SHiP

Search for Hidden Particles

by **Walter M. Bonivento** INFN

on behalf of the Collaboration of 235 authors belonging to 45 institutions in 14 countries

Korea	Gyeongsang National University	**C.S. Yoon**	C.S. Yoon, K.Y. Lee, S.H. Kim, B.D. Park
	Jeju National University, Assoc. to Gyeongsang		Jong-Kwan Woo, JeWou Ko, Dong Liu
	Gwangju National University of Education, Assoc. to Geyongsang		Yeong Gyun Kim
	CSU, Assoc. to Geyongsang		Ki-Young Choi

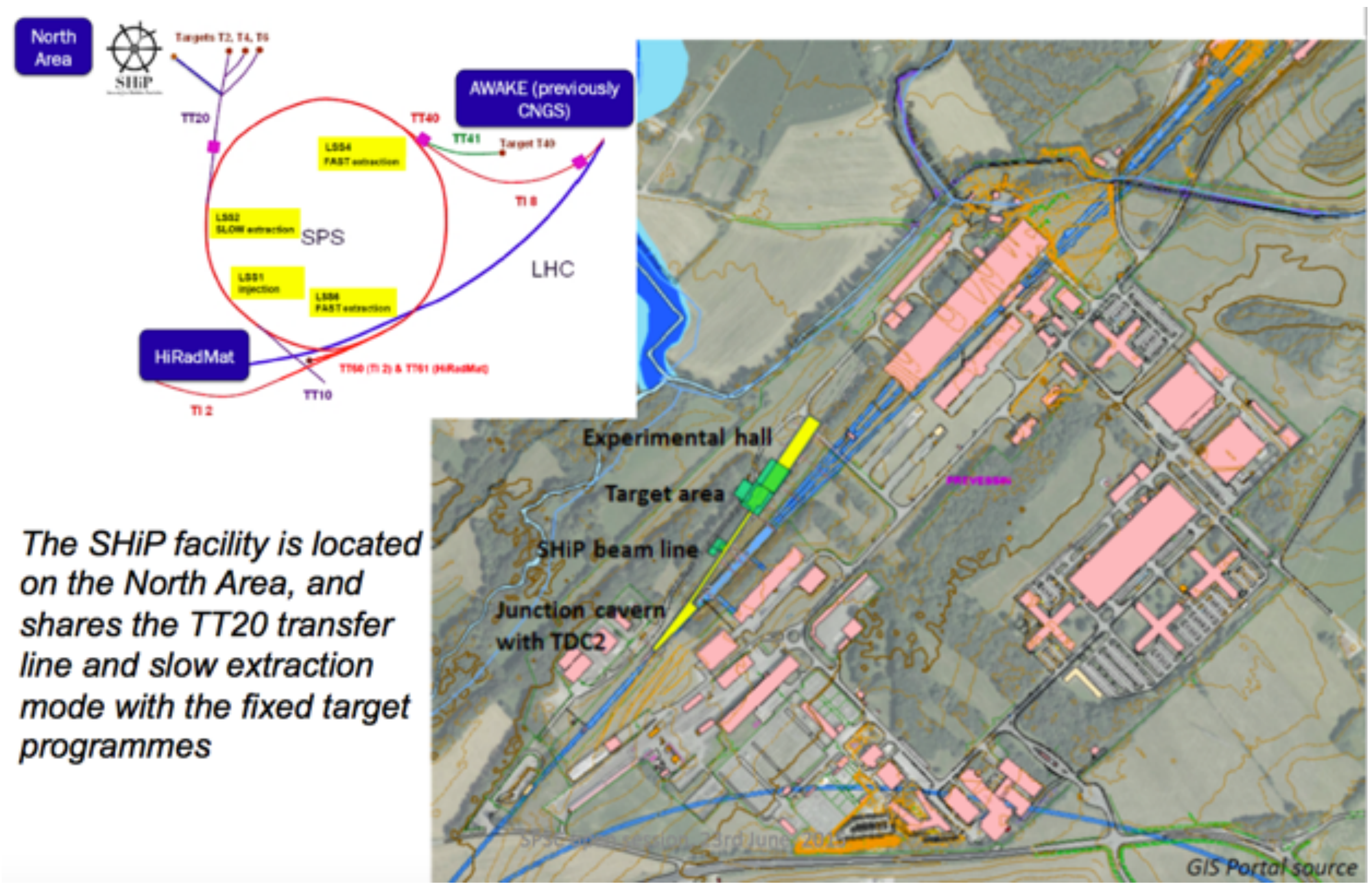
PROTON BEAM DUMPS: THE PAST

Experiment	Location	approx. Date	Amount of Beam (10^{20} POT)	Beam Energy (GeV)	Target Mat.	Ref.
CHARM	CERN	1983	0.024	400	Cu	[16]
PS191	CERN	1984	0.086	19.2	Be	[17, 18]
E605	Fermilab	1986	4×10^{-7}	800	Cu	[19]
SINDRUM	SIN,PSI					
ν-Cal I	IHEP Serpukhov	1989	0.0171	70	Fe	[20–22]
LSND	LANSCE	1994-1995 1996-1998	813 882	0.798	H20, Cu W,Cu	[23]
NOMAD	CERN	1996-1998	0.41	450	Be	[18, 24]
WASA	COSY	2010		0.550	LH2	[25]
HADES	GSI	2011	0.32 pA*t	3.5	LH2,No,Ar+KCl	[26]
MiniBooNE	**Fermilab**	**2003-2008** **2005-2012** **2013-2014**	**6.27** **11.3** **1.86**	**8.9**	**Be** **Be** **Steel**	**[27]** **[28]** **[29]**

+ DONUT FNAL 3.6×10^{-3} 800 W

PROTON BEAM DUMP: (hopefully) THE FUTURE!

400GeV p, 2×10^{20}pot/5 year (already reached yearly rate with LNGS)

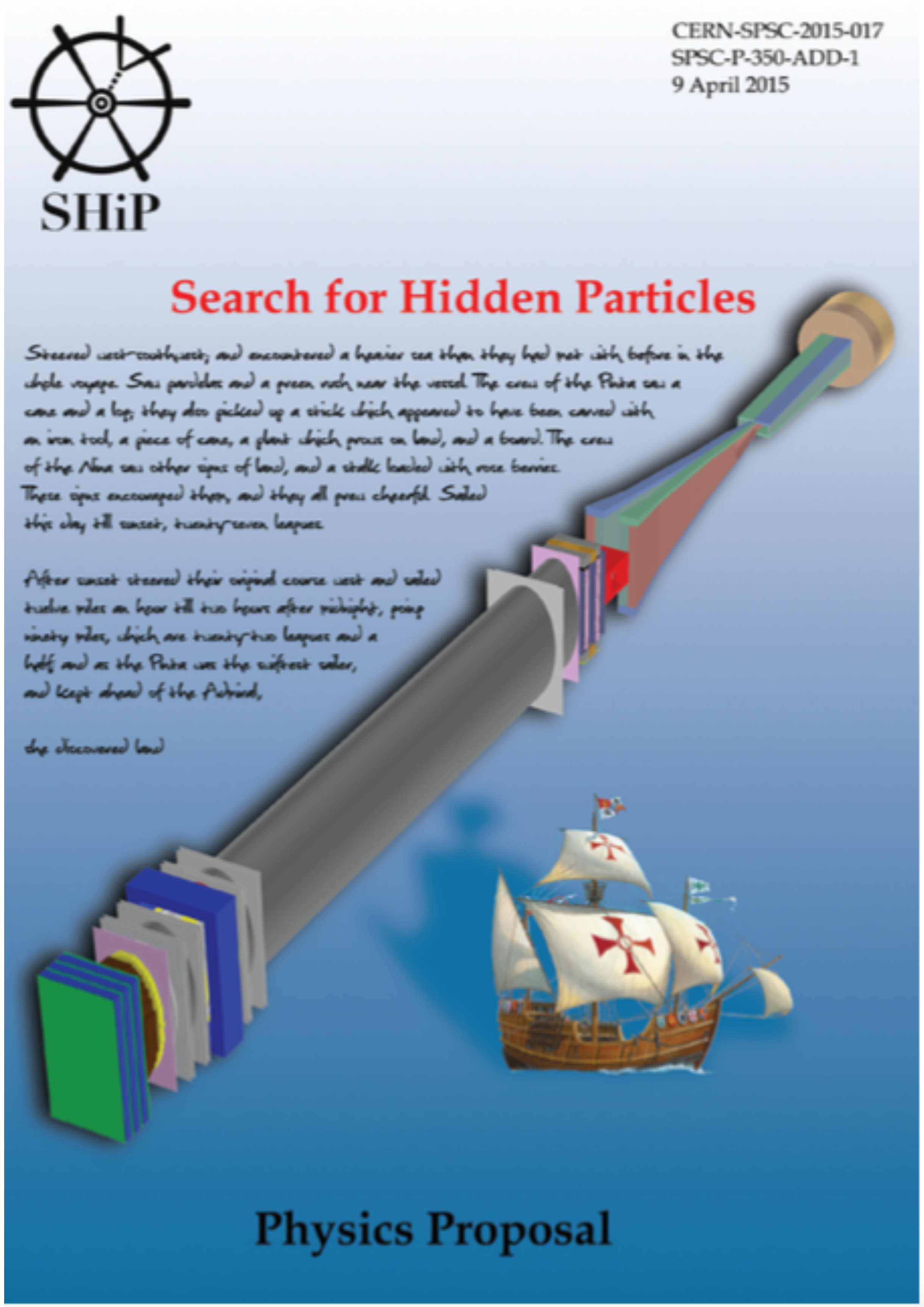


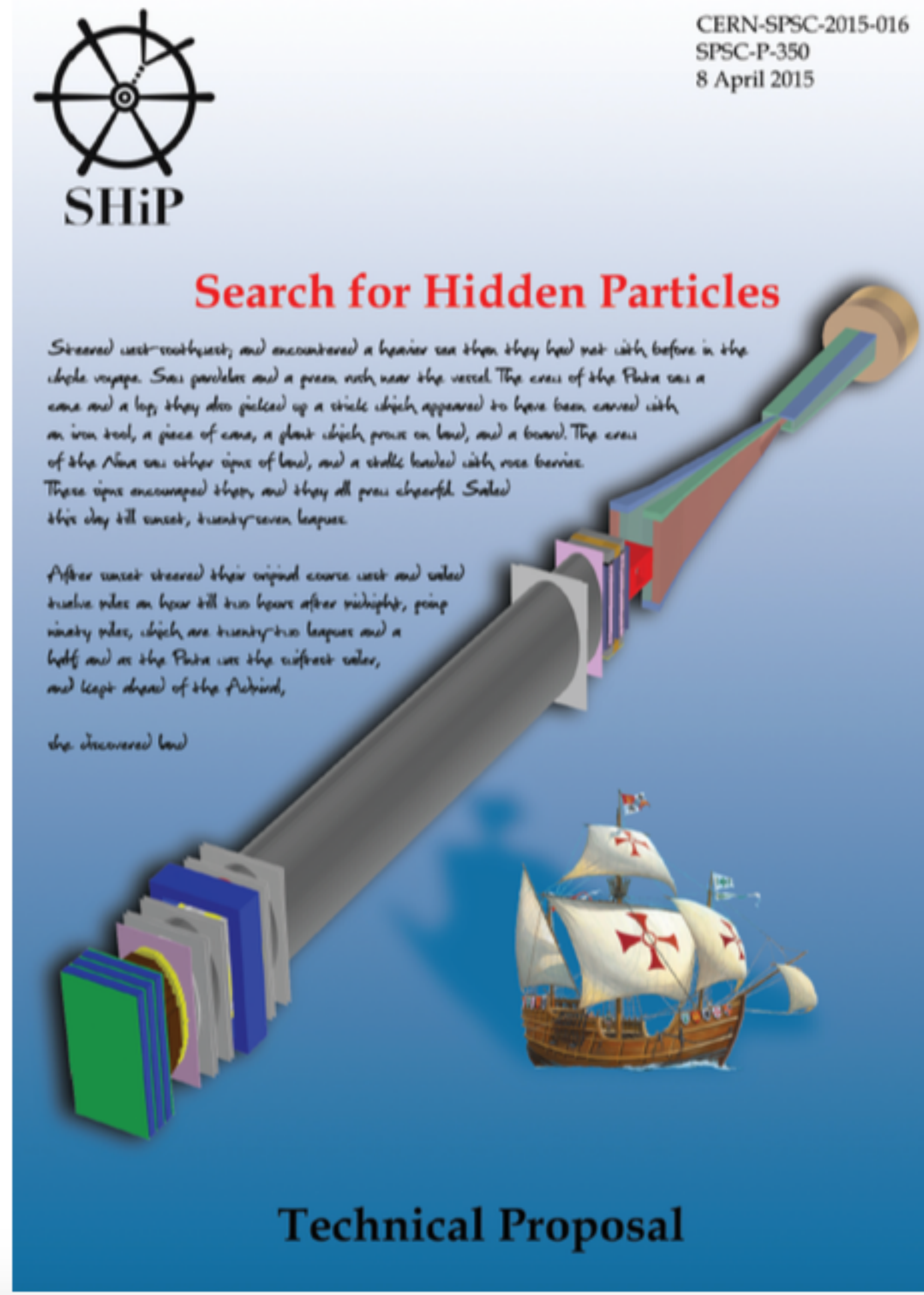
The SHiP facility is located on the North Area, and shares the TT20 transfer line and slow extraction mode with the fixed target programmes

Figure of merit:

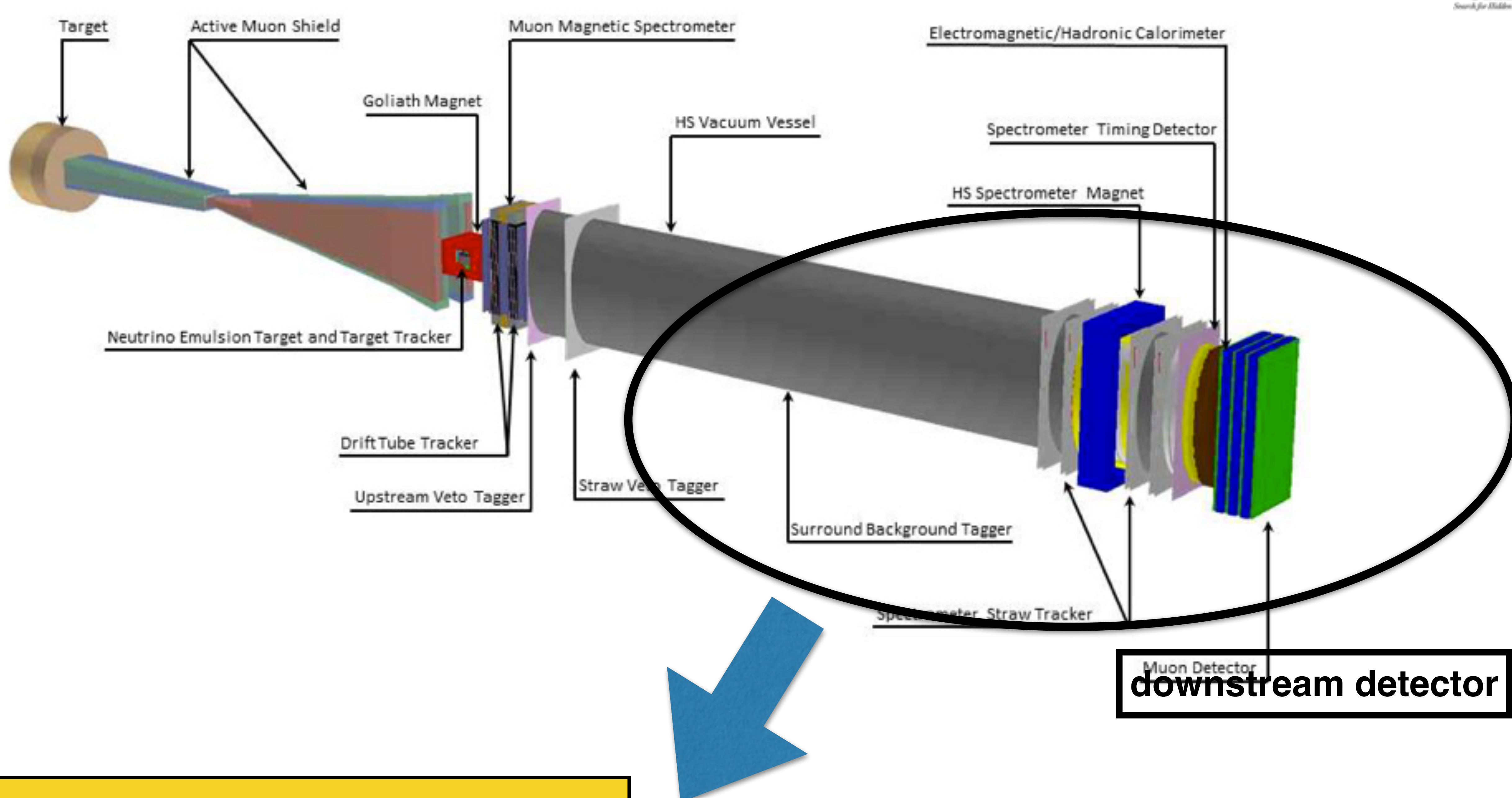
$\#(\nu_\tau)$SHiP/DONUT=600

#(HNL)SHiP/CHARM=10k

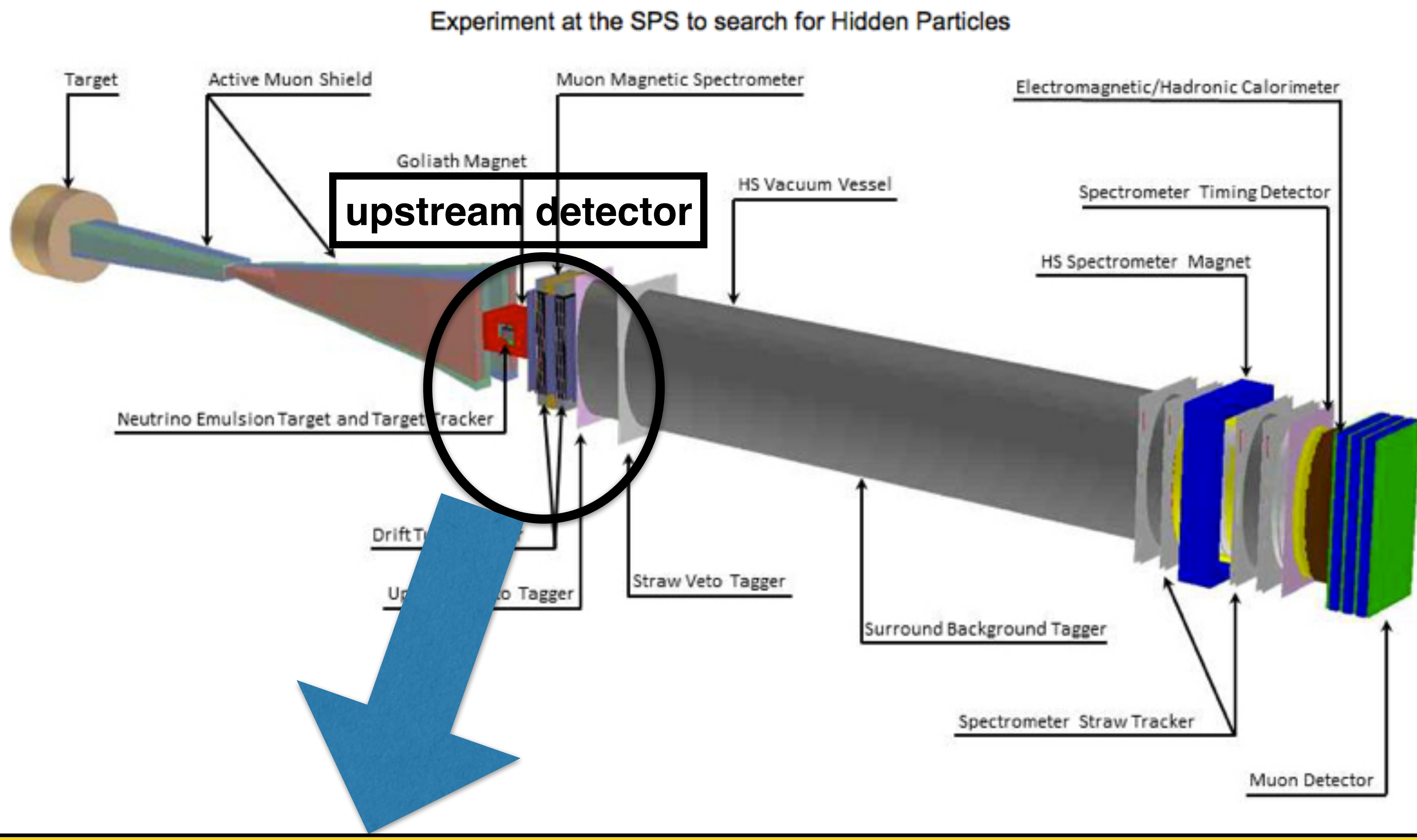

CERN-SPSC-2015-017
SPSC-P-350-ADD-1
9 April 2015
SHiP
Search for Hidden Particles
Physics Proposal


CERN-SPSC-2015-016
SPSC-P-350
8 April 2015
SHiP
Search for Hidden Particles
Technical Proposal

Experiment at the SPS to search for Hidden Particles

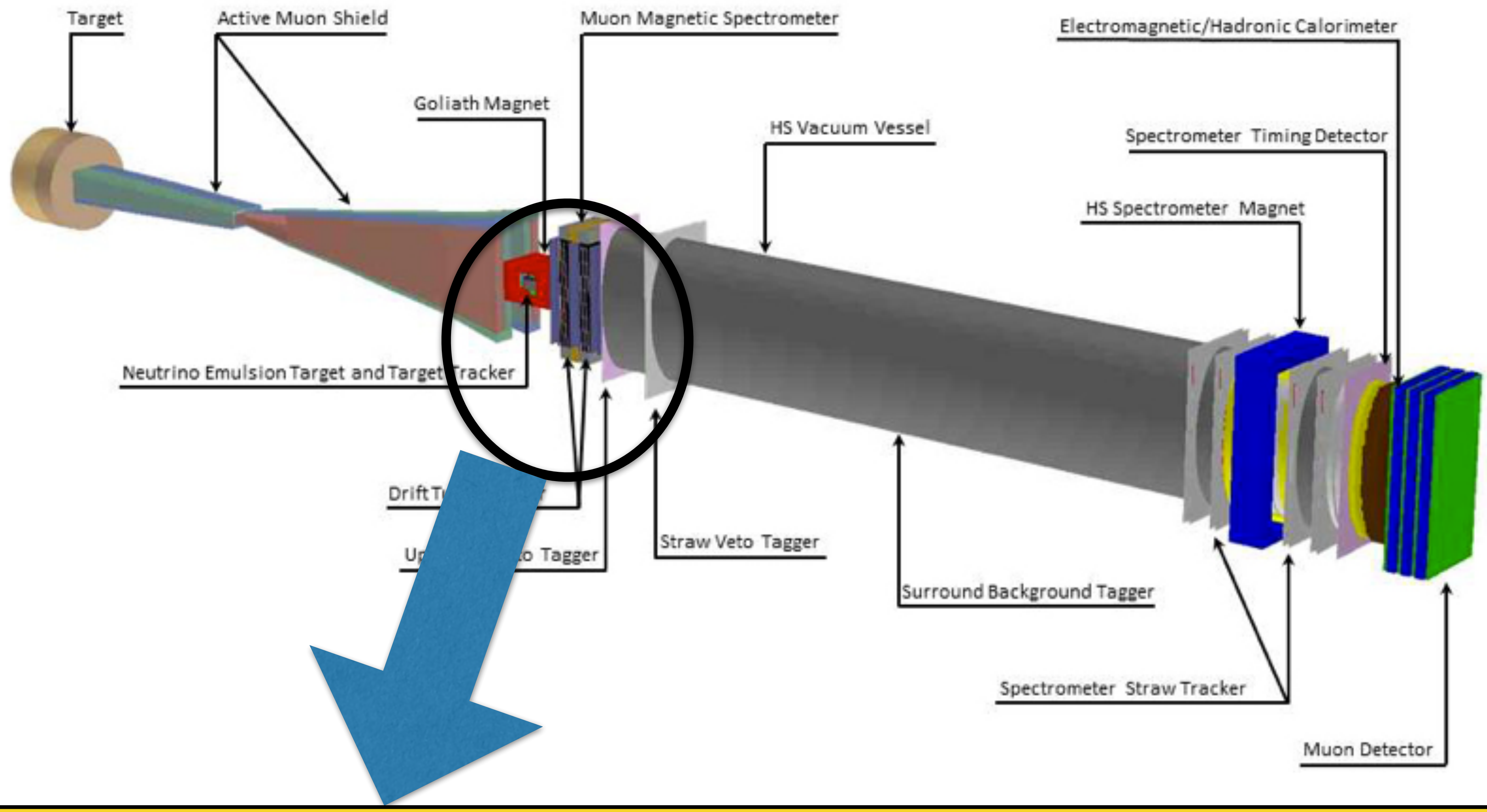


DIRECT EVIDENCE OF NP : DETECTION of long lived particles with masses below few GeV



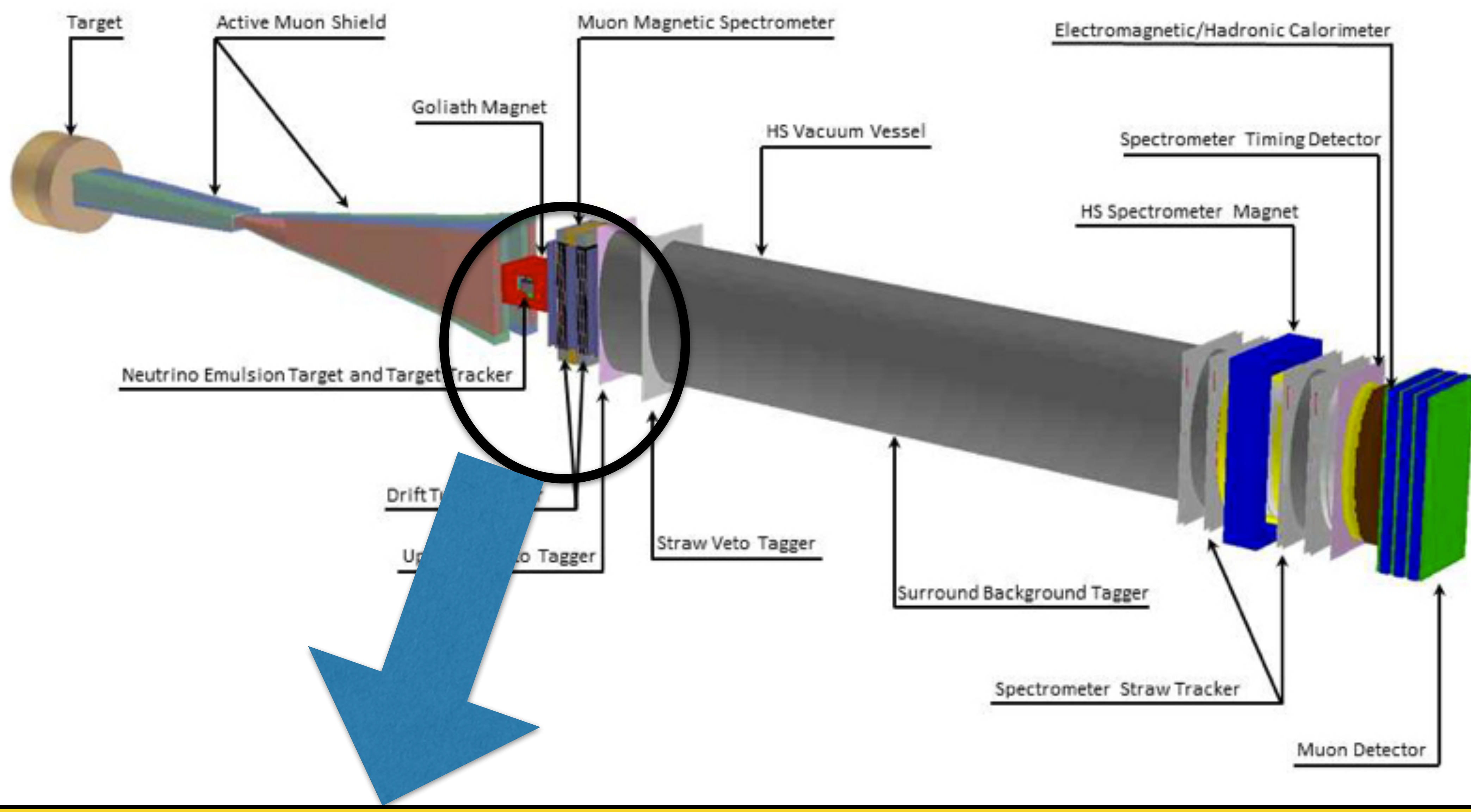
DIRECT EVIDENCE OF NP :
DETECTION of dark matter particles with masses below few GeV

Experiment at the SPS to search for Hidden Particles



DIRECT EVIDENCE OF NP :
DETECTION of dark matter particles with masses below few GeV
+
INDIRECT EVIDENCE OF NP in ν_τ scattering: violation of lepton universality (lepto-quarks)

Experiment at the SPS to search for Hidden Particles



DIRECT EVIDENCE OF NP :
DETECTION of dark matter particles with masses below few GeV
+
INDIRECT EVIDENCE OF NP in ν scattering: violation of lepton universality (lepto-quarks)
+
new or more precise structure functions in ν scattering

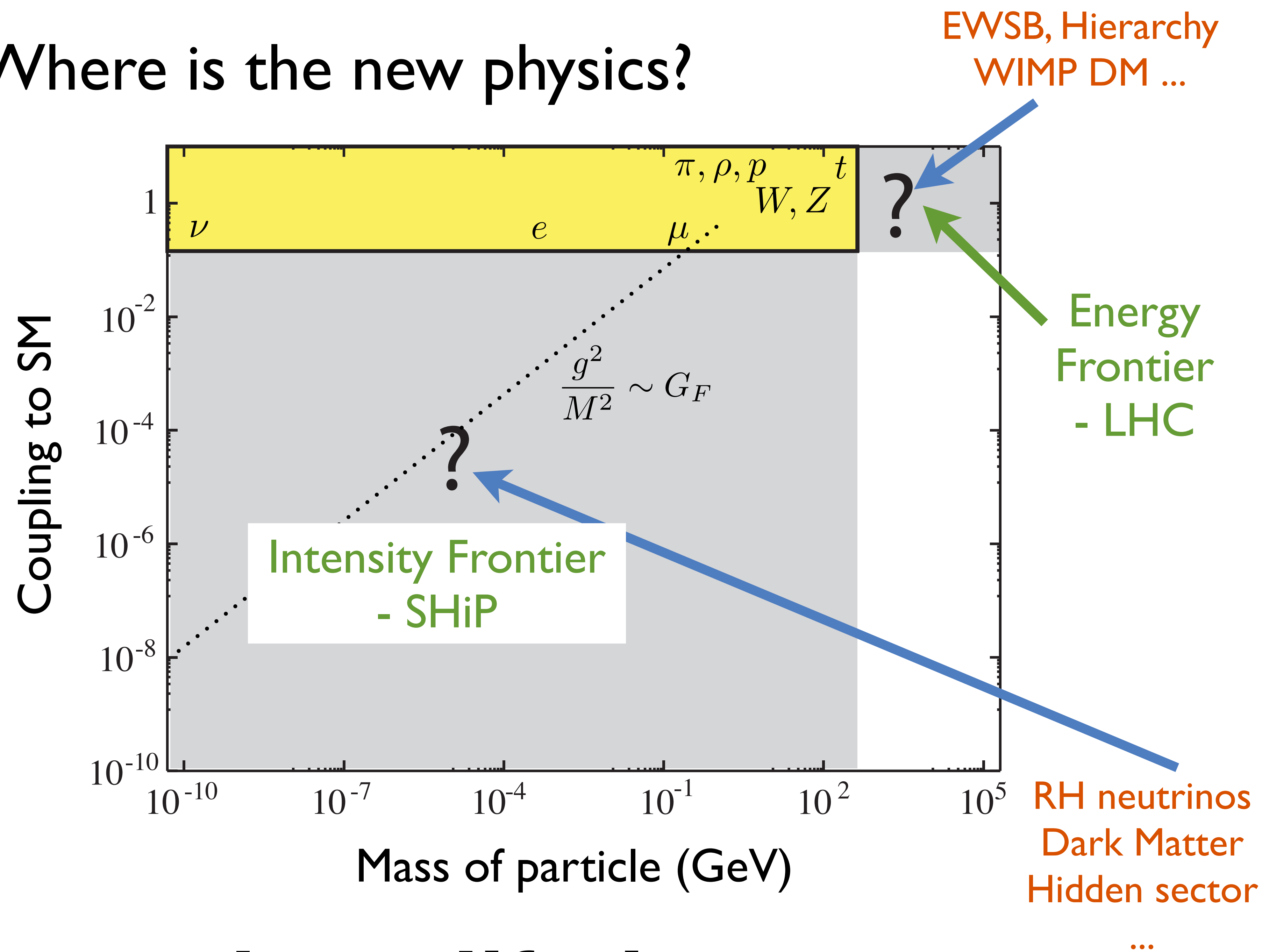
DIRECT DETECTION: long list of models that we can test in unexplored parameter domains

	Main production modes	background after selection
massive neutrinos (HNL)	c-hadron decays	0
dark photons (dark vector)	QCD	
- to SM		0
- to dark matter		≠ 0
dark scalars (dark Higgs)	b-hadron decays	0
dark pseudo-scalars (ALP, PNGB) coupling to:		
- fermions	b-hadron decays	0
- photons	Primakoff	(≠ 0)(*)
low mass SUSY	c and b hadron decays	0

(*)under study

Why small masses and couplings

Where is the new physics?



—>long lifetimes

The Nobel Prize in Physics 2015

Photo © Takaaki Kajita

Takaaki Kajita

Prize share: 1/2

Photo: K. McFarlane. Queen's University /SNOLAB

Arthur B. McDonald

Prize share: 1/2

NOT ON THE PHONE HERE!

The Nobel Prize in Physics 2015 was awarded jointly to Takaaki Kajita and Arthur B. McDonald *"for the discovery of neutrino oscillations, which shows that neutrinos have mass"*

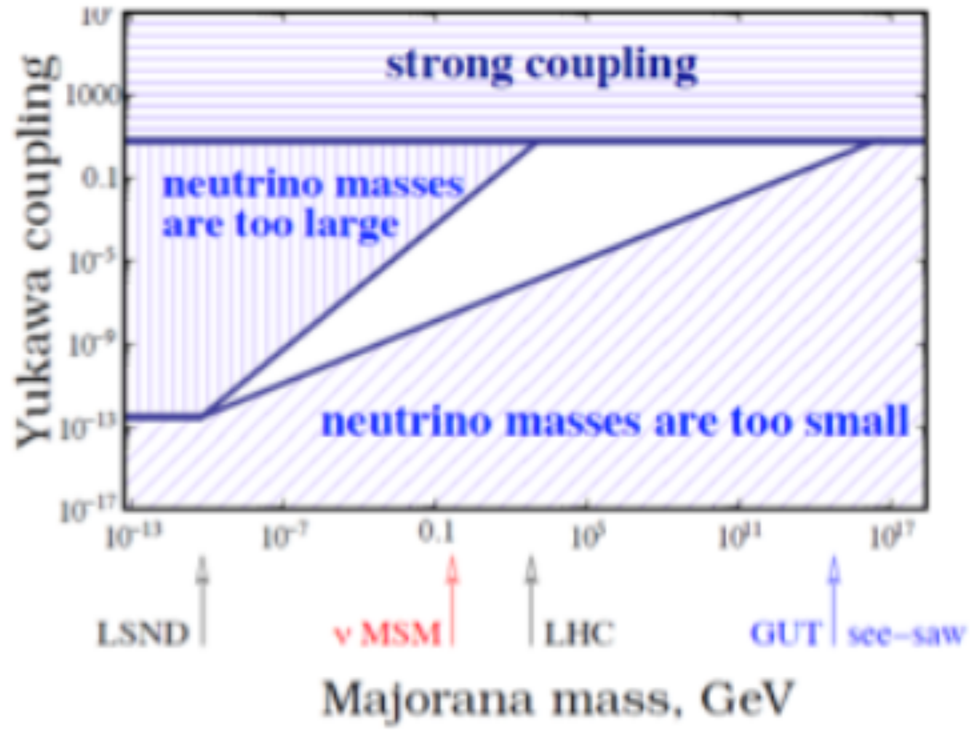
Next obvious question

Where does the ν mass come from?

—> it is clear that experimental effort (and possibly prizes…) has to be now directed in this direction!

One remarkable possibility:

see-saw mechanism (type I) with one/two/three massive and sterile Majorana-type neutrinos

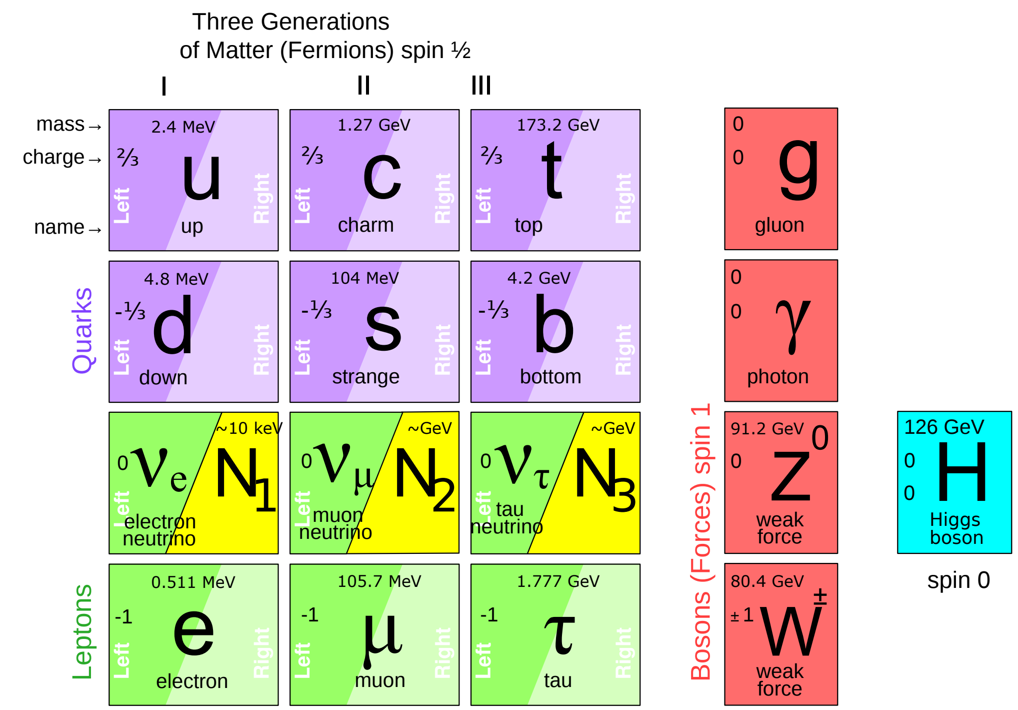


The νMSM and its fellows

3 Majorana (HNL) partners of ordinary ν, with $M_N<M_W$

In a peculiar parameter space (N_2 and N_3 almost degenerate in mass and with m=O(GeV) and N_1 decoupled with m=O(keV)), νMSM explains:

neutrino masses (see-saw), baryogenesis (via lepto-genesis) and DM (N_1)! (but, in this version of the theory, DM has to be generated outside the νMSM, by e.g. the decay of an inflaton—>see Higgs portal)



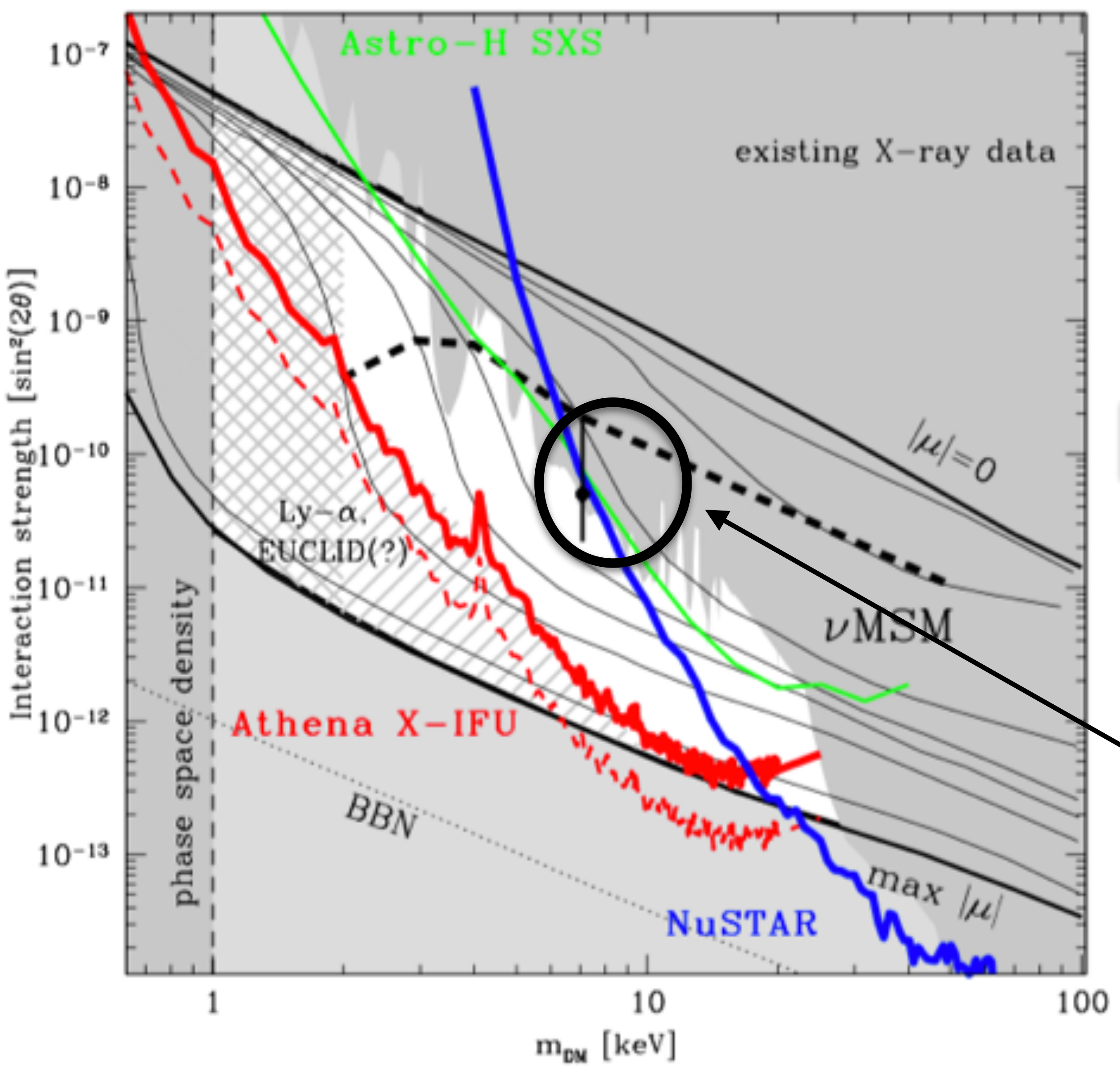
***νMSM:** T.Asaka, M.Shaposhnikov PL **B620** (2005) 17*
M.Shaposhnikov Nucl. Phys. B763 (2007) 49

No hierarchy problem (if also the inflaton or the NP yielding N_1 has mass below EW scale)

Naturalness of the above parameter space comes from a U(1) lepton symmetry, broken at 10^{-4} level.

+ all other, less noble but less constrained, variations of this theory

Future prospects of N_1 detection



Parameter space of sterile neutrino DM in the νMSM, from arXiv:1509.02758 Hatched range shows projected sensitivity reach of the future Lyman-α and weak lensing probes (future Euclid mission). Red thick solid curve shows the sensitivity limit of Athena X-IFU (launch 2028), calculated for a 1 Msec exposure. ~~Green curve shows the sensitivity of Astro-H / SXS (to be launched 2016)~~, blue curve corresponds to the sensitivity of NuSTAR, also for 1 Msec long exposures.

smoking gun: big debate!

So by the start of SHiP N_1 can be discovered but not excluded

$N_{2,3}$ production

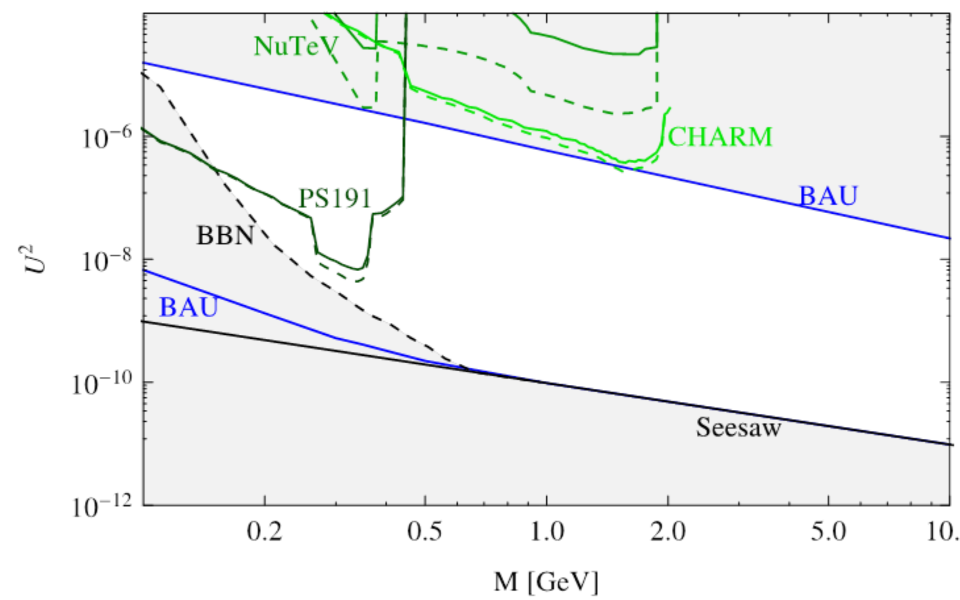
Interaction with the Higgs v.e.v.
->mixing with active neutrinos
with U^2

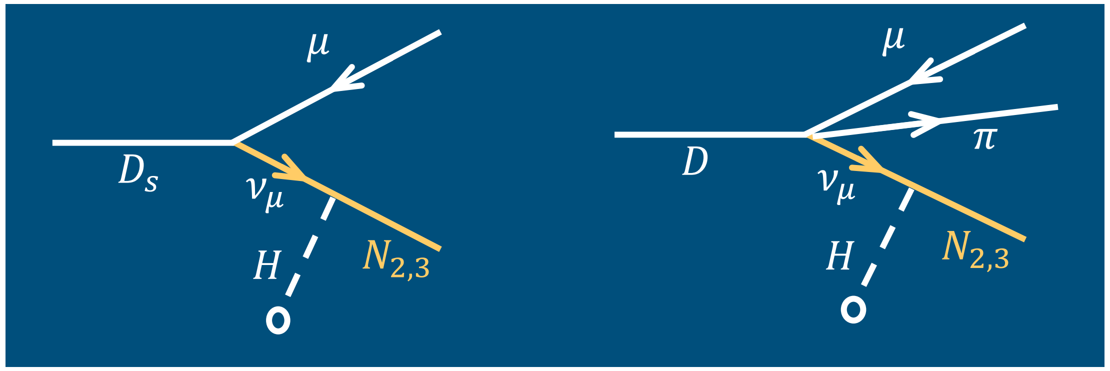
in the vMSM strong limitations
in the parameter space (U^2,m)

a lot of HNL searches in the past
but, for $m>m_K$, with a sensitivity
not of cosmological interest

ex. meson decays —>

inverted mass hyerarchy

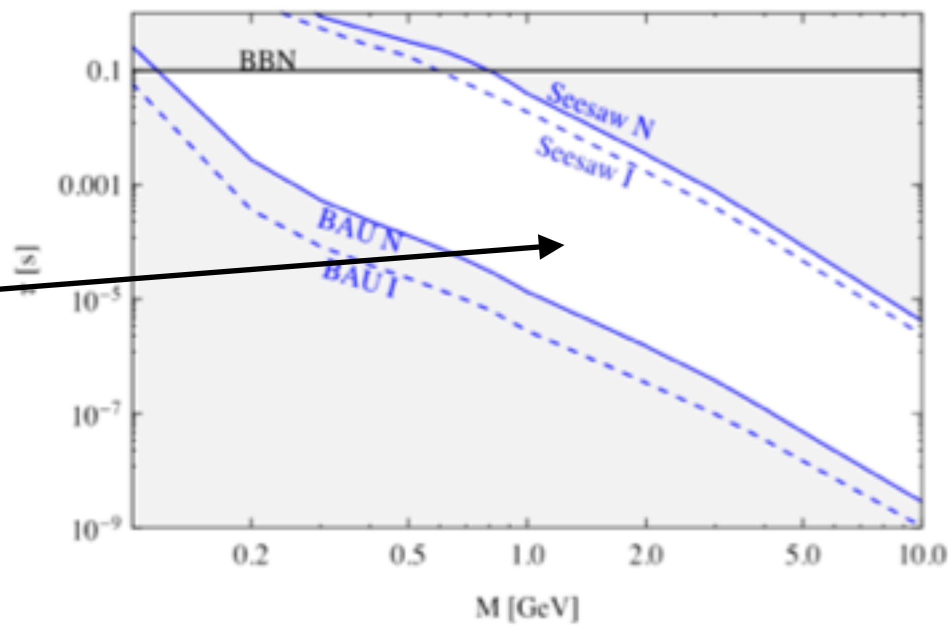




$N_{2,3}$ decays

Very weak HNL-active ν —>at masses below few GeV, $N_{2,3}$ have very long life-time

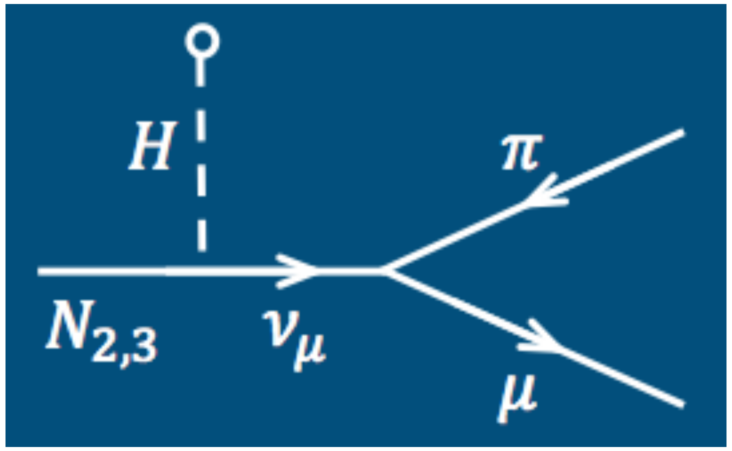
decay paths of O(km)!: for $U^2_\mu=10^{-7}$, $\tau_N=1.8\times10^{-5}$ s



Various decay modes : the BR's depend on flavor mixing

Decay mode	Branching ratio
$N_{2,3}\to \mu/e + \pi$	0.1 - 50 %
$N_{2,3}\to \mu^-/e^- + \rho^+$	0.5 - 20 %
$N_{2,3}\to \nu + \mu + e$	1 - 10 %

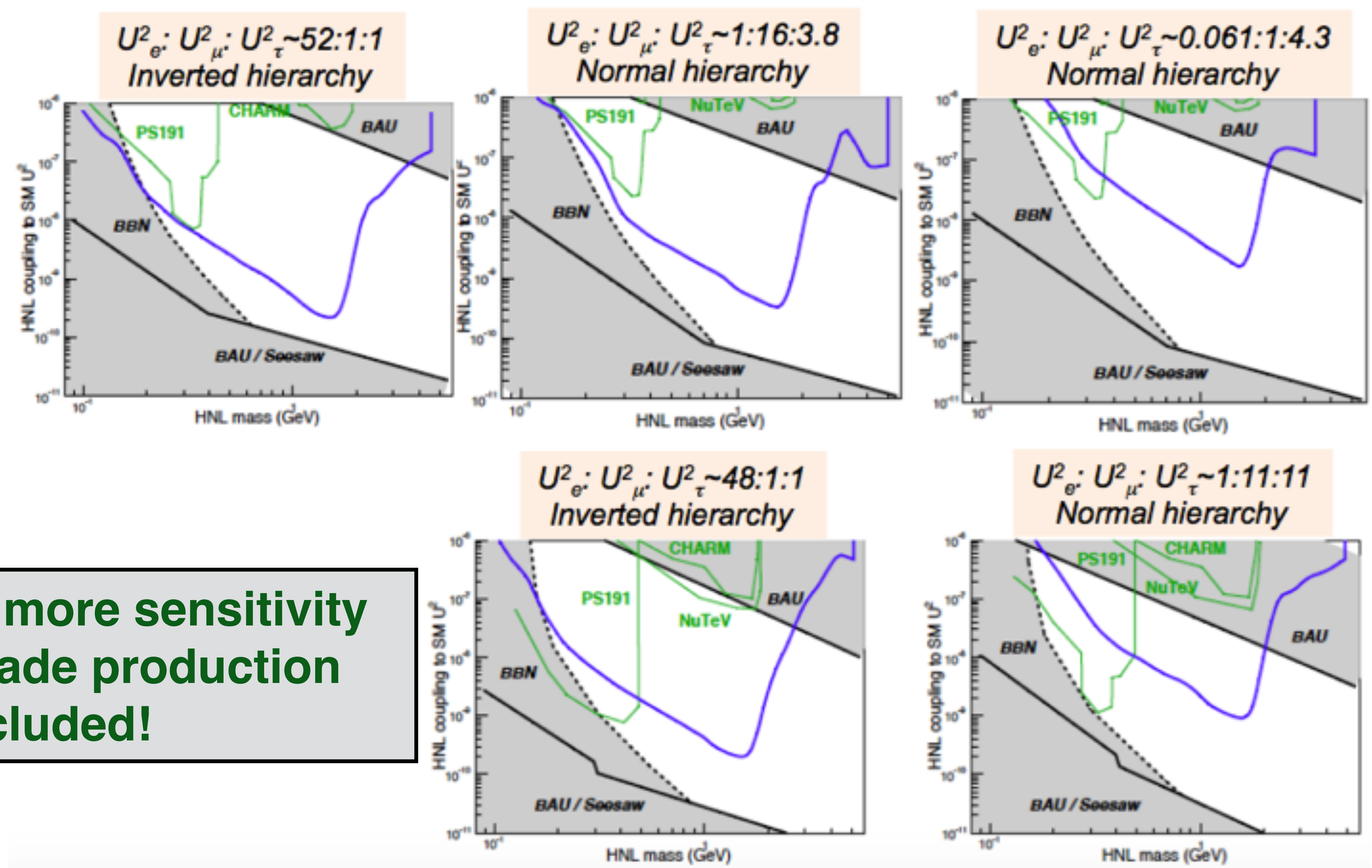
The probability that $N_{2,3}$ decays within the fiducial volume of the experiment $\propto U_\mu^2$



—> number of events $\propto U_\mu^4$ if N detected

SHIP sensitivity to HNL

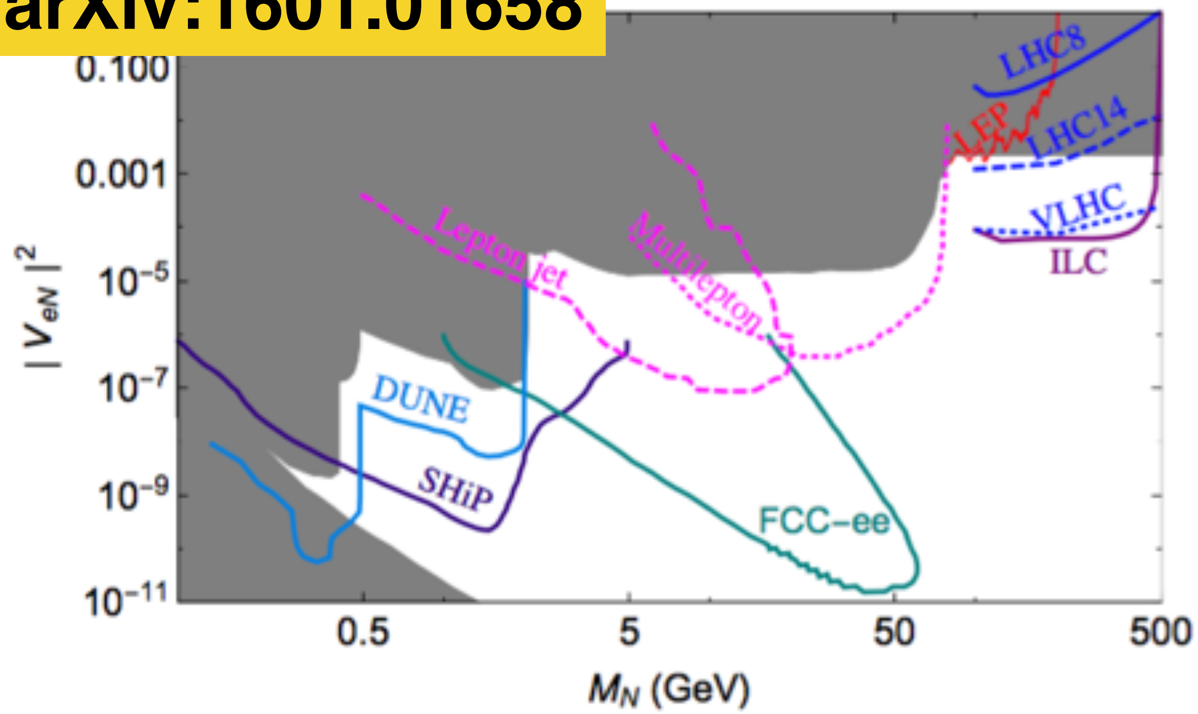
SHIP will scan most of the cosmologically allowed (in the context of νMSM) region below the charm mass

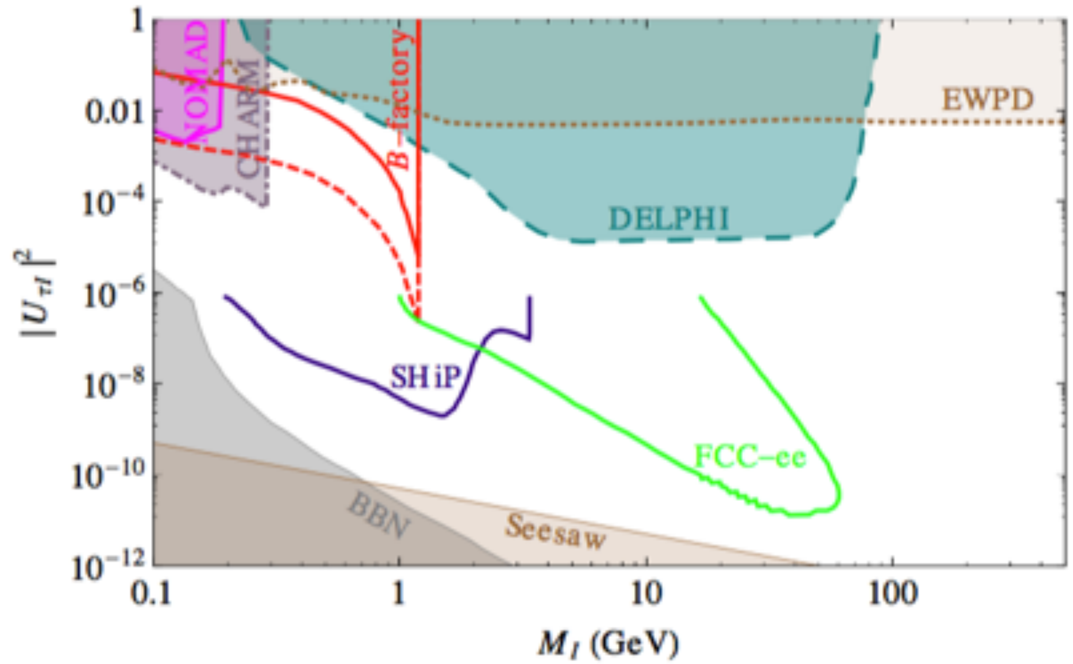


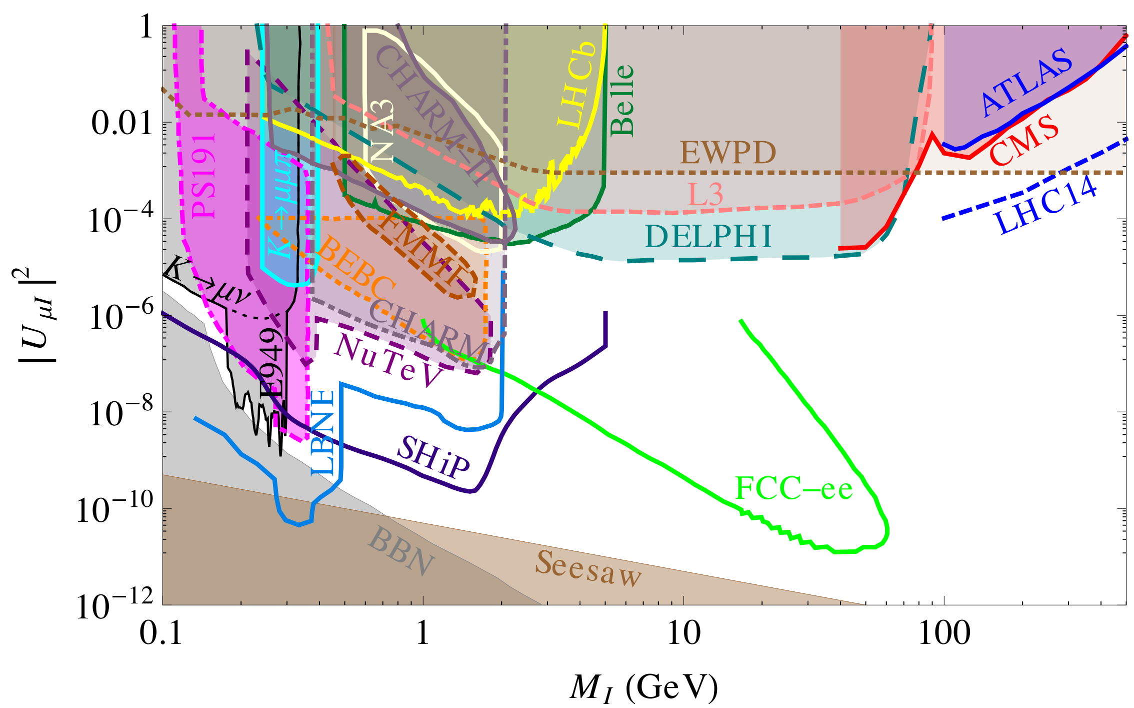
still some more sensitivity from cascade production not yet included!

Also FCC-ee and LHC could say something

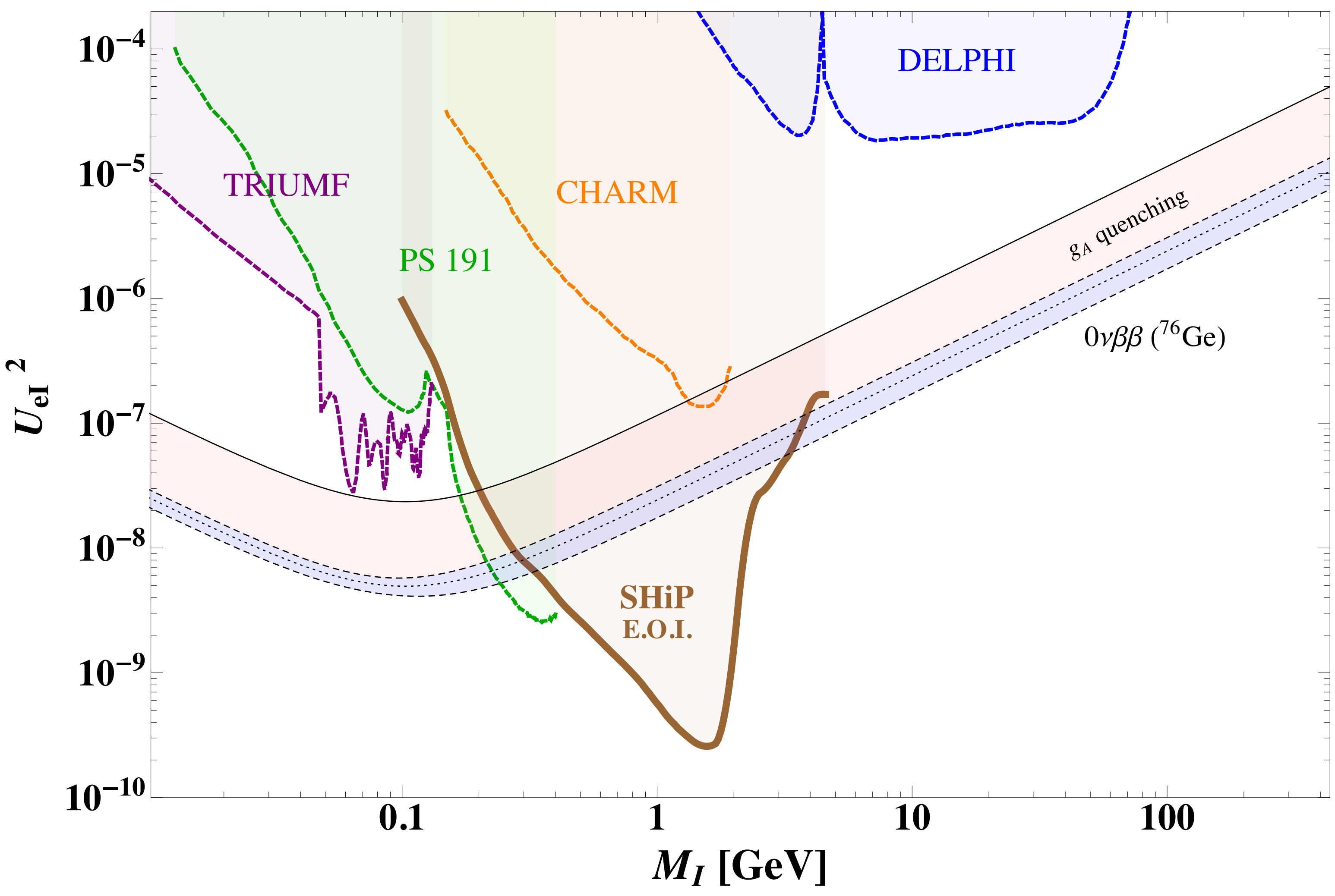
arXiv:1601.01658



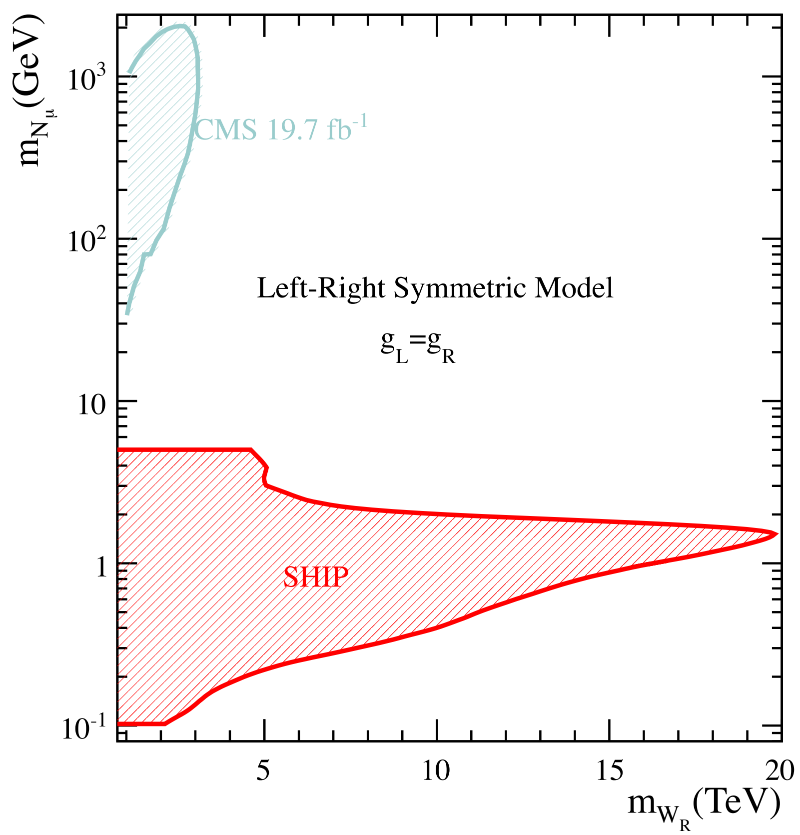


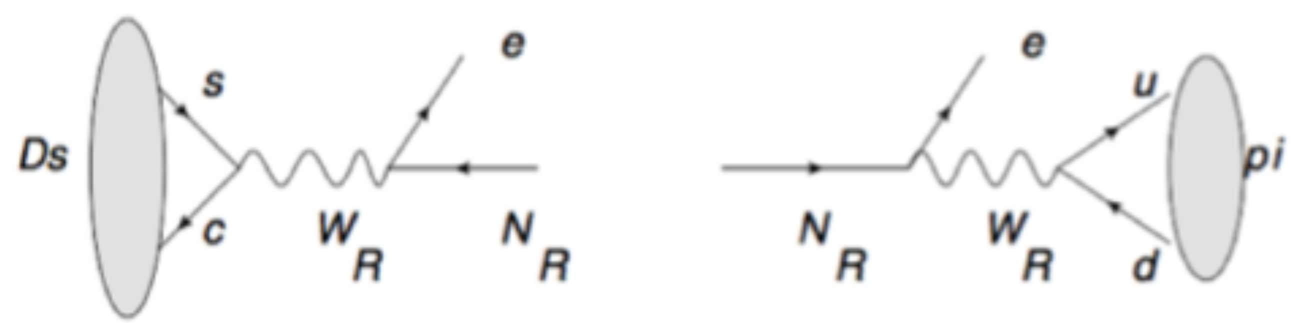


Outside see-saw models, for single heavy neutrinos also 0νββ plays a role in the exclusion planes…

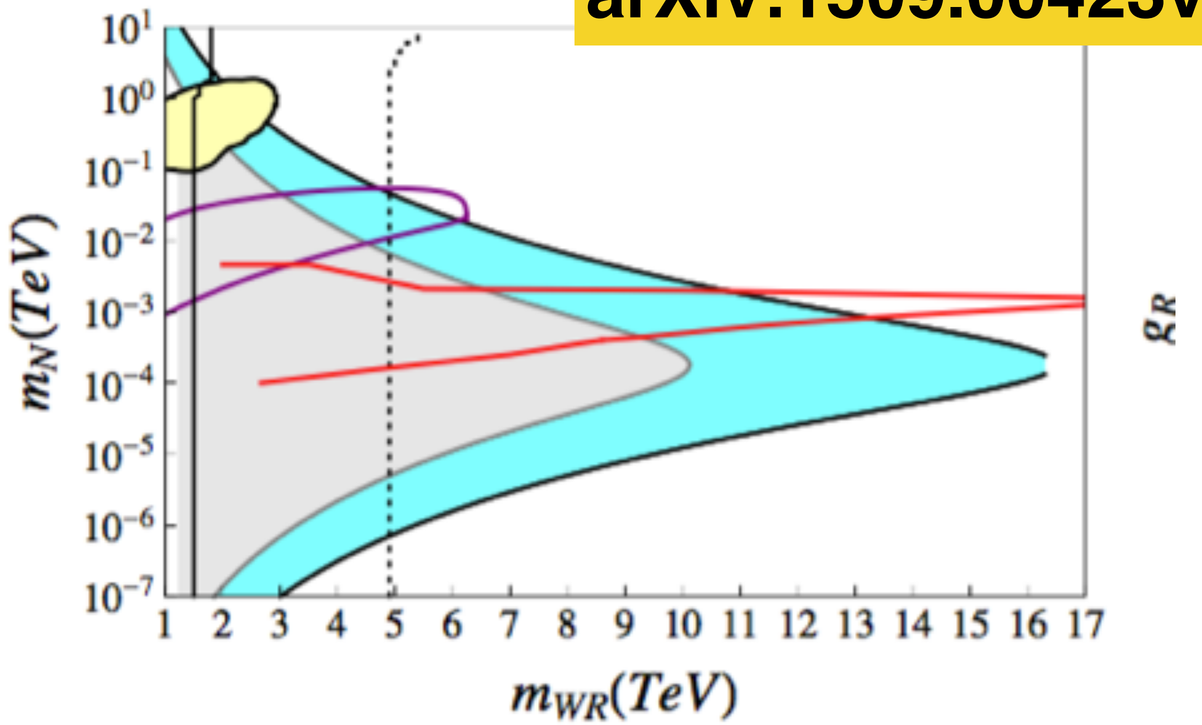


Not only νMSM for the sterile ν's: interpretation in the context of Left-Right symmetric model

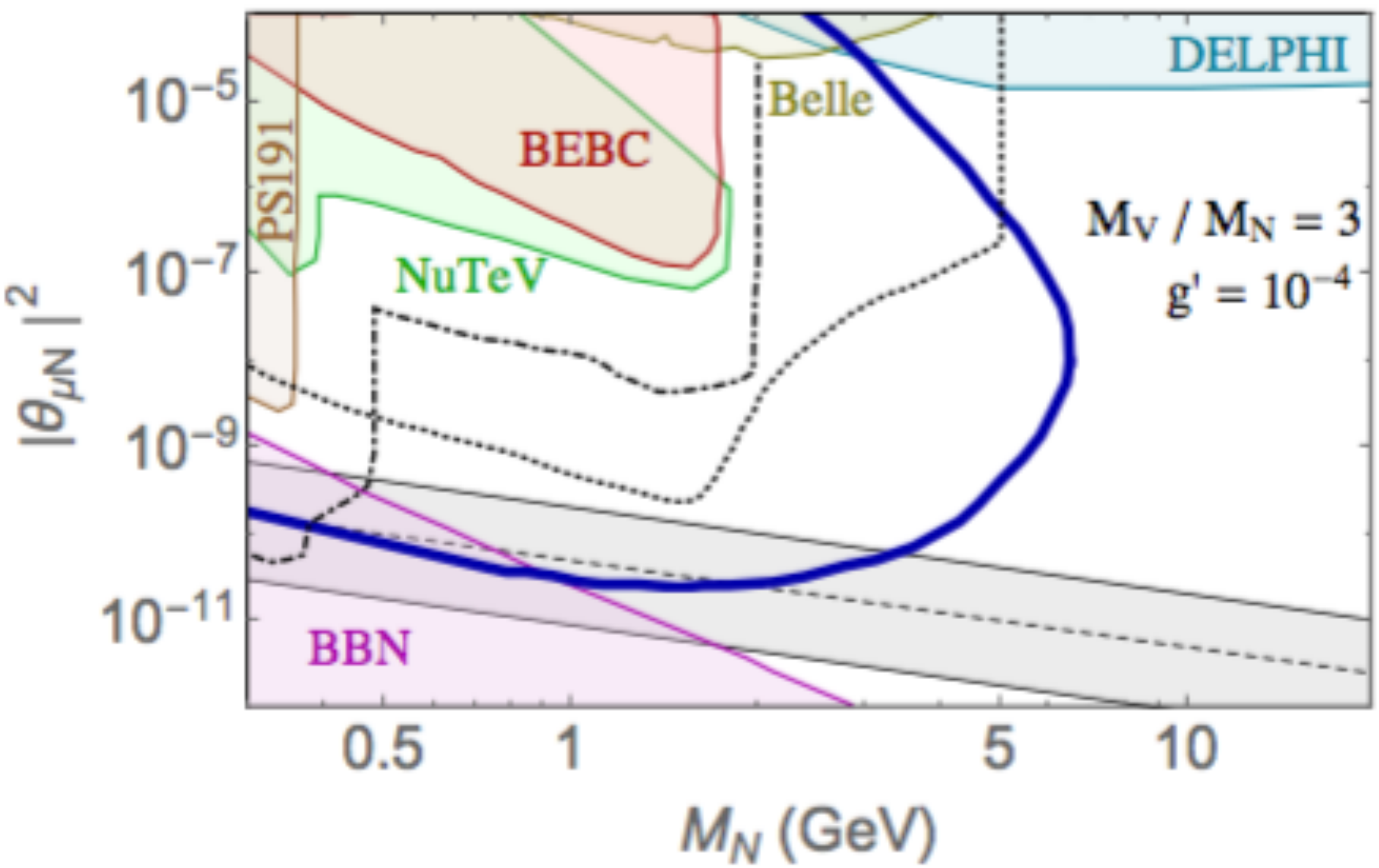


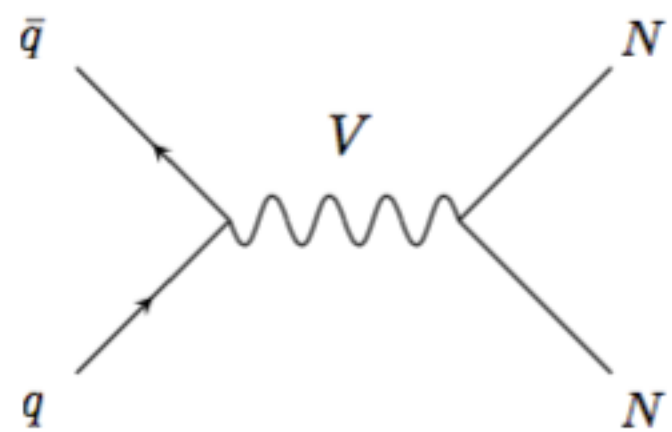


arXiv:1509.00423v1



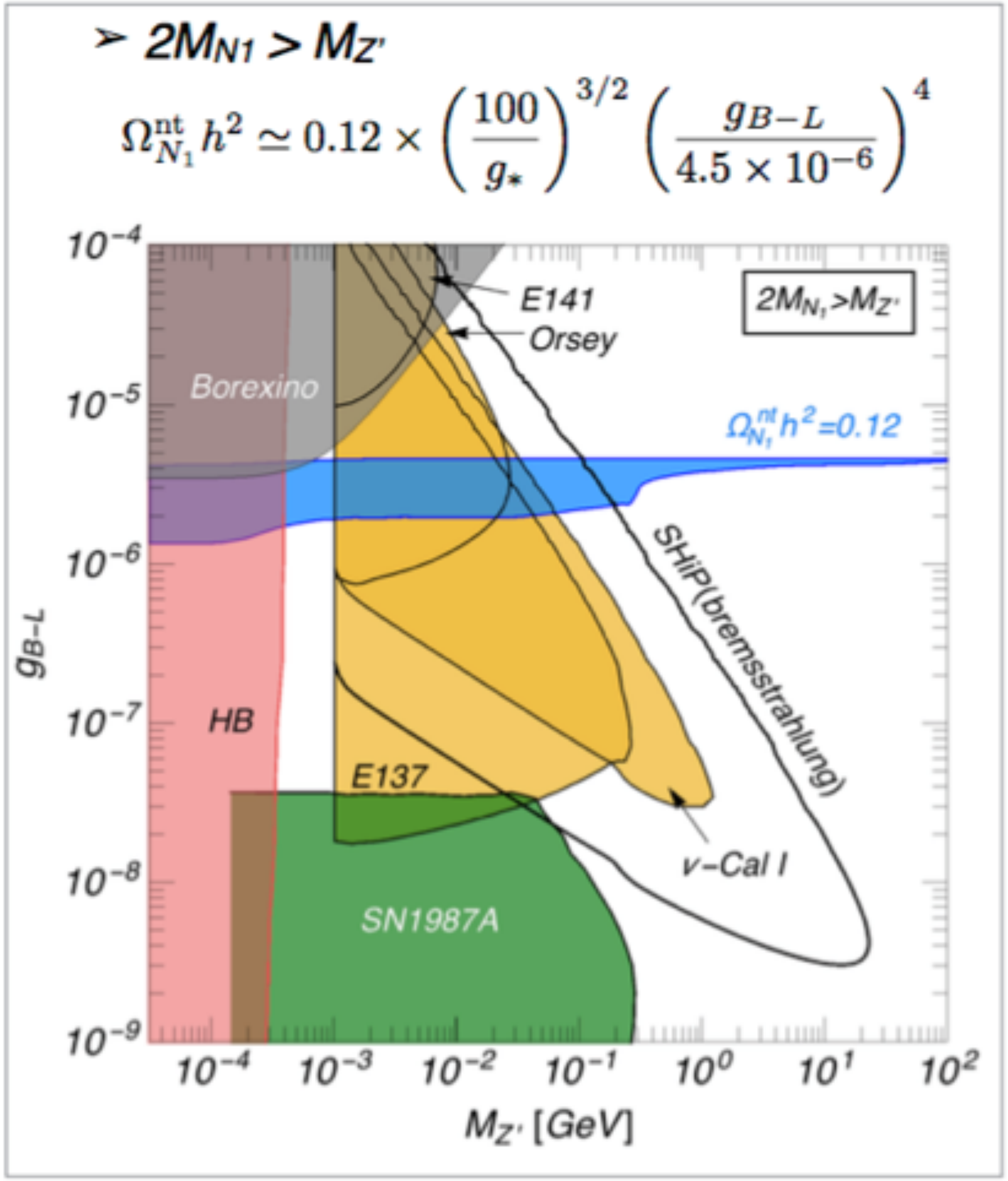
Not only νMSM for the sterile ν's (2): enhanced sterile ν production via **new dark gauge force, e.g B-L gauge symmetry**

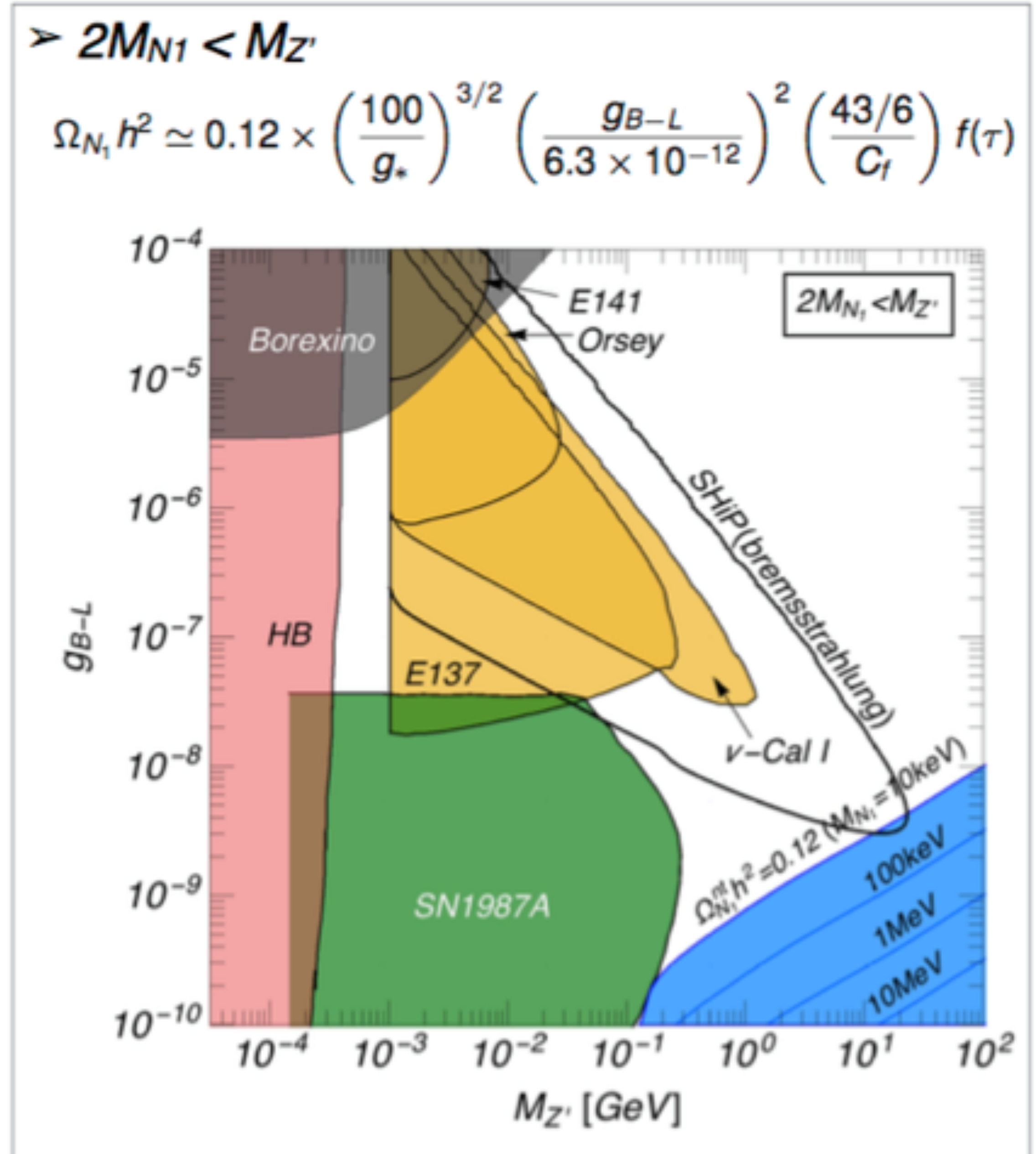




arXiv:1604.06099

Again B-L: UvMSM





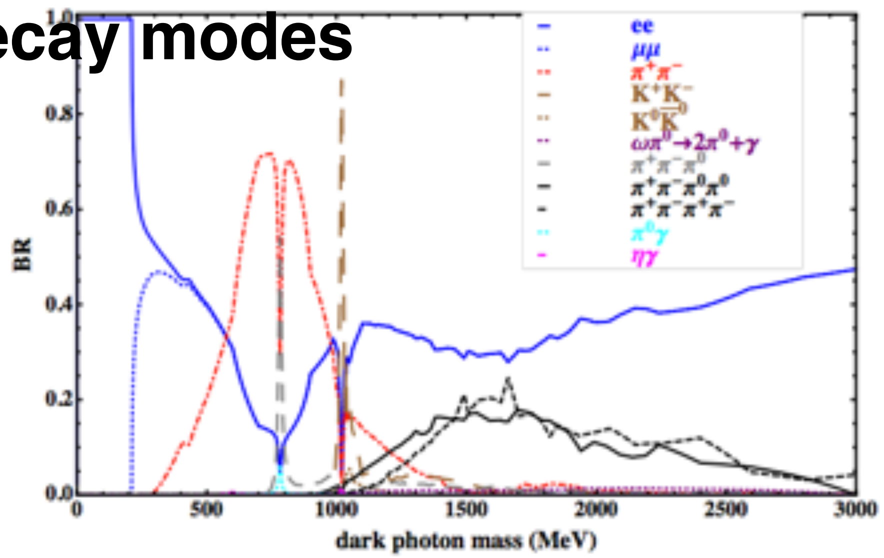
SHiP can be a powerful tool for searching the freeze-in scenario

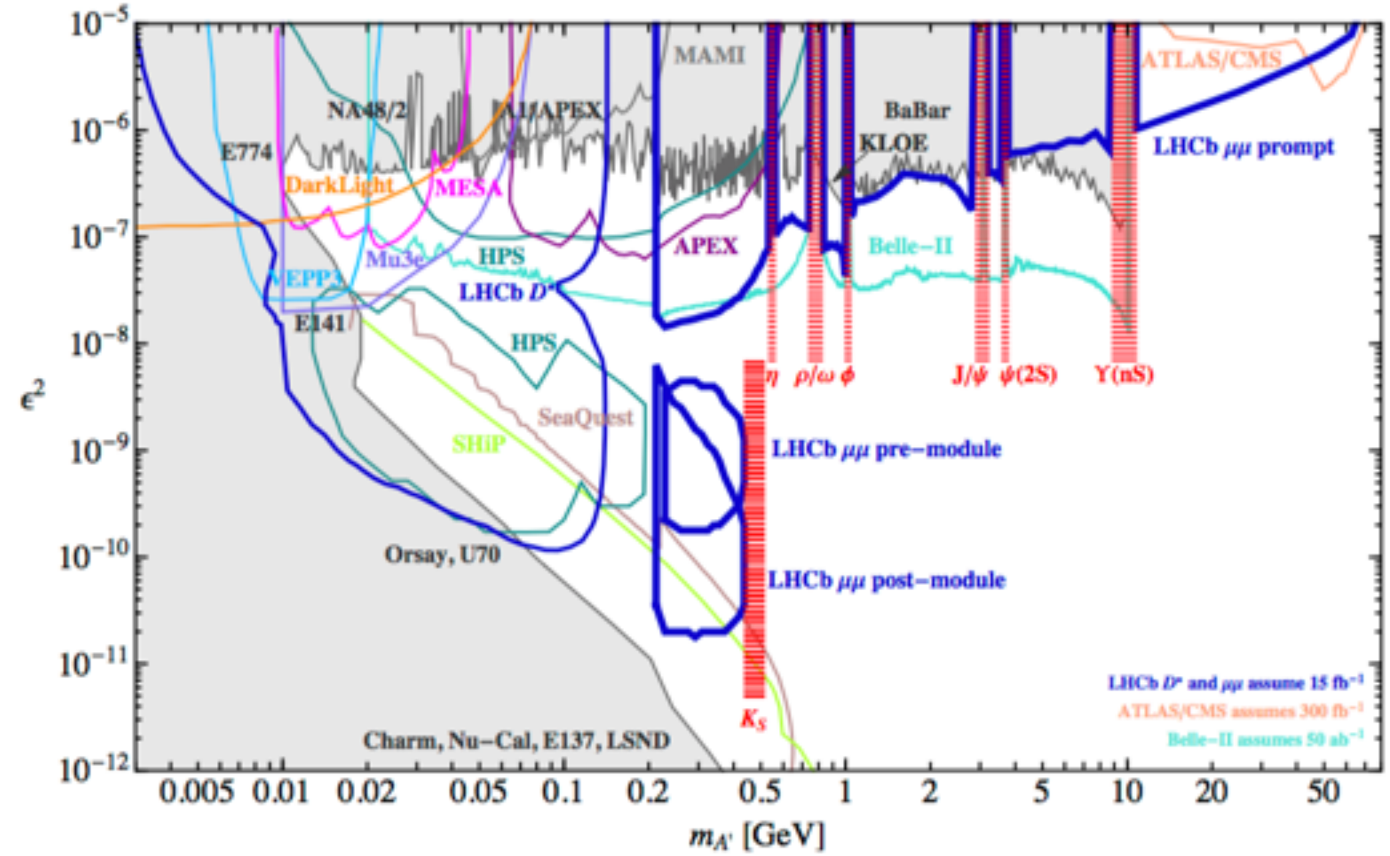
arXiv:1606.09317v

Dark photon coupling to SM particles

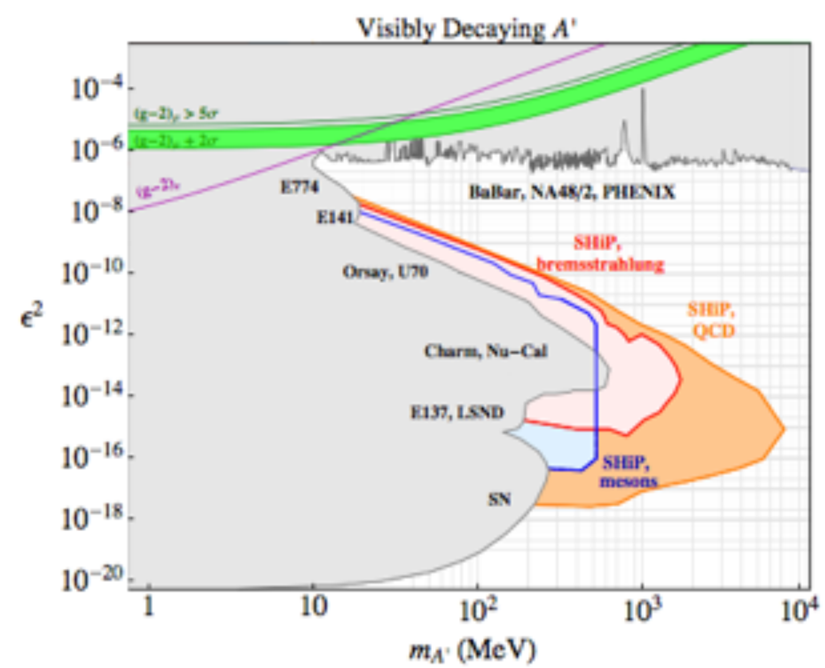
arXiv:1509.06765

decay modes



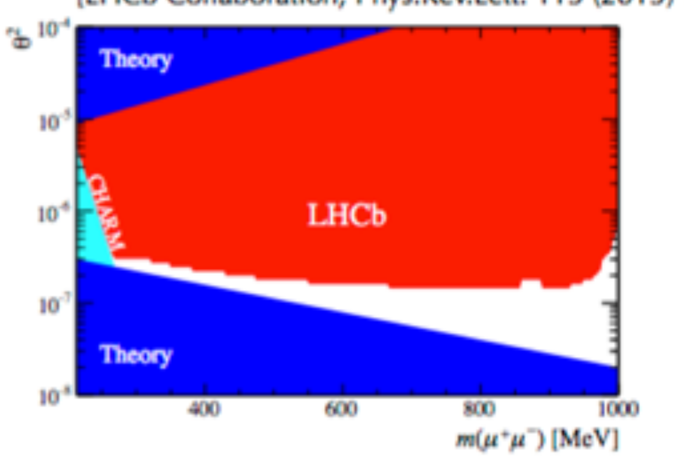


only a beam dump with ILC could <u>maybe</u> cover also the SHiP sensitivity region…

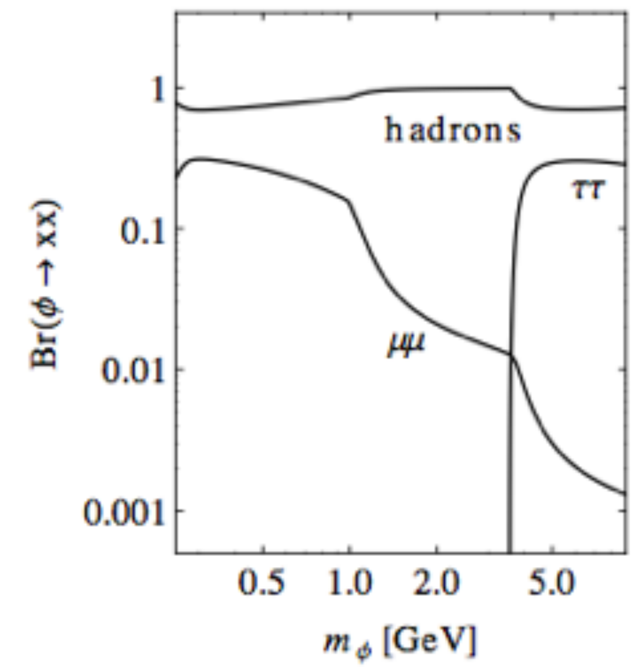


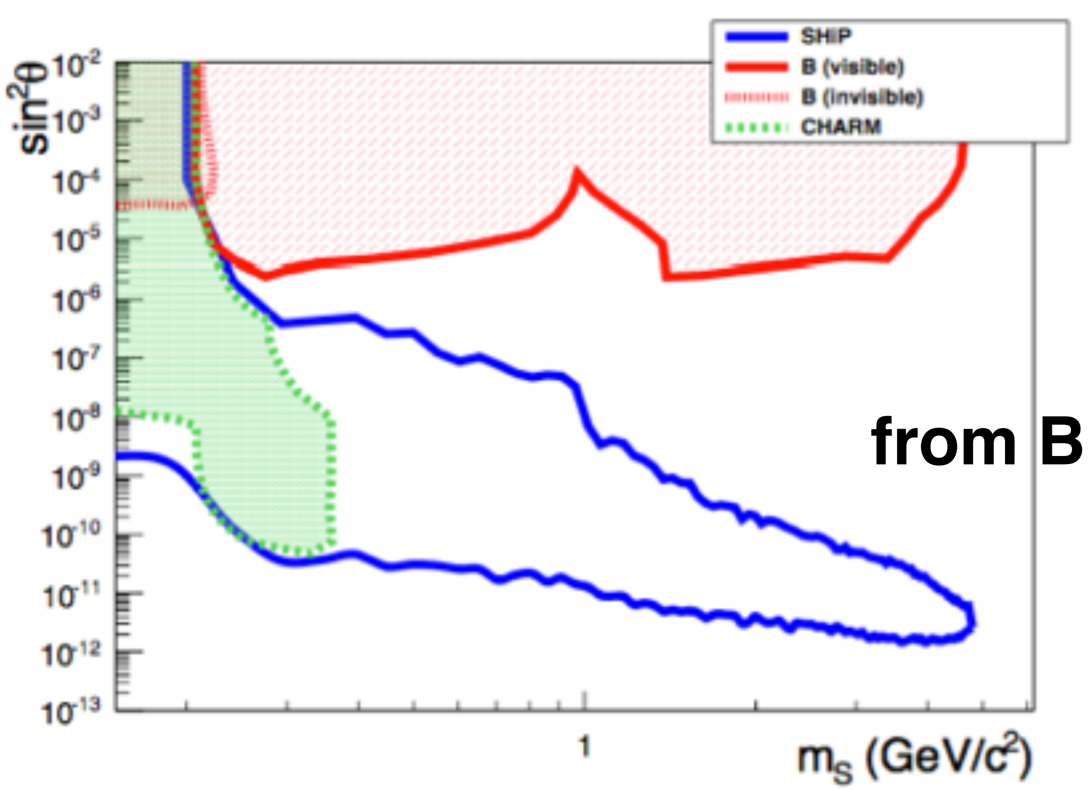
Dark Higgs

[LHCb Collaboration, Phys.Rev.Lett. 115 (2015) 1

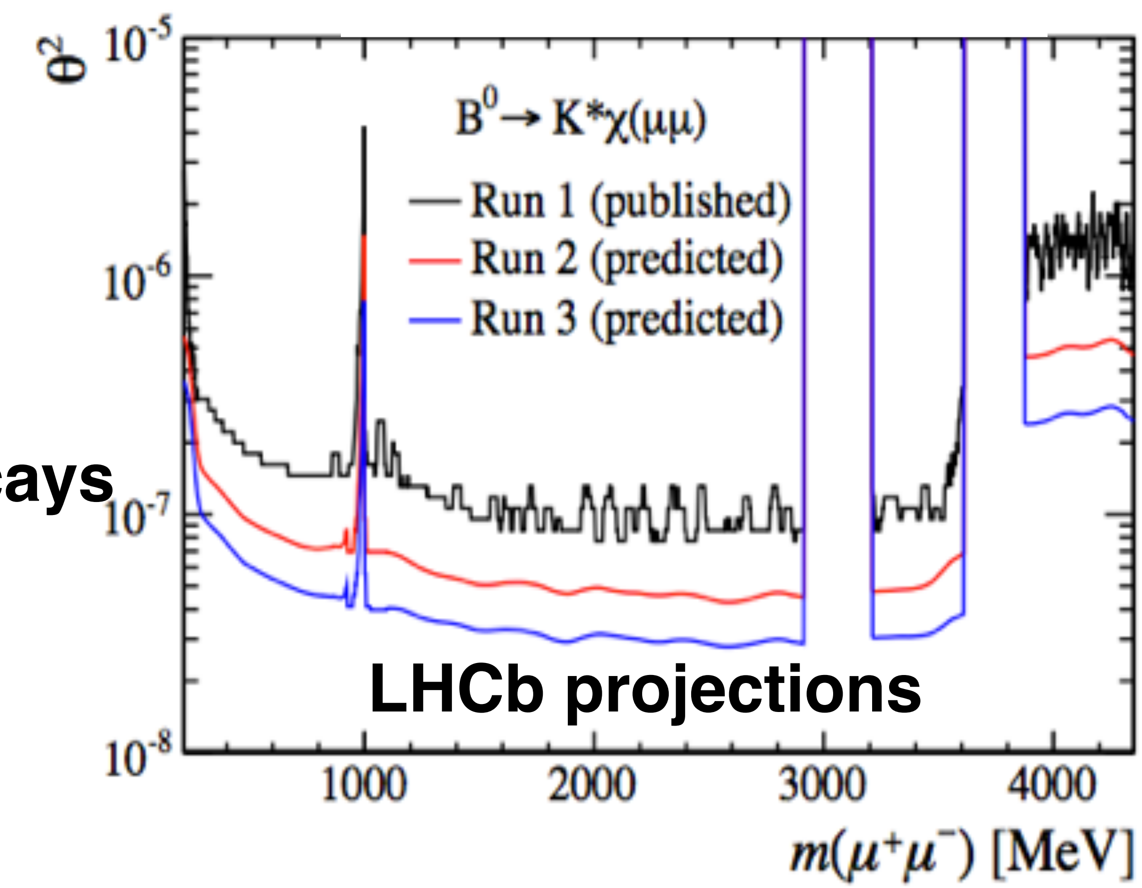


decay modes





from B decays

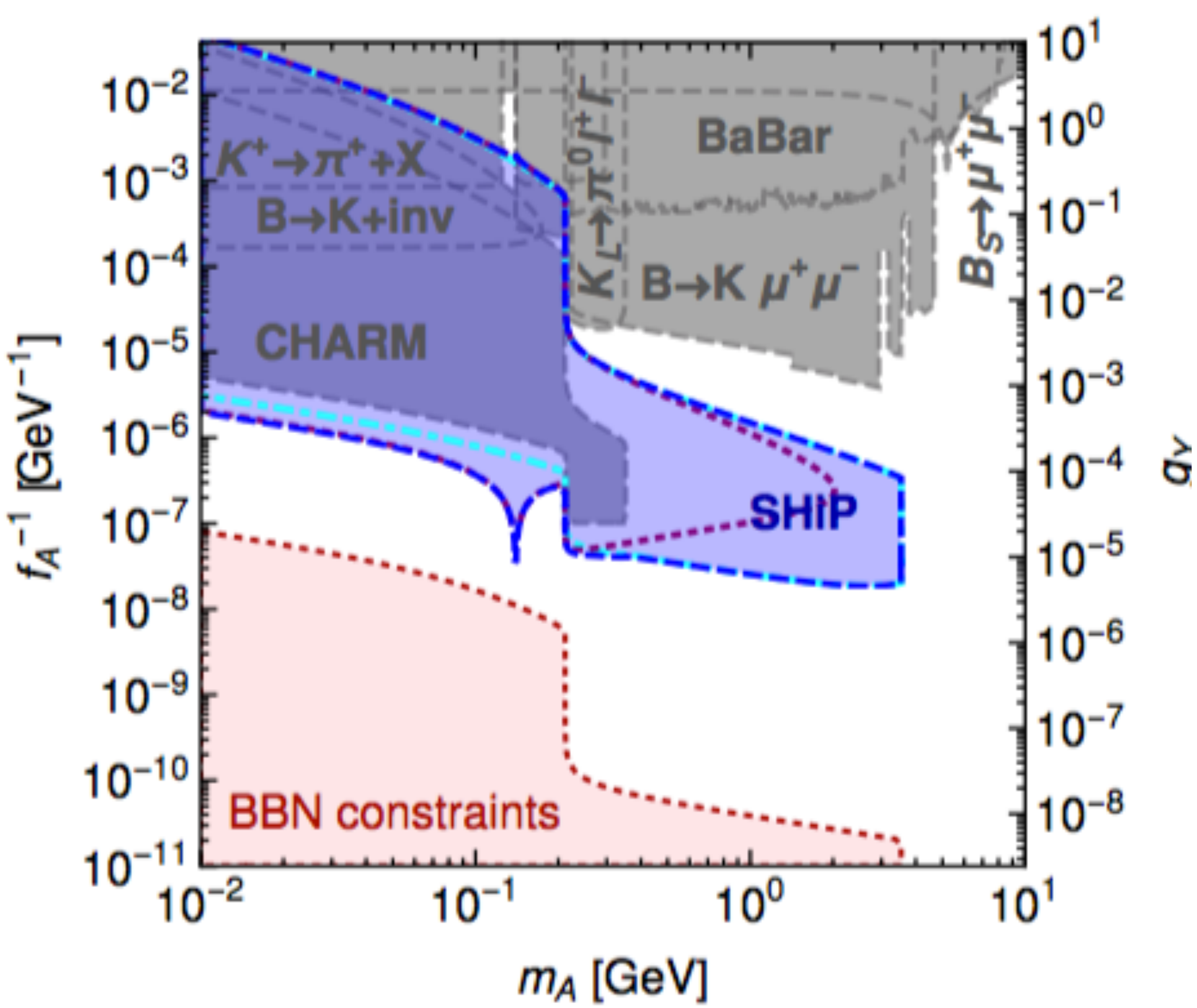


LHCb projections

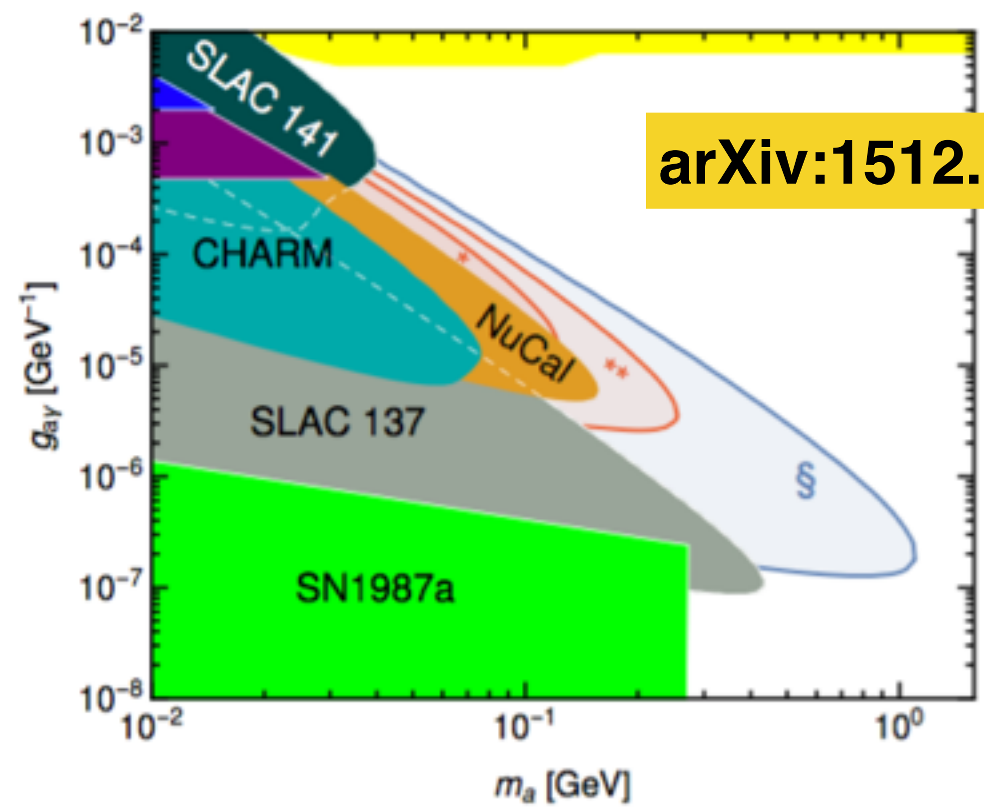
complementary!

Pseudo-scalar portal: ALP or PNGB

coupling to fermions only:
produced in B decays
decay to fermions



coupling to photons only:
decay to photons

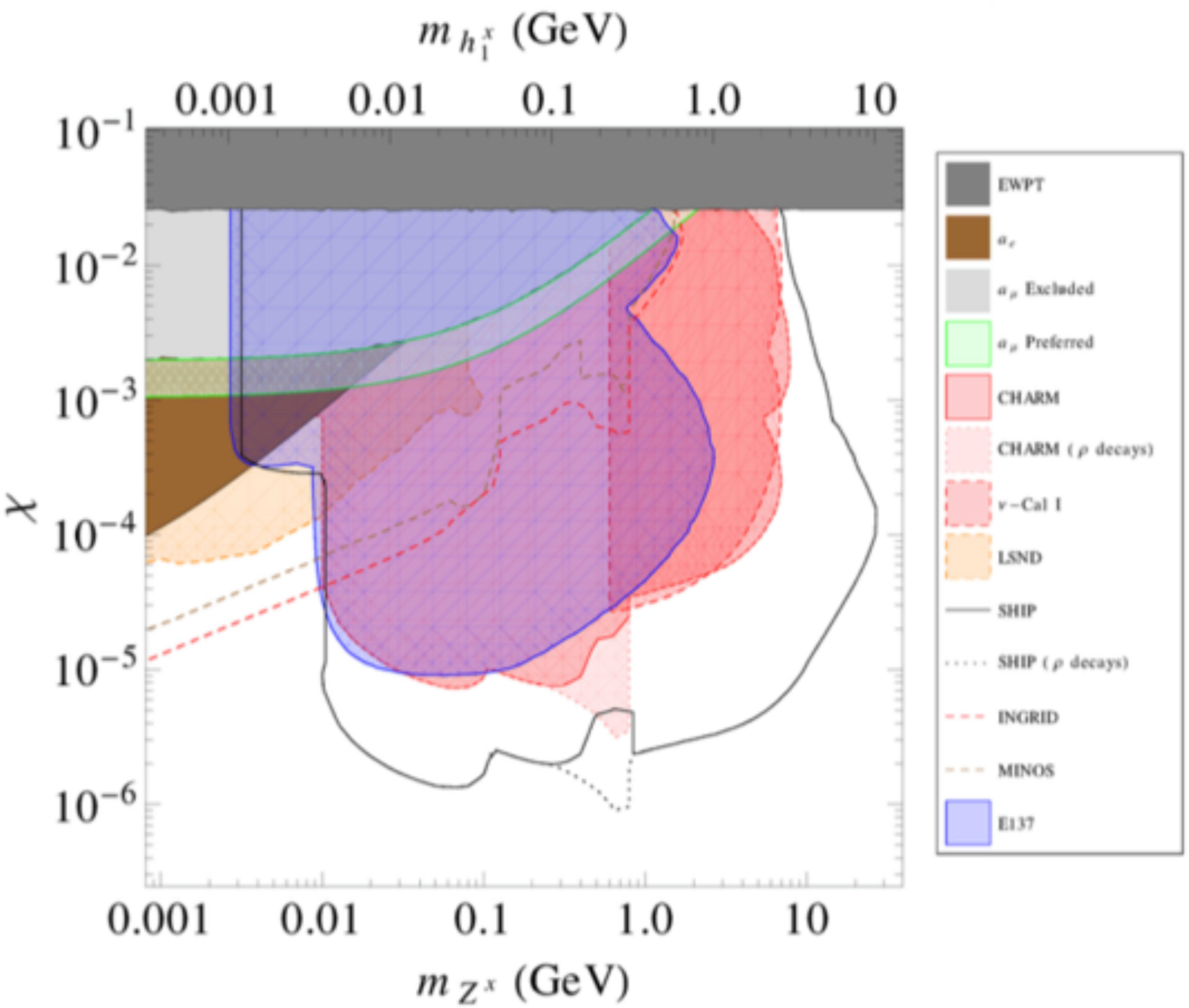


arXiv:1512.03069

we are currently studying backgrounds and possible detector improvements for reconstruction of the photon direction

The SUSY/Portals connection

Morrissey et al



[SHiP Physics, Alekhin, ..., DM, Spray, ... 2015]

New studies on SUSY (I)

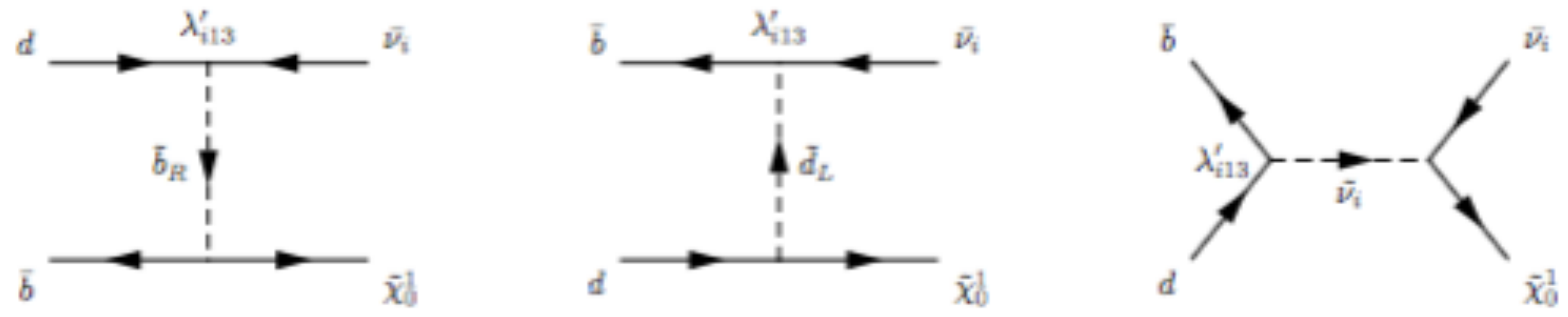
Phys. Rev. D 92, no. 7, 075015 (2015)

Search for SUSY renegades, below the EW scale

Neutralino's in RPV SUSY models

In the constrained MSSM with 5 parameters the lightest neutralino must be heavier than 46GeV but in general even massless neutralino is allowed

production: from decays of D and B mesons



decay: eeν, $\mu\mu$ν, πe, πμ, Ke, Kμ like the HNL

New studies on SUSY (I)

TABLE I. Estimates of SHiP sensitivity to and CHARM bounds on combinations of RPV couplings. In the first three rows we set $M_{\tilde{\chi}_1^0} = 1\,\mathrm{GeV}$ and $M_{\tilde{\chi}_1^0} = 4\,\mathrm{GeV}$ for the last three rows. Indices $j, k = 1, 2$ and $i = 1, 2, 3$ indicate flavor of the final-state leptons.

λ	Expected sensitivity SHiP, $M_{\tilde{f}}^2/\mathrm{TeV}^2$	Upper limit CHARM, $M_{\tilde{f}}^2/\mathrm{TeV}^2$
$\sqrt{\lambda'_{121}\lambda_{ijk}}$	2.4×10^{-3}	2.5×10^{-2}
$\sqrt{\lambda'_{121}\lambda'_{j11}}$	1.2×10^{-3}	–
$\sqrt{\lambda'_{121}\lambda'_{j21}}$	1.4×10^{-3}	–
$\sqrt{\lambda'_{113}\lambda_{ijk}}$	2.4×10^{-3}	2.5×10^{-2}
$\sqrt{\lambda'_{113}\lambda'_{j11}}$	3.9×10^{-3}	–
$\sqrt{\lambda'_{113}\lambda'_{j21}}$	4.0×10^{-3}	–

For coupling of order 1 the mass reach for s-fermion masses (assumed the same in this paper) is O(30TeV)

New studies on SUSY (II)

arXiv:1511.05403

If SUSY is spontaneously broken at not very high energy scale (see models with gauge mediation of SUSY breaking as an example), the particles from SUSY breaking sector may show up at quite low energies.

The Goldstino supermultiplet contains the Goldstino (the Nambu–Goldstone field, fermion) and its superpartners, scalar and pseudoscalar s-goldstinos.

S-goldstino couplings to the SM fields are inversely proportional to the parameter of the order of squared scale of SUSY breaking F in the whole model

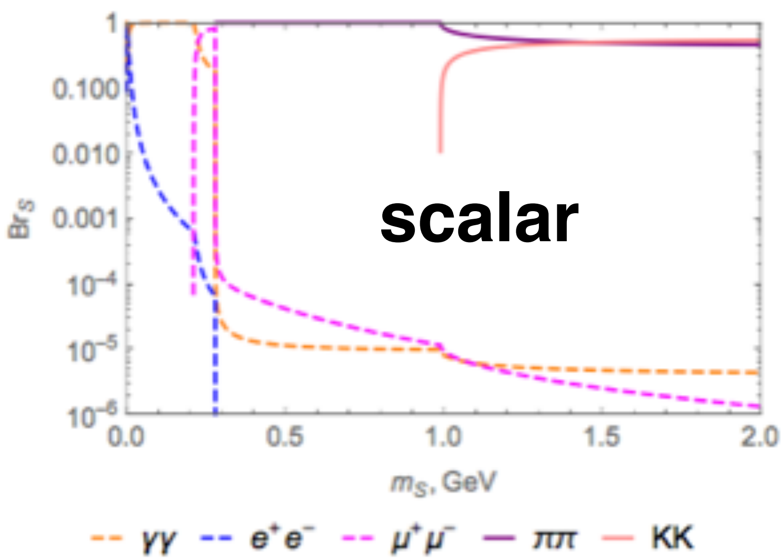
—> their couplings are anticipated to be rather weak.

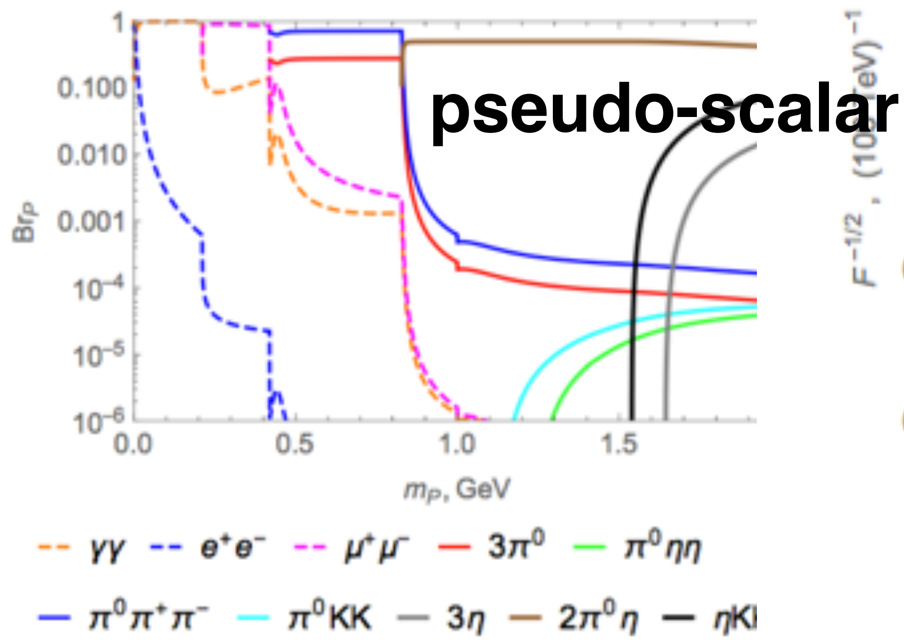
—>test the SUSY breaking scale by hunting for the light s-goldstinos

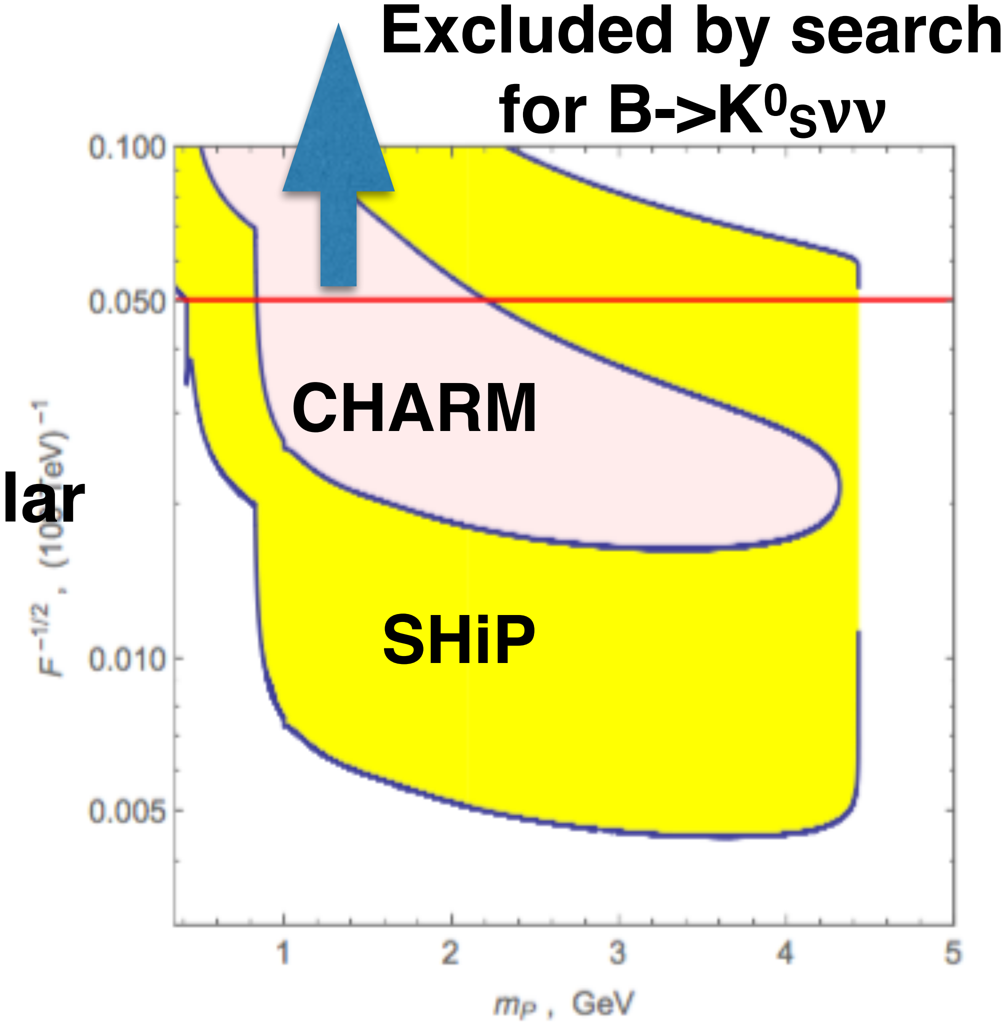
New studies on SUSY (II)

Production: B and D decays

Decay:







SHiP can probe the supersymmetry breaking scale

up to 10^3 TeV for the model without flavor violation and up 10^5 TeV for the model with flavor violating parameters

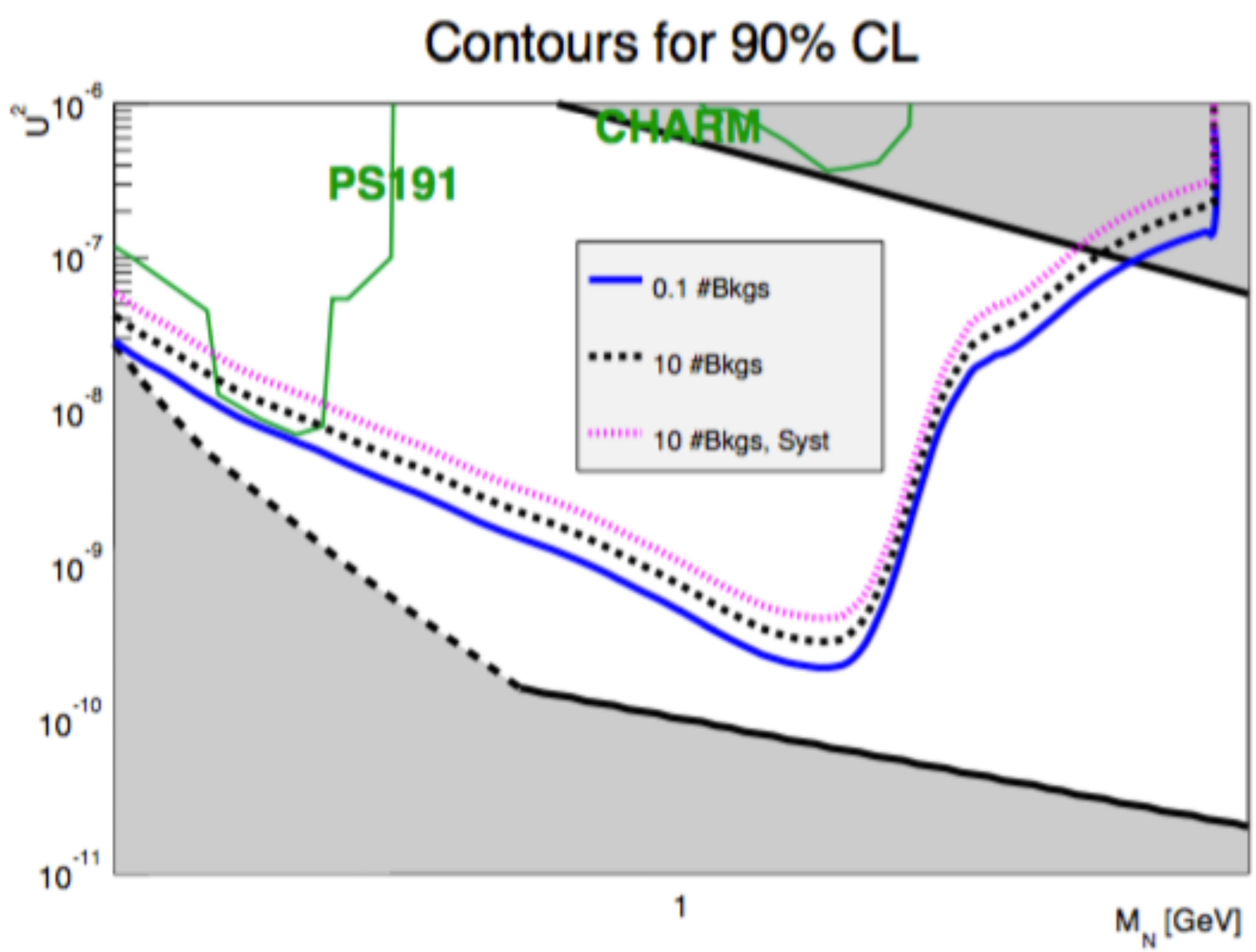
Backgrounds for the downstream detector:

as said above from TUNED-ON-DATA MonteCarlo we found 0 in > 2e20 pot (*)

TUNING of MC is always improving and is a high priority of SHiP now

(*) except for ALP—>γγ under study

…but even in case of few background events…



Physics with the upstream detector

Structure functions in the Standard Model

ν_τ DIS

Nucl. Phys. B84, 467 (1975)

$$W_{\mu\nu} = \bar{\sum_{\text{spin } N}} \sum_F \langle N|J_\mu^\circledast|F\rangle\langle F|J_\nu|N\rangle\,\delta(q+p-p_F)$$
$$= -\delta_{\mu\nu}W_1 - \frac{1}{M^2}p_\mu p_\nu W_2 - \frac{1}{2M^2}\epsilon_{\mu\nu\alpha\beta}p_\alpha q_\beta W_3 - \frac{1}{M^2}q_\mu q_\nu W_4$$
$$- \frac{1}{2M^2}(p_\mu q_\nu + p_\nu q_\mu)W_5\,,$$

decomposition of the hadronic tensor with them reversal invariant structure functions $W_i(q^2,\nu)$
(p is 4momentum of nucleon)

Assuming Bjorken scaling

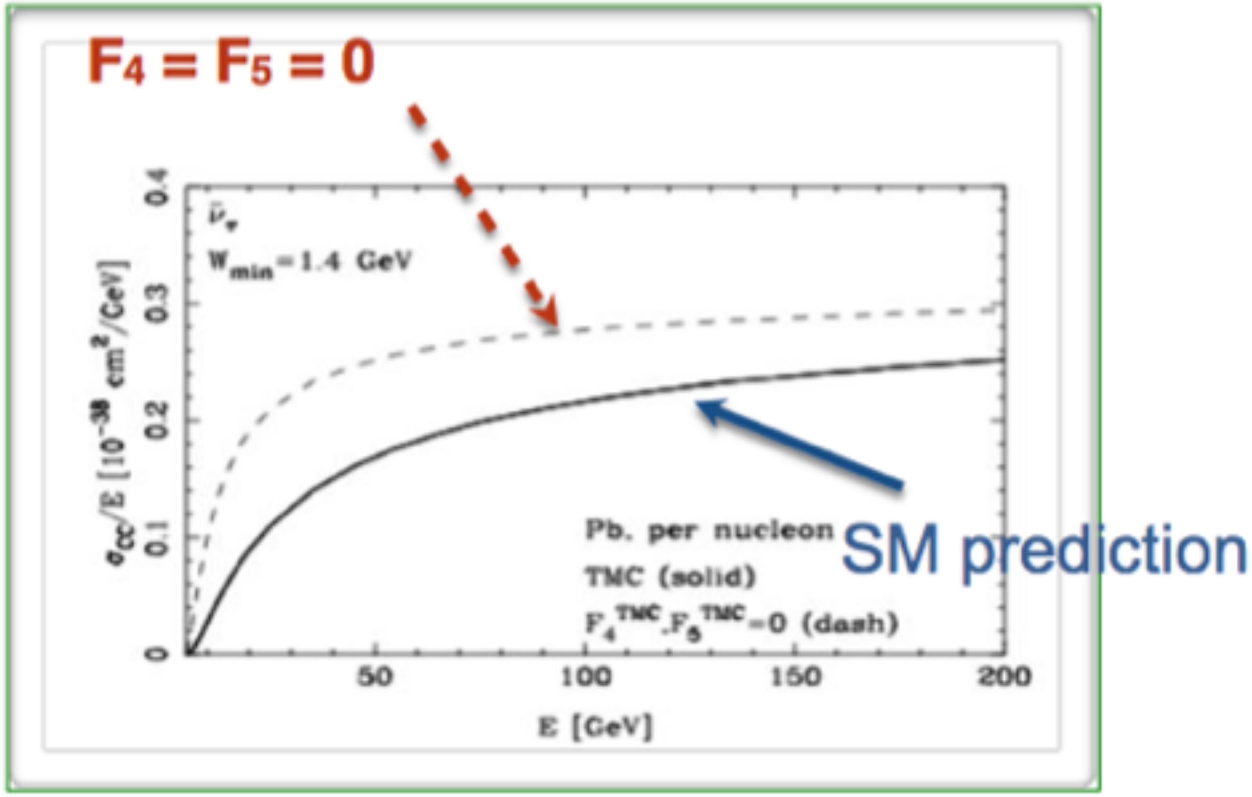
$$\lim_{\text{Bj}} MW_1 = F_1(x)\,, \qquad \lim_{\text{Bj}} \nu W_k = MF_k(x)\,,$$

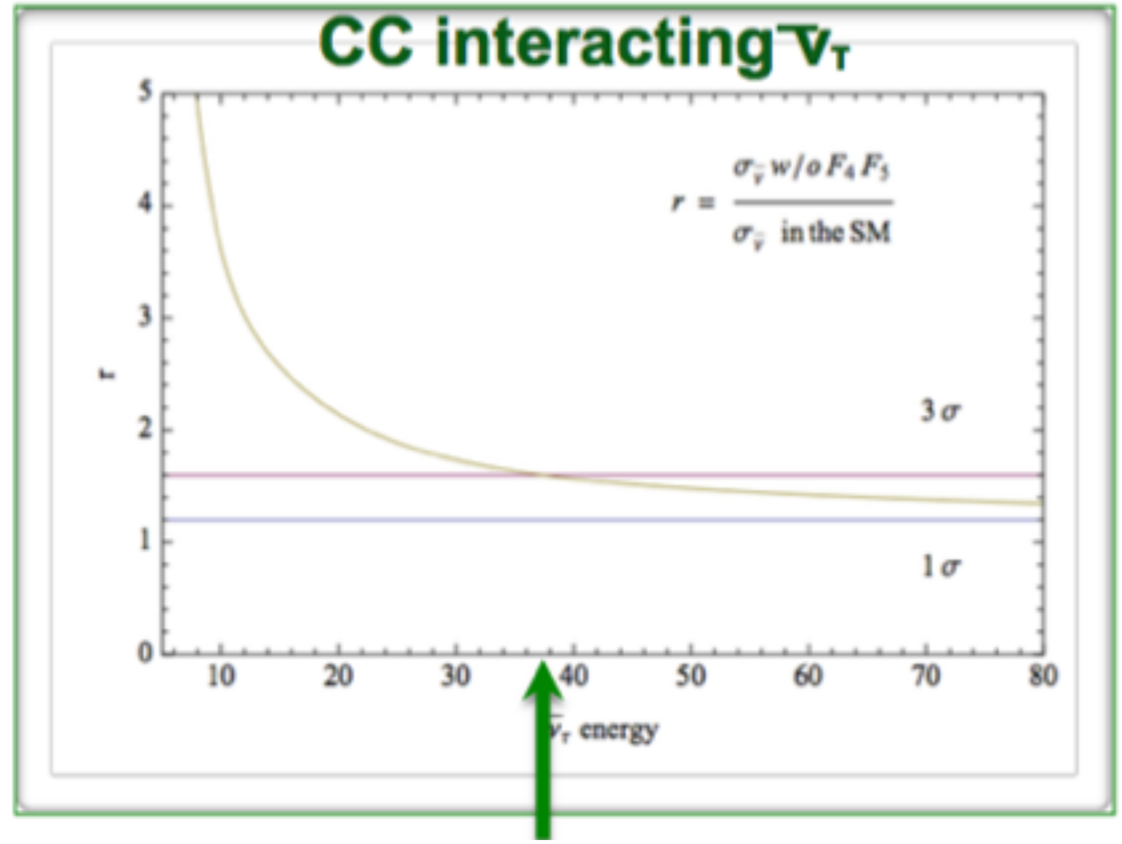
$$\frac{\mathrm{d}^2\sigma^{\nu,\bar\nu}}{\mathrm{d}x\,\mathrm{d}y} = \frac{G^2ME}{\pi}\left\{\left(xy+\frac{m^2}{2ME}\right)yF_1 + \left[(1-y)-\left(\frac{M}{2E}xy+\frac{m^2}{4E^2}\right)\right]F_2 \right.$$
$$\left. \mp\left[xy(1-\tfrac{1}{2}y)-\frac{m^2}{4ME}y\right]F_3 + \frac{m^2}{M^2}\left[\left(\frac{M}{2E}xy+\frac{m^2}{4E^2}\right)F_4 - \frac{M}{2E}F_5\right]\right\}$$

Assuming $2xF_1 = F_2$ (Callan-Gross), and $-xF_3=F_2$, verified experimentally, it follows that $F_4=0$ and $2xF_5=F_2$ (Albrecht-Jarlskog). LO QCD (parton model) confirms these relations.

F_4 and F_5 cannot be measured in ν_μ and ν_e scattering since they are suppressed by mass terms

ν_τ DIS





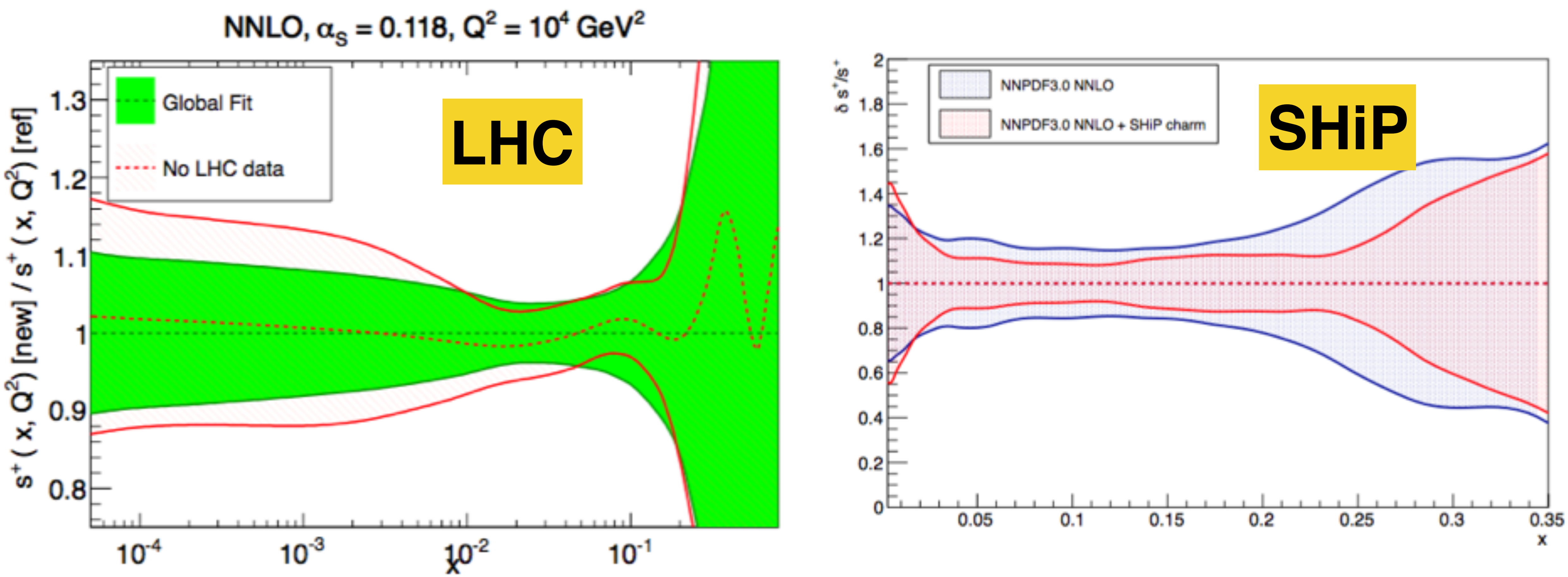
With SHiP we can test for the first time the full neutrino DIS formula providing one of last remaining fundamental tests of the SM.

NB: $\sigma(\nu_\tau)<\sigma(\nu_\mu)$ in the SM, and half the difference comes from reduced phase space and half from F_5

…and not to forget that the anti-ν_τ was not observed so far…

ν_μ DIS

s-quark structure function



LHC and SHiP will probe the strangeness distribution in different ranges of x.

With $Q^2 \sim M_W^2$ measurements of W and W+c production at the LHC constraint on strangeness at $x < 10^{-2}$

SHiP is sensitive above this range

Searches for NP

ν_τ DIS

Lepton universality tests

Phys.Rev. D92 (2015) 7, 073016

No wonder that the third generation is the most interesting in this respect, less tested, higher mass ecc.(e.g. 2HDM)

Also some hints of LUV from LHCb, B Factories ecc.

In the presence of NP, the effective Hamiltonian for the scattering process $\nu_\tau + N \rightarrow \tau + X$

$$\mathcal{H}_{eff} = \frac{4G_F V_{ud}}{\sqrt{2}} \Big[(1+V_L) [\bar{u}\gamma_\mu P_L d] [\bar{l}\gamma^\mu P_L \nu_l] + V_R [\bar{u}\gamma^\mu P_R d] [\bar{l}\gamma_\mu P_L \nu_l]$$

$$+ S_L [\bar{u} P_L d] [\bar{l} P_L \nu_l] + S_R [\bar{u} P_R d] [\bar{l} P_L \nu_l] + T_L [\bar{u}\sigma^{\mu\nu} P_L d] [\bar{l}\sigma_{\mu\nu} P_L \nu_l] \Big]$$

In which G_F is the Fermi coupling constant
$V_{q\bar{q}}$ is Cabibbo-Kobayashi-Maskawa (CKM) matrix element
$P_{L,R} = (1 \mp \gamma_5)/2$, $\sigma_{\mu\nu} = i[\gamma_\mu, \gamma_\nu]/2$

DIS cross section written including possible BSM couplings between light quarks and third generation leptons and compared to SM

We studied so the effect on total cross sections; differential yet to be done

Effect of NP on cross section: scalar-tensor model

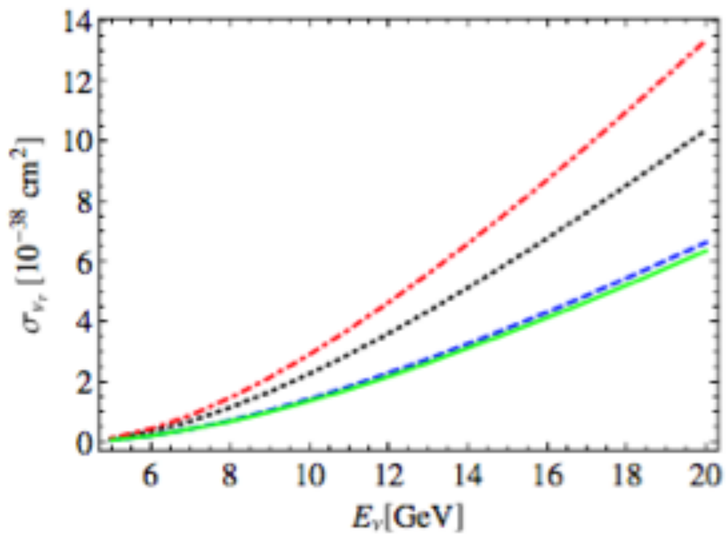


FIG. 10 (color online). $S \pm T$ model: The total cross section of $\nu_\tau + N \to \tau + X$ in the scalar-tensor model. The green solid line corresponds to the standard model prediction $S_R = S_L = T_L = 0$. The blue dashed, black dotted and red dot dashed lines correspond to $(S_R, S_L, T_L) = (-0.19, 0.68, 0.072)$, $(1.98, 0.42, -0.13)$, $(-1.87, -1.31, 0.18)$.

parameters allowed by τ hadronic branching ratio values

$A_S = S_R + S_L$ $B_S = S_R - S_L$

$$\frac{d\sigma_{\rm LQS}}{dxdy} = \frac{G_F^2 M E_\nu}{4\pi}(A_S^2 + B_S^2)y\left(xy + \frac{m_\ell^2}{2ME_\nu}\right)F_1,$$

$$\frac{d\sigma_{\rm LQT}}{dxdy} = \frac{8G_F^2 M E_\nu}{\pi}T_L^2\left(y\left(xy + \frac{m_\ell^2}{2ME_\nu}\right)F_1 + 2\left(1 - y - \frac{Mxy}{4E_\nu} - \frac{m_\ell^2}{8E_\nu^2}\right)F_2 - \frac{m_\ell^2}{ME_\nu}F_5\right)$$

Preliminary results

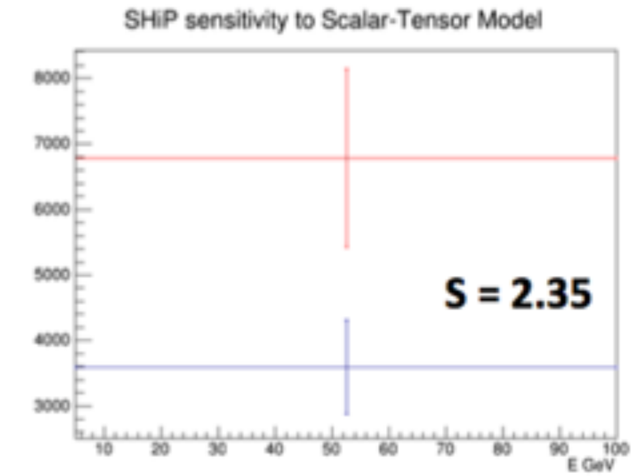
blue=SM

red=scalar and tensor model (e.g a scalar Leptoquark);

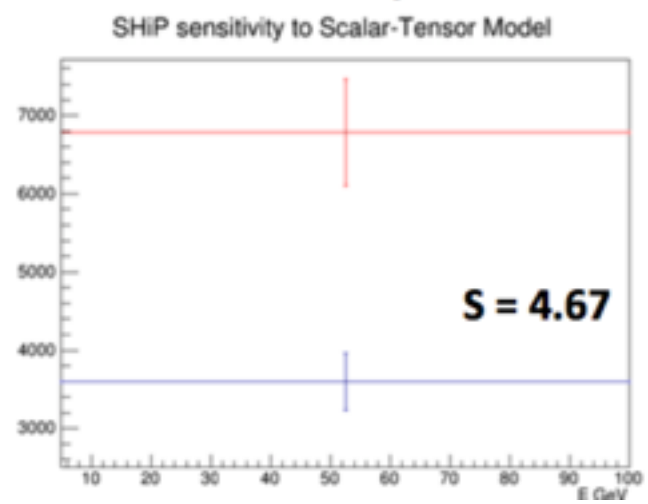
results depend on the level of total error: normalization important!

$$S = \frac{Num_{NP} - Num_{SM}}{NP_{Err}}$$

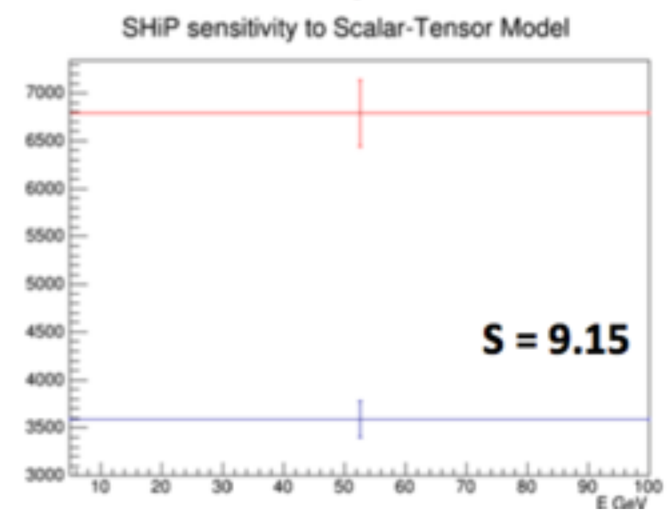
20% SysErr



10% SysErr

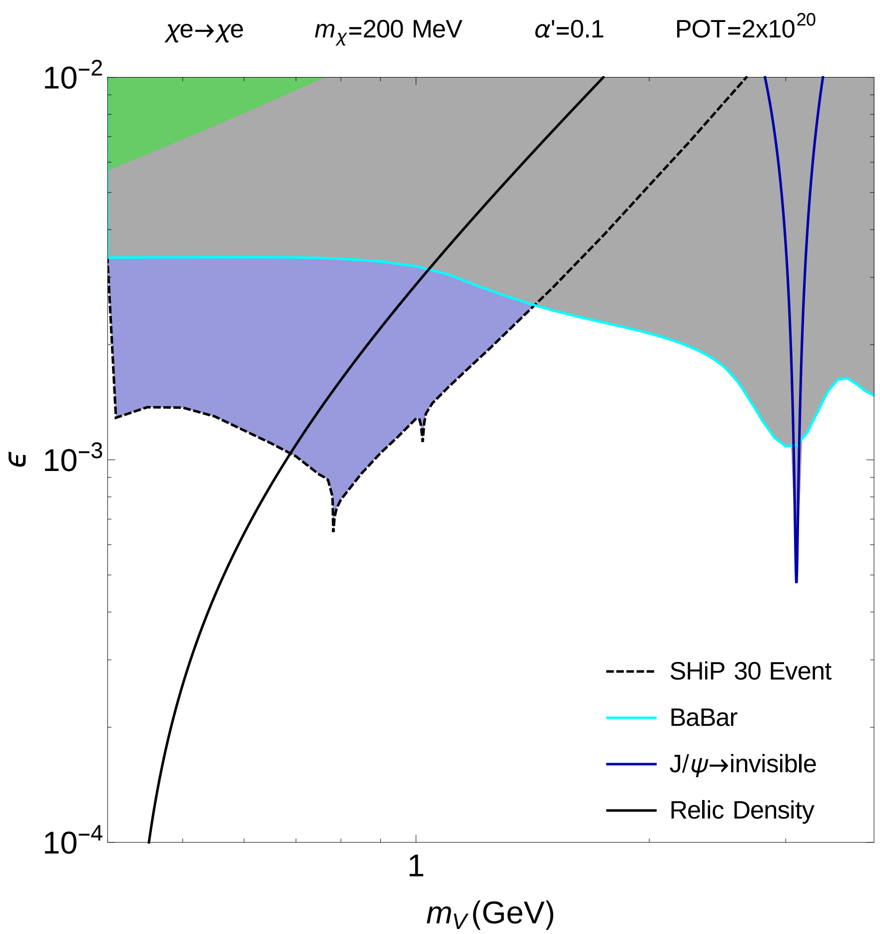


5% SysErr



χ scattering

Dark photon decaying to dark matter



DeNiverville et al.

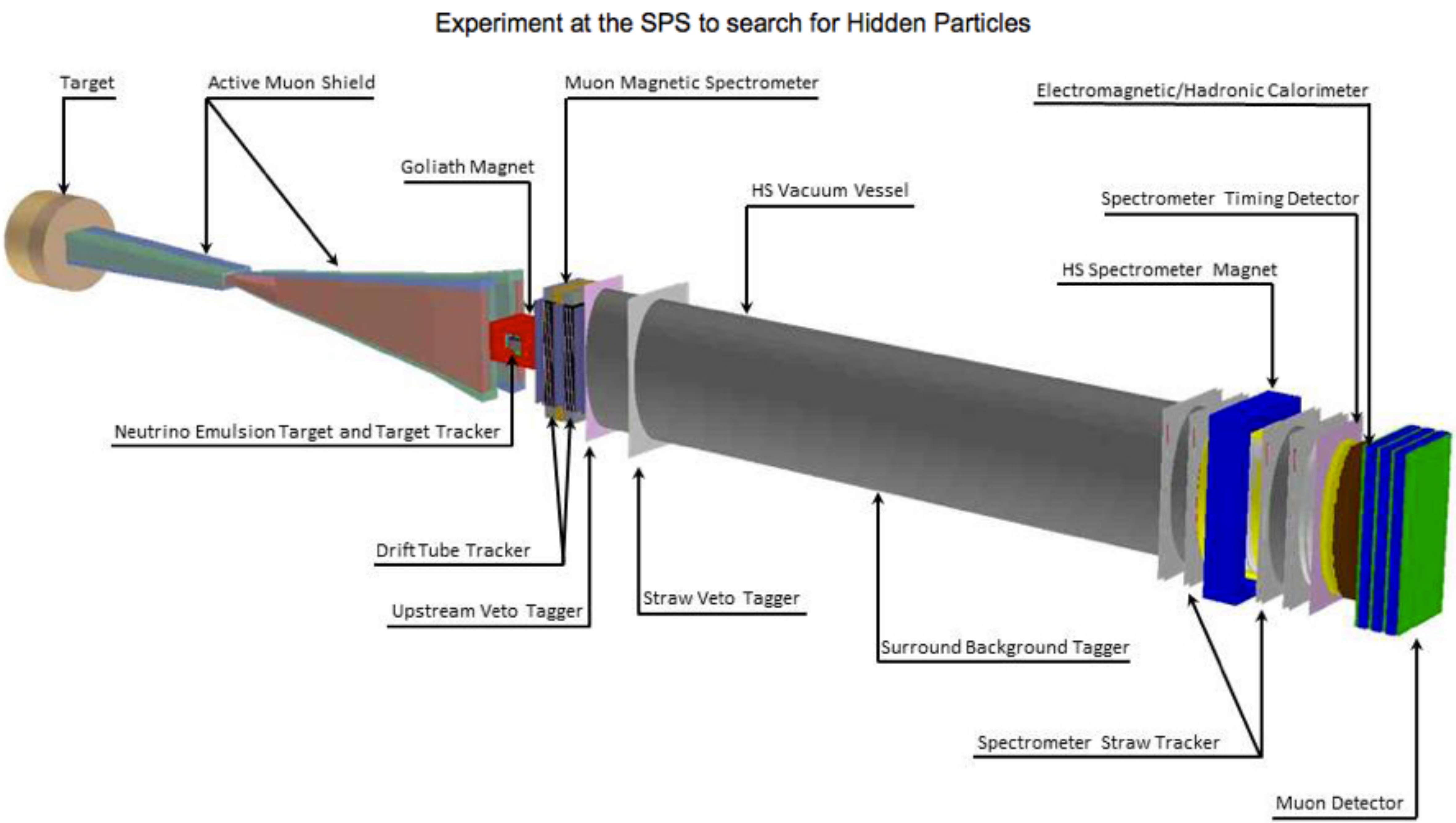
Detect neutral current interaction on atomic e-

—>not a background-free search (but calculable)

after cuts (angle 10-20mrad, E<20GeV), the beam backgrounds:

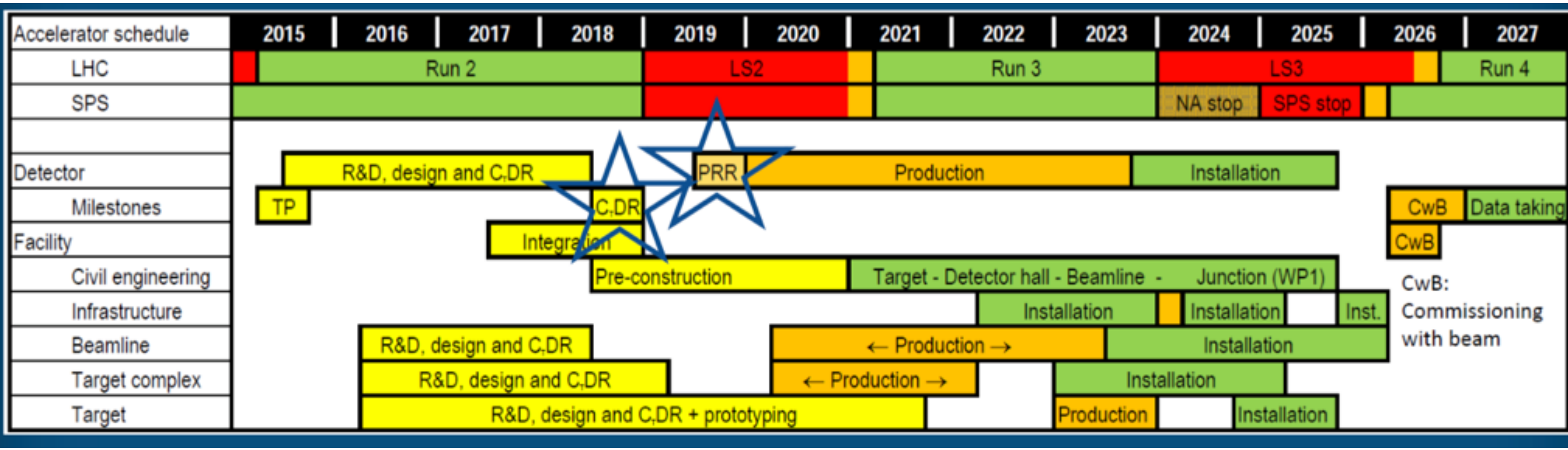
	ν_e	$\bar{\nu}_e$	ν_μ	$\bar{\nu}_\mu$	all
Elastic scattering on e^-	16	2	20	18	56
Quasi - elastic scattering	105	73			178
Resonant scattering	13	27			40
Deep inelastic scattering	3	7			10
Total	137	109	20	18	284

The TP detector



Relevant news on the experimental side since the TP

Time table



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 C.DR
PRR
Production
Installation
Milestones
TP
C.DR
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 C.DR
← Production →
Installation
Target complex
R&D, design and C.DR
← Production →
Installation
Target
R&D, design and C.DR + prototyping
Production
Installation
CwB: Commissioning with beam

SPS Committee minutes

The SPSC **has reviewed** the proposal for "A Facility to Search for Hidden Particles (SHiP) at the CERN SPS" (Technical Proposal P-350 and Physics case P-350-ADD-1), submitted in April 2015 following an earlier submission of the Expression of Interest EoI-010 in October 2013. The review included several lists of questions sent to the proponents, which were all answered including submission of a proposal addendum P-350-ADD-2 in October 2015.

In the review process the Committee **was impressed** by the dedication of the SHiP proponents and their responsiveness to the Committee's requests. In particular significant progress has been made since the EoI, along the lines of the SPSC112 recommendations, including optimisation of the proton beam dump design, broadening of the physics case and adaptation of the SHiP scheduling to external constraints. The CERN SPS offers a unique opportunity for the proposed programme and the SHiP proponents have the potential strength to build the proposed detector setup.

The main physics motivation of SHiP is to explore the domain of hidden particles, searching in particular for new scalar, fermionic and vector particles. These would be produced in a proton beam dump at 400 GeV, either directly or from decays of charm or beauty particles. The experiment would be sensitive to a hitherto unexplored region of parameter space, spanning masses from a few hundred MeV to a few GeV and over two orders of magnitude in squared couplings. The main experimental signature involves two charged decay tracks, and will be complemented by decays to neutral particles. The experiment is also proposed to be equipped with an emulsion target, which would allow for unprecedented tau neutrino and antineutrino measurements and valuable QCD studies. Furthermore it would extend the hidden sector search to scattering of dark matter particles. The facility could accommodate additional detectors extending the range of dark matter searches. The SPSC supports the motivation for the search for hidden particles, which will explore a domain of interest for many open questions in particle physics and cosmology, and acknowledges the interest of the measurements foreseen in the neutrino sector. SHiP could therefore constitute a key part of the CERN Fixed Target programme in the HL-LHC era.

19/1/2016 SPS Committee Meeting minutes (ii)

The SPSC **supports** the updated SHiP schedule, which takes into account the HL-LHC preparation constraints during LS2, and defers any significant civil engineering investments for SHiP to the period following full approval of SHiP. The SPSC **notes** that, in this updated schedule, the time scale for the SHiP comprehensive design study, required for a final decision, coincides with the expected revision of the EU HEP strategy. The Committee **also notes** the plans of the incoming CERN Management to set up a working group to prepare the future of the CERN Fixed Target programme after LS2, as input to the next EU strategy update. In this context the SPSC **recommends** that the SHiP proponents proceed with the preparation of a Comprehensive Design Report (CDR), and that this preparation be made in close contact with the planned Fixed Target working group.

Preparation of the CDR should include further optimisation of the beam dump facility in the direction of a multipurpose area, test beams of detector prototypes where needed, detailed simulations of the detector response to all signal and background signatures, further theoretical studies of expected signals and comparisons with alternative search programmes. The Committee **encourages** the proponents to define a programme of measurements concerning production of charm in a SHiP-like target, important for normalisation purposes. The SPSC **also encourages** the proponents to further explore the potential benefit of inputs from the ongoing NA62 experiment to strengthen the experimental evaluation of SHiP backgrounds and systematics. The resources needed for the preparation of the SHiP CDR in the coming years should be secured within a MoU between CERN and the SHiP proponents' institutes.

Research Board 9 March meeting minutes

F. Gianotti presented the draft mandate for a new "**Physics Beyond Colliders**" study group [2]. The CERN management wishes to launch an exploratory study aimed at exploiting the full scientific potential of its accelerator complex through projects complementary to the LHC, HL-LHC and possible future colliders (such as HE-LHC, CLIC, or FCC). These projects would target fundamental physics questions that are similar in spirit to those addressed by high-energy colliders, but that require different types of beams and experiments. The study should provide input for the future of CERN's scientific diversity programme, which today consists of several facilities and experiments at the Booster, PS and SPS. Complementarity with similar initiatives elsewhere in the world should be sought, so as to optimize the resources of the discipline globally, create synergies with other laboratories and institutions, and attract the international community. Examples of physics objectives include searches for rare processes and very-weakly interacting particles, measurements of electric dipole moments, etc. The group will be led by three coordinators representing the scientific communities of theory, accelerators and experimental particle physics. Following consultation with the relevant communities, they will define the structure and the main activities of the group and appoint convenors of thematic working groups as needed. They will call a kick-off meeting in the first half of 2016, organize regular plenary meetings, and monitor the overall scientific activity. The scientific findings will be collected in a report to be delivered by the end of 2018, and will serve as input to the next update of the European Strategy for Particle Physics. In discussion it was clarified that the focus of this study will be accelerator-based particle physics rather than atomic, nuclear or medical physics; axion searches may be included if they require features that are uniquely available at CERN, as would future plans for antiproton and muon facilities. **The Research Board took note.**

Research Board 9 March meeting minutes (ii)

The SPSC has reviewed the proposal for “A Facility to Search for Hidden Particles DRAFT CERN-DG-RB-2016-461

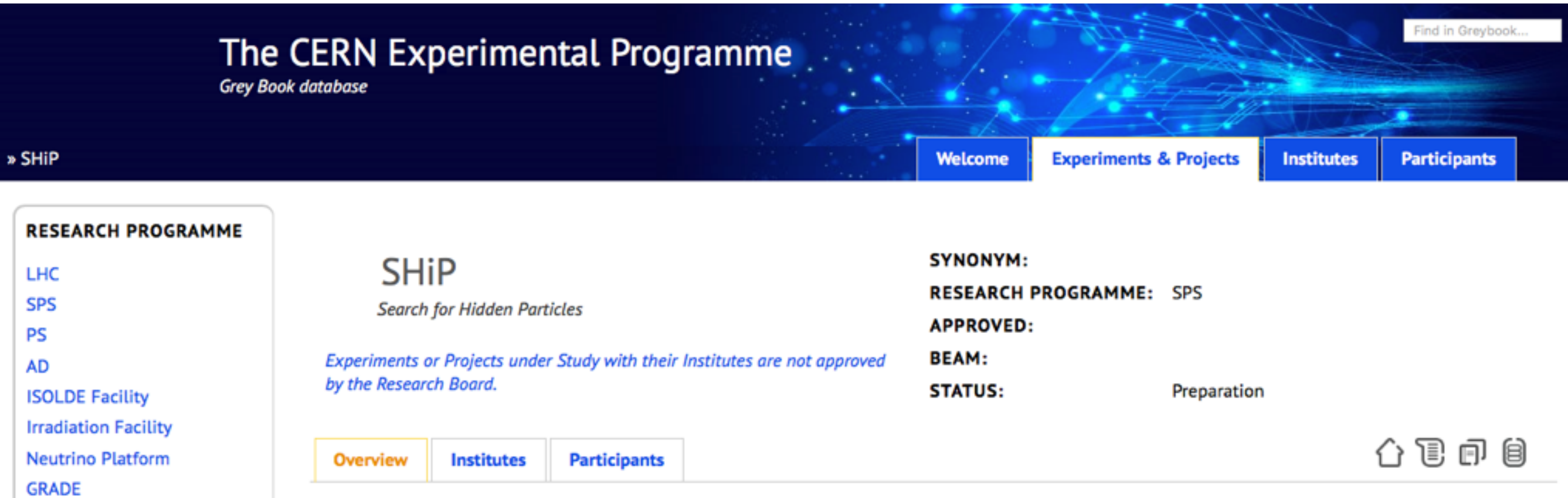
(**SHiP**) at the CERN SPS” submitted in April 2015. The review included questions from the referees that were all answered, including submission of an addendum in October 2015 [6]. Significant progress has been made during the review, including optimisation of the proton beam-dump design, broadening of the physics case and adaptation of the schedule to external constraints. The SPSC supports the motivation for the search for hidden particles, which will explore a domain of interest for many open questions in particle physics and cosmology, and acknowledges the interest of the measurements foreseen in the neutrino sector. The committee encourages the proponents to further explore the potential benefit of inputs from NA62 to strengthen the experimental evaluation of backgrounds and systematic uncertainties. The Research Board endorsed the recommendation from the SPSC that the collaboration should perform a comprehensive design study, focussed on the SHiP detector, including detailed simulations of the response to the signal and background signatures and comparisons with alternative search programmes; it should be performed in close collaboration with the Physics Beyond Colliders study group (discussed in item 2), which will consider physics motivations and technical optimisation of a beam-dump facility at CERN and other possible experiments that might use it. The study should be completed in time for the next update of the European Strategy for Particle Physics, on the timescale of three years, and the decision on approval will be taken following the conclusion of that update.

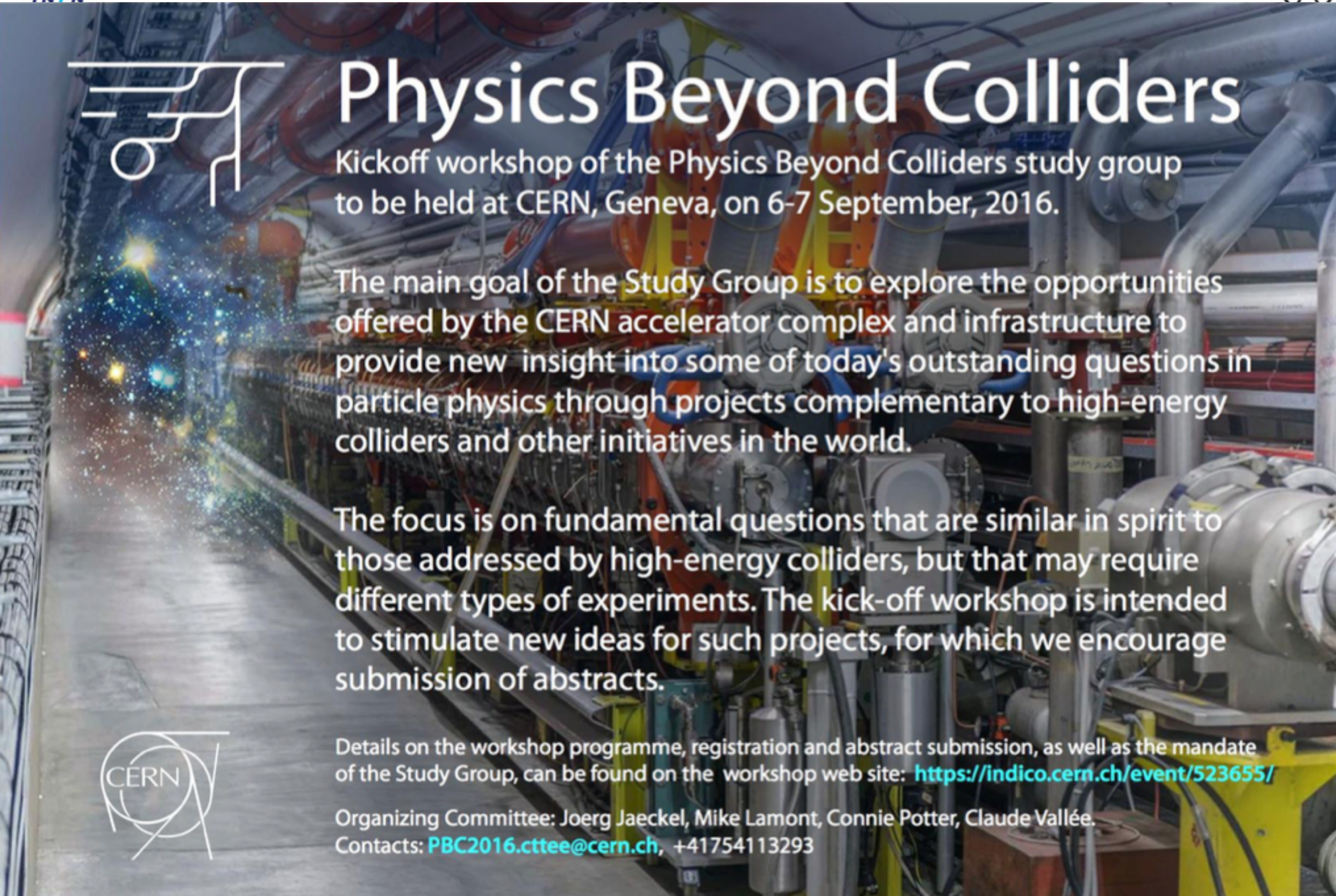
MTP2017

Changes since the previous MTP

- The proposed SHiP beam-dump experiment at the SPS has been recommended to produce a comprehensive design study over the next three years. Within the more general context of the "Physics Beyond Colliders" study group, some funding is made available from the accelerator R&D budget line to complete technical feasibility studies of a beam dump facility in the CERN North Area as input to the next ESPP, with the intention that a decision on approval will be taken once the strategy update has been completed.

GREY BOOK : SHIP as CERN recognised project




Physics Beyond Colliders
Kickoff workshop of the Physics Beyond Colliders study group
to be held at CERN, Geneva, on 6-7 September, 2016.
The main goal of the Study Group is to explore the opportunities offered by the CERN accelerator complex and infrastructure to provide new insight into some of today's outstanding questions in particle physics through projects complementary to high-energy colliders and other initiatives in the world.
The focus is on fundamental questions that are similar in spirit to those addressed by high-energy colliders, but that may require different types of experiments. The kick-off workshop is intended to stimulate new ideas for such projects, for which we encourage submission of abstracts.
CERN
Details on the workshop programme, registration and abstract submission, as well as the mandate of the Study Group, can be found on the workshop web site: https://indico.cern.ch/event/523655/
Organizing Committee: Joerg Jaeckel, Mike Lamont, Connie Potter, Claude Vallée.
Contacts: PBC2016.cttee@cern.ch, +41754113293

CDS to 2018 – year by year

Activity				2016	2017	2018
Radiation protection	HSE/RP	RP studies	FTE	0.3	0.45	0.8
			FELL/FSU [MCHF]	0.11	0.11	0.11
Target complex	EEN/STI	R&D for CDR	Material [kCHF]		0.17	1.14
			FTE		0.25	2.2
			FELL etc [kCHF]		0.06	0.9
Safety engineering	HSE	CDR prep	Material [MCHF]	0.17	0.17	0.17
			FTE	0.5	0.5	0.5
Extraction, beam-line and splitter	TE/ABT	CDR prep	Material [MCHF]	0.4	0.4	0.5
			FTE	1	1	1
		TOTAL	**Material**	**0.68**	**0.91**	**2.82**
			FTE	**1.8**	**2.2**	**4.5**

Total of 4.41 MCHF and 8.5 FTEs
(versus “3.8 MCHF and 9 FTEs required between 2016 and end of 2018” in the Addendum).

Objectives of the CDR

Reoptimization effort underway:

- three options for the decay vessel: metal (TP), concrete (also with vacuum) and He balloon, possibly conical

- optimisation of muon filter, magnetisation of hadron absorber

- PID detectors (ECAL technology, HCAL+MUON optimisation, RICH under discussion)

- timing detector technology choice

- Surround veto technology

-reoptimisation of the emulsion detector and magnet

- new RPCs for the muon spectrometer of neutrino detectors

NEW GROUPS WELCOME!!!!!

Planning few calibration side experiments

Measurement of muon flux to calibrate the muon deflection from the filter

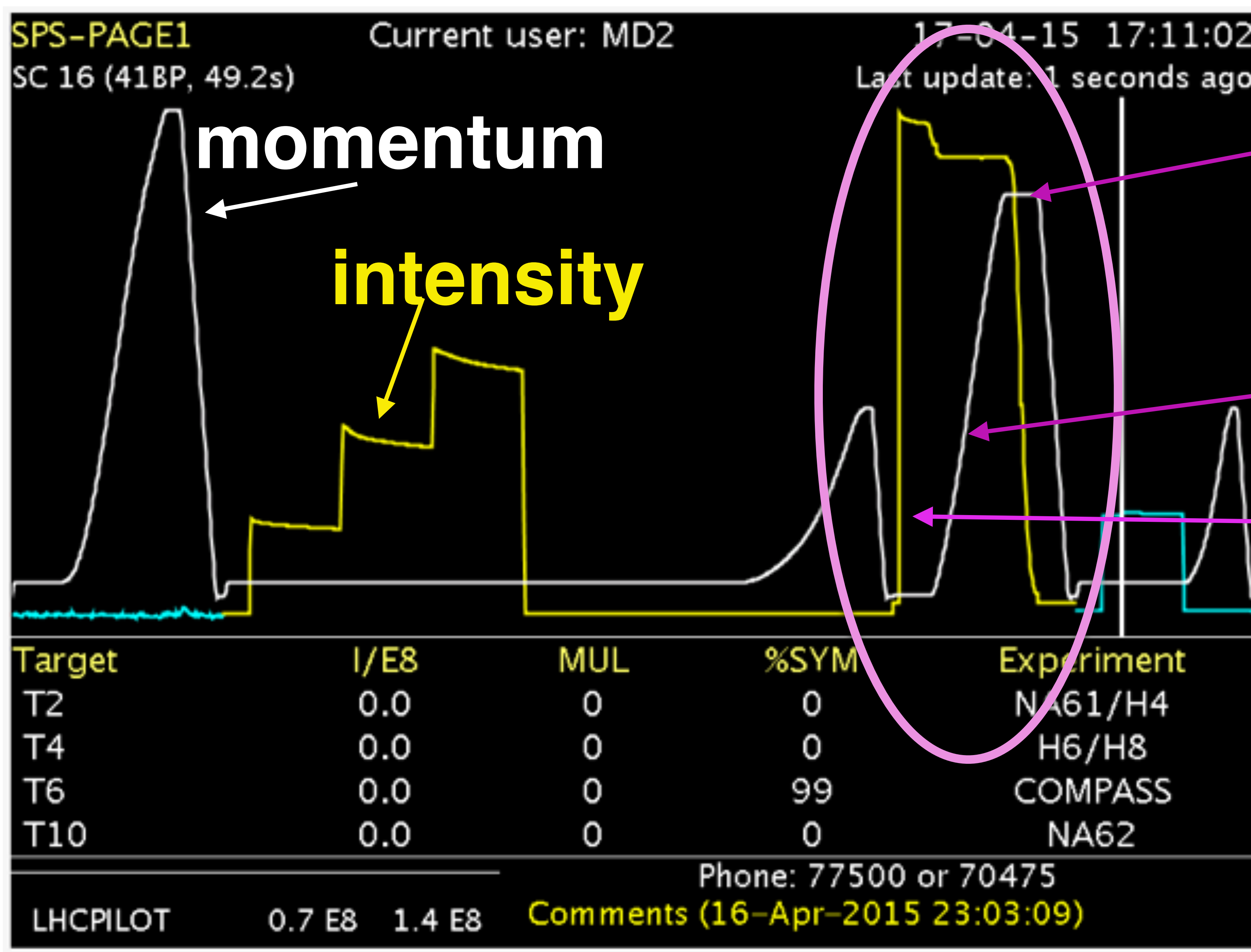
Measurement of charm production

Discussions ongoing with existing collaborations for a collaboration and some new ideas.

Main new technological challenge compared to LNGS: the slow extraction of the whole SPS beam

Tested this year!

49.2s



extraction during the flat top of 1s into the TT20 transfer line to the North Area

acceleration to 400 GeV

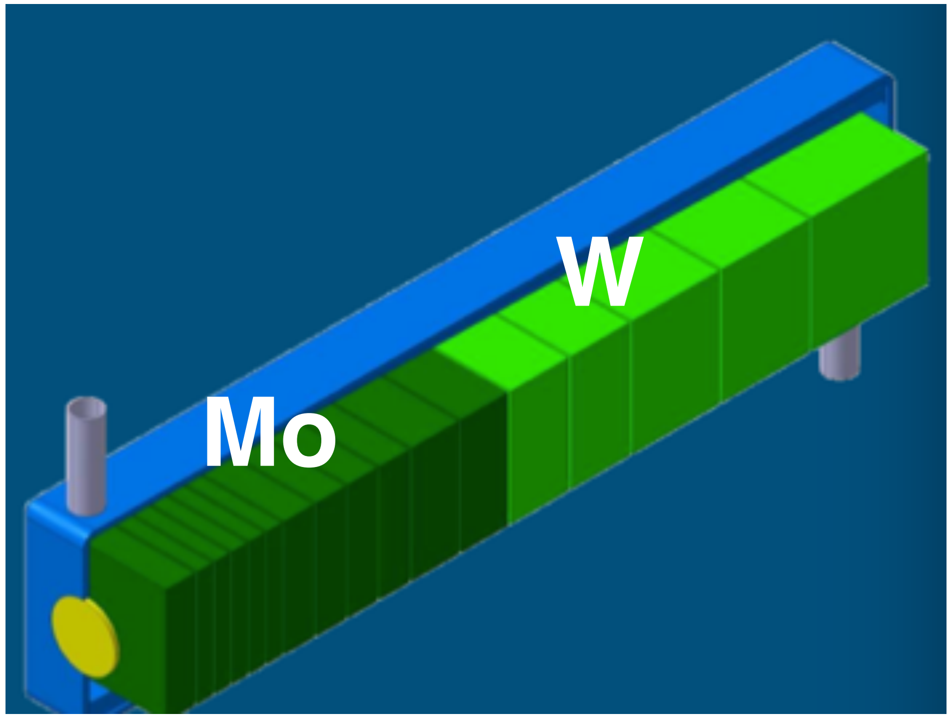
single injection of protons from PS to SPS

Few times 10^{12} protons/spill for a couple of hours!
The main challenge is now to go to 4×10^{13} protons/spill —> R&D planned

Target and muon filter

Longitudinally segmented hybrid target: Mo(58cm)/W(58cm)

the beam is spread on the target to avoid melting

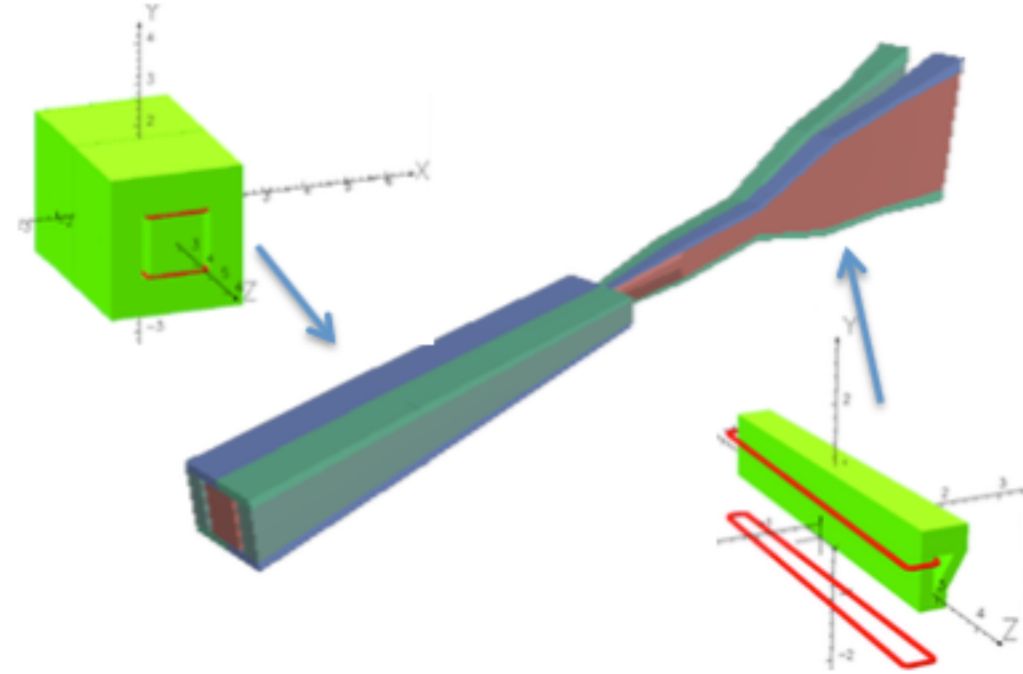


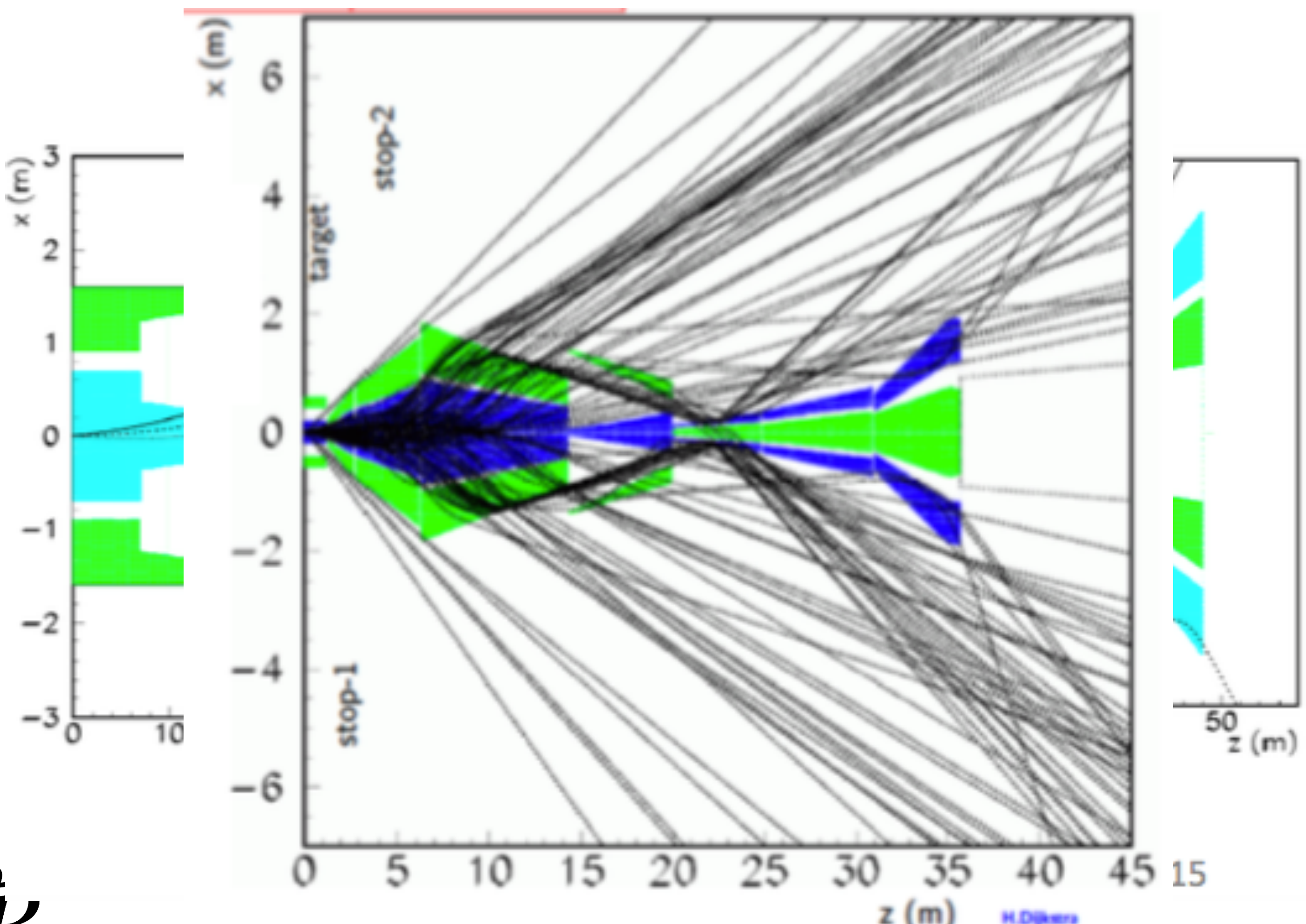
It is followed by a muon filter.

The issue is not trivial since the muon flux is enormous: 10^{11}/ SPS-spill(5×10^{13} pot)

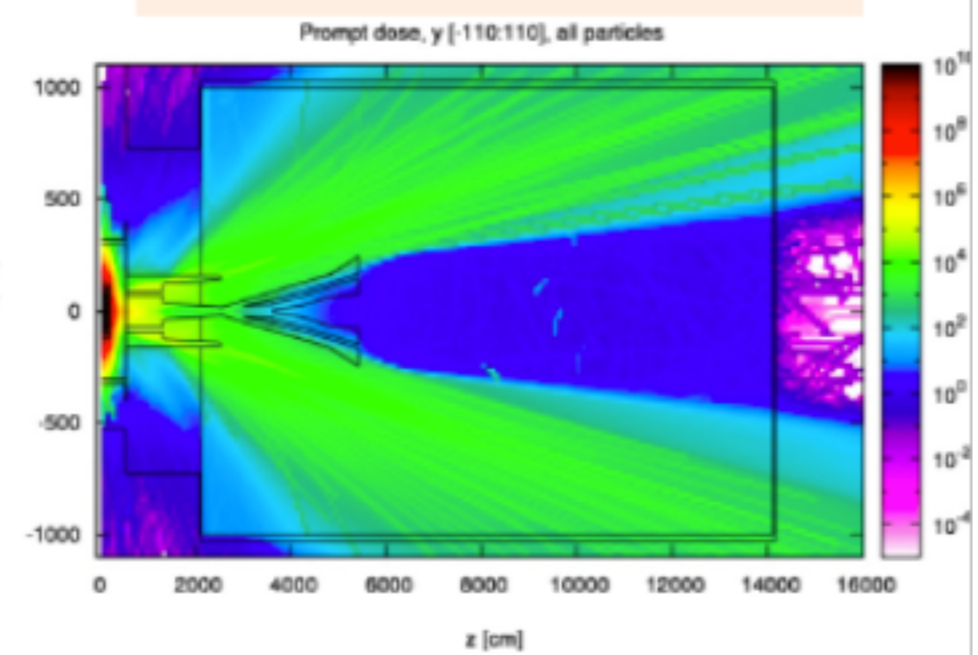
Muon active Filter

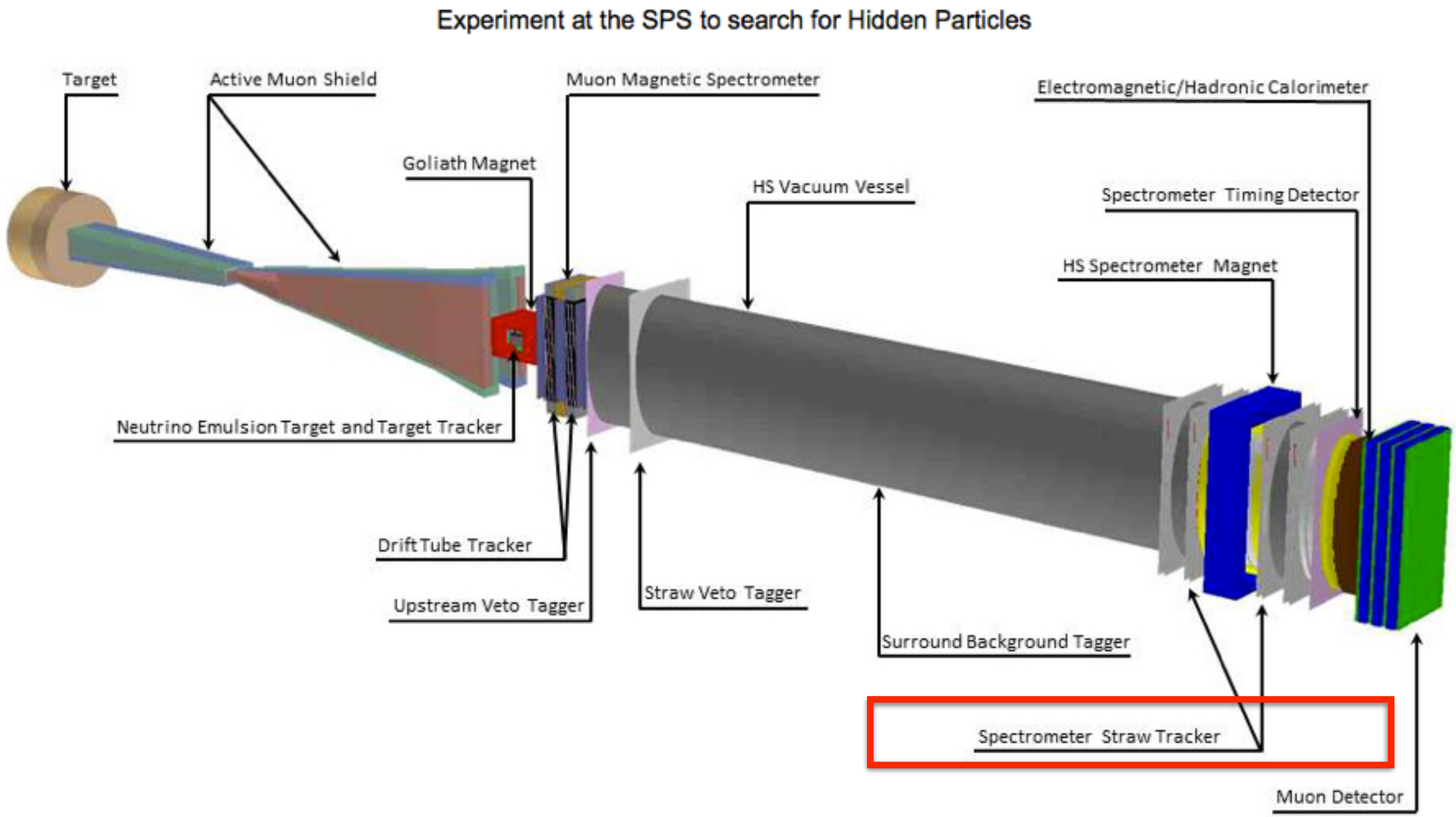
- ✓ *Muon flux limit driven by emulsion based neutrino detector and HS background*
- ✓ *Active muon shield based entirely on magnet sweeper*
  with a total field integral B_y = 86.4 Tm
  Realistic design of sweeper magnets in progress
  Challenges: flux leakage, constant field profile, modeling magnet shape
- ✓ *< 7k muons / spill (E_μ > 3 GeV), well below the emulsion saturation limit*
- ✓ *Negligible flux in terms of detector occupancy*



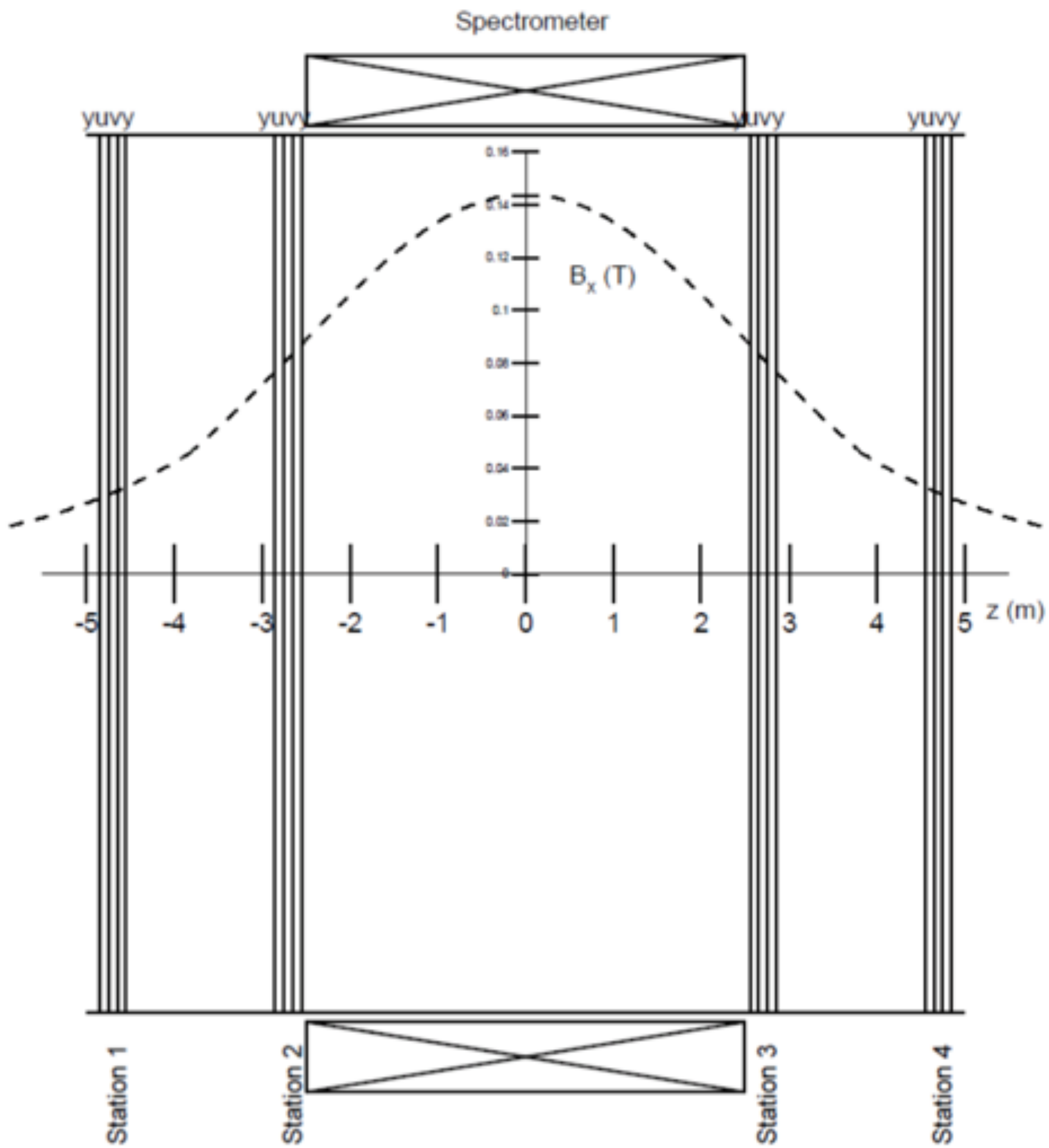


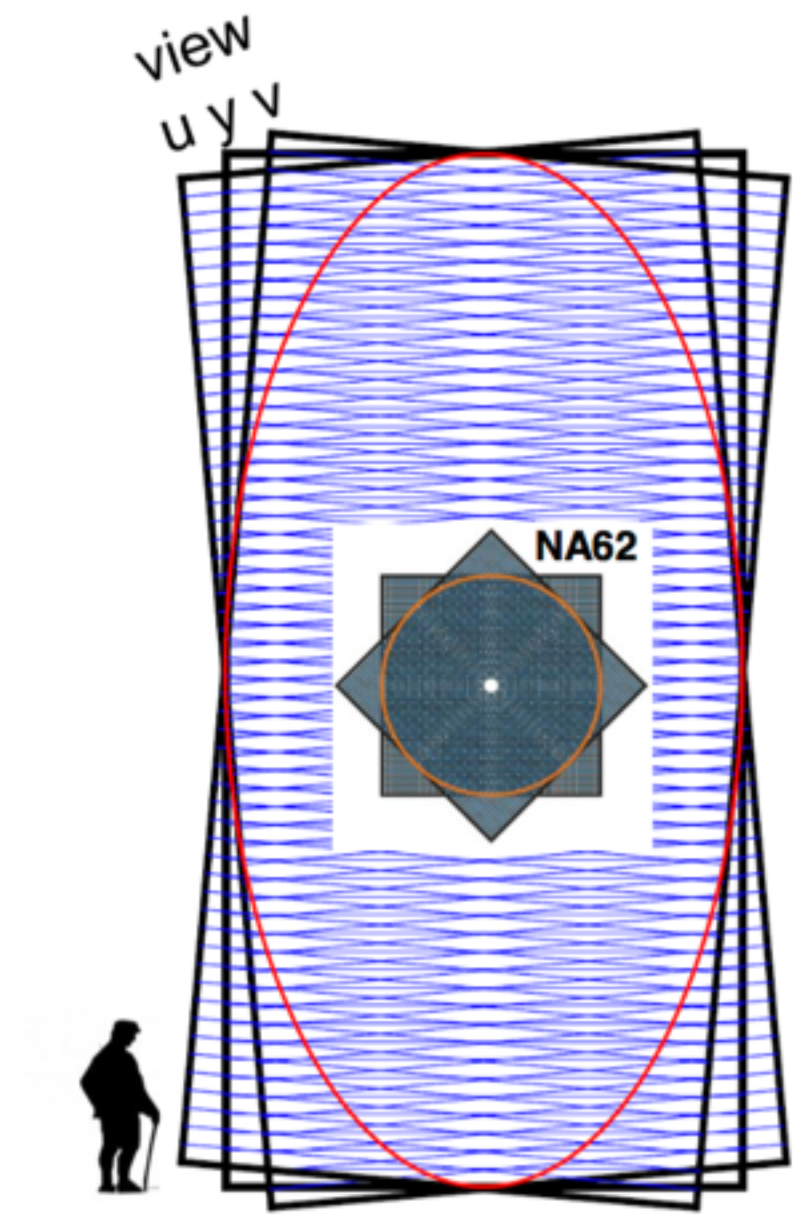
Dose rate in the SHiP hall



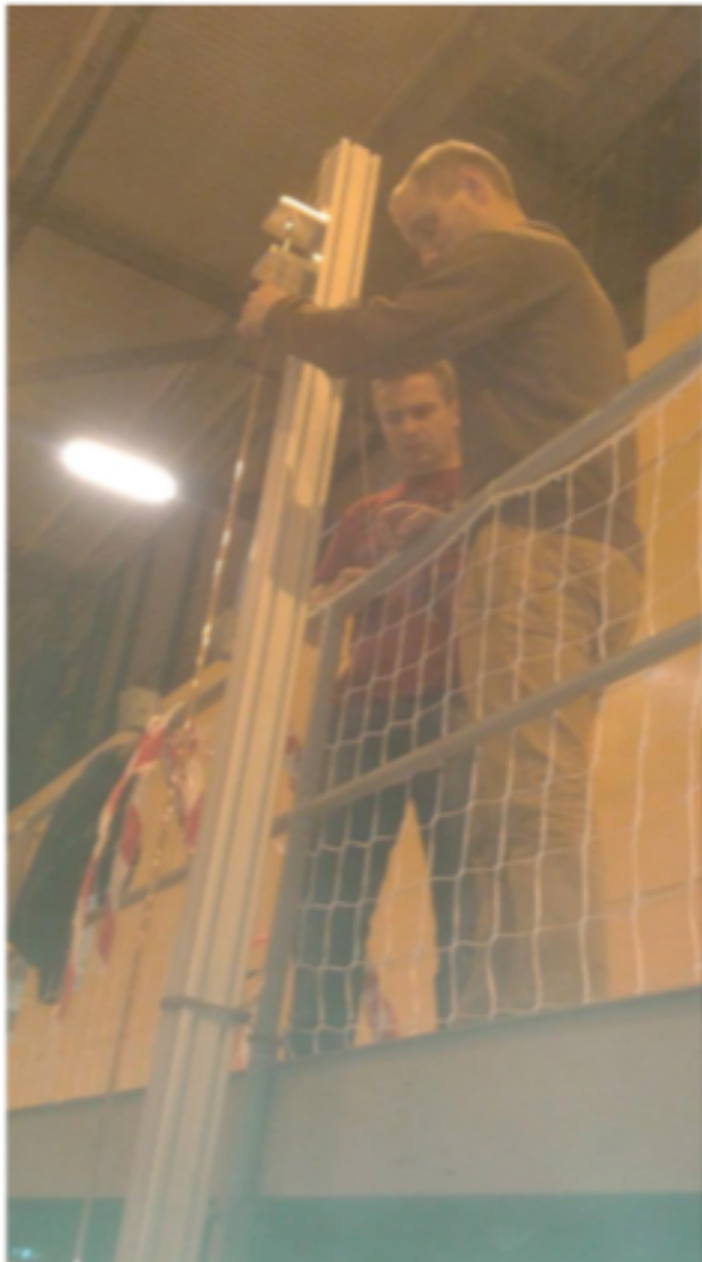

Experiment at the SPS to search for Hidden Particles
Target
Active Muon Shield
Muon Magnetic Spectrometer
Electromagnetic/Hadronic Calorimeter
Goliath Magnet
HS Vacuum Vessel
Spectrometer Timing Detector
HS Spectrometer Magnet
Neutrino Emulsion Target and Target Tracker
Drift Tube Tracker
Upstream Veto Tagger
Straw Veto Tagger
Surround Background Tagger
Spectrometer Straw Tracker
Muon Detector

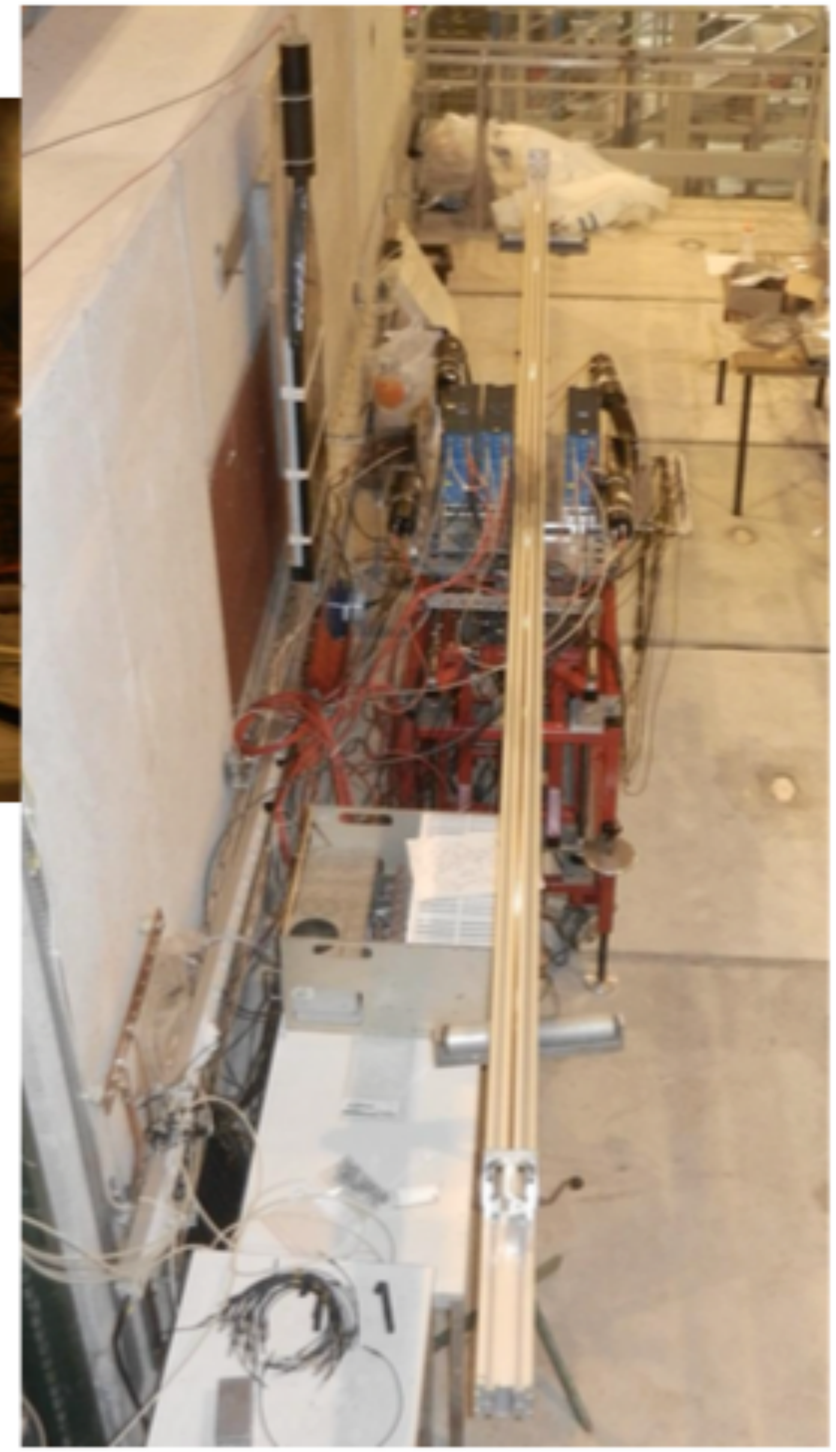
Straw tracker



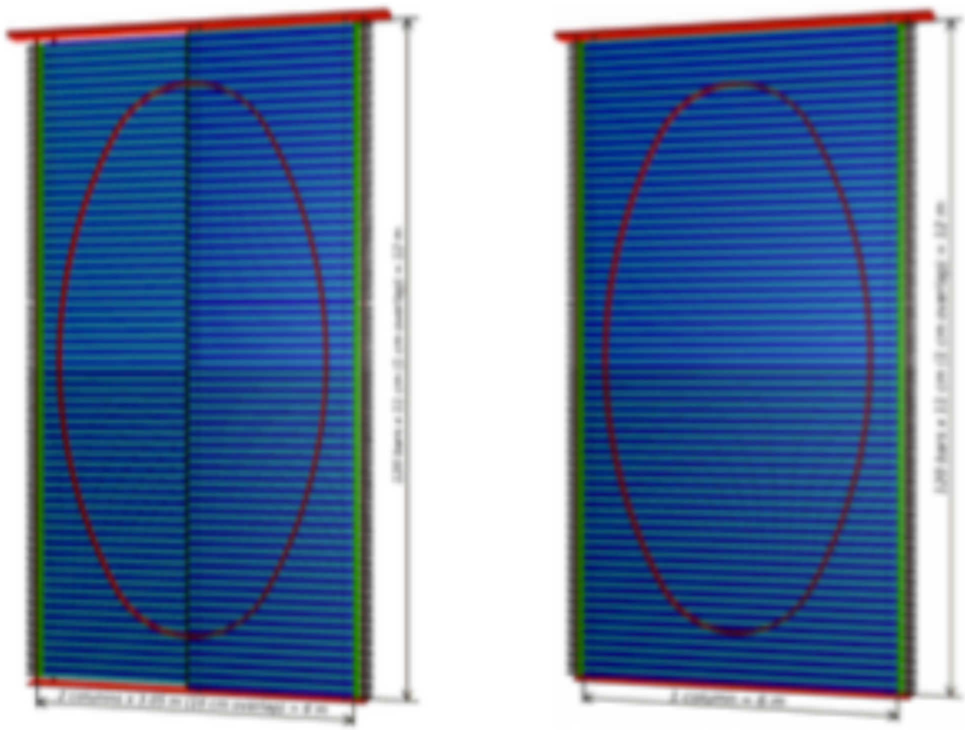


5m straws!





Timing detector



Main characteristics:

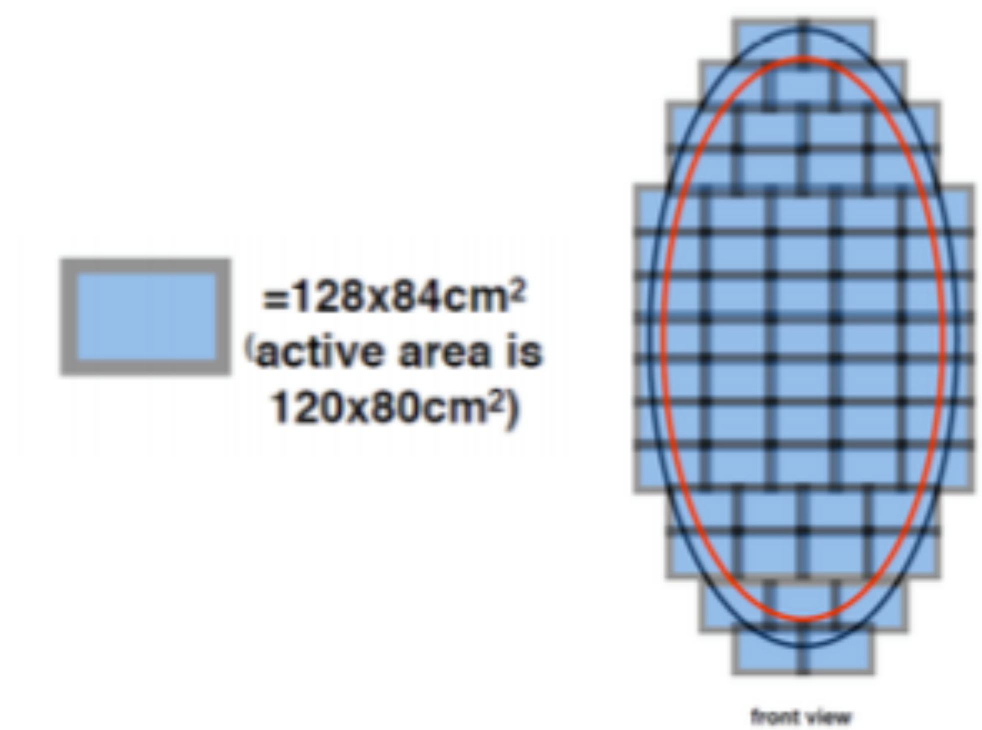
Plastic scintillators

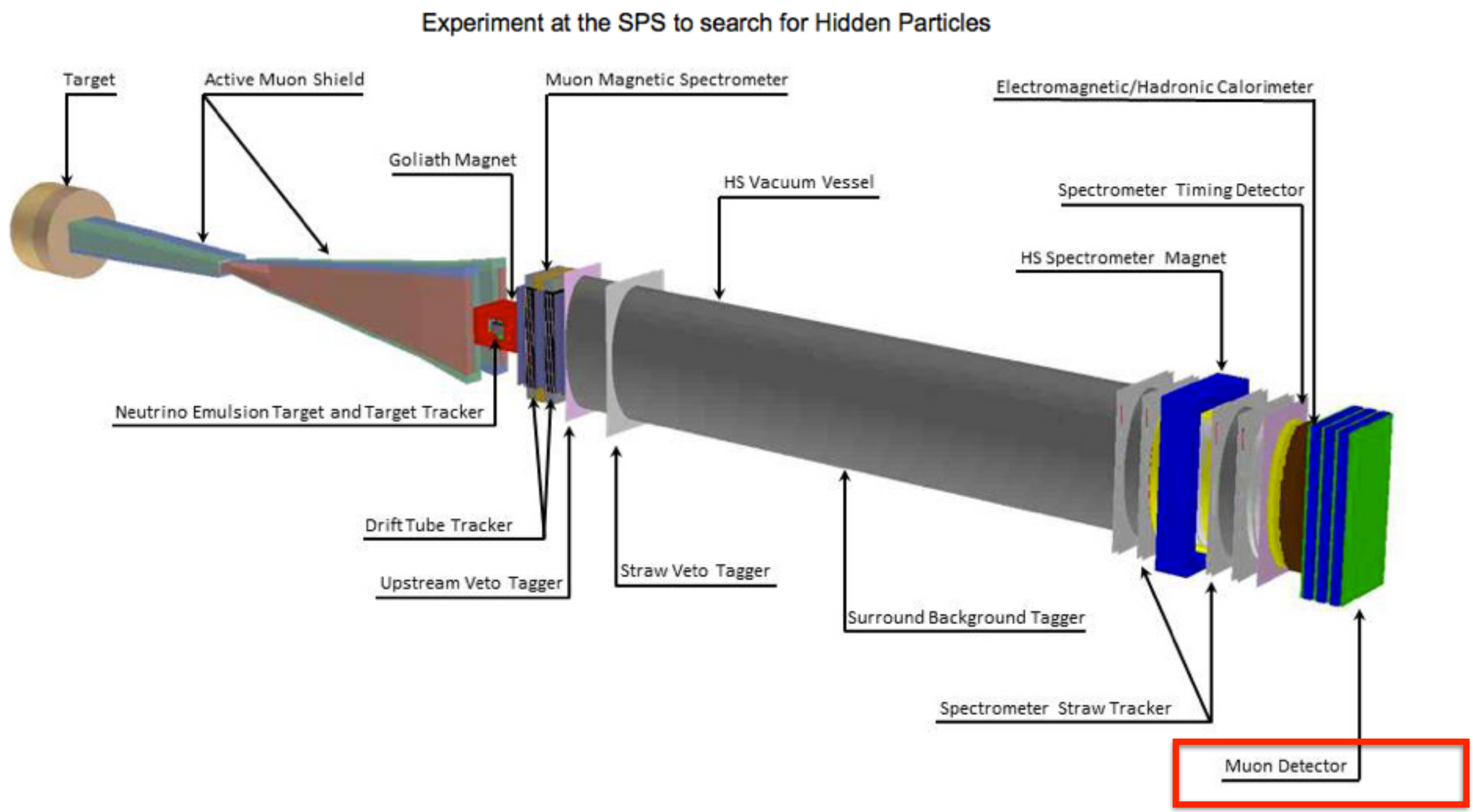
- 2 columns of 305x11x2 cm3 bars
  - Readout with PMTs
  - Readout with SiPMs
- 1 bar of 6m (technically challenging)
- 5 columns readout with SiMPs

Main characteristics:

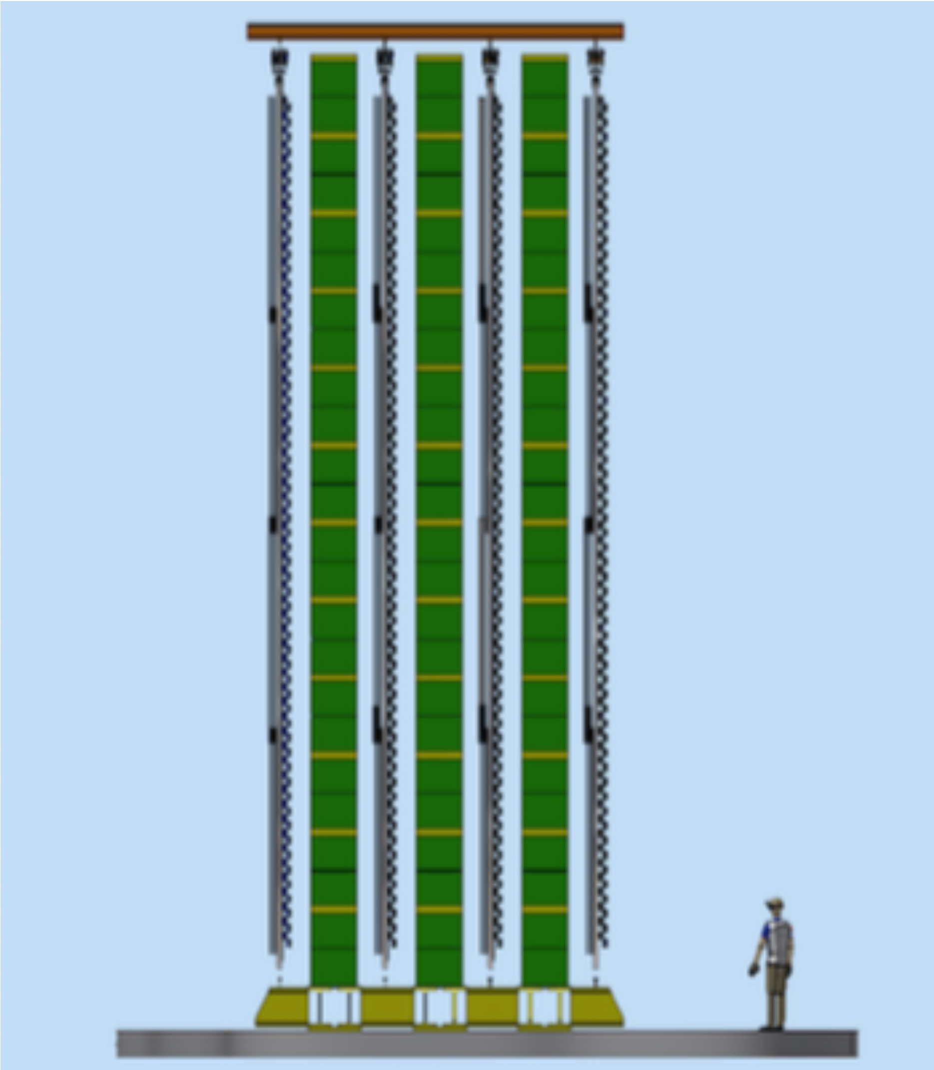
MRPC

- Combination of Alice-TOF and EEE detectors:
  - An OR-red double stack configuration with 120 cm long strips.



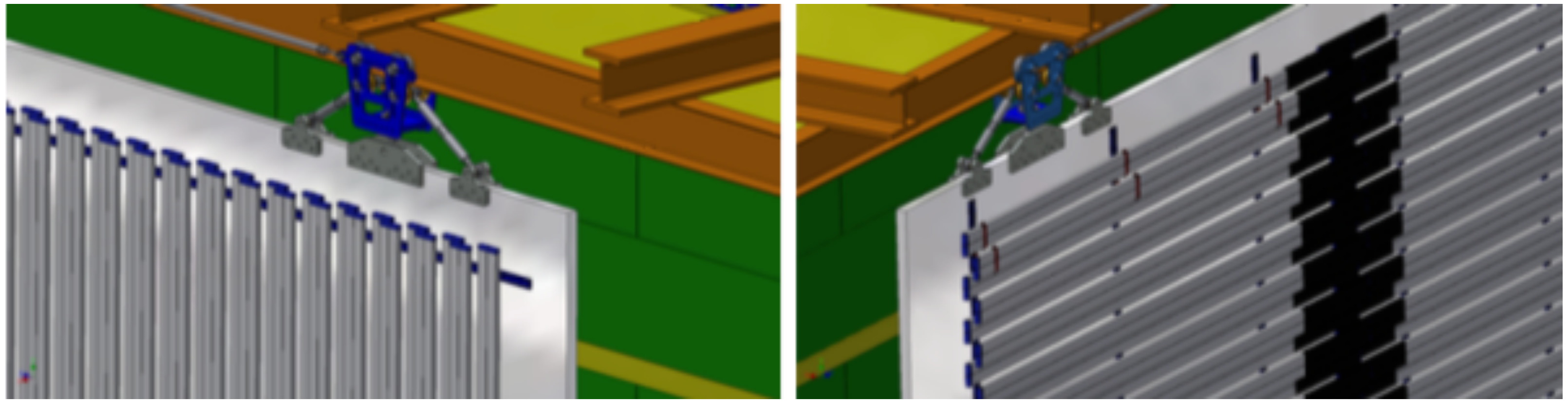

Experiment at the SPS to search for Hidden Particles
Target
Active Muon Shield
Muon Magnetic Spectrometer
Electromagnetic/Hadronic Calorimeter
Goliath Magnet
HS Vacuum Vessel
Spectrometer Timing Detector
HS Spectrometer Magnet
Neutrino Emulsion Target and Target Tracker
Drift Tube Tracker
Upstream Veto Tagger
Straw Veto Tagger
Surround Background Tagger
Spectrometer Straw Tracker
Muon Detector

MUON

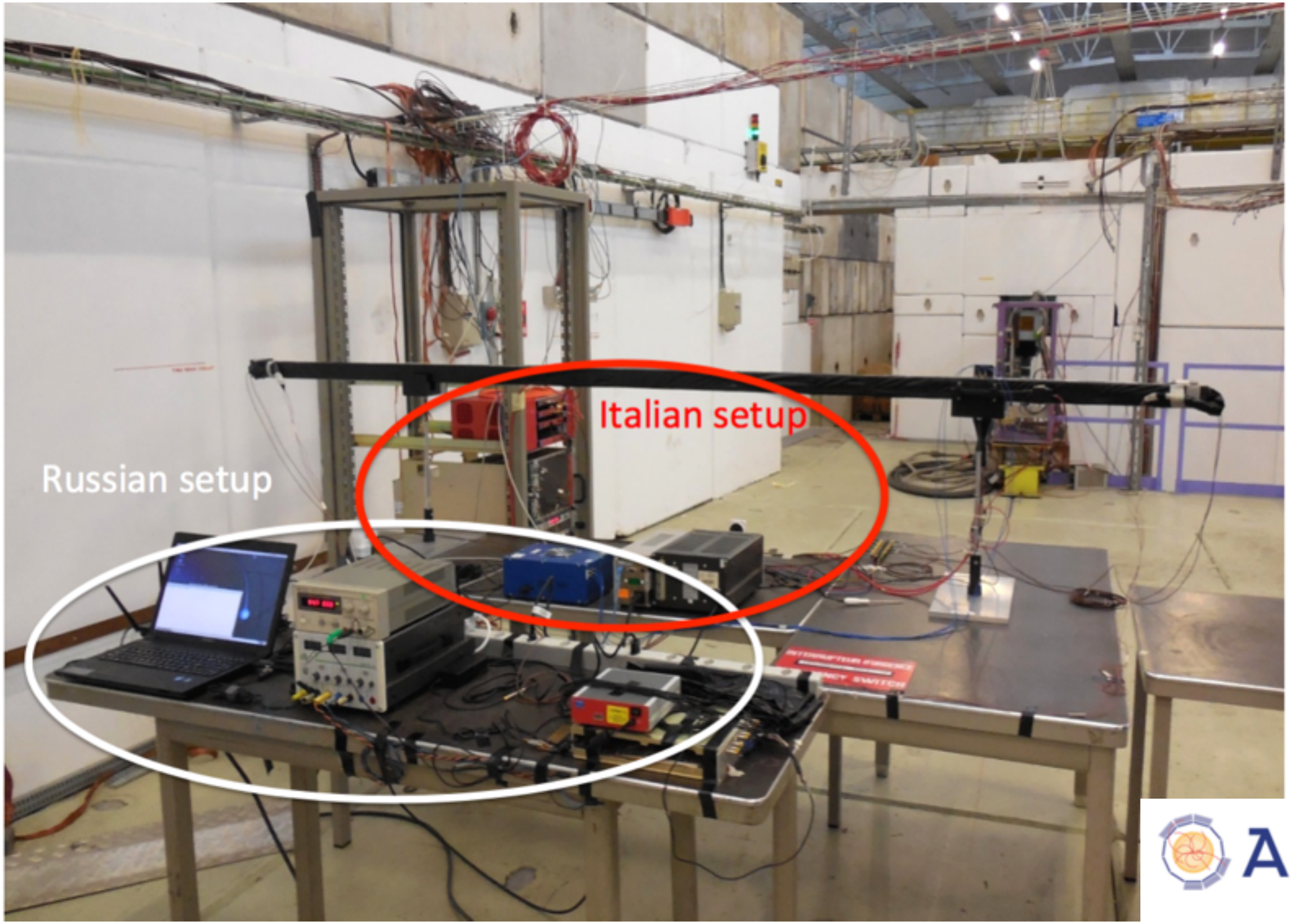


Detector layout

scintillating strips with WLS fibres

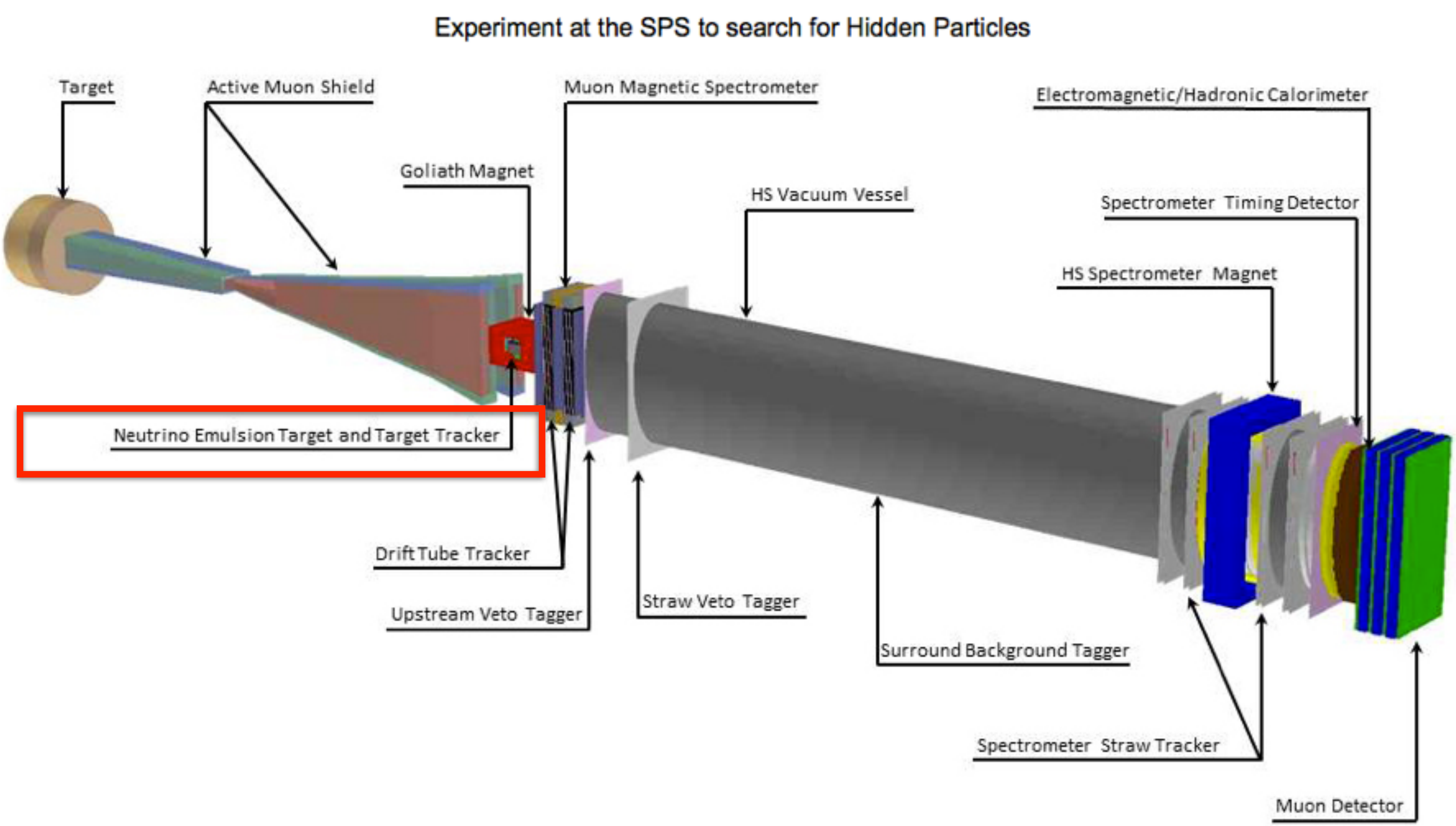


MUON



AIDA 2020

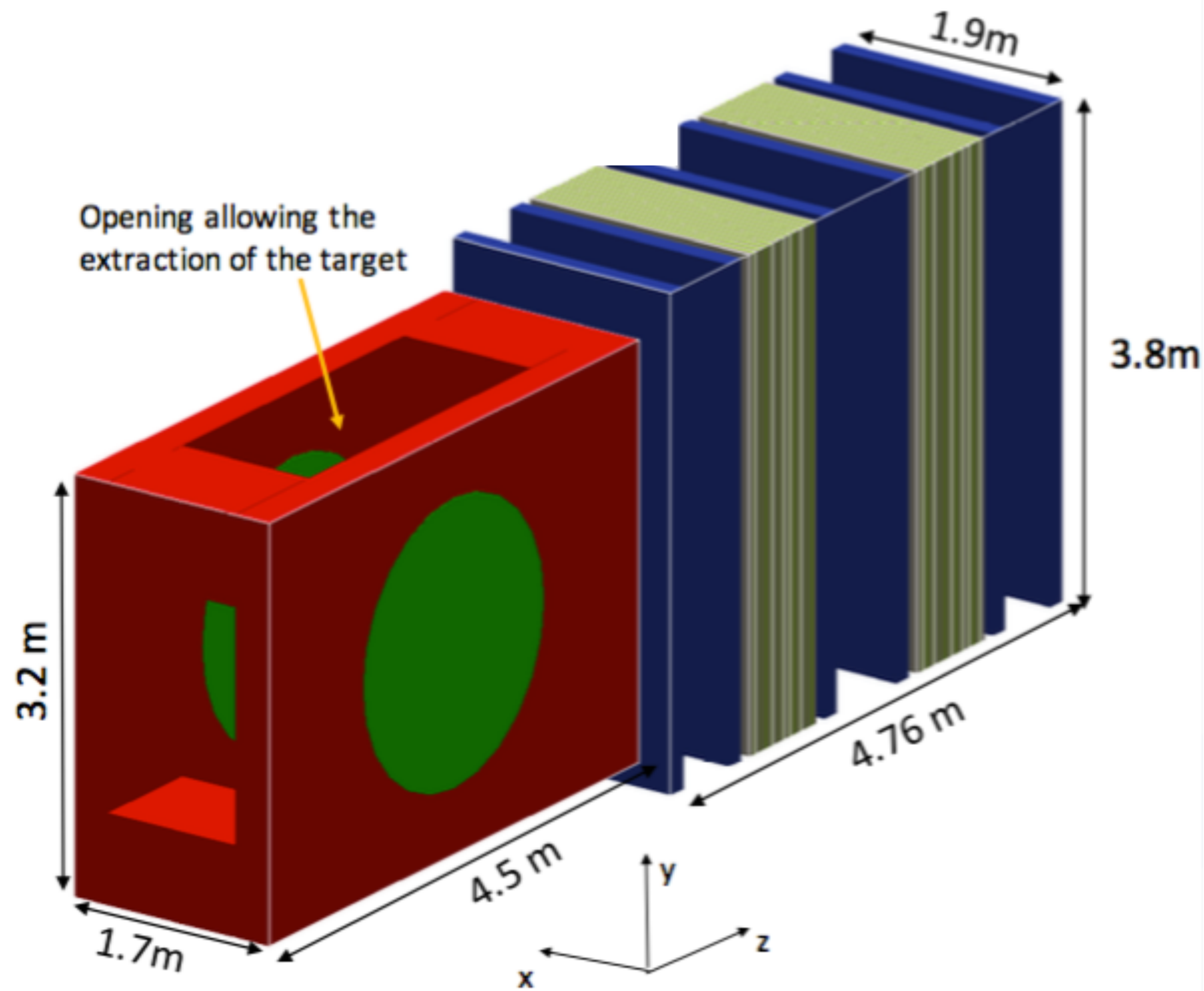
Test beam funded by AIDA 2020



Experiment at the SPS to search for Hidden Particles
Target
Active Muon Shield
Muon Magnetic Spectrometer
Electromagnetic/Hadronic Calorimeter
Goliath Magnet
HS Vacuum Vessel
Spectrometer Timing Detector
HS Spectrometer Magnet
Neutrino Emulsion Target and Target Tracker
Drift Tube Tracker
Upstream Veto Tagger
Straw Veto Tagger
Surround Background Tagger
Spectrometer Straw Tracker
Muon Detector

Light ν's detector

Emulsion based detector with the LNGS OPERA brick technolgy, but with a much smaller mass (750 bricks) very compact (2m), upstream of the HNL decay tunnel —> with B field and followed by a muon detector (to suppress charm background



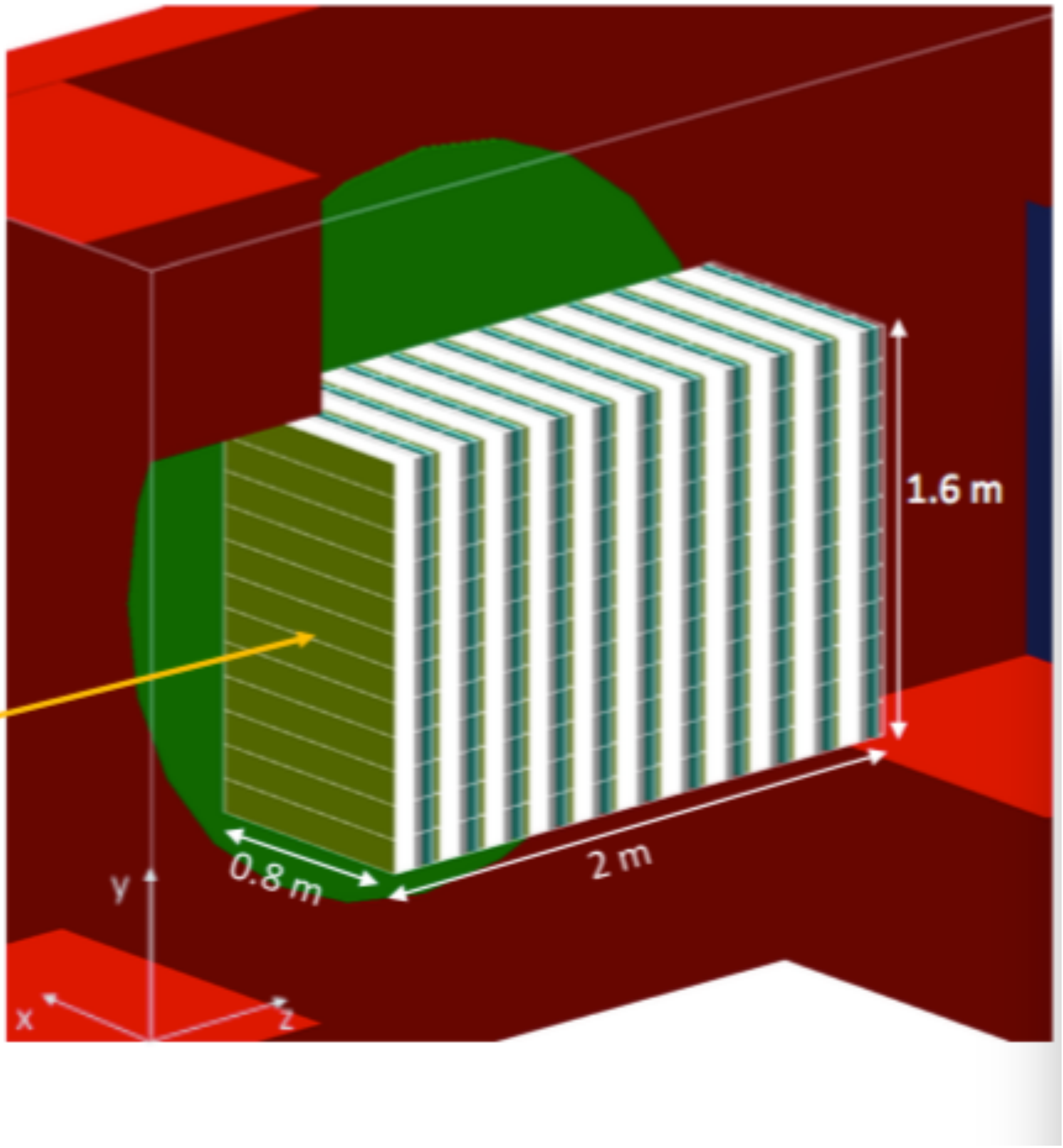
Korean colleagues involved!

Neutrino target

- 6 columns (along x direction)
- 12 rows (along y direction)
- 11 walls (along z direction)
- 12 layers of Target Trackers (upstream layer acting as veto)

Total dimensions: $0.8 \times 1.6 \times 2\ m^3$

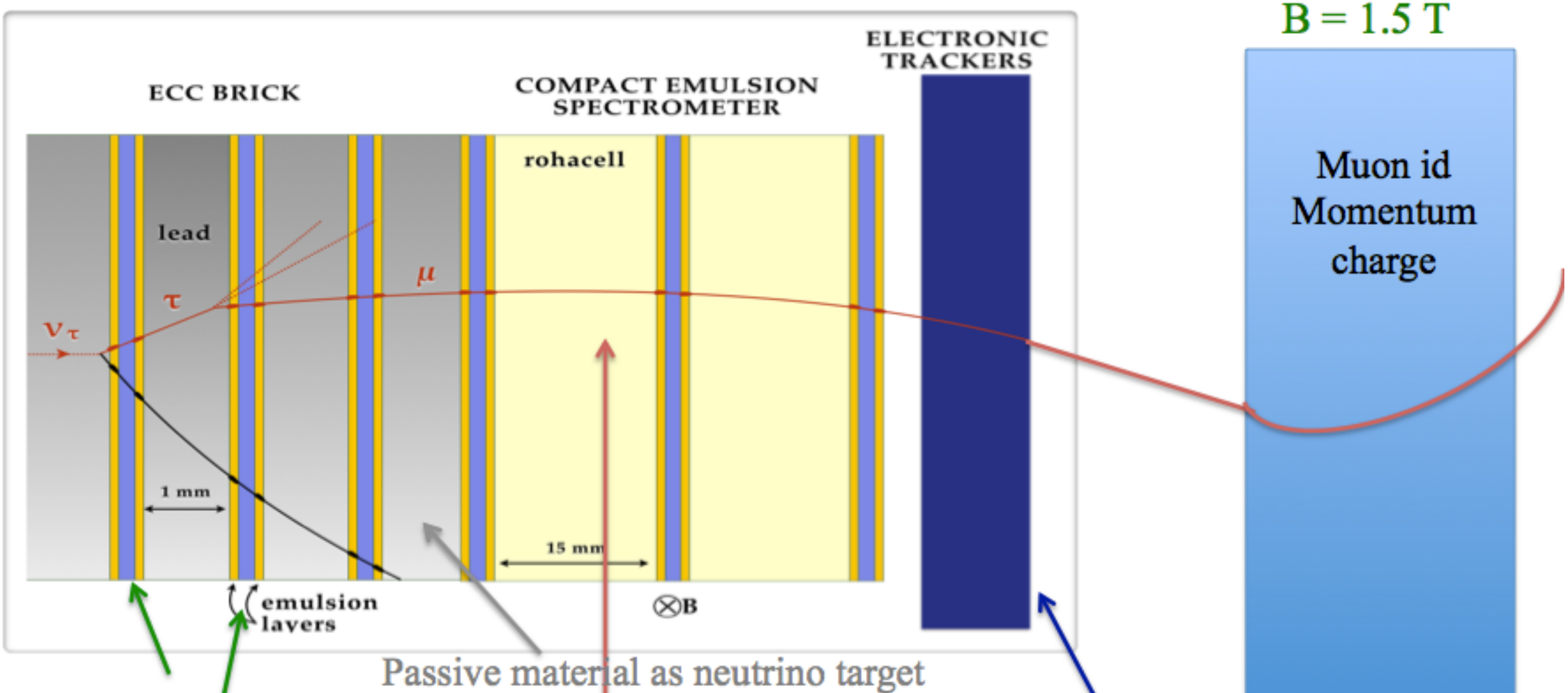
Incoming ν flux



Neutrino target

Hybrid detector principle

Muon spectrometer
B = 1.5 T



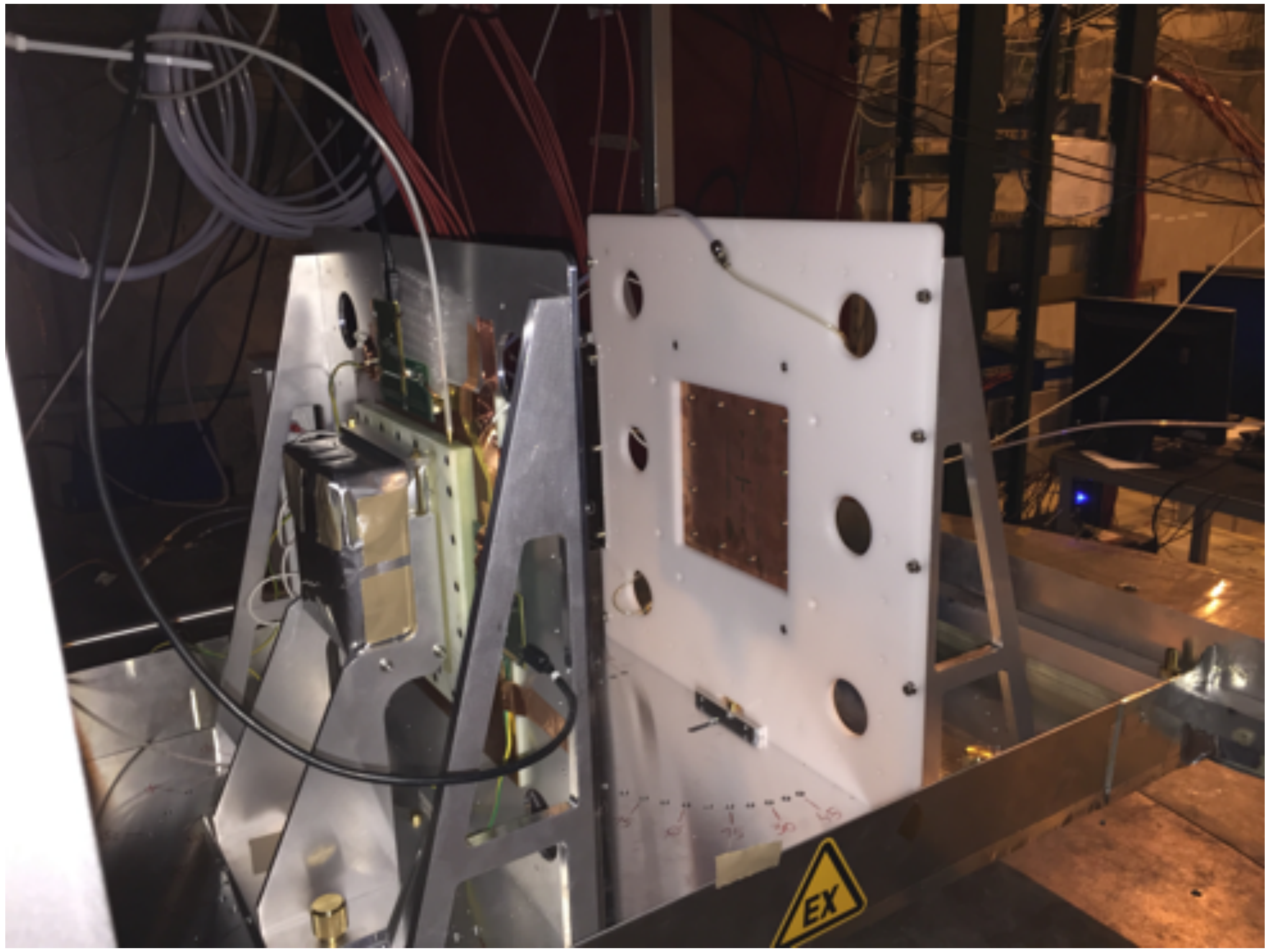
Passive material as neutrino target

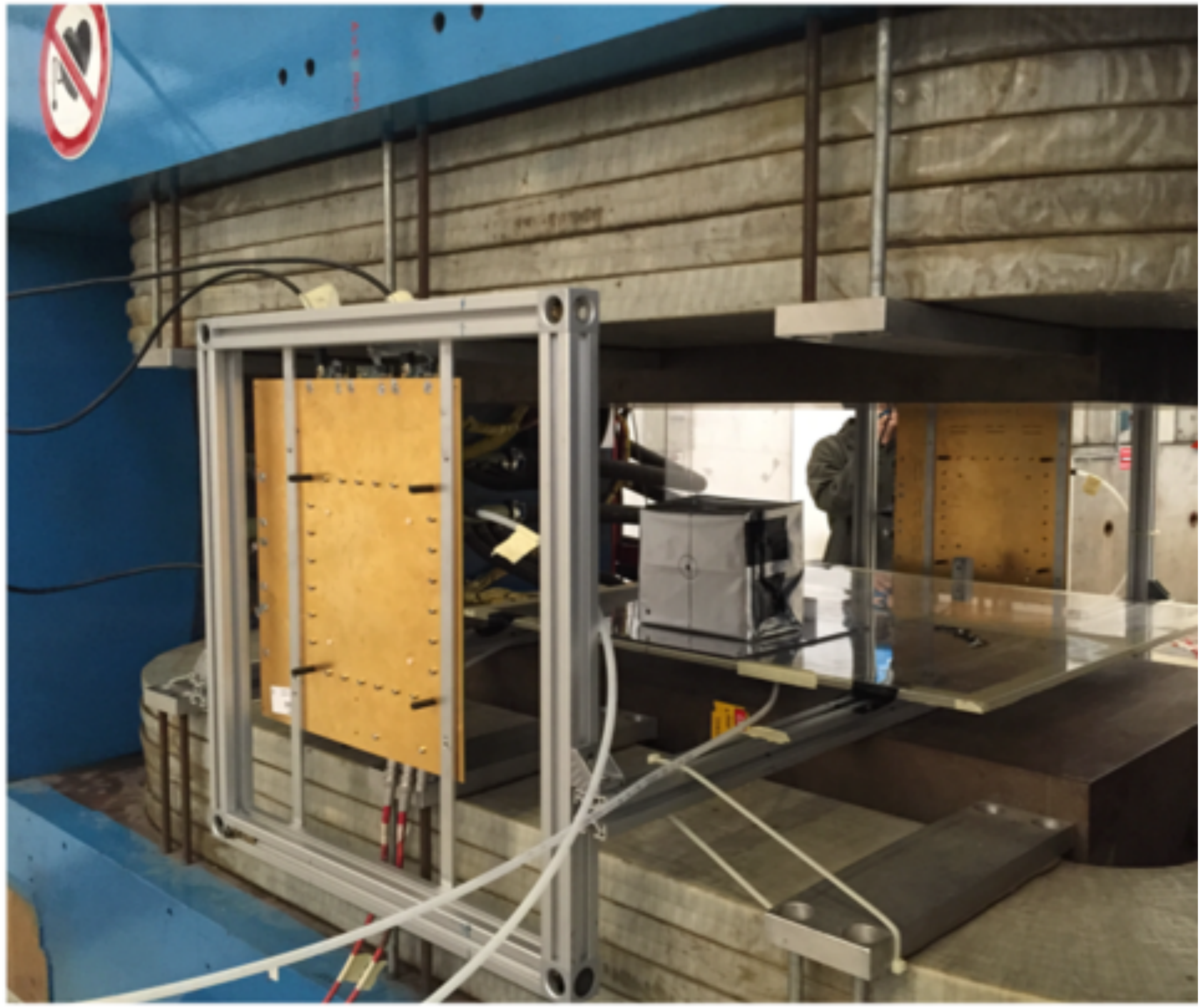
Nuclear emulsions as μm accuracy trackers: τ production and decay vertices

Electronic trackers to provide the "time stamp" and match emulsion tracks

measure the charge of τ daughters

Neutrino target





also tested together with GEMs and μWells and with MicroMegas

Test beam funded by AIDA 2020

Objectives of the CDR

Reoptimization effort underway:

- three options for the decay vessel: metal (TP), concrete (also with vacuum) and He balloon, possibly conical

- optimisation of muon filter, magnetisation of hadron absorber

- PID detectors (ECAL technology, HCAL+MUON optimisation, RICH under discussion)

- timing detector technology choice

- Surround veto technology

-reoptimisation of the emulsion detector and magnet

- new RPCs for the muon spectrometer of neutrino detectors

In particular:

ECAL is now a Shashik calorimeter in the TP

BUT we need it granular (—>very expensive) and, to study ALP->γγ, with reconstruction of the photon direction, with angular resolution better than previously achieved

Various options:
- pre shower

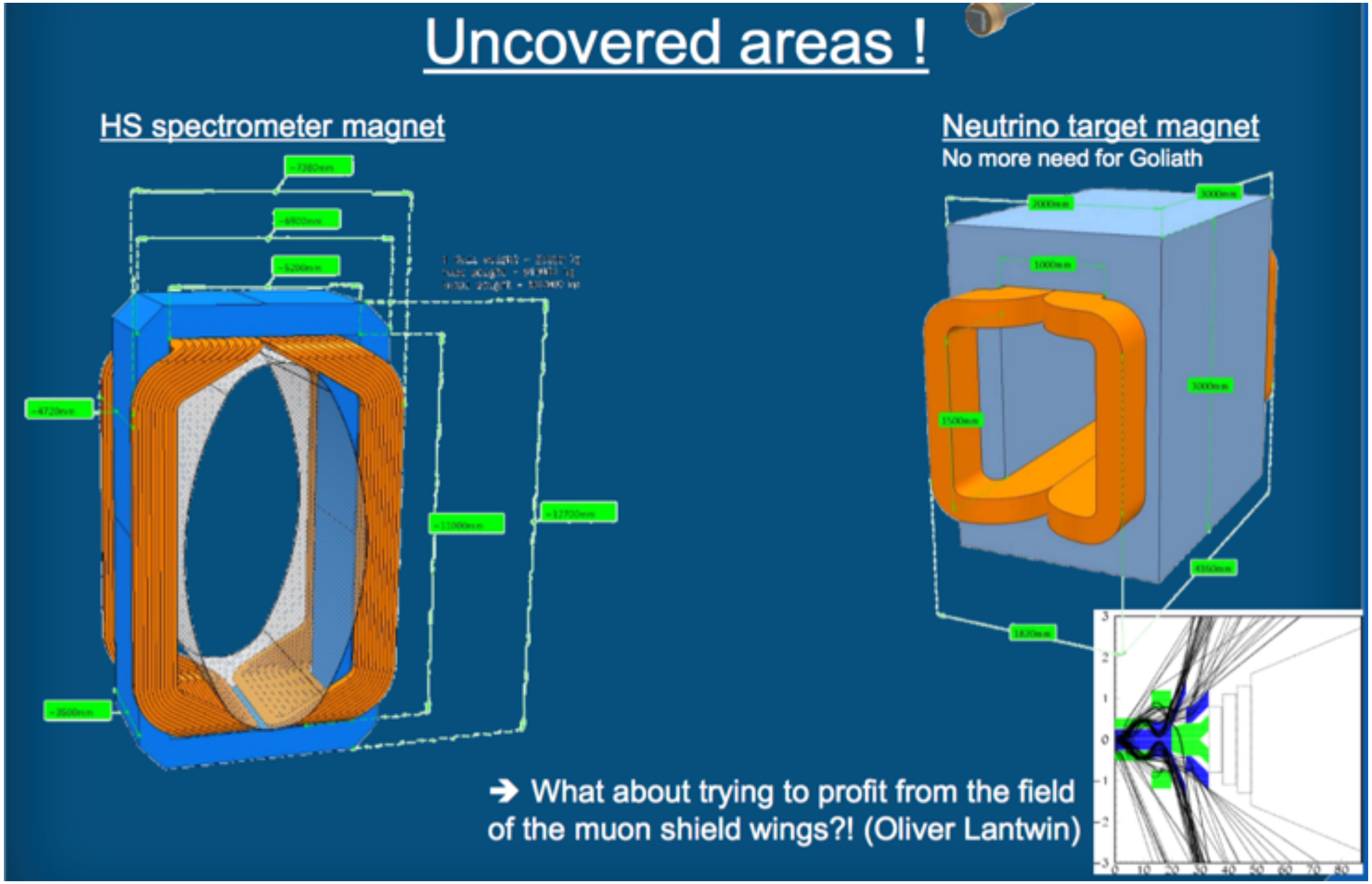
- Scintillating strips

- Gas calorimeter with RPC readout

New idea of adding a RICH detector —> to be designed from scratch!

IDEAL FOR NEW GROUPS that can take the leadership of these activities!!!!

New magnet design



Very interesting task for a Technical University !

Take home message!

We have shown here that an intensity/acceptance increase compared to past hadronic beam dump experiments gives access to a very rich physics program

Many models (and theories…SUSY…), that provide a deep connection with cosmology, can be tested in an unexplored range of parameters

SHiP will also allow to complete the experimental tests of the SM description of deep inelastic ν scattering with the reconstruction of the ν_τ interactions

The protons are there…