DAMSA Experiment at Fermilab

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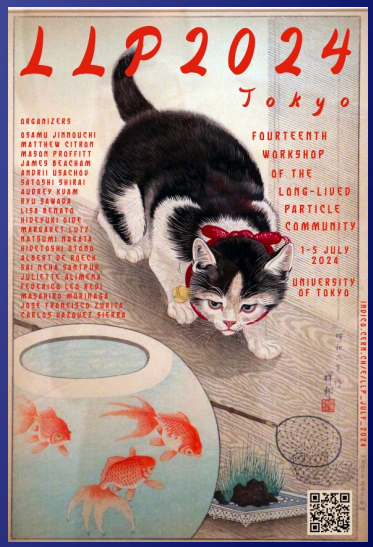
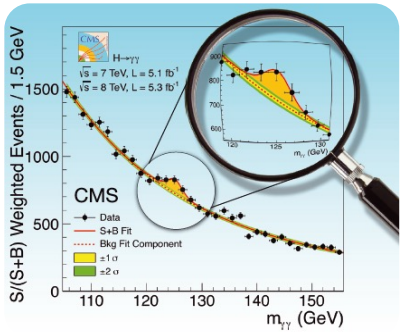
On behalf of the DAMSA Collaboration

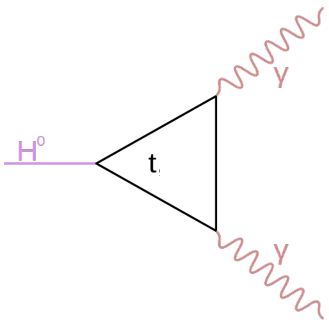


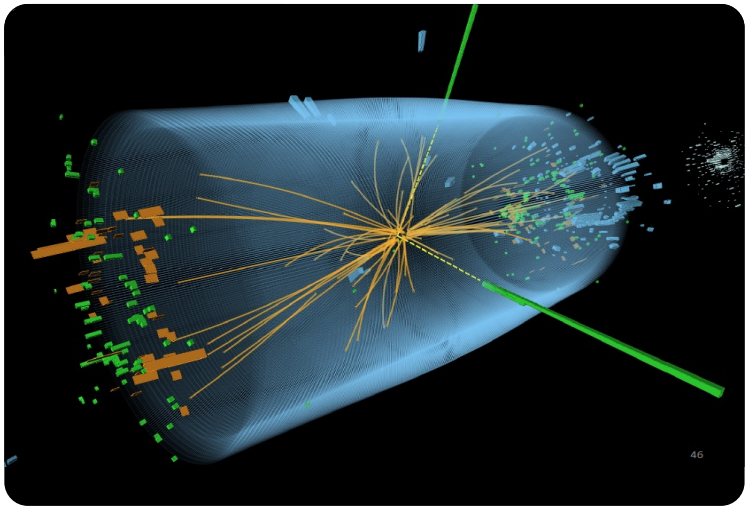
LLP 2024 Workshop, U. of Tokyo, July 1~5, 2024

Very successful SM

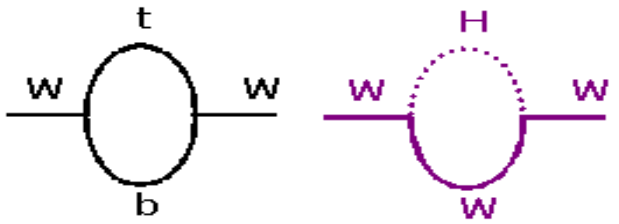
Higgs Discovery

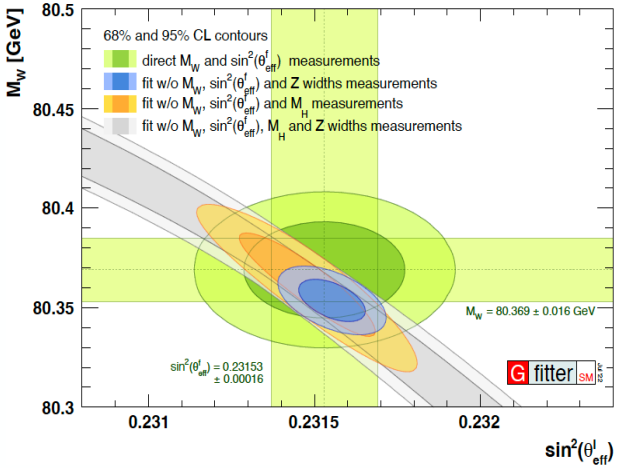






Electroweak Mixing Angle

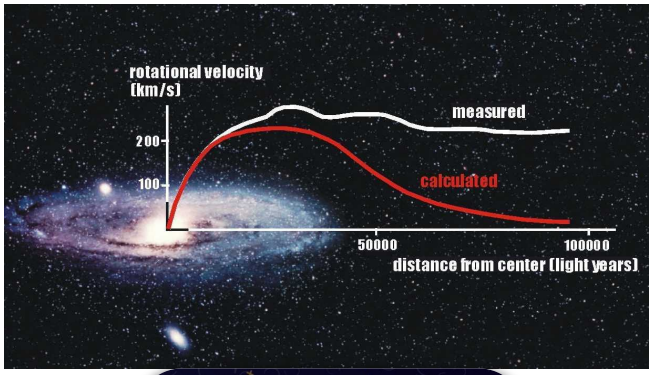


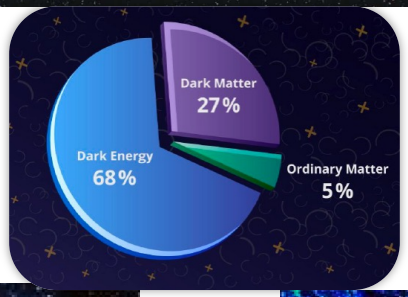


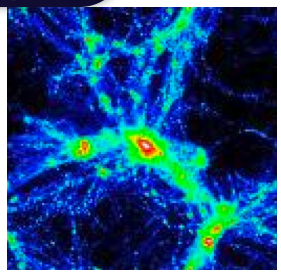
$\sin^2 \theta^{\ell} = 0.23157 \pm 0.00031$
CMS-PAS-SMP-22-010

Beyond SM: Dark Matter

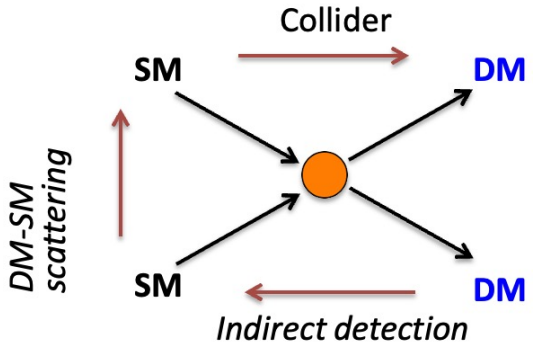
Compelling Evidences

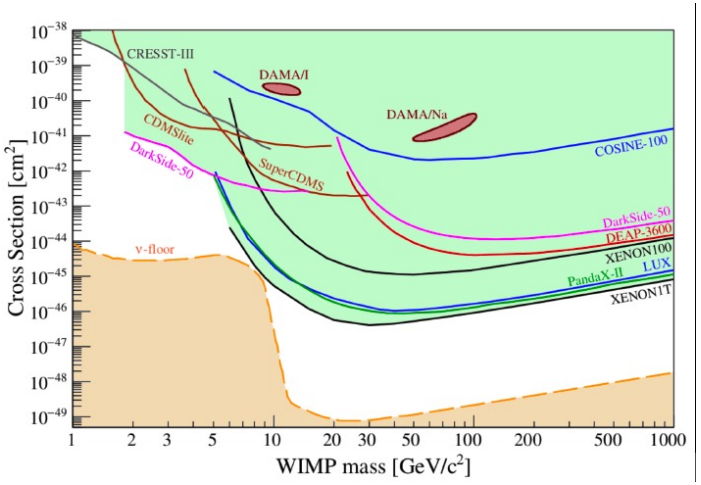






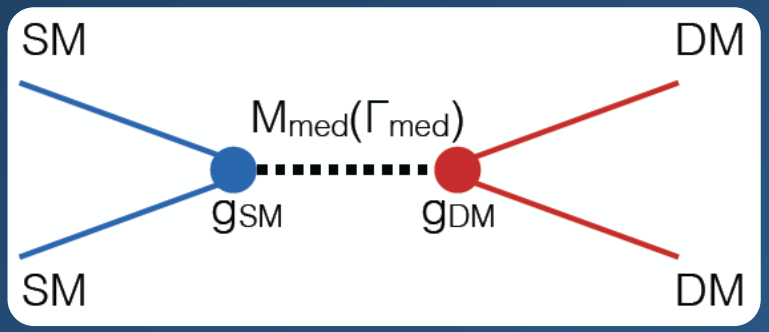
No dark matter particles so far





DAMSA Experiment

- A **very short baseline** dark messengers (mediators) search and discovery experiment at high intensity proton beams



- Stands for **D**ump produced **A**boriginal **M**atter **S**earches at an **A**ccelerator (DAMSA)
  - 담사 (潭思) = 깊은생각 – Rumination or Reflection

    J. Yu *et al.*, PRD 107, L031901 (2023)

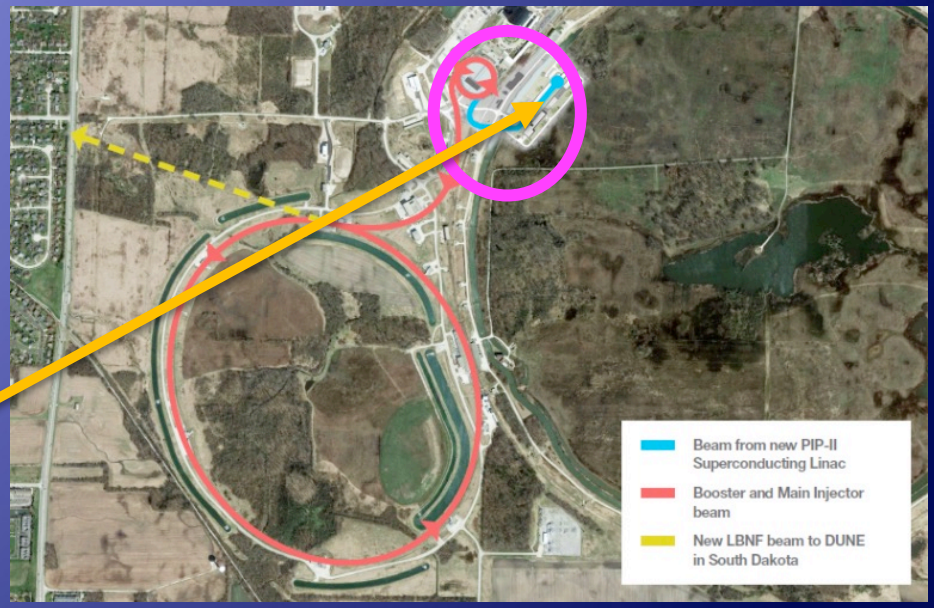
- Aims to discover dark messengers in the low mass regime: axion-like particle (ALP), dark photons
  - Originally developed for 600MeV proton beams at a nuclear rare isotope facility in Korea
  - The 800MeV PIP-II at Fermilab

PIP-II Accelerator at Fermilab

- PIP-II (Proton Improvement Plan – II) provides
  - New SRF LINAC for proton injector to Booster at 800MeV
  - Booster cycle rates upgrade for increased proton beam intensity at 8 GeV for 1.2MW beam power from main injector
  - The essential first element for DUNE (2% used)
  - Total proton current of 2mA ➔up to ~4x10^{23} PoT/yr

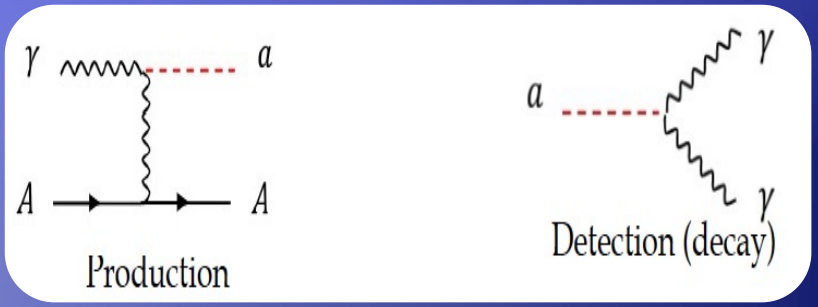
- PIP-II era begins in 2029, DUNE in 2031

- Mu2e (8GeV)
- Fixed target, test beams (120 GeV)
- 800 MeV beam available for other exp like DAMSA

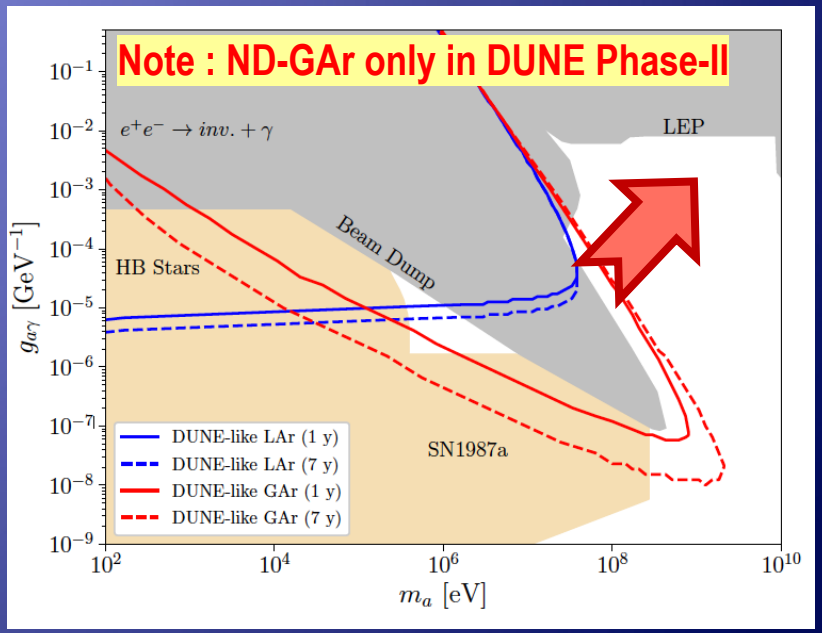


Physics Strategy

- Photons are sources for dark messengers production
  - ALP in two-photon final state by the Primakoff process

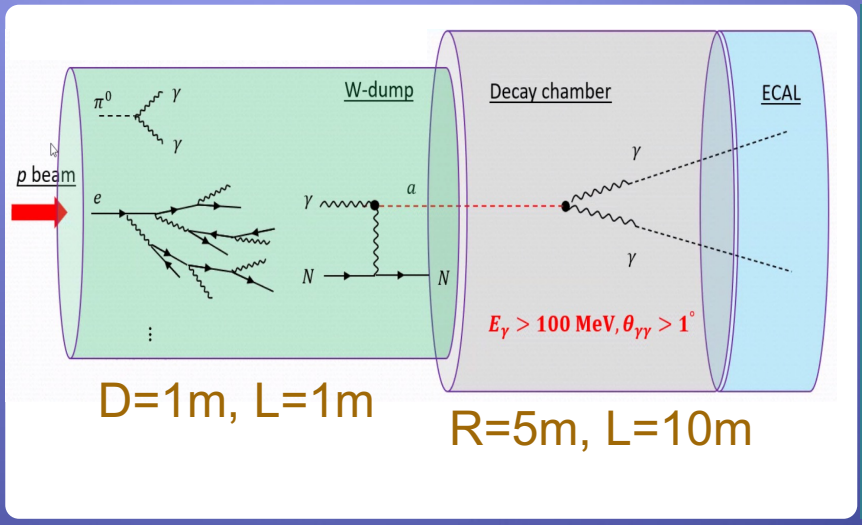


- Produce as many photons as possible from the beam
- Capture as many ALPs in as wide a mass range as possible
- Mitigate the backgrounds from neutral particles, using two EM particle final states
- Place the detector very close to the beam



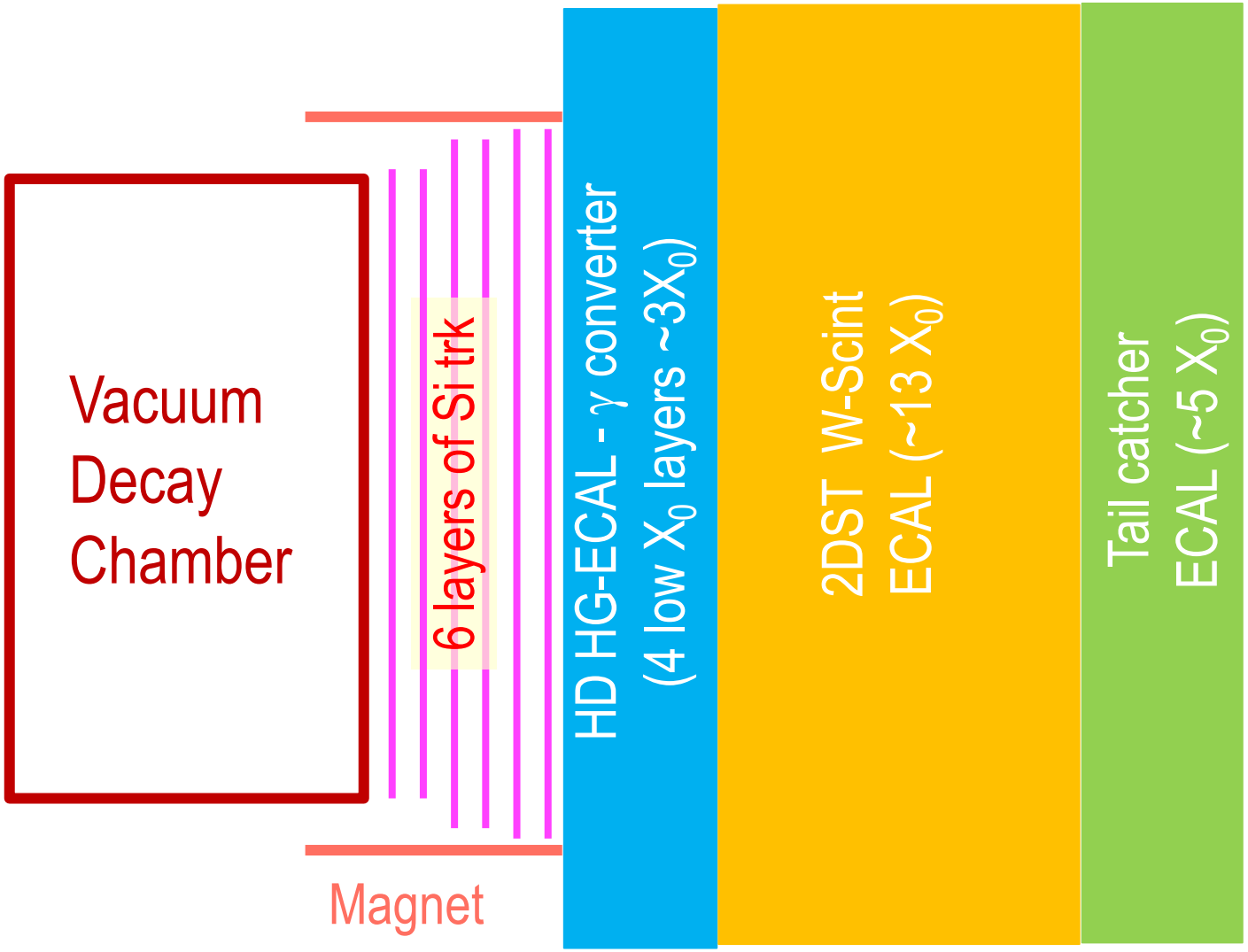
Conceptional Design

- Inject and absorb as many protons and produce as large number of γ in the **dump** as possible
- Allow higher coupling ALP's to **decay in the vacuum** w/ as small number of neutrons escaping the dump as possible
- Place the **detector as close to the dump as possible** on axis to expand the mass reach to higher mass region
- Search for ALP to two photons, dark photons to e^-e^+

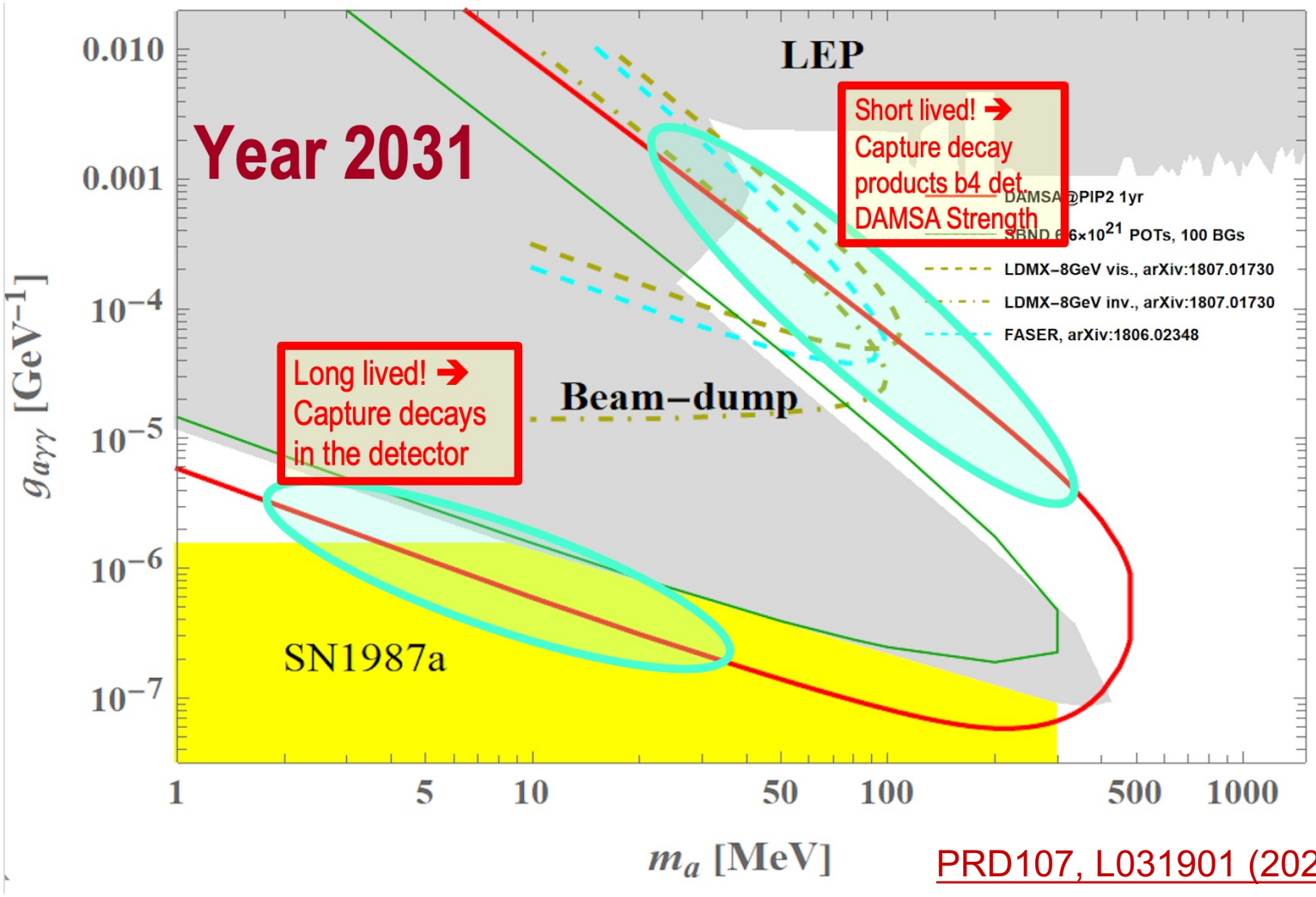


- Good vertex pointing resolution for $\gamma\gamma$ and e^+e^-
- Sub-ns timing difference resolution (0.1ns)
- Low E threshold identification of e^+e^-
- Good mass resolution

Conceptional Design



DAMSA Sensitivity



PRD107, L031901 (2023)

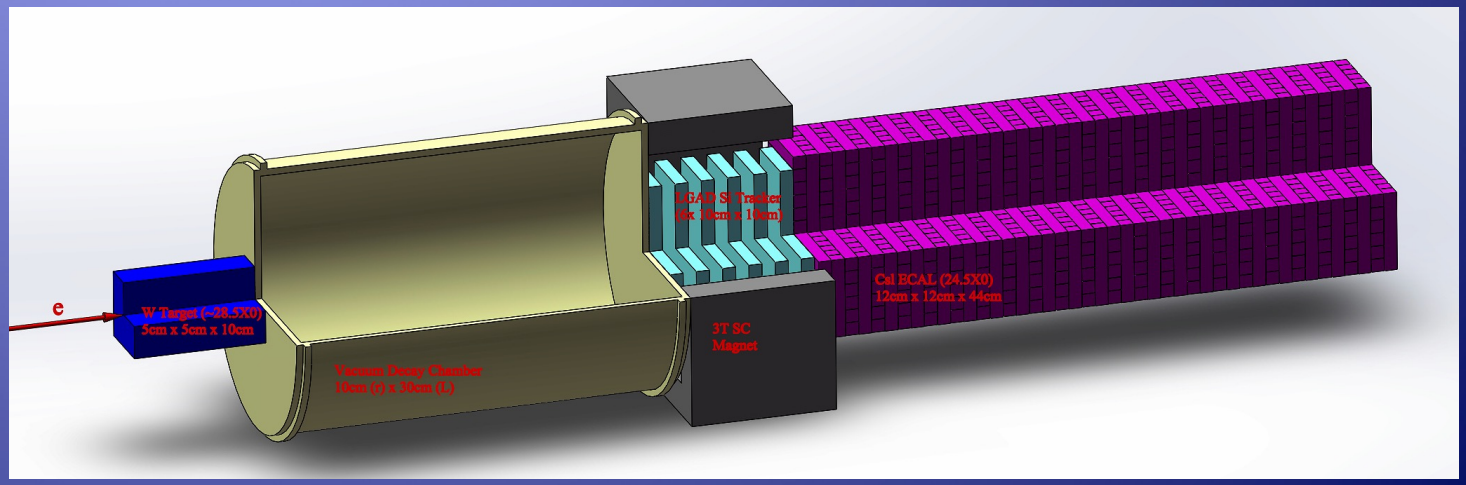
Where is the DAMSA experiment?

- DAMSA has been introduced to the community for last 3 years, more intensely since 2023
  - Concept included in a few Snowmass2021 white papers
  - Physics case study published on PRD107, L031901 (2023)
  - Multiple presentations made at conferences, workshops, P5 town hall meeting, and seminars in the U.S., SK and CERN
  - Met w/ Fermilab directorate several times
- DAMSA collaboration building ongoing
  - Lead Investigators:
    J. Estrada (FNAL), U.K. Yang (SNU), and J. Yu (UTA)
    12 US + 11 SK institutions on DAMSA
  - Facility and experiment are being defined
  - Funding applications being submitted
  - Task force for F2D2 (Fermilab Facility for Dark matter Discovery) was formed in 2024 by Fermilab

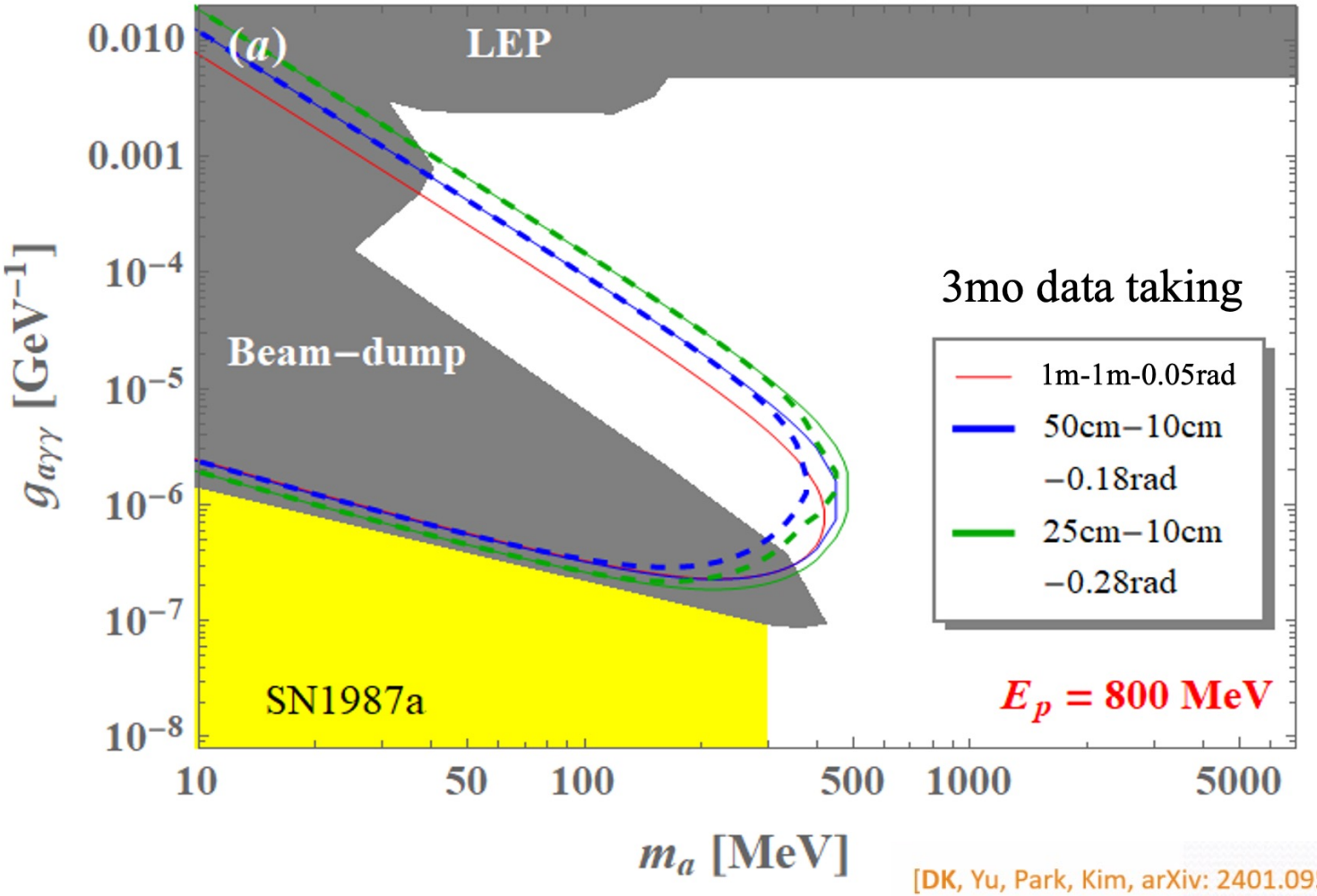
DAMSA Pilot experiment

- **Goal: do a physics demonstrator in the next 2 yrs**
- Beam: 300 MeV e-beams at Fermilab FAST

  ➔ greatly reduced neutron bkgds, compared to proton beam
- Target: 5cm x 5cm x 10cm W target (~28.5X_0)
- Vacuum decay chamber : 10cm (R) x 30cm (L)
- Detector: 6 layers of 10cm x 10cm Si tracker (LGAD) under magnetic field + CsI ECal total absorption (24X_0)



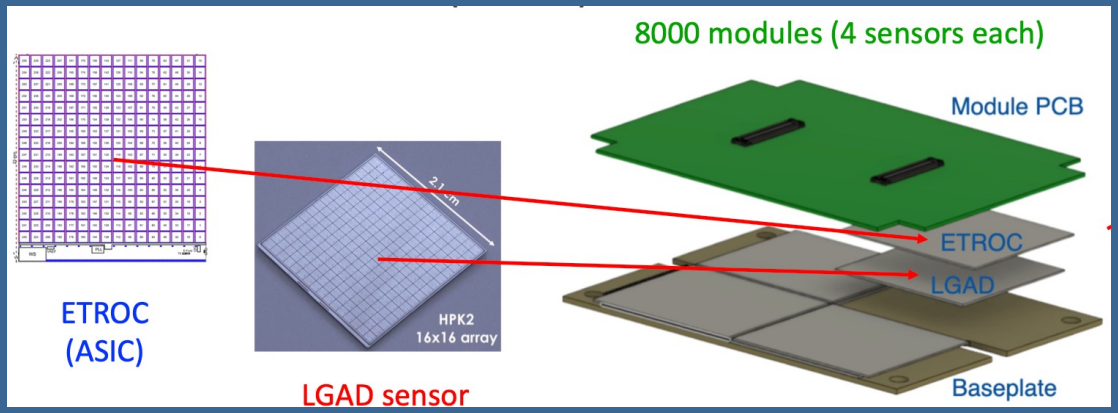
Pilot DAMSA Sensitivity

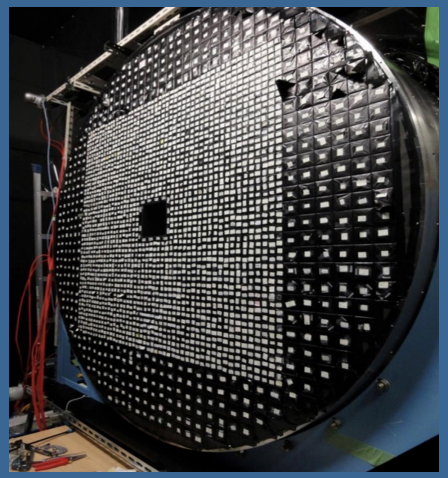


[DK, Yu, Park, Kim, arXiv: 2401.09529]

Detectors R&D

- Use the LGAD detector as tracker: (Korea CMS)
  - The Low Gain Avalanche Diode consists of 16x16 pixels of 1.3x1.3mm^2
  - Position resolution of 35 – 50 μm
  - Timing resolution per track <35ps (single hit resolution <50ps)
  - High radiation tolerance

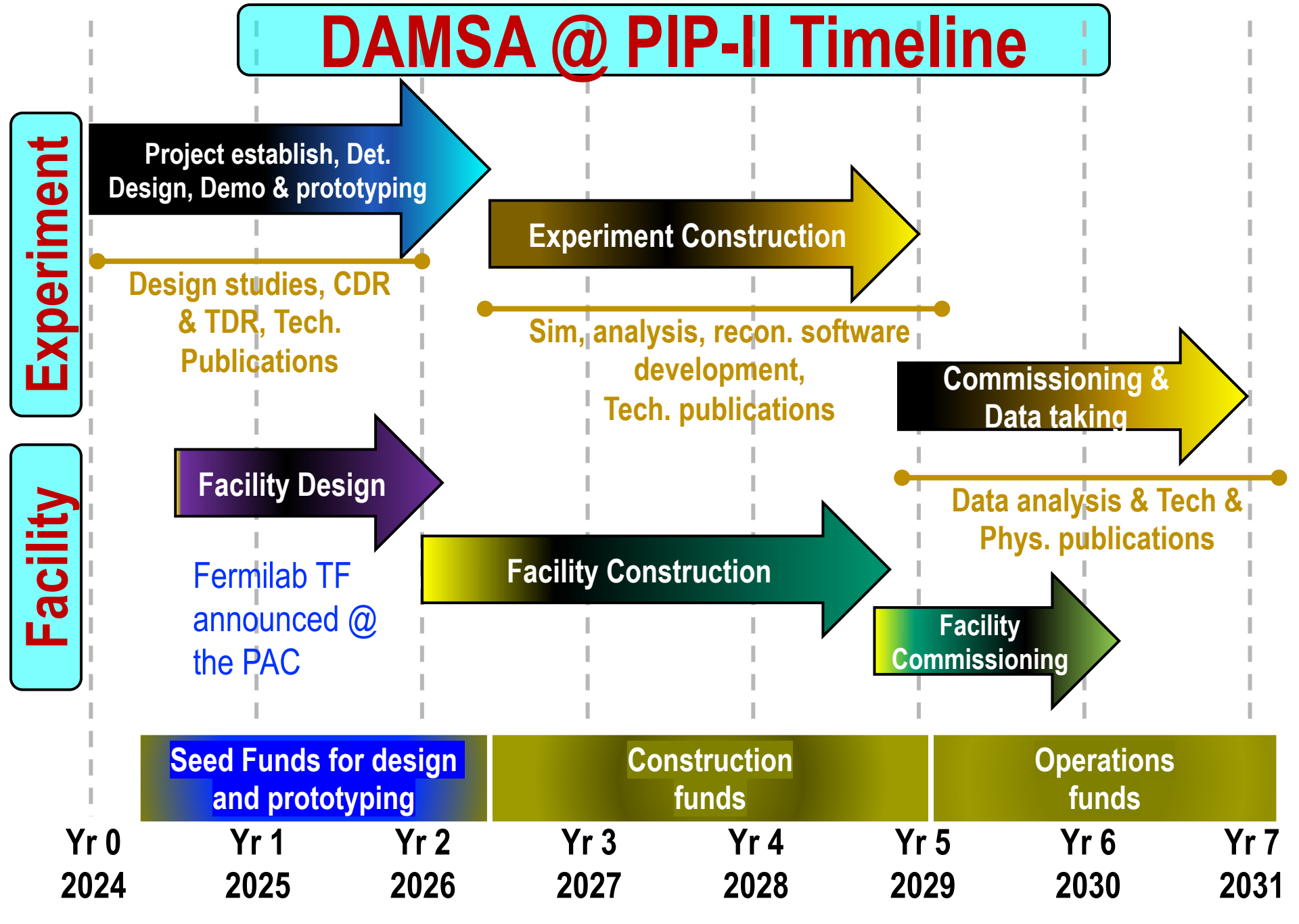




- Use CsI crystal for ECal used for K-TeV exp. at Fermilab built by U. of Chicago: 16 of 5x5x50cm^3 CsI crystal bars in hand

DAMSA: Staged Plan

- Stage 0 → e-beam background validator
  - Measure and validate the MC neutron and photon bkg counts
- Stage 1 → The a 2γ demonstrator @ e-beam
  - Build a demonstrator with only W target, vacuum decay chamber and an ECAL (CsI would be ideal but this could be made of scintillators) + charged particle veto counters
- Stage 2 → The a 2e demonstrator @ e-beam
  - Upgrade the stage 1 demonstrator with Si tracker (and magnet)
  - Demonstrate the expanded signal capture
- Stage 3 → The neutron bkg demonstrator @ p-beam
  - Move the demonstrator to a low E, low power proton beam
  - Demonstrate neutron background handling
- Stage 4 → The full scale DAMSA @ p-beam
  - Move the complete detector to available proton beam facilities
  - Perform search and discovery


DAMSA @ PIP-II Timeline
Experiment
Facility
Project establish, Det. Design, Demo & prototyping
Design studies, CDR & TDR, Tech. Publications
Experiment Construction
Sim, analysis, recon. software development, Tech. publications
Commissioning & Data taking
Data analysis & Tech & Phys. publications
Facility Design
Fermilab TF announced @ the PAC
Facility Construction
Facility Commissioning
Seed Funds for design and prototyping
Construction funds
Operations funds
Yr 0 2024
Yr 1 2025
Yr 2 2026
Yr 3 2027
Yr 4 2028
Yr 5 2029
Yr 6 2030
Yr 7 2031

Fermilab Plan

Fermilab Facility for Dark Matter Discovery (F2D2)

- PIP-II beam dump facility to host dark sector ASTAE experiments, aligned with P5

> **New Initiative: A Portfolio of Agile Projects to Search for Direct Evidence of New Particles**
>
> the hidden sectors through the Vector and Heavy Neutral Lepton portals. At Fermilab, PIP-II is expected to make many more protons than needed for DUNE, and we anticipate proposals for experiments using the excess protons. These experiments should compete in the portfolio for agile projects (see Recommendation 3a and Section 6.2).

Exploring the Quantum Universe

- White paper from the workshop on physics program, experiments contains proposals for dark sector particle discovery w/ the PIP-II beam w/ strong Fermilab leadership
  - DAMSA: Very short baseline beam dump experiment
  - OSCURA: Skipper CCD, low threshold
  - PIP2-BD: 100t LAr Scintillator
  - And other opportunities
- Could provide a steady stream of scientific results in the ACE-MIRT era
- Forming a task force to develop a more detailed picture of what would be required to be realize these opportunities

Physics Opportunities at a Beam Dump Facility at PIP-II at Fermilab and Beyond

A. A. Aguilar-Arevalo[1], J. L. Barrow[2], C. Bhat[3], J. Bogenschuetz[4], C. Bonifazi[5,6], A. Bross[3], B. Cervantes[1], J. D'Olivo[1], A. De Roeck[7], B. Dutta[8], M. Eads[9], J. Eldred[3], J. Estrada[3], A. Fava[3], C. Fernandes Vilela[10], G. Fernandez Moroni[3], B. Flaugher[3], S. Gardiner[3], G. Gurung[4], P. Gutierrez[11], W. Y. Jang[4], K. J. Kelly[8], D. Kim[8], T. Kobilarcik[3], Z. Liu[2], K. F. Lyu[2], P. Machado[3], R. Mahapatra[8], M. Marjanovic[11], A. Mastbaum[12], V. Pandey[3], W. Pellico[3], S. Perez[13], J. Reichenbacher[14], D. Rodrigues[13,15], A. Sousa[16], B. Simons[3,9], D. Snowden-Ifft[17], C.- Y. Tan[3], M. Toups[3], N. Tran[3], Y.-T. Tsai[18], R. G. Van de Water[19], R. Vilar[20], S. Westerdale[21], J. Yu[4], J. Zettlemoyer[3], and R. Zwaska[3]

arXiv:2311.09915

By Kevin Burkett (PPD head) at PAC meeting (Jan. 2024)

Summary

- DAMSA is a discovery experiment for dark messengers
- DAMSA has been making serious and steady progress
  - Aim to be ready even for PIP-II LINAC beam in 2029
  - Perfect fit to ASTAE program in the recently released P5 report
- Collaboration building ongoing but still has long ways to go! Fermilab formed a TF to define the facility
  - Whitepaper released to the archive on PIP-II Beam Dump physics opportunities (2311.09915)
- DAMSA presents an excellent opportunity to play a major role in dark messenger searches and discovery