SHiP: a new facility to search for long lived neutral particles and investigate the ν_τ properties

SHiP

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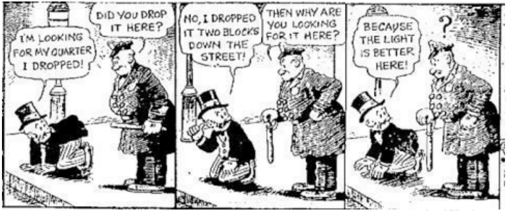
Introduction

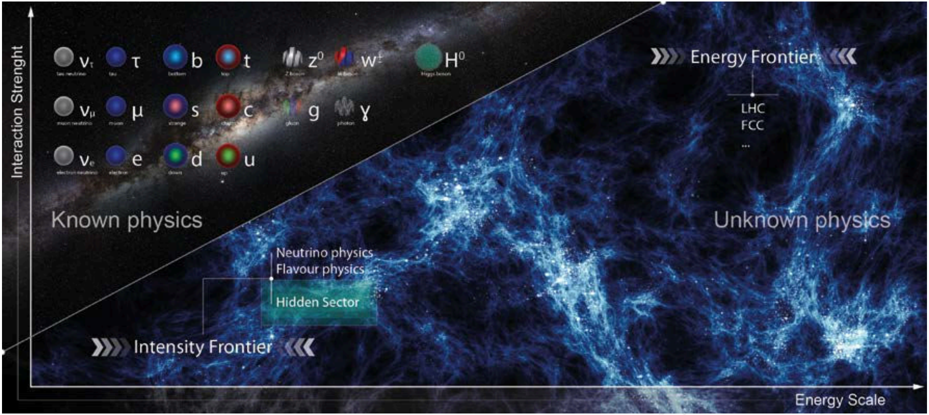
- **Standard Model** success: observation of the Higgs boson!
- **Unexplained** phenomena still require new physics. But where?

- Neutrino masses and oscillations:
  Right-handed see-saw neutrino masses from $\mathbf{1}$ **eV** to $\mathbf{10^{15}}$ **GeV**
- Dark matter:
  $\mathbf{10^{-22}}$ **eV** (super-light scalars) to $\mathbf{10^{20}}$ **GeV** (wimpzillas, Q-balls)
- Baryogenesis:
  Mass of new particle from $\mathbf{10}$ **MeV** to $\mathbf{10^{15}}$ **GeV**



Where is new physics? Experimental approach

- ➜ Unsolved problems $\Longrightarrow$ there must be new particles
- ➜ Why didn't we detect them? Too heavy or too weakly interacting



Richard Jacobsson and Daniel Dominguez

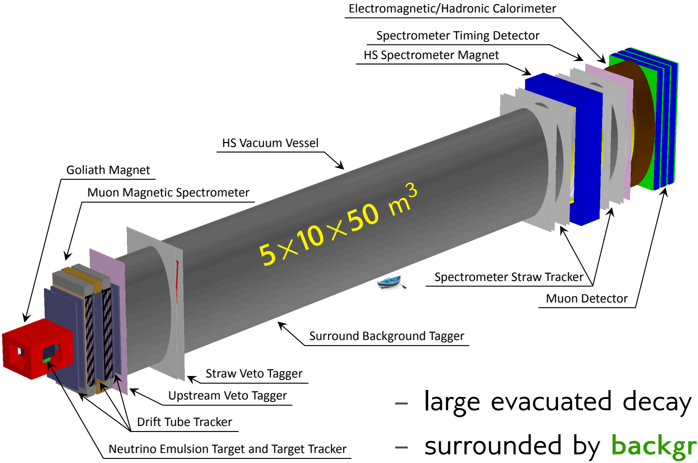
SHiP: Search for Hidden Particles

- SHiP is a new proposed experiment at the CERN SPS, aiming to search for neutral hidden particles with mass up to $\mathcal{O}(10)$ GeV and extremely weak couplings, down to 10^{-10}.
- production and decay of hidden particles:

  - large decay volume followed by spectrometer, calorimeter, PID
  - shielding from SM particles: hadron absorber + VETO detectors

- High intensity 400 GeV beam dump $\Longrightarrow$ high flux of neutrinos (all species).
- facility ideally suited for studying ν_τ and observing $\bar{\nu}_\tau$, produced in charm decays such as $D_s \to \tau^+ \left(\to \mu^+ \nu_\mu \boldsymbol{\bar{\nu}_\tau}\right) \boldsymbol{\nu_\tau}$

The Hidden Sector detector



- large evacuated decay volume (10^{-6} bar)
- surrounded by **background taggers**
- as close as possible to target
- in a μ-free area thanks to **active shield**

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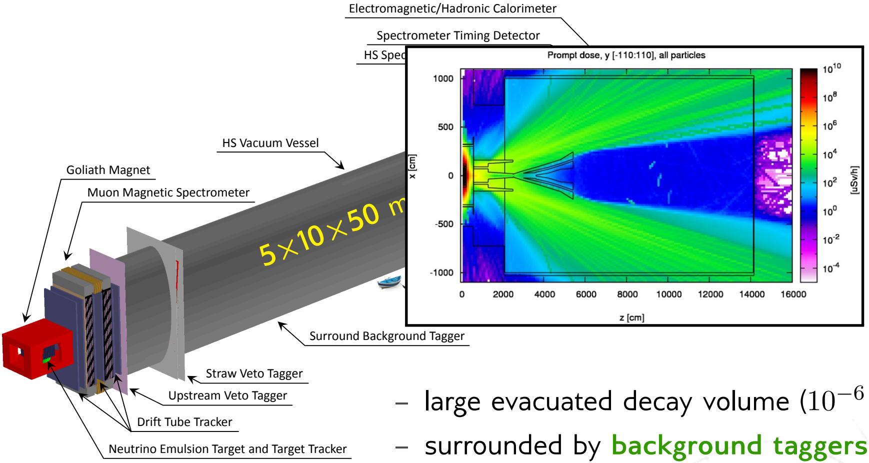

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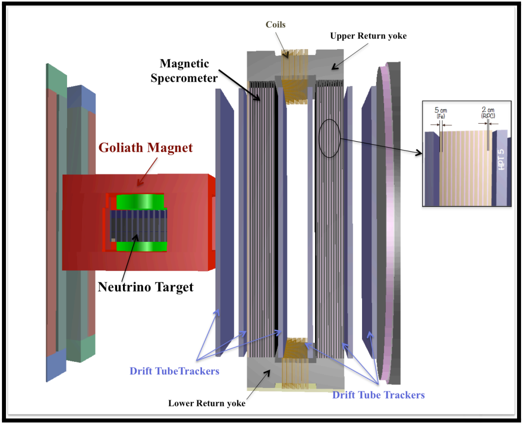
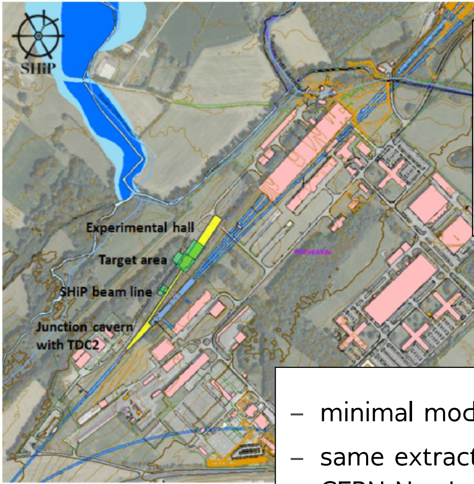
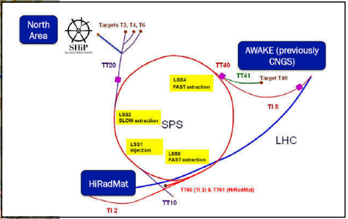
The ν_τ detector



Target made of interlaced layers of emulsion bricks and scintillating fibres, resolution of 1 µm $\Longrightarrow$ charge of τ daughters.
Muon tracker: RPCs and drift tubes. Also tags BG for HS physics.

The facility at the SPS





- minimal modification to the SPS complex
- same extraction and transfer line as other CERN North Area facilities
- 190 m long, 20 m wide hall

Background sources and strategy

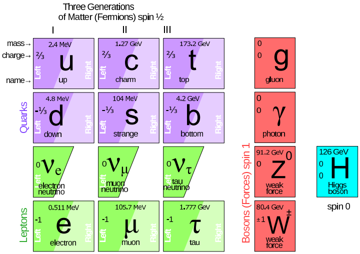
- ➜ **cosmic + beam μ** can scatter/DIS on the cavern/vessel walls ➜ μ shield, liquid scintillator, topology + pointing
- ➜ **random combinations** of tracks from different events/vertices ➜ timing detector, vertex quality
- ➜ **ν interactions** in the material of the HS detector and upstream (closely mimick HP decay topology) ➜ ν detector, upstream veto, straw veto, topology + pointing

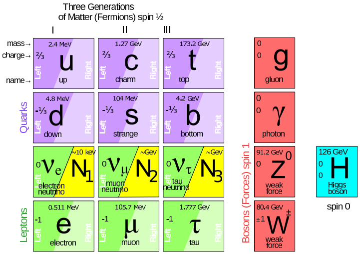
Selection efficiency

Sample	Multiplicity	Fiducial vol	Track q.	BG cuts/VETO
$HNL \to \pi\mu$	97.5 %	76.1 %	87.0 %	94.2 %
$\gamma' \to \mu\mu$	99.6 %	85.2 %	94.4 %	94.0 %
ν background	79.1 %	21.0 %	6.5 %	0.0 %

Overall $\lesssim 0.1$ background events / 5 years is attainable!

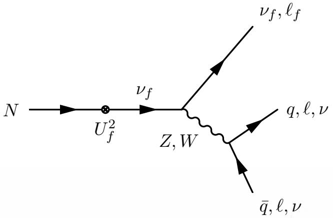
The νMSM Asaka, Blanchet, Shaposhnikov, Phys.Lett. B631 (2005) 151-156





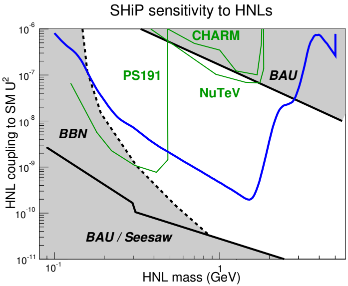
Suitable values of m_N and U_f^2 allow to simultaneously explain:

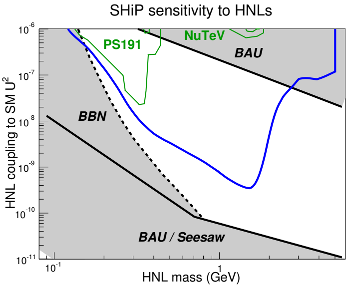
- ν oscillations induced by massive states N_2, N_3
- dark matter: N_1 with mass ~keV
- BAU: leptogenesis due to Majorana mass term



SHiP sensitivity to N_2, N_3

- production in charm and beauty meson decays
- decay into $h\ell$ and $\ell\ell\nu$





➜ interpretation of limits is model dependent (above: IH and NH)

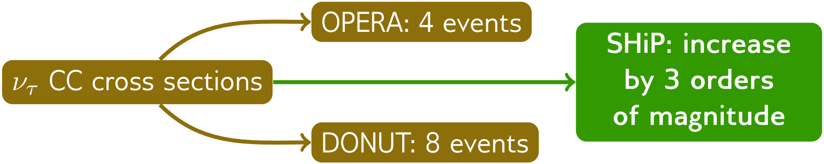
➜ νMSM parameter space almost totally explored for $m_N \leq 2$ GeV!

➜ sensitive to most theories with similarly long lived massive particles

Physics with ν_τ

Neutrino detector (mostly lead) allows to:

- identify flavour
- measure charge of emerging μ and τ



ν_τ CC cross sections

OPERA: 4 events

DONUT: 8 events

SHiP: increase by 3 orders of magnitude

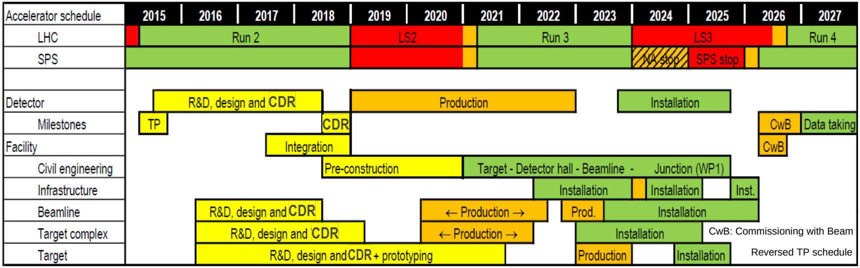
→ PDF improvements with ν-nucleon DIS

→ tests of lepton universality

→ **BONUS:** dark matter scattering...

What’s next

- ➜ **Technical ↗ and Physics ↗ proposals** prepared in 2014-2015
  - feasibility studies, facility design, engineering, test beams, sensitivities
- ➜ **Green lights** from the SPSC, recommendation to produce CDR (Comprehensive Design Report) for European HEP strategy 2019
- ➜ **10 years** from Technical Proposal to data taking
  - schedule optimized for minimal interference with SPS operation



Accelerator schedule	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LHC	Run 2				LS2		Run 3			LS3		Run 4	
SPS										NA stop	SPS stop		
Detector	R&D, design and **CDR**				Production				Installation				
Milestones	TP			**CDR**								CwB	Data taking
Facility			Integration									CwB	
Civil engineering				Pre-construction			Target - Detector hall - Beamline - Junction (WP1)						
Infrastructure							Installation			Installation	Inst.		
Beamline		R&D, design and **CDR**				← Production →		Prod.	Installation				
Target complex		R&D, design and **CDR**				← Production →			Installation				
Target		R&D, design and **CDR** + prototyping							Production	Installation			

CwB: Commissioning with Beam

Reversed TP schedule

Conclusions

- ➜ **General purpose** experiment to look for weakly interacting long lived particles
  - probes unexplored regions of the Hidden Sector in several New Physics theories
  - covers cosmologically interesting regions
- ➜ **Unique** opportunity for **ν_τ physics** allowing for
  - $\bar{\nu}_\tau$ discovery
  - σ and form factors measurements
  - also dark matter search
- ➜ **Complements** LEP/LHC and makes best use of the existing SPS complex

SHiP

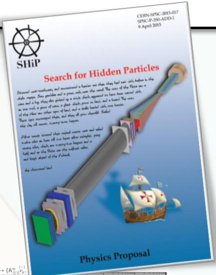
`ship.web.cern.ch`

Questions?

– spare slides –

A wide physics case…

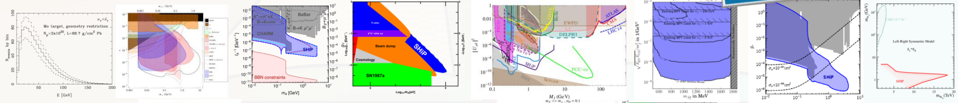
- Theories including HNLs are not the only ones probed by SHiP!
- Below, just a small extract from the SHiP Physics Paper…

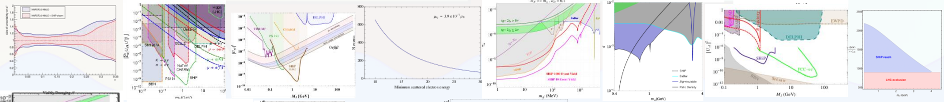

CERN-SPSC-2015-017
SPSC-P-350-ADD-1
9 April 2015

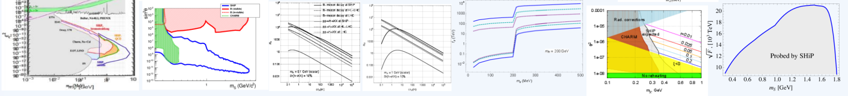
SHiP

Search for Hidden Particles

Physics Proposal

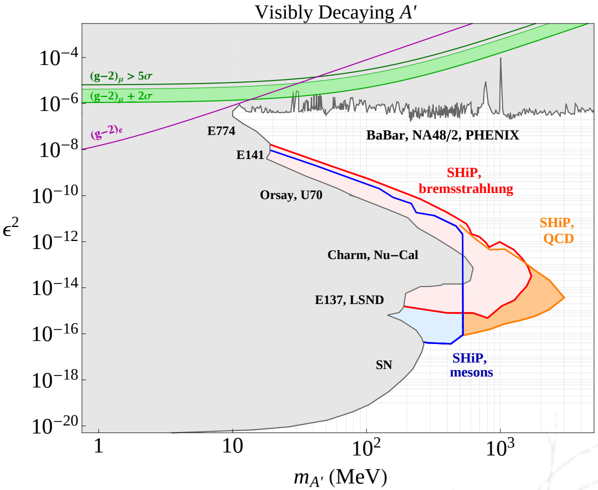






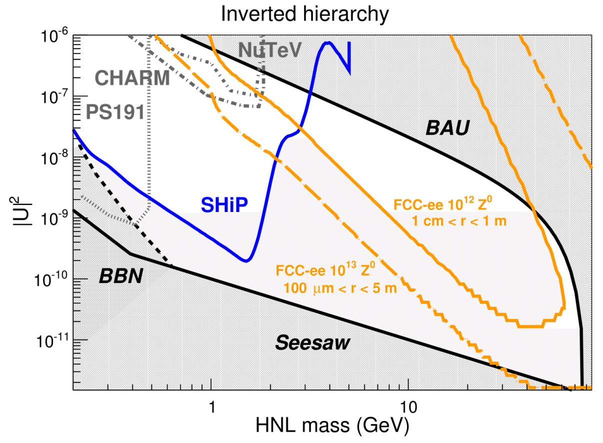
…and so much more…

SHiP sensitivity: vector portal



Sensitivity studied considering $\Gamma_{tot} = \Gamma(\ell^+\ell^-) + \Gamma(\text{hadrons})$.

HNLs at future colliders

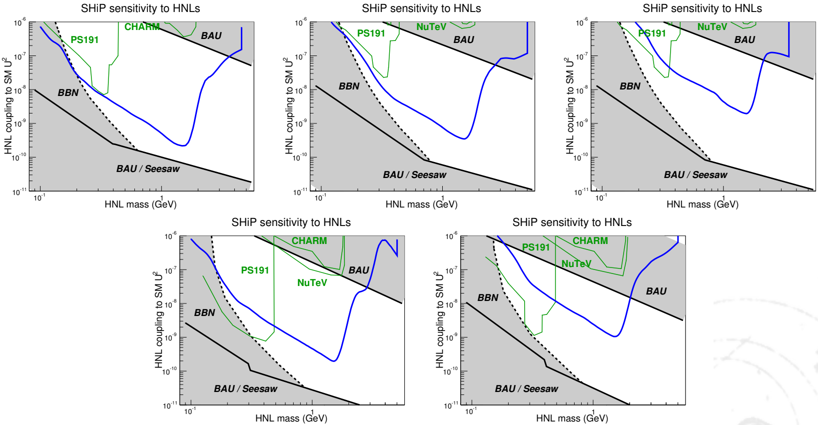


http://arxiv.org/abs/1411.5230

http://arxiv.org/abs/1503.08624

SHiP sensitivity to HNLs

- scenarios I-III: benchmarks with U_e^2, U_μ^2, U_τ^2 dominating (JHEP 0710 (2007) 015)
- scenarios IV-V: baryogenesis numerically proven (JCAP 1009(2010)001)



Sensitivity with non-zero background

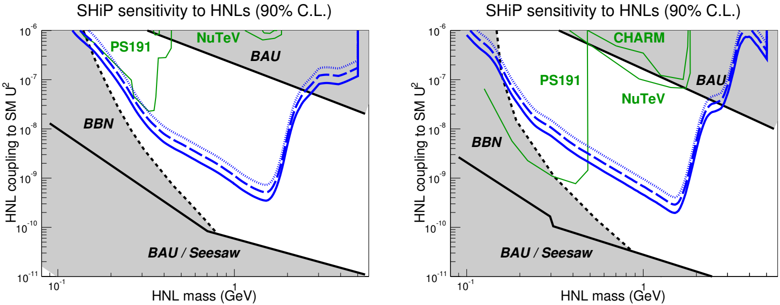
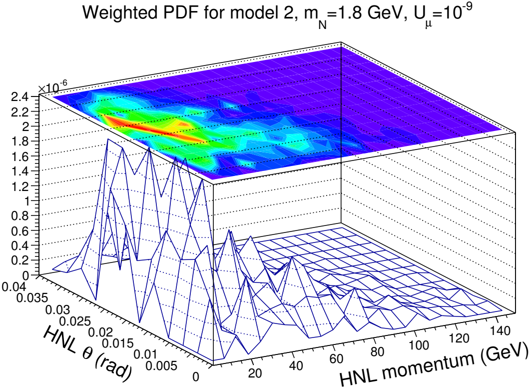


Figure: Variation of the sensitivity contours for scenarios II (left) and IV (right) as a function of the background estimates. The solid blue curve represents the 90% C.L. upper limit assuming 0.1 background events in 2×10^{20} proton-target collisions. The dashed blue curve assumes 10 background events. The dotted blue curve assumes a systematic uncertainty of 60% on the level of background, i.e. 10 ± 6 background events.

Estimating SHiP's physics reach

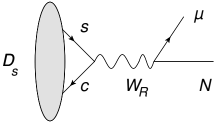
$\Phi(p.o.t) \times \mathcal{BR}(pp \to NX) \times \mathcal{P}_{vtx} \times \mathcal{BR}(N \to visible) \times \mathcal{A}$

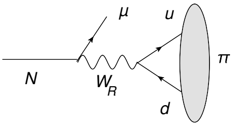
- HNL's momentum and angle are stored in a binned PDF
- HNL spectra are re-weighted by the probability $\mathcal{P}_{vtx}(p, \theta \,|\, m_N, U_f^2) \sim \int_V e^{-l/\gamma c\tau} dl$
- Integral of the weighted PDF gives the total probability $\mathcal{P}_{vtx}(m_N, U_f^2)$ that HNLs leave a vertex in SHiP's fiducial volume

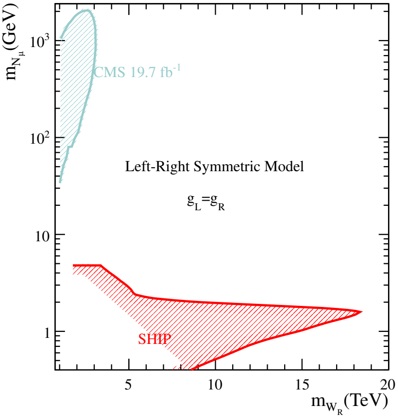


Weighted PDF for model 2, m_N=1.8 GeV, $U_\mu=10^{-9}$

Sensitivity in the Left-Right symmetric model



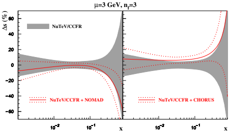




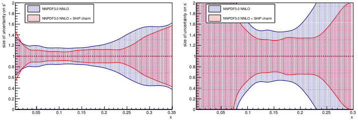
- SHiP limits on m_{W_R} can be extracted from the HNL limits by $|U_{\mu I}|^2 \to (m_{W_L}/m_{W_R})^4$
- LHC can perform direct searches on both W_R and N_R
- SHiP can only look for N_R, but in a domain inaccessible to LHC
- based on CMS, *Eur. Phys. J. C 74 (2014) 3149*, and Helo, Hirsch, Kovalenko, *Phys.Rev. D89 (2014) 073005*

Tests of perturbative QCD and lepton universality

- ➜ PDF improvements with ν-nucleon DIS: strange sea quark content currently relies on $\mathcal{O}(5000)$ charm di-μ events:

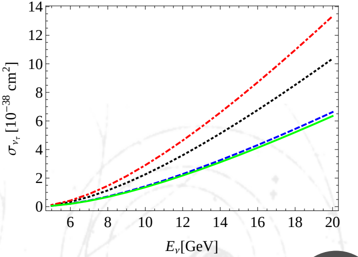


SHiP $> 10^5$ evts



LHC and SHiP will probe different ranges of x.

- ➜ Lepton universality tests:
  - hints from LHCb, B factories, ...
  - DIS σ including BSM: *Liu, Rashed, Datta PRD92(2015)7, 073016*, to compare to σ_{SM}
  - results depend on our knowledge of the ν_τ flux!



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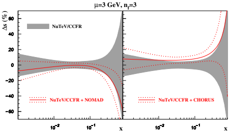
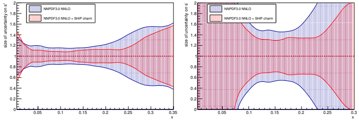


SHiP $> 10^5$ evts ⟶



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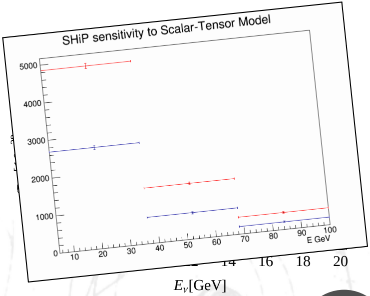
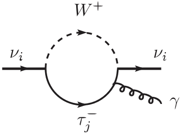
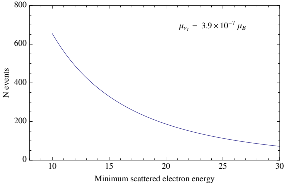


Neutrino magnetic moment





If neutrinos are Dirac particles they can get a magnetic moment:

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

BSM can enhance μ_ν. (E.g.: *Shrock, Nucl.Phys. B206 (1982) 359*)

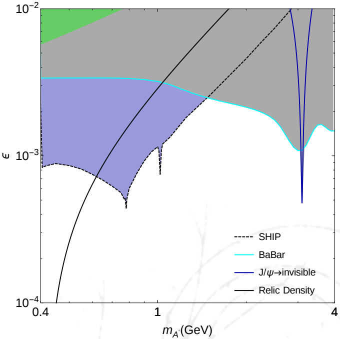
$$e\nu \to e\nu \Longrightarrow \left.\frac{dN}{dE_e}\right|_{\mu_\nu} = \frac{\pi\alpha^2\mu_\nu^2}{m_e^2}\left(\frac{1}{E_e} - \frac{1}{E_\nu}\right)$$

Remove BG from νN scattering: $\theta_{\nu e}^2 < 2m_e/E_e \Longrightarrow$ sensitivity: $N_{evt} \sim 4.3 \times 10^{15}\mu_\nu^2/\mu_B^2$. Prev. limits from 10^{-7} (ν_τ) to 10^{-11} (ν_e).

Dark matter search

Detect dark matter from dark photon decay through elastic scattering on electrons: $\chi e^- \to \chi e^-$. Signature in the emulsion target: a vertex with only e^- coming out. Simulation $\Longrightarrow$ background from neutrino scattering can be reduced with kinematical selections to 284 events / 5 y.

Dark photon parameter space for $\gamma' \to$ invisible decays excluded by SHiP at 90% C.L., with such expected background and for $m_\chi = 200$ MeV and $\chi\gamma'$ coupling $\alpha' = 0.1$:



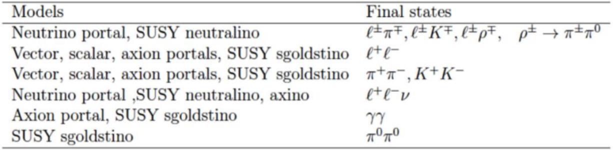
LFV processes

- **ν oscillations** provide evidence of LFV in the neutral sector
- **LFV** in charged sector foreseen with $\mathcal{BR} \sim \mathcal{O}(10^{-40})$!
- **New physics** models can enhance these $\mathcal{BR}$s
  - in seesaw models charged LFV can happen in tree or loop diagrams
  - $\ell \to 3\ell'$ generally favoured with respect to $\ell \to \ell'\gamma$ (type 2 and 3 seesaw)
- $\boldsymbol{\ell \to 3\ell'}$ related by unitarity to $Z^0, h, V \to \ell^+\ell'^-$ and $\ell \to \ell'$ conversion in nuclei (most stringent limits so far by SINDRUM II)
  - $\tau \to 3\mu$ and $\mu \to 3e$ can provide better limits than direct searches e.g. for $\phi \to e\mu$, $J/\Psi \to e\mu$
  - $\mathcal{BR}(\tau \to 3\mu) < 1.2 \times 10^{-8}$ (BaBar,Belle,LHCb) *HFAG, arXiv:1412.7515*
- **SHiP** will collect 3×10^{15} τ in the forward region
  - requires changes to conceptual design (upgrade):
  - 1 mm W target: 100× less τ, but decaying outside target
  - LHCb VELO + Si tracker + hadron absorber + μ spectrometer
  - sensitivity $\sim 10^{-10}/\sqrt{N_{\text{targets}}}$

The Hidden Sector

$$L_{world} = L_{SM} + L_{mediation} + L_{HS}$$

- **Neutrino portal**: new Heavy Neutral Leptons coupling with Yukawa coupling, $L_{NP} = F_{\alpha I}\left(\bar{L}_{\alpha}\widetilde{\Phi}\right)N_{I}$
- **Vector portal**: massive dark photon coupling through loops of particles charged both under *U(1)* and *U'(1)*: $L_{VP} = \epsilon F'_{\mu\nu}F^{\mu\nu}$
- **Scalar portal**: light scalar mixing with the Higgs $L_{SP} = \left(\lambda_i S_i^2 + g_i S_i\right)\bar{\Phi}\Phi$
- **Axion portal**: axion-like particles, $L_{AP} = \frac{A}{4f_A}\epsilon^{\mu\nu\lambda\rho}F_{\mu\nu}F_{\lambda\rho}$
- **SUSY**: neutralino, sgoldstino, gaugino…

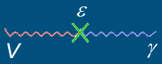


Models	Final states
Neutrino portal, SUSY neutralino	$\ell^\pm\pi^\mp, \ell^\pm K^\mp, \ell^\pm\rho^\mp, \quad \rho^\pm \to \pi^\pm\pi^0$
Vector, scalar, axion portals, SUSY sgoldstino	$\ell^+\ell^-$
Vector, scalar, axion portals, SUSY sgoldstino	$\pi^+\pi^-, K^+K^-$
Neutrino portal ,SUSY neutralino, axino	$\ell^+\ell^-\nu$
Axion portal, SUSY sgoldstino	$\gamma\gamma$
SUSY sgoldstino	$\pi^0\pi^0$

New Physics prospects in Hidden Sector

Standard Model portals:

- **D = 2: Vector portal**

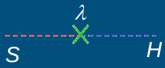


  - Kinetic mixing with massive dark/secluded/paraphoton V : $\frac{1}{2}\varepsilon F^{SM}_{\mu\nu}F^{\mu\nu}_{HS}$

  ➔Motivated in part by idea of "mirror world" restoring left and right symmetry, constituting dark matter, g-2 anomaly, …

  - Production: proton bremsstrahlung, direct QCD production $q\bar{q} \to V, qg \to Vq$, meson decays ($\pi^0, \eta,\ \omega,\ \eta', \ldots$)

- **D = 2: Scalar portal**

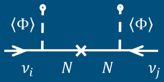


  - Mass mixing with dark singlet scalar χ : $(gS + \lambda S^2)H^\dagger H$

  ➔ Mass to Higgs boson and right-handed neutrino, inflaton, dark phase transitions BAU, dark matter, "dark naturalness",..

  - Production: Direct $p + target \to X + S,$ meson decays e.g. $B \to KS,\ K \to \pi S$

- **D = 5/2: Neutrino portal**



  - Mixing with right-handed neutrino N (Heavy Neutral Lepton): $Y_{I\ell} H^\dagger \bar{N}_I L_\ell$

  ➔ Neutrino oscillation, baryon asymmetry, dark matter

  - Production: Leptonic, semi-leptonic decays of heavy hadrons

- **D = 4: Axion portal**

  - Mixing with Axion Like Particles, pseudo-scalars pNGB, axial vectors *a* : $\frac{a}{F}G_{\mu\nu}\tilde{G}^{\mu\nu}, \frac{\partial_\mu a}{F}\bar{\psi}\gamma_\mu\gamma_5\psi$, etc

  ➔ Generically light pseudo-scalars arise in spontaneous breaking of approximate symmetries at a high mass scale F

  ➔ Extended Higgs, SUSY breaking, dark matter, possibility of inflaton,…

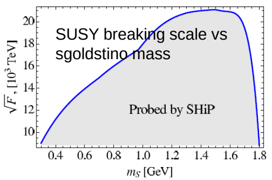
- Production: Primakoff production, mixing with pions and heavy meson decays

- **And higher dimensional operator portals**

  - Chern-Simons portal (vector portal)

New Physics prospects in Hidden Sector

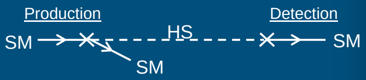
- <u>**SUper-SYmmetric “portals”**</u>
  - Some of SUSY low-energy parameter space open to complementary searches
  - Sgoldstino S(P) : $\frac{M_{\gamma\gamma}}{F} S F^{\mu\nu} F_{\mu\nu}$
  - Neutralino in R-Parity Violating SUSY
  - Hidden Photinos, axinos and saxions….


SUSY breaking scale vs sgoldstino mass

➔ <u>A very large variety of models based on these or mixtures thereof</u>

◉ Two search methods:

1. “Indirect detection” through portals in (missing mass)
2. <u>“Direct detection” through both portals in and out</u>



➔ *SHiP has significant sensitivity to all of these!*

Assumption invisible decay width $\chi\bar{\chi}$ is absent or sub-dominant, $m_\chi > \frac{1}{2} m_{portal}$, where χ hidden sector particle

Sterile Neutrinos

Fermions get mass via the Yukawa couplings:

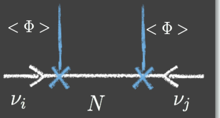
$$-\mathcal{L}_{\text{Yukawa}} = Y^d_{ij}\overline{Q_{Li}}\phi D_{Rj} + Y^u_{ij}\overline{Q_{Li}}\tilde{\phi}U_{Rj} + Y^\ell_{ij}\overline{L_{Li}}\phi E_{Rj} + \text{h.c.},$$

If we want the same coupling for neutrinos, we need right-handed (sterile) neutrinos… the most generic Lagrangian is

$$\mathcal{L}_N = i\overline{N}_i\partial_\mu\gamma^\mu N_i - \frac{1}{2}M_{ij}\overline{N^c}_i N_j - Y^\nu_{ij}\overline{L_{Li}}\tilde{\phi}N_j$$

Kinetic term | Majorana mass term | Yukawa coupling

$$U_{I\ell} \sim \frac{M_D^\ell}{M_N^I} = \frac{Y_{I\ell}v}{M_N^I}$$



Seesaw mechanism:

$$\mathcal{V} = (\nu_{Li}, N_j)$$

$$M_\nu = \begin{pmatrix} 0 & M_D \\ {M_D}^T & M_N \end{pmatrix}$$

$$-\mathcal{L}_{M_\nu} = \frac{1}{2}\overline{\mathcal{V}}M_\nu\mathcal{V} + h.c.$$

$$\lambda_\pm = \frac{M_N \pm \sqrt{M_N^2 + 4M_D^2}}{2}$$

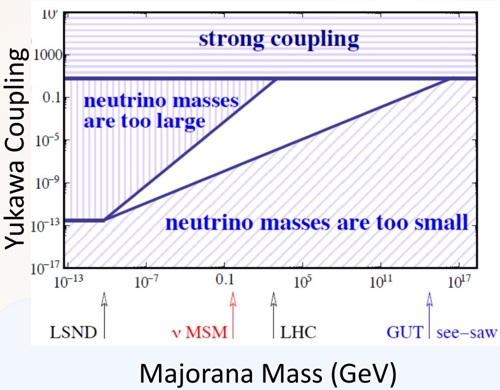
if $M_N \gg M_D$:

$$\lambda_- \sim \frac{M_D^2}{M_N}$$

$$\lambda_+ \sim M_N$$

Sterile neutrino masses

Seesaw formula $m_D \sim Y_{I\alpha} < \phi >$ and $m_\nu = \frac{m_D^2}{M}$



- Assuming $m_\nu = 0.1\text{eV}$
- if $Y \sim 1$ implies $M \sim 10^{14}\text{GeV}$
- if $M_N \sim 1\text{GeV}$ implies $Y_\nu \sim 10^{-7}$

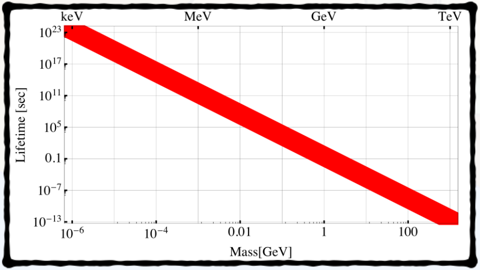
remember $Y_{top} \sim 1.$ and $Y_e \sim 10^{-6}$

If we want to explain the smallness of neutrino masses (in a natural way) the mass of sterile neutrinos should be at least at the GeV scale

Constraints on N_1

The decay mode $N \to \nu\nu\nu$ is always present

$$LT = \left(\frac{U^2 G_F^2 M_N^5}{86\pi^3}\right)^{-1} \simeq 0.3 \left(\frac{1GeV}{M_N}\right)^4 sec$$

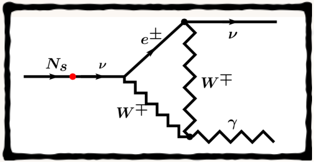


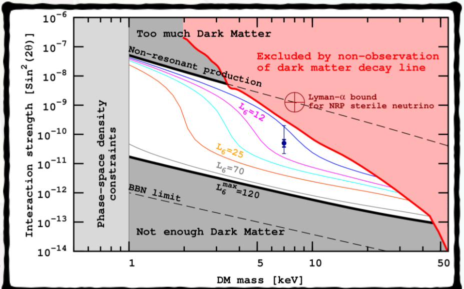
This gives an upper bound for the mass of the mass of the sterile neutrino Dark Matter

- $M_N \sim 1KeV \Longrightarrow \tau_N \sim 10^{24} sec$
- $\frac{\text{Age of the Universe}}{\tau_N} \sim 10^{-6}$

Constraints on N_1

DM sterile neutrinos decay subdominantly as $N_1 \to \nu\gamma$ with a branching ration $\mathcal{B}(N_1 \to \gamma\nu) \sim \frac{1}{123}$





Discussion in the community, not yet clear if this is a “good” signal, needs confirmation

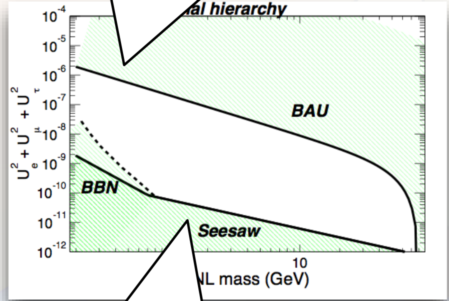
Bulbul et al. 2014 (arXiv:1402.2301)

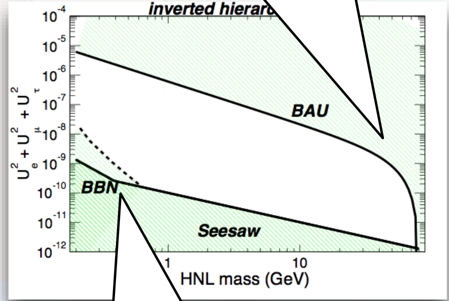
Boyarsky et al. 2014 (arXiv:1402.4119)

Constraints on N_2, N_3

If U^2 is too large, $N_{2,3}$ are in **thermal equilibrium** during the expansion of the Universe

At $M_N \geq M_W$ the rate is **enhanced** by $N \rightarrow Wl$ leading to stronger constraints on U^2

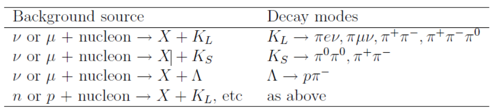




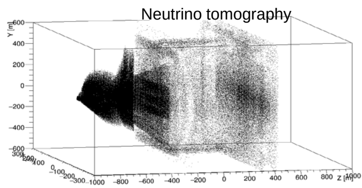
The **seesaw** limit defines the region where $N_{2,3}$ can explain the observed active neutrino Δm^2

If $\tau(N_2, N_3) < 0.1\ s$, they cannot affect the **Big Bang nucleosynthesis**

Backgrounds with TP detector

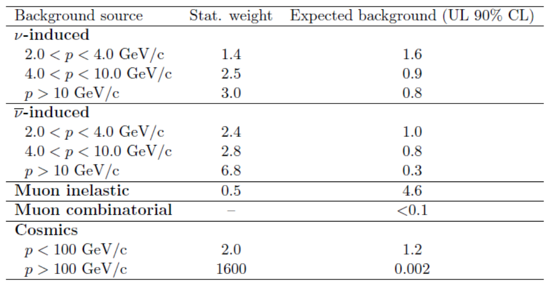


Background source	Decay modes
ν or μ + nucleon $\rightarrow X + K_L$	$K_L \rightarrow \pi e \nu, \pi \mu \nu, \pi^+\pi^-, \pi^+\pi^-\pi^0$
ν or μ + nucleon $\rightarrow X + K_S$	$K_S \rightarrow \pi^0\pi^0, \pi^+\pi^-$
ν or μ + nucleon $\rightarrow X + \Lambda$	$\Lambda \rightarrow p\pi^-$
n or p + nucleon $\rightarrow X + K_L$, etc	as above



Neutrino tomography

- <u>Background summary: no evidence for any irreducible background</u>
  - No events selected in MC ➔ Expected background UL @ 90% CL



Background source	Stat. weight	Expected background (UL 90% CL)
ν-induced		
$2.0 < p < 4.0$ GeV/c	1.4	1.6
$4.0 < p < 10.0$ GeV/c	2.5	0.9
$p > 10$ GeV/c	3.0	0.8
$\overline{\nu}$-induced		
$2.0 < p < 4.0$ GeV/c	2.4	1.0
$4.0 < p < 10.0$ GeV/c	2.8	0.8
$p > 10$ GeV/c	6.8	0.3
Muon inelastic	0.5	4.6
Muon combinatorial	–	<0.1
Cosmics		
$p < 100$ GeV/c	2.0	1.2
$p > 100$ GeV/c	1600	0.002

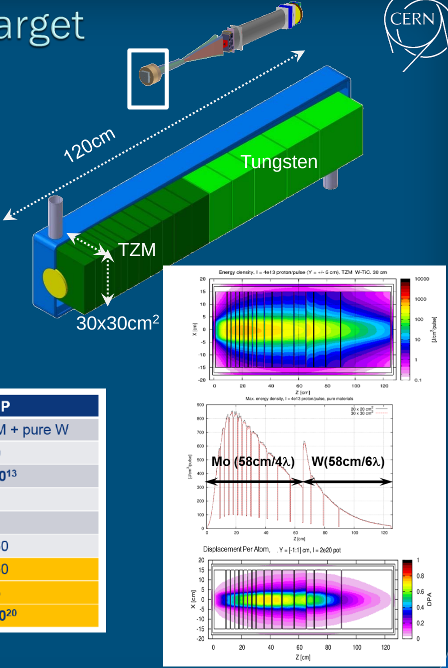
SHiP target

Design considerations with 4x10^{13} p / 7s

➔ 355 kW average, 2.56 MW during 1s spill

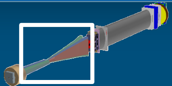
- High temperature
- Compressive stresses
- Atomic displacement
- Erosion/corrosion
- Material properties as a function of irradiation
- Remote handling (Initial dose rate of 50 Sv/h…)

➔ Hybrid solution: Mo allow TZM (4λ) + W(6λ)

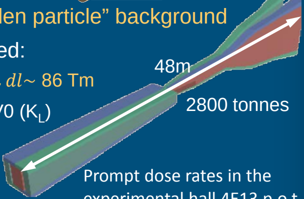


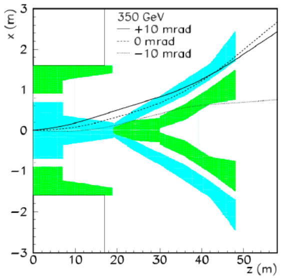
	DONUT [1)]	CHARM [2)]	SHiP
Target material	W-alloy	Cu (variable ρ)	TZM + pure W
Momentum (GeV/c)	800	400	400
Intensity	0.8*10^{13}	1.3*10^{13}	**4*10^{13}**
Pulse length (s)	20	23*10^{-6}	1
Rep. rate (s)	60	~10	7.2
Beam energy (kJ)	1020	830	2560
Avg. beam power (spill) (kW)	51	3.4*10^{7} (fast)	2560
Avg. beam power (SC) (kW)	17	69	355
POT	Few 10^{17}	Few 10^{18}	**2*10^{20}**

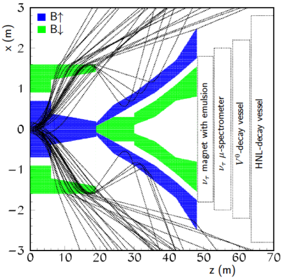
Active muon shield



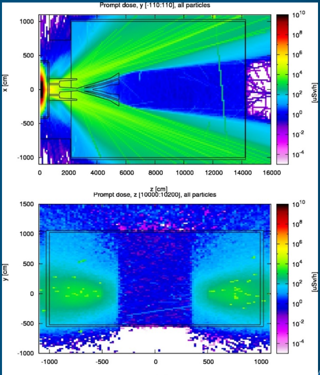
- Muon flux limit driven by emulsion based ν-detector and "hidden particle" background
- Passive and magnet sweeper/passive absorber options studied:
  - Conclusion: Shield based entirely on magnetic sweeping with $\int B_y \, dl \sim 86$ Tm
  - ➔ <$7\text{x}10^3$ muons / spill (E_μ > 3 GeV) which can potentially produce V0 (K_L)
  - ➔ Negligible occupancy





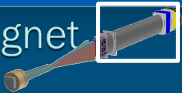


Prompt dose rates in the experimental hall 4E13 p.o.t. / 7s



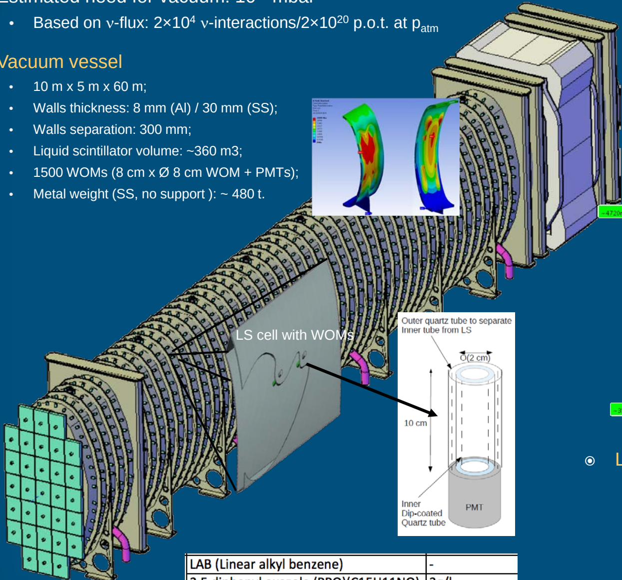
➔ Challenges: flux leakage, constant field profile, modelling magnet shape

TP: Vessel and spectrometer magnet

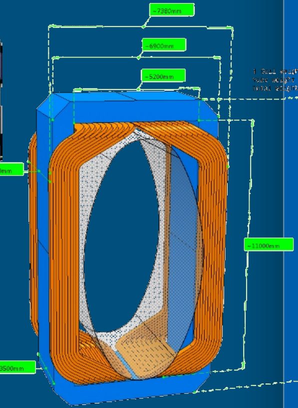


- Estimated need for vacuum: 10^{-3} mbar
  - Based on ν-flux: 2×10^{4} ν-interactions/2×10^{20} p.o.t. at p_{atm}

- Vacuum vessel
  - 10 m x 5 m x 60 m;
  - Walls thickness: 8 mm (Al) / 30 mm (SS);
  - Walls separation: 300 mm;
  - Liquid scintillator volume: ~360 m3;
  - 1500 WOMs (8 cm x Ø 8 cm WOM + PMTs);
  - Metal weight (SS, no support): ~ 480 t.

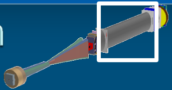


LAB (Linear alkyl benzene)	-
2.5 diphenyl oxazole (PPO)(C15H11NO)	3g/l

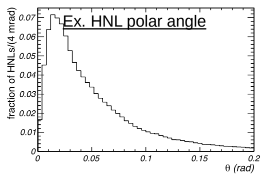


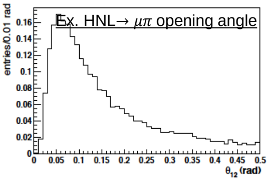
- Low power magnet designed
  - Field integral: 0.65Tm over 5m
  - Current 2500 A (1.7 A/mm2
  - Power consumption < 1 MW
  - Weight ~800 tonnes

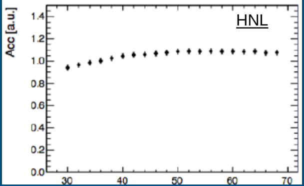
HS detector optimization

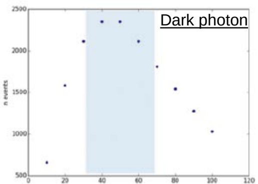


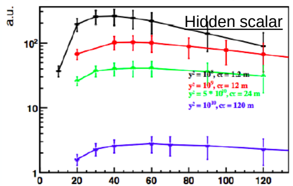
- Optimization of geometrical acceptance for a given E_{beam} and Φ_{beam}
  - Hidden particle lifetime (~flat for longlived)
  - Hidden particle production angles (~distance and transversal size)
  - Hidden particle decay opening angle (~length and transversal size)
  - Muon flux (~distance and acceptable occupancy)
  - Background (~detector time and spatial resolution)
  - Evacuation in decay volume / technically feasible size ~ W:5m x H:10m





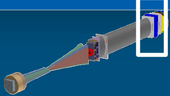






➔ Acceptance saturates ~40m – 50m

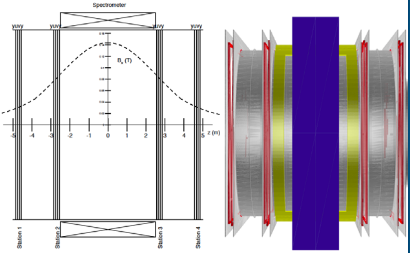
HS tracking system



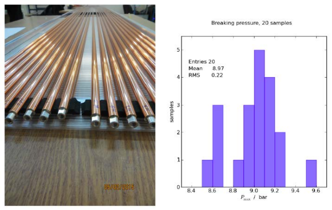
- NA62-like straw detector

Parameter	Value
Straw	
Length of a straw	5 m
Outer straw diameter	9.83 mm
Straw wall (PET, Cu, Au)	
PET foil thickness	36 μm
Cu coating thickness	50 nm
Au coating thickness	20 nm
Wire (Au-plated Tungsten)	
diameter	30 μm
Straw arrangement	
Number of straws in one layer	568
Number of layers per plane	2
Straw pitch in one layer	17.6 mm
Y extent of one plane	~ 10 m
Y offset between straws of layer 1&2	8.8 mm
Z shift from layer 1 to 2	11 mm
Number of planes per view	2
Y offset between plane 1&2	4.4 mm
Z shift from plane 1 to 2	26 mm
Z shift from view to view	100 mm
Straw station	
Number of views per station	4 (Y-U-V-Y)
Stereo angle of layers in a view Y,U,V	0, 5, -5 degrees
Z envelope of one station	~ 34 cm
Number of straws in one station	9088
Straw tracker	
Number of stations	4
Z shift from station 1 to 2 (3 to 4)	2 m
Z shift from station 2 to 3	5 m
Number of straws in total	36352

Horizontal orientation of 5m straws



First production of 5m straws at JINR



- Straws in test beam 2016
  - Study sagging effects and compensation
  - Read out of signal, attenuation / two-sided readout
- Upstream straw veto may be based on same technology

JINR Dubna (NA62, SHiP): Straws
St Petersburg (CMS, SHiP): Infra