Angular Resolved Thomson Parabola for Laser-Plasma Accelerators

Infraestructuras Científicas y Técnicas Singulares

CENTRO DE LÁSERES PULSADOS

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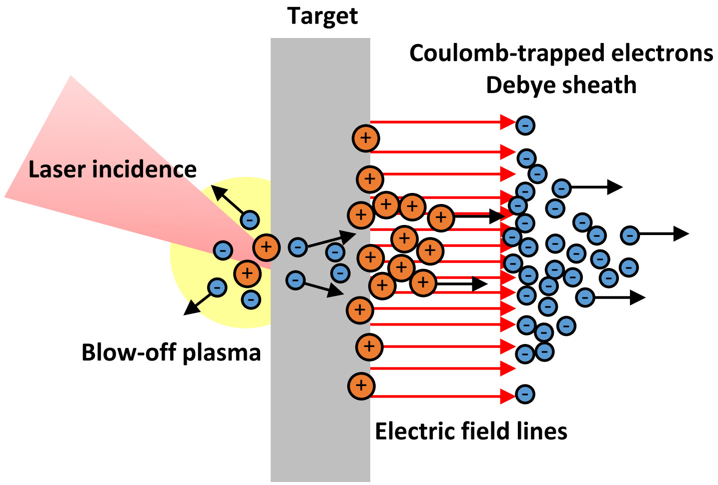
Motivation

Most common ion acceleration scheme in LPA: **T**arget **N**ormal **S**heath **A**cceleration (**TNSA**)

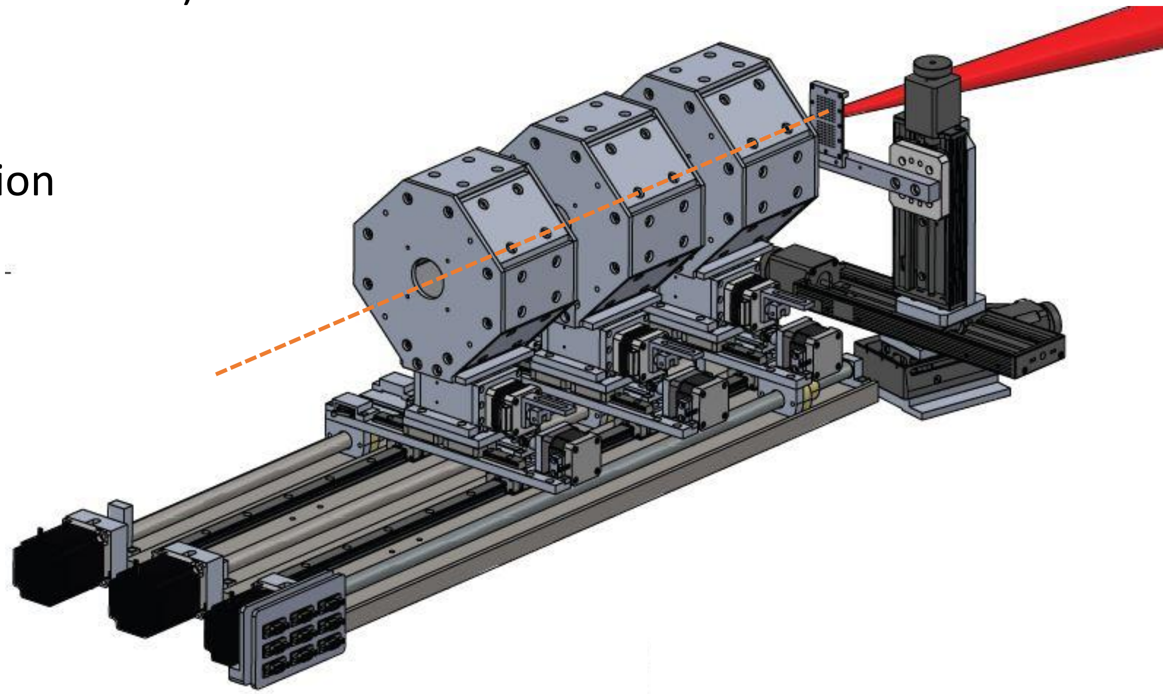


Specific beam properties

- Multi-species (mainly protons and light ions due to q/m)
- Quasi-Maxwellian spectrum with cutoff on 10s MeV
- High total divergence (20°-50°)
- Moderate charge (typically below 1 nC)
- Highly-correlated coordinate-momentum: good transversal beam quality
- Short duration (picosecond)

Applications favored by possibility of beam transport and focalization (thanks to the small transversal emittance).

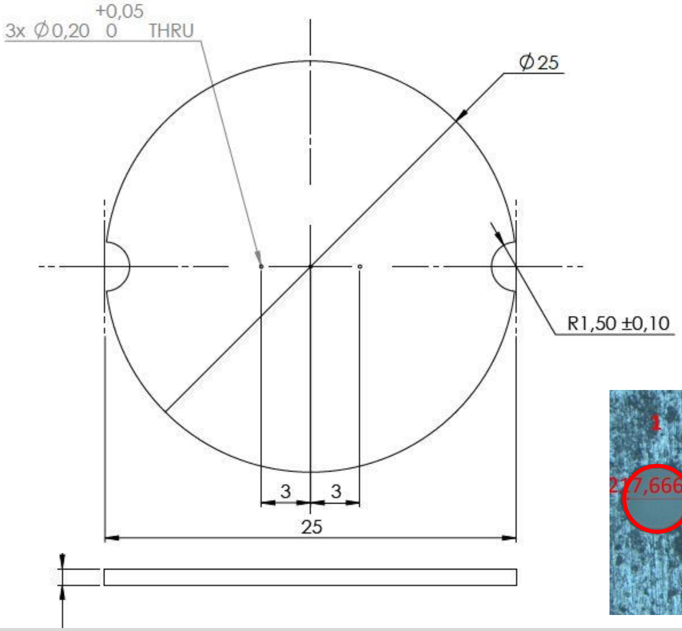
- Transient phenomena (plasma) ultrashort probing
- Isochoric heating of dense plasmas
- Fast ignition in ICF
- Material science
- Radio-pharmacy/medical purposes (towards hadrontherapy)



Thomson Parabola:

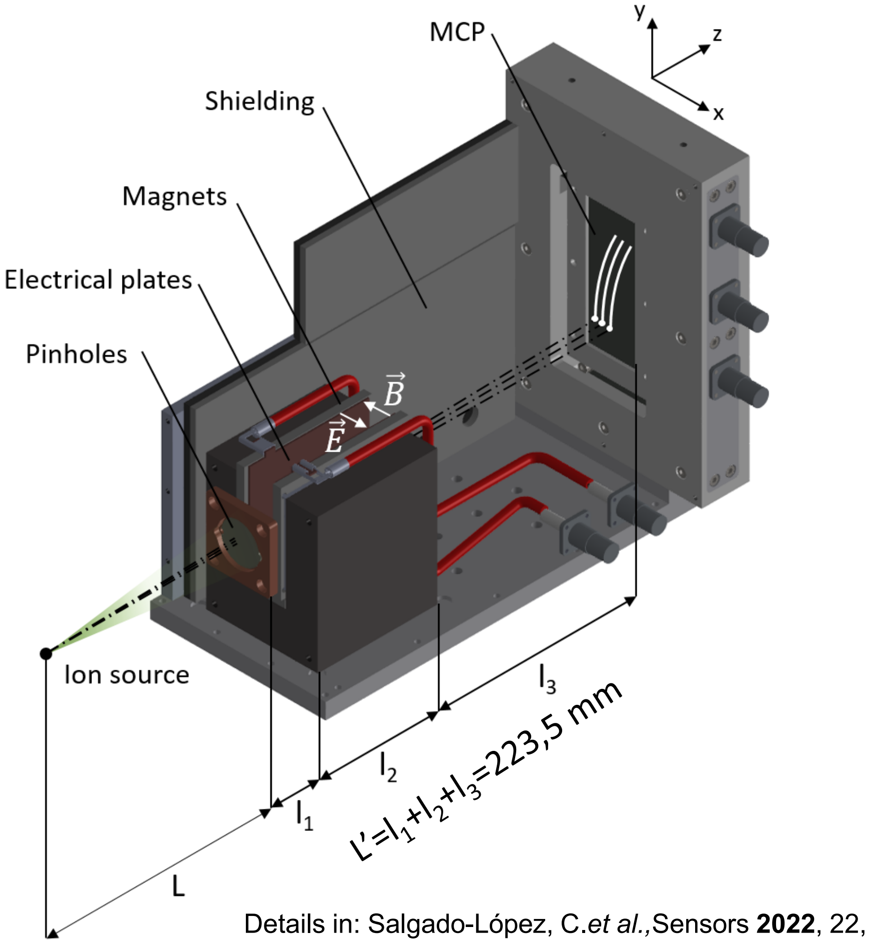
- Species-discrimination (different charge-to-mass ratio species)
- Fine spectral resolution for extremely broadband beams
  - Available range 0,3 - 25 MeV with ΔE (@20 MeV) = 1,3 MeV
- Main drawback: **lack of angular resolution**

Mask pinhole array = multiple traces (tomography-like measurement)

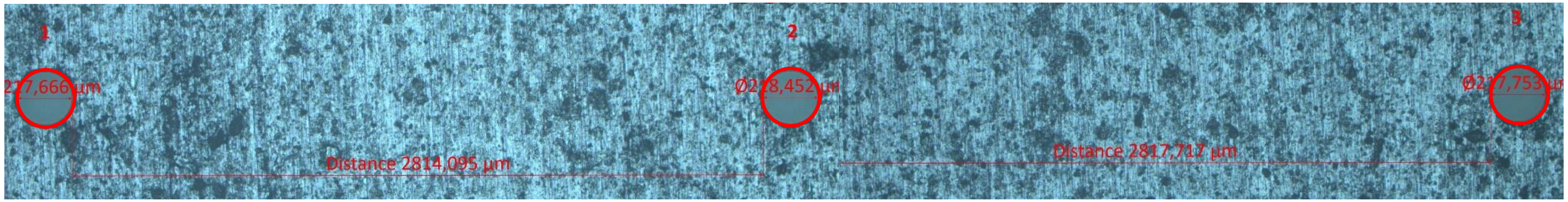


$$y^2 = \frac{q}{m}\frac{l_2 l_3 B^2}{E} x$$

Access to all (or partially) information **simultaneously** in single-shot HHR

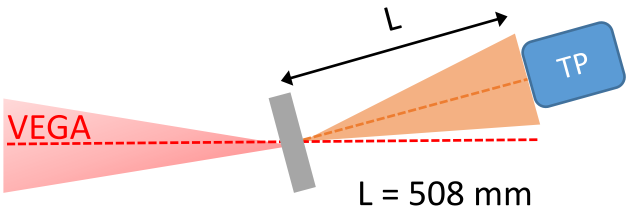


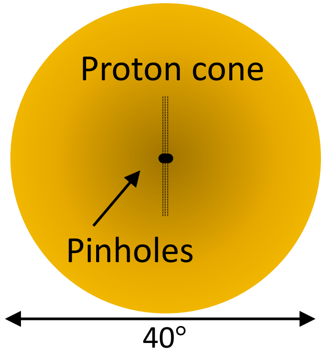
Details in: Salgado-López, C. *et al.*, Sensors **2022**, 22, 3239. https://doi.org/10.3390/s22093239



Setup 1: small magnification, 3 pinholes

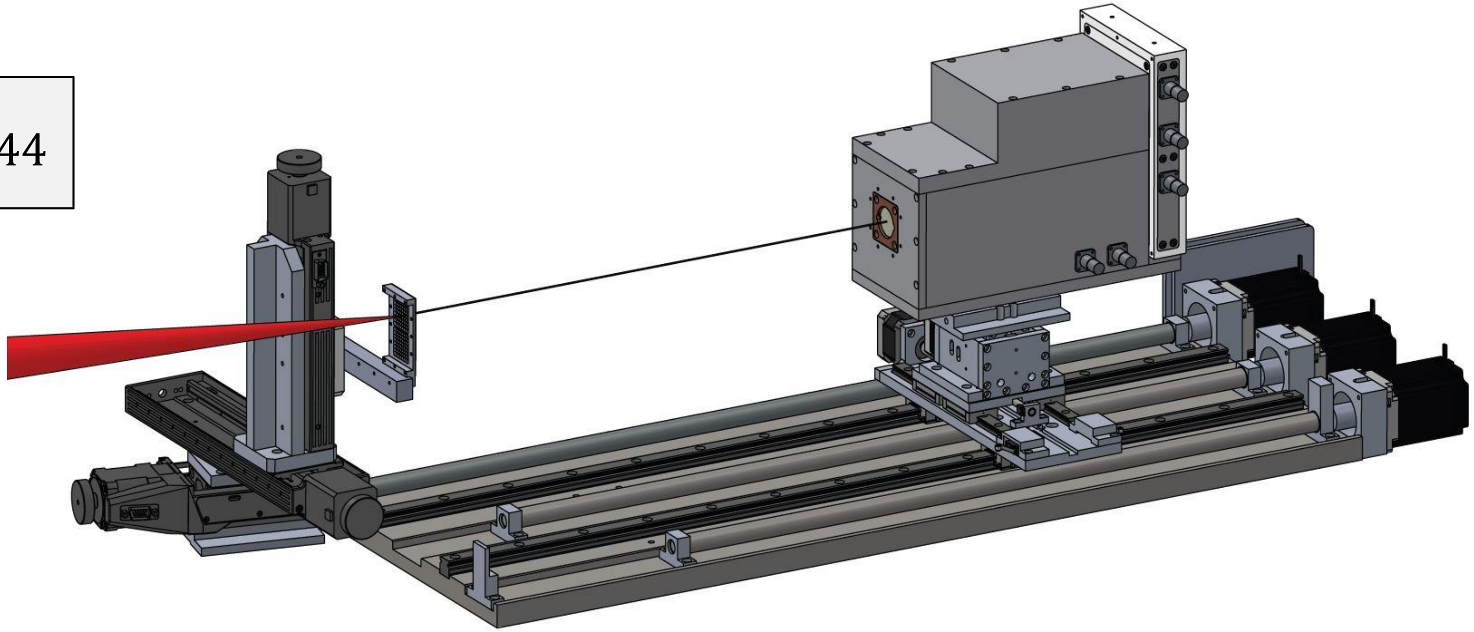
PW laser **VEGA 3**:
- E = 11 J
- λ = 760 - 840 nm (Ti:Sa)
- τ = 180 fs
- OAP F/11: 10 µm ø spot
- p-pol, AOI 10º
- $I_{FWHM} \approx 2 \times 10^{19}$ W/cm^2
- 3 µm Al target

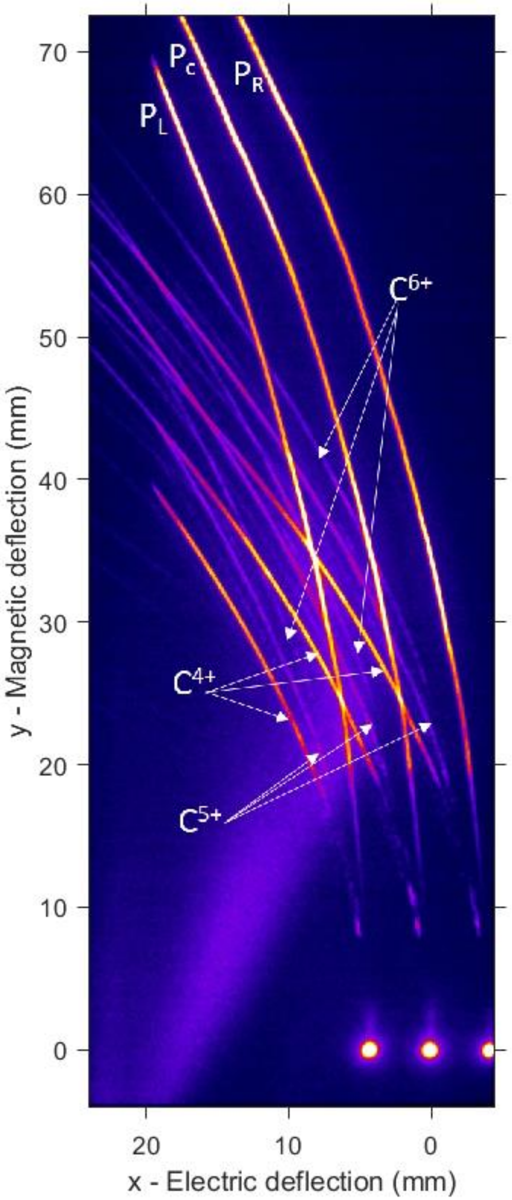




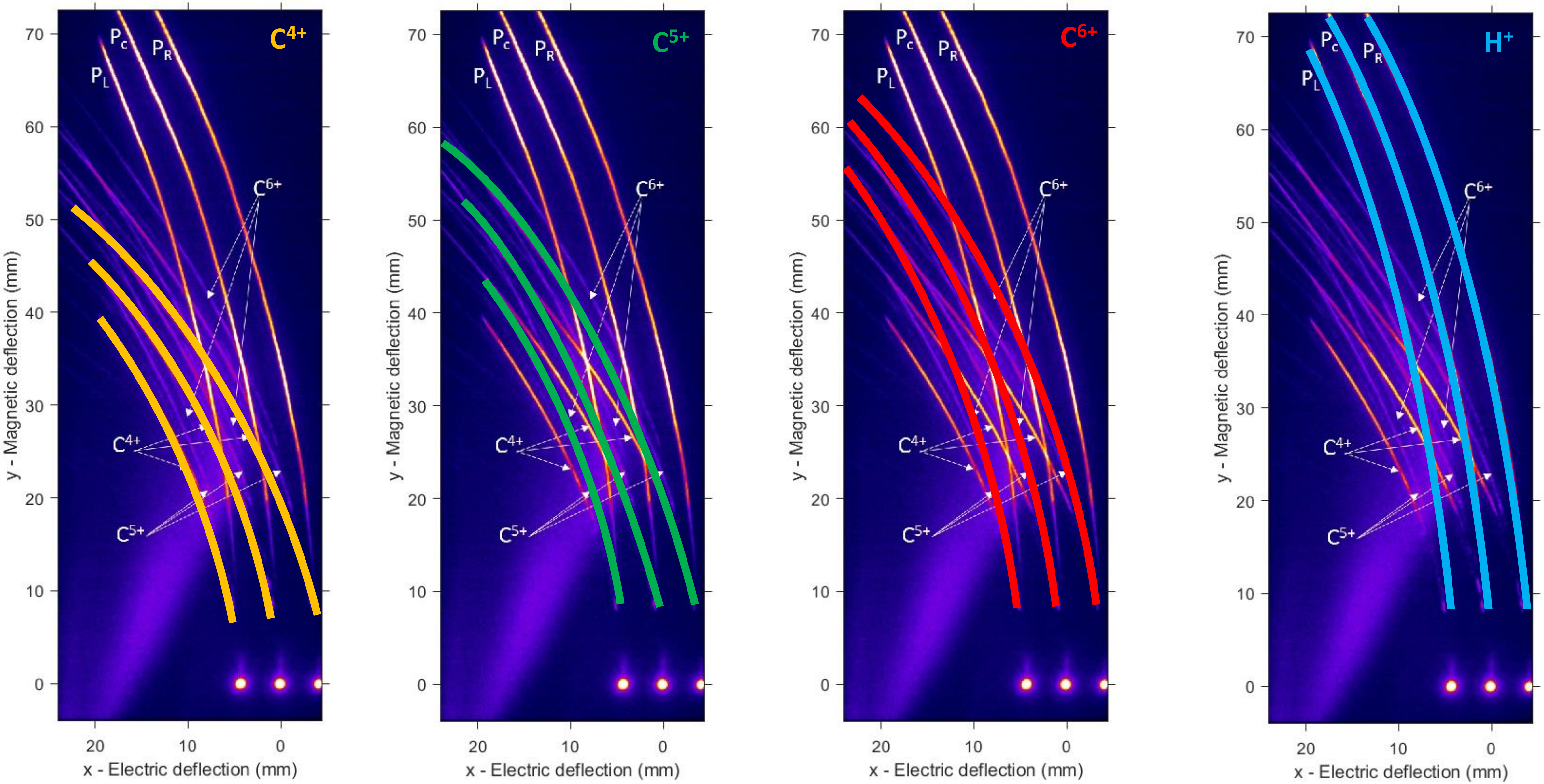
$\Delta\alpha = 0{,}3°$

$$\frac{L'}{L} = 0{,}44$$

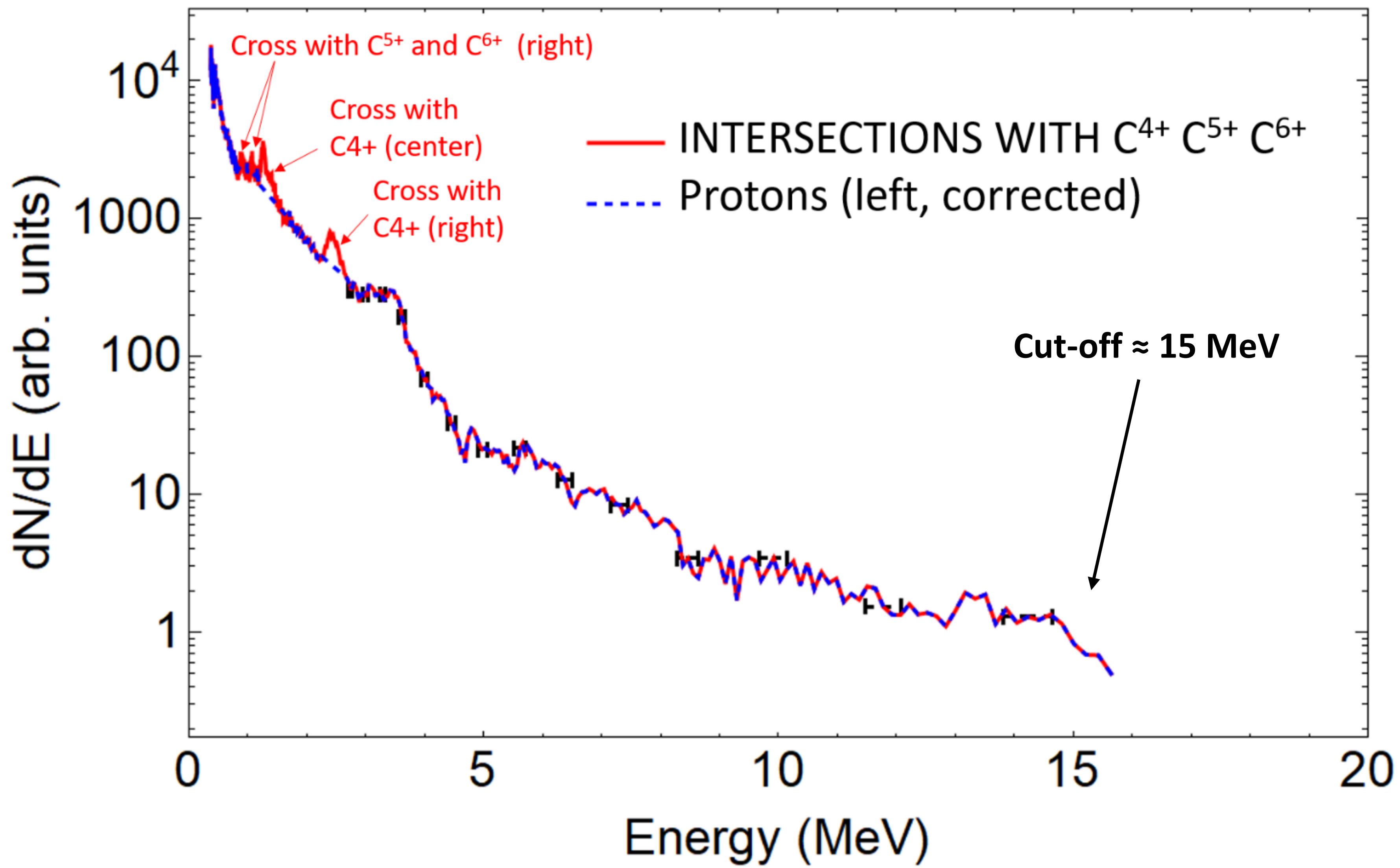


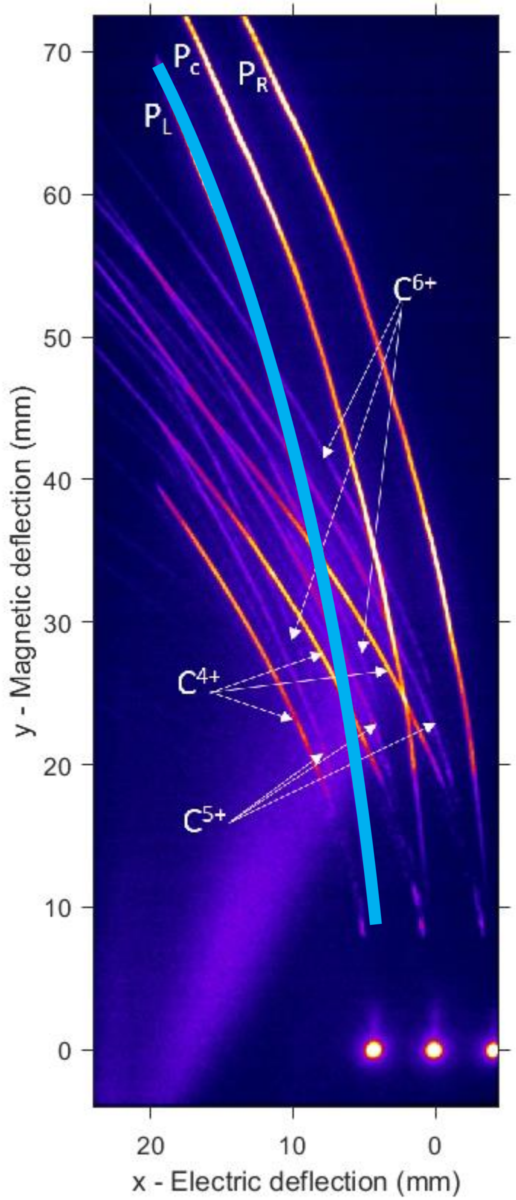


Setup 1: species identification

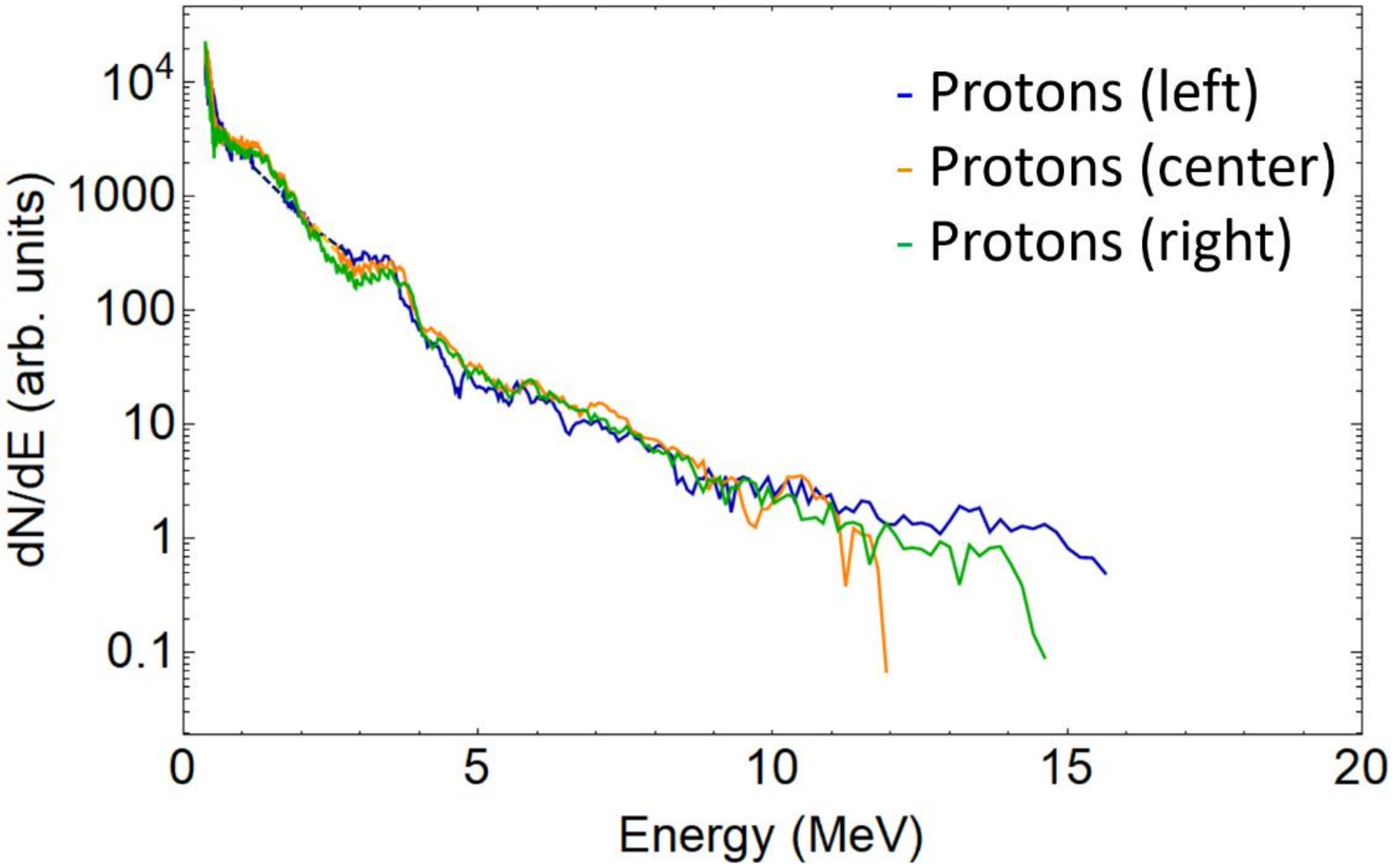


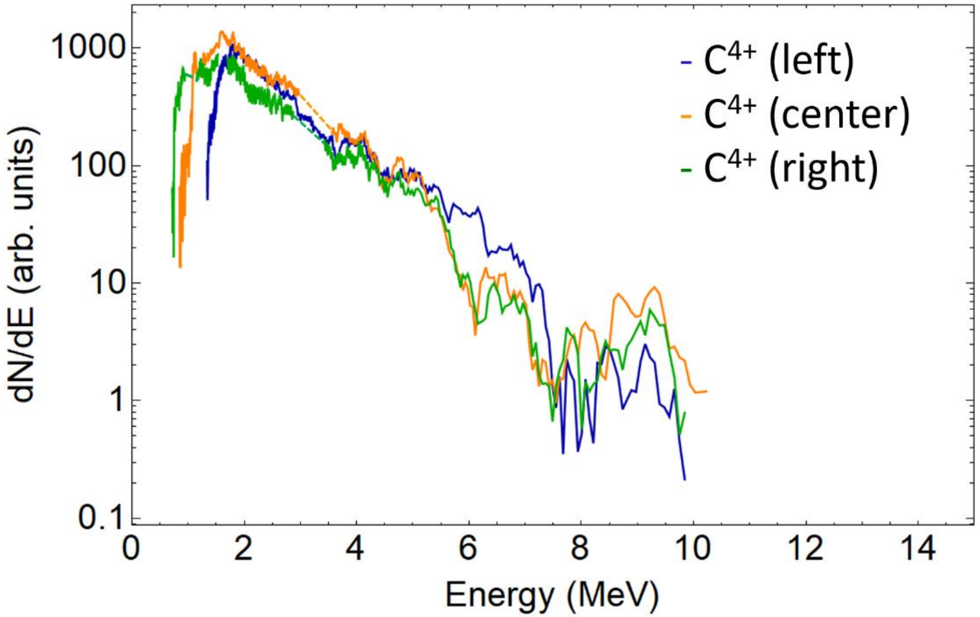
Setup 1: proton spectrum

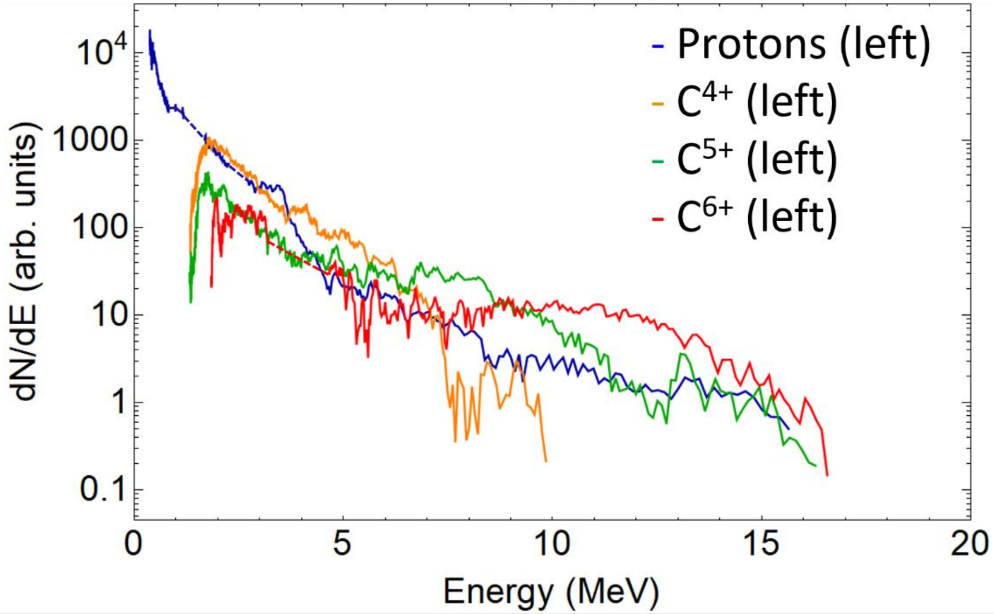




Setup 1: spectra comparison



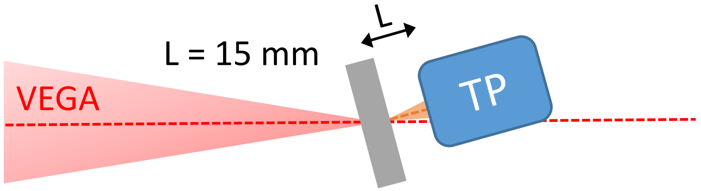


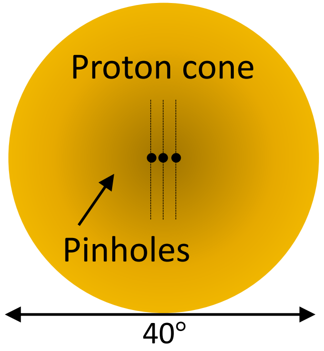


Step forward: improve **resolution** + increase **area** probed

PW laser VEGA 3:
- E = 22 J
- τ = 240 fs
- $I_{FWHM} \approx 3 \times 10^{19}$ W/cm^2
- 6 µm Al target

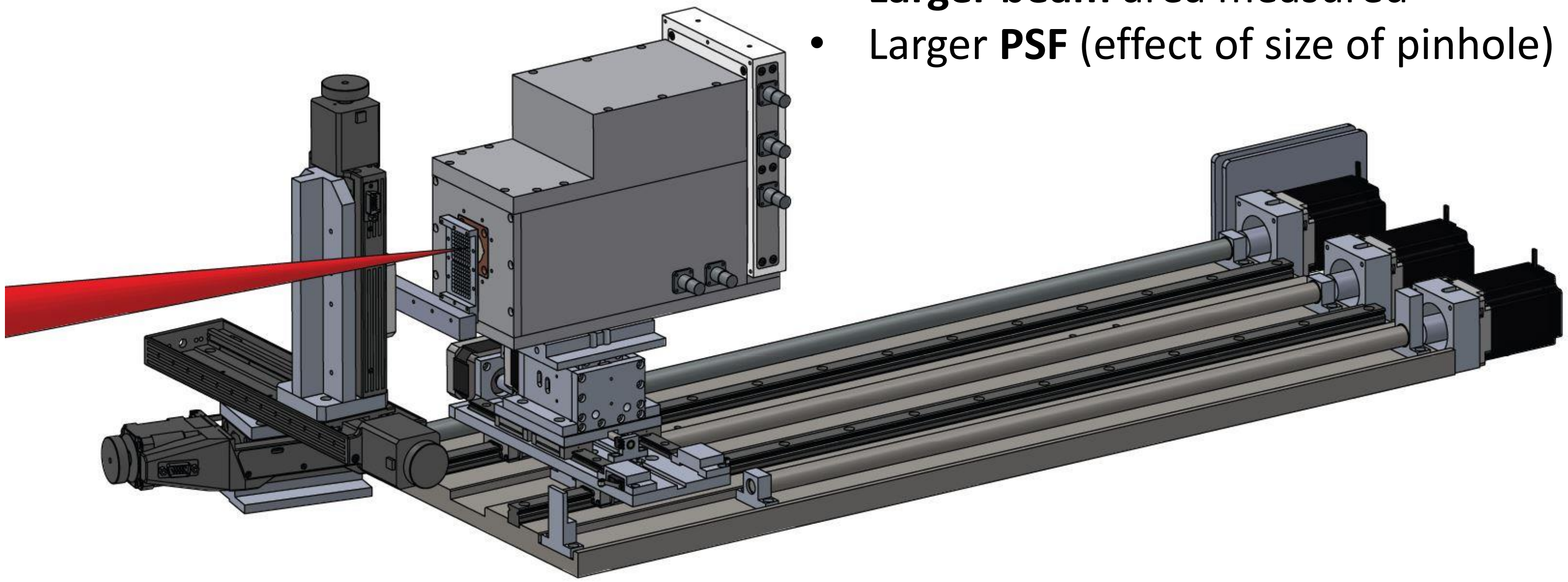
$$\frac{L'}{L} = 15$$

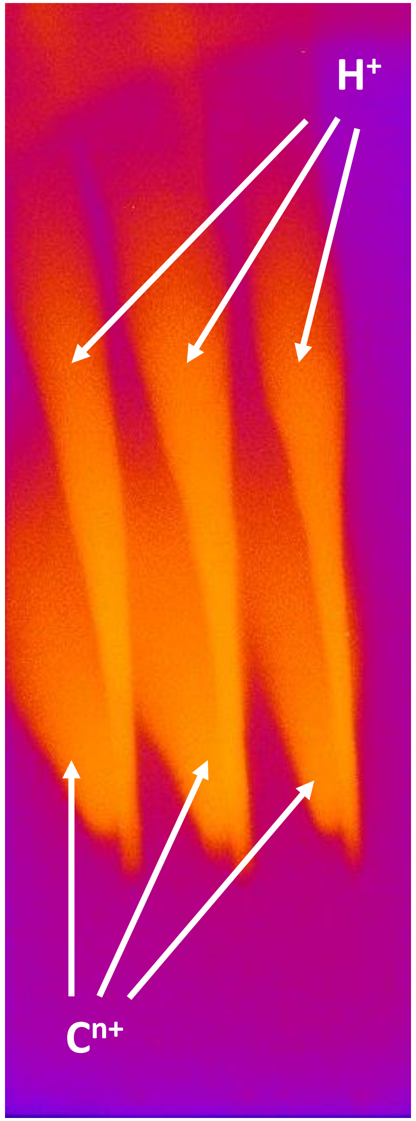




$$\Delta\alpha = 2°$$

Look the beam closely means:
- **Thicker traces** (spatial and angular resolution, higher angular acceptance of individual pinholes) – but less spectral resolution
- **Larger beam** area measured
- Larger **PSF** (effect of size of pinhole)



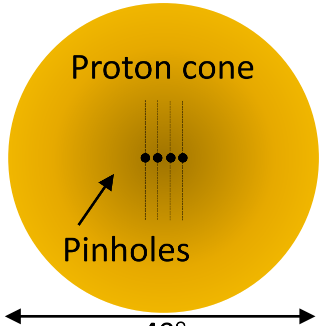


Setup 3: larger magnification, scintillator, 4 pinholes

New device configuration:

- 4 pinholes
- Active detector for particles: 1,5mm-thick BC-400 plastic scintillator
- Light/Carbon ions shielding: 12µm-thick Pokalon film
- Active detector for X-rays: Lanex scintillating screen
- Absence of carbon ions: switch off E-field

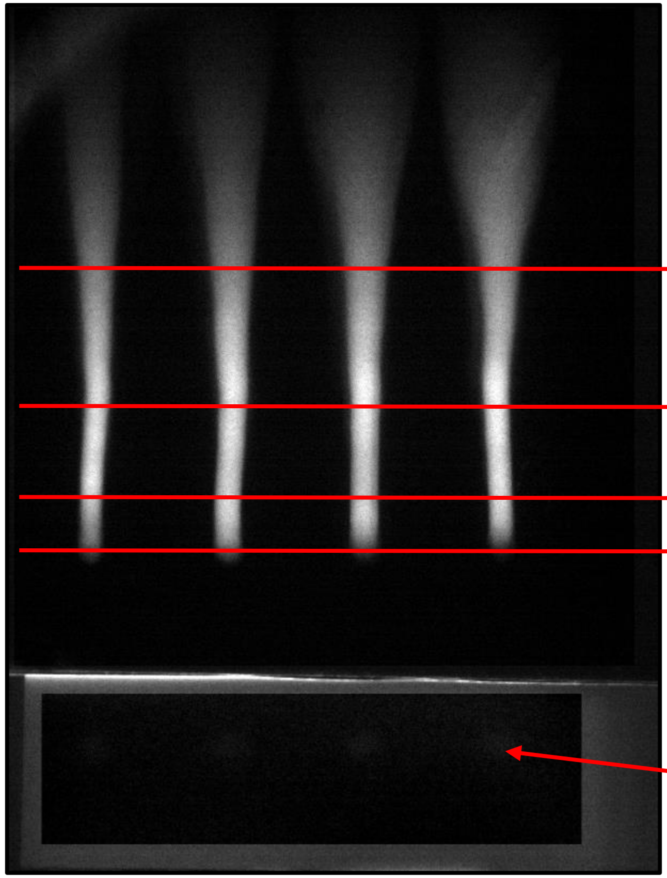
Within angular acceptance of beam transport optics



$\Delta\alpha = 2°$

L' increased

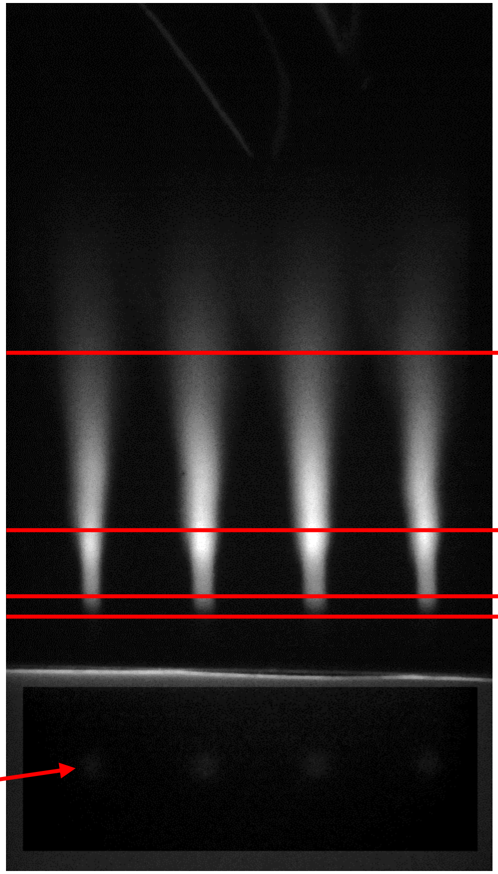
$$\frac{L'}{L} = 25$$



X-ray spots

Same L'

$$\frac{L'}{L} = 15$$



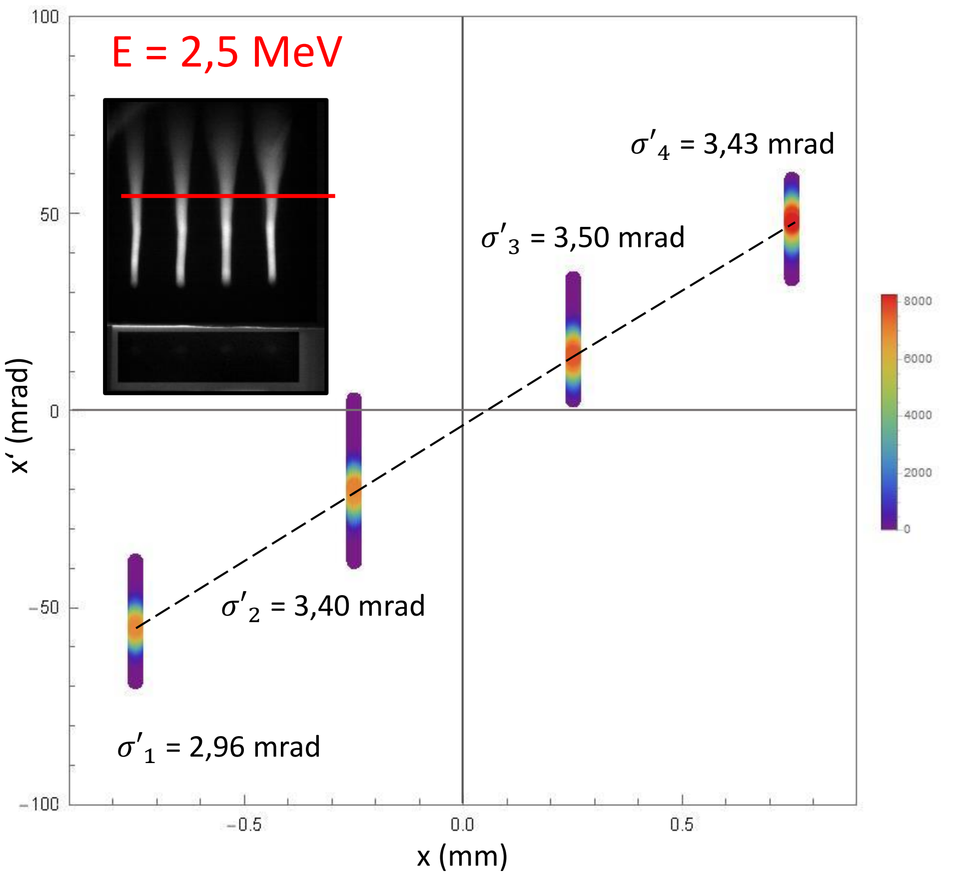
Setup 3: trace space

Raw trace thickness deconvolved with square function of pinhole aperture projection onto detector

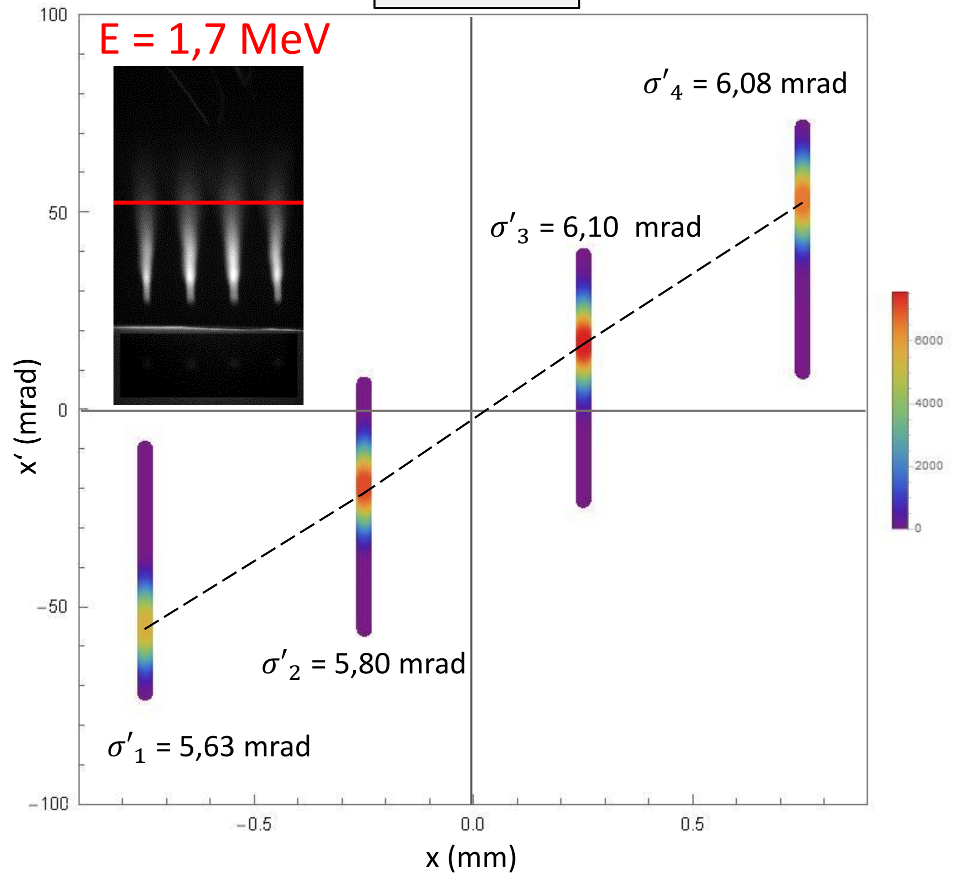
σ'_i = rms divergence of i-th beamlet

Energy-resolved horizontal **trace-space** (at pinhole plane)

$$\frac{L'}{L} = 25$$



$$\frac{L'}{L} = 15$$



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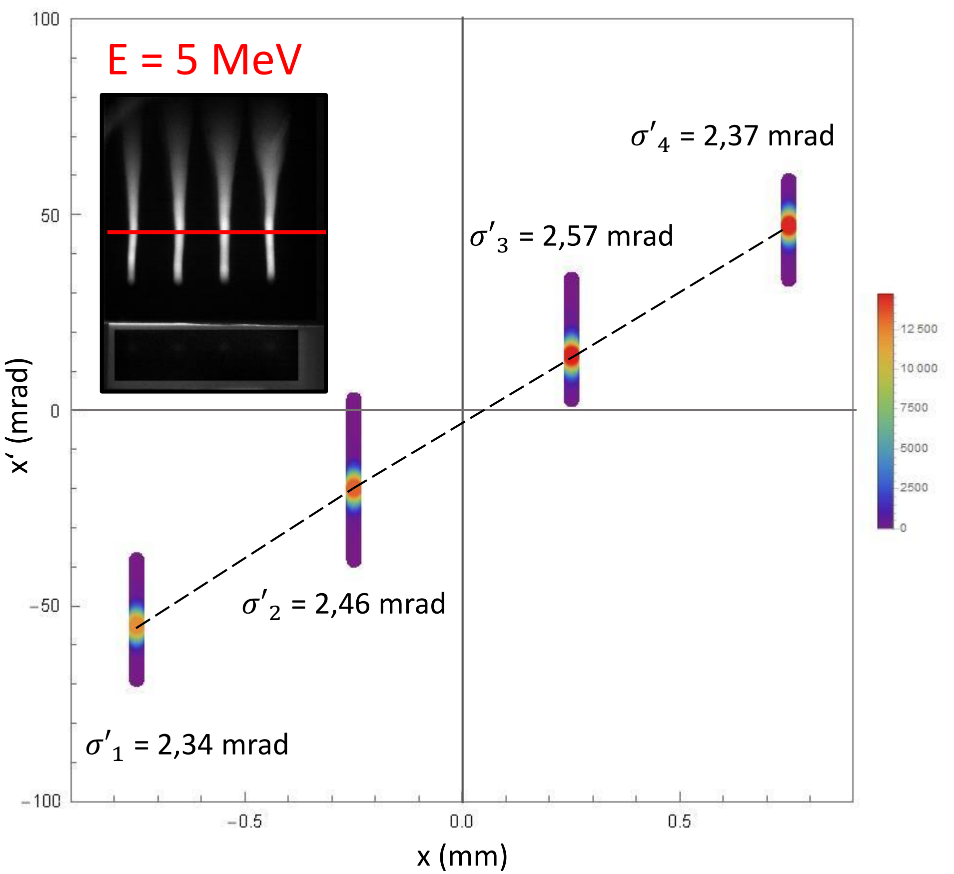

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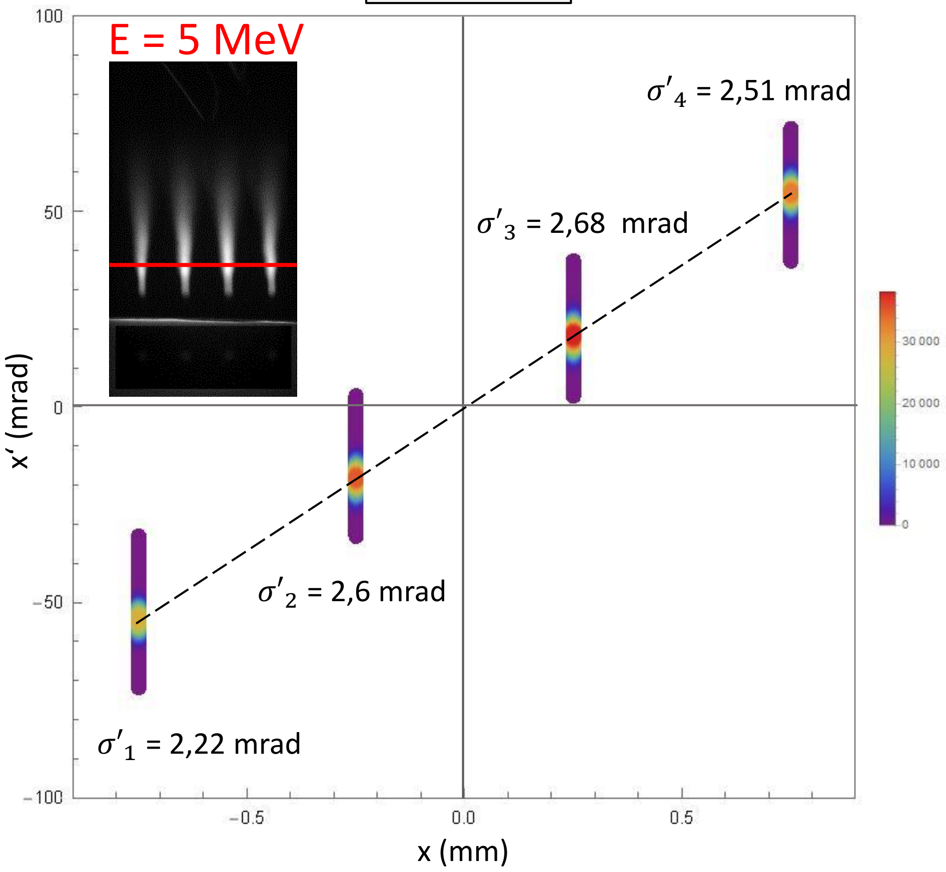

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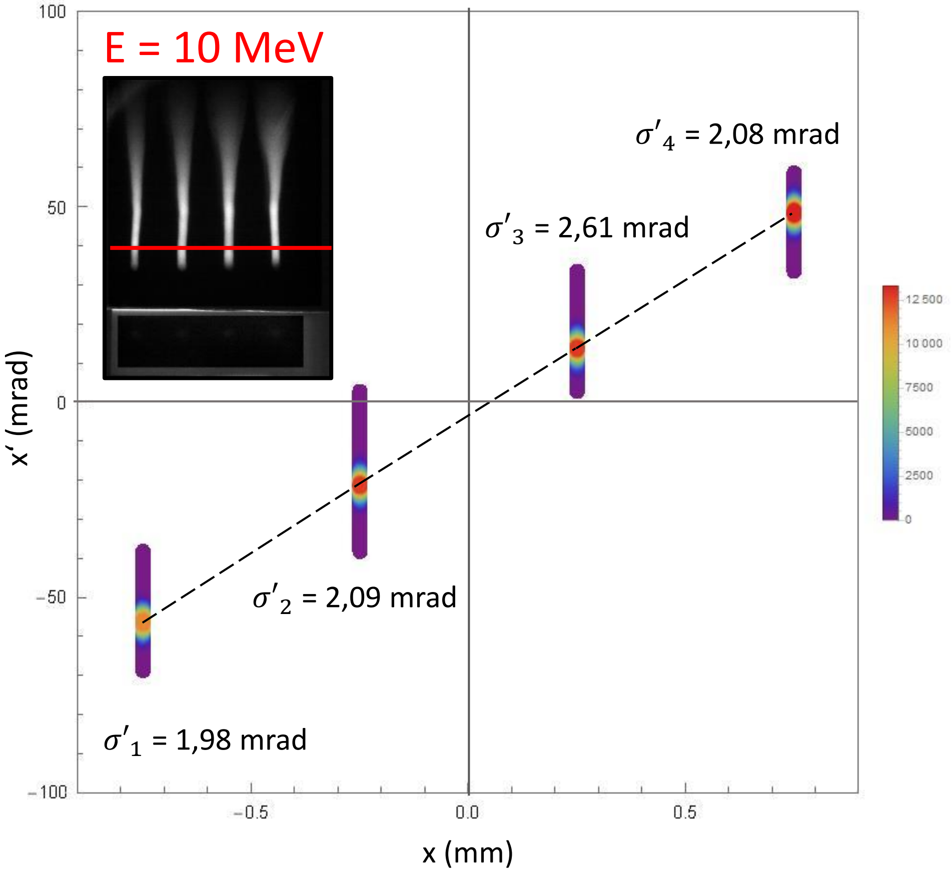

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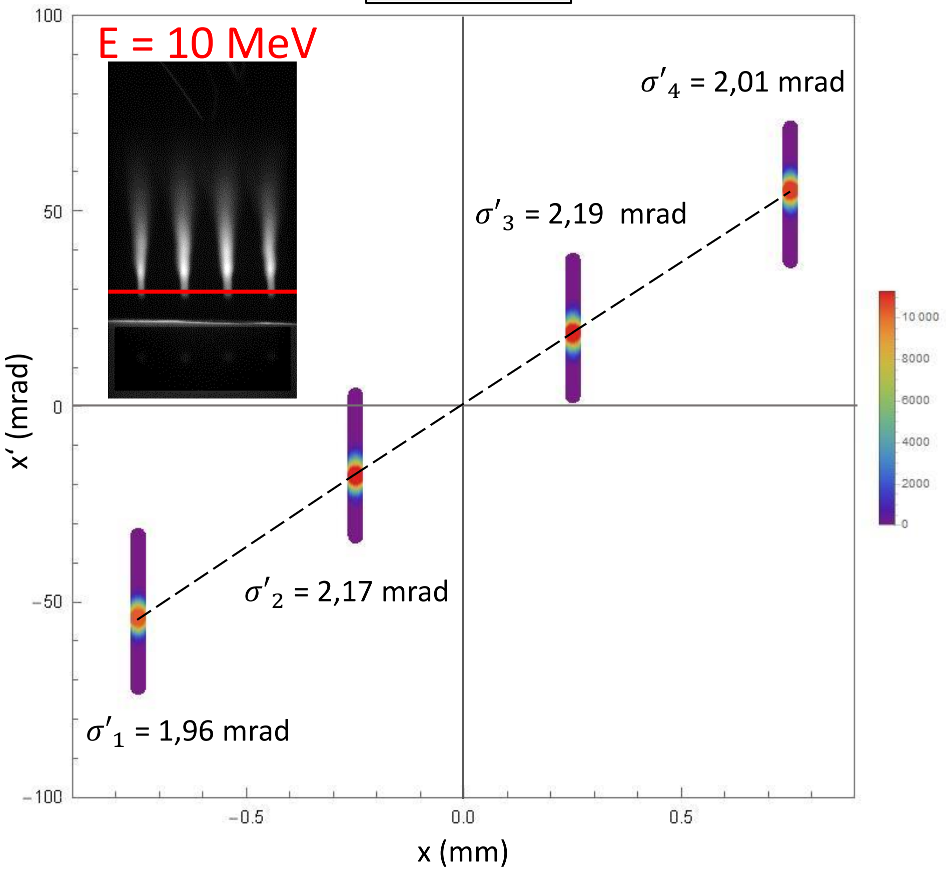

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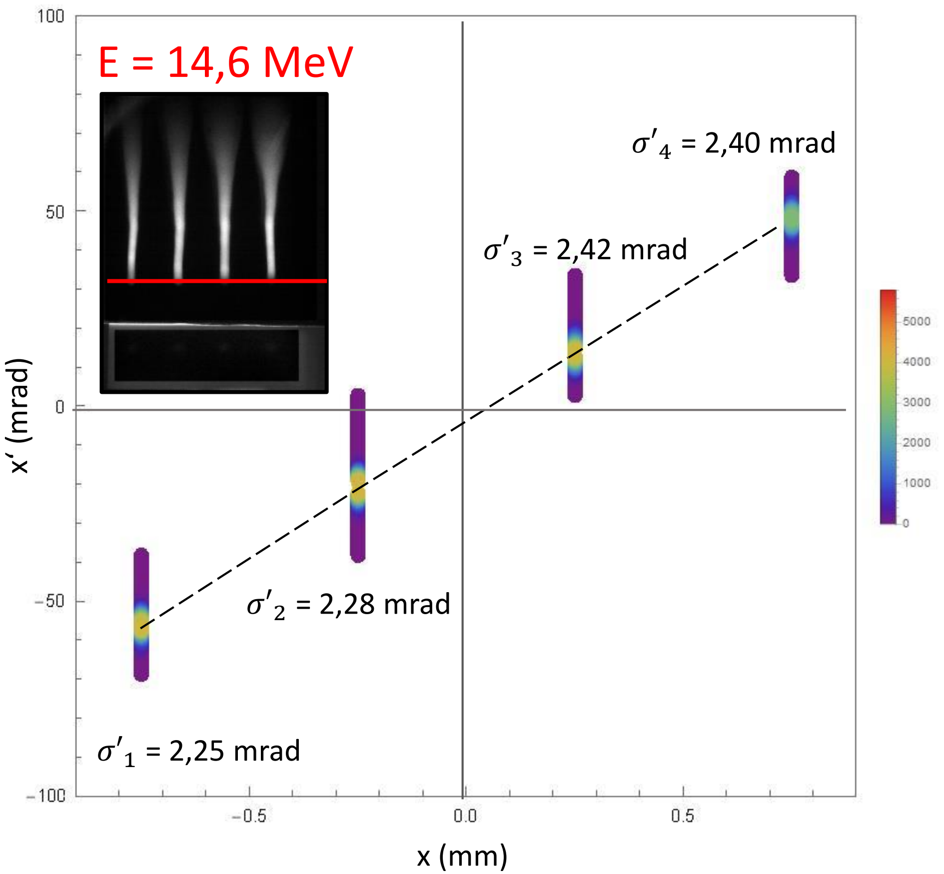
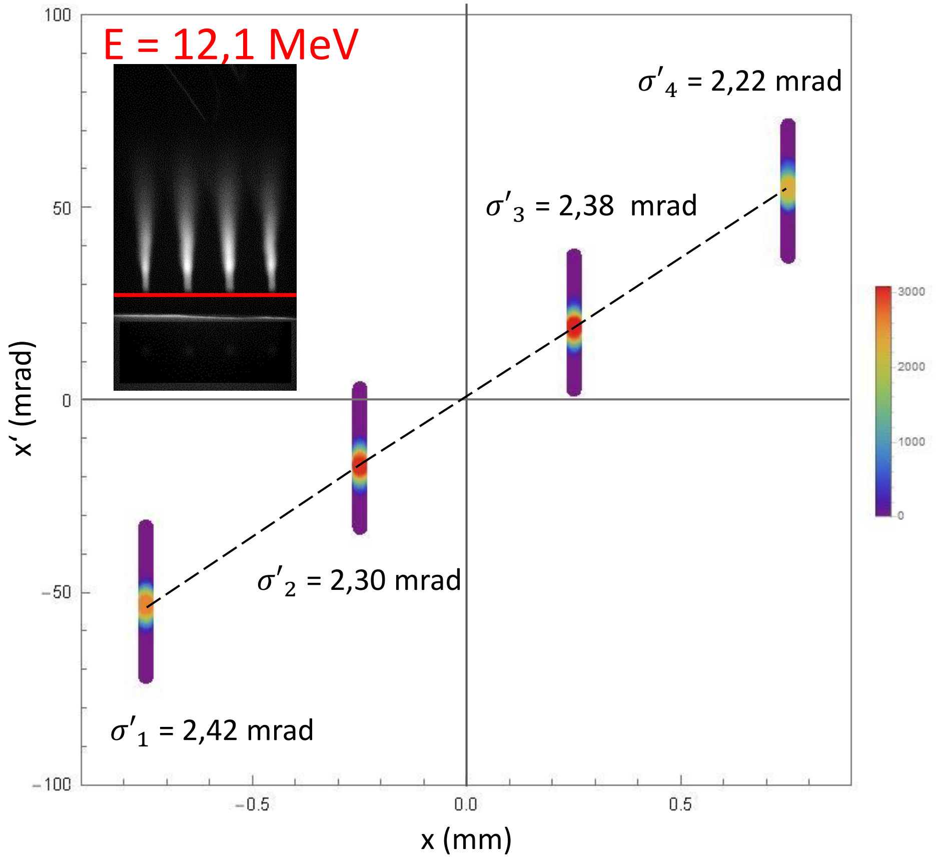


$\frac{L'}{L} = 15$

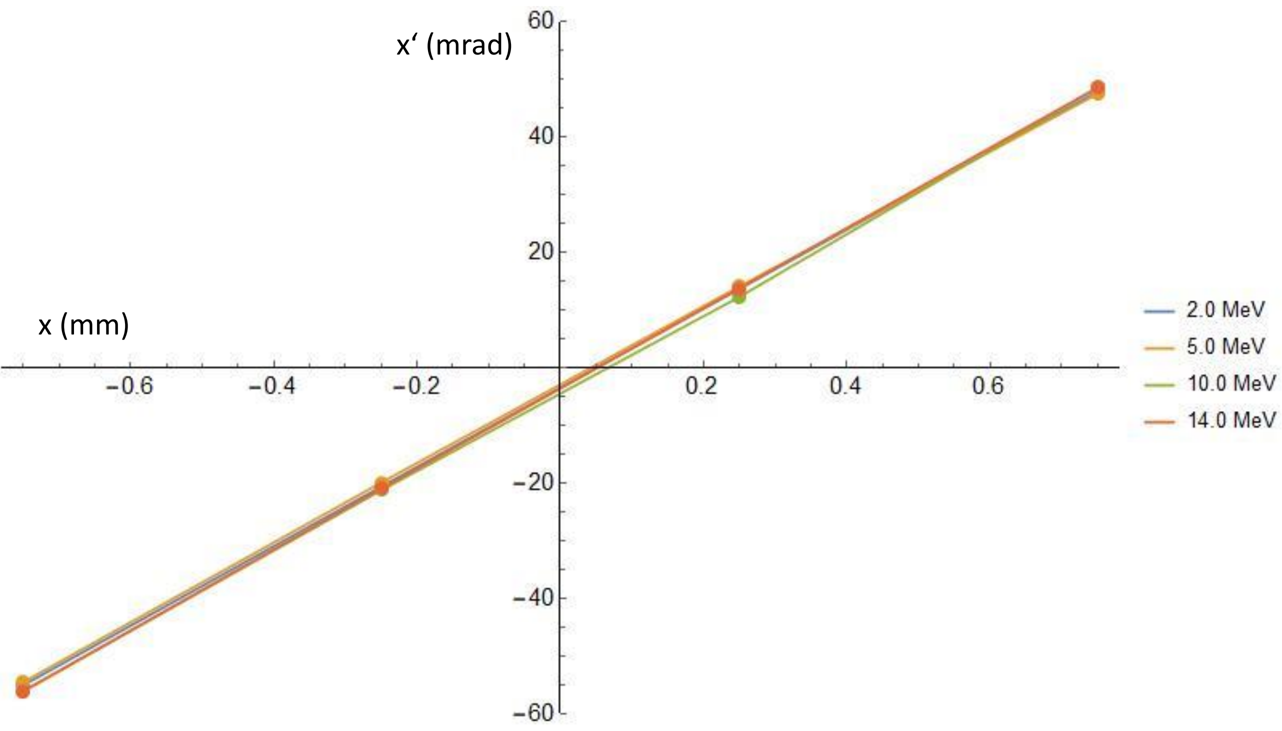


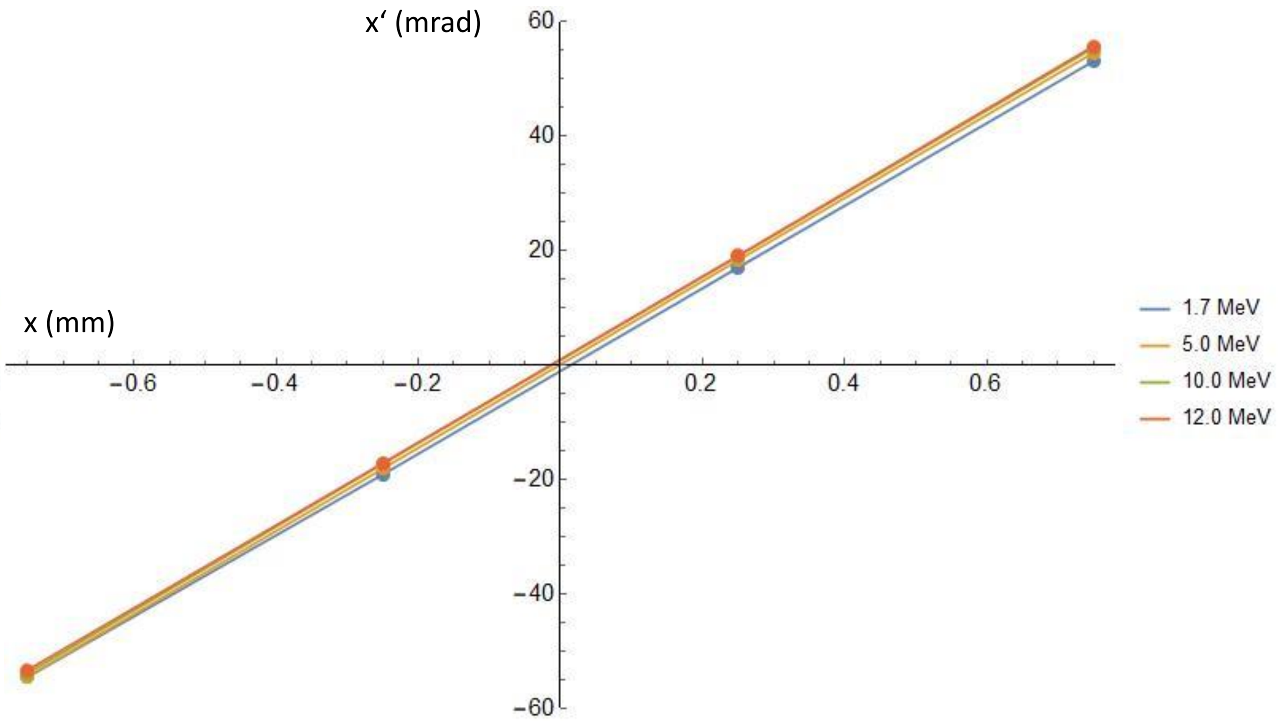
Setup 3: barycenter

Almost linear correlation

$$\frac{L'}{L} = 25$$

$$\frac{L'}{L} = 15$$





Setup 3: Horizontal rms geometrical emittance

Slit-method (1D pepper-pot) analogy yields horizontal emittance

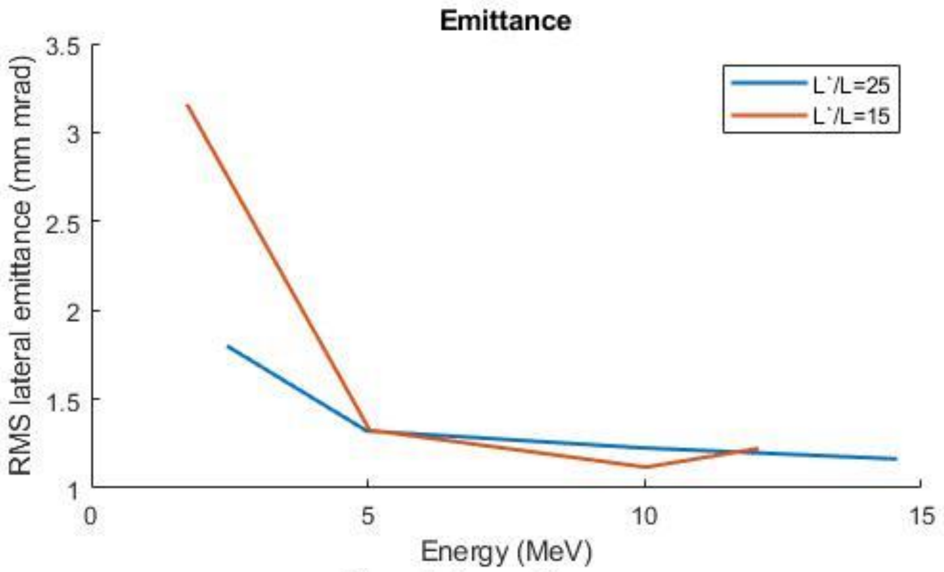
$\frac{L'}{L} = 25$

$\varepsilon_{2,5MeV}$ = 3,35 mm mrad
ε_{5MeV} = 2,45 mm mrad
ε_{10MeV} = 1,23 mm mrad
$\varepsilon_{14,6MeV}$ = 1,16 mm mrad

$\frac{L'}{L} = 15$

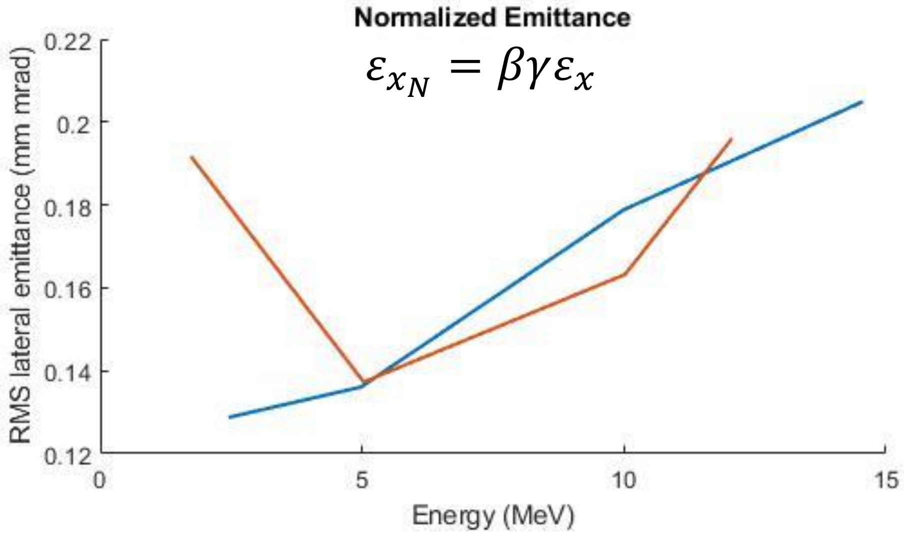
$\varepsilon_{1,7MeV}$ = 3,16 mm mrad
ε_{5MeV} = 1,33 mm mrad
ε_{10MeV} = 1,12 mm mrad
$\varepsilon_{12,1MeV}$ = 1,22 mm mrad

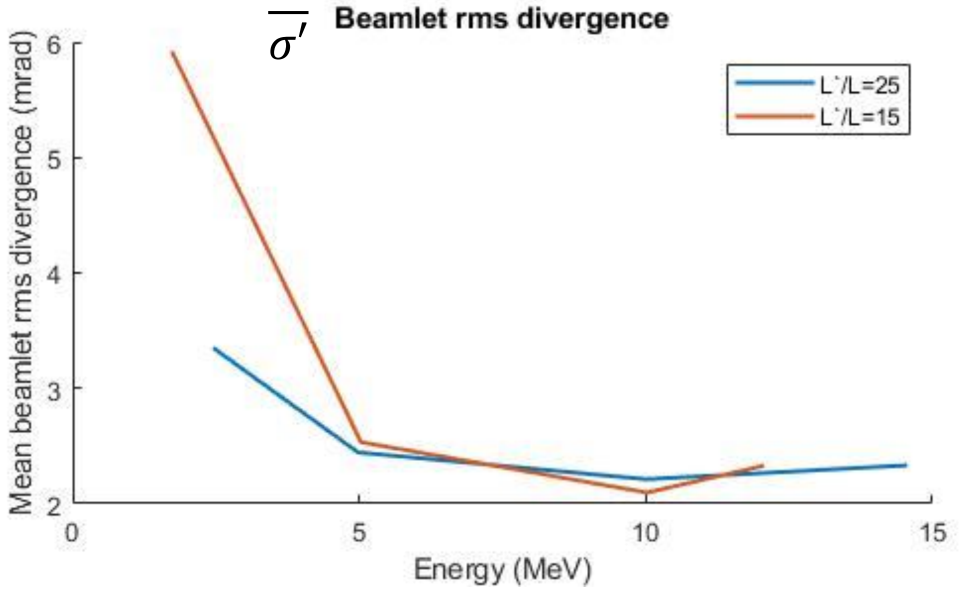
Relative Error < 10%



$$\varepsilon_x^2 = \langle x^2 \rangle \langle x'^2 \rangle - \langle x x' \rangle^2$$

$\int \varepsilon(E)$= total emittance





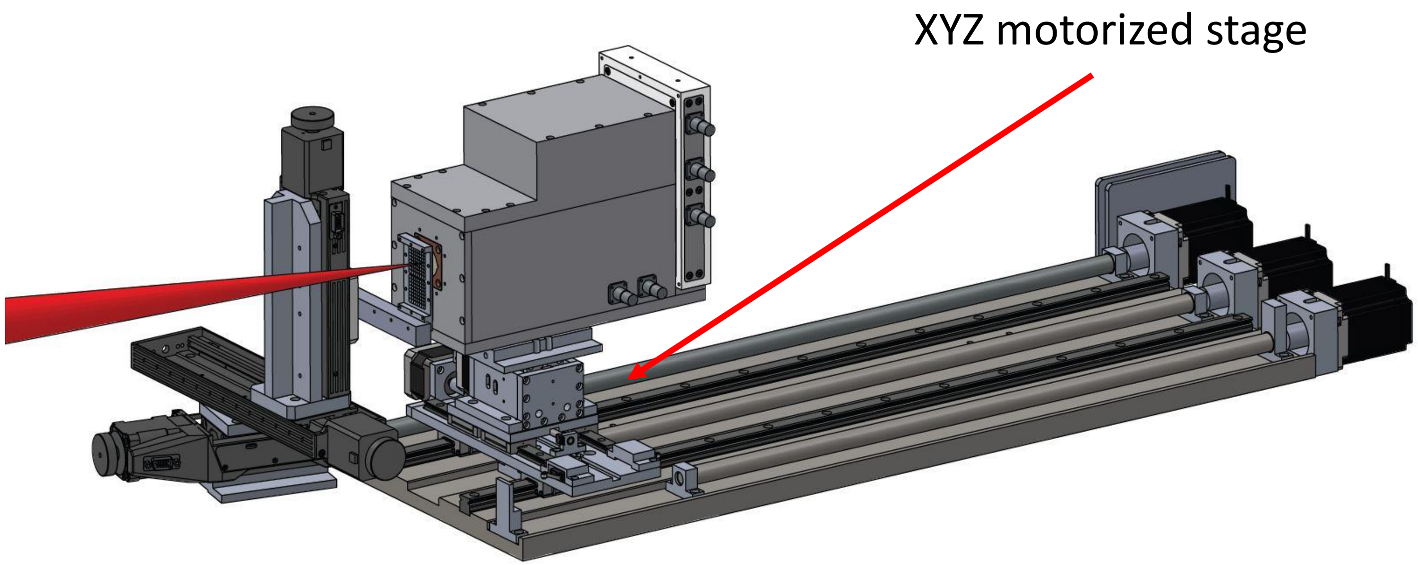
Previous TNSA results:

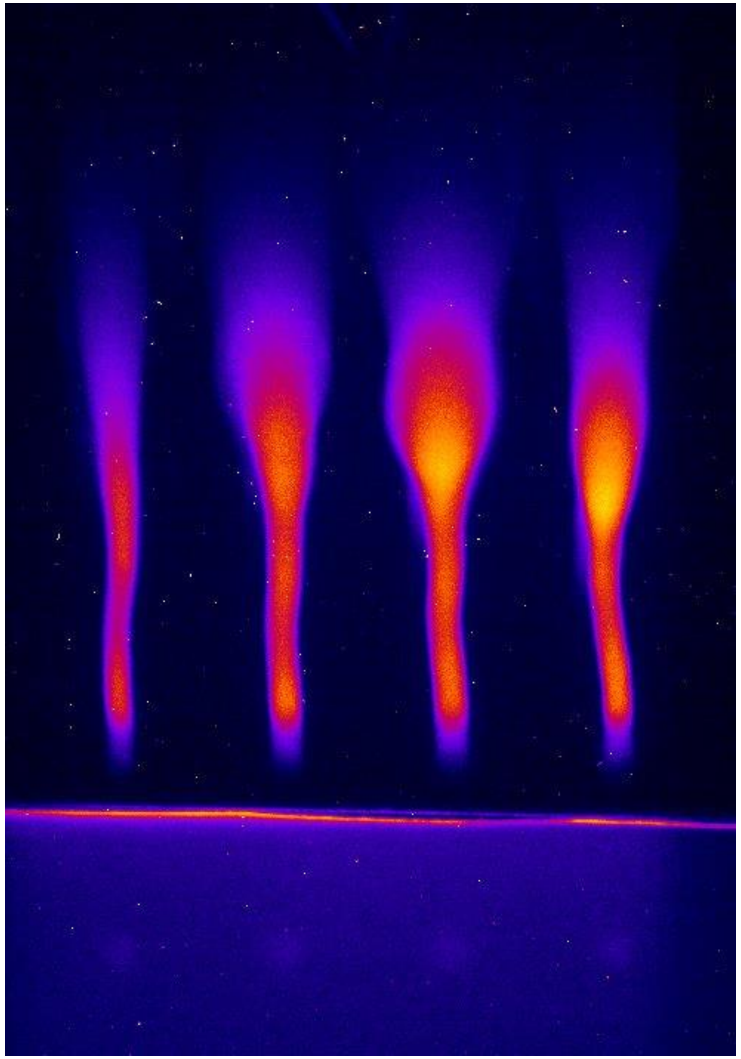
- Cowan *et. al.*, PRL 2004. $\boldsymbol{\varepsilon_{x_N} = 0,0126}$ **mm mrad** (for >10 MeV protons)
- Borghesi *el al.*, PRL 2004. $\boldsymbol{\varepsilon_{x_N} = 0,3}$ **mm mrad** (for 15 MeV protons)

Setup 3: Full beam scan

By repositioning the detector: full angular scan was done at VEGA 3, data under analysis.

- $\theta_{vertical}$ = -1,8° to 3° in $\Delta\theta \approx$ 0,5° steps
- $\theta_{horizontal}$ = -15° to 15° in $\Delta\theta \approx$ 2° steps





Severe difference between traces/energies have been observed in some shots

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Summary

Angular Resolved Thomson Parabola for Laser-Plasma Accelerators

- **Versatile instrument** development and test for **LPA ion beam characterization**
- **Angular-resolved** (tomography) of **Thomson-Parabola** traces: **energy** and **species differentiation**
- **Energy-resolved** measurement of proton beam **lateral trace space** and **emittance.**
- **Instantaneous** and **single shot, HRR compatible: statistical measurement, beam stability** control …
- Ideal candidate for **beam monitor of LPA transported beams**

Recent published article with technical details and first commissioning test of the device:

Salgado-López, C.et al., Sensors 2022, 22, 3239. https://doi.org/10.3390/s22093239

Article under development for trace-space and emittance measurement

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