SHiP

SEARCH FOR HIDDEN PARTICLES

A new experiment proposal

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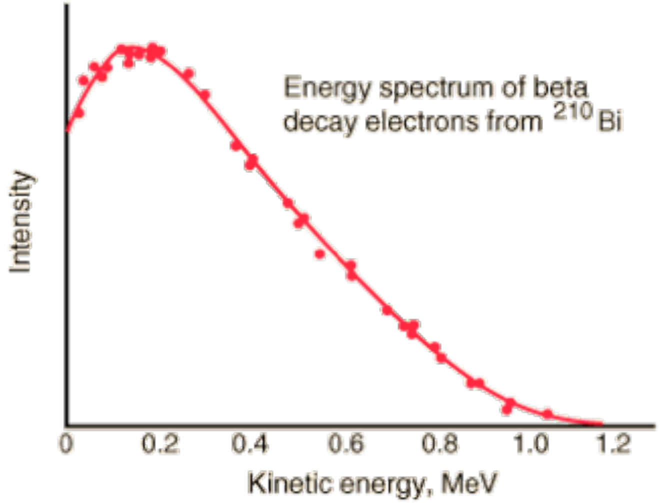
Outline of the talk

- The physics case for a beam dump facility
- Physics beyond the Standard Model and Neutrino Physics
- The SHiP experiment
  - The detector for hidden particles
  - The tau neutrino detector

History lesson - 1930s:

- Back then, the "Standard Model" was photon, electron, nucleons
- Beta decay: $n \rightarrow p + e^-$

Continuous spectrum!



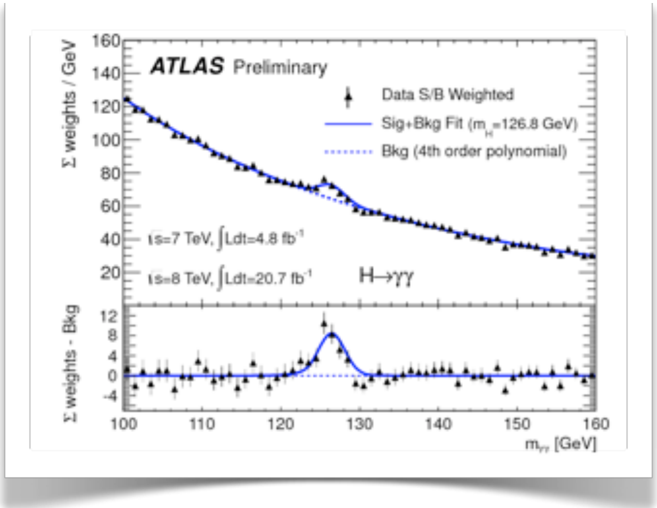
- Pauli proposes a radical solution - the neutrino!

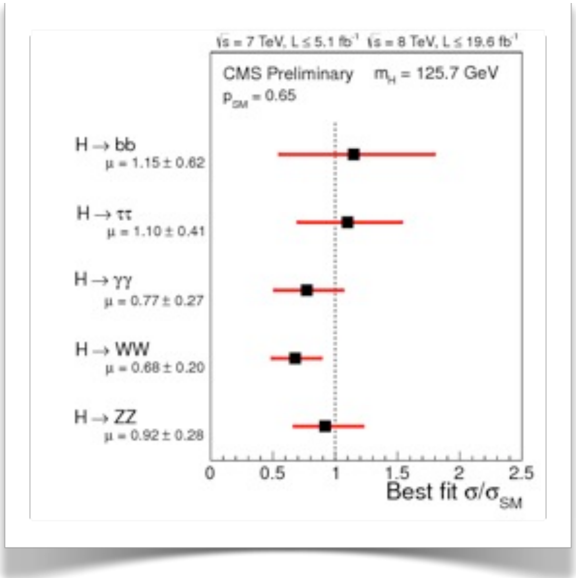
$$n \rightarrow p + e^- + \bar{\nu}$$

- Great example of a hidden sector!
  - neutrino is electrically neutral (QED gauge singlet)
  - very weakly interacting and light
  - interacts with "Standard Model" through "portal" - $\boxed{(\bar{p}\gamma^\mu n)(\bar{e}\gamma_\mu}\nu)$

Today, 2014 - Where are we?

- Higgs!
- Triumph of the Standard Model!





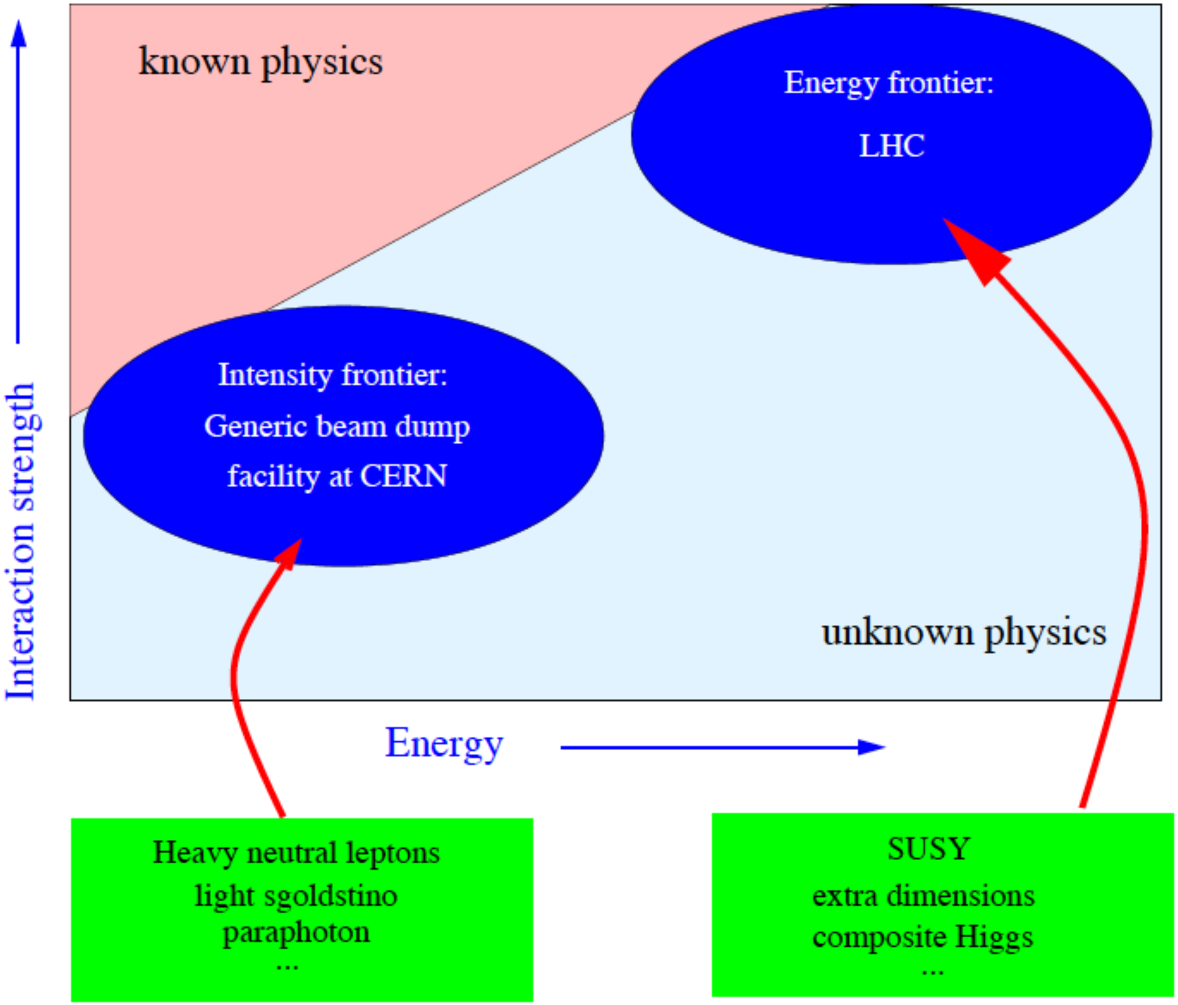
- Still, many reasons to believe there is new physics

Theoretical: naturalness (Higgs, CC), flavor, Strong CP, Unification, Gravity ...

Empirical: Dark Matter, Neutrino Oscillations, Baryon Asymmetry

- Unfortunately, there are no guarantees of discovery
- All searches for new physics are now fishing expeditions!

Search for new physics with accelerators: Physics case for a beam dump facility



Heavy neutral leptons
light sgoldstino
paraphoton
…

SUSY
extra dimensions
composite Higgs
…

hidden sector:

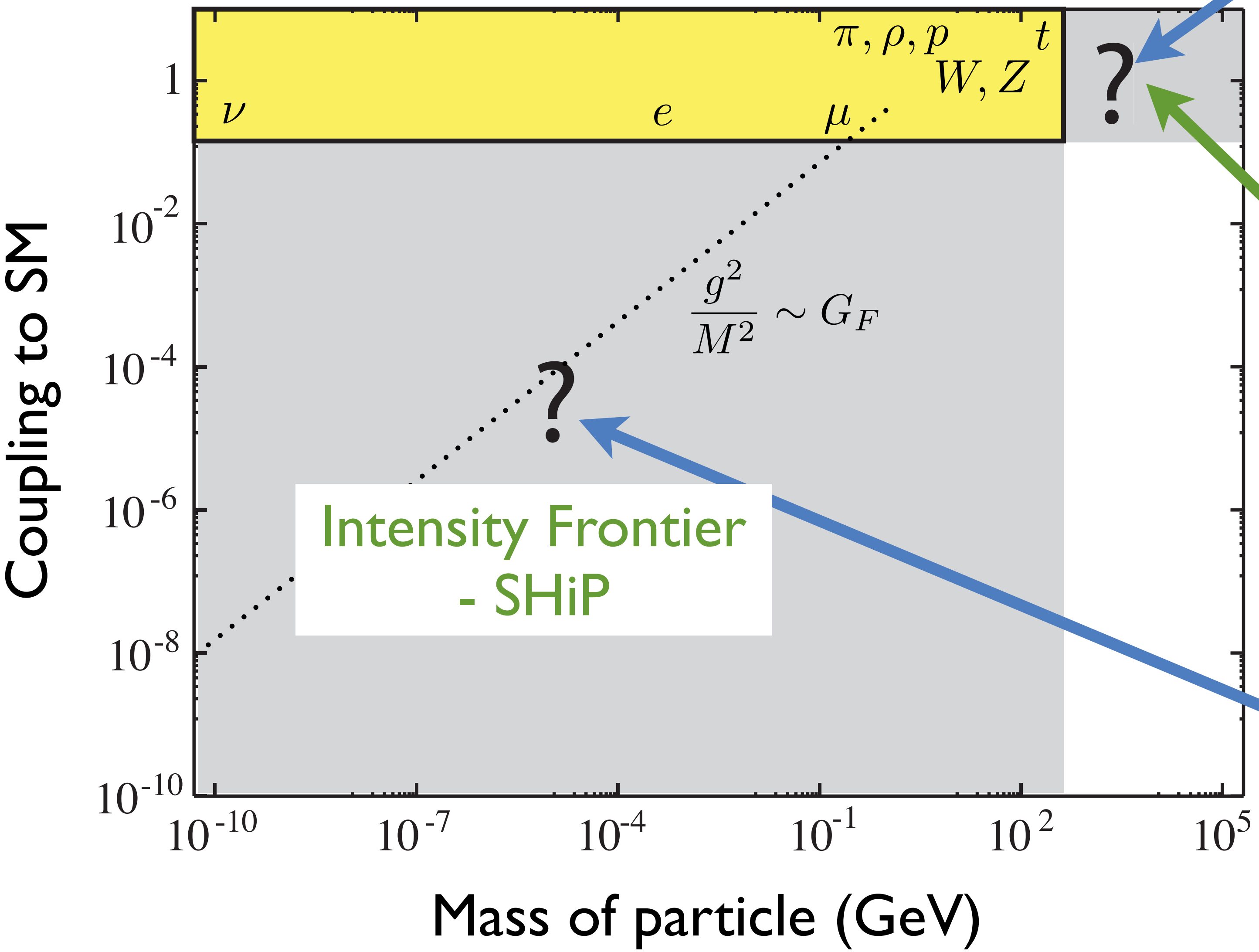
HNL: baryon asymmetry of the Universe, dark matter, neutrino masses

sgoldstino, light neutralino: SUSY

paraphoton: mirror matter, dark matter

Physics case for a beam dump facility

Where is the new physics?



Intensity Frontier
- SHiP

EWSB, Hierarchy
WIMP DM ...

Energy
Frontier
- LHC

RH neutrinos
Dark Matter
Hidden sector
...

Light Hidden particles → singlets with respect to the SM gauge group → couple to different singlet composite operators (**Portals**) of the SM

Renormalizable

$$L H N$$ Neutrino portal

$$(\mu S + \lambda S^2) H^\dagger H$$ Higgs Portal

$$-\frac{\kappa}{2} B_{\mu\nu} V^{\mu\nu}$$ Vector Portal

Higher dimension operators

$$\frac{\partial_\mu a}{f_a} \bar{\psi} \gamma^\mu \gamma^5 \psi$$ Axion Portal

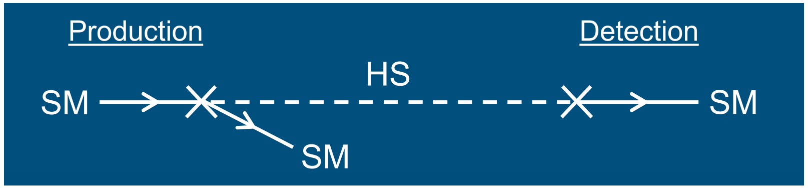
$$\frac{1}{\Lambda^2} \bar{\chi} \chi \bar{q} q + \ldots,$$

Dark Matter

Light mediator

$$g_\chi \phi \bar{\chi} \chi + g_q \phi \bar{q} q + \ldots$$

Direct detection:



Production

Detection

HS

SM

SM

SM

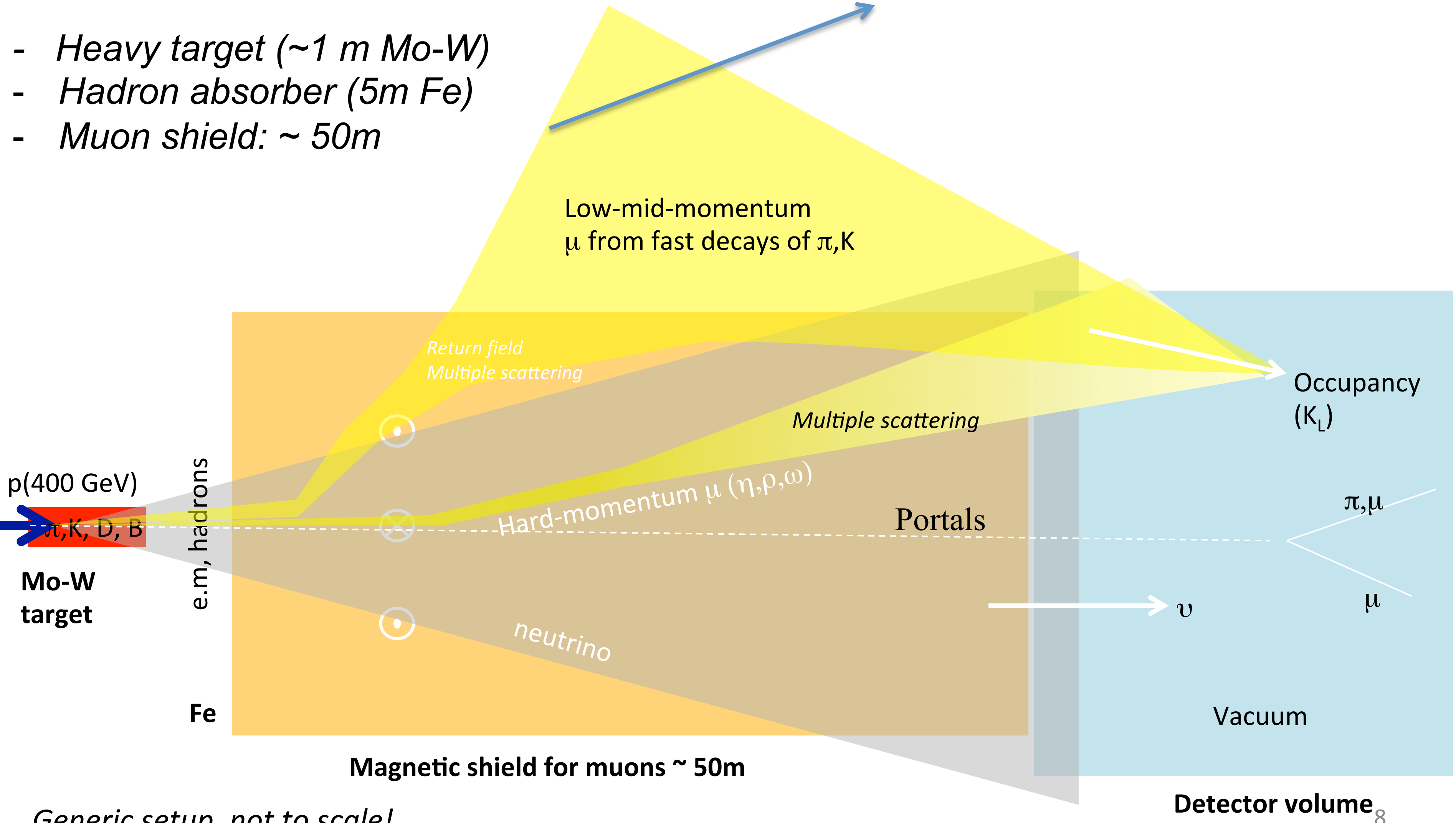
Beam dump facility

(different from a conventional neutrino facility)

One spill: 4×10^{13} p.o.t.
spill duration 1s ~ 4×10^{9} muons

Initial reduction of beam induced backgrounds

- *Heavy target (~1 m Mo-W)*
- *Hadron absorber (5m Fe)*
- *Muon shield: ~ 50m*

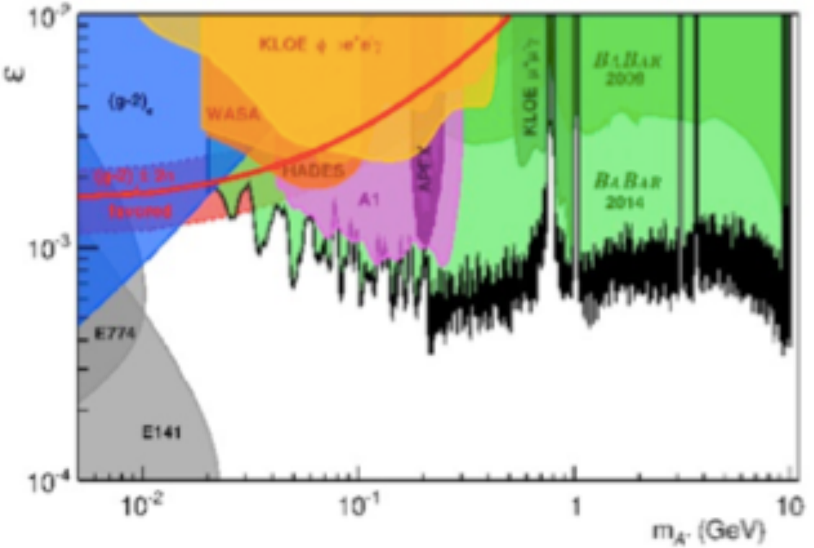


Generic setup, not to scale!

Search for hidden photons (vector portal)

- Assuming no lighter hidden particles, γ' decay into SM particles through a virtual photon:

$$\gamma' \to e^+e^-, \quad \mu^+\mu^-, \quad q\bar{q}, \ldots$$



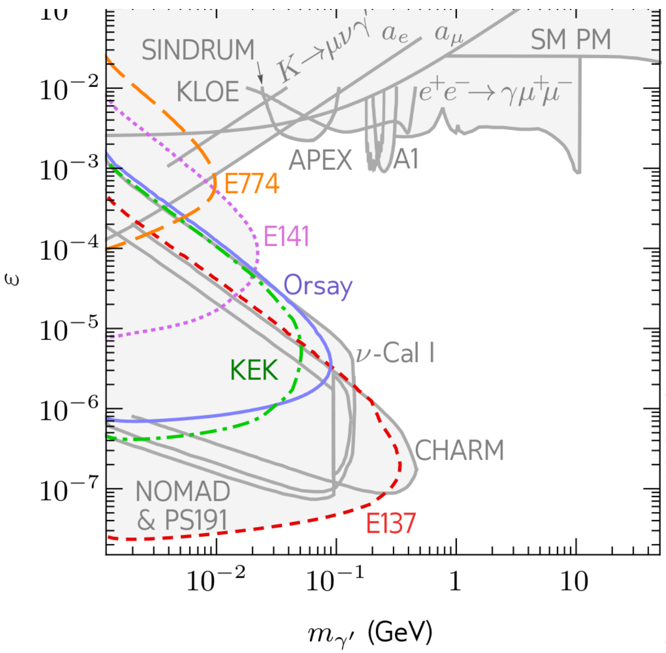
- decay length $c\tau \sim \varepsilon^{-2} m_{\gamma'}^{-1}$
- cosmological constraints (nucleo-synthesis): $\tau < 0.1$ s $\Rightarrow \varepsilon^2 m_{\gamma'} > 10^{-21}$ GeV

γ' production

- proton bremsstrahlung:
    - initial-state radiation from the incoming proton, followed by a hard proton-nucleus interaction

- secondary particles decay:

Mass interval (GeV)	Process	$n_{\gamma'}/p.o.t$
$m_{\gamma'} < 0.135$	$\pi^0 \to \gamma\gamma'$	$\varepsilon^2 \times 5.41$
$0.135 < m_{\gamma'} < 0.548$	$\eta \to \gamma\gamma'$	$\varepsilon^2 \times 0.23$
$0.548 < m_{\gamma'} < 0.648$	$\omega \to \pi^0\gamma'$	$\varepsilon^2 \times 0.07$
$0.648 < m_{\gamma'} < 0.958$	$\eta' \to \gamma\gamma'$	$\varepsilon^2 \times 10^{-3}$

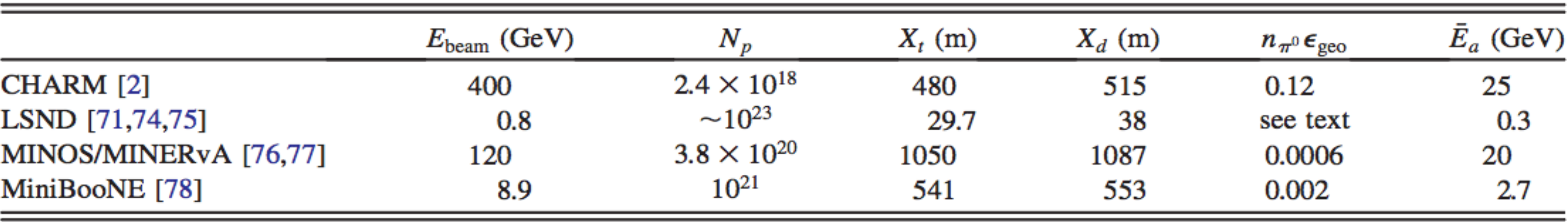


Axion portal, e.g. PNGB

- PRD 82, 113008 (2010), Discovering new light states at neutrino experiments
- Approximate symmetry, broken at a high mass scale F, gives rise to light pseudoscalars, pseudo-Nambu-Goldstone bosons (or “axions”) with couplings to SM X-particle of the order of m_X/F
- Production from mixing with π^0
- Lifetime
- for $m_a < 400$MeV, total width ~ $\Gamma ee + \Gamma\mu\mu$

$$N_a = \left(\frac{F_\pi}{F}\right)^2 n_{\pi^0} N_p \epsilon_{\text{geo}}.$$

$$\Gamma_\ell = \frac{m_a}{8\pi}\left(\frac{m_\ell}{F}\right)^2\sqrt{1-(4m_\ell^2/m_a^2)},$$



	E_{beam} (GeV)	N_p	X_t (m)	X_d (m)	$n_{\pi^0}\epsilon_{\text{geo}}$	$\bar{E}_a$ (GeV)
CHARM [2]	400	2.4×10^{18}	480	515	0.12	25
LSND [71,74,75]	0.8	$\sim 10^{23}$	29.7	38	see text	0.3
MINOS/MINERvA [76,77]	120	3.8×10^{20}	1050	1087	0.0006	20
MiniBooNE [78]	8.9	10^{21}	541	553	0.002	2.7

Higgs portal

- Winkler et al., Constraints on light mediators: confronting dark matter searches with B physics, PLB 727 (2013) 506.
- Clarke et al., Phenomenology of a very light scalar (100MeV ÷10GeV) mixing with the SM Higgs, JHEP 1402 (2014) 123
- Scale invariance broken at the electroweak scale, by the VEV, → GeV-scale scalar state predicted
- Mass eigenstates are orthogonal rotation of weak eigenstates
- Foreseen in many BSM models including SUSY, Coleman-Weinberg
- Possible interpretation as inflaton, Bezrukov et al, JHEP05(2010) 010

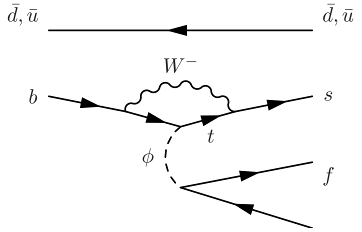
Mass eigenstates

$$\begin{pmatrix} H \\ h \end{pmatrix} = \begin{pmatrix} \cos\rho & -\sin\rho \\ \sin\rho & \cos\rho \end{pmatrix} \begin{pmatrix} \phi_0' \\ S' \end{pmatrix}$$

Weak eigenstates

ϕ_0' is a pure doublet component and ρ a mixing angle

Production and decay modes



Rare B meson decays mediated by a light scalar ϕ

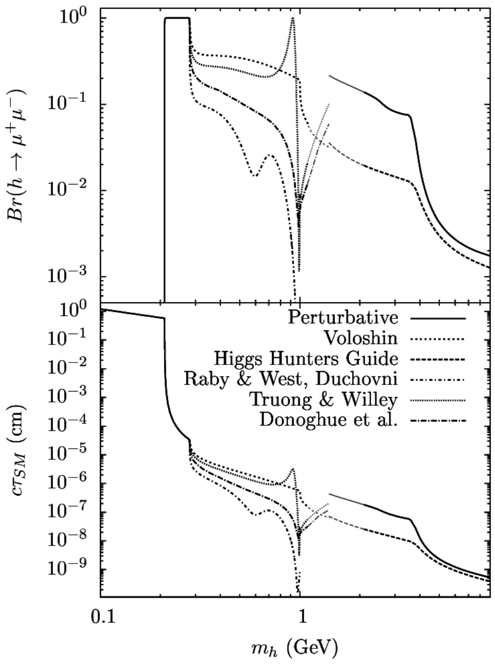
$$\Gamma(D \to \pi\phi) \sim (m_b^2 |V_{cb}^* V_{ub}|)^2 \propto m_b^4 \lambda^5$$

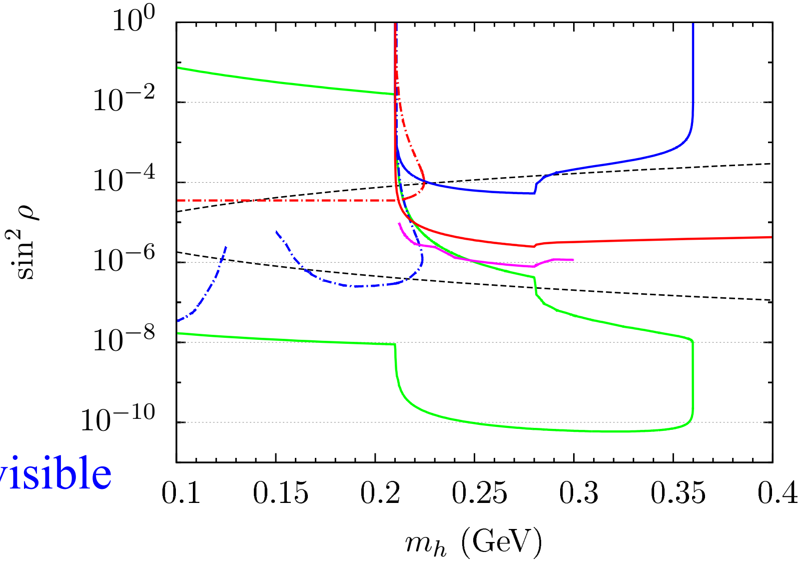
$$\Gamma(B \to K\phi) \sim (m_t^2 |V_{ts}^* V_{tb}|)^2 \propto m_t^4 \lambda^2$$

B decays favoured compared to D

$$\Gamma(\phi \to l^+ l^-) = \sin^2\rho \frac{m_l^2 m_\phi}{8\pi v^2} \beta_l^3$$

where $\beta_l = \sqrt{1 - 4m_l^2/h_\phi^2}$ and $v \simeq 246$ GeV





Blue solid: K → π $\mu^+ \mu^-$

Blue dashed: K → π invisible

solid: B → K $\mu^+ \mu^-$

dashed: B → K invisible

B → K^{*0} $\mu^+ \mu^-$

CHARM beam dump

Motivation for Heavy Neutral Leptons

See-saw generation of neutrino masses

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

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

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

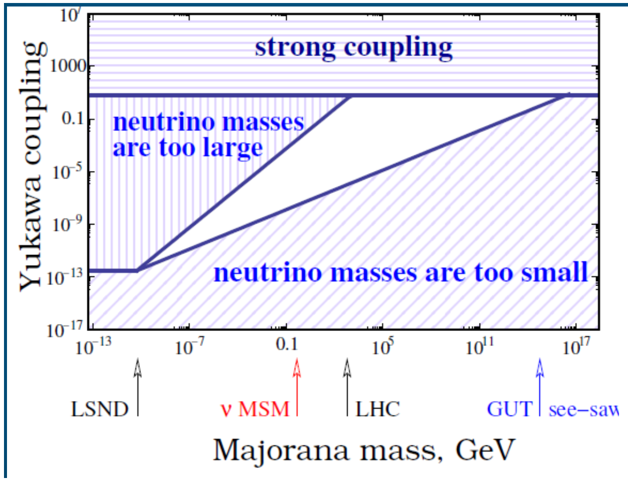
Majorana term which carries no gauge charge

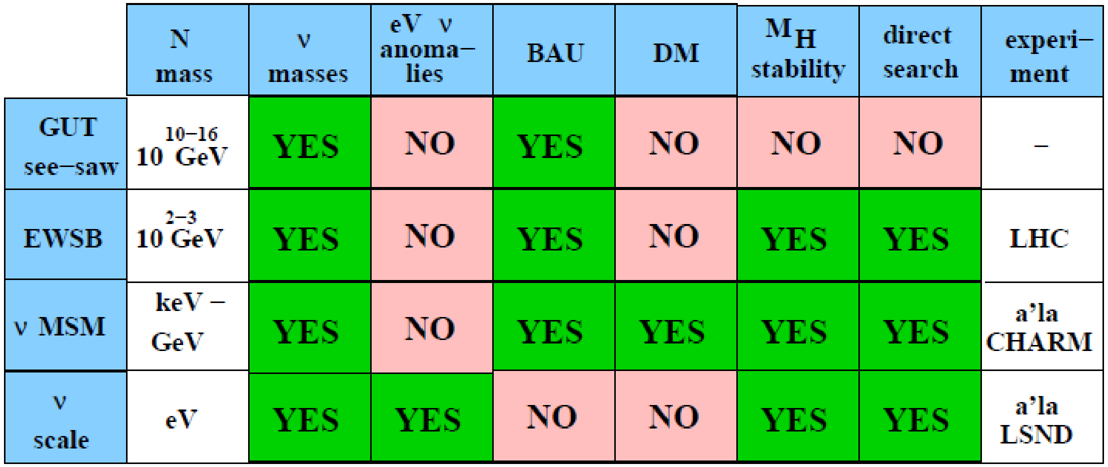
$$v \sim 246 \text{ GeV}$$

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

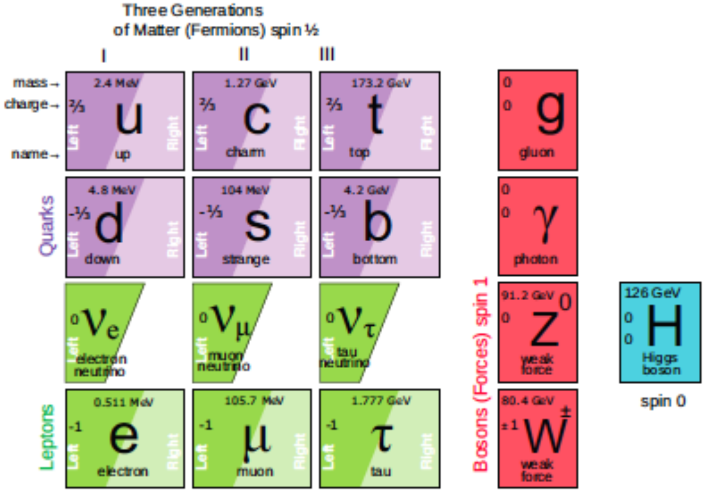
Four “popular” N mass ranges

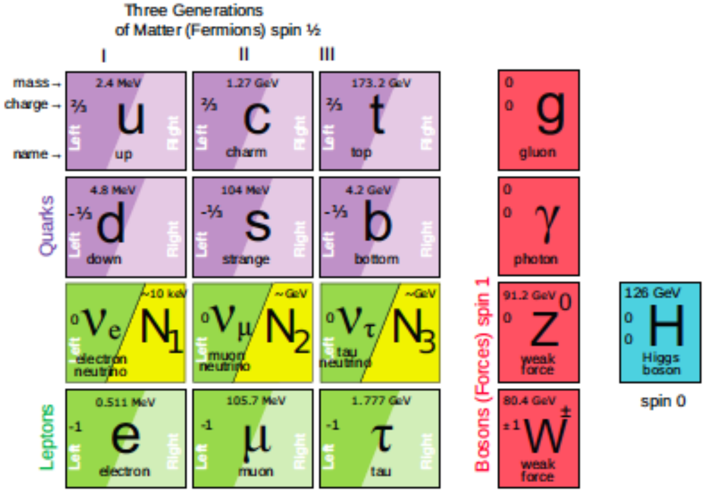




	N mass	ν masses	eV ν anoma–lies	BAU	DM	M_H stability	direct search	experi–ment
GUT see–saw	10^{10-16} GeV	YES	NO	YES	NO	NO	NO	–
EWSB	10^{2-3} GeV	YES	NO	YES	NO	YES	YES	LHC
ν MSM	keV – GeV	YES	NO	YES	YES	YES	YES	a’la CHARM
ν scale	eV	YES	YES	NO	NO	YES	YES	a’la LSND

The νMSM model: leptogenesis and dark matter





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.

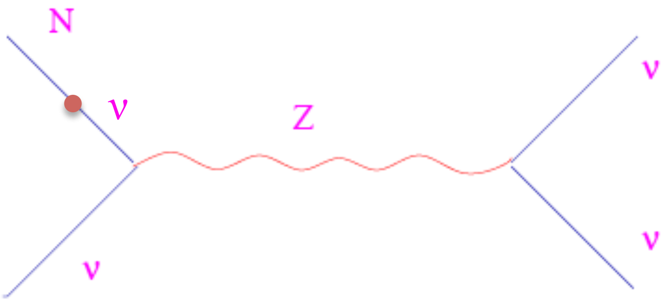
***νMSM**: T.Asaka, M.Shaposhnikov PL **B620** (2005) 17*
M.Shaposhnikov Nucl. Phys. B763 (2007) 49

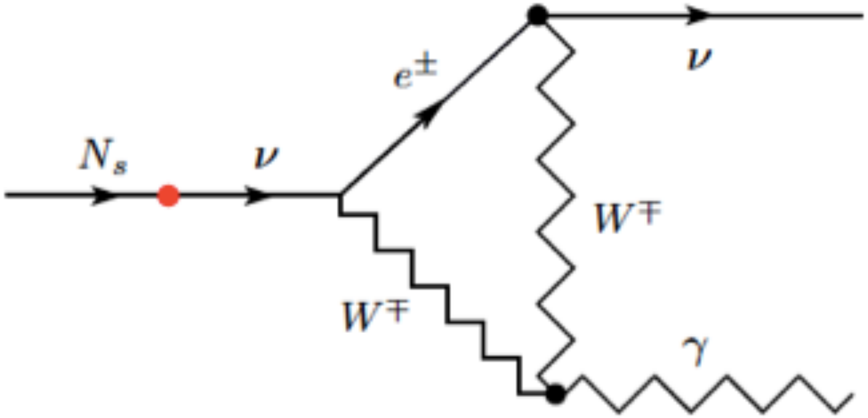
global lepton-number symmetry broken at the level of O(10^{-4}) leads to the required pattern of sterile neutrino masses consistent with neutrino oscillations data

Dark Matter candidate HNL N_1

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

Yukawa couplings are small → N can be very stable.





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

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

Photon energy:

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

Radiative decay width:

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

Interaction strength

New line in photon galaxy spectrum at 3.5 keV?
To be checked with higher accuracy

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)***

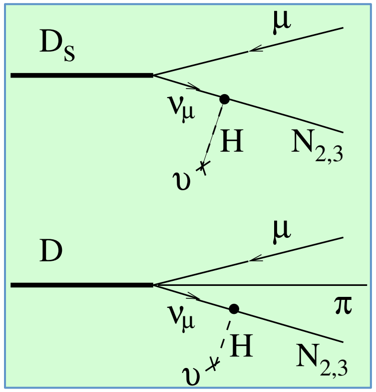
Very weak $N_{2,3}$-to-ν mixing (~ U^2) → $N_{2,3}$ are much longer-lived than SM particles

- Produced in semi-leptonic decays, $\mathrm{K} \to \mu\nu,\ \mathrm{D} \to \mu\pi\nu,\ \mathrm{B} \to \mathrm{D}\mu\nu$

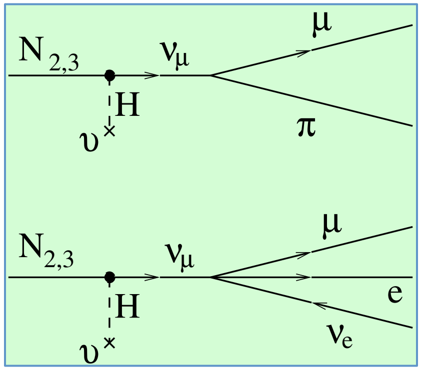
- $\propto \sigma_D \times U^2$
- $U_2^2 = U^2_{2,\nu_e} + U^2_{2,\nu_\mu} + U^2_{2,\nu_\tau}$

Example:

$N_{2,3}$ production in charm



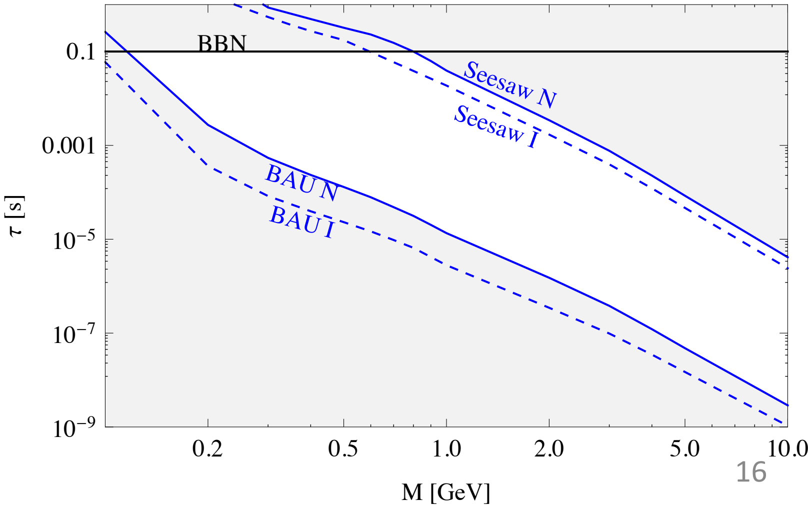
and subsequent decays



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

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

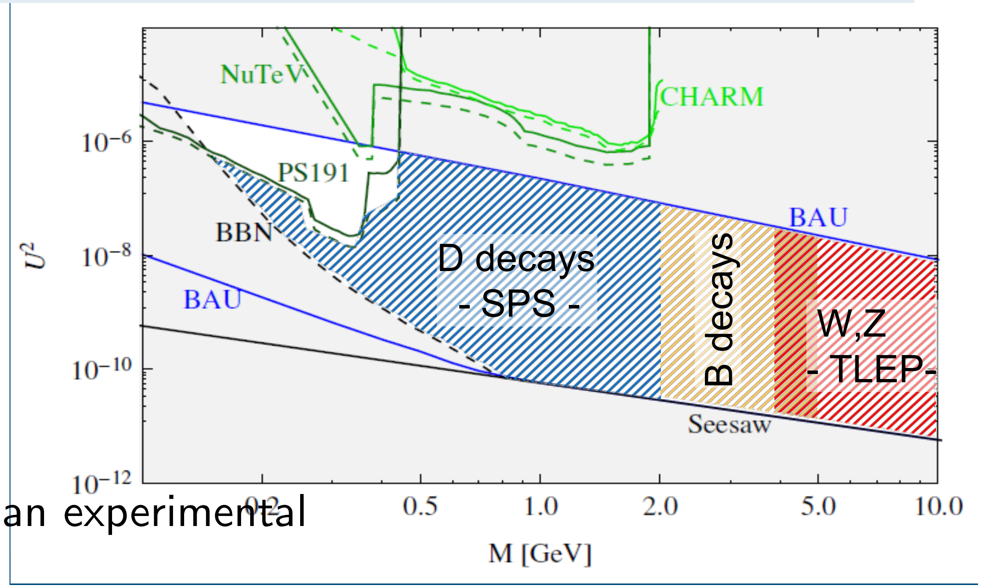
$Br(N \to \mu/e\ \pi)$ ~ 0.1 – 50%
$Br(N \to \mu^-/e^-\ \rho^+)$ ~ 0.5 – 20%
$Br(N \to \nu\mu e)$ ~ 1 – 10%



Experimental and cosmological constraints

Already searches in K/D-decay performed:

- PS191('88)@PS 19.2 GeV, 1.4×10^{19} pot, 128 m from target.
- CHARM('86)@SPS 400 GeV, 2.4×10^{18} pot, 480 m from target.
- NuTev('99)@Fermilab 800 GeV, 2.5×10^{18} pot, 1.4 km from target.
- BBN, BAU and Seesaw constrain more than experimental searches for $M_{\mathrm{N}} > 400$ MeV.



- ***Recent progress in cosmology***

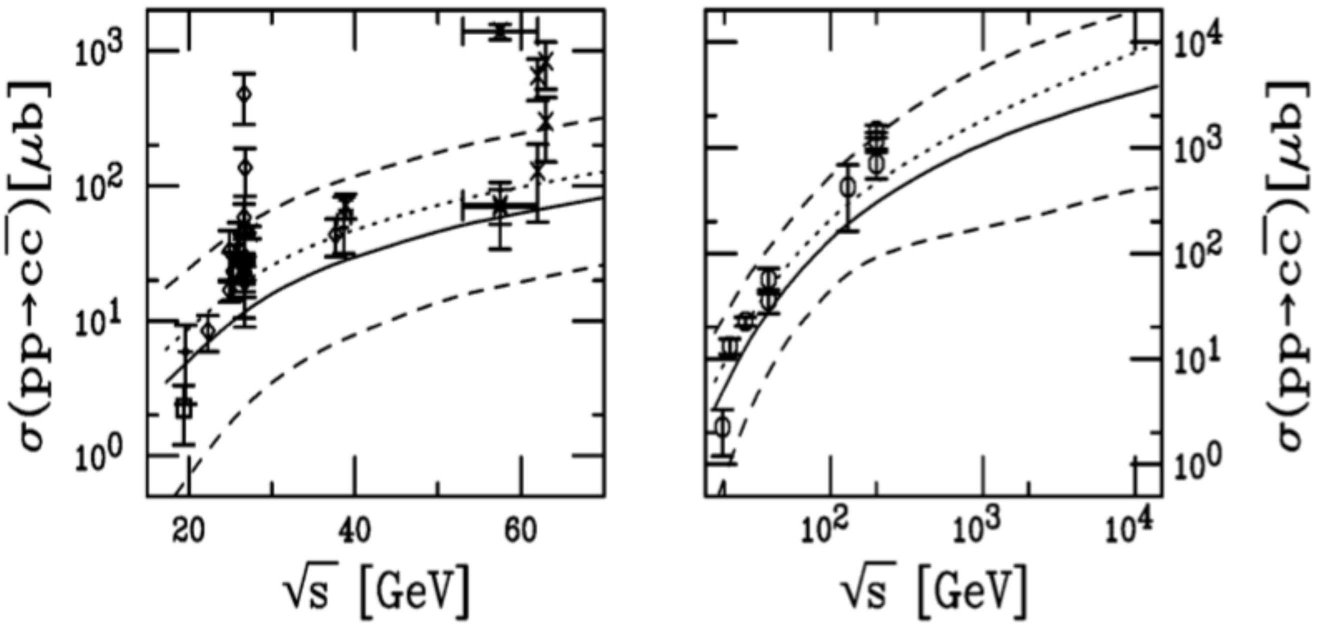
- *The sensitivity of previous experiments did not probe the interesting region for HNL masses above the kaon mass*

→ *Strong motivation to explore cosmologically allowed parameter space*

This domain has been only marginally explored, experimentally!

Sensitivity for $N_{2,3} \propto U^4$

- PS-191: Used K decays → limited to 500 MeV (PLB 203 (1988) 332)
- Goal: Extend mass range to ~ 2 GeV by using charmed hadron decays
- B-decays: 20÷100 smaller σ, and B → Dμν, i.e. limited to ~ 3 GeV still



arxiv.org/pdf/0709.2531v1

Where to produce charmed hadrons?

LHC ($\sqrt{s} = 14$ TeV): with 1 ab^{-1} (~ 3-4 years): $\sim 2 \times 10^{16}$ in 4π

SPS (400 GeV p-on-target (pot) $\sqrt{s} = 27$ GeV): with 2×10^{20} pot (~ 3-4 years): $\sim 2 \times 10^{17}$

The acceptance of a beam dump facility is much larger for long lived particles

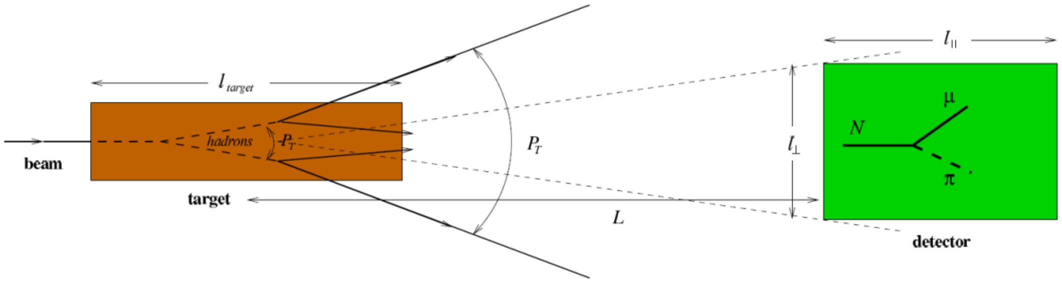
Experimental requirements

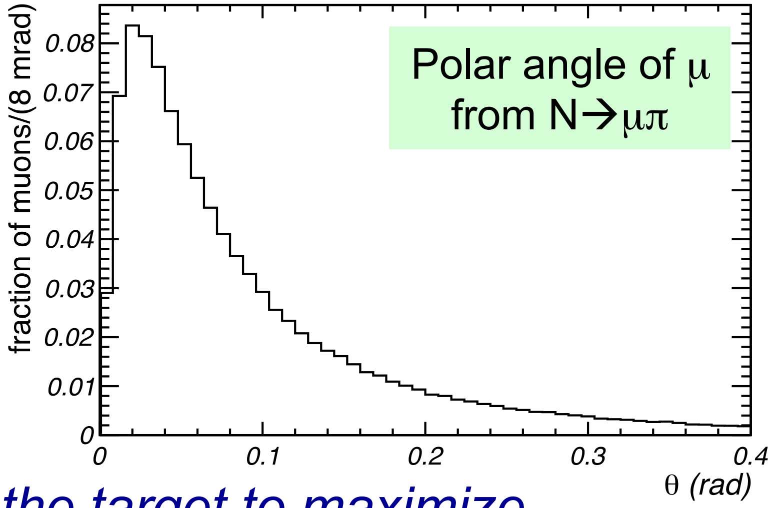
- *Search for HNL in Heavy Flavour decays*

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

CNGS: 1.8×10^{20} pot, 2011 run: 4.8×10^{19} pot

- *HNLs produced in charm decays have significant P_T*





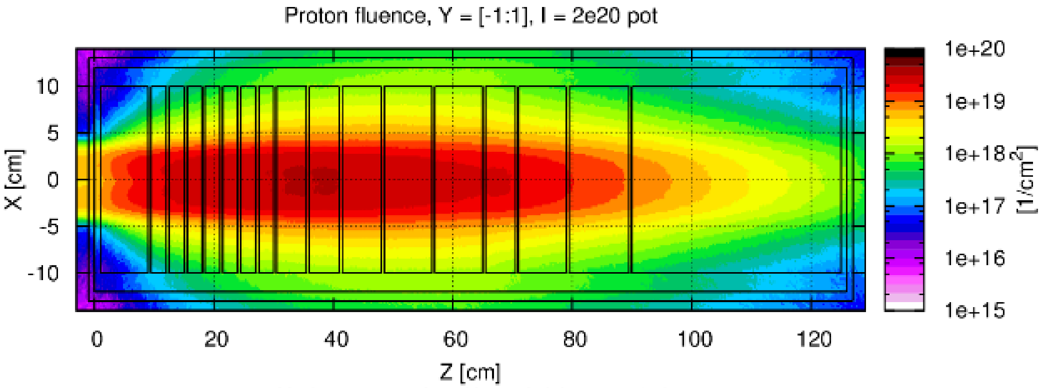
Detector must be placed close to the target to maximize geometrical acceptance

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

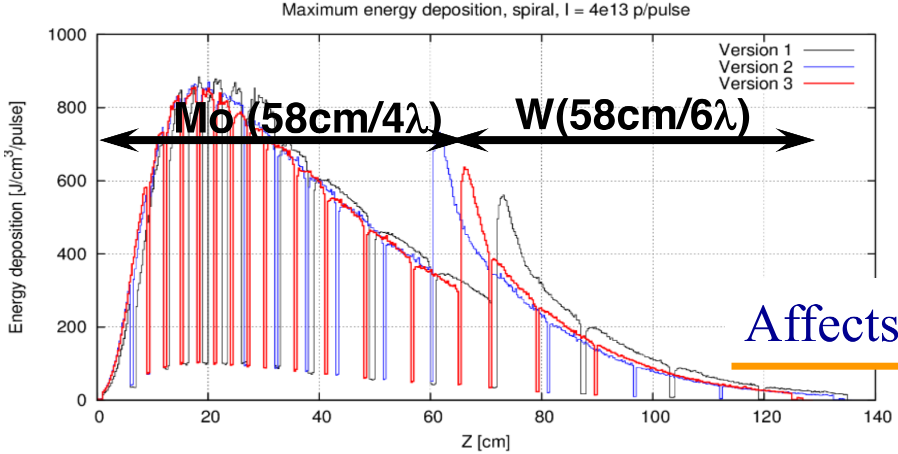
Target configuration

<u>Design considerations</u>

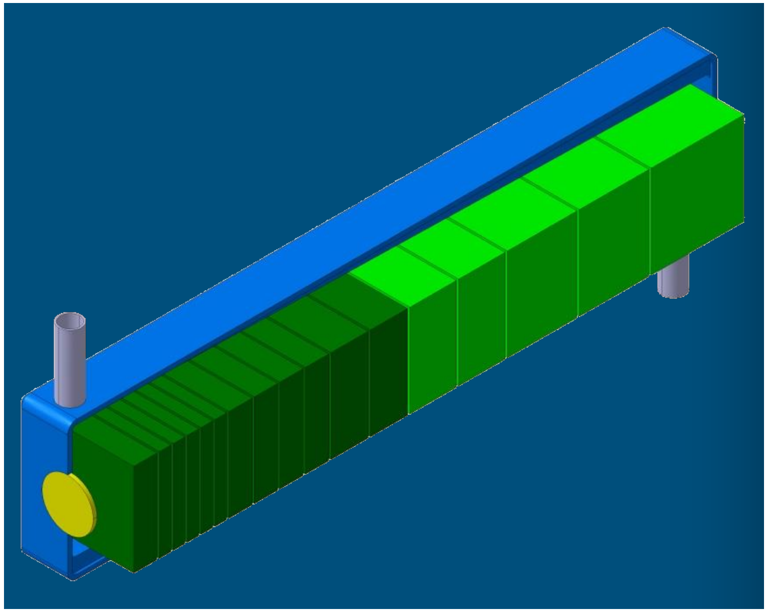
- High temperature
- Compressive stresses
- Atomic displacement
- Erosion/corrosion
- Material properties as a function of irradiation
- Remote handling (Initial dose rate of 50 Sv/h…)



Proton fluence, Y = [-1:1], I = 2e20 pot

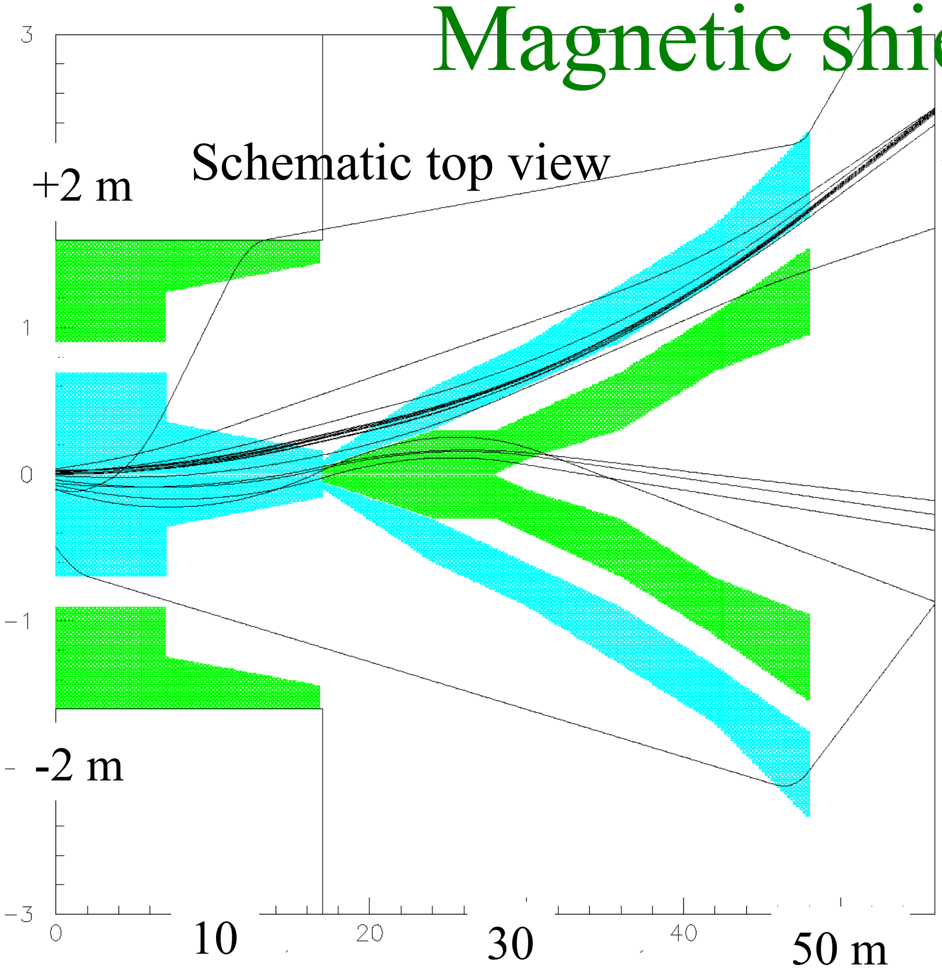


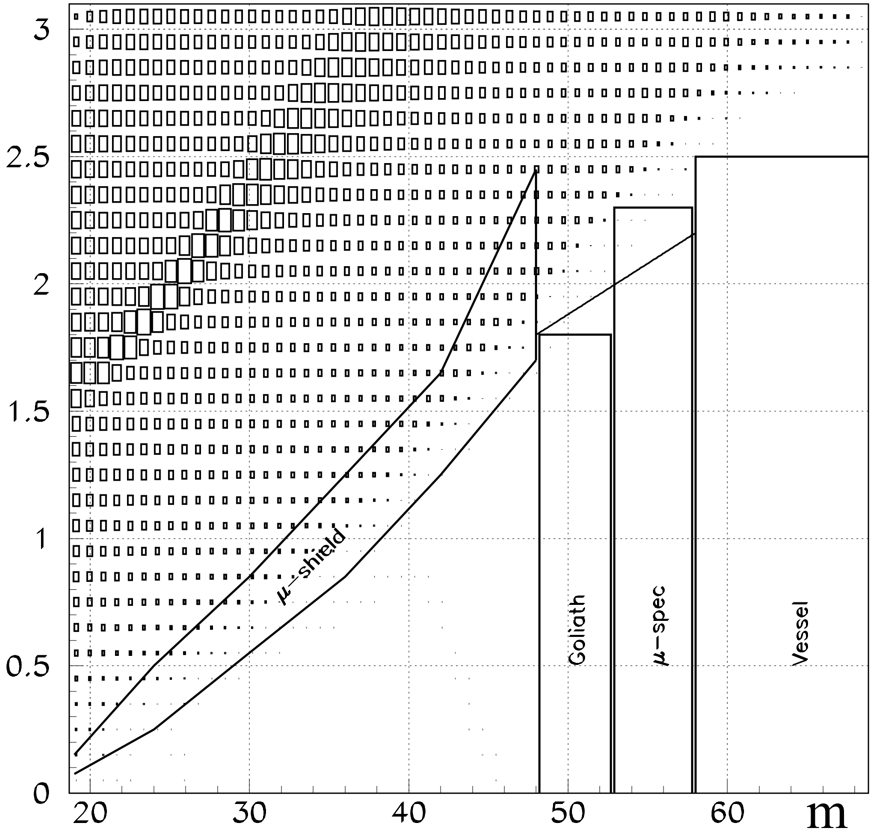
Maximum energy deposition, spiral, I = 4e13 p/pulse



Affects neutrino components and rates

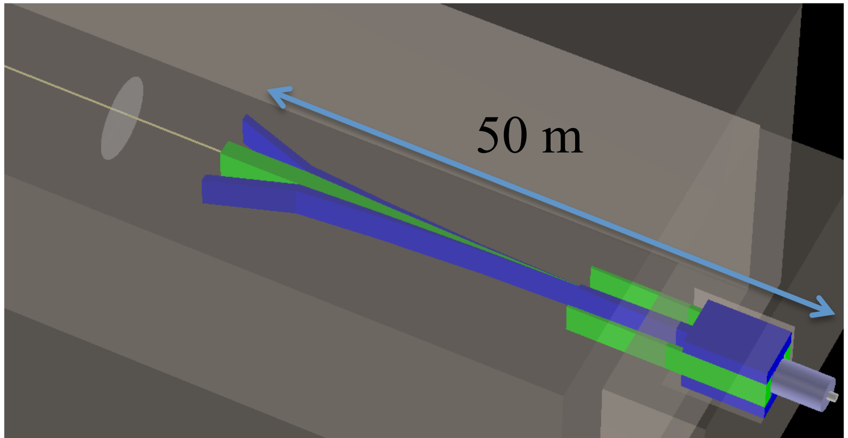
Magnetic shield for muons

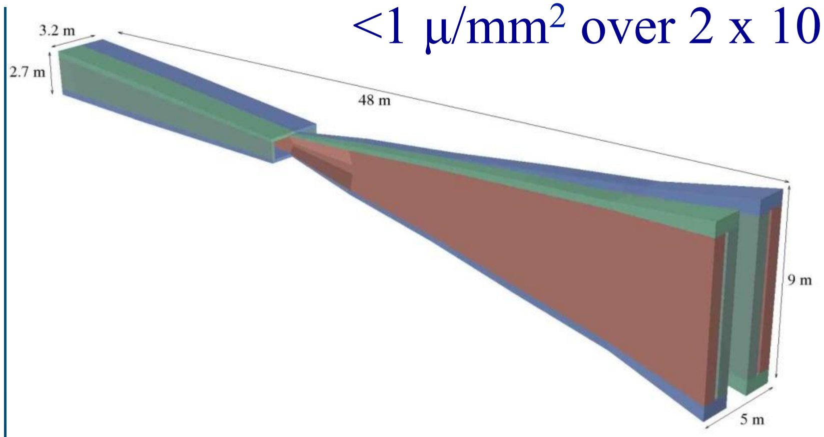




<10^5 μ/spill

<1 μ/mm^2 over 2 x 10^{19} pot





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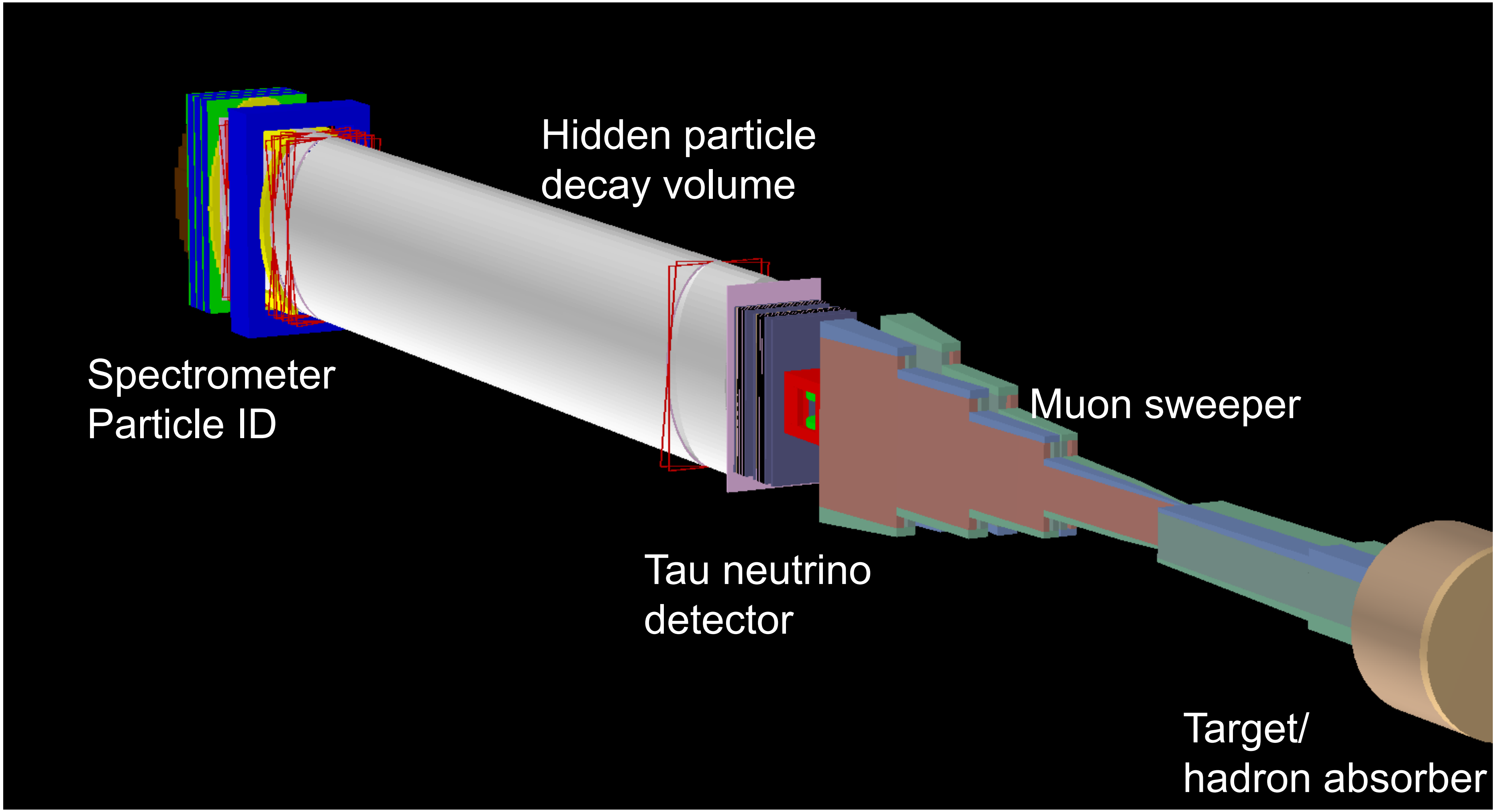
Experimental setup



Hidden particle
decay volume

Spectrometer
Particle ID

Muon sweeper

Tau neutrino
detector

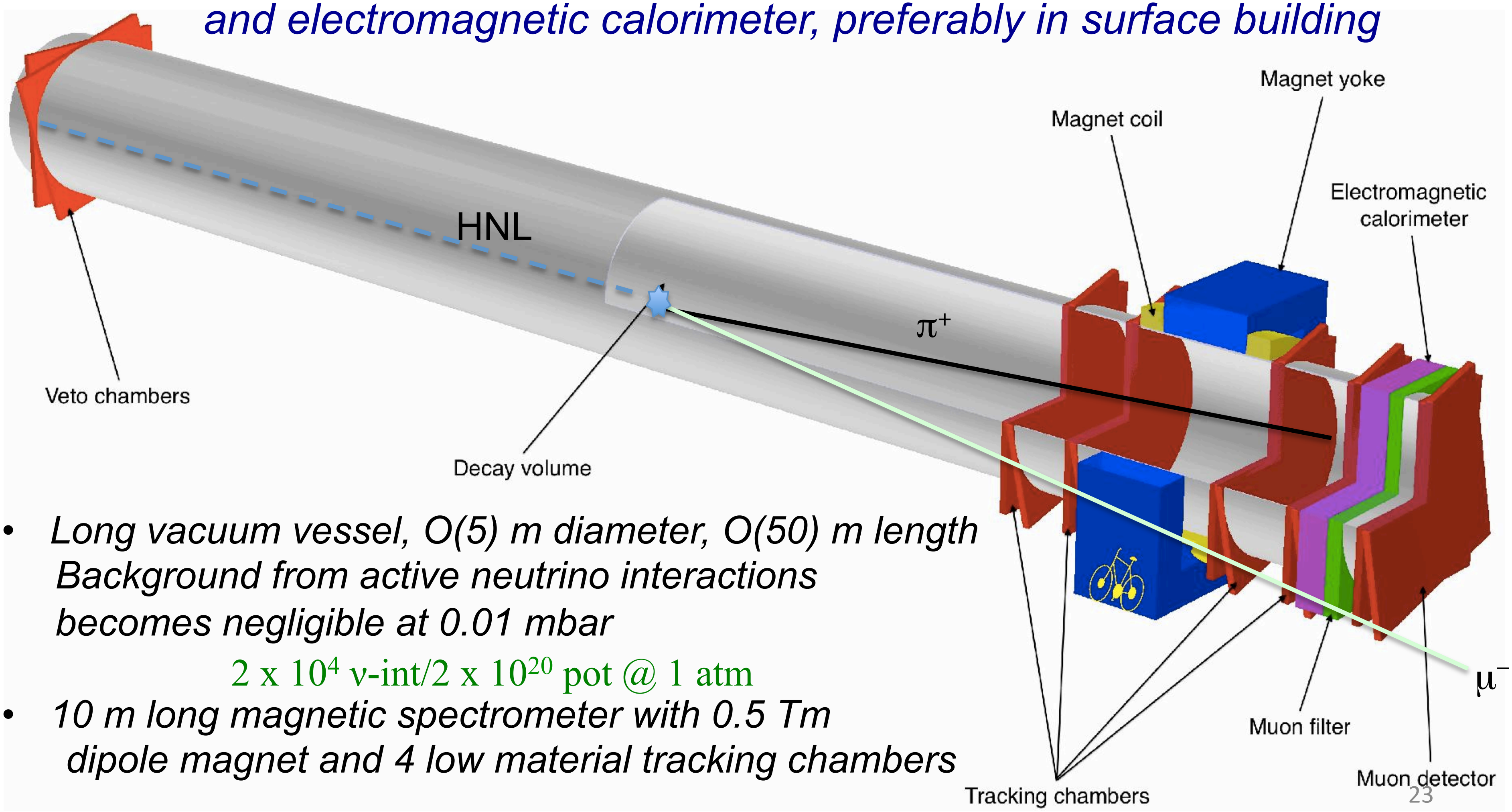
Target/
hadron absorber

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*



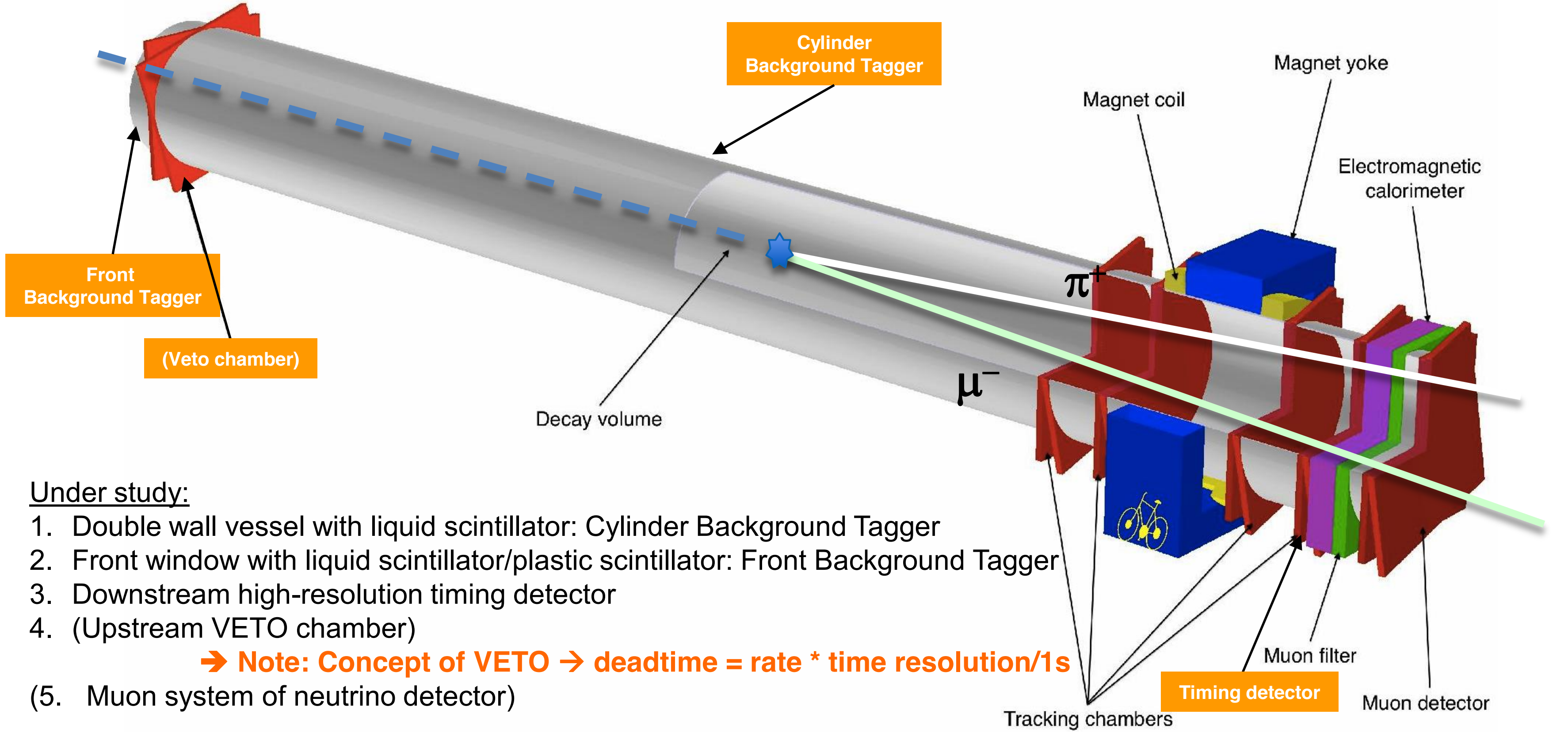
- *Long vacuum vessel, O(5) m diameter, O(50) m length Background from active neutrino interactions becomes negligible at 0.01 mbar*

  2×10^4 ν-int/2×10^{20} pot @ 1 atm

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

Background free experiment: background suppression

1. Neutrino inelastic scattering (e.g. $\nu_\mu + p \rightarrow X + K_L \rightarrow \mu\pi\nu$) ➔ Detector under vacuum, accompanying charged particles (tagging, timing), topological
2. Muon inelastic scattering ➔ Accompanying charged particles (tagging, timing), topological
3. Muon combinatorial (e.g. $\mu\mu$ with μ mis-ID) ➔ Tagging, timing and topological
4. Neutrons ➔ Tagging, topological
5. Cosmics ➔ Tagging, timing and topological



Under study:

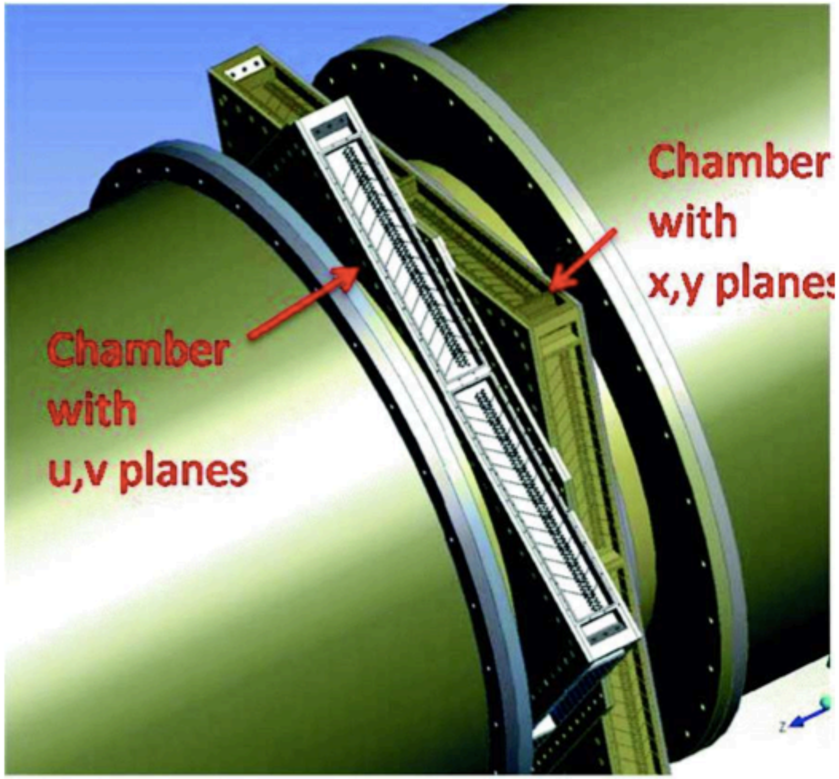
1. Double wall vessel with liquid scintillator: Cylinder Background Tagger
2. Front window with liquid scintillator/plastic scintillator: Front Background Tagger
3. Downstream high-resolution timing detector
4. (Upstream VETO chamber)

➔ Note: Concept of VETO → deadtime = rate * time resolution/1s

(5. Muon system of neutrino detector)

Tracking chambers

Same as NA62 $(K^+ \to \pi^+ \nu\bar{\nu})$
2m diameter vessel at 0.01 µbar
10 mm diameter straws made of PET → working well in vacuum
$X/X_0 = 0.5\%$ for 4 view stations
120 µm resolution/straw



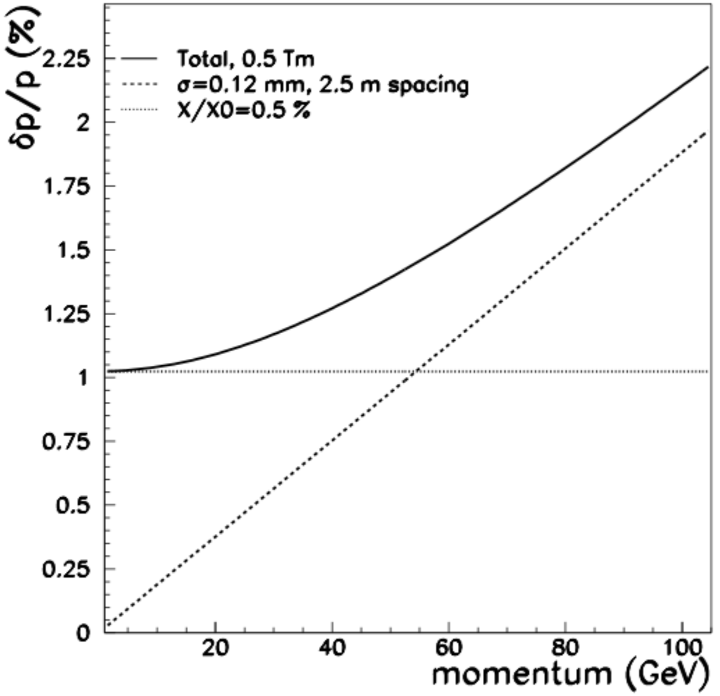
Magnet and e.m. calo

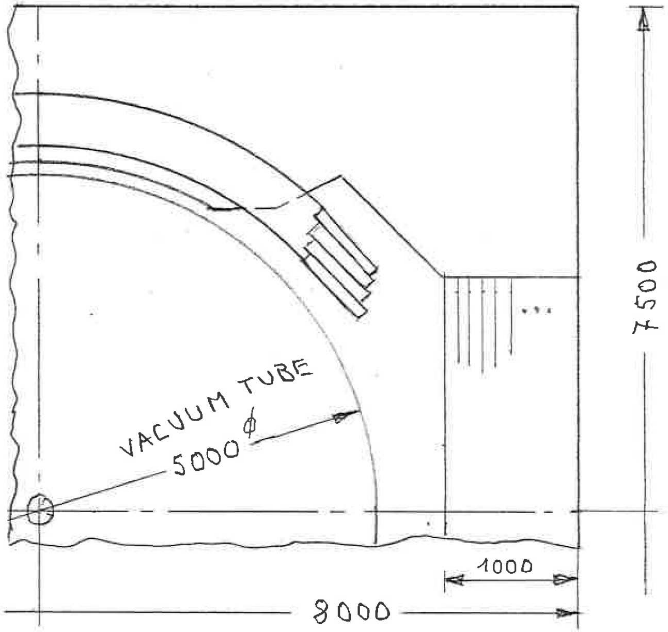
- With X/X0=0.5 $\%$ chambers: modest 0.5 Tm
- Need $\sim 20\ \mathrm{m}^2$ aperture.

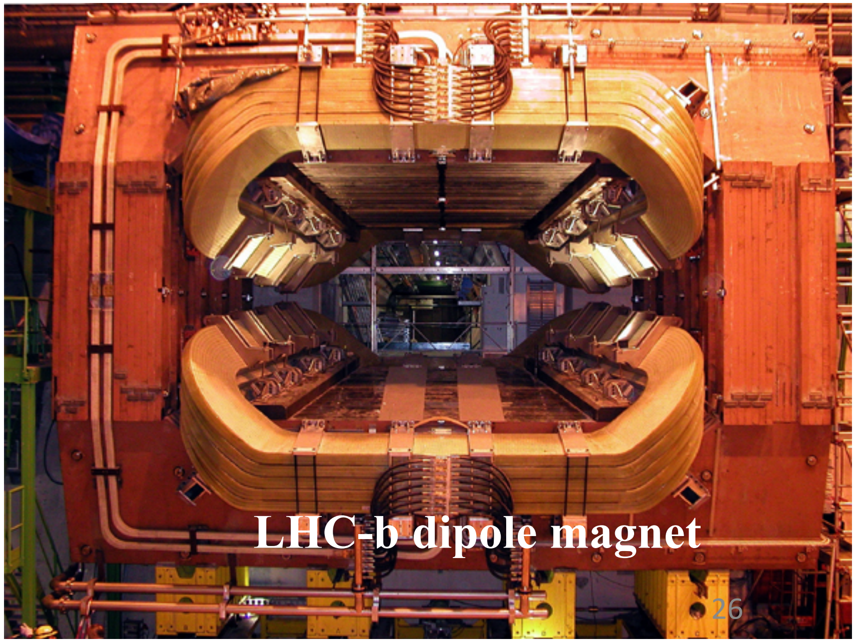
LHCb magnet: 4 Tm, $16\ \mathrm{m}^2$ aperture

Preliminary calculations (W.Flegel):

- Needs 30 $\%$ less iron/yoke than LHCb.
- Consumes 3 times less power.





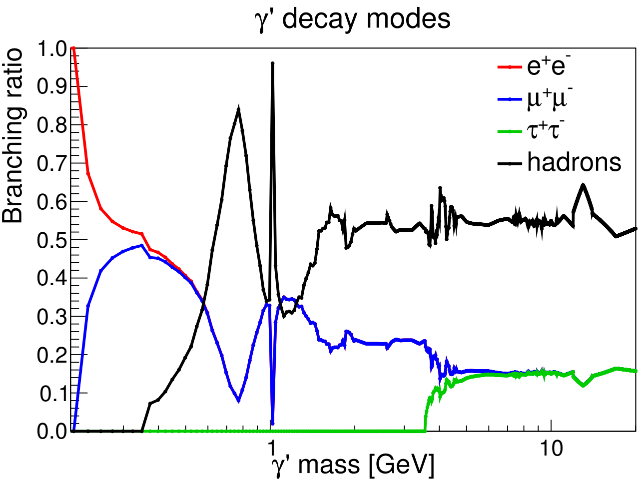


LHC-b dipole magnet

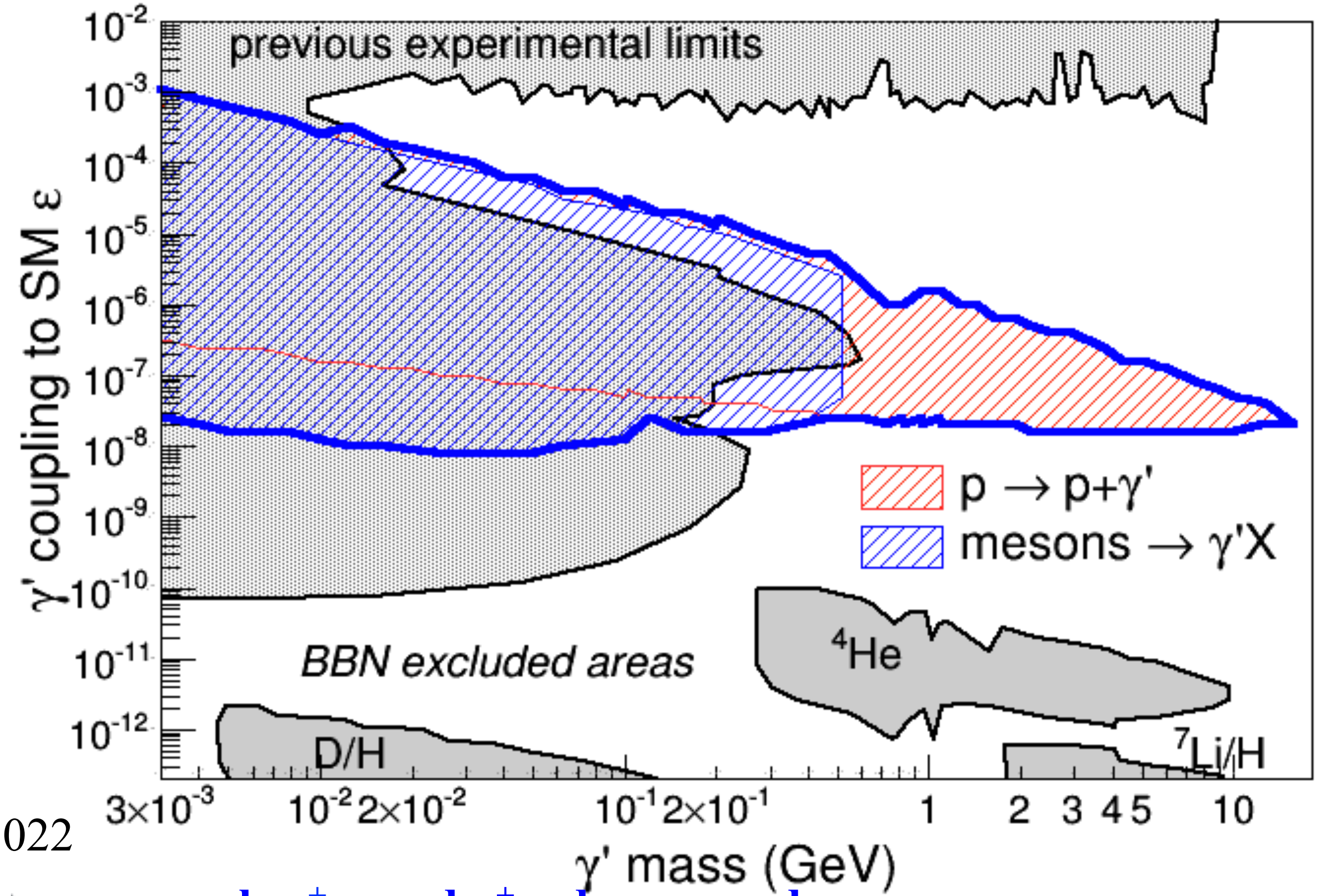
LHCb Shashlik ECAL:

- $6.3\times 7.8\ \mathrm{m}^2$
- $\frac{\sigma(E)}{E} < 10\%/\sqrt{E} \oplus 1.5\%$

Sensitivity to dark photons



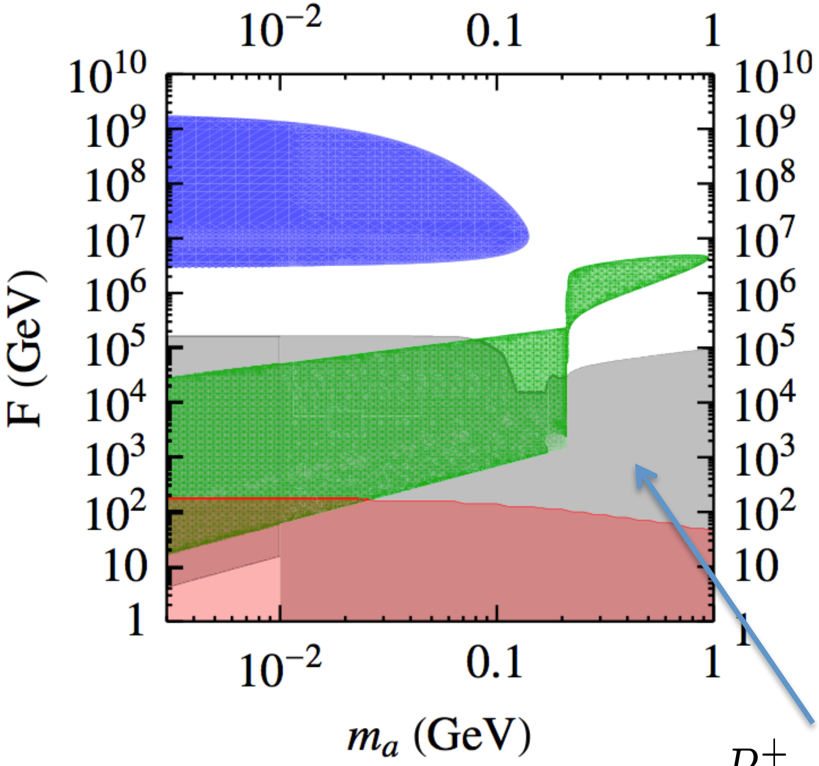
Phys. Lett. B731 (2014) 320

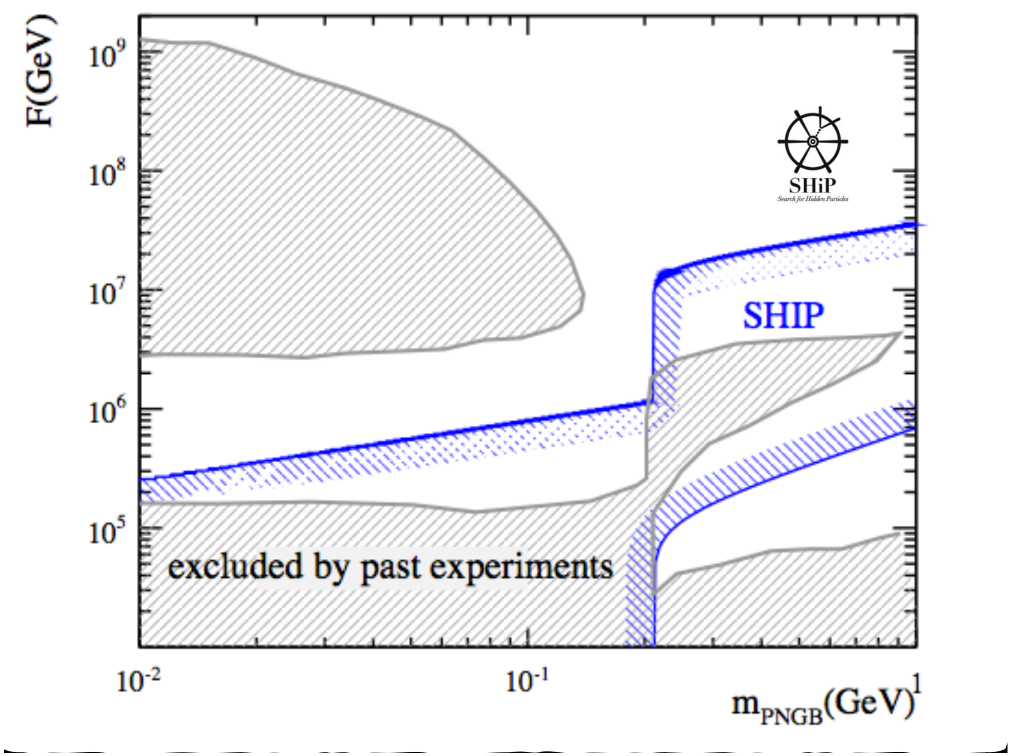


Phys.Rev. D90 (2014) 035022

only e^+e^- and $\mu^+\mu^-$ decays used

Sensitivity to PNGB





$B^+ \to K^+ l^+ l^-$

Limits from Supernova SN 1987a

CHARM

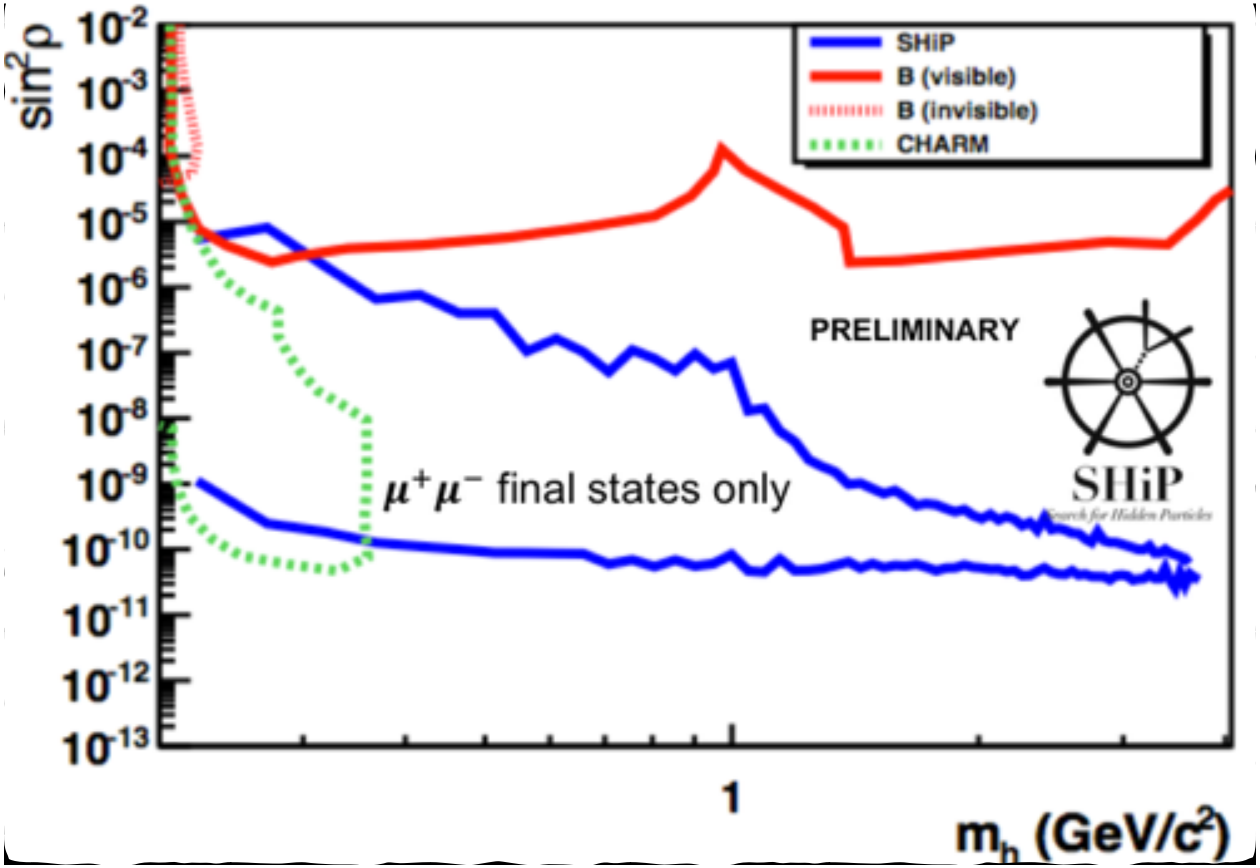
meson decays

muon anomalous magnetic moment

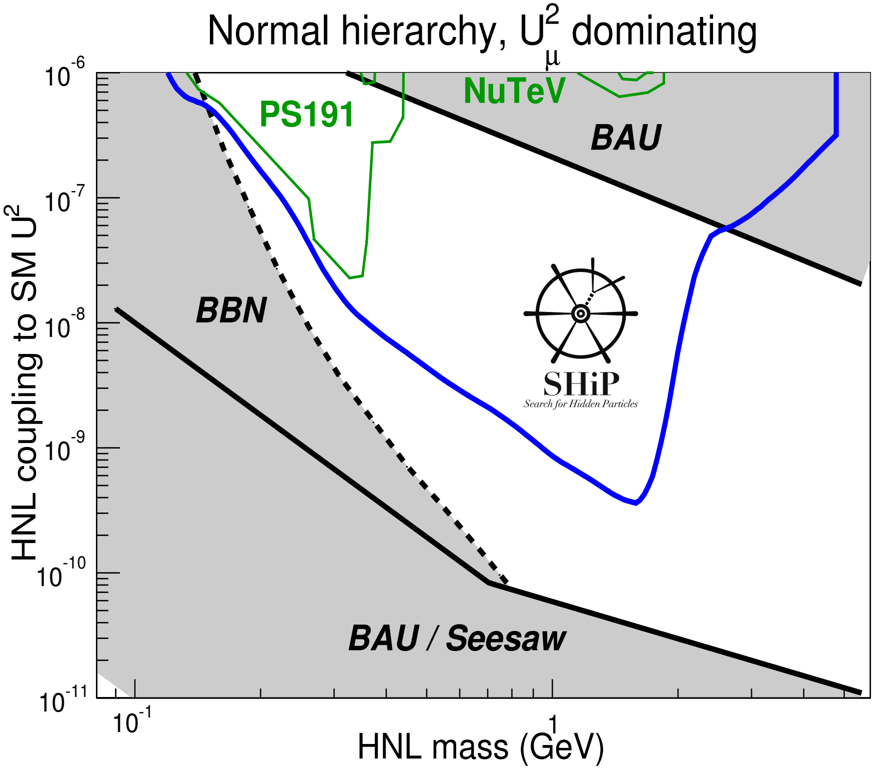
Sensitivity to light scalar

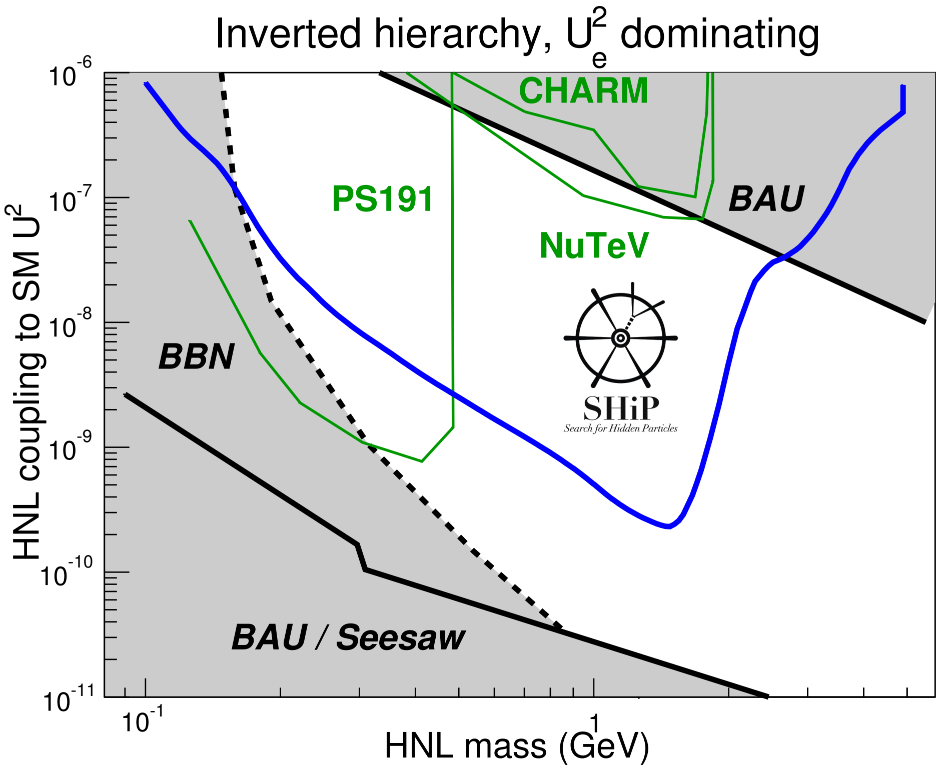
$$B \to K\,h$$

$$h \to \mu^+\mu^-$$

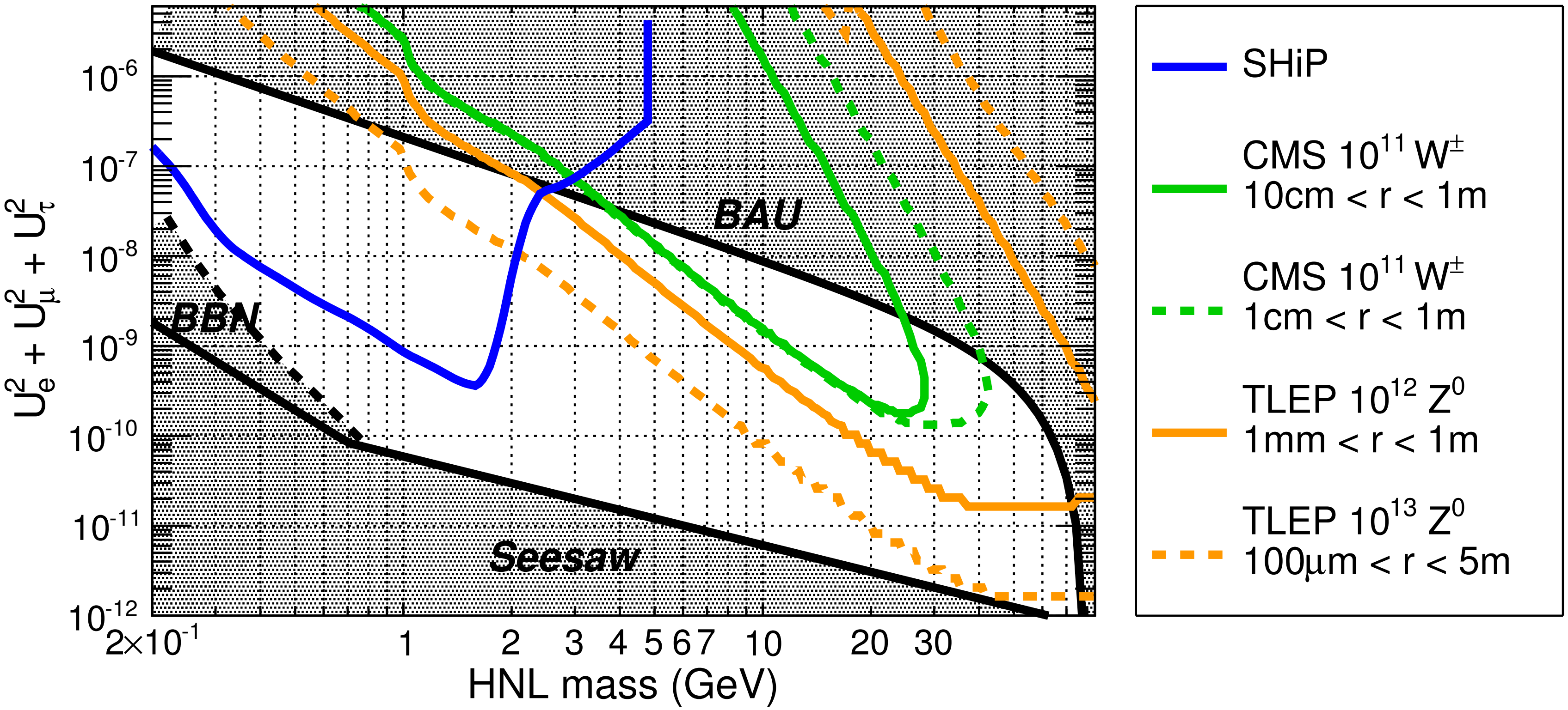


Exclusion limits in the Heavy neutral lepton search





SHIP sensitive to a significant part of the parameter space

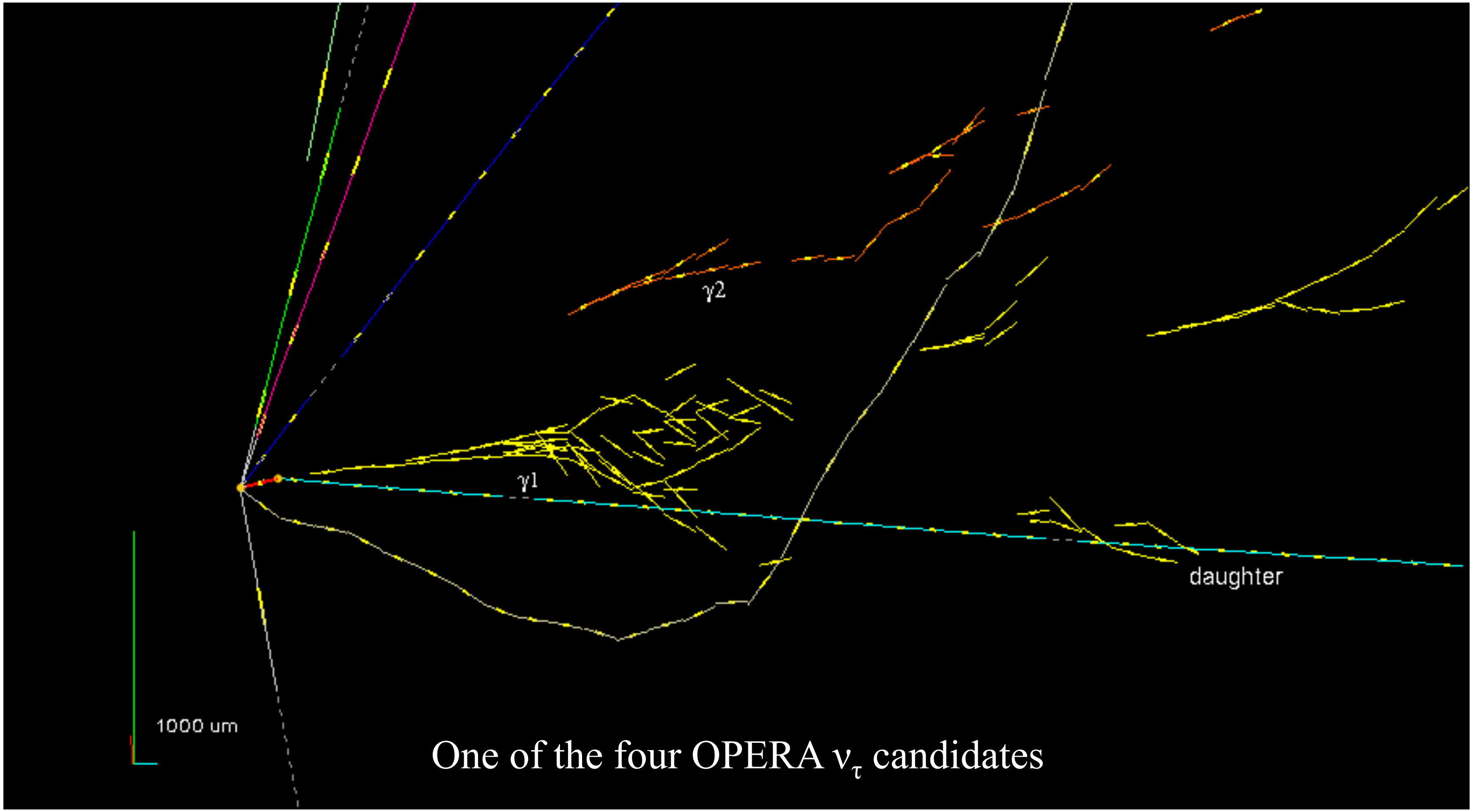


ν_τ: *the less known particle in the Standard Model*

DONUT: 9 observed ν_τ candidate events (leptonic number not measured)

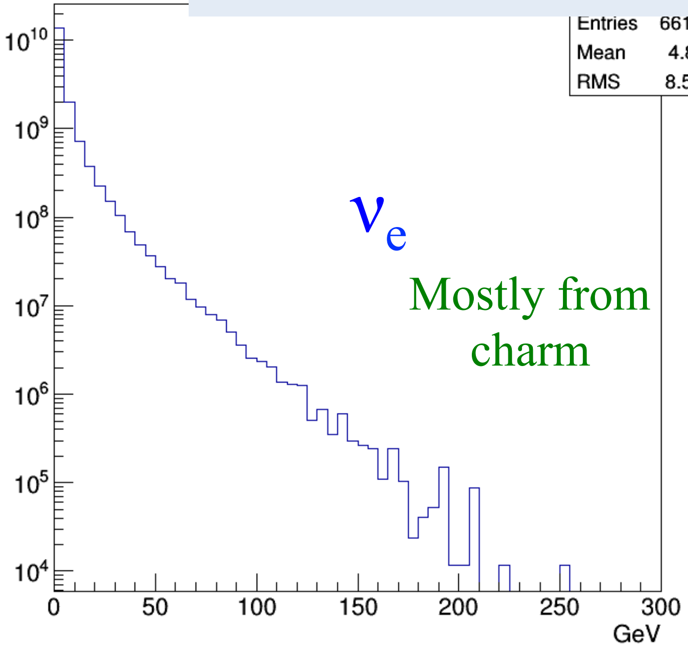
OPERA: First observation of $\nu_\mu \rightarrow \nu_\tau$ oscillation in appearance mode (4.2σ result)

$\bar{\nu}_\tau$ not detected yet!



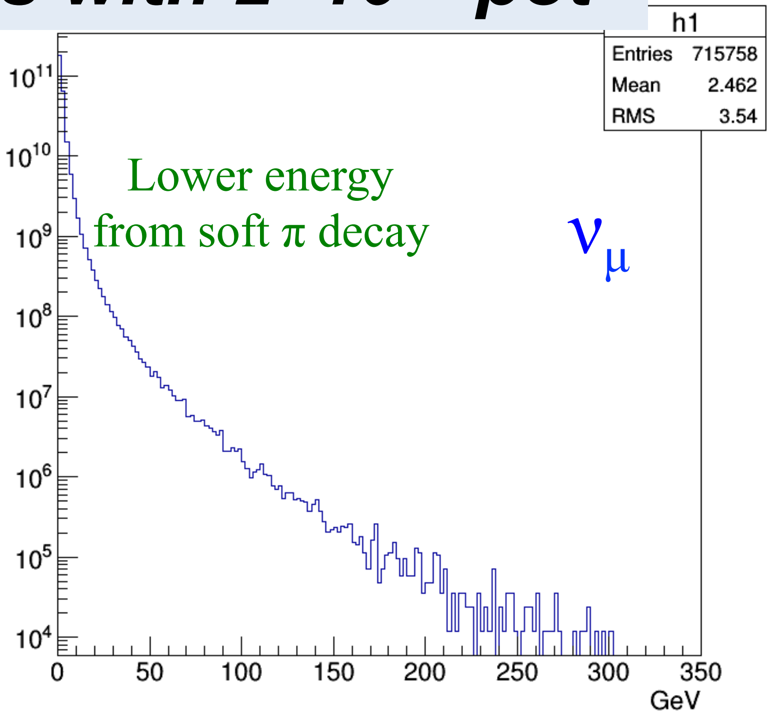
One of the four OPERA ν_τ candidates

Standard Model: ν_τ physics with 2×10^{20} pot



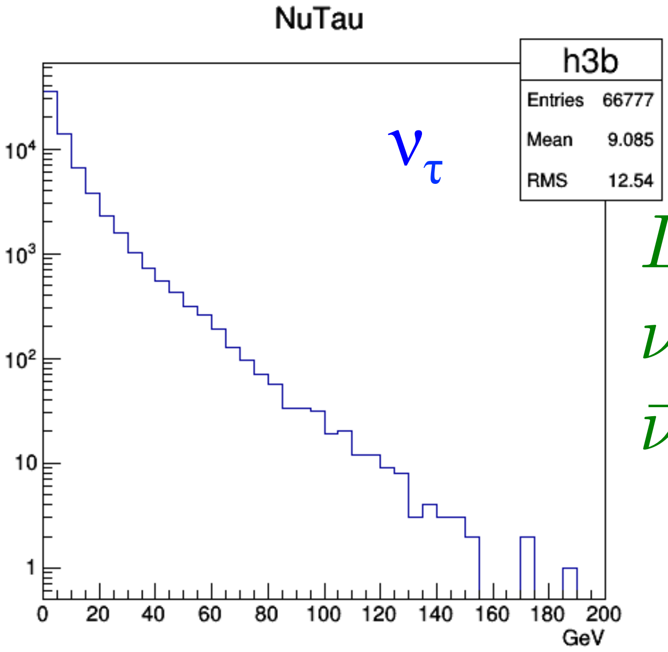
ν_e

Mostly from charm



Lower energy from soft π decay

ν_μ

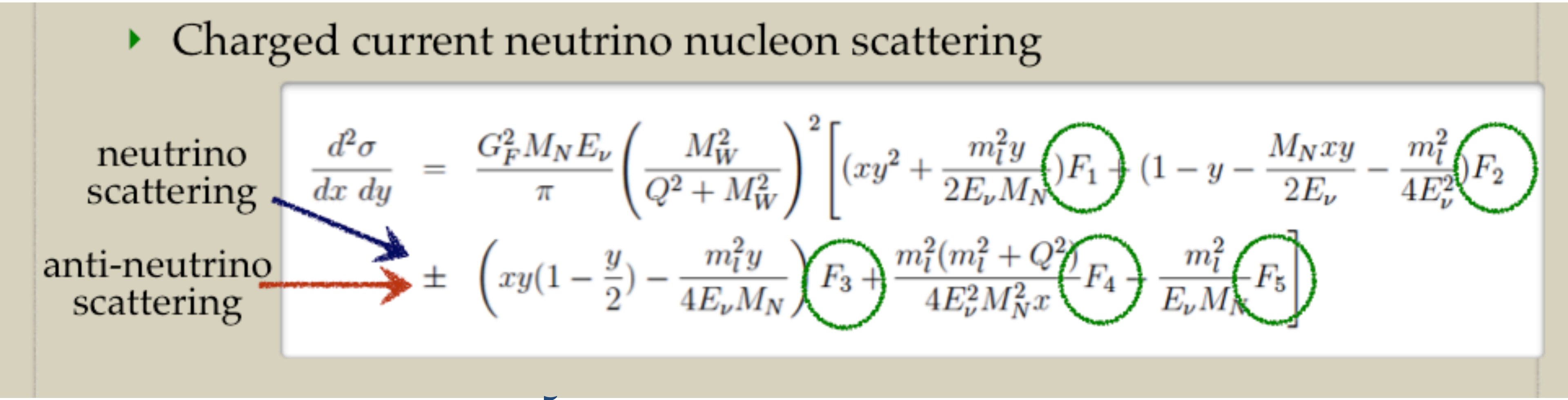


ν_τ

$$D_s \to \tau\nu_\tau\text{, present configuration:}$$
$$\nu_e \simeq 7.1\%,\ \nu_\mu \simeq 92.5\%,\ \nu_\tau \simeq 0.4\%$$
$$\bar{\nu}_\mu/\nu_\mu \simeq 62\%,\ \bar{\nu}_e/\nu_e \simeq 1,\ \bar{\nu}_\tau/\nu_\tau = 1$$

Standard Model: ν_τ physics with 2×10^{20} pot

- $\simeq 3500\ \nu_\tau$ interactions with 6 tons detector ($\simeq 5\%$ of OPERA films)
- Discovery of $\bar{\nu}_\tau$
- ν_τ and $\bar{\nu}_\tau$ cross-section
- ν_τ magnetic moment
- Structure functions (F_4 and F_5 never measured)
- F_1, F_2 and F_3 measured with $2\times10^6\nu_\mu$ interactions



- Charged current neutrino nucleon scattering

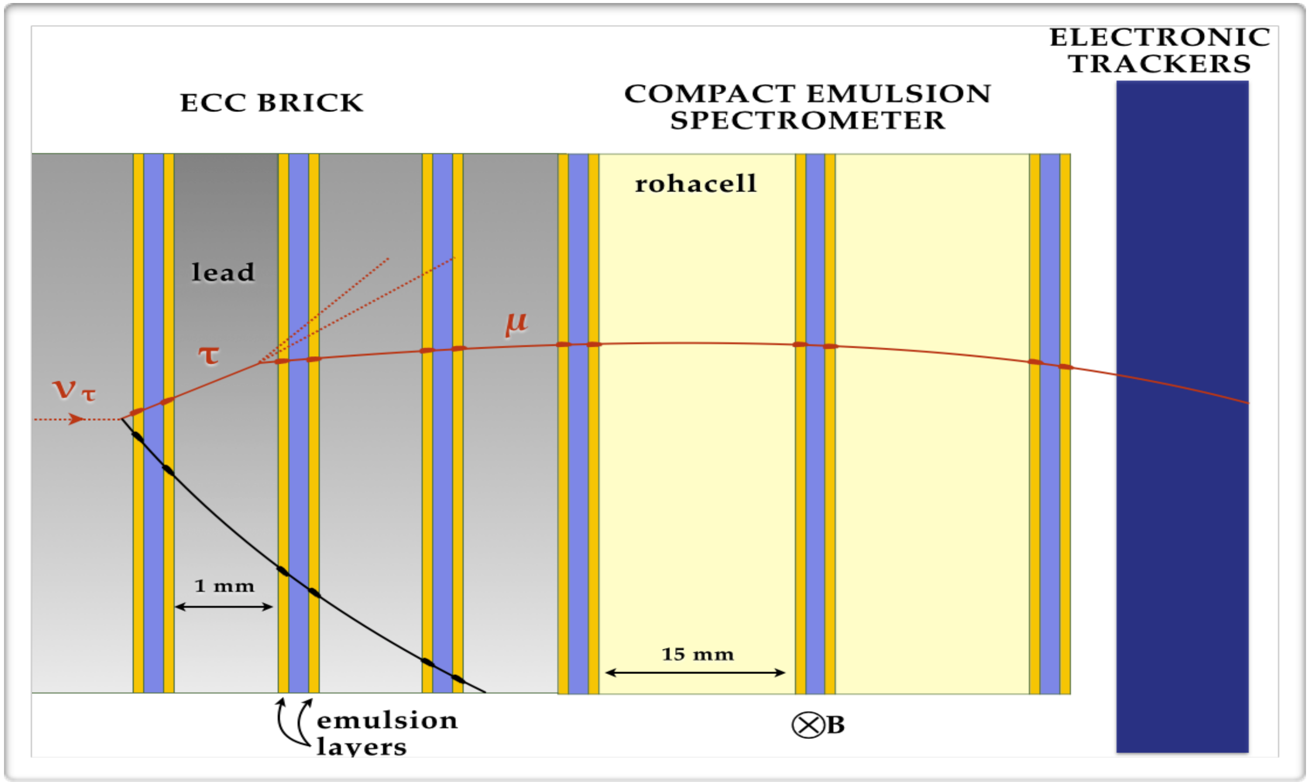
neutrino scattering

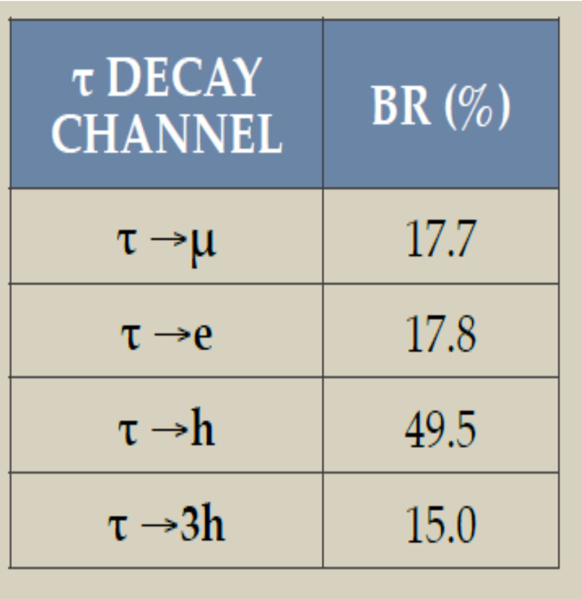
anti-neutrino scattering

$$\frac{d^2\sigma}{dx\,dy} = \frac{G_F^2 M_N E_\nu}{\pi}\left(\frac{M_W^2}{Q^2+M_W^2}\right)^2\left[\left(xy^2+\frac{m_l^2 y}{2E_\nu M_N}\right)F_1 + \left(1-y-\frac{M_N x y}{2E_\nu}-\frac{m_l^2}{4E_\nu^2}\right)F_2 \pm \left(xy\left(1-\frac{y}{2}\right)-\frac{m_l^2 y}{4E_\nu M_N}\right)F_3 + \frac{m_l^2(m_l^2+Q^2)}{4E_\nu^2 M_N^2 x}F_4 - \frac{m_l^2}{E_\nu M_N}F_5\right]$$

ν_e interactions (10^5) to measure charm production yield
→ constraint normalization also for HNL

Hybrid detector principle



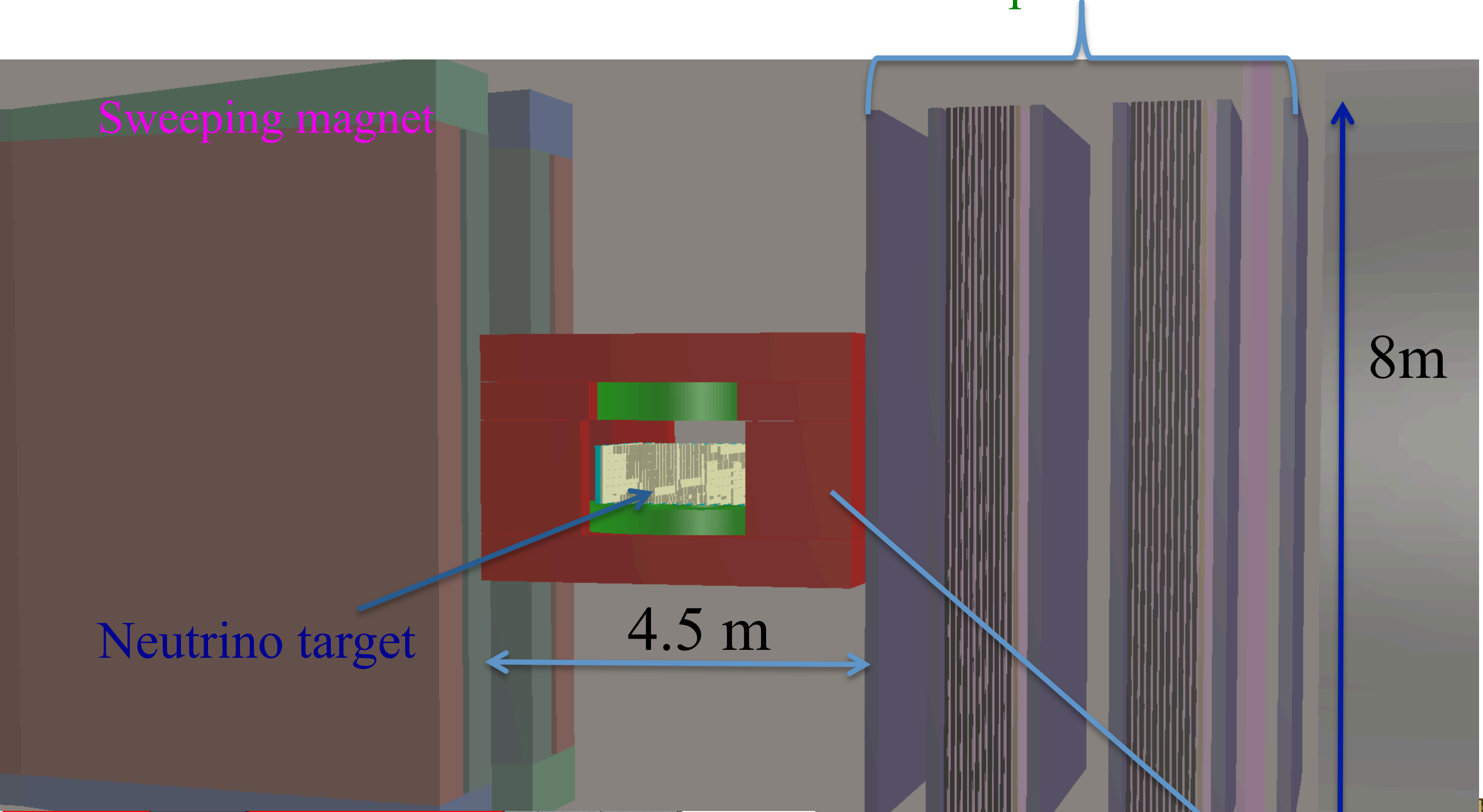


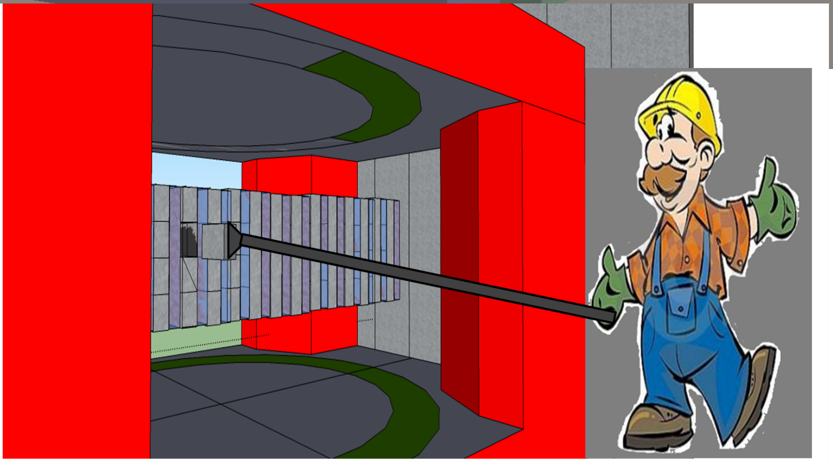
τ DECAY CHANNEL	BR (%)
τ →μ	17.7
τ →e	17.8
τ →h	49.5
τ →3h	15.0

This configuration (ECC + an emulsion spectrometer) never used so far!
TESTS are needed to finalize the geometry and performances

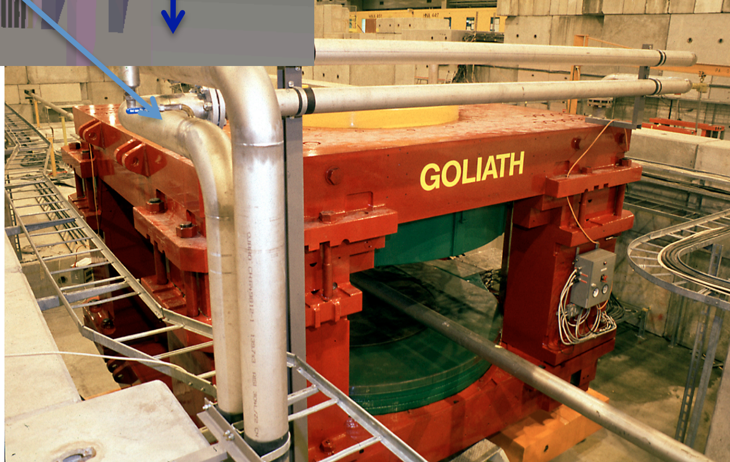
- Nuclear emulsions as trackers with micrometric resolution
- Detect τ-lepton production and decay vertices
- Compact emulsion spectrometer to measure the charge of τ decays
- Electronic detectors to provide the“time stamp ” and reconstruct μ charge/momentum

The neutrino detector



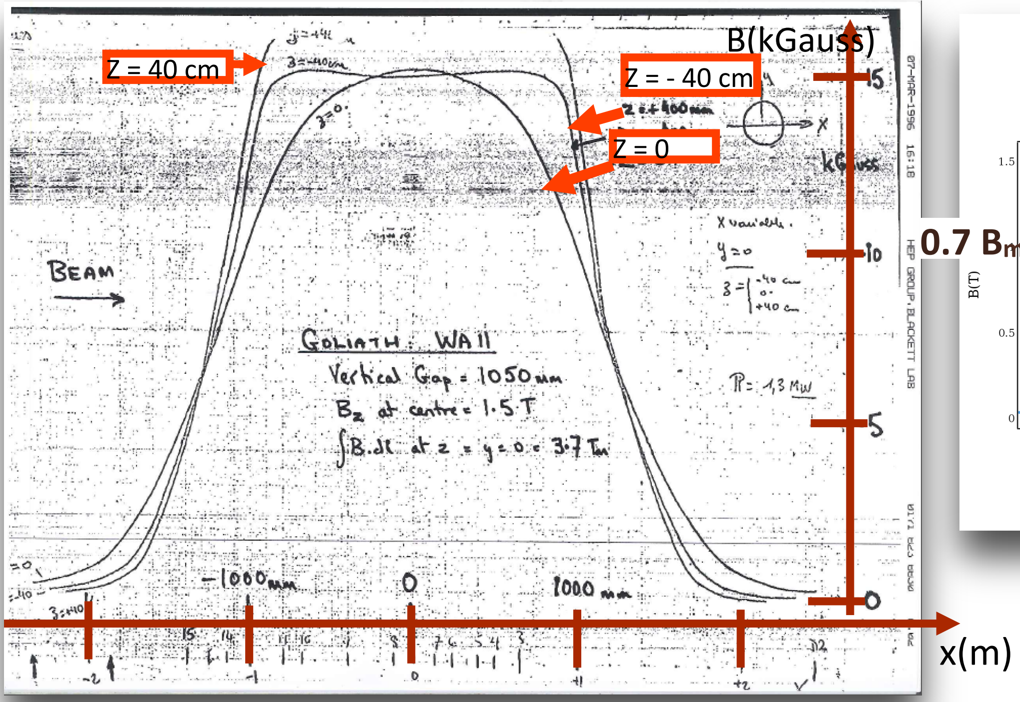


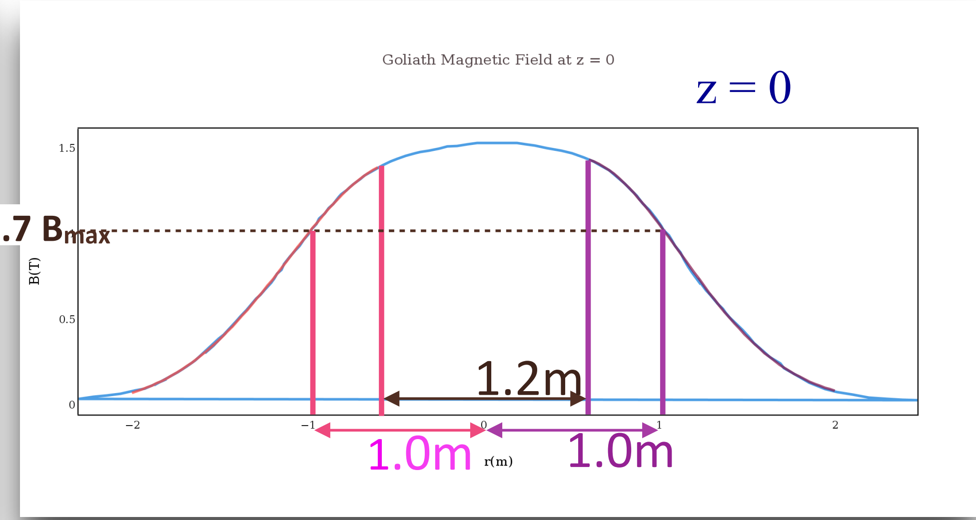
Magnet available

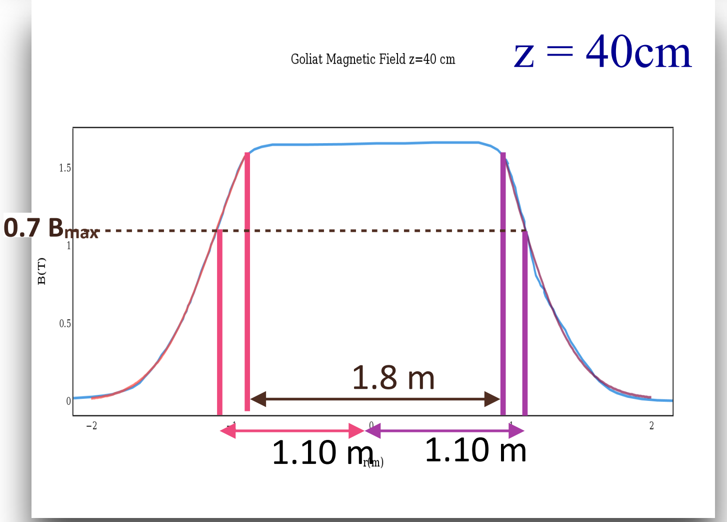


Magnetic Field

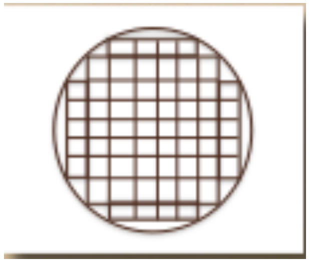
$y = 0 \rightarrow r = |x|$

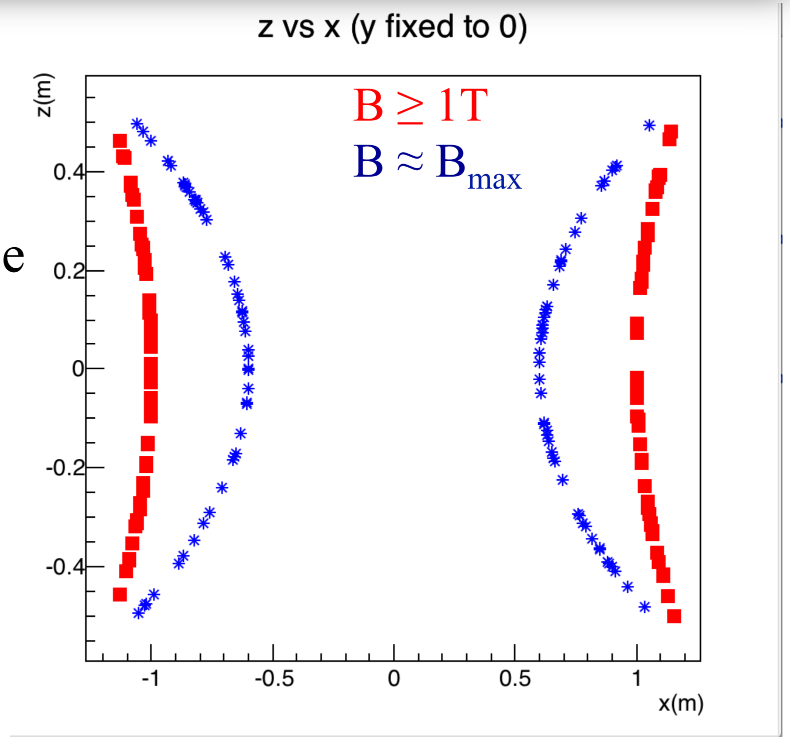




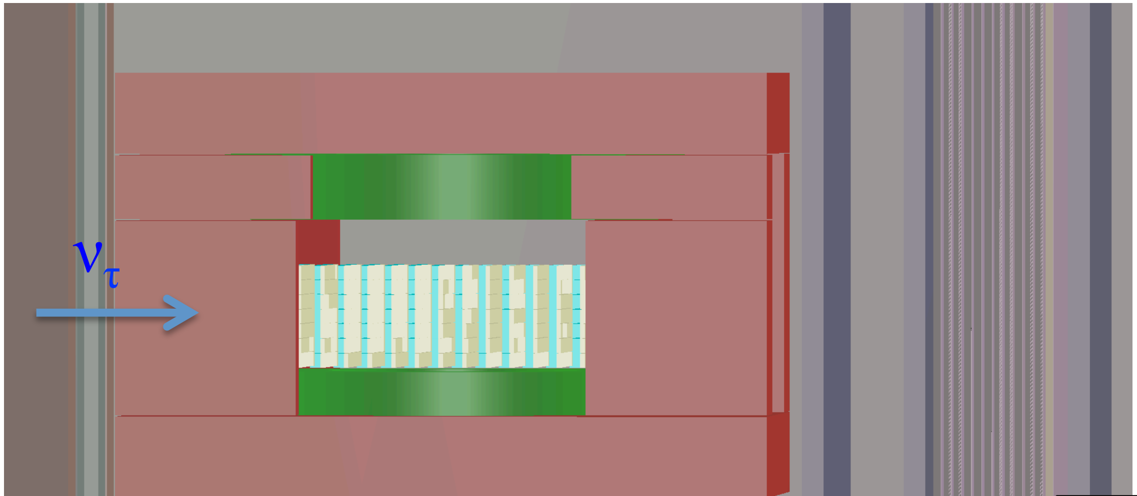


Cilyndrical shape





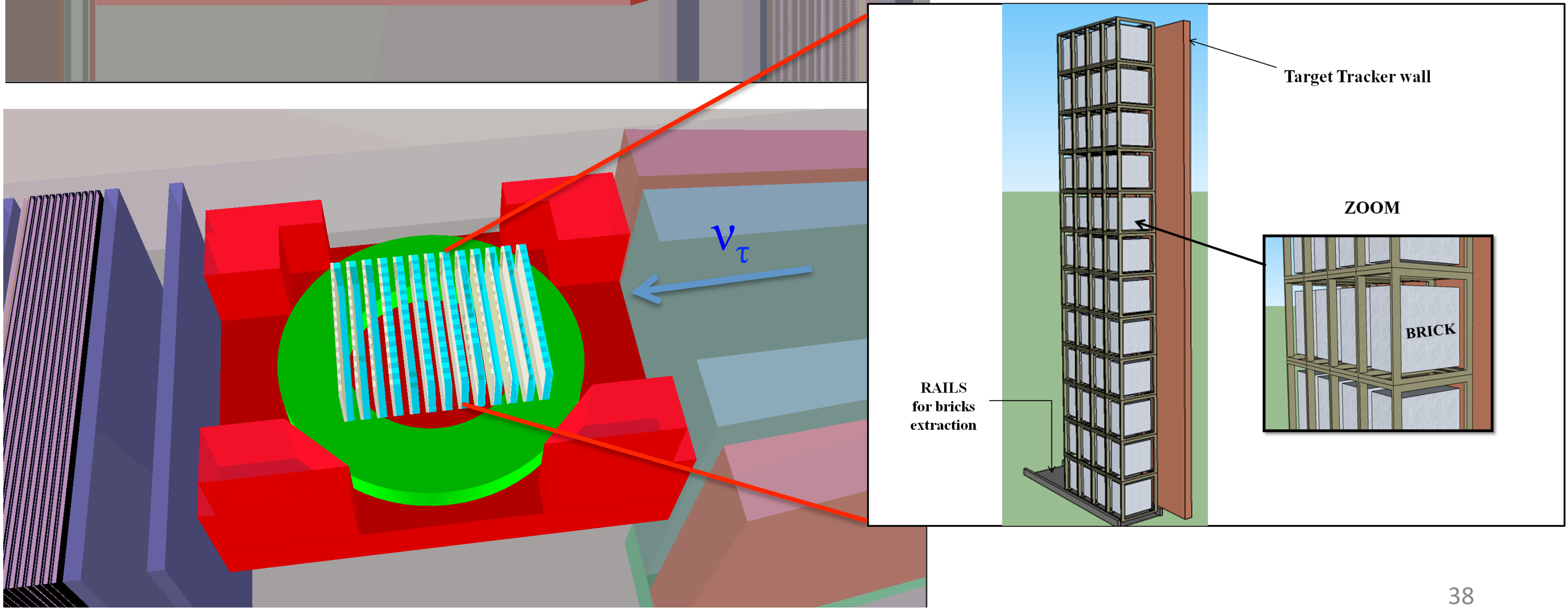
Magnetized target region



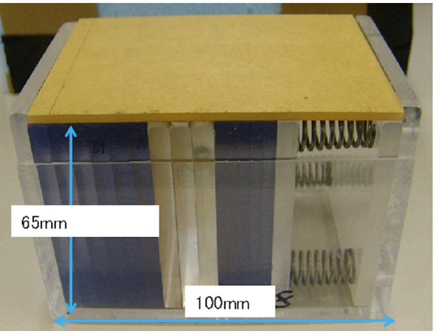
Target region: 13 mini-walls
One wall contains 48 bricks
target mass ~ 6 ton

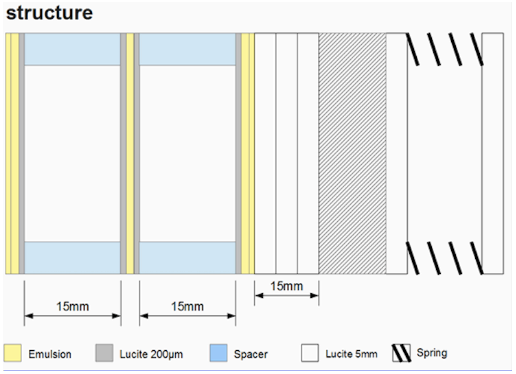
TARGET TRACKER:

- 250 µm Scintillating fibres, read out by SiPMs
- GEM
- Micromegas



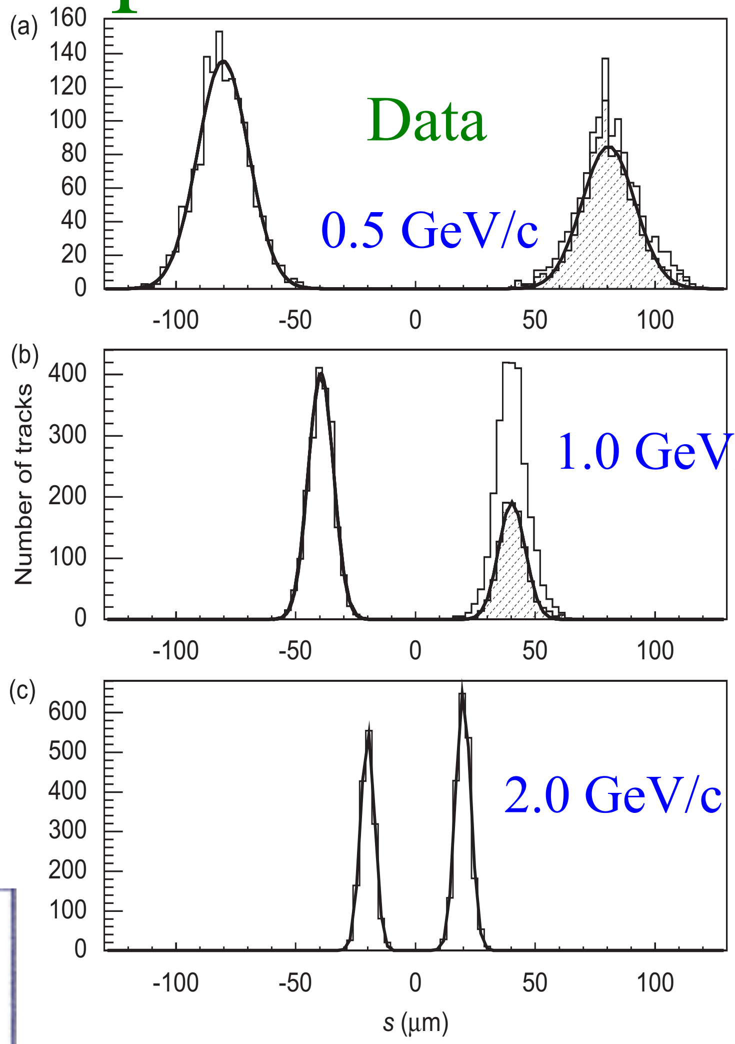
Compact emulsion spectrometer



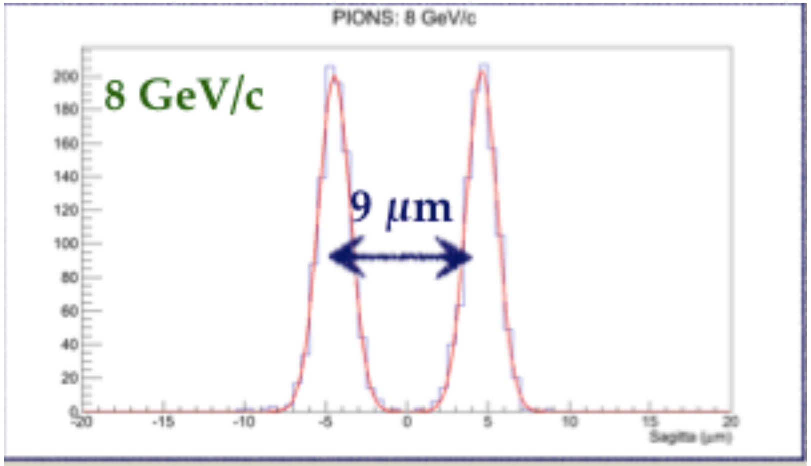


3 emulsion films interleaved with 1.5 cm air gap in a magnetic field (~ 1T), 3cm thick device, H. Shibuya et al NIM A592 (2008) 56

- Emulsion films alternated by low density material (Rohacell, 30÷100 kg/m^3)
- the charge of 8 GeV muons detectable (±4.5 μm) → require precise alignment

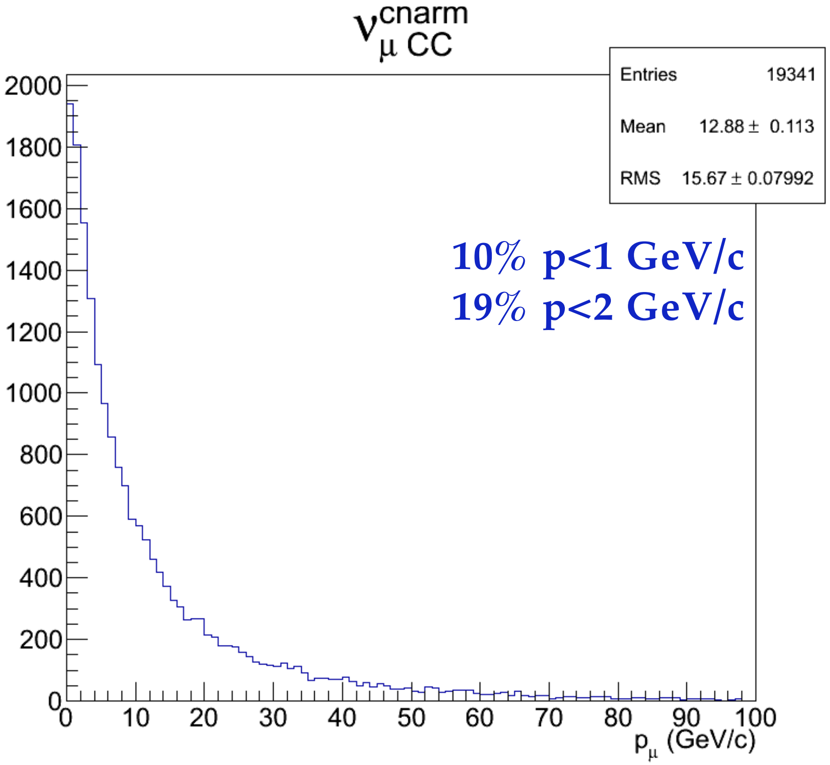


Sagitta measurement



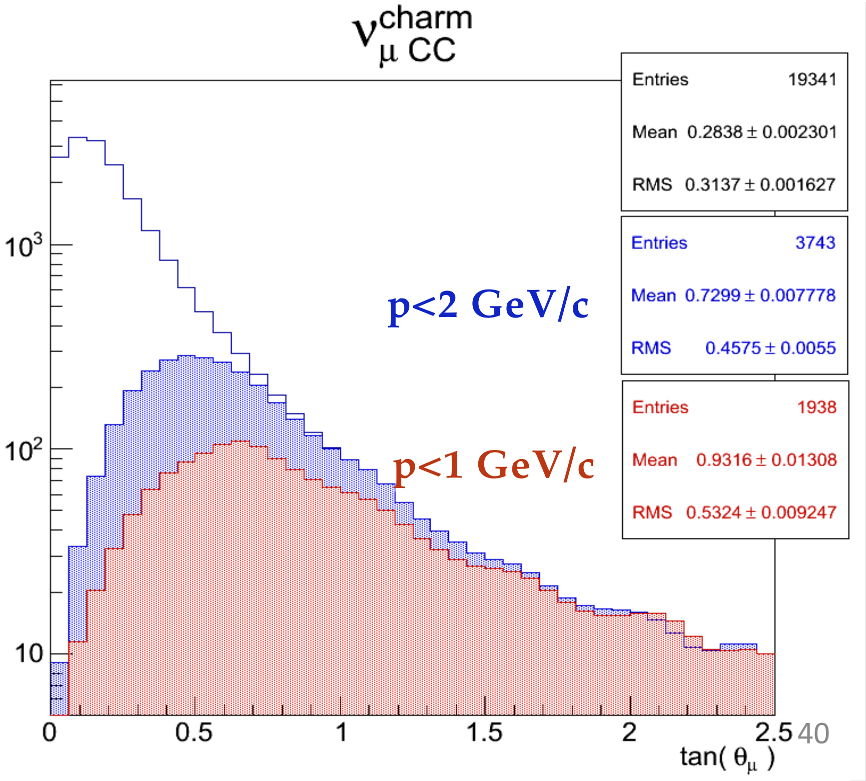
Muon detector requirements

- Detector performances driven by background rejection → minimise muon misidentification
- Soft and large angle muons → difficult to be identified
- Large acceptance and fine graining to identify P < 2 GeV
- 4.5 x 4.5 m^2 to detect angles up to $\tan(\vartheta) \leq 1$
- High sampling to use momentum/range correlation



10% p<1 GeV/c

19% p<2 GeV/c

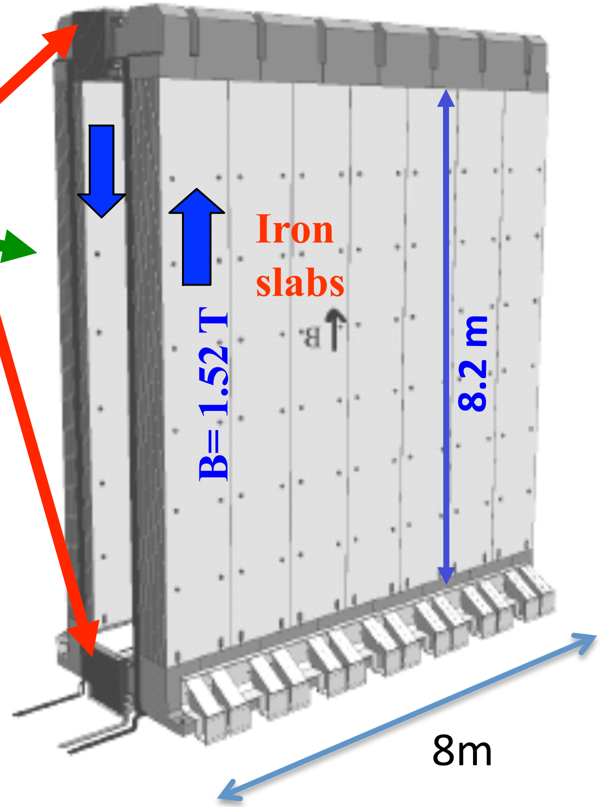


p<2 GeV/c

p<1 GeV/c

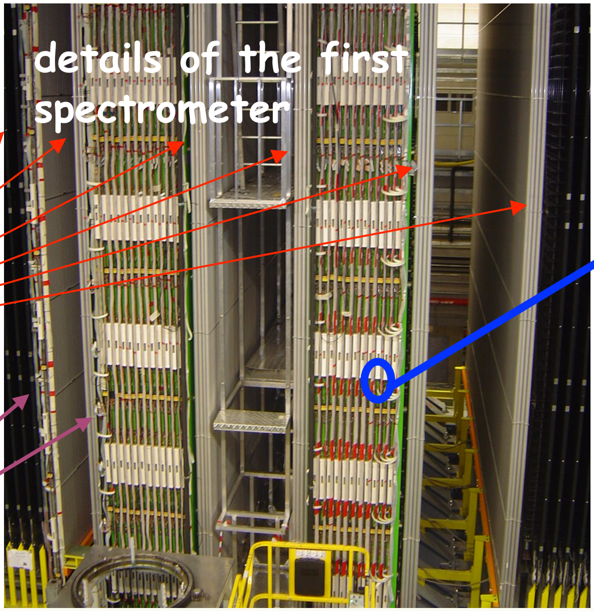
The magnetic spectrometer as a muon detector (OPERA one is an option)

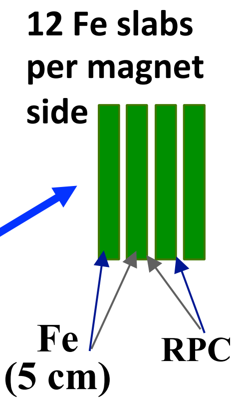
One spectrometer is composed by:
1 dipolar magnet (1.52 T)
22 RPC layers as inner tracker inside magnetized iron
6 drift tubes stations (PT stations)
2 external XPC stations (RPCs with strips at ±43°)

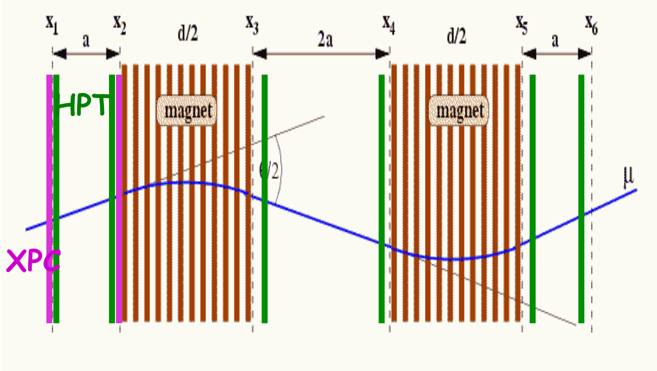


Precision Trackers (drift tubes)

XPCs







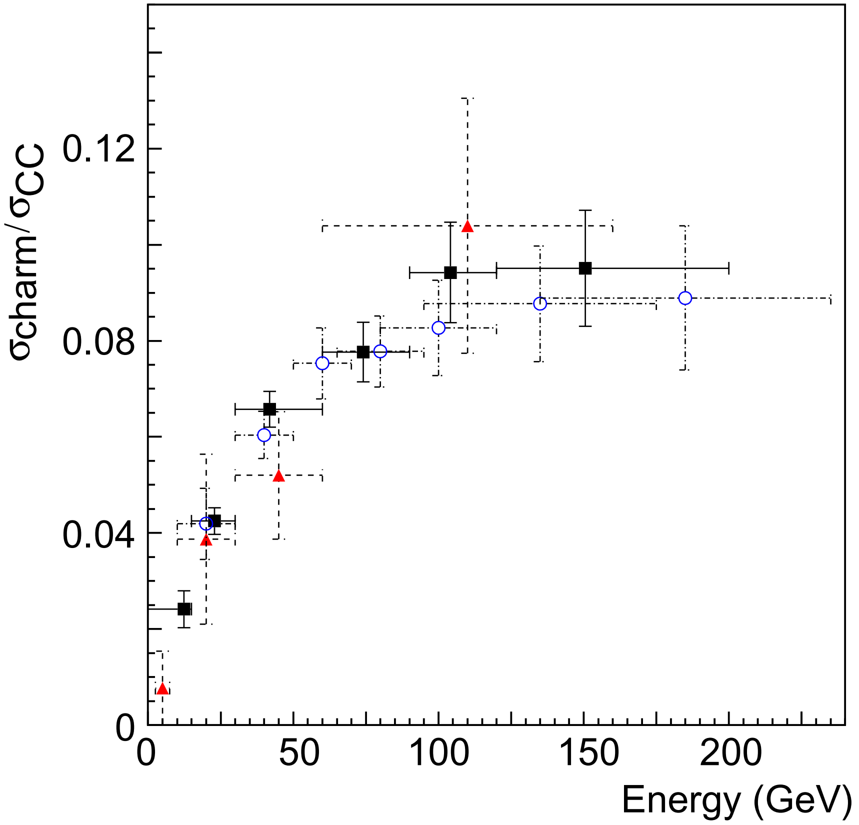
Charm bkg rejection in ν_μ CC events

Muon identification (with TT) > 95%

$\Delta p/p < 20\%$ for $p<30$ GeV

Charge misidentification < 0.3%

ν-induced charm production



CHORUS , New Journal of Physics 13 (2011) 093002

$$f(charm) = \frac{\int \Phi_{\nu_\mu} \sigma^{CC}_{\nu_\mu} \left(\frac{\sigma_{charm}}{\sigma^{CC}_{\nu_\mu}} \right) dE}{\int \Phi_{\nu_\mu} \sigma^{CC}_{\nu_\mu} dE} \approx 2\%$$

In ν_μ interactions: σ_{charm} ~ 2%, ~ 11000 charm

In anti-ν_μ interactions:
anti-ν_μ /ν_μ ~ 63%, $\sigma_{\nu\text{-bar}}/\sigma_\nu$ = 0.5 ~ 3500 events
only 32 observed by CHORUS

- Strange quark content obtained by the comparison of charm production in neutrino and anti-neutrino interactions
- Charm production with electronic detector tagged by dimuon events (high energy cut to reduce background): insensitive to the low energy region, slow-rescaling threshold → charm quark mass

Search for multi-quark states in ν interactions: charmed pentaquarks

Weakly decaying charmed hadron (below 2.8 GeV)

Unlike other processes like e+ e- scattering, the θ^0_c production in anti-neutrino interactions is favoured by the presence of three valence quarks

G. De Lellis et al. / Nuclear Physics B 763 (2007) 268–282

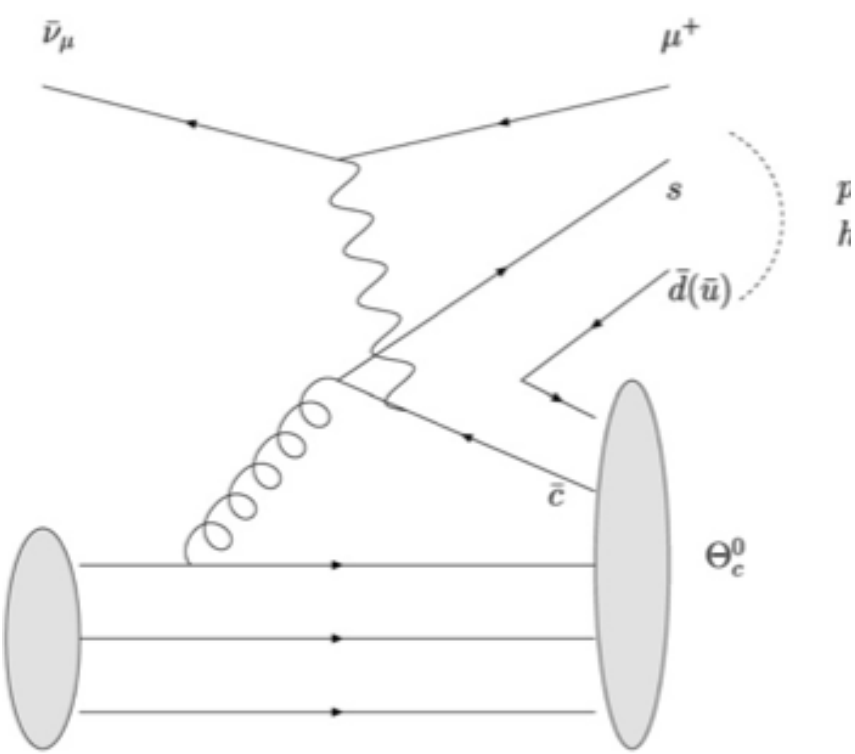


Fig. 1. Θ_c^0 production in $\bar{\nu}_\mu$ interactions.

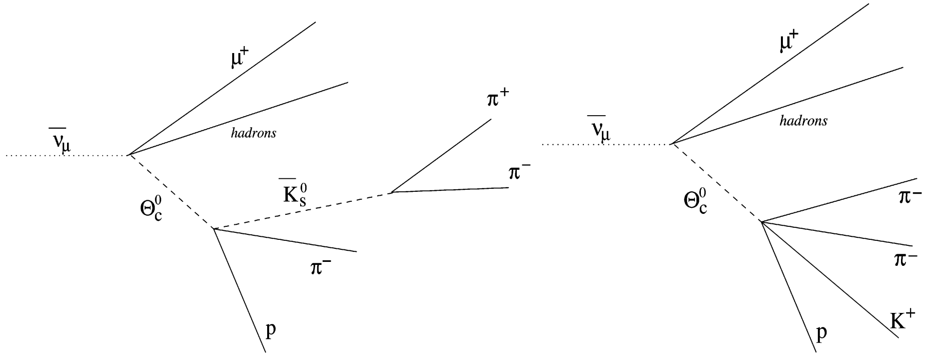


Fig. 2. Decay topology of Θ_c^0 events produced in $\bar{\nu}_\mu$ interactions with two and four prongs.

$$\sigma_{\Theta_c^0}/\sigma_{\bar{\nu}} < 0.039 \text{ at } 90\% \text{ C.L.}$$

lifetime equal to $0.5\tau_{D^0}$

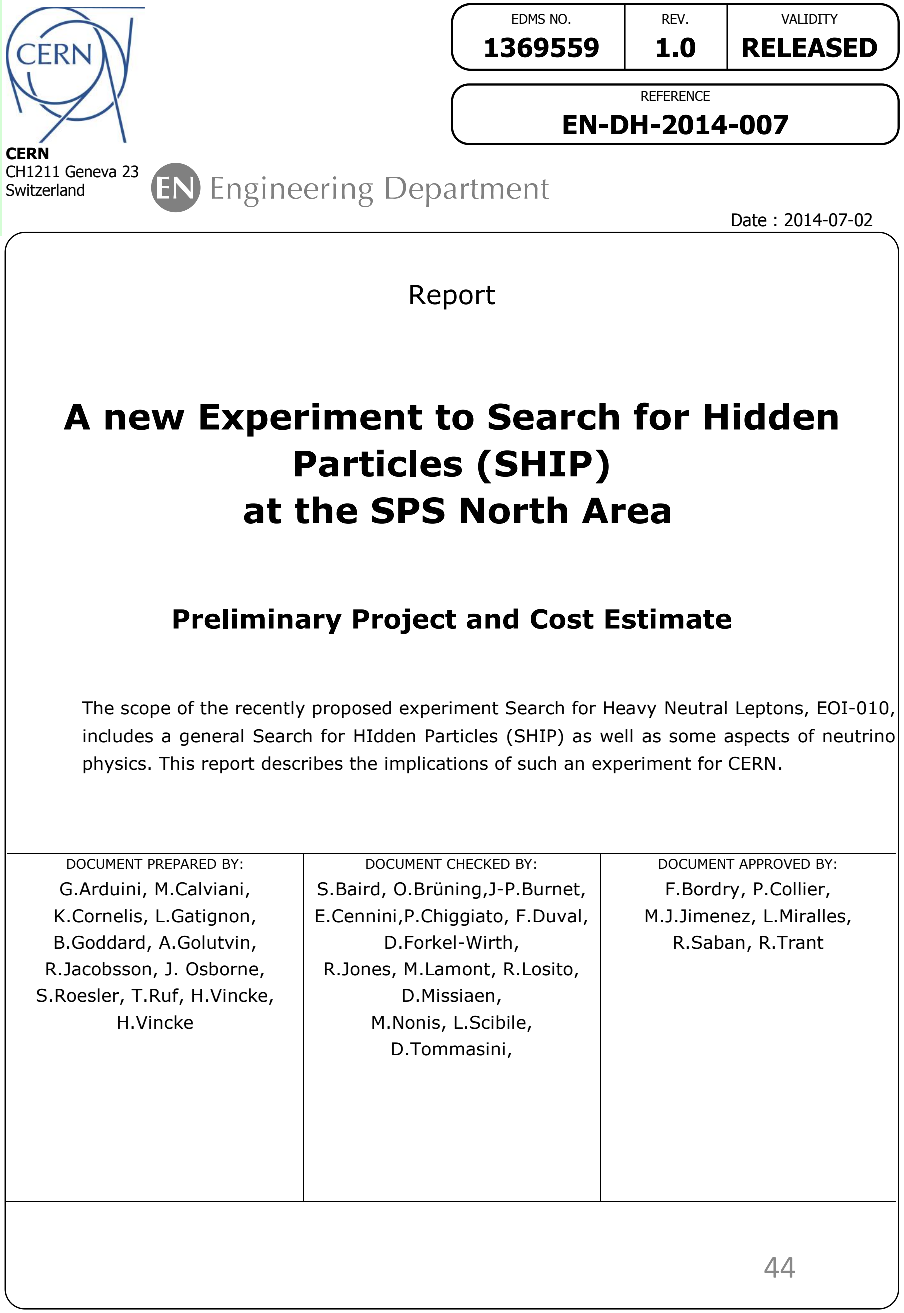
Not a tight bound, larger than D^0 prod,
Limited by the anti-nu statistics

SHiP: 2 orders of magnitude better

CERN task force to evaluate required infrastructure

- Following the SPSC encouragement in January 2014, CERN DG formed a dedicated Task Force
- The Task Force report (80 pages) published and discussed at the extended CERN directorate meeting on July 18th
- Detailed cost, manpower and schedule
- Encouraged to go ahead and report a Technical Proposal by next Spring

SHiP is currently a collaboration of 44 Institutes from 13 Countries
Bulgaria, Chile, Denmark, France, Germany, Italy, Japan, Russia, Sweden, Switzerland, Turkey, UK, USA.



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EN Engineering Department

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1369559	**1.0**	**RELEASED**

REFERENCE
EN-DH-2014-007

Date : 2014-07-02

Report

A new Experiment to Search for Hidden Particles (SHIP) at the SPS North Area

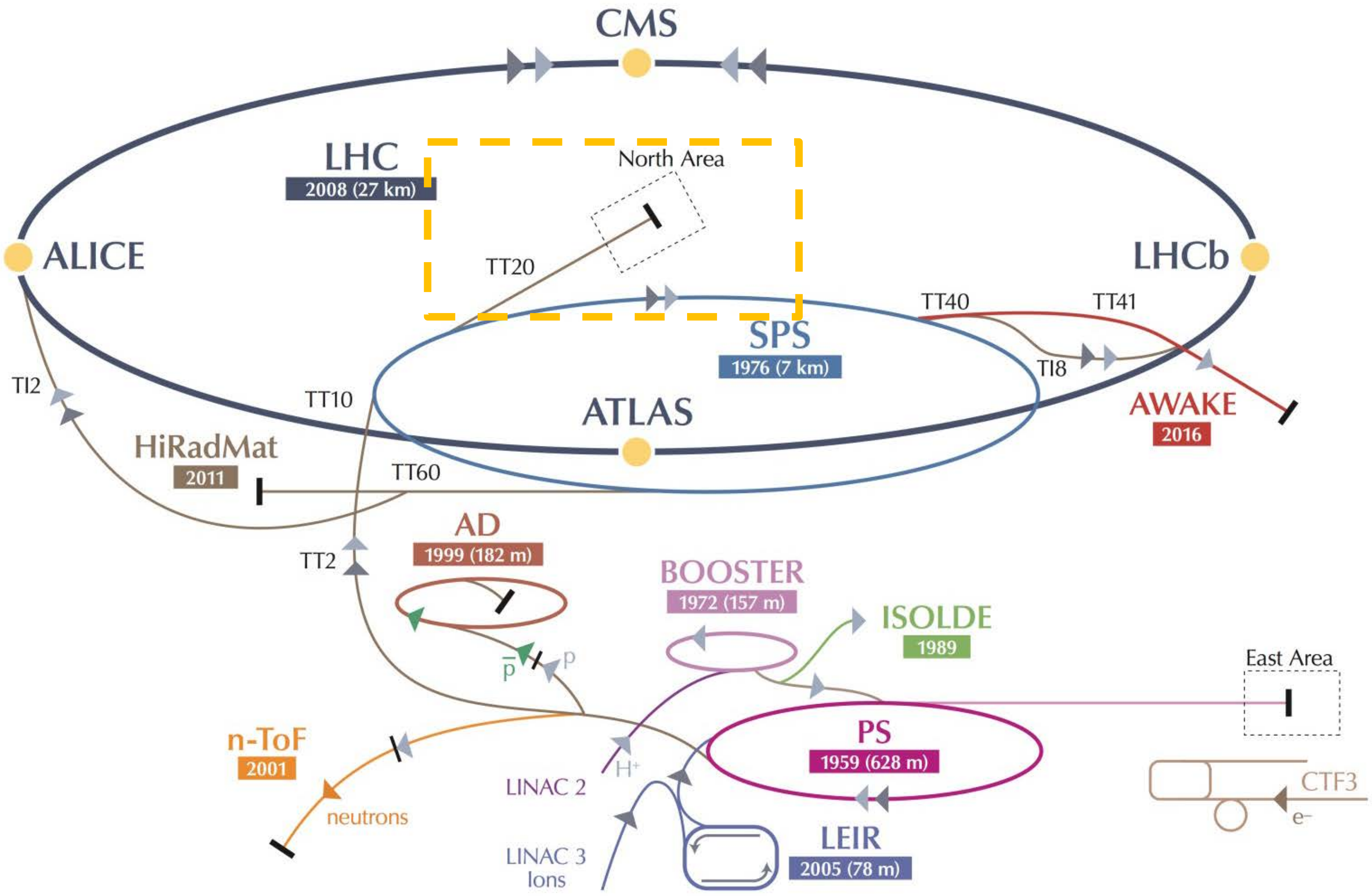
Preliminary Project and Cost Estimate

The scope of the recently proposed experiment Search for Heavy Neutral Leptons, EOI-010, includes a general Search for HIdden Particles (SHIP) as well as some aspects of neutrino physics. This report describes the implications of such an experiment for CERN.

DOCUMENT PREPARED BY:	DOCUMENT CHECKED BY:	DOCUMENT APPROVED BY:
G.Arduini, M.Calviani, K.Cornelis, L.Gatignon, B.Goddard, A.Golutvin, R.Jacobsson, J. Osborne, S.Roesler, T.Ruf, H.Vincke, H.Vincke	S.Baird, O.Brüning,J-P.Burnet, E.Cennini,P.Chiggiato, F.Duval, D.Forkel-Wirth, R.Jones, M.Lamont, R.Losito, D.Missiaen, M.Nonis, L.Scibile, D.Tommasini,	F.Bordry, P.Collier, M.J.Jimenez, L.Miralles, R.Saban, R.Trant

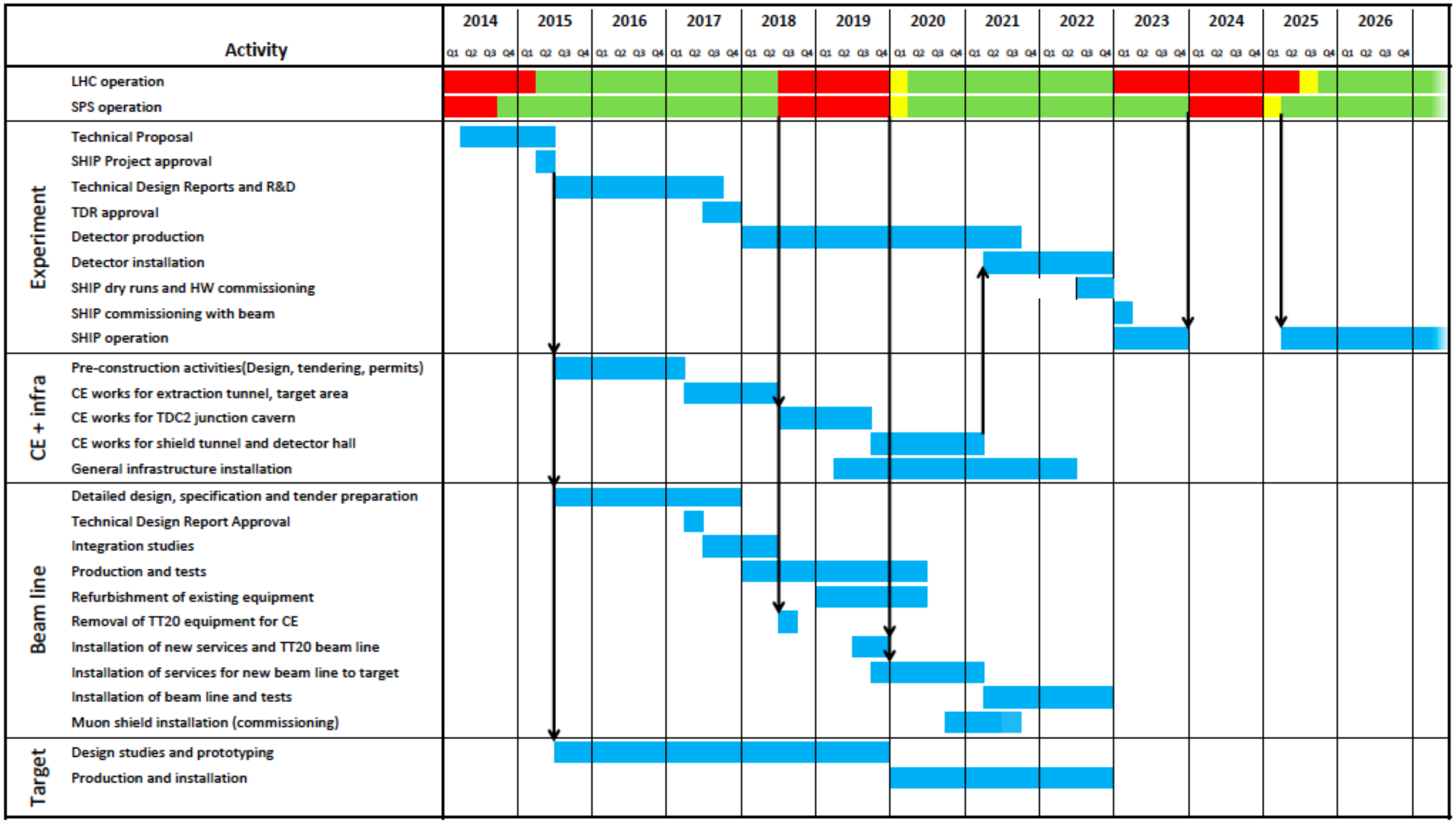
CERN Accelerator complex

proposed location by CERN beams and support department



Prevessin North Area from task force report

Planning schedule of the SHIP facility



	Activity
	LHC operation
	SPS operation
Experiment	Technical Proposal
	SHIP Project approval
	Technical Design Reports and R&D
	TDR approval
	Detector production
	Detector installation
	SHIP dry runs and HW commissioning
	SHIP commissioning with beam
	SHIP operation
CE + infra	Pre-construction activities(Design, tendering, permits)
	CE works for extraction tunnel, target area
	CE works for TDC2 junction cavern
	CE works for shield tunnel and detector hall
	General infrastructure installation
Beam line	Detailed design, specification and tender preparation
	Technical Design Report Approval
	Integration studies
	Production and tests
	Refurbishment of existing equipment
	Removal of TT20 equipment for CE
	Installation of new services and TT20 beam line
	Installation of services for new beam line to target
	Installation of beam line and tests
	Muon shield installation (commissioning)
Target	Design studies and prototyping
	Production and installation

A few milestones:

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

Theoretical paper: exploiting physics case

2 Physics case

- 2.1 Tau neutrino physics
- 2.2 Neutrino portal
  - 2.2.1 Particle physics notations
  - 2.2.2 Seesaw Lagrangian
  - 2.2.3 Seesaw formula and scale of seesaw
  - 2.2.4 Dirac and Majorana masses: HNL phenomenology
  - 2.2.5 HNL and baryon asymmetry of the Universe
  - 2.2.6 HNL and dark matter
  - 2.2.7 νMSM
  - 2.2.8 HNL in astrophysics
- 2.3 Vector portal
  - 2.3.1 Dark photons
  - 2.3.2 Z'
  - 2.3.3 Millicharge fermions
  - 2.3.4 Chern-Simons portal
- 2.4 Scalar portal
  - 2.4.1 2HDM, 3HDM
- 2.5 Axion-like particles
- 2.6 SUSY models
  - 2.6.1 R-parity violating models
  - 2.6.2 Sgoldstino

F. Tramontano

M. Shaposhnikov

F. Vissani

Maxim Pospelov

Christophe Grojean

Joerg Jaeckel

Tau neutrino physics

- S. Alekhin, Protvino, Higher order QCD corrections for DIS, strangeness, α_s, global fit sensitivity (ABMPDF)
- A. Guffanti, Copenhagen, Strangeness, α_s determination, global fit sensitivity (NNPDF)
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Conclusions

- Searches for new physics beyond SM: explore the high intensity frontier
- SM guaranteed physics program: $\bar{\nu}_\tau$ discovery, ν_τ cross-section studies and more
- Technical proposal in preparation (Spring 2015)