Search for BSM physics at the Beam Dump Facility (BDF) at CERN: SHiP and TauFV

Andrey Golutvin (Imperial College London / NUST-MISiS)

Standard Model is great but it is not a complete theory

Experimental facts of BSM physics

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

Theoretical shortcomings

Gap between Fermi and Planck scales, Dark Energy, connection to gravity, resolution of the strong CP problem, divergence of the Higgs mass, the pattern of masses and mixings in the quark and lepton sectors, …

No clear guidance at the scale of New Physics

Scale of NP: See-saw generation of neutrino masses

Most elegant way to incorporate non-zero neutrino mass to the SM Lagrangian is given by the see-saw formula:

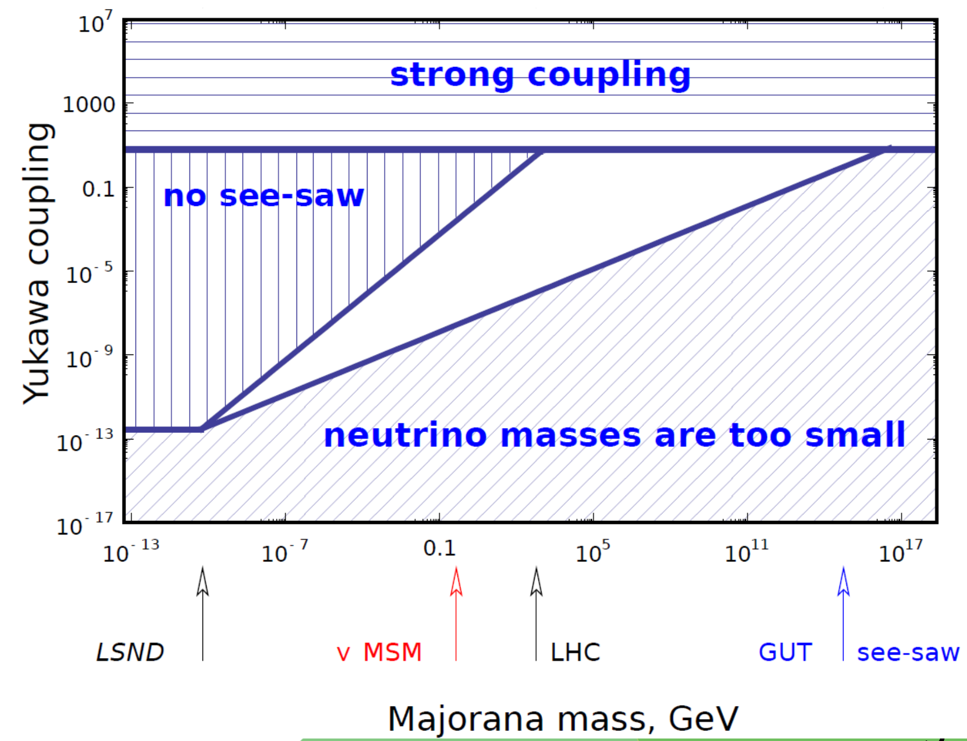
$$m_\nu = \frac{m_D^2}{M}$$

where $m_D \sim Y_{I\alpha} < \phi >$ *- typical value of the Dirac mass term and M is Majorana mass term*

Example:

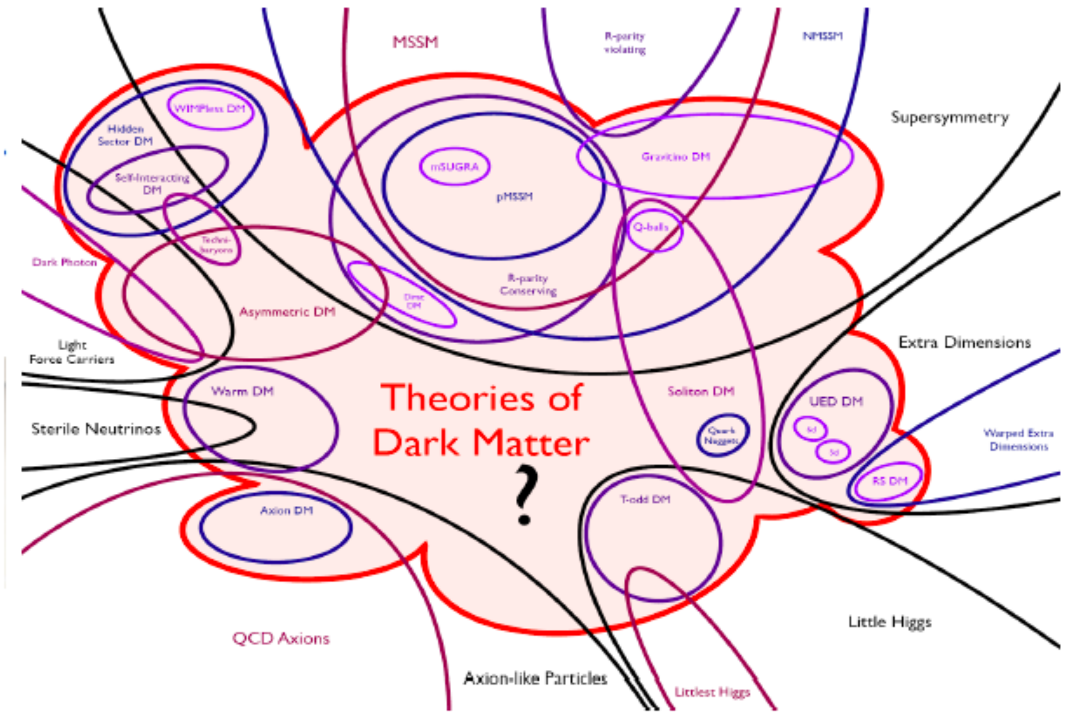
For M ~ 1 GeV and m_ν ~ 0.05 eV it results in m_D ~ 10 keV and Yukawa coupling ~ 10^{-7}

Smallness of the neutrino mass hints either on very large M or very small $Y_{I\alpha}$



Scale of NP: Dark Matter

The energy scale(s) of new physics



T. Tait, DM@LHC '14

The prediction for the mass scale of Dark Matter spans from 10^{-22} eV (ALPs) to 10^{20} GeV (Wimpzillas, Q-balls)

BSM theories with a new energy scale *(which may also contain "light" particles)*

GUT → *(SM particles)* ~ 10^{16} GeV

Composite Higgs → *(Higgs)* ?

Large extra dimensions → *(Branons)* ?

Peccei-Quinn symmetry → *(Axions)* 10^{9}-10^{12} GeV

Models with Hidden Sector → *(Various mediators: dark photons, scalars, ALPs)* ?

So, there is always a good reason to increase the energy (even √s > 14 TeV) and intensity, even if the scale of NP happens to be inaccessible directly. LHC is also one of the best machines at the Intensity Frontier !

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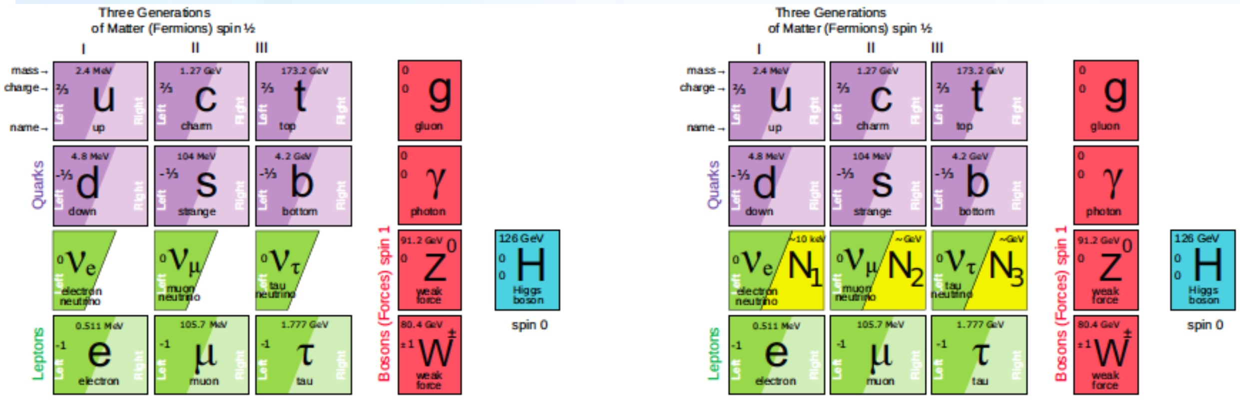
SHiP Search for Hidden Particles

LHCb

BSM theories with no NP between Fermi and Planck scales

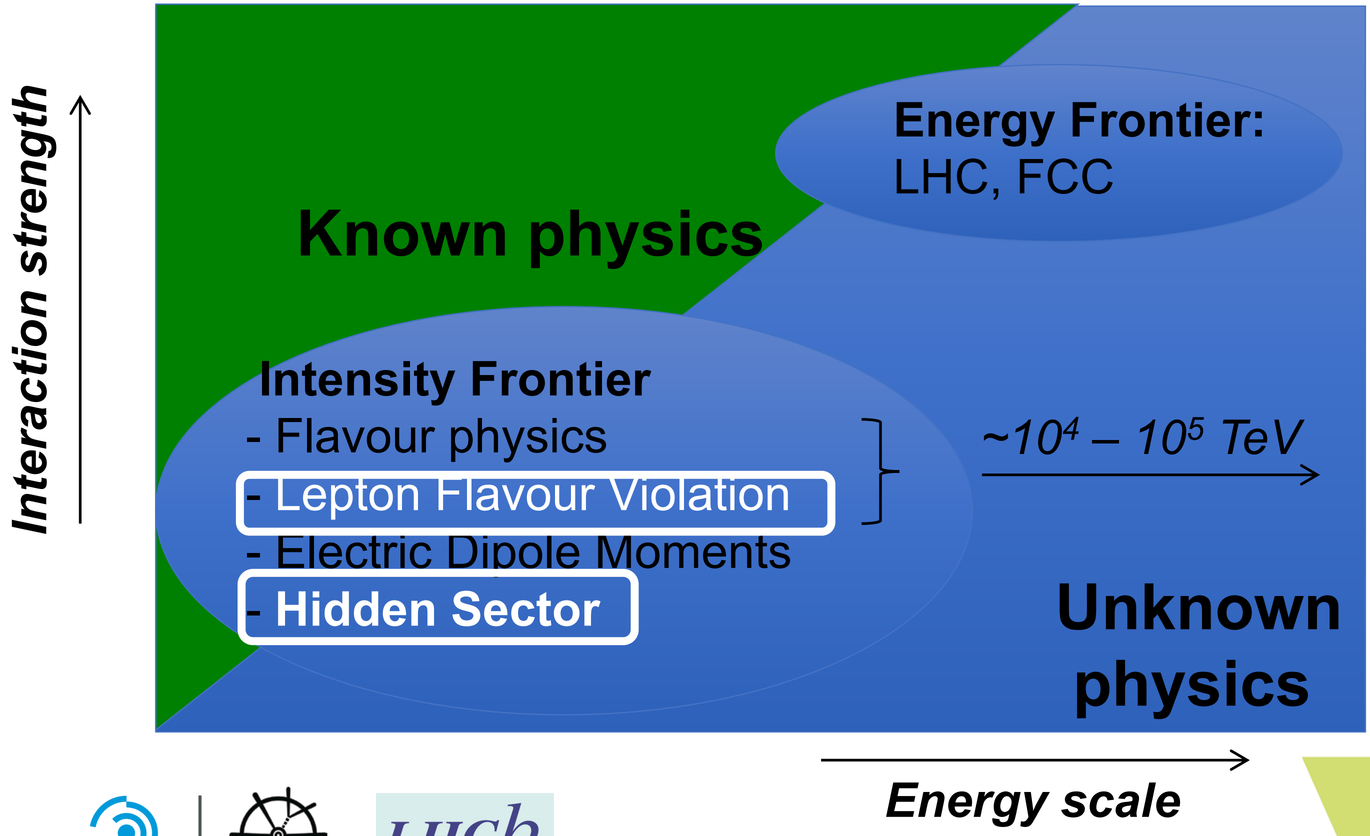


N_1 → Dark Matter
$N_{2,3}$ → Neutrino masses and BAU

νMSM (T.Asaka, M.Shaposhnikov PL B620 (2005) 17) explains all experimental evidences of the BSM physics at once by adding 3 Heavy Neutral Leptons (HNL): N_1, N_2 and N_3

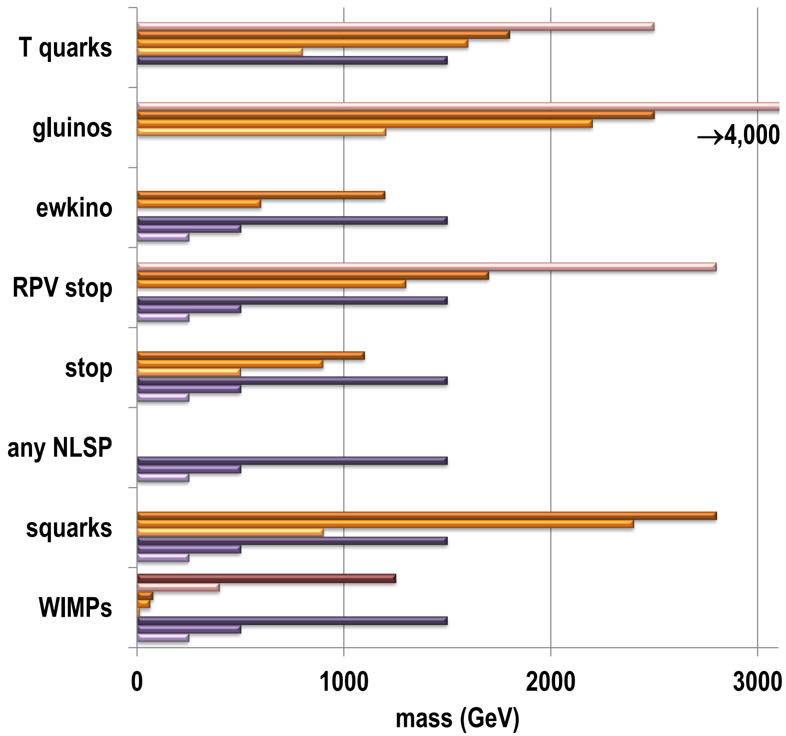
Quest for New Physics

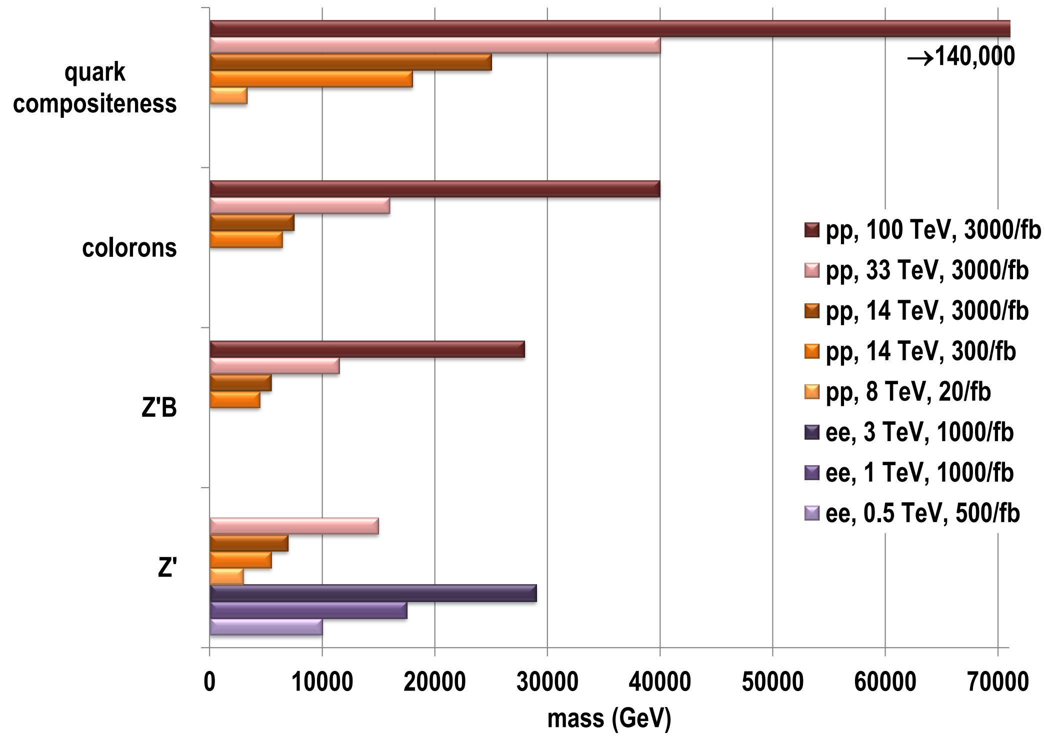
- ✓ *Higgs discovery made the SM complete*
- ✓ *SM s a great theory but does not represent the full picture*
- ✓ *NP should exist but we have no definitive predictions on the masses and coupling constants of NP particles*



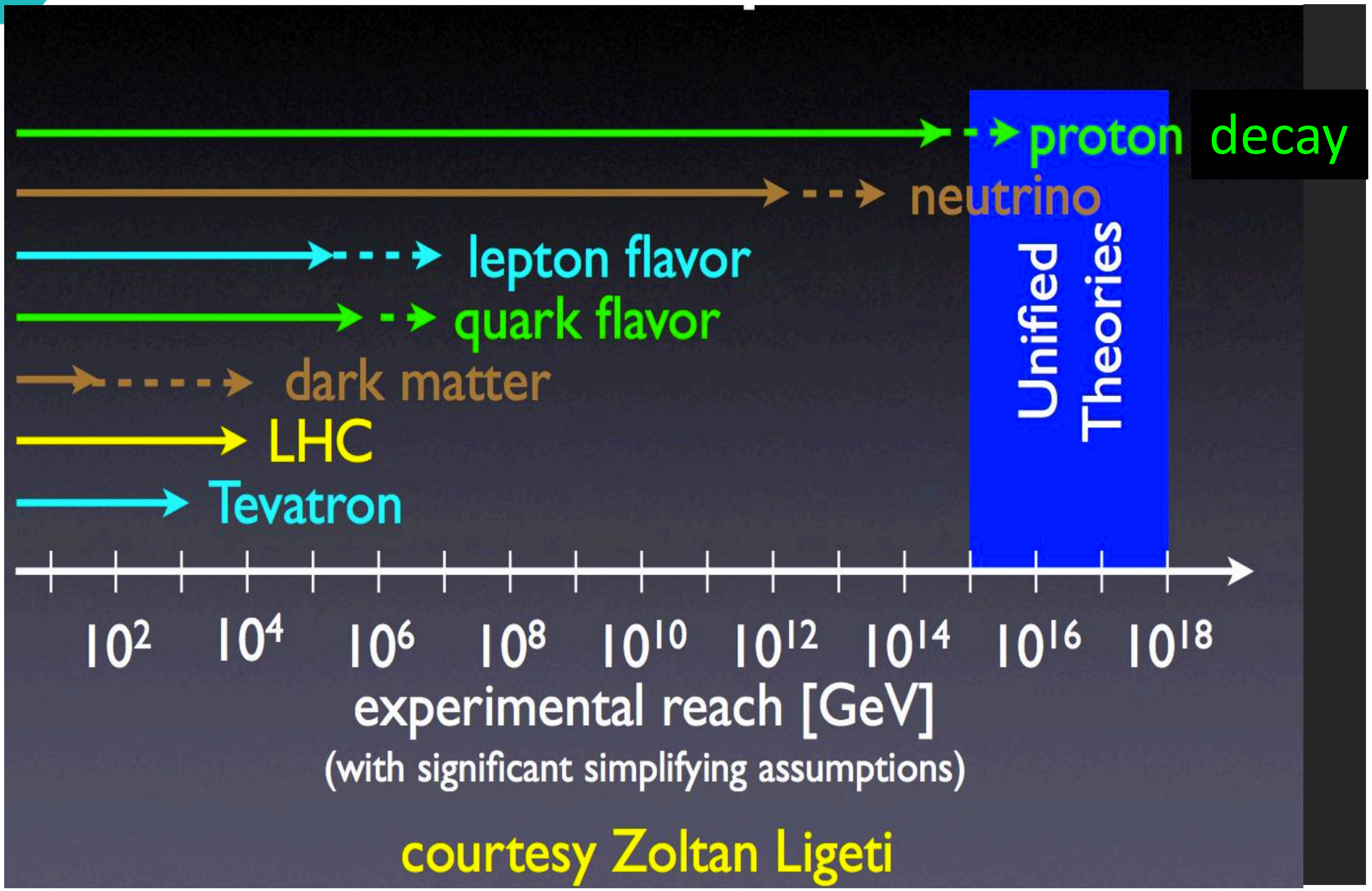
Reach at the Energy Frontier

No sign of New Physics yet





Exploration power of the Intensity Frontier



Hidden Sector

Many theoretical models (portal models) predict new massive light particles which can be tested experimentally

SHiP Physics Paper – Rep.Progr.Phys.79(2016) 124201 (137pp),
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Hidden Particles:

- ✓ ***Light Dark Matter (LDM)***
- ✓ ***Portals (mediators) to Hidden Sector (HS):***
  - *Heavy Neutral Leptons (spin ½, coupling coefficient U^2)*
  - *Dark photons (spin 1, coupling coefficient ε)*
  - *Dark scalars (spin 0, coupling coefficient $\sin\theta^2$)*
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Properties of Hidden Particles

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

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*
- *May decay to various final states*

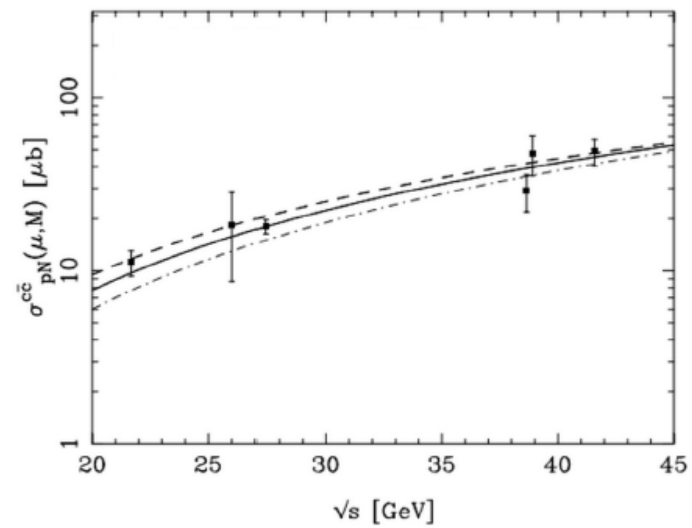
Portal models	Final states
HNL	$l^+\pi^-$, l^+K^-, $l^+\rho^-$
Vector, scalar, axion portals	l^+l^-
HNL	$l^+l^-\nu$
Axion portal	$\gamma\gamma$

Full reconstruction and PID are essential to minimize model dependence

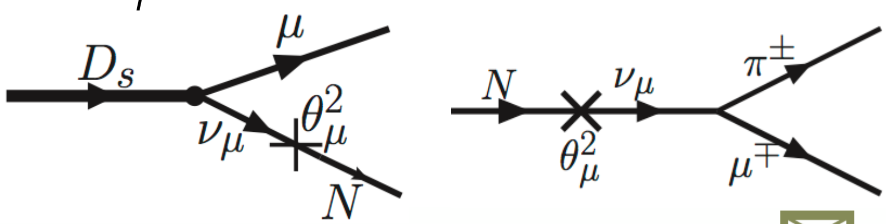
Experimental challenge is background suppression

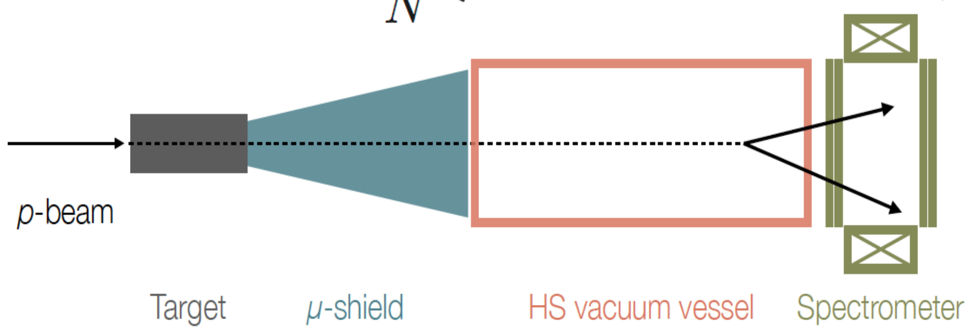
General experimental requirements
to search for decaying Hidden Particles

- ✓ *Particle beam with maximal intensity*
- ✓ *Search for HS particles in Heavy Flavour decays*
  Charm (and beauty) cross-sections strongly depend on the beam energy.
  At CERN SPS: σ(pp→ssbar X)/σ(pp→ X) ~ 0.15
  σ(pp→ccbar X)/σ(pp→ X) ~ $2\ 10^{-3}$
  σ(pp→bbbar X)/σ(pp→ X) ~ $1.6\ 10^{-7}$



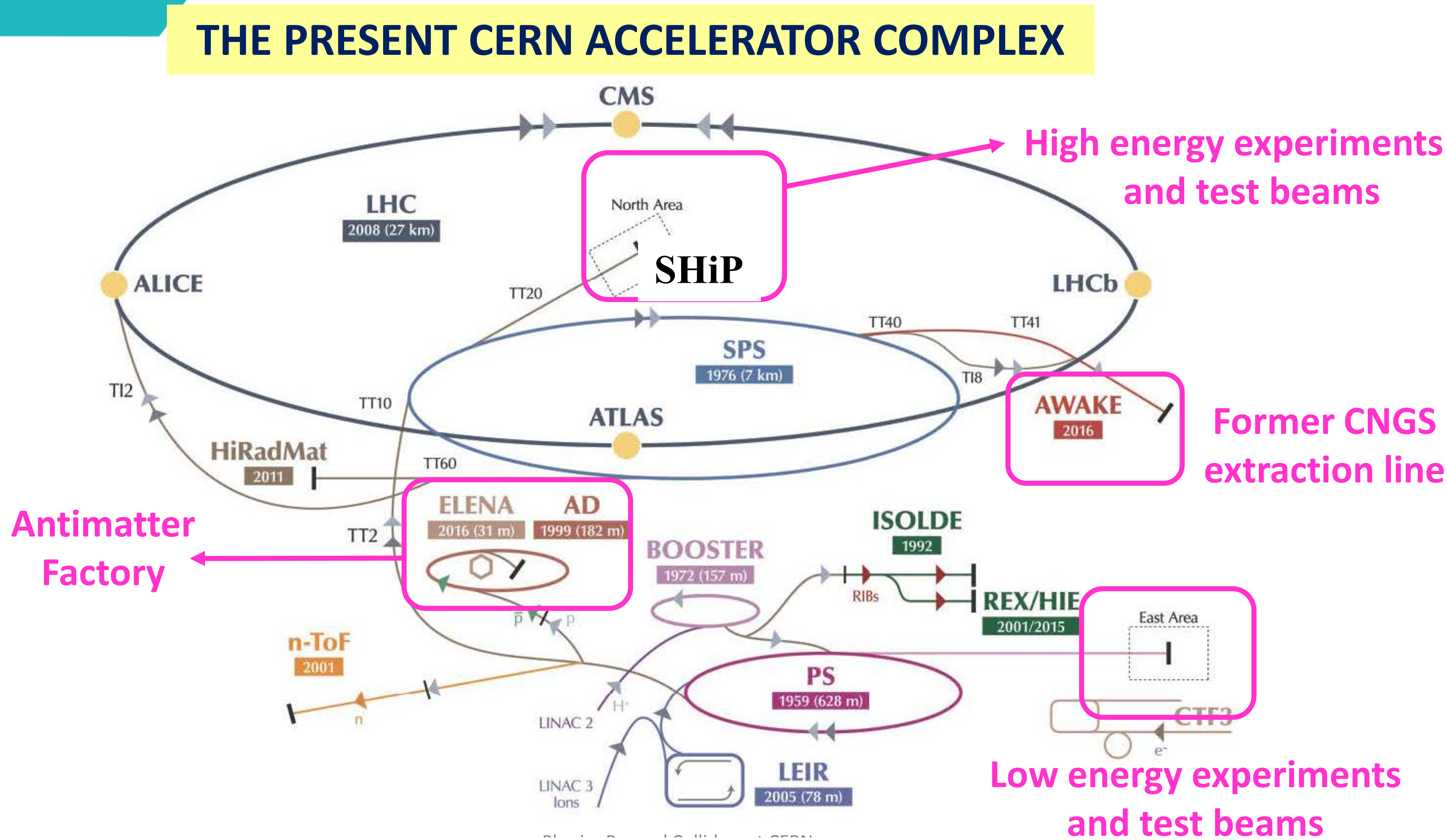
- ✓ *HS produced in charm and beauty decays have significant P_T*





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

The highest intensity can actually be achieved at the LHC's injector: SPS

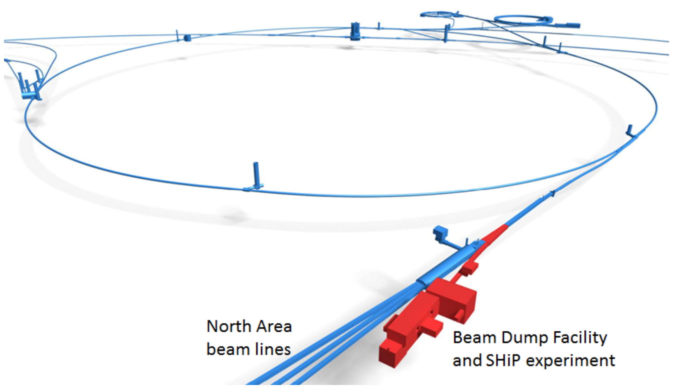


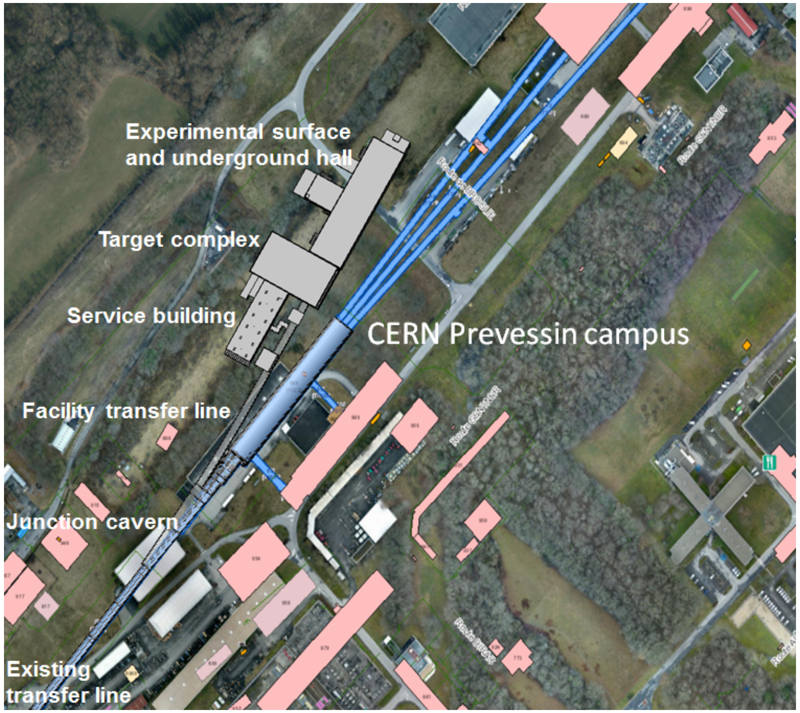
Nominal year of the SPS operation → 200 days with typical machine availability ~80%; 20% of the SPS physics time to run LHC and 80% - to run fix target programme

Beam Dump Facility (BDF) at CERN

✓ Location at CERN

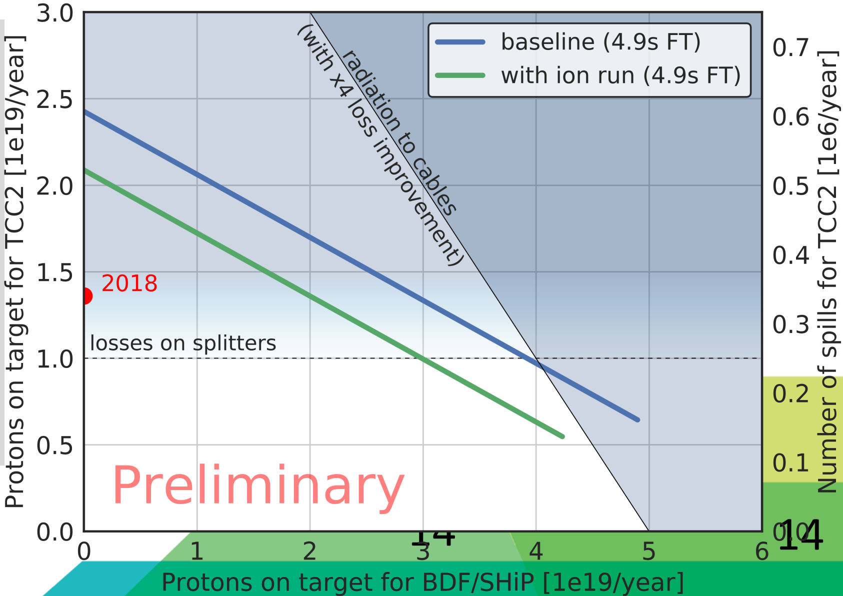
New 400 GeV proton beam line branched off the splitter section of the SPS transfer line to the North Area





✓ Proton yield and beam delivery

- *Nominal beam intensity 4×10^{13} pot per spill*
- *Baseline scenario: annual yield of 4×10^{19} pot to the BDF, and 10^{19} pot to the other experiments in the North Area, while respecting HL-LHC requirements*
- *SHiP sensitivities assume 5×10^{20} pot in five years of nominal operation*



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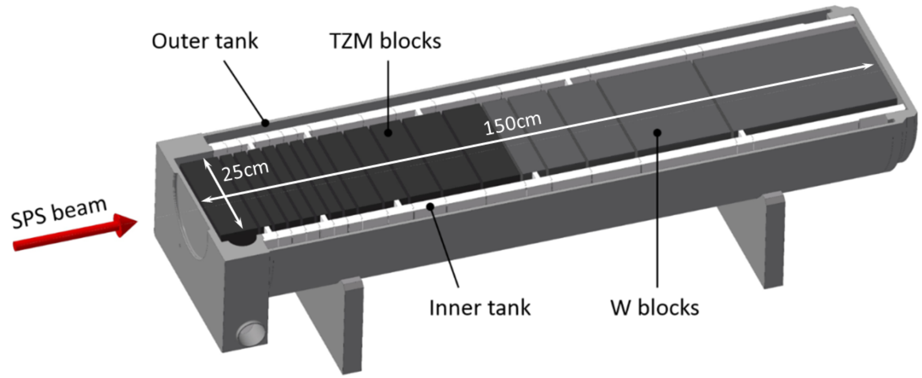
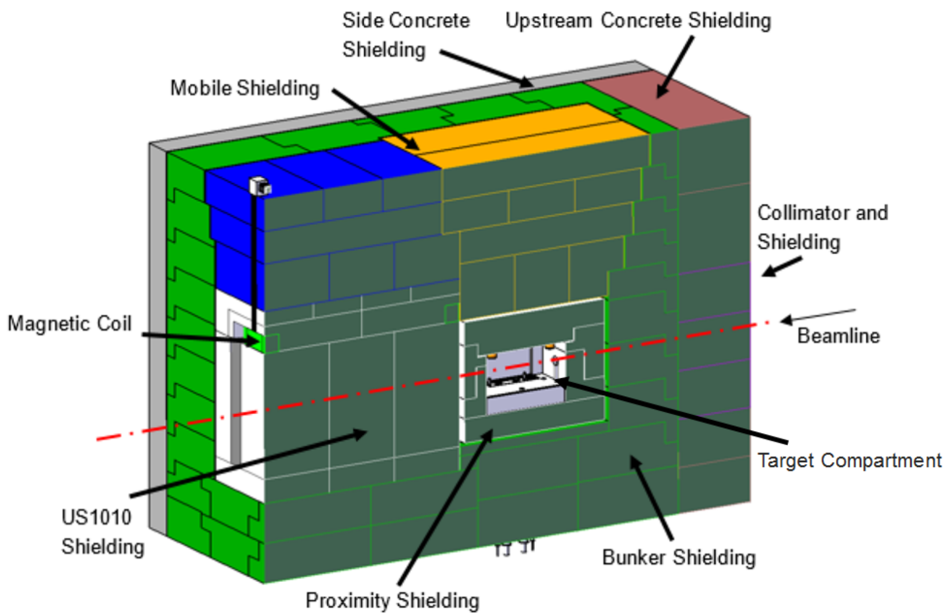
SHiP Search for Hidden Particles

Beam Dump Facility (BDF) at CERN

✓ ***Target***

- *Made of blocks of TZM alloy, in the proton shower core, followed by pure Tungsten*
- *Total depth 12 λ_{int}*
- *Absorbs majority of hadrons before their semileptonic decays*





✓ ***Target complex***

- *Hadron stopper (5 m long) absorbs hadron and em-radiation emerging from the target*
- *Equipped with a coil which magnetises the iron shielding blocks to serve as the first section of the muon shield*

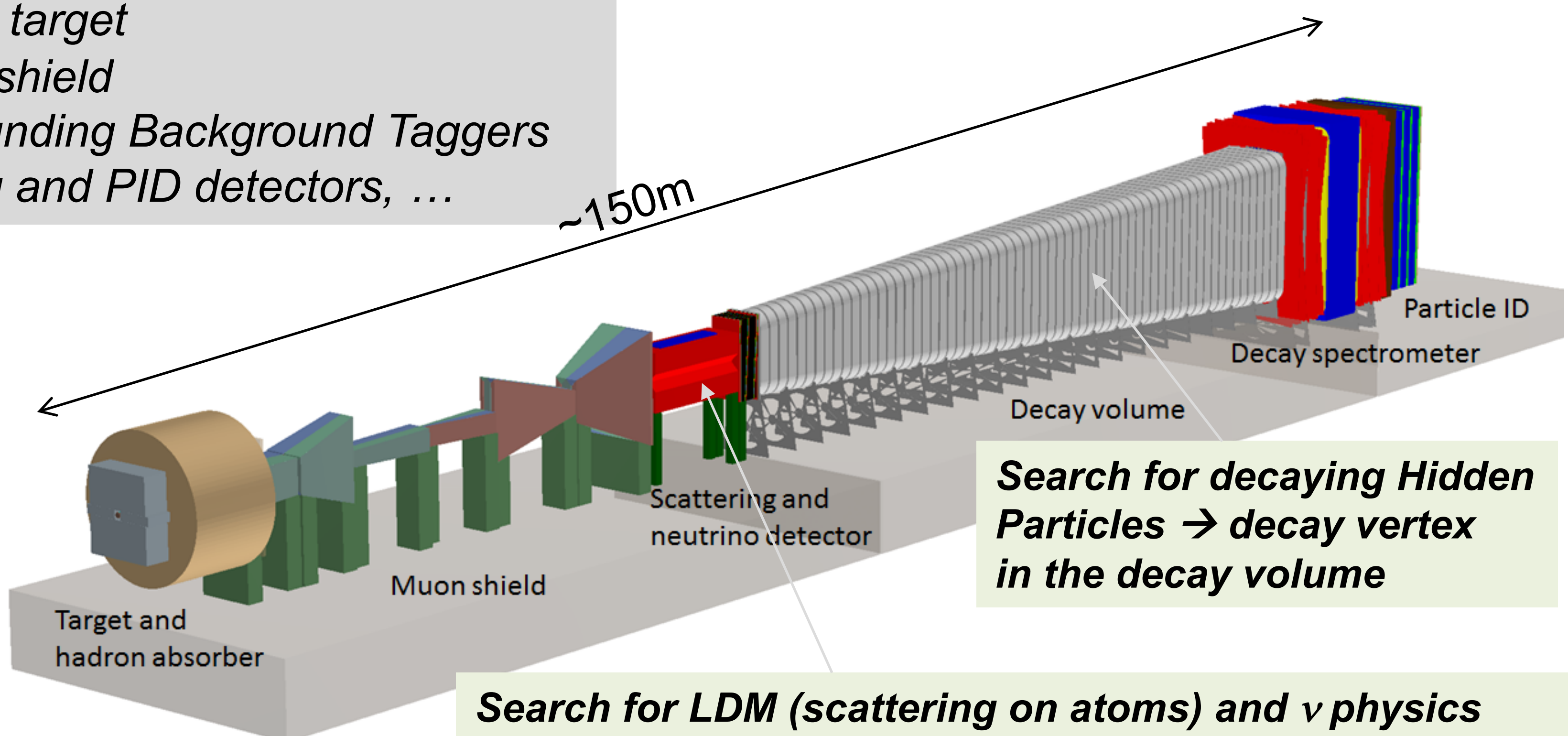
SHiP detector at BDF/CERN

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 Background Taggers*
- *Timing and PID detectors, …*

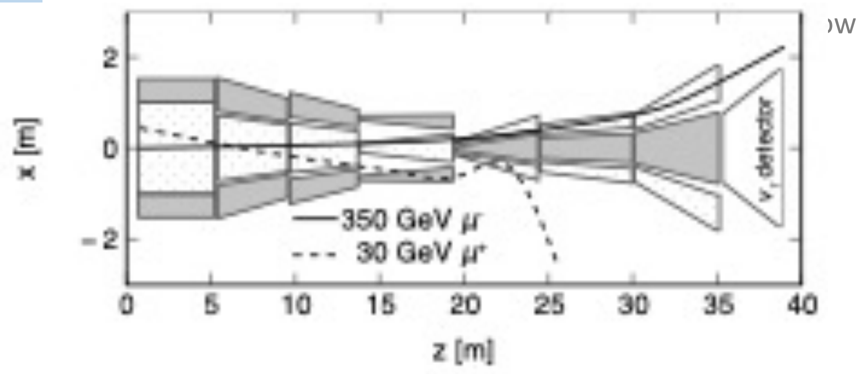


Search for decaying Hidden Particles → decay vertex in the decay volume

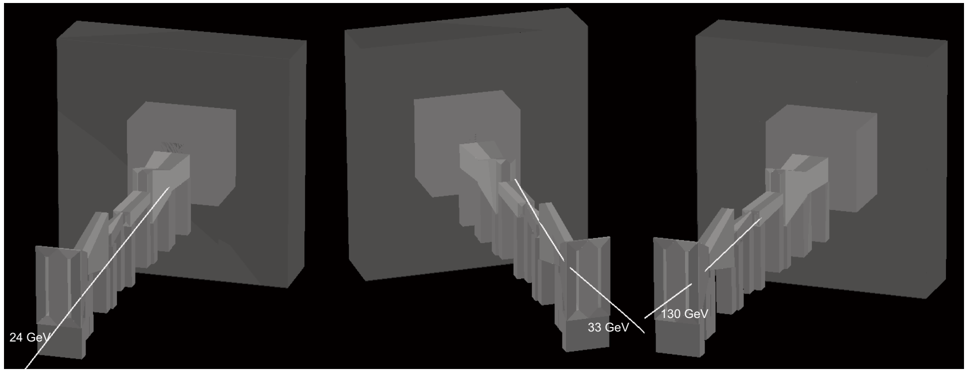
Search for LDM (scattering on atoms) and ν physics Specific event topology in emulsion. Background from neutrino interaction for LDM searches can be reduced to a manageable level

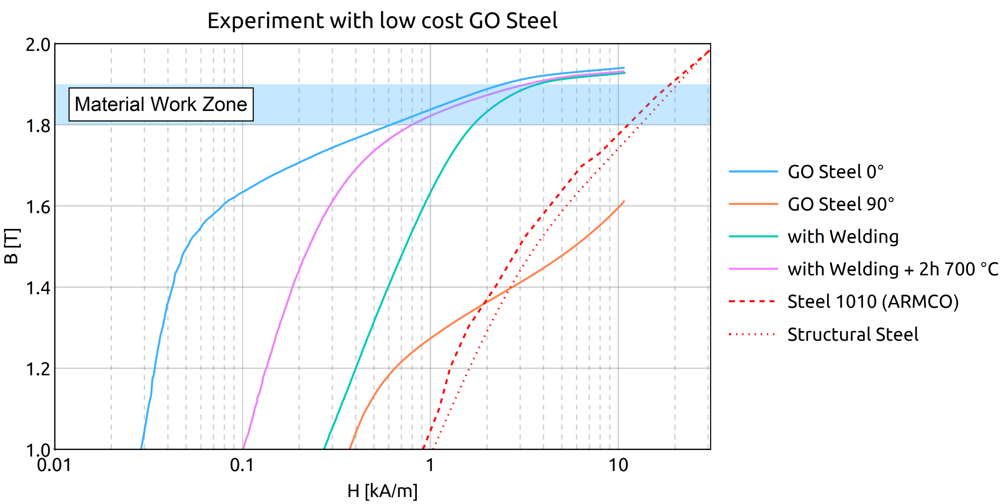
Active Muon Shield

- ✓ *Shield is entirely based on magnetic sweeping*
- ✓ *Initial muon flux ~10^{11} muons / sec*
- ✓ *Residual flux ~50 kHz → negligible occupancy!*

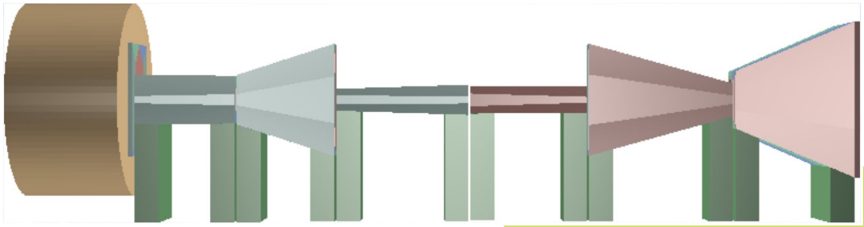


***Huge object:** 5m high, 40m long, Weight ~2000 tons, made of 300 mkm thick sheets of GO steel to achieve 1.8 T field*





Shape optimised using Machine Learning technique



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Decaying Hidden Particles

- ***Neutrino portal***
  LFV final states → HNL signal can easily be discriminated against other portals

- ***Vector portal***
- ***Scalar portal***
- ***ALP***

Note:
Identical final states with charged particles
(but different BRs of decay channels
and different kinematics of decay products)
→ Need significant statistics to discriminate between portals

ALPs can decay to the 2-photon final state with sizeable BR
→ Electromagnetic calorimeter is essential to distinguish between ALP signal and dark photon, or dark scalar

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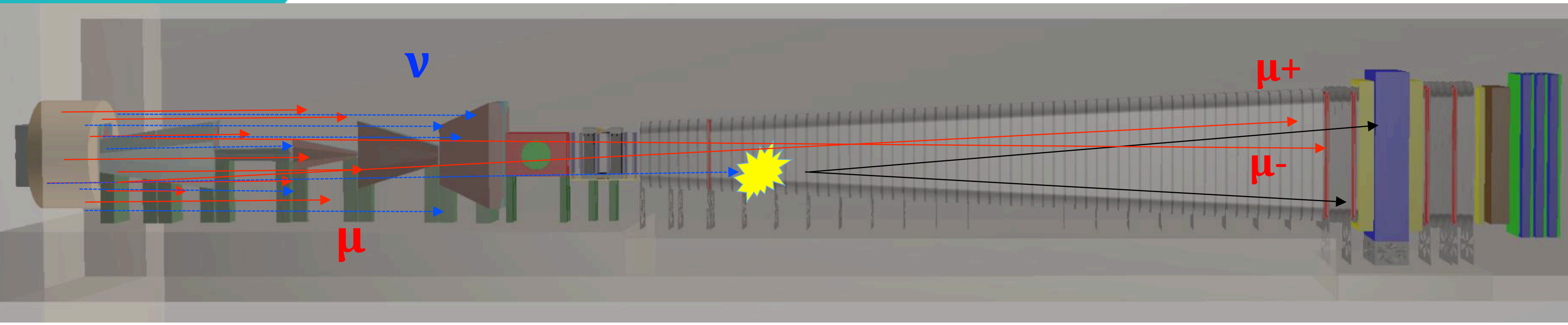
Event selection for decaying Hidden Particles

- ✓ *Event selection is based on very high signal efficiency and redundant background suppression*
- ✓ ***Common selection to ensure model independent search***
- ✓ ***All HS models require an isolated vertex in the decay volume***

Cut	Value
Track momentum	> 1.0 GeV/c
Dimuon distance of closest approach	< 1 cm
dimuon vertex	fiducial (> 5 cm from inner wall)
IP w.r.t target (fully reco)	< 10 cm
IP w.r.t target (partially reco)	< 250 cm

- ✓ ***Redundancy cuts:***
  - *- Veto criteria from the taggers*
  - *- PID cuts*
  - *- Time coincidence cut (to reject combinatorial background)*

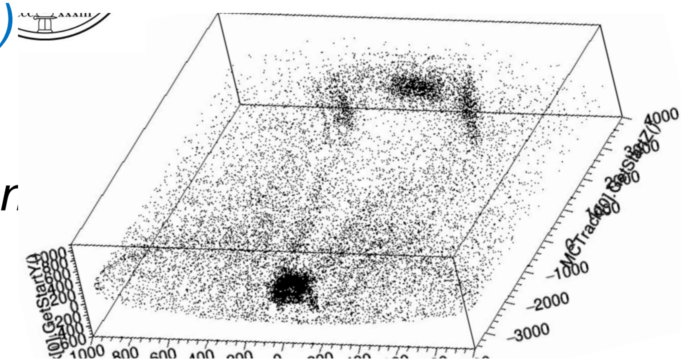
Backgrounds



Three main classes of background:

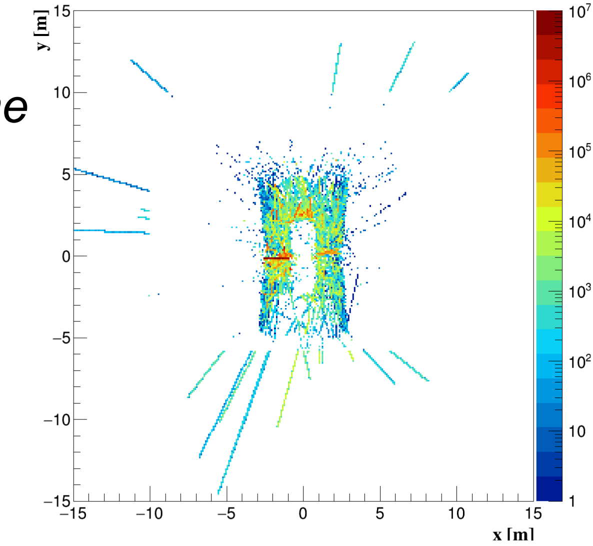
- ***Neutrino induced***] *interactions in the SND and the walls of decay volume*
- ***Muon inelastic***] *and surrounding infrastructure*
- ***Combinatorial muon*** *from muons survived the muon shield and entered the decay volume*

1. Neutrino induced *(10 years of SHiP by the FairShip)*



- *dominated by interactions in the SND and walls of the decay volume*
- *Only 2 events (from γ-conversions) survived selection, rejected by the cut on the opening angle*
- *Simulation is ongoing to increase the background data sample by an order of magnitude*

Backgrounds



2. **Muon inelastic** *(5 years of SHiP by the FairShip)*
   - *Dominated by interactions in the walls of the decay volume*
   - *Zero background after selection + veto in the taggers*
   - *Assuming no correlation between the veto and selection cuts → $< 6\times10^{-4}$ @ 90%CL*

3. **Muon combinatorial** *(1 spill of SHiP by the FairShip)*
   - *Estimated using fully reconstructed muons which pass the muon shield and enter the detector acceptance*
   - *Assume no correlation between selection, veto and timing cuts. Requirement to be in a time window of 3σ time resolution (100 ps) gives large extra suppression factor*
   - *Machine Learning technique is currently being used to generate very large sample of "dangerous" muons*

Background summary

Background source	Expected events
Neutrino background	< 1
Muon DIS (factorization)	< 0.0006
Muon Combinatorial	4.2×10^{-2}

@ 90% CL

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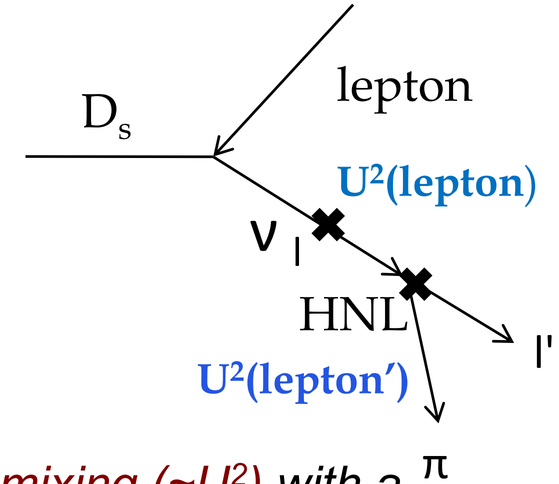
Neutrino portal

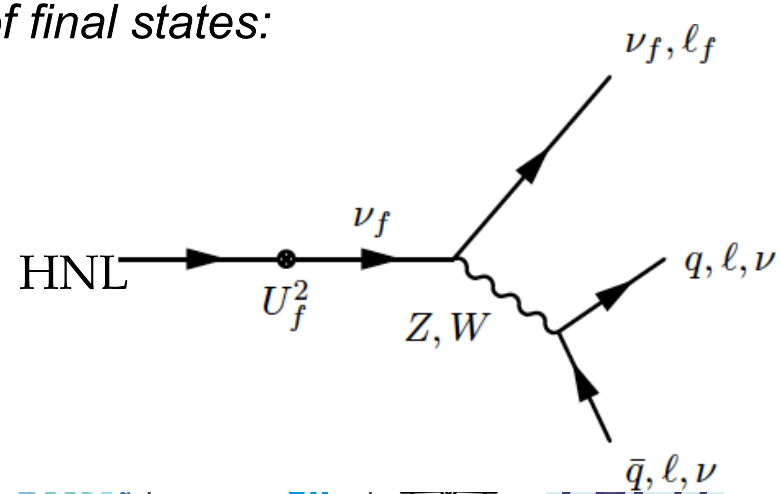
HNLs can be produced in decays of heavy flavours to ordinary neutrinos through kinetic mixing, ~U^2:

Production channels

- $D \to K \ell N$
- $D_s \to \ell N$
- $D_s \to \tau \nu_\tau$ followed by $\tau \to \mu \nu N$ or $\tau \to \pi N$
- $B \to \ell N$
- $B \to D \ell N$
- $B_s \to D_s \ell N$
- $B_c \to lN$ *(b-c transition)*



Then HNLs decay again to SM particles through mixing (~U^2) with a SM neutrino. This (now massive) neutrino can decay to a large amount of final states:



Decay channels

$N \to H^0 \nu$, with $H^0 = \pi^0, \rho^0, \eta, \eta'$

$N \to H^\pm \ell^\mp$, with $H = \pi, \rho$

$N \to 3\nu$

$N \to \ell_i^\pm \ell_j^\mp \nu_j$

$N \to \nu_i \ell_j^\pm \ell_j^\mp$

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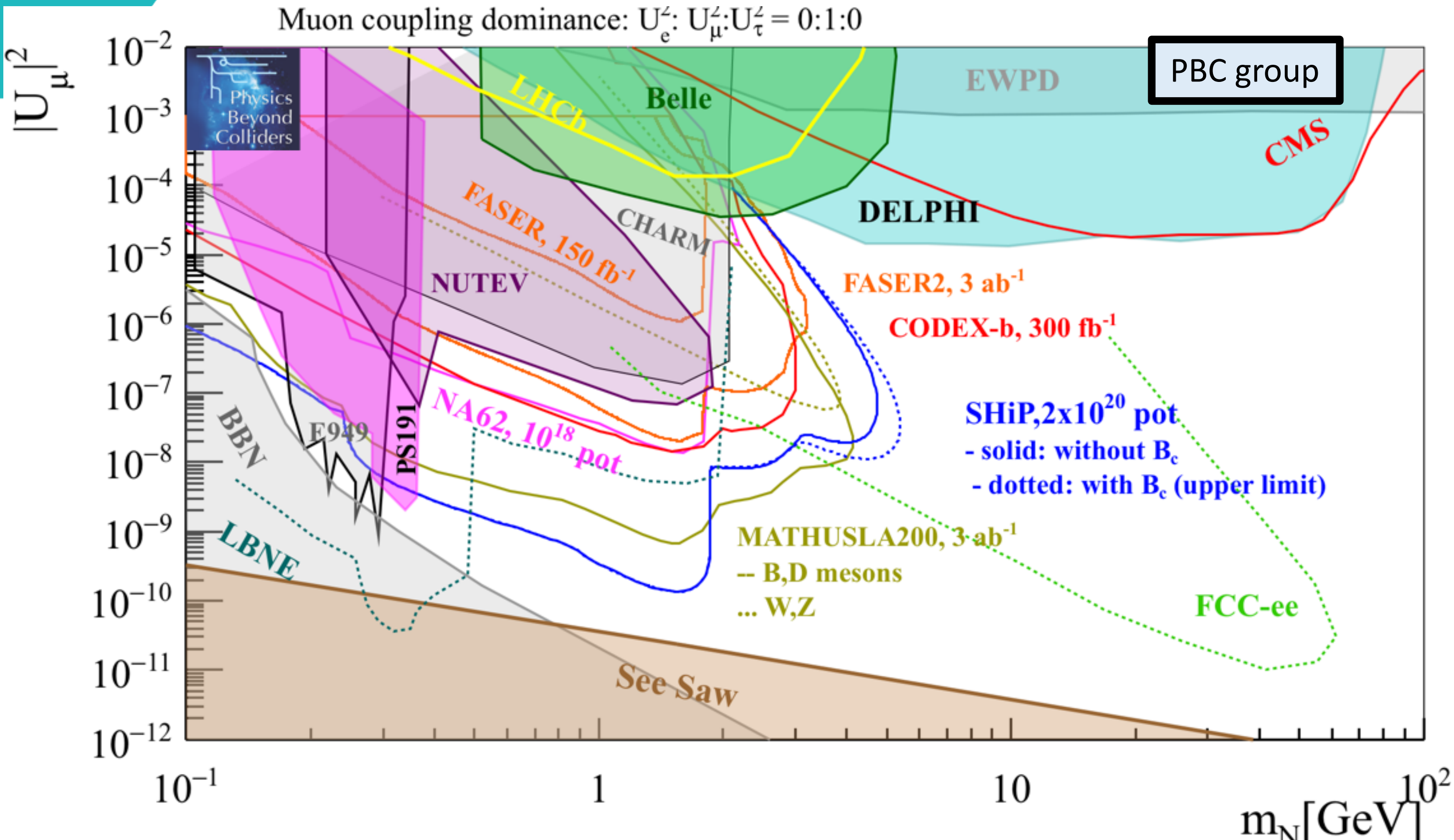
HNL sensitivities (νMSM)



- ✓ $M_{HNL} < M_b$ LHCb, Belle2 ***SHiP will have much better sensitivity***
- ✓ $M_b < M_{HNL} < M_Z$ ***FCC in e^+e^- mode*** *(improvements are also expected from ATLAS / CMS)*
- ✓ $M_{HNL} > M_Z$ ***Prerogative of ATLAS/CMS @ HL LHC***

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

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Vector portal

Production:

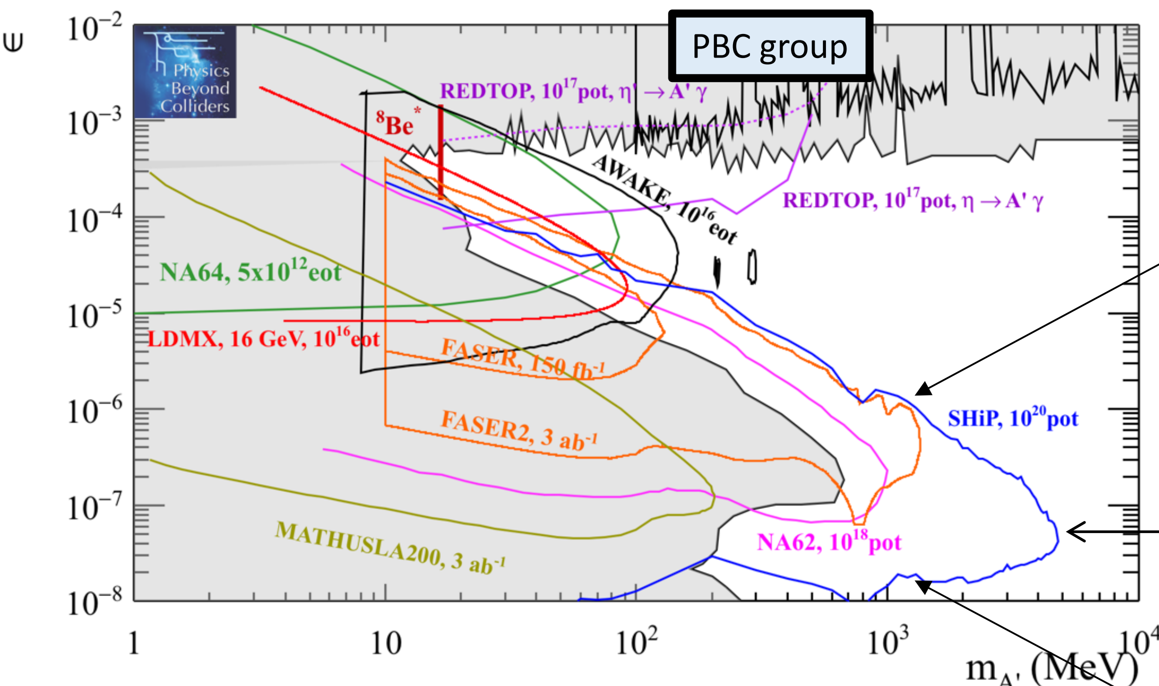
- Meson decays, e.g. $\pi^0 \rightarrow \gamma V (\sim\varepsilon^2)$
- p bremsstrahlung on target nuclei, $pp \rightarrow ppV$
- largest M_V in direct QCD production $qg \rightarrow V$

Decay: into a pair of SM particles: e^+e^-, $\mu^+\mu^-$, $\pi^+\pi^+$, KK, $\eta\eta$, $\tau\tau$, DD, …

A lot of experimental results expected in coming years

EM showers are not taken into account as a source of dark photons

→ Expect significant improvement of sensitivity at low $m_{A'}$



Decay before reaching detector $N \sim \exp(-\epsilon^2 m^2/p)$

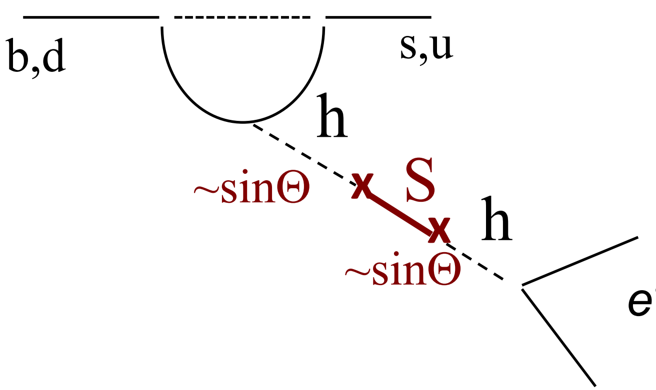
Kinematic limit

Lifetime too large: $N \approx (\epsilon)^4$

SHiP is unique up to O(10GeV) and $\varepsilon \sim 10^{-8}$

Scalar portal

Dark Scalar particles can couple to the Higgs in FCNC transition in K and B decays:

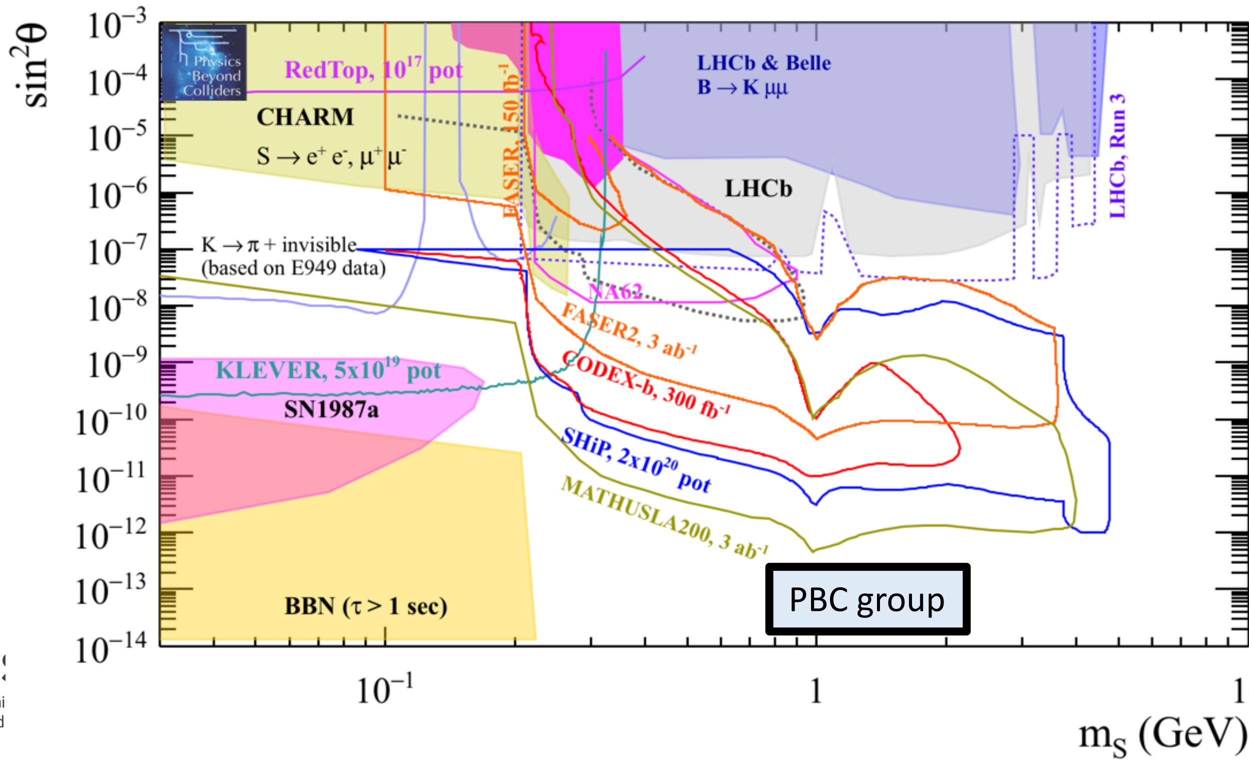


$$\Gamma(K \to \pi\phi) \sim (m_t^2 |V_{ts}^* V_{td}|)^2 \propto m_t^4 \lambda^5$$

$$\Gamma(D \to \pi\phi) \sim (m_b^2 |V_{cb}^* V_{ub}|)^2 \propto m_b^4 \lambda^5$$

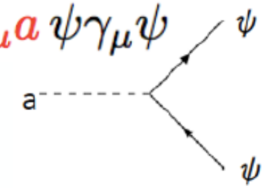
$$\Gamma(B \to K\phi) \sim (m_t^2 |V_{ts}^* V_{tb}|)^2 \propto m_t^4 \lambda^2$$

e^+e^-, $\mu^+\mu^-$, $\pi^+\pi^-$, K^+K^- …

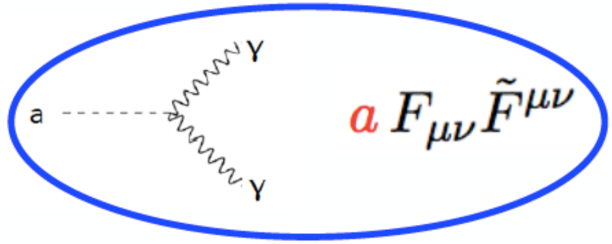


ALPs

ALPs can couple to fermions $\partial_\mu a\, \bar\psi \gamma_\mu \psi$



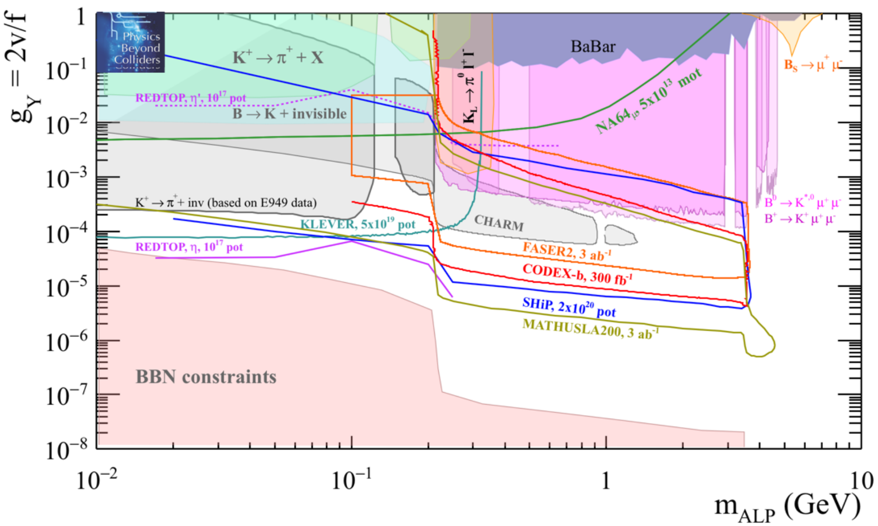
and to photons

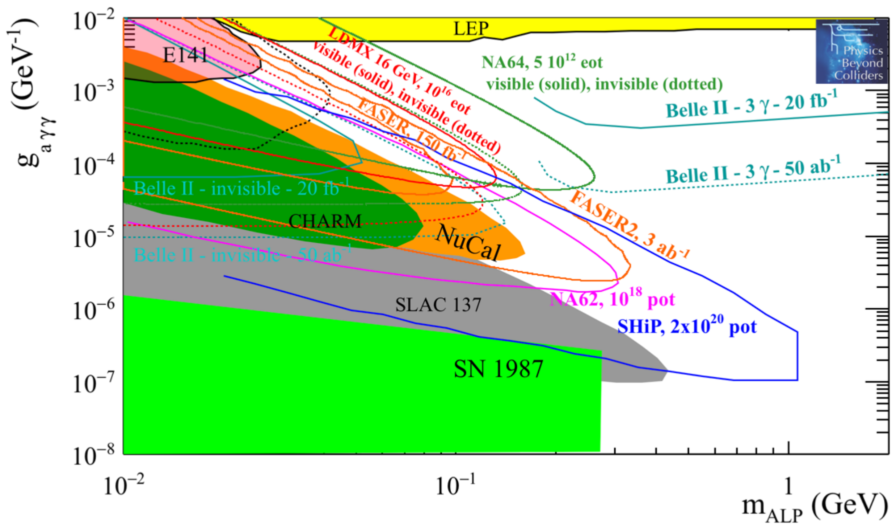


$a\, F_{\mu\nu}\tilde{F}^{\mu\nu}$

Two photon final state necessitates electromagnetic calorimeter with a capability to determine directions of the photons in order to reconstruct the decay vertex of ALP → $\gamma\gamma$

*→ **Additional experimental challenge !** (compared to vector and scalar portals)*

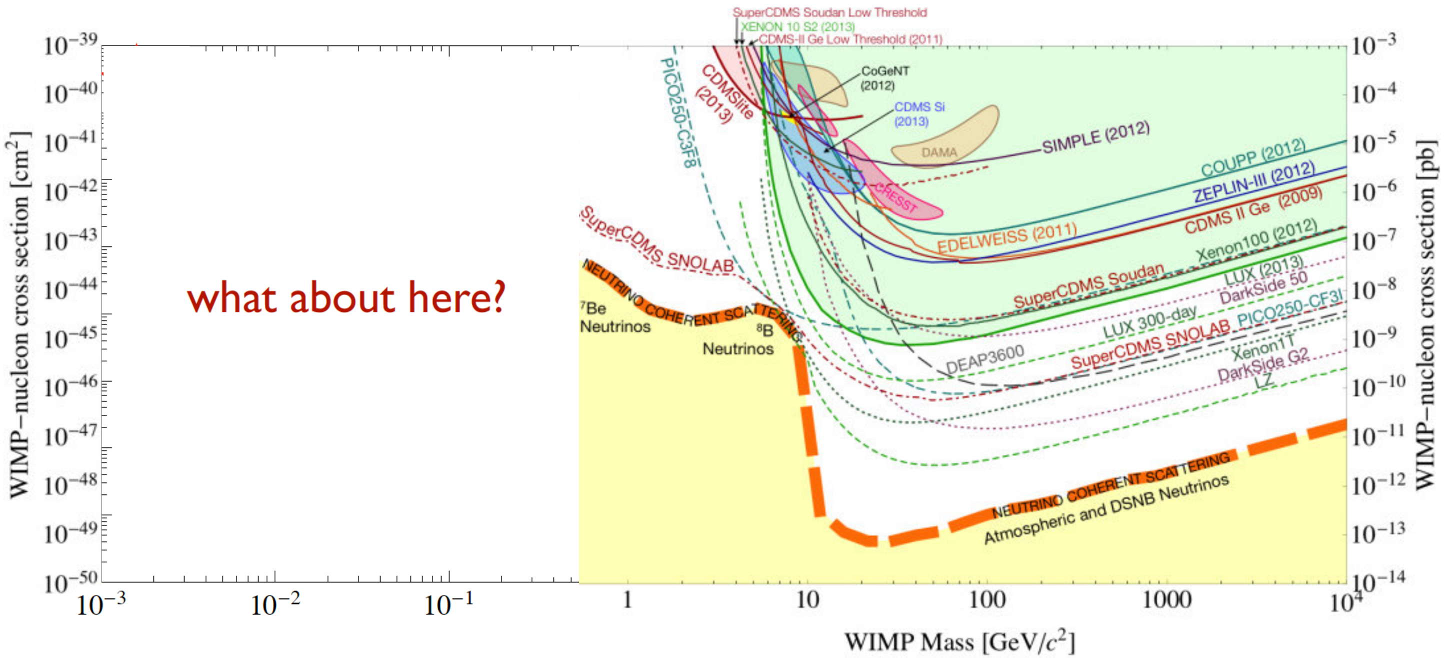




Observation of vWIMP in $\gamma\gamma$–final state is a strong discrimination of the ALP signal against dark vector and dark scalar

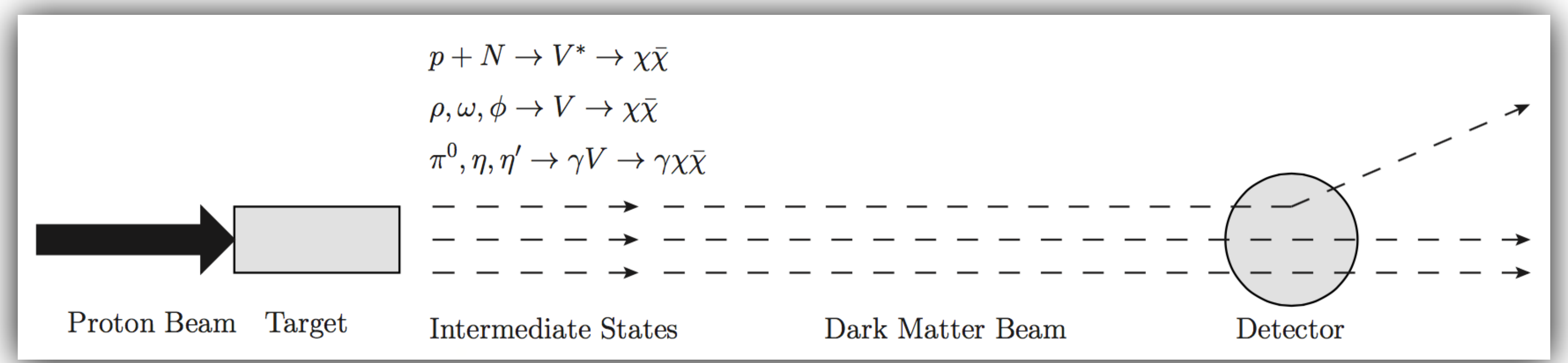
Light dark matter search

- The prediction for the mass scale of Dark Matter spans from 10^{-22} to 10^{20} GeV
- Extensive experimental search for WIMP with masses 10 GeV/c^2 -1 TeV/c^2



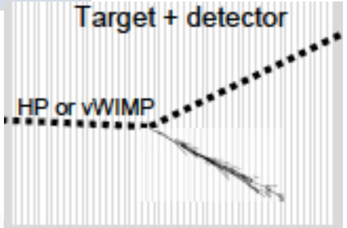
- **Essential to explore sub-GeV mass range for Dark Matter**
- **High luminosity fixed target experiments can play an important role**

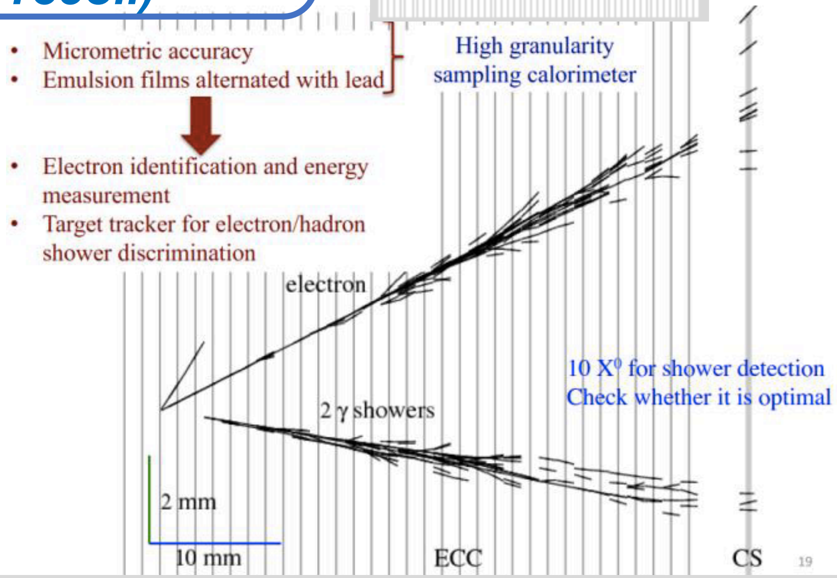
Basic idea: use the neutrino detector as a dark matter detector, looking for recoil, but now from a **relativistic beam**



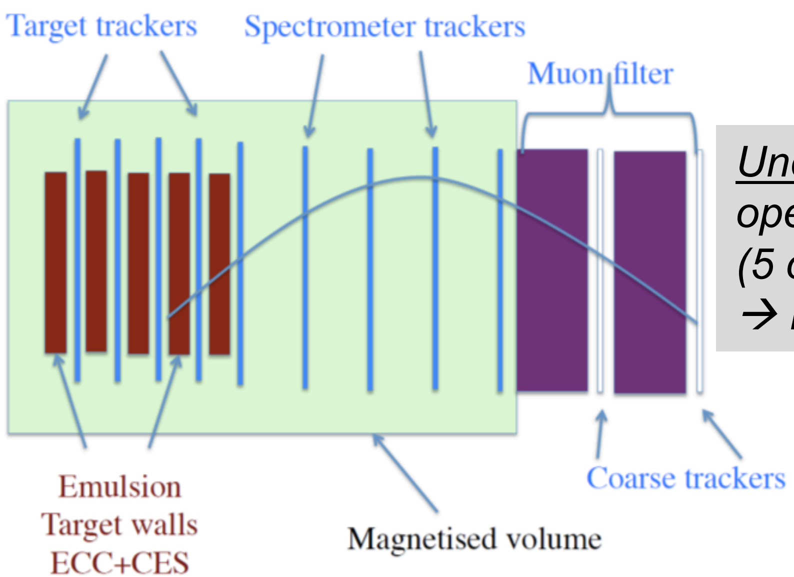
Search for Light Dark Matter

LDM can scatter on atoms of the dense material of the SHiP Scattering and Neutrino Detector (SND)
→ detection signature: EM shower (or nuclei recoil)

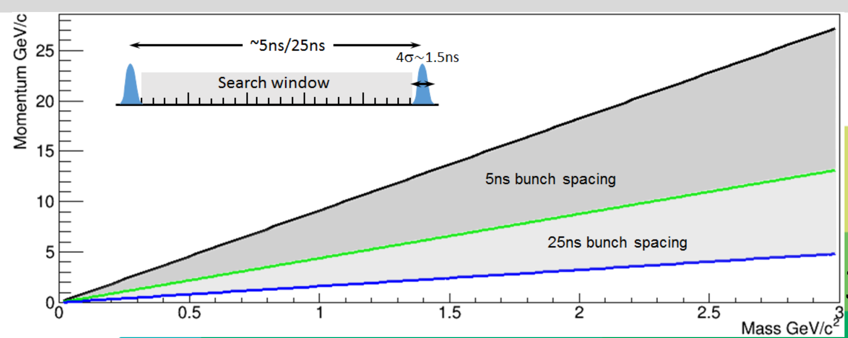




- *Reconstruction of the EM showers in emulsion demonstrated with OPERA data*
- *Complement emulsion detector with fast electronic Target Tracker to improve electron reconstruction*

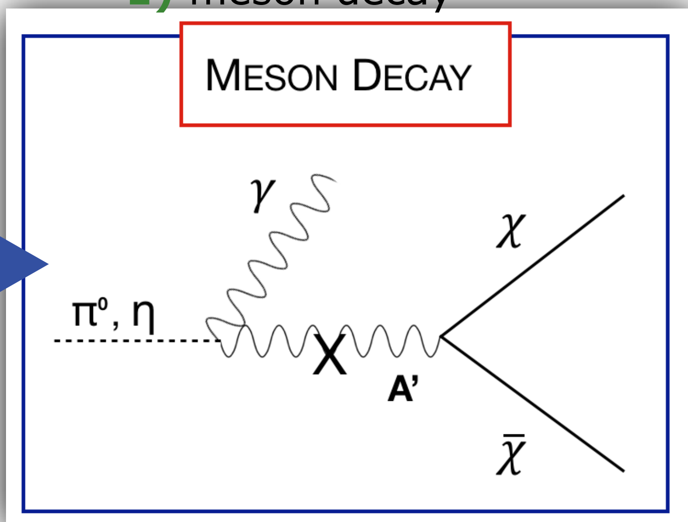


Under study: Elimination of the neutrino background by ToF operating with the SPS bunched beam: 4σ /spacing = 1.5ns / (5 or 25ns) & ~40 m distance from the target
→ Requires 0.5 ns time resolution of the Target Tracker

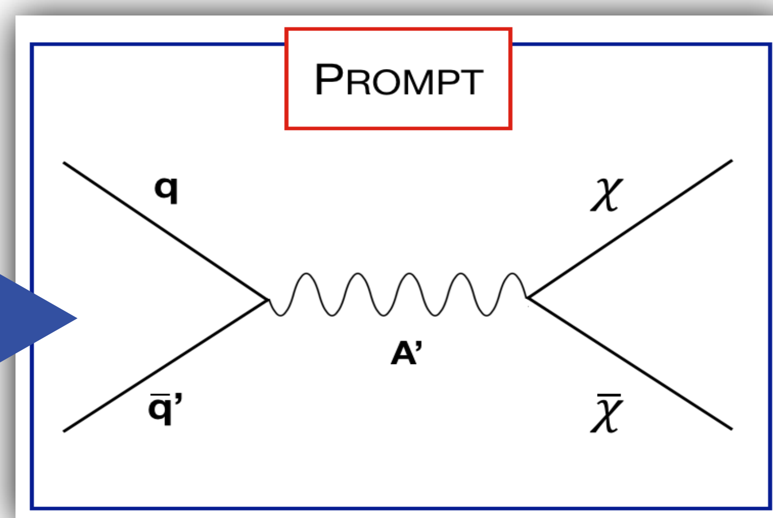


LDM production @SHiP

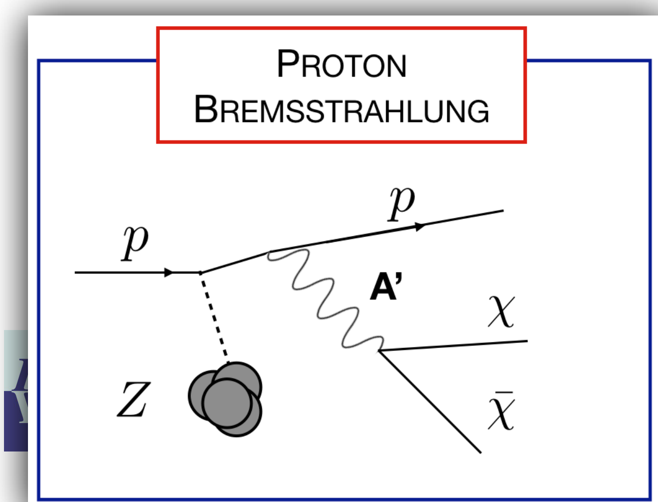
1) meson decay



2) prompt QCD



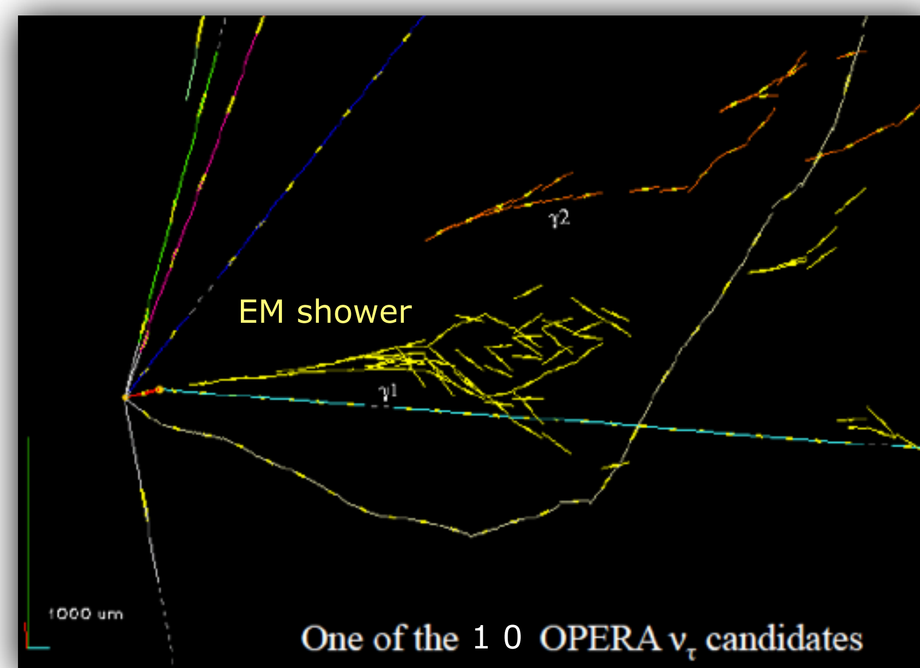
3) proton bremsstrahlung



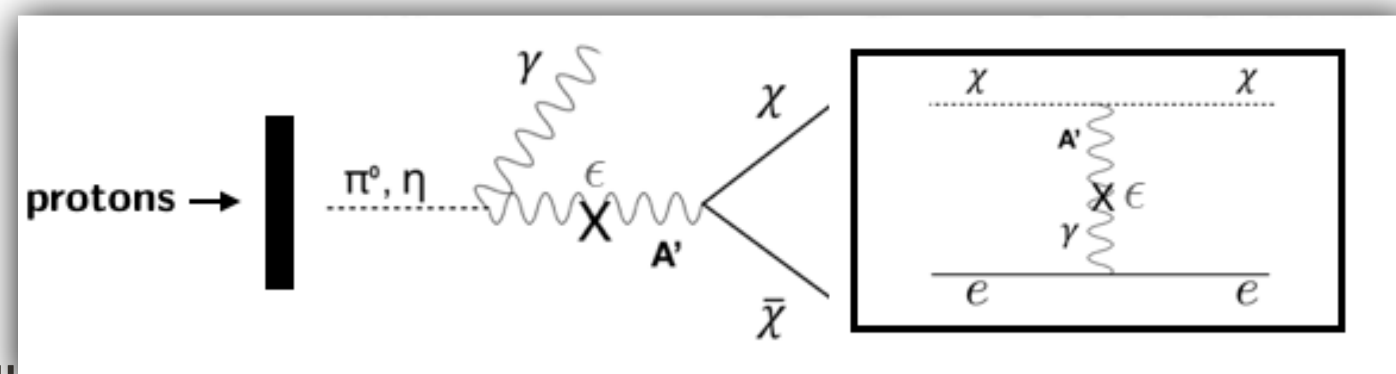
Negligible in the mass range under investigation

LDM detection in the emulsion target

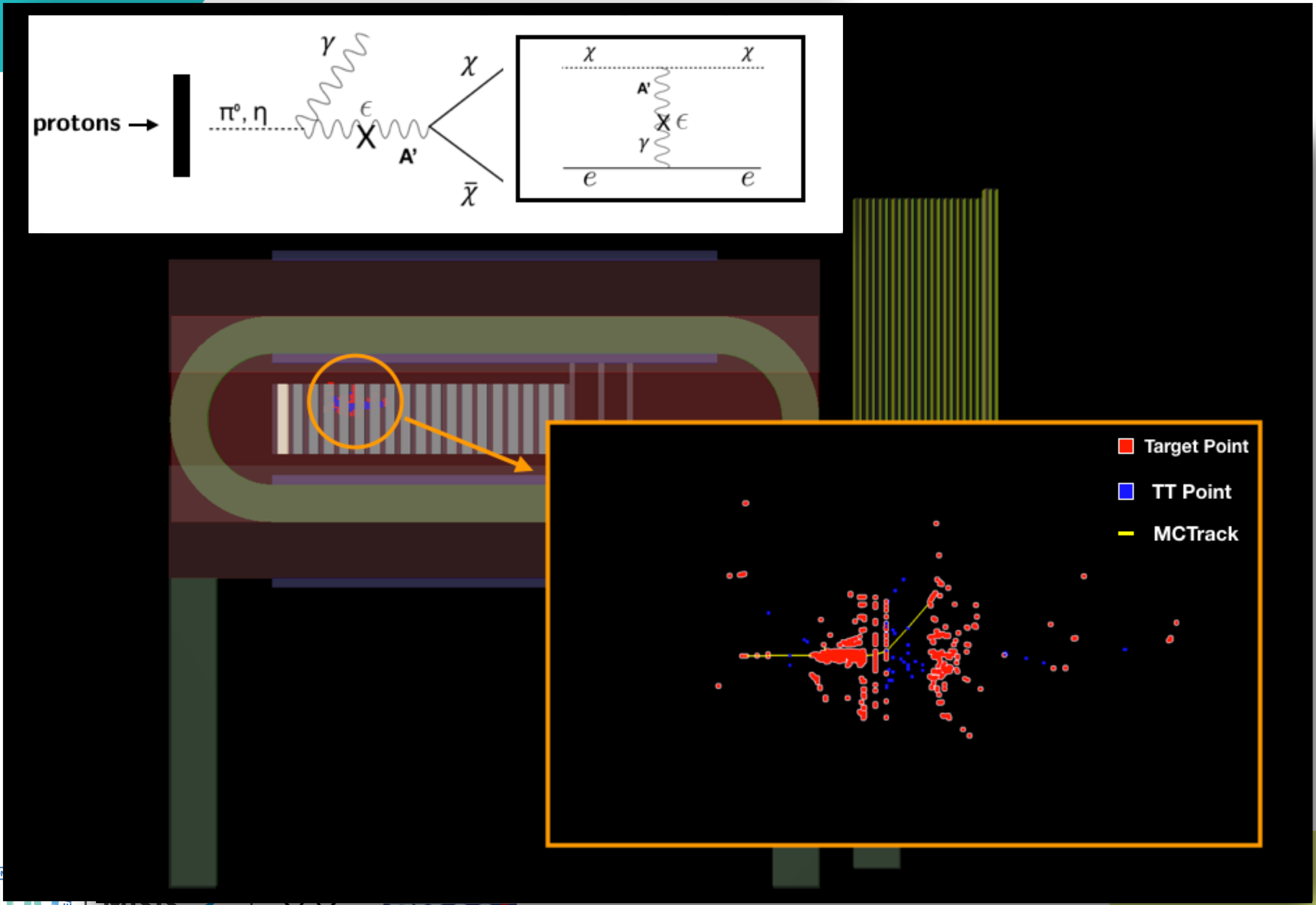
The Emulsion Target properties allow the search for **Light Dark Matter** particles (mass < 1 GeV/c^2) scattering off electrons



- **Electron identification**: electromagnetic shower reconstruction with calorimetric technique
- Angular resolution: **mrad**
- **Micrometric precision** in primary and secondary vertices separation

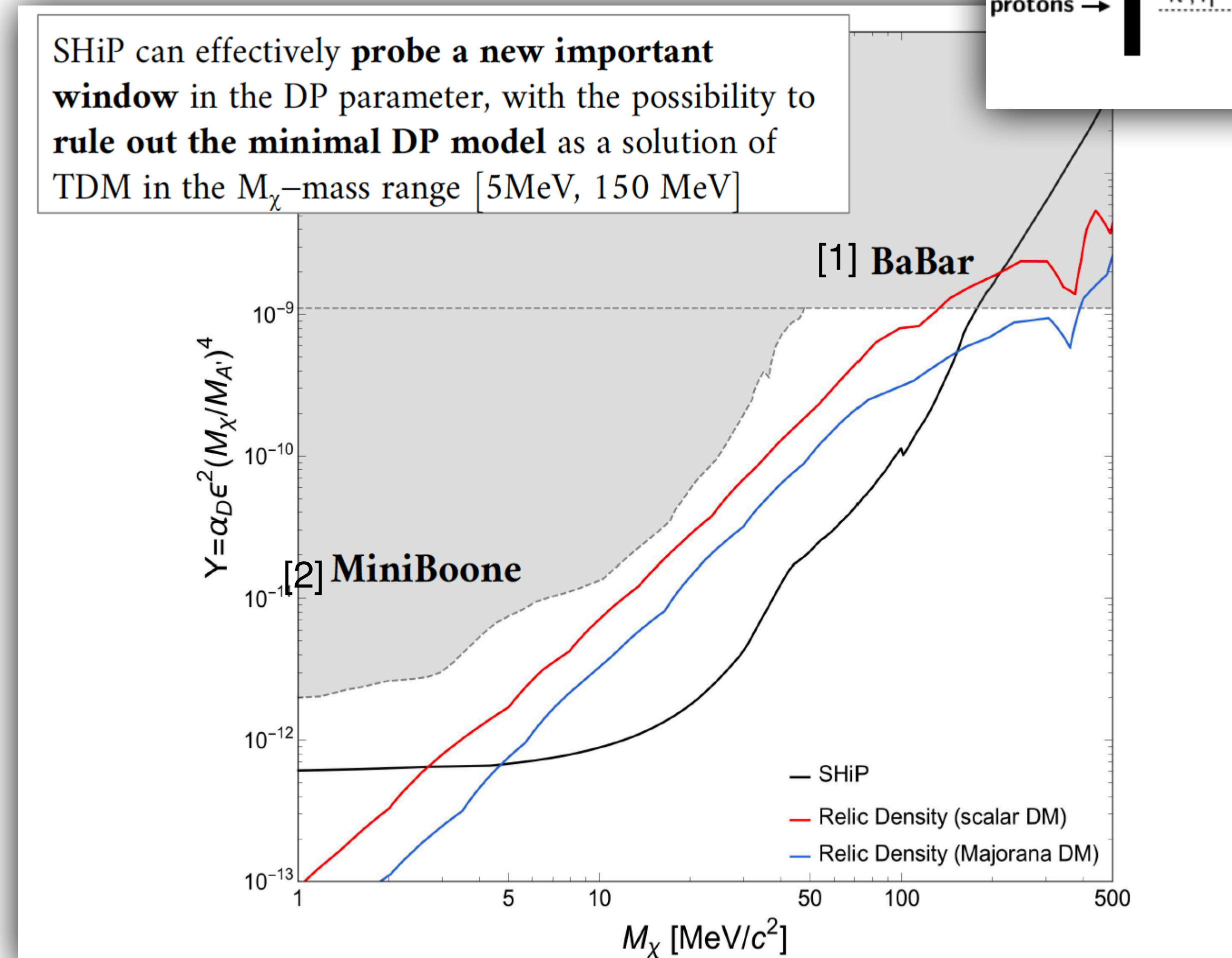


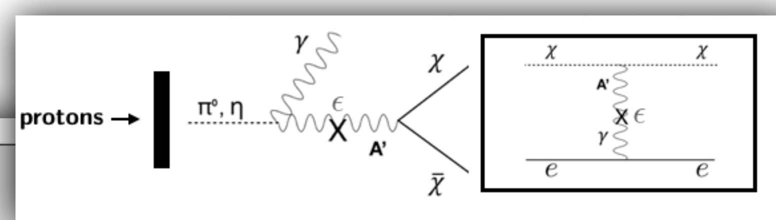
LDM signal events in the emulsion target



SHiP sensitivity to LDM

SHiP can effectively **probe a new important window** in the DP parameter, with the possibility to **rule out the minimal DP model** as a solution of TDM in the M_χ–mass range [5MeV, 150 MeV]





Benchmark model

$$\alpha_D = 0.1 \qquad \left(\frac{M_\chi}{M_{A'}}\right) = \frac{1}{3}$$

$$Y = \alpha_D \epsilon^2 \left(\frac{M_\chi}{M_{A'}}\right)^4$$

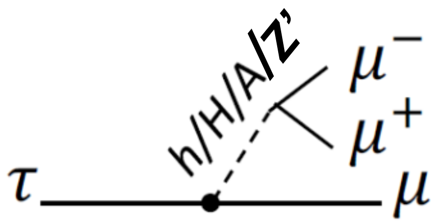
[1] arXiv:1702.03327

[2] arXiv:1807.06137

Search for Lepton Flavour violation with TauFV in τ decaus

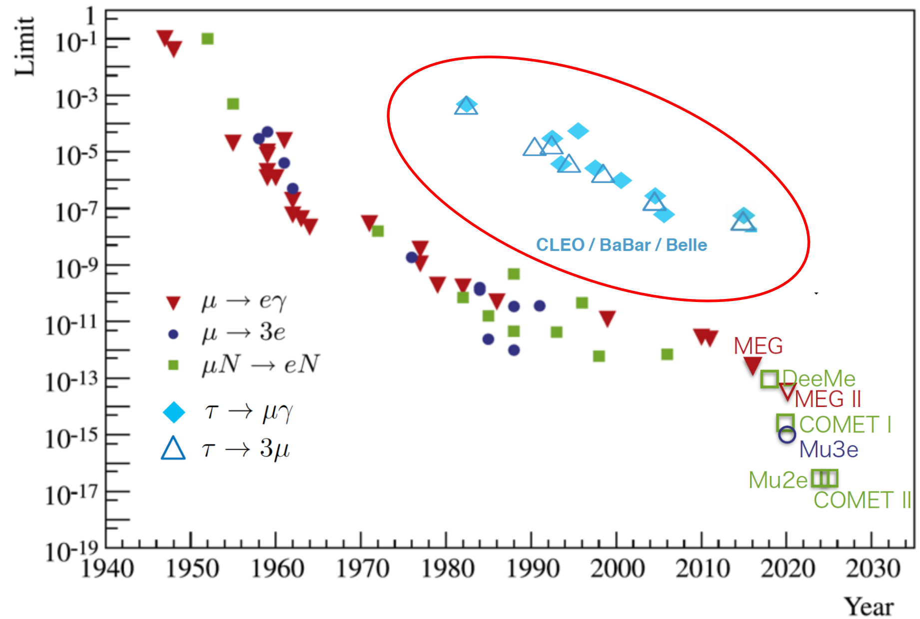
Long-standing, and well motivated (particularly since the discovery of neutrino oscillations) programme of searches for charged Lepton Flavour Violation

Less stringent limits in 3rd generation, but here BSM effects may be higher



Let's take $\tau \to \mu\mu\mu$ as benchmark mode. Current best 90 % CL limits:

Belle	2.1 x 10^{-8}	[PLB 687 (2010) 139]
BaBar	3.3 x 10^{-8}	[PRD 81 (2010) 111101]
LHCb	4.6 x 10^{-8}	[JHEP 02 (2015) 121]



Most improvement in coming decade is expected from Belle II, who can reach 1x10^{-9} [arXiv:1011.0352] and will do even better if they achieve ~zero bckgd [arXiv:1808.10567]

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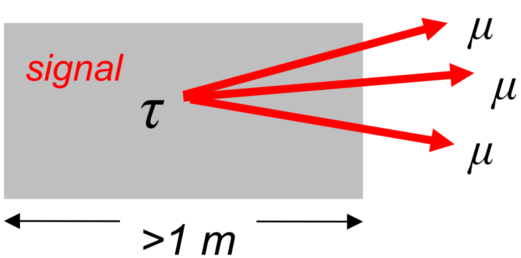
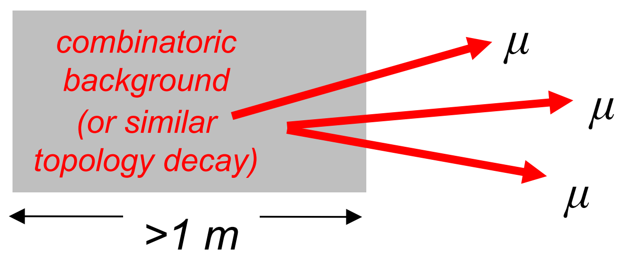
LHCb

Physics opportunity: LFV τ decays at the SPS BDF

Enormous τ production rate in SPS beam from $D_s \to \tau\nu$! Consider possibility of using Beam Dump Facility (BDF) being planned at CERN. However SHiP target unsuited for searches for ultra-rare τ decays, because of excessive multiple scattering

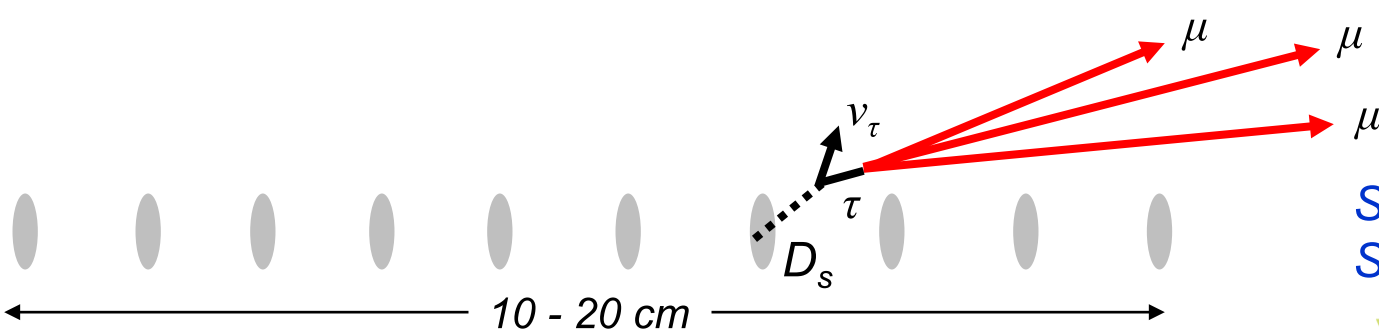


impossible to distinguish from…



…due to lack of useful vertexing and poor mass resolution

Instead, design dedicated experiment upstream of SHiP, with thin, distributed targets, to bleed off ~2% of the beam intended for SHiP → 2 mm of tungsten



Synergetic with SHiP operation !

Signal yields, and comparison with other experiments

With 2 mm of W we expect 4 x 10^{18} PoT in 5 years of operation.
0.17 % of interactions will produce charm, from this expect:

8 x 10^{13} $D_s \to \tau\nu$ decays

Comparing to past and existing flavour experiments:

- *~10^2 times number produced at LHCb IP in runs 1 & 2;*
- *~10^5 times number of $\tau^+\tau^-$ pairs produced during operation of Belle*

Moreover, production is strongly forward peaked, allowing a reasonable detector geometry to collect ~50% of all $\tau \to \mu\mu\mu$ decays. Assuming a total efficiency of 10% for geometrical selection and basic reconstruction cuts, and taking as a benchmark BR($\tau \to \mu\mu\mu$) = 1 x 10^{-9}, then the following yields are expected

Future experiment	Yield	Extrapolated from
TauFV (4 x 10^{18} PoT)	8000	Numbers on this slide
Belle II (50 ab^{-1})	9	PLB 687 (2010) 139
LHCb Upgrade I (50 fb^{-1})	140	JHEP 02 (2015) 121
LHCb Upgrade II (300 fb^{-1})	840	ditto

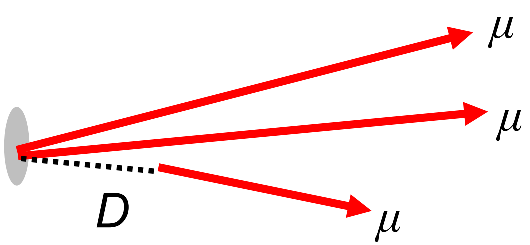
Clear opportunity to benefit from higher signal yield than at any other facility !

Signal yields isn't everything, backgrounds

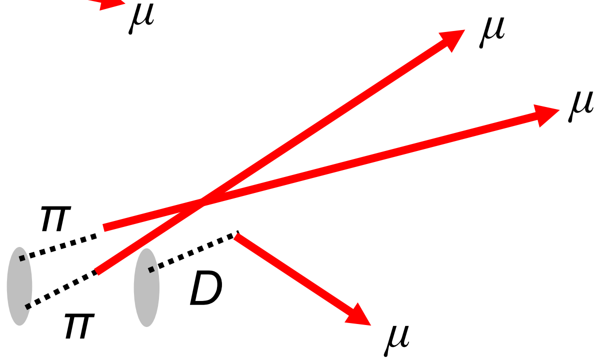
τ LFV searches at Belle II will be extremely clean, with very little background (if any), thanks to pair production and double-tag analysis technique. In contrast, TauFV (& hadron collider experiments) must contend with two background sources

1) Combinatorics

e.g. from wrong association of EM produced dimuons and with muon from D decay…



…or mis-association of genuine muon with decays in flight or punch through…



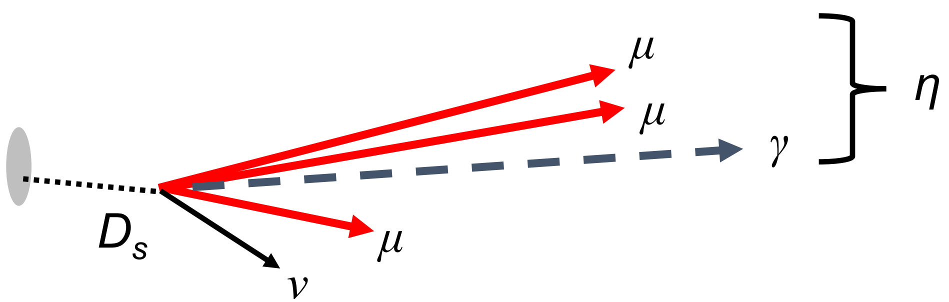
…or random association of three decays in flight etc

Signal yields isn't everything, backgrounds

τ LFV searches at Belle II will be extremely clean, with very little background (if any), thanks to pair production and double-tag analysis technique. In contrast, TauFV (& hadron collider experiments) must contend with two background sources

2) Specific backgrounds

Genuine tri-muon vertices arise from D and D_s semi-leptonic decays, followed by an EM transitions, e.g. $D_s \to \eta(\mu\mu\gamma)\mu\nu$



Background modes normalised to $D_s \to \eta(\mu\mu\gamma)\mu\nu$ (BR ~ 10^{-5})

Decay channel	**Relative abundance**
$D_s \to \eta(\mu\mu\gamma)\mu\nu$	1
$D_s \to \varphi(\mu\mu)\mu\nu$	0.87
$D_s \to \eta'(\mu\mu\gamma)\mu\nu$	0.13
$D \to \eta(\mu\mu\gamma)\mu\nu$	0.13
$D \to \omega(\mu\mu)\mu\nu$	0.06
$D \to \rho(\mu\mu)\mu\nu$	0.05

Other LFV/LNV physics

Other LFV tau decays which are natural goals for TauFV

$\tau^- \to e^- e^+ e^-$

$\tau^- \to \mu^- e^+ e^-$

$\tau^- \to e^- \mu^+ \mu^-$

$\tau^- \to \mu^+ e^- e^-$

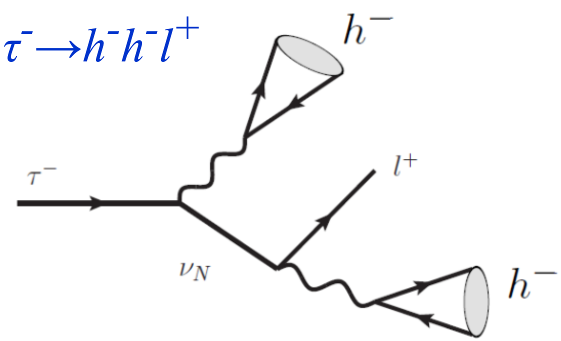
$\tau^- \to e^+ \mu^- \mu^-$

note that these decays have much lower backgrounds, so here extremely high sensitivity expected

In addition, there will be a correspondingly large sample of charm decays (e.g. ~5 x 10^{15} D^0s produced, which is 10^5 times more than at Belle II)

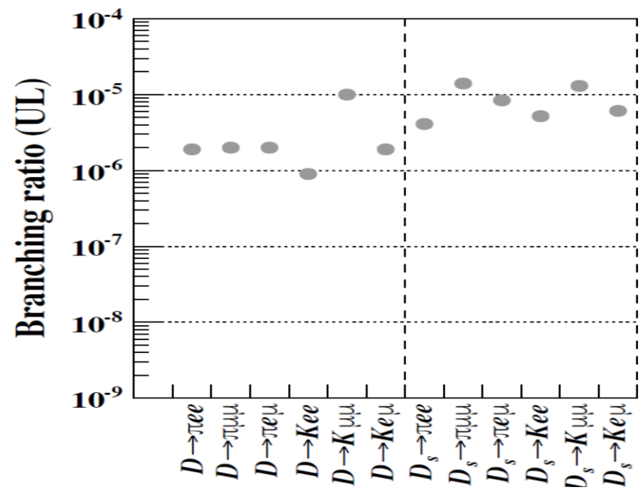
→ super precise lepton number violation studies in both tau and charm decays

$\tau^- \to h^- h^- l^+$



$D \to h l^- l^-$

(and not to forget LFV D decays, e.g. $D \to h \mu^- e^+$)



And maybe also opportunities in kaon LFV decays, such as K^+, $K_L \to \pi \mu e$

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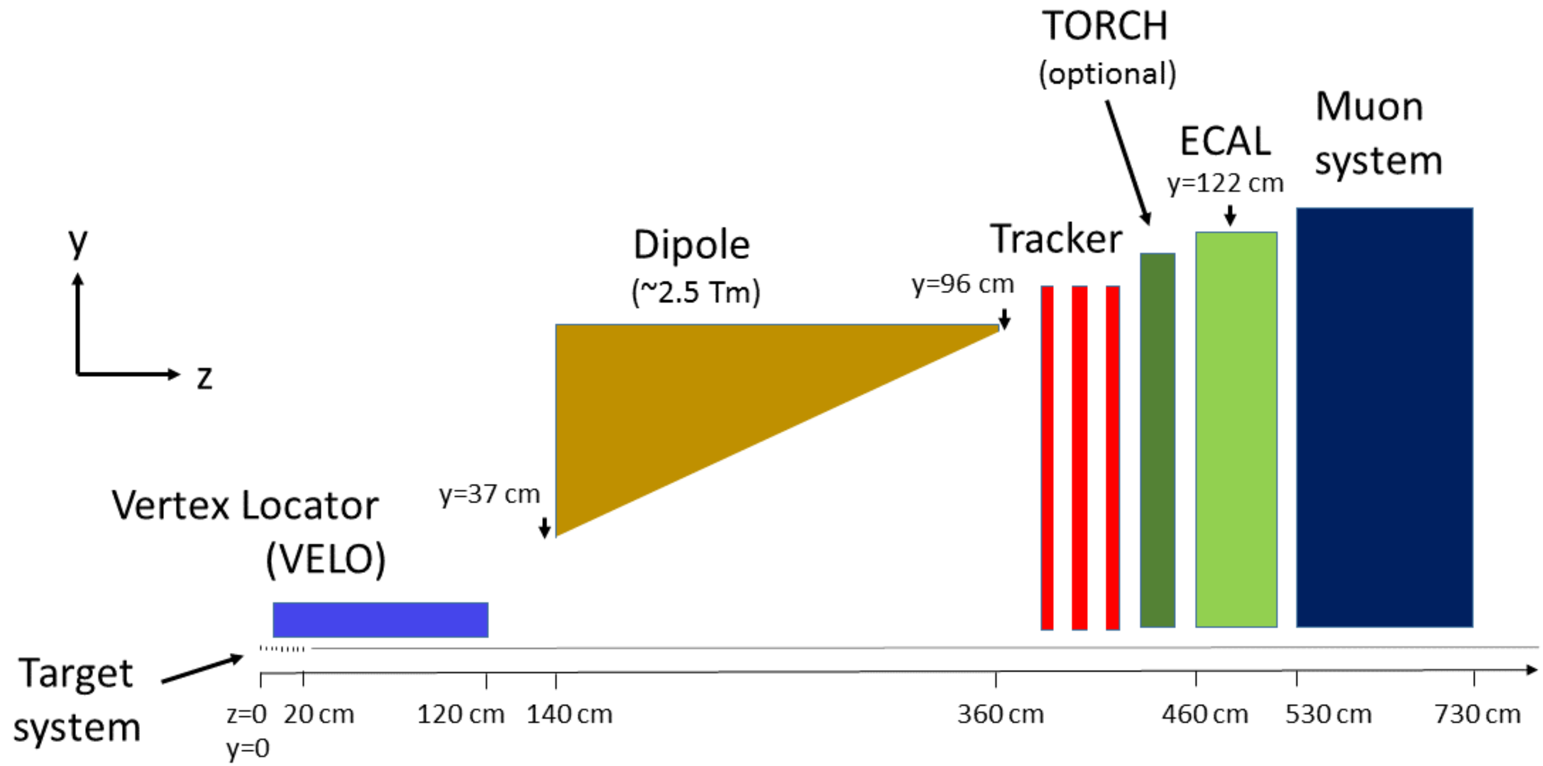
TauFV layout

Half-view schematic of a possible TauFV configuration (non bending plane)



Angular acceptance: 20→260 mrad (geometrical efficiency ~40% for τ→μμμ)

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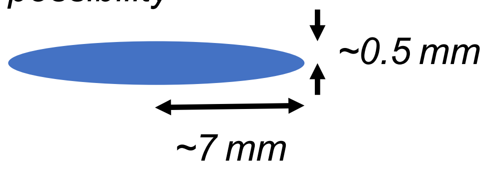
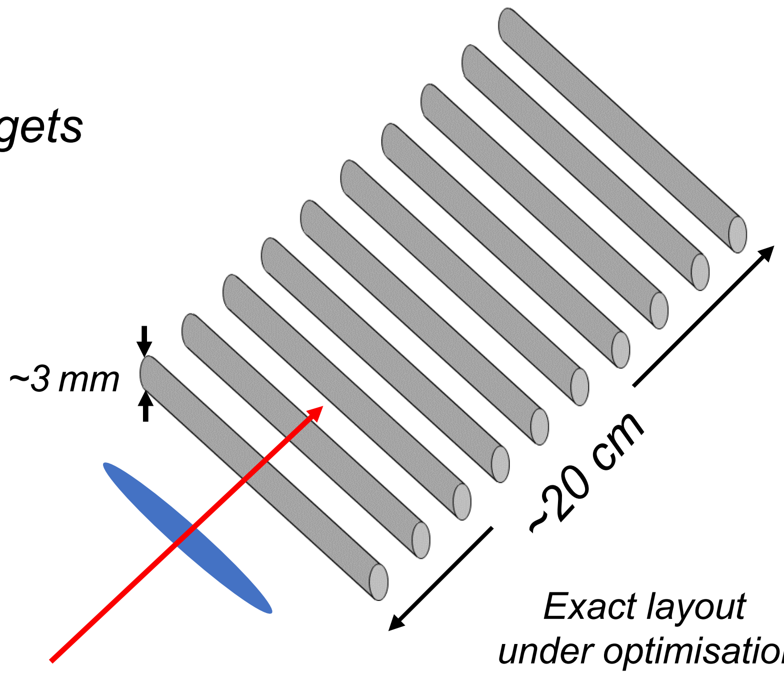
Beam profile and target arrangement

Key idea:

Squeeze beam profile to make compatible with wire (or blade)-like targets

one possibility





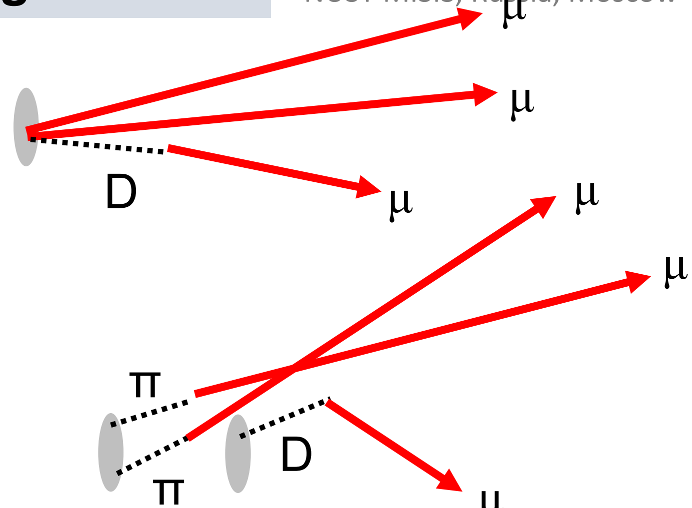
Exact layout under optimisation

Allows for several wires, with much reduced shadowing effects compared to circular profile and disc-like targets

Advantages of distributed target system and wide beam in one dimension:

- *Separates out interactions → invaluable for combinatoric bckgd suppression.*
- *Mild benefits for damping peak rates and dose in VELO*

τ→μμμ: combatting combinatoric background

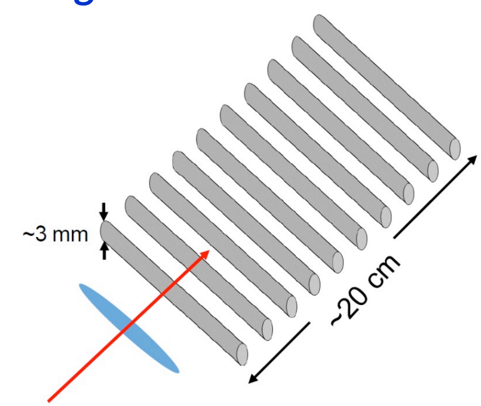


Suppressing this background relies on usual tools of a flavour-physics experiment, in particular:

- *high performance vertex detector*
- *good mass resolution*

Muon candidates must possess good quality vertex, downstream of target, and tracks must have impact parameter relative to found interaction vertices

Distributed target and wide beamspot very helpful in distributing out interactions and reducing fake combinations !



Also essential is role of fast timing provided by VELO, TORCH (~20ps) and ECAL. Spill takes place over ~1s and so precision timing gives extremely powerful discrimination between random associations

Studies ongoing, but current results indicate this background will be sub-dominant and have very small impact on $\tau\rightarrow\mu\mu\mu$ search, even down to BRs of 1 x 10^{-10} !

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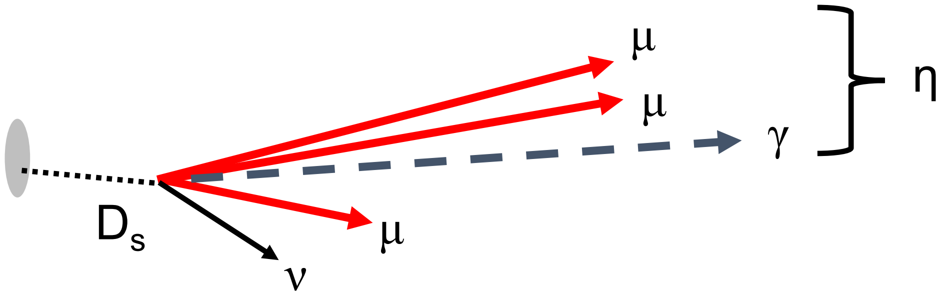
τ→μμμ: combatting charm backgrounds

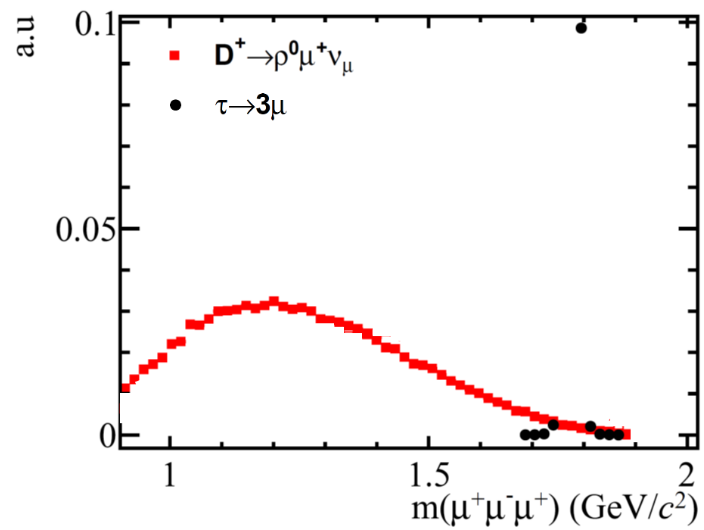


Mode	Relative abundance
$D_s \to \eta(\mu\mu\gamma)\mu\nu$	1
$D_s \to \varphi(\mu\mu)\mu\nu$	0.87
$D_s \to \eta'(\mu\mu\gamma)\mu\nu$	0.13
$D \to \eta(\mu\mu\gamma)\mu\nu$	0.13
$D \to \omega(\mu\mu)\mu\nu$	0.06
$D \to \rho(\mu\mu)\mu\nu$	0.05

These backgrounds afflict $\tau \to \mu^+\mu^-\mu^-$ searches in hadronic environment (but are absent for modes such as $\tau \to \mu^+ e^- e^-$). Various tools are available

- *Invariant mass of candidate*

Provides suppression factor of up to 100, depending on mode



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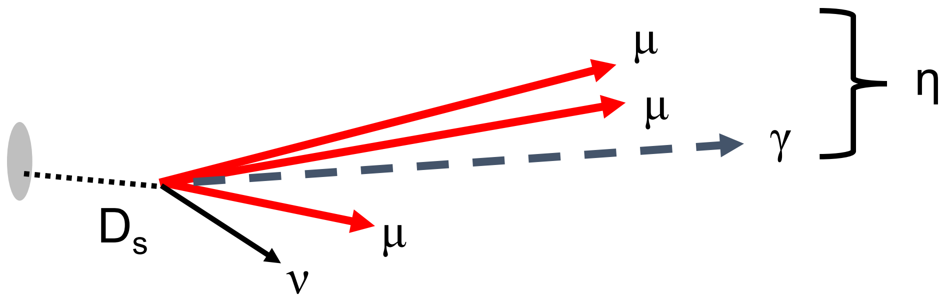

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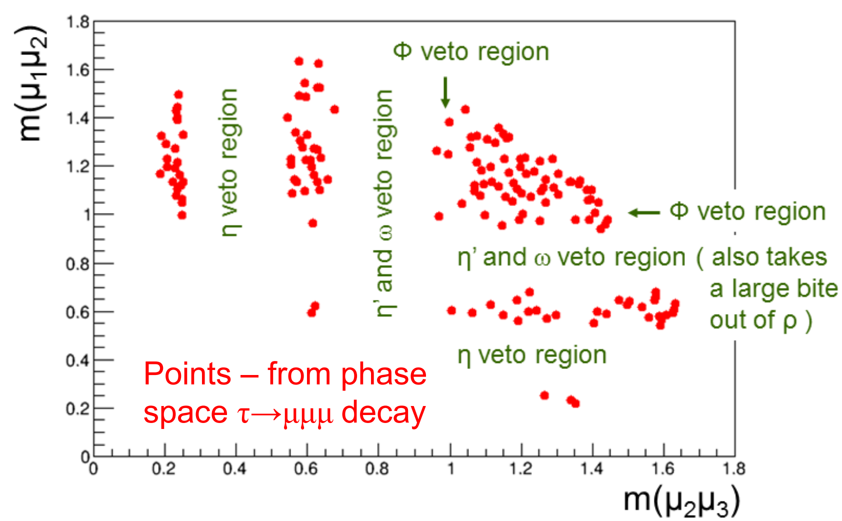
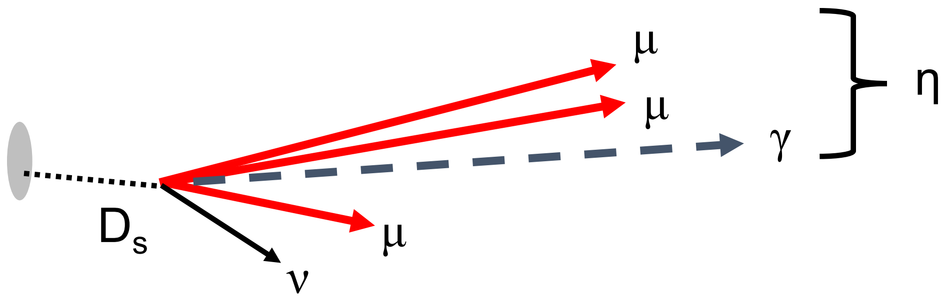
- *Invariant mass of candidate*
- *Invariant mass of dimuon pairs*



Can essentially eliminate all backgrounds (apart from wide ρ), whilst retaining 25% of signal, assuming phase space decay

But this a 'blunt weapon' as introduces model-dependence into result

$\tau \to \mu\mu\mu$: combatting charm backgrounds



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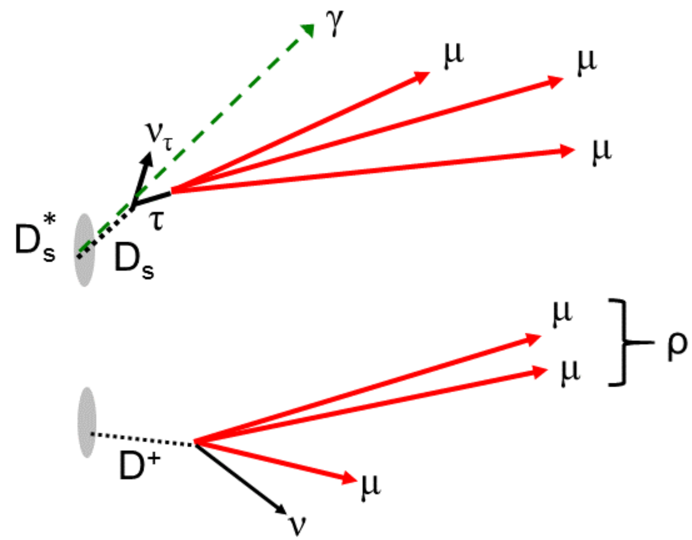
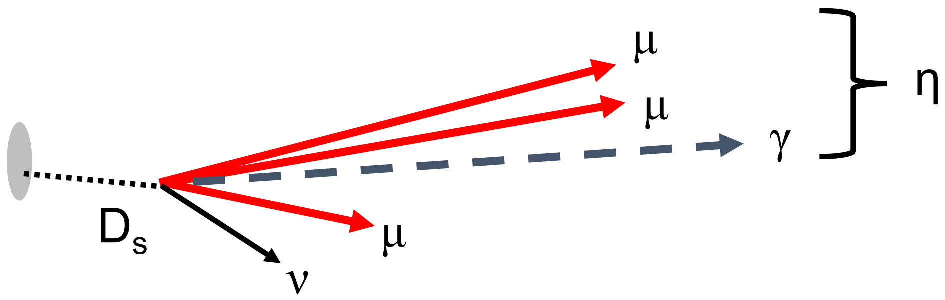
- *Invariant mass of candidate*
- *Invariant mass of dimuon pairs*
- *Photon veto for η and η' modes*
- *Photon tag to select $D_s^* \to D_s(\to \tau\nu)\gamma$*

Suppresses all non-D_s backgrounds; useful for combatting dangerous $D^+ \to \rho(\to \mu\mu)\mu\nu$ contamination



$\tau\rightarrow\mu\mu\mu$: combatting charm backgrounds



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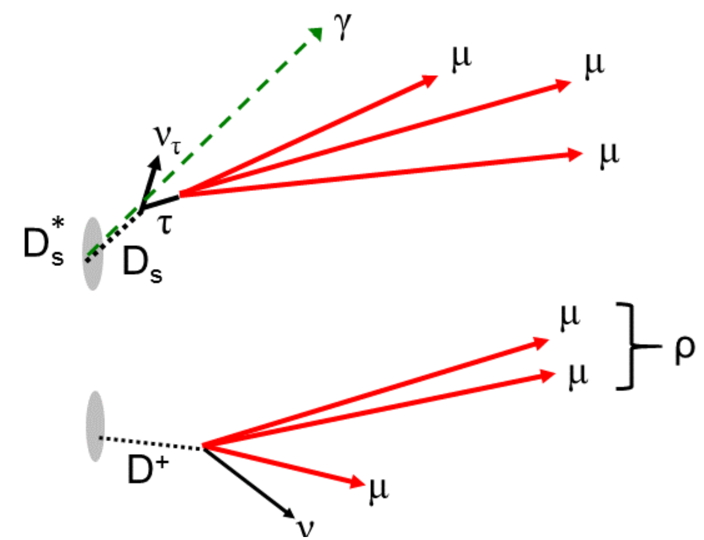
These backgrounds afflict $\tau\rightarrow\mu^+\mu^-\mu^-$ searches in hadronic environment (but are absent for modes such as $\tau\rightarrow\mu^+e^-e^-$). Various tools are available

- *Invariant mass of candidate*
- *Invariant mass of dimuon pairs*
- *Photon veto for η and η' modes*
- *Photon tag to select $D_s^*\rightarrow D_s(\rightarrow\tau\nu)\gamma$*
- *Kinematics relating interaction and decay vertices*



Cut-based studies in progress (full power will come from MVA approach), but we are confident that sensitivities to BRs of a few 10^{-10} are attainable

Conclusions

✓ ***Physics case to search for Hidden Particles is very timely !***
No NP discovered at LHC, *but many theoretical models offer a solution for the BSM experimental facts with light very weakly interacting particles.* ***Must be tested !***

✓ ***BDF @ CERN is ideal place to search for Hidden Particles at high energy and high intensity SPS beams.*** *Two complementary strategies are being explored at SHiP, direct observation of the HS decay vertex and LDM detection via scattering on atoms*

✓ ***Development of BDF at SPS also offers the opportunity to build a fixed-target experiment to search for LFV τ decays, which are long-acknowledged as a very sensitive probe for NP.*** *Aim to exploit enormous τ production rate and dedicated design and to demonstrate sensitivity to benchmark $\tau \to \mu\mu\mu$ mode at the $O(10^{-10})$ level*

✓ ***The rich physics programme to search for Hidden Particles and LFV τ decays at BDF nicely complements searches for NP at the energy frontier and in flavour physics at CERN***

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