Search for Hidden Particles

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on behalf of the SHiP collaboration

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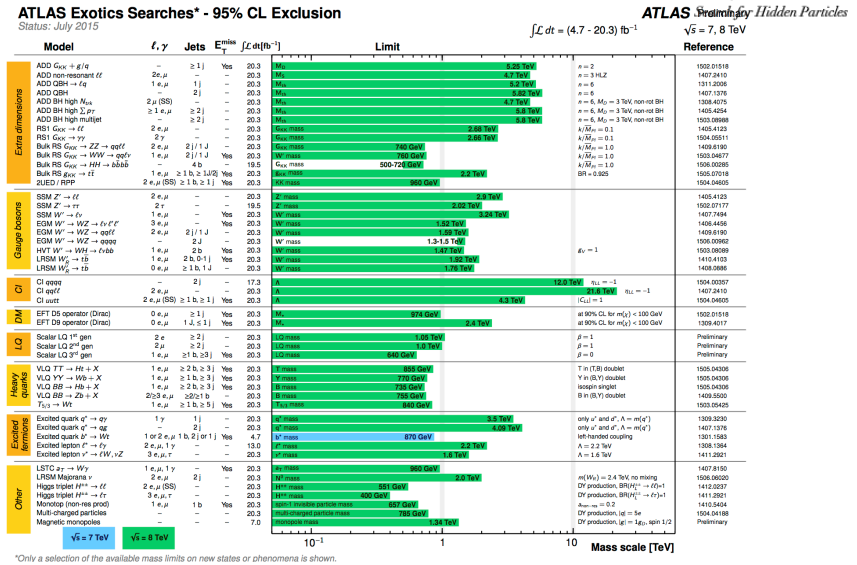
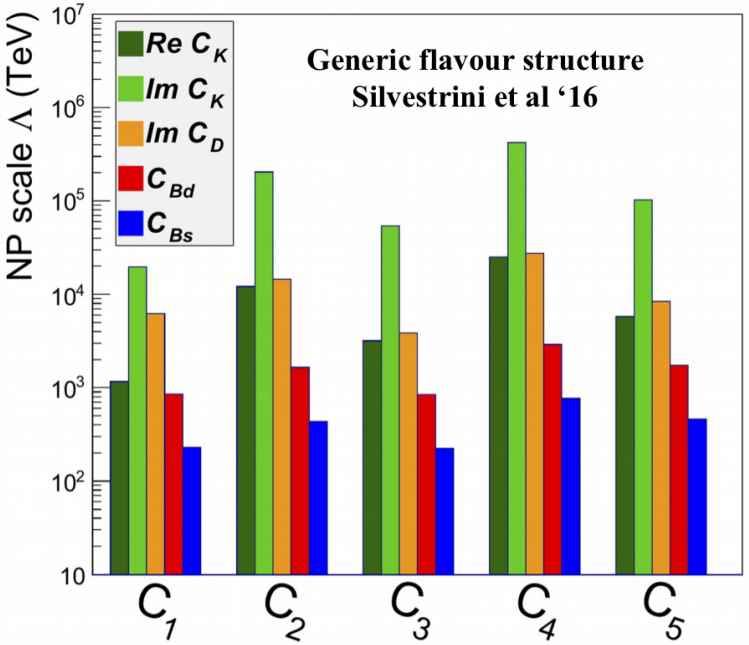
The picture of new physics

- Large number of direct searches resulting in no new physics at scales up to $\sim$ 5TeV
- Even more stringent constraints through indirect flavour measurements
- No smoking gun at high energy scales





A Hidden Sector

- New particles are light and interact very weakly with SM particles through portals
  $\rightarrow$ Provide DM candidate, explain BAU and neutrino masses

$$\mathcal{L}_{\text{World}} = \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{portal}} + \mathcal{L}_{\text{HS}}$$

- Such particles found in very wide range of theories
  $\rightarrow$ SUSY, Axion Like Particles, Heavy Neutral Leptons etc
  $\rightarrow$ **Interactions sufficiently weak, evading precision flavour and electroweak constraints**
  $\rightarrow$ Can search through decays to visible SM particles
- Physics proposal including > 80 theorists

[arXiv:1504.04855]

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

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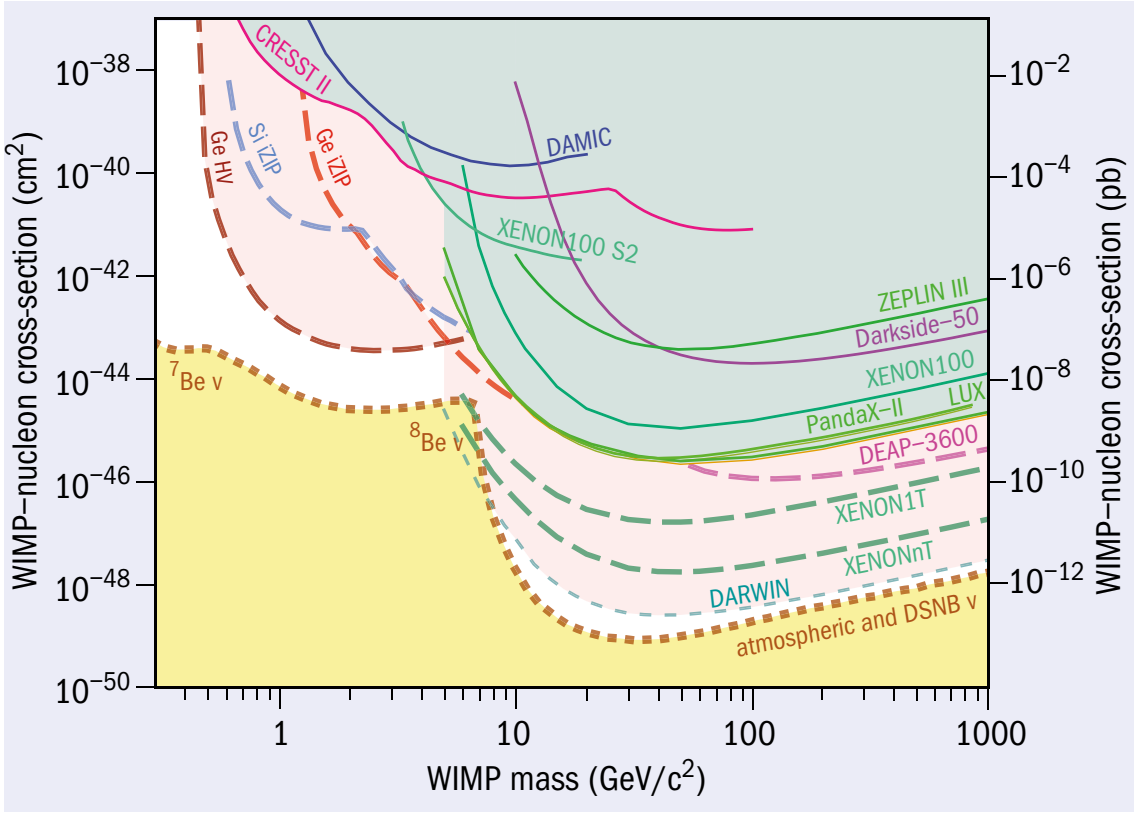
Abstract: This paper describes the physics case for a new fixed target facility at CERN SPS. The SHiP [illegible] unexplored domain of very weakly interacting particles with masses below the [illegible] largely accessible to [illegible] can be used [illegible] 3μ and to search for weakly-interacting sub-GeV dark matter candidates. We discuss the evidence for physics [illegible] interactions between new particles and four different *portals* — scalars, vectors, fermions or axion-like particles. We discuss motivations for different

SHiP will make world-beating and model independent searches in of all of these areas

- Can also search using decays to invisible particles (DM candidates)
  $\rightarrow$ Reoptimise ν_τ detector

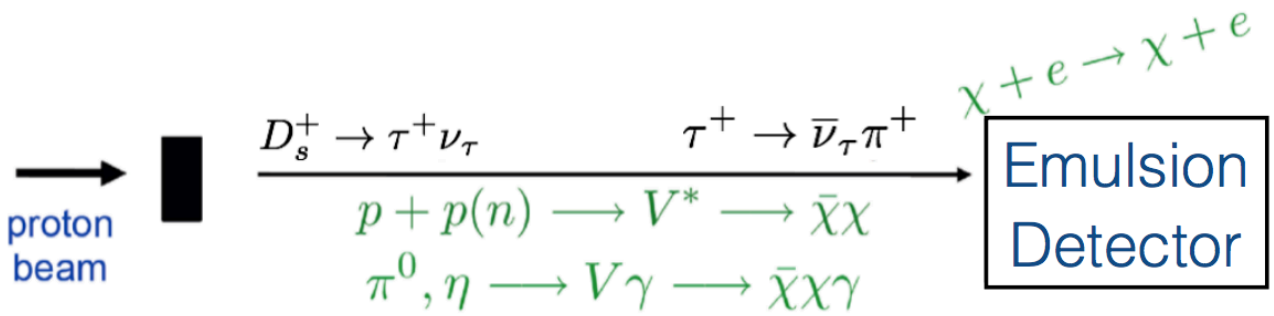
Searches for Light Dark Matter

- DM experiments have in general low sensitivity for masses below a few GeV
- Many models predicting DM candidate in this mass range
  → Important to complement with our physics programme

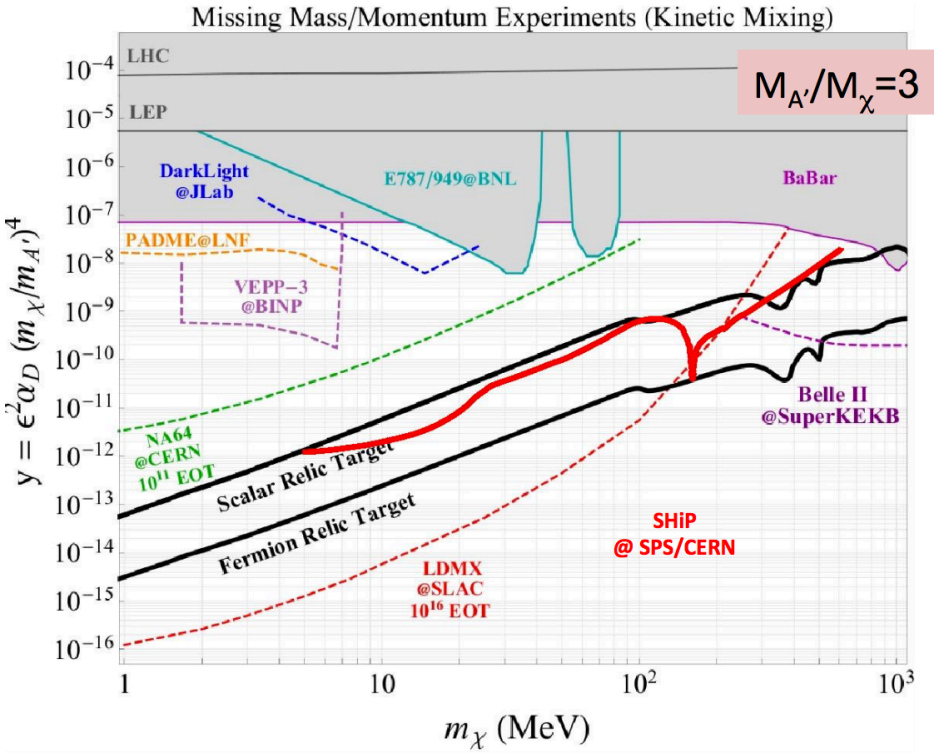


- Light DM models predict a Hidden sector containing a DM candidate
  Hochberg et al [PRL113,171301(2014)], Hochberg et al [PRL115,021301 (2015)], deNiverville et al [PRD92,095005(2015)]...

Searches for Light Dark Matter cont'd



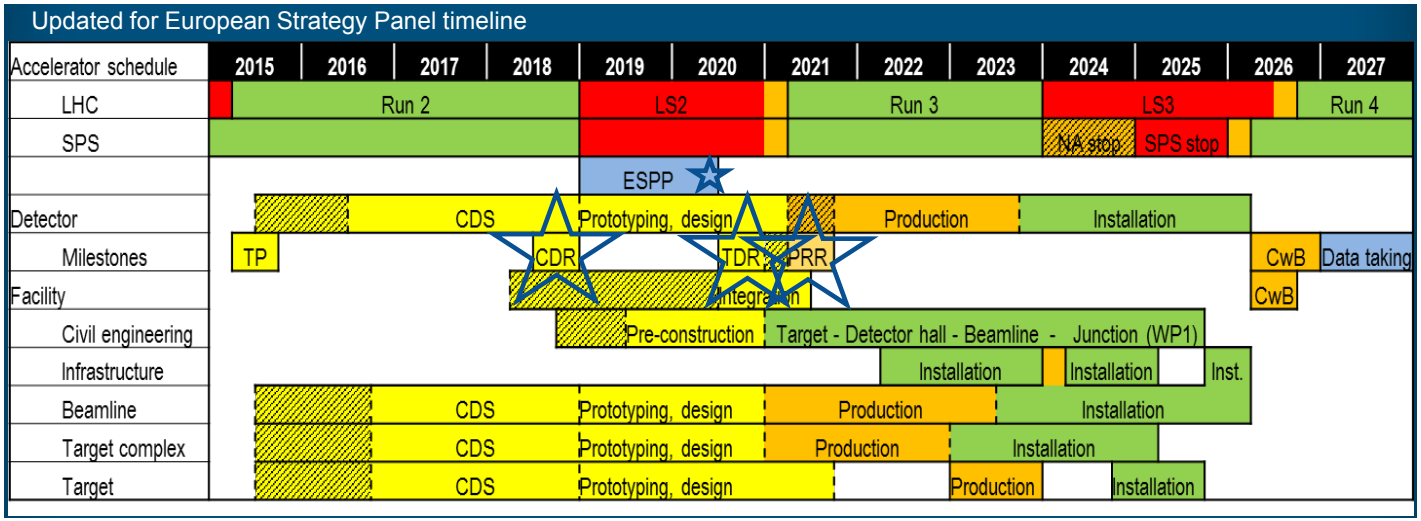
- Mediator of HS decays to DM candidate
  $\rightarrow$ Invisible to downstream SHiP detector
  $\rightarrow$ Detect DM through electron scattering in emulsion detector initially designed for ν_τ physics
- Optimising emulsion detector to take into account this physics case
- **SHiP has the unique ability to simultaneously search for HS particles including the DM candidate!**



Technical Proposal and beyond

- TP reviewed by SPSC and CERN RB and recommended to prepare a Comprehensive Design Study (CDS) by 2018

  → Input to the European strategy consultation in 2019/2020 as a basis for an approval of SHiP



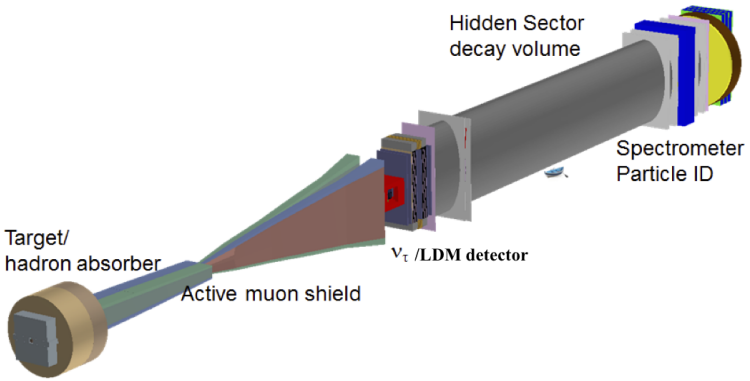
For the CDS: **New phase of optimisation**

- Improve sensitivity to hidden sector searches
  - Re-optimise detector design
- Investigate additional hidden sector models and expand physics case
  - e.g Dark Photon, SUSY, models with multihadron final states, LDM

Evolution of the design

- Improve sensitivity to variety of HS signals
  - While ensuring still a zero background experiment

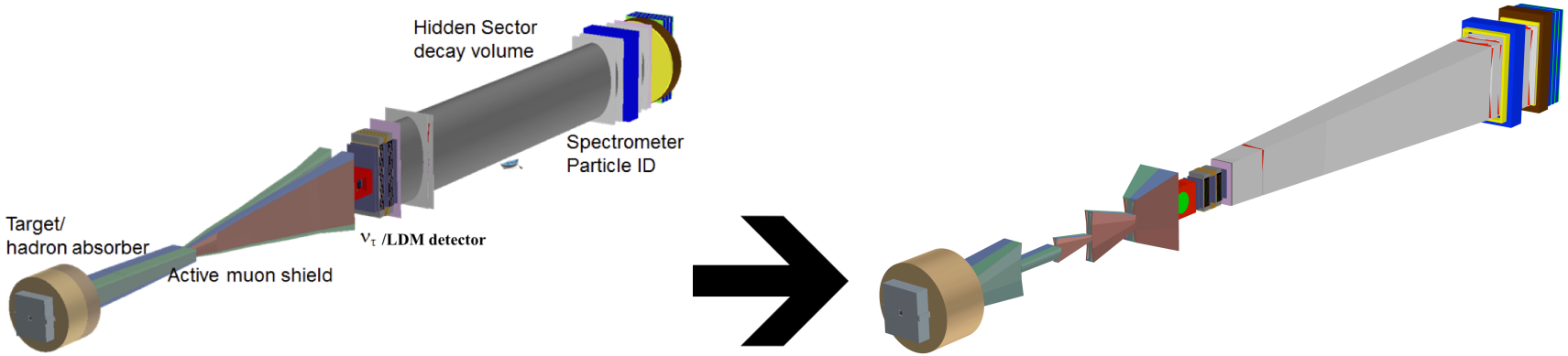
Left: TP SHiP, Right: Star-SHiP



Evolution of the design

- Improve sensitivity to variety of HS signals
  - While ensuring still a zero background experiment
  - Respect cost constraints of the TP

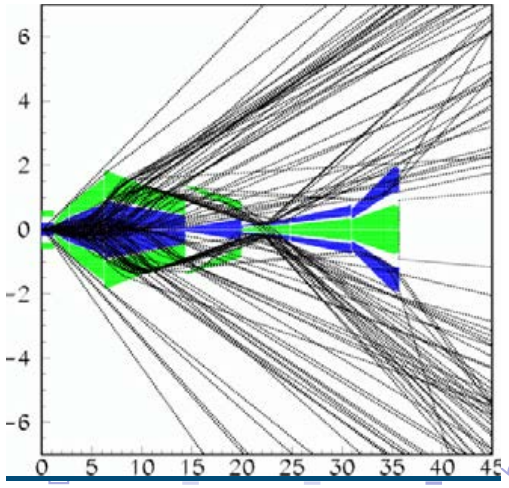
Left: TP SHiP, Right: New SHiP



- Magnetise the hadron stopper → shield shorter and lighter
- Lower muon flux entering shield → Decay volume closer to target

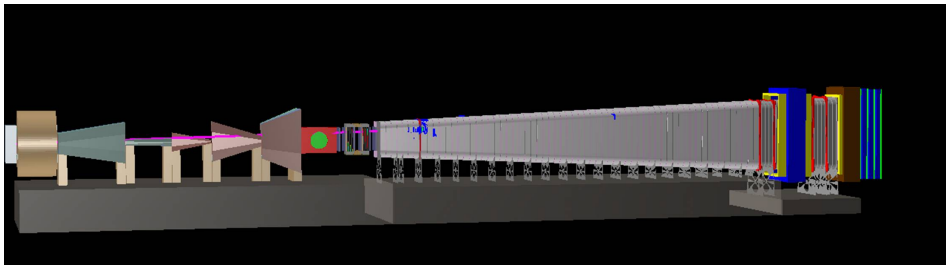
  → Increased signal acceptance and reduced muon background
- Simulate support structures and cavern floor and walls

New muon shield



Evolution of the design cont'd

- Decay vessel now pyramidal frustum shaped
- Vacuum vessel as baseline option



Other design decisions (CDS and beyond):

- Upstream and Surrounding Background Tagger: liquid or plastic scintillator
- Timing detector: Plastic scintillator or MRPC
- Calorimetry and PID: study e,γ, π,μ separation
  - ▷ Crucial to suppress neutrino bkg in $N \to \ell^+\ell^-\nu$

  $\to$ Study some options with test beam in 2017

- Implementing additional HS models in simulation with variety of final states: e.g multihadrons and diphotons
- Detail study of backgrounds with new design

- Prototyping of all subsystems in place many of which close to "module 0" level

Understanding muon flux and charm production

- Muon shield design depends on the muon spectrum

  $\rightarrow$ Validate simulation based estimates of muon spectrum after the hadron absorber induced backgrounds

- Understanding the charm production cross section

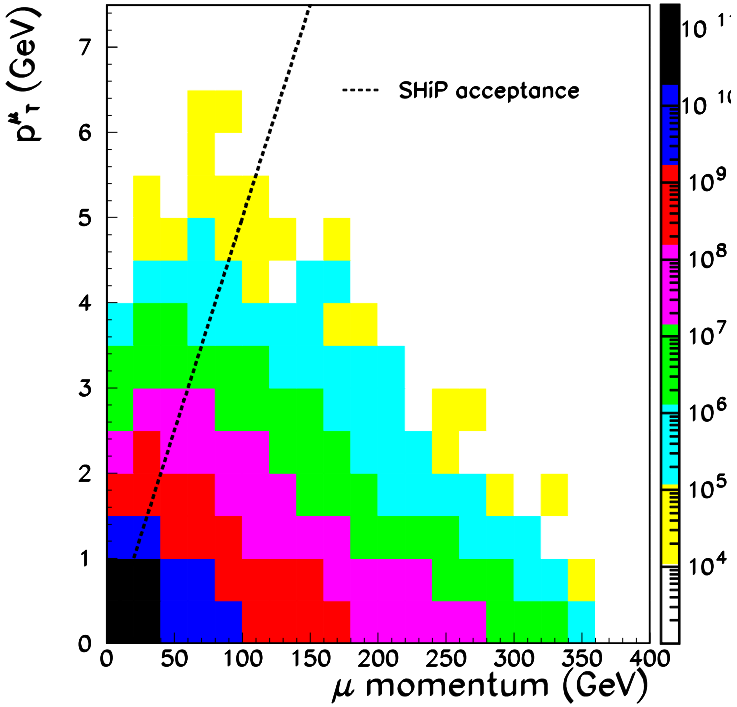
  $\rightarrow$ Important in normalising the signal yield and for validating background estimates from high p_{T} neutrinos

Measuring muon flux

- Expect 6×10^5 μ/s with $p > 100$GeV, $p_{\mathrm{T}} > 3$GeV
- PYTHIA simulations result in limited events in above phase space

  $\rightarrow$ Simulation validated using measurement of flux from CHARM expt.

  $\rightarrow$ Restricted to low p_{T} muons and does not cover dangerous part of phase space
- Use beam-tests to improve statistical uncertainty, allowing to test our simulation and use in optimising muon shield

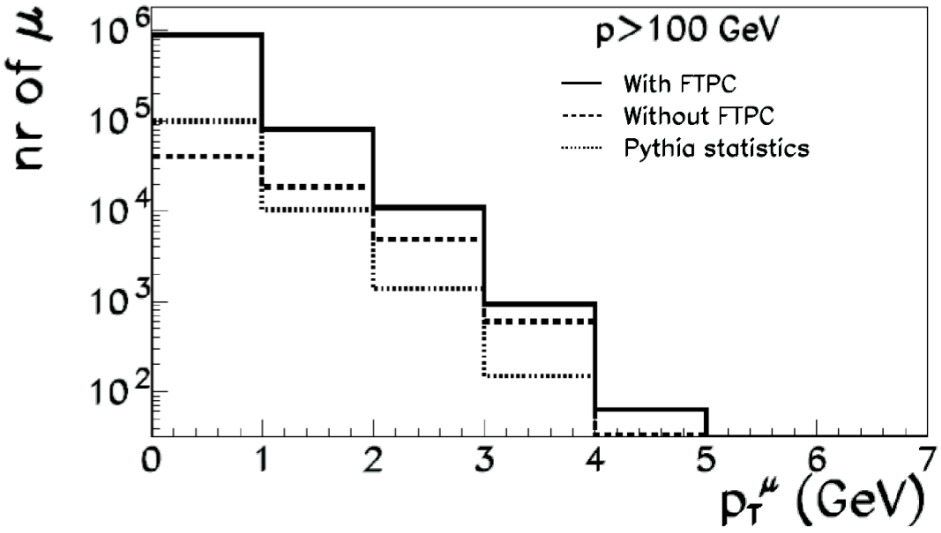


- Find appropriate test beam area for measurement (Collaborate with NA61/SHINE?)
  - Study using simulations

Measuring muon flux cont'd

- Sent EOI to SPSC with proposal based on a NA61/SHINE like detector
  → Install replica SHiP target
  → In order to validate bulk of phase space to $\leq 30\%$ precision need $\sim 10^{11}$ POT
  → 2-3 weeks

van Herwijnen et al[SPSC-EOI-013.pdf]



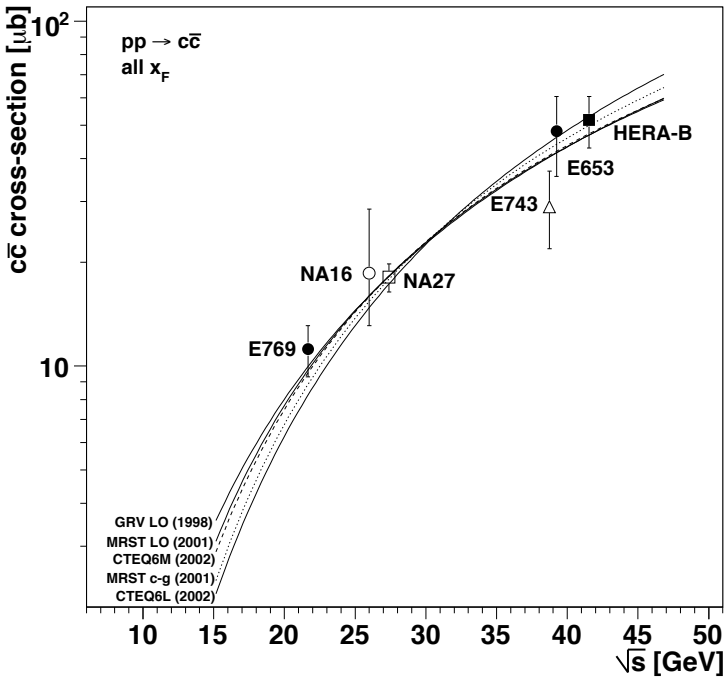
- The BDF target WG is re-evaluating the target design which could result to changes to SHiP target
  → Wait for updated design expected summer 2017
  → Aim to collect data by mid 2018 (before CDS report)

Measuring the charm cross section I

- Need to know the charm production cross-section in proton interactions, including the contribution from hadronic cascades in the SHiP target
  - Normalisation of HS signals and ν_τ cross-section measurements
  - Validating background estimates from high p_{T} neutrinos

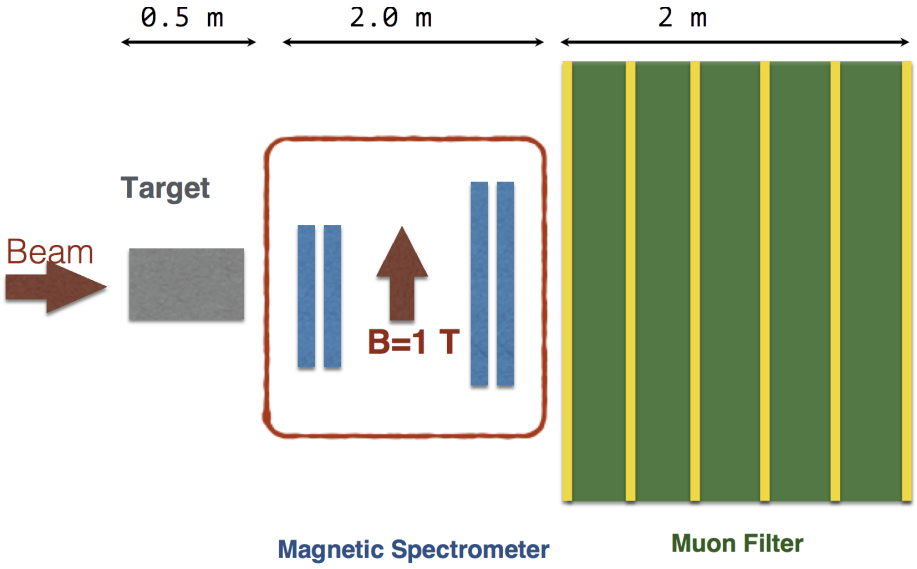
- Current knowledge of inclusive associated charm cross-section measurement is scarce

  $\rightarrow$ Missing information:
  - Contribution from charm production through hadron cascades
  - Kinematic distributions of charmed hadrons

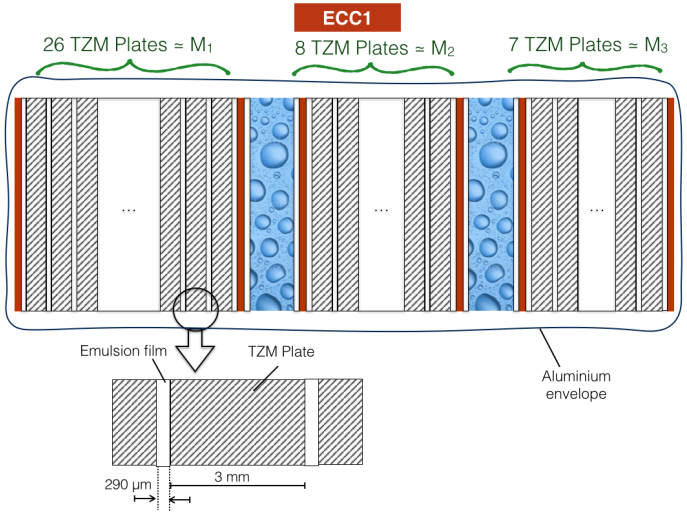


Measuring the charm cross section II

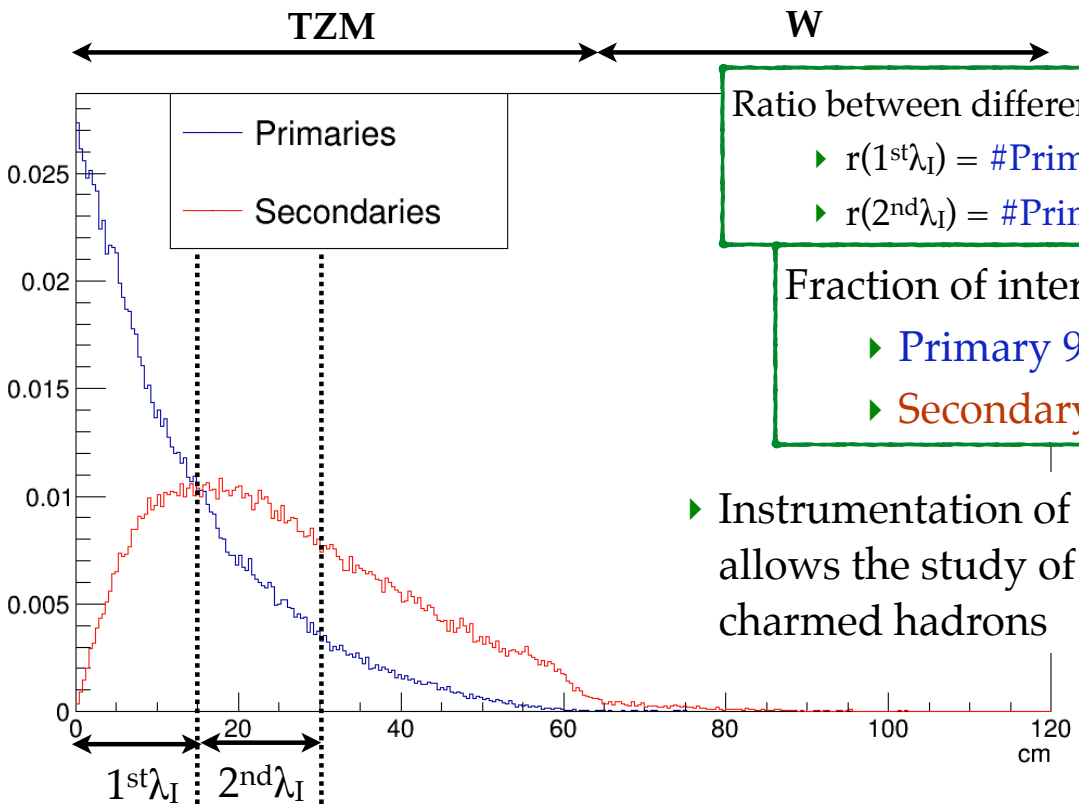
- Propose to measure double-differential cross-section $\frac{d^2\sigma_{cc}}{dEd\theta}$
- Proton collisions with smaller (10×10 cm^2) replica Mo/W target instrumented with nuclear emulsions
- No water cooling required
- Use emulsion as tracking detector to identify hadronic and leptonic charm decay modes



Part of instrumented target ($\sim 1\lambda_I$)



Measuring the charm cross section III



Ratio between different production modes

- $r(1^{st}\lambda_I)$ = #Primary / #Secondary = 2.7
- $r(2^{nd}\lambda_I)$ = #Primary / #Secondary = 0.8

Fraction of interactions within $2\lambda_I$

- Primary 92%
- Secondary 66%

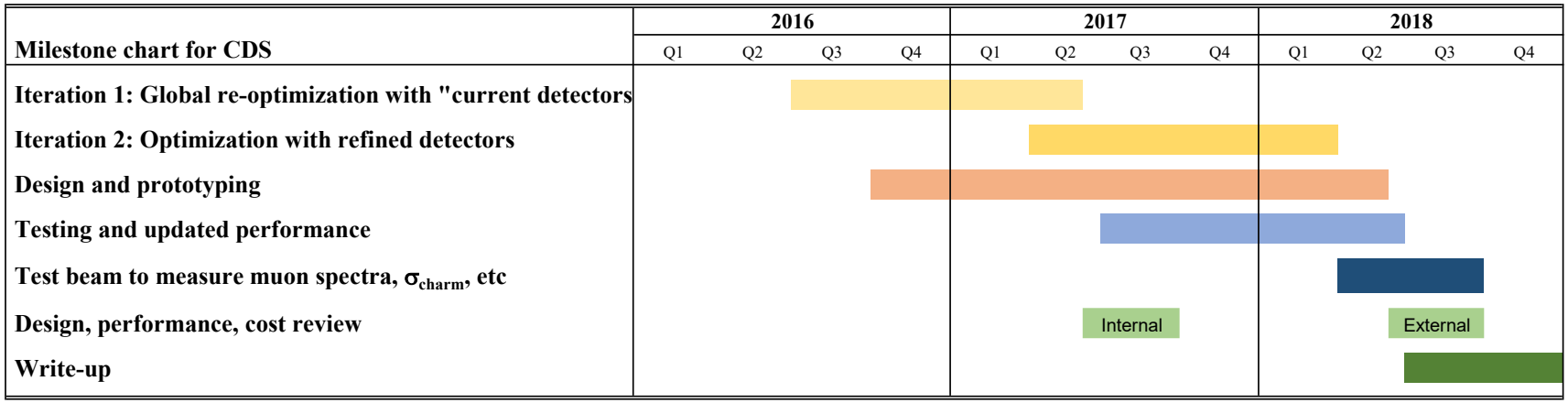
- Instrumentation of first and second λ_I allows the study of a large fraction of charmed hadrons

- Detector design implemented in SHiP's simulation framework
  → Study exposure needed to observe 10000 charmed pairs
  → Require 8×10^7 pot and a total of $250 m^2$ of emulsion surface
- Possible location H4 where the Goliath magnet could be used
- Wait for updated target design expected summer 2017

Summary

A lot of progress since TP. In the next two years:

- Moving onto CDS and TDR stages
- New detector design which significantly increases HS particle acceptance relative to TP design, while satisfying zero background requirement constraints
  - → Reoptimisation under way
  - → Extend physics case to DM searches exploiting SHiPs unique design
- Technology decisions to be made with the help of planned test beams
- Detailed plan of measurements to better understand muon flux and charm production



Backup

First phase reoptimisation

- Decay Volume
  - Pyramidal frustum shape
  - Vacuum baseline, helium balloon as backup
- Detector options
  - Configurations of the LDM/ν_τ emulsion detector
  - Straw tube technology considered for the upstream muon spectrometer
  - Technologies for Upstream and Surround Background Tagger: Liquid and Plastic scintillator + SiPM
  - Technologies for Timing Detector: Plastic Scintillator/MRPC
  - Revisit completely calorimetry and PID
- First iterations and optimisation implemented in our full simulation

$\rightarrow$ Launching complete background simulation

Test beam activities

- 2016
  - Beam time exploited by straw tracker and BDT plastic scintillator option
- 2017
  - Joint test beam for Straw Tracker, SBT, CALO on SPS ($\sim$ 2.5 weeks)
  - Emulsion test beam on PS ($\sim$ 2 weeks)
  - Muon system test beam on PS ($\sim$ 2 weeks)
- 2018 and beyond
  - Likely to have several sub-detector requests as in 2017
  - Tuning of muon spectra
  - Measurement of inclusive charm production