




THE UNIVERSITY of EDINBURGH
School of Physics
& Astronomy

When Supernova Neutrinos Met Liquid Argon:

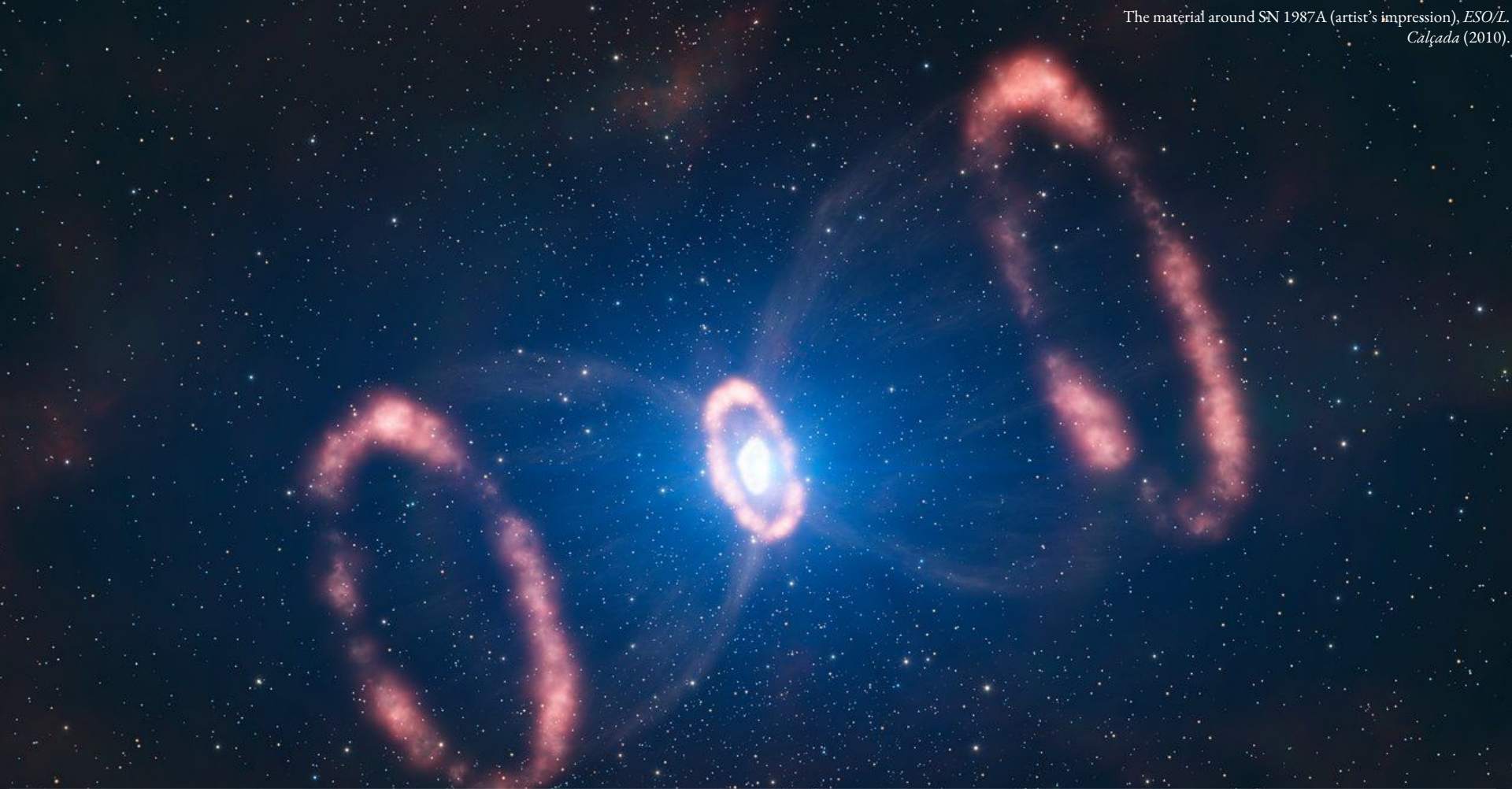
*using muons decaying-at-rest to look for
MeV-scale electron neutrinos in SBND*

View from Calton Hill, Liana Moran (2025)

 Lucy Kotsiopoulos
3rd year PhD student
Supervisor: Dr. Andrzej Szelc

IOP Joint APP and HEPP Annual Conference 2026 | 8-10/04/2026 | Edinburgh, U.K.





Type II core-collapse supernova exploding!

SN1987A, the closest supernova in 400 years



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0.1% light



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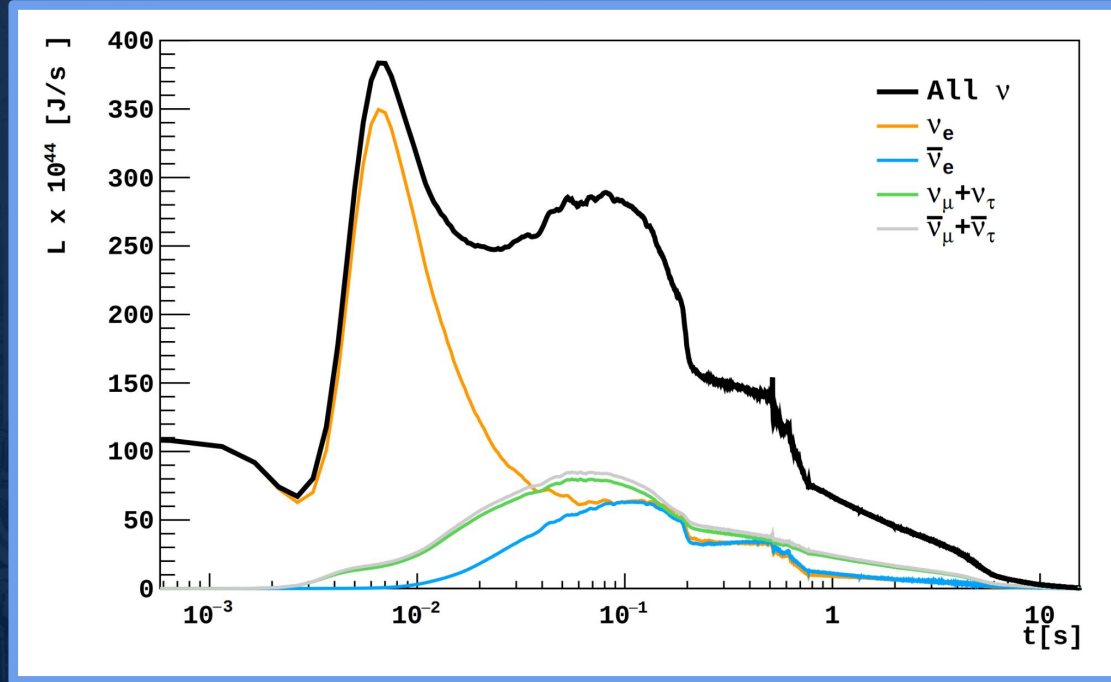
99% neutrinos



Neutrinos carry away all the energy! But which neutrinos?



+
antiparticles
 $\bar{\nu}_e$ $\bar{\nu}_\mu$ $\bar{\nu}_\tau$

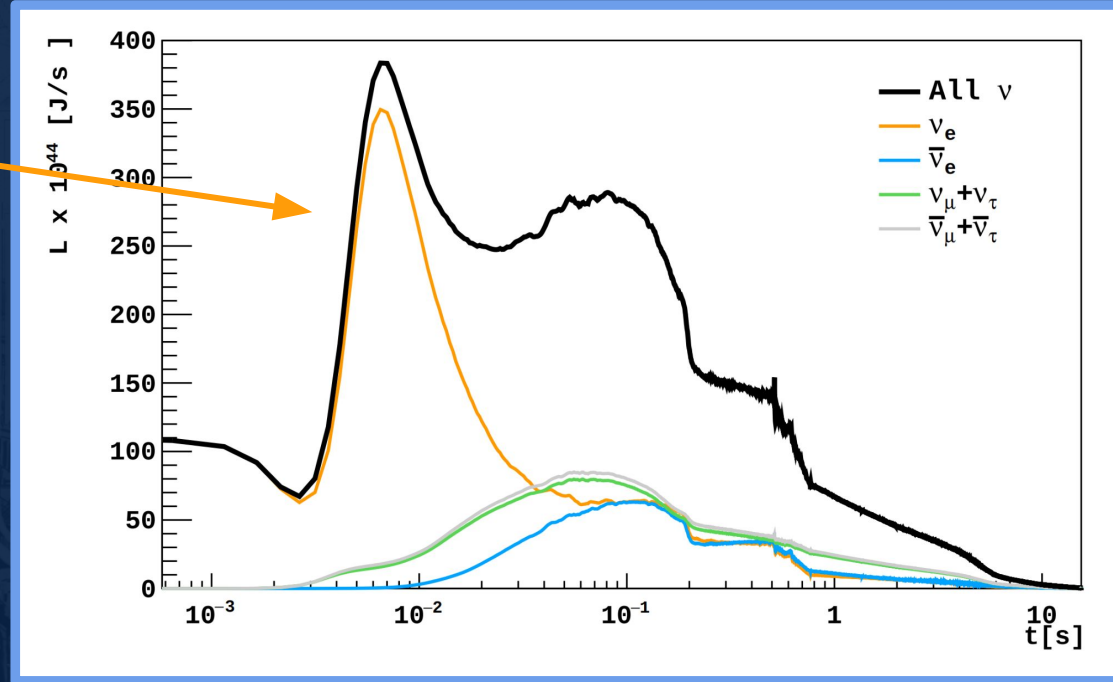


Sensitivity of future liquid argon dark matter search experiments to core-collapse supernova neutrinos, *The DarkSide-20k collaboration* (2020).

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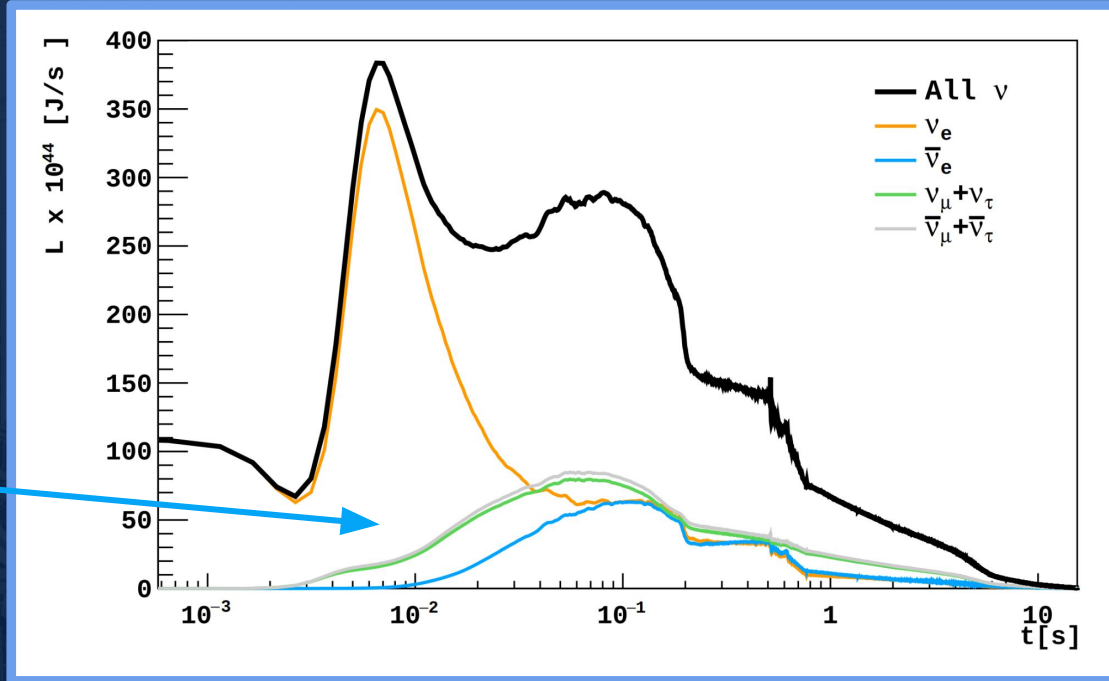


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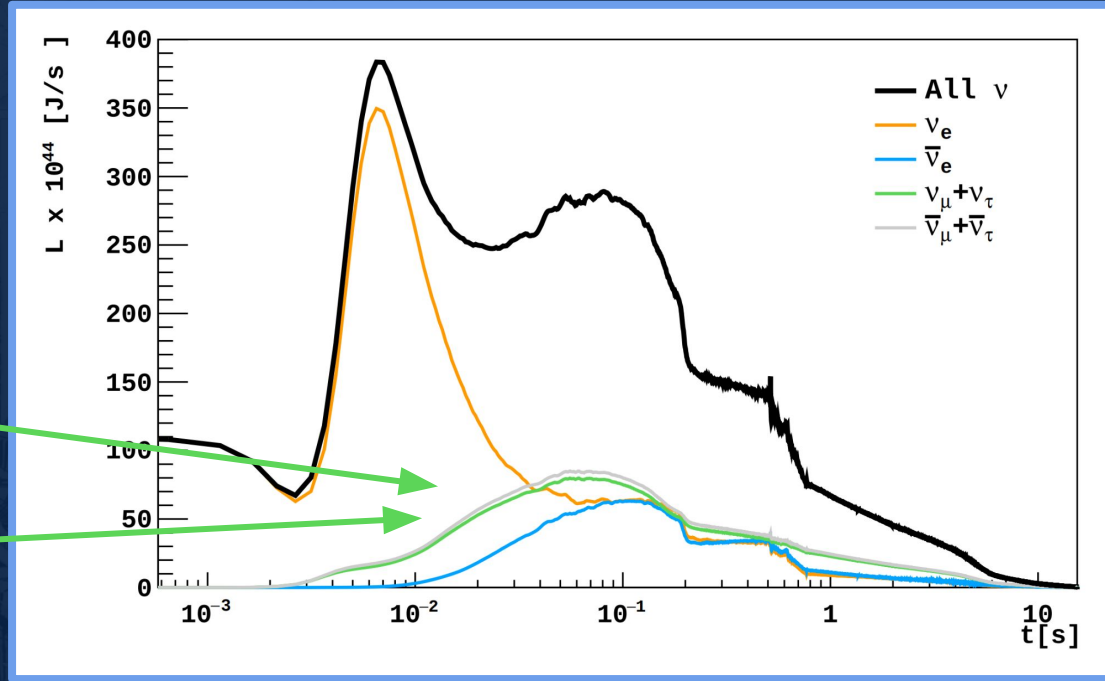
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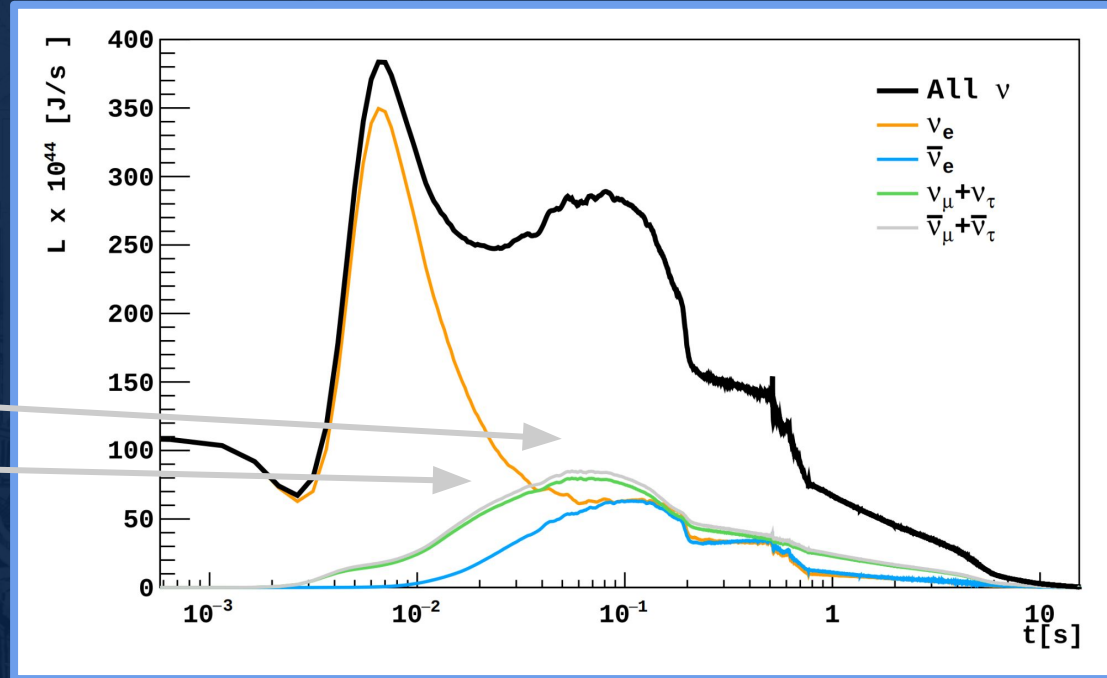


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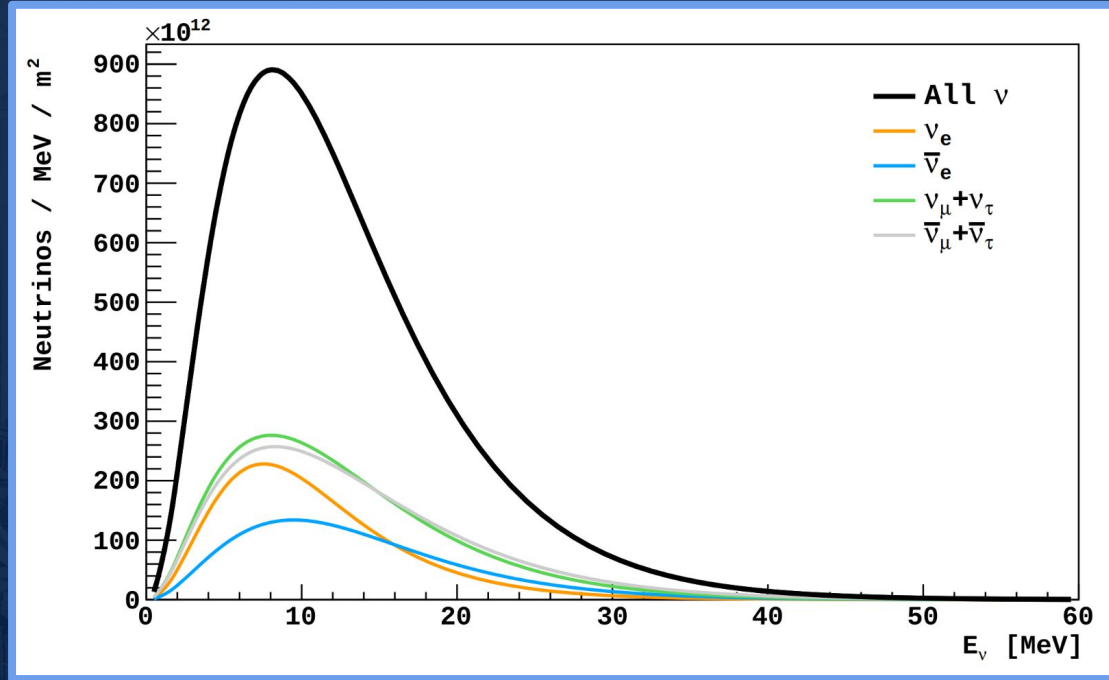


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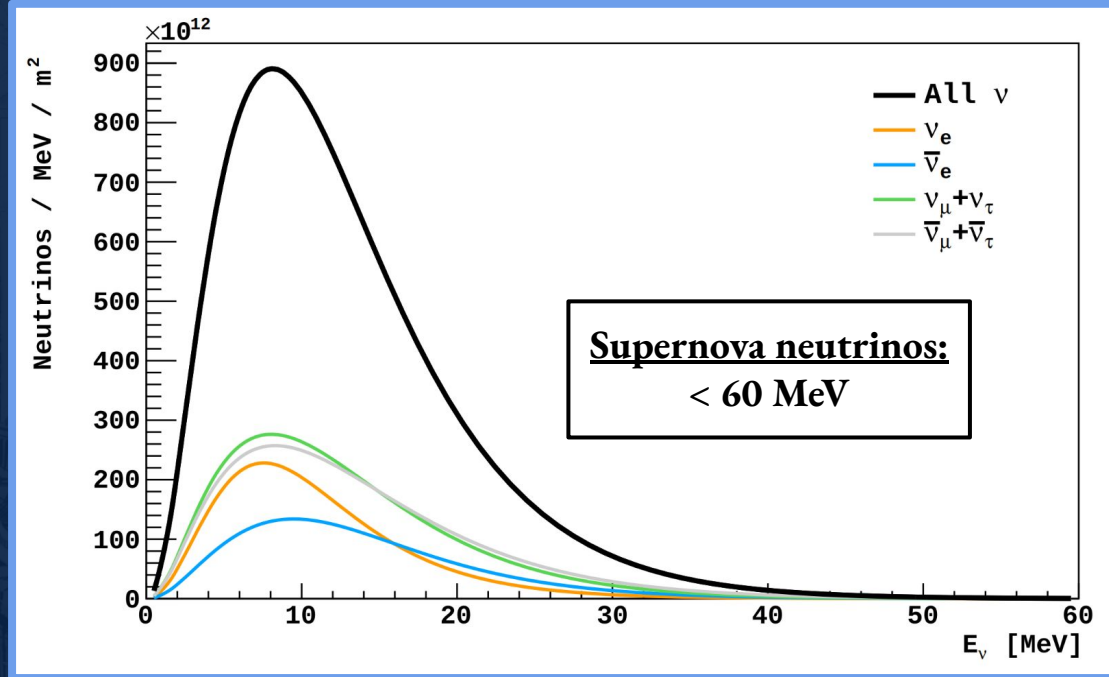


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How can we study supernova neutrinos?



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The last closeby supernova was in... 1987 :(

near = in or near the Milky Way



SN1987A, *European Southern Observatory*, (2007).

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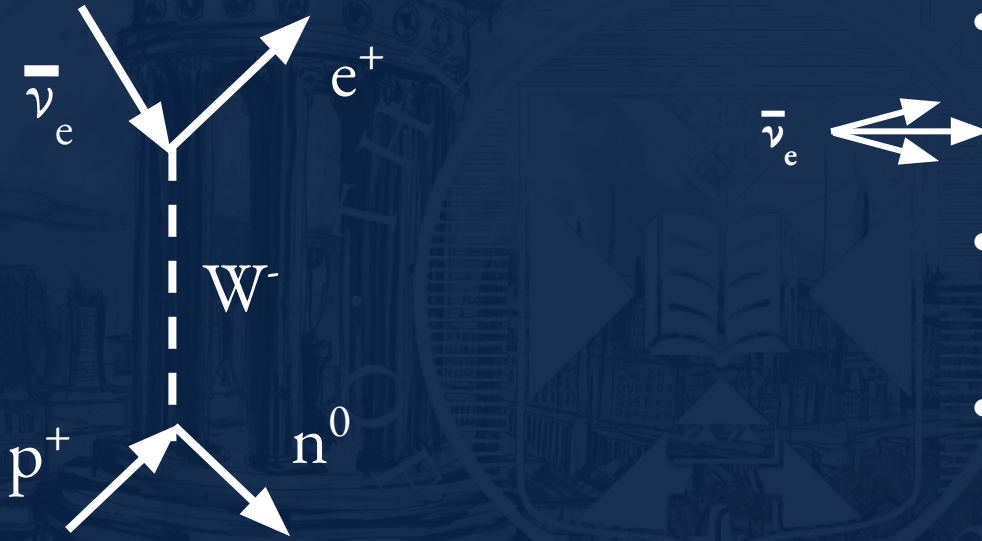
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- **Water Cherenkov detectors, e.g.:**
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 - KM3NeT
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- **Liquid scintillator detectors, e.g.:**
 - NO_vA
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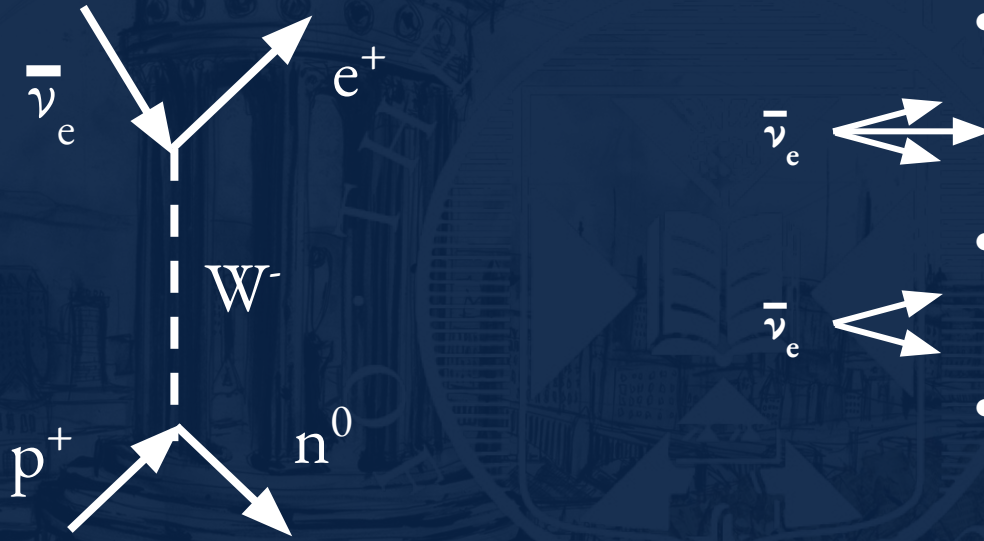
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Inverse Beta Decay (IBD)
charged current

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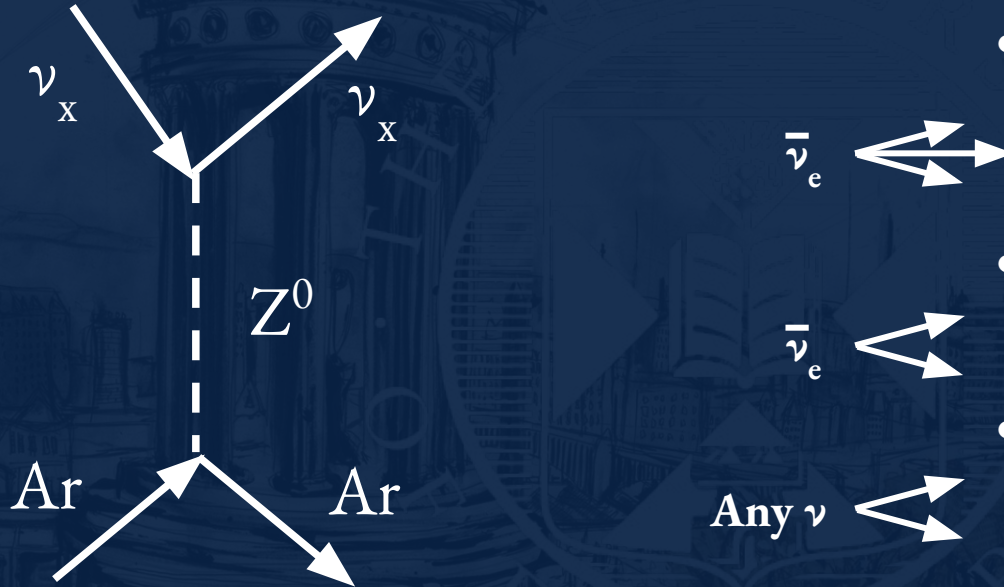
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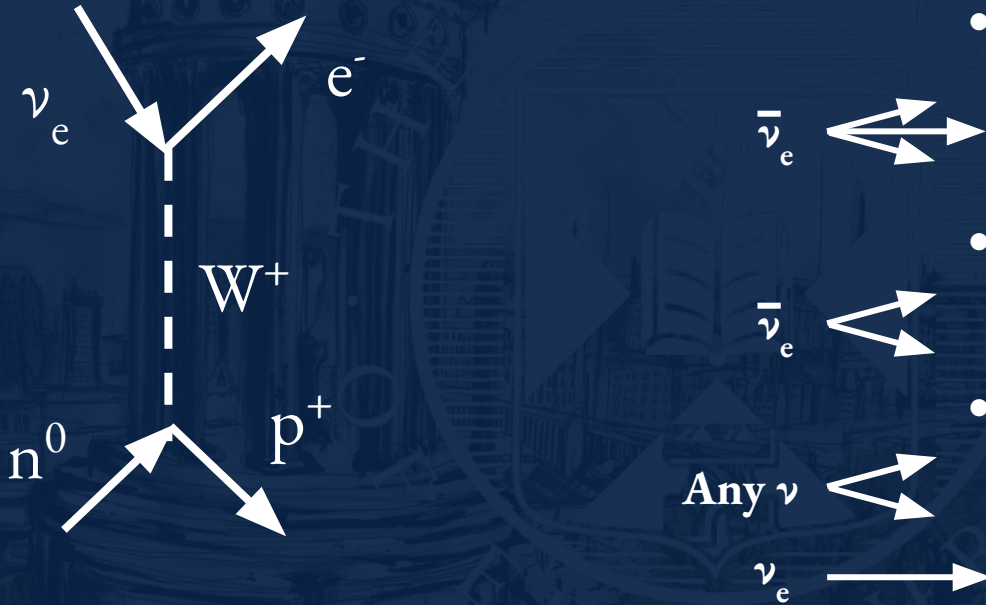
CE ν NS

(Coherent Elastic ν -Nucleus Scattering)

neutral current

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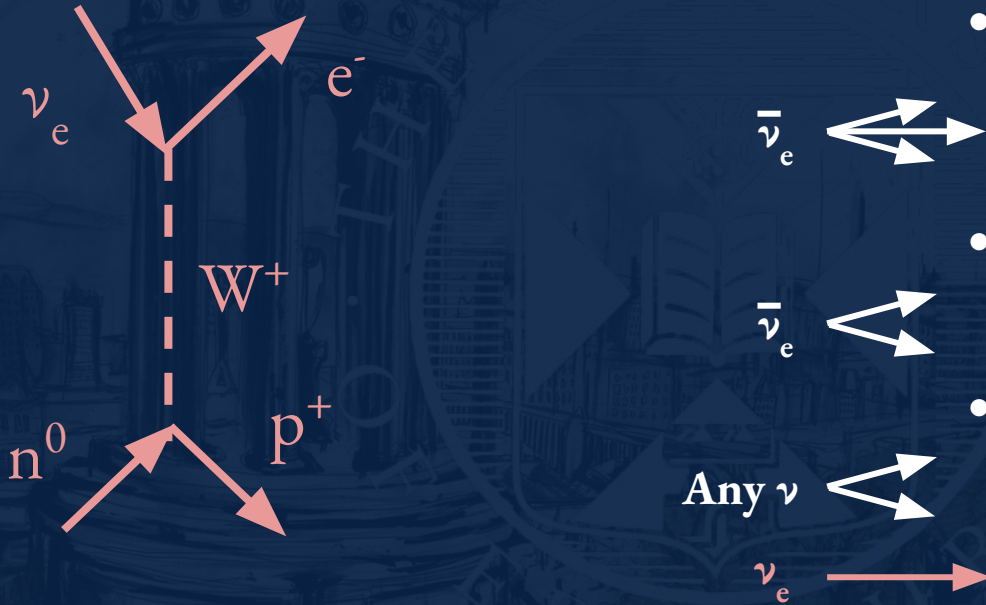
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Electron neutrino absorption
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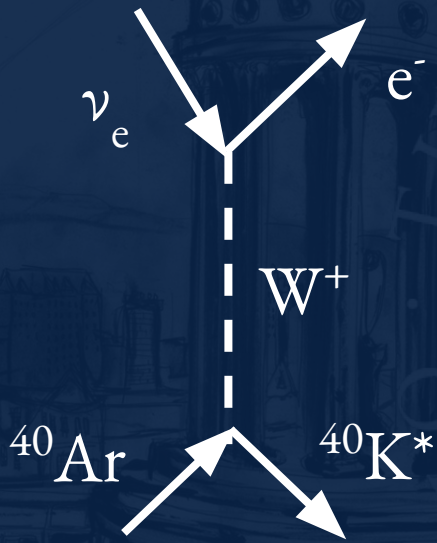


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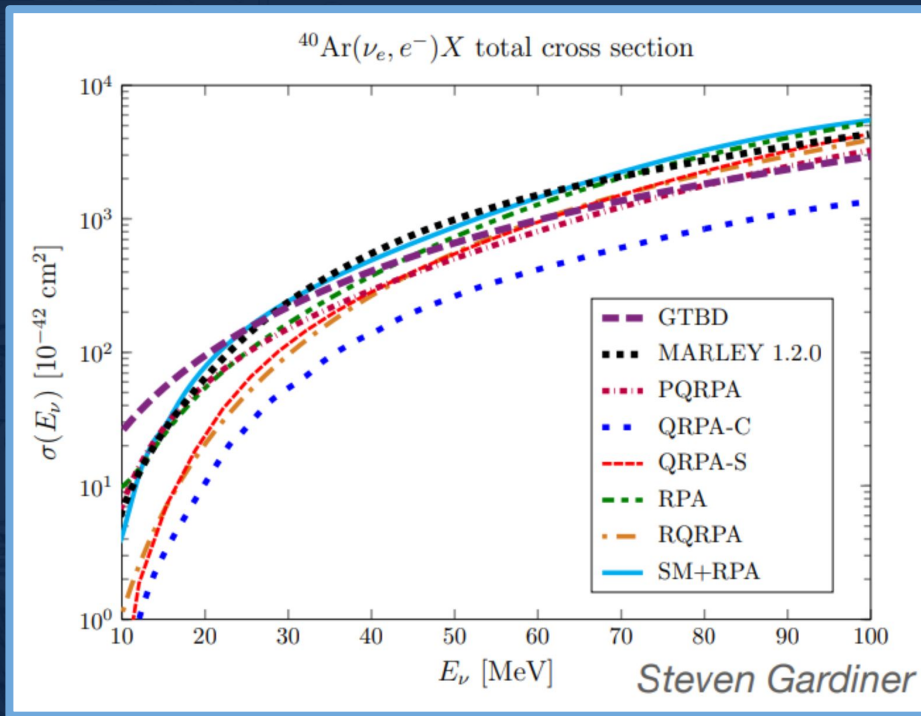
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$^{40}\text{Ar}(\nu_e, e^-)^{40}\text{K}^*$ is very difficult to calculate!

And has never been experimentally measured...



Electron neutrino absorption
charged current



MARLEY Simulation, Steven Gardiner

The Short Baseline Near Detector (SBND)

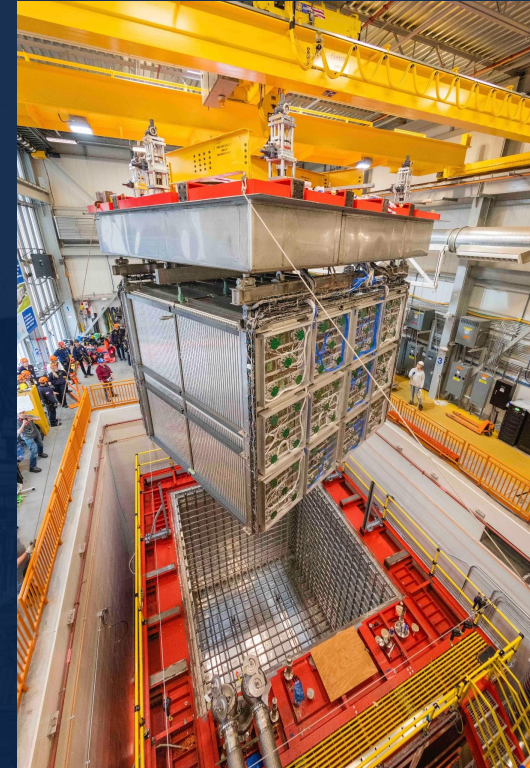
- Located at the Fermi National Accelerator Laboratory (Fermilab) near Chicago, U.S.
- Filled with 112 tonnes of liquid argon (LAr)
- Started taking data in summer 2024
 - Largest worldwide ν -Ar dataset



Wilson Hall, Fermilab



Detector hall for SBND, located 110m downstream of the BNB target on Fermilab's Neutrino Campus, (2018).

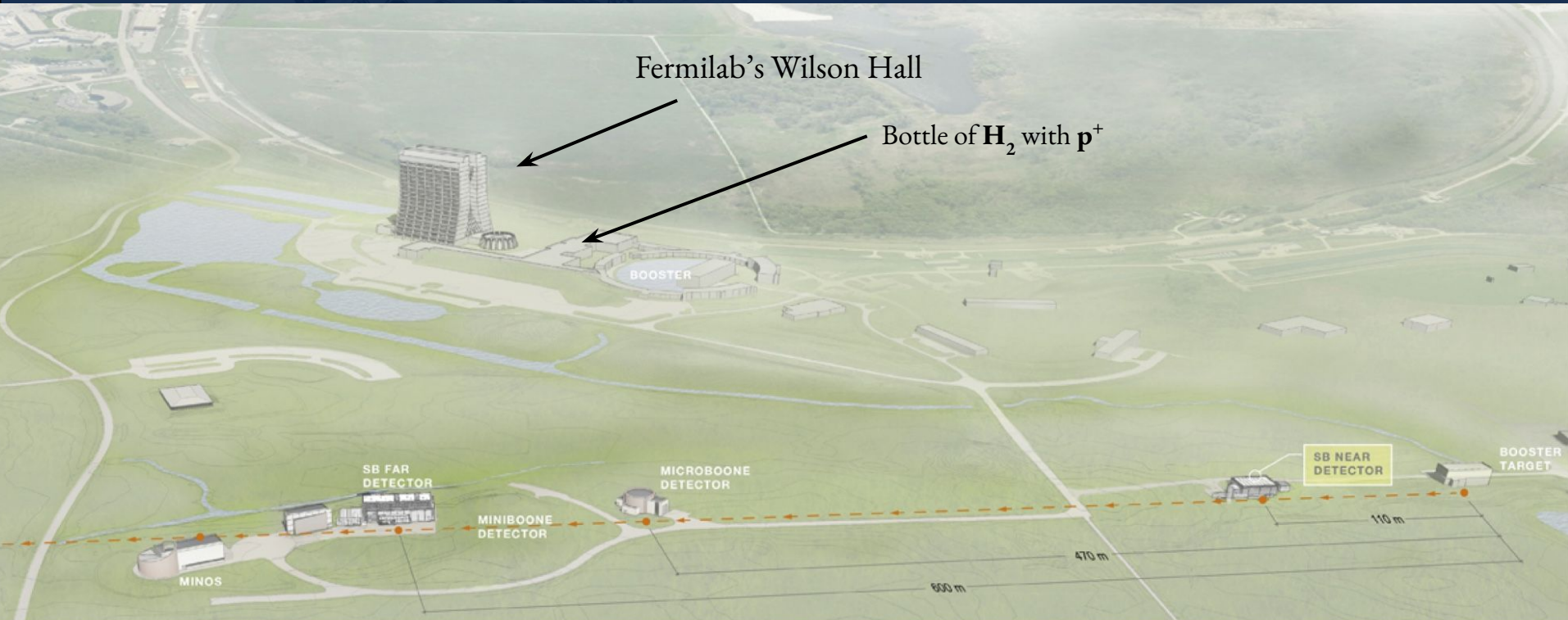


The assembly of detector and cryostat lid being rigged into the SBND membrane cryostat, *Ryan Postel* (2023).

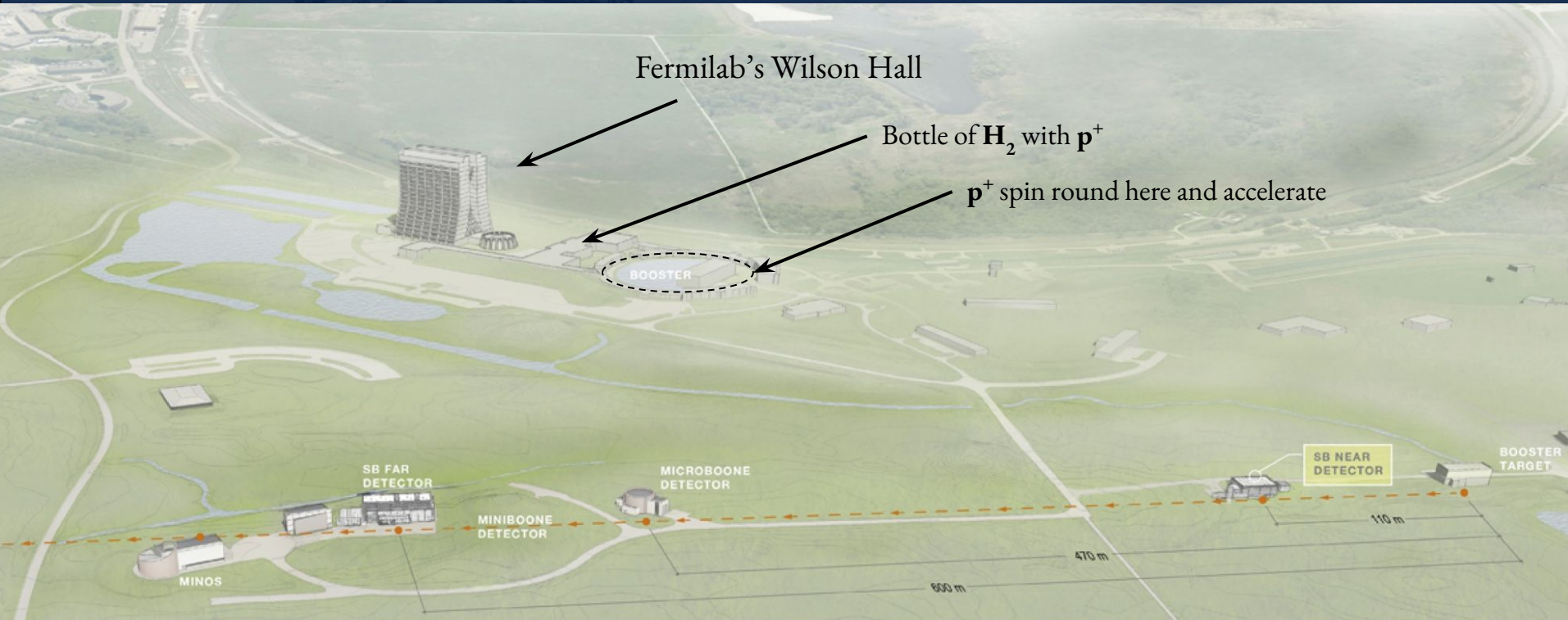
Making SBND's neutrino beam @ Fermilab



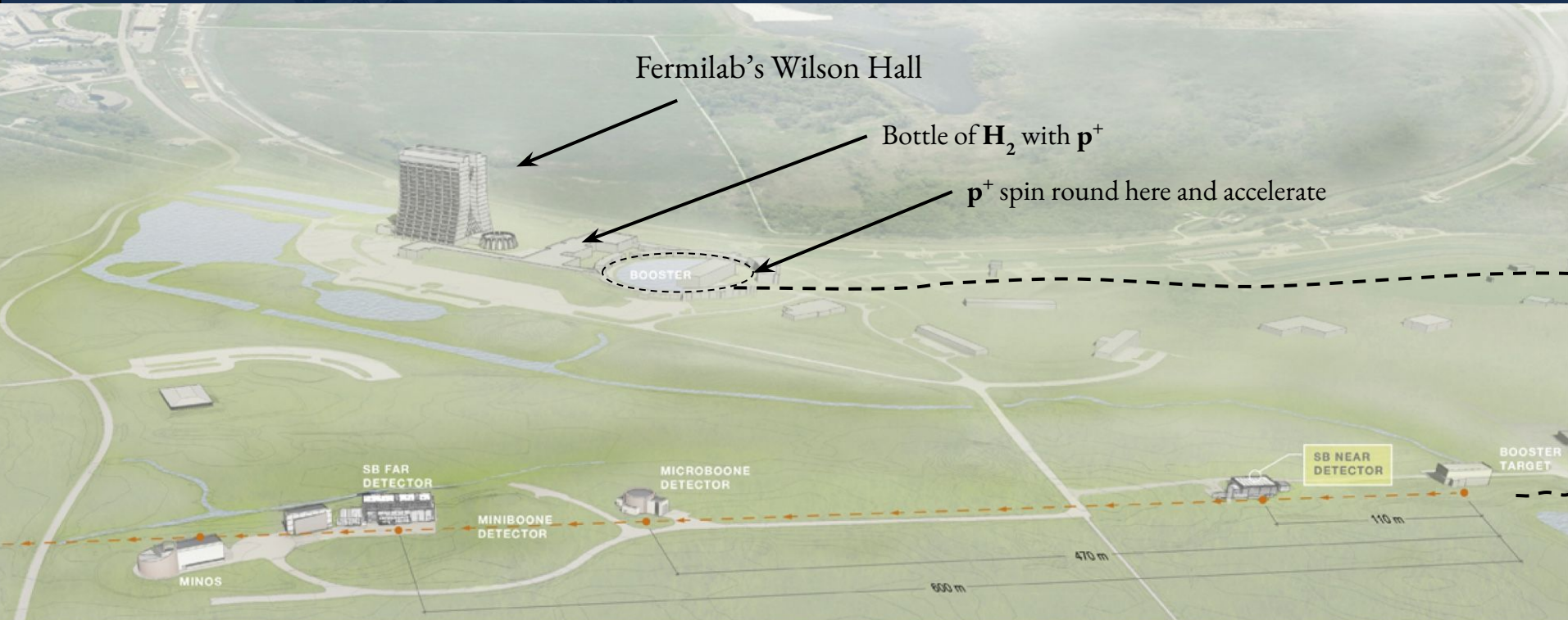
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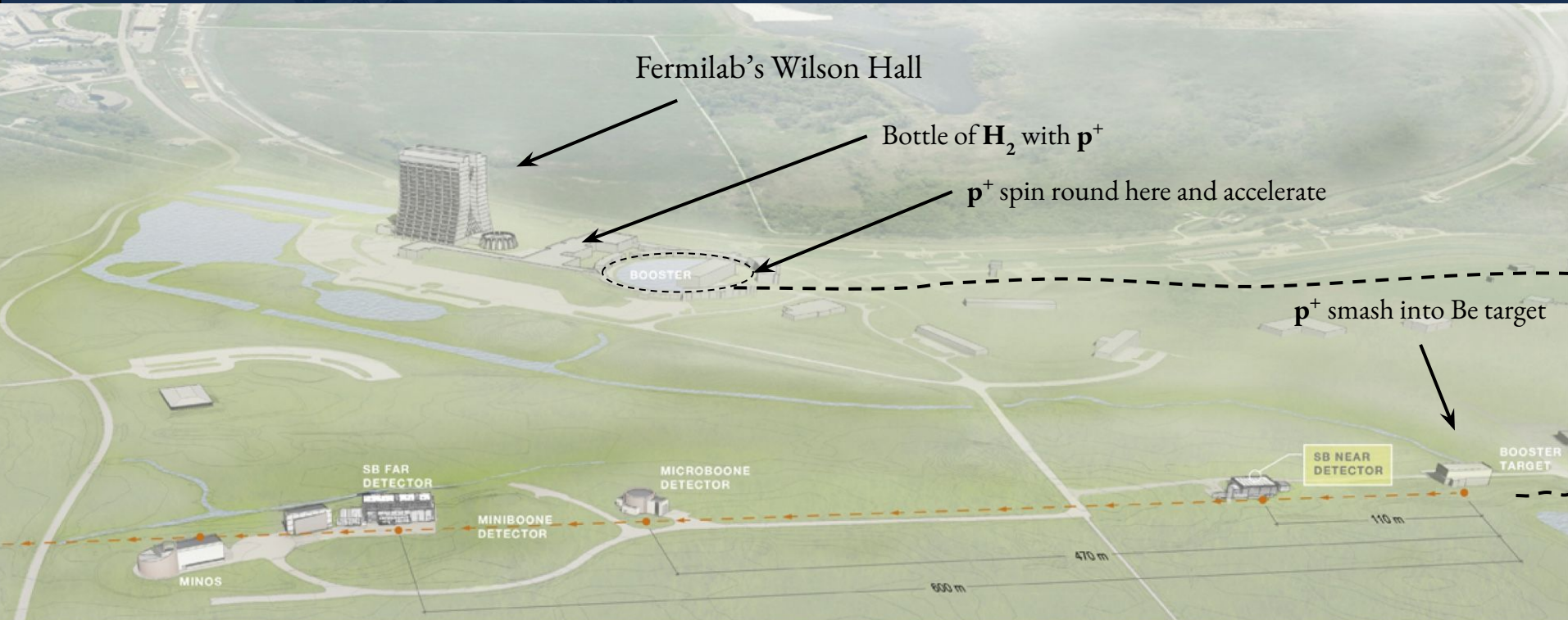
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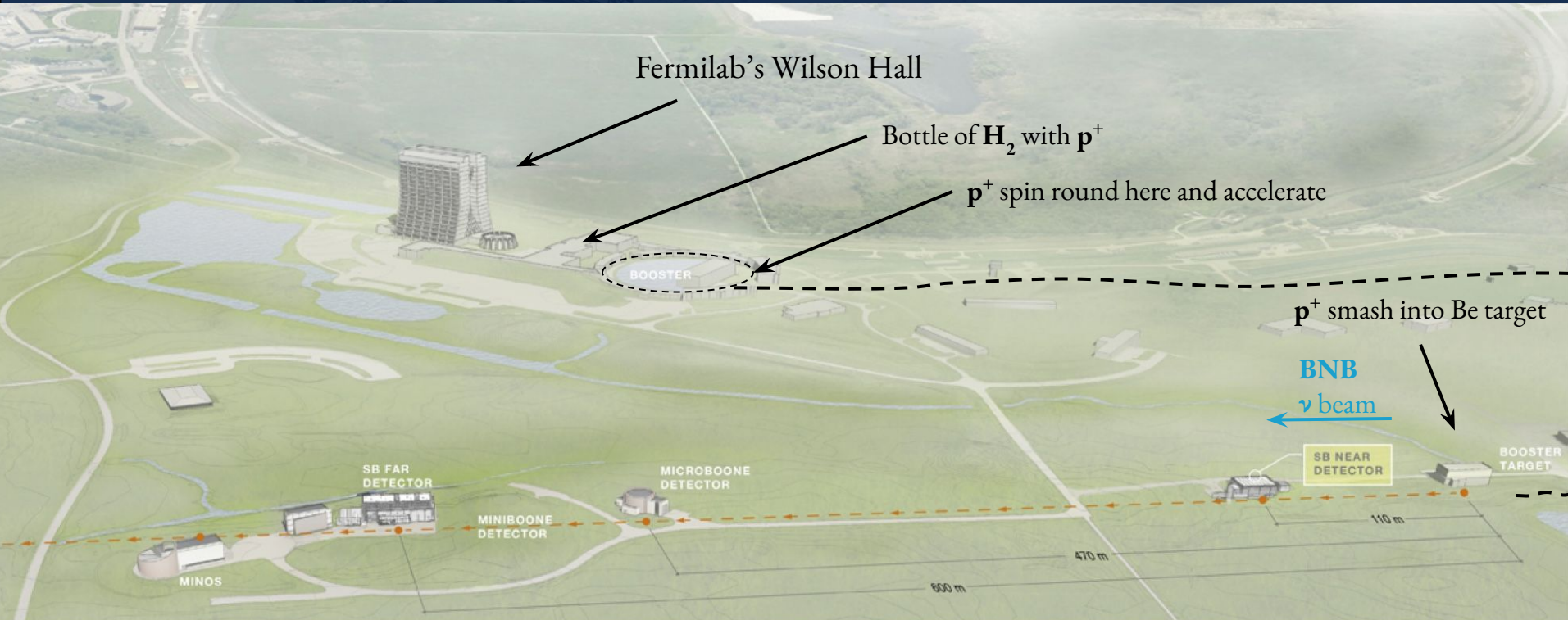
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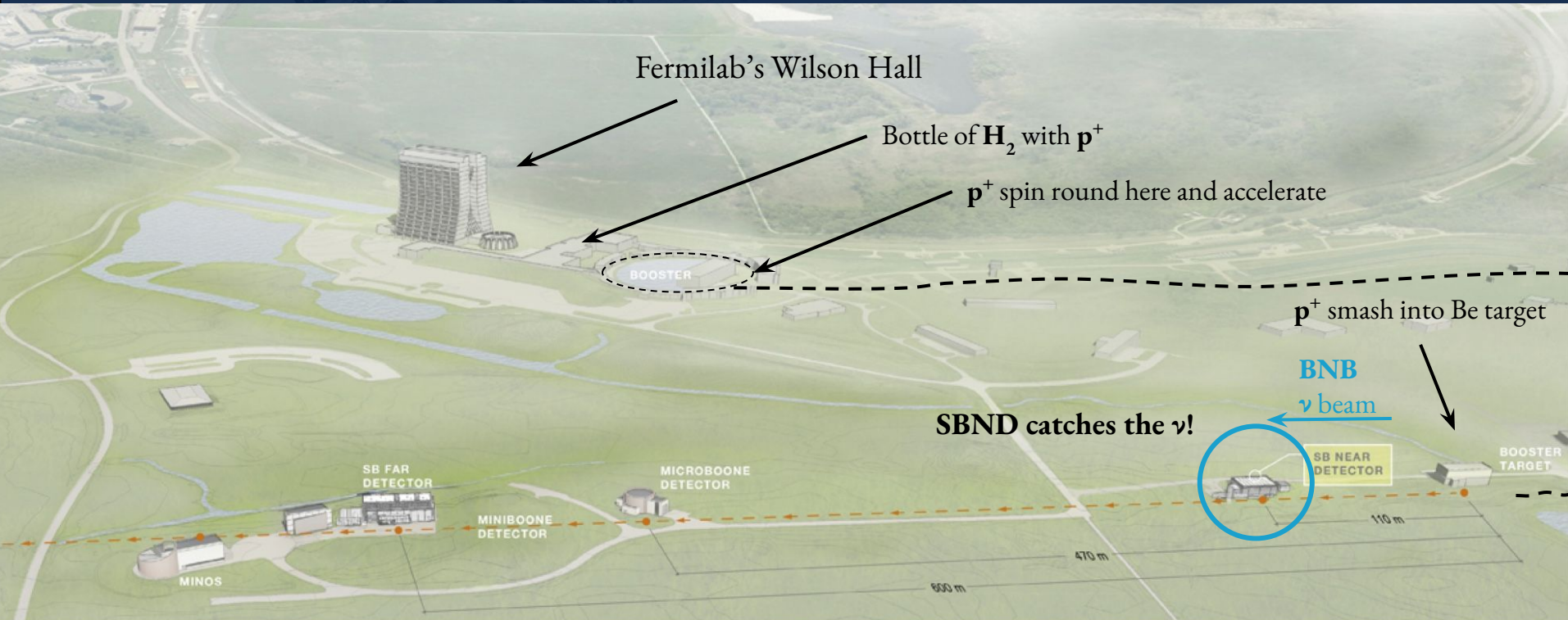
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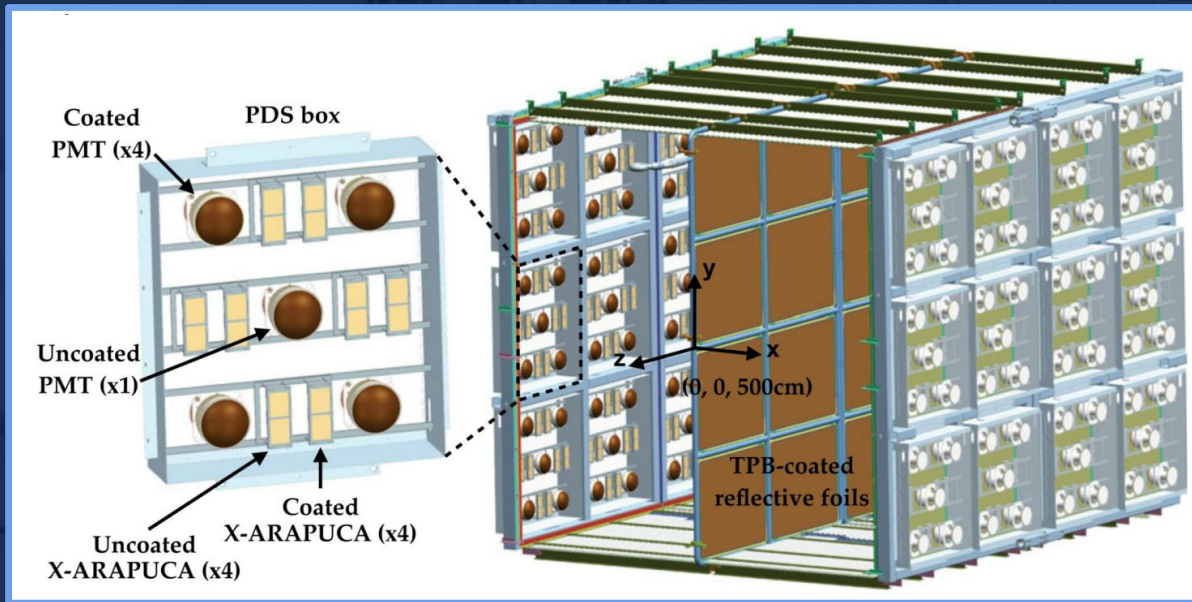


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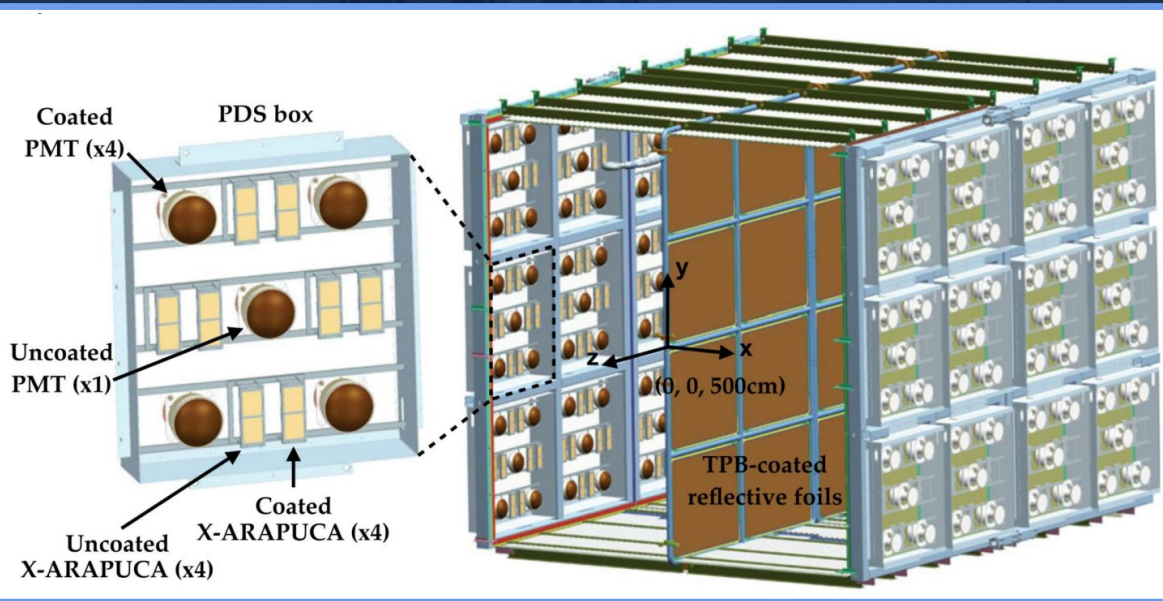
How SBND “catches” neutrinos

- 7000 neutrinos a day, from the **Booster Neutrino Beam (BNB) flux**



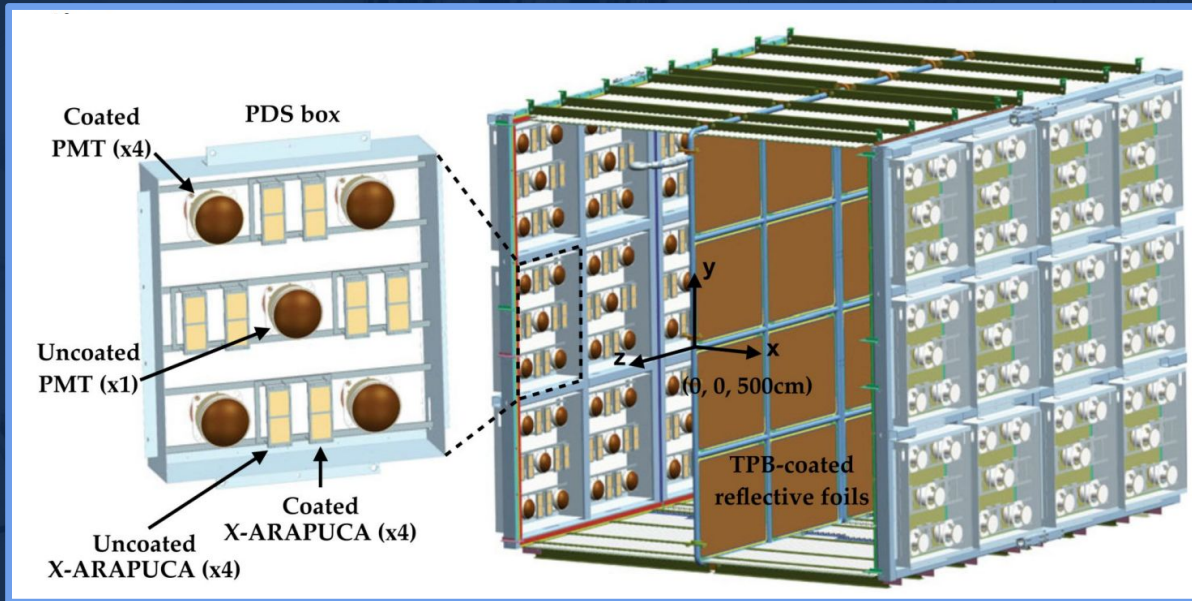
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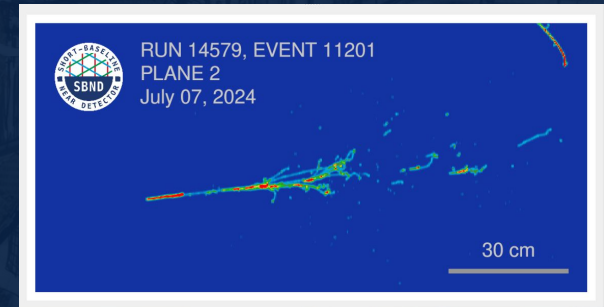


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- **Reconstruct** images using LAr Time Projection Chamber (LArTPC) technology:
 - images of neutrinos!

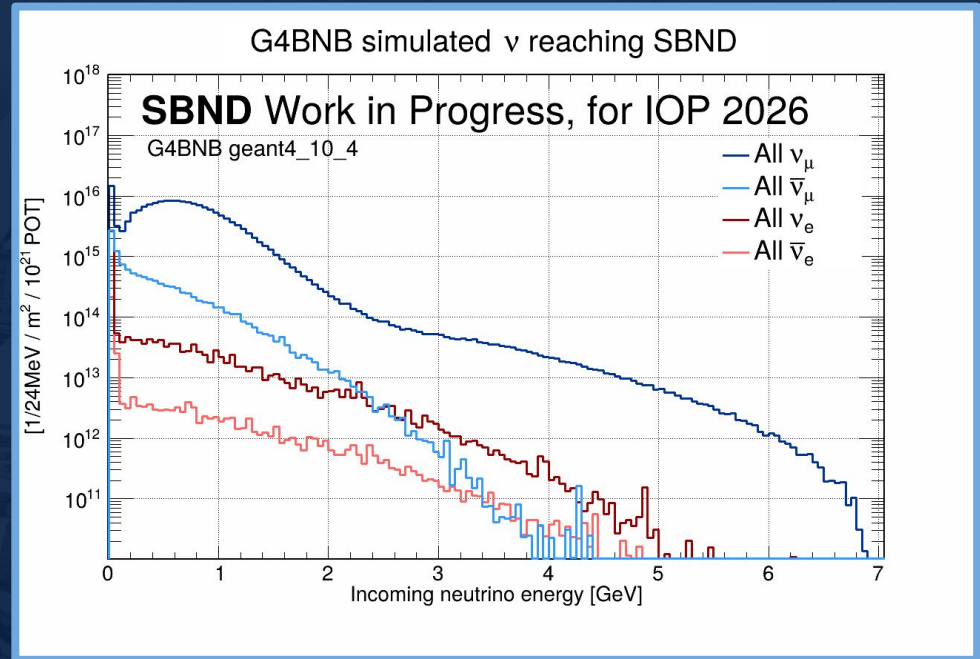


Let's find the supernova neutrinos in BNB

- We use the G4BNB package to *simulate* the Booster Neutrino Beam (BNB): new, updated BNB simulation, using geant4 based programming
- Can extract information about ν ancestors; from **pBe** interaction to ν production!

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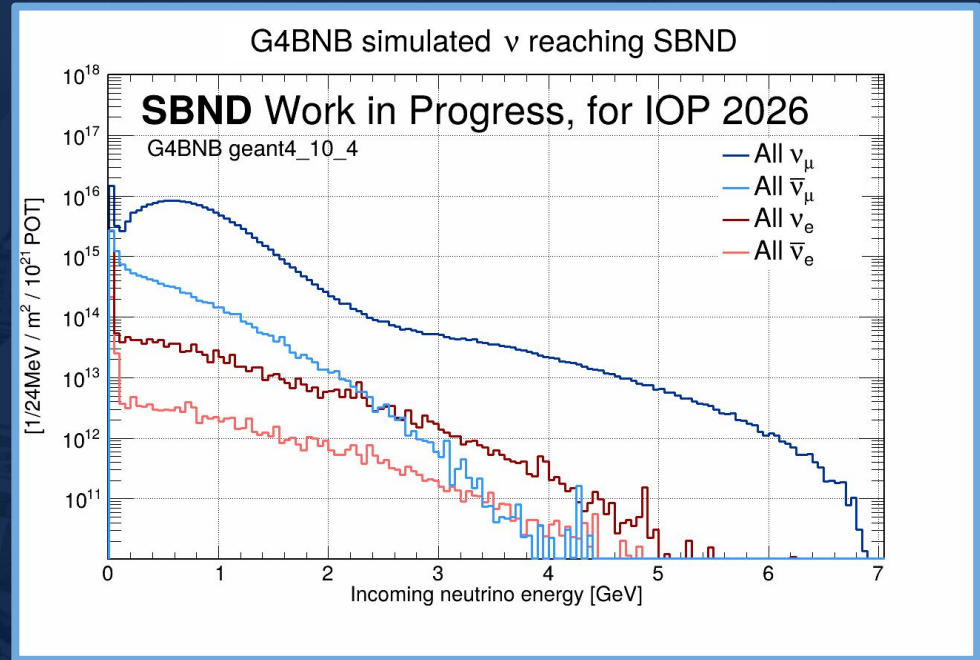
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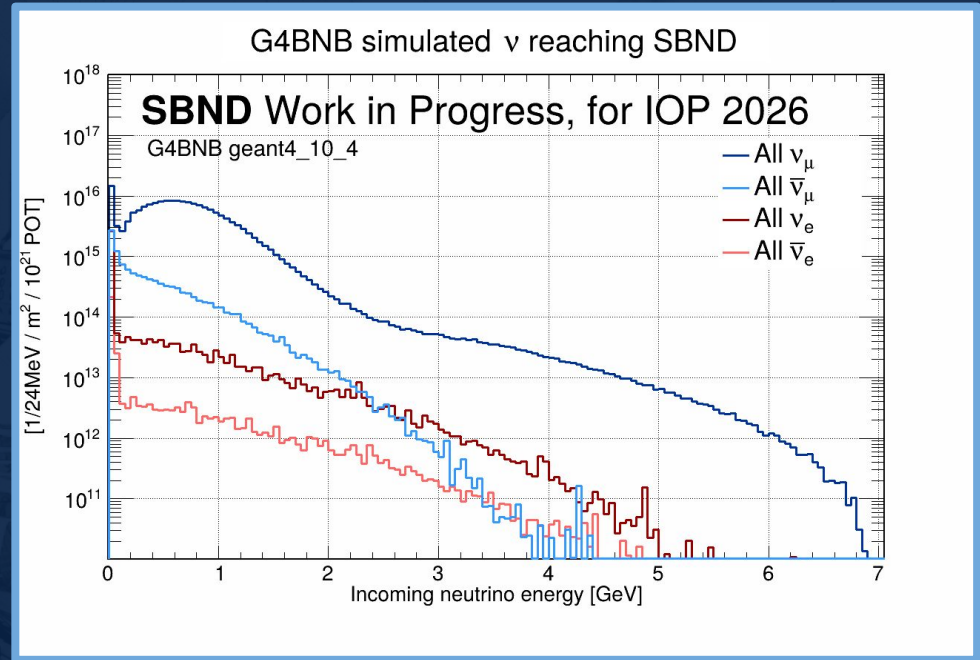
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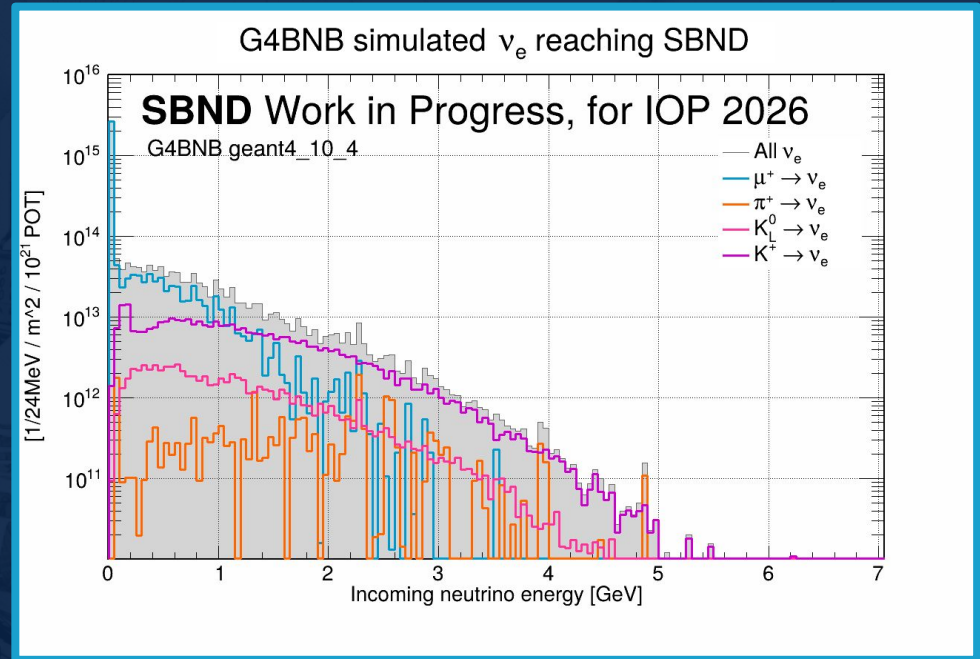


ν_e flux lower, but still there



Looking at ν_e in BNB

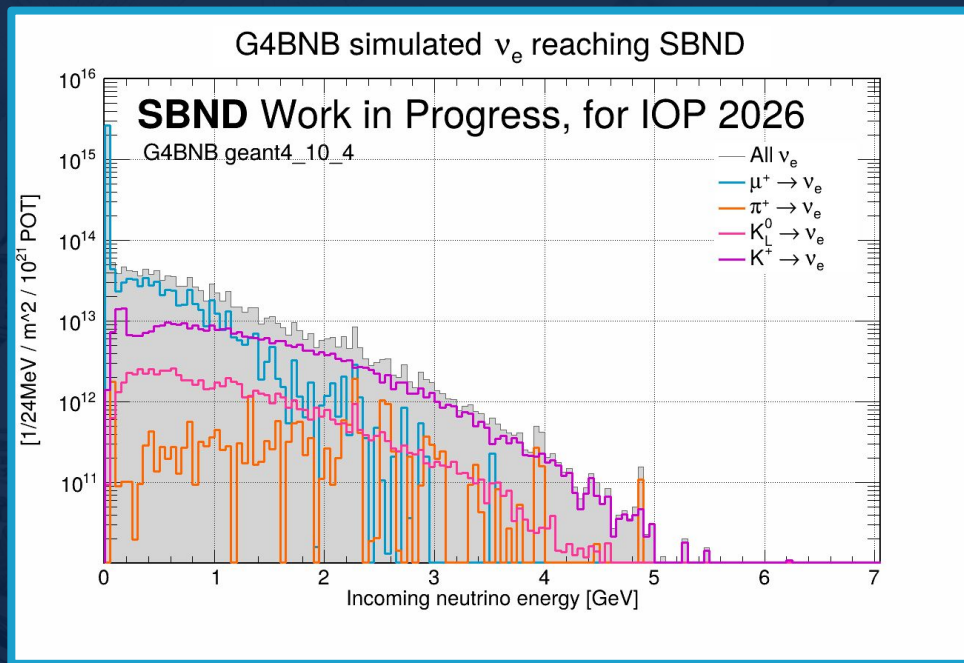
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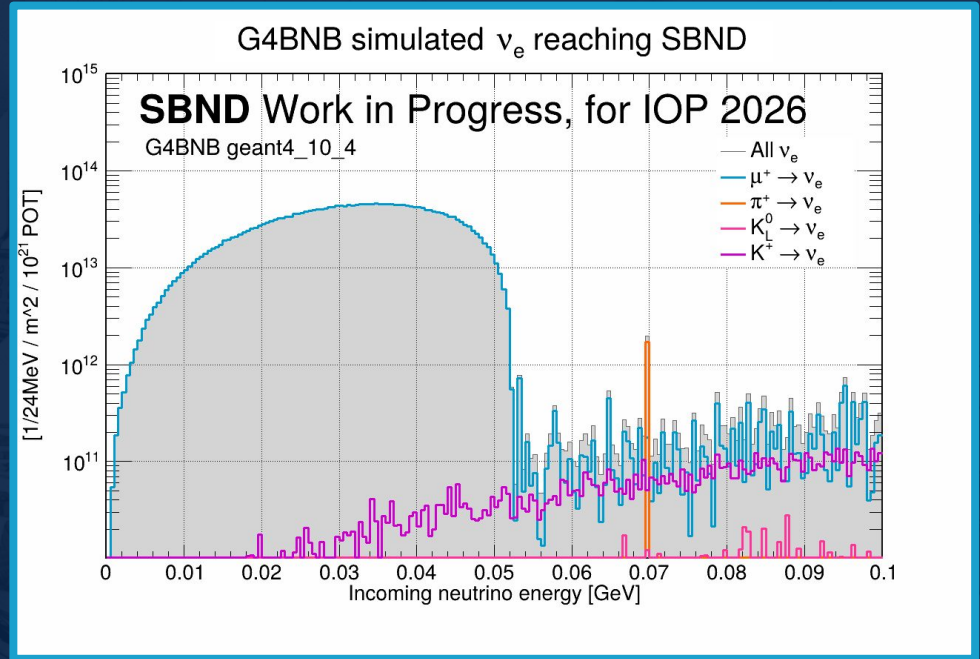
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ν_e from μ^+ have a very high flux

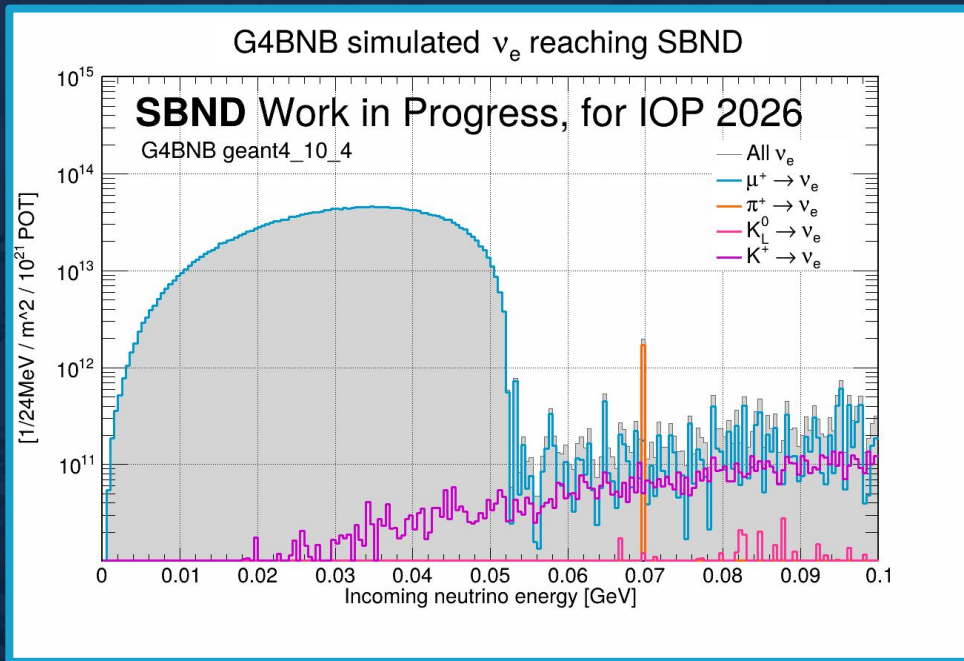


Zooming in at ν_e of 0-100MeV



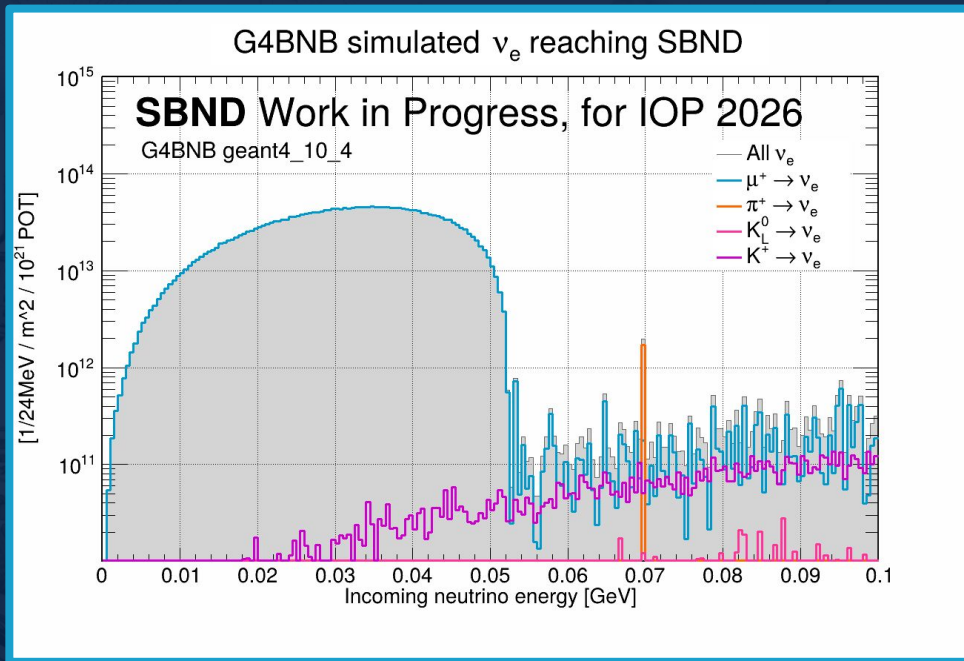
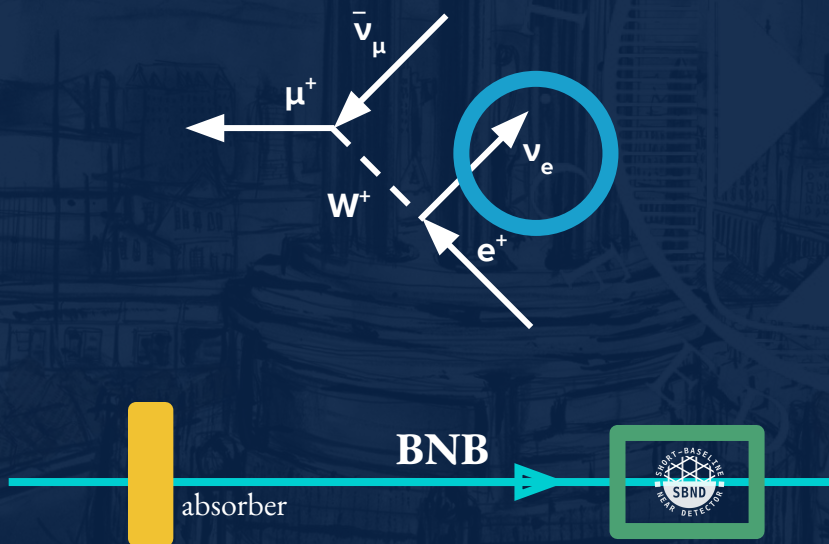
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- Very high flux of ν_e exactly in the supernova neutrino region!
- Their origin is **muons Decaying At Rest (μ DAR)** in the beam pipe absorber (/ beam dump / beam stop)
- Dominating contribution of ν_e below 53MeV

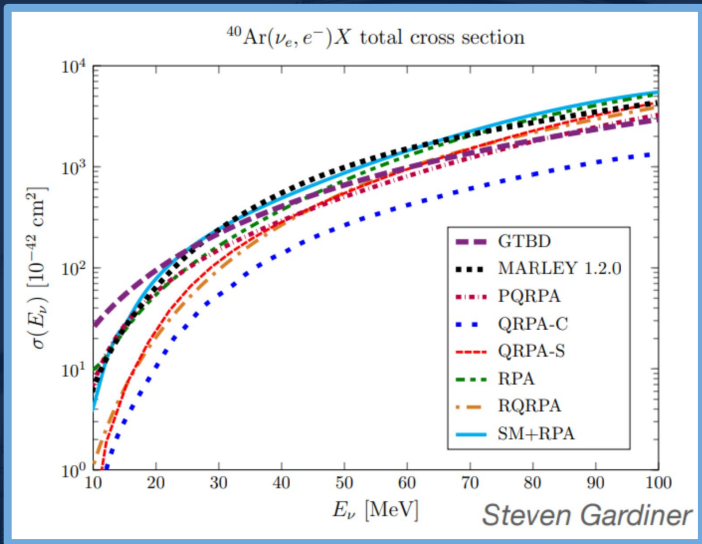


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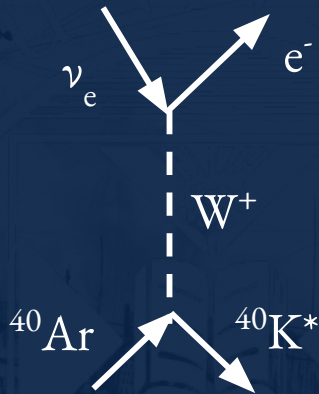
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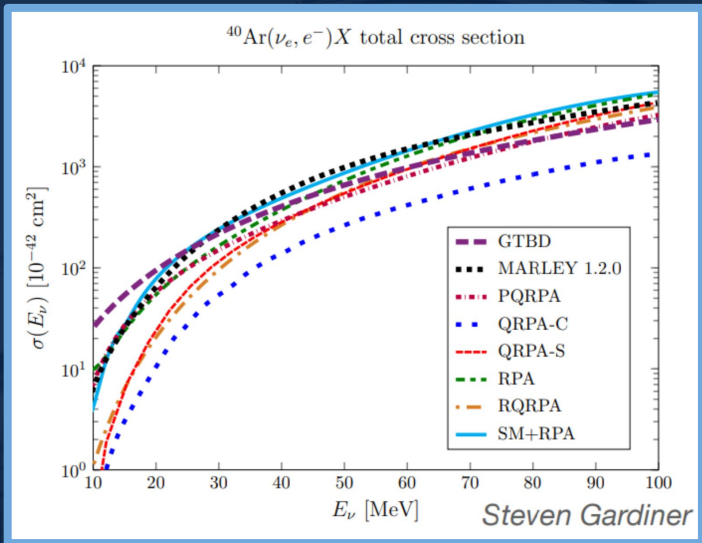
SBND can measure $^{40}\text{Ar}(\nu_e, e^-)^{40}\text{K}^*$ with μDAR !



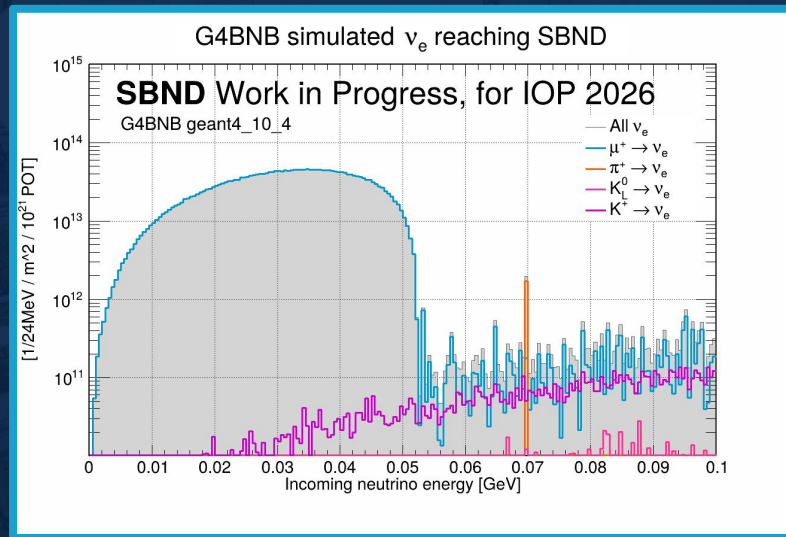
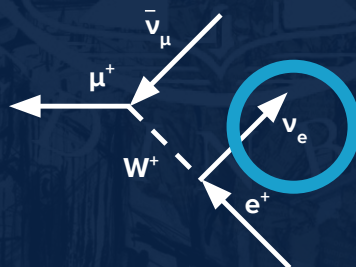
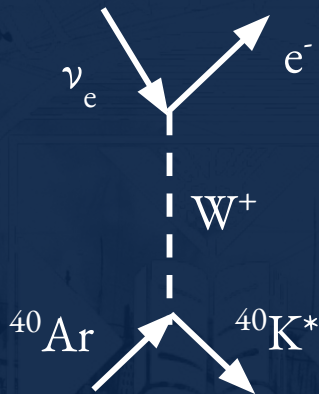
MARLEY Simulation, *Steven Gardiner*



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MARLEY Simulation, Steven Gardiner



Challenges of detecting low energy electron neutrinos from muons Decaying At Rest

1. Does G4BNB correctly simulate them?

This affects how many will **reach** SBND.

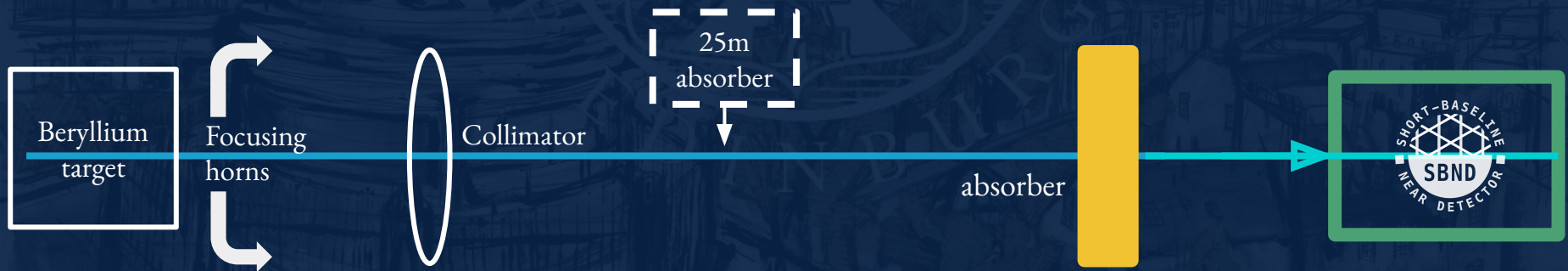
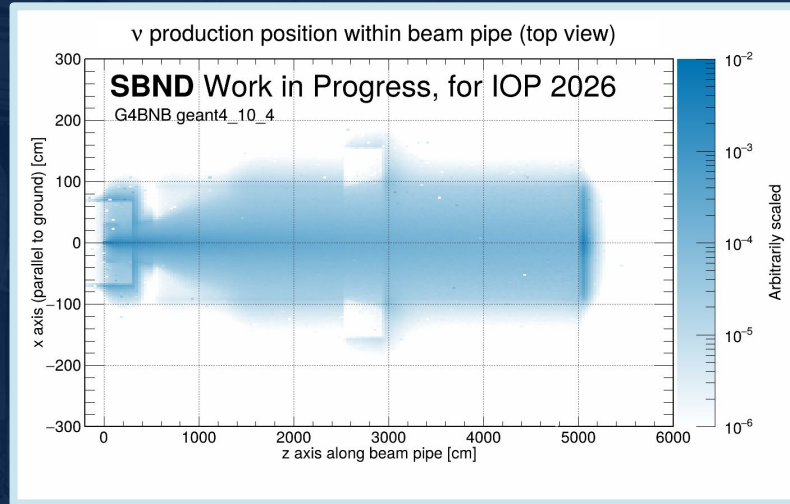
2. Is the current SBND trigger sufficiently configured for this signal?

This affects how many will be **collected** at SBND.

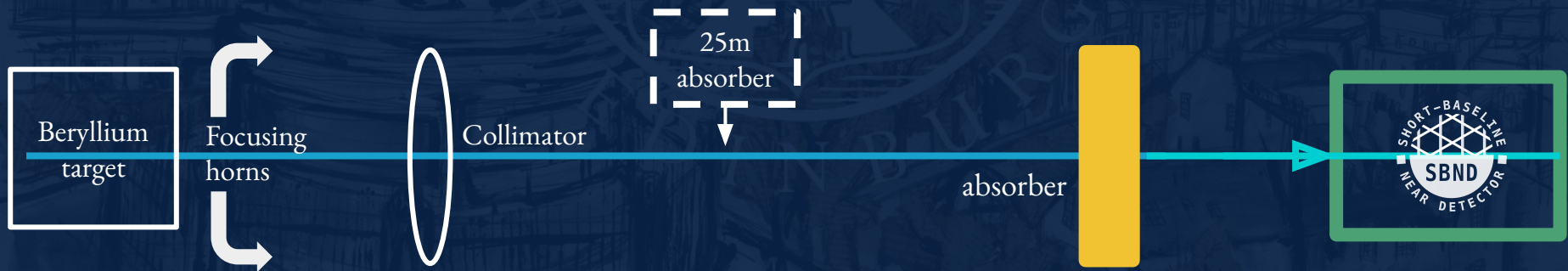
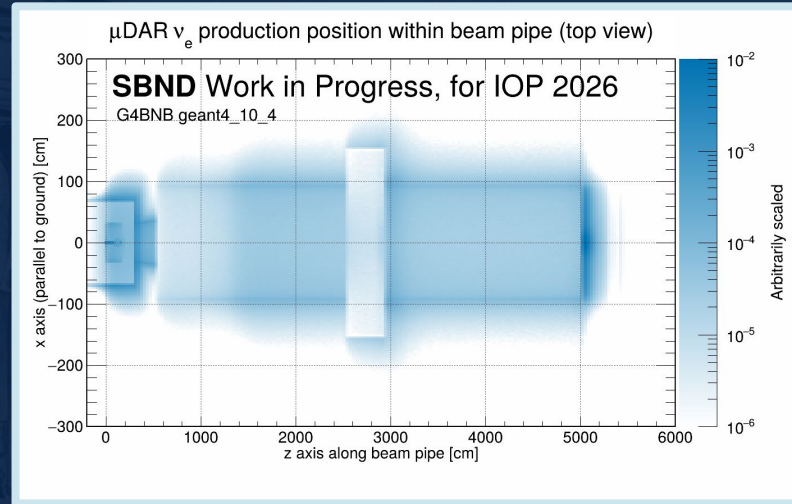
3. How good is SBND's reconstruction efficiency of the interactions' products?

This affects how many we actually **see** in SBND.

Production positions of ν in the beam pipe

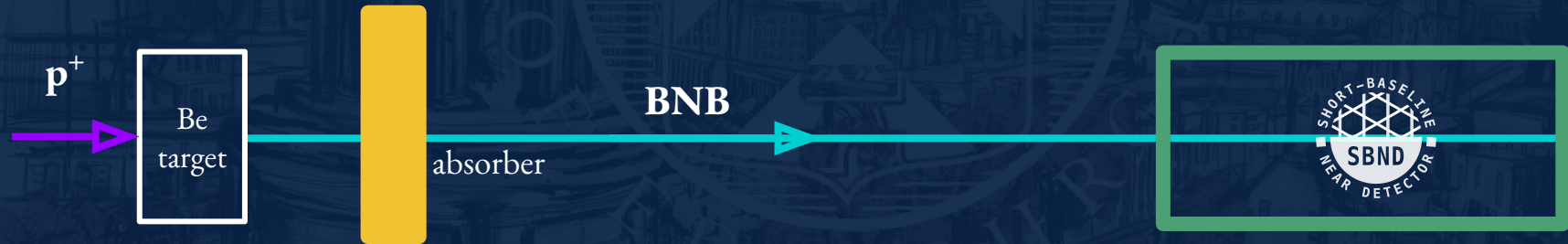


Production positions of $\mu\text{DAR } \nu_e$ in the beam pipe



Additional trigger configuration for μ DARs for Run 2

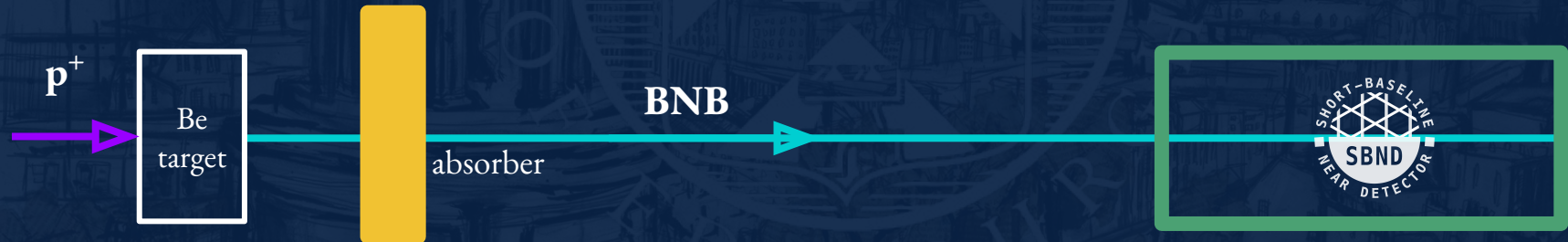
Standard SBND ν trigger:



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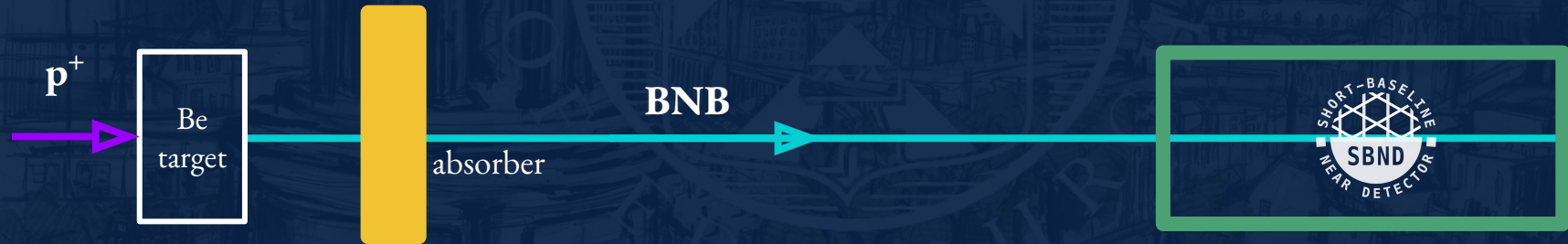
- Based on light produced in SBND



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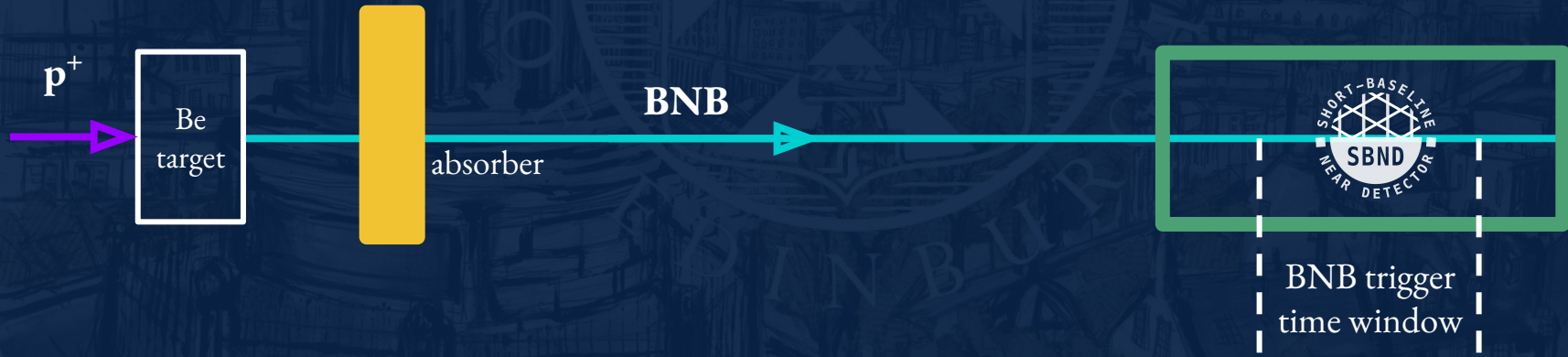
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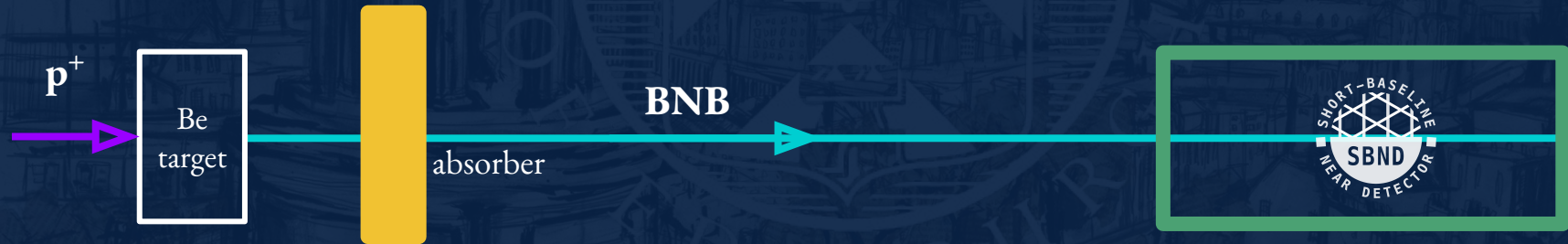
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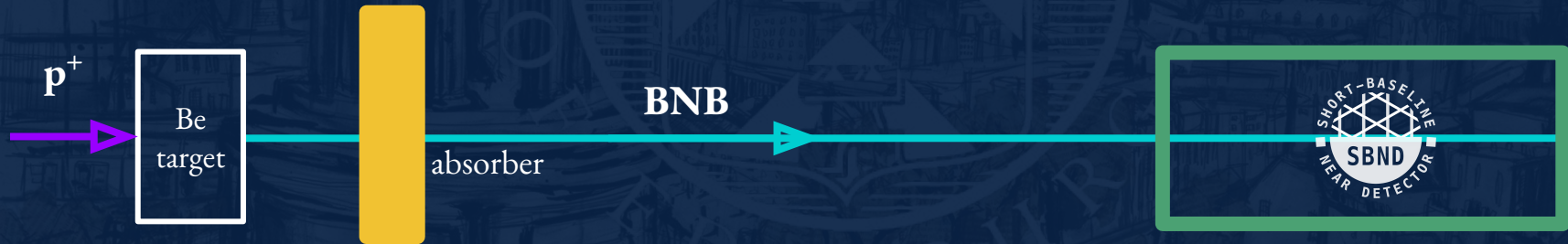
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μ DAR trigger active for Run 2:

- Time window just after standard beam trigger
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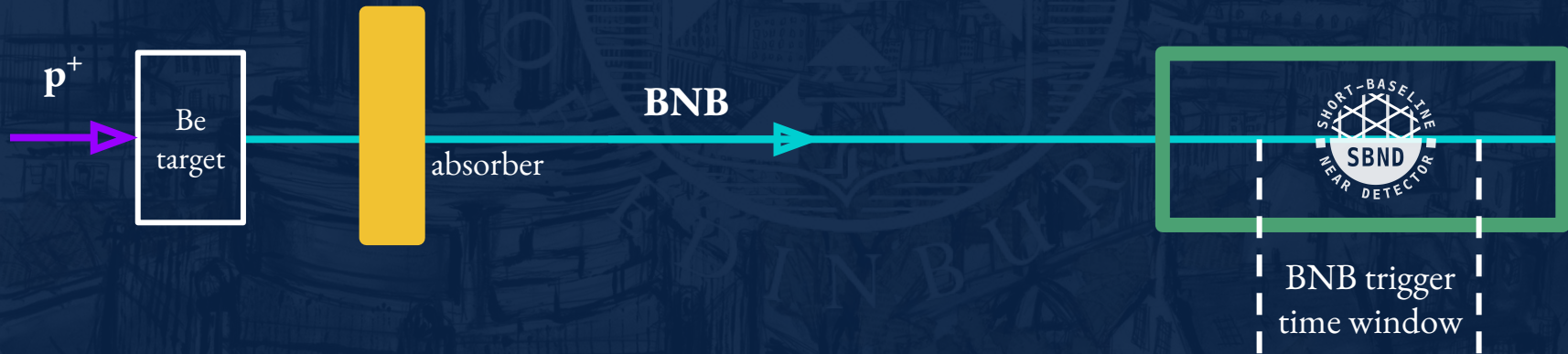
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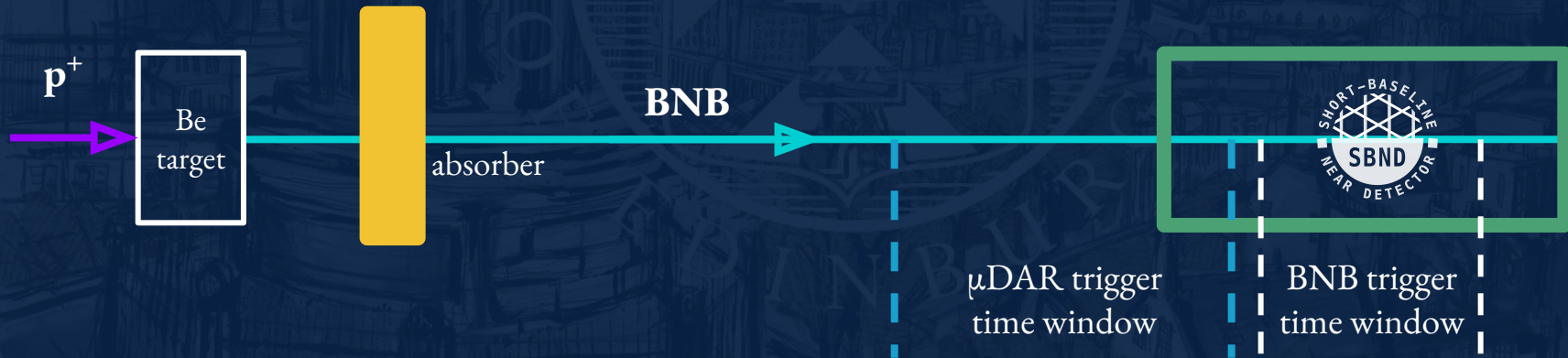
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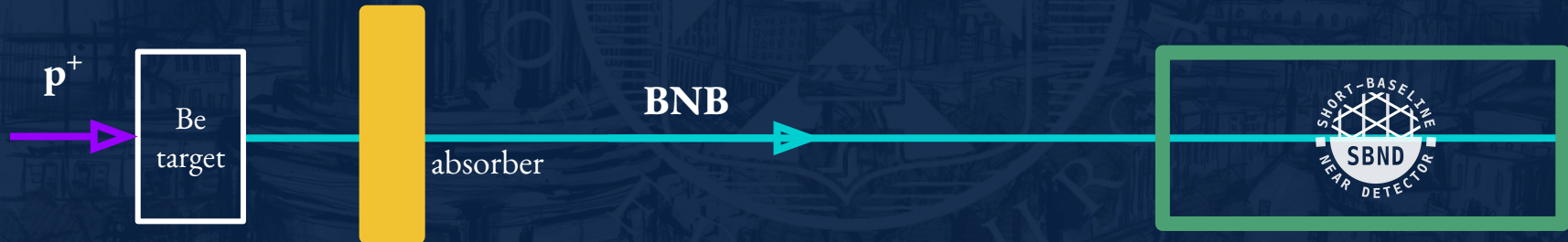
Additional trigger configuration for μ DARs for Run 2

Standard SBND ν trigger:

- Based on light produced in SBND
- Based on BNB arrival to SBND time

μ DAR trigger active for Run 2:

- Time window just after standard beam trigger
- Longer beam window exposure
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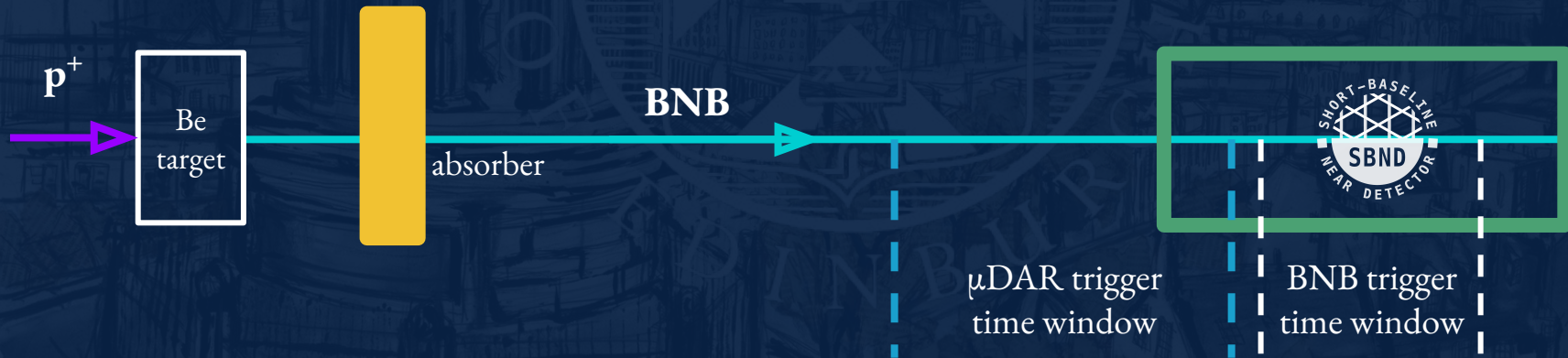
Additional trigger configuration for μ DARs for Run 2

Standard SBND ν trigger:

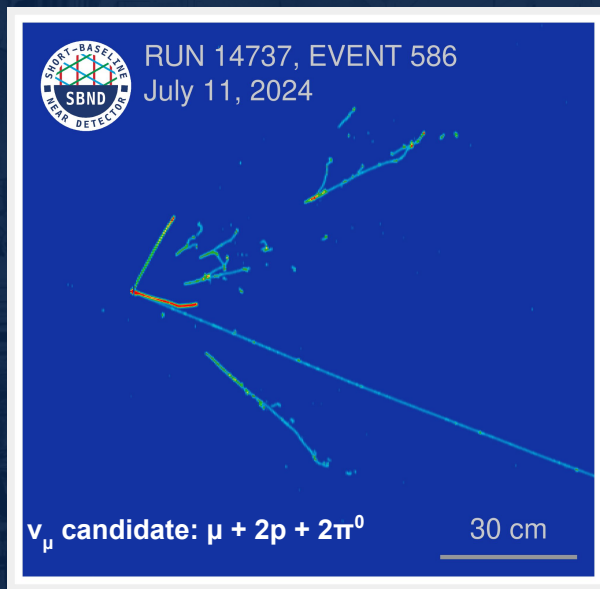
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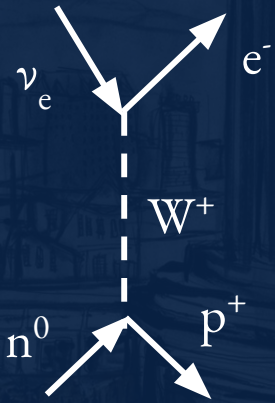


Reconstructing μ DAR signals in SBND

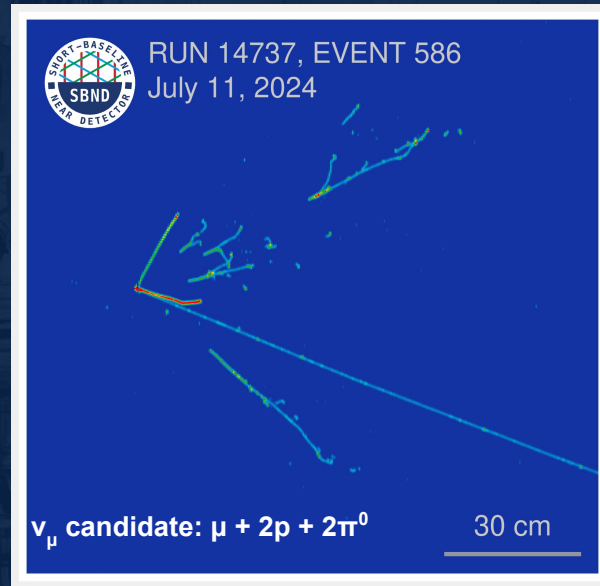


Reconstructing μ DAR signals in SBND

- **Detectable signal in SBND:** released low energy electrons (O(10 MeV)) & de-excitation photons
 - Low energy electrons: very short “lines”
 - Low energy photons: small “dots”

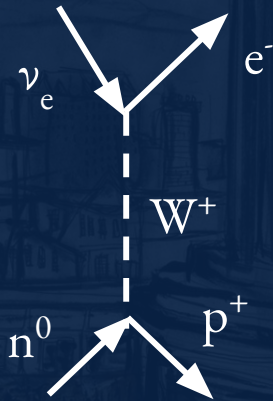


Electron neutrino absorption
charged current

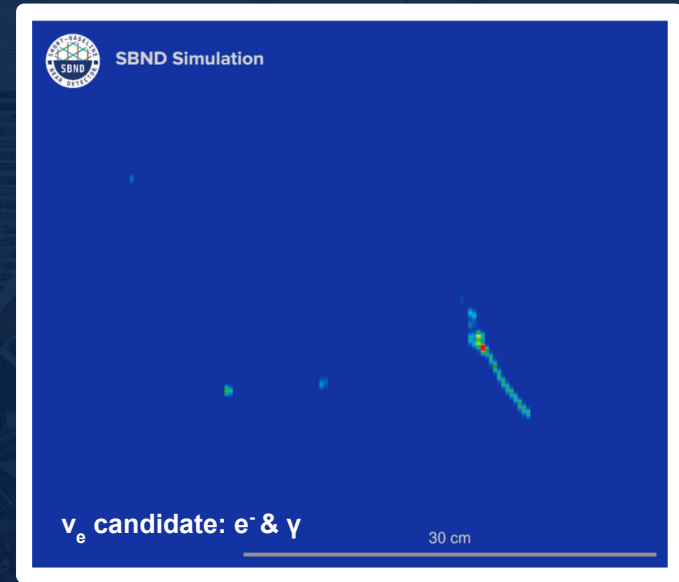
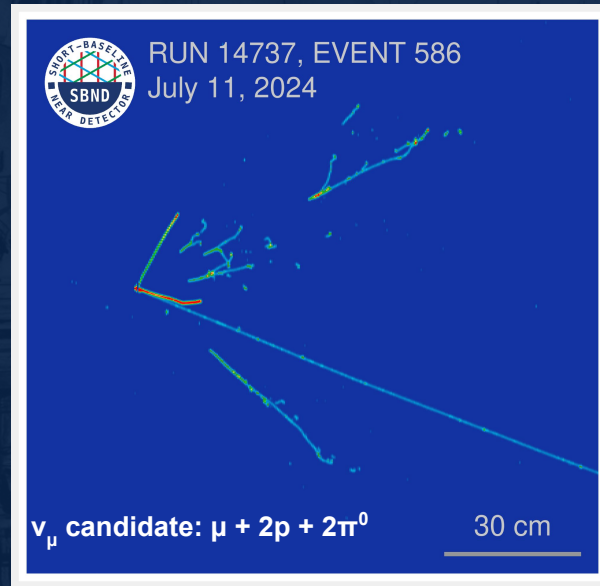


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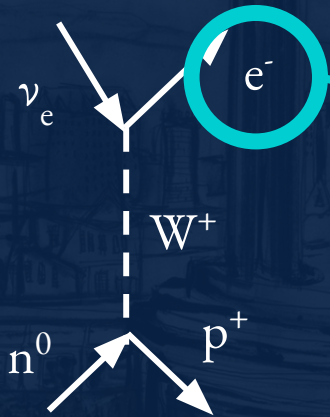


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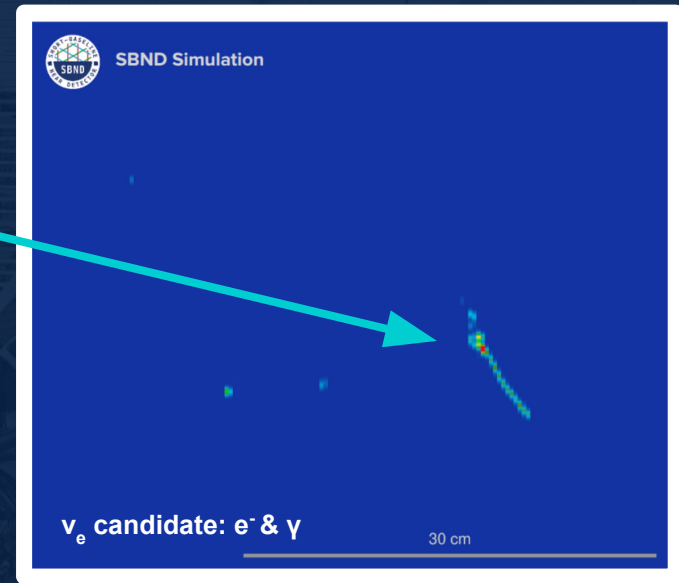
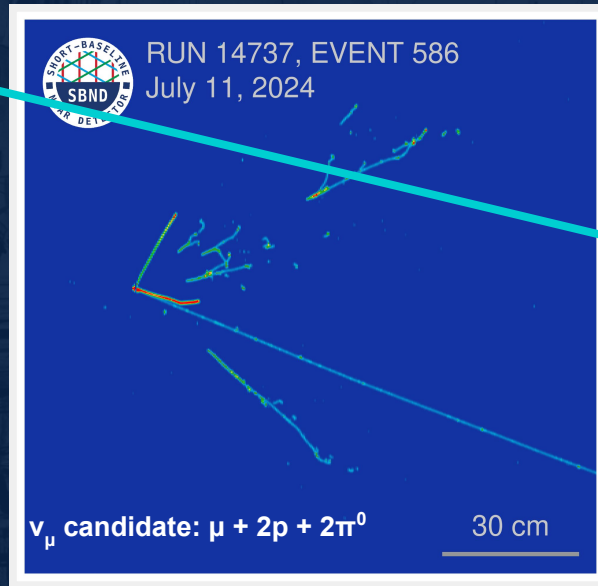


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Electron neutrino absorption
charged current



Progress and future plans

1. Modelling SBND's neutrino flux with G4BNB
 - a. Flux systematic uncertainties package for low energy ν_e underway
2. SBND μ DAR trigger already in place and “triggering” on data!
3. Modelling low energy ν_e interactions in SBND and evaluating reconstruction tools
 - a. Linking dedicated neutrino generator to current SBND workflow: from G4BNB to reconstruction!
4. Finally... measure the $^{40}\text{Ar}(\nu_e, e^-)^{40}\text{K}^*$ cross section!

Thank you!

Please ask questions! Especially "stupid" ones...

Photo credit: Anna Beaver

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When Supernova Neutrinos meet Liquid
Argon: using μ DAR to look for
MeV-scale electron neutrinos in SBND

Summary:

- 99% of a Type II core-collapse **supernova's** energy is emitted in the form of **neutrinos**
- LArTPCs can detect the **electron neutrino flavour** extremely well
- There is **no data** on the **charged current ν_e -Ar interaction** for **10-100MeV energies**
- SBND can measure this cross section with ν_e originating from **muons Decaying At Rest** within the beam
- This is not straightforward, with unique difficulties, including:
 - **beam and flux** simulation assessment
 - system **trigger** needs
 - particular **reconstruction** efforts

Thank you!

Please ask questions! Especially "stupid" ones...

Photo credit: Anna Beaver

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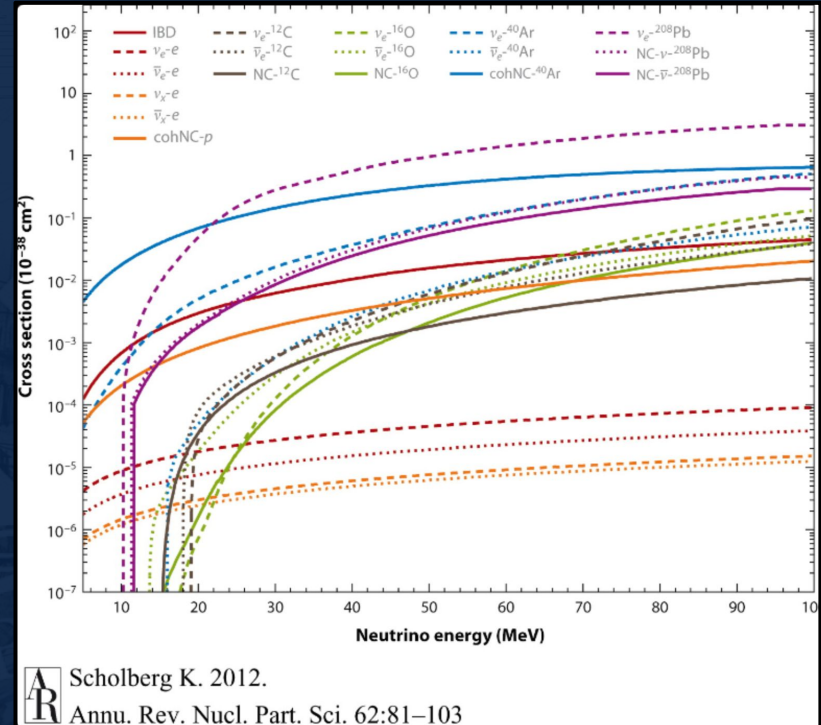
THE UNIVERSITY
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When Supernova Neutrinos met Liquid Argon: using μ DAR to look for MeV-scale electron neutrinos in SBND



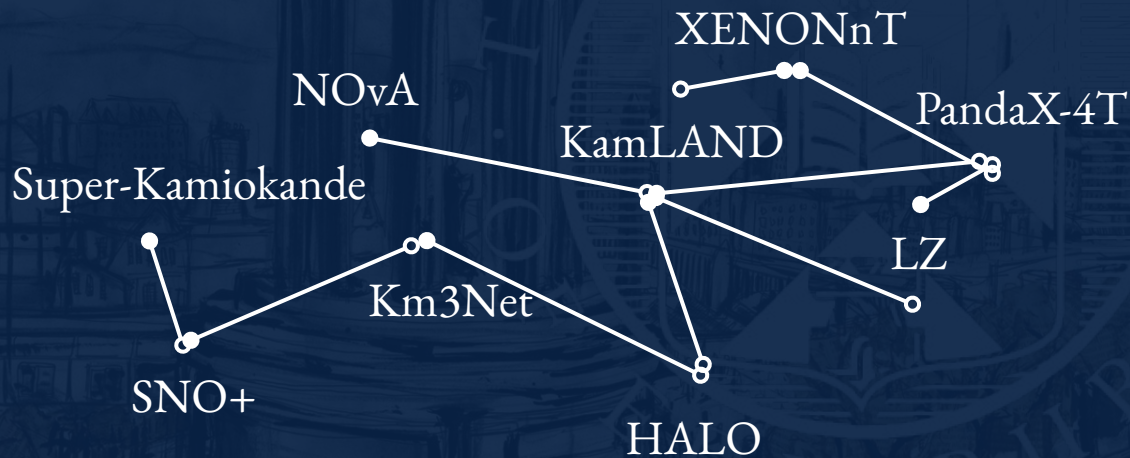
Backup slides

How can we study supernova neutrinos?



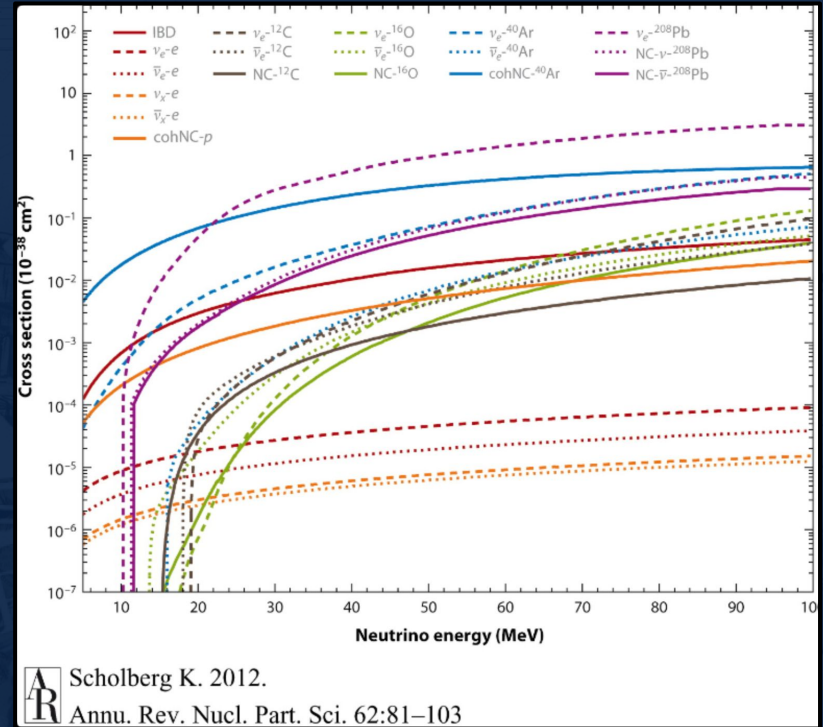
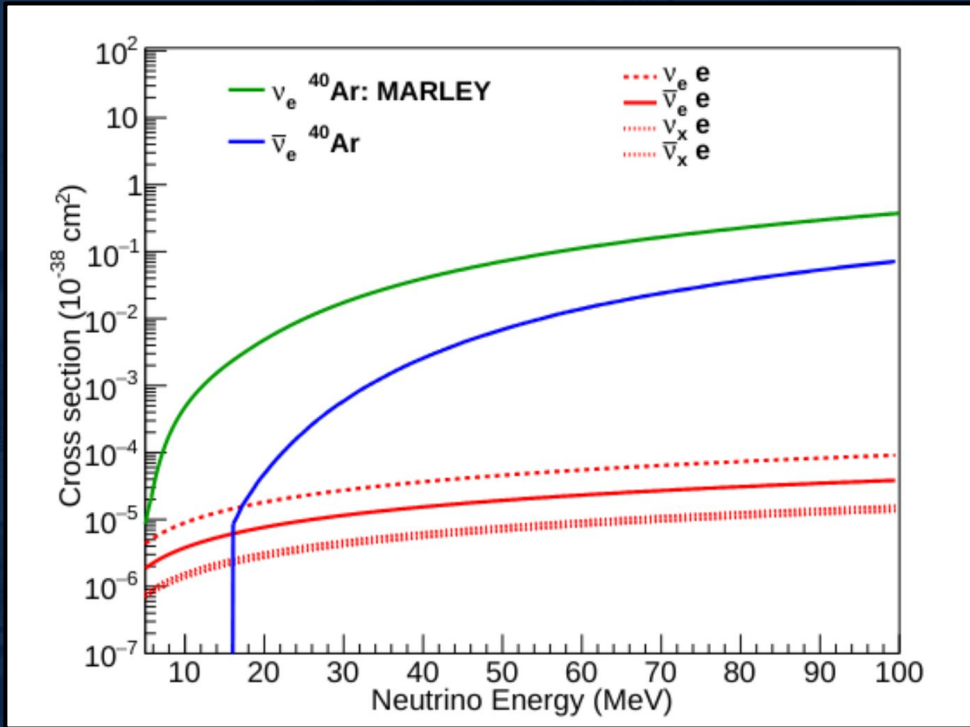
Could neutrinos *warn* us of a supernova's light?


SNEWS 2.0: Supernova Neutrino Early Warning System



We can alert astronomers!

SNN ν_e -Ar cross sections



 Scholberg K. 2012.
 Annu. Rev. Nucl. Part. Sci. 62:81–103

Where do the muons DAR within the beam pipe?

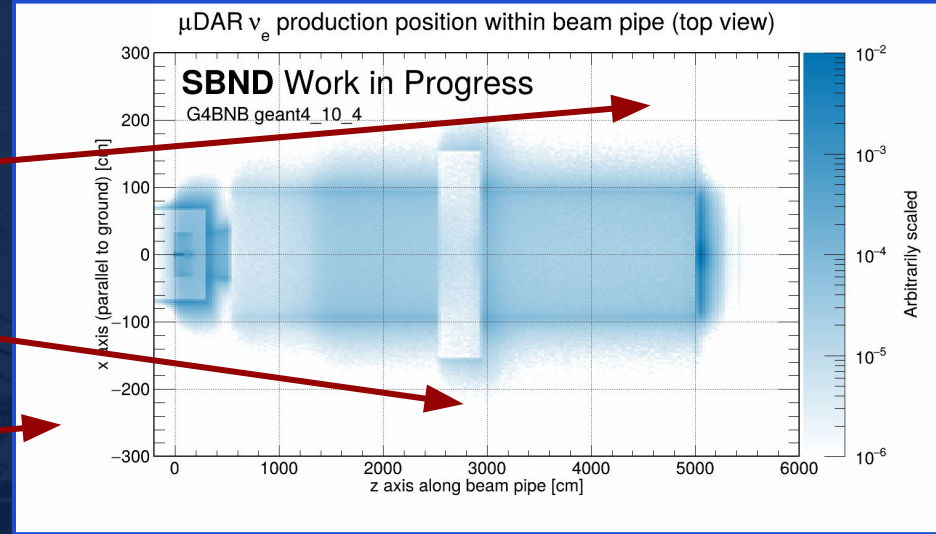
Most μ DAR at absorber:

- Absorber: 39%
- Target Hall: 24%
- 25m absorber: 7%

μ DAR cuts:

if $(p_{\mu^+} < 0.001 \ \& \ \mu^+ \rightarrow \nu_e)$

G4BNB Simulation, *Lucy Kotsiopoulou*, created in beam pipe



Collimator at target hall (blue), *Zarko Pavlovix*

