Search for Hidden Particles (SHiP/NA67) at the dedicated ECN3 Beamdump Facility (BDF)

Heiko Lacker on behalf of the German SHiP groups

KET Strategy Workshop
Bad Honnef, 22.11.2025

Physics Case: Diversity essential!

SM complete, w/o explaining
→ (tiny) ν masses
→ BAU
→ dark matter
...

Low-energy manifestation of UV-complete theory

$$\mathcal{L}_{\text{SM-EFT}} = \mathcal{L}_{\text{gauge}} + \mathcal{L}_{\text{Higgs}} + \sum_{d,i} \frac{c_i^{[d]}}{\Lambda^{d-4}} O_i^{d\geq 5}$$

New „high“-mass states
→ energy frontier
→ rare decays
→ precision measurements
...

Low-energy extensions

$\mathcal{L}_S = c_1 H^\dagger H S + c_2 H^\dagger H S^2,$ Dark scalars

$\mathcal{L}_N = F_{N\alpha} \bar{N}^c \sigma_2 H^* L_\alpha + \text{h.c.},$ Majorana Neutrinos

$\mathcal{L}_V = -\frac{\epsilon}{2} V_{\mu\nu} B^{\mu\nu},$ Dark Photons

$\mathcal{L}_a = \frac{a}{f_a} B_{\mu\nu} \tilde{B}^{\mu\nu}$ ALPs (non-renomalizable)

New „low“-mass, feebly interacting particles
→ rare production cross-sections
→ very long lifetimes

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New „high“-mass states
→ energy frontier
→ rare decays
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Low-energy extensions

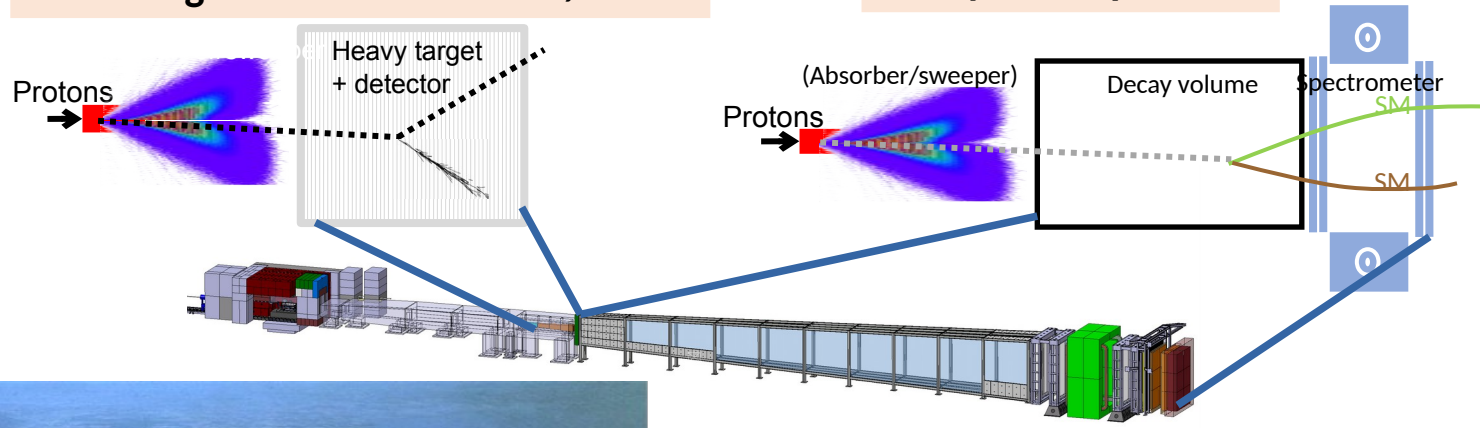
Model-independent

New „low“-mass, feebly interacting particles
→ rare production cross-sections
→ very long lifetimes
→ Special tool: Beamdump experiments complementary to collider searches

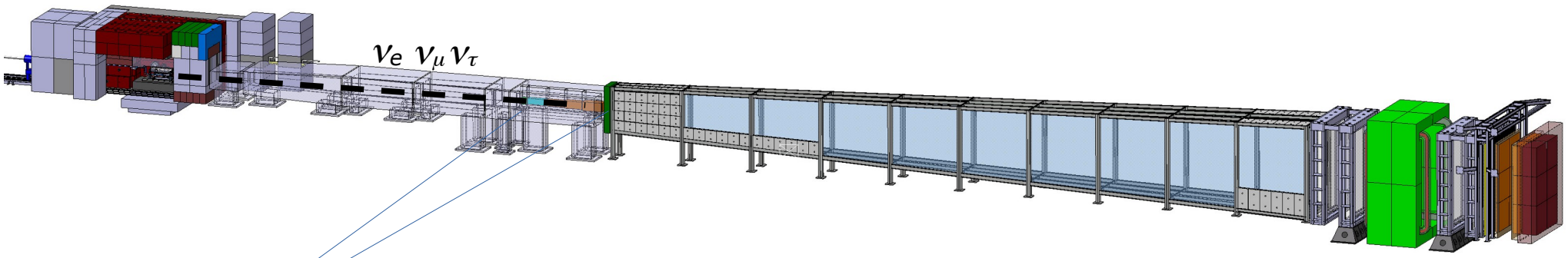
Dedicated BDF with SHiP as a dual-platform experimental setup

Scattering off atomic electrons/nuclei

Decay to SM particles



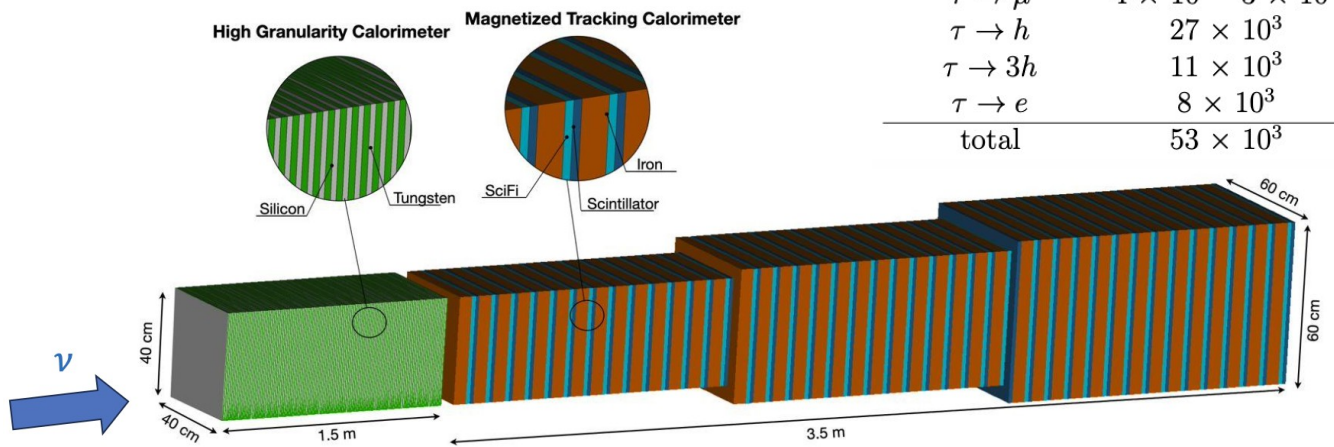
SND@SHiP: Guaranteed neutrino programme



Scattering-and-Neutrino Detector (SND@SHiP)

Expected for 6 x 10^{20} PoT:

Decay channel	ν_τ	$\overline{\nu}_\tau$
$\tau \to \mu$	4×10^3	3×10^3
$\tau \to h$	27×10^3	
$\tau \to 3h$	11×10^3	
$\tau \to e$	8×10^3	
total	53×10^3	

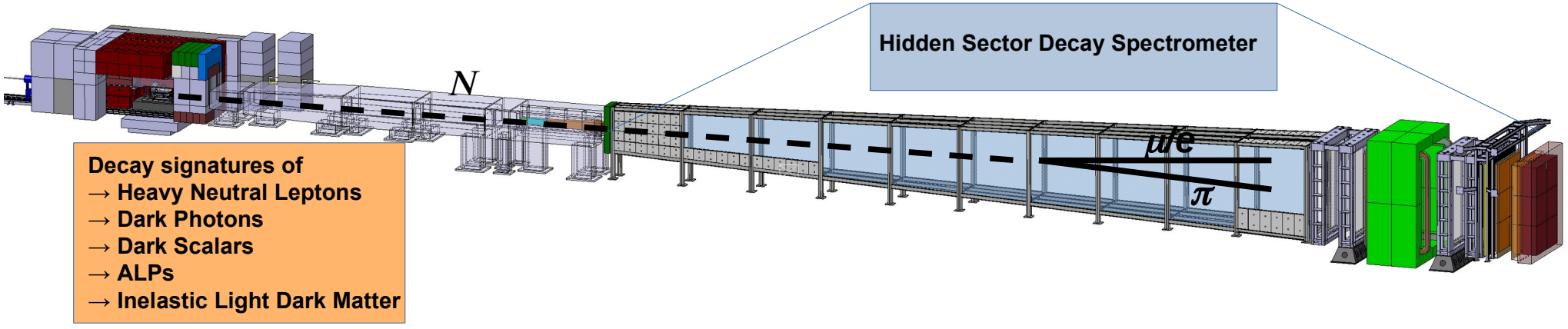


* ν_τ magnetic moment
* ν_τ DIS → Structure functions F_4, F_5
* Lepton flavour universality in ν sector
* νDIS with charm production
  → (nuclear) PDFs
  → e.g. s-quark PDF→M_W determination
* CKM element $|V_{cd}|$
* Charmed Pentaquarks

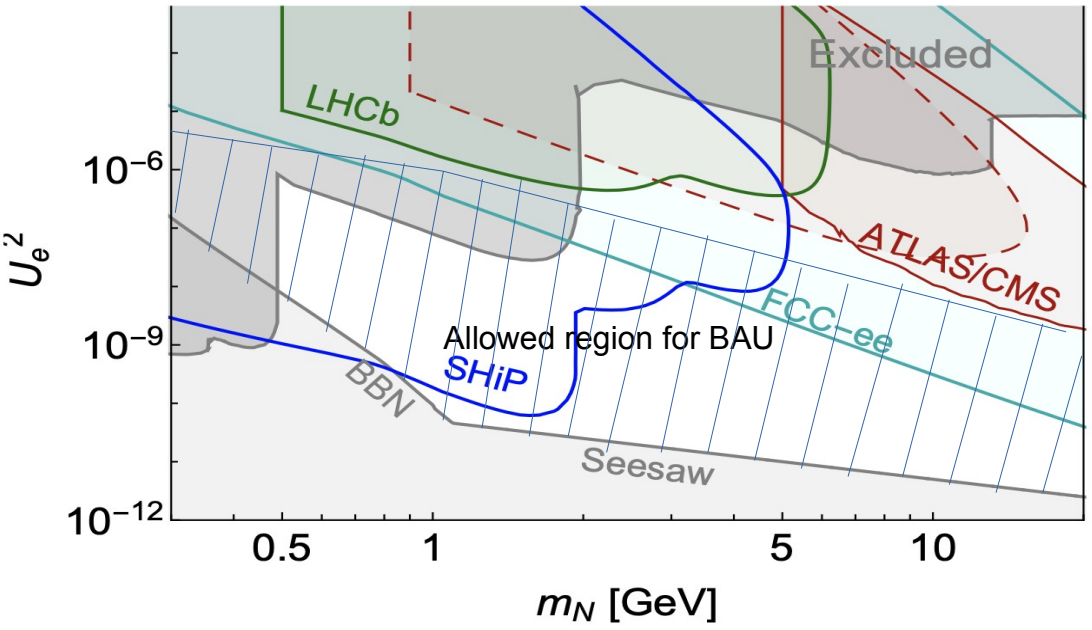
* Search for Light Dark Matter

1st high-stat. ν_τ experiment → test of the least-studied SM particle

Searching for Dark-Sector Particles



Decay signatures of
→ Heavy Neutral Leptons
→ Dark Photons
→ Dark Scalars
→ ALPs
→ Inelastic Light Dark Matter



Significant sensitivity improvement over existing and planned competitors

Complementary to existing and planned colliders

Example of ν Minimal Standard Model: Probes parameter space relevant for BAU and down to seesaw limit

Developments during the last three years

*** Result of KET strategy workshop 2022:**

German SHiP and SHADOWS groups agreed to collaborate on future beamdump experiment at CERN

→ Common R&D funding application to BMFTR, unfortunately not funded for FP24-27

*** CERN Research Board decision (03/2024) for Beam-dump Facility at ECN3 + SHiP to go for TDR**

→ Most of the German SHADOWS groups joined SHiP

*** Medium Term Plan 2025 (07/2024) approved by CERN council: ~60 MCHF for BDF**

*** Since 2024: Optimization of detector design to keep cost under control while maximizing sensitivity**

E.g.: Decay volume under Helium instead of vacuum
with similar background expectation due to contingency in detector concept

*** Estimated overall detector costs remain stable since ECN3 proposal 2023: ~ 51 MCHF**

*** 1st annual report submitted to SPSC by 11/11/2025**

SHiP collaboration with very strong German participation shaping the project from the beginning (2014)

Greybook (21.11.2025):
18 countries
33 institutes + 9 associated institutes + CERN + JINR
302 collaboration members

D: * Berlin (Lacker, Issever)
* Bremen (Ustyuzhanin)
* Freiburg (Fischer, Schumann; Weiser)
* Hamburg (Hagner, Bick)
* KIT: ETP (Ferber, Kieseler, Klute), ITEP (Arndt)
* Mainz (Büscher, Wanke; Wurm)
* Siegen (Cristinziani)

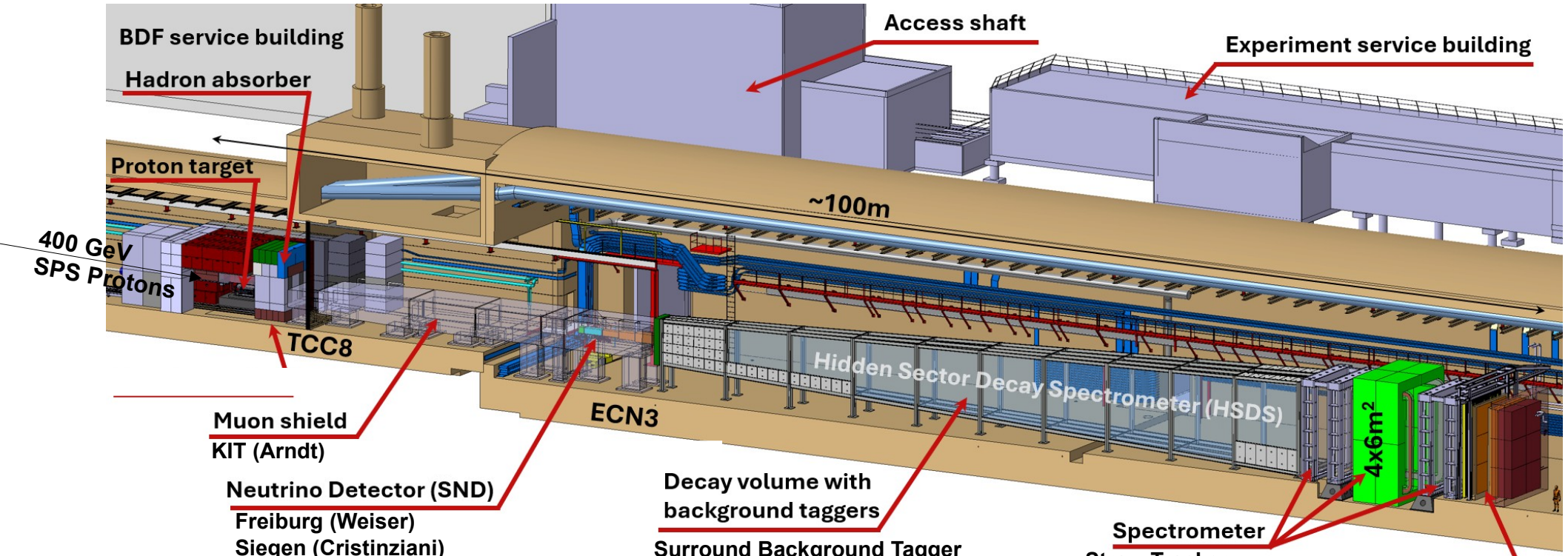
German fairshare (institutes/groups): ~15%

Current detector cost estimate: ~51 MCHF

→ German contribution: ~8.4 MEUR
(assuming 1.1 exchange rate)

Belgium, Bulgaria, Chile, Denmark, France, Georgia, Germany, Italy, Japan, Kasachstan, Netherlands, Portugal, Switzerland, Serbia, South Korea, Turkey, Ukraine, UK, JINR and CERN

Very strong German participation in several key detectors



Muon shield
KIT (Arndt)

Neutrino Detector (SND)
Freiburg (Weiser)
Siegen (Cristinziani)

Computing & Software
KIT (Kieseler, Klute)
Bremen (Ustyuzhanin)

Decay volume with background taggers
Surround Background Tagger
Berlin (Lacker, Issever)
Freiburg (Schumann)
Mainz (Wurm)

SHiP-charm
Siegen (Cristinziani)

Spectrometer
Straw Tracker:
Hamburg (Hagner)

Timing and particle identification
ECAL and HCAL:
Mainz (Büscher, Wanke)
KIT (Ferber, Klute)

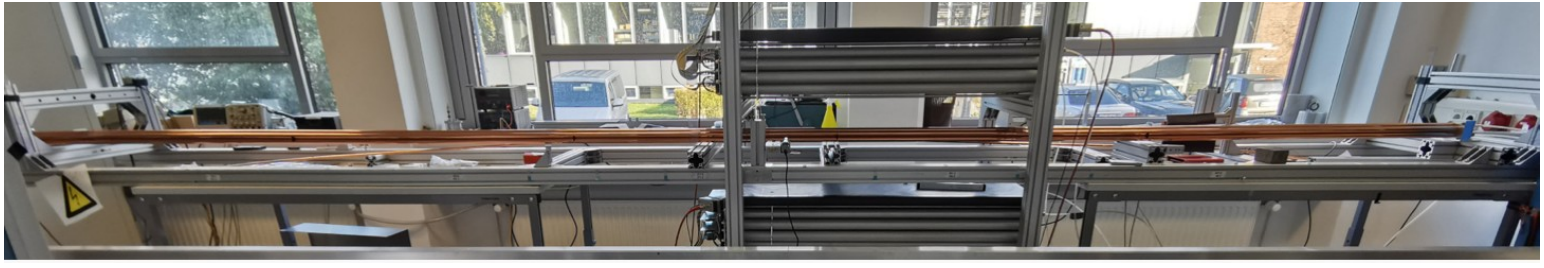
Detector technology/expertise from Germany

Surrounding Background Tagger (Lead by Germany: Berlin, Freiburg, Mainz)

* Tag ν/μ inelastic interactions inside decay volume + muons entering decay volume
* First LS detector based on Wavelength-Shifting Optical Modules
  (thanks to 2xDFG + 1xBMFTR R&D („High-D“))
* Cooperation with TU Berlin (Mechanics) and Jülich (Electronics)

Spectrometer Straw Tracker (Hamburg: lead institute):

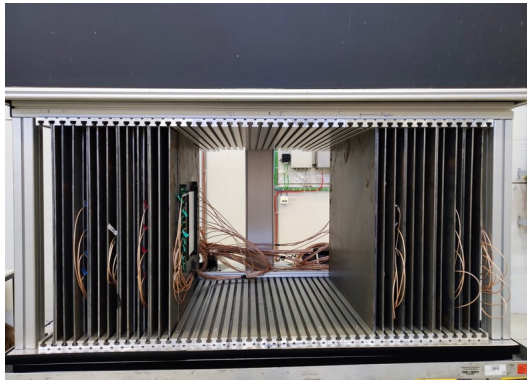
* Large-area detector (4x6 m^2; 2cm Ø) with minimal material budget
* Mechanics based on past BMFTR-funded OPERA technology



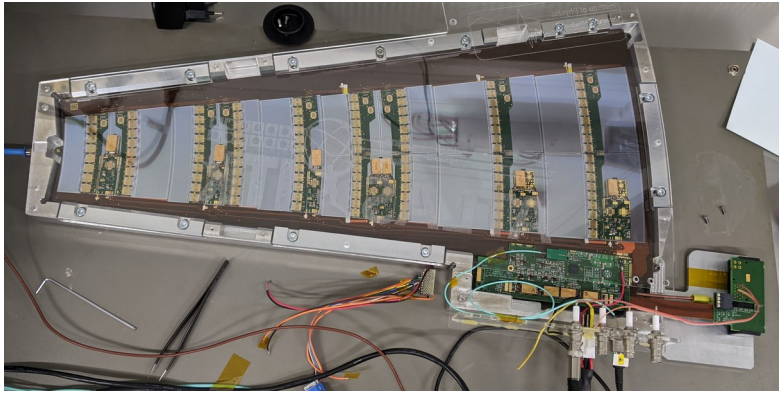
Detector technology/expertise from German institutes

ECAL/HCAL/PID (Mainz, KIT; lead by Germany)

* SplitCal technology developed by Mainz
* Essential for ALP → γ+γ



Scattering-and-Neutrino Detector (Freiburg, Siegen):
* High granular target/ECAL using silicon detectors (Freiburg, Siegen)



Further technology from Germany

Super-conducting Muon Shield (KIT-ITEP):

* Completely new technology using HTS magnets
* Opportunity for technology spin-off (accelerators)

→ High-tech agenda

Return to Germany

*** Physics harvest of CERN investment in ECN3 (60 MCHF), the largest investment that profits from the overall NA consolidation (O(170 MCHF))**

*** Possible industrial return from SHiP to D via small and medium-sized enterprises identified, e .g.: SC μ Shield, SBT**

*** Investment in „brains“: Scientific education and training characteristic for our field**

SHiP-D theses:	BA	MA	PhD
Finalized:	34	20	3
Running:	4	9	10

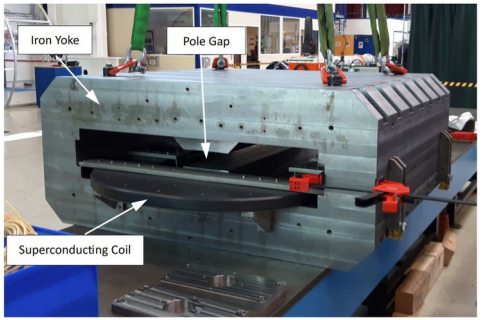
Other possible spin-offs and sustainability aspects

* Full exploitation of SPS physics potential: 2/3 of the SPS protons unused

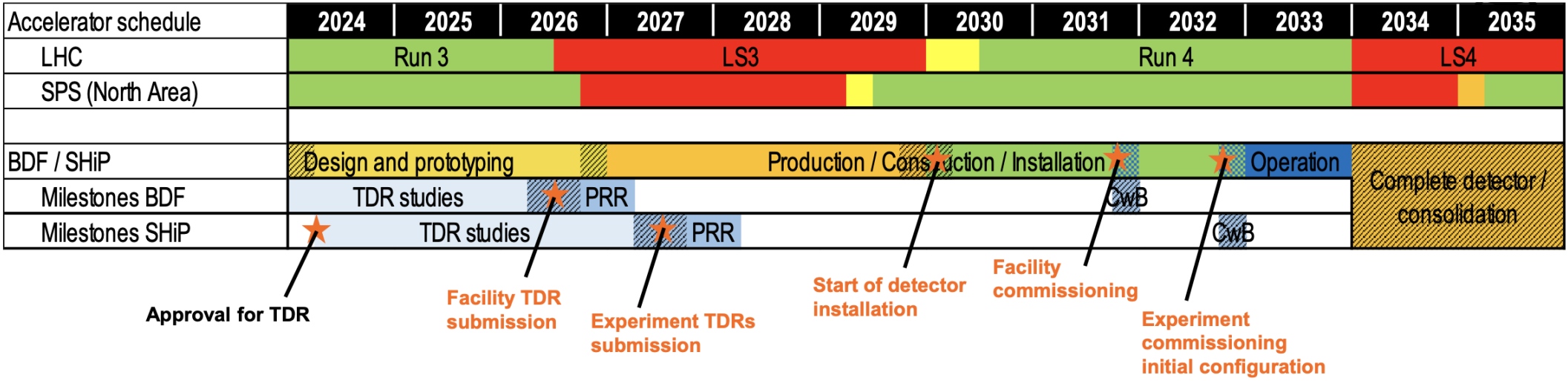
* SHiP Spectrometer magnet
  → New HTS technology in large-aperture low-field magnets
  → Based on MgB_2 cables as used for HL-LHC SC connections
  → Expected power consumption reduction: > 10x

* Re-usage:
  → Liquid-Scint. equipment from Borexino for SBT
  → iron from PS ν facility until 1983 and restoring land at location
  → Reuse of CNGS hadron stopper iron being looked at
  → Reuse of 1100 tonnes of Opera magnetic iron

* Target system: reduce significantly production of activated material and make disposal safer and more efficient.
  → Technology drivers for spallation sources world-wide
  → Opportunity for an irradiation facility at the target region
  (→ Electronics, aviation safety)



Why is funding urgently needed: Time schedule



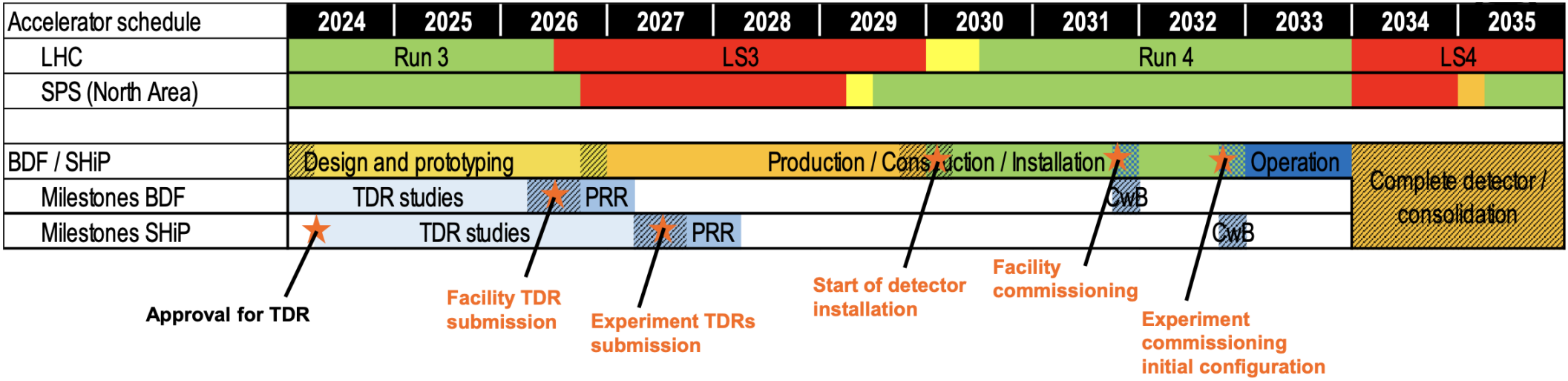
* Facility: TDR 2026 → Facility Commissioning: 2031

* Experiment TDRs: 2027 → Experiment construction: FP27-30, 30-33

* Experiment commissioning: 2032 → first data taking: 2033 (before LS4 crucial!)
  → Sustainable funding from FP27-30 onwards essential („Dringlichkeit“)

* Project length: 15 years of data taking → At least until 2050: a bridge beyond HL-LHC

Why is funding urgently needed: Time schedule



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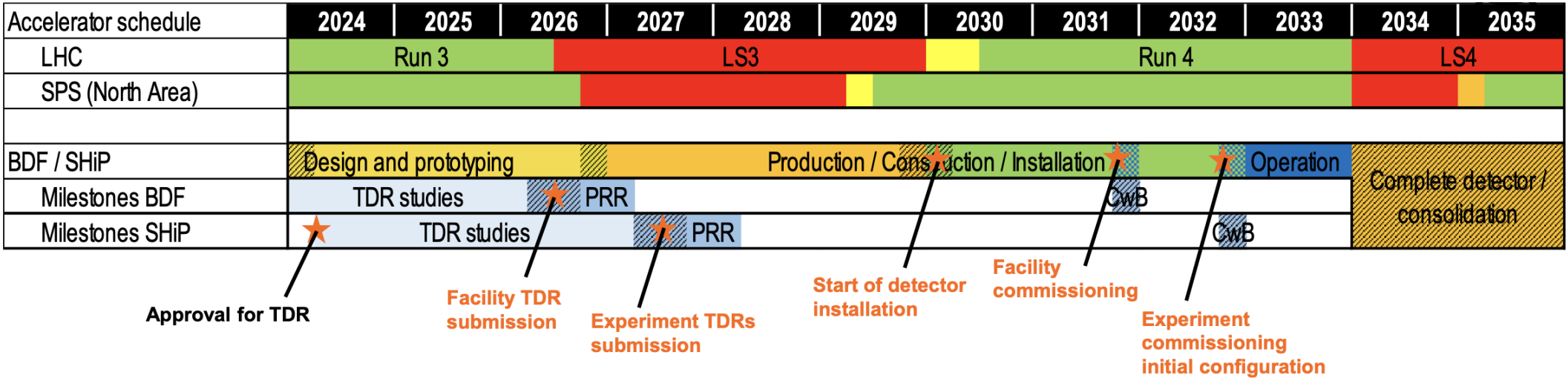
* Funding constraints might require a staged approach to the detector installation before and during LS4

Plan for FP 2027-30



*** Delivery of subdetector TDRs (2027)**

*** Production Readiness Report (2027)**

*** Preproduction + start of Production (2028)**

*** Soft/firmware (readout, DAQ, calibration, reconstruction)**

Expected funding request (preliminary):

*** R&D invest: 0.43 MEUR**

*** Core Invest: 2.1 MEUR**

*** Personnel: 20 FTE**

BDF/SHiP: Summary

*** Excellent physics case → FIP sensitivities complementary to existing and future colliders and unbeaten for several decades to come**
→ Guaranteed neutrino physics programme

*** The flagship in CERN's Beyond Collider Programme + a bridge well beyond HL-LHC**

*** Full exploitation of CERN's investment into SPS NA/BDF + strong German participation (7 institutes, 12 PIs)**
→ Excellent arguments for „Bundesinteresse"

*** FP27-30 crucial for SHiP construction and commissioning before LS4 → „Dringlichkeit"**

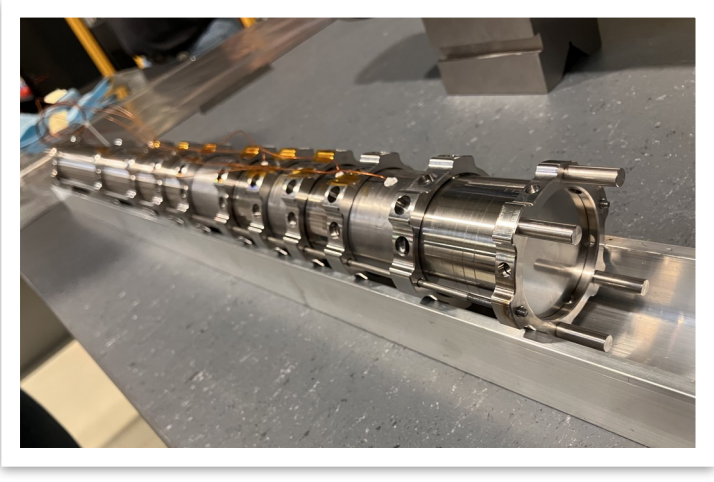
*** Full support in Germany's community input to ESPPU 2026:**

To address the fundamental questions of particle physics, the German community considers a diverse experimental landscape of non-collider experiments, with a complementary physics potential with respect to collider experiments, being as essential.

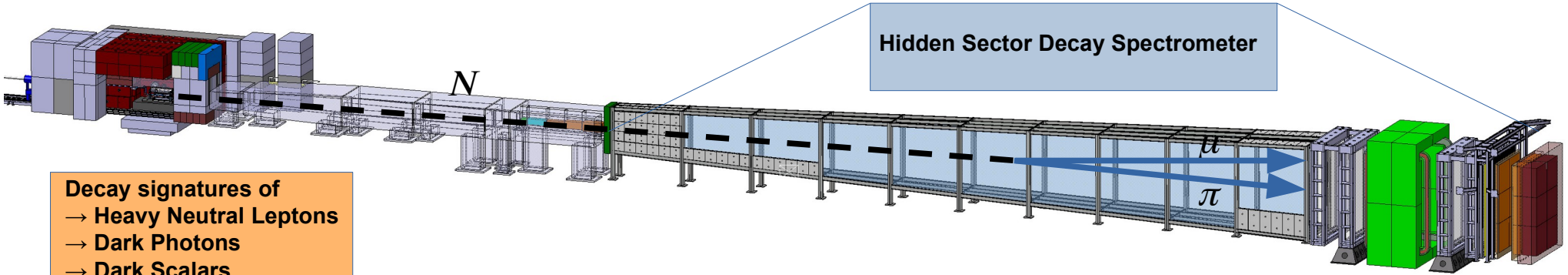
To search for feebly interacting particles, the German community prioritizes the SHiP experiment, hosted in a new beam-dump facility thereby fully exploiting the investment into CERN's north area.

BDF/SHiP: Summary

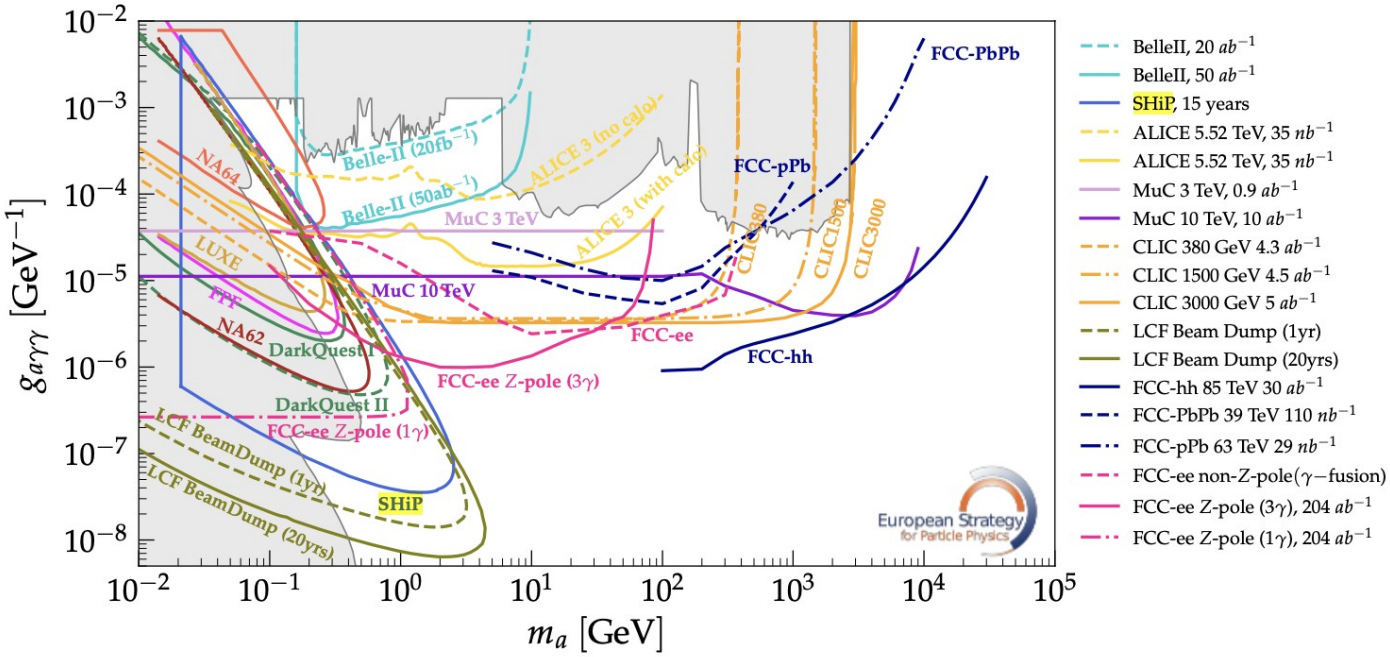
SHiP-D likes to ask for a strong support message at the BMFTR strategy meeting underlining the German Particle Physics Community's ambition to fully exploit and shape CERN's Scientific Programme also in Non-Collider Physics



Searching for Dark-Sector Particles



Decay signatures of
→ Heavy Neutral Leptons
→ Dark Photons
→ Dark Scalars
→ ALPs

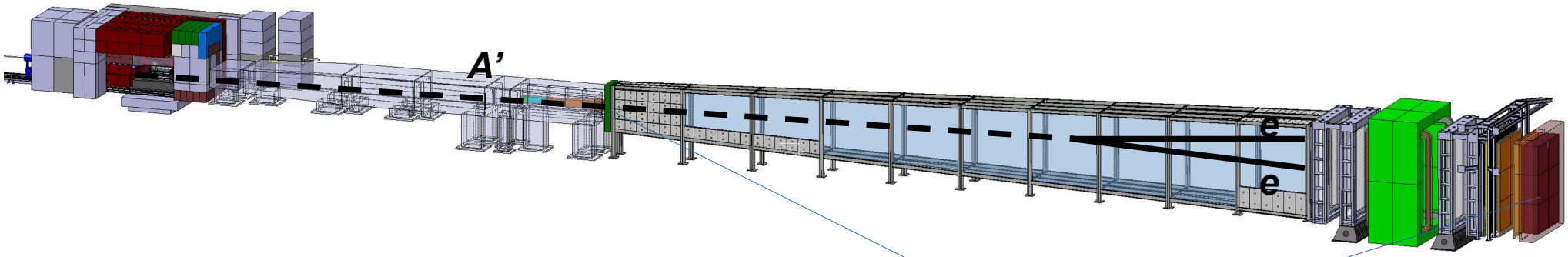


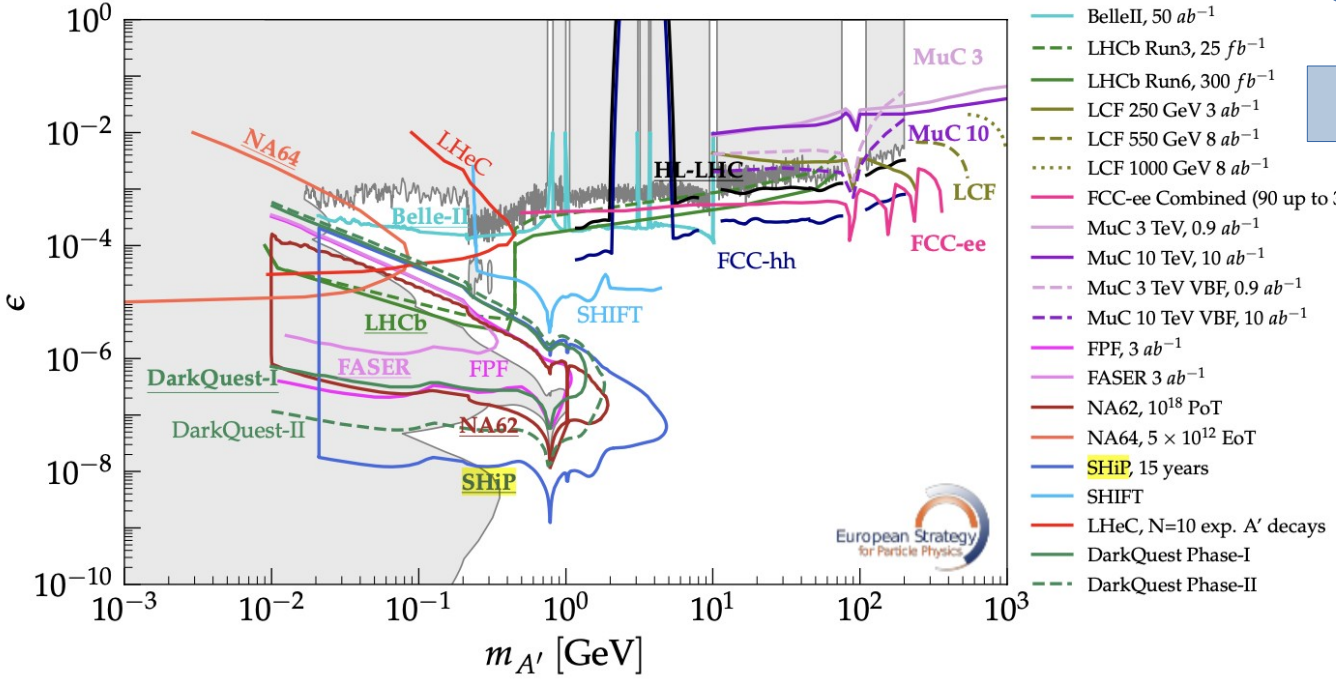
- BelleII, 20 ab^{-1}
- BelleII, 50 ab^{-1}
- SHiP, 15 years
- ALICE 5.52 TeV, 35 nb^{-1}
- ALICE 5.52 TeV, 35 nb^{-1}
- MuC 3 TeV, 0.9 ab^{-1}
- MuC 10 TeV, 10 ab^{-1}
- CLIC 380 GeV 4.3 ab^{-1}
- CLIC 1500 GeV 4.5 ab^{-1}
- CLIC 3000 GeV 5 ab^{-1}
- LCF Beam Dump (1yr)
- LCF Beam Dump (20yrs)
- FCC-hh 85 TeV 30 ab^{-1}
- FCC-PbPb 39 TeV 110 nb^{-1}
- FCC-pPb 63 TeV 29 nb^{-1}
- FCC-ee non-Z-pole($\gamma-$fusion)
- FCC-ee Z-pole (3γ), 204 ab^{-1}
- FCC-ee Z-pole (1γ), 204 ab^{-1}

Significant sensitivity improvement over existing and planned competitors

Complementary to existing and planned colliders

Decay detector: Search for Dark Photons



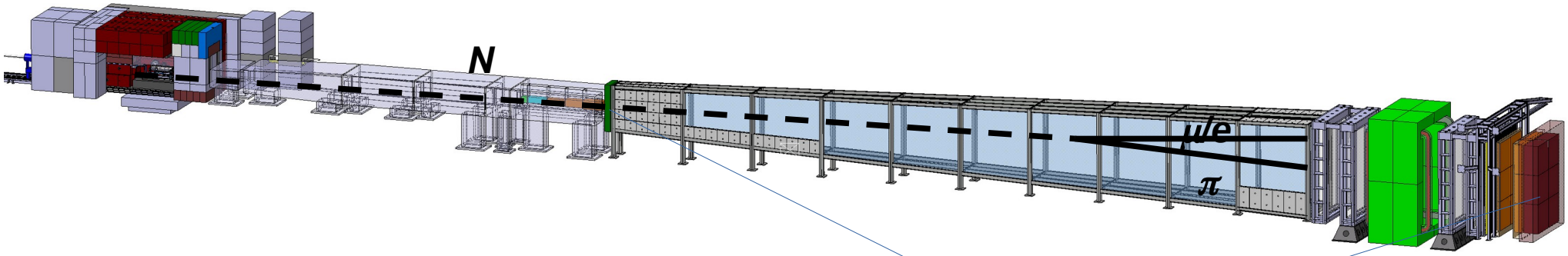


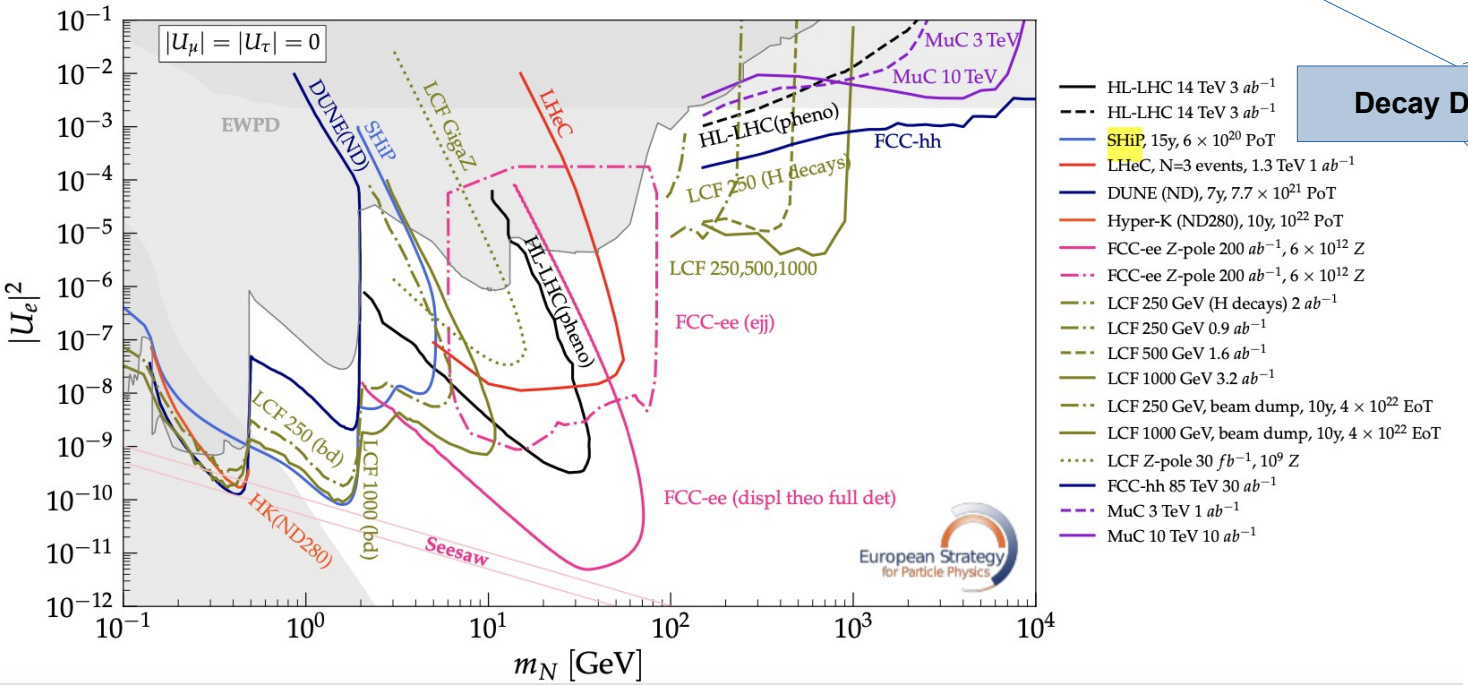
- BelleII, 50 ab^{-1}
- LHCb Run3, 25 fb^{-1}
- LHCb Run6, 300 fb^{-1}
- LCF 250 GeV 3 ab^{-1}
- LCF 550 GeV 8 ab^{-1}
- LCF 1000 GeV 8 ab^{-1}
- FCC-ee Combined (90 up to 365 GeV)
- MuC 3 TeV, 0.9 ab^{-1}
- MuC 10 TeV, 10 ab^{-1}
- MuC 3 TeV VBF, 0.9 ab^{-1}
- MuC 10 TeV VBF, 10 ab^{-1}
- FPF, 3 ab^{-1}
- FASER 3 ab^{-1}
- NA62, 10^{18} PoT
- NA64, 5×10^{12} EoT
- SHiP, 15 years
- SHIFT
- LHeC, N=10 exp. A' decays
- DarkQuest Phase-I
- DarkQuest Phase-II

Decay Detector

Decay signature of DS particles
→ Heavy Neutral Leptons
→ **Dark Photons**
→ Dark Scalars
→ ALPs

Decay detector: Search for Heavy Neutral Leptons

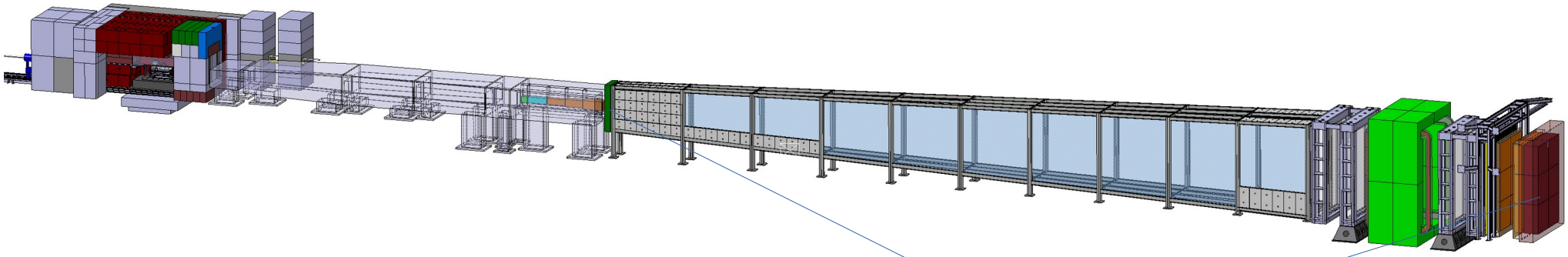


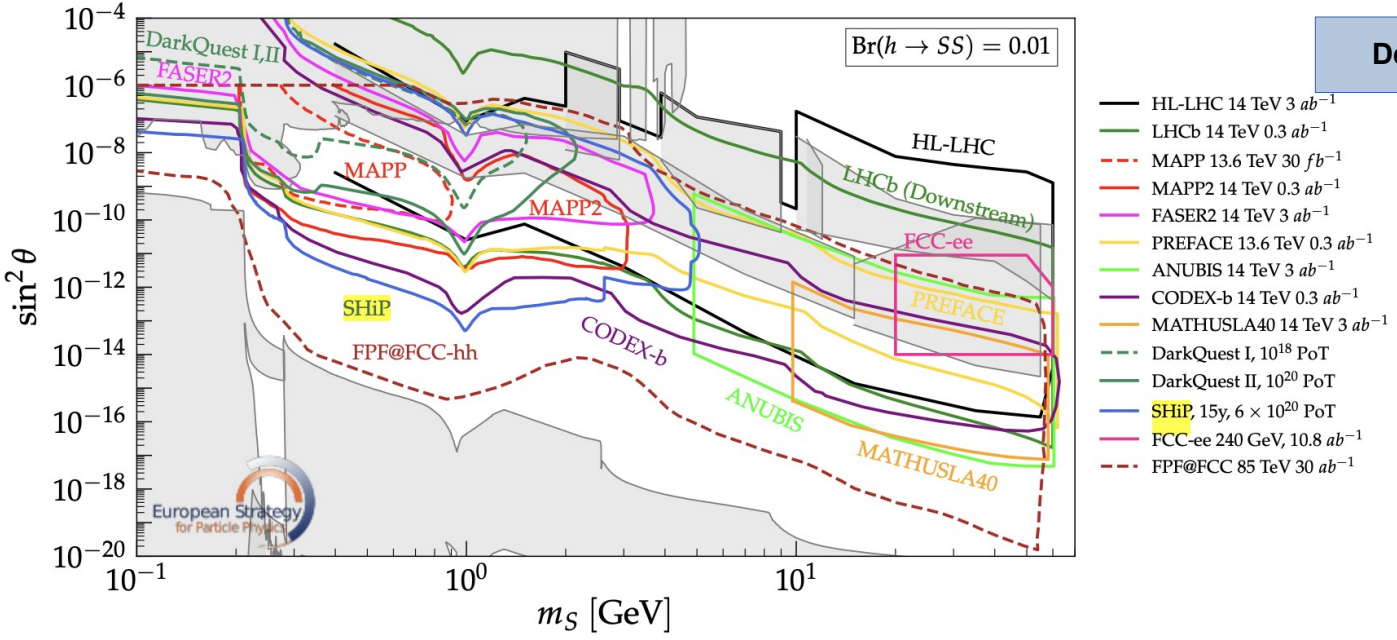


Decay Detector

Decay signature of DS particles
→ **Heavy Neutral Leptons**
→ Dark Photons
→ Dark Scalars
→ ALPs

Decay detector: Search for Dark Scalars with coupling to Higgs





- HL-LHC 14 TeV 3 ab^{-1}
- LHCb 14 TeV 0.3 ab^{-1}
- MAPP 13.6 TeV 30 fb^{-1}
- MAPP2 14 TeV 0.3 ab^{-1}
- FASER2 14 TeV 3 ab^{-1}
- PREFACE 13.6 TeV 0.3 ab^{-1}
- ANUBIS 14 TeV 3 ab^{-1}
- CODEX-b 14 TeV 0.3 ab^{-1}
- MATHUSLA40 14 TeV 3 ab^{-1}
- DarkQuest I, 10^{18} PoT
- DarkQuest II, 10^{20} PoT
- SHiP, 15y, 6×10^{20} PoT
- FCC-ee 240 GeV, 10.8 ab^{-1}
- FPF@FCC 85 TeV 30 ab^{-1}

Decay Detector

Decay signature of DS particles
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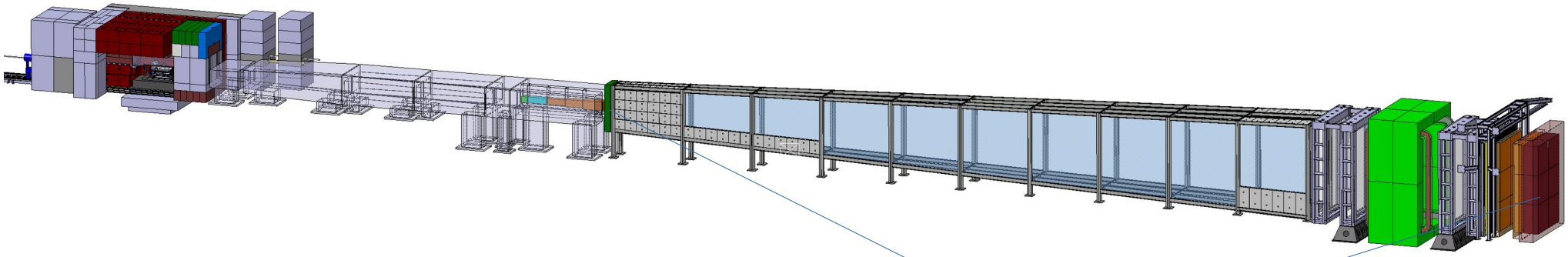
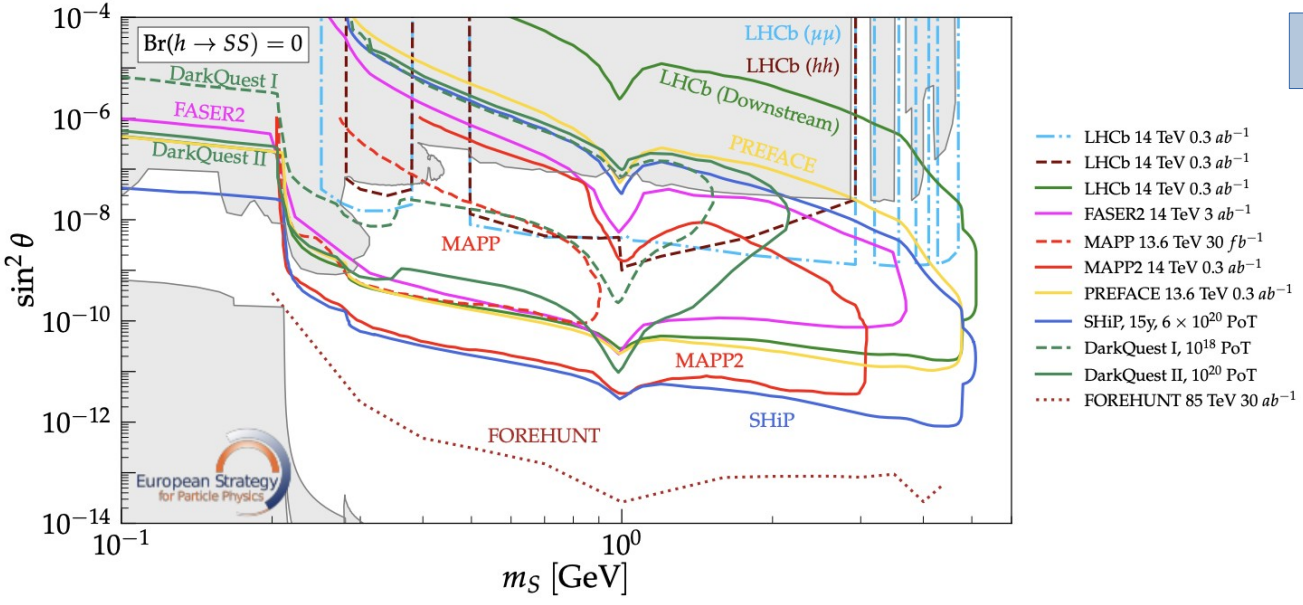
→ **Dark Scalars**
→ ALPs

Decay detector: Search for Dark Scalars with coupling to Higgs





Decay Detector

Decay signature of DS particles
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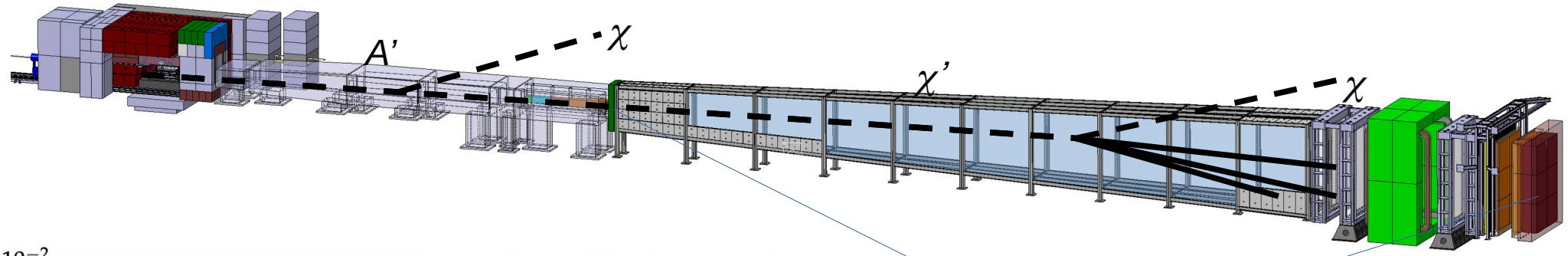
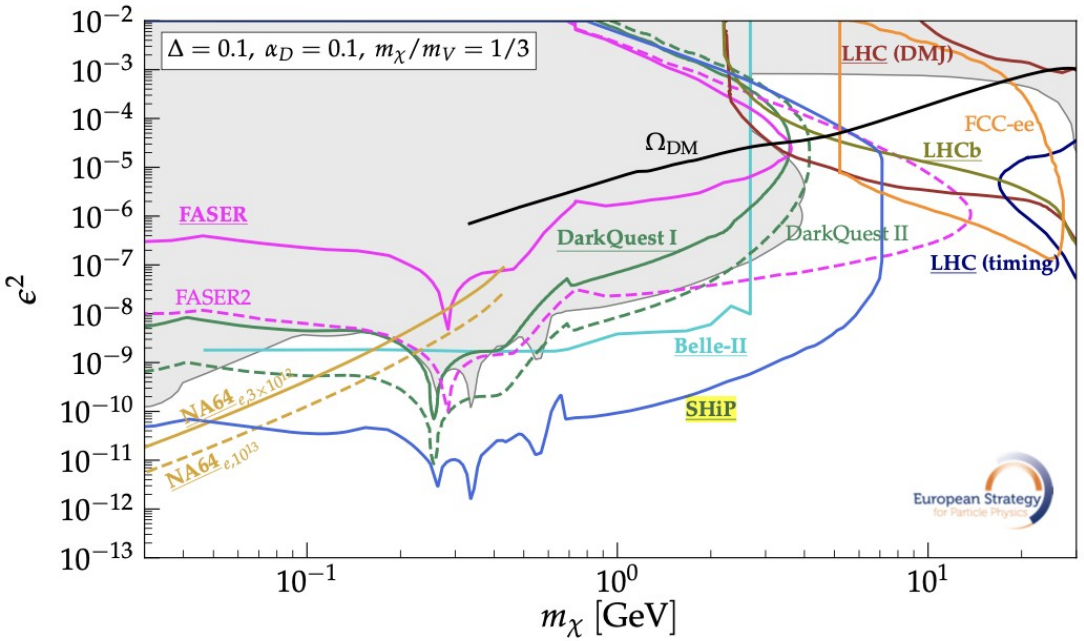
→ Dark Photons
→ **Dark Scalars**
→ ALPs

Decay detector: Search for inelastic DM

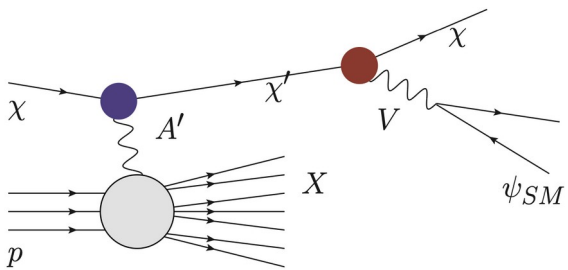




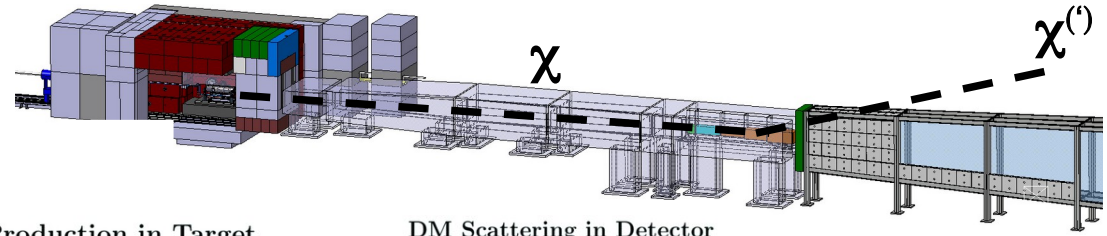
Decay Detector

$$\mathcal{L}_{A'\chi\chi^*} \to \mathcal{L}_{A'\chi\chi'^*}, \quad \Delta \equiv \frac{m_{\chi'} - m_\chi}{m_\chi} > 0$$

Decay signature of inelastic light DM produced in beamdump

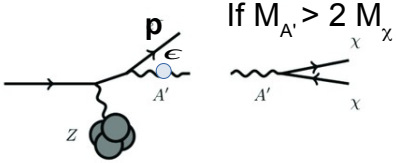


SND@SHiP: Search for (quasi-)elastic light DM

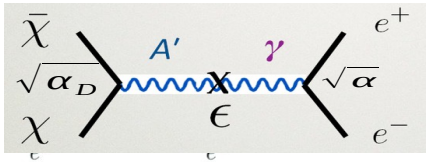


A' Production in Target

If $M_{A'} > 2\,M_\chi$



DM Scattering in Detector



Scattering(-and-Neutrino) Detector (SND@SHiP)

Scattering signature of (quasi-)elastic light DM produced in beamdump