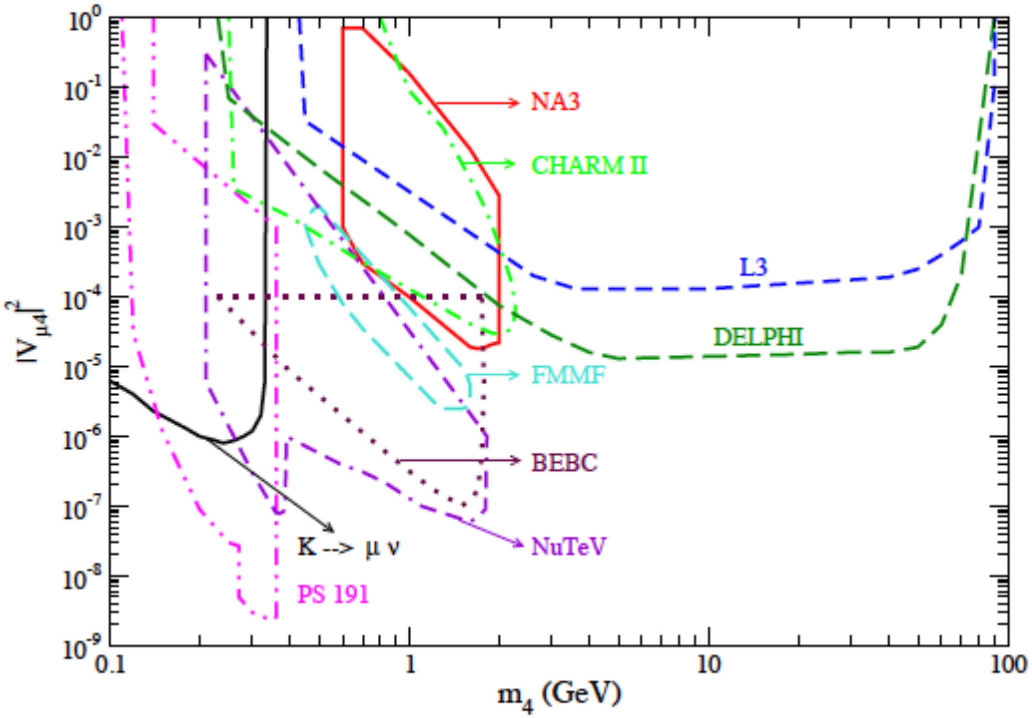
Andrey Golutvin
Imperial College London
(Interim spokesperson)

*Experiment to **S**earch for **Hi**dden **P**articles at the SPS/CERN*



From arXiv:0901.3589, Atre et al

Physics case

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

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

- ✓ ***No signs of NP seen at $\sqrt{s}$ = 8 TeV***
  $M_{NP} > 10^4$ TeV from observables in neutral meson mixing
  (for generic Yukawa coupling)

- ✓ ***Strong motivation to search for BSM physics***
  - *Plenty of scope for New Particles to have light masses but very weakly interacting (hidden) portals: vector, higgs, neutrino or axion-like*
  - ***New possibilities in intensity frontier (SHIP facility) at the SPS/CERN***
    " beam-dump " is an ideal instrument to search for hidden particles
    SPS can provide ~2×10^{20} pot in 4-5 years assuming the same operation as has been demonstrated during CNGS run → data sample with $>10^{17}$ D, $>10^{15}$ τ !

Main objectives in physics

- ✓ *Explore hidden portals of the SM using > 2×10^{20} p.o.t. (>10^{17} D, >10^{15} τ)*

  A few examples in next slides for:

  - *Heavy Neutral Leptons (HNL) in various final states*
  - *Dark photons*
  - *Low energy SUSY*

- ✓ *Neutrino interactions (expect ~3500 ν_τ interactions in 6 tons emulsion target)*

  - *SM ν_τ and anti-ν_τ physics*
  - *Search for New Physics in ν_τ scattering* A. Datta et al., PRD 87 (2013) 013002

- ✓ *New ideas on physics with muons, exploring reach for e.g. $\tau \rightarrow \mu\mu\mu$ and D $\rightarrow \mu\mu$*

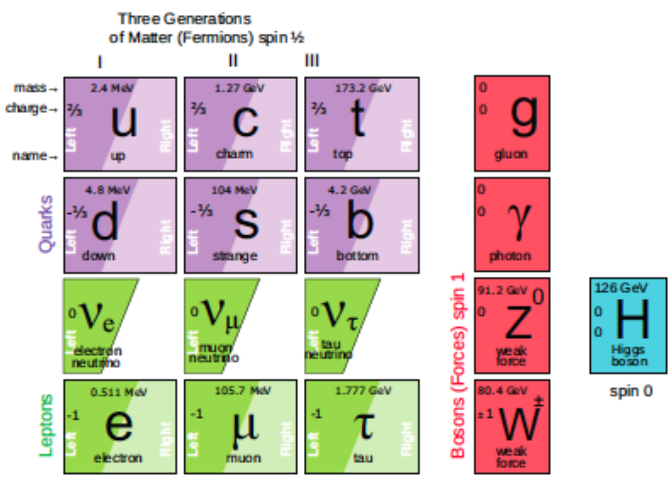
- ✓ *By adding massive ν-type detector SHIP can also have interesting sensitivity to Dark Matter detection through its neutrino-type interactions*

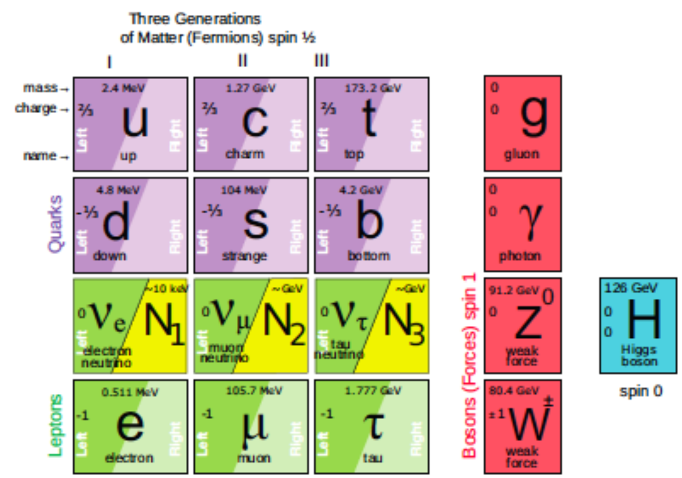
Heavy Neutral Leptons

Minkowski, Yanagida, Gell-Mann, Ramond, Slansky, Glashow, Mohapatra, G. Senjanovic + too many names to write…

- ✓ *Heavy Neutral Lepton (HNL) is simplest and most elegant way to accommodate non-zero neutrino mass in the SM*

- ✓ ***νMSM*** *(T.Asaka, M.Shaposhnikov PL* ***B620*** *(2005) 17) can also explain Dark matter and Baryon dominated Universe by adding 3 HNL:* ***N_1, N_2 and N_3***





- ✓ *N_1 plays a role of DM candidate*
  $M(N_1)$ ~ a few keV

- ✓ *$N_{2,3}$ explain BAU and non-zero neutrino mass (using see-saw mechanism)*
  $M(N_{2,3}$) ~ a few GeV

Heavy Neutral Leptons: N_1

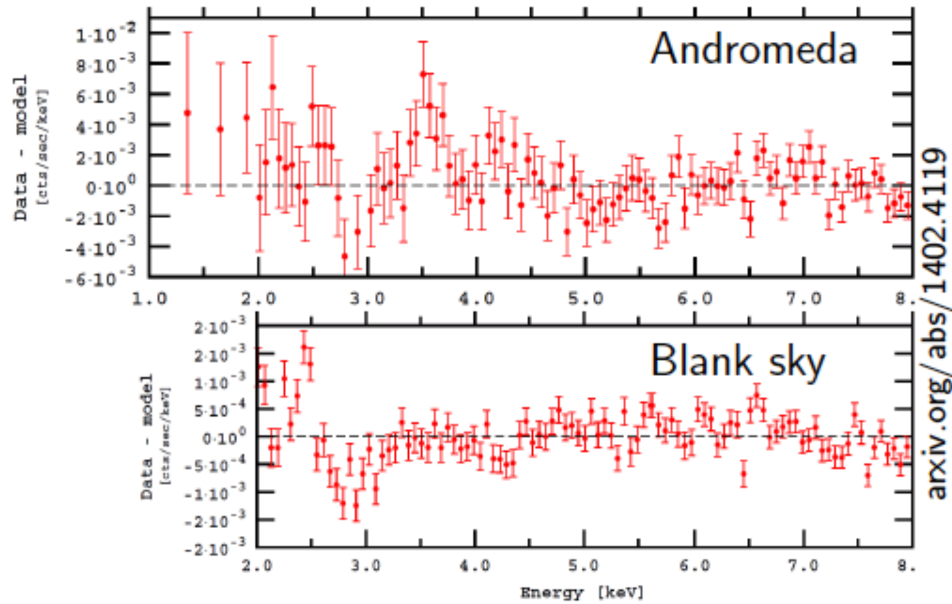
✓ *N_1 should be sufficiently stable*
  → *super-weak N_1-to-ν mixing such that $\tau(N_1) > \tau(\text{Universe})$*

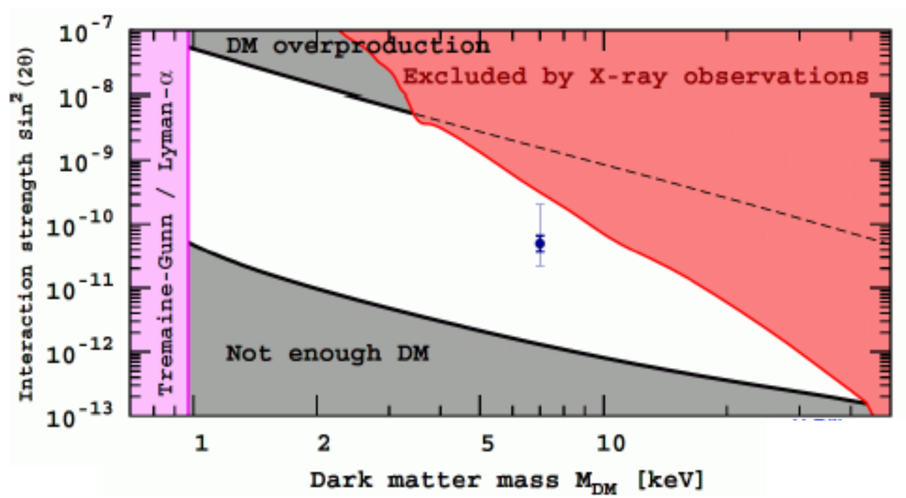
Observable decay mode: $N_1 \rightarrow \nu\gamma$
  → *search for mono-line in galactic photon spectrum*

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 the Astro-H mission (to be launched in 2015) with better energy resolution, $\Delta E/E \sim 0.1\%$

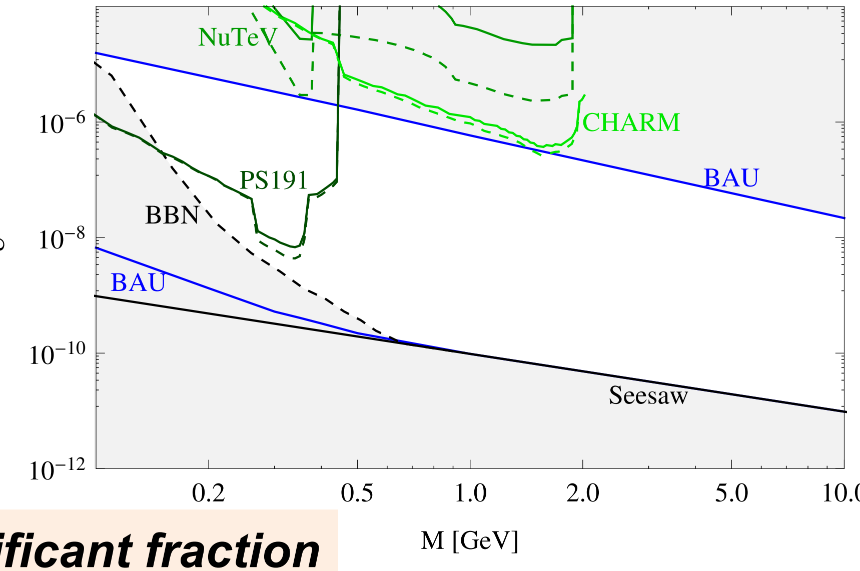




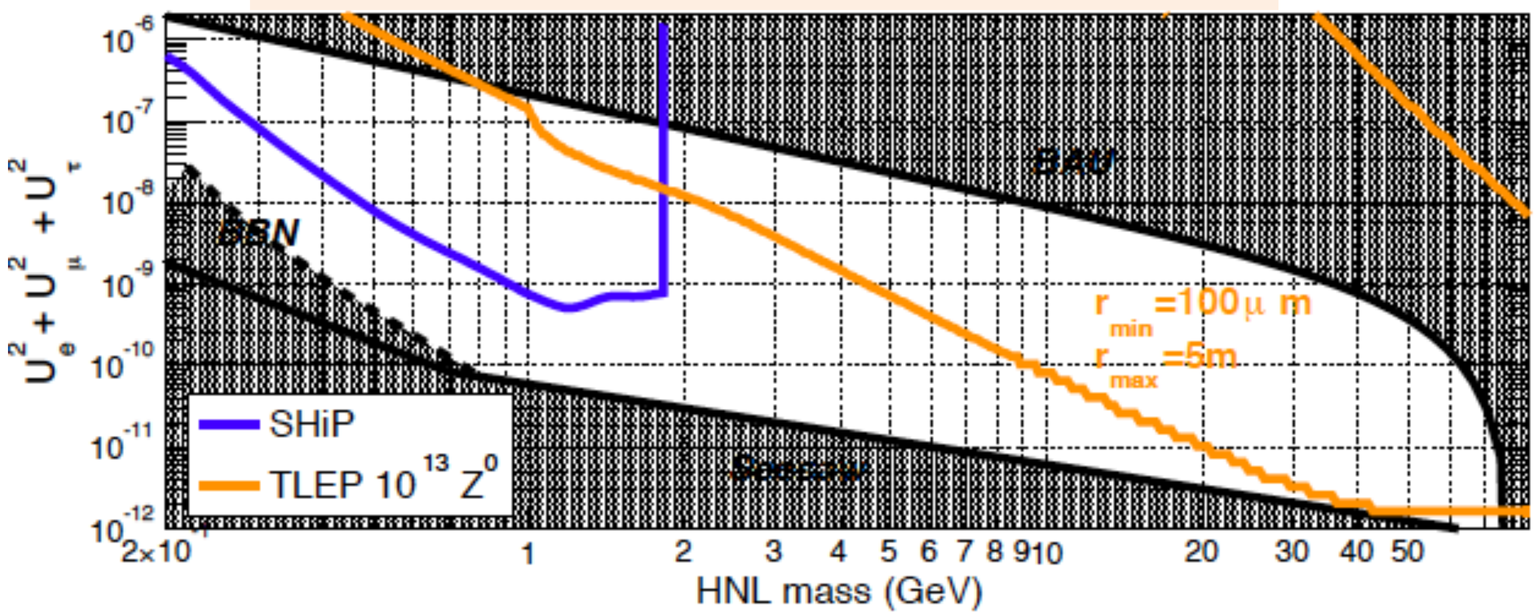
Heavy Neutral Leptons: $N_{2,3}$

Advances in theoretical understanding give bounds on HNL mixing

- ✓ *Additional phases due to Majorana nature of $N_{2,3}$ → CPV can be increased dramatically and can explain BAU !*
- ✓ *Very weak $N_{2,3}$-to-ν mixing (~ U^2) → $N_{2,3}$ are much longer-lived than the SM particles*



SHIP will be sensitive to significant fraction of preferred parameter space



Sensitivity to Dark photons

(messengers between our world and dark sector)

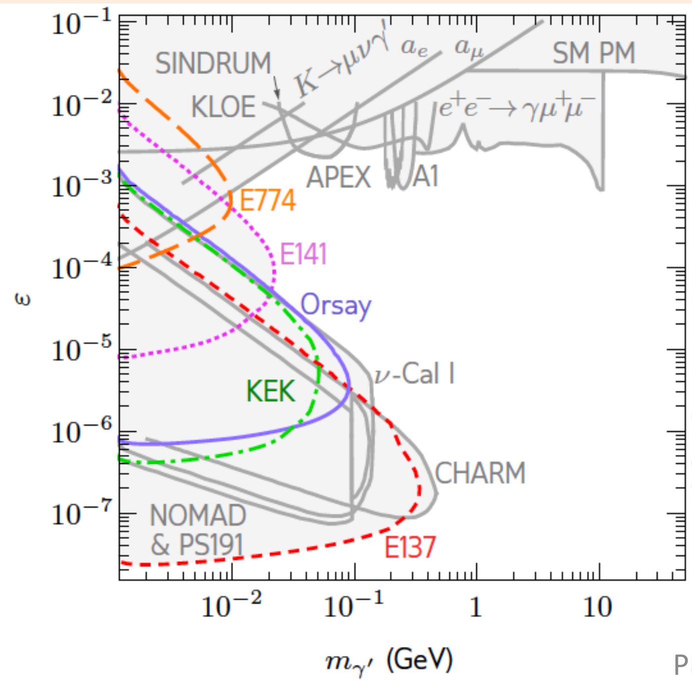
Mirror matter: P, C and PC are not conserved → introduce the symmetry between left and right mirror particles

(Okun, Voloshin, Ellis, Schwarrz, Tyupkin, Kolb, Turner, Georgi, Ginsparg, Glashow, …)

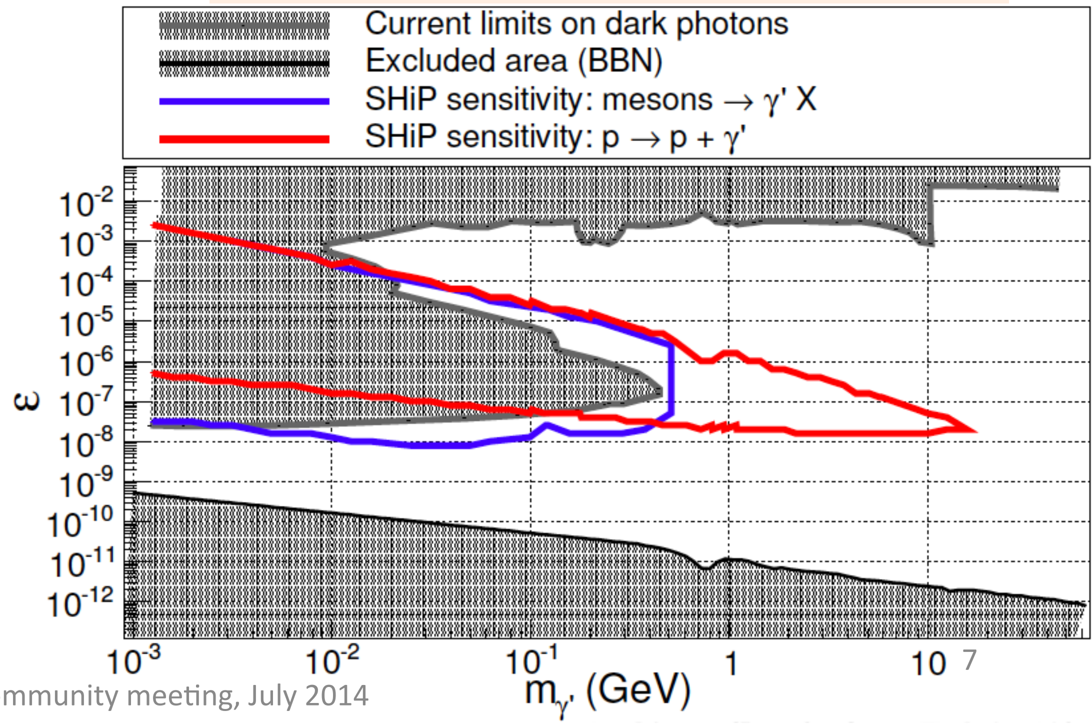
Even more general approach: dark sector may have complicated structure, not associated with ideas of mirror symmetry

(e.g. "SuperUnified theory of Dark Matter" by Arkani-Hamed and Weiner)

Previous experimental constraints

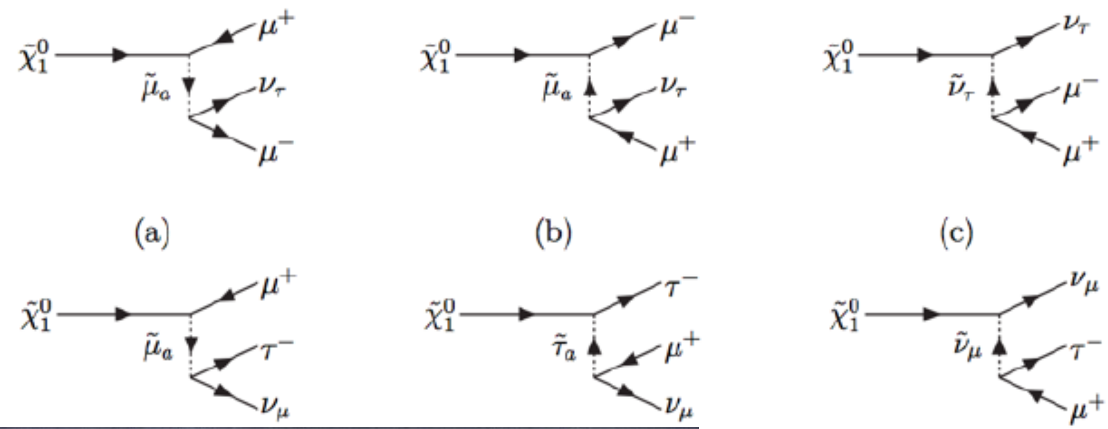


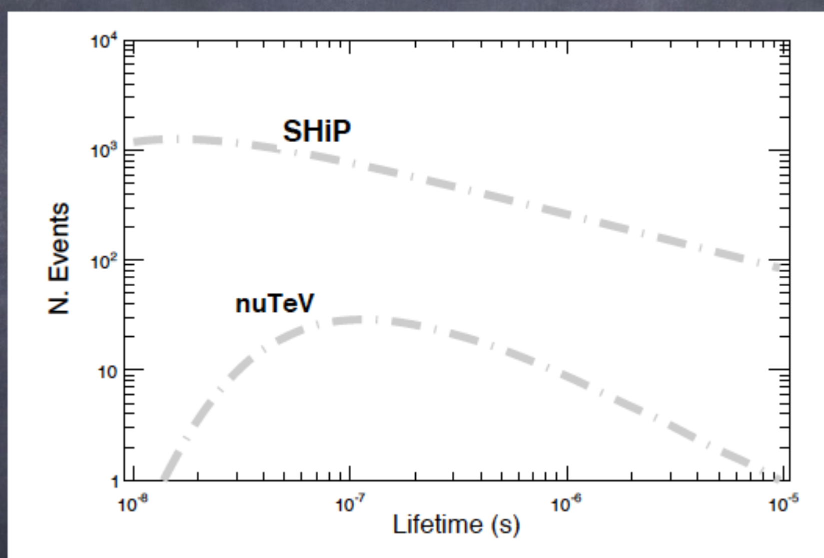
SHIP sensitivity reach at 90% CL with 2× 10^{20} pot



Light SUSY neutralinos

- ✓ *Can be produced in charm decays, e.g.* $D^0 \rightarrow \nu\,\chi_0$, $D^+ \rightarrow \mu^+\,\chi_0$
- ✓ *Decay final states:*





Number of events for $BR(B^+ \to \ell^+\chi_0) = 10^{-7}$ which is equivalent to $BR(D^+ \to \ell^+\chi_0) = 10^{-9}$ and $\chi \to \ell^+\ell^-\nu$

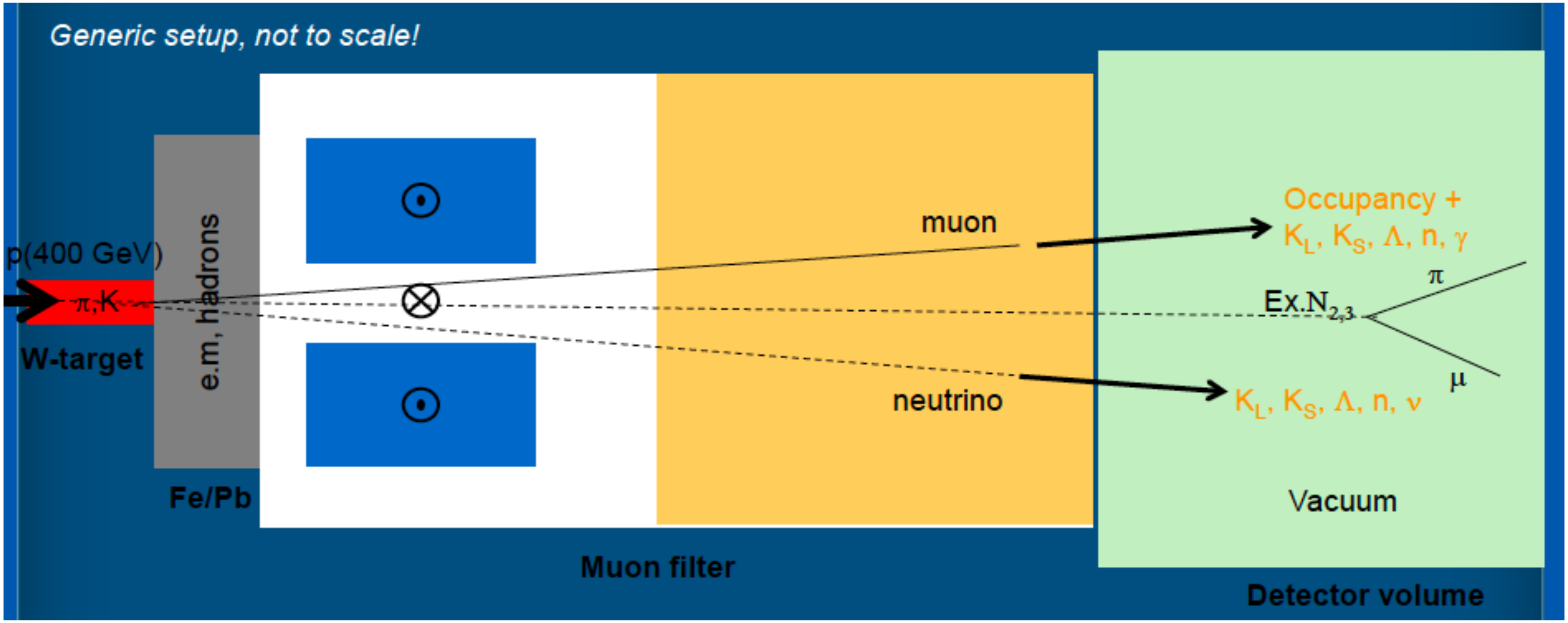
SHIP experimental area

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 $10\mu s$ → < 500 muons

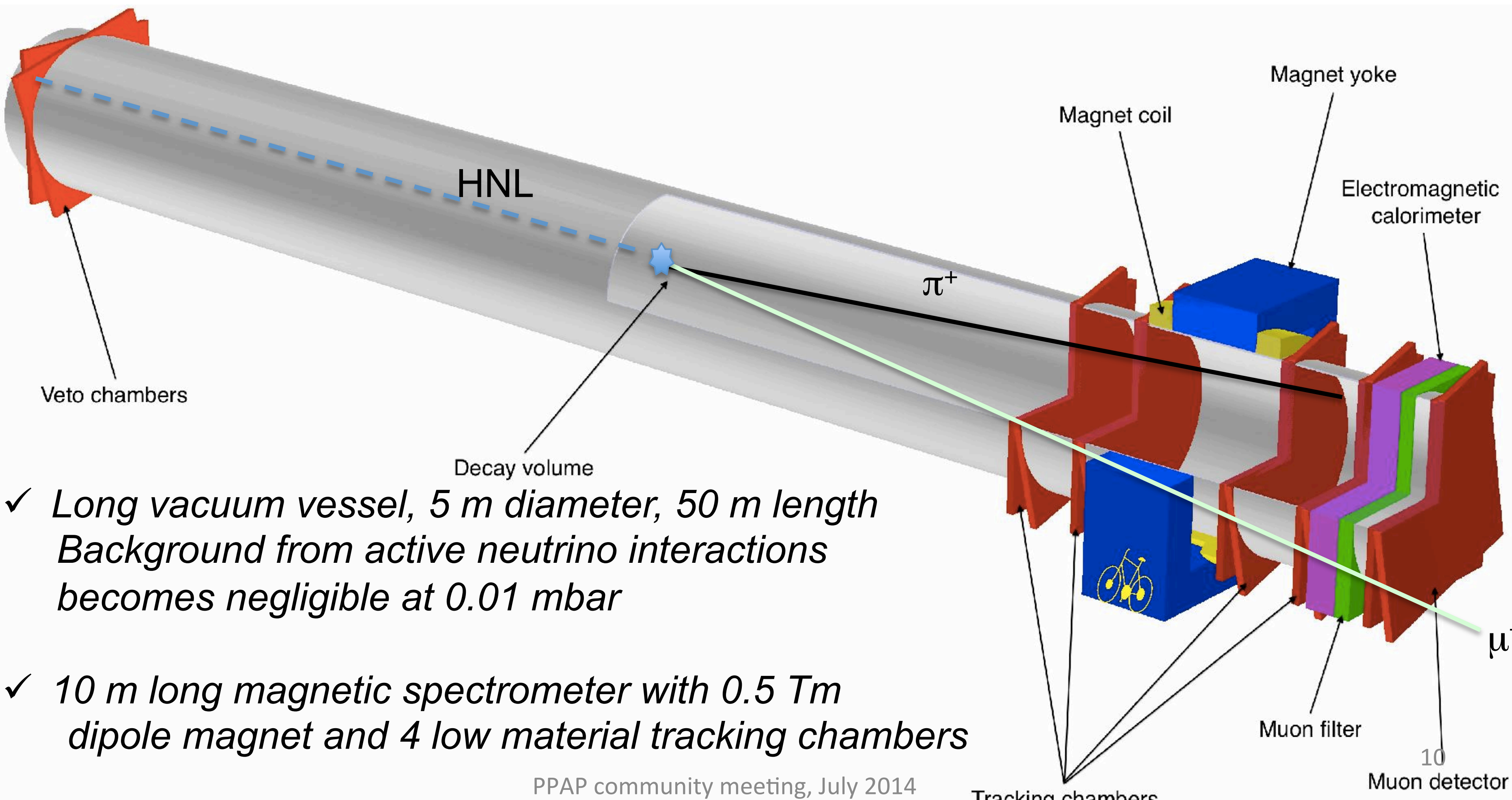


Proper optimization of the muon shield is one of the key issues!

Initial detector concept

Detector uses existing technologies and would require a modest R&D phase

Main elements: *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*

Status of the SHIP review by the SPSC

- ✓ *EoI submitted to the SPSC (CERN-SPSC-2013-024, arXiv 1310.1762) and presented at its open session*

  → *October 2013*

- ✓ *SPSC assigned 4 referees who asked a number of questions*

- ✓ *Response to the questions snoopy.web.cern.ch/snoopy/EOI/SPSC-EOI-010_ResponseToReferees.pdf*

  → *January 3, 2014*

- ✓ *Official feedback from the SPSC* → *January 17, 2014*

"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."

CERN Task Force to evaluate required infrastructure

- ✓ *Following SPSC review, CERN DG has formed a dedicated Task Force to evaluate required infrastructure*
- ✓ *The Task Force report published and discussed at the extended CERN directorate meeting on July 18*

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EN Engineering Department

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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.

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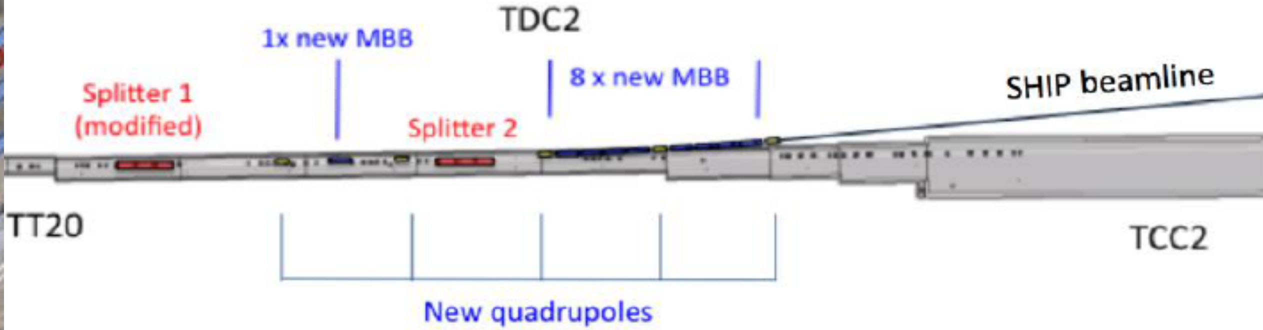
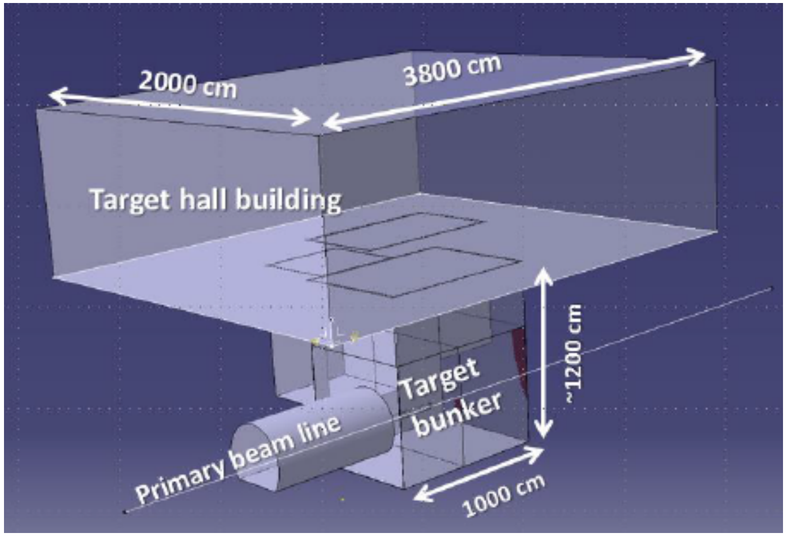
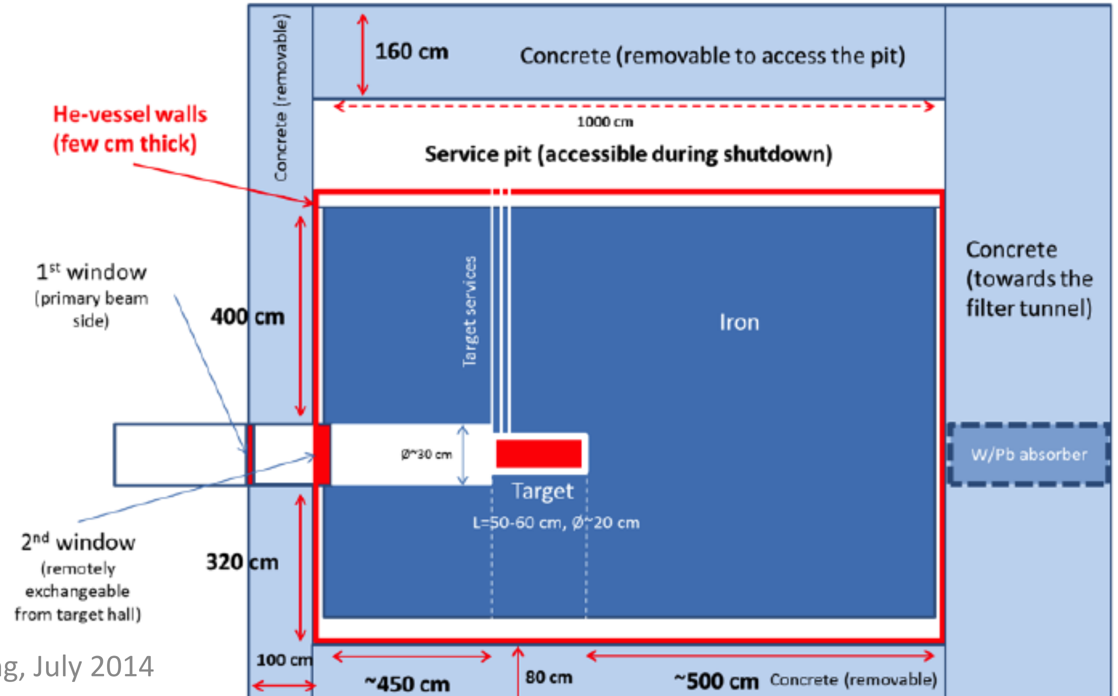
SHIP experimental area

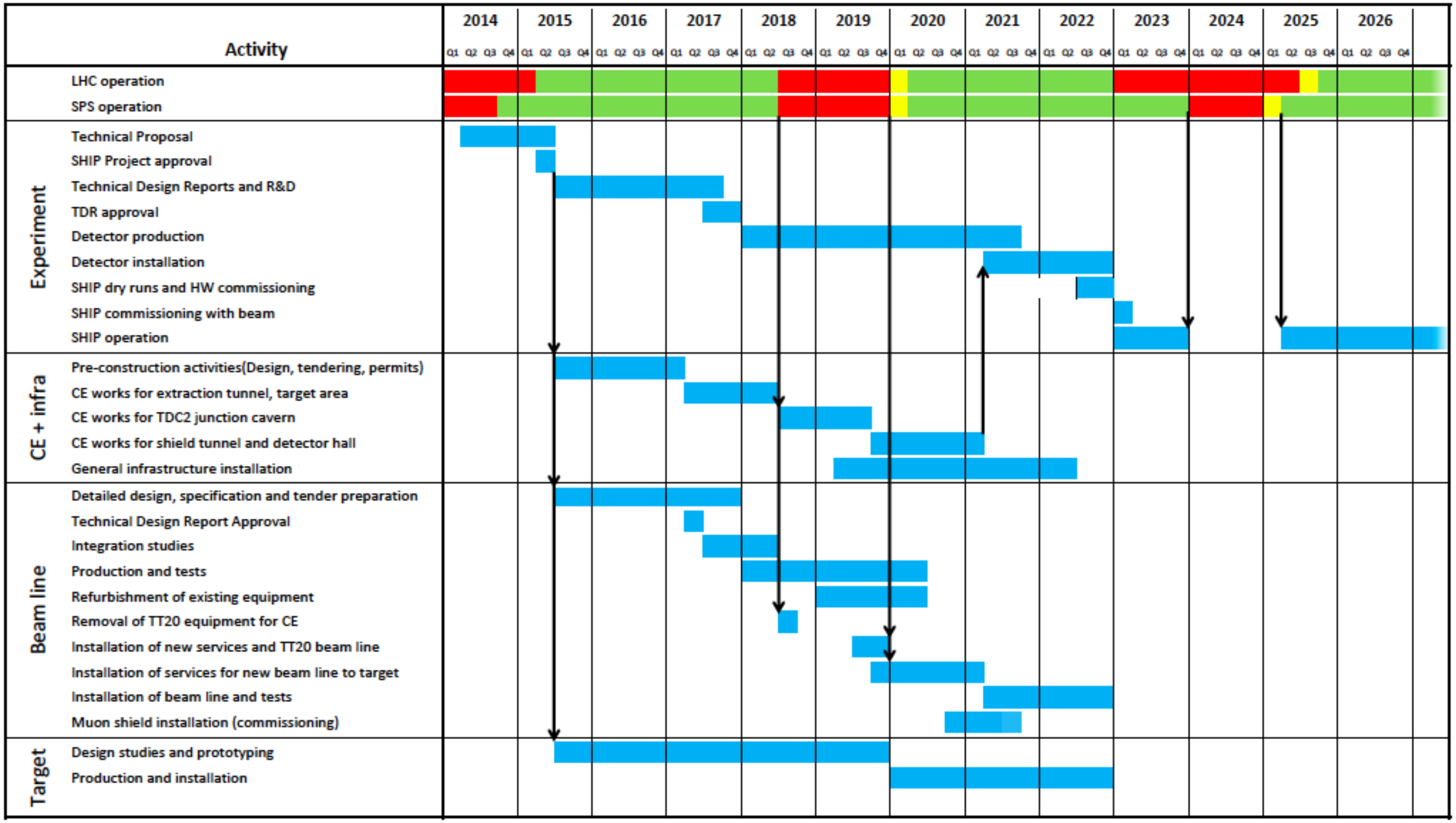


Detailed civil engineering and target station plan evaluated by relevant CERN divisions





Planning schedule of the SHIP facility



A few milestones:

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

SHIP proto-collaboration

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

- ✓ *43 groups from 15 countries expressed an interest to join, **including 5 groups from UK: Imperial College London, University of Liverpool, University College London, University of Manchester and University of Warwick***
  So far we have visited 7 UK institutes with seminars, plan more seminars

- ✓ ***Next SHIP collaboration meeting at CERN on September 24-25th***

Summary

- ✓ *SHIP is proposed to search for NP in the largely unexplored domain of new, very weakly interacting particles with masses below the Fermi scale*
- ✓ *Ongoing discussions with interested groups and with CERN experts*
- ✓ ***The impact of the discovery of a new light particle is hard to overestimate !***
- ✓ ***SHIP will perfectly complement the searches for NP at the LHC and in neutrino physics***
- ✓ *Possible contribution of UK groups is currently being discussed*
  Clear interest in developing physics case, optimization of the muon shield, trigger/DAQ, core software, scint./light-sensor detectors, …

We are actively looking for new collaborators in the UK
Please let us know if you are interested to join !

BACK-UP Slides

Very preliminary cost and manpower estimates

Item	Cost [MCHF]
Extraction and proton beam line	19.9
Extraction upgrades, beam interlock	0.4
New MSSB splitter/switch magnets	4.2
Other magnets	1.6
Powering, including cables	6.0
Beam vacuum	3.0
Beam instrumentation	1.9
Beam interlocks	0.4
Other beam line costs	2.4
Target Station	17.1
Target (+spare) plus exchange system	4.6
Hadron absorber	8.1
Helium enclosure of target station	2.0
Removable shielding	0.5
Controls	0.9
Prototypes and testing	1.0
Muon filter	11.0
Muon shield, passive option, reusing 800 t of lead from OPERA	11.0
Civil Engineering	45.1
Junction cavern	5.0
Extraction tunnel	8.4
Target cavern	8.9
Muon filter tunnel	1.9
Experimental cavern	15.1
New access road	0.9
Site investigation	0.2
Studies	0.7
Contingency	4.0
Infrastructure	20.8
Cooling plants	4.9
Ventilation plants	5.1
Electrical infrastructure beam line zone	0.8
Electrical infrastructure target area and muon filter	1.4
Electrical infrastructure detector cavern	1.8
Access system beam lines, target and detector cavern	1.8
Safety systems	1.0
Radiation protection	1.5
Transport: cranes target station, detector cavern, shafts	1.9
Transport and handling	0.6
Total	**113.9**

Table 14: Material costs for the SHIP facility (excl. detectors), including the cost of fellows.

The cost of the SHIP detector is estimated to be ~45 MCHF incl. ν_τ detector

Item	Staff FTE	Fellows MCHF
Extraction and proton beam line	31.5	1.5
Extraction upgrades	1	0.1
New MSSB splitter/switch magnets	3	0.2
Other magnets	2	
Powering, including cables	12	
Beam vacuum	2	0.2
Beam instrumentation	4	0.4
Interlocks	1	
Other beam line costs	6.5	0.6
Target Station	35	1.6
Target (+spare) & exchange syst		0.6
Hadron absorber		0.6
Helium enclosure of target station	35	
Removable shielding		
Controls		0.4
Prototypes and testing		
Muon filter		
Muon shield, passive opt.,OPERA PB		
Civil Engineering	10	0.7
Junction cavern		
Extraction tunnel		
Target cavern		
Muon filter tunnel	10	0.7
Experimental cavern		
New access road		
Site investigation		
Infrastructure	14.4	1.2
Cooling plants	3.0	
Ventilation plants	2.0	
Electrical infrastructure	1.3	0.8
Access &safety beam lines+detector	1.5	
Safety systems	1.3	
Radiation protection	4.0	0.4
Transport : cranes, lifts, tooling	1.3	
Total	**90.9**	**5.0**

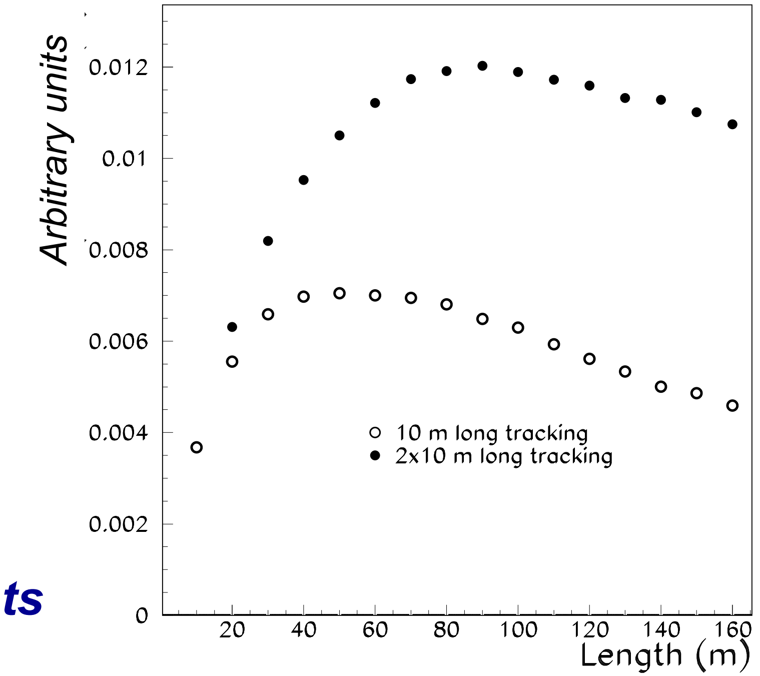
Table 15: Very preliminary manpower estimates for the SHIP project. Fellows are listed for information, but their cost is included in Table 14.

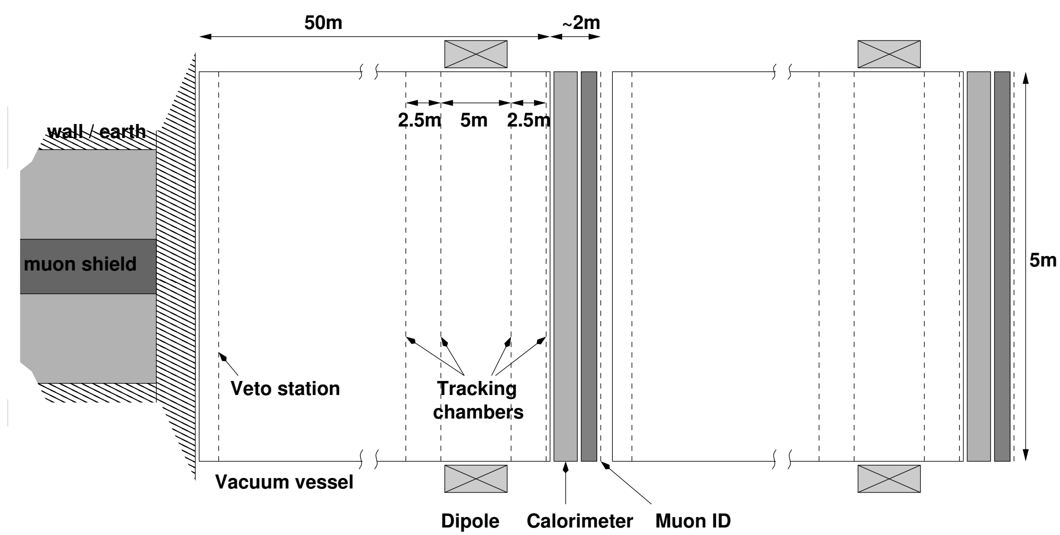
Initial detector concept

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

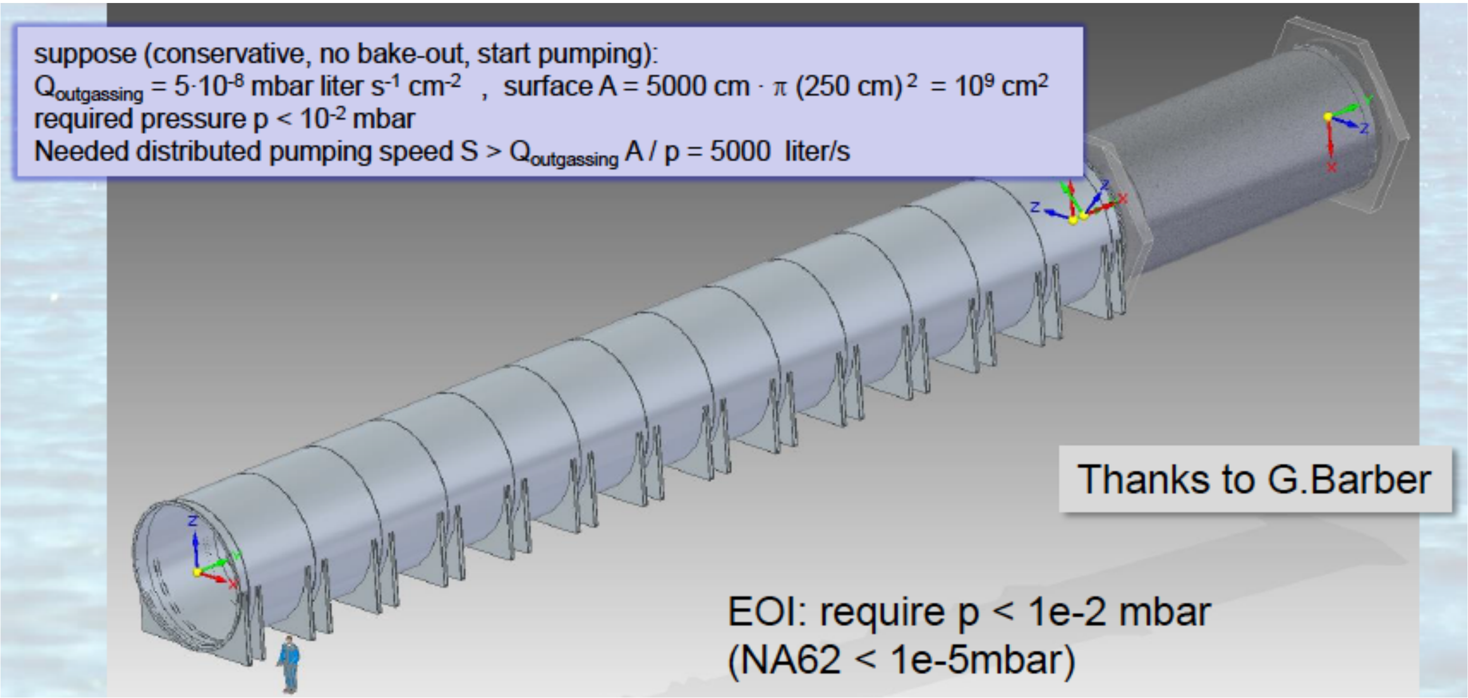




Vacuum vessel and Magnet

- ✓ *Need conceptual design, with properly addressed engineering issues (Modern submarine but not Noah's arc)*

- ✓ *Investigate an option with larger angular coverage, larger magnet aperture*



- ✓ *Design of the vessel flanges*
  Thinnest possible entrance window → can be useful for optimization of the VETO detectors outside of the vacuum vessel

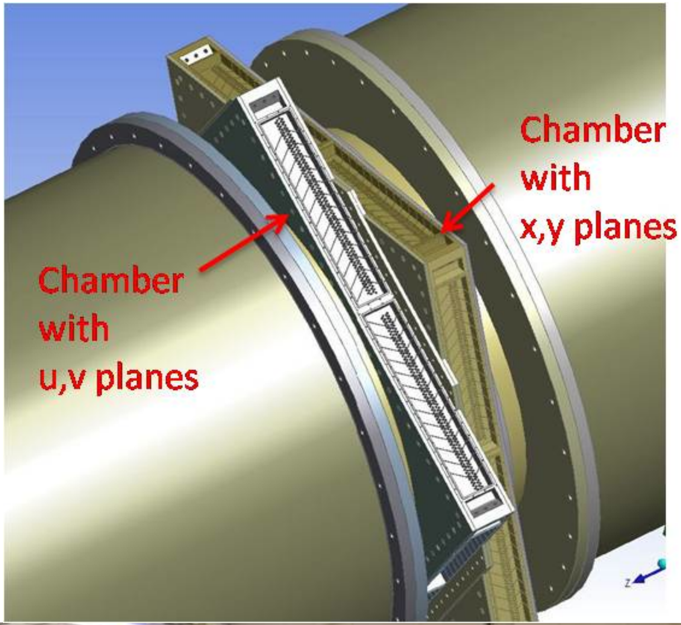
- ✓ *Vacuum system, possibility to pump down to 10^{-3} mbar*

Tracking spectrometer

- ✓ *Simple affordable dipole a la LHCb (0.5 Tm field integral should be sufficient for very light material budget)*
- ✓ *Current design is based on NA62 straw tube technology*

What needs to be modified:

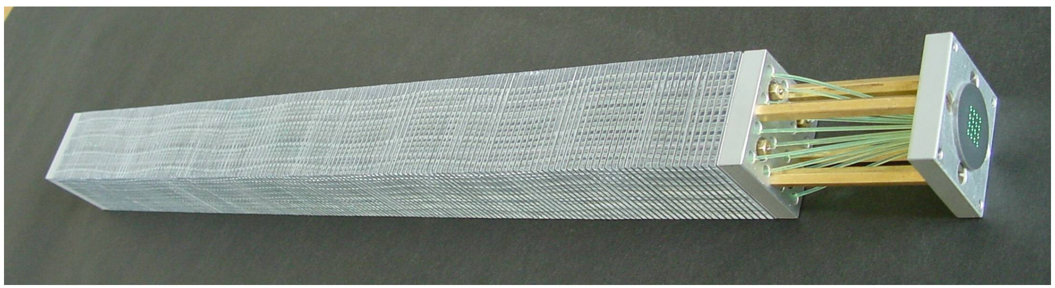
- *Length of the straws*
- *Configuration inside the layer. Vertical location in SHIP*
- *Can one improve two tracks resolution in time (up to ~30 ns)*



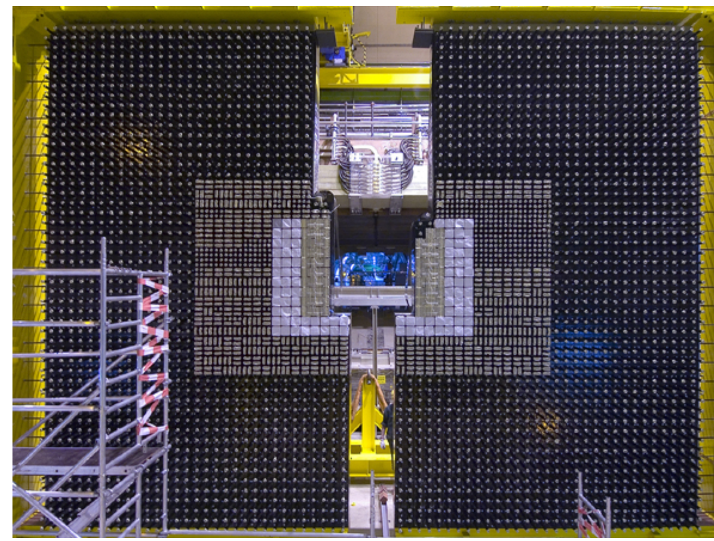
Calorimeter system & Muon detector

✓ *Current ideas are based on use of Shashlik calorimeter technology (demonstrated in many experiments, including LHCb and COMPASS)*

- Provides good energy resolution, well matching spectrometer momentum resolution for charged tracks, at modest cost



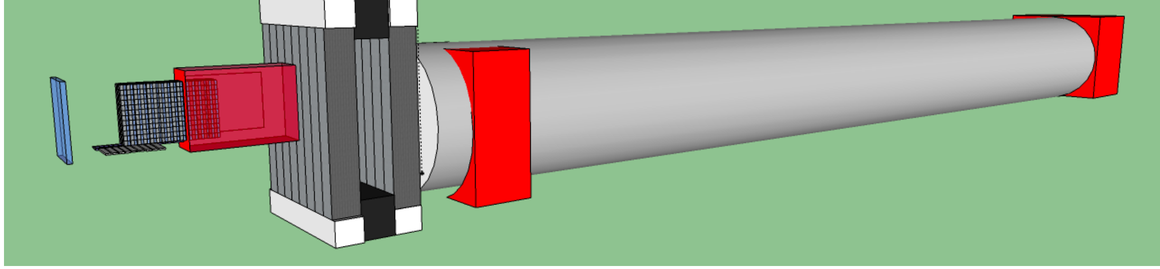
sampling ratio can be adjusted to achieve needed resolution



✓ *For the Muon detector two options are being currently discussed: scintillating strips with SiPM readout and RPC.*

✓ ***Careful optimization of the combined CALO and Muon detector performance to achieve best possible pion / muon discrimination***

ν_τ detector



Design issues:

- *neutrino flux calculation: better estimate of tau neutrino fluxes*
- *implement bricks/CES into simulation framework*
- *choice: magnetized/non-magnetized target area*
- *target geometry (depends on magnetization):*
  length vs depth of target
  CES details
  tracker choice and number of layers, etc…

Emulsion specific:

- *emulsion plate choice*
- *scanning technology*
- *scanning strategy*

Compare technologies for electronic detectors to measure muon charge and momentum, and to provide "time stamp"

- *SciFi option has a lot of similarity with the SciFi tracker for the LHCb upgrade*
- *Triple GEM option*

Collaboration matters

Three stages in the preparation of the experiment: first the work for the TP which should be completed early 2015, then the TDRs to be finished by 2018, and finally the construction to start data taking in 2022.

✓ ***Contribution to the Technical Proposal to be completed by March 2015***

This document requires mainly an intellectual contribution. The current detector choices are based on existing technologies, so no essential R&D is required for the TP. Expect a tangible contribution to the detector conceptual design, evaluation of the physics reach, or software, simulation and computing activities. If considered necessary by the group, this phase may also include eventual R&D and test beam activity

✓ ***Assuming that the TP is approved by the CERN committees, the time scale for the preparation of the TDRs is 2016-2018. In particular the groups are expected***

- formulate an interest in a hardware and software contribution for the construction;
- give an estimate of the strength of their group during the work for the technical proposal and for the preparation of the TDR

✓ ***Assuming that the TDRs are approved by 2018, it would be valuable to understand the groups' prospects for contributing to the construction of the SHIP detector in 2018-2022***