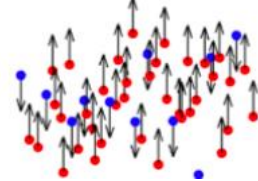
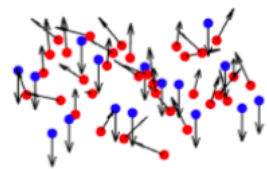
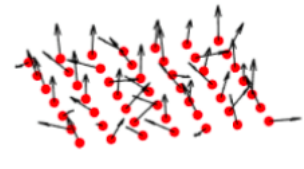
$T_2$



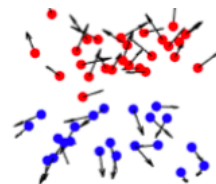
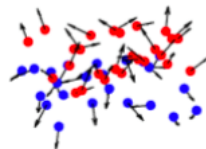
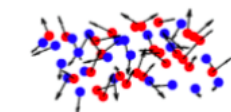
Kinetic evolution of an initially ordered particle ensemble in **laser-wakefield acceleration**



Spin precession in electro-magnetic fields described by the **Thomas-BMT equation**



Unordered spins individually flip in z-direction due to the **Sokolov-Ternov effect**



Beam splitting in two polarized beams due to the **Stern-Gerlach effect**



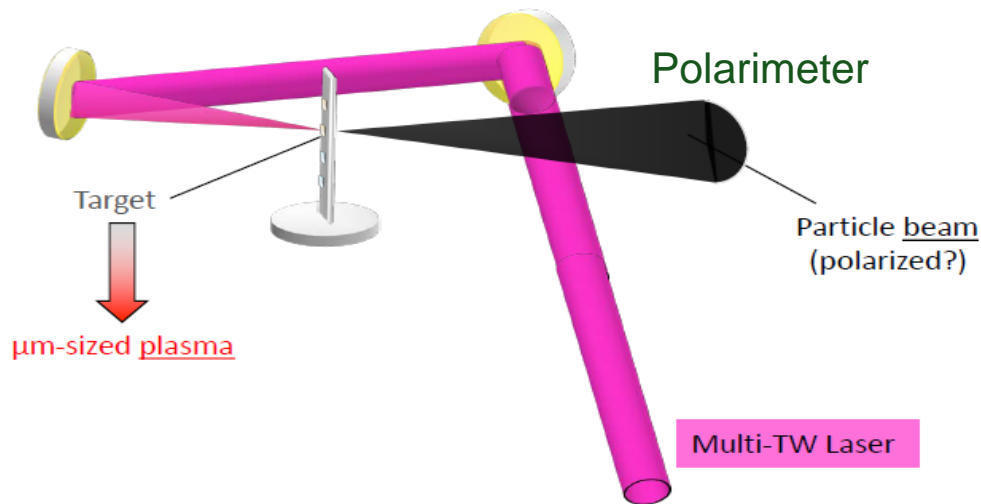
# PERFORMED AN PLANNED EXPERIMENTS

at high-power laser systems

Typical peak power

Secondary Particles

Laser-induced Laser-plasma acceleration



1 TW

Photons (XUV), electrons (?)



10 TW

Electrons



100 TW

Protons (MeV)



1 PW

Protons, ions (10 MeV)



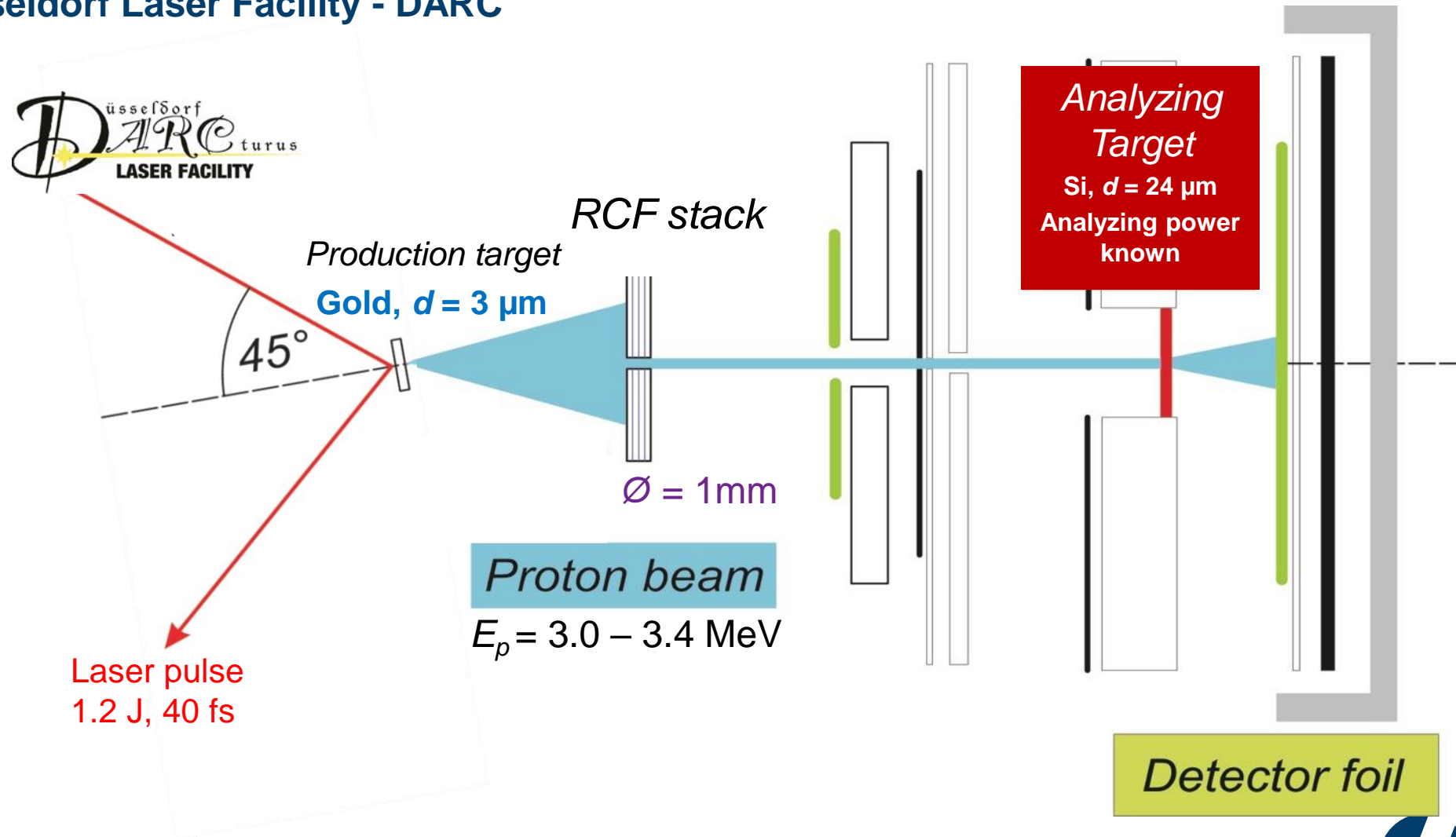
10 PW

Protons (GeV)



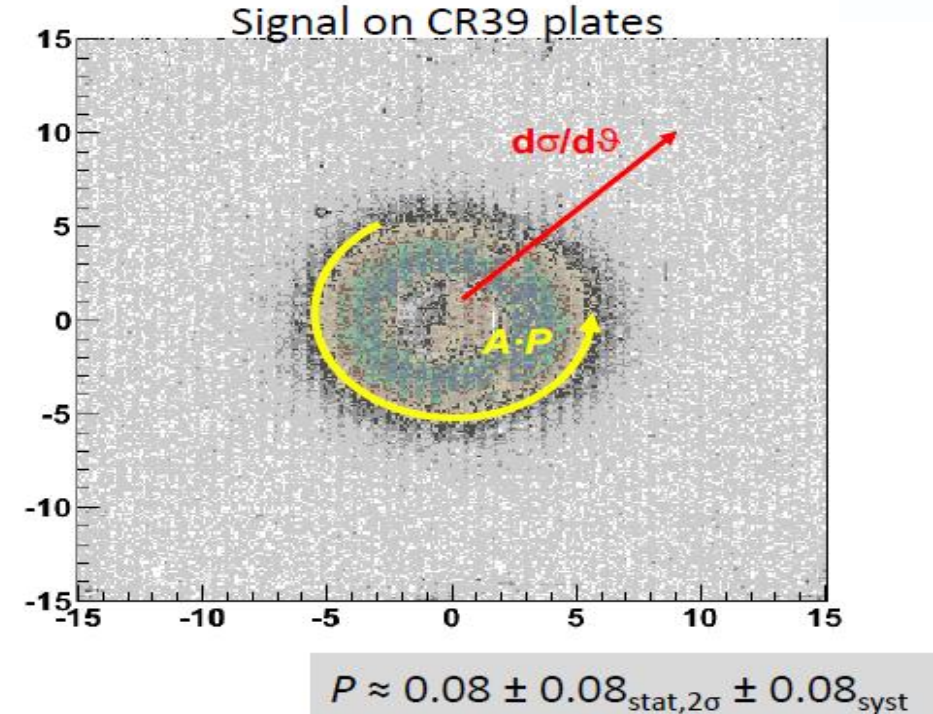
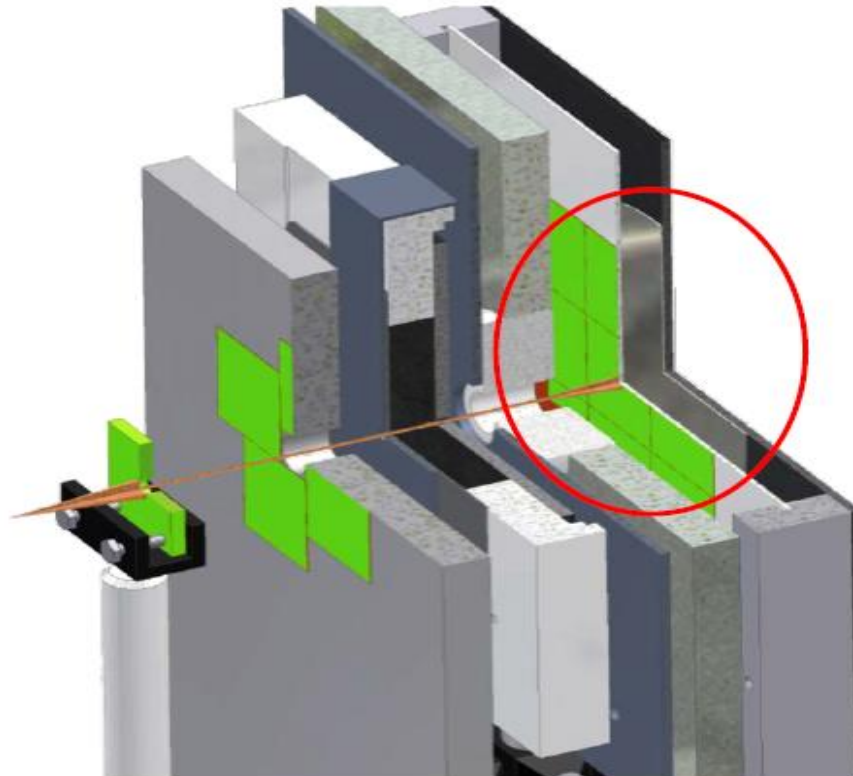
# HISTORY: FIRST POLARIZATION EXPERIMENT

at the Düsseldorf Laser Facility - DARC



# HISTORY: POLARIMETRY FOR MEV PROTONS

Poton scattering in Si target (for protons of a few MeV)

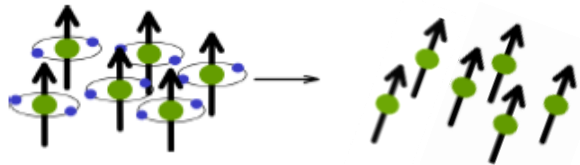


N. Raab et al., Polarization Measurements of laser-accelerated protons,  
Physics of Plasmas 21, 023104 (2014)

# REALIZATION OF POLARIZED GAS TARGET

## Gained knowledge

Polarization is preserved

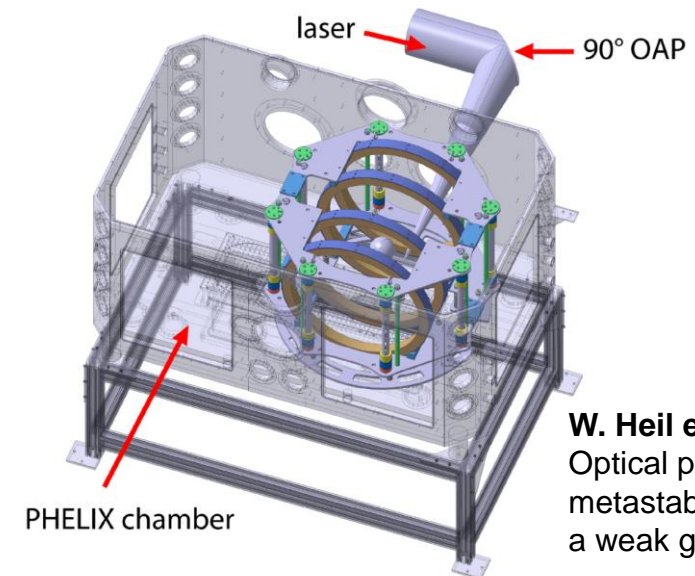


**Thomas-BMT  
equation**

- Spins only precess during the acceleration process but they do not flip → Thomas-BMT equation
- Pre-polarized gas target promises to give rise to a highly polarized relativistic proton beam

## Possible experimental realization: Polarized $^3\text{He}$ target

Start of measurements @ **PHELIX** **GSI**  
Unpolarized  $^3\text{He}$  already accelerated up to 4.65 MeV  
(paper published in Plasma Physics and Controlled Fusion)

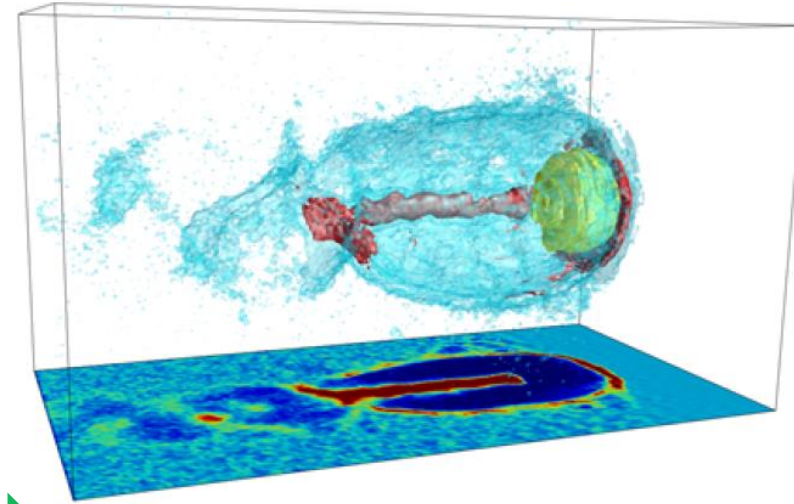
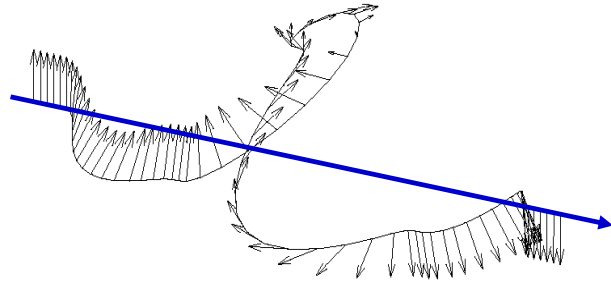


**W. Heil et al., Mainz**  
Optical pumping of metastable  $^3\text{He}$  atoms in a weak gas discharge.

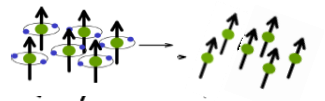
➔ New approach with two atomic pre-polarized target

# PARTICLE SPINS IN LASER-INDUCED PLASMAS

Implementation of particle spins into simulation codes (in collaboration with A. Pukhov, )



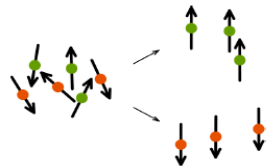
PIC Code (VLPL)



Sokolov-Ternov effect



➔ Characteristic time for spin flips too short



Stern-Gerlach effect



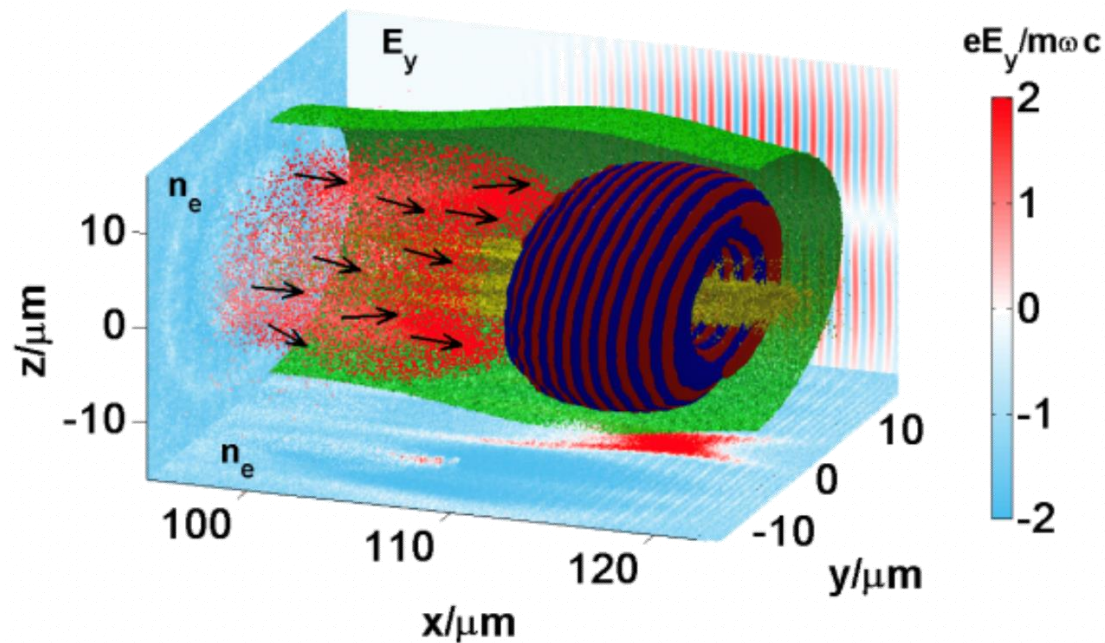
PIC Code (VLPL)

➔ Force for spatial separation on the given length scale too small



# POLARIZED ELECTRON BEAMS

Polarized electron target: Based on the Jülich polarized hydrogen target



*New J. Phys.* 21 (2019) 073052

<https://doi.org/10.1088/1367-2630/ab2fd7>

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### PAPER

## Polarized electron-beam acceleration driven by vortex laser pulses

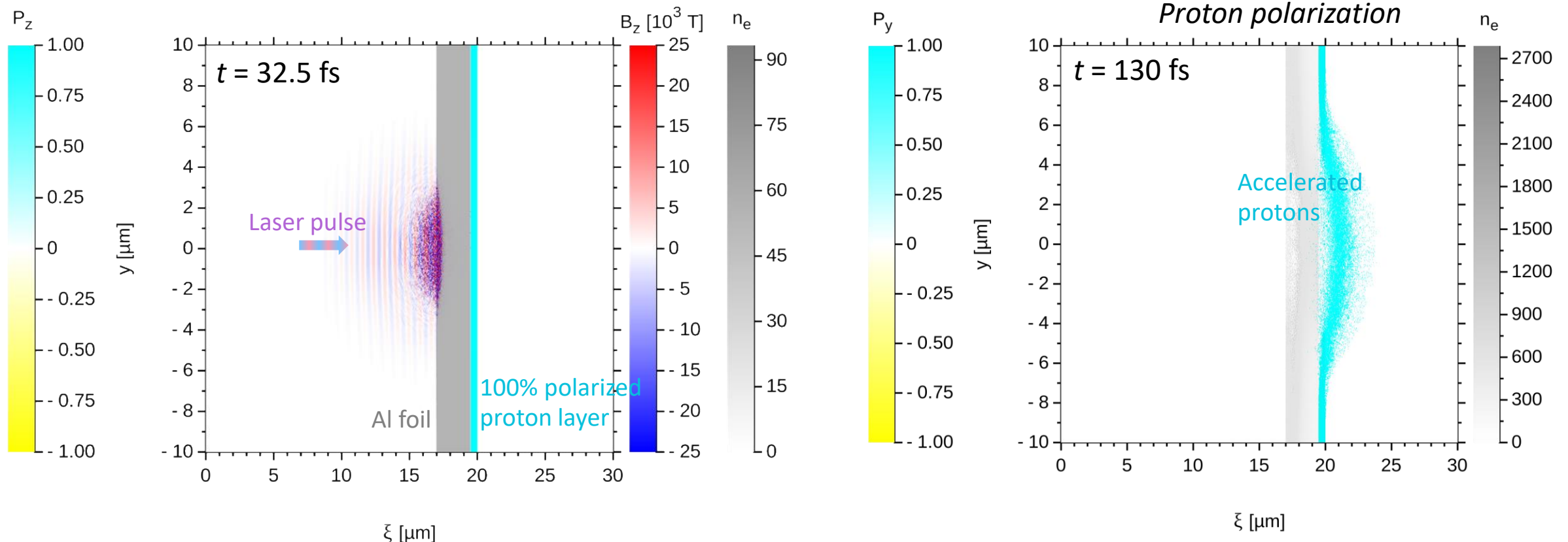
Yitong Wu<sup>1,2</sup> , Liangliang Ji<sup>1,3</sup> , Xuesong Geng<sup>1</sup>, Qin Yu<sup>1</sup>, Nengwen Wang<sup>1</sup>, Bo Feng<sup>1</sup>, Zhao Guo<sup>1</sup> ,  
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Markus Büscher<sup>5,6</sup>, T Peter Rakitzis<sup>7,8</sup> , Alexander Pukhov<sup>4</sup>, Baifei Shen<sup>1,3,9</sup> and Ruxin Li<sup>1,3,10</sup>

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# A FIRST PIC SIMULATION W/ PARTICLE SPINS

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

Laser acceleration via TNSA mechanism at the ARCturus laser system



➡ Proton polarization is conserved during acceleration

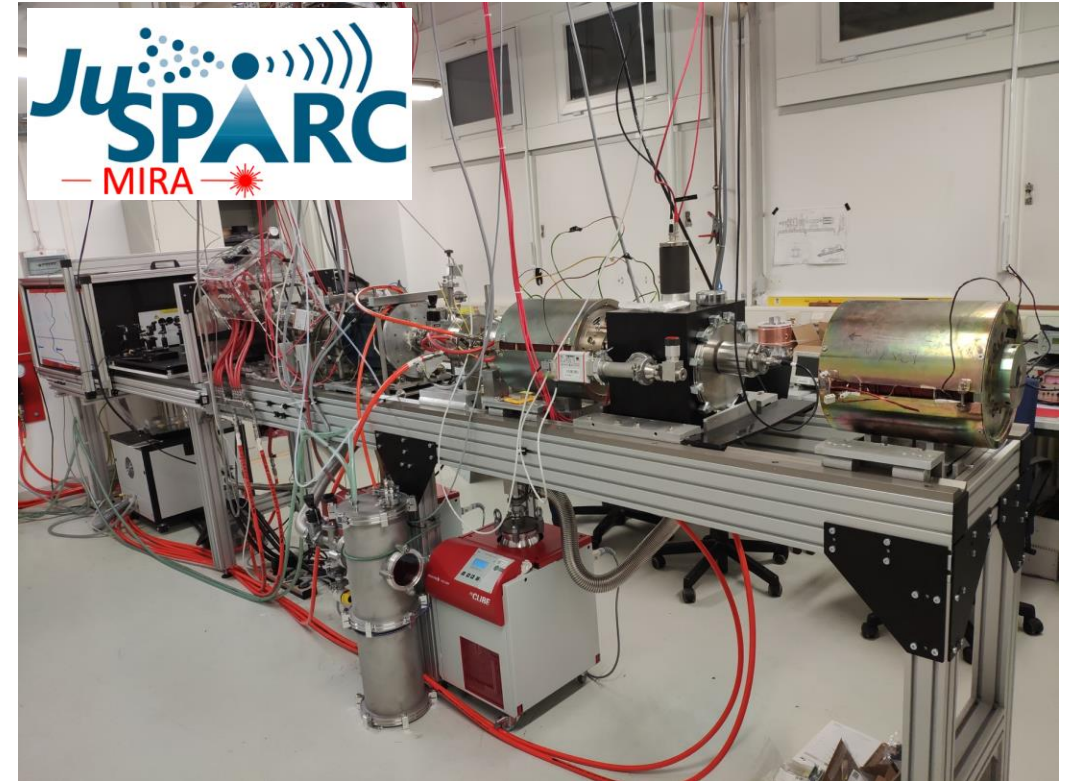
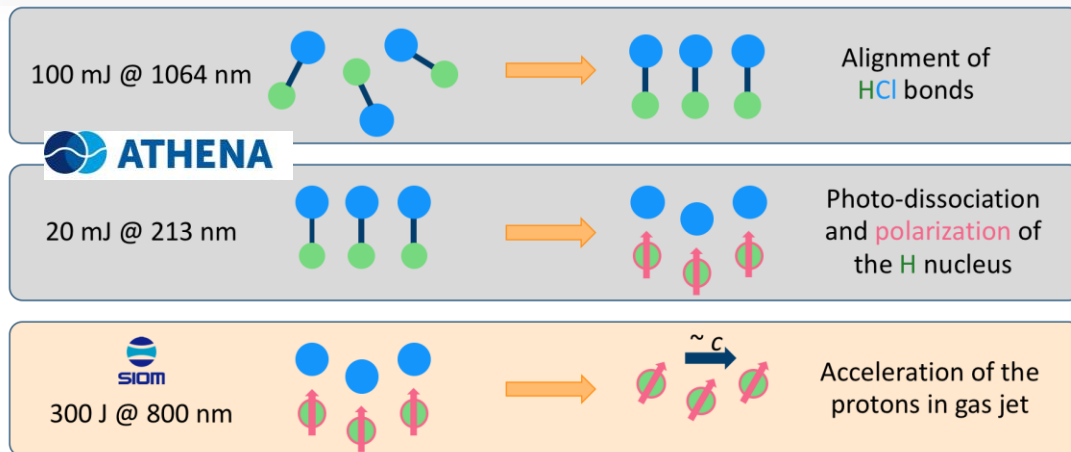
Publication in High Power Laser Science and Engineering, (2019), Vol. 7

# A TARGET FOR POLARIZED PROTON BEAMS

*High Power Laser Science and Engineering*, (2019), Vol. 7, e16, 6 pages.

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## Polarized proton beams from laser-induced plasmas

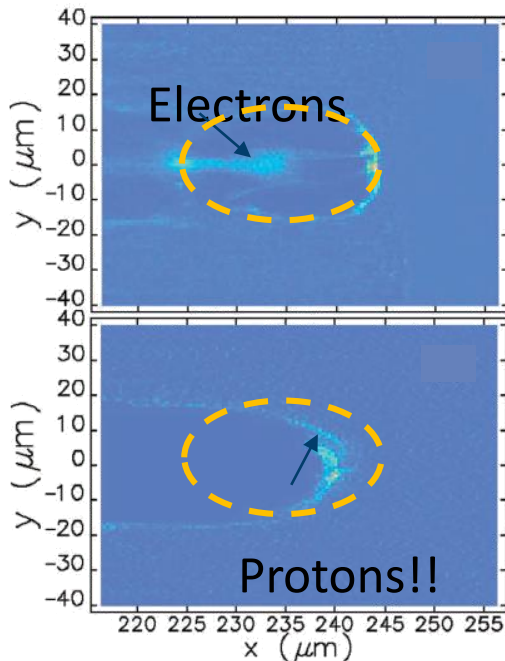




# GEV PROTON ACCELERATION @ 10 PW LASER

## Predicted acceleration scheme for protons and planned experiments

- Acceleration in electron bubble-channel structure:  
e<sup>-</sup> at the rear of the bubble, ions at the front.
- Gas mixtures required (protons & heavier nuclei)
- High Laser powers required ( $\geq 10$  PW)
- The trapped protons, surfing on the field, can be accelerated over a long distance and achieve a very large energy gain
- Experiments are planned at SULF in Shanghai
- Commissioning of the 10 PW laser system



High plasma density and laser intensity required  
Heavier ions contribute to the formation of a longer-lasting electron bubble

➡ **Possibility to produce GeV polarized proton beam.**

$\lambda_L = 800 \text{ nm}$ ,  $a_0 = 316/\sqrt{2}$ ,  $\Delta x = 10 \text{ μm}$ ,  
 $\rho_H = 10^{20} \text{ cm}^{-3}$ ,  $\rho_T = 1.4 \cdot 10^{21} \text{ cm}^{-3}$ ,  $t = 854 \text{ fs}$ ;  
 doi: 10.1103/PhysRevE.76.055402.

### Laser parameter for SULF

- Central wavelength:  $\sim 800 \text{ nm}$
- Pulse energy:  $\sim 300 \text{ J}$
- Pulse duration:  $\sim 30 \text{ fs}$
- Contrast ratio:  $\sim 10^{11}$
- Focused intensity:  $> 10^{22} \text{ W/cm}^2$

- Visit in Nov. 2018





# PARTICIPATION IN ATHENA<sub>h</sub>

Development of polarized targets for proton and ion acceleration (and, maybe, electrons)

- Hyperpolarized  $^3\text{He}$  gas-jet („static“ polarization)

First experiments @PHELIX in 2019

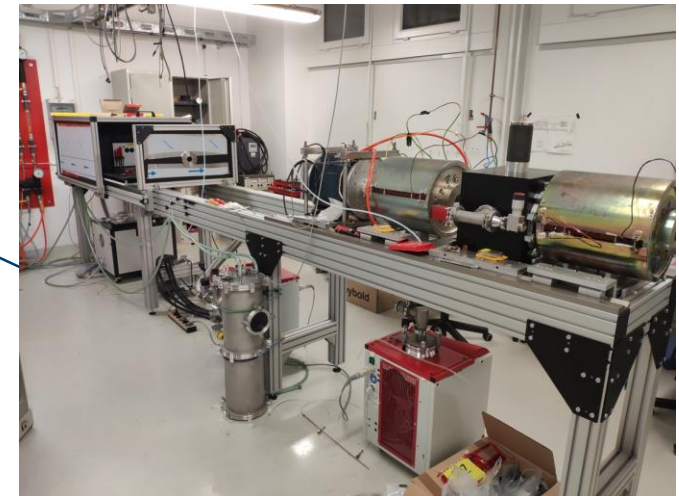


- Nuclear polarized H atoms from HCl jet („dynamic“ polarization)

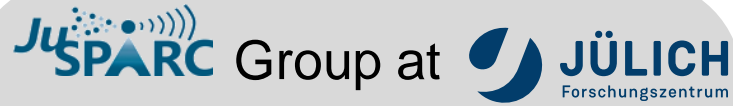
Commissioning @SIOM in 2020



- Polarized molecular Hydrogen gas target
- Polarized solid HD and D<sub>2</sub> Target



# ACKNOWLEDGEMENT



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