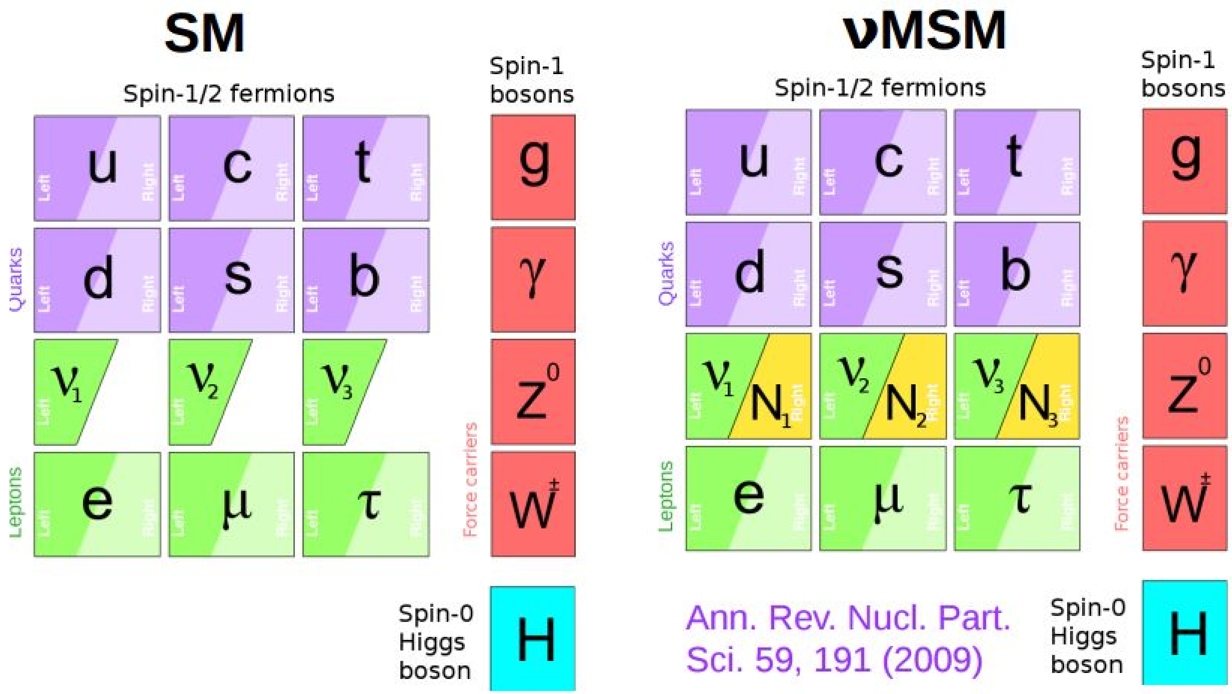
Displaced Heavy Neutral Lepton at the LHC run-II

2017 SPS-CHIPP Joint annual meeting
25.08.2017

Arnaud Dubreuil on behalf of the ATLAS displaced HNL group

Sterile neutrino for the SM



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

vMSM model: addition of 3 right-handed terms to the SM lagrangian, with Majorana mass

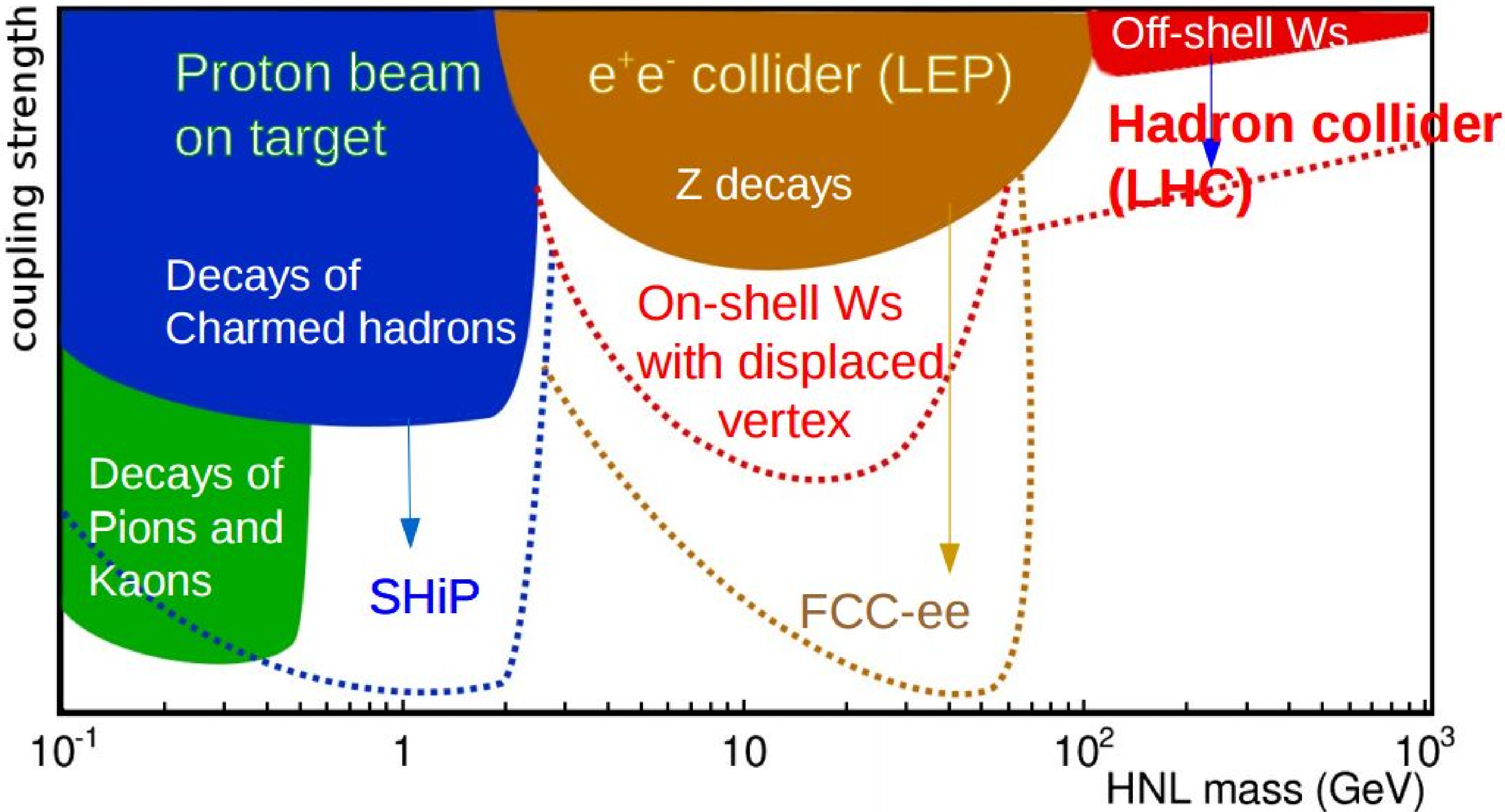
- N_1 (keV): DM
- $N_{2,3}$ (GeV): BAU, neutrino masses

Sterile neutrino, massive neutrino, Majorana neutrino, Heavy Neutral Lepton, right-handed neutrino…
Same particle, different names.

HNL production

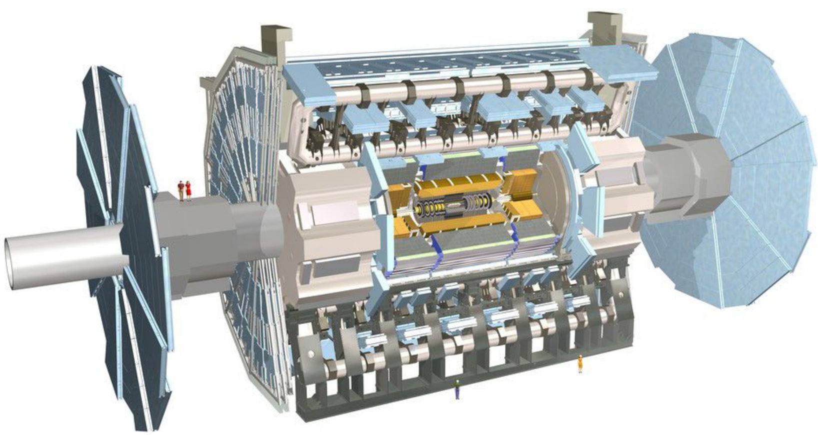
Very small mixing to the SM particles

- High intensity beam (LHC is a W factory - ~10^9 Ws / year)
- Displaced decay

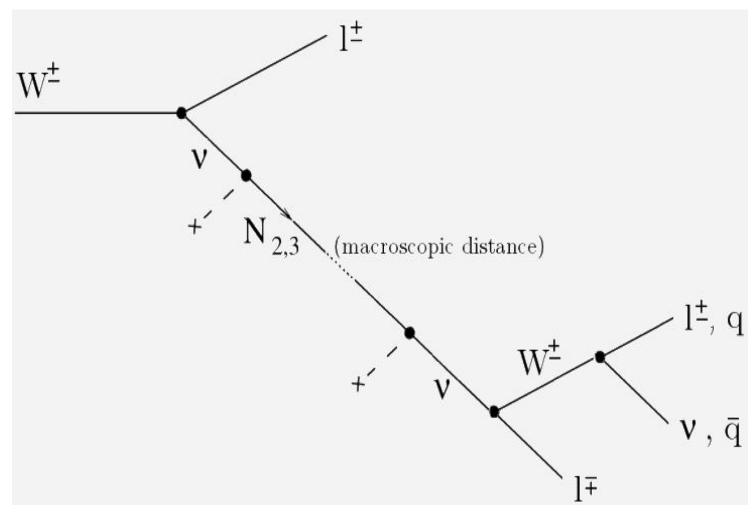


HNL with ATLAS LHC

- First search ever for HNL at a hadron collider (small team, growing)
- Long lifetime, displaced decay, special reconstruction needed in the ATLAS software (aka large radius tracking)
- Analysis cutflow and selection close to be frozen
- Background and systematics studies ongoing
- Aiming at final results for December



HNL signature in ATLAS



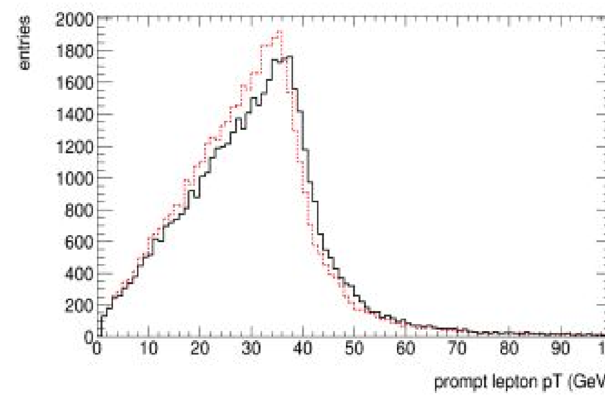
Signature at the LHC

- 1 prompt lepton essential for triggering
- Displaced vertex containing two displaced leptons (muon or electron):

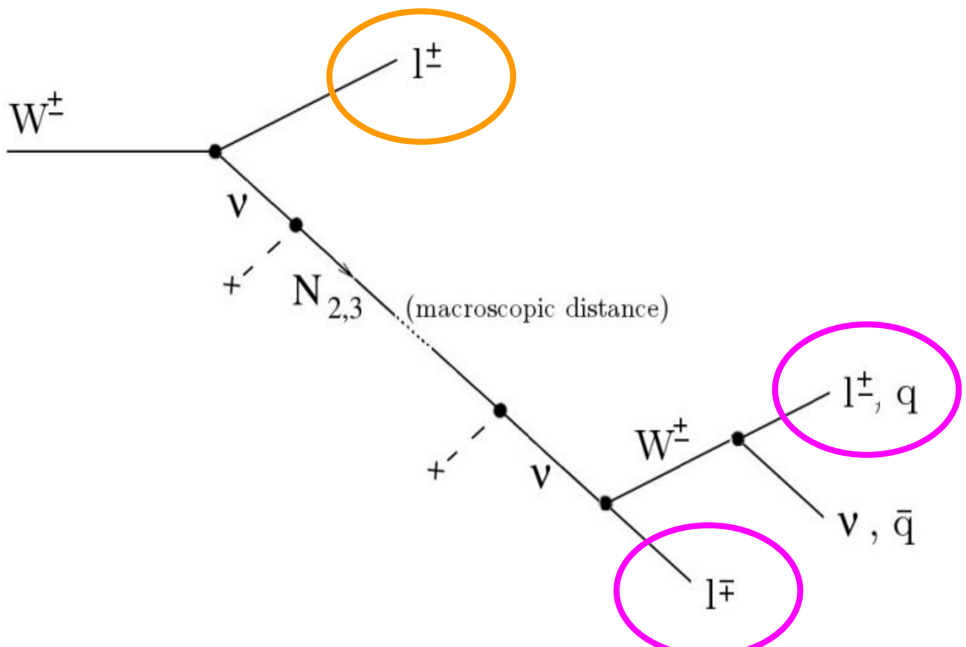
  $\longrightarrow$ used to reduce/suppress background

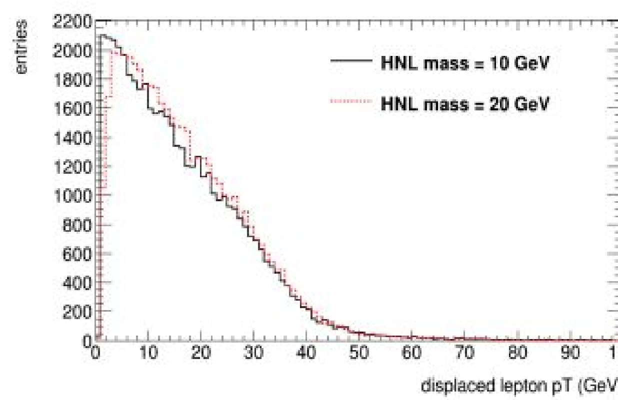
  Possibility to study a hadronic decay channel

(generator-level pT distributions)



Displaced HNL mass range: 4 to 30 GeV



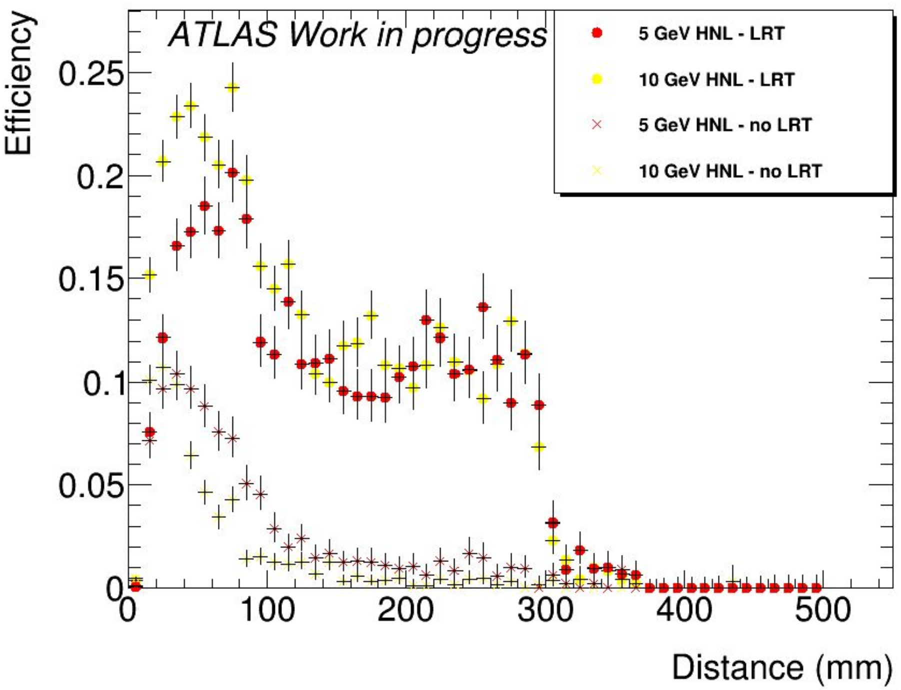


Large radius tracking benefit

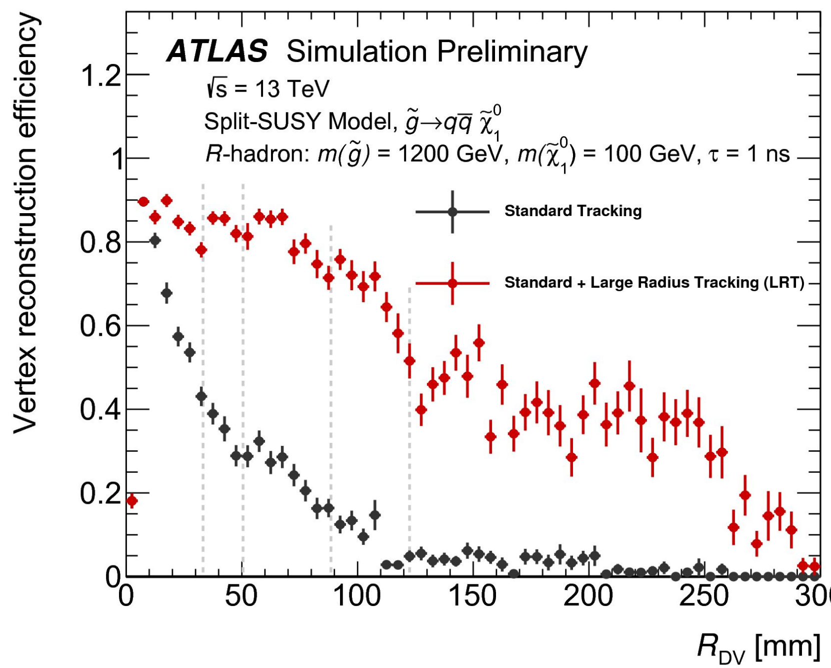
LRT is implemented in ATLAS software for run II

Essential increase of the vertexing reconstruction efficiency

Our analysis



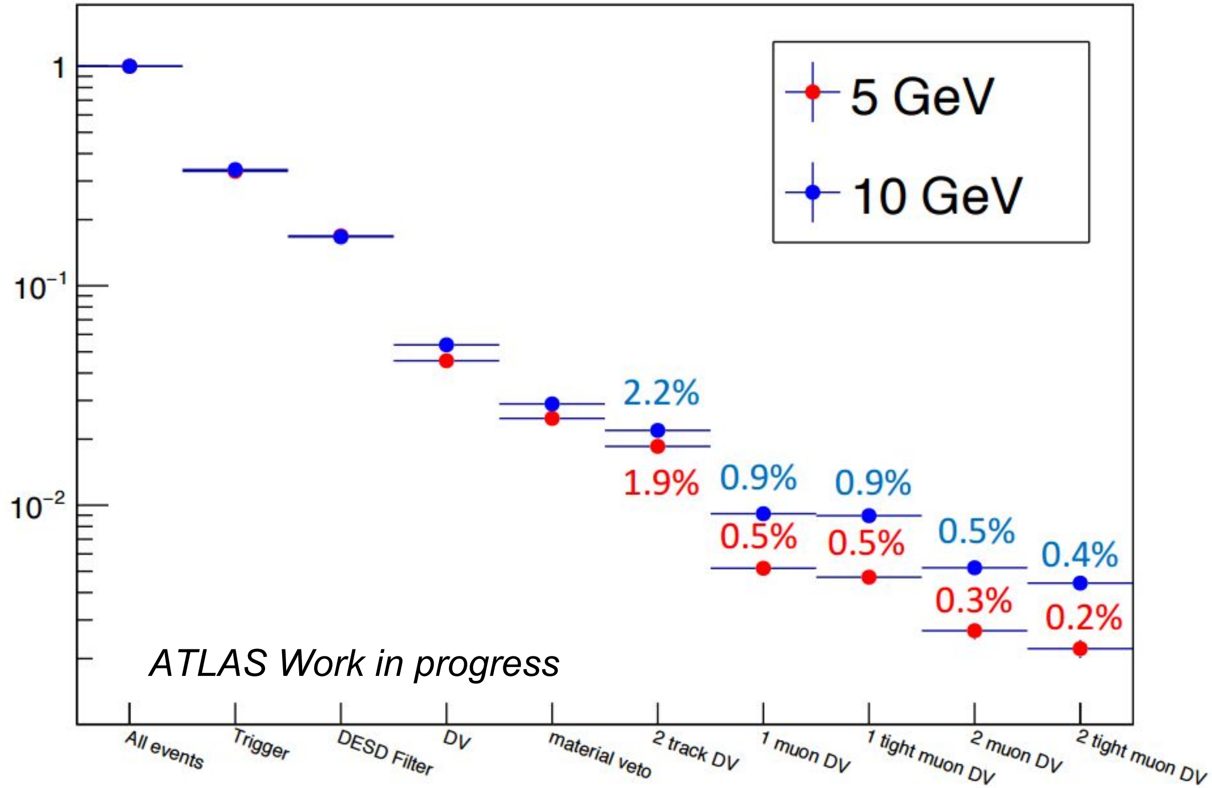
Run-II LRT effect on vertexing reconstruction



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2017-026/

HNL analysis selection

- Event passing trigger (single muon, 26 GeV p_T) and dedicated filter (to reduce datafile size)
- Looking only at displaced vertices (>30mm displacement from IP)
- Passing ATLAS detector material map veto (to reject fake vertices from hadronic interactions)
- Requiring (at least) 2 tracks to be in the DV, then 1 muon in the DV
- Then another lepton in the DV (either muon or electron - here, only muons included)
- Then different internal quality requirements to refine the selection (collimation, reconstruction quality…)
- Assumed overall efficiency: ~1% (add electrons)
- Currently adding cosmic muon veto in the cutflow

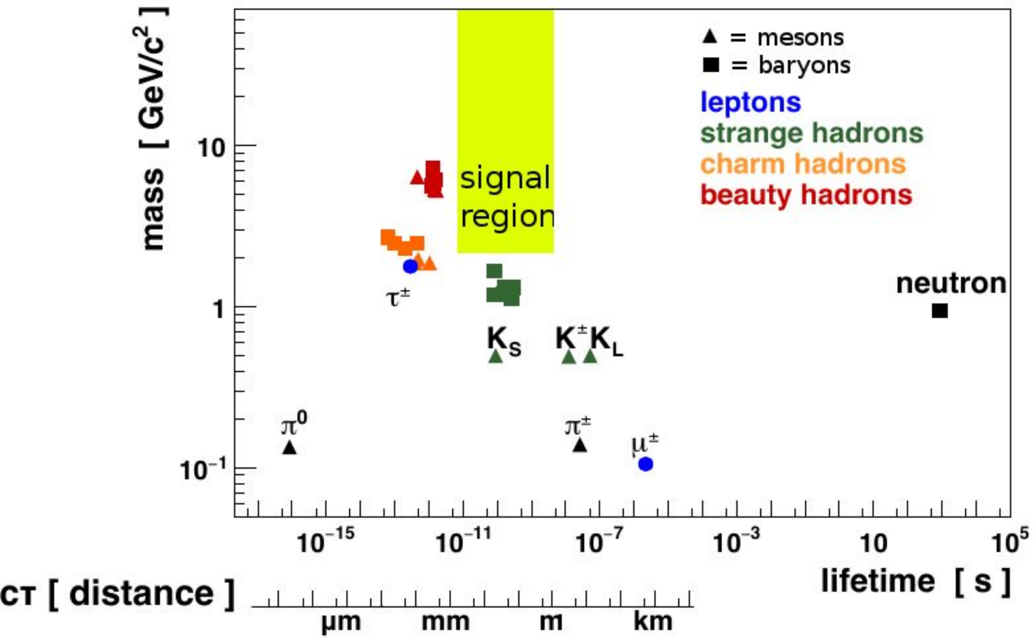


Background - sources

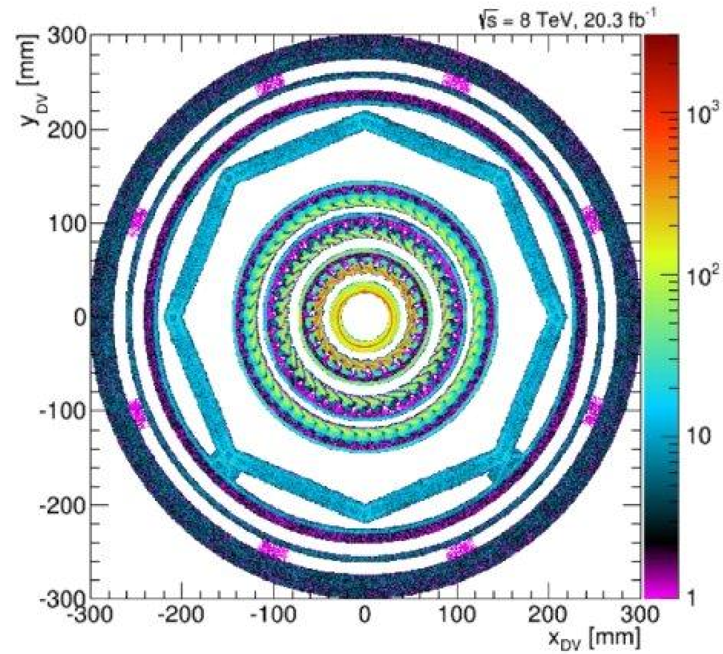
4 candidates for background origin:

- **Random crossing tracks**, a DV made by two random tracks from plieup pp collisions
- **Hadronic interactions** with detector material, charged hadrons reconstructed as a vertex at some distance of the interaction point, faking a DV
- **Cosmic muons**: back-to-back displaced muons (plans to reject it using ΔR)
- **Metastable particle decays**

Metastable particle decays around our signal region



Material map



Background - Control and Signal region

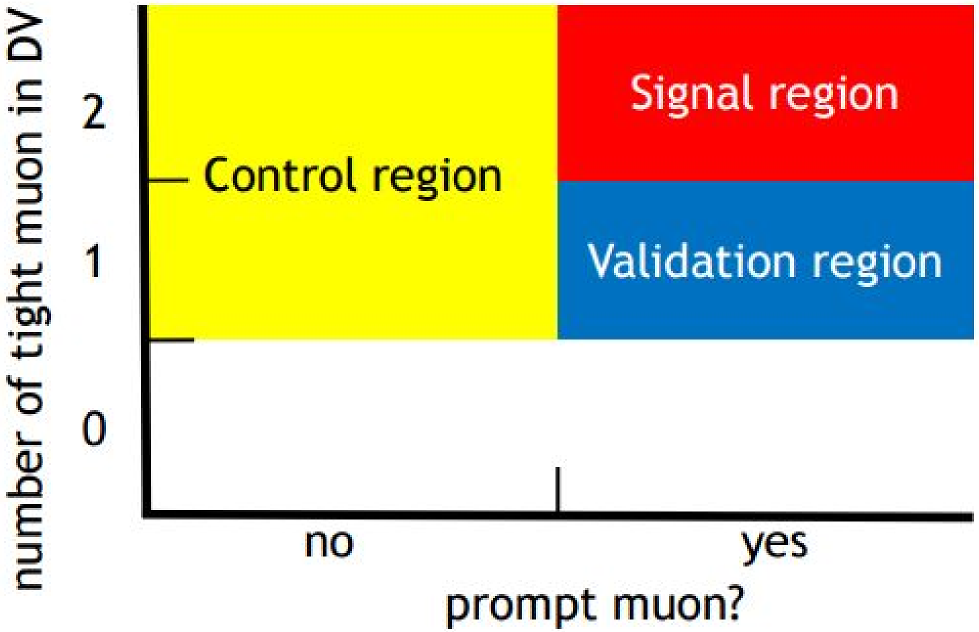
Signal: prompt muon $p_T > 28$ GeV, 2 muons in the DV

Control region: NO prompt muon with $p_T > 28$ GeV

Additionnal requirement for signal DV:

- DV mass > 4 GeV

In CR: p_{DV}: probability for an event to have a DV passing our selection



Background estimation

p_{DV} * (nb of triggered events with a reconstructed isolated prompt muon p_T > 28 GeV) = nb of expected background events

Preliminary results for background study:

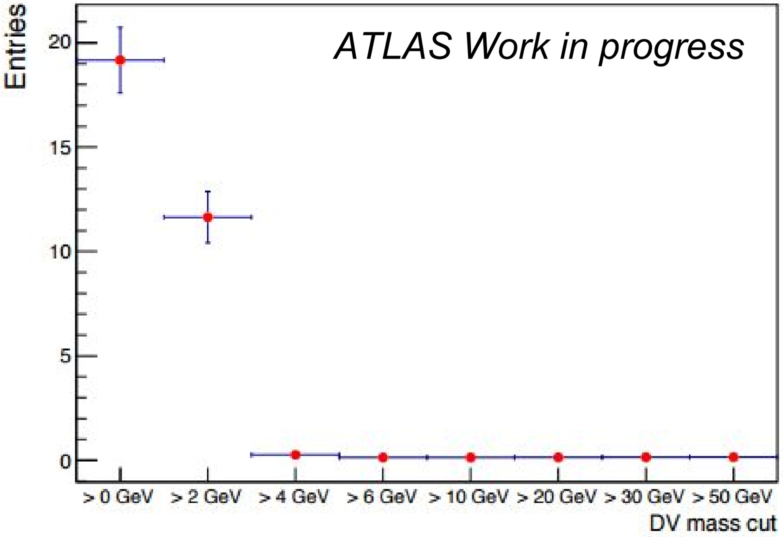
After full selection (without electrons), with a 4 GeV mass cut on the DV mass, and cosmic veto applied

p_{DV}^{2mu} = 7.1±5.0 x10^{-6}

Number of expected background = 0.2 ± 0.2

For other mass cuts:

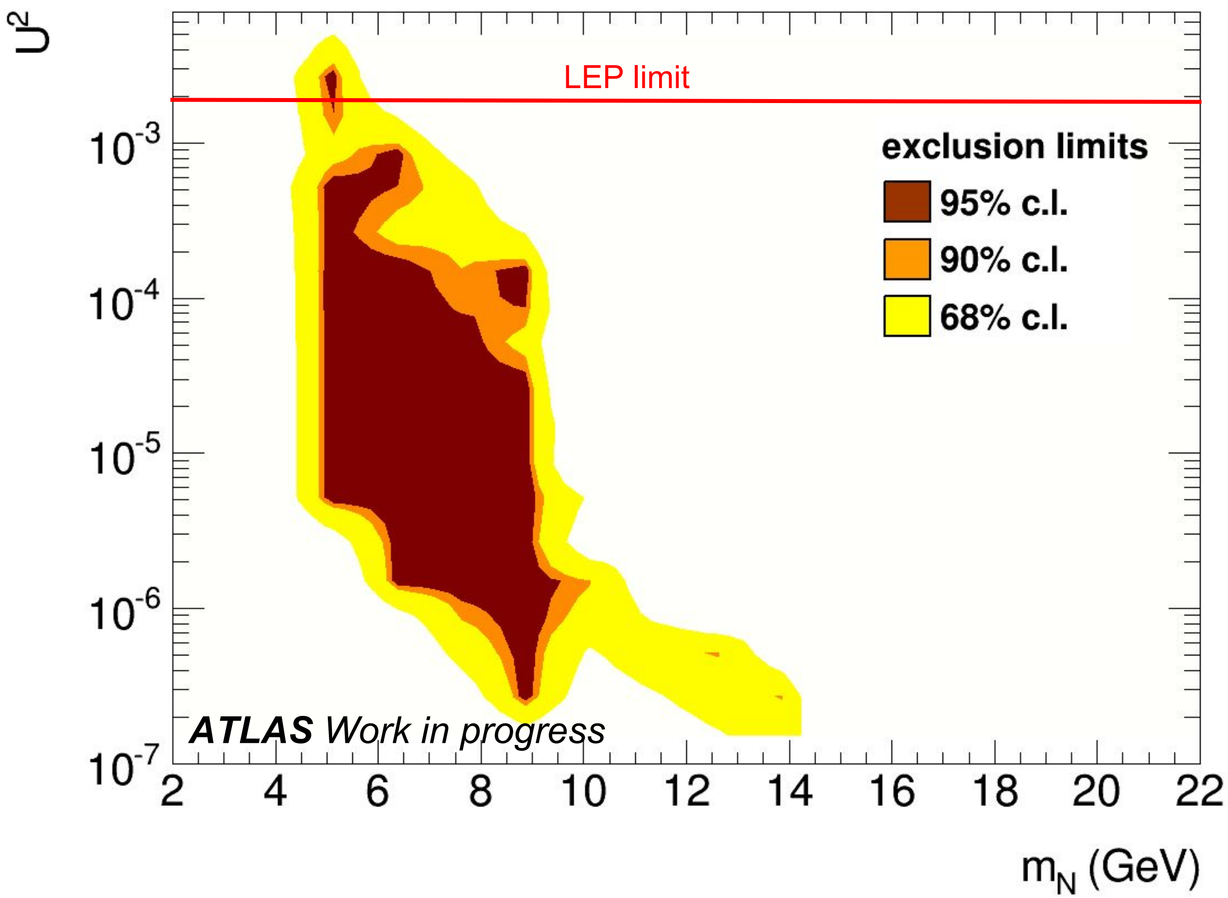
mass cut (GeV)	P_{DV}^{2mu}	# of expected backgrounds
	$(1.6\pm0.1)\times10^{-4}$	19 ± 2
> 2	$(1.7\pm0.2)\times10^{-4}$	12 ± 1
> 4	$(7.1\pm5.0)\times10^{-6}$	0.2 ± 0.2
> 6	$(6.0\pm6.0)\times10^{-6}$	0.1 ± 0.1
> 10	$(1.5\pm1.5)\times10^{-5}$	0.1 ± 0.1
> 20	$(7.7\pm7.7)\times10^{-5}$	0.1 ± 0.1
> 30	$(1.8\pm1.8)\times10^{-4}$	0.1 ± 0.1
> 50	$(5.0\pm5.0)\times10^{-4}$	0.1 ± 0.1



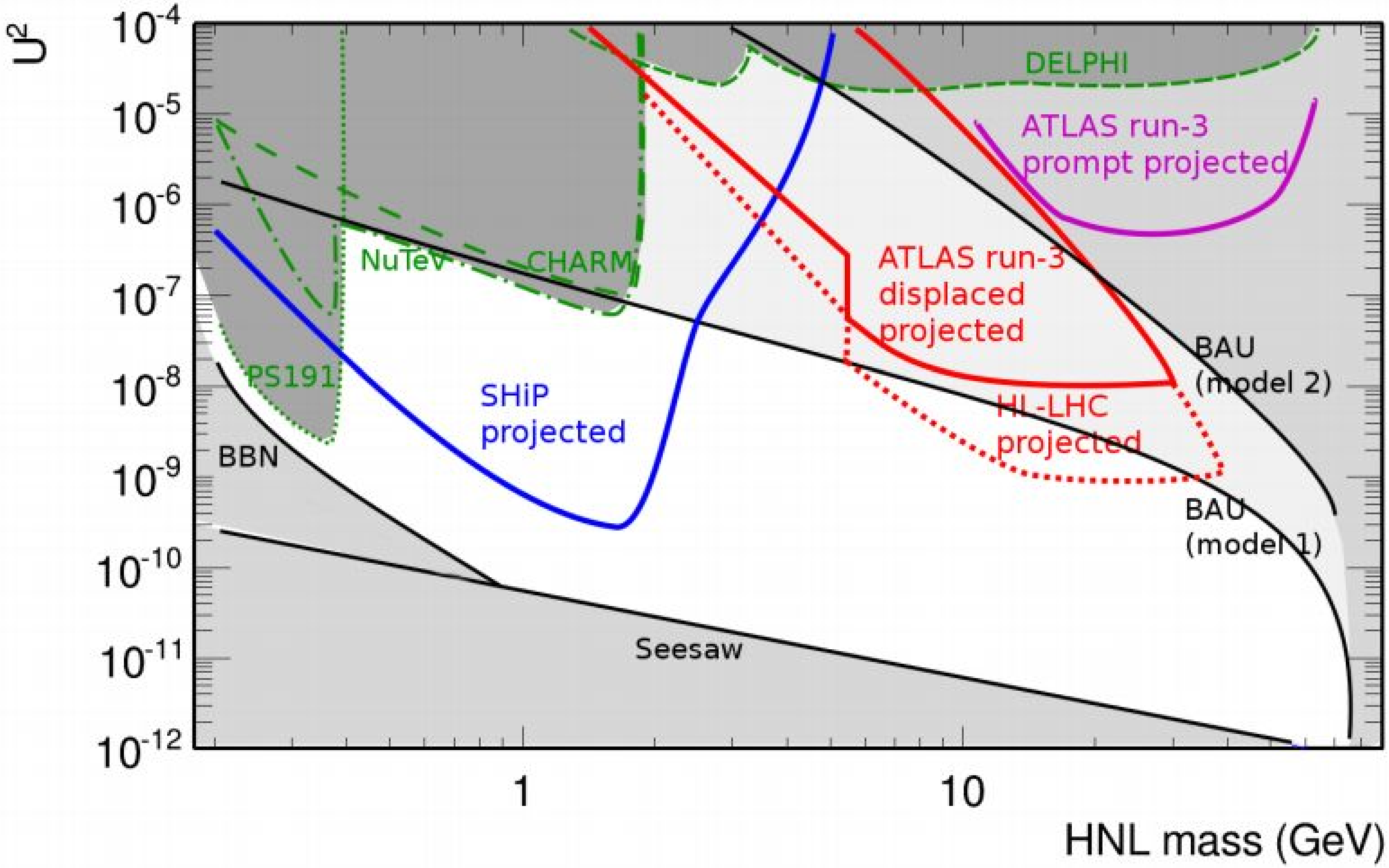
Exclusion limits

"**Exercise**" on what we expect to see

- With a supposed realistic maximum selection efficiency of 1%
- Assuming cut at 4 GeV in DV mass and 0 background



assume SHiP technical proposal
assume 300 (3000) fb^{-1} @ 14 TeV in ATLAS



Also assuming optimized triggers and optimized displaced tracks reconstruction

Ref: [NuPhys 2016]

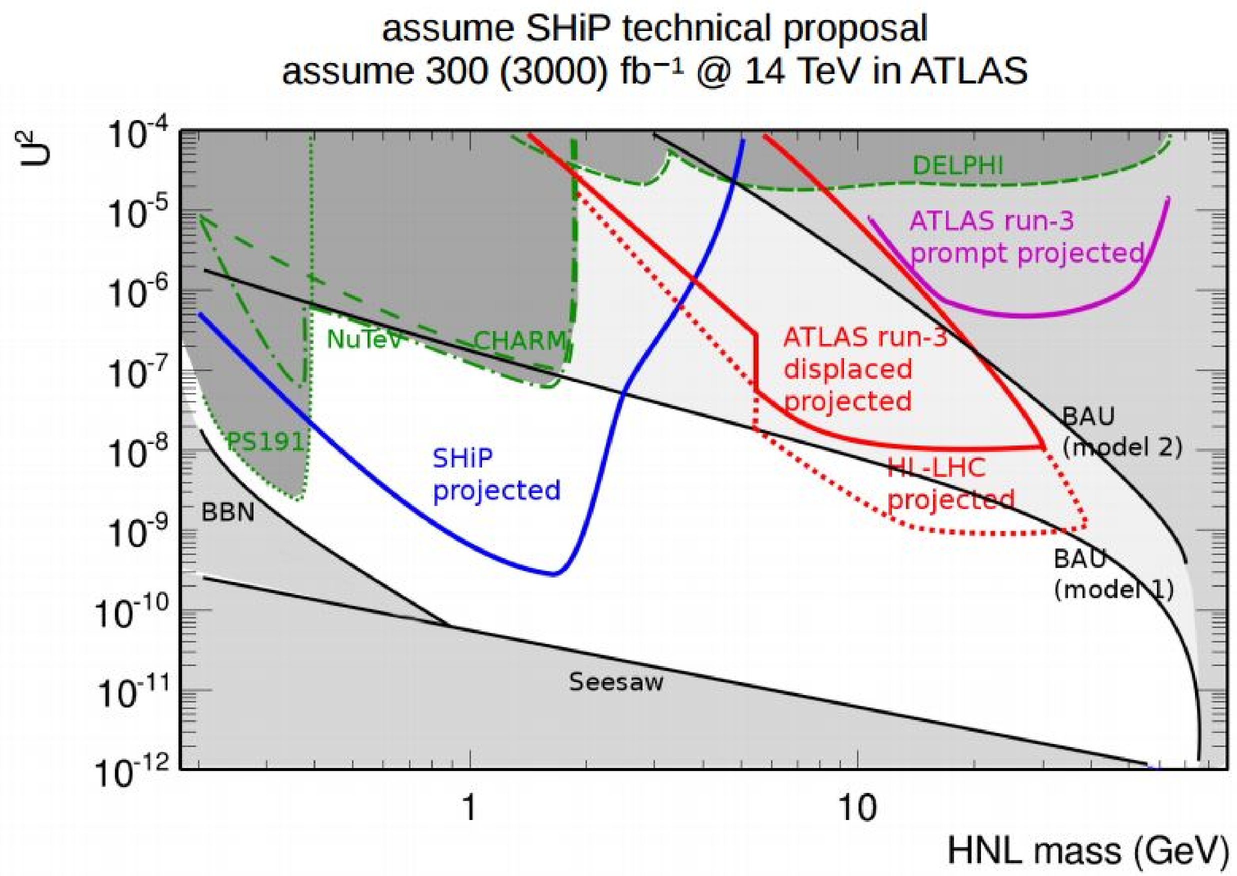
Summary and future

- **Heavy Neutral Lepton is a potentially powerful problem solver for a lot of HEP unresolved issues (DM, BAU, v masses)**
- Displaced HNL analysis soon to closure in **ATLAS**
  - Selection almost frozen
  - Background study being finalized
  - Systematics
  - Limit plot to be produced (or… ?)
  - Note writing
- Also a prompt HNL analysis progressing and soon to closure (mass range > 20 GeV)

- Future search planned with the **SHiP experiment**, mostly dedicated to HNL discovery
- Future **HL-LHC** benefit, more luminosity, more Ws…
- Later: **FCC-ee**...

Thank you

Backup slides



BAU model 1: PRD 87, 093006 (2013) (N 1 does not participate in BAU → dark matter)

BAU model 2: PRD 90, 125005 (2014) (allow all three Ns to participate in BAU)

Background estimation

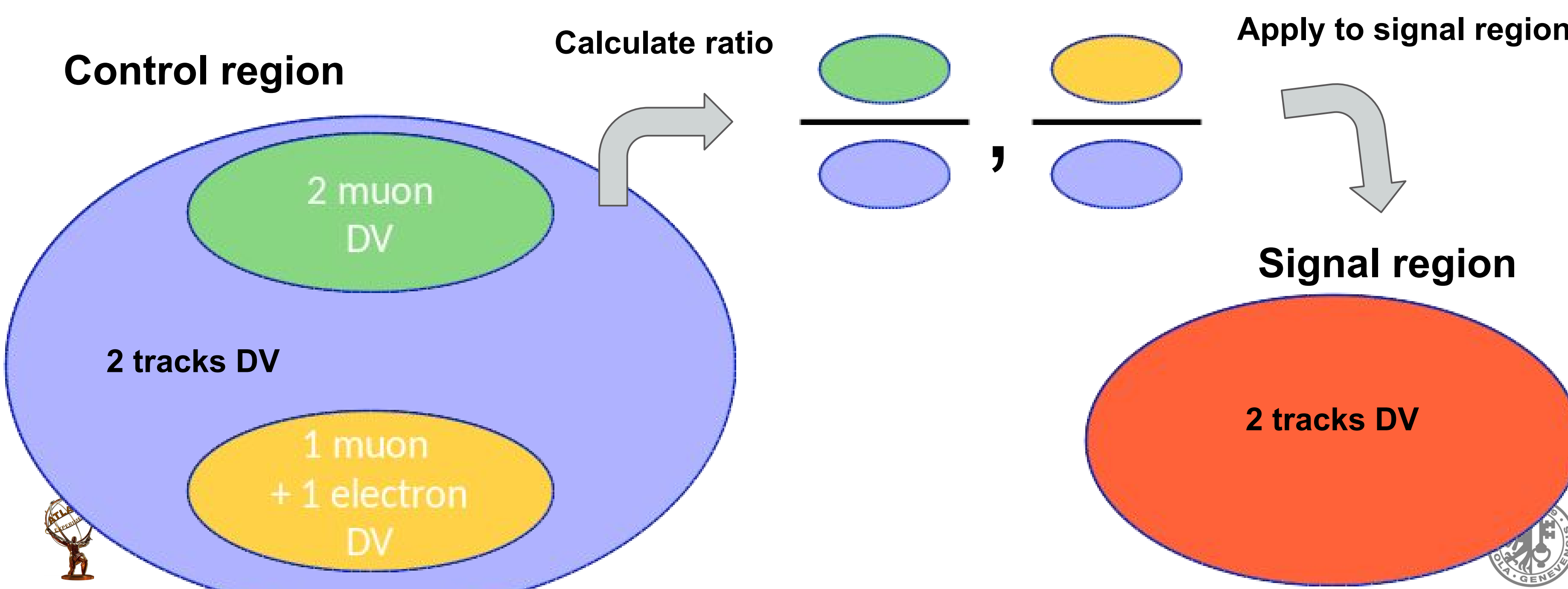
The backgrounds in SR are estimated using data, with DV in CR.

We assume that:

The fraction of the number of DV with (2 muons) or (1 muon+1electron) to 2 tracks DV, is independent from the presence of a prompt muon.

<u>Estimation of the background:</u>

p_{DV} * (nb of triggered events with a reconstructed isolated prompt muon p_T > 28 GeV) = nb of expected background events



Basic idea of large radius tracking in run II

HNL : displaced vertices : need large radius tracking

Standard tracking find tracks from the interaction point, potentially leaving hits from displaced tracks unused.

Large d0 tracking performs tracking on the unused hits, with loose cuts.