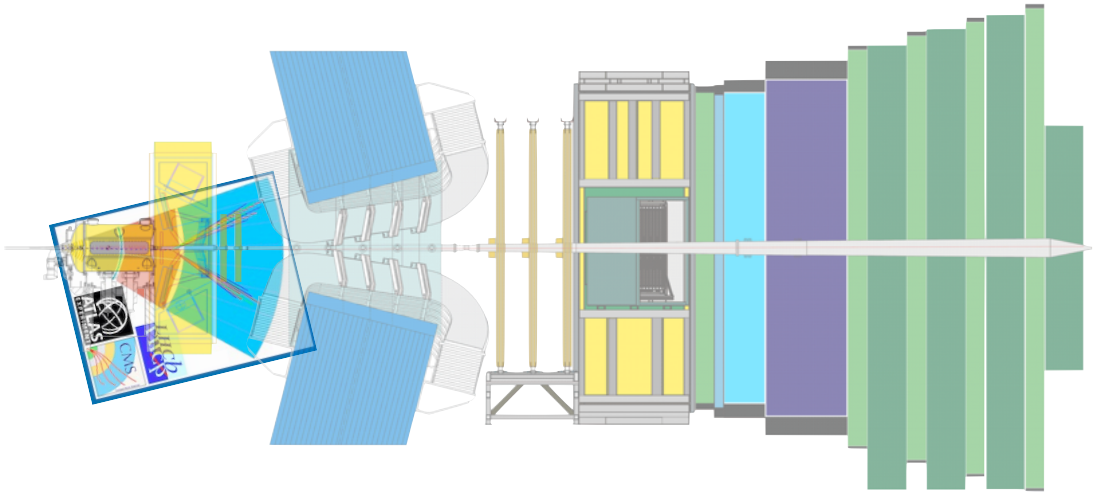
Long Lived Particle studies at LHCb

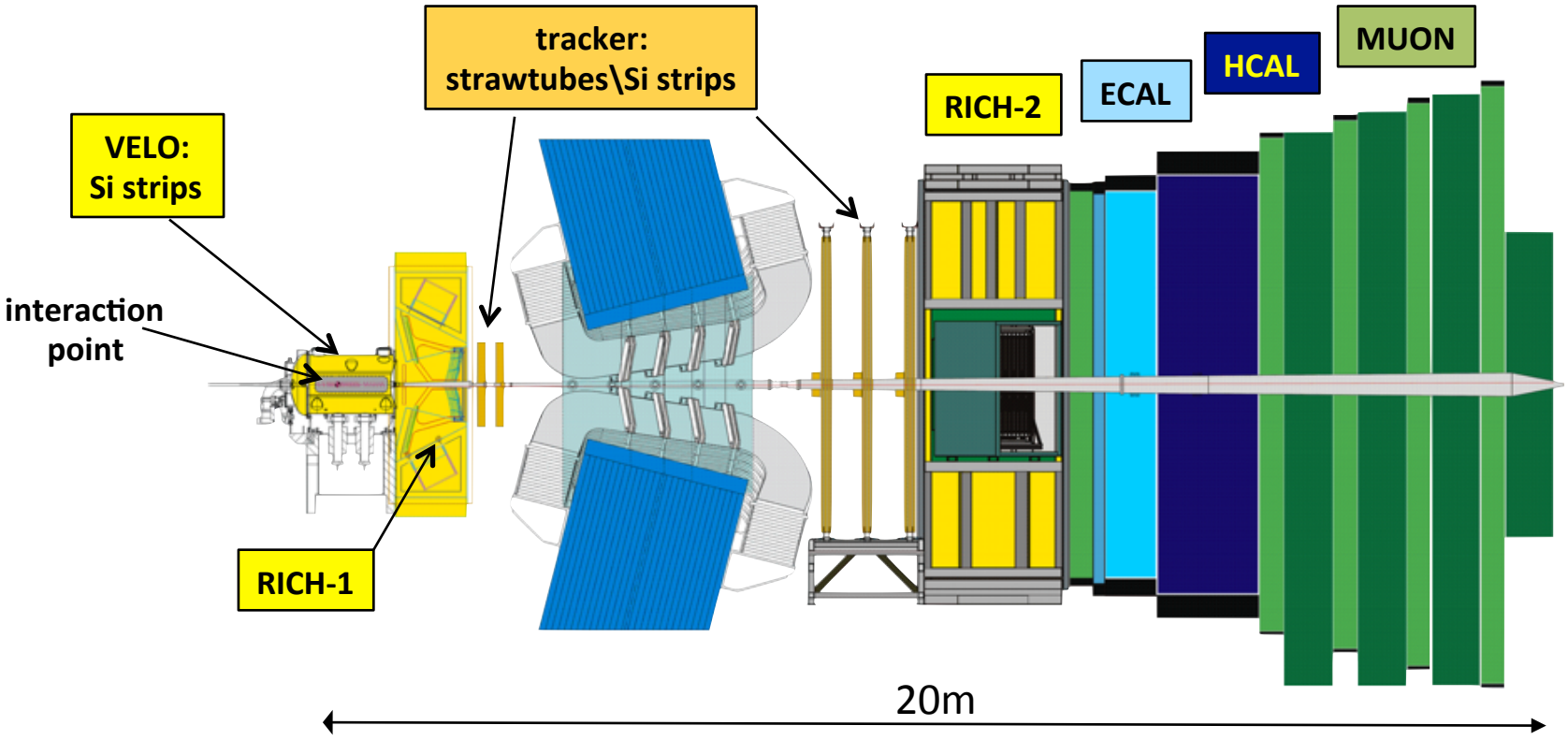
Long lived particle mini-workshop
CERN, May 12th, 2016
https://indico.cern.ch/event/517268/



Wouter Hulsbergen (Nikhef)
on behalf of the LHCb collaboration

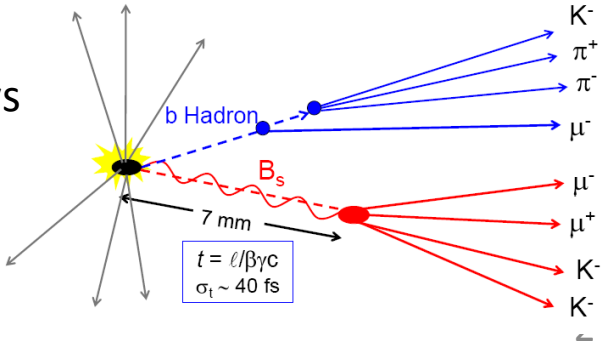
Int.J.Mod.Phys. A 30, 1530022 (2015)

The LHCb detector

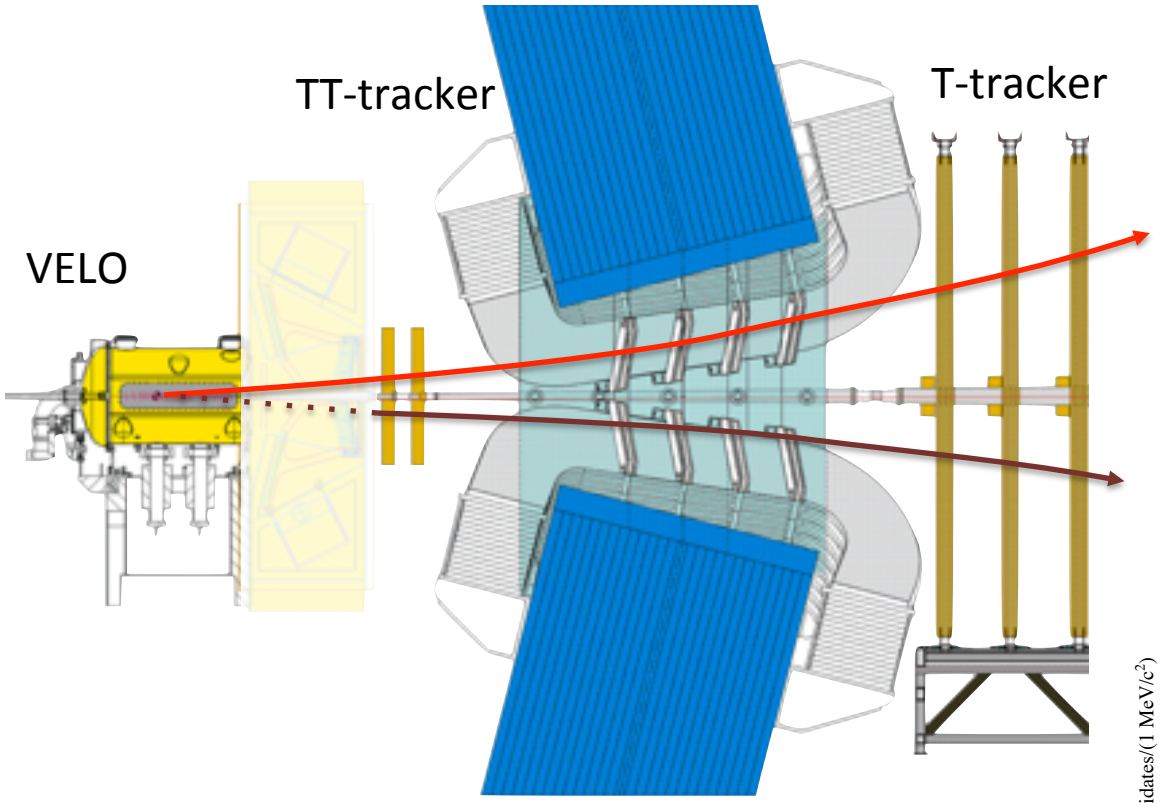


Requirements set by flavour physics

- vertex resolution: resolve Bs flavour oscillations
- excellent p/π/K/μ/e separation: B flavour tagging, rare decays
- momentum resolution: resolve $B/B_s/D/D_s$ etc
- forward acceptance: 10-300 mrad, $2<\eta<5$
- small pile-up (typically 1-2 visible interactions)



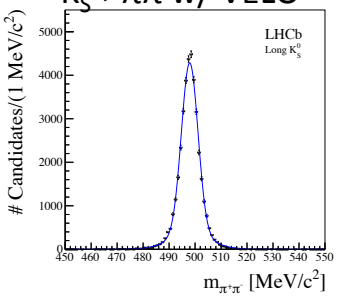
how long is long-lived in LHCb?



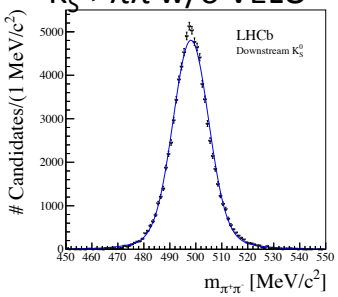
tracks with VELO hits

tracks without VELO hits:
- worse mom and vtx resolution
- not available in trigger

K_S->ππ w/ VELO



K_S->ππ w/o VELO



'reconstructable' decay-lengths are:

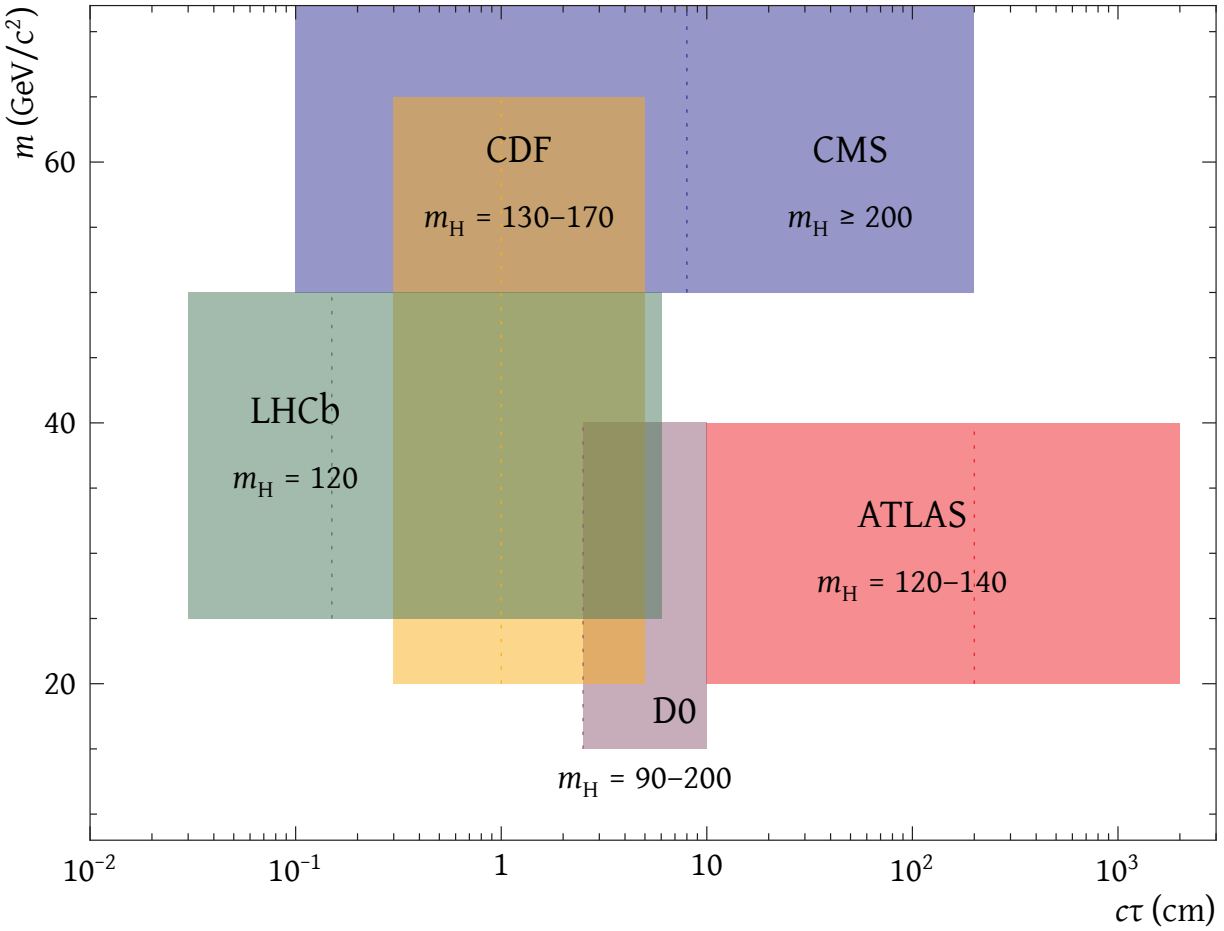
- within VELO: ideally <~ 50 cm (in reality more like ~20cm)
- up to TT: <~200 cm (but not in trigger)

summary of features relevant for LLP searches

- acceptance: **2<eta<5**
  - fully reconstructed resonances must have large boost: **βγ>~3**
  - reasonable efficient only for light objects (<100 GeV)
- decay lengths: **<20cm** (trying to extend to 200cm)
- good mass resolution: 0.5% (two prongs up to m=10GeV) to 2% (for Z->μμ)
- good jet reconstruction (within ~2.2 < η < ~4.2)
  - energy resolution ~10% for jets with pT>10 GeV
  - b(c) tagging efficiency ~65%(25%) for 0.3% light-parton contamination
- calibration+reco in real time: high bandwidth, inclusive trigger (~10kHz)
  - inclusive (hadronic) b, charm
  - 'high pT' muons, electrons: pT>~5GeV (low compare to GDPs)
  - di-muons, practically all!
  - n-jets
- relatively low lumi (bad!), but low pile-up, 1-2 visible interactions (good!)

schematic illustration of difference in coverage

- regions with (subset of) published limits for the LLP->di-jet analysis (see suppl. mat. of cds/record/1975714)



- LHCb covers region at relatively small mass and lifetime

LLP analysis in LHCb

published:

- majorana neutrinos in B→πμμ (arXiv:1401.5361)
- hidden sector χ→μμ in B→K*μμ (arXiv:1508.04094)
- Hidden Valley pions decaying to two jets (arXiv:1412.3021)
- charged massive stable particles (using RICH, arXiv:1506.09173)

work in progress/plans/ideas:

- displaced vertex with jets and lepton (e.g. neutralino)
- events with two displaced vertices (e.g. Higgs decay to 2 v-pion)
- di-muons (motivation e.g. arXiv:1603.08926)
- di-electrons (motivation e.g. arXiv:1509.06765)

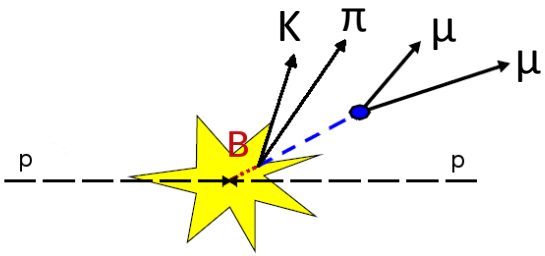
(some more details on later slides)

PRL 115, 161802 (2015)

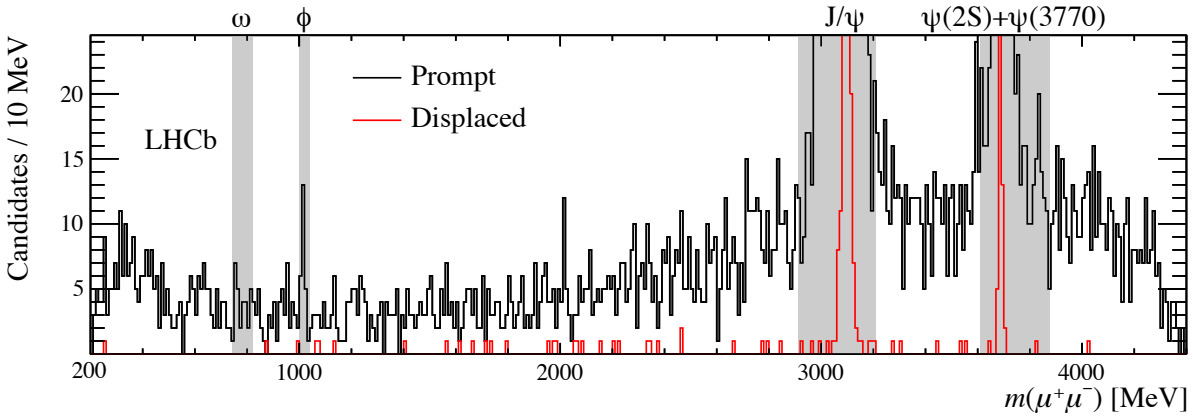
hidden sector $\chi \to \mu\mu$ in $B \to K^* \mu\mu$

- new light narrow scalar resonances, e.g.
  - (prompt) axion (e.g. Freytsis, Ligeti and Thaler, arXiv:0911.5355)
  - (long-lived) inflaton (e.g. Bezrukov and Gorbunov, arXiv:0912.0390)

  accessible via mixing with SM Higgs



- signature: identify μμ mass peak in B->K*μμ events
  - exploit excellent mass resolution (0.2-2 GeV) in clean B sample
  - consider both prompt and long-lived χ
  - selection exploits 'uBoost', to get efficiency flat in (m_χ,τ_χ)
  - normalize to inclusive B->K*

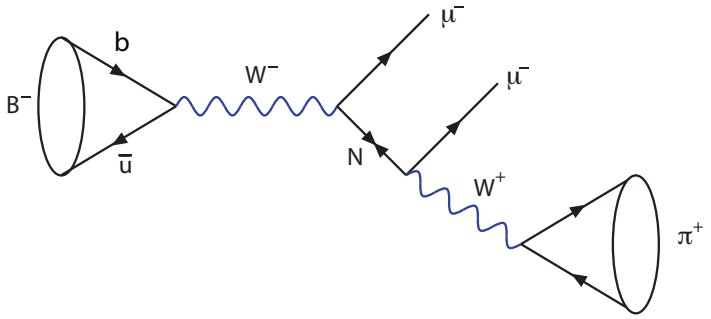


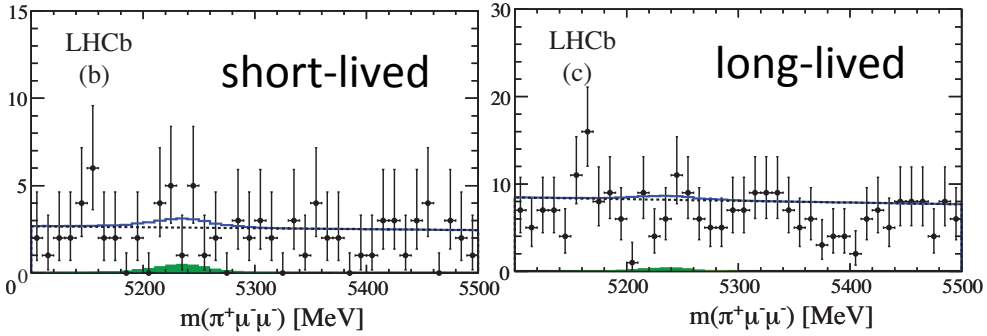
see paper for run-1 limits on
Br(B->K*X) x Br(X->μμ)
as function of (m,τ),
and for derived limits on
axion and inflaton models

PRL 112, 131802 (2014)

majorana neutrinos in B→πμμ

- motivation:
  - some implementations of see-saw predict GeV-scale neutrinos
  - accessible in B and D decays through N-ν mixing
  - clean signature if N is majorana: same-sign muons
  - lifetime is predicted function of N-ν coupling strength
- main search channel in LHCb: $B^+ \to \pi^- \mu^+ \mu^+$
  - look for B mass peak
  - then extract limit as function of N mass
  - consider both prompt and long-lived N





- see paper for run-1 BF limits as function of (m,τ) and derived limits on $|V_{N\mu}|^2$
- for overview, see e.g. Deppisch, Dev, Pilaftsis (arXiv:1502.06541)

- other searches: B->Kμμ, B->D_sμμ, $D_{(s)}$->πμμ

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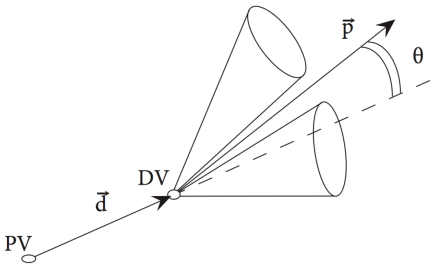
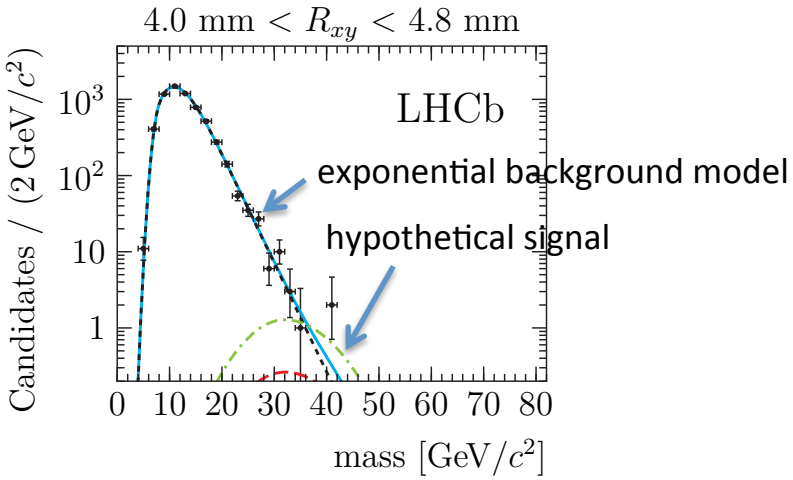
LLPs decaying to two jets

- motivation
  - appear in R-parity violating SUSY and in Hidden Valley models
  - interesting scenario for LHCb: $H^0(125) \rightarrow \pi_v\pi_v$, with $\pi_v \rightarrow q\bar{q}$
    - relatively light (so in LHCb acceptance)
    - well-defined 'simplified model' (SM Higgs decay)
- search strategy in LHCb
  - identify displaced vertex with two associated jets
  - reduce backgrounds with cuts on jet quality 'pointing' and material interaction veto
  - extract limits from fit to di-jet mass in bins of lateral displacement (R_{xy})





- see paper for BF limits in range 25<m<50 GeV and 1<t<100ps
- best sensitivity for m≈50 GeV and t≈5ps:
  exclude 20%-ish Higgs BF with 0.6/fb

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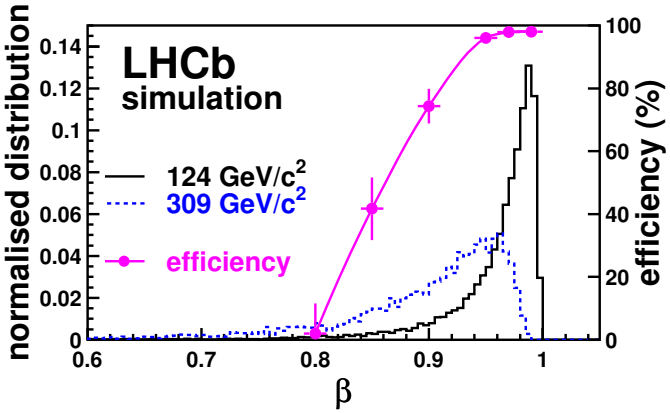
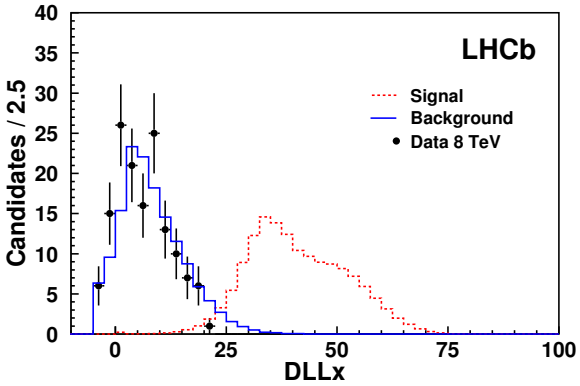
slow massive stable charged particles

- motivation: SUSY sleptons, R-hadrons, etc
  - sleptons (only weak interaction) most interesting for LHCb
- CMSP search in LHCb:
  - consider **stau** pair production via Drell-Yan with $124<m_{\tau}<309$
  - staus look just like muons, but much smaller velocity for equal momentum
  - identify by lack of radiation in Cherenkov detector (RICH)
  - combine with energy deposit in vertex detector and calorimeters





- see paper for limits: current results not competitive with ATLAS/CMS for this model and mass range
- possibly more promising for CMSPs with mass around 10 GeV

Interesting new ideas (to be) followed up in LHCb

- "Inclusive Dark Photon Search at LHCb" (Ilten e.a., arXiv:1603.08926)
  - massive dark sector photon A' couples to SM photon via kinetic mixing
  - signature: resonance in (prompt or displaced) di-muons spectrum
  - extract mixing parameter by normalizing to SM $\gamma^* \to \mu\mu$
  - competitive limits for A' with mass [210-520] MeV and [10-40] GeV
- "Dark photons from charm mesons at LHCb" (Ilten e.a., . arXiv:1509.06765)
  - same motivation, but now look at $A' \to e^+e^-$ in $D^{*0} \to D0\ A'$ decays
  - D* decays provide abundant and clean source of photons in LHCb
  - sensitive to A' with mass below 100 MeV
- Heavy neutrinos in on-shell W decays (e.g. Izaguirre and Shuve, arXiv:1504.02470)
  - like the $B \to \mu\mu\pi$ analysis, but now using $W \to \mu\mu qq'$
  - low mass not competitive with B decays, so look at mass range [5-50] GeV
- "Emerging jets" (Schwaller, Stolarski, Weiler, arXiv:1502.05409)
  - jets with many displaced vertices is smoking gun for dark parton 'shower'

LHCb future

- run-1: collected 3/fb with average pile-up of ~1.8
- run-2: expect about 5/fb with pile-up of ~1.2
- LS2: upgrade of LHCb detector to allow running at higher lumi
  - upgrade of vertex detector, tracking system, PID
  - upgrade of all electronics to allow trigger-less (40 MHz) readout
- run-3: run at ~5x higher pile-up to collect about 50/fb
  - improved efficiency for highly displaced tracks
  - more data