JuSPARC-1 / ATHENA / JuSPARC-2

JuSPARC WORKSHOP | 28 MARCH 2019 | MARKUS BÜSCHER

Mitglied der Helmholtz-Gemeinschaft

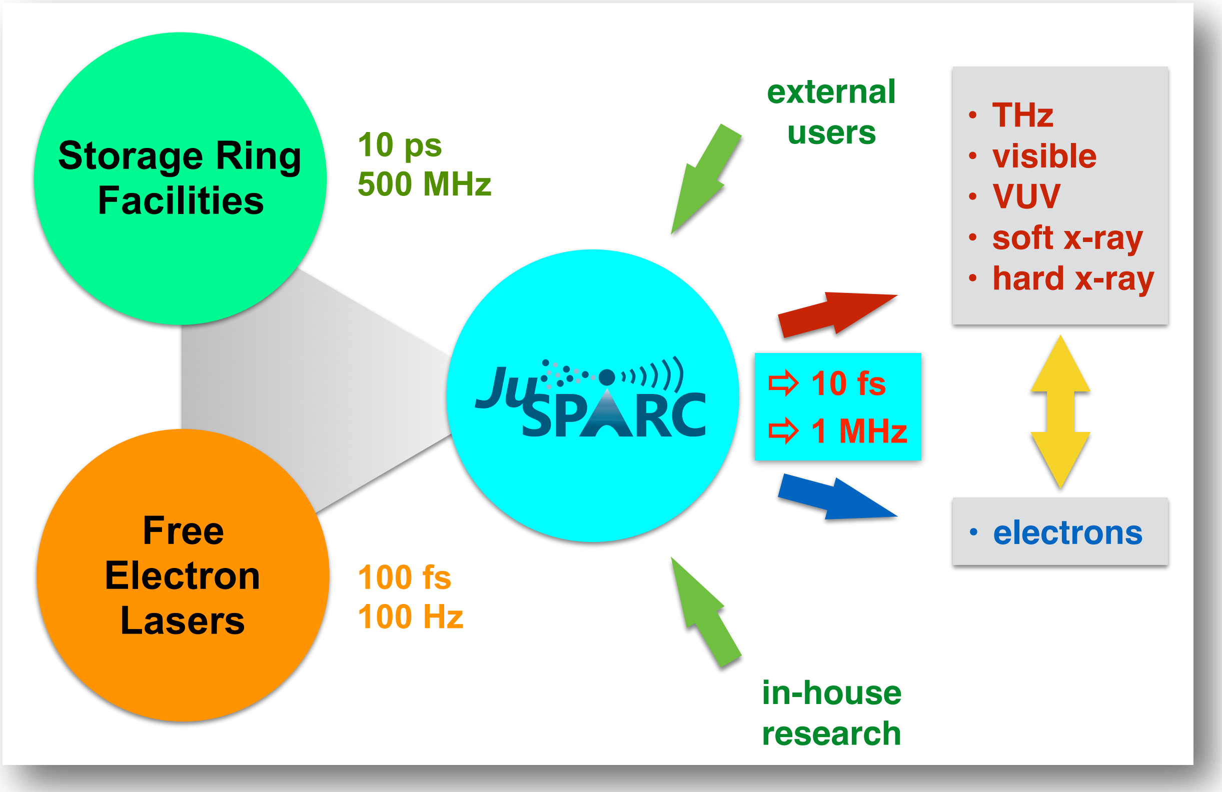
JuSPARC

ATHENA
The Helmholtz-Project for Laser-Plasma-Acceleration

JÜLICH
Forschungszentrum

*Ju*SPARC

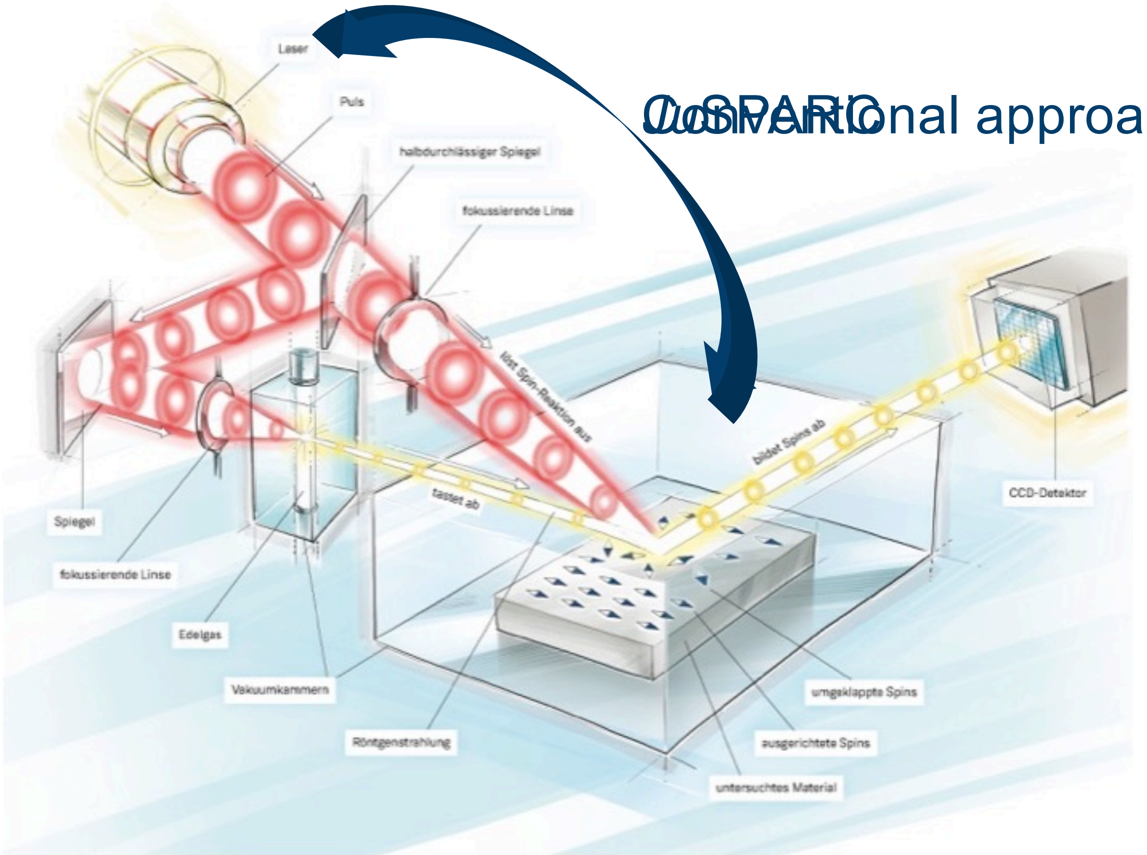
= Jülich Short-pulsed Particle and Radiation Center



THE BASIC IDEA: "*THE EXPERIMENT DEFINES THE FACILITY*"

Conventional approach

JuSPARC



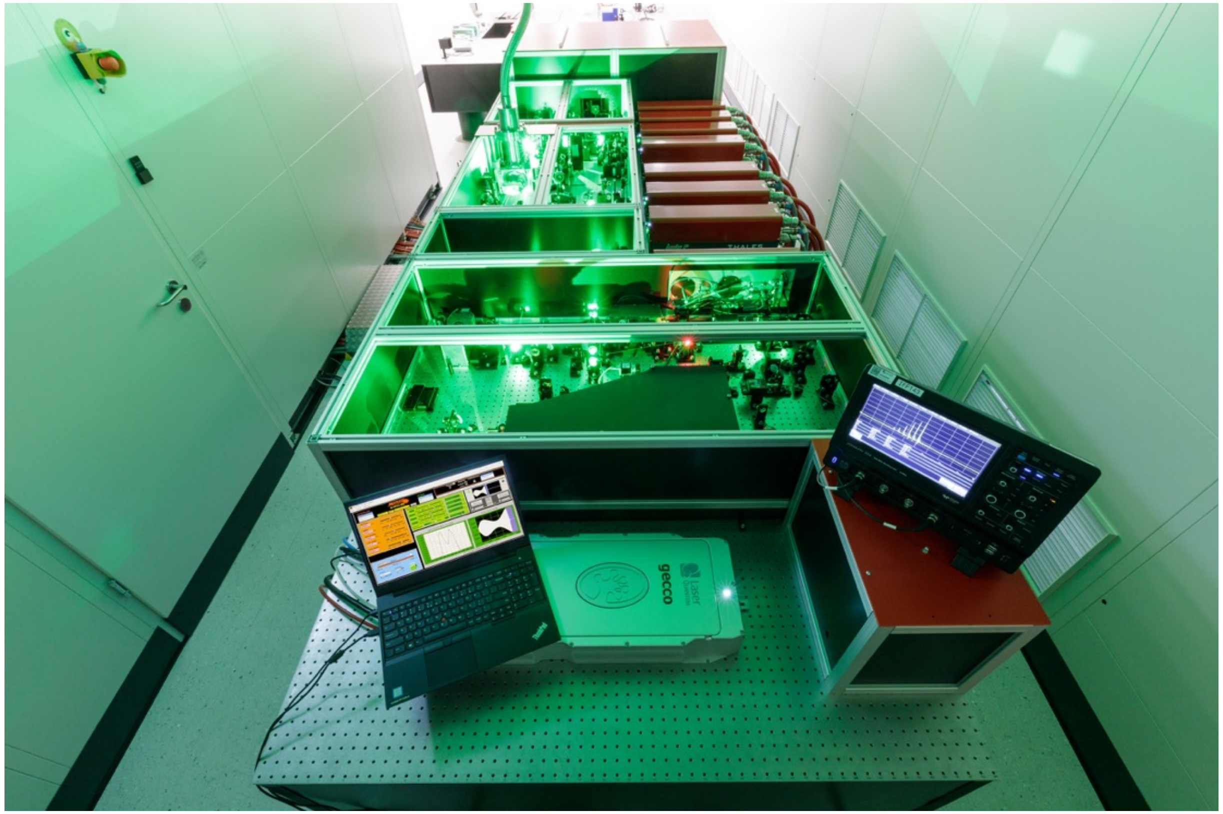
*Ju*SPARC-0: LASER SYSTEM (SINCE 2010)

KMLABS inc.
LEADING IN ULTRAFAST

Pulse energy 2 mJ
Pulse duration 35 fs
Repetition rate 3 kHz

cf. talk by Roman Adam

*Ju*SPARC-1: SOFT X-RAY MAGNETO OPTICS



THALES

Pulse energy 2 mJ → 40 mJ
Pulse duration ≤30 fs
Repetition rate 1 kHz

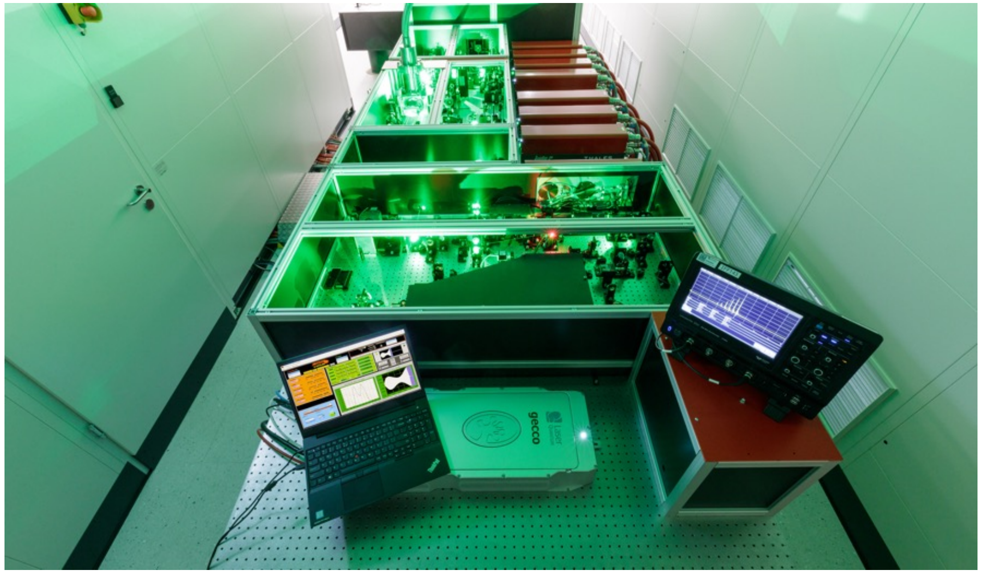
cf. talk by Roman Adam

JuSPARC

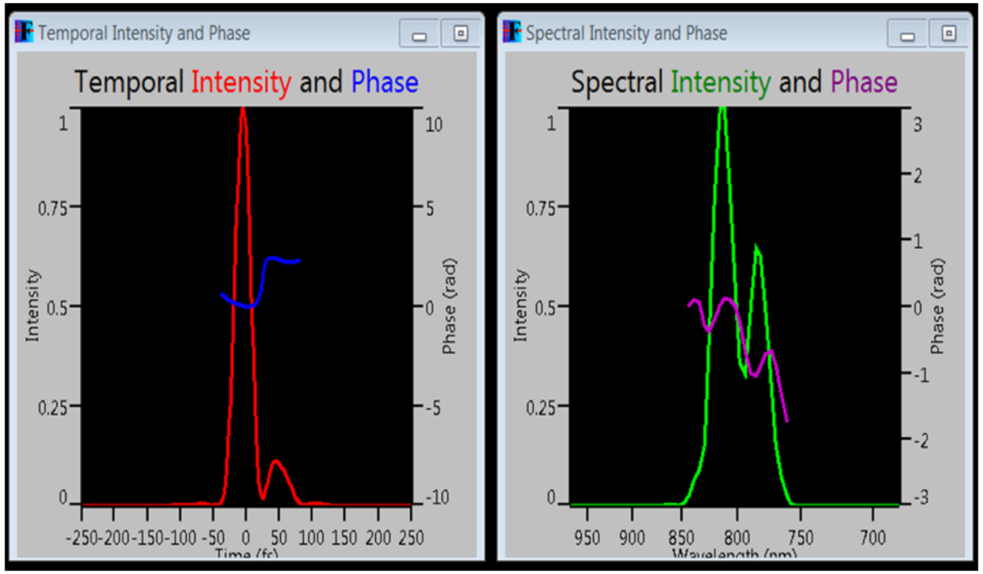
JÜLICH Forschungszentrum

*Ju*SPARC-1: LASER PERFORMANCE

Acceptance Test Report, 28/11/2018



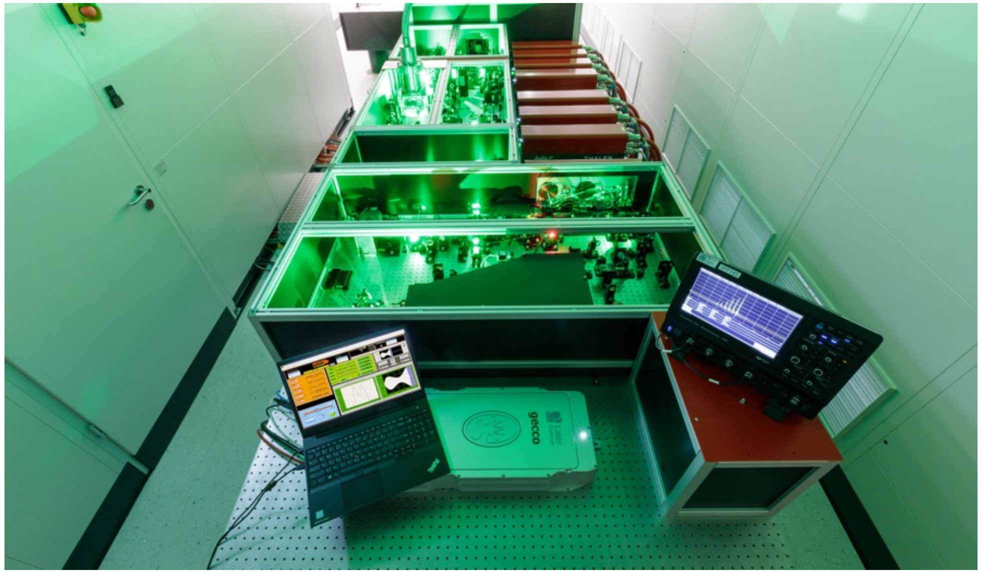
THALES



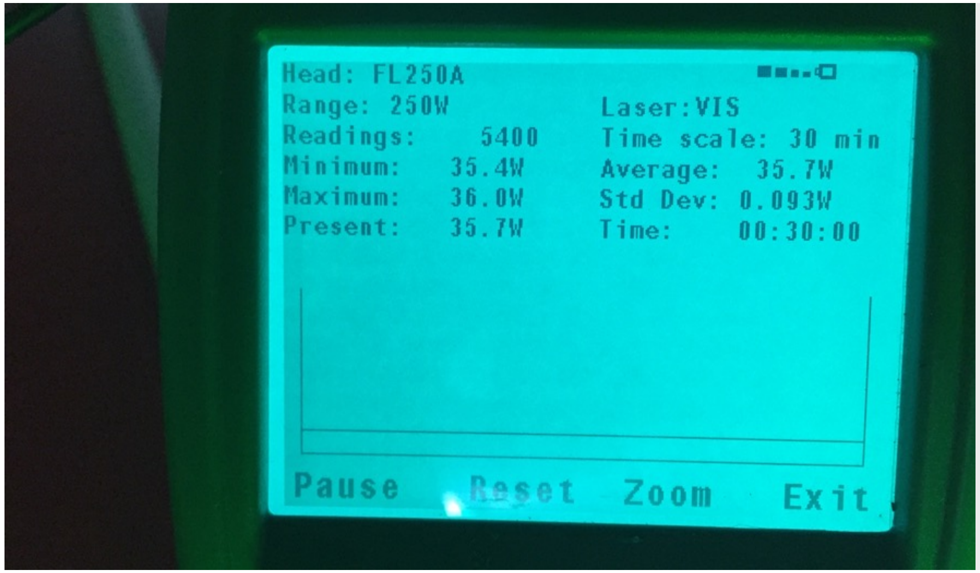
Pulse duration 29 fs

*Ju*SPARC-1: LASER PERFORMANCE

Acceptance Test Report, 28/11/2018



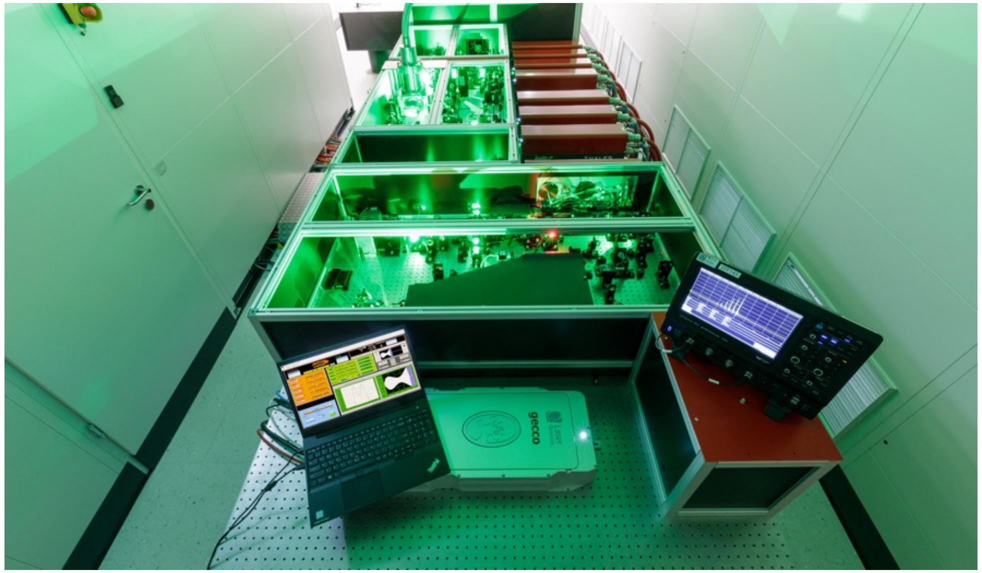
THALES



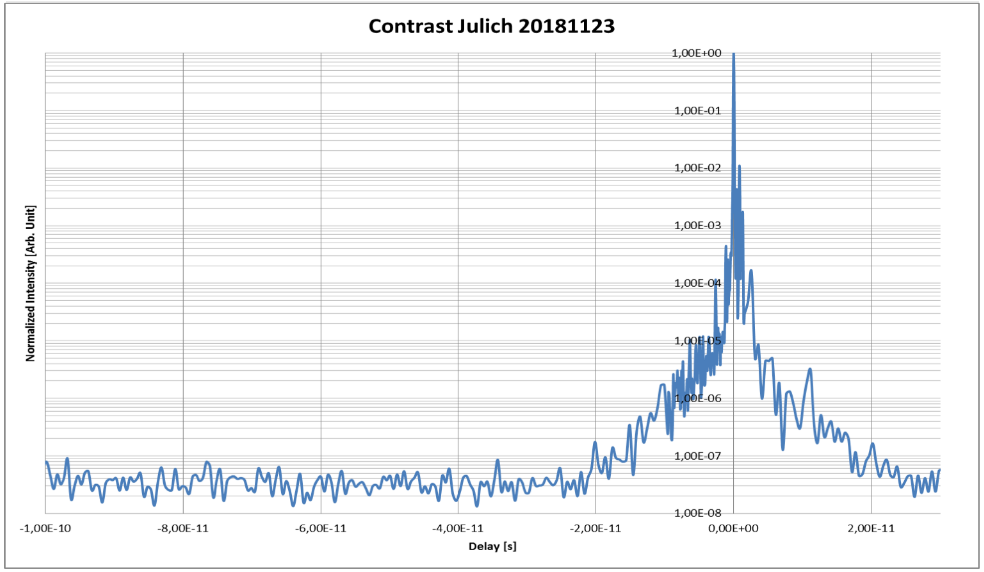
Energy stability (over 500 shots) ≤ 1% rms

*Ju*SPARC-1: LASER PERFORMANCE

Acceptance Test Report, 28/11/2018



THALES



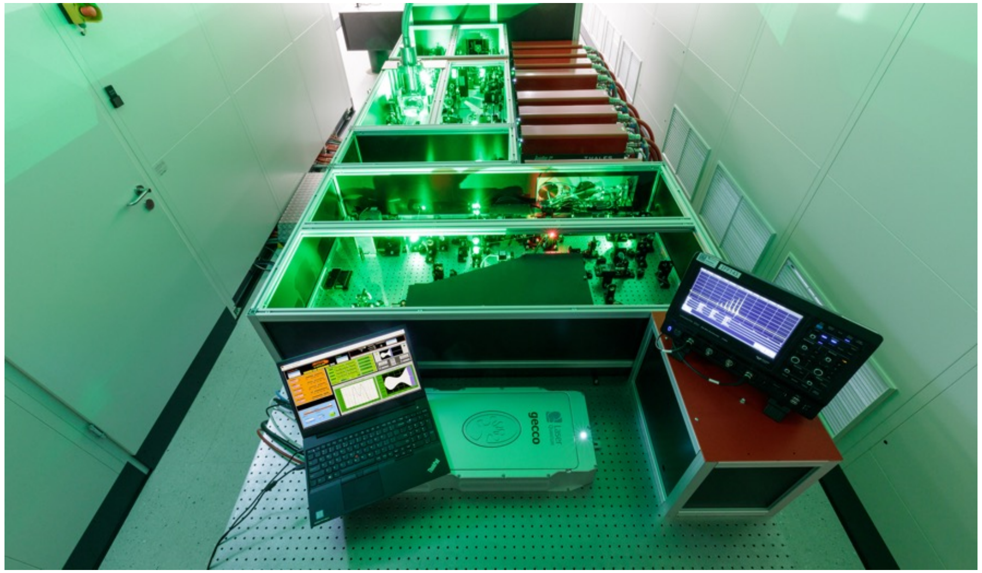
Contrast ratio

(Specified: 10^6:1 at 100ps / 10^5:1 at 10ps / 10^4:1 at 5ps

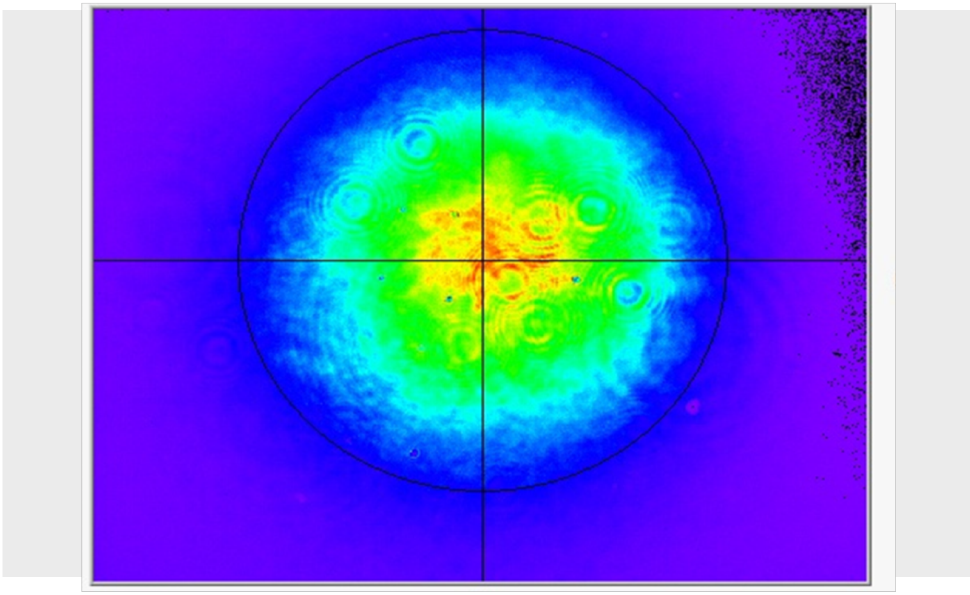
Measured: 1 order of magnitude better)

*Ju*SPARC-1: LASER PERFORMANCE

Acceptance Test Report, 28/11/2018



THALES

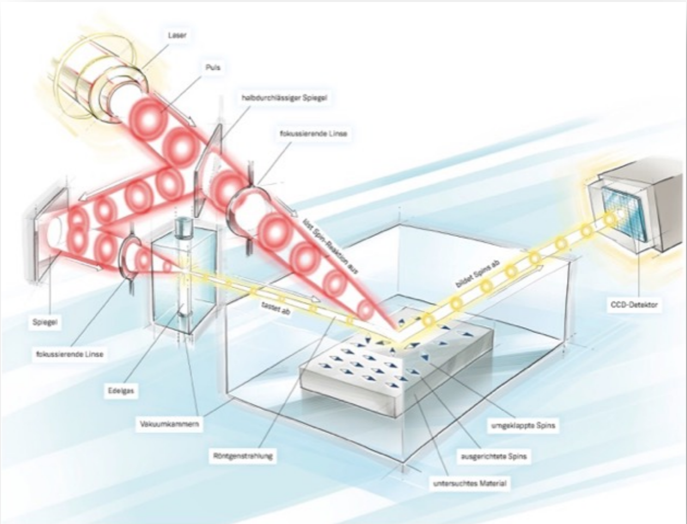


Beam profile

(M^2 = 1.76)

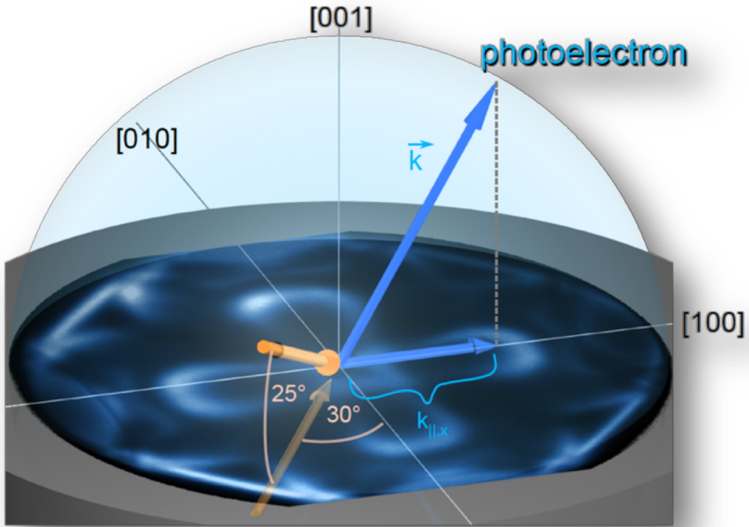
“THE EXPERIMENT DEFINES THE FACILITY”

“Photon in / Photon out”



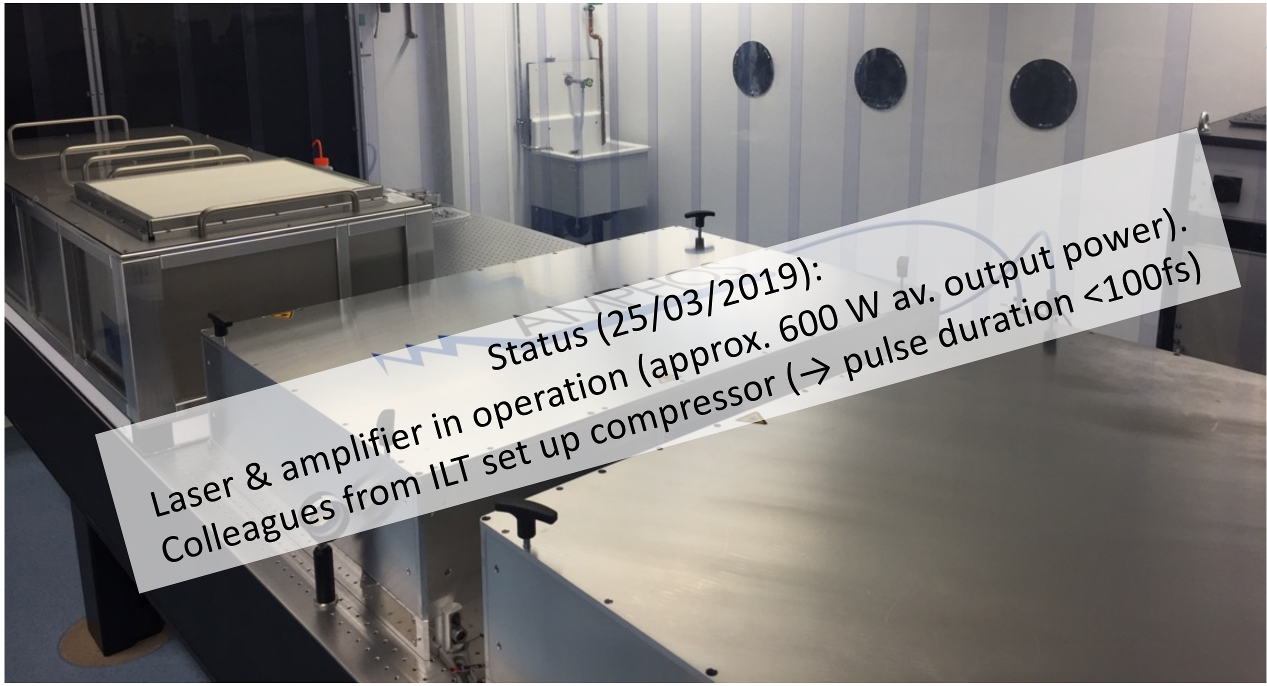
☞ Highest possible pulse energy at maximum repetition rate

“Photon in / Electron out”



☞ Smaller pulse energy at even higher repetition rate

*Ju*SPARC-1: MOMENTUM MICROSCOPY



AMPHOS

Fraunhofer ILT

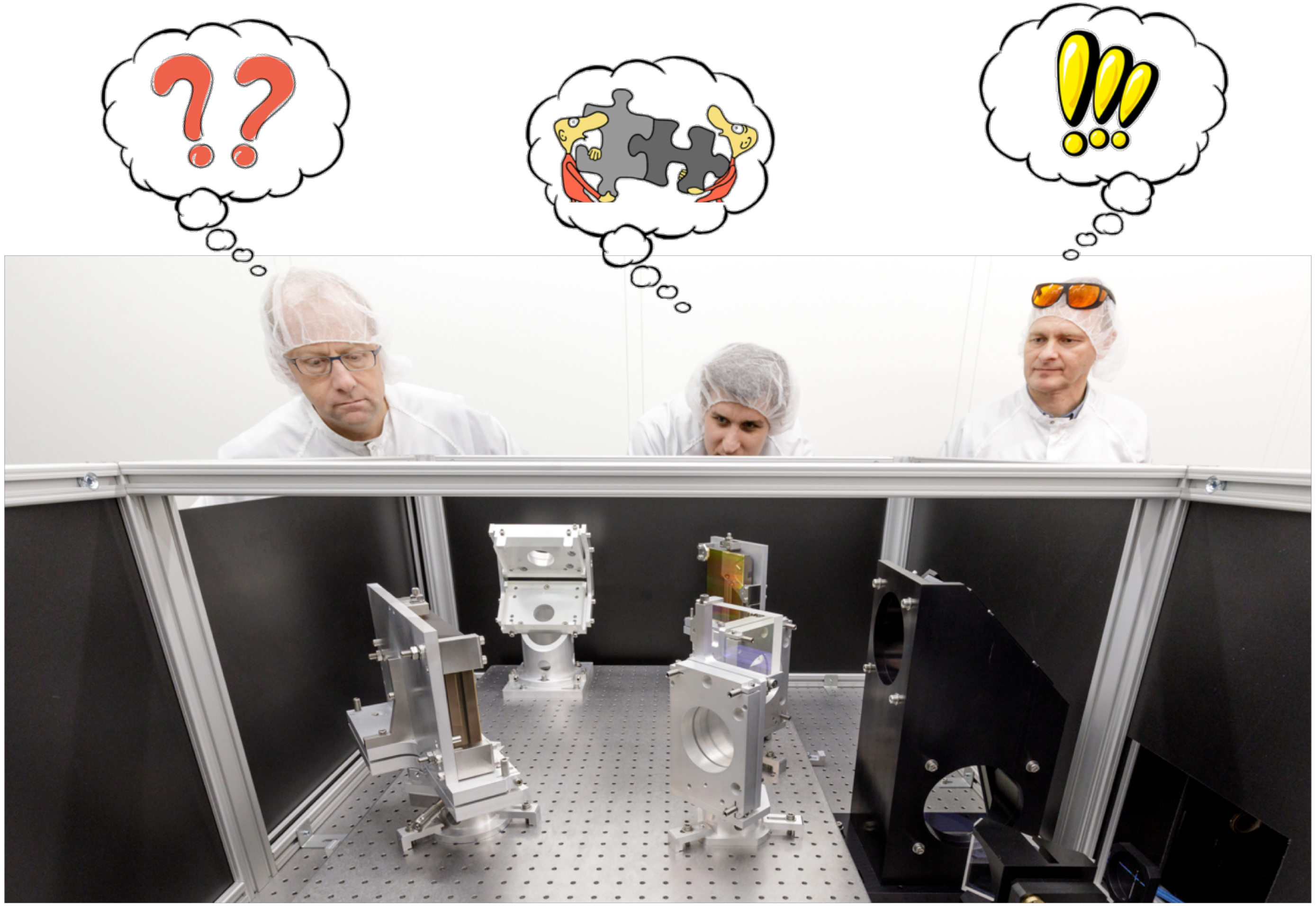
Pulse energy 0,05 mJ
Pulse duration 100 fs
Repetition rate 10 MHz

cf. talk by Christian Tusche

KICK-OFF: JAN. 24, 2019

JÜLICH Forschungszentrum

WHAT'S NEXT … ?



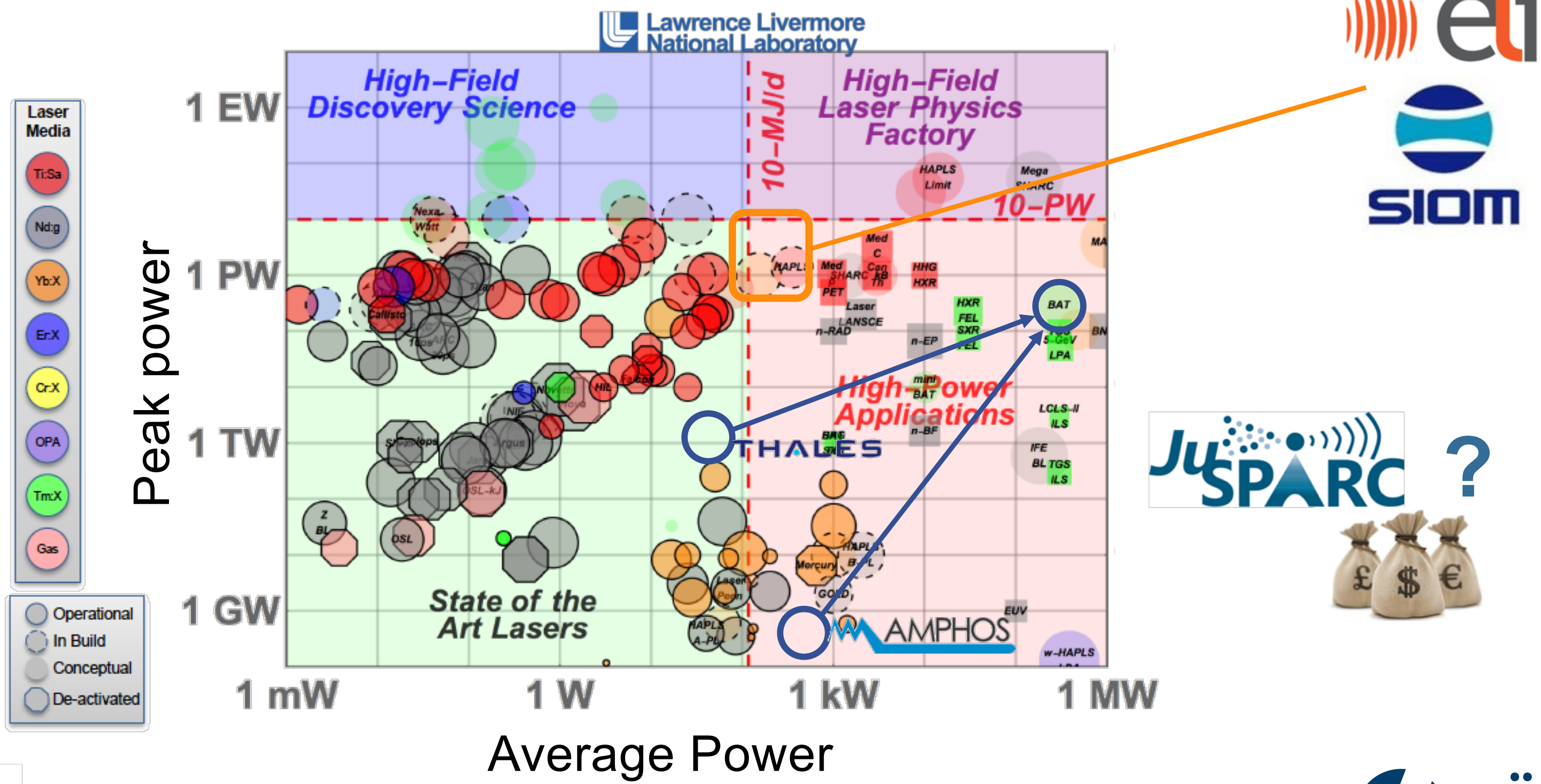
LET‘S ORGANIZE A WORKSHOP …

Donald Trump und Kim Jong Un, Hanoi, Feb. 28, 2019

“We both felt very good about having this summit in Vietnam because you really are an example of what can happen with good thinking.”

TOWARDS *Ju*SPARC-2

Increase peak power at while maintaining high repetition rate



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TOWARDS *Ju*SPARC-2

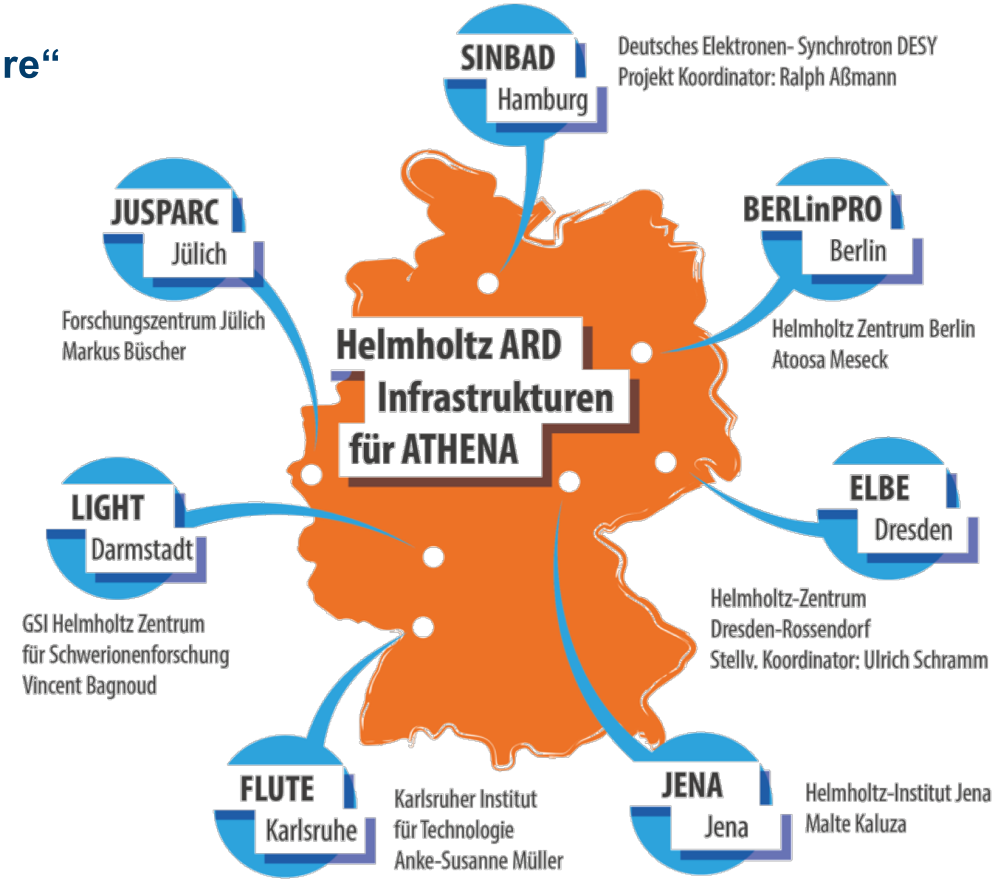
	Typical peak power	*Secondary Particles*
JuSPARC	1 TW	*Photons (XUV), electrons (?)*
IPP Institute of Plasma Physics of the Czech Academy of Sciences	10 TW	*Electrons*
Düsseldorf ARCturus Laser Facility	100 TW	*Protons (MeV)*
PHELIX	1 PW	*Protons, ions (10 MeV)*
SIOM	10 PW	*Protons (GeV)*

ATHENA

„Accelerator Technology Helmholtz Infrastructure“

ATHENA

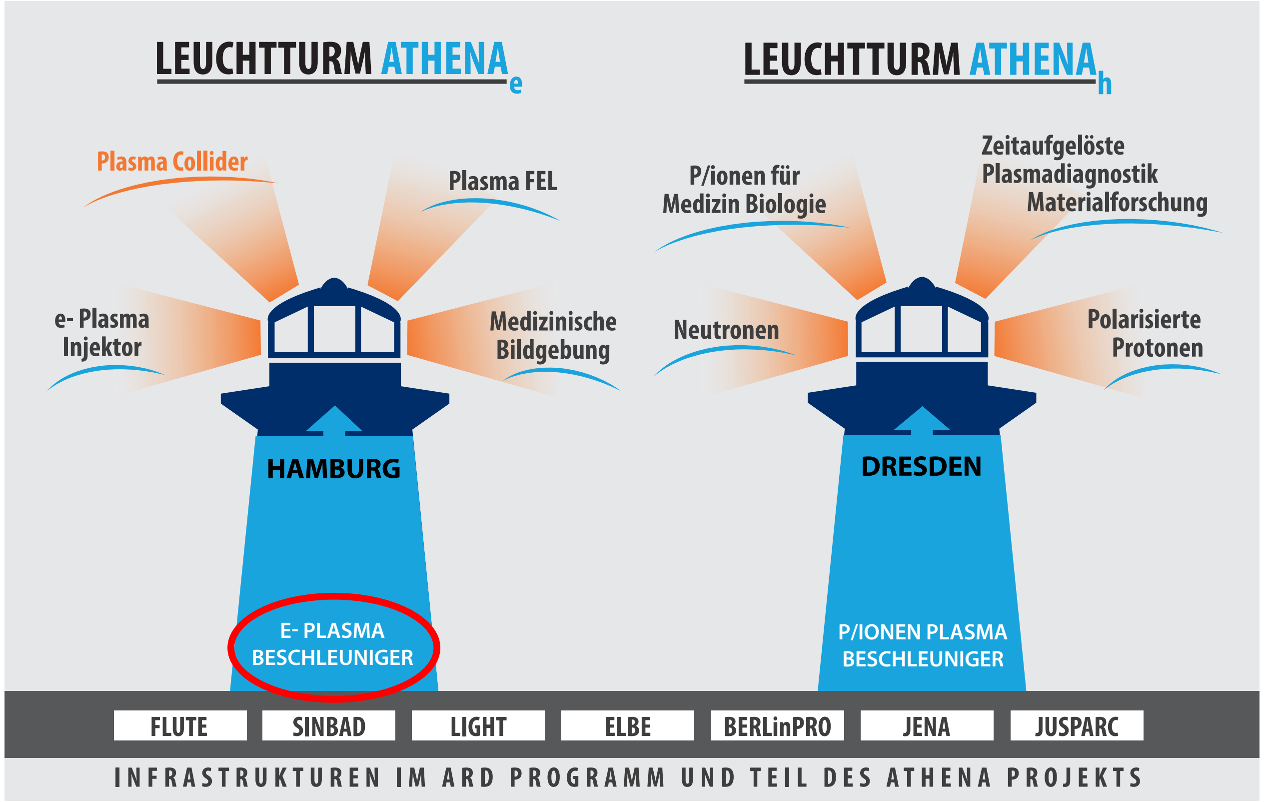
The Helmholtz-Project for
Laser-Plasma-Acceleration



ATHENA

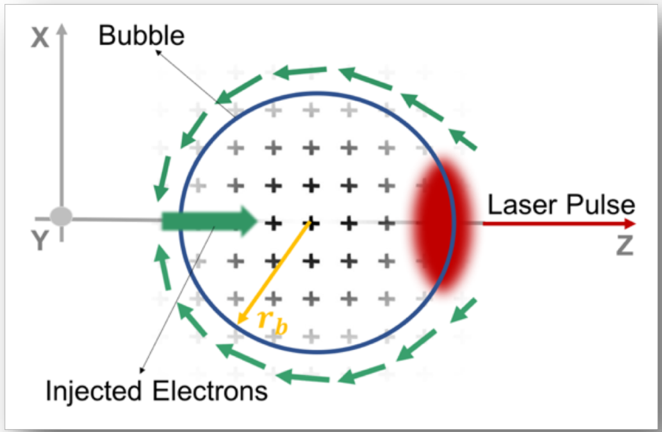
HGF R&D platform for accelerator technology (2018 – 21)

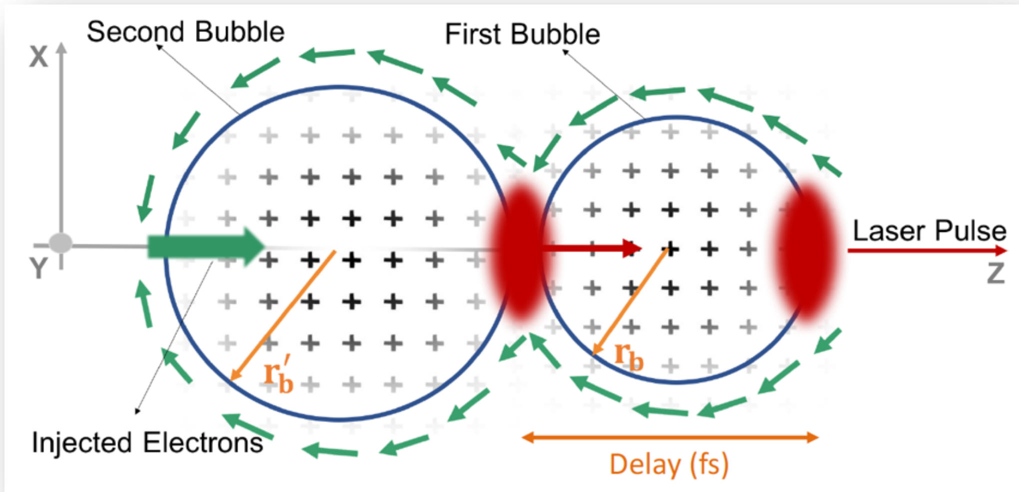
ATHENA
The Helmholtz-Project for
Laser-Plasma-Acceleration



TOWARDS *Ju*SPARC-2: ELECTRON ACCELERATION

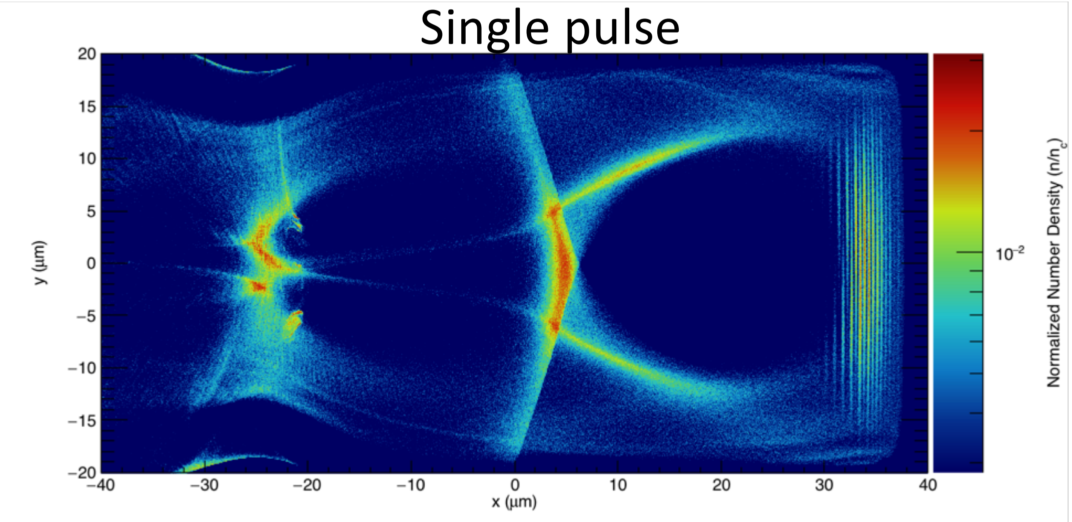
Optimization of injection into a plasma wake cavity

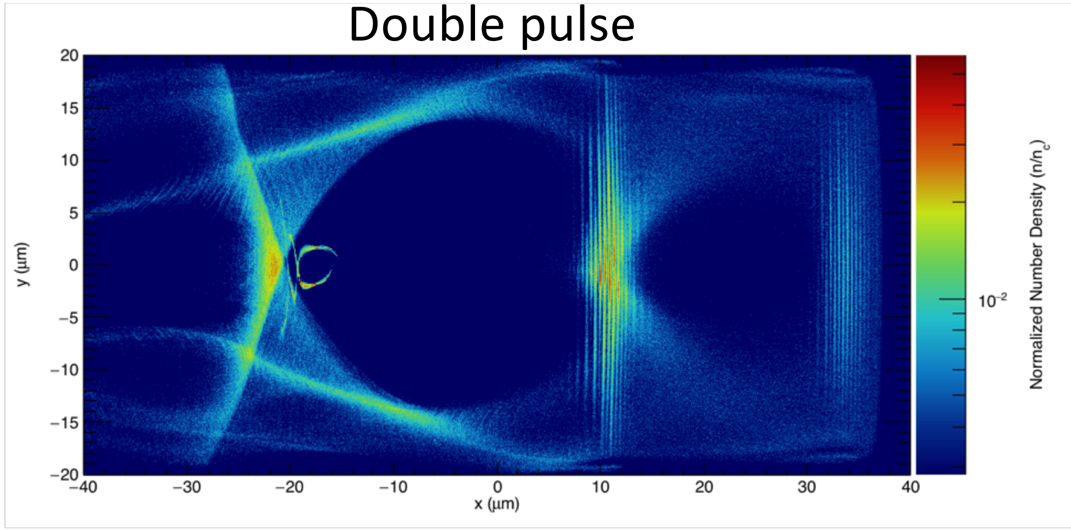




TANDEM-PULSE ELECTRON ACCELERATION

2d PIC simulations with EPOCH on JURECA



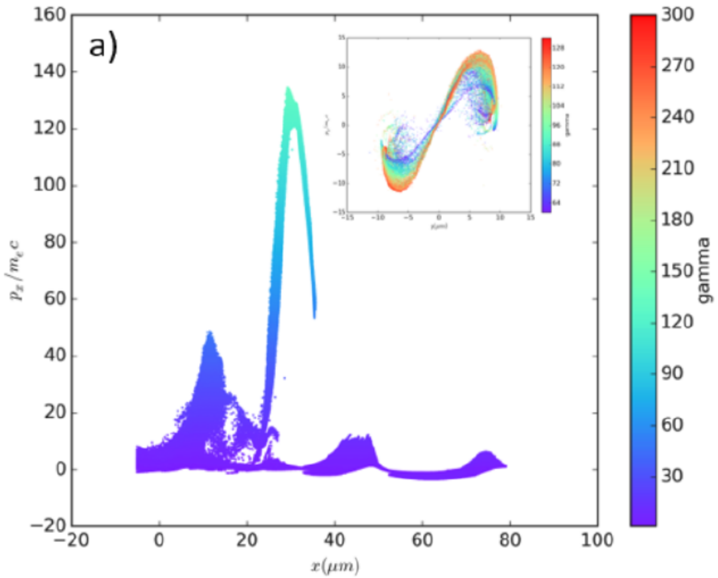


Zahra Chitgar et al., subm. to Plasma Physics and Controlled Fusion

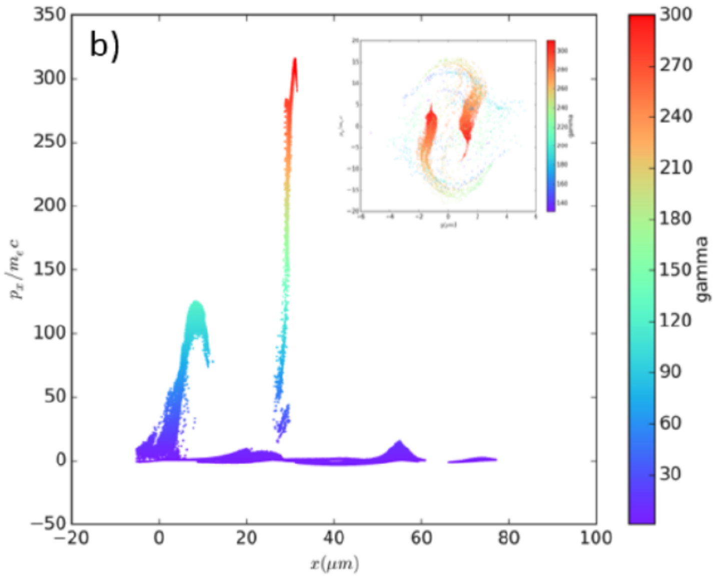
TANDEM-PULSE ELECTRON ACCELERATION

Increased acceleration efficiency (simulation)

Pulse energy	3.4 J
Pulse length	20 fs
Focal spot	10 µm
Target	He gas
Target density	$1.9 \cdot 10^{17}$ cm^{-3}



Single pulse



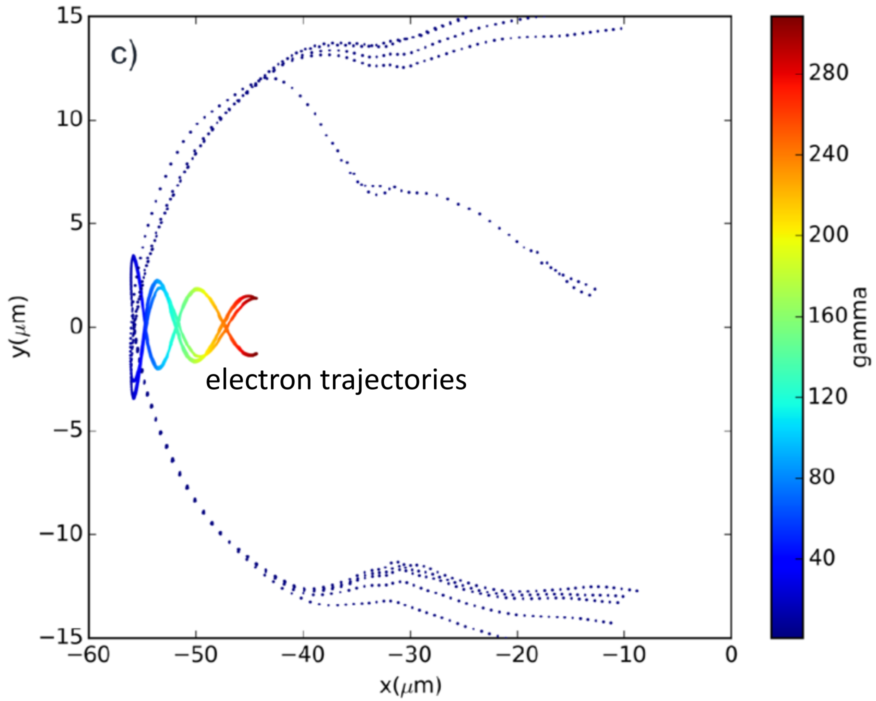
Double pulse

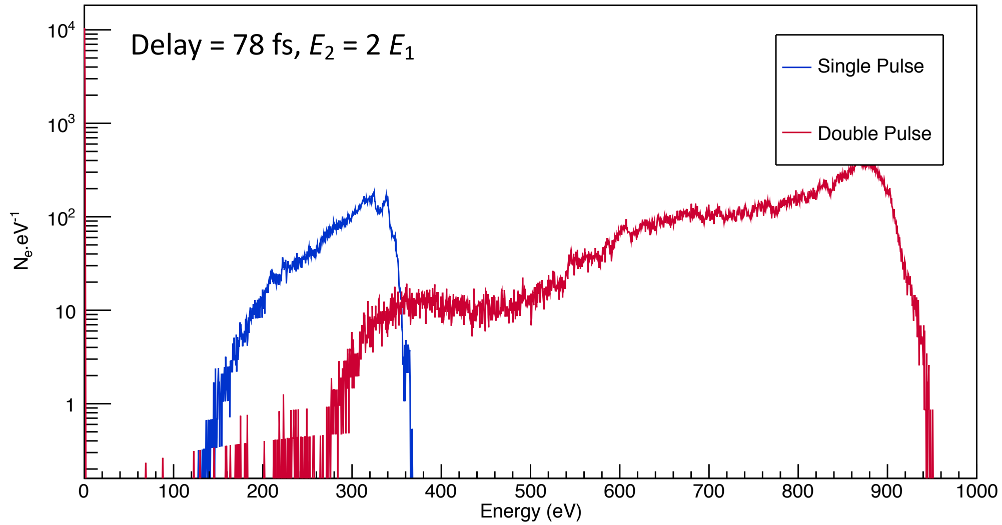
Zahra Chitgar et al., subm. to Plasma Physics and Controlled Fusion

TANDEM-PULSE ELECTRON ACCELERATION

Increased X-ray flux (simulation)

Pulse energy	2 J
Pulse length	20 fs
Focal spot	10 µm
Target	He gas
Target density	$9.2 \cdot 10^{17}\ \mathrm{cm}^{-3}$



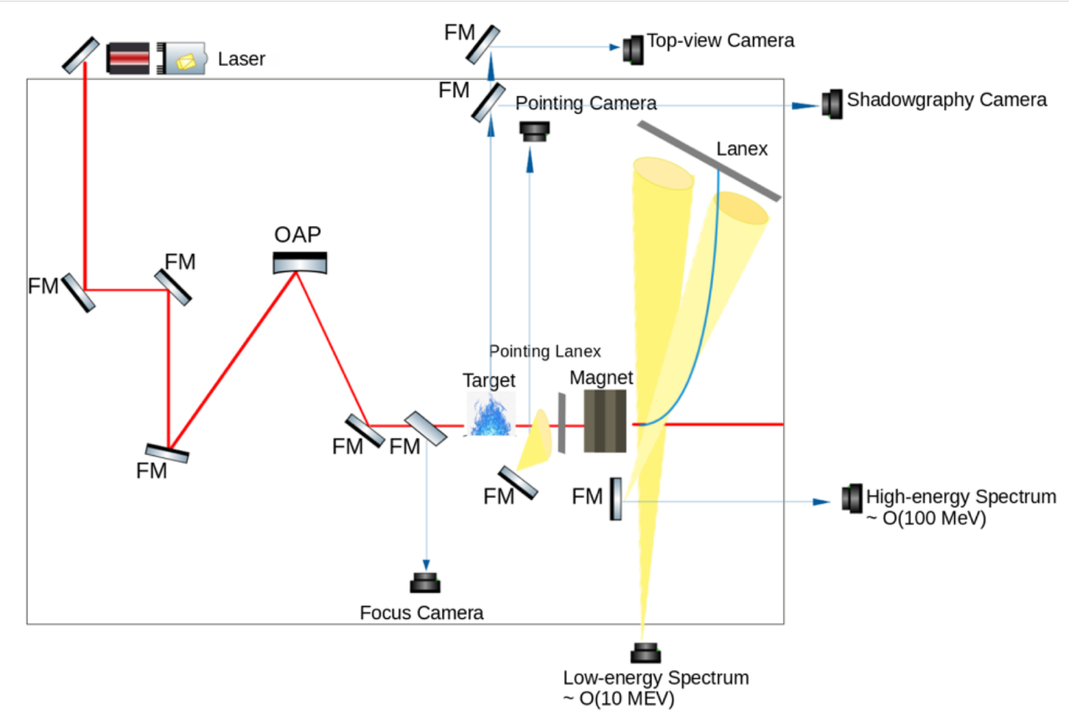


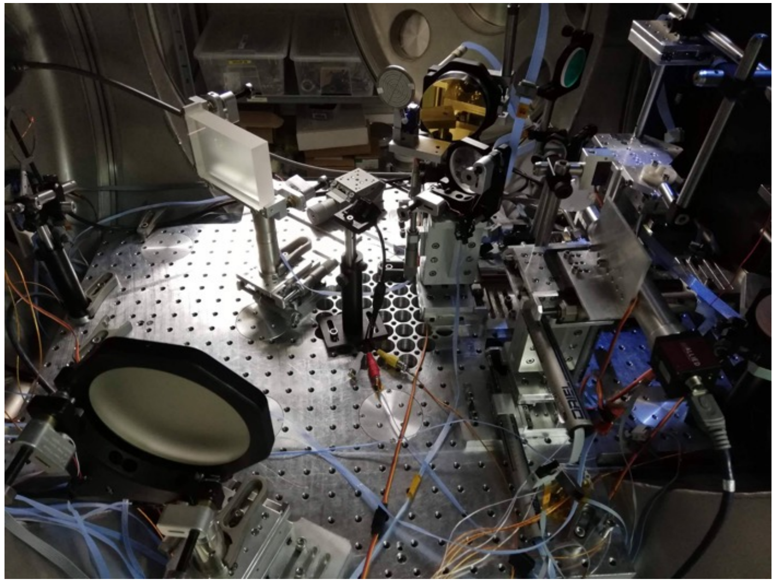
Zahra Chitgar et al., subm. to Plasma Physics and Controlled Fusion

TANDEM-PULSE ELECTRON ACCELERATION

Ongoing experiment @IPP/Prague

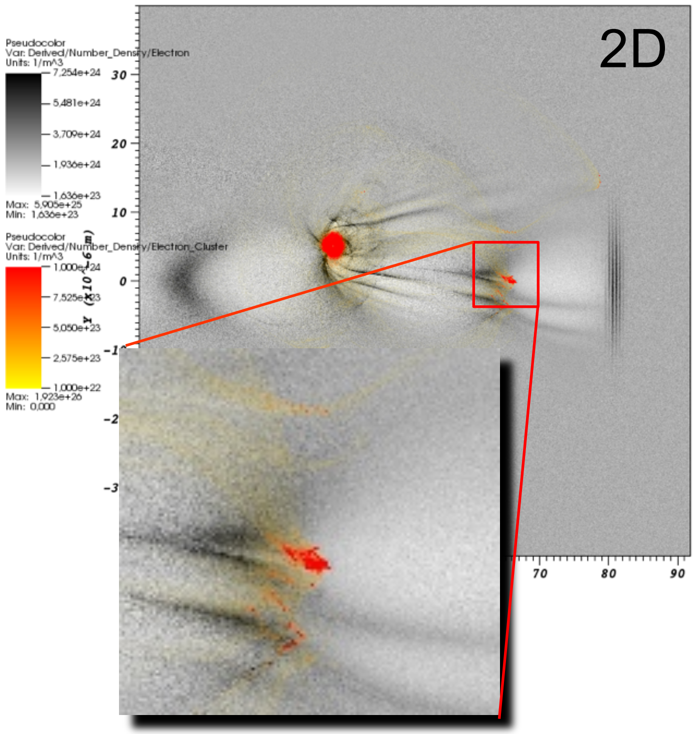
Total pulse energy	300 mJ
Pulse length	25, 40 fs
Pulse delay	40 – 150 fs
Intensity	$3 \cdot 10^{18}$ W/cm^2
Target	He gas jet

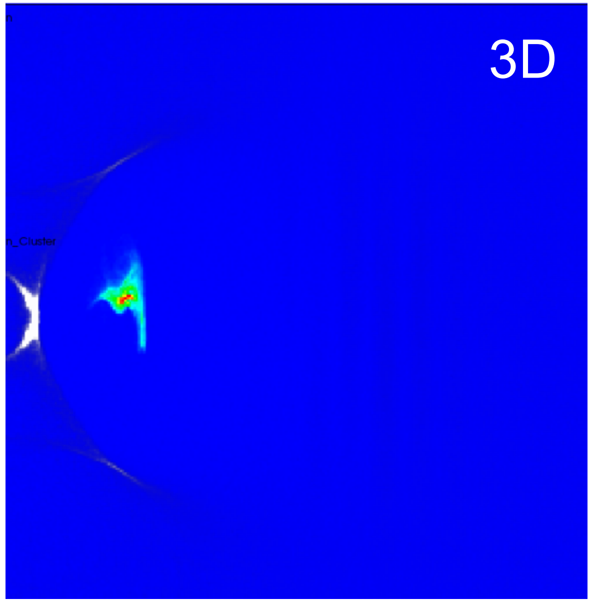




TOWARDS *Ju*SPARC-2: TARGET DEVELOPMENTS

Injection of as electron bunches from nm-sized solid targets into a wake field (EPOCH simulations)





TOWARDS *Ju*SPARC-2: TARGET DEVELOPMENTS

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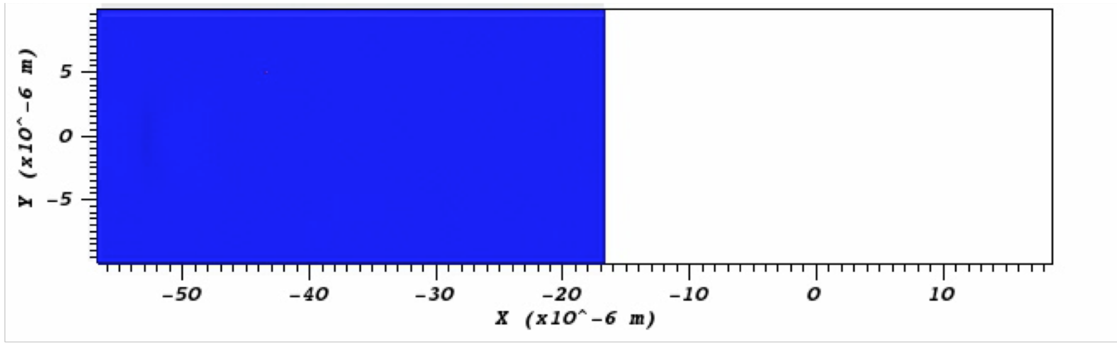
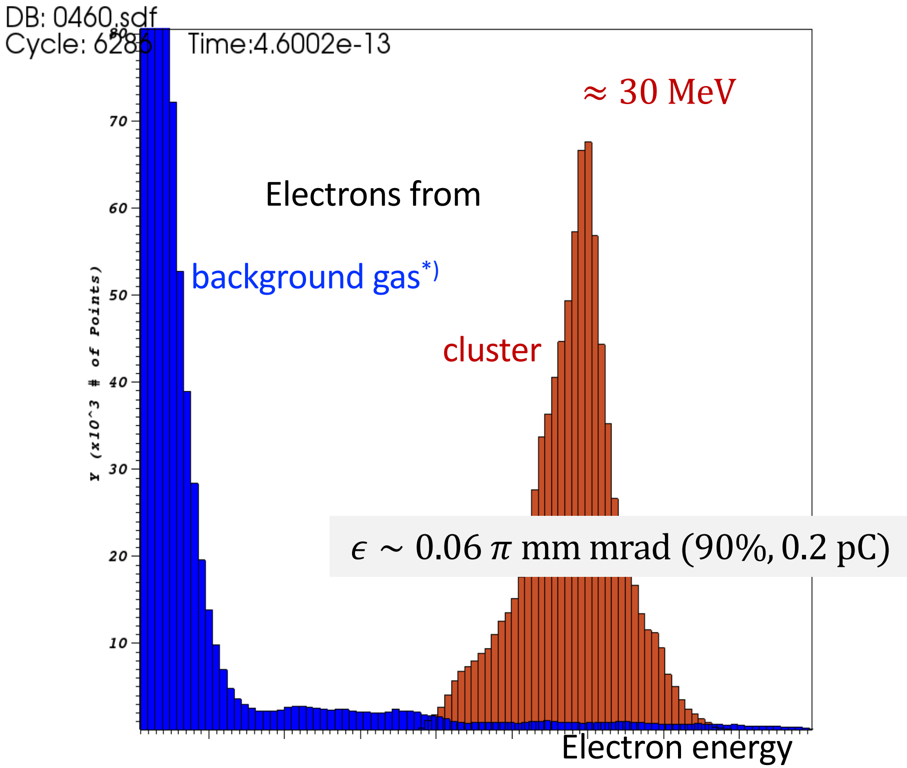


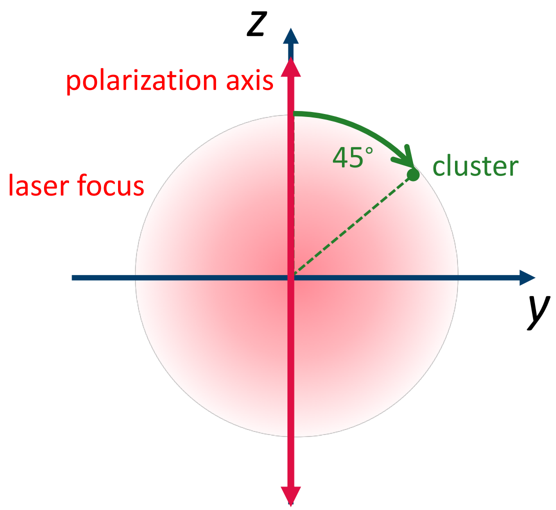
Pulse energy	40 mJ
Pulse duration	25 fs
Focus Ø	10 µm
Wavelength	1 µm
Rep. Rate	1 kHz
Cluster material	SiO_2
Cluster size	100 nm
Gas density (H_2)	$3{\cdot}10^{19}$ cm^{-3}

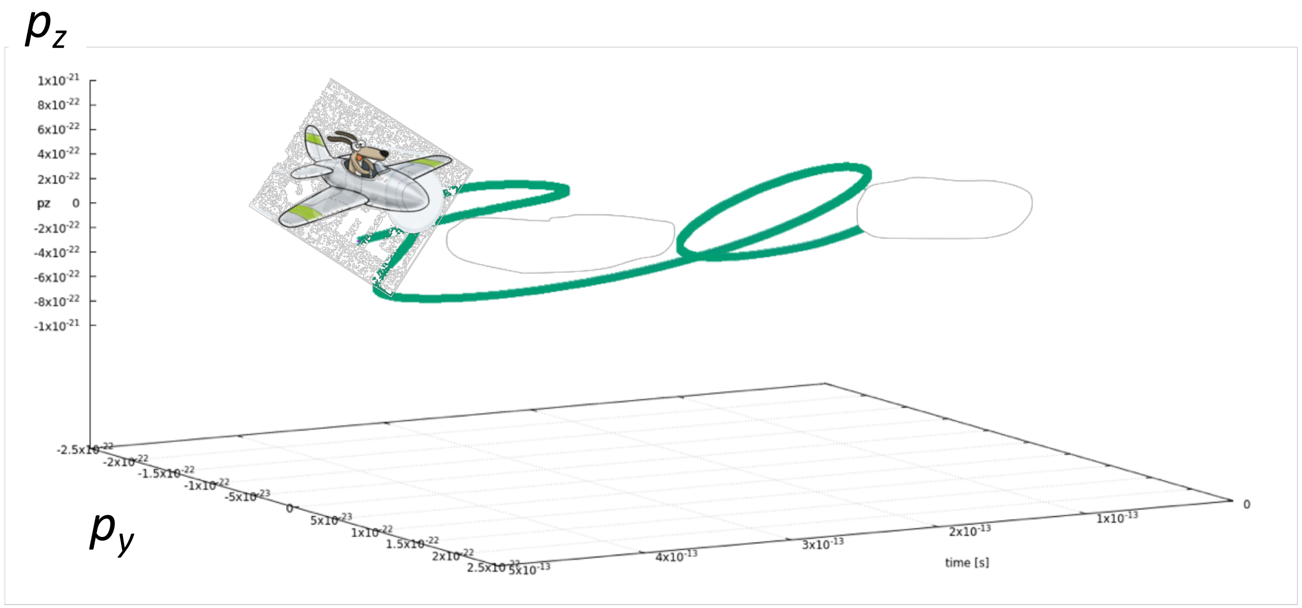


*) no self-injection!

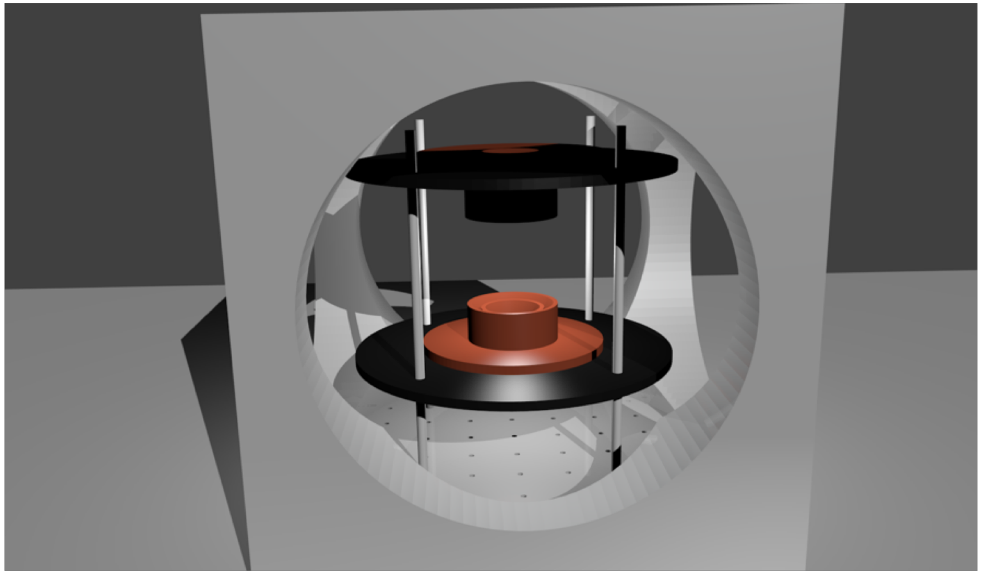
TOWARDS *Ju*SPARC-2: TARGET DEVELOPMENTS

Circular electron trajectories after out-of-plane injection





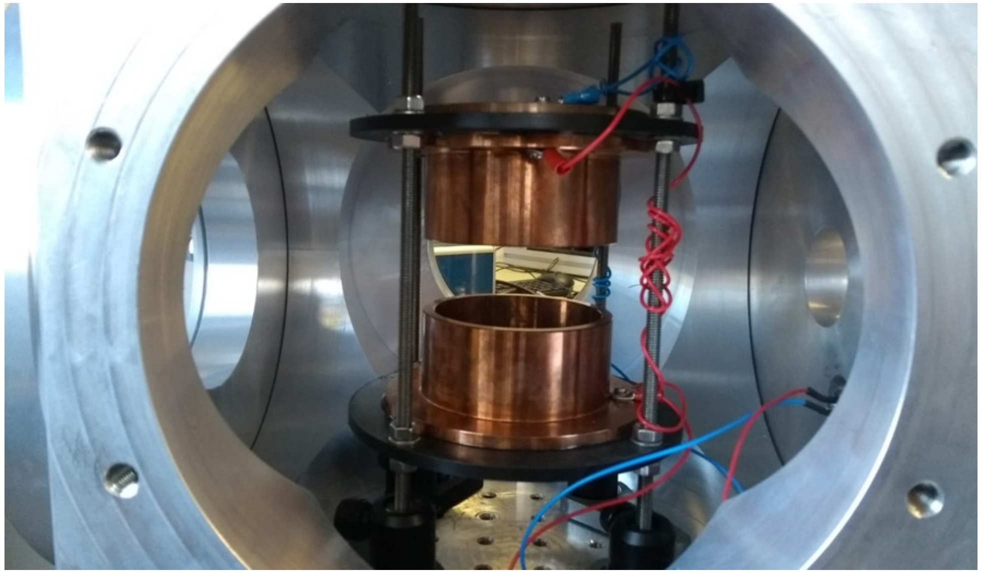
Development of Cluster Targets



Trapping & control of cluster position

Penning/optical trap for SiO_2 cluster

(Ph.D. work A.Sobotta @FZJ)



First tests @3 kHz/2 mJ laser: April 2019

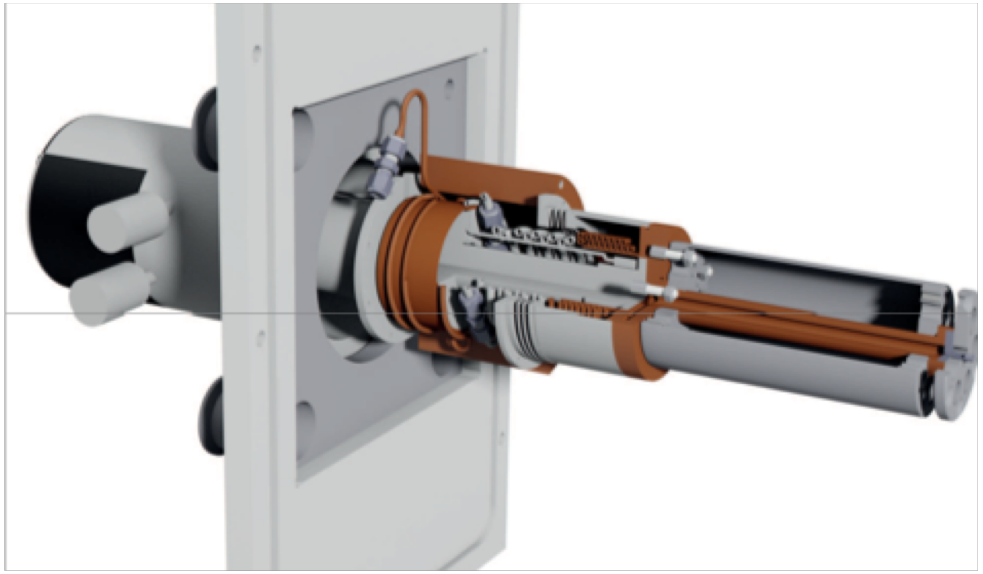
Development of Cryogenic Cluster Targets

Nm-sized cryogenic hydrogen clusters for a laser-driven proton source

S. Grieser,[1, a)] B. Aurand,[2, b)] E. Aktan,[2] D. Bonaventura,[1] M. Büscher,[3] M. Cerchez,[2] I. Engin,[3] L. Leßmann,[1] C. Mannweiler,[1] R. Prasad,[2] O. Willi,[2] and A. Khoukaz[1]
[1)] *Institut für Kernphysik, Westfälische Wilhelms-Universität Münster, 48149 Münster, Germany*
[2)] *Institut für Laser- und Plasmaphysik, Heinrich-Heine-Universität, 40225 Düsseldorf, Germany*
[3)] *Peter Grünberg Institut, PGI-6, Forschungszentrum Jülich, 52428 Jülich, Germany*

(Dated: 1 November 2018)

A continuous cryogenic hydrogen cluster-jet target has been developed for laser-plasma interaction studies, in particular as a source for the acceleration of protons. Major advantages of the cluster-jet target are the compatibility with pulsed high repetition lasers and the absence of debris. The cluster-jet target was characterized using the Mie-scattering technique allowing to determine the cluster size and to compare it with an empirical prediction. In addition, an estimation of the cluster beam density was performed. The system was implemented at the high power laser system ARCTURUS and first successful measurements show the acceleration of protons after irradiation by high intensity laser pulses with a repetition rate of five Hertz.



arXiv:1810.13371v1 [physics.plasm-ph] 31 Oct 2018

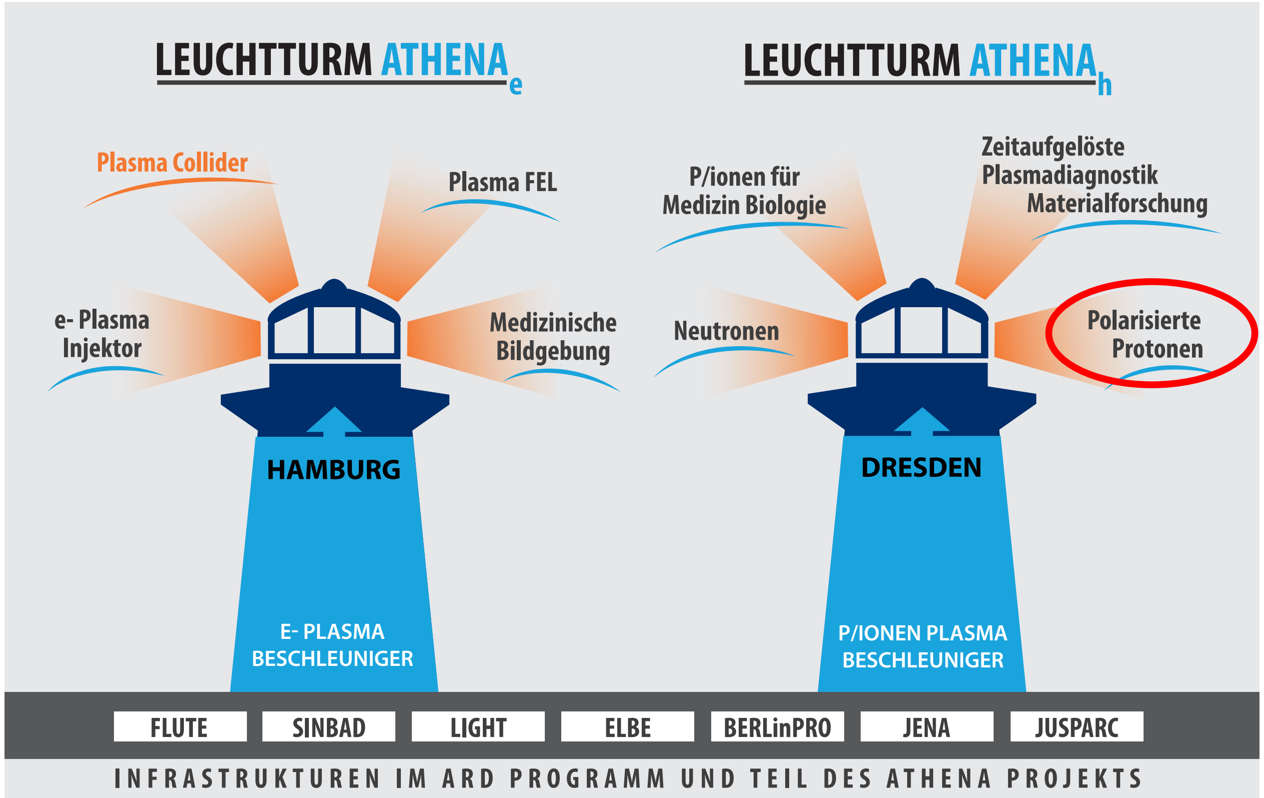
Accepted for publication in Rev. Sci. Instrum.

Nm-sized cryogenic hydrogen clusters
(built by WWU Münster / operated at HHU Düsseldorf)

ATHENA

HGF R&D platform for accelerator technology (2018 – 21)

ATHENA
The Helmholtz-Project for
Laser-Plasma-Acceleration



THEORY OF POLARIZED BEAMS

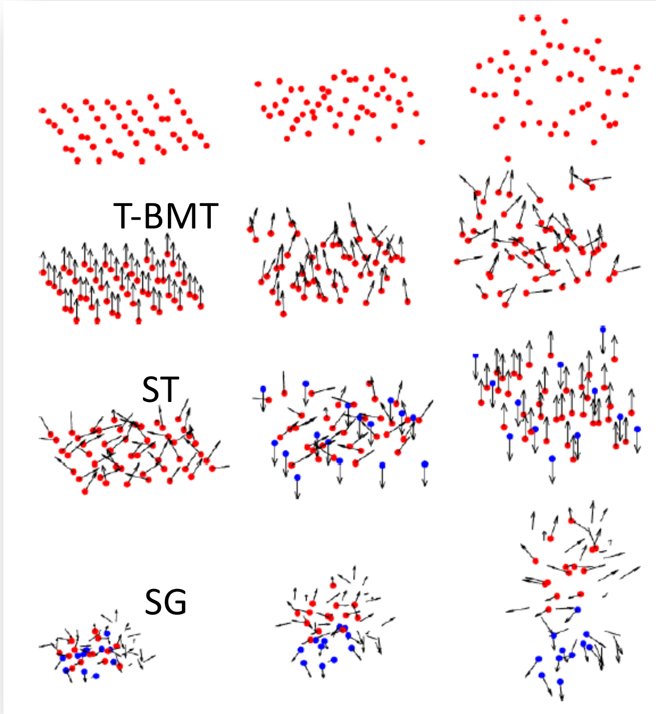
Collaboration with: HHU Düsseldorf, SIOM Shanghai

Spin-polarized particle beams from laser-plasma accelerators

Johannes Thomas[1], Anna Hützen[2,3], Andreas Lehrach[4,5], Alexander Pukhov[1], Liangliang Ji[6,8], Yitong Wu[6,7], and Markus Büscher[2,3]

[1] *Institut fuer Theoretische Physik I, Heinrich-Heine-Universität Düsseldorf, Universitätsstr. 1, 40225 Düsseldorf, Germany*
[2] *Peter Grünberg Institut (PGI-6), Forschungszentrum Jülich, Wilhelm-Johnen-Str. 1, 52425 Jülich, Germany*
[3] *Institut für Laser- und Plasmaphysik, Heinrich-Heine-Universität Düsseldorf, Universitätsstr. 1, 40225 Düsseldorf, Germany*
[4] *JARA-FAME (Forces and Matter Experiments), Forschungszentrum Jülich and RWTH Aachen University, 52056 Aachen, Germany*
[5] *Institut für Kernphysik, Forschungszentrum Jülich, Wilhelm-Johnen-Str. 1,, 52425 Jülich, Germany*
[6] *State Key Laboratory of High Field Laser Physics, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China*
[7] *Center of Materials Science and Optoelectronics Engineering, University of Chinese Academy of Sciences, Beijing 100049, China and*
[8] *CAS Center for Excellence in Ultra-intense Laser Science, Shanghai 201800, China*

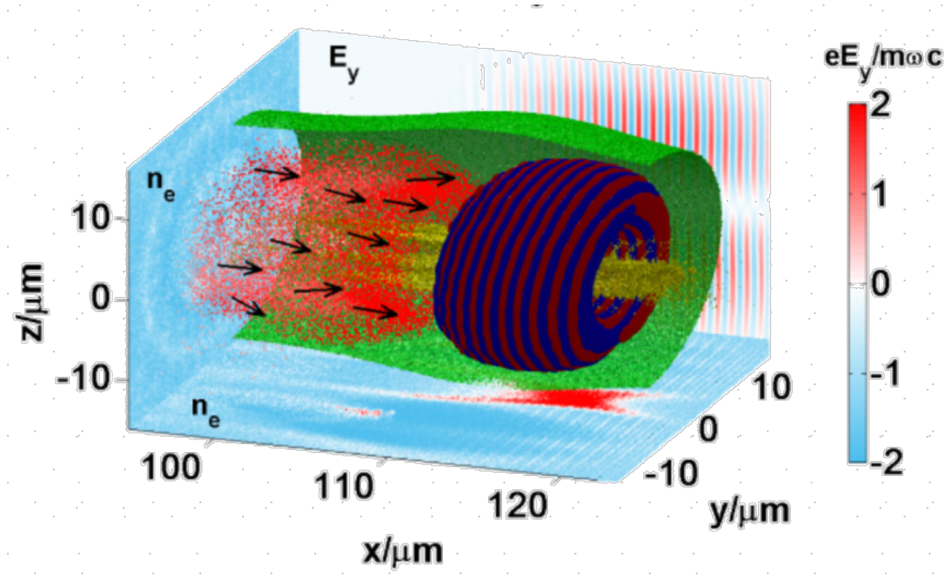
In this work we show under which conditions it is possible to accelerate polarized electron and proton beams in strong plasma and laser fields without destroying the initially given polarization. We discuss all relevant mechanisms that may have an influence on beam polarization in laser-plasma accelerators, i.e., the T-BMT equation, the Sokolov-Ternov effect and the Stern-Gerlach force. We derive analytical scaling laws for the polarization and the depolarization time originating from these effects and proof that the main polarization-limiting effect in laser-plasma-accelerators is the rotation of the single particle spins around the local electromagnetic fields.



To be subm. to Phys. Rev. Accel. Beams

POLARIZED ELECTRON BEAMS

Collaboration with: HHU Düsseldorf, SIOM Shanghai, Univ. Crete



Polarized electron-beam acceleration driven by vortex laser pulses

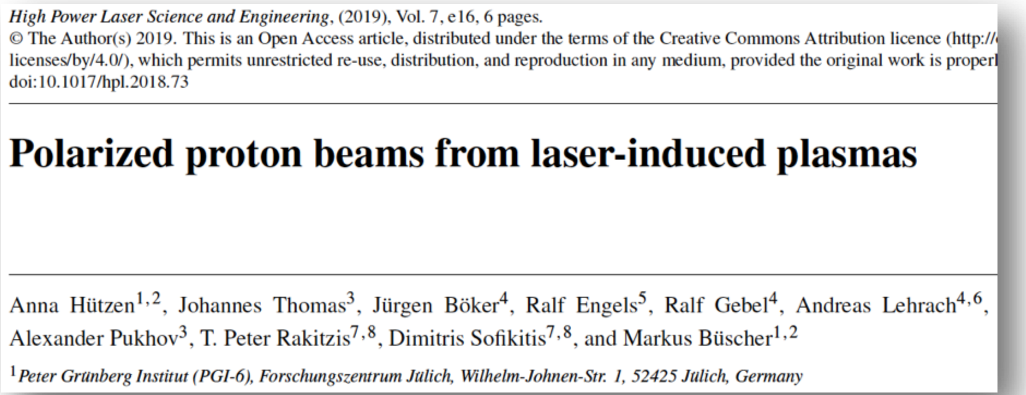
Yitong Wu,[1,2] Liangliang Ji,[1,3*] Xuesong Geng,[1,2] Qin Yu,[1] Nengwen Wang,[1] Bo Feng,[1,2] Zhao Guo,[1,2] Weiqing Wang,[1,2] Chengyu Qin,[1,2] Xue Yan,[1,2] Lingang Zhang,[1] Markus Büscher,[4,5] Anna Hützen,[4,5] Alexander Pukhov,[6] Johannes Thomas,[6] T. Peter Rakitzis,[7,8] Baifei Shen,[1,3,9#] and Ruxin Li[1,3,10§]

[1]State Key Laboratory of High Field Laser Physics, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China

Subm. to Nature Commum.

POLARIZED PROTON BEAMS

Collaboration with: HHU Düsseldorf, SIOM Shanghai, Univ. Crete


High Power Laser Science and Engineering, (2019), Vol. 7, e16, 6 pages.
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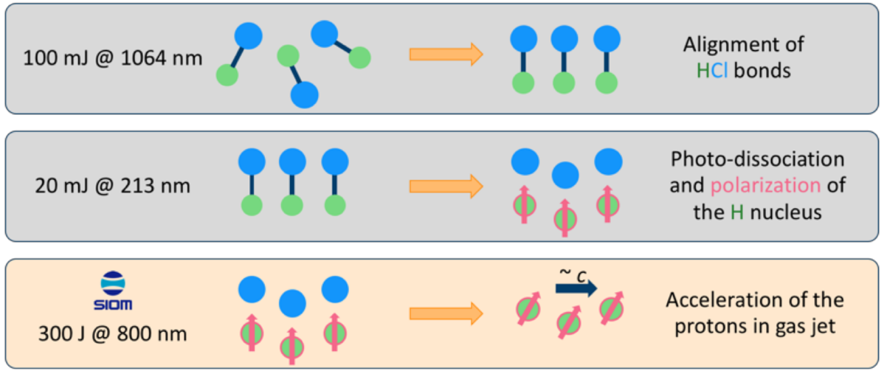
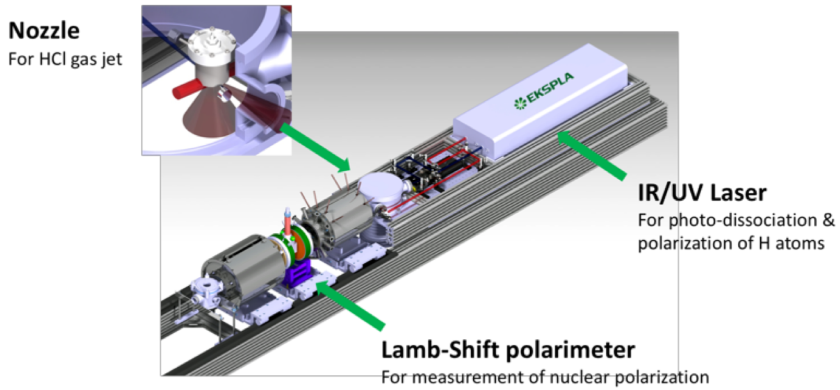
doi:10.1017/hpl.2018.73

Polarized proton beams from laser-induced plasmas

Anna Hützen[1,2], Johannes Thomas[3], Jürgen Böker[4], Ralf Engels[5], Ralf Gebel[4], Andreas Lehrach[4,6], Alexander Pukhov[3], T. Peter Rakitzis[7,8], Dimitris Sofikitis[7,8], and Markus Büscher[1,2]

[1] *Peter Grünberg Institut (PGI-6), Forschungszentrum Jülich, Wilhelm-Johnen-Str. 1, 52425 Jülich, Germany*





10 PW LASER SULF SHANGHAI

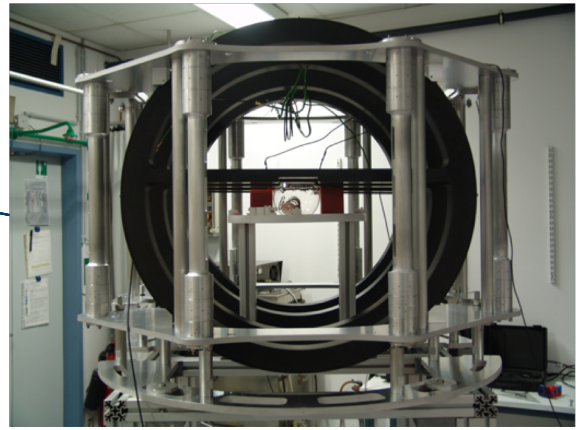
First experiments on Proton acceleration: May 2019 (@5 PW)

POLARIZED TARGETS …

… for electron, proton and ion acceleration

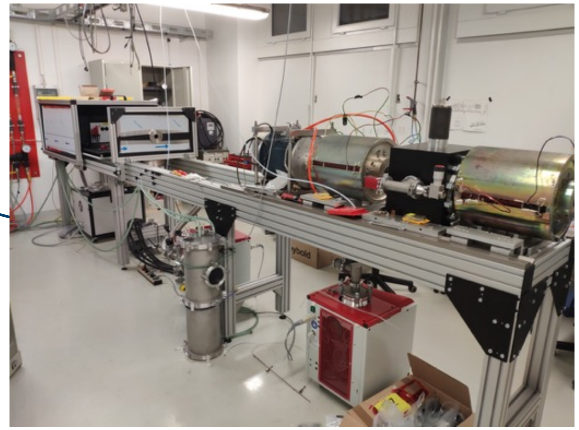
- Hyperpolarized ^{3}He gas-jet („static“ polarization)

  First experiments @Phelix in 2019



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

  Commissioning @SIOM in 2020 (Ph.D. A.Hützen, C.Kannis)



- Polarized molecular Hydrogen gas target
- Polarized solid HD and D_2 Target

"Now! ... *That* should clear up a few things around here!"