IMPERIAL

Update on Novel Radiators

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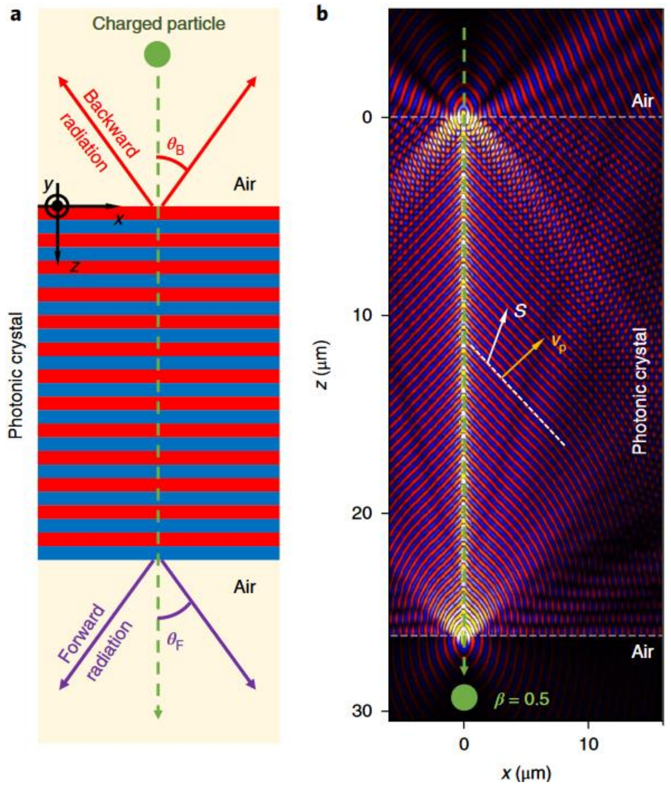
LHCb-UK Upgrade II Meeting – University of Birmingham

July 9, 2024

Overview

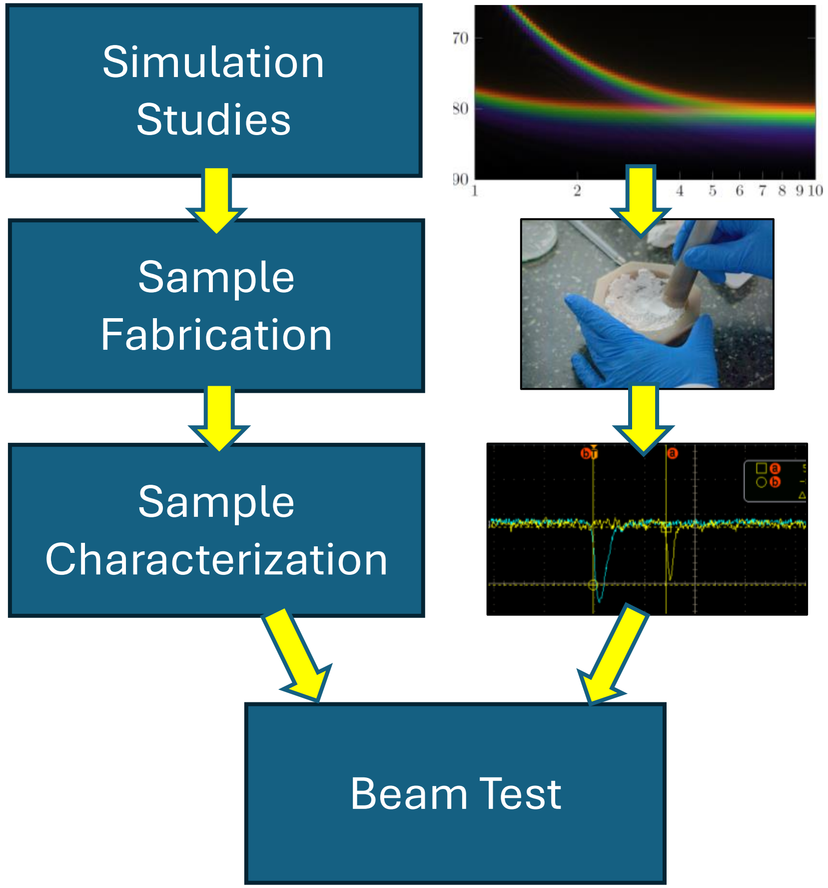
- ❑ Goal: Study whether metamaterials can be utilized as an effective radiator for PID
- ❑ Photonic Crystal is the most studied structure
  - Layers of dielectric material with alternating high/low refractive index
- ❑ Superposition of Transition Radiation (TR) formed at layer interface analogous to Cherenkov Radiation
  - Angle of emitted light is proportional to track velocity
- ❑ May still be possible to exploit traditional Cherenkov radiation in a crystal



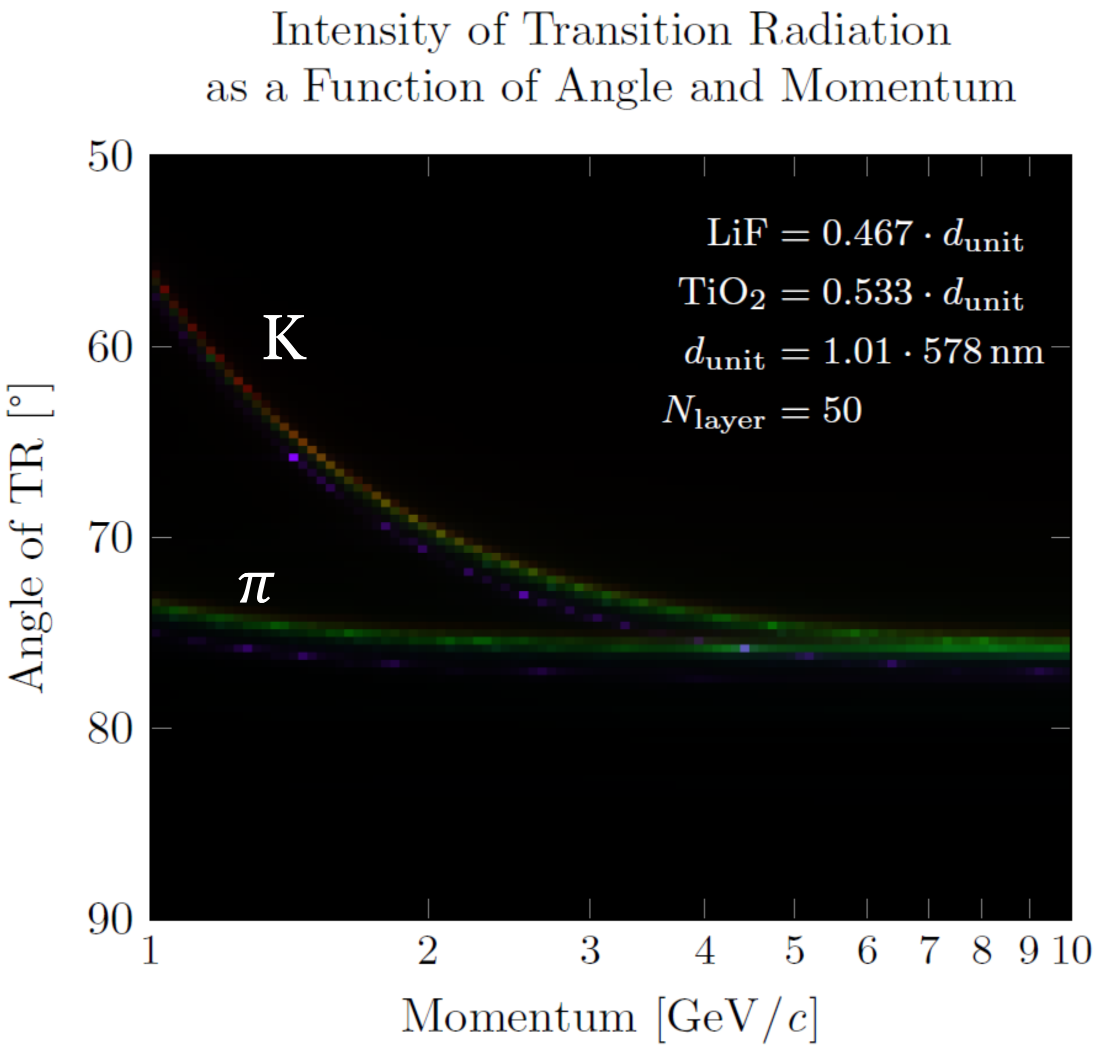
Nature Physics volume 14, pages 816–821 (2018)

Workflow

- ❑ Simulation development by **Henry Linton**
- ❑ Sample Fabrication:
  - Henry Royce Institute for Advanced Materials
  - Amorphous Solid
    - Equal mixture of powders, melted and fused into a crystal
  - Layered photonic crystal
    - Layer and press materials in a hydraulic press
    - Sinter the resulting pellet
- ❑ Characterization via bench testing
  - Study light output from incident electrons by Sr^{90} source

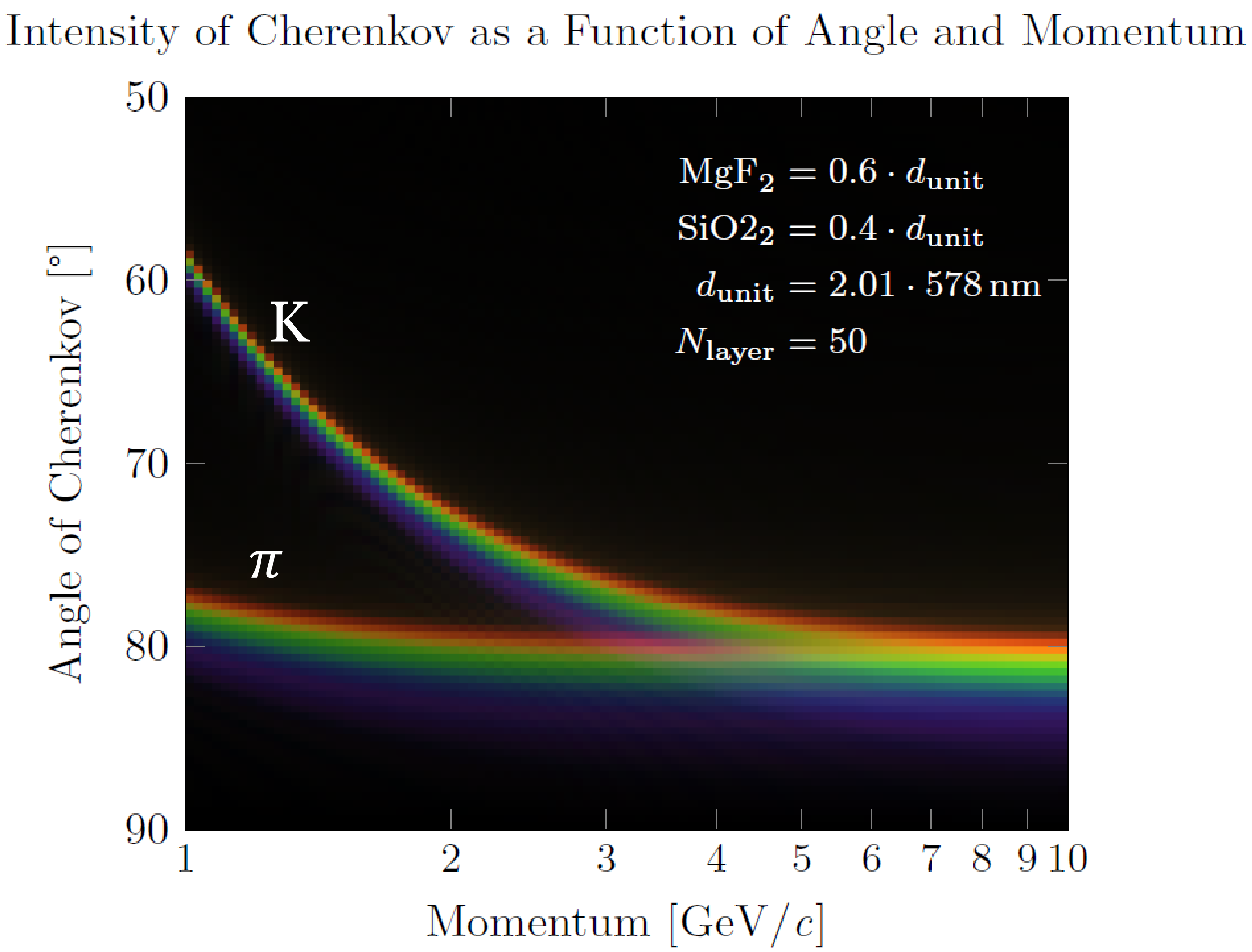


Transition Radiation Simulation (Henry Linton)



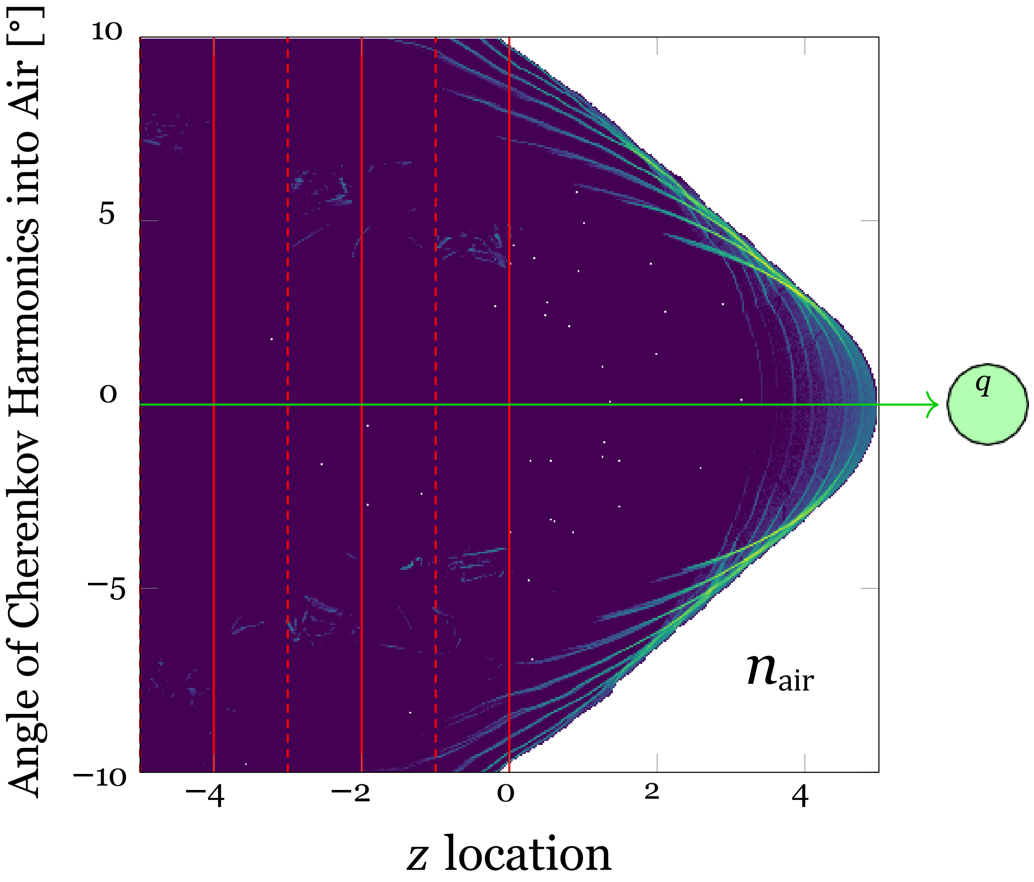
- ❑ Simulation of traditional Cherenkov radiation
- ❑ 50-layer **$\mathrm{TiO_2}$-LiF** photonic crystal
- ❑ Separation of K/π at low $\vec{p}$
- ❑ Low light yield

Cherenkov Radiation Simulation (Henry Linton)



- Simulation of traditional Cherenkov radiation
- 50-layer **SiO_2-MgF_2** photonic crystal
  - Current baseline sample to be produced
- May be a suitable replacement for gaseous radiator
- Separation of K/π at low $\vec{p}$

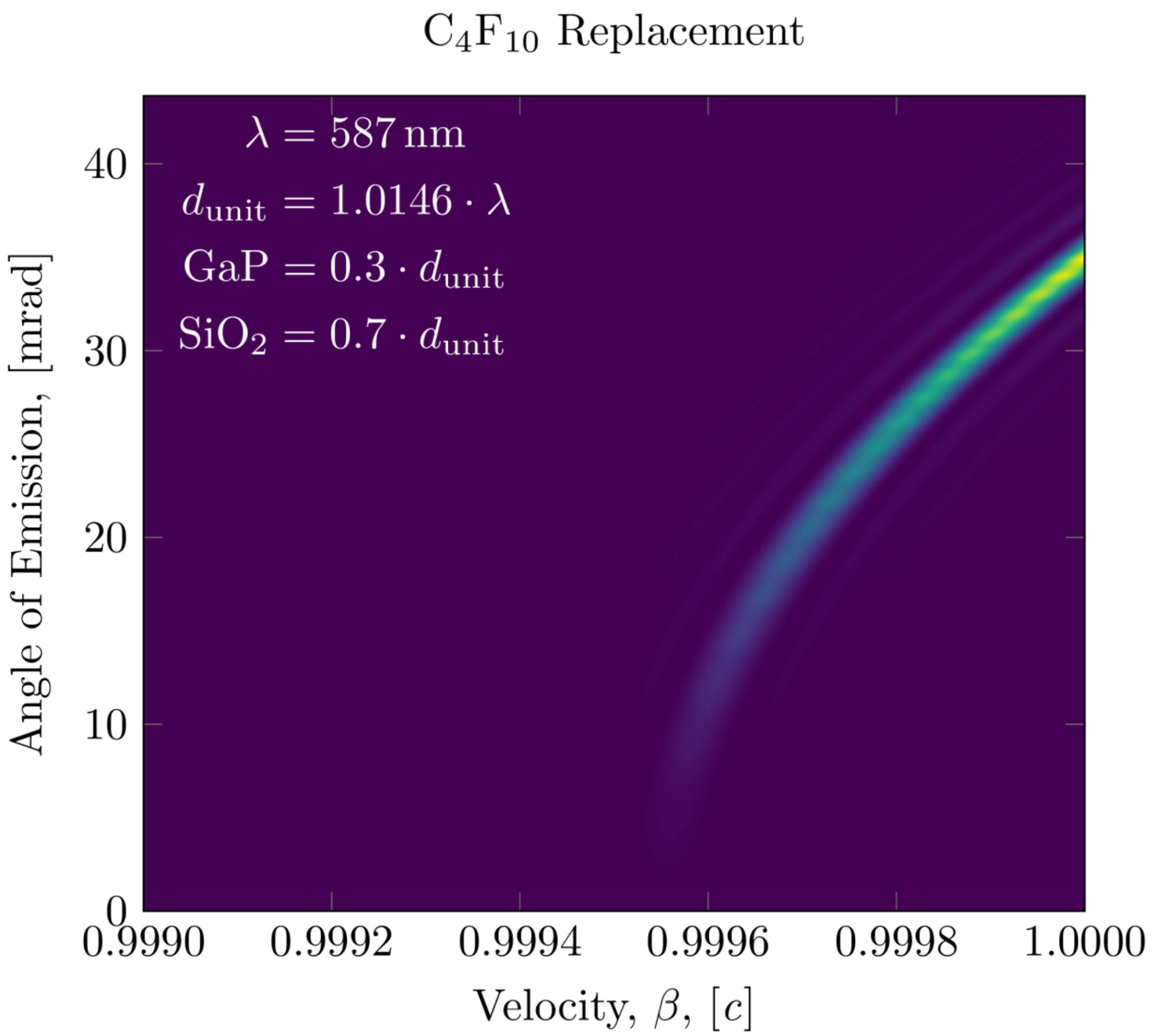
Cherenkov “Harmonics” (Henry Linton)



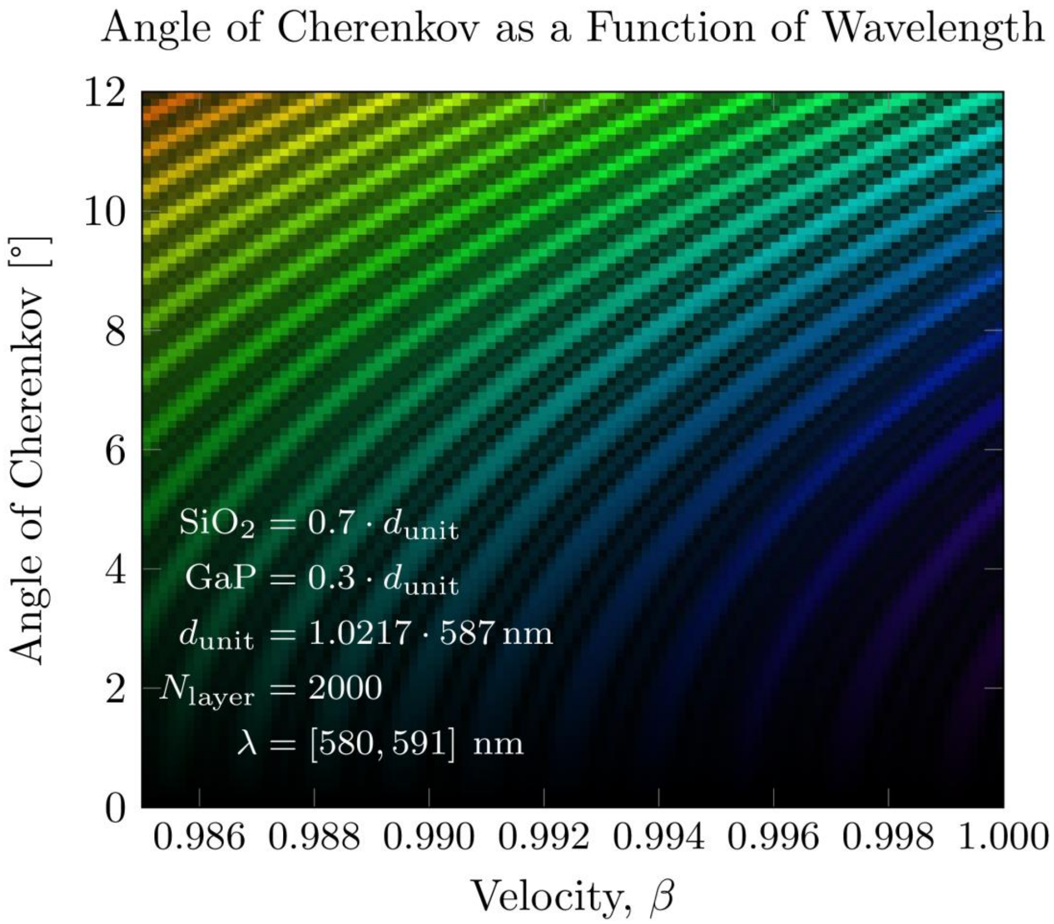
- ❑ Cherenkov radiation in layered photonic crystal results in “harmonics”
- ❑ Material here is arbitrary
  - *n* chosen to make radiation more visible
- ❑ Produced at a controllable angle
  - **Should be able to mimic C_4F_{10} using a solid crystal**

Cherenkov “Harmonics” (Henry Linton)

- Angle of harmonic Cherenkov vs. track velocity
- Material with ***n*≈C_4F_{10}**
  - Requires *many* layers to reach this angular resolution (**20k here**)



Cherenkov “Harmonics” (Henry Linton)



- ❑ Dispersion becomes an issue with Cherenkov harmonics
  - Seen here for Aerogel-like material
  - Note small wavelength range
- ❑ Start by fabricating a homogenous crystal & look for Cherenkov light
- ❑ Continue to study photonic crystal fabrication & minimize dispersion

Sample Fabrication: Amorphous Solid

- Homogenous Crystal Procedure:
  - Grind MgF_2 and SiO_2 into fine powders
  - Mix powders into equal parts by volume
  - Heat powders in a high-temperature furnace to make an amorphous solid
- First attempt at Royce institute on 11-12 June
- Powder Grinding:
  - Fritsch Pulverisette 6 planetary mill
  - Two stage grinding process
    1. 6x 2cm balls + 20g material
    2. Grind for 10min @ 450rpm
    3. Remove large grind balls, replace with 100g of 3mm balls
    4. Add 10g ethanol. Grind for 10min @ 450rpm
    5. Dry slurry in petri dish

Prepped Planetary Mill

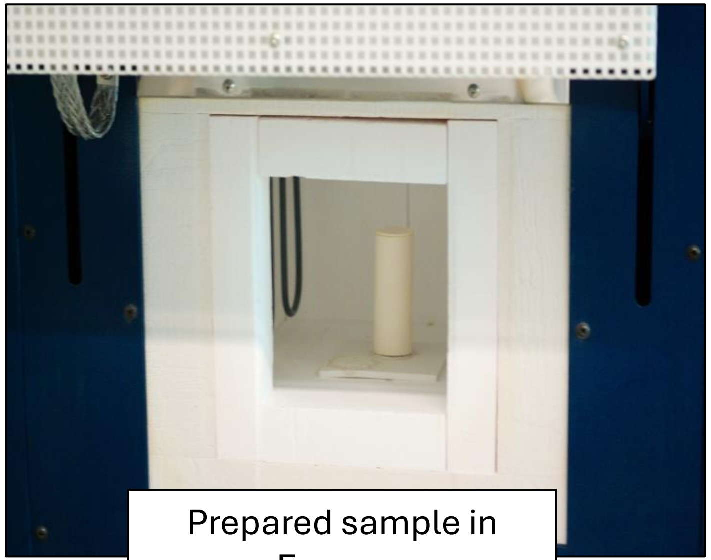
Stage 1 Grind

Powder Mixing

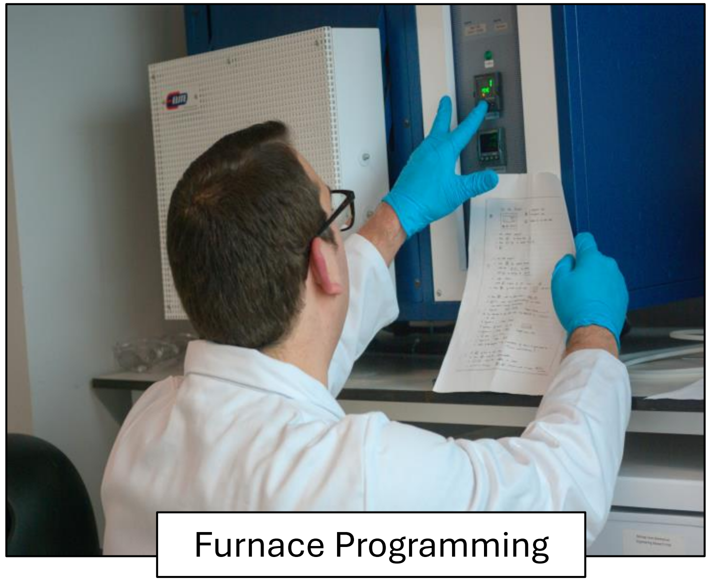
Stage 2 Grind

Sample Fabrication: Amorphous Solid

- Powders are loaded into an alumina crucible for baking
- Baking recipe
    1. Heat the sample to 1400°C in 20°C/min steps
    2. Hold the sample at 1400°C for 2h
    3. Reduce the temperature to 400°C in 10°C/min steps
    4. Hold the sample at 400°C for 2h
    5. Reduce the temperature to 20°C in 10°C/min steps



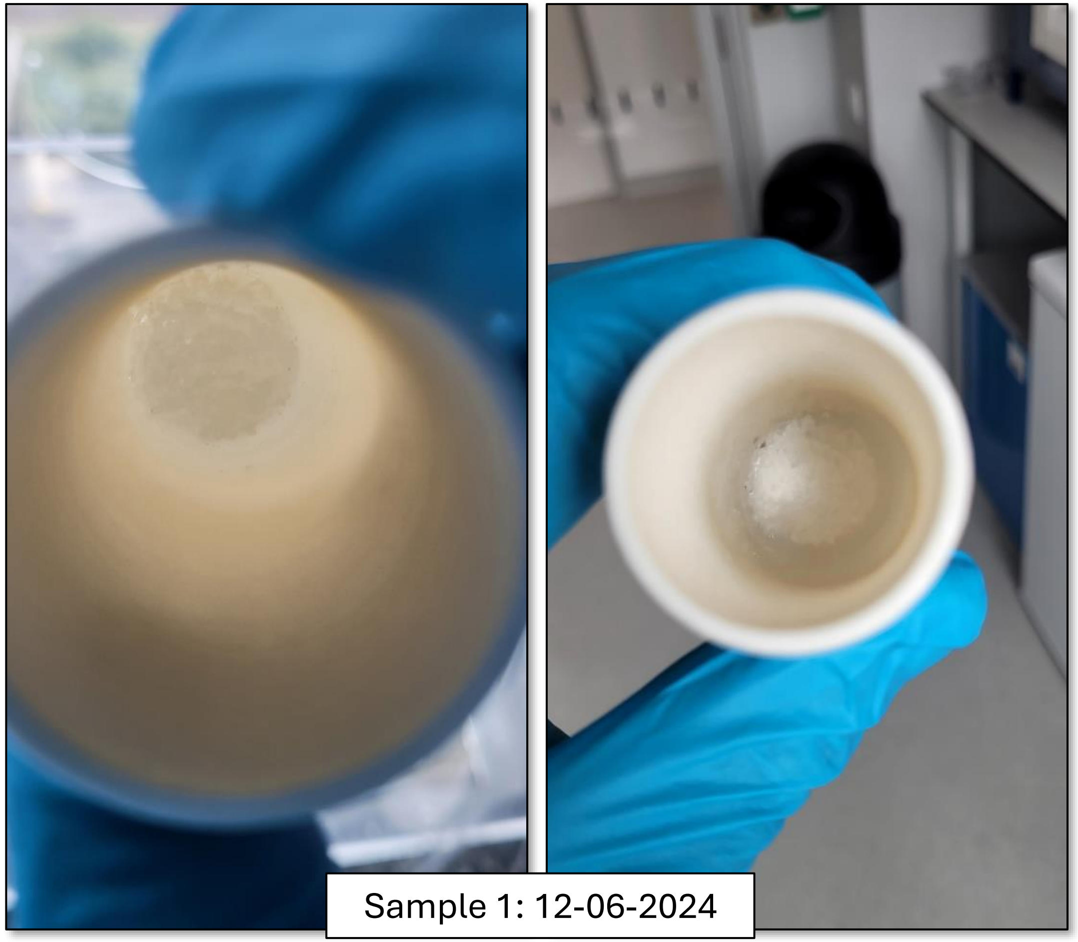
Prepared sample in Furnace



Furnace Programming

Sample Fabrication: Amorphous Solid

- Resulting sample appears as a fused block of smaller pieces
- Only the first attempt!
- Suspected the heating temperature was too low:
  - Max temperature achieved: 1400°C
  - Melting point of SiO_2: 1610°C
  - Adjusted recipe and tried again
- Suspected cooldown rate was too fast


Sample 1: 12-06-2024

Sample Fabrication: Amorphous Solid (Take 2)

- Powders prepared as previously
- Added pressing step before baking:
  - Added powders into 25mm pellet die
  - Pressed to 4T force to form a pellet
  - Pellet loaded into crucible as before, baked
- Bakeout Procedure:
  1. Heat the sample to 1200°C in 50°C /min steps
  2. Heat the sample to 1650°C in 20°C/min steps
  3. Hold the sample at 1650°C for 2h
  4. Lower the temperature to 500°C in 5°C/min steps
  5. Hold the sample at 500°C for 4h
  6. Lower the temperature to 20°C in 2°C/min steps
  7. Let the sample cool naturally over night.

Sample loaded in press

Resulting pellet

Loaded crucible(s)

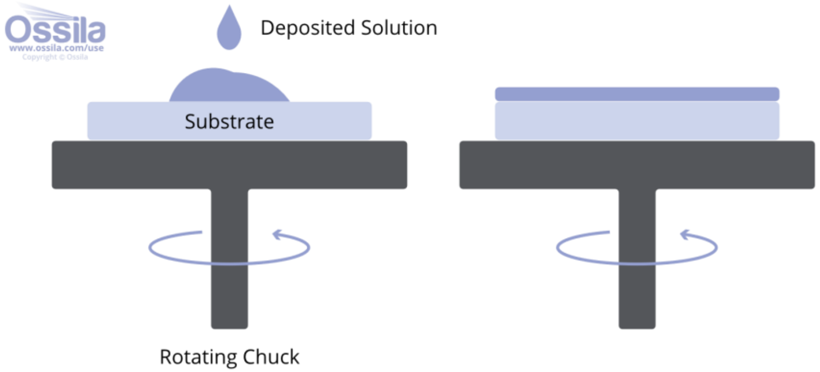
Prepped Furnace

Sample Fabrication: Amorphous Solid (Take 2)

- Encountered some issues in heating
  - Max furnace temp: 1700°C
  - Abnormalities in heating led us to stop the process and advance to annealing stage
- Resulting sample also unsuitable
  - Still a fused bit of crystal at the base of the crucible
  - Opaque
- Suspected issues:
  - Never reached melting point for SiO_2
  - Noticed some film deposited on the crucible lid and walls
  - Possible that MgF_2 is evaporating

Spin Coating

- ❑ Spin coating offers a potential method to make **Photonic Crystal sample** with layer thickness that we are trying to achieve (100 – 500nm)
- ❑ Procedure:
  - Create slurries/solutions of powdered materials with Ethanol
  - Pipette the solution onto a glass substrate, vacuumed to the spinning chuck
  - Allow first sample to dry before depositing the next layer, and repeat
  - Final low-temp annealing step to sinter layers together
- ❑ Some concerns to be discussed with Royce experts:
  - Opacity of resulting samples
  - Durability of layers during deposition



https://www.ossila.com/pages/solution-processing-techniques-comparison

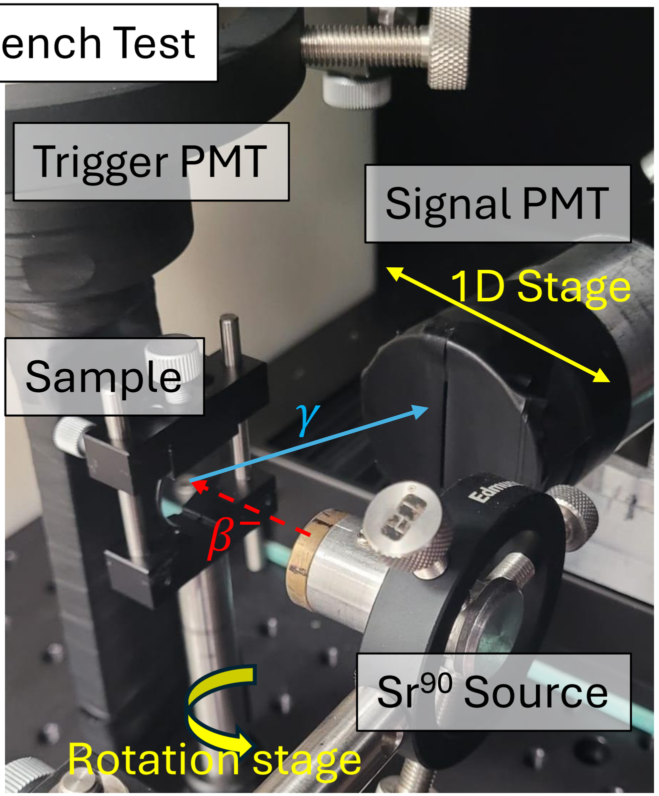
Continued Productions

- ❑ Believe that our best chance at success is an amorphous solid
  - Quality of first samples not usable
  - Intended to learn manufacturing procedure
  - Plenty of raw material
- ❑ Consultation with Royce Experts about alternative methods and/or improvements
  - Ceramics and Glasses research dept. within Imperial Department of Materials may also offer insights

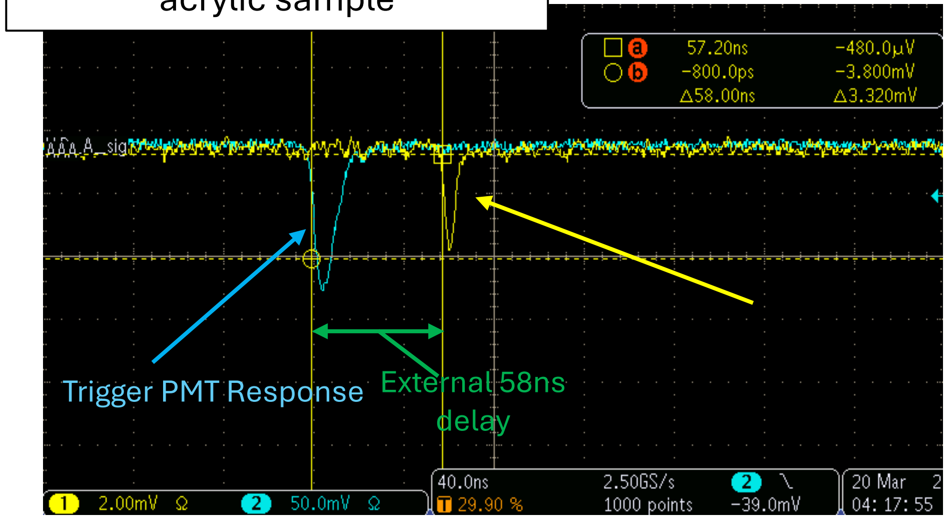
Bench Tests

- ❑ Bench test set up to look for light
  - MSc students improved setup earlier in the year
    - Some hardware issues (suspect PMTs) resolved
    - Trigger and Signal PMT look for coincident signals from 2MBq Sr^{90} source
  - Scan in position and angle

Bench Test



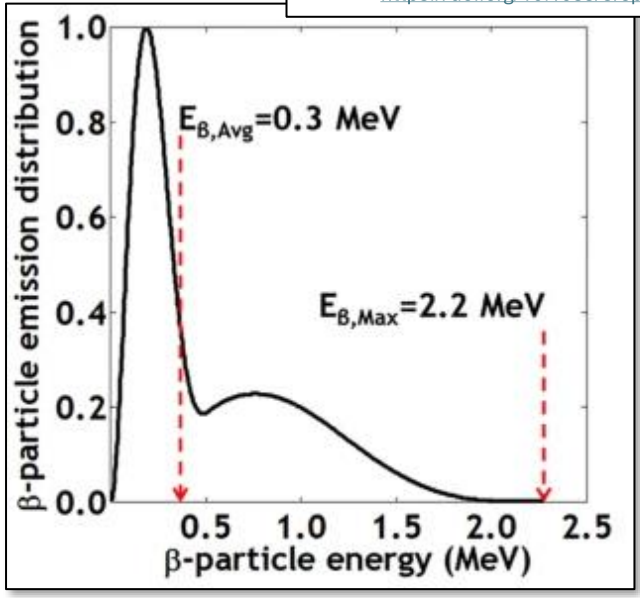
Coincident light signal from acrylic sample



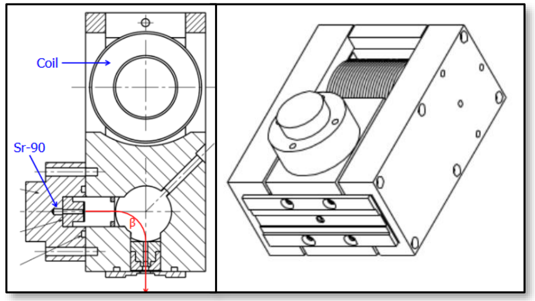
Energy Selection

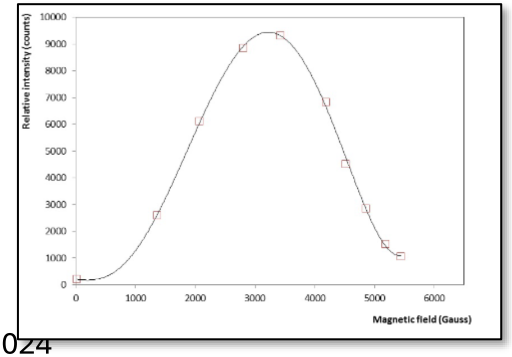
- Due to wide energy spectrum, selection of incident particle energy is crucial to our bench tests
- Device in [PH-EP-Tech-Note-2015-003] makes this possible
- Adapted this design to fit our mechanics
- Plan to implement this shortly

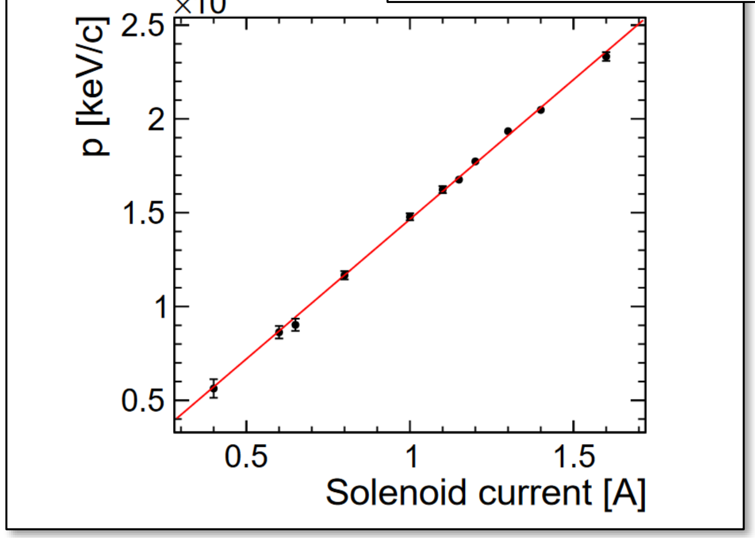
Dixon, J. *et al. Evaluation of a Silicon* ^{90}*Sr Betavoltaic Power Source*. *Sci Rep* **6**, 38182 (2016). https://doi.org/10.1038/srep38182

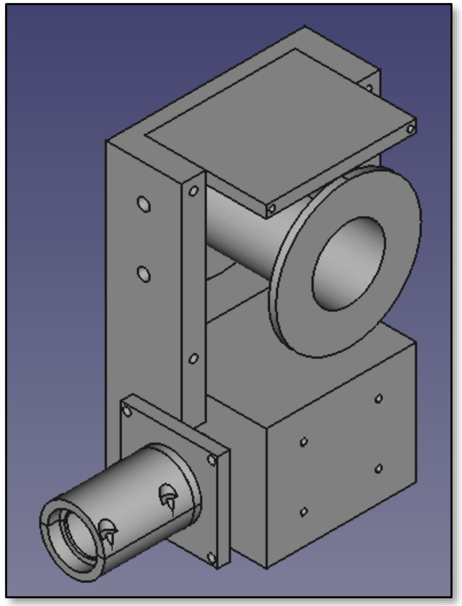


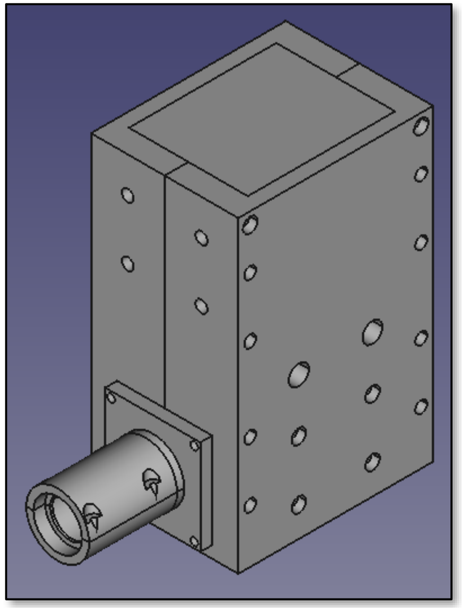
Characterisation of a Sr-90 based electron monochromator - Arfaoui, S; CERN *et al* - PH-EP-Tech-Note-2015-003











Outlook

- ❑ Continue to make samples this summer
  - Must have sufficient optical quality for characterization
  - Striving for a C_4F_{10} replacement
  - Start with a sample tuned for lab energies, adjust for higher energy beam tests
- ❑ Excellent developments in simulation from Henry Linton are driving our current investigations
  - Defining a geometry that maximizes light yield, hopefully minimizes dispersion
  - Samples we are making designed with this aim
- ❑ Ultimately would like to take advantage of any beam time presented to us