



**QUEEN'S
UNIVERSITY
BELFAST**



**Particle Accelerators
and Beams Conference 2025**
9–10 July 2025 | Oxford

Laser energised Travelling Charge Accelerator for nuclear medicine and beyond



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Queen's University Belfast**



EPSRC

Pioneering research
and skills



Target Normal Sheath Acceleration (TNSA)

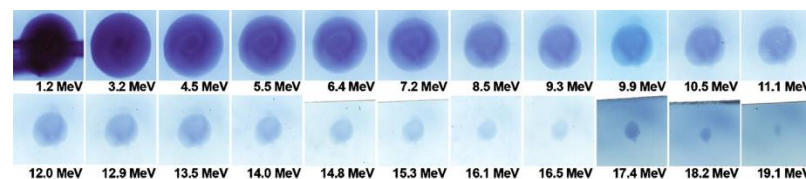
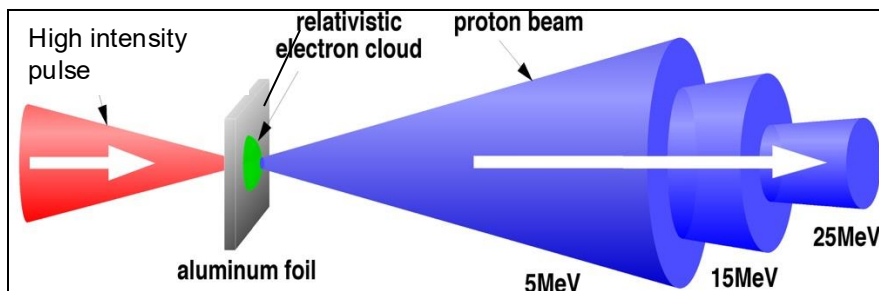
Short duration at source: bursts with duration \sim ps

Acceleration time comparable with laser-drive duration

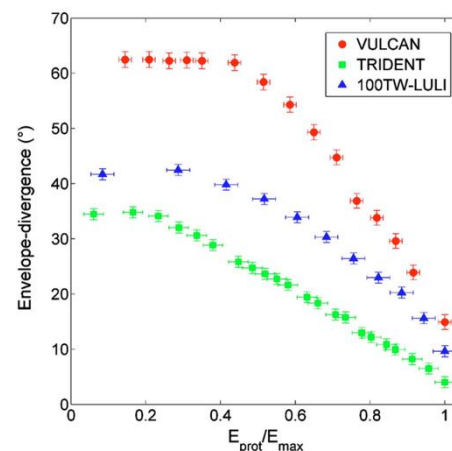
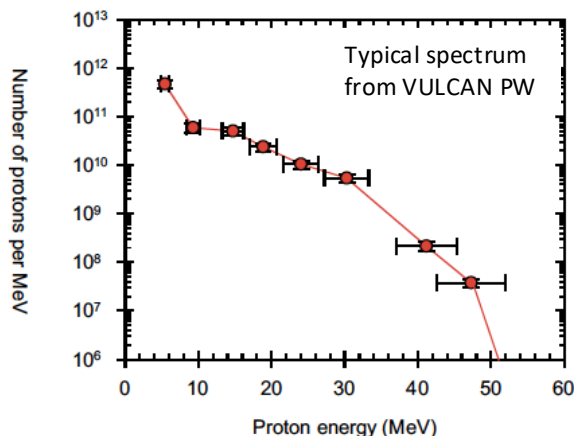
Strong ΔE - Δt correlation and ultralow transverse emittance ($< 0.1 \pi$ mm.mrad @ 15 MeV)

$$kT_{hot} \approx U_p = m_e c^2 \sqrt{1 + \frac{a_0^2}{2}} - m_e c^2$$

Acceleration field: **TV/m**



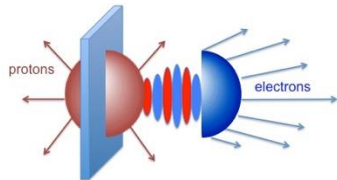
**Broad spectrum
with low particle
number at high
energies**



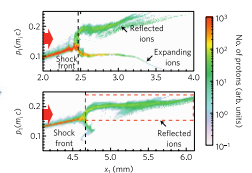
**Several 10s of
degrees of
divergence**

Current motivations in the field of laser-ion acceleration

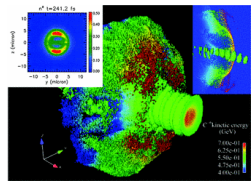
Energy increase



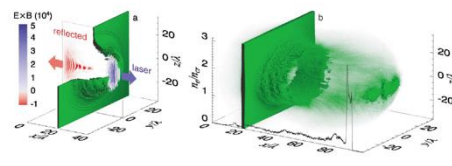
Coulomb explosion



Shock acceleration

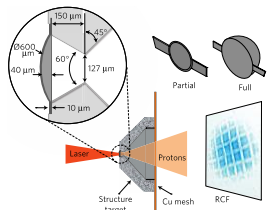
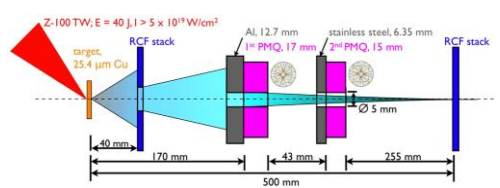
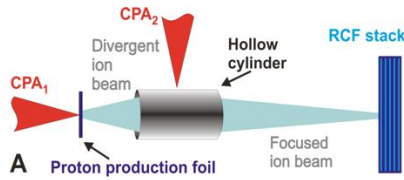
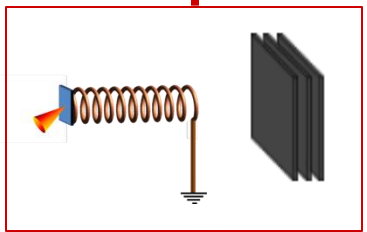
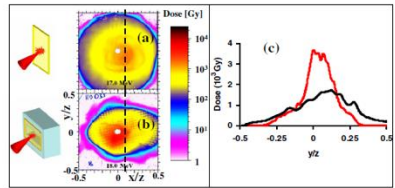
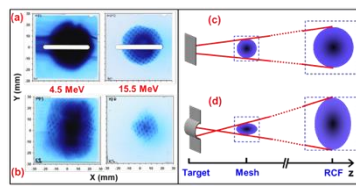
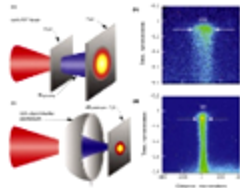


Relativistic transparency



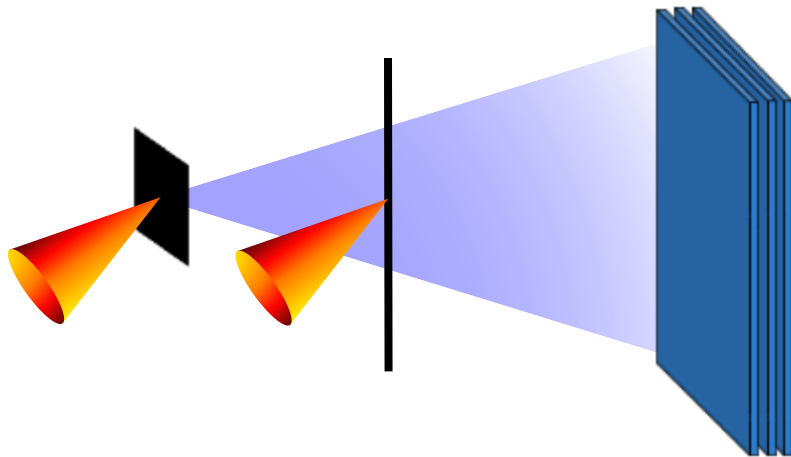
Radiation pressure acceleration

Focusing and Energy selection

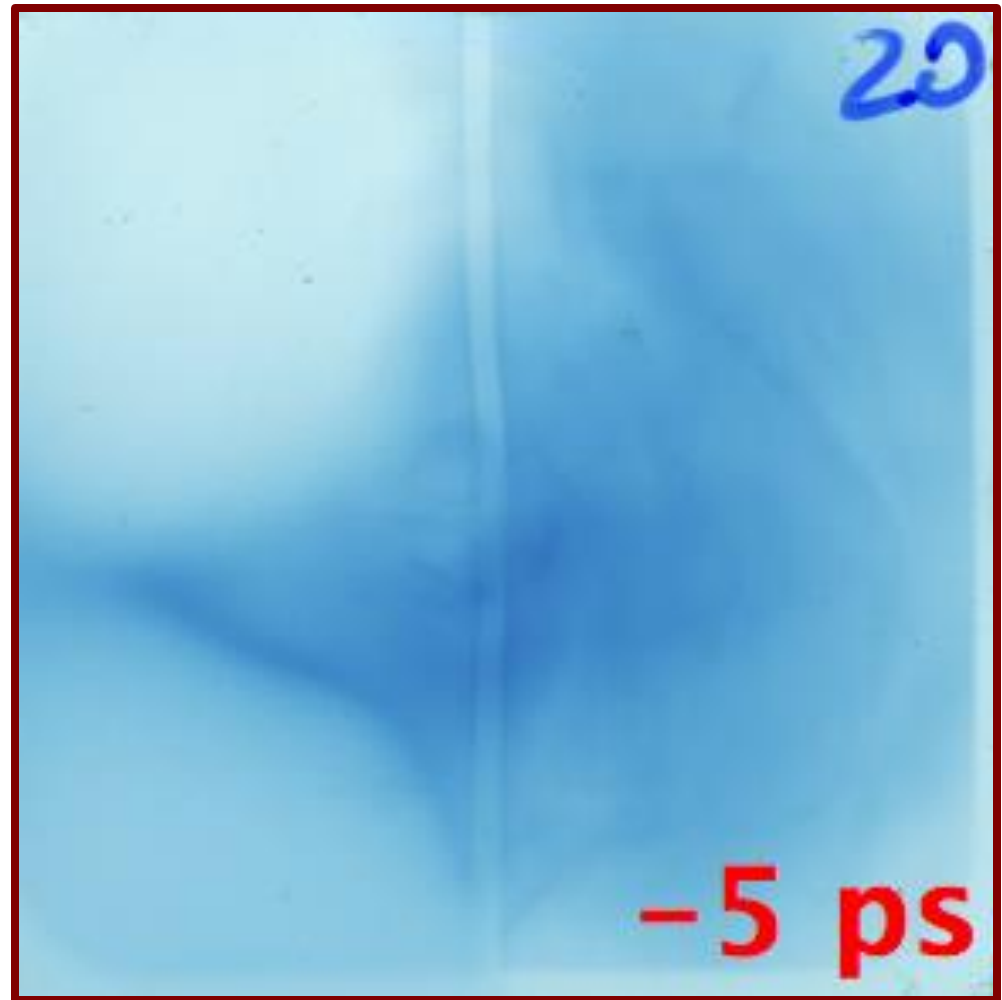


Charging and discharging following laser interaction

Proton imaging of laser irradiated wire



Multi-frame snapshot from a single shot

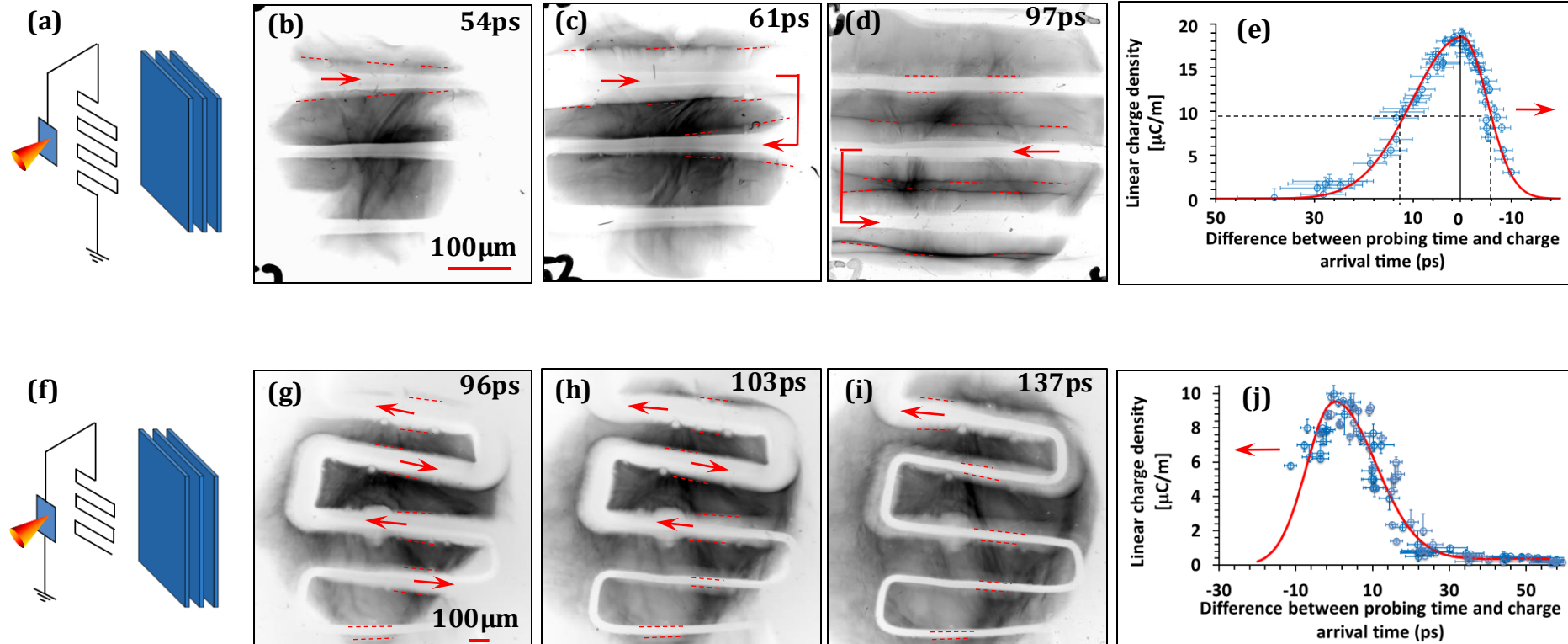


And far from target, travels as KAm pulse

S. Kar et. al., Nature Communications, 7:10792 (2016);

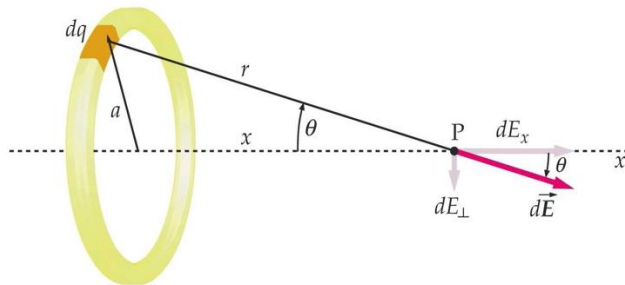
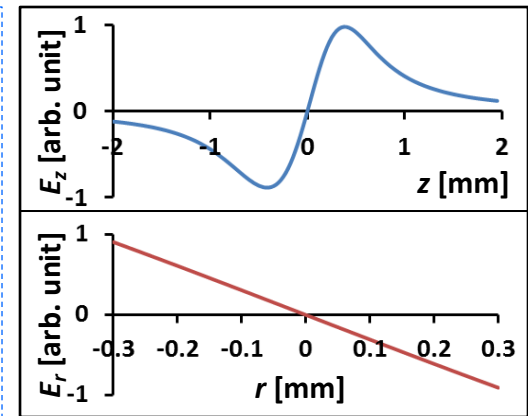
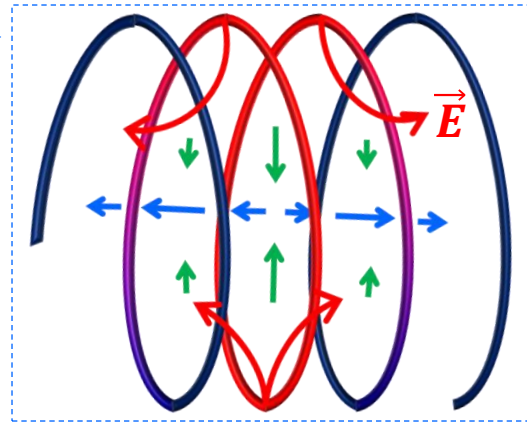
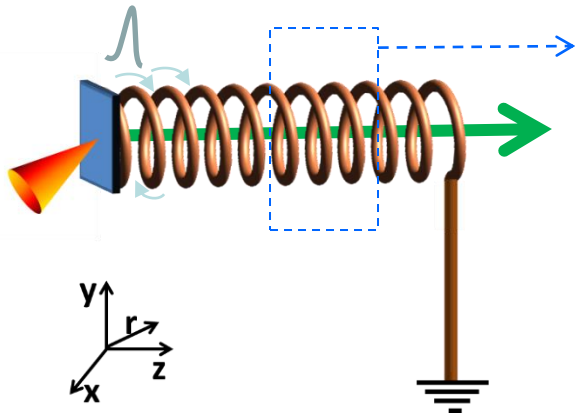
S. Kar et. al., Phys. Plasmas, 23, 055711 (2016);

H. Ahmed, S. Kar et. al., Nucl. Instrum. Methods A, 829, 172 (2016).



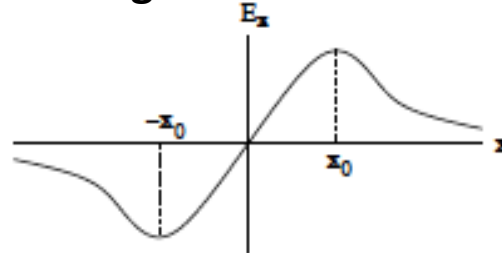
Not only the current pulse travels over the bends,
reflects from an open end.

Laser Energised Travelling wave Accelerator



Analogy with the field of a charged ring

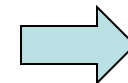
Longitudinal field



$Q \sim 60 \text{ nC}$, $a = 0.4 \text{ mm}$

$$x_0 = \frac{a}{\sqrt{2}}$$

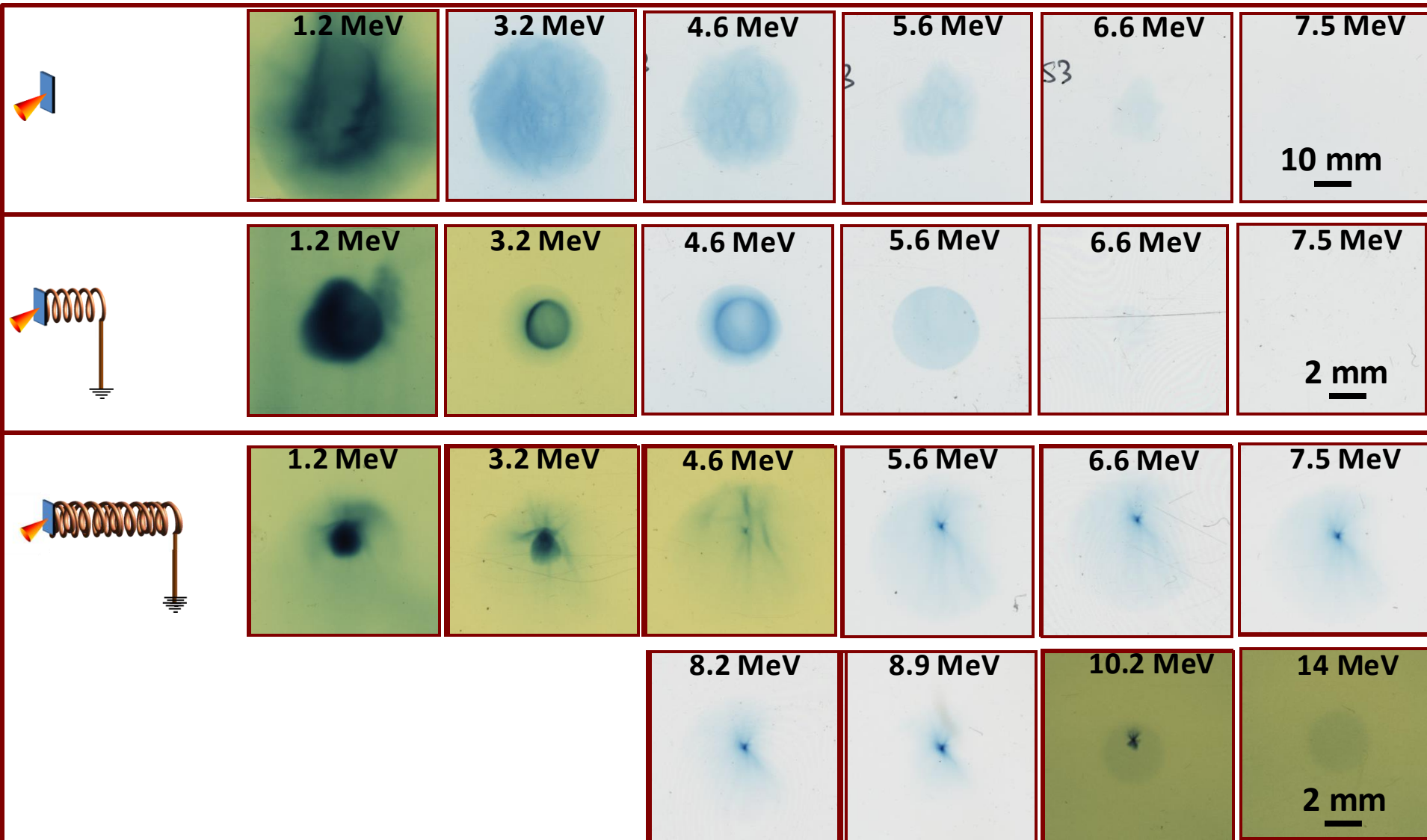
$$E_{\max} = \frac{Q}{2\pi\epsilon_0 a^2} \frac{\sqrt{2}}{3\sqrt{3}}$$



$E \sim \text{MV/mm}$

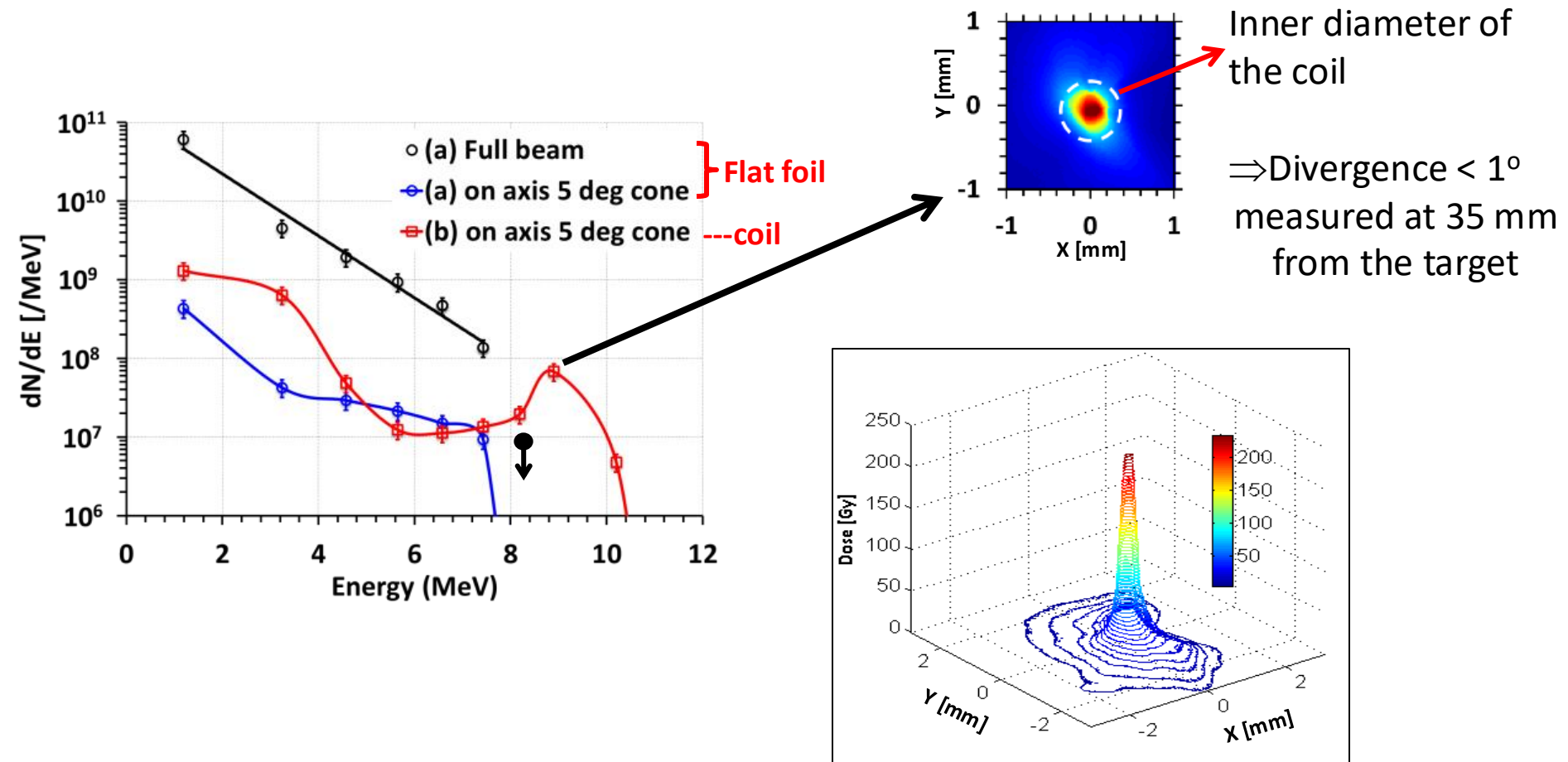
Proof-of-principle experiment

S. Kar et. al., Nature Communications, 7, 10792 (2016)



Proof-of-principle at University-scale laser (ARCTURUS)

S. Kar et. al., Nature Communications, 7, 10792 (2016)

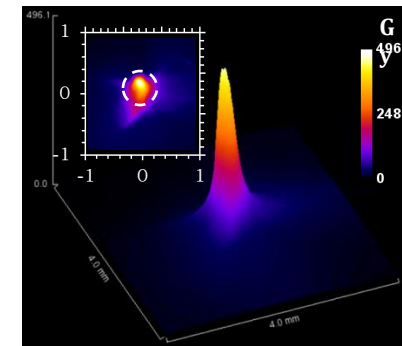
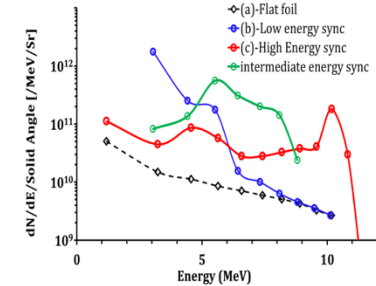
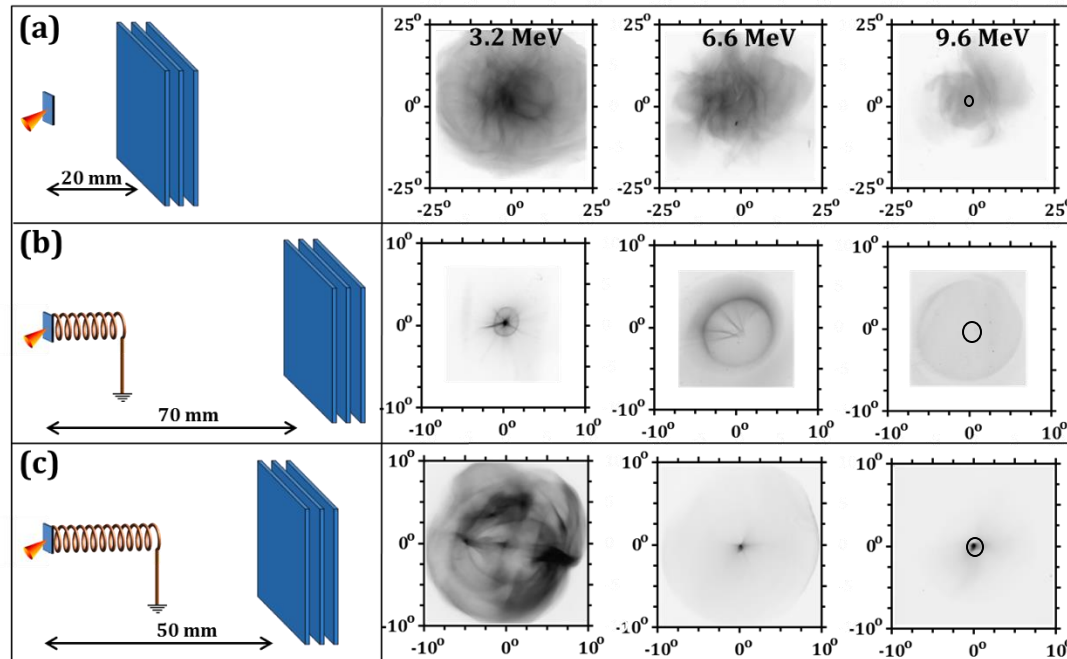


Experimental Data

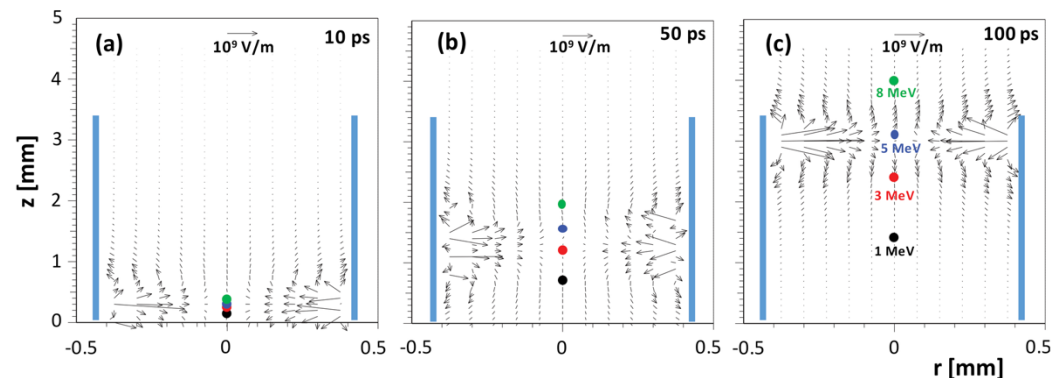
TARANIS Laser at Queen's Univ. Belfast

S. Kar et. al., Phys Plasma, 23, 055711 (2016)

(~ 5 J on target in ~ 0.5 ps, f/3 focusing, $I_0 \sim 2 \times 10^{19}$ W/cm²)



Field dynamics
leading to
chromaticity

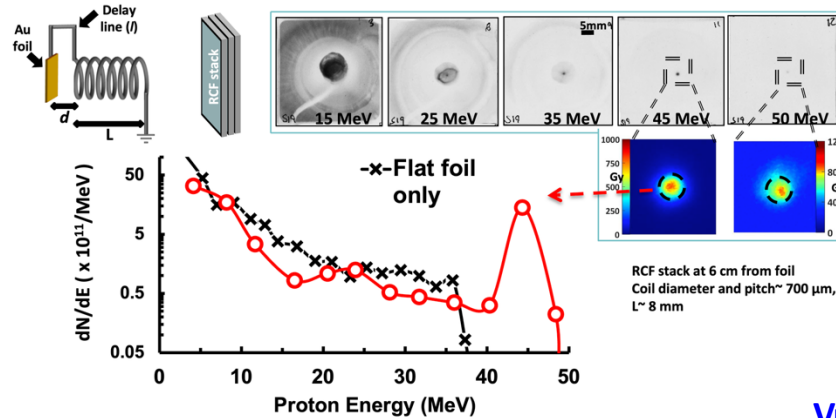


Recent experimental data

- High energy implementation

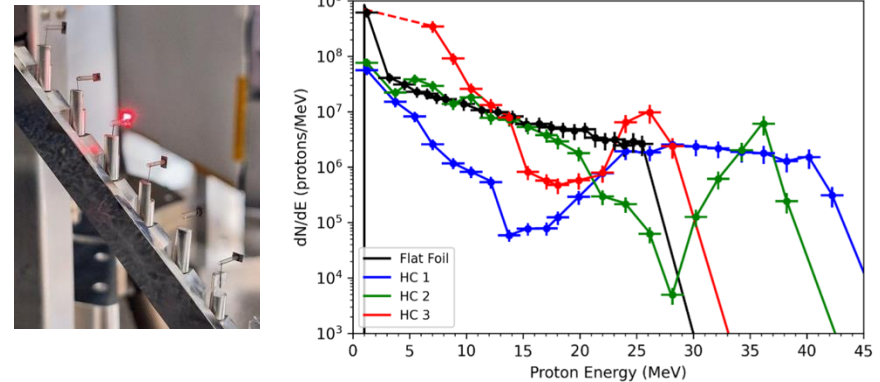
Titan Laser, LLNL; Vulcan PW, CLF
 150-300 J, 750 fs, 2×10^{20} W/cm²

H. Ahmed *et al*, Sci. Rep., 11, 699 (2021)



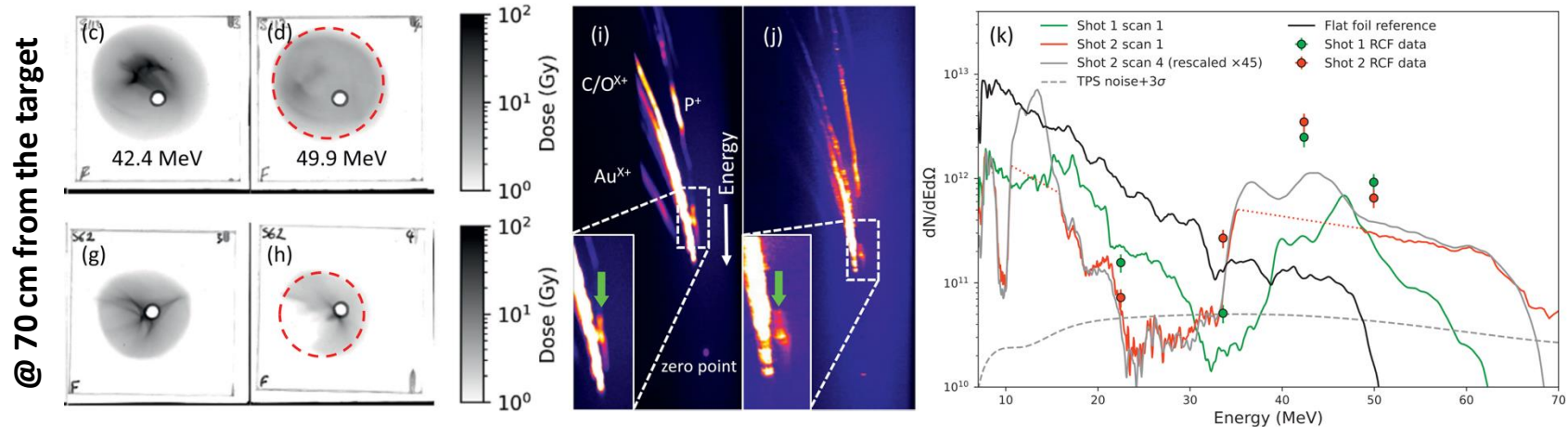
ELI-BI, Prague
 10 J, 30fs, 5×10^{20} W/cm²

O. Cavanagh *et al*, in preparation



Vulcan PW, CLF:
 300 J, 750 fs, 3×10^{20} W/cm²

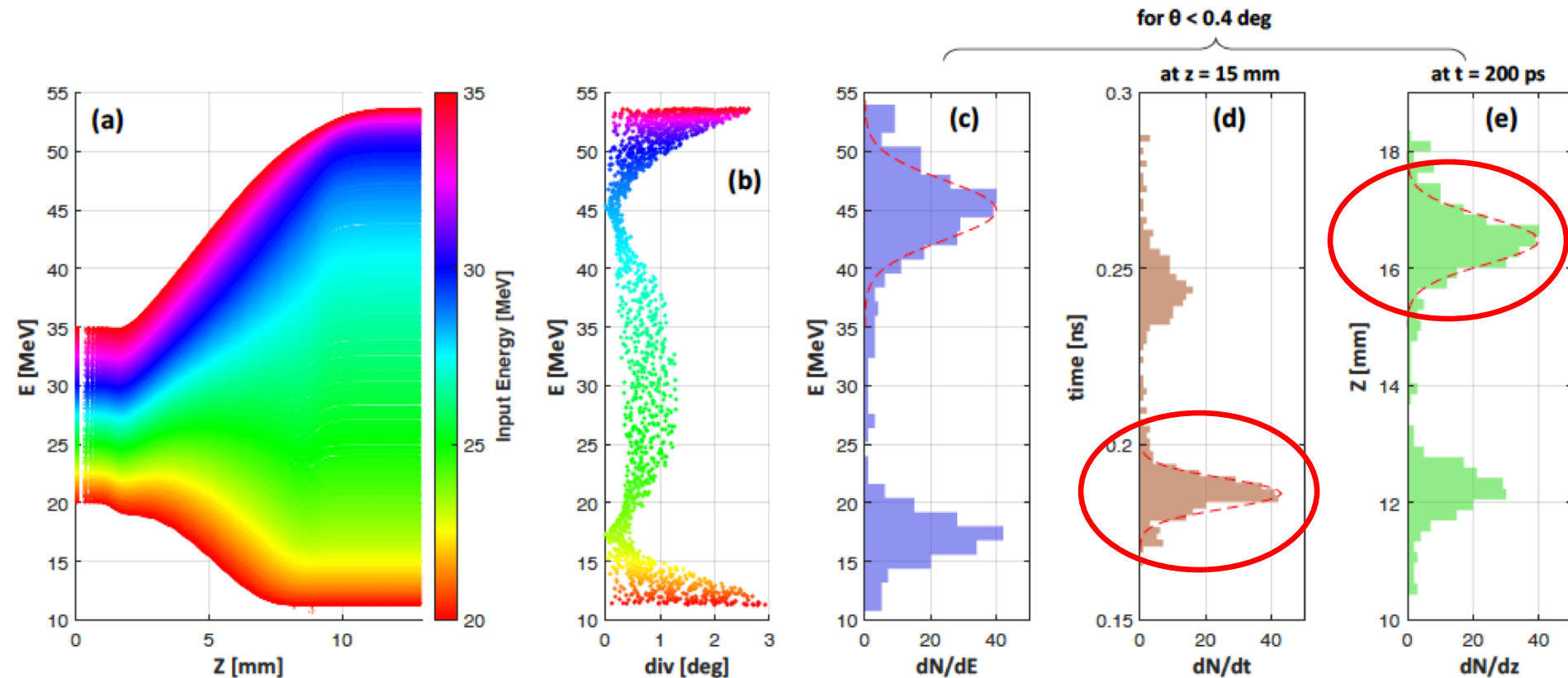
P. Martin *et al*, High Power Laser Sc. Eng., 12, 88 (2024)



Recent experimental data

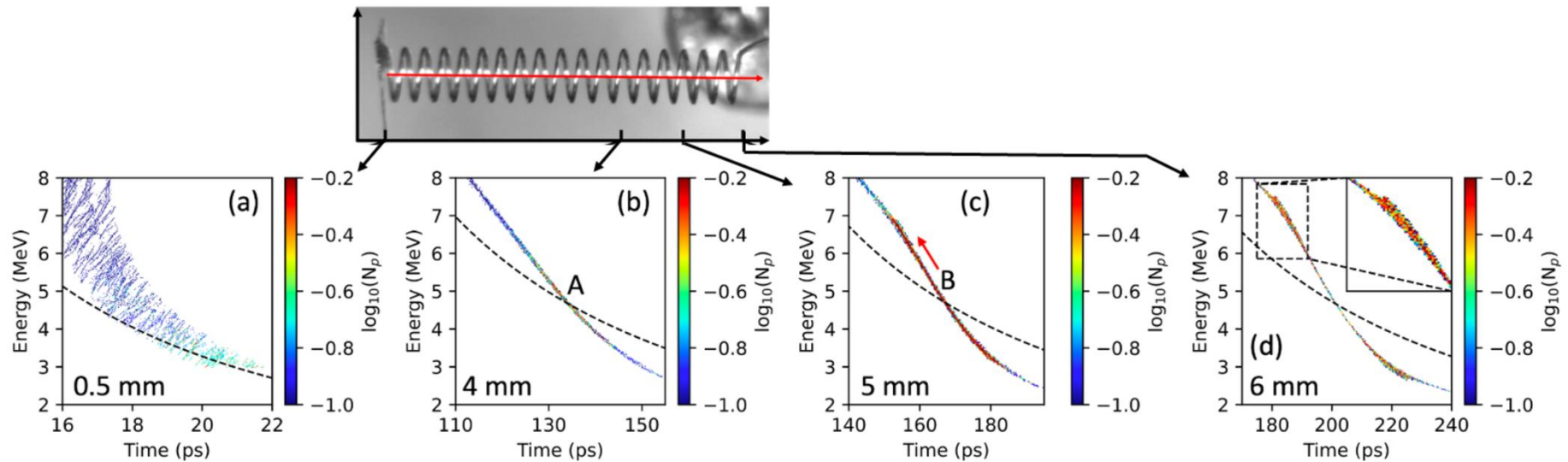
- High energy implementation

H.Ahmed *et al*, Sci. Rep., 11, 699 (2021)

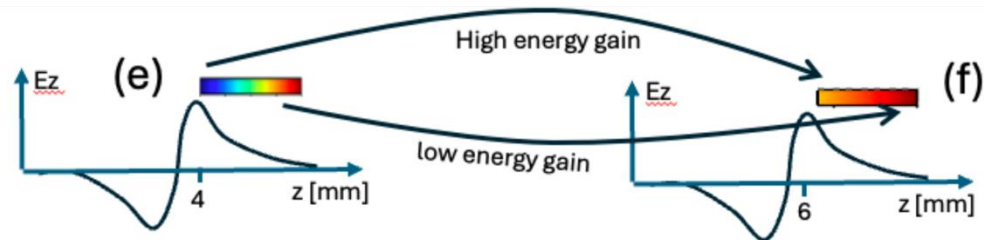


- High spatio-temporal bunching
- No loss of TNSA laminarity

Helical coils as an ultrafast phase rotator



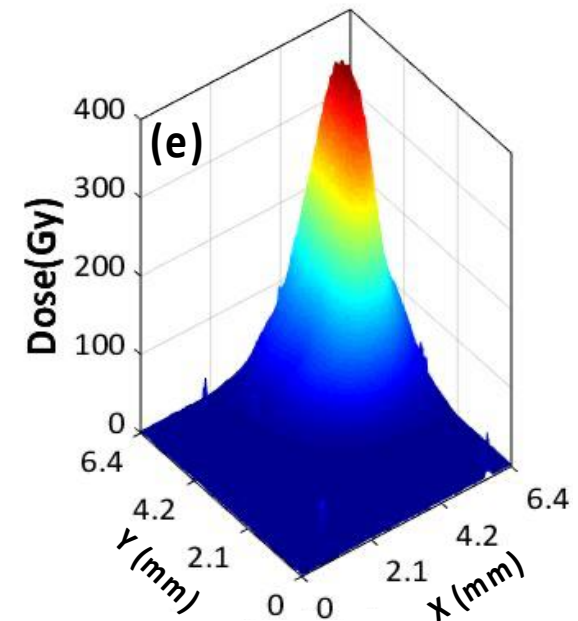
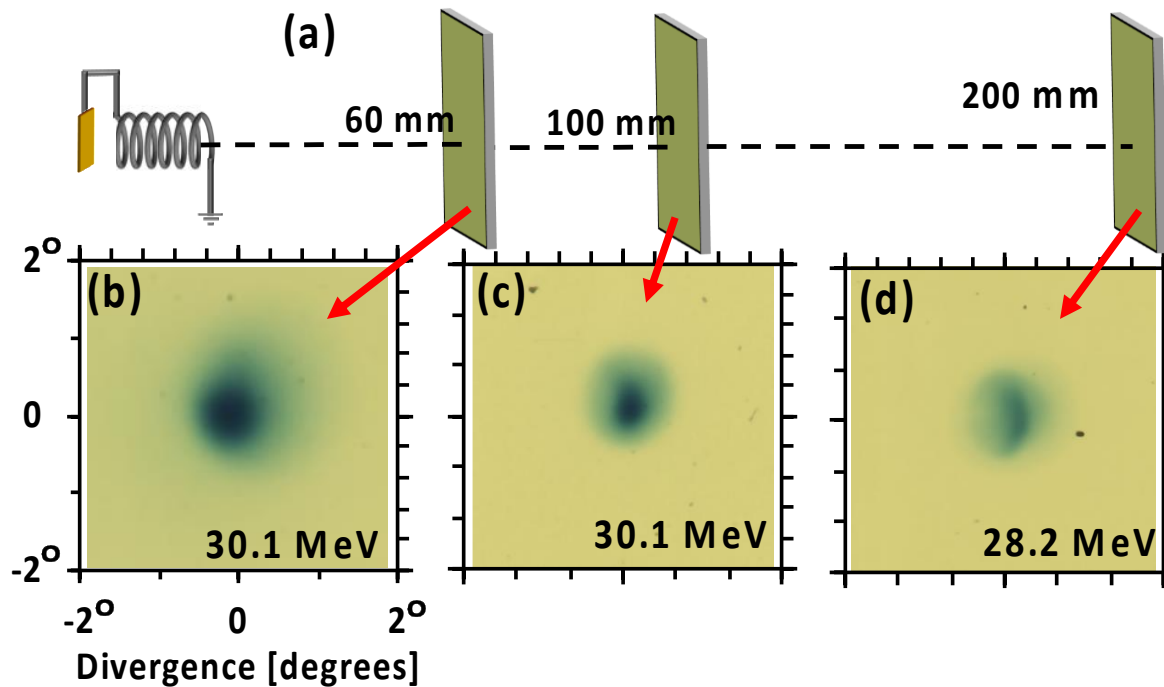
**Snowplough
bunch
compression**



Recent experimental data

- High energy implementation

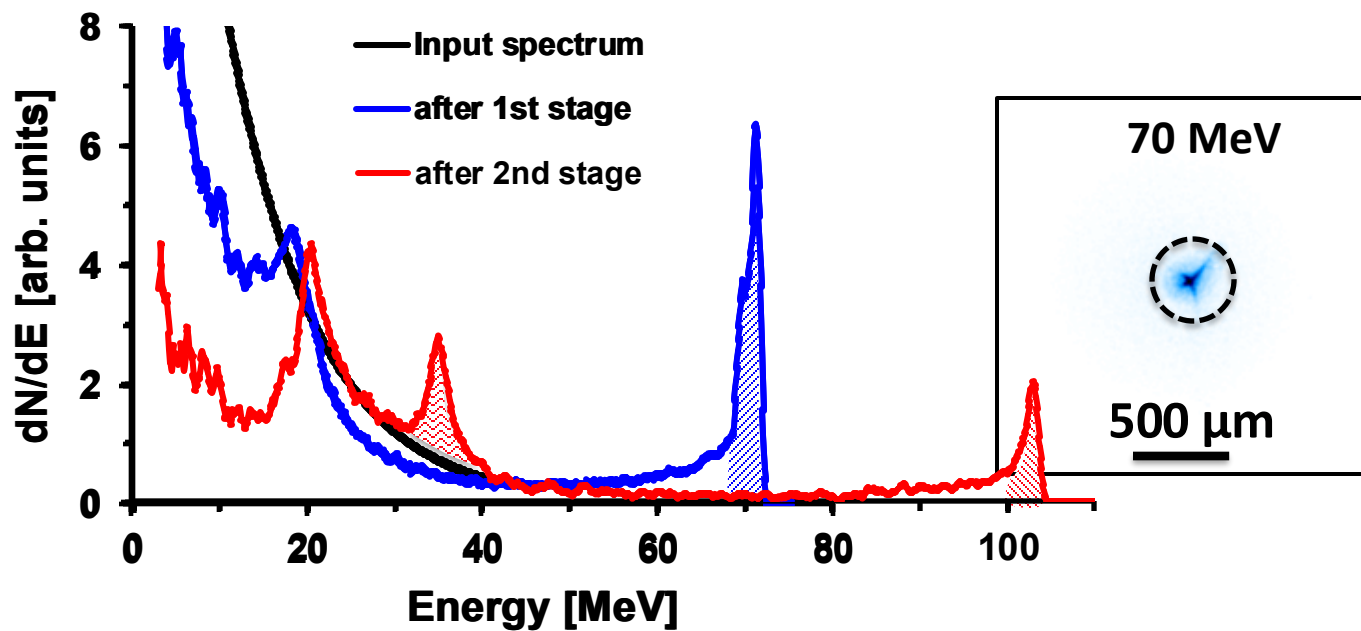
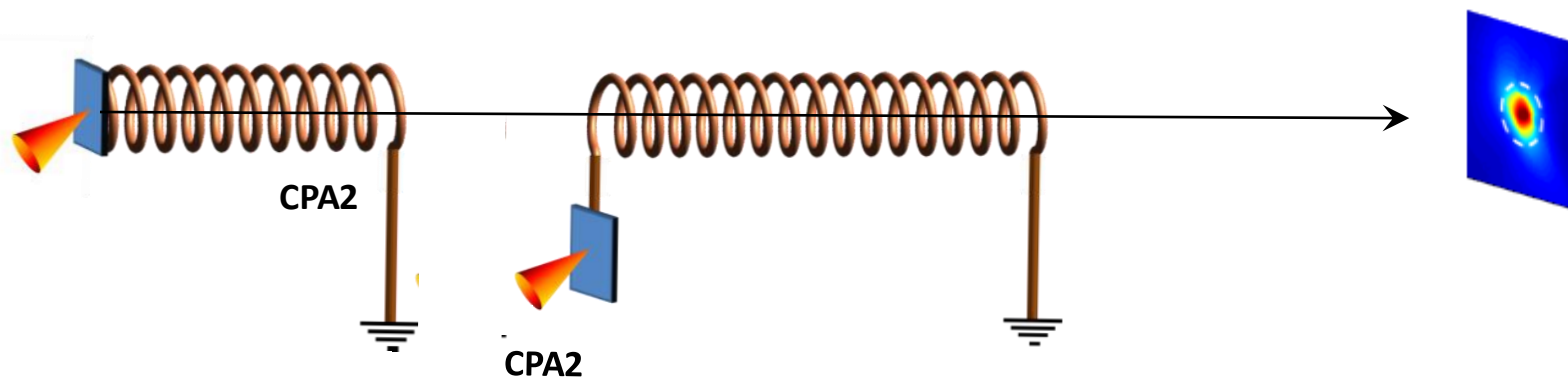
H.Ahmed *et al*, Sci. Rep., 11, 699 (2021)



- FWHM divergence : ~ 0.2 deg
- Transverse emittance : 0.15π mm.mrad

STAGING

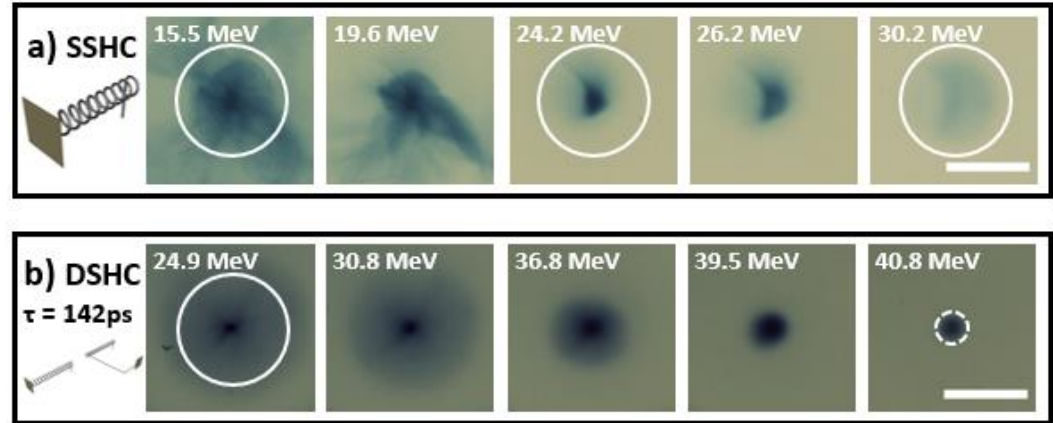
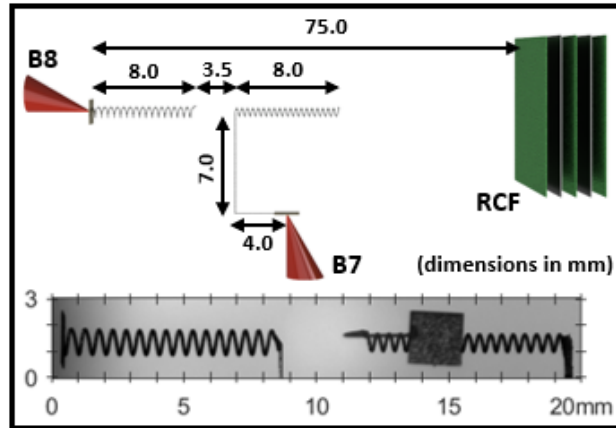
S. Kar et. al., Nature Communications, 7, 10792 (2016)



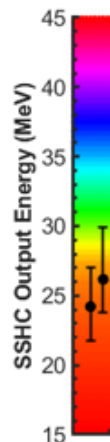
STAGING: proof of principle

S. Ferguson et. al., New J. Phys. 25, 013006 (2023)

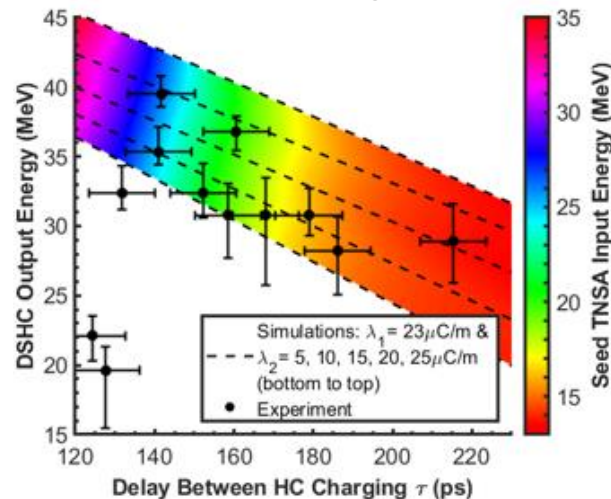
Vulcan TAW, CLF: 50 J, 750 fs, 5×10^{19} W/cm²



Single stage



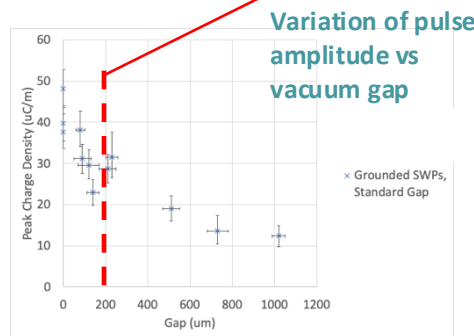
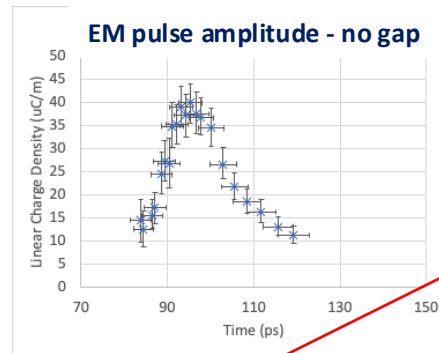
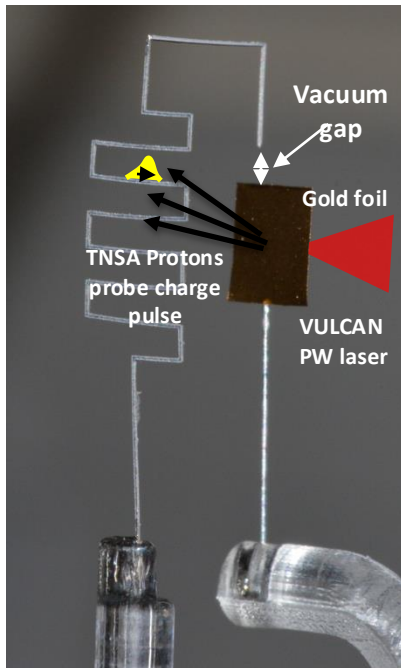
Double stage



Timing is key to an optimized performance

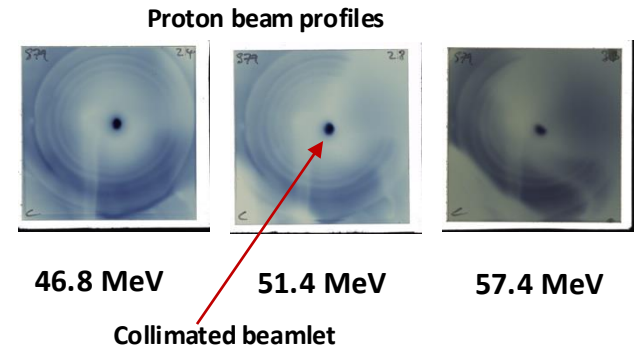
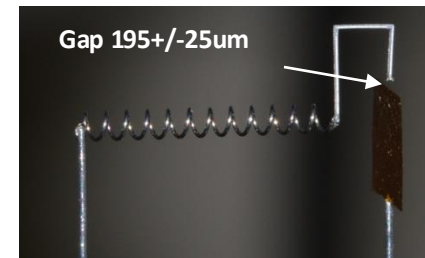
EM Pulse coupling through vacuum gap => Disconnected coil targets

Characterization of EM pulse transmission through vacuum gap



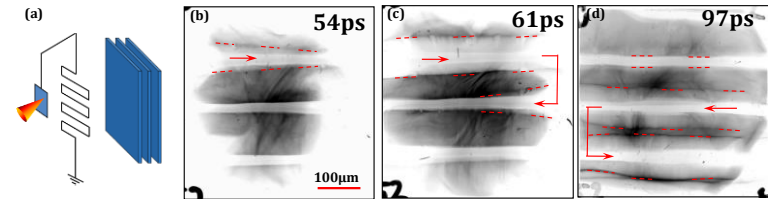
Measurements from VULCAN PW experiment

Demonstration of detached coil operation

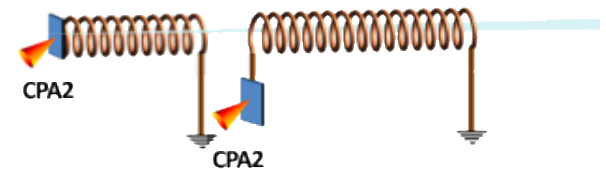
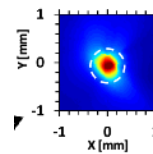
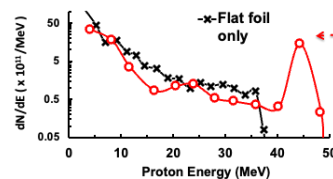


Conclusions :

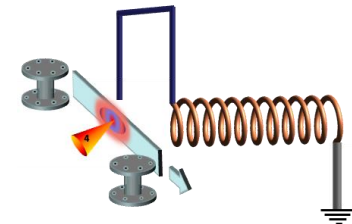
➤ Transient charging of laser irradiated target generates ultra-short EM pulse propagating along the supporting wire, in a quasi-TEM mode and with minimal loss.



➤ the unique properties (finite size + high speed + high intensity) of the EM pulse is exploited to create a device for simultaneous focussing, energy selection and re-acceleration of proton beams.



➤ Promising data obtained experimentally, which opens of possibility of high-rep operation.



Thank you for your attention.