# Heavy Neutrino Searches at ATLAS

Matthias Danninger on behalf of ATLAS Canada

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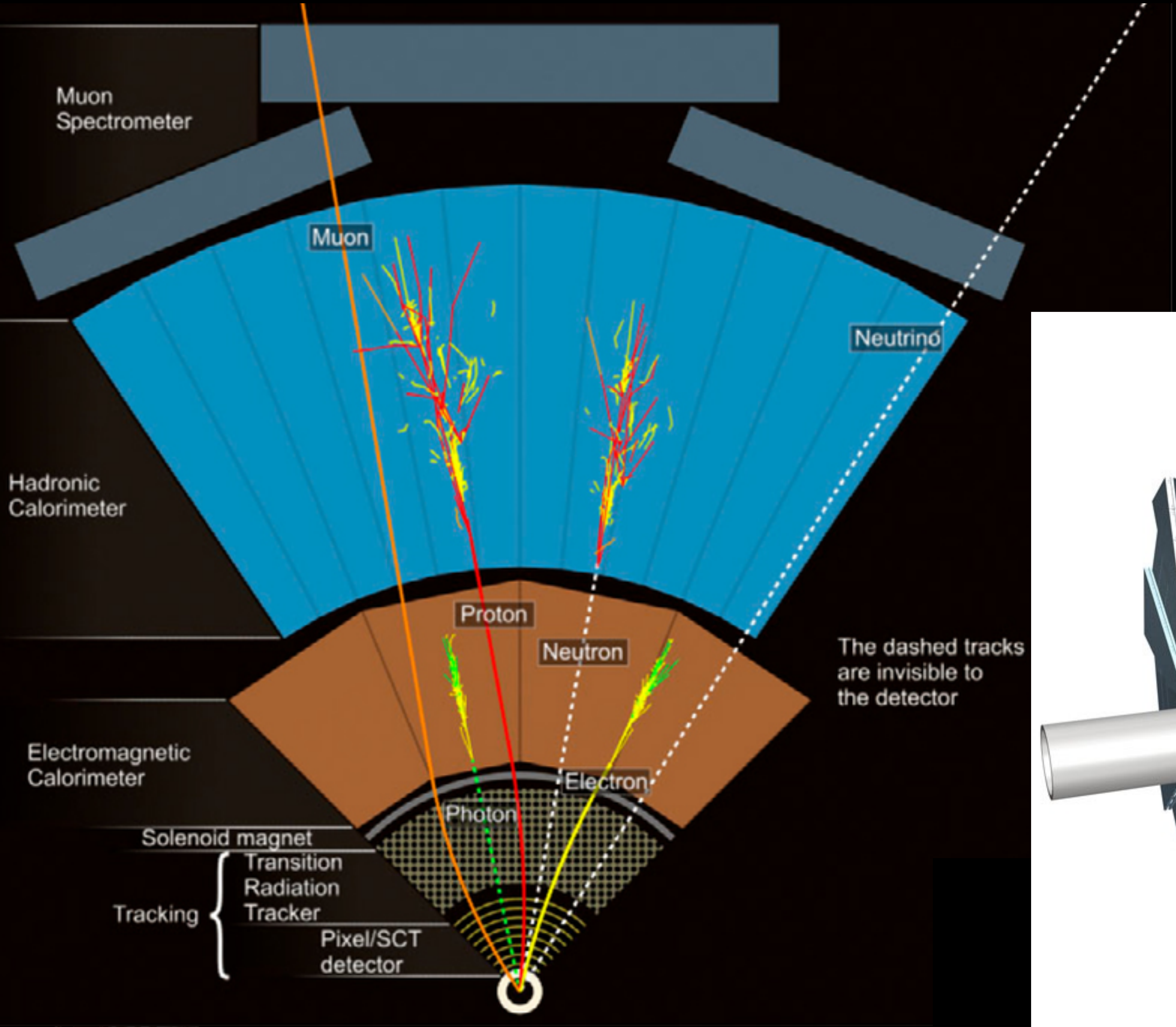
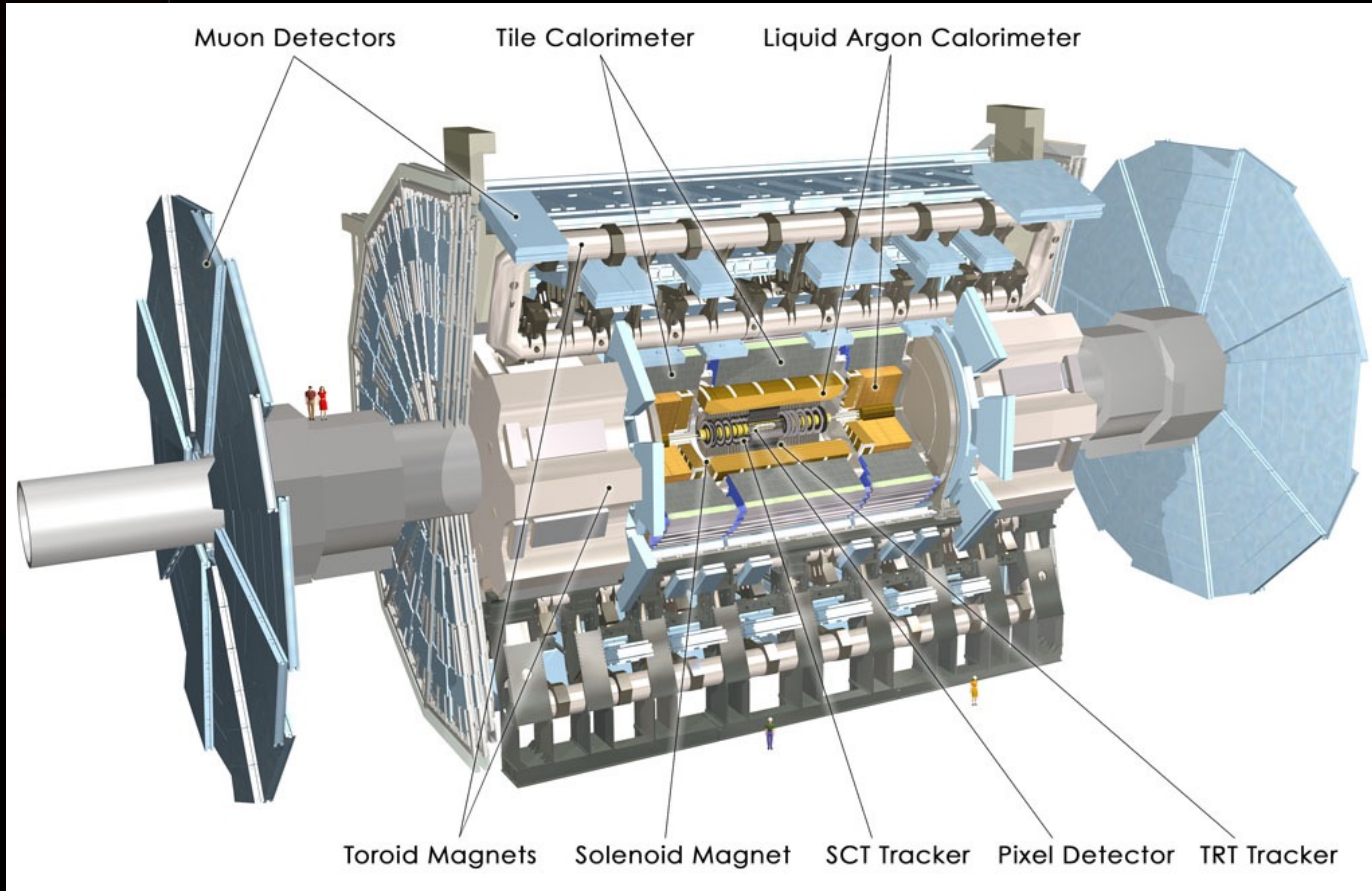
SIMON FRASER UNIVERSITY

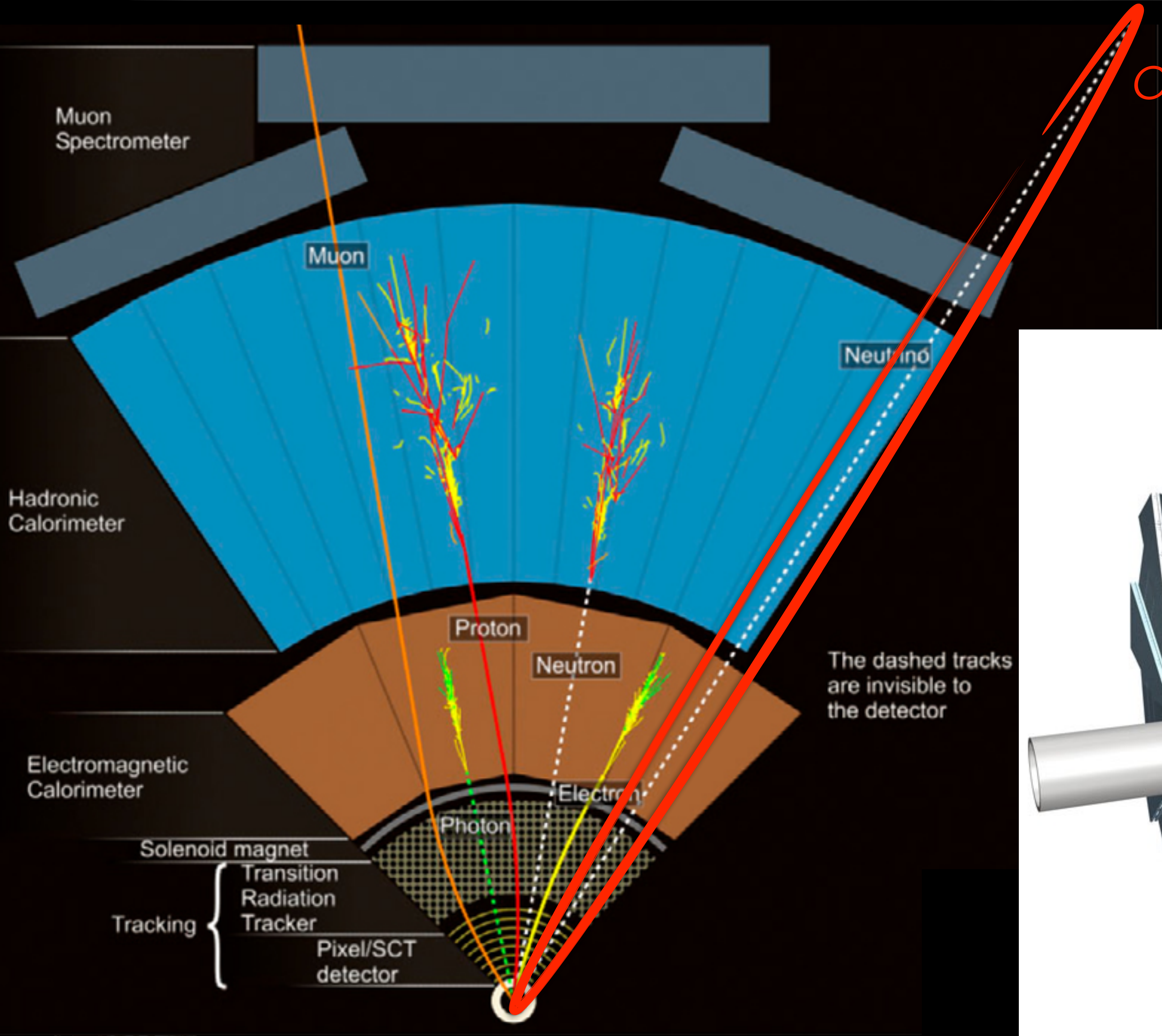
# The ATLAS experiment @ the LHC



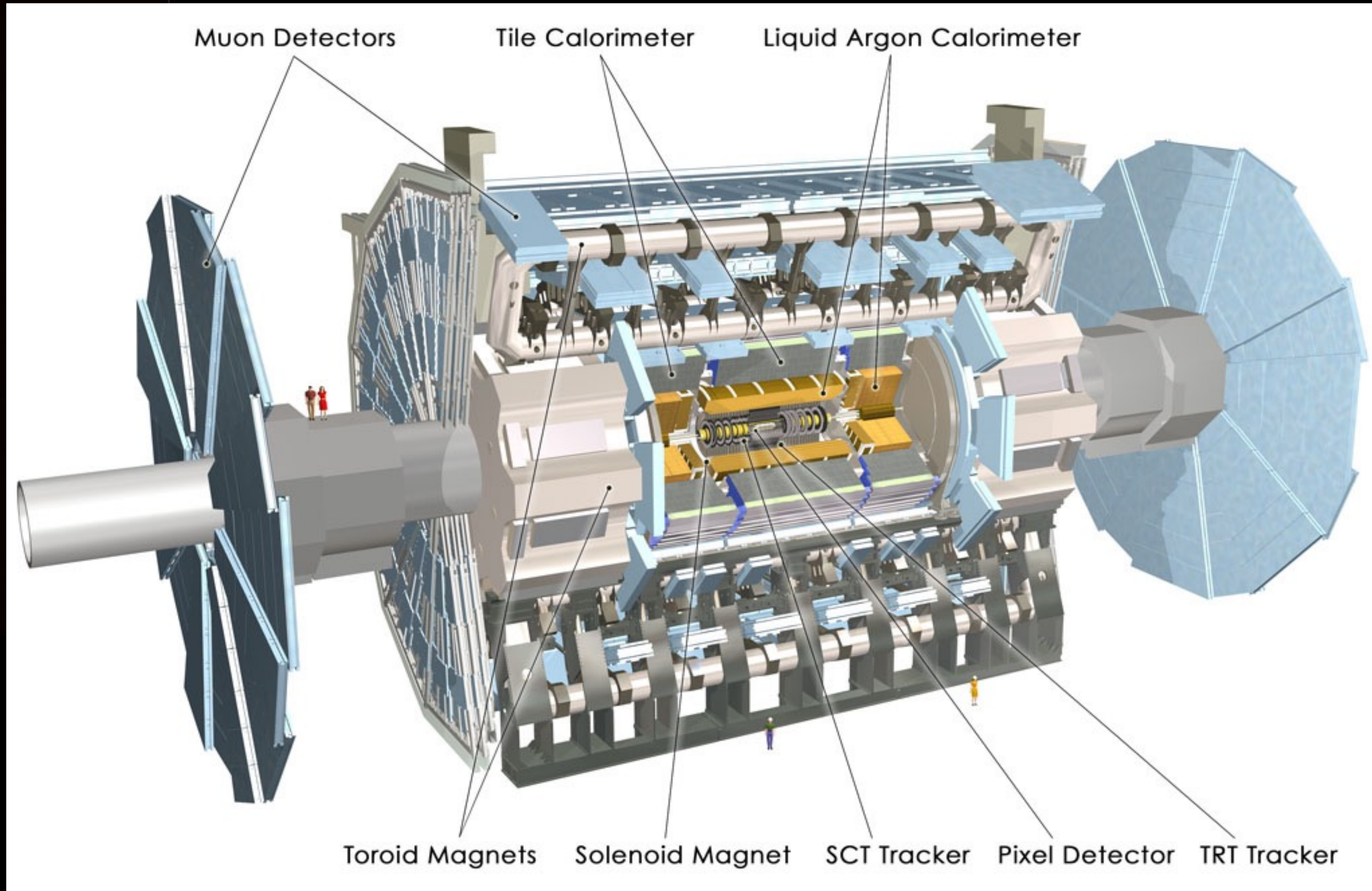



# The ATLAS experiment @ the LHC






*Obviously, not the focus of this talk!*



# Heavy Neutrino theoretical models



- Experimental signature of neutrino oscillation concludes neutrinos have very small masses
  - Several searches at *ATLAS* try to explain it and why they are so small

- Left Right Symmetric Models — ***LRSM***
  - Restores parity by introducing heavy right-handed $W_R/Z_R$ bosons and Heavy Neutral Leptons (HNLs)
    —> postulates heavy new ***SU(2)***$_R$ for SM ***SU(2)***$_L$
  - Models naturally embed the Seesaw Mechanism which couples light $\boldsymbol{\nu}_L$ to HNLs through a mass mixing matrix
    —> allows HNLs at GeV/TeV scale (good for ATLAS!)
  - Models consider SeeSaw type I, II, and III

- Neutrino Minimal Standard Model ($\boldsymbol{\nu}$MSM)
  - Incorporates SeeSaw type I mechanism
  - Small $\boldsymbol{\nu}_L$ masses result from large mass of HNLs
  - Includes HNLs without additional vector bosons

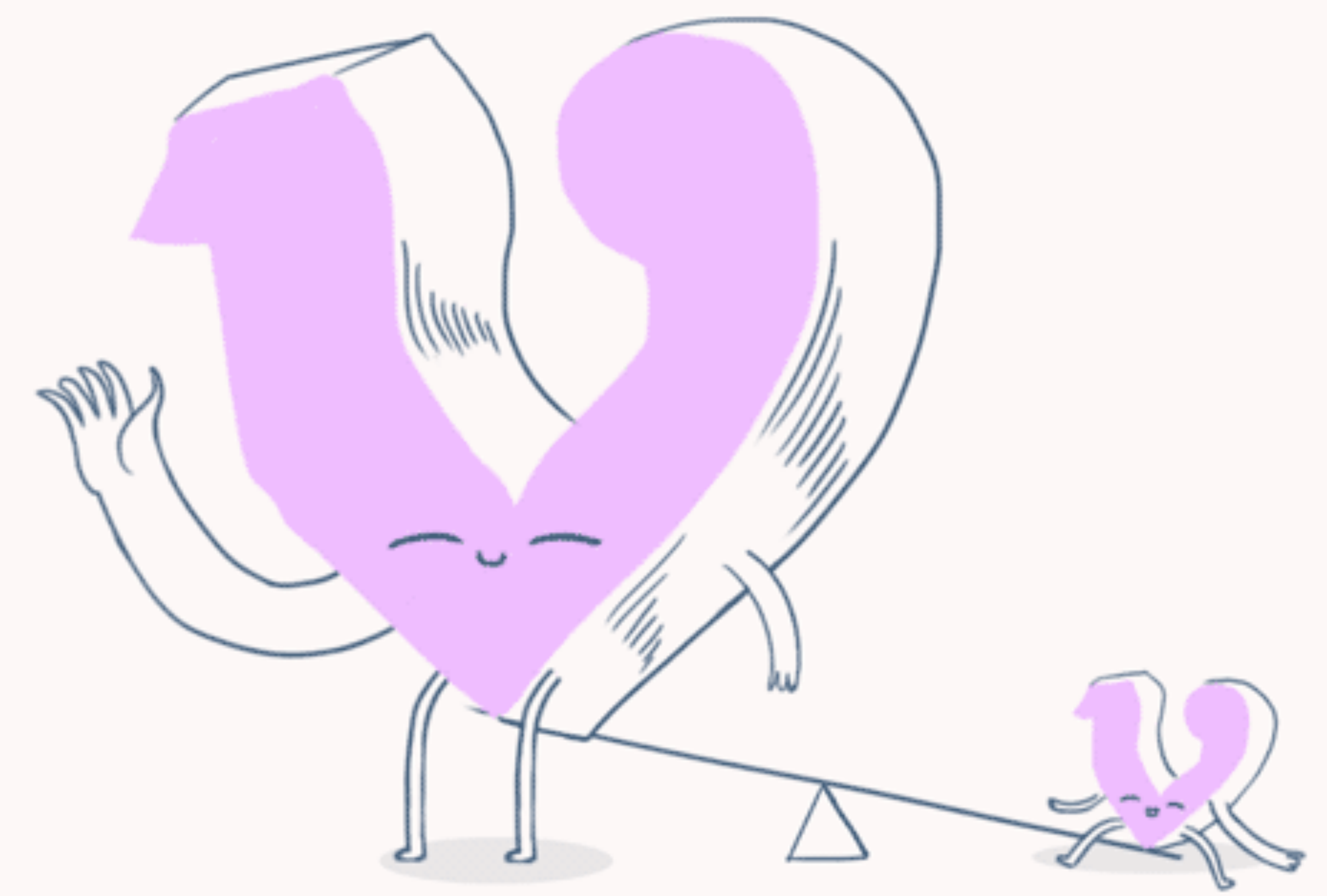


*image credit symmetry-magazine*


*Analysis Overview:*

- Search for HNLs & WR in LRSM
- Search for HNLs in type III SeeSaw models ($L^{\pm}$, $N^{0}$)
- Search for HNLs in $\boldsymbol{\nu}$MSM



*image credit M. Komm*


*Analysis Overview:*

- *Search for HNLs & $W_R$ in LRSM*
- Search for HNLs in type III SeeSaw models ($L^{\pm}$, $N^0$)
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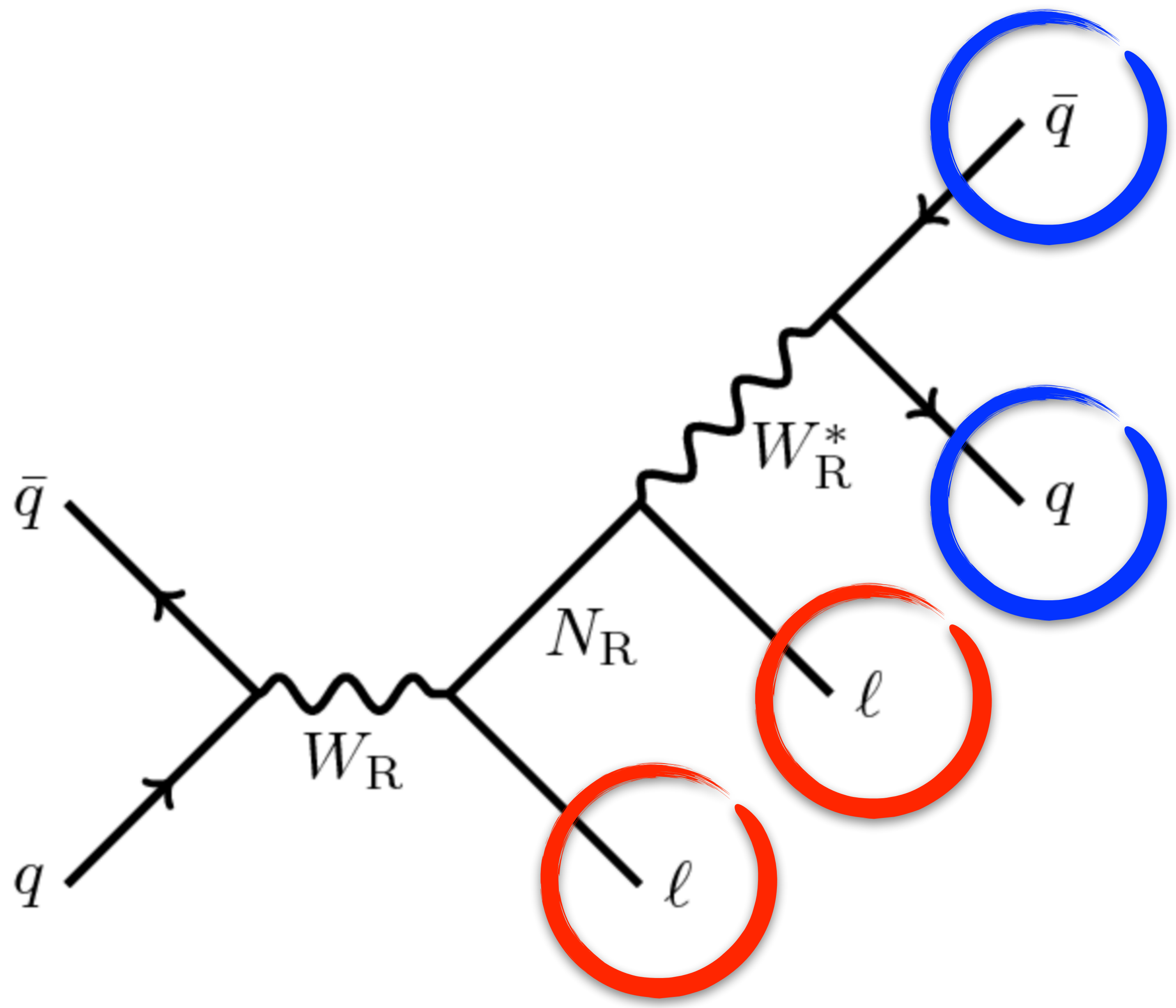
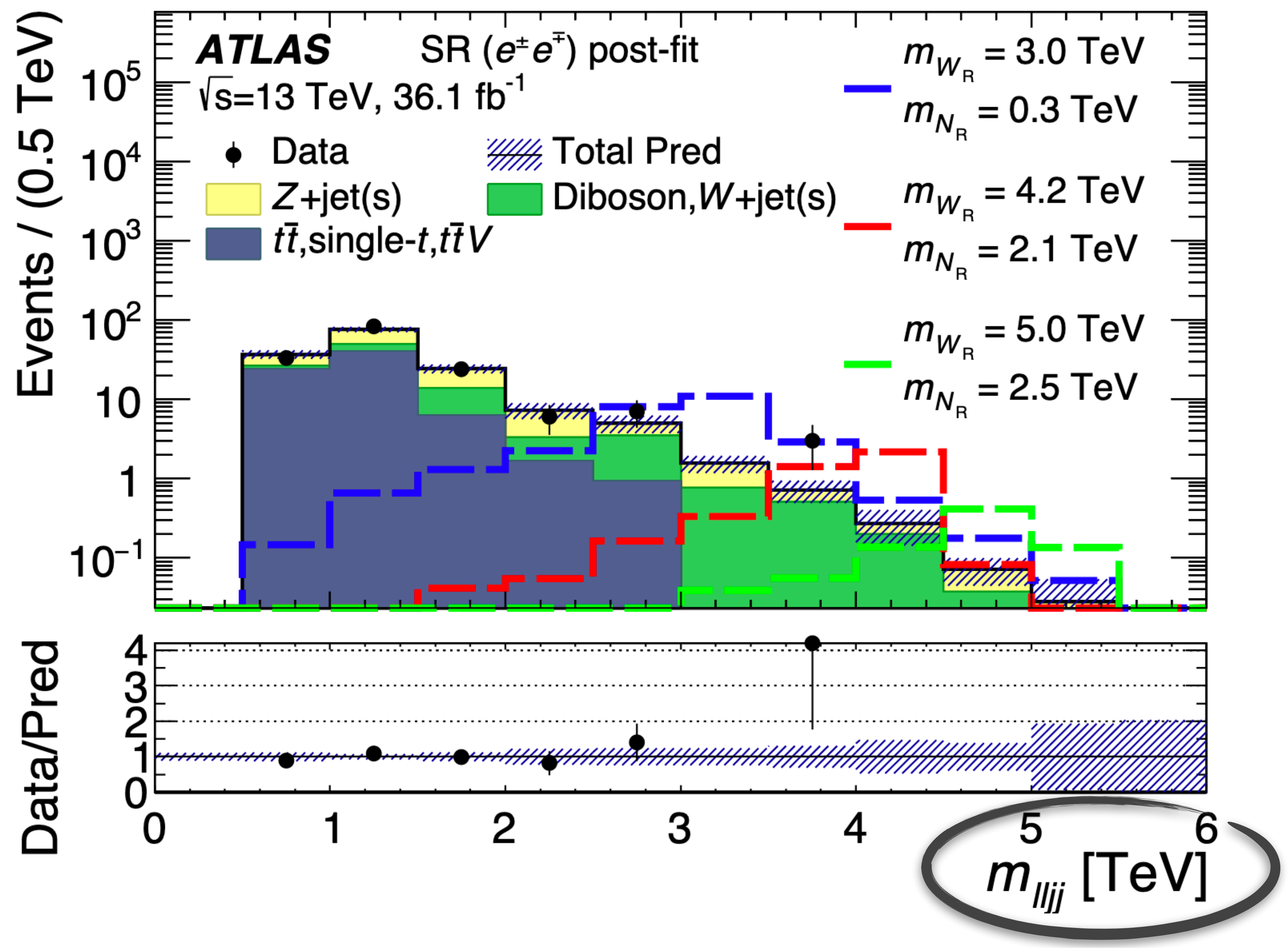
*image credit M. Komm*

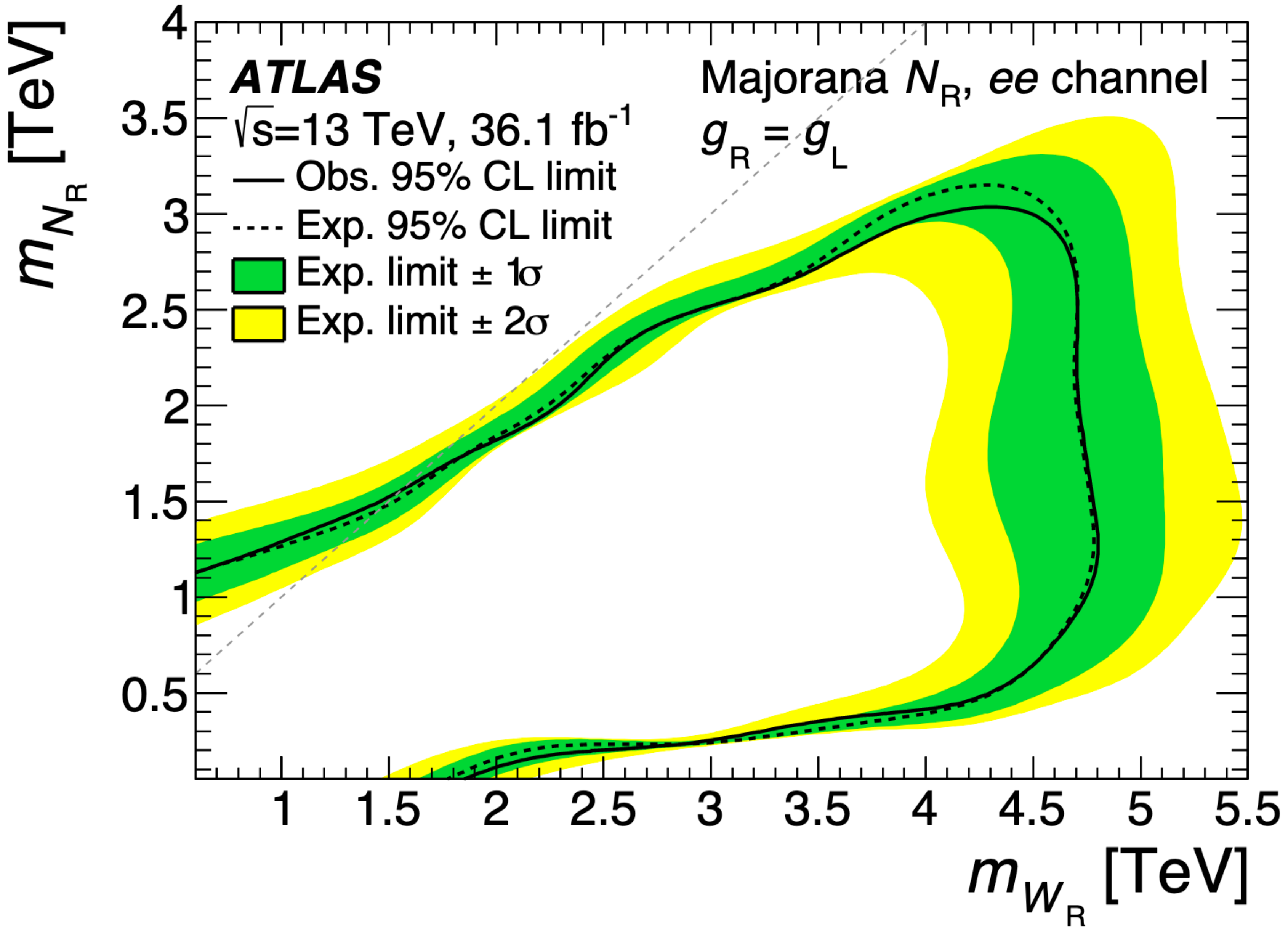
# Search for HNLs and $W_R$ in LRSM

JHEP 01 (2019) 016
EXOT-2017-18

- Search in the 2D plane of $N_R$ and $W_R$
- Assume perfect symmetry at high scales: $g_L = g_R$
- Using dilepton events (**ee/$\mu\mu$**) with **jets**



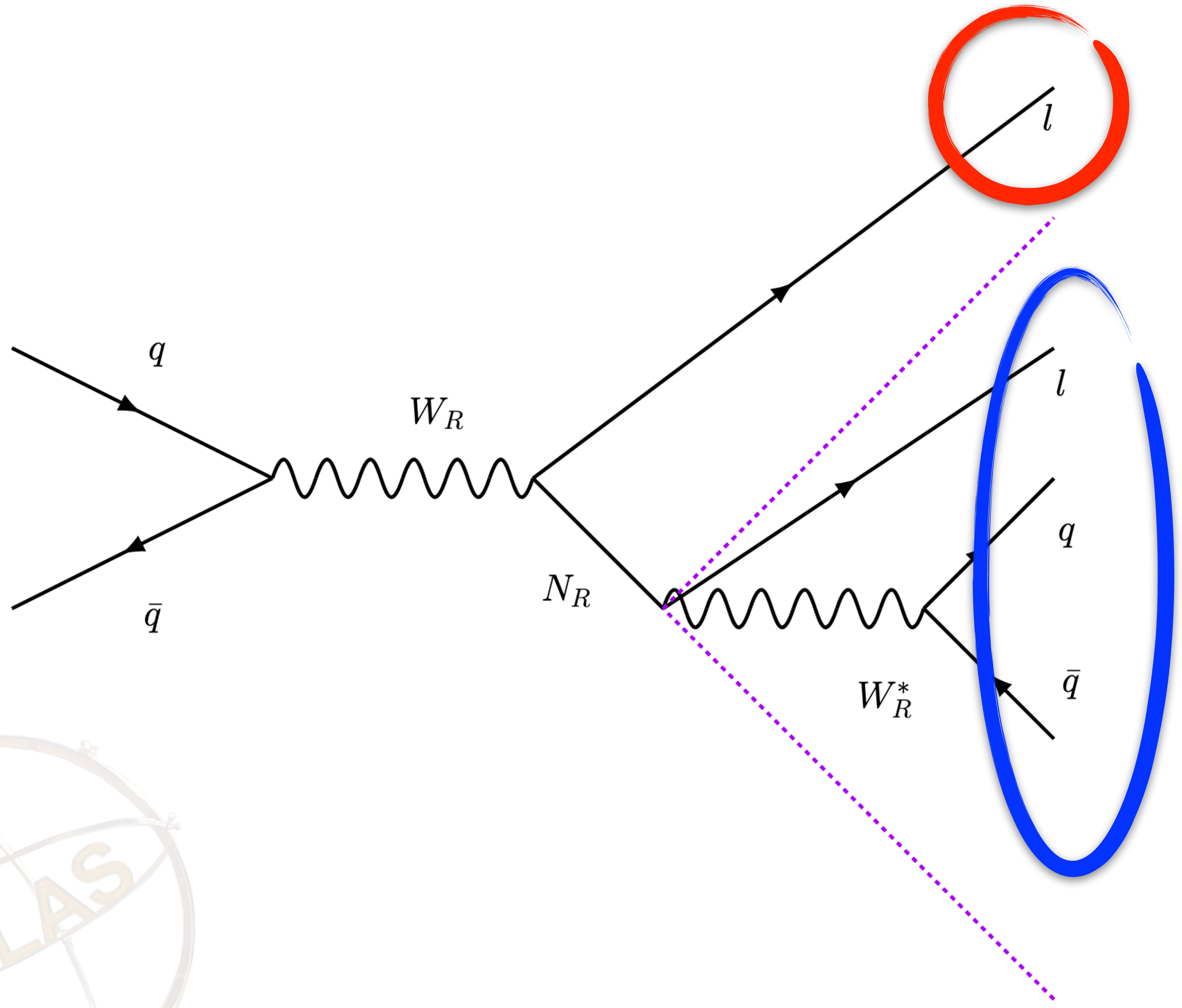



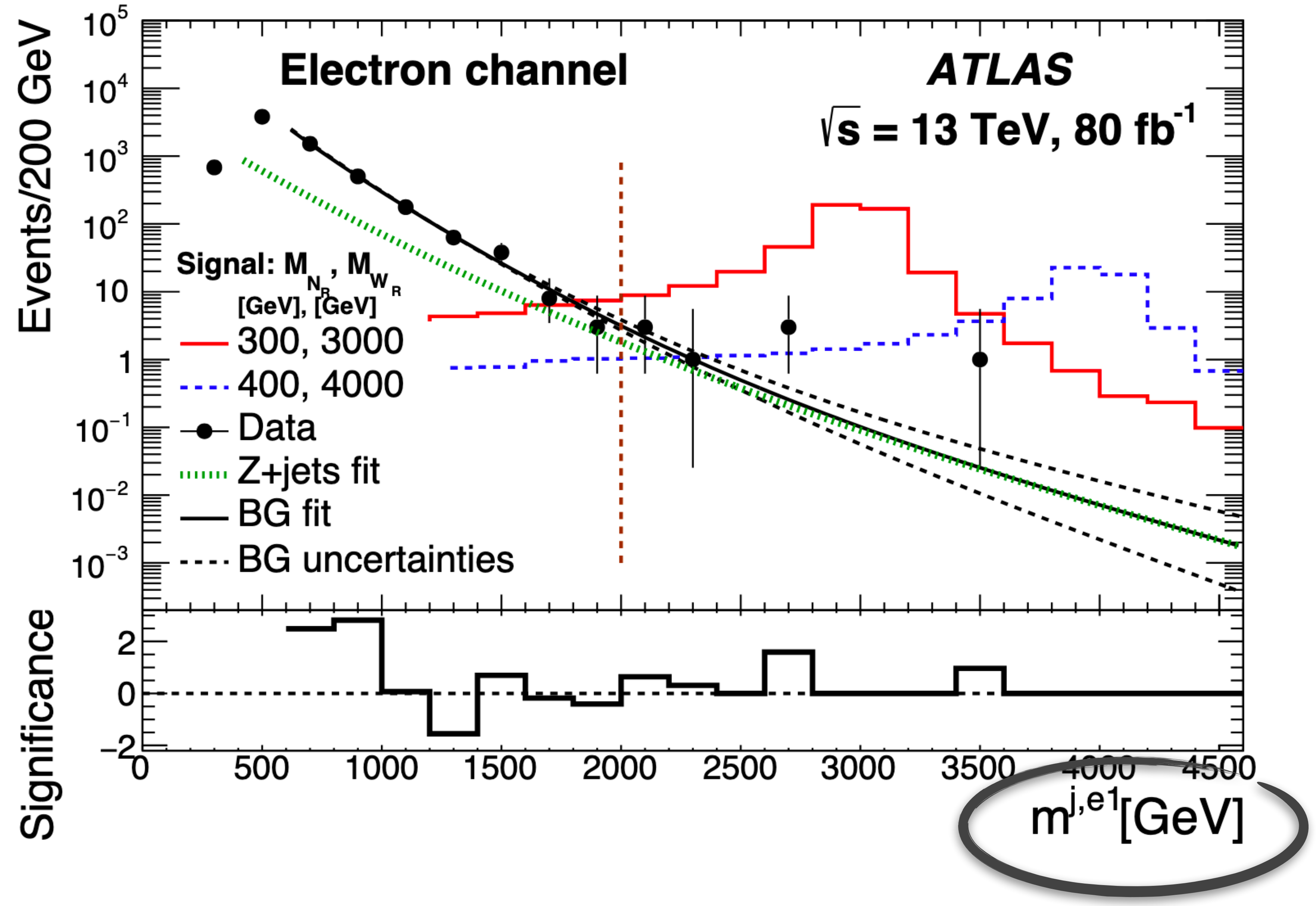
# Search for HNLs and $W_R$ in LRSM — boosted

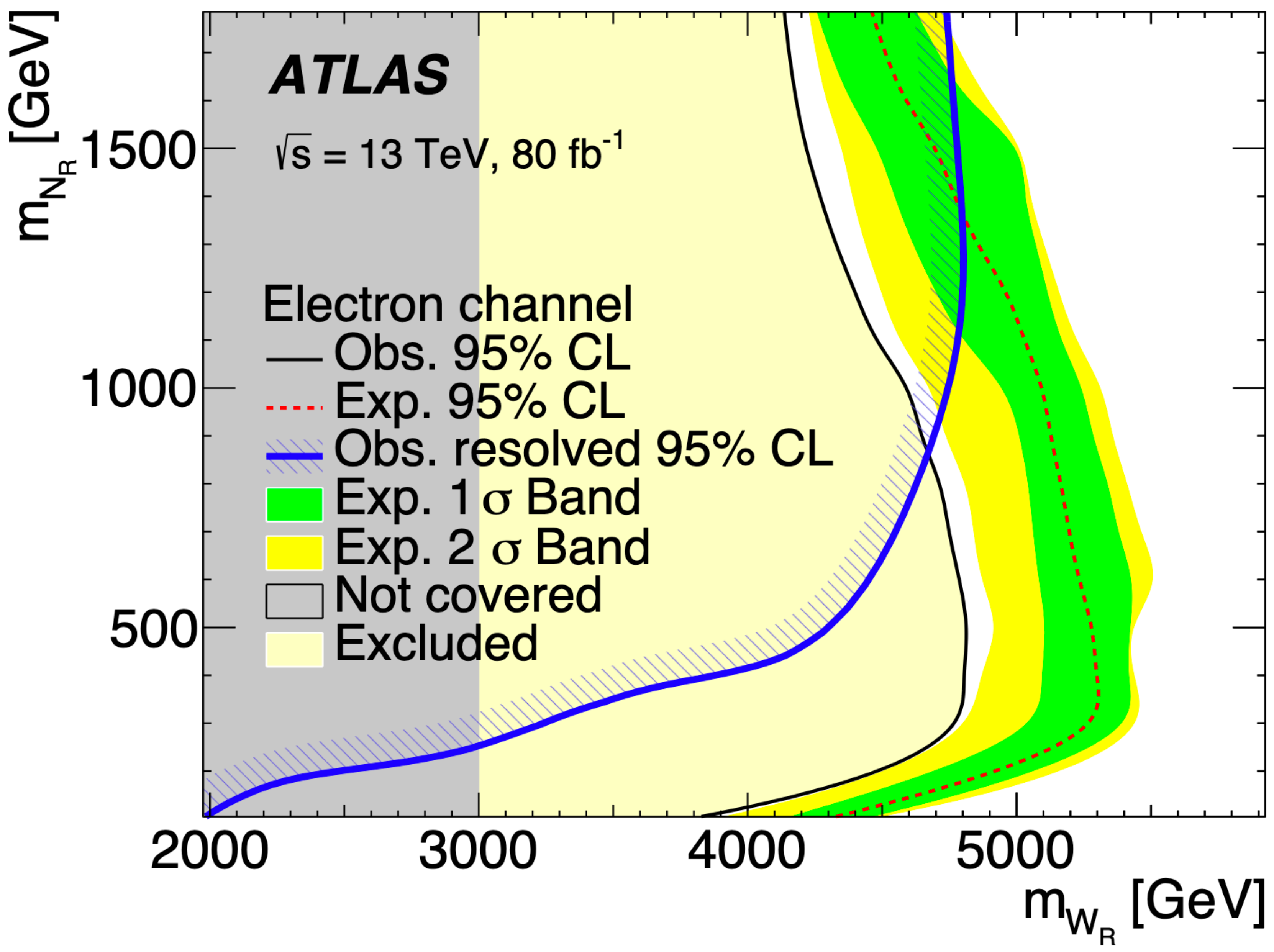
PLB 798 (2019) 134942
EXOT-2018-15



- Search in the 2D plane of $N_R$ and $W_R$
- Assume perfect symmetry at high scales: $g_L=g_R$
- **Boosted topology when $m_{W_R} >> m_{N_R}$**
- Using events (**e/$\mu\mu$**) with large-radius **jet**




*Analysis Overview:*

- Search for HNLs & $W_R$ in LRSM
- *Search for HNLs in type III SeeSaw models ($L^{\pm}$, $N^{0}$)*
- Search for HNLs in $\nu$MSM



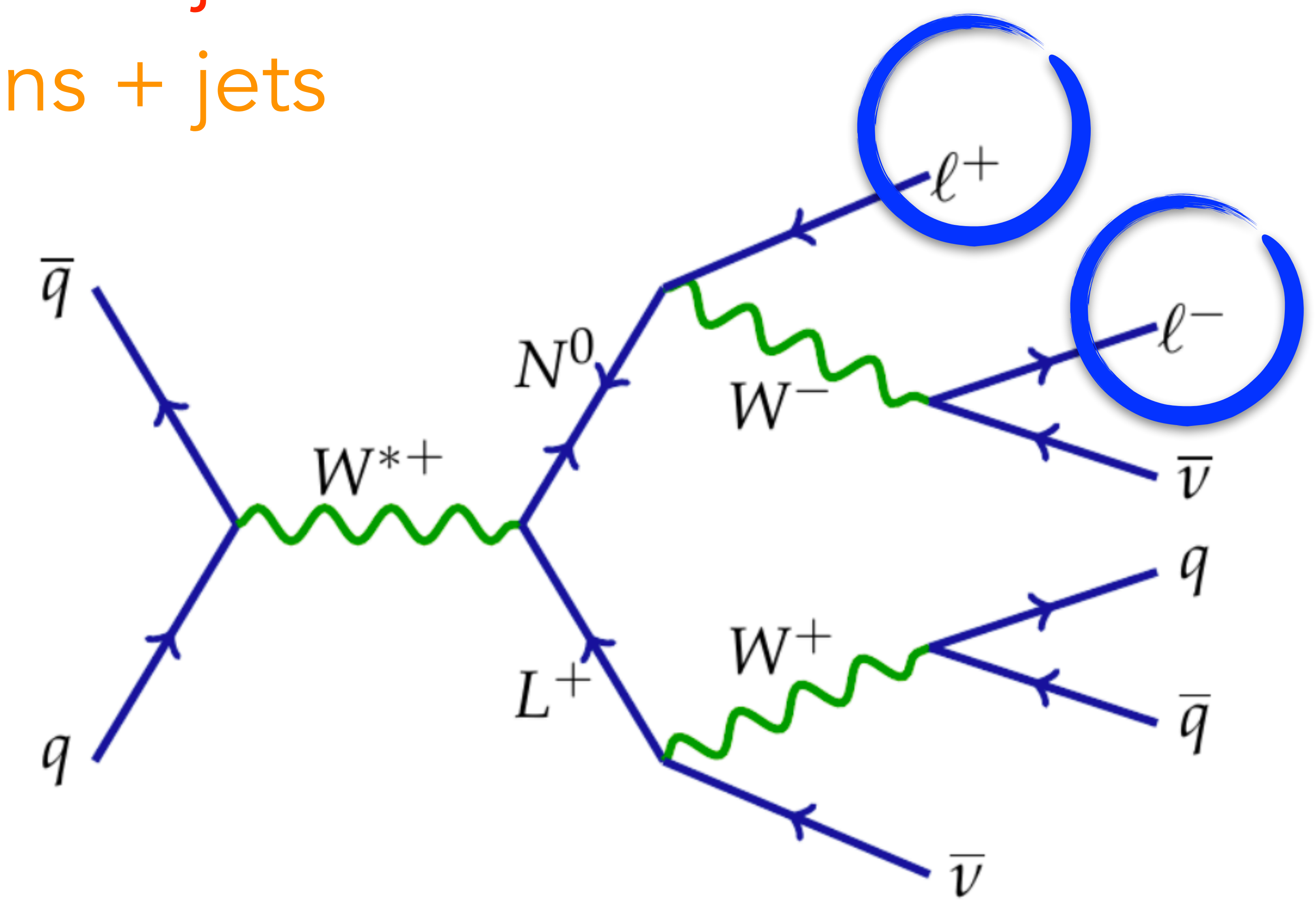
*image credit M. Komm*

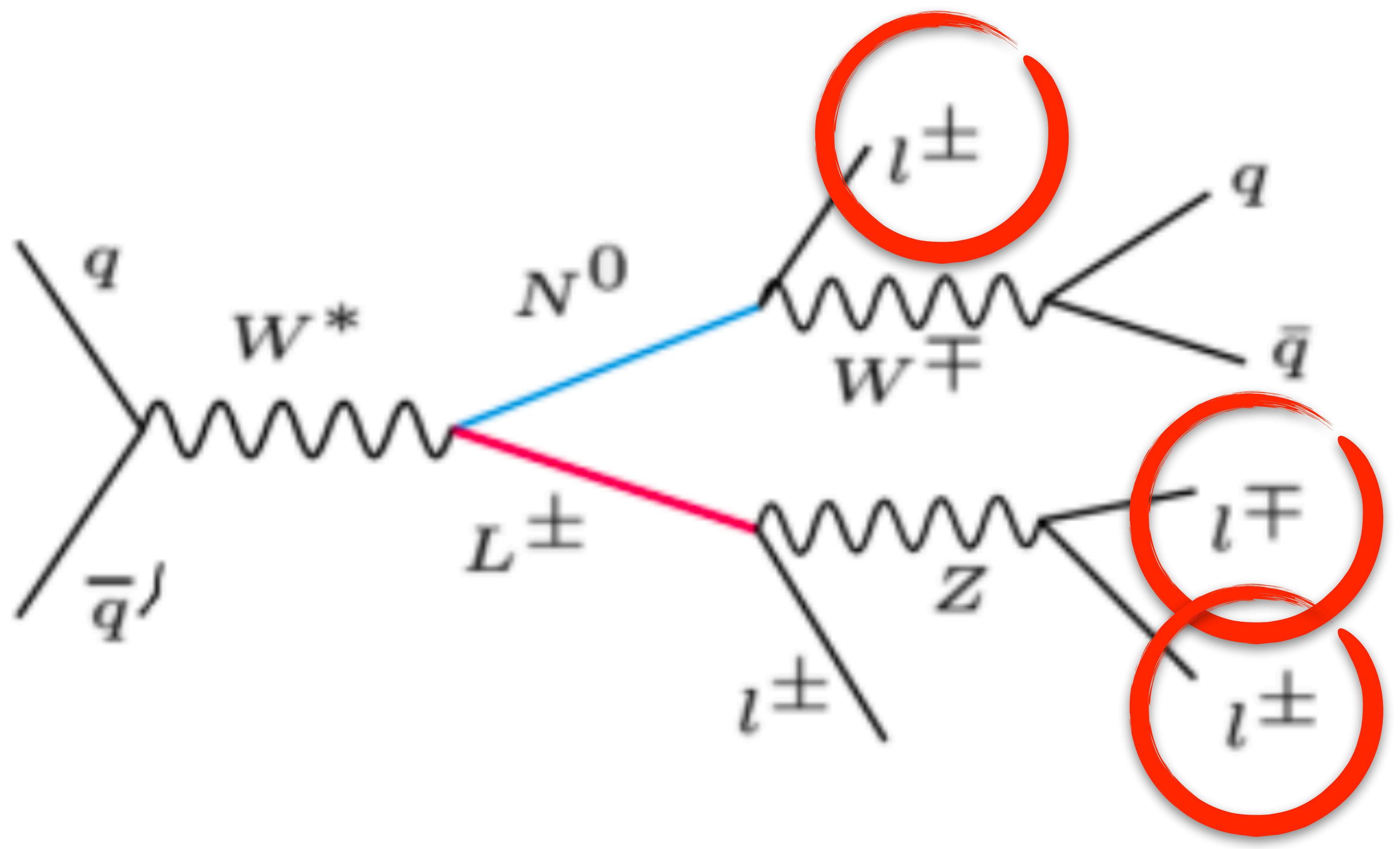
# Search for type III Fermionic Triplet

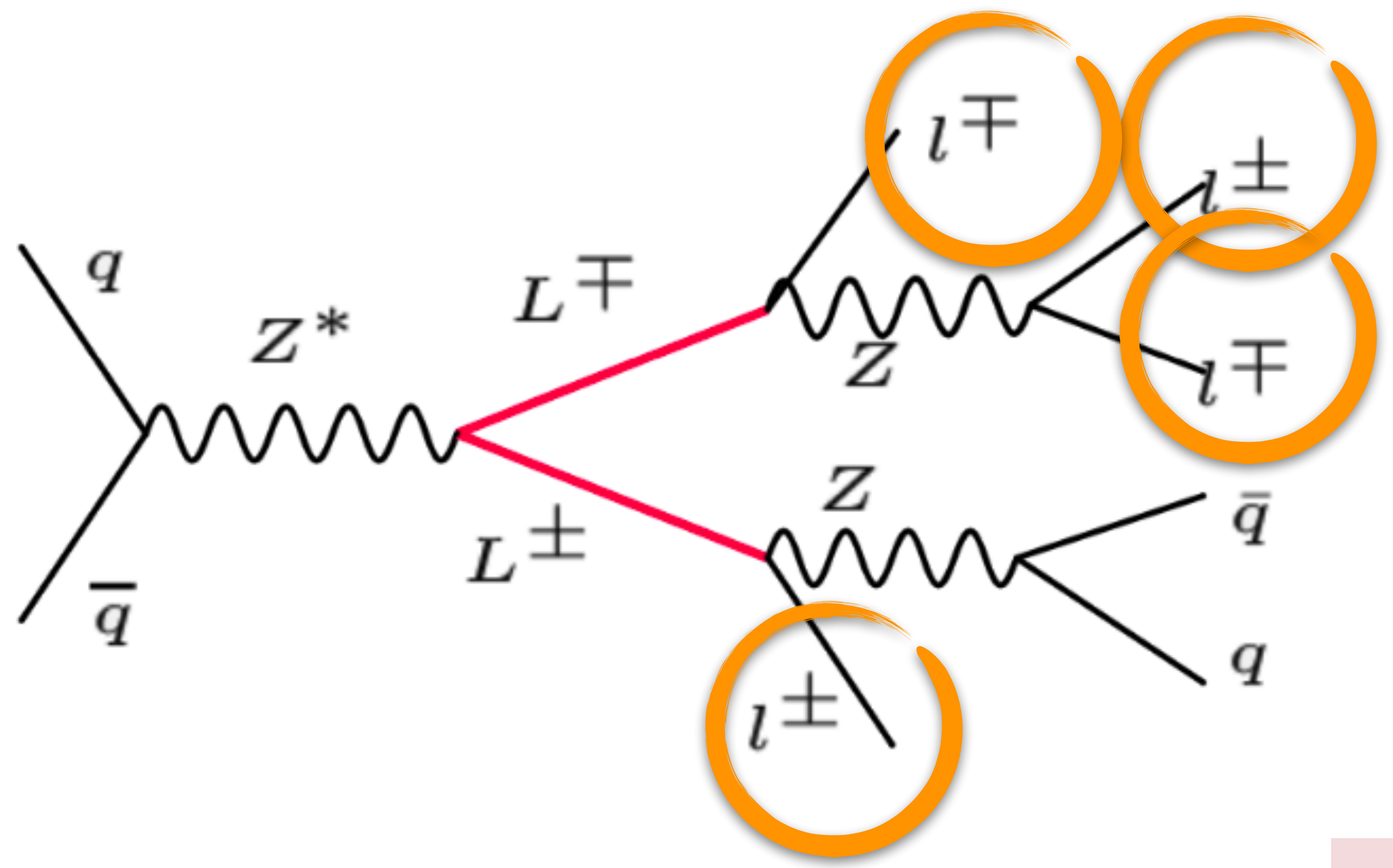
ATLAS-CONF-2021-023



- Search for mass-degenerate fermonic triplet ($L^{\pm}$, $N^0$)
- Assume equal branching $\mathcal{B}_e = \mathcal{B}_\mu = \mathcal{B}_\tau = 1/3.$
- Three main topologies considered:
  - 2 leptons + jets
  - 3 leptons + jets
  - 4 leptons + jets




Main backgrounds in this search:

- Rare top events (3t, 4t, tt+W/H/Z) & Diboson events (irreducible)
- Fake non-prompt leptons (reducible)

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ATLAS-CONF-2021-023

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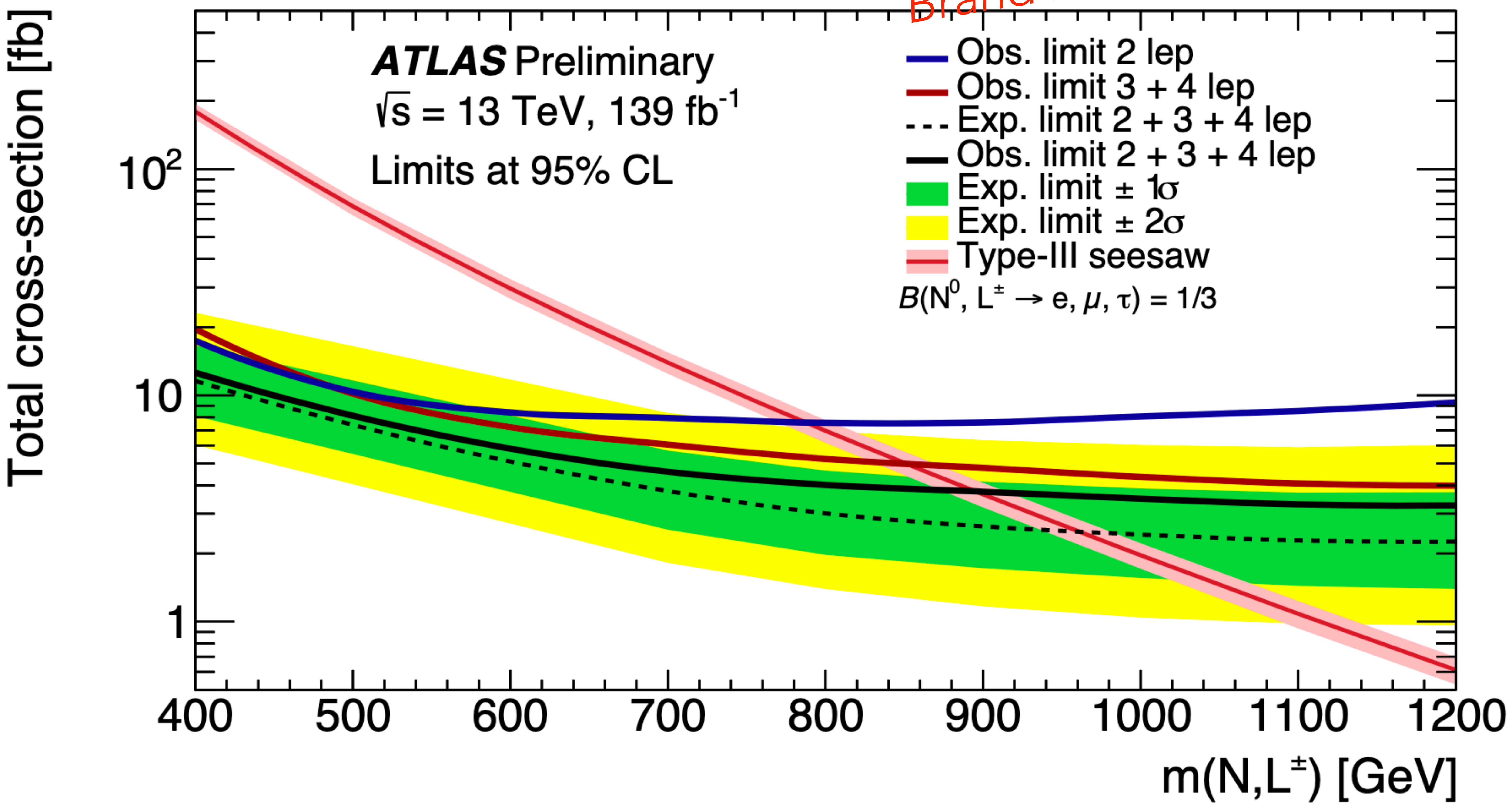
Brand new result this week!



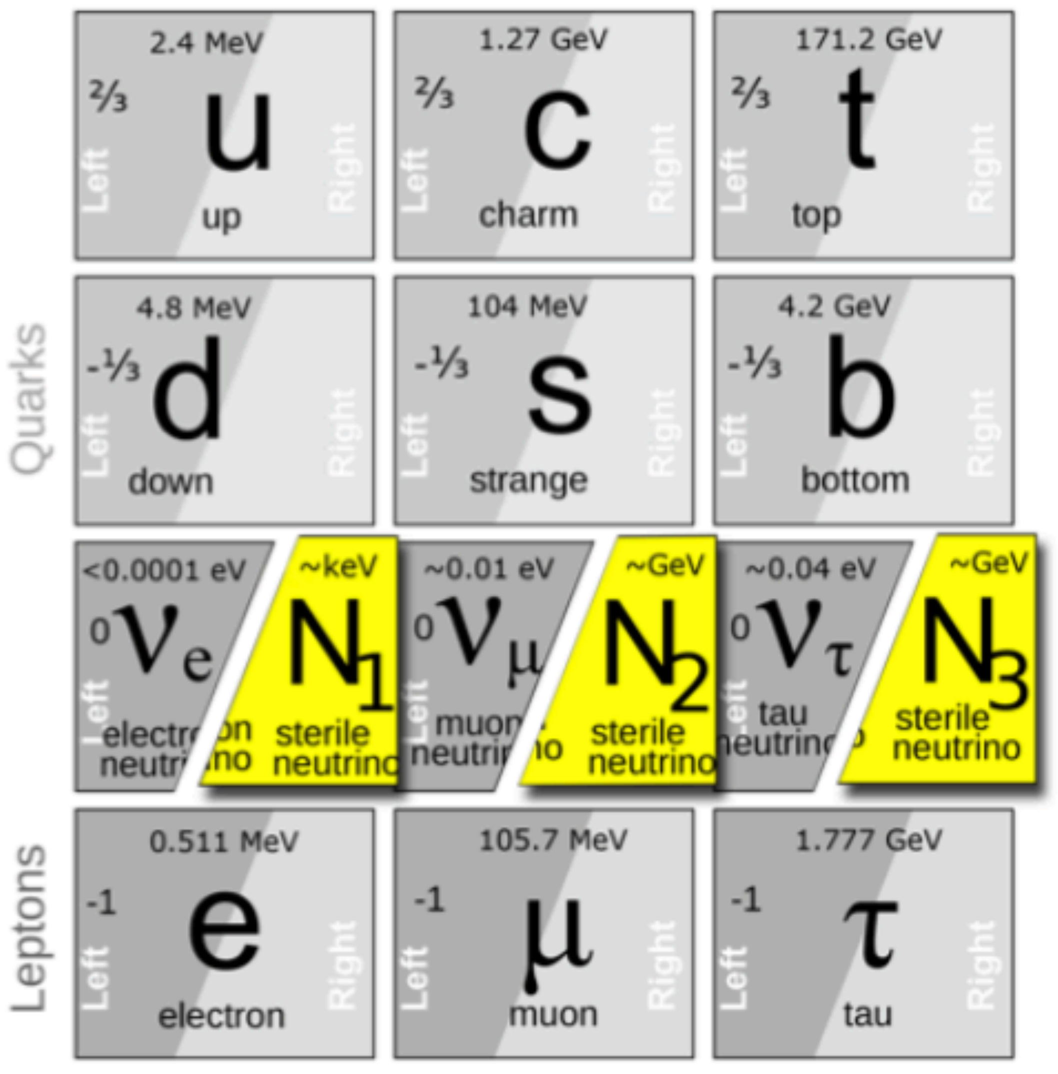

## *Analysis Overview:*

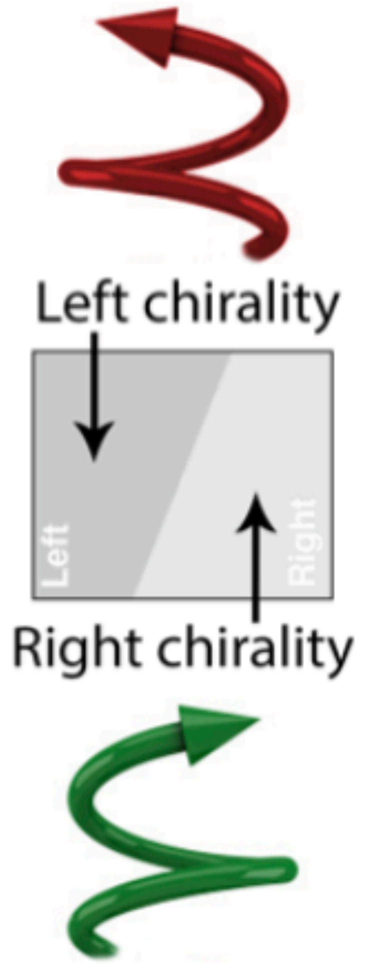
- Search for HNLs & $W_R$ in LRSM
- Search for HNLs in type III SeeSaw models ($L^{\pm}$, $N^0$)
- ***Search for HNLs in νMSM***

*image credit M. Komm*

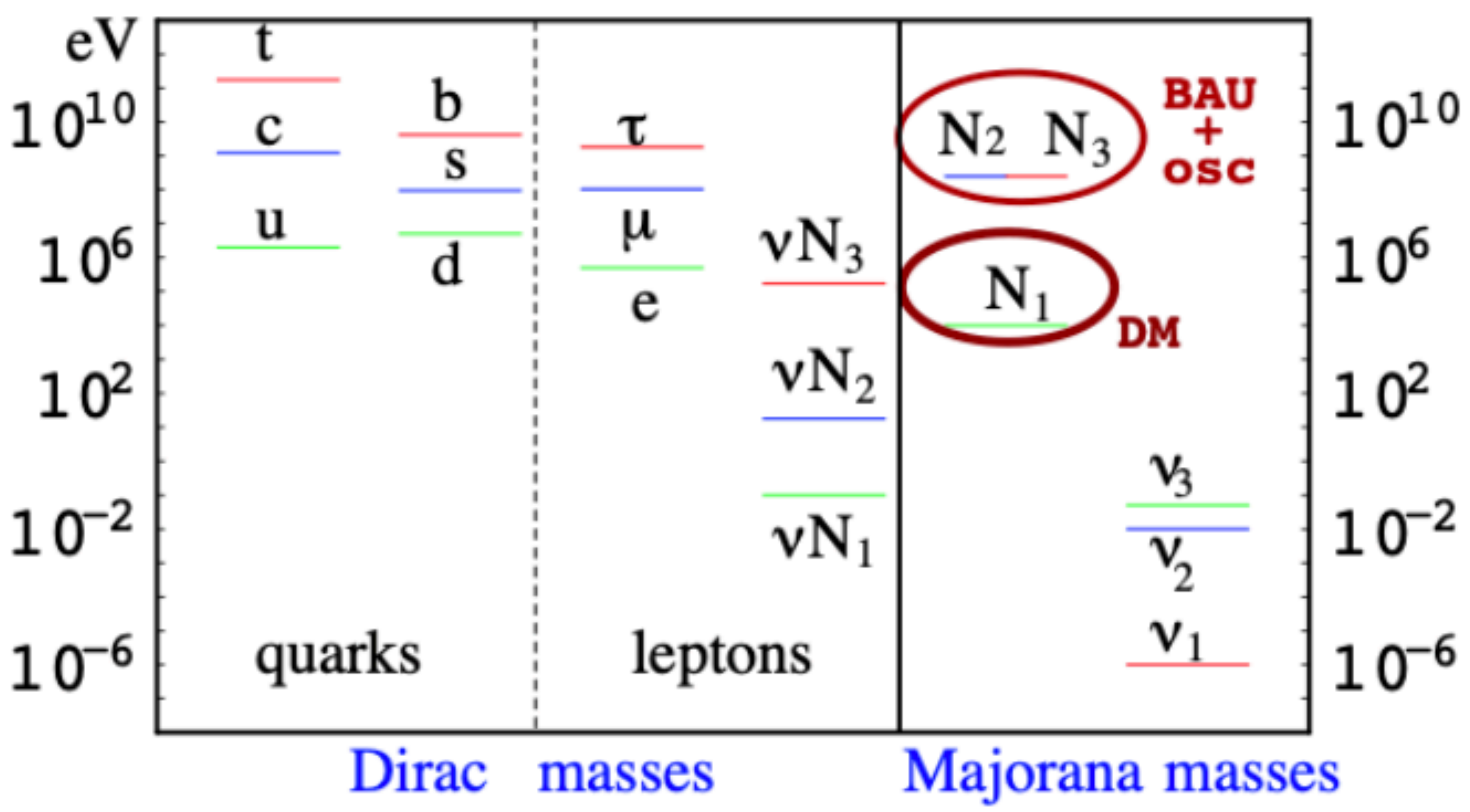
# Indirect Searches for long-lived particles



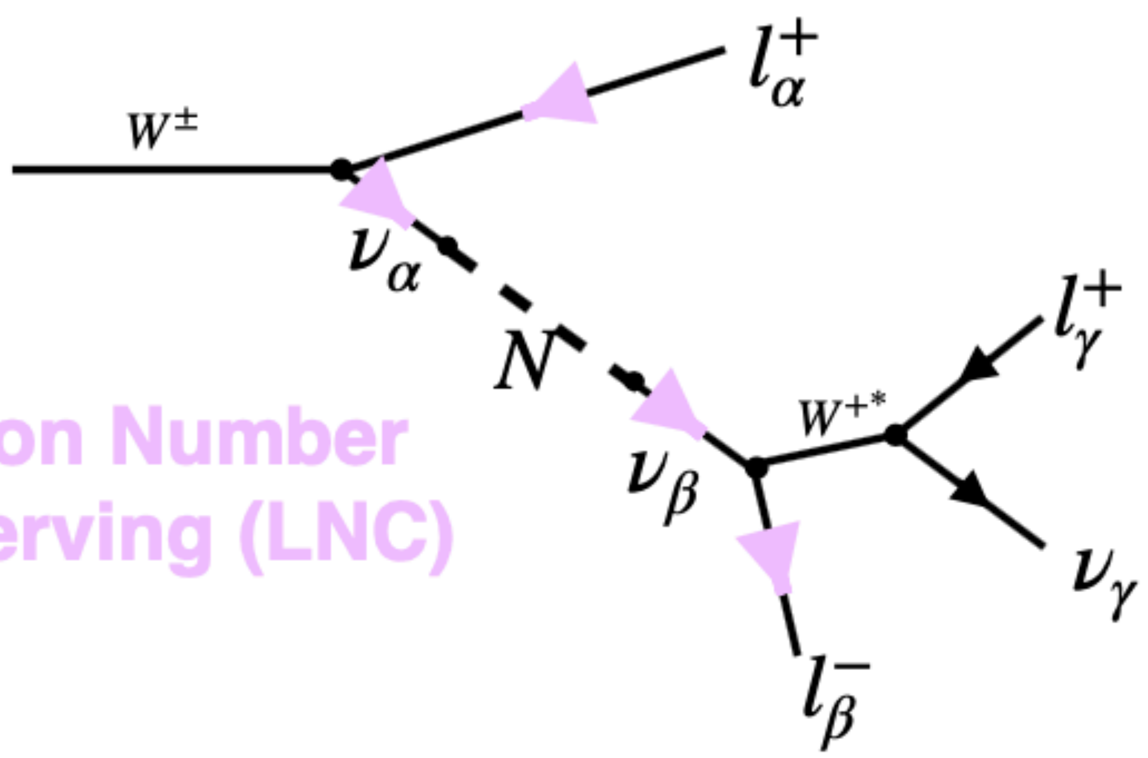


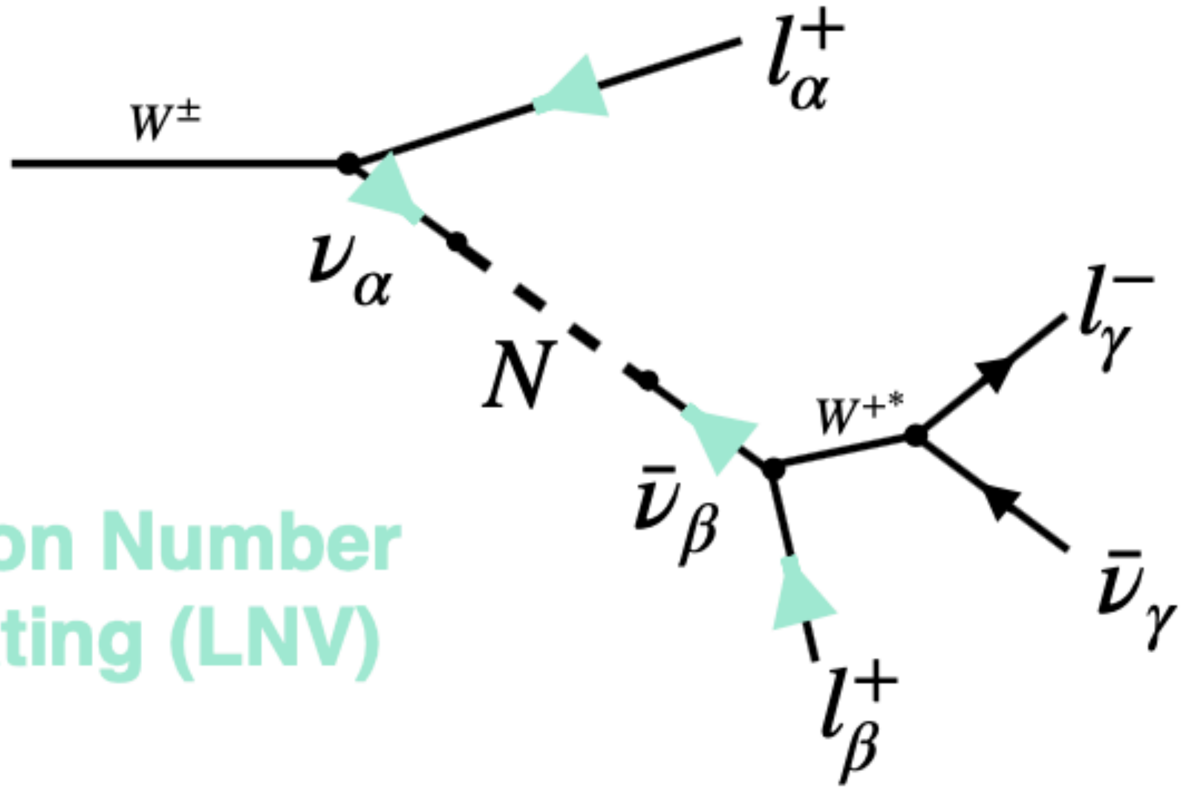

- Introduce right-handed sterile neutrino states or **heavy neutral leptons** (HNL)
- HNLs with GeV masses could help explain Standard Model neutrino oscillations, baryon asymmetry of the universe and dark matter




Lepton Number Conserving (LNC)



Lepton Number Violating (LNV)



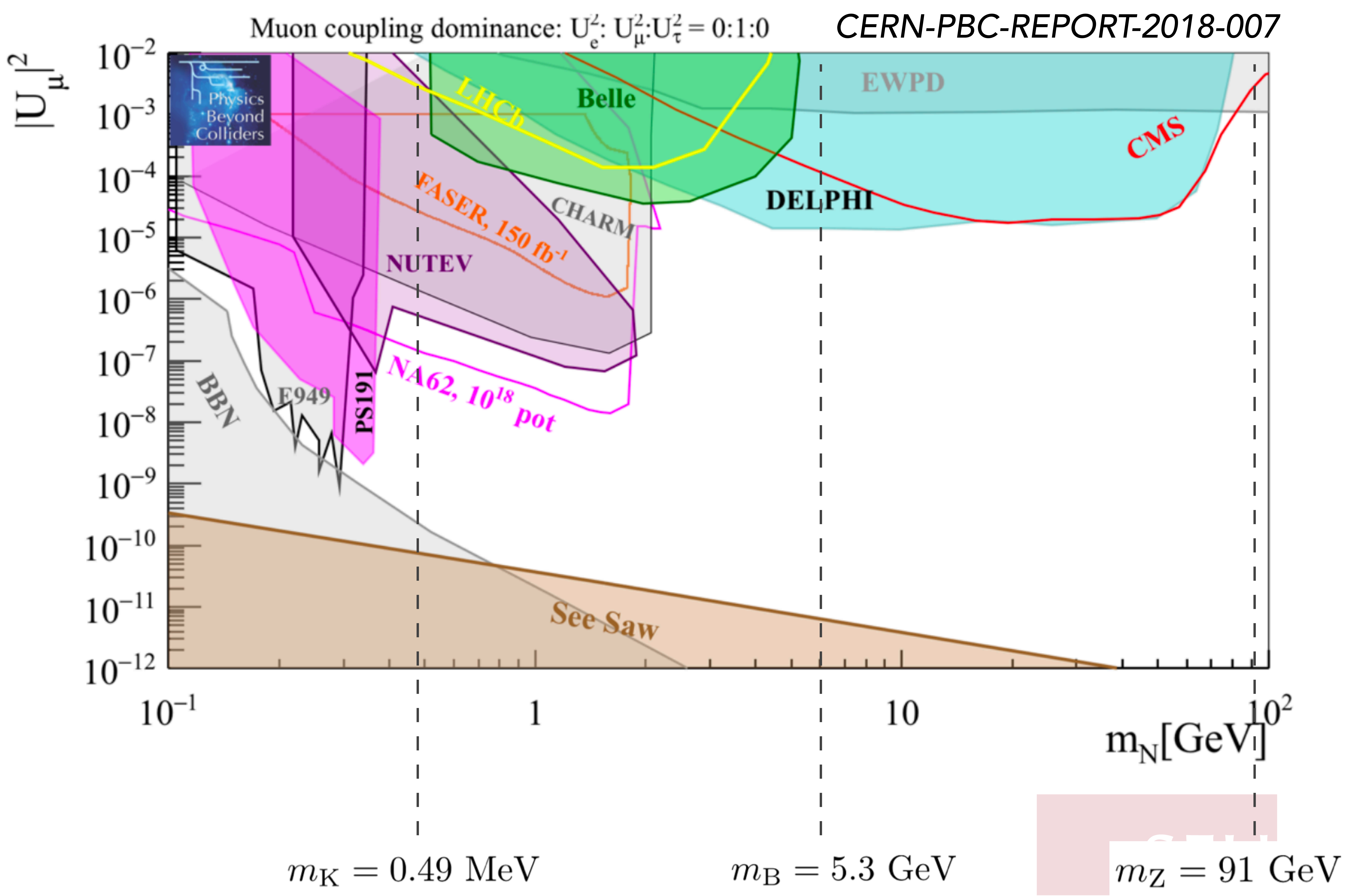
# HNL Experimental plane — colliders & fixed target



probing heavy neutral leptons (HNLs) at various experiments

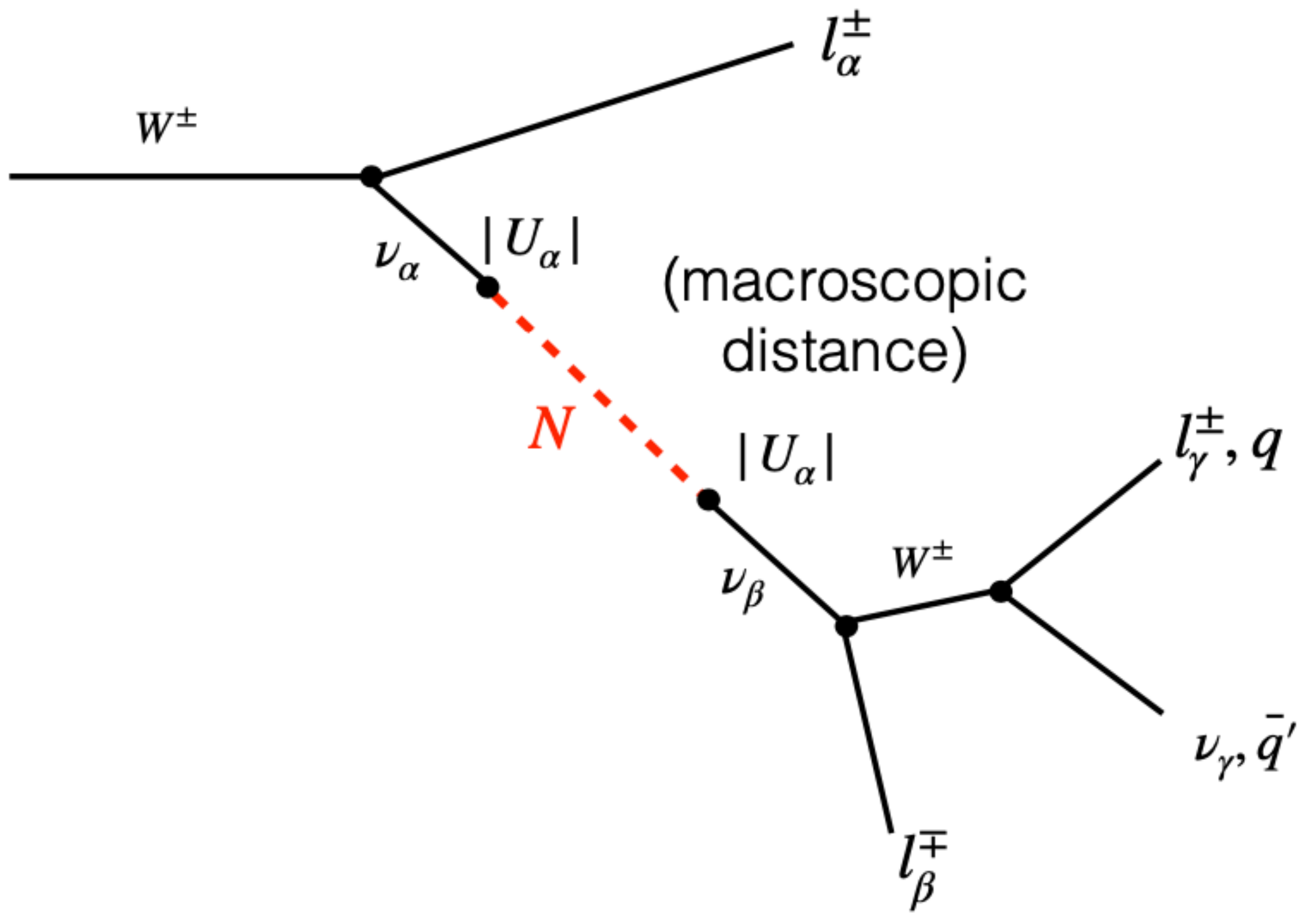
- below Kaon mass can use decays $K^{\pm} \to \ell^{\pm} N,\ K^{\pm} \to \mu\mu\pi$ (e.g. NA62)
- below B or D meson masses $B^{\pm}, D_s^{\pm}, \tau^{\pm} \to \ell^{\pm} N,\ D^0 \to \ell^{\pm}\pi^{\mp} N$ (e.g. Belle, LHCb)
- below W, Z boson masses results from LEP ( $Z \to N\nu$), actively explored also at ATLAS, CMS
- above W, Z boson masses decay to onshell bosons $W^{\pm} \to \ell^{\pm} N,\ N \to \ell^{\pm} W^{\mp}, \nu Z, \nu H$

*CERN-PBC-REPORT-2018-007*



# ATLAS HNL searches — prompt and long-lived




prompt HNL Signal:
- Prompt tri-lepton event
- Sensitive to higher masses

long-lived HNL Signal:
- Prompt lepton
- Displaced vertex (DV) with 2 leptons with opposite charge
- $m_{HNL} < m_W$ HNL becomes long-lived

$$\sigma(pp \to W) \cdot \mathcal{B}(W \to \ell N) = \sigma(pp \to W) \cdot \mathcal{B}(W \to \ell \nu) \cdot |U|^2 \left(1 - \frac{m_N^2}{m_W^2}\right)^2 \left(1 + \frac{m_N^2}{2m_W^2}\right)$$



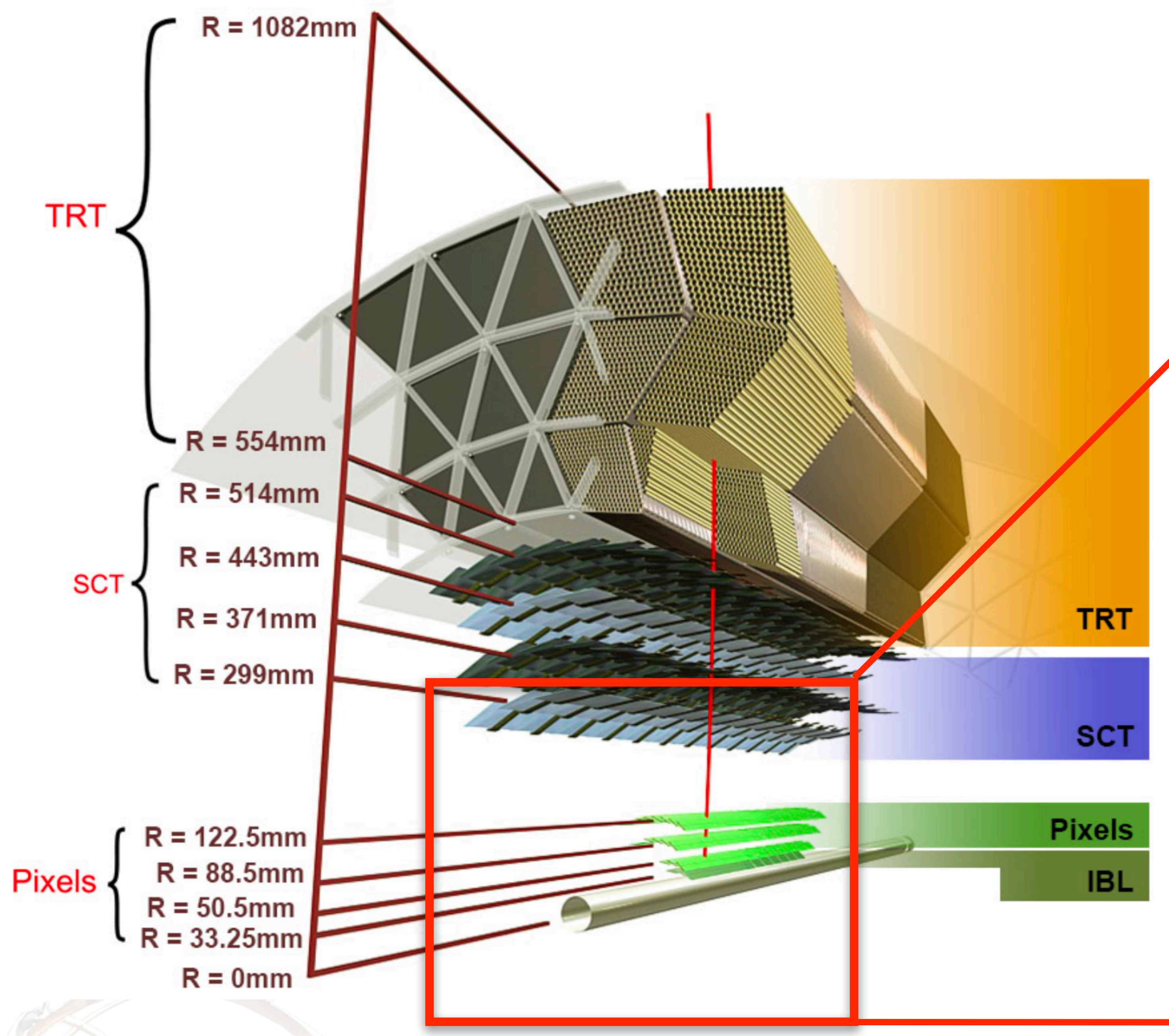


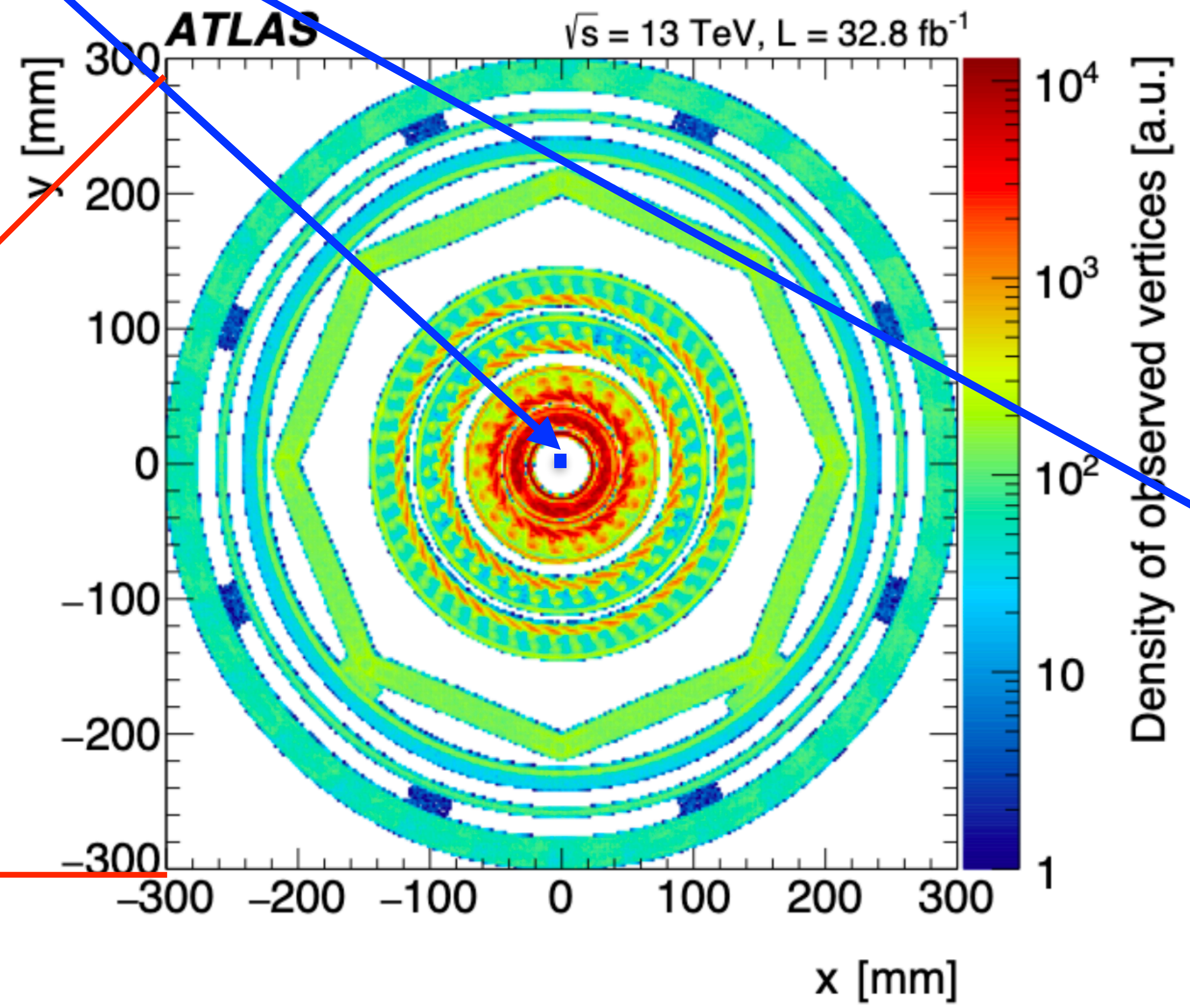
*image credit D. Trischuk*

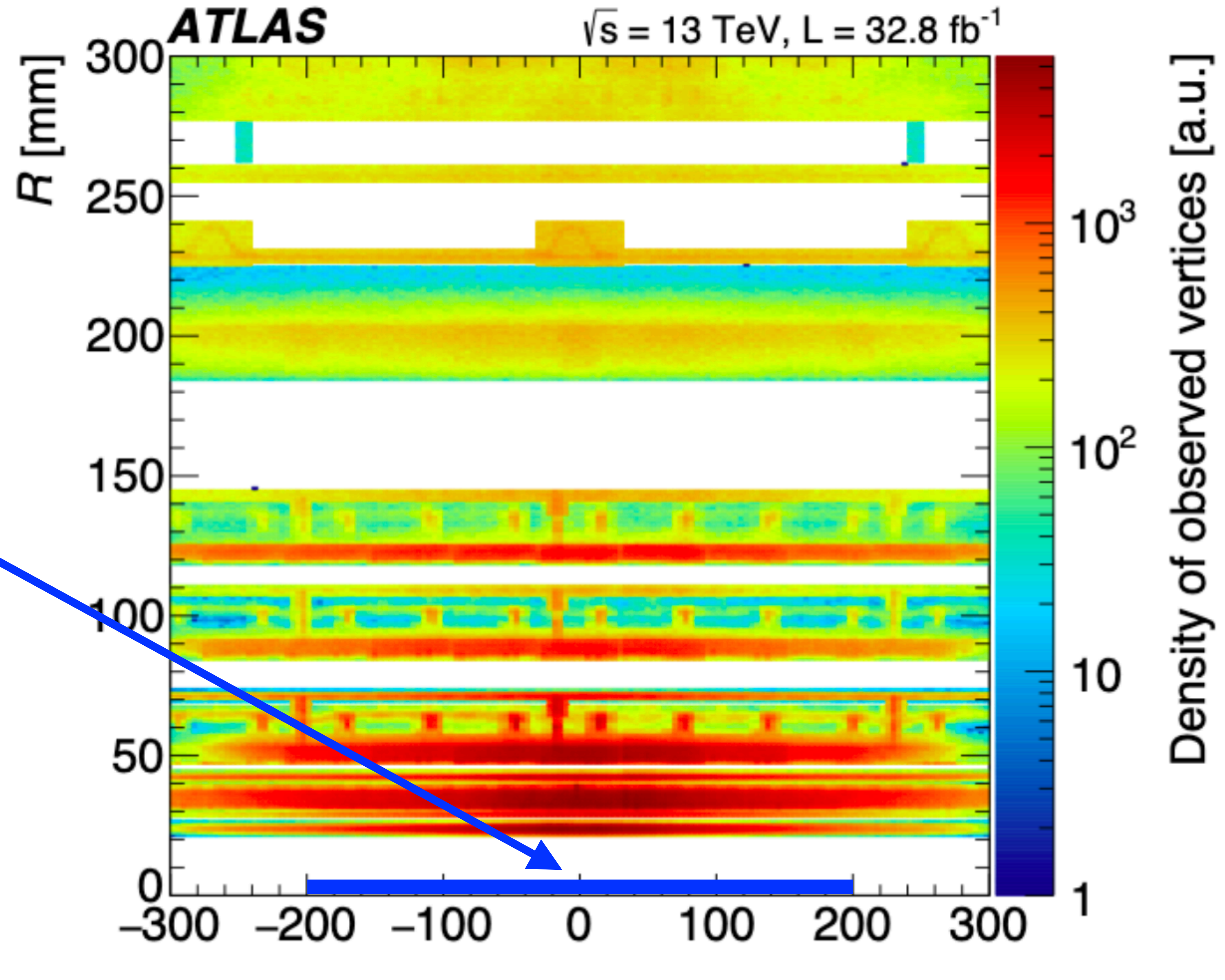
# Why LLP searches use non-standard reconstructions?



If you want to reconstruct a charged particle with Impact Parameters **($d_0$,$z_0$)** outside the **prompt phase-space** —> **you need special reconstruction**




SUSY-2016-08

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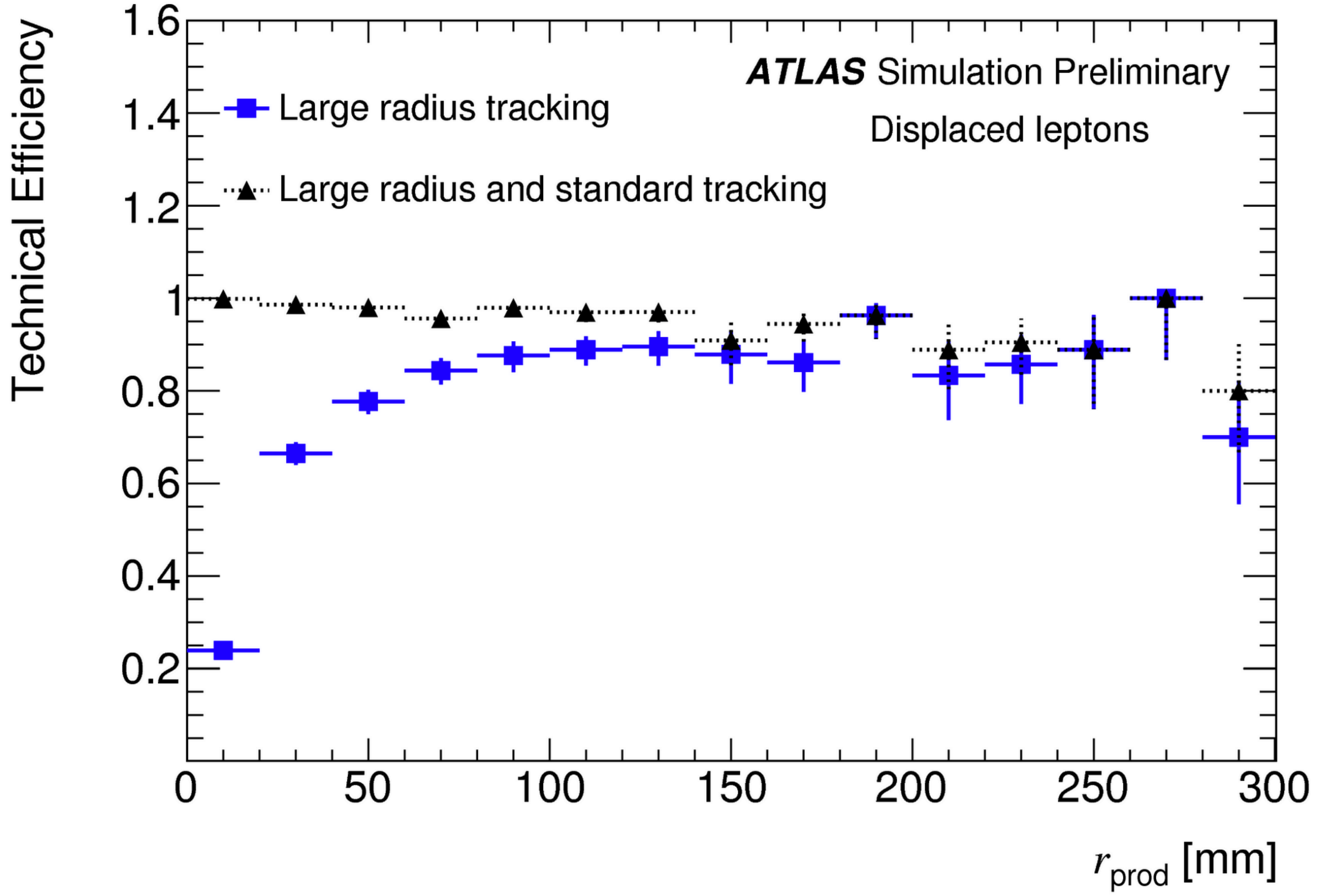
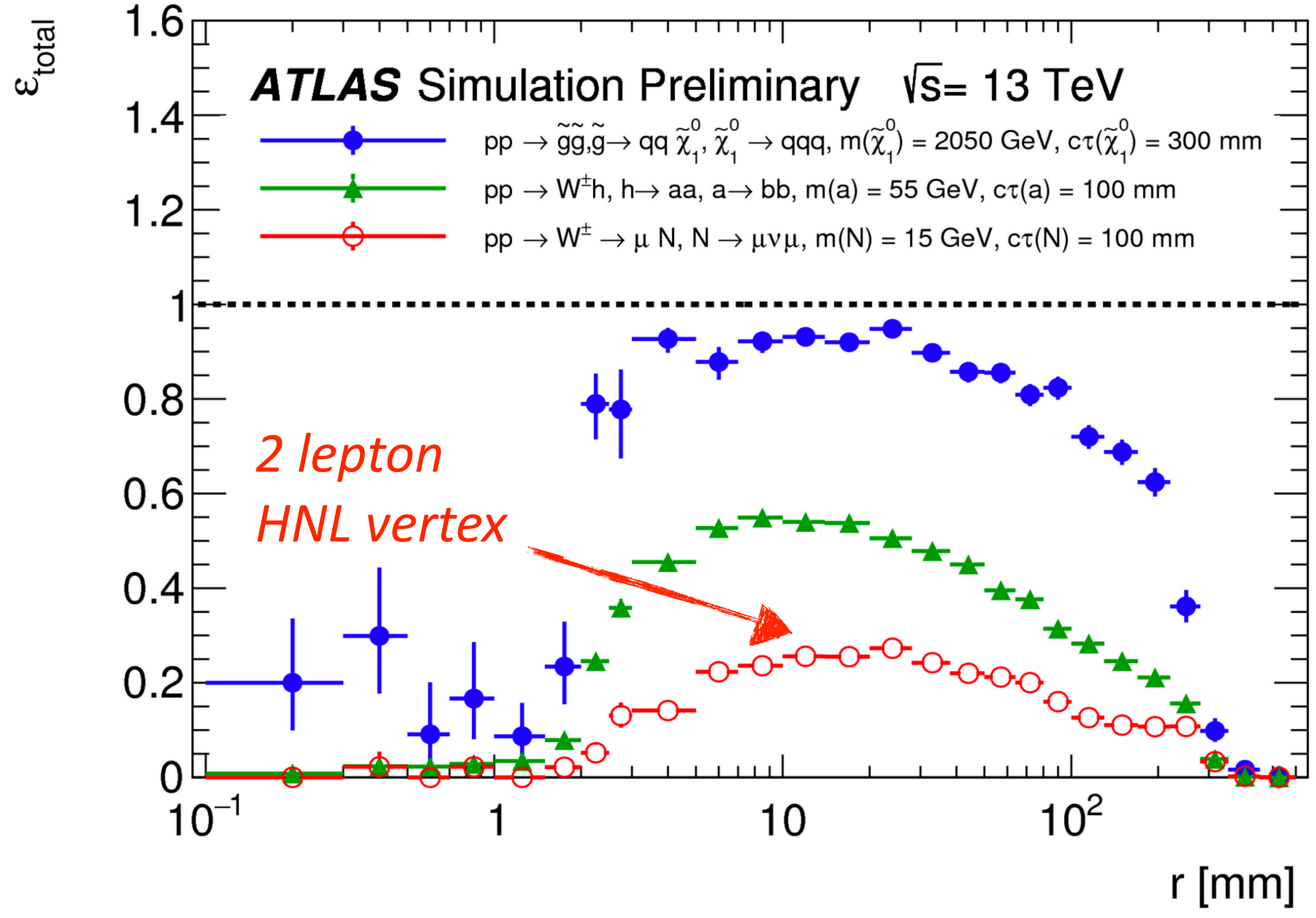
SUSY-2016-08

# Long-lived special reconstructions

ATL-PHYS-PUB-2017-014
ATL-PHYS-PUB-2019-013



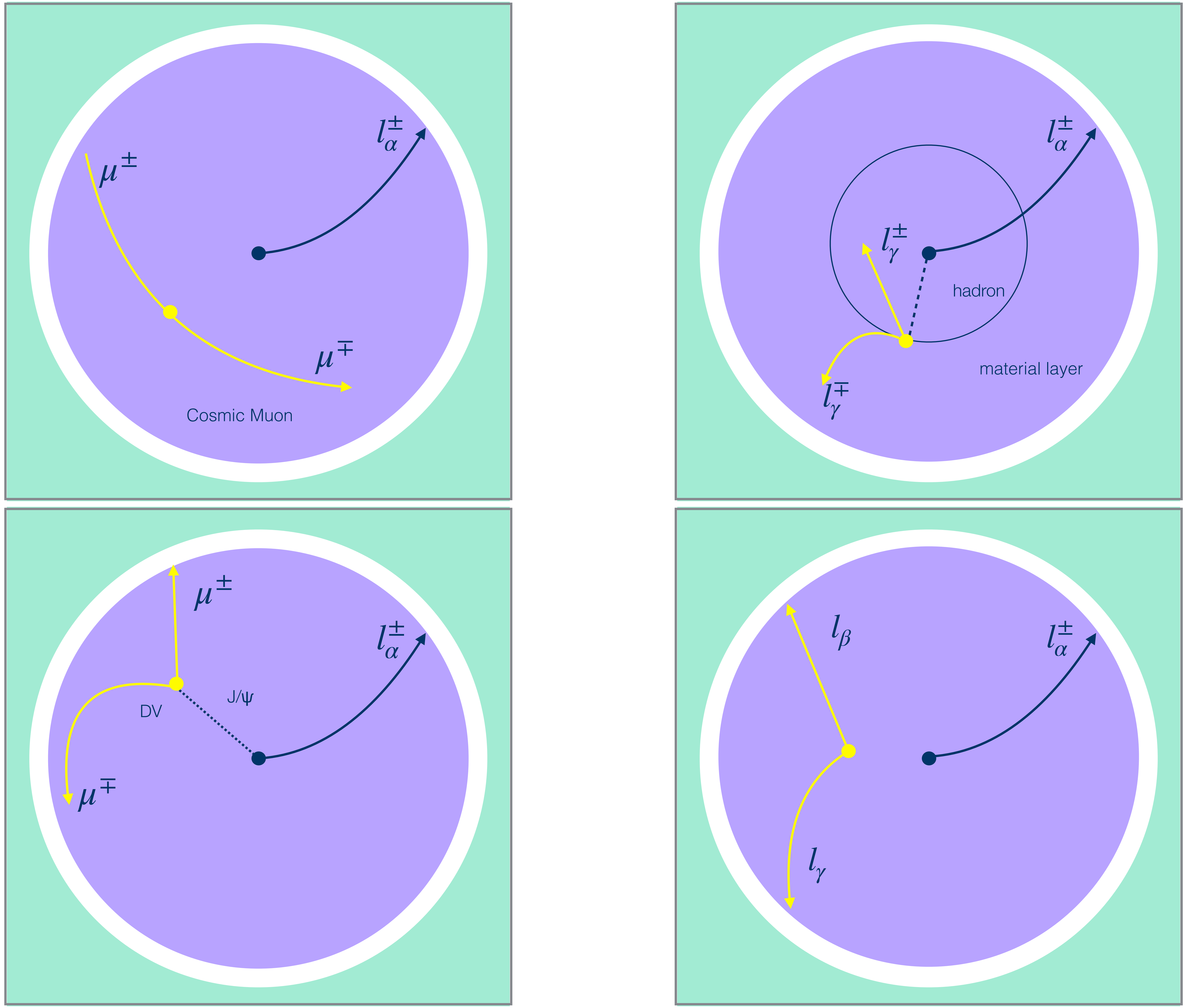

- Default tracking on ATLAS turns off at $d_0$ > 10mm
- Computationally expensive; only available for 10% of data
- We use these tracks (and standard tracks) to form displaced vertices

# Challenges to remove non-standard backgrounds



**Cosmic muon**
+ prompt lepton

**Material interaction**
+ prompt lepton




**Metastable particle decay**
(e.g. J/ψ)
+ prompt lepton

**Random track crossing**
+ prompt lepton

*image credit D. Trischuk*

# ATLAS HNL searches — prompt and long-lived

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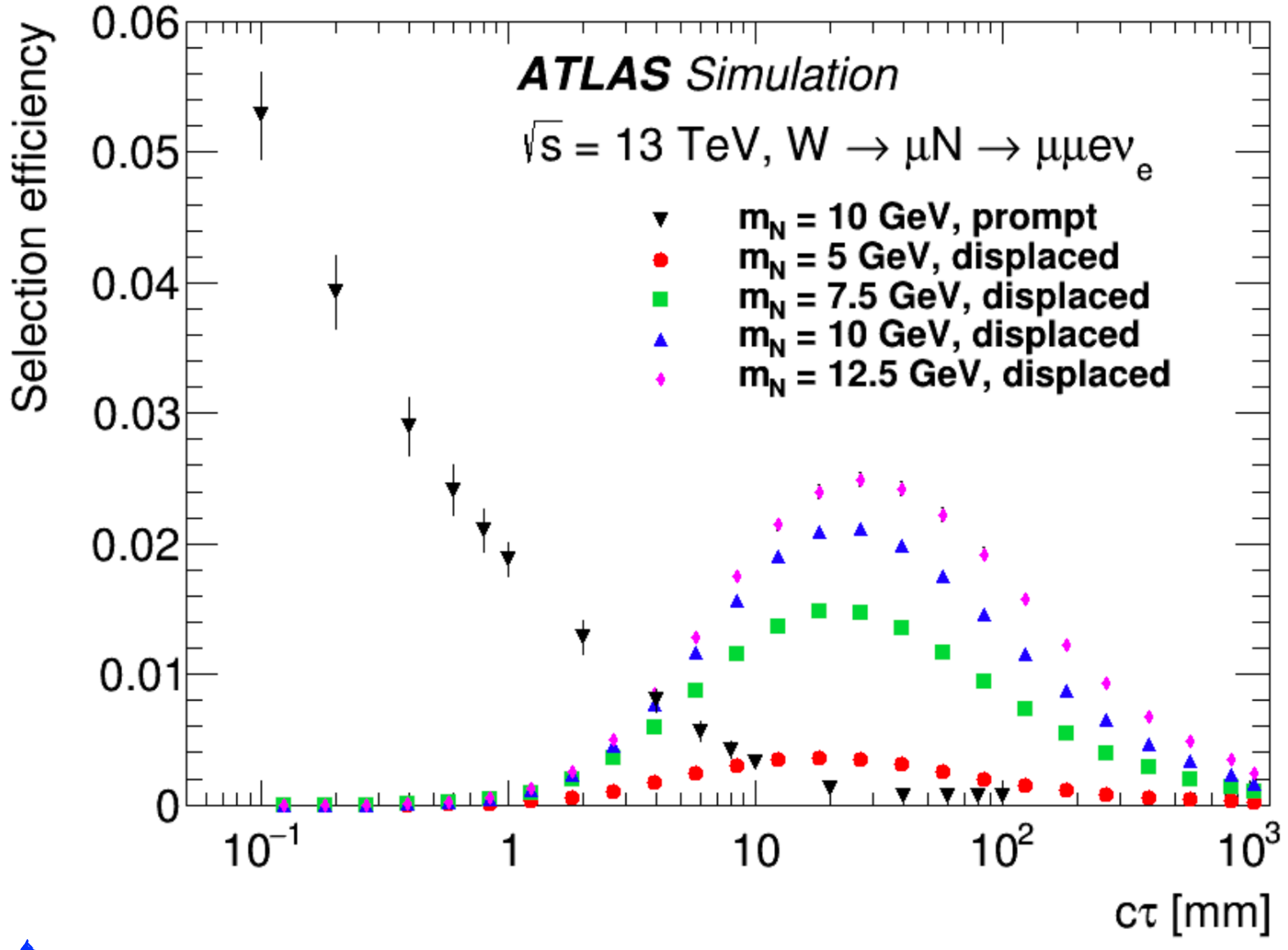
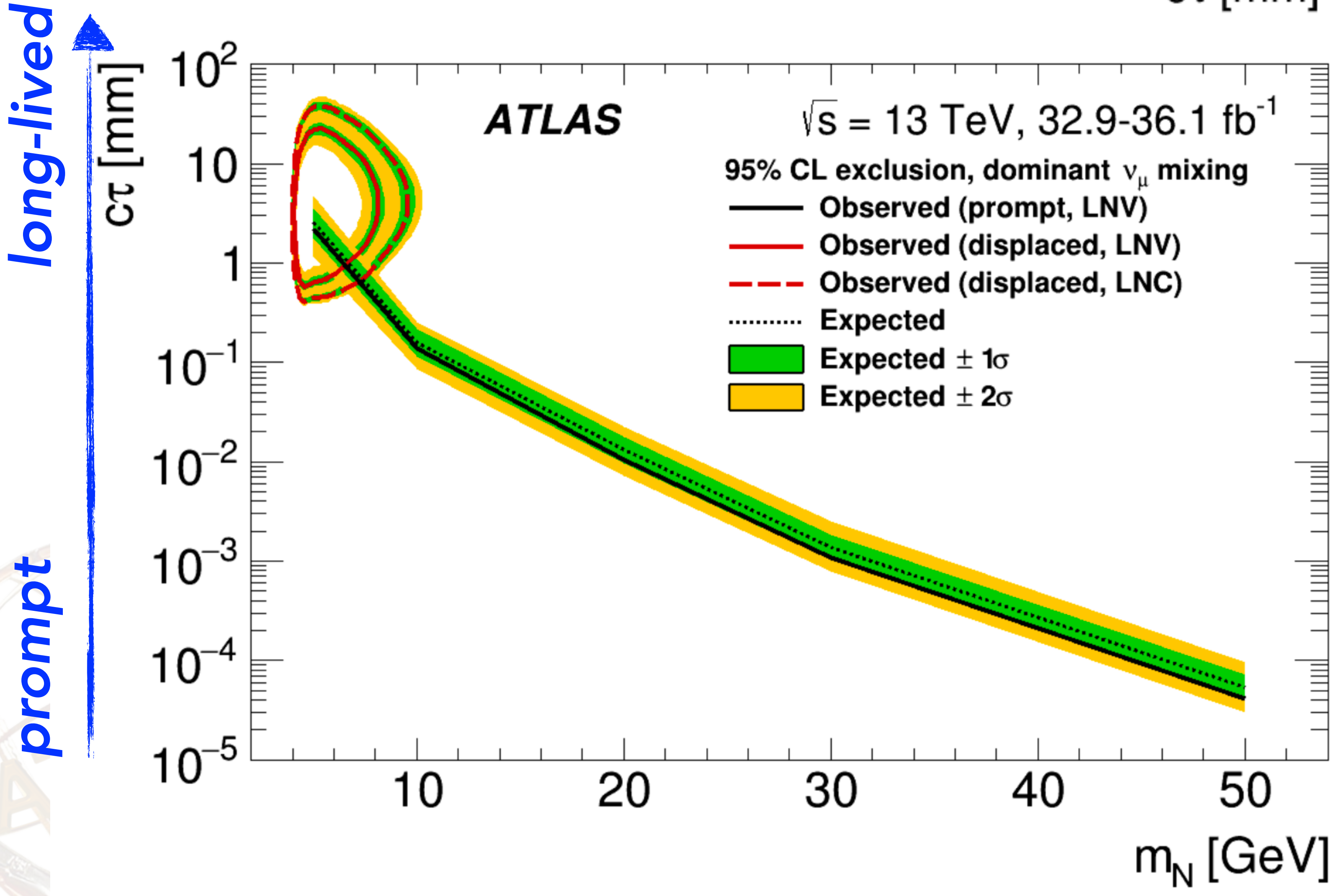
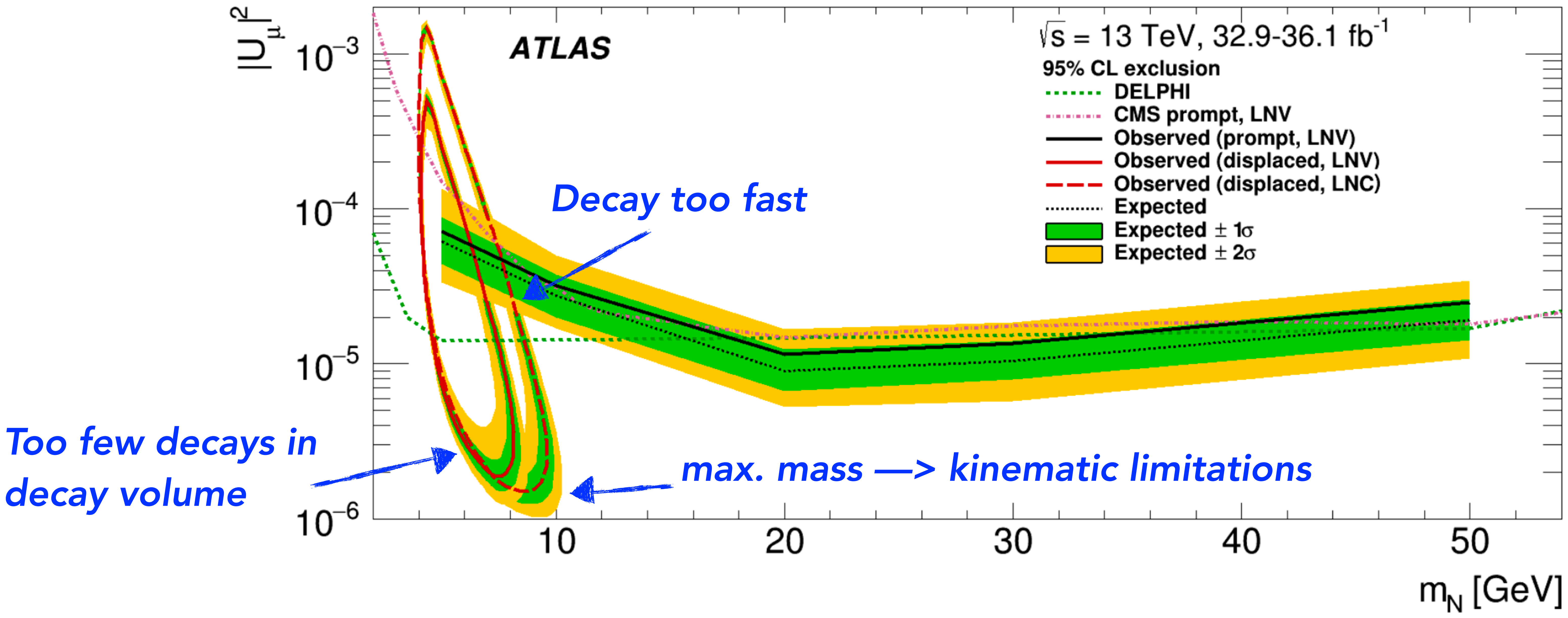
EXOT-2017-26



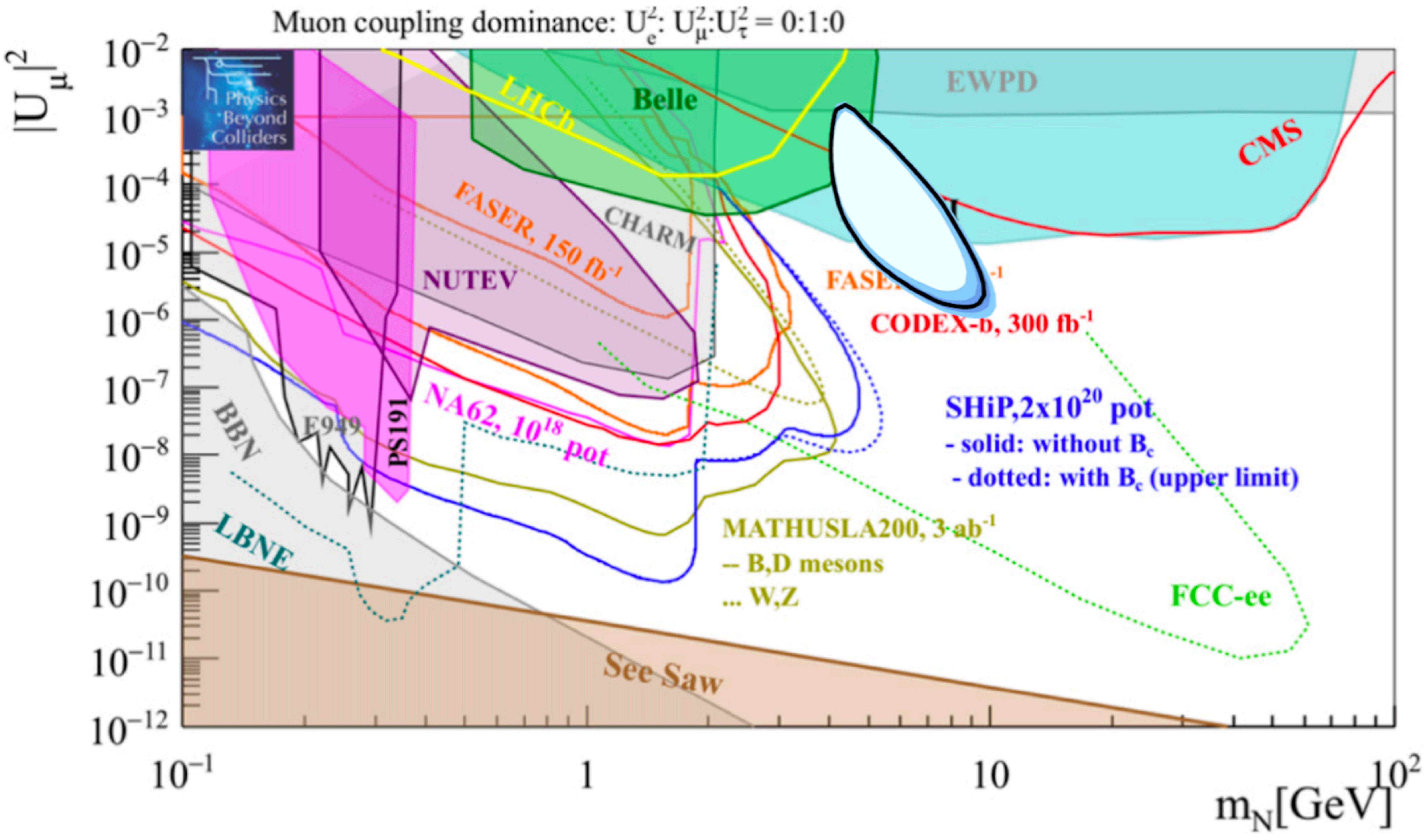



# ATLAS HNL searches — prompt and long-lived



- Unique sensitivity to HNL coupling —> strength in relatively low-mass region
- Future ATLAS searches will push down to *lower couplings* and *additional couplings*






*plot from CERN-PBC-REPORT-2018-007 privately annotated with ATLAS result*

# Global constraints on Sterile Neutrinos

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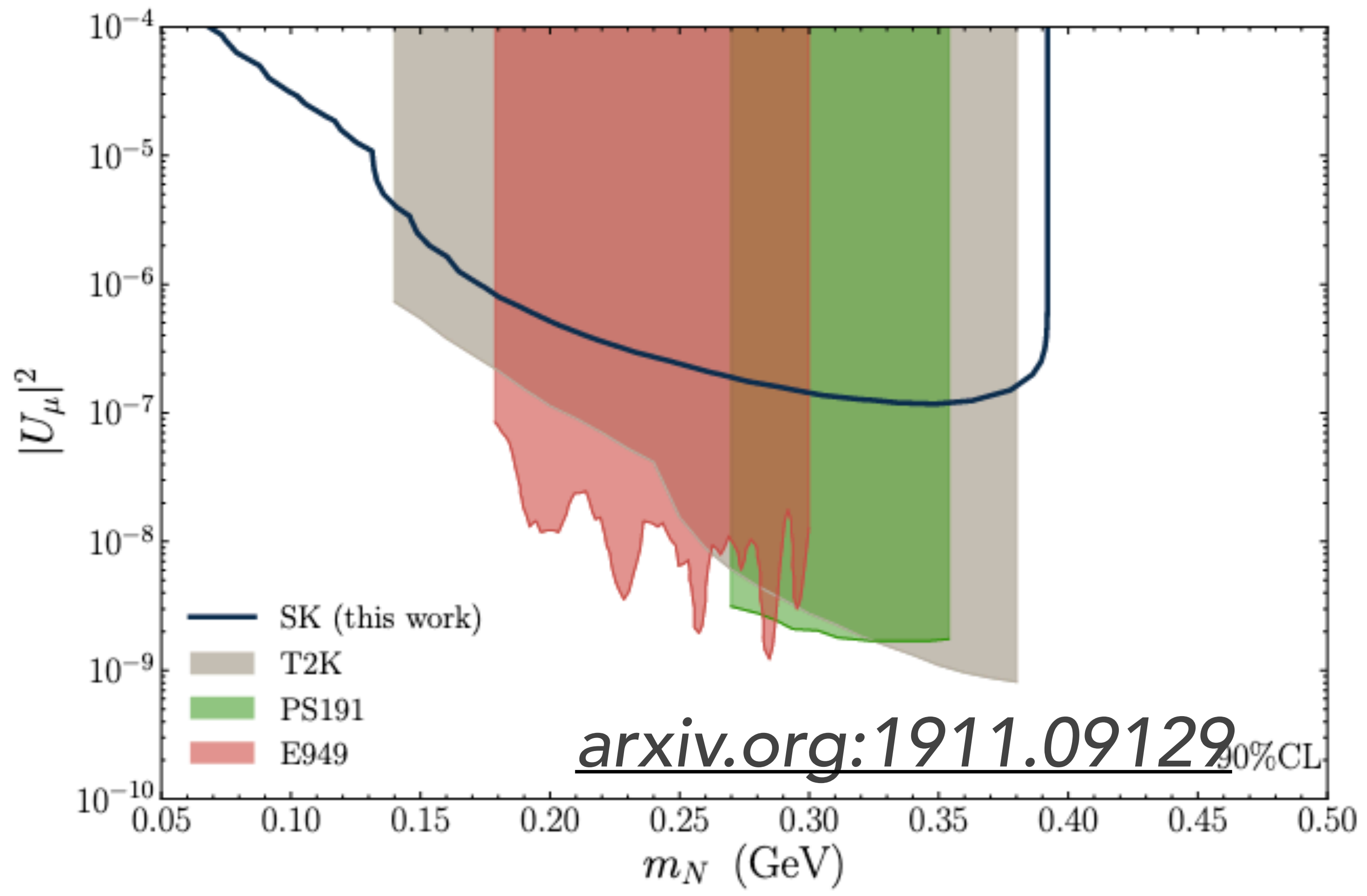
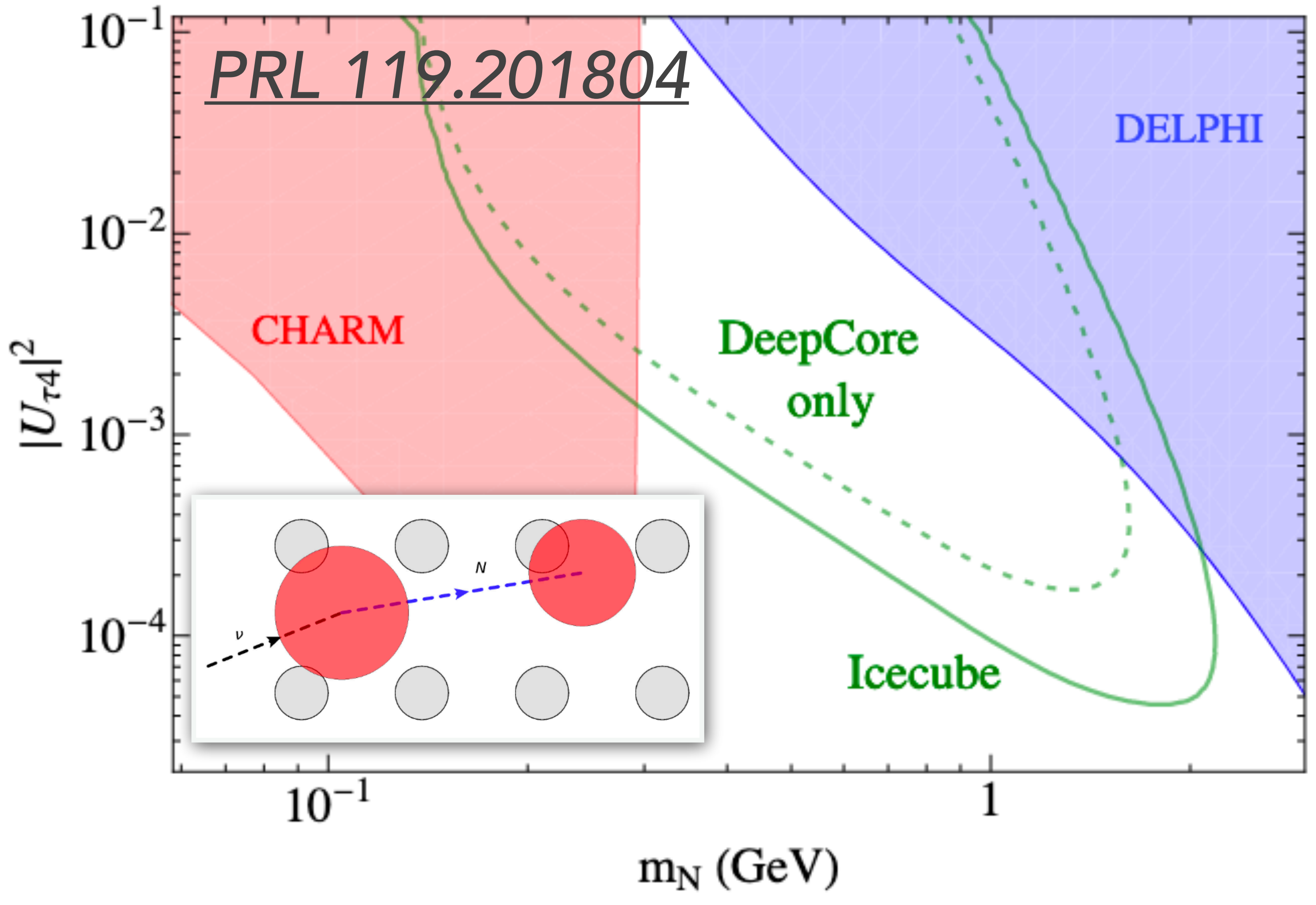
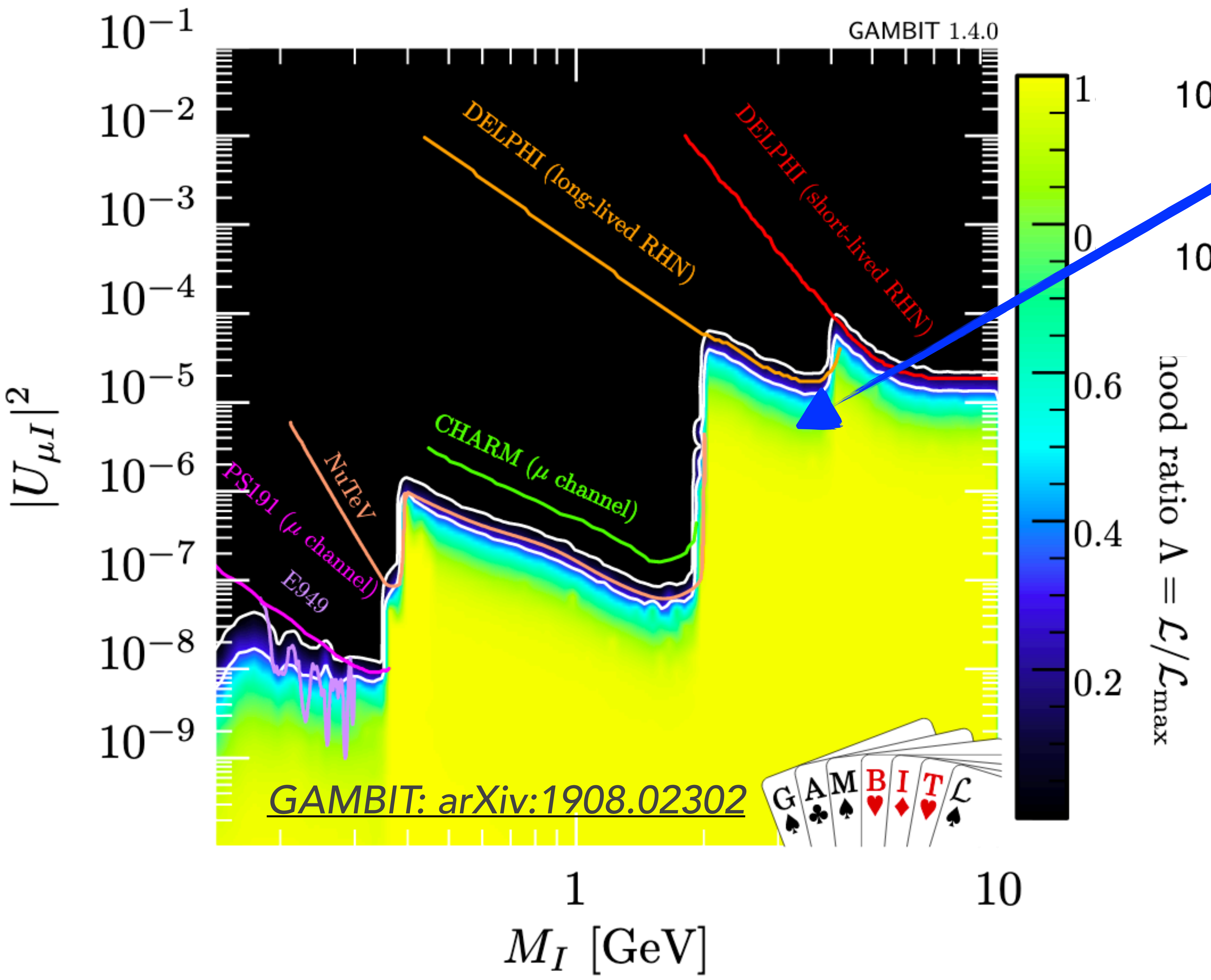
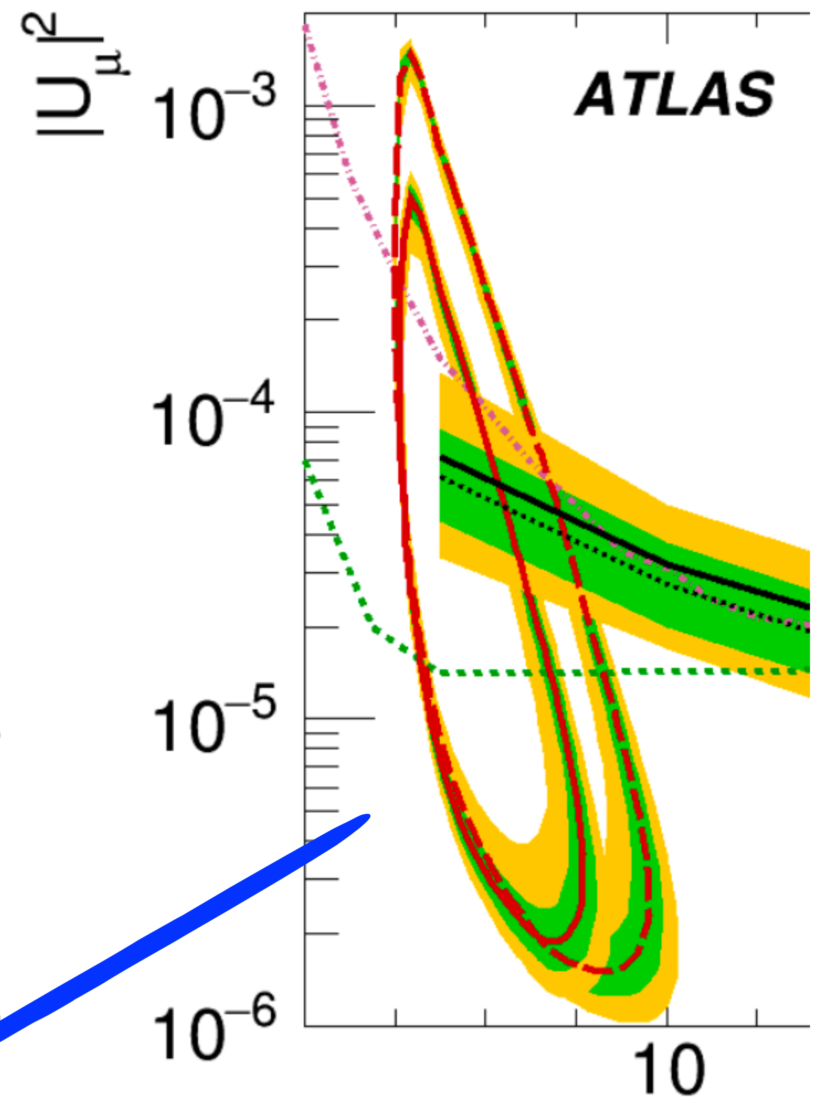
- Complementarity of searches is enormous for HNLs




EWPO, 0νββ, cLFV, CKM unitarity, BBN, direct searches, ν-osc.



# Conclusions



- Heavy Neutrino searches are an exciting challenge in ATLAS
- HNL searches still have huge potential to grow in ATLAS
  → full LHC Run2 data still being analyzed; stay tuned!
  → especially long-lived signatures exciting!
- Exciting prospects for next LHC data taking run
  - We benefit from technical advances
  - New opportunities for discovery
- Complementarity to other experiments makes this an exciting and rich field!

# Backup