Right-handed neutrinos: can LHC find them?

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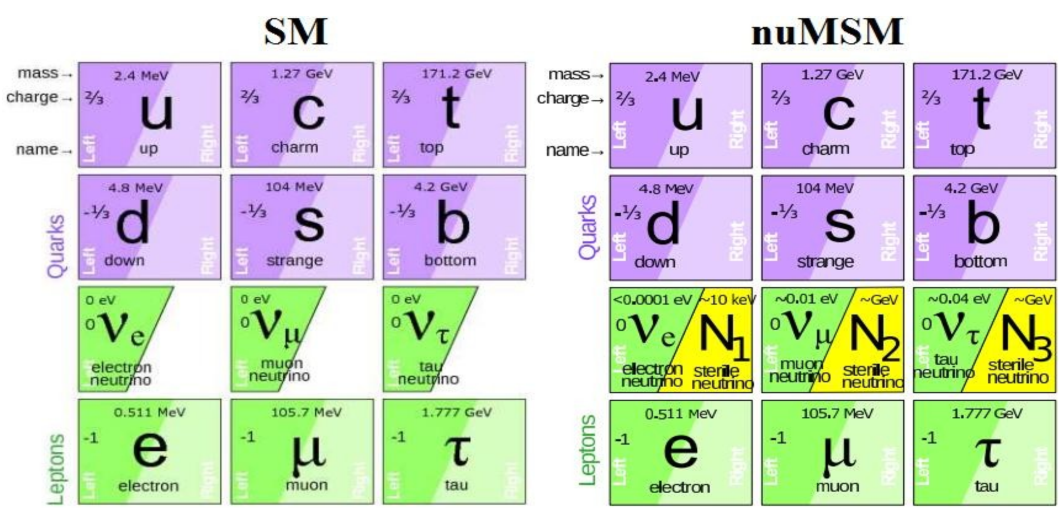
The neutrino Minimum Standard Model (νMSM)

Ann. Rev. Nucl. Part. Sci. 59, 191 (2009)

- Postulate three majorana right-handed neutrinos with masses below the EW scale
- Explain neutrino masses, and accommodate for dark matter and matter-antimatter asymmetry

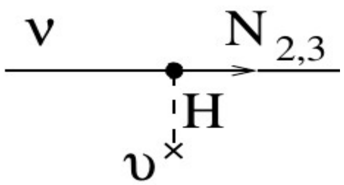


Light (N_1) stable dark matter

$N_{2,3}$ long-lived

Direct searches for $N_{2,3}$

- Production through mixing with ordinary neutrinos
- Probe small mixing → need many neutrinos
- Possibilities at existing accelerator facilities:



ν source	$N_{2,3}$ mass	best machine	number of νs	remarks
c	< 2 GeV	SPS dump	$5 \cdot 10^{16}$	SHiP experiment
τ	< 2 GeV	KEKb	10^{9}	third generation
b	< 5 GeV	KEKb	10^{8}	
		LHC	10^{13}	low acceptance / large backgrounds
W	< 80 GeV	LHC	10^{9}	**focus of this talk**
Z	< 90 GeV	LEP1	$7 \cdot 10^{6}$	difficult at hadron colliders

- For M > 2 GeV, best current constraints are from LEP1
- Tiny mixing / long lifetime (10^{-11} – 0.1 s) allowed by observations and cosmology
  - Displaced vertices!
  - Could be done at the LHC (Phys. Rev. D 89, 073005 (2014))
  - Need also SHiP, FCC

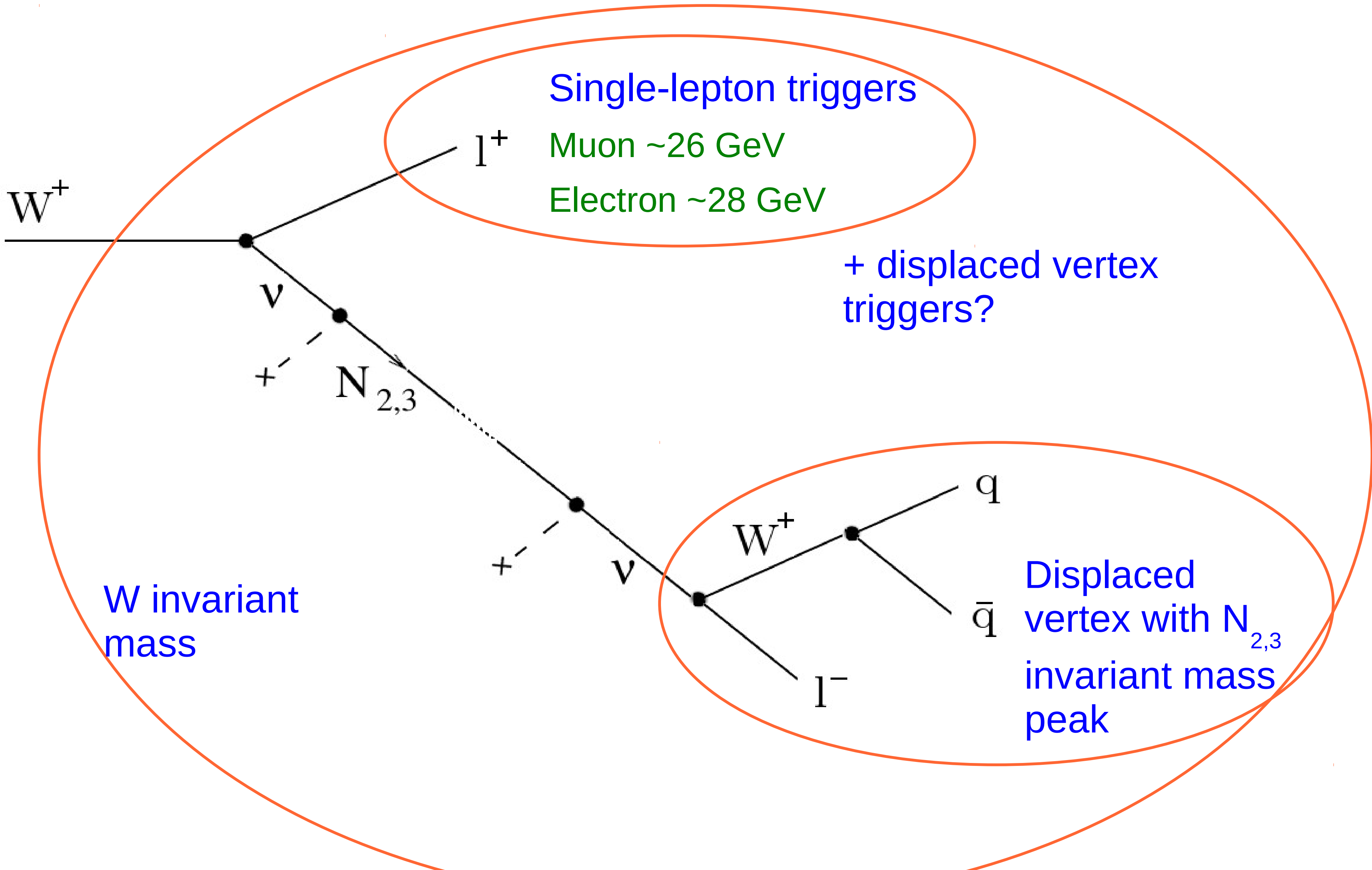
Lepton collider vs. hadron collider

- e^+e^-
  - Can exploit Z resonance
  - No trigger issues
- pp
  - Cross section: W ~10X larger than Z
  - Use lepton from W for triggering and for flavour analysis

Neutrinos from W decays at the LHC

- Run1 (8 TeV)
  - Already produced $5 \cdot 10^8$ νs (e+μ) in each experiment
- Run2 (14 TeV)
  - 10^9 νs (e+μ) for each 25 fb^{-1} in each experiment

Main signature in ATLAS or CMS



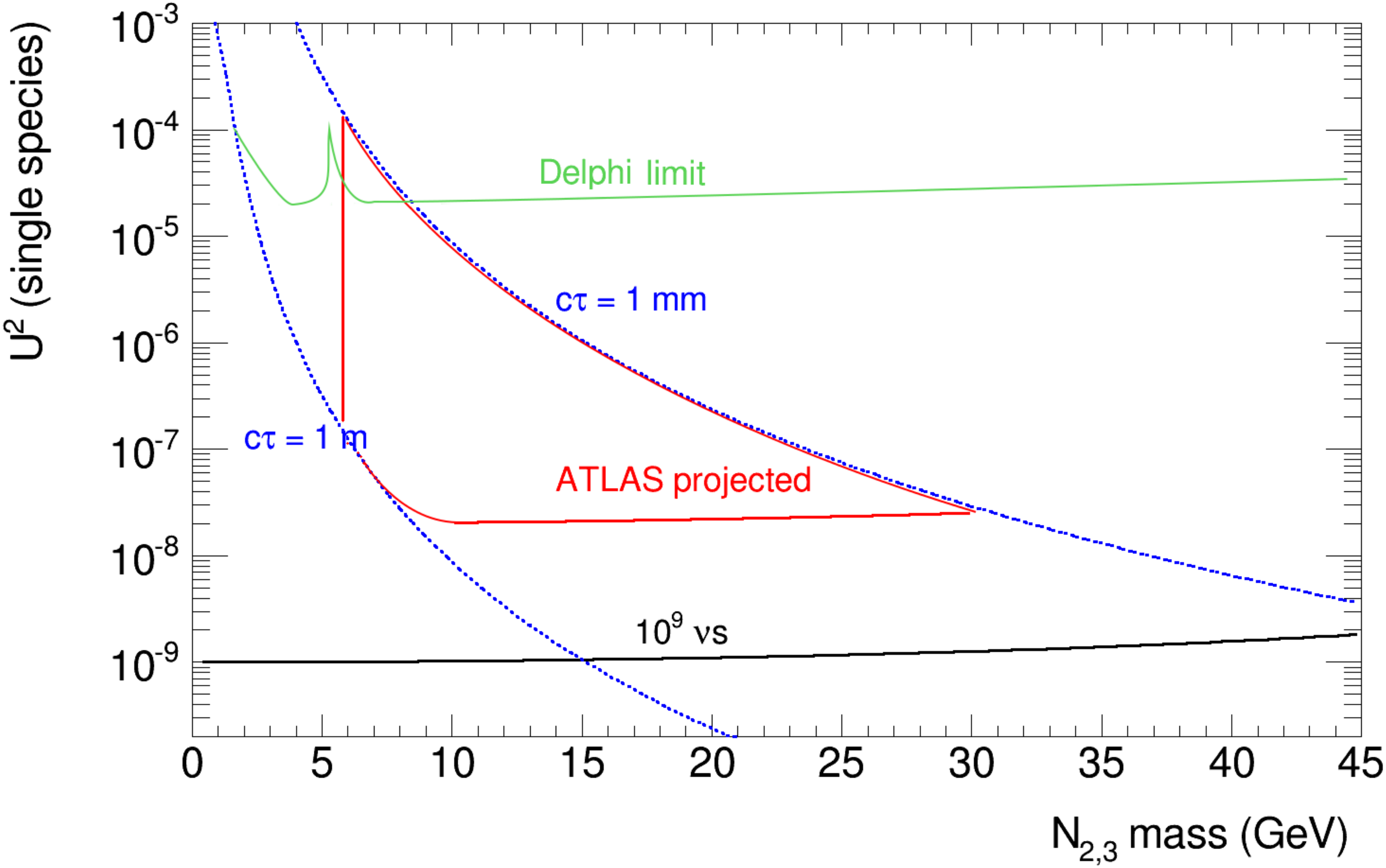
ATLAS search – assumptions on backgrounds

- Based on experience with previous ATLAS searches for displaced vertices in inner detector (PLB 707, 478 (2012), PLB 719, 280 (2013), ATLAS-CONF-2013-092 (2013))
  - Adequate track and vertex reconstruction tools, similar backgrounds
  - Not sensitive to $N_{2,3}$ signature due to high pT thresholds imposed by requirement to trigger on displaced lepton
- Two main background sources at vertex distance > 1 mm
  - Metastable hadron decays (B, K)
  - Hadronic interactions with material
- Three very effective cuts to reduce these to negligible levels
  - Material veto (3D map in latest analysis)
  - Vertex invariant mass > 6 GeV
  - Vertex N_{tracks} > 4 OR require a lepton among them

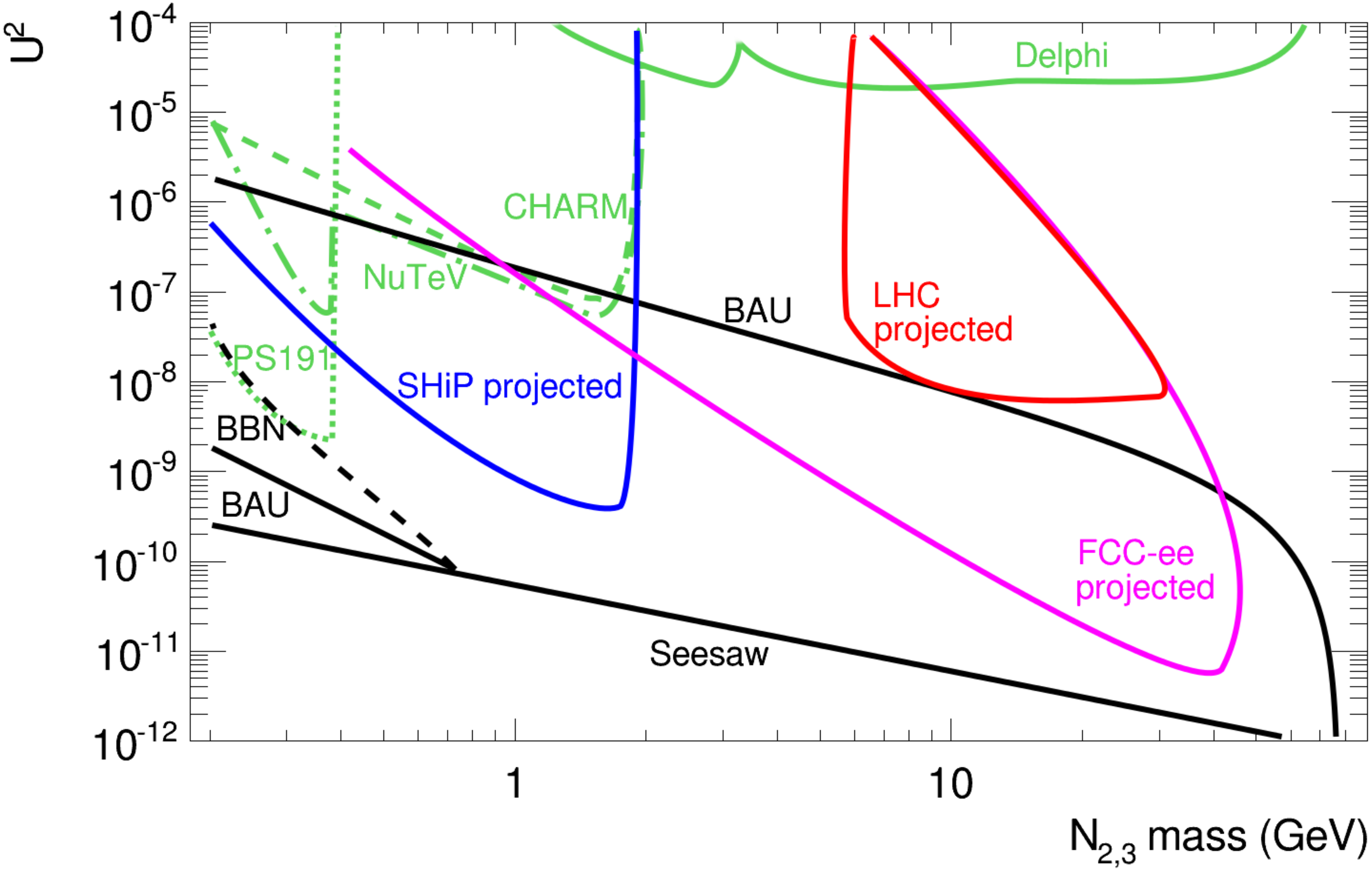
ATLAS search – assumptions on efficiencies

- Decay distance acceptance for displaced vertex analysis
  - 1 mm $\lesssim c\tau \lesssim$ 1 m
  - Formulas (Phys Rev D 29, 2539 (1984)) used to relate that to constraints on $N_{2,3}$ mass and mixing
- Reconstruction efficiencies (conservative assumptions):
  - Branching ratio (hadronic $N_{2,3}$ decay): 50%
  - Trigger (single muon): 50%
  - Track and vertex reconstruction: 20% – based on previous experience, mainly due to tracks with large impact parameter
- Comparison with best limits in relevant mass range
  - Delphi LEP1 analysis (Z. Phys. C 74, 57 (1997))

ATLAS reach estimate (50 fb^{-1} @ 14 TeV)



The (approximative) big picture



Extra plot

ATLAS reach estimate (20 fb^{-1} @ 8 TeV)