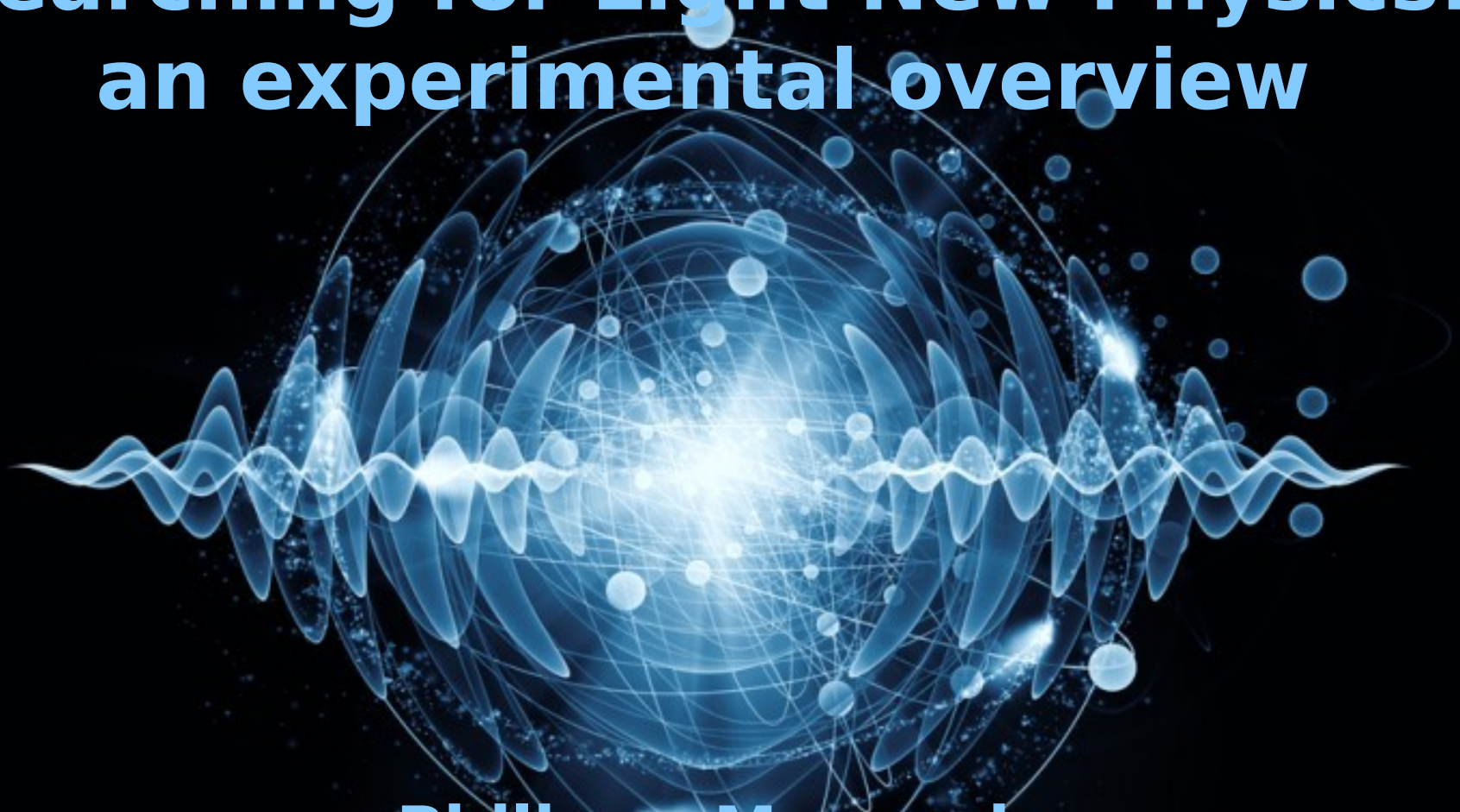
Searching for Light New Physics: an experimental overview



Philippe Mermod

ZPW2015

Zurich, 7 January 2015

Unsolved problems

→ hints at fundamental discoveries still to come

- Many free parameters
- Forces do not unify
- Naturalness

- Gravity
- Dark matter
- Matter-antimatter asymmetry

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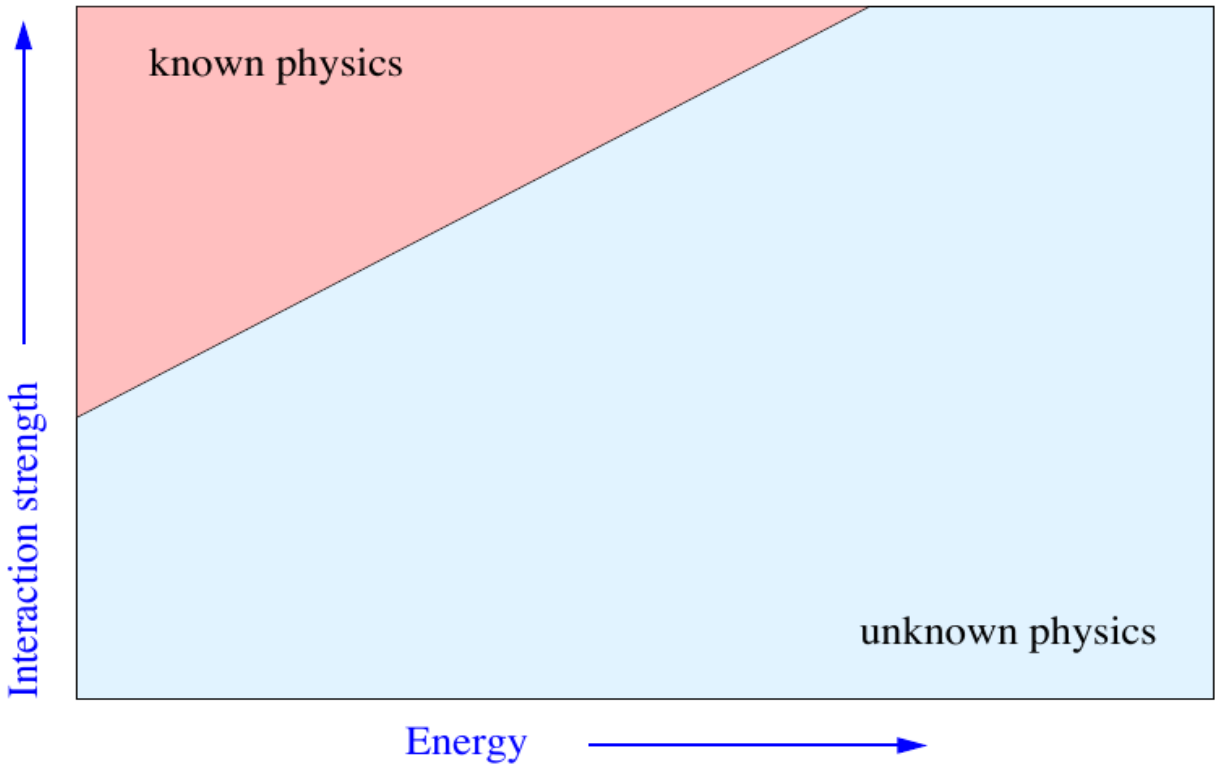

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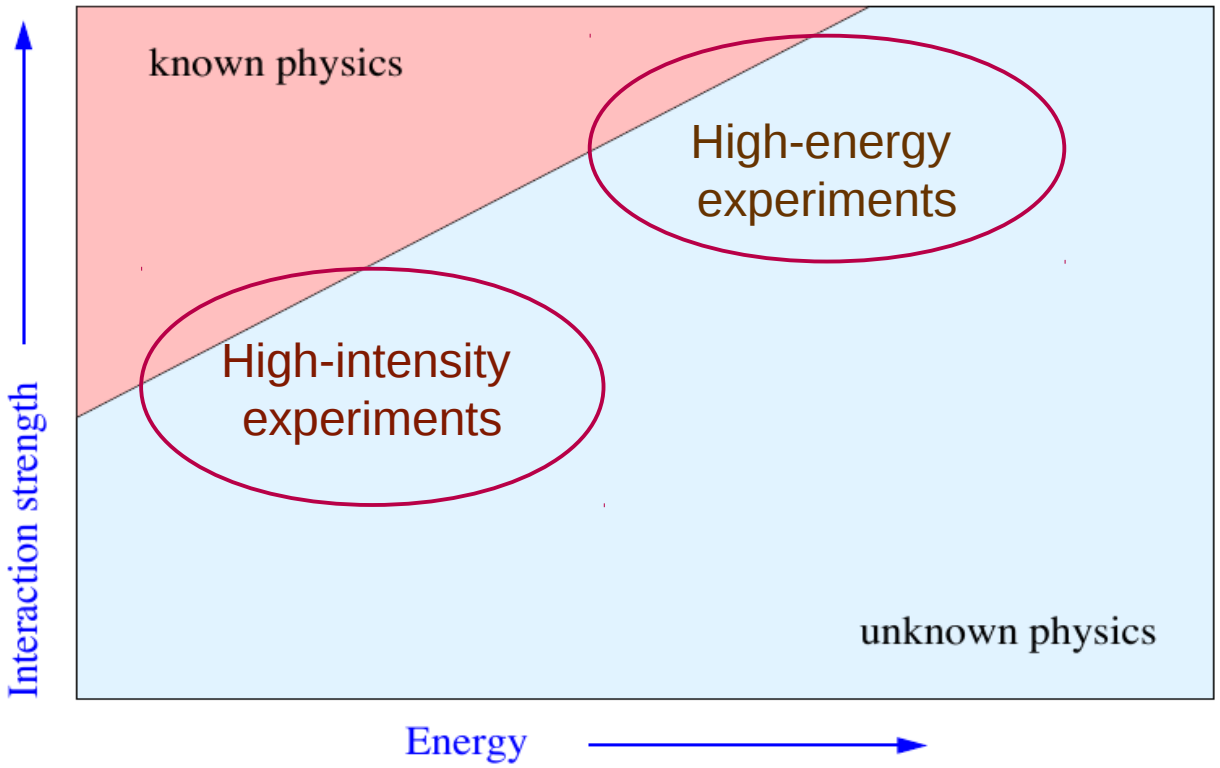


Example scenarios of light new physics

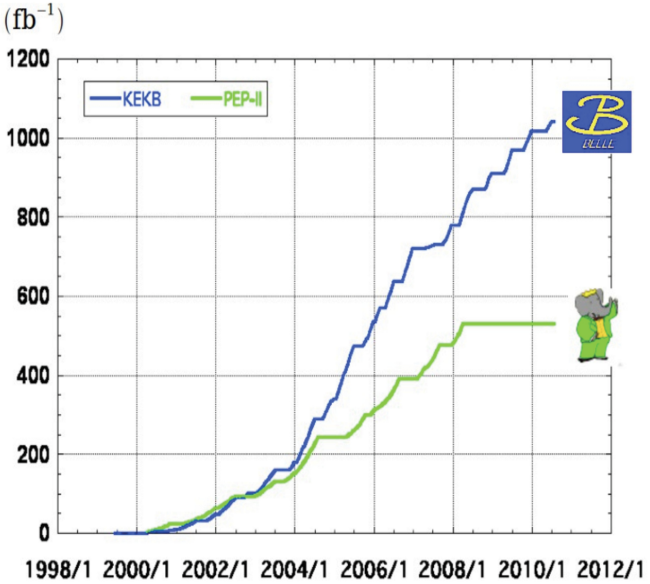
No new particle $\gtrapprox$ EW scale postulated

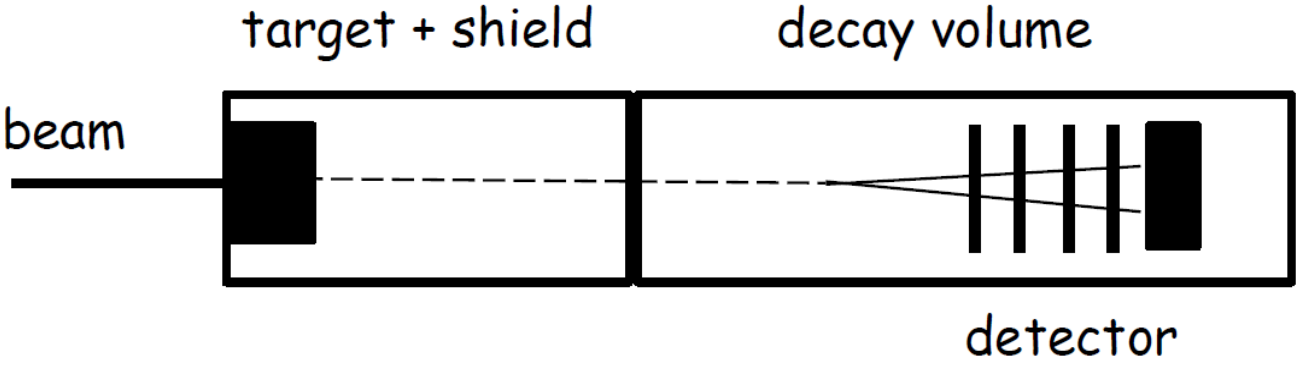
- Dark photon
- Heavy neutral lepton

→ See next talk for theory overview

Experimental strategies to search for light new physics

- High-intensity colliders
  - B factories
  - LHC
- Fixed-target facilities
  - Electron beam dump
  - Proton beam dump

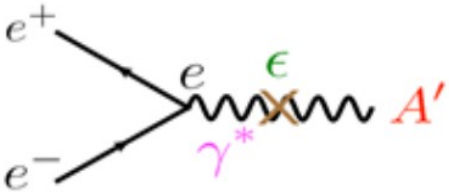


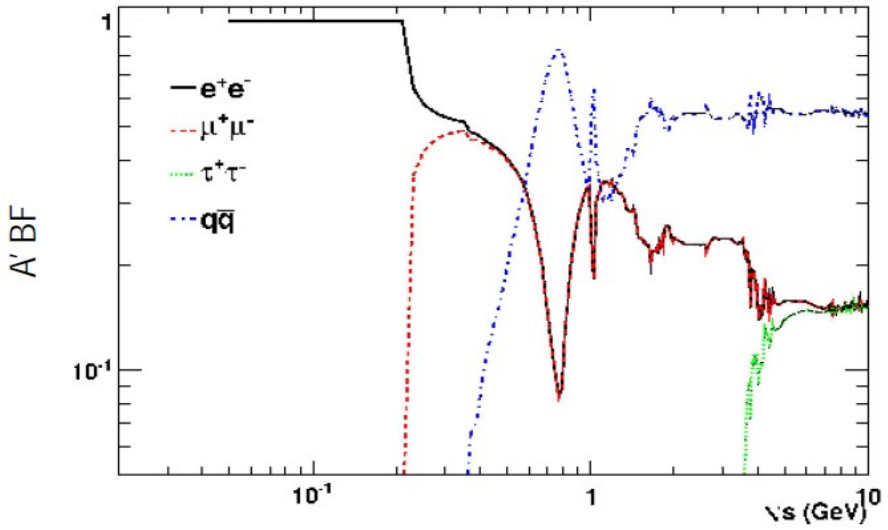


Dark photon

hidden sector charged under U(1)'

- Connexion to
  - Muon g-2
  - Dark matter, positron excess in cosmic rays...
- Production via kinetic mixing with the photon
  - Coupling to charged particles suppressed by ε
- Decay to lepton/quark pairs
  - Search for resonances

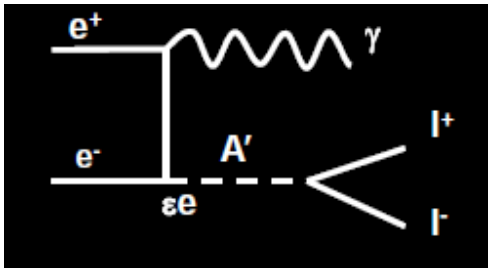


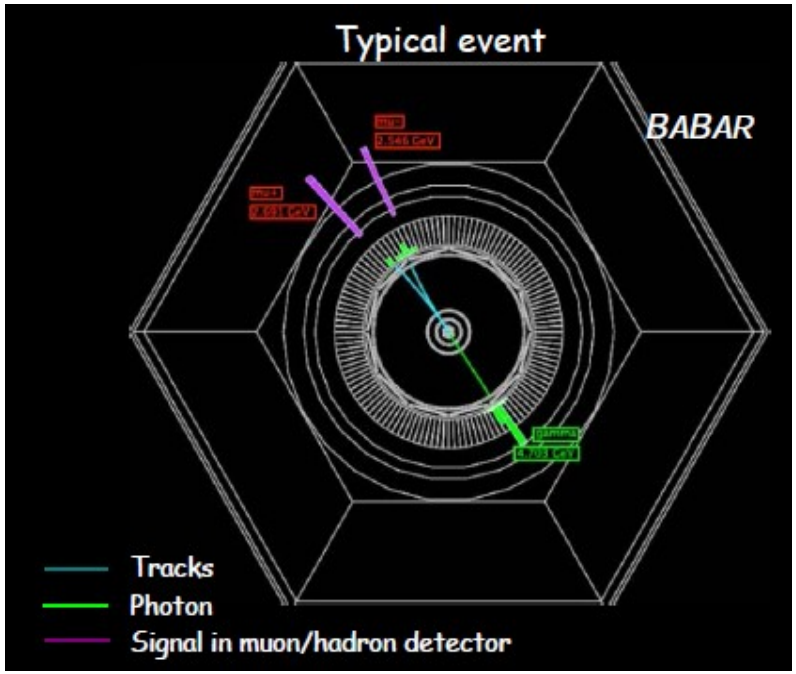


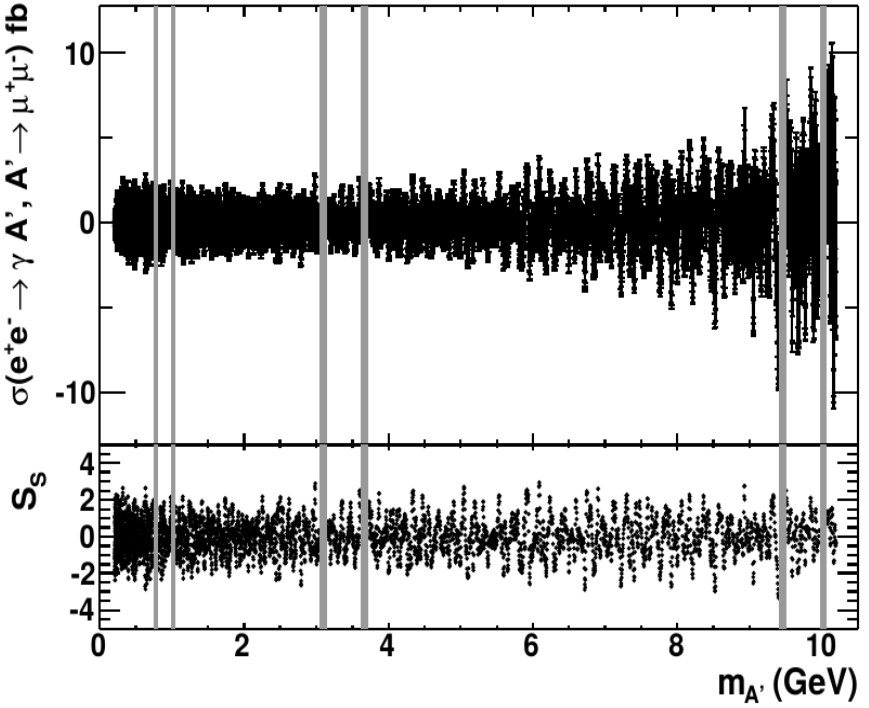
Dark photon search with BaBar

PRL 113, 201801 (2014)

- Main channels
  - $e^+e^- \rightarrow \gamma A'$, $A' \rightarrow l^+l^-$ ($l = e,\mu$)
  - $e^+e^- \rightarrow \gamma A'$, $A' \rightarrow$ invisible
- Probe mass range 0.02 – 10 GeV

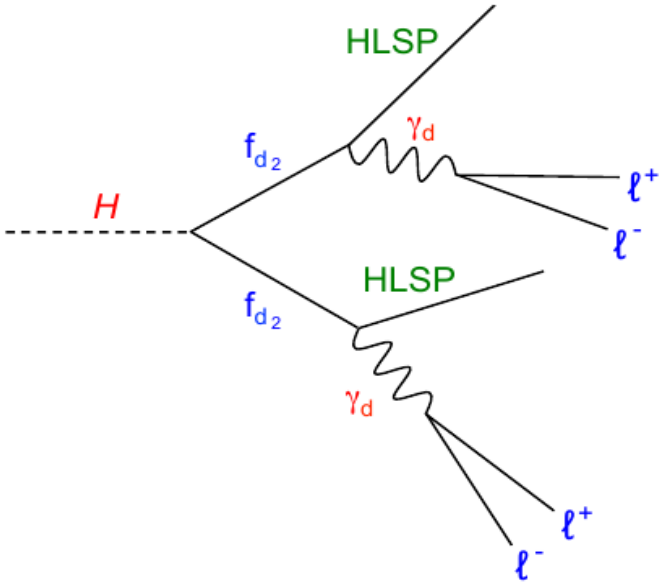




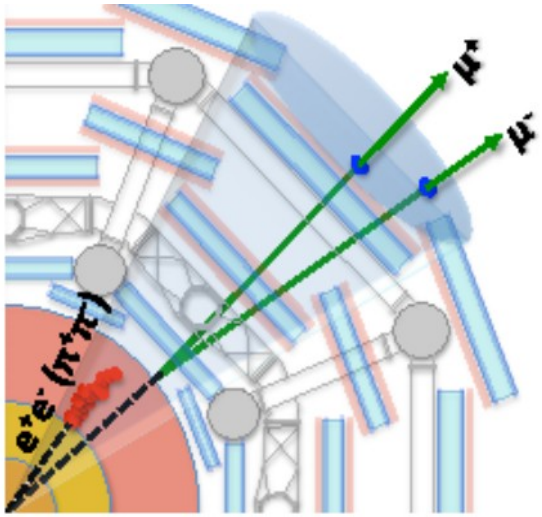


Dark photon search with ATLAS

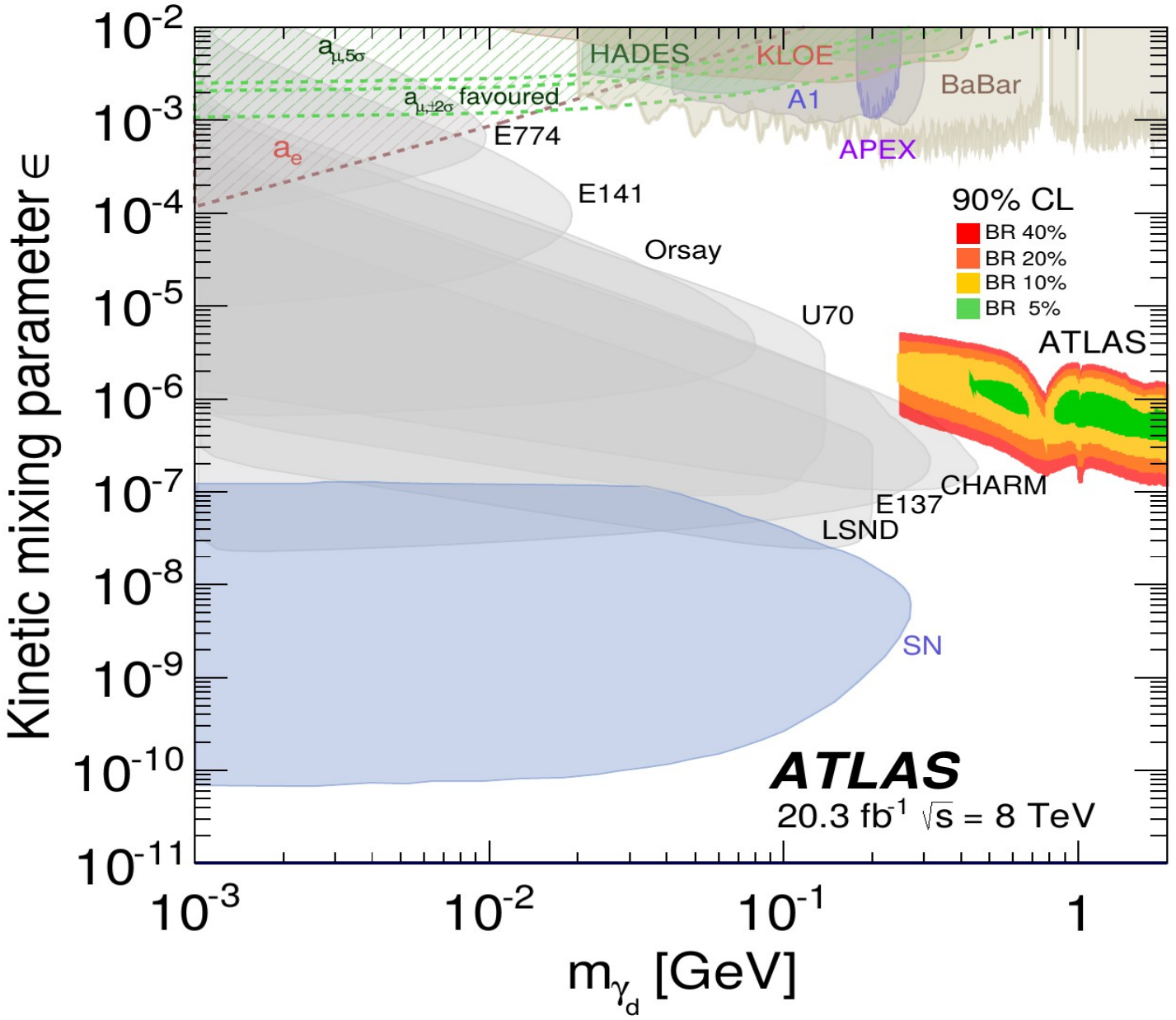
JHEP 11, 088 (2014)



- "Higgs portal"
  - Decay to light hidden fermions
  - Search for collimated leptons from hidden photon decay ("lepton-jets")
  - Search also for displaced decays
- Interpretation depends on additional assumption on Higgs decay branching ratio

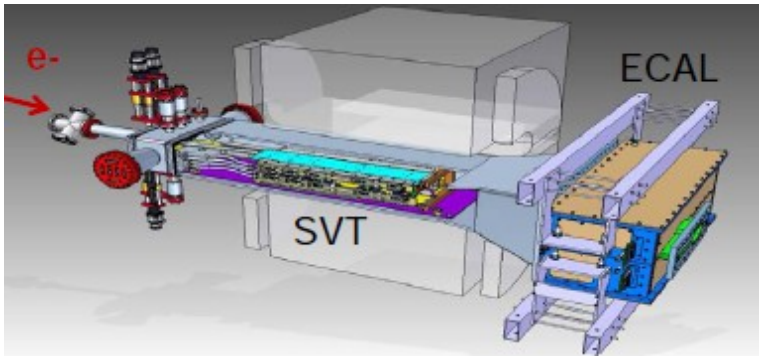


Hidden photon limits

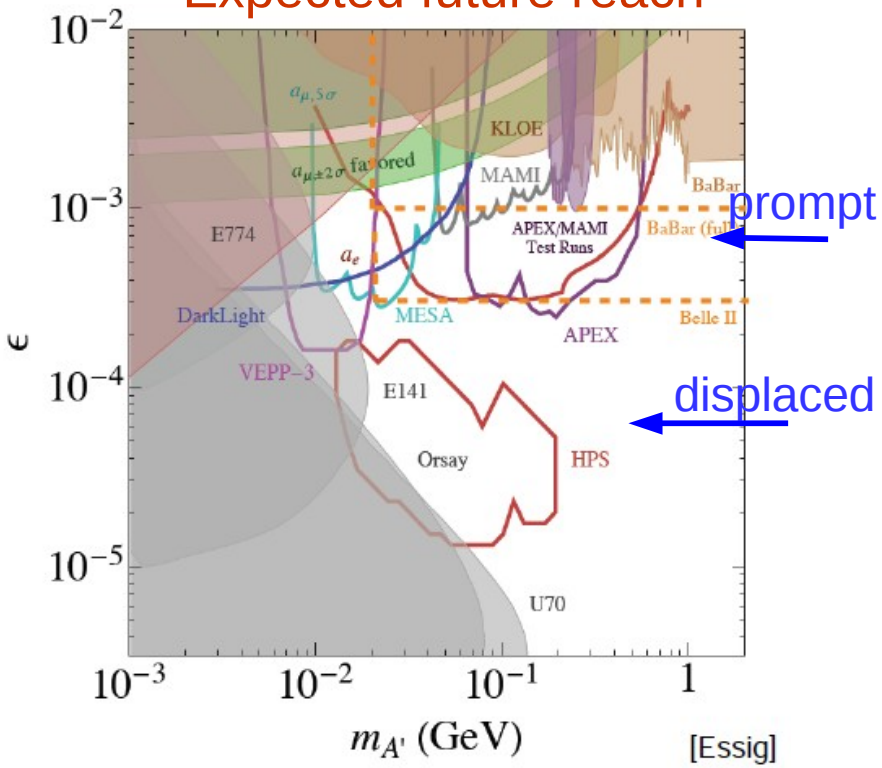


Planned electron beam-dump experiments at JLAB

- Heavy Photon Search (HPS)
  - Large forward-acceptance spectrometer
  - Test run in 2012
  - Should run this year
- DarkLight
  - Compact 4π detector
  - Measure full reaction $e^-p \rightarrow e^-pA' \rightarrow e^-pe^+e^-$
  - Should run in 2016



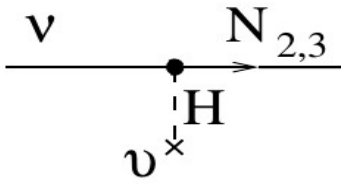
Expected future reach

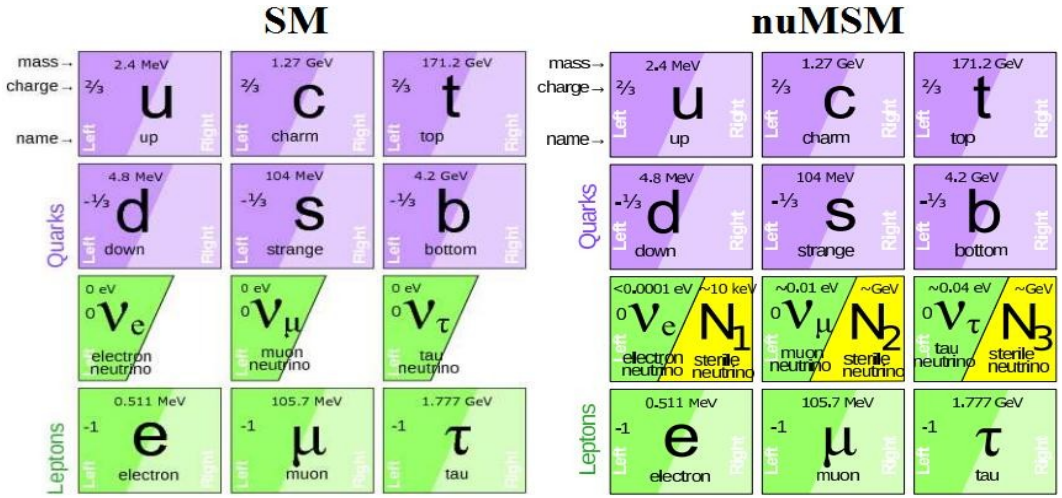


Heavy neutral lepton (HNL)

right-handed / sterile neutrino

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





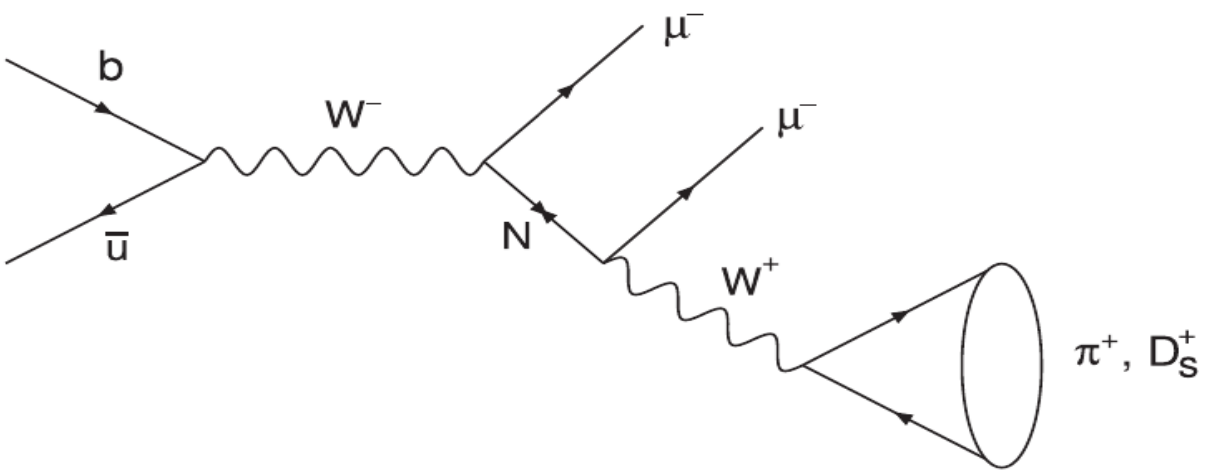
N_1 stable dark matter

$N_{2,3}$ long-lived,

mass in 0.2-100 GeV range

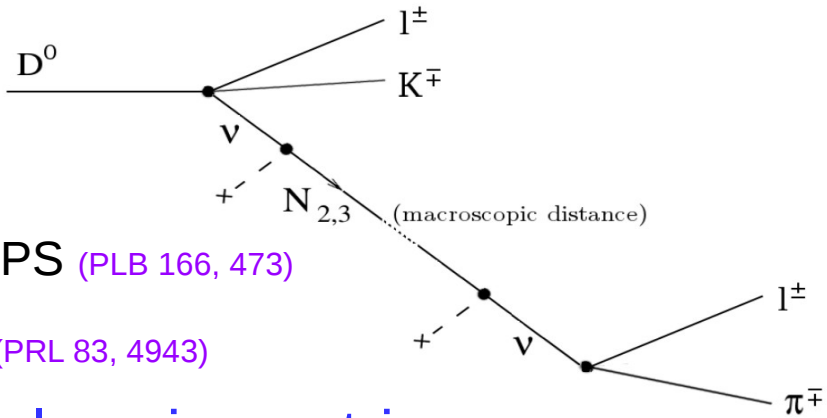
Special case: Majorana neutrinos

- Neutrinoless double-β decay allowed if neutrinos are (only) Majorana
- Majorana HNLs can also give same-sign lepton signatures at colliders
  - Probe muon-neutrinos in addition to electrons
  - Searches were performed at Belle (JHEP 05 030), BaBar (PRD 85, 071103), LHCb (PRD 85, 112004), ATLAS (ATLAS-CONF-2012-139), CMS (PLB 717, 109)



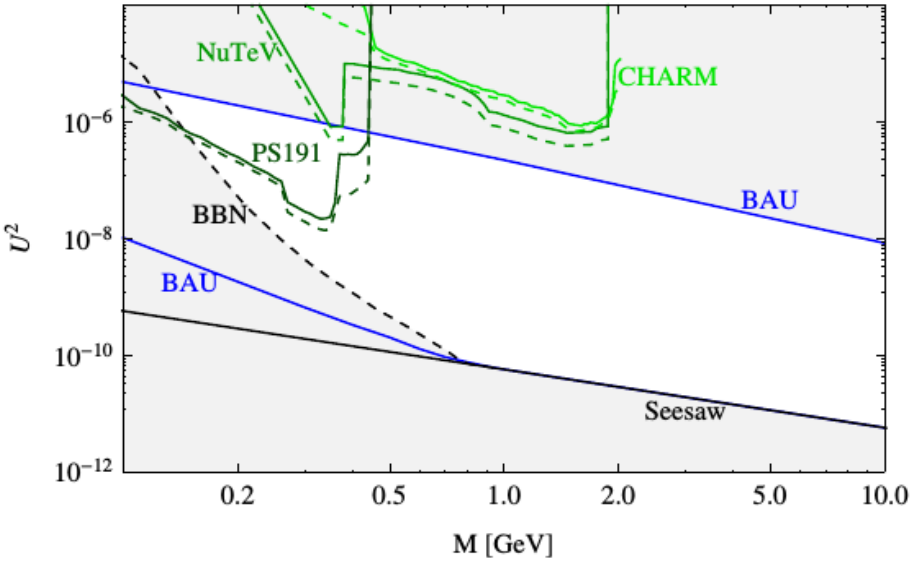
HNL searches at proton beam dump experiments

- Neutrinos from charm decays
  - Probe masses < 2 GeV
  - CHARM experiment at CERN SPS (PLB 166, 473)
  - NuTeV experiment at Fermilab (PRL 83, 4943)

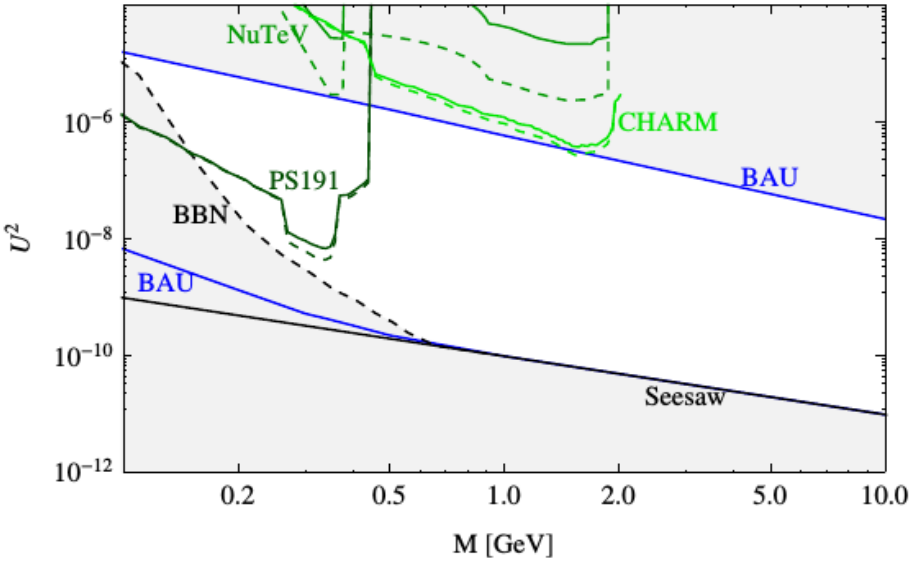


- Constraints from theory/cosmology in neutrino minimum standard model (Ann. Rev. Nucl. Part. Sci. 59, 191)

Normal hierarchy

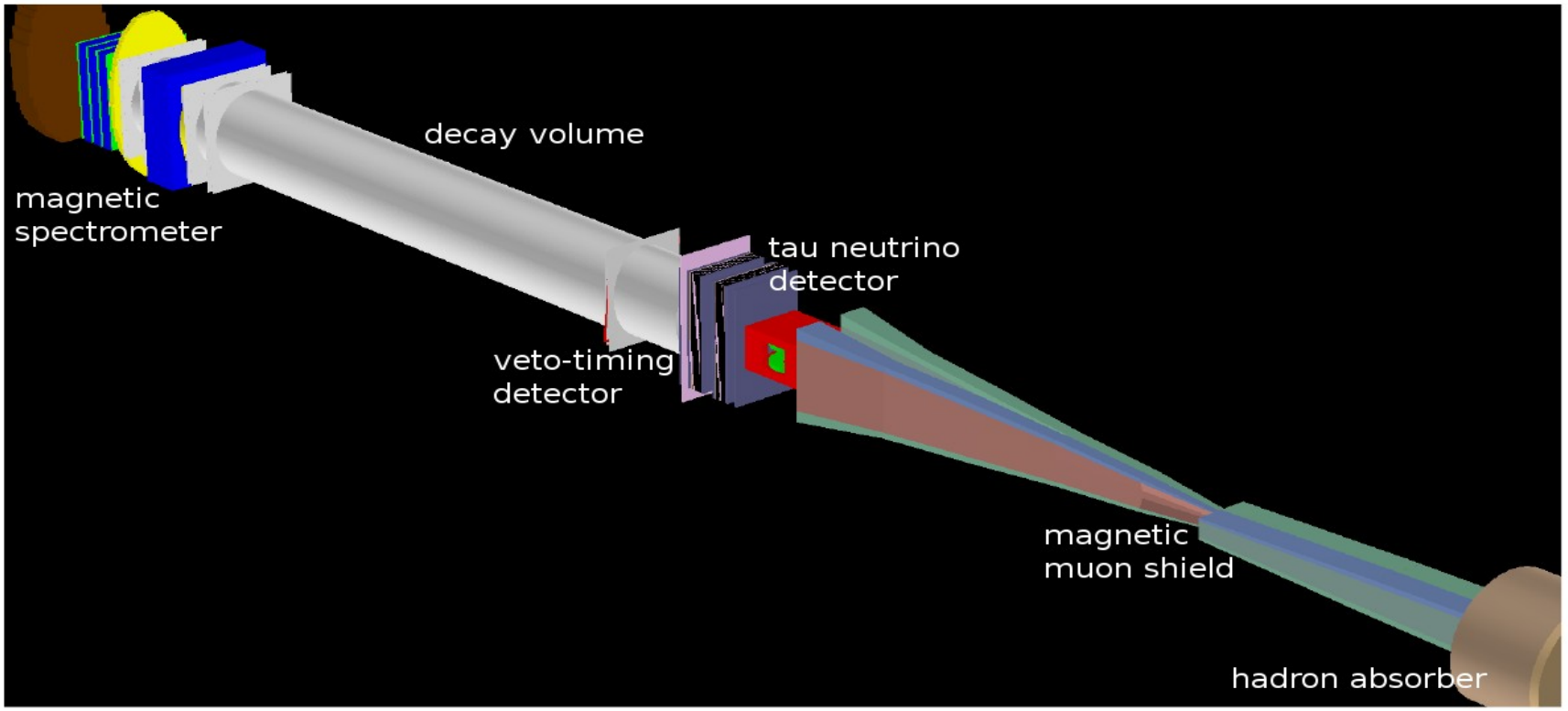


Inverted hierarchy



Search for Hidden Particles (SHiP)

- > 10^{16} neutrinos from charm decays
  - Probe tiny HNL couplings (mass below 2 GeV)
- Expression of interest well received by CERN SPS committee arXiv:1310.1762
- TDR scheduled for 2017, physics runs in 2025



Neutrinos from W and Z decays at colliders

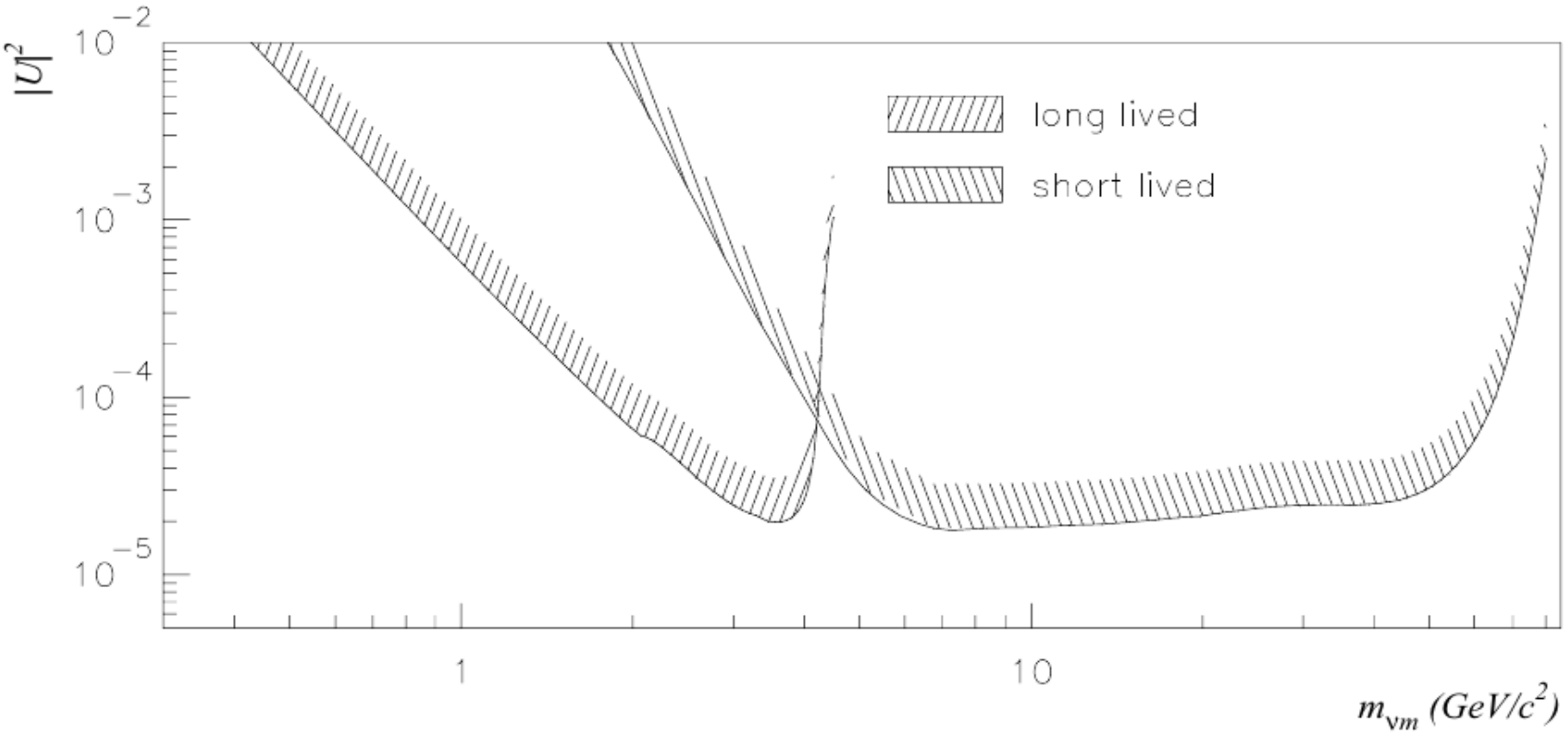
- Can probe HNL masses up to 90 GeV
- LEP1 (Z resonance)
  - Search made by Delphi using ~10^6 νs (e+μ) from Z decays
  - Displaced decays for masses up to 4 GeV
- Tevatron (2 TeV)
  - ~10^7 νs (e+μ) from W decays
  - Can only probe couplings corresponding to prompt decays → large backgrounds, no search made
- LHC Run1 (8 TeV)
  - Already produced $5 \cdot 10^8$ νs (e+μ) from W decays in each experiment
  - Displaced decays for masses up to ~30 GeV
- LHC Run2 (14 TeV)
  - Expect ~10^9 νs (e+μ) for each 25 fb^{-1} from W decays in each experiment

HNL search with Delphi

Z. Phys. C 74, 57 (1997)

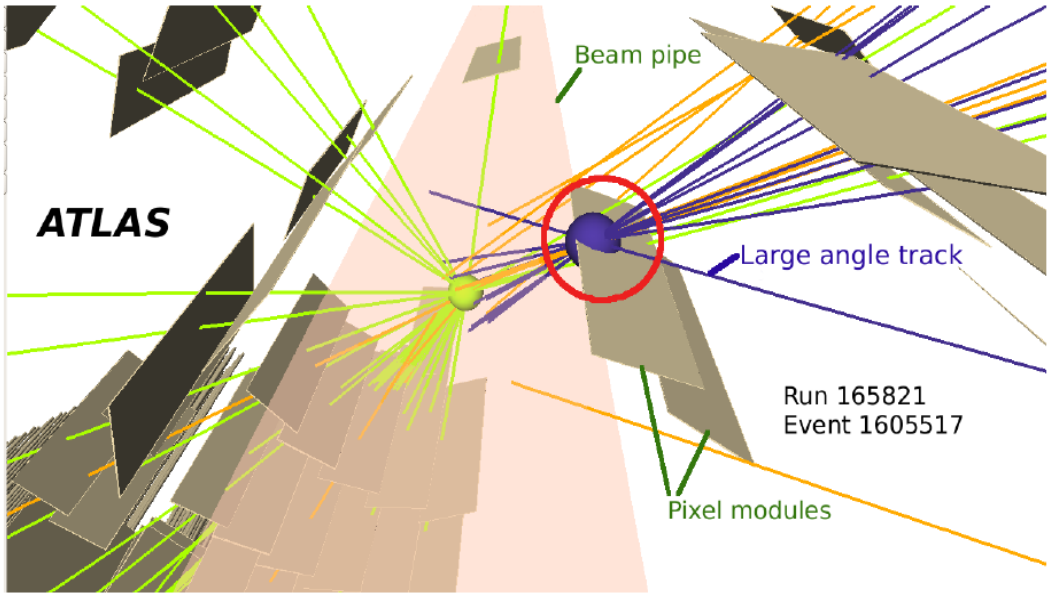
Search for heavy neutral leptons in Z decays

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

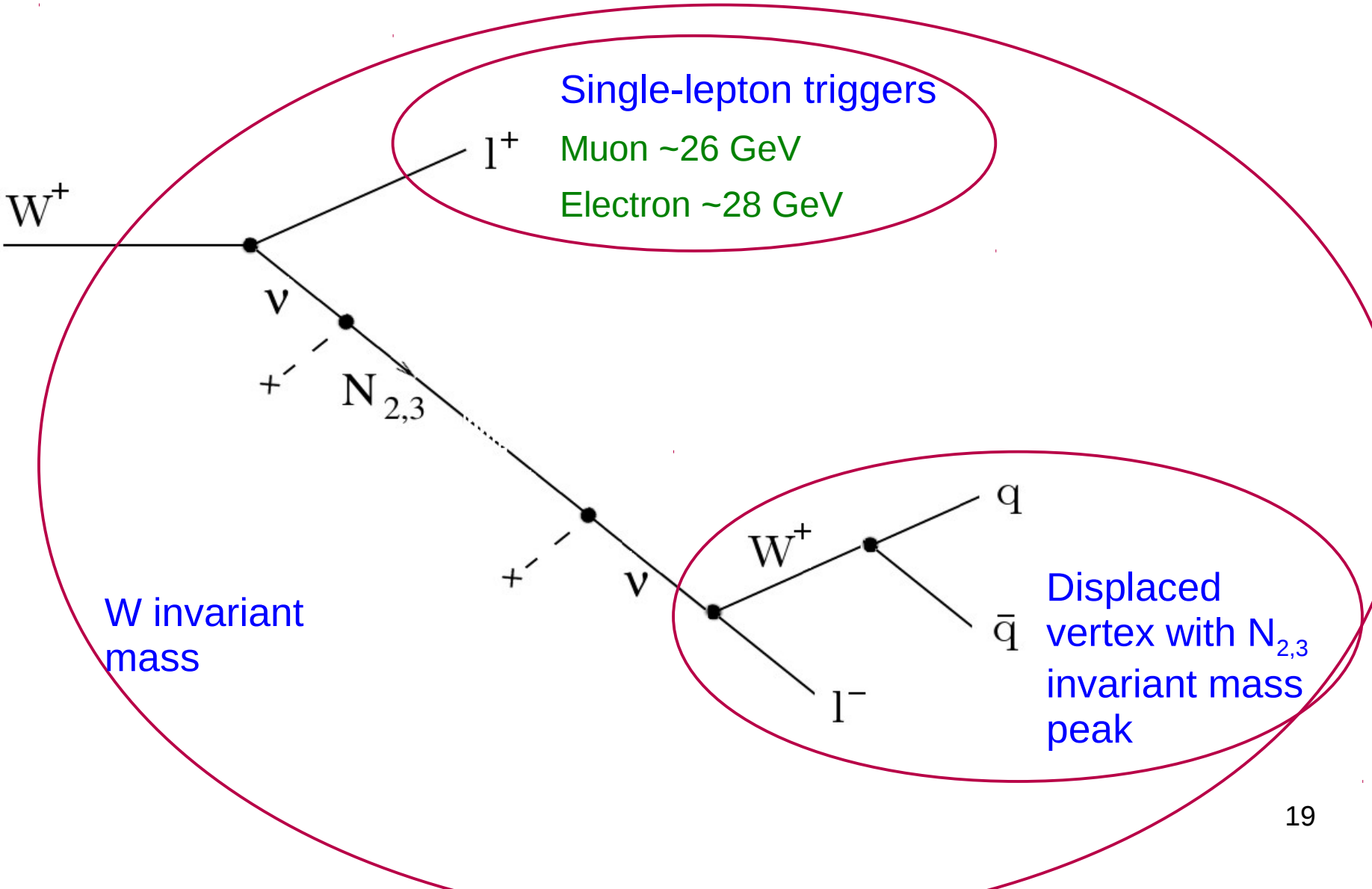


HNL search at the LHC using W decays

- Previous searches for displaced vertices in inner detectors (PLB 707, 478; PLB 719, 280; ATLAS-CONF-2013-092; JHEP 02, 085; arXiv:1409.4789; arXiv:1411.6977; arXiv:1411.6530)
  - Adequate track and vertex reconstruction tools, similar backgrounds
  - Not sensitive to HNLs due to high pT thresholds (based on models of heavy new physics)
- Requirements on displaced vertex can reduce backgrounds to negligible levels
- Dedicated HNL search possible and needed (PRD 89, 073005)

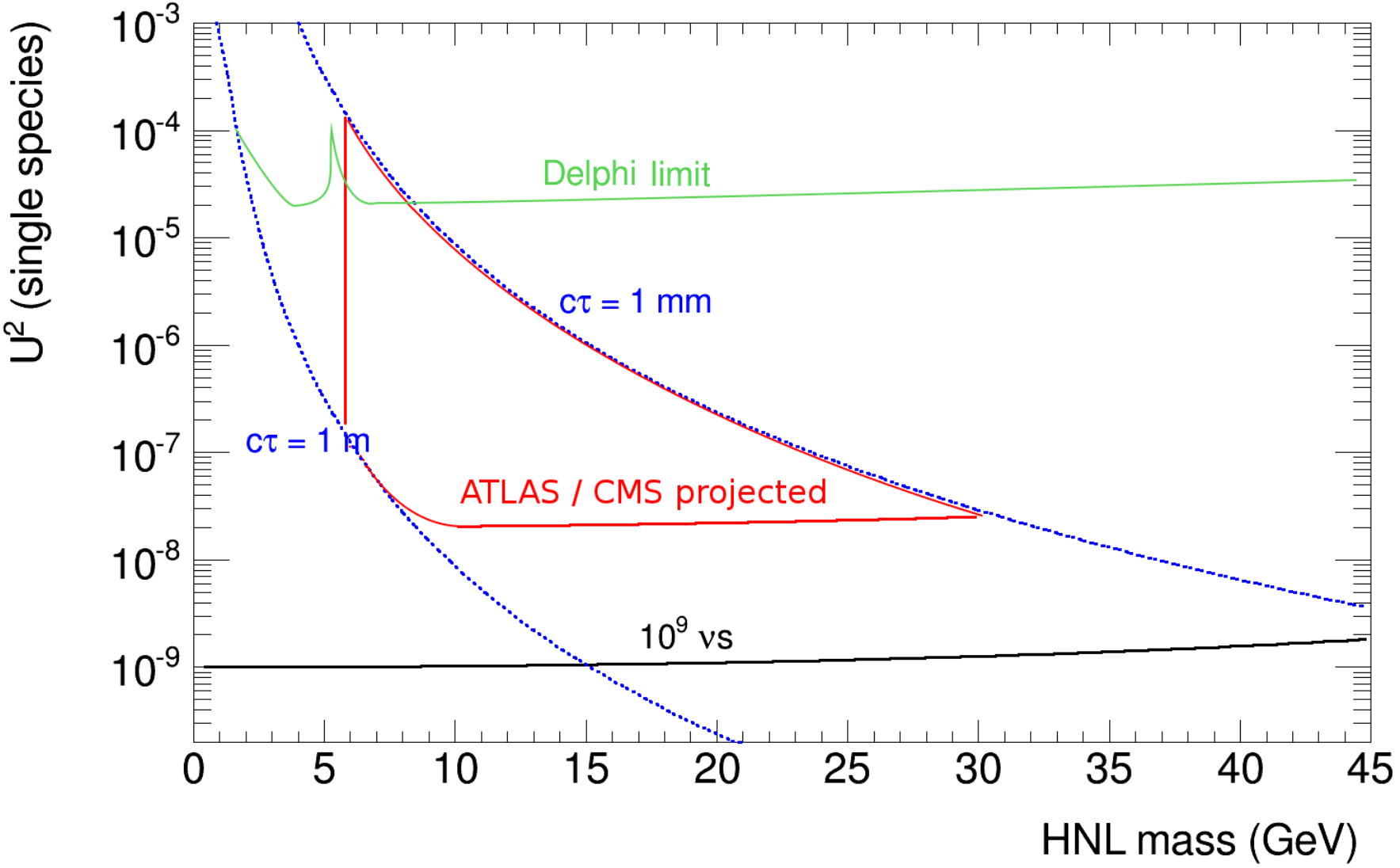


specific HNL signature to look for at ATLAS and CMS



ATLAS and CMS reach estimate

assuming 25 fb^{-1} @ 14 TeV in each experiment



HNL searches at future circular colliders

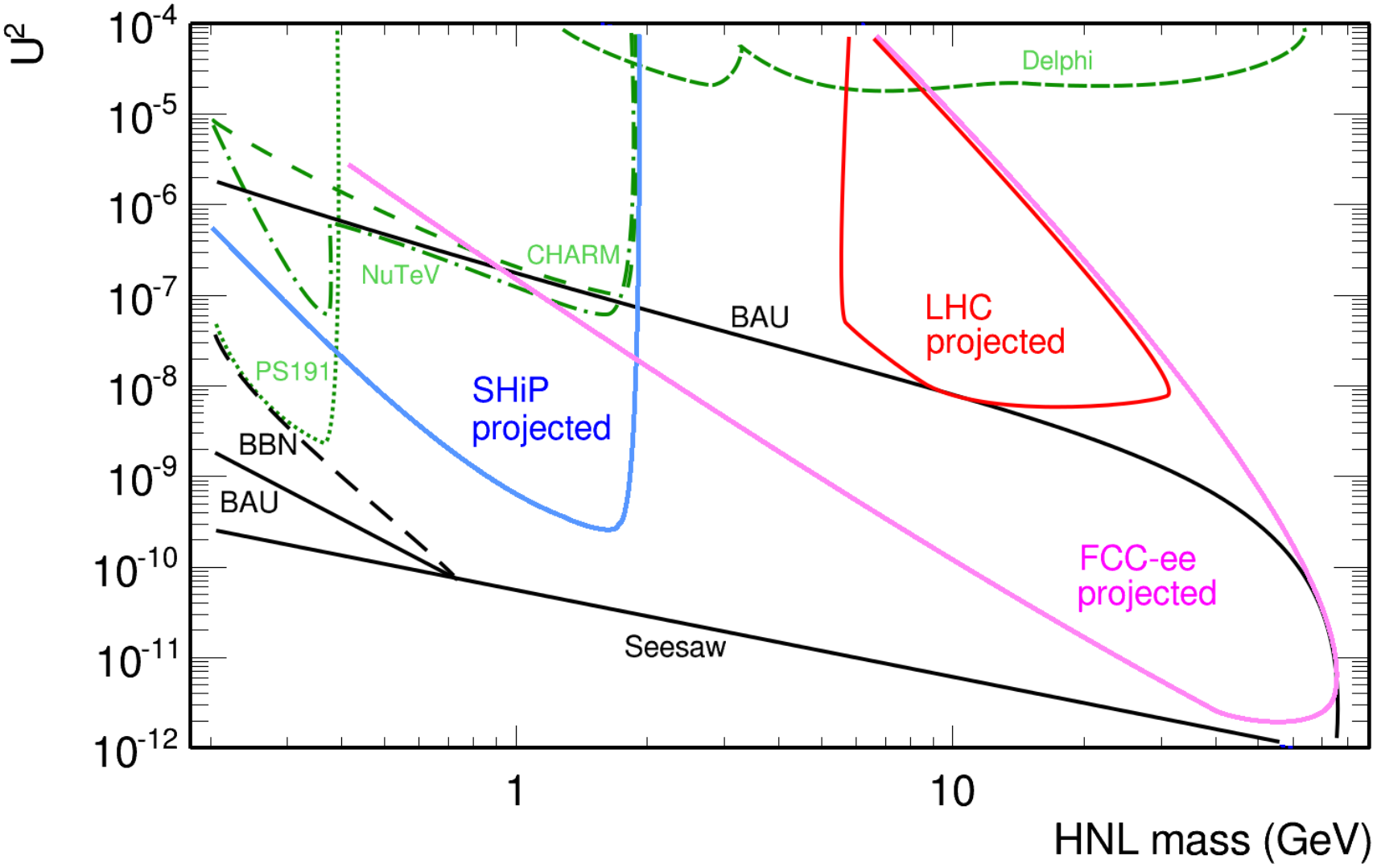
arXiv:1411.5230

- 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

The (approximate) big picture

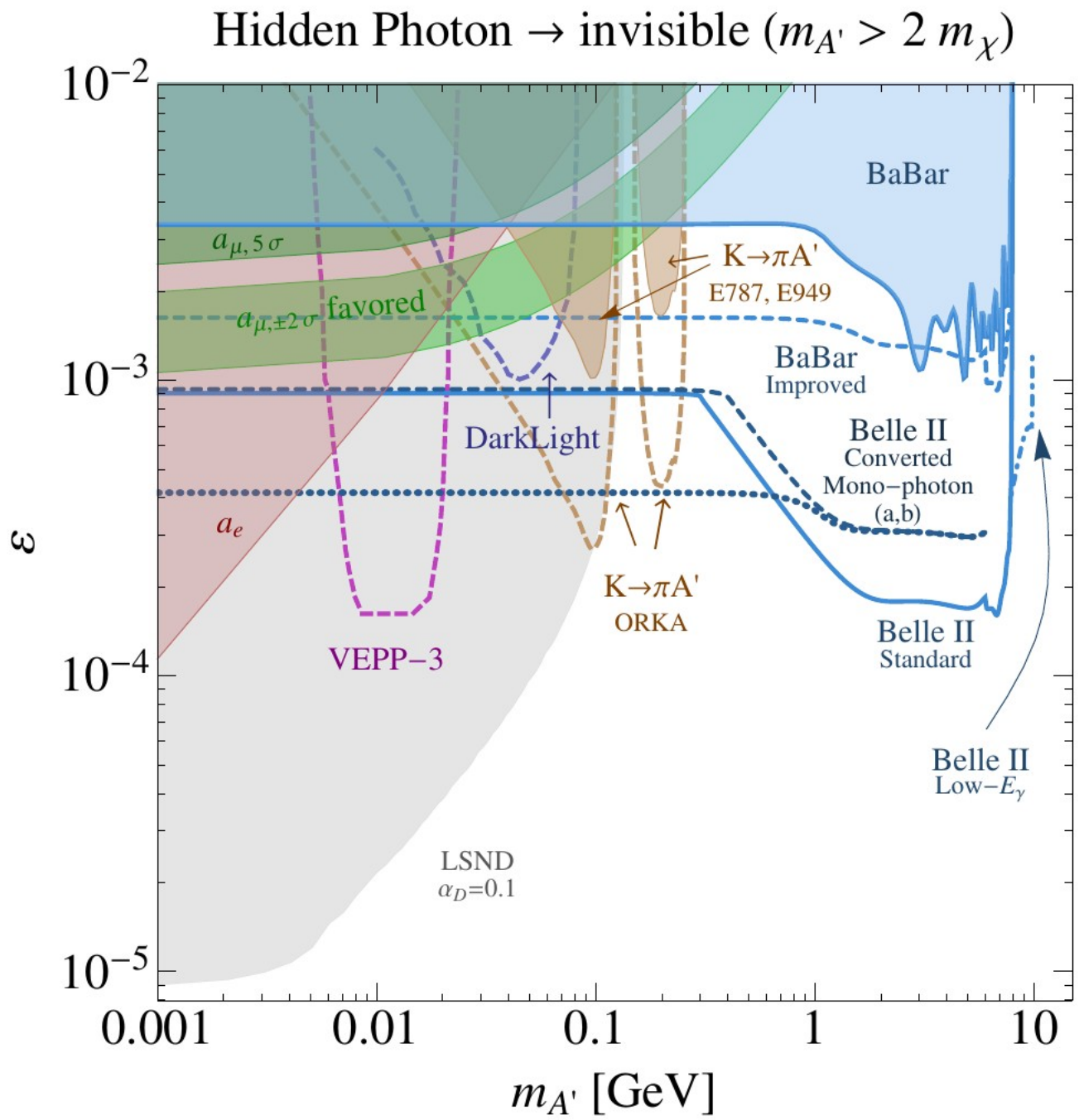
assumes 50 fb^{-1} @ 14 TeV in both ATLAS and CMS
assumes 10^{13} Zs for FCC-ee with LHC-sized detector



Summary

- Given lack of evidence for massive new physics, light new physics is a hot topic
  - Hidden sectors, dark photons
  - Direct search for right-handed neutrinos
  - Axions etc...
- Complementary searches can be made at colliders and dedicated beam-dump experiments
- New ambitious projects are being proposed to probe most of the allowed parameter space
  - HPS experiment
  - SHiP experiment
  - Future Circular Colliders

(extra slides)


Hidden Photon → invisible ($m_{A'} > 2\,m_\chi$)
10^{-2}
10^{-3}
10^{-4}
10^{-5}
ε
0.001
0.01
0.1
1
10
$m_{A'}$ [GeV]
BaBar
$a_{\mu,5\,\sigma}$
$a_{\mu,\pm2\,\sigma}$ favored
K→πA'
E787, E949
BaBar
Improved
DarkLight
Belle II
Converted
Mono−photon
(a,b)
a_e
K→πA'
ORKA
VEPP−3
Belle II
Standard
Belle II
Low−E_γ
LSND
α_D=0.1

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