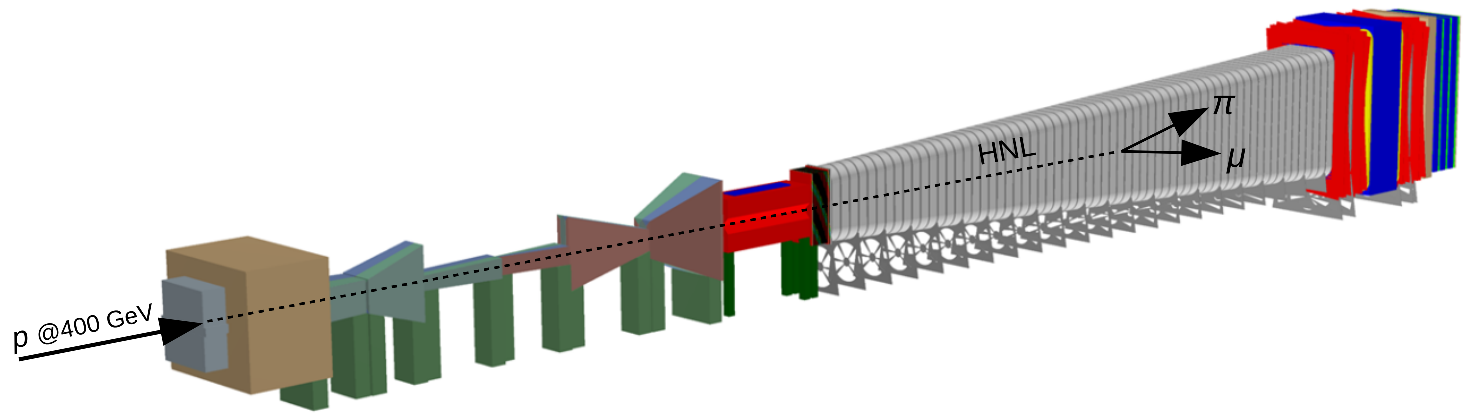
SHiP



Marc Schumann
U Freiburg

see also BDF report by Matthew Fraser

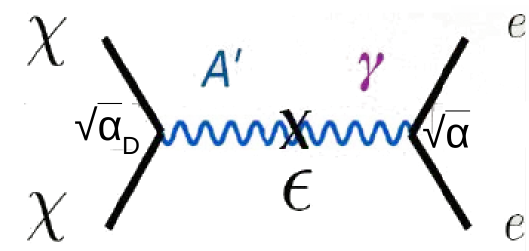
PBC General Working Group Meeting
CERN, December 2-3, 2021

marc.schumann@physik.uni-freiburg.de
www.app.uni-freiburg.de

Motivation

- Standard Model incomplete
- many BSM models predict „hidden sector“ (HS) which is super-weakly coupled to the SM

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



Portal	Interaction term
Scalar (e. g. dark scalar, dark Higgs)	$(H^\dagger H)\phi$
Vector (e. g. dark photon)	$\varepsilon F_{\mu\nu} F'_{\mu\nu}$
Fermion (e. g. heavy neutral lepton (HNL))	$H^\dagger \overline{N} L$
Axion-like particle (ALP)	$a F^{\mu\nu} \tilde{F}^{\mu\nu}$

- SHiP is a general purpose beam-dump experiment to search for such **hidden sector particles**, e.g.,
  ►dark photons, ►ALPs, ►dark scalars, ►light dark matter,
  ►heavy neutral leptons (HNL, e.g., RHν), etc.

HS: Experimental Features

- production: meson decays (π, **K, D**, B), p-Bremsstrahlung, QCD
  ► production BF ~ 10^{-10}
- features: ► neutral
  ► long-lived
  ► travel (almost) unperturbed through matter
- final states

Models	Final states
Neutrino portal, SUSY neutralino	$\ell^\pm\pi^\mp, \ell^\pm K^\mp, \ell^\pm\rho^\mp, \quad \rho^\pm \to \pi^\pm\pi^0$
Vector, scalar, axion portals, SUSY sgoldstino	$\ell^+\ell^-$
Vector, scalar, axion portals, SUSY sgoldstino	$\pi^+\pi^-, K^+K^-$
Neutrino portal ,SUSY neutralino, axino	$\ell^+\ell^-\nu$
Axion portal, SUSY sgoldstino	$\gamma\gamma$
SUSY sgoldstino	$\pi^0\pi^0$

- signature: isolated decay vertex pointing back to target
- detector requirements:
  ► full reconstruction and PID to distinguish between models
  ► cover fully (without ν) and partially reconstructed (with ν) final states
  ► rare signals require sophisticated background suppression
  → **aim for zero background**

SHiP Backgrounds

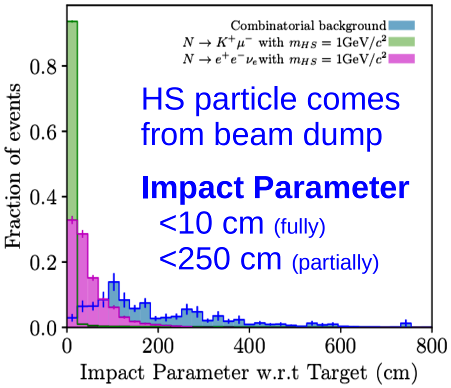
- extensive MC-based background study
- MC validated against data *e.g., simulation of μ-production: JINST 14 (2019) P11028*
  μ-flux from replica target: EPJ C 80 (2020) 3, 284
  → more tests with muon shield prototype are planned

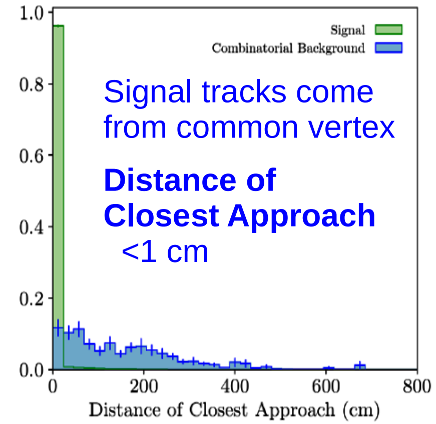
3 main background sources

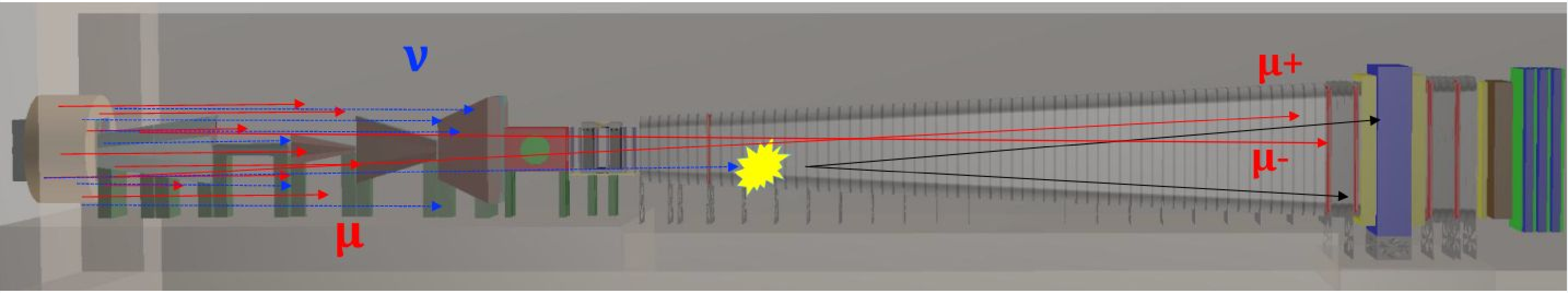
- μ combinatorial background
- μ deep inelastic scattering
- ν deep inelastic scattering

Background reduction/rejection

- detector design (μ shield, decay vessel)
- selection criteria
- timing (Δt<100 ps)
- background taggers (UBT, SBT)







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3 main background sources

	Expected [2×10[20] pot]
μ combinatorial background	4.2×10^{-2}
μ deep inelastic scattering	$<6\times10^{-4}$
ν deep inelastic scattering	<0.1 (fully) | <0.3 (partially)

Background reduction/rejection

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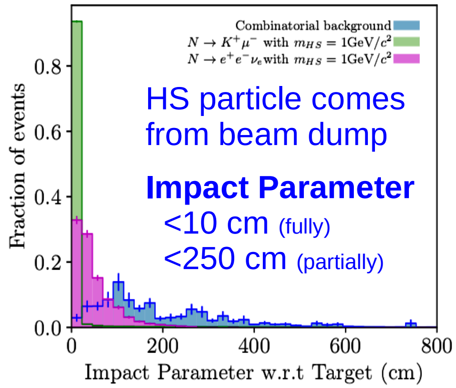
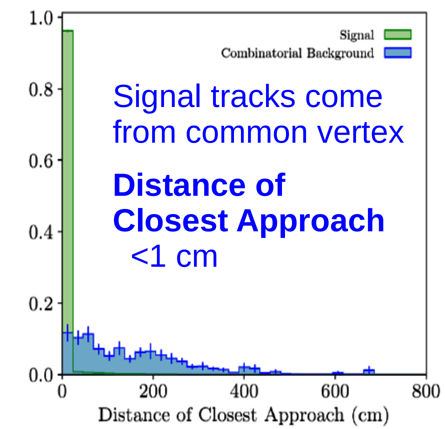
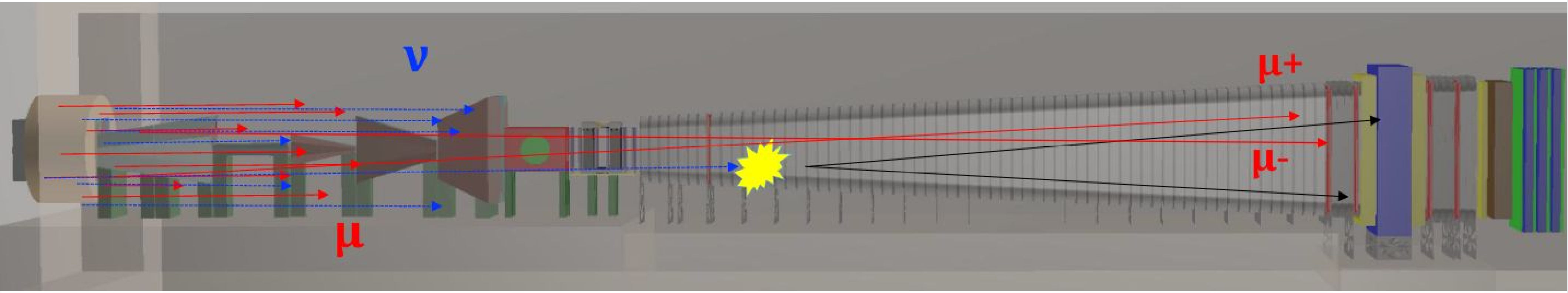
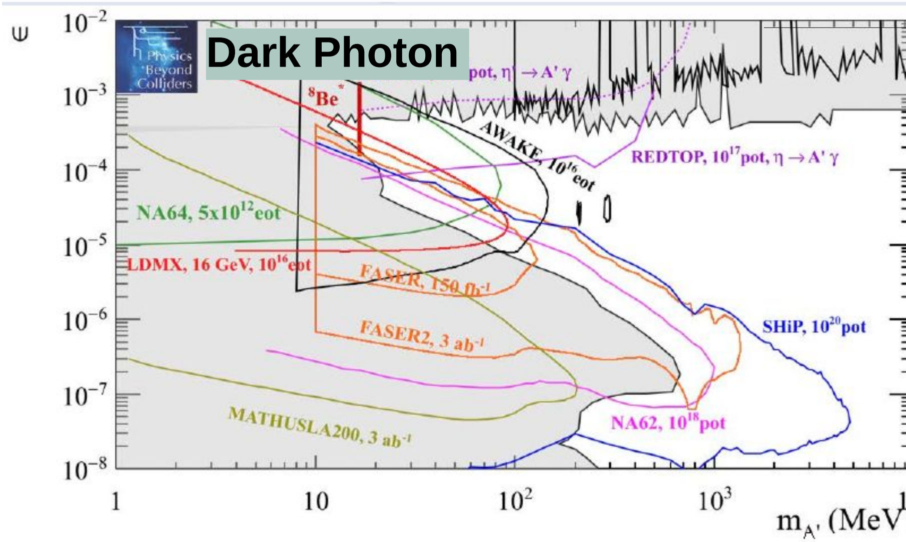
Background goal can be reached with high level of redundancy



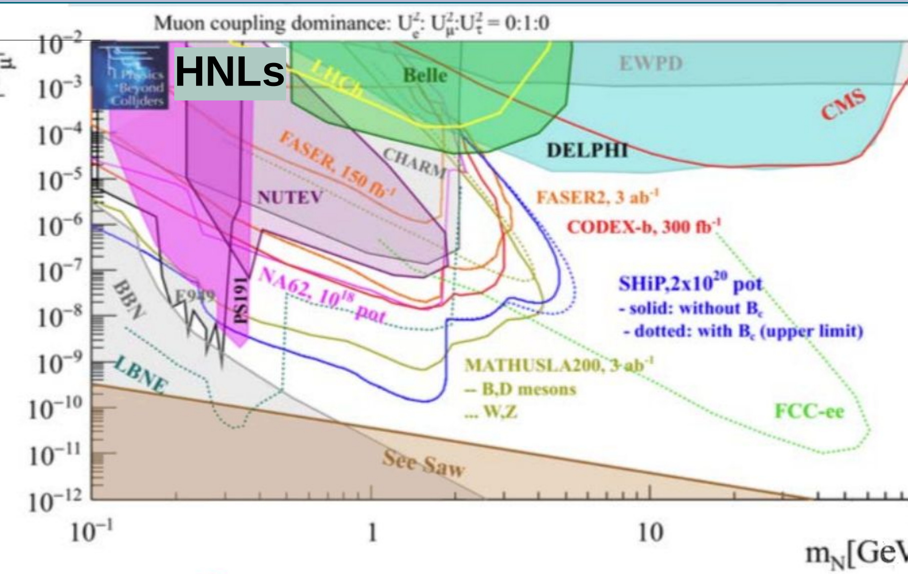




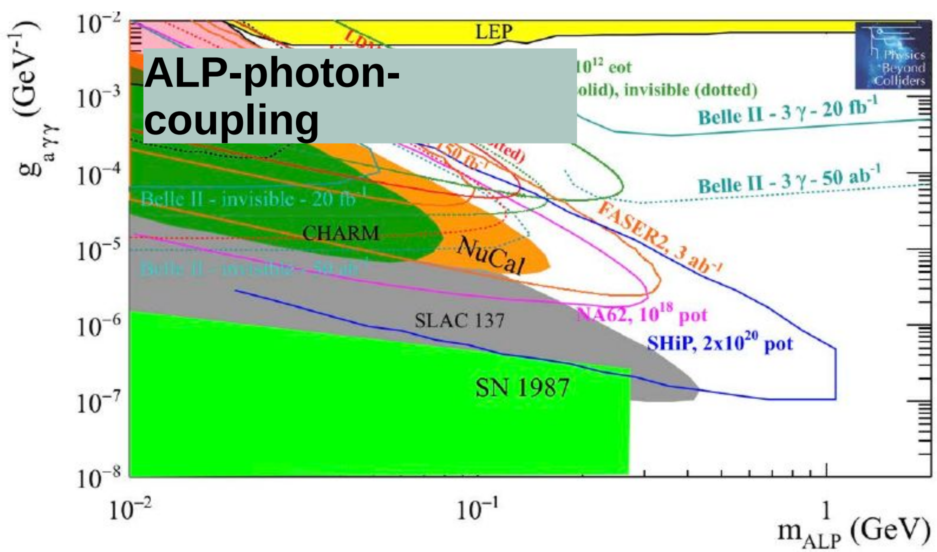
SHiP Science: Examples

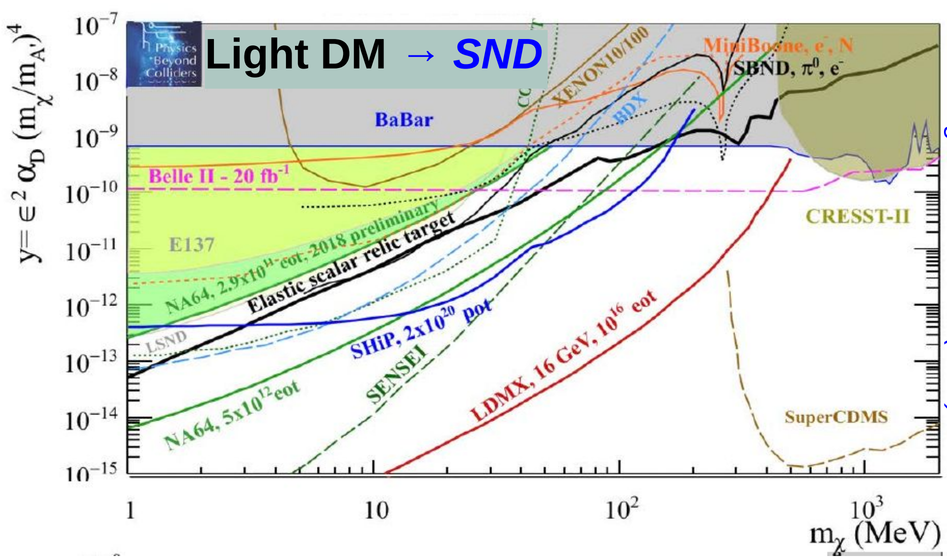


Dark Photons: EPJ C 81 (2021) 451



HNL: JHEP 04 (2019) 077





Light DM: JHEP 04 (2021) 199

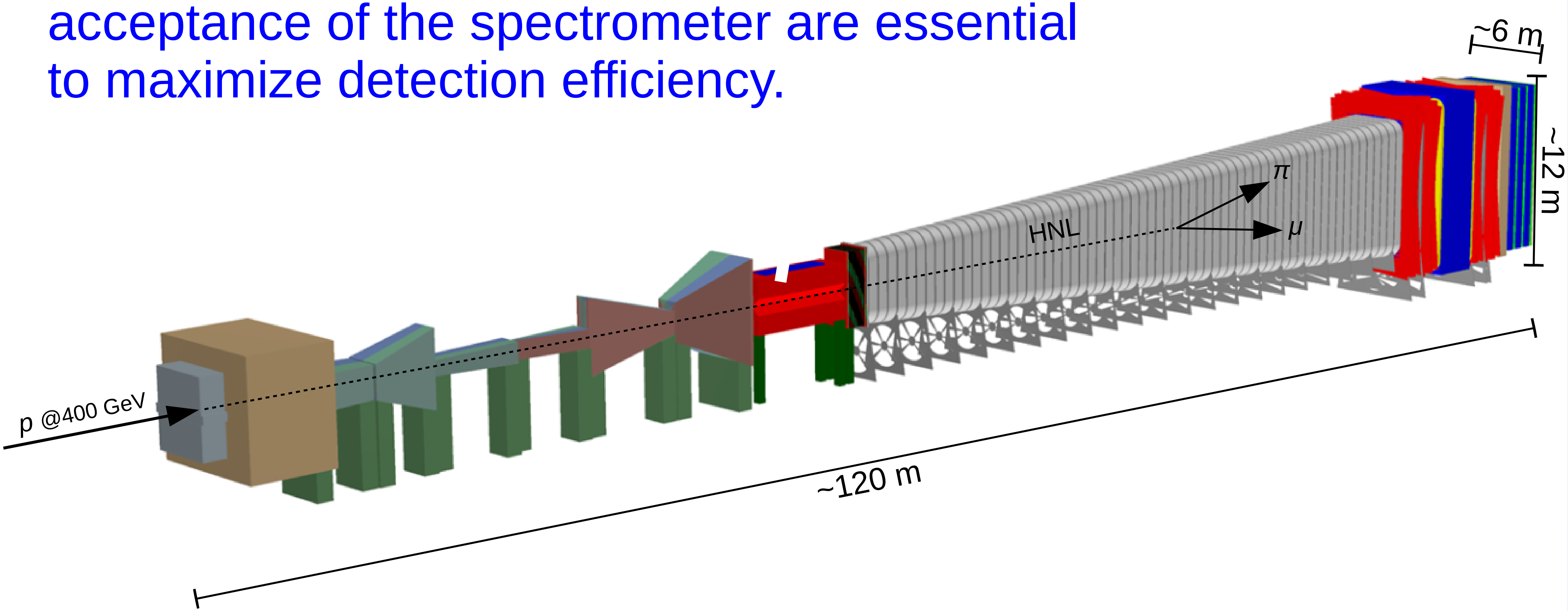
Physics Case is strong and unbeaten

EPPSU: BDF/SHiP is forerunner in dark-sector searches

SHiP Design (CDS)

Compehensive Design Study: CERN-SPSC-2019-049
arXiv:2112.01487

Long decay volume and large geometrical acceptance of the spectrometer are essential to maximize detection efficiency.



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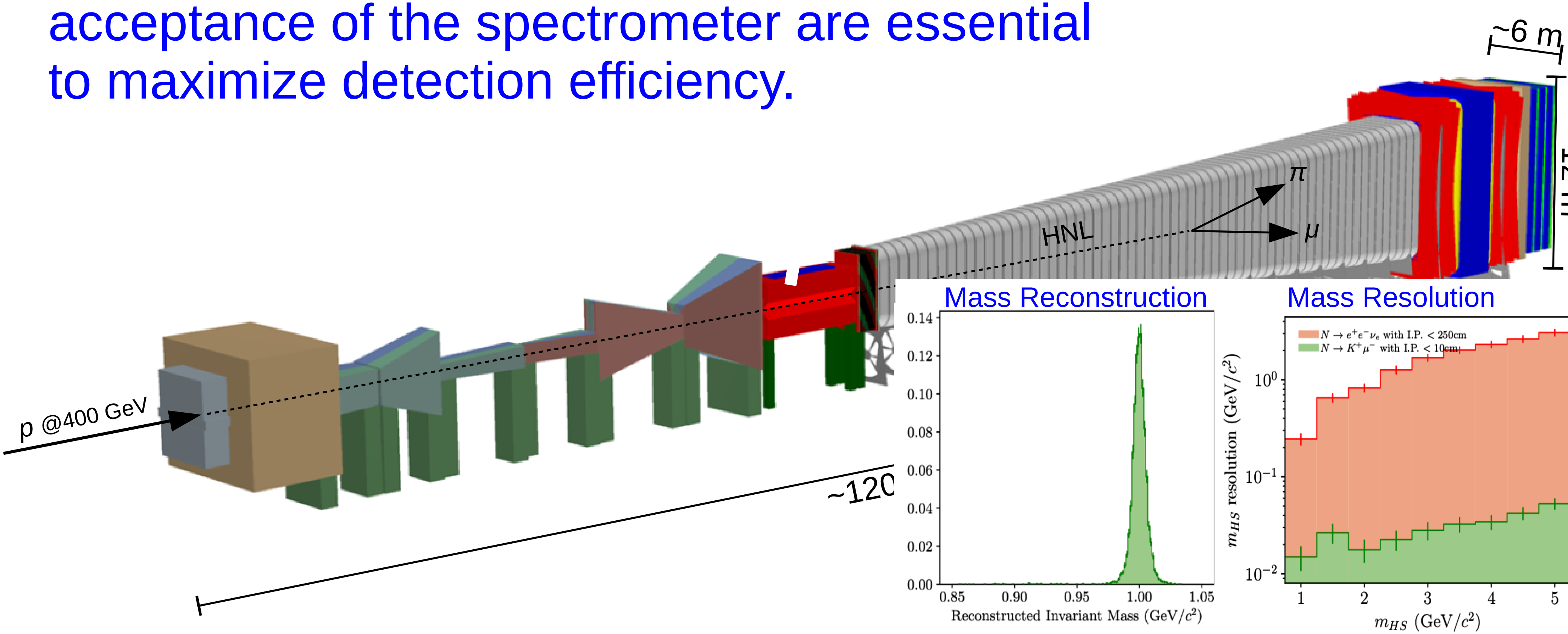


- Design for zero background: SHiP is a discovery experiment
- In case of discovery: SHiP will measure particle properties

SHiP Design (CDS)

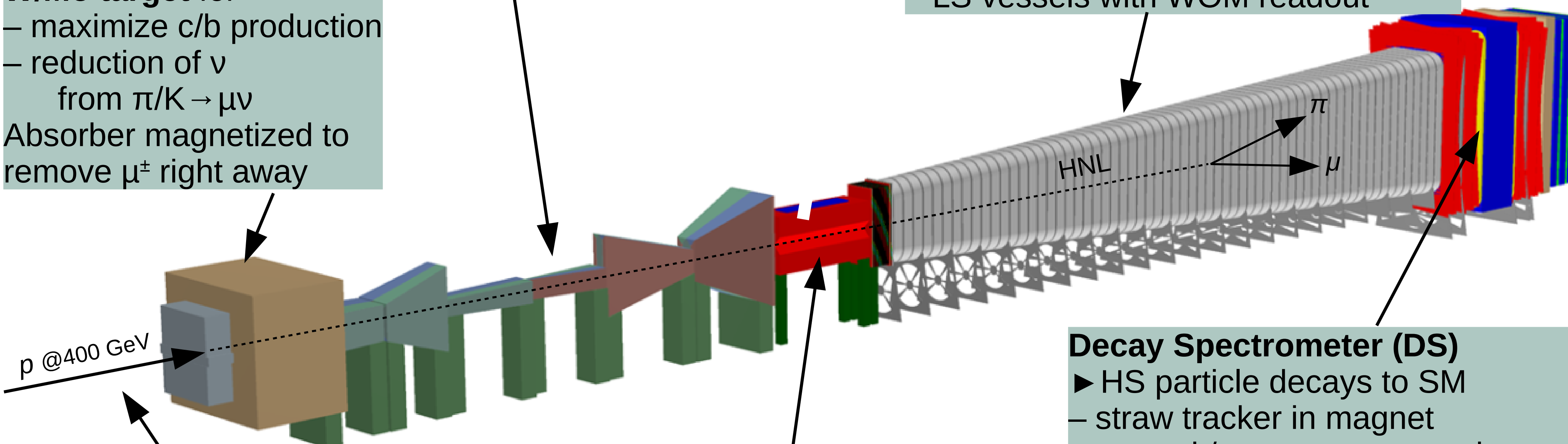
Compehensive Design Study: CERN-SPSC-2019-049

arXiv:2112.01487

μ-Shield: only μ, ν (+NP) escape target
– μ-shield to sweep away $\mu^{\pm}$
– reduction $O(10^6)$ achieved in CDS

Surround Background Tagger (SBT)
► id of μ/ν-induced inelast. i/a in SND and decay volume walls
– LS vessels with WOM readout

W/Mo target for
– maximize c/b production
– reduction of ν from π/K → μν
Absorber magnetized to remove $\mu^{\pm}$ right away



Decay Spectrometer (DS)
► HS particle decays to SM
– straw tracker in magnet
→ track/vertex reconstruction
– scint. bars + SiPMs
→ timing with ~100ps resolution to reduce combinatorial backgrnds
– ECAL (SplitCal)
– hadron absorber
– μ-detector (scint. tiles+SiPMs)
PID

SPS beam ideally suited to produce c/(b) hadron decays

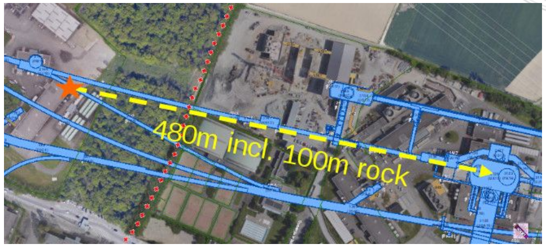
Scattering+Neutrino Detector (SND)
► light DM scattering, τ-neutrino physics
► yield normalization for HS search
– hybrid spectrometer in magnet (absorber, nucl. emulsions, fast tracker)
– muon id system

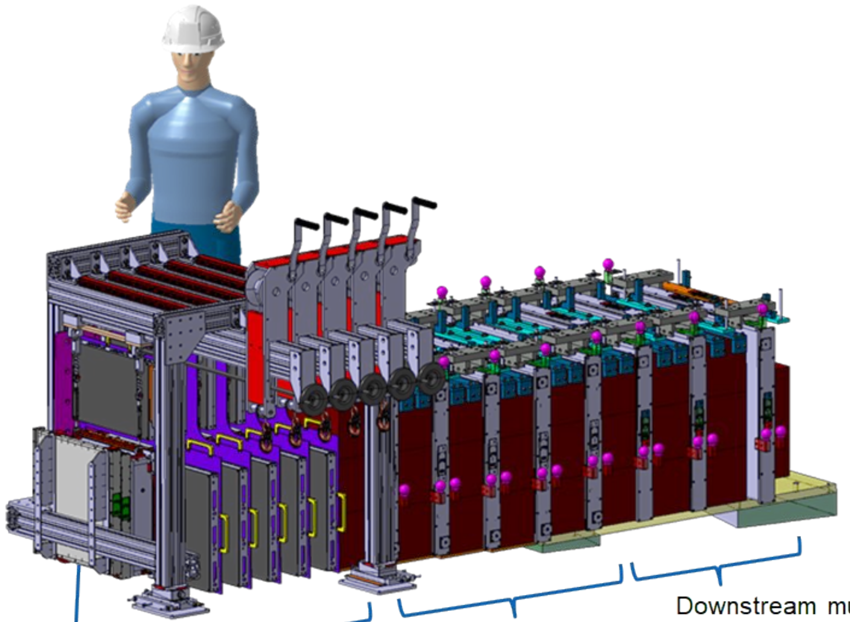
Magnet: JINST 15 (2020) 01, P01027

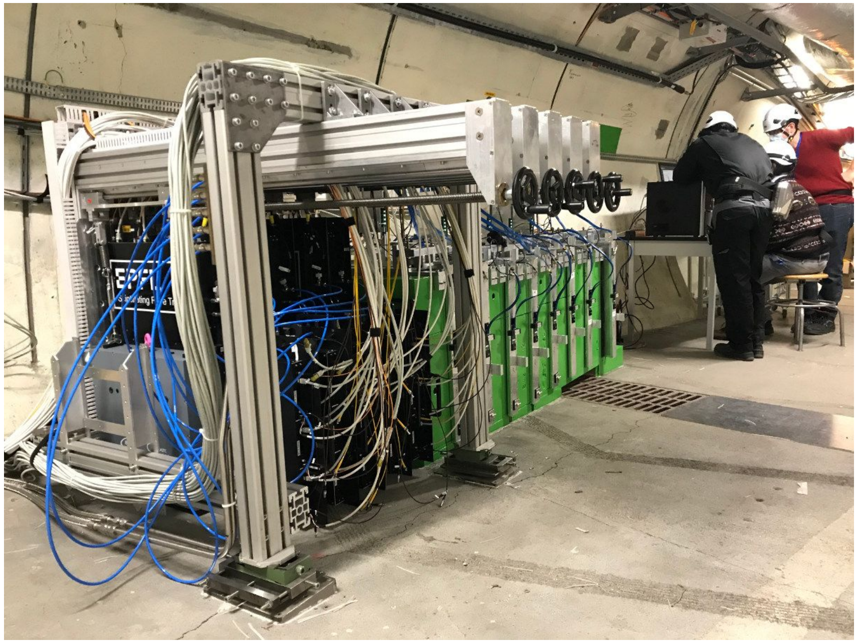
Detector technology application: SND@LHC

arXiv:2002.08722

- SND@LHC approved by CERN in April 2021
- Construction/commissioing onoing right now



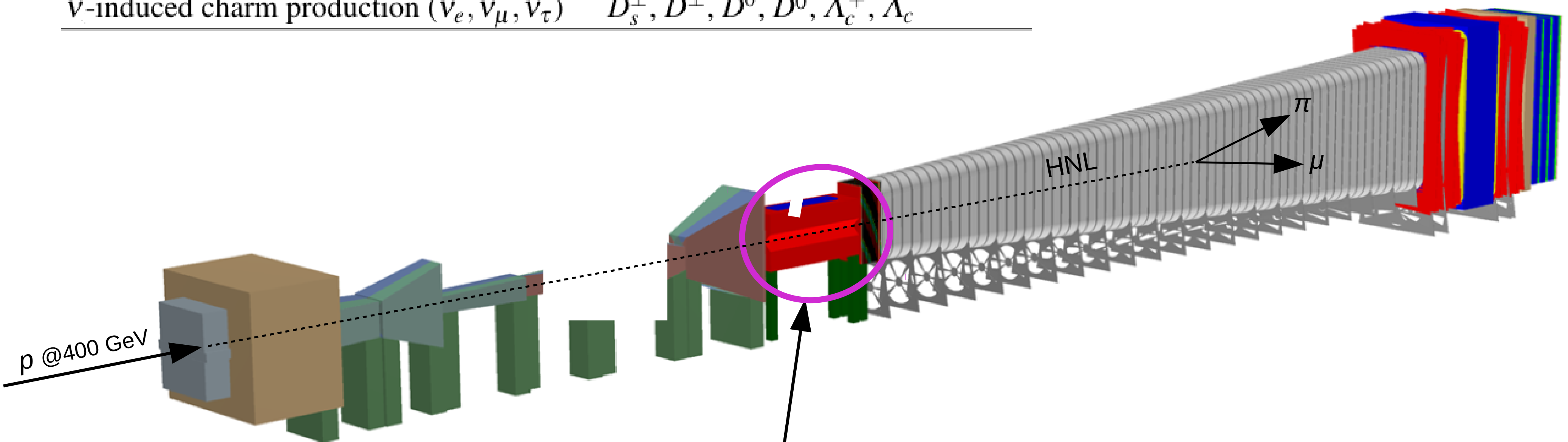




- Goal: neutrino physics and light DM searches
  AND pathfinder detector for SHiP
- SND@LHC collaboration are mainly SHiP institutions
- Data taking expected to start in March 2022

SND @ SHiP

Physics model	Final state
LDM	electron, proton, hadronic shower
ν_τ, $\overline{\nu}_\tau$ measurements	$\tau^\pm$
ν-induced charm production (ν_e, ν_μ, ν_τ)	$D_s^\pm$, $D^\pm$, D^0, $\overline{D^0}$, Λ_c^+, $\overline{\Lambda_c}^-$



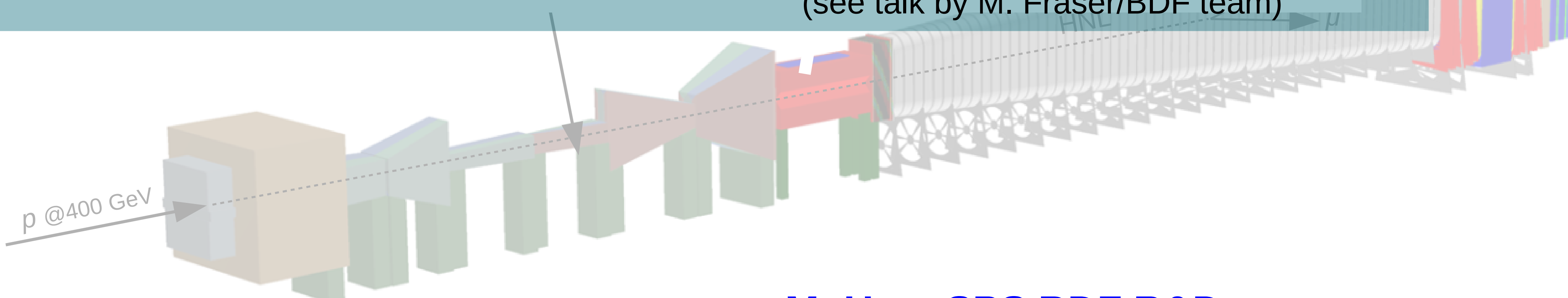
Scattering+Neutrino Detector (SND)

- replace emulsions by electronic trackers (e.g., Si)
- relax severe constraints on μ-rate passing μ-shield
- allow shorter μ-shield → more compact
- more sophisticated cuts possible
  → keep zero-background goal

BDF/SHiP R&D

Activities for next 3 years:

Review of Detector Technologies
Optimization of Detector Layout
more compact → infrastructure cost reduction
→ smaller footprint
→ alternative locations?
(see talk by M. Fraser/BDF team)



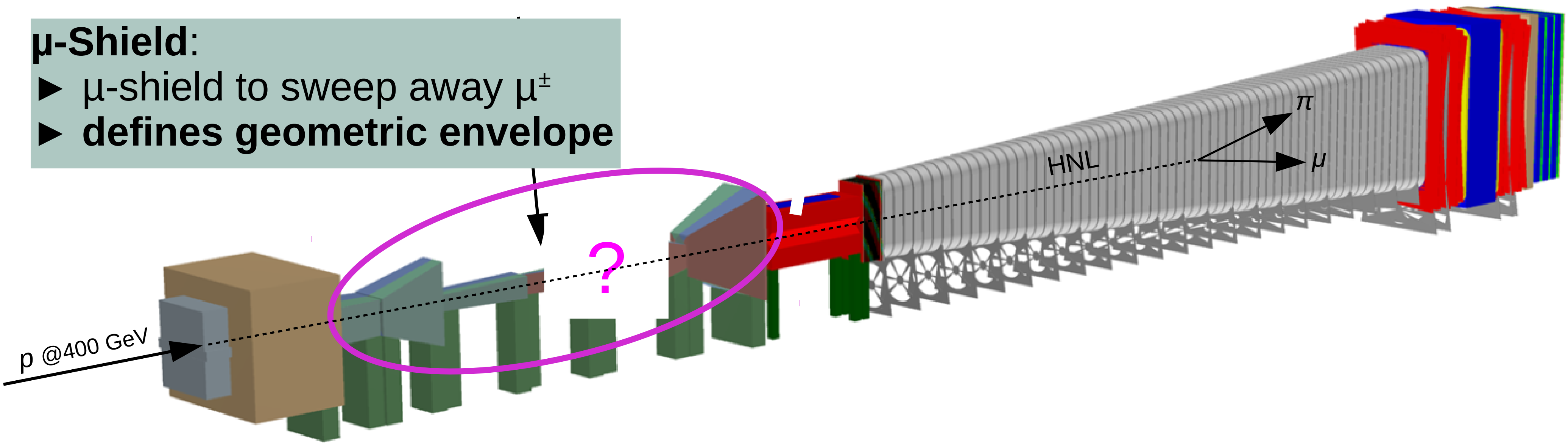
MoU on SPS BDF R&D program
between CERN and SHiP Collaboration+
(29 institutions propose contributions)

3 main projects (addenda)
- ►Muon Shield
- ►Vacuum Decay Volume
- ►BDF Performance Optimizaton

Design Study of μ-Shield

R&D to evaluate technologies through prototypes and beam tests, optimisation of design/engineering

μ-Shield:
- ► μ-shield to sweep away $\mu^{\pm}$
- ► **defines geometric envelope**

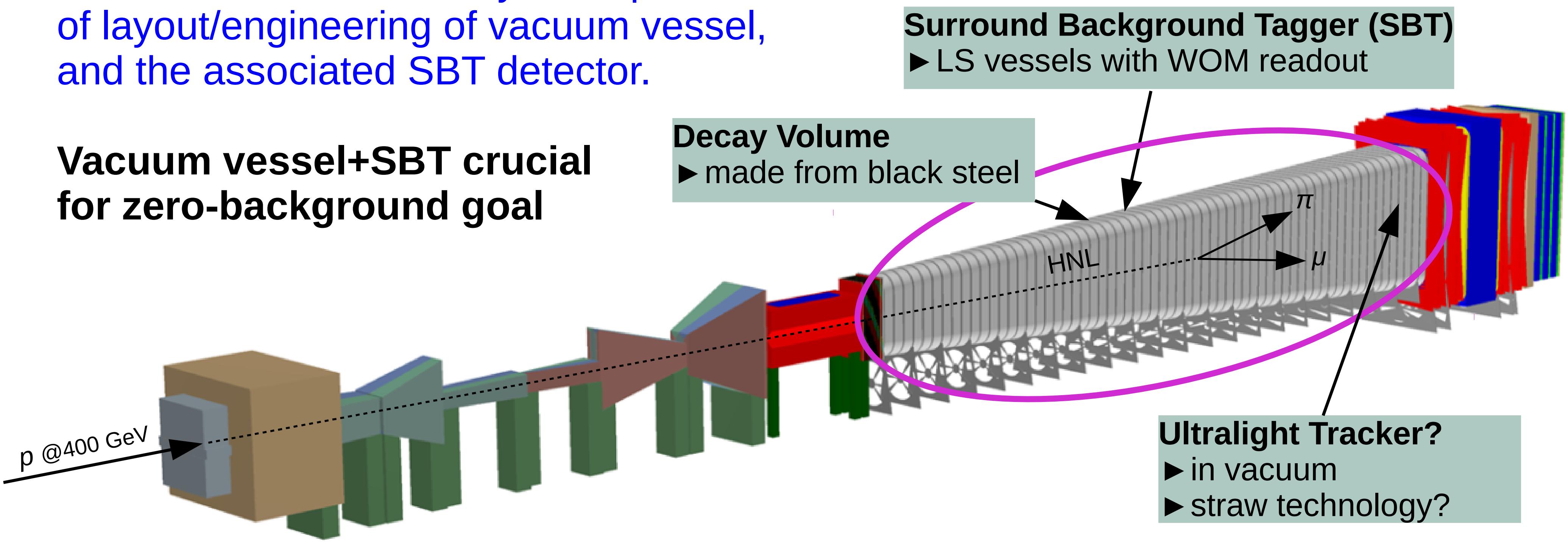


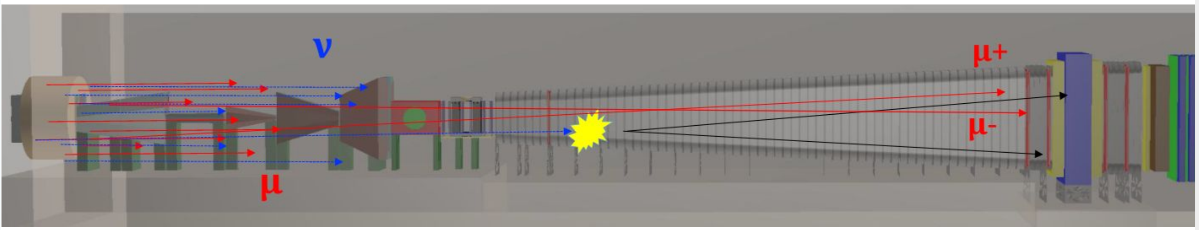
WP1: sub-assembly prototype using baseline technology (grain oriented steel)
WP2: alternative technologies (e.g., SC)
WP3: test beam measurements
WP4: prelim. design of μ-shield adapted to location of BDF

Vacuum Decay Volume

R&D addresses feasibility and optimisation of layout/engineering of vacuum vessel, and the associated SBT detector.

Vacuum vessel+SBT crucial for zero-background goal





WP1: joint optimization/engineering of vacuum vessel + SBT

WP2: optimisation of LS-SBT + prototype

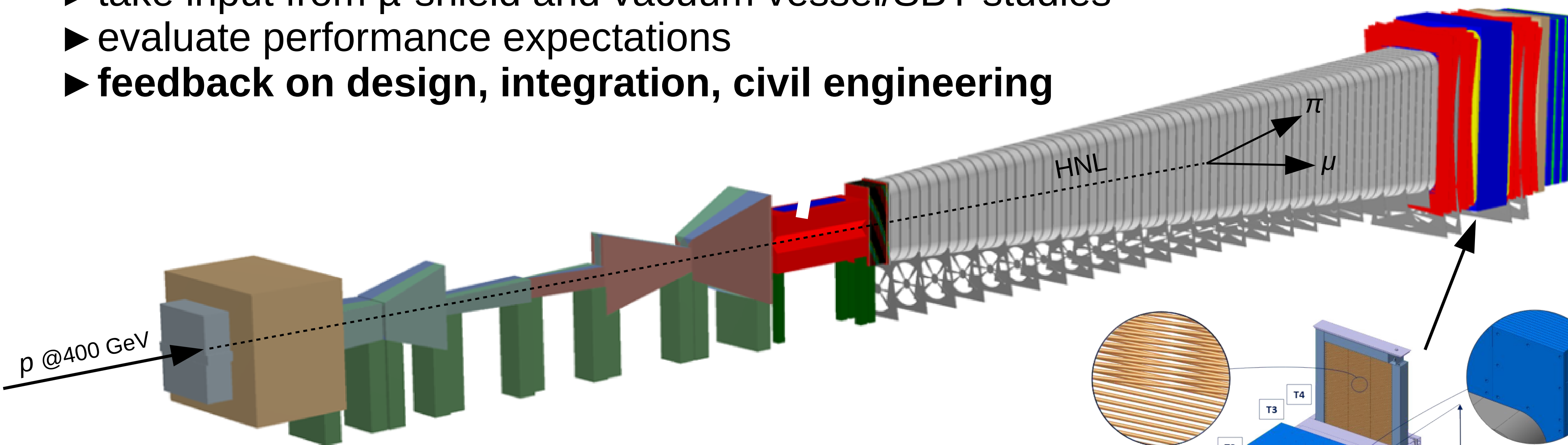
WP3: R&D for ultralight large-acpt tracker

WP4: construction of full-size vessel prototype with front-/endcaps and vacuum capabilities

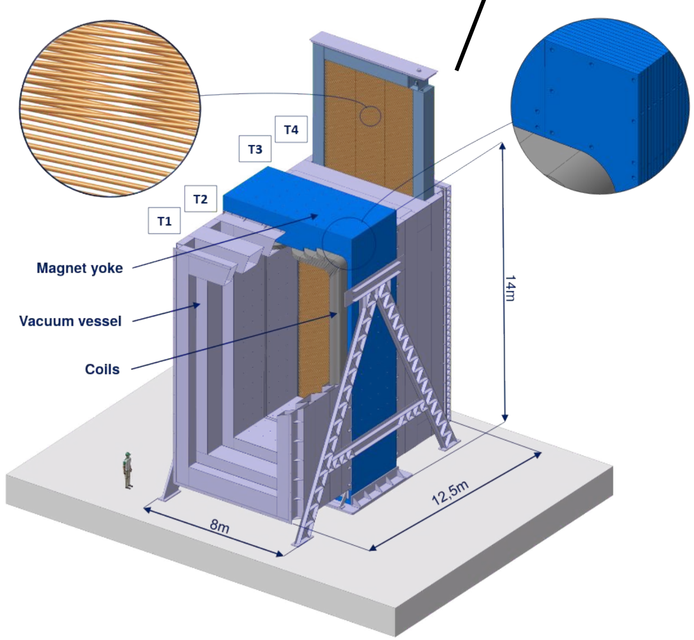
Facility Performance Optimization

R&D addresses overall optimization of BDF experimental configuration and experimental conditions, and the **evaluation of its physics potential**

- ▶ take input from μ-shield and vacuum vessel/SBT studies
- ▶ evaluate performance expectations
- ▶ **feedback on design, integration, civil engineering**

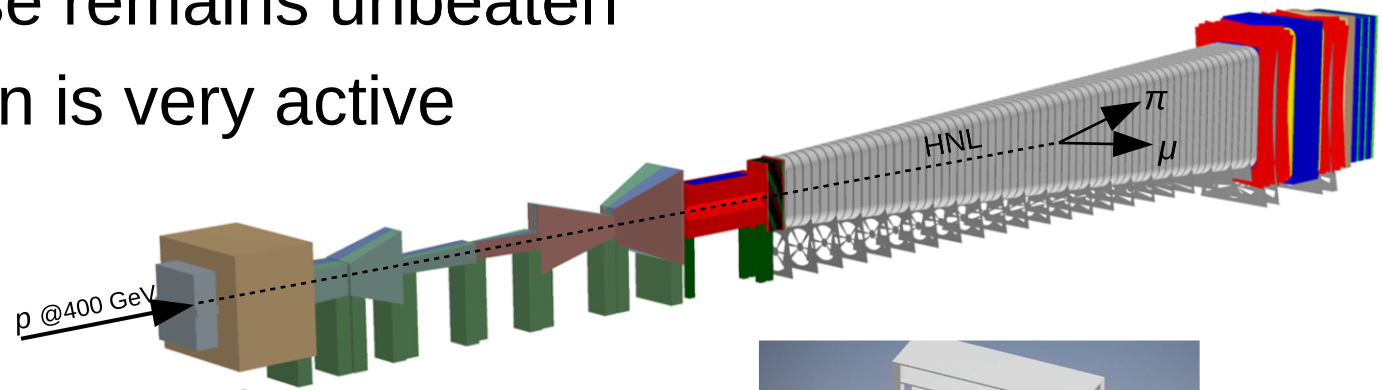


WP1: sensitivity simulations
WP2: physics optimization of μ-shield + vacuum vessel
WP3: detailed background studies
WP4: signal yield studies + new theory ideas
→ ensure competitiveness of BDF

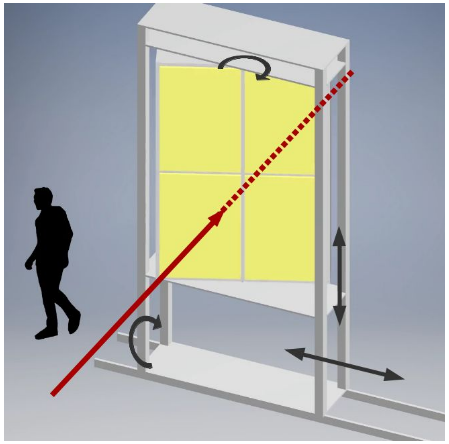


SHiP Summary

- SHiP science case remains unbeaten
- SHiP collaboration is very active



- R&D on BDF in the next 3 years
  ► μ-shield
  ► vacuum decay vessel + SBT
  ► optimization of facility‘s performance
  → *MoU out for signatures*



- Investigation of detector improvement + cost reduction
  ► SND: replace emulsions by electronic Si-trackers
- SND@LHC approved, data in 2022
- New groups are embarking on SHiP