SHiP Experiment

Forum talk

April 20, 2016

SHiP
Search for Hidden Particles

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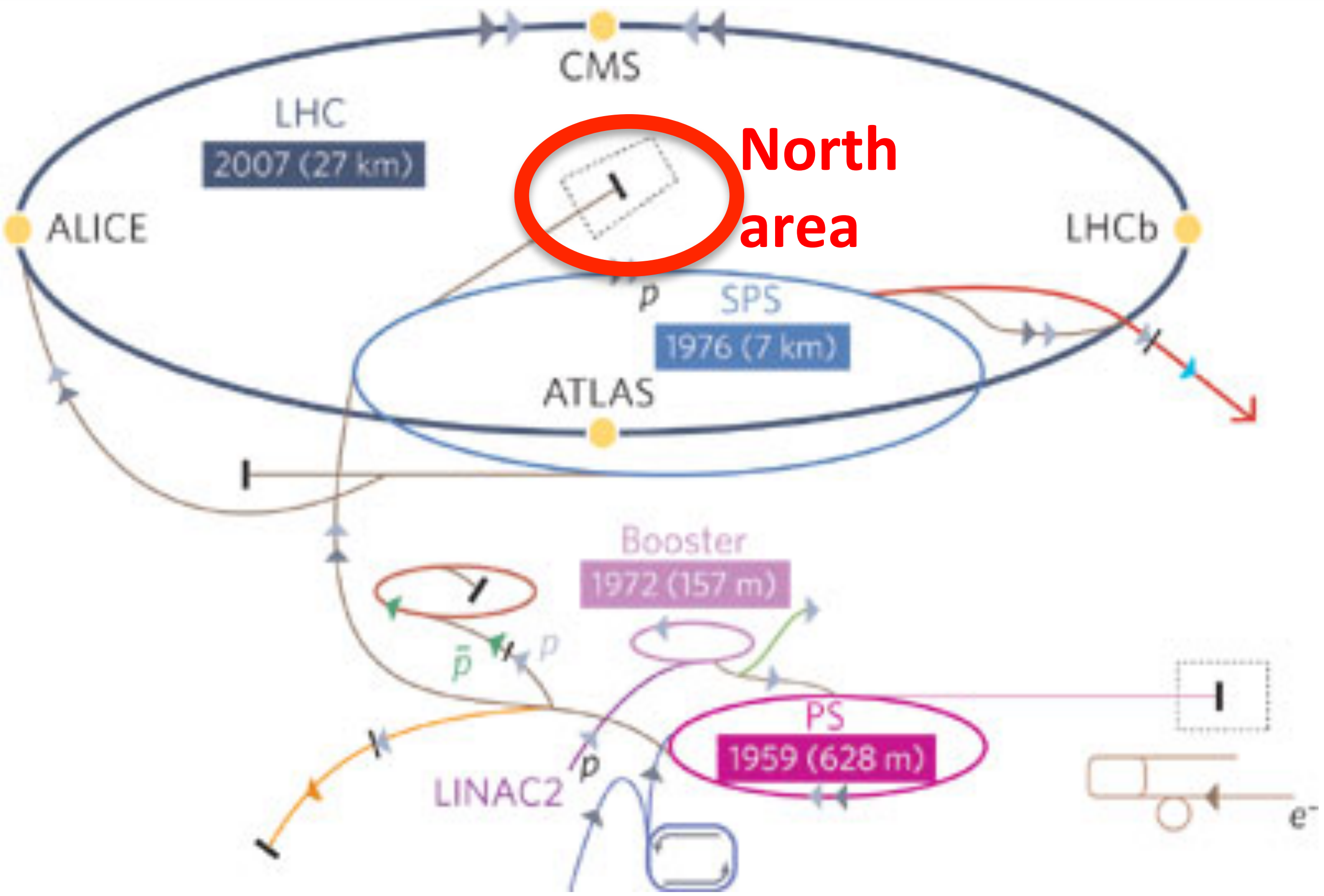
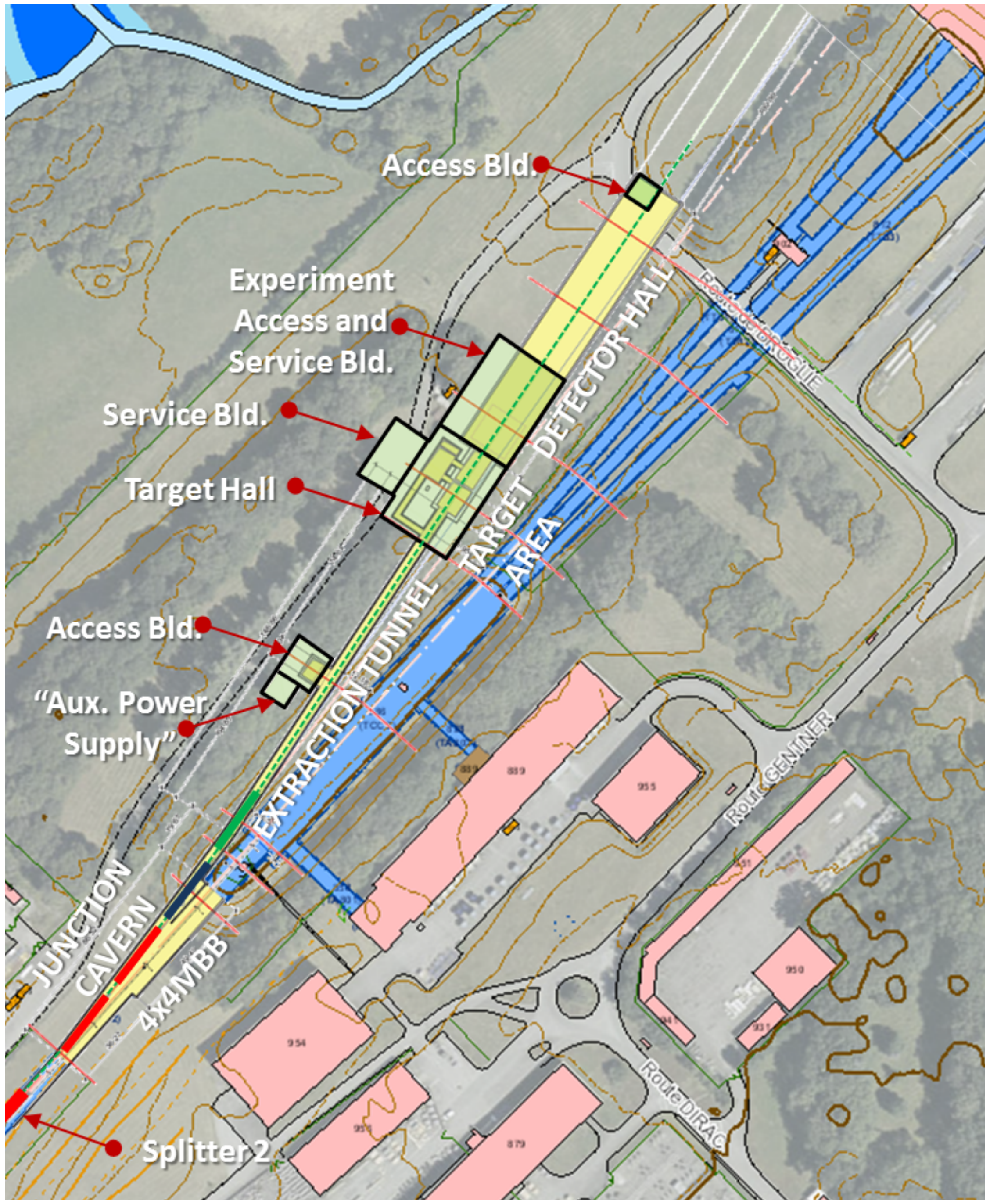
Proposal for a new facility at the SPS



G. Conti @ Blois '15



- **400 GeV protons** from SPS, E_{CM}=27 GeV

Spill = 4x10^{13} protons on target per **cycle** of 7.2s with **slow beam extraction** (1s)

reduces **detector occupancy**, hence combinatorial background

reduces **heat load of the target**

- **4x10^{19}** protons on target per year (~200 days of running)

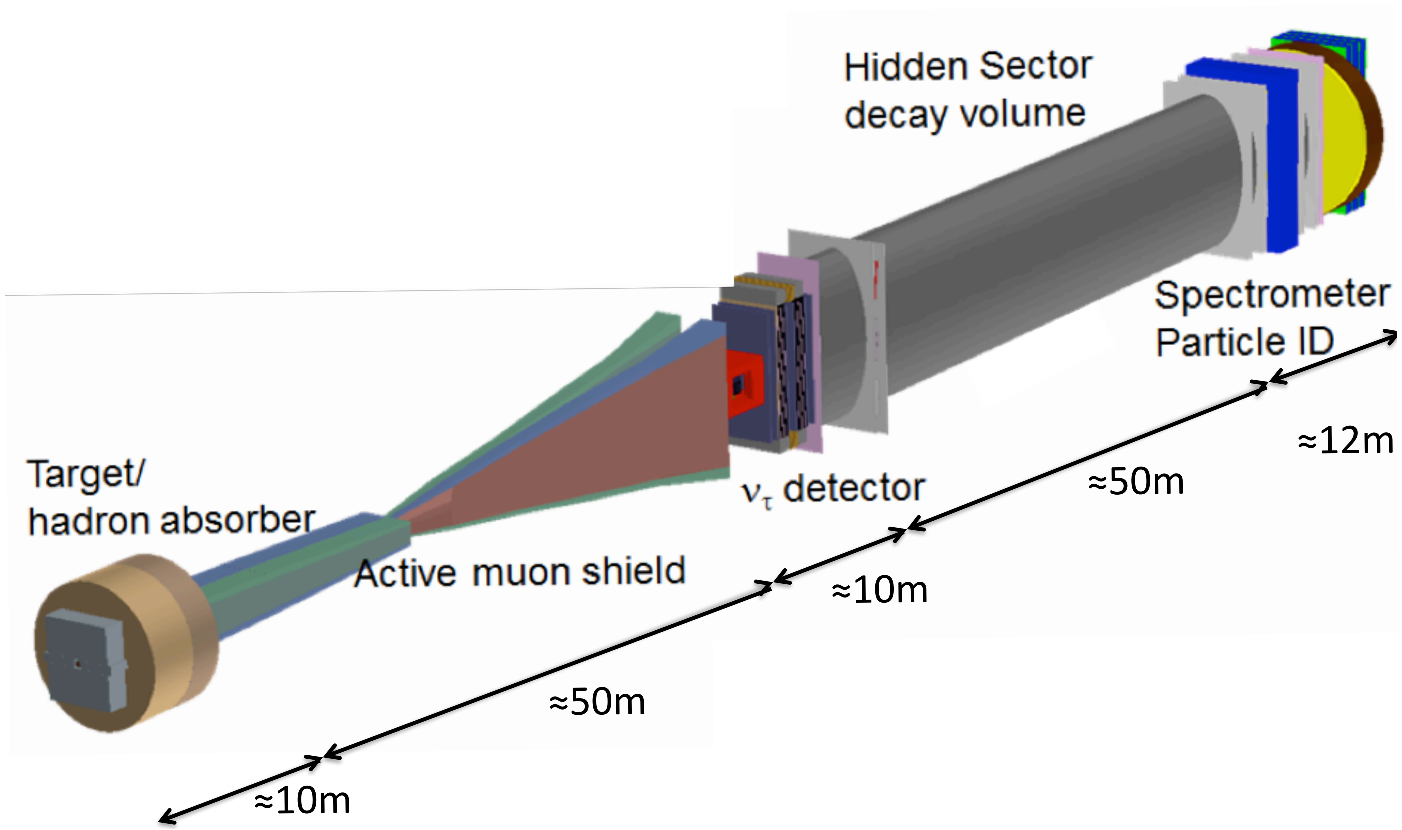
2x10^{20}p over 5/10 years

SHiP: Searching for Hidden Particles

beam dump experiment:

400 GeV CERN SPS protons on fixed target

$\sqrt{s}$~27 GeV 2x10^{20} protons over 10 years, i.e. $\mathcal{L} = 10^{39}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$



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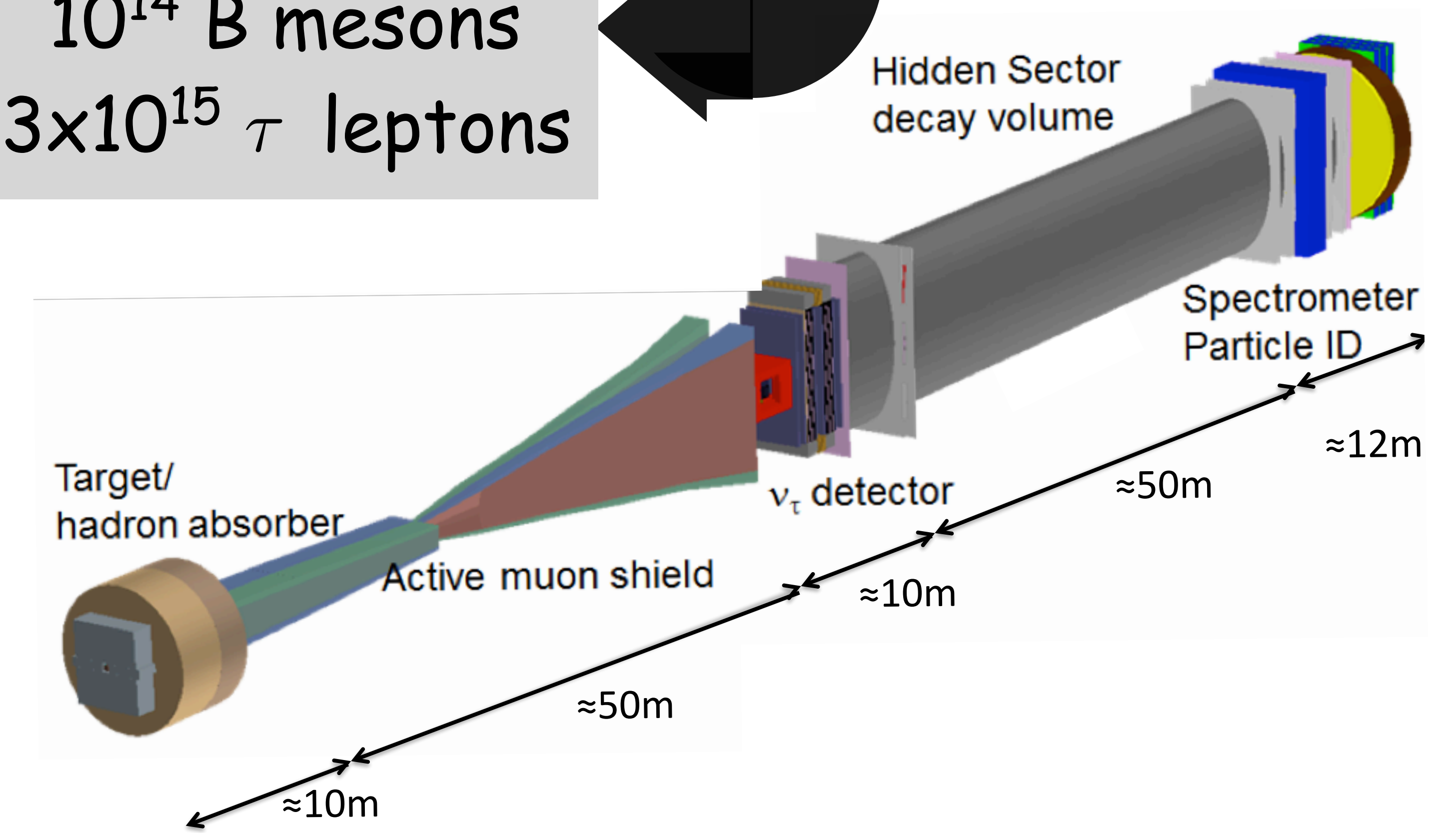
8x10^{17} D mesons
10^{14} B mesons
3x10^{15} τ leptons



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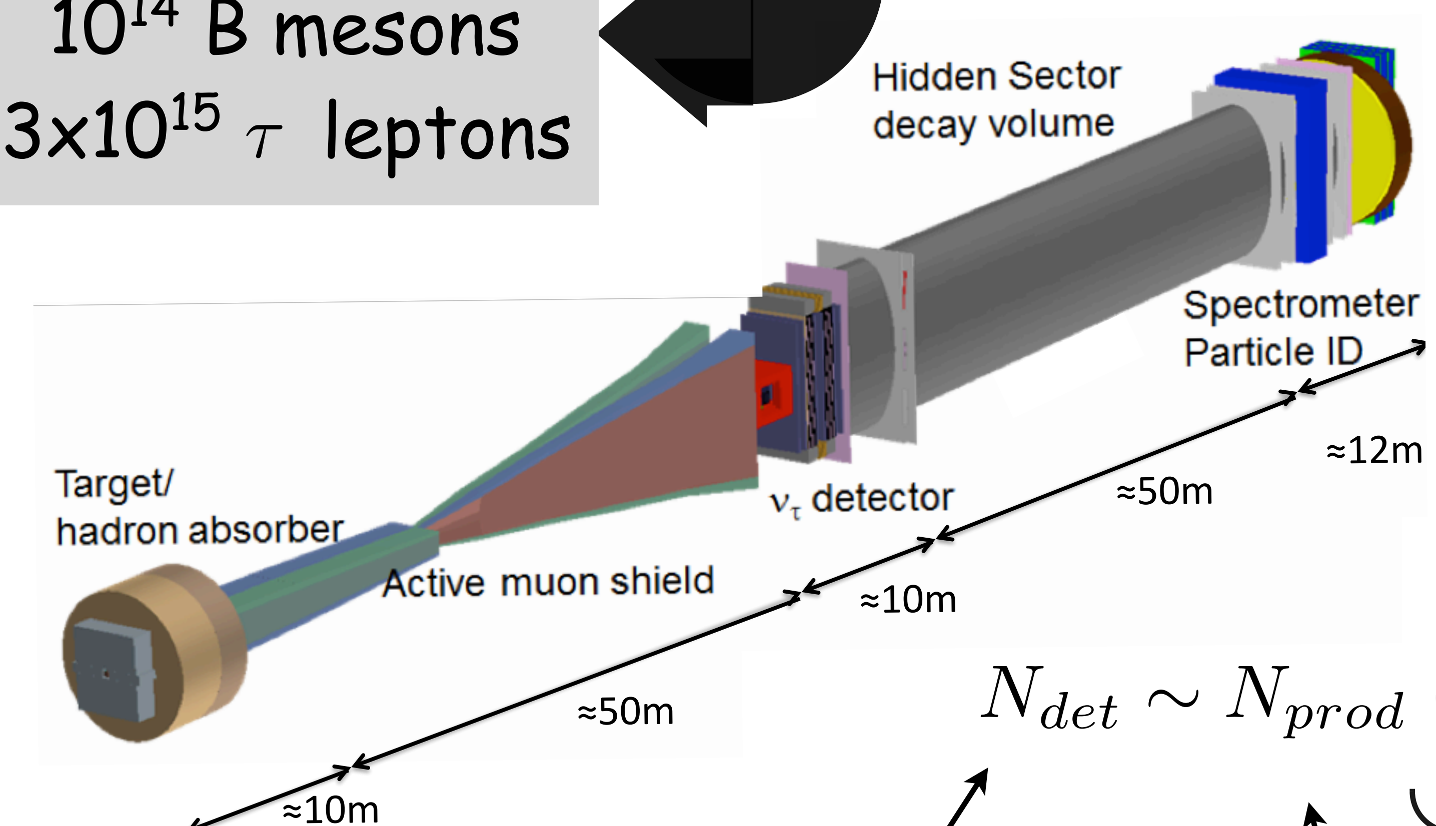
two characteristics

»large distance target-detector: l≈70m

»large detector length: Δl≈50m



$$N_{det} \sim N_{prod} \left(\exp\left(-\frac{l}{\gamma\beta c\tau}\right) - \exp\left(-\frac{l+\Delta l}{\gamma\beta c\tau}\right) \right)$$

particles detected

particles produced

prob. of decay inside the detector

SHiP: Searching for Hidden Particles

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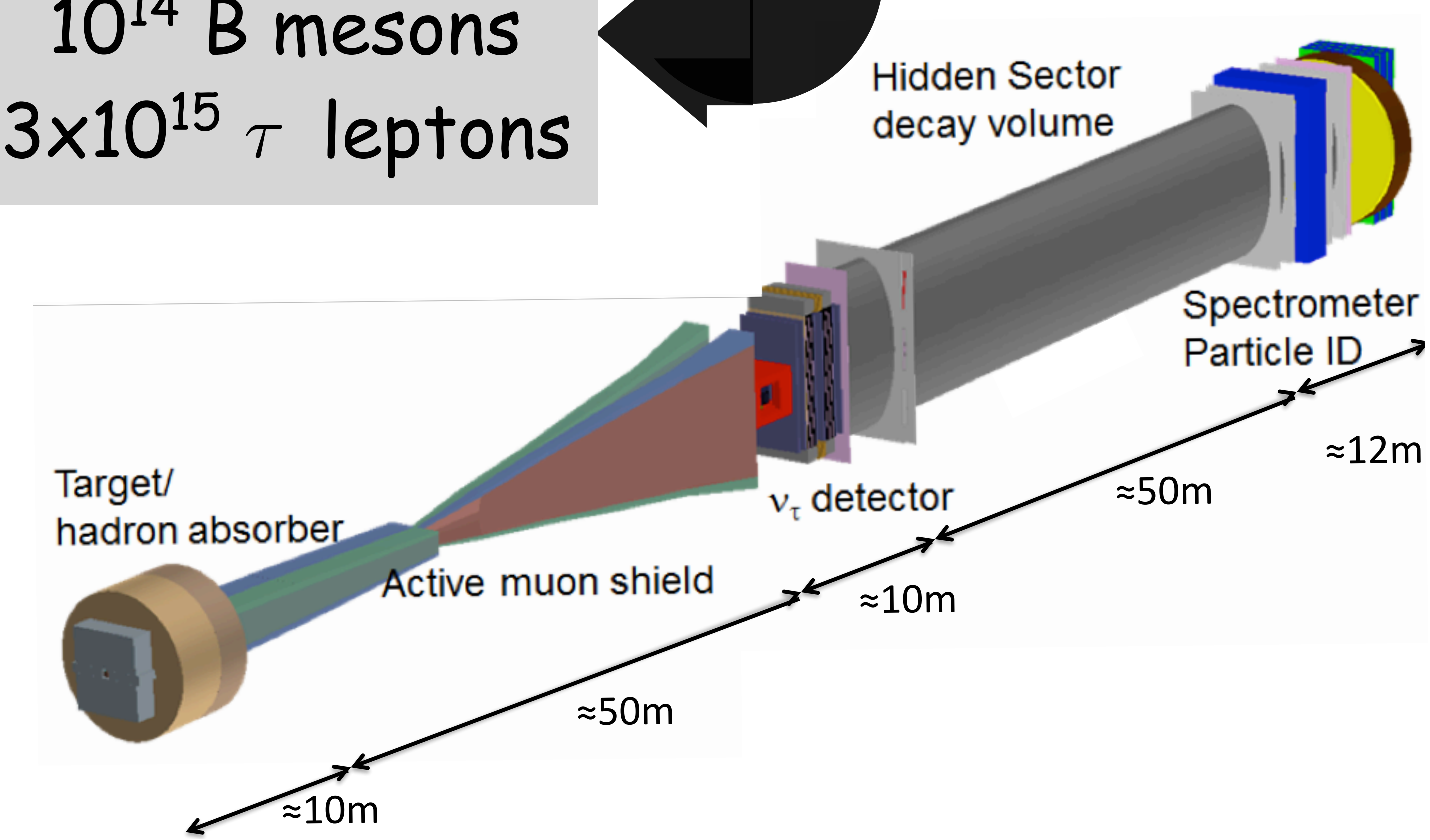

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» **hadron absorber:**
stop all π and K before decay

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sweep muon away from fiducial decay volume

designed as a very low background experiment

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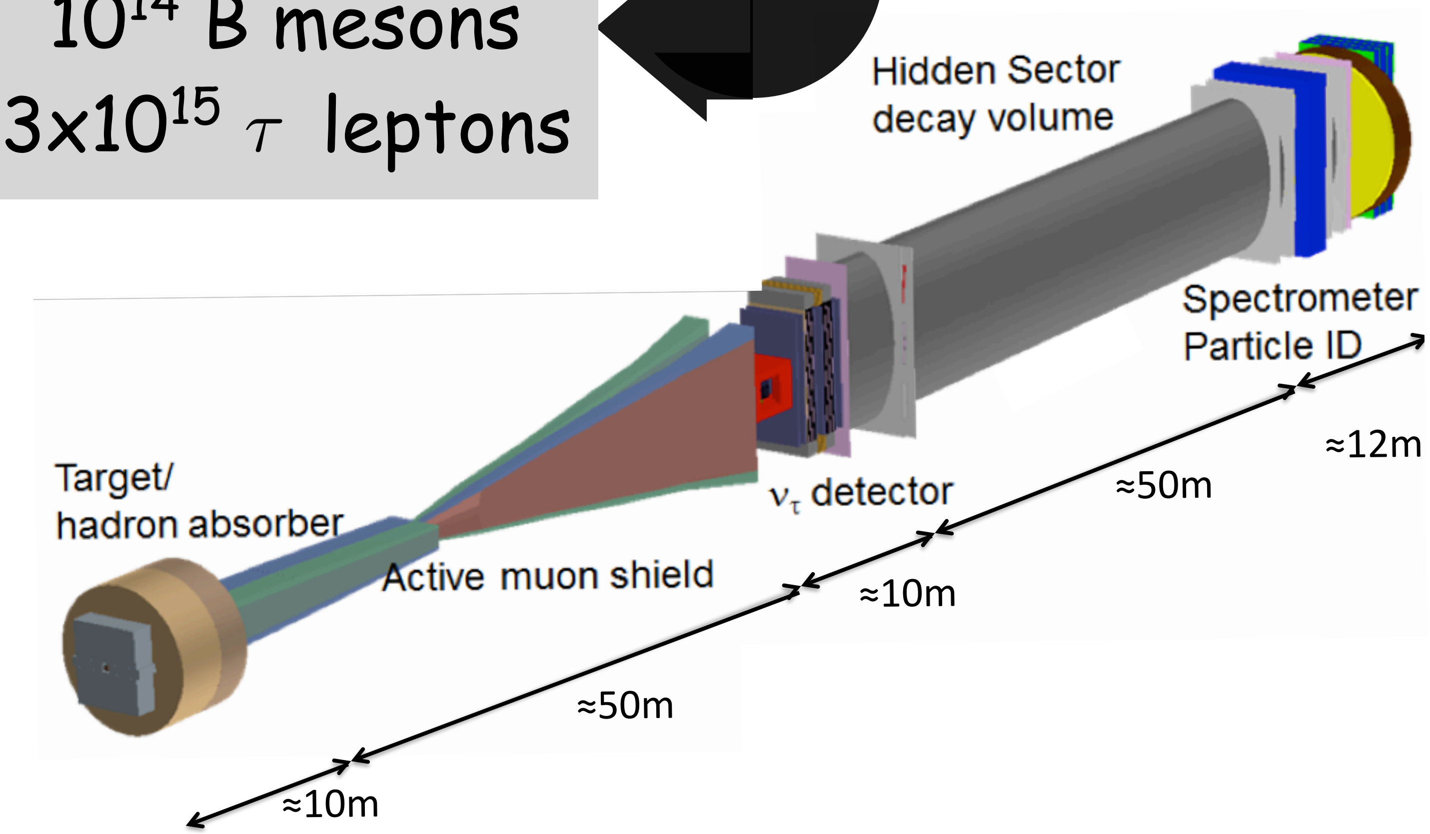

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Search for rare events triggered by light and weakly coupled new particles, e.g. in decays of B and D mesons

designed as a very low background experiment

SHiP & the rest of the world

Experiment	PS191	NuTeV	CHARM	SHiP
Proton energy (GeV)	19.2	800	400	400
Protons on target ($\times 10^{19}$)	0.86	0.25	0.24	20
Decay volume (m^3)	360	1100	315	1780
Decay volume pressure (bar)	1 (He)	1 (He)	1 (air)	10^{-6} (air)
Distance to target (m)	128	1400	480	80-90
Off beam axis (mrad)	40	0	10	0

sterile neutrinos

Higgs portal

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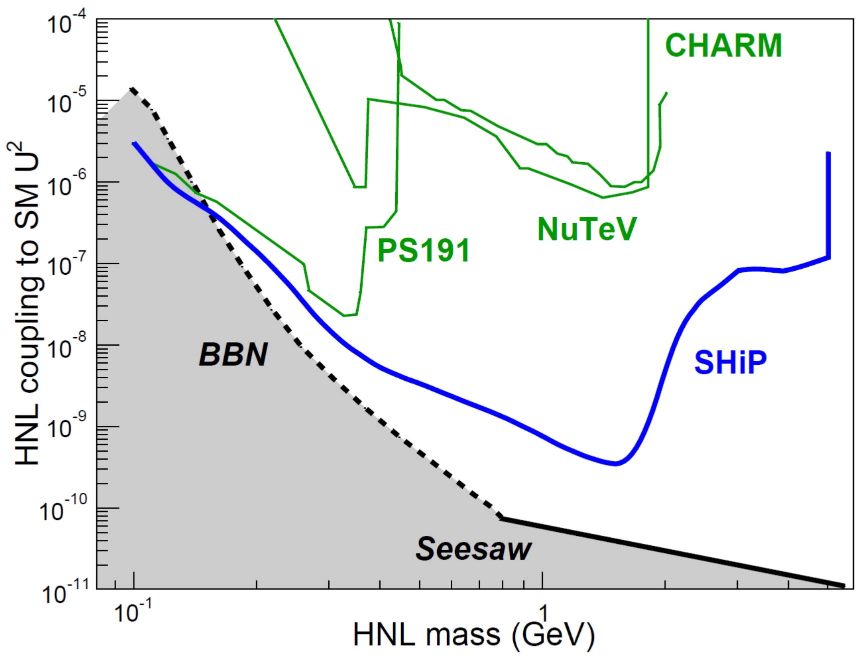

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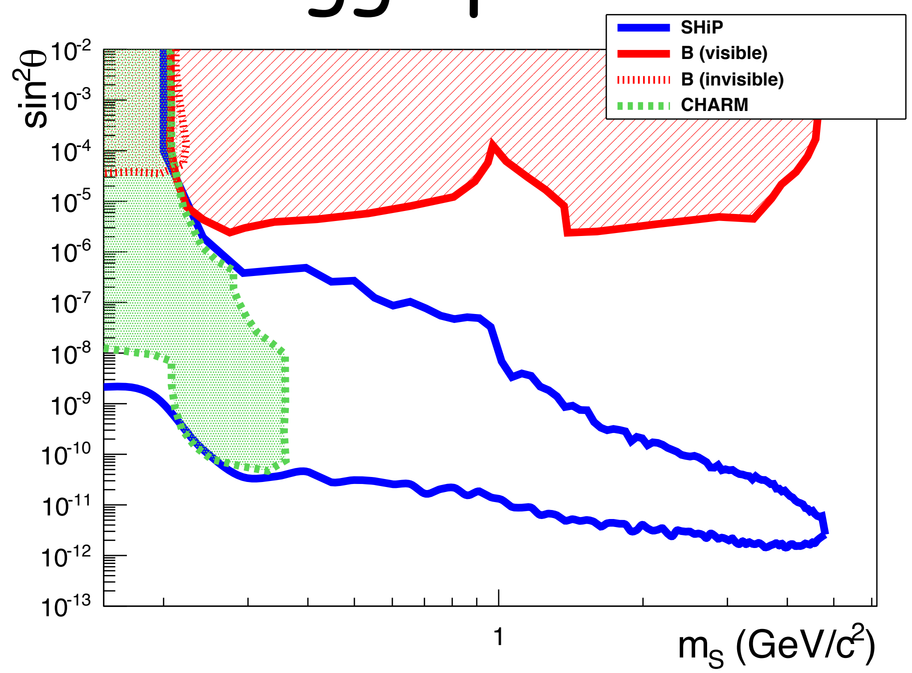
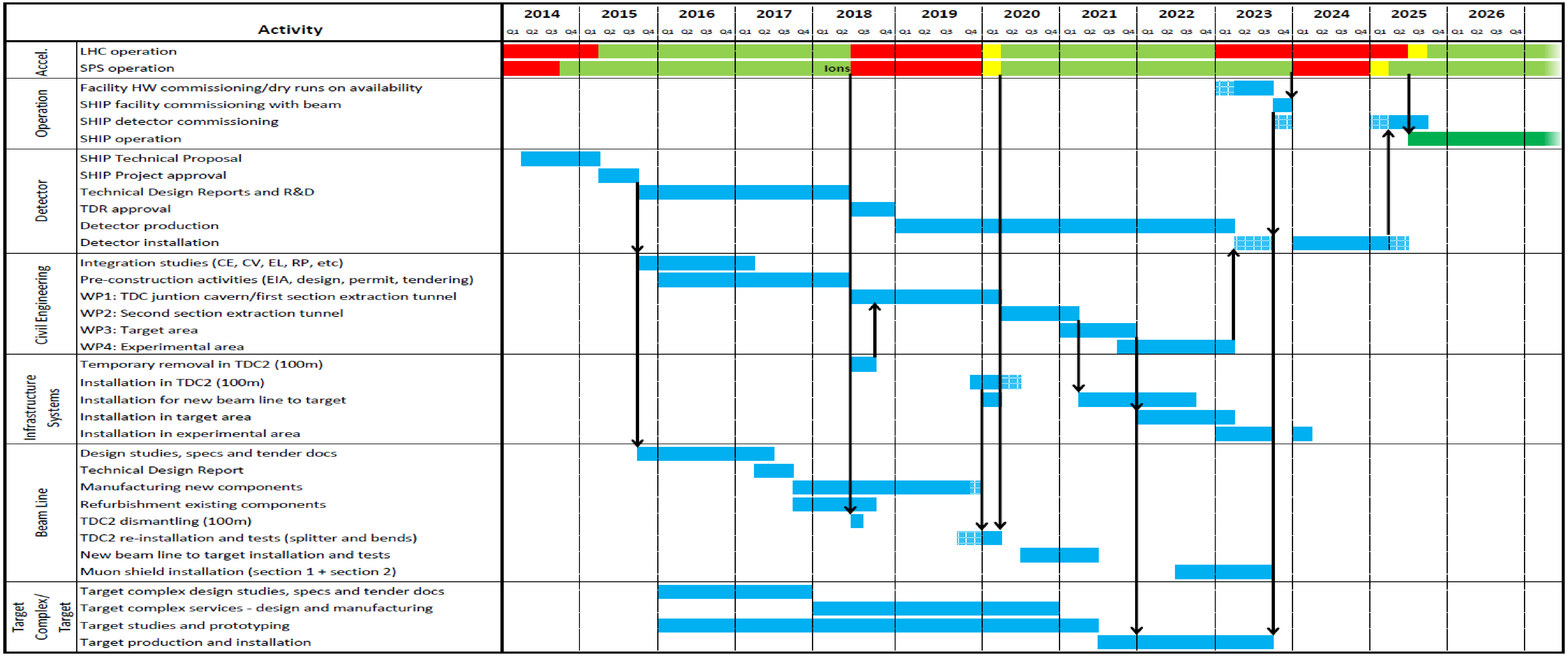


Figure 1.2: (Left) Sensitivity contours for the HNL coupling to active neutrino, $U^2 = U_e^2 + U_\mu^2 + U_\tau^2$ as function of the HNL mass assuming $U_e^2 : U_\mu^2 : U_\tau^2 = 1 : 16 : 3.8$. (Right) Sensitivity contours for a light hidden scalar particle of mass m_S coupling to the Higgs with $sin^2\theta$ mixing parameter and decaying in $e^+e^-, \mu^+\mu^-, \pi^+\pi^-, K^+K^-$ final states (solid blue line). Red dashed area is the excluded region from B-factories in the visible modes, red dotted area is the excluded region from B-factories in the invisible modes and green shaded area in the exclusion region from the CHARM experiment.

SHiP timeline



A few milestones:

- ✓ ***Form SHIP collaboration***
- ✓ *Technical proposal* submitted to SPSC April 2015

We expect CERN to decide on the strategy for the SHIP beam within a year after TP submission !

- ✓ *Technical Design Report* → *2018*
- ✓ *Construction and installation* → *2018 – 2022*
- ✓ *Data taking and analysis of $2{\times}10^{20}$ pot* → *2023 - 2027*

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SHiP timeline

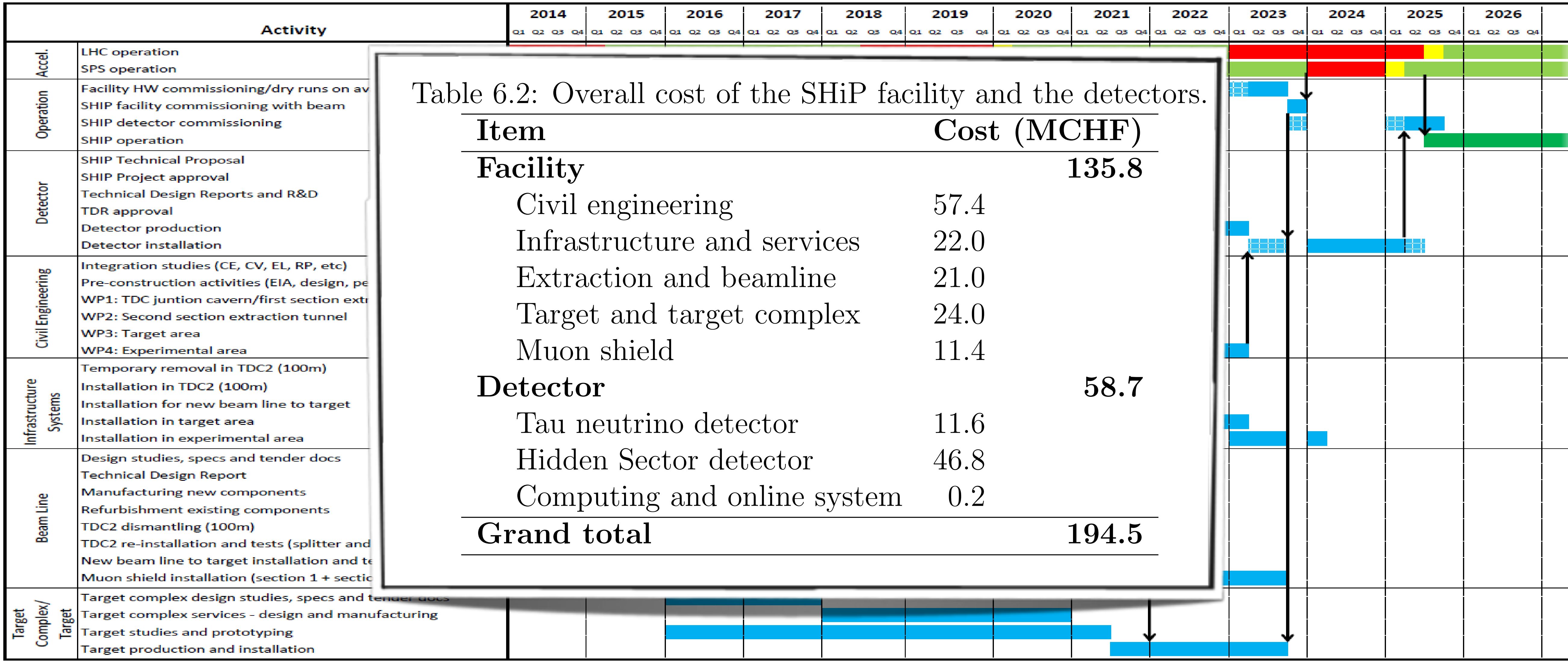

Table 6.2: Overall cost of the SHiP facility and the detectors.

Item	Cost (MCHF)	
Facility		**135.8**
Civil engineering	57.4	
Infrastructure and services	22.0	
Extraction and beamline	21.0	
Target and target complex	24.0	
Muon shield	11.4	
Detector		**58.7**
Tau neutrino detector	11.6	
Hidden Sector detector	46.8	
Computing and online system	0.2	
Grand total		**194.5**

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SHiP initial proposals

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

SHiP
Search for Hidden Particles

CERN-SPSC-2015-016
SPSC-P-350
8 April 2015

Technical Proposal

A Facility to Search for Hidden Particles (SHiP) at the CERN SPS

The SHiP Collaboration[1]

CERN-SPSC-2015-016 / SPSC-P-350
08/04/2015

Abstract

A new general purpose fixed target facility is proposed at the CERN SPS accelerator which is aimed at exploring the domain of hidden particles and make measurements with tau neutrinos. Hidden particles are predicted by a large number of models beyond the Standard Model. The high intensity of the SPS 400 GeV beam allows probing a wide variety of models containing light long-lived exotic particles with masses below $\mathcal{O}(10)$ GeV/c^2, including very weakly interacting low-energy SUSY states. The experimental programme of the proposed facility is capable of being extended in the future, e.g. to include direct searches for Dark Matter and Lepton Flavour Violation.

[1] Authors are listed on the following pages.

arXiv:1504.04956

Prepared for submission to JHEP

A facility to Search for Hidden Particles at the CERN SPS: the SHiP physics case

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CERN-SPSC-2015-017 / SPSC-P-350-ADD-1
09/04/2015

Abstract: This paper describes the physics case for a new fixed target facility at CERN SPS. The SHiP (*Search for Hidden Particles*) experiment is intended to hunt for new physics in the largely unexplored domain of very weakly interacting particles with masses below the Fermi scale, inaccessible to the LHC experiments, and to study tau neutrino physics. The same proton beam setup can be used later to look for decays of tau-leptons with lepton flavour number non-conservation, $\tau \to 3\mu$ and to search for weakly-interacting sub-GeV dark matter candidates. We discuss the evidence for physics beyond the Standard Model and describe interactions between new particles and four different *portals* — scalars, vectors, fermions or axion-like particles. We discuss motivations for different models, manifesting themselves via these interactions, and how they can be probed with the SHiP experiment and present several case studies. The prospects to search for relatively light SUSY and composite particles at SHiP are also discussed. We demonstrate that the SHiP experiment has a unique potential to discover new physics and can directly probe a number of solutions of beyond the Standard Model puzzles, such as neutrino masses, baryon asymmetry of the Universe, dark matter, and inflation.

⋆Editor of the paper
§Convener of the Chapter

arXiv:1504.04855

SHiP: Physics Case

Concerns about our future:

1) to which extent the various concepts are competitive, complementary, realistic or redundant, in terms of both physics and technology?

2) should the community continue with its current R&D efforts or consider adopting other programmes?

3) what should be the priorities in view of what we know today and the physics cases?

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What SHiP is good for

1) heavy neutral lepton (HNL) aka Majorana/sterile neutrino

2) light scalars, light vectors (aka dark photons) with mass below O(10)GeV

3) τ and ν_τ physics (3 orders of magnitude more statistics than today)

4) SM measurements

The Higgs boson and the gauge principle

Particle physics is not so much about particles but more about fundamental principles

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!!! Are gauge theories the right principle to understand/describe fundamental interactions? !!!

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$$\mathcal{L}_{\rm Higgs} = V_0 - \mu^2 H^\dagger H + \lambda \left(H^\dagger H\right)^2 + \left(y_{ij}\bar{\psi}_{Li}\psi_{Rj}H + h.c.\right)$$

- V_0 → vacuum energy, cosmological constant: $V_0 \approx (2\times 10^{-3}\ \mathrm{eV})^4 \ll M_{\rm PL}^4$
- μ^2 → hierarchy problem: $m_H \approx 100\ \mathrm{GeV} \ll M_{\rm Pl}$
- λ → triviality/stability of EW vacuum
- y_{ij} → mass and mixing hierarchy
- $h.c.$ → flavour & CP

Higgs interactions: many different couplings not set by any gauge symmetry

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- V_0 → *vacuum energy cosmological constant* $V_0 \approx (2\times10^{-3}\ \text{eV})^4 \ll M_{\text{PL}}^4$
- $-\mu^2 H^\dagger H$ → *hierarchy problem* $m_H \approx 100\ \text{GeV} \ll M_{\text{Pl}}$
- $\lambda (H^\dagger H)^2$ → *triviality/stability of EW vacuum*
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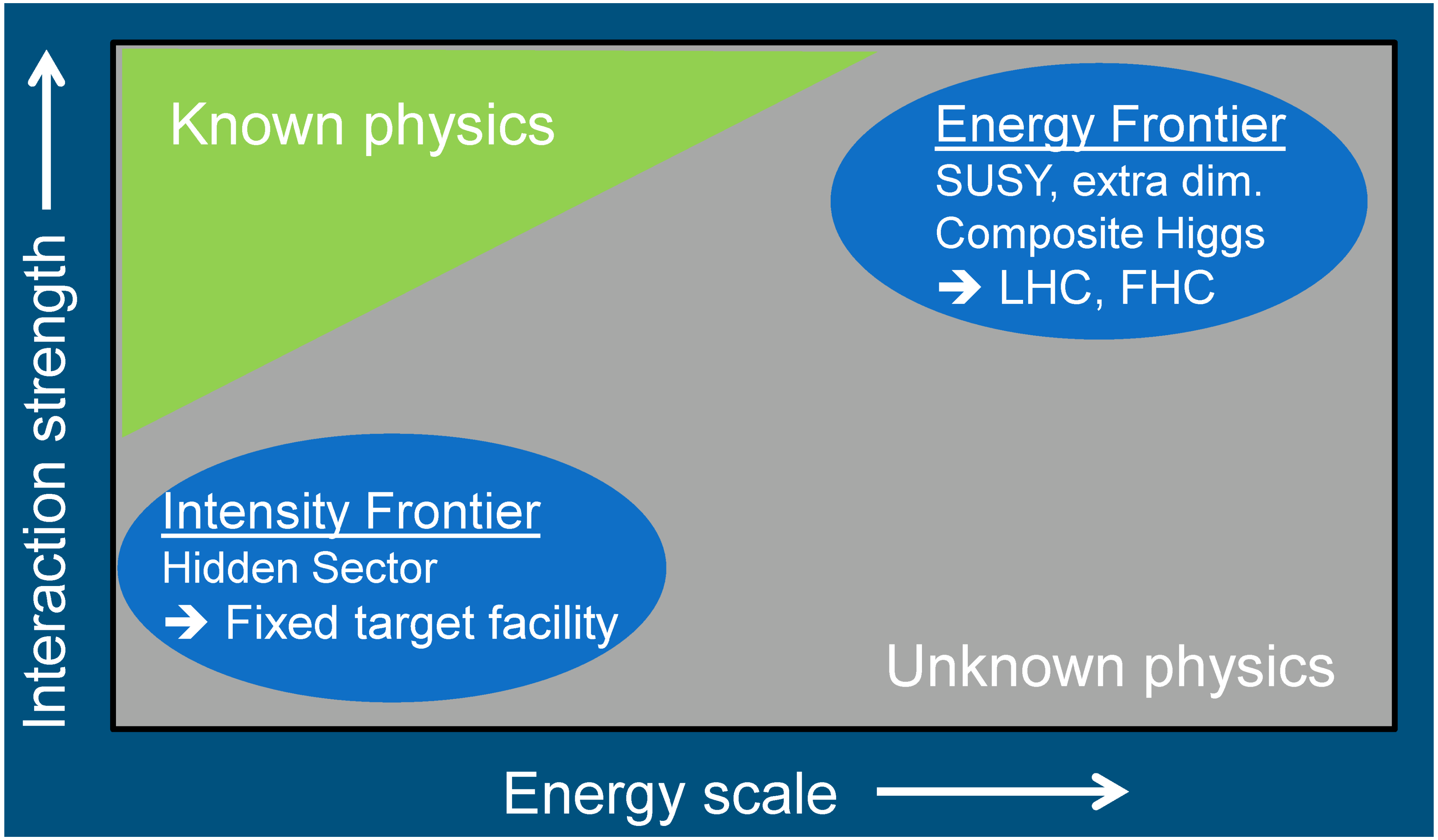
What are the interactions of the non-SM matter?

The interactions of the non-SM matter

the jury is still out



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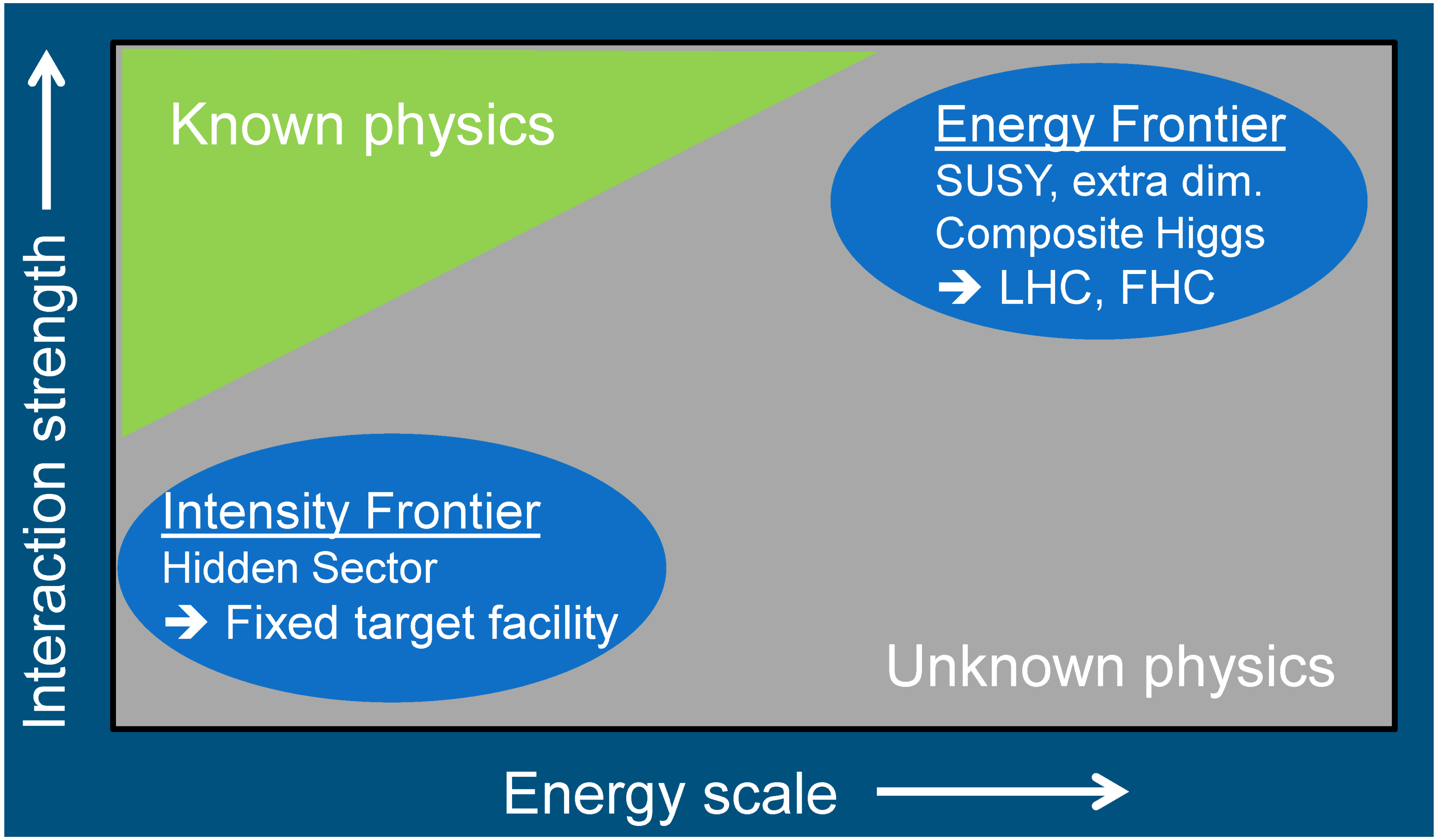

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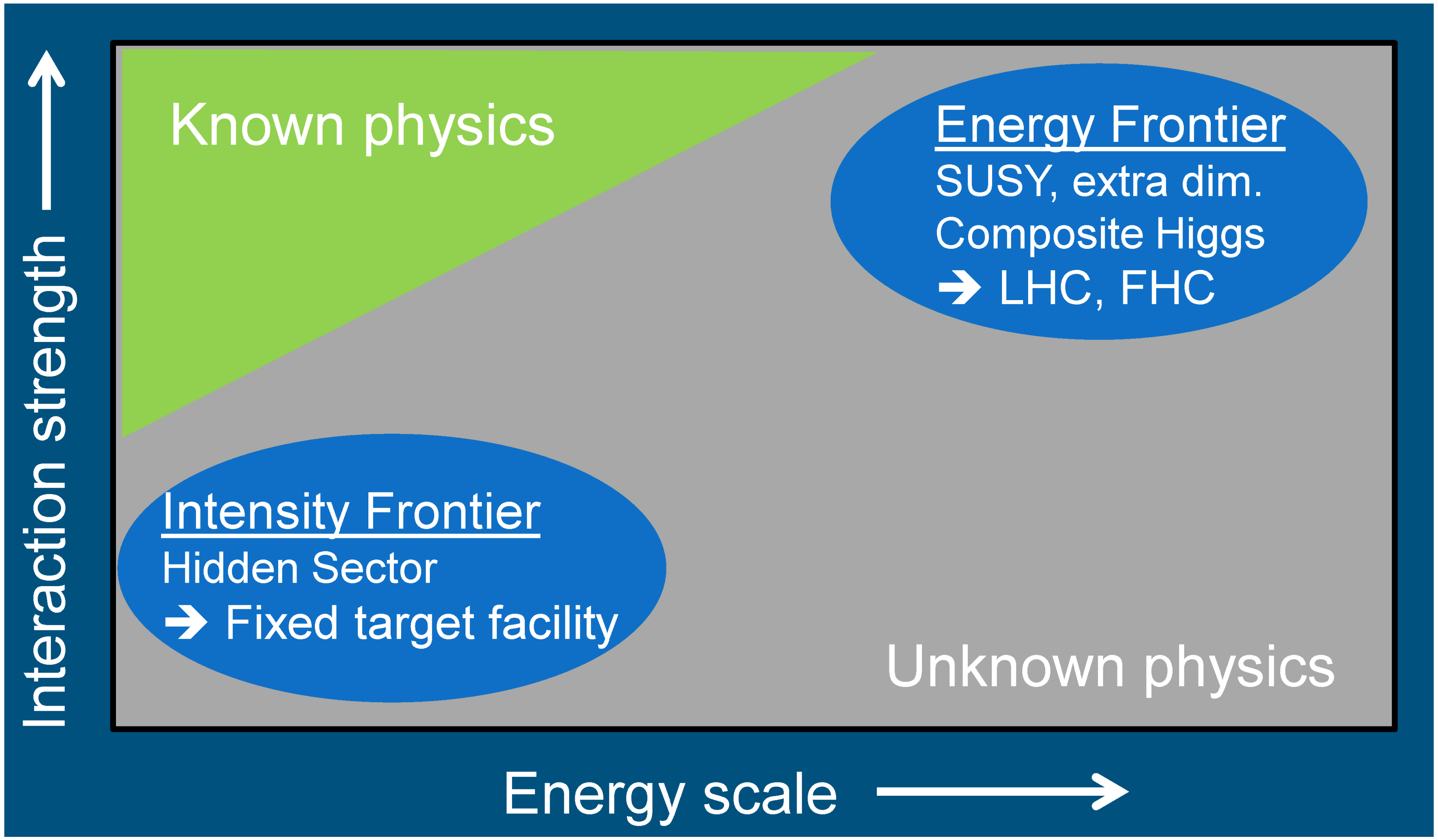

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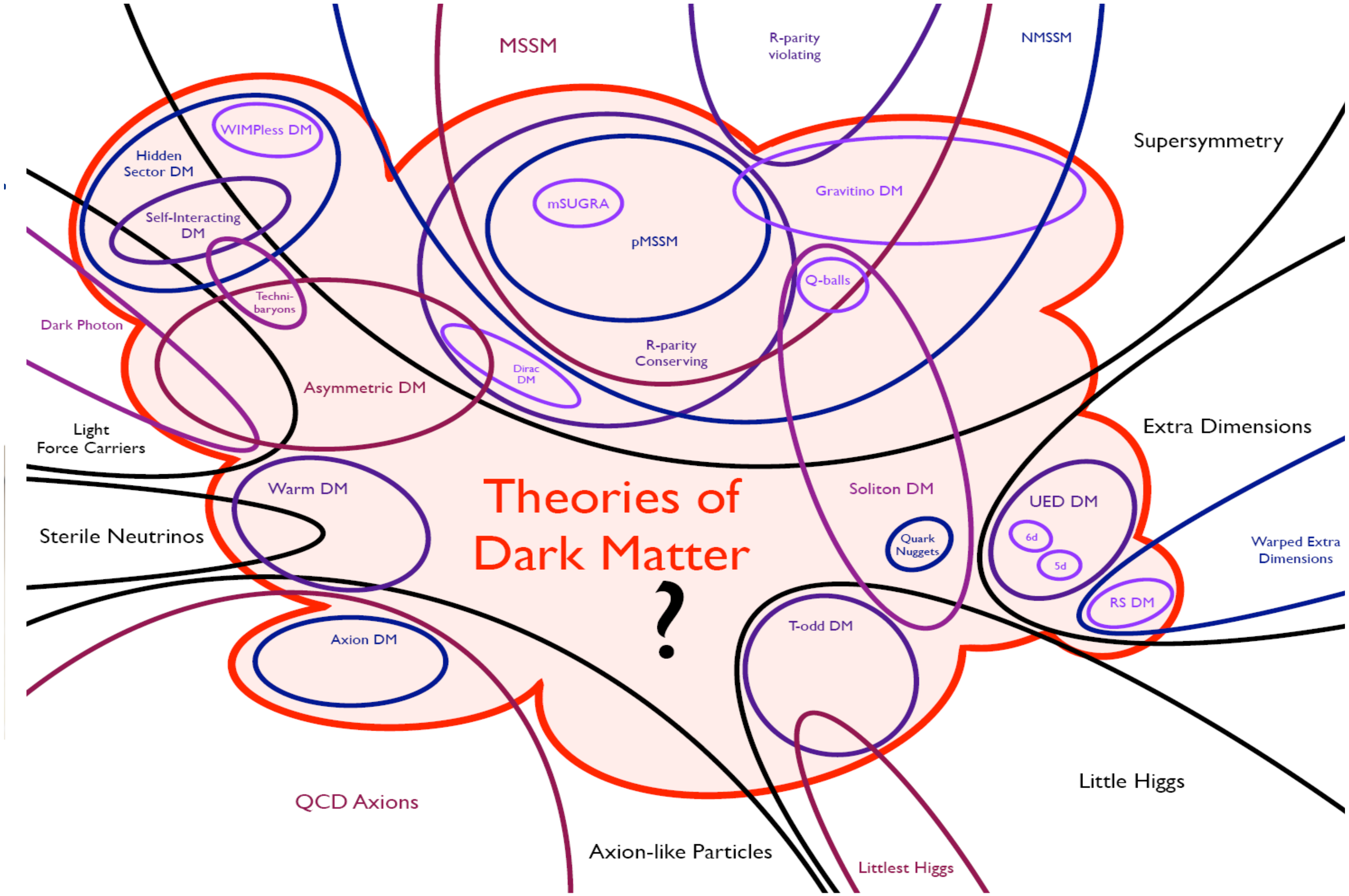
Except for the QCD axion,
light weakly coupled new sector was not part of the theory Grand Picture

The energy scale(s) of new physics



T. Tait, DM@LHC '14

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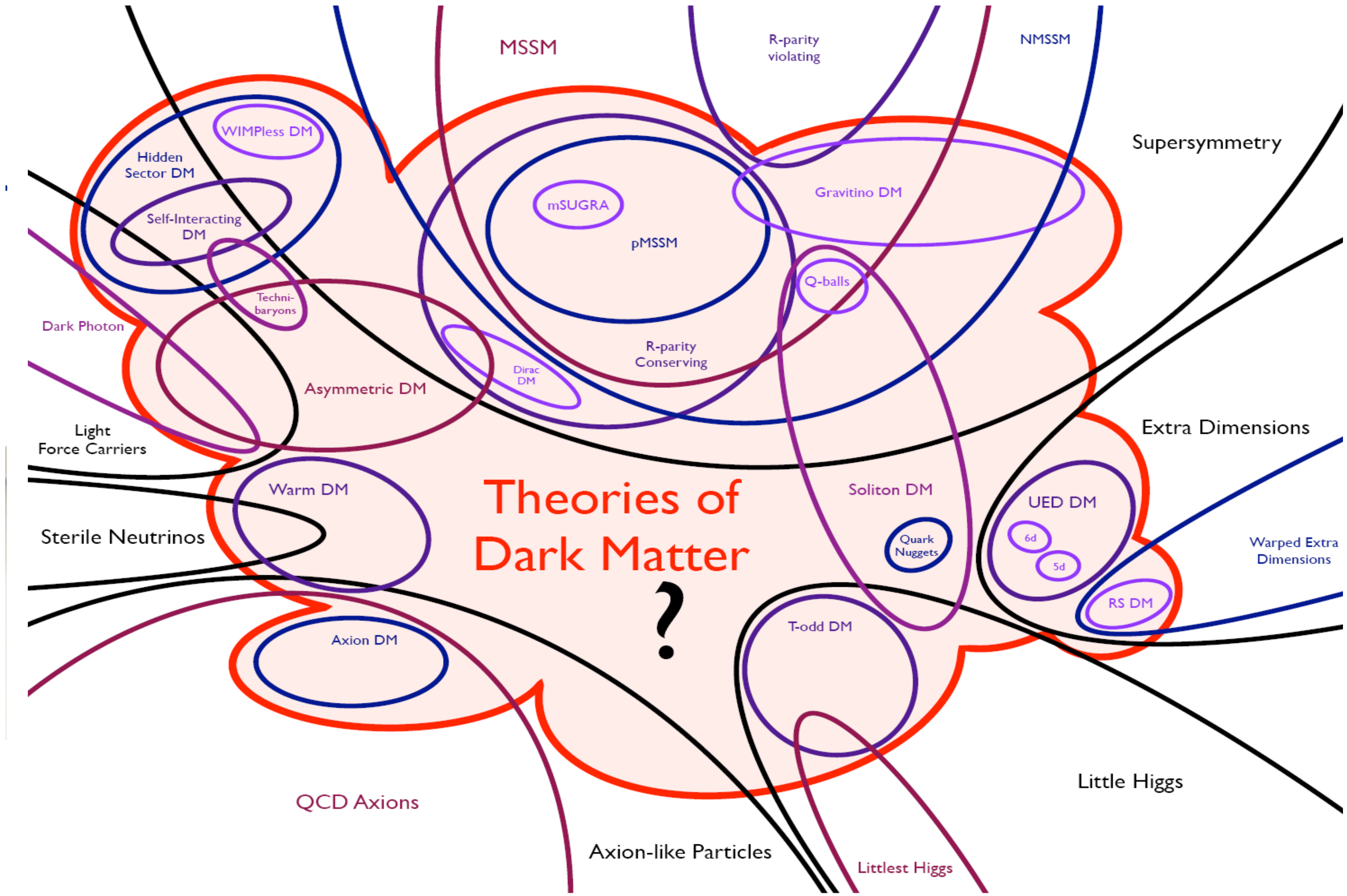


T. Tait, DM@LHC '14

The prediction about the mass scale of DM comes with large error bars:

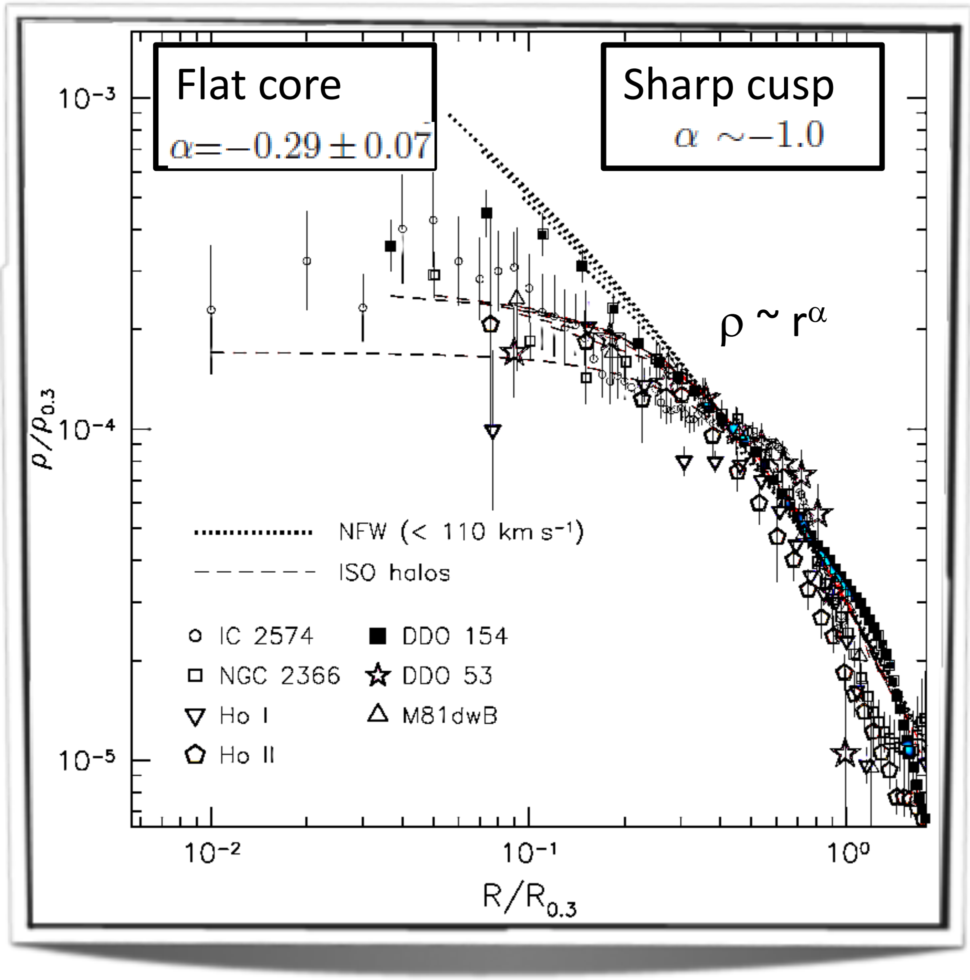
$$10^{-22}\,\mathrm{eV} < m_{DM} < 10^{20}\,\mathrm{GeV}$$

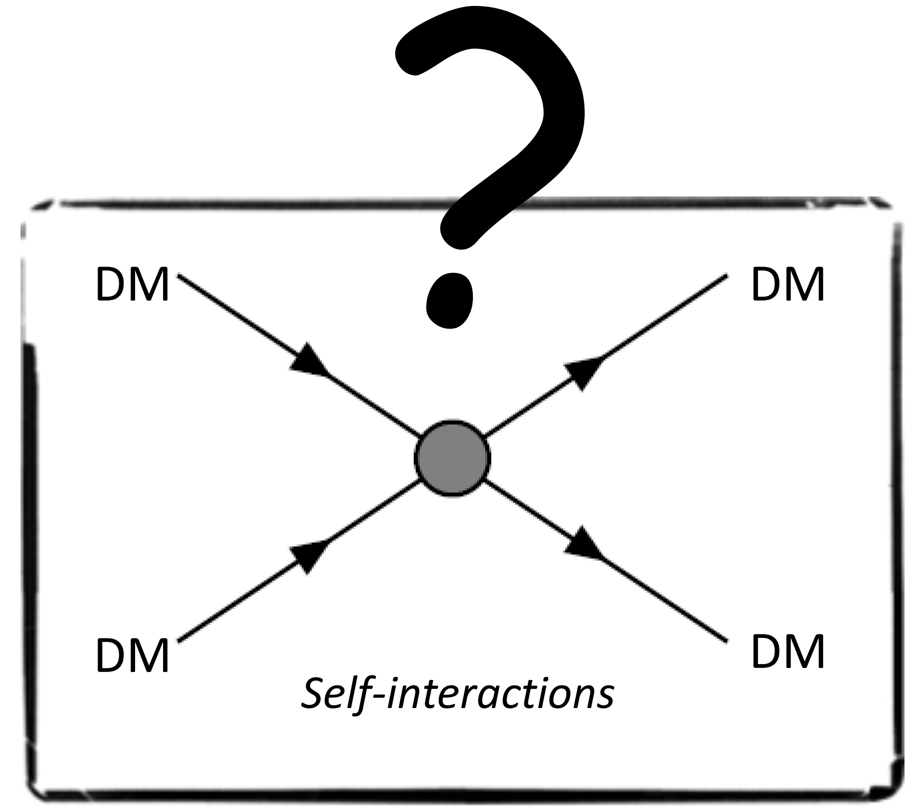
(ALPs) (Wimpzillas, Q-balls)

An interesting experimental clue (?)

Distributions of DM are flatter than what ΛCDM predicts

S.H. Oh et al. '15





$$\sigma/m_\chi \sim 1\ \mathrm{cm}^2/\mathrm{g} \ \approx\ 2\ \mathrm{barns/GeV}$$

S. Tullin, IFAE '15

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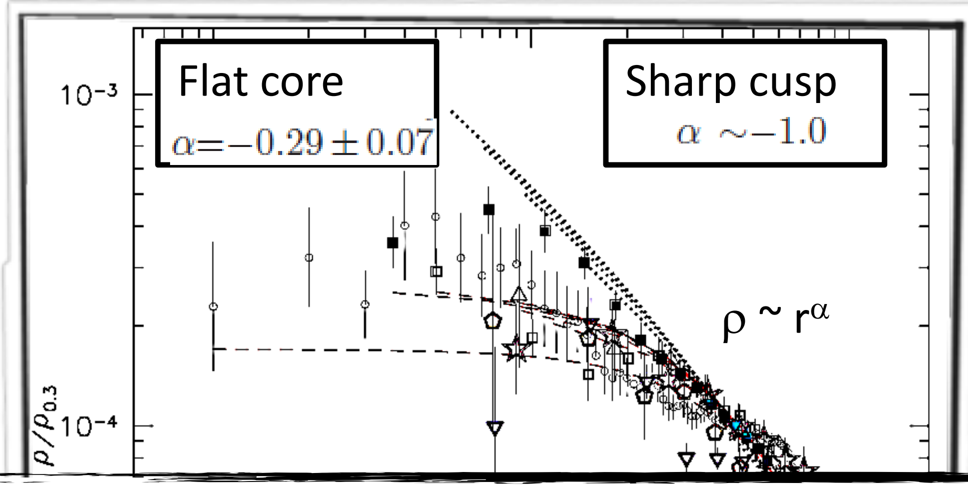
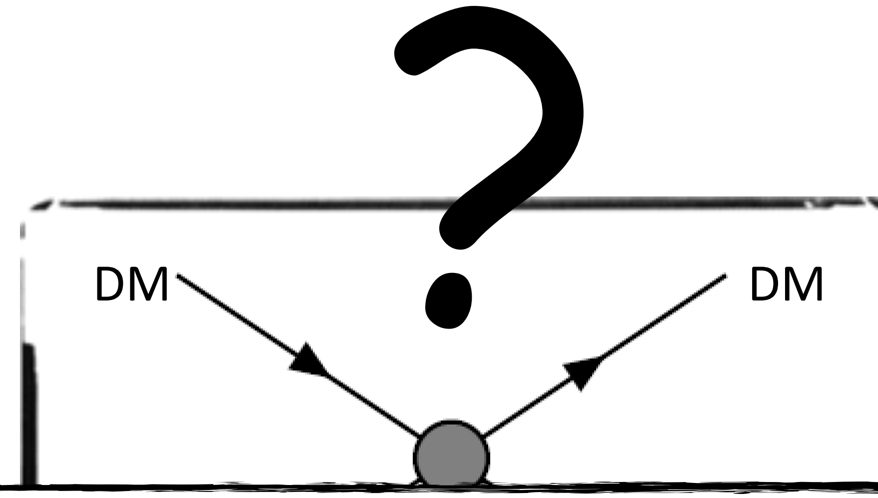




Cores in different systems are probing self-interactions at different energies

Low energies ($v/c \sim 10^{-4}$)

Medium energies ($v/c \sim 10^{-3}$)

High energies ($v/c \sim 10^{-2}$)

Like probing DM at different colliders w/. different beam energies

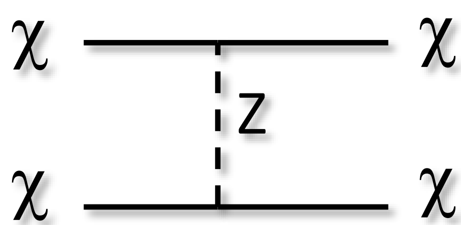
All consistent with the self-interacting DM picture

S. Tullin, IFAE '15

Self-Interacting DM

S. Tullin, IFAE '15

~WIMP DM~



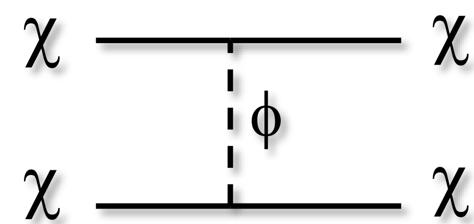
self-interaction

$$\sigma \sim \frac{g^4\, m_\chi^2}{m_Z^4} \sim 10^{-36}\,\mathrm{cm}^2$$

$$m_\chi \sim 100\,\mathrm{GeV}$$

$$\sigma/m_\chi \sim 10^{-14}\,\mathrm{cm}^2/\mathrm{g}$$

~ Light mediator DM~



self-interaction

$$\sigma \sim \frac{g^4\, m_\chi^2}{m_\phi^4}$$

$$\sigma/m_\chi \sim 1\,\mathrm{cm}^2/\mathrm{g}$$

$$m_\phi \sim 1 - 100\,\mathrm{MeV}$$

Dark photon? Dark Higgs?

Are DM self-interactions controlled by gauge symmetry? which one?

Couplings Hidden Sectors to SM

matter that is neutral under SM gauge group
can still couple to SM matter via the following portal interactions

J=1/2	J=0			J=1
$y\,\bar{L}HN$	$\|H\|^2(\alpha\mu S+\lambda S^2)$	$G_{\mu\nu}\tilde{G}^{\mu\nu}\dfrac{a}{f}$	$\bar{\psi}\gamma^\mu\gamma^5\psi\dfrac{\partial_\mu a}{f}$	$\epsilon\,B_{\mu\nu}V_{\mu\nu}$

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What are the constraints on these couplings
as a function of the mass of the hidden particles?

How to improve these constraints?

How to probe phenomenologically viable regions of the parameter space?

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Who ordered that?

neutrino mass, DM, asymmetry matter-antimatter, inflation...

1

HNL = Sterile Neutrinos

Heavy Neutral Lepton

M. Shaposhnikov @ SHiP symposium '15

- Origin of active neutrino masses via type I see-saw (requires at least 2 HNL)
- Dark matter candidate (requires 1 HNL)
- Baryon asymmetry of the Universe (requires at least 2 HNL)
- Neutrino anomalies (LSND, MiniBOONe, reactor), requires HNL with eV scale mass

LSND

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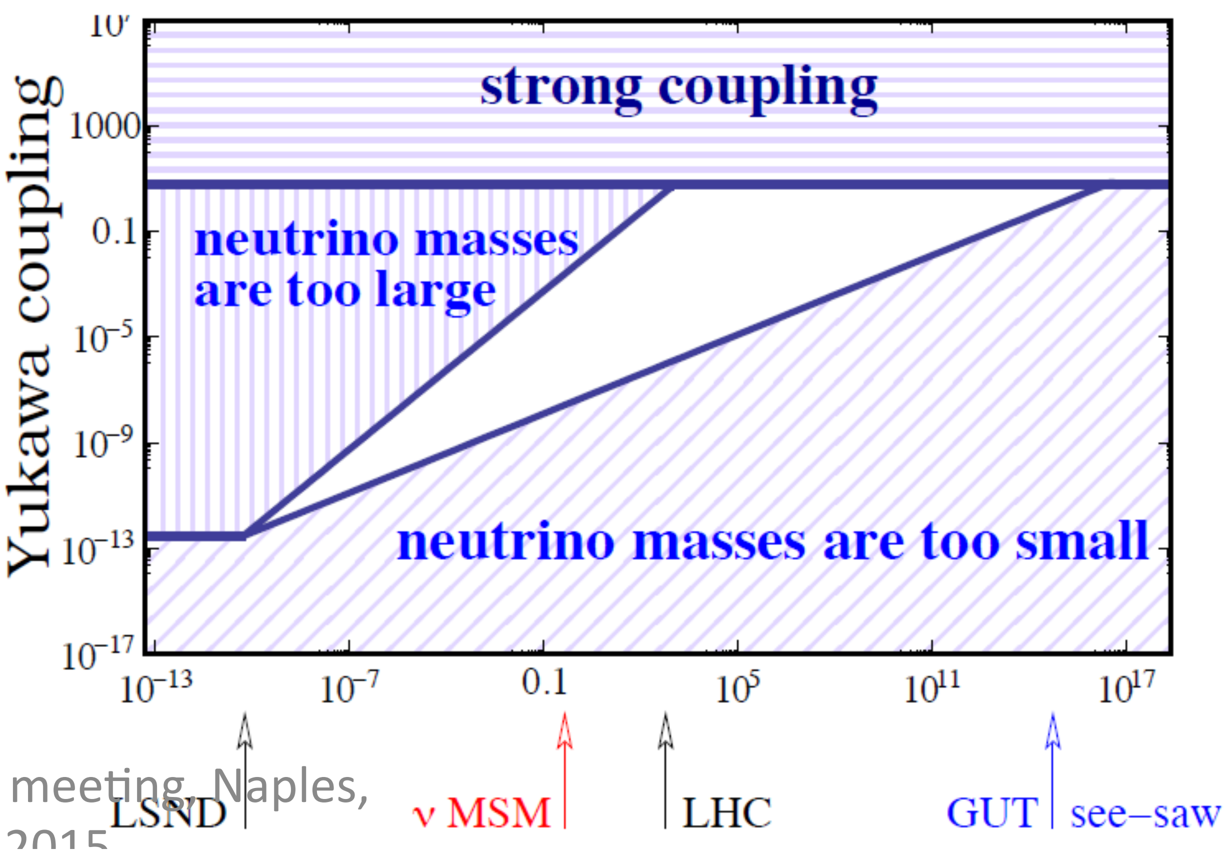
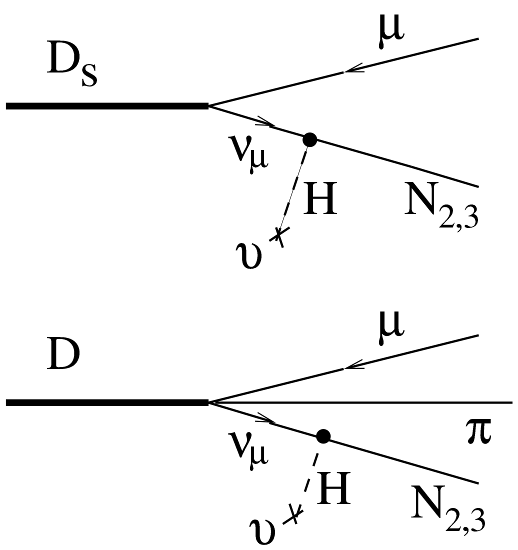


Smallness of the neutrino mass hints either on very large M or very small Yukawa couplings

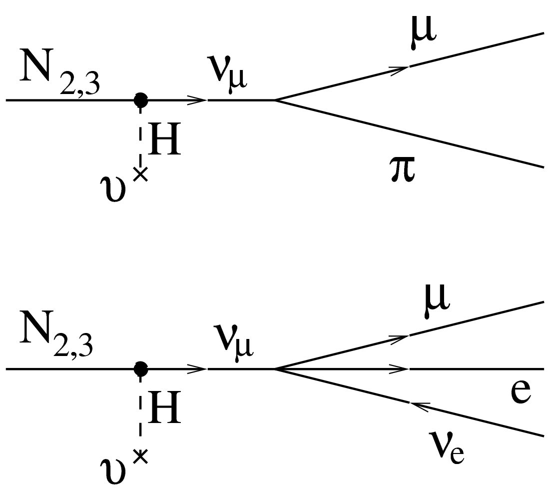
Different experiments will probe different mass scales

Heavy Neutral Lepton @ SHiP

Production

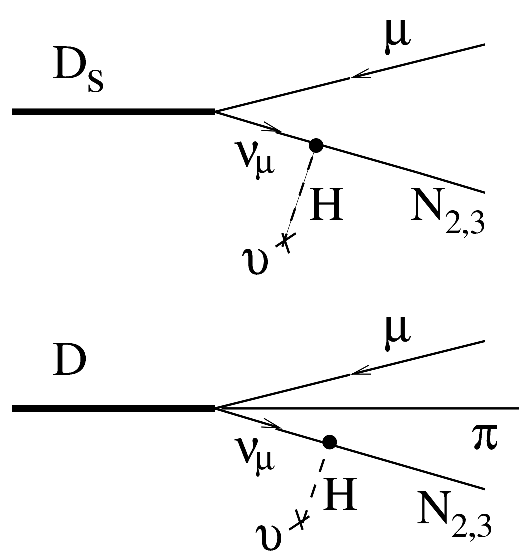


Decay

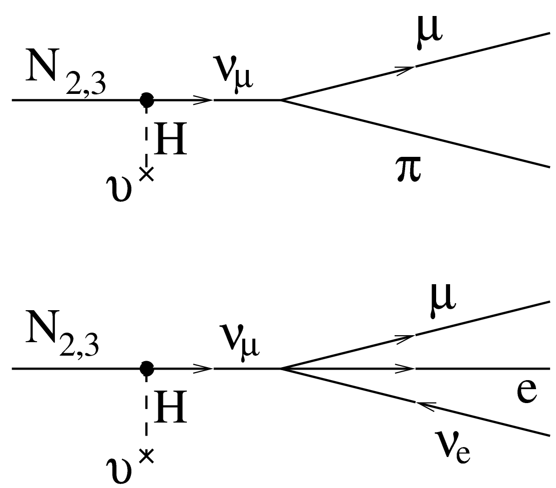


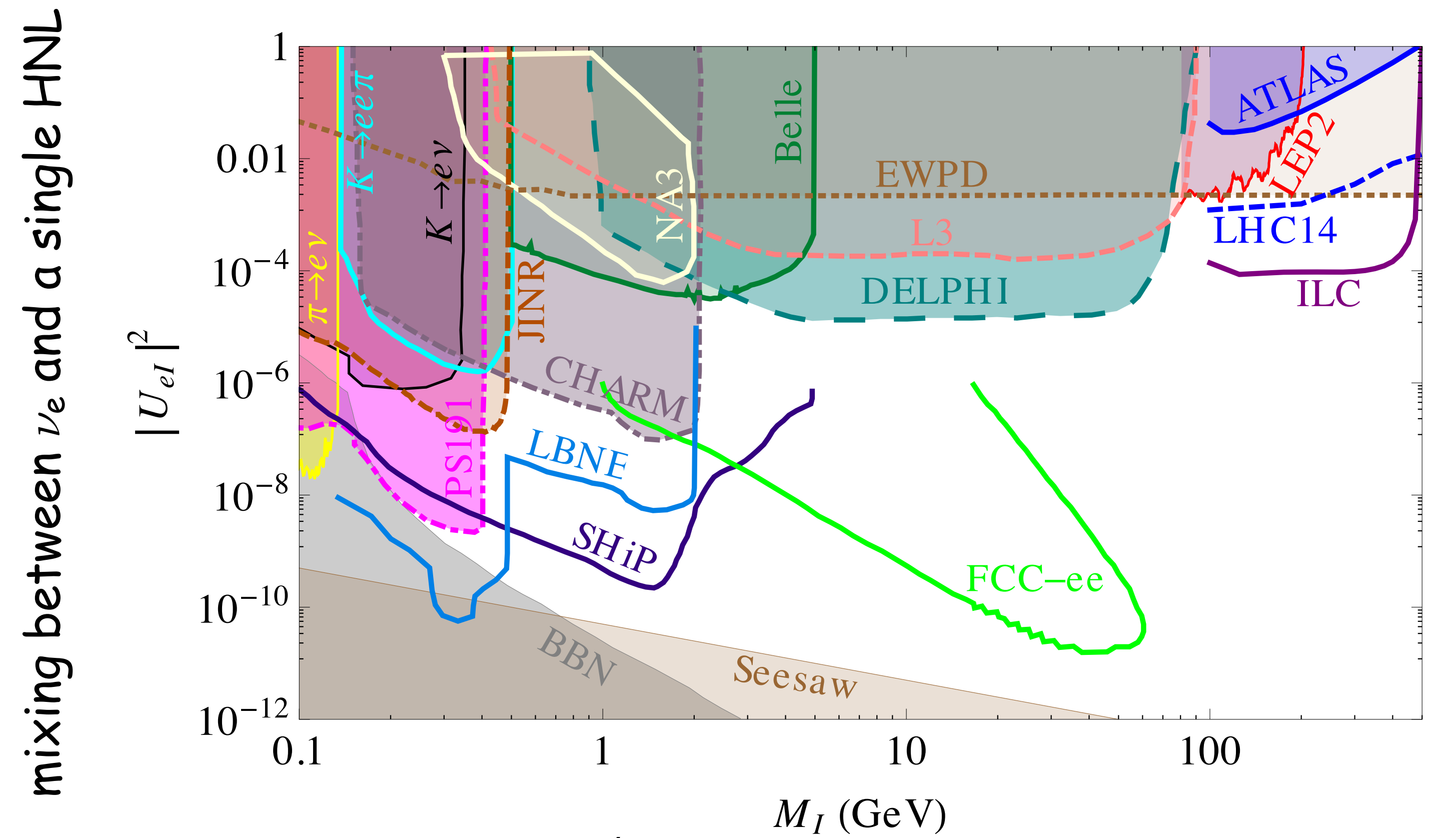
Heavy Neutral Lepton @ SHiP

Production



Decay





2

Scalar Hidden Sector

Scalar Portal

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{2}\partial_\mu S \partial^\mu S + (\alpha_1 S + \alpha S^2)(H^\dagger H) + \lambda_2 S^2 + \lambda_3 S^3 + \lambda_4 S^4$$

S mixes with the Higgs and inherits some couplings to SM matter

Higgs mixing	$g_\star = \sin\theta \simeq \theta \simeq \frac{\alpha_1 v}{m_h^2}\,.$

$-\frac{g_\star\, m_f}{v}\, S\, \bar{f} f$	Couplings to SM matter

Scalar Portal

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{2}\partial_\mu S \partial^\mu S + (\alpha_1 S + \alpha S^2)(H^\dagger H) + \lambda_2 S^2 + \lambda_3 S^3 + \lambda_4 S^4$$

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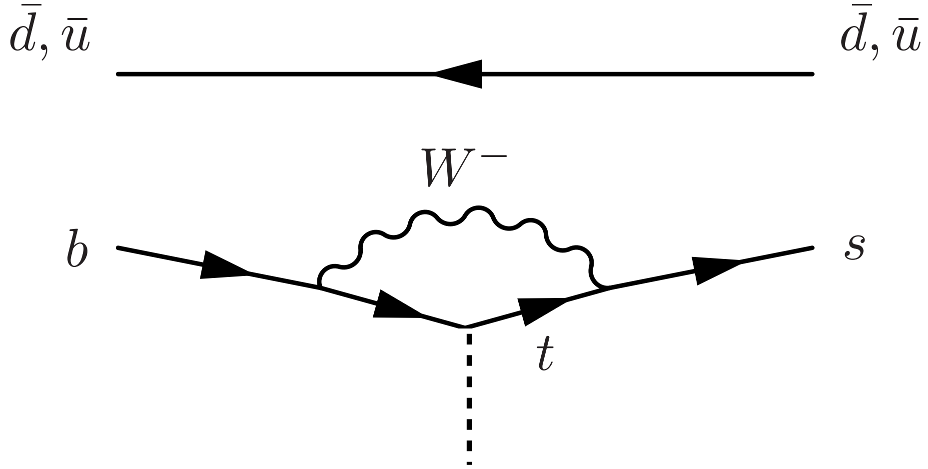
Higgs mixing

$$g_\star = \sin\theta \simeq \theta \simeq \frac{\alpha_1 v}{m_h^2}\,.$$

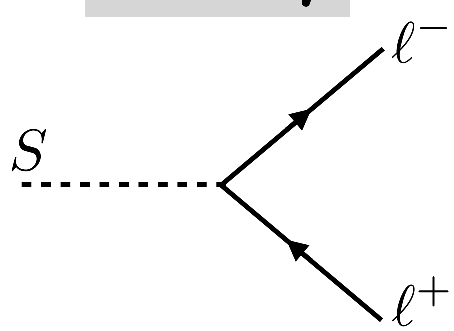
Couplings to SM matter

$$-\frac{g_\star\, m_f}{v}\, S\, \bar{f} f$$

Production: B→K+S



Decay



Scalar Portal

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{2}\partial_\mu S \partial^\mu S + (\alpha_1 S + \alpha S^2)(H^\dagger H) + \lambda_2 S^2 + \lambda_3 S^3 + \lambda_4 S^4$$

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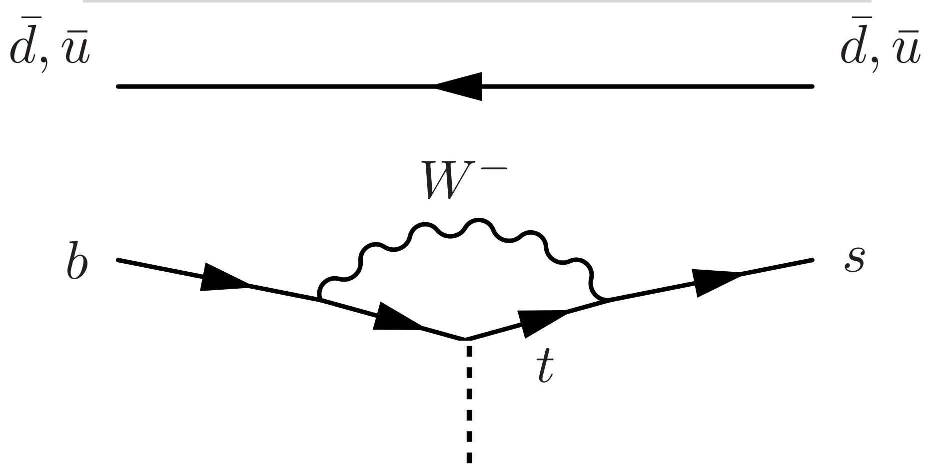
Higgs mixing

$$g_\star = \sin\theta \simeq \theta \simeq \frac{\alpha_1 v}{m_h^2}\,.$$

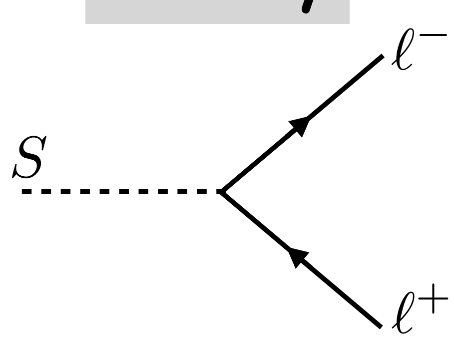
Couplings to SM matter

$$-\frac{g_\star m_f}{v} S \bar{f} f\,.$$

Production: B→K+S



Decay



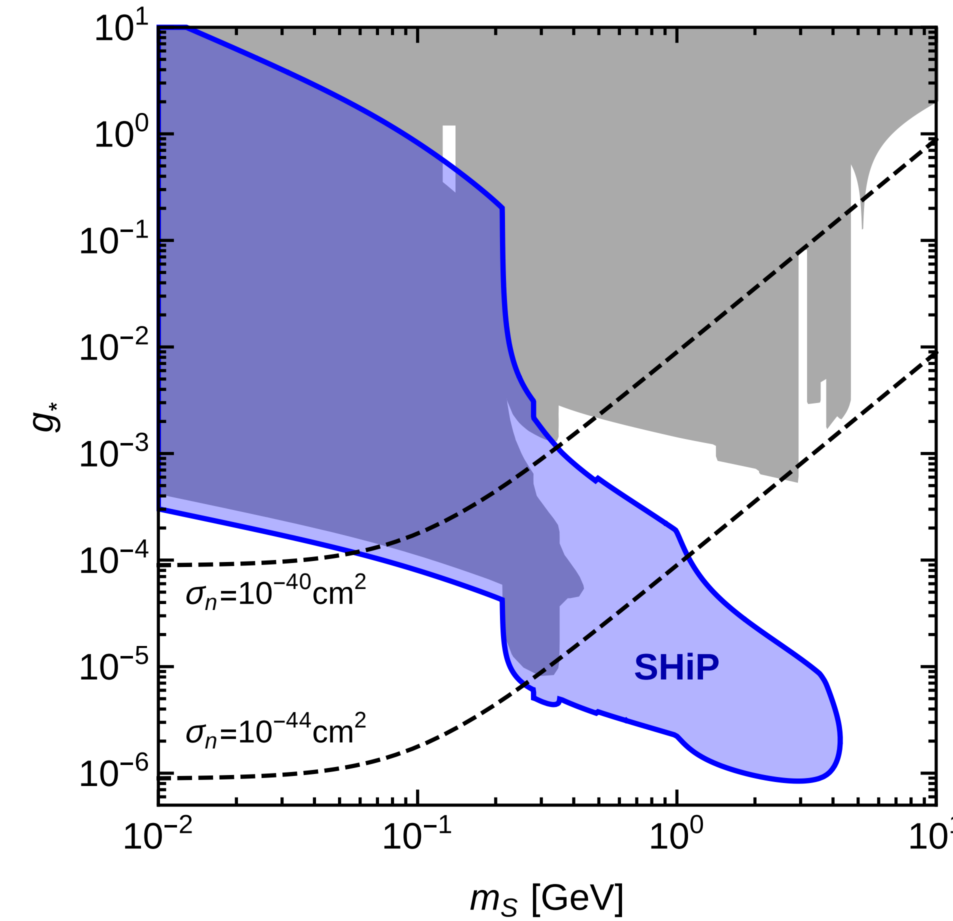


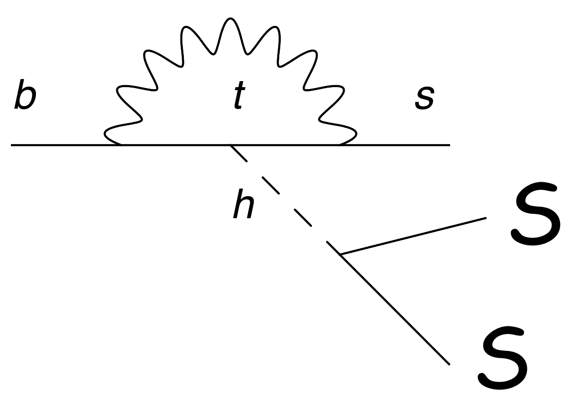
Figure 3.9: Projected sensitivity of SHiP for a scalar S with Yukawa-like couplings to all SM fermions, in comparison to the existing bounds. The decays $S \to ee, \mu\mu, \pi\pi$ and KK are considered. Both S production from B and K decays are considered with the assumption that all B mesons but only 0.2% of the kaons decay before being stopped. Also shown are contours of constant DM nucleon cross section, where we assumed that S acts as the mediator between DM and nucleons

Scalar Portal

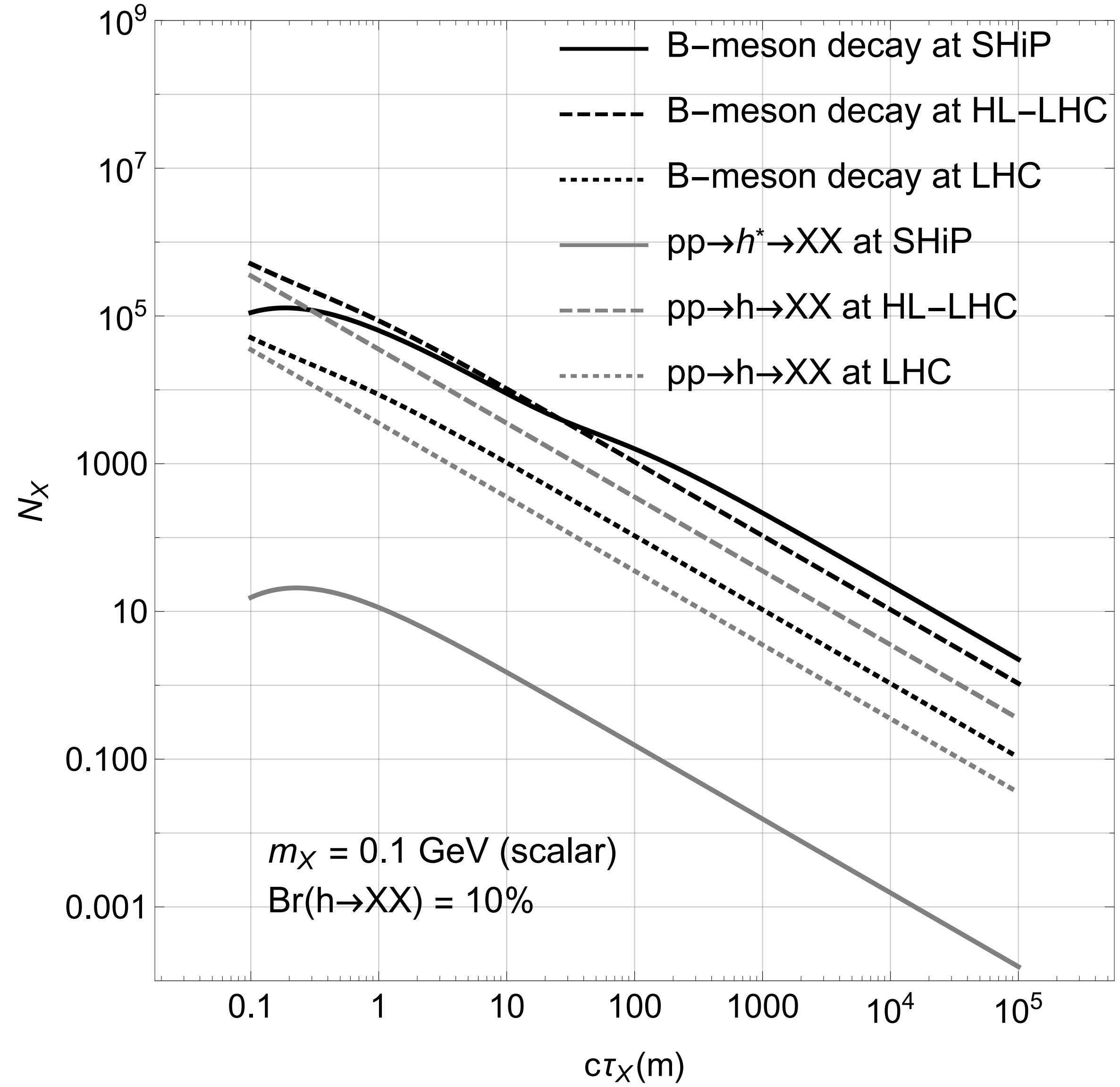
$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{2}\partial_\mu S \partial^\mu S + \alpha S^2 (H^\dagger H) + \lambda_2 S^2 + \lambda_4 S^4.$$

no mixing with Higgs: S is paired-produced

Production:
B→K+SS



Production:
pp→h*→SS



SHiP has superior signal yield to the LHC
and has greater sensitivity to long-lived particles
than does the HL-LHC.

Scalar Portal: which mass range?

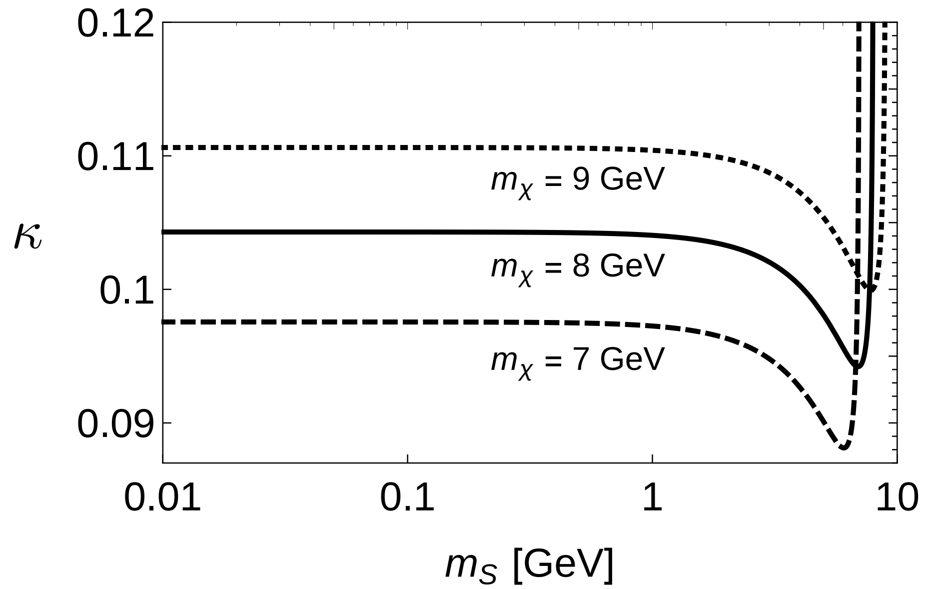
S mixes with Higgs and couples to DM

$$\mathcal{L} = \mathcal{L}_{\rm SM} - \frac{g_\star\, m_f}{v}\, S\, \bar{f} f \; - \frac{1}{2}\kappa\, S \bar{\chi}\chi$$

DM-nucleon xs

$$\sigma_n \simeq 10^{-40}{\rm cm}^2 \left(\frac{\kappa}{0.1}\right)^2 \left(\frac{g_\star}{0.01}\right)^2 \left(\frac{\rm GeV}{m_S}\right)^4$$

$\chi\chi \to SS$



coupling κ as a function of the the mediator mass m_S to correctly reproduce the cosmic DM relic abundance

Scalar Portal: which mass range?

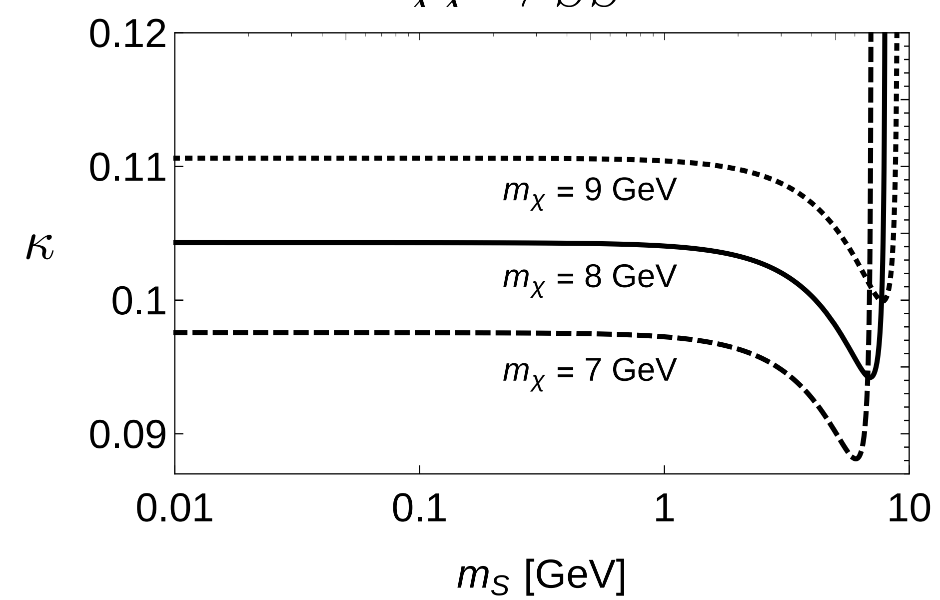
S mixes with Higgs and couples to DM

$$\mathcal{L} = \mathcal{L}_{\rm SM} - \frac{g_\star m_f}{v} S \bar{f} f - \frac{1}{2}\kappa S \bar{\chi}\chi$$

DM-nucleon xs

$$\sigma_n \simeq 10^{-40}{\rm cm}^2 \left(\frac{\kappa}{0.1}\right)^2 \left(\frac{g_\star}{0.01}\right)^2 \left(\frac{\rm GeV}{m_S}\right)^4$$

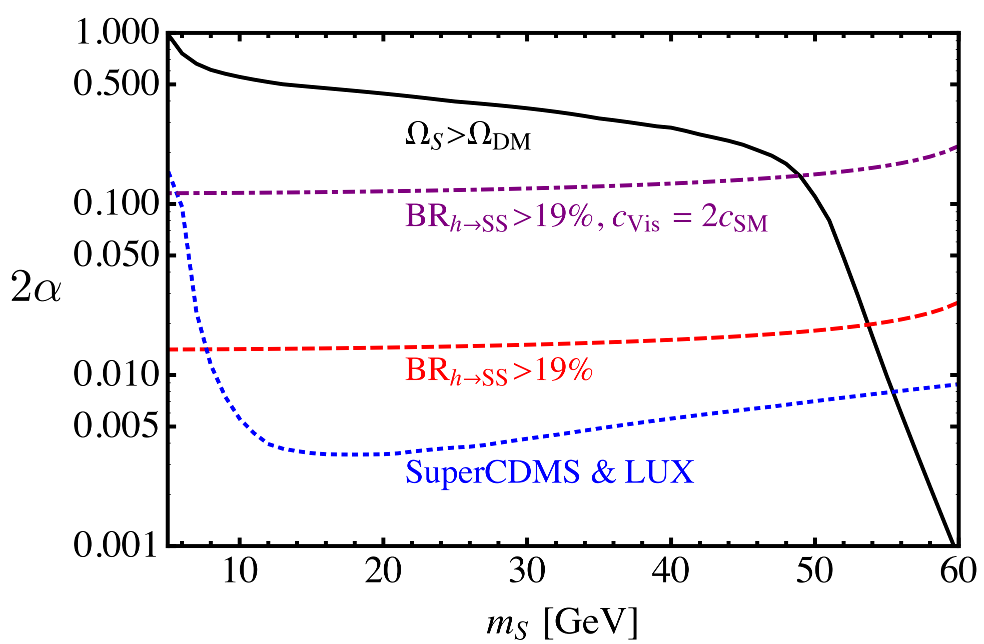
$\chi\chi \to SS$



coupling κ as a function of the the mediator mass m_S to correctly reproduce the cosmic DM relic abundance

S doesn't mix with Higgs and is DM itself

$$\mathcal{L} \supset \alpha S^2 |H|^2$$



$$\Omega h^2 (30\,{\rm GeV}) \sim 0.11 \left(\frac{0.18}{\alpha}\right)^2$$

invisible Higgs width constraint
&
direct DM searches
rule out this minimal DM portal

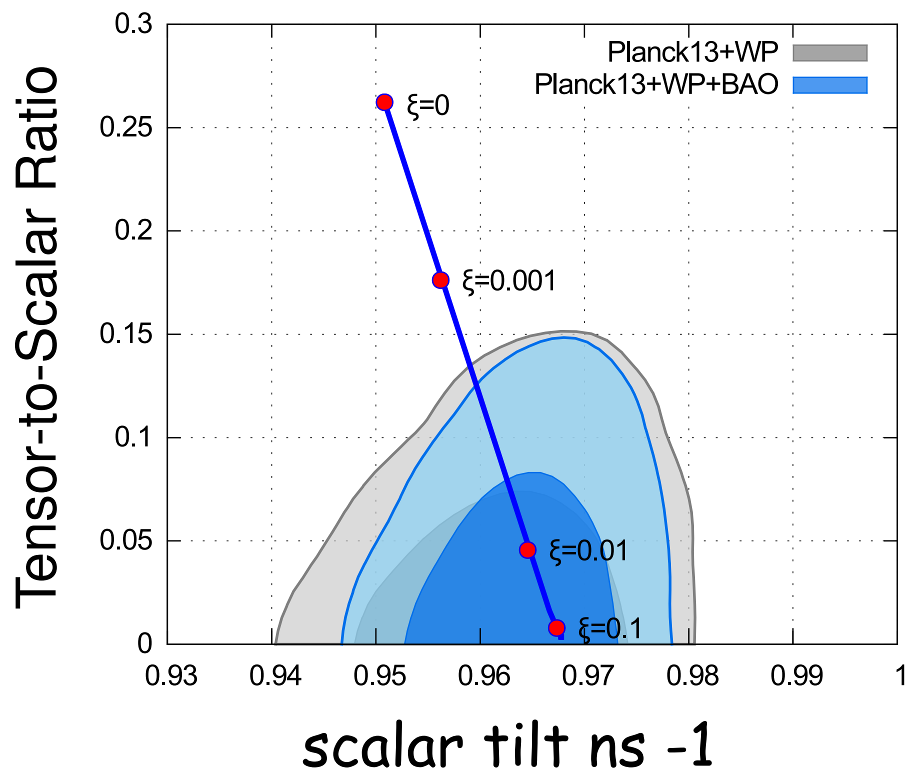
Scalar Portal: light inflation

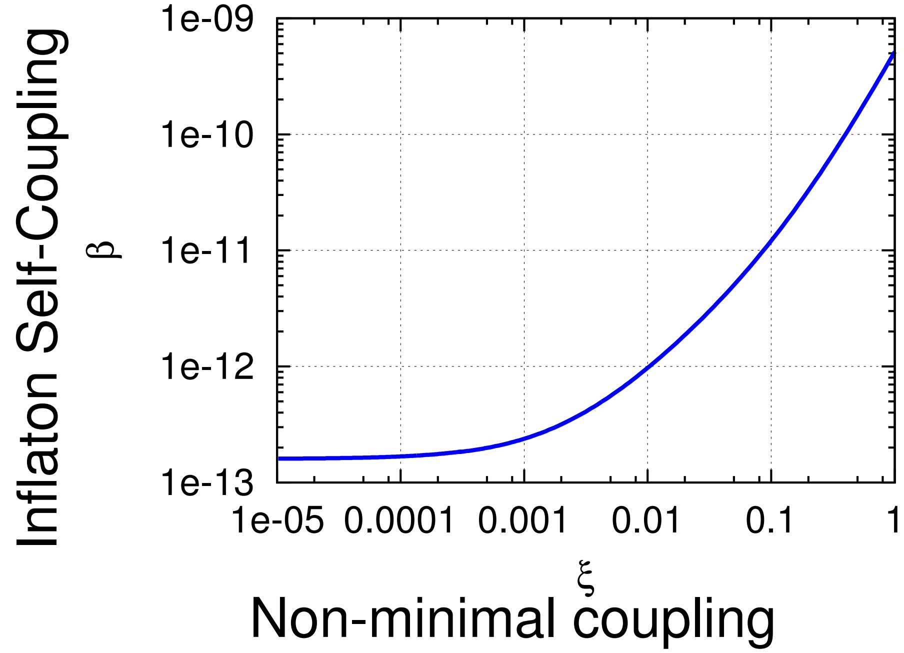
$$\mathcal{L}_{SSM} = \mathcal{L}_{\rm SM} + \frac{(\partial_\mu S)^2}{2} + \frac{m_S^2 S^2}{2} - \frac{\beta S^4}{4} - \lambda\left(H^\dagger H - \frac{\alpha}{\lambda}S^2\right)^2 - \frac{M_P^2 + \xi S^2}{2} R$$

no-scale model

Inflaton mass depends on interaction strength: $m_\chi = m_h\sqrt{\beta/2\alpha}$

Higgs-inflaton mixing $\theta^2 = 2\beta v^2/m_\chi^2$

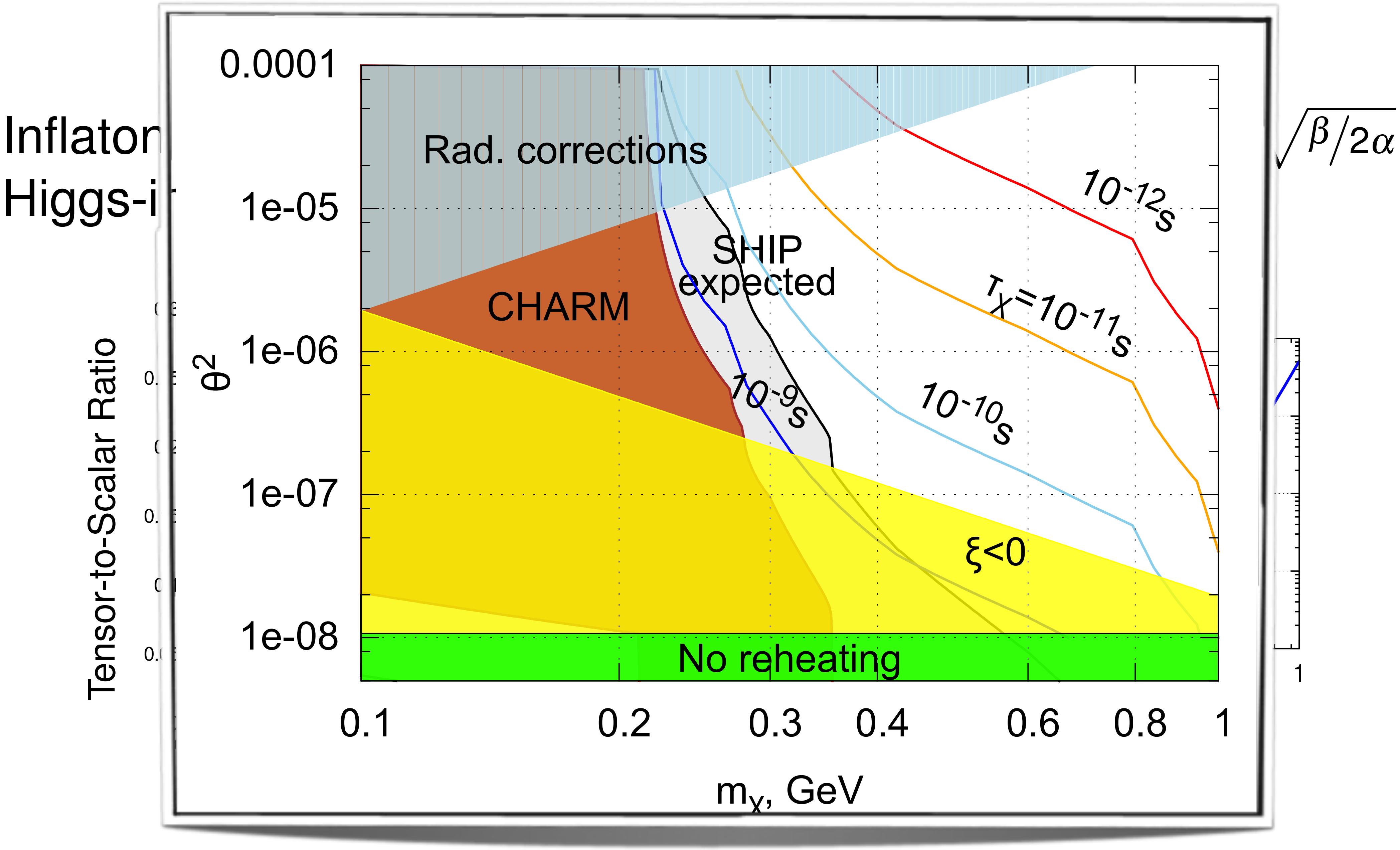




$$\text{Br}(B \to \chi K) \simeq 4.8\times 10^{-6} \times \left(1 - \frac{m_\chi^2}{m_b^2}\right)^2 \left(\frac{\theta^2}{10^{-6}}\right)$$

Scalar Portal: light inflation

$$\mathcal{L}_{SSM} = \mathcal{L}_{\rm SM} + \frac{(\partial_\mu S)^2}{2} + \frac{m_S^2 S^2}{2} - \frac{\beta S^4}{4} - \lambda\left(H^\dagger H - \frac{\alpha}{\lambda}S^2\right)^2 - \frac{M_P^2 + \xi S^2}{2} R$$



$$\mathrm{Br}(B \to \chi K) \simeq 4.8 \times 10^{-6} \times \left(1 - \frac{m_\chi^2}{m_b^2}\right)^2 \left(\frac{\theta^2}{10^{-6}}\right)$$

3

Vector Hidden Sector

A few physically motivated examples

- Dark photons: kinetic mixing, minicharged particles $\mathcal{L} = -\frac{1}{4}V_{\mu\nu}^2 - \frac{\kappa}{2}V_{\mu\nu}F^{\mu\nu} + |D_\mu\phi|^2 - V(\phi)$
- Gauges B-L, L_μ-L_τ
- Baryonic vector, aka leptophobic dark vector

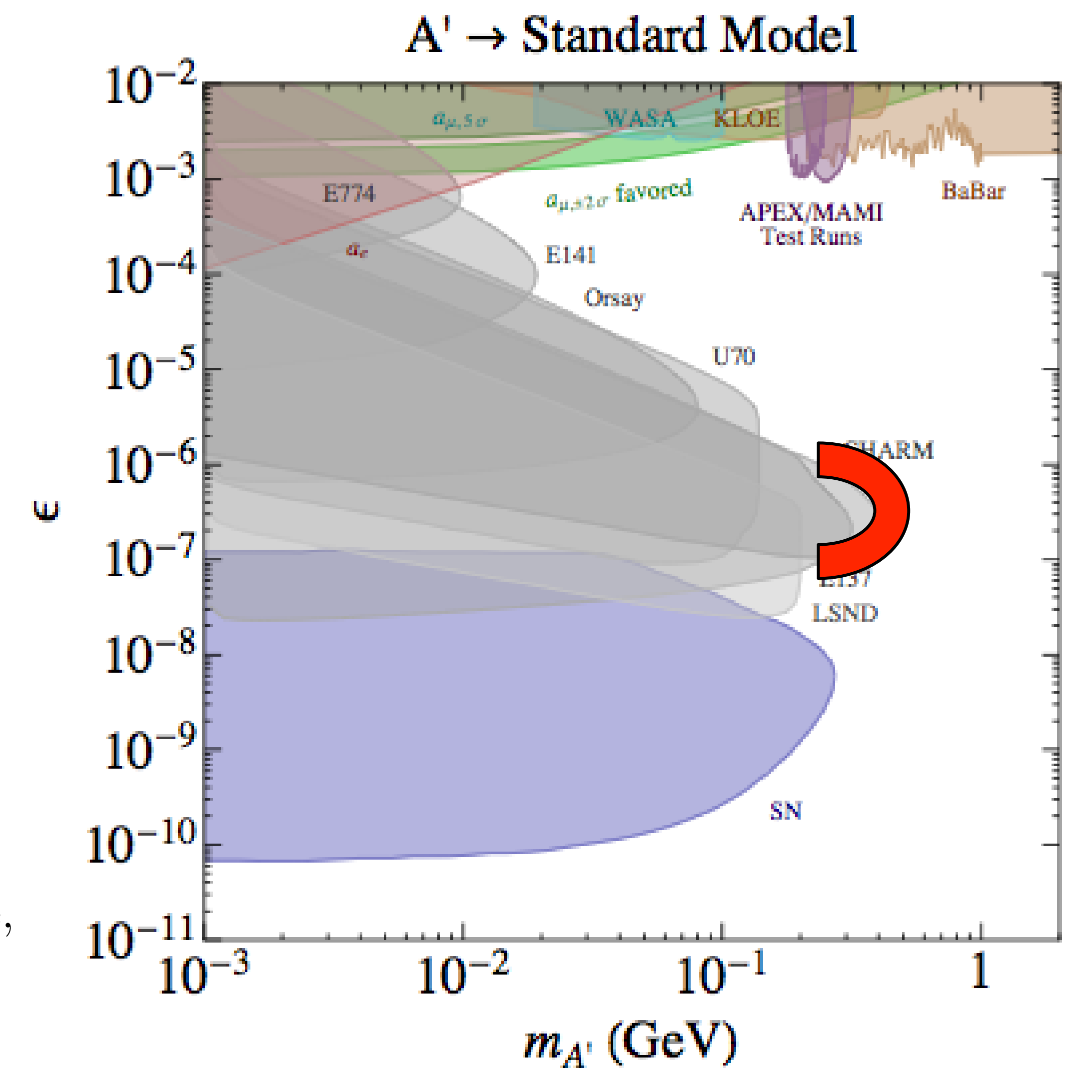
$$\mathcal{L} = \mathcal{L}_\chi - \frac{1}{4}V_{\mu\nu}^2 + \frac{1}{2}m_V^2 V_\mu^2 - \frac{\kappa}{2}V_{\mu\nu}F^{\mu\nu} + g_B V_\mu J_B^\mu \qquad J_B^\mu \equiv \frac{1}{3}\sum_i \bar{q}_i\gamma^\mu q_i$$

Why?

0. Theoretical motivation to look for an extra U(1) gauge group.
(E.g. test SU(3)×SU(2)×U(1) structure wherever we can.)
1. Recent intriguing results in astrophysics. 511 keV line, PAMELA positron rise, ...
2. Self-interaction of WIMP dark matter
3. More than a decade old discrepancy of the muon g-2.
4. Other motivations (E.g. providing a new mechanism for populating the RH neutrino dark matter: Shuve, Yavin)

M. Pospelo @ Naples '15

Dark photons @ SHiP



The decays to leptons and new "dark states" χ are elementary to handle,

$$\Gamma_{A'\to l^+l^-} = \frac{1}{3}\epsilon^2\alpha m_V \left(1+\frac{2m_l^2}{m_V^2}\right)\sqrt{1-\frac{4m_l^2}{m_V^2}}.$$

$$\Gamma_{A'\to \chi\bar{\chi}} = \frac{1}{3}\alpha_D m_V \left(1+\frac{2m_\chi^2}{m_V^2}\right)\sqrt{1-\frac{4m_\chi^2}{m_V^2}},$$

$$\Gamma_{V\to \mathrm{hadrons}} = \frac{1}{3}\alpha\epsilon^2 m_V\sqrt{1-\frac{4m_\mu^2}{m_V^2}}\left(1+\frac{2m_\mu^2}{m_V^2}\right)R(s=m_V^2),$$

Decay length can be microscopic if the mixing angle is very small.
For 200 MeV particle

$$c\tau_{A'}\gamma \sim 40\ \mathrm{m}\times\left(\frac{10^{-6}}{\epsilon}\right)^2\times\frac{\gamma}{100}.$$

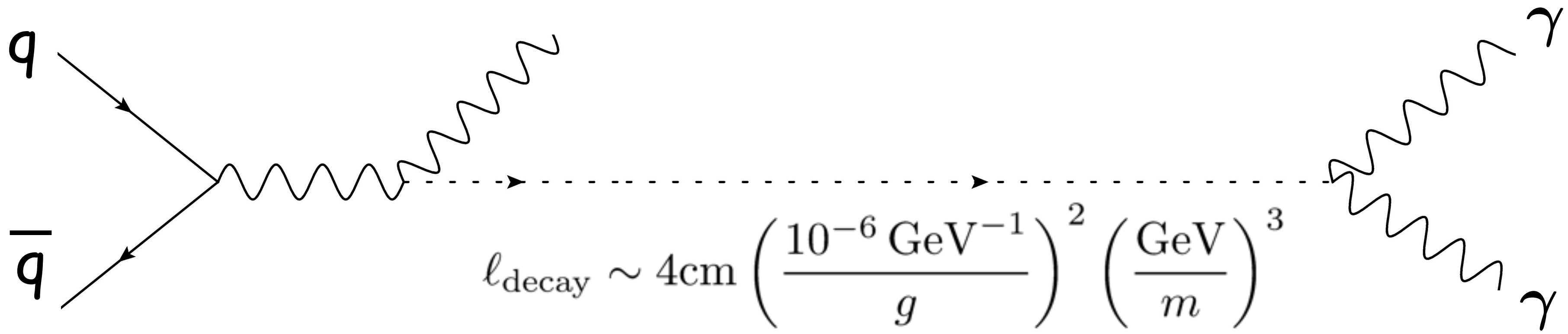
4

Other BSM @ SHiP

ALPs

$$\mathcal{L}_{\mathrm{ALPSM}} = \sum_{f=q,\ell} \frac{C_{Af}}{2\,f_A} \bar{f}\gamma^\mu\gamma^5 f\,\partial_\mu A - \frac{\alpha}{8\pi}\frac{C_{A\gamma}}{f_A} F_{\mu\nu}\tilde{F}^{\mu\nu}\,A - \frac{\alpha_3}{8\pi}\frac{C_{A3}}{f_A} G^b_{\mu\nu}\tilde{G}^{b\,\mu\nu}\,A$$

$$\Gamma(A \to ii) = \frac{d(G) g_{Ai}^2 m_A^3}{64\pi}$$

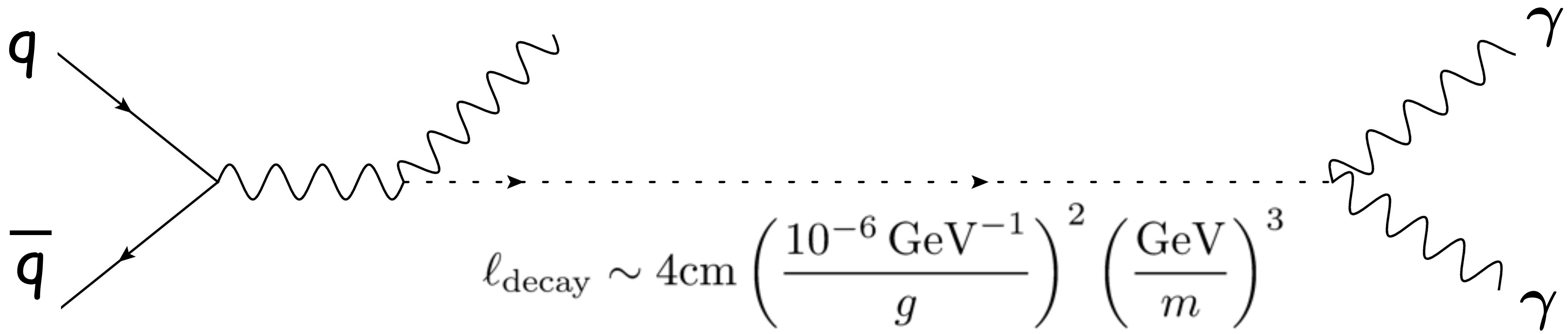


$$\ell_{\mathrm{decay}} \sim 4\mathrm{cm}\left(\frac{10^{-6}\,\mathrm{GeV}^{-1}}{g}\right)^2\left(\frac{\mathrm{GeV}}{m}\right)^3$$

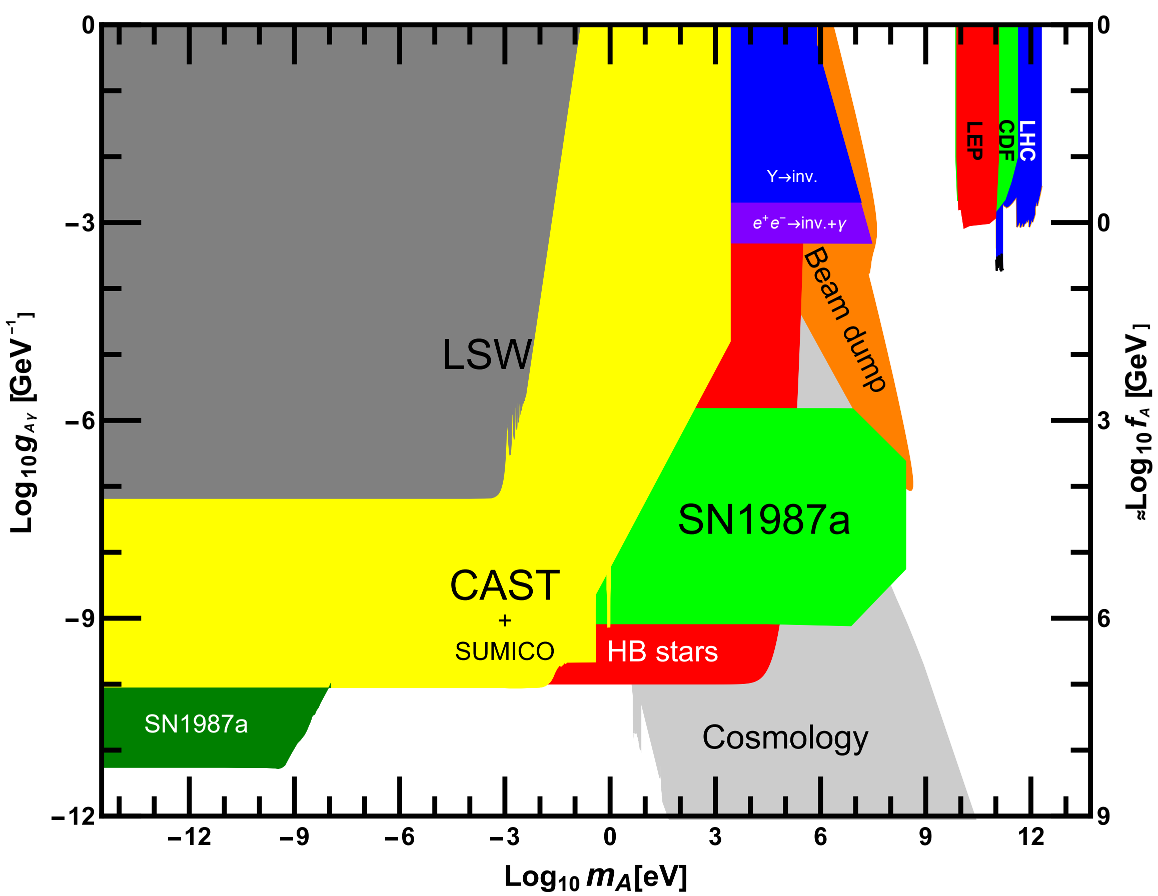
ALPs

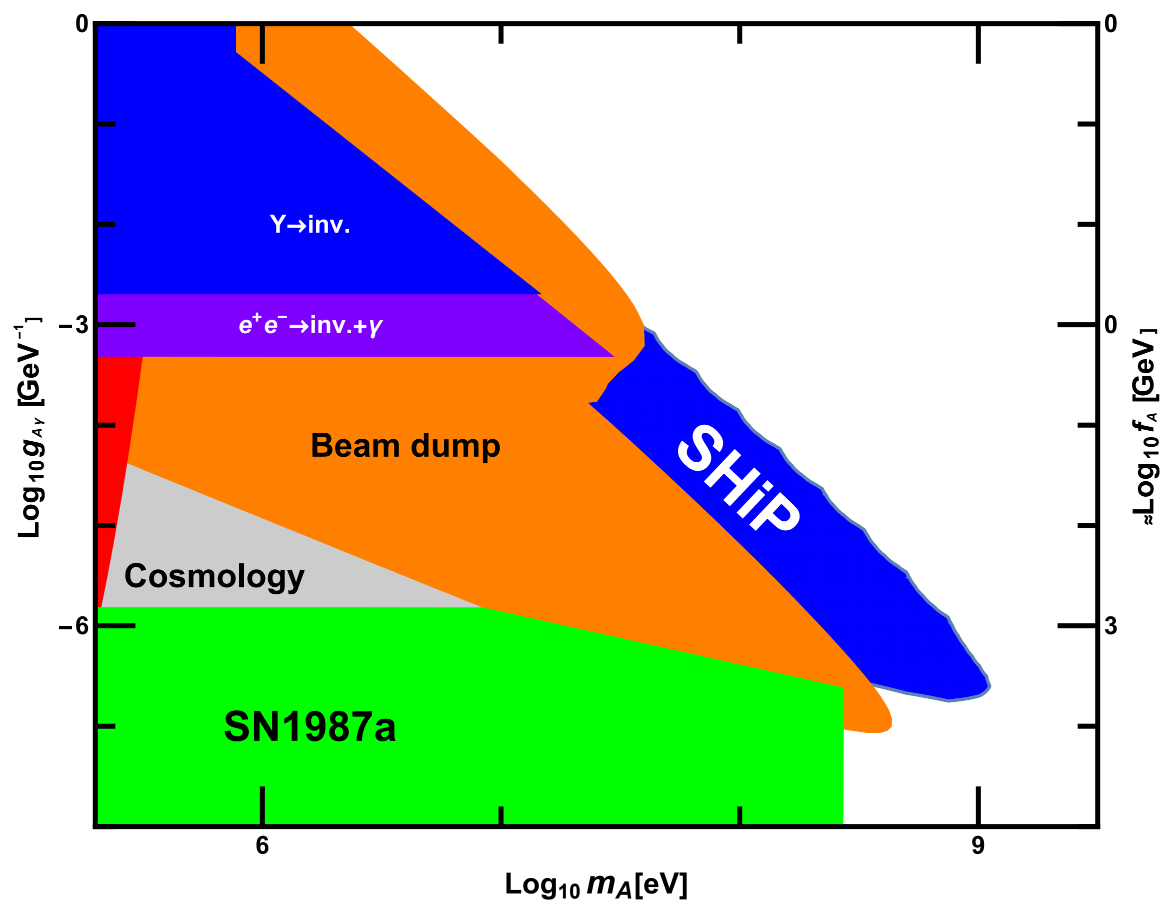
$$\mathcal{L}_{\rm ALPSM} = \sum_{f=q,\ell} \frac{C_{Af}}{2\,f_A} \bar f \gamma^\mu \gamma^5 f\, \partial_\mu A - \frac{\alpha}{8\pi}\frac{C_{A\gamma}}{f_A} F_{\mu\nu}\tilde F^{\mu\nu} A - \frac{\alpha_3}{8\pi}\frac{C_{A3}}{f_A} G^b_{\mu\nu}\tilde G^{b\,\mu\nu} A$$

$$\Gamma(A\to ii) = \frac{d(G) g_{Ai}^2 m_A^3}{64\pi}$$



$$\ell_{\rm decay} \sim 4{\rm cm} \left(\frac{10^{-6}\,{\rm GeV}^{-1}}{g}\right)^2 \left(\frac{\rm GeV}{m}\right)^3$$





Light neutralino

Conventional bound $M_{\tilde{N}}$>46 GeV holds only in CMSSM
astro bound (neutrino + DM) assumes Ñ stable
light neutralino possible if R-parity violatoin

Production

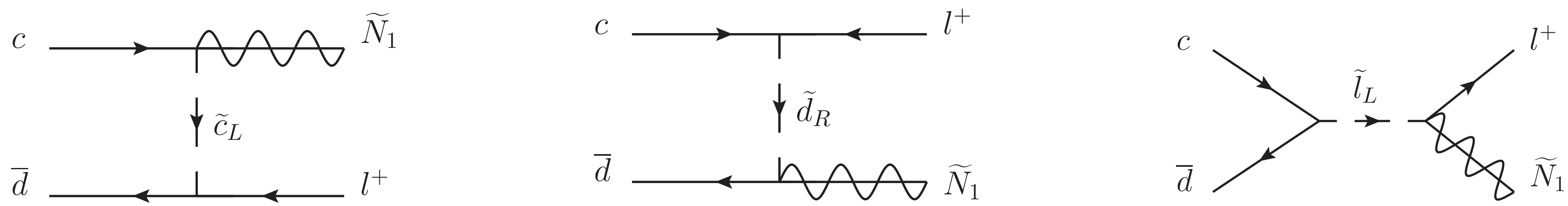
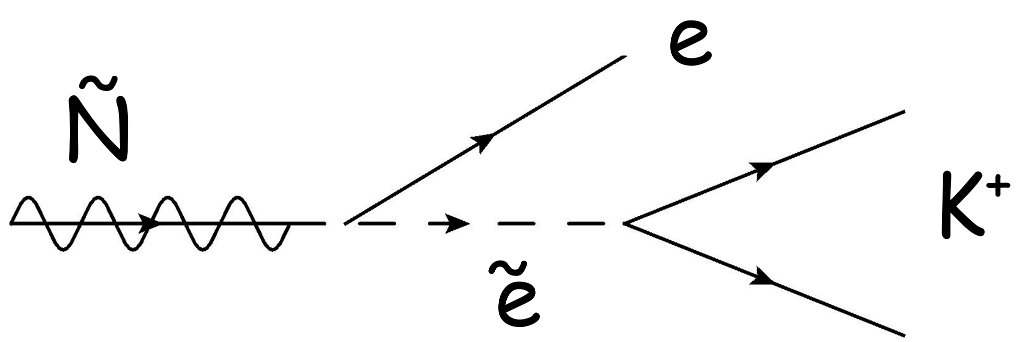


Figure 6.1: Relevant Feynman Diagrams for $D^+ \to \widetilde{N}_1^0 + \ell^+$.

Decay



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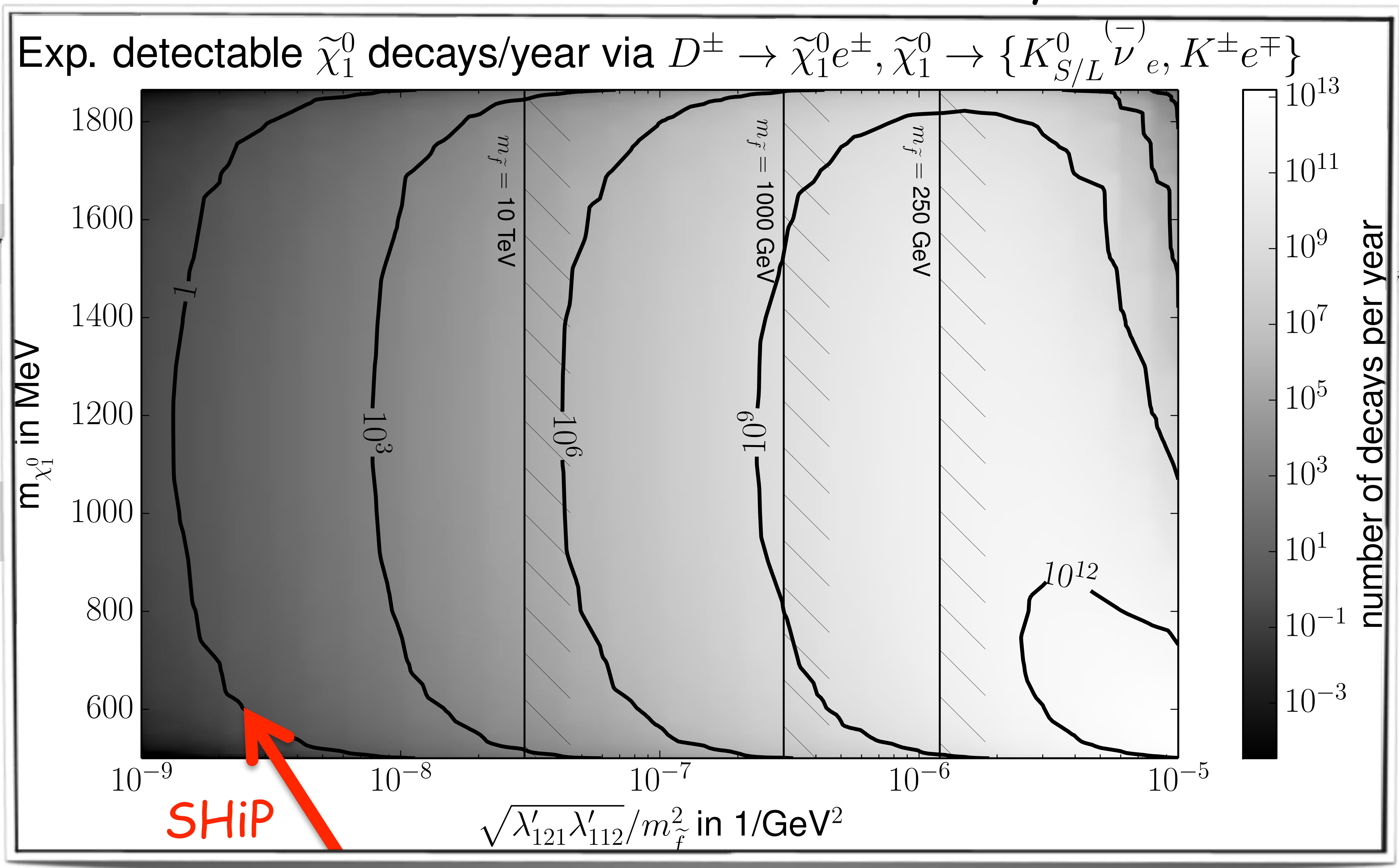


Light sGoldstinos

$$pp \to S(\text{gluon fusion}),\ \mathrm{S} \xrightarrow{\text{long lived}} \ell^+\ell^-, \pi^+\pi^-, \pi^0\pi^0$$
$$pp \to D + X \to S + X',\ S \xrightarrow{\text{long lived}} \ell^+\ell^-, \pi^+\pi^-, \pi^0\pi^0,$$

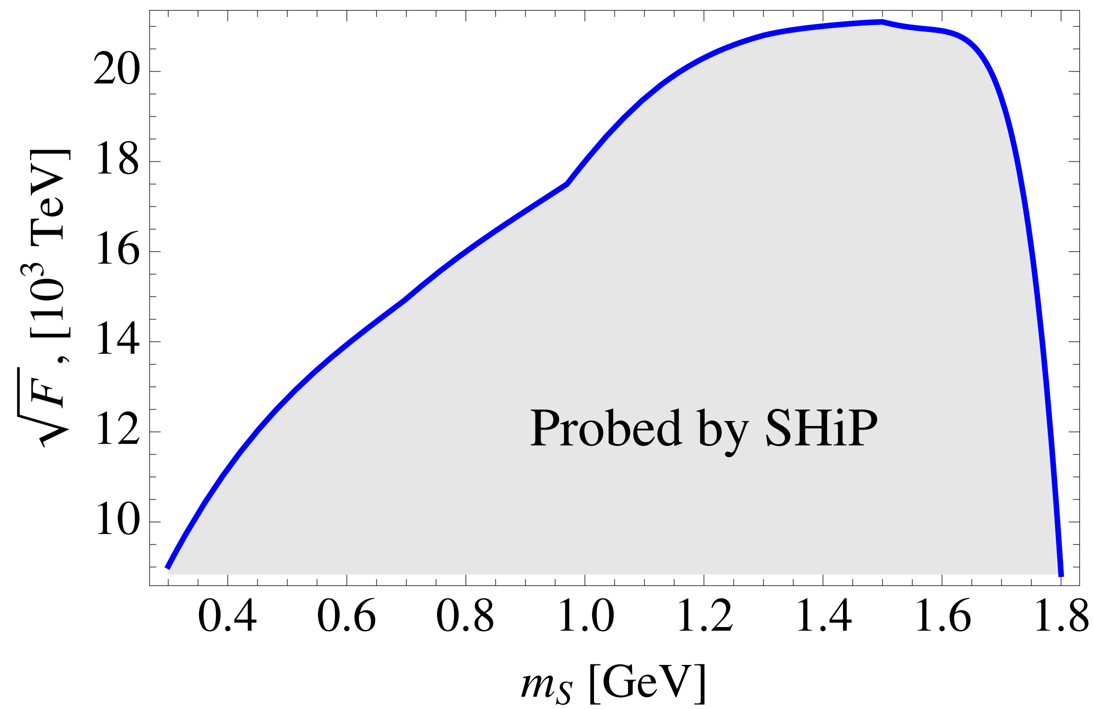


Figure 6.3: SUSY breaking scale $\sqrt{F}$ probed by SHiP as a function of the sgoldstino mass $m_S < m_D$ in the lepton flavour violating case, Eq. (6.3.8). The down-squark left-right mass matrix element was chosen $\tilde{m}^{LR\,2}_{D_{12}} = (100\,\mathrm{GeV})^2$ and the gaugino mass $M_3 = 3\,\mathrm{TeV}$. The result scales with $\tilde{m}^{LR\,2}_{D_{12}}$ and M_3 as shown in Eq. (6.3.13).

Other scenarios considered in Physics Case

- Dirac gauginos
- Hidden photinos
- axinos, saxion

5

SM physics @ SHiP

MOTIVATION FOR ν_τ STUDIES

- Less known particle in the Standard Model
- First observation by DONUT at Fermilab in 2001 with 4 detected candidates, *Phys. Lett. B504 (2001) 218-224*
- 9 events (with an estimated background of 1.5) were reported in 2008 with looser cuts

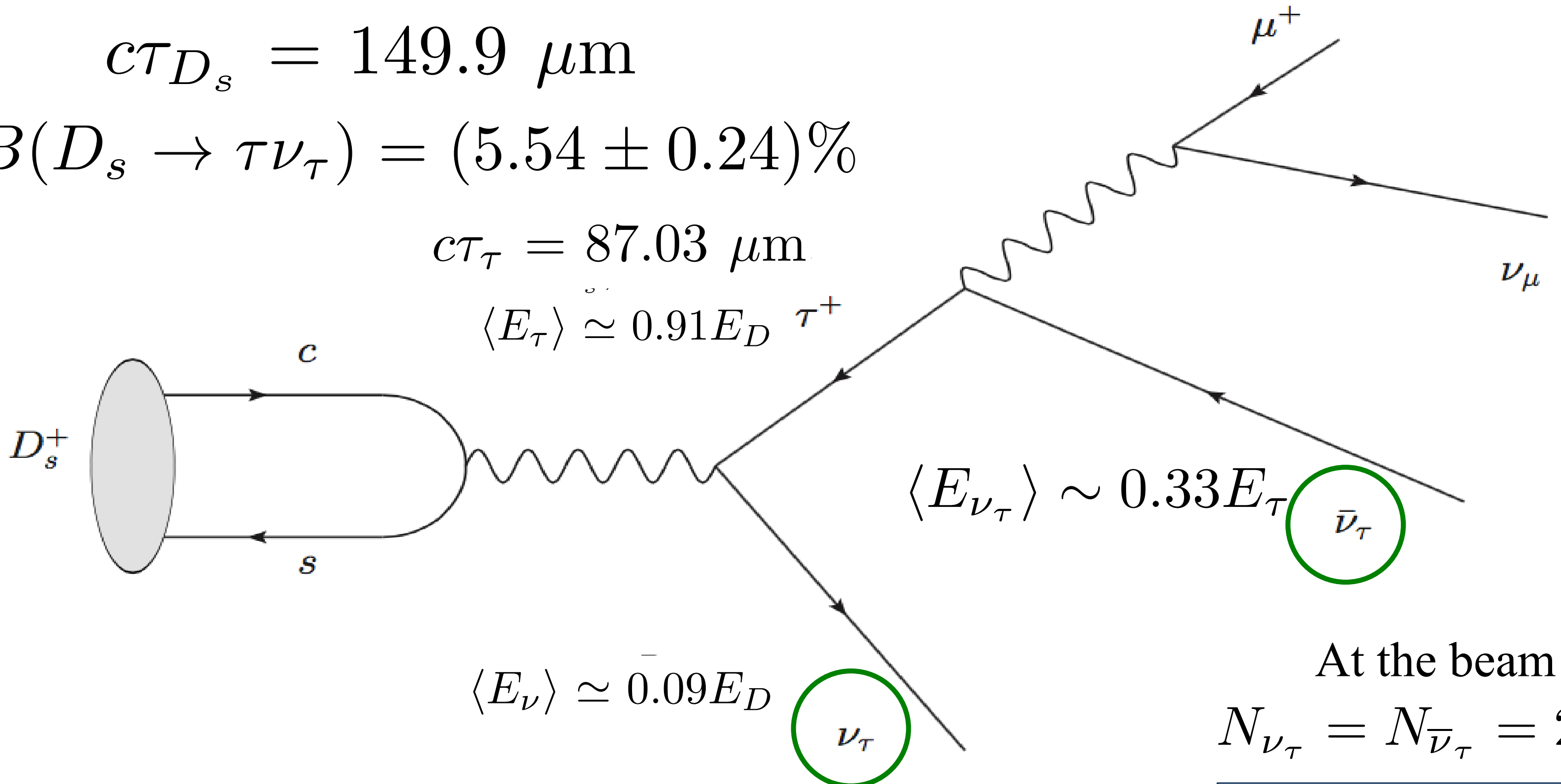
$$\sigma^{\text{const}}(\nu_\tau) = (0.39 \pm 0.13 \pm 0.13) \times 10^{-38}\ \text{cm}^2\ \text{GeV}^{-1}$$

- 5 ν_τ candidates reported by OPERA for the discovery (5.1σ result) of ν_τ appearance in the CNGS neutrino beam
- Tau anti-neutrino never observed

De Lellis @ SHiP Open Symposium '15

ν_τ @SHiP

$$c\tau_{D_s} = 149.9\ \mu\text{m}$$
$$B(D_s \to \tau\nu_\tau) = (5.54 \pm 0.24)\%$$

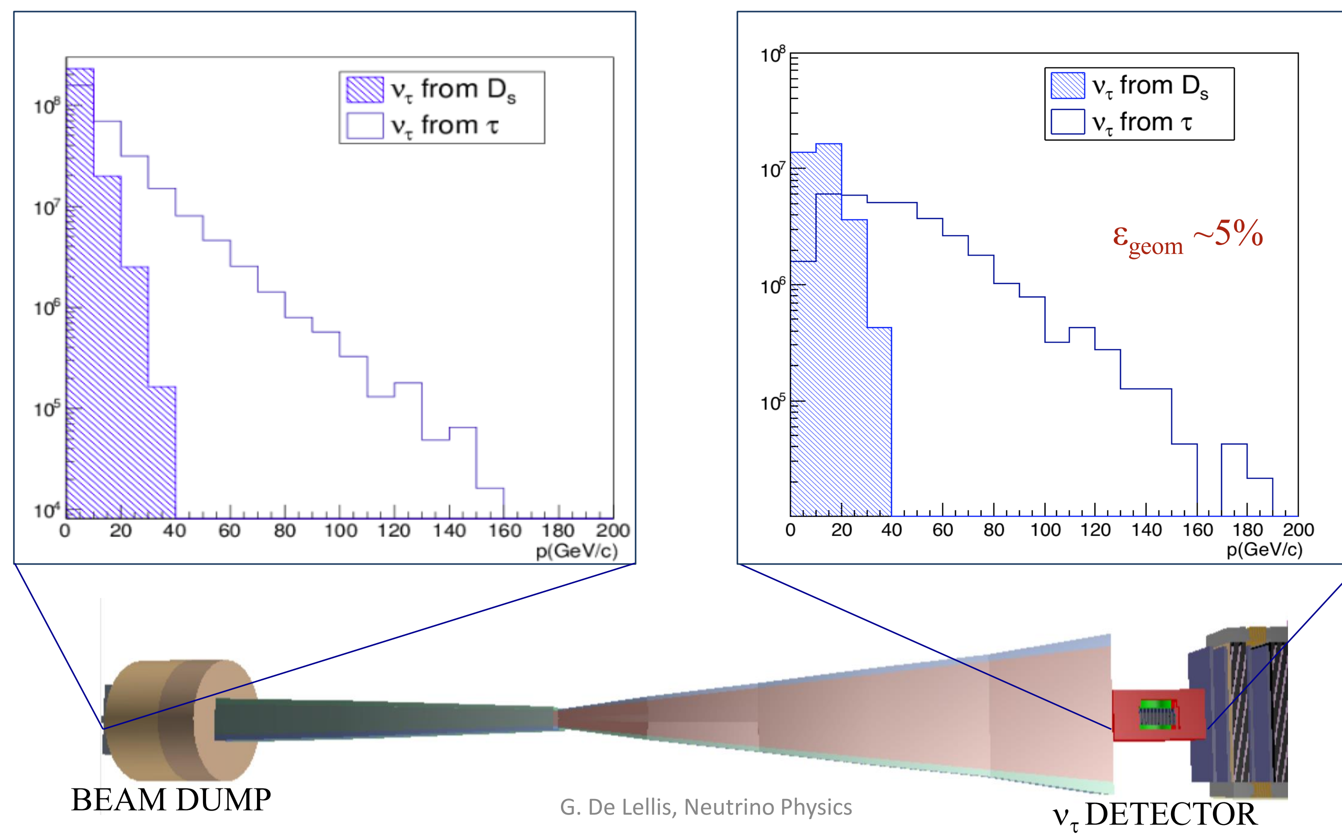


At the beam dump*

$$N_{\nu_\tau} = N_{\overline{\nu}_\tau} = 2.8 \times 10^{15}$$

At the neutrino detector*

$$N_{\nu_\tau} = N_{\overline{\nu}_\tau} = 1.4 \times 10^{14}$$



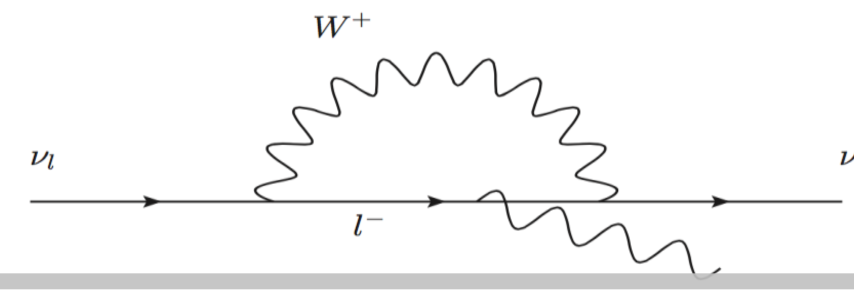
G. De Lellis, Neutrino Physics 6

TAU NEUTRINO MAGNETIC MOMENT

De Lellis @ SHiP Open Symposium '15

A massive neutrino may interact e.m.

→ magnetic moment proportional to its mass



$$\mu_\nu = \frac{3\,e\,G_F\,m_\nu}{8\,\pi^2\,\sqrt{2}} \simeq (3.2\times 10^{-19})\left(\frac{m_\nu}{1\,\mathrm{eV}}\right)\mu_B$$

Current limits:

$$(\nu_e) \quad \mu_\nu < 2.9\cdot 10^{-11}\mu_B$$
$$(\nu_\mu) \quad \mu_\nu < 6.9\cdot 10^{-10}\mu_B$$

μ_ν contribution to νe elastic scattering xs

$$\left.\frac{\sigma_{(\nu e,\bar\nu e)}}{dT}\right|_{\mu_\nu} = \frac{\pi\alpha_{em}^2\mu_\nu^2}{m_e^2}\left(\frac{1}{T}-\frac{1}{E_\nu}\right)$$

No interference as it involves a spin flip of the neutrino

$$\theta^2_{\nu-e} < 2m_e/E_e$$

IN SHiP

SIGNAL SELECTION

$$\theta_{\nu-e} < 30\,mrad$$
E_e > 1 GeV

$$n_{evt} = \frac{\mu_\nu^2}{\mu_B^2}\int \Phi_{\nu_\tau}\sigma^\mu N_{nucl}dE = 4.3\times 10^{15}\frac{\mu_\nu^2}{\mu_B^2}$$

BACKGROUND PROCESSES

$\nu_x + e^-$	$\rightarrow$ $\nu_x + e^-$	NC	390
$\nu_e(\bar\nu_e) + e^-$	$\rightarrow$ $e^- + \nu_e(\bar\nu_e)$	CC	
$\nu_e + n$	$\rightarrow$ $e^- + p$	QE	2440
$\bar\nu_e + p$	$\rightarrow$ $e^+ + n$	QE	
$\nu_e(\bar\nu_e) + N$	$\rightarrow$ $e^-(e^+) + X$	DIS	730

Assuming 5% systematics from DIS measurements

SHiP can explore a region down to

$$\mu_\nu = 1.5\times 10^{-7}\mu_B$$

Strangeness of nucleon

anti-c production

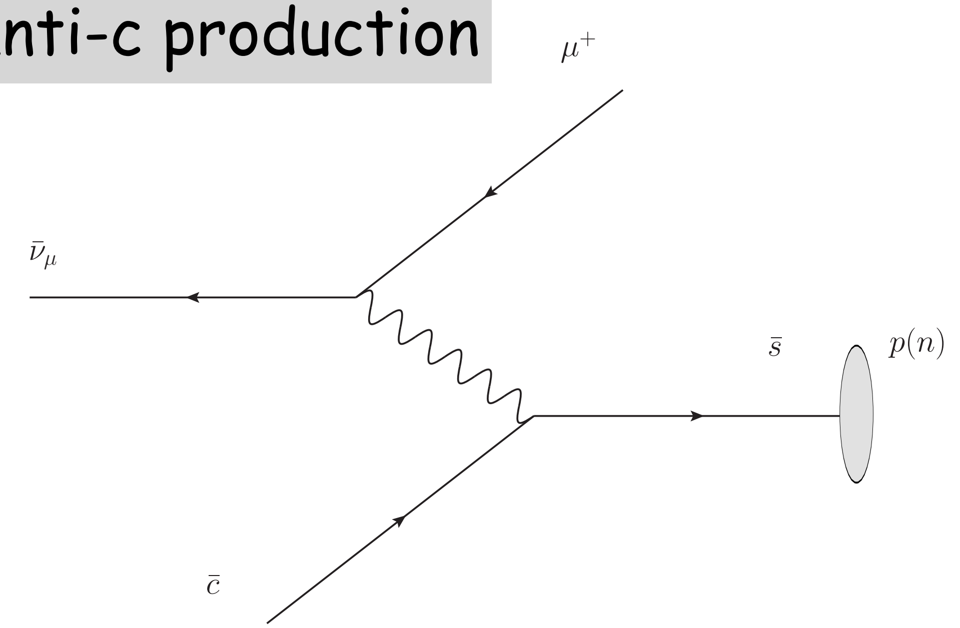


Diagram for anti-charm production in anti-neutrino charged current interactions.

u-initiated prod. is CKM suppressed

strange quark PDF

⇓ ⇓

W mass determination

$\text{LHC}_{14\text{TeV}}$: W produced 80% ud + 20% cs

⇓ ⇓

EW precision tests

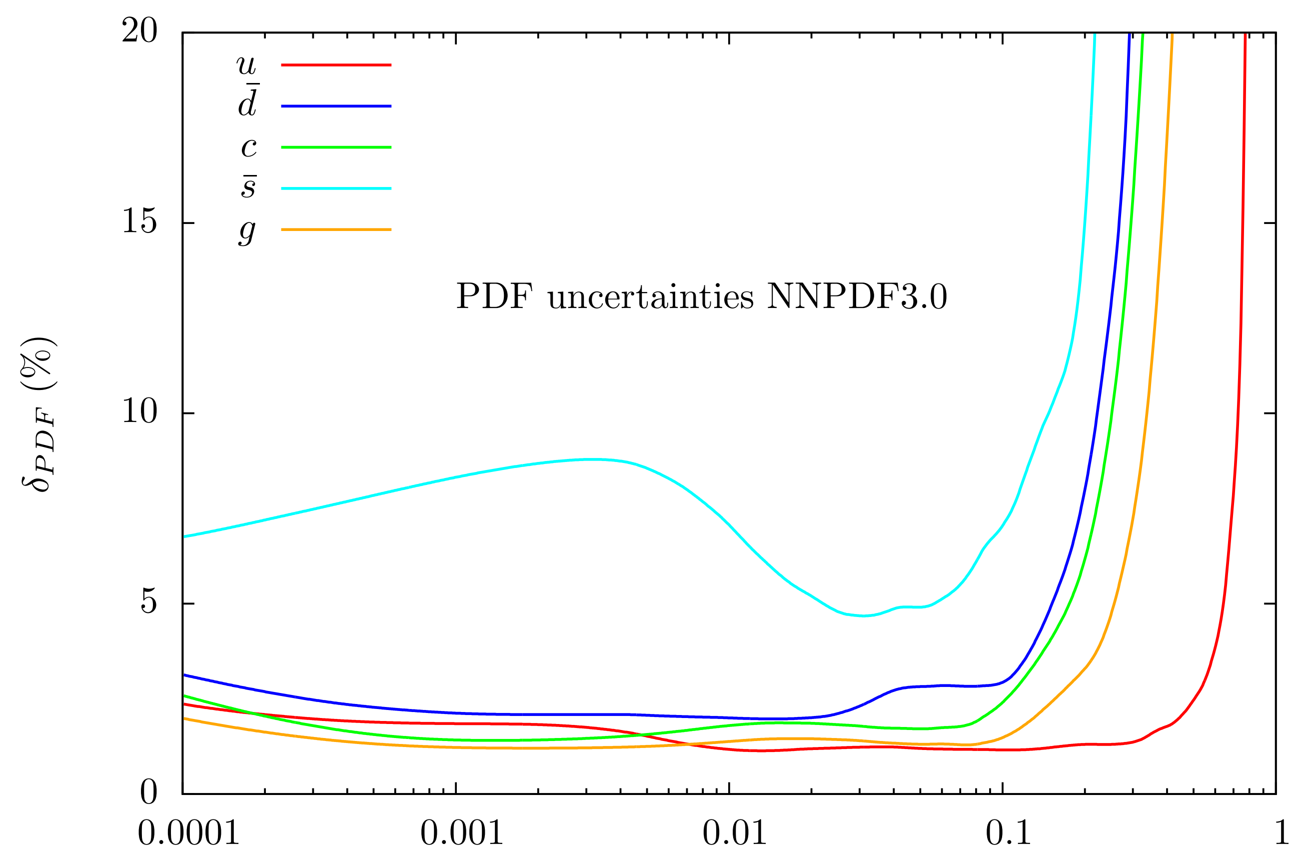
+ Probe BSM

strangeness uncertainty ~3 times larger then the others

current limits from NuTeV

SHiP will have more statistics (x2)

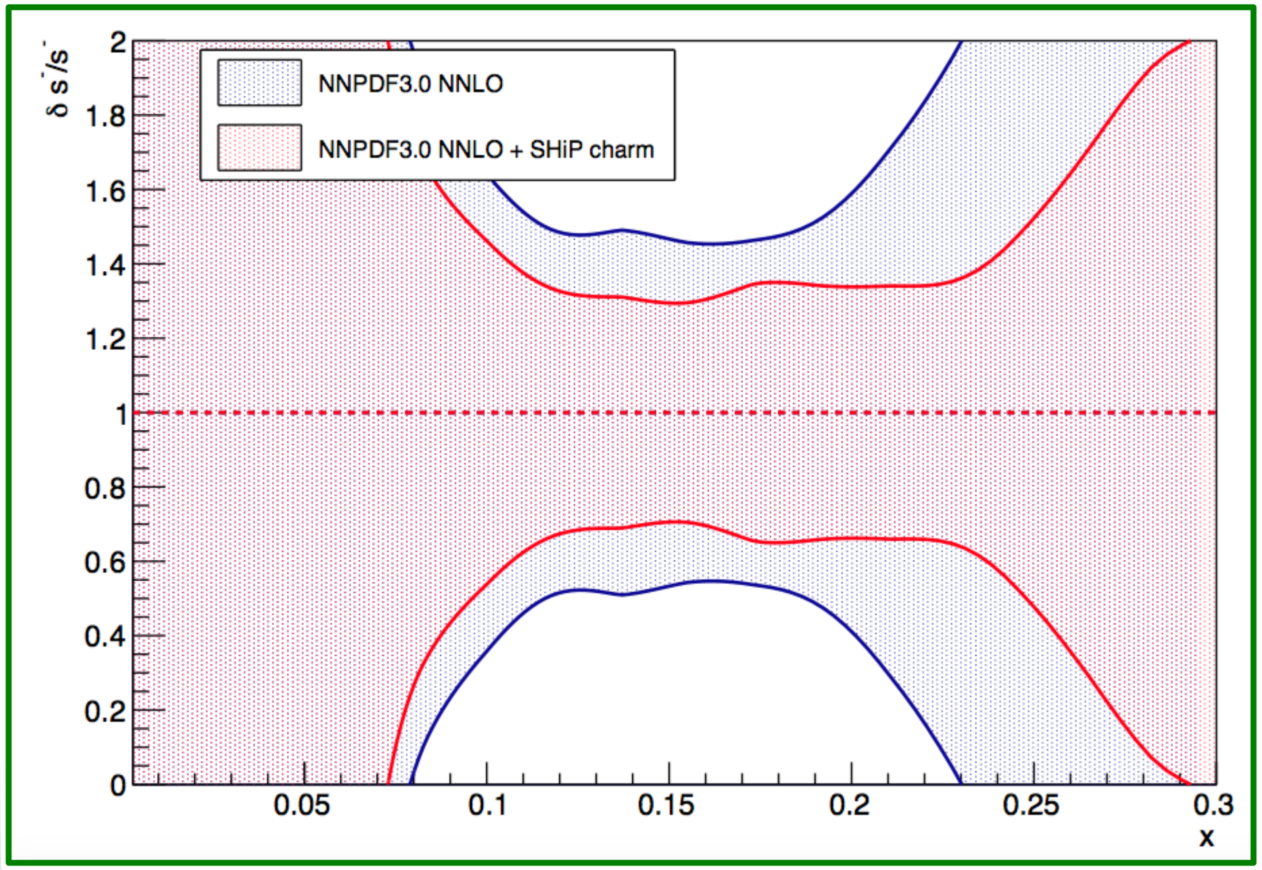
100'000 charm and 50'000 anti-charm

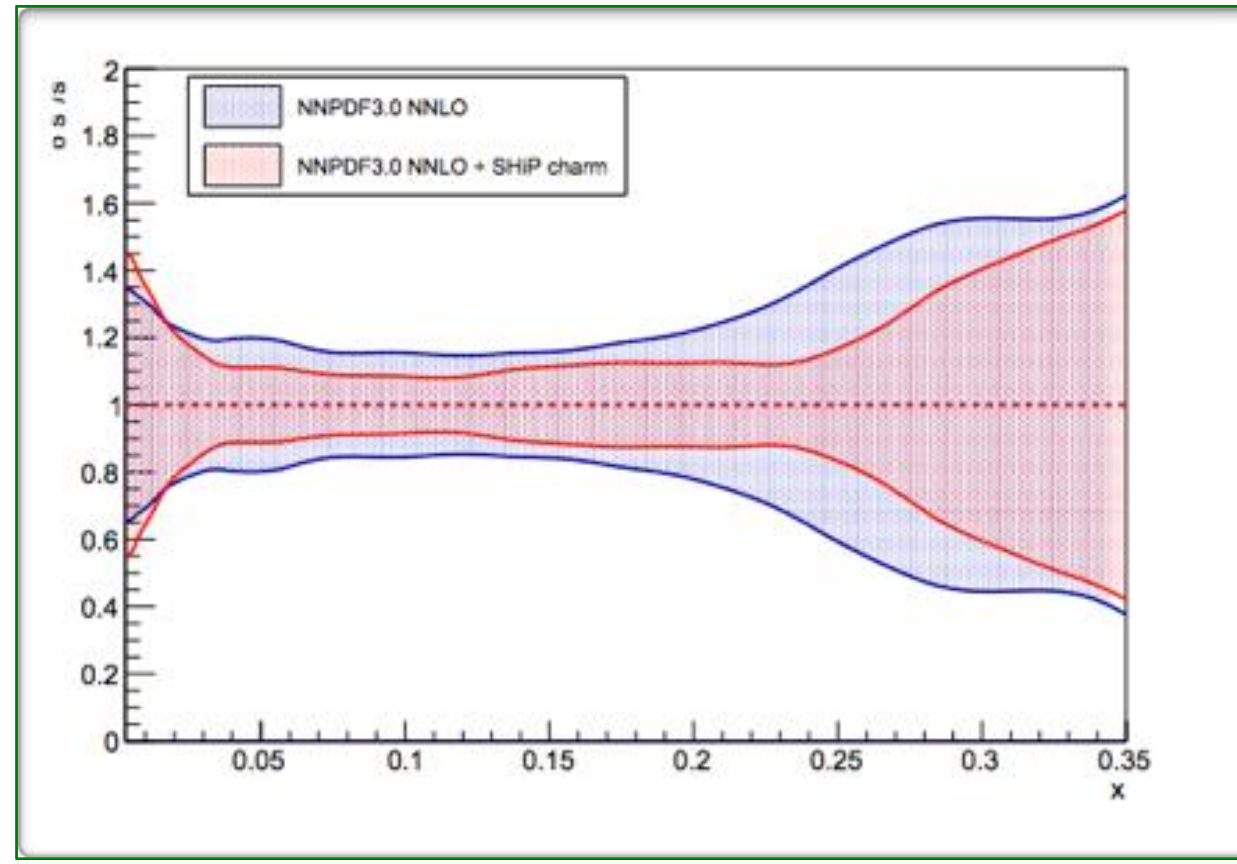


Strangeness of nucleon

anti-c production

strange quark PDF

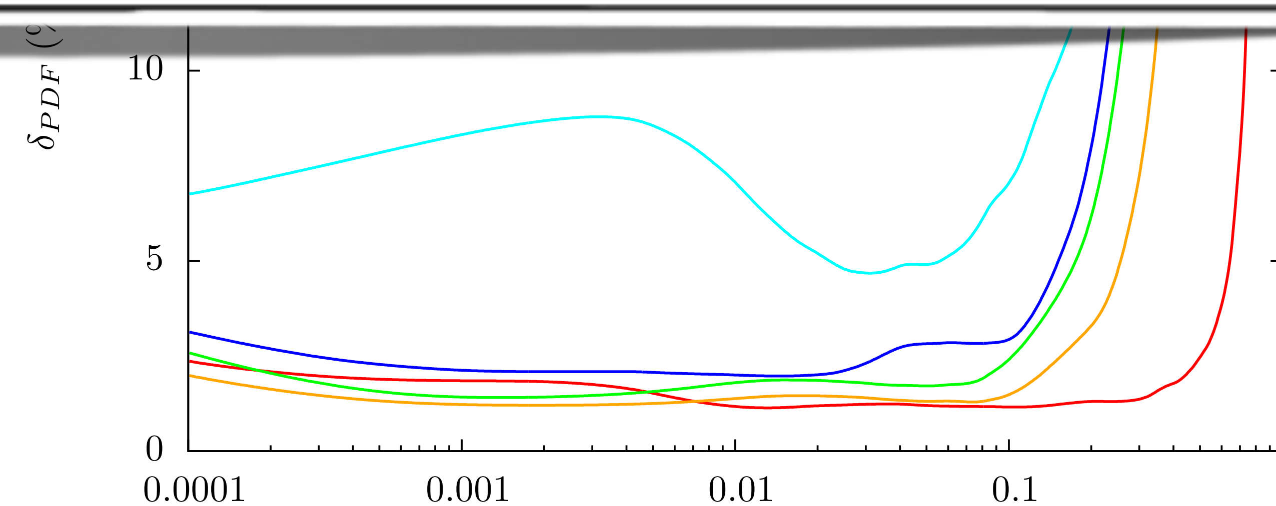




$$s^{-} = s(x) - \bar{s}(x)$$

$$s^{+} = s(x) + \bar{s}(x)$$

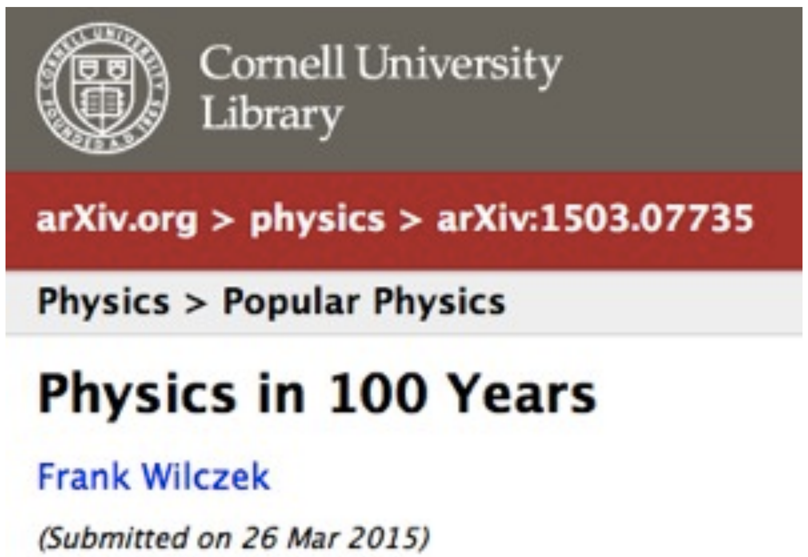
current limits from NuTeV
SHiP will have more statistics (x2)
100'000 charm and 50'000 anti-charm



Other SM topics at SHiP

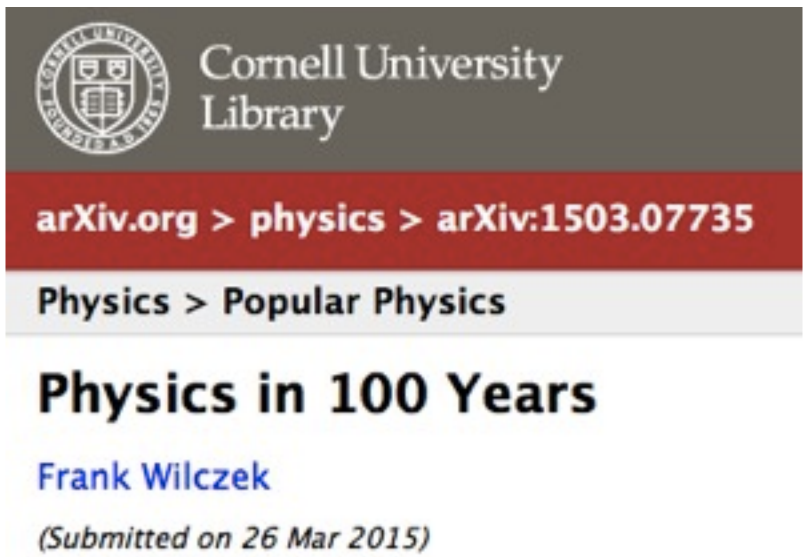
- strong coupling constant measurement (via DIS ν_τ on nucleons and Gross-Lewellin-Smith sum rule)
- measurement of F4 and F5 structure constants, check of the Albrect-Jarlskog relation
- production of exotic baryons (charmed pentaquark)
- bound on Br($\tau \to 3\mu$) (~10^{-10} vs current 10^{-8} BaBar/Belle, 10^{-9} BelleII)

Conclusions



- What are the weak points in our current understanding and practices?
- What are the growth areas in technique and capability?
- Where are the sweet spots where those two meet?

Conclusions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Physics in 100 Years

Frank Wilczek

(Submitted on 26 Mar 2015)

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" Looking and not finding is different than not looking"