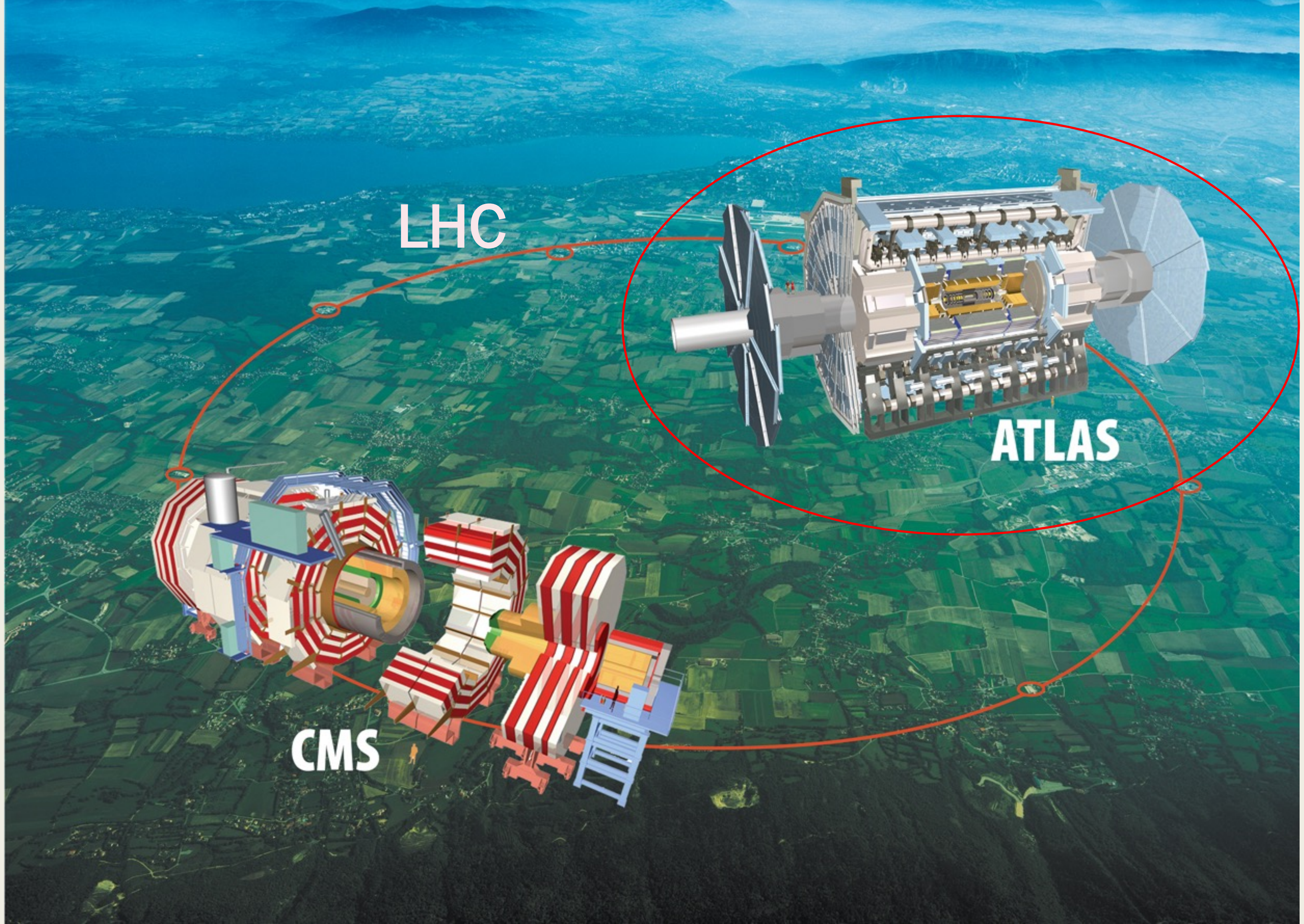
ATLAS @ NBI

Stefania Xella
On behalf of the ATLAS NBI team



LHC and ATLAS

Luminosity $\mathcal{L}$ = how many particles we're able to squeeze through a given space in a given time
$\mathcal{L} \cdot \sigma$ = collision rate

Two successful LHC Runs so far :

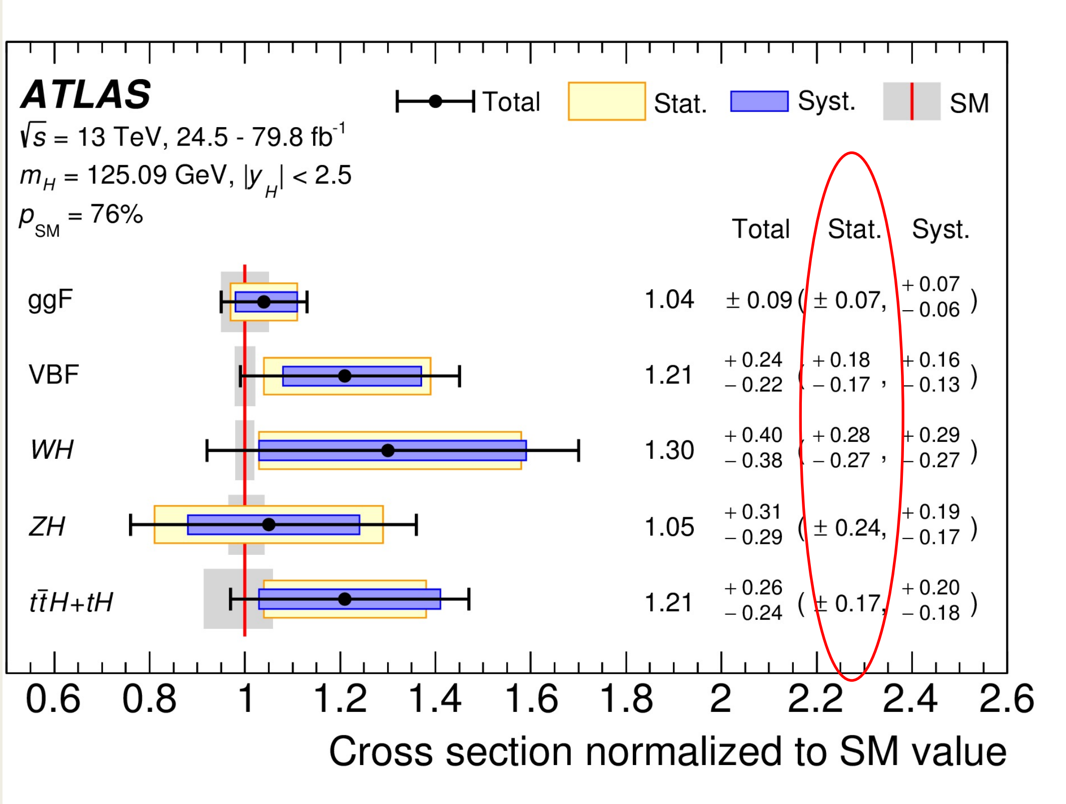
- 2008-2012, pp collision cms energy 7-8 TeV , $\mathcal{L}$ peak 0.75 10^{34} cm^{-2} s^{-1}
- 2015-2018, pp collision cms energy 13 TeV , $\mathcal{L}$ peak 1.7 10^{34} cm^{-2} s^{-1}

ATLAS is a multi-purpose experiment at the LHC (the other is CMS). Some of the successes (imo):

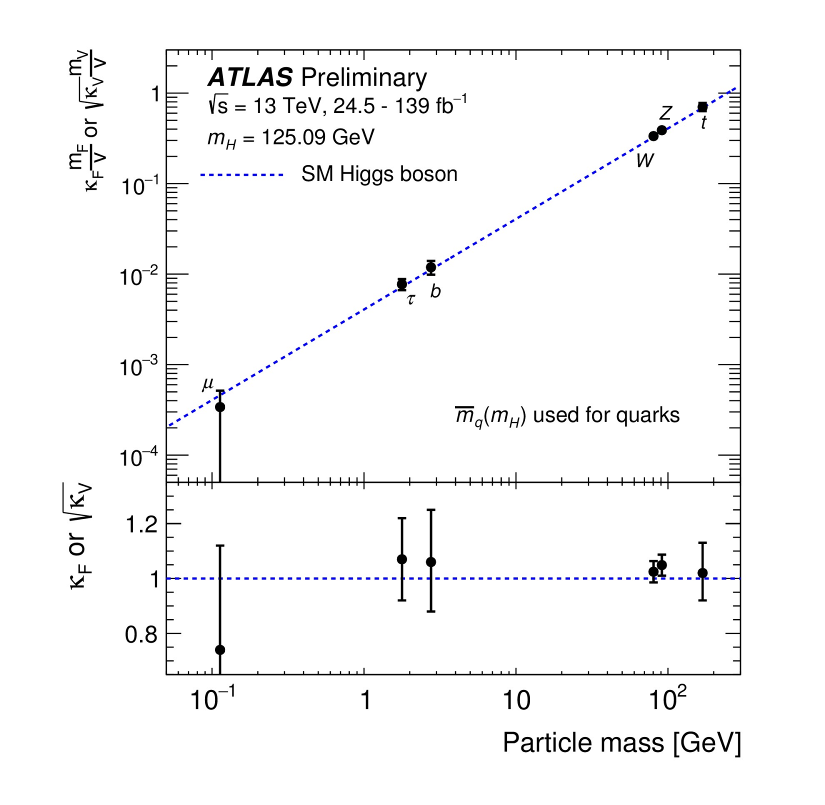
- Observed the Standard Model (SM) Higgs decaying in Z, W, ɣ, τ, b , μ particles and produced in gluon-gluon or Vector Boson fusion processes, or associated with a W or Z or top particle.
- Measured several rare SM processes, uncharted before: 1-3 bosons, 1-4 top quarks,…
  This is important for searches for rare new phenomena, beyond the SM.
- Excluded most obvious (=less likely?) BSM scenarios (in supersymmetry or other exotic theories).
  new particles minimum 1-3 TeV or super-weakly interacting with SM particles
- Showed complementarity with direct and indirect dark matter search experiments.
  collider experiments important role in the quest for dark matter.
- Sensitivity to lepton flavour/lepton number/lepton universality violation.
  In some cases doing better than LEP experiments

Higgs properties [H]

Higgs production modes



Higgs decay modes



No indication of deviations from SM or additional Higgs particles yet

Statistical and systematic errors are comparable -> room for improvements

Higgs decay modes [htt, hzz]

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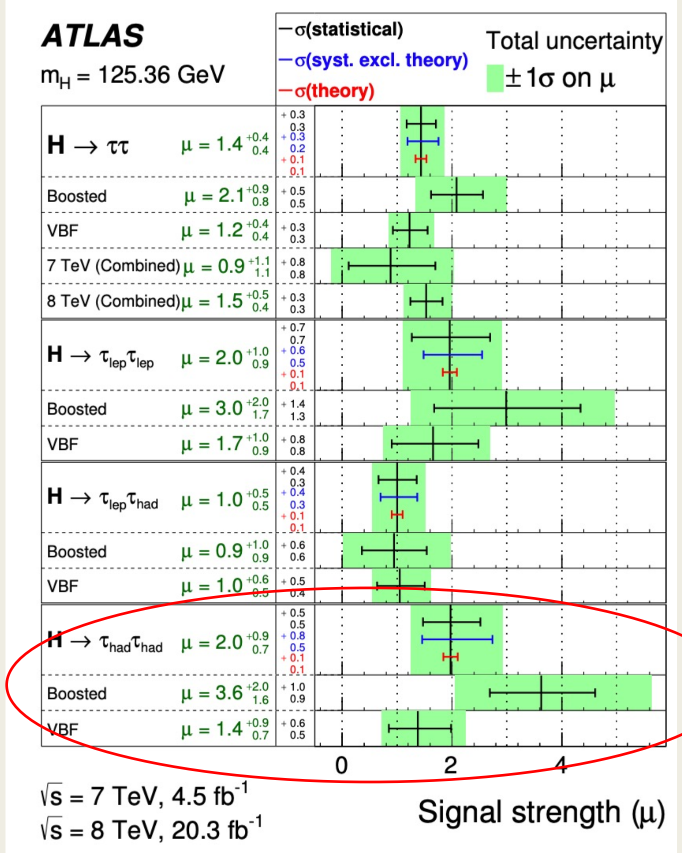
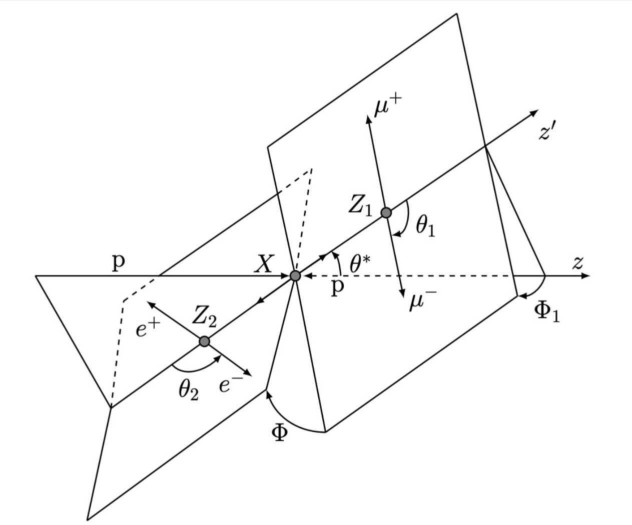
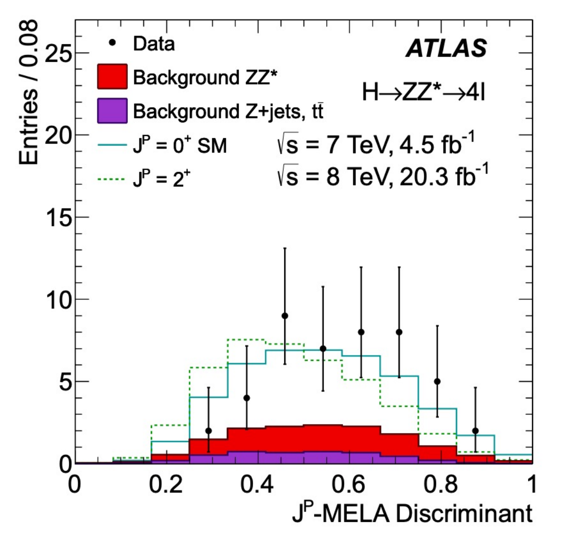
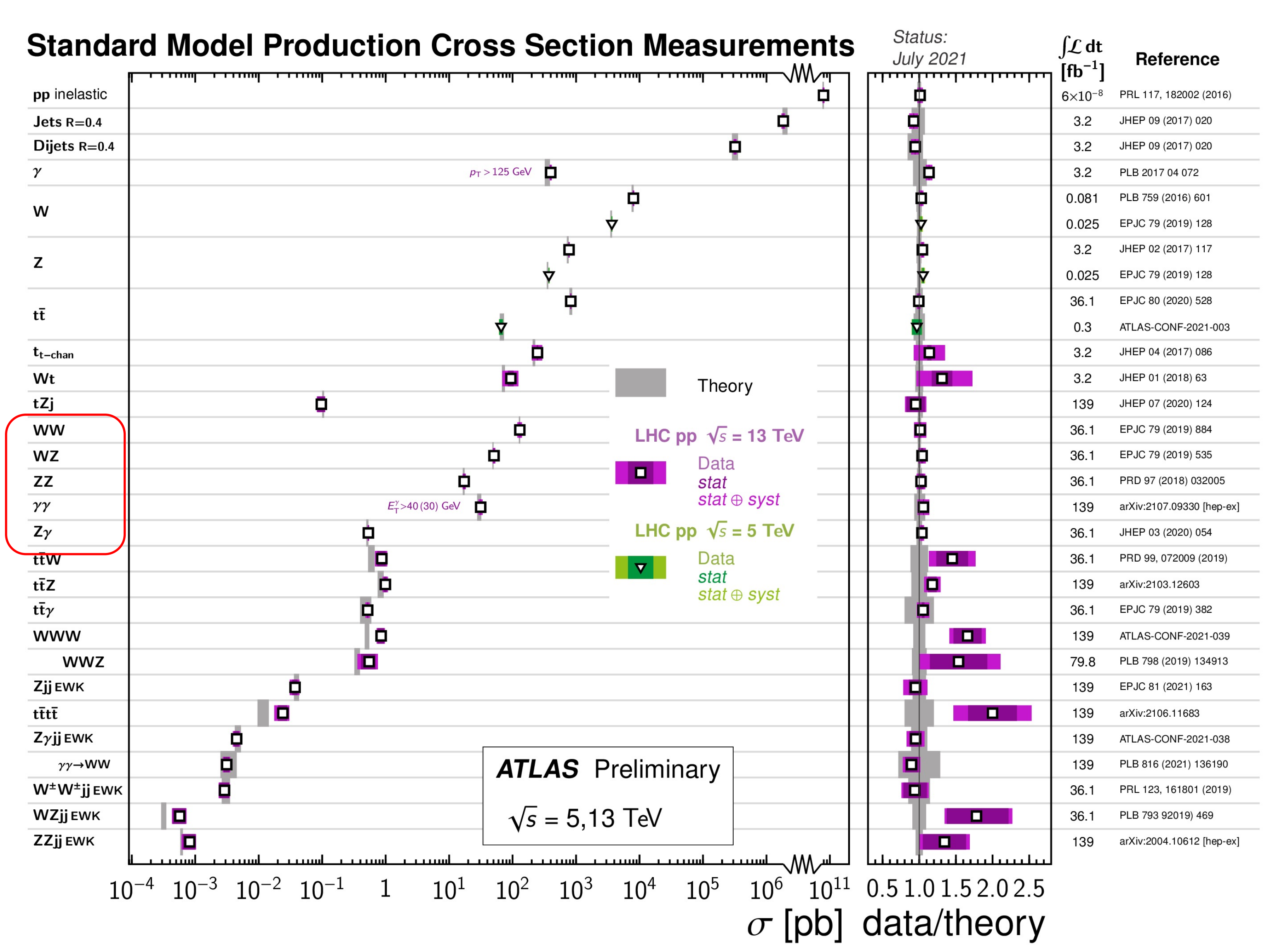
- Developed tau trigger algorithms and tau reconstruction and identification algorithms in Run 1, instrumental for the observation of the Higgs decay to tau leptons with Run 1 data, before CMS.
- Developed the parity and spin analysis of the Higgs boson, and excluded the spin-2 hypothesis, as well as other BSM spin-0 hyptheses, already with Run 1 data alone.







Rare standard Model processes [sm]



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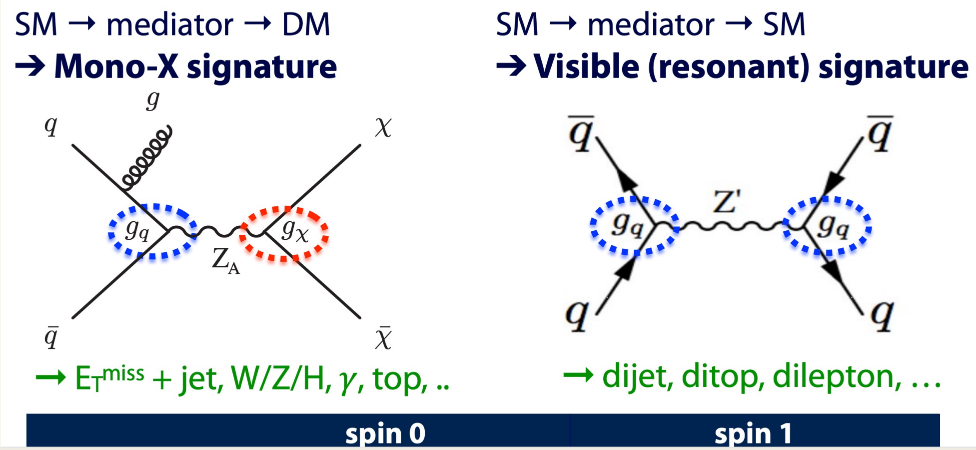
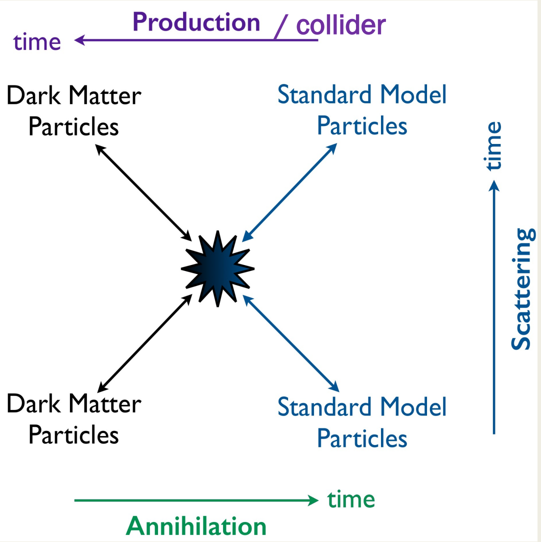
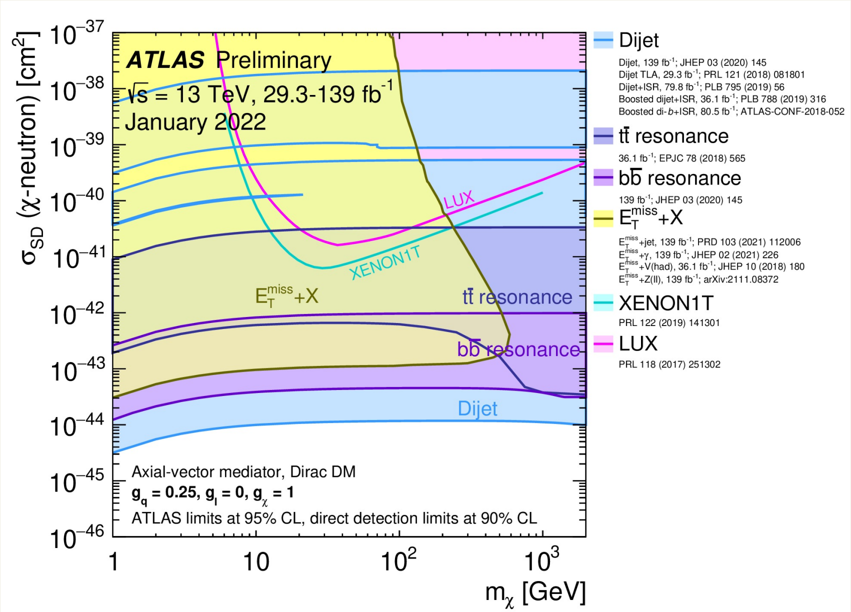
Performed the Run 1 ZZ measurements and set the first limits on anomalous gauge couplings with LHC data

Dark matter







Simplified model for DM :
One new force and one new particle, DM and SM particles interact

Complementarity of colliders and direct searches (eg LUX, Xenon1T) for dark matter

LFV Z decays to $\ell+\tau$ [lfvz1, lfvz2]

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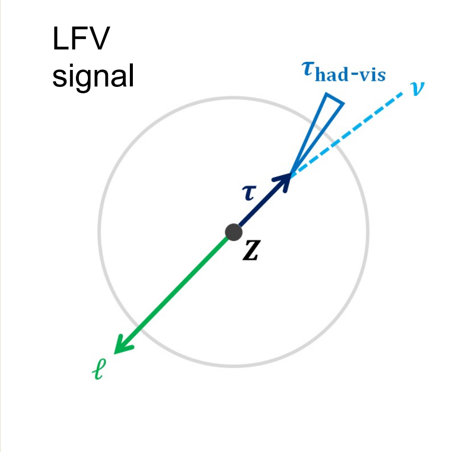
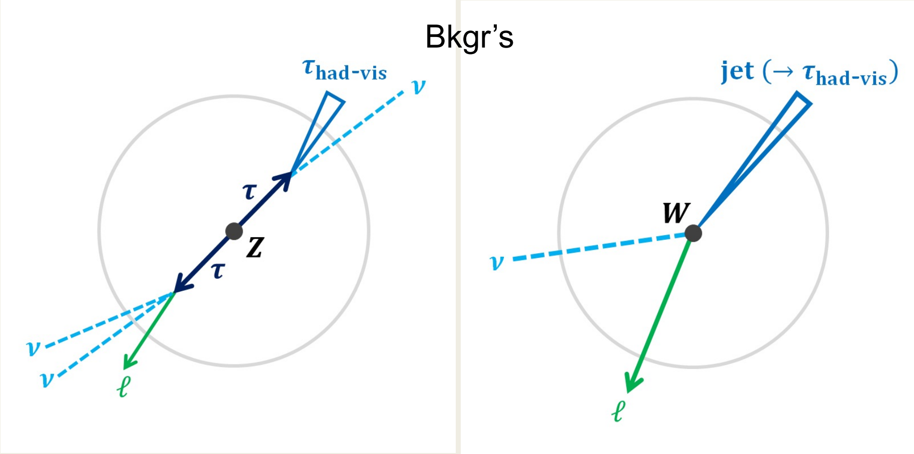
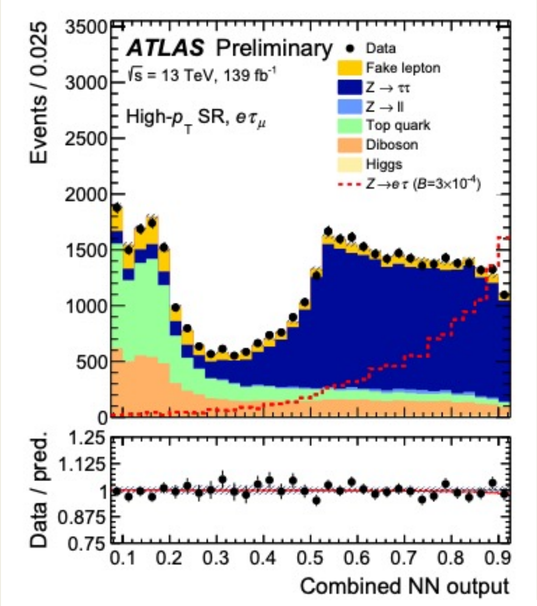
e.g. tau hadronic decays



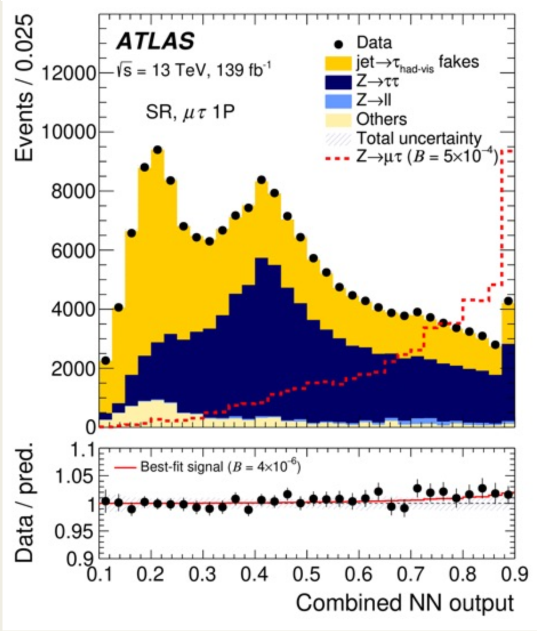




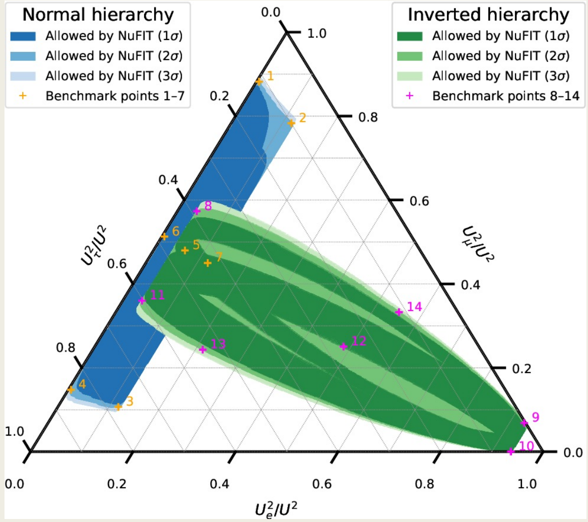
Final state, polarization assumption	Observed (expected) upper limit on $\mathcal{B}(Z \to \ell\tau)$ [$\times10^{-6}$] $e\tau$	$\mu\tau$
$\ell\tau_{\text{had}}$ Run 1 + Run 2, unpolarised τ [10]	8.1 (8.1)	9.5 (6.1)
$\ell\tau_{\text{had}}$ Run 2, left-handed τ [10]	8.2 (8.6)	9.5 (6.7)
$\ell\tau_{\text{had}}$ Run 2, right-handed τ [10]	7.8 (7.6)	10 (5.8)
$\ell\tau_{\ell'}$ Run 2, unpolarised τ	7.0 (8.9)	7.2 (10)
$\ell\tau_{\ell'}$ Run 2, left-handed τ	5.9 (7.5)	5.7 (8.5)
$\ell\tau_{\ell'}$ Run 2, right-handed τ	8.4 (11)	9.2 (13)
Combined $\ell\tau$ Run 1 + Run 2, unpolarised τ	5.0 (6.0)	6.5 (5.3)
Combined $\ell\tau$ Run 2, left-handed τ	4.5 (5.7)	5.6 (5.3)
Combined $\ell\tau$ Run 2, right-handed τ	5.4 (6.2)	7.7 (5.3)
LEP OPAL, unpolarised τ [10]	9.8	17
LEP DELPHI, unpolarised τ [11]	22	12

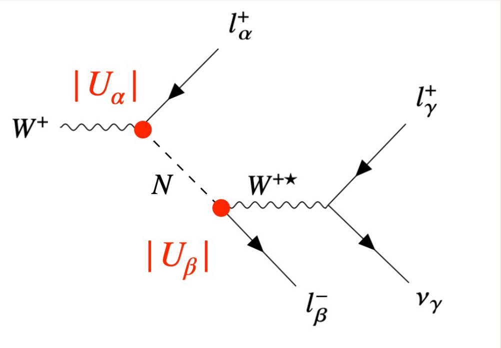
Measurement still statistically limited

ATLAS sets the world best limit

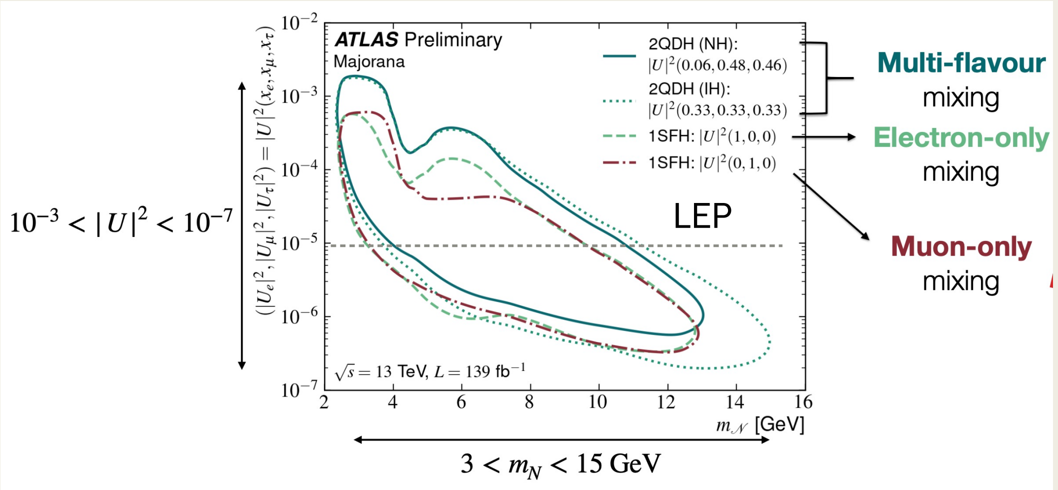


Heavy Neutral Leptons [hnl1, hnl2]





$$\tau_N \propto \frac{1}{m_N^5 |U_\alpha|^2}$$



"Realistic" multi-flavour mixing models consistent with neutrino oscillations data

- Introduce 3 right-handed states, and use seesaw mechanism to explain low mass for weak-interaction neutrinos (and dark matter and baryon asymmetry).
- ATLAS has demonstrated sensitivity to e-N and μ-N mixing at the same level as LEP experiments. Has also published a realistic interpretation of data for full Run 2 data analysis
- Investigate now the Run 2 data sensitivity for tau-N mixing and understand how to improve before Run 3 starts (new triggers)

Total elastic cross section [alfa, tot]

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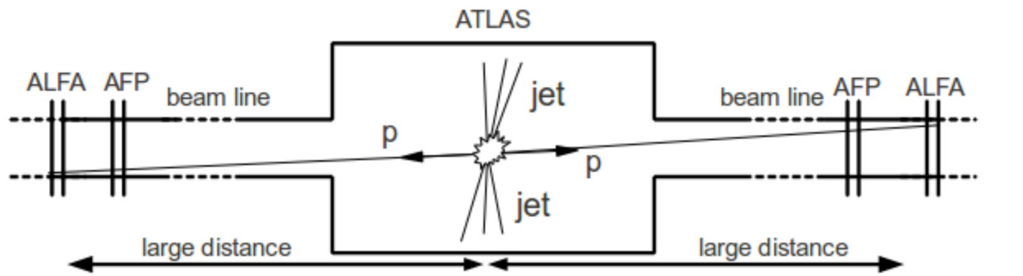
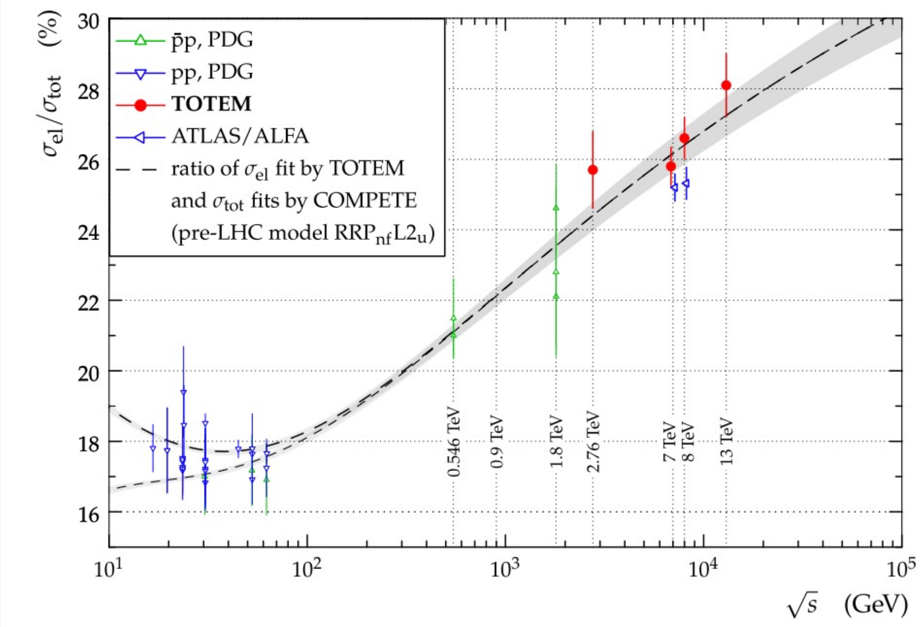
$$\sigma_{\text{tot}}^2 = \frac{16\pi(\hbar c)^2}{1+\rho^2}\frac{d\sigma_{\text{el}}}{dt}\Big|_{t=0}, \qquad \rho = \frac{\text{Re}\,[F_{\text{el}}(t)]}{\text{Im}\,[F_{\text{el}}(t)]},$$

t=4-momentum transfer between protons



- measurement of the differential cross section down to small angles gives not only the elastic cross section by integration, but also the total cross section from which the inelastic cross section can be deduced.
- Dedicated runs with low pileup and high β* (low t) , with ALFA detector , allow to measure unfolded differential elastic Xsection, and then fit it with σtot as free parameters (ρ from models).
- Done measurement at 8 TeV. Working on measurement at 13 TeV.
- A final data taking with ALFA is planned in run 3 with very high-β * optics for a measurement of elastic scattering and associated parameters σtot, ρ and slope. Worth only if cms energy > 13.5 TeV



Run 3 (2022-2025)

- A new run starts in May, pp collision cms energy 13.5 TeV and $\mathcal{L}$ peak 2 10^{34} cm^{-2} s^{-1}
- Run 3 will not add a lot of data, but will be used strategically to focus on new type of searches : eg
  - *long lived particles, super-weakly interacting particles (continue from Run2)*
  - *dijet resonances, etc..*
  - *B physics*
  - *Rare Higgs decays*
- Run 3 will also test completely new software and hardware, which will stay with ATLAS until the end of HL-LHC
  - *New L1 trigger hardware and Central Trigger Processor*
  - *New multi threaded software (eg. tracking) and extensive use + establishment of machine learning for data analysis*

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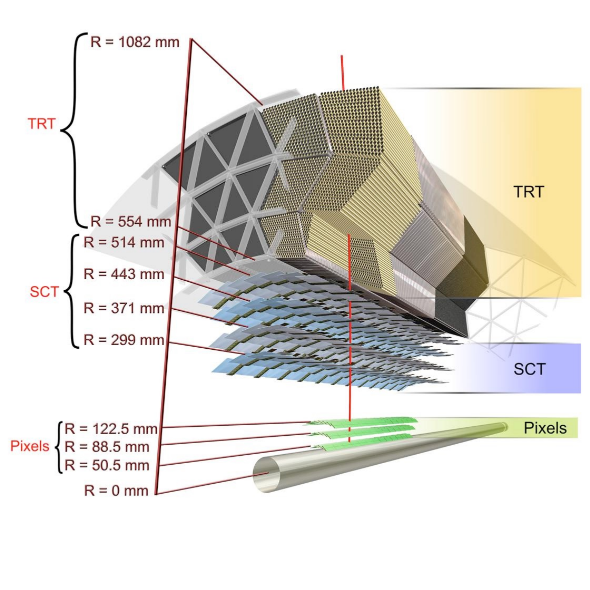
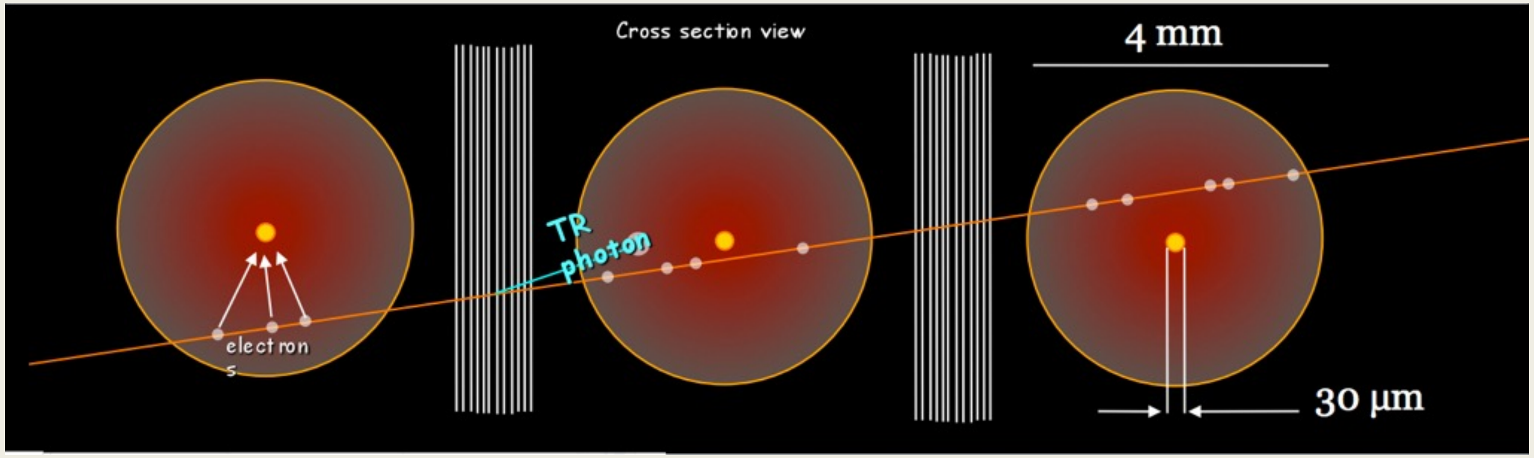
Transition Radiation Tracker (TRT)





NBI contributes to TRT operations and maintenance from start Run 1 until end of Run 3

TRT provides half the momentum resolution and significant e/π rejection, capabilities which are crucial for several analyses

Challenges in Run 3 : deal with leaks – partly radiation induced – of both the cooling gas (a potent greenhouse gas) and the active Xenon gas (important for the electron identification, but at present very expensive).
The effects of closing modules and switching other modules to Argon will be mitigated by improvements in software.

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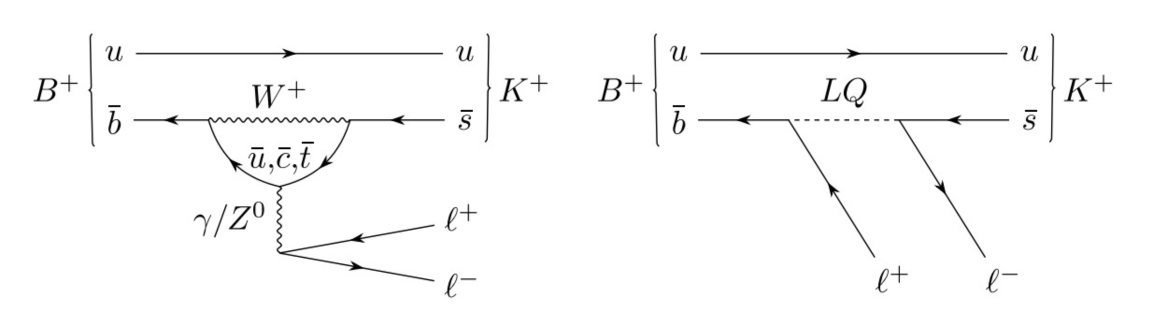
Bphysics



$$R_K = \frac{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to J/\psi\,(\to \mu^+\mu^-)K^+)} \Bigg/ \frac{\mathcal{B}(B^+ \to K^+e^+e^-)}{\mathcal{B}(B^+ \to J/\psi\,(\to e^+e^-)K^+)}\,.$$

K could be other hadrons, eg K^{*0}

B+ could be other B hadron, eg B^0, B^0_s

- This is a rare decay, and the low electron momentum is a trigger challenge for ATLAS.
- Dedicated triggers were included in the last part of Run 2 data taking.
- New triggers are studied for Run 3, and improved data acquisition and rate allocation should allow to make ATLAS competitive.
- In Run 2 we collected enough events with ℓ=e,μ to do a first measurement of R_{K*}
- The analysis strategy is to select events (with ML) independently of the invariant masses, and fit the reconstructed B mass to estimate signal size and separate non-resonant (signal) from resonant (J/ψ control) contributions.

Photon /electron energy reconstruction

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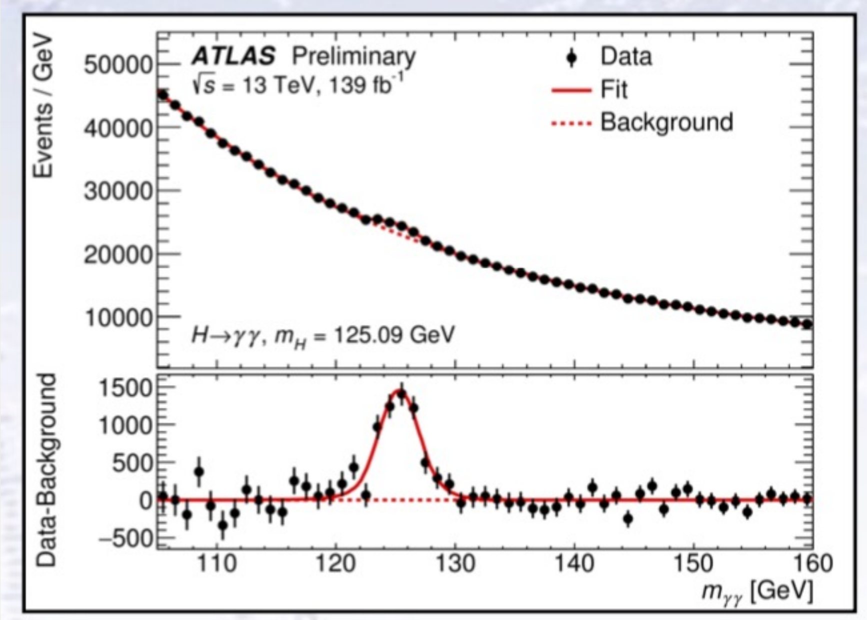
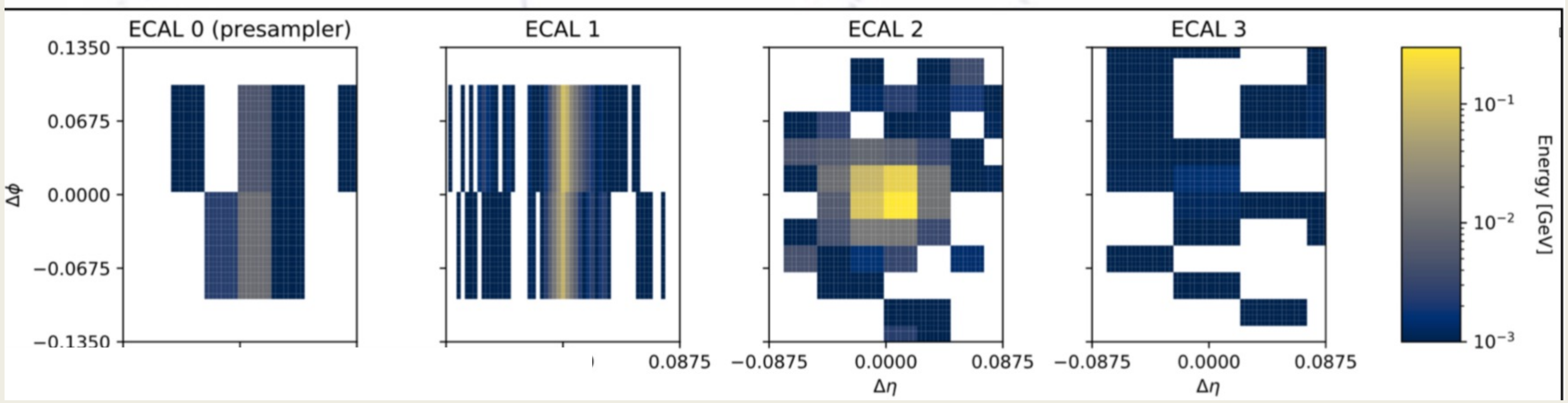
- The photon energy resolution σ(Eγ) is the **dominant performance parameter** for the H ➛ γγ
- Our team wishes to improve this resolution in ATLAS.
- Consider the cell energies in the LAr calorimeter as pixels in four images (one for each layer), and train a Convolutional Neural Network (CNN) to estimate the energy of electron/photon candidates.





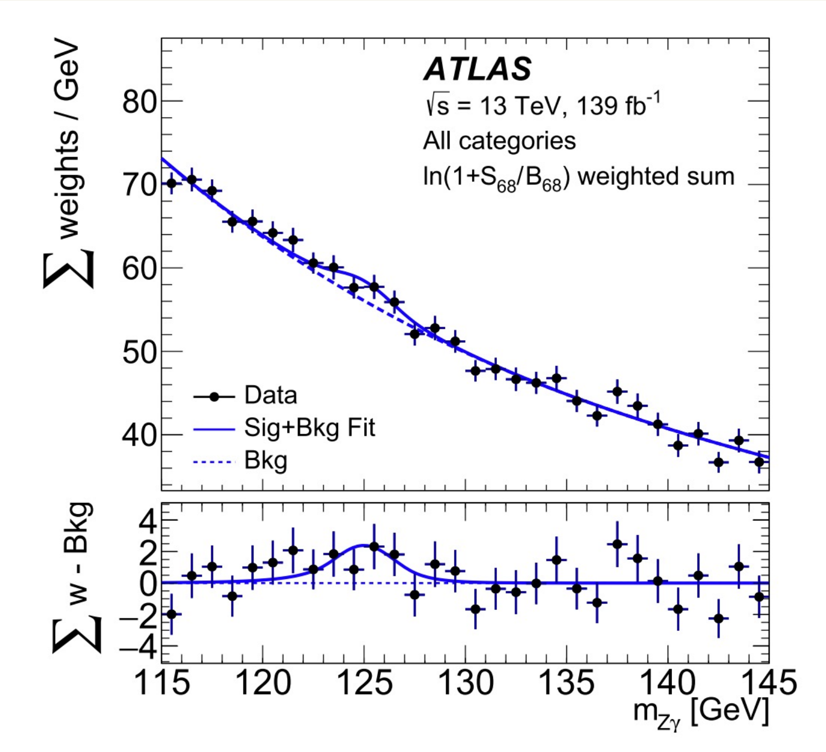
Measured the improvement in data, using electrons (we have billions of Z→ee)

Expected improvement on photons E resolution of 20%

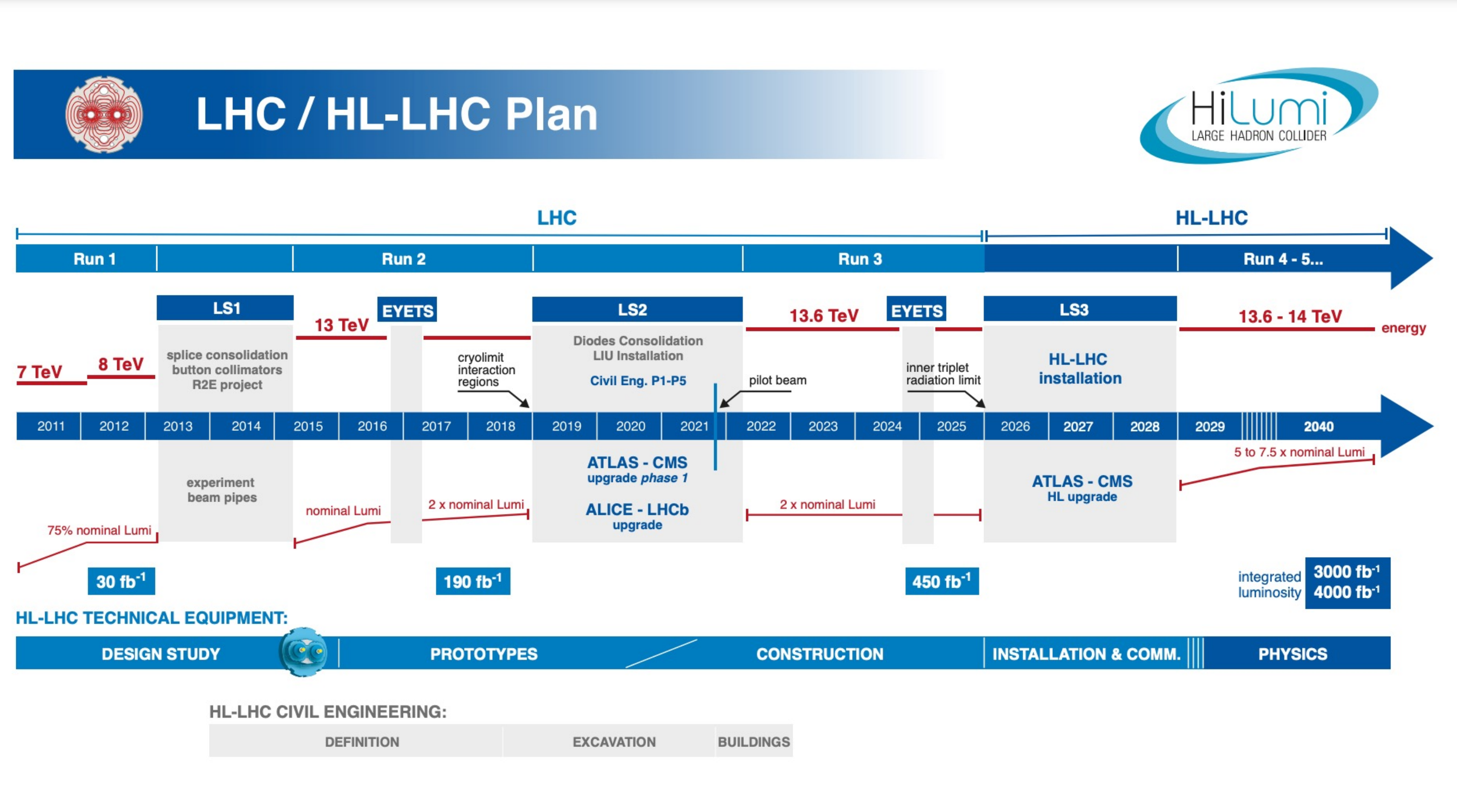
Rare Higgs decays : Z γ

- Current result, no optimized photon energy resolution yet (see right)
- The observed 95% CL upper limit on the $\sigma(pp \rightarrow H) \cdot B(H \rightarrow Z\gamma)$ is 3.6 times the SM prediction for a Higgs boson mass of 125.09 GeV [zg].

- Main background : non resonant Z production in association with a photon
- With expected improvement in photon energy resolution just shown, one can be sure to have a clear observation of thiis H decay within Run 3 end



Beyond Run 3: High Luminosity LHC



Big game changer for improving the SM and beyond SM physics measurements shown earlier.
The high luminosity LHC which will bring 10 times more data, and additionally the ATLAS tracker will have a significant increase in angular acceptance.

New tracking trigger

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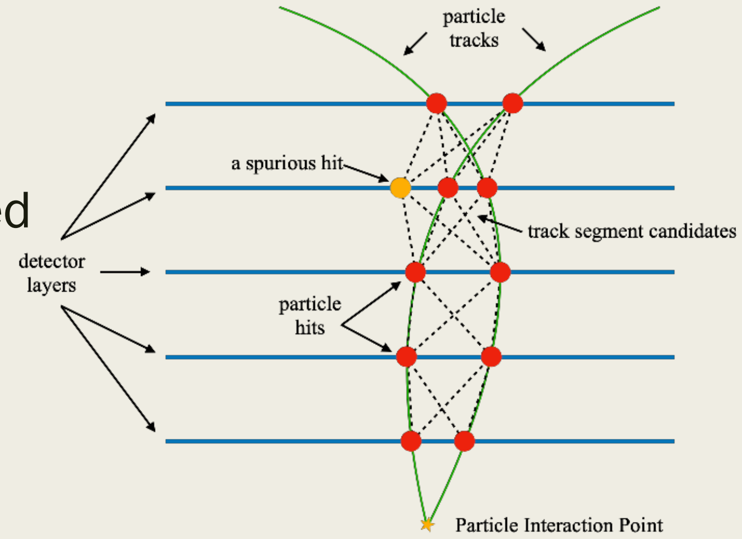
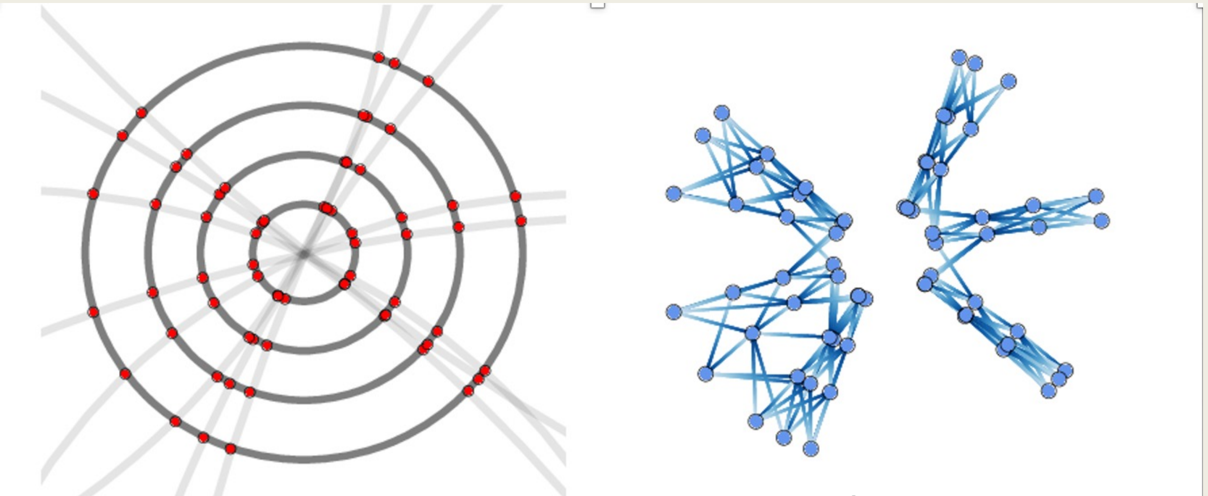
- At HL-LHC the collision data rate will increase by a factor 10
- the ATLAS real-time data selection (trigger) is challenged : speed and efficiency are the critical parameters.
- charged particle track reconstruction is the bottleneck





Particles Xing ITK Tracking detector

Image in Graph neural network

New pattern recognition algorithms development

Focus on choice of

- Hardware implementation (optimal combination of CPU/GPU and possibly FPGAs)

- Algorithm type (neural networks is the option studied now, CNN vs GNN)

ITK DC-DC converter

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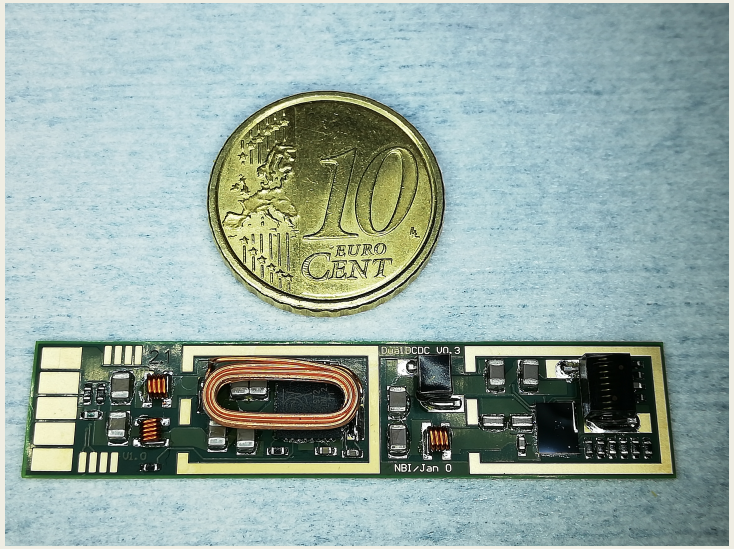
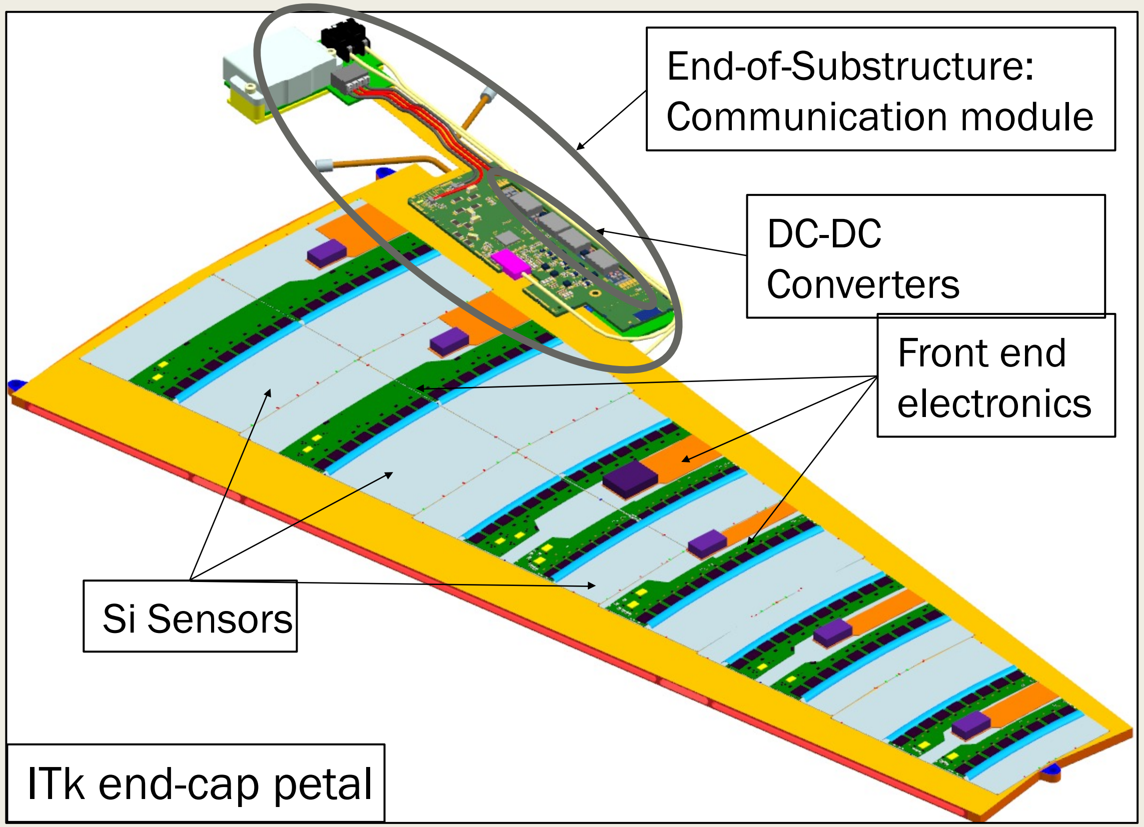
DC-DC Converter is part of the End-of-Substructure communication module , and provides power for this.

- Converting in two steps from input voltage of 11 V first to 2.5 V used for optical chips and further to 1.2 V for electronics

- PCBs (panels of 10 each) by GS Swiss PCB AG, CH
- Automatized component mounting at Danchell A/S, DK
- Functionality testing and burn-in in NBI electronics lab





ITK endcap strip modules

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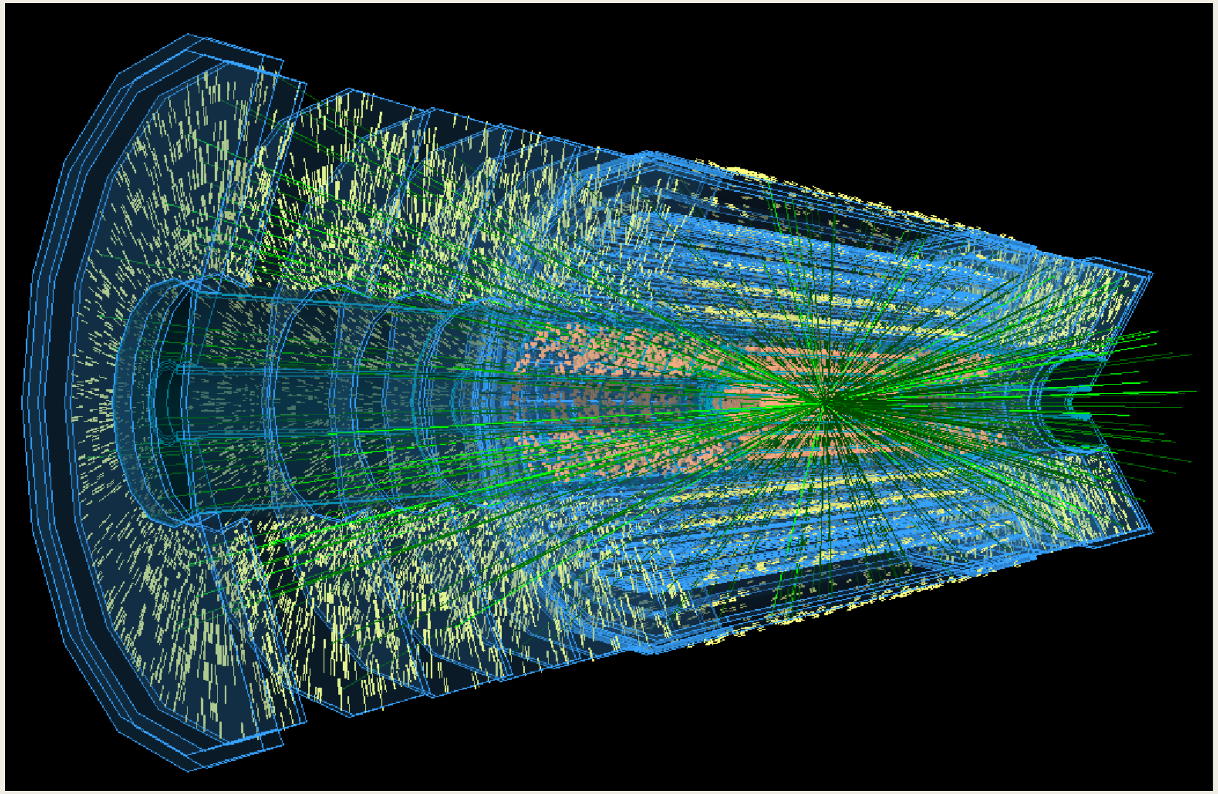
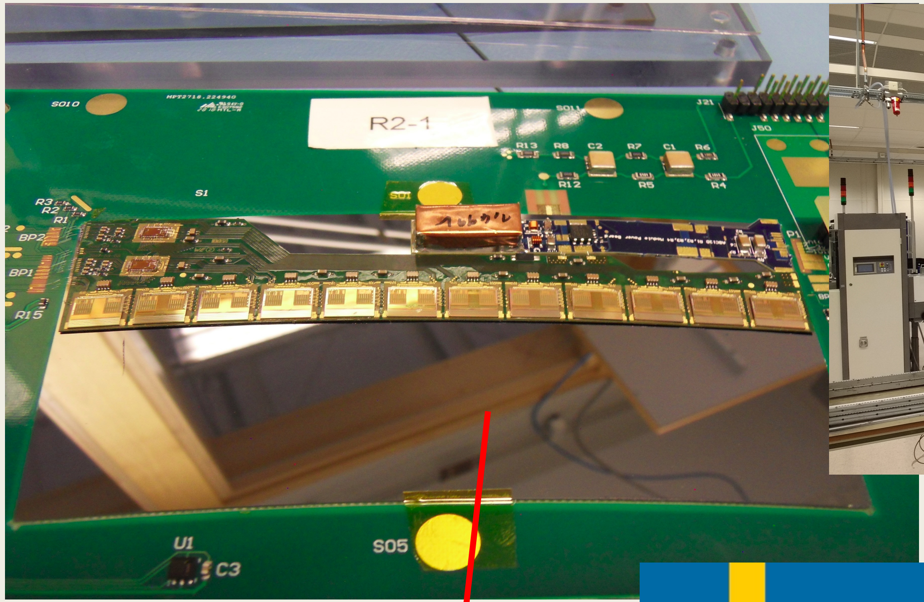
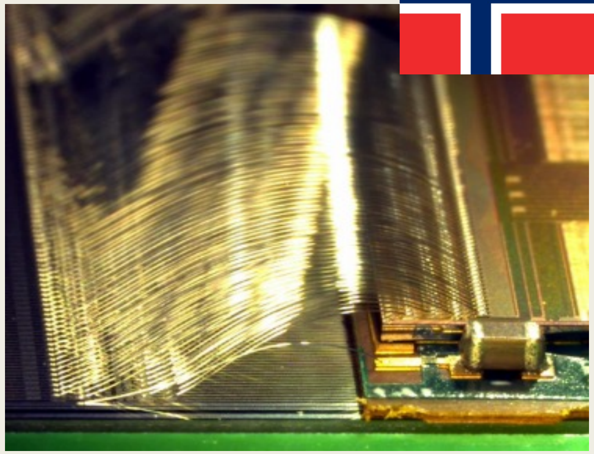
- **600** modules will be produced [~10%] in Scandinavia (in two different geometries)
- Production will run from **2022** to **2025**
- NBI responsible for all module

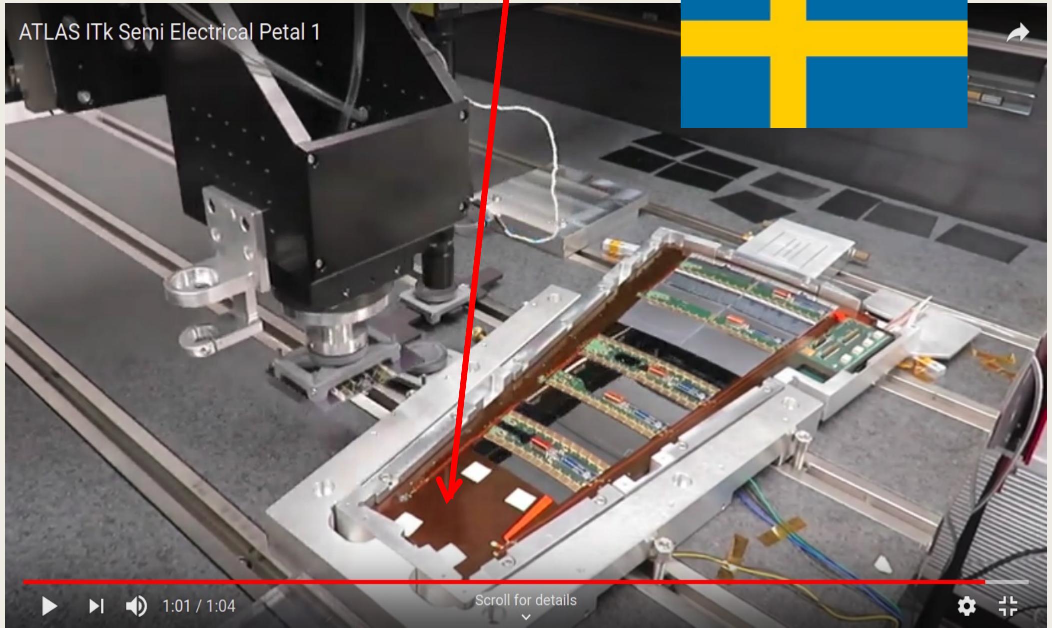
  Quality Control & Assurance
  - *visual inspection*
  - *electrical testing*
  - *metrology*
  - *thermal cycling*



ITK endcap strip modules







New NBI clean-room lab for module production

Who are we ?

Name	Position	Interests
Peter Hansen	Prof. Emeritus	TRT calibration
Mogens Dam	Ass. Prof.	ITK HL-LHC : DC-DC converters , design & production in Denmark
Stefania Xella	Ass.Prof.	Trigger HL-LHC : optimal algorithms for tracking, design of final Trigger system Tau leptons reconstruction Lepton flavour/number, Lepton universality violation
Jørgen Beck Hansen	Ass.Prof.	Total cross section measurement
Troels Petersen	Ass.Prof.	Photon/electron reconstruction Lepton universality violation Higgs rare decays
Oleg Ruchayskyi	Ass. Prof.	Lepton flavour/number violation (STA)
Craig Wiglesworth	Assist. Prof.	ITK HL-LHC: module production & quality control
Alessandra Camplani	Assist. Prof.	Trigger HL-LHC: optimal algorithms for tracking, optimal hardware for tracking
Jimmy Hansen	technician	ITK HL-LHC : DC-DC converters, technical help in testing
	Master students	Lepton flavour violation, photon energy reconstruction, lepton universality violation

Summary

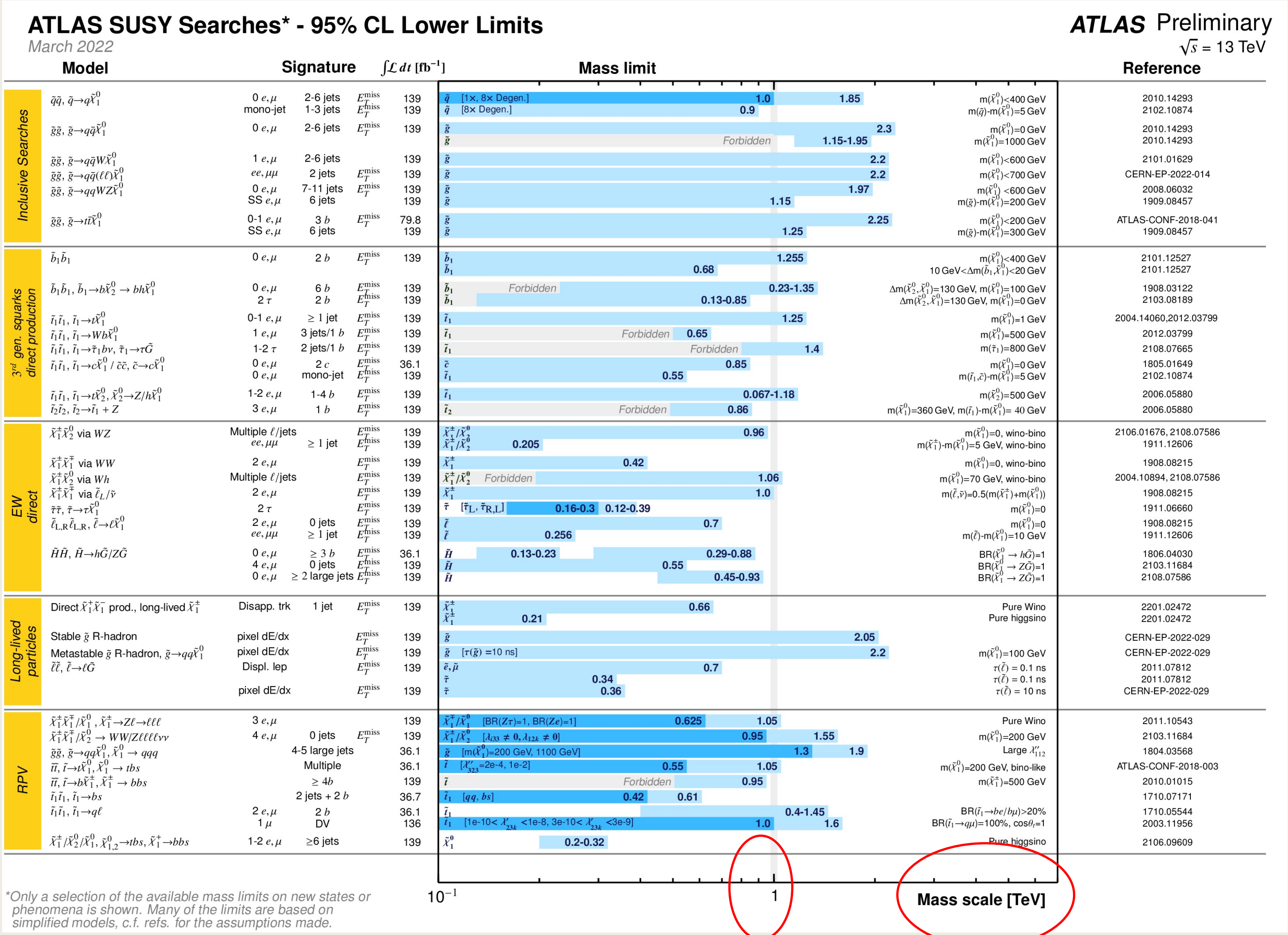
- LHC and ATLAS are an excellent machine and experiment for investigating fundamental new particle and forces at the energy frontier.
- The performance is exceeding what expected for this stage of the physics program thanks to the excellent accelerator team, the inventive of the experimental physicists (new software or hardware, new analysis methods) and the tight collaboration of the theoretical and experimental physicists
  - *We are zooming in on the Higgs particle*
  - *We are testing theory extensions of the SM, looking for the reasons for neutrino mass, dark matter, fine tuning of the SM*
- The ATLAS NBI team contributes strongly to these achievements

Back up

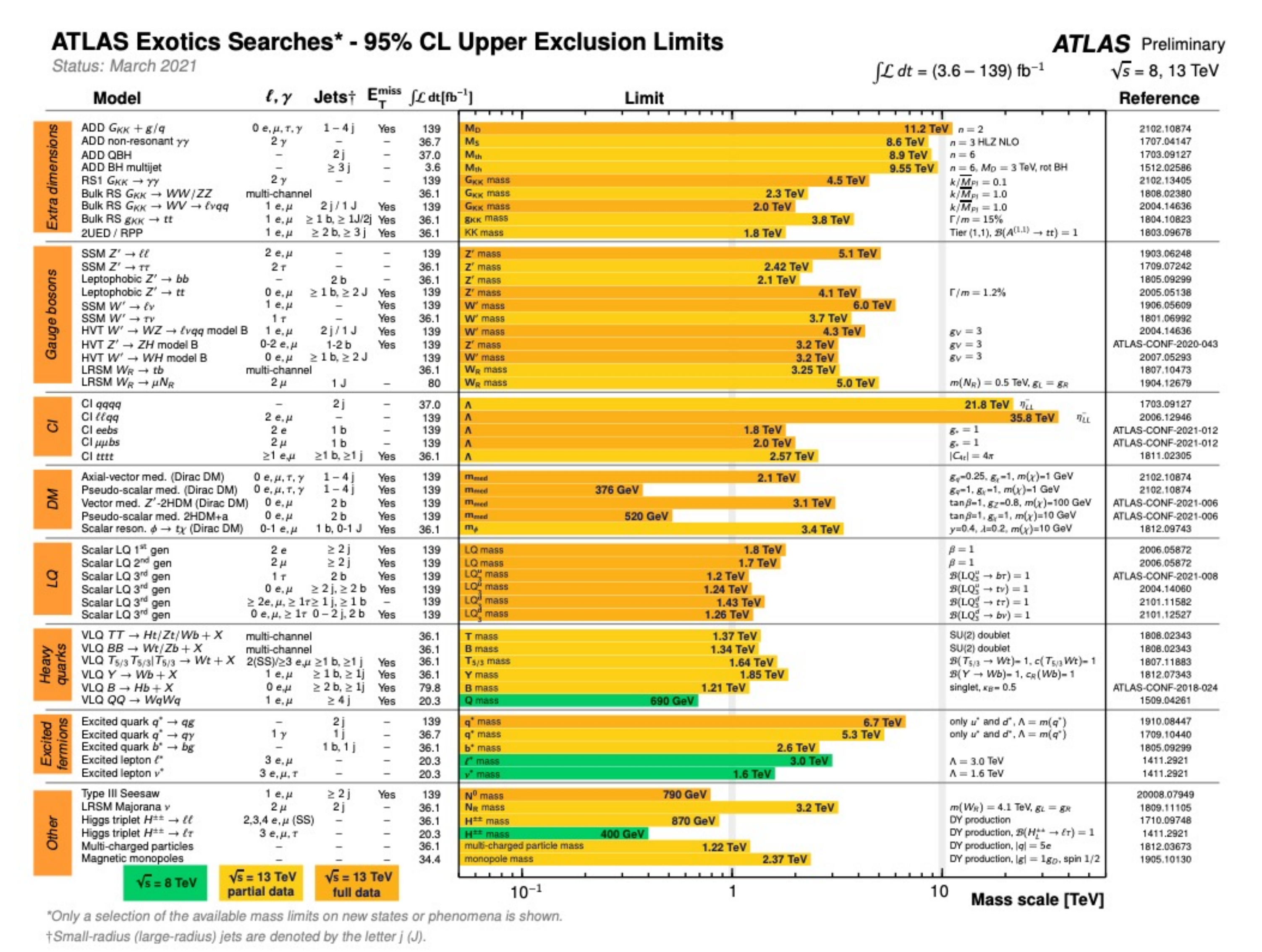
Which responsibilities did/do we have?

- Stefania : ATLAS NBI team leader, representant in TDAQ IB
  - *Exotics subgroup convenor for searches for new physics with leptons + X 2020-2022*
  - *Trigger coordinator 2017-2019*
  - *Tau Trigger & Tau identification coordinator during Run 1 (<2015)*
- Mogens : ATLAS NBI deputy team leader, representant in ITK IB
  - *Responsible for DC-DC converters for the whole endcap strips detector, HL-LHC, ITK*
- Alessandra : ATLAS representant in TDAQ IB
  - *Firmware coordinator, HL-LHC, Trigger (EF)*
- Peter :
  - *TRT project leader 2019-2021*
- Craig :
  - *Trigger Calorimeter reconstruction coordinator 2014-2016*
  - *Overall coordinator for Quality control & assurance procedures, and responsible for scandinavian endcap strip modules. HL-LHC, ITK*
- Jørgen:
  - *Total cross section pp , 8 & 13 TeV , analysis coordinator*

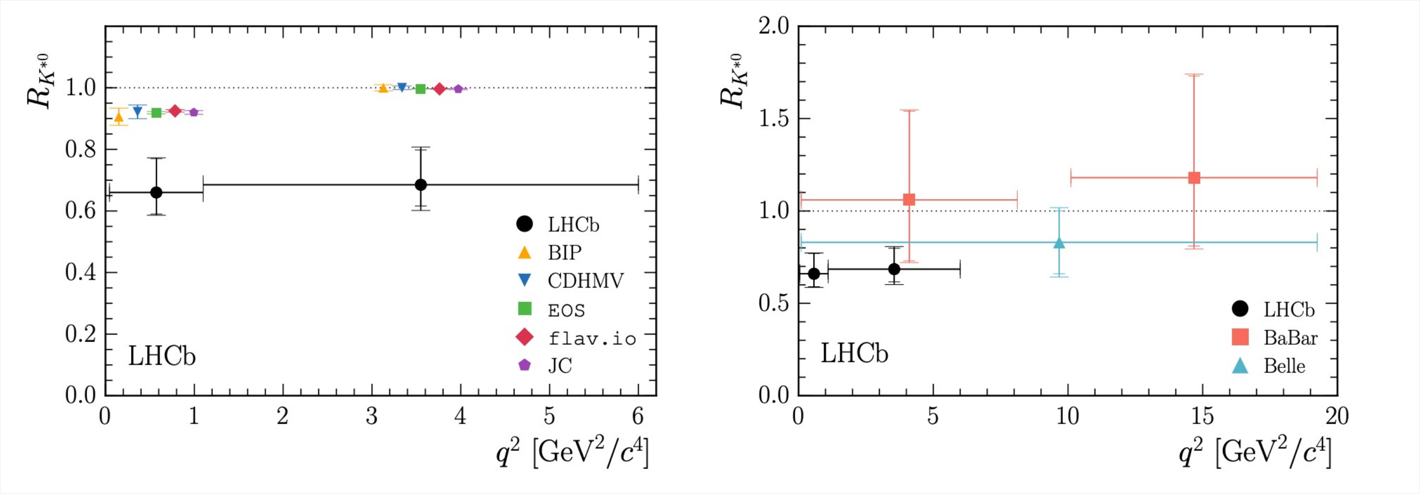
supersymmetry



exotics

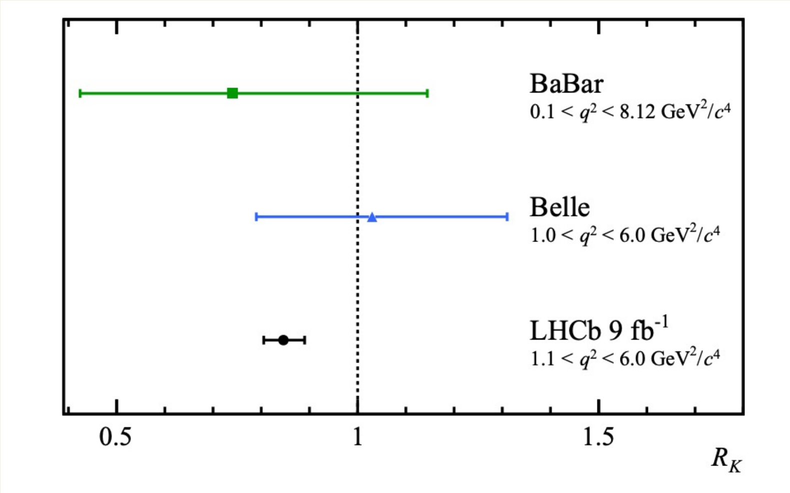

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits
Status: March 2021
ATLAS Preliminary
$\int \mathcal{L}\,dt = (3.6 - 139)\ \mathrm{fb}^{-1}$
$\sqrt{s} = 8, 13$ TeV
Model | ℓ, γ | Jets† | E_T^{miss} | ∫L dt[fb⁻¹] | Limit | Reference
Extra dimensions
ADD $G_{KK} + g/q$ | 0 e, μ, τ, γ | 1 − 4 j | Yes | 139 | M_D 11.2 TeV | n = 2 | 2102.10874
ADD non-resonant γγ | 2 γ | – | – | 36.7 | M_S 8.6 TeV | n = 3 HLZ NLO | 1707.04147
ADD QBH | – | 2 j | – | 37.0 | M_th 8.9 TeV | n = 6 | 1703.09127
ADD BH multijet | – | ≥ 3 j | – | 3.6 | M_th 9.55 TeV | n = 6, M_D = 3 TeV, rot BH | 1512.02586
RS1 $G_{KK} \to \gamma\gamma$ | 2 γ | – | – | 139 | G_KK mass 4.5 TeV | $k/\overline{M}_{Pl} = 0.1$ | 2102.13405
Bulk RS $G_{KK} \to WW/ZZ$ | multi-channel | 36.1 | G_KK mass 2.3 TeV | $k/\overline{M}_{Pl} = 1.0$ | 1808.02380
Bulk RS $G_{KK} \to WV \to \ell\nu qq$ | 1 e, μ | 2 j / 1 J | Yes | 139 | G_KK mass 2.0 TeV | $k/\overline{M}_{Pl} = 1.0$ | 2004.14636
Bulk RS $g_{KK} \to tt$ | 1 e, μ | ≥ 1 b, ≥ 1J/2j | Yes | 36.1 | g_KK mass 3.8 TeV | Γ/m = 15% | 1804.10823
2UED / RPP | 1 e, μ | ≥ 2 b, ≥ 3 j | Yes | 36.1 | KK mass 1.8 TeV | Tier (1,1), $\mathcal{B}(A^{(1,1)} \to tt) = 1$ | 1803.09678
Gauge bosons
SSM $Z' \to \ell\ell$ | 2 e, μ | – | – | 139 | Z′ mass 5.1 TeV | 1903.06248
SSM $Z' \to \tau\tau$ | 2 τ | – | – | 36.1 | Z′ mass 2.42 TeV | 1709.07242
Leptophobic $Z' \to bb$ | – | 2 b | – | 36.1 | Z′ mass 2.1 TeV | 1805.09299
Leptophobic $Z' \to tt$ | 0 e, μ | ≥ 1 b, ≥ 2 J | Yes | 139 | Z′ mass 4.1 TeV | Γ/m = 1.2% | 2005.05138
SSM $W' \to \ell\nu$ | 1 e, μ | – | Yes | 139 | W′ mass 6.0 TeV | 1906.05609
SSM $W' \to \tau\nu$ | 1 τ | – | Yes | 36.1 | W′ mass 3.7 TeV | 1801.06992
HVT $W' \to WZ \to \ell\nu qq$ model B | 1 e, μ | 2 j / 1 J | Yes | 139 | W′ mass 4.3 TeV | $g_V = 3$ | 2004.14636
HVT $Z' \to ZH$ model B | 0-2 e, μ | 1-2 b | Yes | 139 | Z′ mass 3.2 TeV | $g_V = 3$ | ATLAS-CONF-2020-043
HVT $W' \to WH$ model B | 0 e, μ | ≥ 1 b, ≥ 2 J | 139 | W′ mass 3.2 TeV | $g_V = 3$ | 2007.05293
LRSM $W_R \to tb$ | multi-channel | 36.1 | W_R mass 3.25 TeV | 1807.10473
LRSM $W_R \to \mu N_R$ | 2 μ | 1 J | – | 80 | W_R mass 5.0 TeV | $m(N_R) = 0.5$ TeV, $g_L = g_R$ | 1904.12679
CI
CI qqqq | – | 2 j | – | 37.0 | Λ 21.8 TeV | η_{LL}^- | 1703.09127
CI ℓℓqq | 2 e, μ | – | – | 139 | Λ 35.8 TeV | η_{LL}^- | 2006.12946
CI eebs | 2 e | 1 b | – | 139 | Λ 1.8 TeV | $g_* = 1$ | ATLAS-CONF-2021-012
CI μμbs | 2 μ | 1 b | – | 139 | Λ 2.0 TeV | $g_* = 1$ | ATLAS-CONF-2021-012
CI tttt | ≥1 e,μ | ≥1 b, ≥1 j | Yes | 36.1 | Λ 2.57 TeV | $|C_{4t}| = 4\pi$ | 1811.02305
DM
Axial-vector med. (Dirac DM) | 0 e, μ, τ, γ | 1 − 4 j | Yes | 139 | m_med 2.1 TeV | g_q=0.25, g_χ=1, $m(\chi)$=1 GeV | 2102.10874
Pseudo-scalar med. (Dirac DM) | 0 e, μ, τ, γ | 1 − 4 j | Yes | 139 | m_med 376 GeV | g_q=1, g_χ=1, $m(\chi)$=1 GeV | 2102.10874
Vector med. Z′-2HDM (Dirac DM) | 0 e, μ | 2 b | Yes | 139 | m_med 3.1 TeV | tanβ=1, g_Z=0.8, $m(\chi)$=100 GeV | ATLAS-CONF-2021-006
Pseudo-scalar med. 2HDM+a | 0 e, μ | 2 b | Yes | 139 | m_med 520 GeV | tanβ=1, g_χ=1, $m(\chi)$=10 GeV | ATLAS-CONF-2021-006
Scalar reson. $\phi \to t\chi$ (Dirac DM) | 0-1 e, μ | 1 b, 0-1 J | Yes | 36.1 | m_φ 3.4 TeV | y=0.4, λ=0.2, $m(\chi)$=10 GeV | 1812.09743
LQ
Scalar LQ 1st gen | 2 e | ≥ 2 j | Yes | 139 | LQ mass 1.8 TeV | β = 1 | 2006.05872
Scalar LQ 2nd gen | 2 μ | ≥ 2 j | Yes | 139 | LQ mass 1.7 TeV | β = 1 | 2006.05872
Scalar LQ 3rd gen | 1 τ | 2 b | Yes | 139 | LQ_3^u mass 1.2 TeV | $\mathcal{B}(LQ_3^u \to b\tau) = 1$ | ATLAS-CONF-2021-008
Scalar LQ 3rd gen | 0 e, μ | ≥ 2 j, ≥ 2 b | Yes | 139 | LQ_3^u mass 1.24 TeV | $\mathcal{B}(LQ_3^u \to t\nu) = 1$ | 2004.14060
Scalar LQ 3rd gen | ≥ 2e, μ, ≥ 1τ | ≥ 1 j, ≥ 1 b | – | 139 | LQ_3^d mass 1.43 TeV | $\mathcal{B}(LQ_3^d \to t\tau) = 1$ | 2101.11582
Scalar LQ 3rd gen | 0 e, μ, ≥ 1τ | 0 − 2 j, 2 b | Yes | 139 | LQ_3^d mass 1.26 TeV | $\mathcal{B}(LQ_3^d \to b\nu) = 1$ | 2101.12527
Heavy quarks
VLQ $TT \to Ht/Zt/Wb + X$ | multi-channel | 36.1 | T mass 1.37 TeV | SU(2) doublet | 1808.02343
VLQ $BB \to Wt/Zb + X$ | multi-channel | 36.1 | B mass 1.34 TeV | SU(2) doublet | 1808.02343
VLQ $T_{5/3}T_{5/3}|T_{5/3} \to Wt + X$ | 2(SS)/≥3 e,μ | ≥1 b, ≥1 j | Yes | 36.1 | $T_{5/3}$ mass 1.64 TeV | $\mathcal{B}(T_{5/3} \to Wt)$= 1, $c(T_{5/3}Wt)$= 1 | 1807.11883
VLQ $Y \to Wb + X$ | 1 e, μ | ≥ 1 b, ≥ 1j | Yes | 36.1 | Y mass 1.85 TeV | $\mathcal{B}(Y \to Wb)$= 1, $c_R(Wb)$= 1 | 1812.07343
VLQ $B \to Hb + X$ | 0 e,μ | ≥ 2 b, ≥ 1j | Yes | 79.8 | B mass 1.21 TeV | singlet, κ_B= 0.5 | ATLAS-CONF-2018-024
VLQ $QQ \to WqWq$ | 1 e, μ | ≥ 4 j | Yes | 20.3 | Q mass 690 GeV | 1509.04261
Excited fermions
Excited quark $q^* \to qg$ | – | 2 j | – | 139 | q* mass 6.7 TeV | only u* and d*, Λ = m(q*) | 1910.08447
Excited quark $q^* \to q\gamma$ | 1 γ | 1 j | – | 36.7 | q* mass 5.3 TeV | only u* and d*, Λ = m(q*) | 1709.10440
Excited quark $b^* \to bg$ | – | 1 b, 1 j | – | 36.1 | b* mass 2.6 TeV | 1805.09299
Excited lepton ℓ* | 3 e, μ | – | – | 20.3 | ℓ* mass 3.0 TeV | Λ = 3.0 TeV | 1411.2921
Excited lepton ν* | 3 e, μ, τ | – | – | 20.3 | ν* mass 1.6 TeV | Λ = 1.6 TeV | 1411.2921
Other
Type III Seesaw | 1 e, μ | ≥ 2 j | Yes | 139 | N^0 mass 790 GeV | 20008.07949
LRSM Majorana ν | 2 μ | 2 j | – | 36.1 | N_R mass 3.2 TeV | $m(W_R) = 4.1$ TeV, $g_L = g_R$ | 1809.11105
Higgs triplet $H^{\pm\pm} \to \ell\ell$ | 2,3,4 e, μ (SS) | – | – | 36.1 | $H^{\pm\pm}$ mass 870 GeV | DY production | 1710.09748
Higgs triplet $H^{\pm\pm} \to \ell\tau$ | 3 e, μ, τ | – | – | 20.3 | $H^{\pm\pm}$ mass 400 GeV | DY production, $\mathcal{B}(H_L^{\pm\pm} \to \ell\tau) = 1$ | 1411.2921
Multi-charged particles | – | – | – | 36.1 | multi-charged particle mass 1.22 TeV | DY production, |q| = 5e | 1812.03673
Magnetic monopoles | – | – | – | 34.4 | monopole mass 2.37 TeV | DY production, |g| = 1g_D, spin 1/2 | 1905.10130
$\sqrt{s}$ = 8 TeV
$\sqrt{s}$ = 13 TeV partial data
$\sqrt{s}$ = 13 TeV full data
10^{-1}
1
10
Mass scale [TeV]
*Only a selection of the available mass limits on new states or phenomena is shown.
†Small-radius (large-radius) jets are denoted by the letter j (J).

B anomalies



LHCb Run 1 , 3 fb-1 [lhcb1]

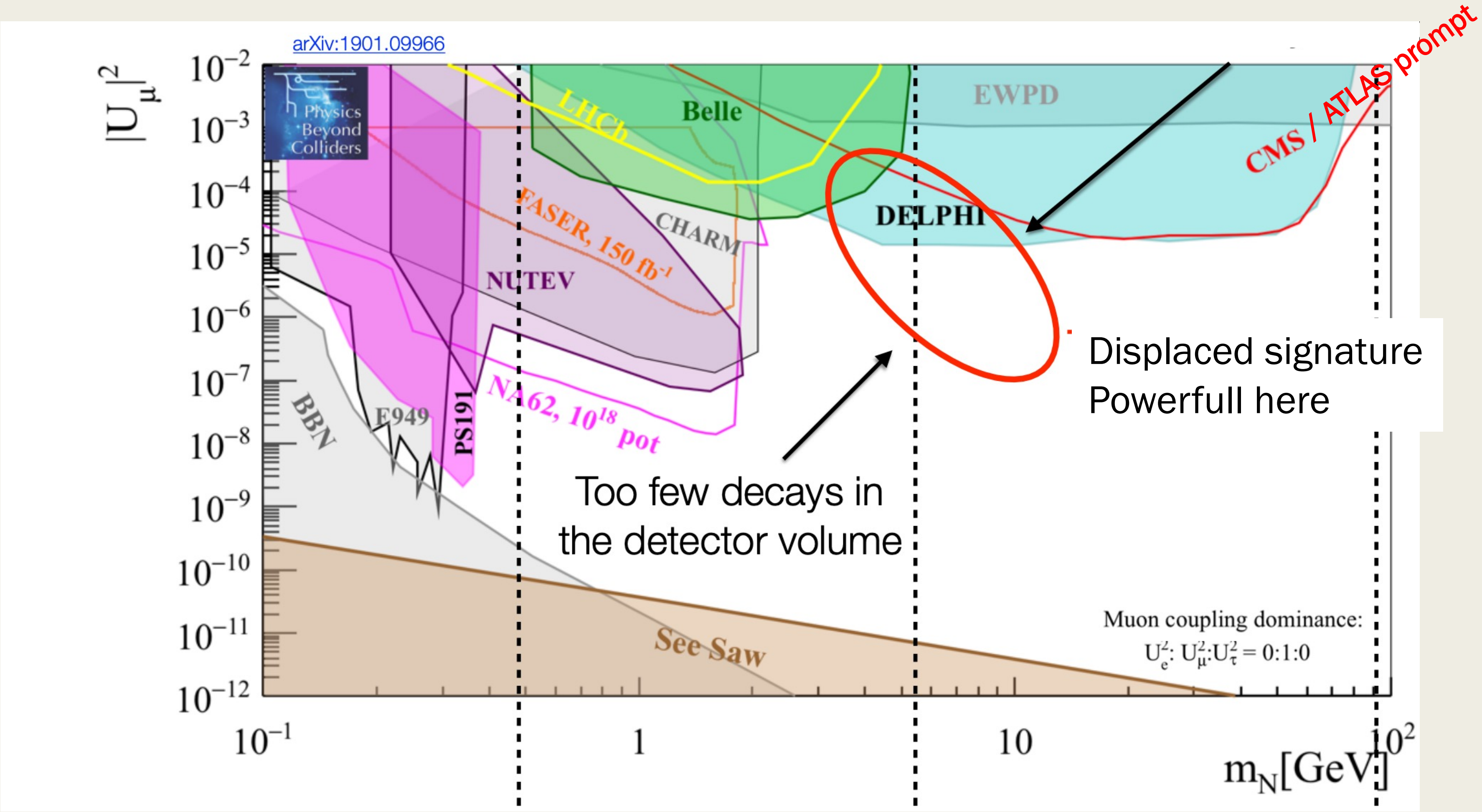
LHCb Run 2, 9 fb-1 [lhcb2]



LHCb Run 2, 9 fb-1 [lhcb3]

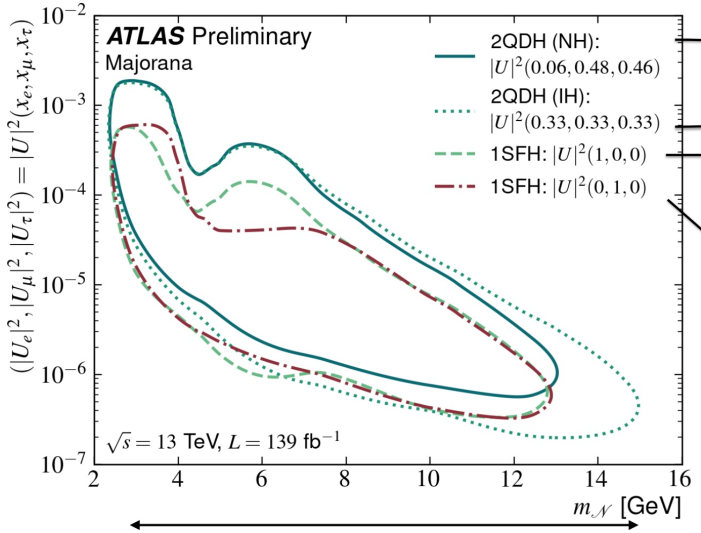
$$R_{K^0_S} = 0.66\,^{+0.20}_{-0.14}\,(\text{stat.})\,^{+0.02}_{-0.04}\,(\text{syst.})\,,$$
$$R_{K^{*+}} = 0.70\,^{+0.18}_{-0.13}\,(\text{stat.})\,^{+0.03}_{-0.04}\,(\text{syst.})\,.$$

Heavy neutral leptons



Heavy neutral leptons

$10^{-3} < |U|^2 < 10^{-7}$



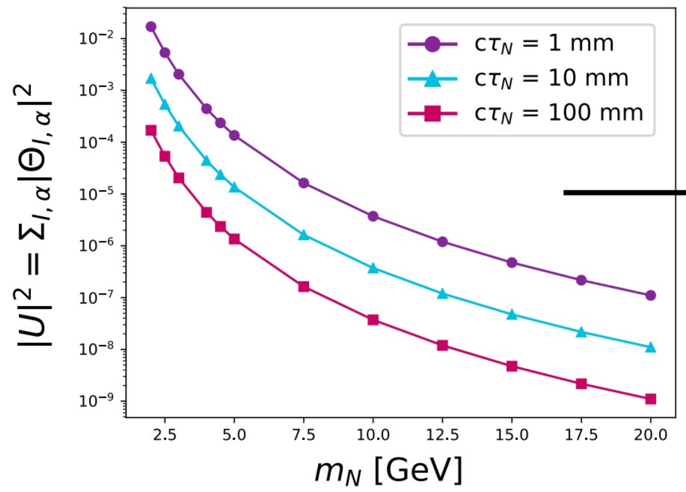
Multi-flavour mixing

Electron-only mixing

Muon-only mixing

$3 < m_N < 15$ GeV

Full Run 2 result - displaced signature search

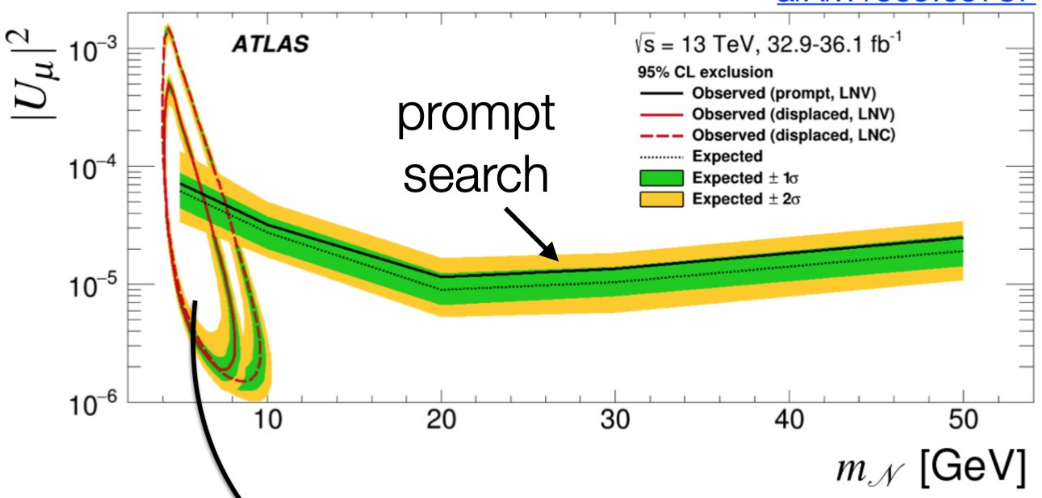


muon-only mixing

$U_e^2 : U_\mu^2 : U_\tau^2 = 0:1:0$

Partial Run 2 result

arXiv:1905.09787



Displaced HNL result with **2016 data only**