Introduction to DAMSA Experiment

Mitchell Conference, TAMU
May 23 – 25, 2024

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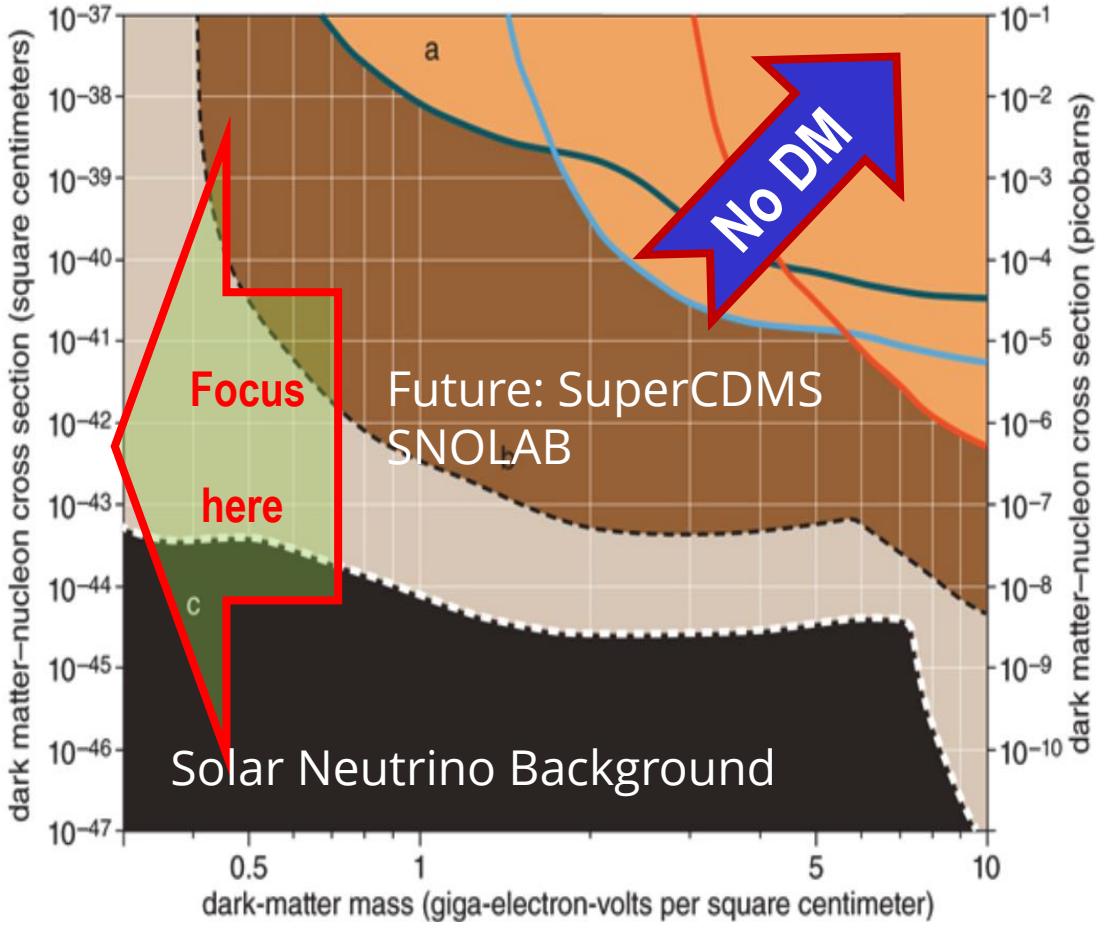
For DAMSA Collaboration

What is DAMSA?

- A **very short baseline** dark sector particle (DSP) search and discovery experiment at high intensity p beams
- Stands for **D**ump produced **A**boriginal **M**atter **S**earch at an **A**ccelerator (DAMSA)
  - 담사 (潭思) = 깊은생각 – Rumination or Reflection
    - J. Yu *et al*., PRD 107, L031901 (2023)
- Aims to discover DSP's in the low mass regime at an accelerator ➔ E_{beam} below the pion threshold beneficial
  - Originally developed for 600MeV proton beams at a nuclear rare isotope facility
  - The 800MeV PIP-II and the ACE beams at Fermilab fit the bill
- DAMSA can be at any accl. facility, including CERN

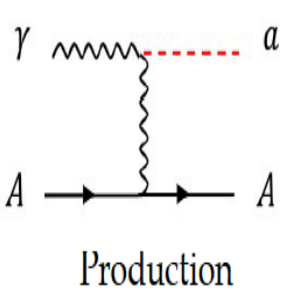
Physics Motivation For DSP

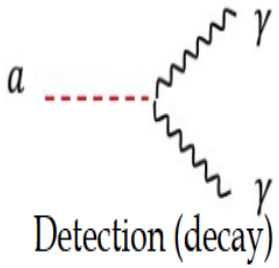
- Direct searches have challenges in kinematic reach, leaving low mass range un-explored
- Strategy:
  - Search for dark sector particles in unexplored kinematic regime
  - Make and discover DSPs in an accelerator
  - Establish infra to better understand DM

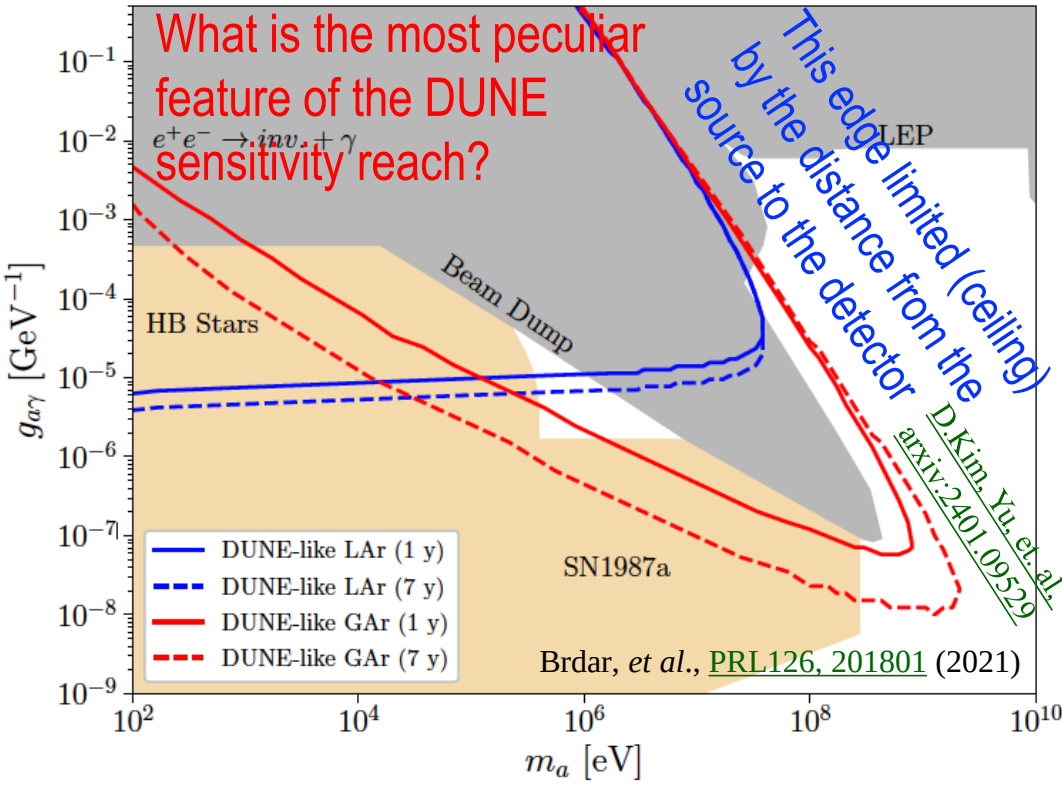


DAMSA Physics Strategy

- Photons are the sources for dark sector particle production
  - Use case: Search for Axion-like particles (ALP) in **two-photon** final state via the Primakoff process







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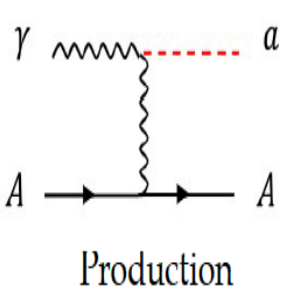
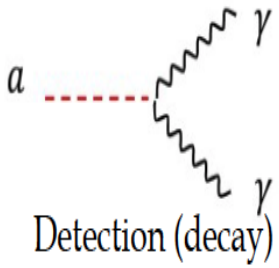
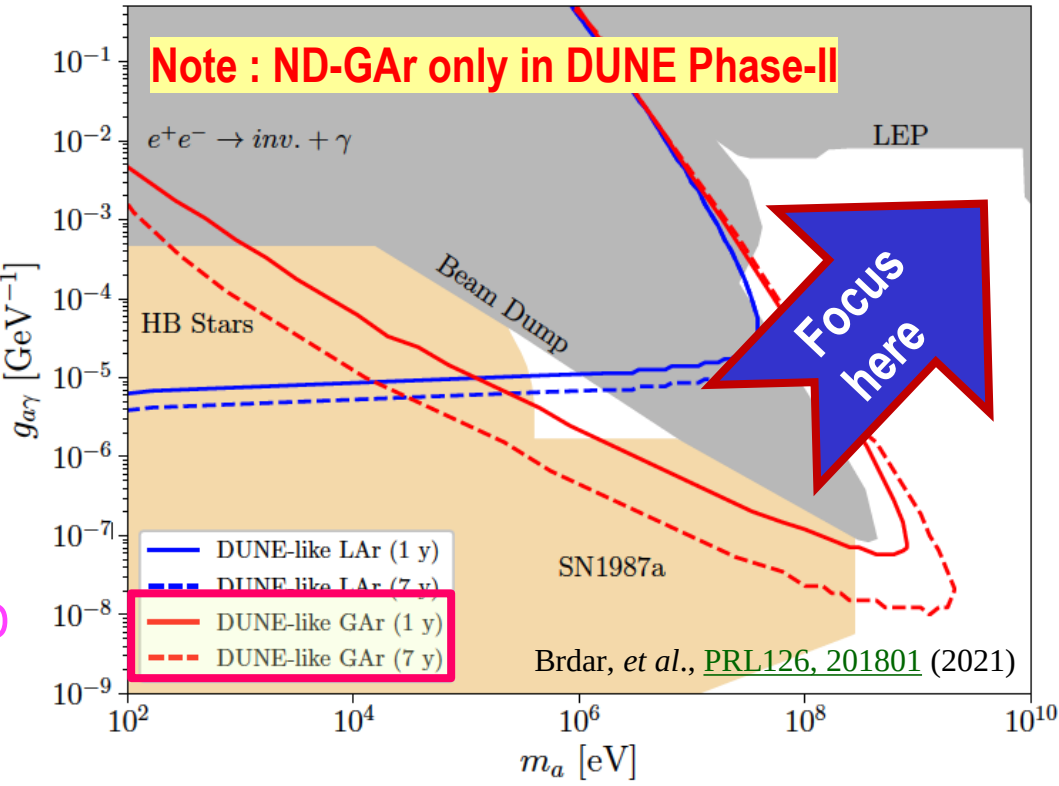


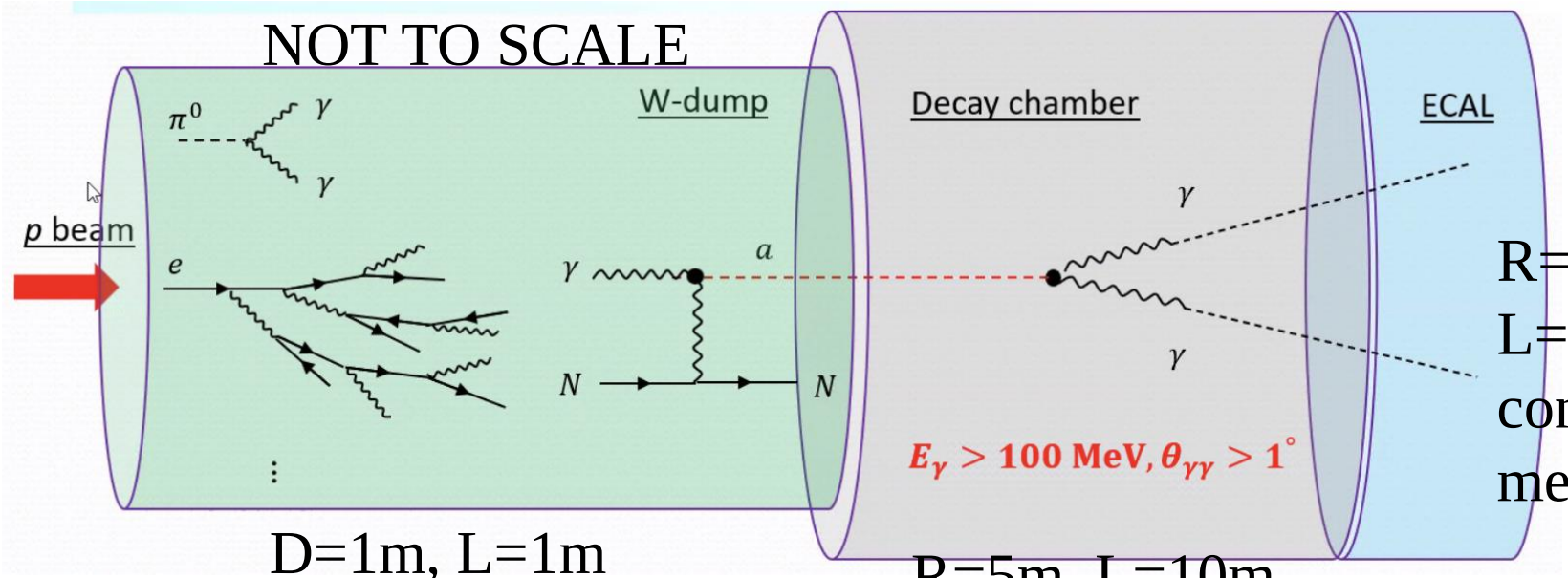


- Produce as many photons as possible in the dump
- Capture as many ALPs as possible in as wide a mass range as possible
- Mitigate the backgrounds from neutral particles, leveraging two EM particle final states
- Place the detector very close to the beam



DAMSA Exp. Concept

- 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

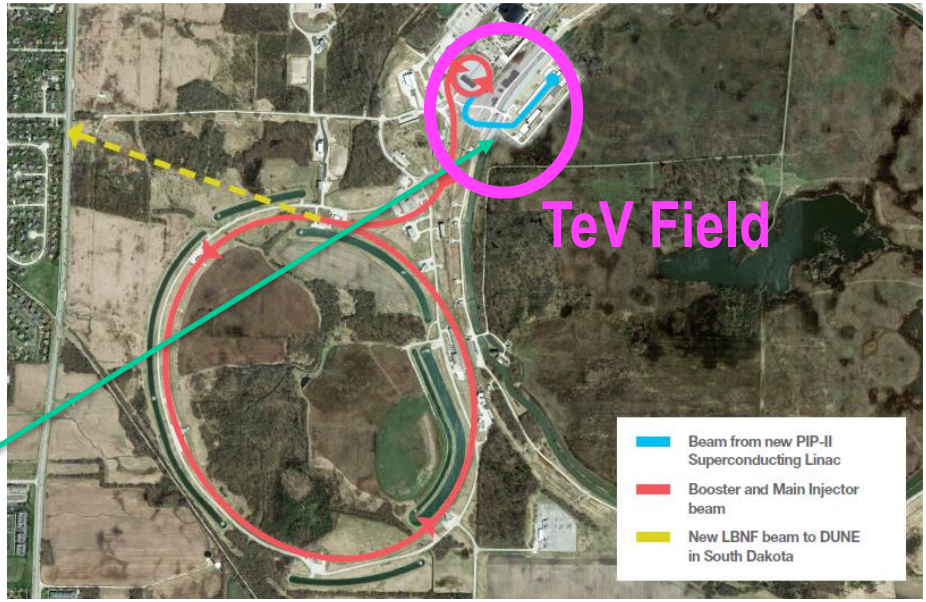


The three key elements

- The bad man
- The ugly
- The good actor

Accelerator Complex in the PIP-II Era

- PIP-II (Proton Improvement Plan – II) provides
  - New SRF LINAC for proton injection into Booster at 800MeV
  - Booster cycle rates upgrade for increased proton beam intensity at 8GeV for 1.2MW beam power from main injector
- PIP-II LINAC is the essential first element for DUNE
  - Total proton current of 2mA ➔up to ~4×10^{23} PoT/yr
  - 1 – 2% used for dnstream
- PIP-II era begins in **2029**, DUNE 2031
  - Mu2e (8GeV)
  - Fixed target, test beams (120 GeV)
  - 0.8 GeV beam available for other exp, such as beam dump experiments like DAMSA

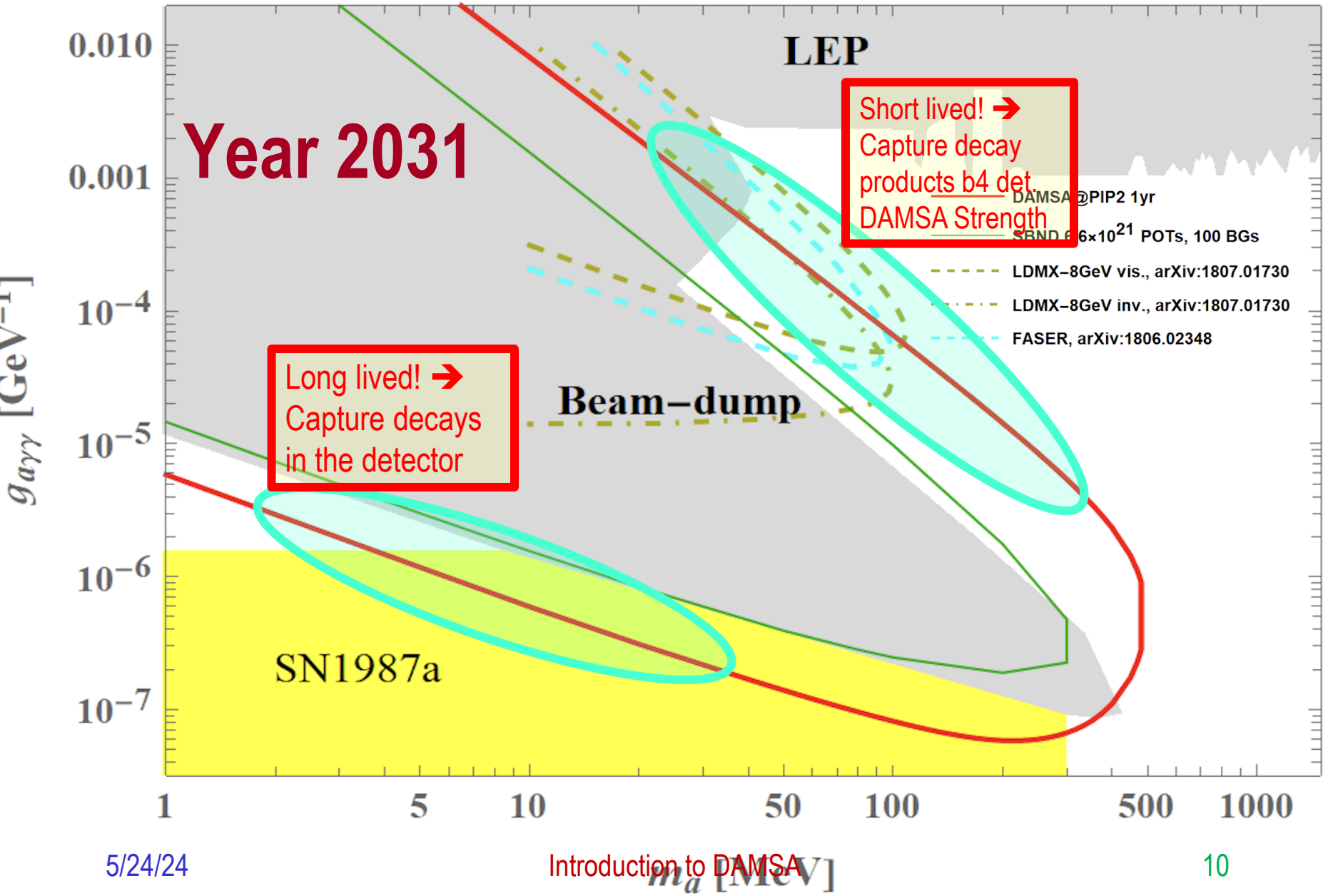


B. Flauger

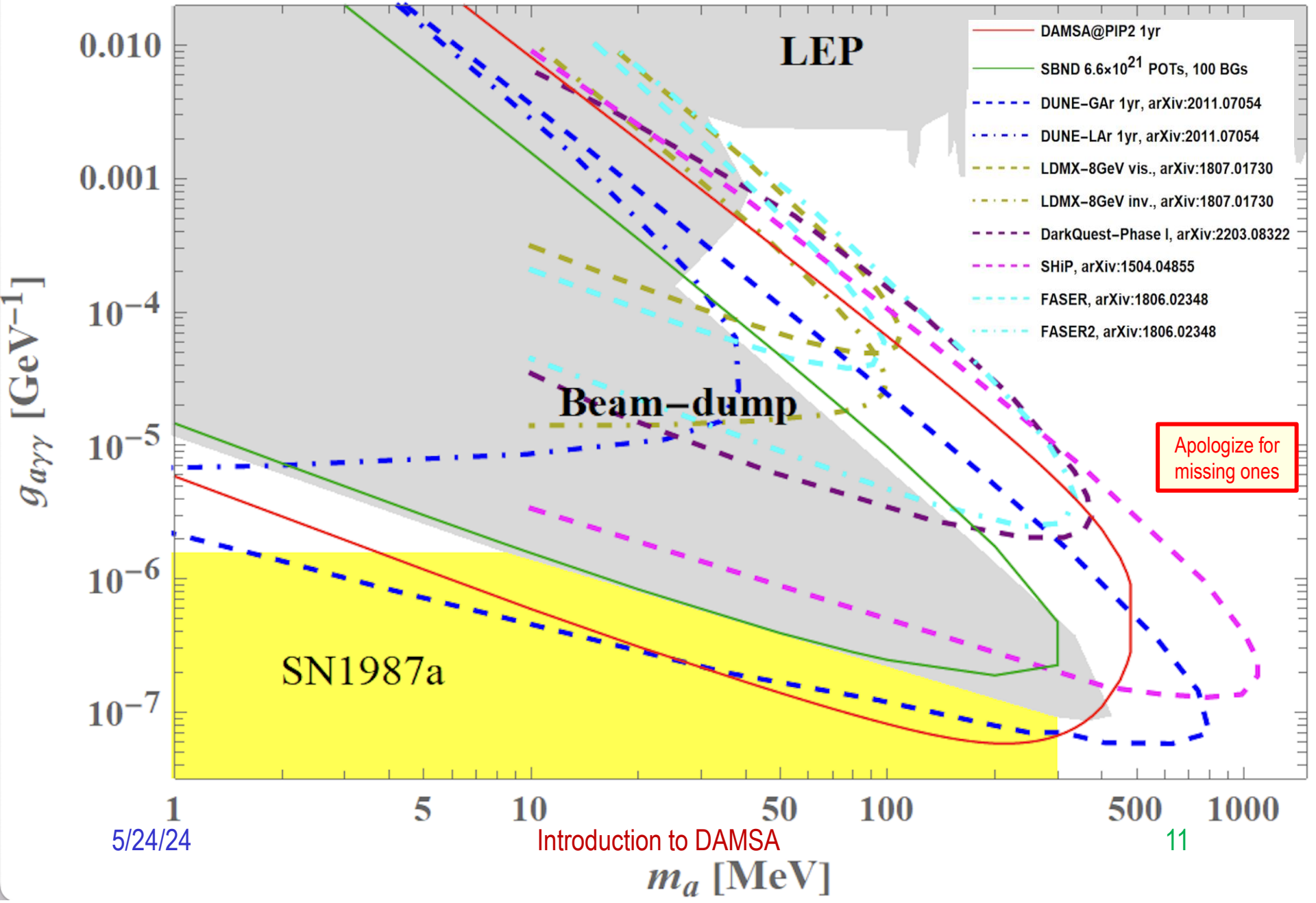
Physics Driven DAMSA Detector

- Discover dark sector particles beyond 2γ ALP, such as
  - Dark photon / ALP to e+e-
  - Low mass dark matter, etc
- Based on the signal and neutron background mitigation studies, using GEANT4 ➔ Detector assumptions
  - Fine granularity for a **superb shower position and angular resolutions** for 2 EM particle vertex pointing & DCA precision better than 1cm in the vacuum decay volume
  - **Fast timing** capability at sub-ns level (~100ps) for two EM particle arrival time differences
  - Capability of measuring up to 500 MeV photons with as **fine a mass resolution** as accomplishable

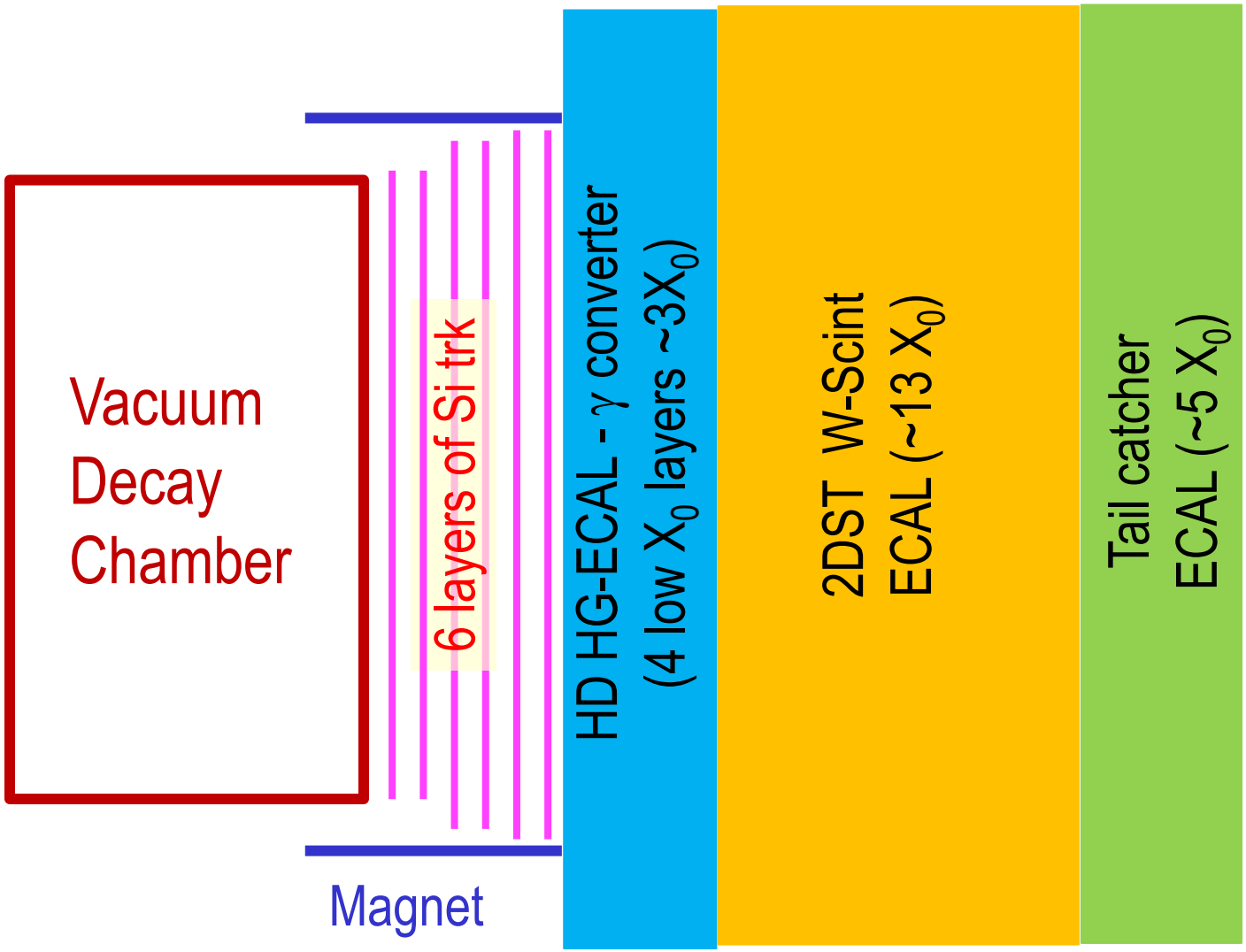
DAMSA Sensitivity – Running Experiments



DAMSA Sensitivity – All Experiments



Detector Design Concept



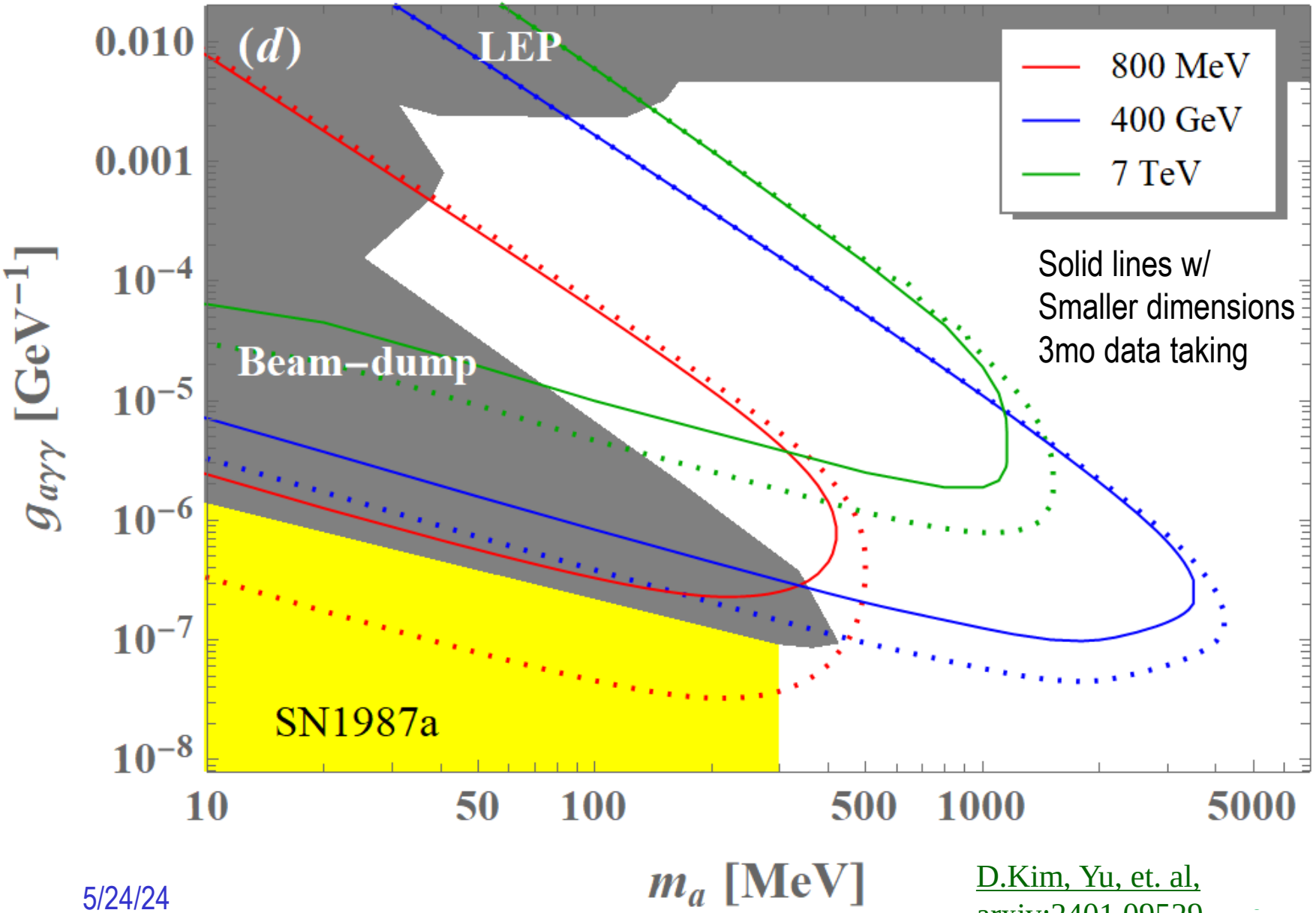
Where is the DAMSA experiment?

- DAMSA has been introduced to the community throughout the past 2.5 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 and seminars in the U.S., SK and CERN in 2023 and 2024
    - Presented at a couple of P5 townhall meetings
  - Met w/ Fermilab directorate in April, May, Aug, Sept. 2023 and Jan. 2024
- DAMSA collaboration building ongoing
  - Lead Investigators: J. Yu (UTA), J. Estrada (FNAL), UK Yang (SNU)
    - 12 US + 11 SK institutions on DAMSA
  - Facility and experiment are being defined
  - Funding applications being submitted
- DAMSA can be a network of experiments at different facilities

The Little DAMSA

- The question: Can we access the targeted parameter space with a dramatically smaller scale experiment (2401.09529)?
  - Concept Study: L_{dump}=1m, L_{vac}=10m, θ_{det}=0.5rad, N_{yr}=1yr
  - Smaller scale: L_{dump}=1m, L_{vac}=1m, θ_{det}=0.05rad, N_{yr}=3mo

Small Scale DAMSA Sensitivity

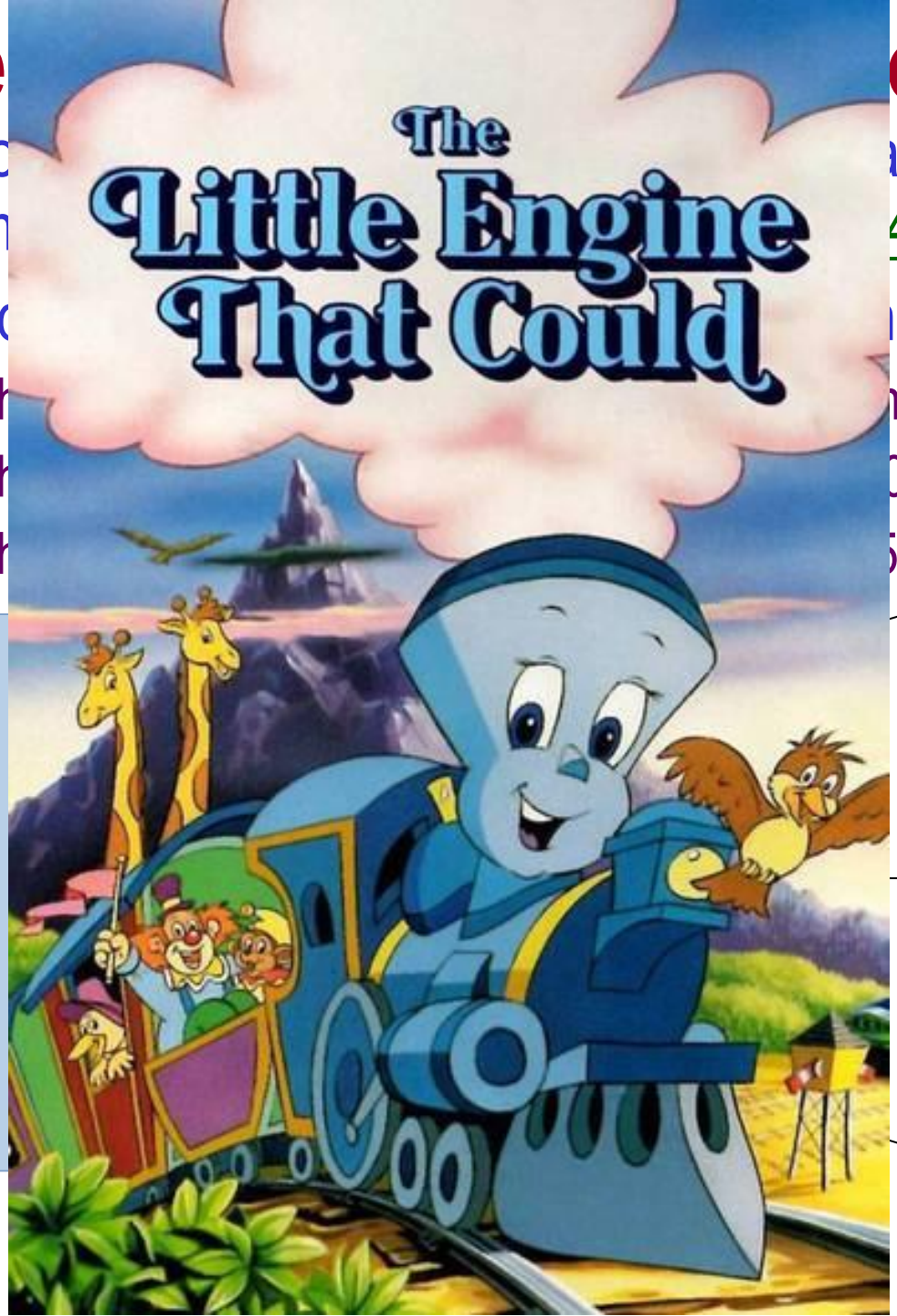


5/24/24

D.Kim, Yu, et. al,
arxiv:2401.09529

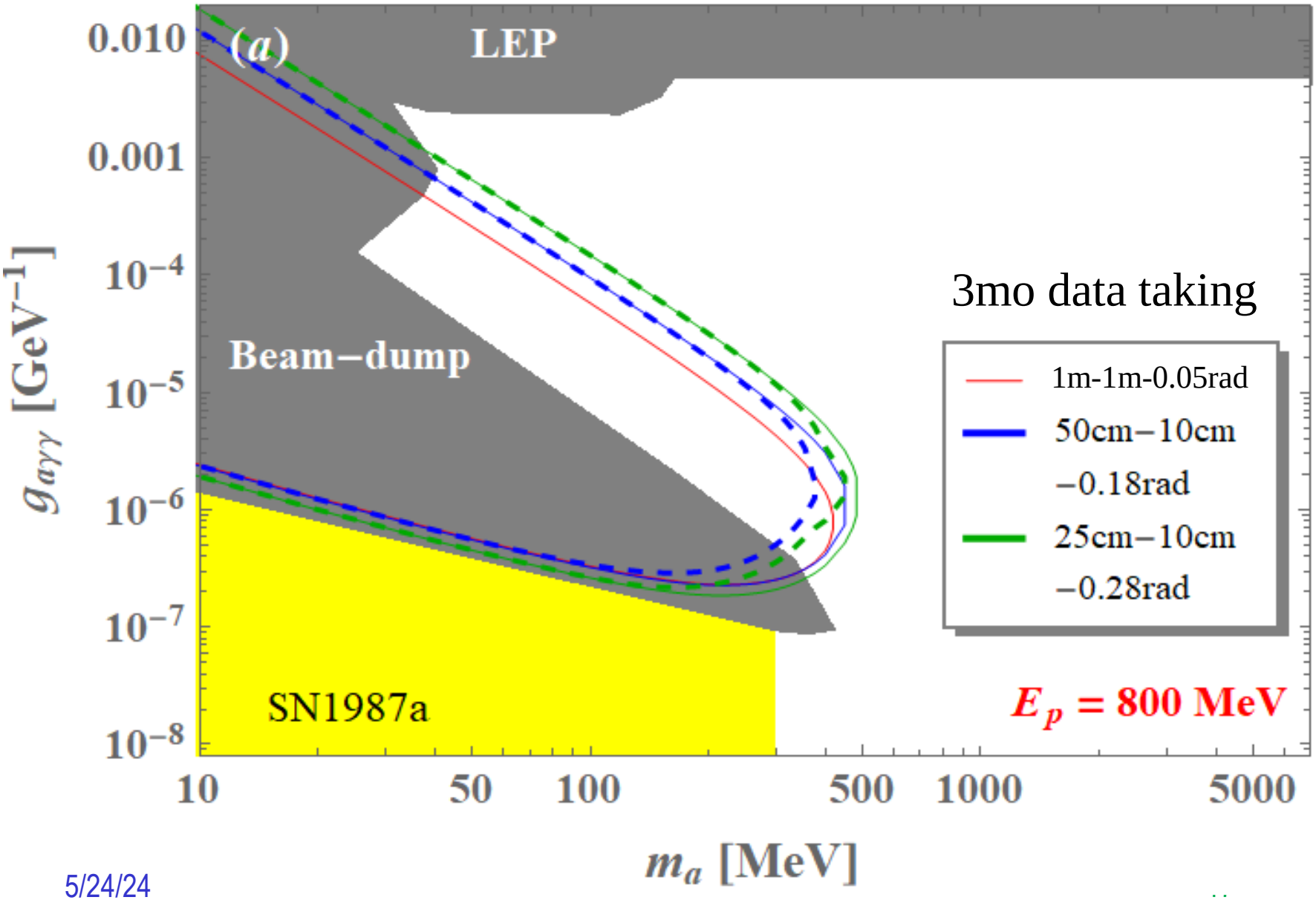
The ould!

- The questic ameter space with a dram 401.09529)?
- Further stuc g cases
  - Reduce th e depth (10^{-2})
  - Reduce th 0.1m from 1m (10^{-3})
  - Reduce th 5m (case 2)



Proton

The Little DAMSA Sensitivity

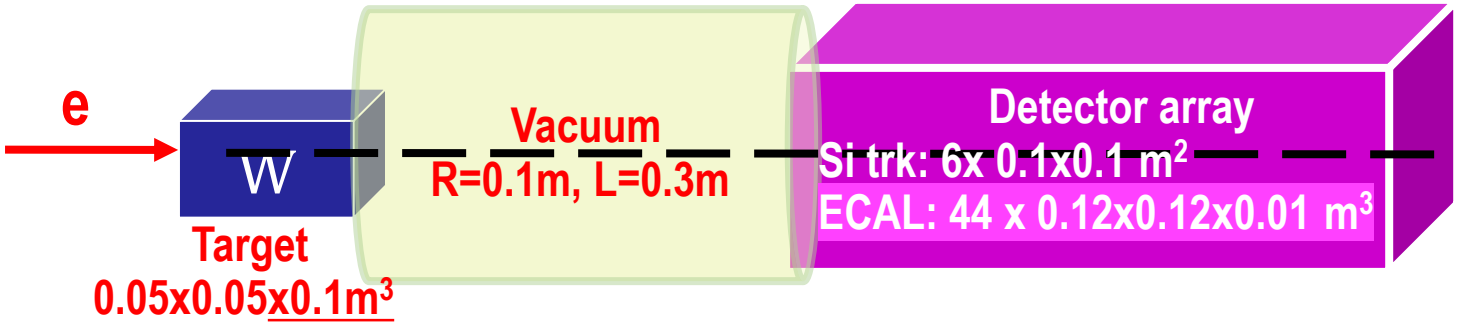


Why Pilot DAMSA?

- Given the results of the Little DAMSA sensitivity study, it is possible for us to think about very small pilot detector
- Primary issues to demonstrate
  - Physics case feasibility
  - Background validation and handling
  - Necessity for beam dump facility
- Strategy for pilot
  - Find a pathway to focus on physics case feasibility test
    - Need a facility that has as little neutron background from the dump as possible
  - Focus on the fast-decaying particles with high coupling

The Little DAMSA Pilot Experiment!

- **Goal: Mount and complete a physics demonstrator in the next 2 yrs**
- Beam: 300MeV e-beams at Fermilab FAST or ESA @ SLAC➔ greatly reduced neutron backgrounds, compared to proton beams
- Target: 5cmx5cmx10cm W block (~28.5X_0)
- Vacuum decay chamber : 10cm (r) x 30cm (L)
  - Enable the two EM particles from the vertex in vacuum to be separated
- Detector: 6 x 10cmx10cm Si tracker + 44 x 12cmx12cmx1cm (24.5X_0) 4D CsI total absorption ECal



Little DAMSA – Staged Plan

- Stage 0 ➔ e-beam background validator
  - Measure and validate the MC neutron and photon bck counts
- Stage 1 ➔ The a2γ 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 a2e demonstrator @ e-beam
  - Upgrade the stage 1 demonstrator with Si tracker (and magnet)
  - Demonstrate the expanded signal capture
- Stage 3 ➔ The neutron bck demonstrator @ p-beams
  - Move the demonstrator to a low E, low power proton beams
  - Demonstrate neutron background handling
- Stage 4 ➔ The full scale DAMSA @ p-beams
  - Move the complete detector to available proton beam facilities
  - Perform search and discovery

Potential Fermilab Experimental Facility

- Proposed Name: F2D2
  - **F**ermilab **F**acility for **D**ark matter **D**iscovery
  - Sited on part of the Tevatron field, out of any ACE plan
- Requirements
  - Basic assumption : multiple experiments operate simultaneously, mixture of on and off-axis
  - Sufficient footprint per experiment
  - Sufficient height of the hall w/ a large capacity crane coverage
  - Sufficient overburden (>=40.m.w.e.)

Conclusions

- DAMSA is a DSP search and **discovery** experiment
- DAMSA has been making serious and steady progress
  - Aim to be ready for PIP-II LINAC beam in 2029
  - Perfect fit to **ASTAE** program in the recently released **P5 report**

From the P5 Report – 1

- Explicit recommendations on leveraging PIP-II LINAC and support for ASTAE program

5.1.3 – New Initiative: A Portfolio of Agile Projects to Search for Direct Evidence of New Particles

Another strategy to look for long-lived particles at colliders is to construct auxiliary experiments that are placed far away from the primary collision points. Proposed auxiliary experiments like CODEX-b and MATHUSLA can extend the sensitivity to BSM particle lifetimes in Higgs decays by several orders of magnitude. Experiments at the proposed Forward Physics Facility at CERN like FASER2 and FORMOSA would be sensitive to 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).

From the P5 Report – 2

- Search for ALP well-suited for agile portfolio

4.1.3 – New Initiative: A Portfolio of Agile Projects for Dark Matter

In pursuit of understanding dark matter, a diverse and agile portfolio of ASTAE experiments, as described in Section 6.2, offers the potential for significant discoveries and technological advancements. Small but sensitive detectors are ideal for studying low mass dark matter since the needed size of the detectors scales roughly with the dark matter mass. This strategic approach focuses on two promising areas: hidden sector models and QCD axions, both of which boast high-priority benchmark models that can best be addressed by this scale of experiment.

Accelerator-based searches for the production of hidden sector particles leverage beam dumps at existing beamlines and have sensitivity to thermal benchmark models in the MeV-GeV mass ranges. The direct searches for these hidden sector particles utilize innovative materials and ultra-low noise detectors with the ability to detect down to sub-eV energy depositions to reach the benchmarks. This synergistic combination of approaches is necessary to understand and unlock the secrets of hidden sector dark matter.

The search for axions and ALPs is also well-suited for this agile portfolio. Specific

From the P5 Report – 3

- **ASTAE** – Advancing Science and Technology through Agile Experiments – A portfolio of small-scale DOE experiments and funding
  - Definition of Agile: timeline of 5 years and cost $5M – $25M

Recommendation 3: Create an improved balance between small-, medium-, and large-scale projects to open new scientific opportunities and maximize their results, enhance workforce development, promote creativity, and compete on the world stage.

In order to achieve this balance across all project sizes we recommend the following:

a. Implement a new small-project portfolio at DOE, Advancing Science and Technology through Agile Experiments (ASTAE), across science themes in particle physics with a competitive program and recurring funding opportunity announcements. This program should start with the construction of experiments from the Dark Matter New Initiatives (DMNI) by DOE-HEP (section 6.2).

Area Recommendation 2: For the ASTAE program to be agile, we recommend a broad, predictable, and recurring (preferably annual) call for proposals. This ensures the flexibility to target emerging opportunities and fields. A program on the scale of $35 million per year in 2023 dollars is needed to ensure a healthy pipeline of projects.

Fermilab Facility for Dark Matter Discovery (F2D2)

K. Buckett, PPD head
Fermilab PAC, 1/9/24

- 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

FNAL response to P5: Develop a series of Initiatives

- Lay out Vision and Implementation for each
  - Implementation: include schedule, milestones, and resources
  - Some will be a plan to make a plan
    - → Examples: ACE-MIRT, ACE-BR, Dark Wave Lab Axion Facility, F2D2,
- Needed for
  - FNAL planning and Community planning
  - Alignment with DOE and with other labs/stakeholders
  - (PEMP notable) Performance Evaluation and Management Plan
- Engage with FNAL scientists and Users/Affiliates forming small task forces to develop each initiative
  - → Goal: Full set of initiatives by end of Summer

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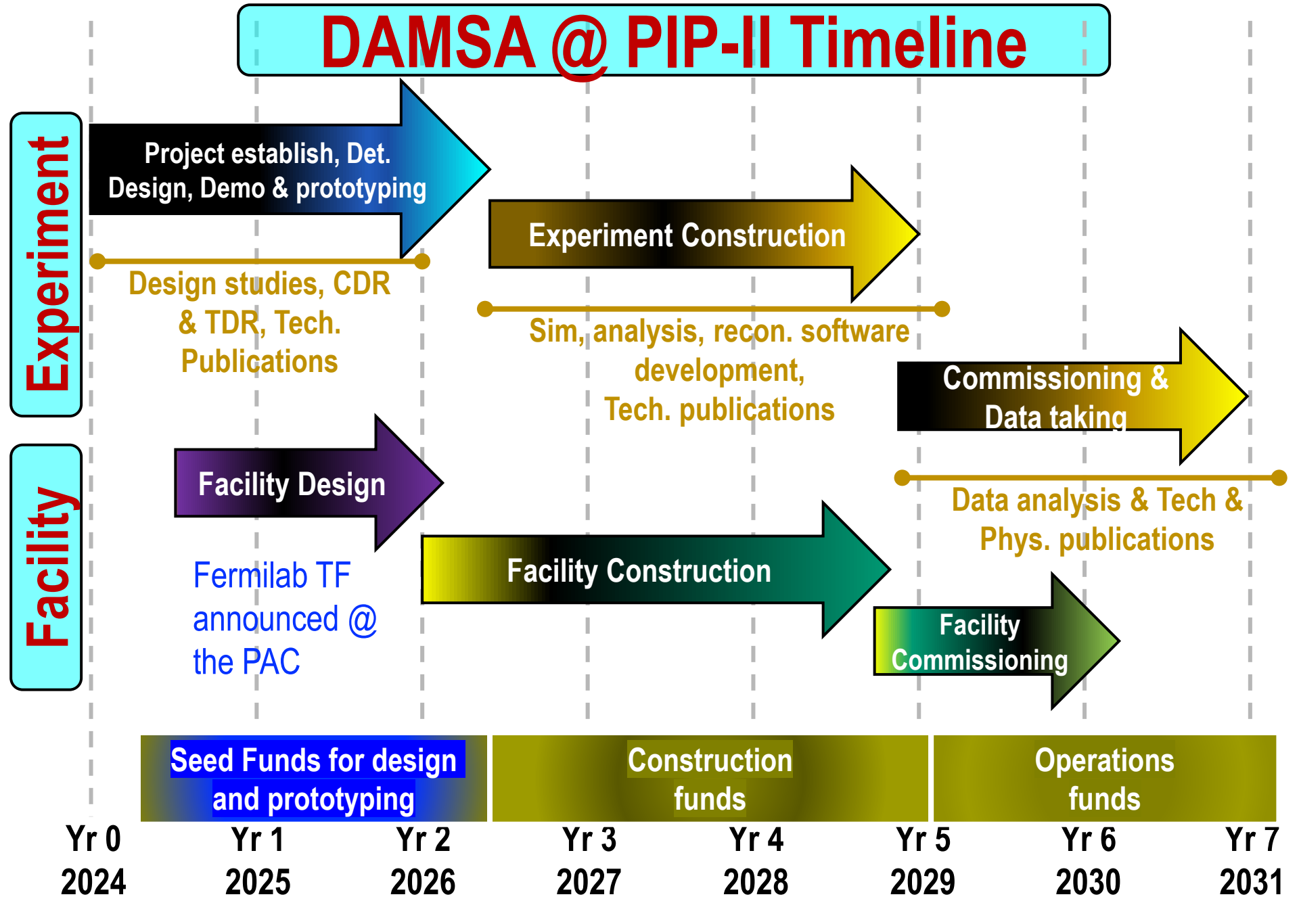
- DAMSA has been making serious and steady progress
  - Aim to be ready even for PIP-II LINAC beam in 2029
  - Perfect fit to **ASTAE** program in the recently released **P5 report**
  - Staged demonstrator experiments is being developed
- Collaboration building ongoing but still has room!
- Fermilab TF to make a recommendation on F2D2 formed
  - Whitepaper released to the archive on PIP-II Beam Dump physics opportunities (2311.09915)
- DAMSA presents an excellent opportunity to produce and discover DSP in beams
- Your ideas of new DAMSA physics topics essential

Back Up


DAMSA @ PIP-II Timeline
Experiment
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
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