E-336 FY22 Progress and Plans for FY23

Feasibility studies of the FACET-II beam interaction with nanotube materials

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E336 - Science goals and definition of success

- Science goals
  - Proof-of-principle experiment - demonstrate feasibility of the study of beam-nanotarget interaction and of beam-induced wakefields in nanotargets
  - Observation of electron beam nano-modulation
  - Observation of betatron X-ray radiation
  - Confirmation of simulation models

- Definition of success:
  - Evidence for clearly distinguishable interaction of FACET-II beam with structured solid targets in comparison to amorphous targets (1.5 years)
  - Systematic parametric study of beam-nanotarget interaction for various sample thickness, pore diameter, material type, and beam parameters, and comparison/ validation against theory, to support signature and evidence of beam nano-modulation (3 years - dependent on delivered beam parameters)

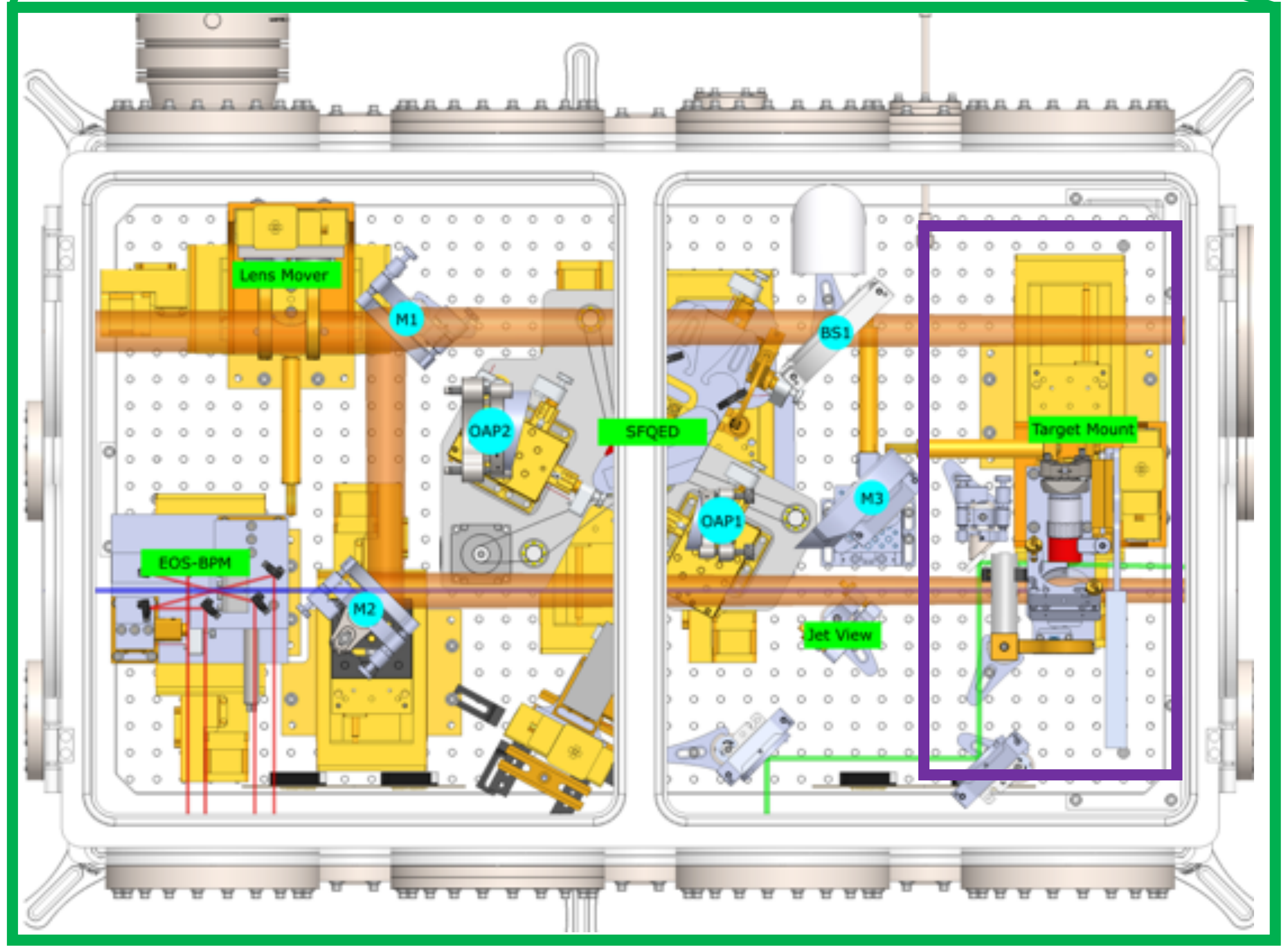
E336 - Experimental timeline

- Since spring 2022:
  - Experimental safety review carried out
  - Mount with fine angular control installed
  - Nanotargets installed and beam damage tested

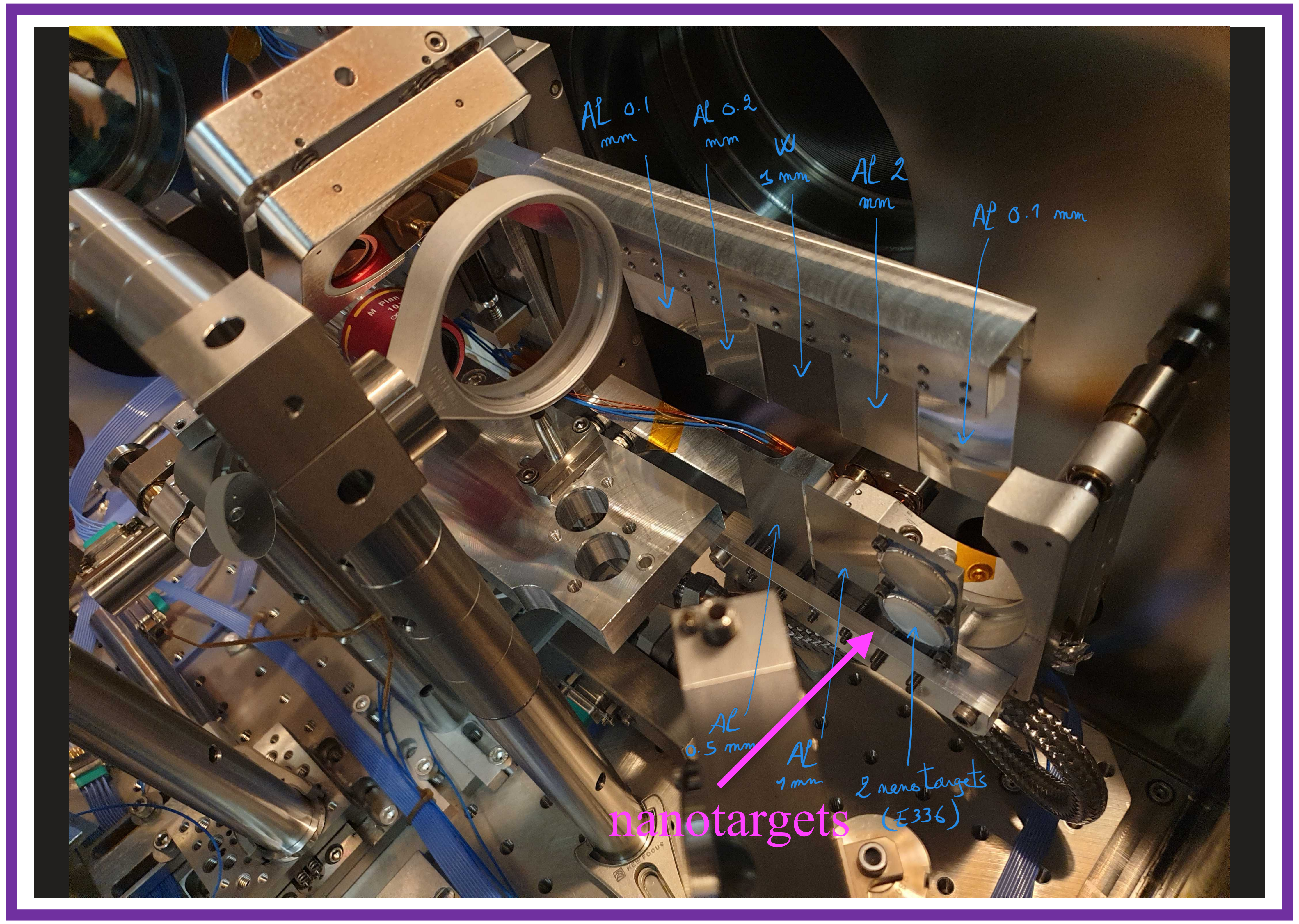
- Timeline going forward:
  - Phase 1 - FY23: angular readback for the mount on every shot, invasive diagnostics for absolute angular alignment, first tests of beam-nanotarget interaction.
  - Phase 2 - FY24-25: iterate to improve/upgrade experimental hardware, advanced characterization of beam-nanotarget interaction with full set of sample and with improved FACET-II beam parameters
  - Phase 3 (conditional): going from transverse wakefields and beam dynamics to longitudinal wakefields

Experimental layout

Experimental vacuum chamber (Picnic Basket)



Nanotargets are mounted on the E305 target mount:



Diagnostics and observables

Main observables:

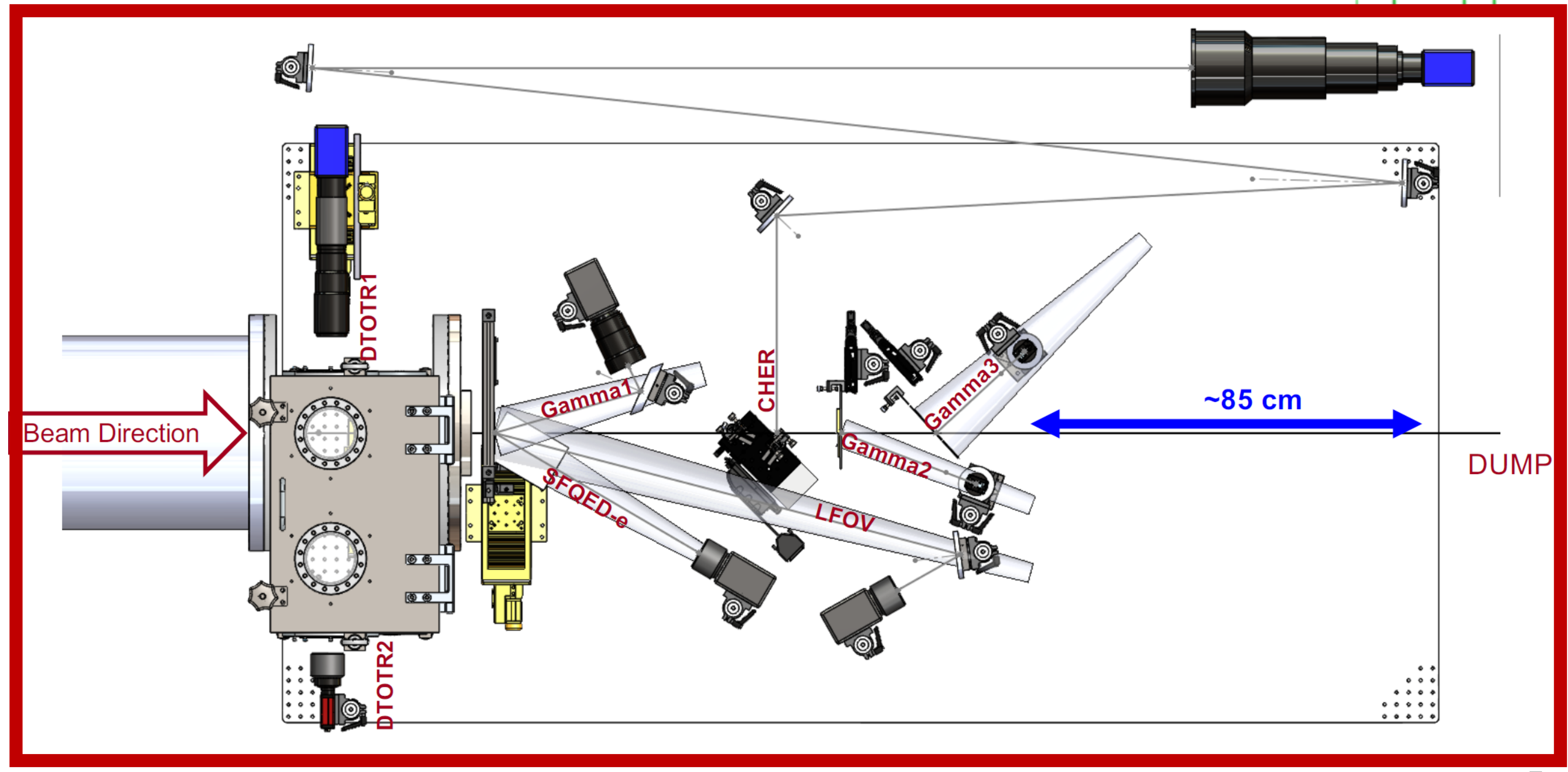
- Growth of transverse momentum spread
- Beam kicks for tilted nanotargets
- X rays and gamma rays

Electrons:

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

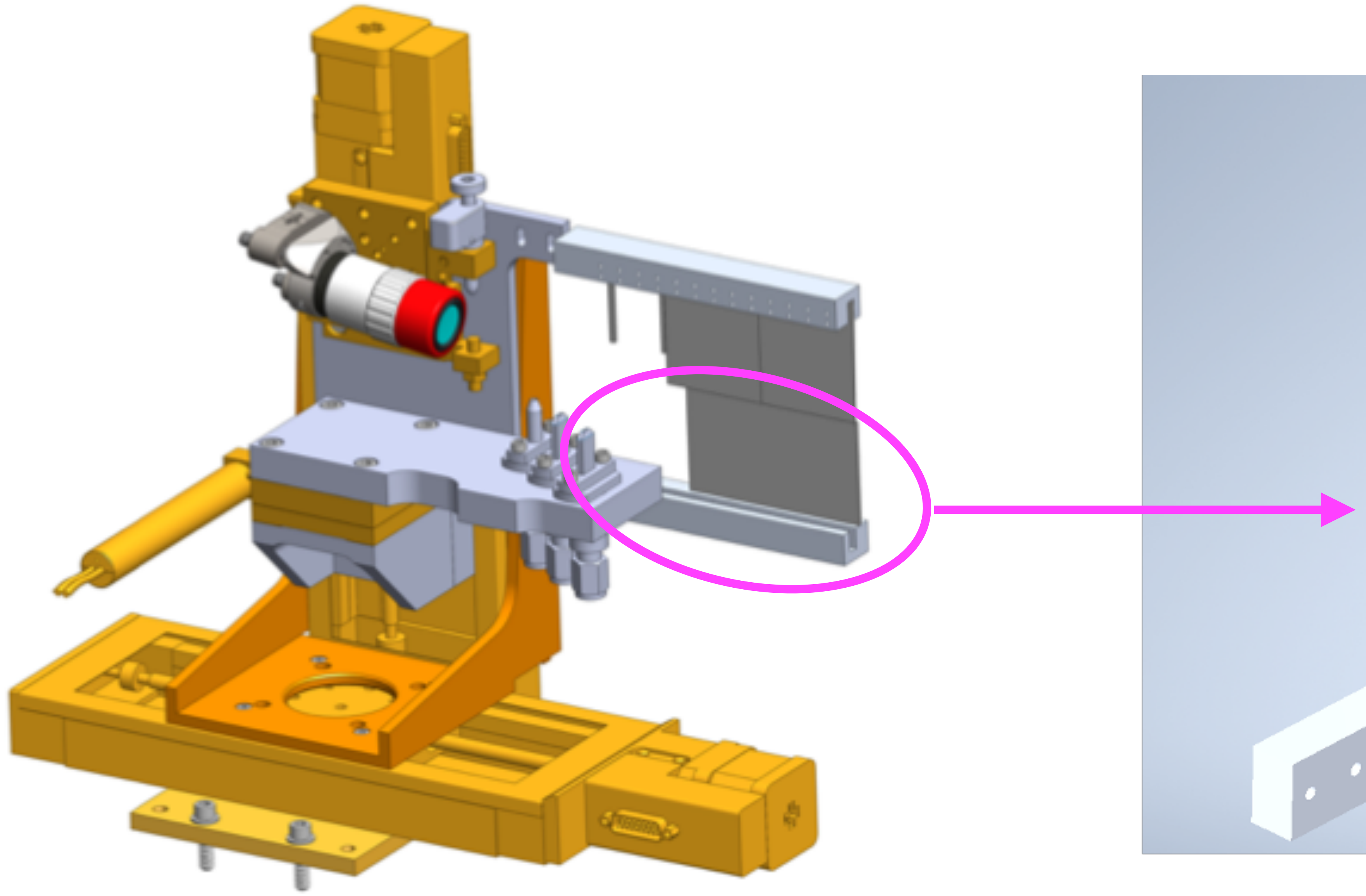
Gammas:

- γ screens at the dump table and Gamma Detection Chamber (UCLA)

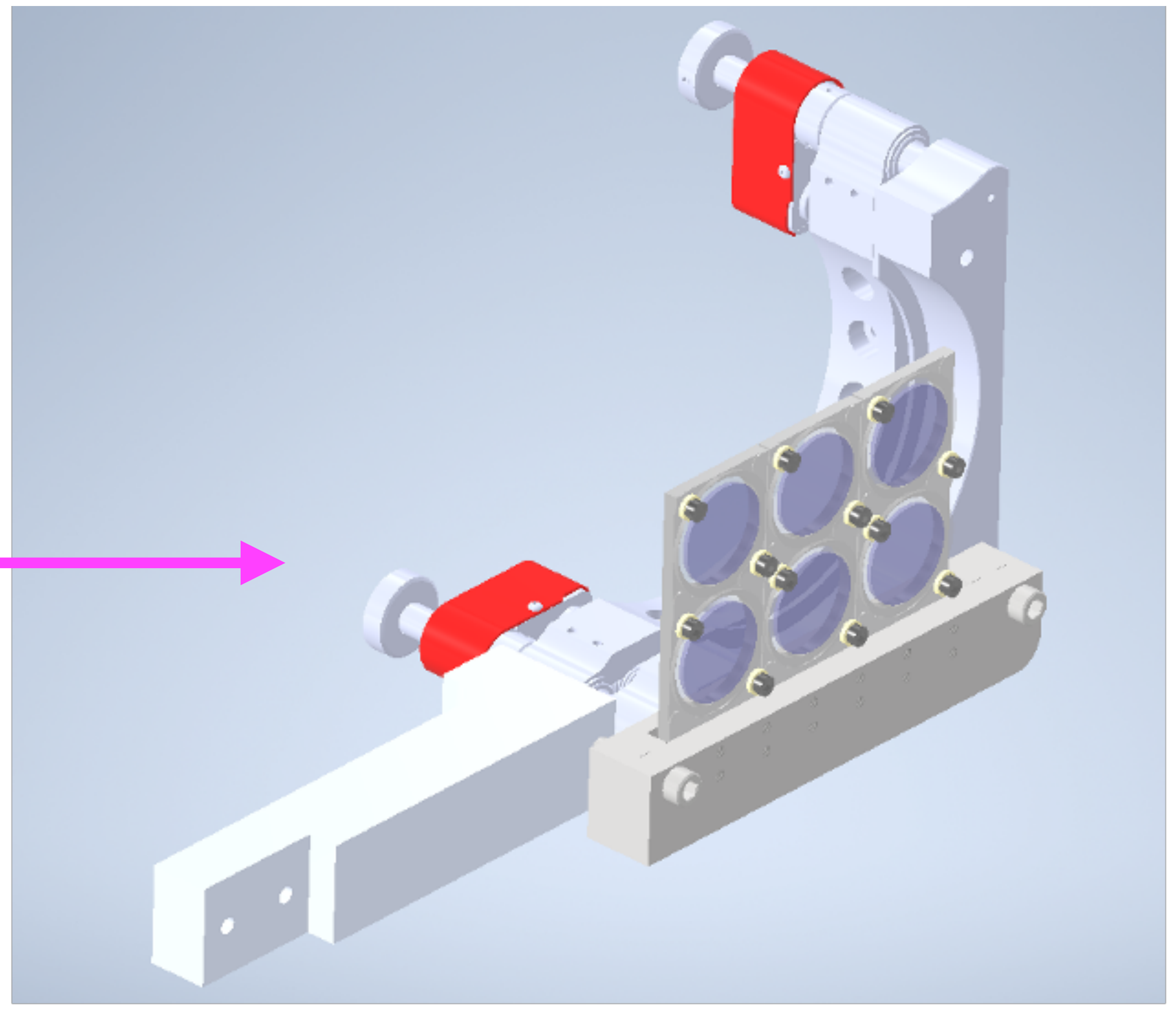


E336 - FY22 Progress

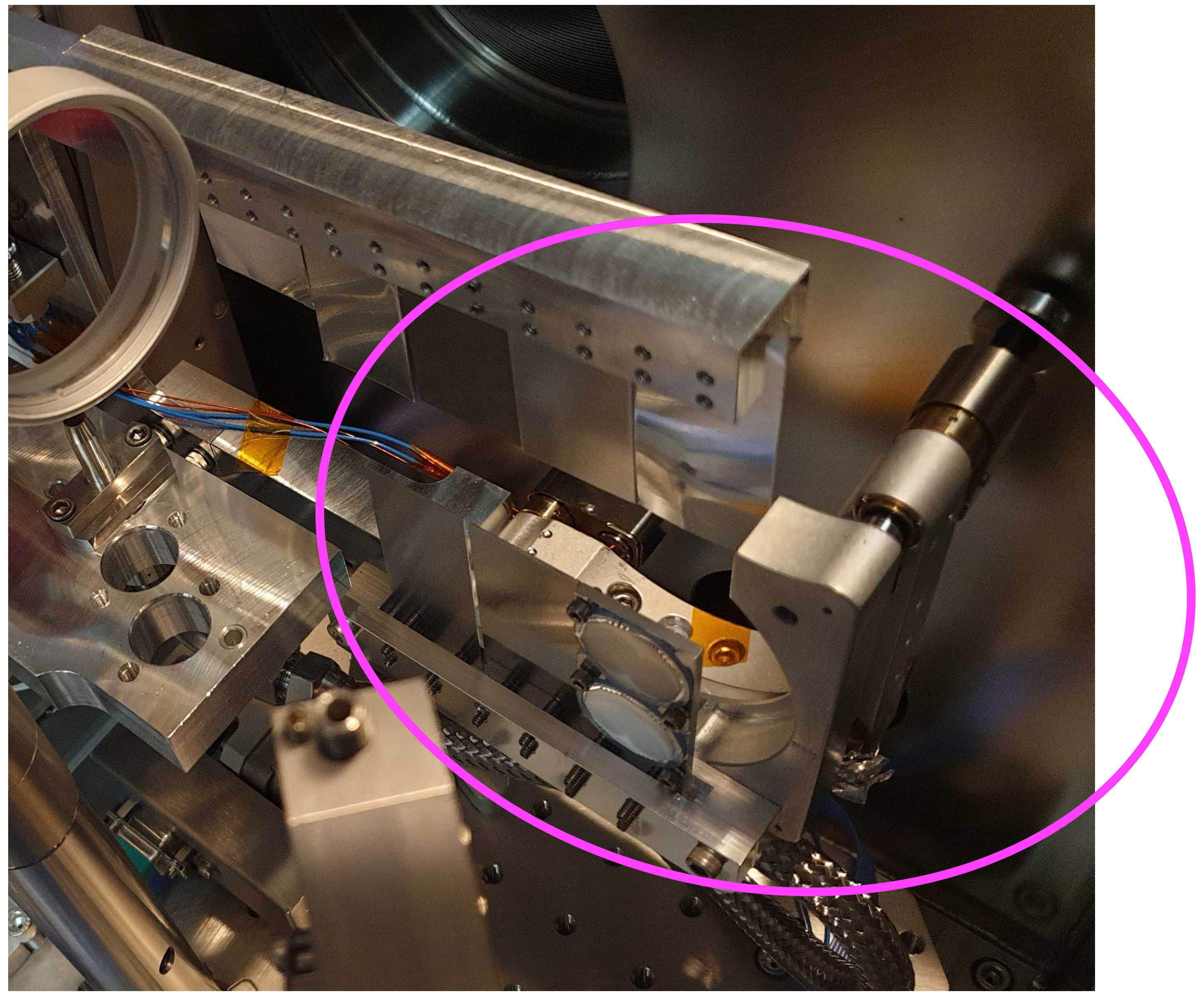
- Mounting and angular control for nanotarget in the Picnic Basket chamber:
  - Decided to modify E305 target mount in the least invasive way to other experiments
  - Angular control is obtained using tip/tilt pico motors on a mirror mount on which the samples are installed
  - The set-up fulfils E336 requirements (from last PAC: angular requirements = 10-20 μrad precision and 2-3 degrees range; positioning requirements = 10-100 μm precision and 5 cm range)



Original design or E305 target mount



Proposed modification of the bottom solid target holder



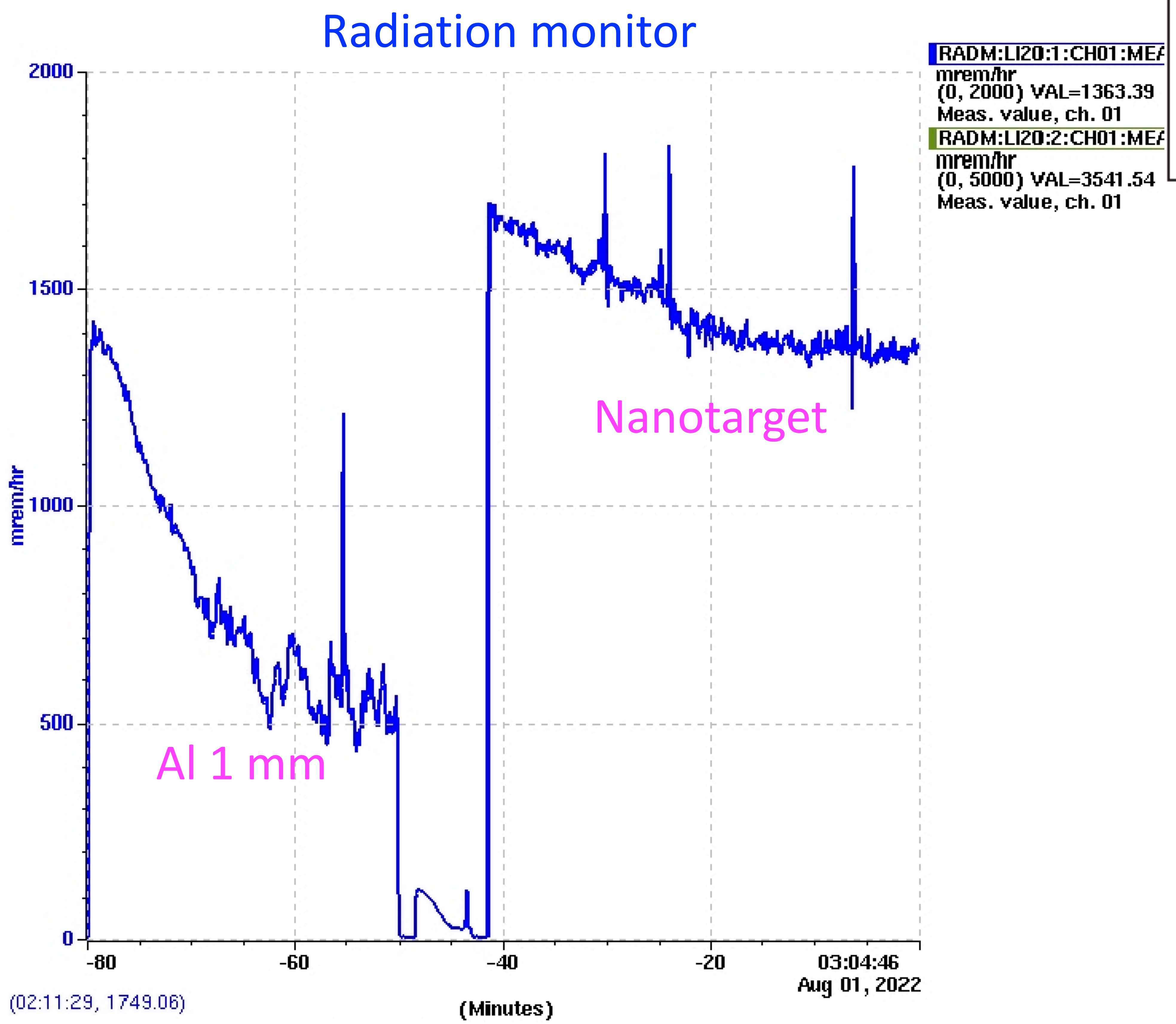
Installed and tested/ validated July 19, 2022

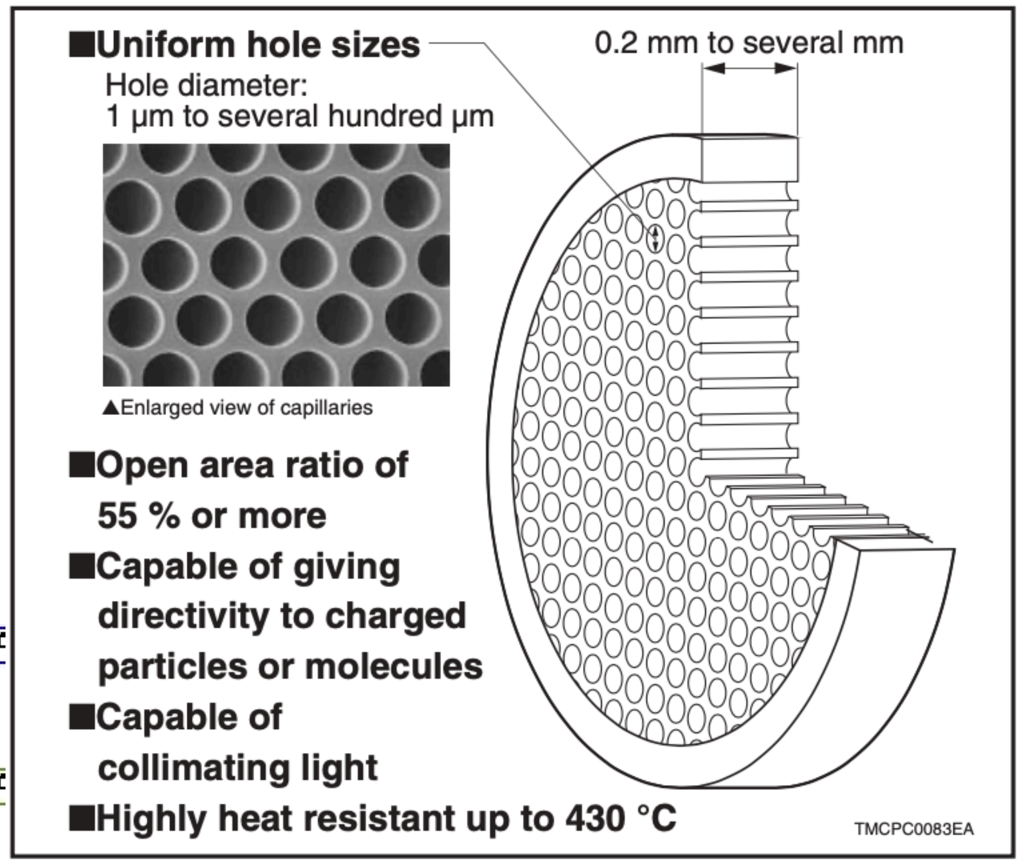
E336 - FY22 Progress

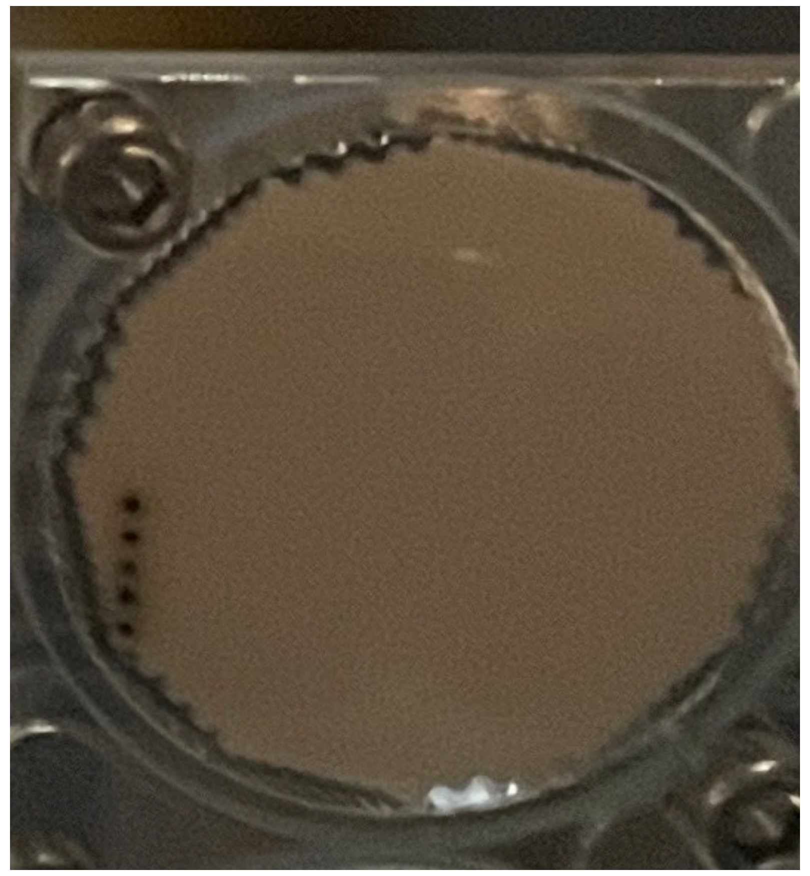
- Tested beam damage of nanotargets
  - Sample installed: 1-mm thick, 6 micron-diameter nanotubes made in lead glass
  - 2 hours of E336 beamtime on August 1, 2022 to test sending beam into nanotargets and study damage
  - Irradiated two positions, then re-optimized L2 phase for best drilling/compression (Al 0.1 mm drilled in 3 min at 10 Hz), and then tested again Al 1 mm and nanotarget in optimized conditions.
  - Although damage is observed, nanotarget is fairly resistant:

    nanotarget: 15% decrease in 15 min
    Al 1 mm: 50% decrease in 15 min

    with beam at 10 Hz







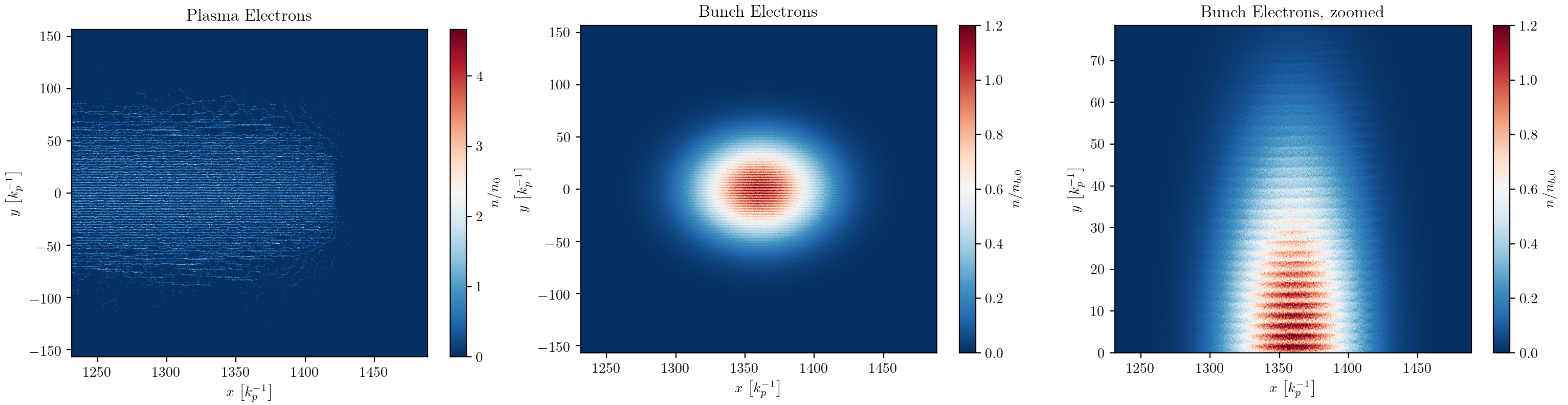
Nanotarget after E336 shift

E336 - FY22 Progress

- 2D PIC simulation campaign for E336 - modelling beam ionization of non-conducting material

Silica with 200 nm nanotubes

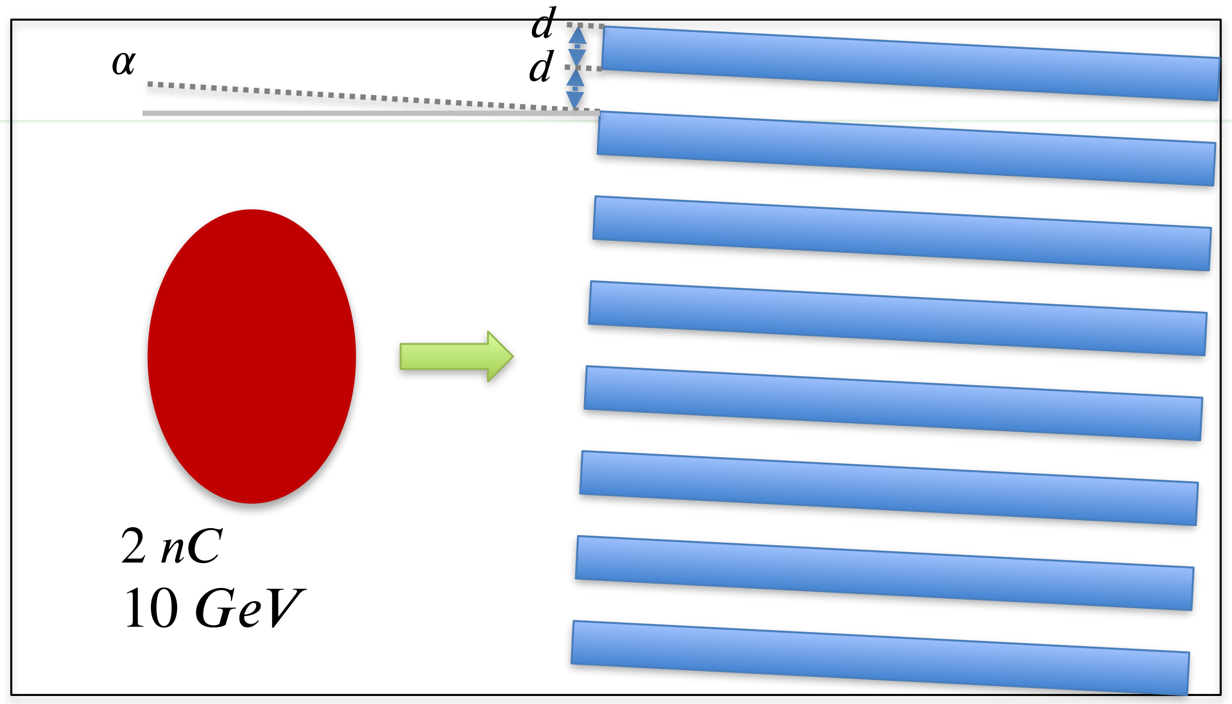
Beam size and bunch length of 5 microns



- Beam self fields are strong enough to ionize.
- Partially-ionized plasma can screen beam self fields, thereby limiting further ionizing.
- This self-consistent dynamics results in a few percent of ionization, enough to enable the nanotube plasma response responsible for the transverse beam dynamics and nano-modulation.
- The beam gets nano-modulated similarly to the case where a plasma is initialized directly.

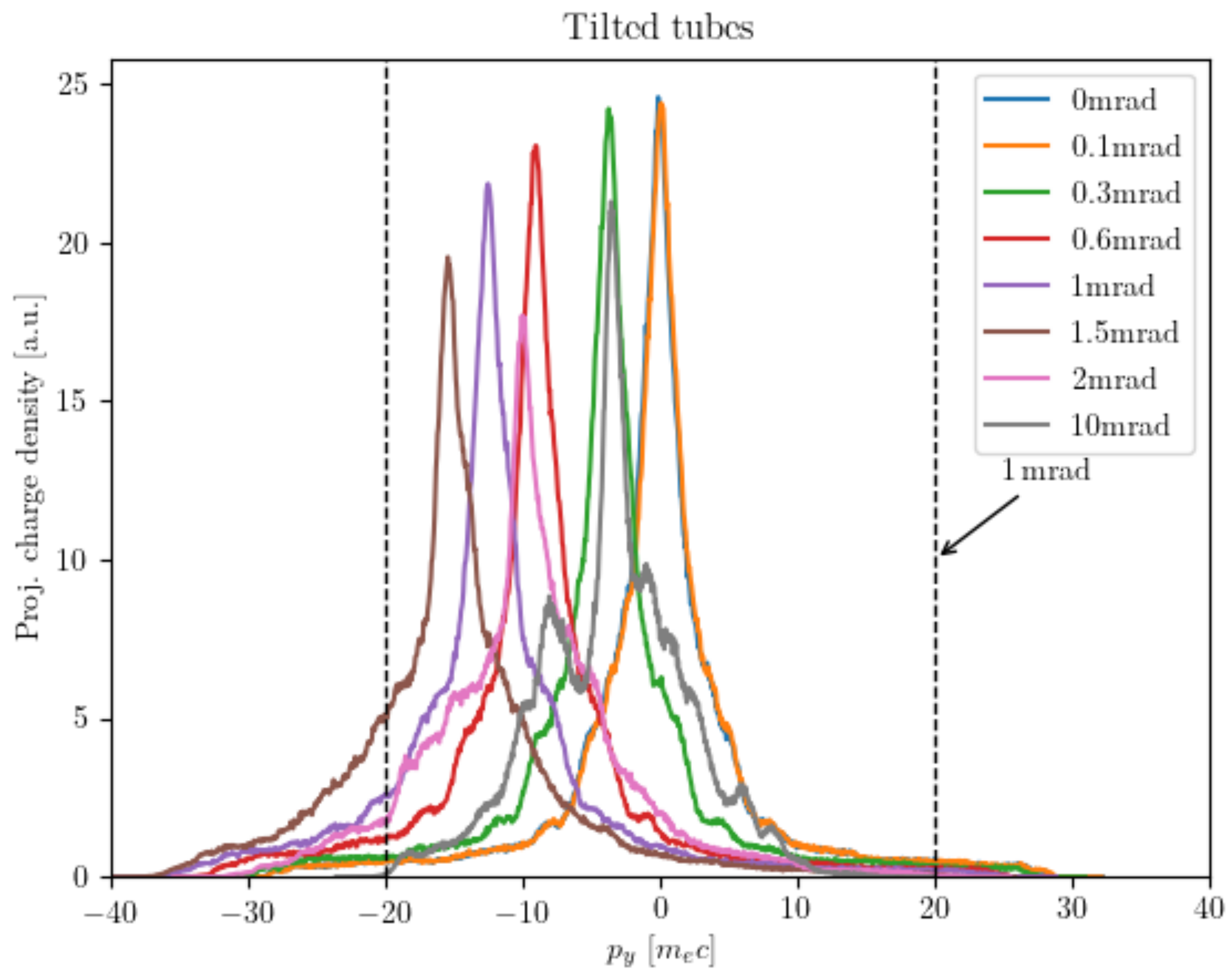
E336 - FY22 Progress

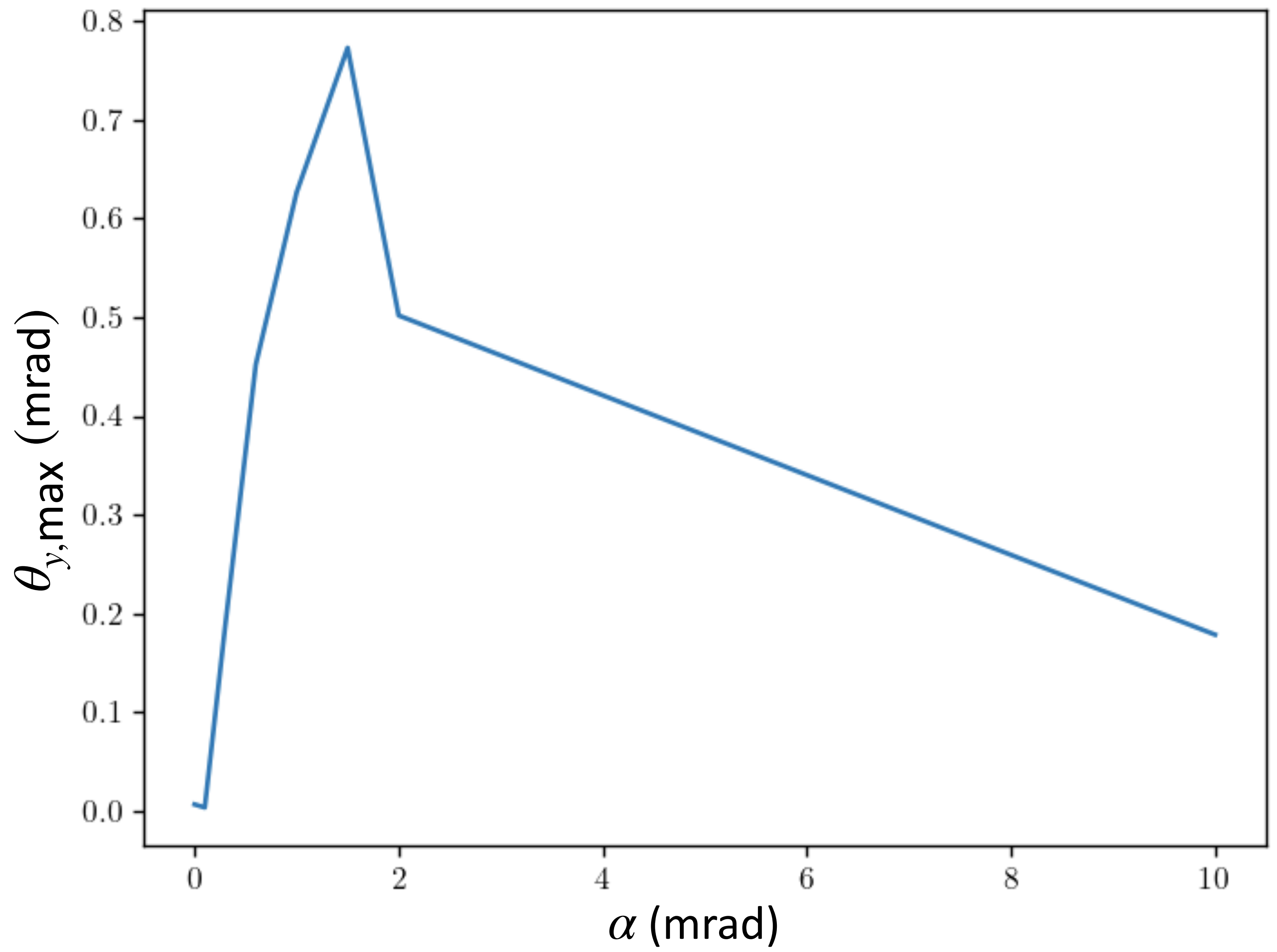
- 2D PIC simulation campaign for E336 - modelling tilted nanotargets



Alumina with 2000 nm nanotubes

Beam size and bunch length of 5 microns





- The beam is kicked when the nanotarget is tilted, providing a powerful mean to fine tune alignment and a straightforward signature of the beam-nanotarget interaction.
- The maximum kick of 0.75 mrad is reached for a tilt of 1.5 mrad.

E336 - Plans for FY23

- Plans for E336 experimental set-up:
  - Angular readback for the mount on every shot; design on-going with an alignment laser diode to be coupled in and out of the PB chamber
  - Invasive diagnostics for absolute angular alignment; uses green diode aligned to beam vector (beam off) and allows to tune for retro-reflection from the nanotarget
  - Both diagnostics were already reviewed in the E336 experimental safety review.

- Plans for E336 shifts:
  - Full 2D angular scan of the sample using the tip/tilt picomotors, looking for beam kicks.
  - Characterize beam-nanotarget interaction once angular alignment is achieved, compare to amorphous material.

Facility upgrades

<u>Desired facility upgrades:</u>

E336 benefits from the highest bunch densities and smallest emittances.

- The charge per tube goes as Q/σ_r^2 (areal charge density), and the scale of the transverse force acting on beam particles goes as $n_b d$ (with d the nanotube diameter).

- The emittance acts against beam transverse modulation, with an effective force in the envelope equation going as ϵ_n^2/d^3 which must be small compared to the force from the nanotube plasma response.

Example: for $d = 0.3\ \mu m$ *and* $10\ \mu m$ *beam size, 50 kA and 5 mm.mrad works, 20 kA and 20 mm.mrad doesn't.*

Collaboration and publications

Collaboration and institutions:

- IP Paris/LOA: Sébastien Corde, Max Gilljohann, Yuliia Mankovska, Pablo San Miguel Claveria, and Alexander Knetsch
- UC Irvine: Peter Taborek and Toshiki Tajima
- Fermilab: Henryk Piekarz and Vladimir Shiltsev
- SLAC: Robert Ariniello, Henrik Ekerfelt, Mark Hogan, and Doug Storey
- CEA: Xavier Davoine and Laurent Gremillet
- IST: Bertrand Martinez
- INFN: Alexei Sytov and Laura Bandiera

Publications and conferences:

White paper for Snowmass
in AF6 Advanced Accelerator Concepts
arXiv:2203.07459

Channeling Acceleration in Crystals and Nanostructures and Studies of Solid Plasmas: New Opportunities

Robert Ariniello[1], Sebastien Corde[2], Xavier Davoine[3], Henrik Ekerfelt[4], Frederico Fiuza[4], Max Gilljohann[2], Laurent Gremillet[3], Yuliia Mankovska[2], Henryk Piekarz[5], Pablo San Miguel Claveria[2], Vladimir Shiltsev[5], Peter Taborek[6], and Toshiki Tajima[6]

E336 abstracts submitted to AAC'22 (BNL, Nov 6-11, 2022):
by Robert Ariniello (exp) to WG4 and by Alexander Knetsch (th/sim) to WG2

Thank you for your attention