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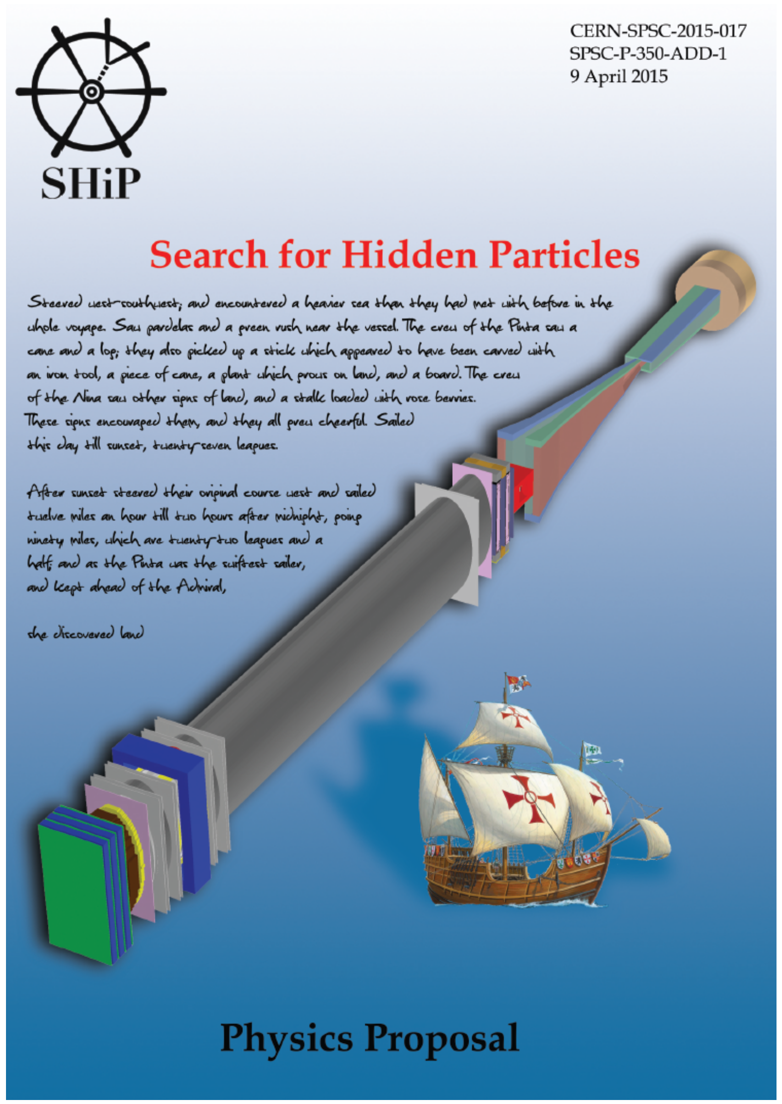
SHiP
Search for Hidden Particles

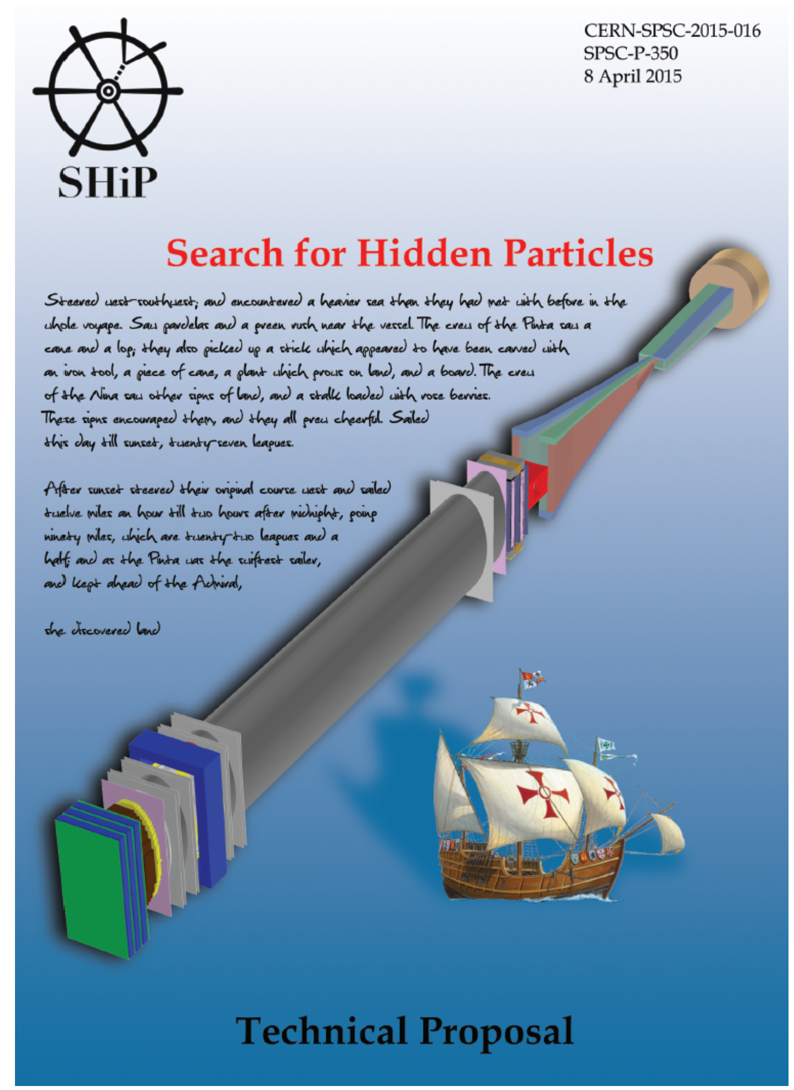
The SHiP experiment at CERN

Andrey Golutvin (Imperial College London/CERN)
Nico Serra (Universität Zürich)

CERN/EPFL/Korean Theory Institute
February 2017

Introduction





- The technical proposal (250 physicists, 46 institutes, 16 countries) submitted to CERN in Apr 2015 (arXiv:1504.04956)
- Physics Paper (85 physicists, 65 institutes) accepted for publication in Review on Progress in Physics (arxiv:1504.04855)

SHiP Collaboration

~250 scientific authors

16 member countries: Bulgaria, Chile, Denmark, France, Germany, Italy, Japan, Korea, Portugal, Russia, Sweden, Switzerland, Turkey, United Kingdom, Ukraine, United States of America + CERN, DUBNA

48 member institutes: Sofia, Valparaiso, Niels Bohr Institute Copenhagen, LAL Orsay, LPNHE Paris, Berlin, Humboldt University Hamburg, Mainz, Bari, Bologna, Cagliari, Ferrara, Lab. Naz. Gran Sasso, Frascati, Naples, Rome, Aichi, Kobe, Nagoya, Nihon, Toho, Gyeongsang, LIP Coimbra, Dubna, ITEP Moscow, INR Moscow, P.N. Lebedev Physical Institute Moscow, Kurchatov Institute Moscow, IHEP Protvino, Petersburg Nuclear Physics Institute St. Petersburg, Moscow Engineering Physics Institute, Skobeltsyn Institute of Nuclear Physics Moscow, Yandex School of Data Analysis, Stockholm, Uppsala, CERN, Geneva, EPFL Lausanne, Zurich, Middle East Technical University Ankara, Ankara University, Imperial College London, University College London, Rutherford Appleton Laboratory, Bristol, Warwick, Taras Shevchenko National University Kyiv, Florida

5 associated institutes: Jeju, Gwangju, Chonnam, National University of Science and Technology "MISIS" Moscow, St. Petersburg Polytechnic University

Introduction

Experimental facts of BSM physics

- Neutrino masses & oscillations
- Baryon Asymmetry of the Universe (BAU)
- The nature of non-baryonic Dark Matter (DM)

Many theoretical ideas, including those which predict new light particles, and which can be tested experimentally

SHiP is designed to find a solution for BSM physics by searching for very weakly interacting particles of <10 GeV mass

Brief history of SHiP:
✓ Letter Of Intent - October 2013
✓ Technical Proposal & Physics Paper - April 2015

Reviewed by the SPSC and CERN RB by March 2016, and recommended to prepare a Comprehensive Design Study (CDS) by 2018
→ Input to the European strategy consultation to take a decision about approval of SHiP in 2019/2020

Introduction

$L = L_{SM} + L_{mediator} + L_{HS}$

Visible Sector

Mediators or portals to the HS:
vector, scalar, axial, neutrino

Hidden Sector
Naturally accommodates Dark Matter (may have rich structure)

✓ *HS production and decay rates are strongly suppressed relative to SM*
- *Production branching ratios $O(10^{-10})$*
- *Long-lived objects*
- *Interact very weakly with matter*

Models	*Final states*
HNL, SUSY neutralino	$l^+\pi^-$, l^+K^-, $l^+\rho^-$ $\rho^+\rightarrow\pi^+\pi^0$
Vector, scalar, axion portals, SUSY sgoldstino	l^+l^-
HNL, SUSY neutralino, axino	$l^+l^-\nu$
Axion portal, SUSY sgoldstino	$\gamma\gamma$
SUSY sgoldstino	$\pi^0\pi^0$

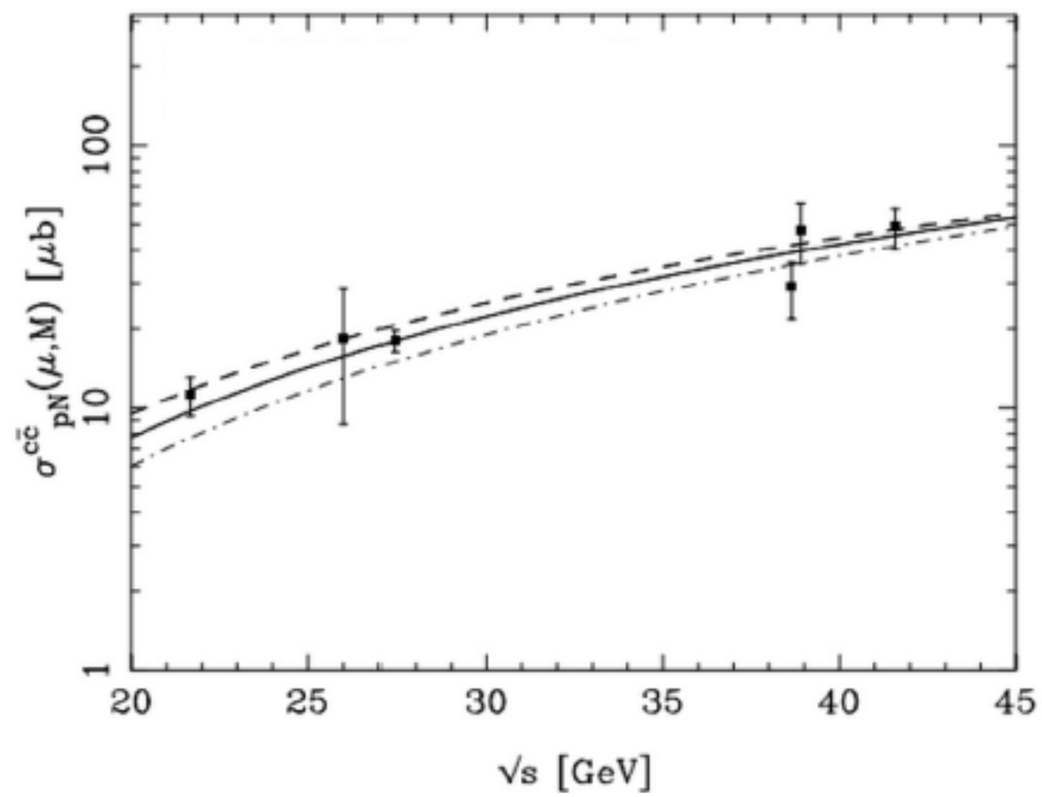
Full reconstruction and PID are essential to minimize model dependence

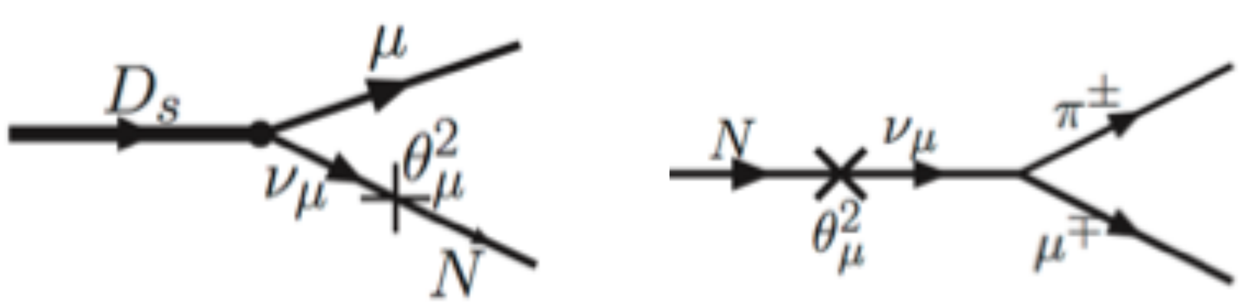
Experimental challenge is background suppression

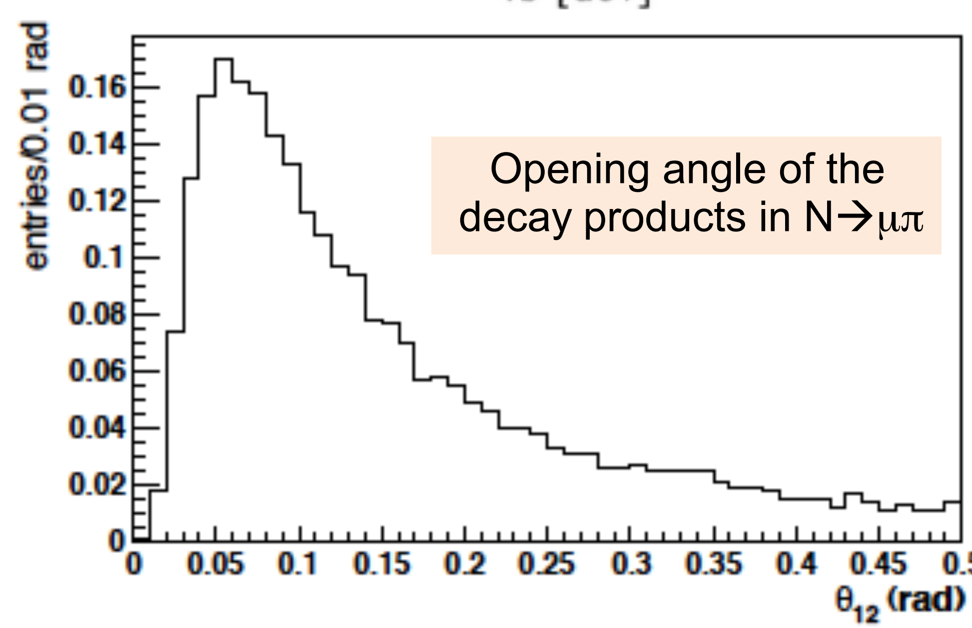
Experiment

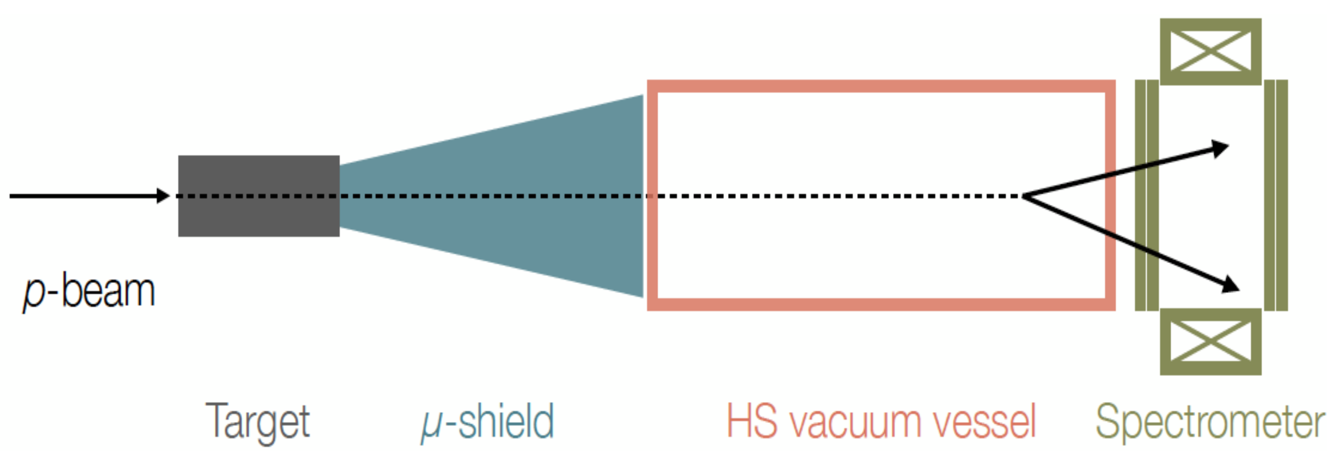
✓ *Search for HS particles in Heavy Flavour decays*
Charm (and beauty) cross-sections strongly depend on the beam energy

✓ *HS produced in charm and beauty decays have significant P_T*







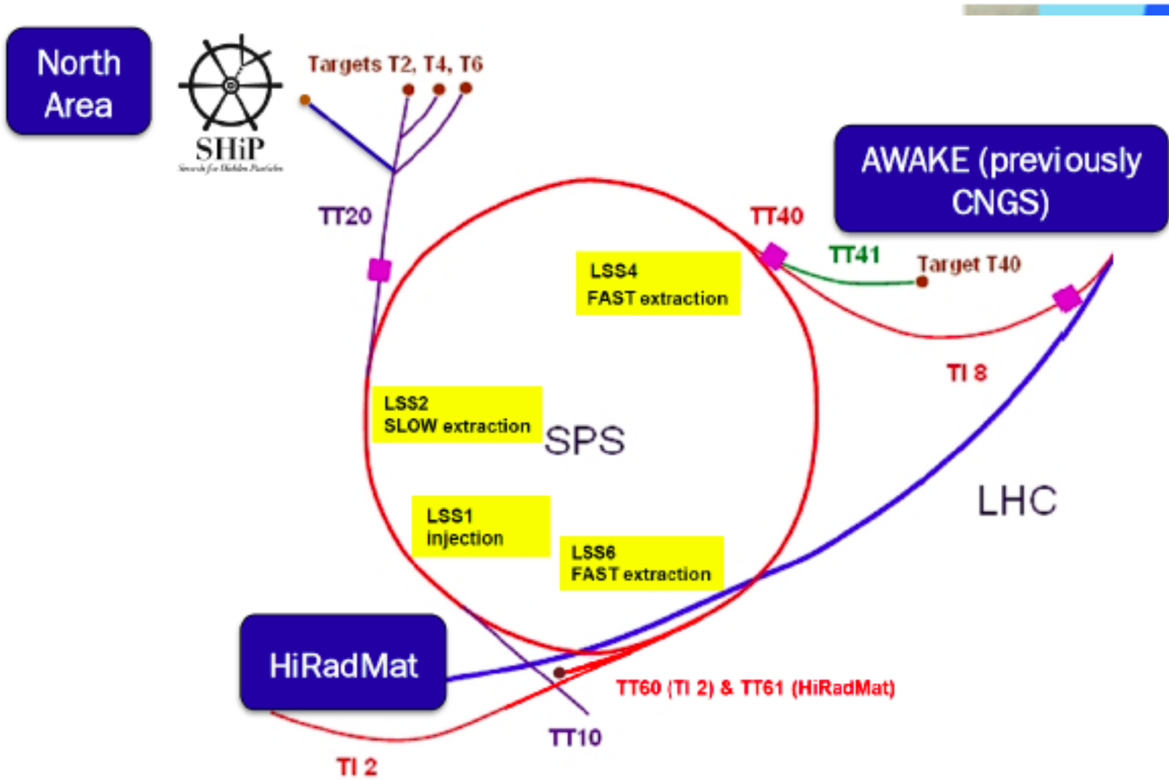


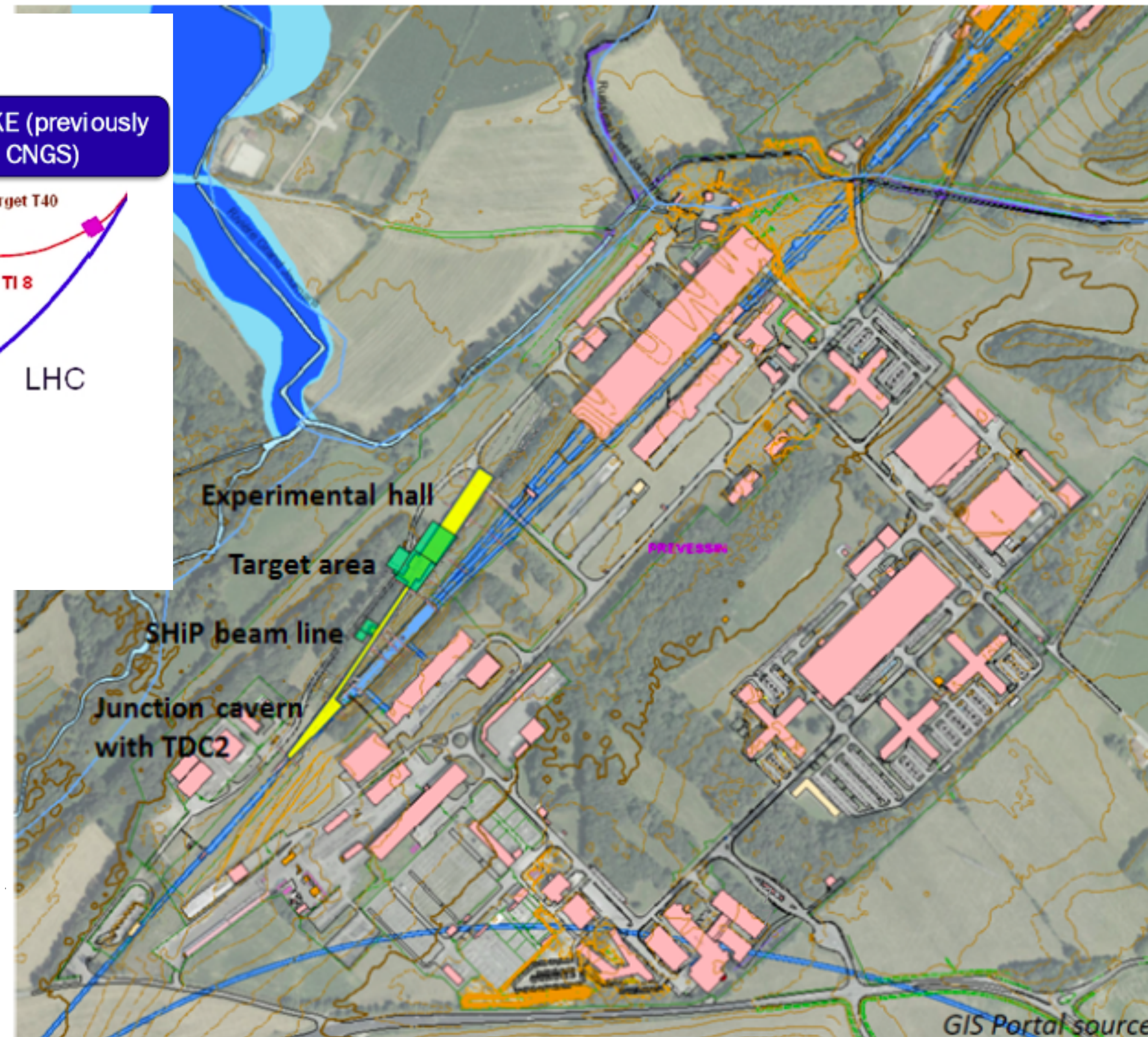
Detector must be placed close to the target to maximize geometrical acceptance
Effective (and "short") muon shield is essential to reduce muon-induced backgrounds

The BDF at the SPS

(Prevessin North Area site)

Proposed implementation is based on minimal modification to the SPS complex





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

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The SHiP Experiment

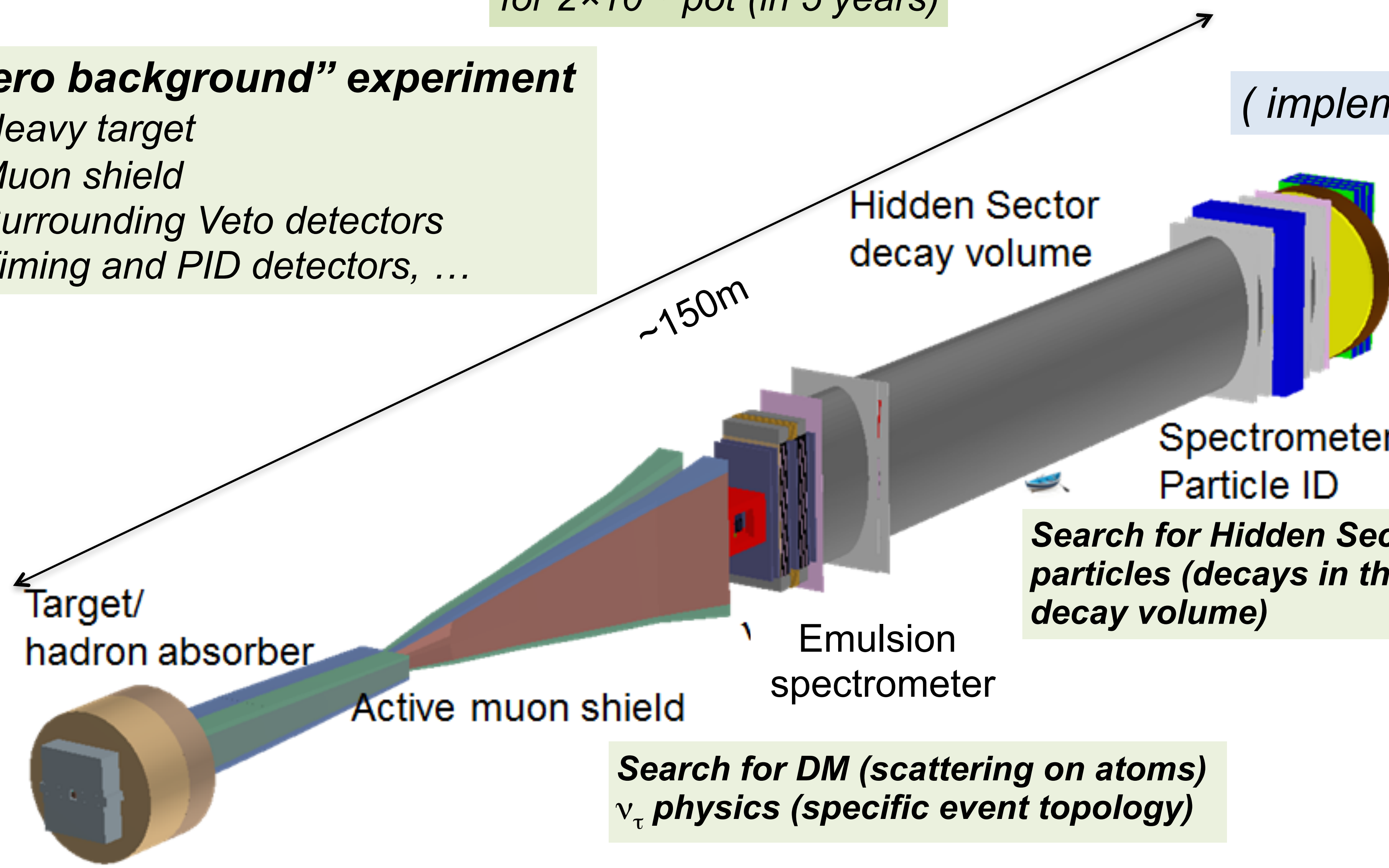
SHiP
Search for Hidden Particles

SHiP Technical Proposal:
1504.04956

$>10^{18}$ D, $>10^{16}$ τ, $>10^{20}$ γ
for 2×10^{20} pot (in 5 years)

"Zero background" experiment
- *Heavy target*
- *Muon shield*
- *Surrounding Veto detectors*
- *Timing and PID detectors, …*

(implemented in Geant4 for TP)



Search for Hidden Sector particles (decays in the decay volume)

Search for DM (scattering on atoms)
ν_τ physics (specific event topology)

Optimization Phase

✓ *Improve SHiP (TP) sensitivity to new very weakly particles: HNLs, dark photons, dark scalars, … and tau neutrino physics*

✓ *Further extend physics case. SHiP has very good potential to search for Light Dark Matter via its scattering on atoms of emulsion spectrometer*

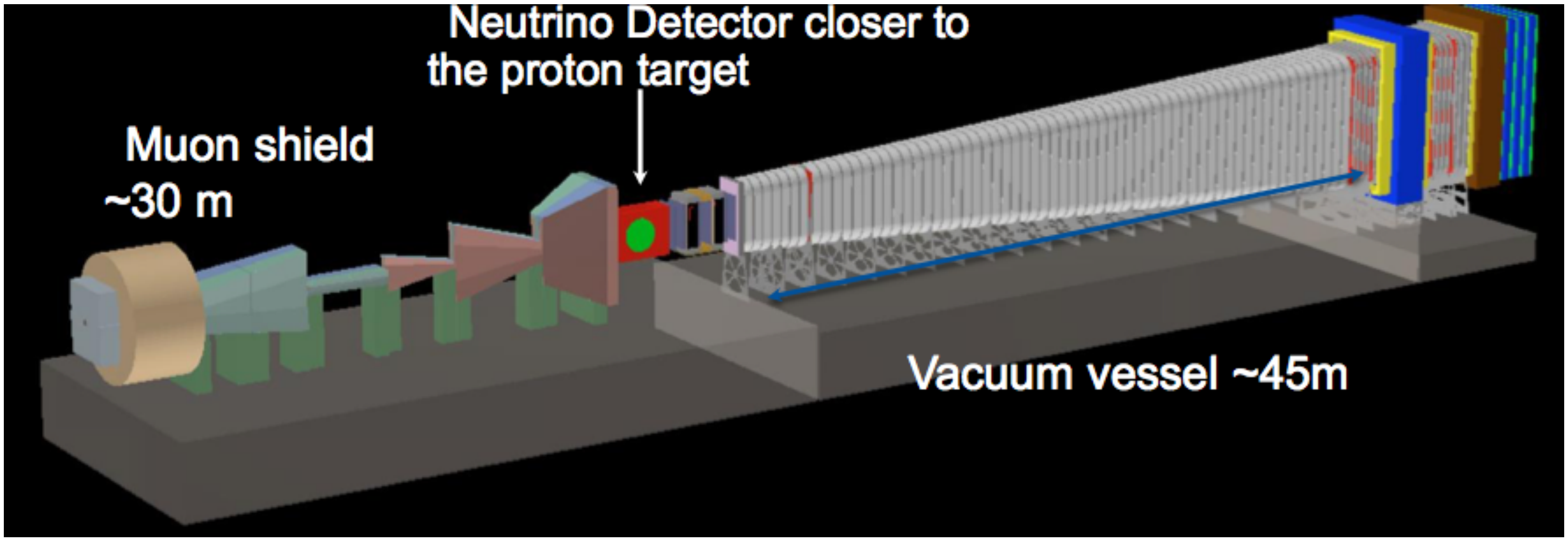
✓ *Keep background under control and at O(0.1) level*

Improve SHiP TP version *respecting cost constraints*

→

Introduction

✓ *Configuration of the muon shield (**MC to be validated with data**)*
✓ *Shape, dimension and evacuation of the decay volume*



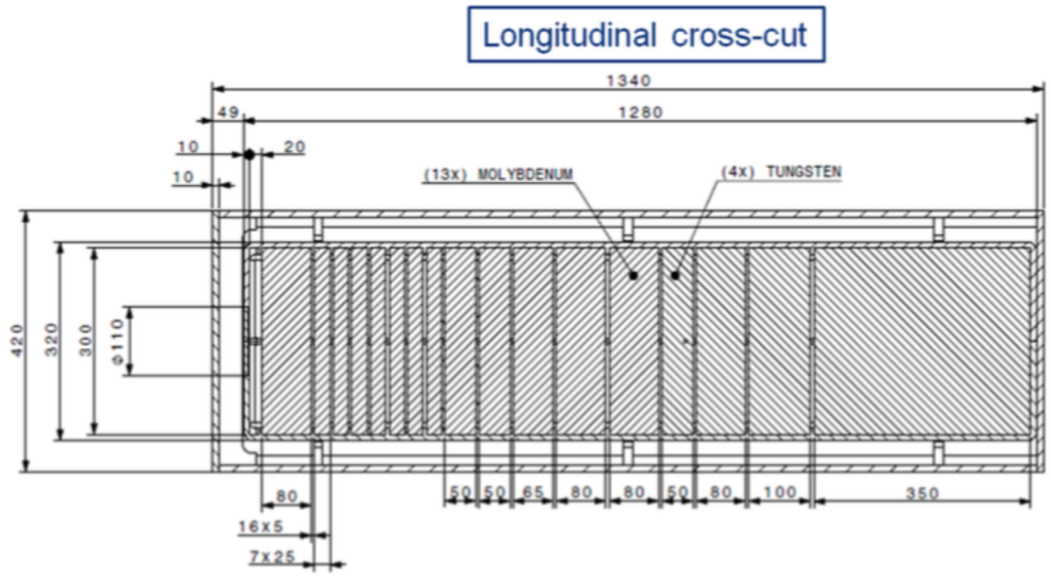
✓ *Optimization of physics performance for various sub-detectors*
✓ *Revisit detector technologies, including new sub-detectors,
to further consolidate background rejection and extend PID*

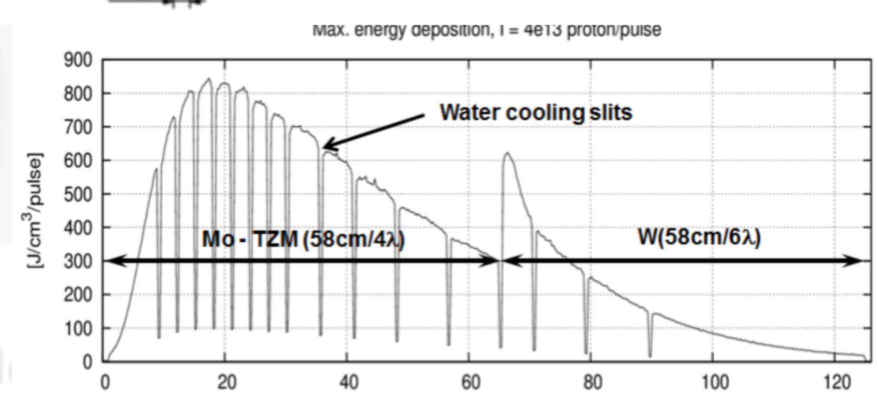
Updated background estimates and signal sensitivities, and cost

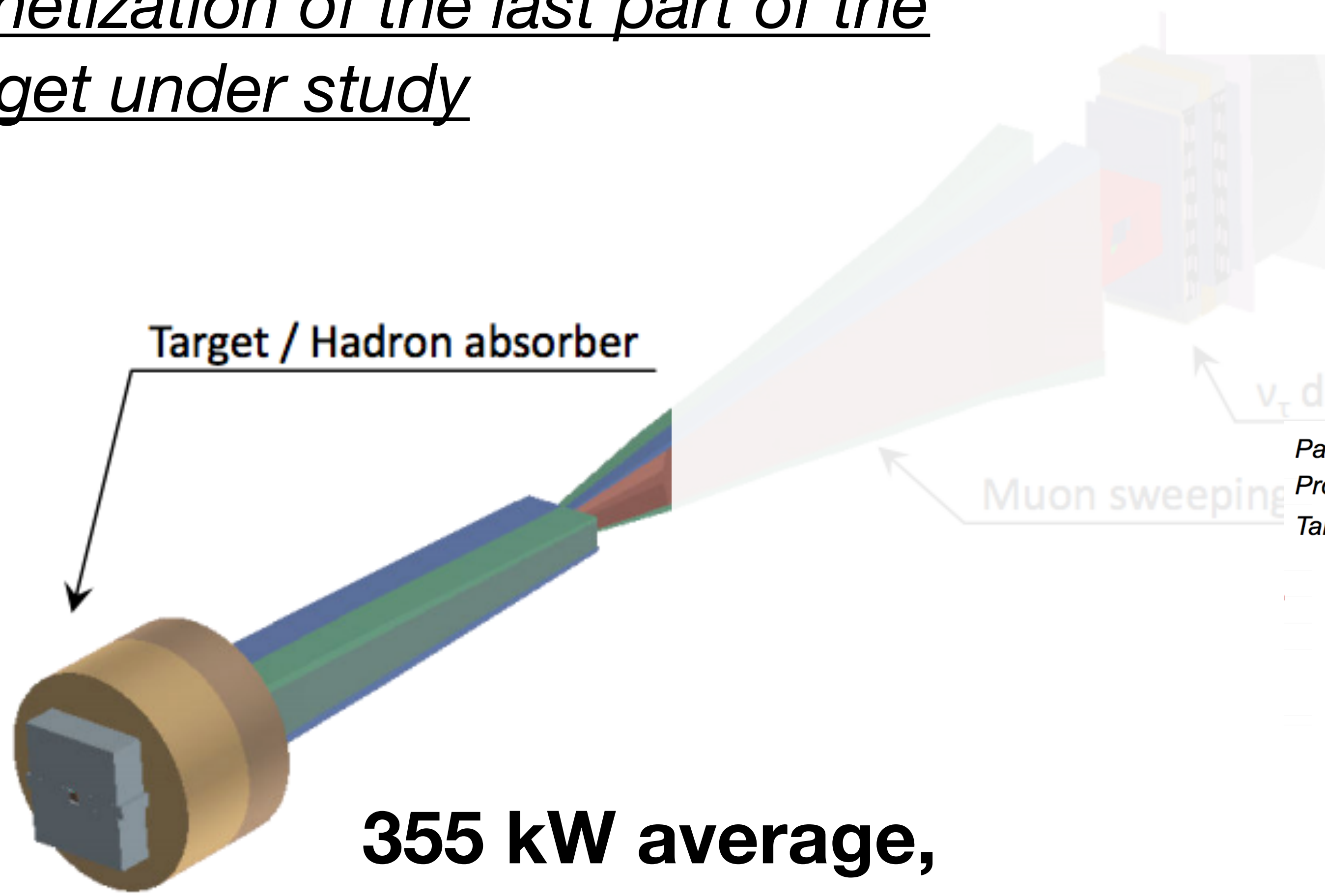
✓ *Contribution from the secondary interactions in the target improves
signal yield by ~50% (**to be validated with data)***

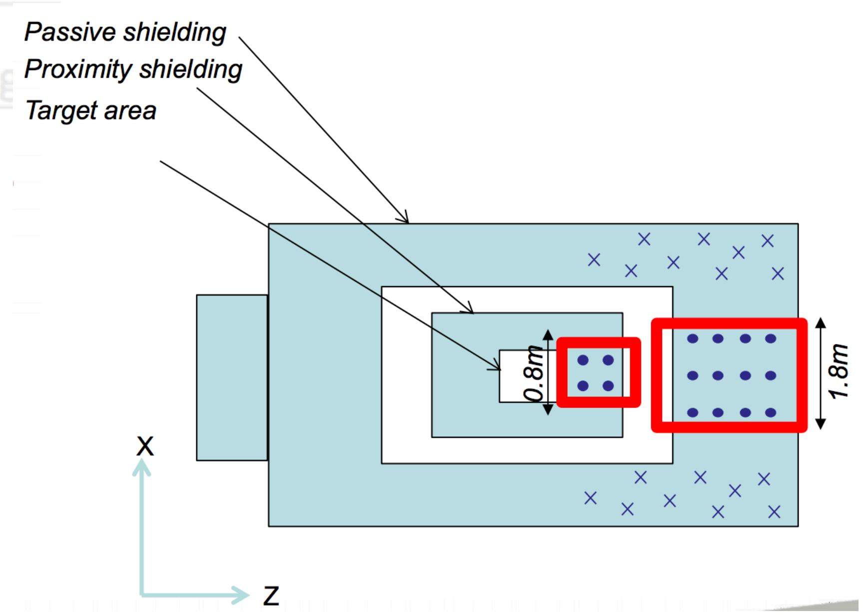
Target

- *Layers of Titanium/Zirconium/ Molibdenum for 4λ_{int} in the core of the beam*
- *Followed by Layers of pure W*
- *Each layer is cooled by water*
- *Alternative cooling with He under study*
- *Magnetization of the last part of the target under study*









355 kW average,
2.56 MW during 1s spill

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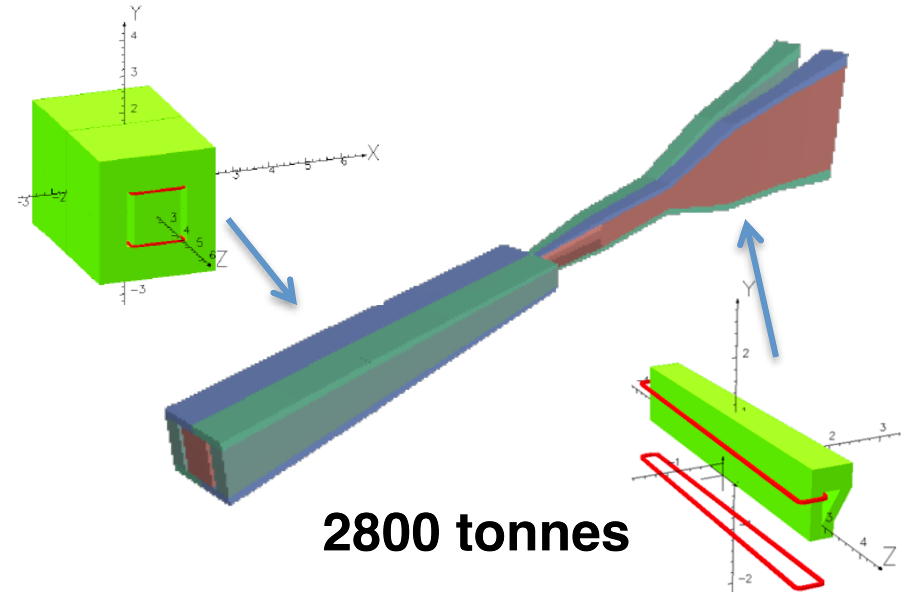
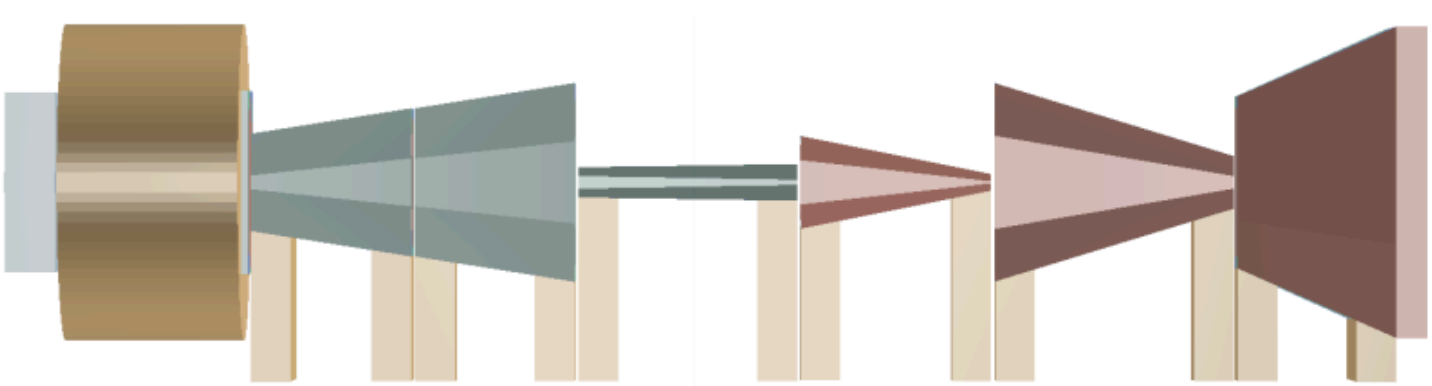
Muon Shield

SHiP
Search for Hidden Particles

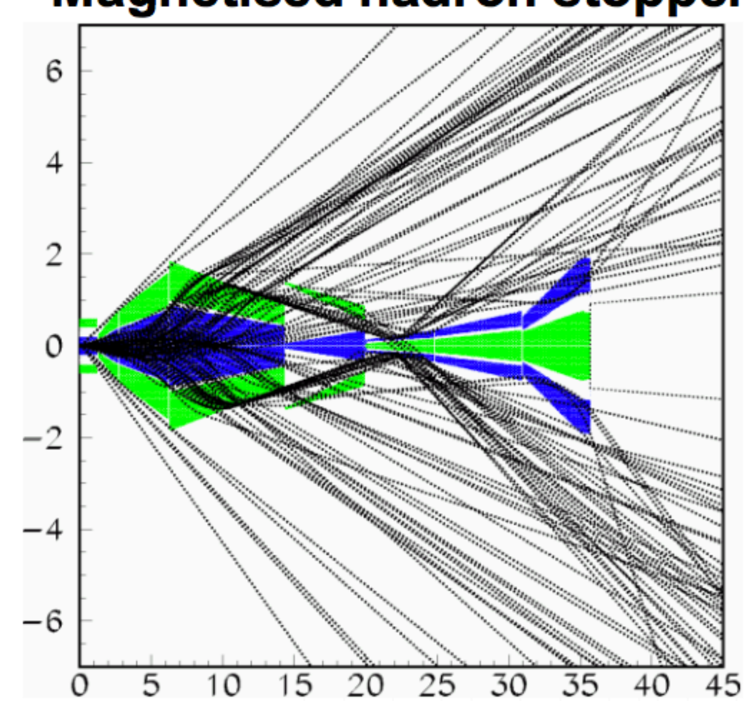
- ✓ *Muon flux limit driven by emulsion based neutrino detector and HS background*
- ✓ *Active muon shield based entirely on magnet sweeper with a total field integral B_y = 86.4 Tm*
  Realistic design of sweeper magnets in progress
  Challenges: flux leakage, constant field profile, modeling magnet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



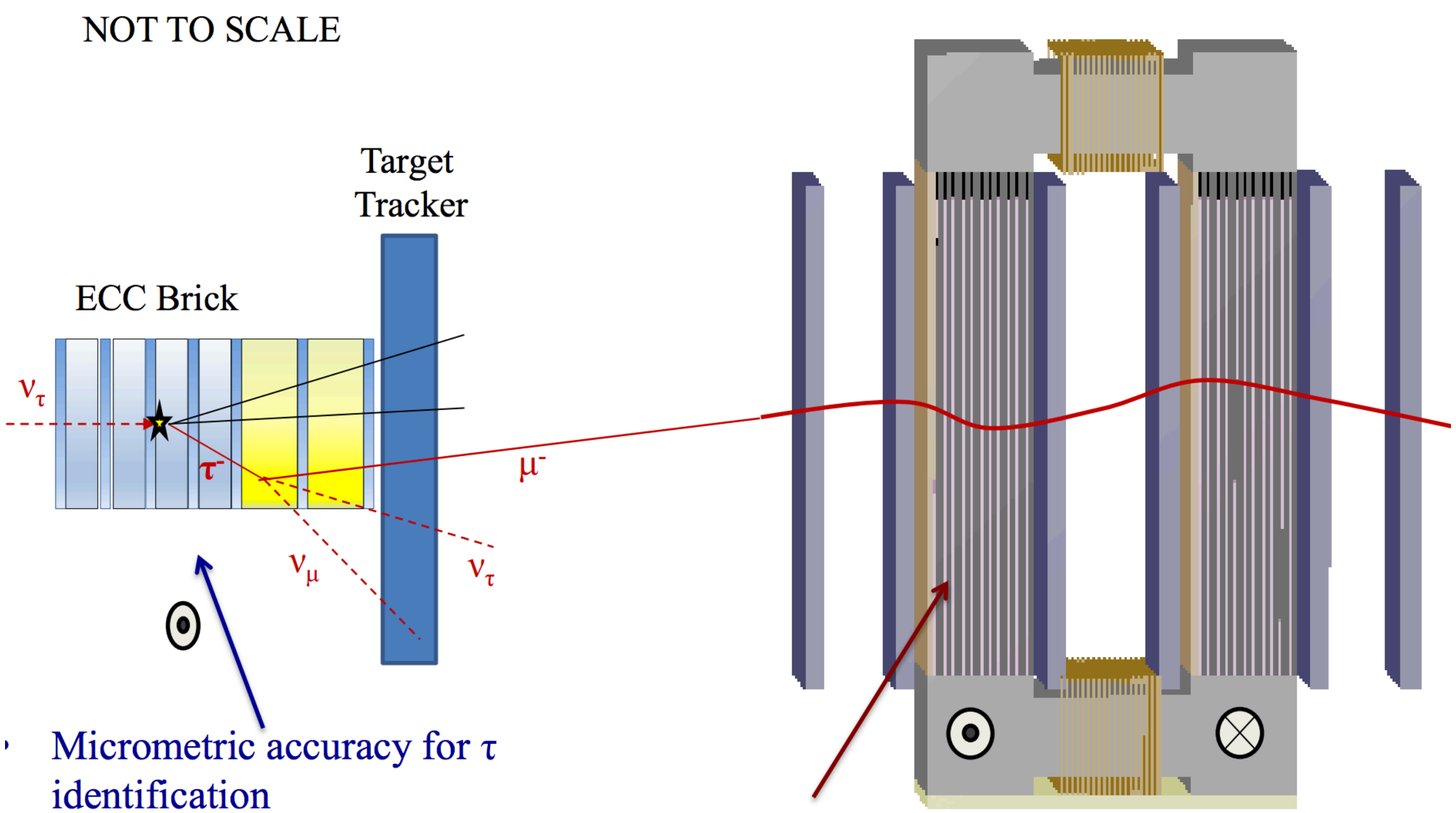
- ***Magnetizing the target allows to get ~5m closer to the tracker***
- ***Weight drops by 65%***

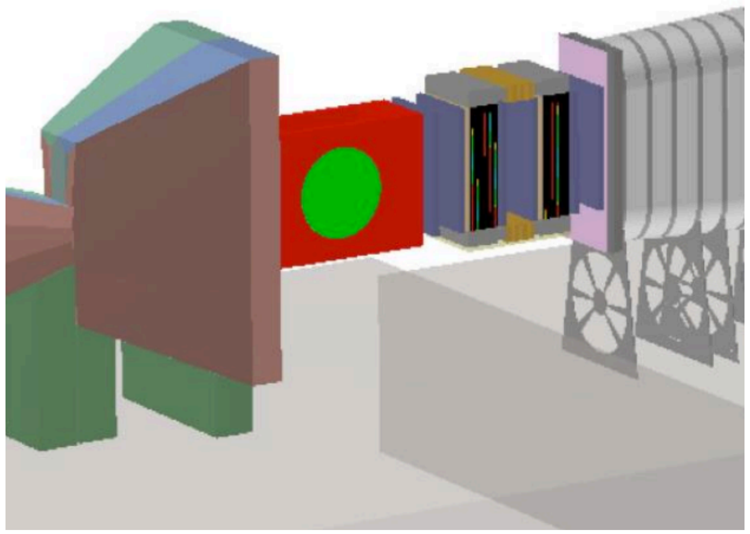


Magnetised hadron stopper



ν Tau Detector





- Only 9 tau neutrinos events recorded
- We can fully reconstruct 3000-4000 vets
- tau neutrino cross section measurements
- Charm physics with taus
- Proton structure function
- Large electron neutrino flux to measure Charm production

decay channel	ν_τ			$\overline{\nu}_\tau$		
	N^{exp}	N^{bg}	R	N^{exp}	N^{bg}	R
$\tau \to \mu$	570	30	19	290	140	2
$\tau \to h$	990	80	12	500	380	1.3
$\tau \to 3h$	210	30	7	110	140	0.8
Total	1770	140	13	900	660	1.4

HS Detector: Tracking

- Vacuum: 10^{-3} mbar for the TP (can relax this requirement)
- Large vacuum vessel (5mx10mx50 m)
- *Liquid Scintillator around decay vessel*
- Timing detector with <100ps resolution

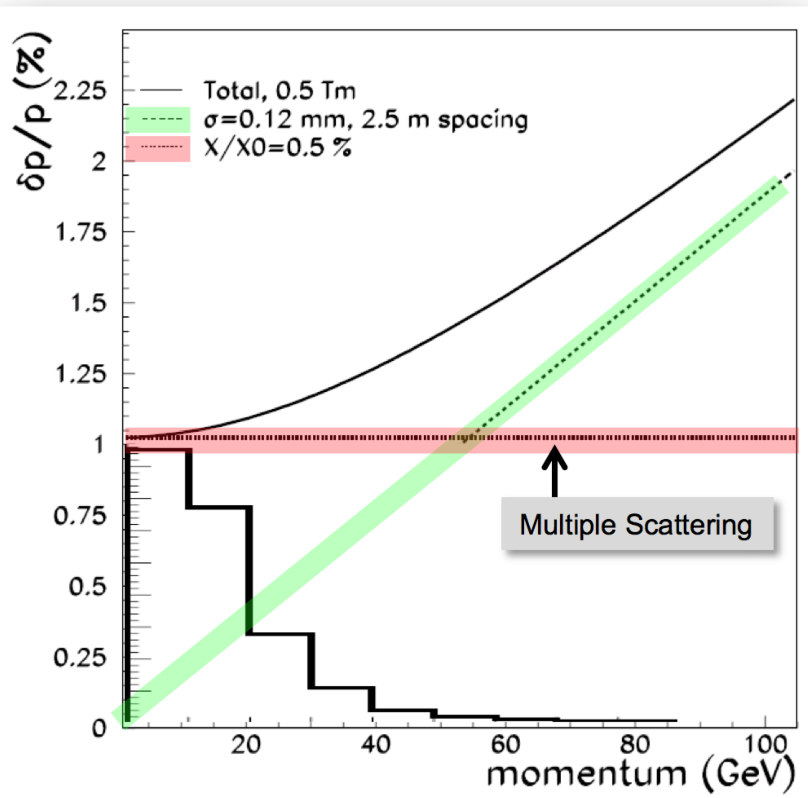
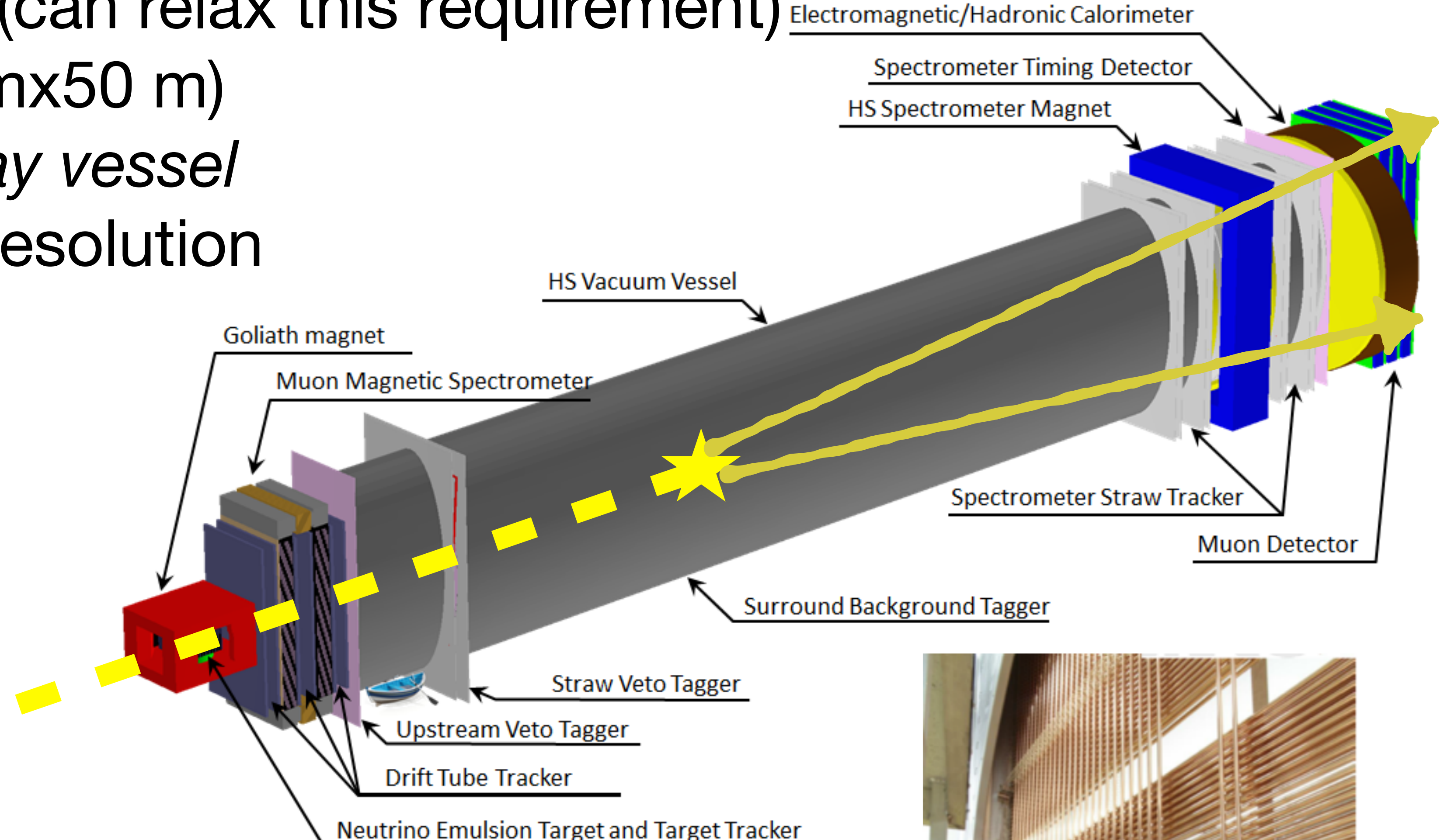


Figure 11: Estimated momentum resolution of the spectrometer (solid line) with separate contributions from multiple scattering (dotted line) and chamber resolution (dashed line).



Straw tubes similar to NA62 with 120um spatial resolution and 0.5% X_0/X

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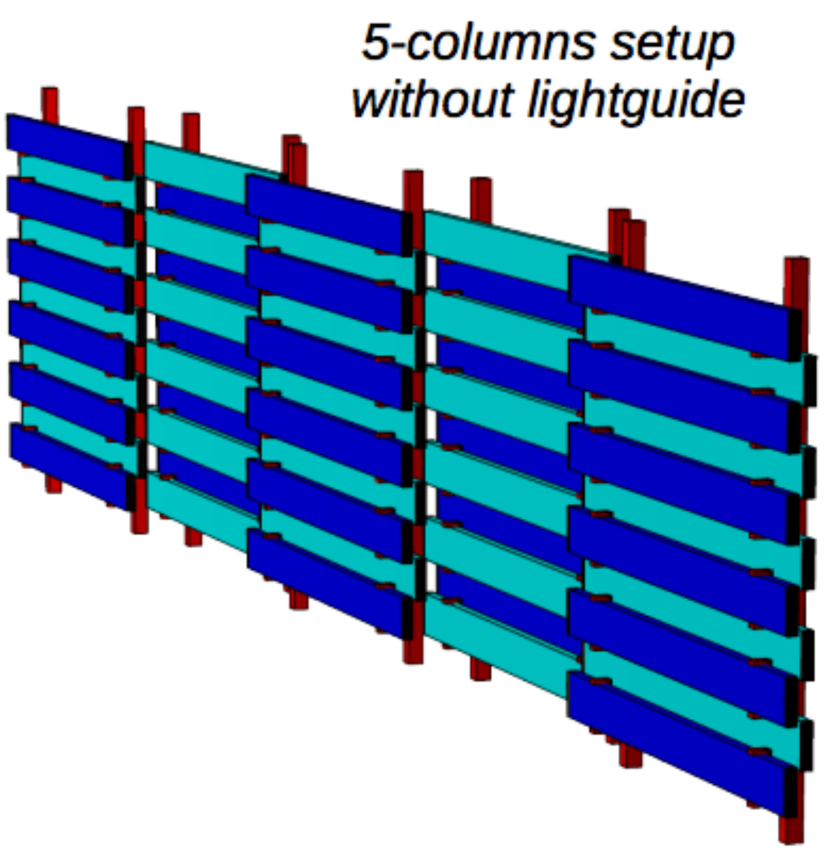
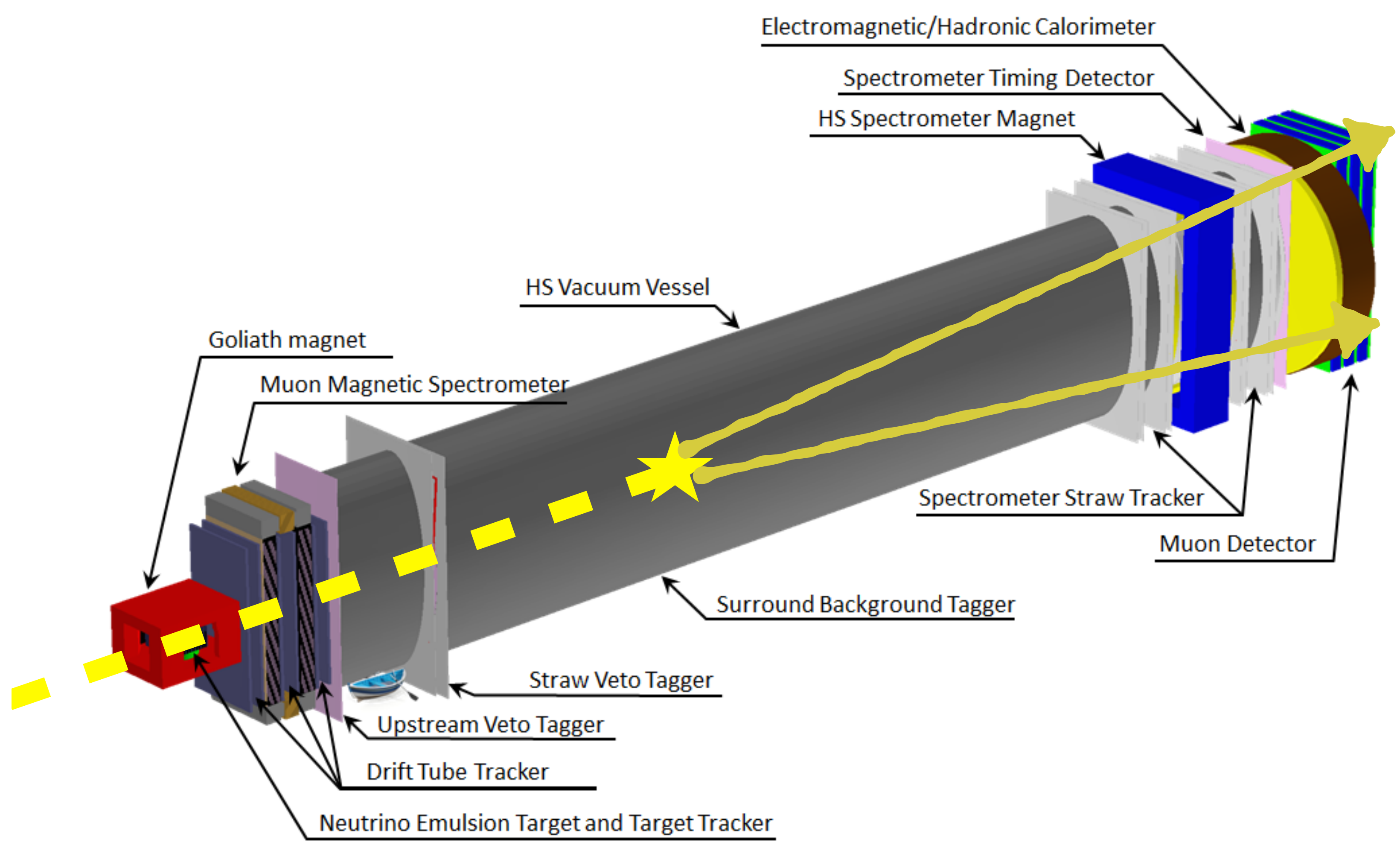
HS Detector: Timing Veto





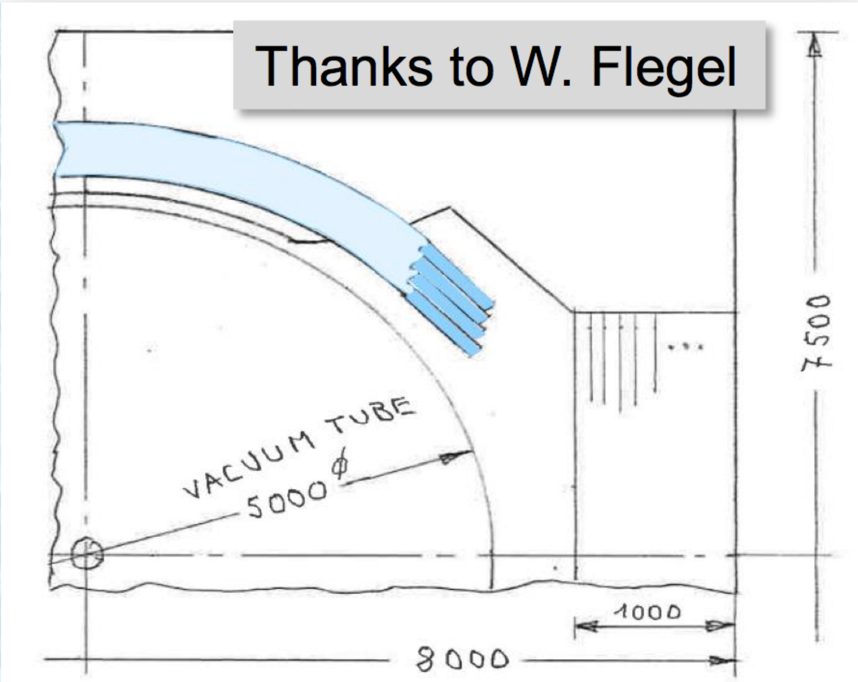
Various design under study (alternative design with MRPC)

- 6m long bars read by PMTs, more realistic design with shorter bars
- Replace PMTs by SiPM

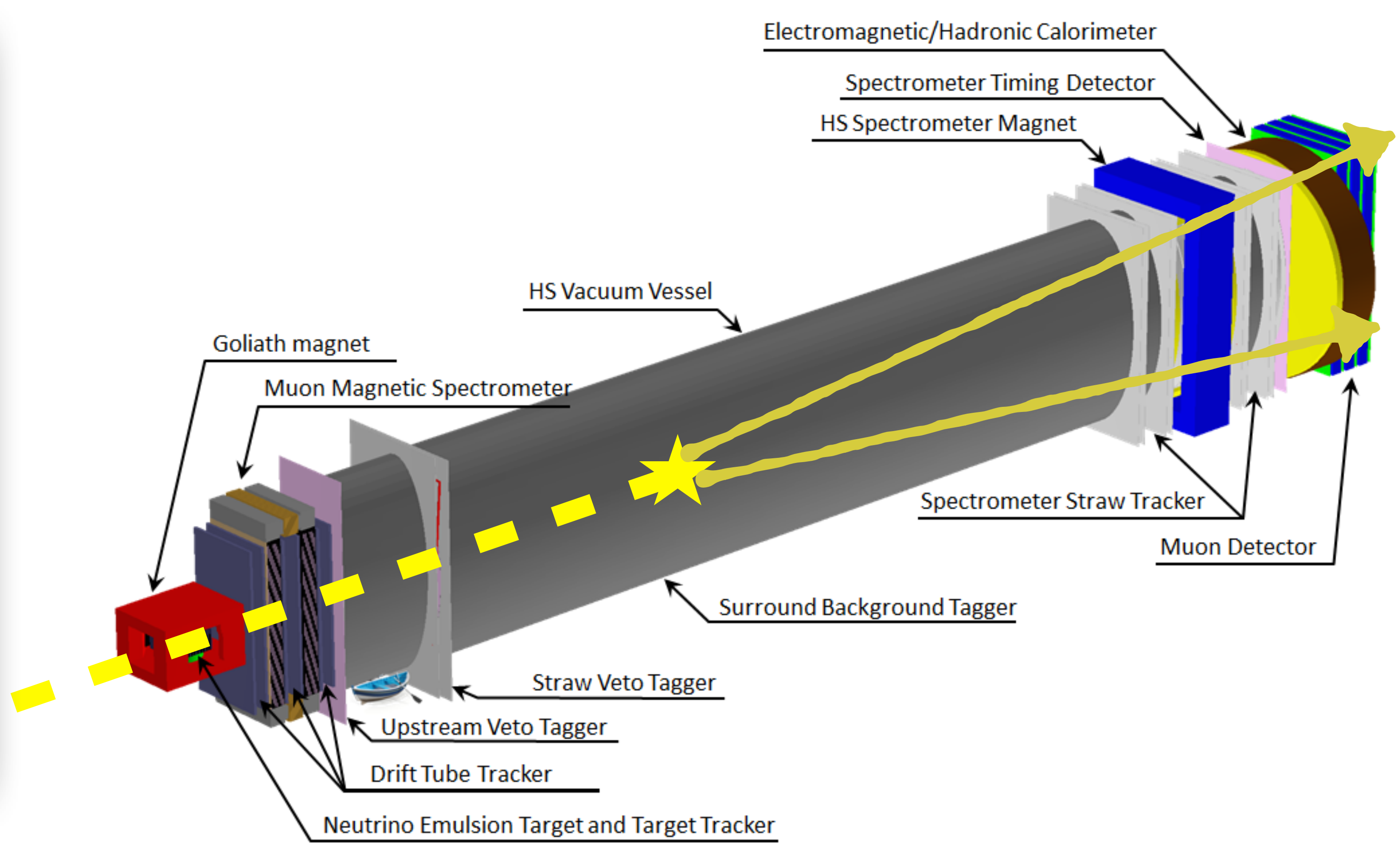
Challenges:

- Dark rate, typical value (Hamamatsu, C-series of sensL) is 100 kHz/mm2= 10 MHz/cm2
-

HS Detector: Magnet



Given such a magnet and tracker, we are still dominated by MS (0.5% total x/x0 for 4 views/station)

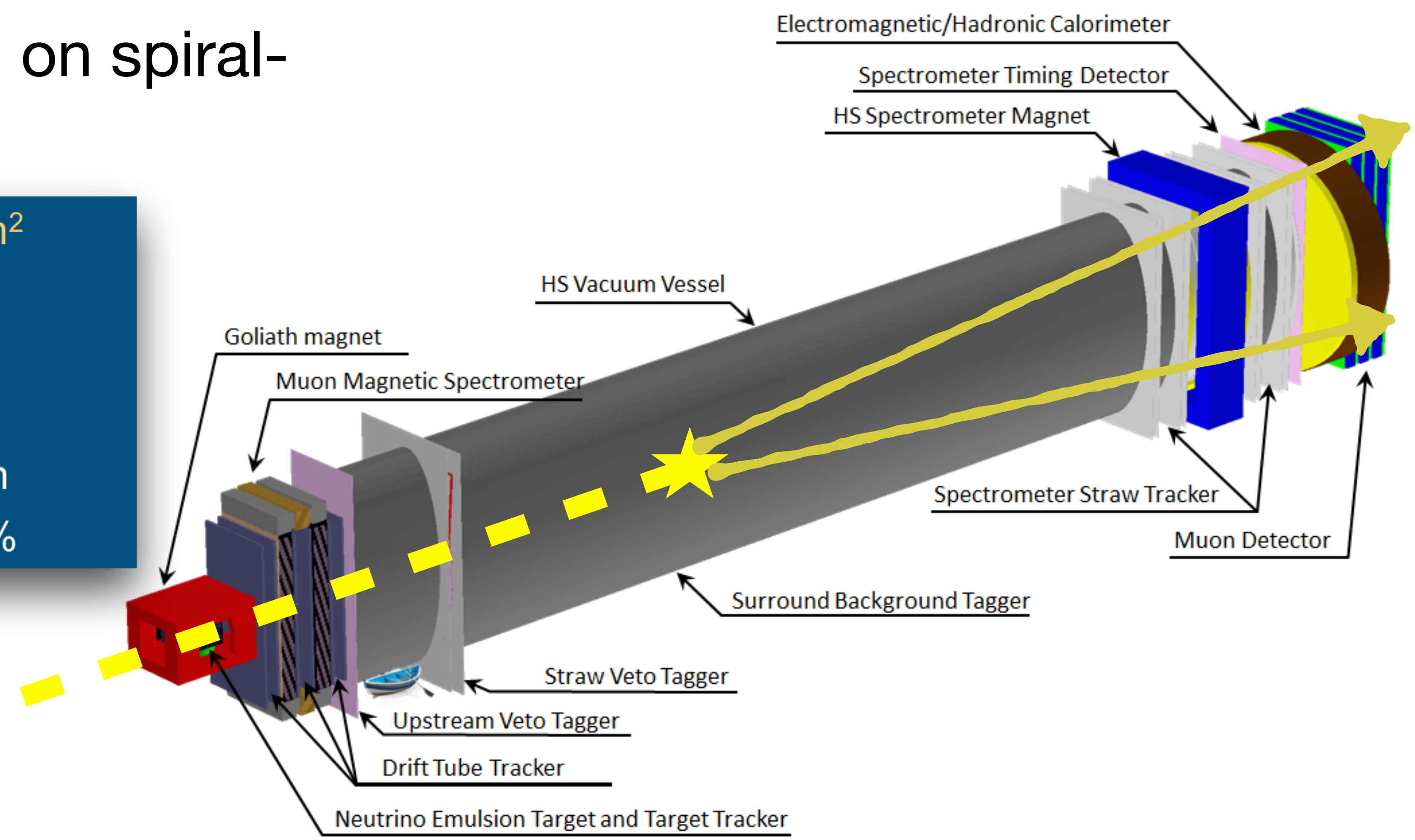


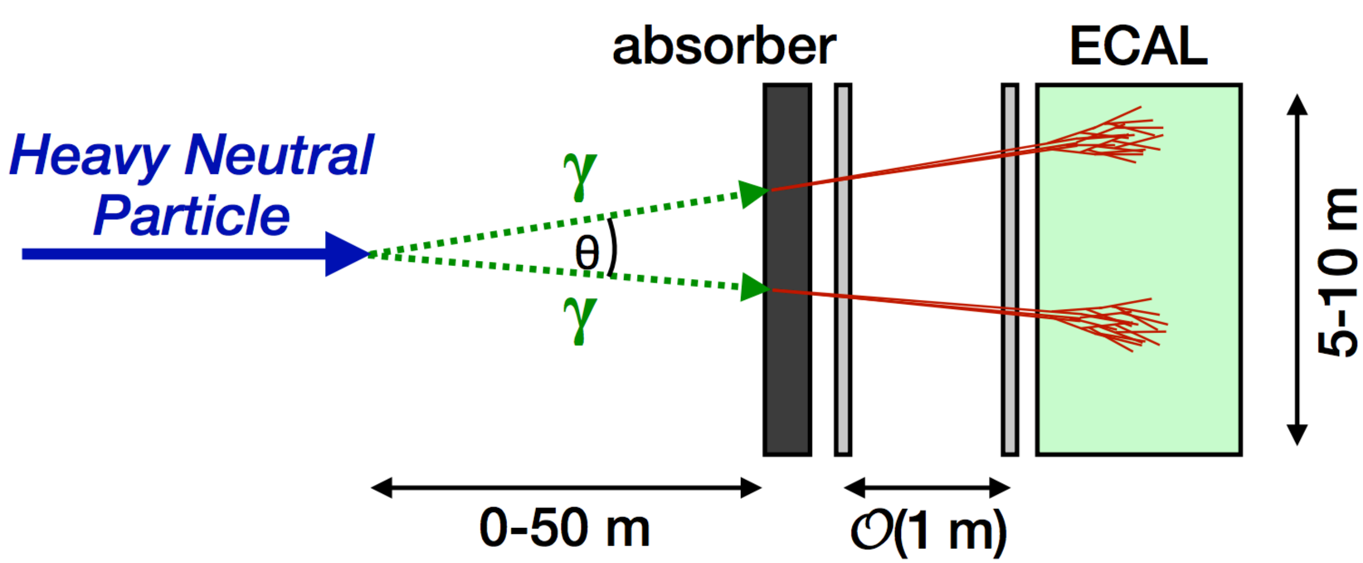
With a yoke with outer dimension of $8.0 \times 7.5 \times 2.5\,\mathrm{m}^3$, and two Al-99.7 coils, the proposed magnet provides a peak field of $\sim 0.2\,\mathrm{T}$, and a $\int BdL \approx 0.5\,\mathrm{Tm}$ over a length of $\sim 5\,\mathrm{m}$. For comparison, the LHCb magnet mentioned above contains $\sim 40\ \%$ more iron for its yoke, and dissipates three times more power.

HS Detector: Calorimeter

Possible Calorimeter based on spiral-fibre Shashlik module

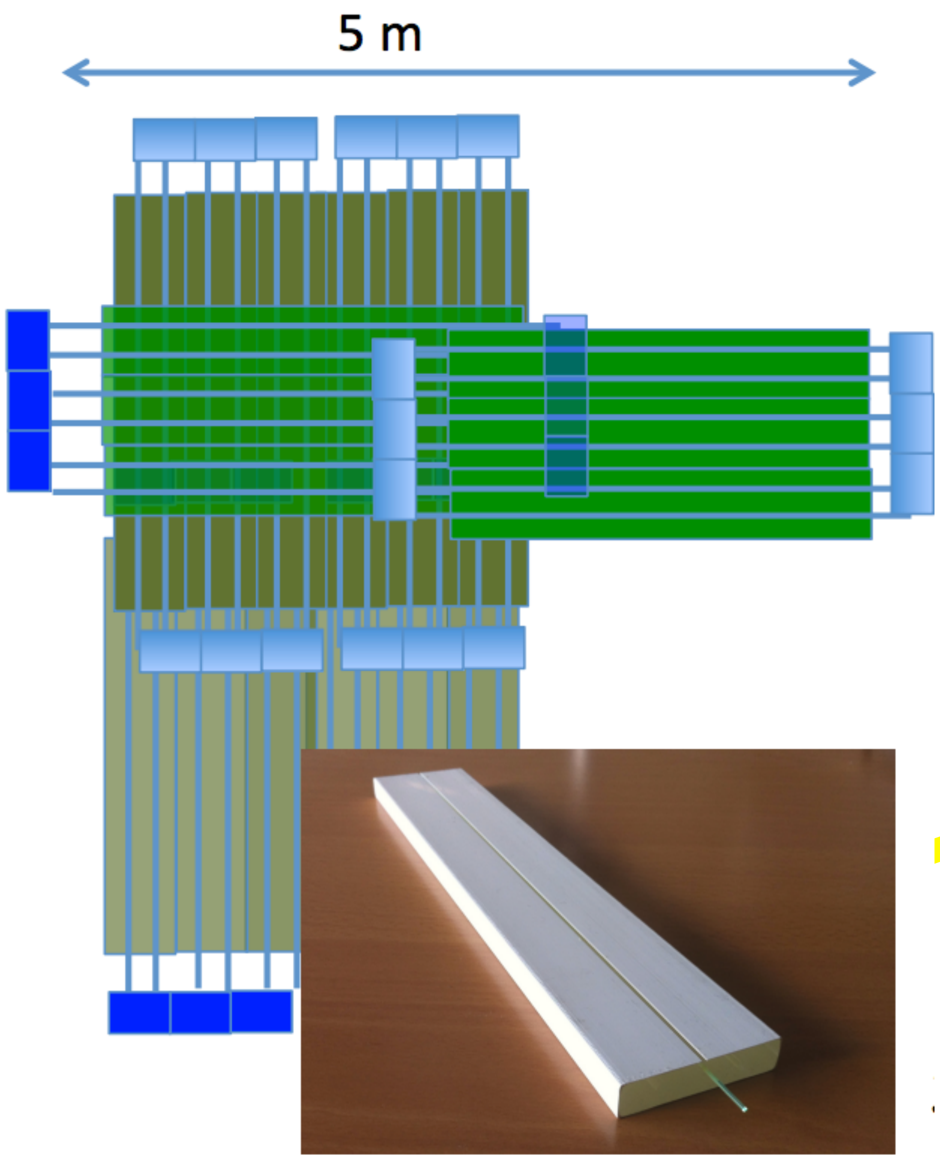
Dimensions	38.2x38.2 mm^2
Radiation length	17.5mm
Moliere radius	36mm
Radiation thickness	22.5 X0
Scintillator/lead thickness	1.5mm/0.8mm
Energy resolution	6.5%/√E ⊕ 1%

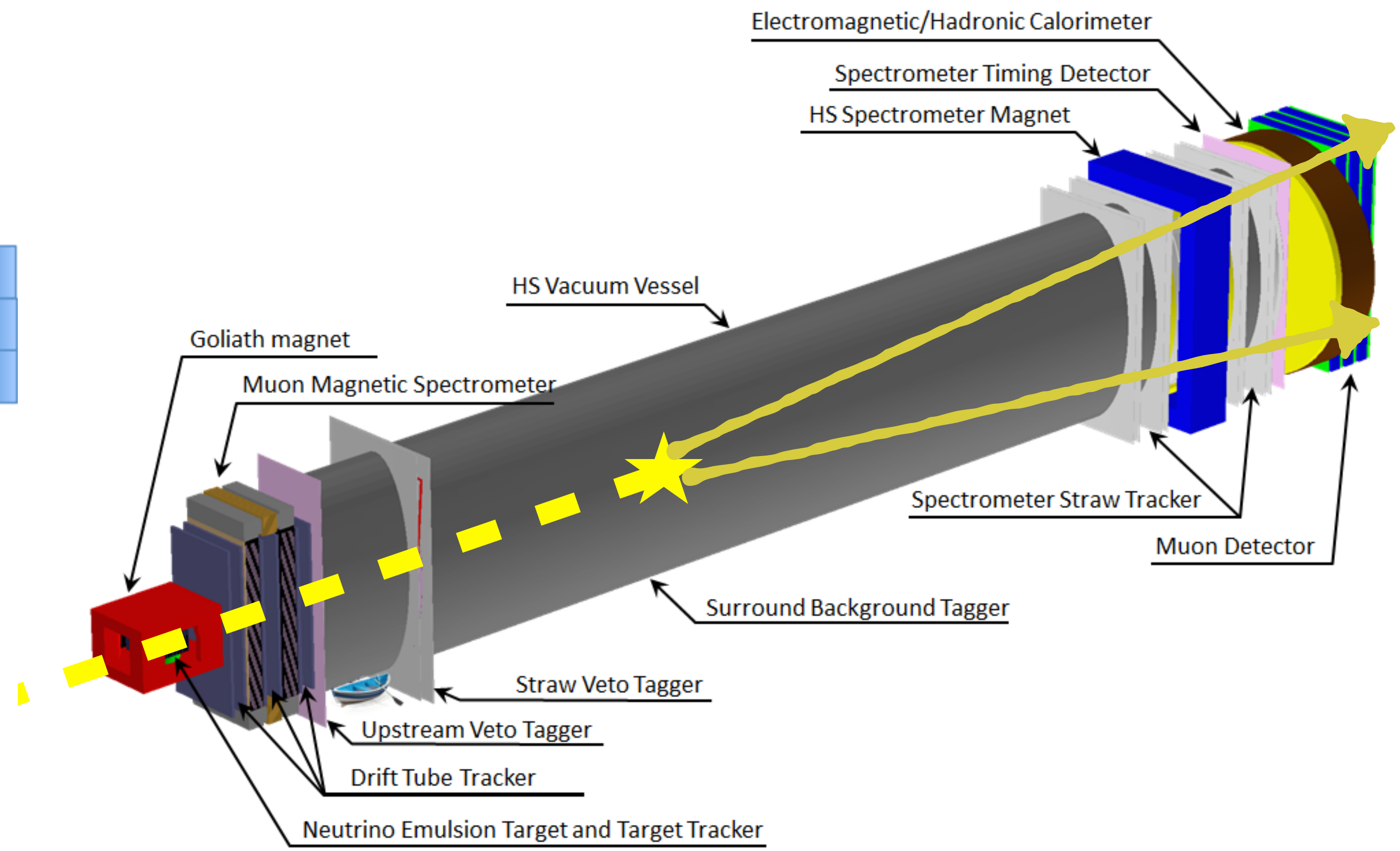




- Different options under study
- Preshower and calorimeter with pointing capabilities for the diphoton final state under study

HS Detector: Muon Det





One of the main backgrounds are muons, so it more a muon veto than a muon detector

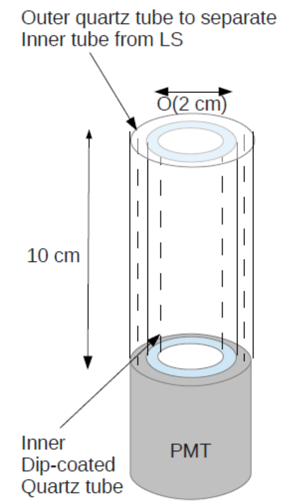
HS Detector: Veto

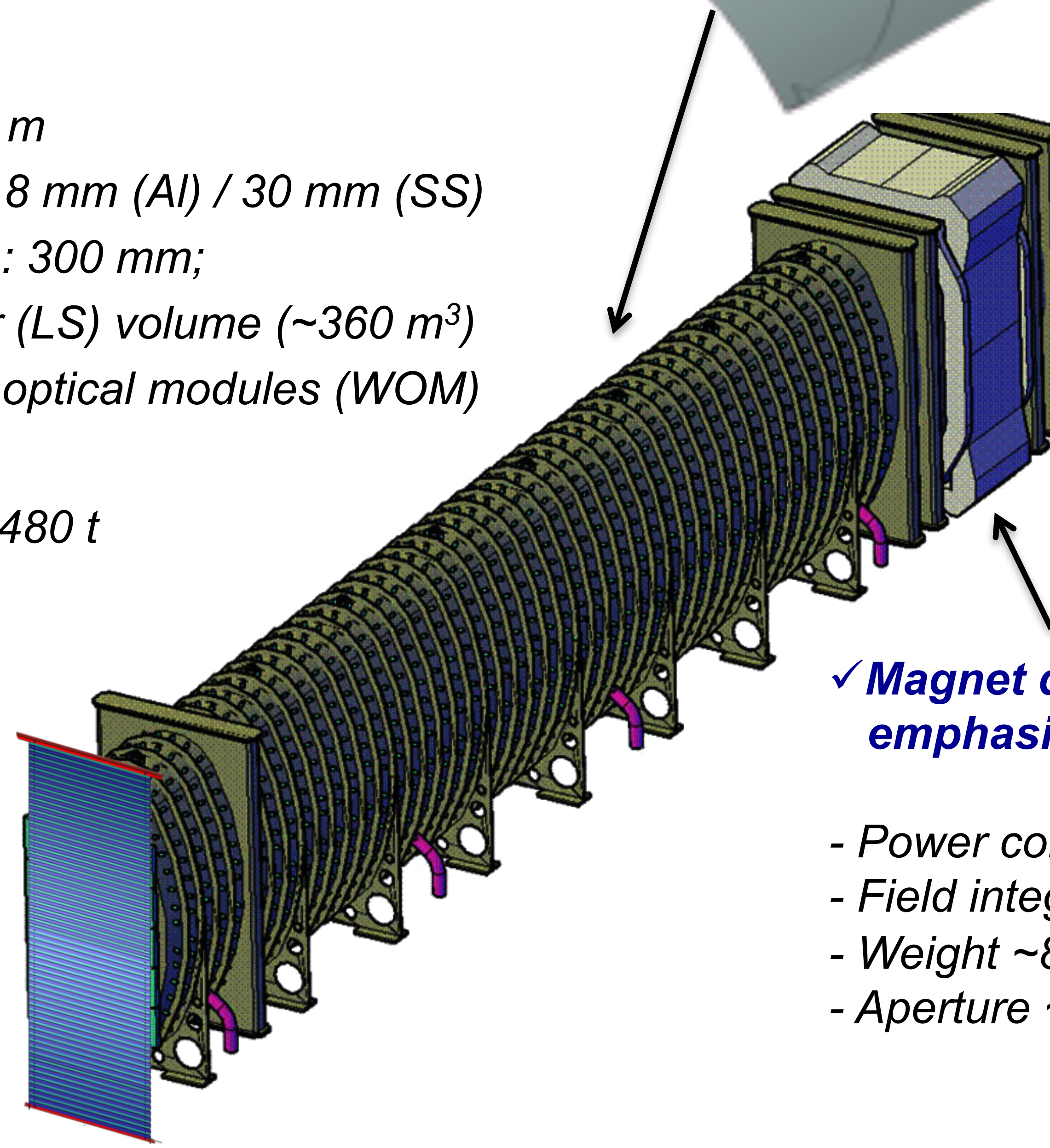
✓ ***Estimated need for vacuum:***
~ 10^{-3} mbar

✓ ***Vacuum vessel***

- *10 m x 5 m x 60 m*
- *Walls thickness: 8 mm (Al) / 30 mm (SS)*
- *Walls separation: 300 mm;*
- *Liquid scintillator (LS) volume (~360 m^3) readout by WLS optical modules (WOM) and PMTs*
- *Vessel weight ~ 480 t*

LS cell with WOMs





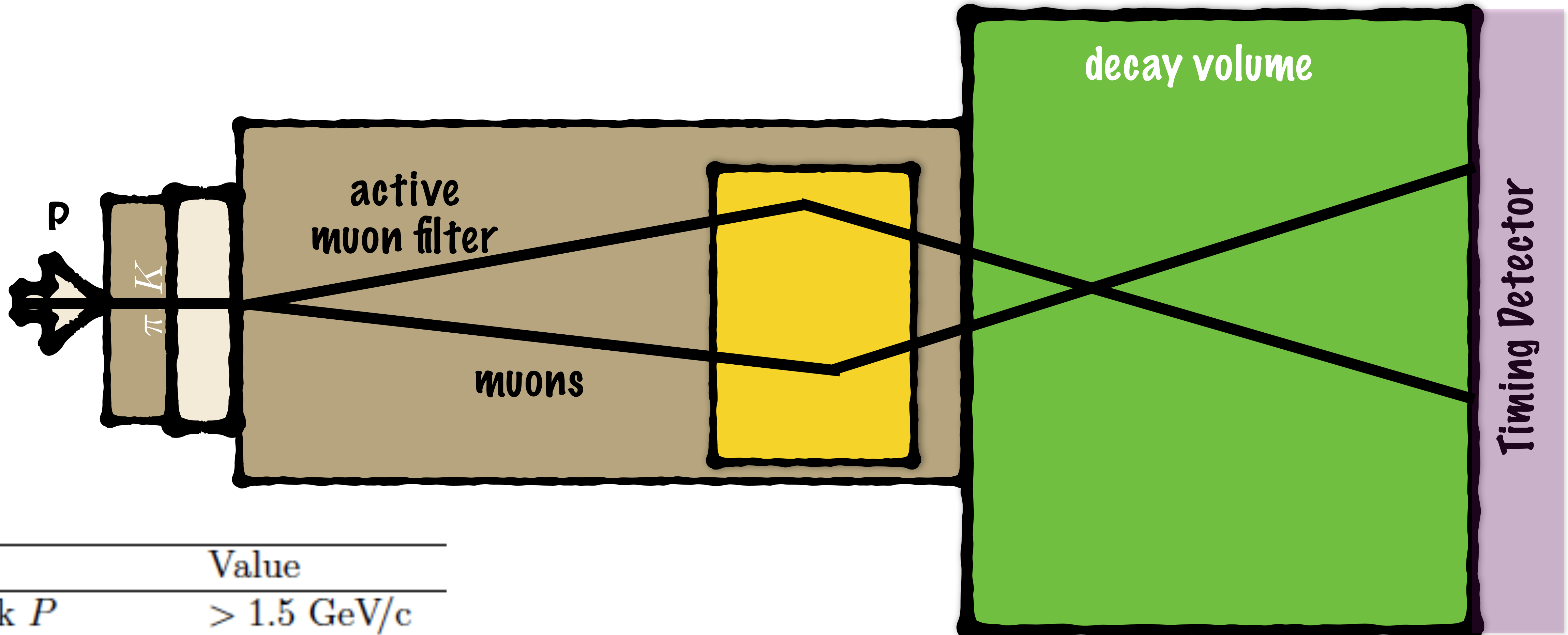
✓ ***Magnet designed with an emphasis on low power***

- *Power consumption < 1 MW*
- *Field integral: 0.65Tm over 5m*
- *Weight ~800 t*
- *Aperture ~50 m^2*

Alternative proposal with plastic scintillators

Background

Combinatorial background due to two muons that scatter and enter the decay volume



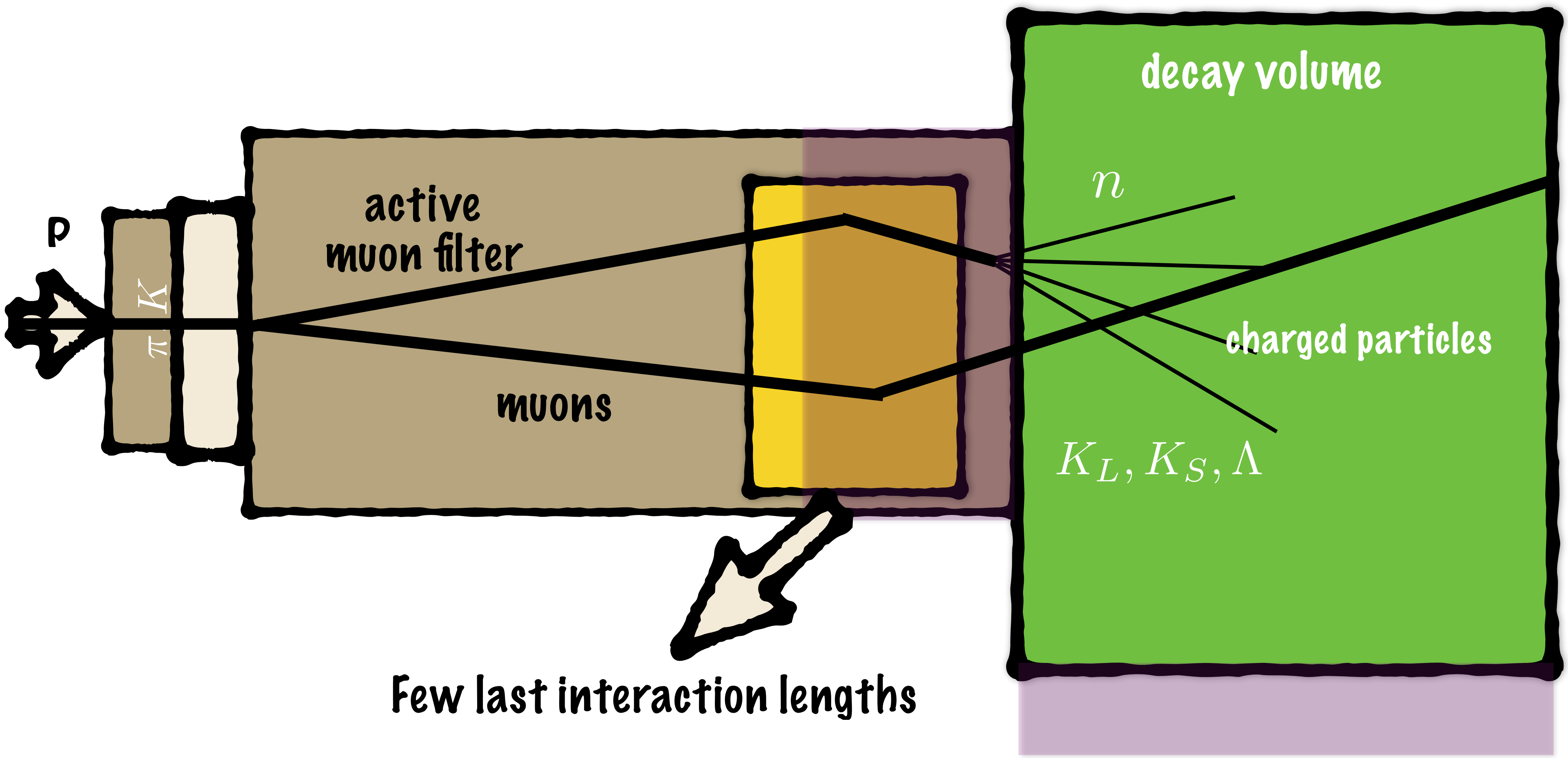
Cut	Value
Track P	> 1.5 GeV/c
Track χ^2/ndof	< 25
dimuon DOCA	< 1 cm
dimuon vertex	fiducial
dimuon mass	> 0.2 GeV/c^2
IP w.r.t target	< 2.5 m
Efficiency	10^{-4}

Suppressed by:

- *Basic kinematic and topological cuts* $\sim 10^4$
- *Timing veto detectors* $\sim 10^7$
- *Upstream veto and surrounding veto taggers* $\sim 10^4$

Background

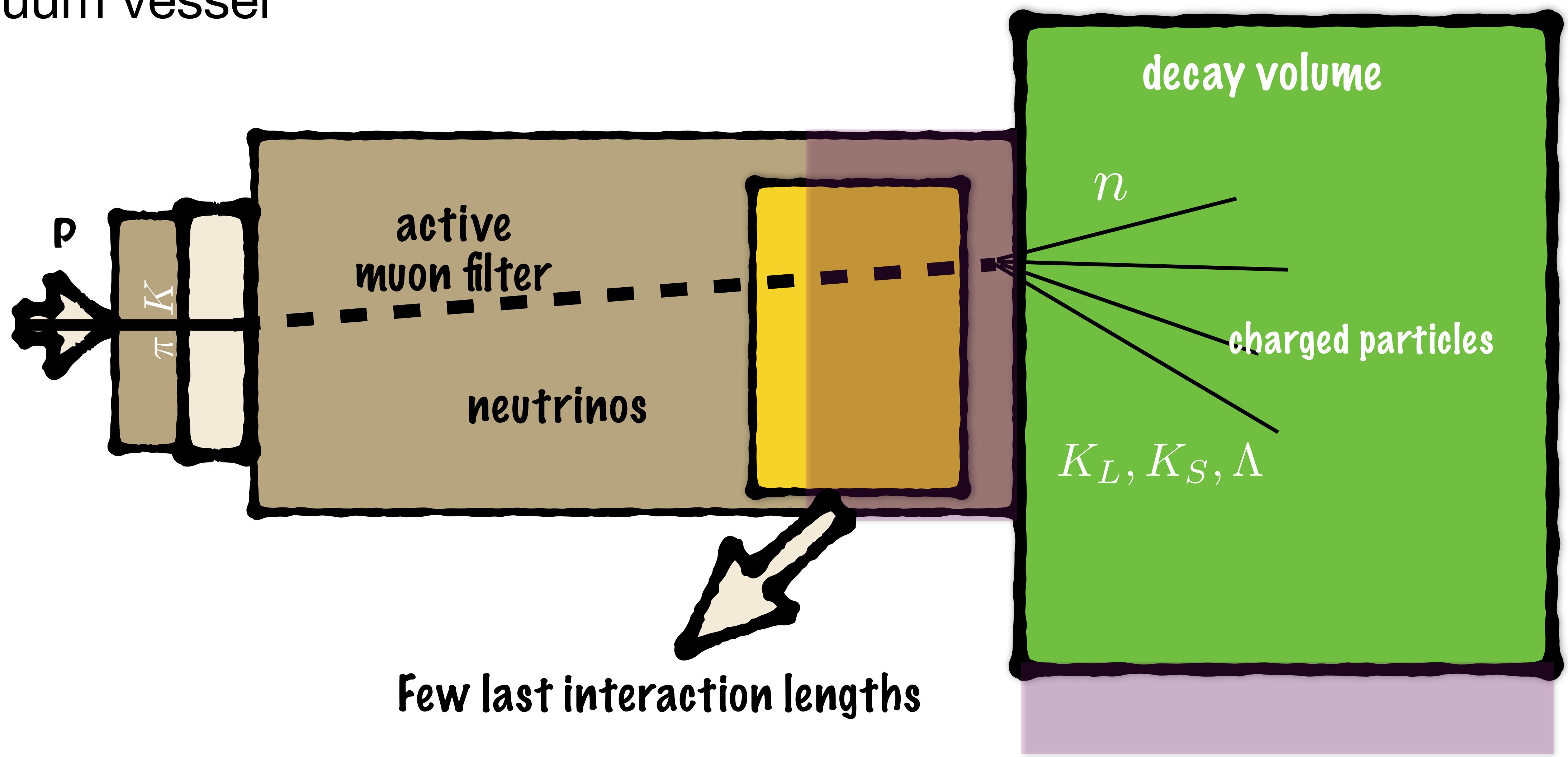
Inelastic scattering due to muons or scattering the in the vicinity of the decay volume



- Vetos and Kinematic cuts (in addition to the muon sweeper) allow to bring this background to a negligible level

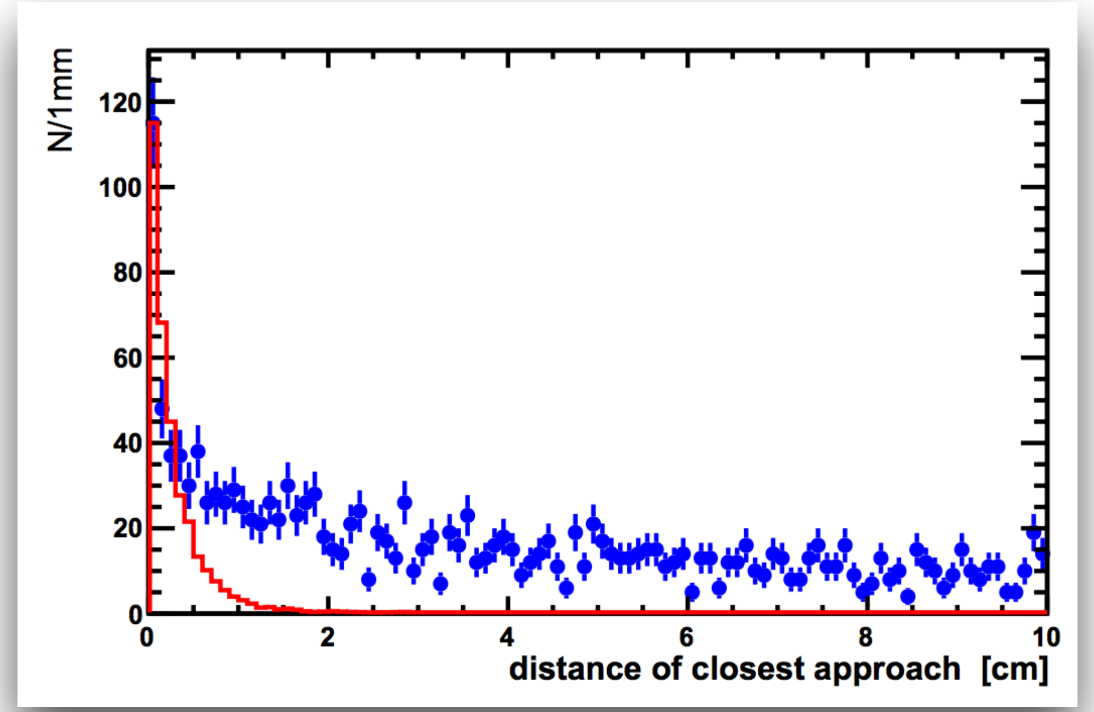
Background

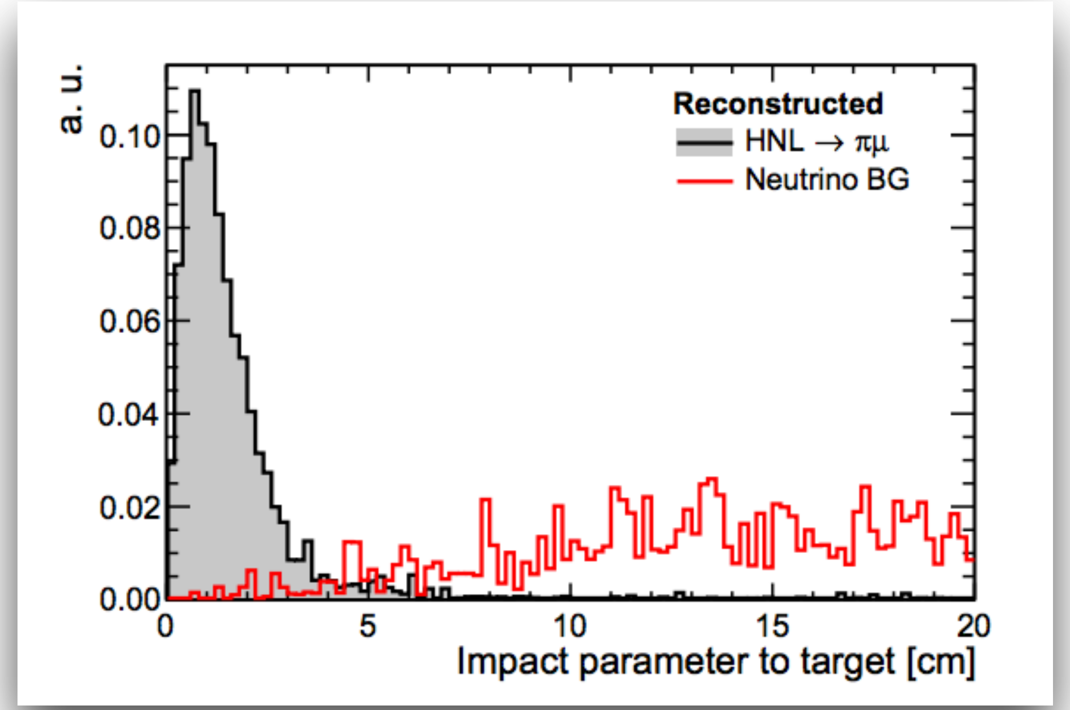
Main background from neutrino inelastic scattering in the vicinity of the vacuum vessel

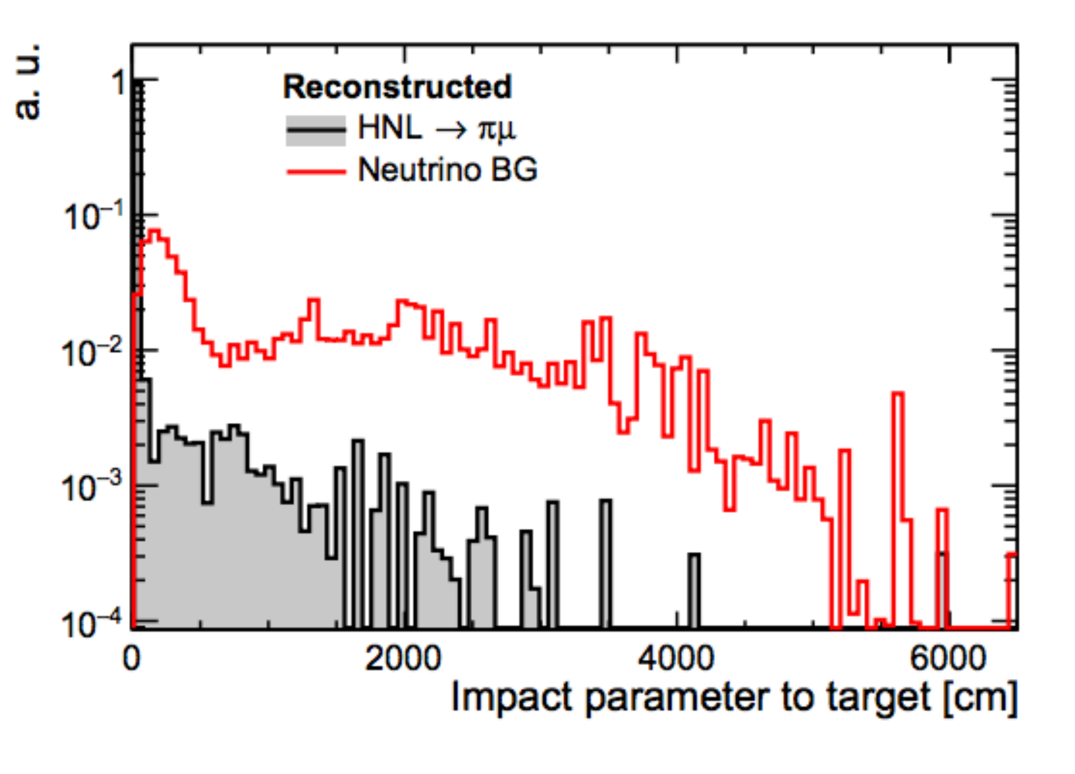


- Fiducial volume and kinematic cuts and veto to suppress this background

Kinematic Selection





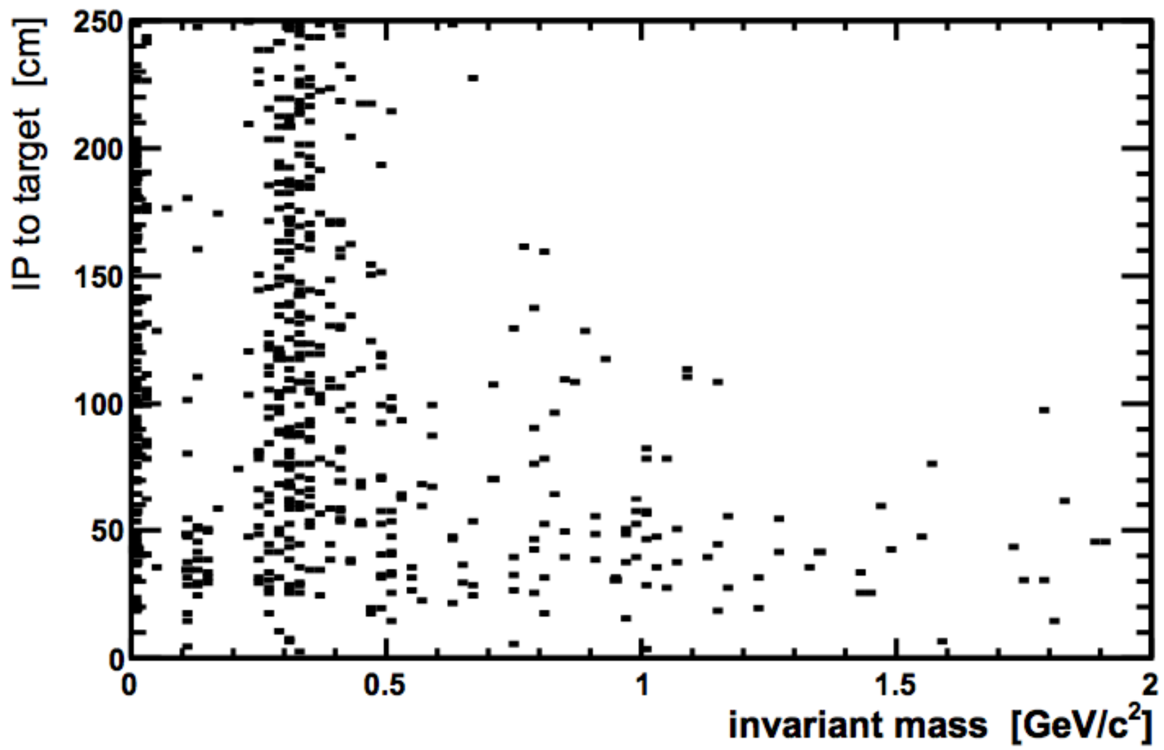


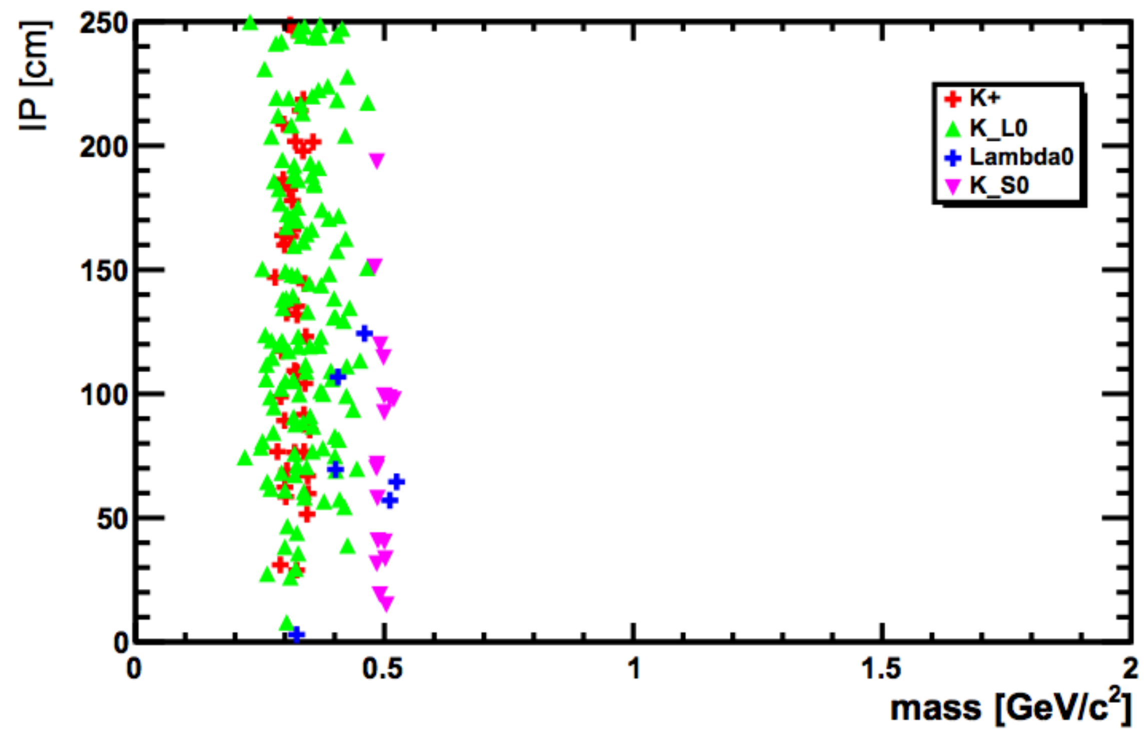
Very simple selection reduces the bkg to only a few in 5 years:

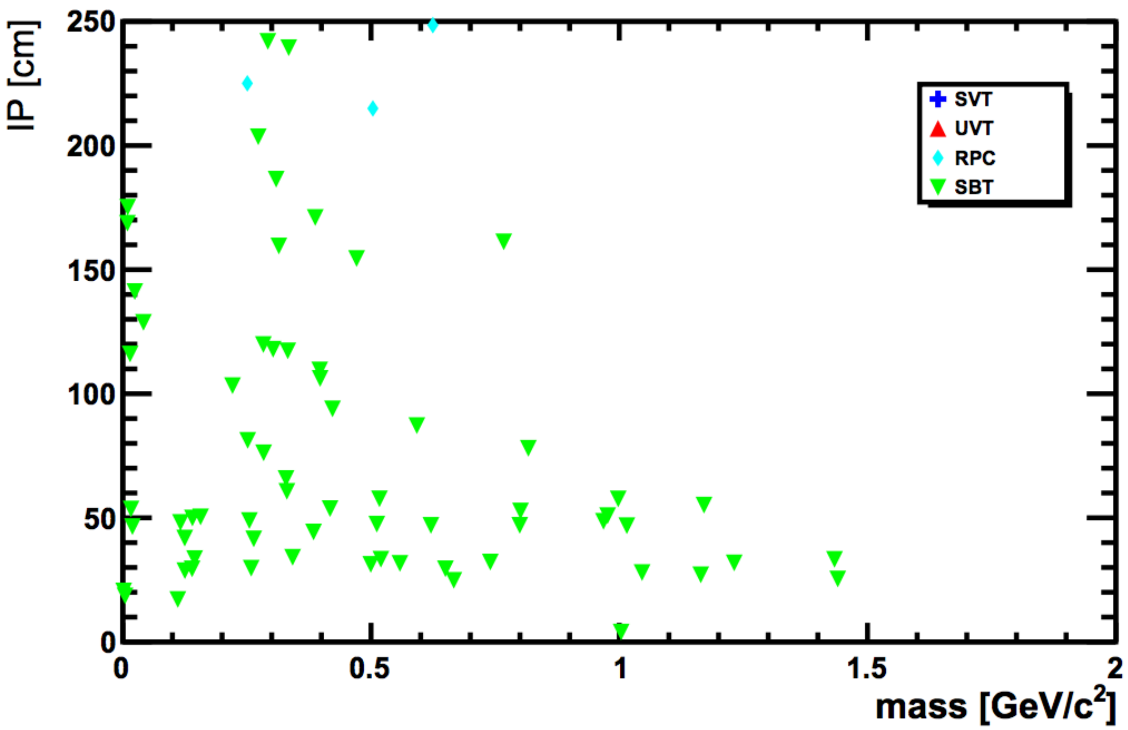
- Fiducial volume
- DOCA
- IP wrt target
- Vetos

Realistic to reach 0.1 expected bkg events for exclusive channels we have been studying so far

Muon Background





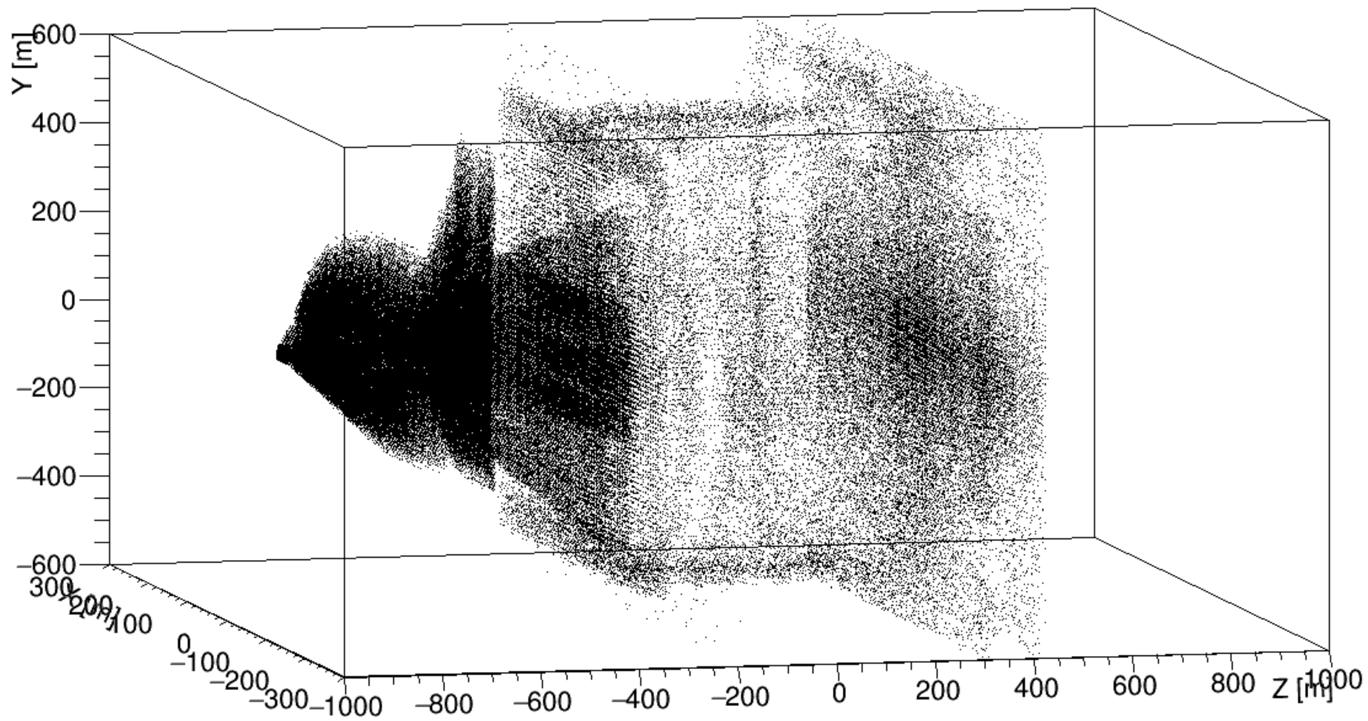


Visible contribution from long living strange neutral resonance

Background negligible once veto on the incoming muon is considered (expected less than 10^{-3} bkg events)

Neutrino Background

Neutrino scattering in the surroundings (generated 7.5 years of SHiP)



- High background rejection for two body charged decays (e.g. $N \to \pi^+\ell^-$) due to pointing and isolation
- Very good background rejection also for channels with π^0 when the vertex is known (e.g. $N \to \rho^+(\pi^+\pi^0)\ell^-$)
- High background rejection for leptonic final states (e.g. $N \to \ell^+\ell^-\nu$) due to particle identification (important for sterile neutrinos where U_τ^2 dominates)

HNL Prospects@SHiP

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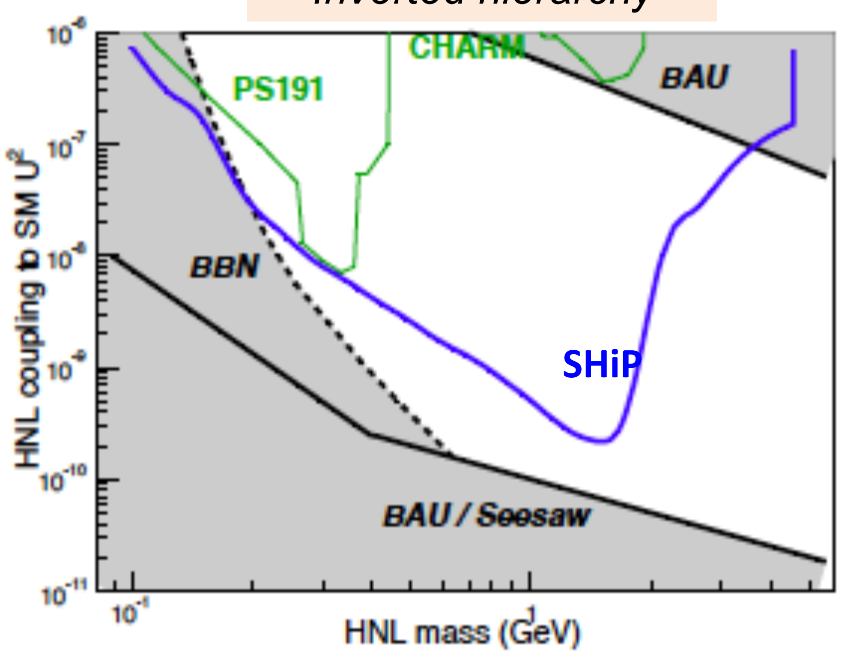
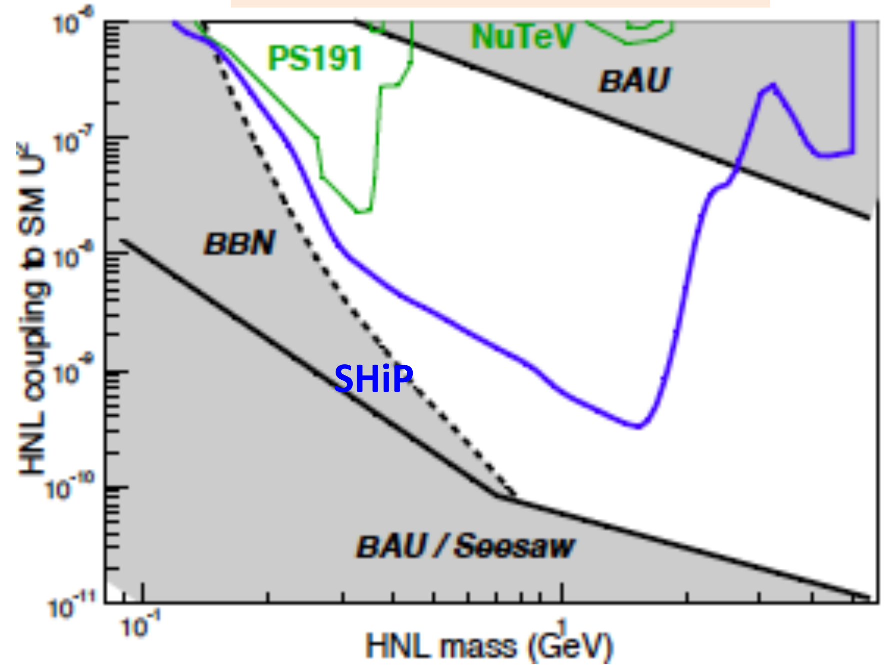
BAU constraint is model-dependent (shown below for νMSM)

U^2_e: U^2_μ: U^2_τ~52:1:1
Inverted hierarchy



U^2_e: U^2_μ: U^2_τ~1:16:3.8
Normal hierarchy

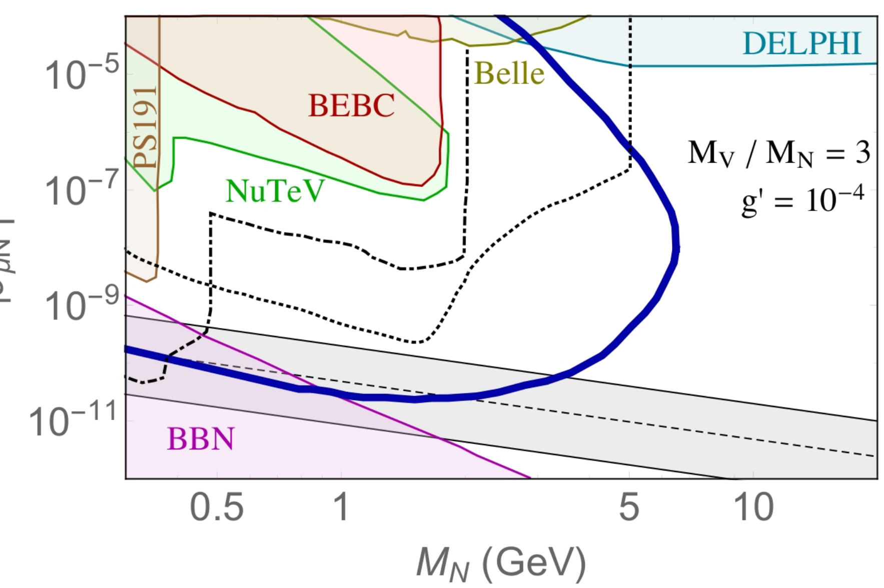


Further studies:

Drewes et al. (2016)
Hernandez et al. (2016)
Hernández (2015)
Drewes & Garbrecht (2012)
Abada et al. (2015)

Enhanced HNL production
(B-L gauge symmetry)

Batell, Pospelov, Shuve
1604.06099



SHiP sensitivity covers large area of parameter space below the B mass
Moving down towards the ultimate see-saw limit

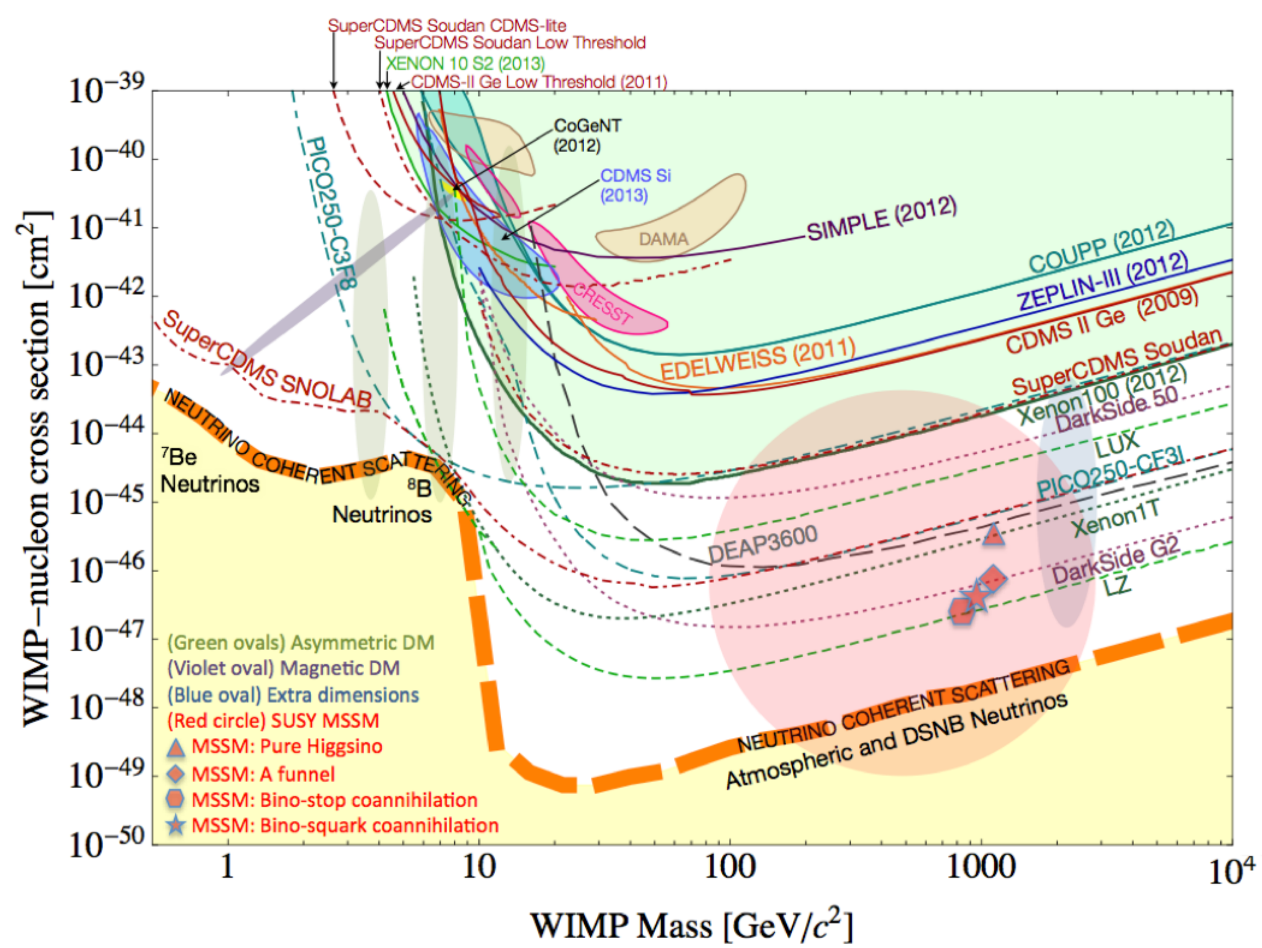
LDM Searches

The prediction for the mass scale of DM spans from 10^{-22} eV to 10^{20} GeV

✓ *WIMP DM is a popular theoretical paradigm (“WIMP miracle”)*
✓ *Extensive exp. search for WIMPs with masses 10 GeV – 1 TeV*
Sensitivity is very limited below few GeV

Large classes of theor. models can make the observed relic density with sub-GeV DM:

- *Hidden-sector models*
- *Supersymmetry*
- *Strongly Interacting DM (SIMP)*
- *Extra dimensions*



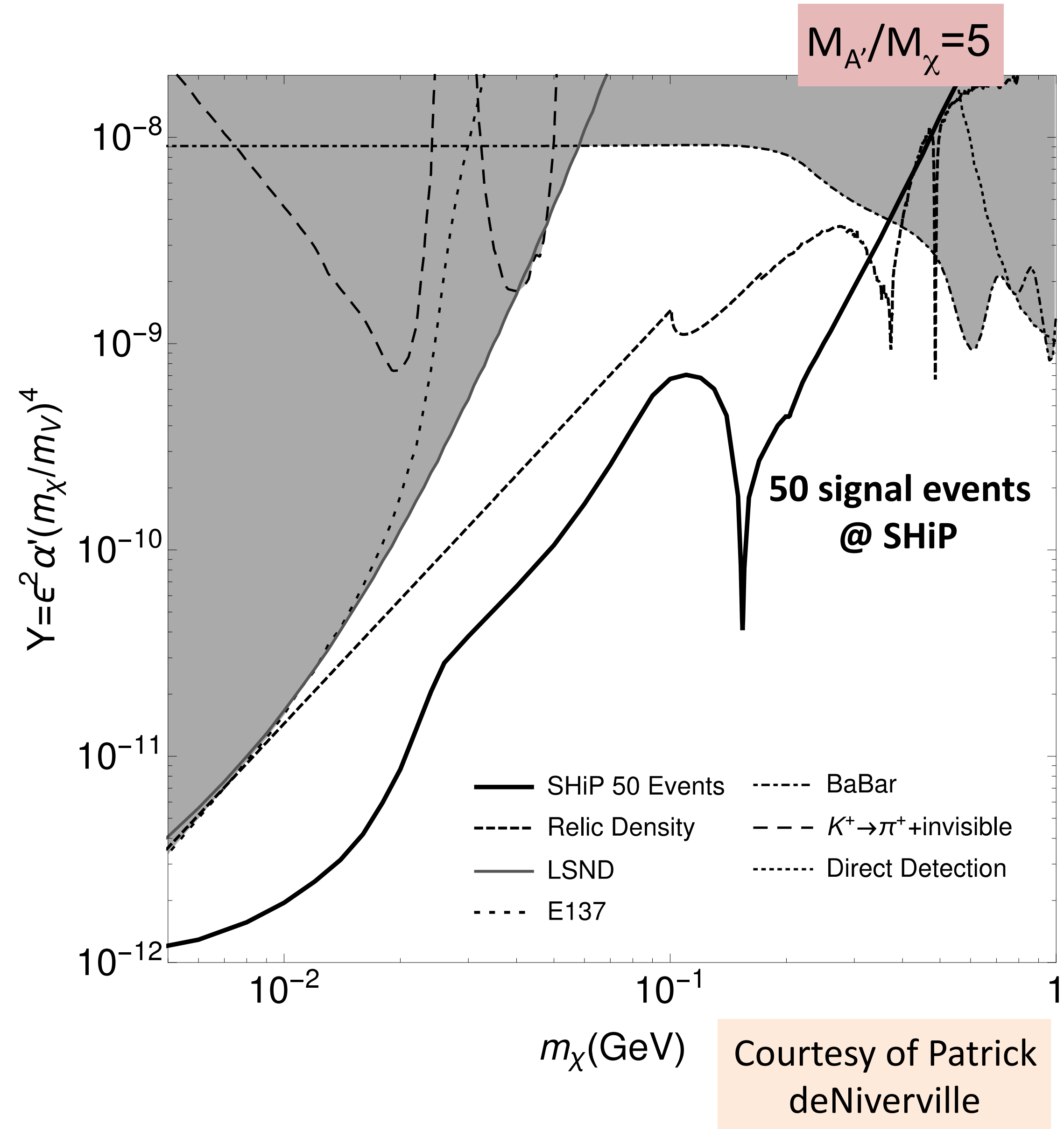
Essential to explore the sub-GeV mass range for DM

LDM Searches

LDM (χ) can be generated in a beam-dump, *for example in* ***decays of HS mediators****,*
e.g. dark photons A' → χχ

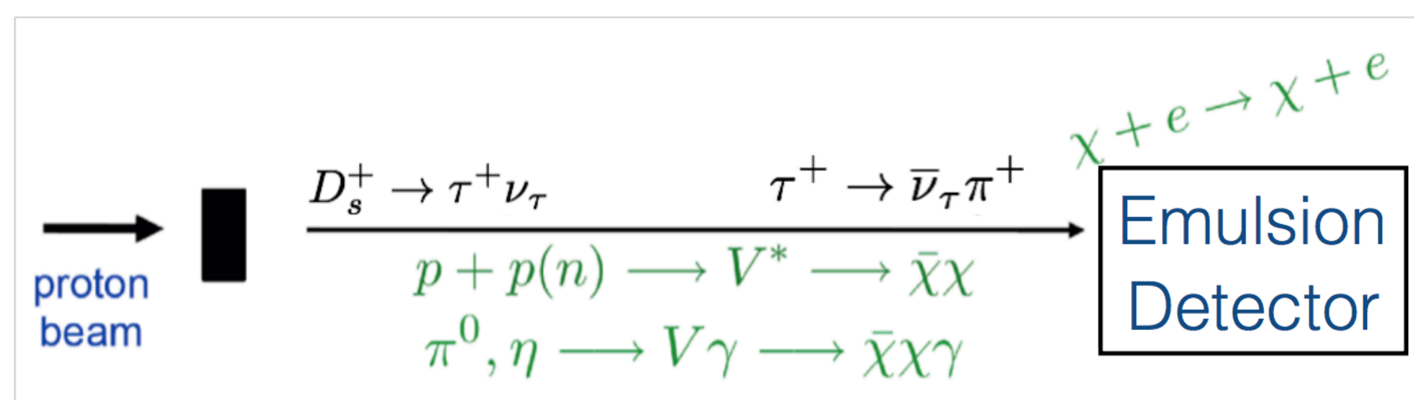
>10[20] photons expected in SHiP can be used as ***a LDM beam***

Detect LDM via its scattering on atoms of emulsion spectrometer



SHiP would be able to probe even beyond relic density in minimal hidden-photon model provided that the ***background from neutrino interactions Is kept under control***

Requires dedicated study/beam test for CDS !



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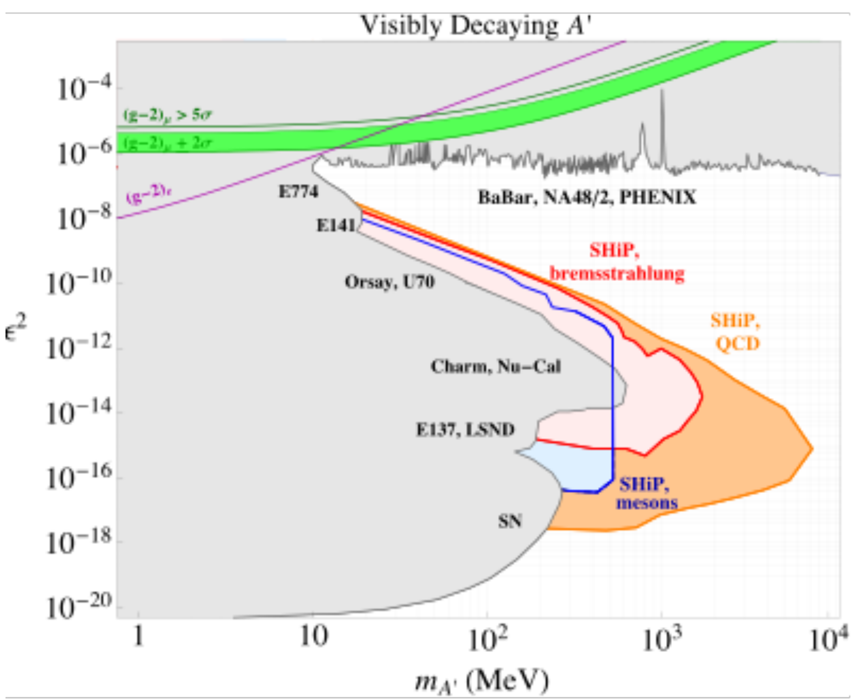
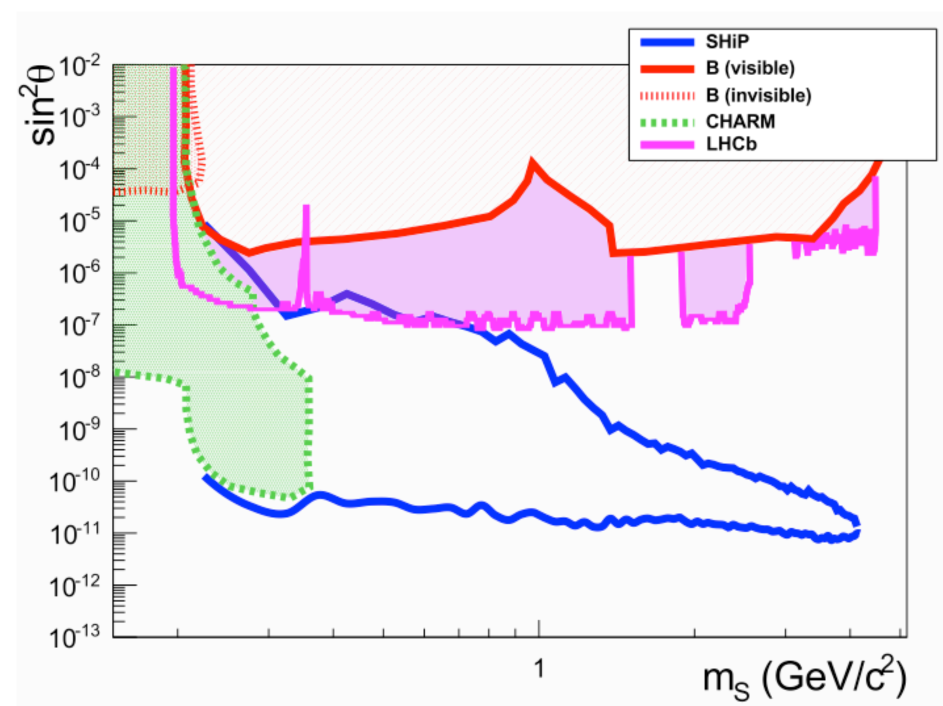
Other Portals

SHiP
Search for Hidden Particles

- ✓ ***Dark photons*** → *U(1) associated particle **A' (γ')** in HS that can have non-zero mass and mix with the SM photon with ε*
  *Produced in bremsstrahlung and QCD processes or in decays **of** π^0 → $\gamma'\gamma$, η → $\gamma'\gamma$, ω → $\gamma'\pi^0$ **and** η' → $\gamma'\gamma$*
- ✓ ***Hidden scalars, S,*** *can mix with the SM Higgs with $\sin^2\Theta$ Mostly produced in penguin-type B and K decays*

*Search for **the decay vertex** into a pair of SM particles into e^+e^-, $\mu^+\mu^-$, $\pi^+\pi^+$, KK, $\eta\eta$, $\tau\tau$, DD, …*





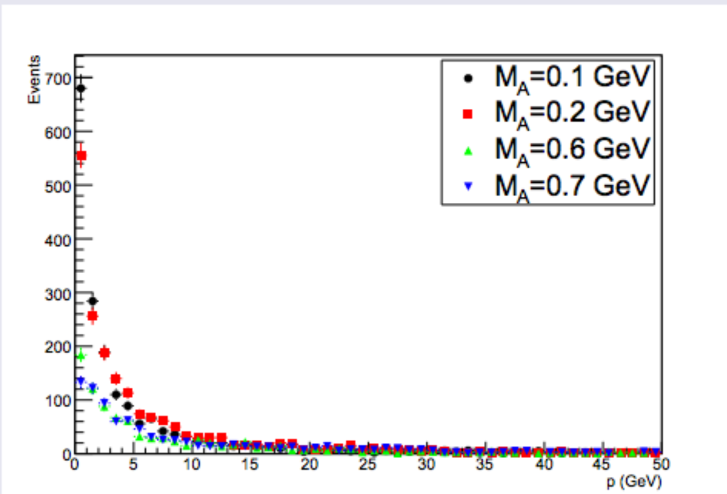
- We should study cascade production for other portals, e.g. Dark Photon

SHiP probes unique range of couplings and masses
(complimentary to existing experiments)

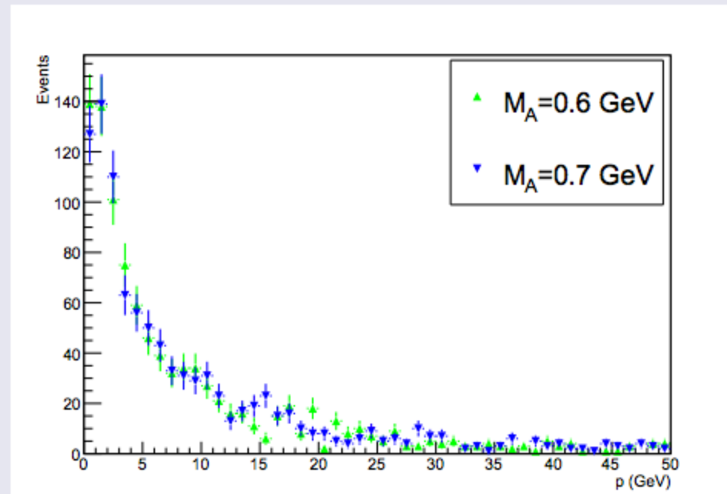
Other Portals

√ ***We are implementing many models in our full MC simulation (FairSHiP) to provide official sensitivity for as many channels as possible***

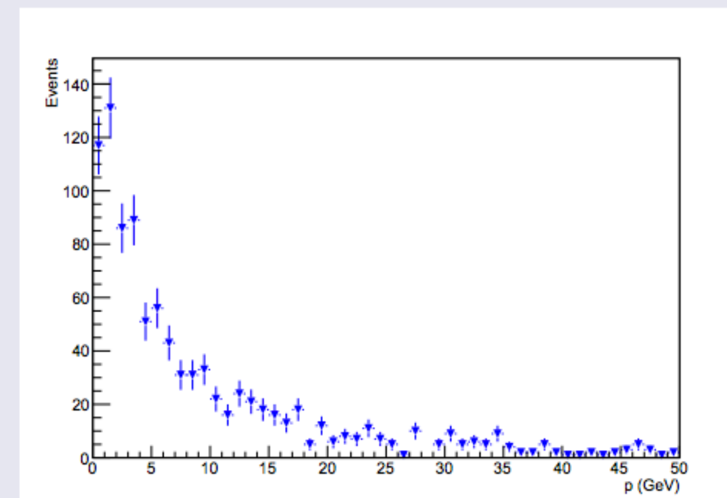
$\gamma' \to e^+e^-$

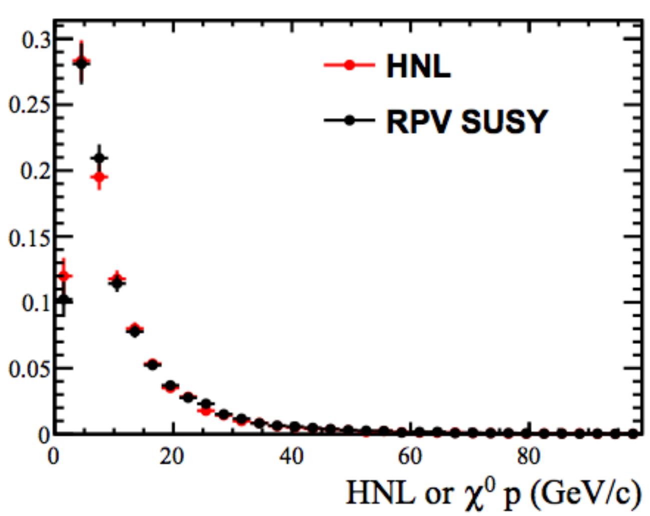


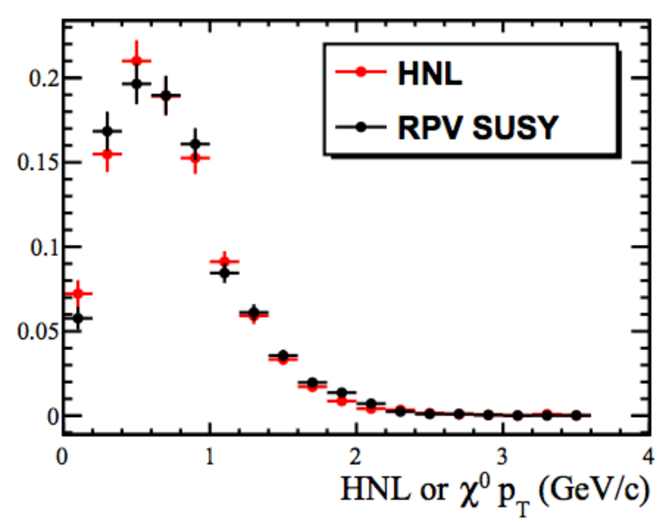
$\gamma' \to \mu^+\mu^-$

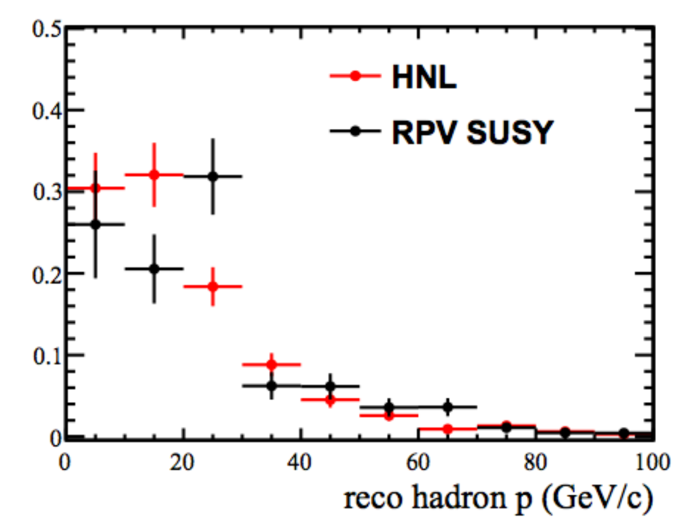


$\gamma' \to$hardons (π at this $m_{\gamma'}$)



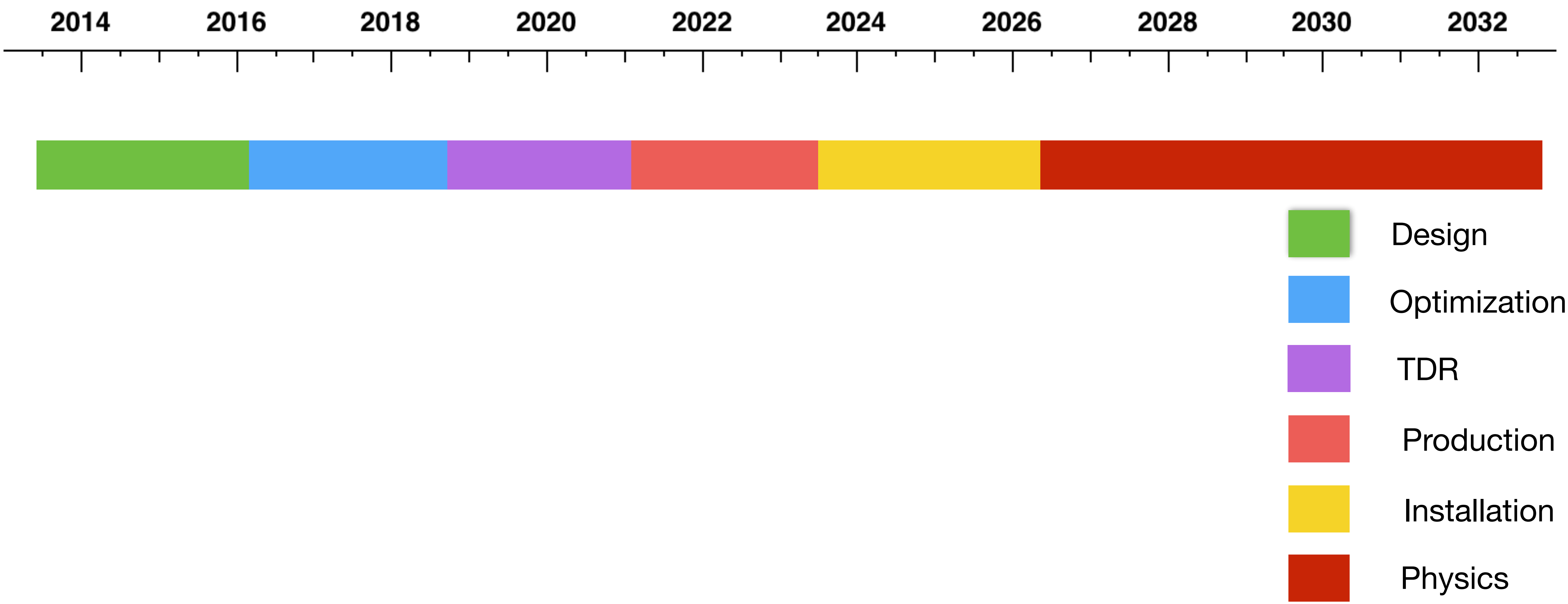






√ ***Cascade production of charm and beauty taken into account, we have to implement this for other mesons and photons (large impact on the DP searches)***

Status of SHiP



Status of SHiP

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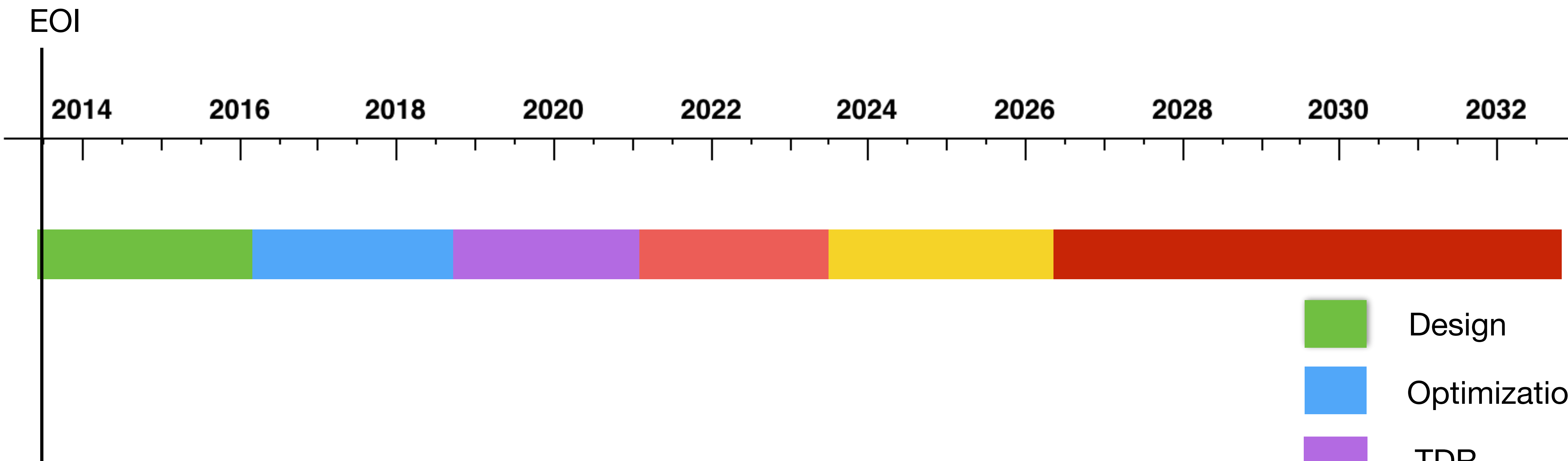
SHiP
Search for Hidden Particles



CERN-SPSC-2013-024 / SPSC-EOI-010
October 8, 2013

Proposal to Search for Heavy Neutral Leptons at the SPS

W. Bonivento[1,2], A. Boyarsky[3], H. Dijkstra[2], U. Egede[4], M. Ferro-Luzzi[2], B. Goddard[2], A. Golutvin[4], D. Gorbunov[5], R. Jacobsson[2], J. Panman[2], M. Patel[4], O. Ruchayskiy[6], T. Ruf[2], N. Serra[7], M. Shaposhnikov[6], D. Treille[2 (‡)]

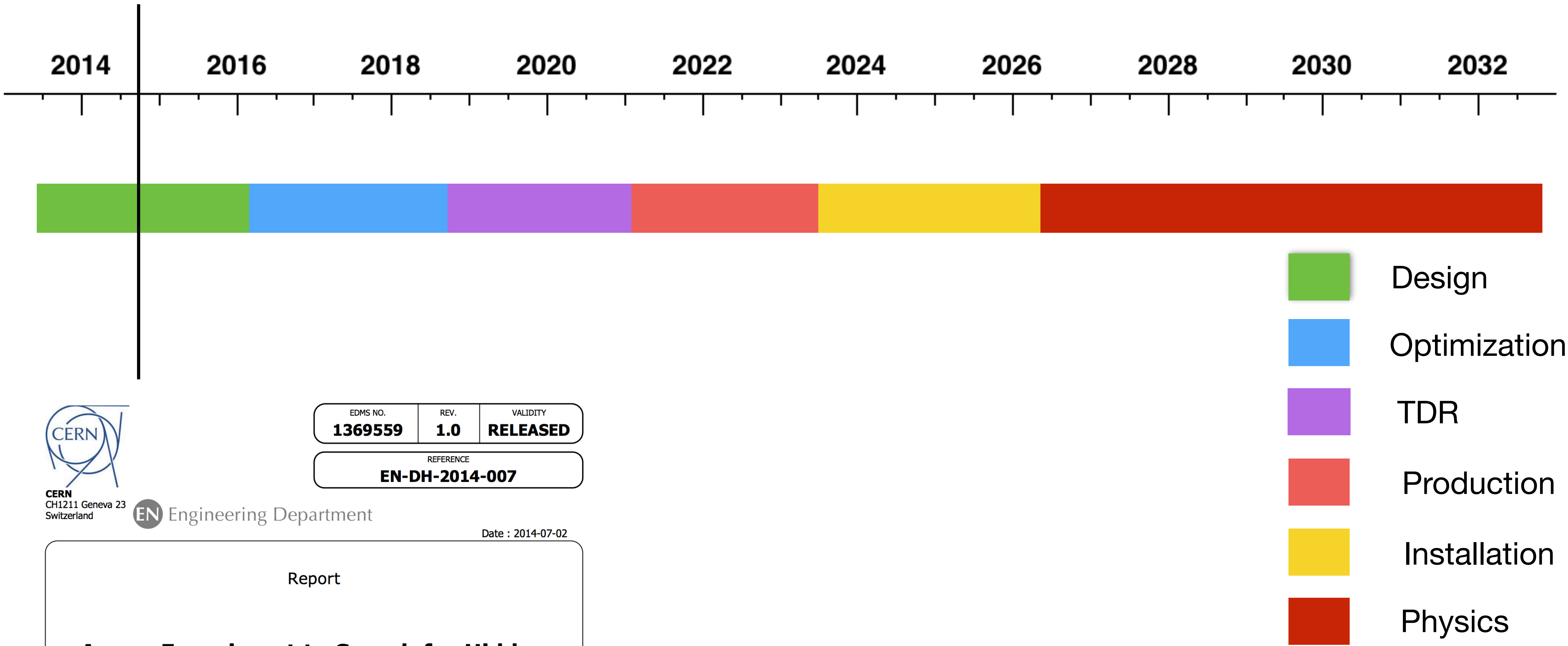
[1] *Sezione INFN di Cagliari, Cagliari, Italy*
[2] *European Organization for Nuclear Research (CERN), Geneva, Switzerland*
[3] *Instituut-Lorentz for Theoretical Physics, Universiteit Leiden, Niels Bohrweg 2, Leiden, The Netherlands*
[4] *Imperial College London, London, United Kingdom*
[5] *Institute for Nuclear Research of the Russian Academy of Sciences (INR RAN), Moscow, Russia*
[6] *Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland*
[7] *Physik-Institut, Universität Zürich, Zürich, Switzerland*
[(‡)] *retired*

Executive Summary

A new fixed-target experiment at the CERN SPS accelerator is proposed that will use decays of charm mesons to search for Heavy Neutral Leptons (HNLs), which 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.

Status of SHiP

CERN Task
Force Report



CERN
CH1211 Geneva 23
Switzerland

Engineering Department

EDMS NO.	REV.	VALIDITY
1369559	1.0	RELEASED

REFERENCE
EN-DH-2014-007

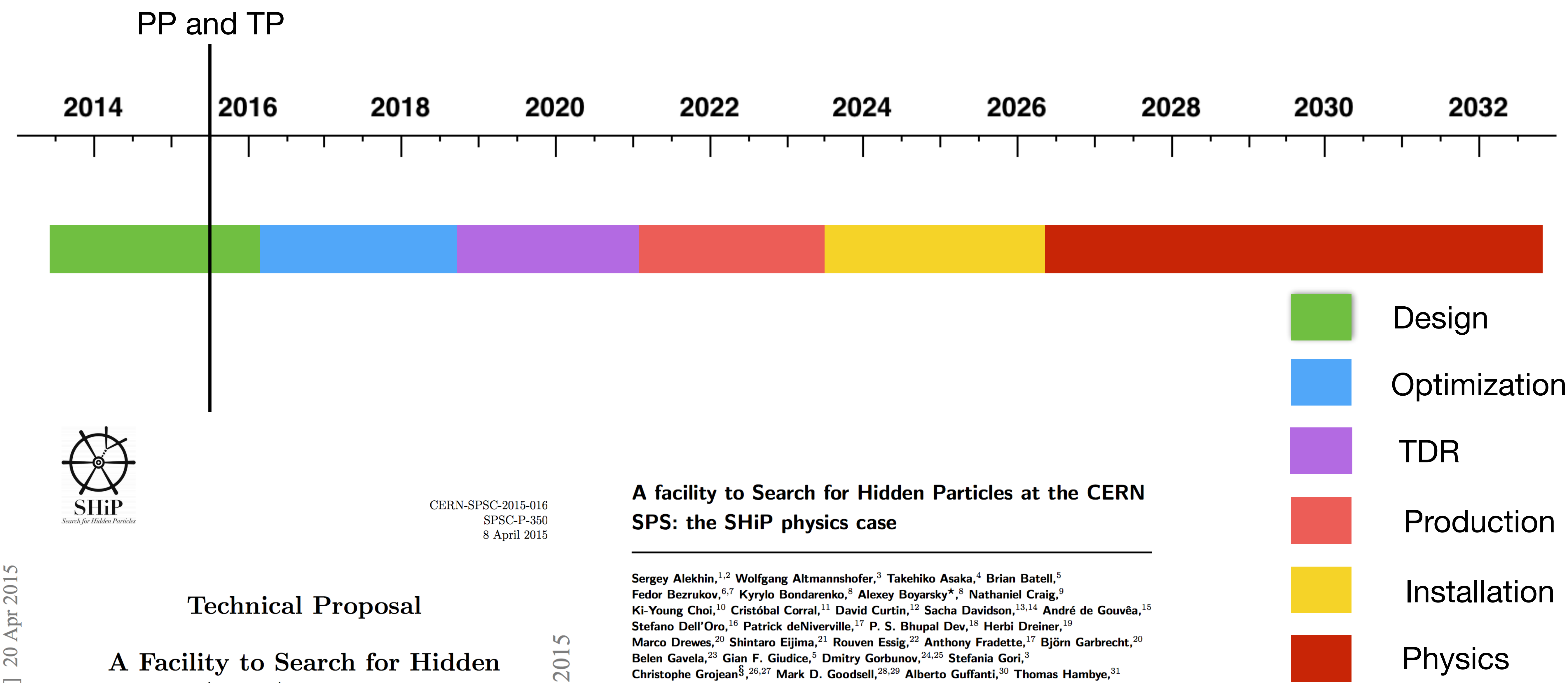
Date : 2014-07-02

Report

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

Preliminary Project and Cost Estimate

Status of SHiP



SHiP
Search for Hidden Particles

CERN-SPSC-2015-016
SPSC-P-350
8 April 2015

[physics.ins-det] 20 Apr 2015

Technical Proposal

A Facility to Search for Hidden Particles (SHiP) at the CERN SPS

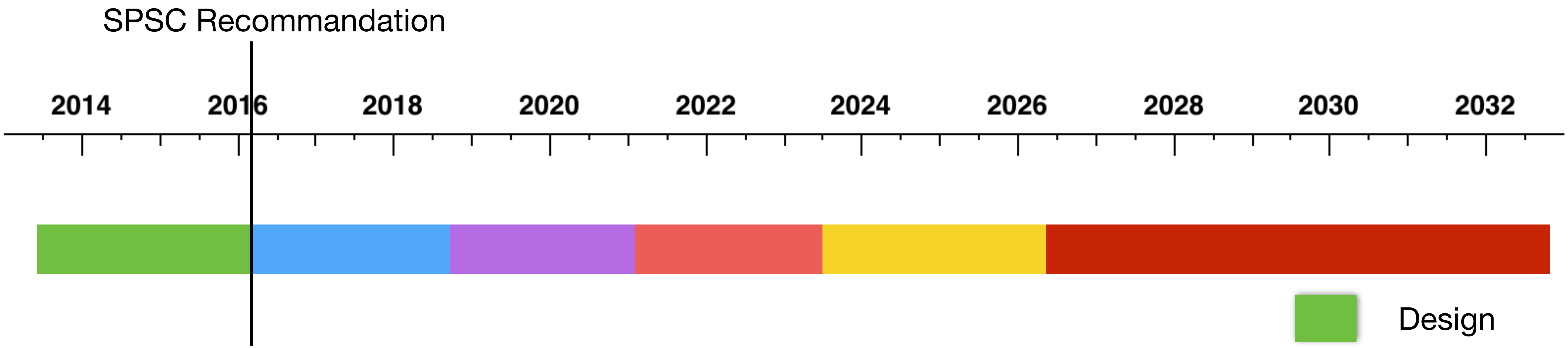
The SHiP Collaboration[1]

355v1 [hep-ph] 19 Apr 2015

A facility to Search for Hidden Particles at the CERN SPS: the SHiP physics case

Sergey Alekhin,[1,2] Wolfgang Altmannshofer,[3] Takehiko Asaka,[4] Brian Batell,[5]
Fedor Bezrukov,[6,7] Kyrylo Bondarenko,[8] Alexey Boyarsky⋆,[8] Nathaniel Craig,[9]
Ki-Young Choi,[10] Cristóbal Corral,[11] David Curtin,[12] Sacha Davidson,[13,14] André de Gouvêa,[15]
Stefano Dell'Oro,[16] Patrick deNiverville,[17] P. S. Bhupal Dev,[18] Herbi Dreiner,[19]
Marco Drewes,[20] Shintaro Eijima,[21] Rouven Essig,[22] Anthony Fradette,[17] Björn Garbrecht,[20]
Belen Gavela,[23] Gian F. Giudice,[5] Dmitry Gorbunov,[24,25] Stefania Gori,[3]
Christophe Grojean§,[26,27] Mark D. Goodsell,[28,29] Alberto Guffanti,[30] Thomas Hambye,[31]
Steen H. Hansen,[32] Juan Carlos Helo,[11] Pilar Hernandez,[33] Alejandro Ibarra,[20]
Artem Ivashko,[8,34] Eder Izaguirre,[3] Joerg Jaeckel§,[35] Yu Seon Jeong,[36] Felix Kahlhoefer,[27]
Yonatan Kahn,[37] Andrey Katz,[5,38,39] Choong Sun Kim,[36] Sergey Kovalenko,[11]
Gordan Krnjaic,[3] Valery E. Lyubovitskij,[40,41,42] Simone Marcocci,[16] Matthew Mccullough,[5]
David McKeen,[43] Guenakh Mitselmakher ,[44] Sven-Olaf Moch,[45] Rabindra N. Mohapatra,[46]
David E. Morrissey,[47] Maksym Ovchynnikov,[34] Emmanuel Paschos,[48] Apostolos Pilaftsis,[18]
Maxim Pospelov§,[3,17] Mary Hall Reno,[49] Andreas Ringwald,[27] Adam Ritz,[17]
Leszek Roszkowski,[50] Valery Rubakov,[24] Oleg Ruchayskiy⋆,[21] Jessie Shelton,[51]
Ingo Schienbein,[52] Daniel Schmeier,[19] Kai Schmidt-Hoberg,[27] Pedro Schwaller,[5]
Goran Senjanovic,[53,54] Osamu Seto,[55] Mikhail Shaposhnikov⋆,§,[21] Brian Shuve,[3]
Robert Shrock,[56] Lesya Shchutska§,[44] Michael Spannowsky,[57] Andy Spray,[58] Florian Staub,[5]
Daniel Stolarski,[5] Matt Strassler,[39] Vladimir Tello,[53] Francesco Tramontano§,[59,60]
Anurag Tripathi,[59] Sean Tulin,[61] Francesco Vissani,[16,62] Martin W. Winkler,[63]
Kathryn M. Zurek[64,65]

Status of SHiP



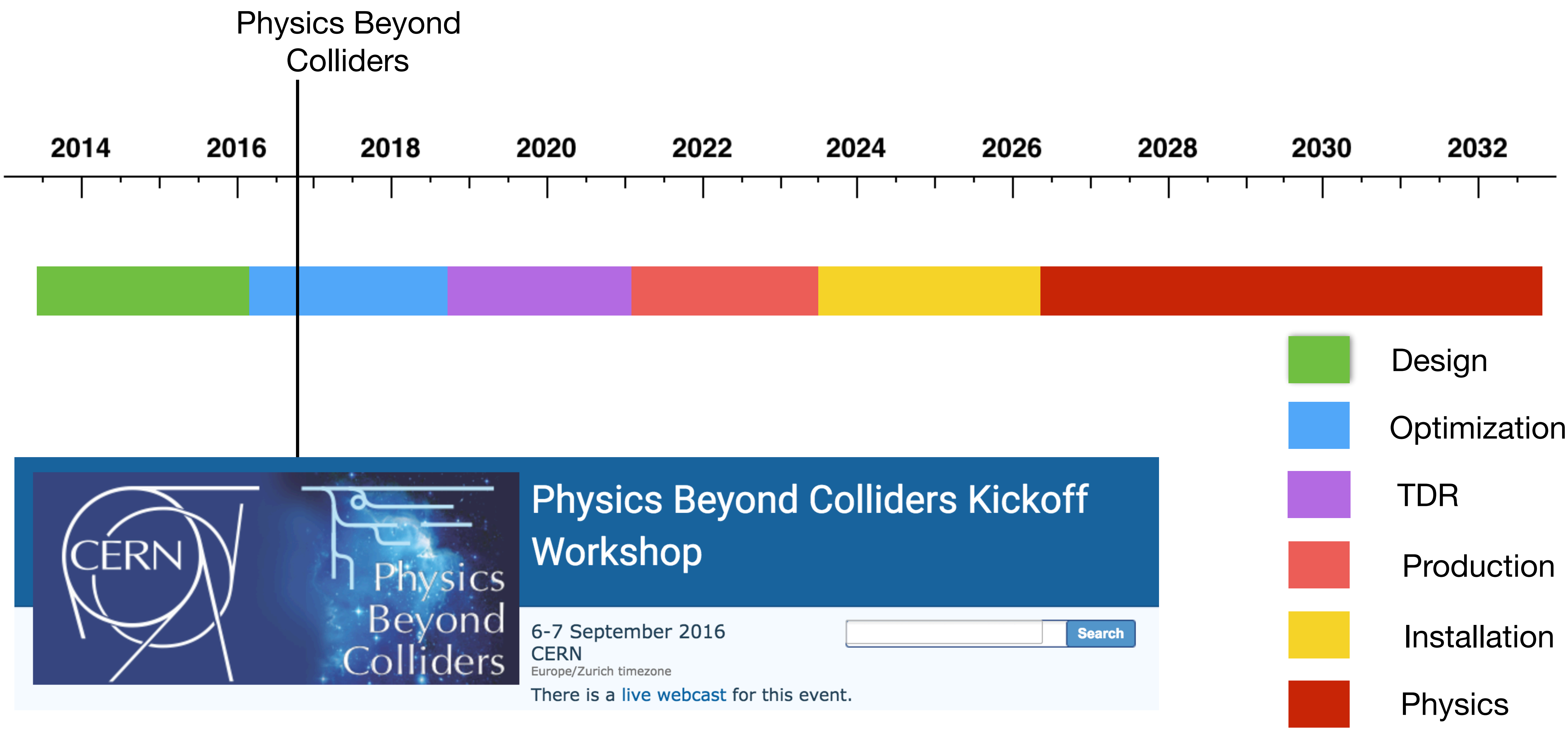
7.1 P-350 (SHIP)

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

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

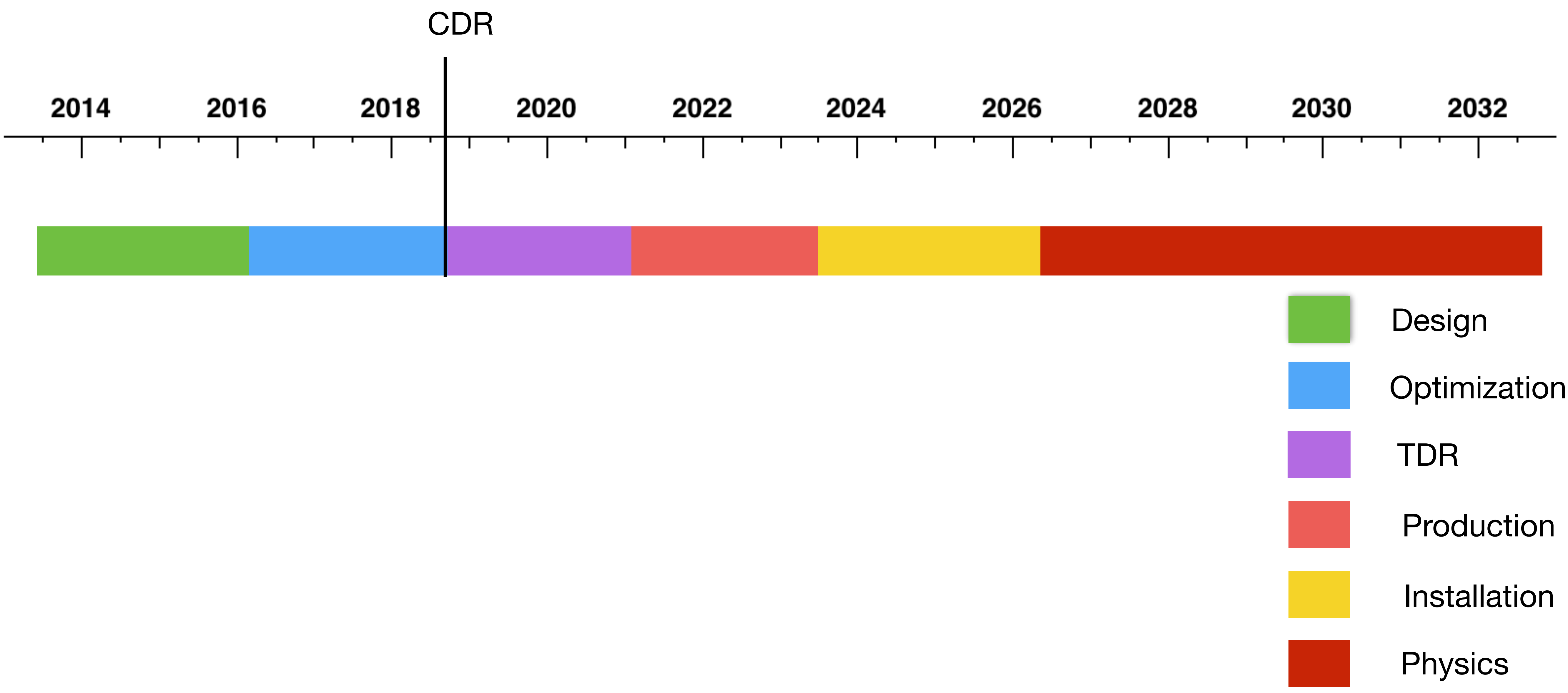
The main physics motivation of SHiP is to explore the domain of hidden particles, searching in particular for new scalar, fermionic and vector particles. These would be produced in a proton beam dump at 400 GeV, either directly or from decays of charm or beauty particles. The experiment would be sensitive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

Status of SHiP

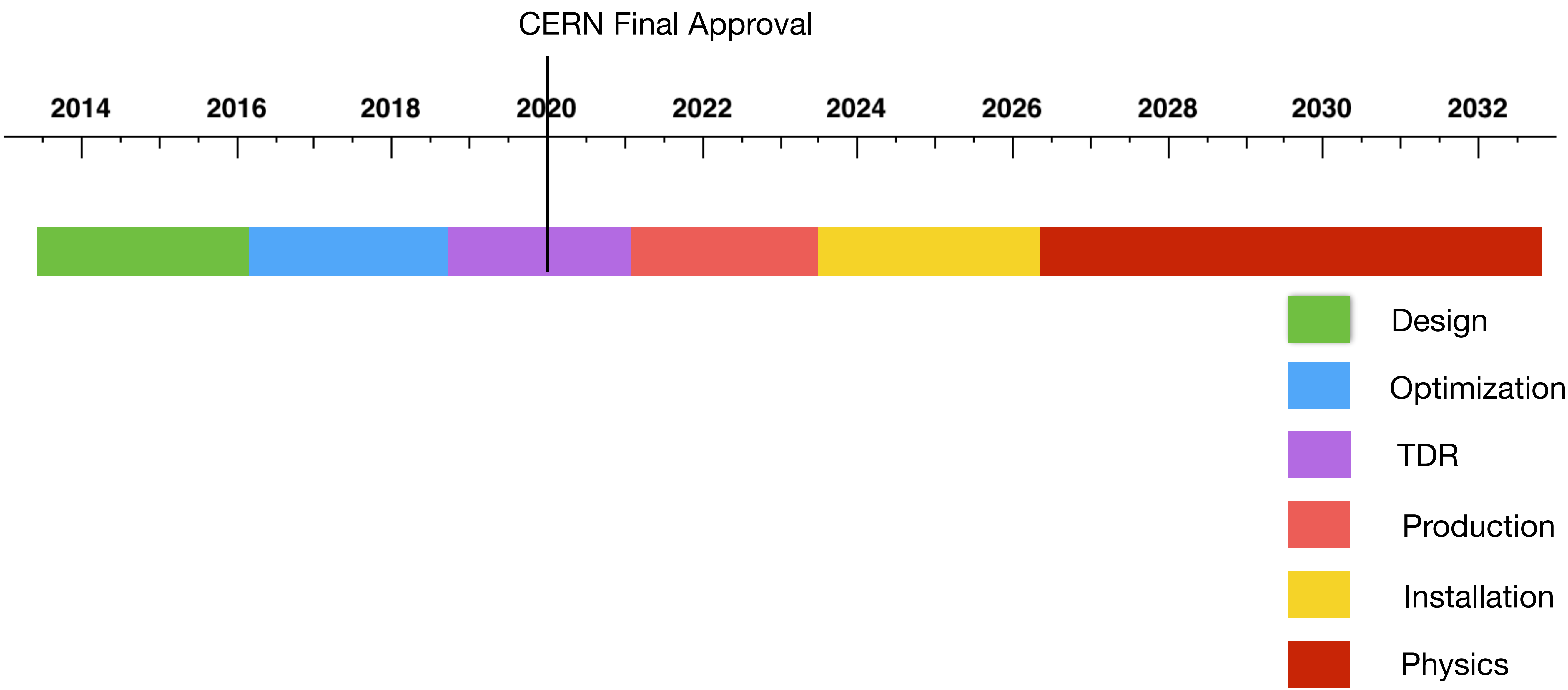


- Several other experiment proposing to explore similar physics case as SHiP, e.g. NA62 in dump mode after LS2
- Lot of work done for the new Beam Dump Facility (see Fabiola's presentation at ECFA)

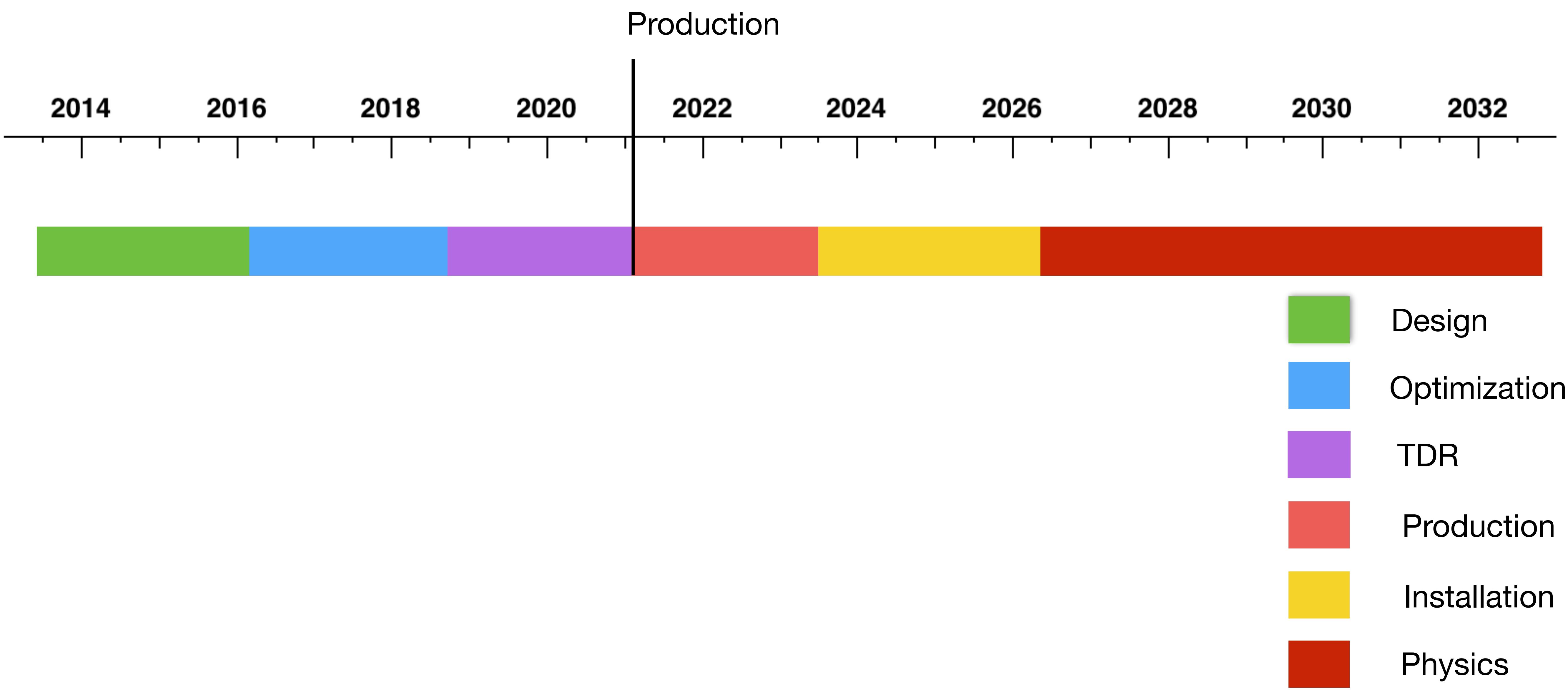
Status of SHiP



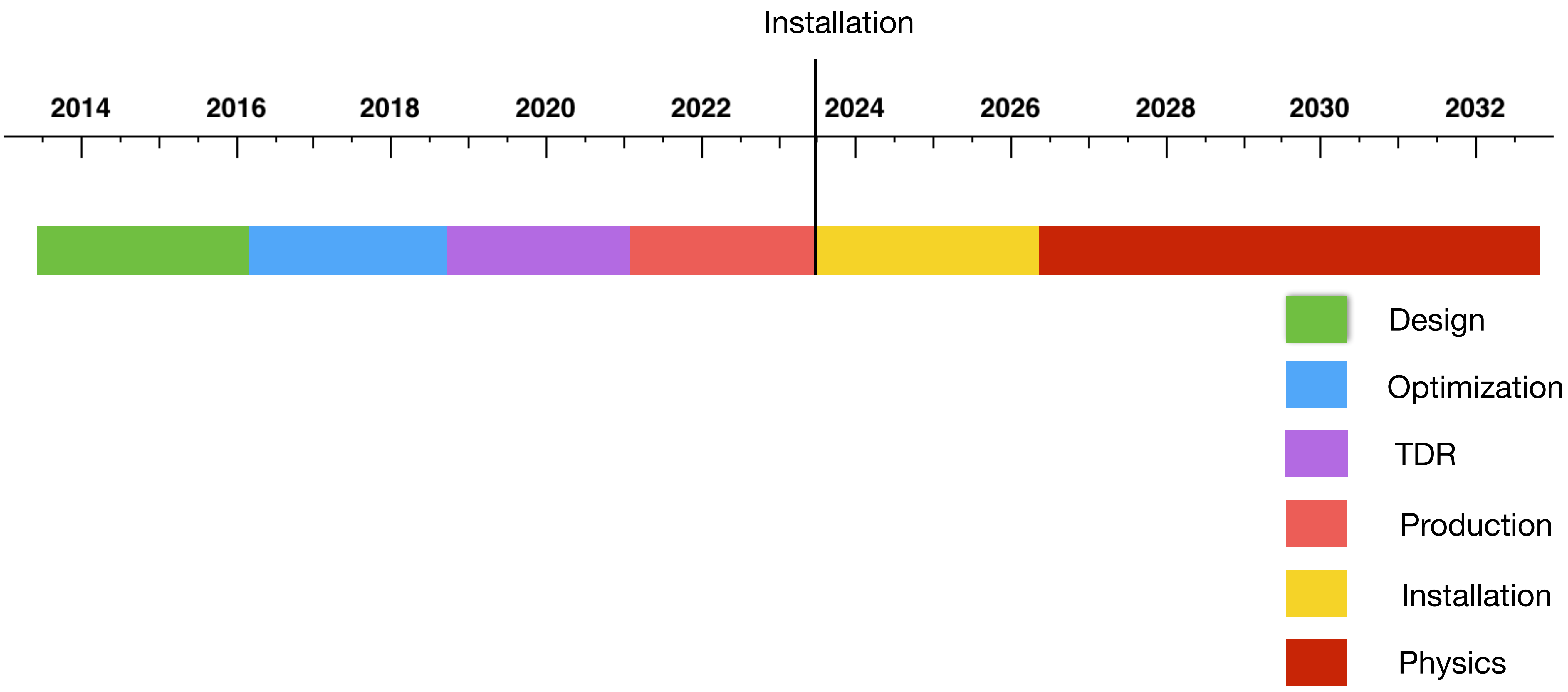
Status of SHiP



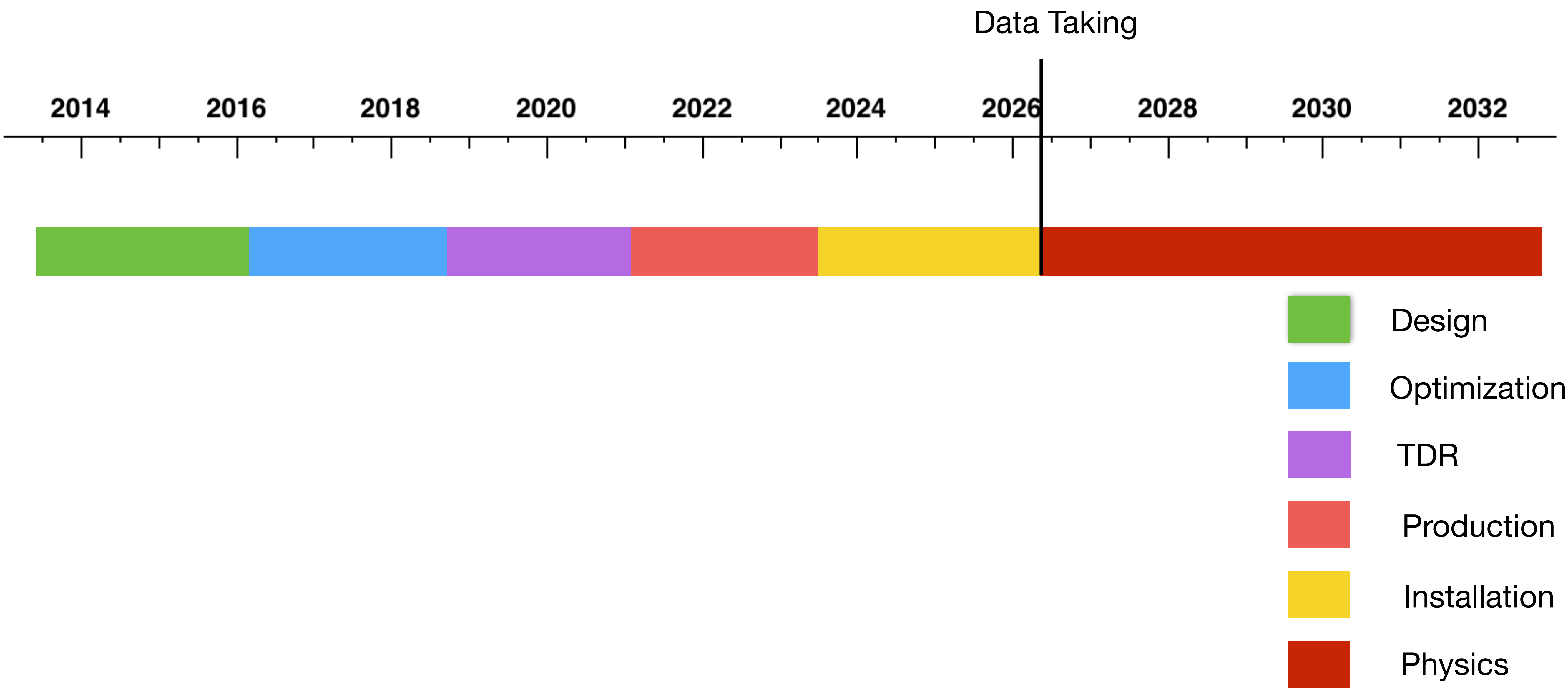
Status of SHiP



Status of SHiP



Status of SHiP



Questions for theorists

- We are trying to optimize the experiment to have an inclusive search of very weakly interacting long living particles below 10GeV

- How interesting is the diphoton channel, we are studying the possibility to design a calorimeter with pointing

- How interesting are multi hadron channels? We can take this into account in the optimization

- We also plan to use the tau neutrino detector for the HS, this could be interested for models with hidden particles with short lifetime

- Invariant mass resolution of a few MeV is possible, we do not need it for discovery, but it could help to disentangle different models (same for pion/kaon separation)

Conclusions

- Comprehensive Design Study will be input to the Physics Beyond Colliders working group —> Report for the European Strategy Meeting

- Several progresses since the TP:
  - Cascade production of D and B
  - Many models are being implemented
  - Relax vacuum requirements
  - Magnetization of the target, optimisation of the muon shield
  - Search for LDM in the tau neutrino detector

- More work to do to implement cascade production of other HS particles and optimise the detector (collaboration with theorists very important)

- SHiP has the potential to improve by several oder of magnitudes the search for hidden particles below ~10GeV

- We are aiming to have a zero bkg experiment, important for the discovery and to fully exploit the potential of the SPS

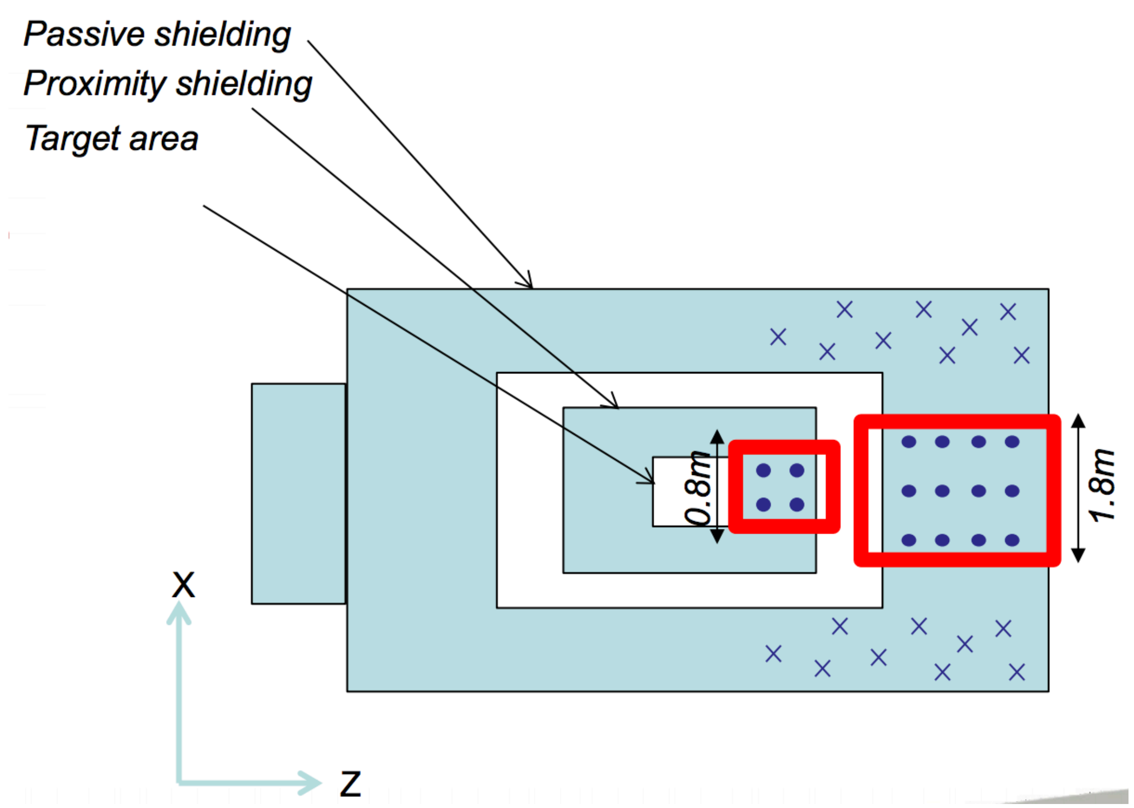
Thanks for the attention

Magnetization

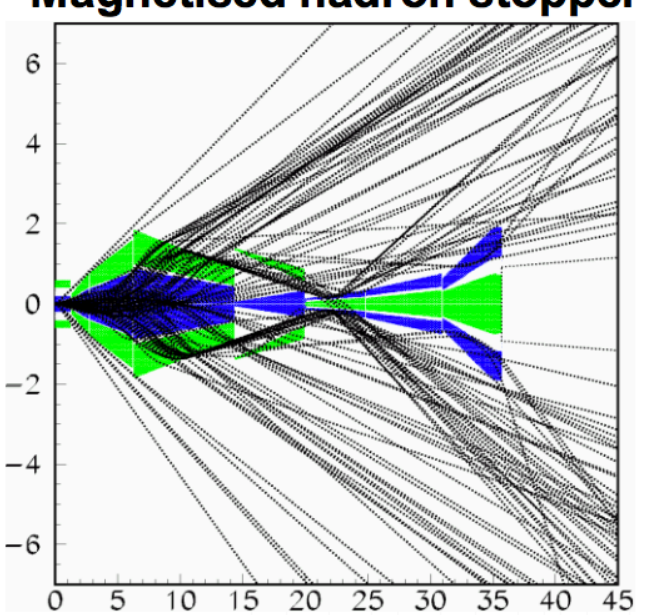
Magnetising the hadron absorber allows attacking muons earlier

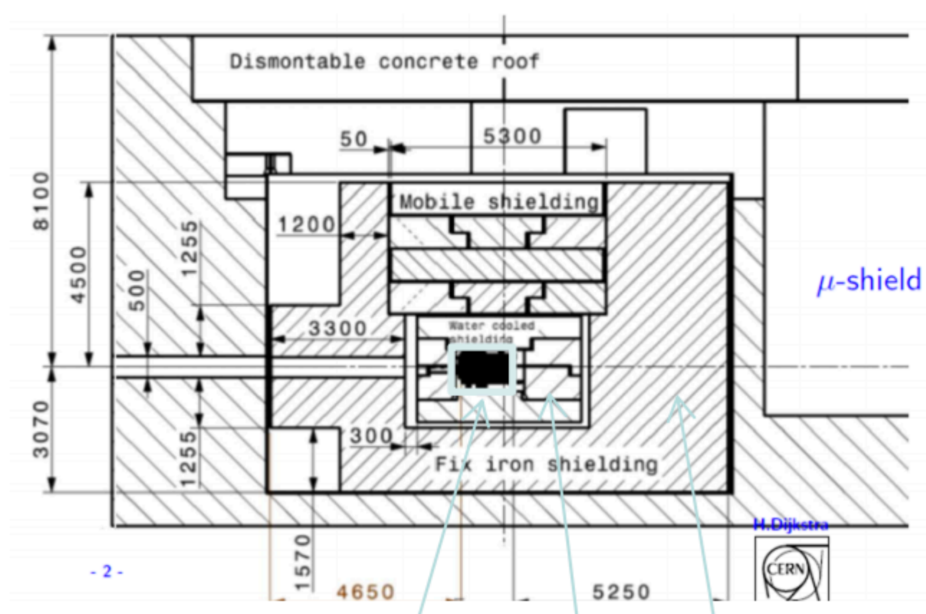
➔ remainder of the muon shield shortened by ~5m and required aperture reduced:

- Physics – the detector is closer to the target and increased geometric bite of the experiment
- Engineering
    - weight drops by 65%
    - Cost reduced



Magnetised hadron stopper



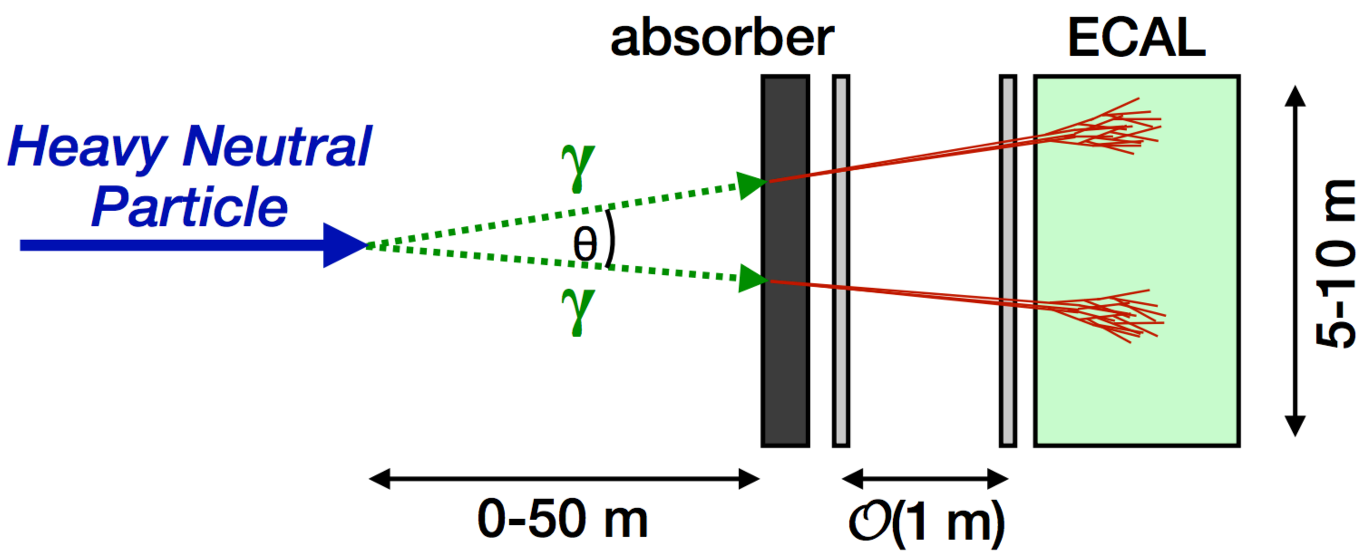


Diphoton Search

Neutral decays to photons (e.g. *ALP* → γγ):

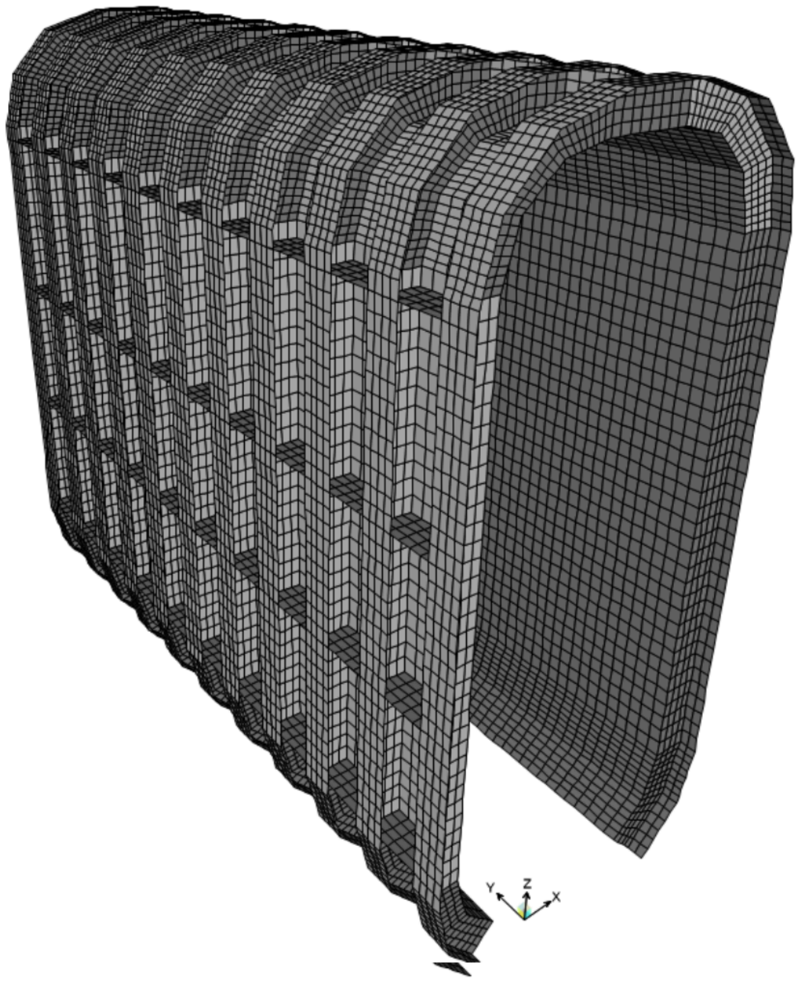
Vertex unknown
⟹ mass unknown.

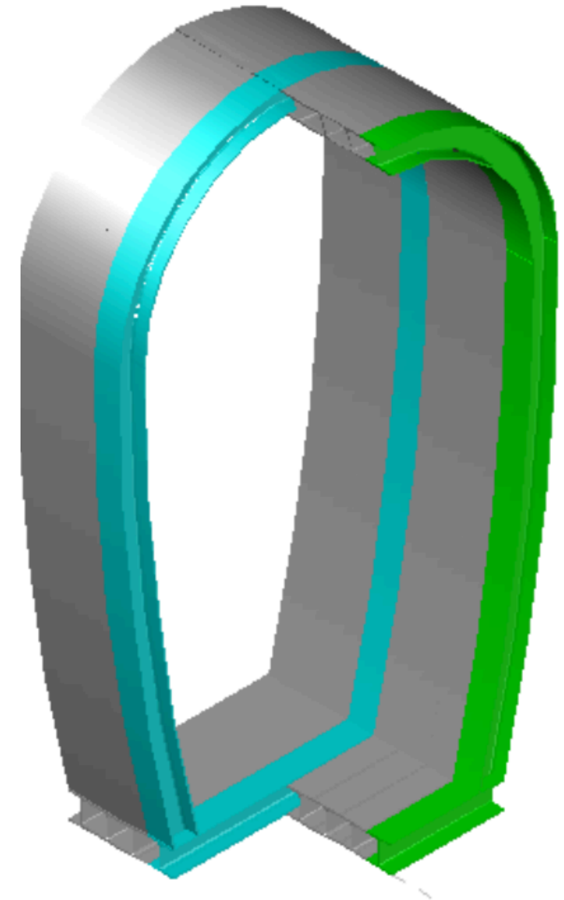
$$m = \frac{1}{z_{ECAL} - z_{vertex}} \sqrt{E_{\gamma_1} E_{\gamma_2} \cdot d_{12}^2}$$



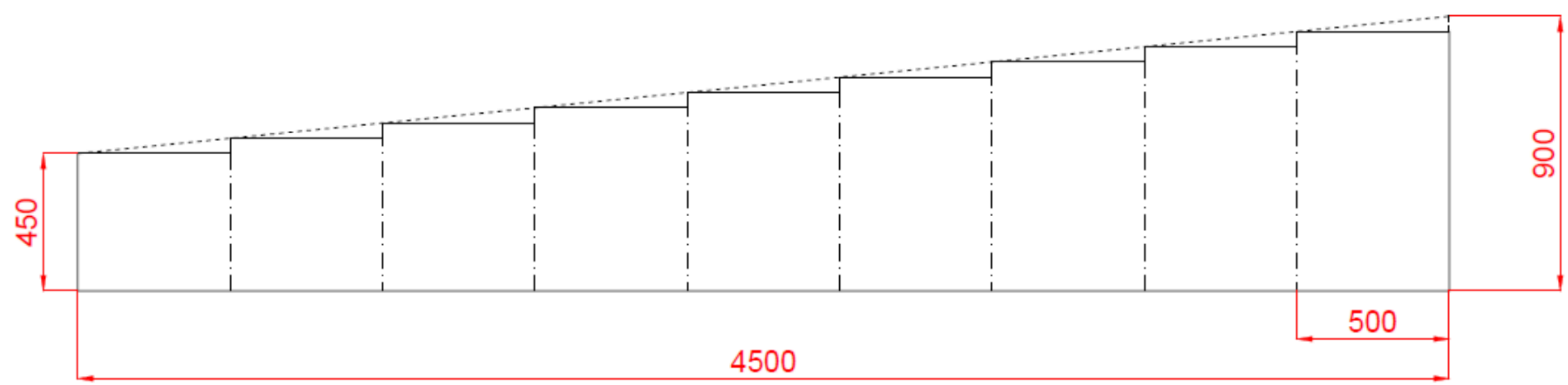
- ***Example:*** 20 GeV particle of mass 1 GeV, decaying into 2 photons:
  ➜ opening angle ≤ 100 mrad.
  ➜ mass resolution of 100 MeV corresponds to **$\sigma(\theta) \leq 10$ mrad.**
  (Simulation by Walter: *$\sigma(\theta) \sim 10$ mrad/$\sqrt{E}$* necessary).
- **Angular resolution of 10 mrad** converts to **$\sigma_{xy} \approx 1$ cm**
  for preshower detectors which are 1 m apart.
- **Absorber:** iron or lead with **~ 2-3 X_0 thickness**

Vacuum Vessel





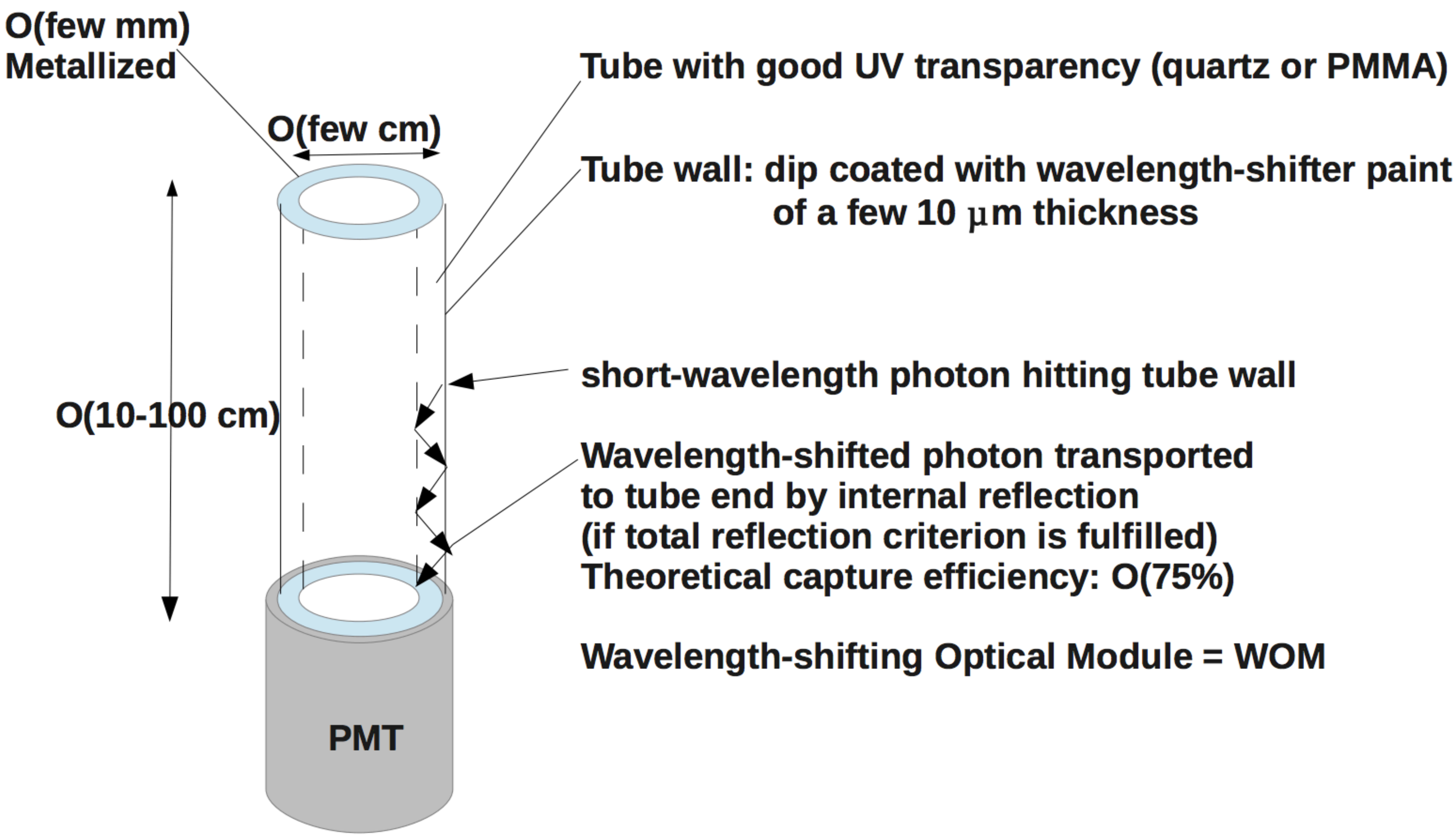
Schematic view of vessel



SBT

Plans for a large extension of the IceCube detector triggered following R&D idea:

Schulte, Voge, Hoffmann, Böser, Köpke, Kowalski, “A large-area single photon sensor employing wavelength-shifting and light-guiding technology”, 1307.6713 [astro-ph.IM]

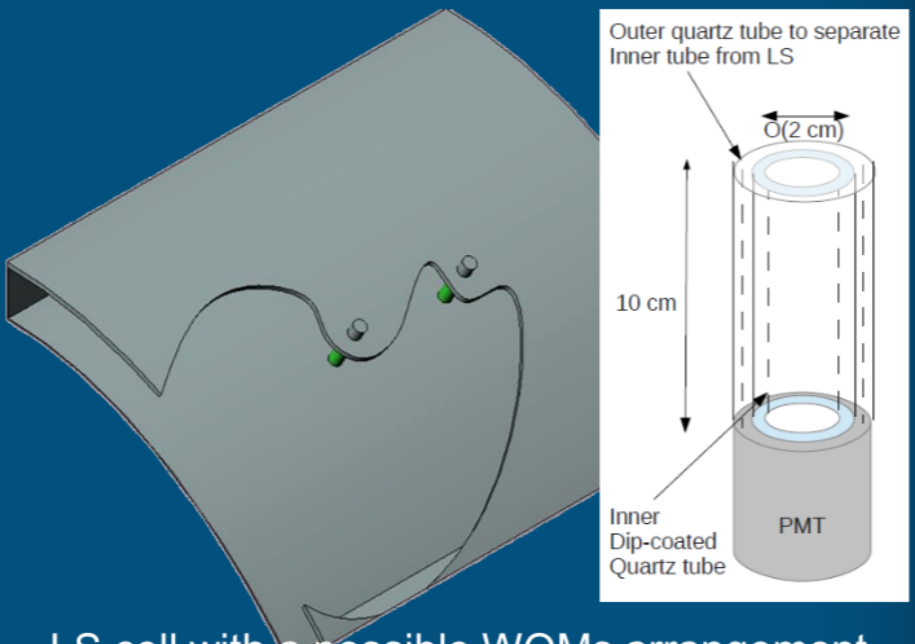


LiSci

Cylinder (Front) Background Tagger

- Based on 10cm thick layer of liquid scintillator (LS) cells with double HAMAMATSU R1924A PMT (25 mm cathode) for coincidence
  - LS cell dimensions and wave-length shifting optical modules (WOM) locations optimized for light collection and time resolution
    ➔ 1.5 - 2m x 1m for option 1
  - ➔ Cheap LS, no requirement on natural radioactivity as for double beta decay experiments

Mixture Option	Components of the mixture	Concentration
1	b-PBD (C24H22N2O)	31mg/l
	Mineral Oil	-
2	LAB (Linear alkyl benzene)	-
	PMP (C18H20N2)	1.5g/l
3	Naphyenic oil (Nyflex222B)	-
	PMP (C18H20N2)	1.5g/l
4	LAB (Linear alkyl benzene)	-
	2.5 diphenyl oxazole (PPO)(C15H11NO)	3g/l
5	PXE (phenyl-o-xyxlethane) (C16H18)	-
	PMP (C18H20N2)	1.5g/l



LS cell with a possible WOMs arrangement

- LS options discussed with CERN HSE:
  - Chemically all OK
  - Environmentally option 2 and 4 are preferred
  - Option 4 could be produced at Kurchatev Institute with a company nearby at a low price

The Standard Model

Challenges:
- Large area
- Required time resolution <100ps

SAINT-GOBAIN CRYSTALS	ELJEN Technology	Light output	Wavelength	Decay const	Att. length
BC-404	EJ-204	68 %	408 nm	1.8 ns	1.6 m
BC-408	EJ-200	64 %	425 nm	2.1 ns	~4 m

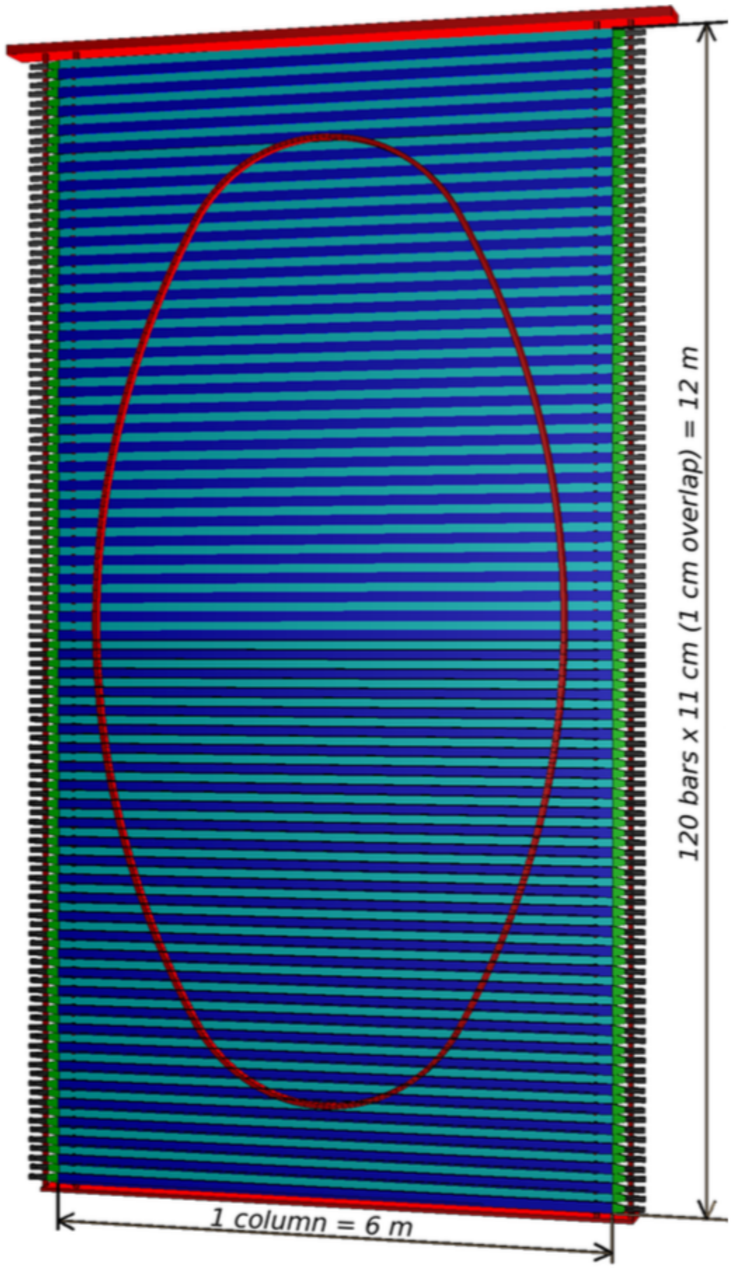
NA61/SHINE, bars with PMTs
UniGe 2006

Energy loss in plastic: dE/dxmin = 2 MeV/cm, light yield: 10000 photons/MeV ⇒

for 2.5 cm bar: Nγ= 2.5 x 2 x 10k = 50 k

For long bar mainly those γ which have total internal reflection (θ >39°) are detected

NA61/SHINE ToF
- 100ps resolution in NA61/Shine ToF
- Size of scintillator counter $120 \times 10 \times 2.5\ cm^3$
- Total active area $1.2 \times 7.2\ m^2$



SBT plastic

Veto system for the OKA experiment in IHEP

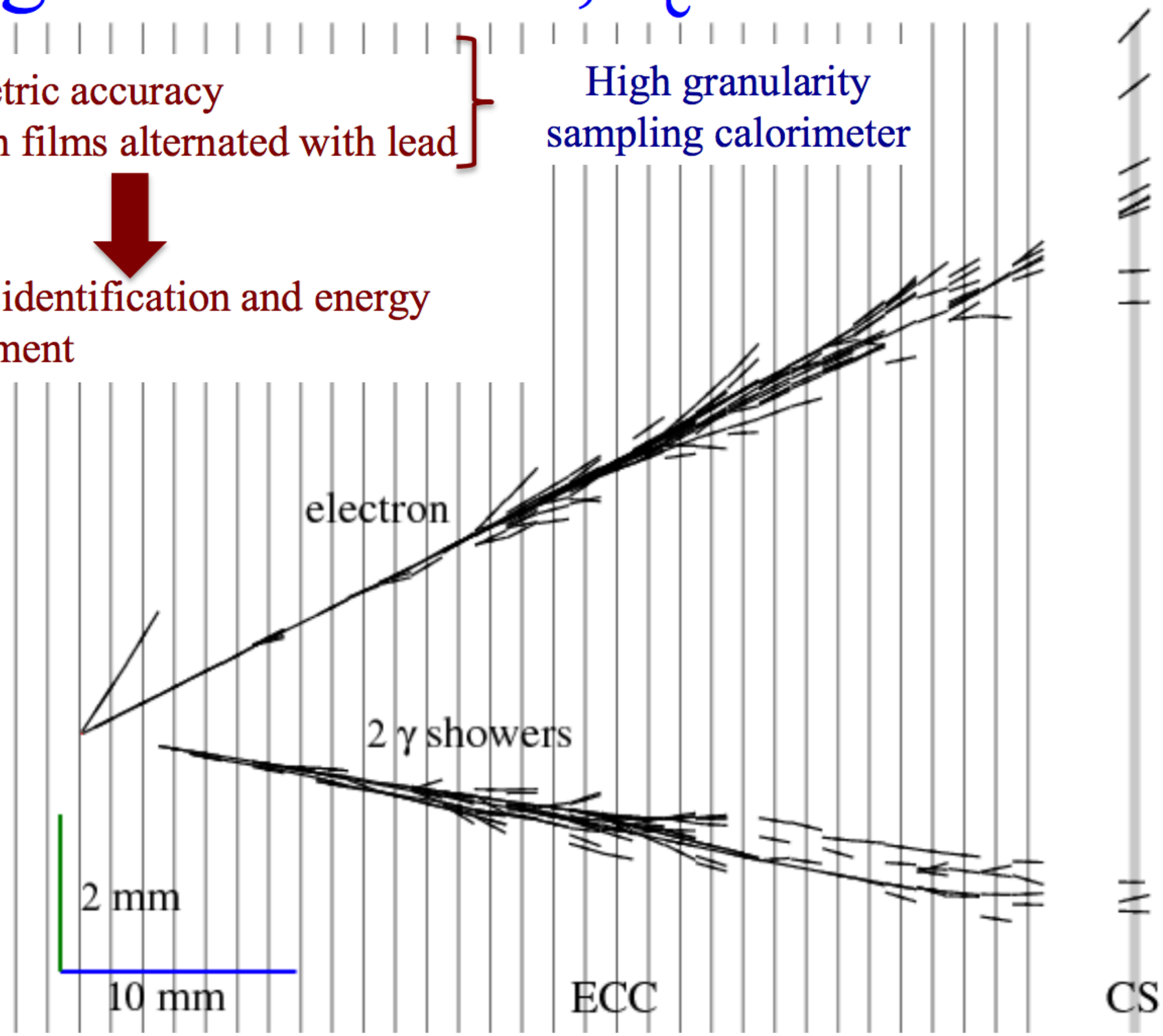
LDM @ SHiP

Light dark matter, ν_e like event

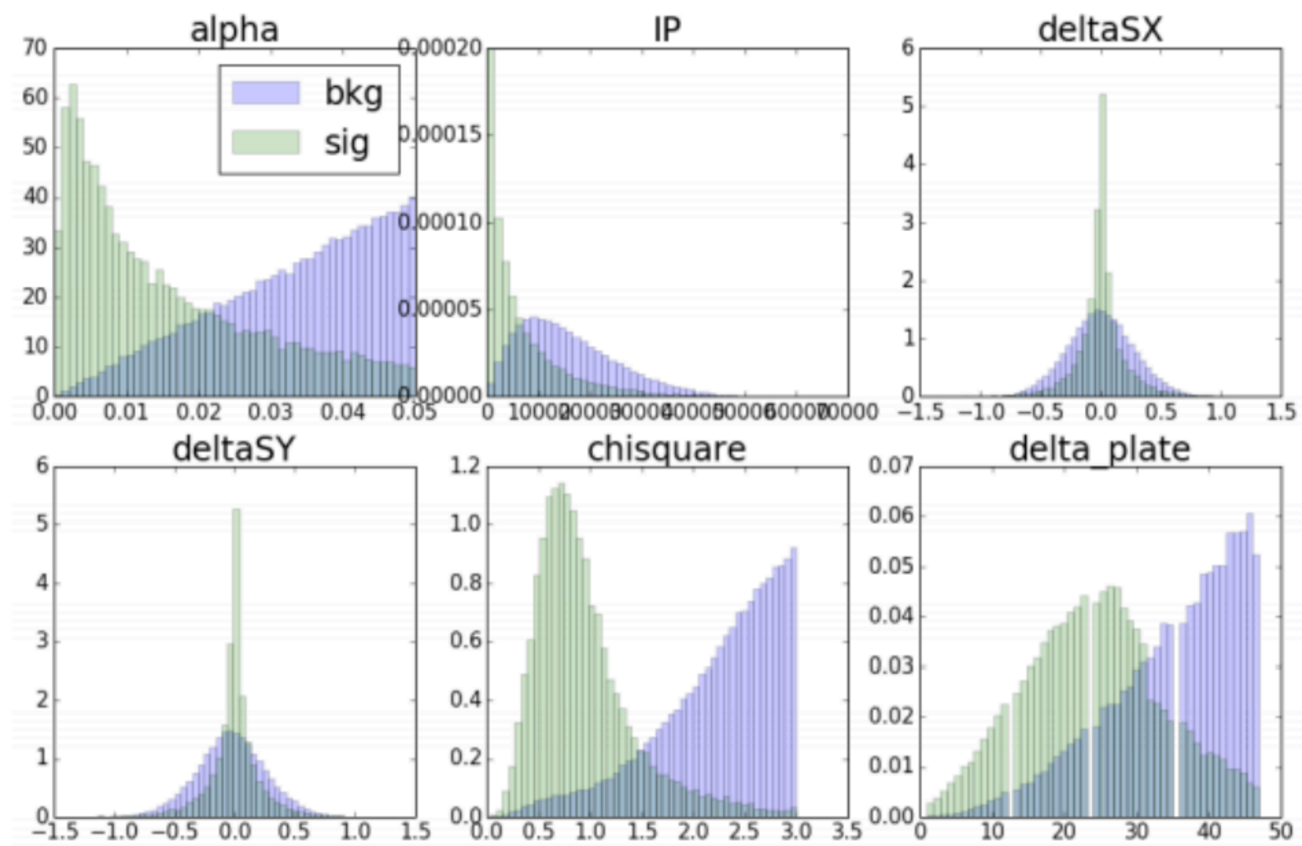
- Micrometric accuracy
- Emulsion films alternated with lead

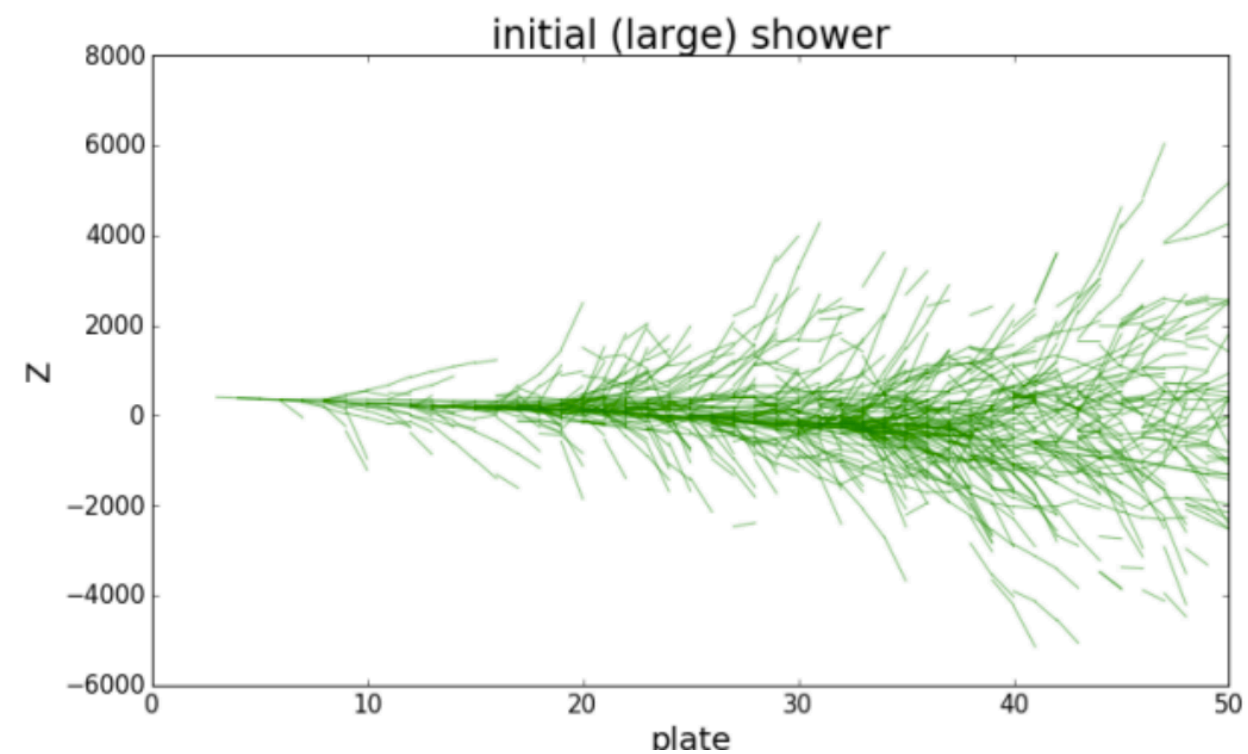
High granularity sampling calorimeter

- Electron identification and energy measurement



LDM @ SHiP





- Electron identification and energy measurement is a key issue for the LDM identification and background rejection
- New software tools under development by Yandex School of Data Analysis
Machine learning-powered searches of EMshowers
in the Emulsion Cloud Chamber data

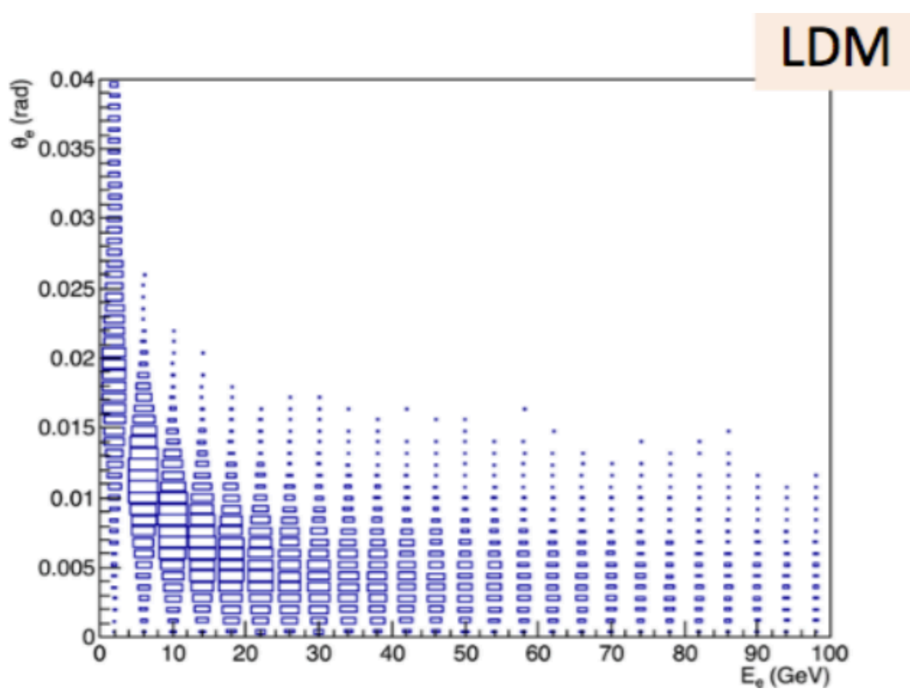
LDM @ SHiP

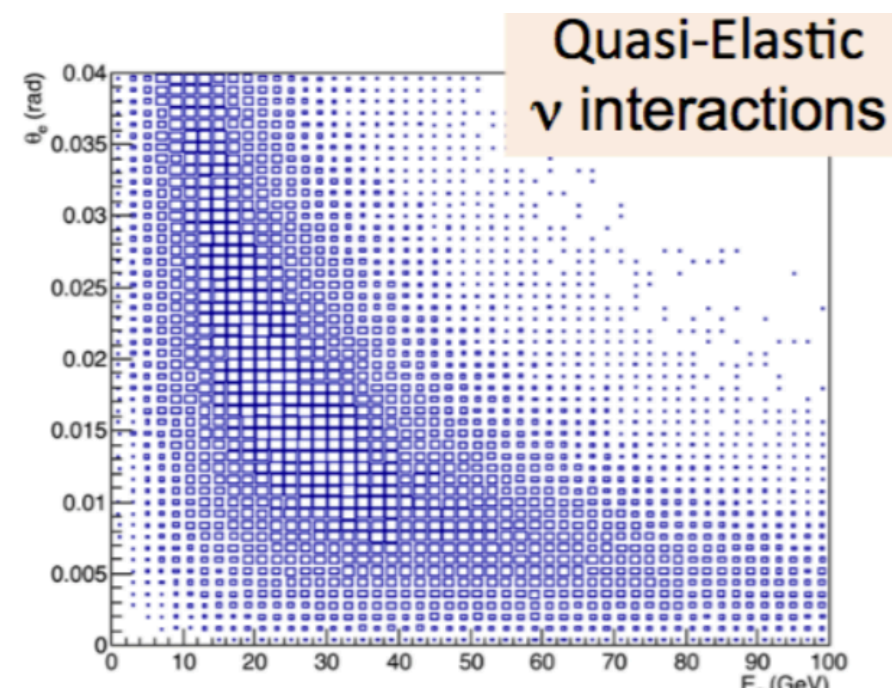
Universität Zürich[UZH]
Physik-Institut

SHiP
Search for Hidden Particles

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

Preliminary estimation reported in TP
- 10 t of lead assumed
- Cut on energy and electron angle





PLANS
- detailed evaluation of background from neutrino interactions using current detector geometry
- Study of kinematical variables for signal/background discrimination (MVA selection)

Introduction