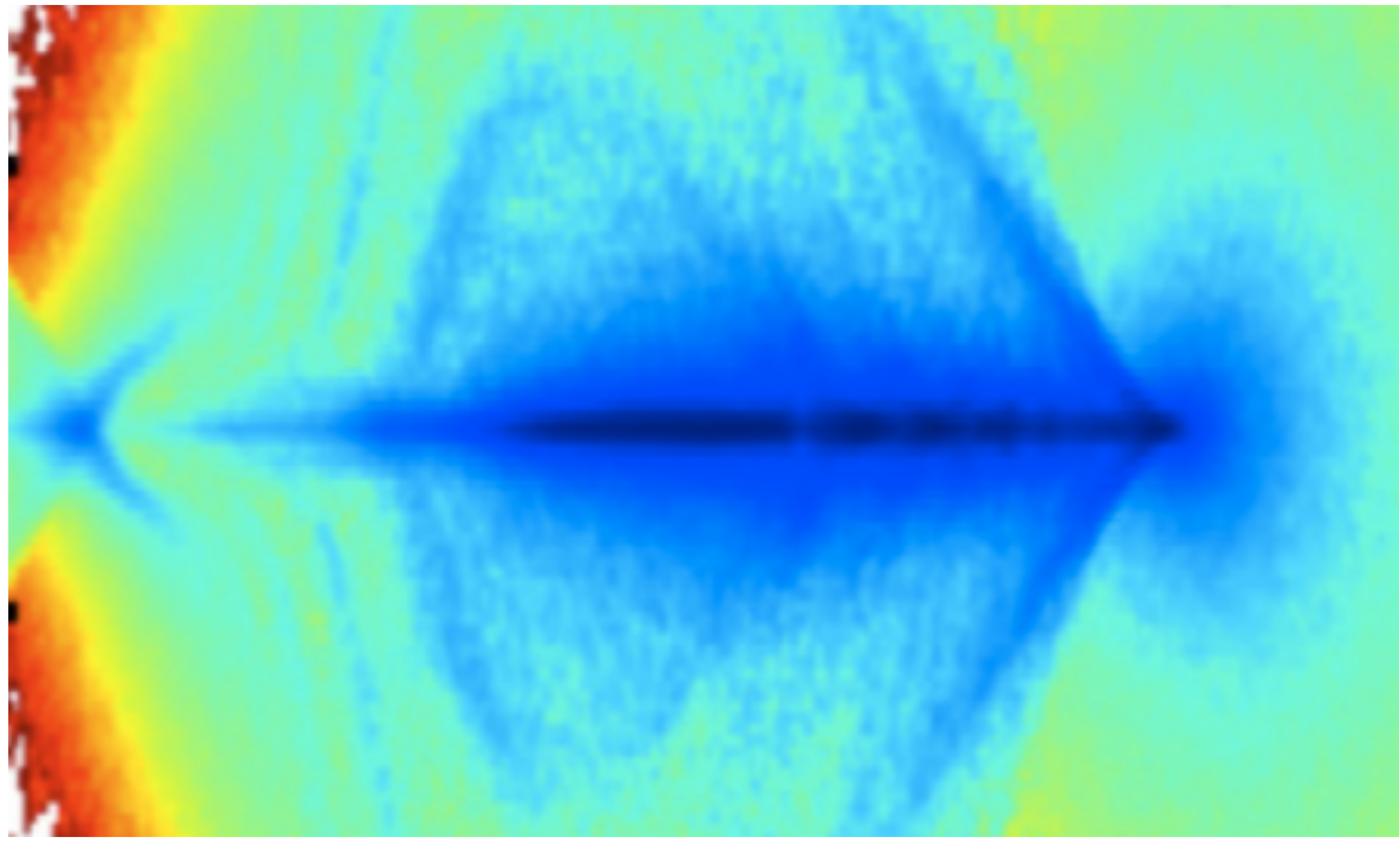
E-332 FY22 Progress and Plans for FY23



Principal Investigators: Sébastien Corde, Matteo Tamburini

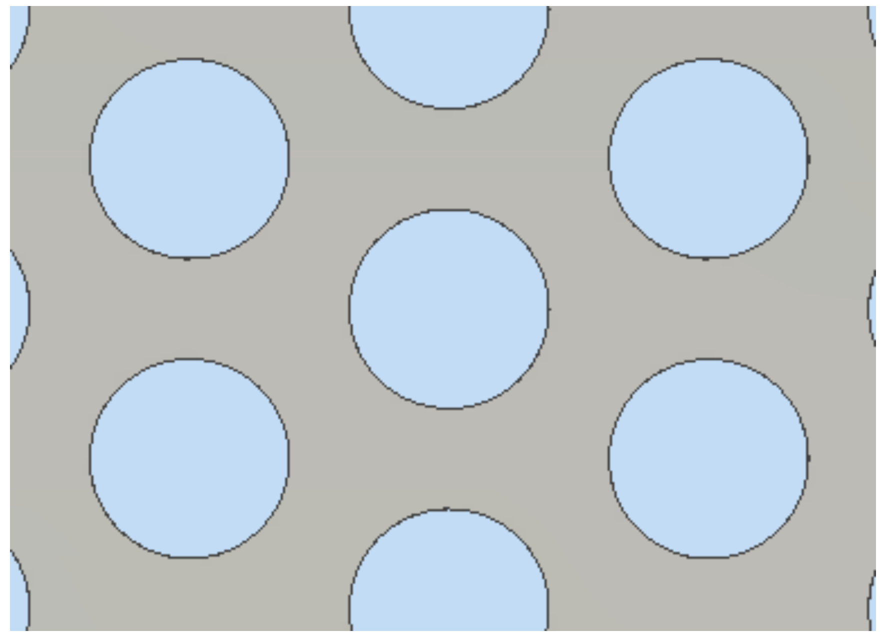
Collaborators: E-305 collaboration

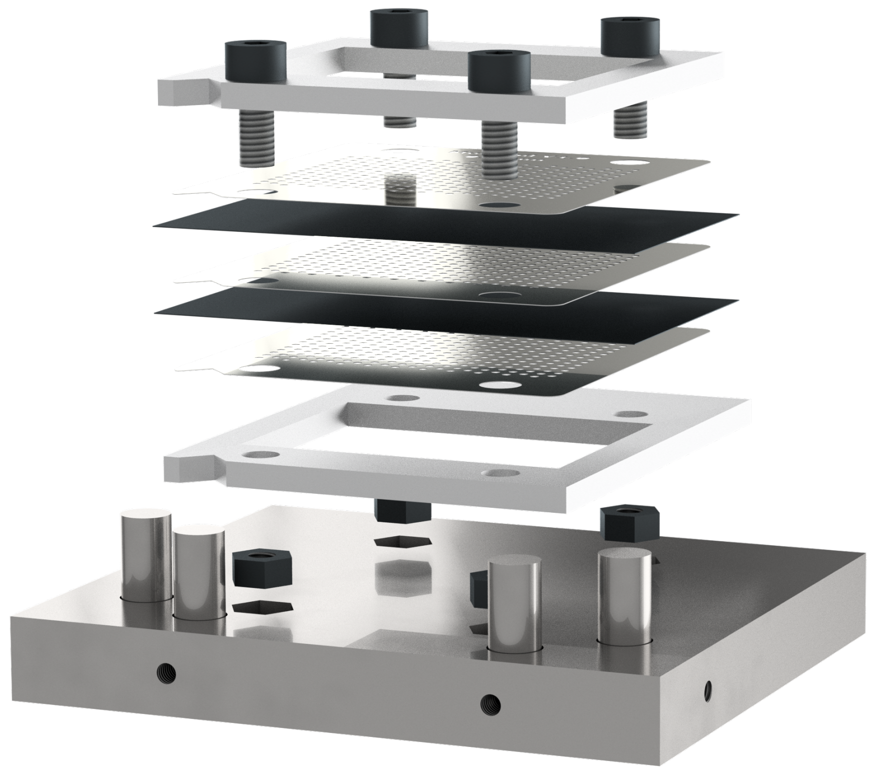
Science goals & definition of success

Phase 1: Demonstration of near-field CTR focusing and of gamma-ray generation (1st and 2nd year)

- Single foil: show evidence of weak NF-CTR focusing by using electron diagnostics (1 year)
- Stack of foils: show evidence of strong NF-CTR focusing by using electron and gamma diagnostics. Characterisation of NF-CTR focusing vs multiple scattering as a function of beam and foil parameters by measuring the gamma-ray emission boost with multiple beam-foil interactions (1 year).

From 100 μm to 1 μm





Phase 2: Demonstration of high gamma-ray yield with efficiency around 10% (2nd and 3rd year)

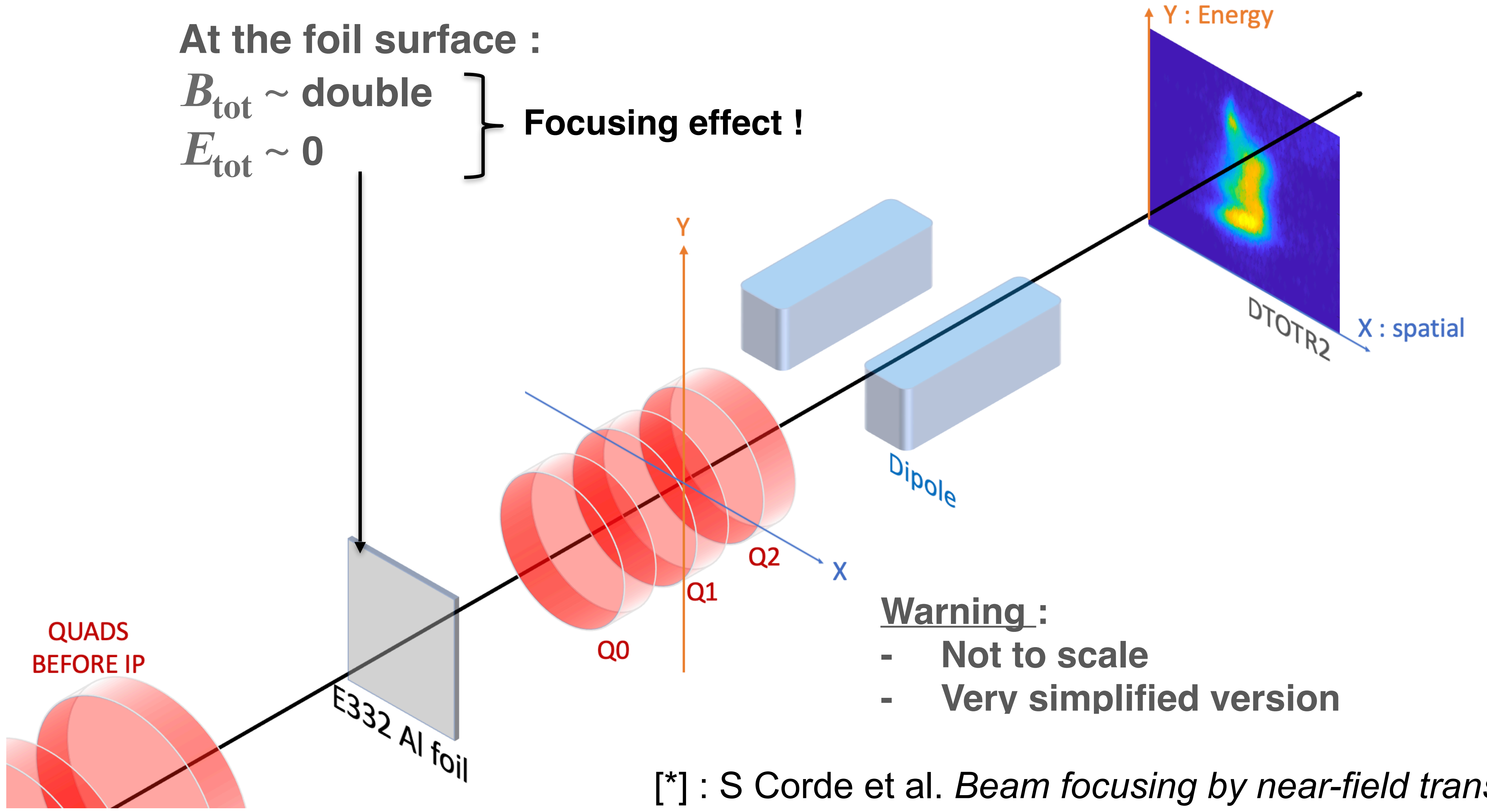
Phase 3: Demonstration of beam focusing to solid-density and of SFQED effects (3rd and 4th year)

Science goals & definition of success for the first 2 years

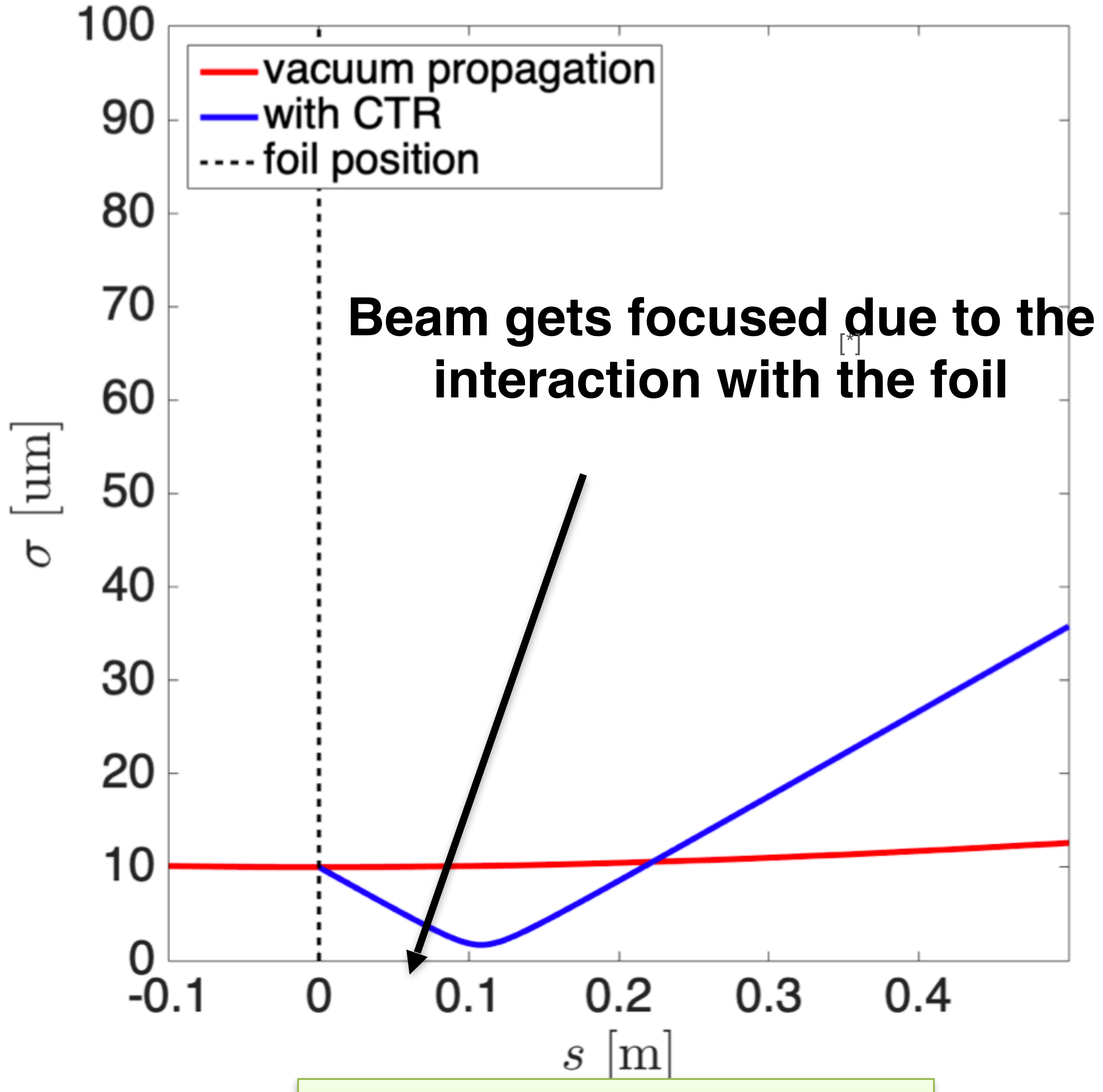
Phase 1: Demonstration of near-field CTR focusing and of gamma-ray generation (1st and 2nd year)

- Single foil: show evidence of weak NF-CTR focusing by using electron diagnostics (1 year)
- Stack of foils: show evidence of strong NF-CTR focusing by using electron and gamma diagnostics. Characterisation of NF-CTR focusing vs multiple scattering as a function of beam and foil parameters by measuring the gamma-ray emission boost with multiple beam-foil interaction(1 year).

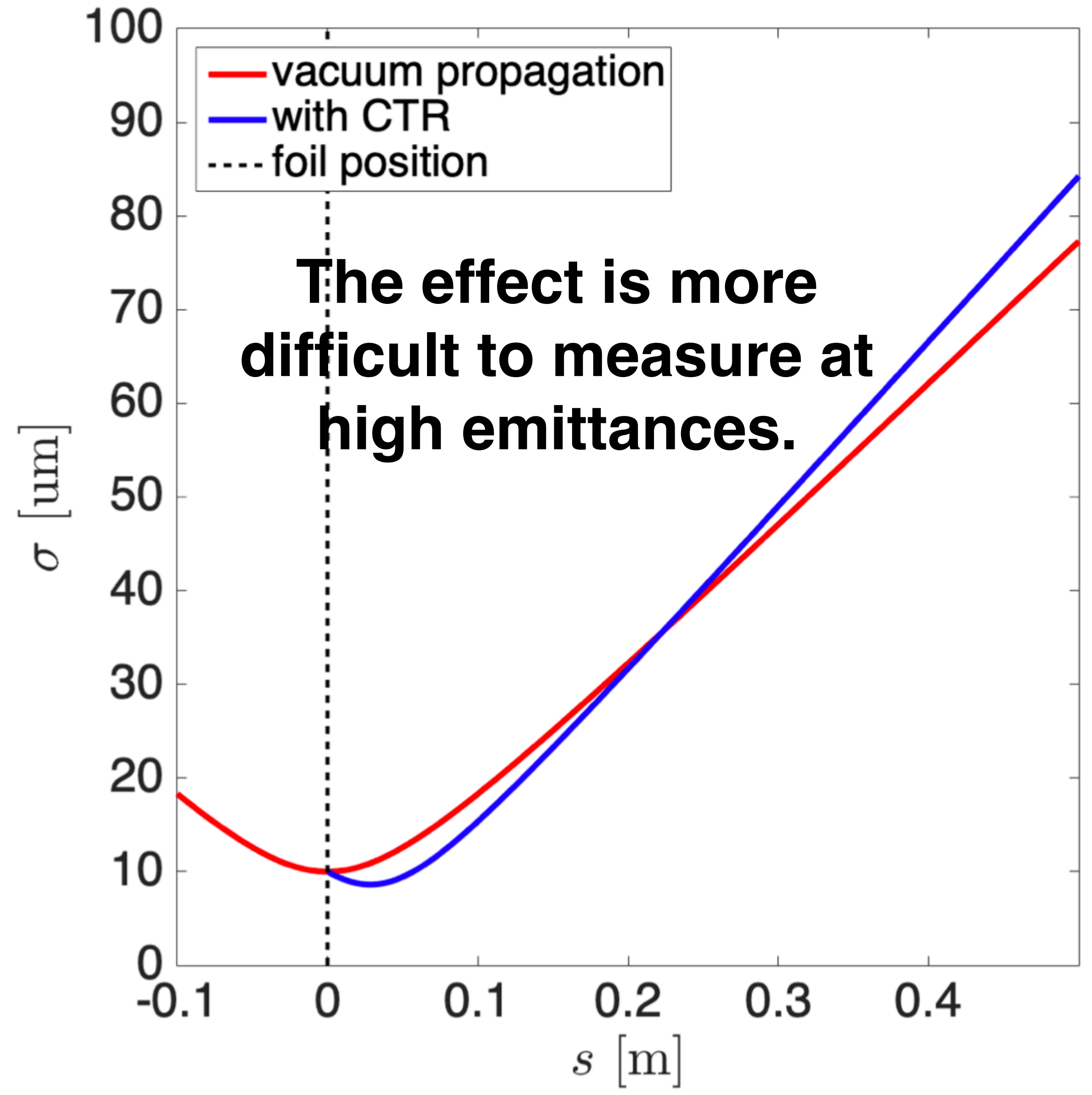
<u>Goal</u> : Demonstrate Near-field CTR based self-focusing.
Required: high quality beam & low multiple scattering



<u>Warning</u> :
- Not to scale
- Very simplified version



$\varepsilon_N = 3$ μm rad



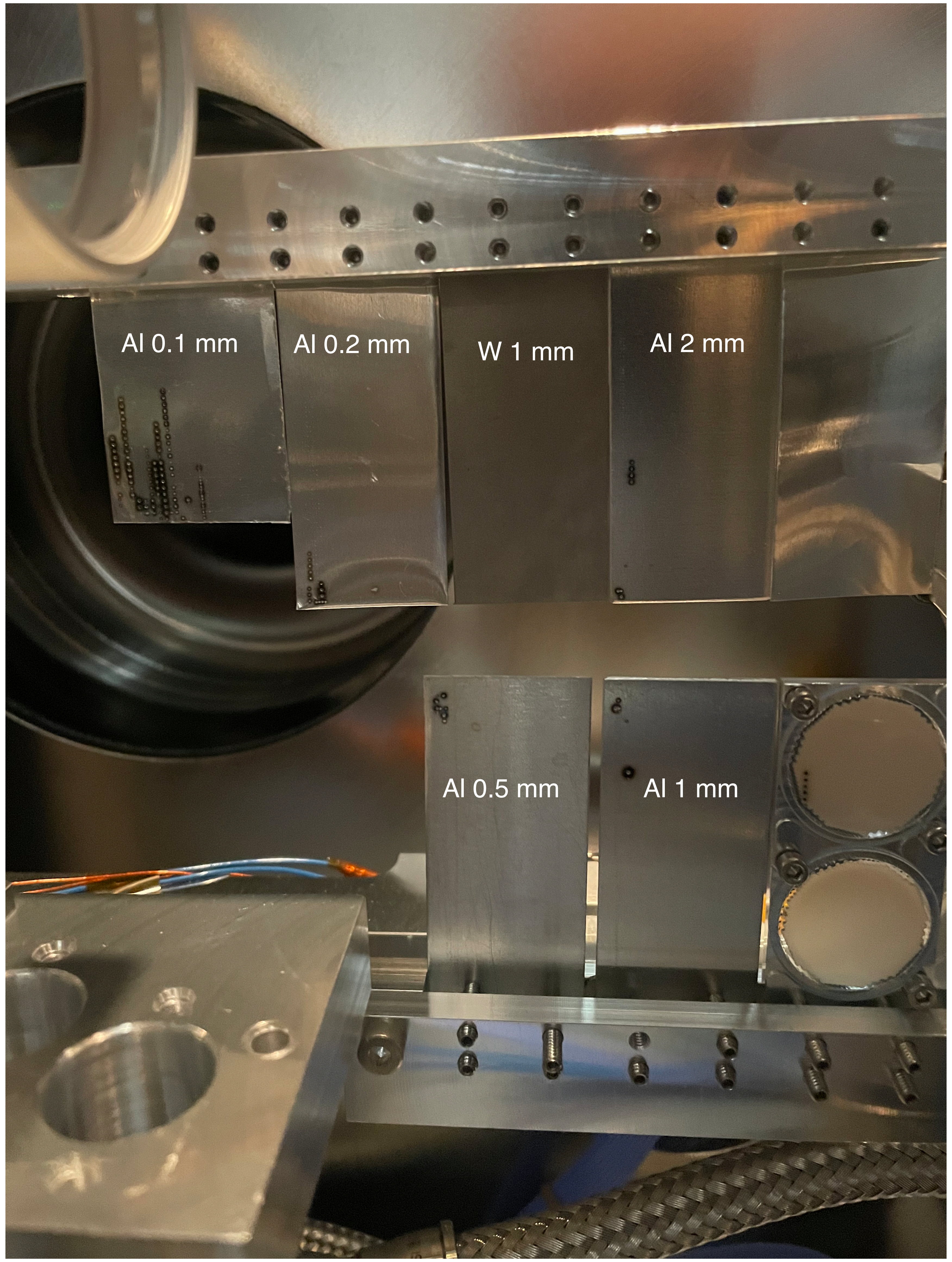
$\varepsilon_N = 30$ μm rad

[*] : S Corde et al. *Beam focusing by near-field transition radiation*. Research Report. IP Paris ; CEA ; MPIK, sept. 2020

Experimental timeline

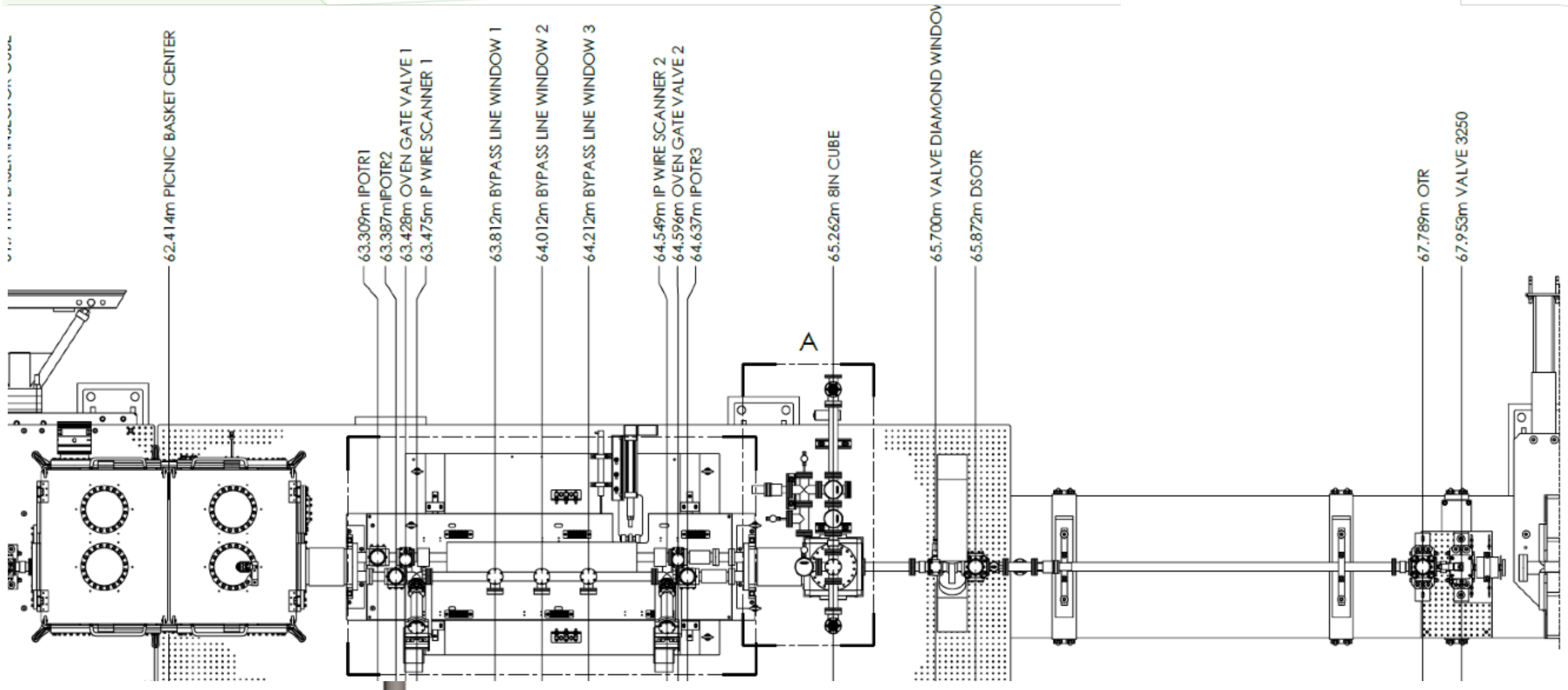
- May 11 ($\sigma_x = ??\ \mu m$, $\sigma_y = ??\ \mu m$):
- Operating the machine at 1Hz, DAQ commissioning.
- June 13 ($\sigma_x = ??\ \mu m$, $\sigma_y = ??\ \mu m$):
- Measuring beam on DTOTR/GAMMA1 cameras with and without Al 0.1 mm.
- Quad-scans performed to assess beam waist position
- July 18 ($\sigma_x = 46\ \mu m$, $\sigma_y = 48\ \mu m$): **First holes**
- First evidence of holes being drilled in foils (holes completely drilled in 2 minutes with Al 0.1 mm).
- Data of GAMMA1 signal decreasing with time while shooting at a fixed foil position
- July 25 ($\sigma_x = 47\ \mu m$, $\sigma_y = 33\ \mu m$):
- We were able to use the new Quad-Scan functions of the DAQ and take comprehensive data.
- Quad-scans of M_{12} performed and very clear data has been taken.
- August 1 ($\sigma_x = 49\ \mu m$, $\sigma_y = 39\ \mu m$): **Compression optimisation**
- Holes were drilled in the foils and an optimization of bunch compression was made using L2 phase (chirp scan).
- Data of GAMMA1 signal for different foil thicknesses as a function of time.
- August 4 ($\sigma_x = 40\ \mu m$, $\sigma_y = 46\ \mu m$): **First test of NF-CTR**
- Data was taken for different compressions to search for a NFCTR effect.
- Scans with and without foil were taken.
- August 12 ($\sigma_x = 41\ \mu m$, $\sigma_y = 46\ \mu m$):
- Object plane scan of the beam interacting with the Al 0.1 mm foil.
- Data taken for different foil thicknesses.
- Compare foil damage for different thicknesses with different repetition rates.
- August 20 ($\sigma_x = 30\ \mu m$, $\sigma_y = 51\ \mu m$): **Small β function**
- Scan of β function from 50 cm to 5 cm : beam drilled holes faster at 5 cm.
- Raster scan on the 0.1mm Al foil with β = 5 cm.
- Foil damage analysis by looking at GAMMA cameras for different β

July 18, 2022
First holes!



(σ_x , σ_y) : from wirescanner before/after the shift.

Diagnostics and observables



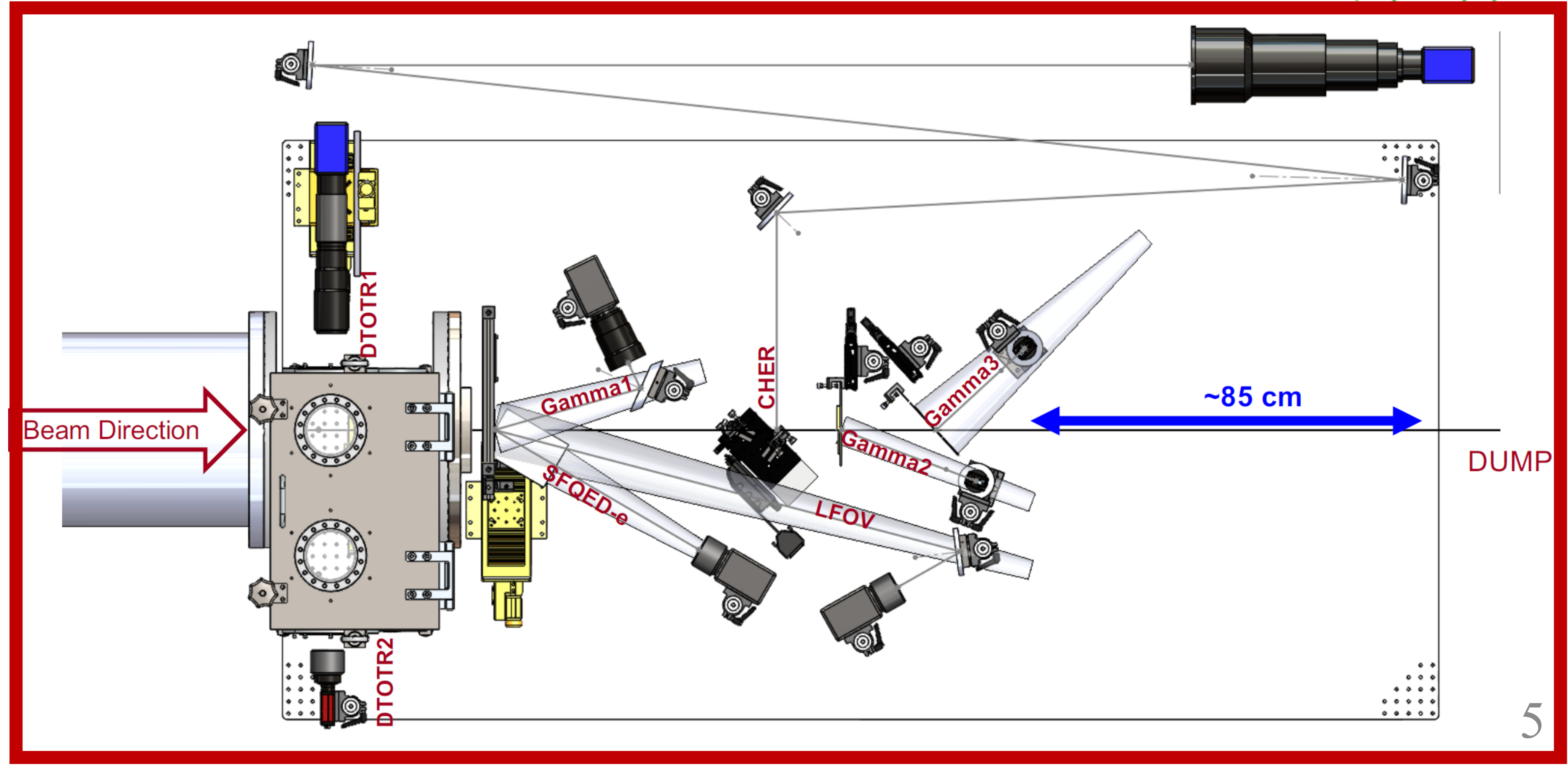
Main observables:

- Change in electron beam parameters due to NF-CTR focusing

- Gamma rays

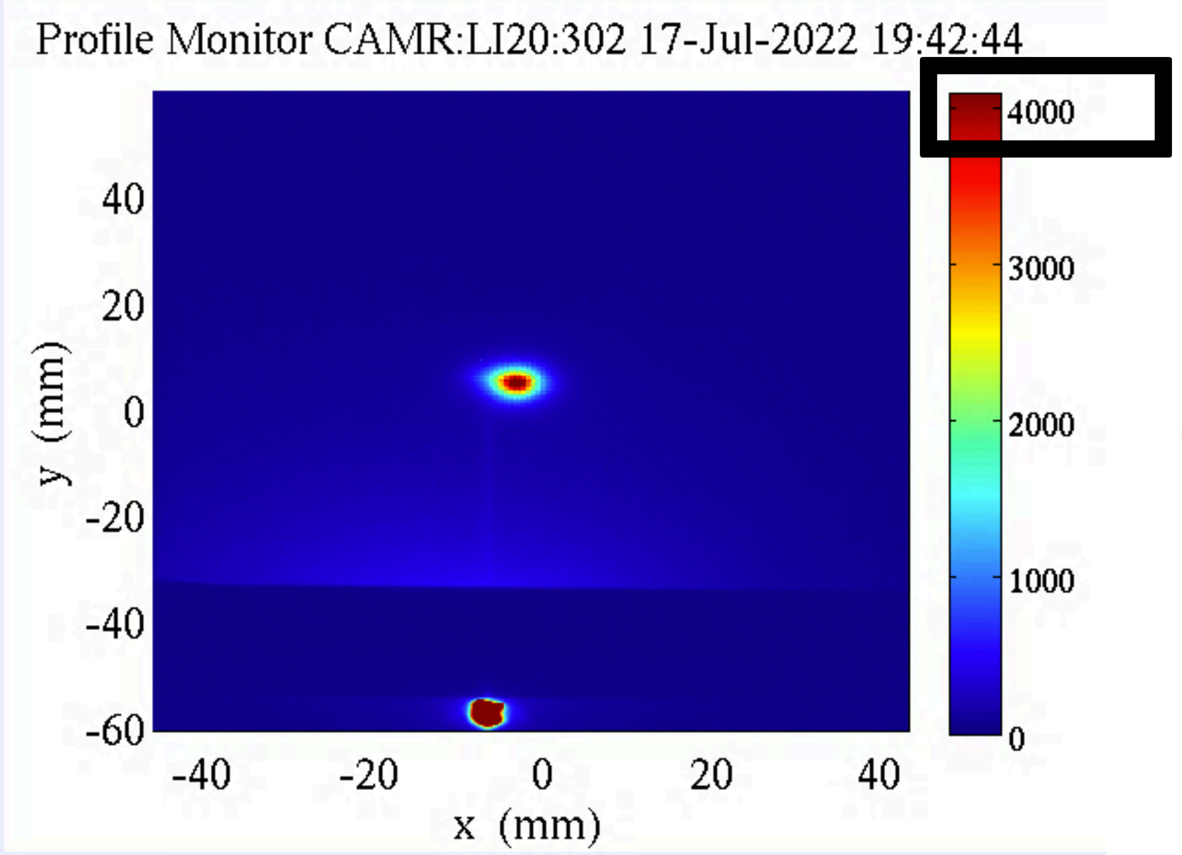
Electrons:
- Coherent OTR prevents the use of profile monitors downstream of IP
- High-resolution in-vacuum OTR at the dump table (DTOTR)

Gammas:
- γ screens at the dump table (incl. CsI to detect small gamma signals)



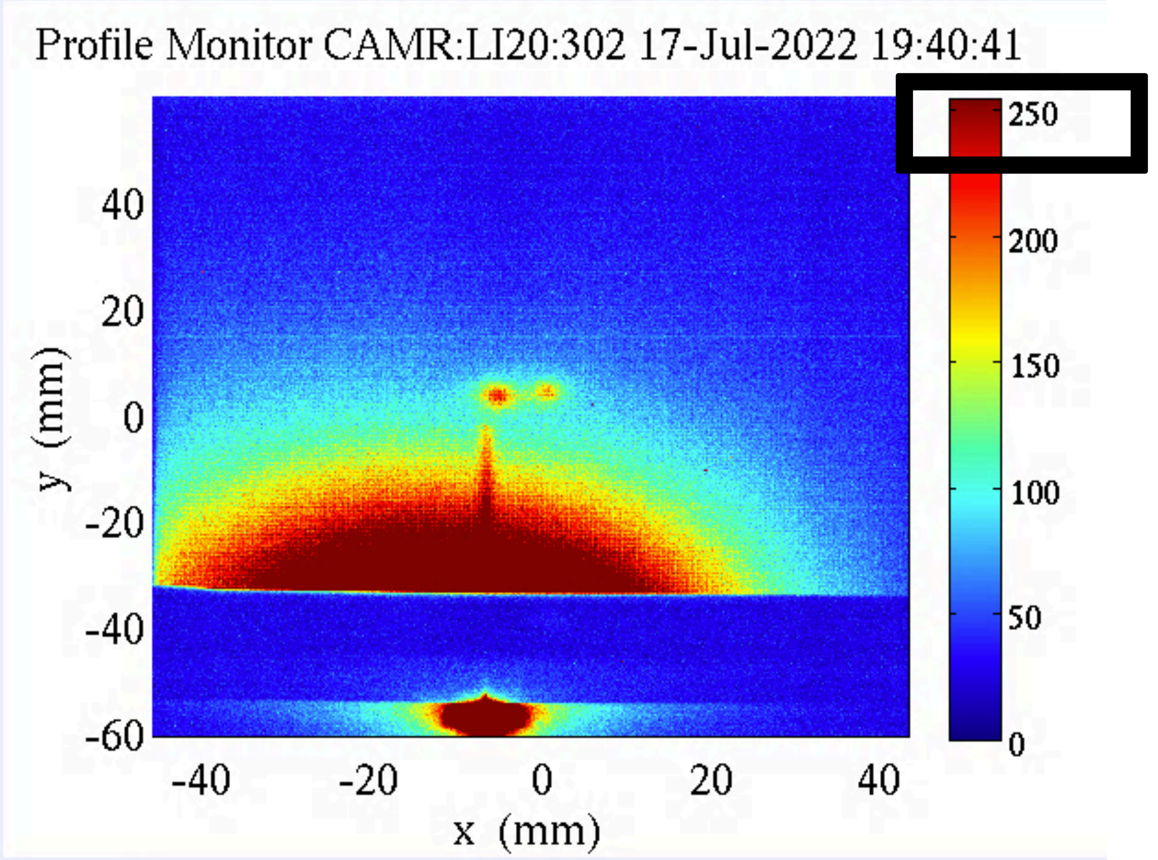
Progress to date: first holes and GAMMA1 signal (July 18 shift)

i. First evidence of holes being drilled in foils (holes completely drilled in 2 minutes with Al 0.1 mm).
ii. Data of GAMMA1 signal decreasing with time while shooting at a fixed foil position
iii. Foil damage is **proxy for strong NF-CTR (Ohmic heating by surface currents)**

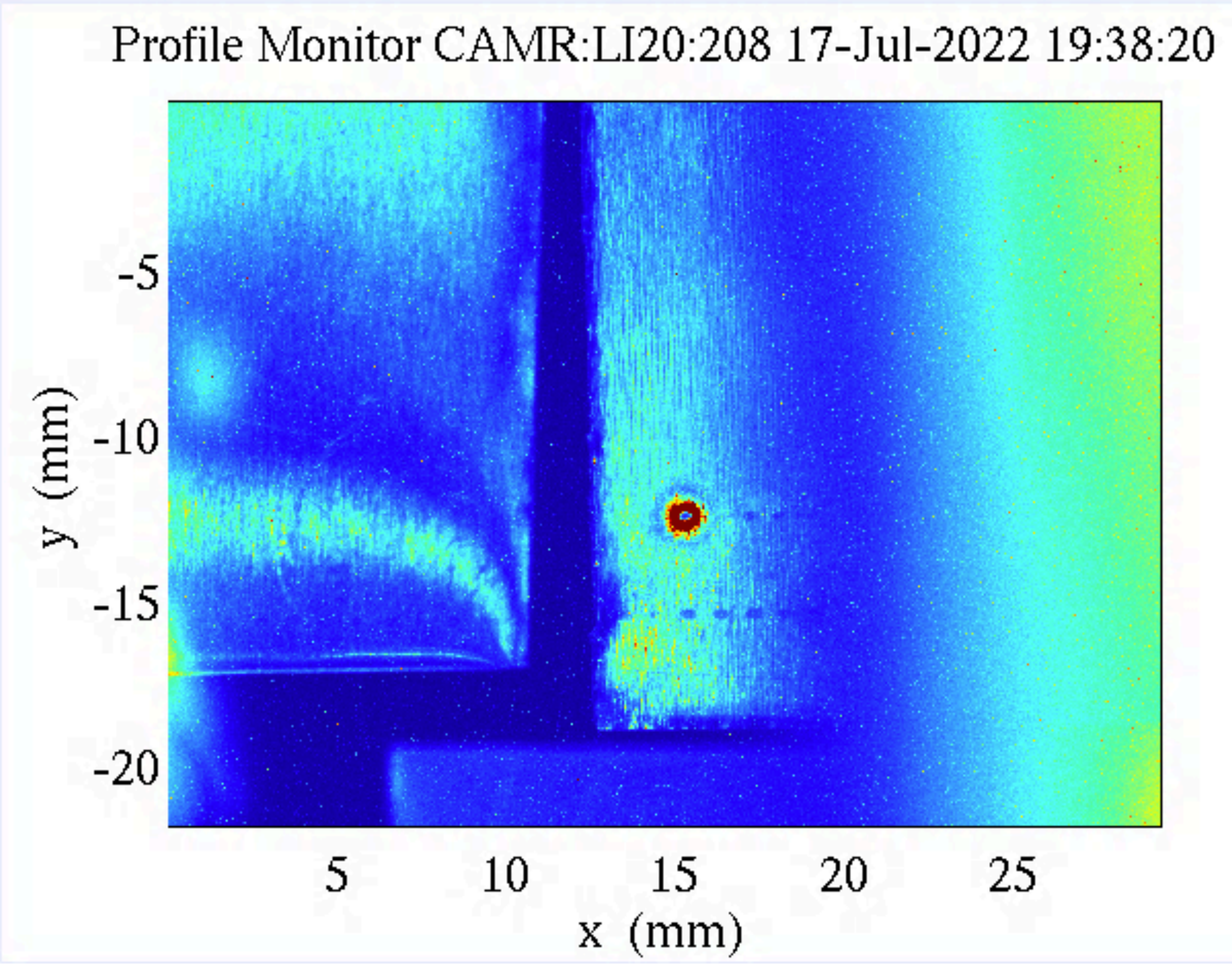


Gamma signal after 0 min at 10Hz (Al 0.1 mm)

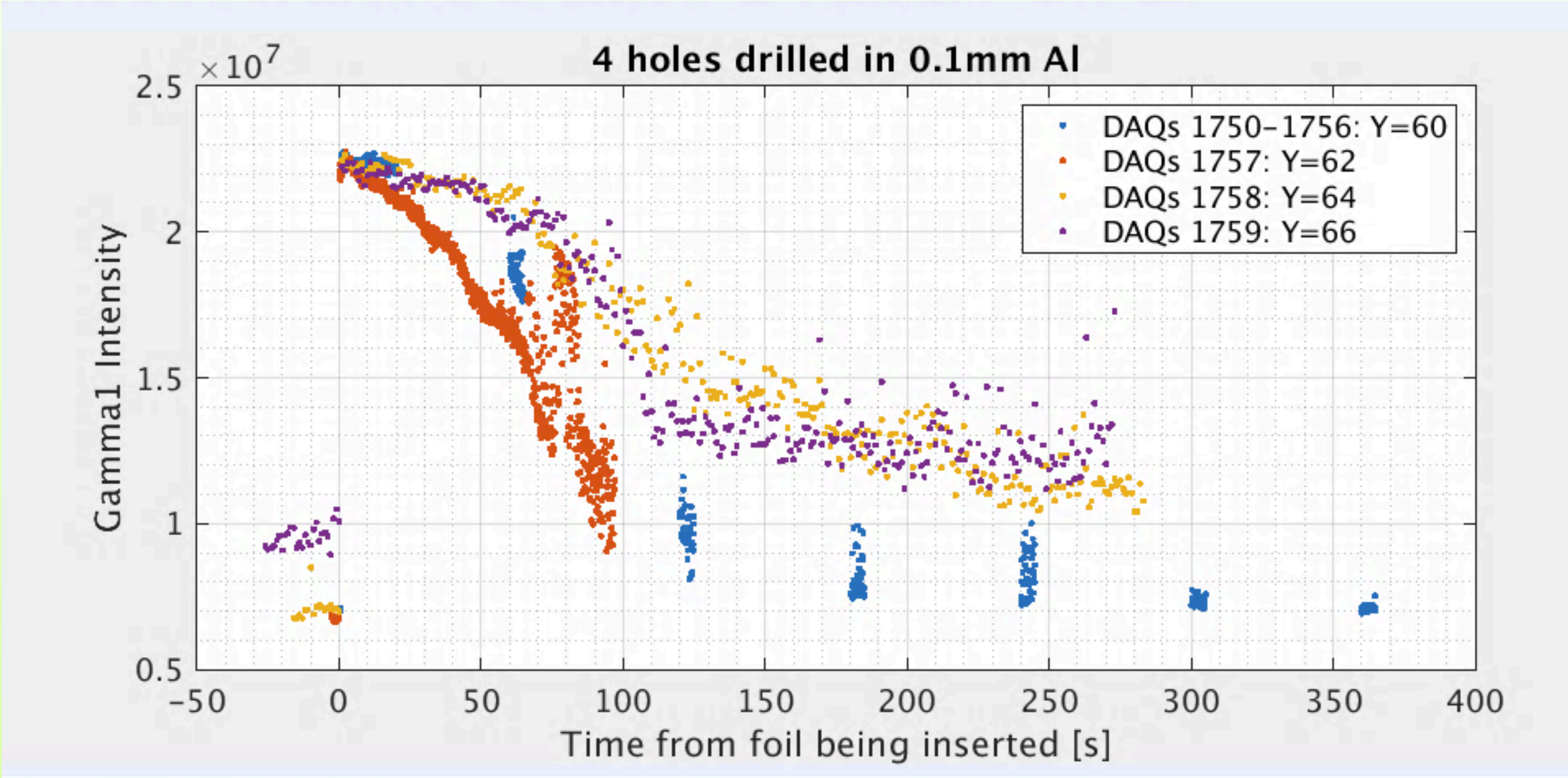
After 10 min



Gamma signal after 10 min at 10Hz (Al 0.1 mm)



First time drilling a hole

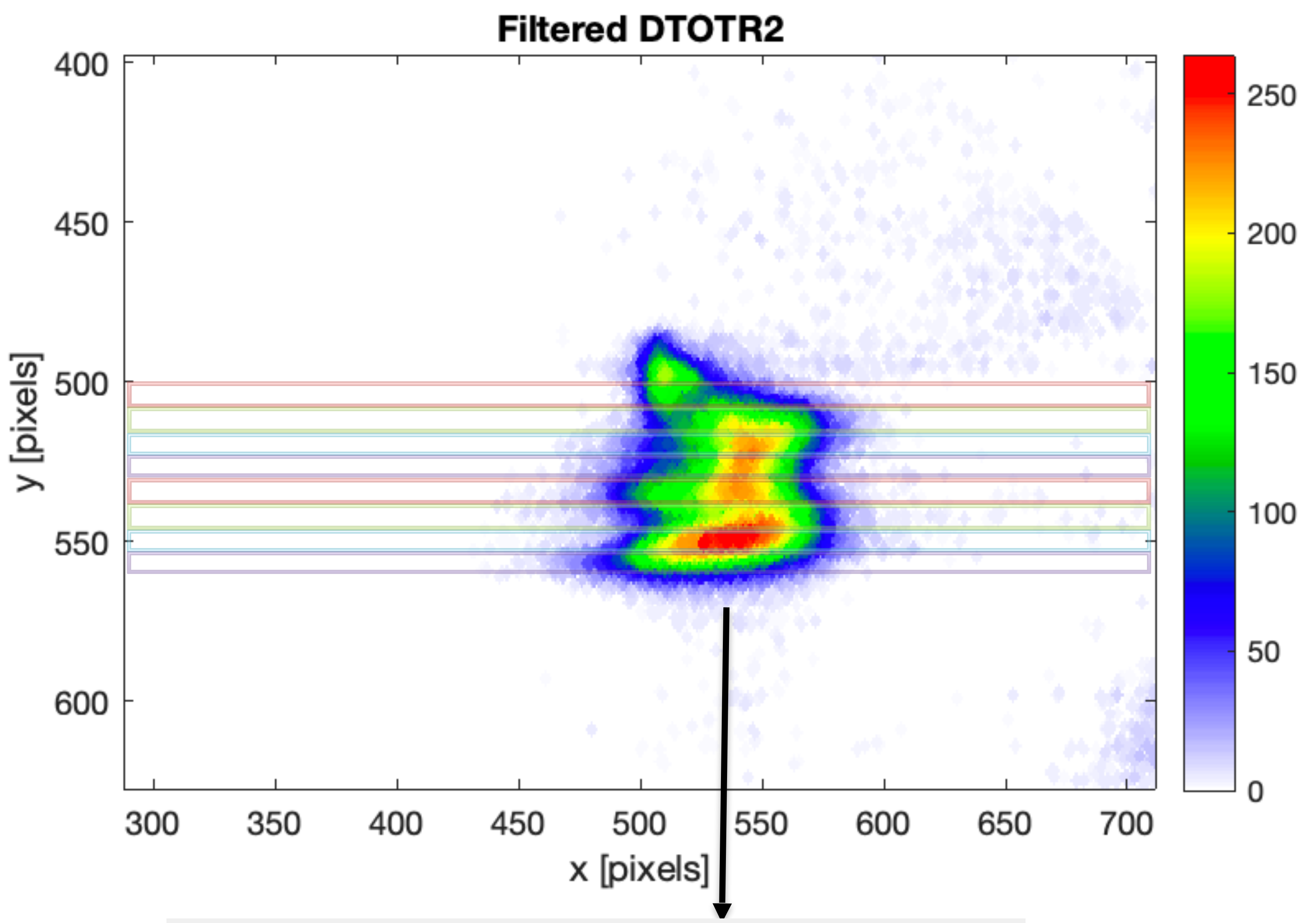


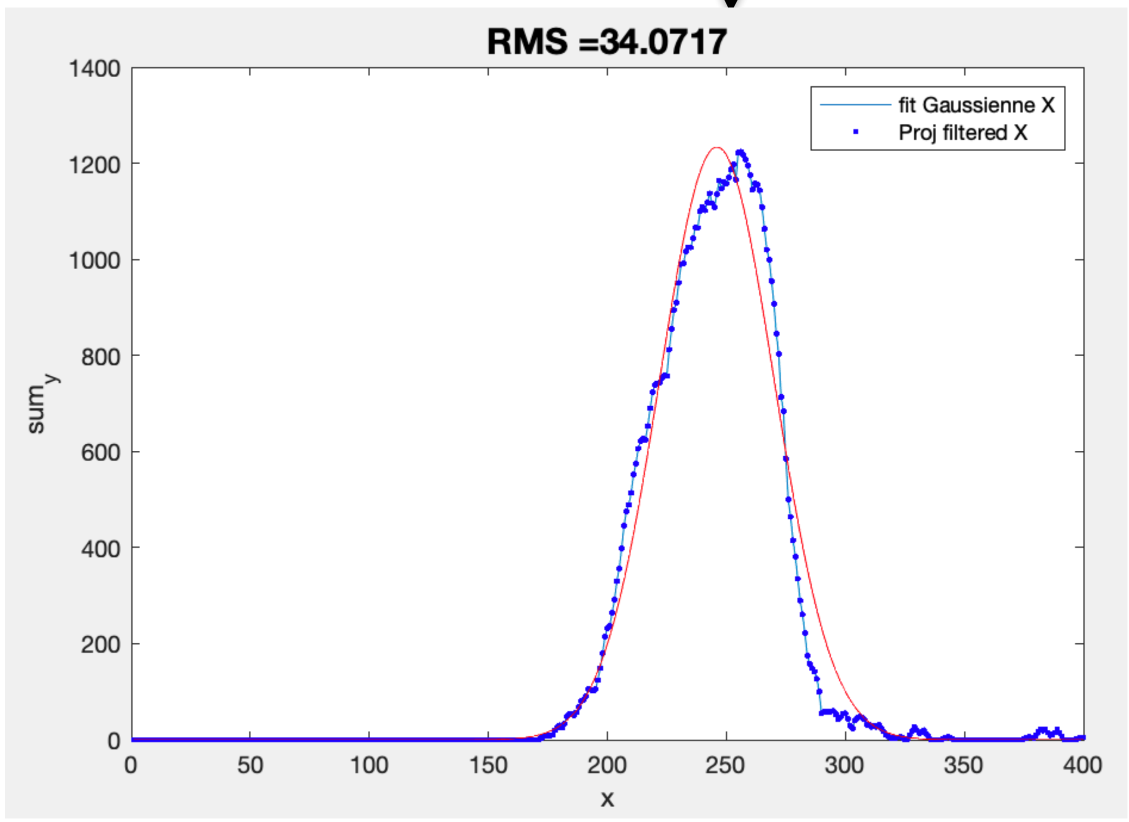
- GAMMA1 signal decreasing gradually after inserting the foil due to the hole being drilled.

Drilled through Al 0.1mm with the e-beam over 1000 shots.

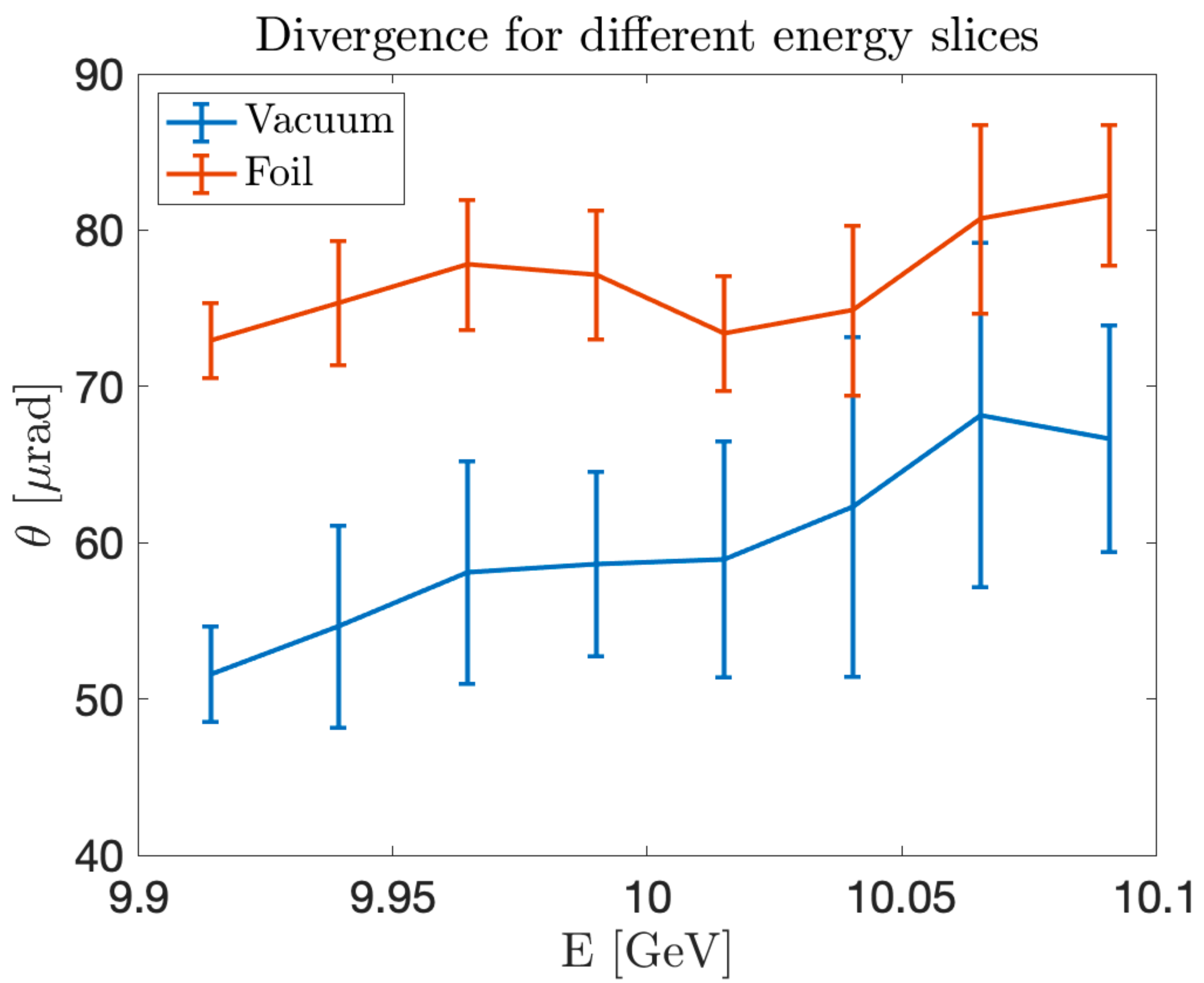
Progress to date: looking at a change of divergence (August 4 shift)

(Data taken by doing a raster scan on the foil)





We fit each energy slice with a gaussian shape

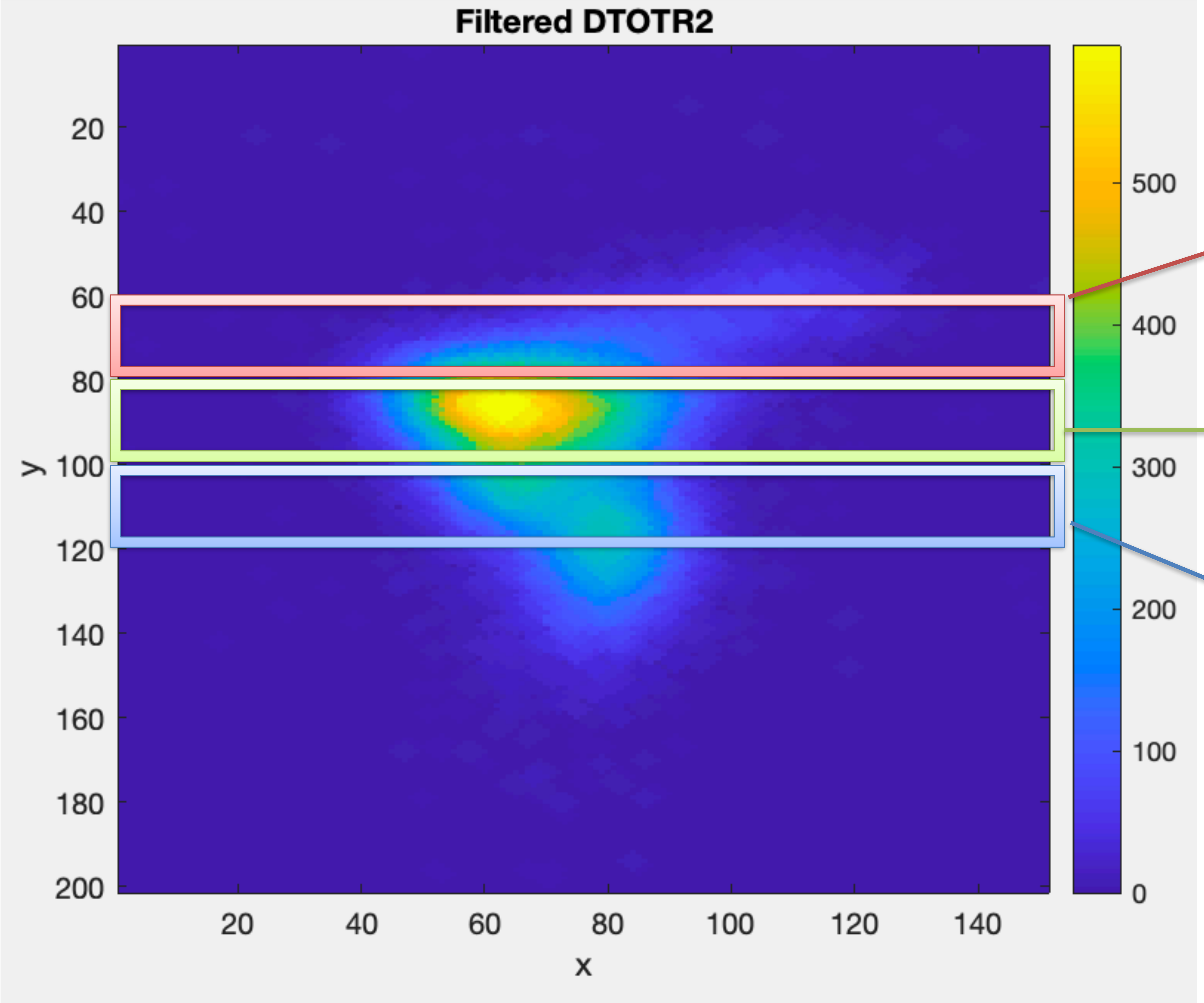


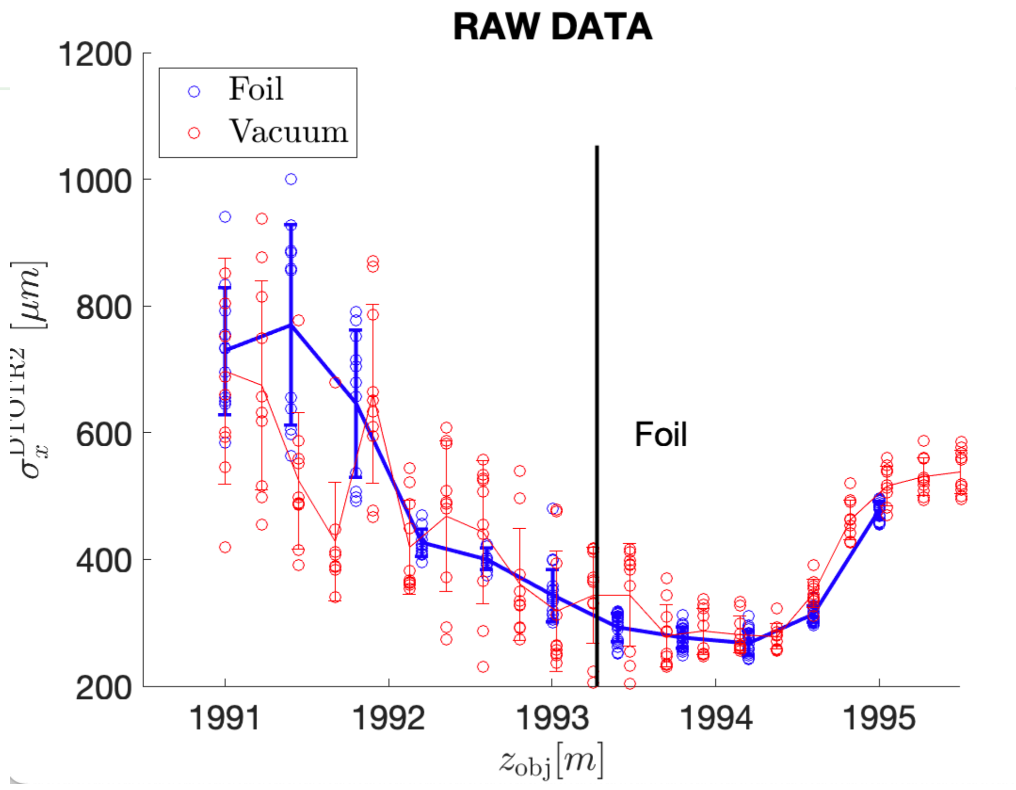
For these beam parameters and Al 0.1mm, we expect :

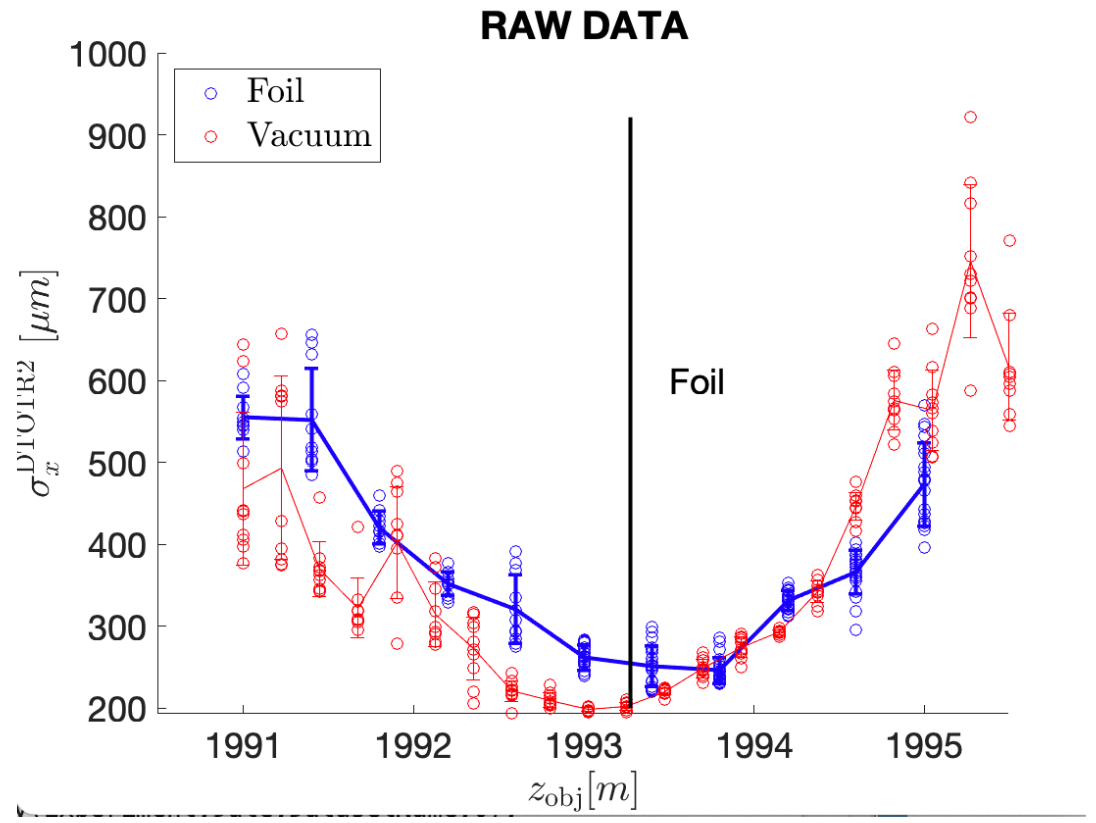
- Increase of divergence ~ 10-15% due to NFCTR
- Multiple scattering contribution of 34 µrad

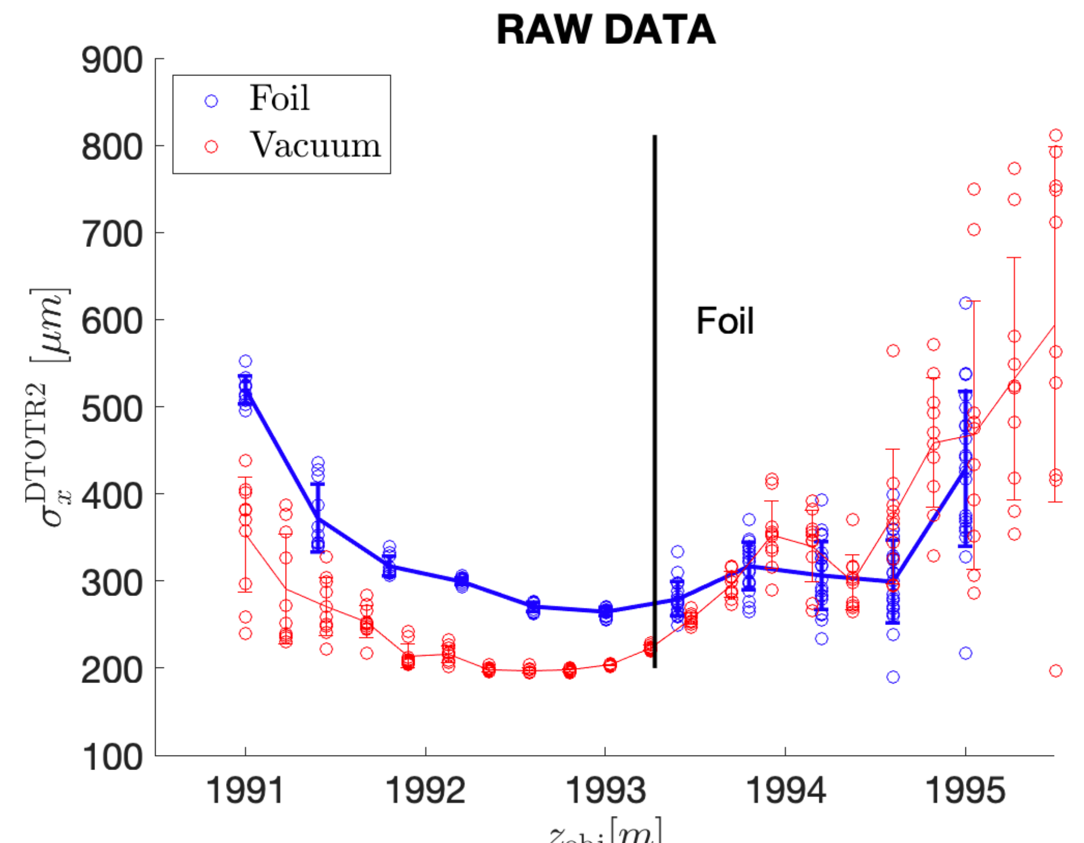
Progress to date: object plane scans (August 12 shift)

By taking a slice (first vacuum set of data):







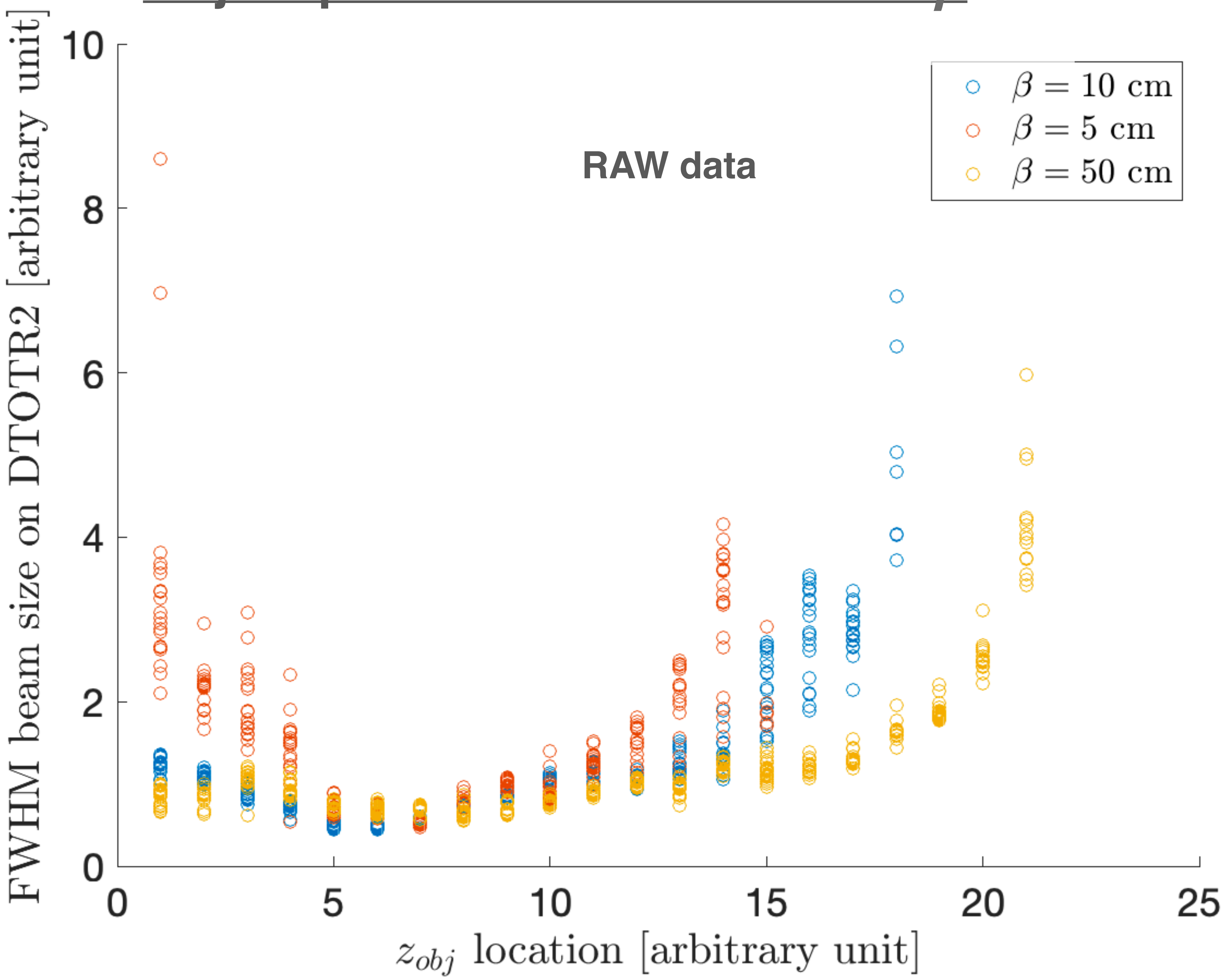


We observe a higher divergence with foil

Progress to date: lowering β (August 20 shift)

- Scan of β function from 50 cm to 5 cm : beam drilled holes faster at 5 cm.
- Raster scan on the 0.1mm Al foil with β = 5 cm.
- Object plane scan in vacuum for different β
- Foil damage analysis by looking at GAMMA cameras for different β

Object plane scans for different β



- $\beta = 5$ cm diverge more than 10 cm and 50 cm.

- Waist location doesn't evolve too much with β.

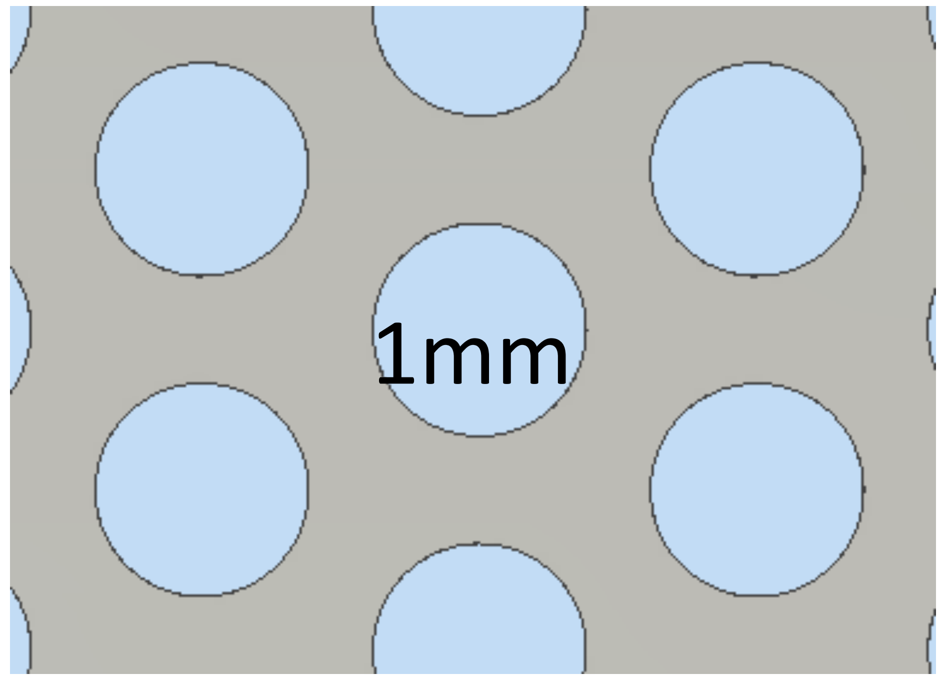
Summary & next steps

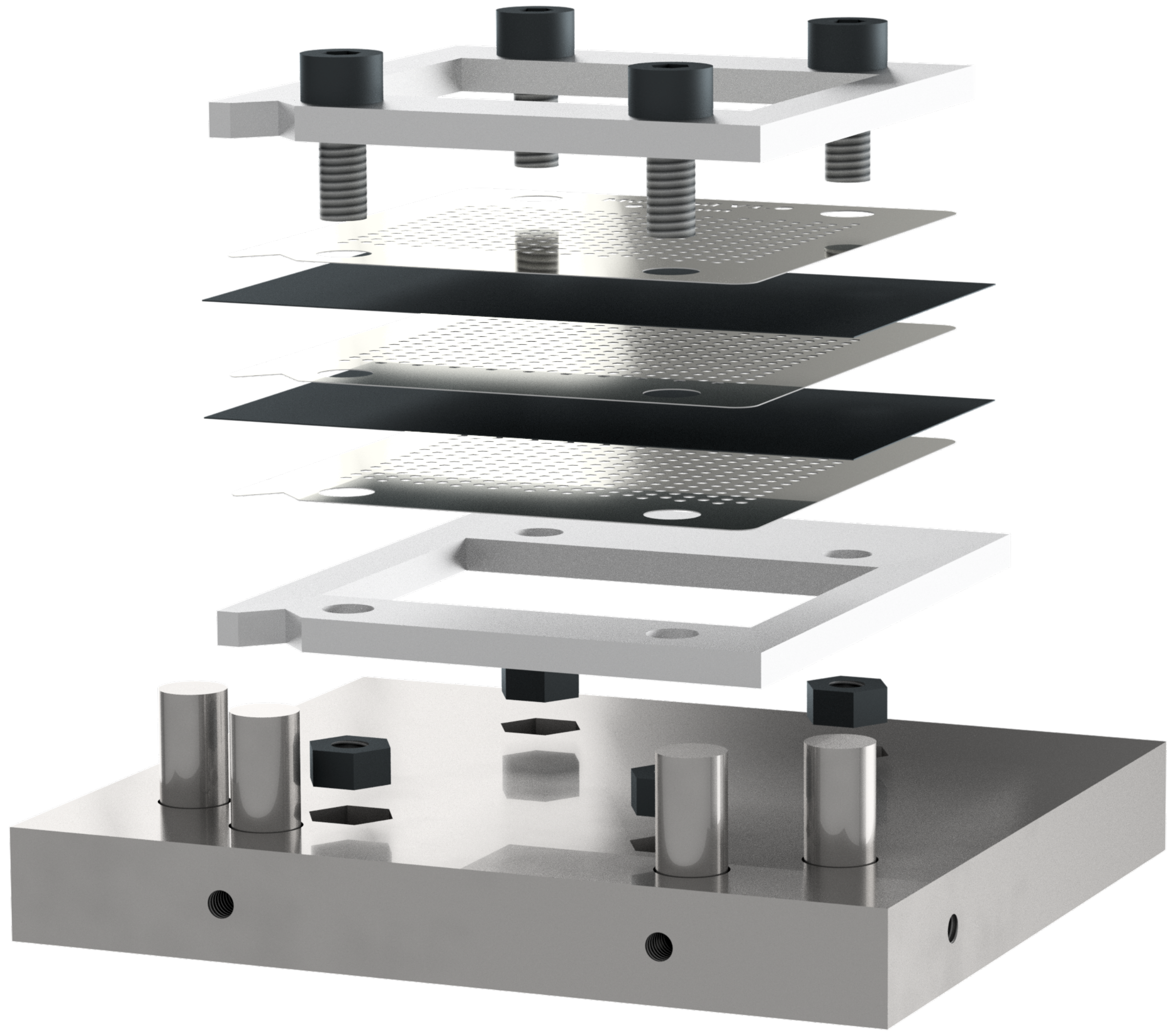
Summary

- We are now able to perform raster and quad scans to take usefull data.
- Clear effect of divergence increase after the foil : is it mostly NF-CTR or multiple scattering?
- Carried out preliminary tests at smaller β

Experiment priorities

- Replace the current foils with thinner ones ($1\ \mu$m) to suppress multiple scattering
- Replace the single foil with a stack of up to 100 foils: this should increase the NF-CTR effect (whereas multiple scattering is a function of the sum of the foil thicknesses).
- Verify that small β provides smaller beam size or if other effects prevent us from focusing more (e.g. dispersion in energy).
- Carry out the experiment at smaller emittance.
- Gain better knowledge of the longitudinal phase space of the beam





Potential evolution of the experiment & Desired facility upgrades

Possible evolution of the experiment (not exhaustive):

- Use of a plasma lens (to reduce beam size on solid target)

- Explore laserless SFQED (nonlinear Breit-Wheeler pair production)

Desired facility upgrades (not exhaustive):

- Low emittance: critical for strong NF-CTR focusing and reaching small spot sizes

- High peak current and small bunch length: NF-CTR and gamma-ray emission are most efficient in the radiating regime $\sigma_z \lesssim \sigma_r$, and the bunch length cannot be reduced in plasma or foil (in contrast to the beam size).

Backup slides

Collaboration and institutions

I. Andriyash, S. Corde, M. Gilljohann, A. Knetsch, O. Kononenko, Y. Mankovska, A. Matheron, P. San Miguel Claveria, V. Zakharova

C. Keitel, S. Montefiori, A. Sampath, M. Tamburini

X. Davoine, J. Faure, L. Gremillet, S. Passalidis

H. Ekerfelt, C. Emma, F. Fiuza, E. Gerstmayr, S. Gessner, M. Hogan, A. Marinelli, J. Peterson, B. O'Shea, D. Storey, X. Xu, V. Yakimenko

C. Joshi, K. Marsh, W. Mori, N. Nambu, Z. Nie, Y. Wu, C. Zhang

R. Ariniello, J. Cary, C. Doss, K. Hunt-Stone, V. Lee, M. Litos

E. Adli

J. Yan, N. Vafaei-Najafabadi

Publications & students involved

A. Matheron (PhD student), P. San Miguel Claveria (former PhD student)

S. Montefiori (PhD student), A. Sampath (former PhD student)

J. Peterson (PhD student)

- A. Matheron, P. San Miguel Claveria, R. Ariniello, H. Ekerfelt, F. Fiuza, S. Gessner, M. F. Gilljohann, M. J. Hogan, C. H. Keitel, A. Knetsch, M. Litos, Y. Mankovska, S. Montefiori, Z. Nie, B. O'Shea, J. R. Peterson, D. Storey, Y. Wu, X. Xu, V. Zakharova, X. Davoine, L. Gremillet, M. Tamburini, S. Corde, "**Probing strong-field QED in beam-plasma collisions**", arXiv:2209.14280 (2022).

- A. Sampath, X. Davoine, S. Corde, L. Gremillet, M. Gilljohann, M. Sangal, C. H. Keitel, R. Ariniello, J. Cary, H. Ekerfelt, C. Emma, F. Fiuza, H. Fujii, M. Hogan, C. Joshi, A. Knetsch, O. Kononenko, V. Lee, M. Litos, K. Marsh, Z. Nie, B. O'Shea, J. R. Peterson, P. San Miguel Claveria, D. Storey, Y. Wu, X. Xu, C. Zhang, M. Tamburini, "**Extremely Dense Gamma-Ray Pulses in Electron Beam-Multifoil Collisions**", Phys. Rev. Lett. **126**, 064801 (2021).