The SHIP project at CERN

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on behalf of the SHIP collaboration

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

Victoria Mini-Workshop - 11/09/2014

SHIP

SHIP is a proposal for a beam dump experiment at CERN/SPS (400GeV p)

Main goals (so far…):

1) detection of long lived particles, weakly interacting or sterile: statistical sensitivity with respect to previous experiments of similar type x10000 (this is the first dedicated experiment ever!)

- **A. HNL's: from D decays**
- **B. massive photons: from p brehmsstrahlung and γ mixing**
- **C. PNGB(Pseudo Nambu Goldstone bosons): from π0 mixing**
- **D. Light inflaton: from B decays**

—> the "portals": A is neutrino, B is vector, C is axial, D is scalar —>CONNECTION WITH DARK MATTER

2) study of ν_τ interactions with statistical sensitivity with respect to previous experiments of similar type x200

Scientific motivation

Shaking hands…

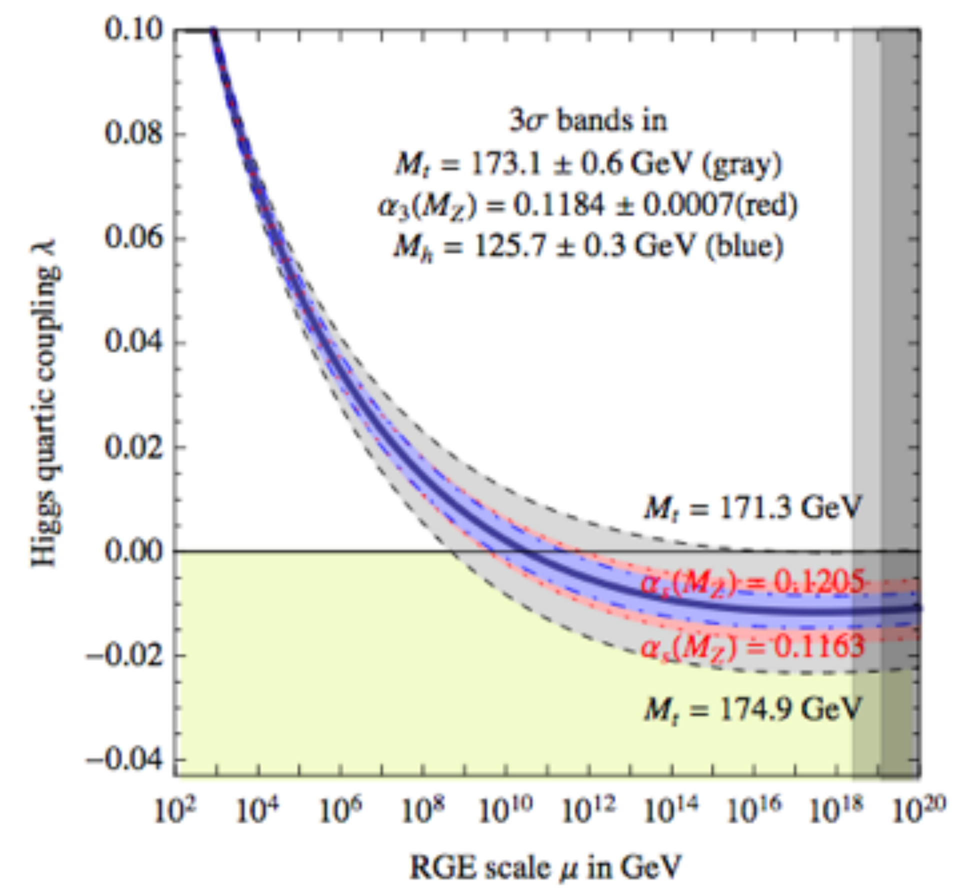
SM was recently fully confirmed by the Higgs-boson discovery! (with the exception of the anti-ν_τ, whose detection is one of the goals of SHIP)

However…

However: no NP anywhere! Also, naturalness is now severely challenged.

The peculiar Higgs mass suggest that, even in absence of NP, the Universe is metastable.

SM could well be valid up to Planck scale but we have to explain some facts: neutrino oscillations, bariogenesis, dark matter (+inflation, dark energy…)



JHEP 1312 (2013) 089

The νMSM and its variants

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

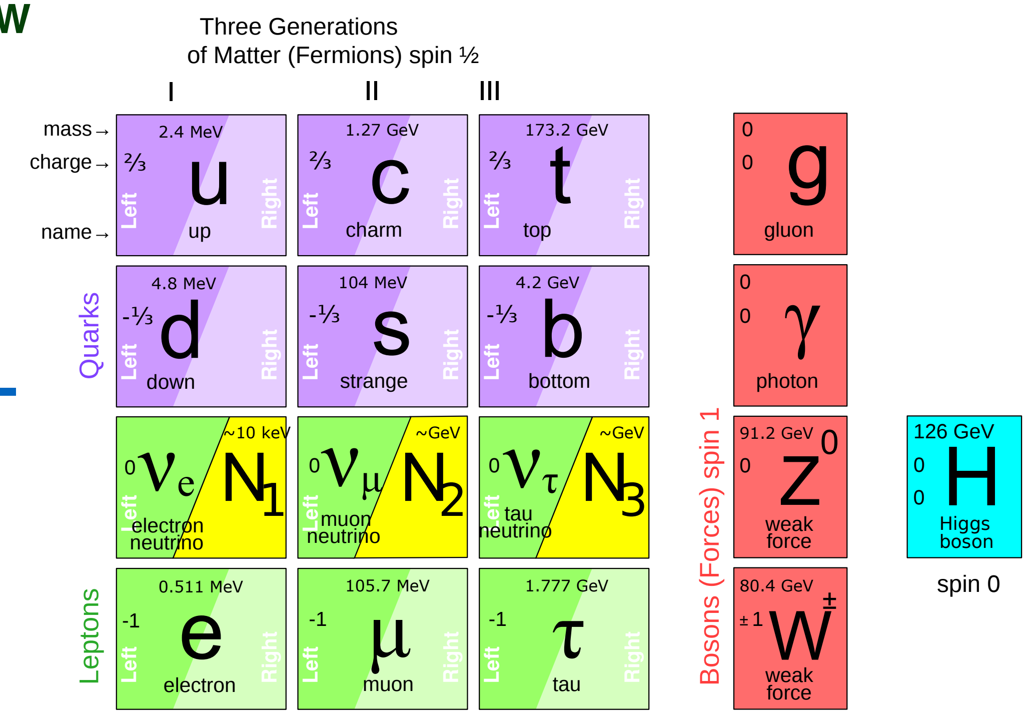
In a peculiar parameter space (N_2 and N_3 almost degenerate in mass and with m=O(GeV) and N_1 decoupled with m=O(keV)), νMSM explains:

neutrino masses (see-saw), baryogenesis (via lepto-genesis) and DM (N_1)! (signal at 3.5KeV debated now!)

No hierarchy problem

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

Forgetting about DM, it is also possible to build a model without the above degeneracies with larger allowed parameter space



$N_{2,3}$ production

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

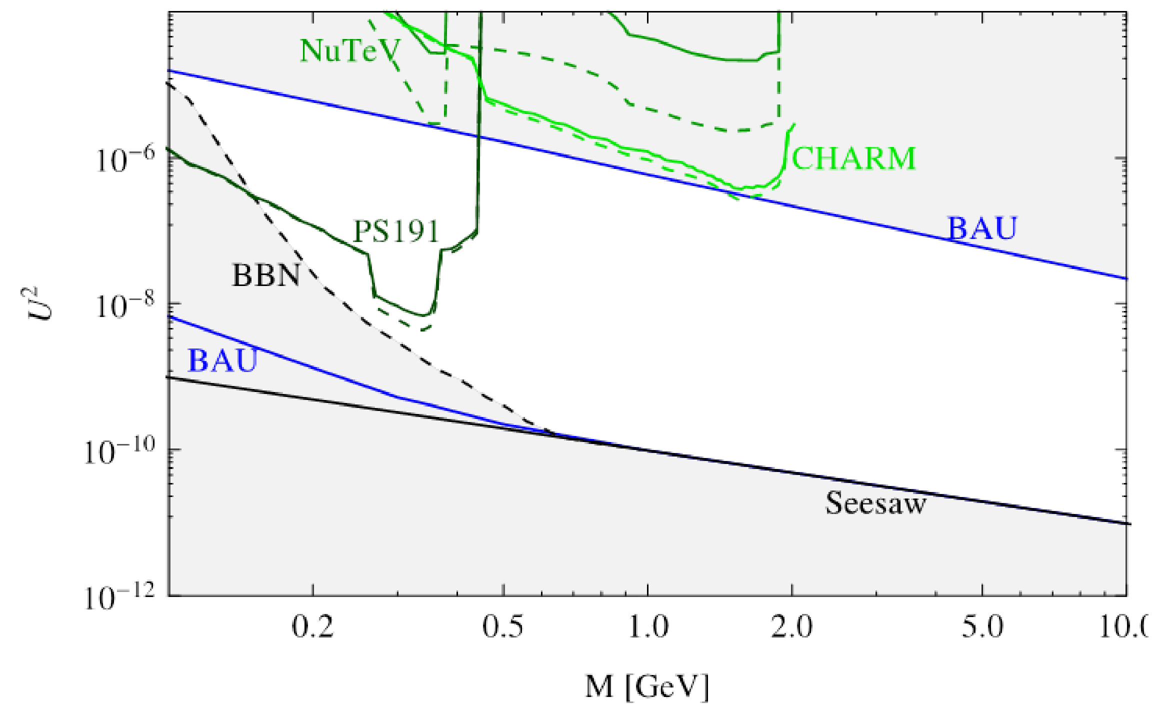
in the νMSM strong limitations in the parameter space (U^2,m)

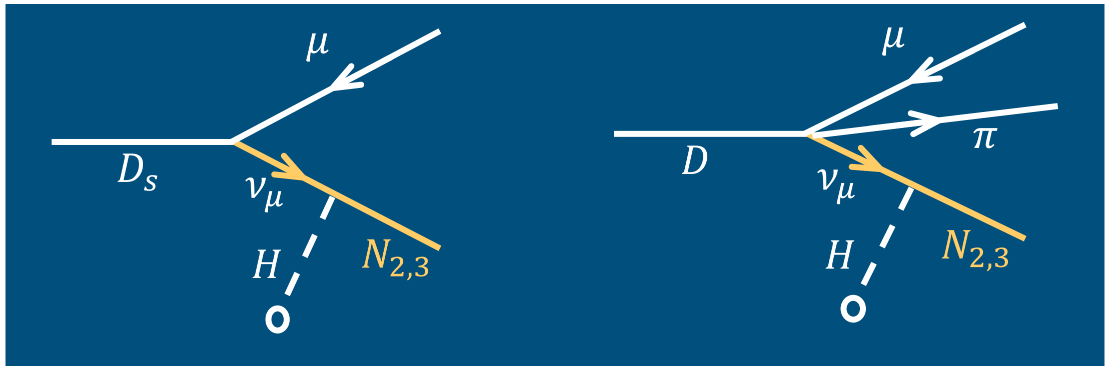
a lot of HNL searches in the past but, for m>m_K, with a sensitivity not of cosmological interest (e.g. LHCb with B decays obtained $U^2 \approx 10^{-4}$, arXiv:1401.5361)

this proposal: search in D meson decays (produced with high statistics in fixed target p collisions at 400 GeV)

Taking into account the existing beams and those possibly existing in the near future, this is the best experiment to problem the cosmologically interesting region

inverted mass hyerarchy

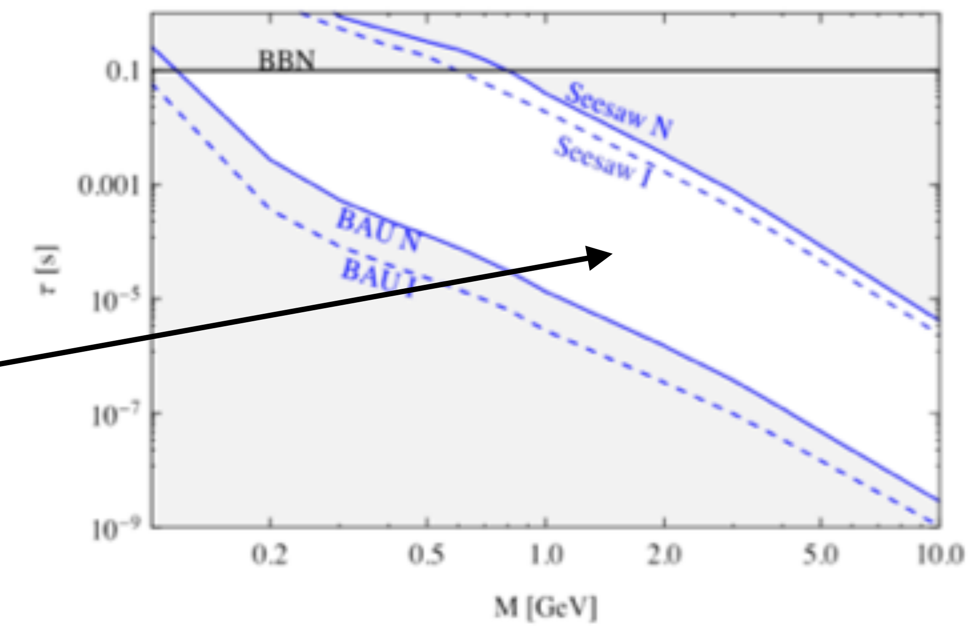




$N_{2,3}$ decays

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

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

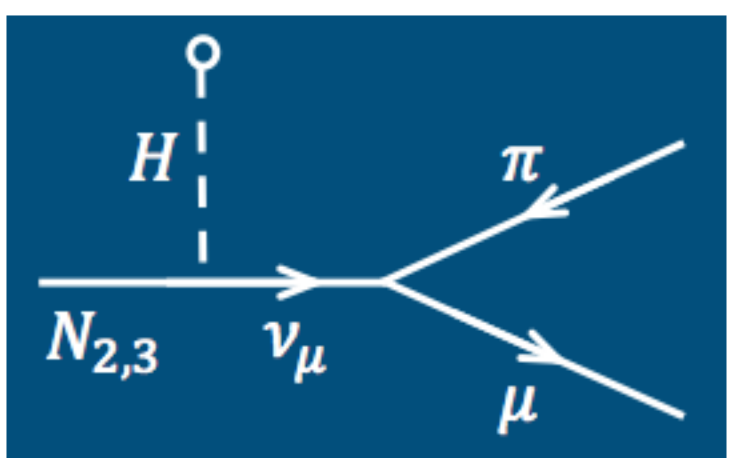


Various decay modes : the BR's depend on flavor mixing

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

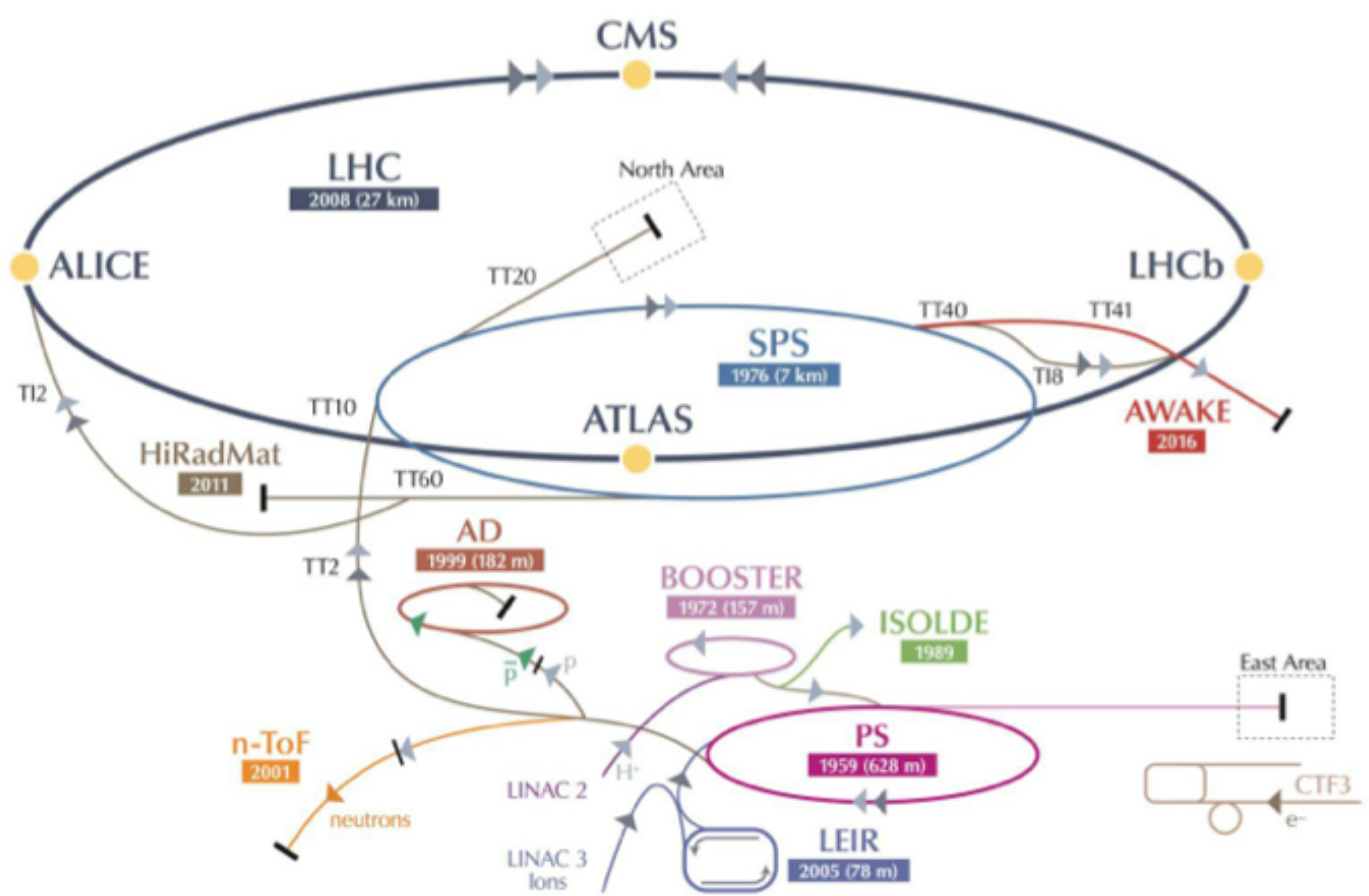
—> number of events $\propto U_\mu^4$

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



The experiment

CERN accelerator complex

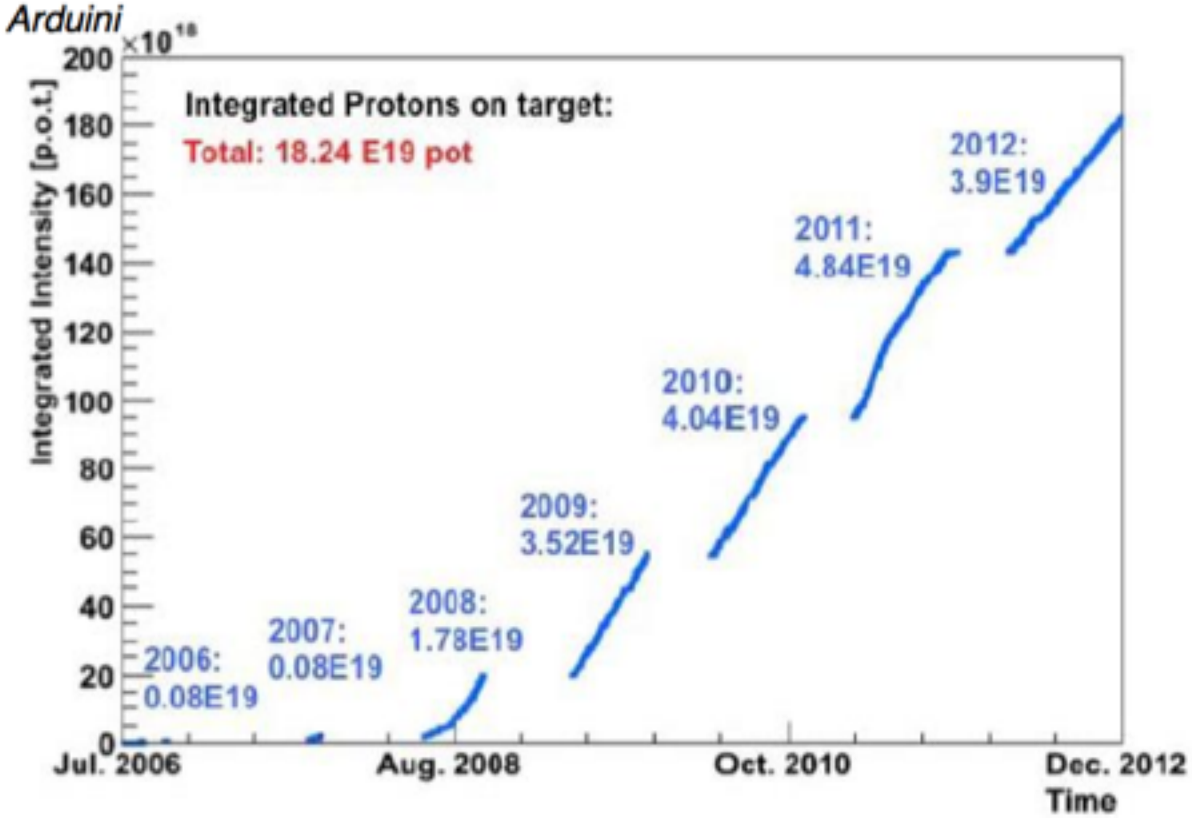


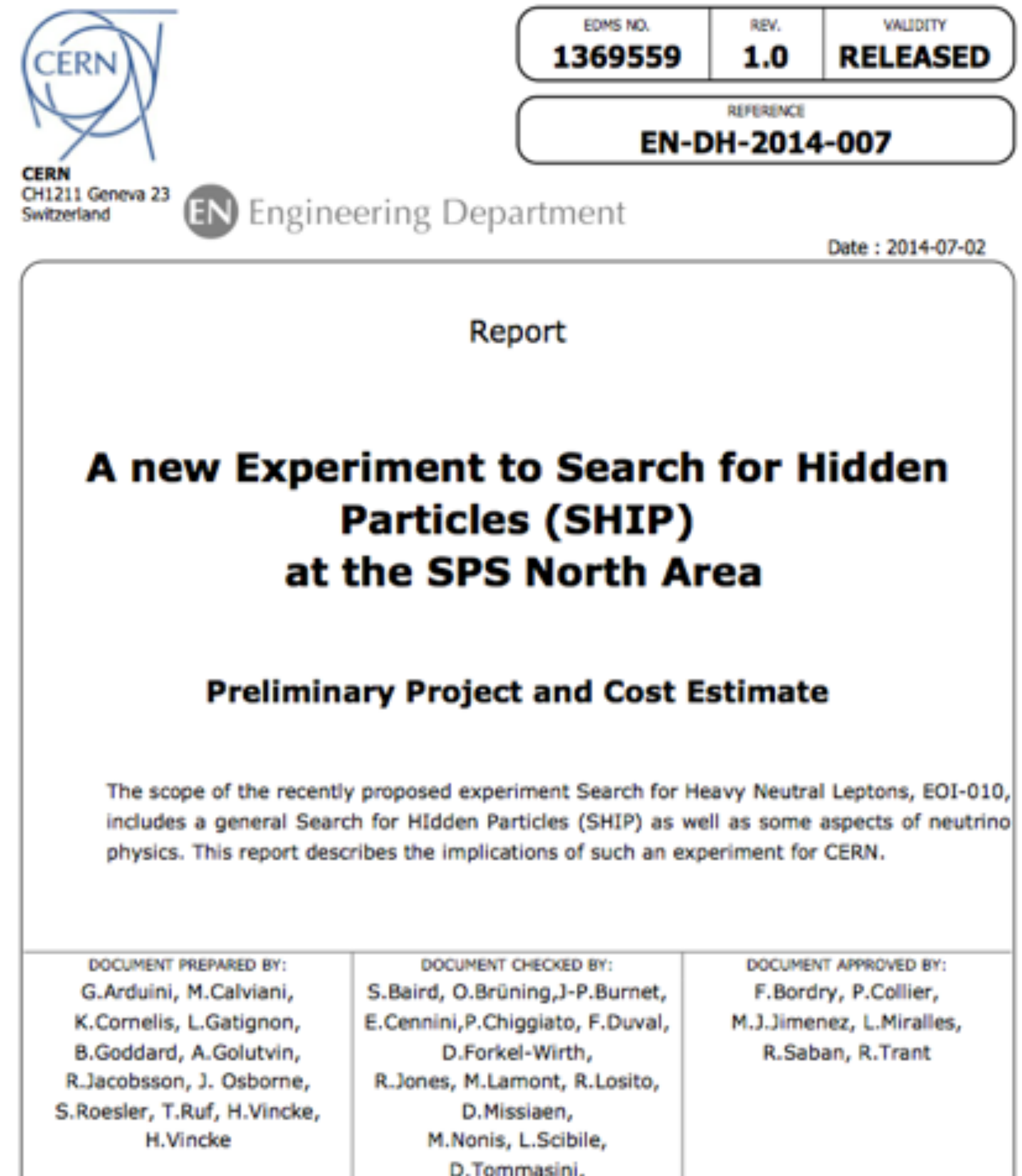
The beam

Extracted SPS beam 400GeV;

like CNGS 4.5×10^{19} pot/year
—> in 5 years it will be 2×10^{20}pot

G. Arduini





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EDMS NO.	REV.	VALIDITY
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.

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Possible layout

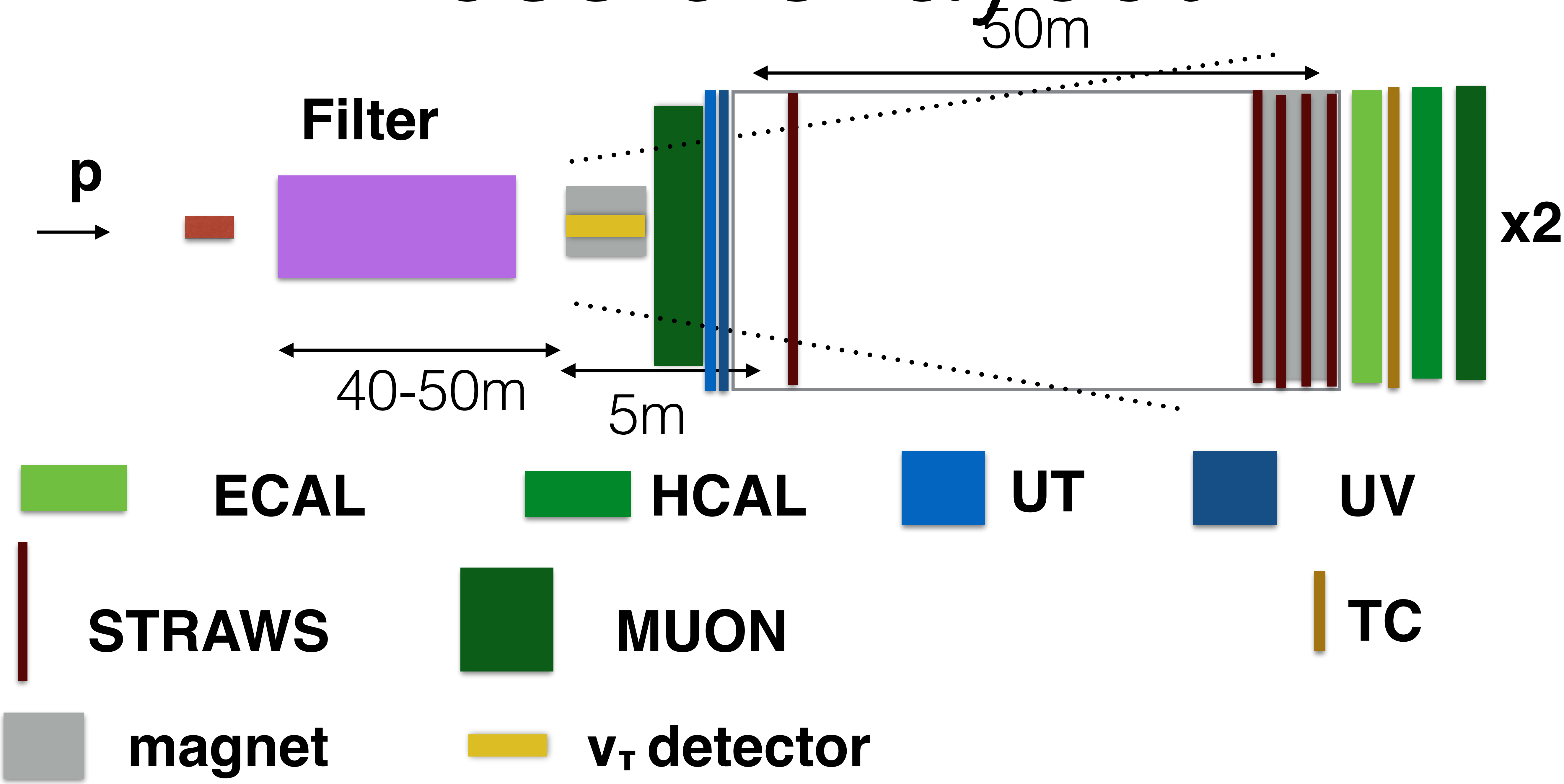


Figure 20: Schematic layout of the civil engineering complex.

The key features of this layout are:

- 85m long Junction Cavern in the TDC2 line
- 170m long machine Extraction Tunnel (4m wide by 4m high similar to TDC2)
- 15m long by 15m wide Access building including a shaft to reach the Extraction Tunnel line

Target and muon filter

W target of 50cm : the beam is spread on the target to avoid melting

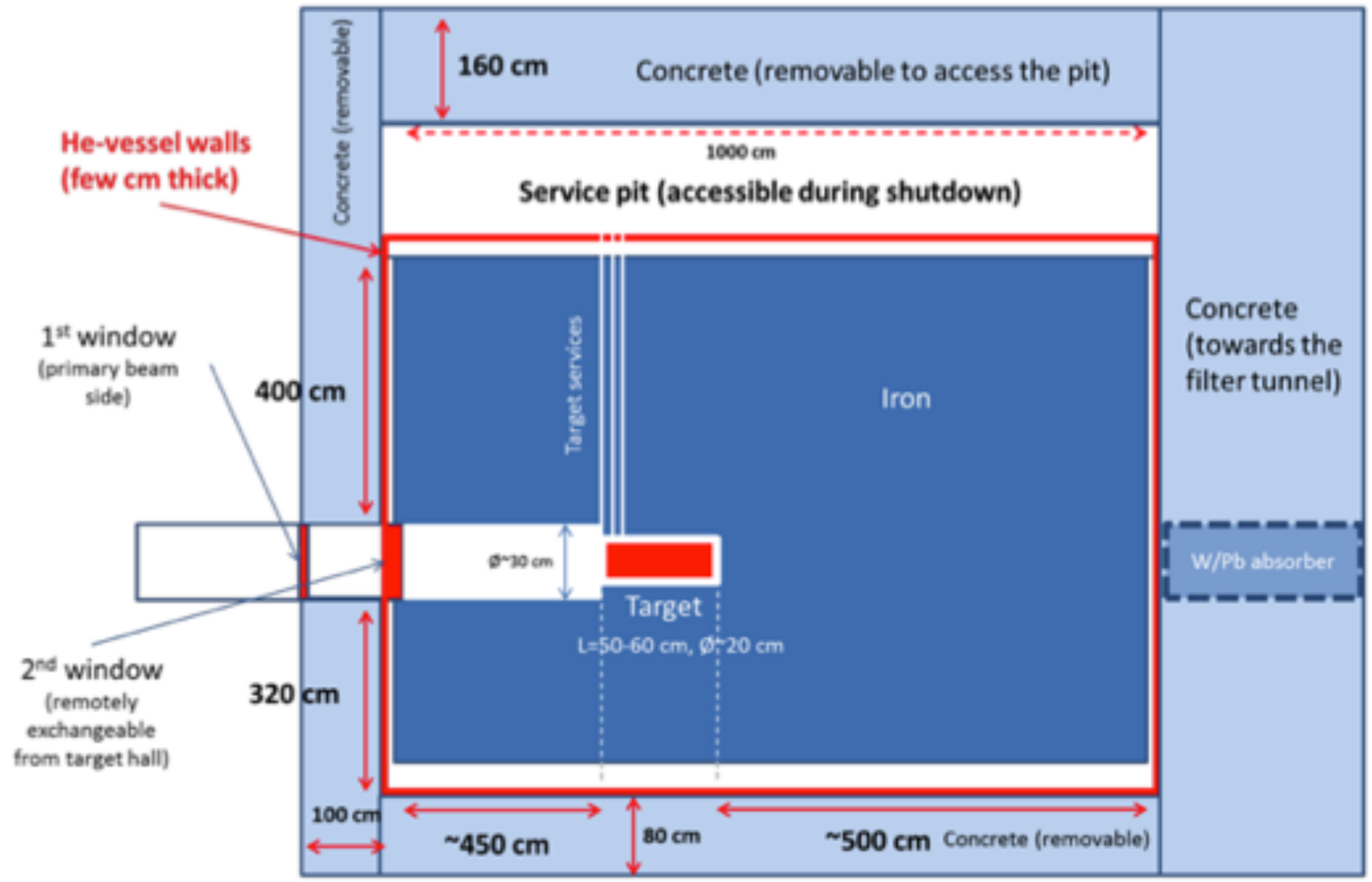
It is followed by a muon filter. Now the preferred option is an active filter with sweeping magnets. Yet, we have no technical design for this.

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

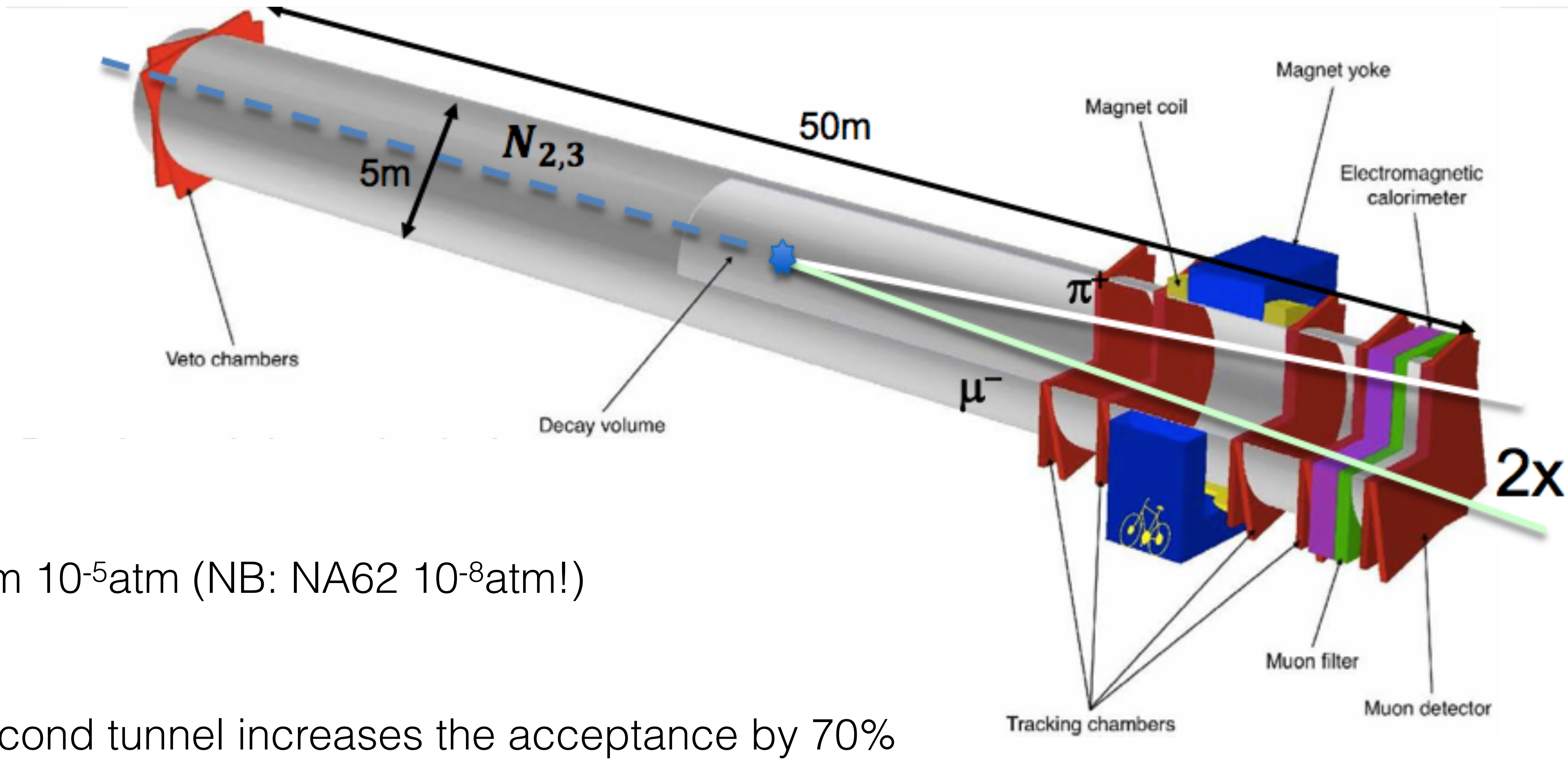
1 sec extraction, continuous

—> this is good for detector operation but does not allow any timing with the beam pulse (e.g. for detecting dark matter particles)

—> under study also the possibility to run with bunched beam



Decay tunnel and spectrometer



Vacuum 10^{-5}atm (NB: NA62 10^{-8}atm!)

The second tunnel increases the acceptance by 70%

Detectors and DAQ

Almost no R&D to do, we can make it with detectors already built in the past, optimizing the parameters

Muon detector, baseline now is extruded scintillator bars read out by SiPM —> experience from SuperB, but also RPC are considered.

Trigger and DAQ: a simplified version of the HLT of LHCb upgrade (i.e. no L0)

computing: FairRoot framework —> simulation tools in place, some detector description already there!

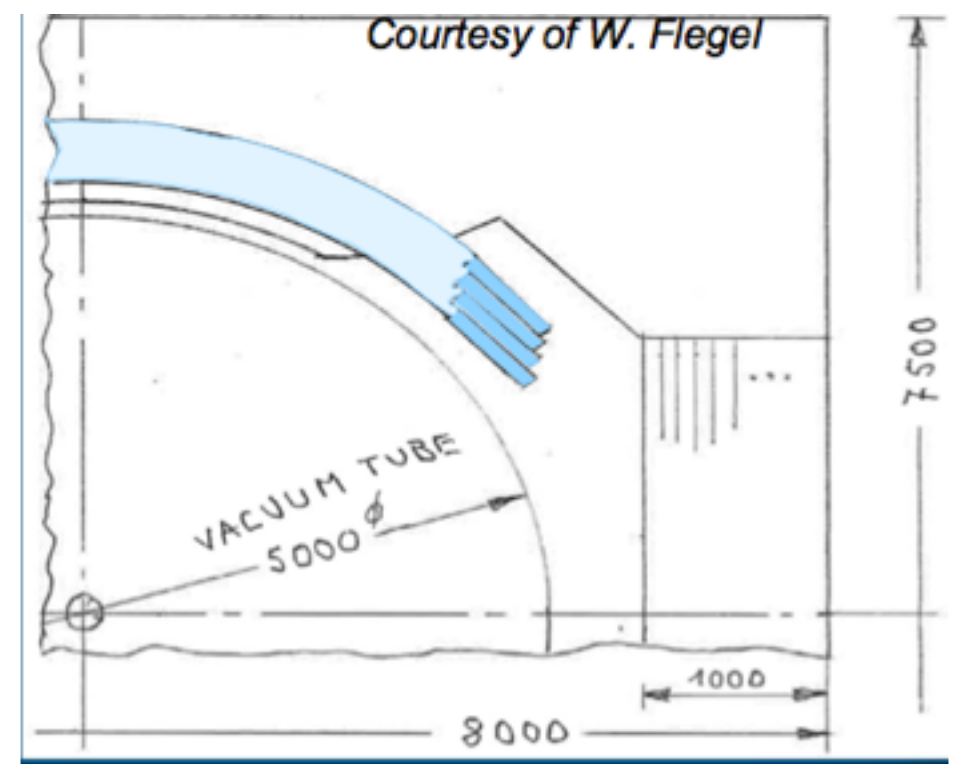
The spectrometer magnet

A dipole magnet very similar to the LHCb one but with 40% less iron and three times less power

LHCb: 4Tm and aperture ~ 16 m^2

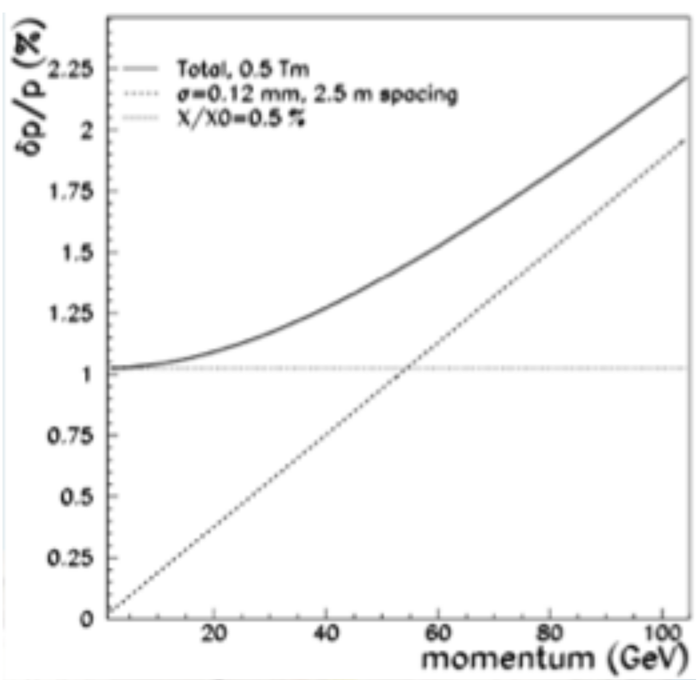
This design:

- aperture 20 m^2
- Two coils Al-99.7
- peak B field ~ 0.2 T
- field integral ~ 0.5 Tm su 5 m



Tracking and VETO

Straw tubes similar to NA62 with 120 μm space resolution, 0.5% X_0/X.

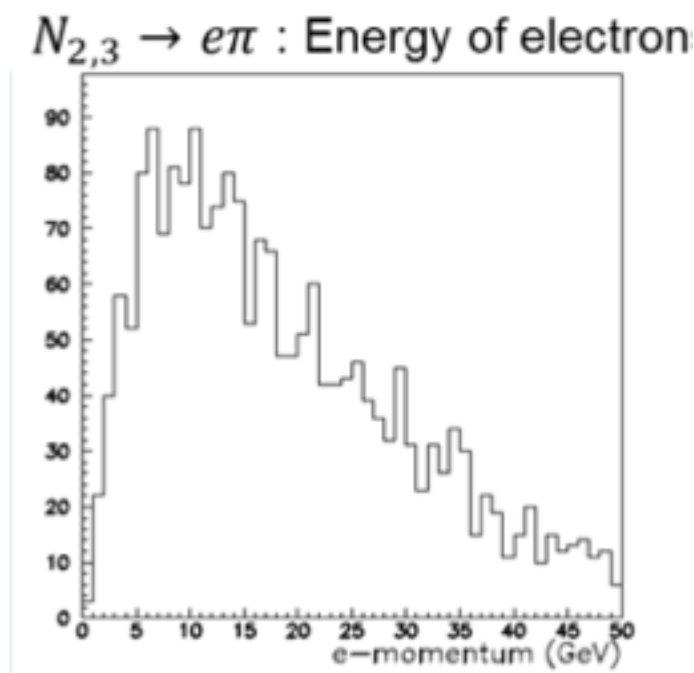


Main difference to NA62:

A. 5m lenght
B. vacuum 10^{-2} mbar
C. 2kHz/straw of 1cm diam
D. configuration X,X-θ,X+θ,X with small θ

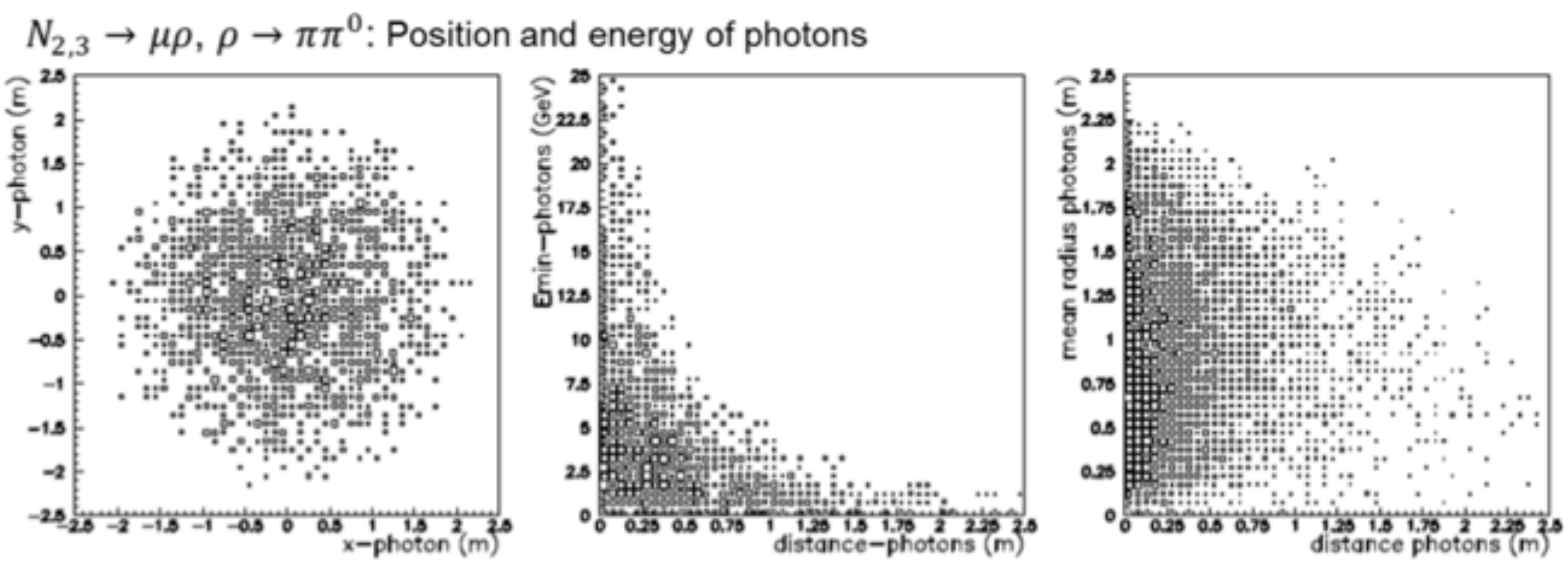
Other channels

An e.m. calo allows the reconstruction of additional decay modes:



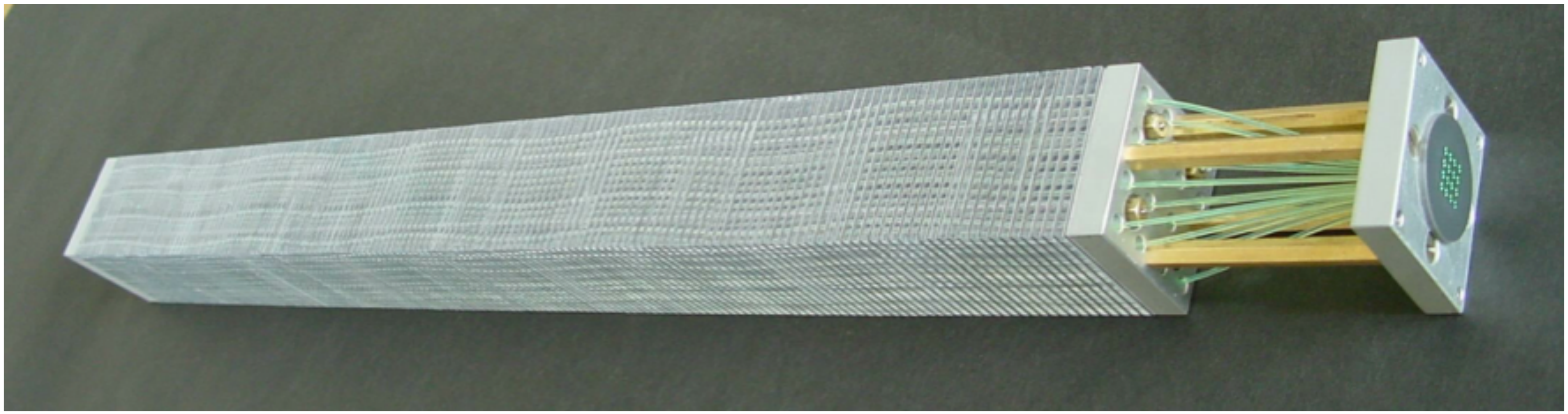
$N \to e^+\pi^-$ allowing to access the limit on Ue (since the flavor structure is not known these channels could also be favored)

$N \to \mu^+\rho^-$ with $\rho^- \to \pi^-\pi^0$ that allows to improve the limit on U_μ (about the same BR of $\mu^+\pi^-$, for m>700Mev)



Assuming 10x10cm2 cells

A possibile calorimeter



The spiral Shashlik ECAL

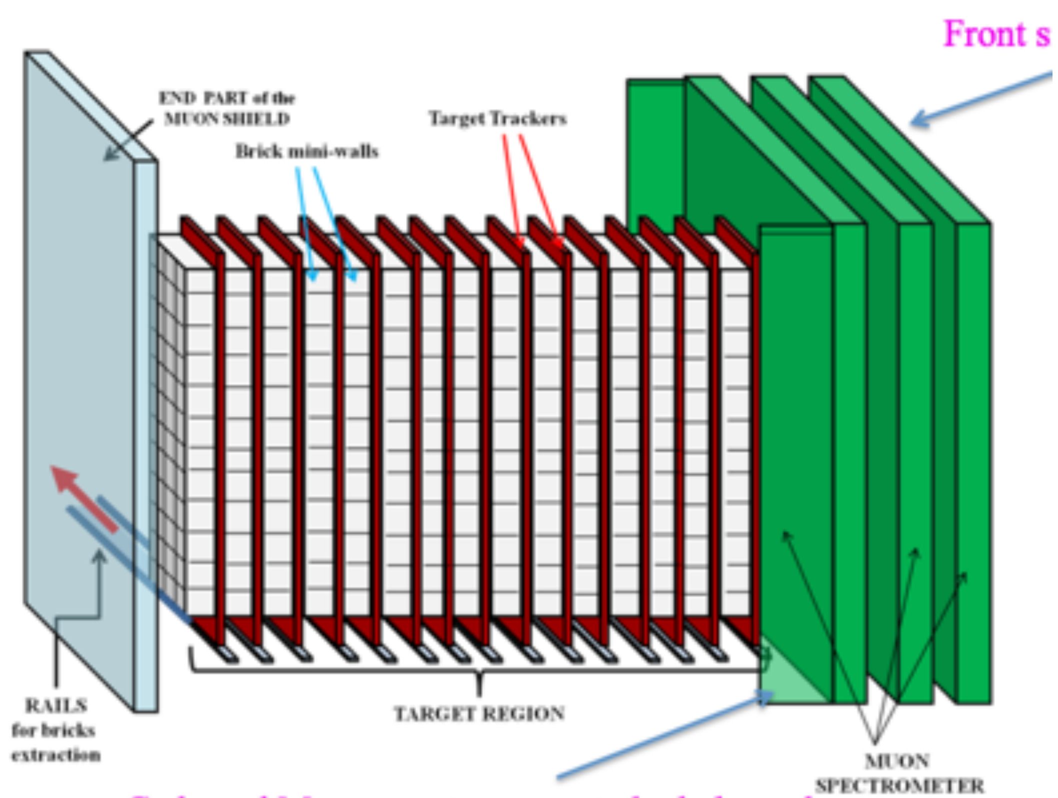
Uniformity few %, time resolution σ~1ns and σ(E)/E=6.5%/√E⊕1%

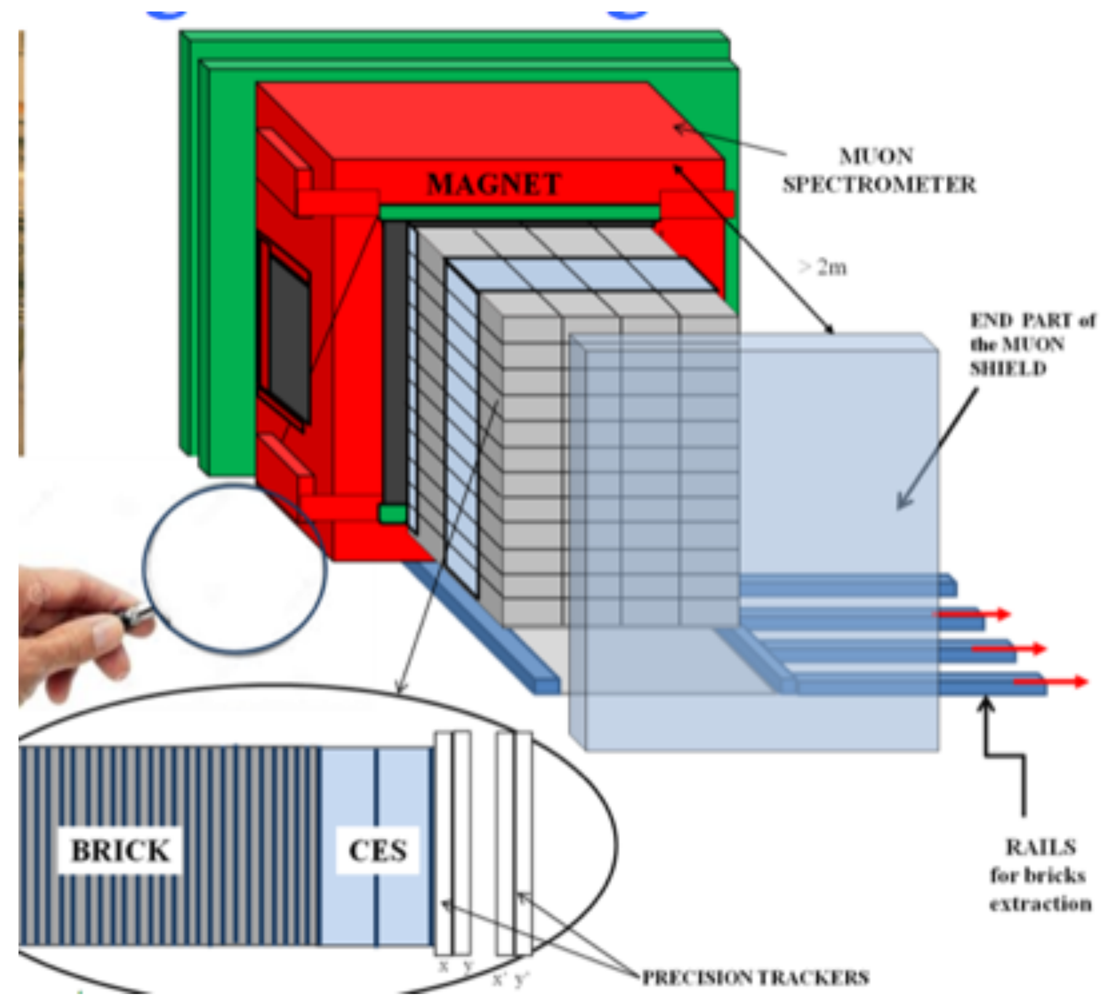
Light $\boldsymbol{\nu}$'s detector

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

Even replacing 10 times the emulsion bricks during the run—> still 5% of the OPERA

Two options under study:



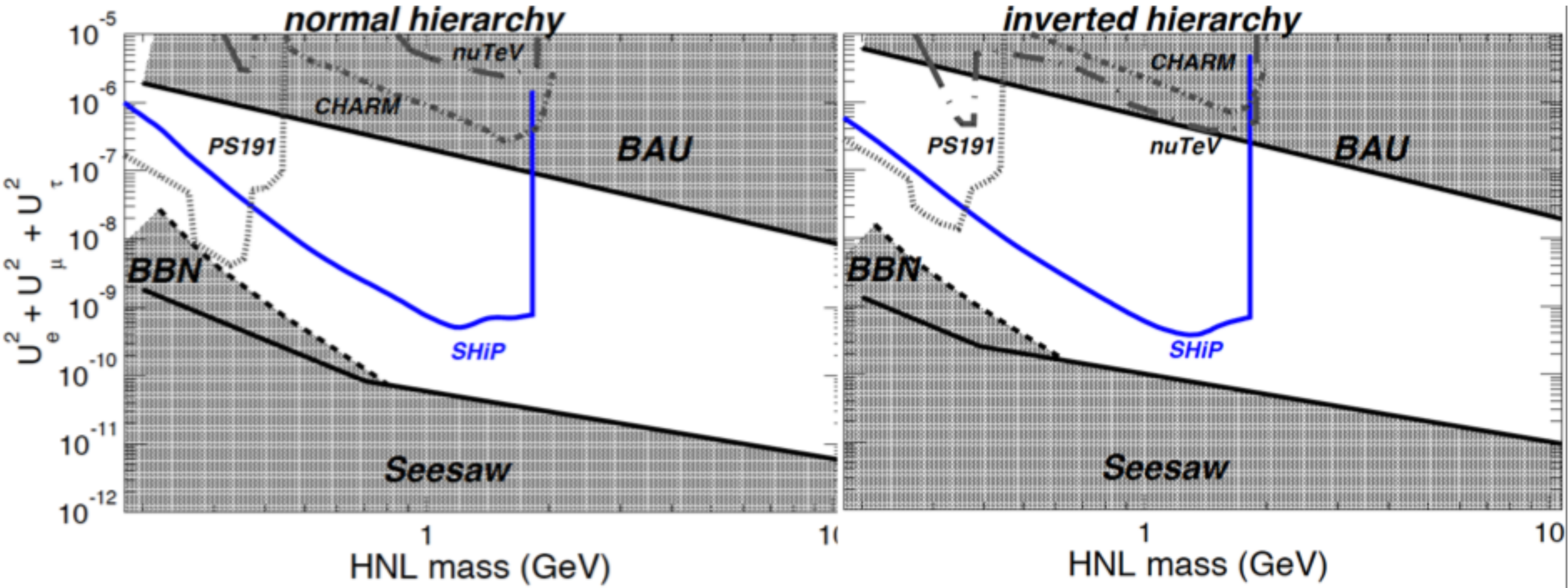


Sensitivity

SHIP sensitivity to HNL

SHIP will scan most of the cosmologically allowed region below the charm mass

Reaching the see-saw limit would require increase of the SPS intensity by an order of magnitude (does not currently seem realistic)

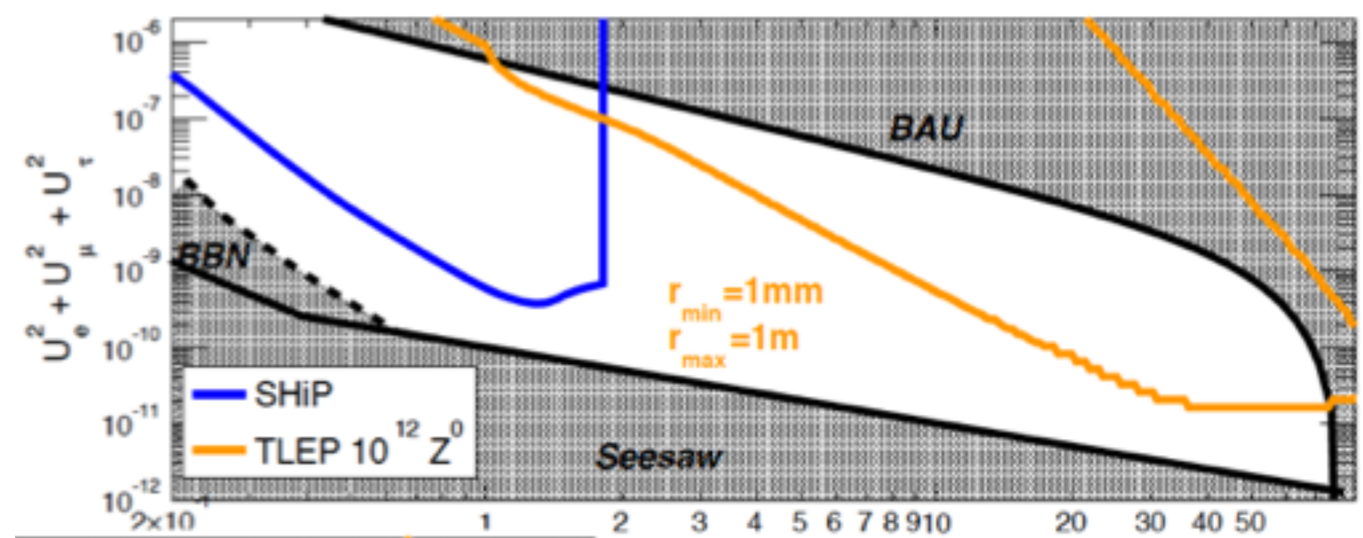


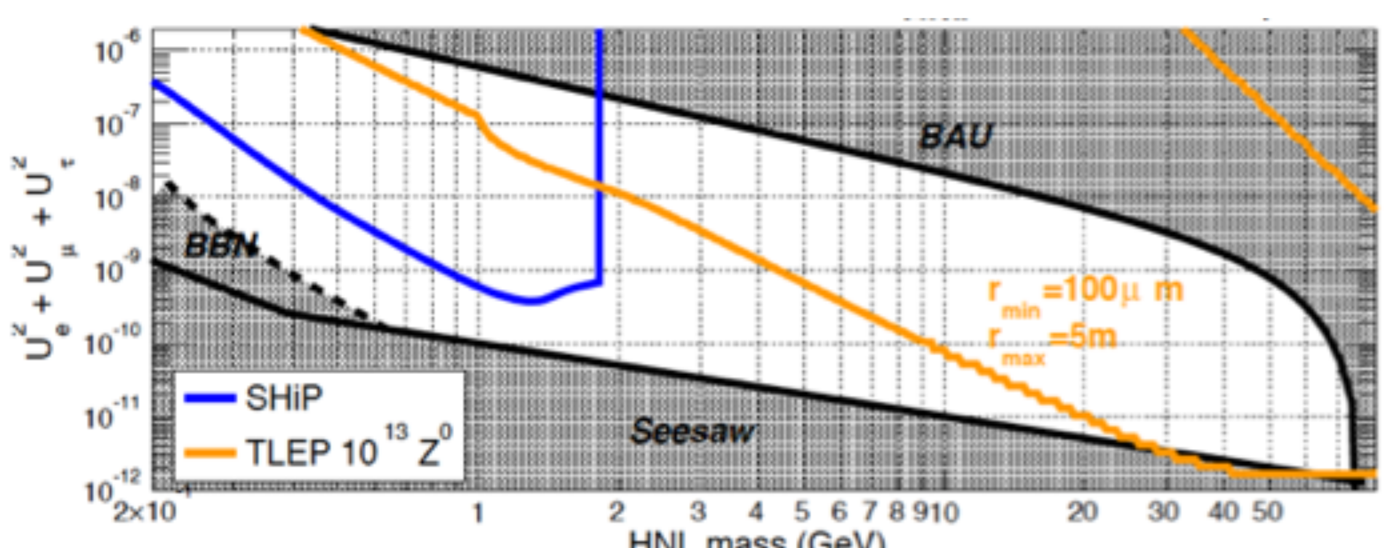
How to go to higher masses

Use processes Z—>Nν with N—>lepton + 2 jets
BR(Z —>νN) ≅ BR(Z—>νν)×U², $\Gamma_N \cong G_F^2 \times M_N^5 \times U^2 \times N_{decay\ channels} / 192\pi^3$

Assuming data sample of 10^{12} Z decays one can reach very interesting sensitivity for $M_N > 10$ GeV

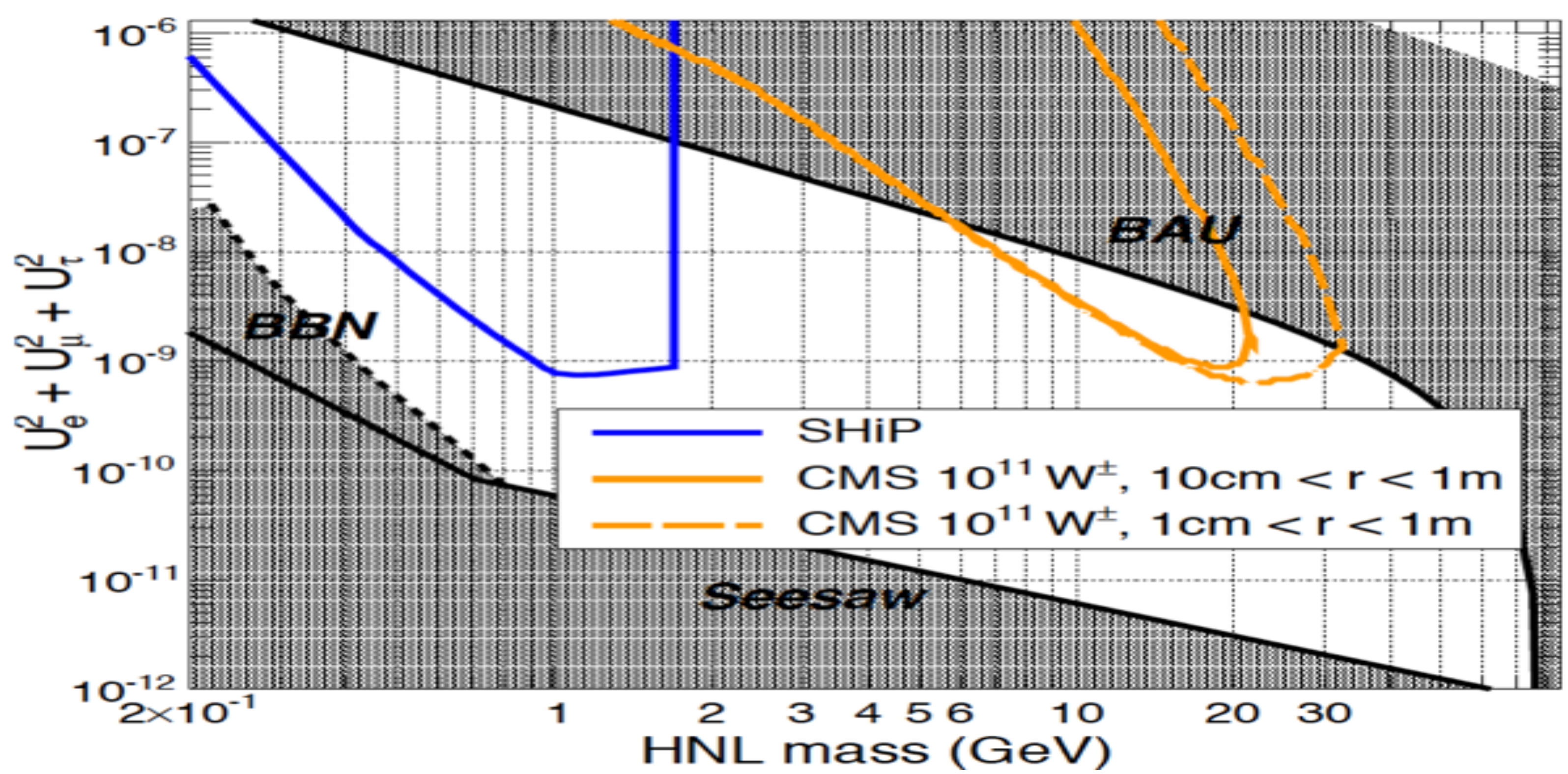
Expected sensitivity of FCC in e^+e^- mode, assuming zero background





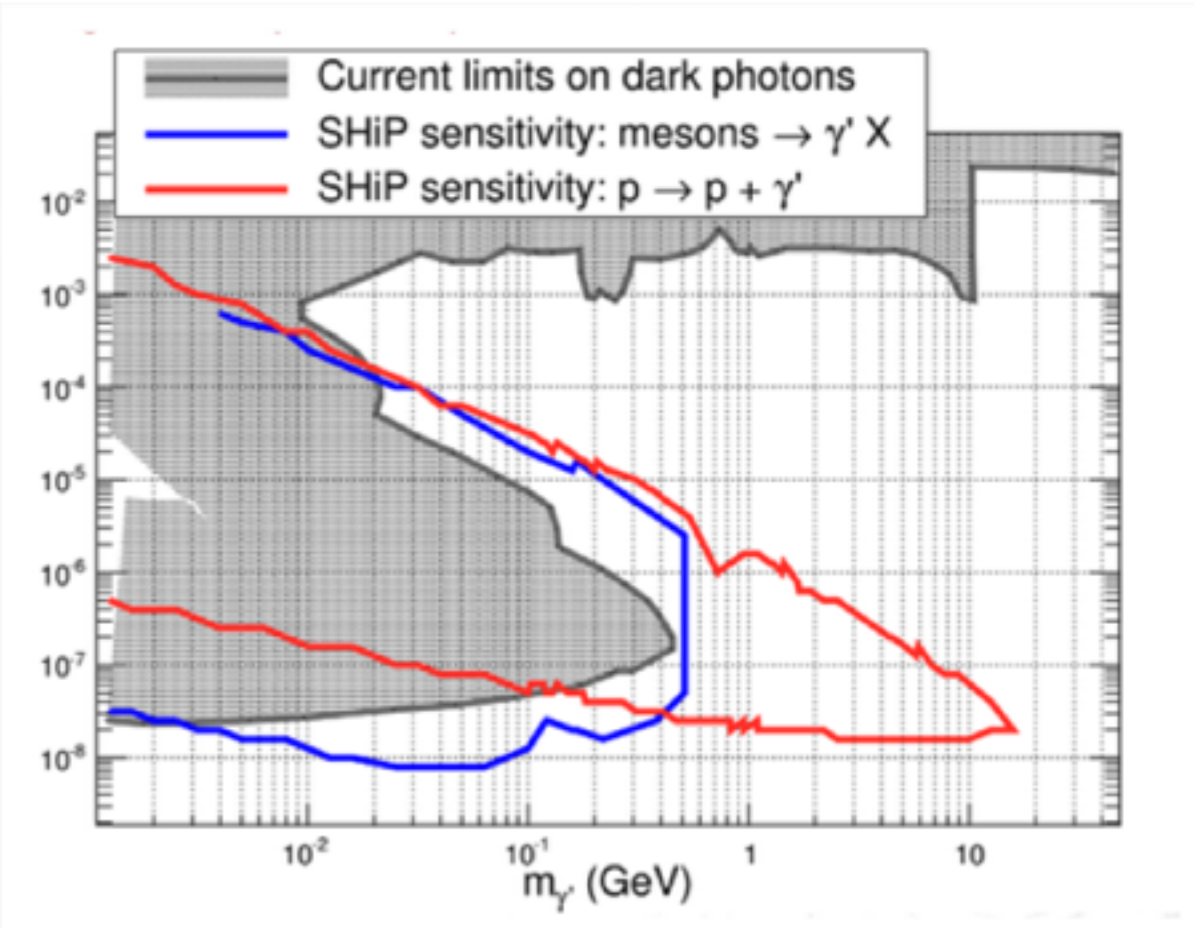
How to go to higher masses(ii)

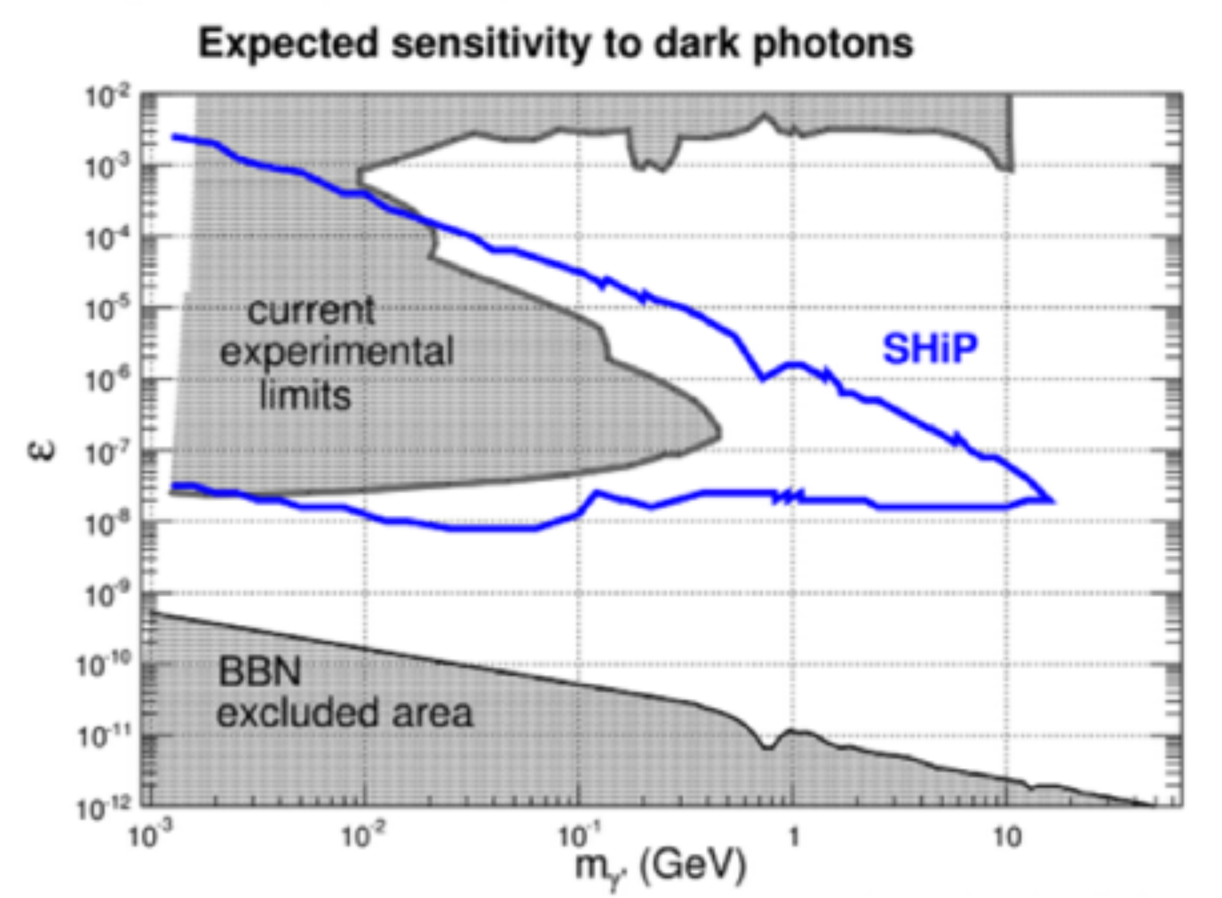
CMS 10^{11} W , assuming zero background



Dark photons

Physics Letters B 731 (2014) 320–326

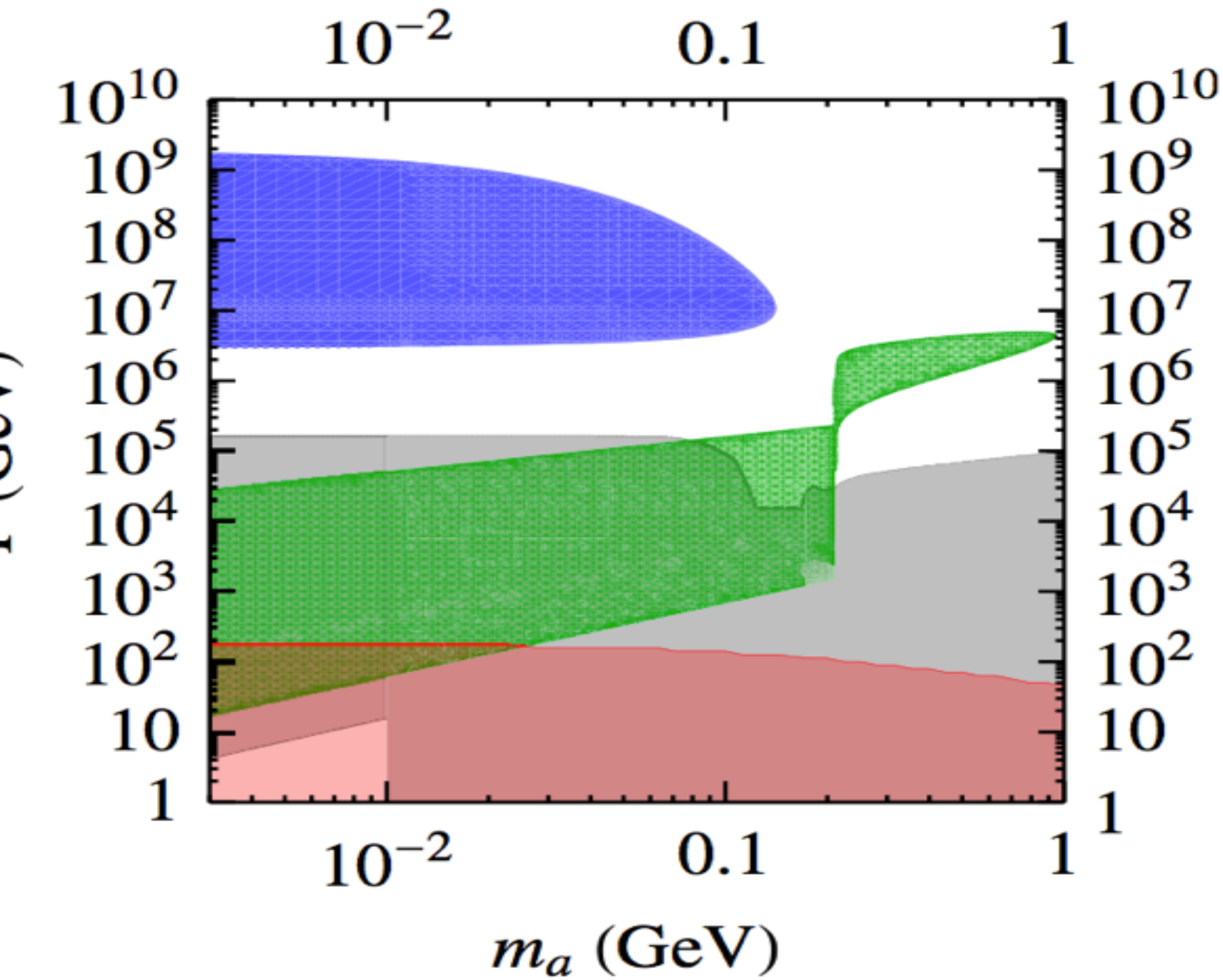




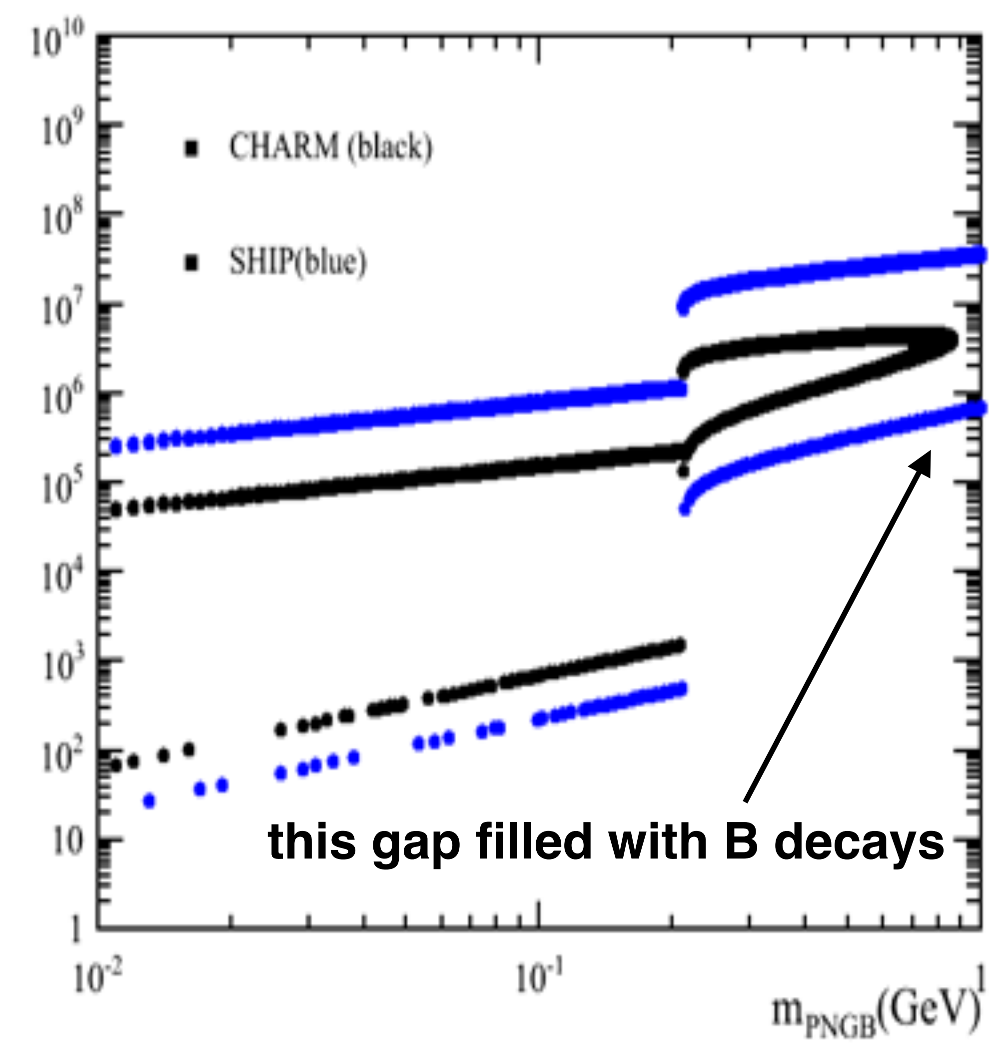
only e^+e^- and $\mu^+\mu^-$ decays

PNGB

PRD 82,113008 (2010)



the eff(geo) just the ratios of z(SHIP)/z(CHARM)



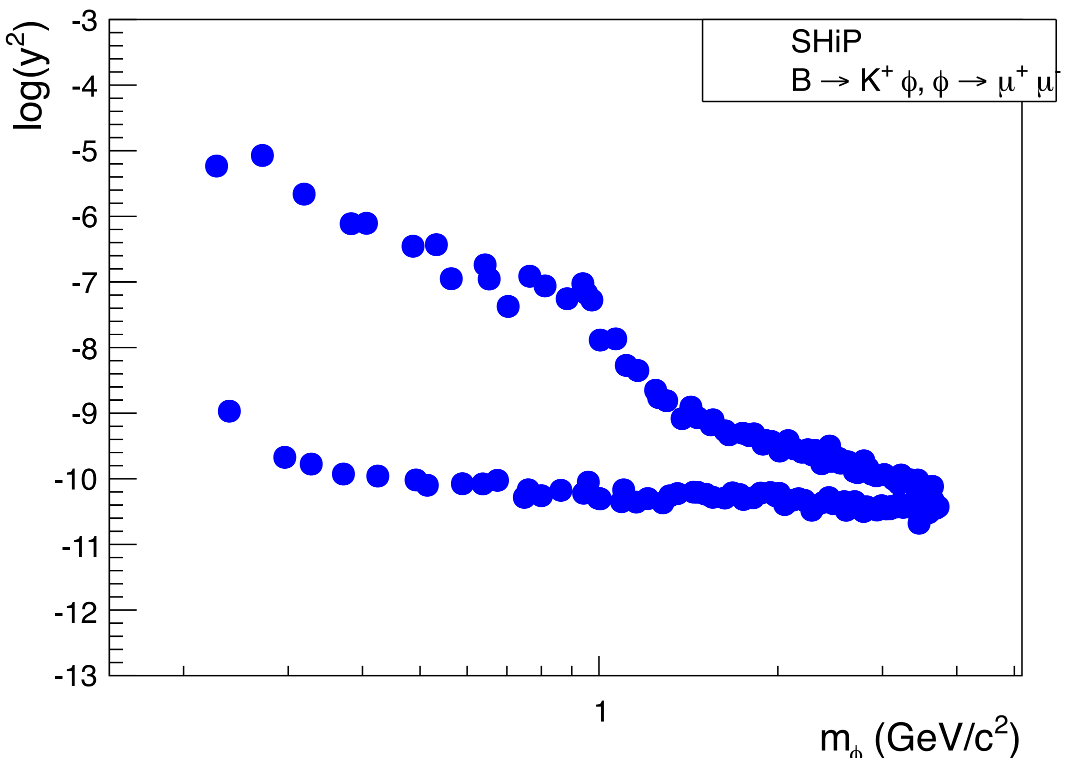
only e^+e^- and $\mu^+\mu^-$ decays

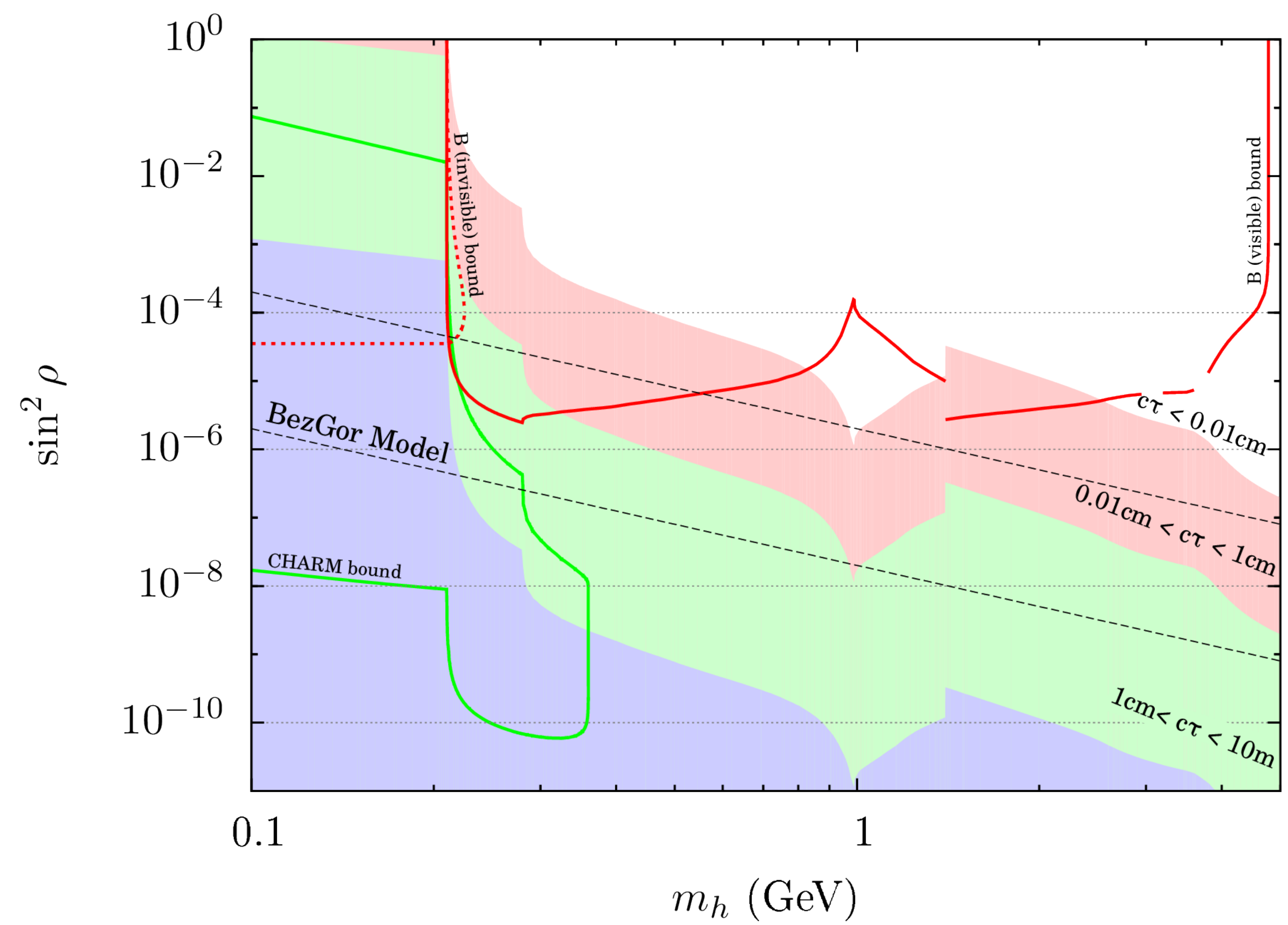
Inflaton

M. Winkler et al., arXiv:1310.6752

J. Clarke et al., arXiv:1310.80.

assuming conservatively $\chi_b=10^{-8}$





SHiP sensitivity for light scalar particles ϕ decaying into two muons for 2 10^{20} pot via the process p+p → B X, B → K ϕ, ϕ→μμ

SHiP limits are fully complementary to those put by Belle/LHCb and extend the sensitivity down to the unexplored range of 10^{-10}

Active neutrino physics: $\boldsymbol{\nu_\tau}$ e $\boldsymbol{\nu}_\mu$

It is possible to achieve a statistics of reconstructed and selected ν_τ interactions >200x the present one:

DONUT observed 9 events (from charm) with a background of 1.5

OPERA observed 4 events (from oscillations)

In general NP in the third generation (i.e. τ) is experimentally less constrained than the other two families

In particular, two important experimental "anomalies" in the charged flavor sector involve the τ lepton:

A. **R(D), R(D*) from B factories —>3.4σ from the SM**

B. **A(CP) (τ—>$\pi K^0_S \nu_\tau$) —>2.8σ from the SM**

Active neutrino physics: $\boldsymbol{\nu_\tau}$ e $\boldsymbol{\nu}_\mu$

—> Differential cross section measurements in CC interactions: Datta, U.Massachussets, is providing calculations of sensitivity to a charged Higgs, to W' and Leptoquarks

Other important measurements:

A. **anti-ν_τ observation (the only SM particle never observed)**

B. **charm production in ν_μ interactions (large statistical increase, >100x, compared to CHORUS and in particular for the anti-ν_μ, : indeed, in a beam dump anti-ν_μ/ν_μ 60%)**

Backgrounds

We aim at 0 background —>we should have estimates of 0.1 events in 2x10^{20}pot

A. **Charged background —> from random combinations of muons from pion decays, (a few 10's in 2x10^{20} pot) primarily a background for μμ final states (dark photons, PNGBs and HNL) —>very much dependent on the type of the muon filter**

B. **Neutral background —>background for HNL (K0L) and more (n): produced by $\nu\mu$ interactions in the last interaction lengths of the muon filter (about 200 reconstructed $\mu\pi$ pairs in 2x10^{20} pot)**

C. **misid —> e.g. K0S—>$\pi\pi$ —> Muon detector and CALO**

So far we made the hypothesis that we need independent detectors to satisfy those needs

at some point we may think to merge functionalities to save money

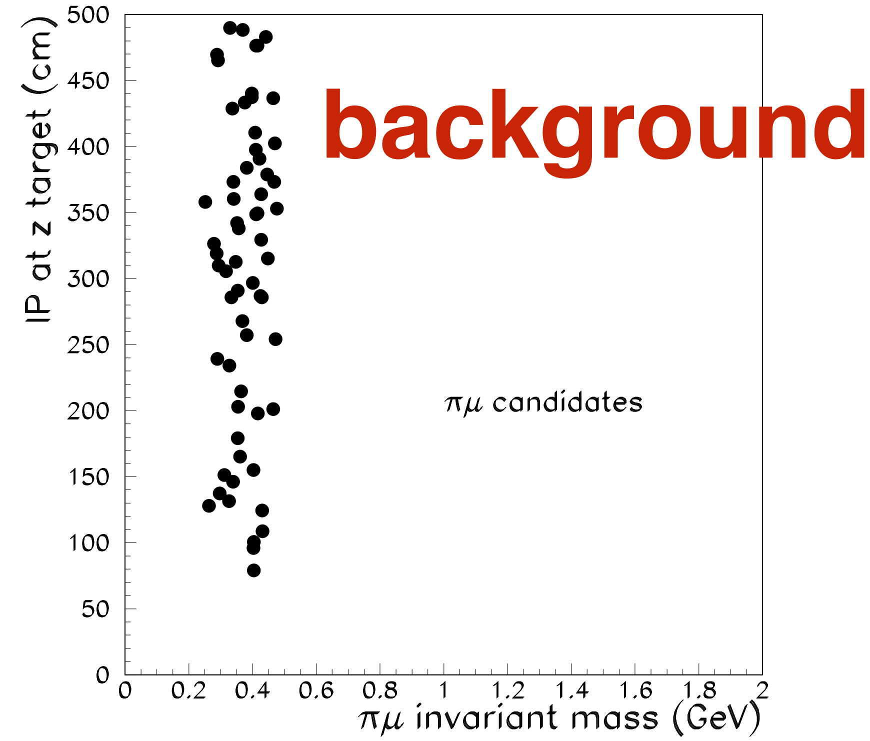
Background

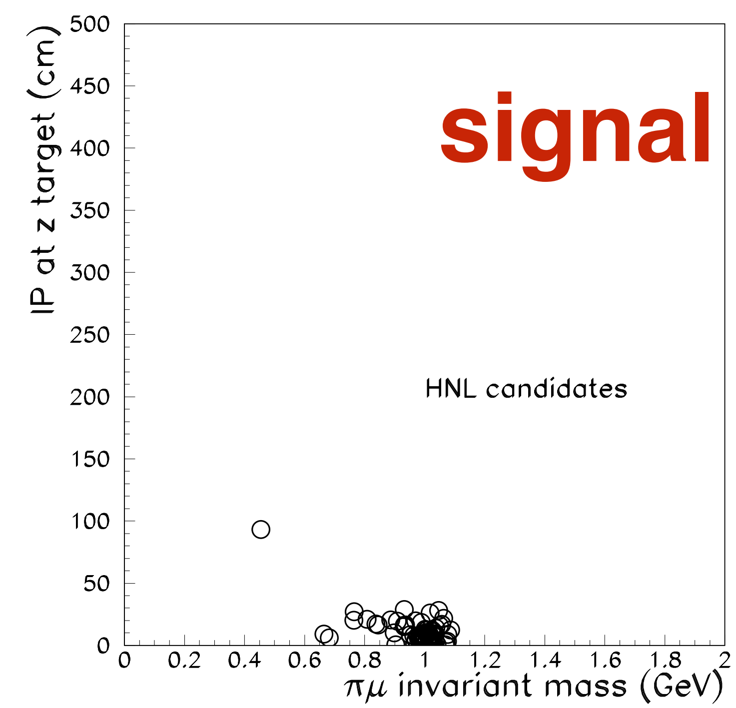
A. **Charged background —> detector with timing <100ps (multi-gap RPC like ALICE or MCP and quarz) and UV (a very high efficiency veto) with scintillators upstream of the decay tunnel**

B. **Neutral background —>**

   A. **K0L —> kinematic selection (IP,PT) and equipping the last part of the muon filter with an upstream tagger (UT) to tag the neutrino interactions**

   B. **n —> under study**





Schedule, committees, collaboration, etc…

EOI (i)

SPC EOI-2013-010 + addendum submitted October 2013

Interaction with the SPSc referees and discussion at the January 2014 meeting.

SPSc recommendation:

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.

Studies from CERN-ACC

discussed at the extended directorate meeting in July. The report was highly appreciated and we received further encouragement to proceed with the preparation of the Technical Proposal.

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EDMS NO.	REV.	VALIDITY
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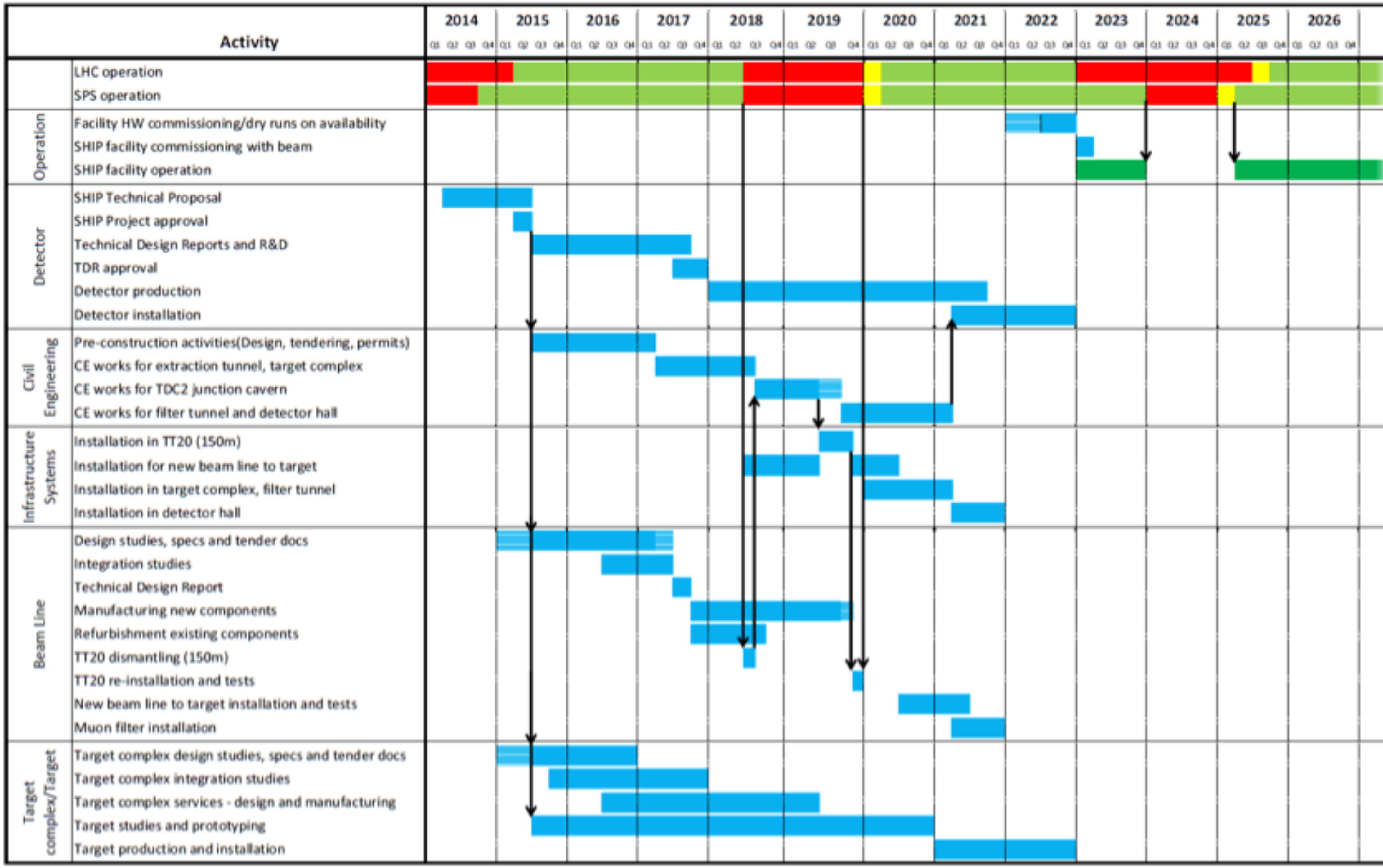
Executive Summary

The SPS configuration and performance have been investigated under the assumption that SHIP shares the protons with the current North Area fixed target program in a way similar to CNGS. The performance of the ZS septa and the induced radioactivity in the SPS extraction region are likely to be key factors in the overall SHIP performance and require further studies. Realistic super-cycle compositions have been elaborated using past experience for the operation of the North Area, CNGS and LHC, and MDs.

Time-table


Activity
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
LHC operation
SPS operation
Operation
Facility HW commissioning/dry runs on availability
SHIP facility commissioning with beam
SHIP facility operation
Detector
SHIP Technical Proposal
SHIP Project approval
Technical Design Reports and R&D
TDR approval
Detector production
Detector installation
Civil Engineering
Pre-construction activities(Design, tendering, permits)
CE works for extraction tunnel, target complex
CE works for TDC2 junction cavern
CE works for filter tunnel and detector hall
Infrastructure Systems
Installation in TT20 (150m)
Installation for new beam line to target
Installation in target complex, filter tunnel
Installation in detector hall
Beam Line
Design studies, specs and tender docs
Integration studies
Technical Design Report
Manufacturing new components
Refurbishment existing components
TT20 dismantling (150m)
TT20 re-installation and tests
New beam line to target installation and tests
Muon filter installation
Target complex/Target
Target complex design studies, specs and tender docs
Target complex integration studies
Target complex services - design and manufacturing
Target studies and prototyping
Target production and installation

The two workshops

June 10-12th, Zurich, CH

Involved 41 institutions from : UK, I, RU, F, D, CH, SVE, CHI, BUL, CERN, JAP,TUR, BRA,NED

second workshop in 2weeks at CERN —>B. Batell talk!

Outlook

We kindly ask help from the theoretical community to prepare our TP, in particular in the framework of the dark sector

About the experiment, we are now defining work packages and tasks which are not covered and may be appealing for new collaborators, that are welcome!