Mu2e-II

Becky Chislett

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Introduction

11 LoIs submitted relating to Mu2e-II detector and DAQ systems (not including the accelerator/theory) :

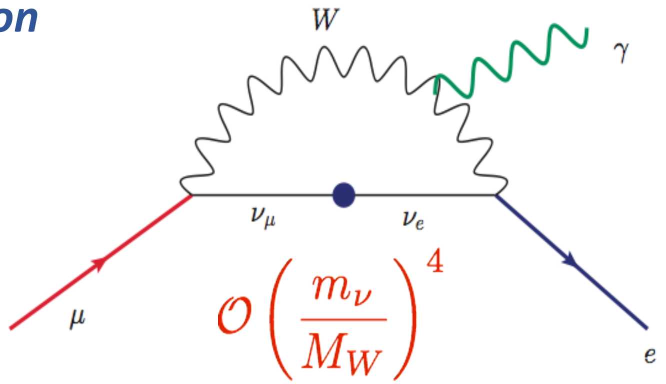
- Mu2e-II
- Considerations for a Mu2e-II Production Target
- Mu2e-II Tracker
- The Mu2e-II Calorimeter
- Crystal and Photosensor Development for a Fast BaF2 Electromagnetic Calorimeter
- An Enhanced Cosmic Ray Veto Detector for Mu2e-II
- Considerations for a Mu2e-II Stopping Target Monitor
- Mu2e-II: a 2-level TDAQ system based on FPGA pre-filtering
- Mu2e-II: a 2-level TDAQ system based on FPGA pre-processing and trigger primitives
- Mu2e-II: TDAQ based on GPU co-processor
- Mu2e-II: a trigger-less TDAQ system based on software

Mu2e-II working groups will perform further studies in these areas leading up to white papers :

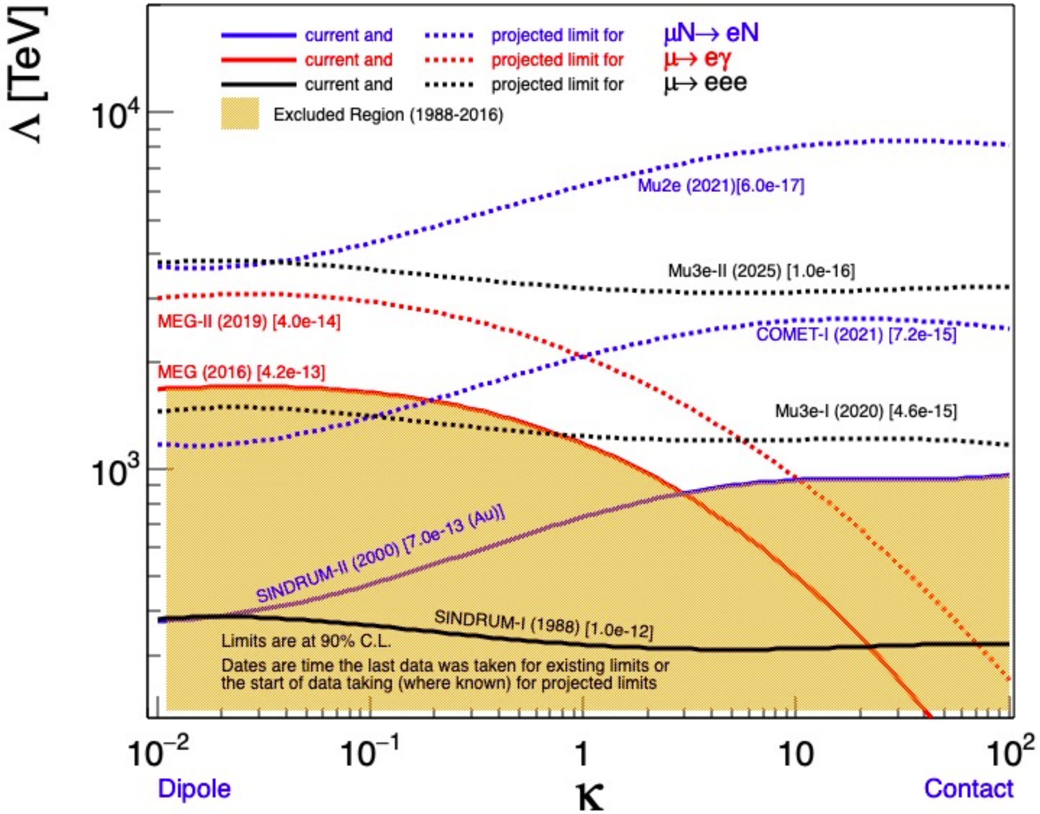
theory, accelerator, radiation, tracker, calorimeter, CRV, sensitivity, TDAQ

Physics Motivation

Mu2e-II aims to improve the sensitivity to the neutrinoless conversion of a muon to an electron in the field of a nucleus by a further order of magnitude than Mu2e (to 3x10^{-18})



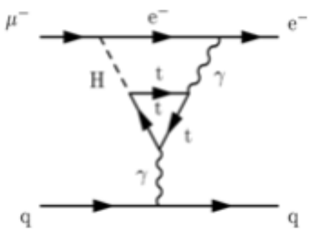
CLFV probes new physics at mass scales beyond the current reach of colliders



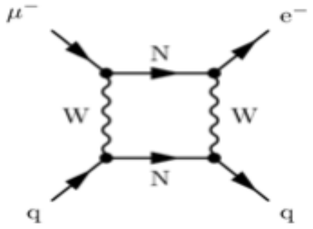
Updated from A. de Gouvea, P. Vogel, arXiv:1303.4097

Sensitive to a wide range of physics models which predict observable rates

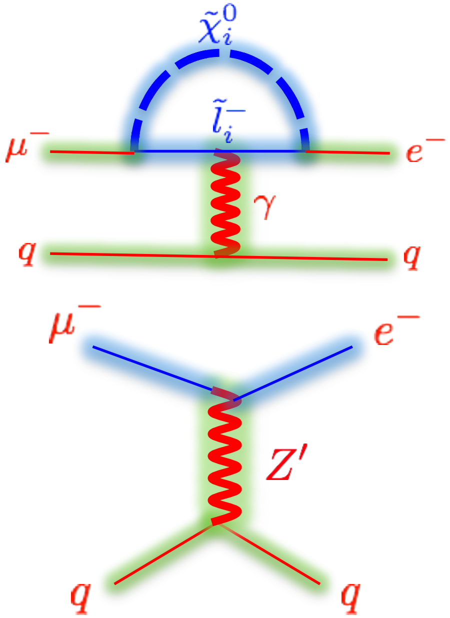
Any observation is a sign of new physics!



Second Higgs Doublet



Heavy Neutrinos



Two possible scenarios :

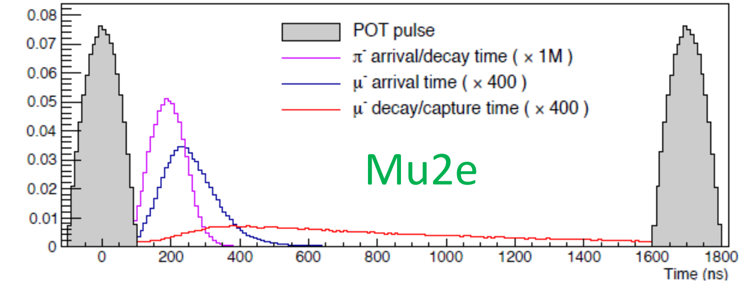
- No observation in Mu2e/COMET motivates pushing to higher mass scales
- Observation in Mu2e/COMET motivates more precise measurements with different targets

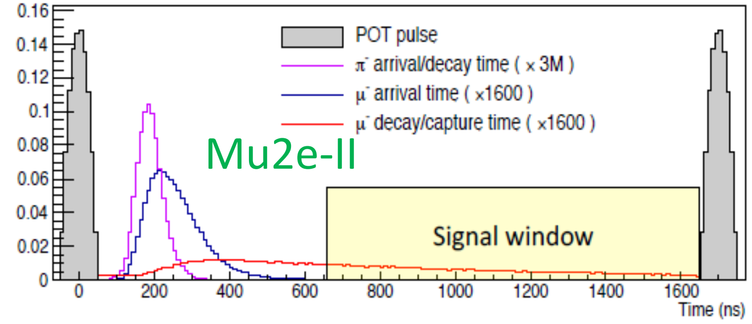
Can also look for muon to positron conversion

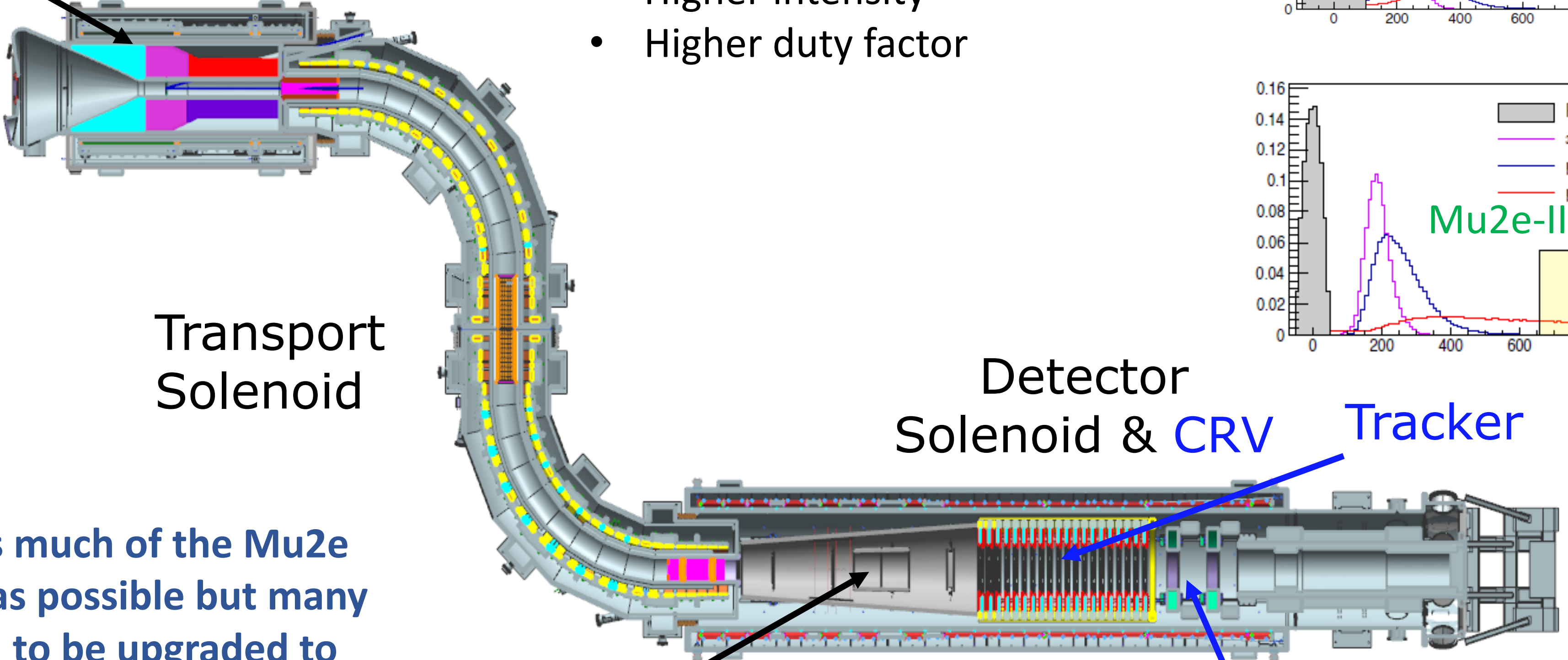
How do we get there?

Make use of the new 800MeV PIP-II beam :

- Narrower pulses
- Less pulse to pulse variation
- Higher intensity
- Higher duty factor



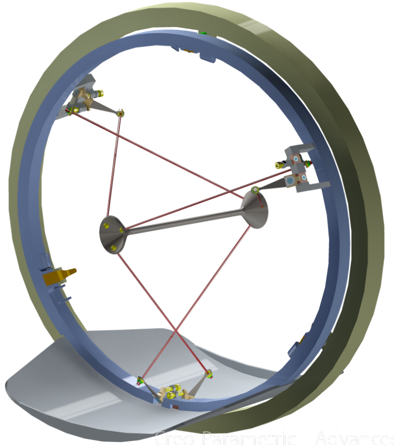




We will use as much of the Mu2e infrastructure as possible but many systems need to be upgraded to deal with the more intense beam and more harsh radiation environment

Production Target

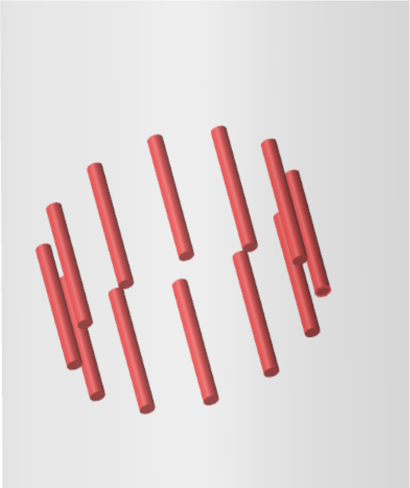
The goal of the production target is to maximise the number of muons stopped in the stopping target per incident proton



For Mu2e-II the use of the PIP-II beamline means:

- 20-25% more fractional power deposition in the target (10% for Mu2e)
- Significantly increased radiation damage

Needs active cooling and mitigation of radiation damage



Rotating Elements

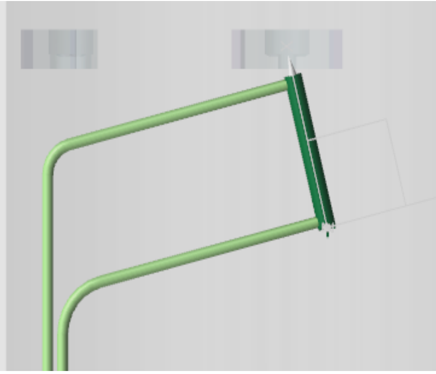
LDRD project funded by Fermilab for 2020-2021 to consider 3 potential designs :

- Rotating system
- Granular system
- Conveyor of spherical target balls

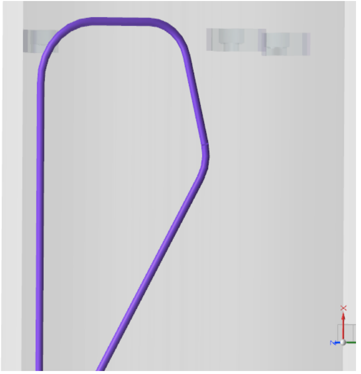
Other considerations :

- Choice of materials for target and support
- Use of a curved target

Simulation is currently ongoing will be used to select at least one for mechanical prototyping over the next year



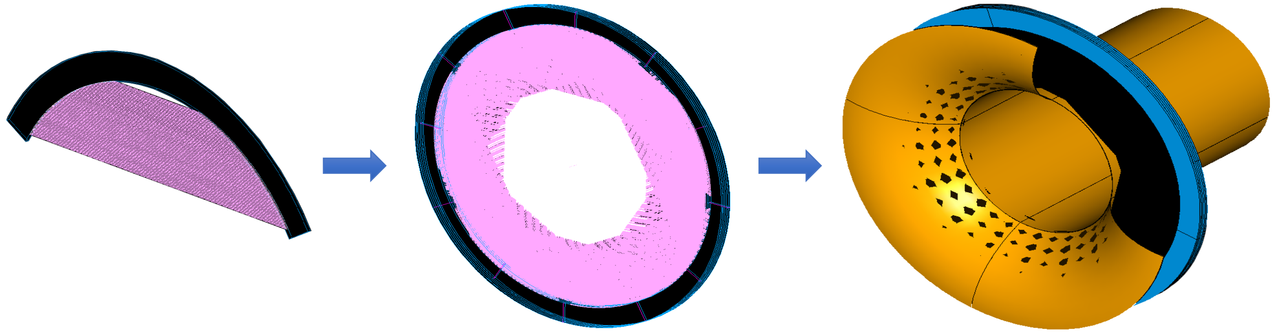
Fixed Granular with Gas Cooling

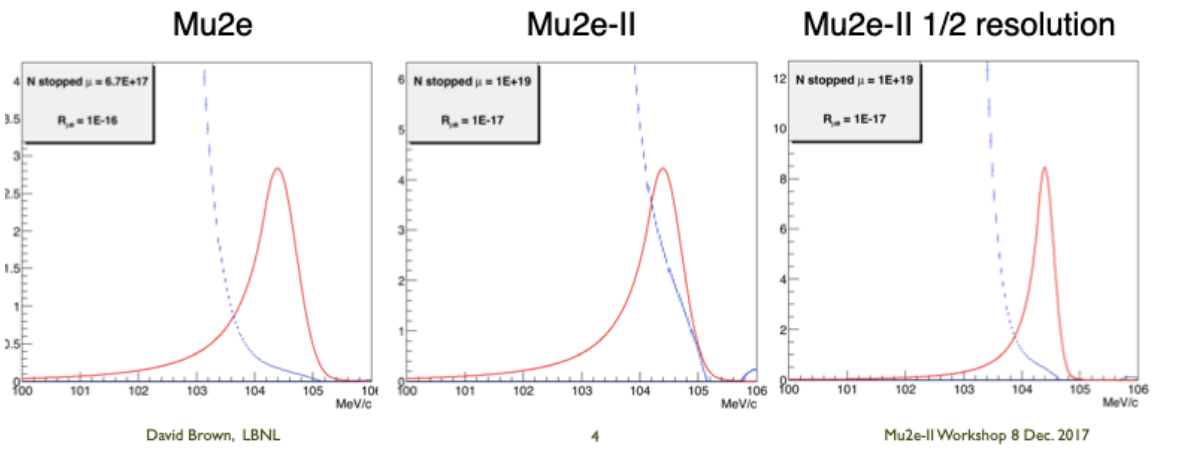


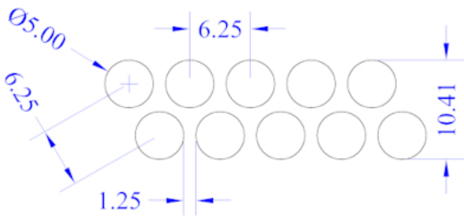
Conveyor

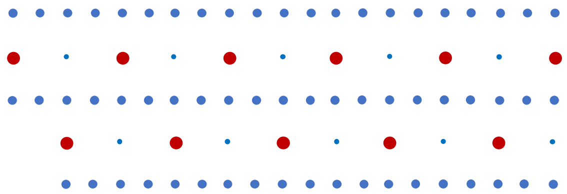
Tracker

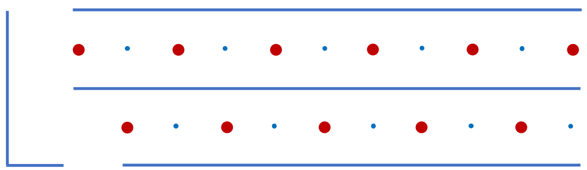
The increased muon intensity in the Mu2e-II experiment means the resolution of the tracker needs to be improved by about a factor 2











Reduction in the tracker mass

- Use thinner (8um) straws – currently testing a prototype and
- Remove the 200 angstrom layer of gold inside each straw

Different detector geometry

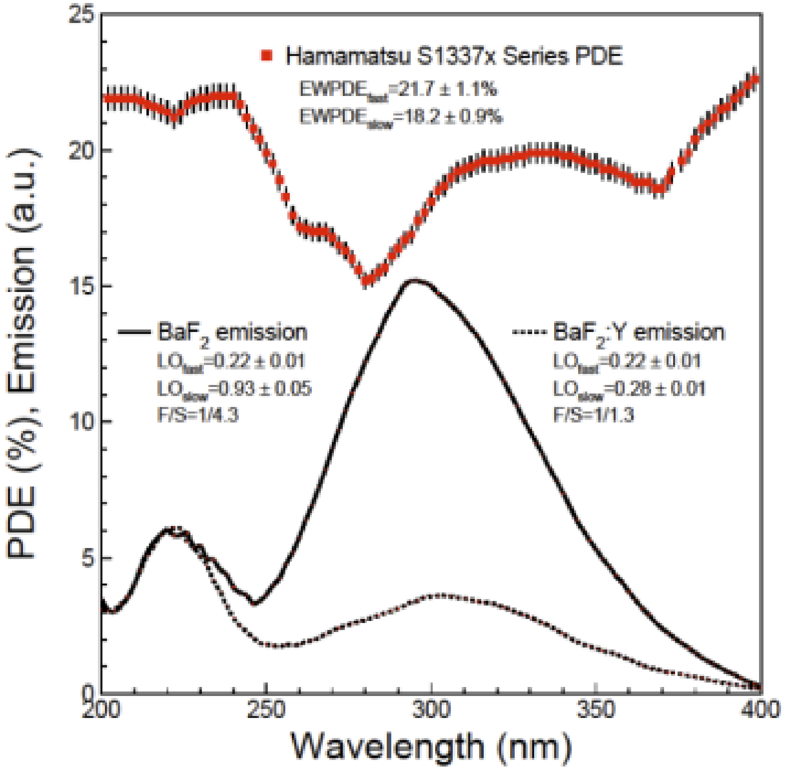
- Use an ultra light gas vessel to ease straw leakage requirements
- Consider an all wires construction and remove the straws
- Or wires separated by mylar walls
- Developing FastSim to assess this along with radiation levels

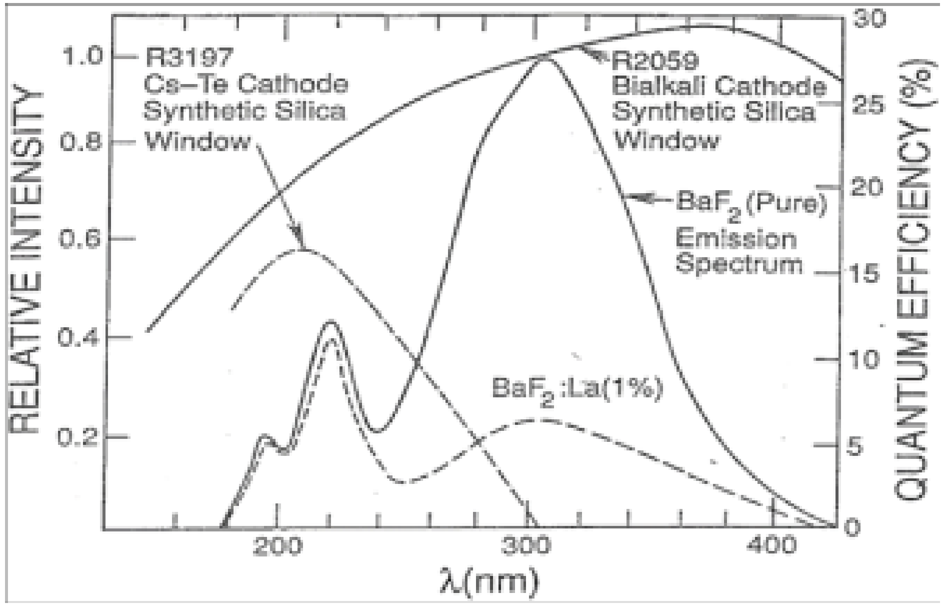
Different detector technology (e.g. Si sensors)

Calorimeter

The increased radiation levels and instantaneous rate in Mu2e-II requires more radiation hard crystals and a faster readout scheme

Currently concentrating of Barium Fluoride crystals, which have a fast (0.6ns) and slow (600ns) component of scintillation light





Looking to suppress the slow component through :

- Yttrium doping
- Use of a solar-blind photosensor
  - Interference filter with thin layers of earth oxides
  - Nanoparticles in a silicon cookie

The radiation hardness of the crystals and the readout electronics is also currently under investigation

These approaches will be refined over the year and other ideas looked into

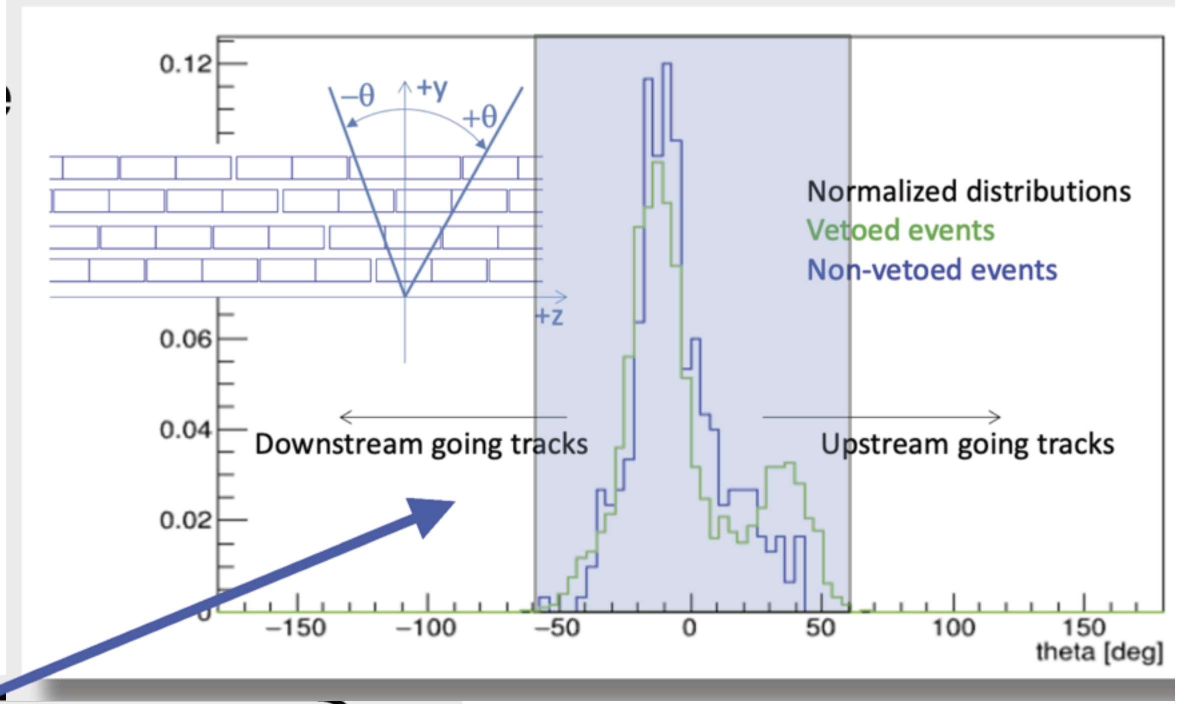
Cosmic Ray Veto

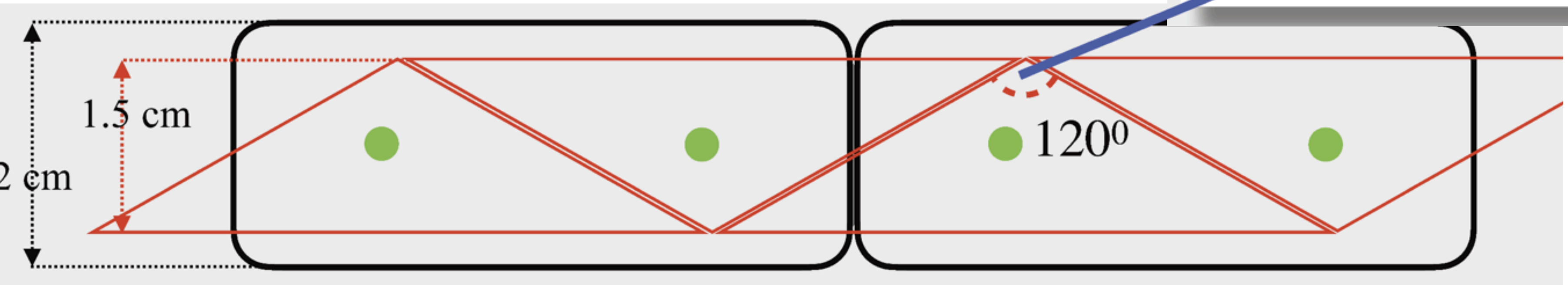
The increases in beam intensity and live time produces challenges for the CRV in Mu2e-II

- Cosmic ray background scales with live time (3x Mu2e)
- The increase in beam rate results in a higher deadtime
- The increase in radiation dose to the electronics
- The reduction in efficiency due to aging

To mitigate this different options are under investigation :

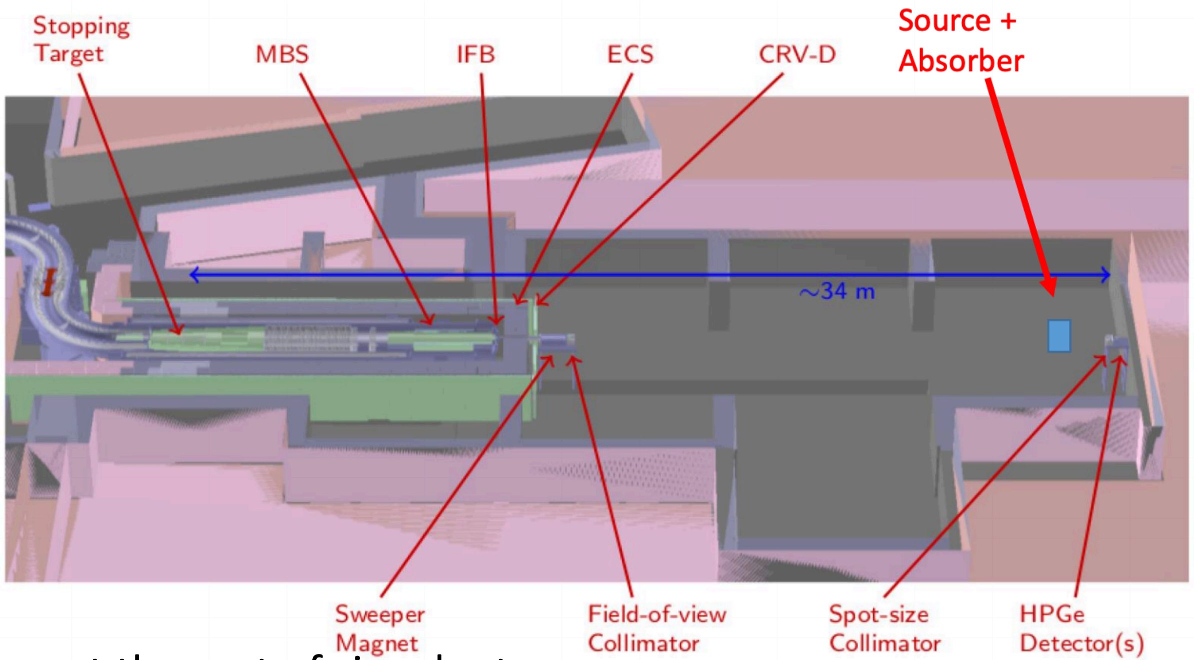
- Increased/improved shielding
- Finer granularity counters
- A triangular design to minimize gap effects
- Use of high rate detectors in hot regions
- Higher efficiency SiPMs
- A smaller detector directly around the stopping target





Stopping Target Monitor

The Mu2e STM provides the normalisation for the experiment using an HPGe and LaBr detector placed in the line of sight of the stopping target



The Mu2e-II environment poses significant challenges for the HPGe detector :

- The more intense prompt beam induced flash with the slow recovery time
- The higher levels of neutron damage

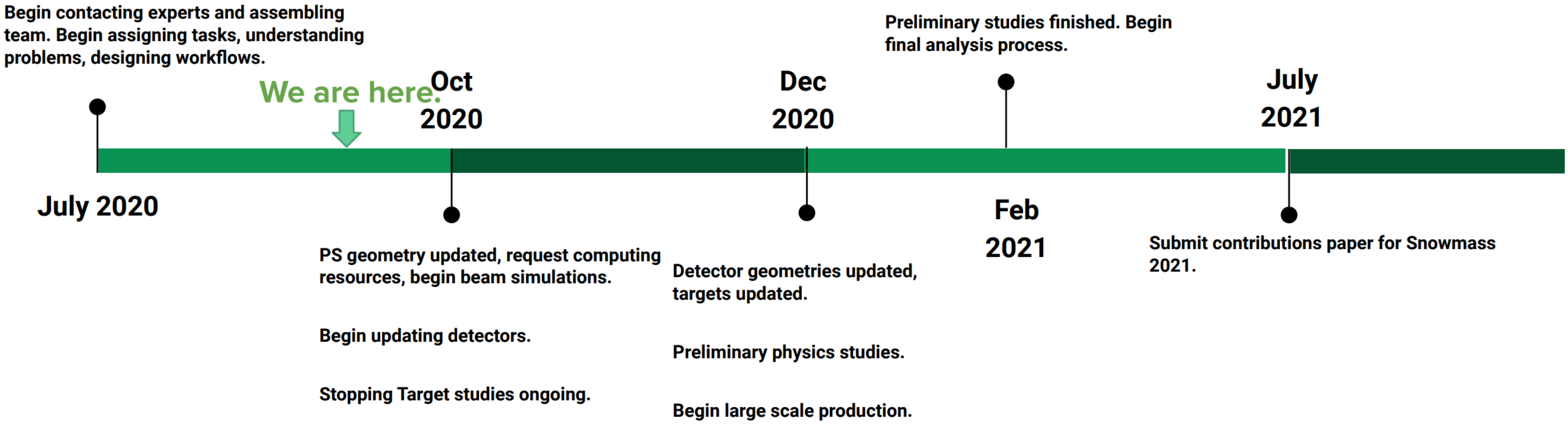
Mitigation strategies being considered :

- Reduce the beam flash by increasing the absorber thickness at the cost of signal rate
- Use the LaBr and calibrate with the HPGe during special low intensity runs
- Gate off the LaBr photodetector during the flash (only for materials with delayed emission lines)
- Move the detector off axis although space may be an issue
- Replace some crystals in the calo with LYSO or LaBr
- Create a tertiary photon beam

These will be refined as the detectors are further characterised throughout the coming year

Sensitivity Estimates

All the new detector studies get fed into the simulation in order to produce the expected single event sensitivity for Mu2e-II



Currently studies are ongoing with different production and stopping targets

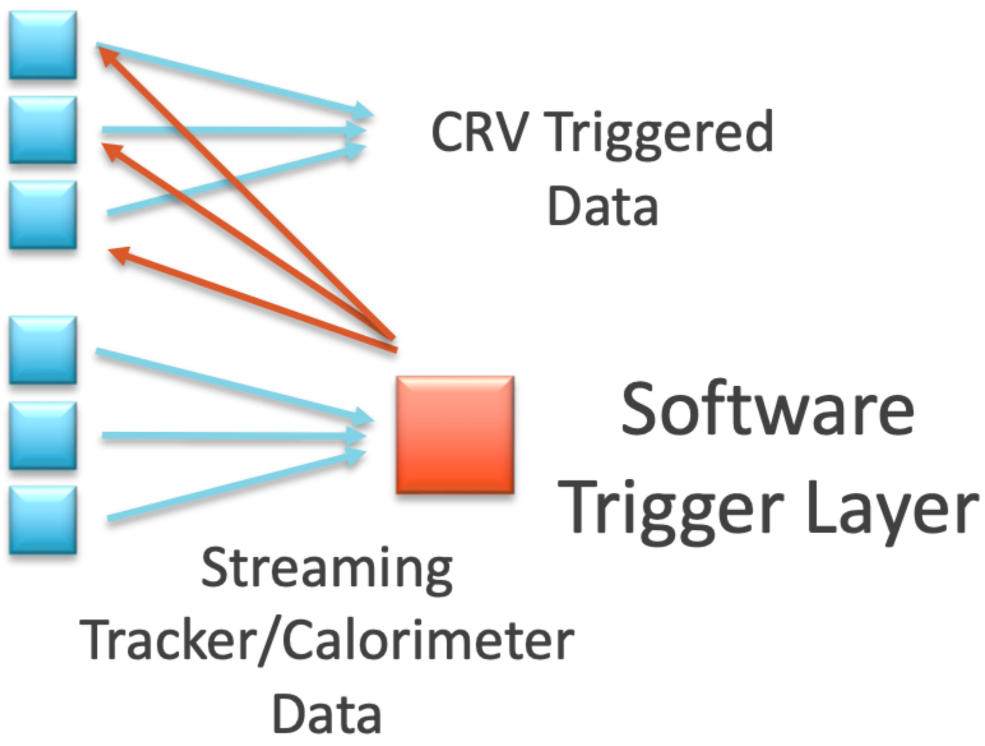
The sensitivity group is in close contact with the development of the other detector systems

TDAQ

The increased data rate, more background and more detector channels mean an expected level of 3000:1 rejection is needed

Other considerations :

- **Reduced or no off spill time** to readout large front end buffers (Mu2e has a second to catch up)
- **Currently no large buffers for the CRV**
- **Streaming vs triggered data taking**
- **Radiation tolerance requirements** – learn from the LHC?



Potential solutions :

1. A 2-level TDAQ system based on FPGA pre-processing and trigger primitives
2. A 2-level TDAQ system based on FPGA pre-filtering
3. TDAQ based on GPU co-processor
4. A trigger-less TDAQ system based on software trigger

The various options are currently being discussed and investigated to work out the best solution

Conclusions

Mu2e-II is the logical next step in the continuing program of muon CLFV studies

- **Mu2e-II will improve upon the sensitivity of Mu2e by an order of magnitude** which is extremely valuable whether a signal is observed at Mu2e/COMET or not
- **Significant work is ongoing to upgrade the Mu2e systems for the Mu2e-II environment**
    - Production Target
    - Stopping Target
    - Tracker
    - Calorimeter
    - Cosmic Ray Veto
    - Stopping Target Monitor
    - TDAQ
- **There is a well defined timeline for all the components to be brought together to produce the white paper(s)**
- **This could be a step towards a substantial high intensity muon facility at FNAL**

We hope that the snowmass process will see the important physics case for building Mu2e-II and the new and useful technologies that are being developed in the process and provide strong support for continued investment in the future