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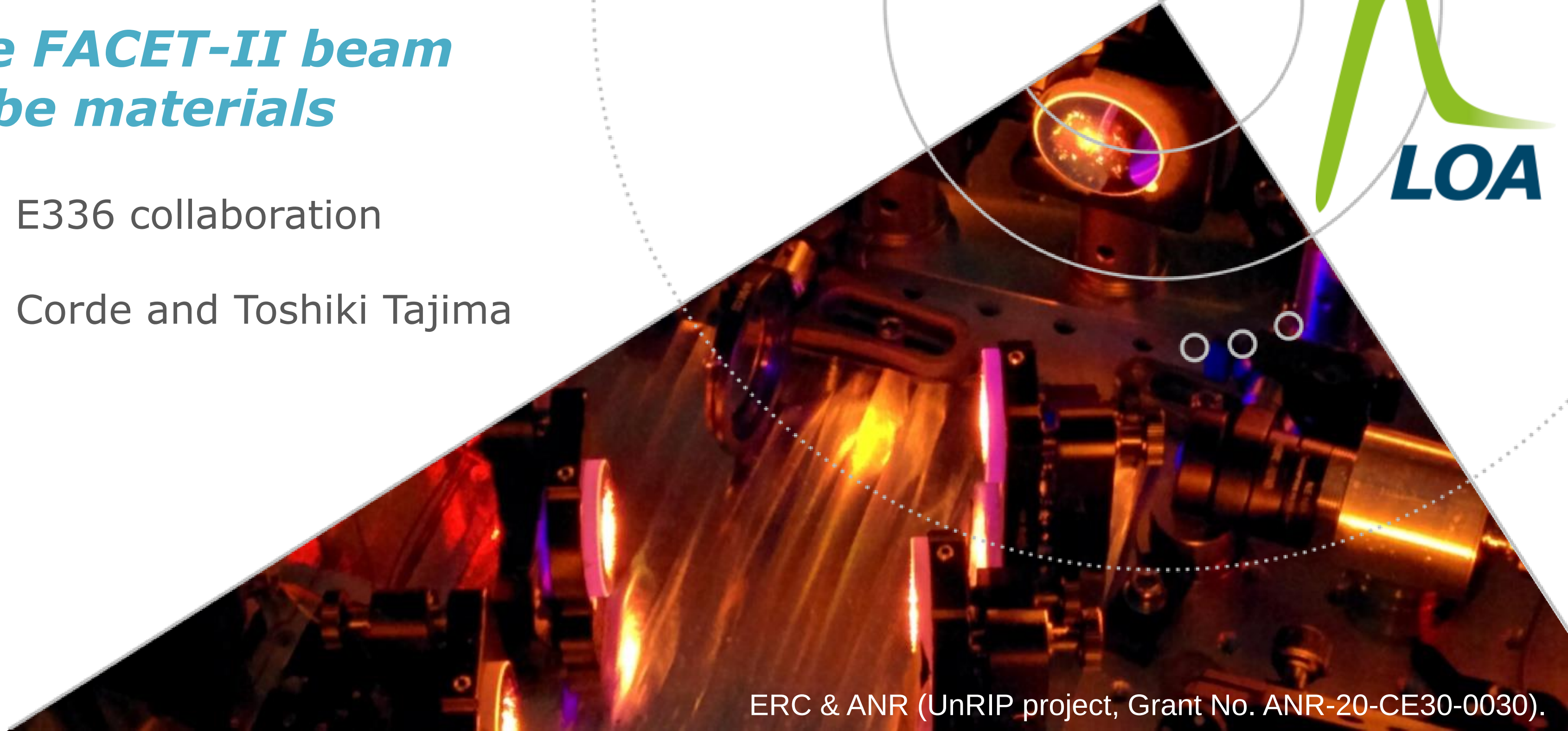
E-336 Progress and Plans for FY24

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

Max F. Gilljohann on behalf of the E336 collaboration

Principal Investigators: Sébastien Corde and Toshiki Tajima

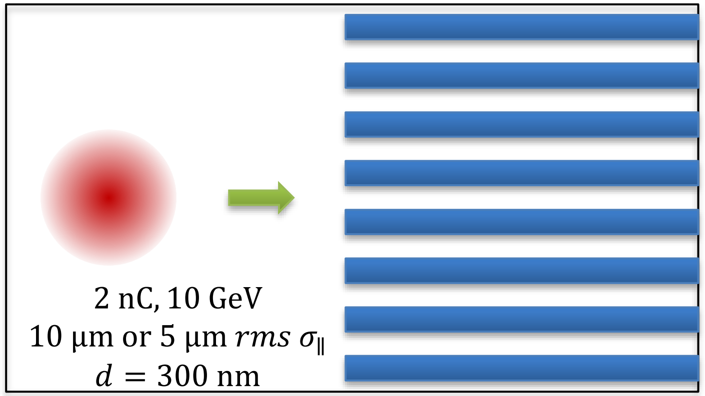


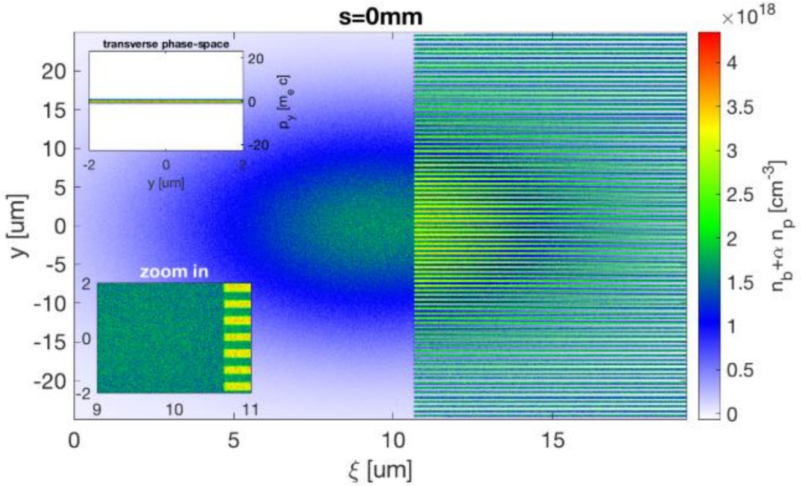
LOA

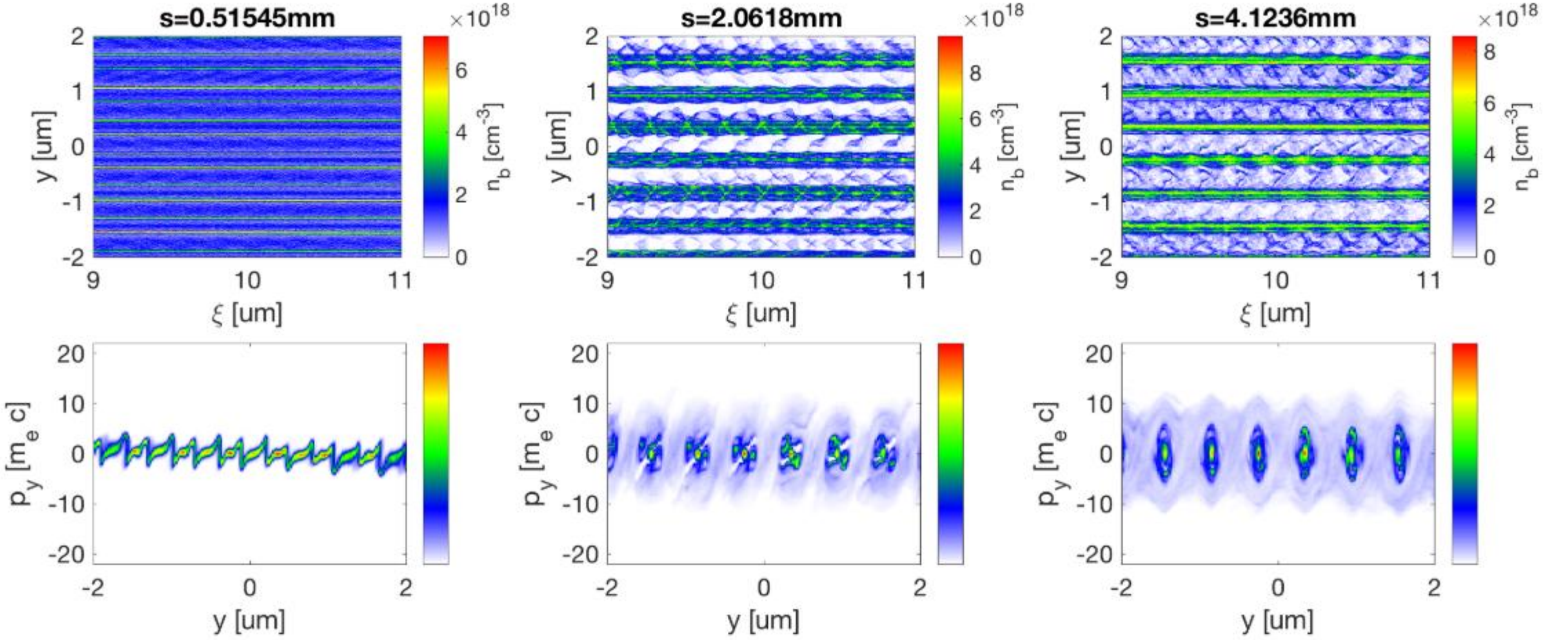
loa.ensta-paris.fr

ERC & ANR (UnRIP project, Grant No. ANR-20-CE30-0030).

E336 – Beam-Nanotarget Interaction







E336 – Science Goals and Definition of Success

Scientific goals

- Proof-of-principle experiment – demonstrate feasibility of studying beam-nanotarget interaction and beam-induced wakefields in nanotargets.
- Observation of electron beam nano-modulation.
- Observation of betatron X-ray radiation.
- Confirmation of simulation models.

Definition of success

- Clearly distinguishable interaction with nanotarget and amorphous targets. (1.5 year)
- Systematic parametric studies with various target and beam parameters.
- Coherence with numerical and analytical models to support the interpretation and understanding of the interaction (beam nano-modulation etc.). (3 year)

E336 – Experimental Timeline

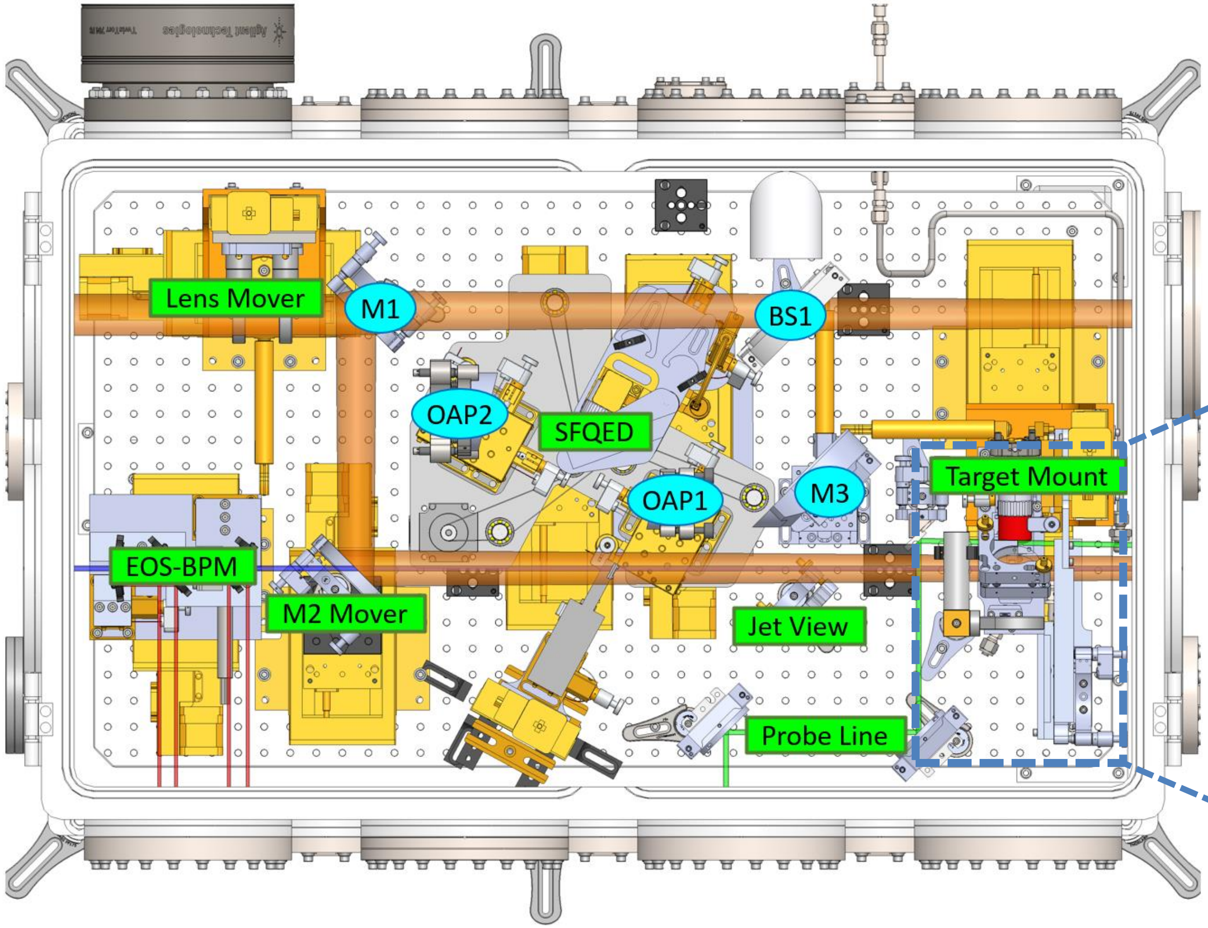
Current state

- Experimental safety review carried out.
- “Nanotargets” installed and beam damage tested.
- Alignment control installed, alignment diagnostic almost ready.

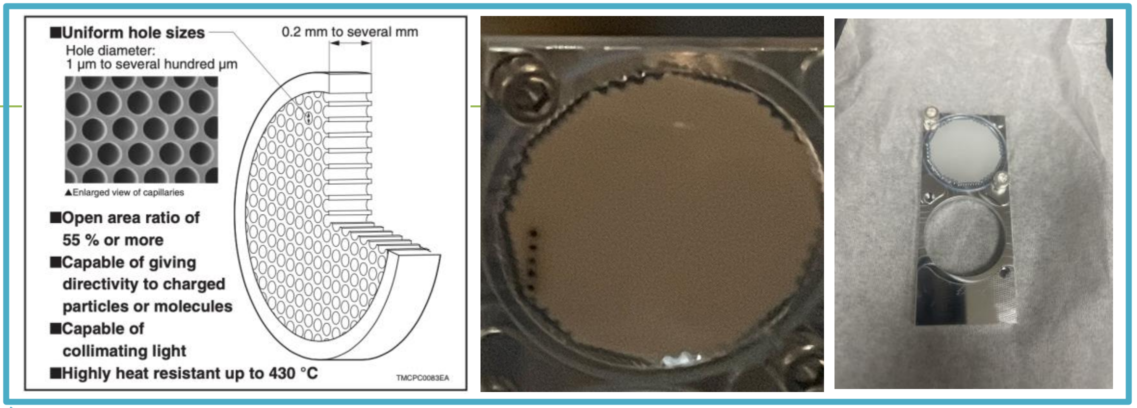
Next steps

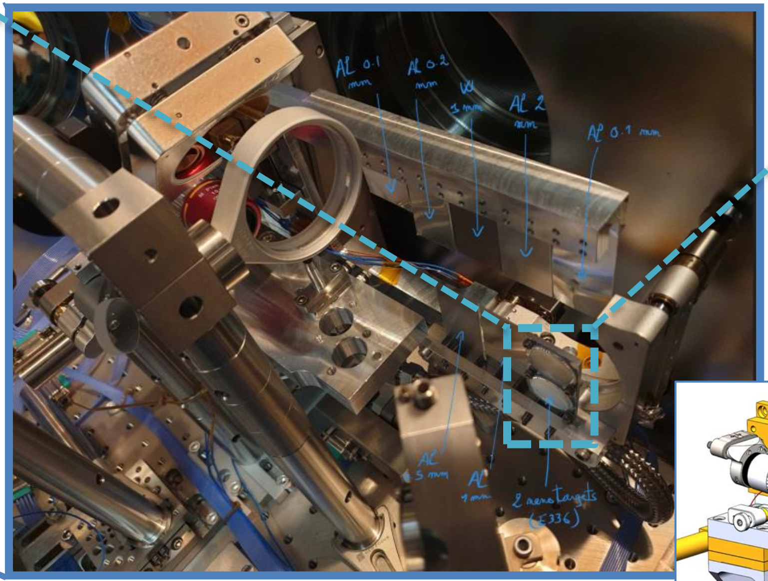
Phase 1 – FY24-25	• Relative angular alignment diagnostic (on-line). • Absolute angular alignment diagnostic (invasive). • First signature of beam-nanotarget interaction.
Phase 2 – FY25-26	• Improve/upgrade experimental hardware and targets. • Advanced characterization of beam-nanotarget interaction with full set of sample and FACET-II beam parameters.
Phase 3 (conditional)	• Going from transverse wakefields and beam dynamics to longitudinal wakefields.

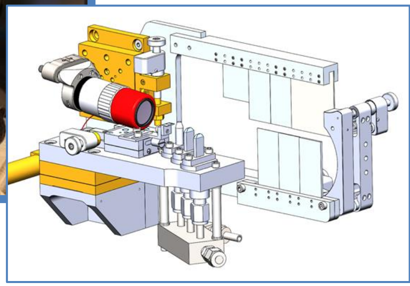
E336 – Experimental layout



Ø6 μm hollow tubes in a glass substrate

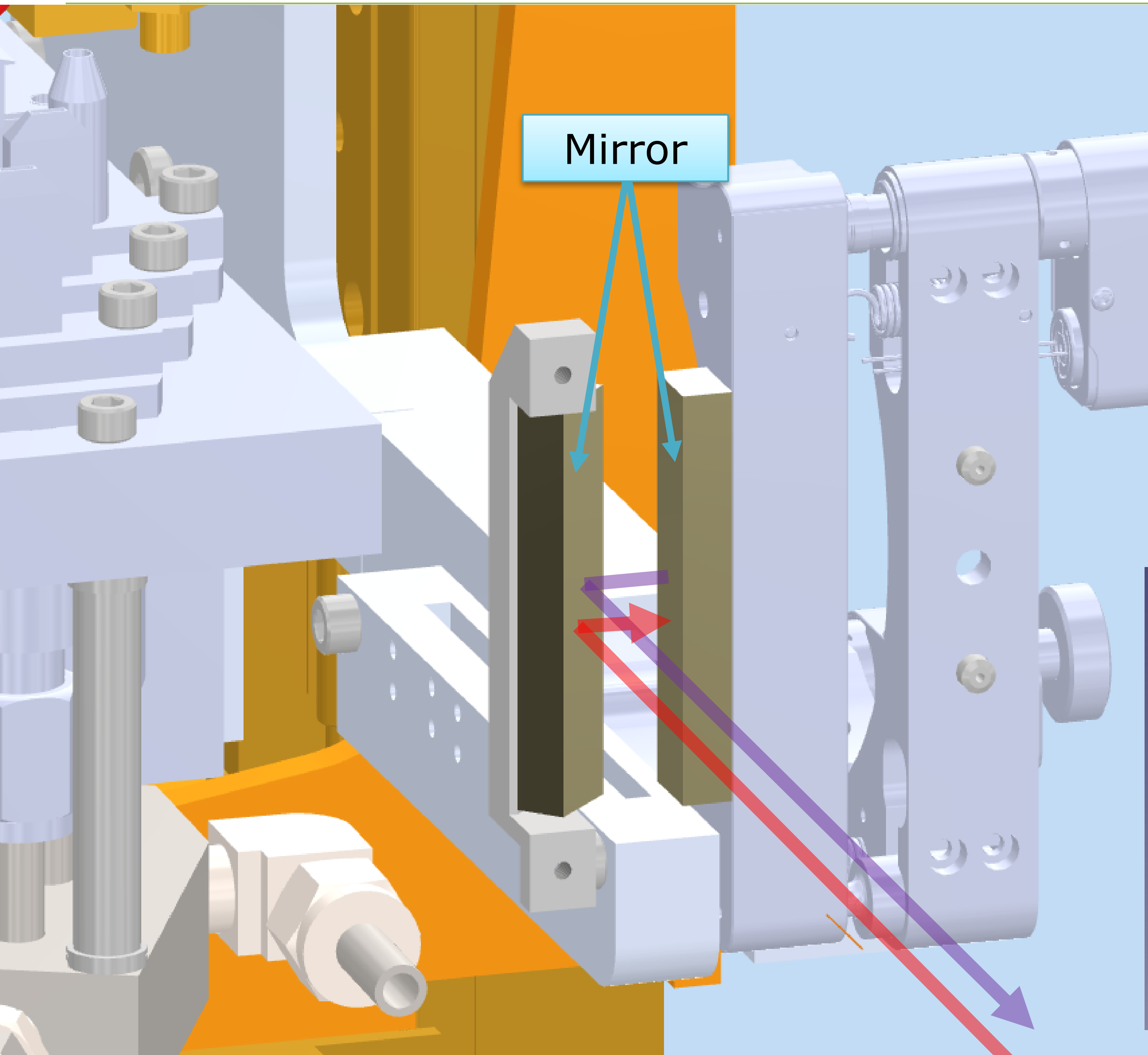


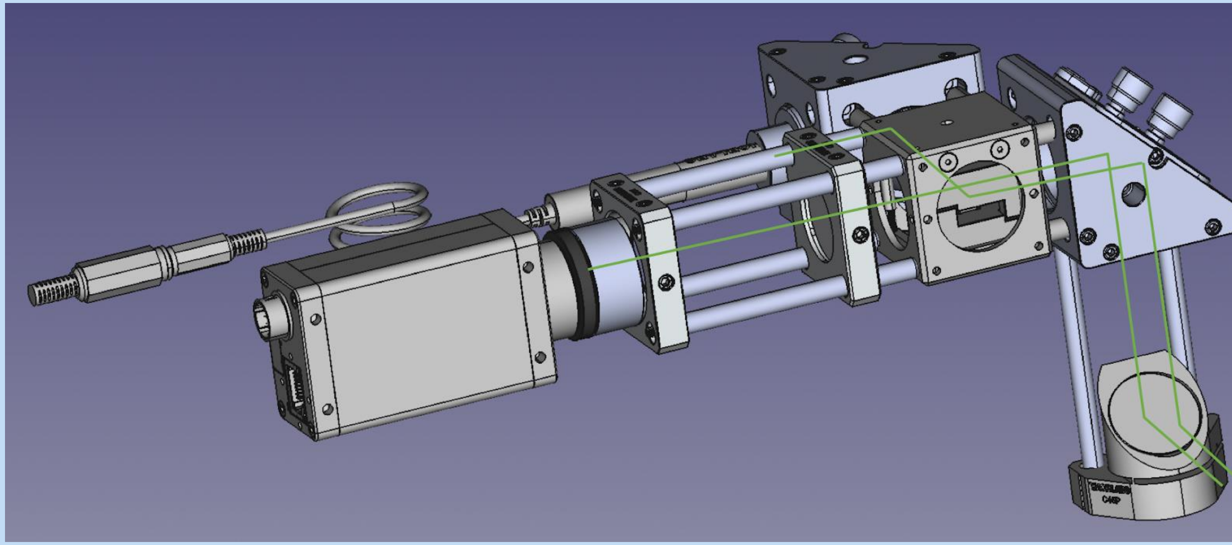




Target mount with 1 μrad tip/tilt resolution

E336 – Relative Alignment Diagnostic





E336 – Observables and Diagnostics

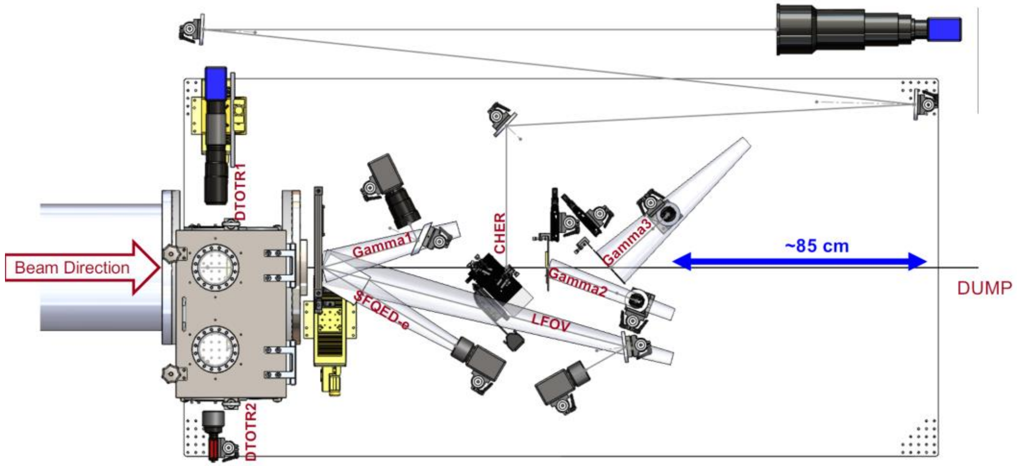
Main observables

- Growth of transverse momentum spread
- Beam deflection (for tilted targets)
- X-rays and γ-rays

Beam Diagnostics

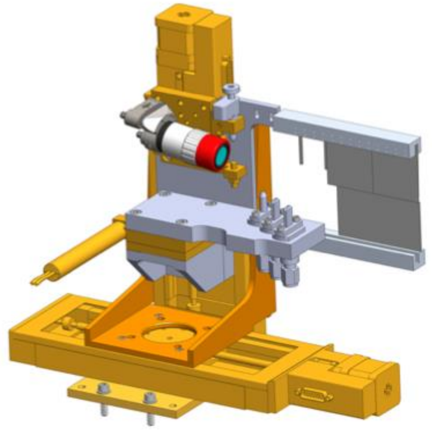
- Electrons
  - High-resolution in-vacuum OTR at the dump table (DTOTR)

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

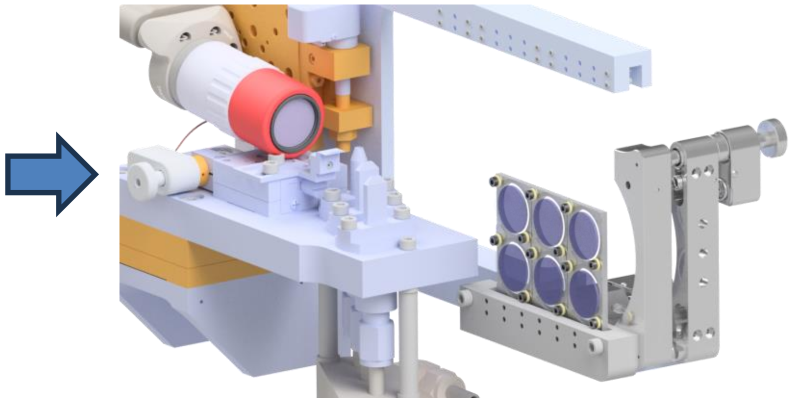


E336 – FY22-FY23 Progress

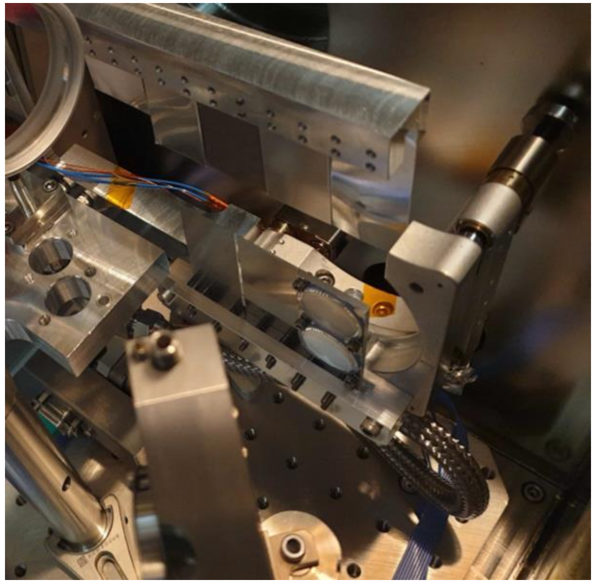
Mounting of angular control for nanotarget

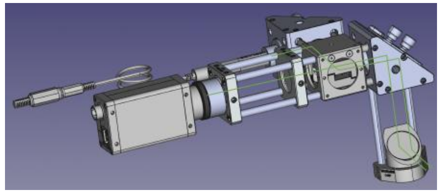


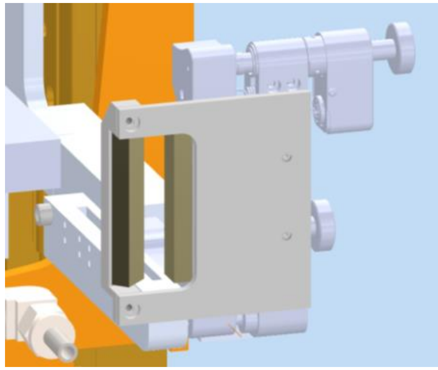
Target assembly before modification



Kinematic mount with E336 samples added to bottom solid target mount





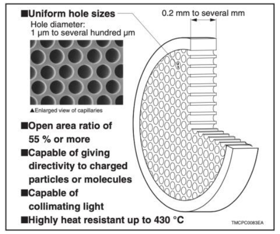


- Modified E305 target mount in the least invasive way to other experiments.
- Angular control using tip/tilt kinematic mount with pico motors.
- This fulfils E336 requirements (according to PAC).
  - Angle: $< 20\ \mu rad$ presicion and $\sim 2\ deg$ range
  - Translation: $10\ \mu m$ to $100\ \mu m$ precision and $5\ cm$ range
- Design of angular diagnostic (almost ready for integration).

E336 – FY22-FY23 Progress

Beam-induced target damage tests

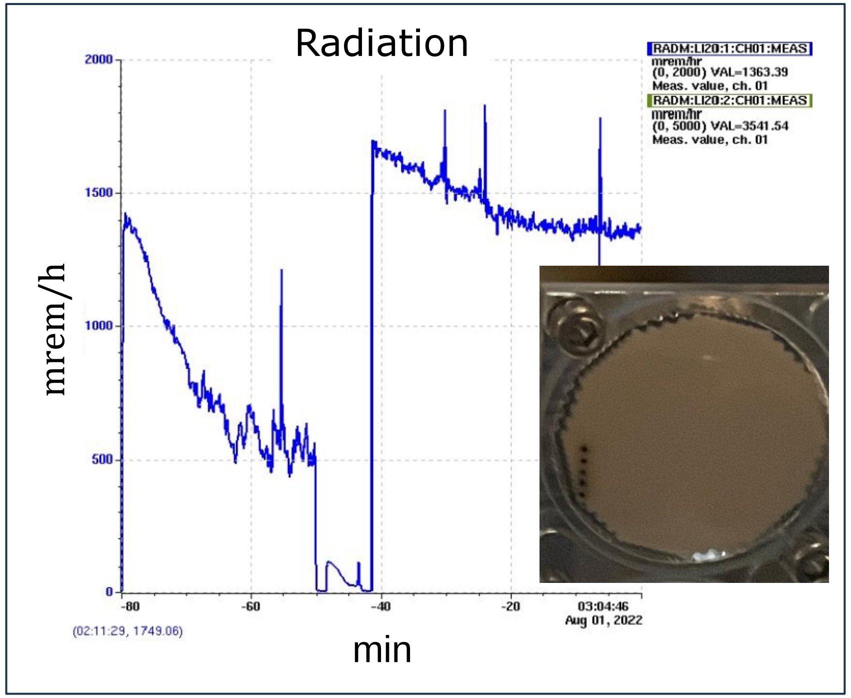
- Sample installed: $1\ mm$ thickness lead glass with $6\ \mu m$ diameter hollow tubes.



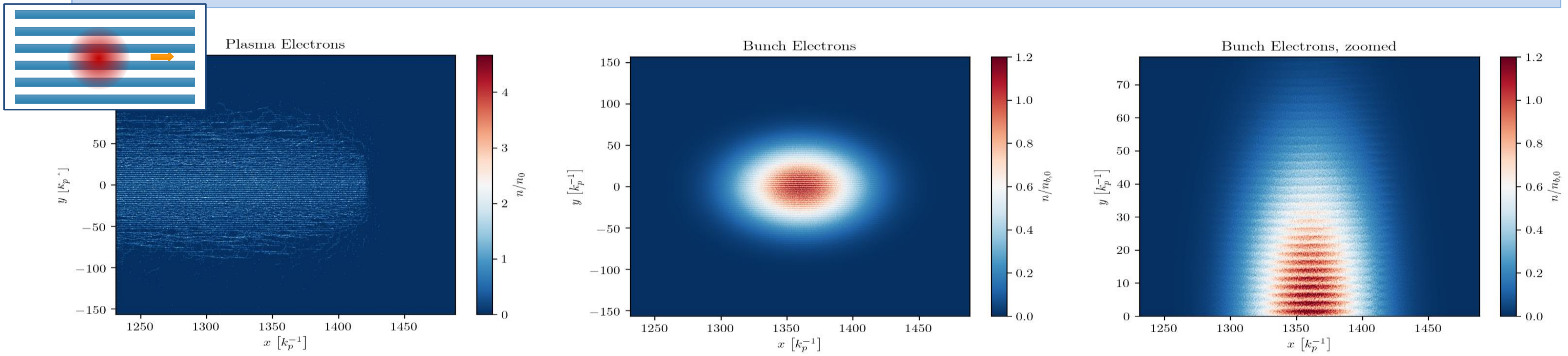
- 2 hours of E336 beamtime on 08/01/22 to send beam into nanotargets and assess the damage.

- 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 @ $10\ Hz$
  - Al $1\ mm$: 50% decrease in 15 min @ $10\ Hz$
    (decrease in radiation)



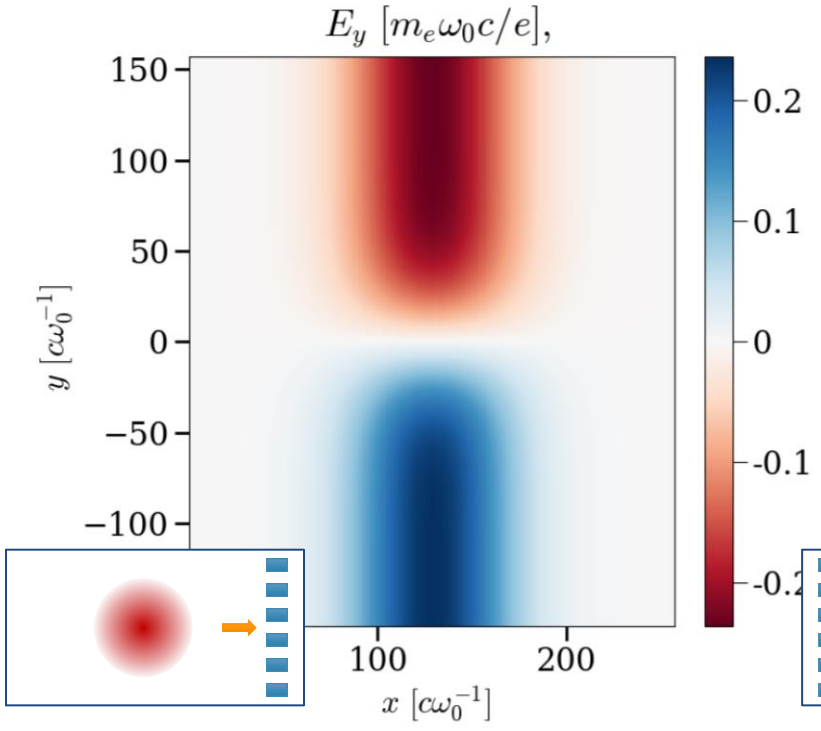
2D PIC simulation campaign – Modelling beam ionization of non-conducting material



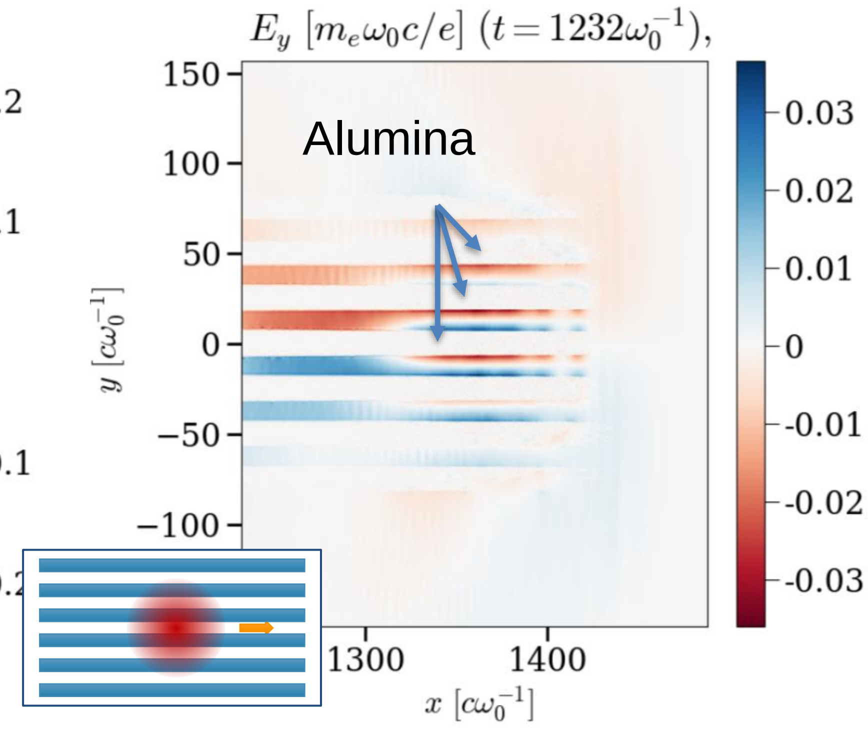
Silica with $\emptyset = 200$ nm hollow tubes and $\sigma_r = \sigma_\parallel = 5$ µm bunch size.

- Beam self-fields are strong enough to ionize.
- Partially ionized plasma can screen beam self-fields and suppress further ionization.
- Ionization is strong enough to enable the nanotube-plasma-response that is responsible for the transverse beam-dynamics and nano-modulation.
- Nano-modulation is similar in the case of fully pre-ionized target.

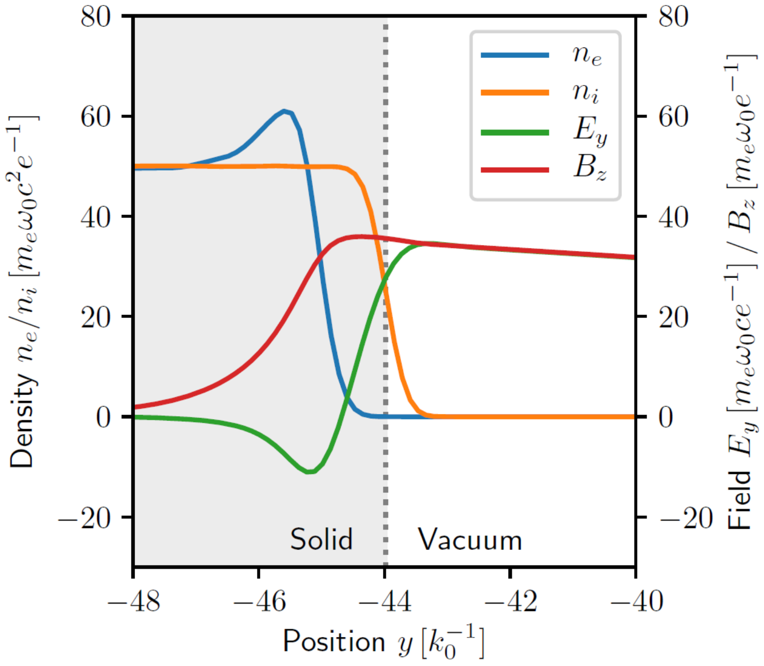
2D PIC simulation campaign – Beam-surface interaction



Beam before entering target

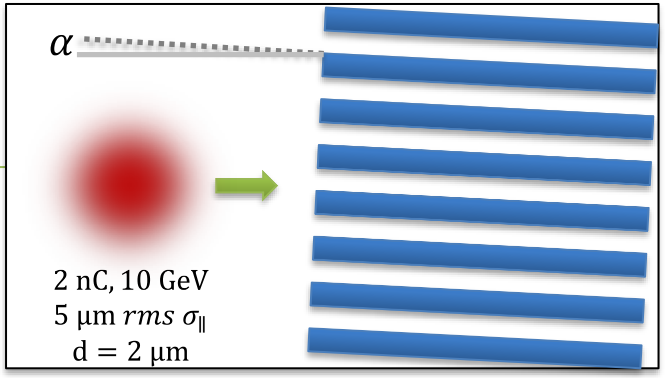


Beam in target

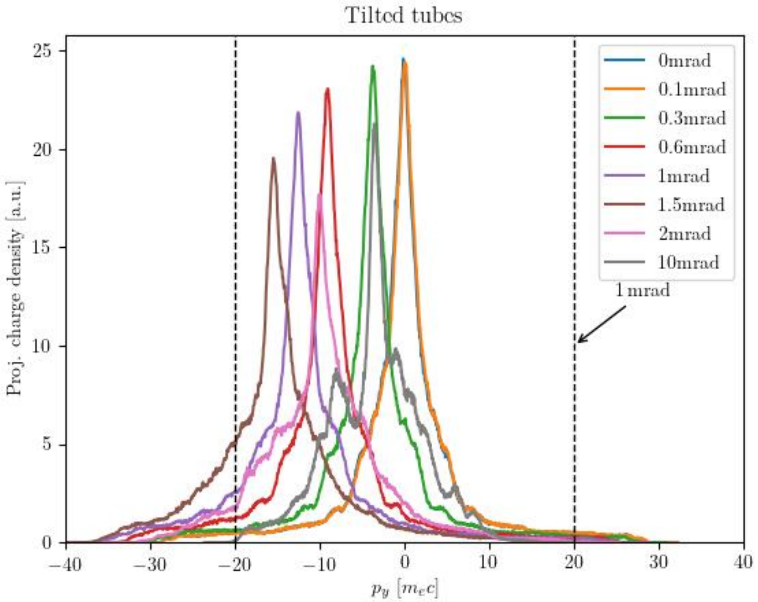


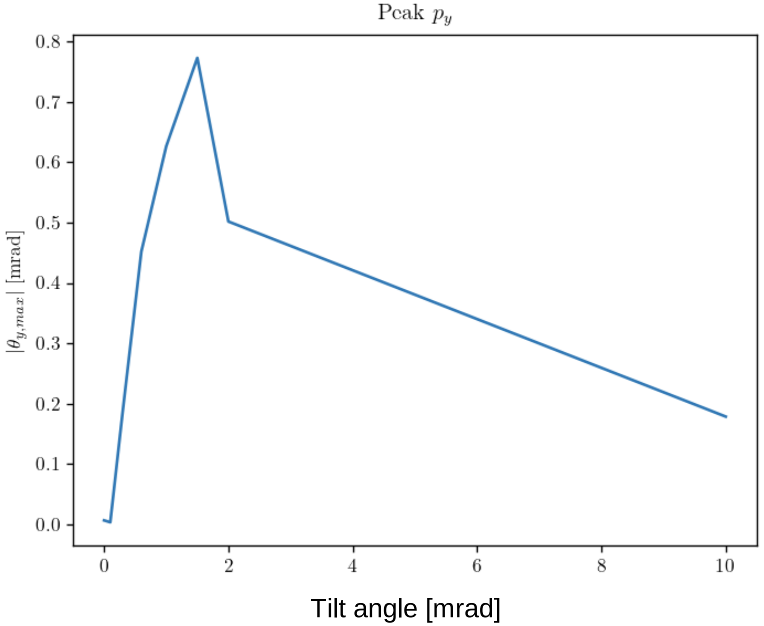
Transverse lineout of E and B fields

- Electric fields of beam electrons are shielded by the surface plasma.
- Magnetic fields penetrate further into the solid than electric fields.
- Beam electrons in this gap are accelerated towards the tube center.



2D PIC simulation campaign – Beam steering with tilted target



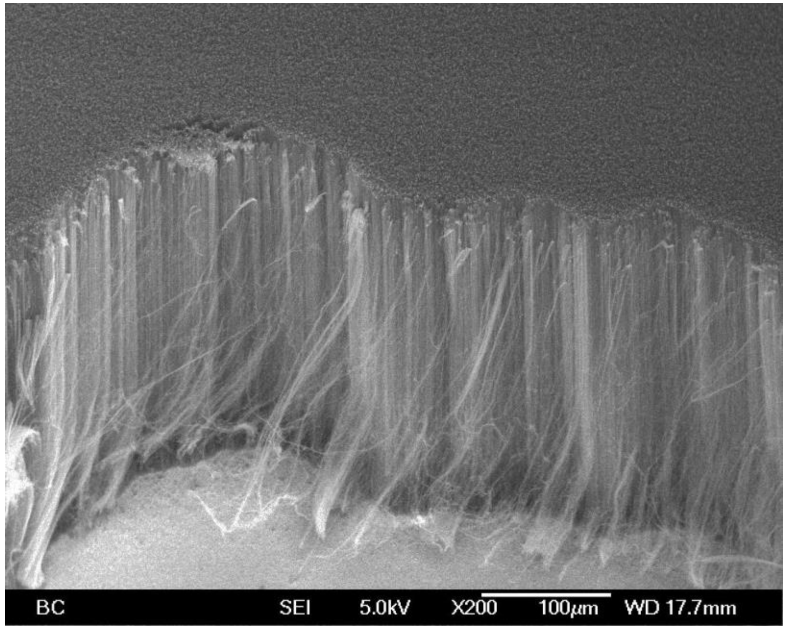


- Beam is deflected when the nanotarget is tilted.
  - Powerful mean to fine-tune the alignment.
  - Straightforward signature of the beam-nanotarget interaction.
- With $\emptyset = 2\ \mu m$ tubes ($\emptyset = 6\ \mu m$ installed), maximum deflection of $0.75\ mrad$ is reached for a tilt of $1.5\ mrad$.

E336 – Target development

Carbon nanotube targets

- Gianluca Cavoto and Ilaria Rago (INFN) joined collaboration.
- Up to $100's$ of micrometer length possible.
- Currently working out sets of parameters that are technically achievable and suitable for E336.



Example from nano-lab.com

E336 – Plans for FY24

Plans for E336 experimental setup

- Comissioning of angular target alignment and relative on-line diagnostic.
- Invasive diagnostic for absolute angular alignment; uses greene (that is aligned to beam axis) to tune the retro-reflection from the nanotarget.
- Both diagnostics were reviewed in the E336 experimental safety review.

Plans for E336 shifts

- Full 2D angular scan of the nanotarget, looking for beam kicks.

- Characterize beam-nanotarget interaction once angular alignment is achieved. Compare to amorphous material.

Desired facility upgrades

- E336 benefits from highest bunch density and smallest emittances.
  - Charge per tube scales with Q/σ_r^2 (areal charge density), and the scale fo the transverse force acting on beam particles goes as $n_b d$ (with the nanotube diameter d).
  - 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 $d = 0.3\ \mu\mathrm{m}$ and $10\ \mu\mathrm{m}$ beam size, $50\ \mathrm{kA}$ and $5\ \mathrm{mm\ mrad}$ works, $20\ \mathrm{kA}$ and $20\ \mathrm{mm\ mrad}$ doesn't.

E336 – Collaboration and Publications

Collaboration and institutions

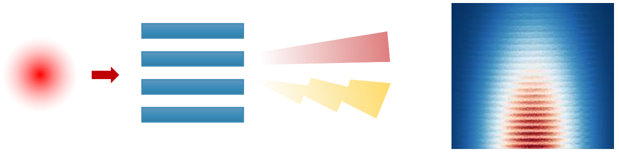
- IP Paris/LOA: Sébastien Corde, Max Gilljohann and Yuliia Mankovska
- UC Irvine: Peter Taborek and Toshiki Tajima
- Fermilab: Henryk Piekarz and Vladimir Shiltsev
- SLAC: Robert Ariniello, Mark Hogan, Alexander Knetsch and Doug Storey
- CEA: Xavier Davoine and Laurent Gremillet
- IST: Bertrand Martinez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

Publications and conferences

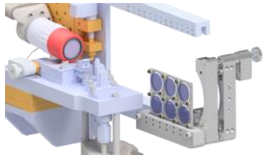
- White paper for Snowmass in AF6 Advanced Accelerator Concepts (arXiv:2203.07459)
- JINST Snowmass paper (close to publication)
- Simulation paper about transverse microbunching in preparation (MG and BM)

- Posters @ EAAC2023 (MG), LPAW 23 (MG), IPAC 2023 (AS), ICABU 2023 (AS, upcoming)
- Talks @ AAC'22 (AK and RA, each), Channeling 2023 (AS)

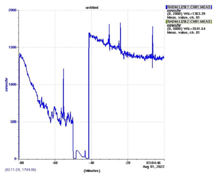
Goal: Studying beam-nanotarget interaction



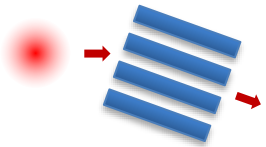
State: Target is installed, alignment diagnostic almost ready for installation



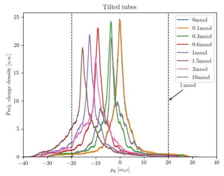
First tests: Beam-induced target damage

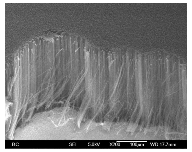


Simulation campaign: Explaining the physics & extracting experimental signatures



FY24 plans: Measuring signatures of beam-nanotarget interaction, commission angular alignment & diagnostic, and working on new targets





Supplementary

E336 – Radiation