JÜLICH
FORSCHUNGSZENTRUM

# Hydrogen cluster-gas mixtures as novel target concept for laser-acceleration experiments

*EMMI Workshop on high energy density plasma diagnostics at FAIR:*

*Novel laser based photon and particle sources*

October 1st, 2013 | Ilhan Engin - IKP *i.engin@fz-juelich.de*

HEINRICH HEINE
UNIVERSITÄT DÜSSELDORF

# Working group

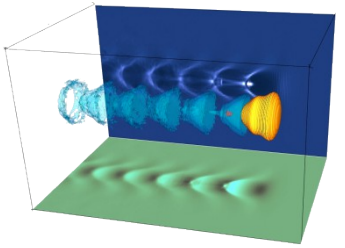
- Peter Grünberg Institute *(FZJ)*

  Institute for Nuclear Physics *(FZJ)* → Prof. M. Büscher *)
- Jülich Supercomputing Centre *(FZJ)* → Prof. P. Gibbon *)
- 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 *)
- Jülich Centre for Neutron Science *(FZJ)* → Prof. T. Brückel *)

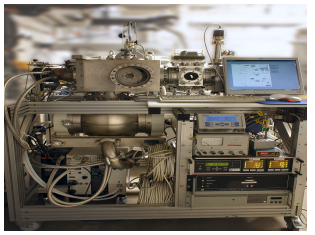
*) group leaders

# Outline

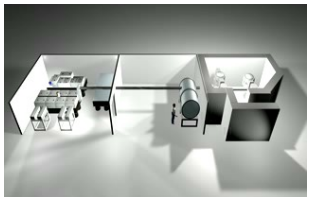
- Introductory Overview



- Cluster-Gas Mixtures

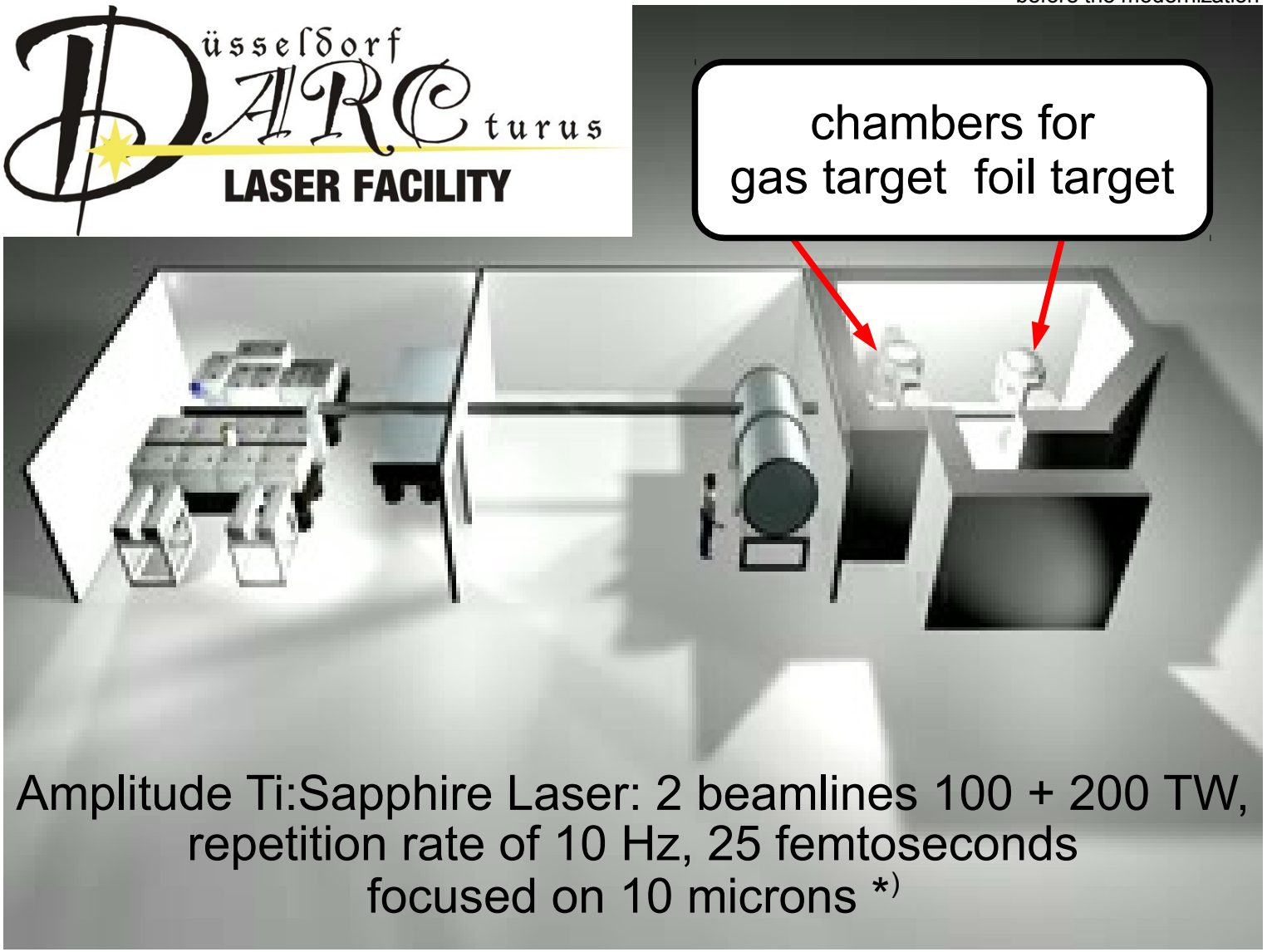


- Planned Experiments at *HHUD*



# Düsseldorf ARCturus Laser facility

*) before the modernization





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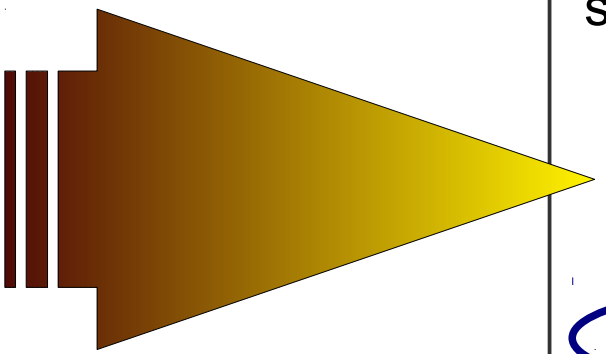
Institute for Laser and Plasma Physics
Prof. O.Willi - *HHUD*

# Laser-induced particle acceleration

**ultra-short high-intense laser pulse**

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



laser with max. rep. rate!

**mass limited target**

gas jets

*underdense plasma*

solid targets (*e.g.* foils)

*overdense plasma*

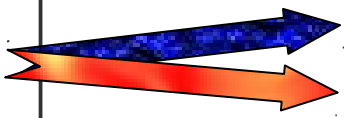
new approach:

**cluster-gas mixture**

future plans:

**$H_2$ pellets**

**charged particles**

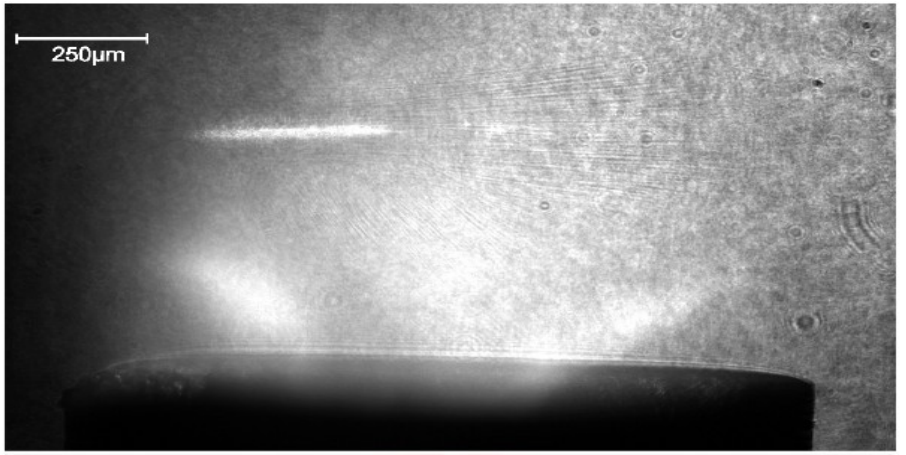


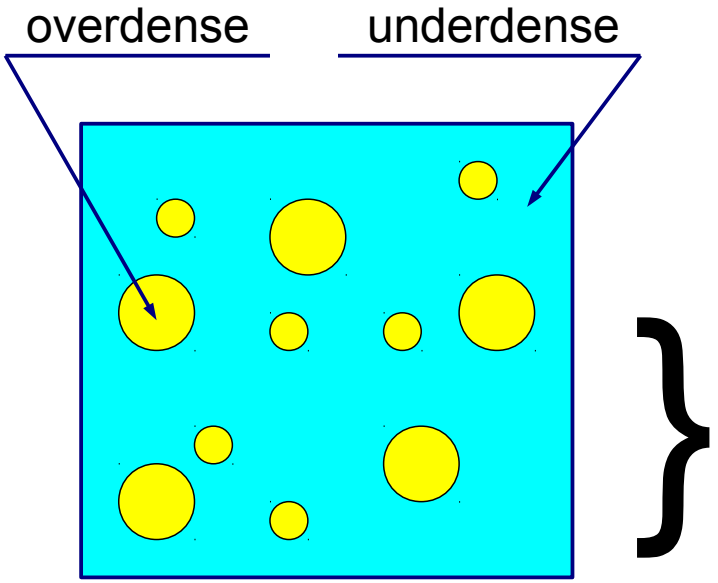
electrons
~ 100 MeV *)

protons / ions
~ 10 MeV *)

*) typical values at *HHUD*

# Cluster-gas mixture

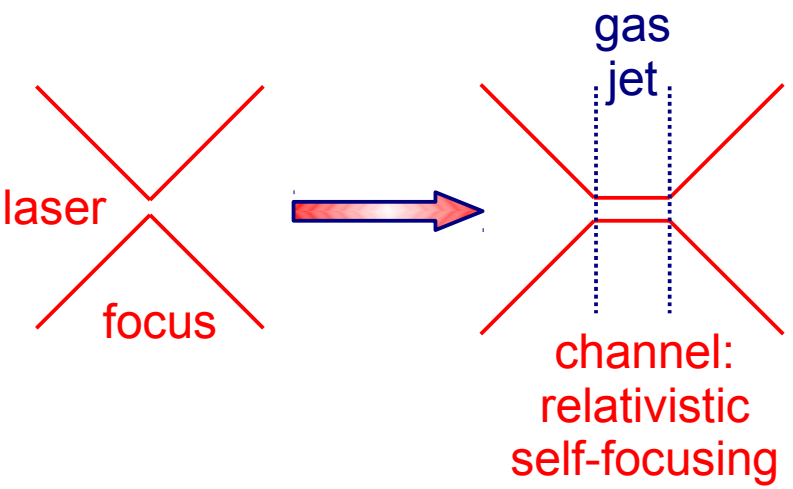



2 standard mechanisms

→ *TNSA*

→ *bubble*




· gas jet density: **$10^{19}$ /cm$^3$**

· cluster density: up to **$10^6$ molec./cluster**

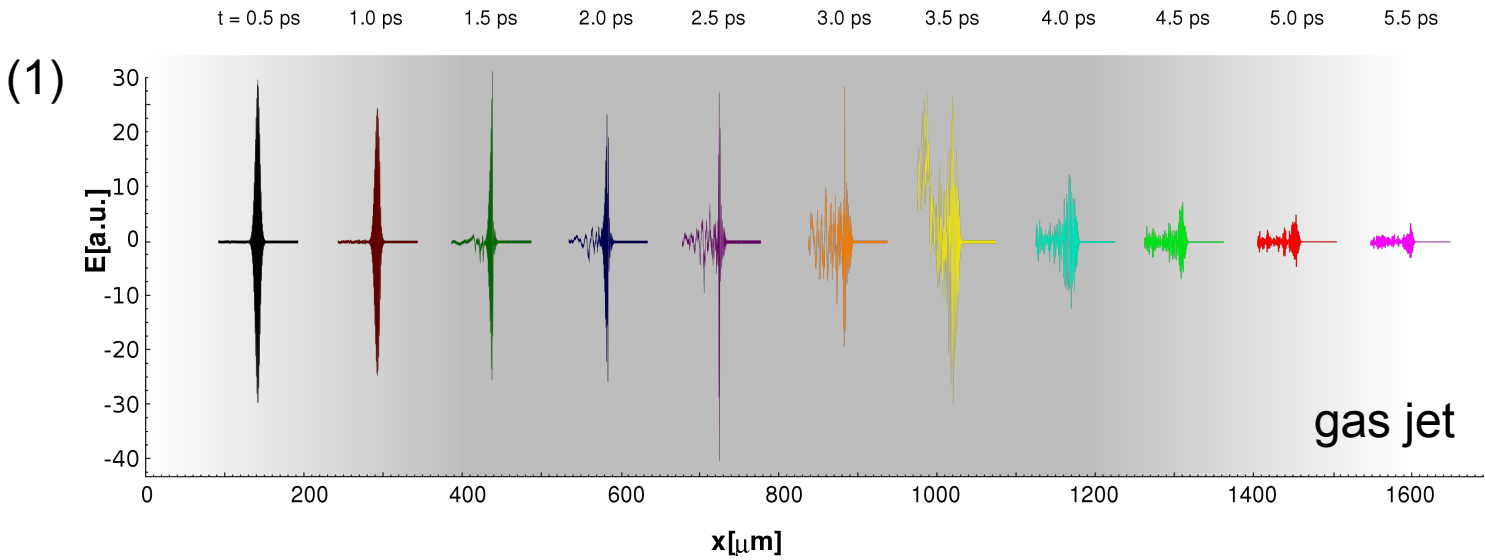
· cluster jet density: **$10^{15}$ atoms/cm$^2$**

· cluster radius: approx. **0.5 – 0.9 µm**

→ in 10 x 10 x 10 µm$^3$: **$10^2$ – $10^3$ cluster**

# Laser pulse in a plasma of a gas jet

M.Hessan – diploma thesis (2011), *FZJ / RWTH AC*



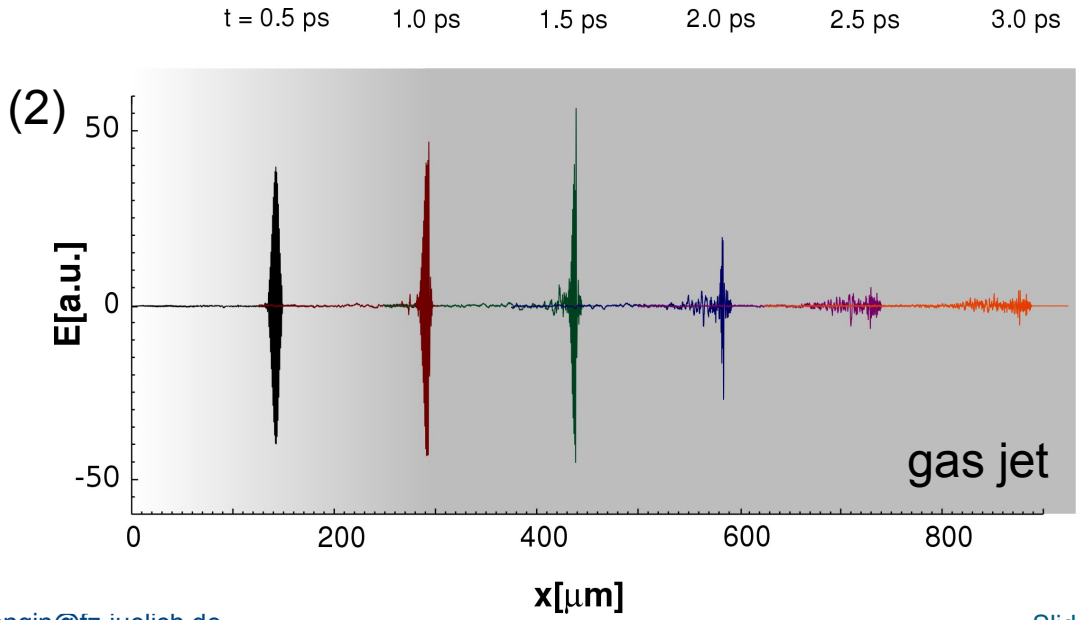

Electric field of the laser pulse

(1) conventional mm nozzle

(2) novel μm nozzle

EPOCH simulation on Juropa

ARCturus laser parameters



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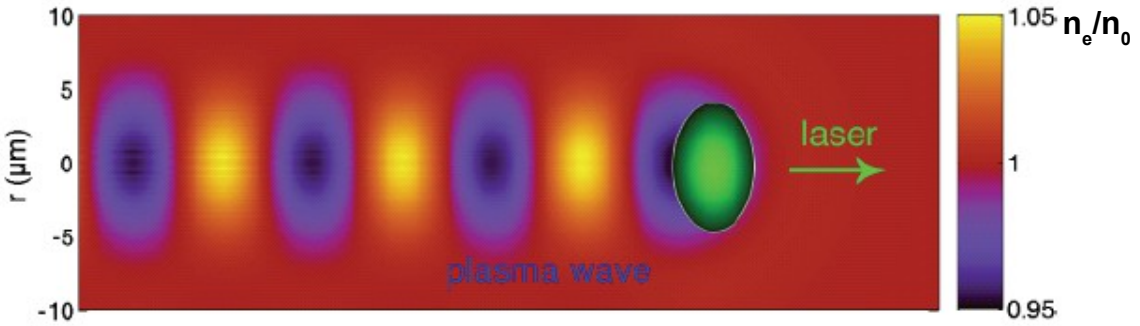
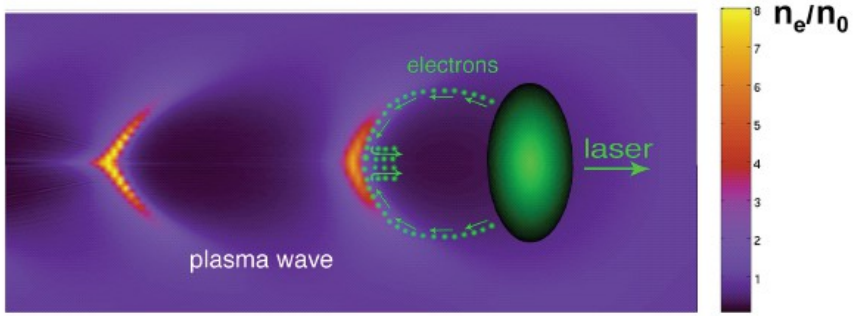
- lower intensities: wake fields




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

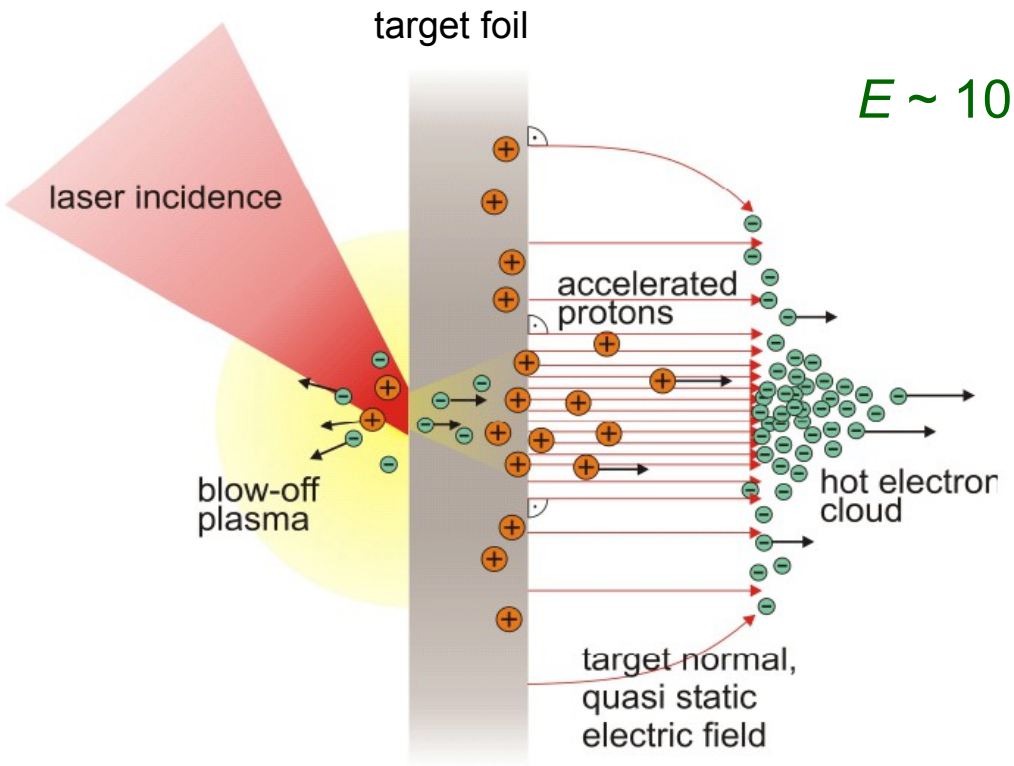
- high intensities: wake fields & bubble regime




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

→ *acceleration of electrons*

# *Target Normal Sheath Acceleration* ***TNSA***




$E \sim 100$ GV/m

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

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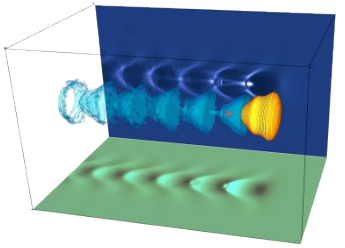
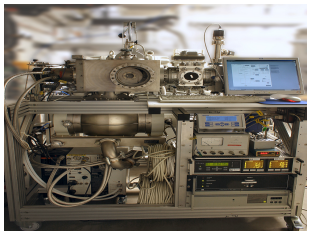
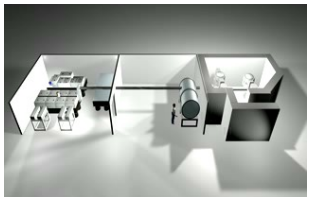


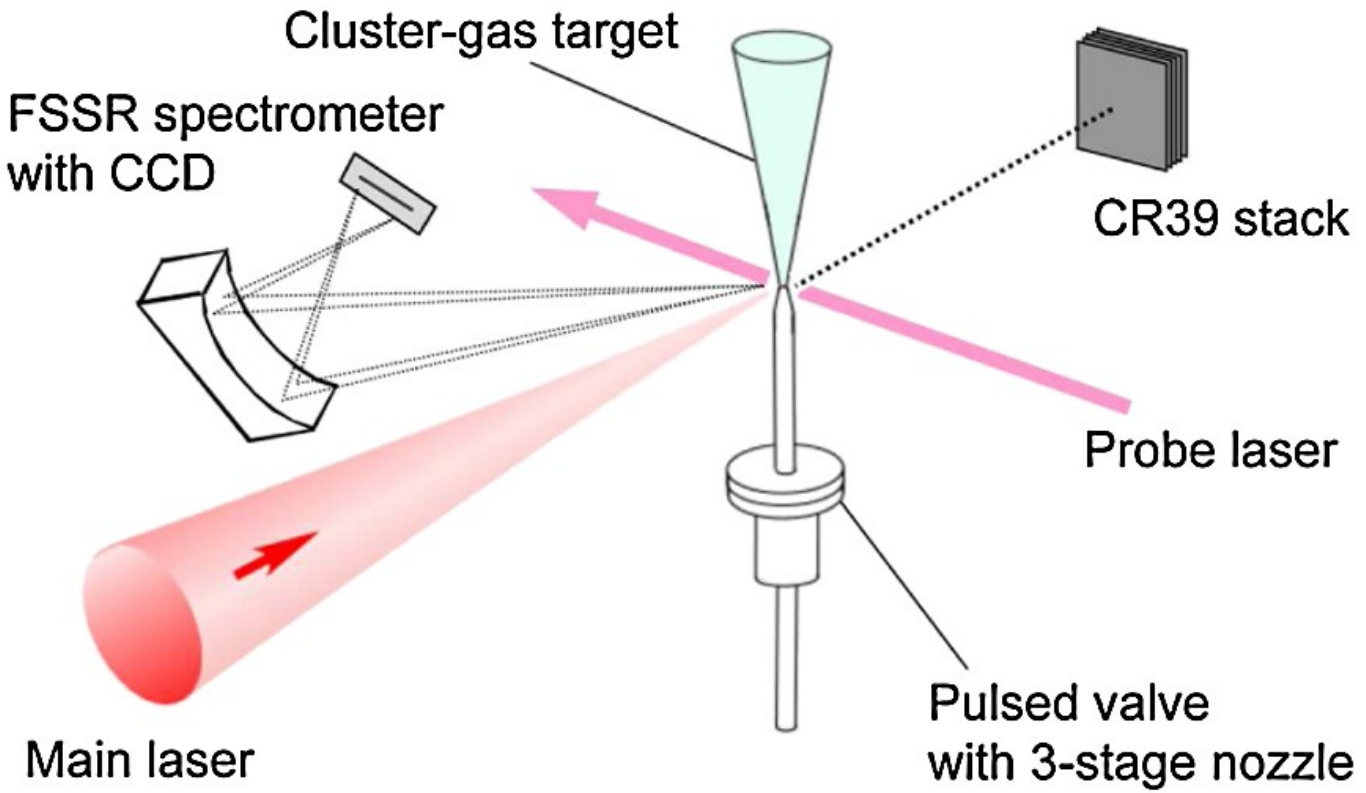
- Cluster-Gas Mixtures



- Planned Experiments at *HHUD*



# Novel target concept: cluster-gas mixtures

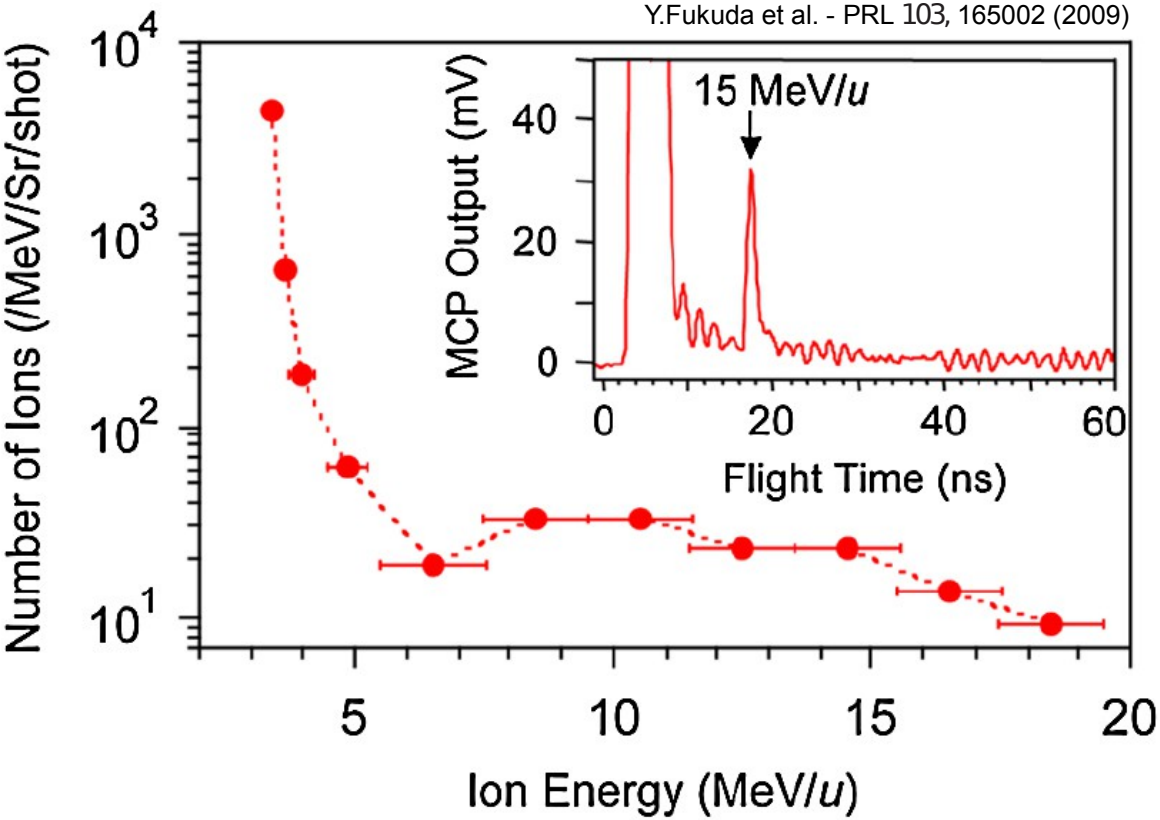



Y.Fukuda et al. - PRL 103, 165002 (2009)

fix target configuration: $CO_2$ cluster in $^4He$ gas

# Novel target concept: cluster-gas mixtures

Y.Fukuda et al. - PRL 103, 165002 (2009)

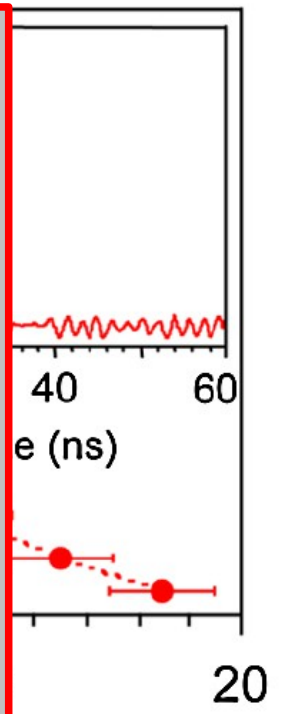



- laser parameters:
  - JLITE-X 4-TW Ti:sapphire
    - → 7 x $10^{17}$ W/cm$^2$
    - → 30 µm (1/e$^2$ intensity)
    - → 40 fs (FWHM), 150 mJ @ 1 Hz

*What ions?*

# Novel target concept: cluster-gas mixtures

Y.Fukuda et al. - PRL 103, 165002 (2009)

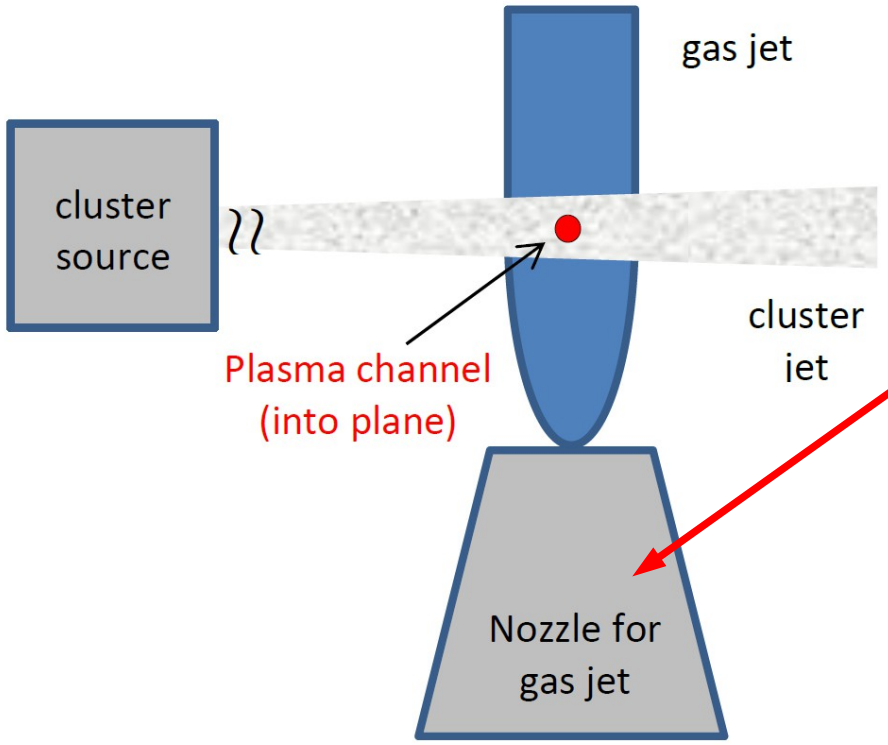


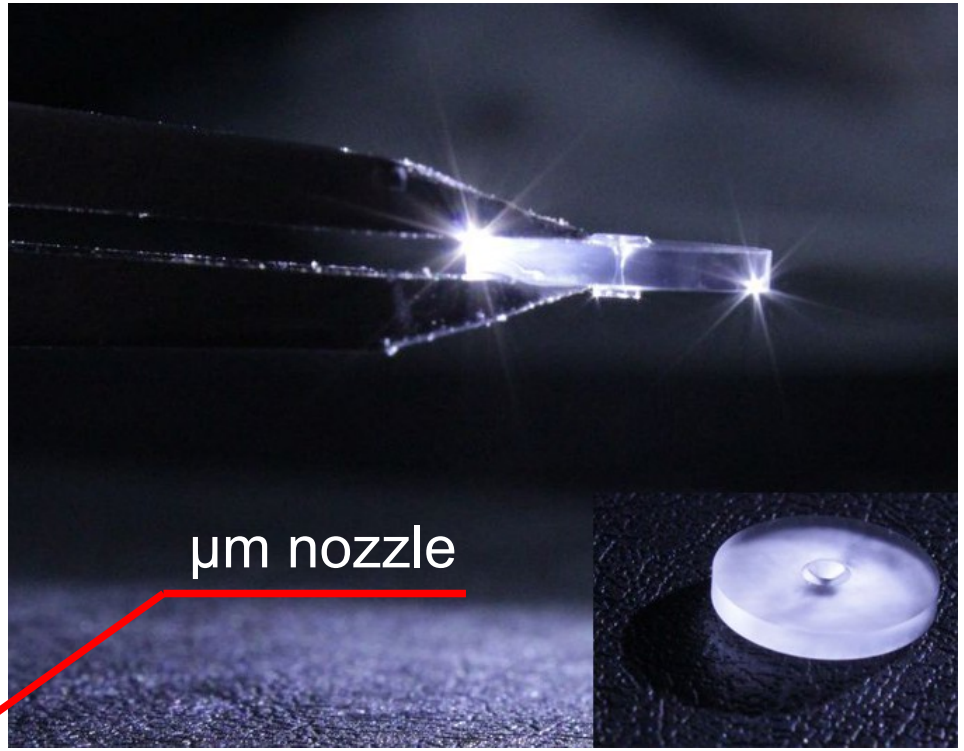

| ARCturus | JLITE-X |
|---|---|
| 100 + 200 TW | 4 TW |
| $10^{20}$ W/cm$^2$ | $10^{17}$ W/cm$^2$ |
| 10 µm | 30 µm |
| 25 fs | 40 fs |
| ~ J | ~$10^{-1}$ J |
| 10 Hz | 1 Hz |

- laser para
  - JLITE
    - 7 x
    - 30
    - 40

*What ions?*

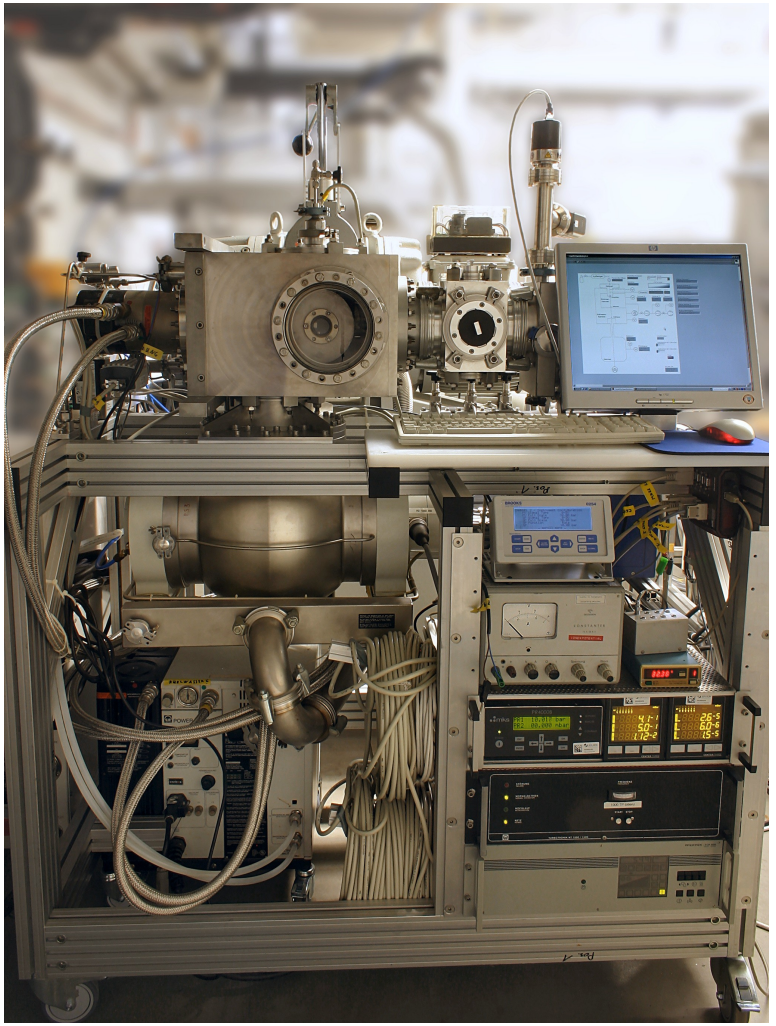
# General setup



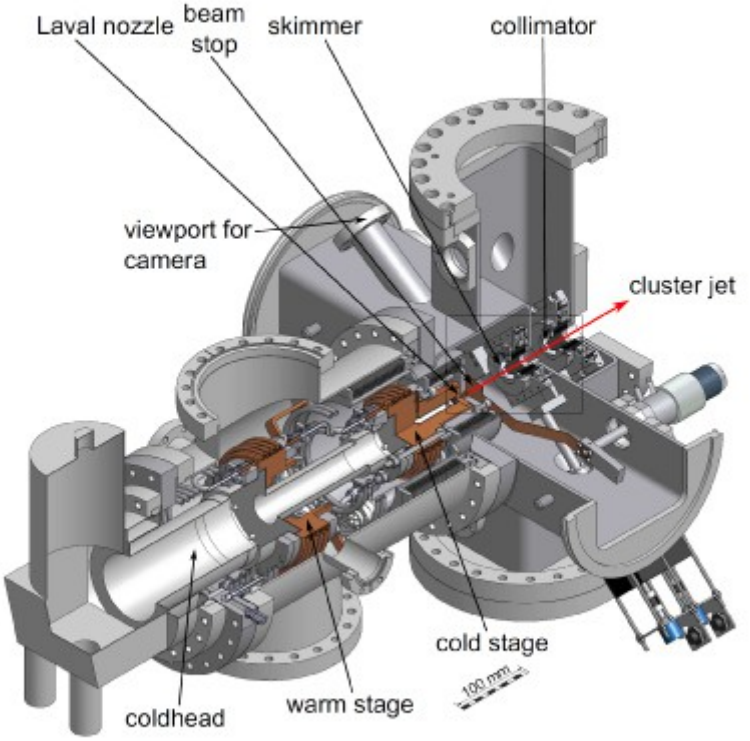

LightFab UG Aachen (2013)
www.lightfab.de

# Münster cluster source



Institute for Nuclear Physics
Prof. A.Khoukaz - *WWUM*

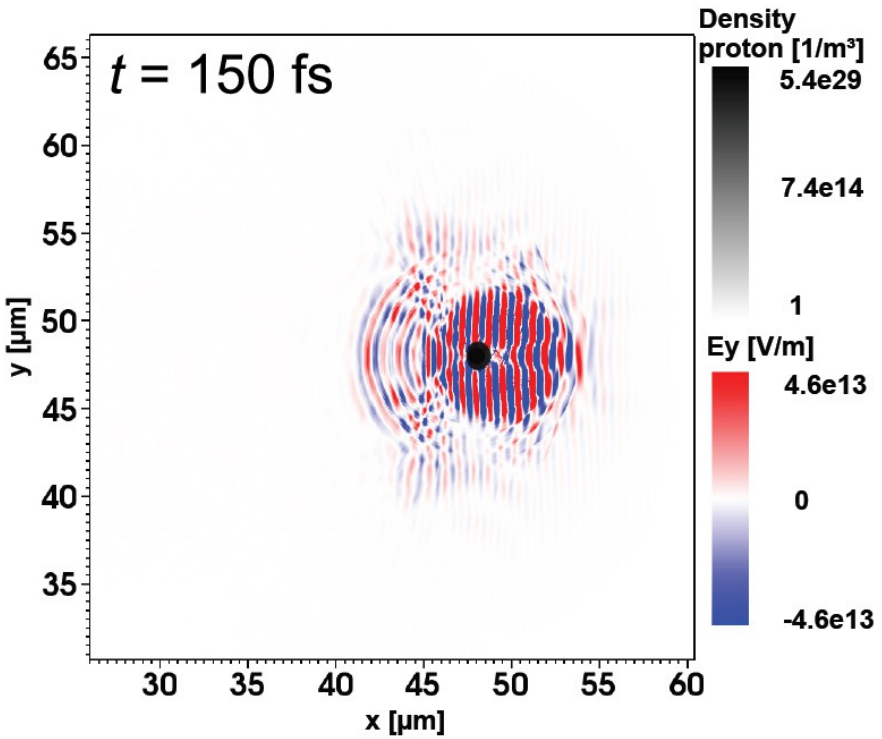
- $H_2$ cluster
- temperature of ~20 K
- cluster density: up to $10^6$ molec./cluster
- cluster jet density: $10^{15}$ atoms/cm$^2$

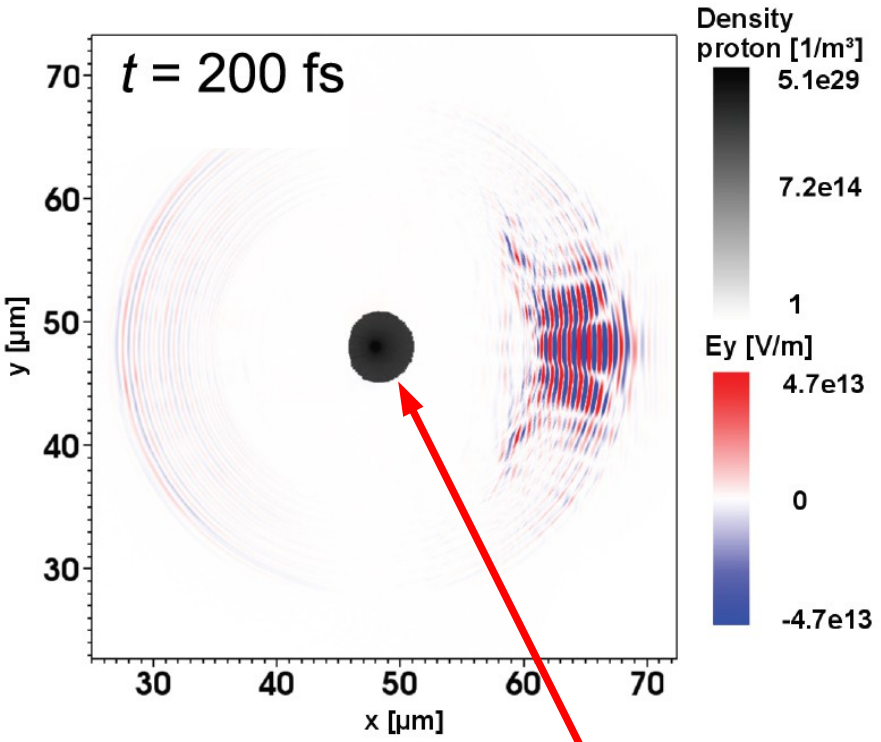



A.Täschner - http://arxiv.org/abs/1108.2653

# Simulations

P.Greven – diploma thesis (2013), *FZJ / RWTH AC*




cluster explodes

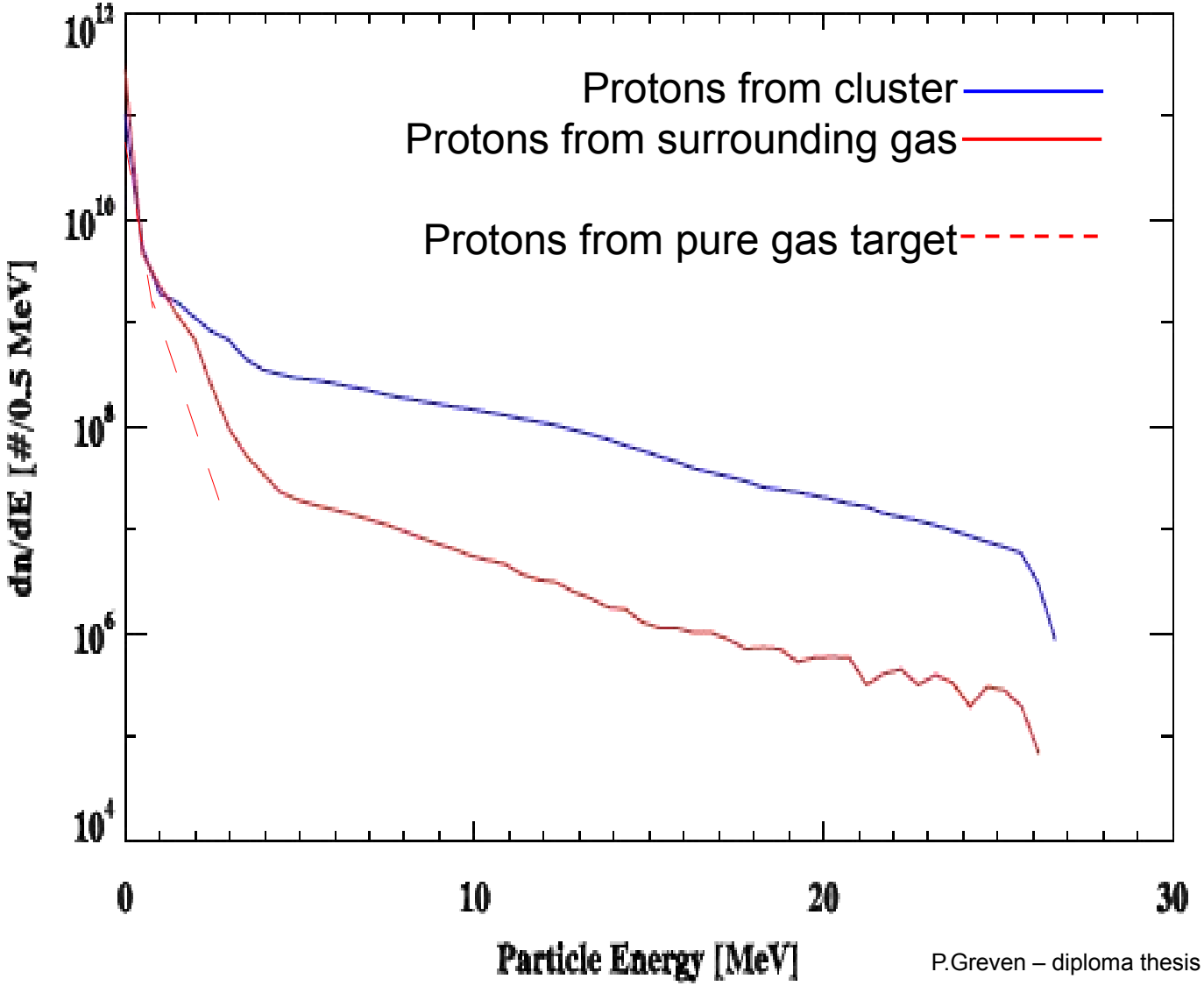
<u>EPOCH simulation on Juropa:</u> $H_2$ cluster in $H_2$ gas

- laser parameters:

  ARCturus 100 + 200 TW Ti:sapphire

  ➔ $10^{20}$ W/cm$^2$, 10 µm, 25 fs (FWHM), 2.5 J

# Simulated energy spectra

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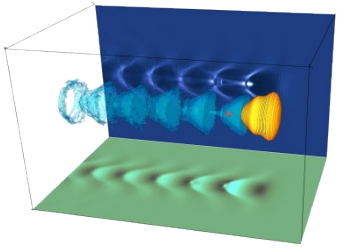

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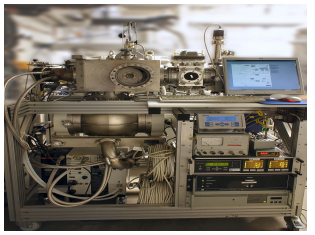

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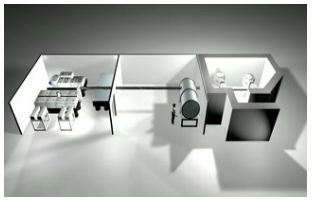
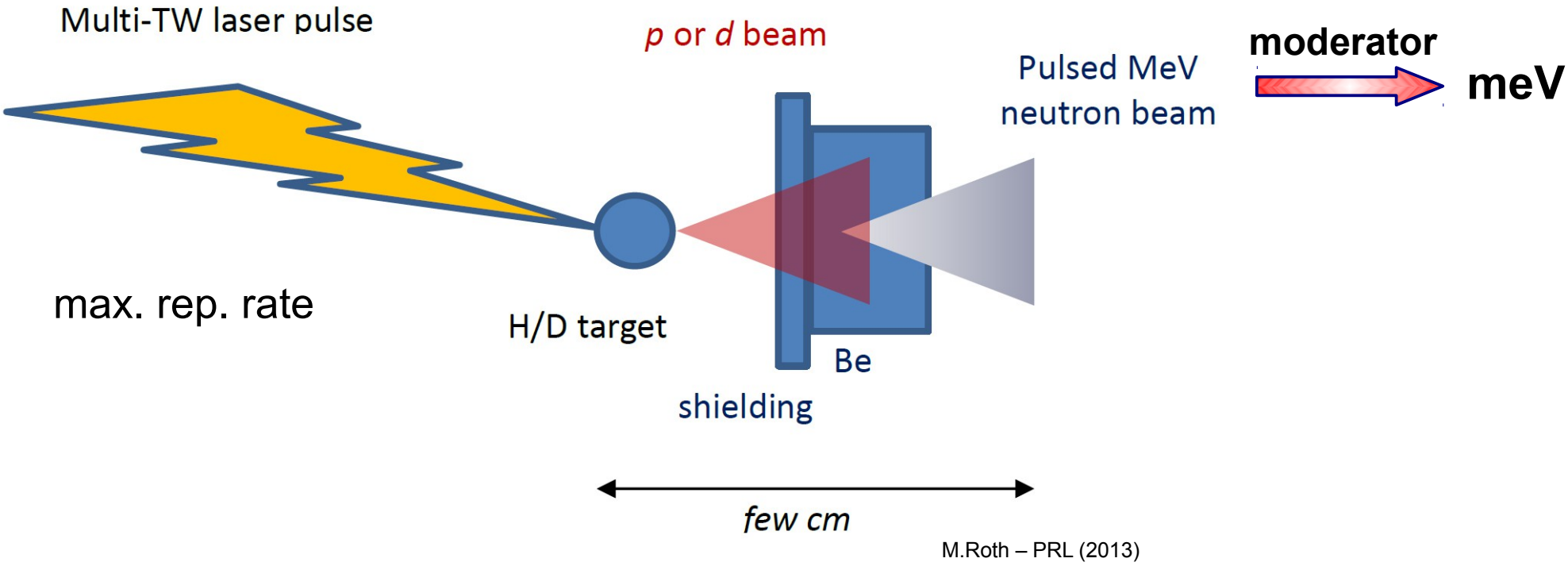


# Neutron production out of $H_2$ or $D_2$ targets




M.Roth – PRL (2013)

1st milestone: source for accelerated *p, d*

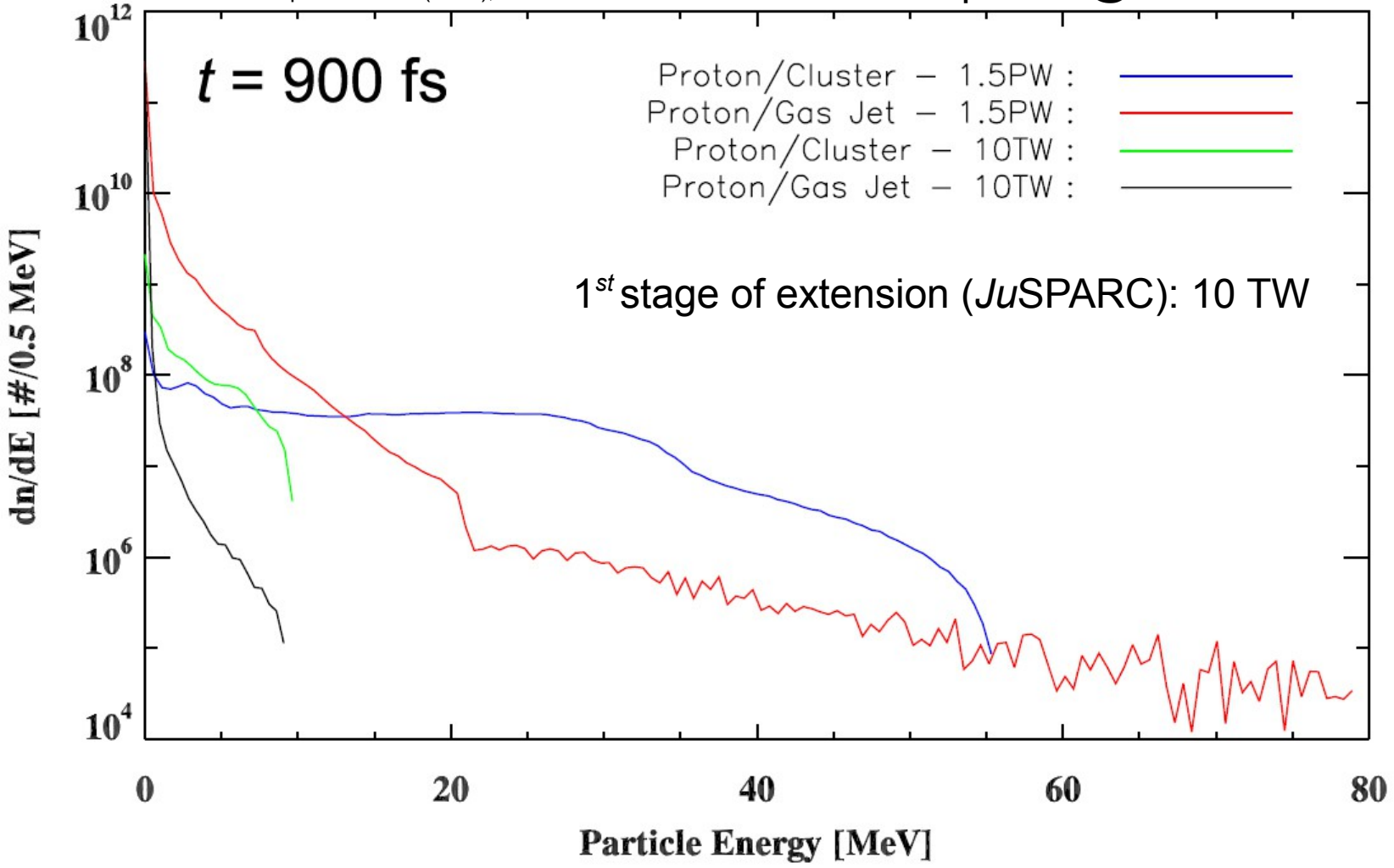
2nd milestone: meV neutron production

→ compact moderators / neutron source vs. nuclear reactors

# Simulation for JuSPARC PW laser facility

P.Greven – diploma thesis (2013), *FZJ / RWTH AC*

rep. rate @ 4 TW: 1 kHz



# Outlook

- fundamental research
  - comprehension of Laser-acceleration mechanisms
  - advantages of Laser-accelerated high-energy protons from a constantly resupplied mass-limited cryogenic $H_2$ or $D_2$ target
- possible applicability, *e.g.* possible neutron gap (~2030) can be filled
- integration in existing or planned infrastructure, *e.g.* the planned *Ju*SPARC *) at FZJ

*) **S**hort-Pulsed **P**article **a**nd **R**adiation **C**enter

# My call for help ;)

- pressure booster:
  - He gas
  - very fast response time
  - 3 bar → 10 – 15 bar
- piezo valve:
  - non-magnetic materials
  - response time ~ ms
  - backing pressures ~ 15 – 20 bar