Hidden sector searches using displaced decays in ATLAS

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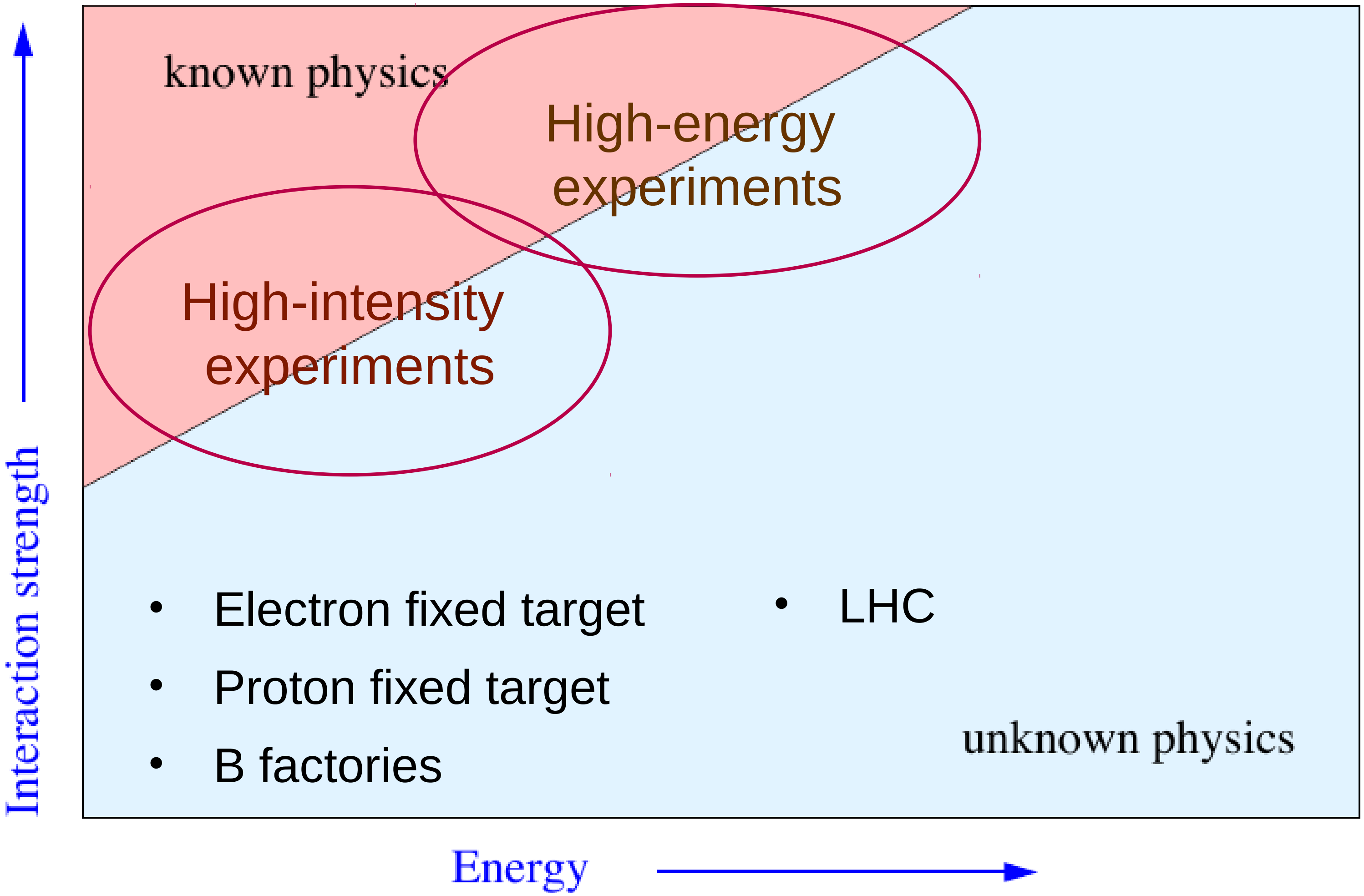
SHiP Collaboration meeting open session
CERN, 8 October 2015

Where to look for new physics?



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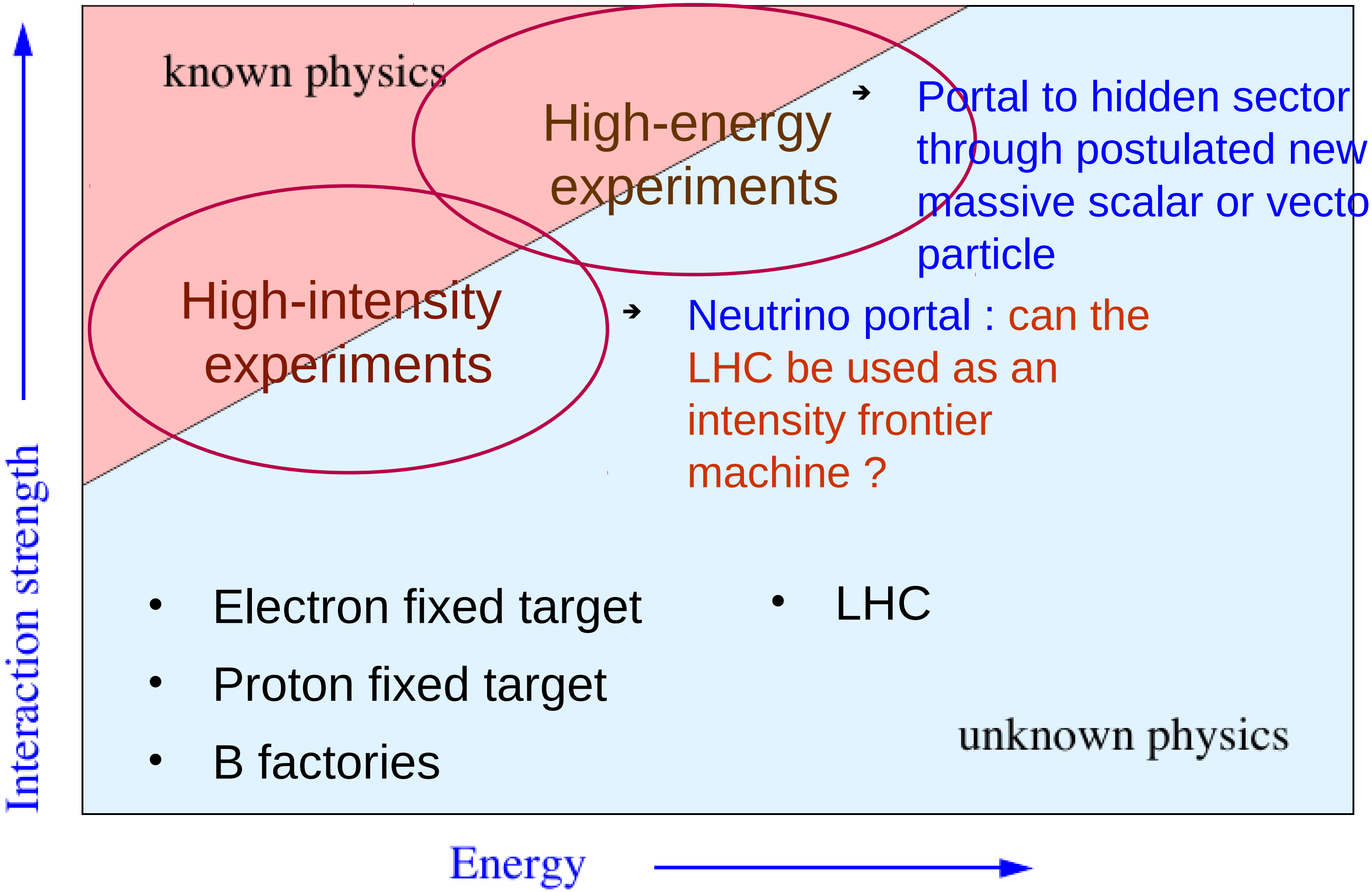


➔ Portal to hidden sector through postulated new massive scalar or vector particle

➔ Neutrino portal : can the LHC be used as an intensity frontier machine ?

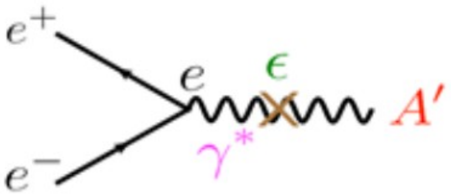
- Electron fixed target
- Proton fixed target
- B factories

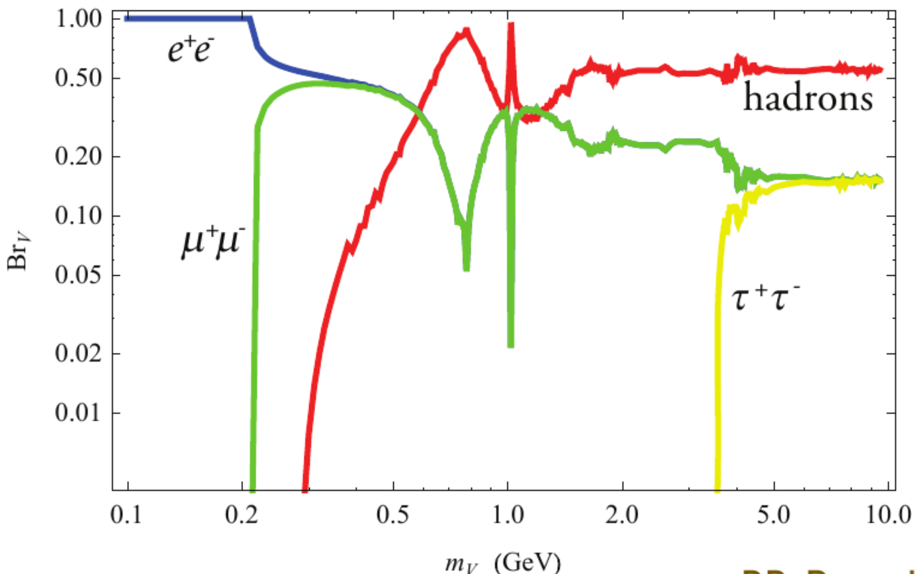
- LHC

Dark photon

hidden sector charged under U(1)'

- g-2, dark matter, positron excess, parity (mirror world),...
- Production via kinetic mixing with the photon
  - Coupling to charged particles suppressed by ε
- Decay to fermion pairs
  - Search for resonances





BB, Pospelov, Ritz

Dark photons in the lab

- Need to produce MANY photons and look for LIGHT resonance
  - B factories
  - Electron fixed-target experiments

Photon portal

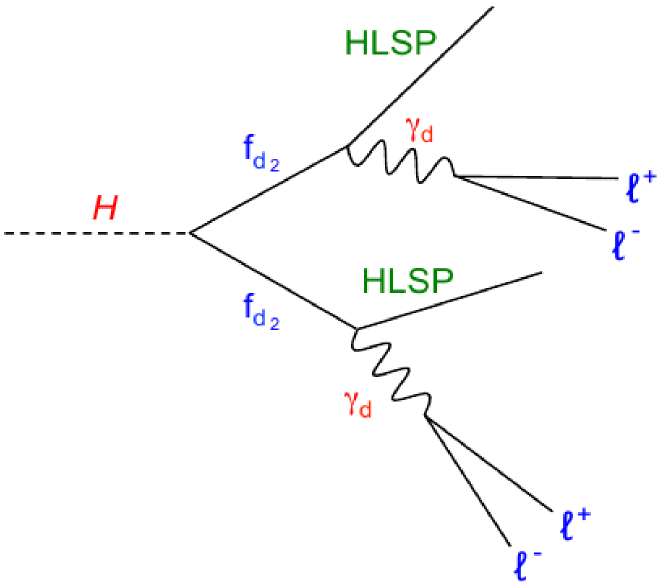
- The LHC is NOT ideal !
  - Not so many photons
  - Large backgrounds at low mass

Higgs portal

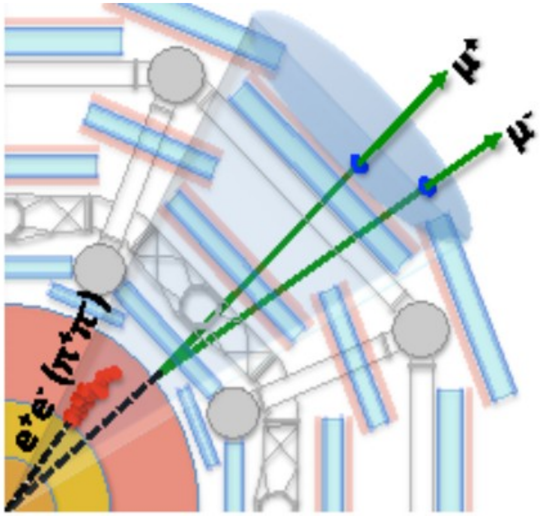
- Strategy at ATLAS : assume production via Higgs decay
  - Hidden fermions f_d coupling to Higgs (assume also $H \rightarrow f_d f_d$ BR) and decaying eg into dark photons
  - No longer a simple scenario of new physics – need a couple new parameters in addition to ε and $m_{\gamma d}$
  - Interesting signatures in ATLAS worth investigating : displaced vertices (special triggers : JINST 8, P07015 (2013))

Displaced lepton-jets with ATLAS

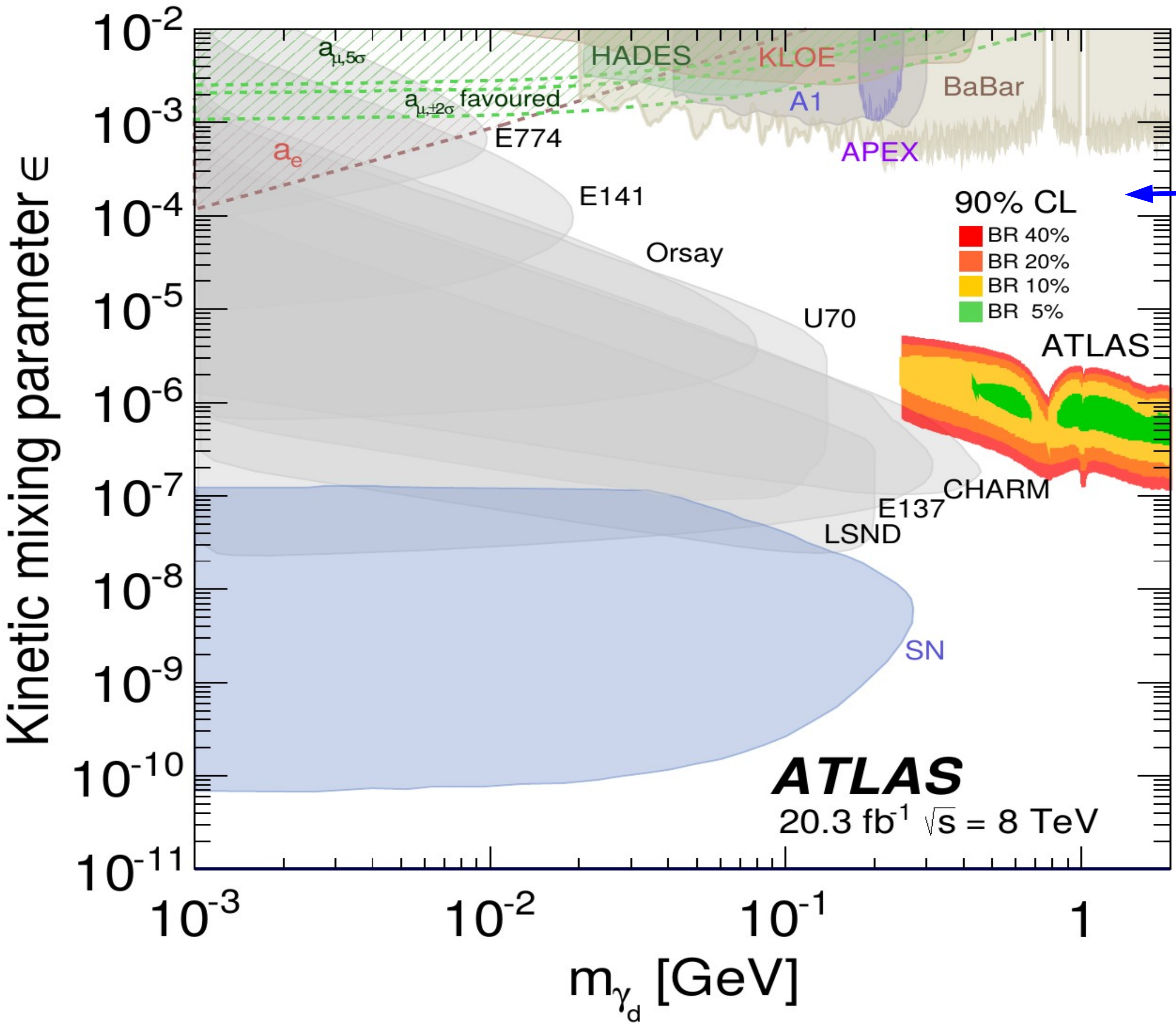
JHEP 11, 088 (2014)



- Dark photon through Higgs portal
- Triggers: either three muons, or special "calorimeter ratio"
- Search for events with two "displaced lepton-jets"
  - definition : at least two collimated tracks in muon spectrometer with no matching track in inner detector, or a narrow trackless calorimeter deposit with low electromagnetic fraction



Dark photon limits



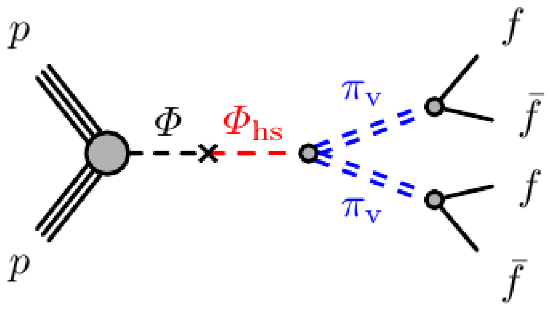
This range probed with prompt lepton-jet analysis (paper coming very soon)

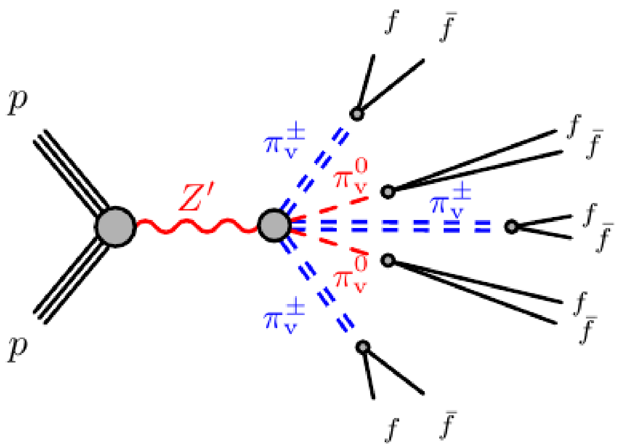
Remember : ATLAS limits rely on more assumptions

Displaced hadronic jets with ATLAS

Phys. Lett. B 743, 15 (2015)
Phys. Rev. D 92 012010 (2015)

- Triggers : special "calorimeter ratio", or special "muon RoI cluster", or jet+MET
- Select events with two displaced jets in hadronic calorimeter (with low EM fraction), in inner tracking detector, or in muon spectrometer
- Interpretation in "Hidden valley" models
  - Scalar and vector portals : assumes heavy mediator and hidden pions decaying back into jets after some distance

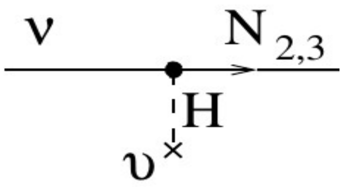


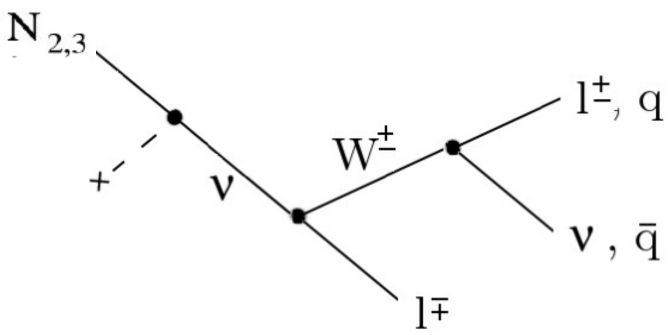


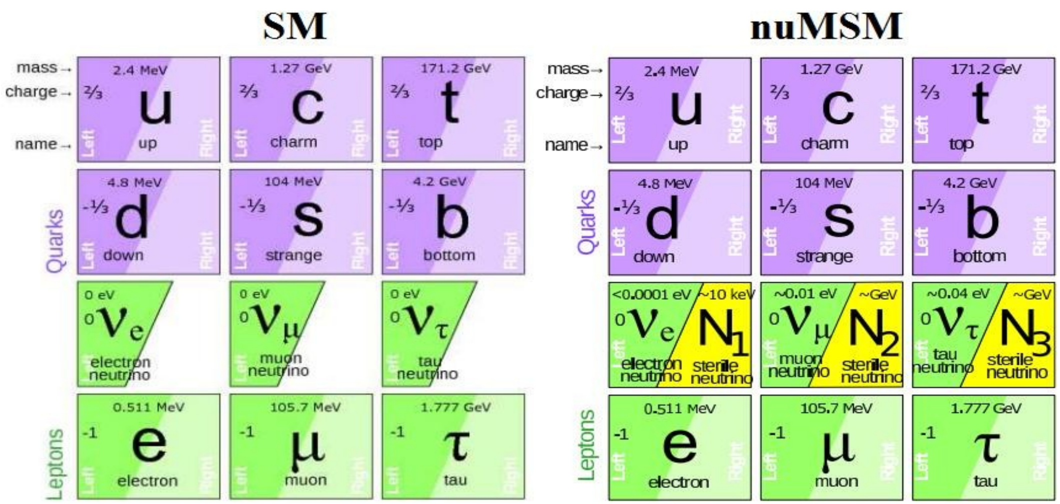
Heavy neutral lepton (HNL)

right-handed neutrino

- Neutrino masses, dark matter, X-ray astronomy, matter-antimatter asymmetry
- Production via mixing to neutrinos (neutrino portal)
- Decay to llν or l+hadron(s)







N_1 stable dark matter

$N_{2,3}$ long-lived, mass in 0.2-100 GeV range

HNLs from W and Z decays at colliders

- Probing masses up to 90 GeV
- LEP1 (Z resonance)
  - Delphi : Z. Phys. C 74, 57 (1997)
  - ~ 10^6 νs from Z decays
  - displaced decays for masses up to 4 GeV
- Tevatron (2 TeV)
  - ~10^7 νs from W decays
  - Low mass or prompt → large backgrounds, no search made
- LHC Run1 (8 TeV)
  - ~10^9 νs from W decays in ATLAS and CMS
  - Displaced decays for masses up to ~25 GeV
- LHC Run2 (14 TeV)
  - ~10^9 νs for each 25 fb^{-1} from W decays in each experiment
  - The LHC is indeed an intensity frontier machine !

small mixing → long lifetime

low mass → long lifetime

Quick comment on displaced vs. prompt HNL signatures

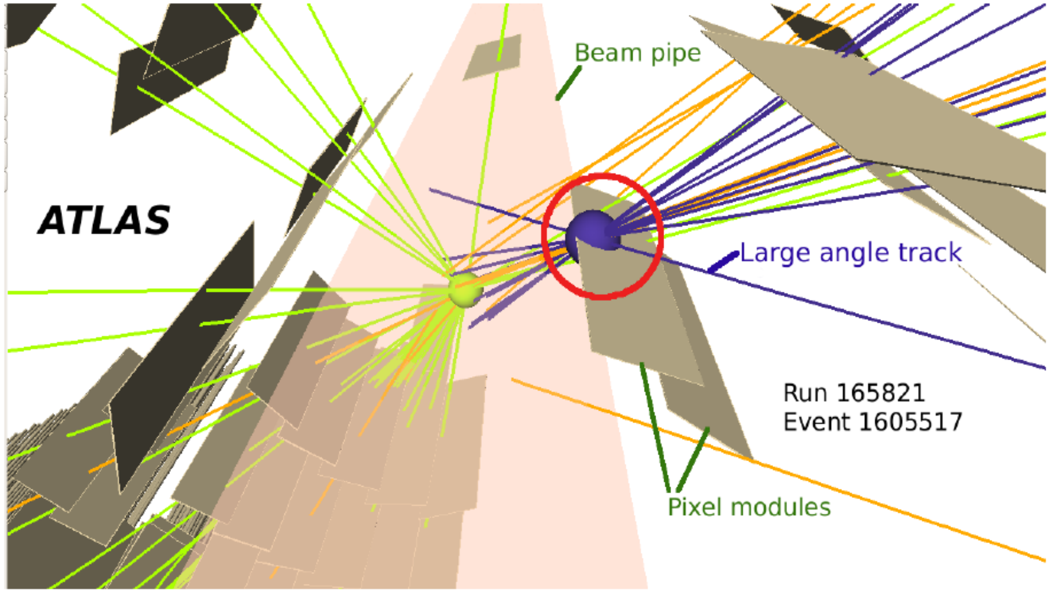
- Here we consider HNLs with masses below W mass
  - Favoured by cosmology
  - Realm of SHiP physics
  - Displaced vertex signature
- HNLs with masses >~100 GeV can also be probed at ATLAS

  (eg JHEP 07, 162 (2015))
  - Off-shell W → can probe only large mixing
  - That leads to prompt decays → to suppress backgrounds, need stringent cuts (high-pT jets, same-sign leptons...)
  - This is not discussed in this talk

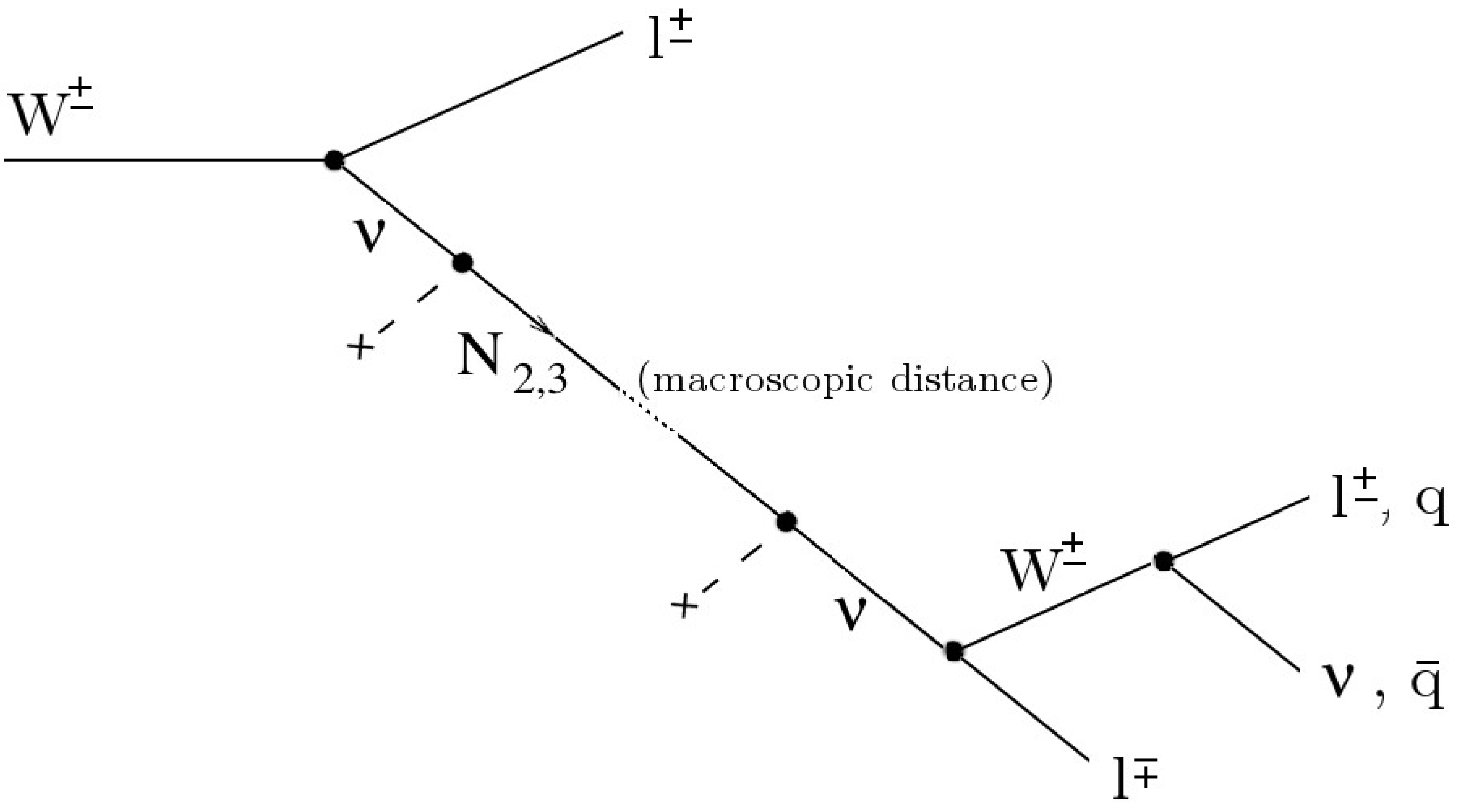
ATLAS search for HNLs from W decays

- Run-1 searches for displaced vertices in inner detector (PLB 707, 478; PLB 719, 280; JHEP 11, 088; PLB 743, 15; PRD 92, 012010; arXiv:1504.05162)
  - Not sensitive to HNLs due to high pT thresholds, or requirement of two displaced vertices
  - Adequate track and vertex reconstruction tools, similar backgrounds

- Dedicated HNL search possible and needed
  - Phys. Rev. D 89, 073005 (2014), arXiv:1312.2900
  - Phys. Rev. D 91, 093010 (2015), arXiv:1504.02470



HNL signature in ATLAS



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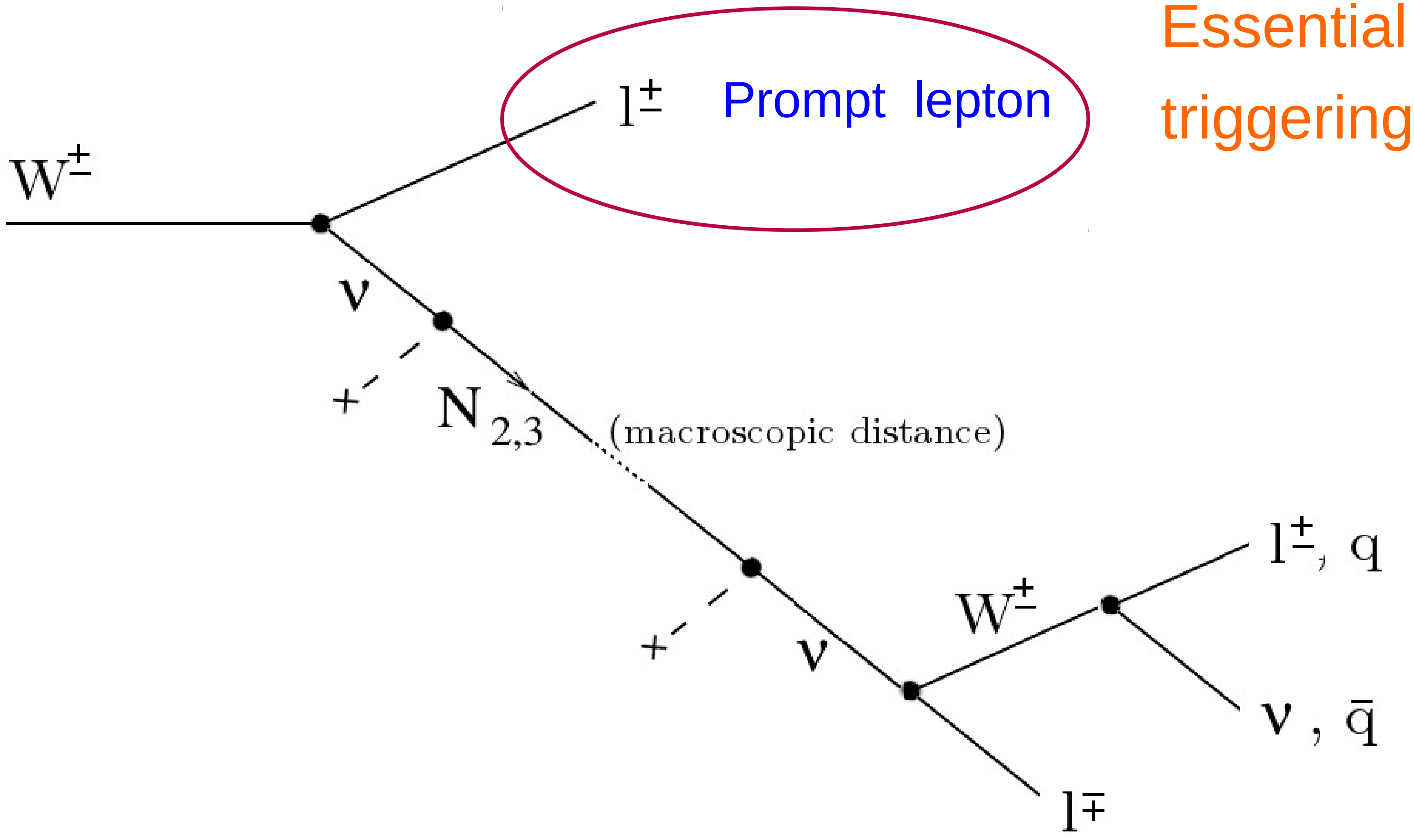
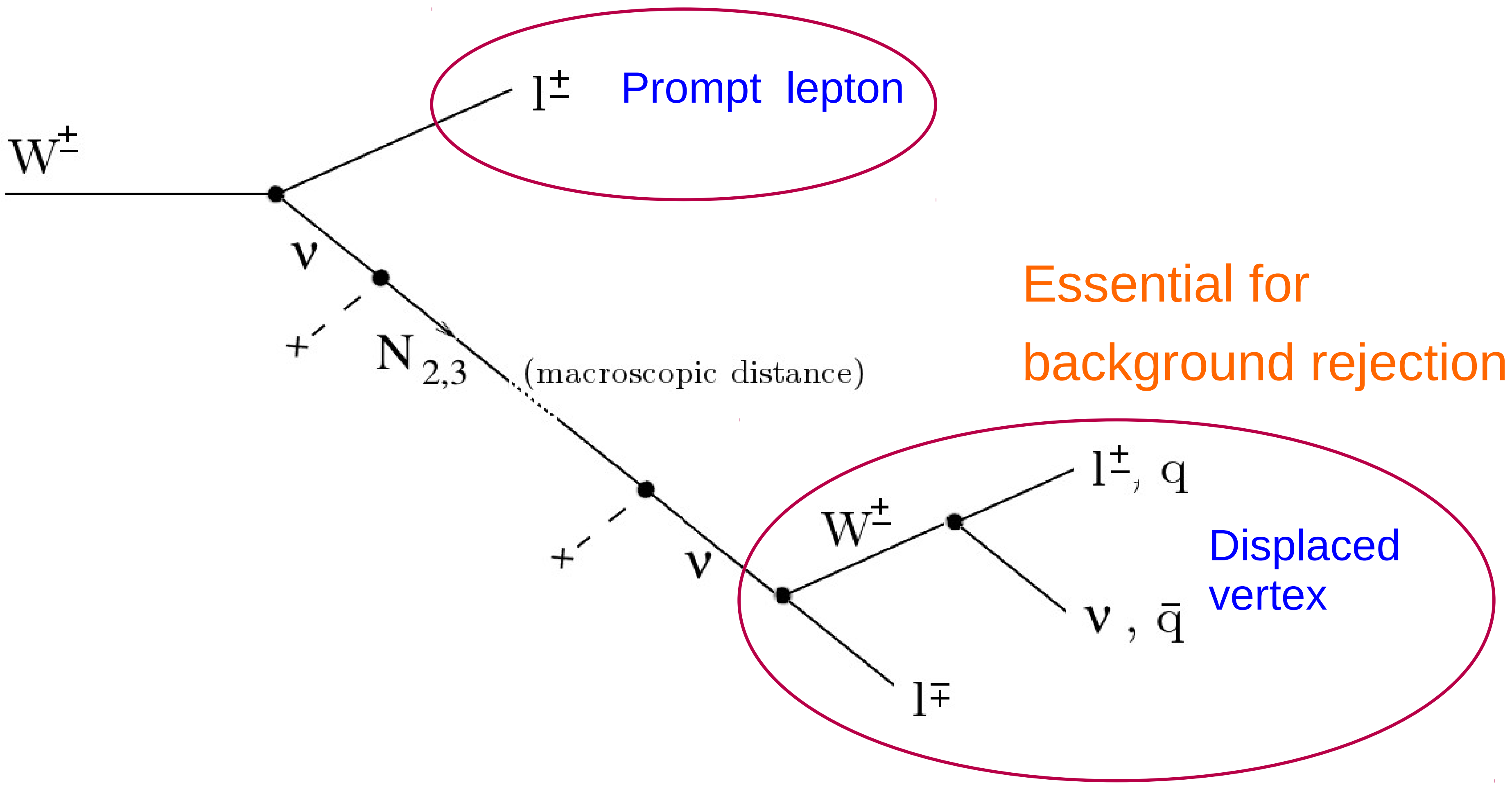


Essential for triggering

HNL signature in ATLAS



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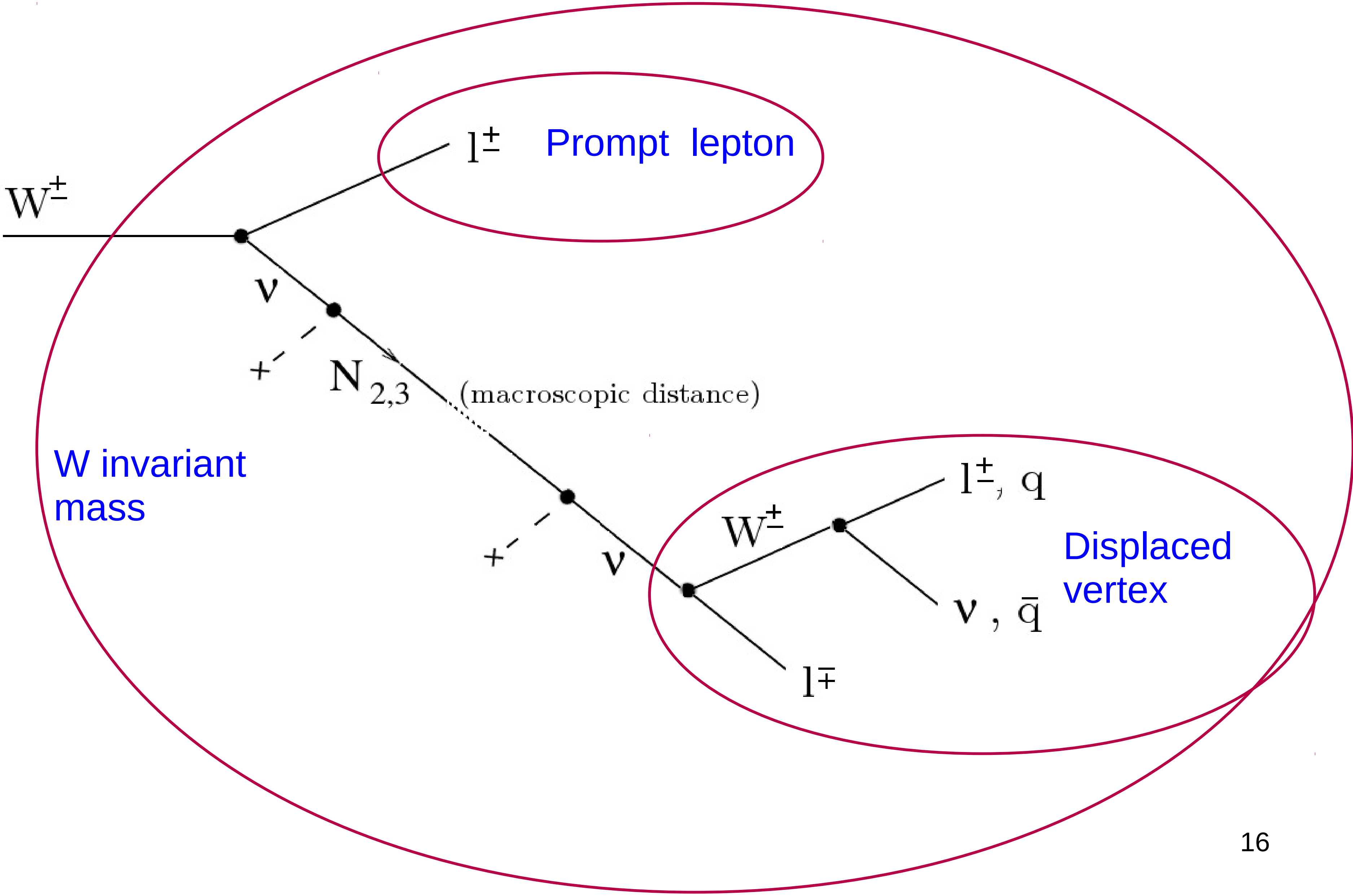

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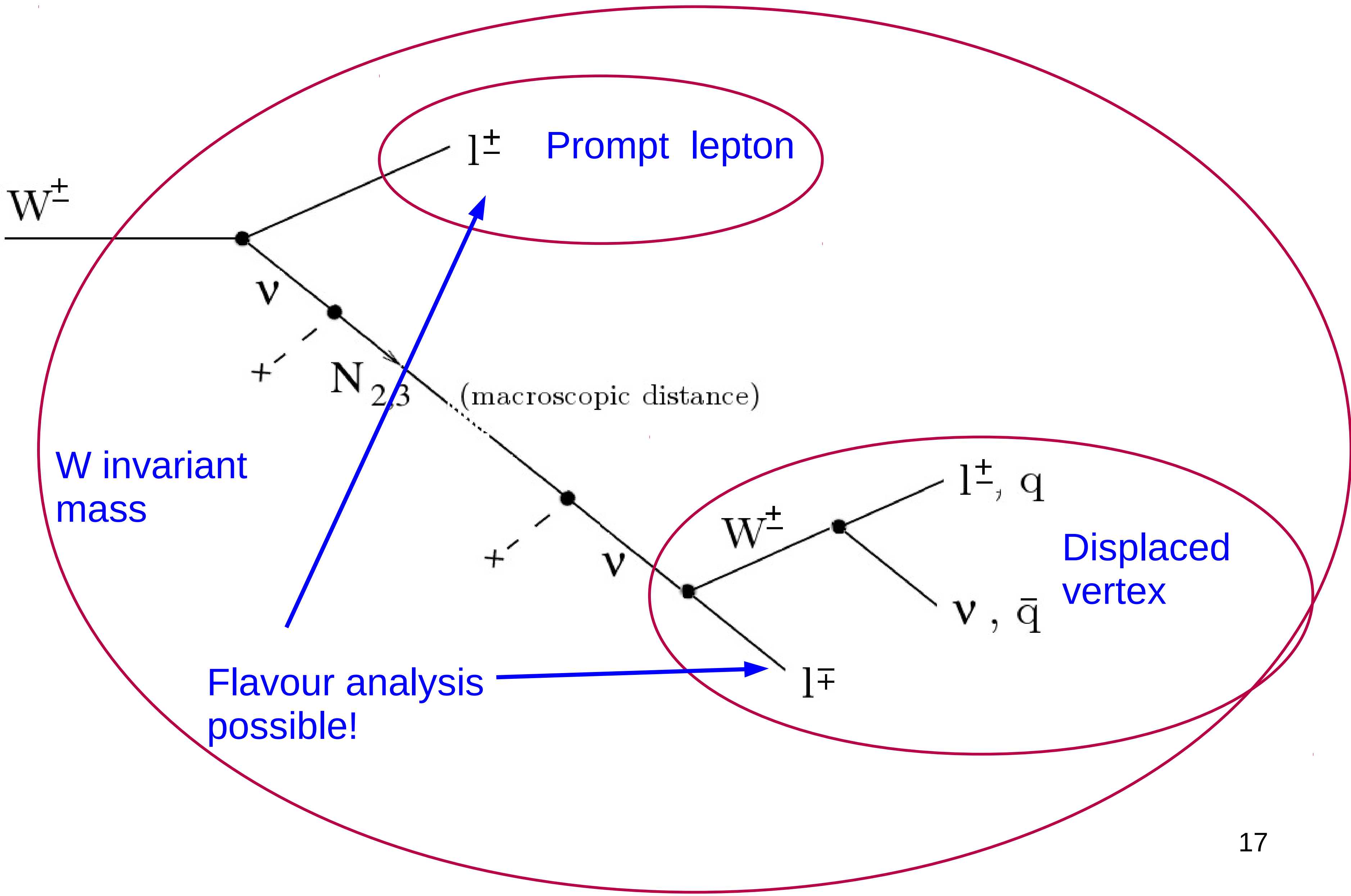
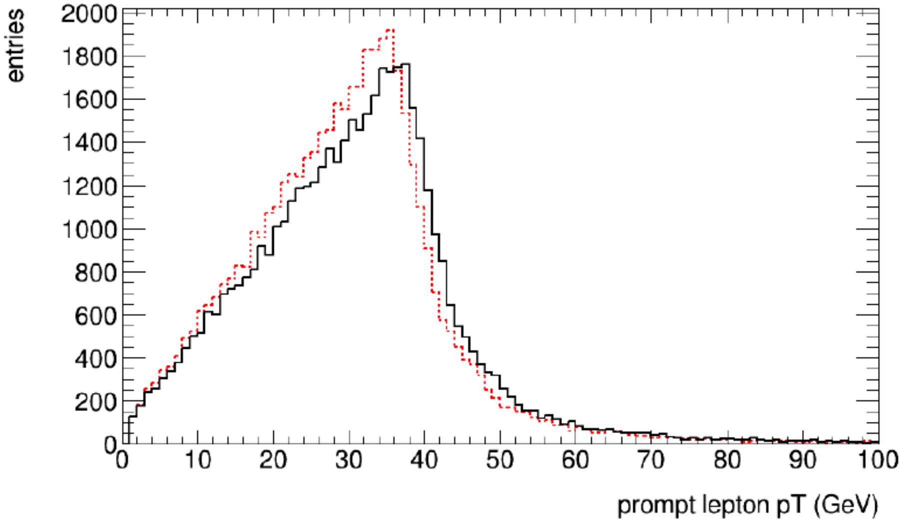
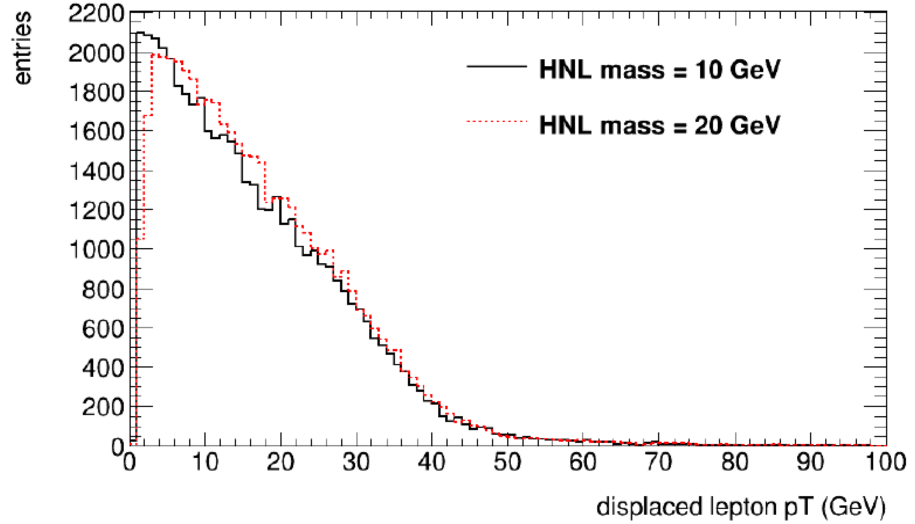


Challenge 1 : low-pT signal





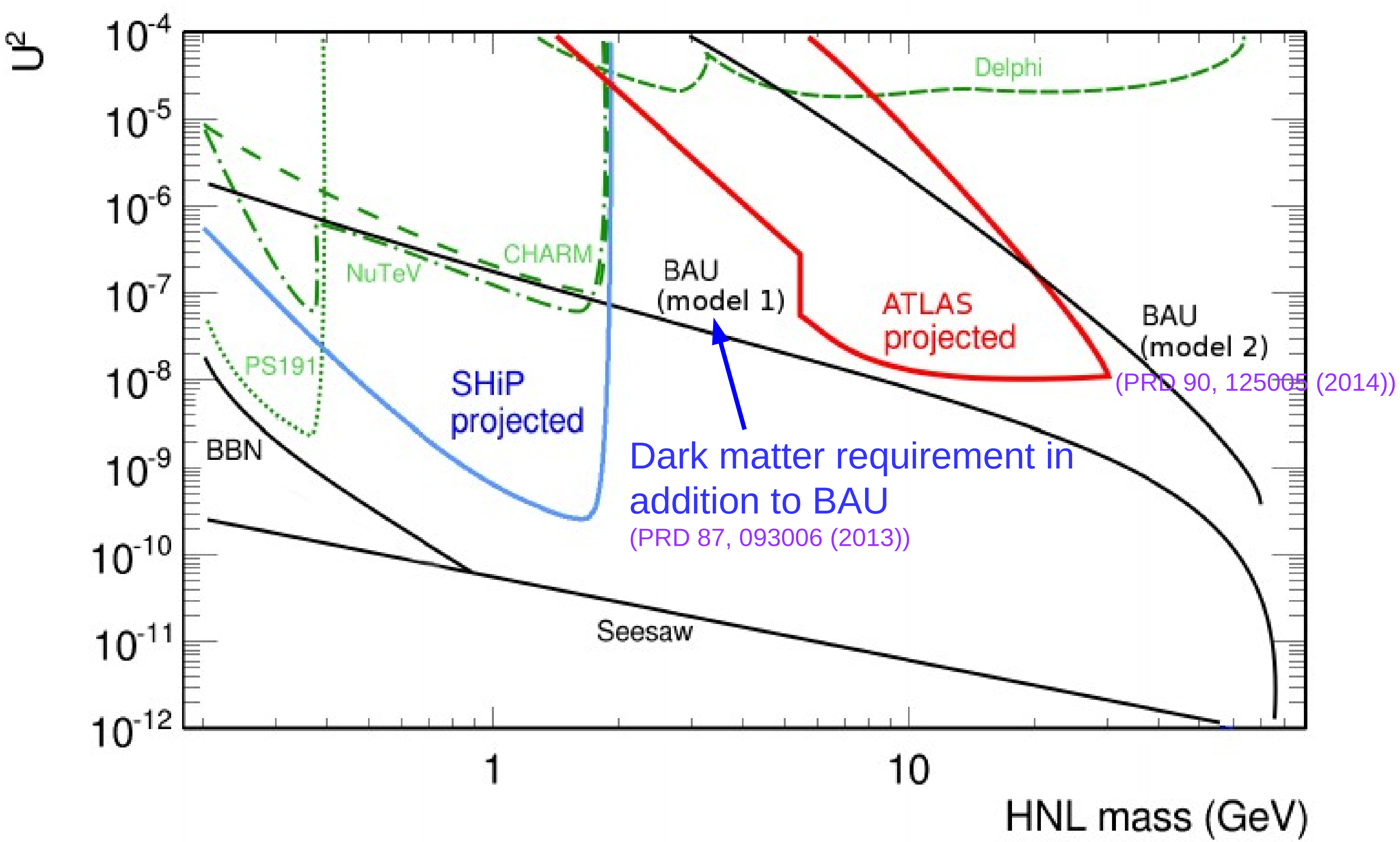
- Prompt lepton used for triggering (~45% efficiency)
- Backgrounds can still be reduced to negligible levels
  - Requirement on vertex distance
  - Lepton identification among particles forming the vertex
  - Requirement on vertex mass
  - Material veto to reduce hadronic-interaction backgrounds
  - Kinematic fit using W mass constraint

Challenge 2 : need for “retracking”

- Standard ATLAS tracking requires low impact parameter (D0), inefficient for displaced tracks
- The data therefore needs processing with special tracking. This is consuming in terms of data storage and CPU and thus a smart filter is needed to reduce event rate/size while retaining signal events.
- Such a filter was implemented for ATLAS HNL analysis in the muon final state
  - One prompt isolated muon with pT > 28 GeV
  - Another muon with pT > 5 GeV and D0 > 1 mm if it is matched with inner detector track
- Will later reprocess the data for retracking with electron final state (more challenging)

Approximate expected sensitivity to HNL

observing 1 event assuming 100 fb^{-1} @ 14 TeV in ATLAS



Summary

- Complementary searches for hidden sectors can be made at dedicated fixed-target experiments and colliders
- New massive particles that couple to both sectors could be accessed by the LHC – but that requires extra assumptions
- The LHC is a W factory, providing access to the neutrino portal at high mass
- Using the unique signature of a displaced vertex, ATLAS can probe unexplored regions of the parameter space for HNL masses between 2 and 30 GeV

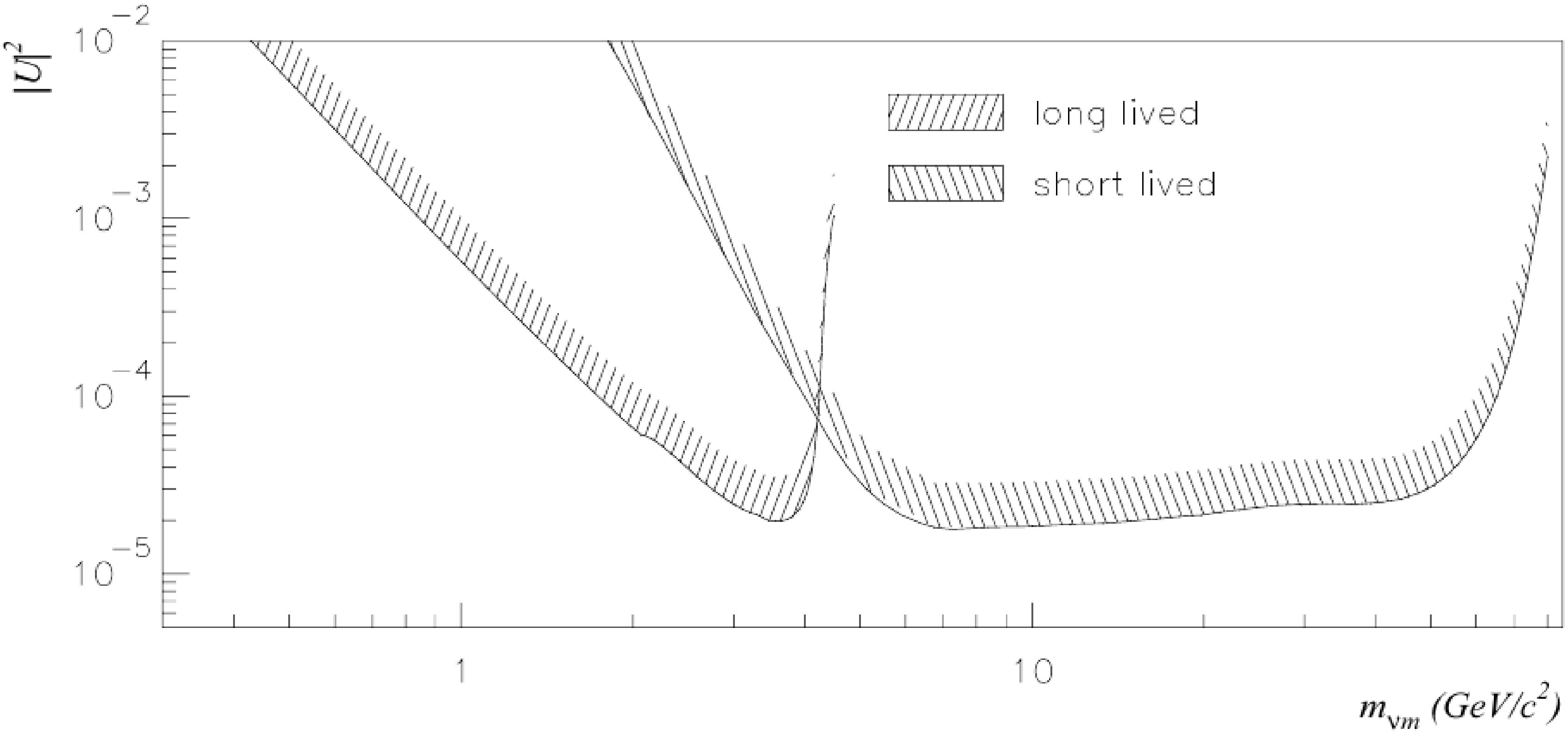
(extra slides)

HNL search with Delphi

Z. Phys. C 74, 57 (1997)

Search for heavy neutral leptons in Z decays

- $3 \cdot 10^6$ Zs
- Both prompt and displaced decays to lW and νZ



HNLs at future circular colliders

- CERN Future Circular Collider (FCC) design study
  - ~100 km ring
  - Conceptual design report to be prepared for 2018
- FCC-ee: 10^{13} Zs, Higgs factory...
- FCC-hh: 100 TeV pp collisions

- Dedicated displaced vertex analyses at FCC can achieve several orders of magnitude improvement in sensitivities to HNLs in mass range 2–90 GeV
  - arXiv:1411.5230

The (approximate) big picture

assumes 50 fb^{-1} @ 14 TeV in both ATLAS and CMS

assumes 10^{13} Zs for FCC-ee with LHC-sized detector