

Nuclear Photonics 2025
October 6 - 10, 2025 in Darmstadt, Germany



Broadband MeV to multi GeV 10 PW laser-driven gamma-rays generation, characterization and possible applications

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OF SCIENCE

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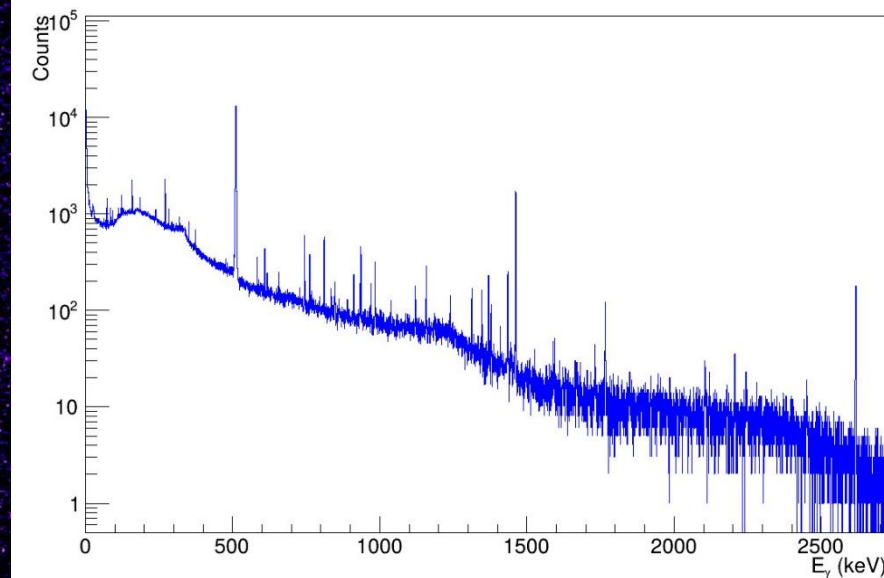
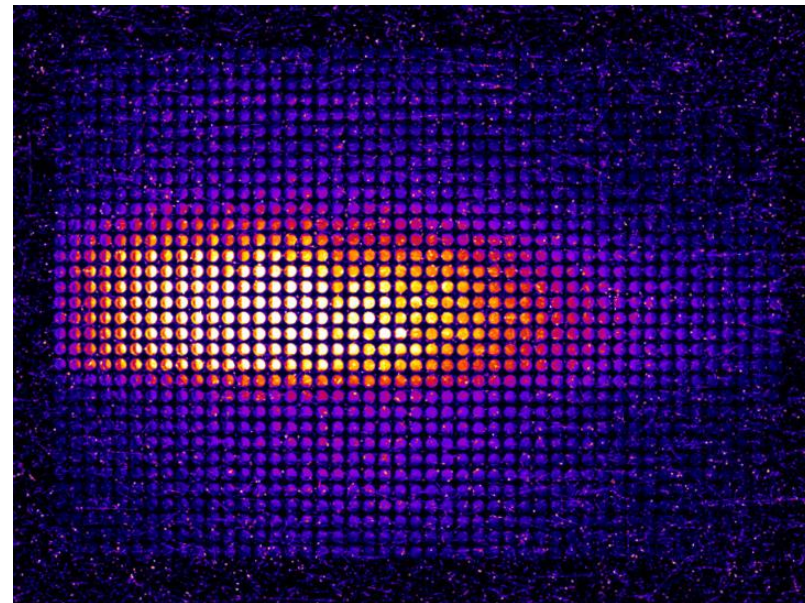
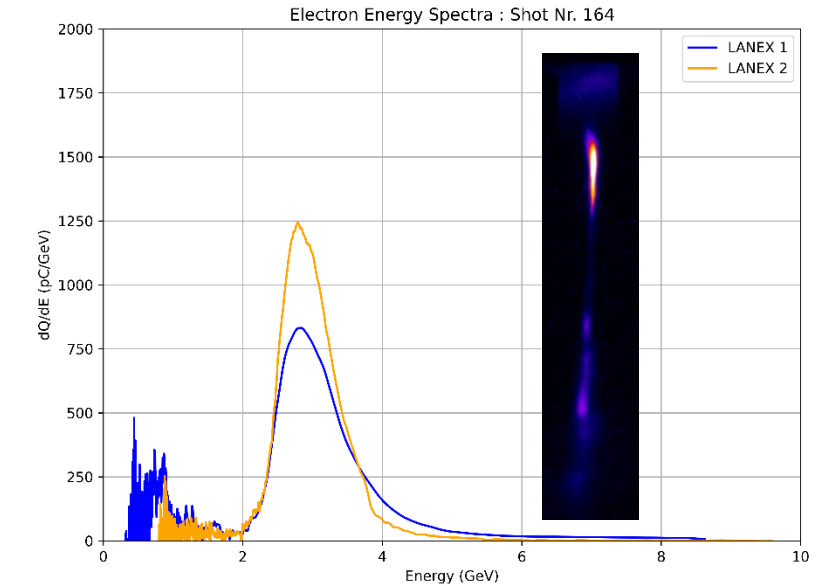
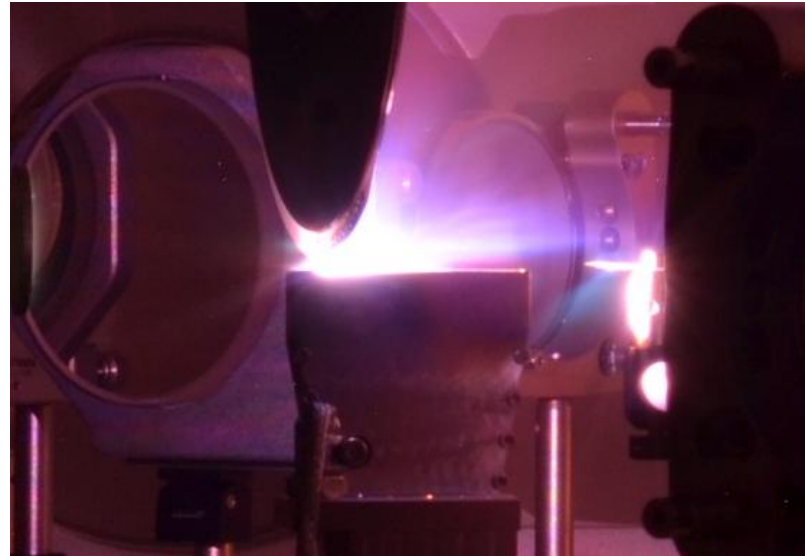


H. Ahmed



D. Choudhury

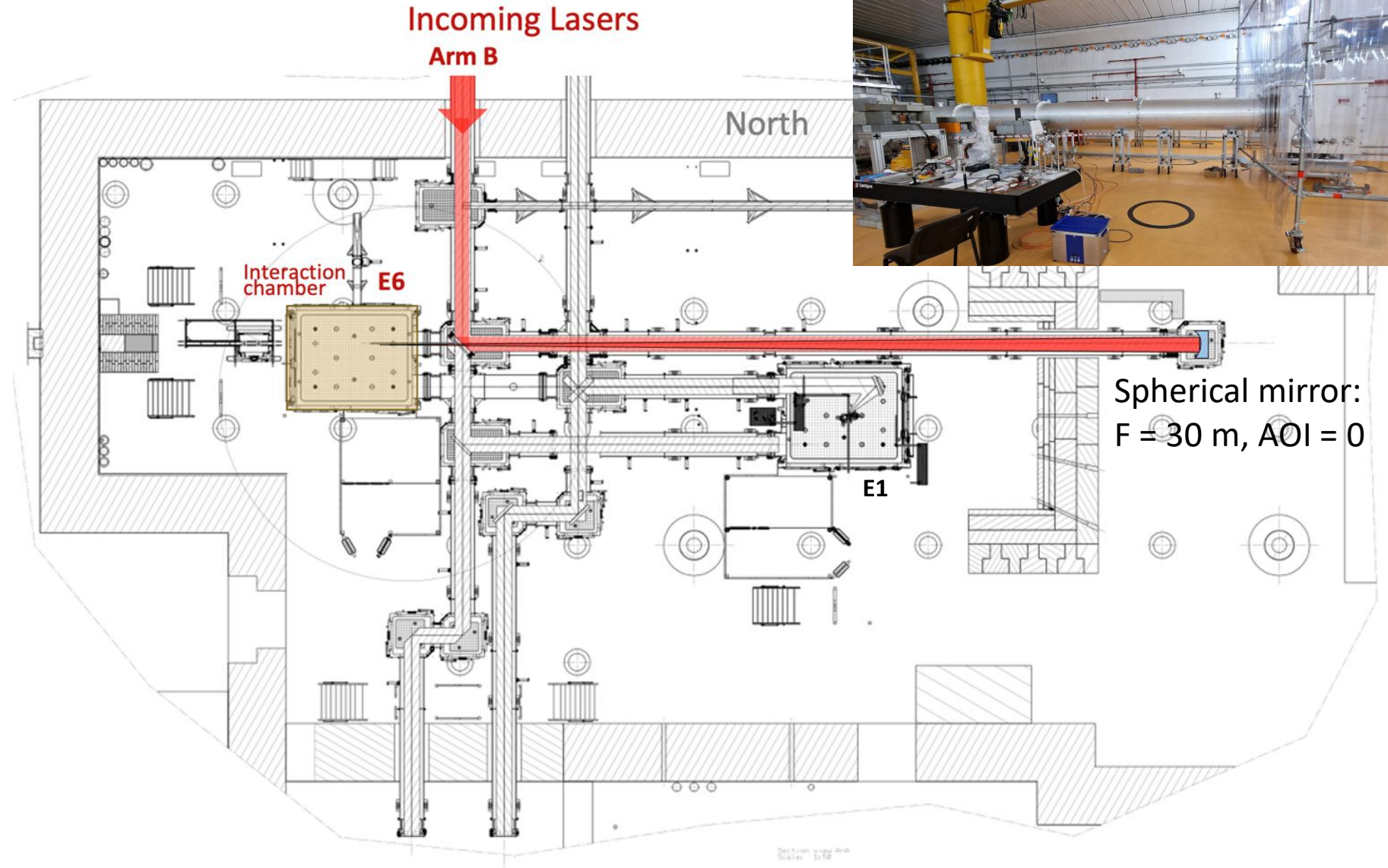
- ❑ The 10 PW E6 experimental area
- ❑ Multi-GeV electron beam
- ❑ Gamma generation
 - Bremsstrahlung
 - Nonlinear reverse Compton
- ❑ Characterization (LYSO/CsI stack)
- ❑ Possible applications
 - QED investigation
 - Photonuclear reactions



The 10 PW E6 experimental area

Laser specification (on target):

- 1 shot/min
- 240 J (max 10 PW)
- 23 ± 1 fs

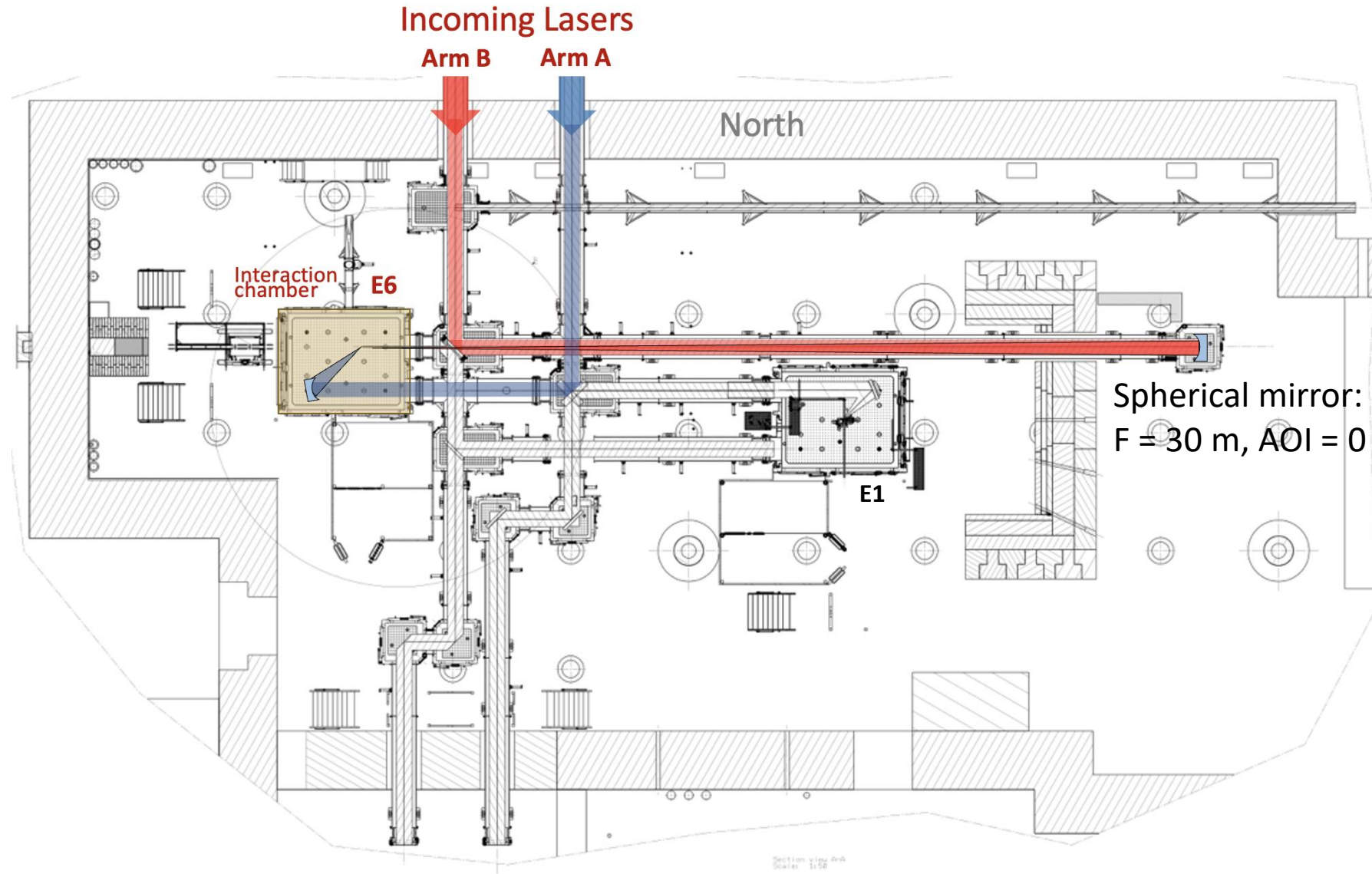


The 10 PW E6 experimental area

Laser specification (on target):

- 1 shot/min
- 240 J (max 10 PW)
- 23 ± 1 fs

2x10 PW arms available

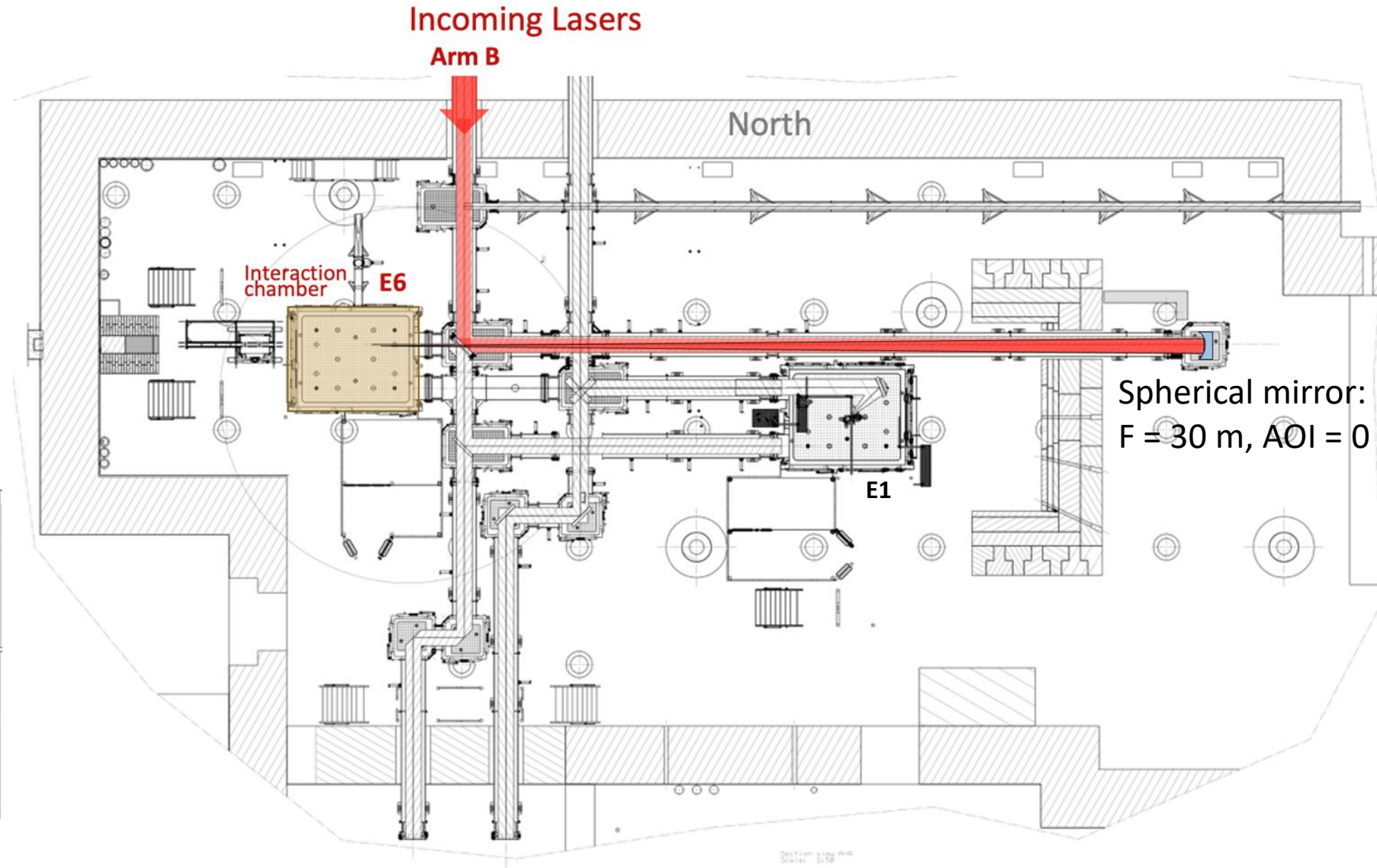
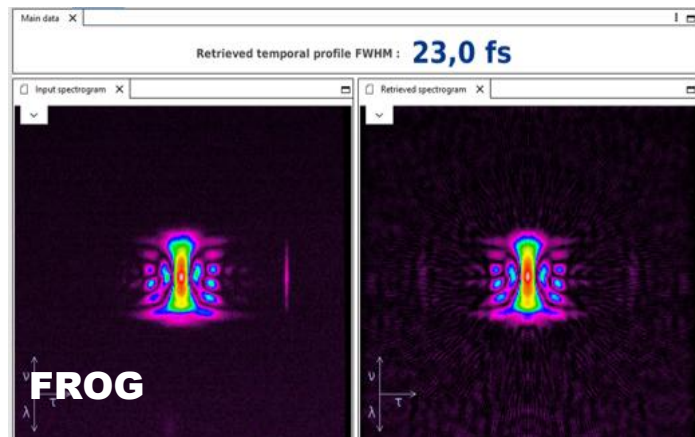


The 10 PW E6 experimental area

Laser specification (on target):

- 1 shot/min
- 185 ± 1 J (nominal 8 PW)
- 23 ± 1 fs

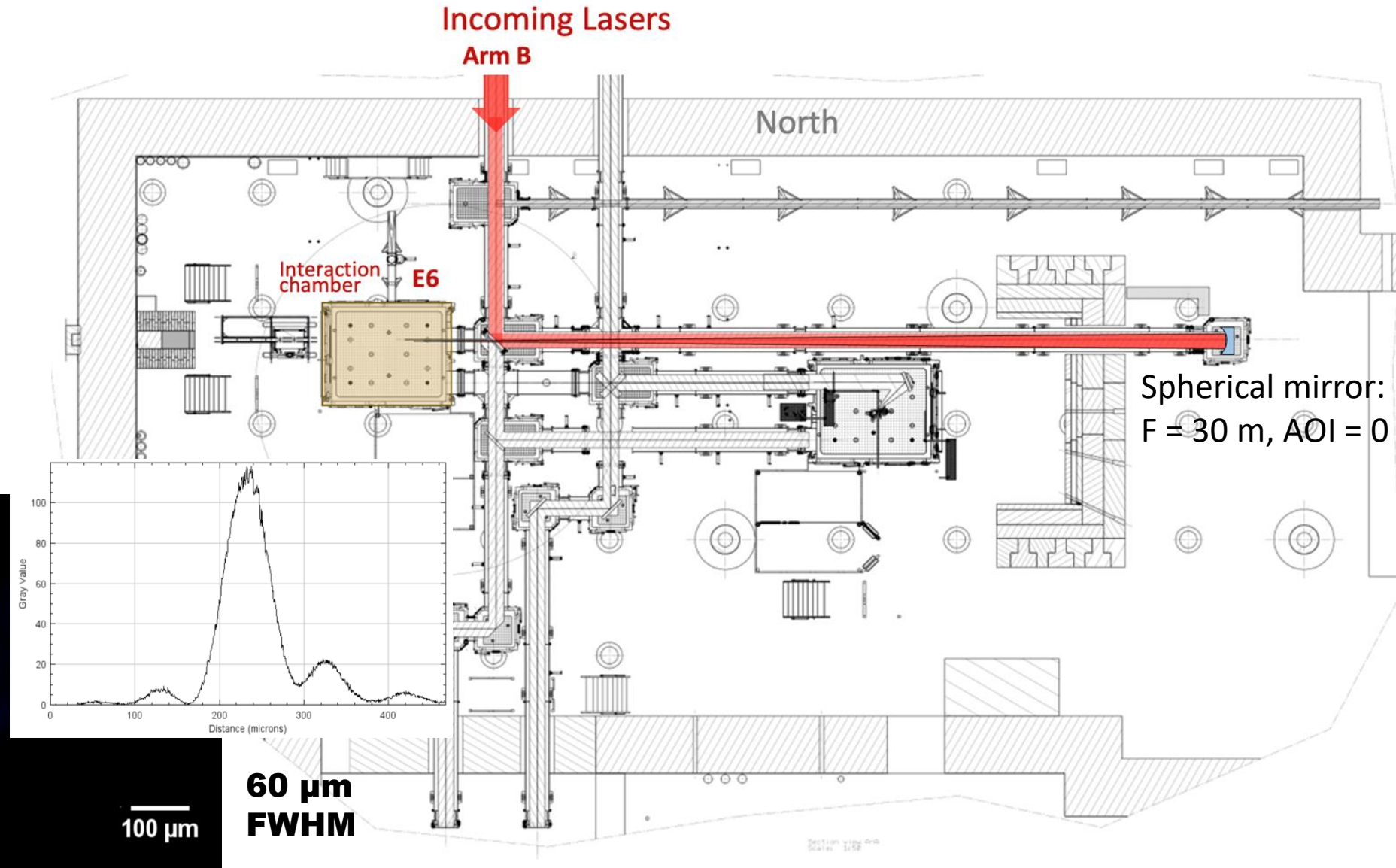
Measured on shot



The 10 PW E6 experimental area

Laser specification (on target):

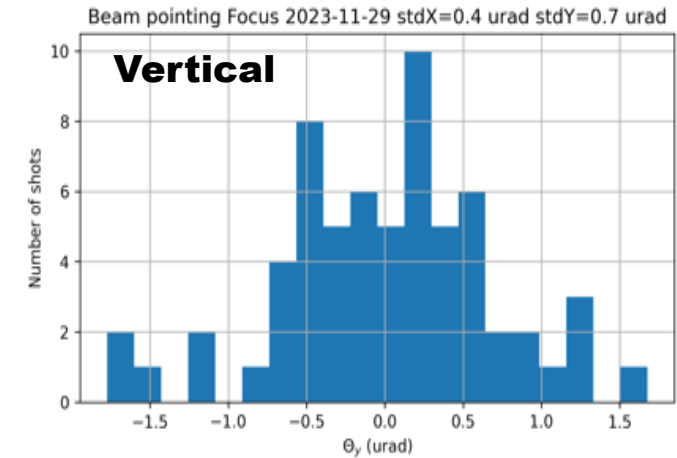
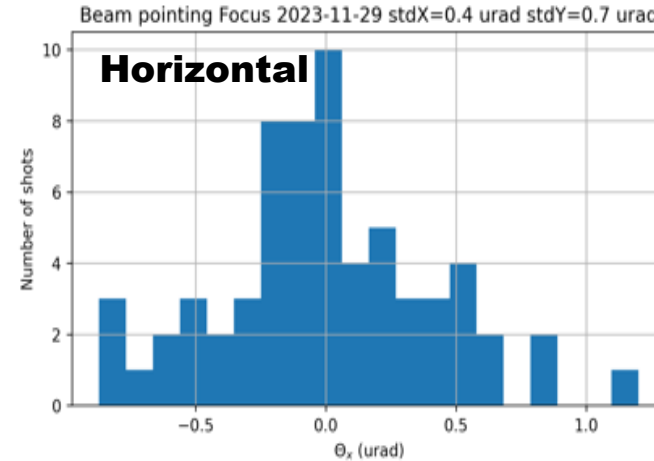
- 1 shot/min
- 185 ± 1 J (nominal 8 PW)
- 23 ± 1 fs
- 60 ± 2 μm FWHM focal spot



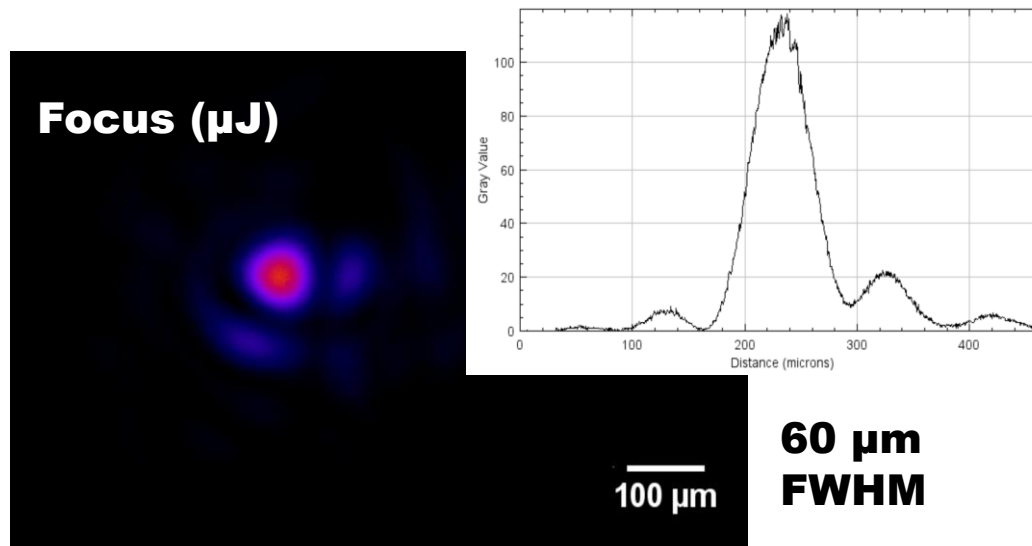
The 10 PW E6 experimental area

Laser specification (on target):

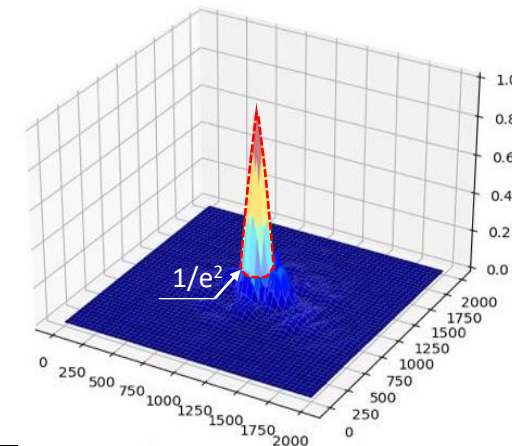
- 1 shot/min
- 185 ± 1 J (nominal 8 PW)
- 23 ± 1 fs
- 60 ± 2 μm FWHM focal spot
- Encircled energy: $\sim 40\%$ @ $1/e^2$
- Energy stability at full power: $\pm 2\%$
- Pointing stability: < 1 μrad



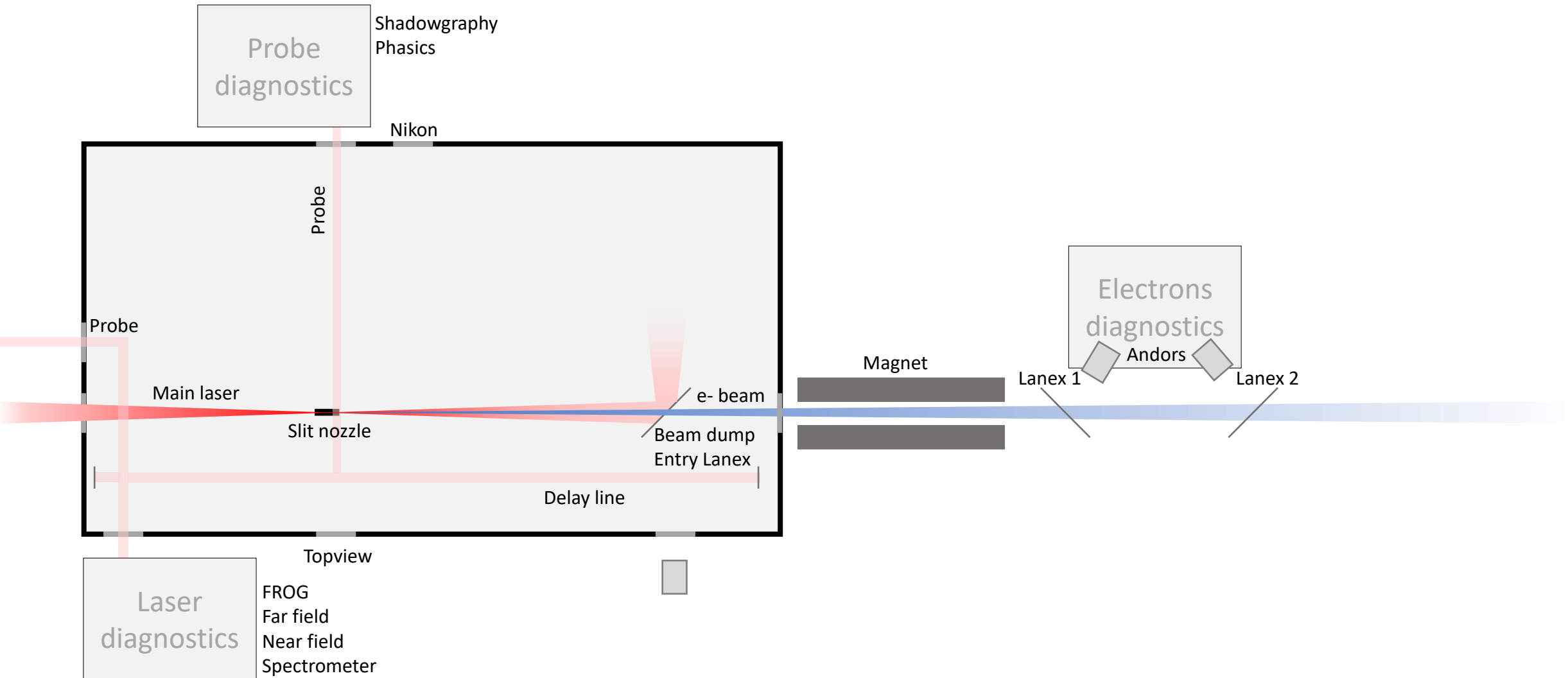
Approx 1 μrad FWHM focus pointing (0.5 - 1 focal spot)



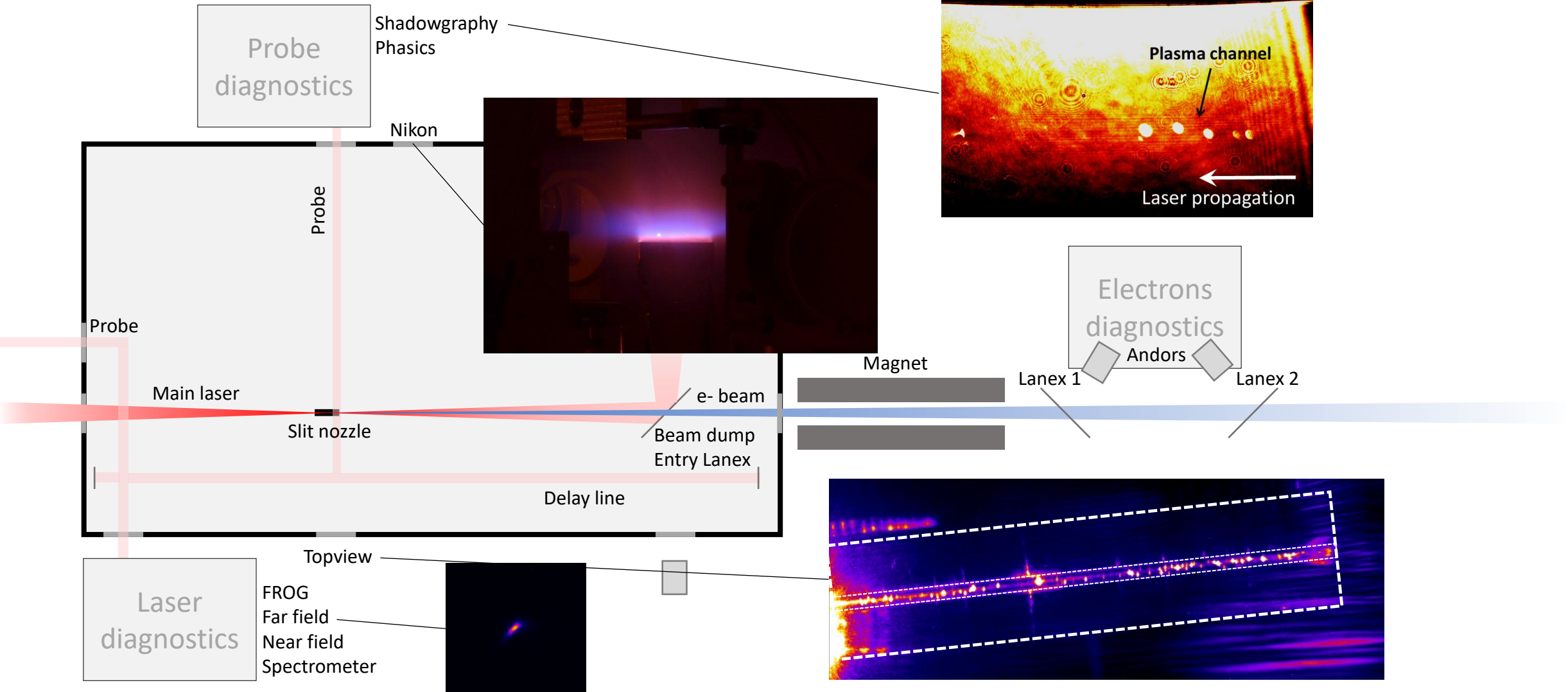
Estimated encircled energy $\sim 40\%$



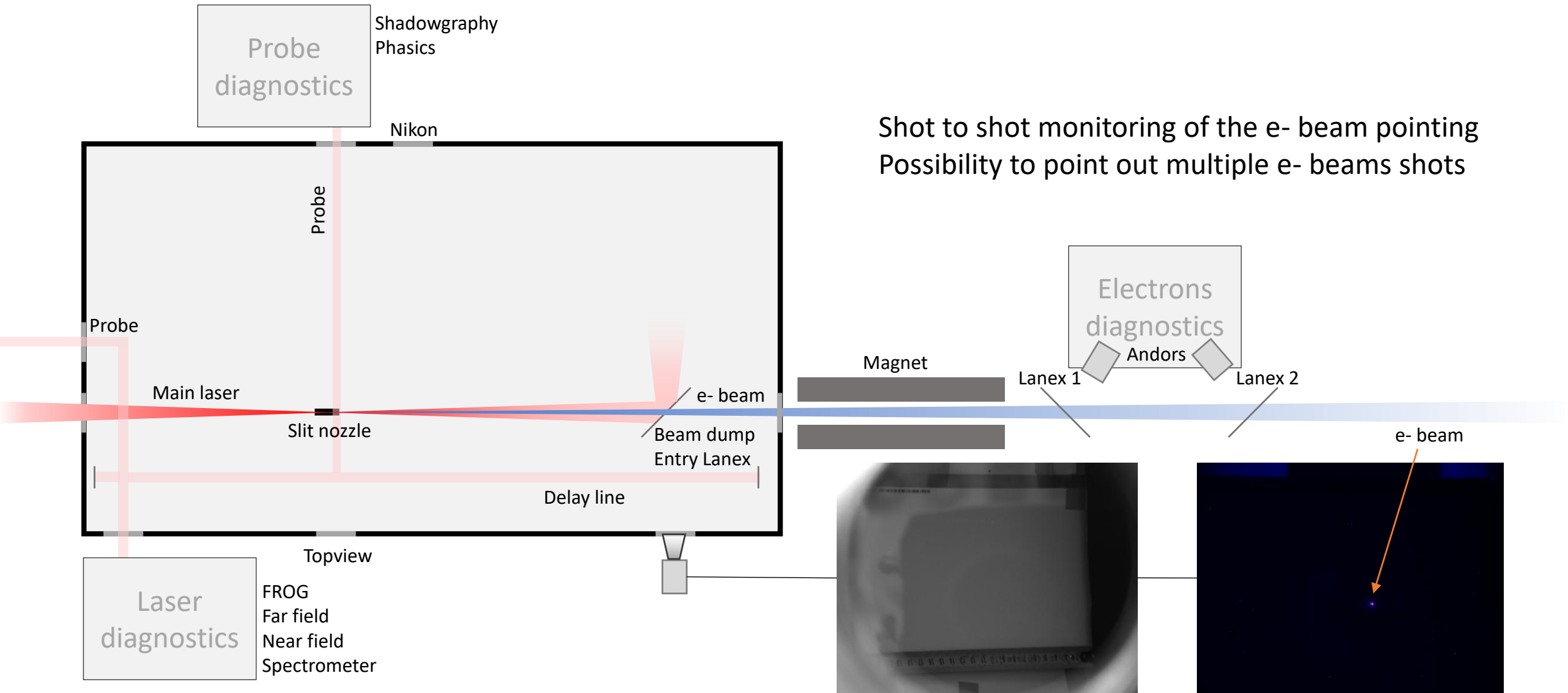
Commissioning experimental campaign 2023/2024:



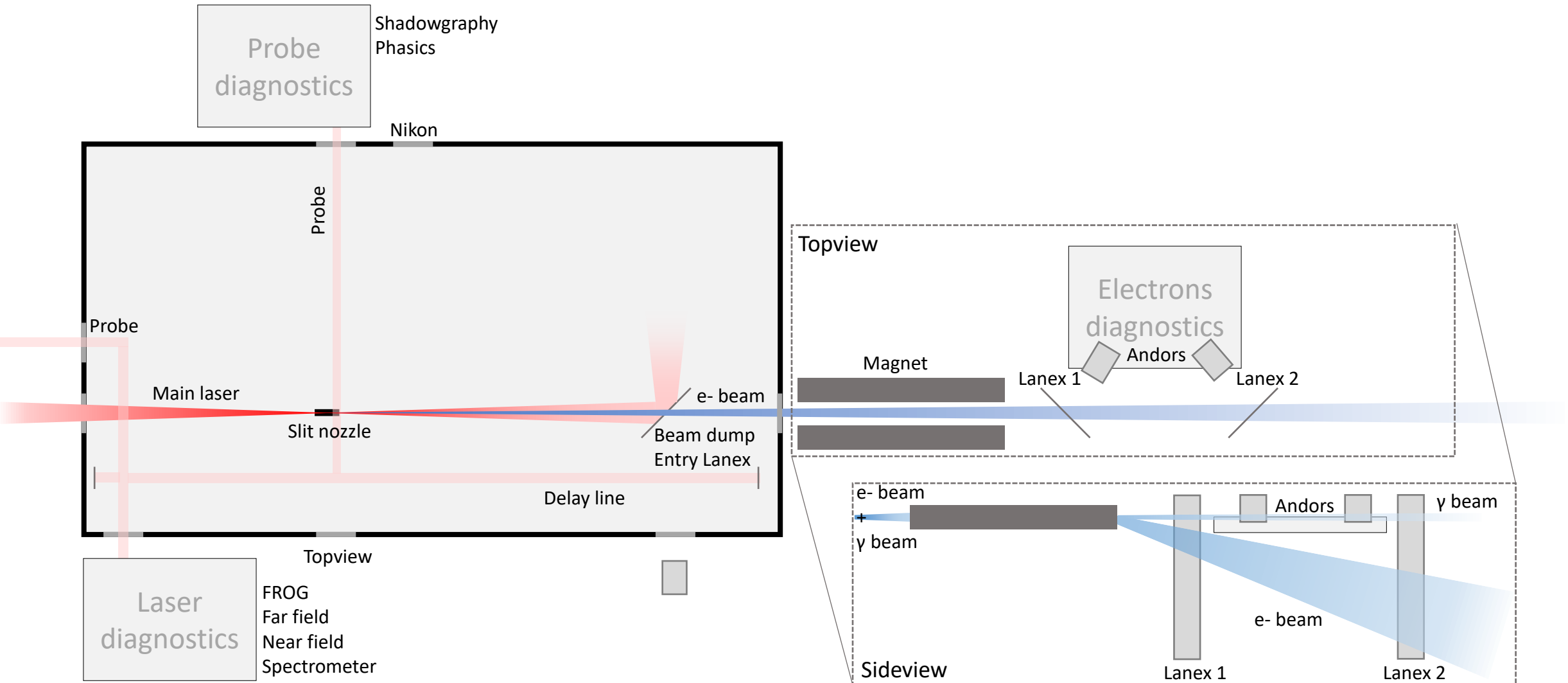
Commissioning experimental campaign 2023/2024:



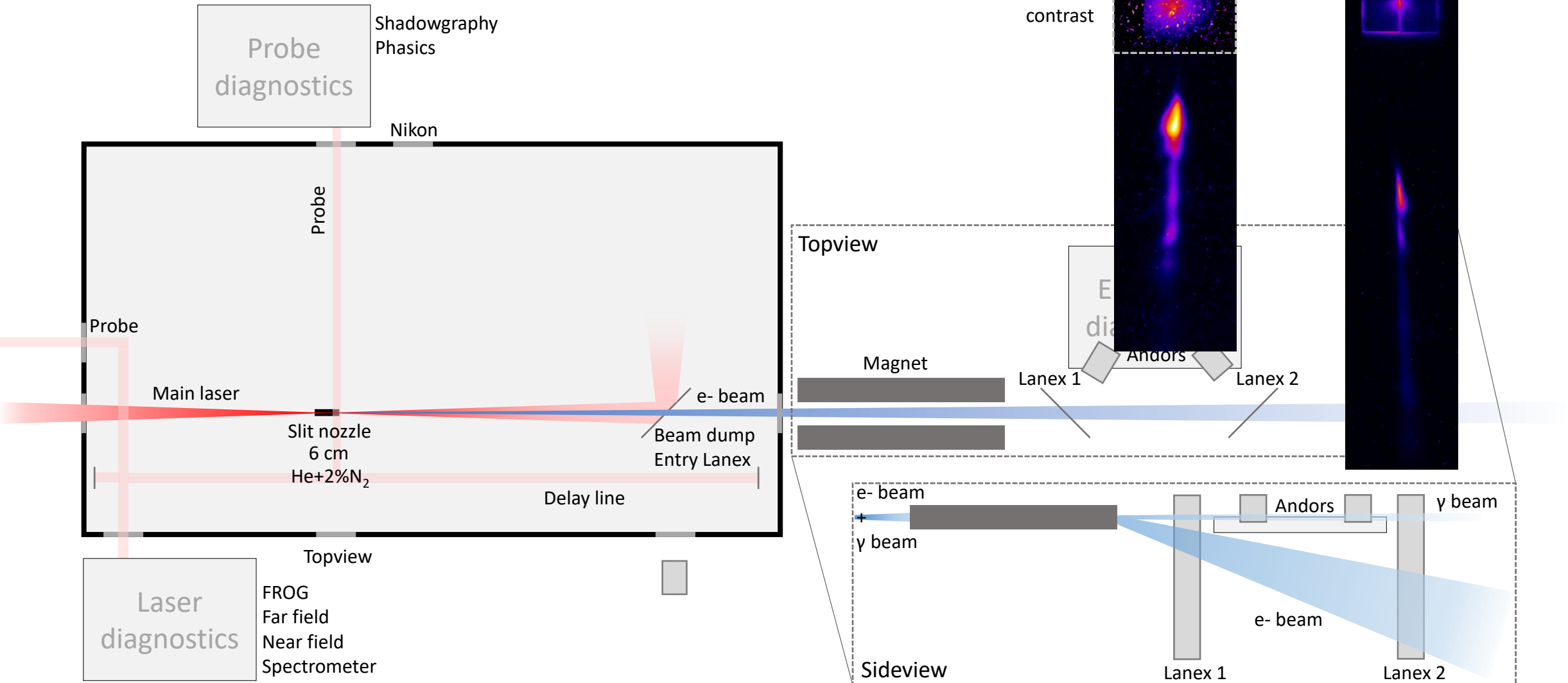
Commissioning experimental campaign 2023/2024:



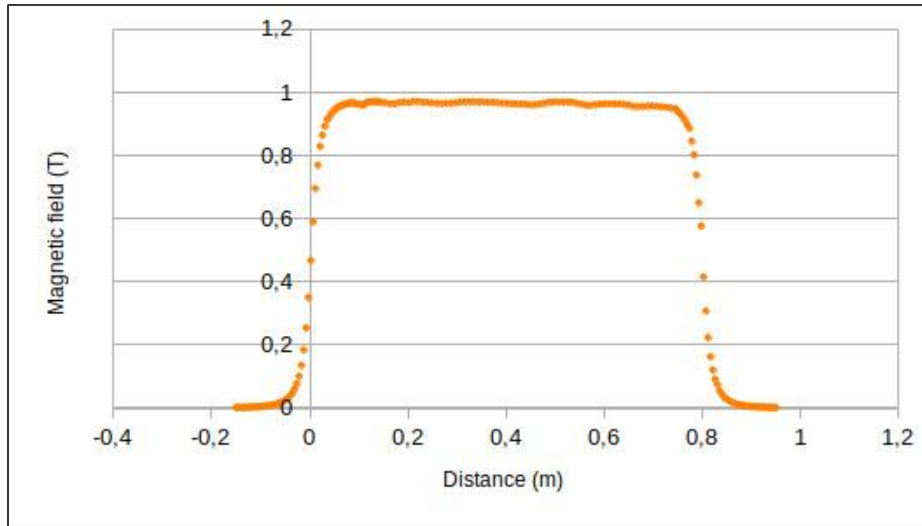
Commissioning experimental campaign 2023/2024:



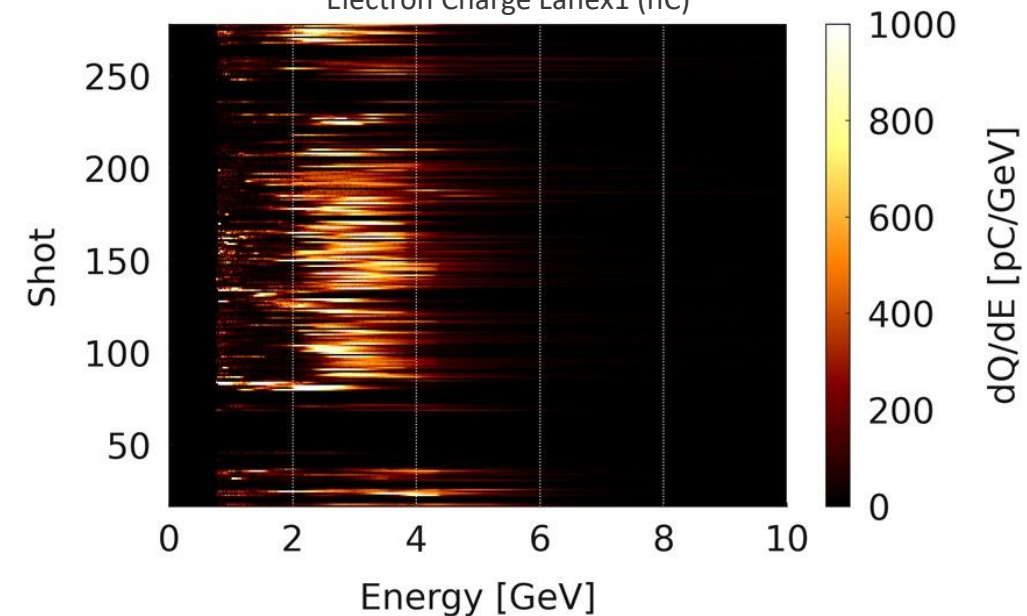
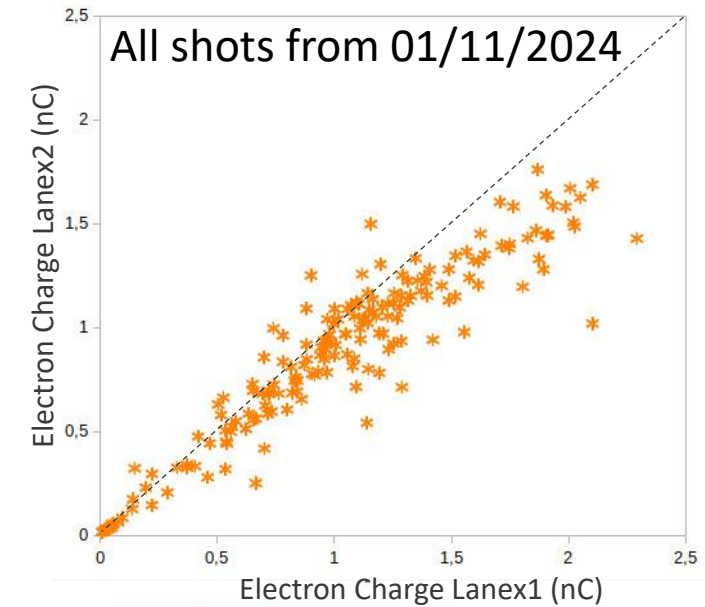
Commissioning experimental campaign 2023/2024:



Commissioning experimental campaign 2023/2024:



Measured B field map +
Geant4 simulations for
deflection estimation



Result of Coulomb interactions of electrons going through matter

$$\frac{d\sigma}{dk} = \frac{d\sigma_n}{dk} + Z \frac{d\sigma_e}{dk} \xrightarrow{* \rho l I / e} \frac{dN}{dE}$$

Theoretical model (Bethe-Heitler formula + corrections)

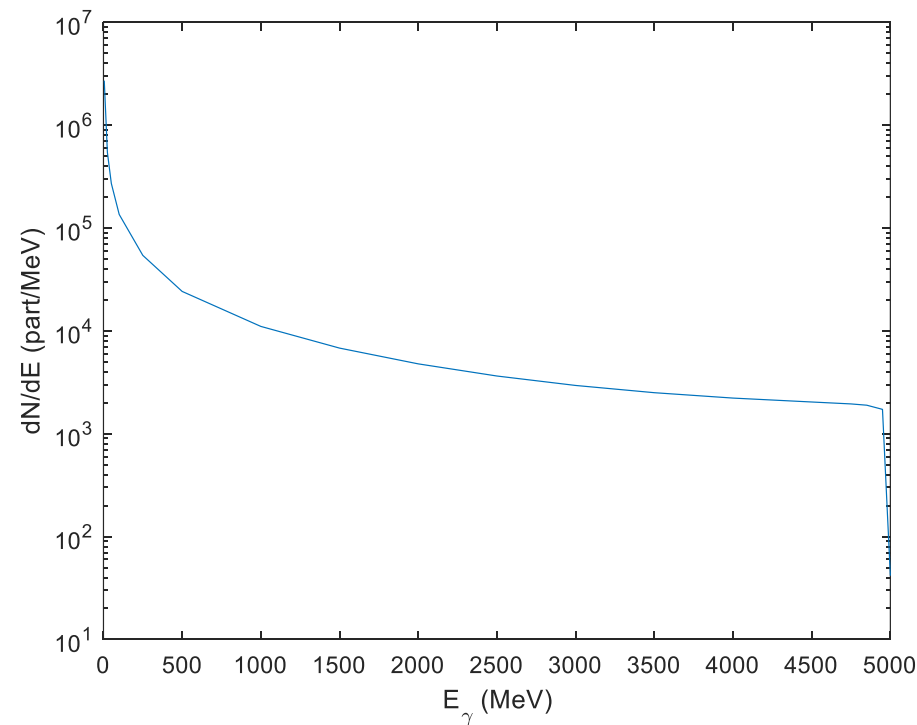
$$\frac{d\sigma_n}{dk} = \frac{4\alpha r_e^2 Z^2}{k} (\chi_{Born}^{unscr} + \delta_{screen} + \delta_{Coul})$$

$$\frac{d\sigma_e}{dk} = \frac{4\alpha r_e^2 Z^2}{k} (f_{e-e} \chi^{Haug} + \delta_{screen}^e)$$

From tabulated values

S.M. Seltzer & M.J. Berger (1986)

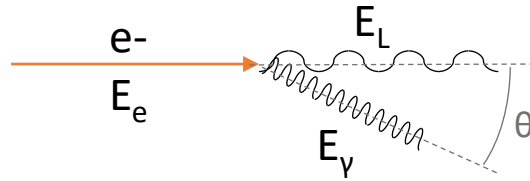
For 5 GeV e-, 1.5 nC, 200 μm C



Linear reverse Compton :

$$E_{\gamma} = \frac{(1 + \beta_e)E_L}{(1 - \beta_e \cos \theta) + \frac{(1 + \cos \theta)E_L}{E_e}}$$

$$E_{\gamma}^{max} = \frac{1}{1 + \frac{(m_e c^2)^2}{4E_e E_L}} E_e$$

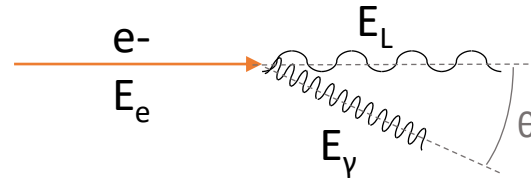


Gamma generation : Nonlinear reverse Compton

Linear reverse Compton :

$$E_\gamma = \frac{(1 + \beta_e)E_L}{(1 - \beta_e \cos\theta) + \frac{(1 + \cos\theta)E_L}{E_e}}$$

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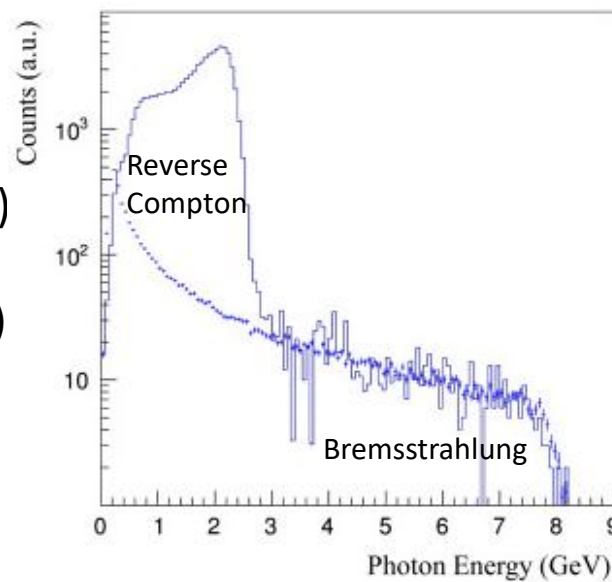


LEPS2 beamline
(Spring8 synchrotron)

$E_e = 8 \text{ GeV}$

$E_L = 4.66 \text{ eV (266 nm)}$

$E_{\gamma max} = 2.89 \text{ GeV}$



N. Muramatsu et al

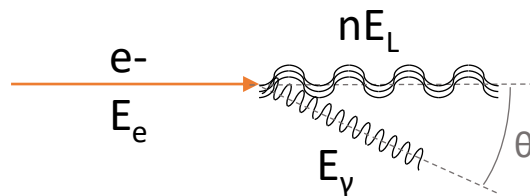


Gamma generation : Nonlinear reverse Compton

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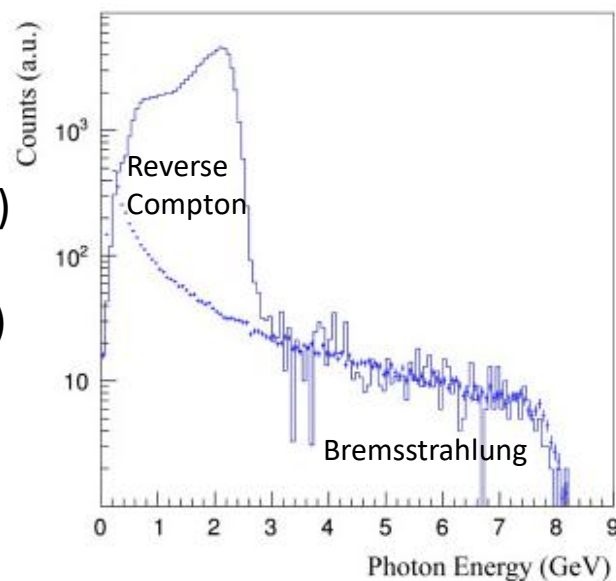
Nonlinear reverse Compton :

Need integration over a range of n depending on laser intensity

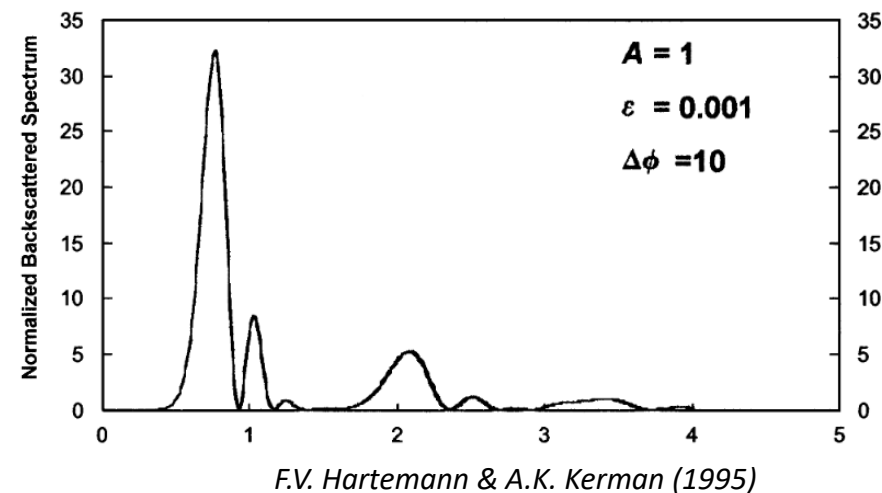
$$a_0 \sim 1$$

LEPS2 beamline
(Spring8 synchrotron)
 $E_e = 8 \text{ GeV}$
 $E_L = 4.66 \text{ eV (266 nm)}$

$E_{\gamma max} = 2.89 \text{ GeV}$



N. Muramatsu et al (2022)



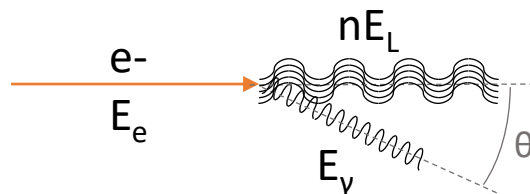
F.V. Hartemann & A.K. Kerman (1995)

Gamma generation : Nonlinear reverse Compton

Linear reverse Compton :

$$E_\gamma = \frac{(1 + \beta_e)E_L}{(1 - \beta_e \cos\theta) + \frac{(1 + \cos\theta)E_L}{E_e}}$$

$$E_\gamma^{max} = \frac{1}{1 + \frac{(m_e c^2)^2}{4E_e E_L}} E_e$$



Fully nonlinear reverse Compton :

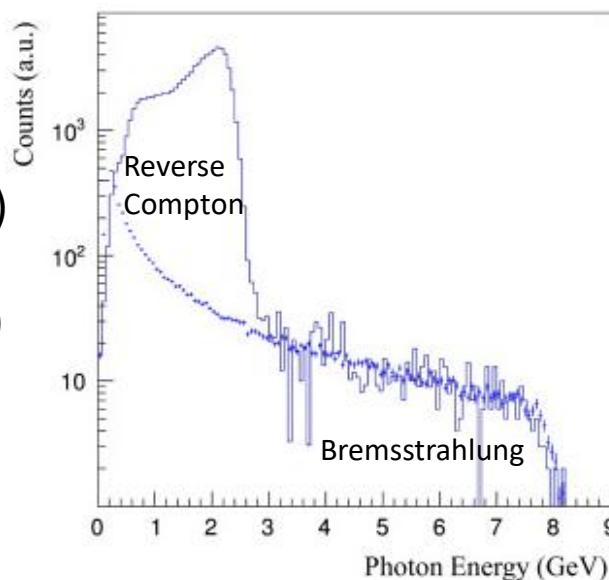
Need integration over a range of n depending on laser intensity

$$\frac{dN}{dE} \propto \int_{\frac{E}{E_c}}^{\infty} K_{5/3}(x) dx$$

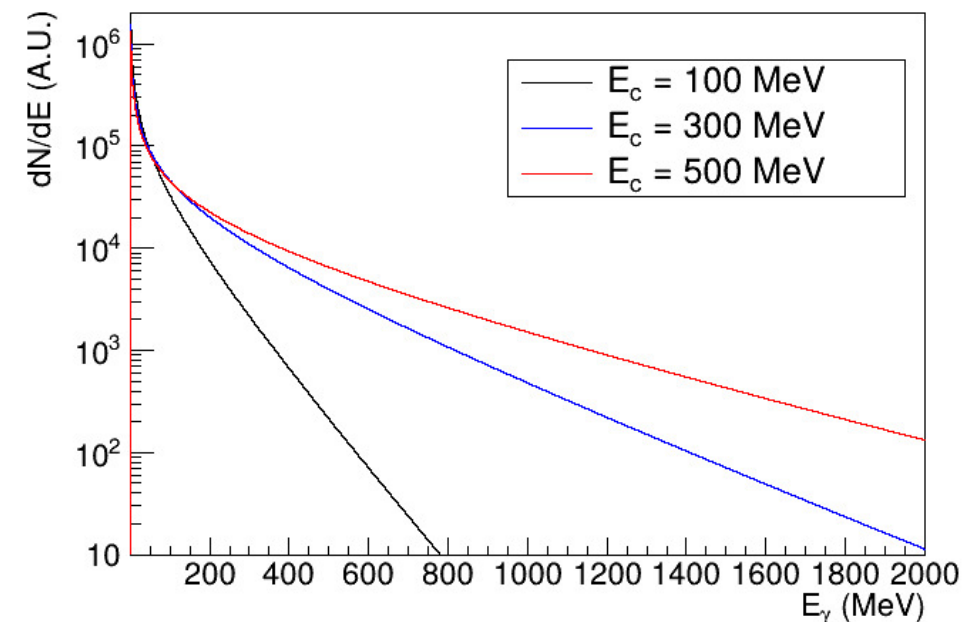
Critical energy: $E_c \propto \gamma_e^2 a_0$

LEPS2 beamline
(Spring8 synchrotron)
 $E_e = 8$ GeV
 $E_L = 4.66$ eV (266 nm)

$E_{\gamma max} = 2.89$ GeV

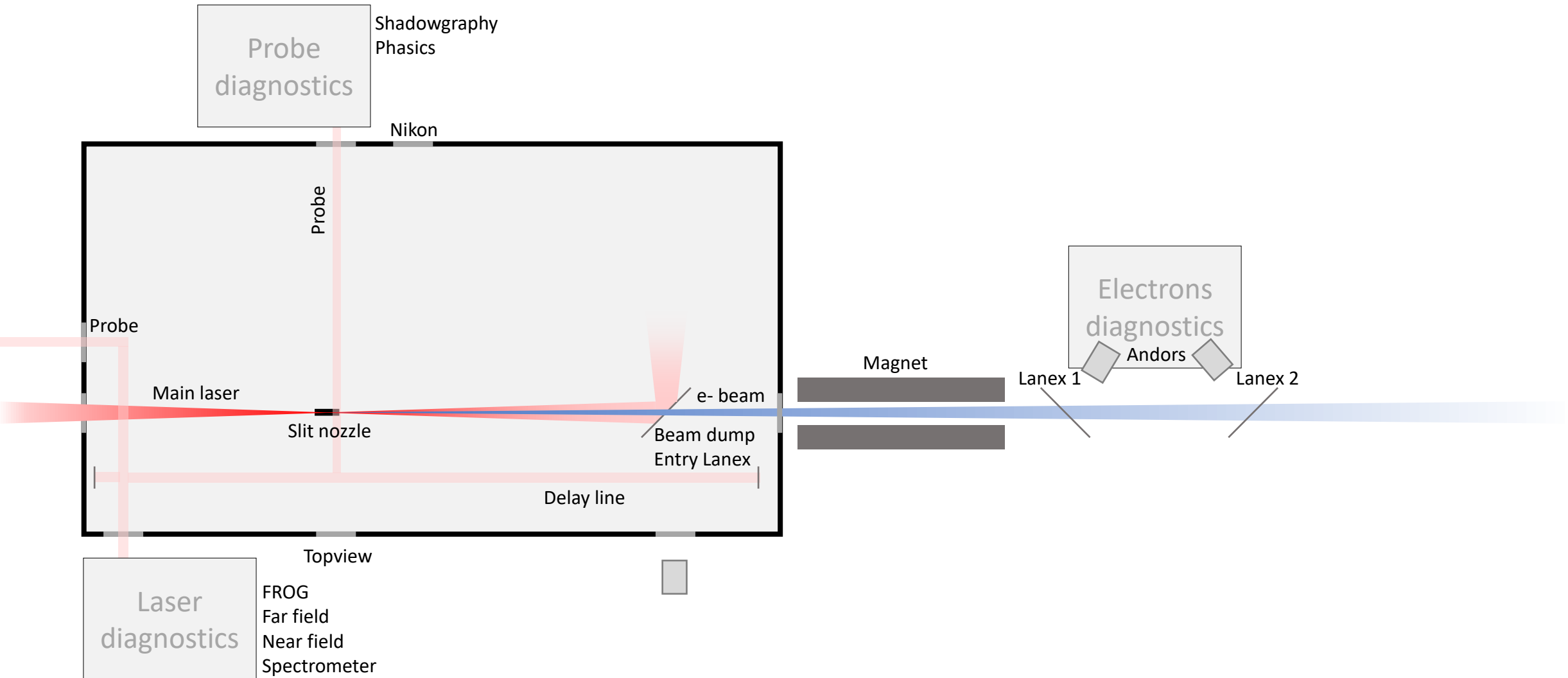


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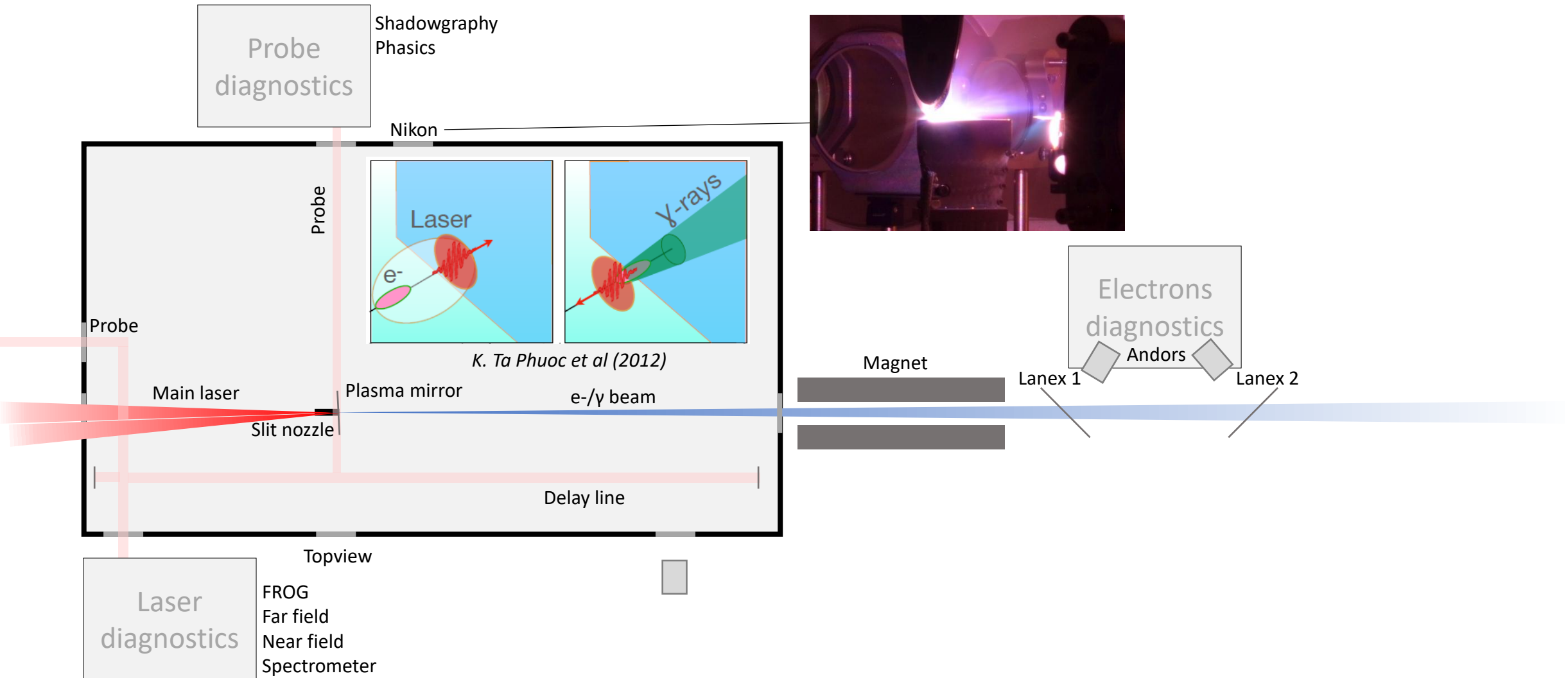
Gamma generation : Nonlinear reverse Compton

Commissioning experimental campaign 2023/2024:



Gamma generation : Nonlinear reverse Compton

Commissioning experimental campaign 2023/2024:



Challenges:

MeV to GeV photons

Sub-ns bunches

Harsh environment (EMP, x-ray flash, ...)

Challenges:

MeV to GeV photons

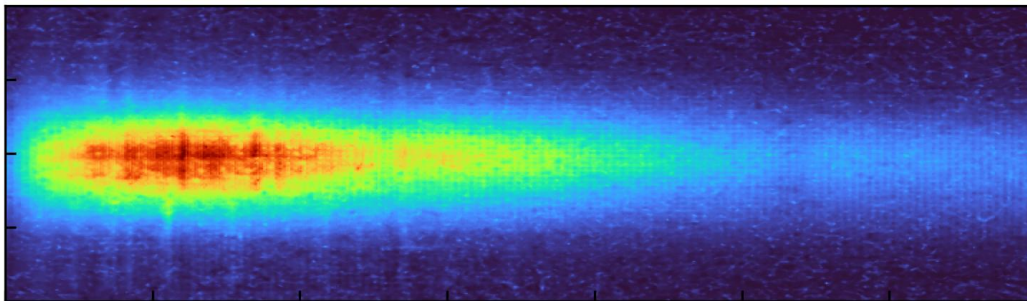
Sub-ns bunches

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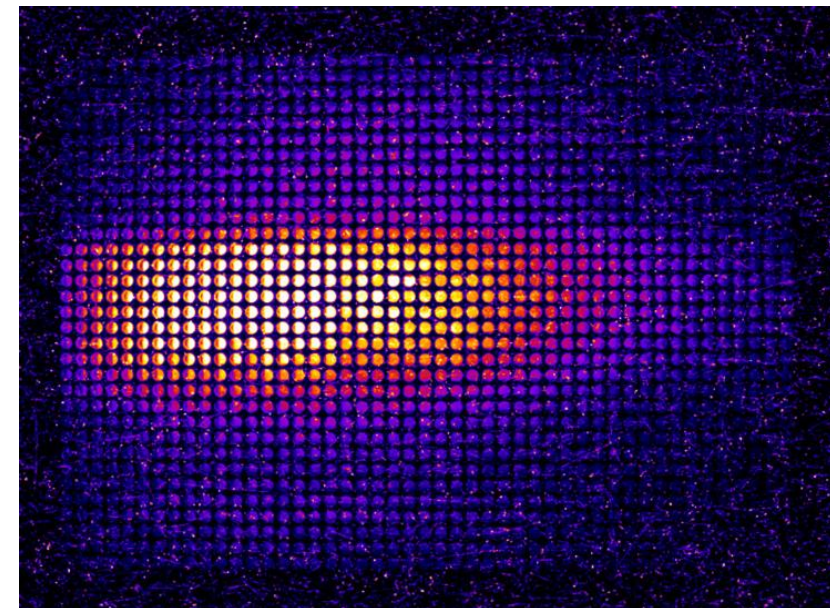
Possible solution:

Pixelated scintillator stack associated with camera

LYSO

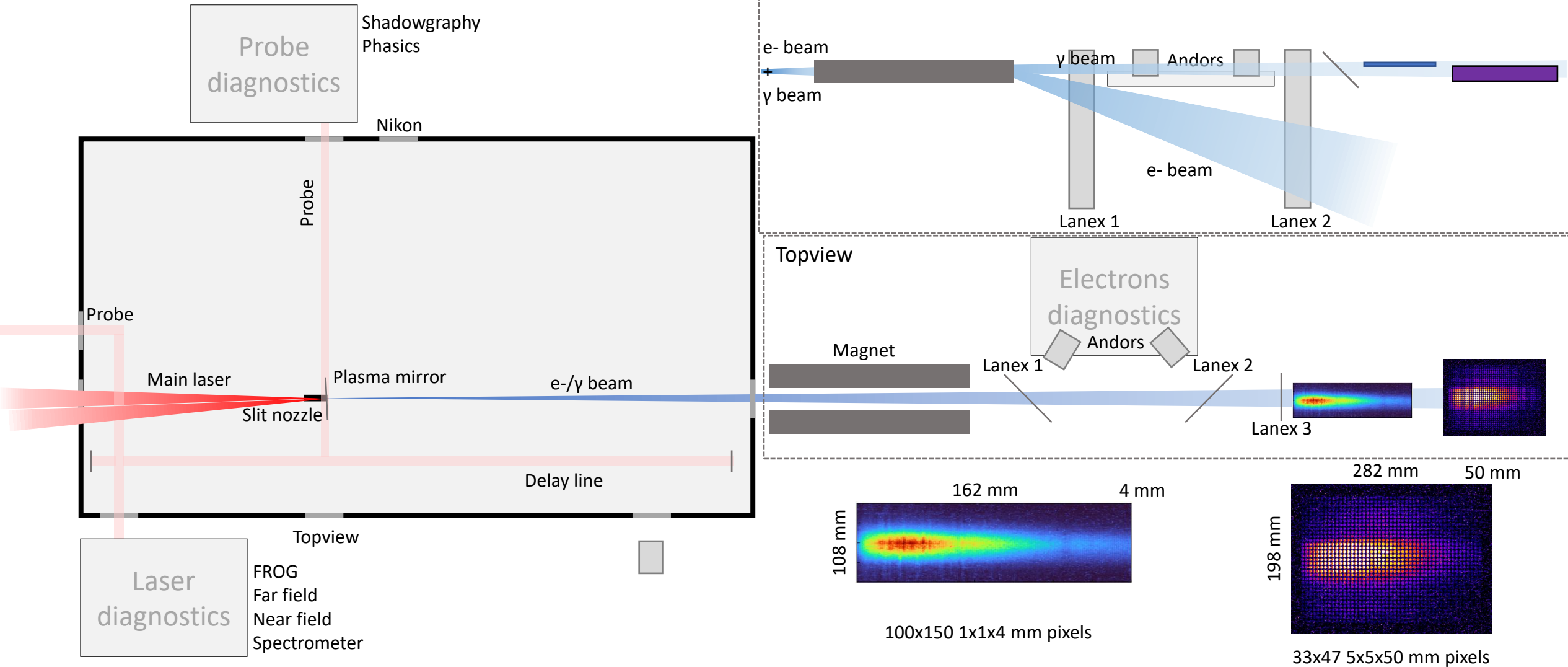


CsI



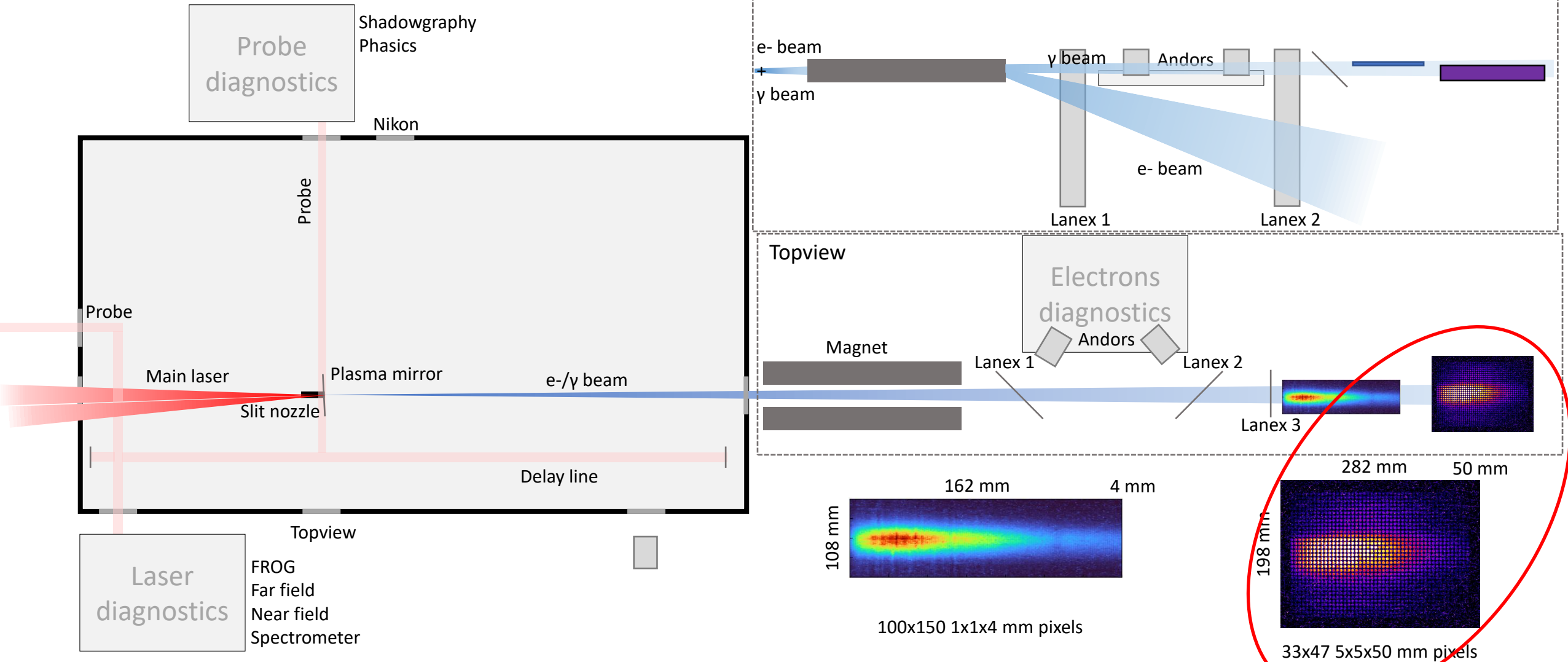
Characterization (LYSO/CsI stack)

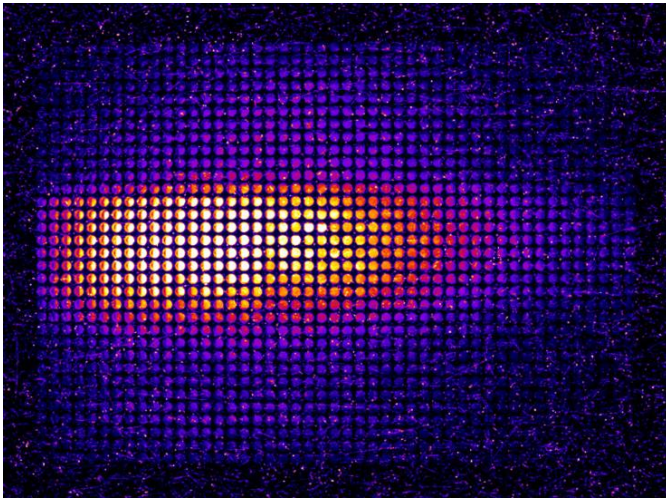
Commissioning experimental campaign 2023/2024:



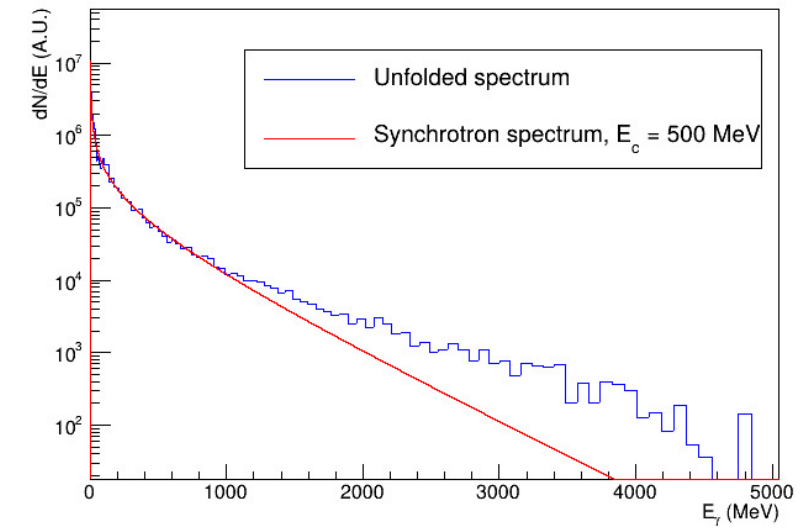
Characterization (LYSO/CsI stack)

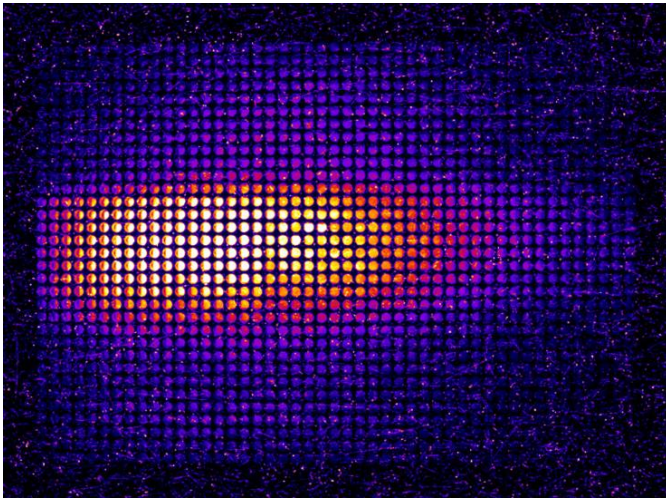
Commissioning experimental campaign 2023/2024:



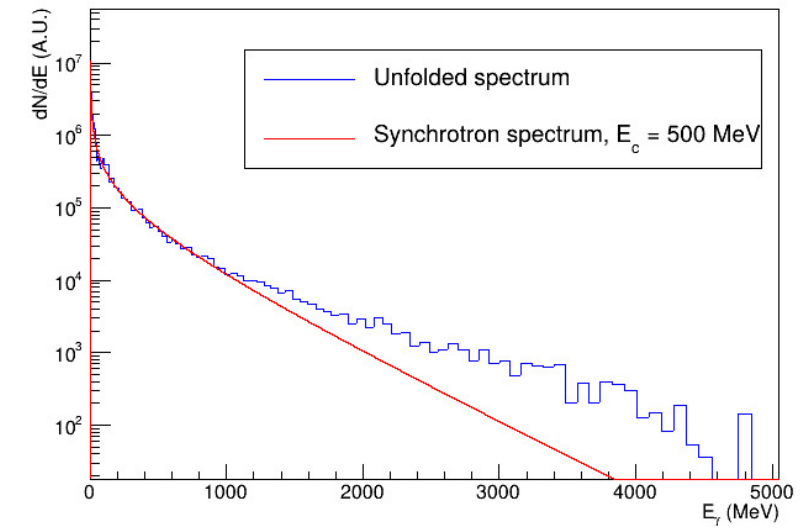


?



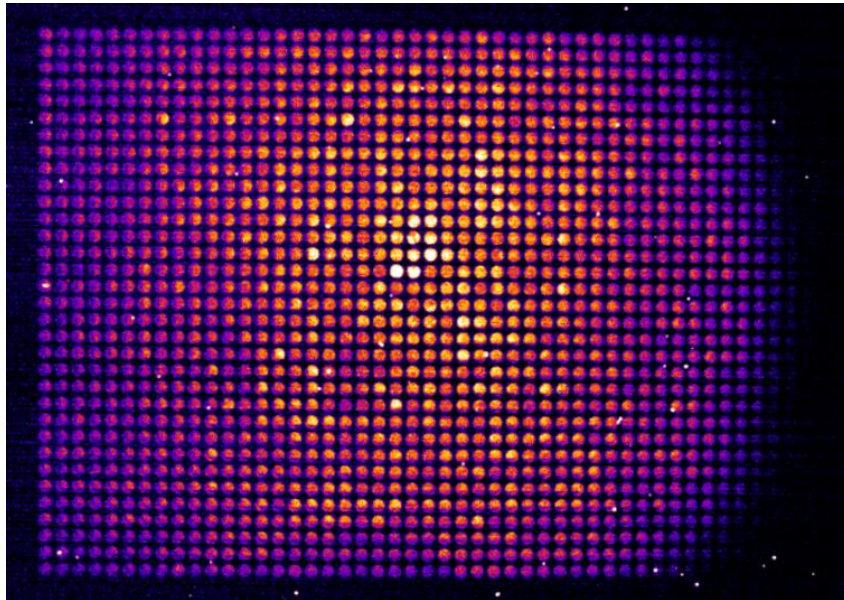


Unfolding procedure
using response matrices

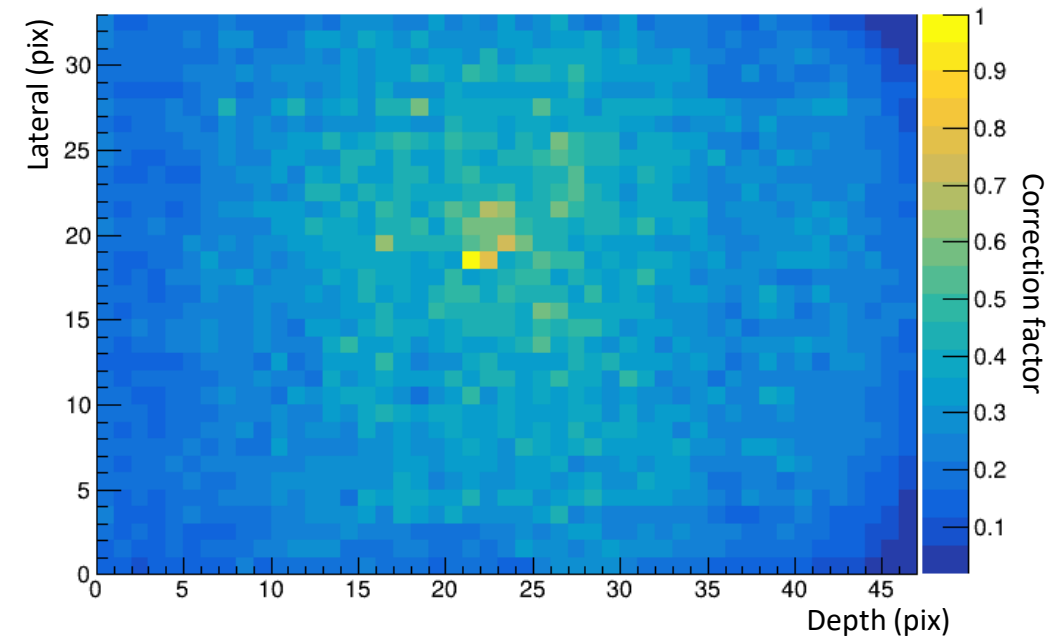


Optical response matrix:

Homogenous X-ray irradiation from the bottom



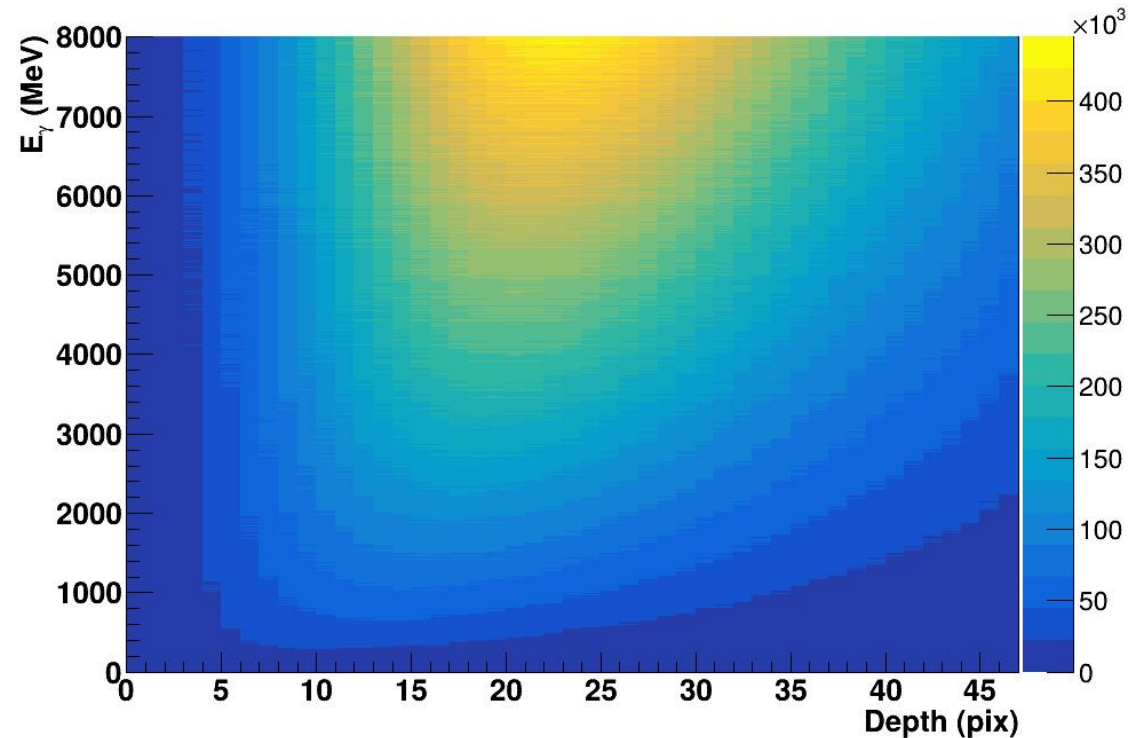
Regular size
pixel integration
→
+ background
subtraction
(X-ray tube off)



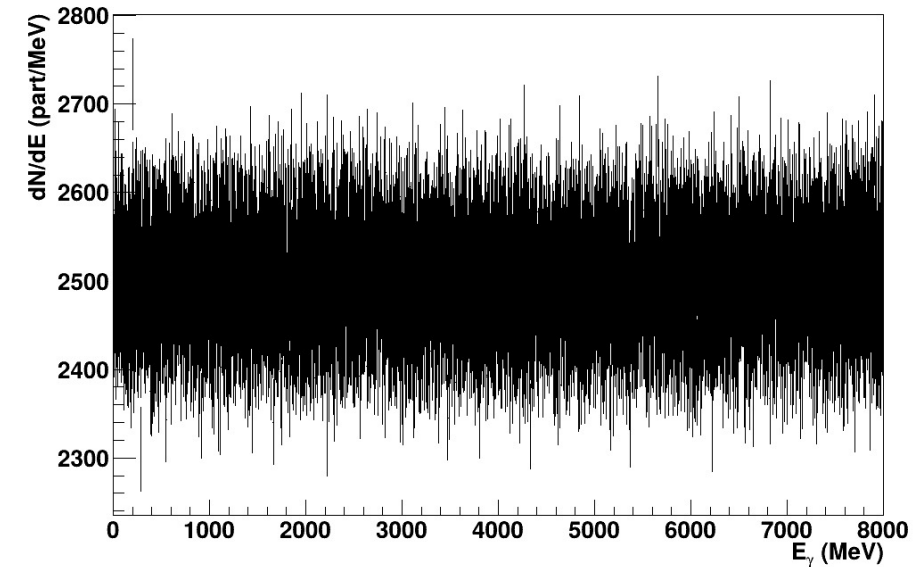
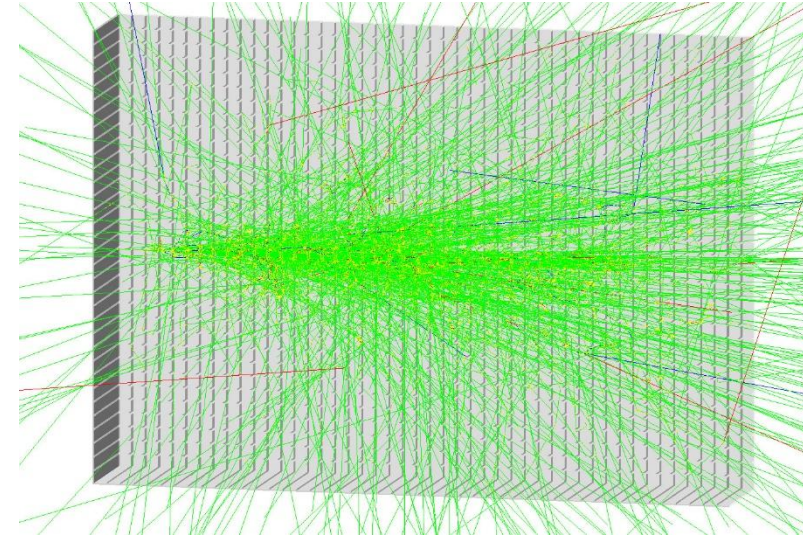
Correction factor to apply to each pixel signal

CsI stack response matrix:

Geant4 simulations to retrieve energy deposition in each pixel according to E_γ

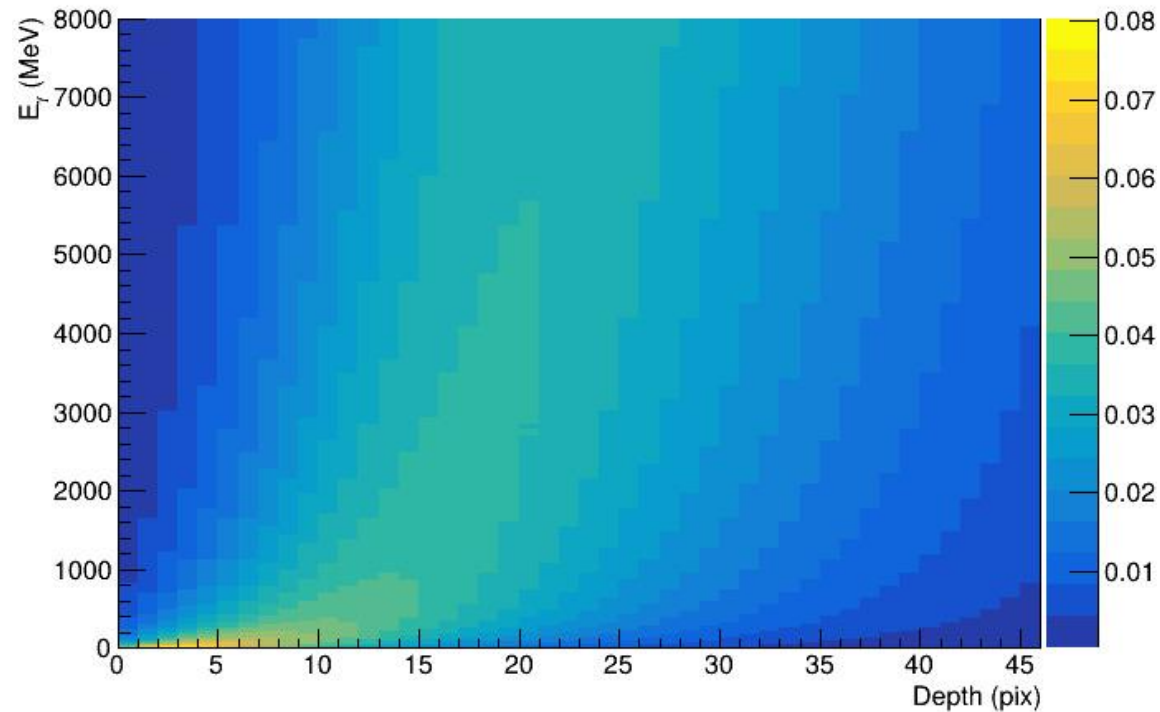


One 3 GeV incoming γ -ray

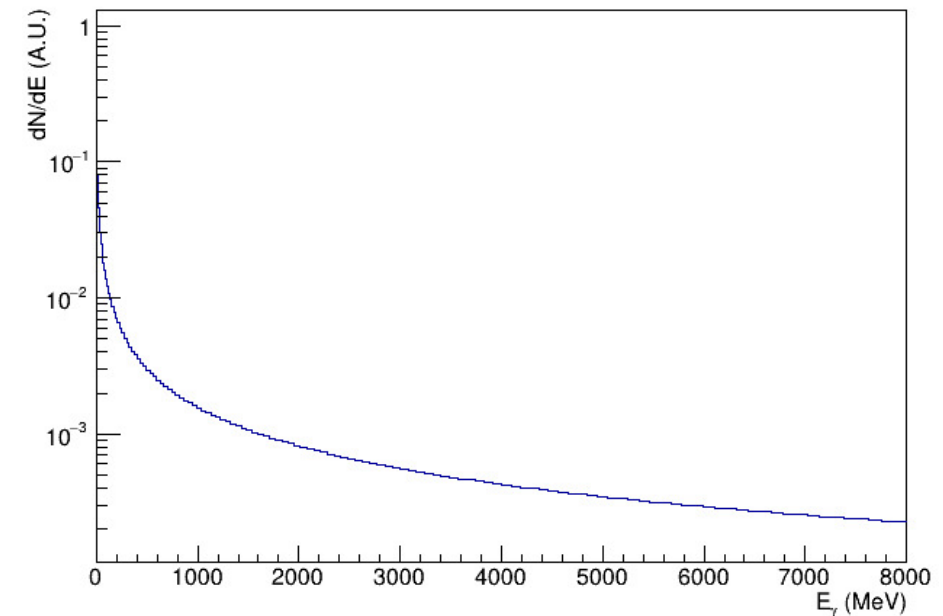
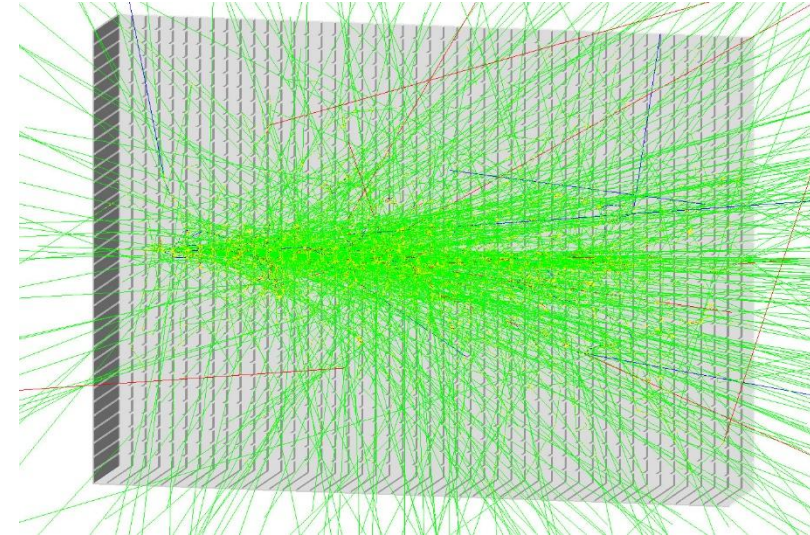


Csl stack response matrix:

Geant4 simulations to retrieve energy deposition
in each pixel according to E_γ
With rebinning and normalization



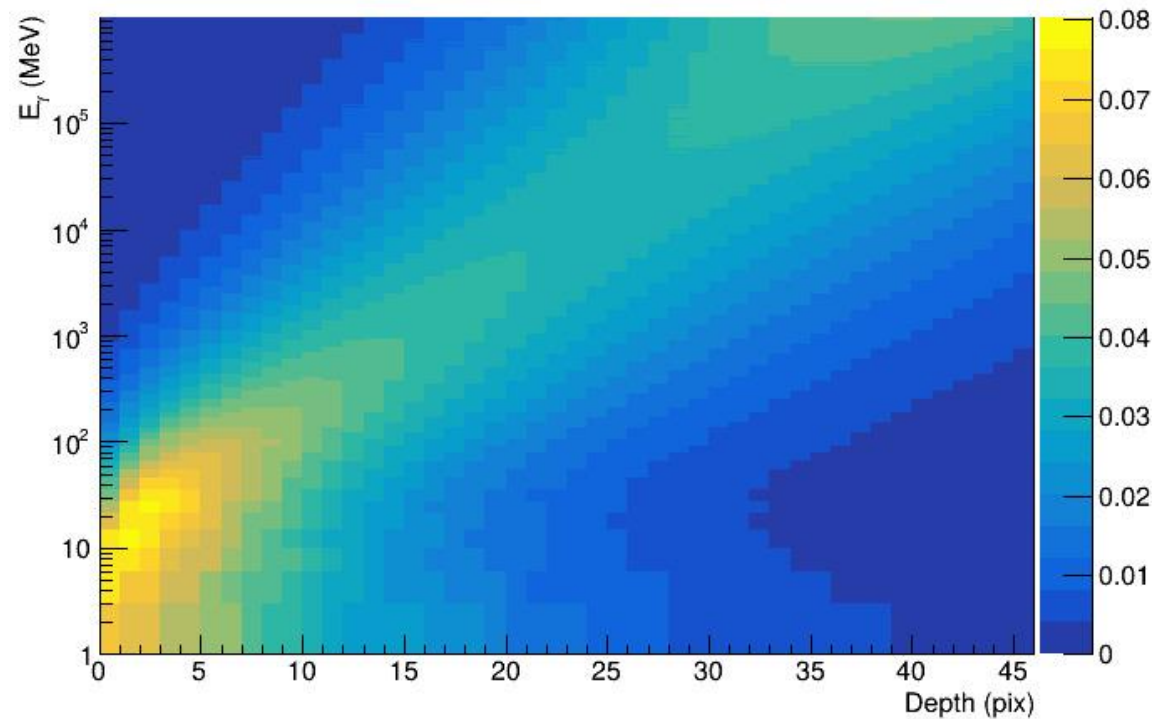
One 3 GeV incoming γ -ray



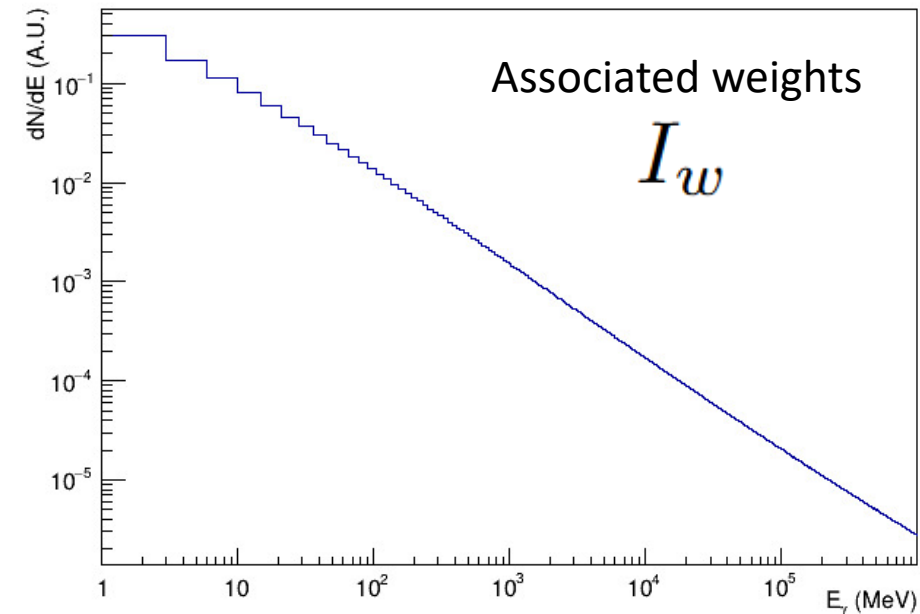
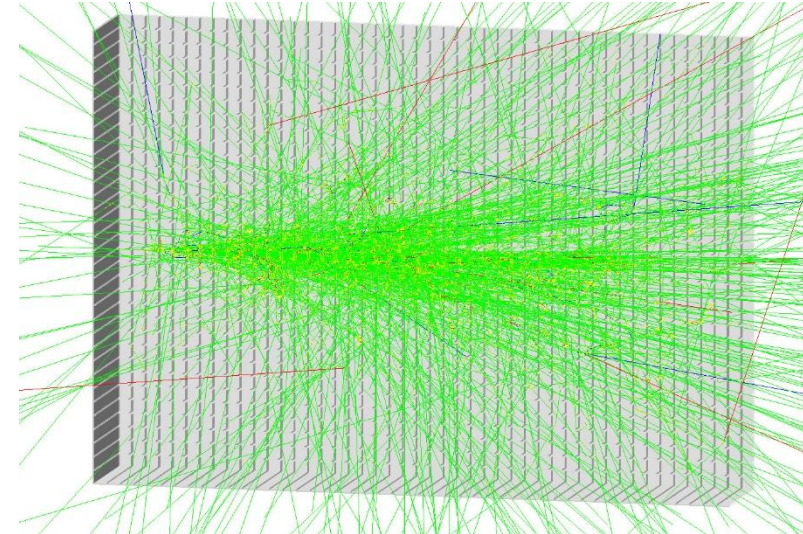
Csl stack response matrix:

Geant4 simulations to retrieve energy deposition
in each pixel according to E_γ
With rebinning and normalization

Response matrix R

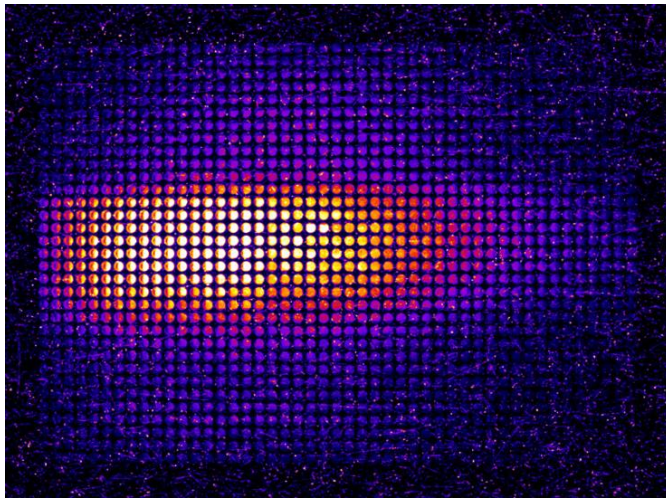


One 3 GeV incoming γ -ray

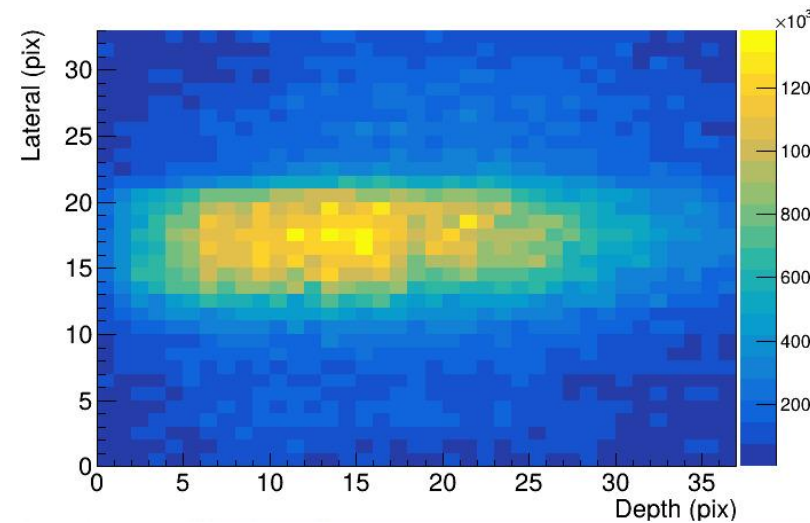


Unfolding procedure:

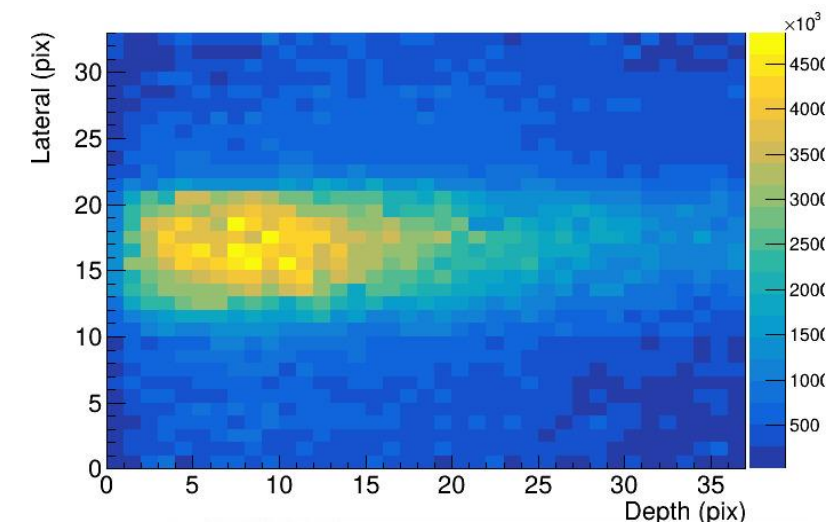
Original image



Pixel counts

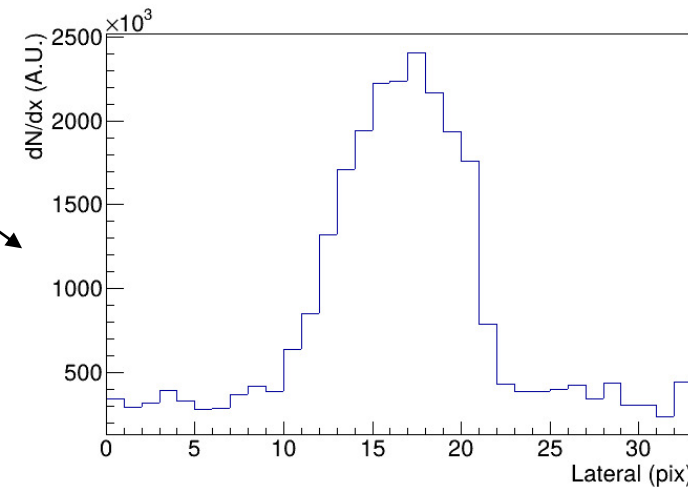
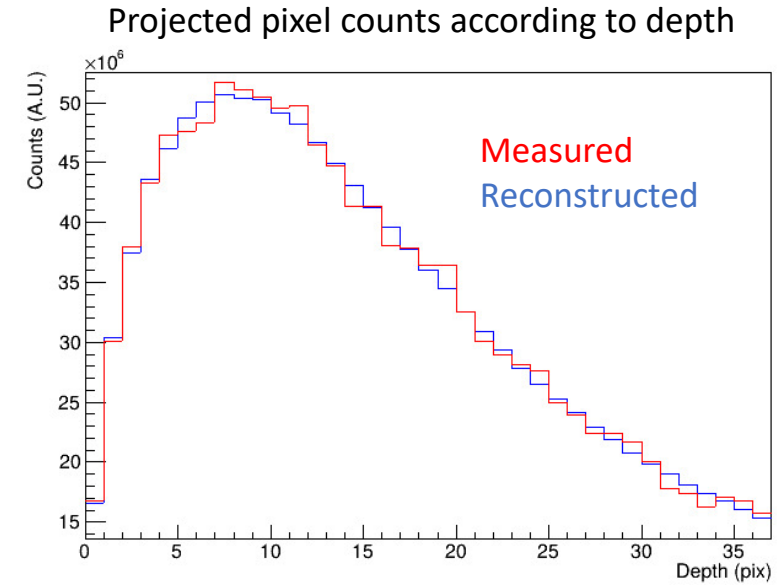
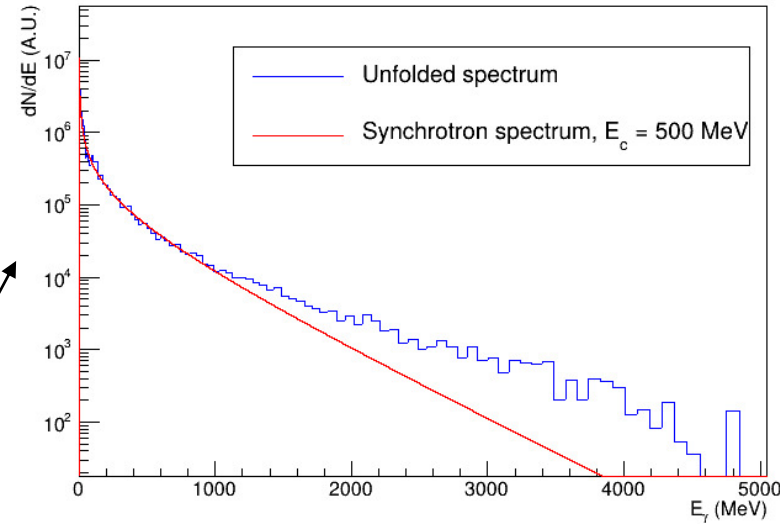
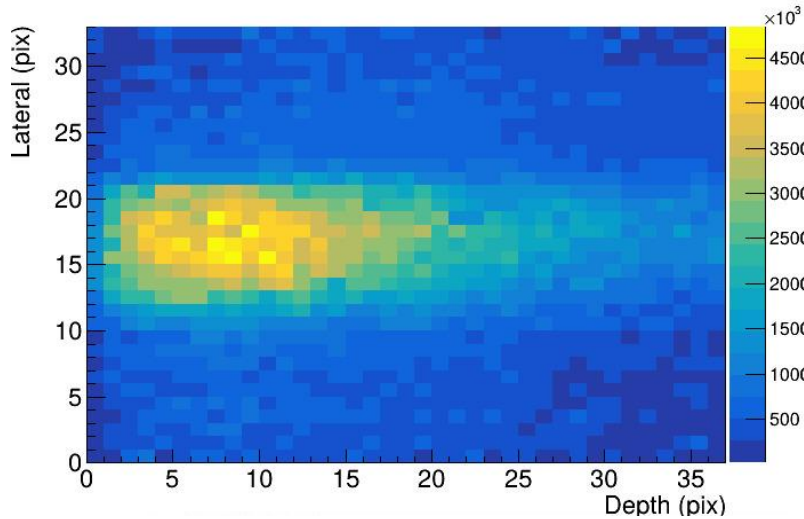


After optical response correction



Unfolding procedure:

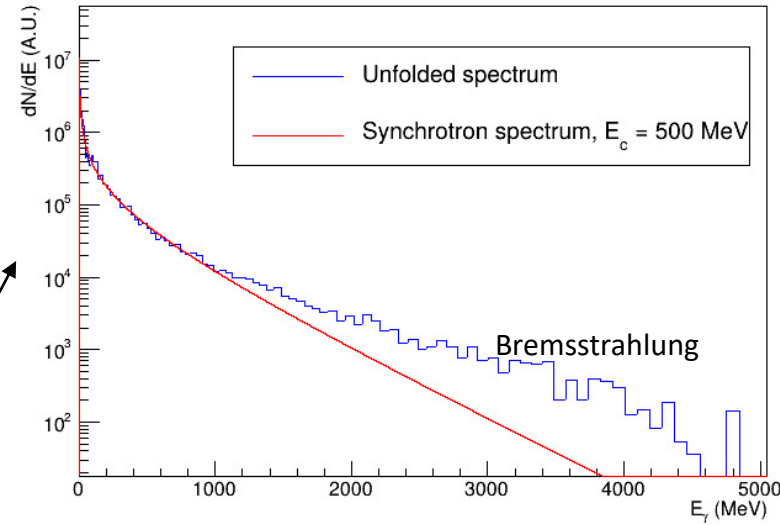
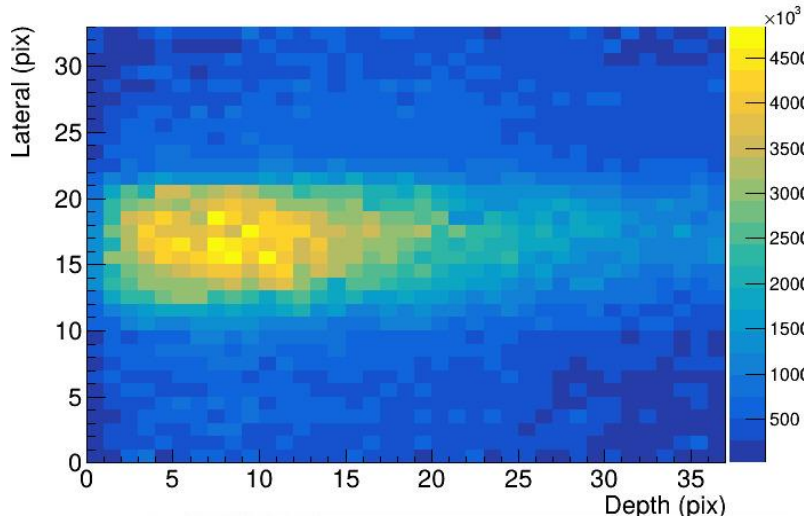
$$\vec{t} = I_w (R^T R + \tau I)^{-1} R^T \vec{m}$$



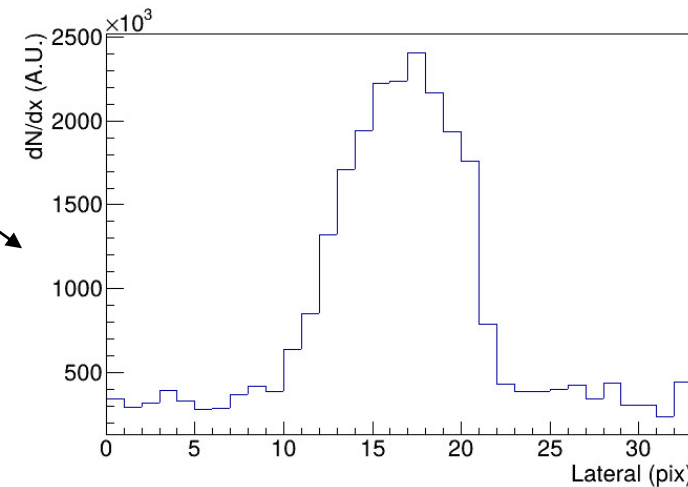
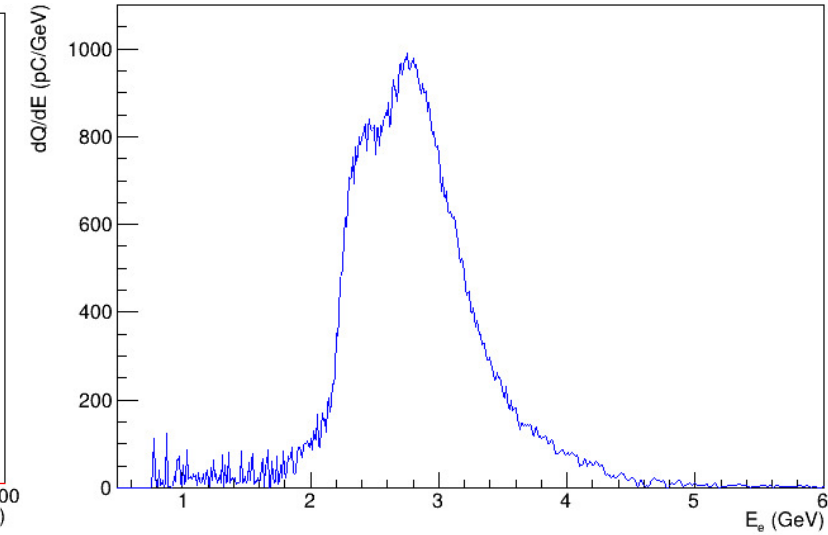
Another unfolding
procedure for
lateral dispersion

Unfolding procedure:

$$\vec{t} = I_w (R^T R + \tau I)^{-1} R^T \vec{m}$$



e- spectrum



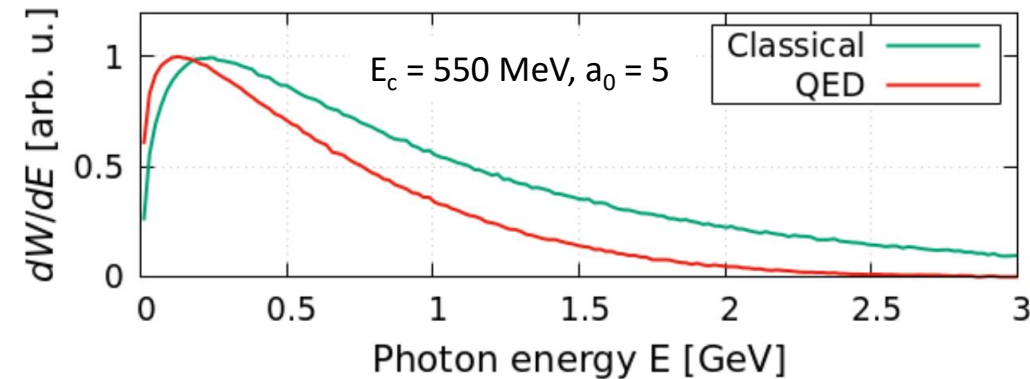
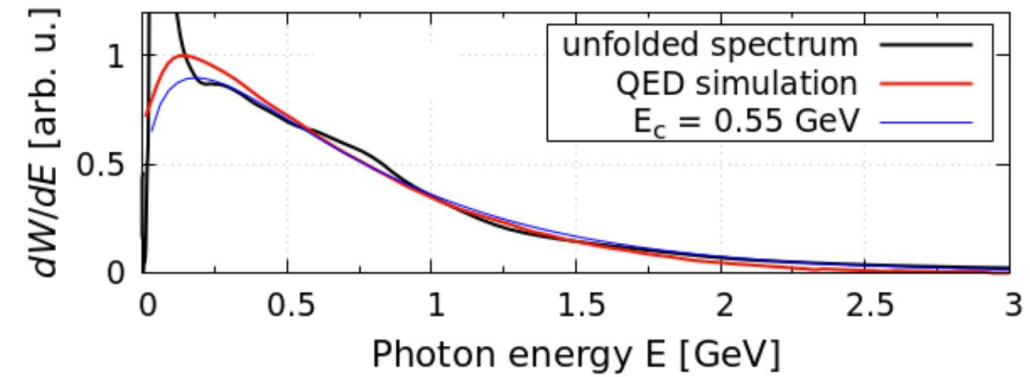
Another unfolding procedure for lateral dispersion

Divergence from classical scaling:

Classically : $E_c \propto \gamma_e^2 a_0$

Wrong if the electric field seen by the electron is non negligible compared to the Schwinger field

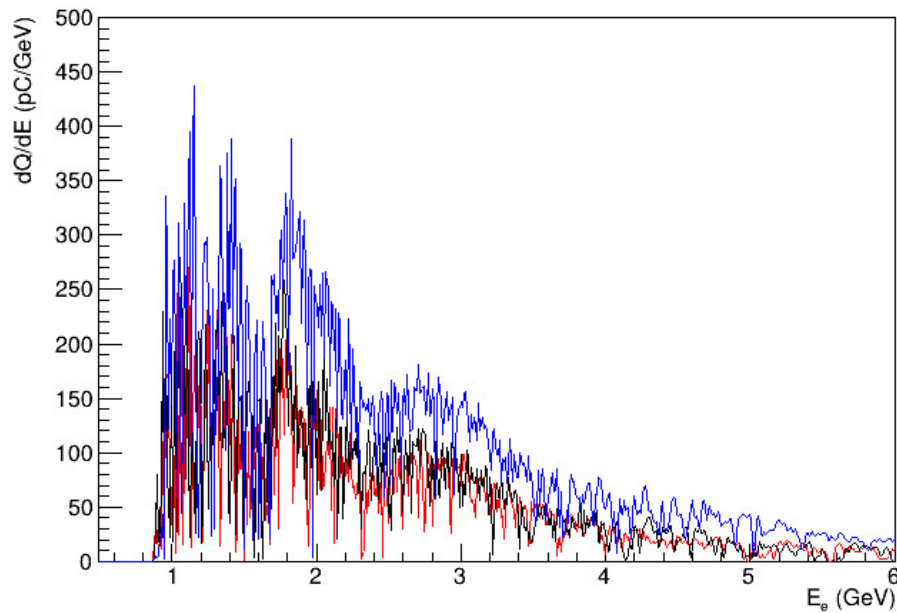
a_0 estimated using simulations (Ptarmigan code) to reproduce measured e- and γ spectra



A. Matheron et al, arxiv (2024)

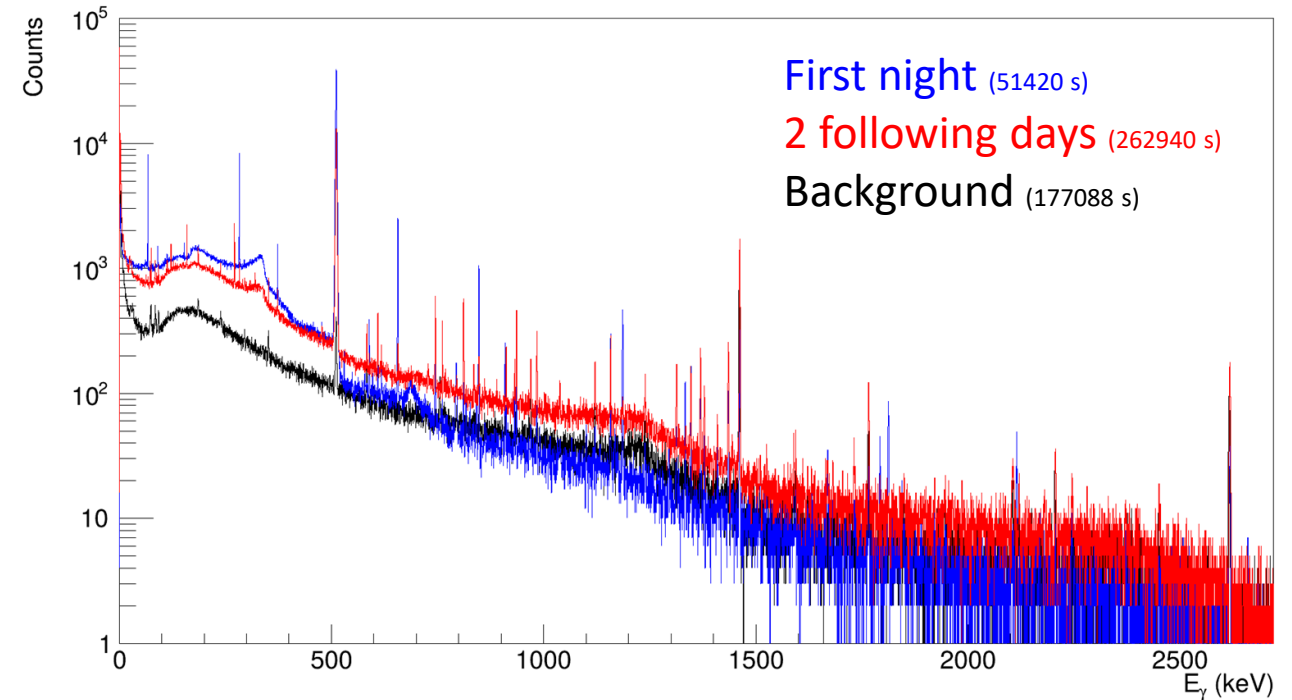
Reproduction of known yields on activation targets (June 2025):

Multi-GeV e- beam + Bremsstrahlung converter (lead)
 ^{nat}Cu & Al activation measured with HPGe station



e- spectra recorded after the converter
40 shots overall with similar spectra

^{nat}Cu & Al activation measured with HPGe station
4 + 1 mm



γ spectra recorded after the irradiation

Possible applications: photonuclear reactions

Reproduction of known yields on activation targets (June 2025):



Target nuclei



Isotope with identified deexcitation gamma lines



^{24}Na used for γ beam
quantitative estimation

Alternatively $^{\text{nat}}\text{Cu}(\gamma, \text{xn})^{64,62,61,60}\text{Cu}$

Goal : reproducing yields measured by Shibata (1986)

Analysis still undergoing

Work done:

- Multi-GeV e-/ γ beams available for experiments at ELI-NP
- Characterization of such beams available on a shot-to-shot basis
- First attempt to use such beams conducted during commissioning experiments

Perspective:

- User experiments (call for proposal open)
- Extra γ beams diagnostics (Compton/pair production) are envisioned
- Improvement of unfolding stability
- Quantitative calibration of the scintillators stack should be done

Thank you for your attention !

Questions ?

ELI - RO

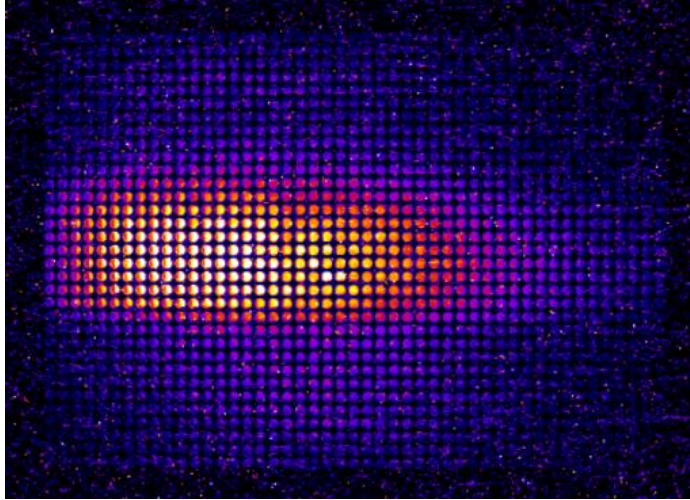


NUCLEU and IOSIN programs

Title

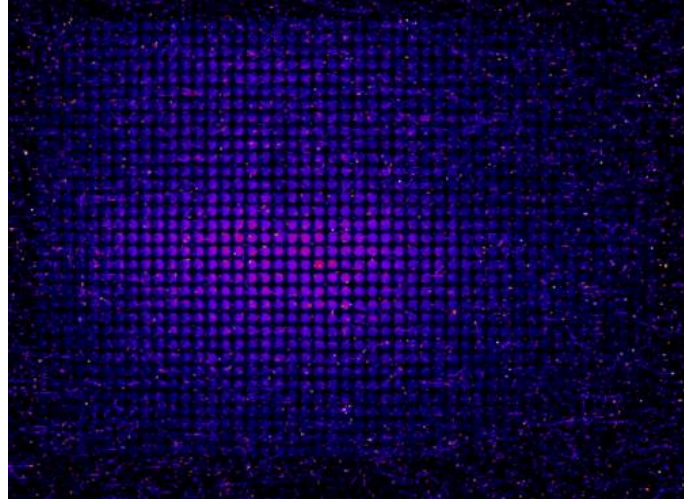
Compton vs Bremsstrahlung

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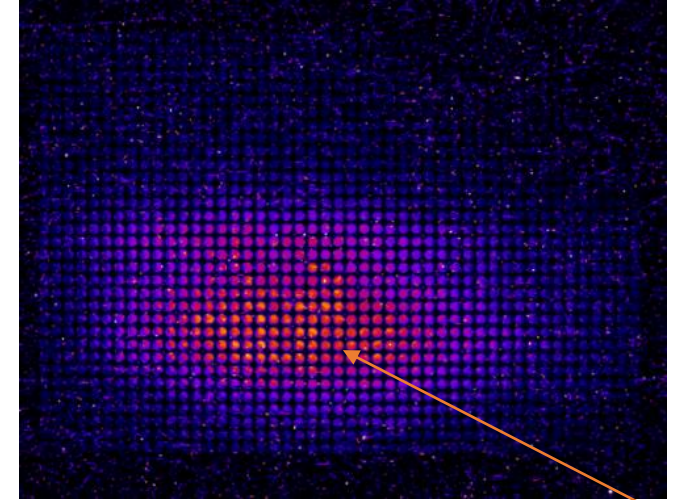
Plasma mirror

104



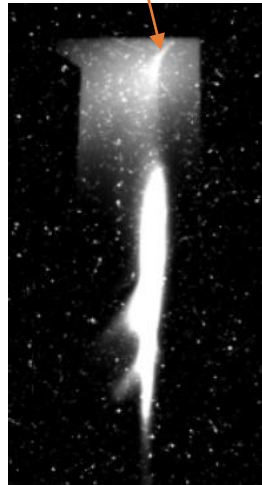
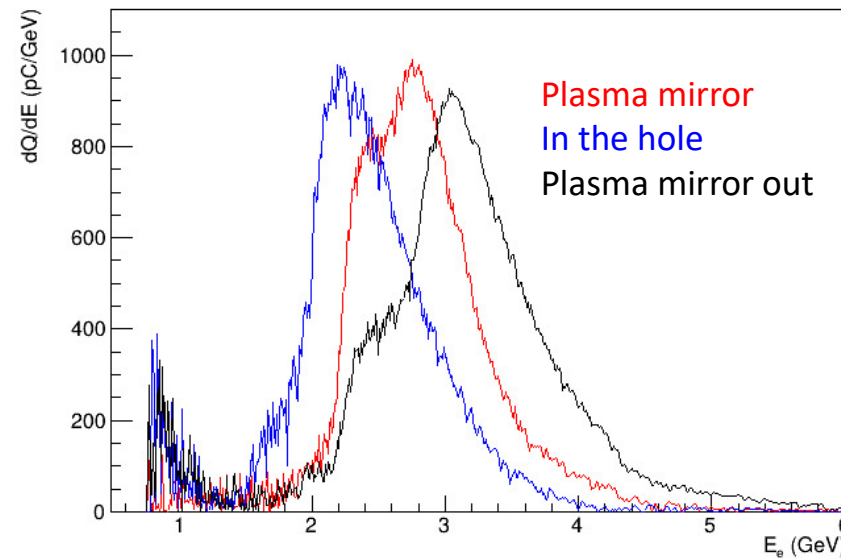
In the hole

105



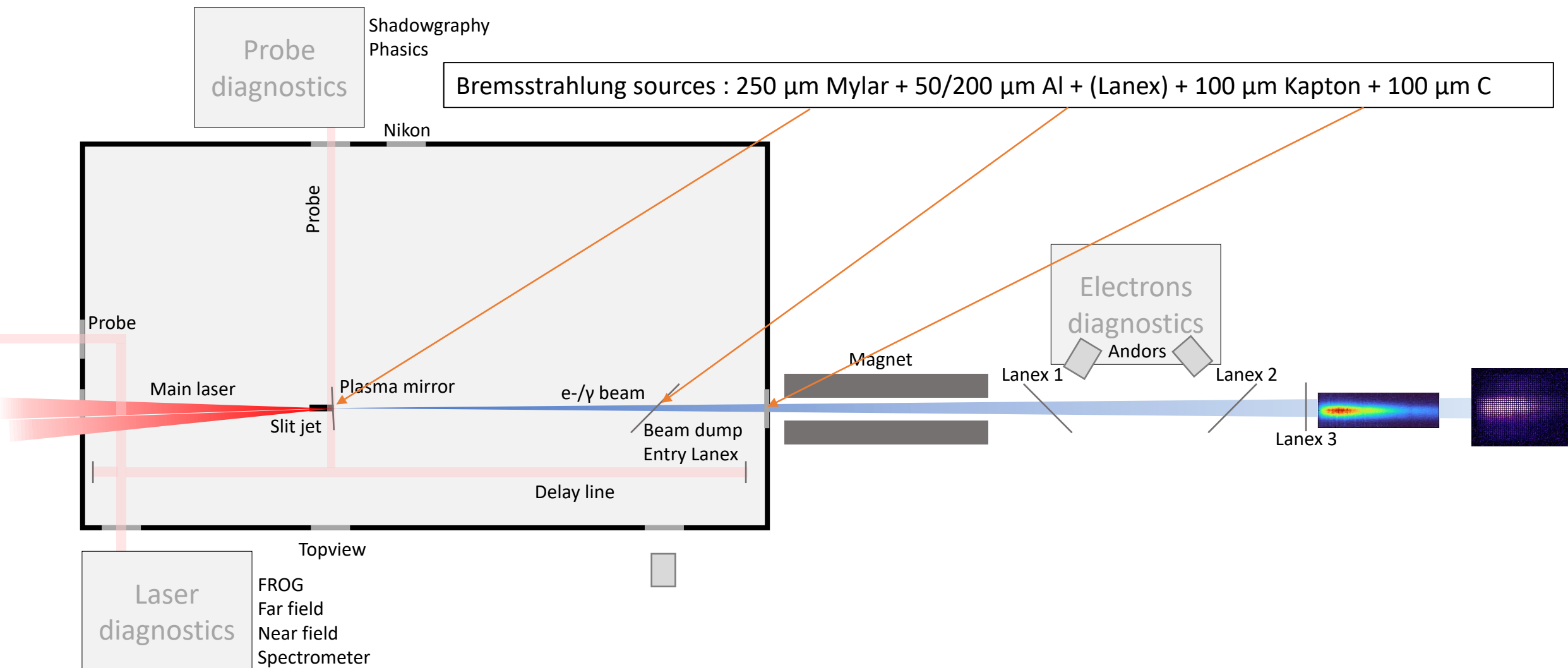
Plasma mirror out

Surely e-



Compton vs Bremsstrahlung

Commissioning experimental campaign 2023/2024:



$$\frac{dW}{dE} \propto \frac{E}{E_c} \int_{\frac{E}{E_c}}^{\infty} K_{5/3}(x) dx$$

