PoP beam modelling

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K. Long, 20 September, 2023

Biological measurement programme & proof-of-principle experiment

- Development of radiation biology programme:
  - At existing facilities:
    - Novel (e.g. laser driven)
    - Conventional

  Josie, Jason, Yolanda taking steps …

- LhARA proof-of-principle experiment:
  - CW: "… include as many of key LhARA elements as possible …"

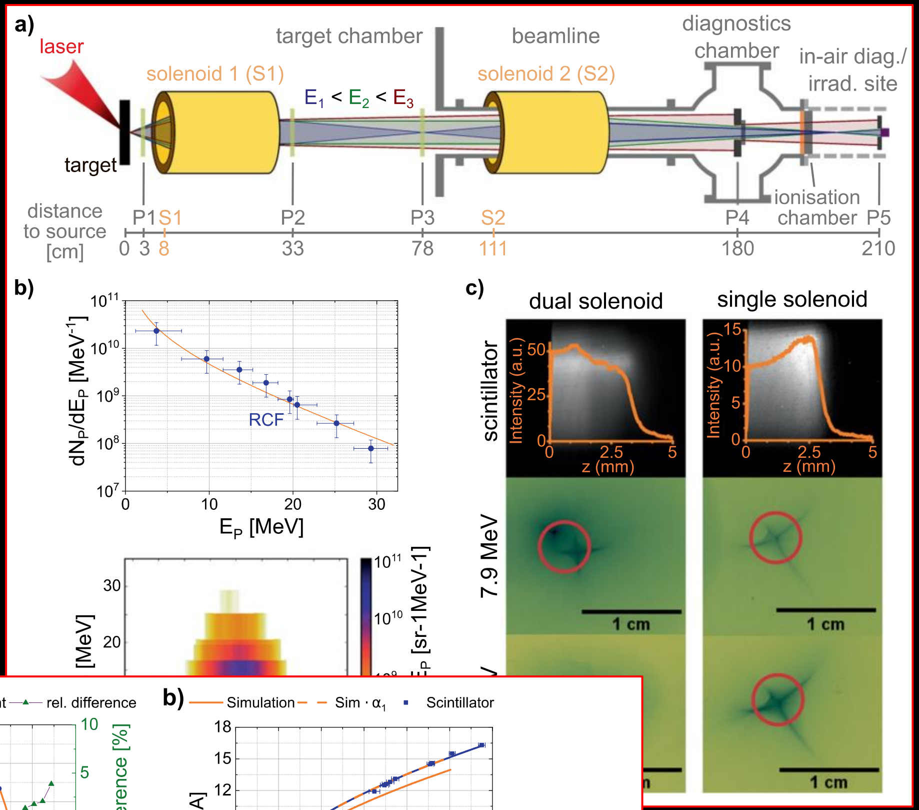
  Focus of today's discussion

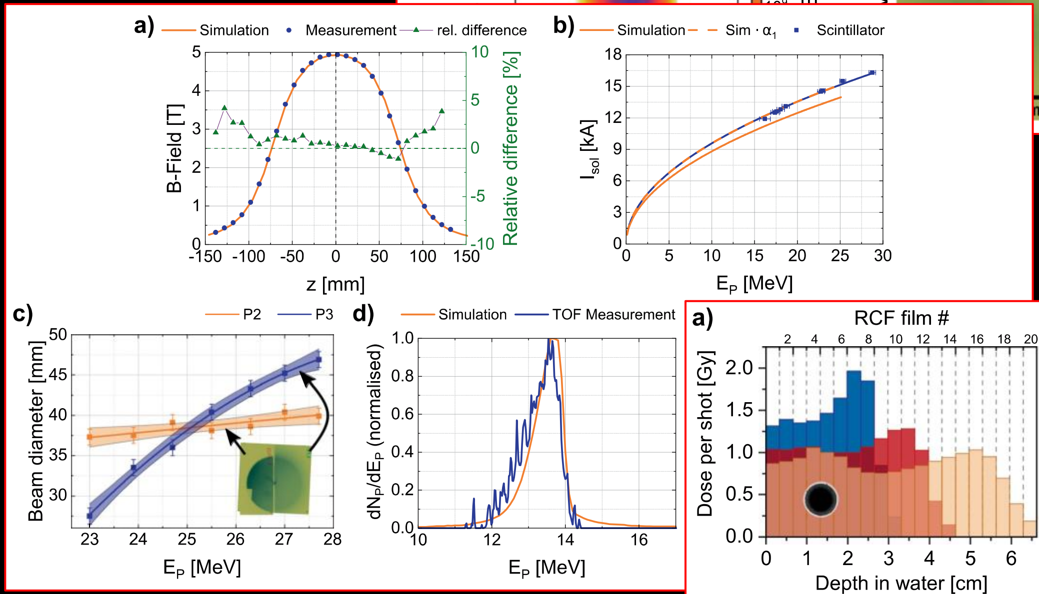
Laser-driven beams for rbio: example 1

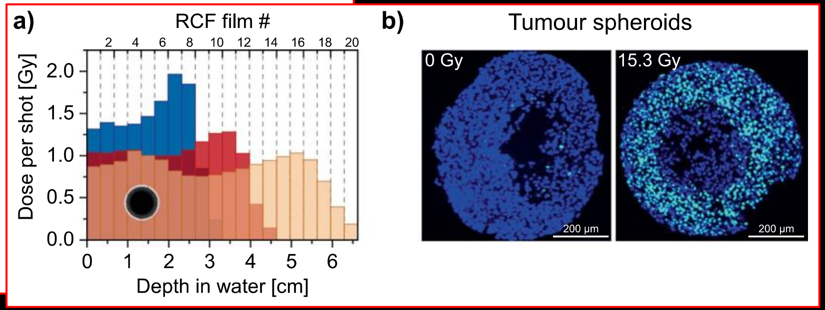
On Draco @ HZDR

DOI: 10.1038/s41598-020-65775-7

- **Draco:**
  - Petawatt laser
    - E = 13 J, τ = 30 fs, 3 µm FWHM
- **Beam line:**
  - Target Normal Sheath Acceleration (TNSA)
  - Pulsed solenoid focusing
    - 19.5T, 2 or 3 pulses/min.
    - S1, S2: 40 mm bore
    - Half angle acceptance 14º
  - Measured transmission (18.6 MeV *p*)
    - 50.6% (dual solenoid)
    - 28.6% (single solenoid)





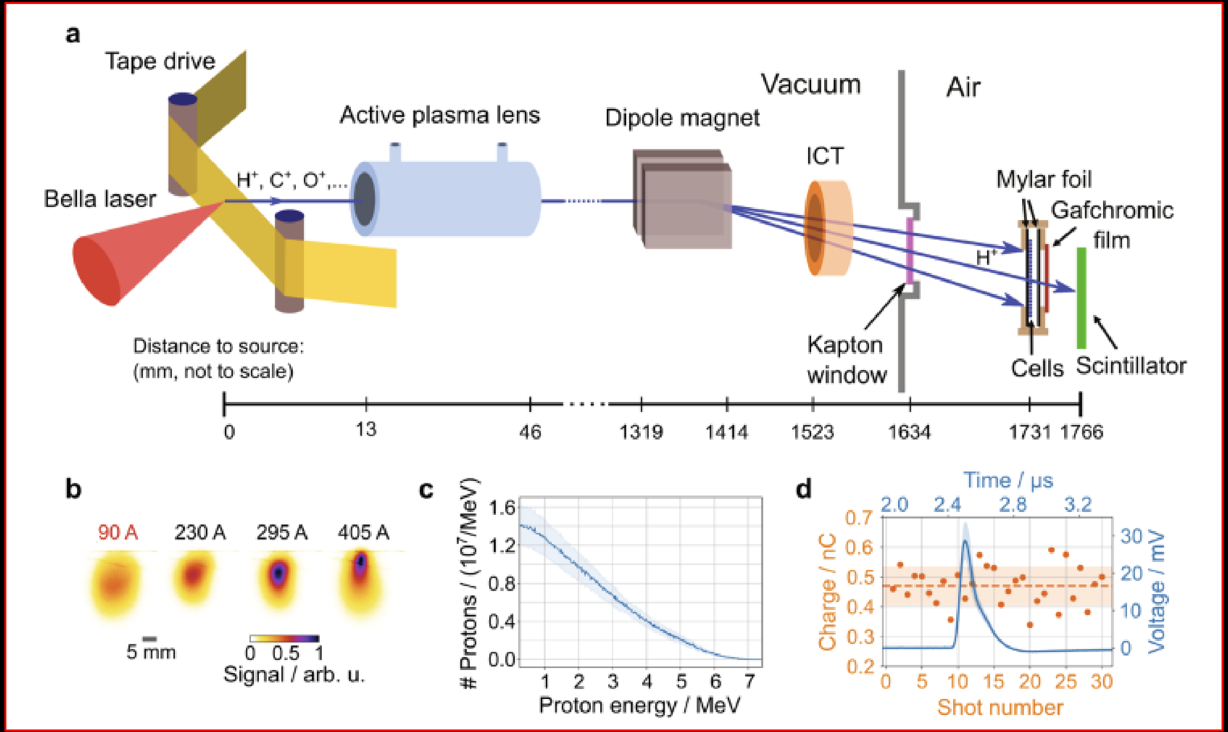


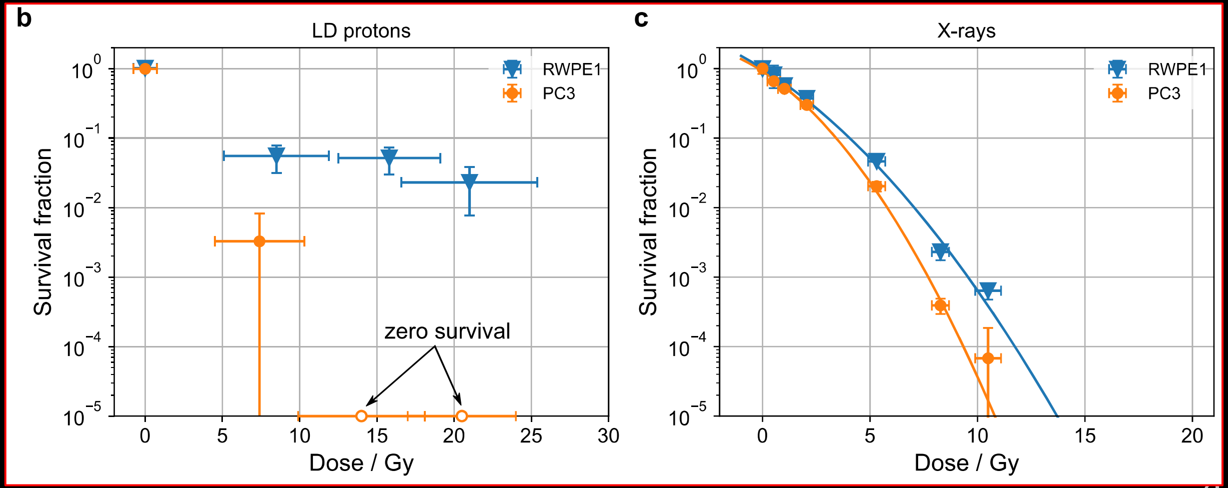
Laser-driven beams for rbio: example 2

On BELLA @ Berkeley

DOI 10.1038/s41598-022-05181-3

- Berkeley Lab Laser Accelerator (BELLA):
  - Petawatt laser
    - E = 35 J, τ = 35 fs, 52 μm FWHM
- Beam line:
  - Target Normal Sheath Acceleration (TNSA)
  - Active plasma lens focusing
    - 1 mm diameter Ar gas filled capillary
    - 33 mm length
    - 13 mm behind the tape drive target
    - ~0.2% transport efficiency for protons with *E* > 1.5 MeV





Variety of initiatives; some key examples

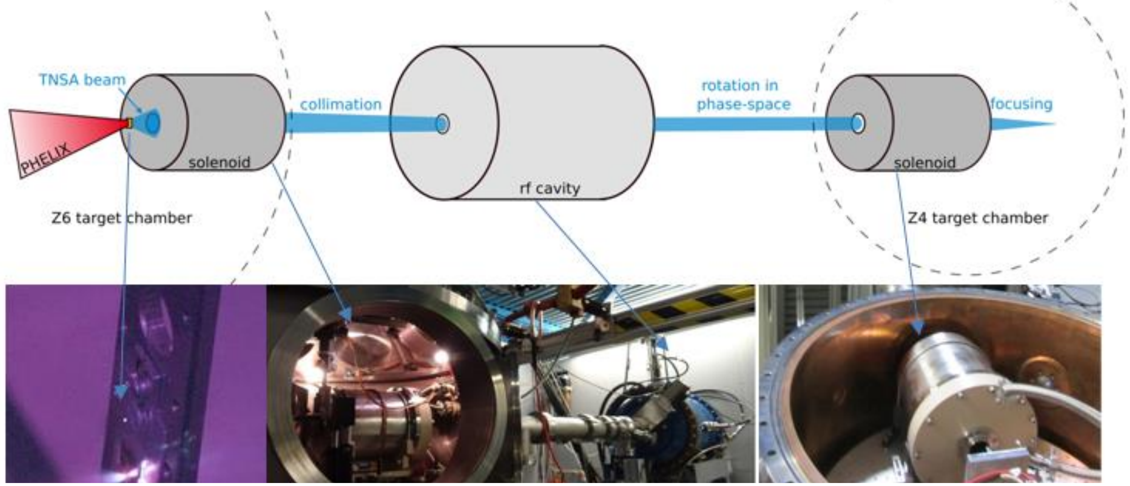
Capture

On PHELIX @ GSI

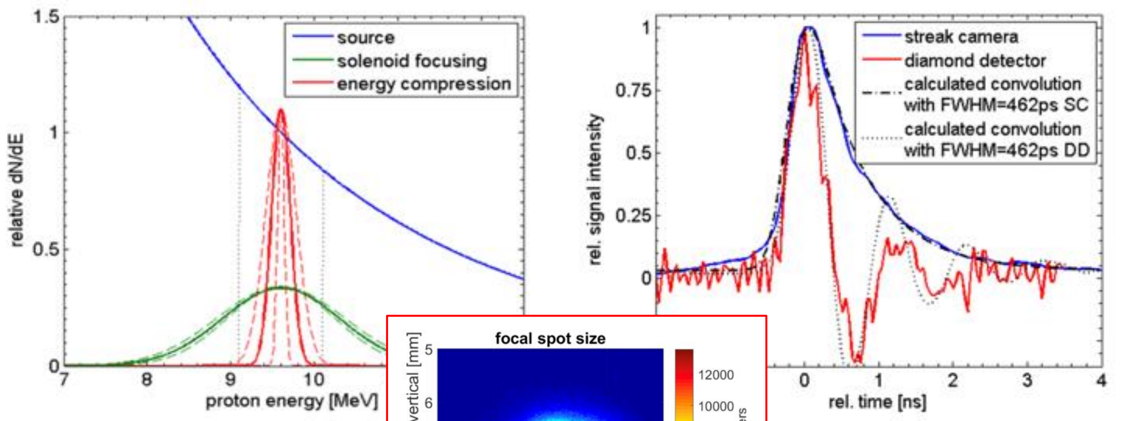
DOI: 10.1063/1.3299391
DOI: 10.1103/PhysRevSTAB.14.121301
DOI: 10.1103/PhysRevSTAB.16.101302
DOI: 10.1103/PhysRevSTAB.17.031302
NIMA 909 (2018) 173–176

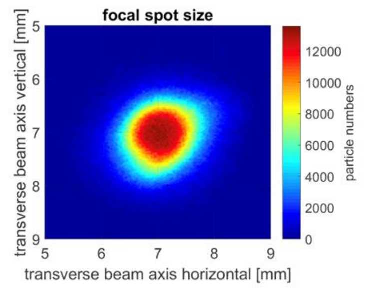
- **PHELIX:**
  - Petawatt High-Energy Laser for Heavy Ion EXperiments
    - E < 25 J, τ = 500 fs, I > 10^{19} J/cm2
- **LIGHT:**
  - Target Normal Sheath Acceleration (TNSA)
  - Ion beam is collimated by a pulsed high-field solenoid
  - Phase rotation in RF cavity
  - Final focus with a second pulsed high-field solenoid

LIGHT – Laser Ion Generation, Handling and Transport



https://www.gsi.de/work/forschung/appamml/plasmaphysikphelix/experimente/light





Variety of initiatives; some key examples

Capture

On CLAPA @ Peking University

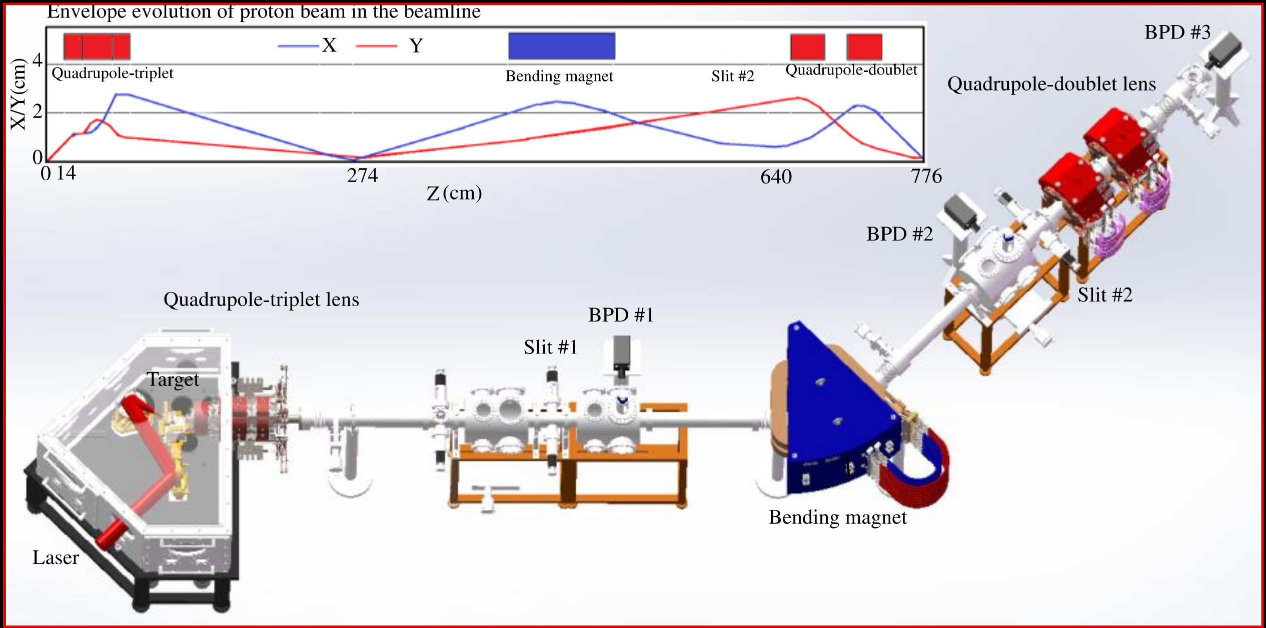
DOI: 10.1103/PhysRevAccelBeams.22.061302
DOI: 10.1103/PhysRevAccelBeams.23.121304

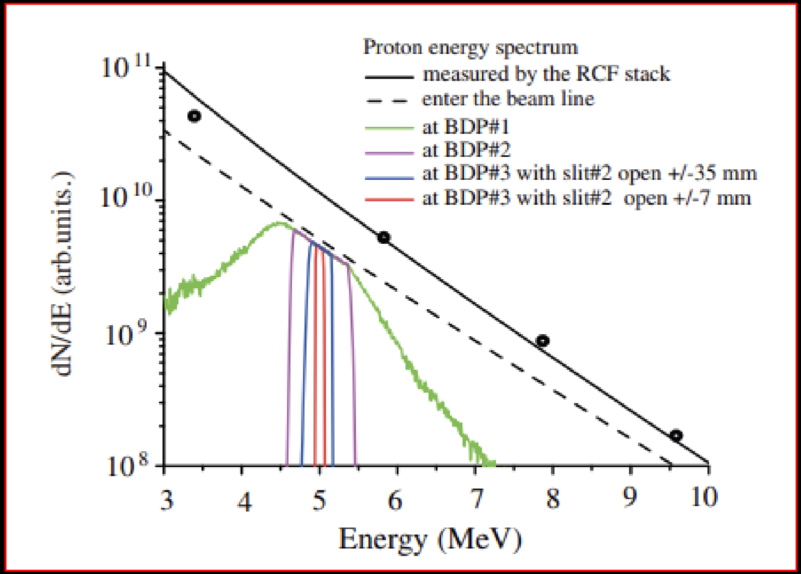
- Compact Laser Plasma Accelerator (CLAPA):
  - Petawatt laser
    - E = 1.3 J, τ = 30 fs, 5 μm FWHM
- Beam line:
  - Target Normal Sheath Acceleration (TNSA)
  - Quadrupole triplet focusing

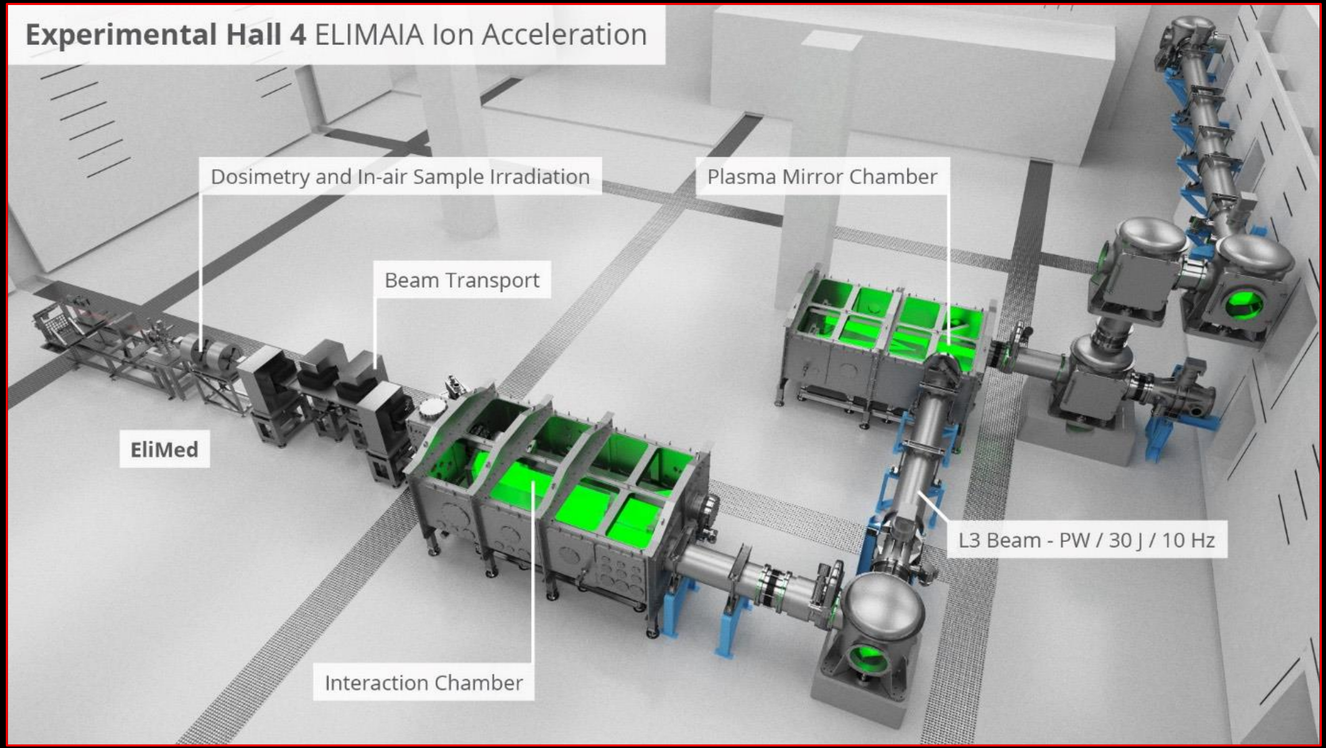
TABLE I. The CLAPA beam line parameters.

Type	Length	Aperture	Max B	# turns	Current
Q1	100 mm	30 mm	5 KGs/cm	16	300 A
Q2	200 mm	64 mm	2.5 KGs/cm	20	540 A
Q3	100 mm	64 mm	2.5 KGs/cm	20	540 A

  - Measured transmission:
    - 88% transmission through triplet
    - ±50 mrad collection angle @ 5 MeV

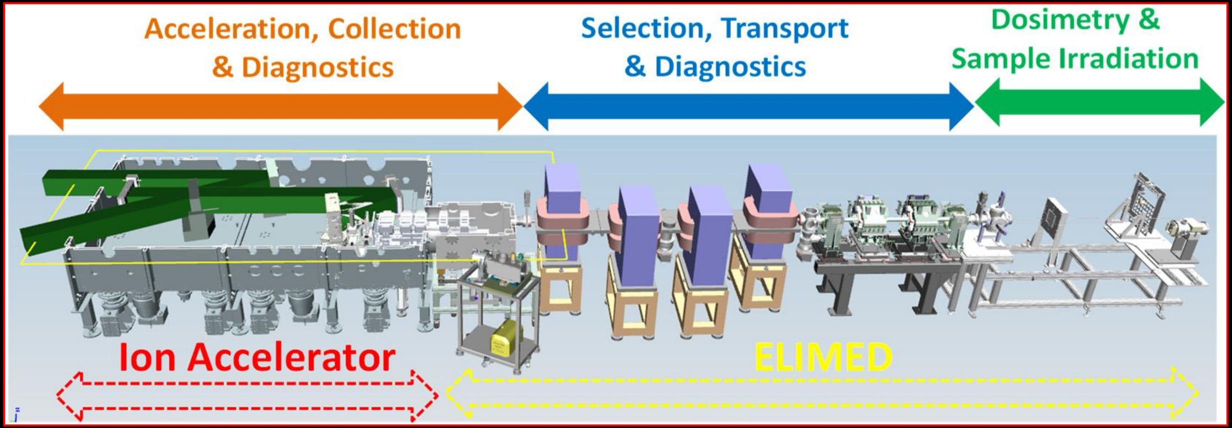


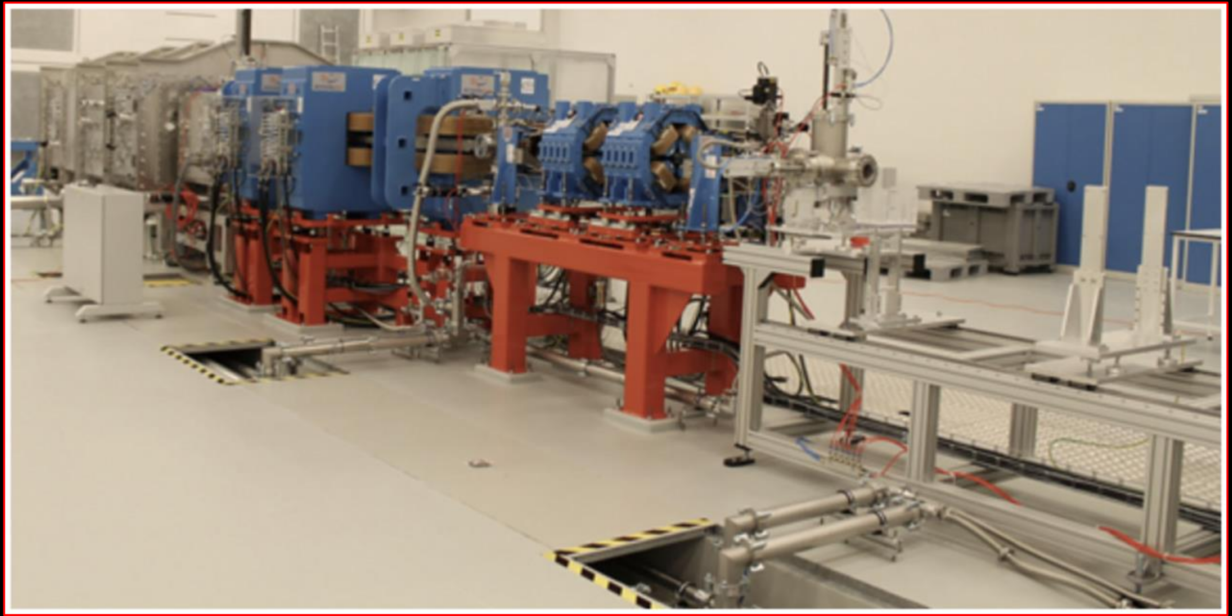




ELIMAIA-ELIMED

Quantum Beam Sci. 2018, 2, 8; doi:10.3390/qubs2020008
Frontiers in Phys. Med. Phys. & Imag. – doi: 10.3389/fphy.2020.564907



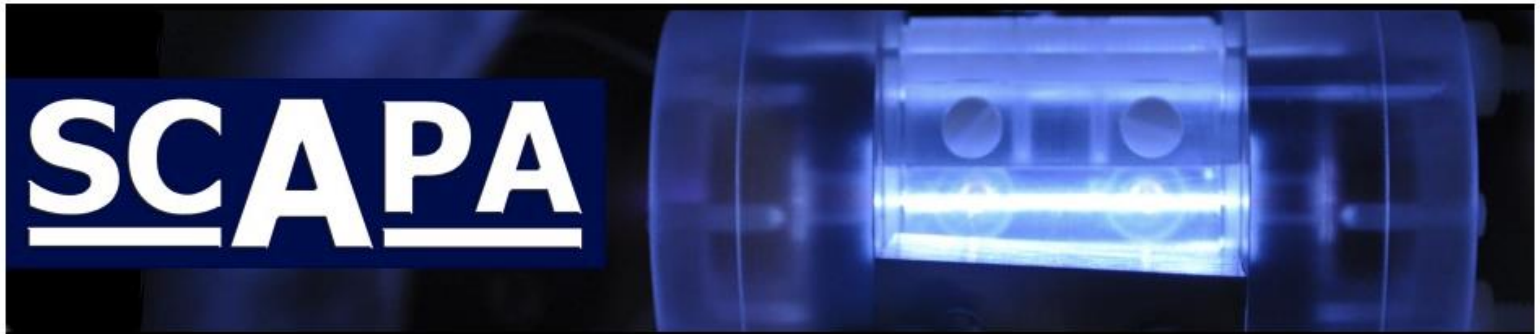


Extreme Light Infrastructure, Prague, Czech Republic:

- ELI Multidisciplinary Applications of laser-Ion Acceleration (ELIMAIA)
  - ELI MEDical and multidisciplinary applications (ELIMED)
    - ELIMAIA section dedicated to ion focusing, selection, characterization, and irradiation
  - Proton energies from 5 to 250 MeV transported to in-air section

Prepare for discussion of PoP experiment in September

Scottish Centre for the Application of Plasma-based Accelerators



Home Contact Facilities Jobs / PhDs Research SCAPA People

- We are generating interest!
  - Natural hosts: SCAPA, perhaps EPAC/EA2
    - But also, perhaps, European labs?
- Biological programme
  - Complementarity of different sources?

EPAC Experimental Area 2

EA2 has been designed as a flexible experimental area capable of undertaking laser-matter interactions with both short (f/3) and long focus (f/35) geometries. The primary aim of EA2 will be to deliver high intensity solid target interactions; however, it will be possible to also deliver liquid and gas targetry, depending on the science or application driver. By the end of the project, the large-scale infrastructure for the area will be delivered, namely the interaction chamber, adaptive optic (AO) chamber and some supporting beam transport. The design of EA2 permits a range of experimental configurations with the single 10 Hz, 1 PW beam, but also has the capability to include a second, high power beamline and multiple optical probes, should these become available as part of a future facility upgrade.

The design of the interaction chamber and complementary diagnostics will allow users to study high energy density states of matter, as well as produce a range of high-energy particle and photon beams for scientific or industrial applications. A number of targetry systems could be used in the EA2 interaction cha mber, including gas cells, tape drive, liquid jets, cryogenic targets and multi-component complex targetry arrays. While some plasma and post-interaction diagnostics will be located in the interaction chamber, it is planned that most secondary-source diagnostics be housed in additional chambers that can be attached to the main interaction chamber as required.

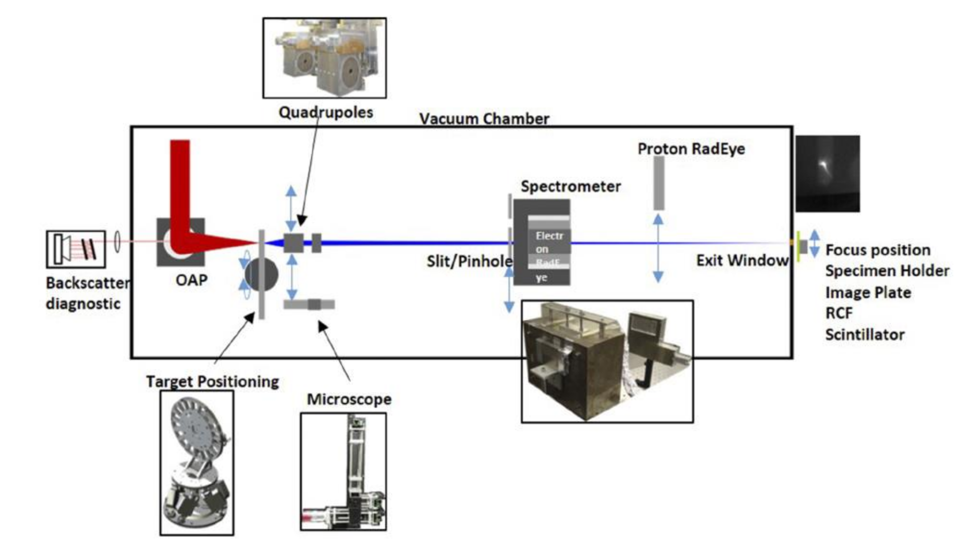
A primary science driver for EA2 will be ion acceleration, where the high intensities coupled with high repetition rate will create a cutting-edge capability for studying the fundamentals of the various ion acceleration mechanisms, as well as optimising these sources for a range of scientific and industrial applications. These sources will be spectrally and spatially characterised by active ion diagnostics, the development of which is currently underway. Once the production of such sources has been established, schemes could be developed to transport laser-generated ion beams within the target area, to provide enhanced energy selection or collimation for a range of applications, including radiobiology or radiation hardness testing. High flux beams of neutrons will also be produced in EA2, most likely via a pitcher-catcher set-up.

With the addition of a second beamline as part of a facility upgrade, multi-beam interactions will be possible (for example, a second petawatt-class beam or lower energy auxiliary beam). These could be performed in dual short-focus mode, or short-long focus mode. The target chamber has been sized sufficiently to accommodate the required beamline optics, as well as the typical post-interaction diagnostics that are currently most commonly used.

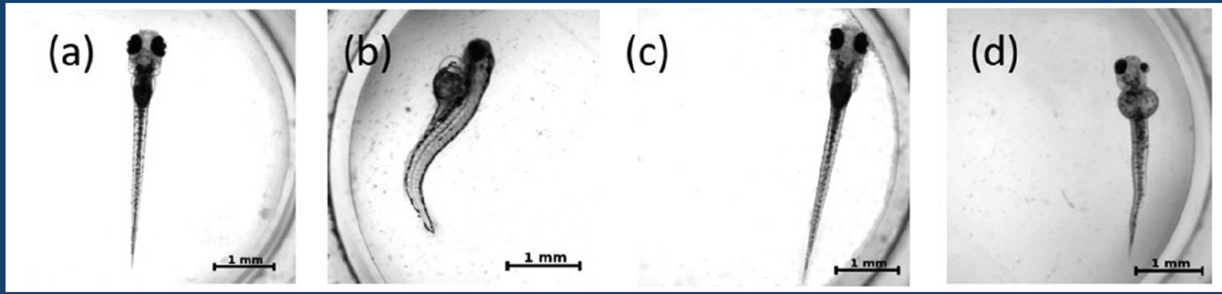
Example Set Ups

A feasibility study of zebrafish embryo irradiation with laser- accelerated protons. doi: 10.1063/5.0008512

ATLAS 300 Laser at the LION Beamline

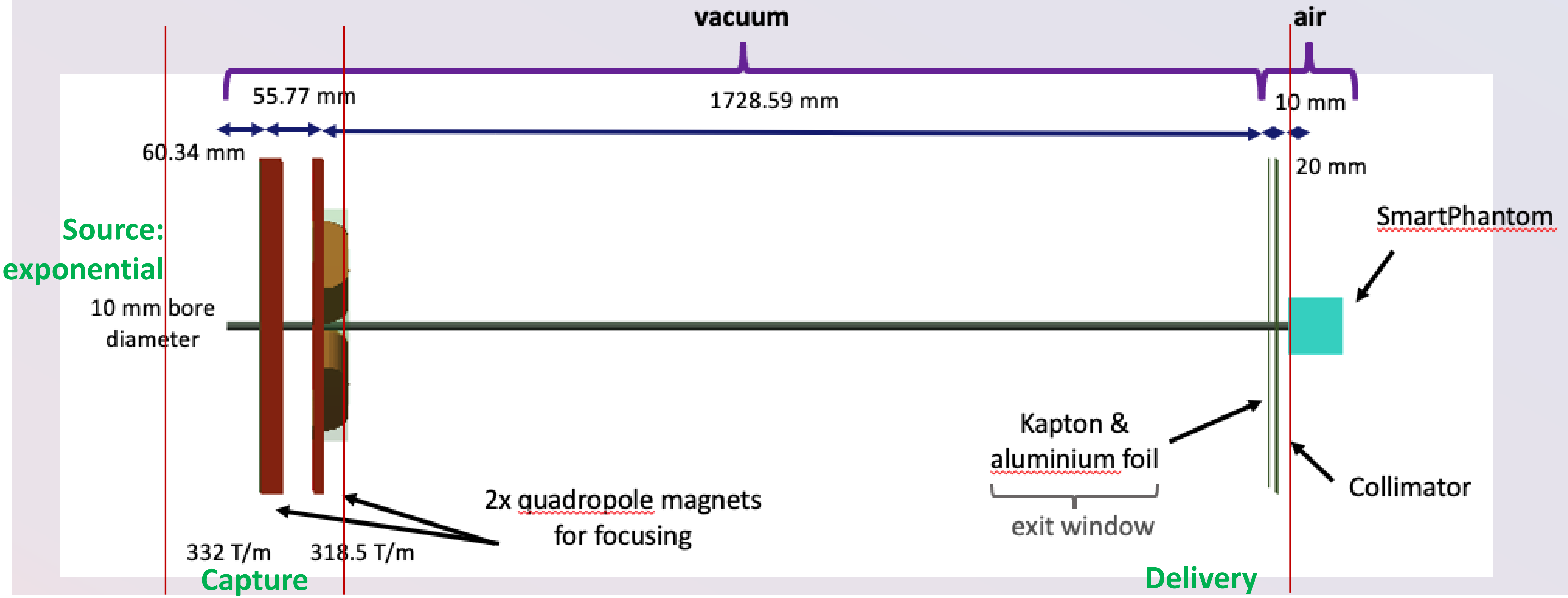


Comparison of Irradiated versus Control Embryos

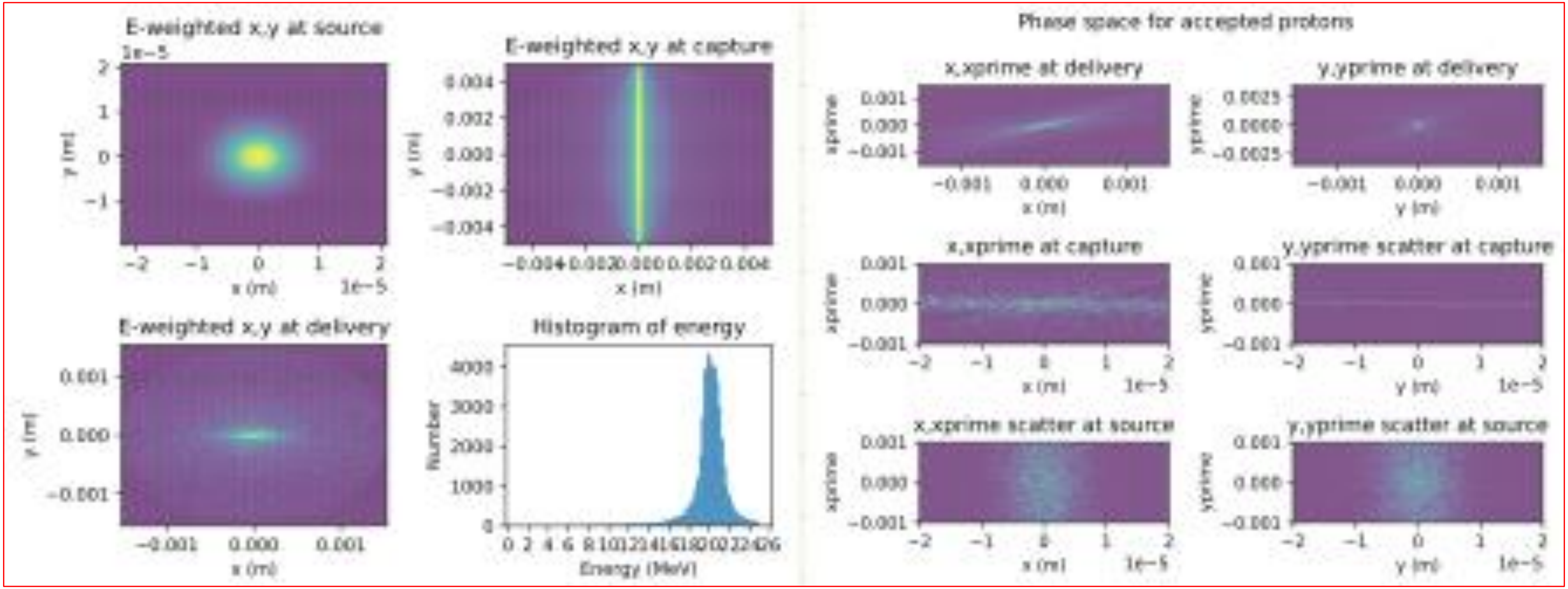


From Maria

LION beamline - BDSIM



Stage	Section	Element	Type	Parameter	Value	Unit	Comment
1	Source	Source	Parameterised TNSA	SourceMode	0		Gaussian kinetic energy
1	Source	Source	Parameterised TNSA	SigmaX	0.000004	m	Gaussian width, x
1	Source	Source	Parameterised TNSA	SigmaY	0.000004	m	Gaussian width, y
1	Source	Source	Parameterised TNSA	Emin	1	MeV	Minimum of energy distribution
1	Source	Source	Parameterised TNSA	Emax	25	MeV	Maximum of energy distribution
1	Source	Source	Parameterised TNSA	nPnts	1000		Number of points to sample for integration of PDF
1	Source	Source	Parameterised TNSA	MinCTheta	0.999556		Maximum theta for flat cos theta
1	Capture	Drift		Length	0.05034	m	Length of first drift
1	Capture	Aperture	Elliptical	RadiusX	0.0015	m	Half aperture in x of elliptical colimator
1	Capture	Aperture	Elliptical	RadiusY	0.00075	m	Half aperture in y of ellipseof elliptical colimator
1	Capture	Drift		Length	0.01	m	Gap between colimator and first quad
1	Capture	Fquad		Length	0.04	m	Length of focusing quad
1	Capture	Fquad		Strength	332	T/m	Strength of focusing quad
1	Capture	Aperture	Circular	Radius	0.005	m	Aperture of quad
1	Capture	Drift		Length	0.02577	m	Gap between colimator first (F)quad and second (D)quad
1	Capture	Dquad		Length	0.02	m	Length of defocusing quad
1	Capture	Dquad		Strength	318.5	T/m	Strength of defocusing quad
1	Capture	Aperture	Circular	Radius	0.005	m	Aperture of quad
1	Delivery	Drift		Length	1.72859	m	Main drift from last quad to kapton/aluminium foils
1	Delivery	Drift		Length	0.01	m	Drift from kapton/aluminium foils to collimator
1	Delivery	Aperture	Circular	Radius	0.0015	m	Collimator before "end station"
1	Delivery	Drift		Length	0.02	m	Final drift



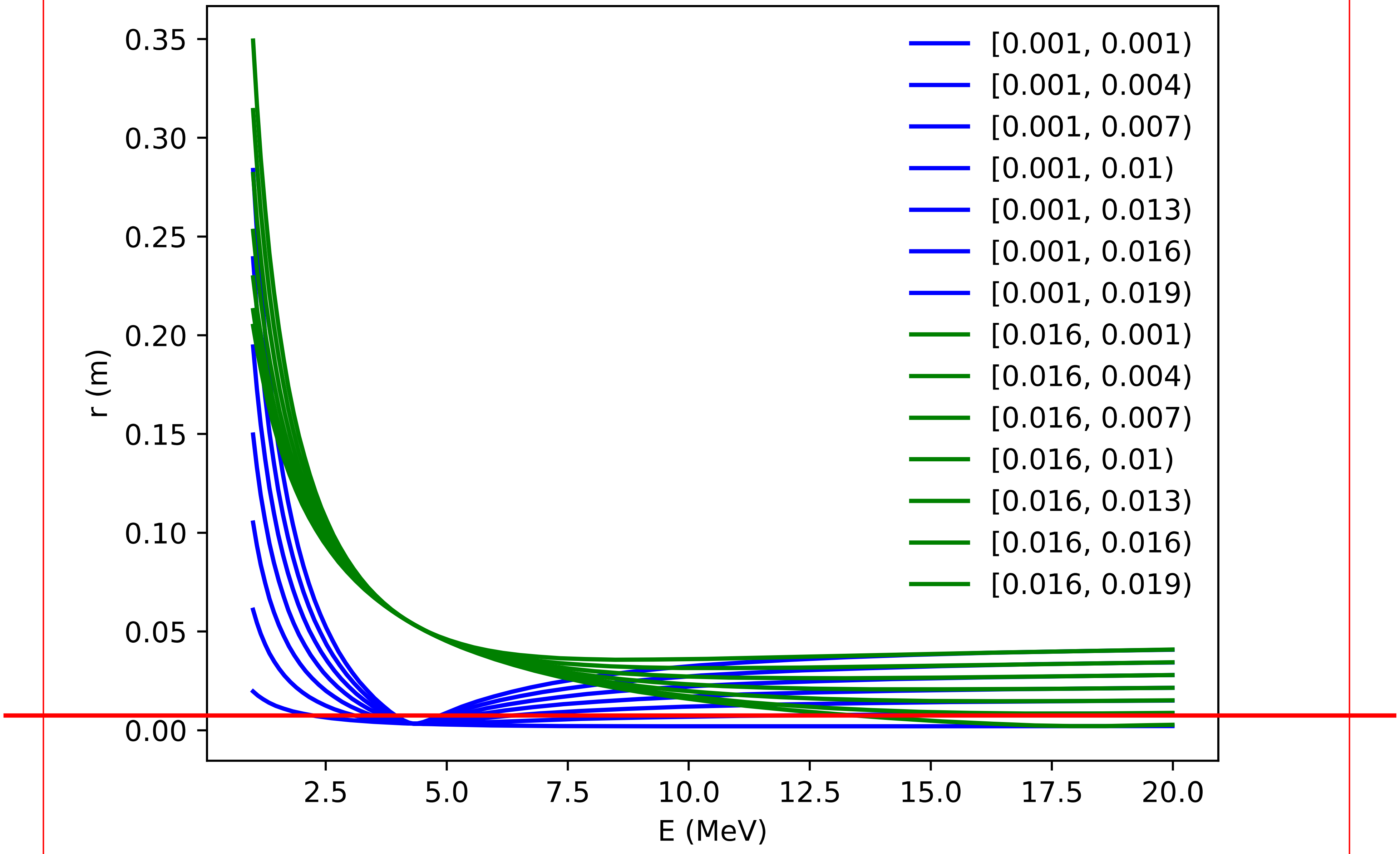
E-weighted x,y at source
1e−5
y (m)
x (m)
1e−5
E-weighted x,y at capture
y (m)
x (m)
E-weighted x,y at delivery
y (m)
x (m)
Histogram of energy
Number
Energy (MeV)
Phase space for accepted protons
x,xprime at delivery
xprime
x (m)
y,yprime at delivery
yprime
y (m)
x,xprime at capture
xprime
x (m)
1e−5
y,yprime scatter at capture
yprime
y (m)
1e−5
x,xprime scatter at source
xprime
x (m)
1e−5
y,yprime scatter at source
yprime
y (m)
1e−5

Stage	Section	Element	Parameter	Name	Value	Unit	Comment
1	Source	Source	Mode	SourceMode	0		Laser-driven proton energy spectrum parameterised
1	Source	Source	Sigma x	SigmaX	0.000004	m	Gaussian width, x
1	Source	Source	Sigma y	SigmaY	0.000004	m	Gaussian width, y
1	Source	Source	Minimum energy	Emin	1	MeV	Minimum of energy distribution
1	Source	Source	Maximum energy	Emax	25	MeV	Minimum of energy distribution
1	Source	Source	Number of points	nPnts	1000		Number of points to sample for integration of PDF
1	Source	Source	Minimum cos theta	MinCTheta	0.999691		Maximum theta for flat cos theta
1	Capture	Drift	Length	DriftLength1	0.06034	m	Length of first drift
1	Capture	Aperture	Elliptical	RadiusX	0.0015	m	Half aperture in x of elliptical colimator
1	Capture	Aperture	Elliptical	RadiusY	0.00075	m	Half aperture in y of ellipseof elliptical colimator
1	Capture	Drift	Length	DriftLength2	0.01	m	Gap between colimator and first quad
1	Capture	Fquad	Length	FQuadLength	0.04	m	Length of focusing quad
1	Capture	Fquad	Strength	FQuadStrength	332	T/m	Strength of focusing quad
1	Capture	Aperture	Circular	FQuadRadius	0.005	m	Aperture of quad
1	Capture	Drift	Length	DriftLength3	0.01	m	Gap between colimator first (F)quad and second (D)quad
1	Capture	Dquad	Length	DQuadLength	0.02	m	Length of defocusing quad
1	Capture	Dquad	Strength	DQuadStrength	318.5	T/m	Strength of defocusing quad
1	Capture	Aperture	Circular	DQuadRadius	0.005	m	Aperture of quad
1	Delivery	Drift	Length	DriftLength1	1.72859	m	Main drift from last quad to kapton/aluminium foils
1	Delivery	Drift	Length	DriftLength2	0.01	m	Drift from kapton/aluminium foils to collimator
1	Delivery	Aperture	Circular	Radius	0.0015	m	Collimator before "end station"
1	Delivery	Drift	Length	DriftLength3	0.02	m	Final drift

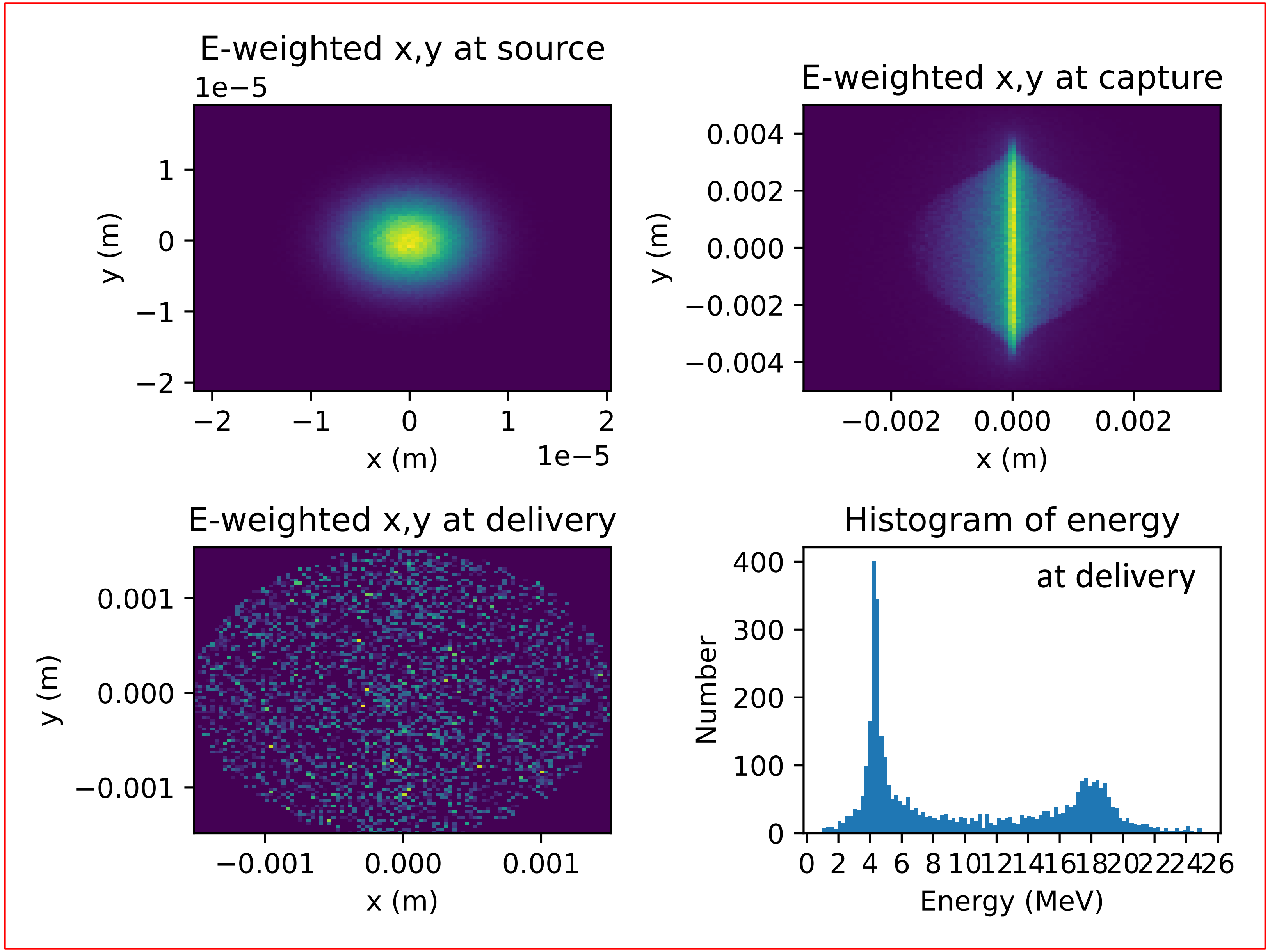
Some parameters from Maria's figure, some from papers.

r at delivery vs energy

(x, y) = (0, 0)
[x’, y’] at source



(x,y) position and energy distribution



Next steps

- Move on to model existing beam lines:
  - DRACO, BELLA, Gemini, …
- Work with CLF on EA2 beam line:
  - Possibly also with ASTeC
- Following today's discussion:
  - Focus on "LhARA PoP" – on SCAPA?
  - Evaluate parallel streams at existing facilities w\ beam lines