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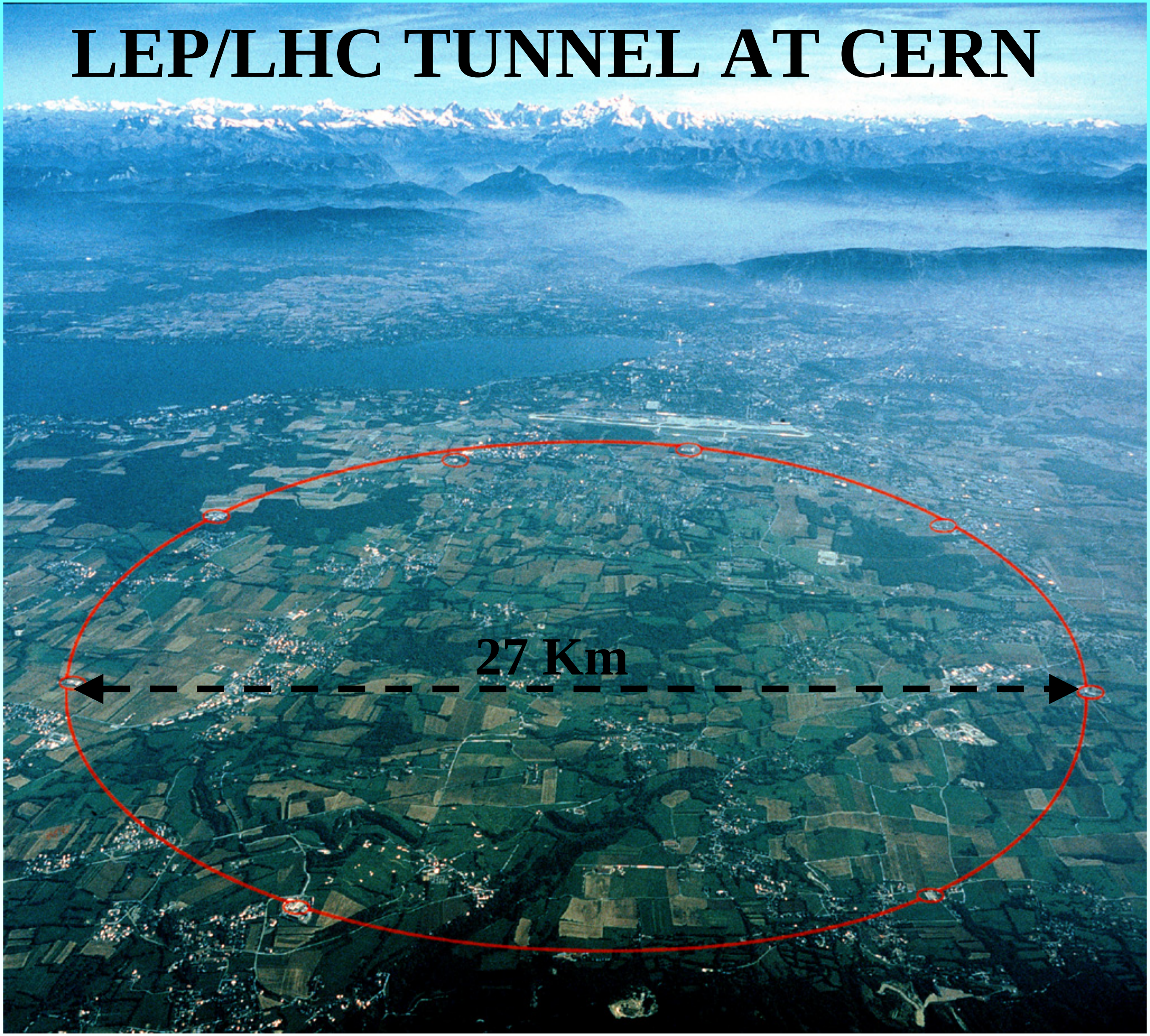
Laser Induced Nuclear Physics And the FAIR Programme

Ken Ledingham

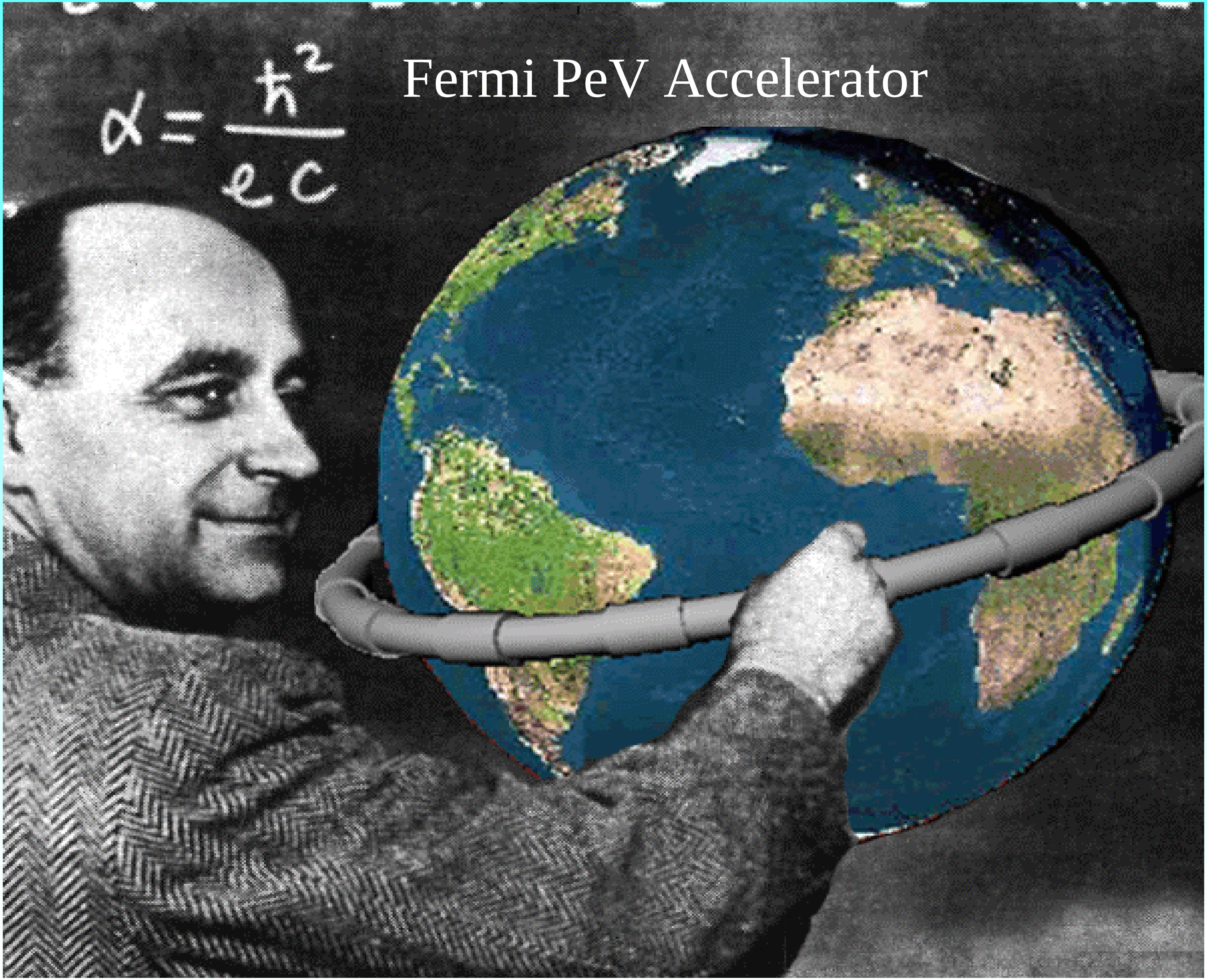
Dept of Physics, University of Strathclyde, Glasgow G4 0NG, Scotland & AWE plc Aldermaston, Reading, RG7 4PR, UK

Is the future of large accelerators limited?

- CERN and GSI have been at the vanguard of nuclear and particle physics for > 50 years.
- However their size is becoming a limiting factor
- Many scientists are looking for more compact accelerators.
- Perhaps laser accelerators is a way forward
- How big are these conventional accelerators???


LEP/LHC TUNNEL AT CERN
27 Km

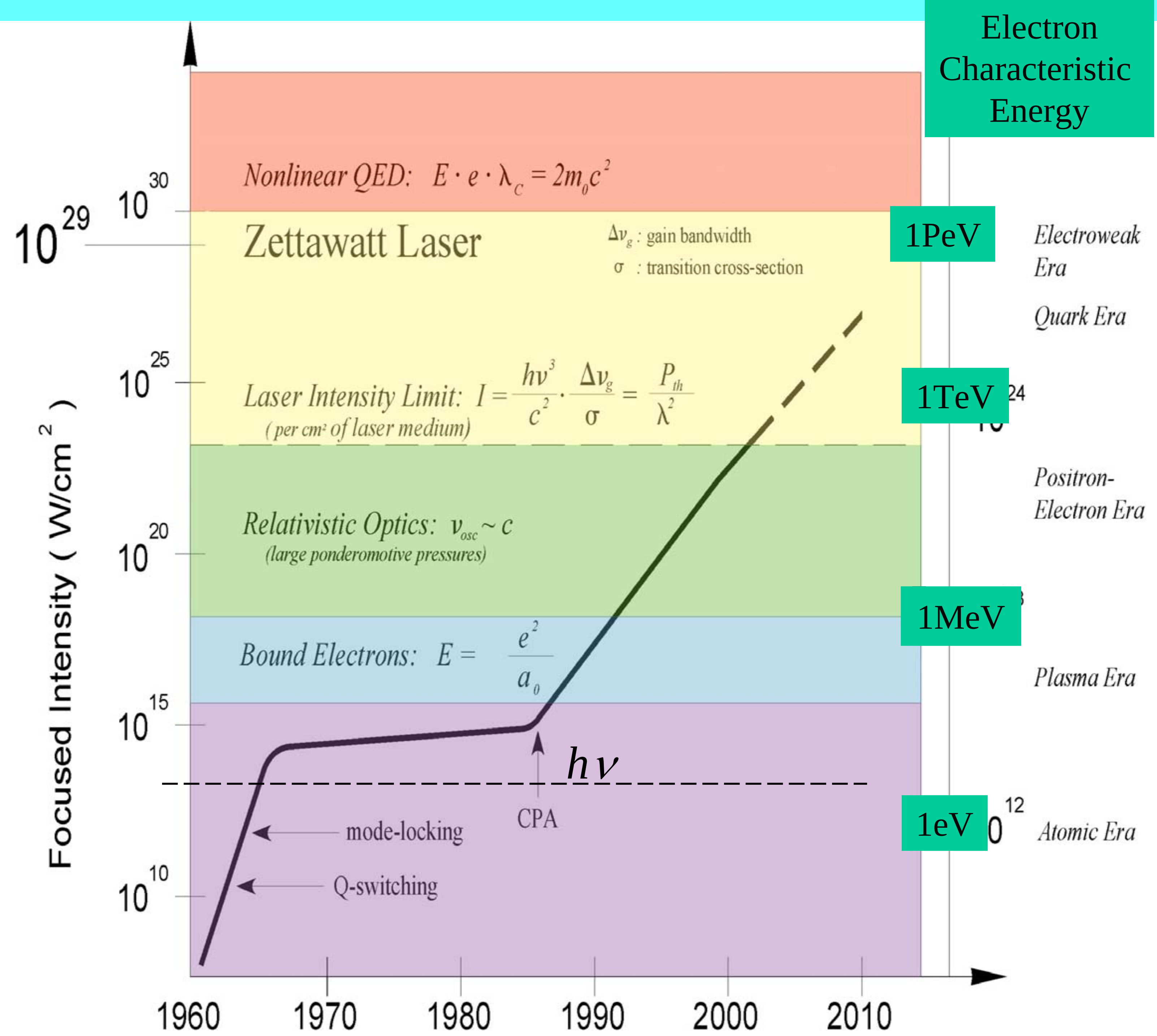
Fermi PeV Accelerator



The History of
High Intensity Lasers

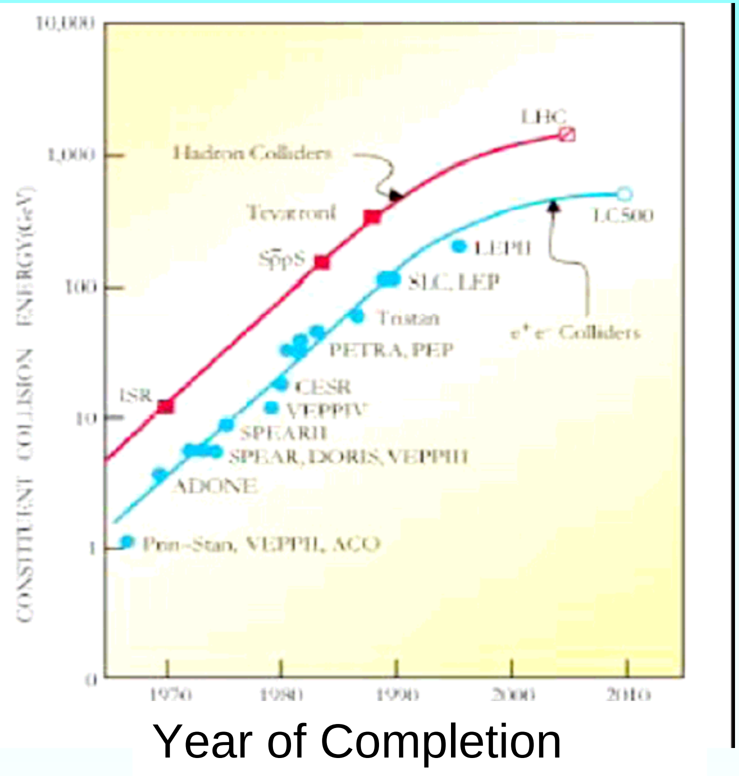
Laser Induced Particle Acceleration and Applications

- Terawatt= 10^{12}W
- Total Electrical Power Generated in the USA = 10^{12}W
- Petawatt =10^{15}W
- There are 15 Petawatt and proposed Petawatt lasers in the world
- Exawatt=10^{18}W
- Zettawatt=10^{21}W

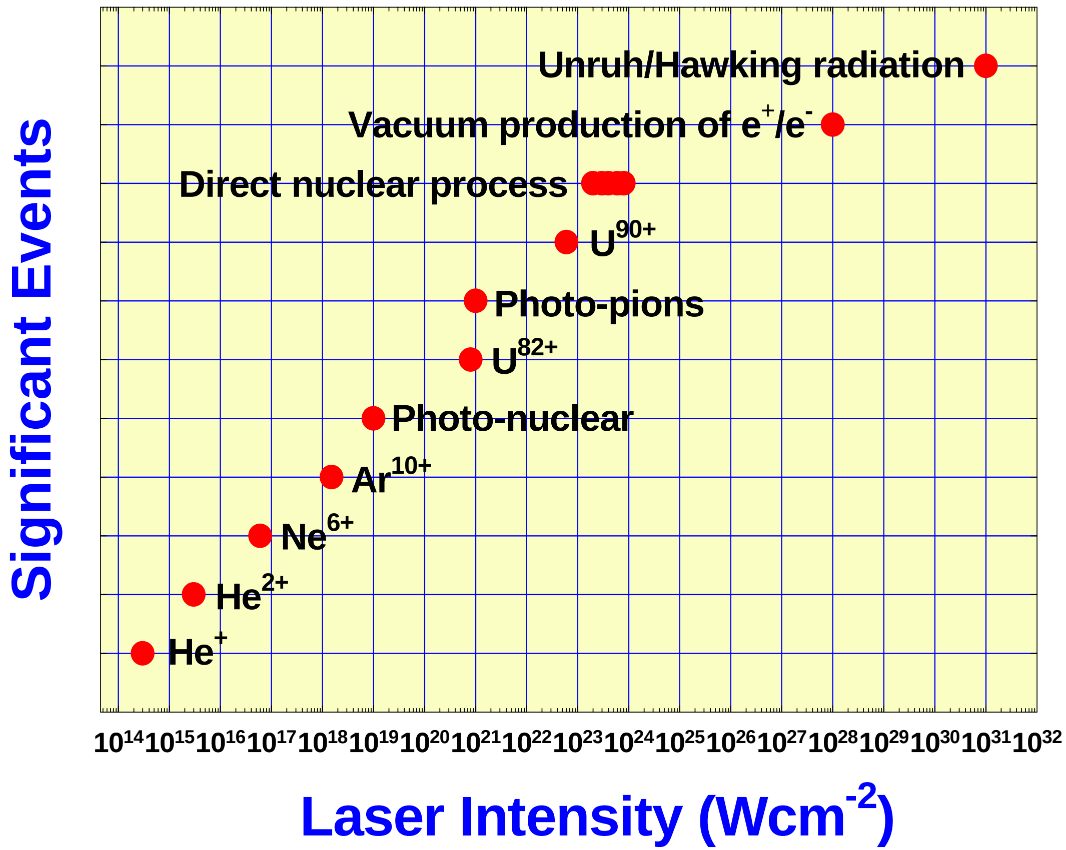


Electron Characteristic Energy
Nonlinear QED: $E \cdot e \cdot \lambda_C = 2m_0c^2$
Zettawatt Laser
$\Delta\nu_g$: gain bandwidth
σ : transition cross-section
Laser Intensity Limit: $I = \frac{h\nu^3}{c^2} \cdot \frac{\Delta\nu_g}{\sigma} = \frac{P_{th}}{\lambda^2}$
(per cm² of laser medium)
Relativistic Optics: $v_{osc} \sim c$
(large ponderomotive pressures)
Bound Electrons: $E = \frac{e^2}{a_0}$
$h\nu$
mode-locking
Q-switching
CPA
1PeV
1TeV
1MeV
1eV
Electroweak Era
Quark Era
Positron-Electron Era
Plasma Era
Atomic Era
Focused Intensity (W/cm^2)
10^{29}
10^{30}
10^{25}
10^{20}
10^{15}
10^{10}
1960
1970
1980
1990
2000
2010

Livingstone Plot



What happens as the laser intensity is increased?



VULCAN petawatt laser (RAL)

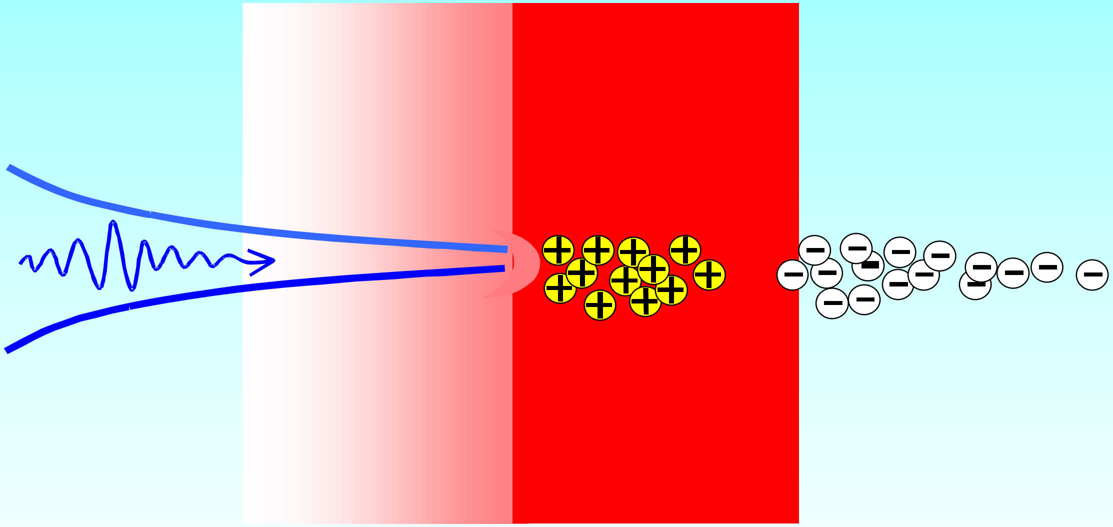
Energy	600 J (on target)
Repetition	1 hour
Wavelength	1.05 μm
Pulse duration	0.6 ps
Intensity	~6×10^{20} Wcm^{-2}
Maximum pulses per week	~25

Petawatt with Extensive Nuclear Shielding

Laser Nuclear Phenomena

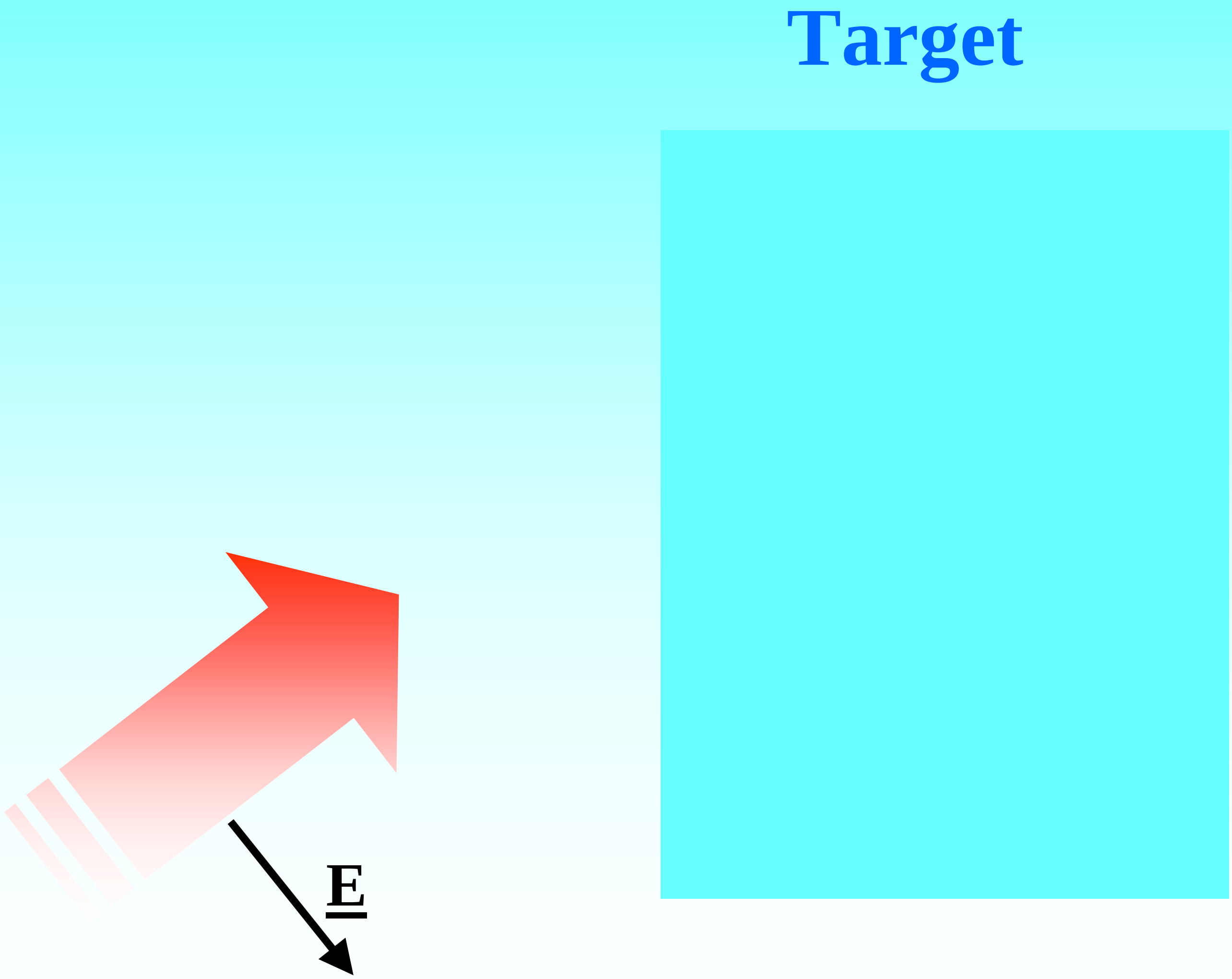
- **PET isotope production**
- **Laser induced nuclear transmutation studies**
- **Laser produced heavy ion reactions**
- **Spallation studies**
- **New experiments including Counter-propagating beam experiments for positron and muon production**

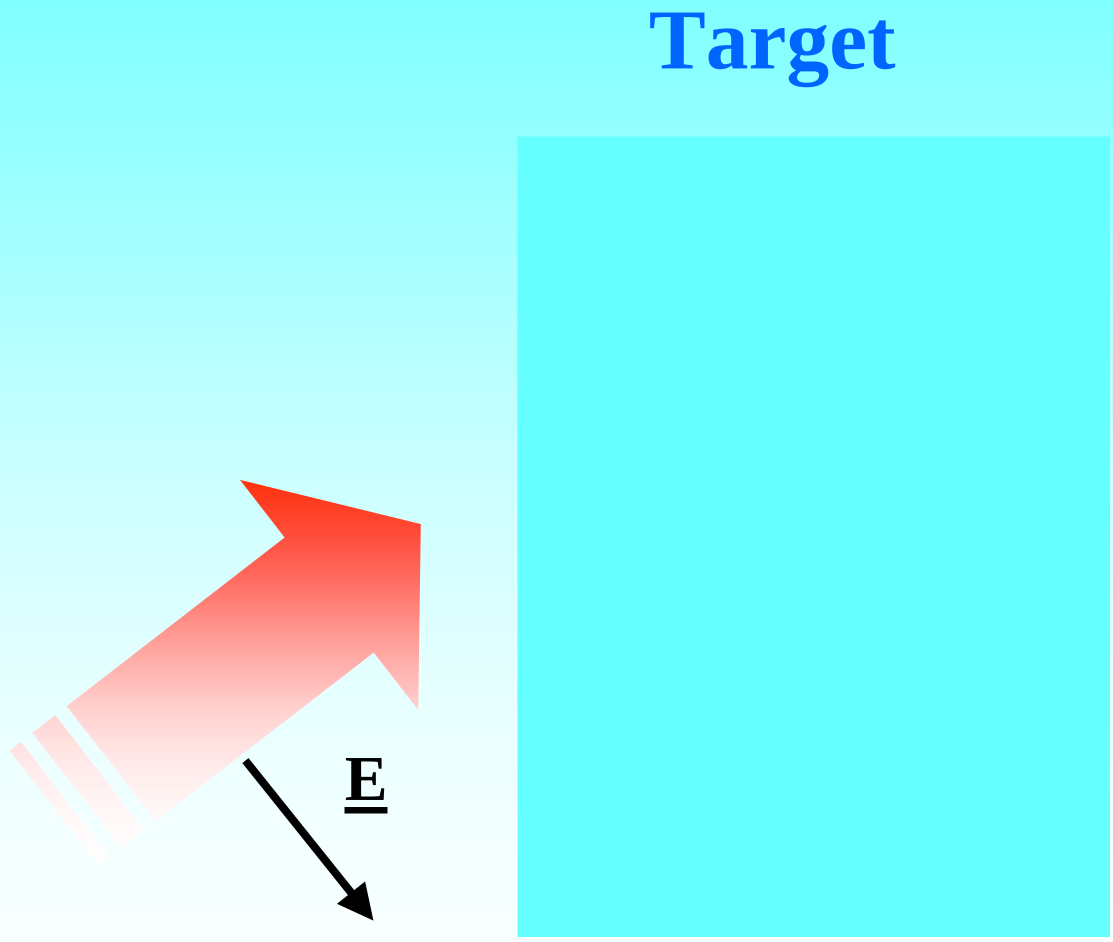
Proton Production

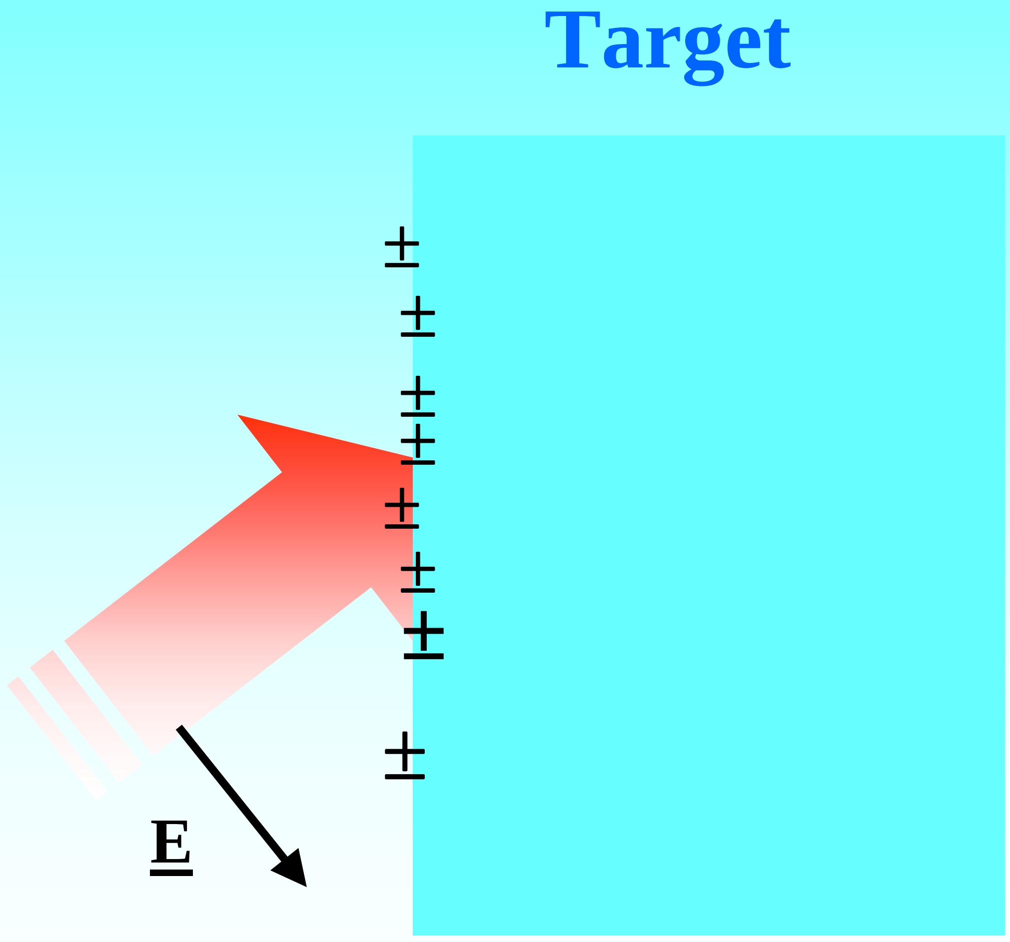


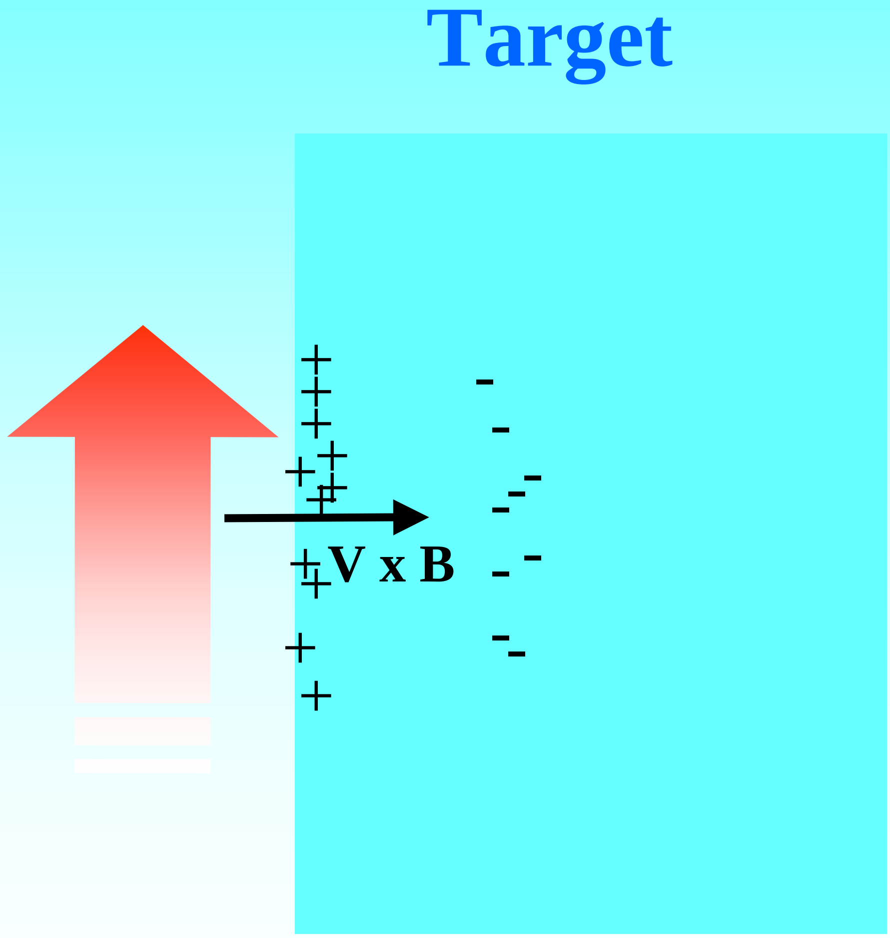
Proton Production

- For metals the protons come from hydrogen in water or contaminants on surface or trapped in the solid ($H_2$0, 100x more than CH)
- The surface contamination is due to poor vacuum conditions in the target chamber
- We think the proton beams are produced thus:

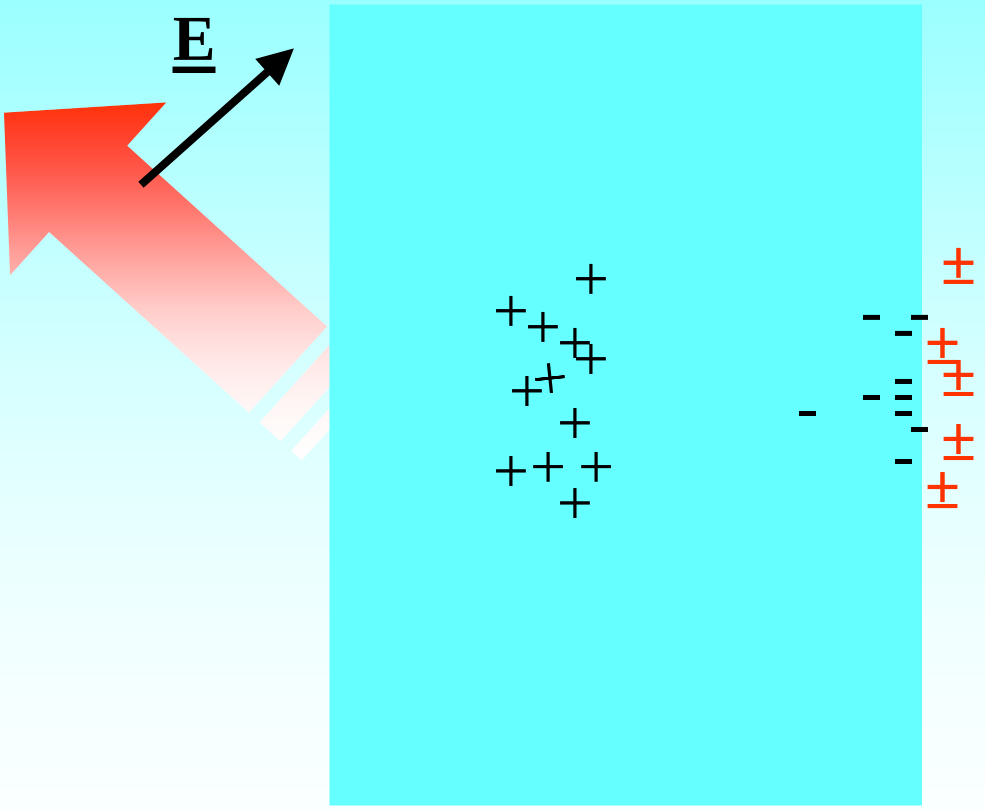

Target
E

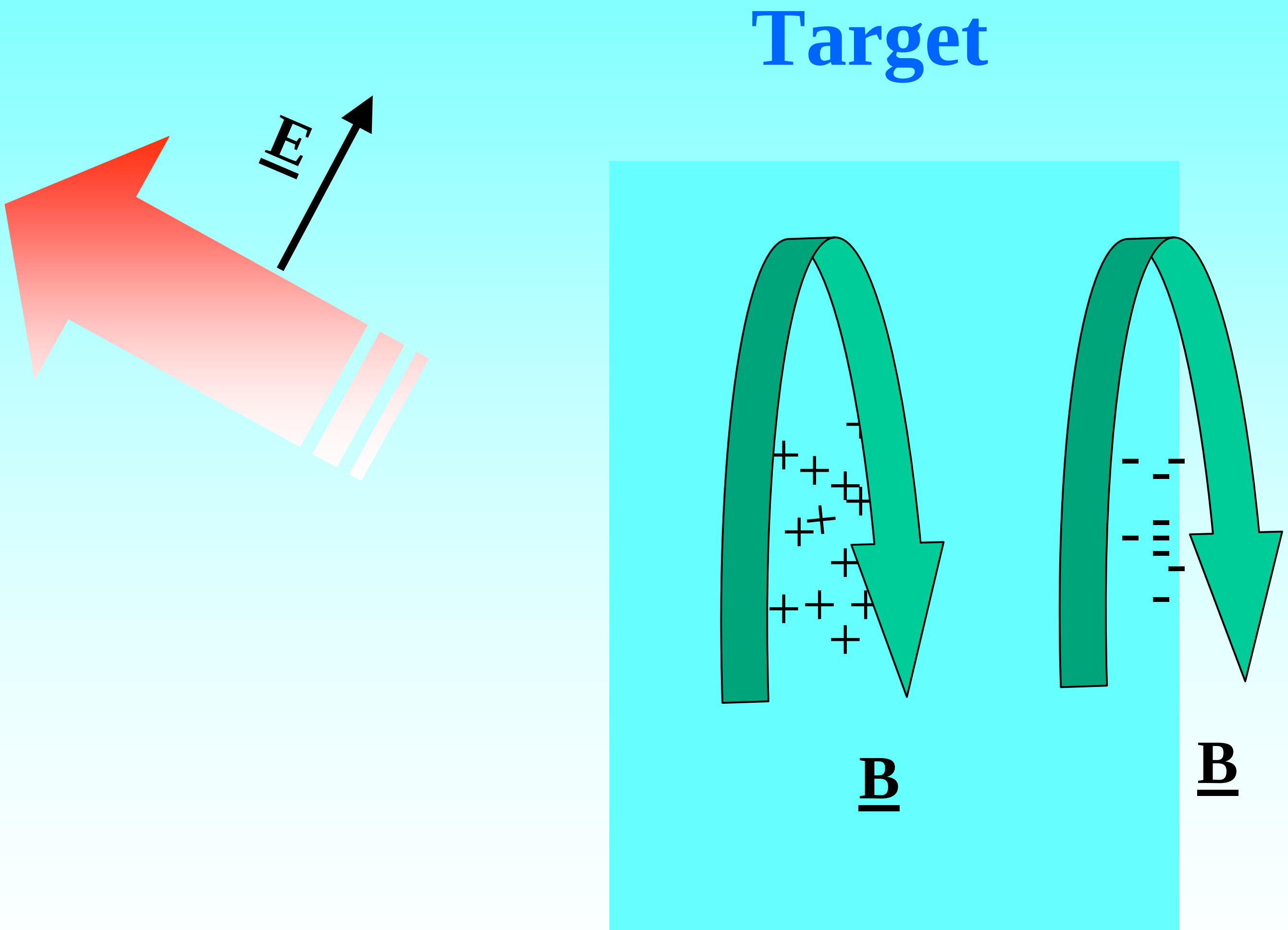

Target
E


Target
E


Target
V x B

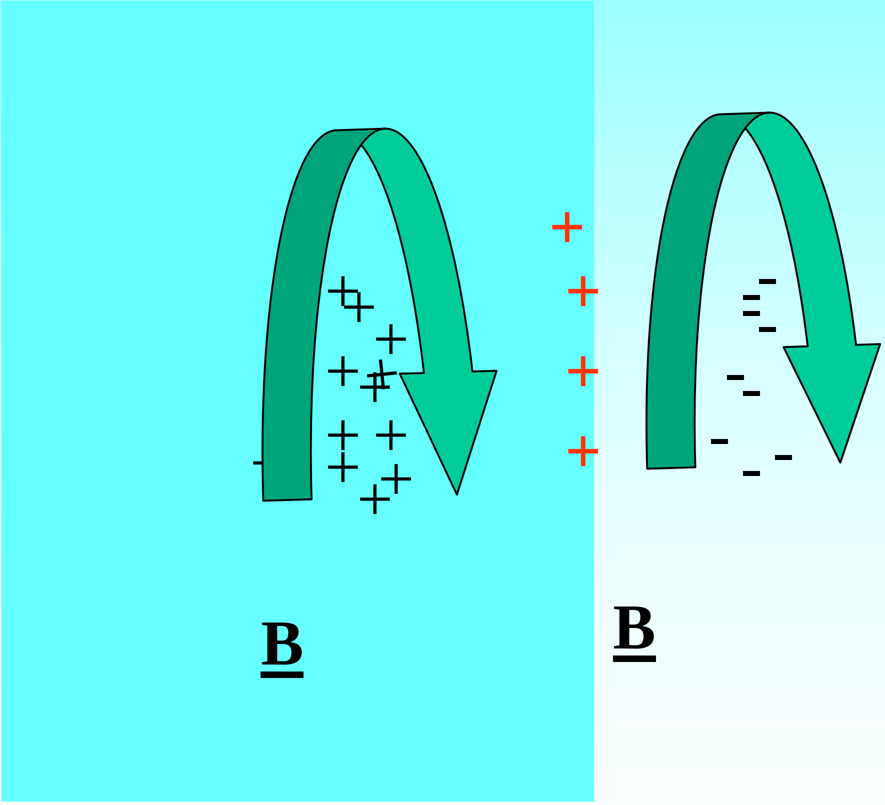
Target



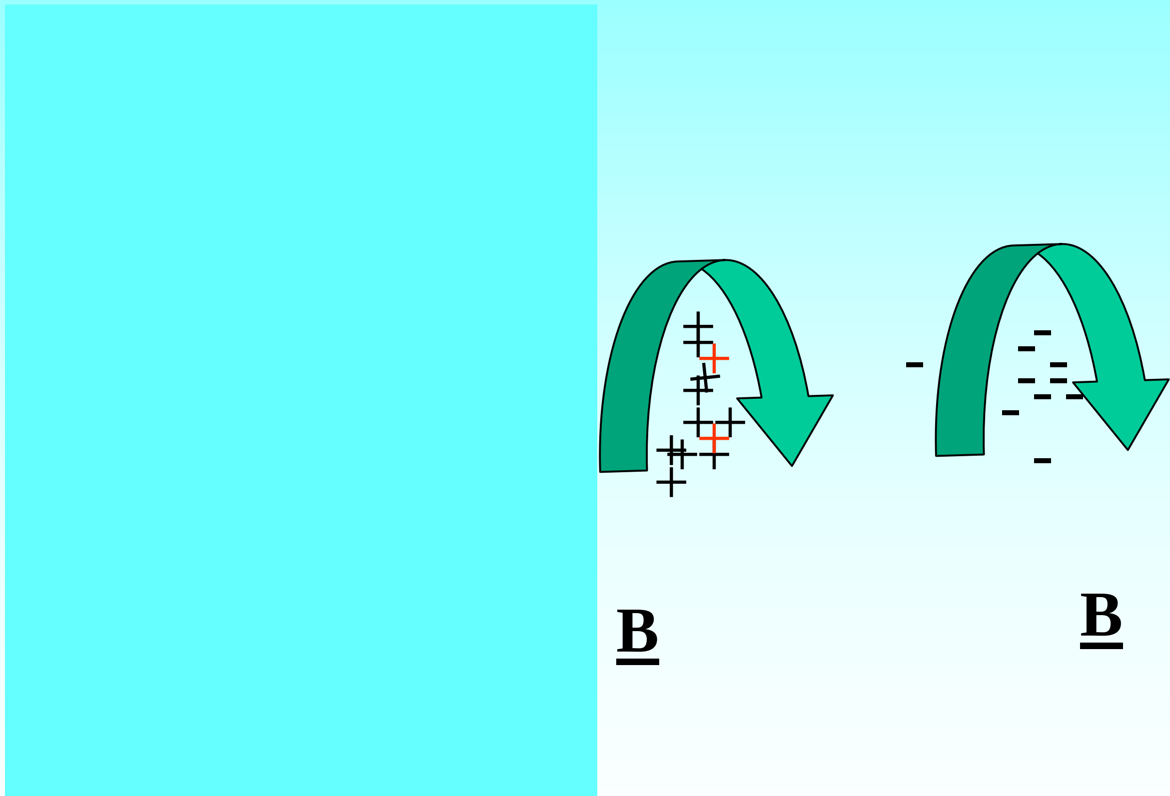


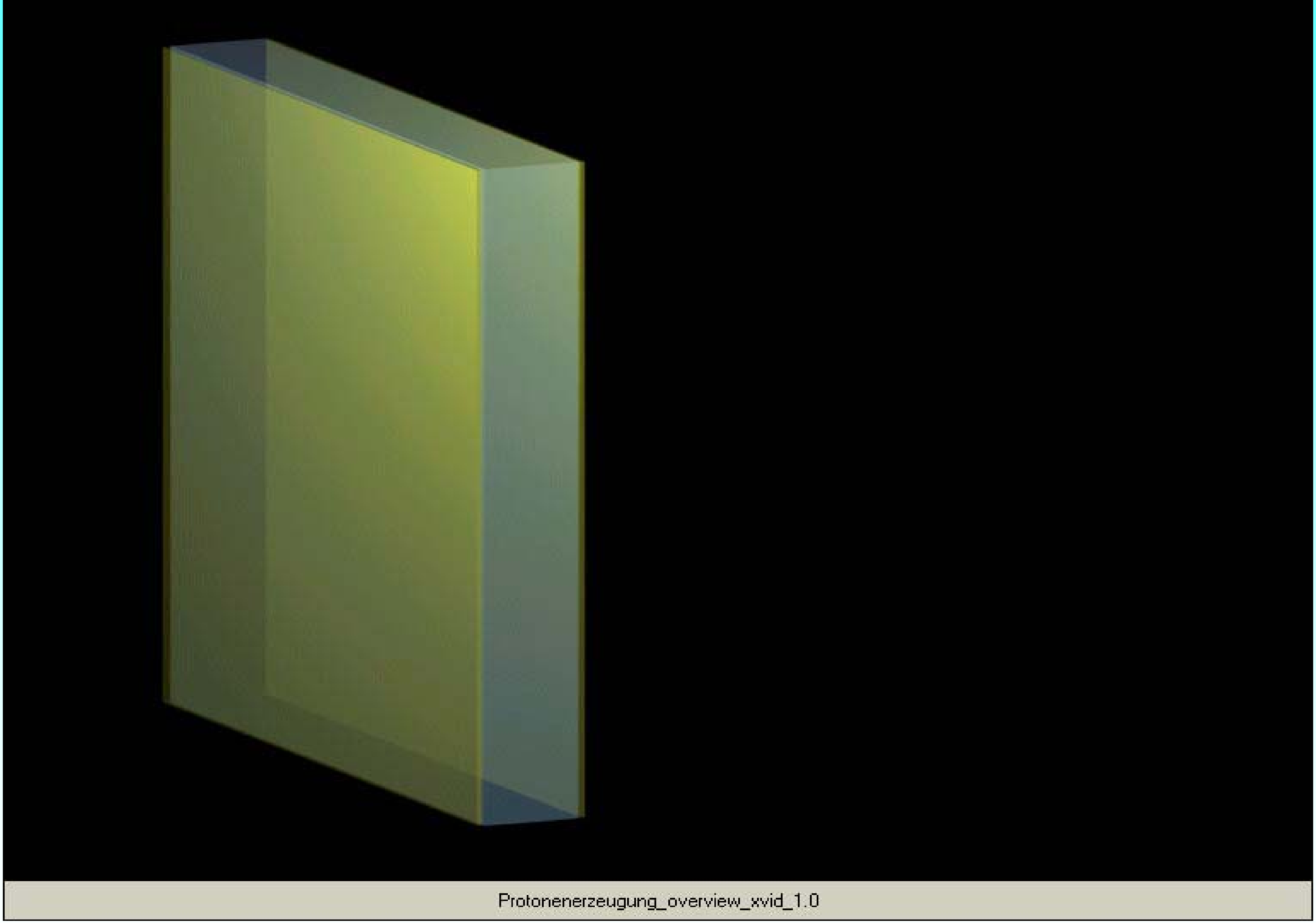
Target
E
B
B

Target



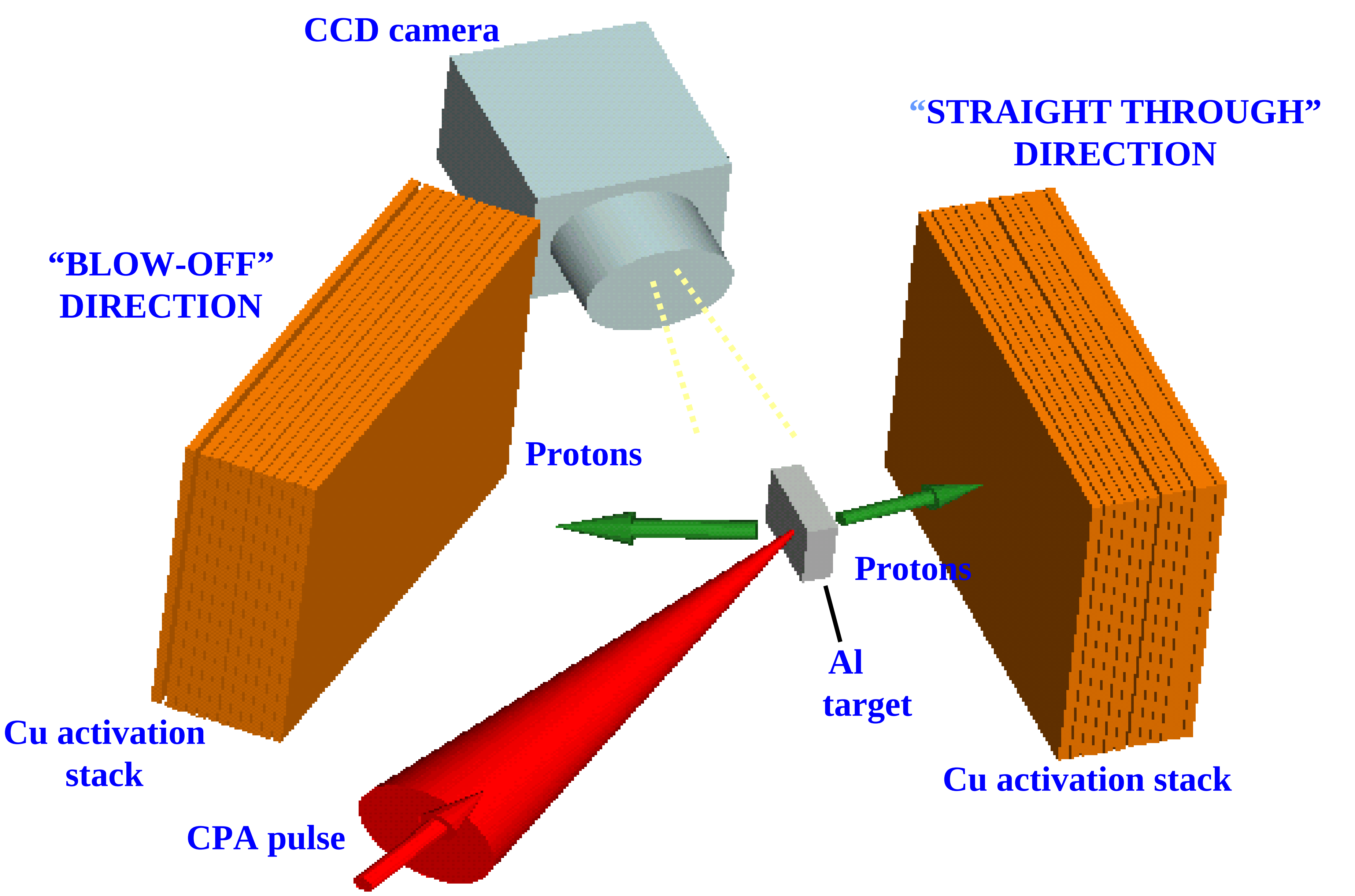
Target



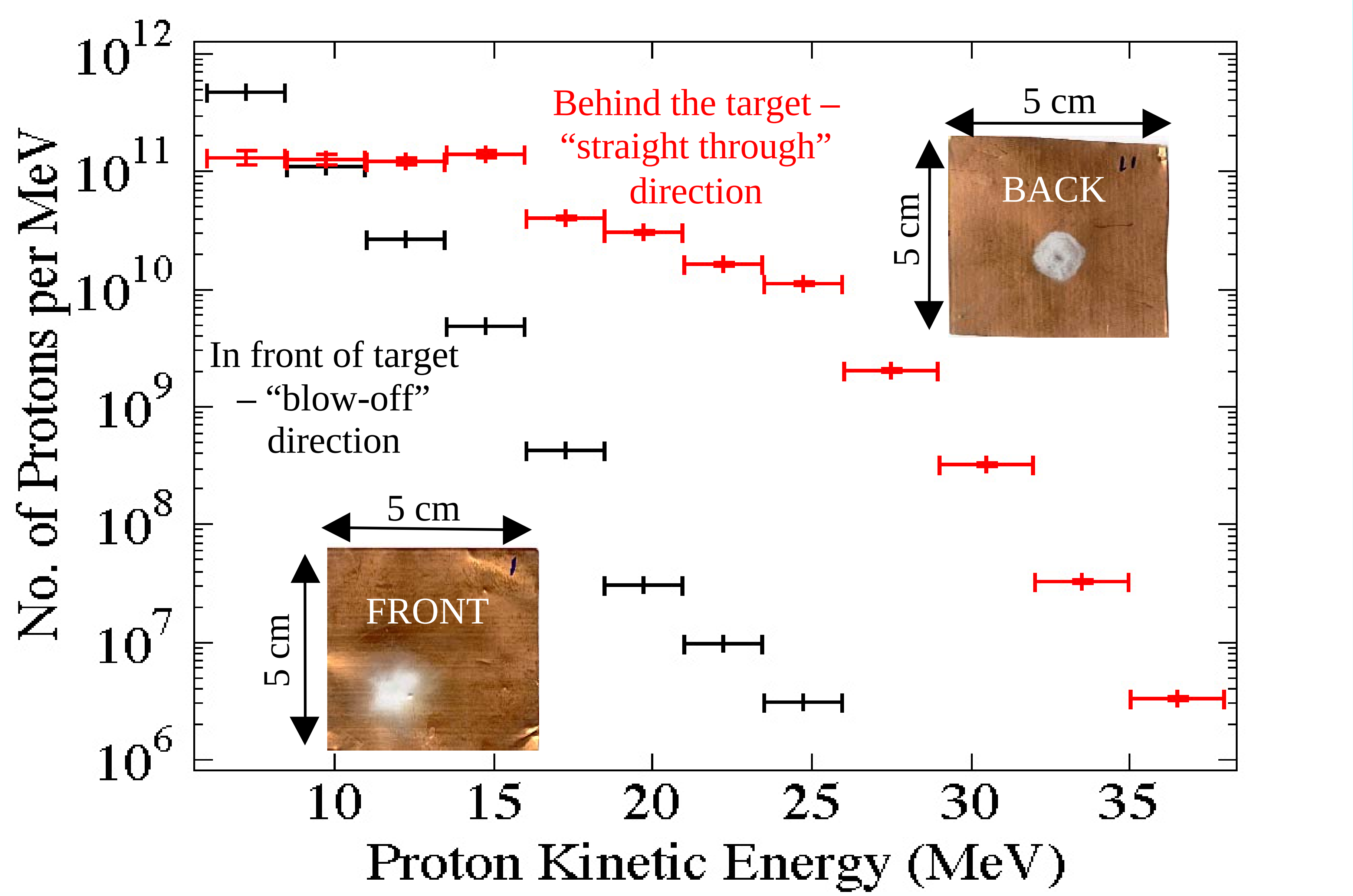


Film Maker Falk Ronneberger University of Jena

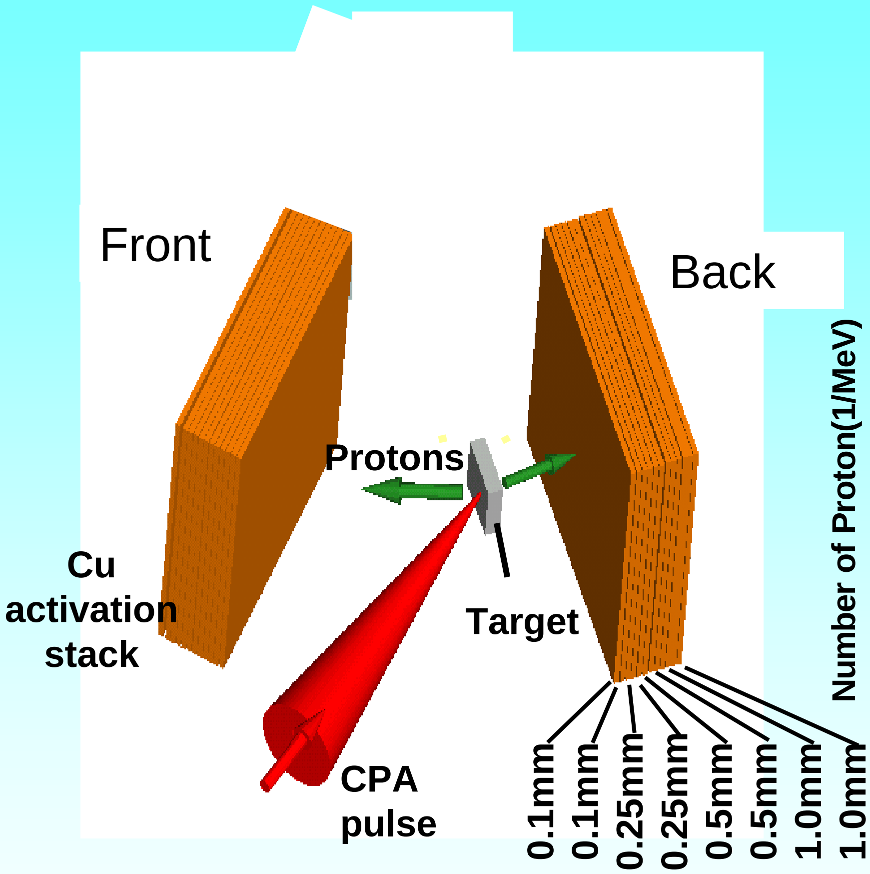
How to measure proton energy spectra using a stack of thin copper foils and activity from a (p,n) reaction in copper to produce ^{63}Zn (38 min half life)

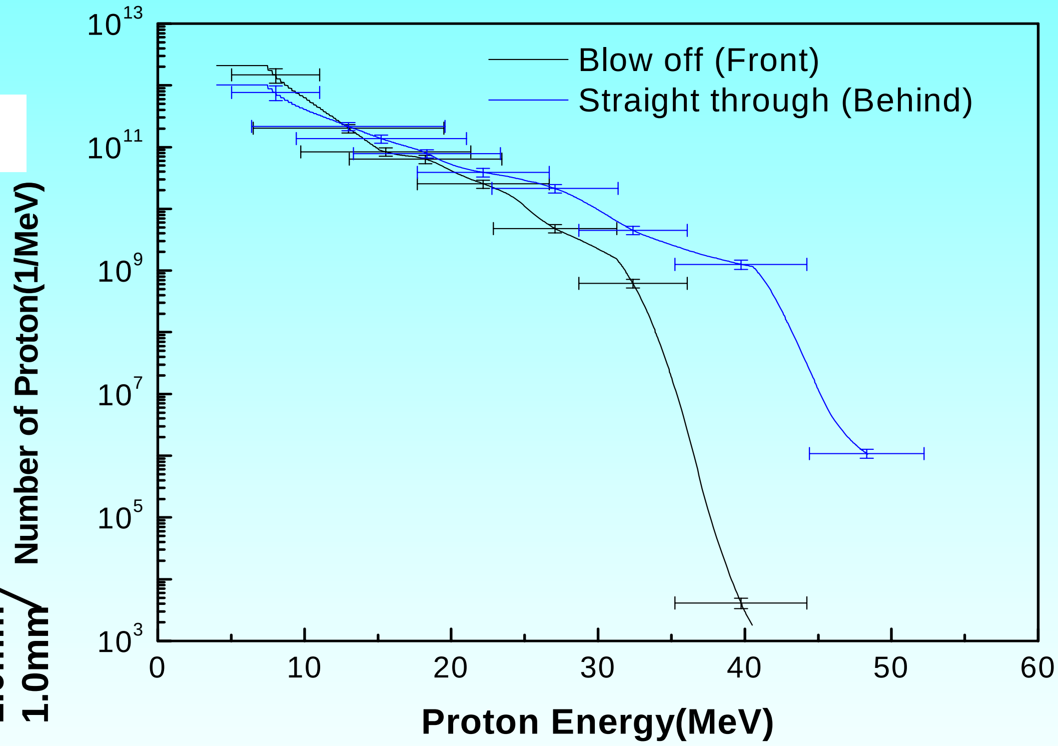

CCD camera
"STRAIGHT THROUGH" DIRECTION
"BLOW-OFF" DIRECTION
Protons
Protons
Al target
Cu activation stack
Cu activation stack
CPA pulse

Proton Spectra from 100TW



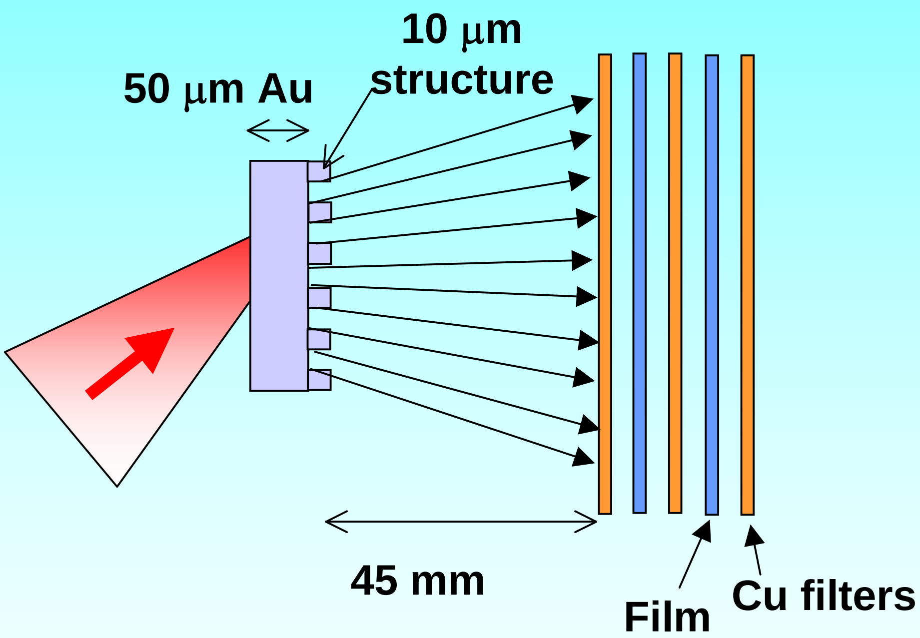
Proton acceleration on Vulcan petawatt



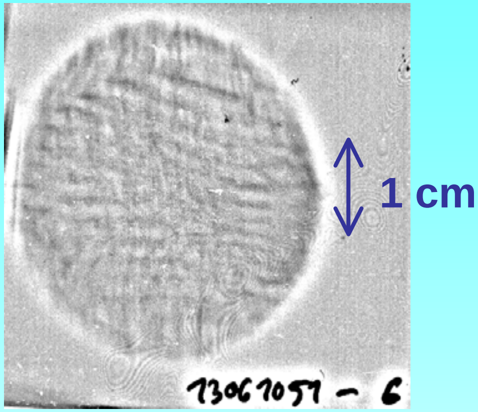


Proton beam quality measurements

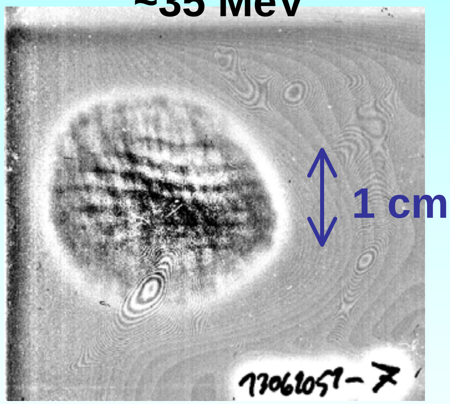
Structure after substracting the general intensity rise in the middle



~28 MeV



~35 MeV

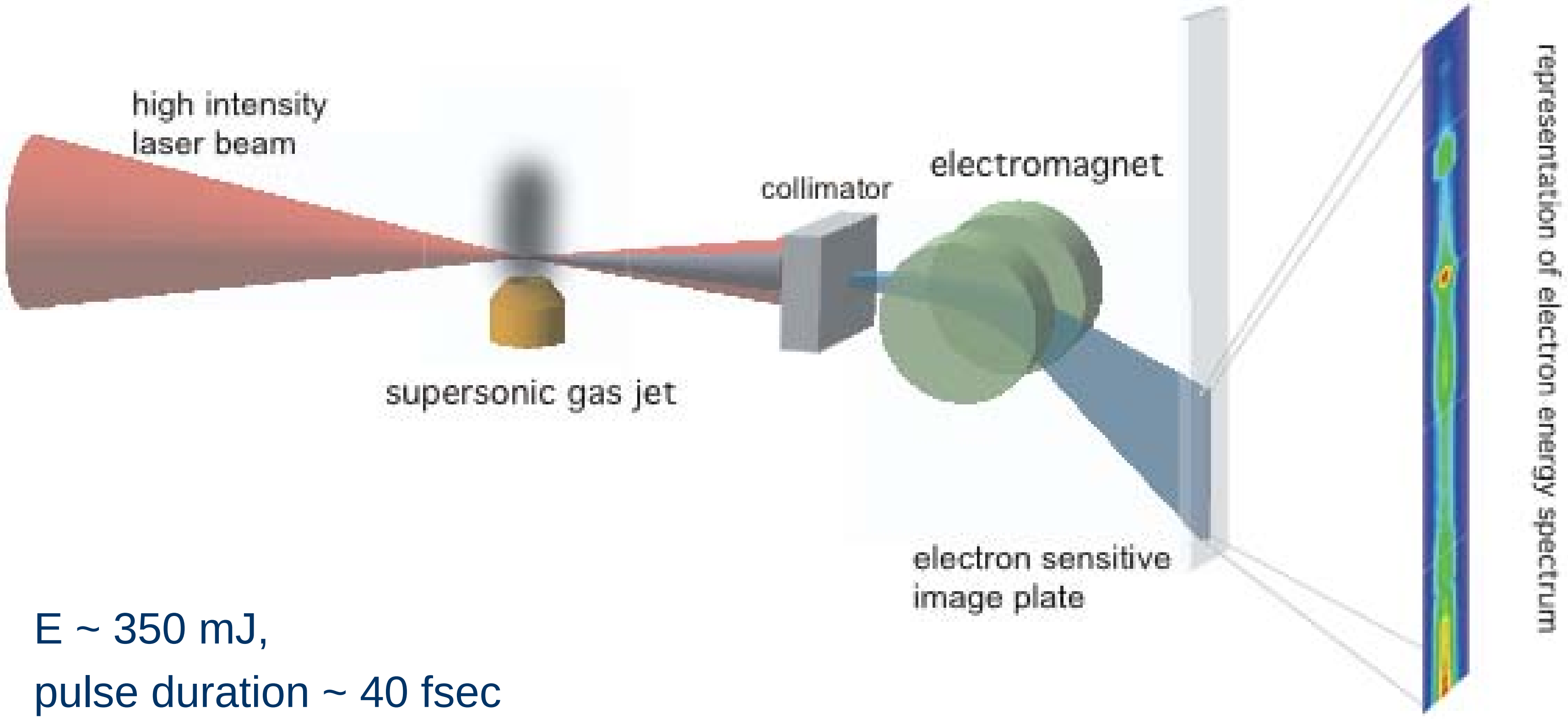


Source size:~40 μm for 40 MeV; :~150 μm for 4 MeV

Normalised emittance $\varepsilon_N < 0.5\ \pi$ mm mrad at 40 MeV

(c.f. CERN Linac2, protons ~50 MeV: $\varepsilon_N \sim 1.7\ \pi$ mm mrad)

High resolution electron spectroscopy using the ASTRA laser system



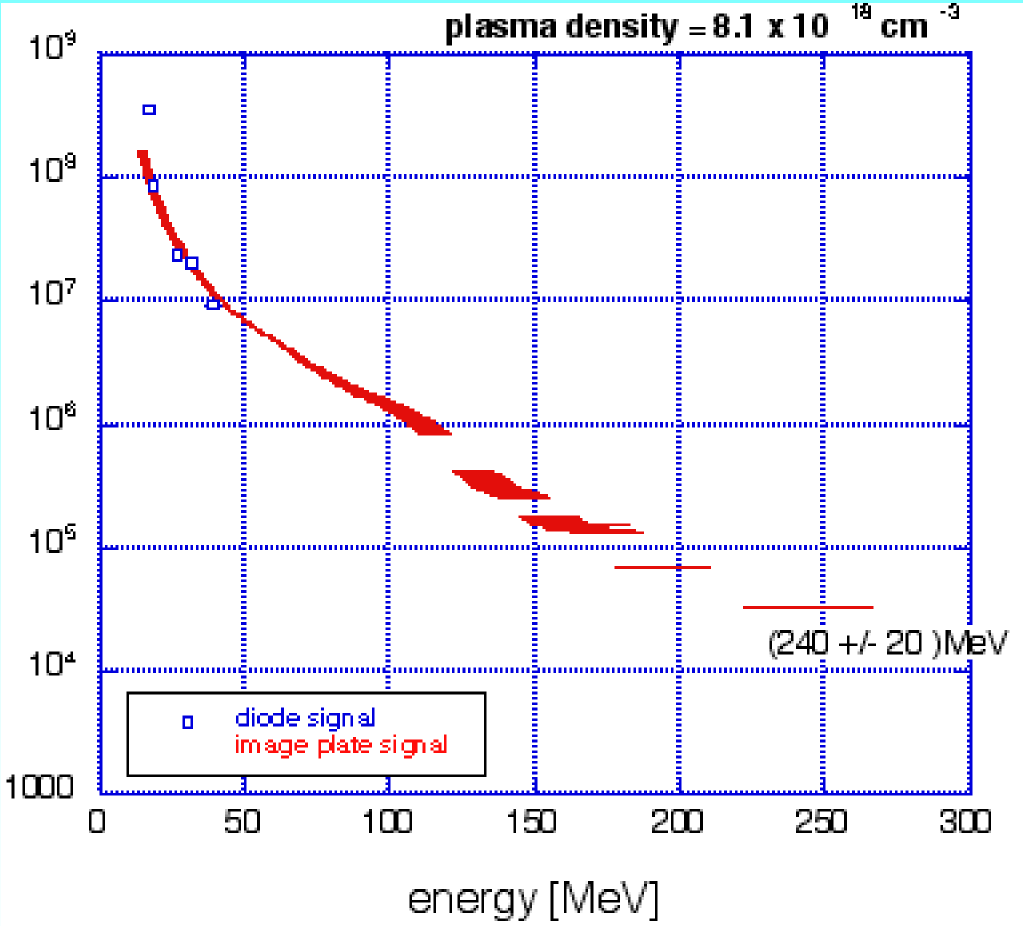
E ~ 350 mJ,

pulse duration ~ 40 fsec

Focal spot ~ 25 µm

Intensity ~ 2 x 10^{18} W/cm^2

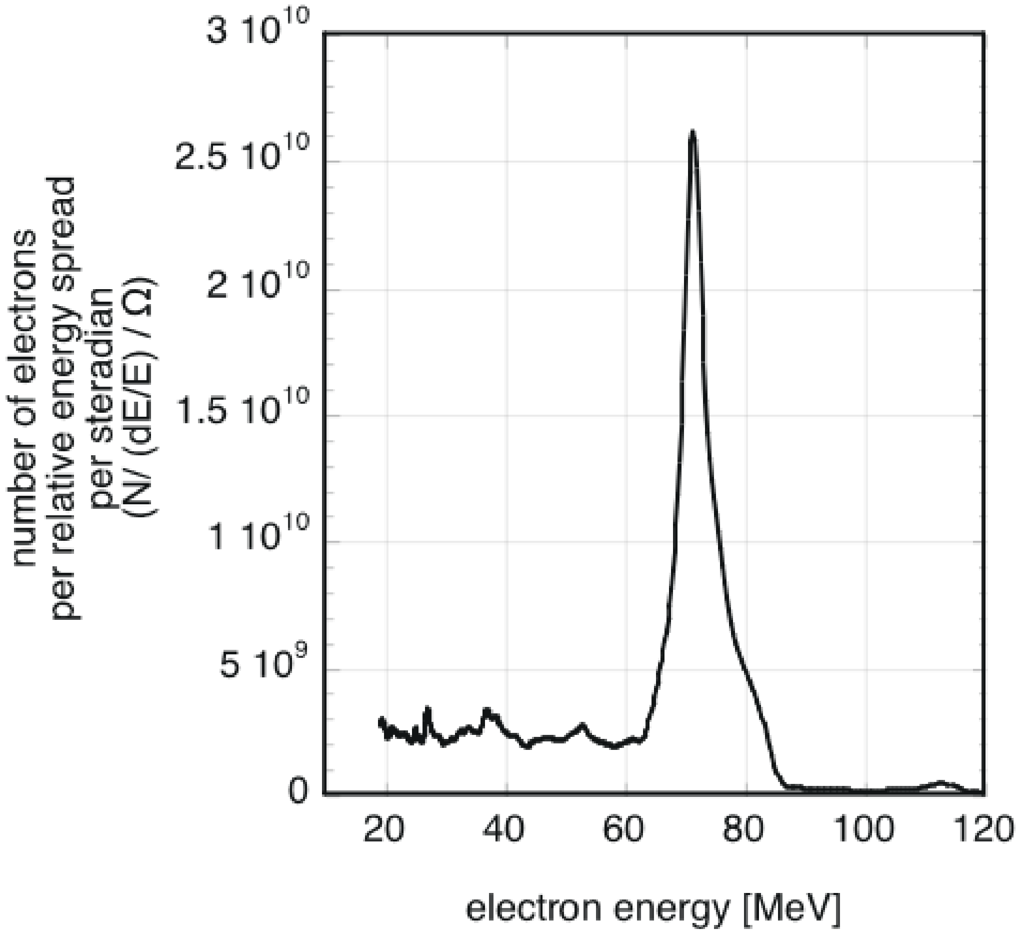
Electron Acceleration Experiment on Vulcan Petawatt



Krushelnick et al (I.C.) with gas targets have measured electrons with energy 240 MeV on VULCAN

Malka et al on the table top laser LOA have measured 200 MeV electrons at similar intensities

Mono-energetic spectra can be observed at higher power ($\Delta E/E = 6\%$)



E ~ 500 mJ,

pulse duration ~ 40 fsec

Focal spot ~ 25 µm

Density ~ 2 x 10^{19} cm^{-3}

Shot-to-shot fluctuations in

a) energy spread

b) peak energy

Careful control of laser and plasma conditions is necessary

Properties of a Petawatt Laser at 10^{21}Wcm^{-2}

- Electrons energies up to 500 MeV now mono-energetic
- Protons up to 60 MeV with mono-energetic protons now possible
- Heavy ions with energies up to 10 MeV/nucleon
- Magnetic Fields up to 600 MG
- Photon Pressures up to GBars

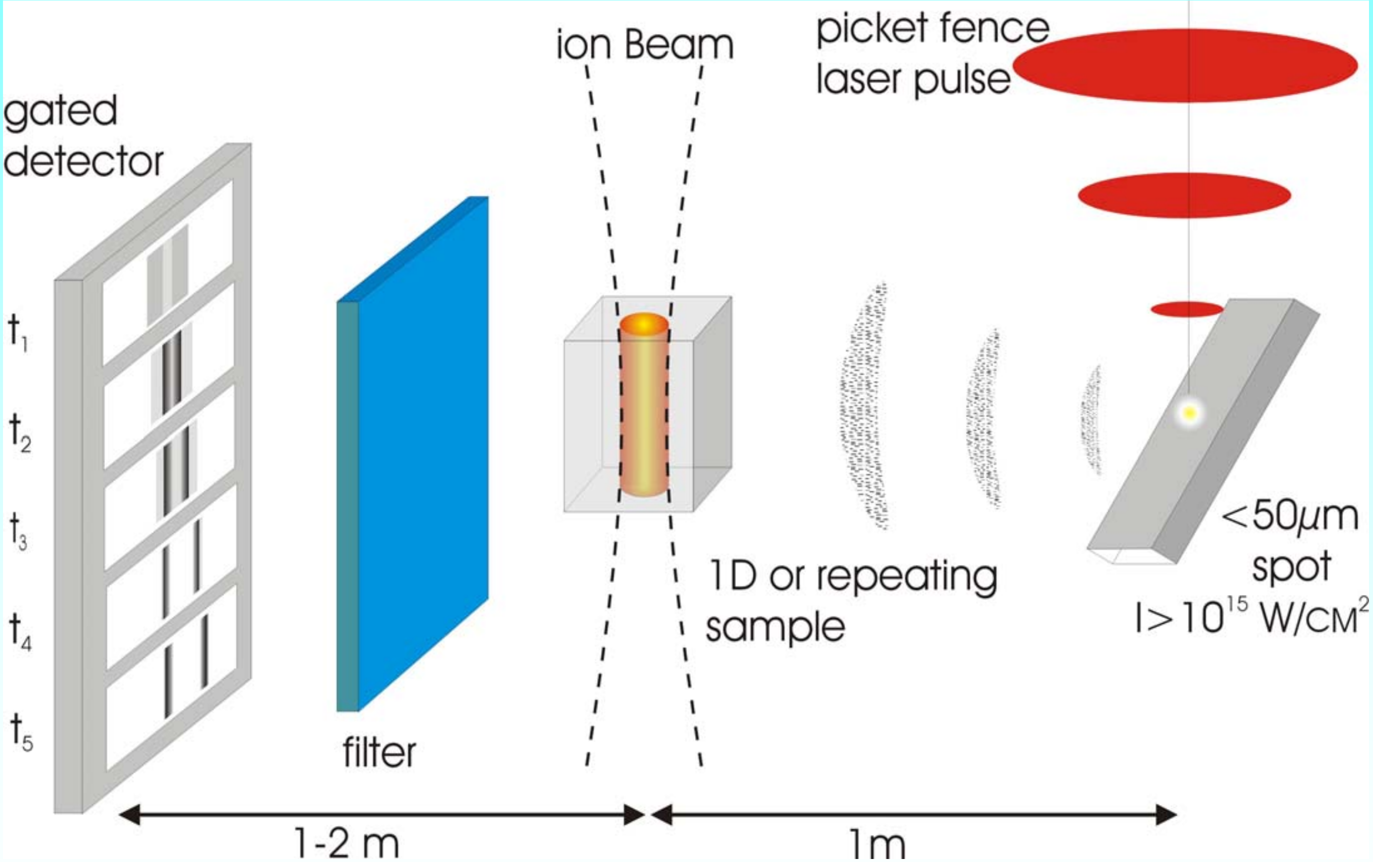
Experiments which can be carried out at GSI

Synergies between Intense Ion (SIS -200 and Laser Beams(Phelix)

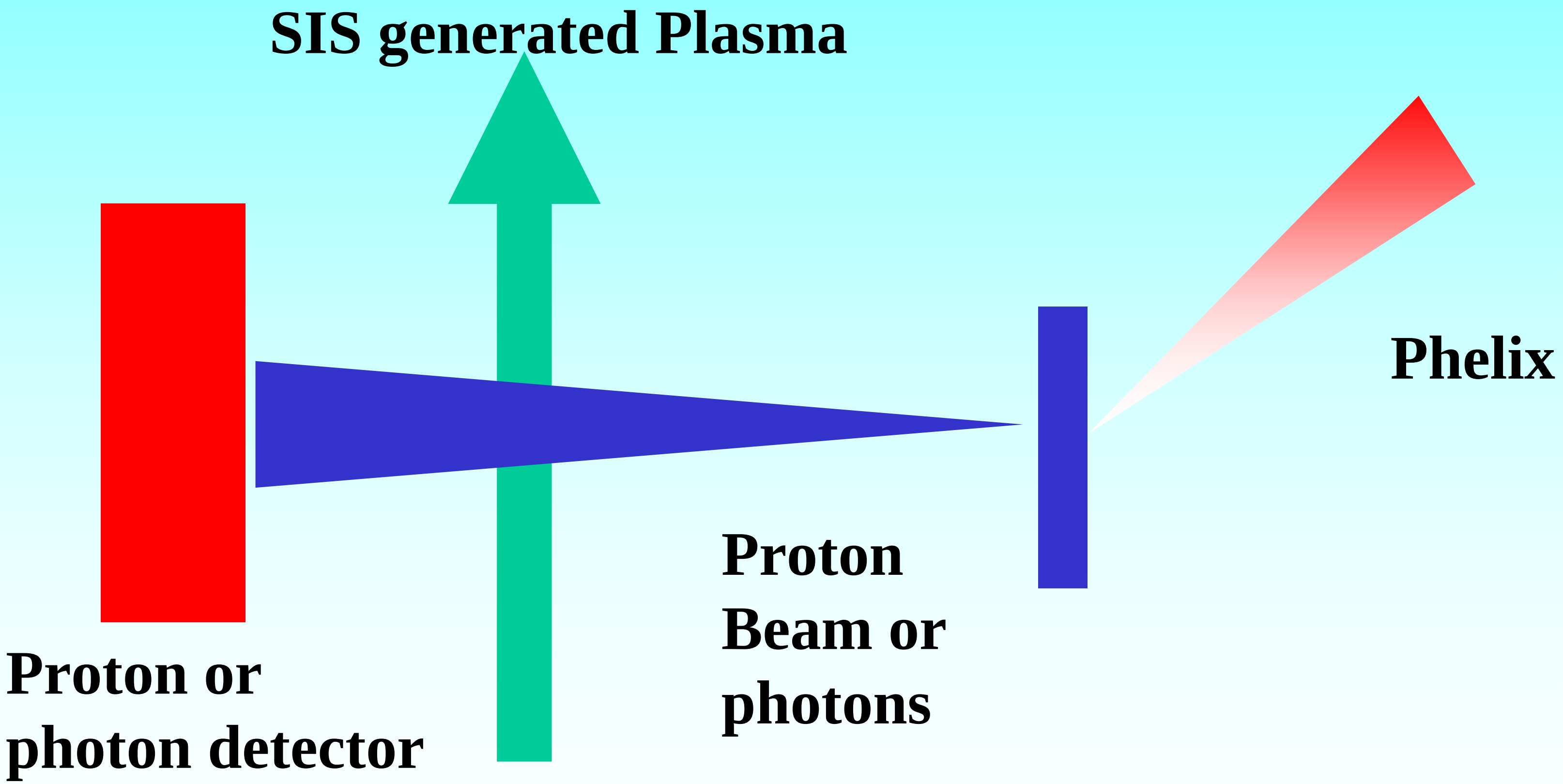
The Physics of Dense Plasmas

- This is the physics of planet interiors and stellar atmospheres
- Visible and UV light cannot be generated through these plasmas
- Short pulses of X rays ~10keV are needed for this especially if high temporal resolution is required

Phelix as a unique Diagnostic to backlight plasmas generated by SIS 200



Proton Radiography as an extension of X-rays for investigating matter under extreme conditions



The Combined Capability of Phelix and SIS 200

- Light or proton propagation in dense plasmas
- Equations of state experiments
- Supernova shock wave experiments
- Phelix providing shock wave and SIS-200 investigating the response of the shock

Personnel

KWD Ledingham, P McKenna, J Yang, S Shimizu,
T McCanny, L Robson, R P Singhal

K Krushelnick, MS Wei,
P Nickelson, S Mangles

RJ Clarke, PA Norreys,
KL Lancaster, S Karsch

J Zweit,
J Gillies

M Zepf

M Roth,
E Brambrink,
M Hegelich

R Chapman,
K Spohr

J Galy,
J Magill