LLP seaches with CODEX-b

COmpact Detector for EXotics at LHCb

[1708.09395]

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on behalf of the CODEX-b WG

Third workshop of the LHC LLP Community,
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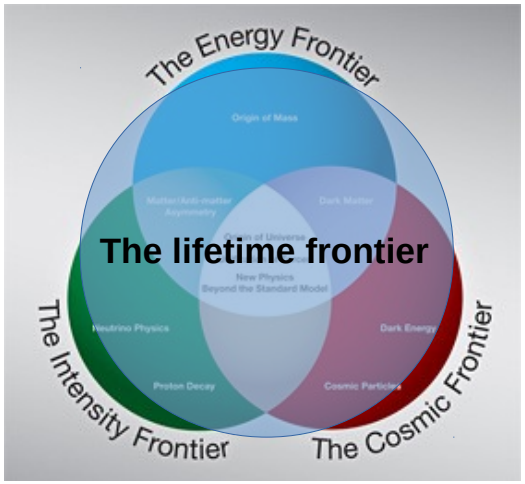
The lifetime frontier at the LHC

- Weakly coupled long lived particles (LLP) encompass all three other frontiers



- The SM already has templates for such particles (ν, K_L^0, ...)

small mixing angle from broken symm.

loop suppression $n \geq 4$

$$\Gamma \sim \varepsilon^2 \left(\frac{m}{\Lambda}\right)^n \Phi$$

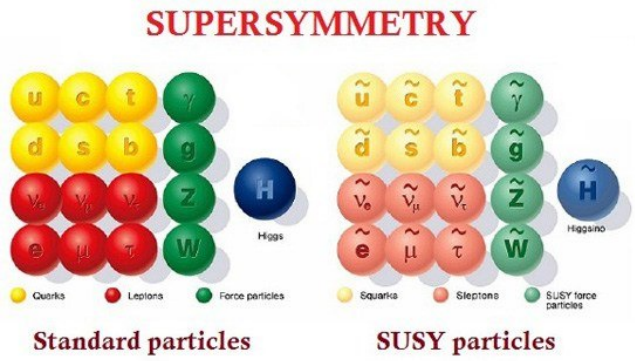
small phase space

mass hiererchy, $m \ll \Lambda$

- Large lifetimes are driven by several factors

- pp collisions at LHC are excellent source of LLP's. But high p_T (ATLAS/CMS) or restricted $c\tau$ (LHCb) searches can miss these.

Cast a wide net



R-parity violation
Gauge mediated SUSY
(mini-)split SUSY
stealth SUSY

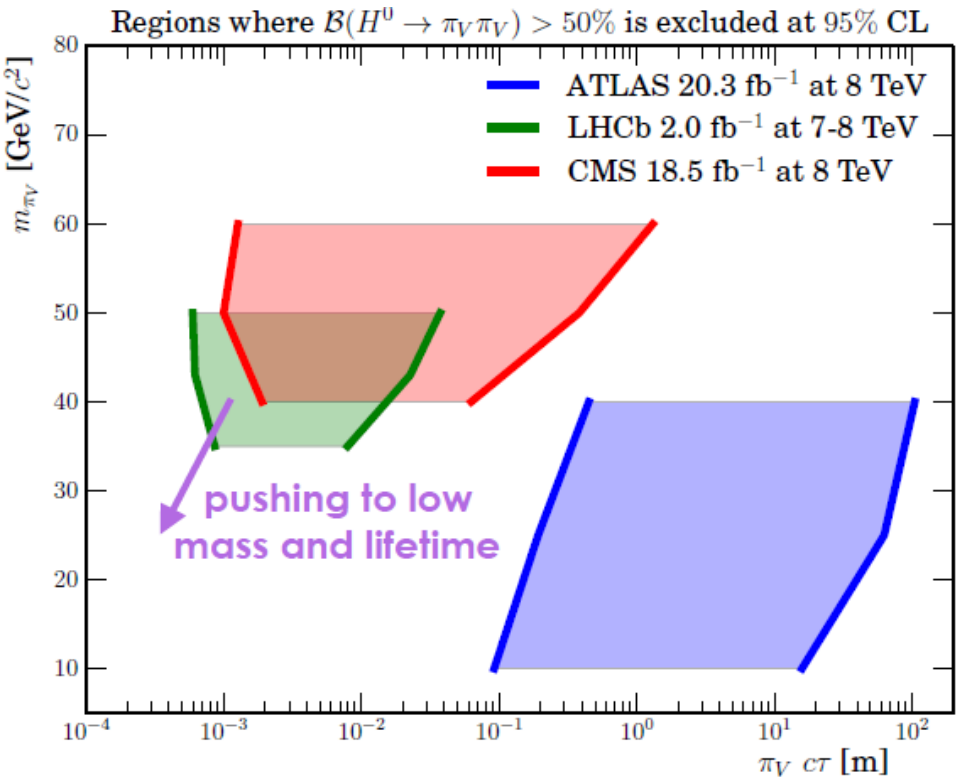
Asym. DM
Freeze-in
Composite DM
Coannihilating DM

Baryogenesis
Neutrino masses
Neutral naturalness
Hidden Valleys

- Lifetimes as long as sub-second-ish (BBN limit) possible
- Masses can range from sub-MeV to 100 GeV

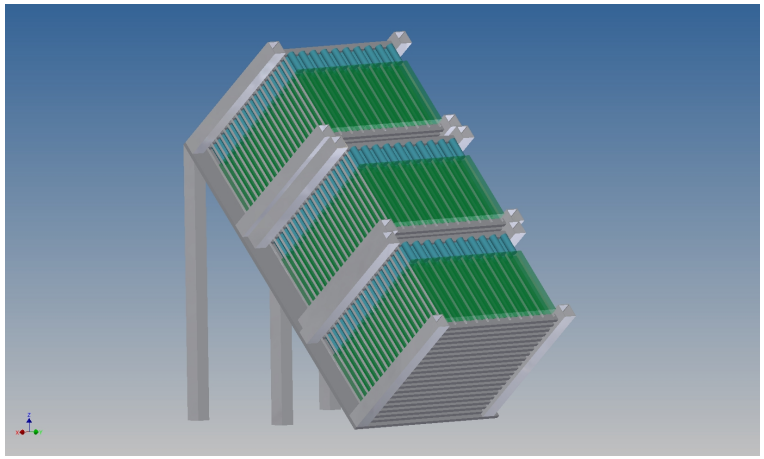
LHCb perspective [see also Elena's talk]

- Complementarity between ATLAS/CMS and LHCb: luminosity, acceptance, triggers, lifetime reach.

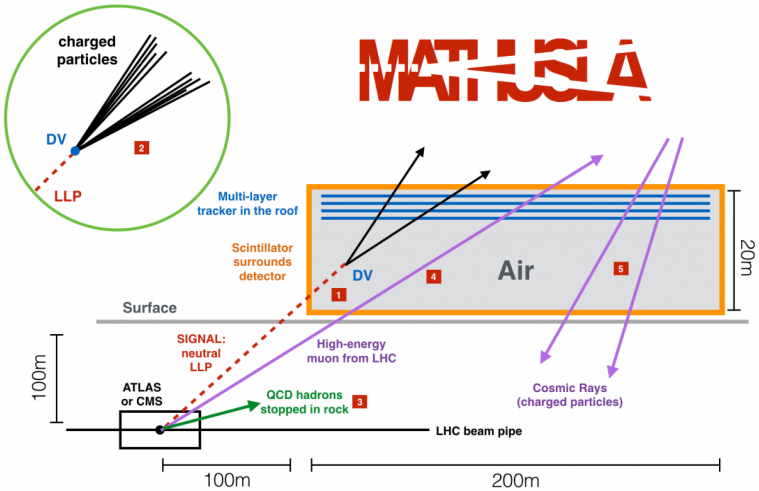


- Our best tracks originate inside the VeLo ($L \sim 20$cm). Longer lifetimes are challenging.

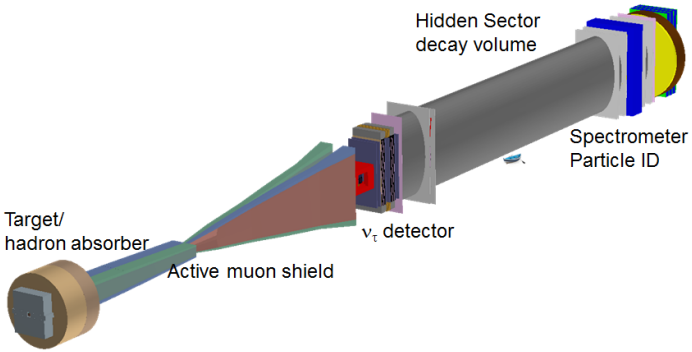
Other LLP detector proposals at the LHC



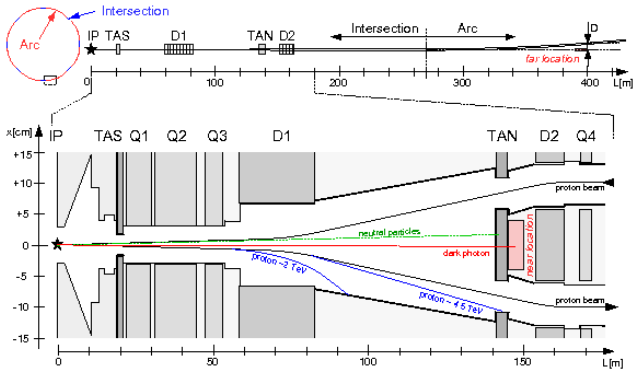
MilliQan: 1607.04669



MATHUSLA: 1606.06298

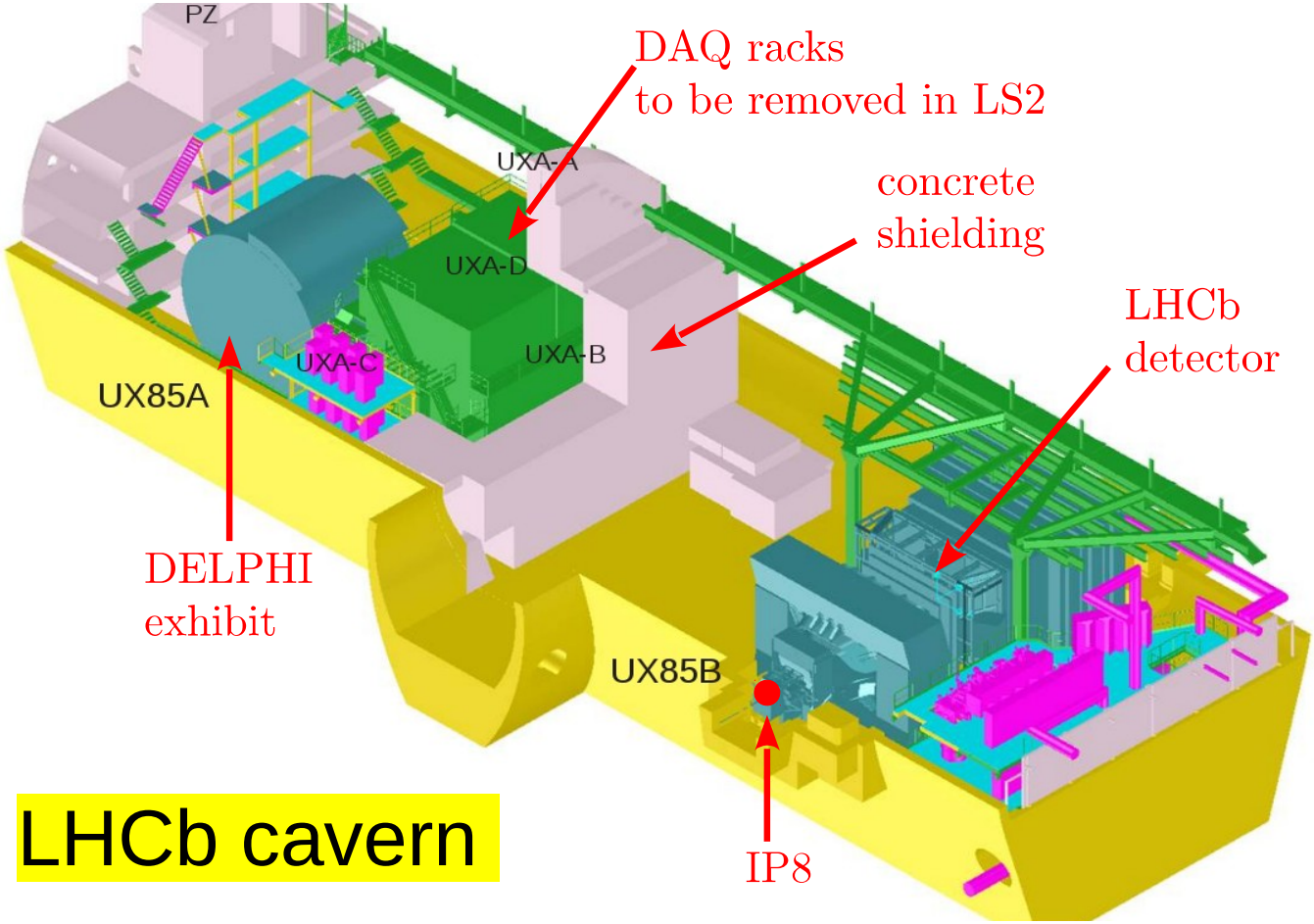


SHiP: 1504.04855



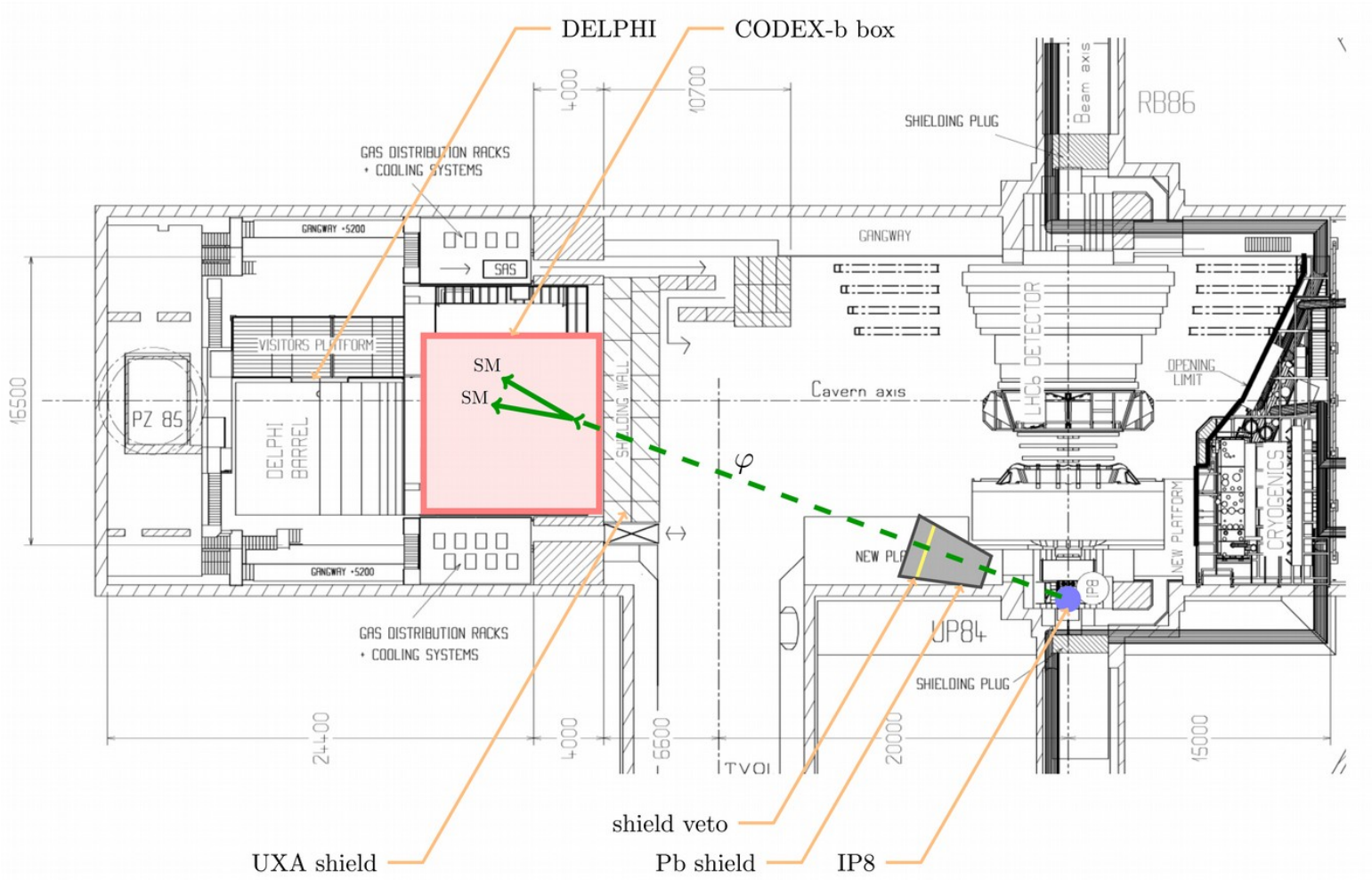
FASER: 1708.09389

CODEX-b: proposal at Point 8



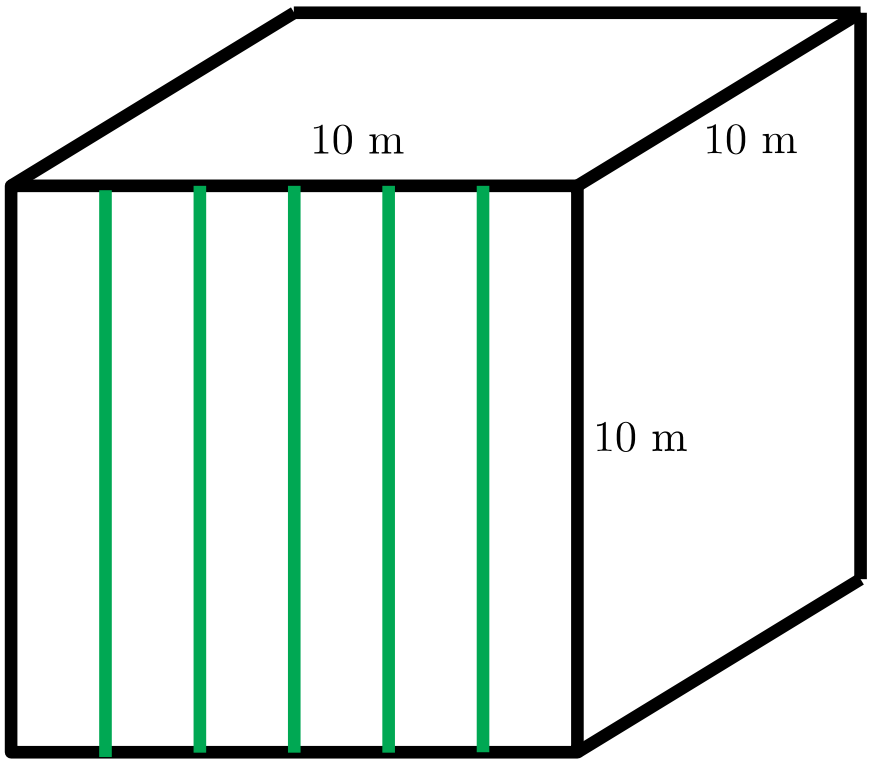
- DAQ racks in UXA-D move to surface for Run 3. Space available.
- Shielded, underground, $10 \times 10 \times 10$ m box, around 25 m from IP.
- Instrument with tracking layers $\Rightarrow$ CODEX-b

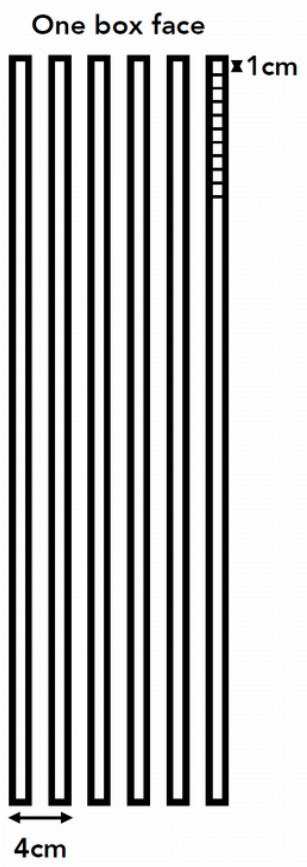
CODEX-b: another view



- If DELPHI is removed, access to even $20 \times 10 \times 10$ m box.
- Angular acceptance $\sim 1\%$.

Minimal geometry for tracking





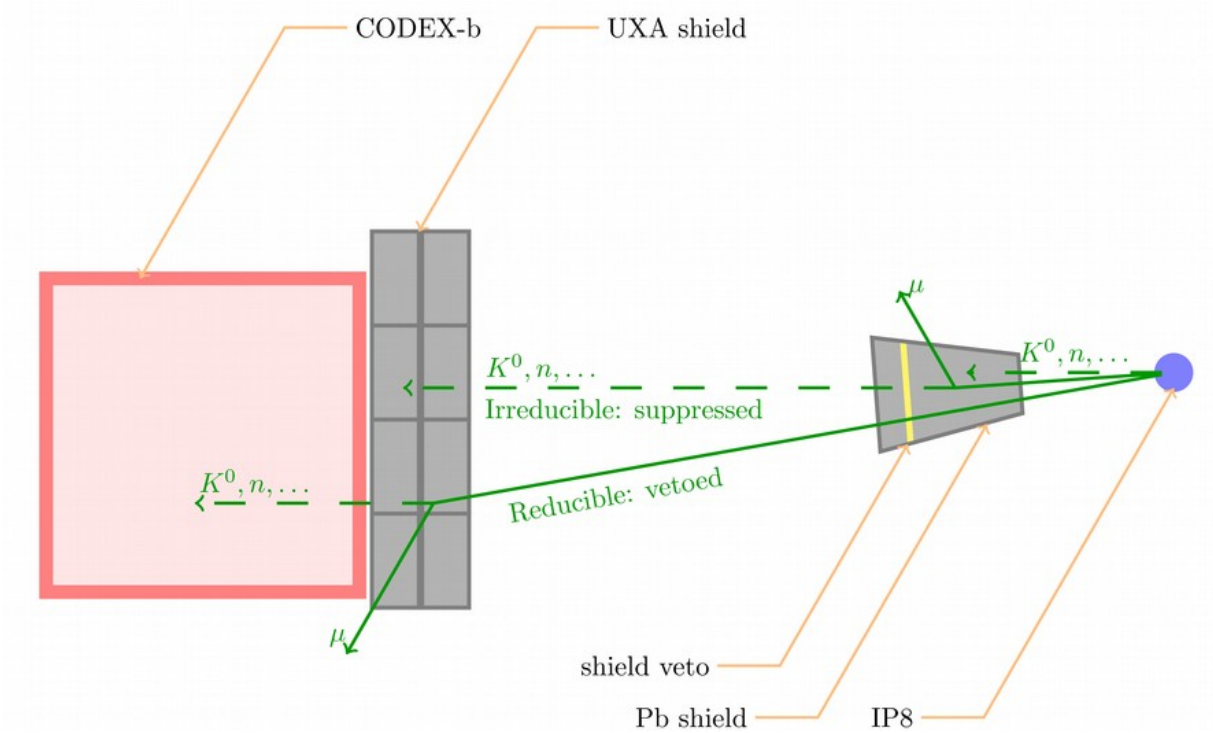
- 6 RPC layers at 4 cm intervals on each box face with 1 cm granularity
- 5 equally spaced triplets along the depth to minimize distance between reconstructed vertex and 1st measurement. $\epsilon_{\text{tracking}} \sim \mathcal{O}(1)$.
- 50-100 ps timing from RPC's foreseen for mass reconstruction

Why is CODEX-b attractive

- Small volume to instrument. Cheaper and more leverage to try out additional calorimetry, 4d-tracking detectors
- Backgrounds are controllable. Underground and existing shields. Space for additional shields
- Only ~ 4 bunch-crossing away from IP8. With good timing (sub-100 ps), can couple with LHCb. Eg. tag a $B \to K^* \varphi$ between the two detectors.
- Complementarity and competitive NP reach wrt other searches.

Minimal shield design

- CODEX-b sits behind the UXA (concrete) shield. From RP group, charged fluxes nominally quite low (access area!).



- Add passive Pb shield to attenuate muon and neutral hadrons. Thin active veto for secondaries inside the shield.

Background studies: simulation

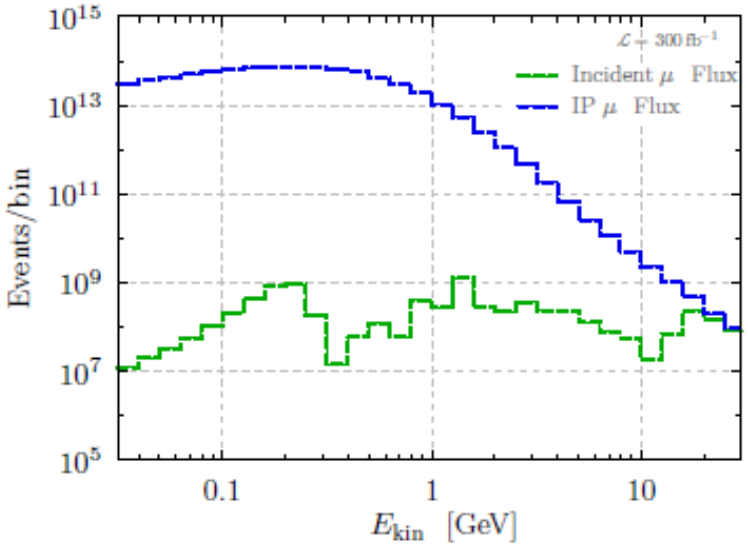
- Min. bias w/ `Pythia8`. HL-LHC projections: 300/fb @ 14 TeV.
- Propagation thru' Pb, air and concrete in Geant4.

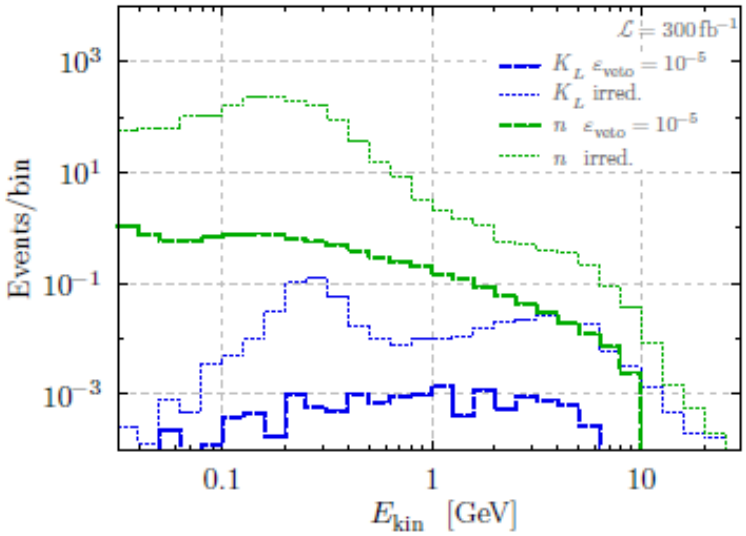
BG species	Particle yields		Baseline Cuts
	irreducible by shield veto	reducible by shield veto	
$n + \bar{n}$	7	$5 \cdot 10^4$	$E_{\rm kin} > 1\,{\rm GeV}$
K_L^0	0.2	870	$E_{\rm kin} > 0.5\,{\rm GeV}$
$\pi^\pm + K^\pm$	0.5	$3 \cdot 10^4$	$E_{\rm kin} > 0.5\,{\rm GeV}$
$\nu + \bar{\nu}$	0.5	$2 \cdot 10^6$	$E > 0.5\,{\rm GeV}$

- Main remnant background is n.
- Air-μ interactions vetoable by front detector face RPC's
- Very little neutrino bkgd.

- Track topology and timing will also help vetoing in the future.
- Study shows active veto suggests $\epsilon_{\rm veto} \sim 10^{-5}$ needed and doable.

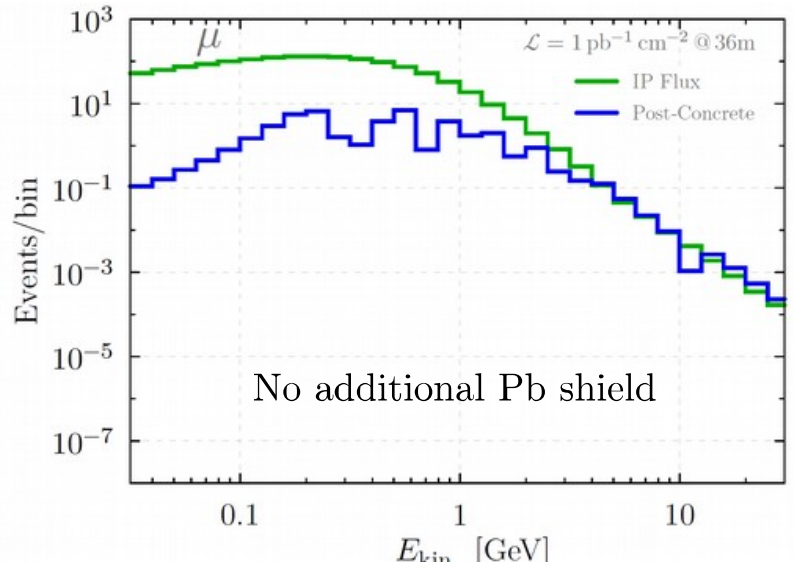
Background studies: simulation (cntd.)





- Spectrum after veto is also soft. Expected multiple scattering is reduced.
- Geant4 study broadly consistent with simplified propagation models with inputs from available data (PDG etc.).

Background studies: validation measurements

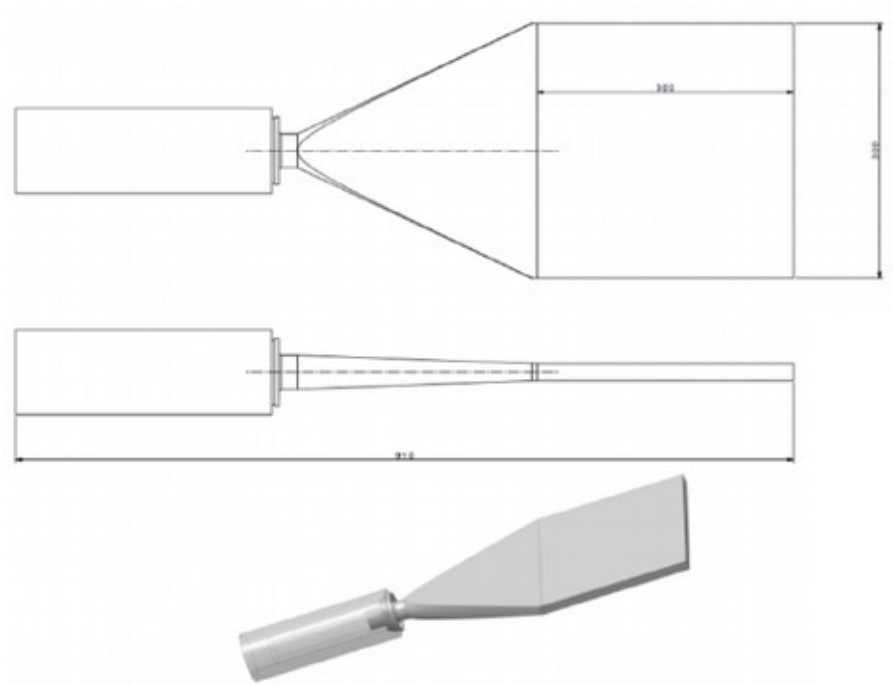


- Neutrals are hard, but charged flux in the simulation can be validated.
- Use to calibrate the simulation as well

- Measure charged flux during current Run 2 behind UXA wall.
- Later, more extensive measurements with different shield thickness, orientations, etc.

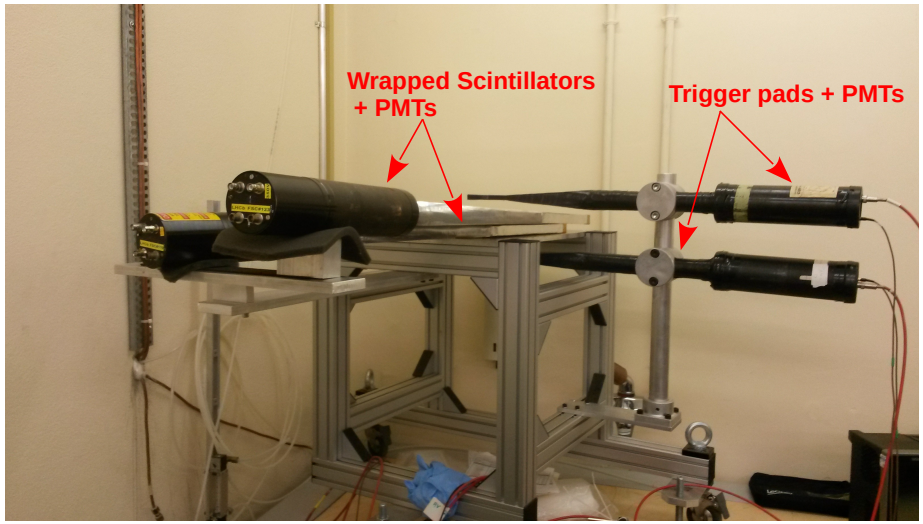
Background studies: measurements (cntd.)

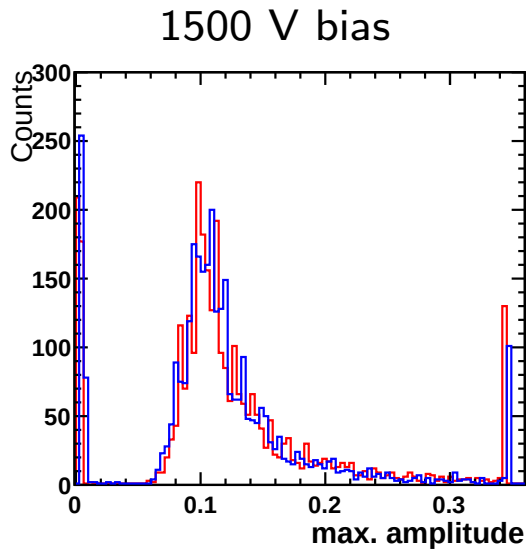
- Two $30 \times 30 \times 2$ cm wrapped plastic scintillators + PMT + mechanical stand.



Background studies: measurements (cntd.)

- Setup tested with cosmics. $\mathcal{O}(3000)$ triggers in a couple of hours.





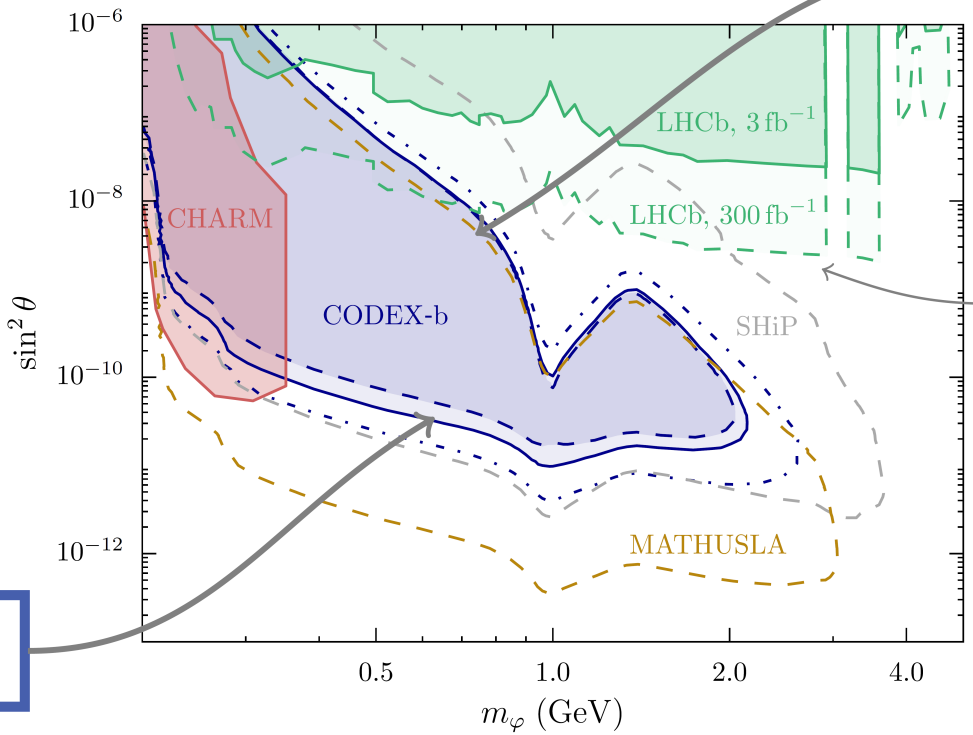
- Hope to get get enough events within around a week in the cavern.

Snapshot of benchmark scenarios

- Evolving situation depending on what timing, calorimetry, PID capabilities of the final detector will be.
- Some benchmark scenarios:
  - Light GeV-scale scalar φ (Higgs mixing)
  - Massive dark photons $\gamma_{\rm d}$ from exotic Higgs decays (kinematic mixing)
  - Heavy Neutral Leptons, (mixing w/ SM neutrinos)
  - Dark glueballs, axion like particles (need calorimetry for γ modes)

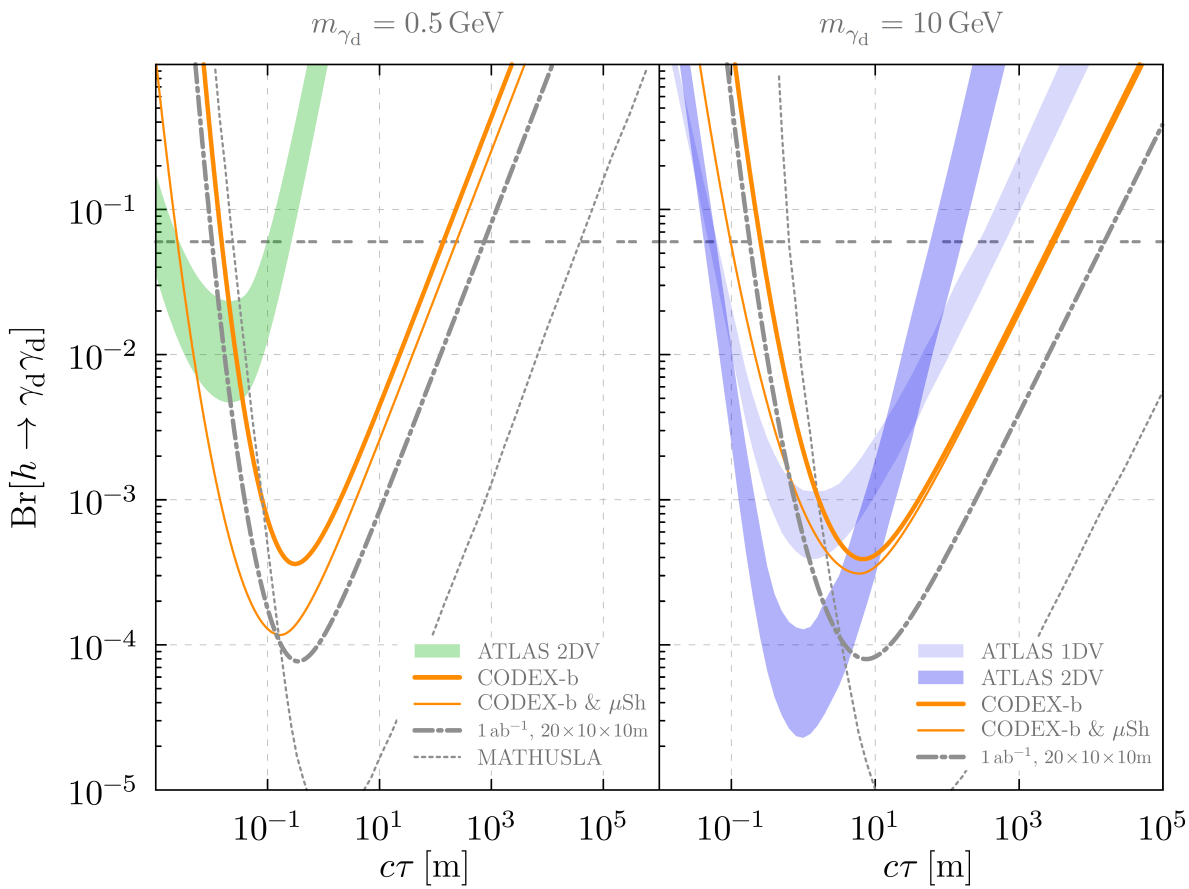
(present reach plots from D. Robinson *et al.*)

$b \to s\varphi$ Higgs-scalar mixing



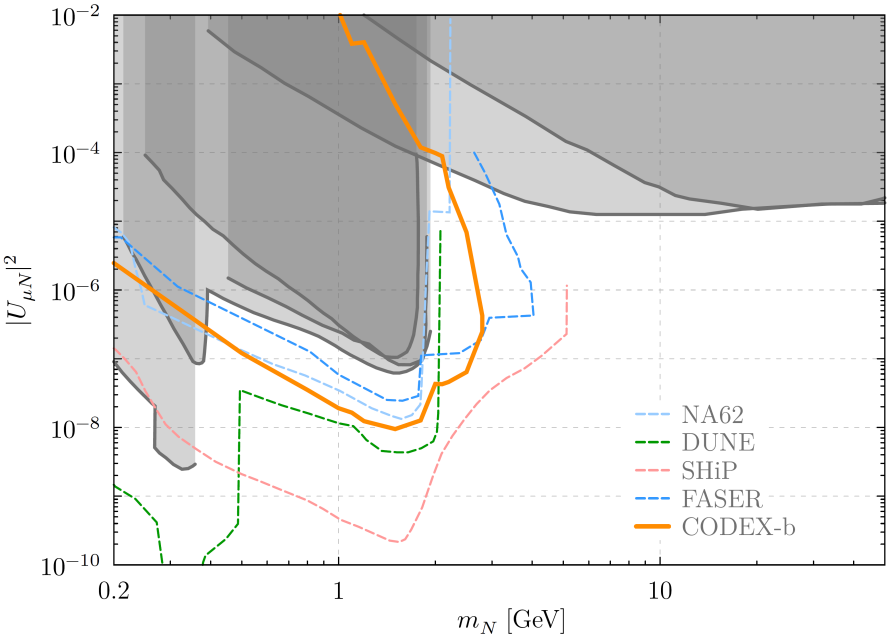
- Extends LHCb reach considerably and covers large part of MATHUSLA/SHiP reach.

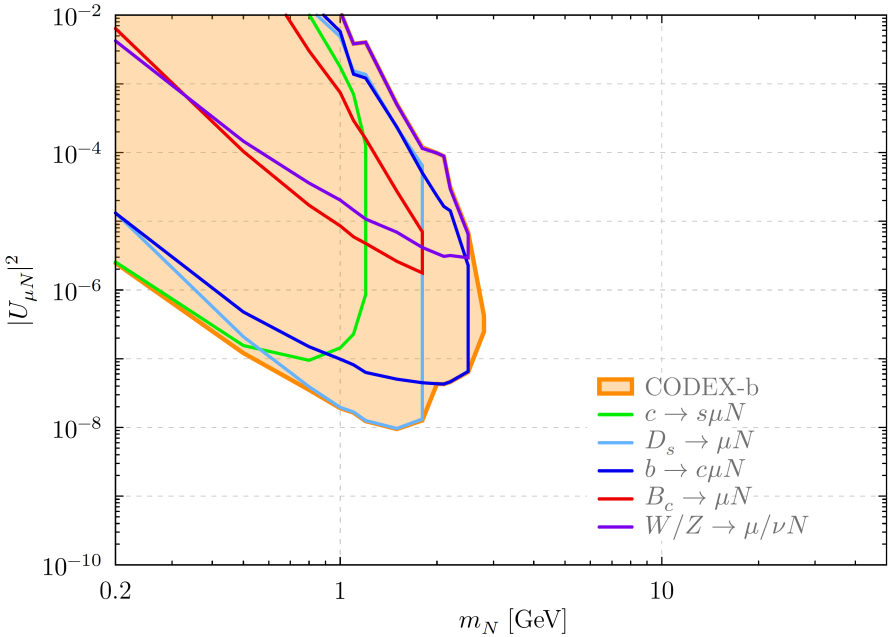
Dark photons from $h \to \gamma_d \gamma_d$ decays



- Extends LHCb reach and at low masses (large boosts), coverage beyond ATLAS.

HNL's: $U_{\ell N}$

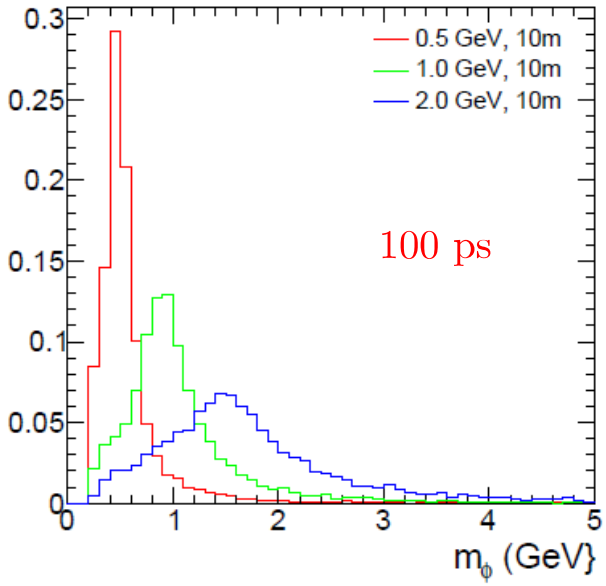


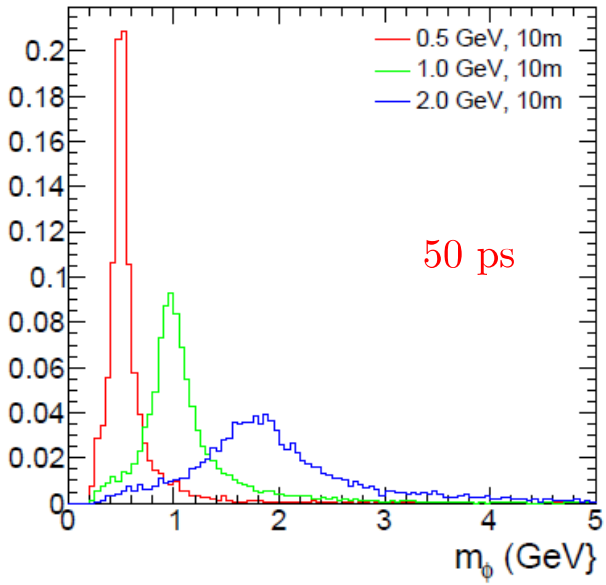


- Different reaches/constraints for $\ell \in \{e, \mu, \tau\}$
- Dominated by charm/B decays at low/high masses.

Mass resolution

- CODEX-b should also be able to do mass analysis depending on tracking + timing resolutions [1705.06327, Curtin/Peskin]
- Require minimum 6 hits/daughter track. Shown for $B \to X\varphi$:





Todo's: near and long-term future

- Studies for physics reach + BG measurements are on track.
- Realistic simulation + tracking in DD4Hep.
- Detector technologies: options for 4d timing+tracking in low radiation/background environment? Calorimetry options?

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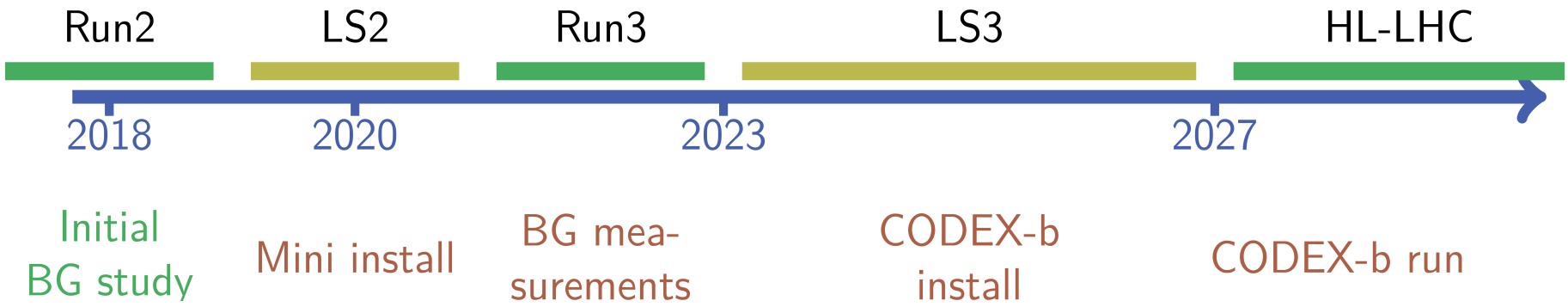

CODEX-b: Who we are

- Theory colleagues:
  S. Knapen, M. Papucci, D. Robinson
- LHCb physicists:
  V. Coco, B. Dey, R. Dumps, V. Gligorov, H. Schindler,
  T. Szumlak, X. Vidal + many others...
- Growing collaboration...you're very welcome to join!!!

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Thanks!