Introduction to DAMSA Experiment

LDW2024, KAIST

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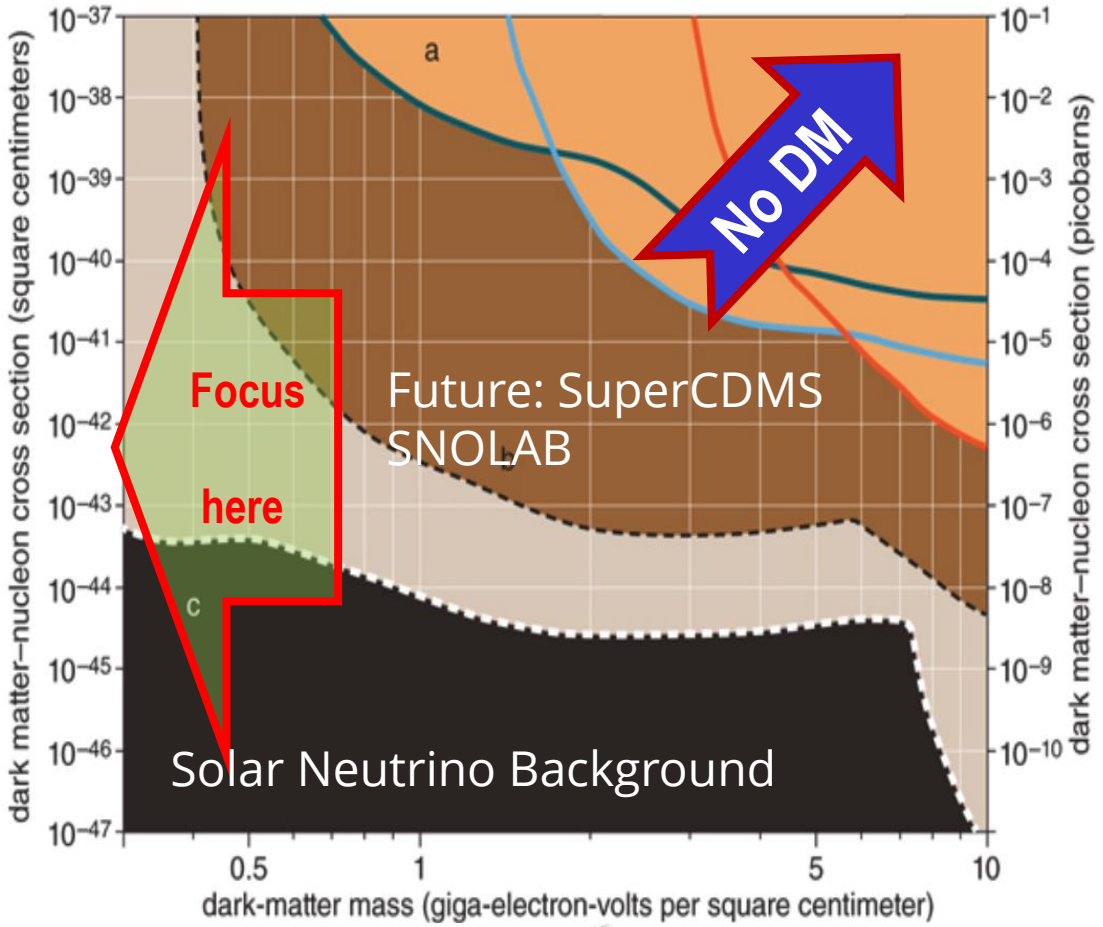
For DAMSA Collaboration

Physics Motivation For DSP

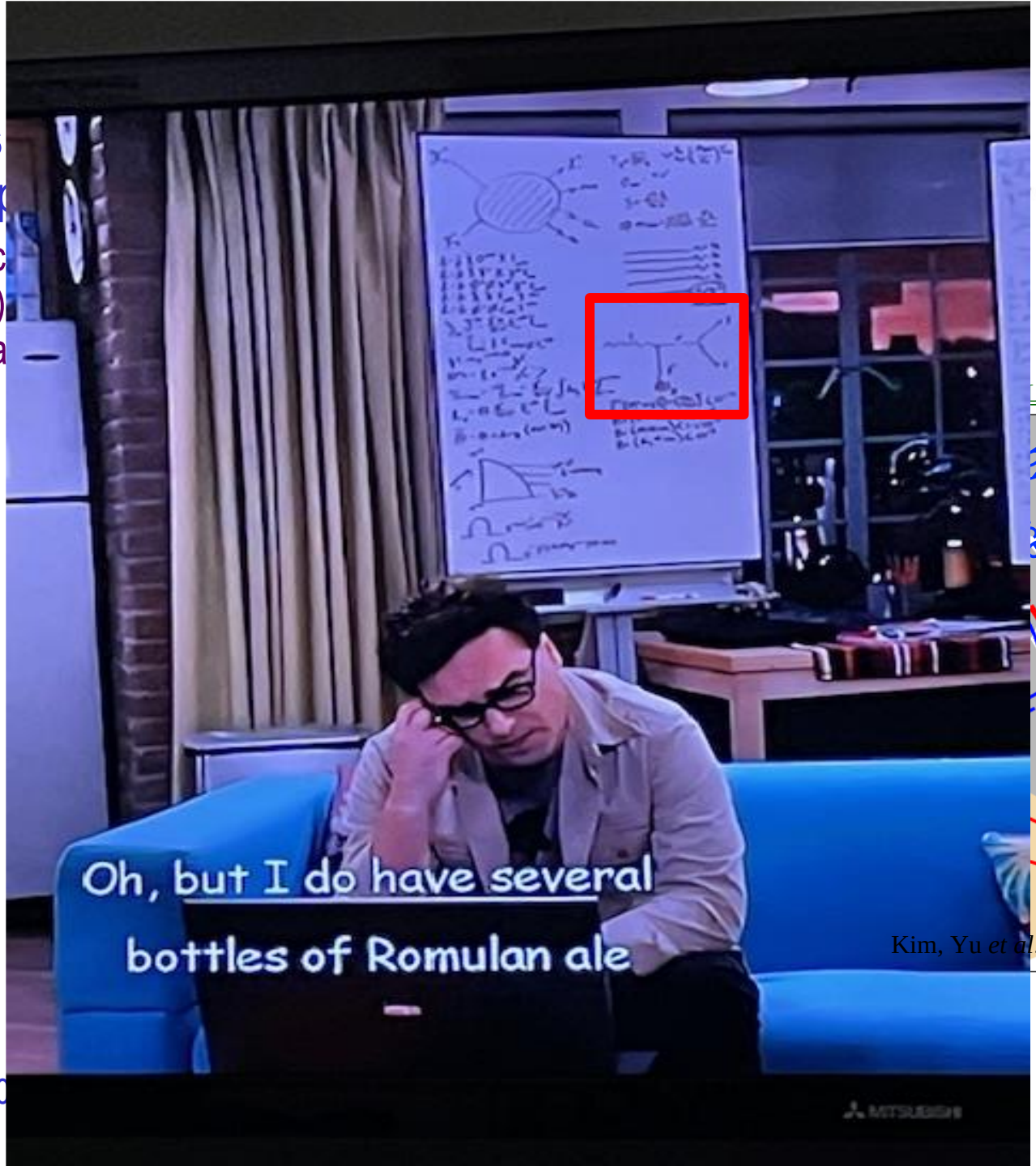
- Direct searches have challenges in kinematic reach, leaving low mass range un-explored
- Strategy:
  - Search for dark sector particles in unexplored kinematic regime
  - Make and discover DSPs in an accelerator
  - Establish infra to better understand DM

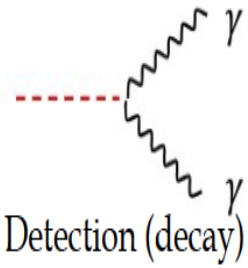


What is DAMSA?

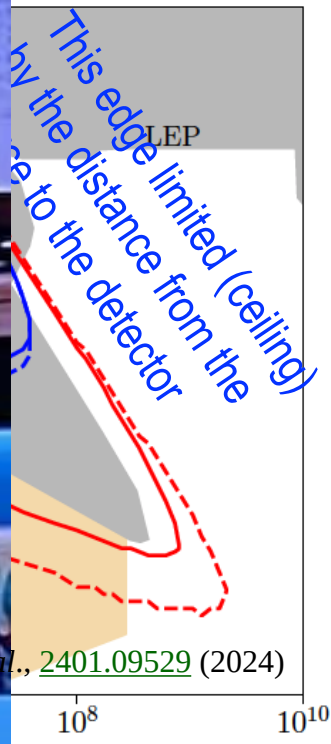
- A **very short baseline** dark sector particle (DSP) search and discovery experiment at high intensity proton beams
- Stands for **D**ump produced **A**boriginal **M**atter **S**earches at an **A**ccelerator = **DA**rk **M**essenger **S**earches at an **A**ccelerator (DAMSA)
  - 담사 (潭思) = 깊은생각 – Rumination or Reflection
    - Concept studies published: 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

- Photons
particle p
  - Use c
(ALP)
Prima





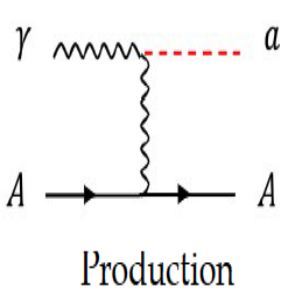
L126, 201801 (2021)

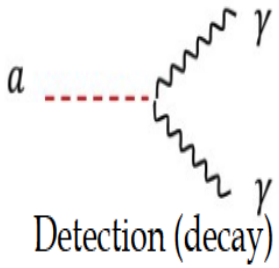


Kim, Yu *et al.*, 2401.09529 (2024)

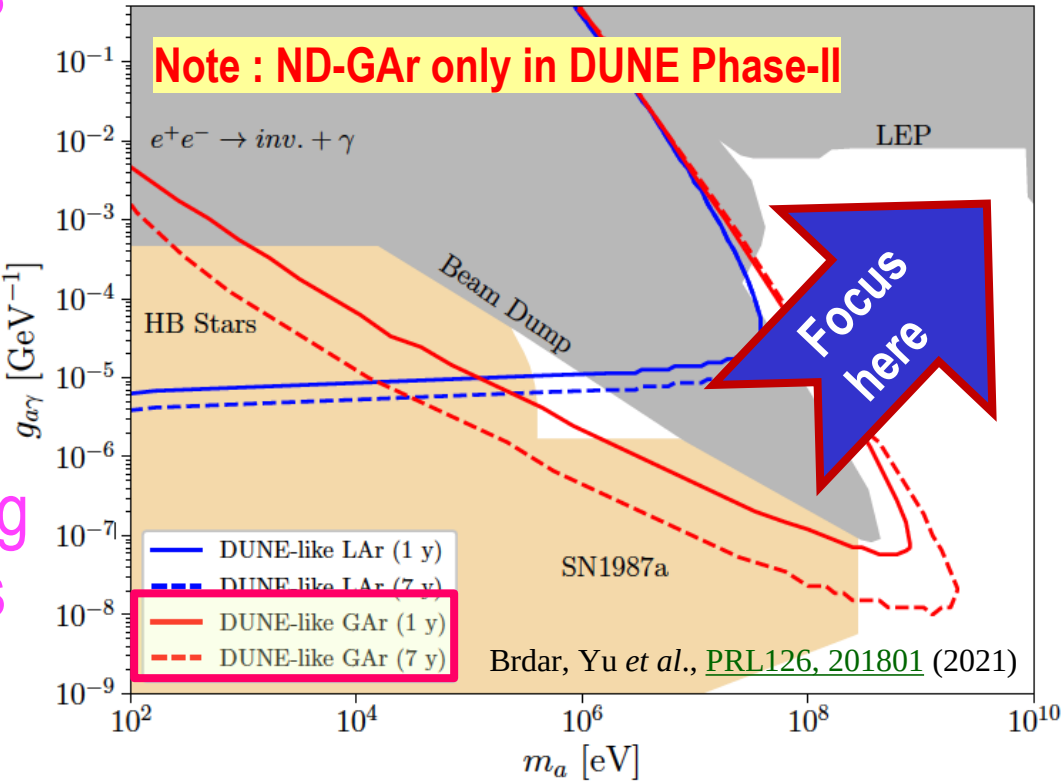
DAMSA Physics Strategy

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



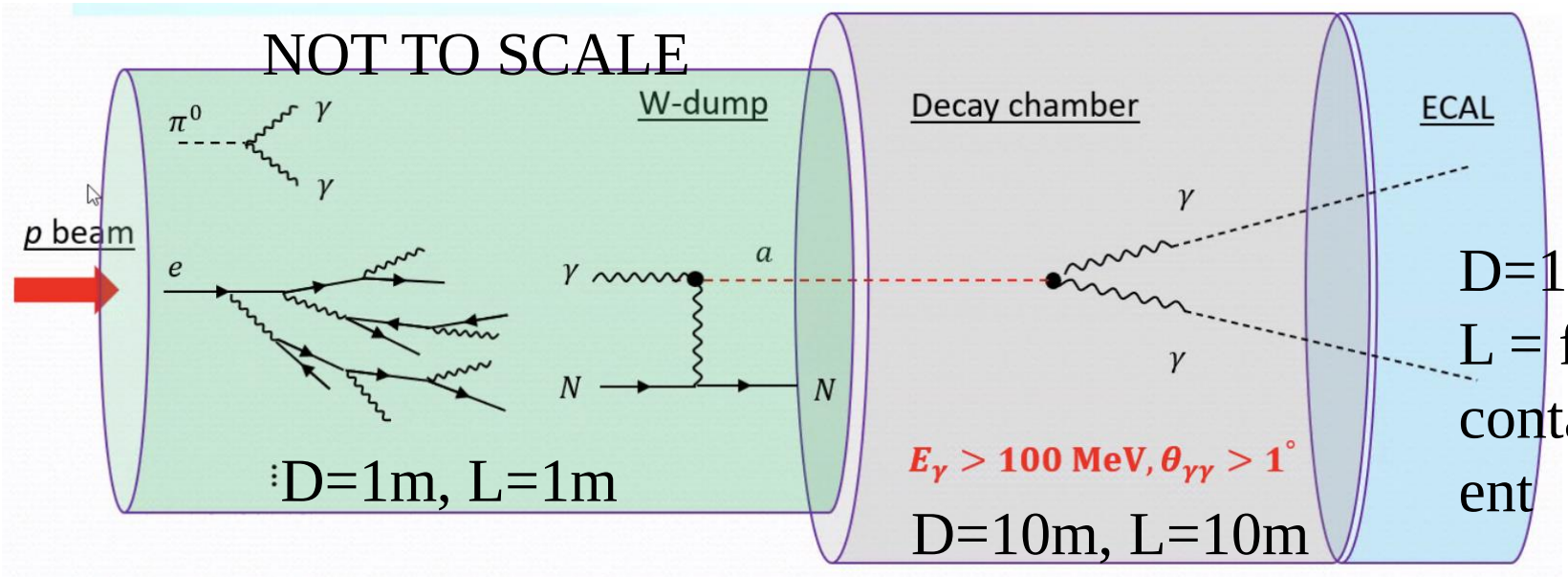


- **Produce** as many photons as possible from the beam
- **Capture** as many ALPs in as wide a mass range as possible
- **Mitigate** the backgrounds from neutral particles, using two EM particle final states
- **Place** the detector very close to the beam



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

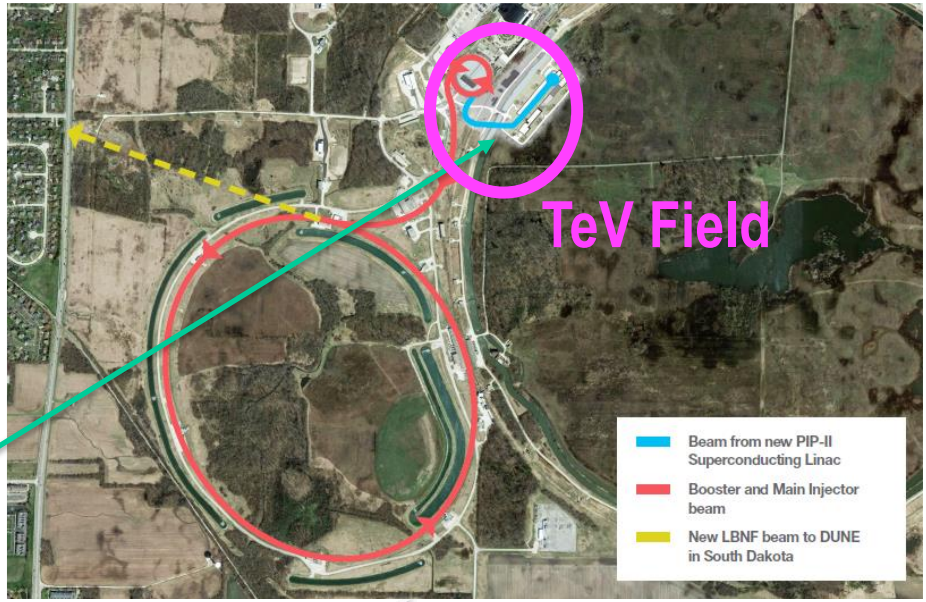


The three key elements

- The bad man
- The ugly
- The good doctor

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
  - <2% used for down stream
- 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

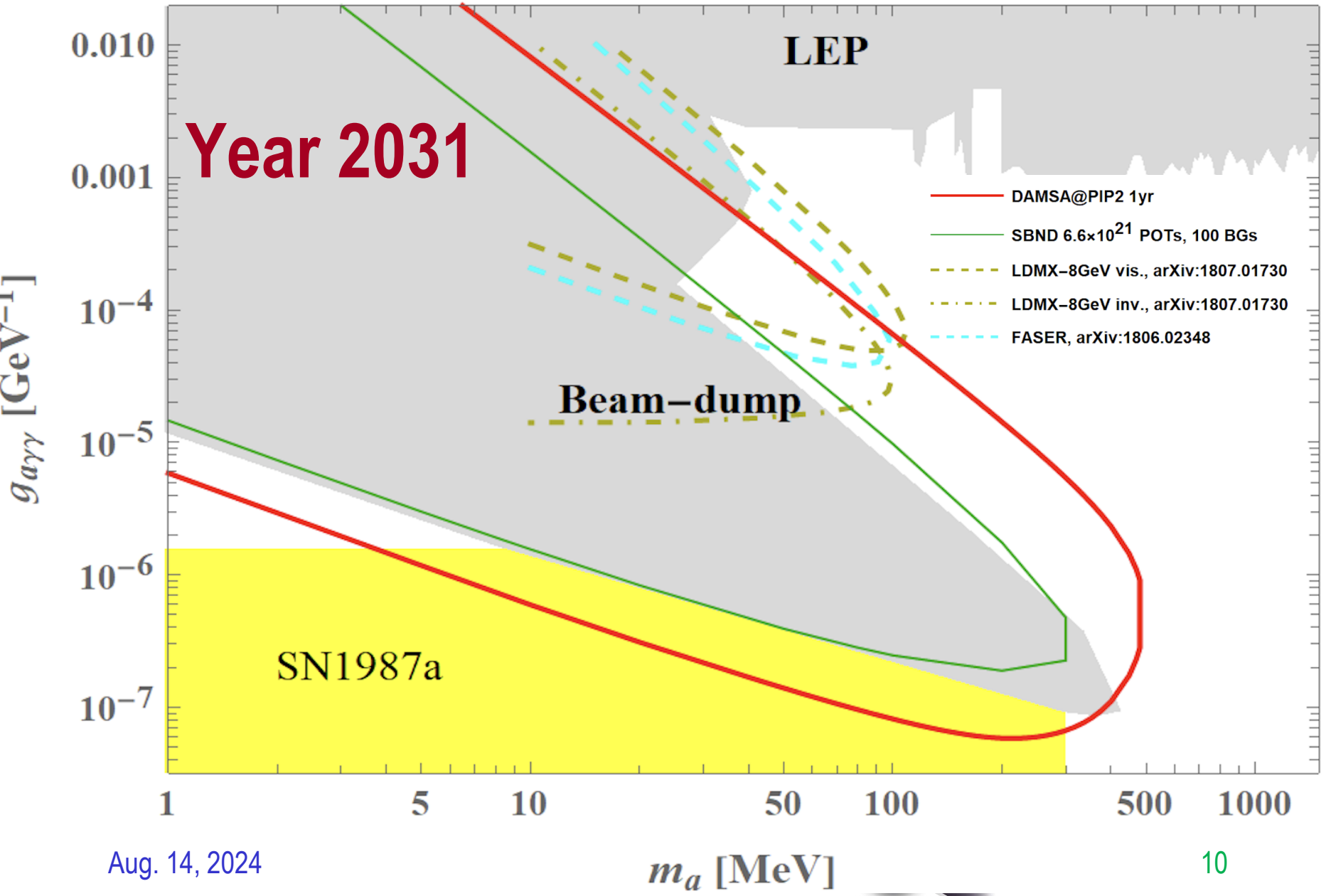


B. Flauger

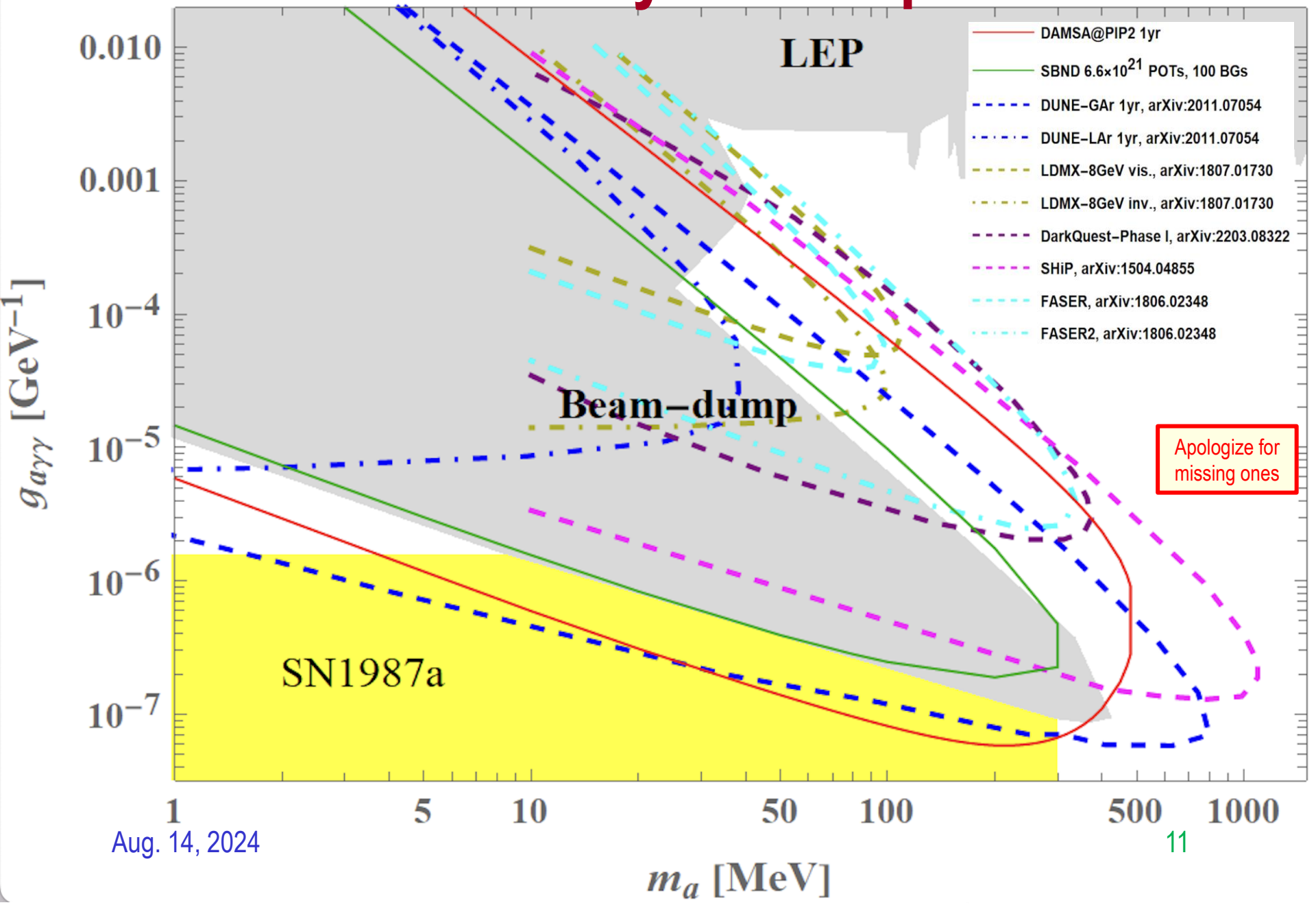
Physics Driven DAMSA Detector

- 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

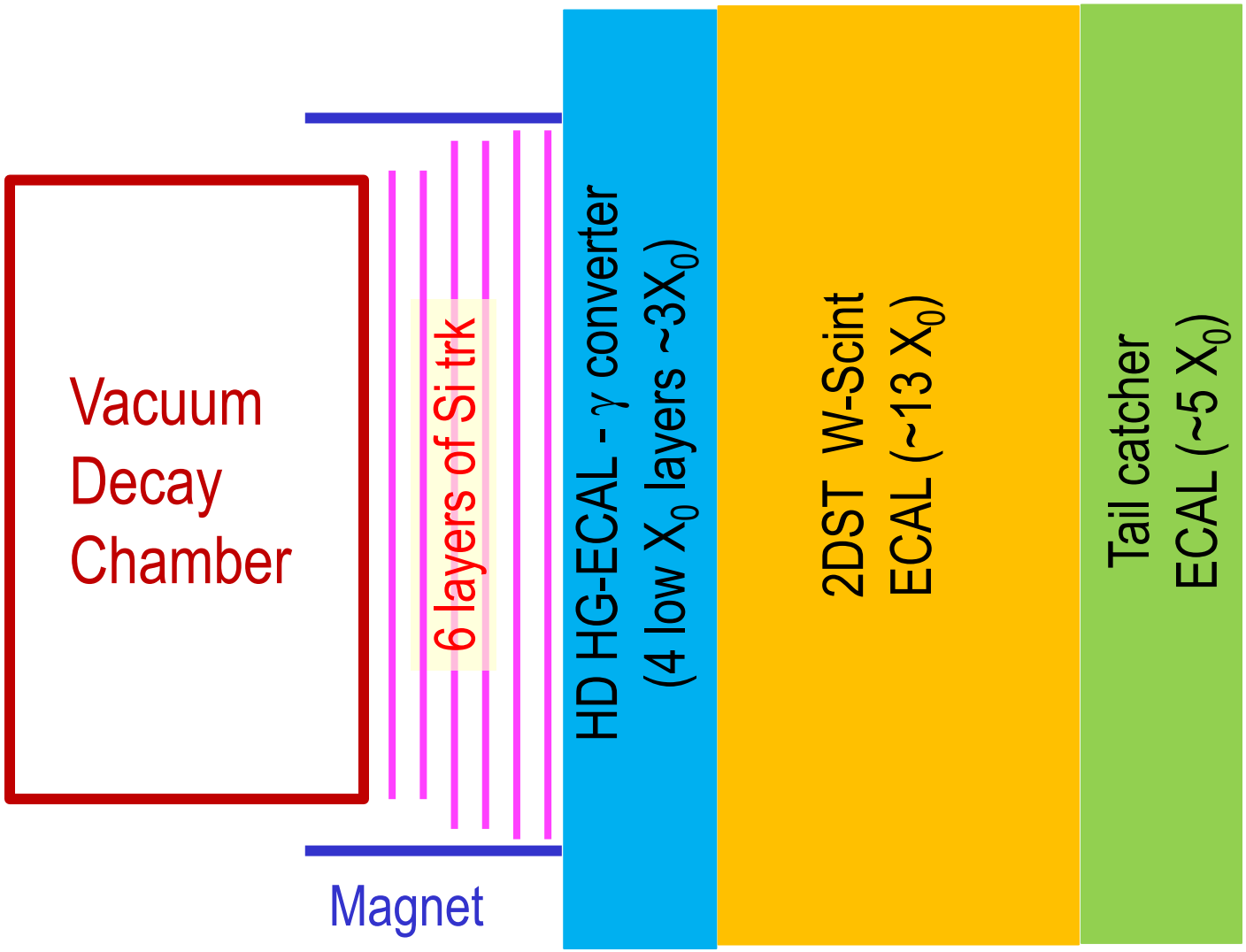
DAMSA Sensitivity – Running Experiments



DAMSA Sensitivity – All Experiments



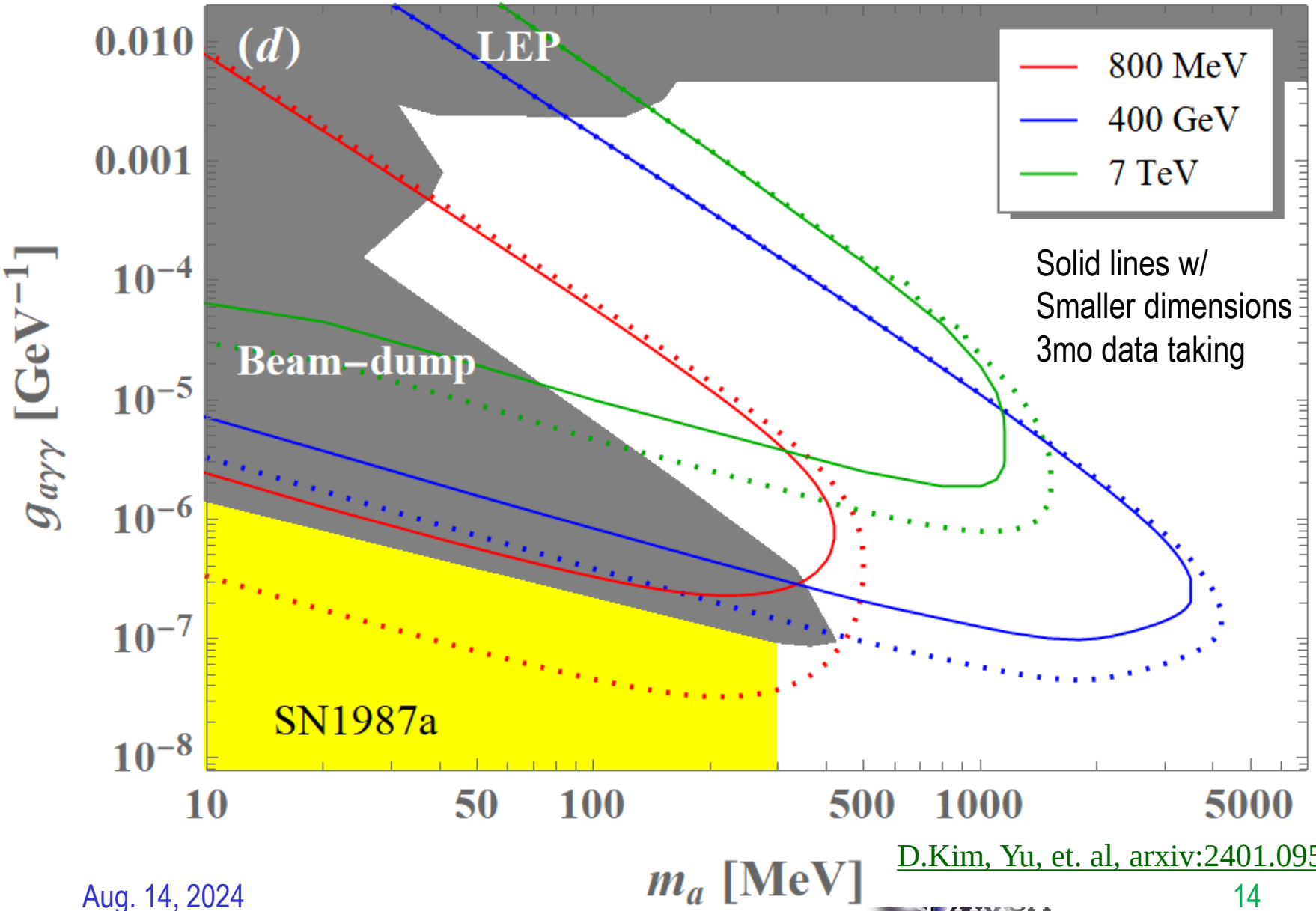
Detector Design Concept



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

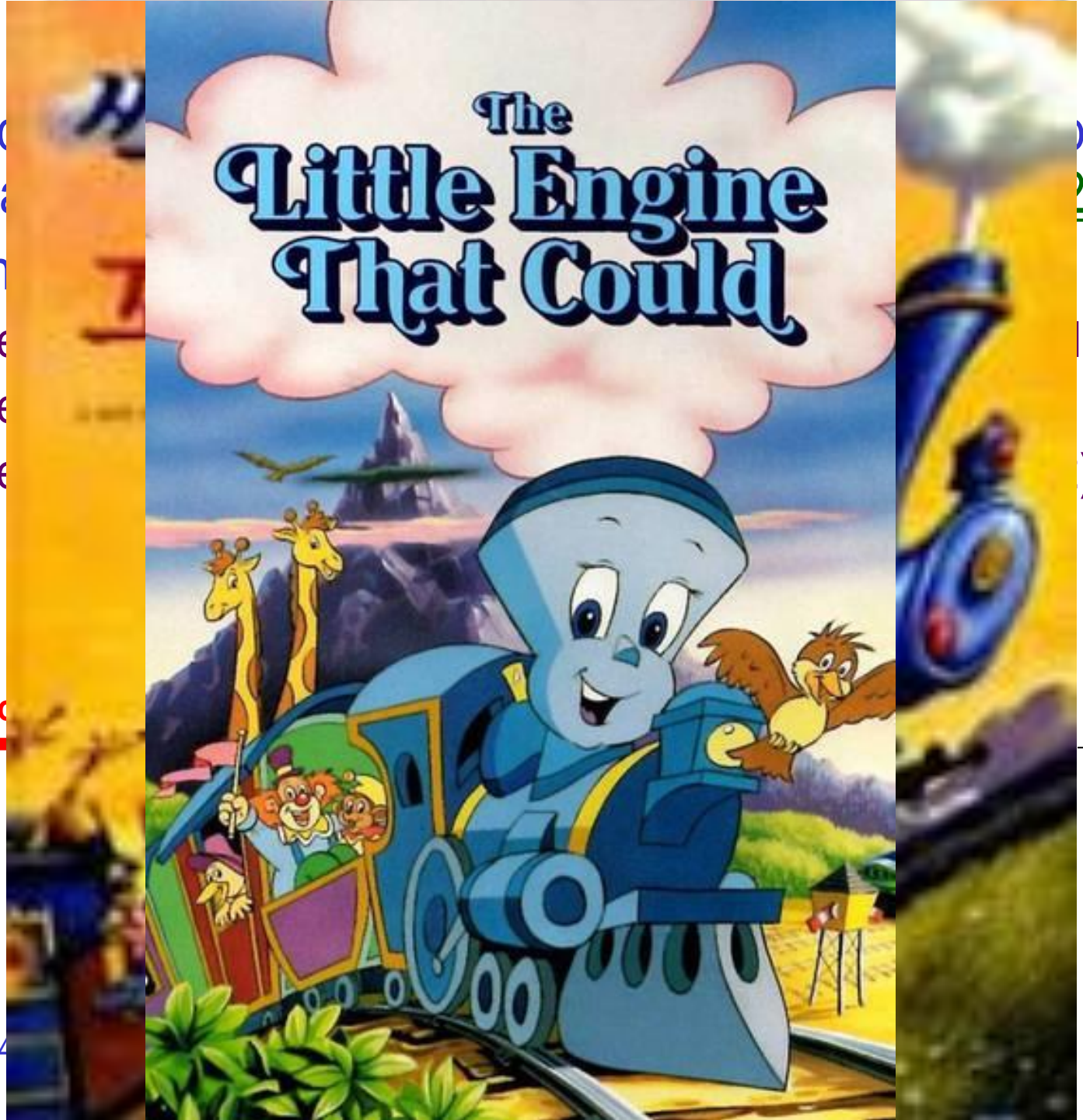
Small Scale DAMSA Sensitivity



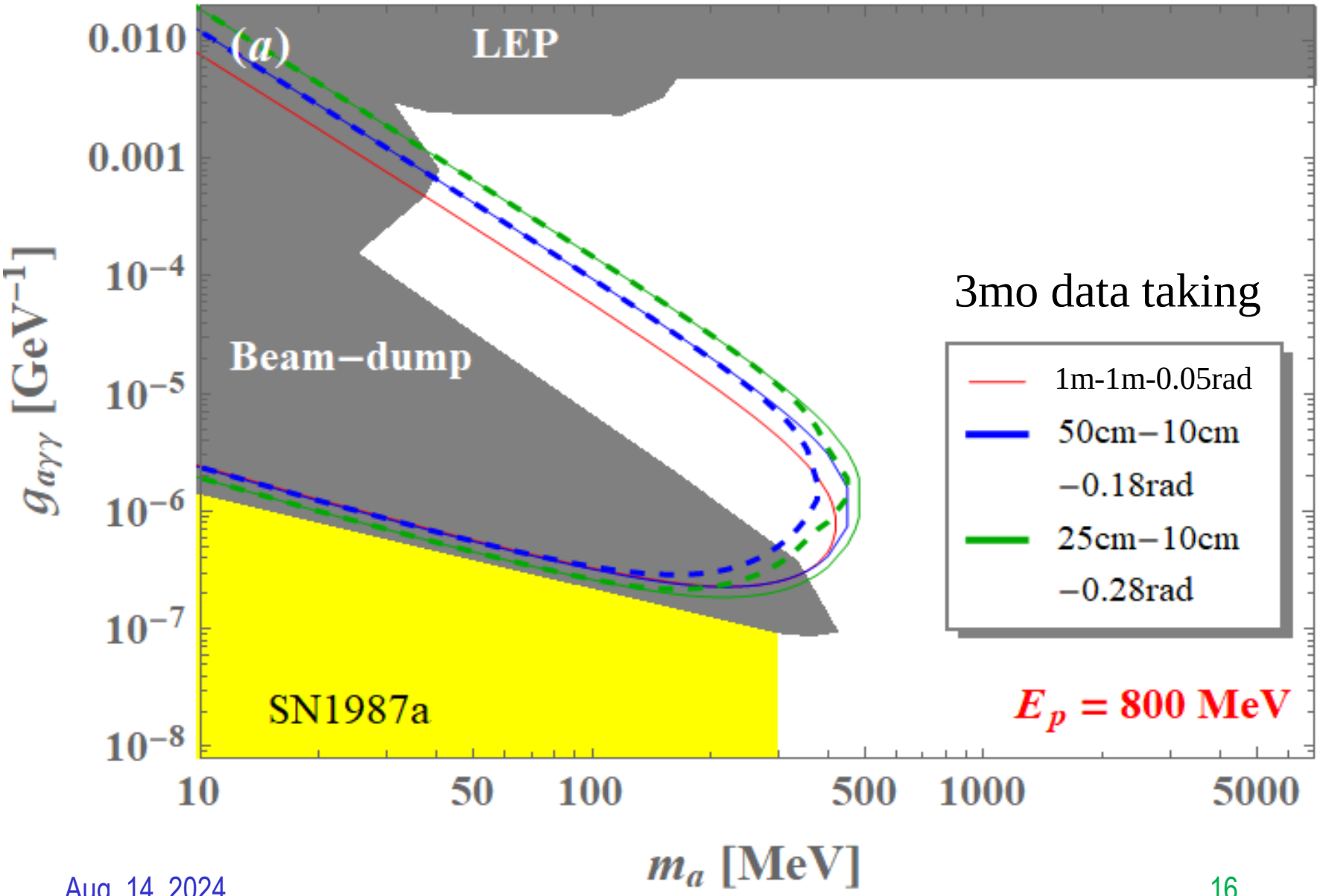
D.Kim, Yu, et. al, arxiv:2401.09529

- The c… …pace with a… …29)?
- Furth…
  - Re… …10^{-2})
  - Re… …1m (10^{-3})
  - Re… …)

Proto…



The Little DAMSA Sensitivity

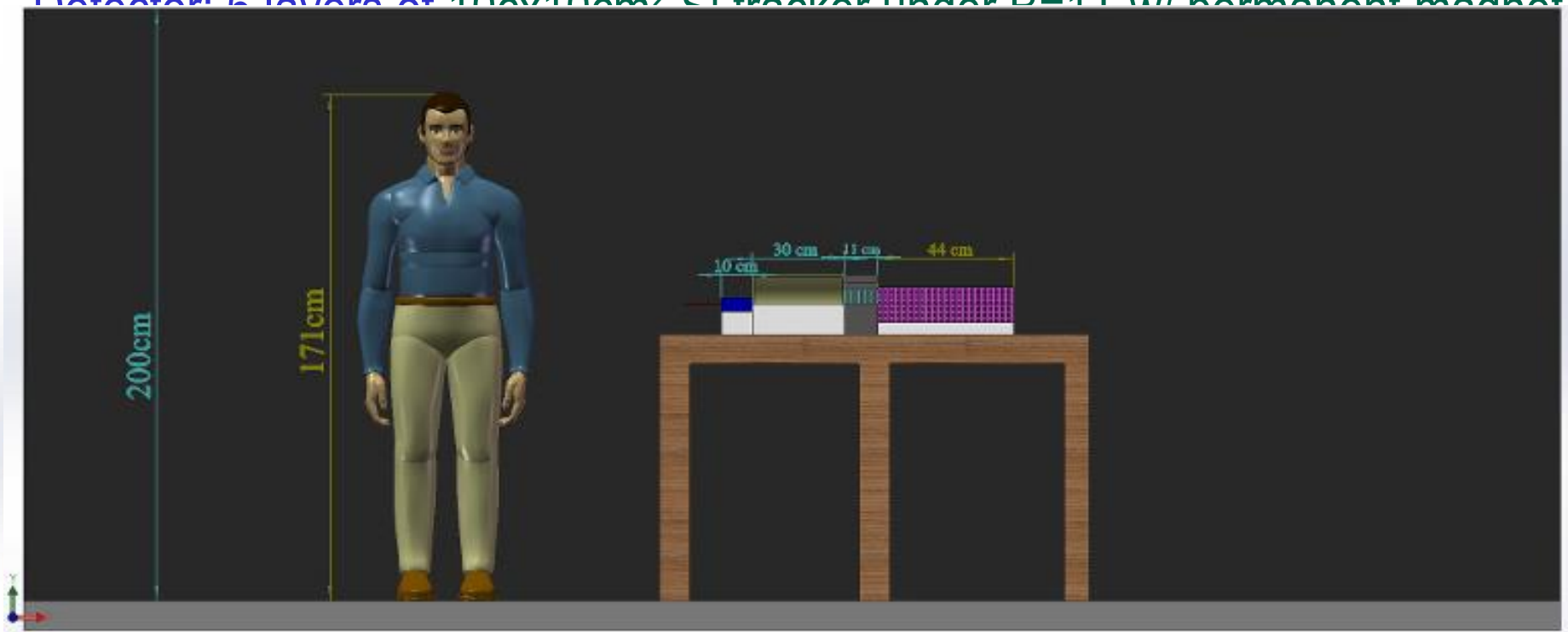


Why Pilot DAMSA?

- 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

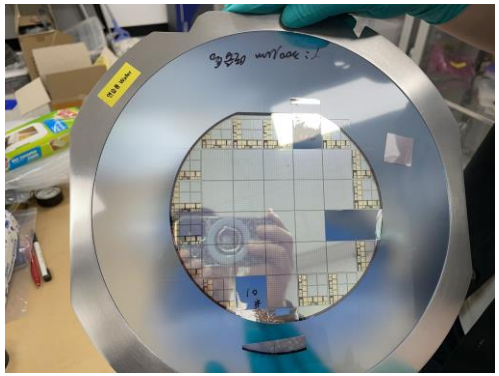
The Little DAMSA Experiment!

- **Goal: Mount and complete a physics demonstrator in the next 3 yrs**
- Beam: 300MeV e-beams at Fermilab FAST or 1GeV e-beams @ANL LEA ➔ greatly reduced neutron backgrounds, compared to proton beams
- Target: 5cm x 5cm x 10cm W target (~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 layers of 10cx10cm^2 Si tracker under B=1T w/ permanent magnet

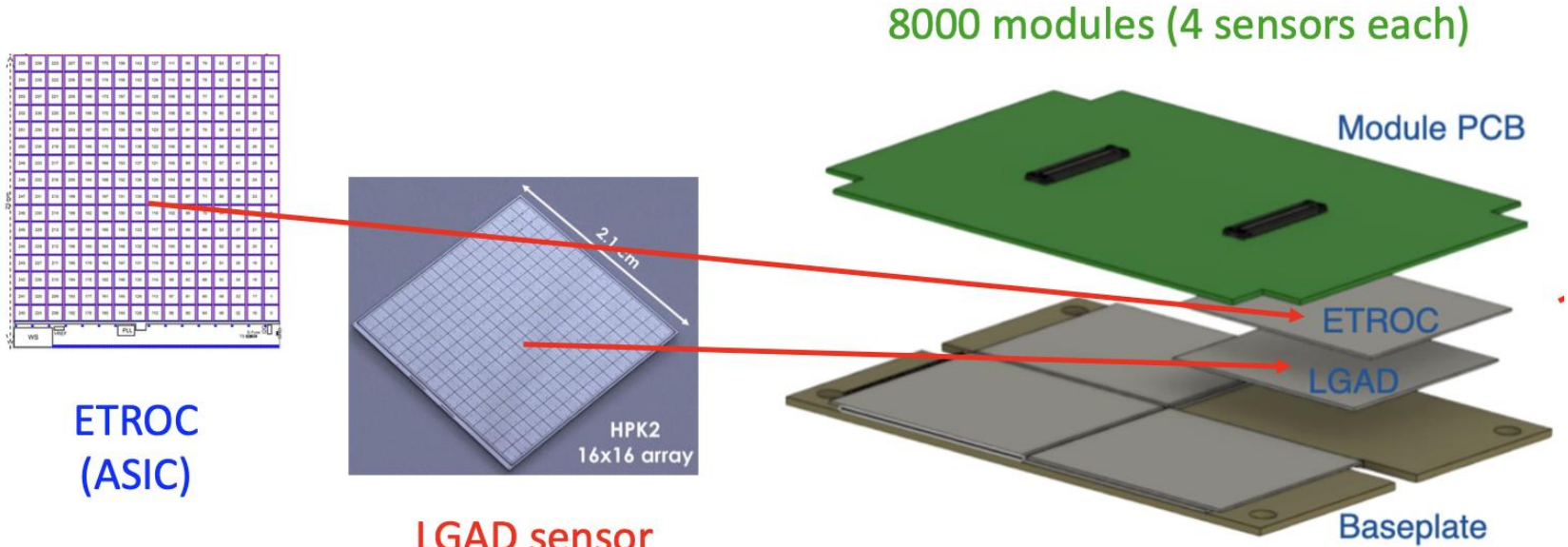


DAMSA – The Tracker

- KNU in SK responsible for CMS forward LGAD detector
- The Low Gain Avalanche Diode (LGAD) consists of 16x16 pixels of 1.3x1.3mm^2
  - Position resolution of 35 – 50 μm
  - Timing resolution per track <35ps (single hit resolution <50ps)

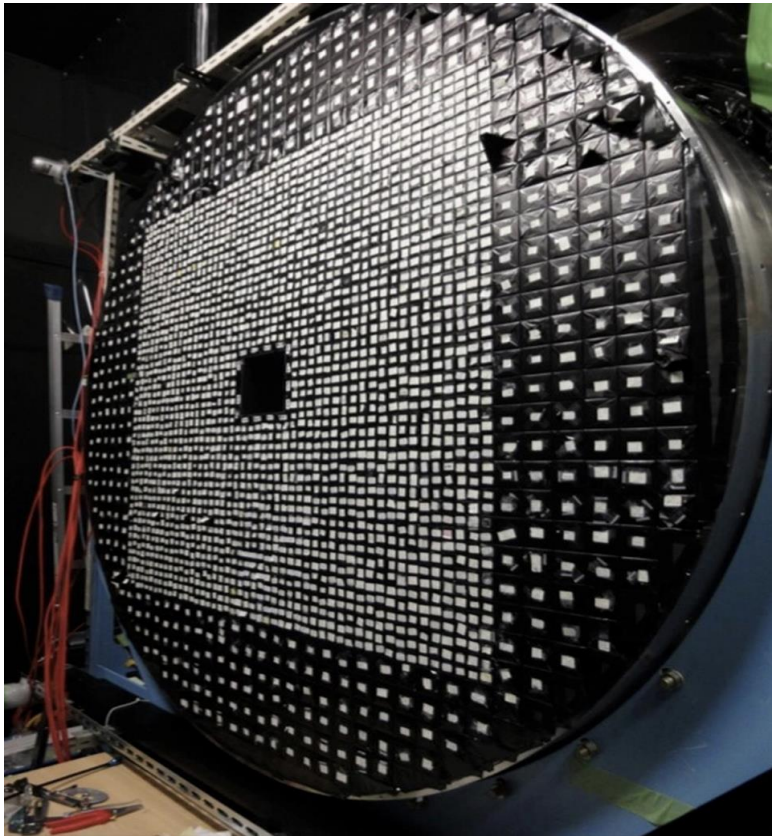


- High radiation tolerance ➔ DAMSA can be a testing ground



DAMSA – The ECAL

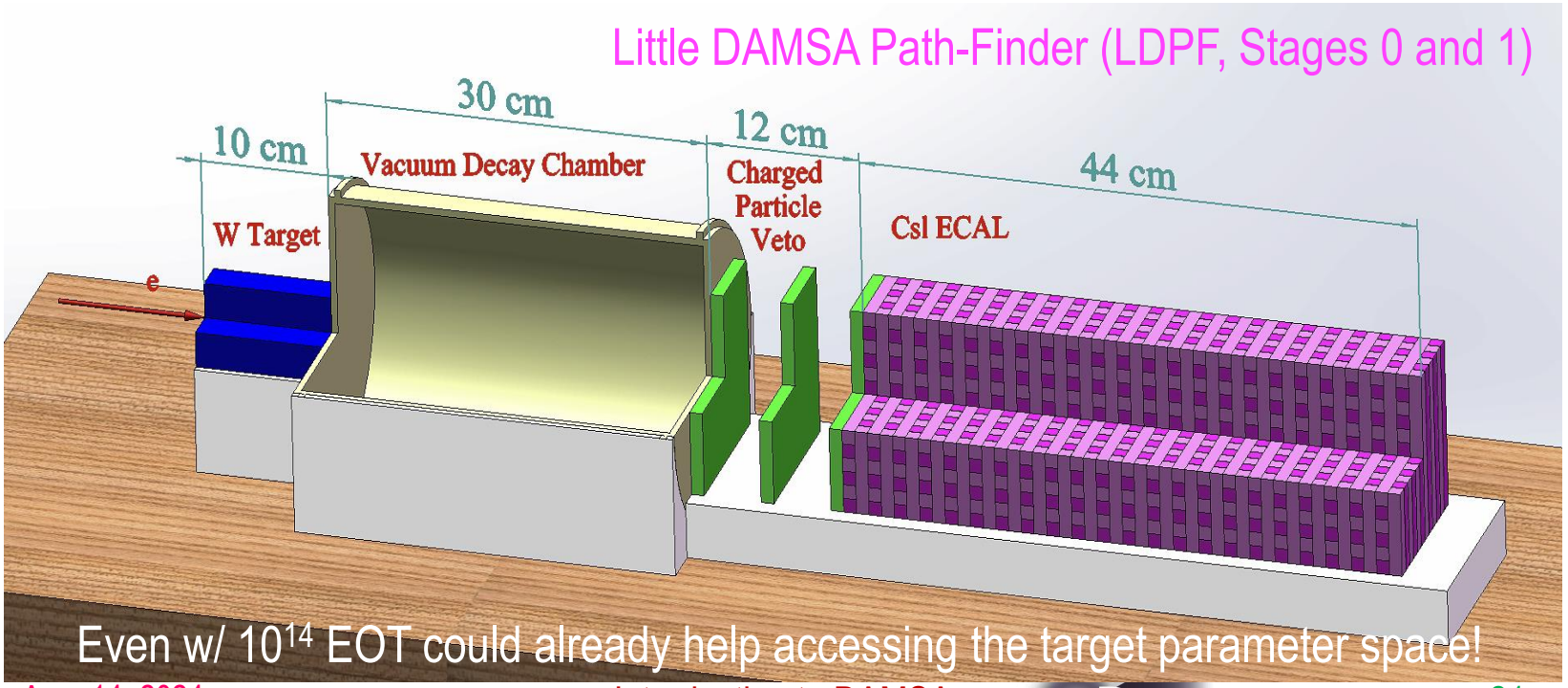
- U. of Chicago built CsI ECAL for K-TeV experiment at Fermilab and the KOTO experiment at KEK
  - Timing resolution of 200ps accomplished
  - Has 16 of 5x5x50cm^3 undoped CsI crystal bars in hand



  - Each of these bars can be cut into 80 or so 1x1x12cm^3 bars, read out by 2 SiPM's mounted on either ends ➔ could provide ~mm level shower position resolution
  - These bars need to be cut, polished, wrapped and SiPM mounted ➔ Working with the Ukrainian company, ISMa (Institute for Scintillation Materials) for initial evaluation of UC Crystals and the performance of the cut pieces

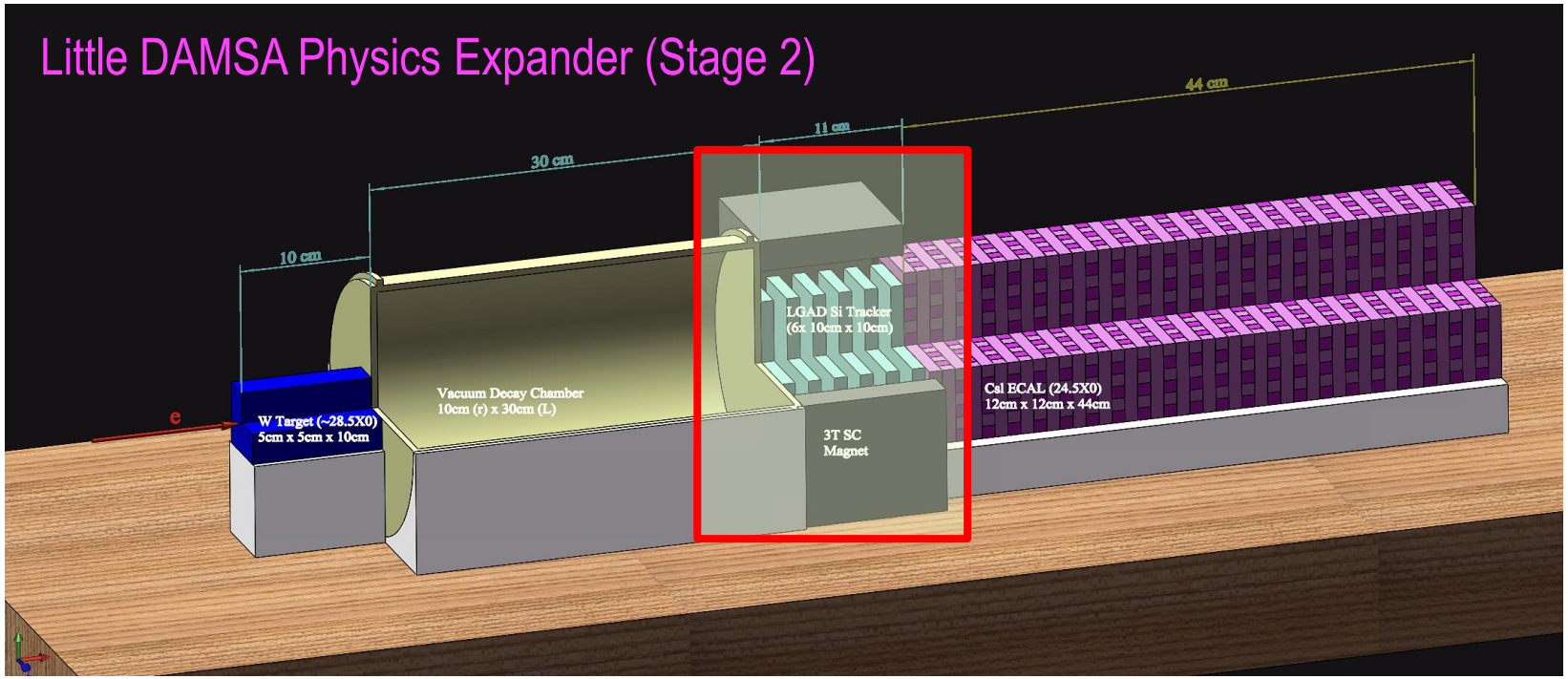
Little DAMSA – Stages 0 & 1

- Stage 0 (yr 1 – 3) ➔ e-beam background validator
  - Measure and validate the MC neutron and photon bck counts
- Stage 1 (yr 1 – 3) ➔ The a2γ demonstrator @ e-beam
  - Build a demonstrator with only W target, vacuum decay chamber and an ECAL + charged particle veto counters which occupy the same location and space as the tracker



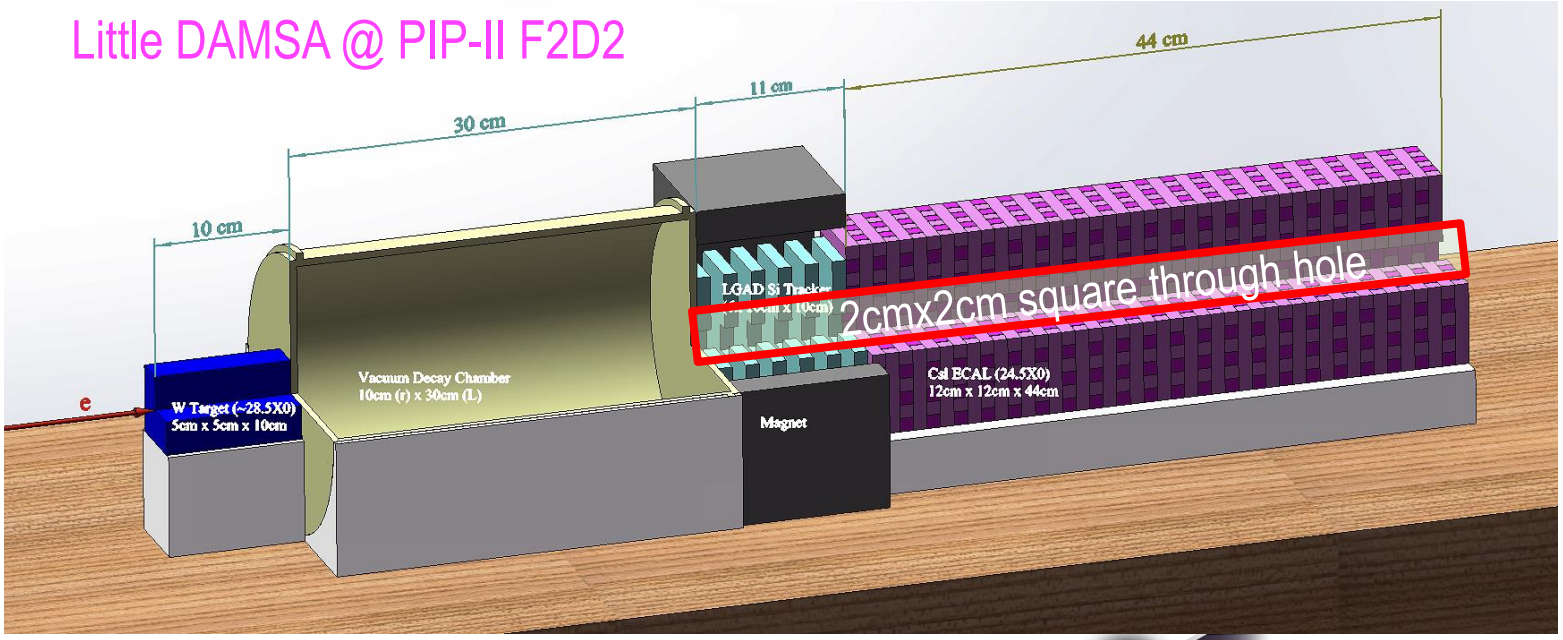
Little DAMSA – Stage 2

- Stage 2 (yr 3 – 4) ➔ The a2e demonstrator @ e-beam
  - Build on the stage 1 demonstrator, add 6 Si tracker layers and a 1T permanent magnet
  - Demonstrate the expanded signal capture



Little DAMSA – Stages 3 & 4

- Stage 3 (yr 4 – 5) ➔ The neutron background validator @ proton beams
  - Move the demonstrator to a low E, low power proton beams
  - Demonstrate neutron background handling
- Stage 4 (yr 4 – 5)➔ The full scale DAMSA @ F2D2
  - Move the complete detector to available proton beam facilities
  - Perform search and discovery

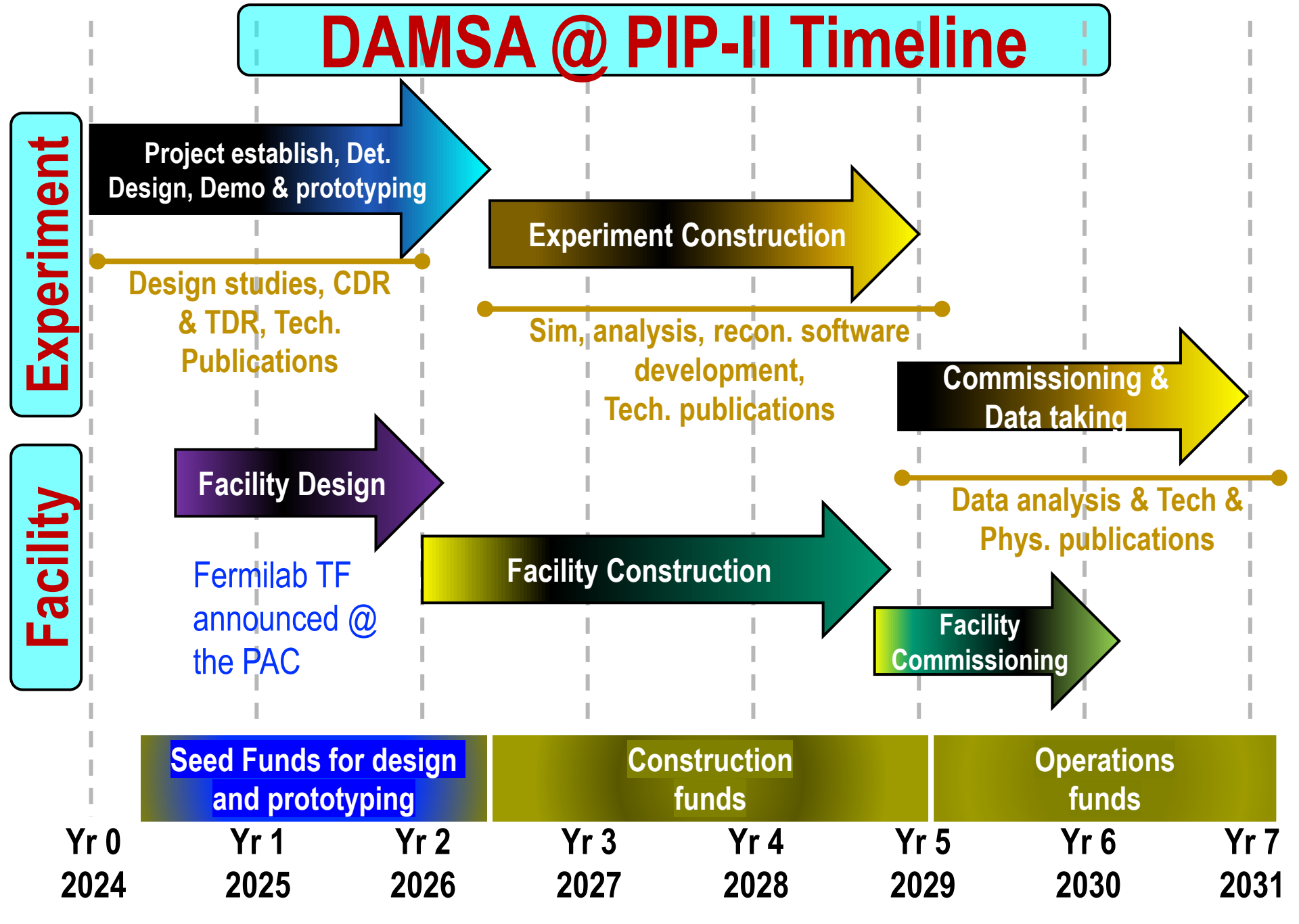


Where is the DAMSA experiment?

- 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 six times, 4 in 2023 & 2 in 2024
  - Updated the US DOE funding managers three times
- Initial DAMSA collaboration building completed
  - Lead Investigators: J. Yu (UTA), J. Estrada (FNAL), UK Yang (SNU)
    - 12 US + 11 SK institutions on DAMSA
    - A healthy mixture of theorists and experimentalists
  - Funding applications being submitted (some successes!!)
- DAMSA can be a network of experiments at different facilities

Potential Fermilab Experimental Facility

- Proposed Name: F2D2
  - **F**ermilab **F**acility fo tter **D**iscovery
  - Sited in the Teva of any ACE plan
- Requirements
  - Basic assump ments operate simultaneously off-axis
  - Sufficient overb e.)
  - Sufficient footp t
  - Sufficient heic ge capacity crane coverage
- TF completed its work and delivered its report


DAMSA @ PIP-II Timeline
Experiment
Project establish, Det. Design, Demo & prototyping
Experiment Construction
Design studies, CDR & TDR, Tech. Publications
Sim, analysis, recon. software development, Tech. publications
Commissioning & Data taking
Facility
Facility Design
Data analysis & Tech & Phys. publications
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

Conclusions

- DAMSA is a table-top DSP search and **discovery** exp.
- DAMSA has been making steady and serious progress
  - Aim to be ready for PIP-II LINAC F2D2 by the end of this decade
    - Fermilab F2D2 TF submitted its initial report
  - An excellent example of agile experiment w/ good physics case
    - Recent US HEP P5 report emphasizes support for AESTE program
  - Staged approach for feasibility tests and physics every step
- Initial DAMSA collaboration building complete
  - Assignment of roles and responsibilities complete
- Little DAMSA Path-Finder experiment is being developed
- DAMSA presents an excellent opportunity to produce and discover DSP in beams

LDW2024 Parting Questions

- **The strength of DAMSA experiment setup**
  - Extremely short baseline ➔ Capture prompt decays
- What other physic topics can we do with the setup like DAMSA experiment?
  - Is there a SM measurement DAMSA can contribute?

✓What modifications to DAMSA experimental configuration that could dramatically expand the physics reach? – μ-detector?

- What are the tools necessary to assess DAMSA physics reach in a timely manner?