Beamdumps – the physics case.

... or why 'half a collider' can be 'beyond colliders'...

Kai Schmidt-Hoberg

Disclaimer: experts in the audience

HELMHOLTZ ASSOCIATION

erc

DESY

Motivation: Light and weakly coupled new physics

- Standard Model incomplete but LHC has seen nothing (except the Higgs)
- New physics may be light and weakly coupled (which is why we are here...)

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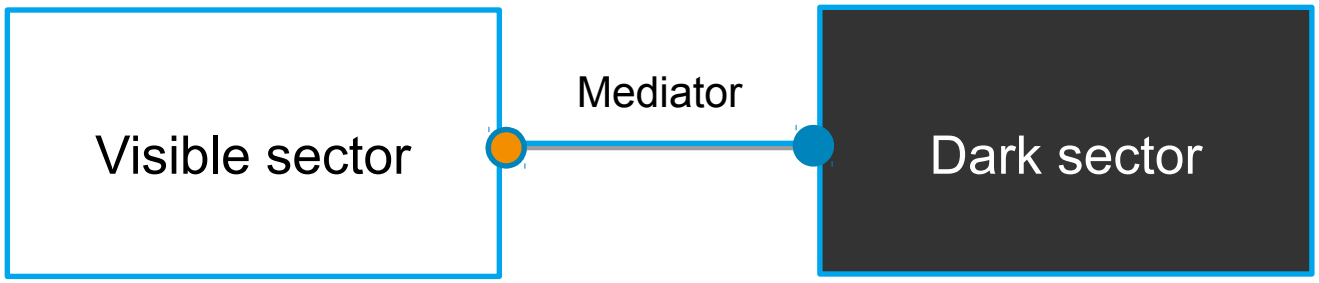

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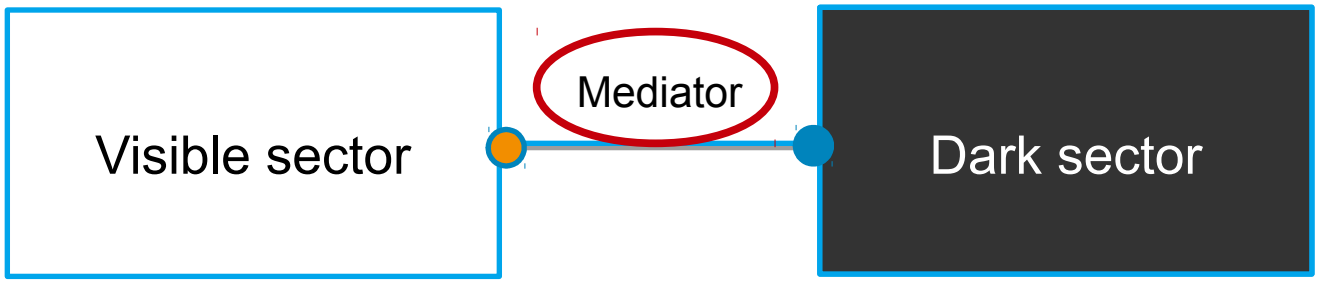

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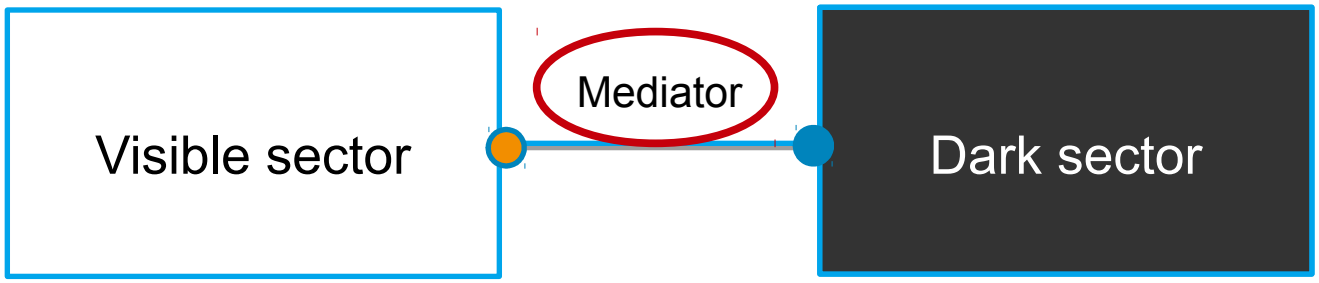

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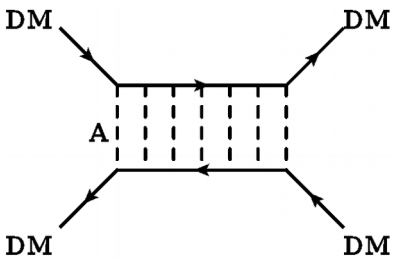
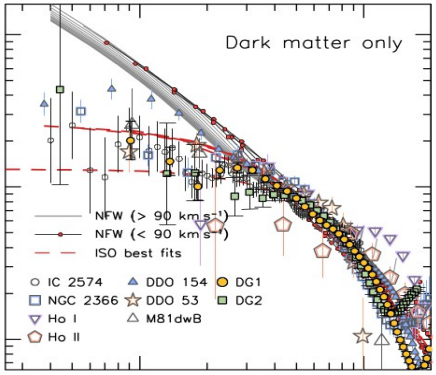
- light mediators offer the possibility to obtain large DM self-interactions





SIDM could resolve e.g. Cusp vs. core problem

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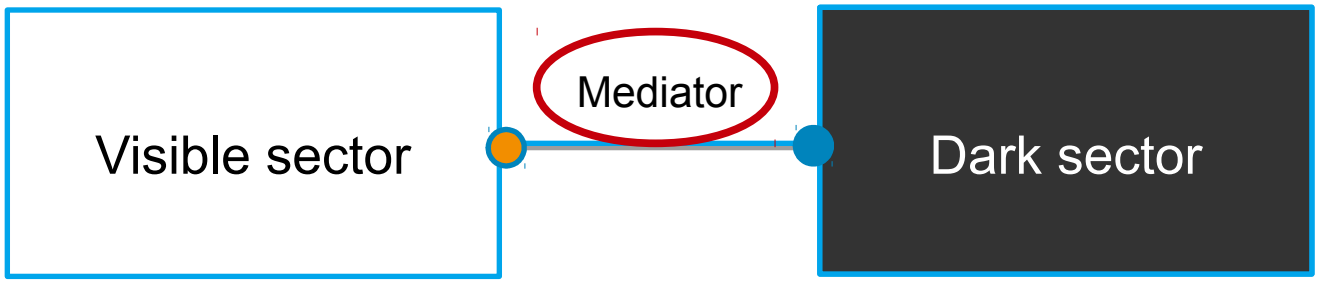

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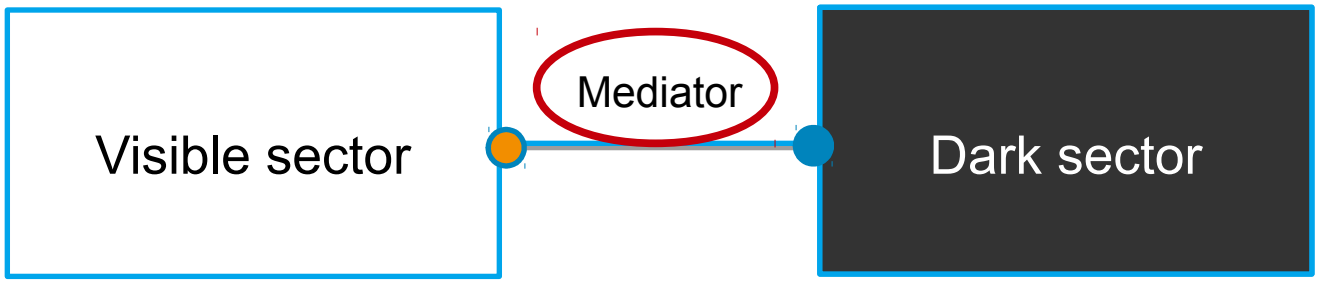
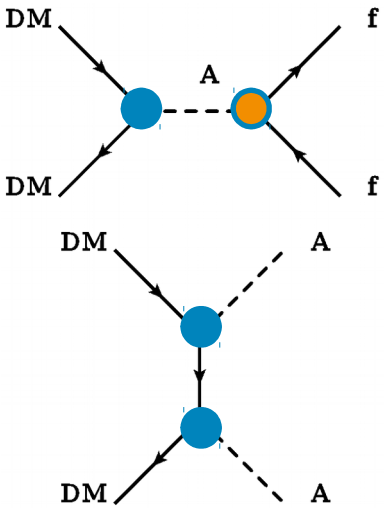
- What are typical signatures at beam dumps?

Motivation: Light and weakly coupled new physics



> Guidance: Dark matter relic abundance



$m_A < m_{DM}$

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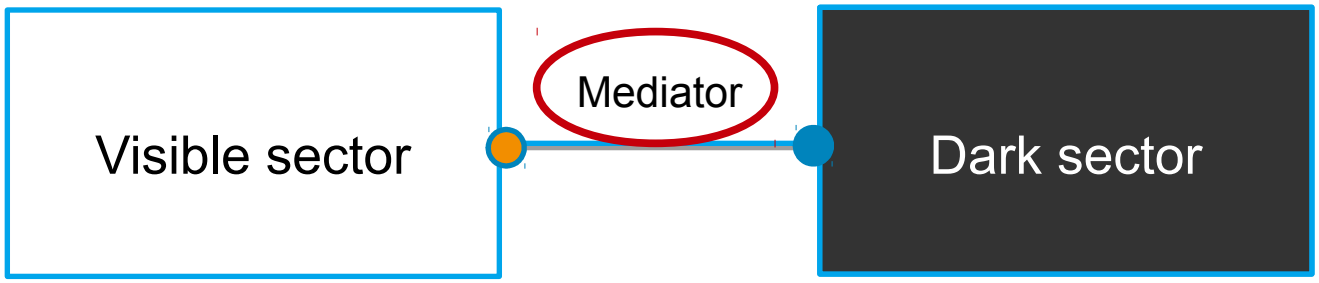

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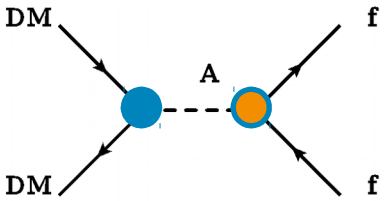

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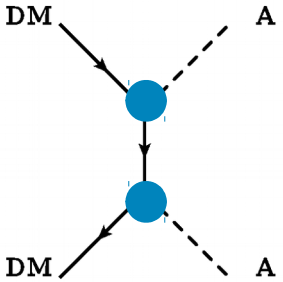

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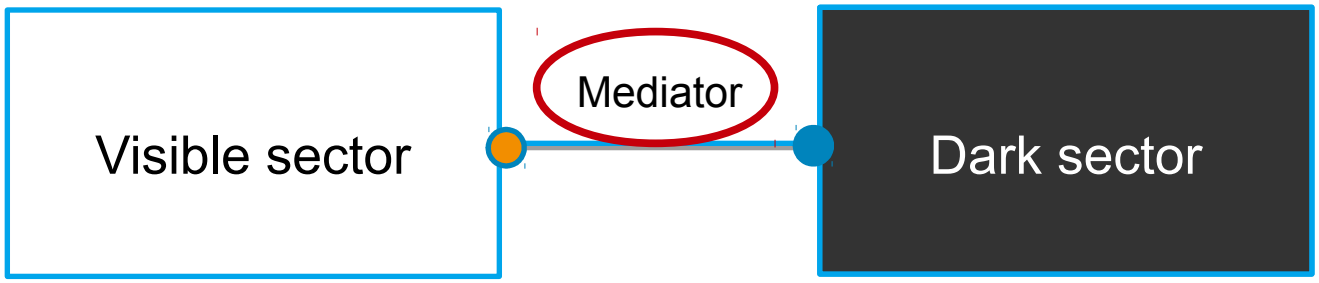

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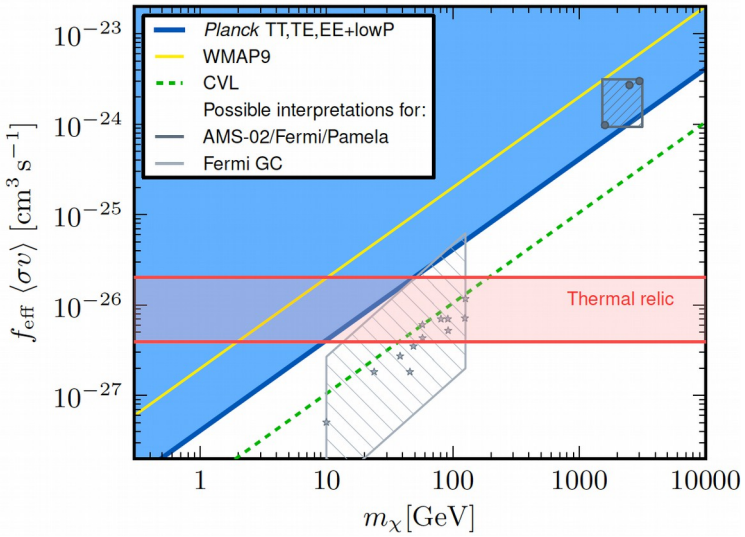

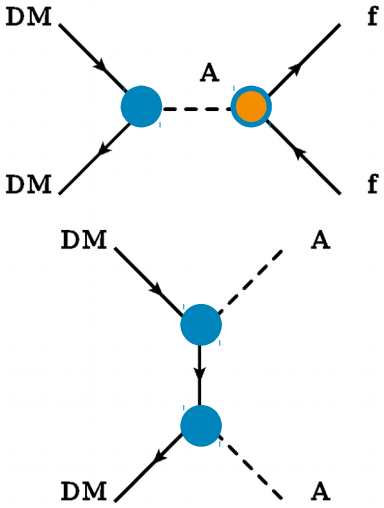

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s-wave strongly constrained!

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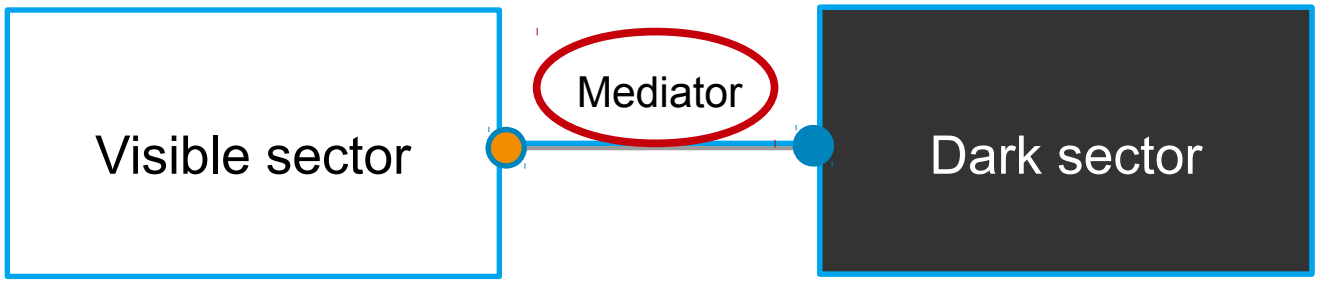

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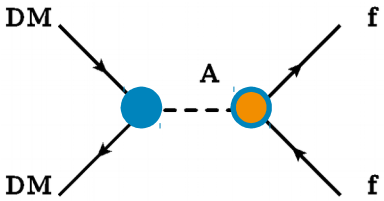
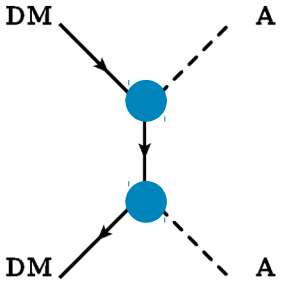


Annihilation s or p-wave,
SM coupling (almost) unconstrained
can be Sommerfeld enhanced



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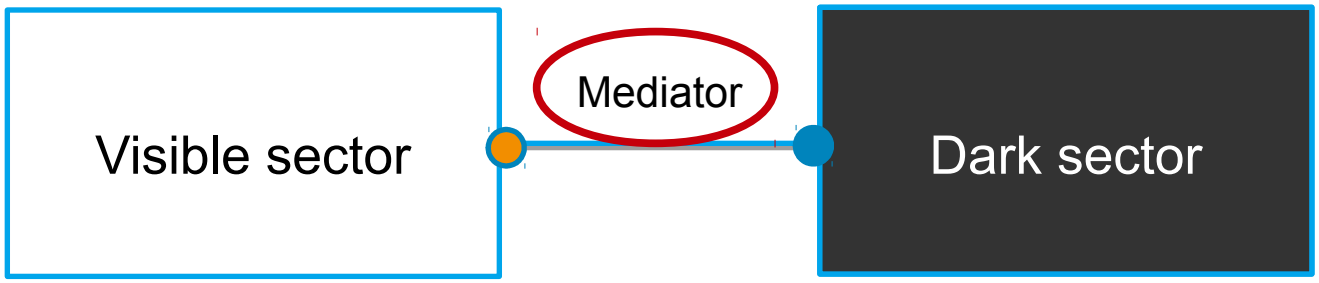

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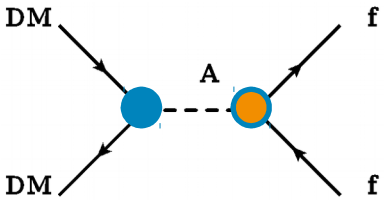

invisible decays

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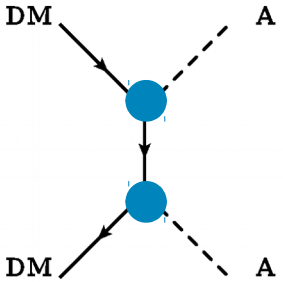

visible decays

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Beam dumps ideal to explore light and weakly coupled new physics:
- very large luminosities
- very low backgrounds (e.g. CHARM had zero events)

> Guidance: Dark matter relic abundance

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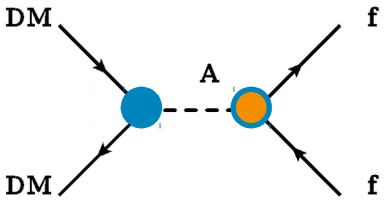

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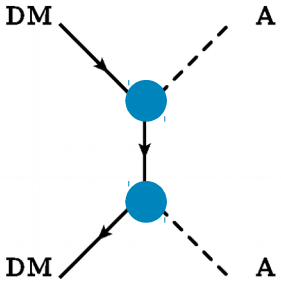

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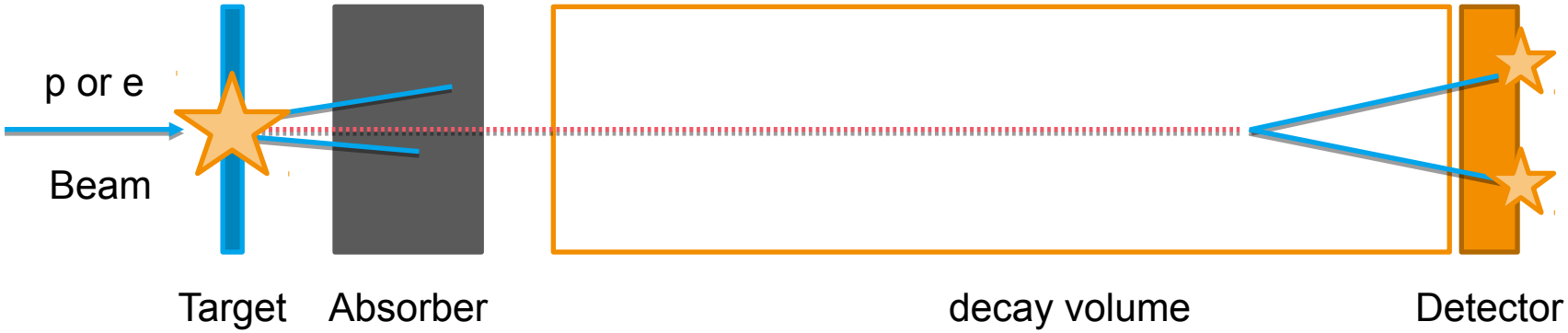
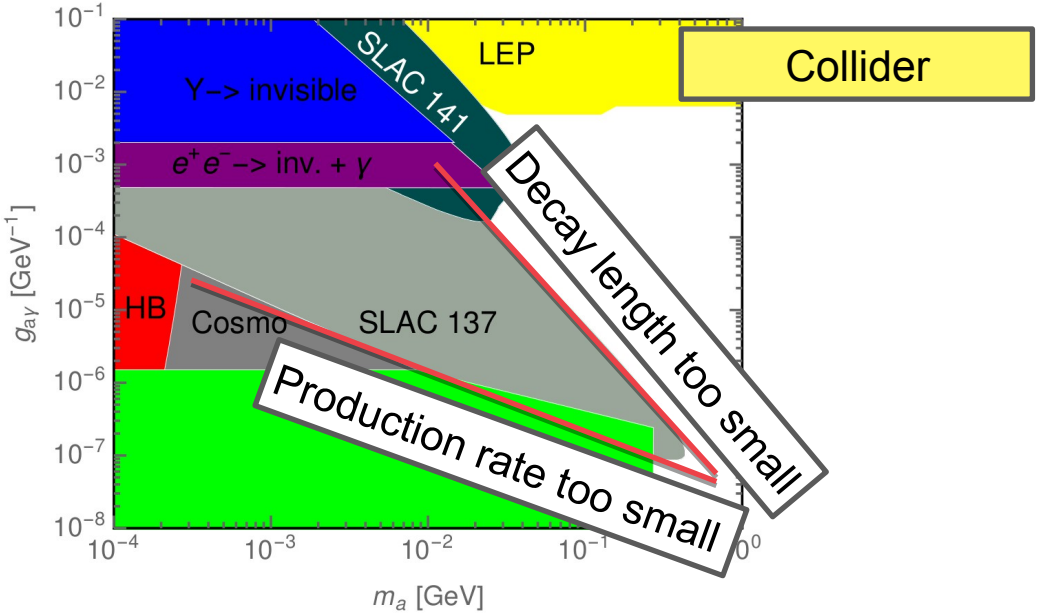
A beam dump from a theorist's perspective



typical sensitivity

- m_A < 10 GeV
- small couplings



SHiP – Search for Hidden Particles

- Expression of Interest - October 2013
- Technical Proposal & Physics Paper - April 2015
- Reviewed by the SPSC in March 2016, and recommended Comprehensive Design Study (CDS) by 2019

→ Input to the European strategy consultation to take a decision about approval of SHiP in 2019/2020

- Envisioned start 2026

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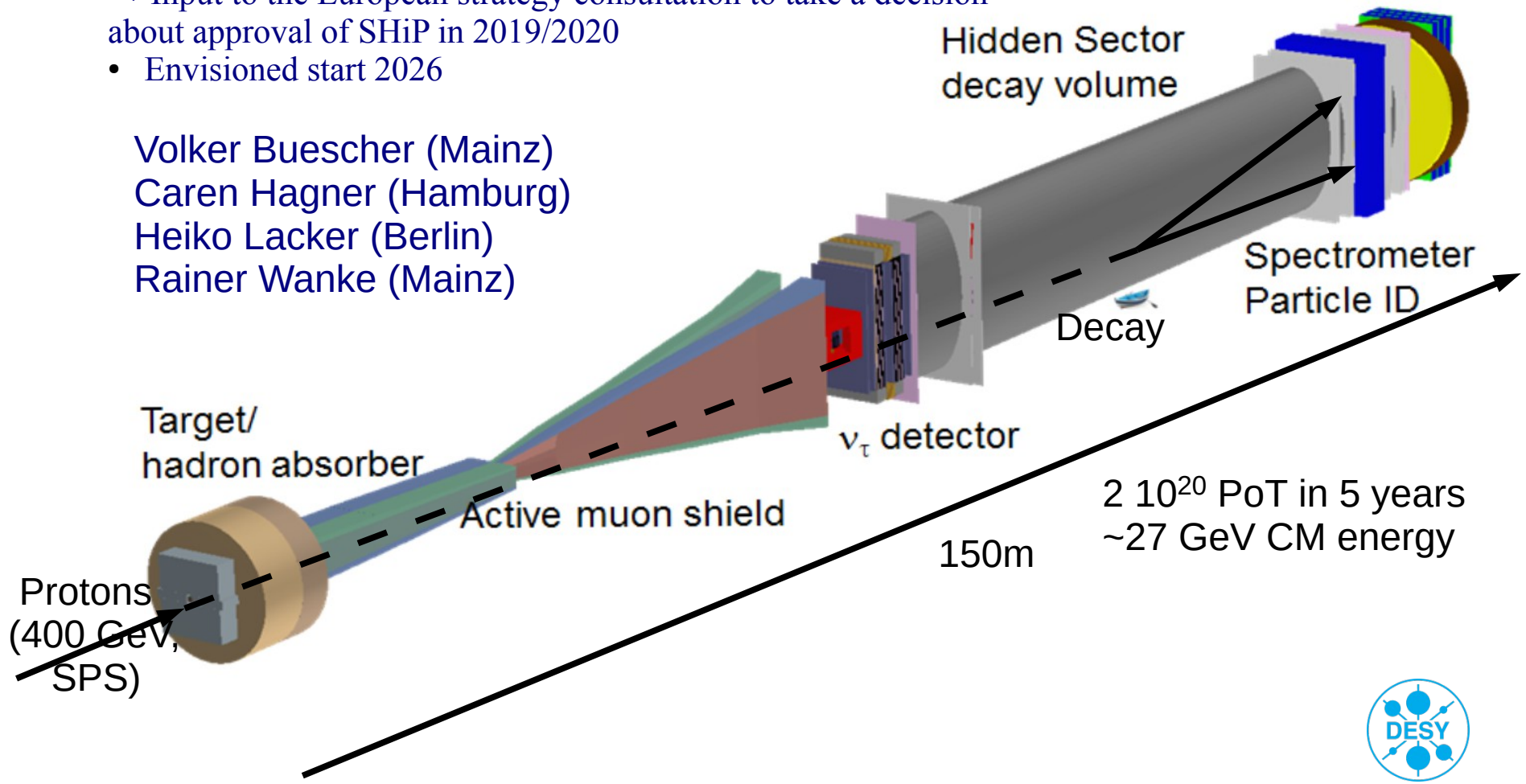

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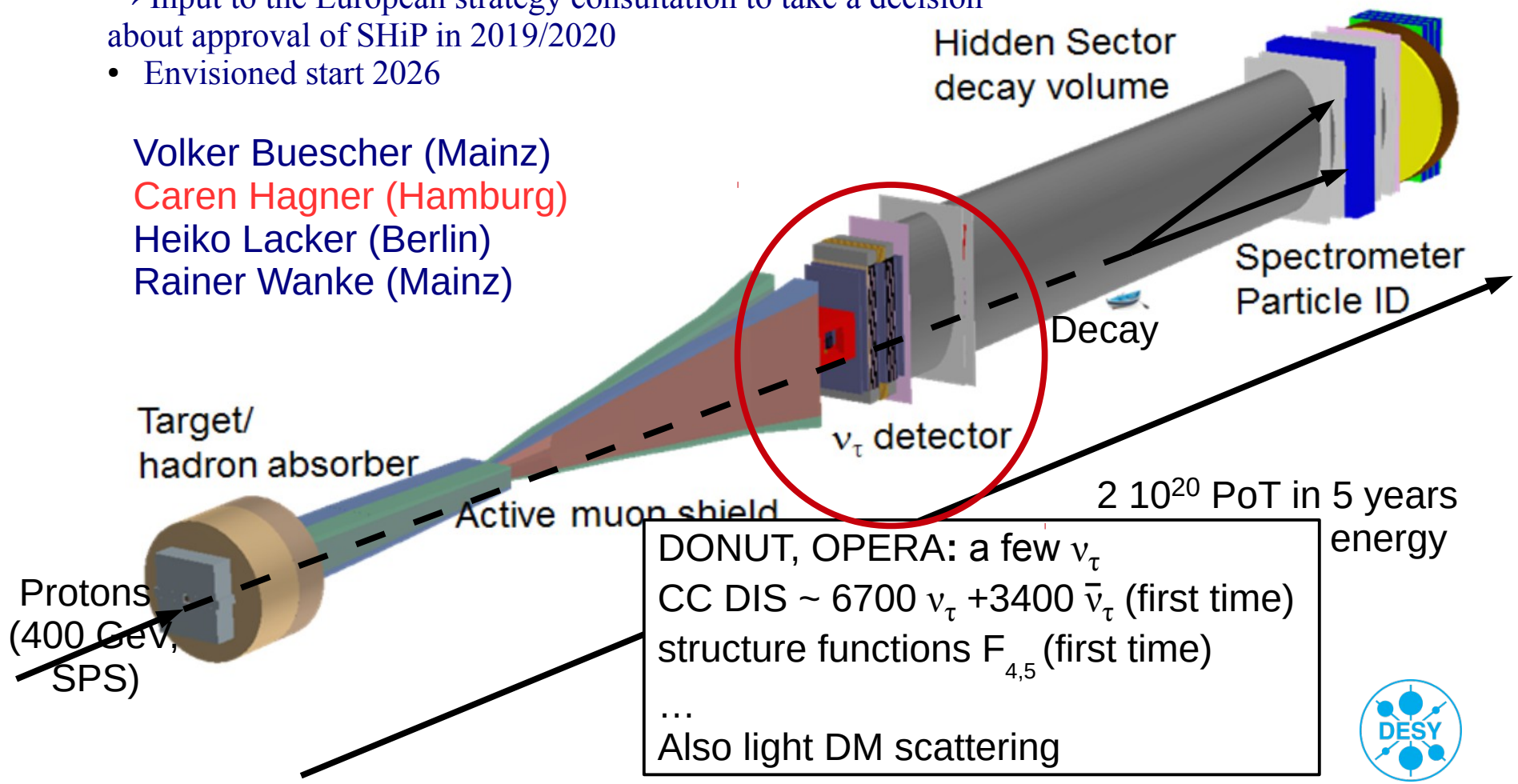


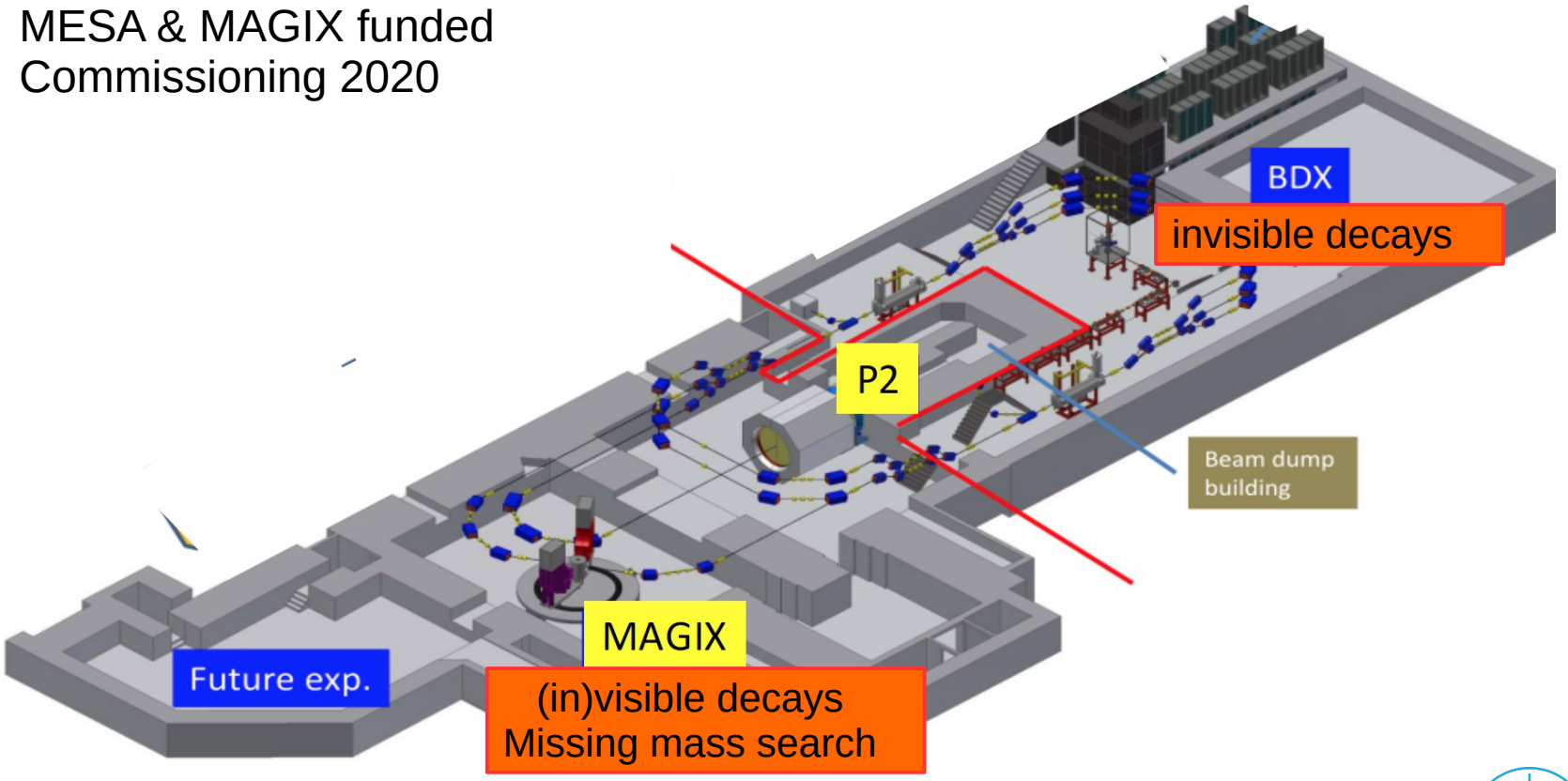
DONUT, OPERA: a few ν_τ
CC DIS ~ 6700 ν_τ +3400 $\bar{\nu}_\tau$ (first time)
structure functions $F_{4,5}$ (first time)
…
Also light DM scattering

MESA – Mainz Energy-Recovering Superconducting Accelerator

Achim Denig (Mainz)

Electrons with Emax = 155 MeV
(below pion threshold – no neutrino background)

MESA & MAGIX funded
Commissioning 2020



Plan: Go through different BSM scenarios at beam-dumps

Portal couplings

$$\mathcal{L} \supset \begin{cases} -\dfrac{\epsilon}{2\cos\theta_W} B_{\mu\nu} F'^{\mu\nu} , & \text{vector portal} \\ (\mu\phi + \lambda\phi^2) H^\dagger H , & \text{Higgs portal} \\ y_n L H N , & \text{neutrino portal} \\ \frac{a}{f_a} F_{\mu\nu} \widetilde{F}^{\mu\nu} , & \text{axion portal.} \end{cases}$$

Dim 4

Dim 5

- dark photons
- scalar and pseudoscalar mediators
- Heavy neutral leptons
- ALPs
- Other scenarios (SUSY...)
- A few words on German contributions

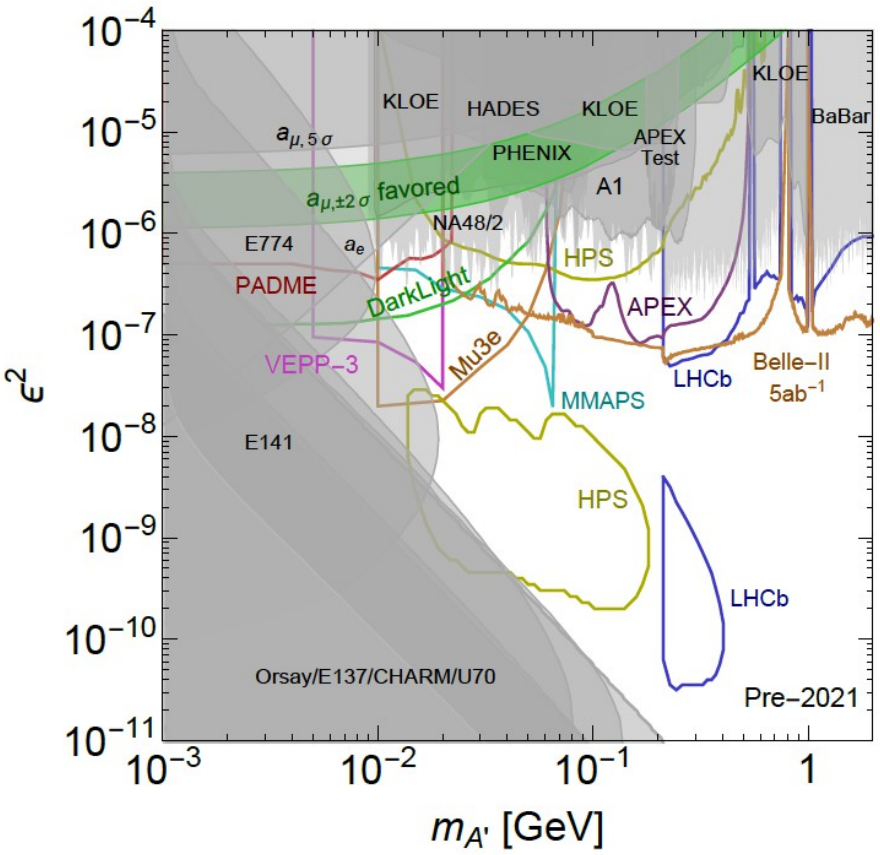
Hidden photons

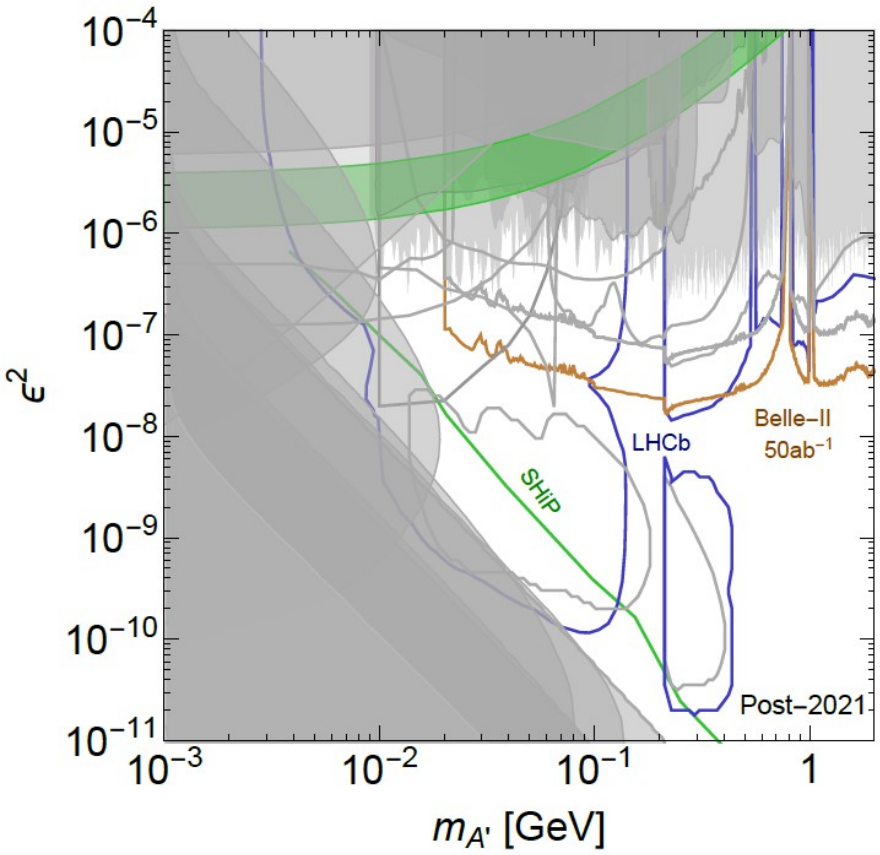
- Extra U(1)s appear in many BSM constructions
- could couple to the SM via mixing (kinetic or mass mixing) or with direct couplings (but anomalies…).
- Kinetic mixing: Photon-like couplings for light A' (Decay to ee, μμ, ππ, ...)
- Naive estimate for GUTs: $\epsilon \sim 10^{-3}$ (10^{-6}) for one (two) loop processes
- A' can mediate DM interactions
- Some additional interest because of $(g-2)_\mu$
- Various production modes depending on environment

Bremsstrahlung: $eZ \rightarrow eZA'$ (or $pZ \rightarrow pZA'$)	electron/proton beam dump
Annihilation: $ee \rightarrow \gamma A'$	electron beam dump
Drell-Yan: $qq \rightarrow A'$	proton beam dump
Meson decay: $\pi \rightarrow \gamma A'$ etc	proton beam dump

Hidden photons

- $m_A < 2\, m_{DM}$: visible decays.





- (g-2) excluded for kinetic mixing

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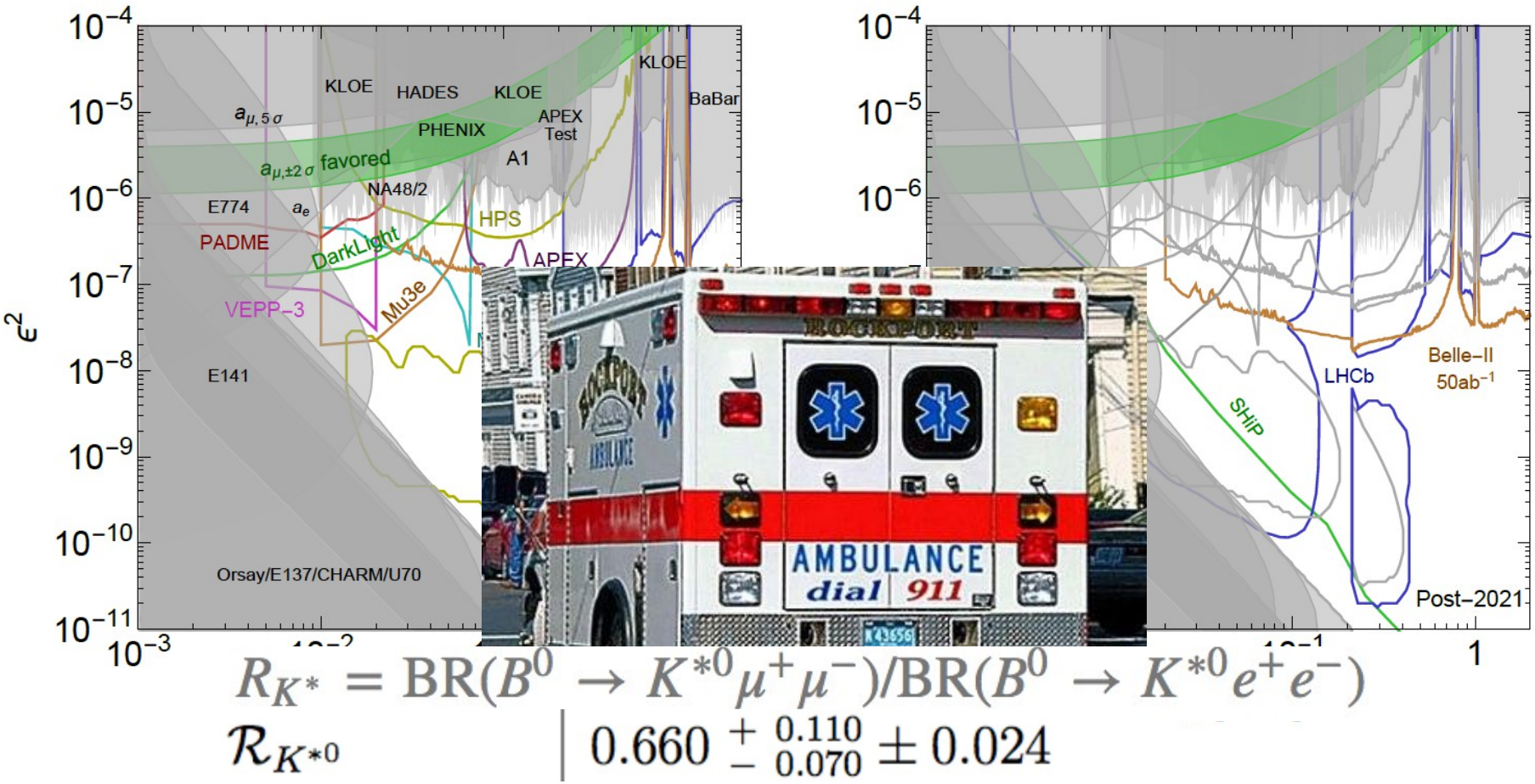

$$R_{K^*} = \mathrm{BR}(B^0 \to K^{*0}\mu^+\mu^-)/\mathrm{BR}(B^0 \to K^{*0}e^+e^-)$$

$$\mathcal{R}_{K^{*0}} \quad \left| \quad 0.660\ ^{+\ 0.110}_{-\ 0.070} \pm 0.024 \right.$$

- (g-2) - muonic dark forces less constrained.

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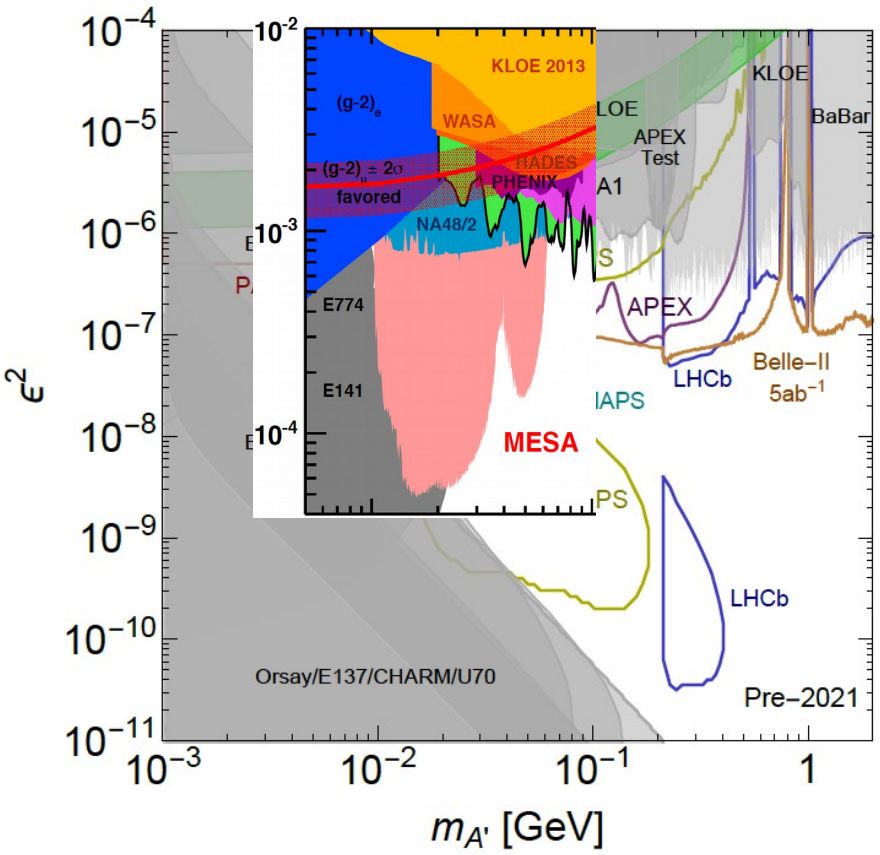

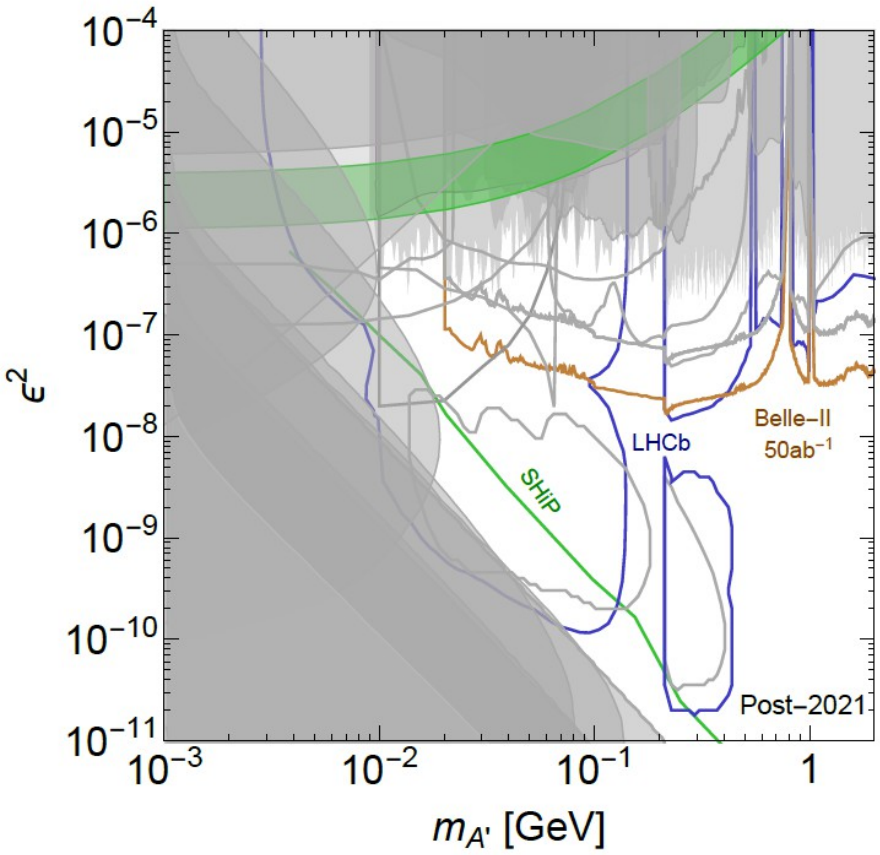

- MESA reach

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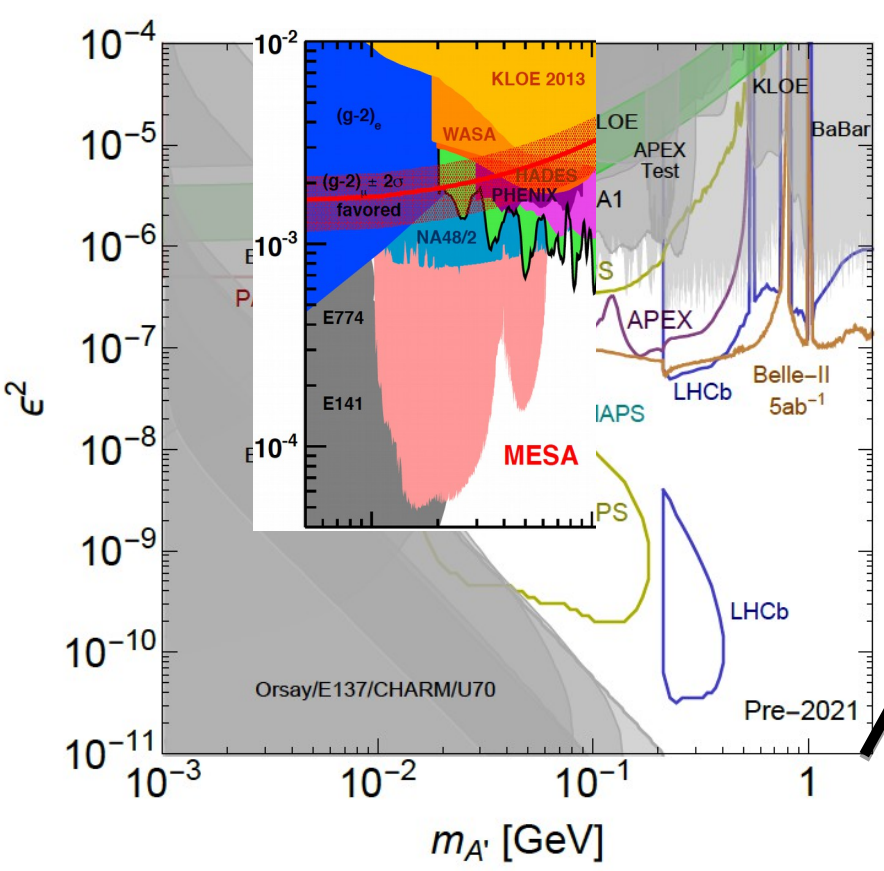
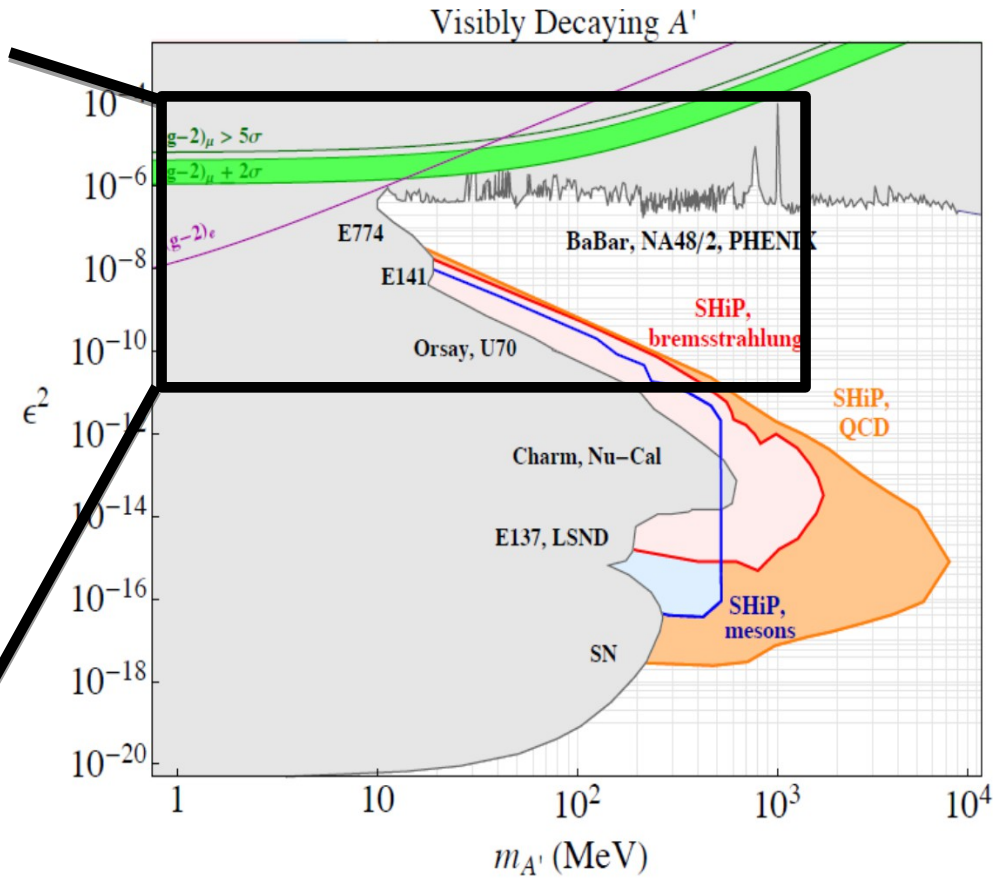
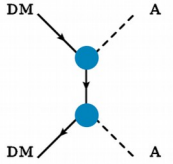




- SHiP in very different region of parameter space compared to all others

How low should we probe? no 'thermal target' as relic is set by α_D



Hidden photons

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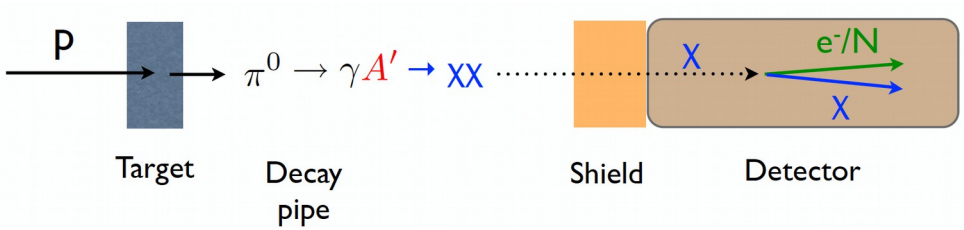
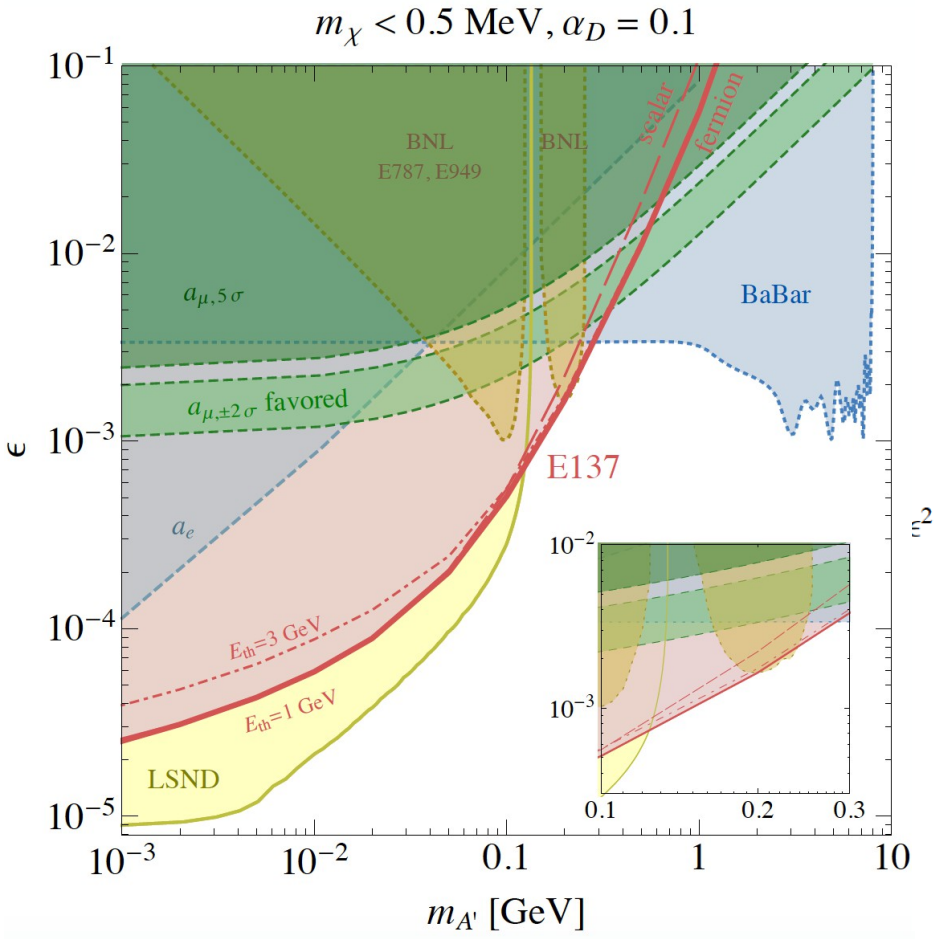
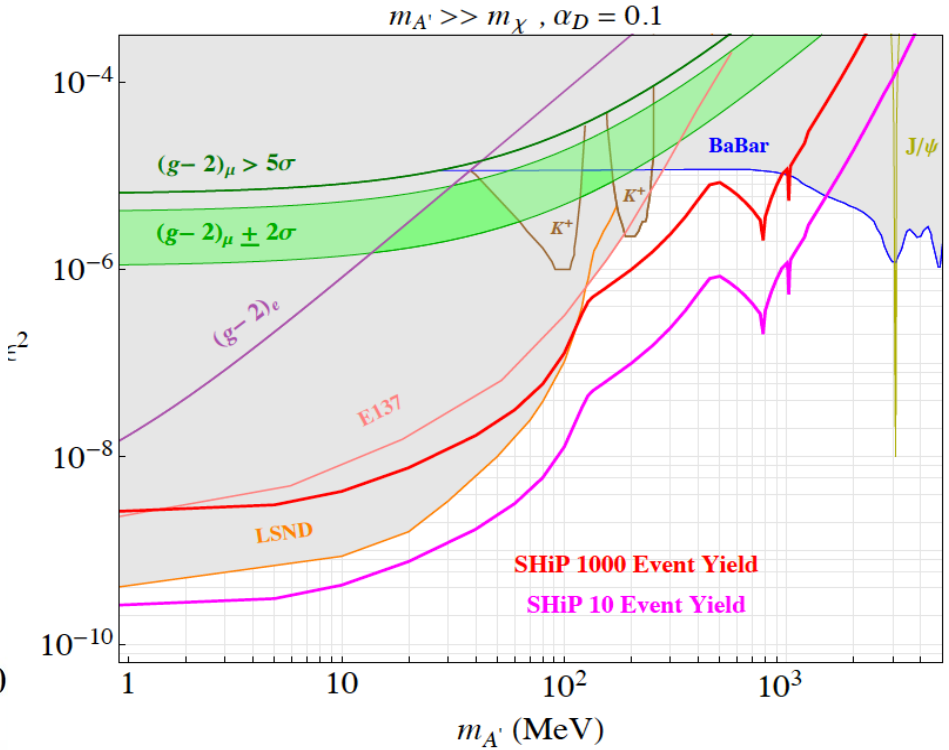
bounds depend a bit on α_D, (g-2) still possible







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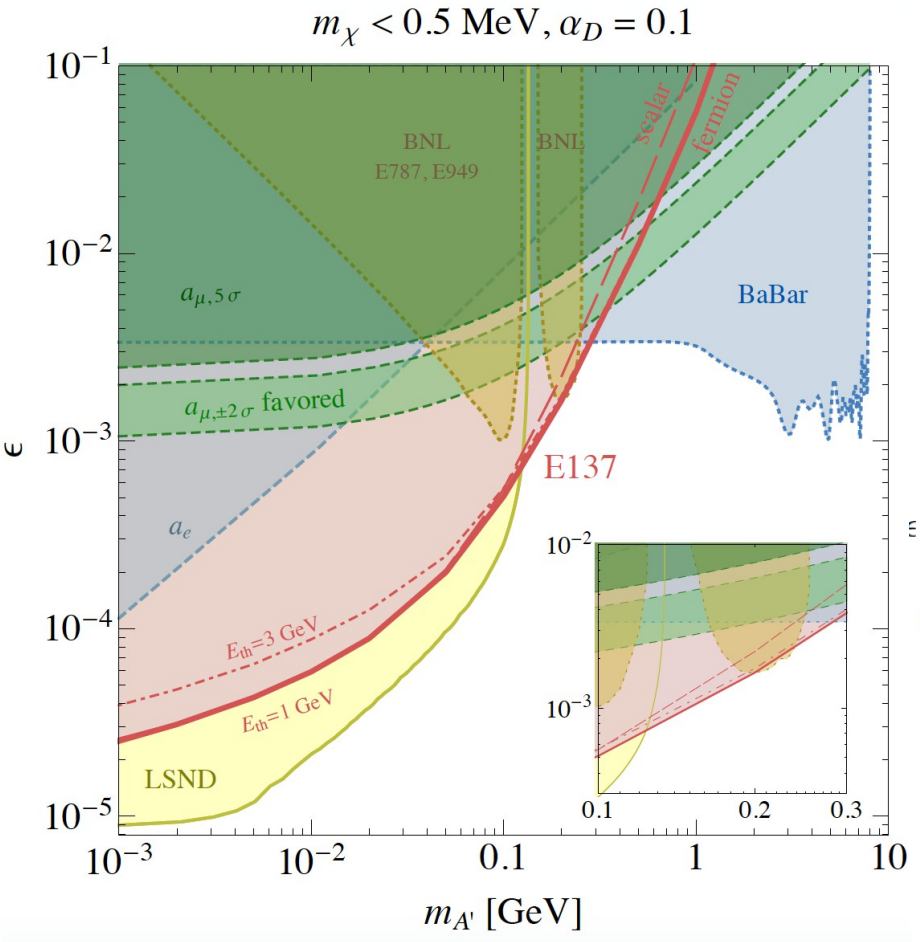

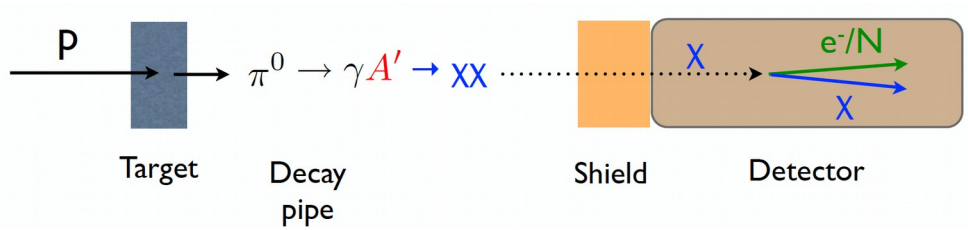

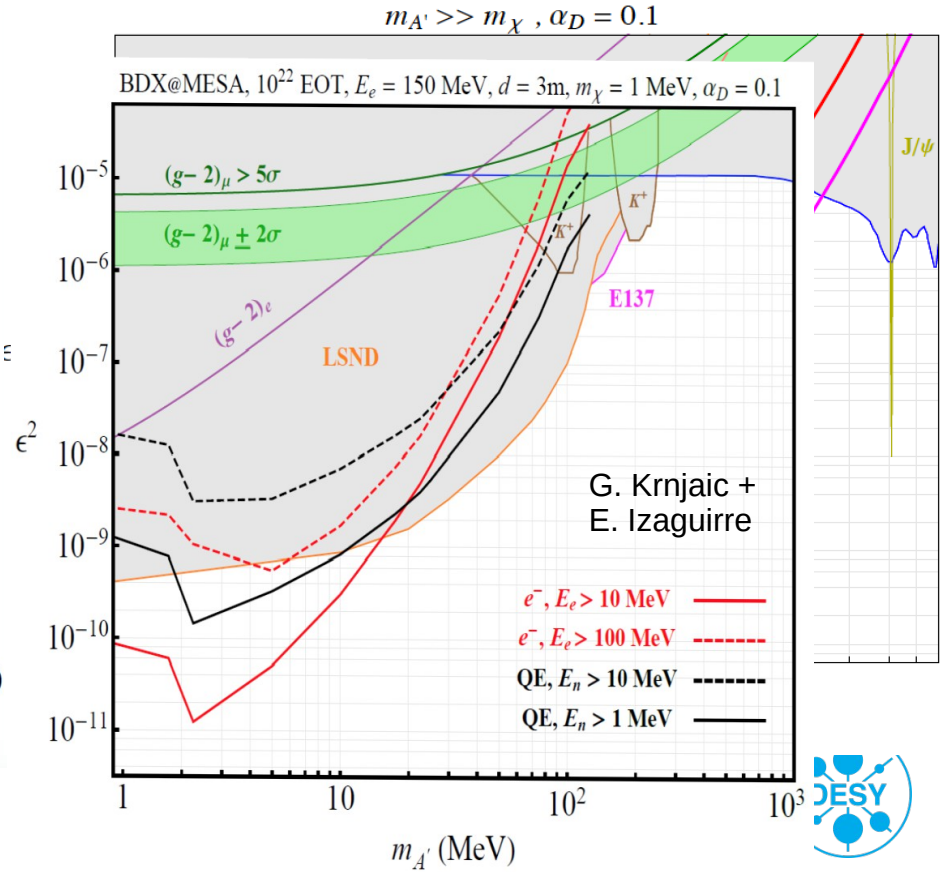

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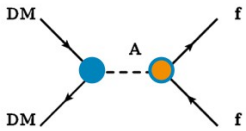

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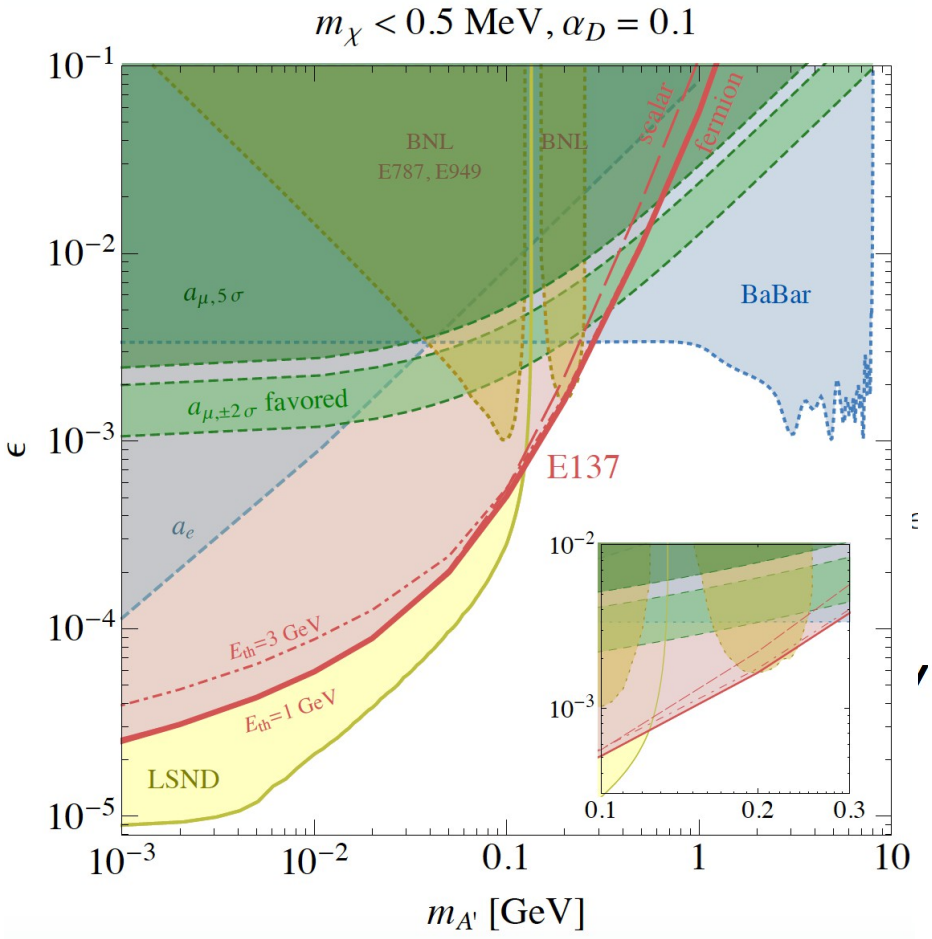
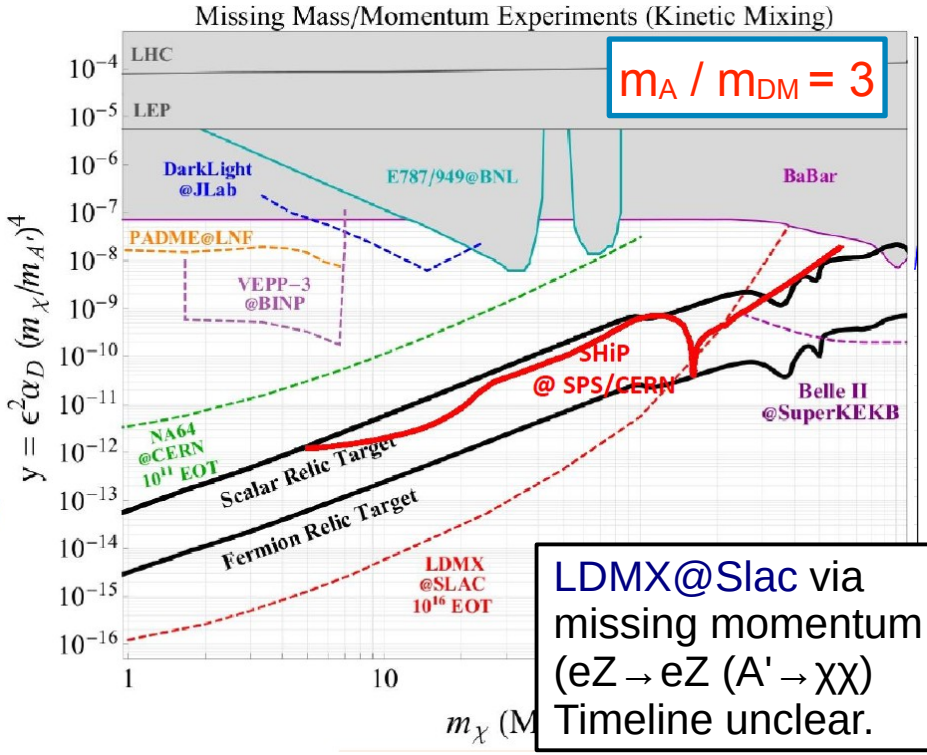


Can achieve thermal relic density for scalar DM

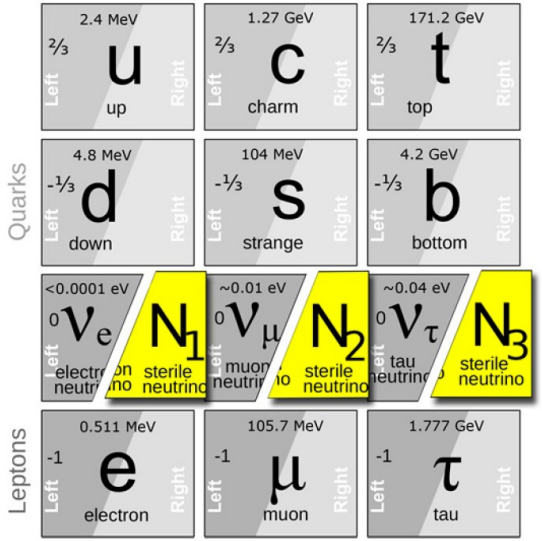
$$\frac{\alpha g_D^2\,\epsilon^2}{4\pi}\left(\frac{m_\chi}{m_{A'}}\right)^4 \gtrsim \langle\sigma v\rangle_{\rm relic}\, m_\chi^2$$



LDMX@Slac via missing momentum ($eZ \rightarrow eZ\,(A' \rightarrow \chi\chi)$) Timeline unclear.

Heavy neutral leptons

- Simple model which can account for dark matter, baryogengesis and inflation? (ask A Ringwald for SM*A*S*H)
- Different models. Prominent example

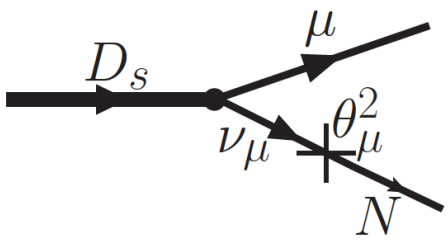


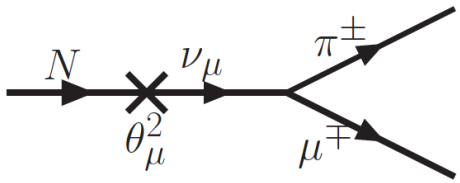
νMSM: T.Asaka, M.Shaposhnikov (2005)

Neutrino masses via seesaw
N_1 (O(keV) mass) as Dark Matter
$N_{2,3}$ (O(GeV mass) generate Neutrino masses and η

Higgs-inflation

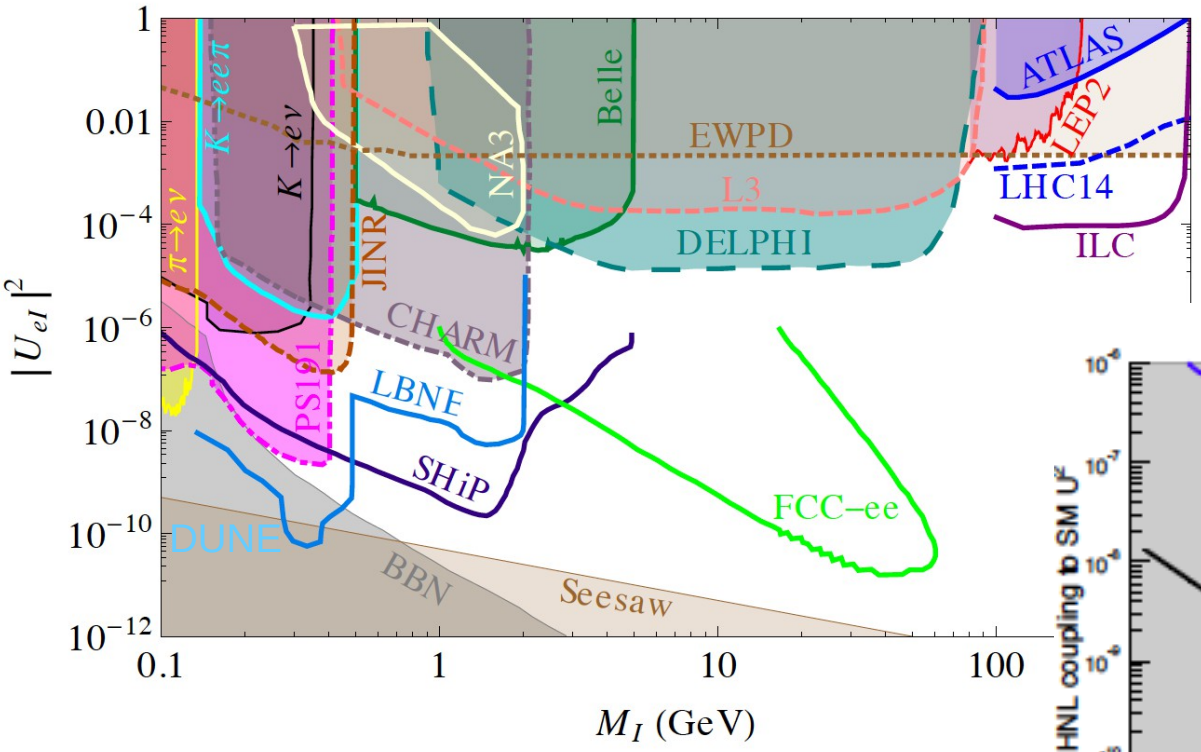
- Production via mixing with active neutrinos

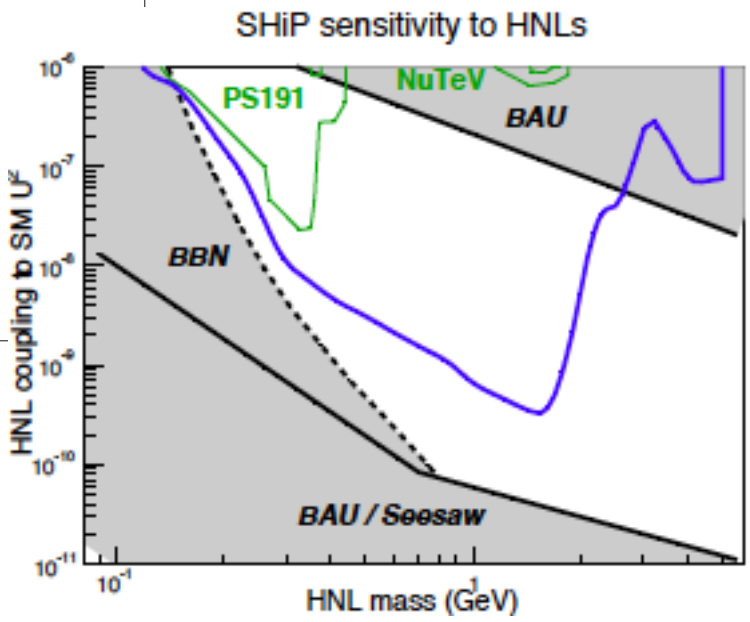




Heavy neutral leptons

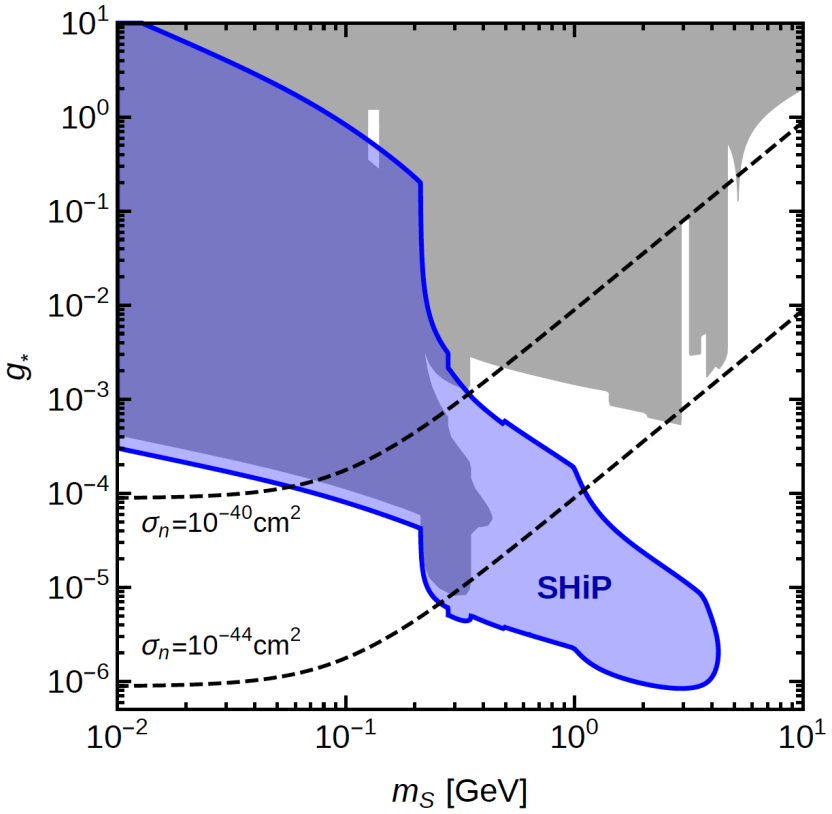
- Parameter space

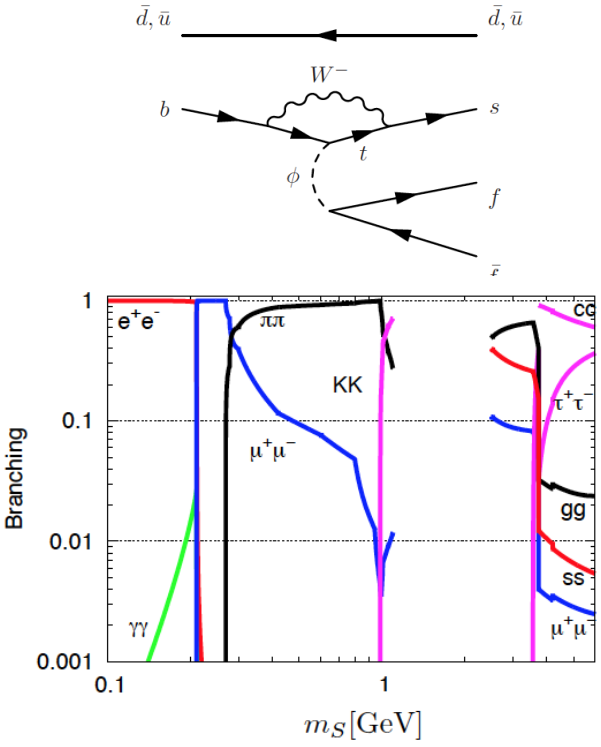




Scalar mediator

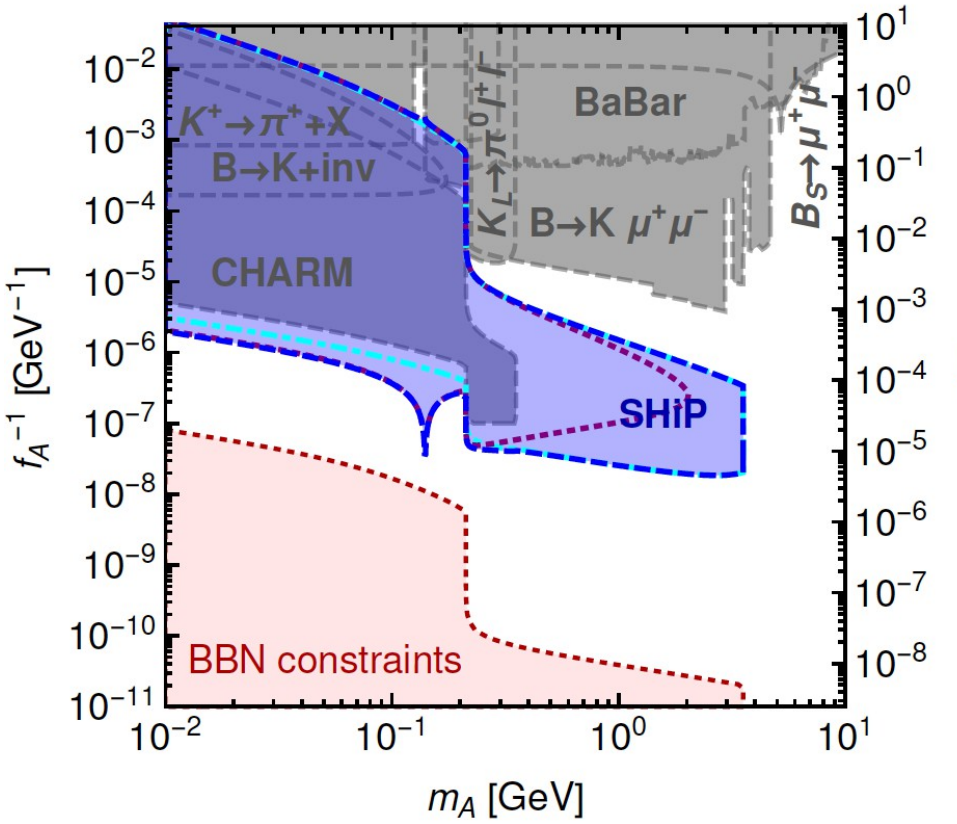
- Scalar mediators naturally present in extended Higgs sectors with singlets → typically Yukawa-like coupling structure
- Strong constraints from DM direct detection experiments
- No indirect detection (p-wave)



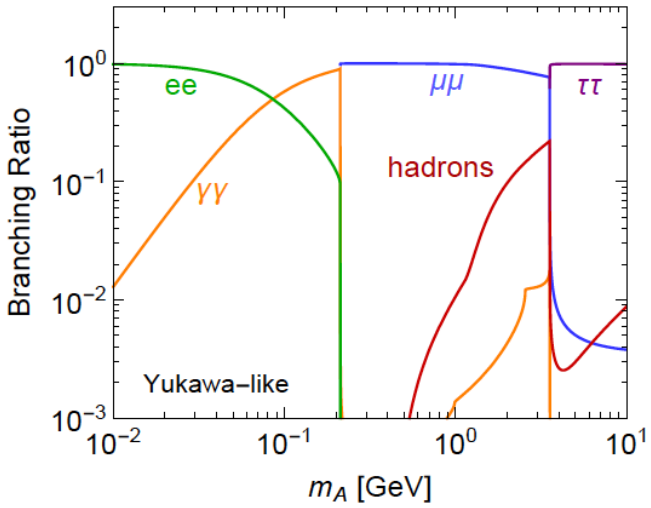


Pseudoscalar mediator

- Pseudoscalar mediators naturally present in extended Higgs sectors with singlets
- No constraints from DM direct detection experiments
- Indirect detection (s-wave, 'Coy DM')



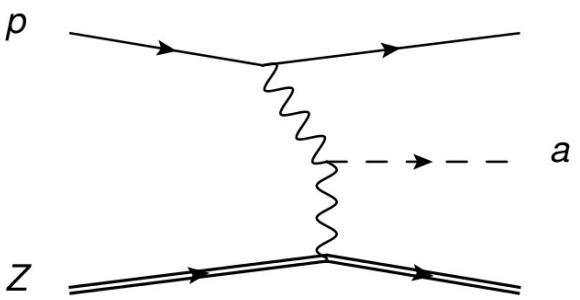
- B → K A is UV sensitive
- Mixing with pions

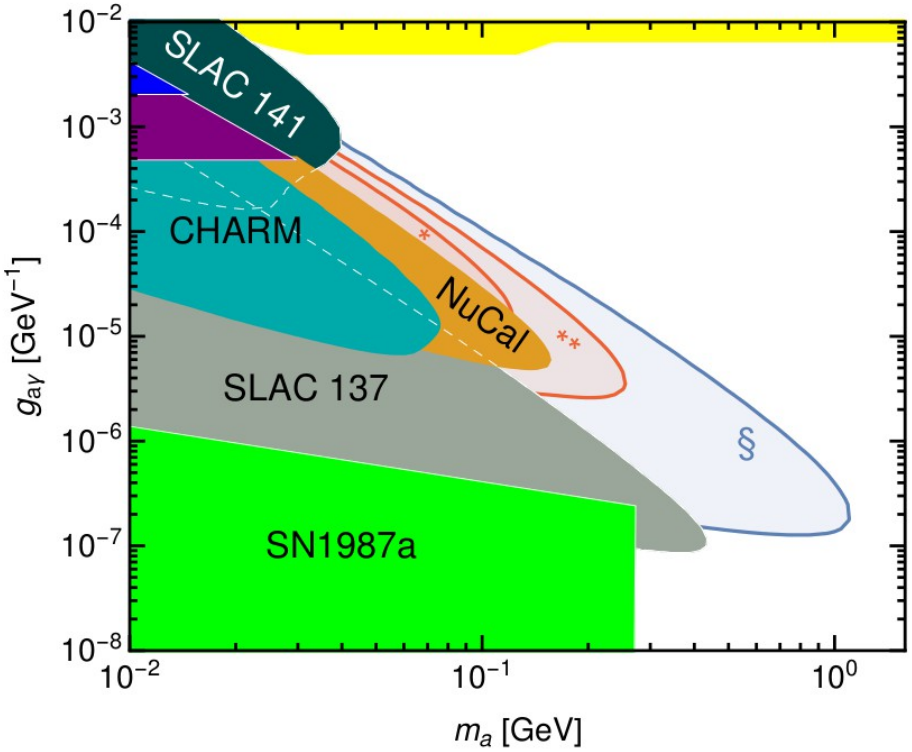


Pseudoscalar mediator (ALPs): photon couplings

- ALPs with dominant couplings to photons

$$-\frac{1}{4}\, g_{a\gamma}\, a\, F^{\mu\nu}\tilde{F}_{\mu\nu}$$

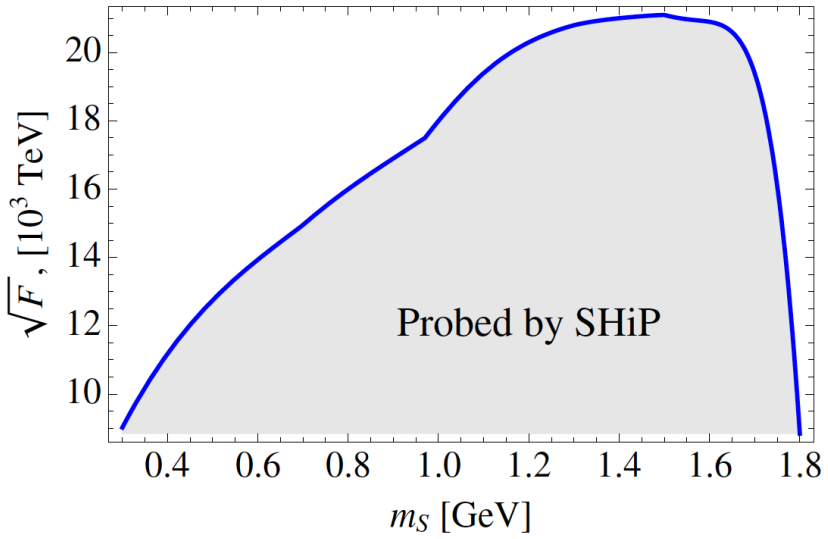




Photon fusion:
ALP production cross section is enhanced proportional to Z^2

Other scenarios (SUSY...)

- Light weakly coupled particles also possible within SUSY (despite prejudice of heavy SUSY from minimal (C)MSSM)
- Light neutralinos possible, similar to HNL for R-parity violation
- Superpartners of axion (axino, saxion), similar to (neutralino, ALPs)
- Fields from the SUSY breaking sector (sgoldstino), g ~ 1/F
- ...

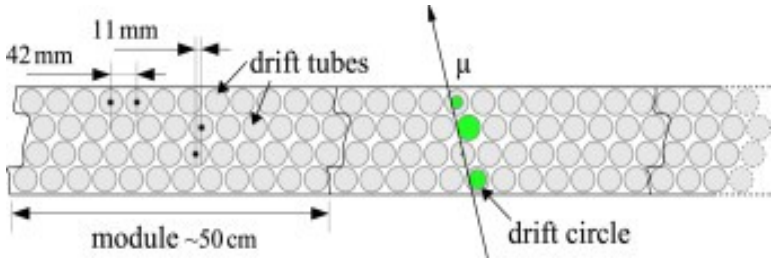


German contributions: Tracker

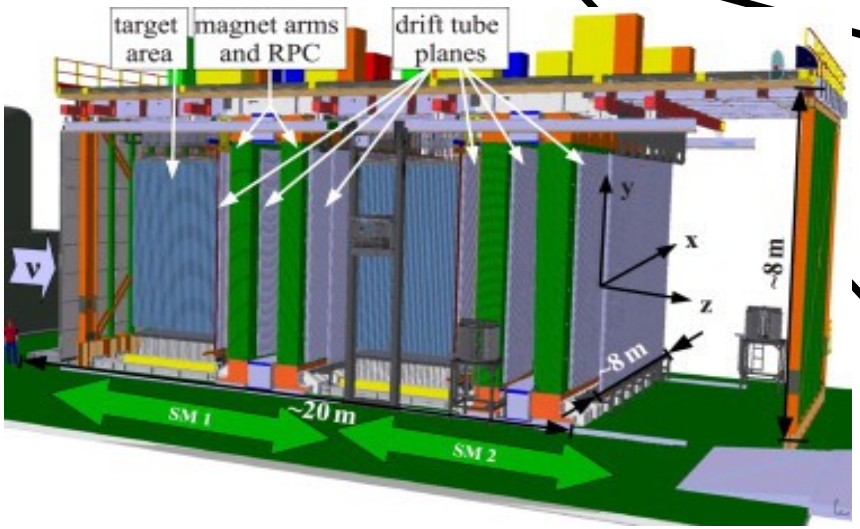
Slide by Heiko Lacker

Muon reconstruction for ν_τ detector

Track reconstruction in spectrometer



Hamburg (OPERA, drift tubes)



Straw tracker

Hidden Sector decay volume

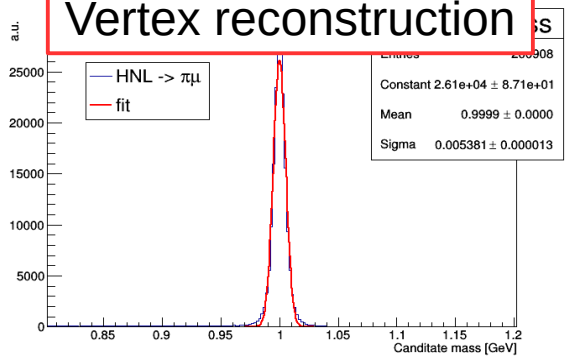
muon tracker

Decay

Spectrometer Particle ID

Berlin

Vertex reconstruction



Target/ hadron absorber

Active muon shield

ν_τ detector

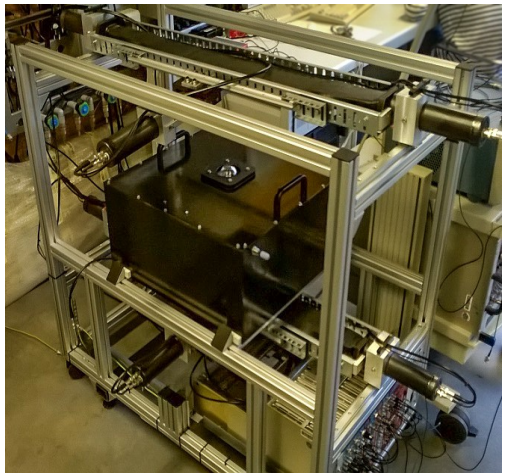
Protons (SPS)

Surround Background Tagger (liquid scintillator)

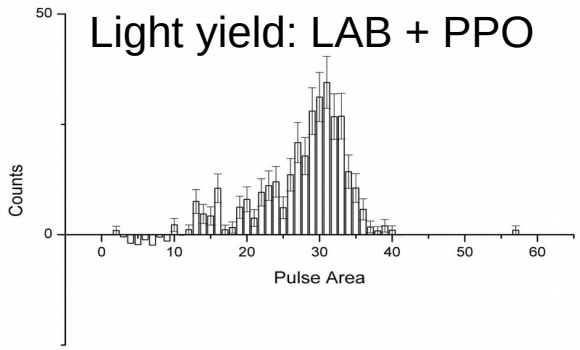
Slide by Heiko Lacker

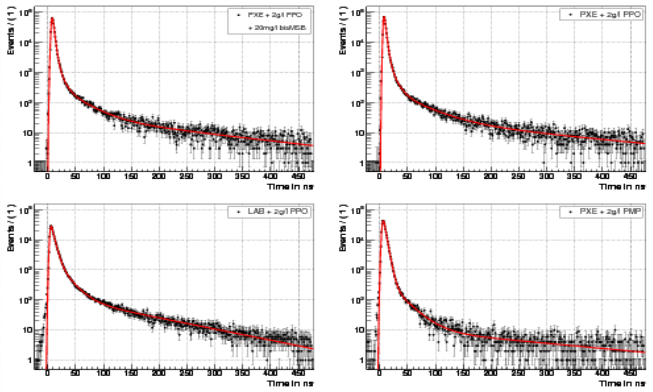
Detection of BG reactions of ν/μ in the walls/surroundings of the decay volume

HU Berlin: Wavelength-Shifting OMs (R&D: DFG funded)



JGU Mainz: liquid scintillator (Borexino, Double Chooz, LENA)



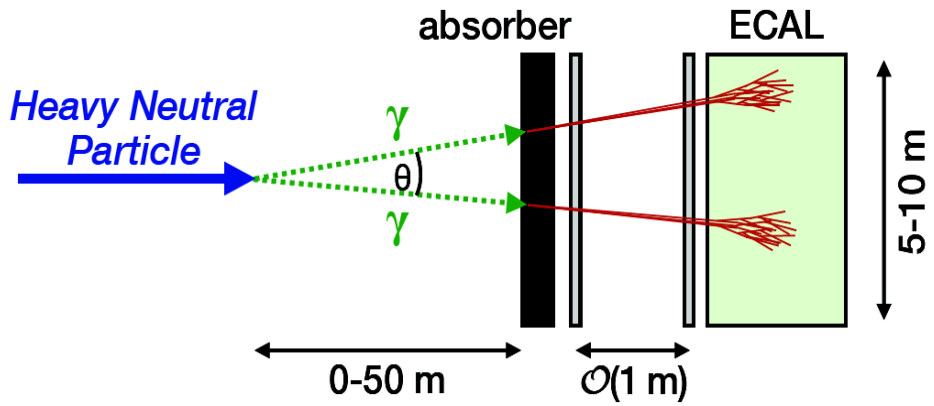


Calorimeter

Slide by Heiko Lacker

Challenge: mass reconstruction of $\gamma\gamma$ final state w/o a-priori knowledge of vertex

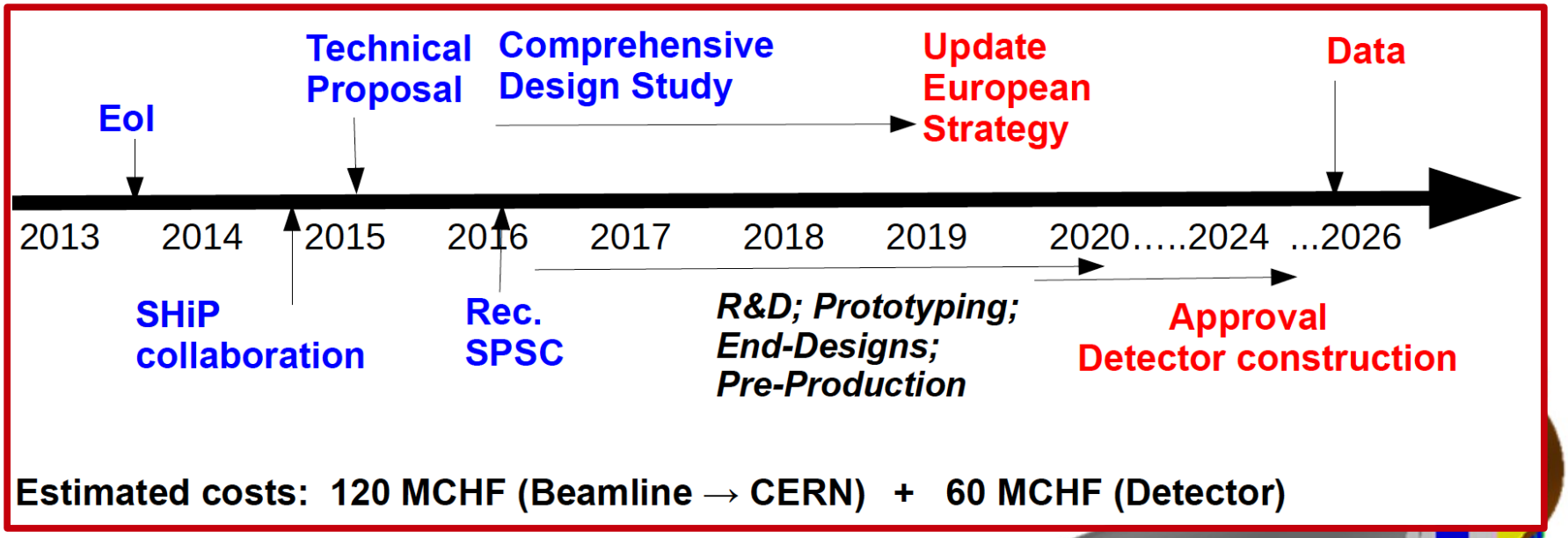
JGU Mainz: pointing calorimeter design

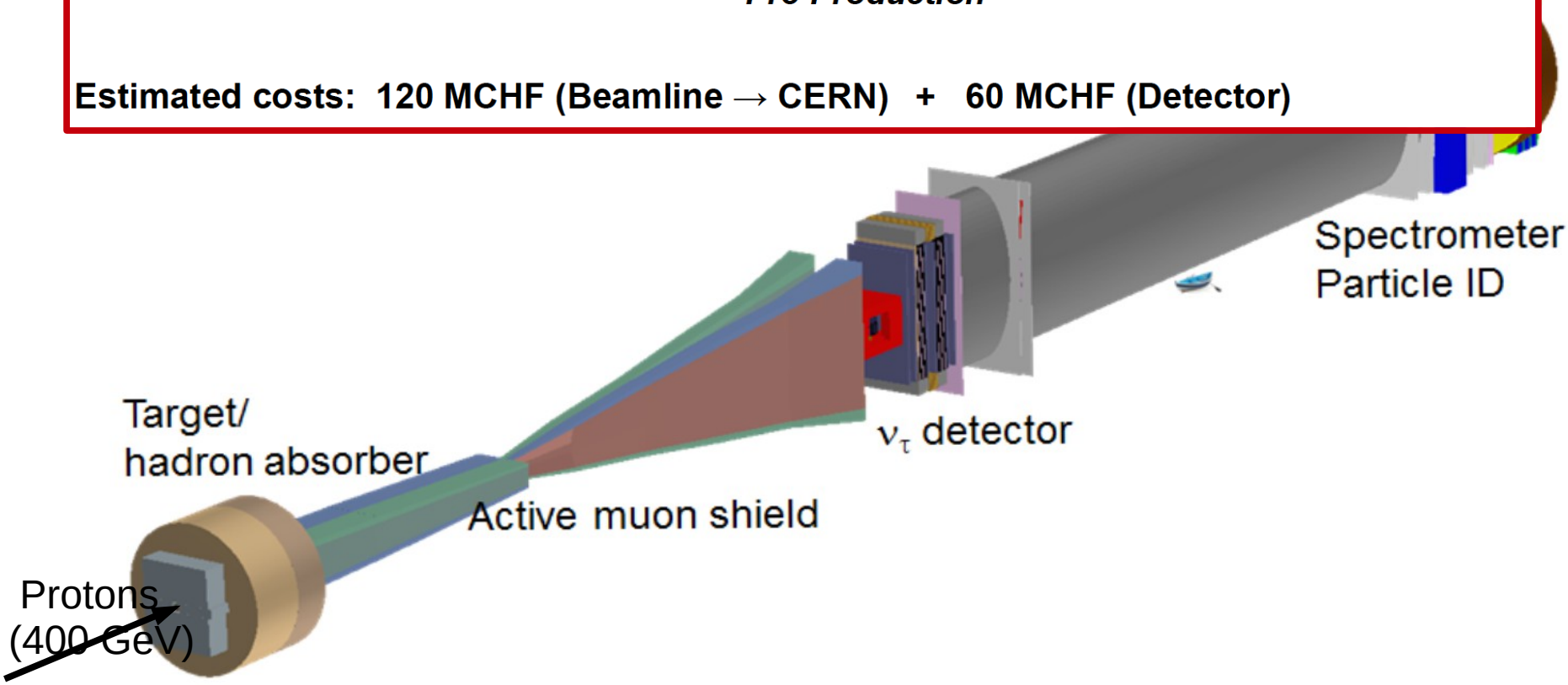


Expertise: Calorimetry (NA62)
Micromegas (ATLAS muon system)

Timeline

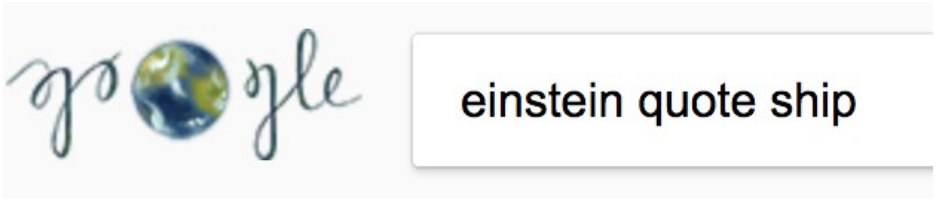
Slide by Heiko Lacker





Summary

- Overall beam dump experiments can significantly contribute to a variety of hidden sector searches and explore large regions of otherwise uncovered parameter space.
- In particular the SHiP experiment has unique potential and is very diverse



A SHiP is always safe at the shore - but that is NOT what it is built for.

- A Einstein