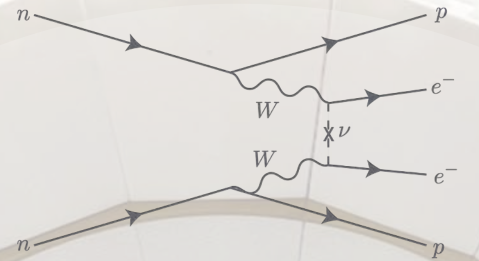

NEXT-100 Electroluminescent Grid Design

Krishan Mistry on behalf of the NEXT collaboration

14 February 2024

Nagoya Workshop on Technology and Instrumentation in Future Liquid Noble Gas Detectors

UTA

ADT
UTA Center for Advanced Detector Technologies

VRES
NEUTRINOS AND RARE EVENT SEARCHES

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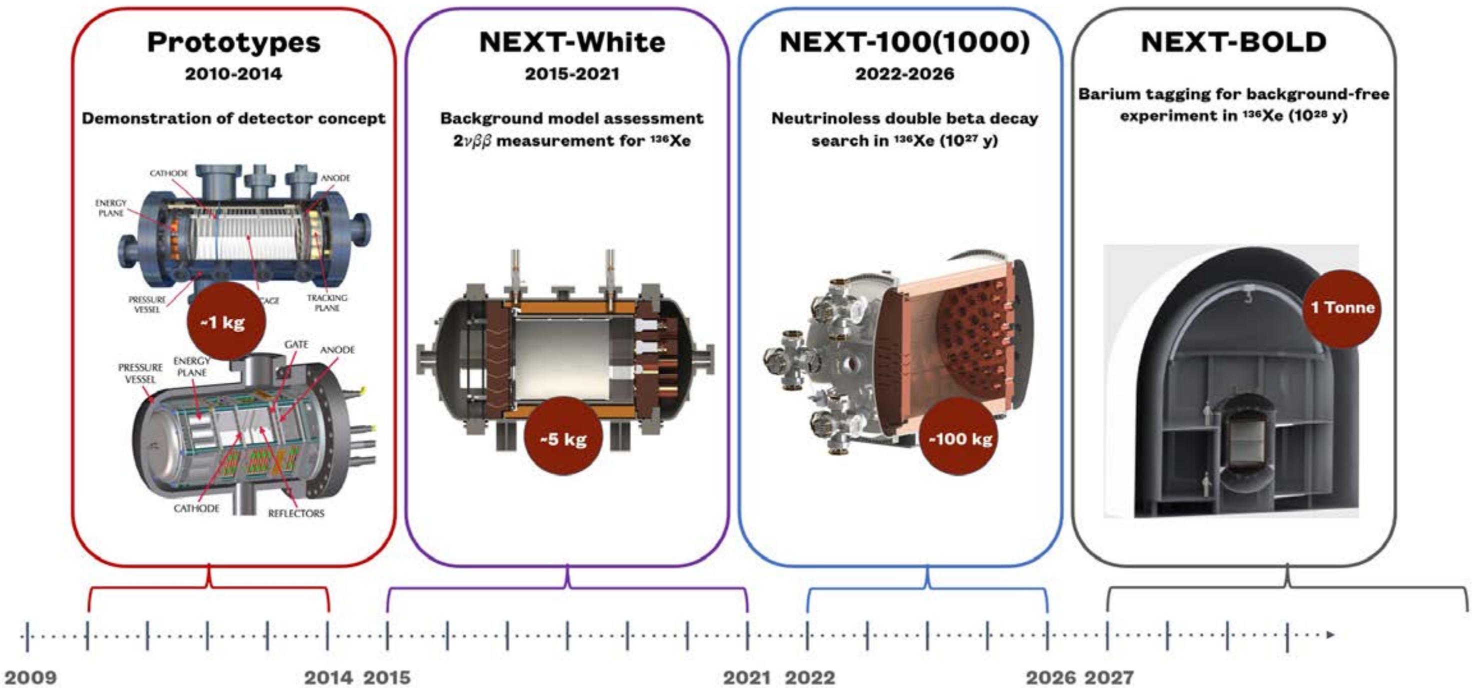
Neutrino Experiment with a Xenon TPC (NEXT)

$0\nu\beta\beta$ experiment with a high-pressure gaseous TPC using
$^{136}Xe \rightarrow {}^{136}Ba^{2+} + 2e^-$ (2.5 MeV)

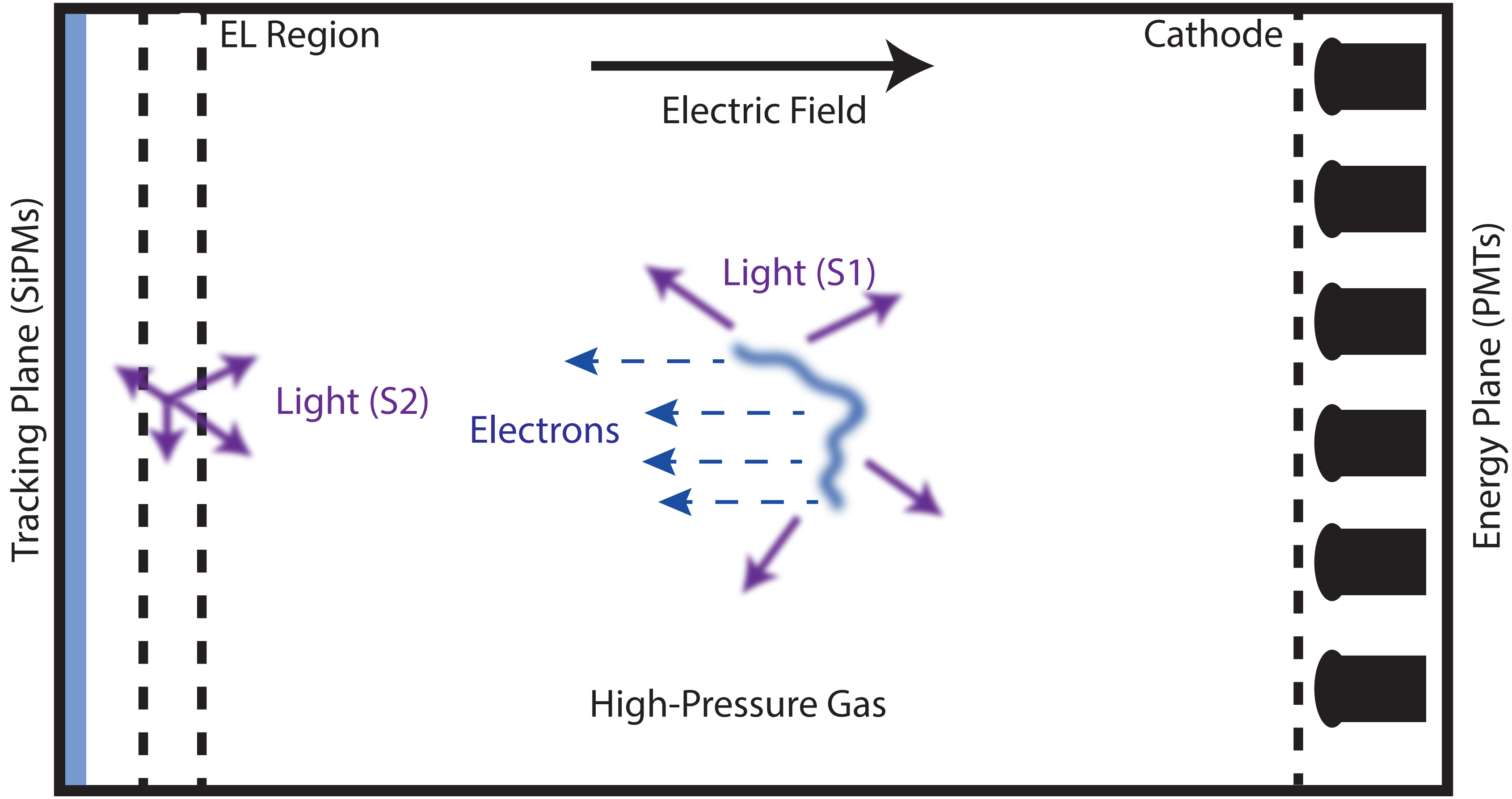
NEXT-100 is preparing for commissioning imminently

We are here!



The NEXT-100 detector concept

- High-pressure gas TPC with electroluminescent amplification
  - Sub-percent energy resolution
  - $0\nu\beta\beta$ tracks are about 20 cm long in 10 bar → Tracking!

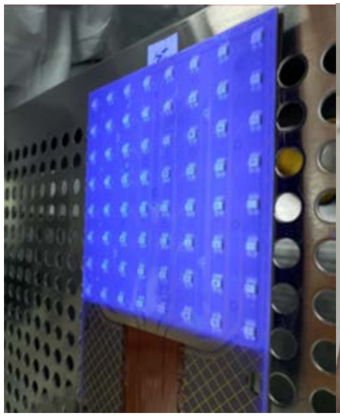


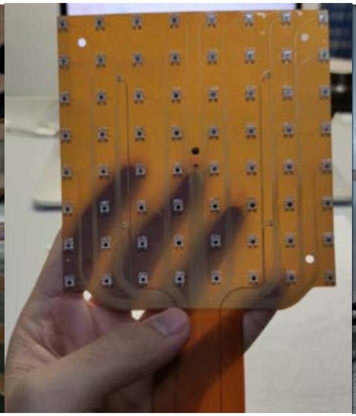
NEXT-100 Assembly

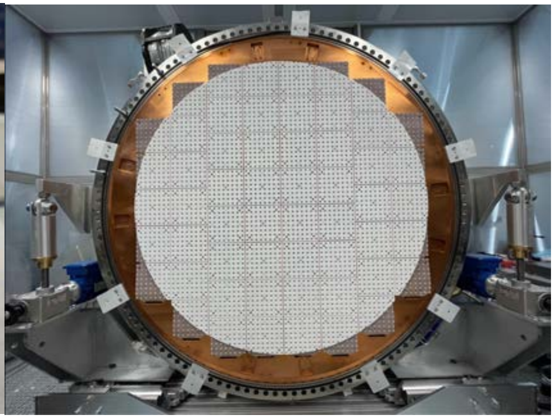
Stainless-steel pressure vessel + lead castle for shielding

PMT energy plane installation with sapphire pressure windows

SiPM tracking plane with Teflon masks

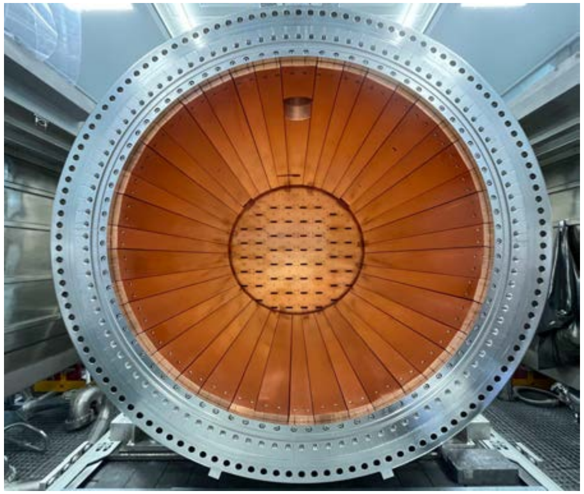






NEXT-100 Assembly

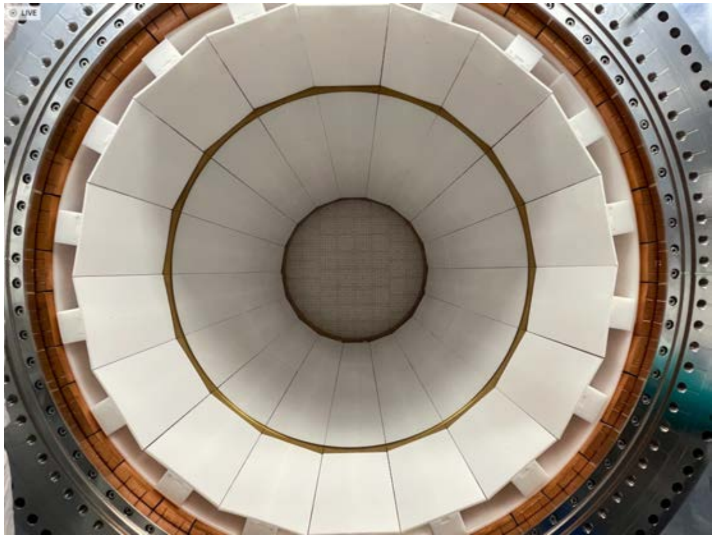
Inner copper shielding



Field cage assembled and inserted

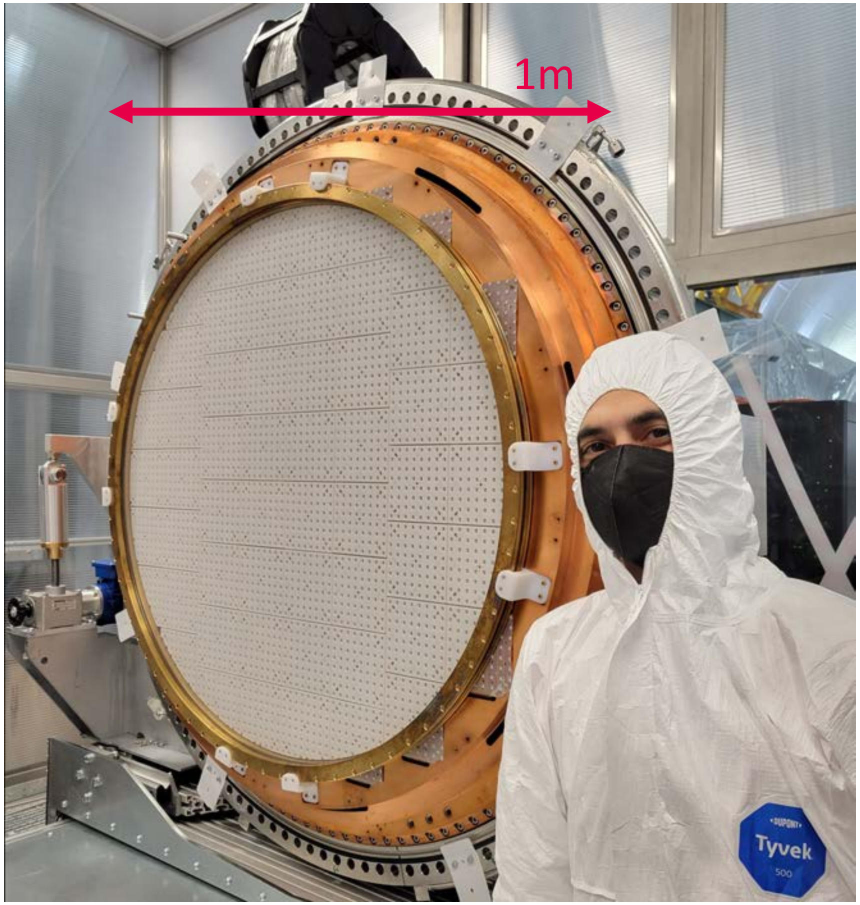
Field cage interior with transparent cathode

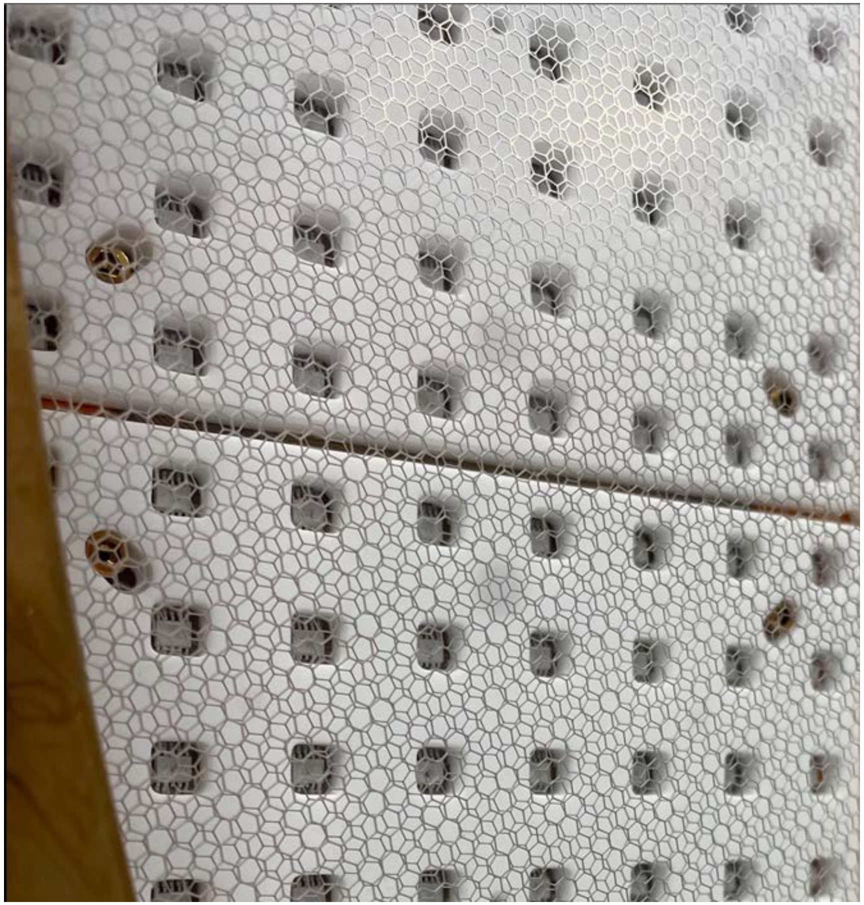
Teflon reflector panels with TPB



NEXT-100 Electroluminescent (EL) Region

Electroluminescent and cathode regions have now been installed
K. Mistry *et al* 2024 *JINST* **19** P02007





EL/Cathode region design requirements

- Specifications:
  - Energy resolution 1% or below
  - Radiopure
  - Support high electric fields for EL (tens of kV/cm)

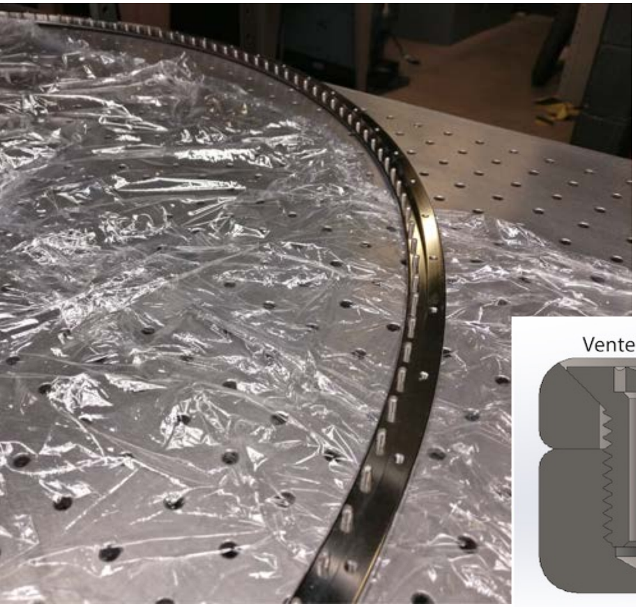
- Design considerations:
  - Mechanically tensioned to reduce electrostatic deflection
  - 1m diameter (amongst the largest sizes to date)
  - Transparent
  - Small grid separation distance, insulator suitable for separation
  - Uniform electric field

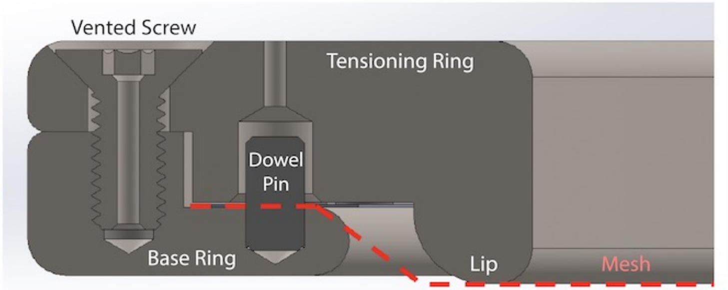
- The cathode can be tensioned less and include more transparency, electric field is lower

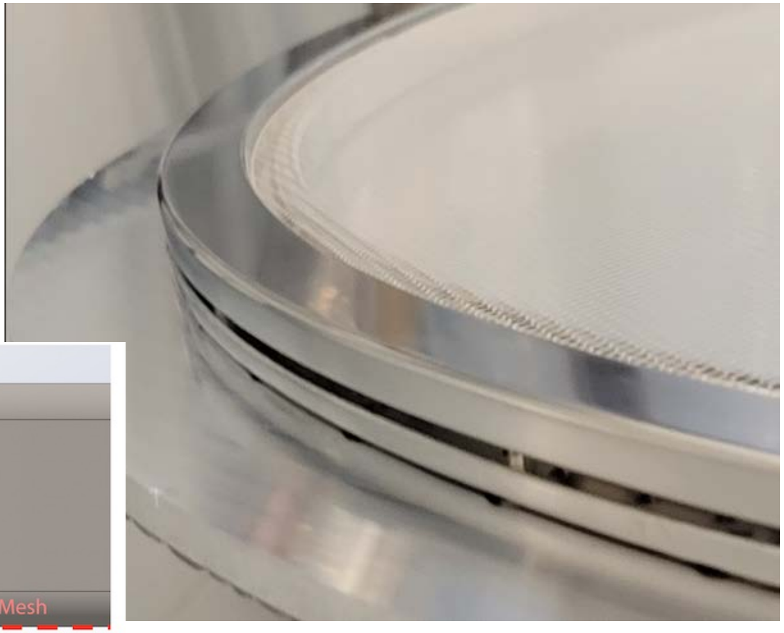
- EL GXe functionally similar to EL LXe TPC without the need to extract the electrons from liquid to gas phase

Frame design

- Mesh sandwiched between two metal frames
  - Hooked in via dowel pins
- A lip on one of the frames will pull the mesh as it is screwed down applying tension
- Use silicon bronze for the frames of NEXT-100
  - Stainless steel plates were not possible to source radiopure in the USA
- Expected tension force applied is 3.6 kN from the tensioning

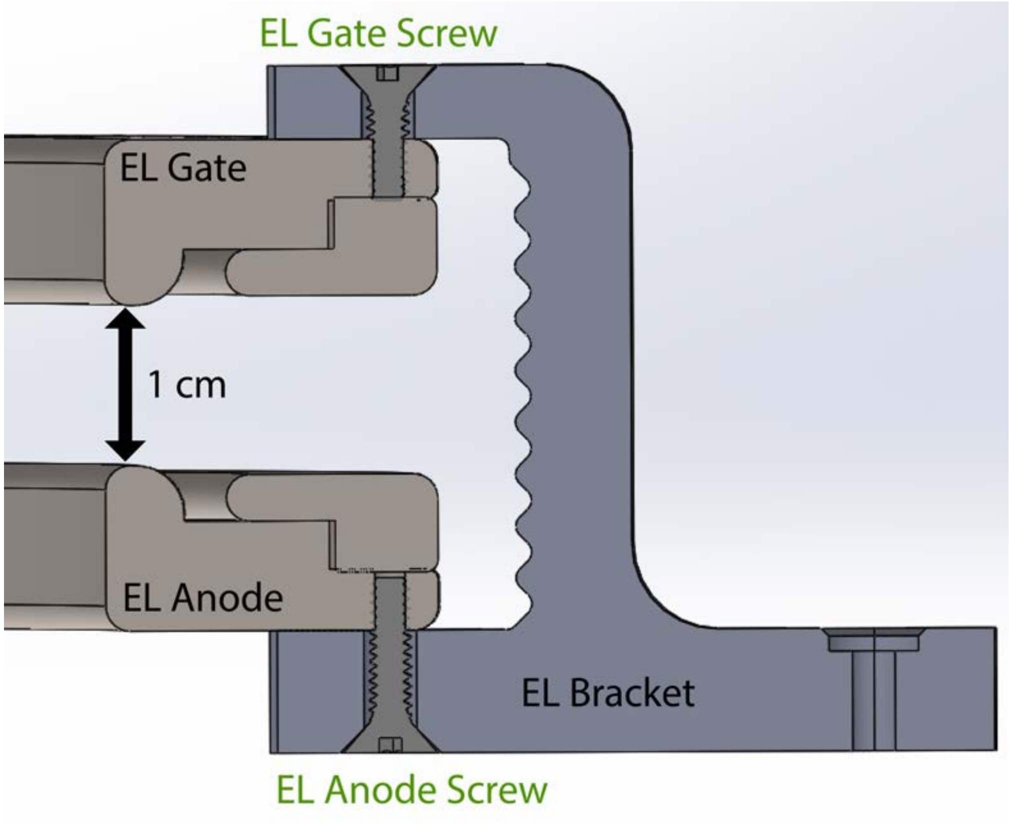






Bracket design

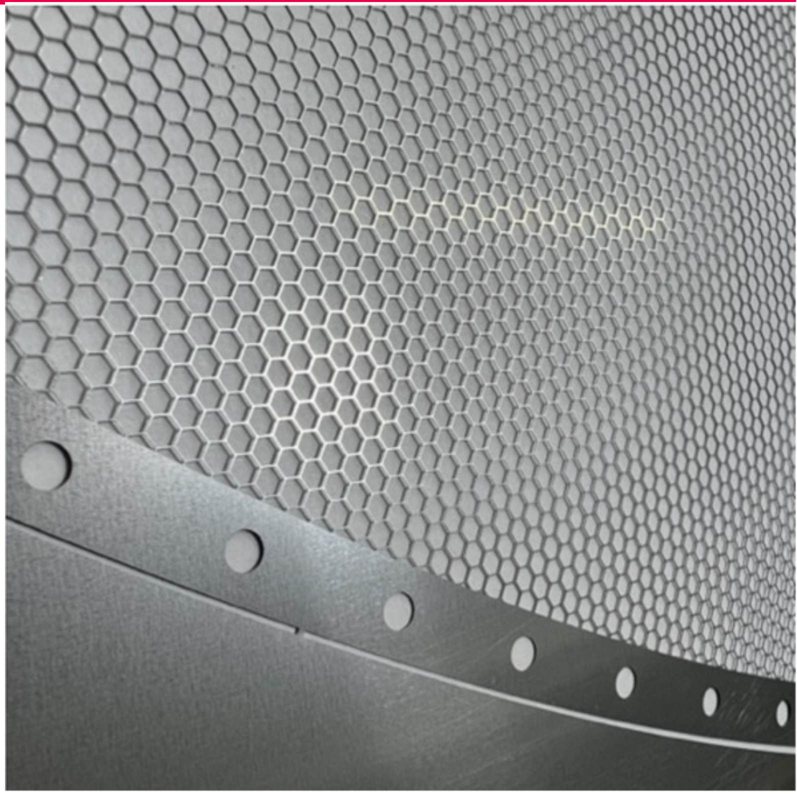
- 8 HDPE brackets with ridged surface
- Separates with a 1 cm gap distance
- U-Shape design prevents breakdown through the plastic



Photochemical Etched Meshes

- Our choice are photochemically etched stainless steel meshes with hexagonal pattern
  - 0.127 mm sheet thickness
  - 0.127 mm wire thickness
  - 2.5/5 mm hexagons (EL/cathode)

- Several benefits in this design:
  - Part can be manufactured in one go
  - Hexagons distribute force more evenly to minimise buckling into a saddle-shape
  - Can achieve tolerance required for mesh
  - Stainless steel provides strength needed to support tension
  - Robust against sparking
  - If hexagon does break, it does not lead to a loose wire that can short to other surfaces



90% transparency EL

95% transparency cathode

Manufacturing R&D

- The size of the mesh manufacture is challenging:
  - We explored using half-sized meshes and joining them
  - Meshes were too thin and were prone to melting using various welding techniques
  - Spot welding left an uneven tension
  - Silver-based solder worked well, but failed over time

- PCM Products is the only manufacturer in the US that had the capability to etch 1 – 1.5 m wide parts

- Problems with buying the stainless-steel sheet at 0.127 mm thickness at ~1m diameter
  - Not a common size in the industry
  - Needed to buy whole coil! ~10k USD

Manufacturing R&D

- Several iterations were made with the manufacturer
  - We had to build a business relationship with this manufacturer since they are our only supplier
  - Our line of work is not that profitable for them so production times are long and expensive
- Prototypes started small and scaled up towards 40cm diameter meshes
  - NEXT-100 meshes at 1m diameter were tried next

Small-scale prototype

→

CRAB-0 at UTA

←

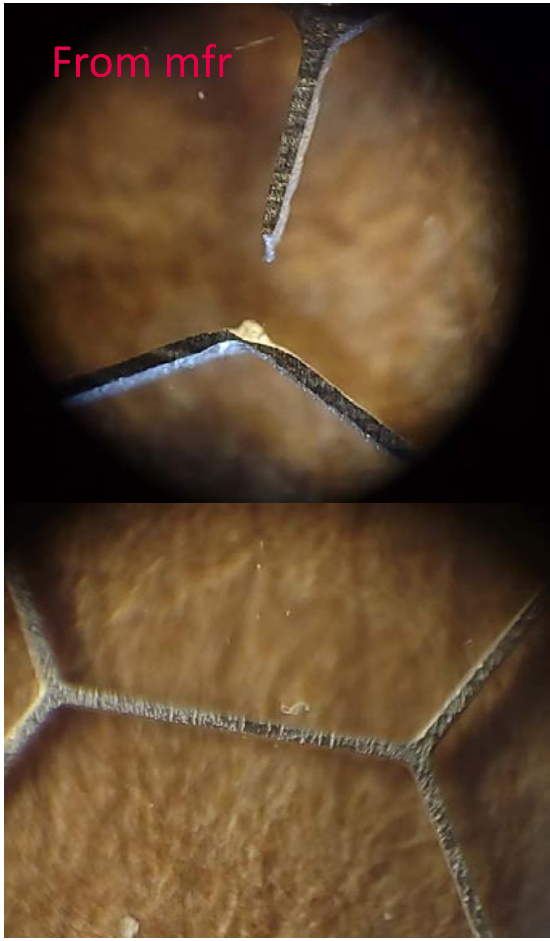
DEMO++ TPC (IFIC) ~ Ø 20cm

→

ANL TPC ~ Ø 40cm

Manufacturing R&D NEXT-100

- First manufacture of NEXT-100 meshes:
  - A handful of over-etched places in each mesh
  - Tensioning exacerbated the problem leading to more breaks
  - We need perfection though!



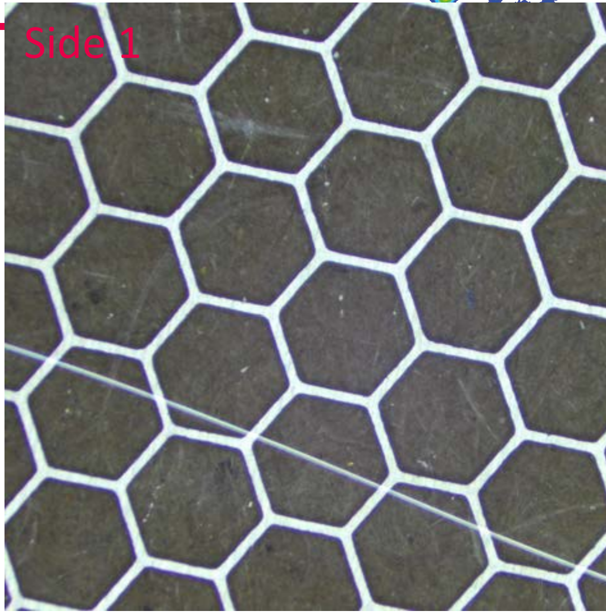
- They were made with an additional acid wash that they call post-etching that helps to remove sharp-points on the mesh
  - It seems that the uniformity of etching at this scale could not be controlled

- We have successfully made tensioned post-etched 40cm diameter meshes with them, just not at 1m scale

Manufacturing R&D NEXT-100

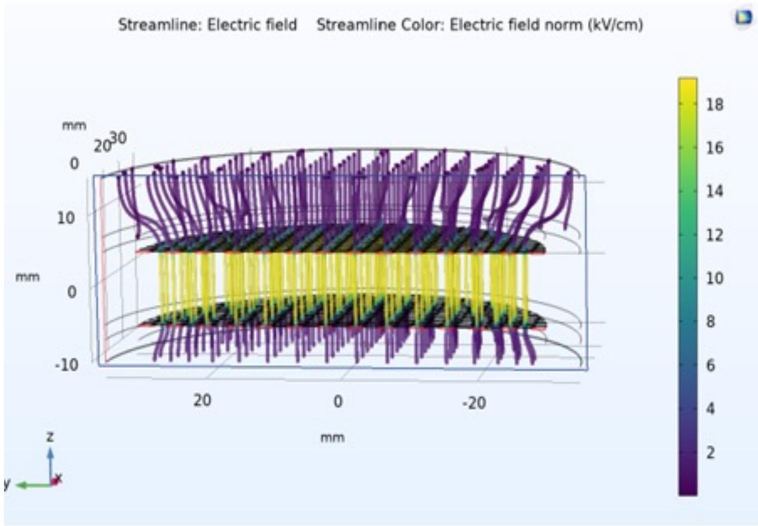
- Meshes installed in NEXT-100 were made without post-etching and the manufacturer used a thicker photoresist

- No breaks from manufacturer, but three on the anode mesh after tensioning
  - We found improvement with the voltage performance (by ~1-2 kV) when the mesh applied at high voltage without breaks
  - We also found that one side of the mesh appears better quality than the other side (maybe due to which side resting on the etching belt and vice versa)

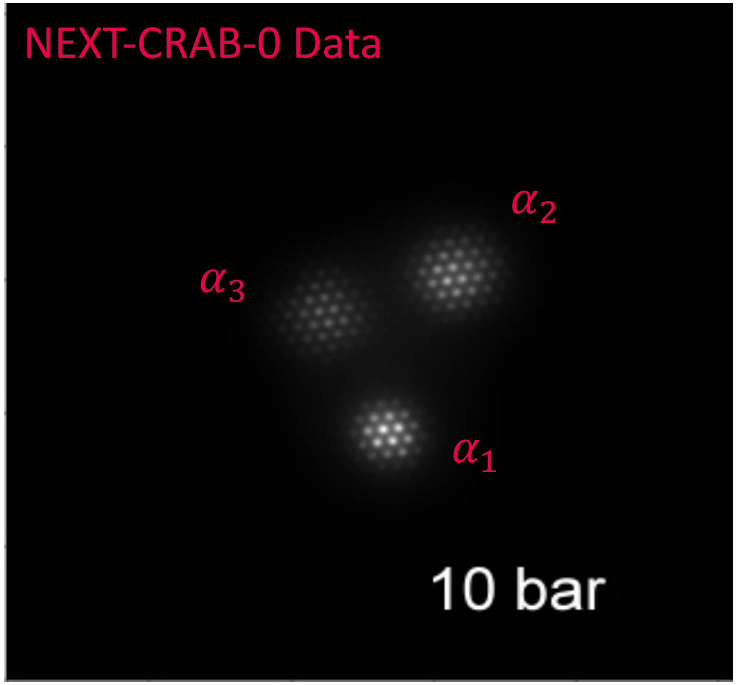


Deployment of meshes

- First deployment of photochemical etched meshes were used in NEXT-CRAB-0 Detector: N.K. Byrnes *et al* 2023 *JINST* **18** P08006



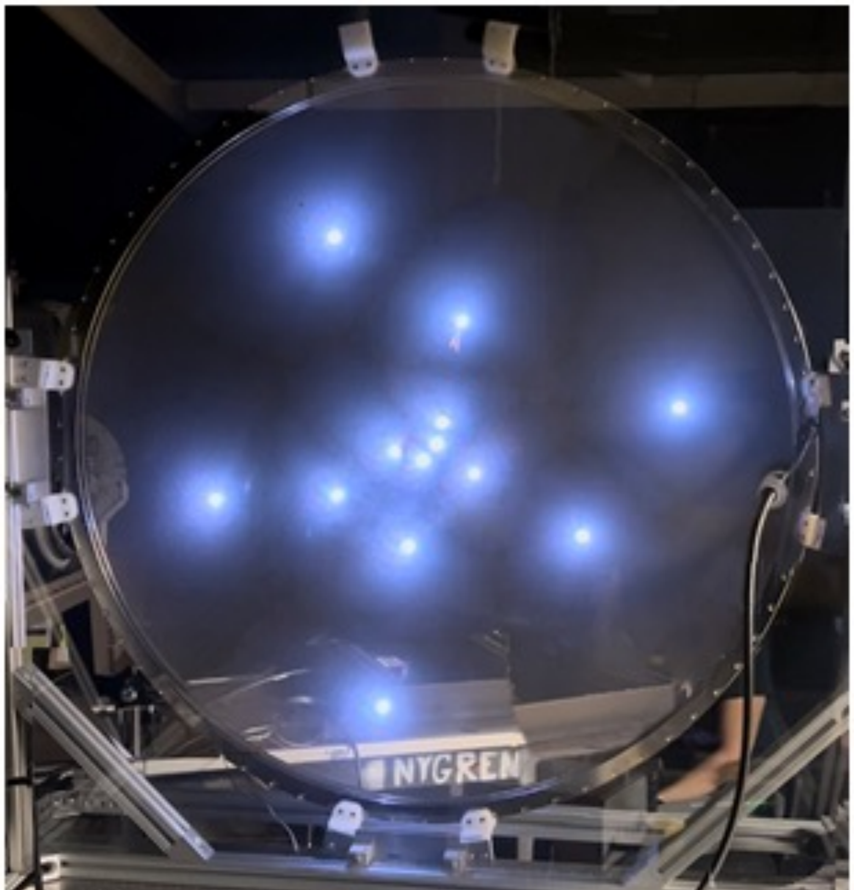
- We use an VUV image intensified cameras to image the EL from alpha particles
  - Stable operation at 14kV/cm at 10bar
  - Electrons funnelled into the hexagon centres due to following electric field lines from the drift
  - Negligible electron loss expected at the mesh boundary

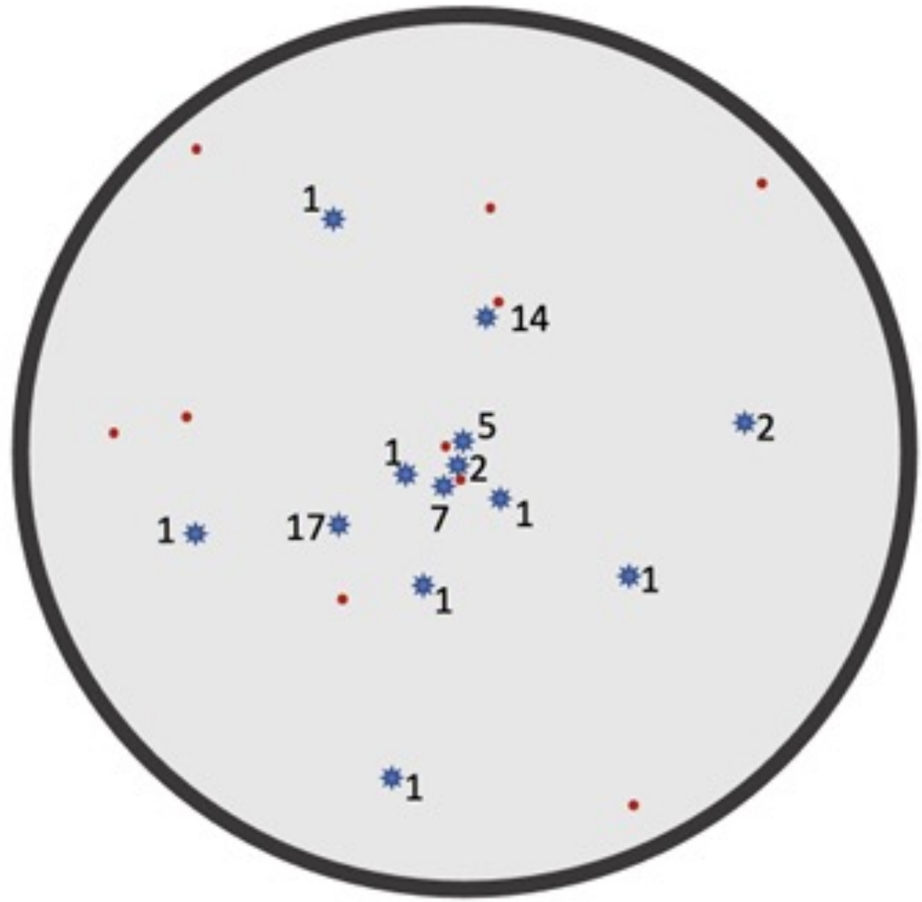


- Our next tests of the performance of the meshes will be with NEXT-100

Profiling of breakdown locations

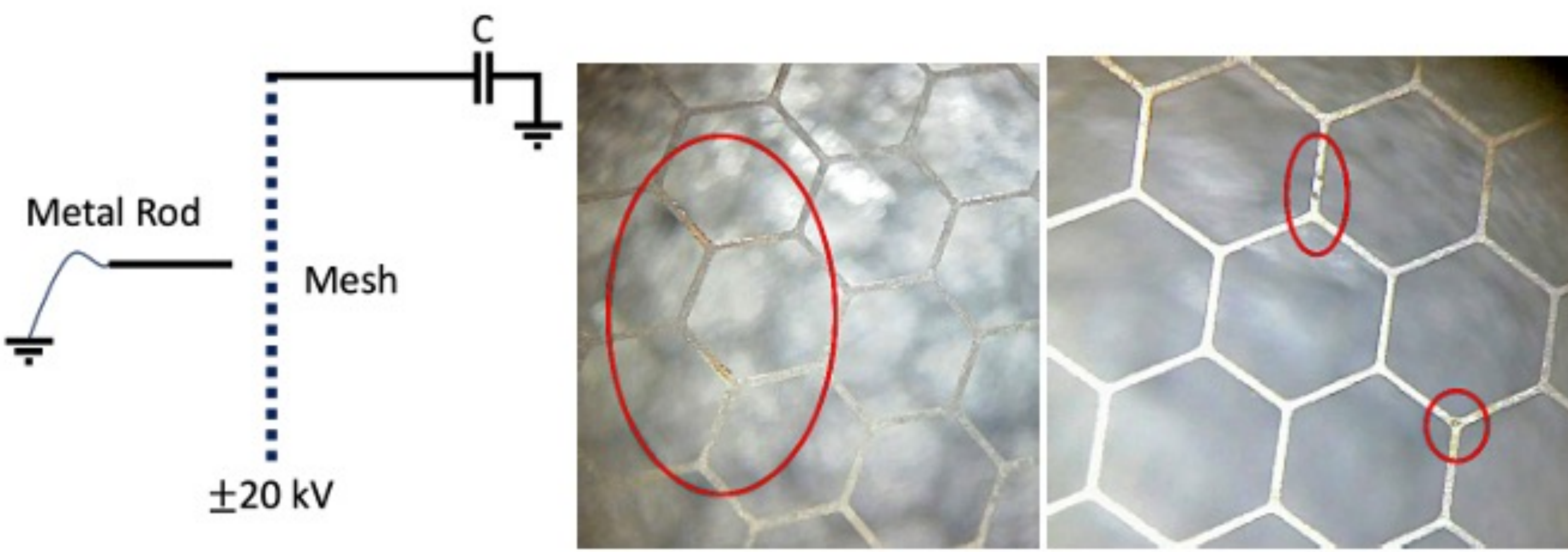
- We used the defective NEXT-100 meshes to study the breakdown positions with defect points
  - We identify the defects by the red dots in the image
  - We did not identify any further damage to the mesh after sparking





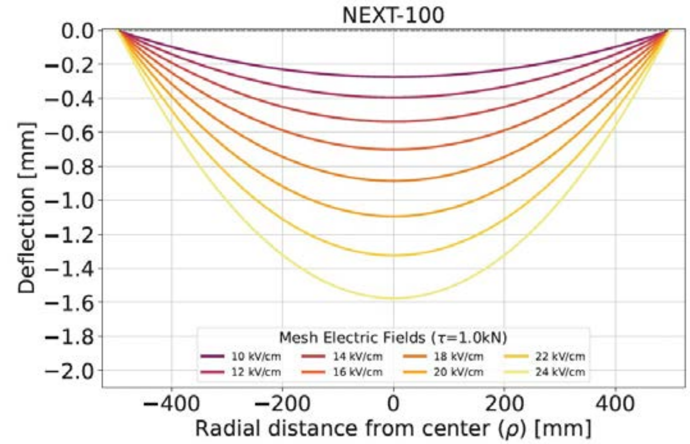
Mesh robustness to sparking

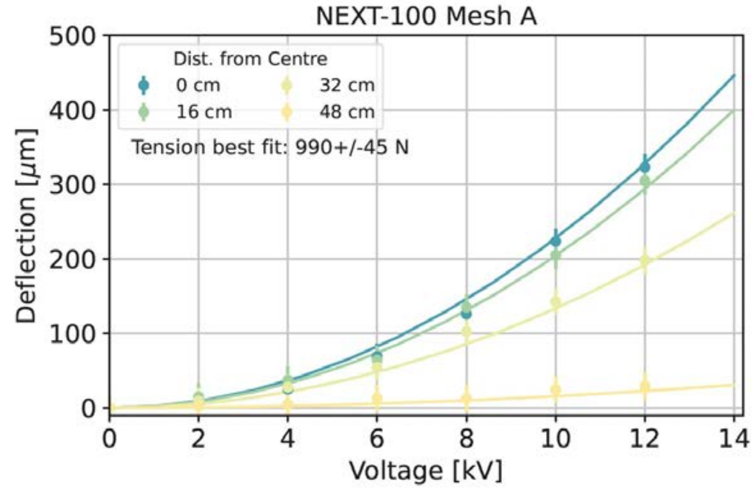
- In a separate test we sparked the mesh surface many more times using the system shown below
- No breaks were induced from the sparks, some surface material was ablated from the surface
- Robustness to sparking is good



Deflection measurements

- Large meshes are prone to electrostatic deflection compromising the gain uniformity and increasing sparking
- We measured the deflection of each mesh prior to installation
- We find the deflection for the NEXT-100 meshes is sufficient to avoid impact on the energy resolution
- Data is fit to an analytical model we developed to extract the mesh tension
- We find our measurements and predictions from the design are smaller by a factor of four
  - Mesh is deflecting more than design, but still ok!



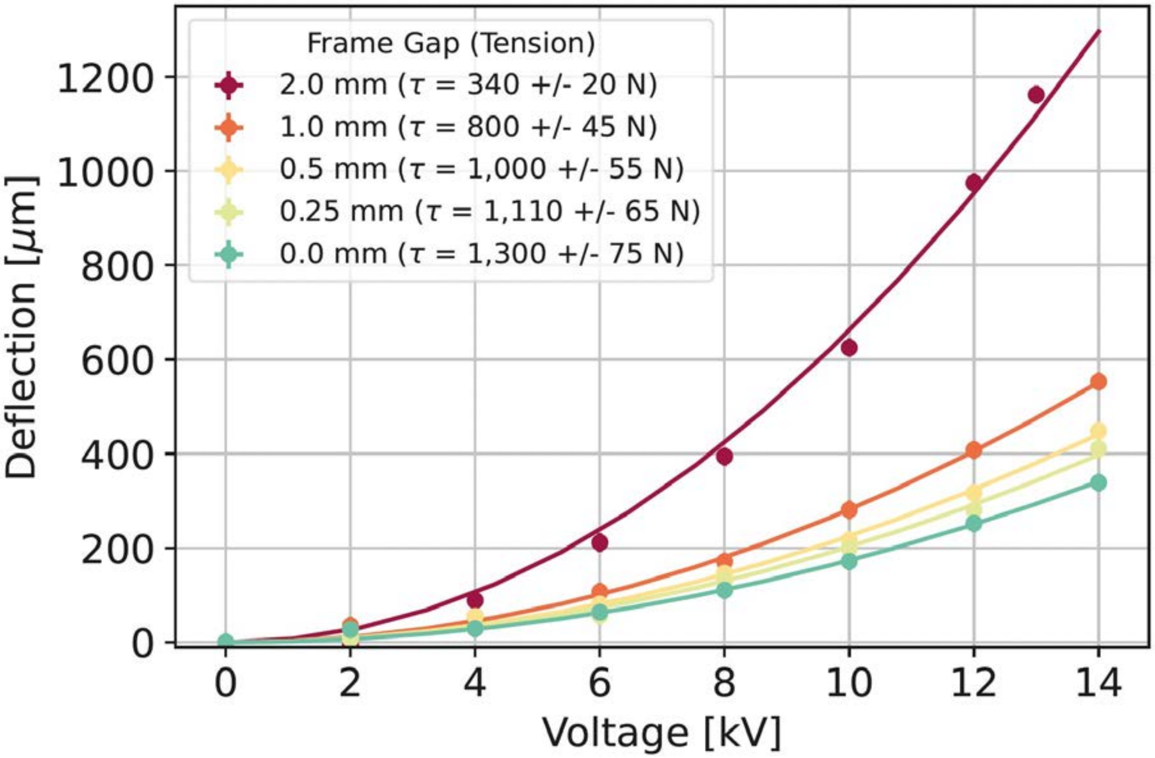


$$z = -\kappa(R^2 - \rho^2), \quad \kappa = \frac{\epsilon R E^2}{4\tau}$$

Can we tension more?

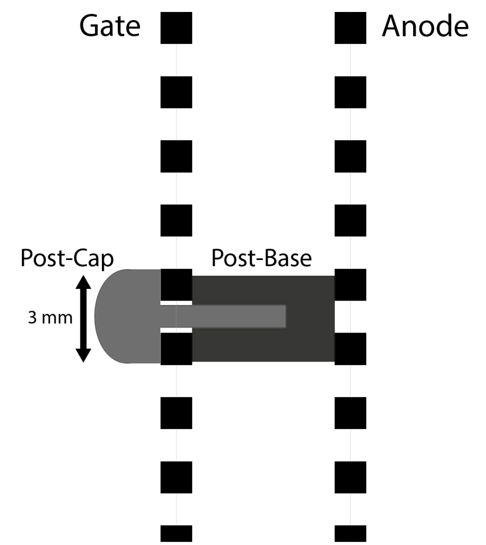
- Tensioning the mesh more will reduce the deflection

- We found that the benefit of tensioning to reduce deflections seems compared to the risk of breaking the mesh seems to plateau



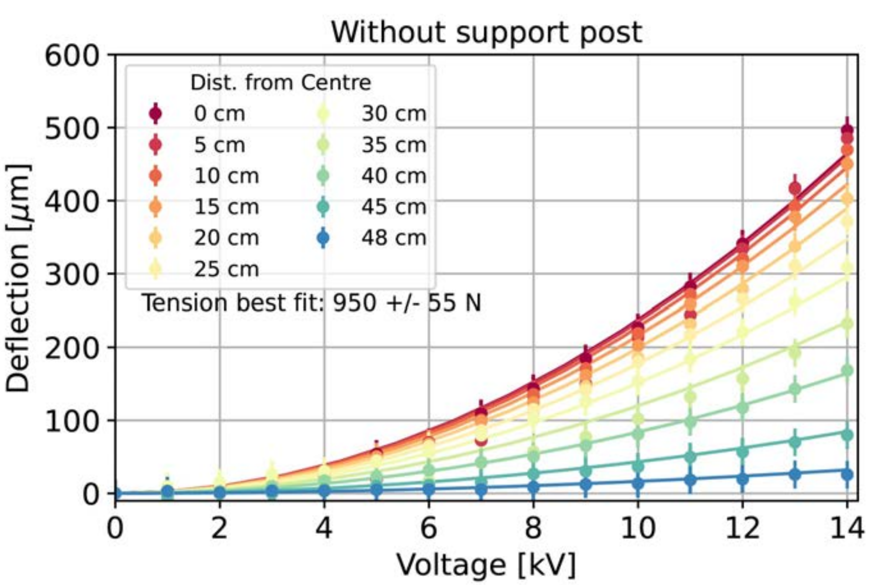
Inclusion of a support post

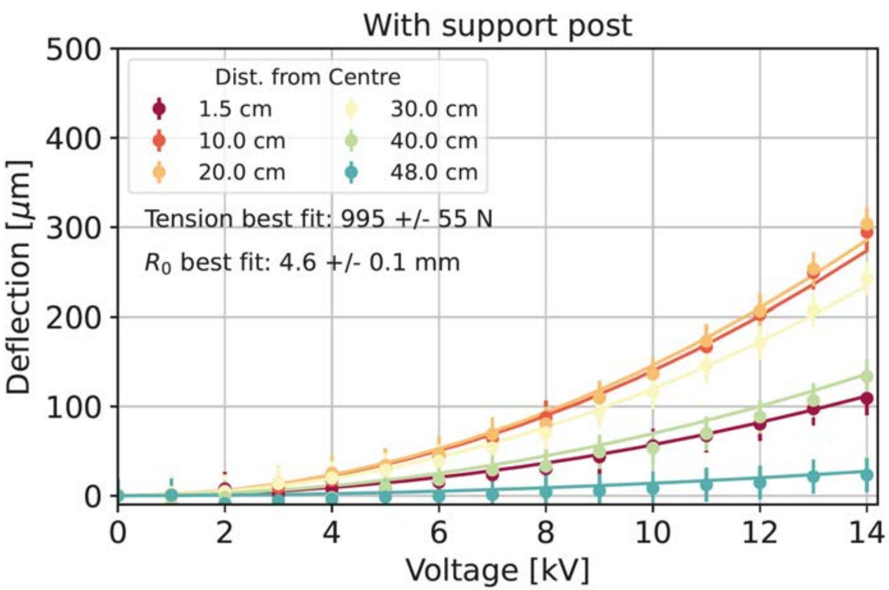
- We have investigated the use of a support post (HDPE) to be placed between the meshes
  - Material choice from studies of various plastics: L. Rogers *et al* 2018 *JINST* **13** P10002



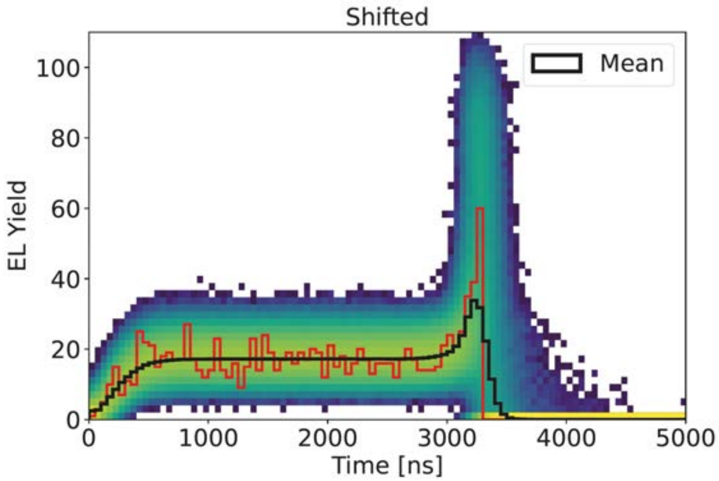
- Benefit in NEXT-100 not enough to require its use
  - May be required for larger meshes

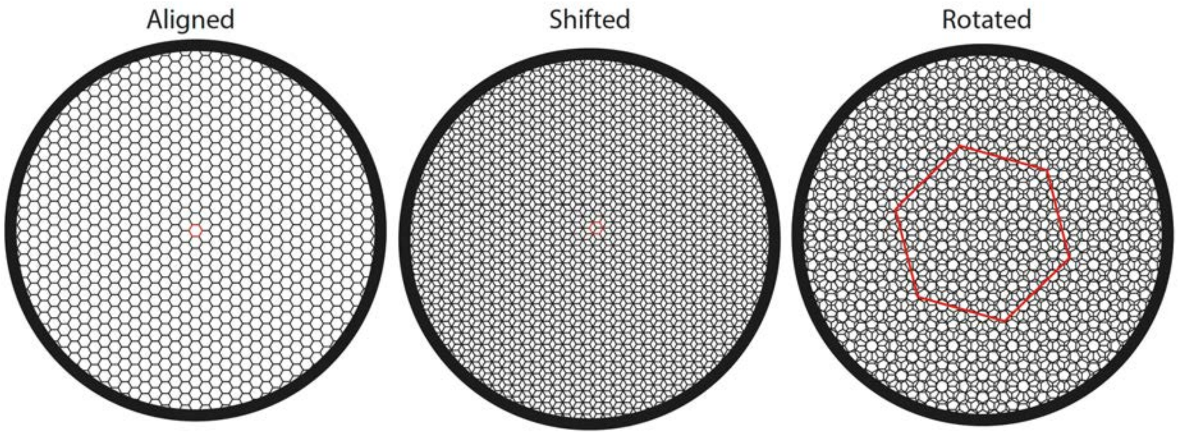
- More R&D is required to investigate charging-up effects of the post





Mesh Rotation and Energy resolution

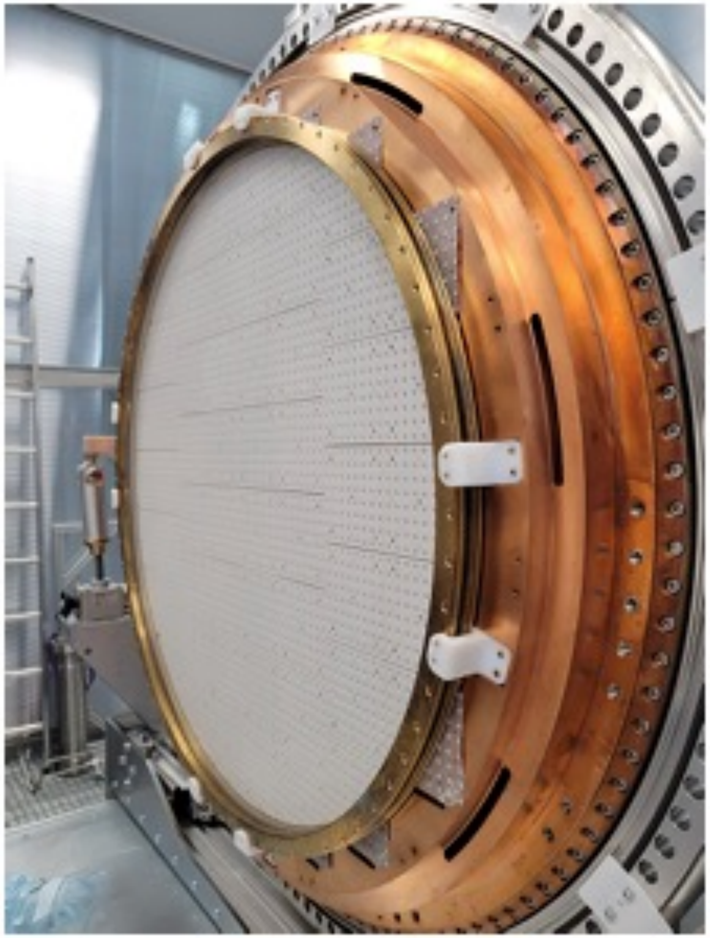




- Mesh rotation changes the pulse shape due to the termination point of field lines
- Shifting the mesh gives a more consistent pulse pattern
- Energy resolution is not impacted significantly by the rotation

Summary

- The NEXT-100 electroluminescent and cathode meshes have been installed in the detector which is beginning commissioning soon
  - Long R&D program to realize 1m photoetched meshes with sub-mm wire pitches and thickness
- Our design mechanically tensions the meshes to reduce the deflection which we have characterized for NEXT-100
- We have also investigated other properties such as robustness to electrical sparking
- Results with NEXT-100 soon!



Extras

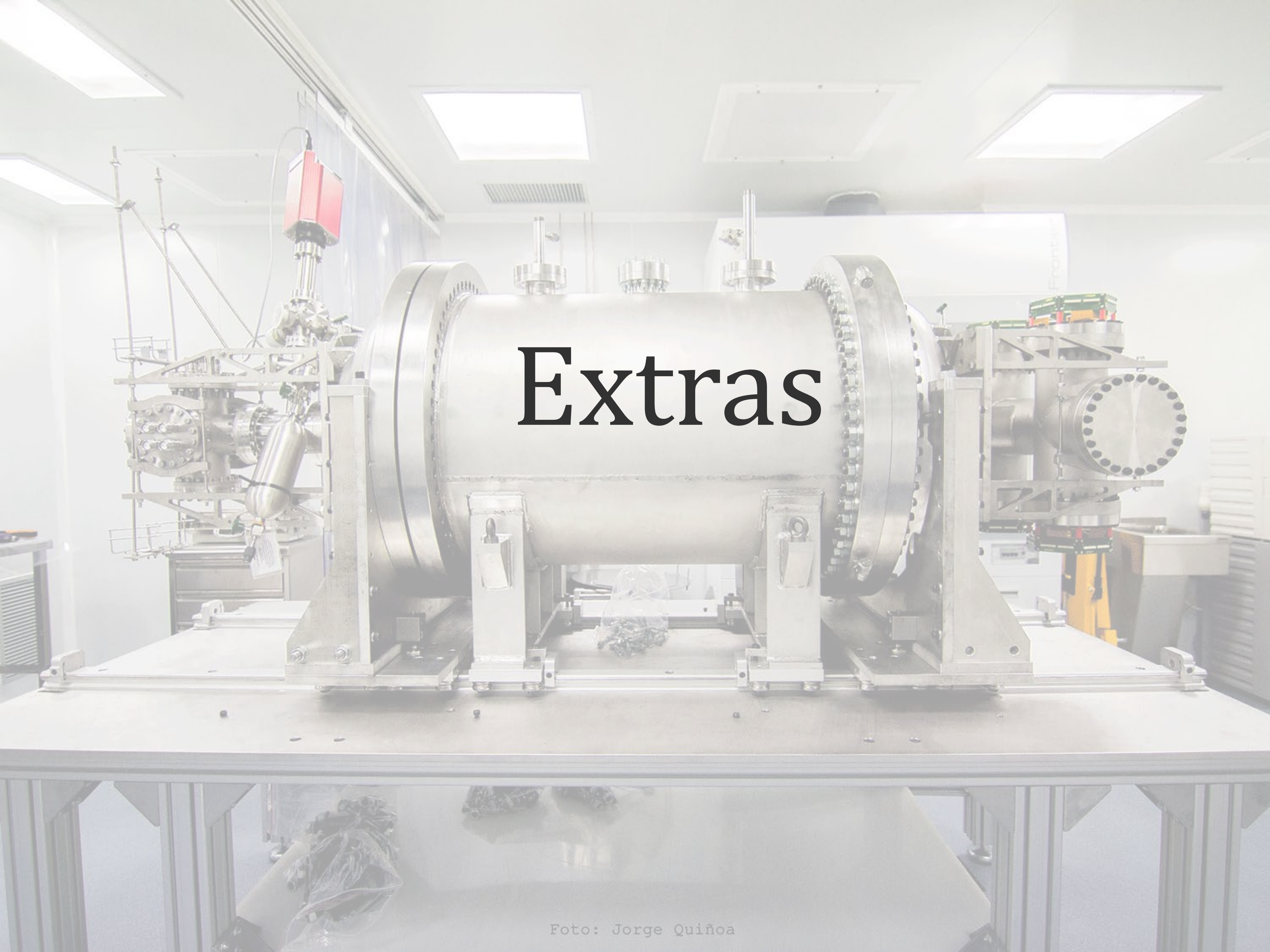
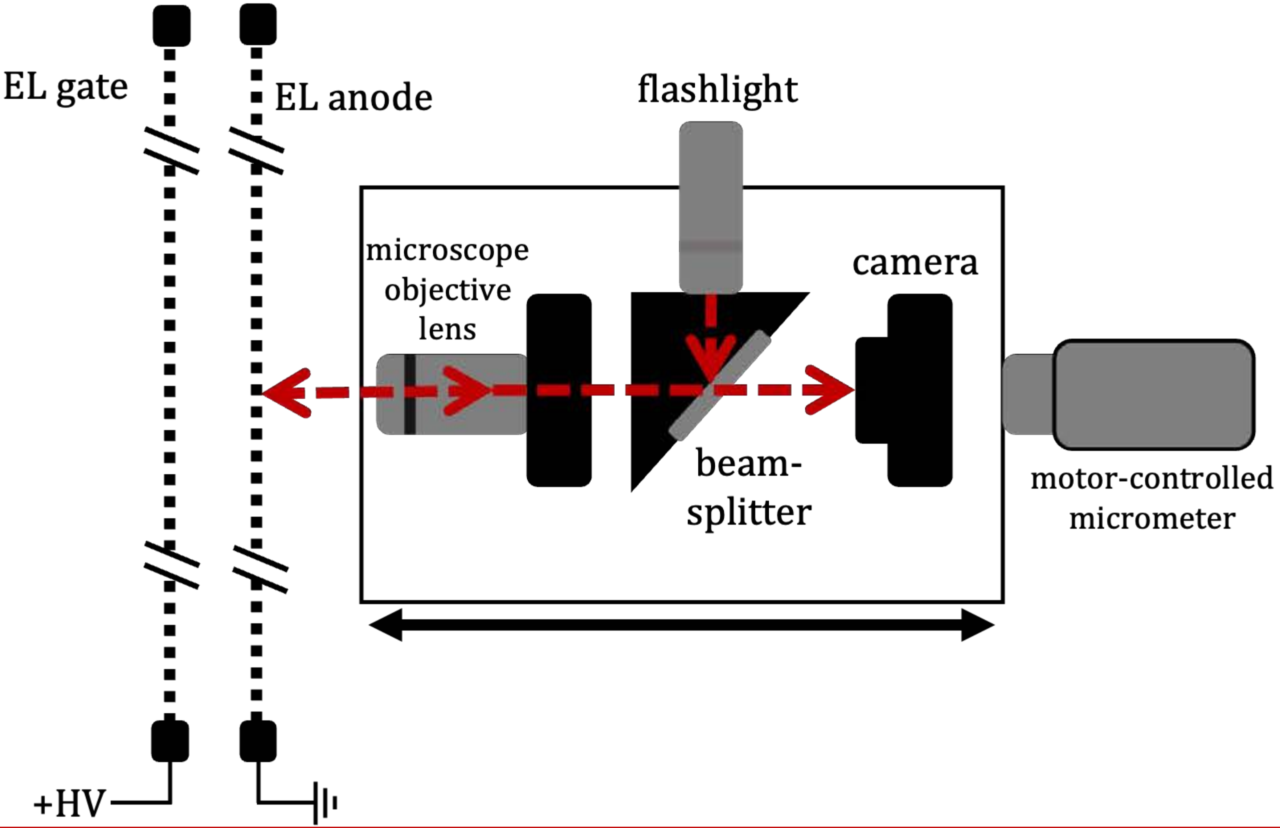
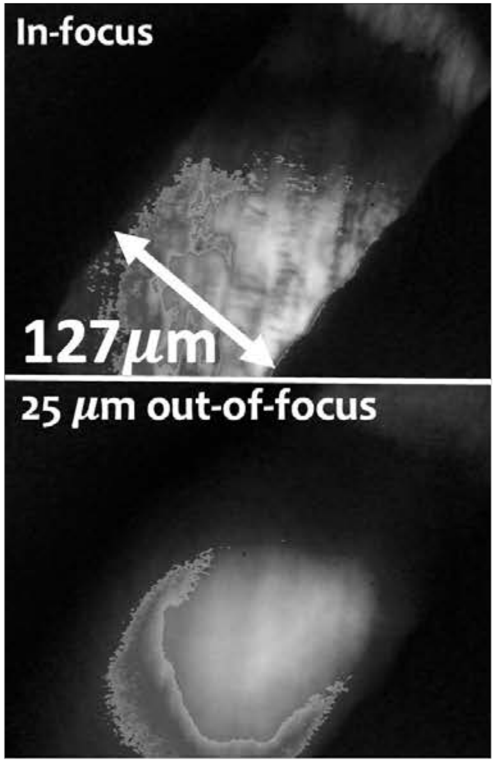


Foto: Jorge Quiñoa

Mesh Deflection Apparatus

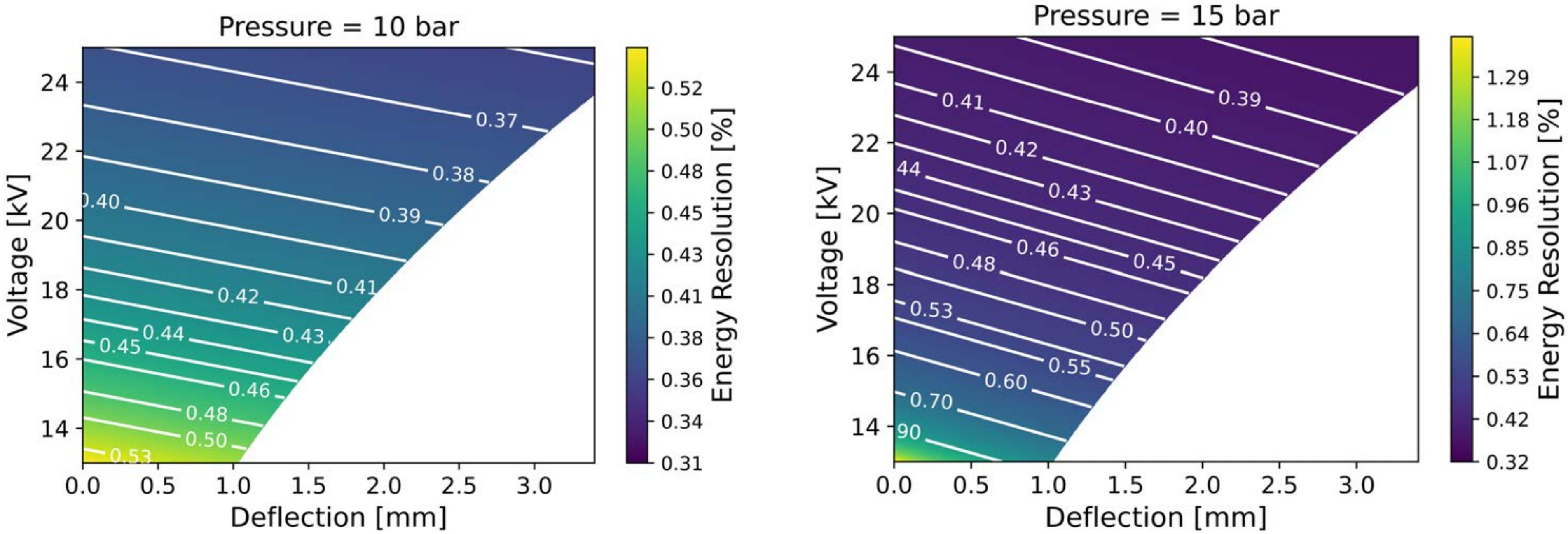
- Bring mesh into focus using camera focused on the mesh using a micrometre stage
- Able to achieve few micron resolutions, limited by positional measurements





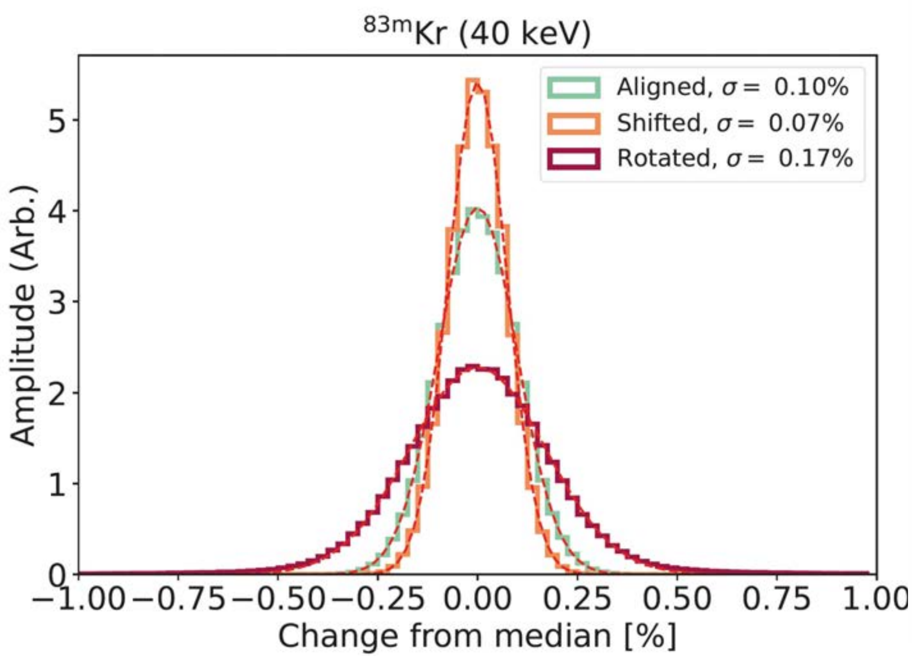
Energy resolution from deflection

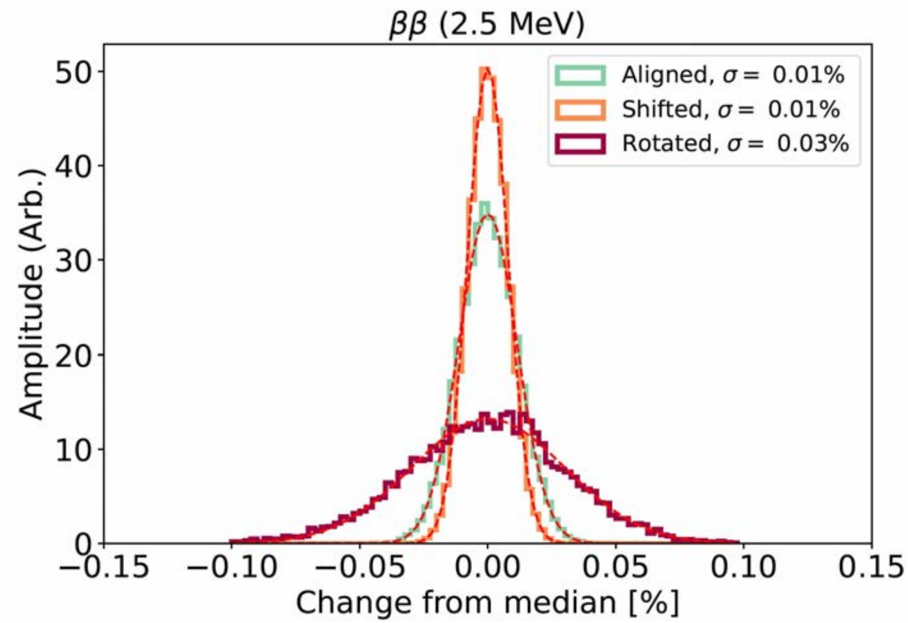
- Energy resolution is sub-percent for a 1kN tensioned mesh at these operating voltages



Mesh Alignment Energy Resolution

- We study energy resolution with 40 keV and 2.5 MeV tracks
- Impact is slightly larger for 40 keV events, but still negligible





Pulse shapes for mesh alignments