Coherent CAPTAIN-Mills

10 ton liquid Argon scintillation detector at Los Alamos National Lab

LIght Detection In Noble Elements Conference

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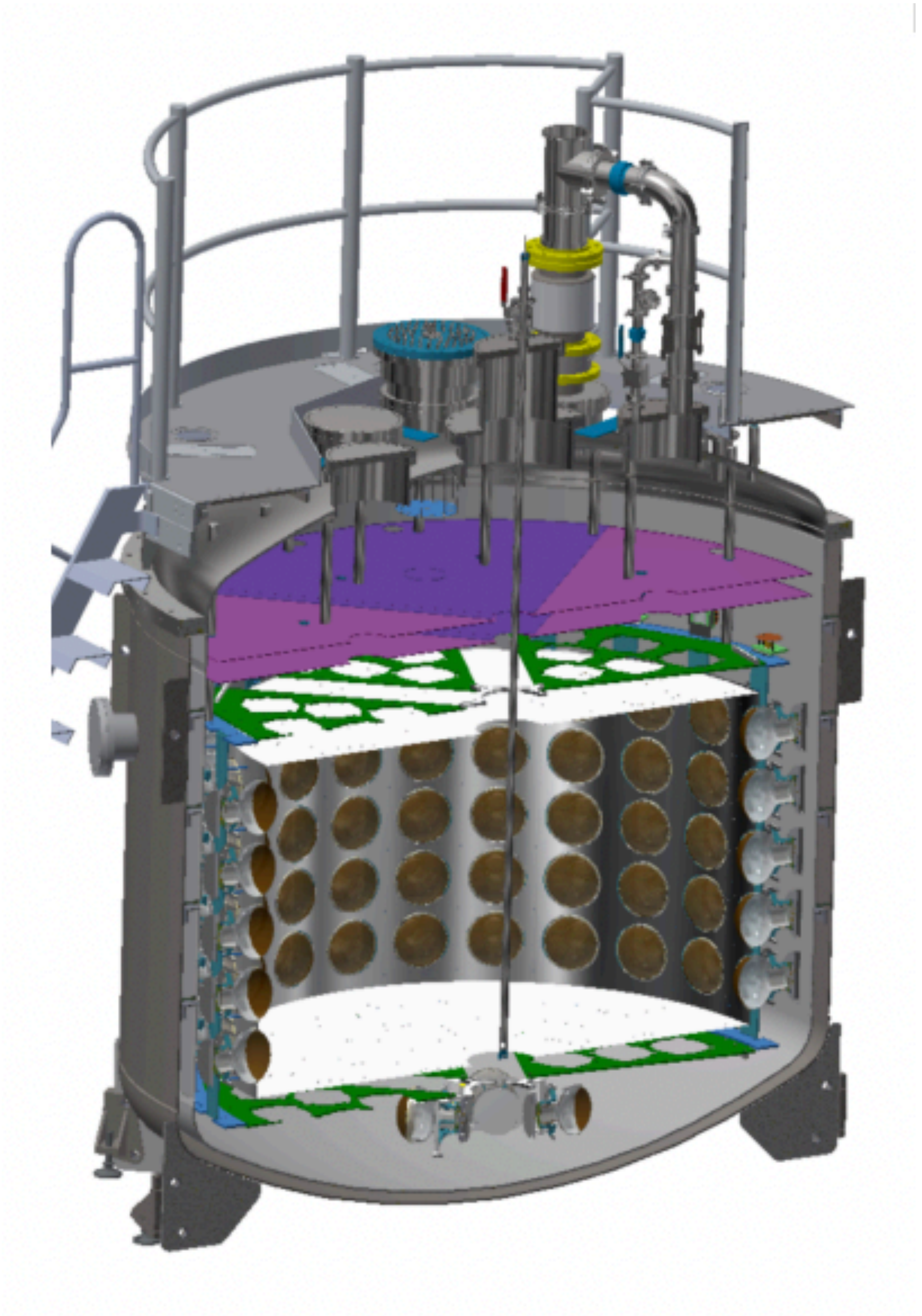
Outline

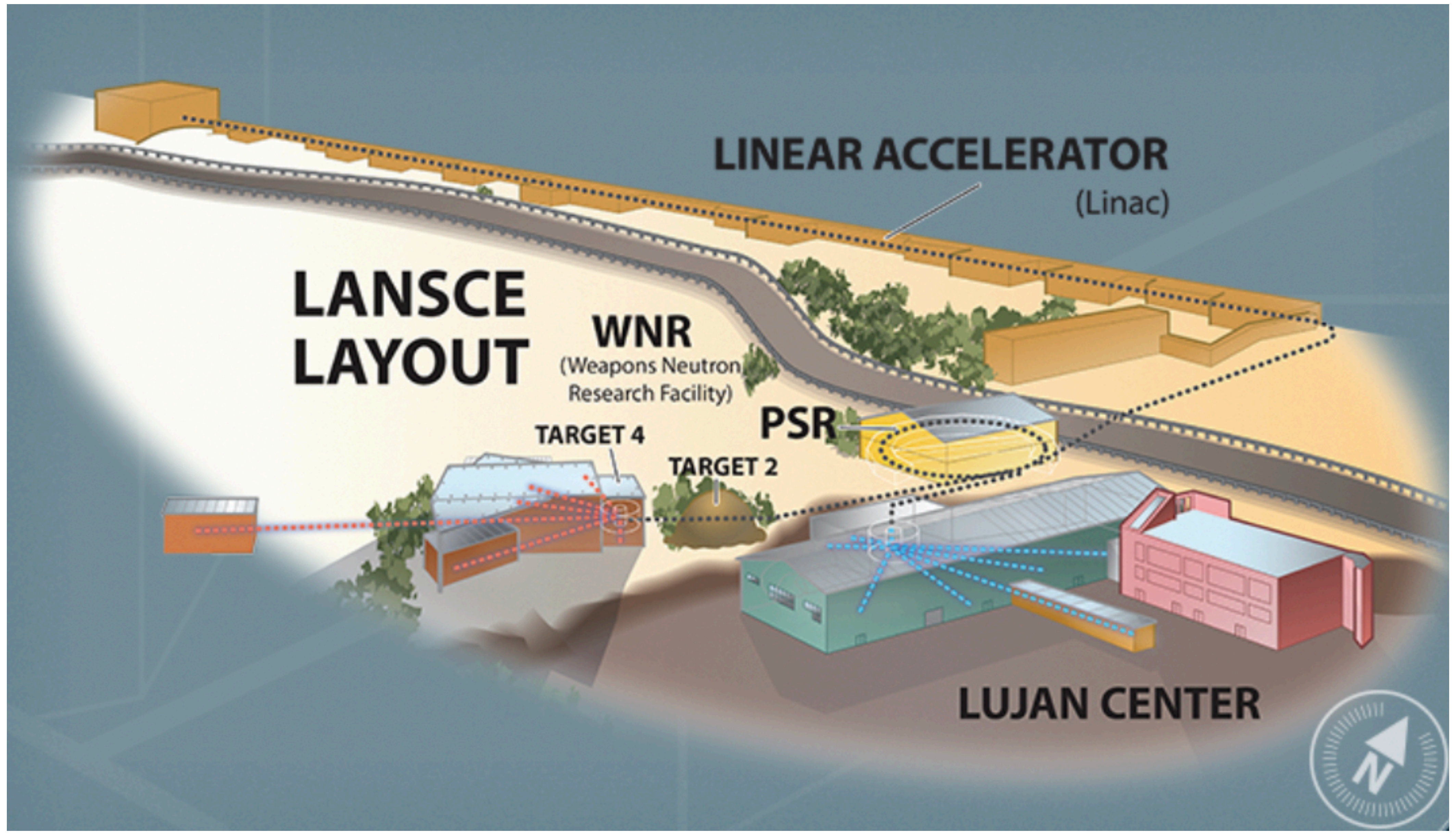
1. The Detector
2. Physics Program
3. Future Upgrades



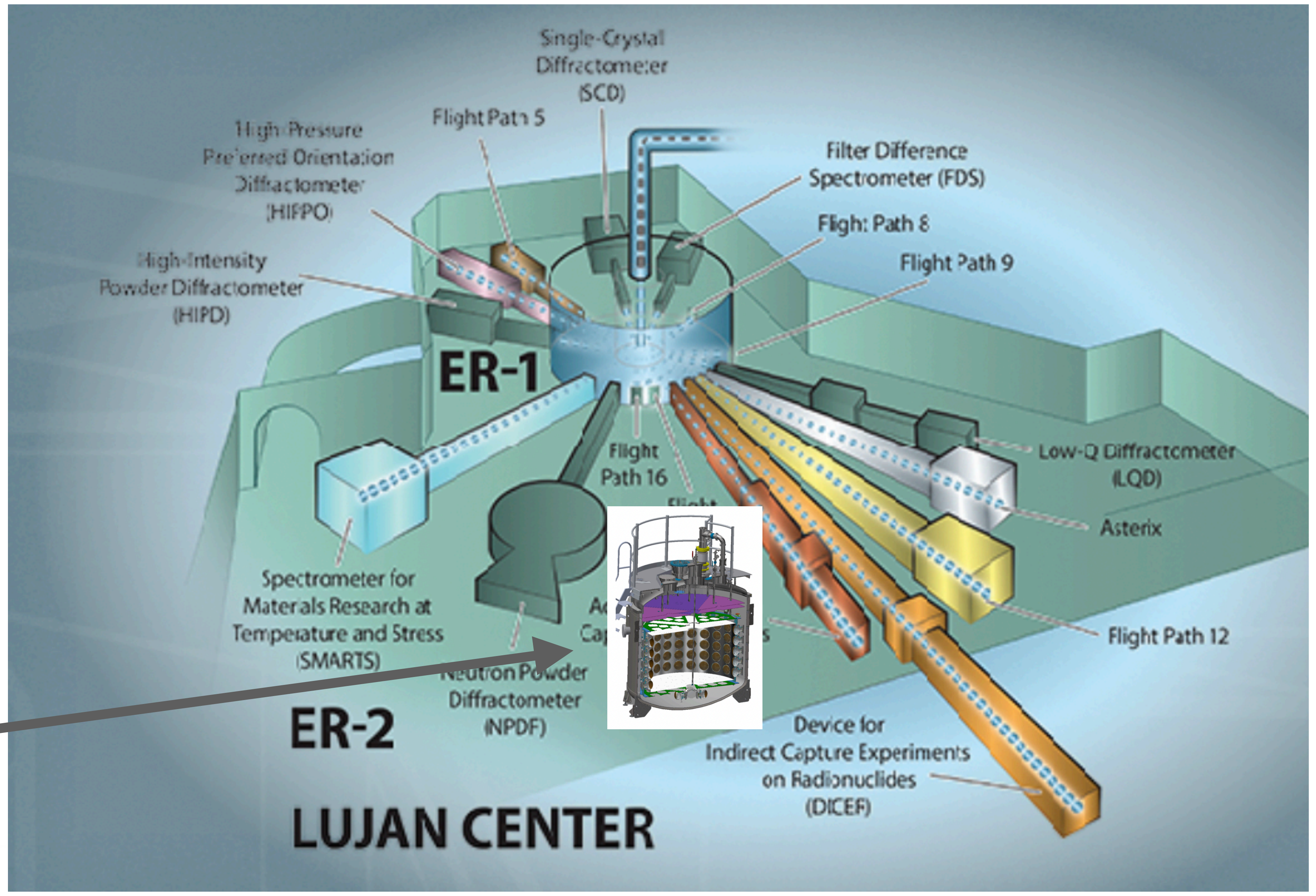
The Detector

Experimental Facilities

Los Alamos Neutron Science Center (LANSCE)



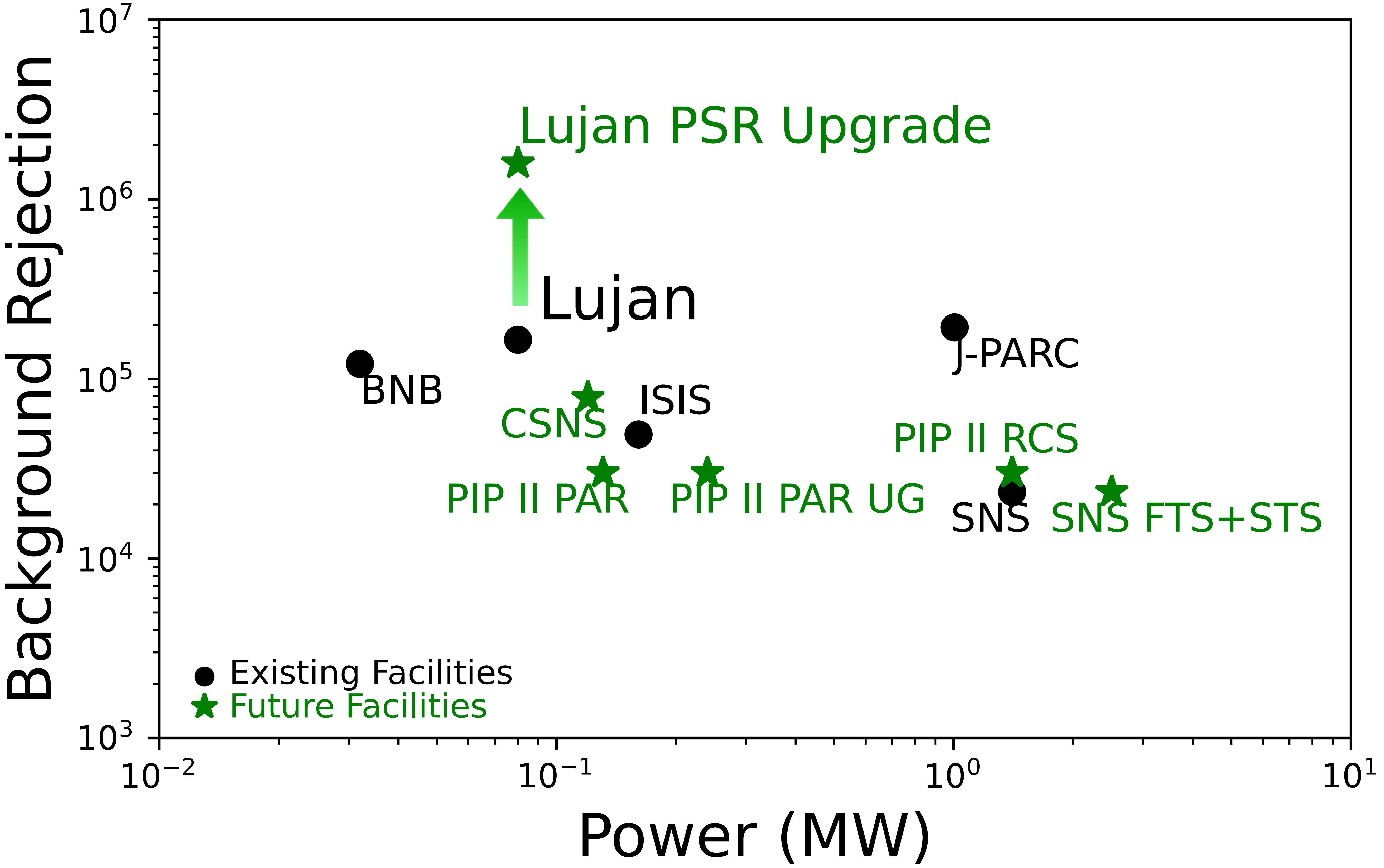
- **800 MeV proton beam** bunched in the proton storage ring (PSR) with100 μAmp current, 290 nsec beam spill, and pulsed at 20 Hz
- Protons incident on tungsten target in Lujan Center, pion decay at rest creates **prompt** flux of 30 MeV ν_μ and delayed flux of $\overline{\nu_\mu}$ and ν_e



CCM Detector

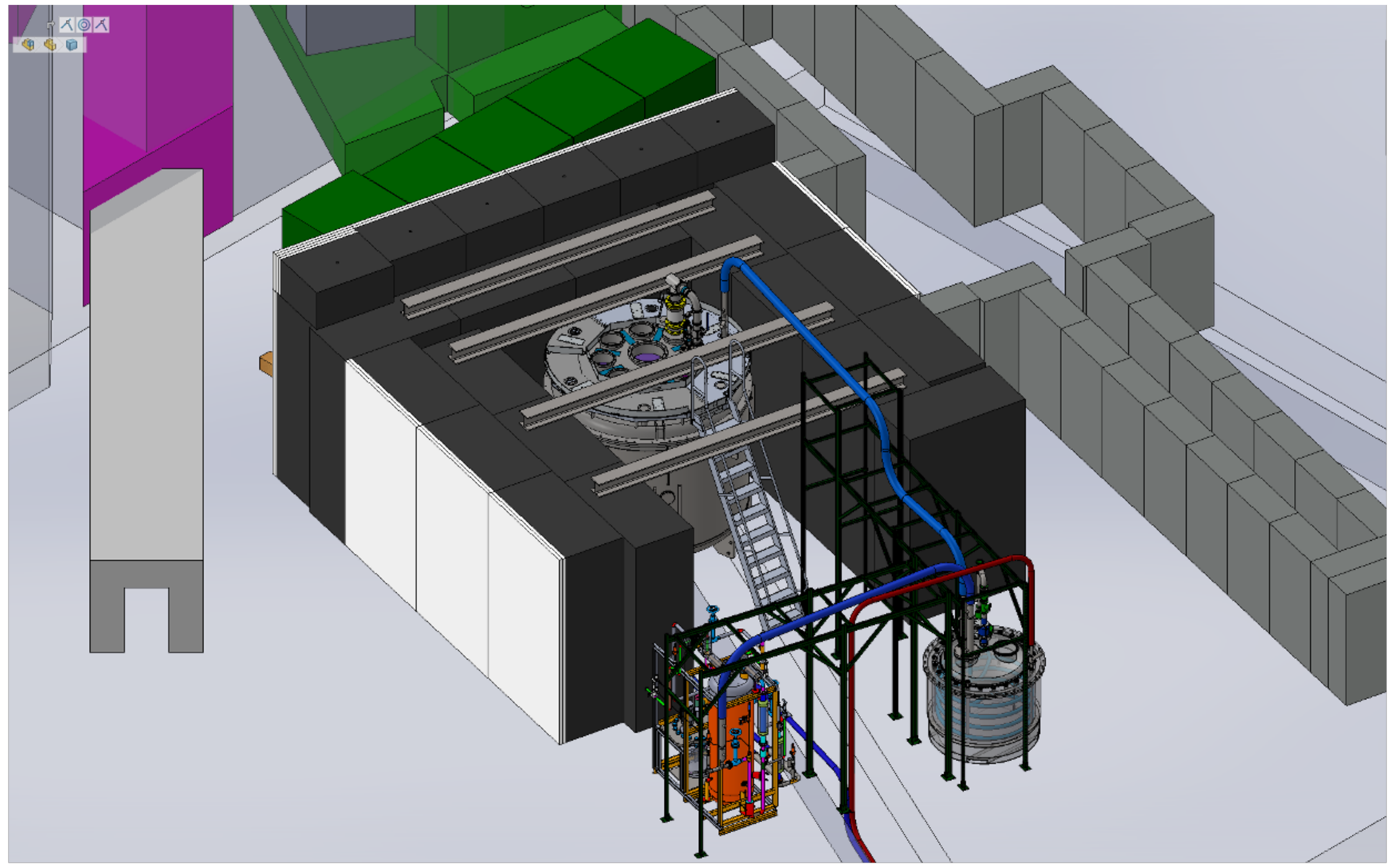
Lujan Facility Capabilities

- Lujan Facility upgrades focusing on **background rejection**, lower power can be compensated with larger detector
- 10 year upgrade to increase background rejection by an order of magnitude through shortening beam spill window from 120 ns to 30 ns



Lujan Facility

- Detector positioned 90˚ off axis from the proton beam and 23m from tungsten target
- ~2.5m diameter and ~2m tall cylindrical cryostat contains 200 8” photomultiplier tubes (PMT) for **5 ton fiducial LAr volume**
- **5 ton optically isolated active veto region** surrounding fiducial volume with 40 1” veto PMTs
- The Lujan facility will receive $2.25 \cdot 10^{22}$ POT in the upcoming 3 year run cycle, producing flux of $5.28 \cdot 10^{5}$ ν /cm²/s



Timeline

Run starts in the next two weeks!

CCM120 Engineering Run

- Prototype detector
- Testing 120 PMTs for SBND
- **Produced physics results**

CCM200 Engineering Run

- Upgraded detector to 200 8” PMTs
- Doubled veto PMT coverage
- Increased forward shielding

CCM200 Physics Run

- Improved DAQ to handle more calibration streams
- Installed additional top-shielding
- New filtration system

2019

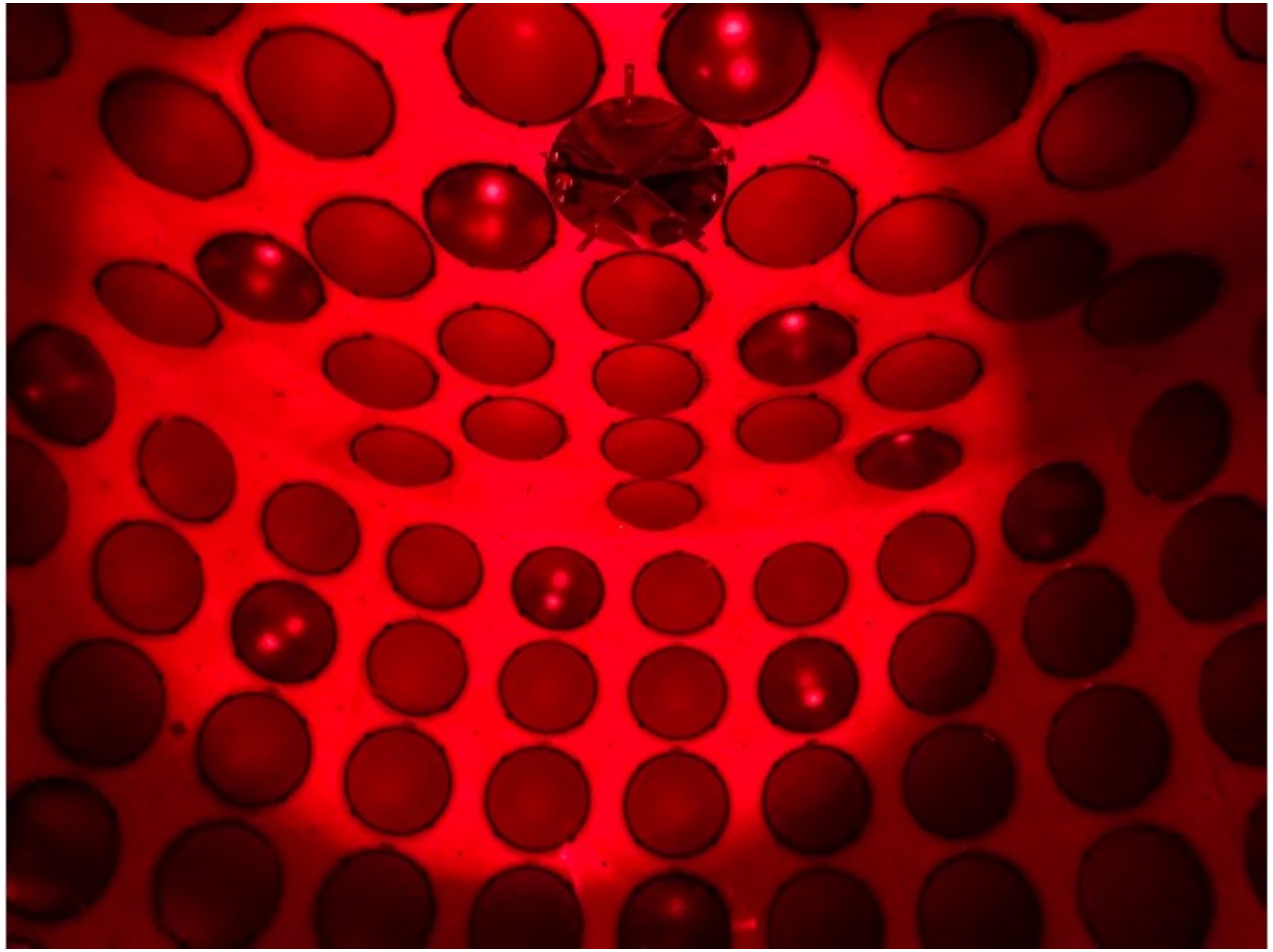
2021

2022

CCM120 physics results published here and here!

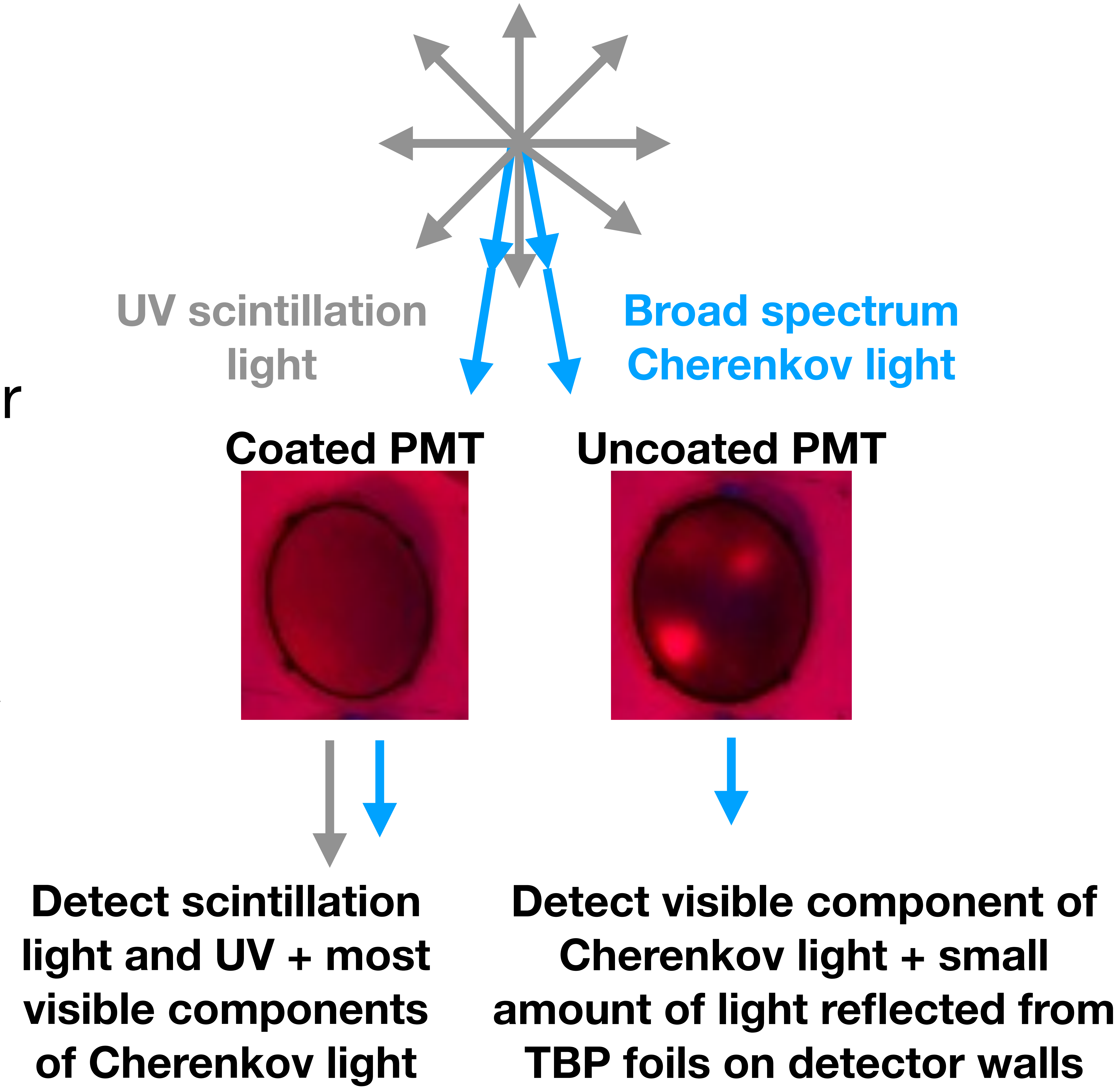
CCM200 Detector

- Electronics have **2ns** sampling time
- Energy detection range from ~10 keV to ~200 MeV
- 80% of PMTs coated in 1,1,4,4-Tetraphenyl-1,3-butadiene (TPB) to **wavelength shift LAr scintillation light**
- TPB foils on walls of the detector **(efforts led by Andrzej Szelc's group)**



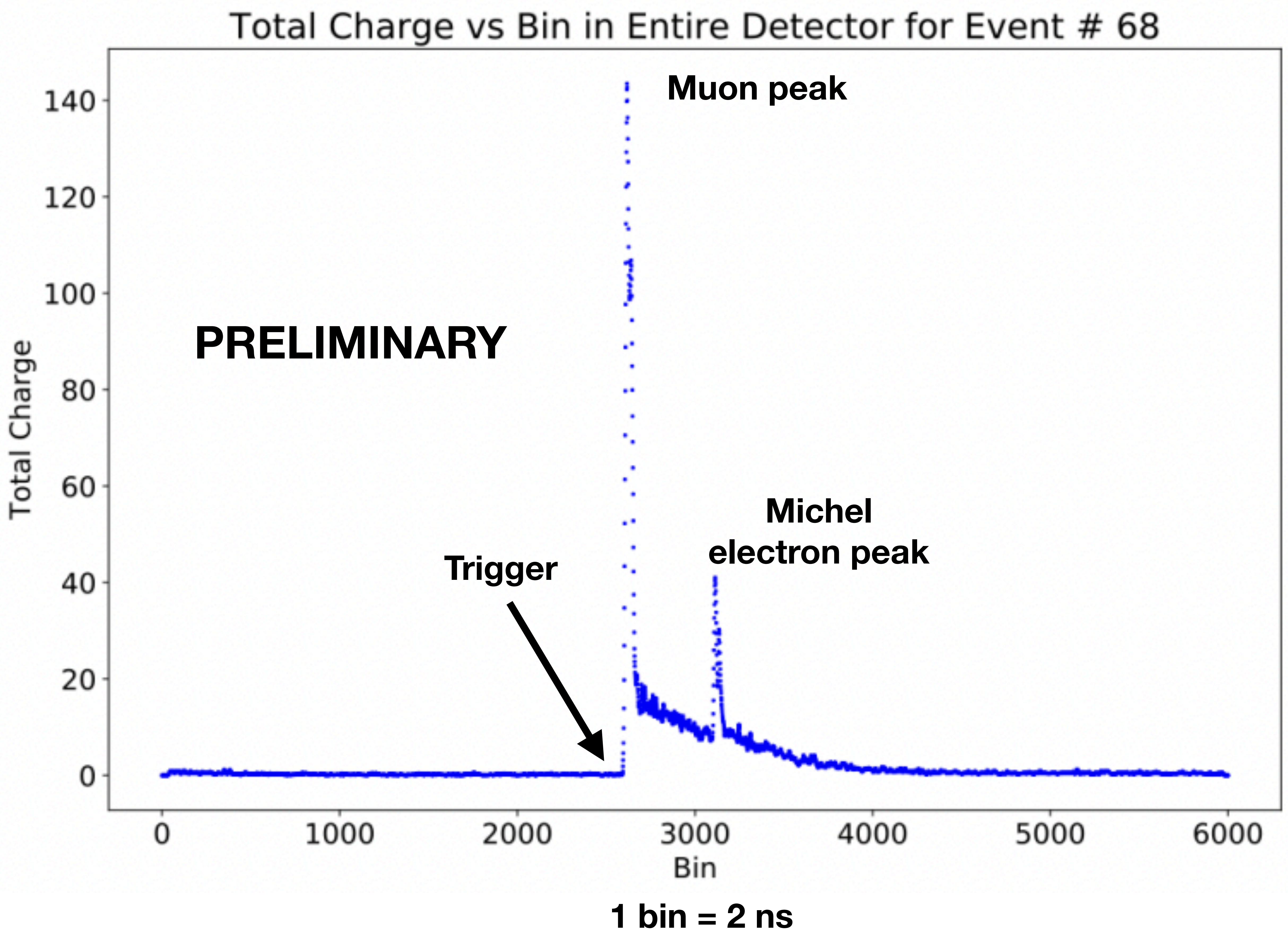
Light Collection

- TBP foils shift 128nm LAr scintillation light to the visible spectrum, allows better absorption by PMTs
- Combination of uncoated and coated PMTs allow for unique capabilities — simultaneous scintillation and Cherenkov light detection
- **Can isolate Cherenkov light in uncoated PMTs**



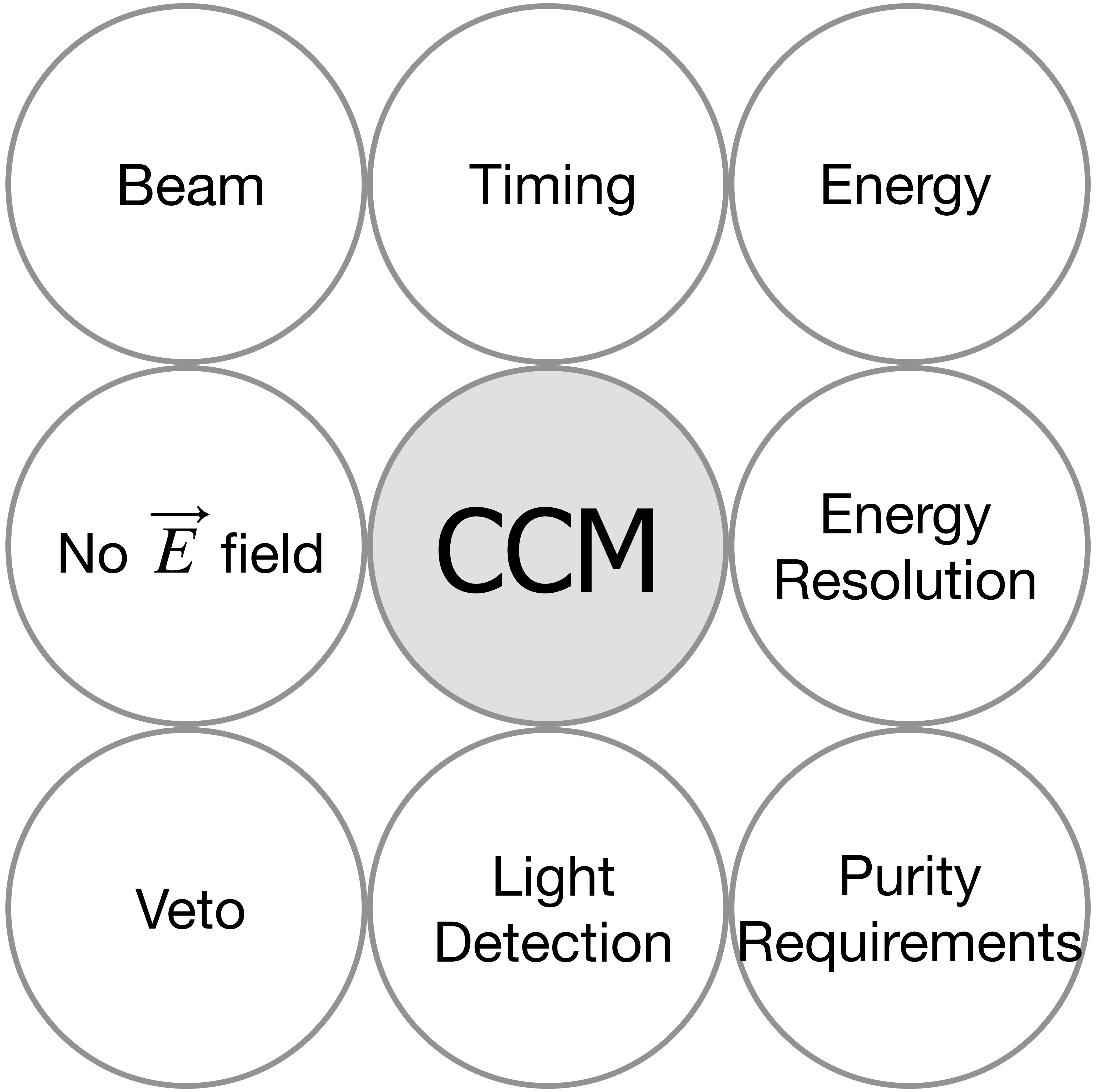
Cherenkov Light Detection

- **Analysis underway to identify Cherenkov light on event by event basis**
- Triggering on cosmic muon events using 5cm X 5cm external detectors that consist of two parallel scintillator panels and SiPM
- Using timing, direction, and uncoated PMTs to focus our search for Cherenkov light
- Provides Michel electron sample for energy calibration up to 50 MeV



Pros of CCM Design

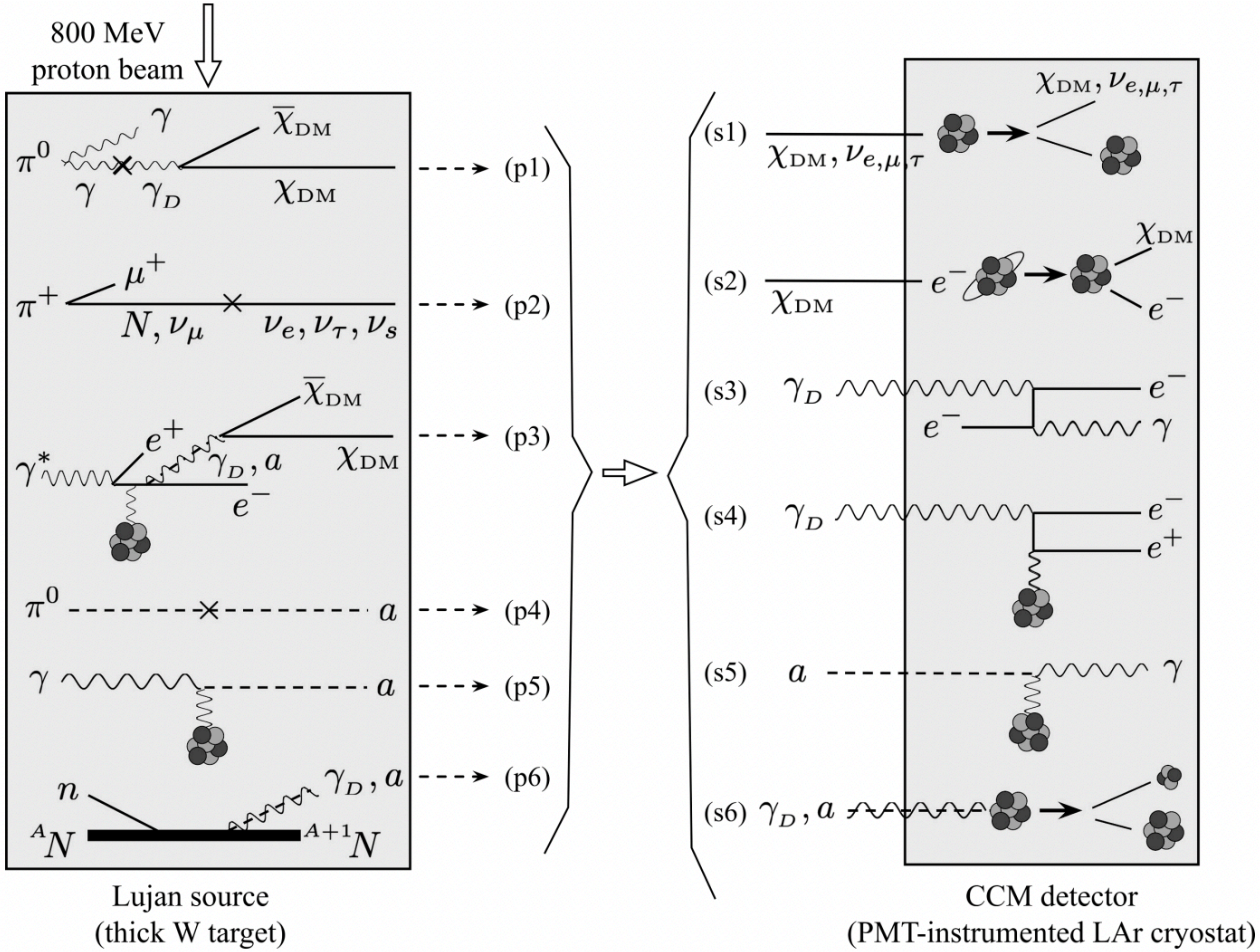
- Short beam duty factor, ~10^{-6}
- Fast timing (2ns sampling)
- Dynamic energy range — from nuclear recoil events at 10 keV to electromagnetic events around 100s MeV
- No electric field doubles photons detected compared to TPC
- High photocathode density allows for energy resolution ~20% and detection of Cherenkov light
- Integrated 5 ton veto region
- Purity requirements not as stringent for TPC



Physics Program

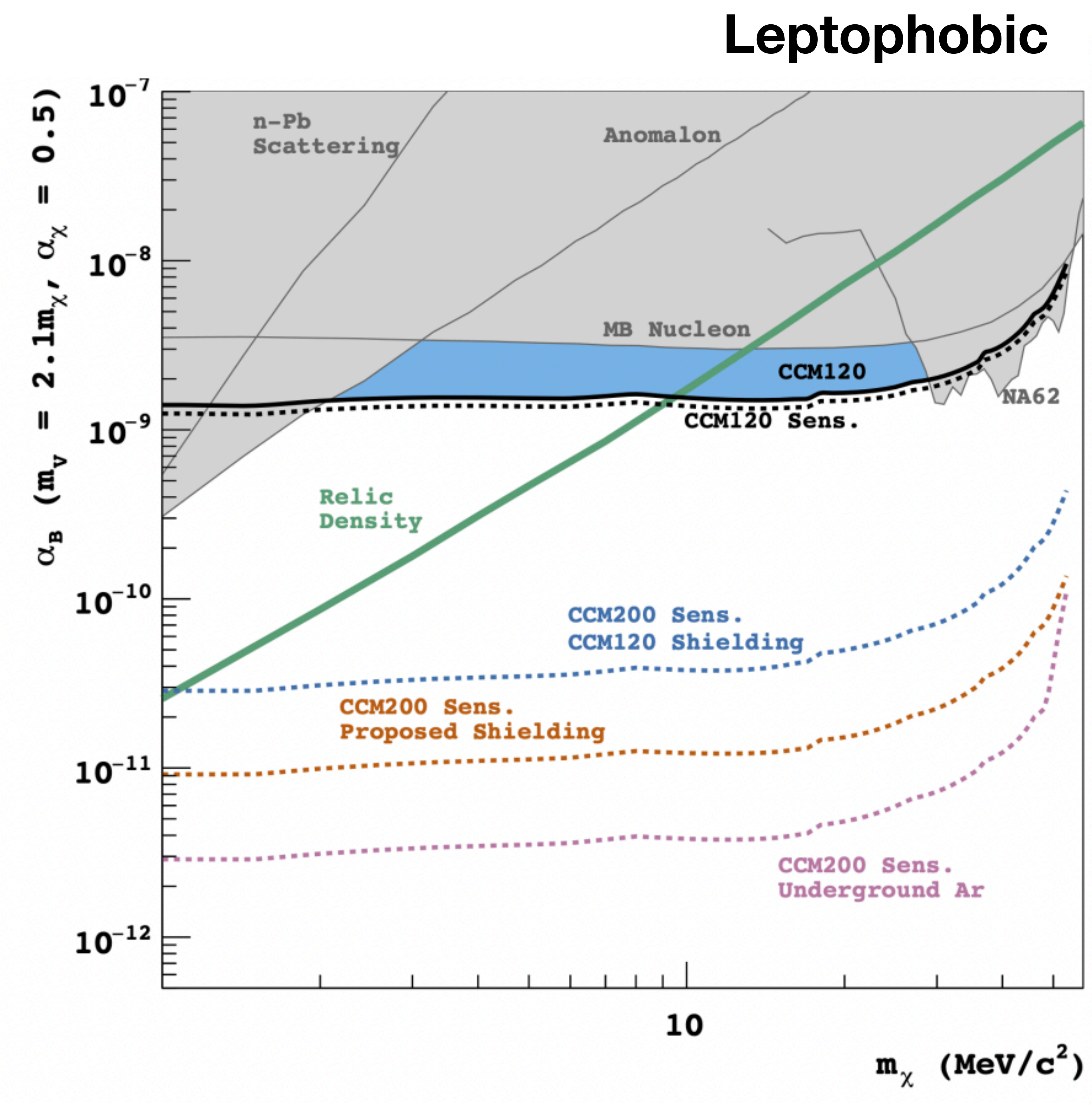
Physics Program Overview

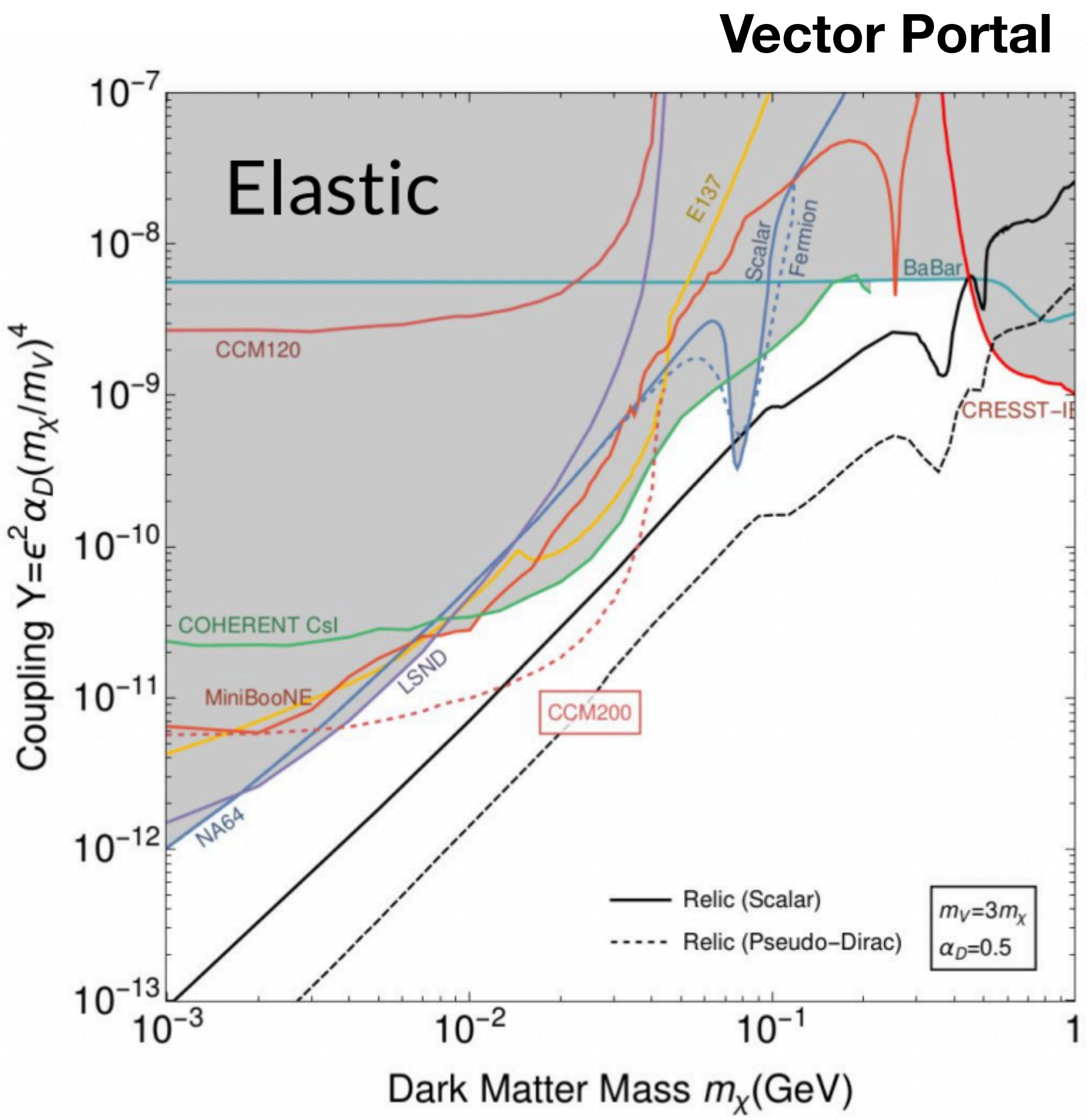
1. Search for light dark matter through coherent scattering off of Argon
    - Includes dark photon, leptophilic, and hadrophilic mediators
2. Search for longer lived dark particles
    - Axion like particles and heavy neutral leptons, dark sector coupling to meson decay as explanation for MiniBooNE excess
3. Precise measurements of neutrino-Argon cross sections $\mathcal{O}(10$ MeV)
    - Capabilities for charged current section measurements (applicable to constraining DUNE supernovae measurements) and detection of CEvNS



Light Dark Matter Search

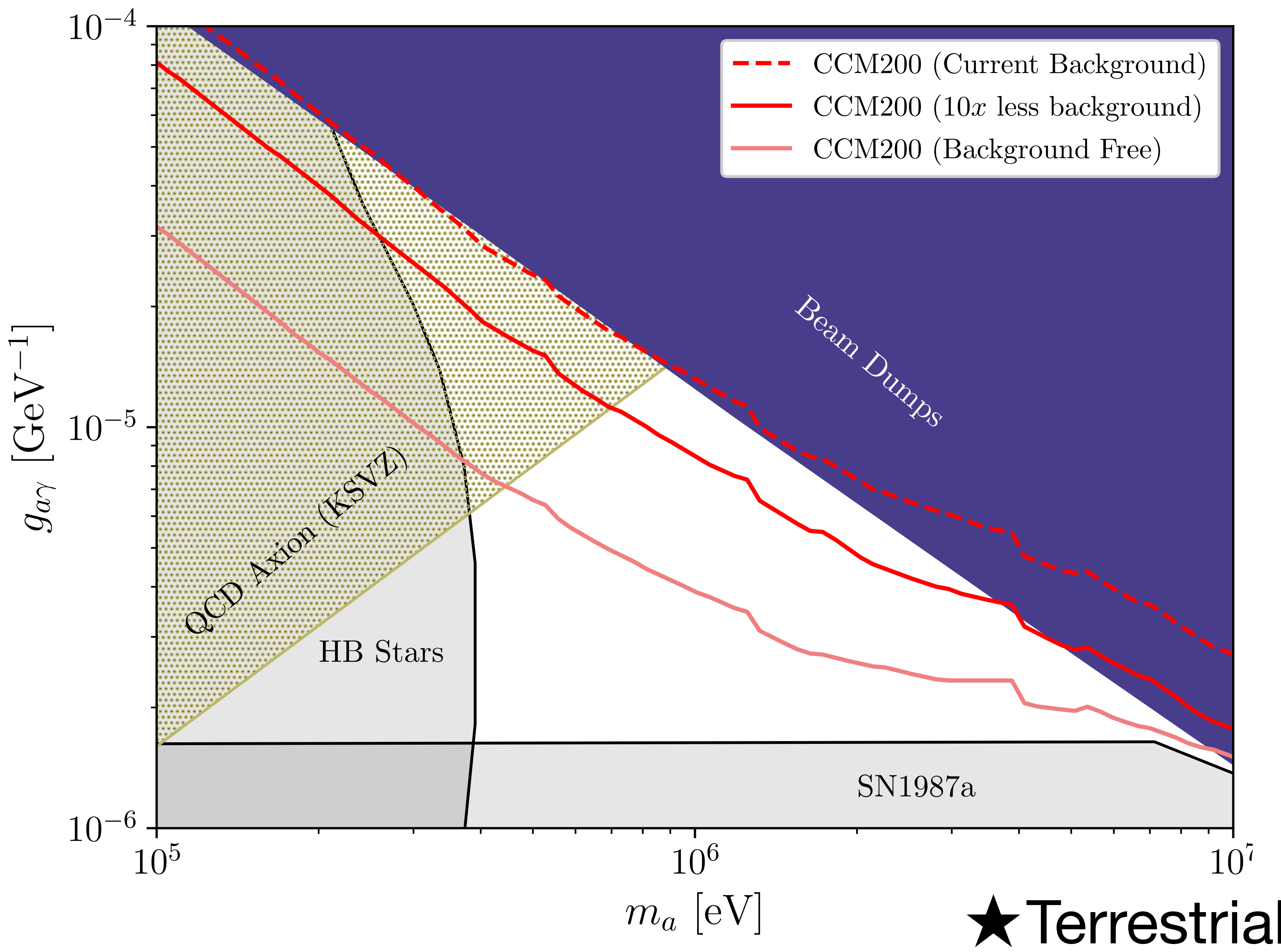
- Left plot shows leptophobic dark matter **limits set from CCM120 engineering run**, published here
    - Considering π^0 decays to final state γ and χ in the tungsten target, detection through coherent scattering off of argon nucleus
- Right plot shows predicted vector portal dark matter sensitivities of CCM200
    - Will begin to test the relic density limit below 50 MeV

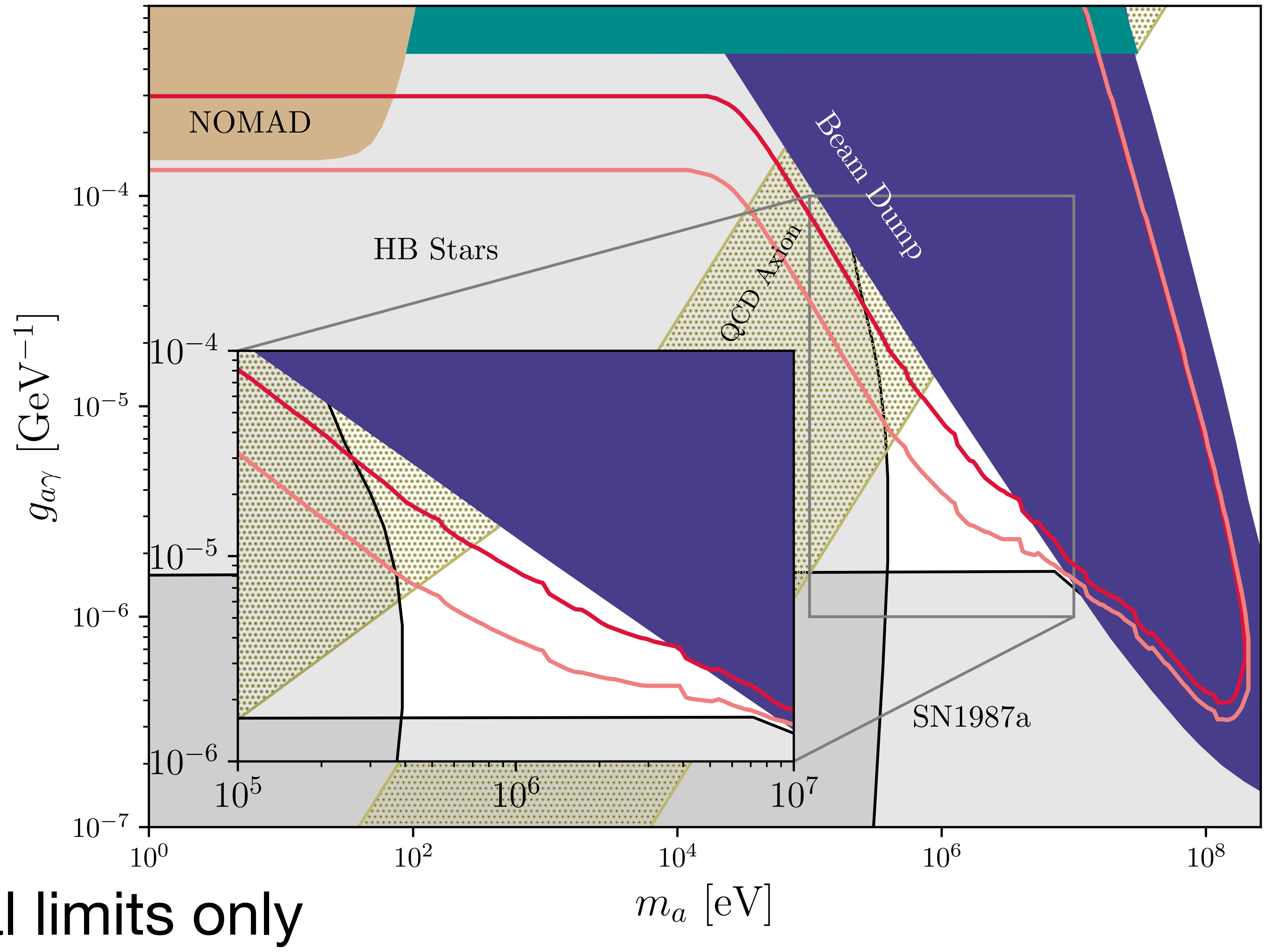




Axion Like Particle Search

- Considering ALP production through intense $e^{\pm}$, γ flux produced in the tungsten target and detection via EM final state particles
- ALP search, motivated by QCD axion, can probe "cosmological triangle"
- **See https://arxiv.org/abs/2112.09979 for further details**

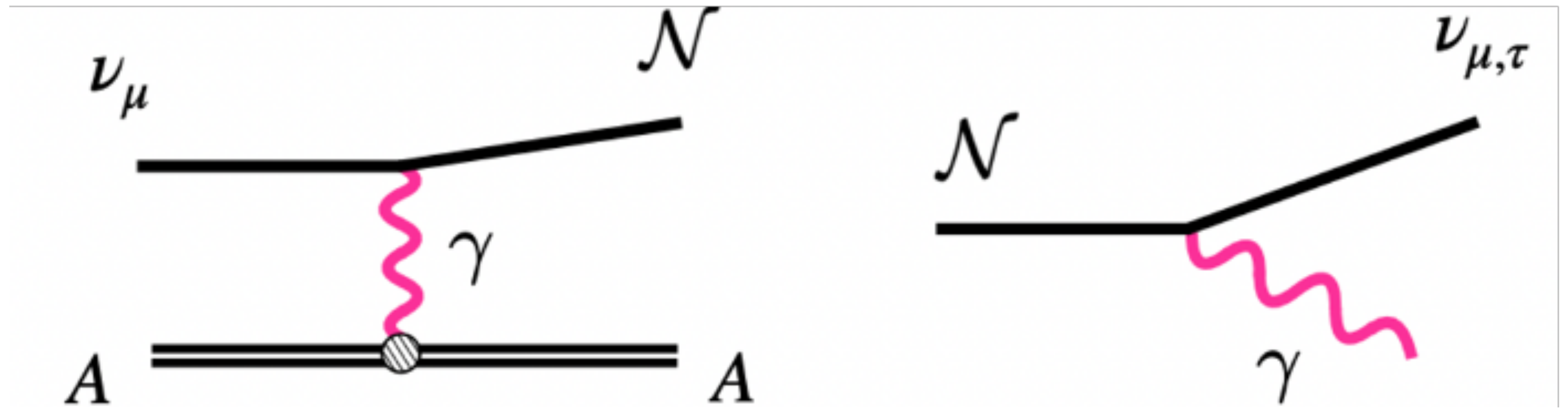




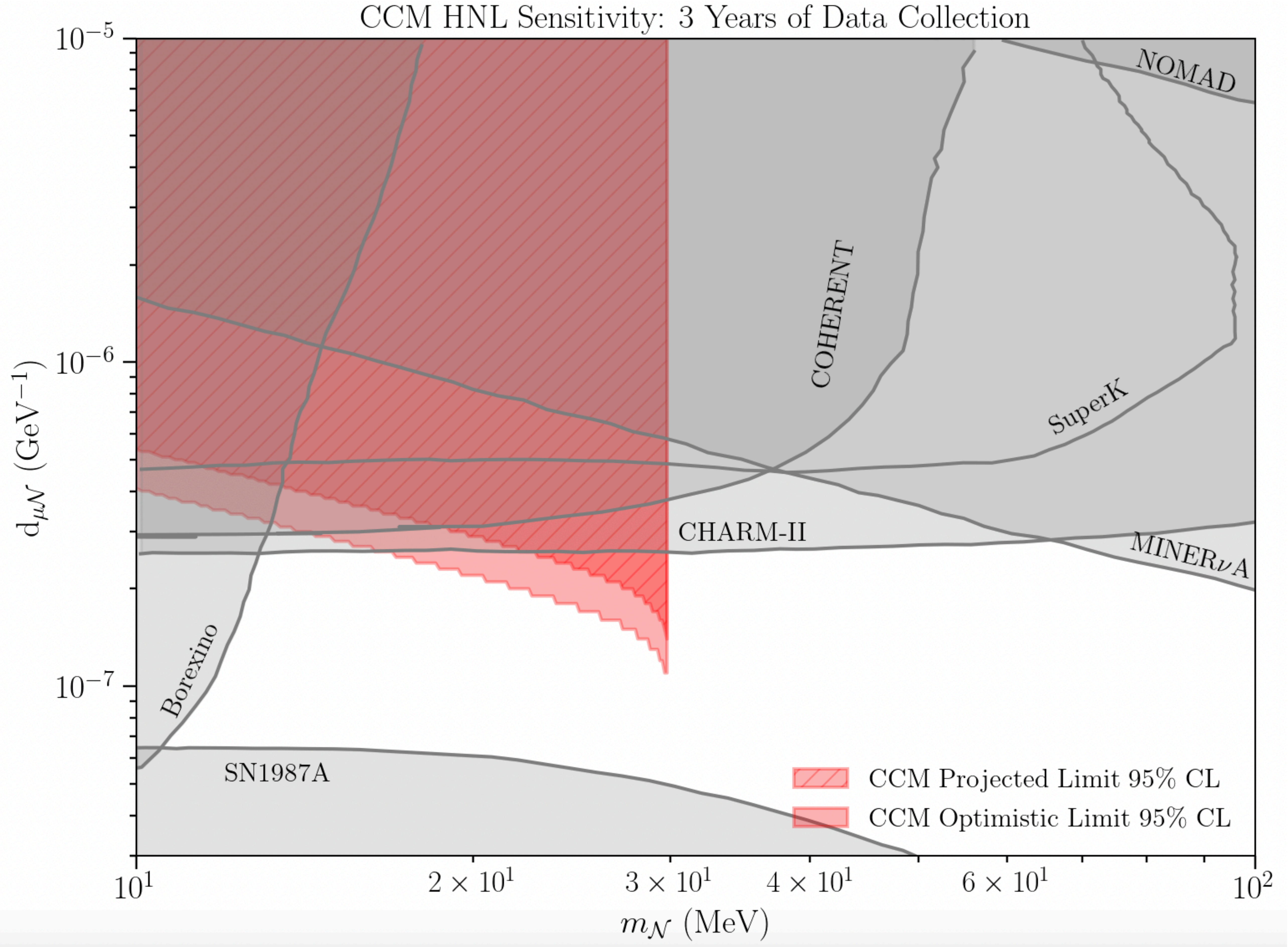
★Terrestrial limits only

Heavy Neutral Lepton Search

- CCM200 3 year run sensitivity to HNL production from neutrino upscattering in shielding and detector materials only



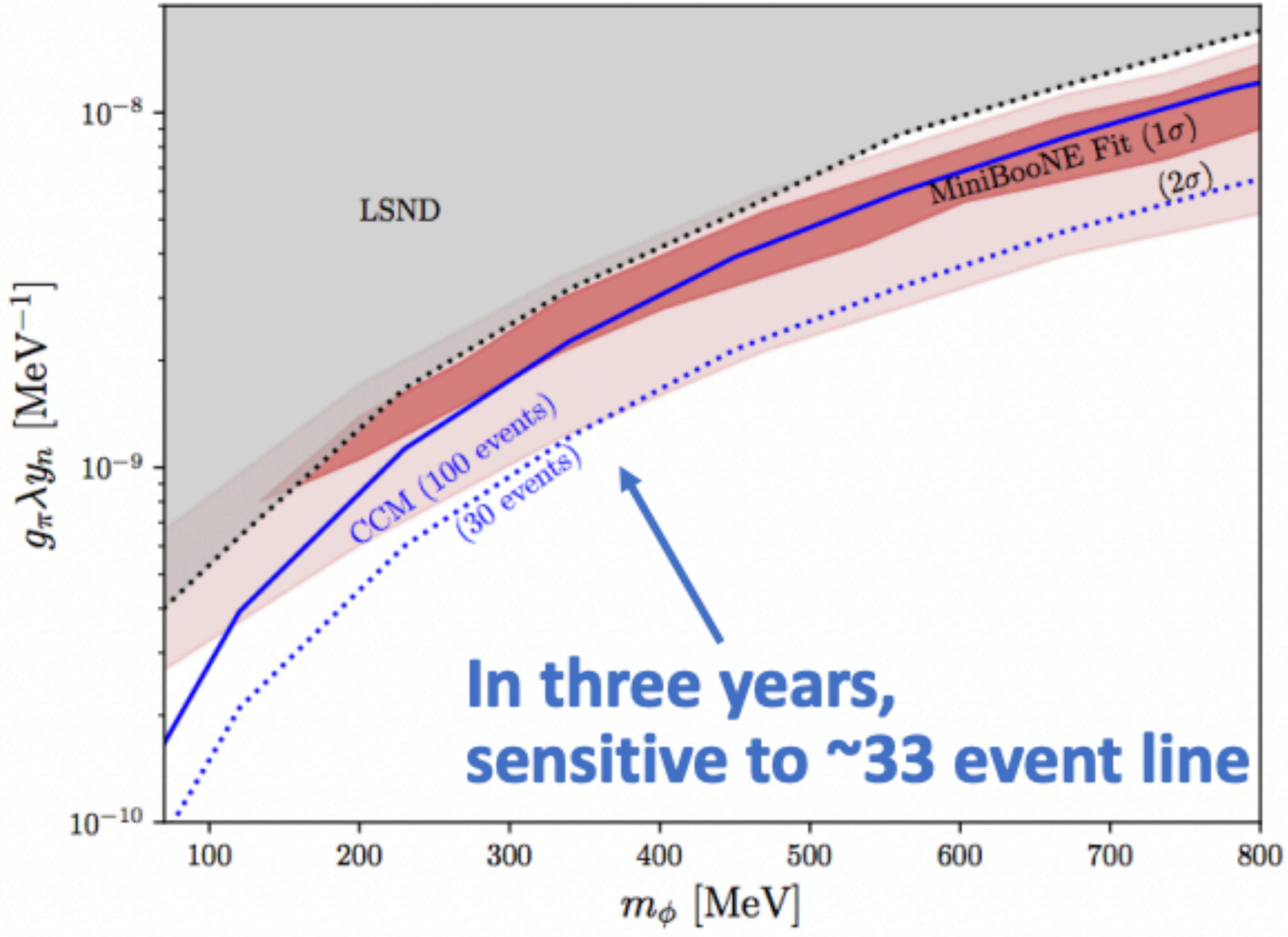
- Lujan facility is spacious enough to allow for increased shielding in future runs



Dark Sector Coupling to Meson Decay

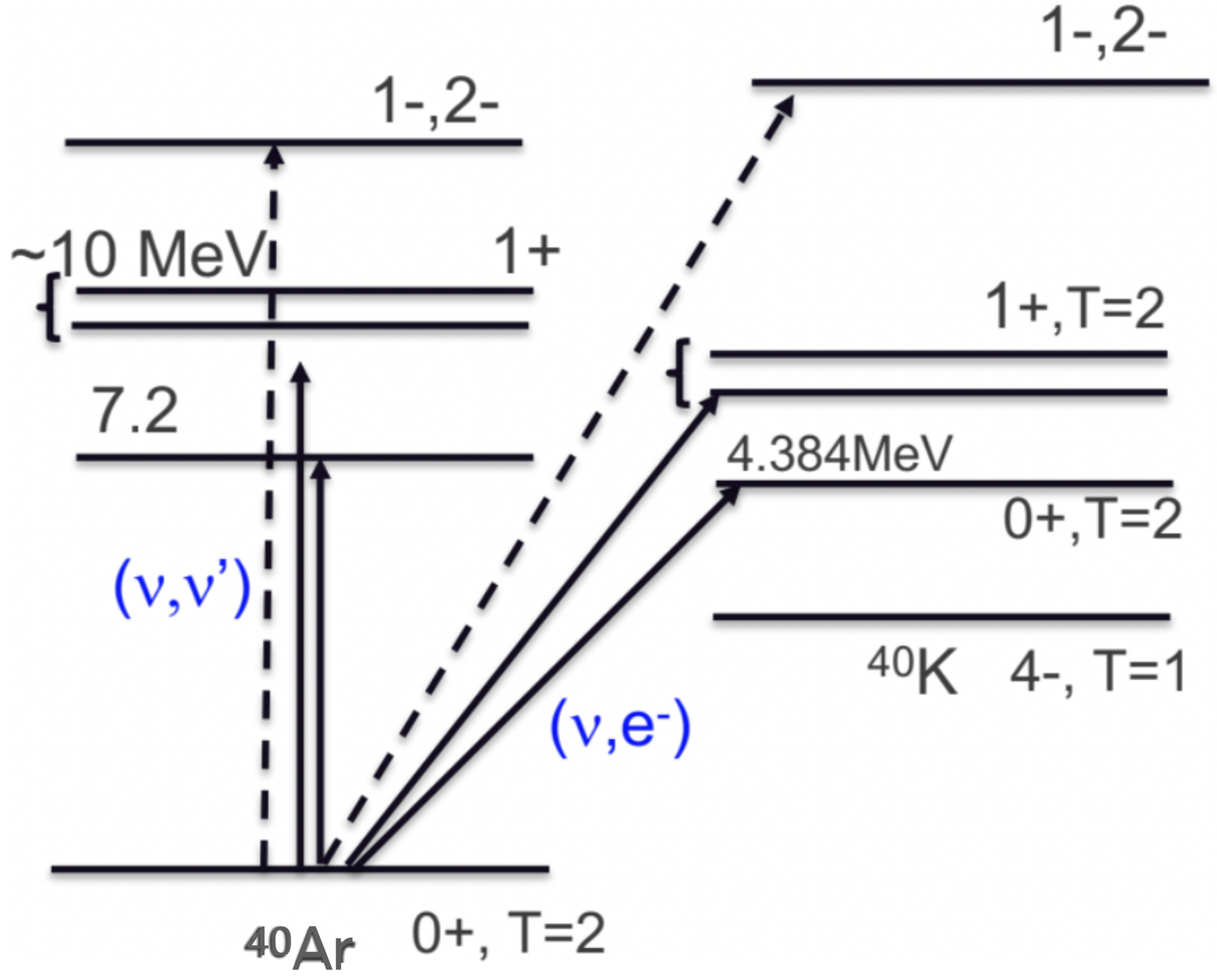
- CCM sensitivity to probe dark sector particles coupling to meson decay as a proposed explanation of MiniBooNE Low Energy Excess
- Considering 3 body meson decay producing scalar (or pseudo-scalar) particles
- Detecting nuclear recoil off Argon atoms or EM final state signatures
- **CCM200 3 year run cycle is predicted to probe 2σ region of MiniBooNE fit**

https://arxiv.org/abs/2110.11944



Cross Sections

- CCM200 has sensitivity to charge current (CC) neutrino interaction on Argon nucleus cross section
- CC measurements are useful to constrain future supernovae neutrino measurements in DUNE and other LAr detectors
- Exploring CEvNS measurements using nuclear recoil signatures



Future Upgrades

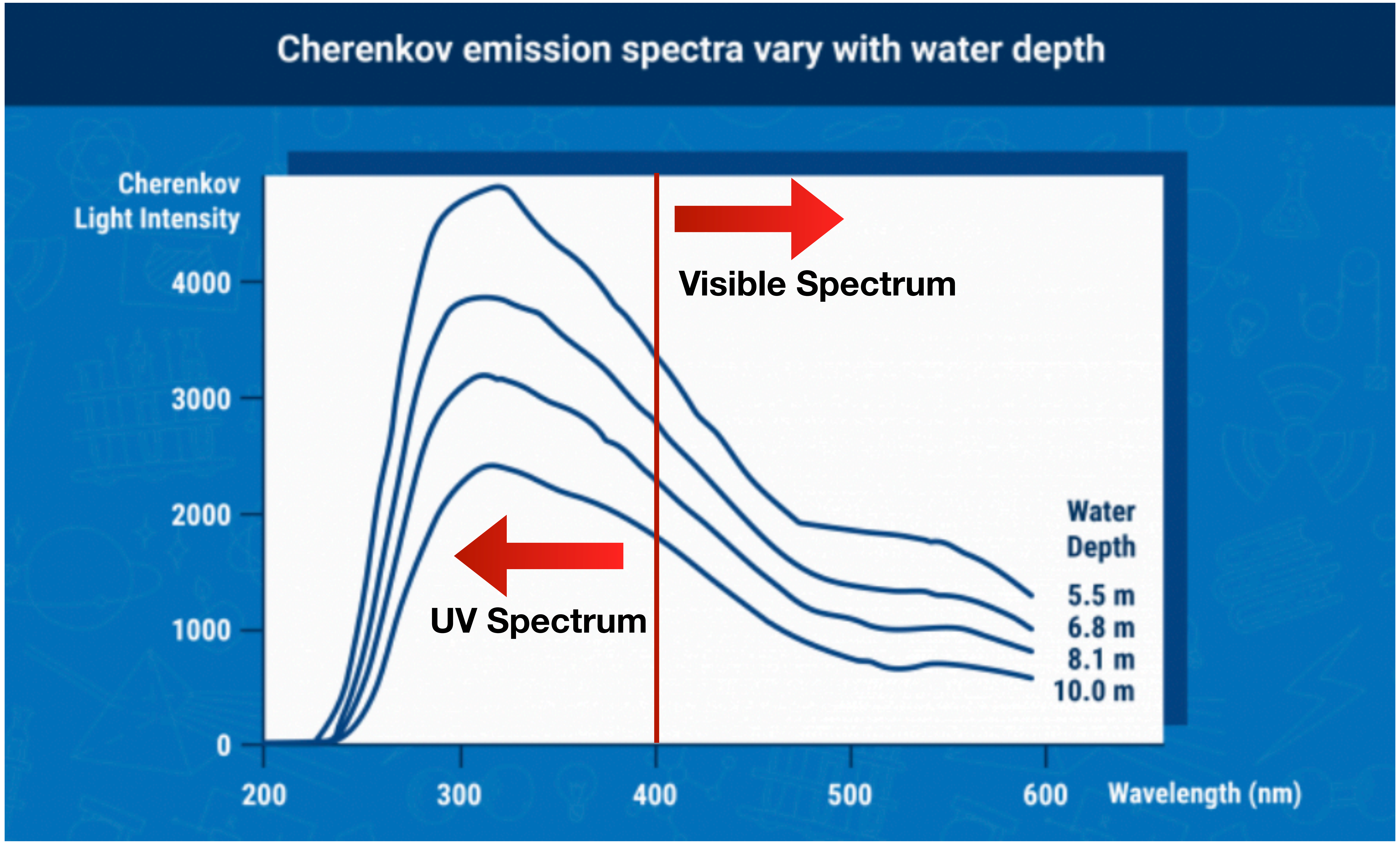
Looking Forward

- CCM200 is **funded for a 3 year run cycle** and will probe many new models/ parameter space in the dark sector
- Next generation CCM1000 detector is being considered to utilize future upgrades to Lujan proton source to reduce backgrounds by an order of magnitude
- CCM1000 or other simultaneous scintillation and Cherenkov light detectors would complement the SNS upgrades and Fermilab's Proton Improvement Plan -II
    - With implementation of a PSR at PIP-II, intense high-energy beam of neutrinos would be suitable for above ground detectors like CCM

Thank you for listening!

Backup

Cherenkov Spectrum



Benefits of Detecting Cherenkov Light

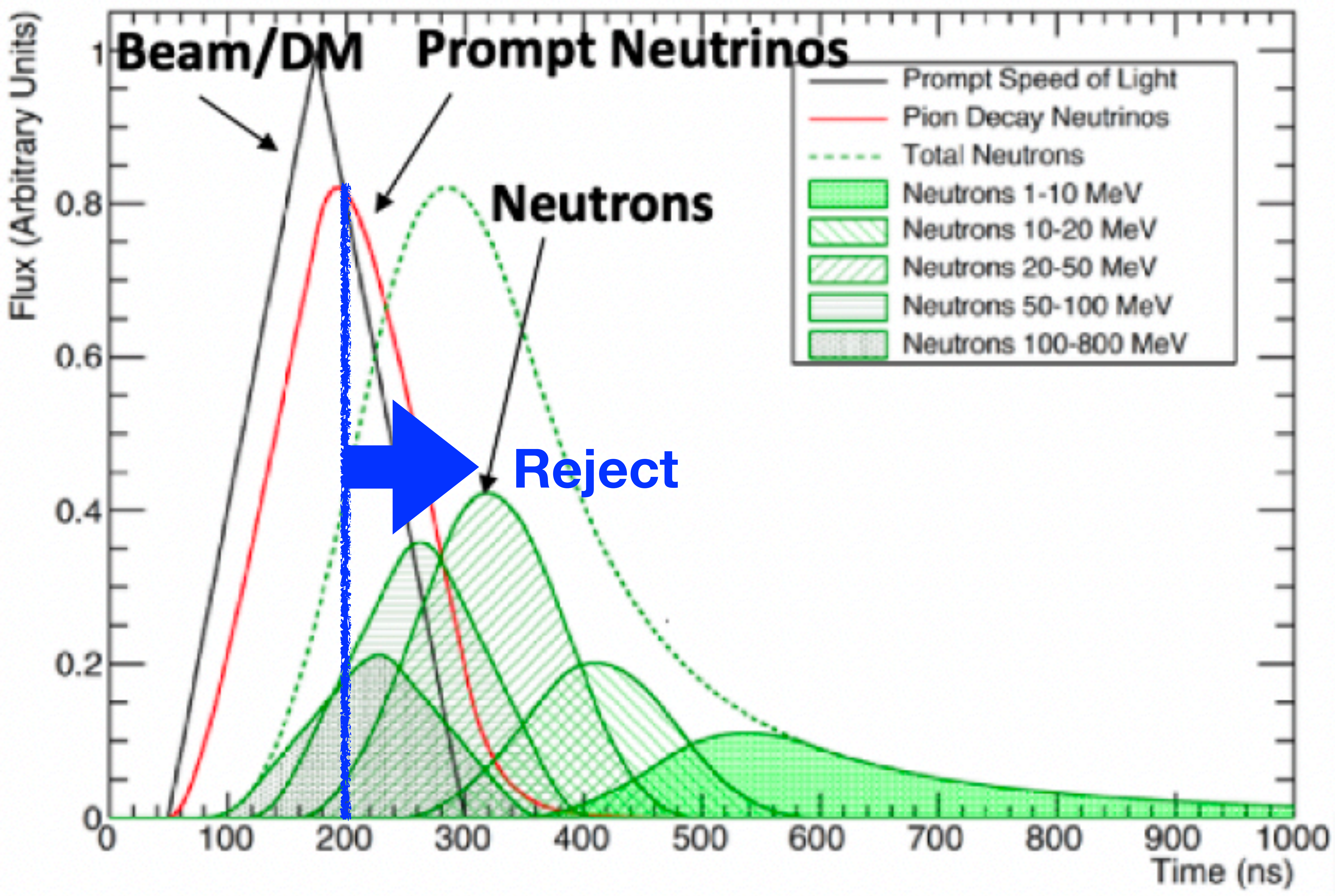
- Our primary background source are neutrons produced in the target so Cherenkov light identification enhances our background rejection

- Particle identification

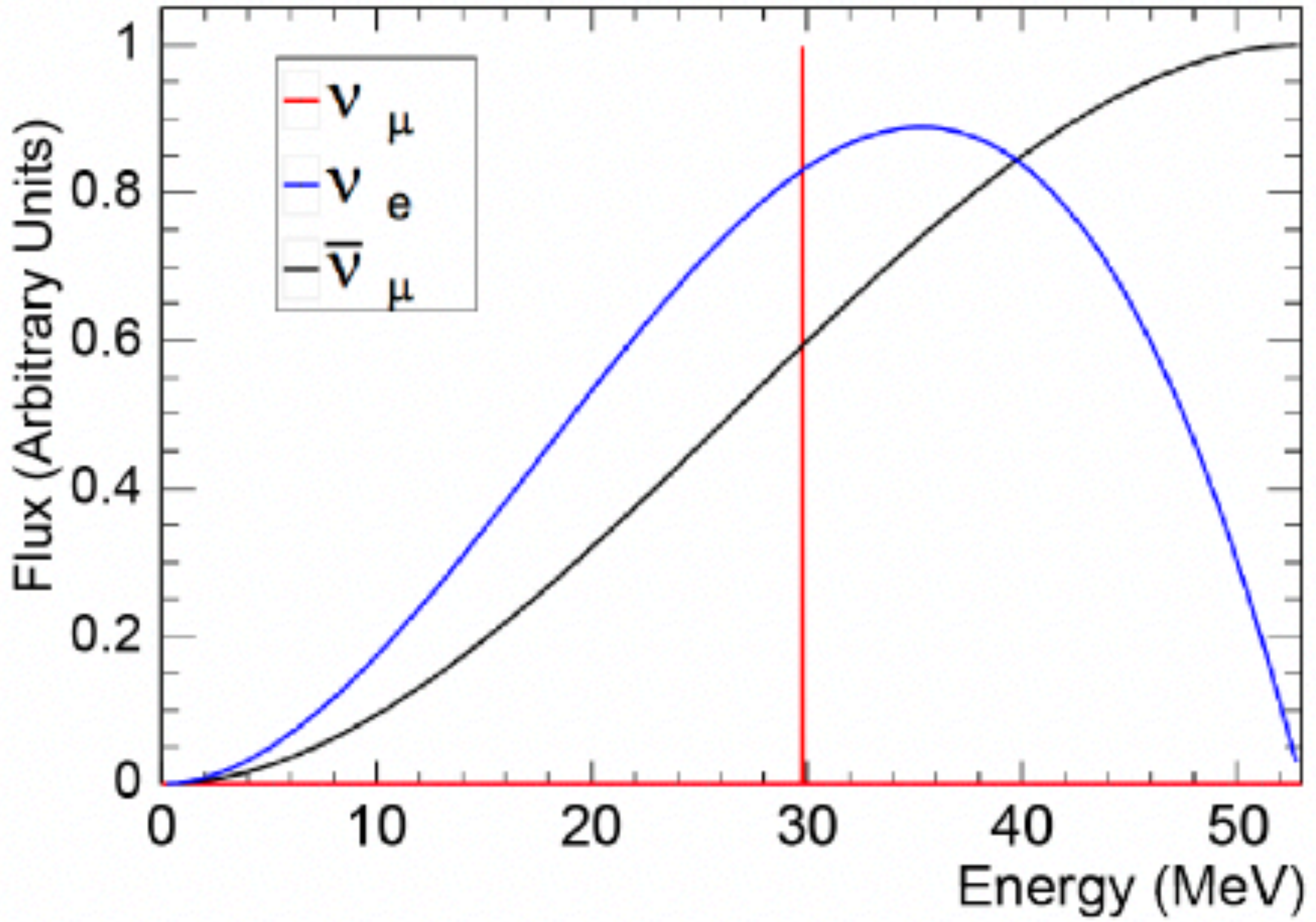
- Directional information of interaction in detector

Timing Cuts

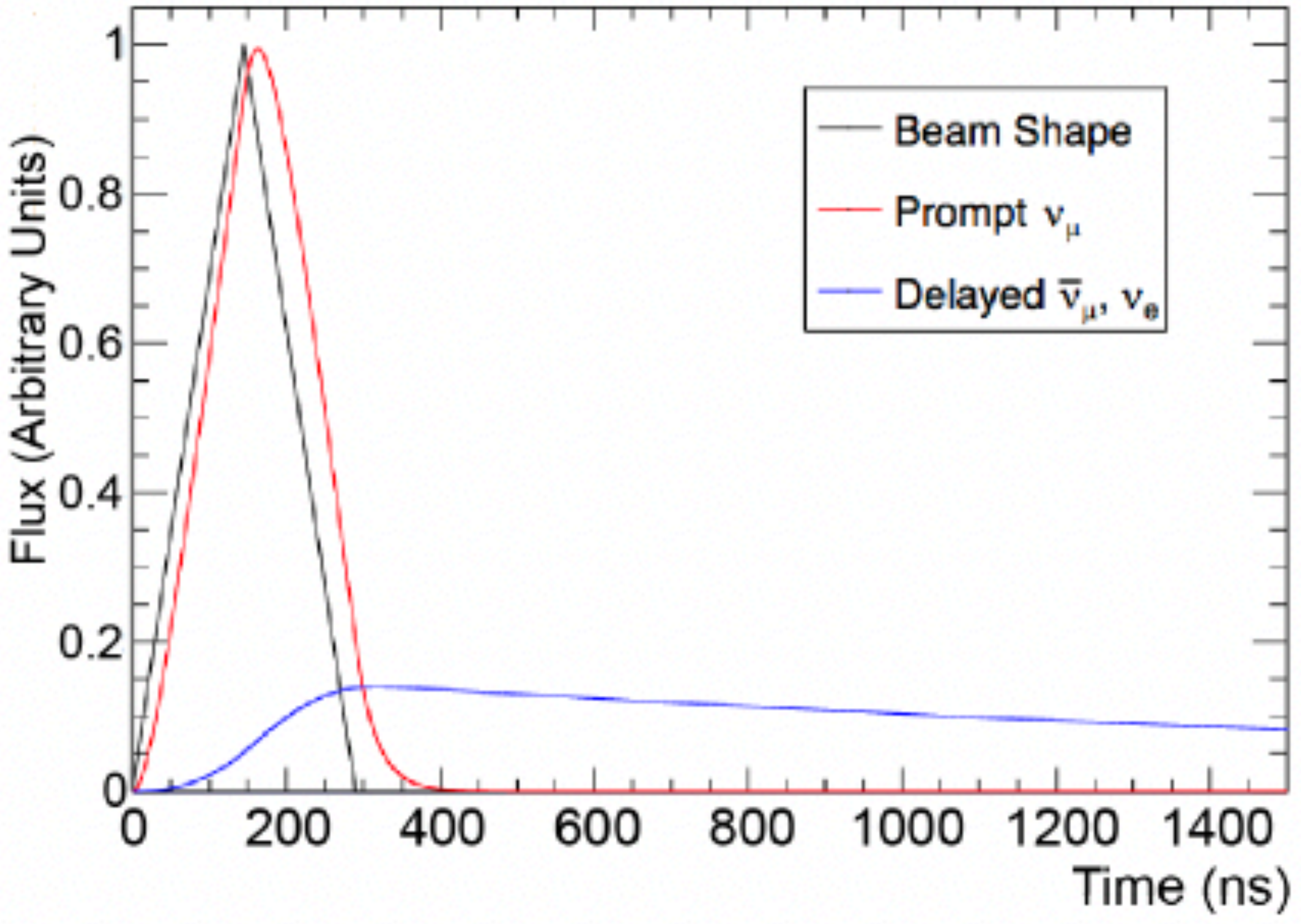
- 190nsec timing cut to remove neutron wall
- Primary neutron background with $E_n \approx$ 20-50 MeV reduced by timing cut (see arXiv:2105.14020 for discussion of timing cuts)
- Fast neutrons absorbed by shielding



ν_μ Timing



ν μ
ν e
ν̄ μ
Flux (Arbitrary Units)
Energy (MeV)
0
10
20
30
40
50
0.2
0.4
0.6
0.8
1



Beam Shape
Prompt ν_μ
Delayed $\bar{\nu}_\mu$, ν_e
Flux (Arbitrary Units)
Time (ns)
0
200
400
600
800
1000
1200
1400
0.2
0.4
0.6
0.8
1

Dark Sector Coupling to Meson Decay