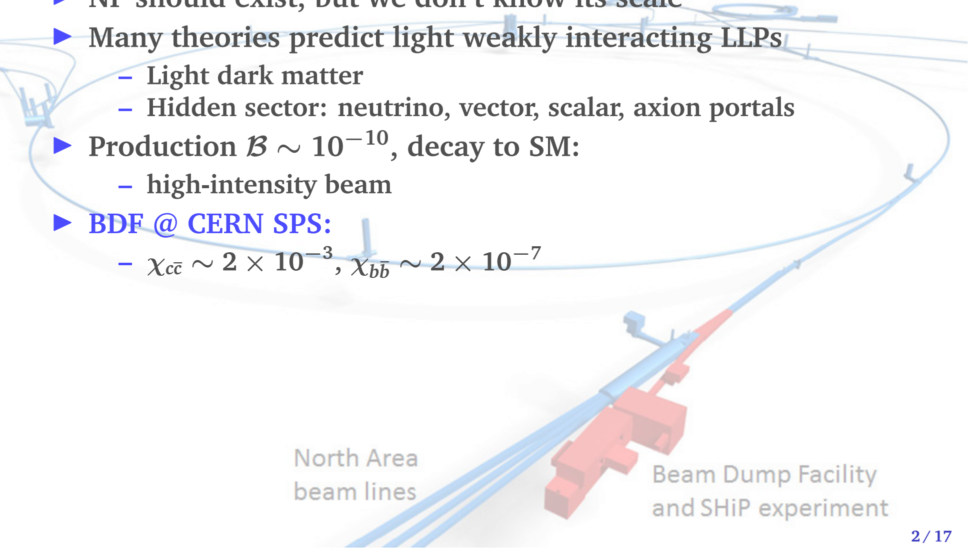
SHiP status report

E. Graverini for the SHiP collaboration

Physics Beyond Colliders annual workshop: January 16, 2019

Hidden sector at the BDF

- NP should exist, but we don't know its scale
- Many theories predict light weakly interacting LLPs
  - Light dark matter
  - Hidden sector: neutrino, vector, scalar, axion portals
- Production $\mathcal{B} \sim 10^{-10}$, decay to SM:
  - high-intensity beam
- BDF @ CERN SPS:
  - $\chi_{c\bar{c}} \sim 2 \times 10^{-3}$, $\chi_{b\bar{b}} \sim 2 \times 10^{-7}$



SHiP

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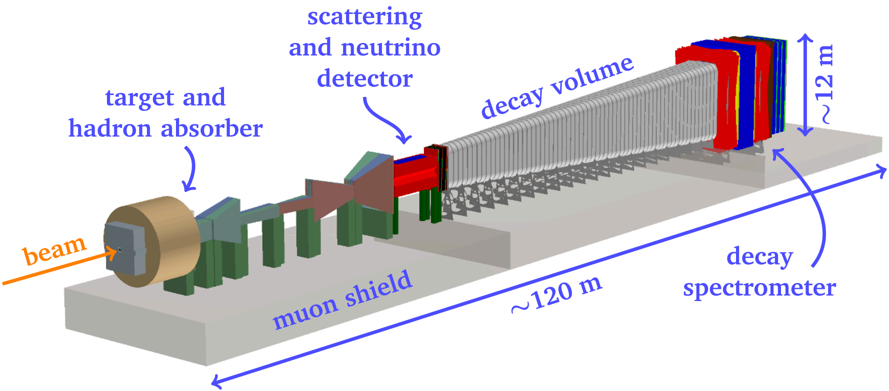
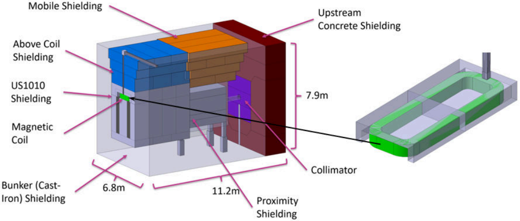
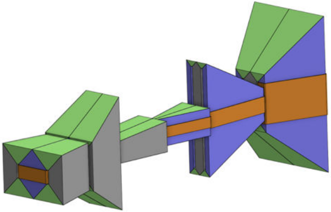


- 2×10^{20} *pot* in 5 years: $> 10^{18} D$, $> 10^{16} \tau$
- zero background beam dump expt. with spectrometry and PID
- large geometrical acceptance: long volume close to dump
- complementary detectors for scattering/decay signatures

Muon shield

- magnetized hadron stopper: immediately separate $\mu^{\pm}$
  $\Longrightarrow$ reduce length of magnet system
- magnetic field configuration optimised with ML
  $\Longrightarrow$ μ rate reduced to $\sim$ 25 kHz
- *note: μ spectrum validated with dedicated expt. (see later)*

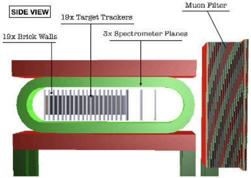


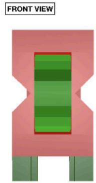


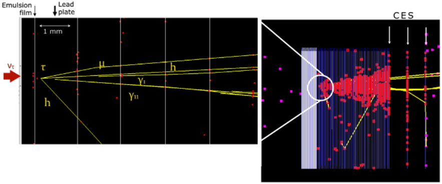
Scattering and Neutrino Detector: ν physics

- distinguish e, μ, τ and hadrons
- major revision following muon shield optimization: $80 \times 80 \times 300$ cm^3, simplified detector
- Target (Emulsion Cloud Chamber + Compact Emulsion Spectrometer) + Downstream Tracker

	$\bar{E}$ [GeV]	CC DIS int.
ν_e	59	1.1×10^6
ν_μ	42	2.7×10^6
ν_τ	52	3.2×10^4
$\bar{\nu}_e$	46	2.6×10^5
$\bar{\nu}_\mu$	36	6.0×10^5
$\bar{\nu}_\tau$	70	2.1×10^4

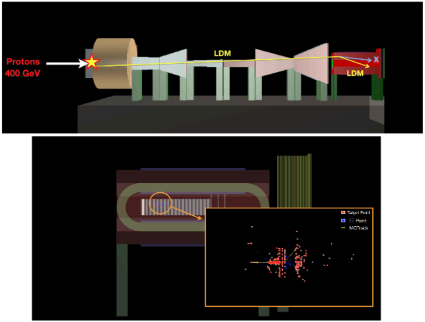


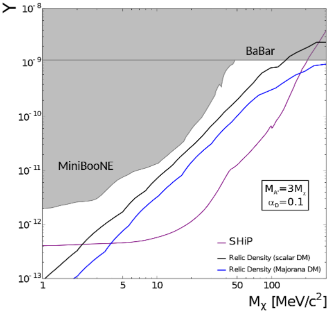




Scattering and Neutrino Detector: LDM

- light dark matter scattering in the emulsion spectrometer
- $\bar{\nu}_e p \to e^+ n$ background reduced using correlation between e^+ angle and energy





Scattering Spectrometer: status

- CES tested at CERN PS in 2017
- μ-RWELL or SciFi for tracking, both tested on beam (2018)
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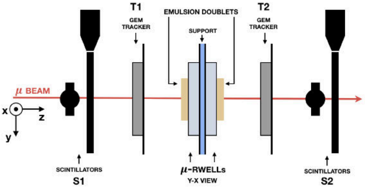
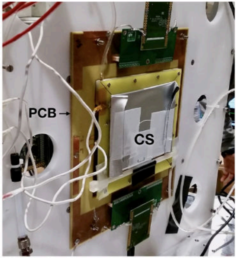
RWELL test beam





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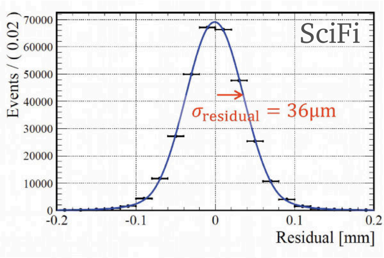
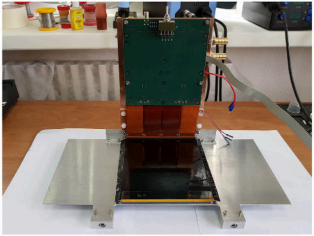


(a)



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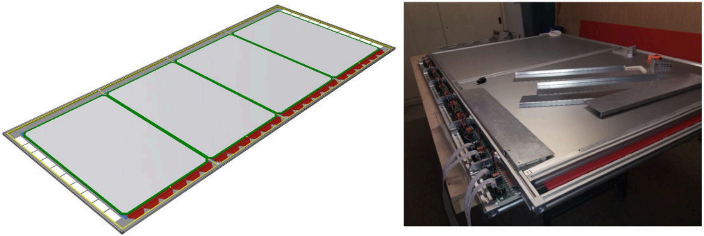
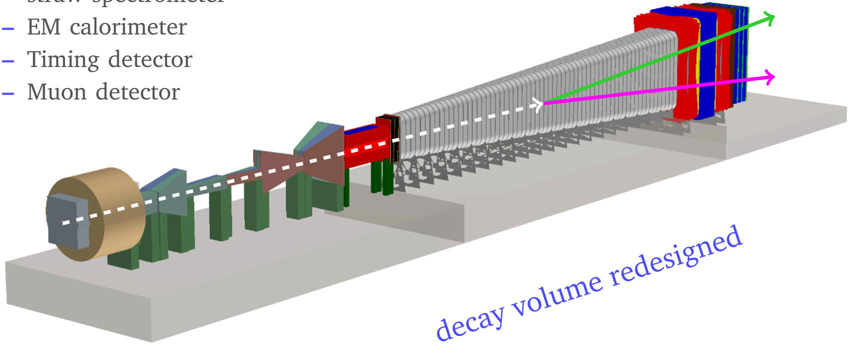


(a) (b)

Decay Spectrometer

– surround background tagger
– straw spectrometer
– EM calorimeter
– Timing detector
– Muon detector



- 0 background $\Longrightarrow$ 2 candidates are a discovery
- measure candidates mass and identify final state
  $\Longrightarrow$ narrow down physics models

Decay Spectrometer: status

SBT Several improvements *w.r.t.* TP. Tested on beam Oct. 2018

SST Straw $\varnothing$ increased to 20mm. Tested on beam: $\sigma_{\text{hit}} \approx 120\mu$m

TD Plastic scint + large-area SiPMs feasible, large-scale prototype yields $\sigma_t \approx 80$ps. RPC alternative tested Oct. 2018 with $\sigma_t \approx 54$ps

ECAL SplitCal with 3 high-res layers for $ALP \to \gamma\gamma$ ($\sigma_\theta \sim$ few mrad)

- measure barycentre at 3 depths with MPGDs; > 1 m lever arm

MUON move to scintillating tiles with SiPM readout. Beam test Oct. 2018, aim at $\sigma_t < 200$ps

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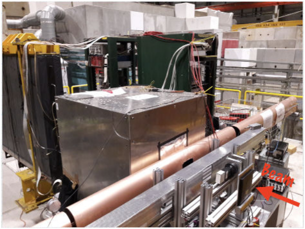

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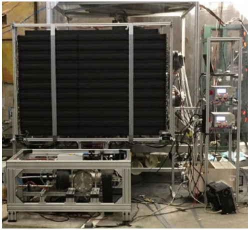

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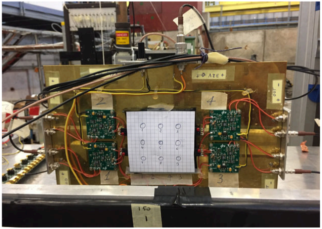
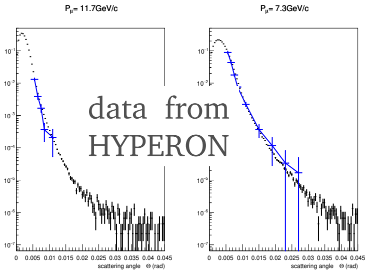
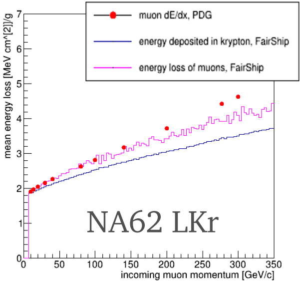


SHiP simulation / validation

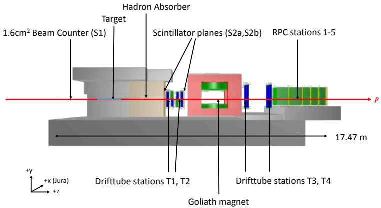
- based on FairRoot, uses:
  - Pythia8 for p-on-target collisions, tuned to include production of c, b mesons from secondaries
  - Geant4 for propagation through the target and detector material. $V^0 \to \mu\mu$, $\gamma \to \mu\mu$, $ee \to \mu\mu$ activated and boosted
  - Genie for neutrino interactions
- several HS models added/extended (HNL, γ', S, RPV $\tilde{\chi}^0$...)
- 1.8×10^9 / 6.5×10^{10} *pot* simulated with $E_{th} = 1$ / 10 GeV
- μ MS and catastrophic energy loss validated with existing data



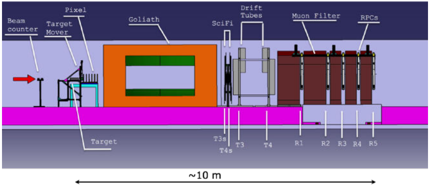


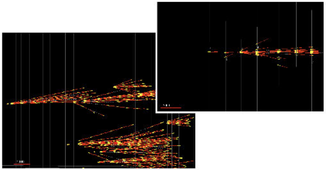
Charm / μ flux measurements (July 2018)

- replica of BDF target + drift tube spectrometer + RPC μ tagger
- $\sim 6 \times 10^{11}$ *pot* recorded, analysis ongoing



- measure of charm production essential for HS and ν_τ studies
- lead target + ECC. 1.6×10^6 *pot* + $10\times$ run after LS2





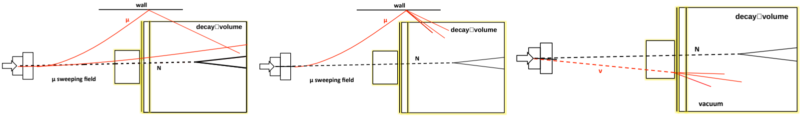
Hidden sector: physics performance

- setup ideally suited for *any* weakly interacting LLP

Cut	Value
Track momentum	$> 1.0\mathrm{GeV}/c$
Children distance of closest approach	< 1 cm
Decay vertex position	($>$ 5 cm from inner wall)
IP w.r.t. target (fully reconstructed)	< 10 cm
IP w.r.t. target (partially reconstructed)	< 250 cm

- event selection: high signal efficiency + redundant BG suppression
- common selection (model independent search)
- redundancy cuts:
  - associated activity in VETO systems
  - PID cuts
  - time coincidence (suppress combinatorial background)
  - opening angle (reject events from γ conversions in the material)

Hidden sector: backgrounds



- **Muon combinatorial:**
  - $10^{16} \xrightarrow{\text{selection}} 10^{9} \xrightarrow{\Delta t < 340\text{ps}} 10^{-2}$ candidates in 5 years @ $90\% CL$
  - ML used to generate large sample of dangerous μ
- **Muon inelastic:**
  - 5 years of SHiP operation simulated
  - correlation between VETO and selection: $< 6 \times 10^{-4}$ @ $90\% CL$
- **ν interactions:**
  - 10 years of SHiP simulated, increasing to 100
  - ν-air: $< 10^{-2}$ in 5 years with pressure ~ 1 mbar
  - ν-material: $5 \times 10^{5} \begin{cases} \xrightarrow{\text{cuts (fully reco)}} 0 \\ \xrightarrow{\text{cuts (part. reco)}} 2 \xrightarrow{\text{opening angle}} 0 \end{cases}$ @ $90\% CL$

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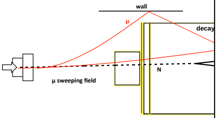

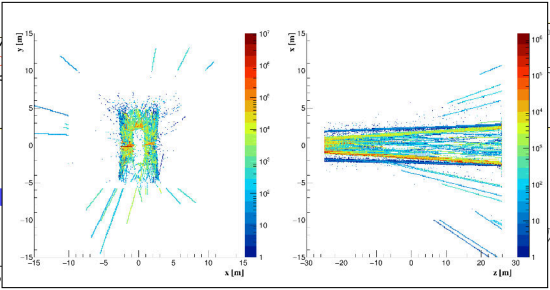

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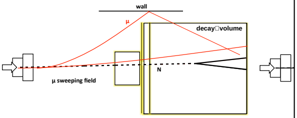

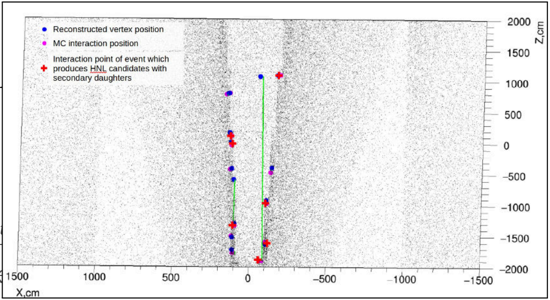

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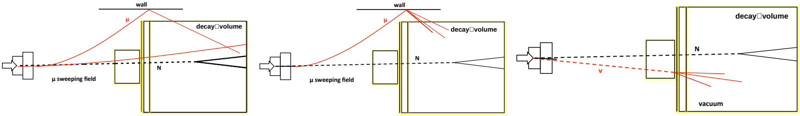

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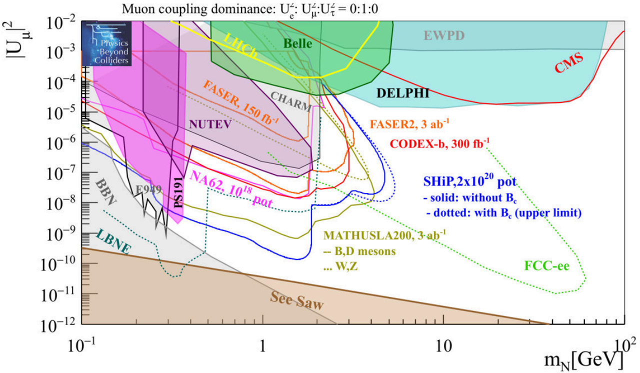
Physics performance: HNL

[hep-ph/1811.00930] [PBC-REPORT-2018-007]



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- great sensitivity also in U_τ^2-enhanced scenario

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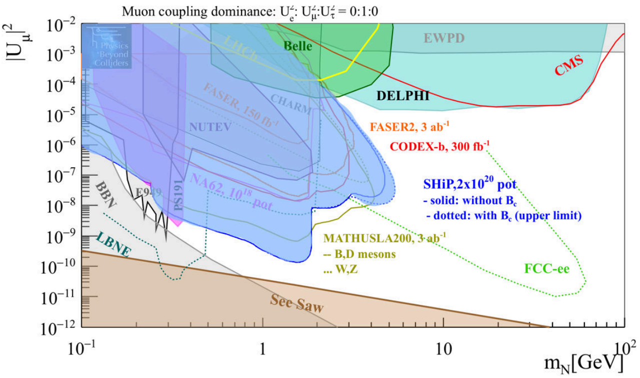

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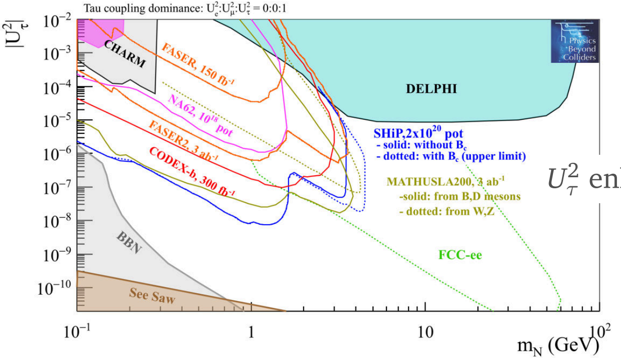

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  - meson decays, proton bremsstrahlung, $qq \to \gamma'$
  - expect improvements at low mass from:
    - cascade production
    - EM showers
- **Dark scalar:**
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- **Axion-like particles:**
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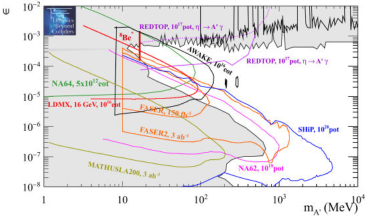

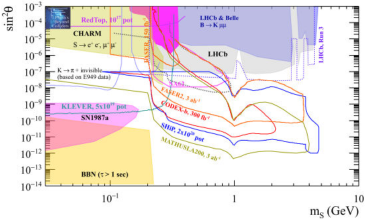

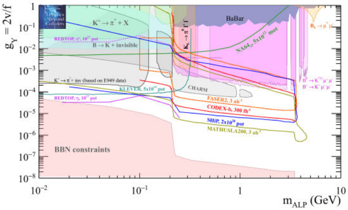

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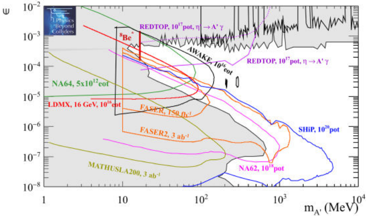

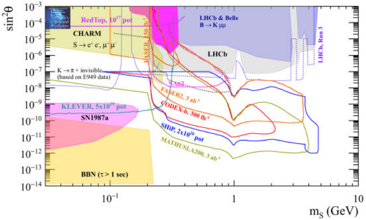

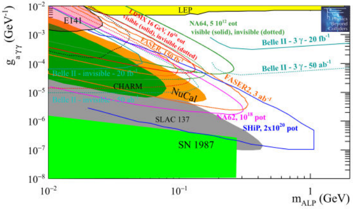

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- preparation of CDR (submission to SPSC in fall 2019)
- continue phase 2 module-level prototyping for test beams
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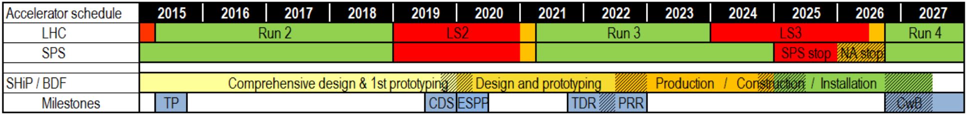
Conclusions + Outlook



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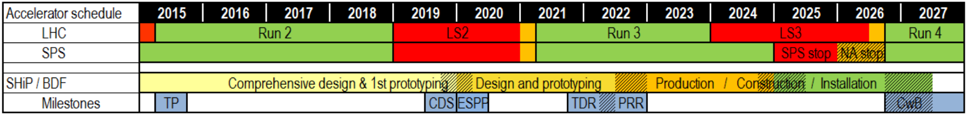
- all sub-detector's phase 1 prototypes tested with nice results
  - schedule driven by SPS/LHC schedule: installation LS3
  - phase 2 prototyping $\stackrel{!}{\rightarrow}$ TDR second half of 2021
- many improvements on background evaluation and sensitivities
  - working hard to simulate more rare events

- comprehensive search for weakly interacting LLPs @ SPS
- complement CERN's energy frontier and flavour programme

Conclusions + Outlook



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