Andrey Golutvin
Imperial College London

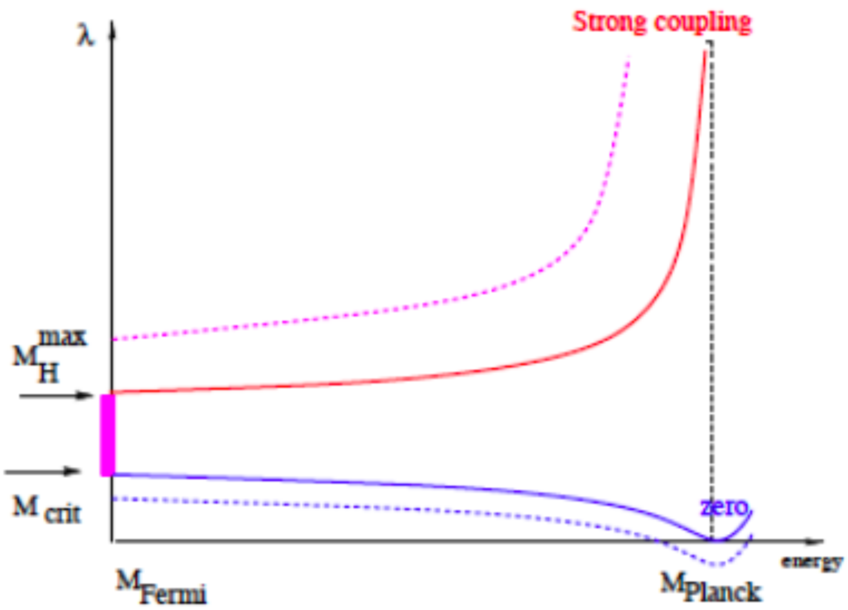
SHiP

Search for Hidden Particles

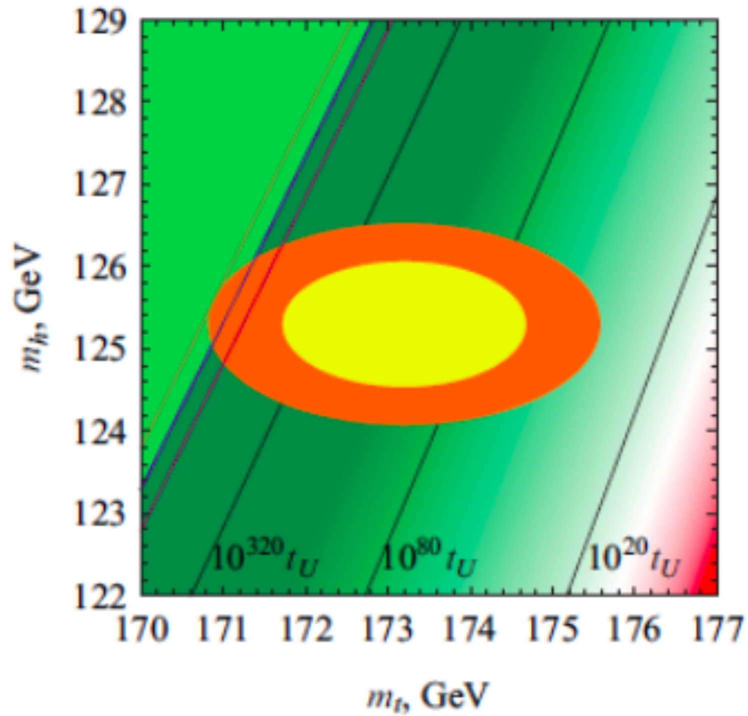
Triumph of the Standard Model

SM may well be a consistent effective theory all the way up to the Plank scale

- ✓ *M_H < 175 GeV → SM is a weakly coupled theory up to the Plank energies !*
- ✓ *M_H > 111 GeV → EW vacuum is stable or metastable with a lifetime greatly exceeding the age of our Universe (Espinosa et al)*



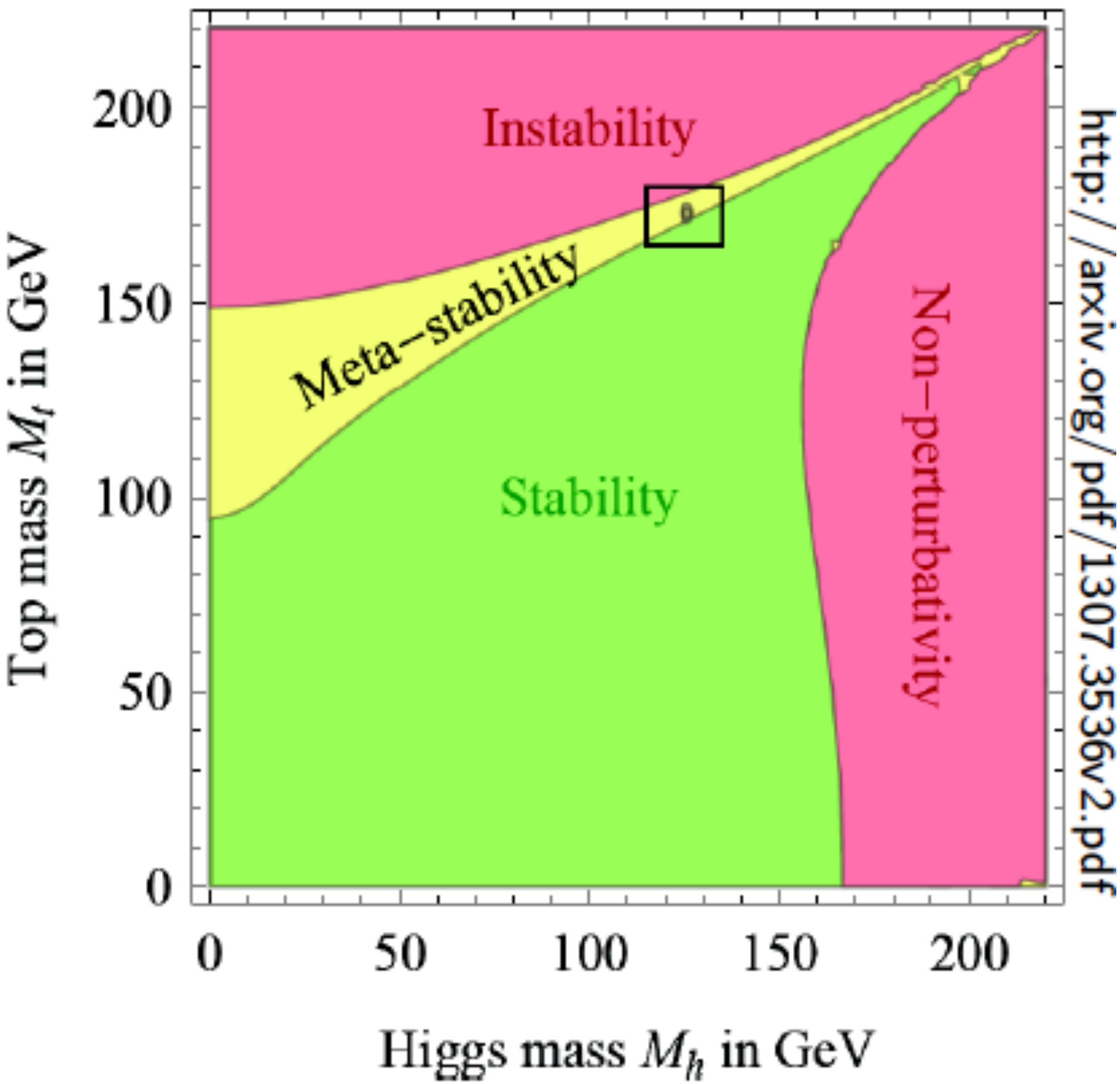
Stable vacuum is perfectly admitted by present data



- ✓ *No sign of New Physics seen*

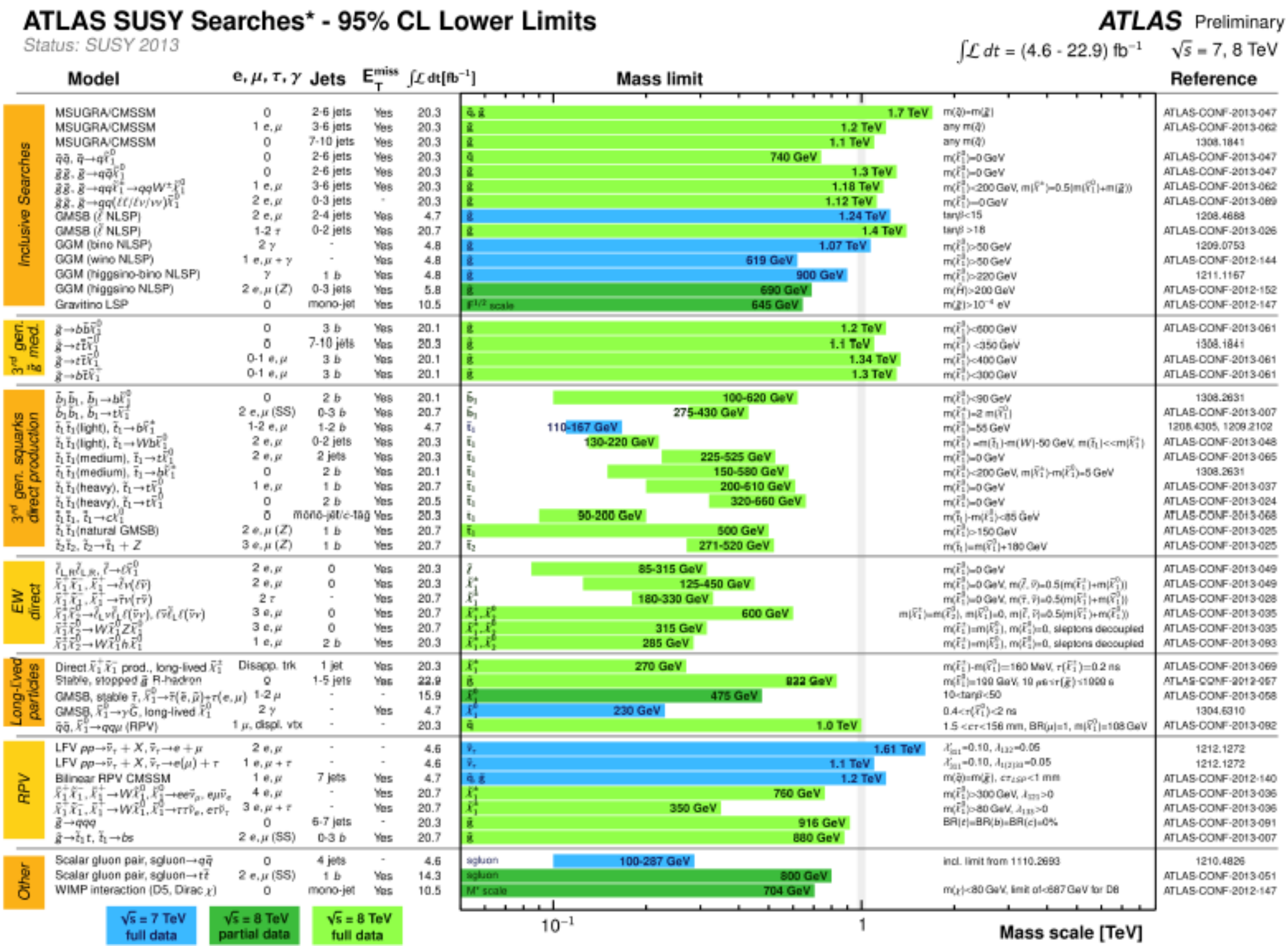
3

Hard to believe that this is a pure coincidence !



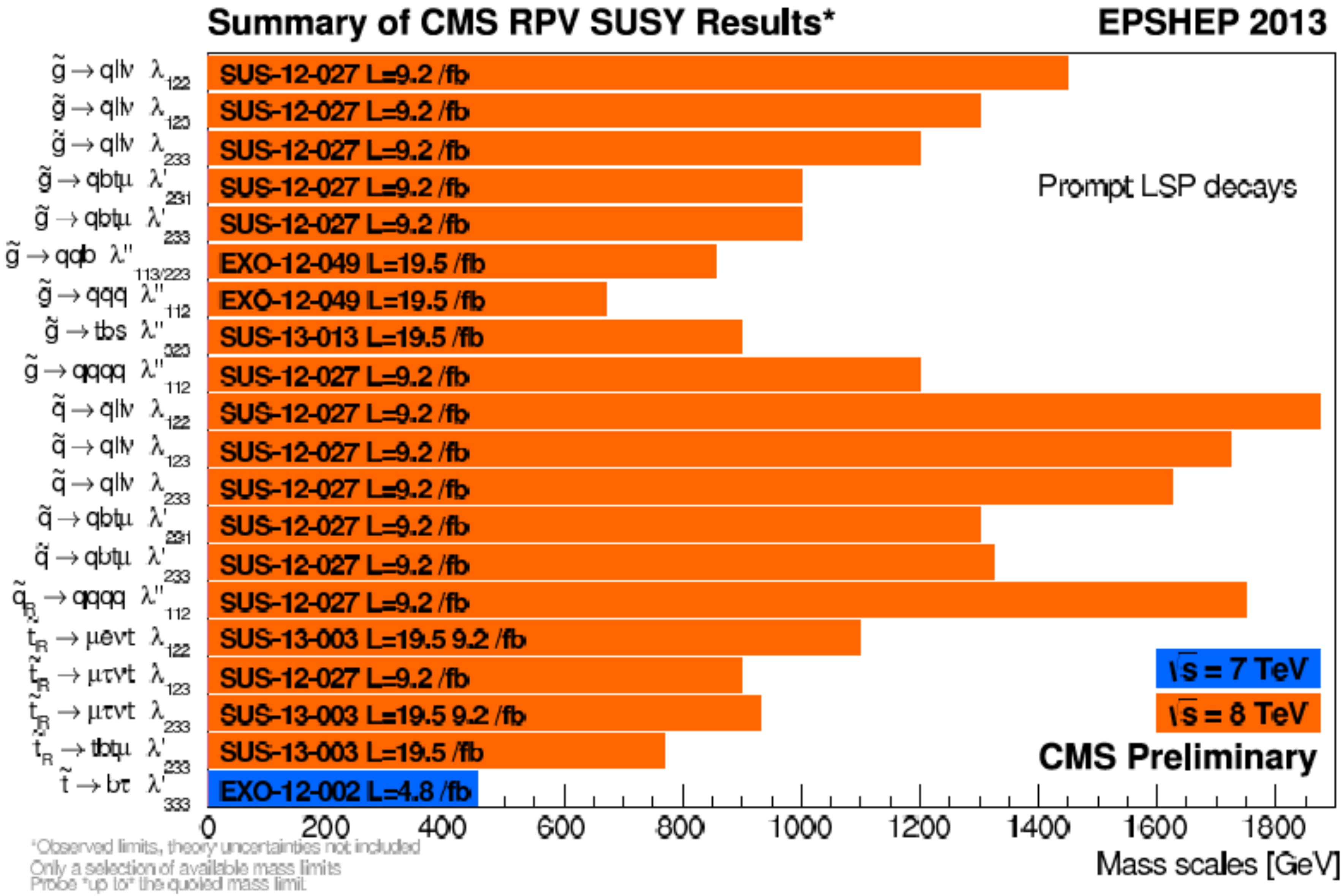
No sign of New Physics seen

What is not found..



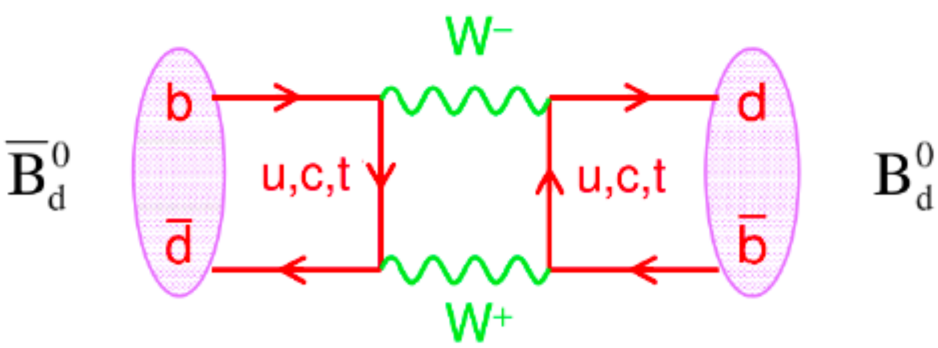
No sign of New Physics seen

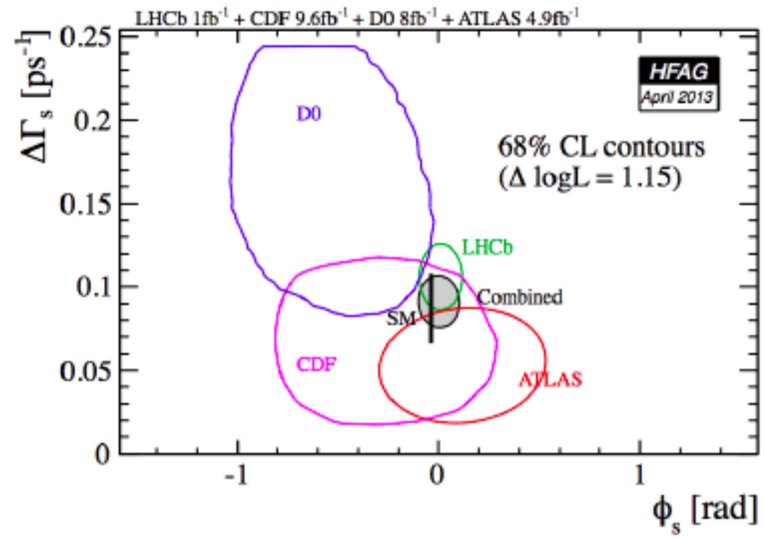
What is not found..



Bounds on the scale of New Physics

Most stringent limits come from observables in K^0 & B^0 mixing





$$M(B_d-\overline{B}_d) \sim \frac{(y_t^2 V_{tb}^* V_{td})^2}{16\pi^2 m_t^2} + c_{NP}\frac{1}{\Lambda^2}$$

c_{NP}:

- ~ 1 $\xrightarrow{\text{tree/strong + generic flavor}}$ $\Lambda \gtrsim 2\times10^4$ TeV [K]
- $\sim 1/(16\pi^2)$ $\xrightarrow{\text{loop + generic flavor}}$ $\Lambda \gtrsim 2\times10^3$ TeV [K]
- $\sim (y_t V_{ti}^* V_{tj})^2$ $\xrightarrow{\text{tree/strong + “alignment”}}$ $\Lambda \gtrsim 5$ TeV [K & B]
- $\sim (y_t V_{ti}^* V_{tj})^2/(16\pi^2)$ $\xrightarrow{\text{loop + “alignment”}}$ $\Lambda \gtrsim 0.5$ TeV [K & B]

Theoretical motivation

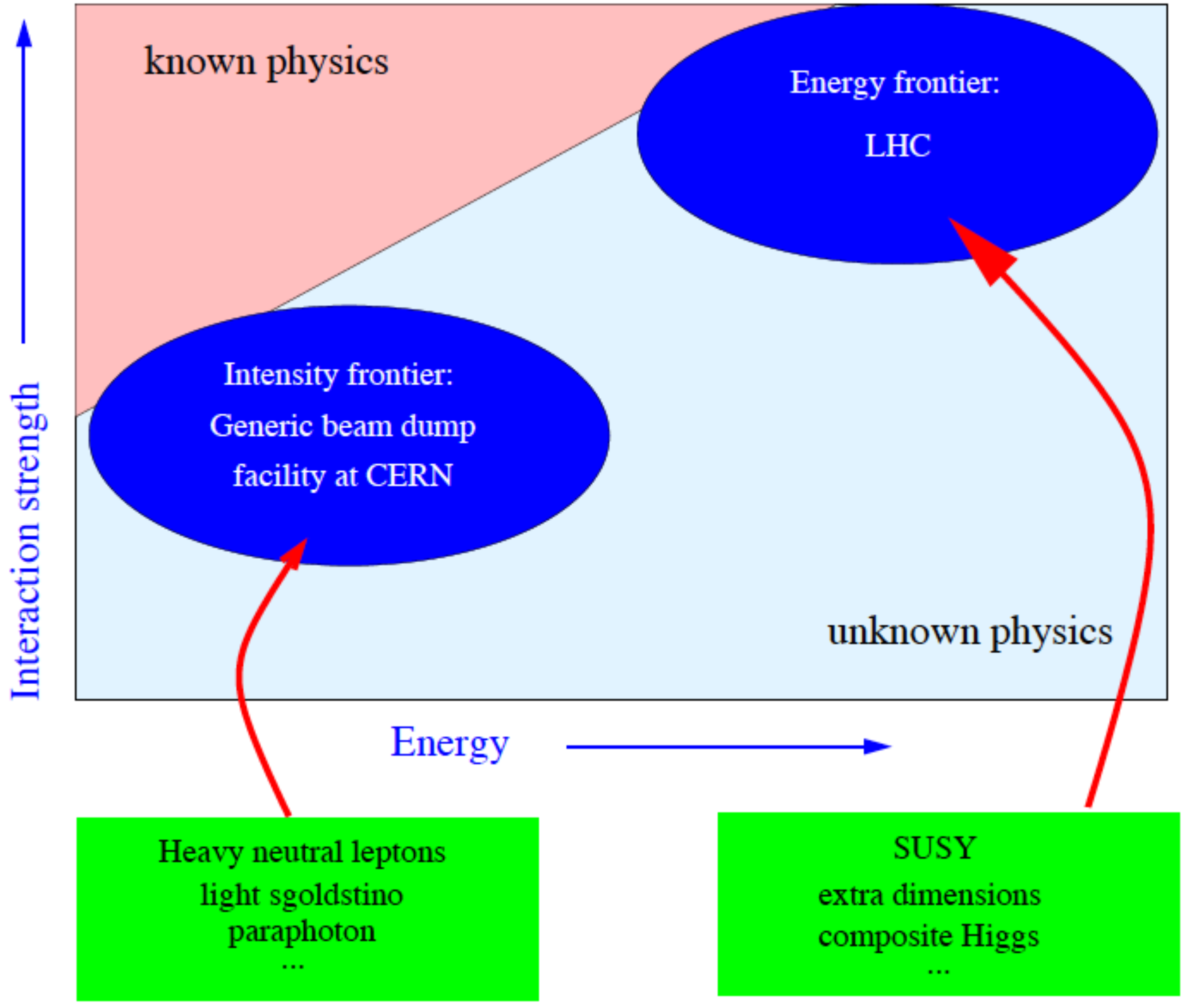
- *Discovery of the 126 GeV Higgs boson → Triumph of the Standard Model The SM may work successfully up to Planck scale !*

Short comings of the SM:

- Neutrino masses & oscillations
- Excess of matter over antimatter in the Universe
- The nature of non-baryonic Dark Matter

Strong motivation to search for physics BSM

Search for BSM physics: how and where ?



hidden sector:

HNL: baryon asymmetry of the Universe, dark matter, neutrino masses

sgoldstino, light neutralino: SUSY

paraphoton: mirror matter, dark matter

Hidden portals: impressive list of ideas in the past

New light hidden particle must be singlet with respect to the gauge group of the SM → they may couple to different singlet composite operators (portals) of the SM

- ✓ *Dim 2: Hypercharge U(1) field, $B_{\mu\nu}$: **vector portal**. New particle – massive vector photon (paraphoton, secluded photon, …); renormalisable coupling – kinetic mixing → $\varepsilon B_{\mu\nu} F'^{\mu\nu}$*
- ✓ *Dim 2 Higgs field $H^\dagger H$: **Higgs portal**. New particle – hidden (dark) scalar; renormalisable coupling → $(\mu\chi + \lambda\chi^2)H^\dagger H$*
- ✓ *Dim 5/2 Higgs-lepton $H^T L$: **neutrino portal**. New particles **H**eavy **N**eutral **L**eptons, HNL; renormalisable coupling → $Y H^T \bar{N} L$*
- ✓ *Dim 4 Axion-like Particles, ALP, pseudo-scalars: **axion portal** Non-renormalisable couplings →* $\frac{a}{F} G_{\mu\nu}\tilde{G}^{\mu\nu}, \quad \frac{\partial_\mu a}{F}\bar{\psi}\gamma_\mu\gamma_5\psi$

Vector portal

Mirror matter: P, C and PC are not conserved - to restore the symmetry between left and right mirror particles should be introduced.

Okun, Voloshin, Ellis, Schwarz, Tyupkin, Kolb, Seckel, Turner, Georgi, Ginsparg, Glashow, Foot, Volkas, Blinnikov, Khlopov, Gninenko, Ignatiev, Berezhiani,...

Even more general approach: dark hidden sector may have complicated structure, not associated with ideas of mirror symmetry (e.g. “SuperUnified theory of Dark Matter” of Arkani-Hamed and Weiner). A possible bridge between hidden and and our world is the vector portal.

The mass of paraphoton (U-boson, secluded photon, dark photon, dark gauge boson, ...) can be in GeV region (SUSY models, arguments coming from DM - change of DM annihilation cross-section, etc).

Holdom, Galison, Manohar, Arkani-Hamed, Weiner, Schuster, Essig, Pospelov, Toro, Batell, Ritz, Andreas, Goodsell, Abel, Khoze, Ringwald, Fayet, Cheung, Ruderman, Wang, Yavin, Morrissey, Poland, Zurek, Reece, Wang, ...

Higgs portal

Higgs portal: convenient parametrisation of an extended Higgs sector: two Higgs doublets, SUSY (e.g. light sgoldstino), scalar singlets, Higgs triplets,...

Extra scalars may be helpful for solution of hierarchy problem, flavour problem, baryogenesis, Dark Matter, neutrino masses, inflation, etc

Patt, Wilczek, Schabinger, Wells, No, Ramsey-Musolf, Walker, Khoze, Ro, Choi, Englert, Zerwas, Lebedev, Mambrini, Lee, Jaeckel, Everett, Djouadi, Falkowski, Schwetz, Zupan, Tytgat, Pospelov, Batell, Ritz, Bezrukov, Gorbunov, Gunion, Haber, Kane, Dawson,...

Neutrino portal *(Heavy Neutral Leptons)*

Minkowski, Yanagida, Gell-Mann, Ramond, Slansky, Glashow, Mohapatra, G. Senjanovic + too many names to write, the whole domain of neutrino physics

Axion portal

Axions to solve strong CP-problem; string theory, extra dimensions: axion-like particles - ALPs (or pseudo-Nambu-Goldstone bosons), dark matter, SUSY, ...

Weinberg, Wilczek, Witten, Conlon, Arvanitaki, Dimopoulos, Dubovsky, Kaloper, March-Russell, Cicoli, Goodsell, Ringwald, Lazarides, Shafi, Choi, Essig, Harnik, Kaplan, Toro, Gorbunov,...

Vector portal observables

Production: through a virtual photon: electron or proton fixed-target experiments, e^+e^- and hadron colliders, $\sigma \propto \epsilon^2$. Decay due to the mixing with photon to the pair of charged particles: $e^+e^-,\ \mu^+\mu^-, \pi^+\pi^-,\ etc,\ etc$ or to invisible particles from the dark sector.

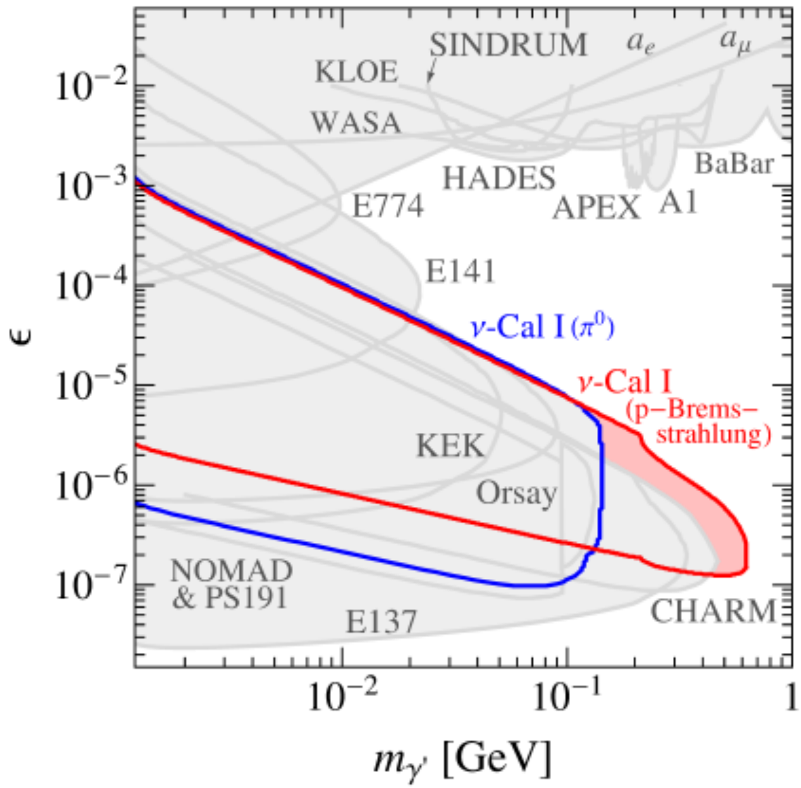
Kinetic mixing of dark (massive) photons with our world

$$\epsilon B_{\mu\nu} F'^{\mu\nu}$$

Constraints are coming from:

- SLAC and Fermilab beam dump experiments E137, E141, E774
- electron and muon anomalous magnetic moments
- KLOE, BaBar
- PS191, NOMAD, CHARM (CERN)

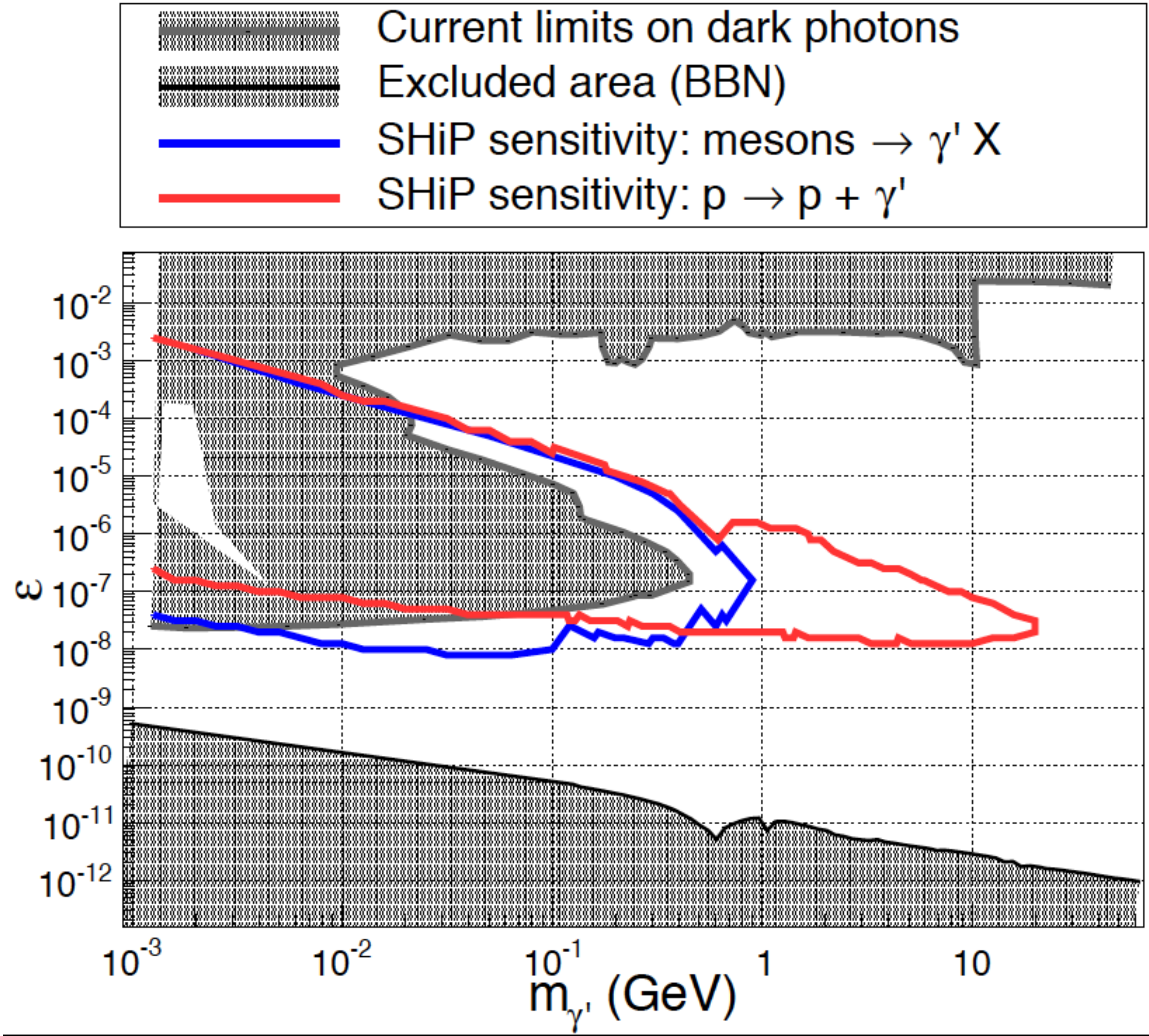
arXiv:1311.3870, Bluemlein et al.



SHIP sensitivity to dark photons

Use the following decays of neutral mesons:

- ✓ $\pi^0 \rightarrow \gamma\gamma$
- ✓ $\eta \rightarrow \gamma\gamma$
- ✓ $\omega \rightarrow \pi^0\gamma$
- ✓ $\eta' \rightarrow \gamma\gamma$



Higgs portal observables *(inflaton)*

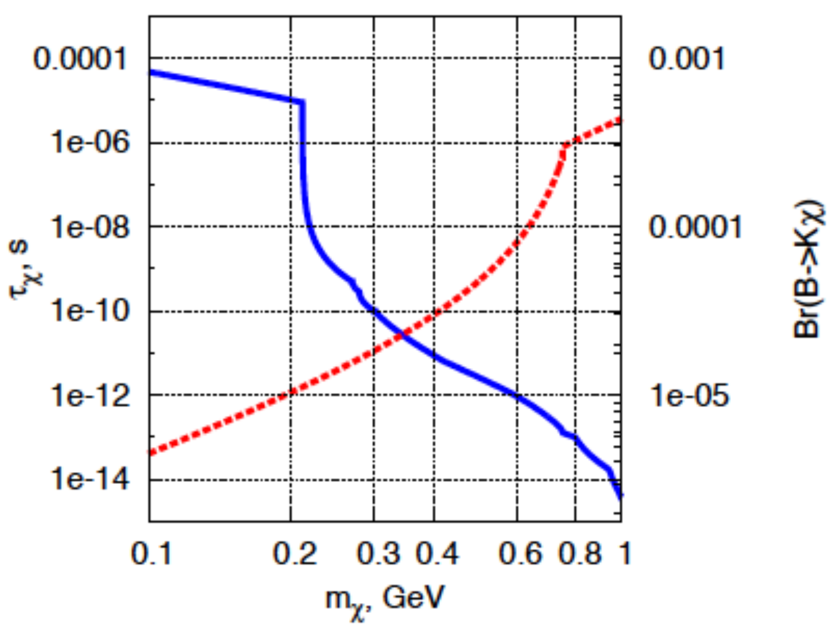
$$(\mu\chi + \lambda\chi^2)H^\dagger H + L_{SM} + L_{hidden}$$

If $\mu << v$, the new scalar χ may be long-lived

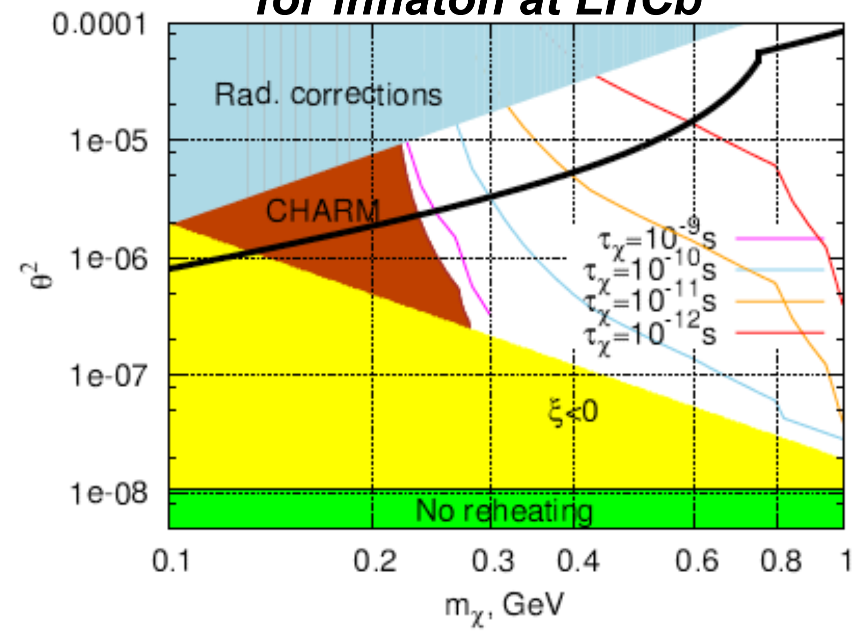
- Direct production $p + \text{target} \to Y + \chi$
- Production via intermediate (hadronic) state

  $p + \text{target} \to \text{mesons} + ...,$ and then hadron$\to \chi + ...$
- Subsequent decay of χ to SM particles
- *Recent example – a model to produce 7 keV N_1 (DM candidate) and inflate the Universe in accordance with BICEP and Planck*

arXiv:1403.4638, Bezrukov, Gorbunov



Synergy with search for inflaton at LHCb

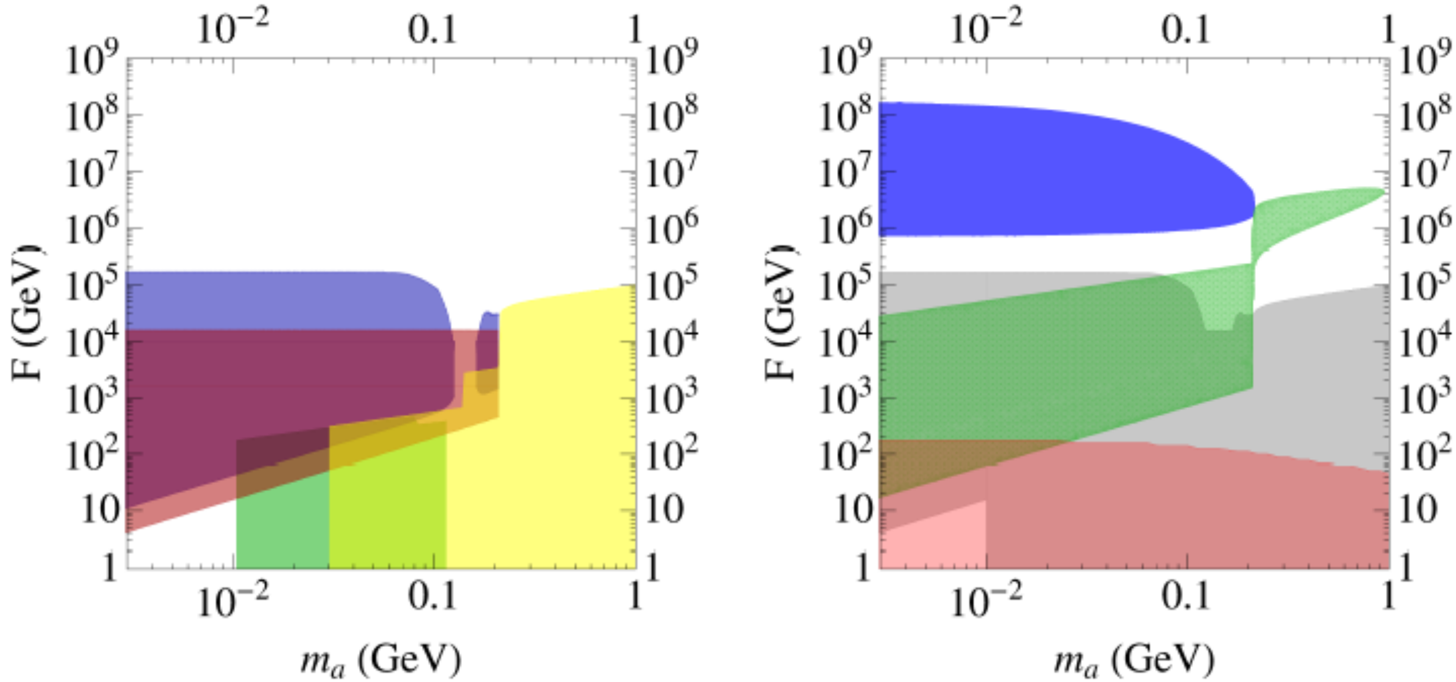


Axion portal observables

Axion-like particles (or pseudo-Nambu-Goldstone bosons), dark matter, SUSY, …

$$\frac{a}{F} G_{\mu\nu} \tilde{G}^{\mu\nu}, \qquad \frac{\partial_\mu a}{F} \bar{\psi} \gamma_\mu \gamma_5 \psi$$

Similar to the Higgs portal, from arXiv:1008.0636, Essig et al

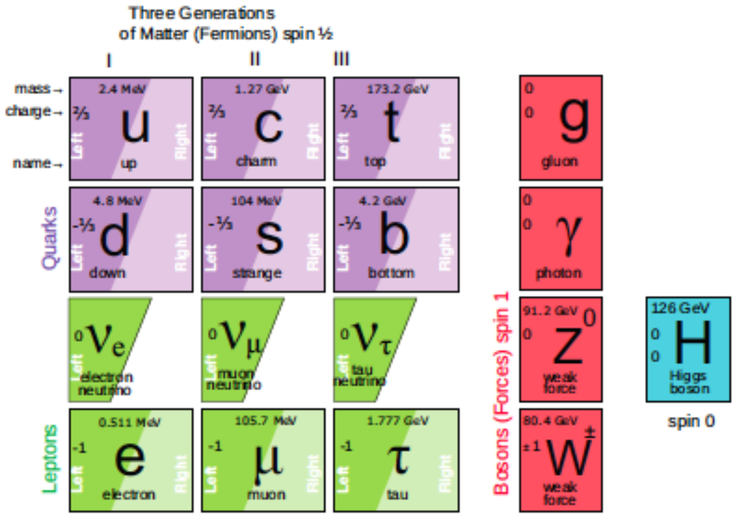


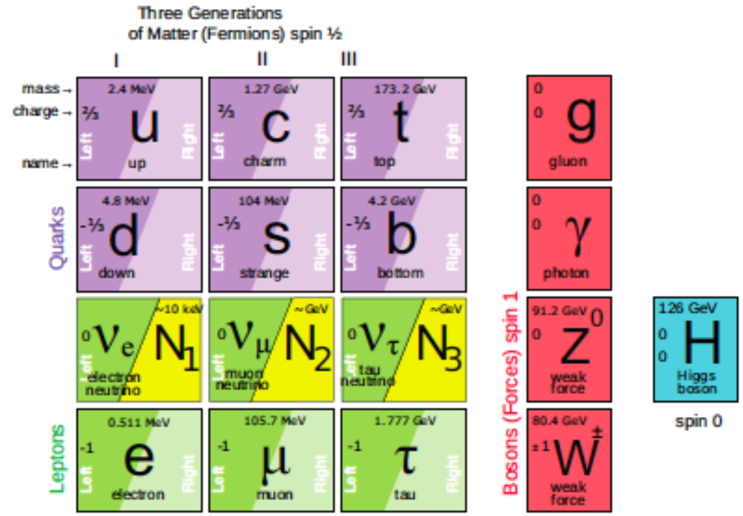
Left: $K^+ \to \text{anything} + e^+e^-$ (green); $K^+ \to \pi^+ +$ invisible (blue); $B^+ \to K^+ l^+ l^-$ (yellow) ($l = e, \mu$); $B^+ \to K^+ +$ invisible (red).

Right: Gray: the combined exclusion region from meson decays; green: CHARM; blue: supernova SN 1987a; red: muon anomalous magnetic moment.

Neutrino portal observables: *(Heavy Neutral Leptons)*

νMSM *(T.Asaka, M.Shaposhnikov PL* ***B620*** *(2005) 17)* ***explains all short comings of the SM at once by adding 3 HNL: N_1, N_2 and N_3***





N = Heavy Neutral Lepton - HNL

Role of N_1 with mass in keV region: dark matter

Role of $N_2,\ N_3$ with mass in 100 MeV – GeV region: “give” masses to neutrinos and produce baryon asymmetry of the Universe

Role of the Higgs: give masses to quarks, leptons, Z and W and inflate the Universe.

See-saw generation of neutrino masses

Most general renormalisable Lagrangian of all SM particles (+3 singlets wrt the SM gauge group):

$$L_{\text{singlet}} = i\bar{N}_I \partial_\mu \gamma^\mu N_I - Y_{I\alpha} \bar{N}_I^c \tilde{H} L_\alpha^c - M_I \bar{N}_I{}^c N_I + \text{h.c.},$$

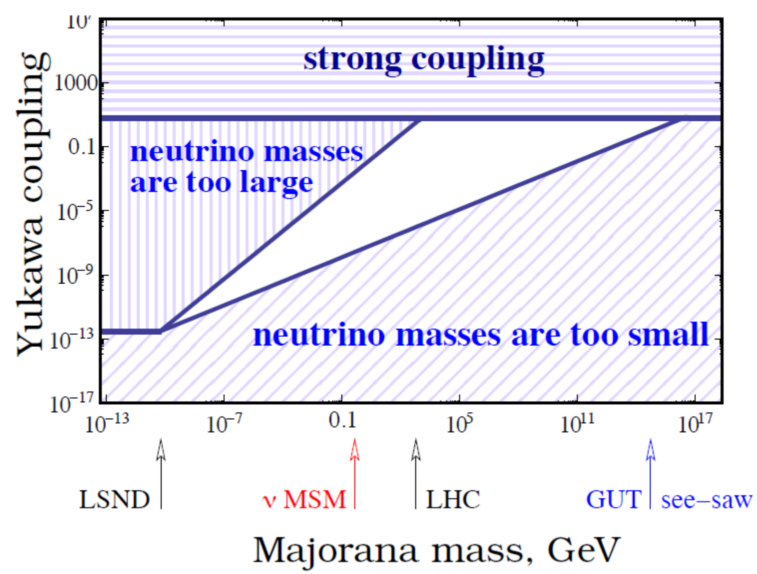
Yukawa term: mixing of N_I with active neutrinos to explain oscillations

Majorana term which carries no gauge charge

The scale of the active neutrino mass is given by the see-saw formula: $m_\nu \sim \frac{m_D^2}{M}$
where $m_D \sim Y_{I\alpha} v$ *- typical value of the Dirac mass term*

Example:

For M ~ 1 GeV and m_ν ~ 0.05 eV it results in m_D ~ 10 keV and Yukawa coupling ~ 10^{-7}



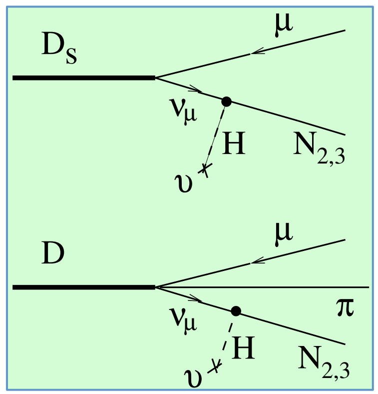
Masses and couplings of HNLs

- ***N_1 can be sufficiently stable to be a DM candidate, $M(N_1)$~10keV***

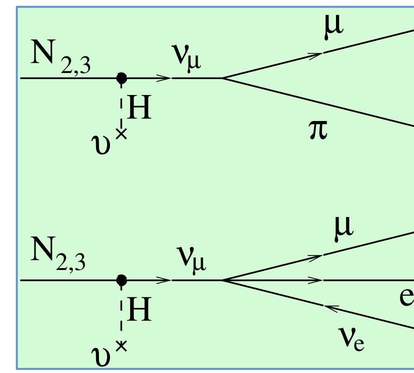
- *$M(N_2) \approx M(N_3)$ ~ a few GeV→ CPV can be increased dramatically to explain Baryon Asymmetry of the Universe (BAU)*

Very weak $N_{2,3}$-to-ν mixing (~ U^2) → $N_{2,3}$ are much longer-lived than the SM particles

Example:
$N_{2,3}$ production in charm



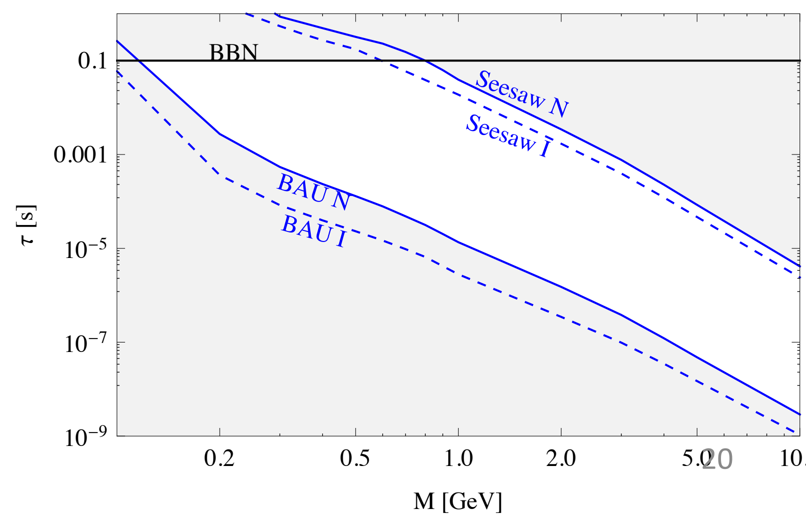
and subsequent decays



- *Typical lifetimes > 10 μs for $M(N_{2,3})$ ~ 1 GeV*
  Decay distance O(km)

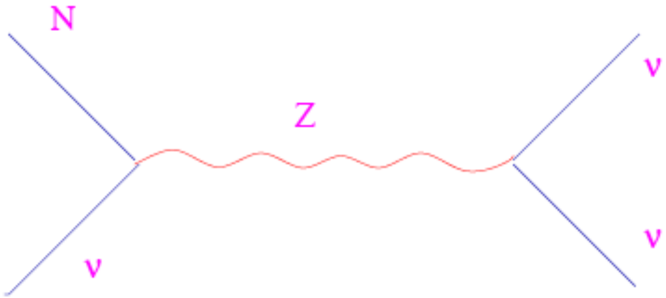
- *Typical BRs (depending on the flavour mixing):*

  $Br(N \rightarrow \mu/e\ \pi)$ ~ 0.1 – 50%
  $Br(N \rightarrow \mu^-/e^-\ \rho^+)$ ~ 0.5 – 20%
  $Br(N \rightarrow \nu\mu e)$ ~ 1 – 10%



Dark Matter candidate HNL N_1

Yukawa couplings are small $\rightarrow$ N can be very stable.



Main decay mode: $N \rightarrow 3\nu$.

Subdominant radiative decay channel: $N \rightarrow \nu\gamma$.

For one flavour:

$$\tau_{N_1} = 10^{14}\,\text{years}\left(\frac{10\ \text{keV}}{M_N}\right)^5\left(\frac{10^{-8}}{\theta_1^2}\right)$$

$$\theta_1 = \frac{m_D}{M_N}$$

Dark Matter candidate HNL N_1

DM particle is not stable. Main decay mode $N_1 \rightarrow 3\nu$ is not observable.

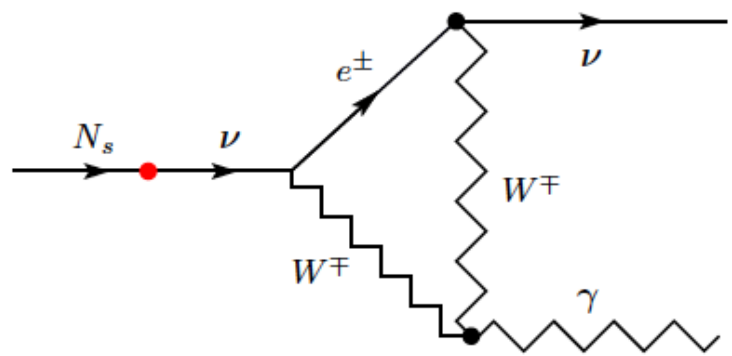
Subdominant radiative decay channel: $N \rightarrow \nu\gamma$.

Photon energy:

$$E_\gamma = \frac{M}{2}$$

Radiative decay width:

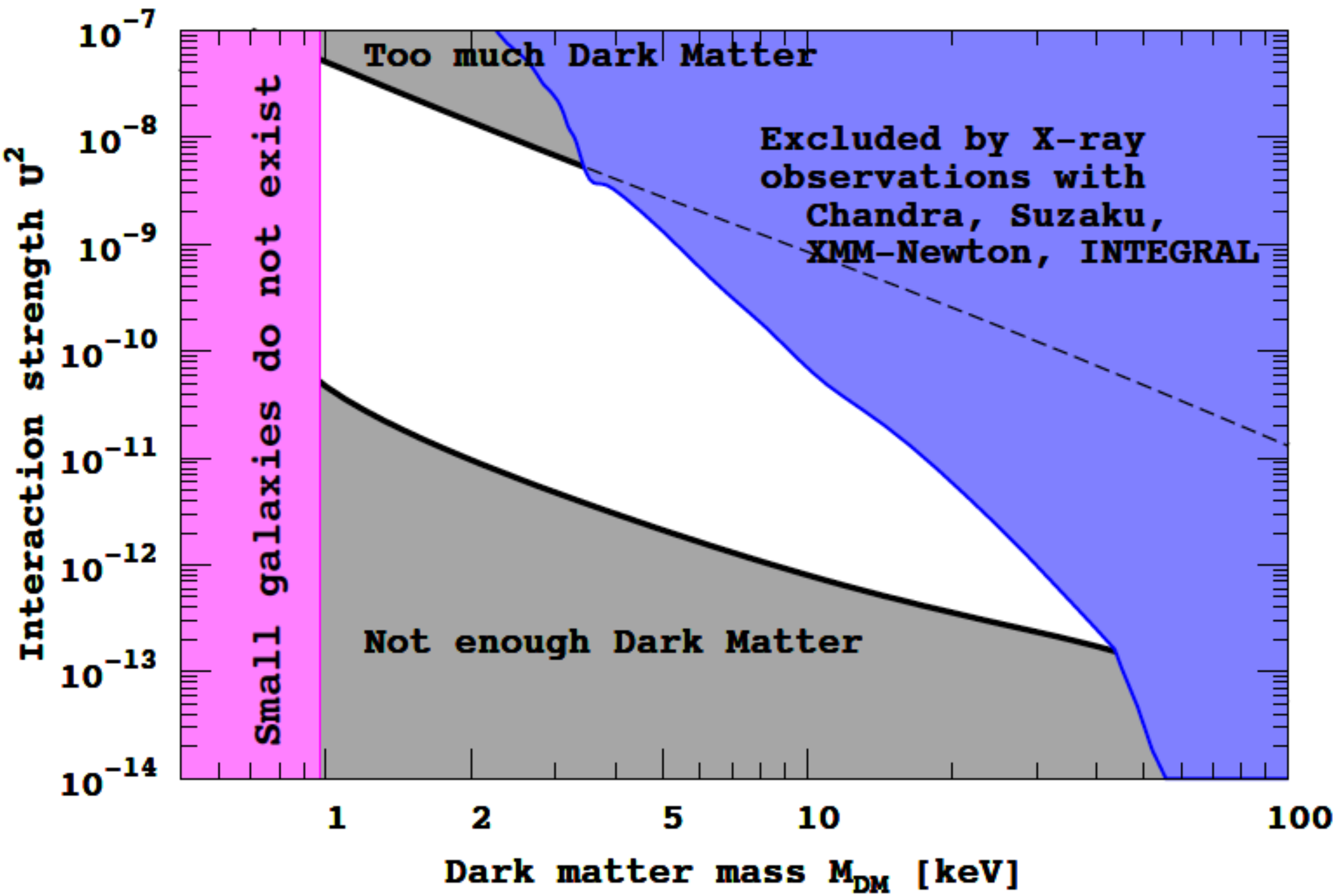
$$\Gamma_{\rm rad} = \frac{9\,\alpha_{\rm EM}\,G_F^2}{256\cdot 4\pi^4}\,\sin^2(2\theta)\,M_N^5$$



Constraints on DM HNL N_1

- ***Stability*** → *N_1 must have a lifetime larger than that of the Universe*
- ***Production*** → *N_1 are created in the early Universe in reactions $l\bar{l} \to \nu N_1$, $q\bar{q} \to \nu N_1$ etc. Need to provide correct DM abundance*
- ***Structure formation*** → *N_1 should be heavy enough ! Otherwise its free streaming length would erase structure non-uniformities at small scales (Lyman-α forest spectra of distant quasars and structure of dwarf galaxies)*
- ***X-ray spectra*** → *Radiative decays $N_1 \to \gamma\nu$ produce a mono-line in photon galaxies spectrum.*

Allowed parameter space for DM HNL N_1



Searches for DM HNL N_1 in space

- Has been previously searched with *XMM-Newton, Chandra, Suzaku, INTEGRAL*
- Spectral resolution is not enough (required $\Delta E/E \sim 10^{-3}$)
- Proposed/planned X-ray missions with sufficient spectral resolution:

Astro-H

LOFT

Athena+

Origin/Xenia

New line in photon galaxy spectrum ???

Two recent publications in arXiv:

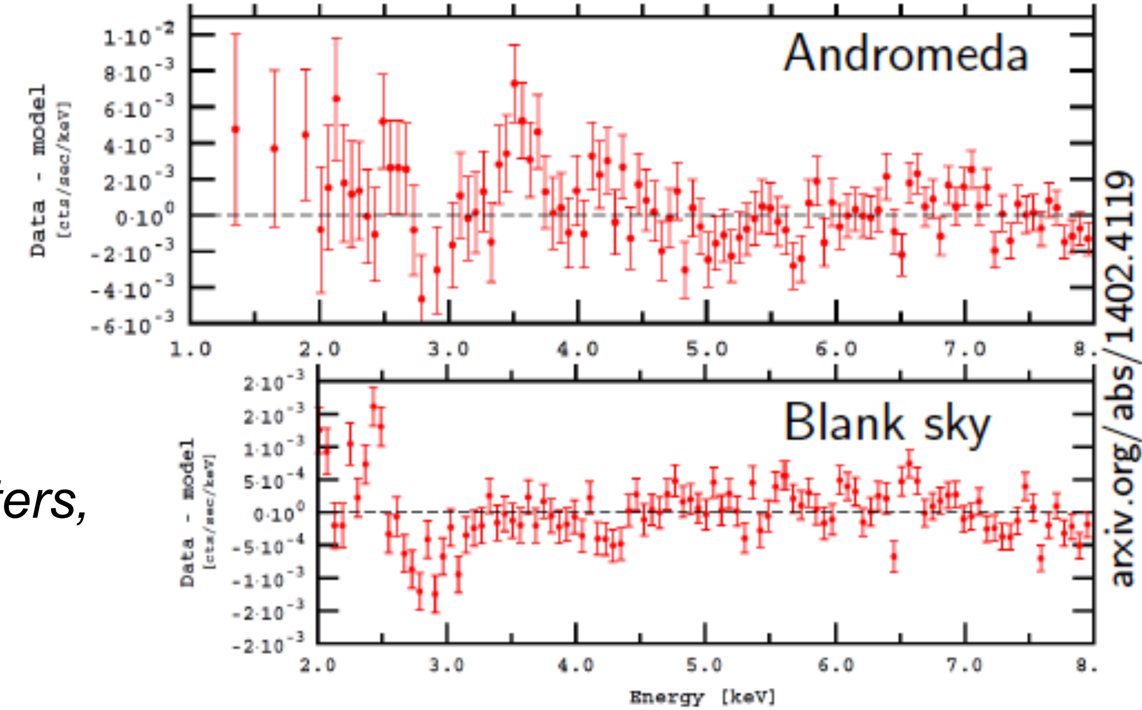
- *arXiv 1402.2301*

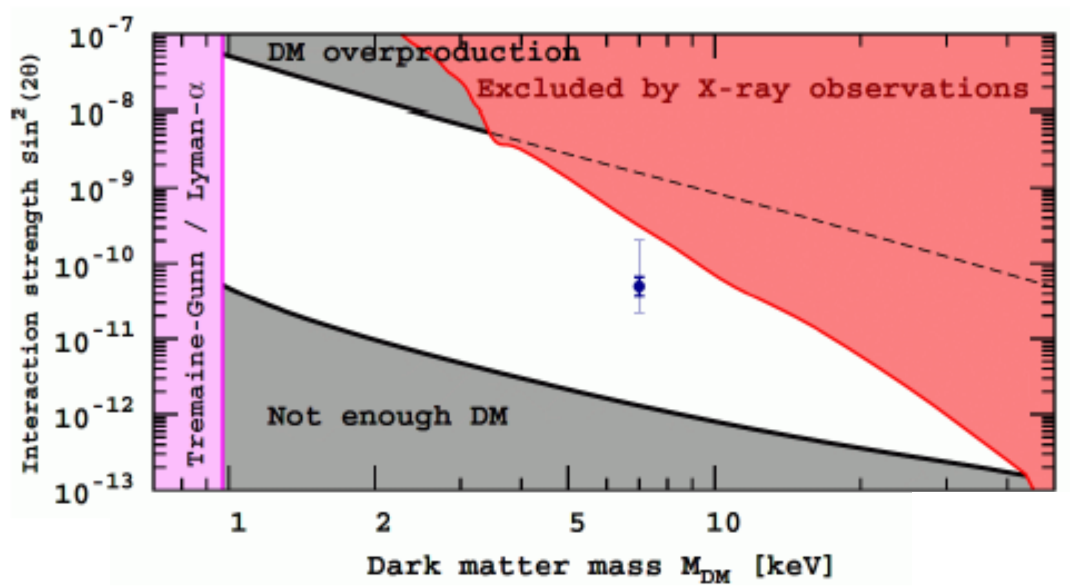
Detection of an unidentified emission line in the stacked X-ray spectrum of Galaxy Clusters, $E_\gamma \sim 3.56$ keV

- *arXiv 1402.4119*

An unidentified line in X-ray spectra of the Andromeda galaxy and Perseus galaxy cluster, $E_\gamma \sim 3.5$ keV

Will soon be checked by Astro-H with better energy resolution



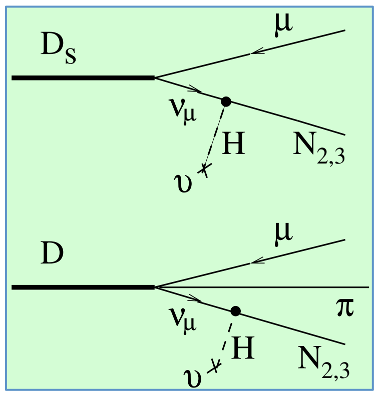


Masses and couplings of HNLs

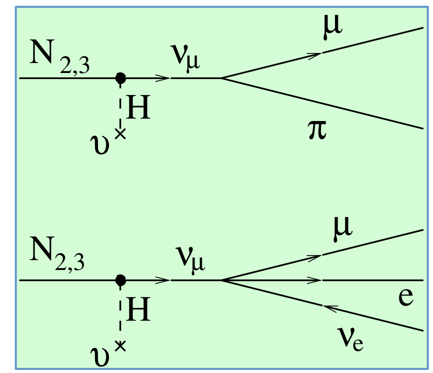
- ***$M(N_2) \approx M(N_3)$ ~ a few GeV → CPV can be increased dramatically to explain Baryon Asymmetry of the Universe (BAU)***

Very weak $N_{2,3}$-to-ν mixing (~ U^2) → $N_{2,3}$ are much longer-lived than the SM particles

Example:
$N_{2,3}$ production in charm



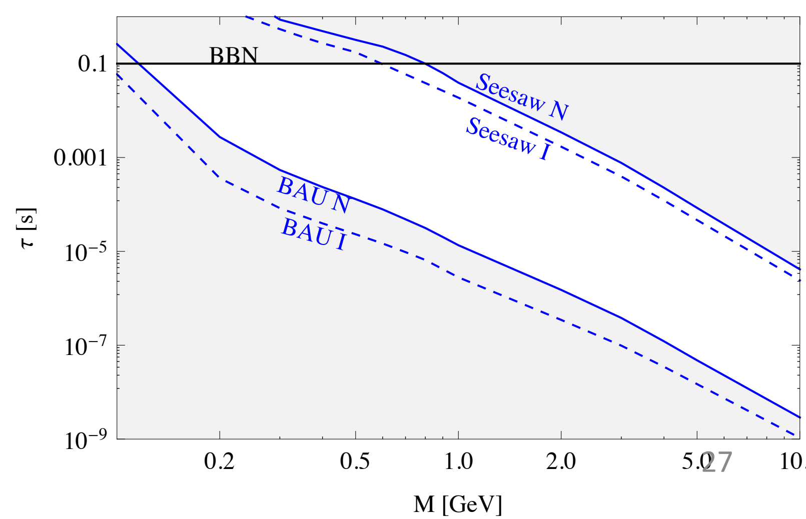
and subsequent decays



- *Typical lifetimes > 10 μs for $M(N_{2,3})$ ~ 1 GeV*
  Decay distance O(km)

- *Typical BRs (depending on the flavour mixing):*

  Br(N → μ/e π) ~ 0.1 – 50%
  Br(N → μ^-/e^- ρ^+) ~ 0.5 – 20%
  Br(N → $\nu\mu$e) ~ 1 – 10%



Baryon asymmetry

Sakharov conditions:

- *CP is not conserved in νMSM*

  6 CPV phases in the lepton sector and 1 CKM phase in the quark sector (to be compared with only one CKM phase in the SM)

- *Deviations from thermal equilibrium*

↓

✓ ***HNL are created in the early Universe***

✓ ***CPV in the interference of HNL production and decay***

✓ ***Lepton number goes from HNL to active neutrinos***

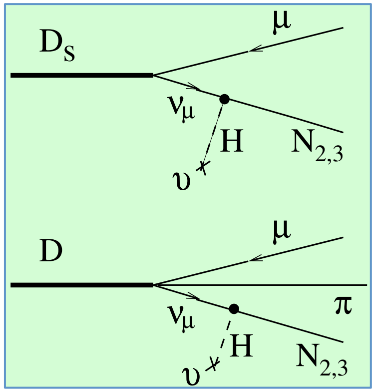
✓ ***Then lepton number transfers to baryons in the equilibrium sphaleron processes***

PS *Explanation of DM with N_1 reduces a number of free parameters*
→ Degeneracy of $N_{2,3}$ masses is required to ensure sufficient CPV

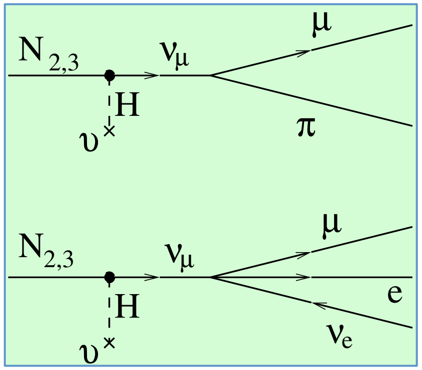
Masses and couplings of HNLs

Very weak $N_{2,3}$-to-ν mixing (~ U^2) → $N_{2,3}$ are much longer-lived than the SM particles

Example:
$N_{2,3}$ production in charm



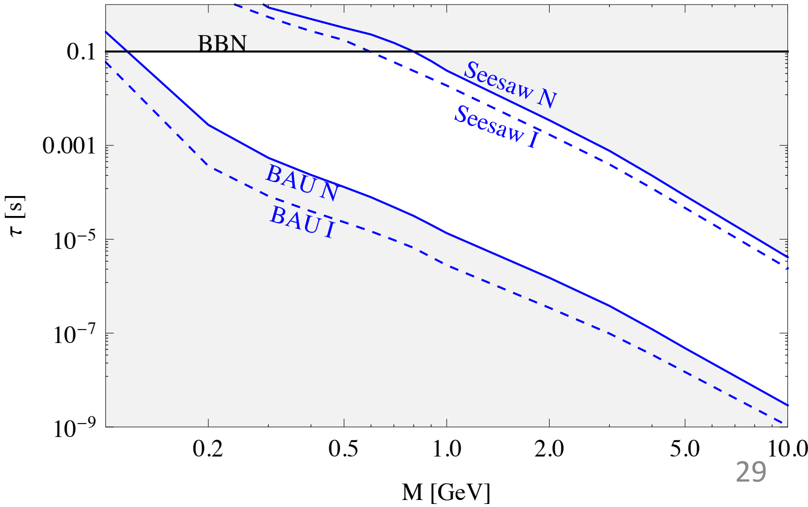
and subsequent decays



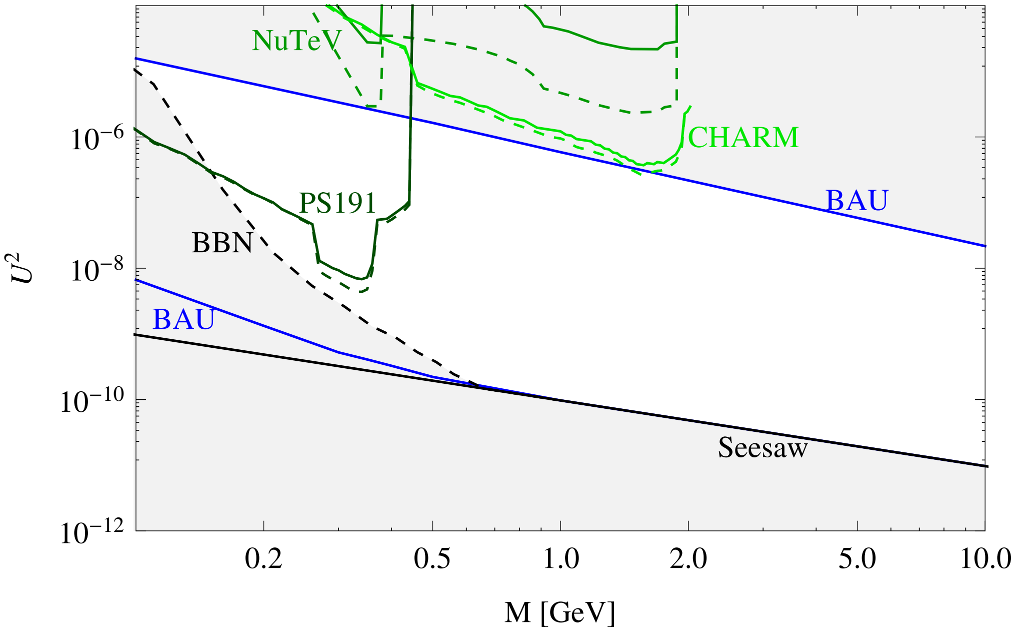
- *Typical lifetimes > 10 μs for $M(N_{2,3})$ ~ 1 GeV*
  Decay distance O(km)

- *Typical BRs (depending on the flavour mixing):*

  Br(N → μ/e π) ~ 0.1 – 50%
  Br(N → μ^-/e^- ρ^+) ~ 0.5 – 20%
  Br(N → $\nu\mu e$) ~ 1 – 10%



Experimental and cosmological constraints



- ***Recent progress in cosmology***

  - *The sensitivity of previous experiments did not probe the interesting region for HNL masses above the kaon mass*

→ *Strong motivation to explore cosmologically allowed parameter space*

Proposal for a new experiment at the SPS, SHIP to search for new long-lived particles produced in charm decays *(more details can be found at http://ship.web.cern.ch/ship)*

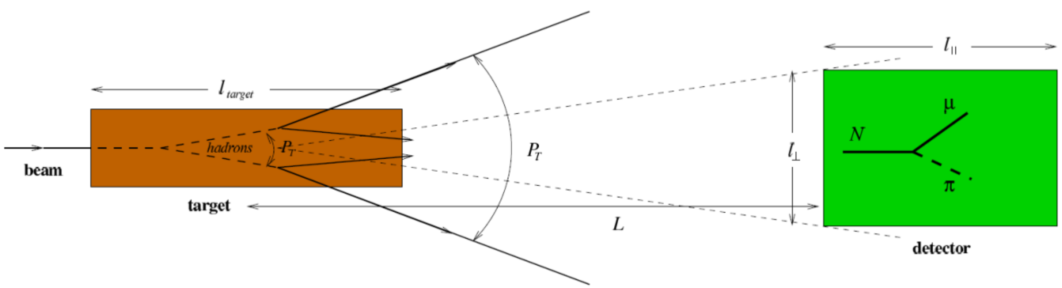
Experimentally this domain has not been very well explored !

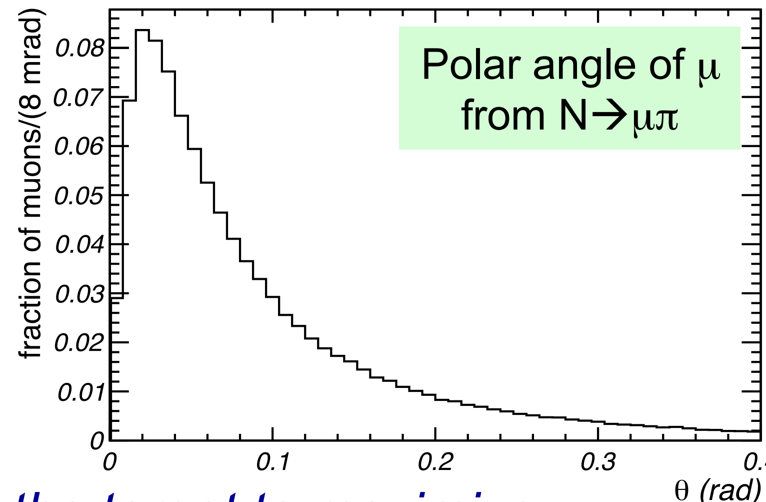
Experimental requirements

- Search for HNL in Heavy Flavour decays

→ Beam dump experiment at the SPS with a total of 2×10^{20} protons on target (pot) to produce large number of charm mesons

- HNLs produced in charm decays have significant P_T





→ Detector must be placed close to the target to maximize geometrical acceptance

→ Effective (and "short") muon shield is essential to reduce muon-induced backgrounds (mainly from short-lived resonances accompanying charm production)

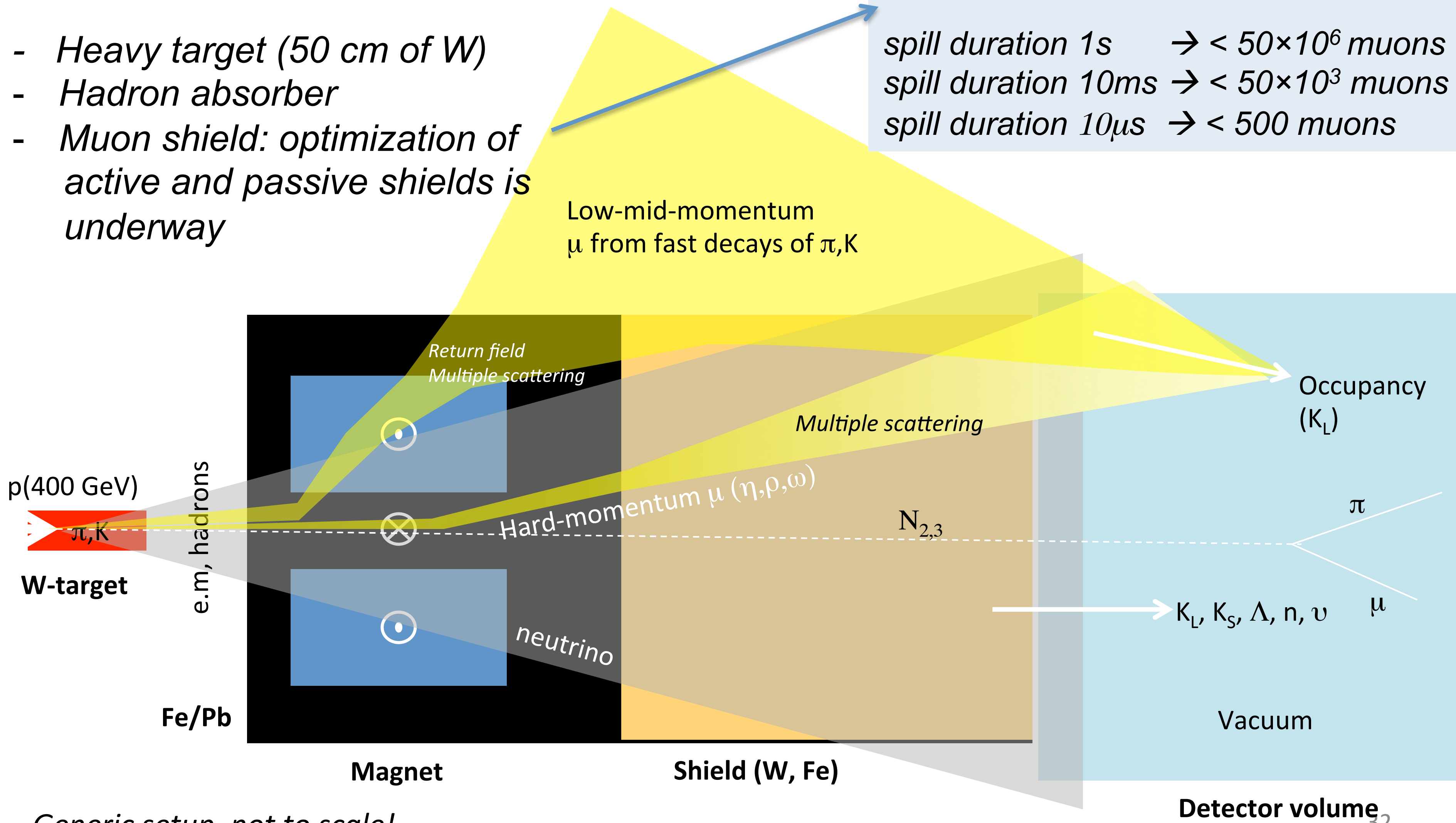
Secondary beam-line
(incompatible with conventional neutrino facility)

Initial reduction of beam induced backgrounds

- *Heavy target (50 cm of W)*
- *Hadron absorber*
- *Muon shield: optimization of active and passive shields is underway*

Acceptable occupancy <1% per spill of 5×10^{13} p.o.t.

spill duration 1s → < 50×10^{6} muons
spill duration 10ms → < 50×10^{3} muons
spill duration 10μs → < 500 muons



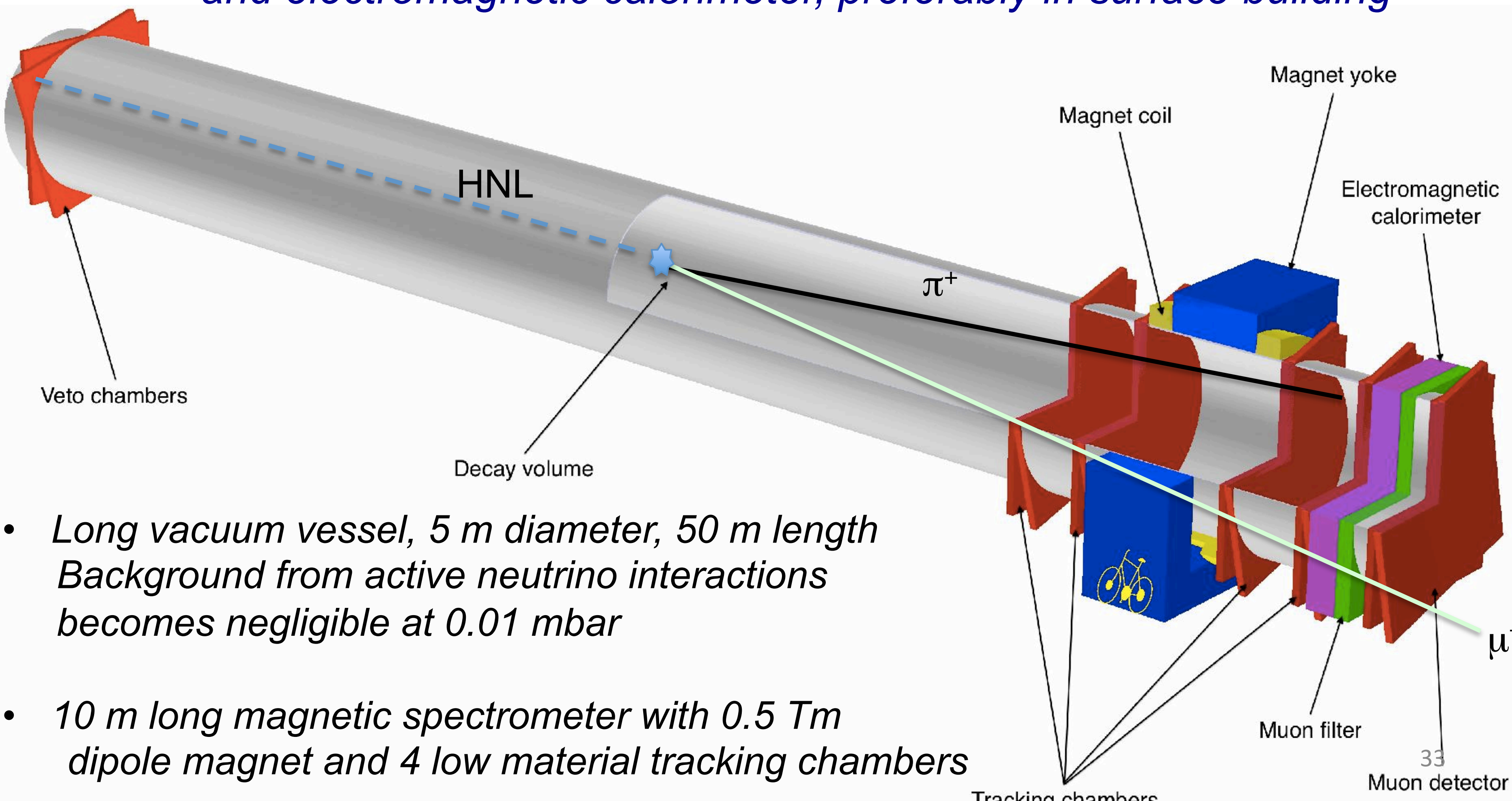
Generic setup, not to scale!

Detector concept

(based on existing technologies)

- *Reconstruction of the HNL decays in the final states:* $\mu^-\pi^+$, $\mu^-\rho^+$ & $e^-\pi^+$

→ *Requires long decay volume, magnetic spectrometer, muon detector and electromagnetic calorimeter, preferably in surface building*



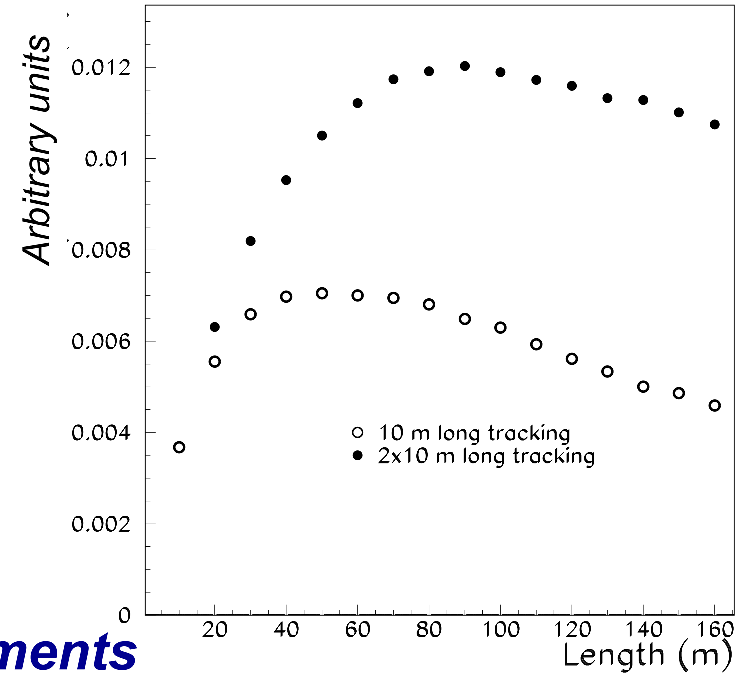
- *Long vacuum vessel, 5 m diameter, 50 m length Background from active neutrino interactions becomes negligible at 0.01 mbar*

- *10 m long magnetic spectrometer with 0.5 Tm dipole magnet and 4 low material tracking chambers*

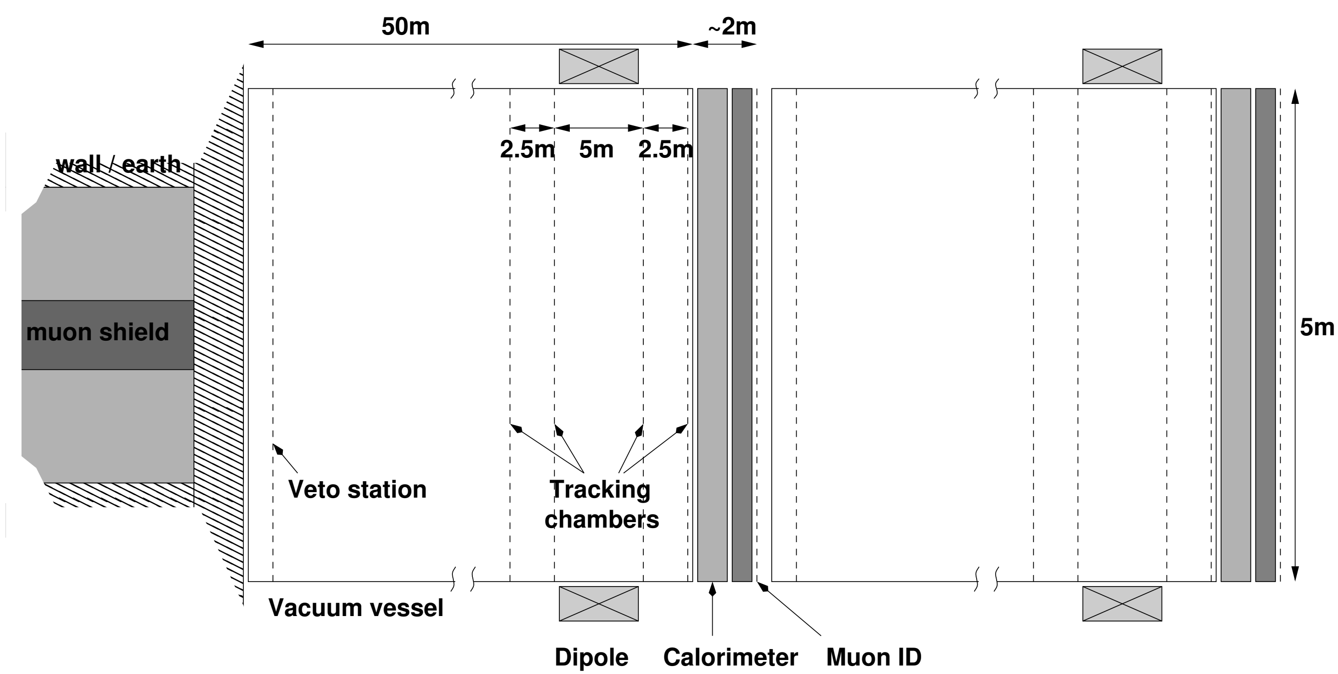
Detector concept (cont.)

Geometrical acceptance

- *Saturates for a given HNL lifetime as a function of detector length*
- *The use of two magnetic spectrometers increases the acceptance by 70%*



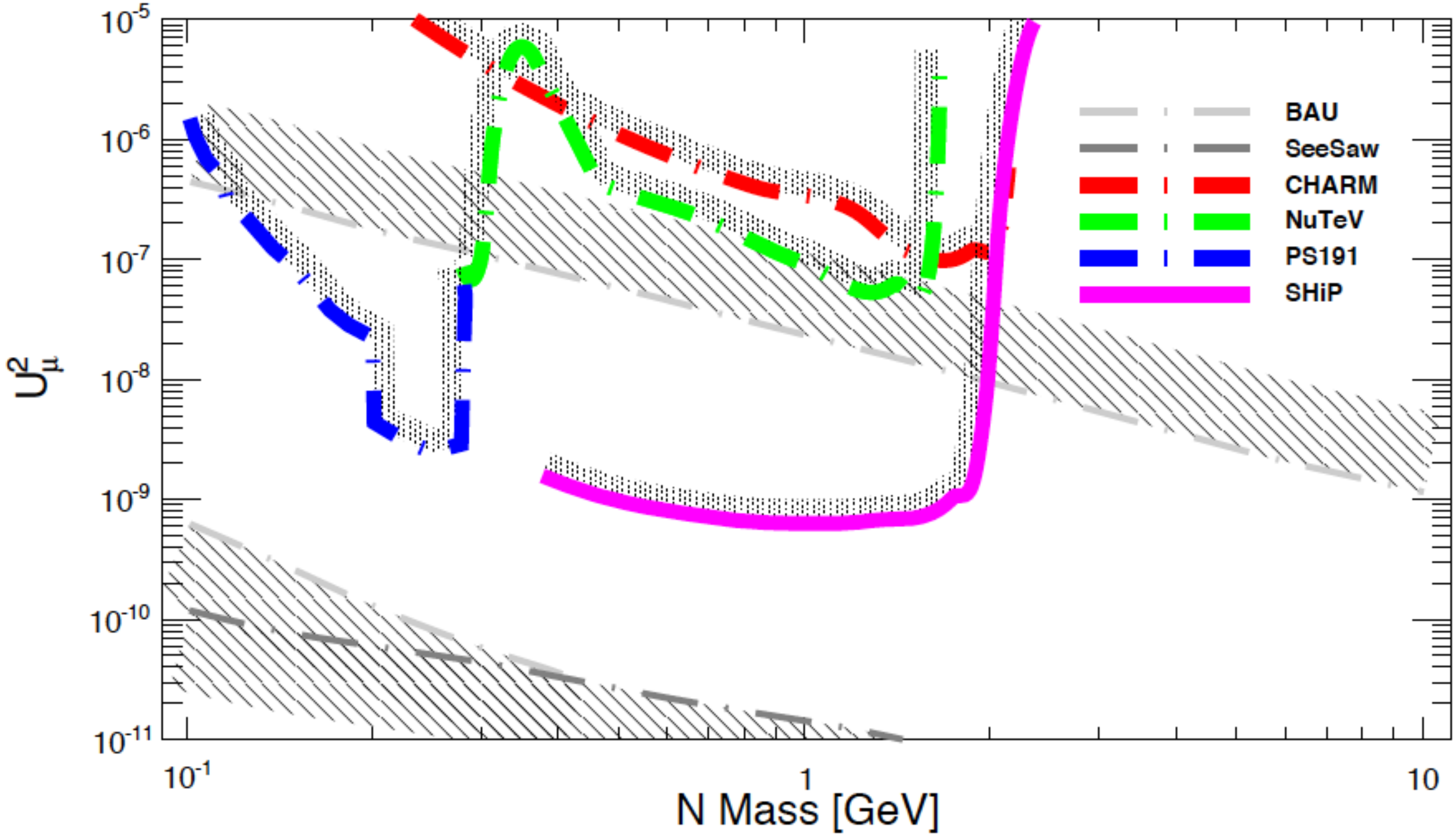
→ *Detector has two almost identical elements*



Expected event yield (cont.)

Assuming $U_\mu^2 = 10^{-7}$ (corresponding to the strongest experimental limit currently for $M_N \sim 1$ GeV) and $\tau_N = 1.8\times10^{-5}$ s

~12k fully reconstructed $N \rightarrow \mu^-\pi^+$ events are expected for $M_N = 1$ GeV



120 events for cosmologically favoured region: $U_\mu^2 = 10^{-8}$ & $\tau_N = 1.8\times10^{-4}$s

Status of the SPSC review

- Oct 2013: submitted our EOI: CERN-SPSC-2013-024 ; arXiv:1310.1762 ; SPSC-EOI-010. - 2013
- SPSC assigned 4 referees, who came with a list of questions.
- 3/1/2014: answers to questions: snoopy.web.cern.ch/snoopy/EOI/SPSC-EOI-010_ResponseToReferees.pdf
- 15/1/2014: SPSC discussed our proposal.

17/1/2014: The official feedback from the Committee is as follows :

"The Committee **received with interest** the response of the proponents to the questions raised in its review of EOI010.
The SPSC **recognises** the interesting physics potential of searching for heavy neutral leptons and investigating the properties of neutrinos.

Considering the large cost and complexity of the required beam infrastructure as well as the significant associated beam intensity, such a project should be designed as a general purpose beam dump facility with the broadest possible physics programme, including maximum reach in the investigation of the hidden sector.
To further review the project the Committee **would need** an extended proposal with further developed physics goals, a more detailed technical design and a stronger collaboration."
Cheers,
Gavin, Lau, Matthew and Thierry
(for the SPS Committee).

Physics case for general beam dump facility

- ✓ ***Study of ν_τ interactions (guarantied SM physics)***

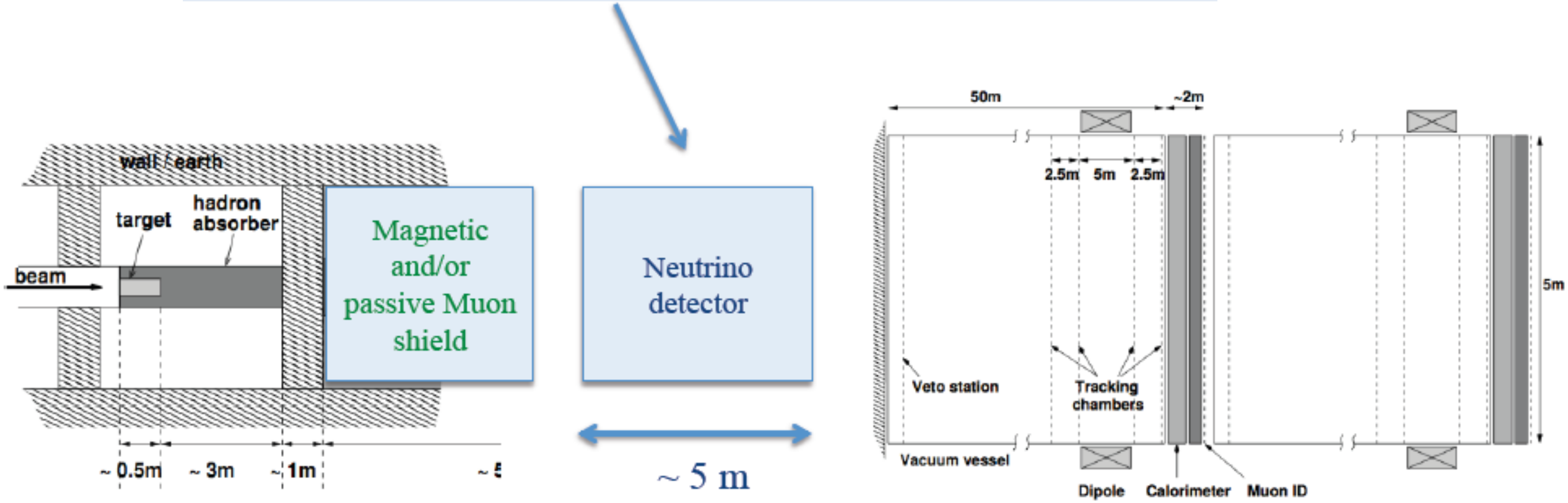
  Ideally suited since ν_τ is produced in $D_s \rightarrow \tau\nu_\tau$ with similar to HNL kinematics

- ✓ ***Search for any weakly interacting yet unstable particles such as HNL, low mass SUSY or paraphotons or …***

- ✓ *Review of the SHIP sensitivities for ν_τ physics and wide class of models with hidden portals is ongoing*

  Expect significant improvement of currently available measurements and constrains everywhere !

SM: ν_τ physics with $2{\times}10^{20}$ pot



- Good physics program with a compact neutrino detector *Expect ~3400 ν_τ interactions in 6 tons emulsion target (5% of OPERA)*
- Tau neutrino and anti-neutrino physics
- Charm physics with neutrinos and anti-neutrinos
- Electron neutrino studies (high energy cross-section, only low energy studies for oscillations) and ν_e induced charm (~1000 events)
- Interested groups: Bari, Bern, Dubna, Frascati, Gran Sasso, Lebedev Physical Institute, Moscow State University, Nagoya, Naples, Rome, Toho

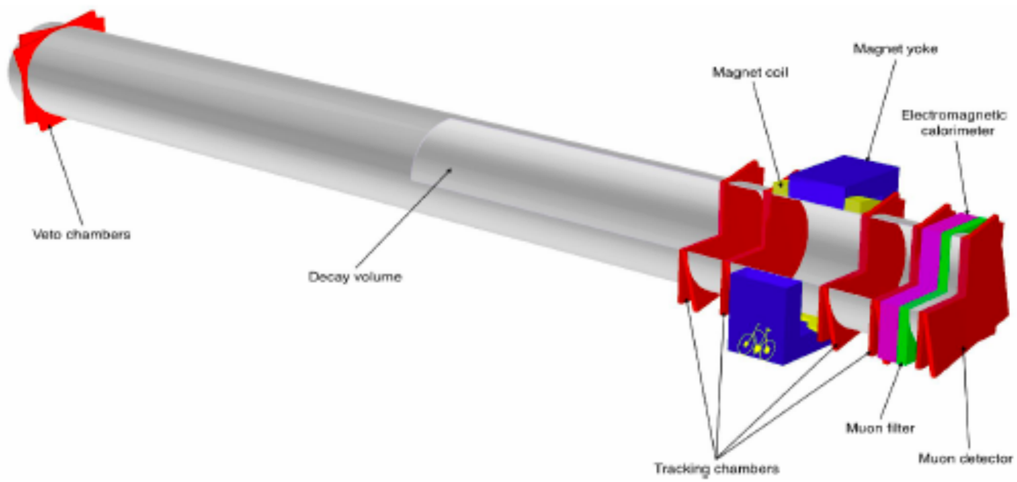
Strengthen collaboration …

http://ship.web.cern.ch/ship

SHIP - Search for HIdden Particles

CERN, Universität Zürich, EPFL Lausanne, INFN Cagliari,
Università Federico II and INFN Napoli, Imperial College London

Experiment to search for Heavy Neutral Leptons at the SPS



We propose a new fixed-target experiment at the CERN SPS accelerator to search for *hidden particles*. In particular, to search for Heavy Neutral Leptons (HNLs) produced in charm decays. HNLs are right-handed partners of the Standard Model neutrinos. The existence of such particles is strongly motivated by theory, as they can simultaneously explain the baryon asymmetry of the Universe, account for the pattern of neutrino masses and oscillations, and provide a Dark Matter candidate.

SHIP is a collaboration of six institutes: CERN, Universität Zürich, École Polytechnique Fédérale de Lausanne, INFN Sezione di Cagliari, Università Federico II and INFN Napoli, Imperial College London. Groups interested in joining should contact Andrey Golutvin and Jaap Panman. The extension of the collaboration will be discussed at the ***First SHIP Workshop*** that will be take place in ***Zürich the 10-12 June 2014***.

1st SHIP workshop, 10-12 June, Zurich

Tuesday 10 June 2014

Registration and coffee - (12:30-13:30)

Welcome - (13:30-13:40)

time	[id] title	presenter
13:30	[0] Welcome and opening of the workshop	STRAUMANN, Ueli

S1 - Theoretical and experimental status of SM and perspectives for new physics - (13:40-14:40)

time	[id] title	presenter
13:40	[1] Theory confronts the naturalness riddle	ALTARELLI, Guido
14:10	[2] What is next? - Experiment view	Dr. TITOV, Maxim

S2 - Vector, axion and Higgs portals - (14:40-16:00)

time	[id] title	presenter
14:40	[5] Scalars and pseudo-scalars	BEZRUKOV, Fedor
15:10	[3] Dark photons	ANDREAS, Sarah
15:40	[4] Experimental sensitivity to dark photons	BRUNNER, Jurgen

S3 - Neutrino portal - (16:30-18:30)

time	[id] title	presenter
16:30	[6] The scale of see-saw and models for neutrino masses	Prof. LINDNER, Manfred
17:00	[7] Expectations for properties of heavy neutral leptons from BSM physics	SHROCK, Robert
17:30	[8] Previous searches of heavy neutral leptons	ROZANOV, Alexandre
18:00	[9] Summary of constraints on heavy neutral leptons	PASCOLI, Silvia

Bar-storming Discussion - (21:30-22:30)

Wednesday 11 June 2014

S4 - Neutrino portal, continued - (08:30-10:30)

time	[id] title	presenter
08:30	[10] Lepton number violation and heavy neutral leptons	HAMBYE, Thomas
09:00	[11] Overview of NuMSM	ASAKA, Takehiko
09:30	[12] Baryogenesis	GARBRECHT, Bjorn
10:00	[13] Heavy neutral leptons in cosmology and astrophysics	RUCHAYSKIY, Oleg

S5 - SUSY and BSM physics - (11:00-12:30)

time	[id] title	presenter
11:00	[14] New physics in charm and bottom decays	ISIDORI, Gino
11:30	[15] R-parity violation and light neutralino	POROD, Werner
12:00	[16] Sgoldstino	Dr. GHILENCEA, Dumitru

Introduction to SHIP Detector - (13:30-13:55)

time	[id] title	presenter
13:30	[17] Overall requirements and layout of SHIP	JACOBSSON, Richard

S6 - Experimental facility and infrastructure - (13:55-15:15)

time	[id] title	presenter
13:55	[18] SPS configuration and beam transfer	Dr. GODDARD, Brennan
14:25	[19] Target complex	CALVIANI, Marco
14:50	[20] Muon shield	RUF, Thomas

The role of CERN in the diversity of physics programs - (15:15-15:45)

time	[id] title	presenter
15:15	[21] The role of CERN in the diversity of physics programs	BERTOLUCCI, Sergio

Coffee break - (15:45-16:10)

S7 - Experimental facility and infrastructure, continued - (16:10-17:00)

time	[id] title	presenter
16:10	[22] Radiation protection aspects	VINCKE, Heinz
16:35	[23] Civil engineering	OSBORNE, John Andrew

S8 - SHIP detector - (17:00-18:40)

time	[id] title	presenter
17:00	[24] Spectrometer - Overview and requirements	FERRO-LUZZI, Massimiliano
17:20	[25] Straw tracker - a possible option	
17:40	[26] Straw tracker – mechanics and manufacturing	
18:00	[27] Calorimeter	
18:20	[28] Calorimeter electronics	

Bar-storming discussion - (21:30-22:30)

Thursday 12 June 2014

S9 - SHIP detector, continued - (08:30-09:30)

time	[id] title	presenter
08:30	[29] Muon detector – MWPC	LANFRANCHI, Gaia
08:50	[30] Muon detector – RPC	Dr. PAOLUCCI, Pierluigi
09:10	[31] Upstream tagger	BONIVENTO, Walter

S10 - Tau neutrino physics and detector - (09:30-10:00)

time	[id] title	presenter
09:30	[32] The upstream detector for neutrino physics	DE LELLIS, Giovanni

Coffee break - (10:00-10:20)

S11 - Tau neutrino physics and detector - (10:20-11:20)

time	[id] title	presenter
10:20	[33] Emulsions and scanning technologies	KOMATSU, Masahiro
10:40	[34] Silicon pixel detector	CASSE, Gianluigi
11:00	[35] Scintillating fibre tracker	TBC

S12 - Computing - (11:20-12:30)

time	[id] title	presenter
11:20	[36] Readout architecture and trigger	DIJKSTRA, Hans
11:45	[37] Status of MC	RADEMAKERS, Fons
12:05	[38] Framework for computing	USTYZHANIN, Andrey

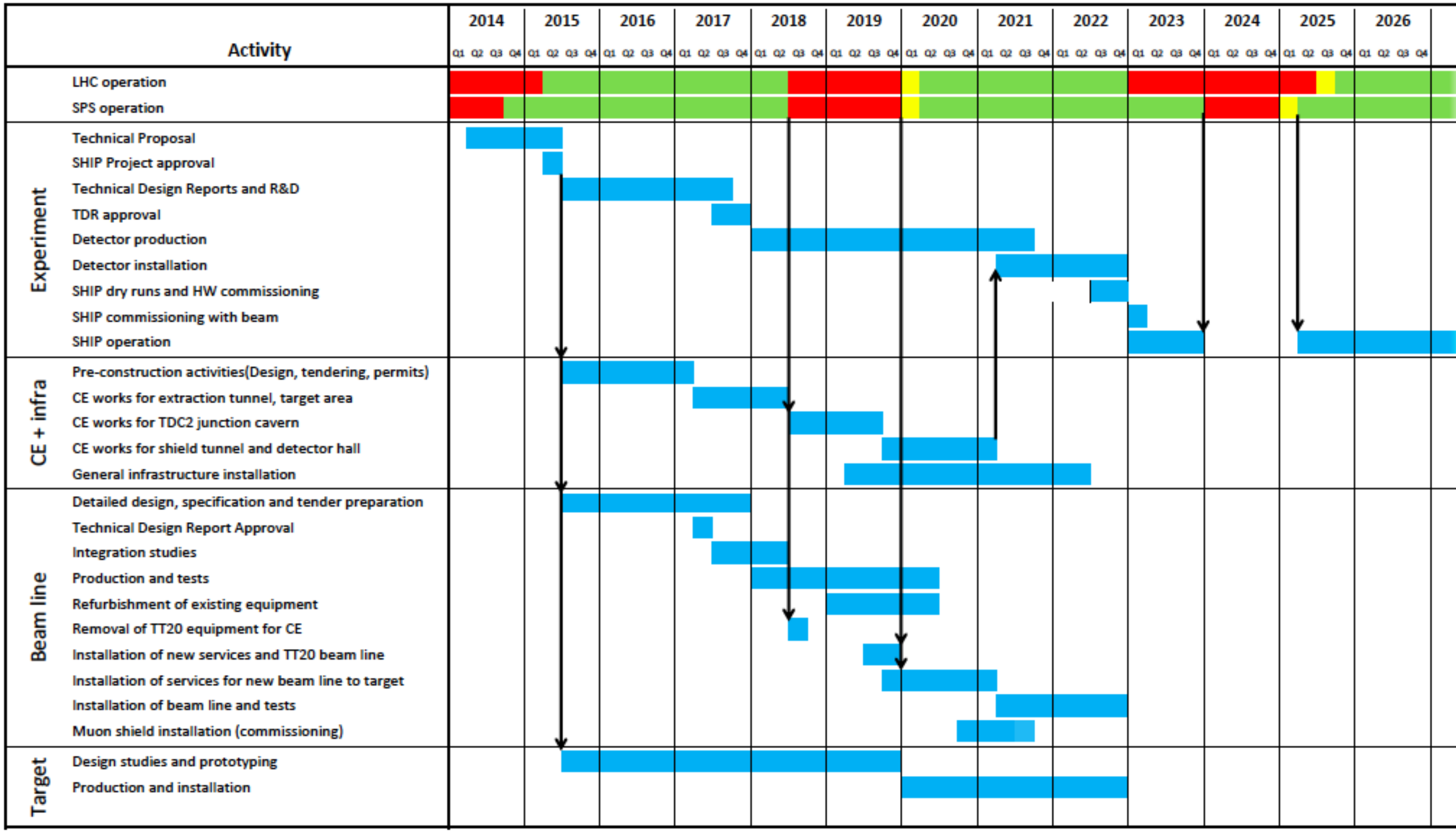
Workshop summary and conclusions - (12:30-13:00)

time	[id] title	presenter
12:30	[39] Workshop Summary	GOLUTVIN, Andrei

Collaboration matters - (14:00-16:00)

Activate SHIP collaboration at this session

Next steps: schedule of the SHIP facility



A few milestones:

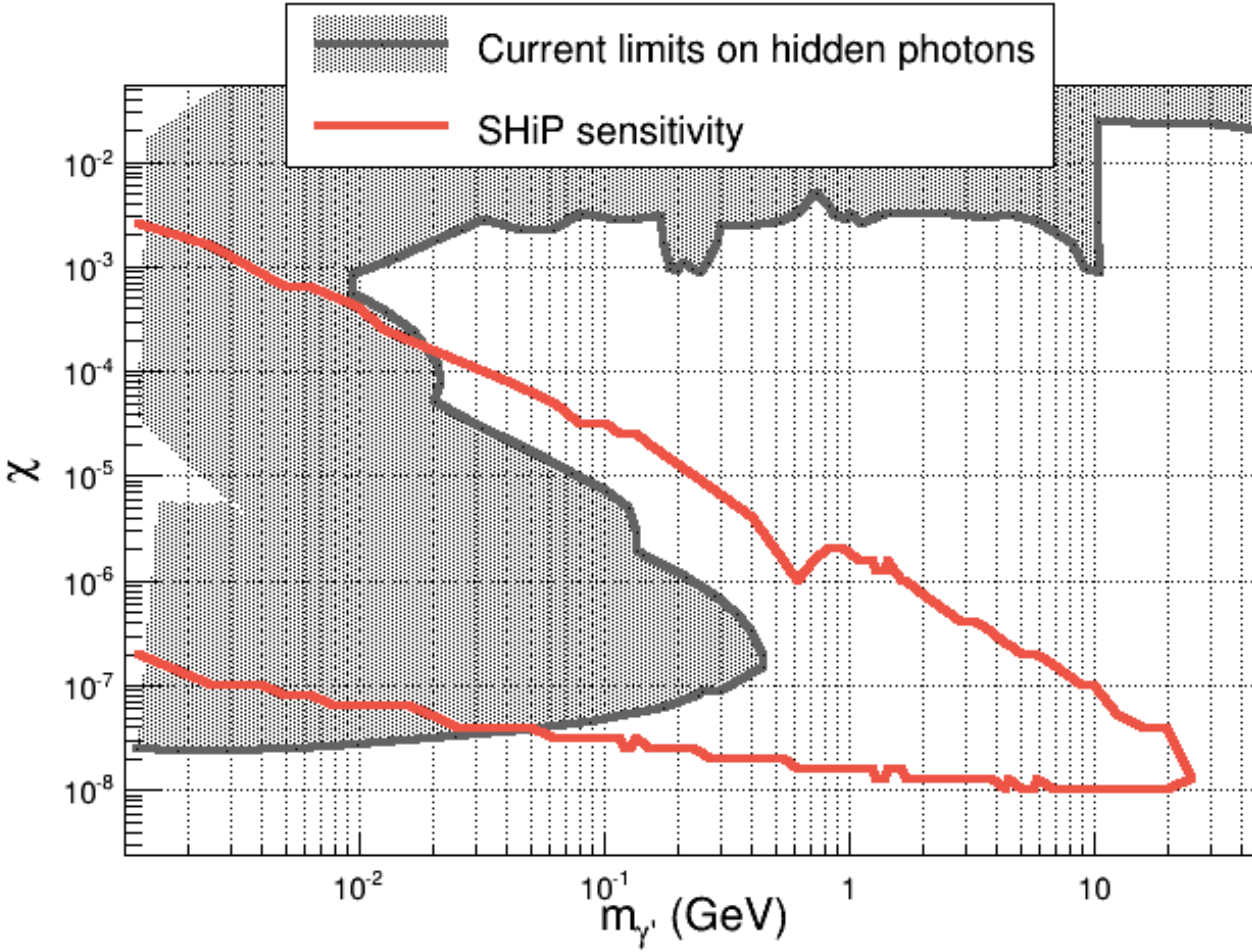
- ✓ ***Form SHIP collaboration*** → ***June-August 2014***
- ✓ *Technical proposal* → *2015*
- ✓ *Technical Design Report* → *2018*
- ✓ *Construction and installation* → *2018 – 2022*
- ✓ *Data taking and analysis of 2×10^{20} pot* → *2023 - 2027*

Conclusion

- *The proposed experiment will search for NP in the largely unexplored domain of new, very weakly interacting particles with masses below the Fermi scale*
- *Detector is based on existing technologies*
  Ongoing discussions of the beam lines with experts
- ***The impact of HNL discovery on particle physics is difficult to overestimate !***
- ***The proposed experiment perfectly complements the searches for NP at the LHC and in neutrino physics***

A collaboration is currently being setup
Let us know if you are interested to join !

BACK UP SLIDES

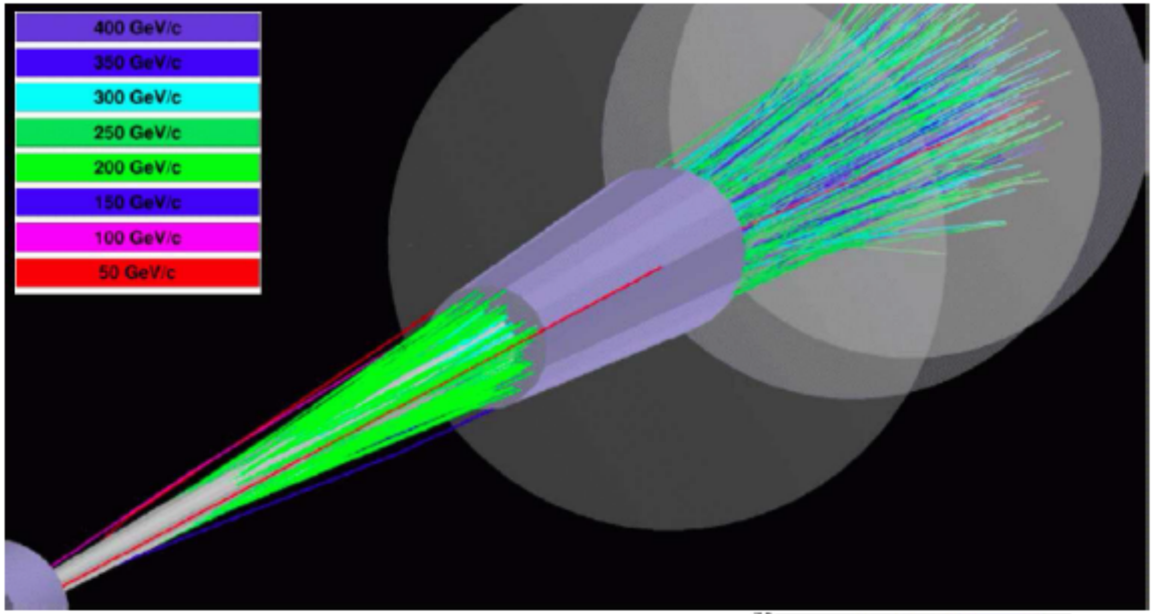


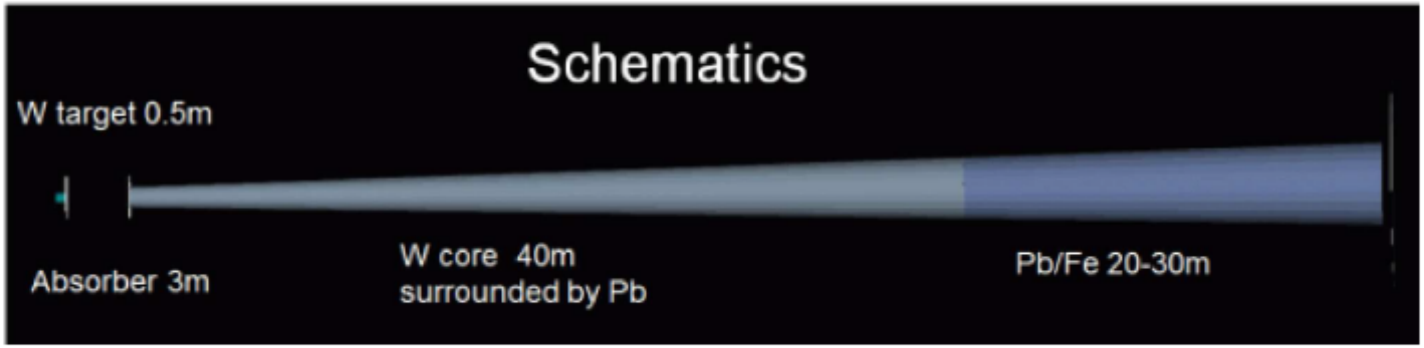
Current limits on hidden photons
SHiP sensitivity
χ
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-2}
10^{-1}
1
10
$m_{\gamma'}$ (GeV)

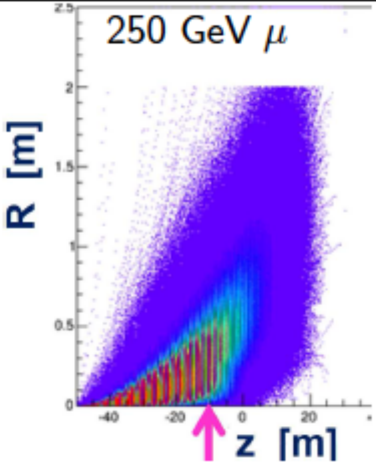
Muon shield optimization

Passive μ-filter

- Geant studies to estimate flux.
- MS and €: limit W-length to 40 m.
- High-p at small θ: W$\varnothing$12-50 cm
- +20-30 m of Pb/Fe :
- reduction of 10^7 possible
- Robust/easy to operate





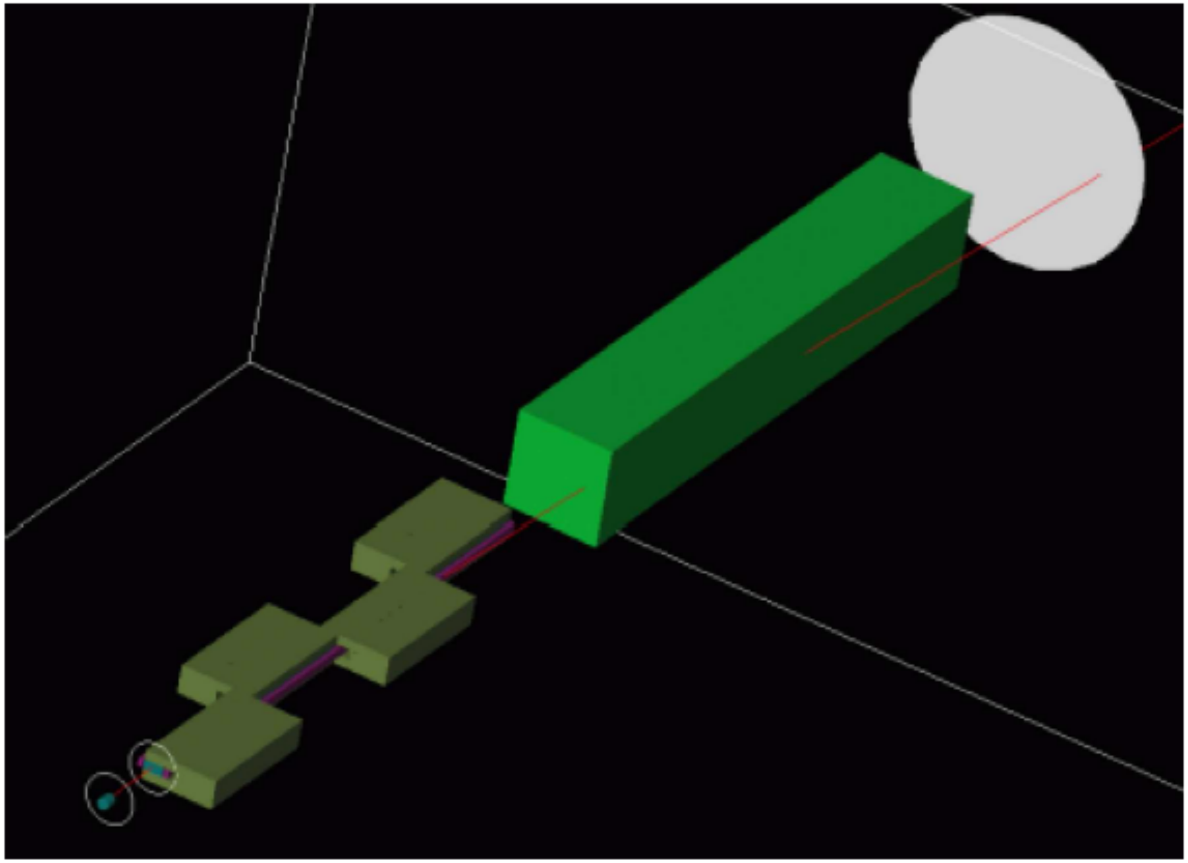


Muon shield optimization

Alternative: Active (+passive) μ-filter

- Use 6 m long C-shaped magnets.
- Produces 40 Tm total field with 4 magnets: high-p swept out.
- Problem: return-B of low-p μ:
  - alternate return-B left/right
  - Add passive Fe-shield

- reduction of 10^7 possible



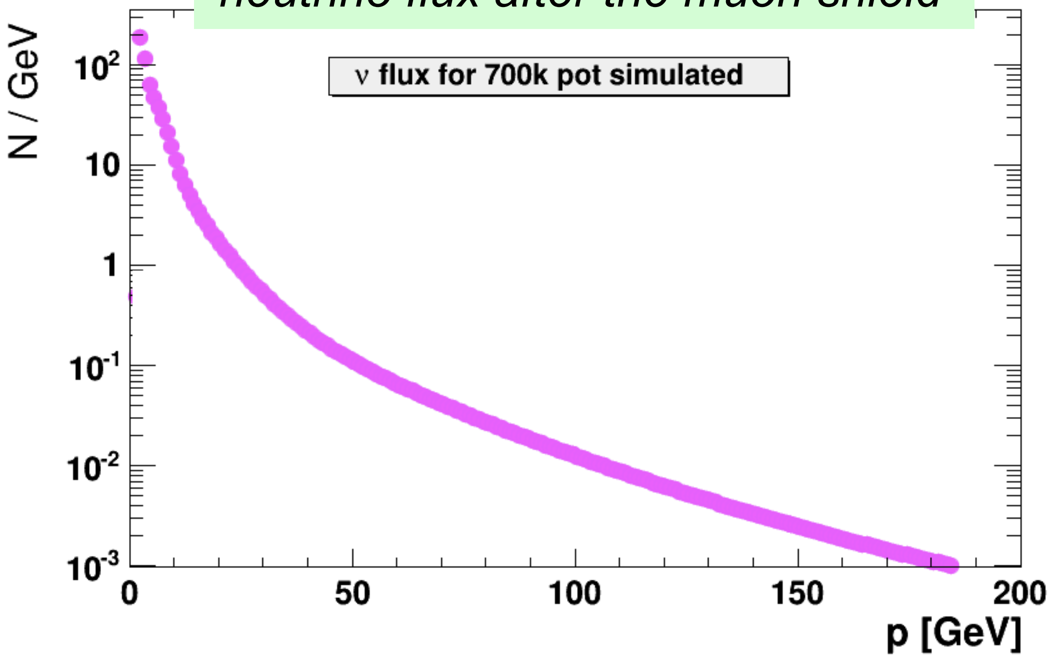
Work in progress, need to optimize together with SPS-spill length, and induced background.

Experimental requirements (cont.)

- *Minimize background from interactions of active neutrinos in the detector decay volume*

→ *Requires evacuation of the detector volume*

Momentum spectrum of the neutrino flux after the muon shield



2×10^4 neutrino interactions per 2×10^{20} pot in the decay volume at atmospheric pressure → becomes negligible at 0.01 mbar

Residual backgrounds

Use a combination of GEANT and GENIE to simulate the Charged Current and Neutral Current neutrino interaction in the final part of the muon shield (cross-checked with CHARM measurement)

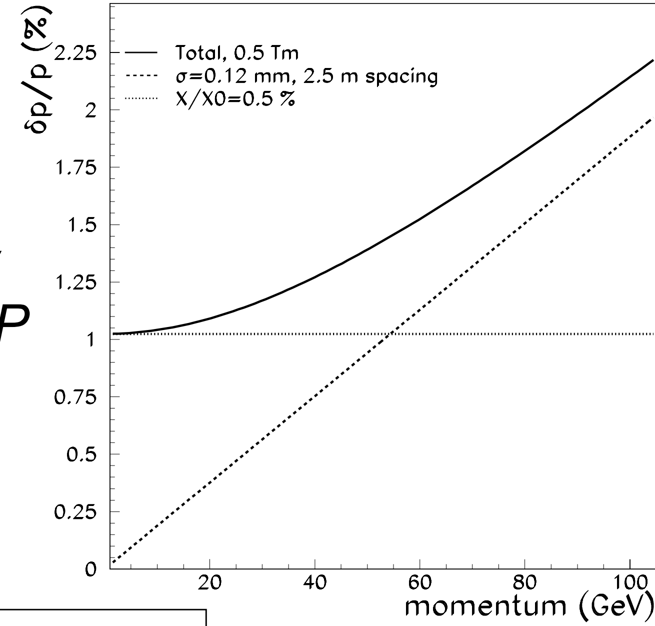
→ *yields CC(NC) rate of ~$6(2)\times10^5$ per int. length per 2×10^{20} pot*

Instrumentation of the end-part of the muon shield would allow the rate of CC + NC to be measured and neutrino interactions to be tagged

- *~10% of neutrino interactions in the muon shield just upstream of the decay volume produce Λ or K^0 (as follows from GEANT+GENIE and NOMAD measurement)*
- *Majority of decays occur in the first 5 m of the decay volume*
- *Requiring μ–id. for one of the two decay products*
  → ***150 two-prong vertices in 2×10^{20} pot***

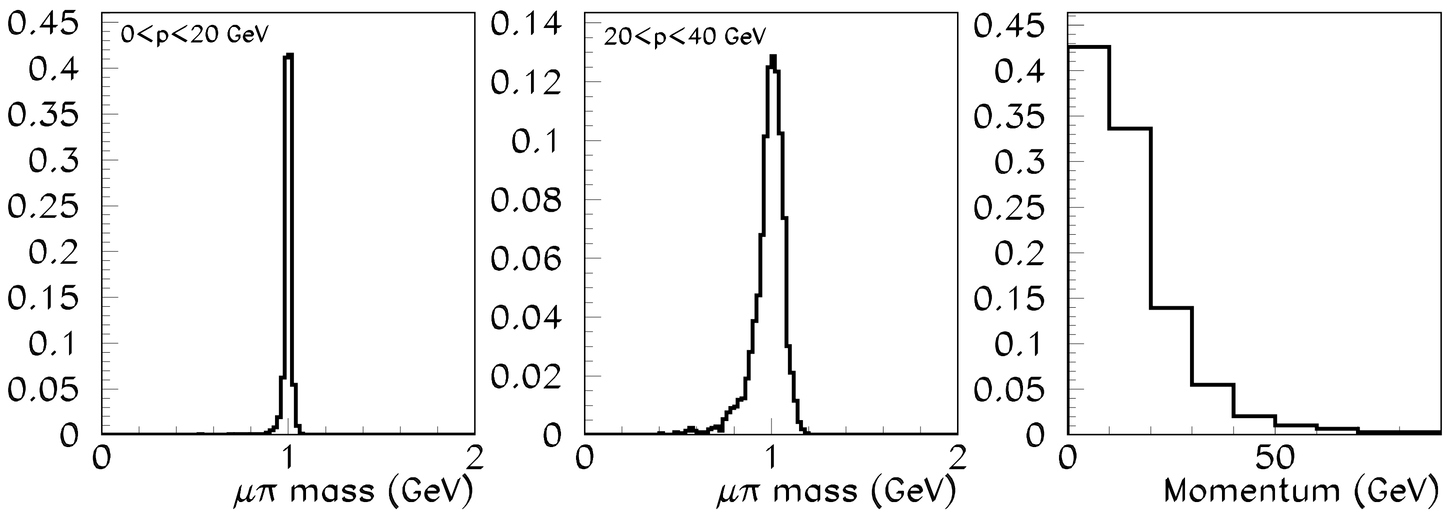
Detector concept (cont.)

Magnetic field and momentum resolution



- *Multiple scattering and spatial resolution of straw tubes give similar contribution to the overall $\delta P / P$*

- *For $M(N_{2,3})$ = 1 GeV 75% of $\mu\,\pi$ decay products have both tracks with P < 20 GeV*



- *For 0.5 Tm field integral σ_{mass} ~ 40 MeV for P < 20 GeV*

→ *Ample discrimination between high mass tail from small number of residual $K_L \to \pi^+\mu^-\nu$ and 1 GeV HNL*

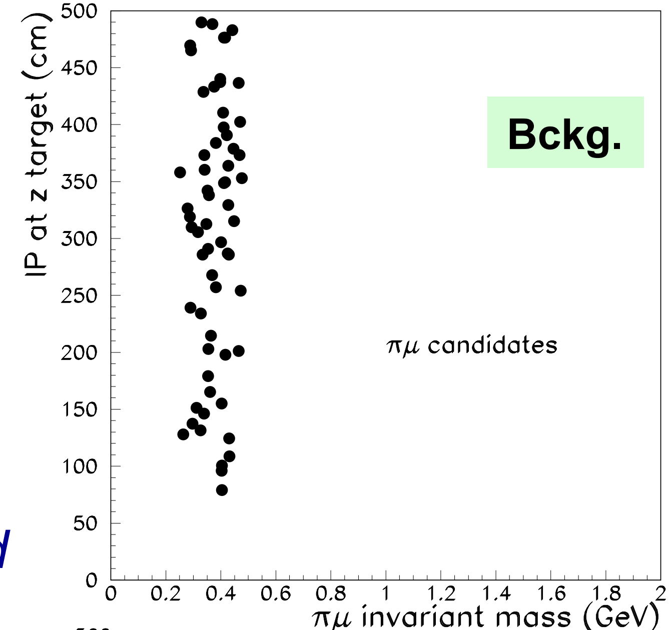
Detector concept (cont.)

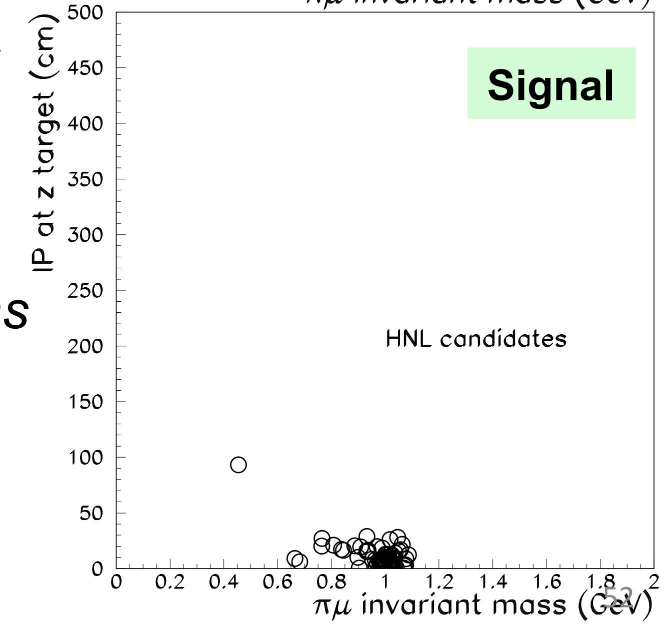
Impact Parameter resolution

K_L produced in the final part of the muon shield have very different pointing to the target compared to the signal events

Use Impact Parameter (IP) to further suppress K_L background

- ***IP < 1 m is 100% eff. for signal and leaves only a handful of background events***
- *The IP cut will also be used to reject backgrounds induced in neutrino interactions in the material surrounding the detector*





Low energy SUSY sector

Light s-goldstinos (super-partners of SUSY goldstinos), e.g. $D \rightarrow \pi X$ with $X \rightarrow \mu\mu$

D.S. Gorbunov (2001)

$$N_{\pi^+\pi^-} \simeq 2 \times \left(\frac{1000\,\mathrm{TeV}}{\sqrt{F}}\right)^8 \left(\frac{M_{\lambda_g}}{3\,\mathrm{TeV}}\right)^4 \left(\frac{m_X}{1\,\mathrm{GeV}}\right)^2$$

R-parity violating neutralinos in SUSY goldstinos, e.g. $D \rightarrow \mu\, \tilde{\chi}_0$ with $\tilde{\chi}_0 \rightarrow \mu^+\mu^-\nu$

A. Dedes, H.K. Dreiner, P. Richardson (2001)

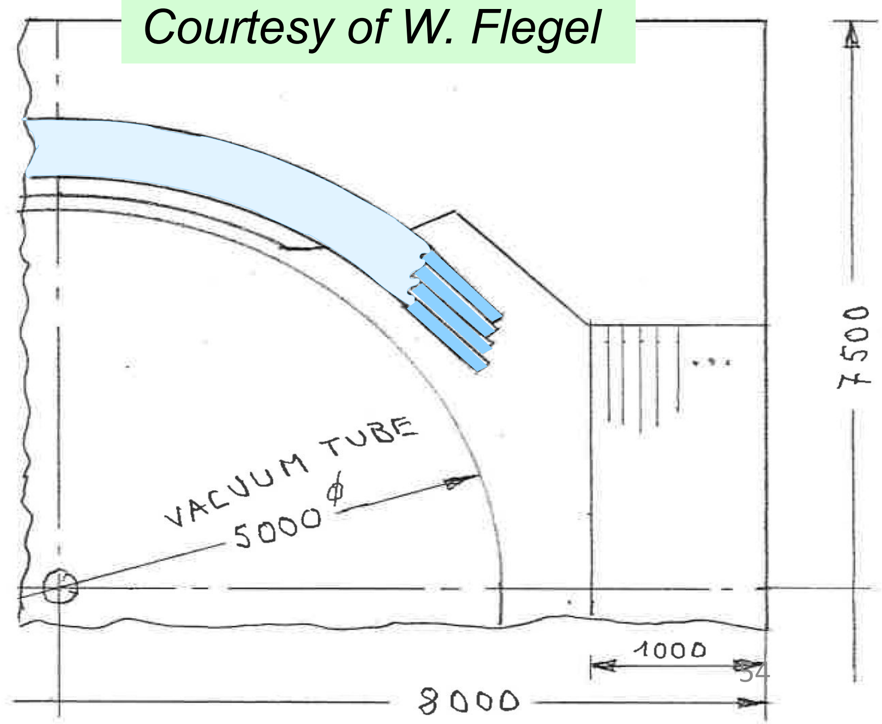
$$N \simeq 20 \times \left(\frac{m_{\chi_0}}{1\,\mathrm{GeV}}\right)^6 \left(\frac{\lambda}{10^{-8}}\right)^2 \left(\frac{\mathrm{Br}\,(D \rightarrow \chi_0 + \ldots)}{10^{-10}}\right)$$

Detector apparatus
based on existing technologies

- *Experiment requires a dipole magnet similar to LHCb design, but with ~40% less iron and three times less dissipated power*

- *Free aperture of ~ 16 m^2 and field integral of ~ 0.5 Tm*

- Yoke outer dimension: 8.0×7.5×2.5 m^3
- Two Al-99.7 coils
- Peak field ~ 0.2 T
- Field integral ~ 0.5 Tm over 5 m length

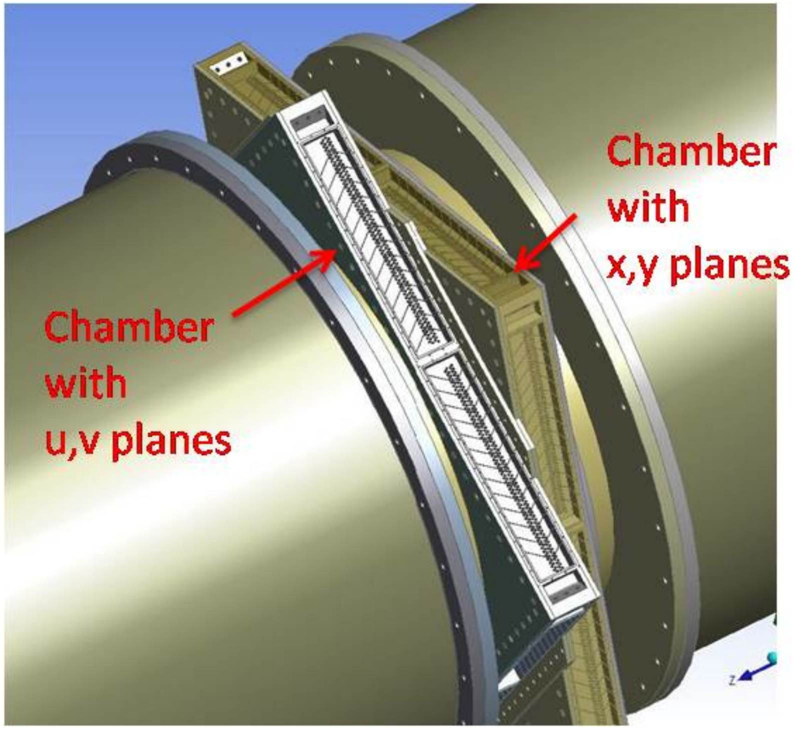


Courtesy of W. Flegel

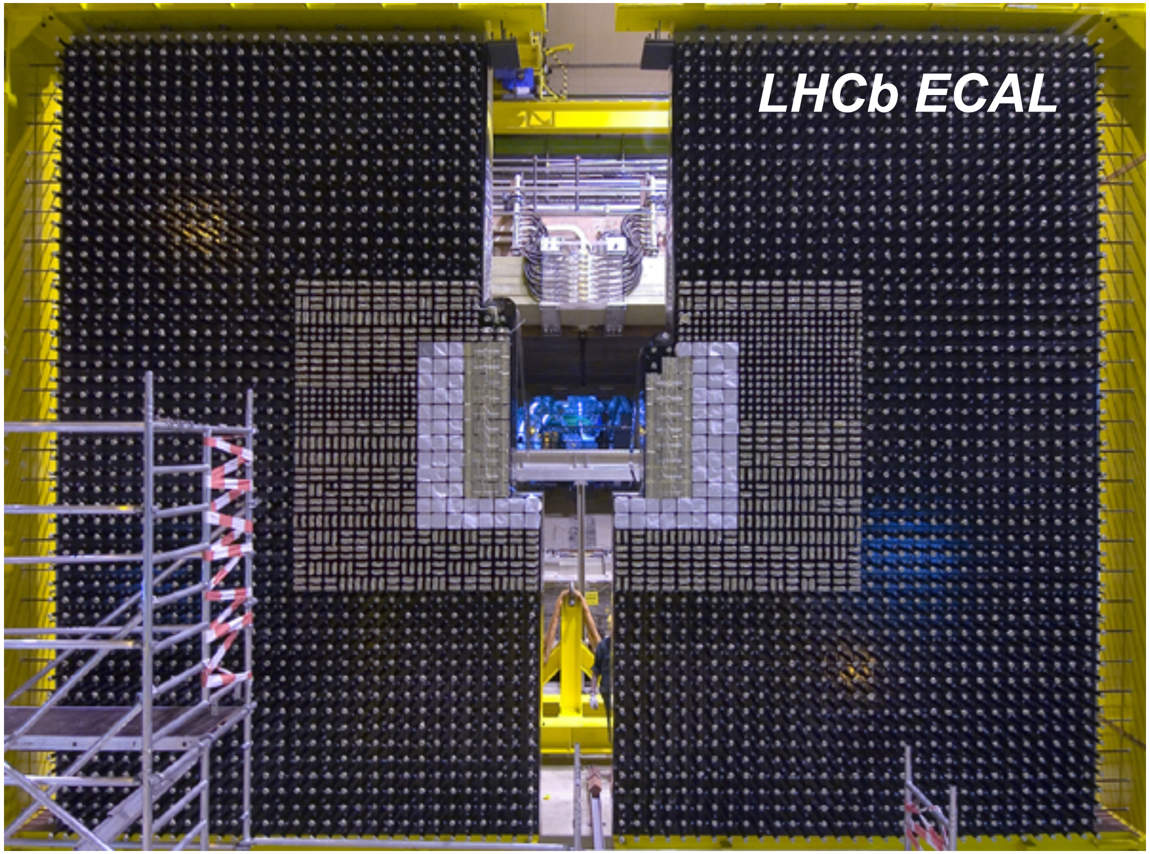
Detector apparatus (cont.)
based on existing technologies

NA62 vacuum tank and straw tracker

- *< 10^{-5} mbar pressure in NA62 tank*
- *Straw tubes with 120 μm spatial resolution and 0.5% X_0/X material budget Gas tightness of NA62 straw tubes demonstrated in long term tests*



Detector apparatus (cont.)
based on existing technologies



LHCb electromagnetic calorimeter

- *Shashlik technology provides economical solution with good energy and time resolution*

Expected event yield

- *Integral mixing angle U^2 is given by $U^2 = U_e^2 + U_\mu^2 + U_\tau^2$*
- *A conservative estimate of the sensitivity is obtained by considering only the decay $N_{2,3} \rightarrow \mu^- \pi^+$ with production mechanism $D \rightarrow \mu^+ NX$, which probes U_μ^2*
- *$U^2 \longleftrightarrow U_\mu^2$ depends on flavour mixing*
- *Expected number of signal events:*

$$N_{signal} = n_{pot} \times 2\chi_{cc} \times BR(U_\mu^2) \times \varepsilon_{det}(U_\mu^2)$$

$n_{pot} = 2 \times 10^{20}$

$\chi_{cc} = 0.45 \times 10^{-3}$

$BR(U_\mu^2) = BR(D \rightarrow N_{2,3}X) \times BR(N_{2,3} \rightarrow \mu\pi)$
$BR(N_{2,3} \rightarrow \mu^- \pi^+)$ is assumed to be 20%

$\varepsilon_{det}(U_\mu^2)$ is the probability of the $N_{2,3}$ to decay in the fiducial volume and μ, π are reconstructed in the spectrometer

Expected event yield (cont.)

- *ECAL will allow the reconstruction of decay modes with π^0 such as $N \rightarrow \mu^-\rho^+$ with $\rho^+ \rightarrow \pi^+\pi^0$, doubling the signal yield*
- *Study of decay channels with electrons such as $N \rightarrow e\pi$ would further increase the signal yield and constrain U_e^2*

In summary, for $M_N < 2$ GeV the proposed experiment has discovery potential for the cosmologically favoured region with $10^{-7} < U_\mu^2 <$ a few × 10^{-9}