20th Advanced Accelerator Concepts Workshop

FACET-II
Facility for Advanced Accelerator Experimental Tests

First X-ray and Gamma-ray measurements at FACET-II

Pablo San Miguel Claveria (LOA, IP Paris / X-GolP, IST Lisbon)

On behalf of:

E300, E305 and E320 Collaborations (SLAC, UCLA, CU Boulder, U. Oslo, Stony Brook U., LOA)

Work supported by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (Miniature beam-driven Plasma Accelerators project, Grant Agreement No. 715807) and by the ANR (UnRIP project, Grant No. ANR- 20-CE30-0030)

Numerical simulations were performed using HPC resources from PRACE (Grant No. 2017174175) and GENCI-TGCC (Grants No. 2018- A0040507594, No. 2019-A0060510786, 2020-A0080510786 and 2021- A0100510786 to run PIC simulations.

ENSTA IP PARIS

cnrs

ÉCOLE POLYTECHNIQUE IP PARIS

INSTITUT POLYTECHNIQUE DE PARIS

loa

erc European Research Council
Established by the European Commission

Overview

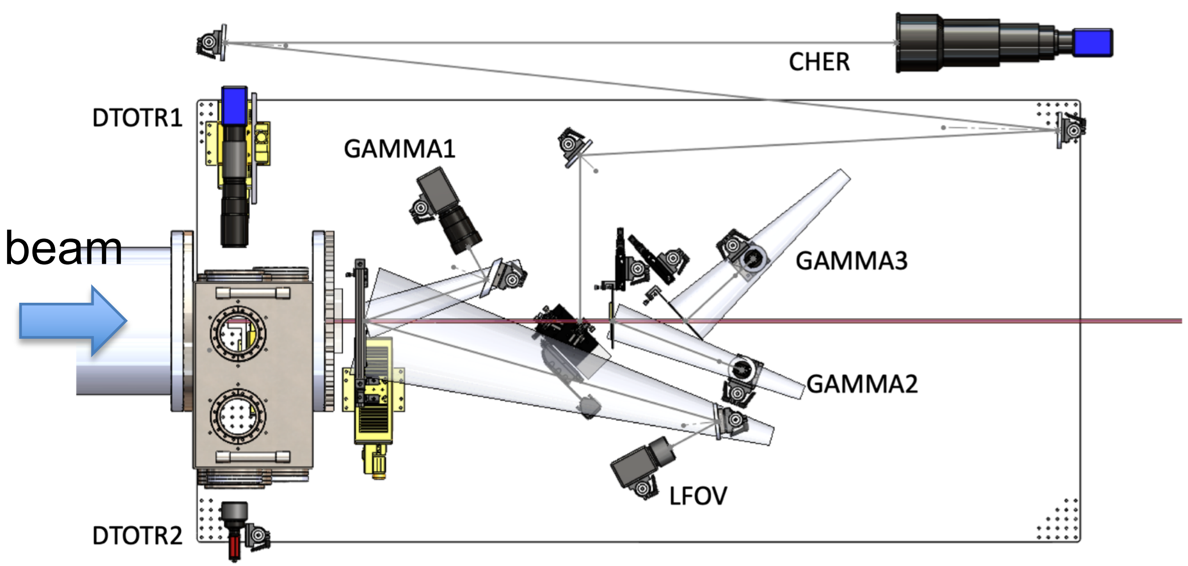
1. Gamma-ray detectors at FACET-II: design and working principles.

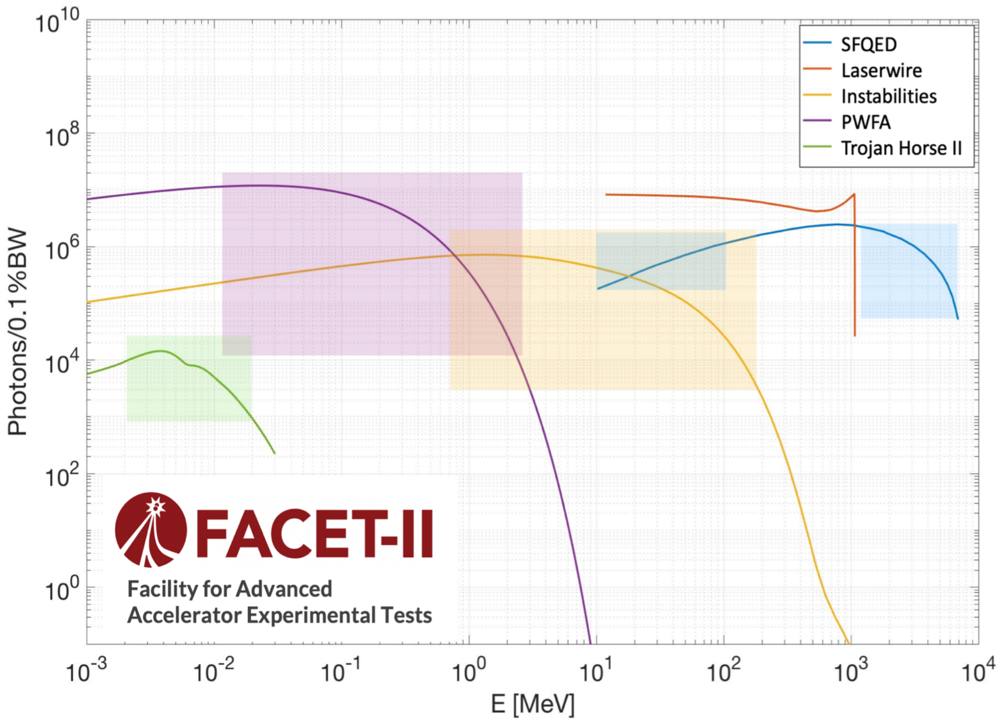
2. Installation and commissioning phase.

3. Experimental goals and first preliminary measurements:
   - Beam-filamentation and gamma-ray burst (E305)
   - Strong-Field QED (E320)
   - Plasma Wakefield acceleration (E300)

Gamma-ray detectors at FACET-II

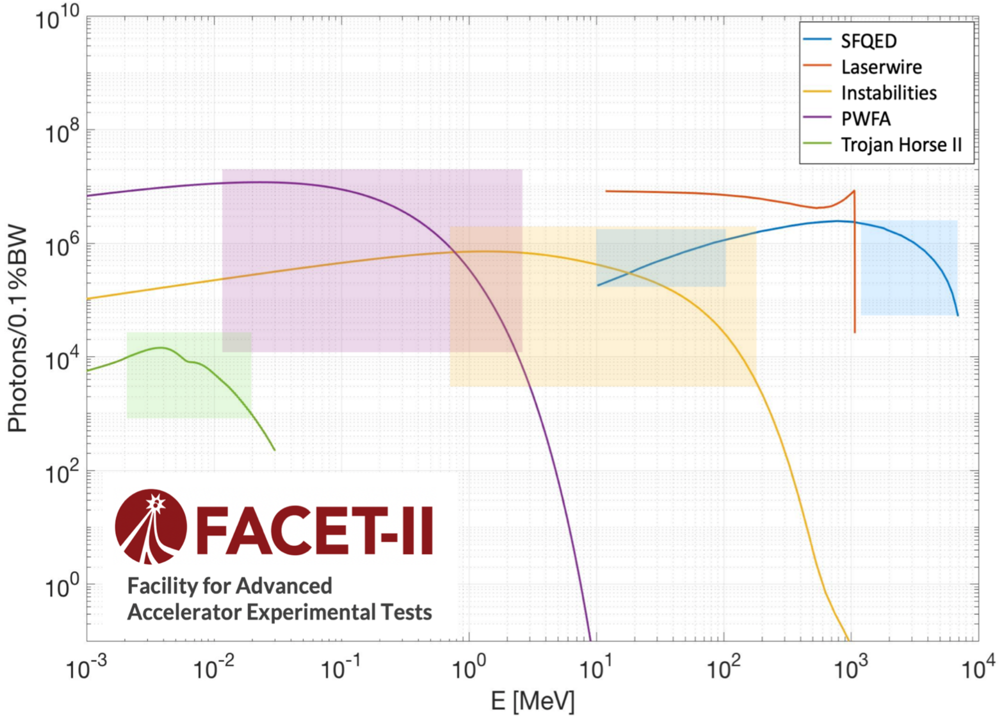
- FACET-II is a user facility: experimental set-up compatible between different experiments.
- Different experiments produce X-rays and ɣ-rays with different energies.
- After some iterations, first set of detectors:
  GAMMA1, GAMMA2 and GAMMA3 at the Dump Table

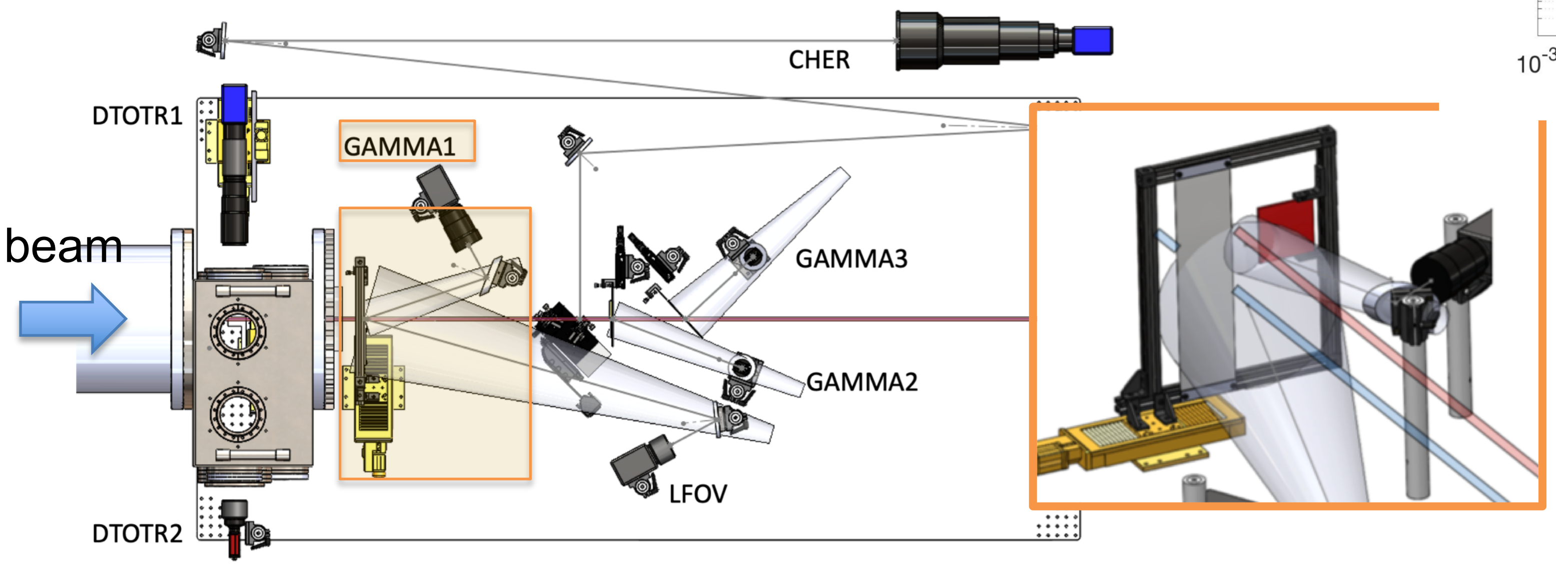




Gamma-ray detectors at FACET-II

- FACET-II is a user facility: experimental set-up compatible between different experiments.
- Different experiments produce X-rays and ɣ-rays with different energies.
- After some iterations, first set of detectors:
  GAMMA1, GAMMA2 and GAMMA3 at the Dump Table



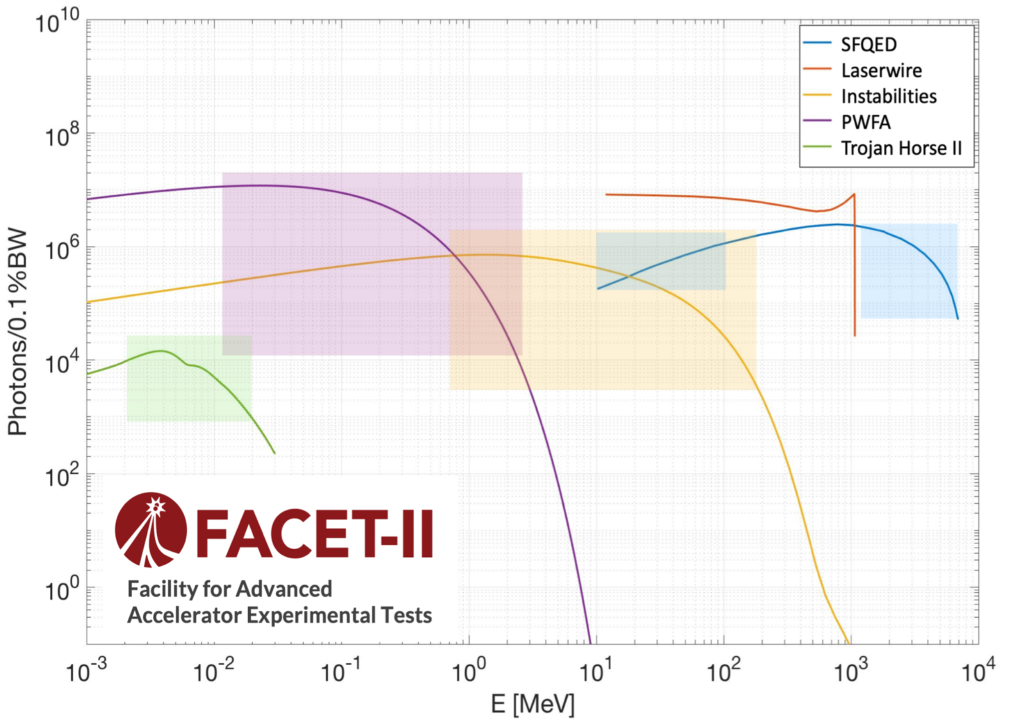


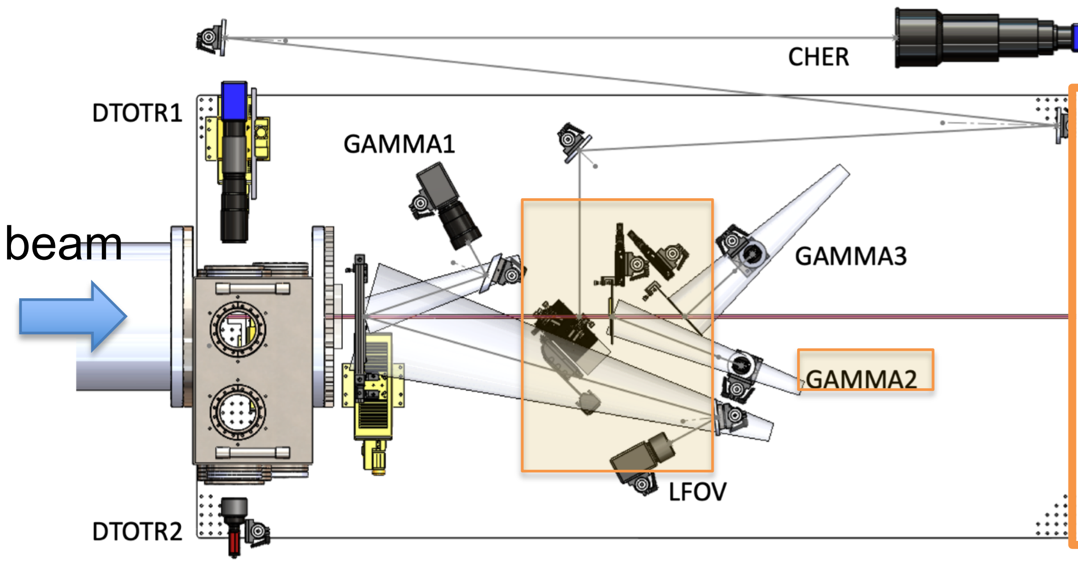
GAMMA1: scintillating screens
- DRZ screen + converter (optional)
- CsI pixelized screen

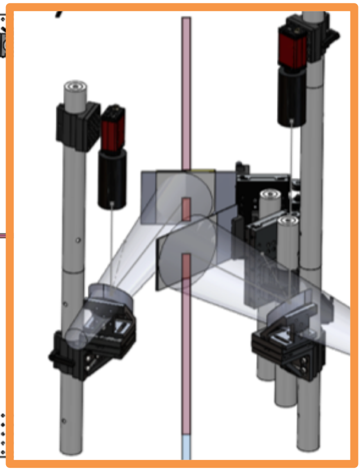
Integrated and angular information

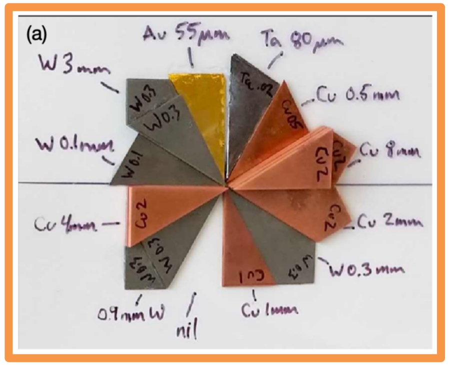
Gamma-ray detectors at FACET-II

- FACET-II is a user facility: experimental set-up compatible between different experiments.
- Different experiments produce X-rays and ɣ-rays with different energies.
- After some iterations, first set of detectors:
  GAMMA1, GAMMA2 and GAMMA3 at the Dump Table







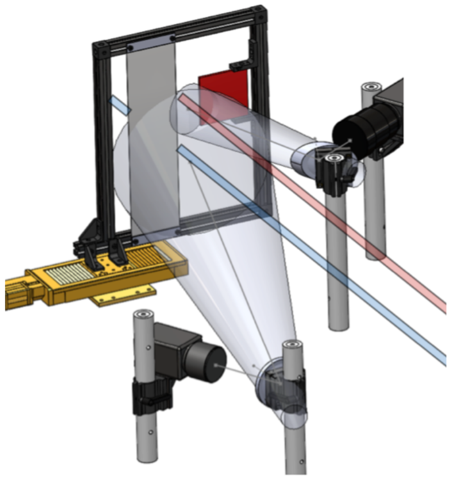


GAMMA2 ~~and GAMMA3~~: filters + scintillating screens

Spectral information

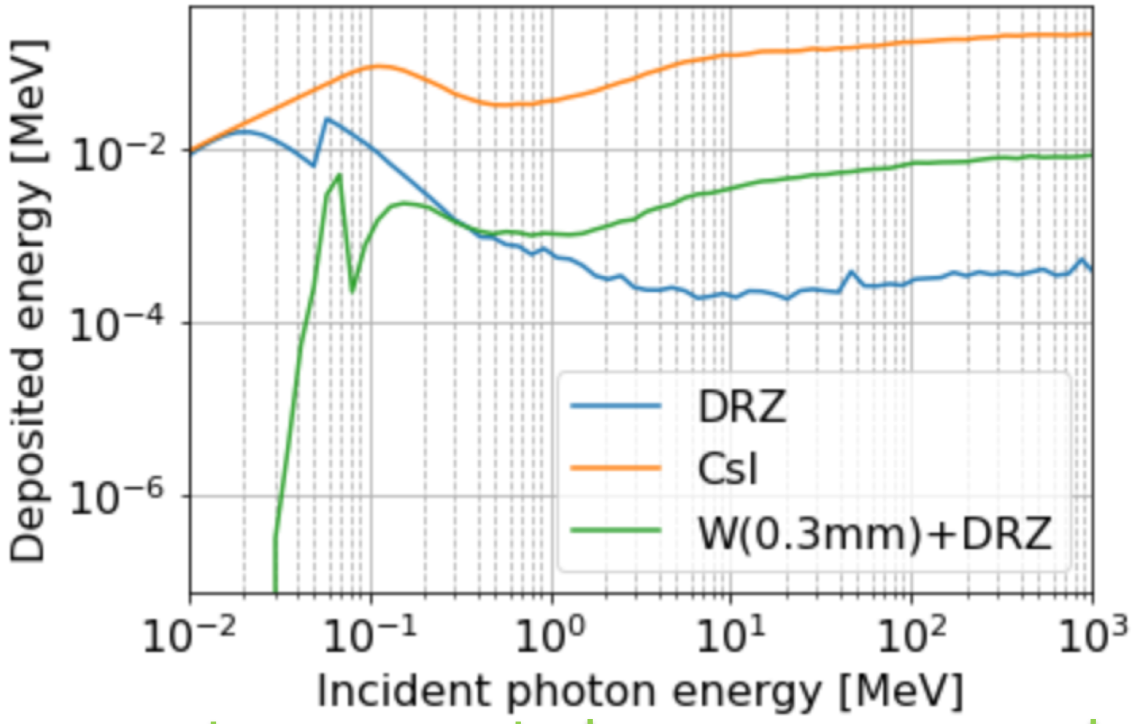
Gamma-ray detectors at FACET-II

- Sensitivity of the screens depends on the incident ɣ-ray energy.
- Different scintillators offer different sensitivities and spatial resolutions at different ɣ-ray energies



CsI pixelized crystal

Lanex screen



Low energies:

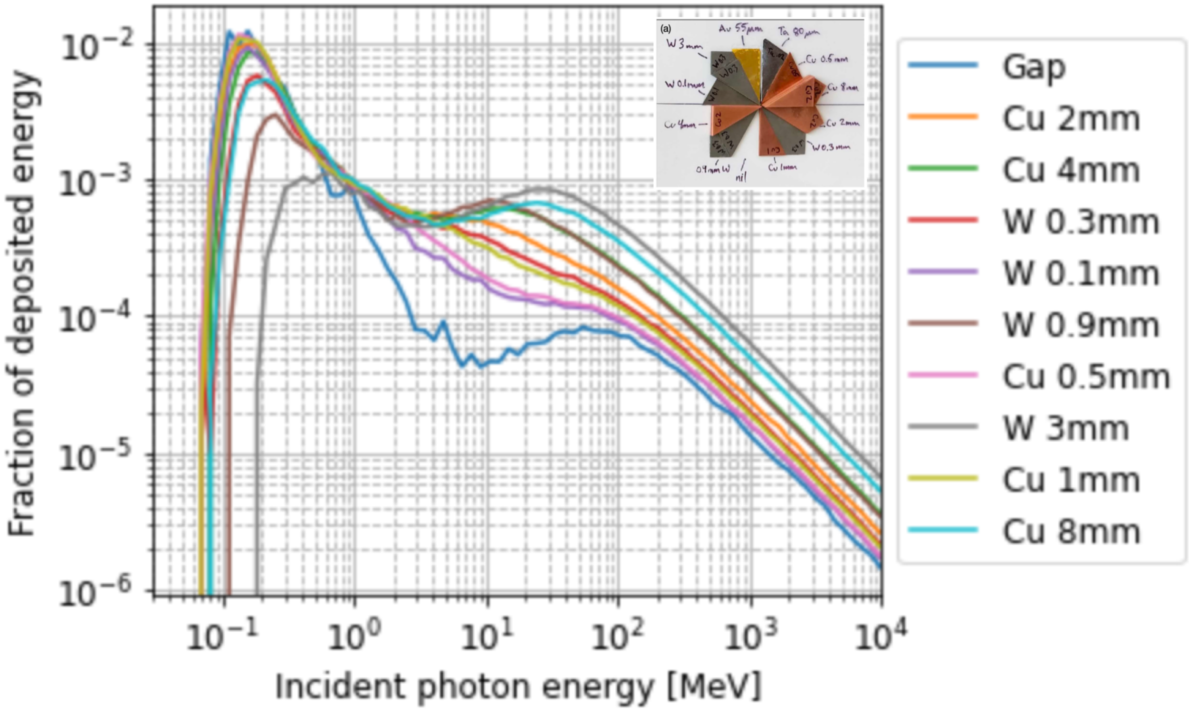
W acts as an absorber.

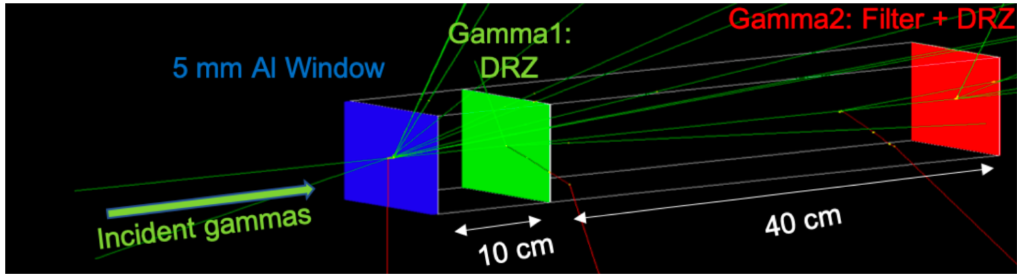
High energies:

W acts as an converter.

Gamma-ray detectors at FACET-II

- Spectral dependence can be used to retrieve spectral information on the incident.
- For instance:
  - Low energy photons leave more signal on the scintillator after thin filters
  - High energy photons leave more signal on the scintillator after thick filters (secondary particle production).
- Comparing experimental data with synthetic signals (using GEANT4) it is possible to retrieve spectral information

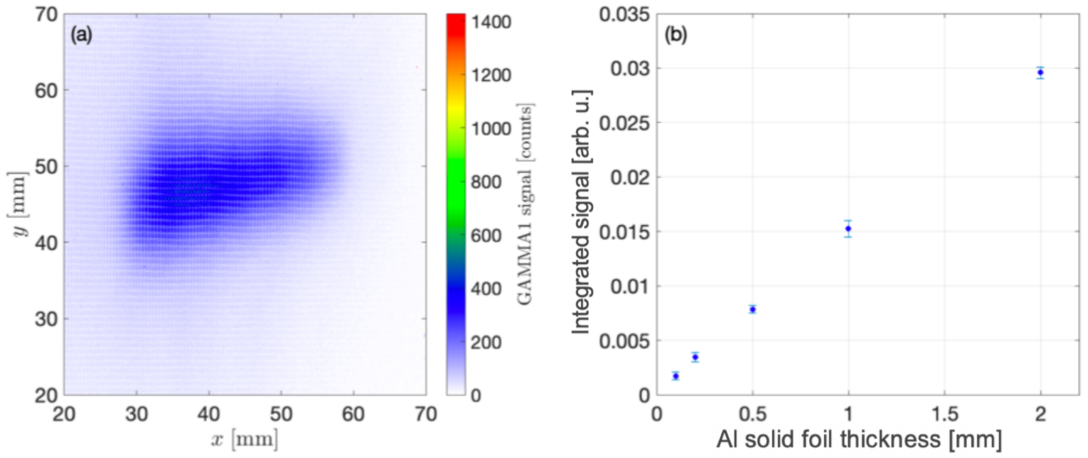




Bremsstrahlung gamma photons from the interaction of 10 GeV FACET-II beam with solid foils

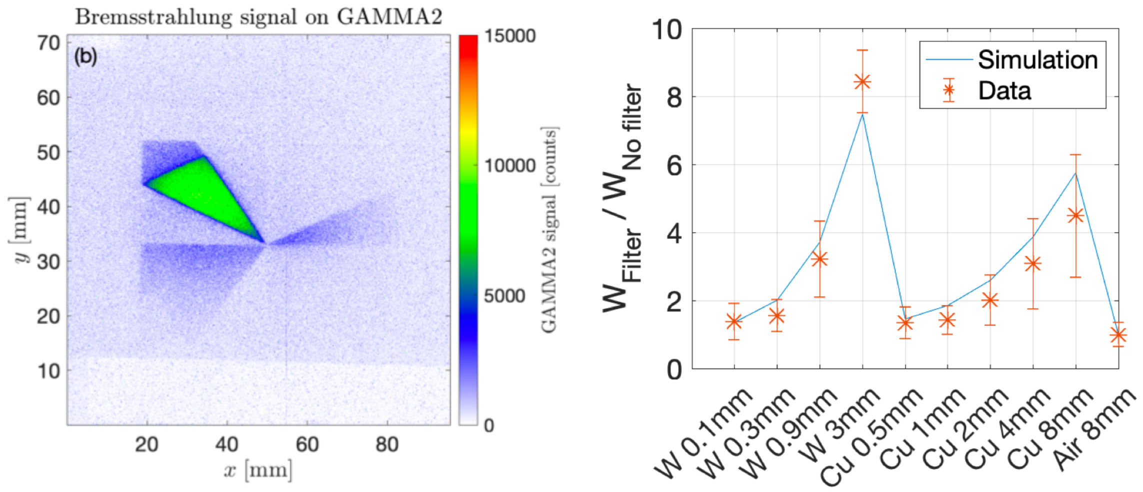
GAMMA1

CsI pixelized crystal



Linearity of the detector checked by changing the Al foil thickness

GAMMA2



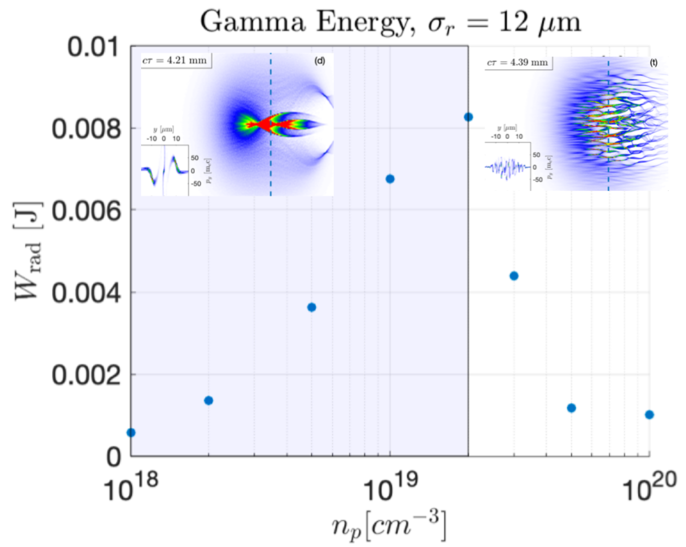
Good agreement with simulations for GAMMA2 signals

Experimental goals and first preliminary measurements

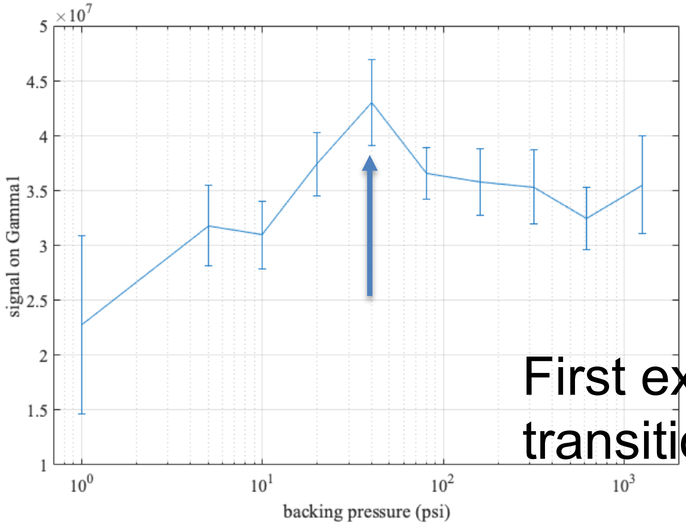
1. E305 Beam filamentation and bright gamma-rays

First goal of E305 experiment:

- transition between blow-out and filamentation regimes
- Simulations show that transition is associated to gamma yield reduction

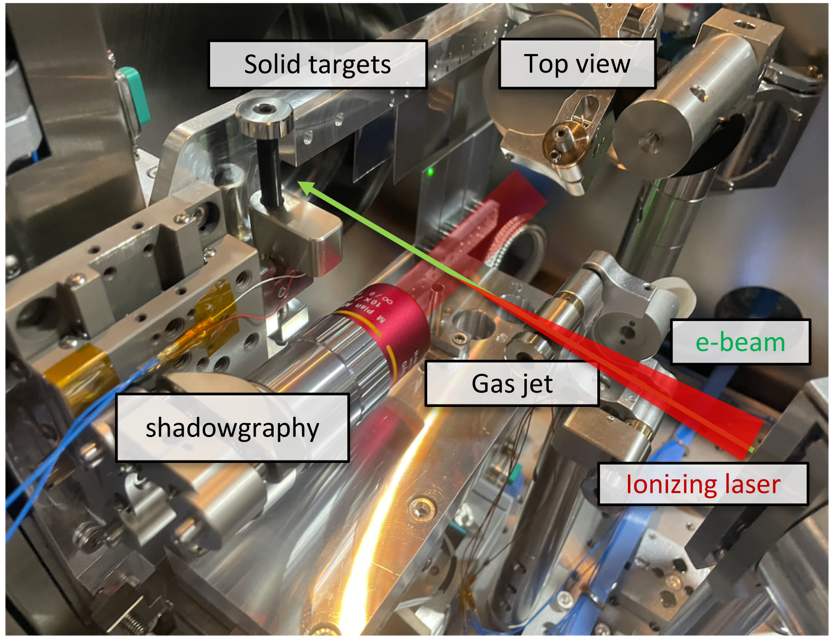


Simulations



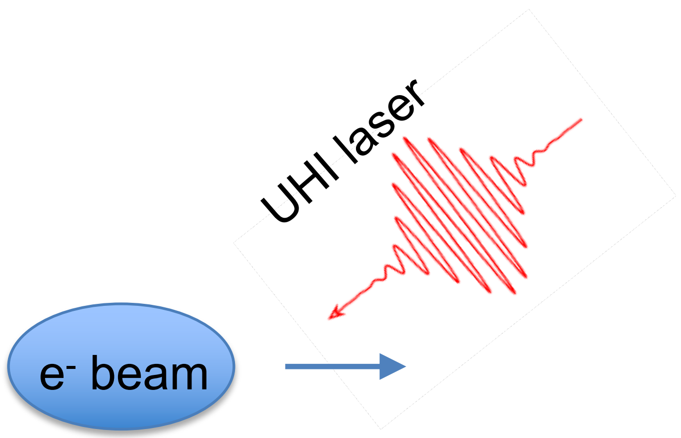
Experiments

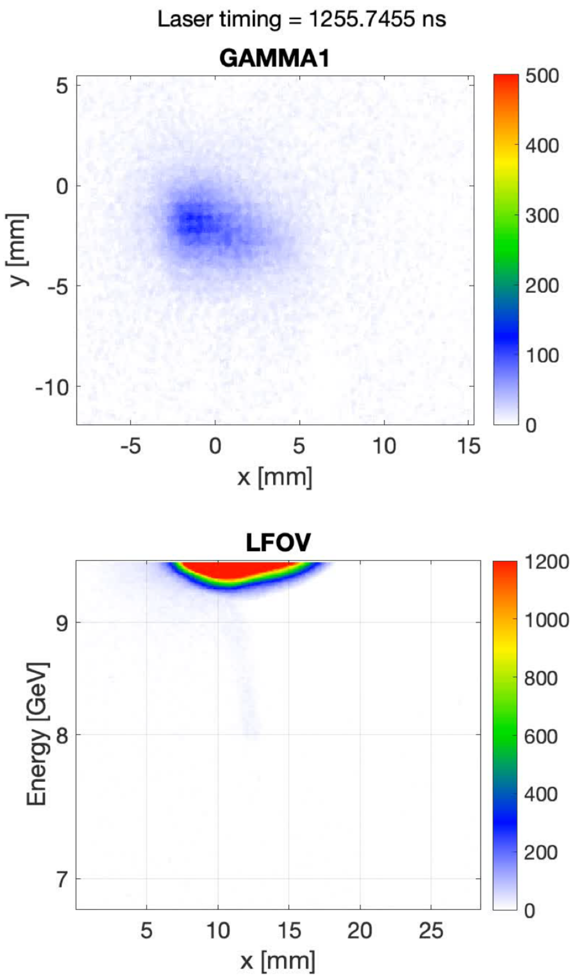
First experimental hints of transition at 40 psi



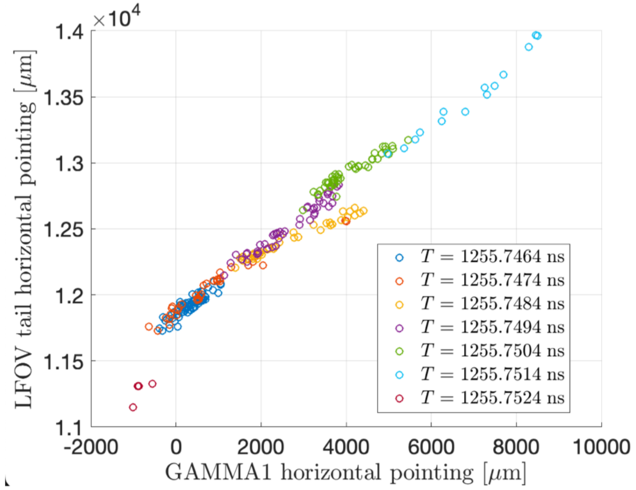
Experimental goals and first preliminary measurements

2. E320 Strong Field QED

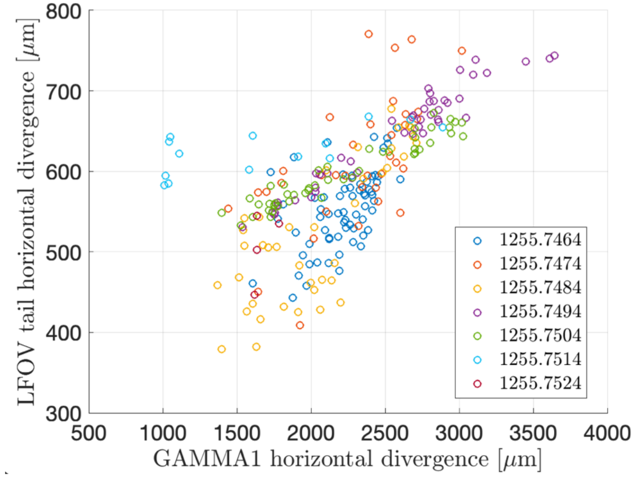




GAMMA1-LFOV pointing correlation



GAMMA1-LFOV divergence correlation



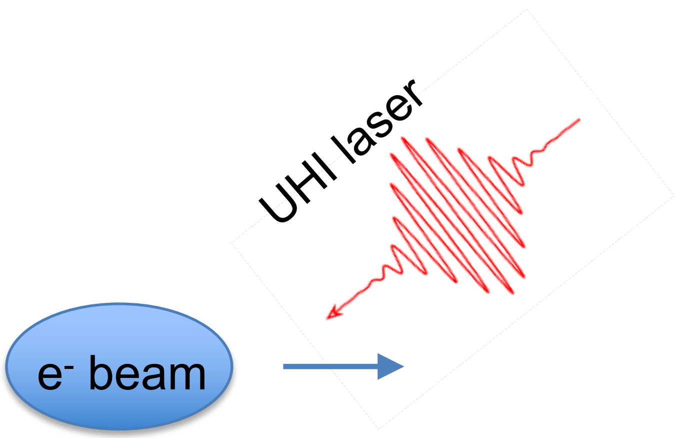
Gamma-ray for SFQED experiment:

- **Useful tool for spatiotemporal overlap.**
- Divergence on laser polarization axis $\propto a_0$[1]

[1] S. Corde et. al. Rev. Mod. Phys. 85, 1 (2013)

Experimental goals and first preliminary measurements

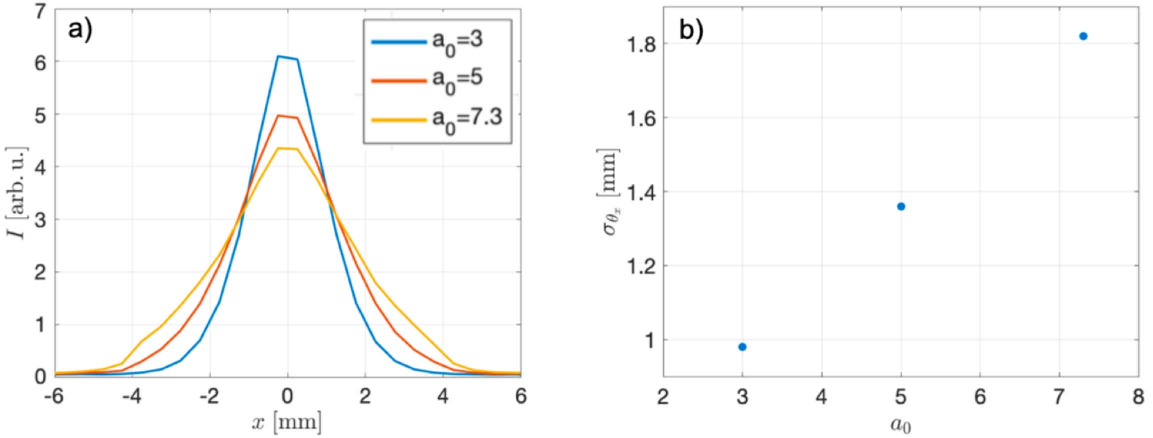
2. E320 Strong Field QED



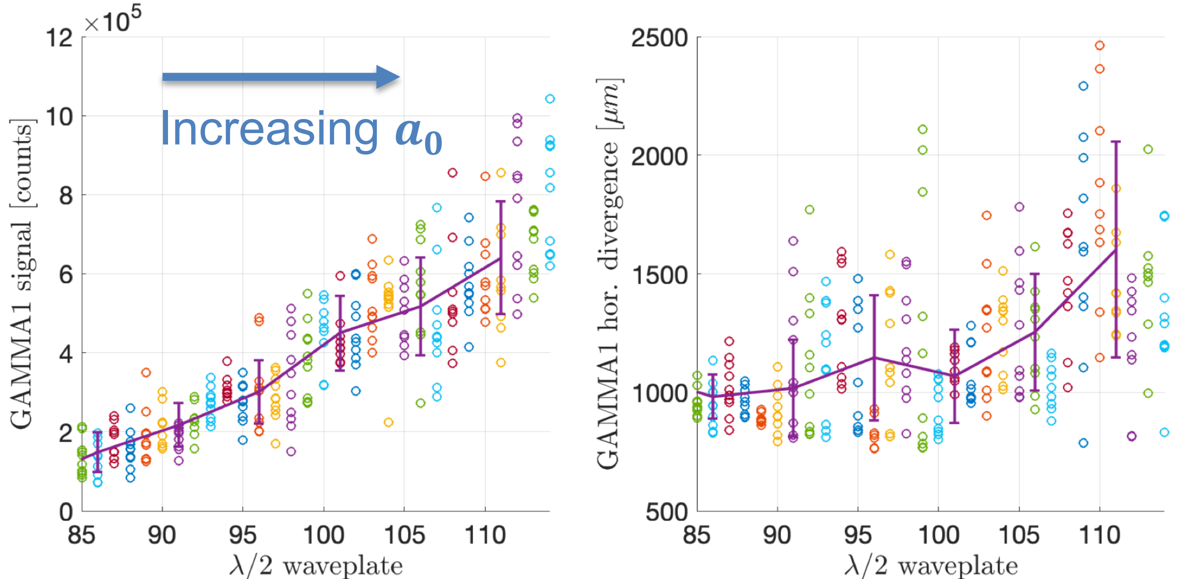
Gamma-ray for SFQED experiment:

- Useful tool for spatiotemporal overlap.
- **Divergence on laser polarization axis ∝ a_0[1]**

Simulations with optimal beam parameters



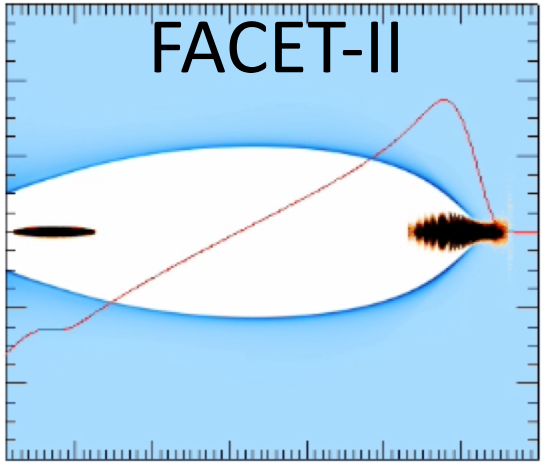
Experimental data: laser energy scan



[1] *S. Corde et. al. Rev. Mod. Phys. 85, 1 (2013)*

Experimental goals and first preliminary measurements

3. E300 Beam-driven Plasma Wakefield Experiment



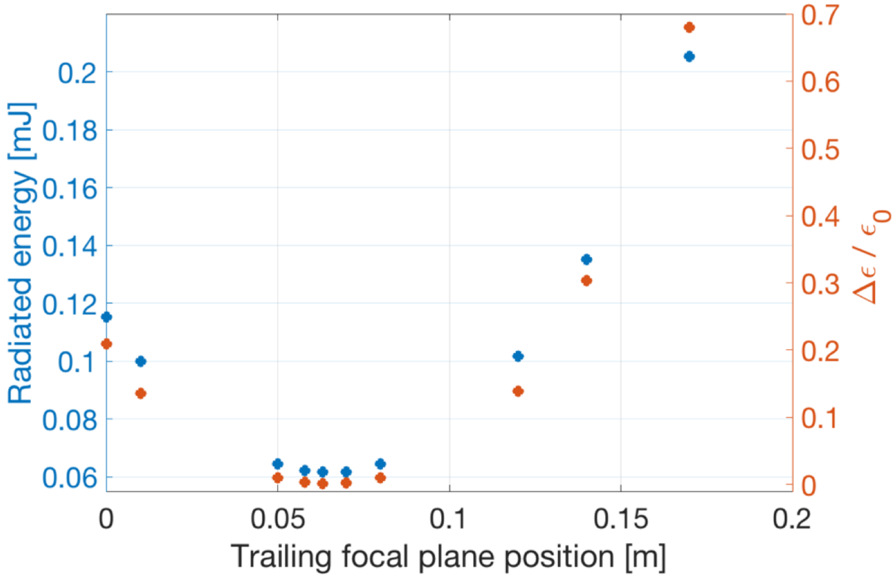
Science goals of E300[2]:

- Pump depletion with high-efficiency, low energy spread.
- **Beam matching, emittance preservation.**

Beam matching dynamics can be measured using betatron radiation[3]

QuickPIC simulations with FACET-II parameters:

- Correlation between betatron radiated energy and emittance growth due to mismatch.
- Mismatch propagation shifts betatron spectrum towards higher energies.



[2] C. Joshi et al 2018 *Plasma Phys. Control. Fusion 60 034001*
[3] ***P. San Miguel Claveria, et al . Phil. Trans. R. Soc. A.377 20180173 (2019),***

Experimental goals and first preliminary measurements

3. E300 Beam-driven Plasma Wakefield Experiment

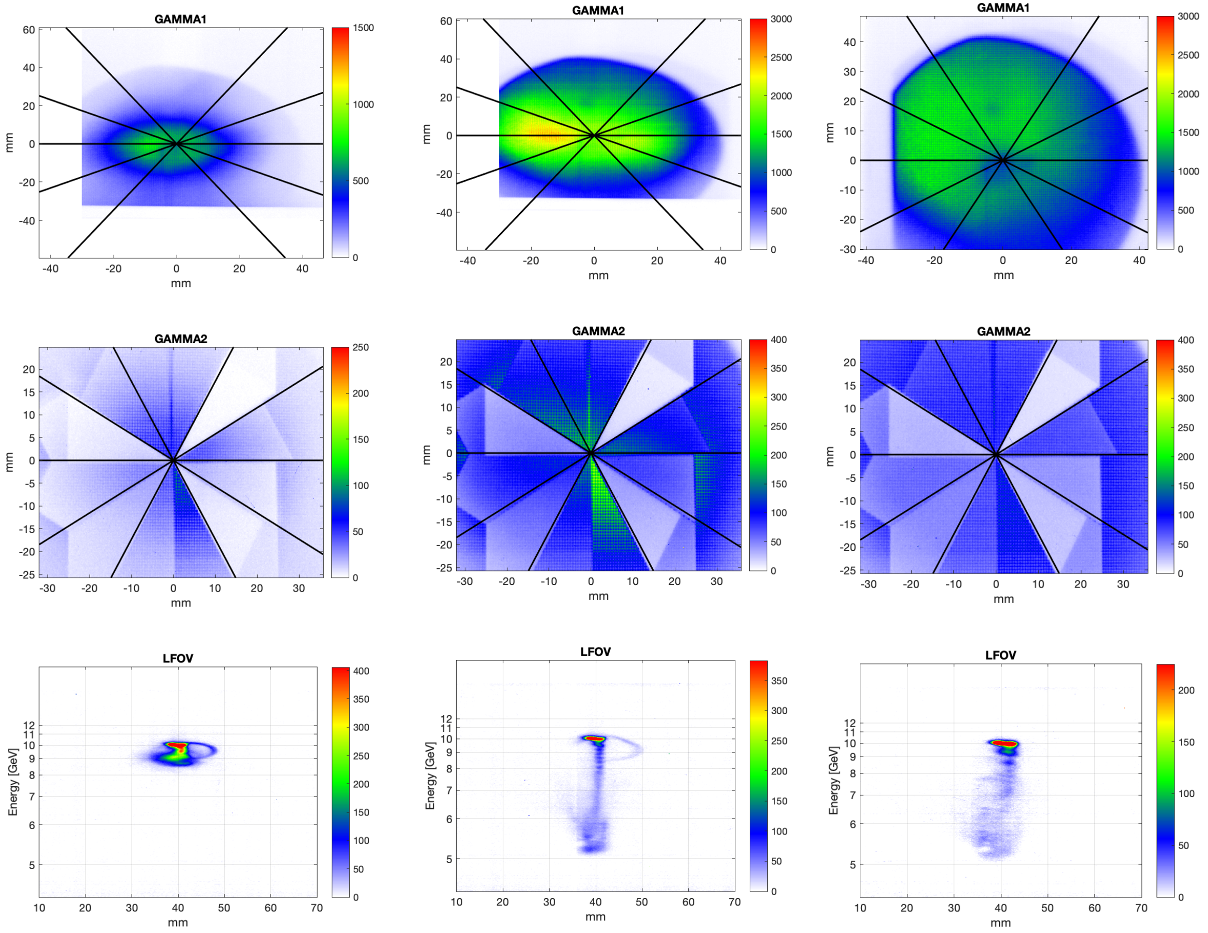
Last summer: Interaction point filled with H_2 - 3m of **beam-ionized plasma** $\rightarrow$ betatron radiation.

$P = 0.08$ Torr | $P = 0.3$ Torr | $P = 1.5$ Torr

GAMMA1

GAMMA2

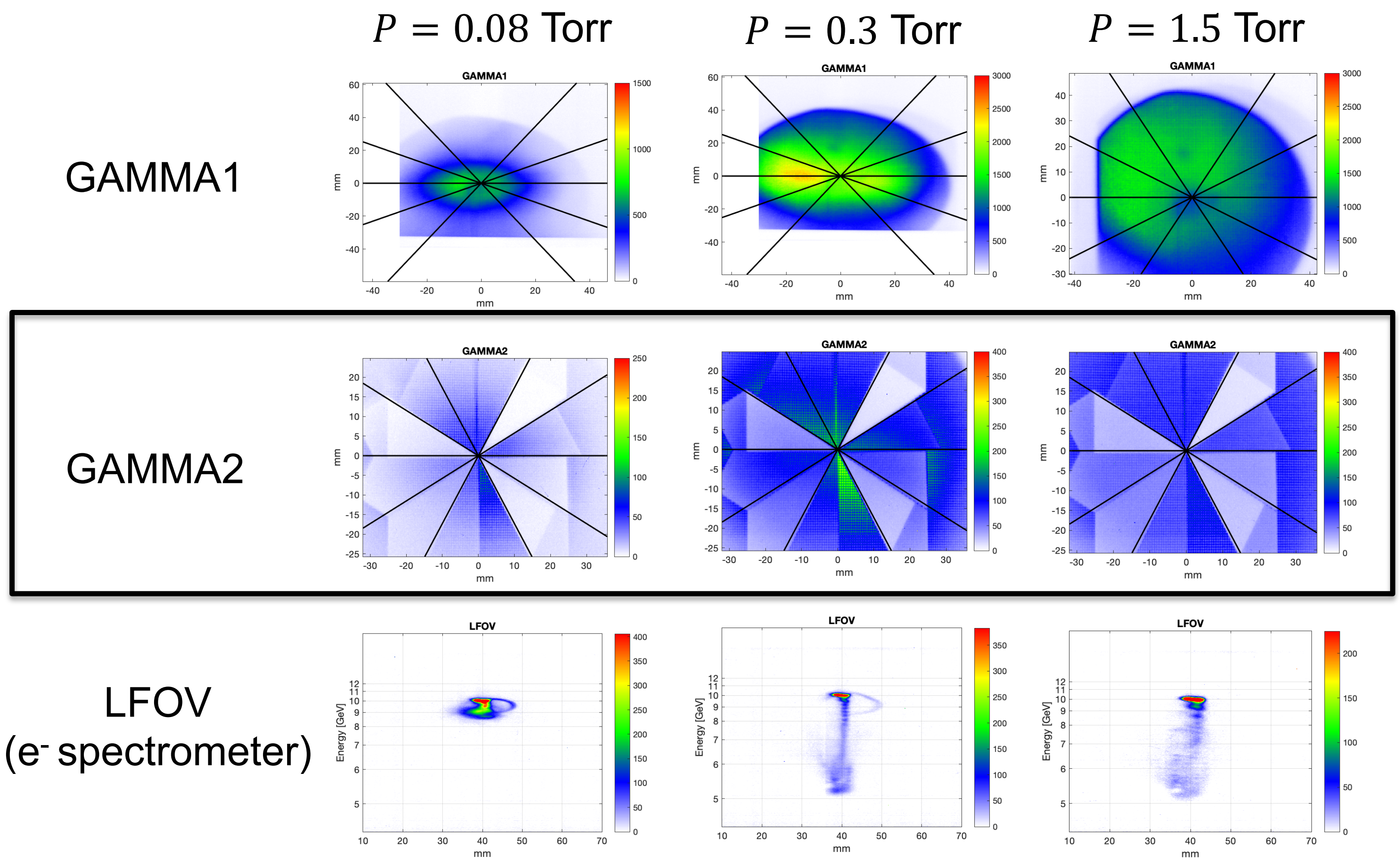
LFOV
(e$^-$ spectrometer)



Experimental goals and first preliminary measurements

3. E300 Beam-driven Plasma Wakefield Experiment

Last summer: Interaction point filled with H_2 - 3m of **beam-ionized plasma** $\rightarrow$ betatron radiation.



Experimental goals and first preliminary measurements

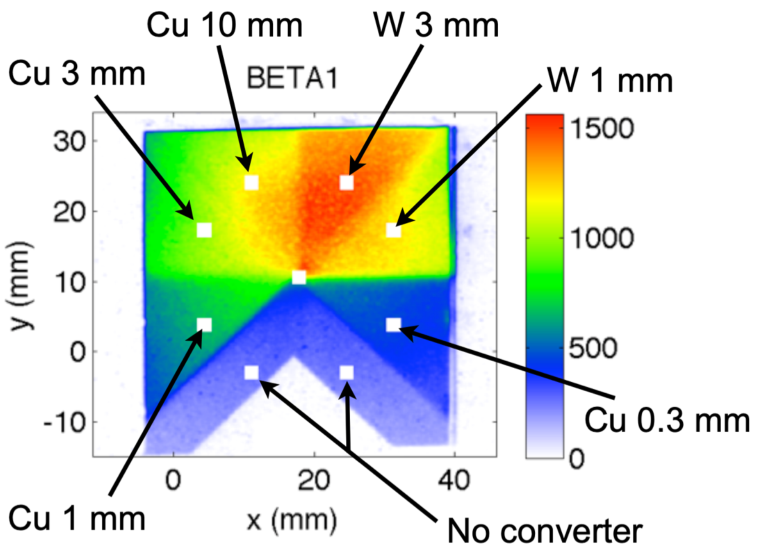
3. E300 Beam-driven Plasma Wakefield Experiment – Spectral measurements

$$\boxed{\hbar\omega_c[\mathrm{eV}] = 5.24 \times 10^{-21}\gamma^2 n_e[\mathrm{cm}^{-3}] r_\beta[\mu\mathrm{m}]}$$ [1]

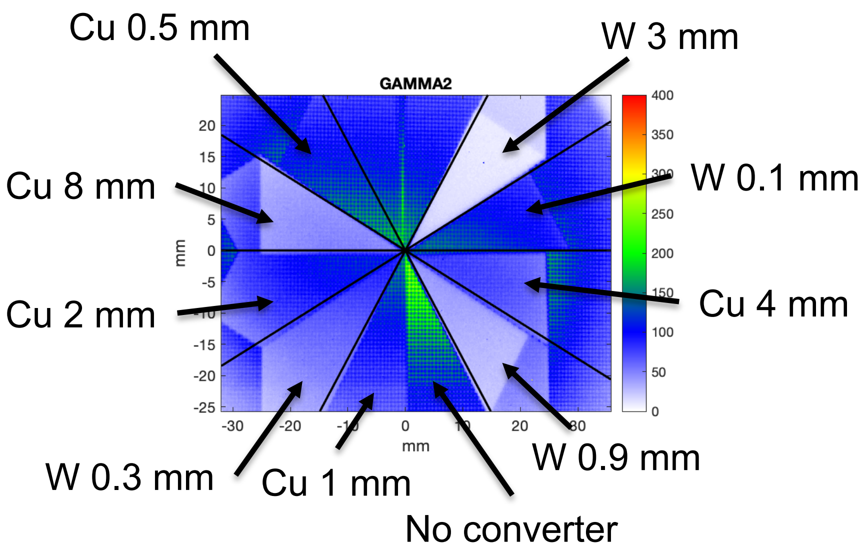
Qualitative behavior follows expected trends:

- Hierarchy between filters inverted from FACET-I (20 GeV) to FACET-II (10 GeV)

FACET-I



FACET-II



[1]S. Corde et. al. Rev. Mod. Phys. 85, 1 (2013)

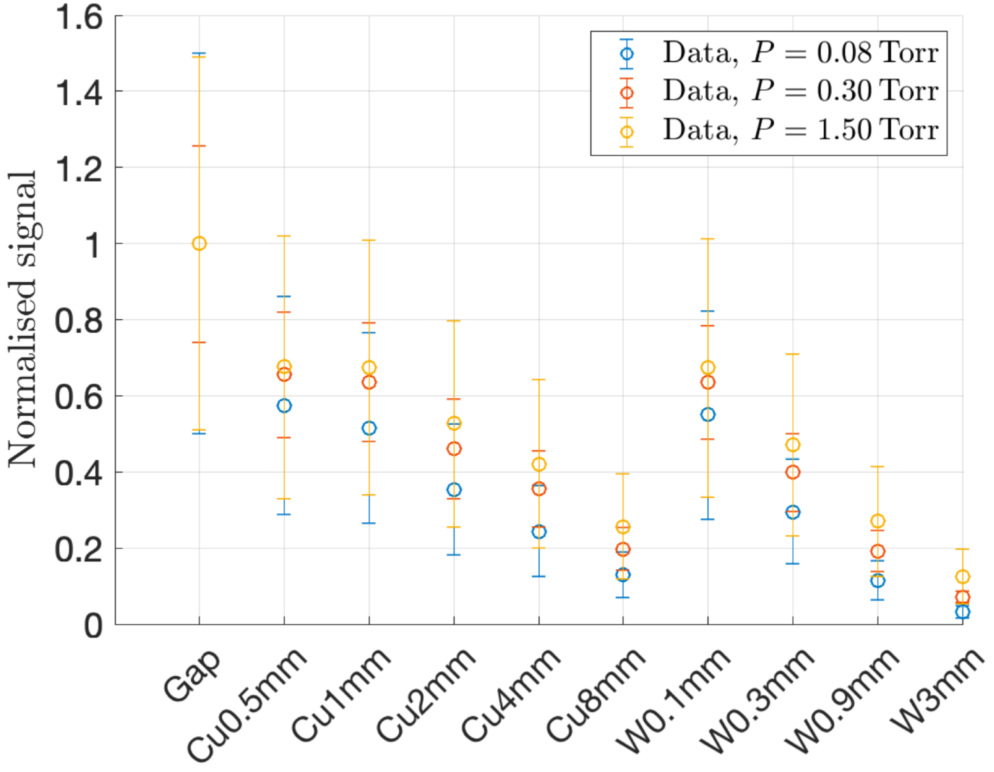
Experimental goals and first preliminary measurements

3. E300 Beam-driven Plasma Wakefield Experiment – Spectral measurements

$$\boxed{\hbar\omega_c[\mathrm{eV}] = 5.24 \times 10^{-21}\gamma^2 n_e[\mathrm{cm}^{-3}] r_\beta[\mu\mathrm{m}]}$$ [1]

Qualitative behavior follows expected trends:

- Hierarchy between filters inverted from FACET-I (20 GeV) to FACET-II (10 GeV)
- In FACET-II density scan, trend of GAMMA2 signals confirm the shift towards higher energy as plasma density increases



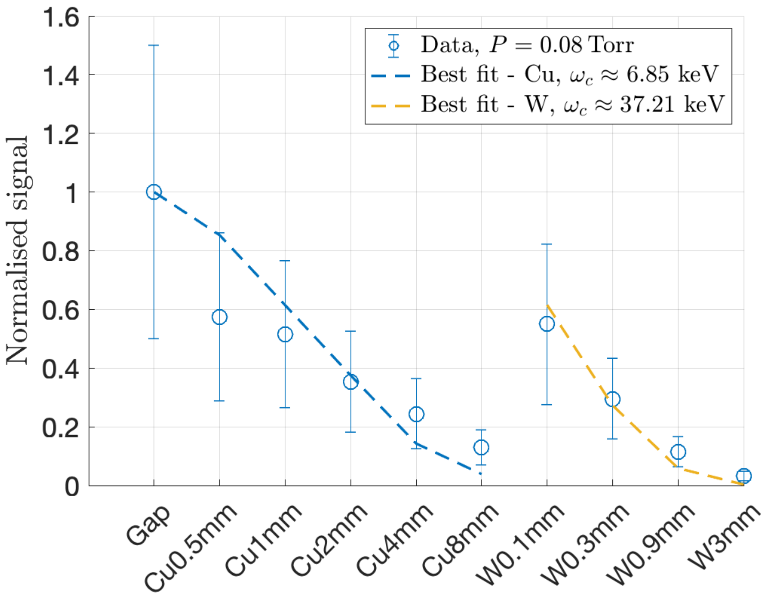
[1]S. Corde et. al. Rev. Mod. Phys. 85, 1 (2013)

Experimental goals and first preliminary measurements

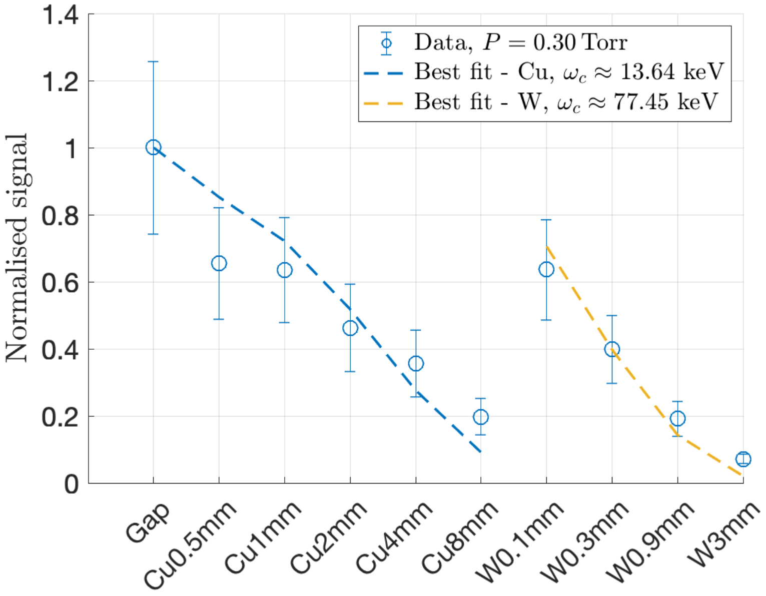
3. E300 Beam-driven Plasma Wakefield Experiment – Spectral measurements

Preliminary study: compare synthetic signal of synchrotron spectra to retrieve experimental critical frequency

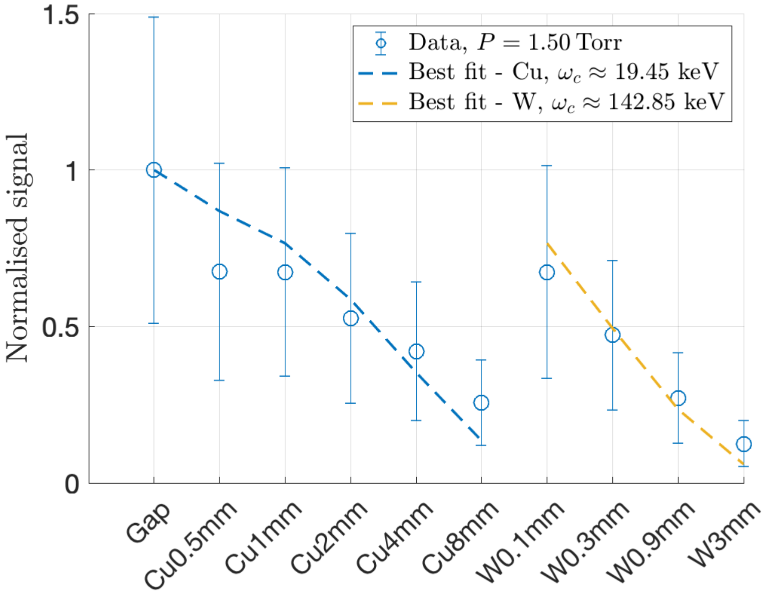
$P = 0.08$ Torr



$P = 0.3$ Torr

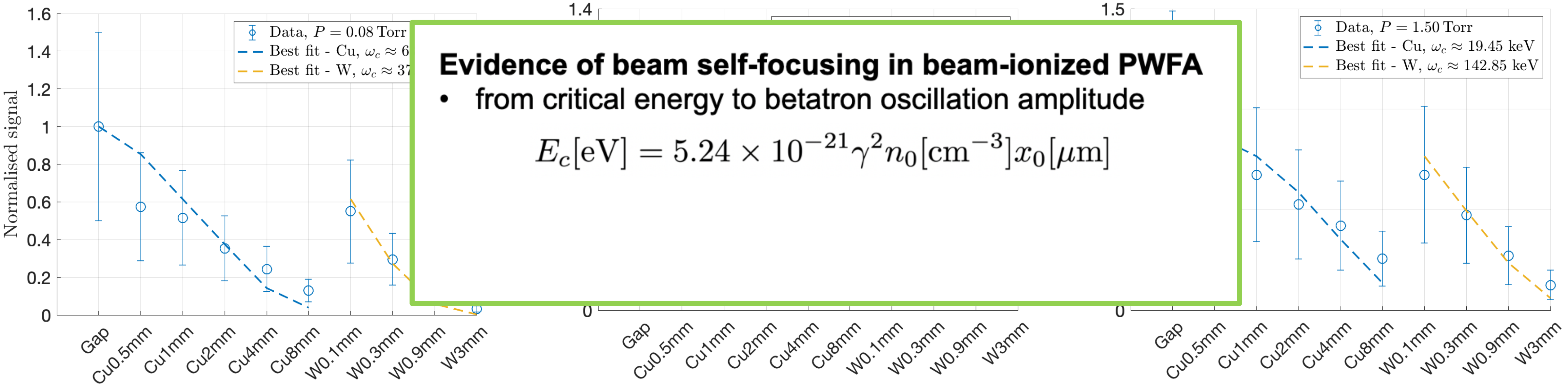


$P = 1.5$ Torr



Preliminary study: compare synthetic signal of synchrotron spectra to retrieve experimental critical frequency

P = 0.08 Torr $(2.5\times10^{15}\ cm^{-3})$ | P = 0.3 Torr $(9.7\times10^{15}\ cm^{-3})$ | P = 1.5 Torr $(4.9\times10^{16}\ cm^{-3})$



Evidence of beam self-focusing in beam-ionized PWFA

- from critical energy to betatron oscillation amplitude

$$E_c[\mathrm{eV}] = 5.24 \times 10^{-21}\gamma^2 n_0[\mathrm{cm}^{-3}]x_0[\mu\mathrm{m}]$$

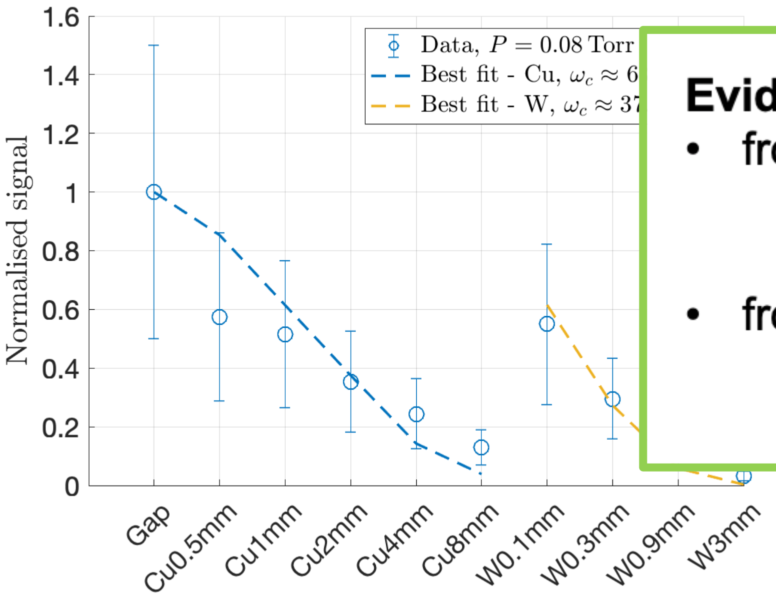
$x_0 \approx 1.36 - 7.42\ \mu m$ | $x_0 \approx 1.24 - 7.07\ \mu m$ | $x_0 \approx 0.8 - 5.81\ \mu m$

Experimental goals and first preliminary measurements

3. E300 Beam-driven Plasma Wakefield Experiment – Spectral measurements

Preliminary study: compare synthetic signal of synchrotron spectra to retrieve experimental critical frequency

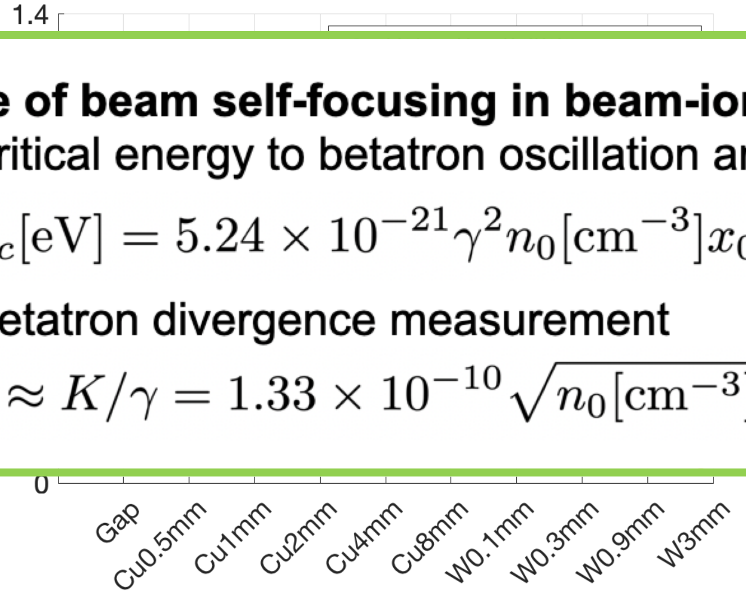
P = 0.08 Torr $(2.5\times10^{15}\ cm^{-3})$



$x_0 \approx 1.36 - 7.42\ \mu m$

$\sigma \approx 9.6\ \mu m$

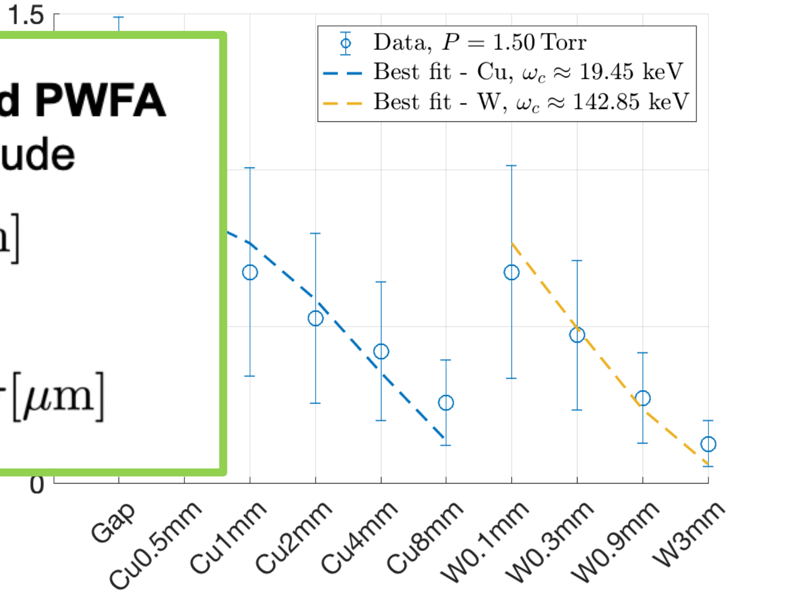
P = 0.3 Torr $(9.7\times10^{15}\ cm^{-3})$



$x_0 \approx 1.24 - 7.07\ \mu m$

$\sigma \approx 5.19\ \mu m$

P = 1.5 Torr $(4.9\times10^{16}\ cm^{-3})$



$x_0 \approx 0.8 - 5.81\ \mu m$

$\sigma \approx 2.14\ \mu m$

Evidence of beam self-focusing in beam-ionized PWFA

- from critical energy to betatron oscillation amplitude

$$E_c[\mathrm{eV}] = 5.24 \times 10^{-21} \gamma^2 n_0[\mathrm{cm}^{-3}] x_0[\mu\mathrm{m}]$$

- from betatron divergence measurement

$$\theta \approx K/\gamma = 1.33 \times 10^{-10} \sqrt{n_0[\mathrm{cm}^{-3}]/\gamma}\,\sigma[\mu\mathrm{m}]$$

Conclusions and perspectives

Conclusions:

- First set of X-ray and ɣ-ray diagnostics at FACET have been designed, installed and commissioned.
  - Integrated and angular information (GAMMA1)
  - Spectral information (GAMMA2)

- GEANT4 simulations are needed for the absolute calibration of these detectors

- During the first user beamtime, these diagnostics have been successfully used to measure:
  - Bremsstrahlung (E332)
  - Inverse Compton Scattering (E320)
  - Betatron radiation (E300) → Evidence of beam self-focusing in beam-ionized plasma

Perspectives:

- Improve robustness of the data (alignment, sensitivities, SNR, data analysis…)

- New Compton-spectrometer and Pair-spectrometer being manufactured at UCLA*

**B. Naranjo et. al. IPAC2021* doi:10.18429/JACoW-IPAC2021-THPAB269

Thanks: E300 Collaboration

LOA (IP Paris): S. Corde, M. Gilljohann, A. Knetsch, O. Kononenko, Y. Mankovska, A. Matheron, G. Raj, P. San Miguel Claveria, V. Zakharova

UCLA: C. Joshi, K. A. Marsh, N. Zan, C. Zhang

SLAC: R. Ariniello, C. Clarke, H. Ekerfelt, S. Gessner, M. Hogan, B. O'Shea, D. Storey

CU Boulder: C. Doss, C. Hansel, V. Lee, M. Litos

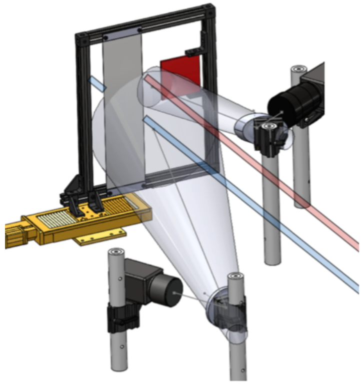
Stony Brook U.: N. Vafaei-Najafabadi

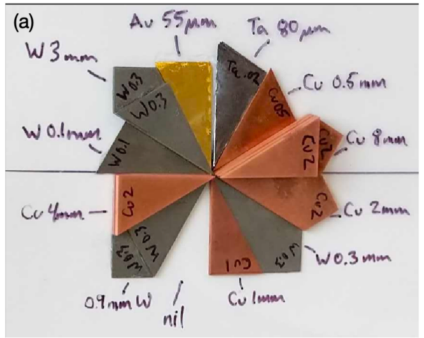
U. Oslo: G. Cao, E. Adli

Summary slide

First set of X-ray and ɣ-ray diagnostics at FACET have been designed, installed and commissioned.

- Integrated and angular information (GAMMA1)
- Spectral information (GAMMA2)

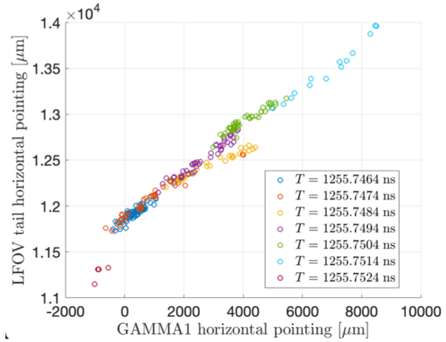




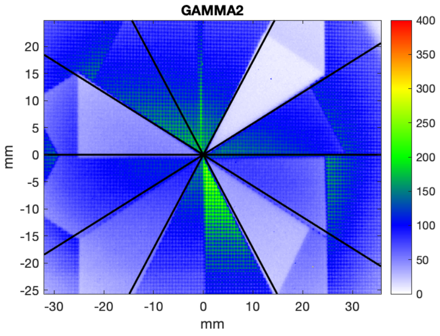
During the first user beamtime, these diagnostics have been successfully used to measure:

- Bremsstrahlung (E332)
- Inverse Compton Scattering (E320)
- Betatron radiation (E300) → Evidence of beam self-focusing in beam-ionized plasma

GAMMA1-LFOV correlation



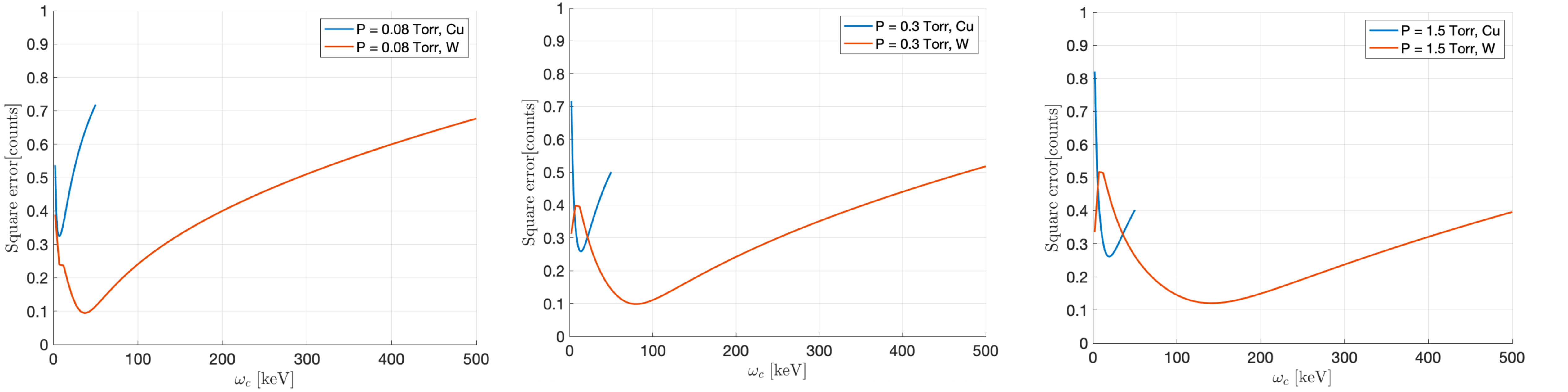
GAMMA2



Back ups

Back ups

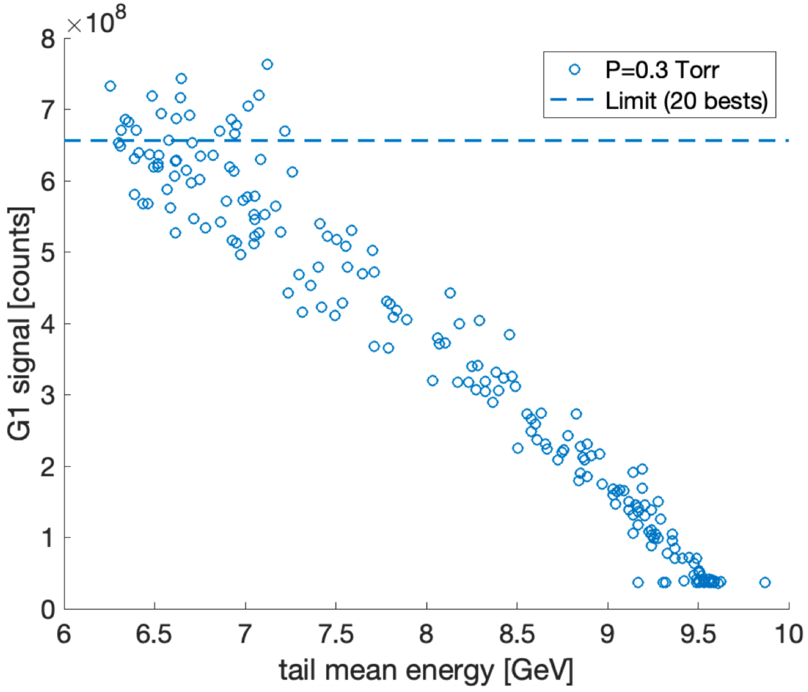
Residuals of critical energy fits



Beam-ionised PWFA with H_2 static filled PB

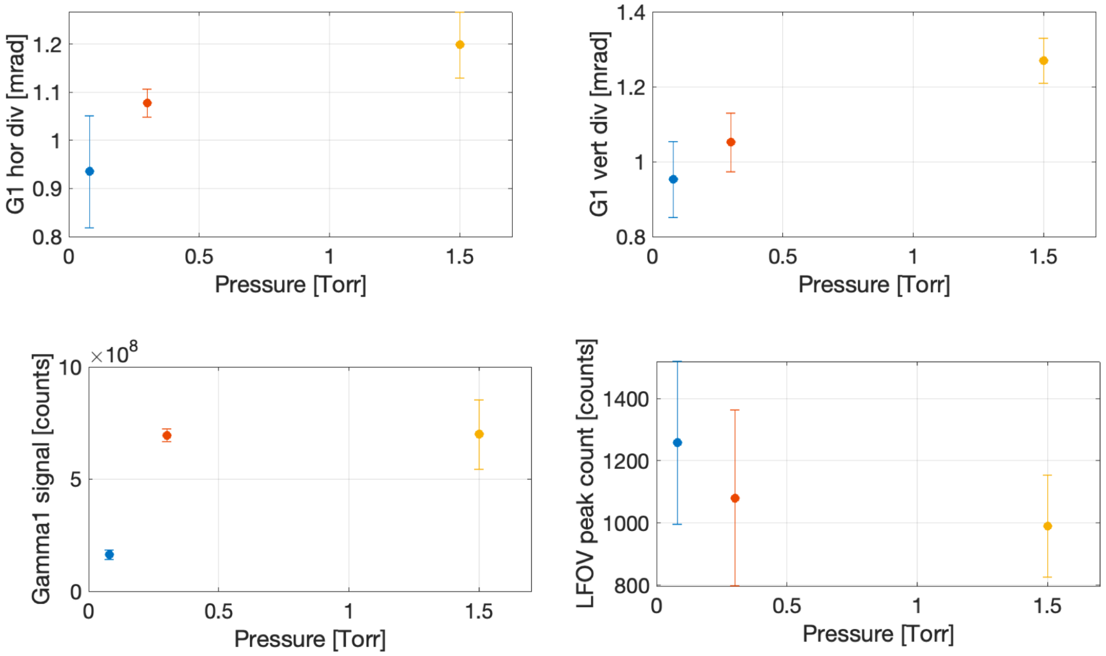
3. Correlations and trends

In each dataset the bad stability leads to large variety of shots



For each pressure, only use 20 shots with highest GAMMA1 signal

For these 20 best-shots, averaged values follow the trends below (w.r.t. pressure)

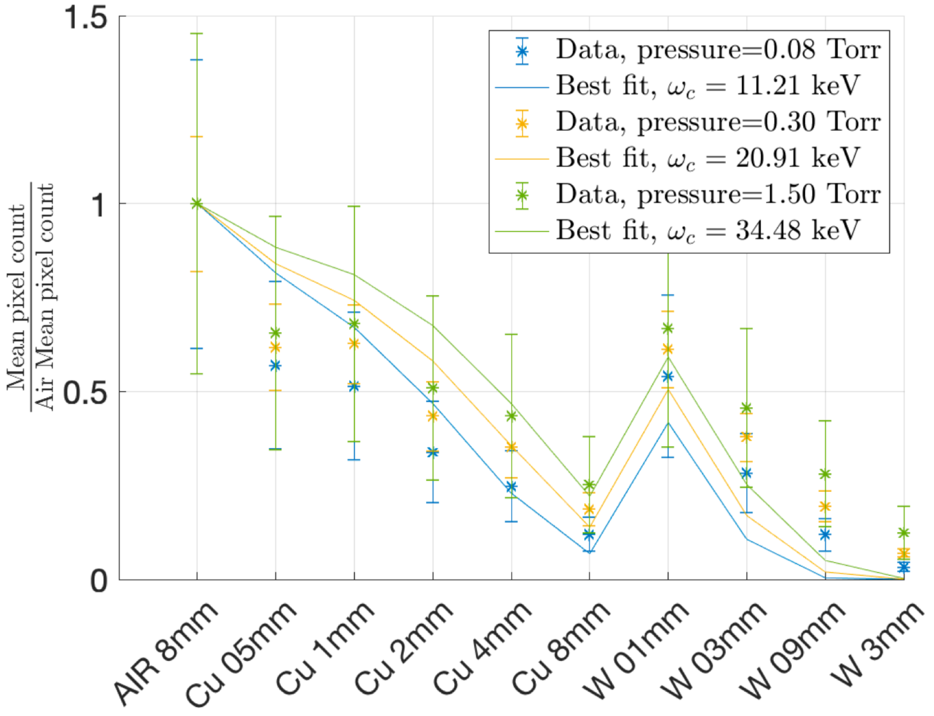


Scalings still need more work to be understood

Beam-ionised PWFA with H_2 static filled PB

4. GAMMA2 analysis and critical energy

First try of critical energy fits



Fit method compares synthetic signals computed synchrotron spectra and GEANT4 simulations with data.

Qualitative trend is the one expected, despite the fit error being quite large. Potential reasons:

- Geant4 simulations (Cu and W compare differently)
- Data anlysis (background subtraction, GAMMA1-2 alignment…)