Higgs, what now?

Measurements of VH, H→bb/cc and the ATLAS Higgs Physics Program in the Post-Higgs-Boson-Discovery Era

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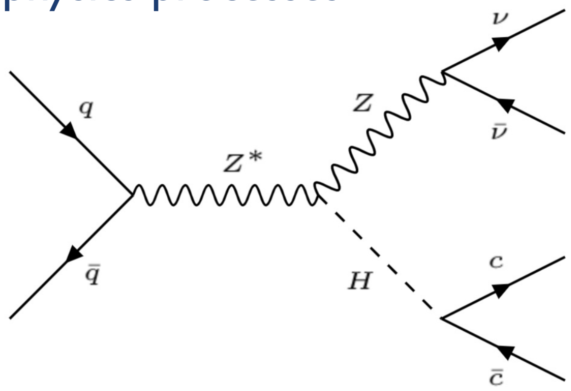
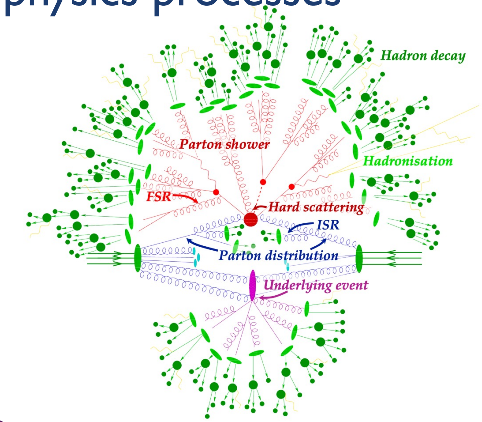
May 29

Why are we doing collider physics?

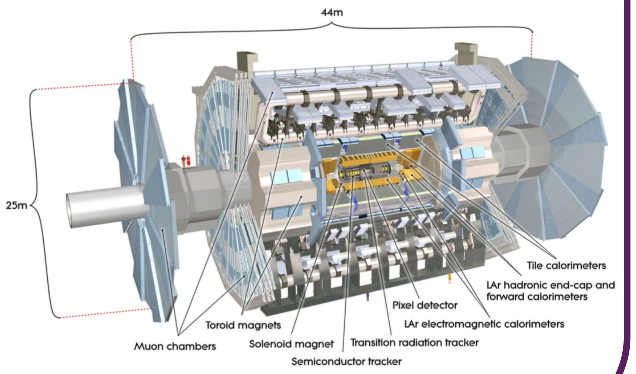
Simulation of high energy physics processes



Simulation of "soft physics" physics processes

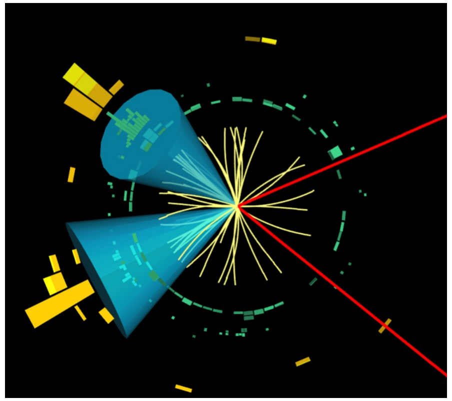


Simulation of ATLAS detector



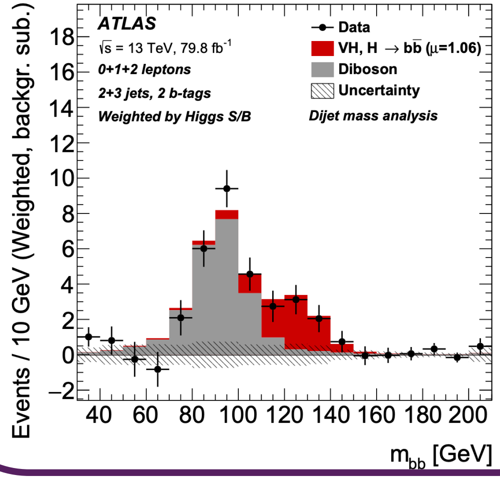
LHC data

Reconstruction in ATLAS detector



Analysis event selection

Statistical analysis



Results

Final results of the statistical analysis quantify

→ Agreement of of the data with predictions (either Standard Model or other models)

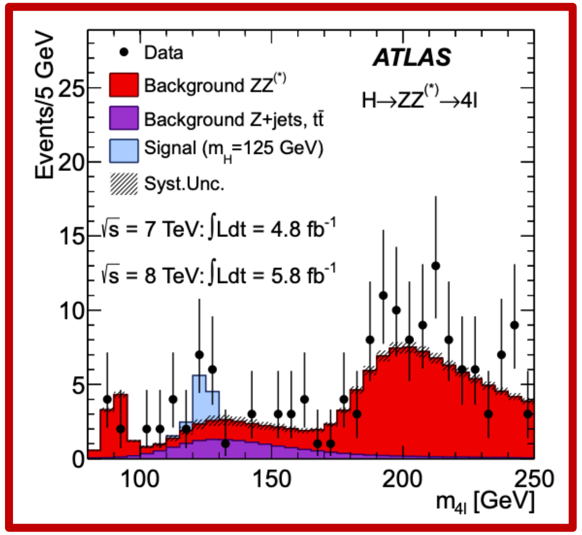
→ Upper limits on unobserved processes

Higgs landscape

- **Higgs boson discovery** in 2012
- Coupling to bosons established in Run I of the LHC

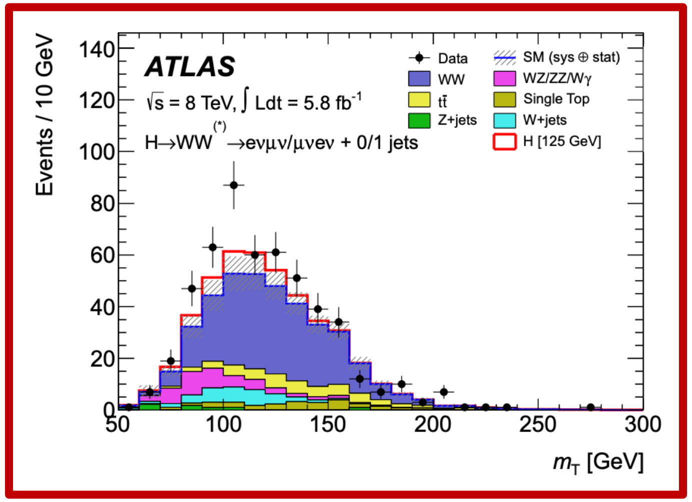
Fermions			Bosons	
I	II	III		
u	c	t	g	H
d	s	b	γ	
e	μ	τ	Z	
ν_e	ν_μ	ν_τ	W	

Quarks: u, c, t, d, s, b
Leptons: e, μ, τ, ν_e, ν_μ, ν_τ



H→ZZ→4l

H→WW→ eνμν

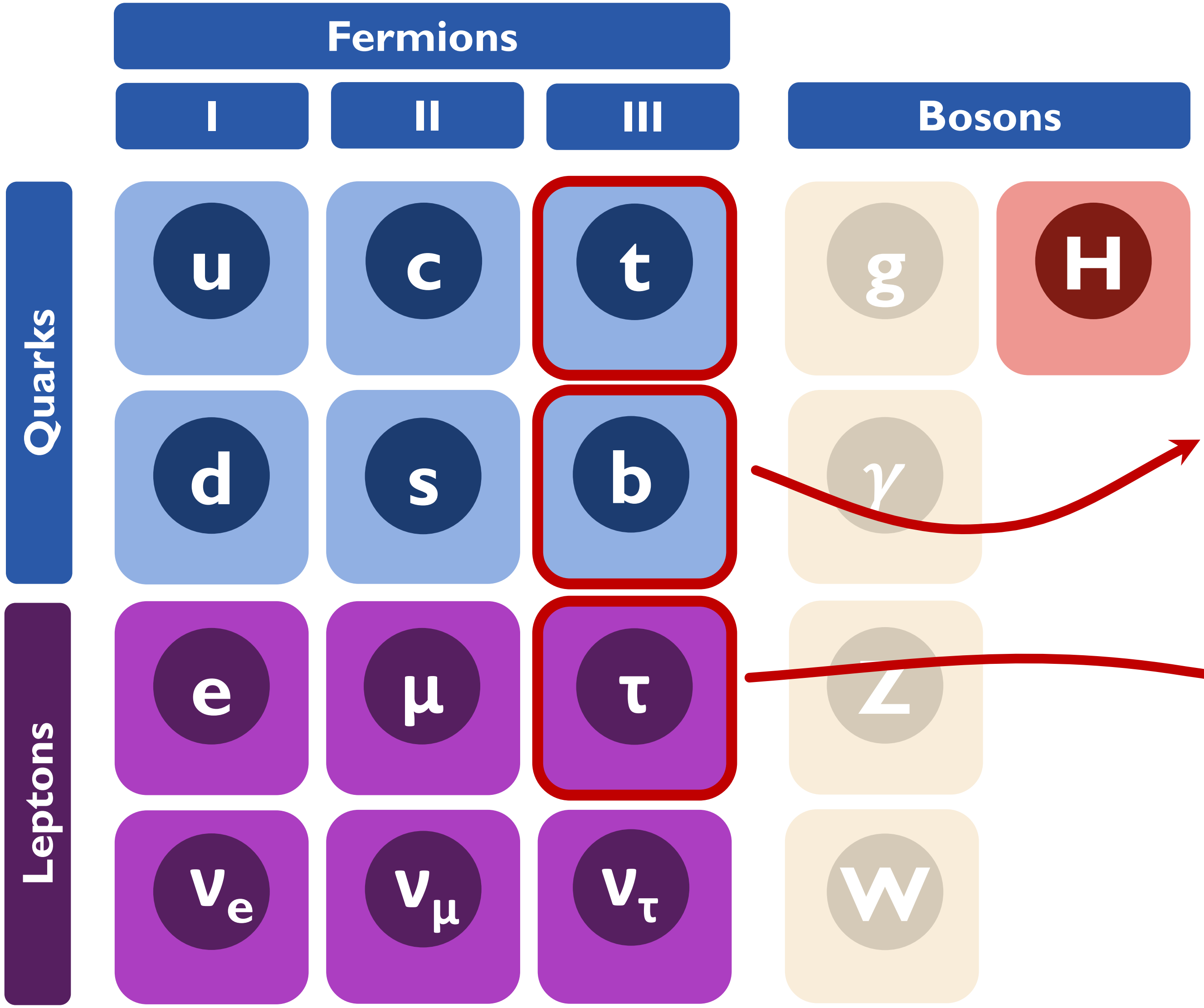


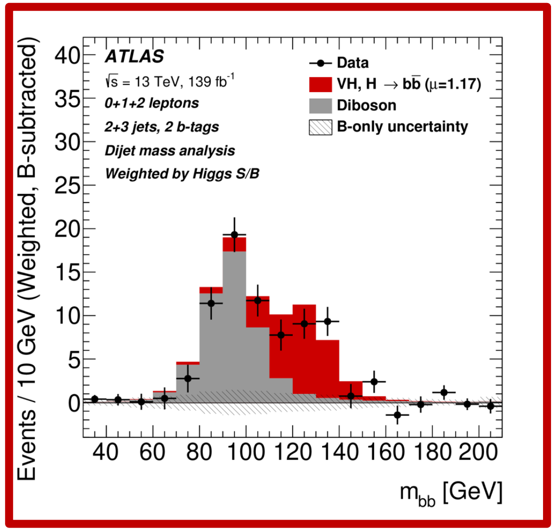
Phys.Lett. B716 (2012) 1-29

Higgs landscape

- Coupling of Higgs to heavy fermions established

→ In direct decays or by measuring ttH production mode



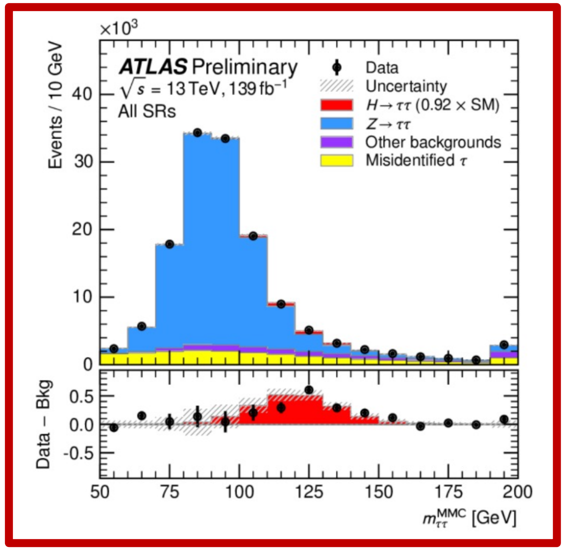


VH, H→bb

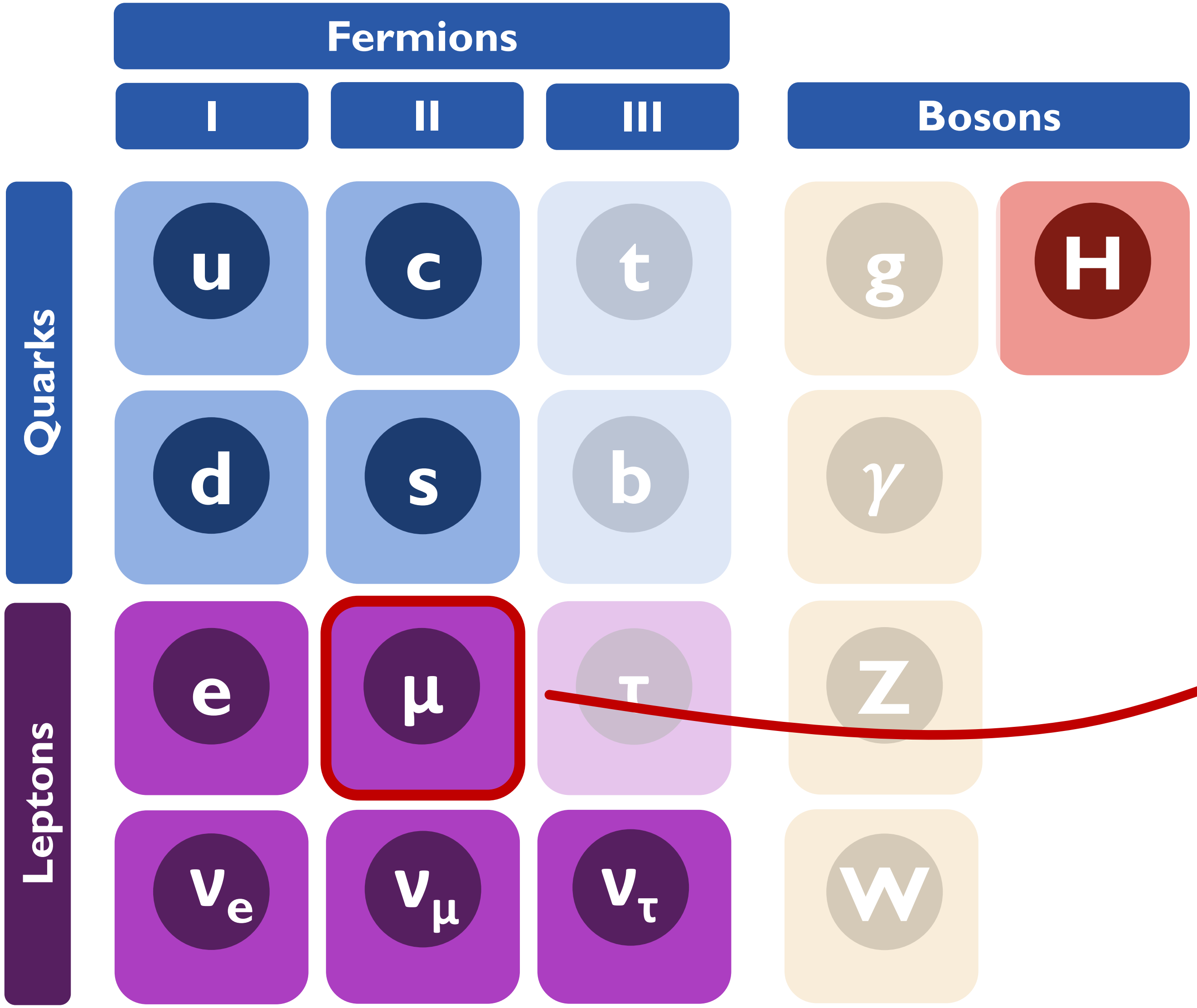
Eur. Phys. J. C 81 (2021) 178

H→ττ

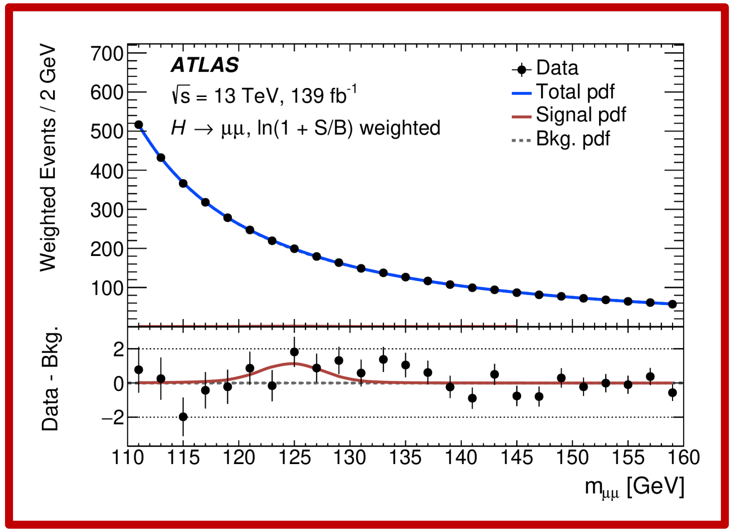
ATLAS-CONF-2021-044



Higgs landscape



- More recently: evidence of Higgs coupling to muons in direct decays



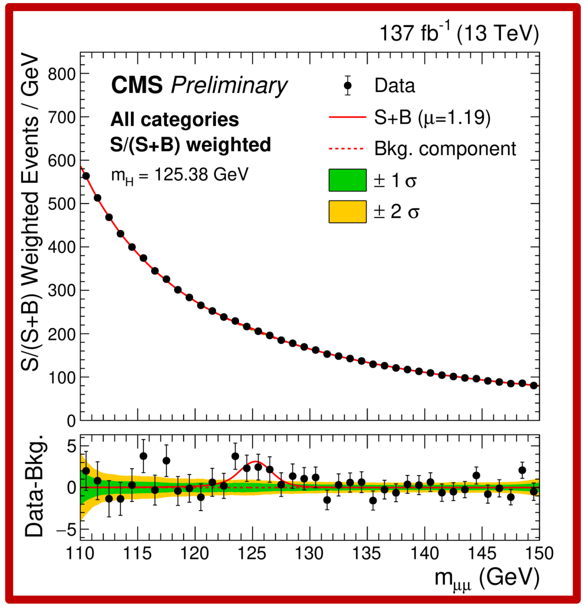
ATLAS

Phys. Lett. B 812 (2021) 135980

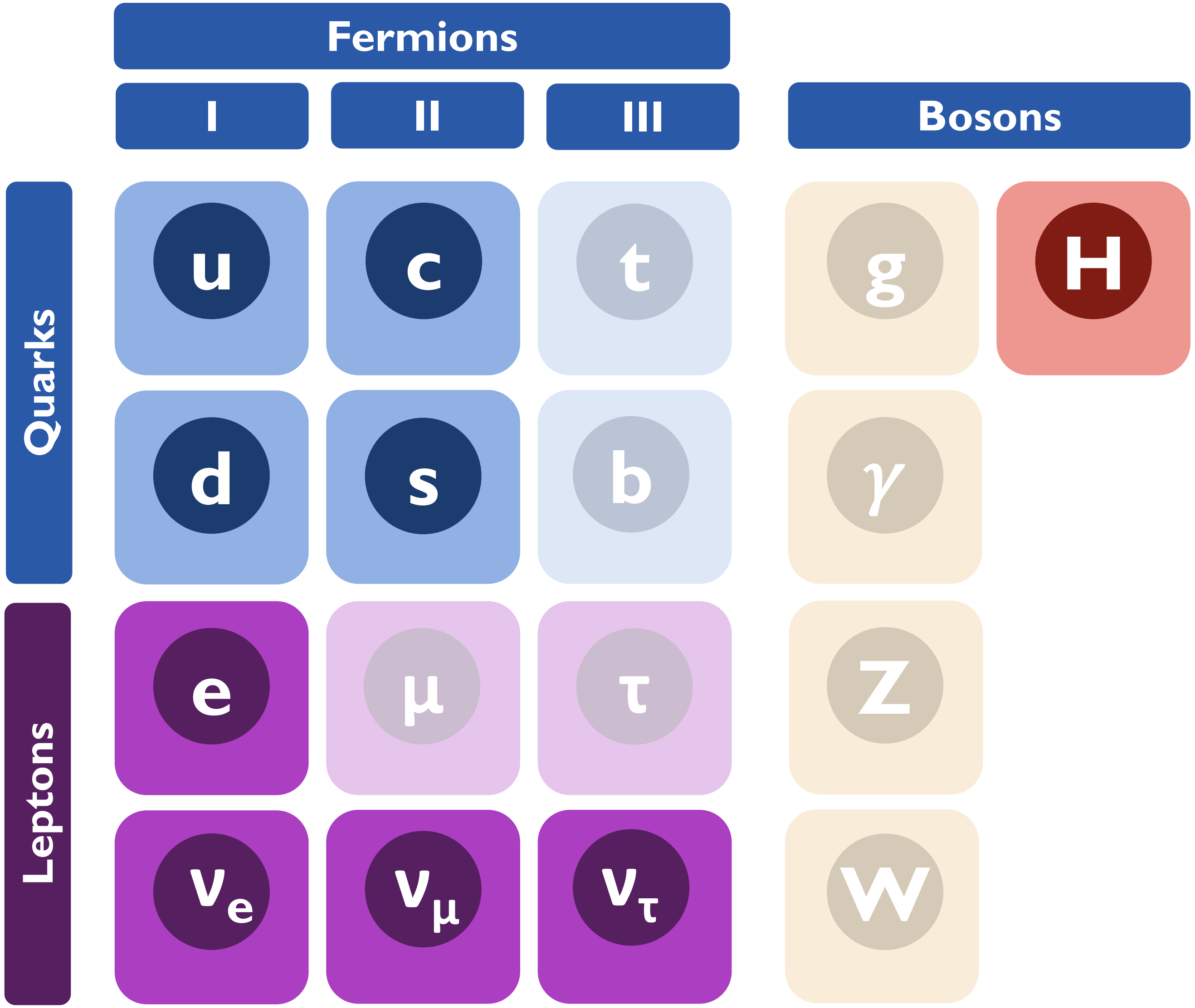
$H \to \mu\mu$

CMS

JHEP 01 (2021) 148



Higgs landscape



- Higgs program at the LHC has been very successful so far
- However, no new physics found at the LHC
- As the most unknow particle, clear motivation to use LHC dataset to probe the Higgs couplings as precisely as possible

→"Higgs a tool for new physics searches"

- Open questions:
  - Coupling to lighter fermions?
  - Higgs self-coupling?
  - Coupling to invisible particles? (e.g. dark matter?)

Higgs as a discovery tool

Can consider grouping Higgs measurements into different categories:

Nature 607, 52 (2022)

Higgs couplings (two-body decays):

New physics can manifest as:

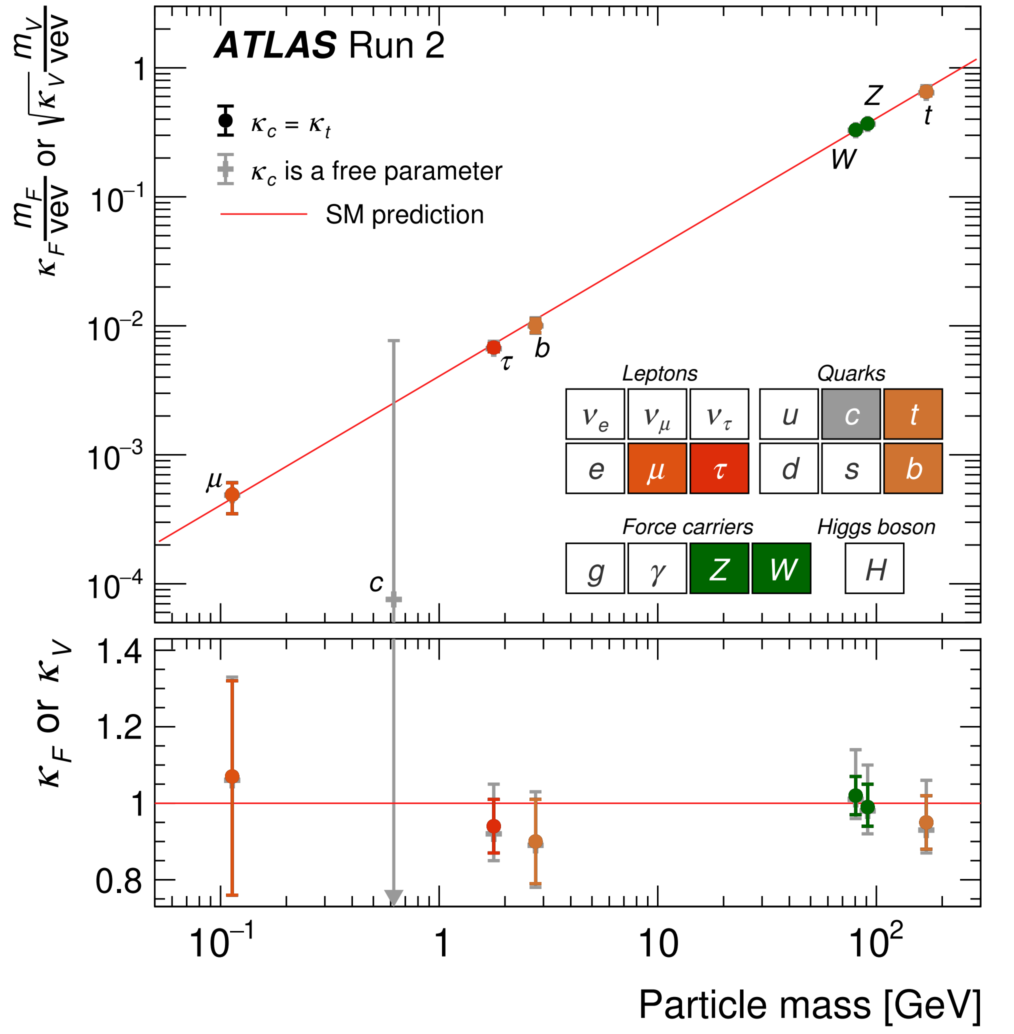
- Precision correction to established decay channels, i.e. H→ZZ, WW, $\gamma\gamma$, bb, ττ → precision/differential measurements
- Significant modifications to more rare decays H→μμ, cc (e.g. arXiv 1804.02400, 1508.01501) → searches

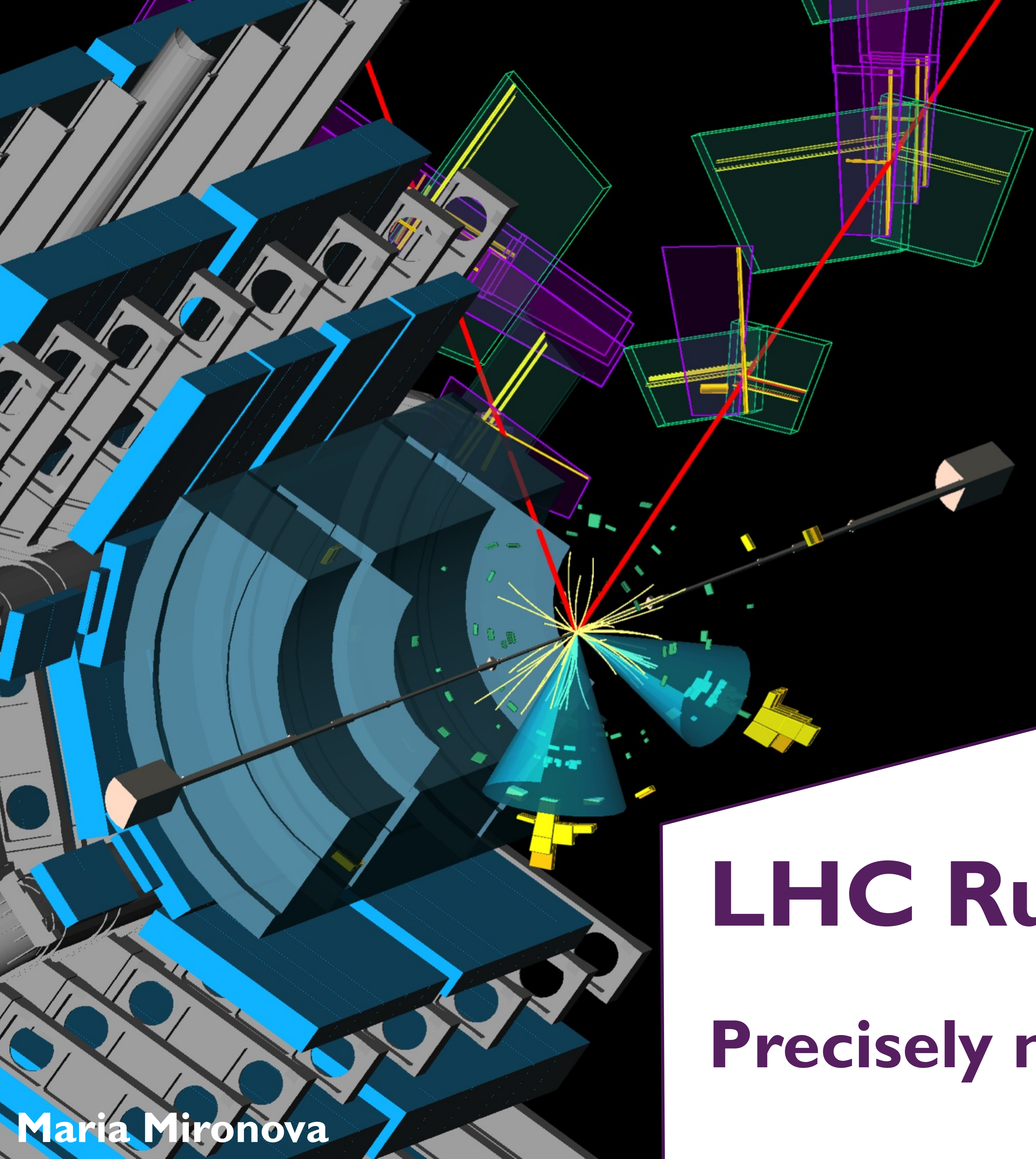
Tri-linear Higgs self-coupling:

- Higgs self-coupling κ_λ one of the main SM parameters not yet measured
- Strong di-Higgs program in ATLAS → largest sensitivity in HH→bbbb, bb$\gamma\gamma$, bbττ (new for LHCP: ATLAS-CONF-2024-006)

Dedicated new physics searches/measurements with Higgs:

- Can set up dedicated analyses targeting specific rare processes or specific kinematics, e.g. H → J/ψ + X decay, H(γγ)+X, Quantum entanglement





LHC Run 2

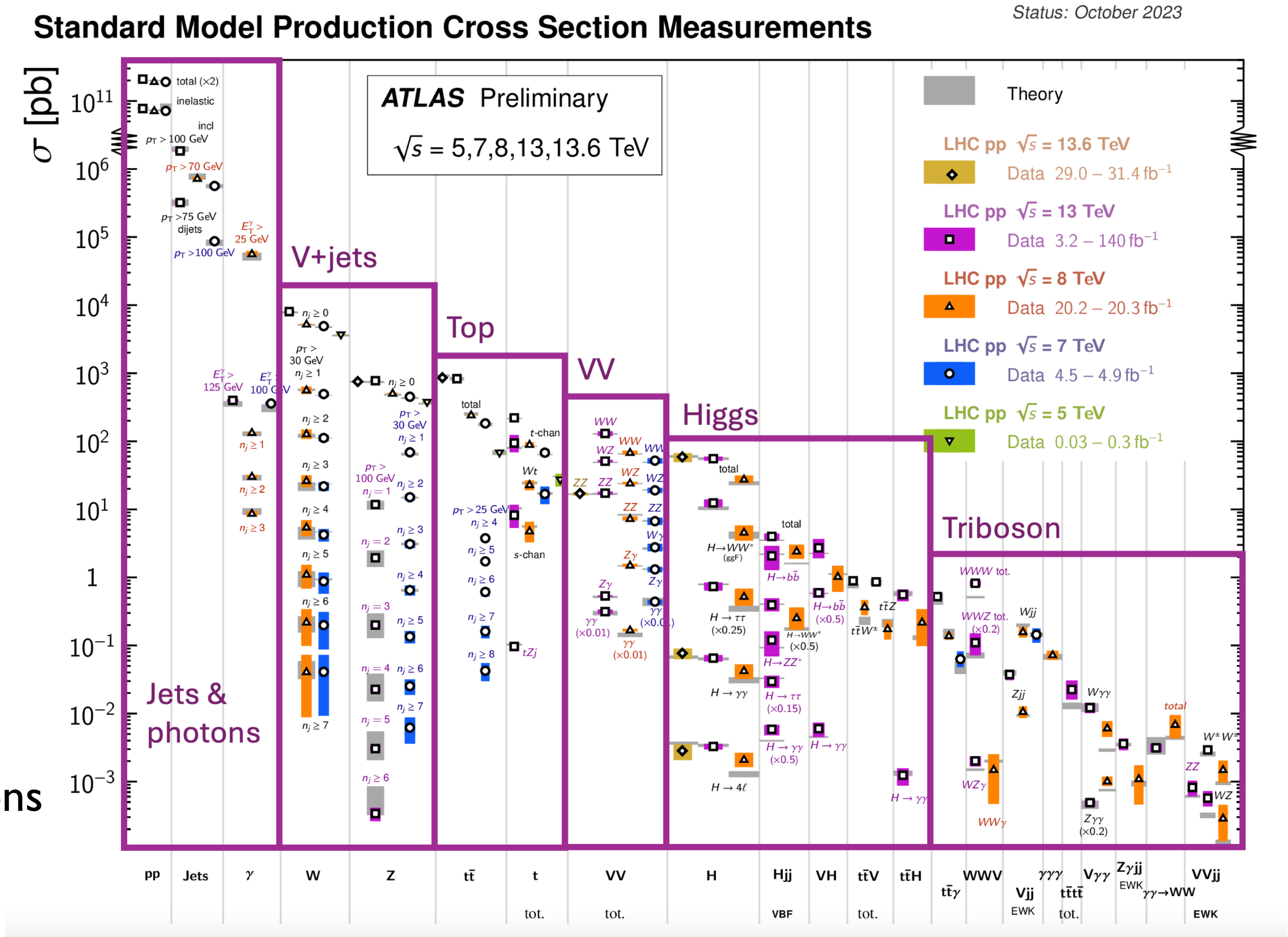
Precisely measuring Higgs couplings

Maria Mironova

Highlights of Run 2 measurements

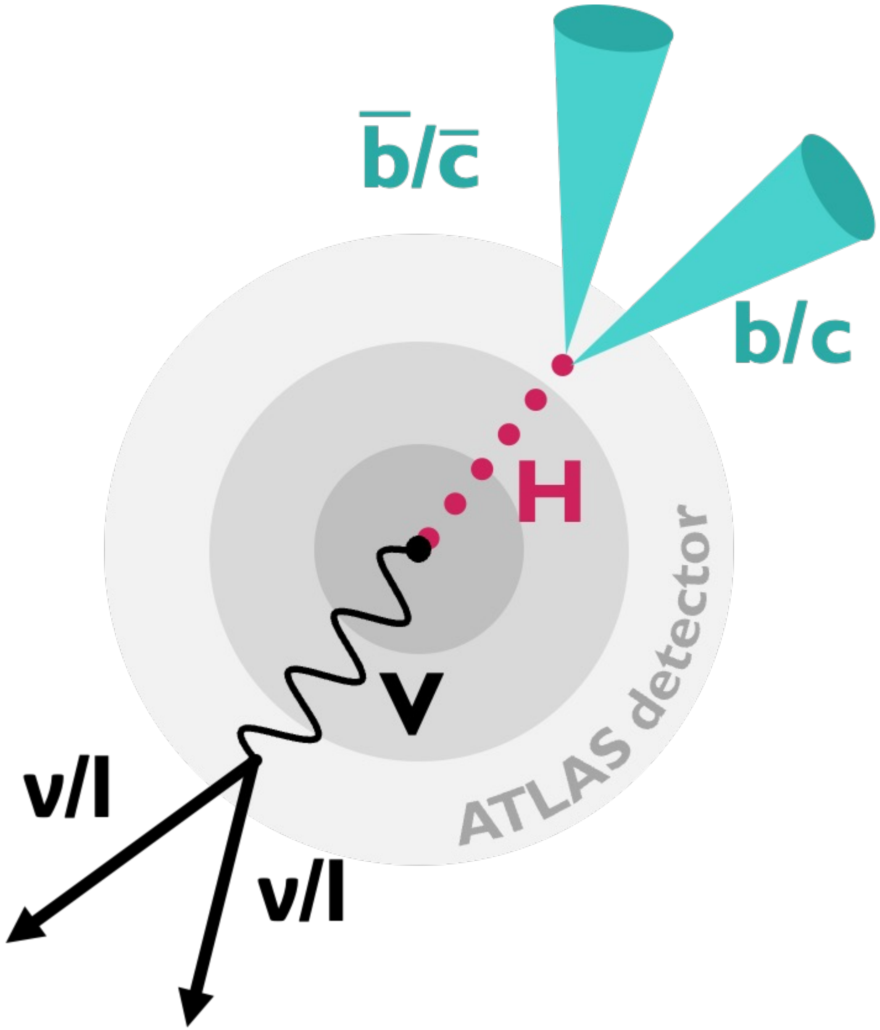
- ATLAS physics program has been hugely successful in probing SM predictions across many orders of magnitude
- Higgs physics program only a subset of the interesting physics measurements in ATLAS
- Specifically, weak boson and top quark measurements are crucial tests of the SM at different center-of-mass energy scales

→ Also important for Higgs measurements, as they are some of the most important backgrounds and drive MC generator decisions



VH, H→bb,cc

- Since Higgs discovery, moving towards studying Higgs boson in detail
- Higgs coupling to b-quarks has been well-established (observation paper), largest contribution to Higgs decay width (branching ratio 58%)
- Higgs coupling to c-quarks is most common Higgs decay channel that has not yet been observed (branching ratio 2.7%)
- New physics effects can manifest both as precision corrections to H→bb decay rate, or significant modifications to the smaller H→cc decay rate (e.g see arXiv 1804.02400, 1508.01501)
- VH(bb/cc) analyses target the VH production mode:
  - Use leptonic decays of the W and Z boson to suppress QCD background
  - Exploit similarity of H→bb/cc decays through similar analysis strategies and common samples and calibrations
  - Exploit flavour tagging to identify jets originating from b- and c-jets

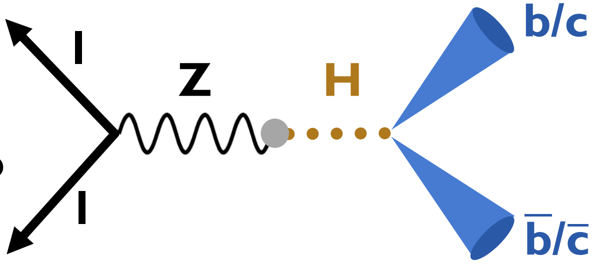


Boosted vs resolved

- Two different topologies used based on transverse momentum of the Higgs boson
- High momentum Higgs boson decays more susceptible to new physics effects

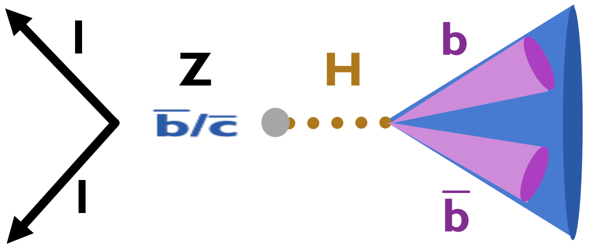
Resolved (low p_T^H)

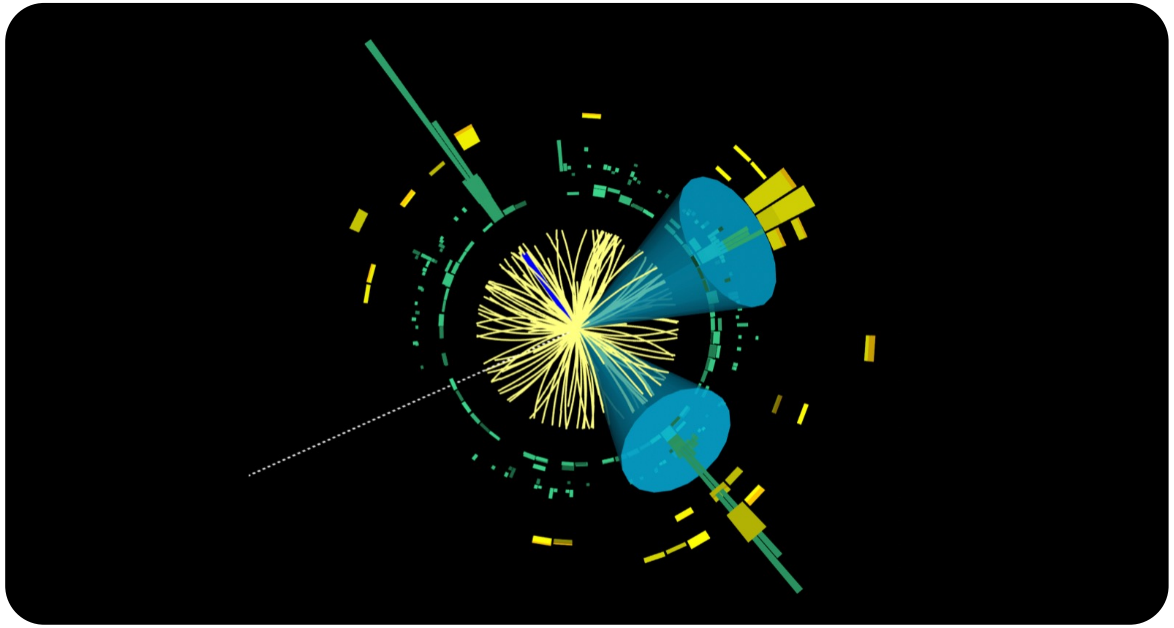
Higgs candidate reconstructed from two R=0.4 jets

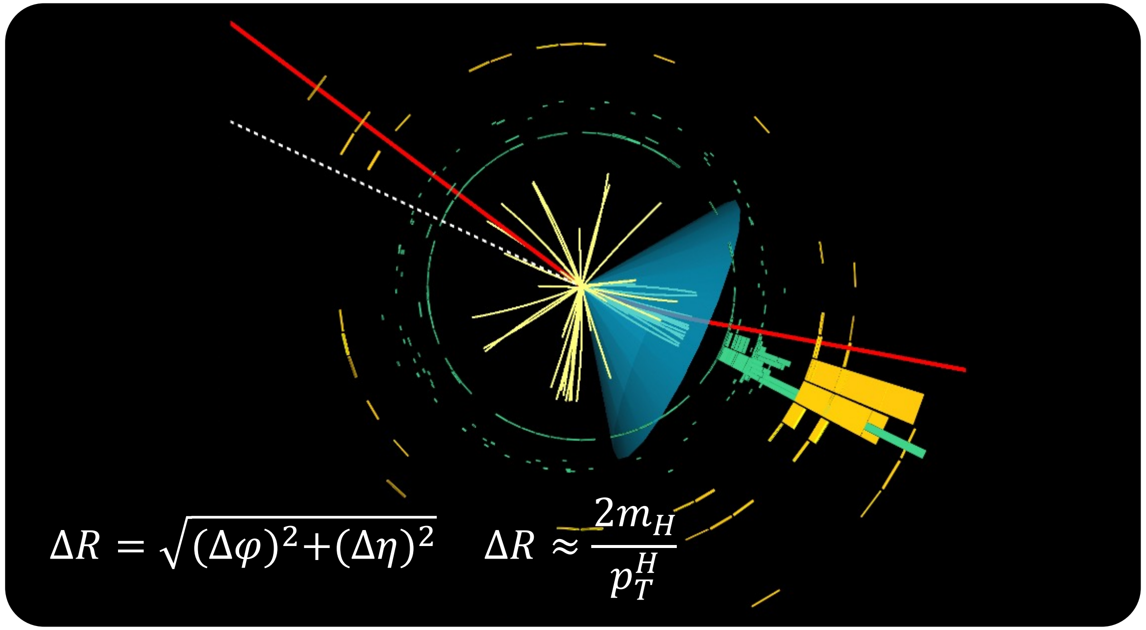


Boosted (high p_T^H)

Higgs candidate reconstructed one R=1.0 jets



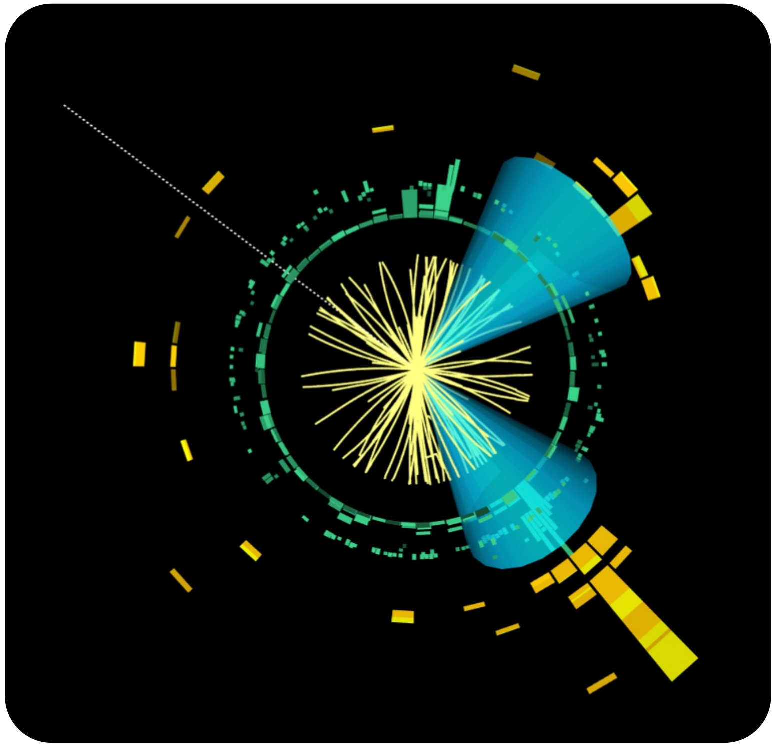


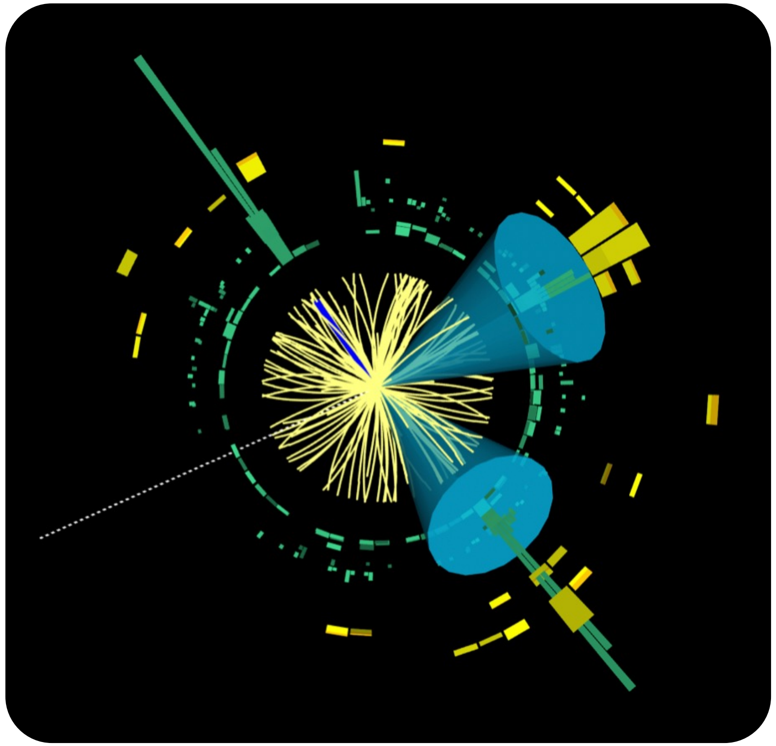


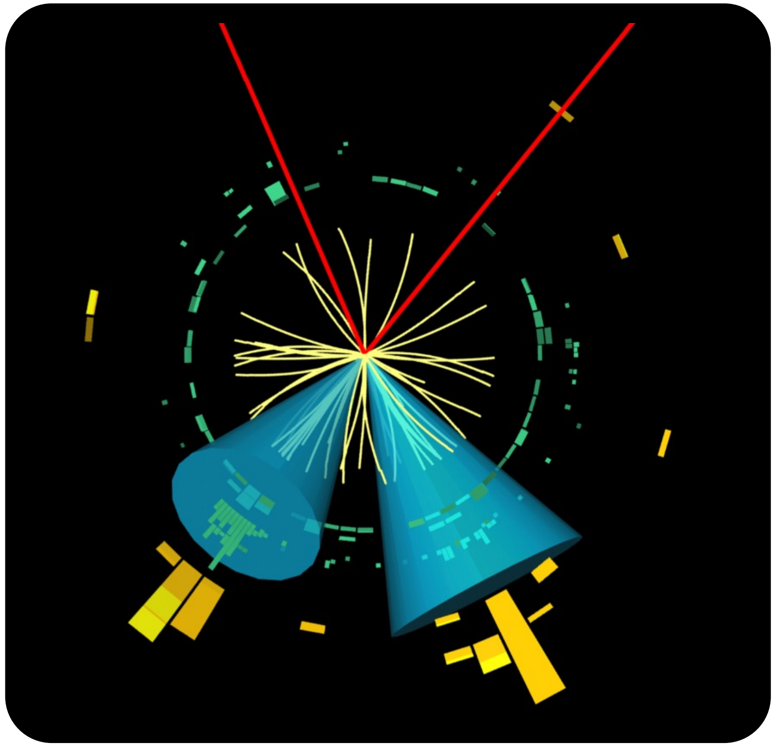
Lepton channels

Categorisation of events into channels by the decay of the vector boson into leptons (electrons or muons)

0 lepton *2 b/c-tagged jets + MET*	***1 lepton*** *2 b/c-tagged jets + lepton +MET*	***2 lepton*** *2 b/c-tagged jets + 2 leptons*







Signal regions

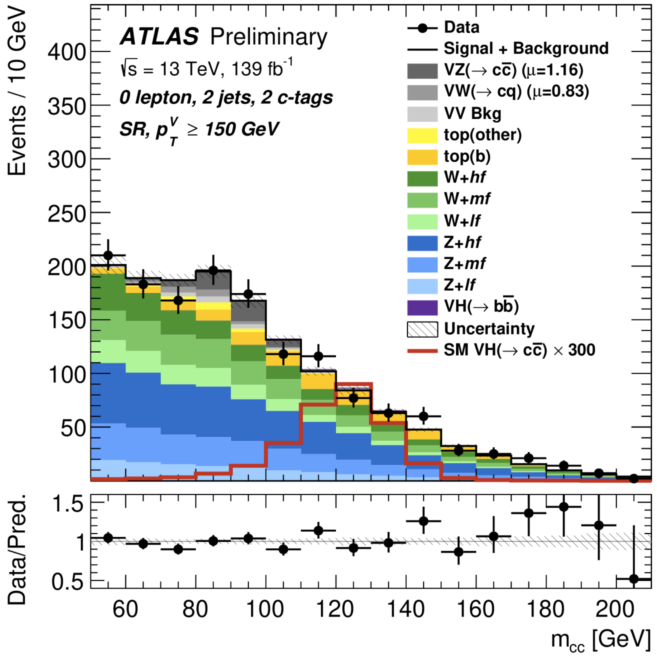
Signal: **VH(→bb/cc)**, **VZ(→cc)**, **VW(→cq)**

Major backgrounds: **W+jets**, **Z+jets**, **Top** → Constrained in dedicated control regions

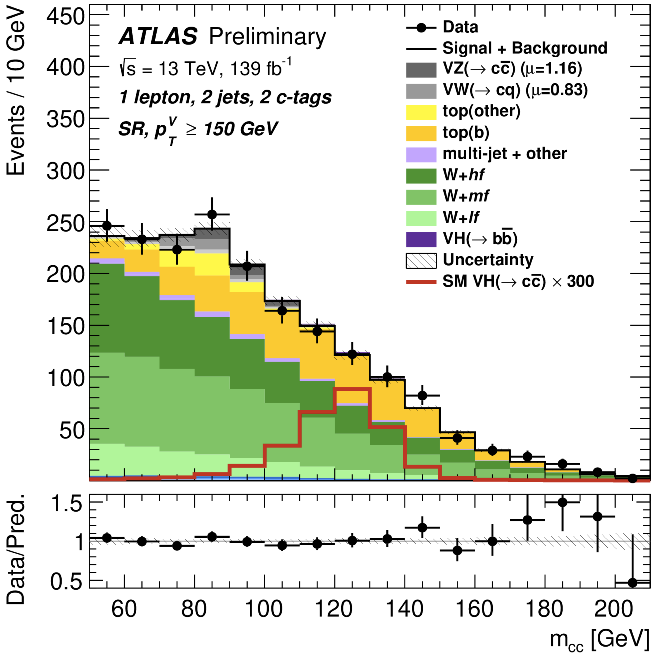
Subdominant backgrounds: **VV background**

2 c-tag

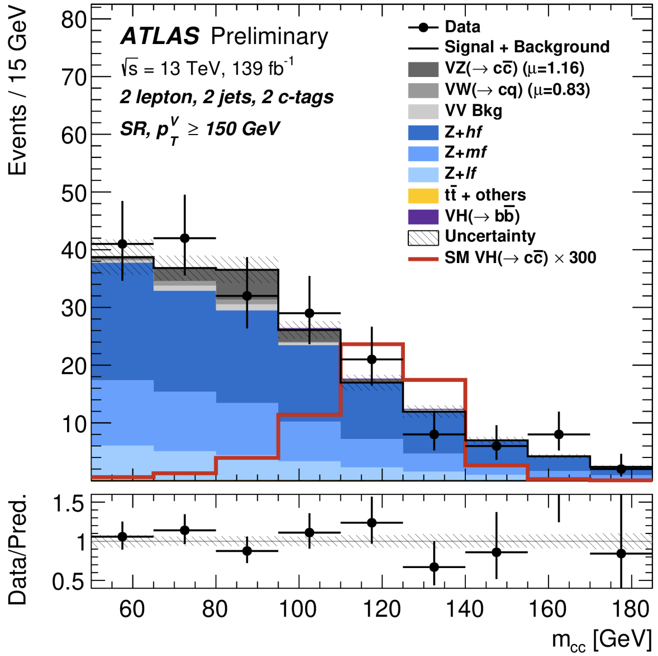
0 lepton



1 lepton



2 lepton

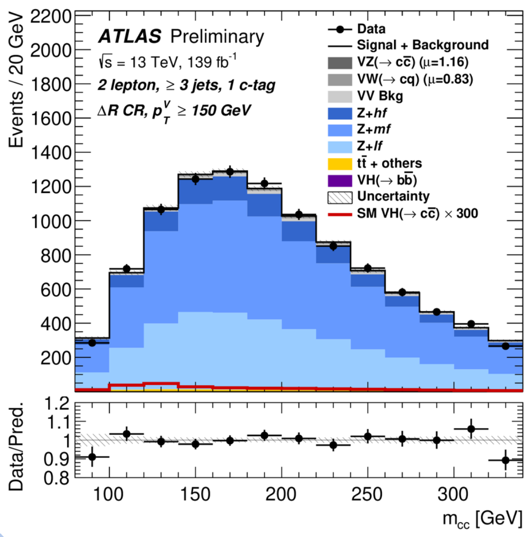


Control regions

- Excellent understanding of background necessary for an analysis with such small signal

→ **all major backgrounds measured in regions with dedicated event selections**

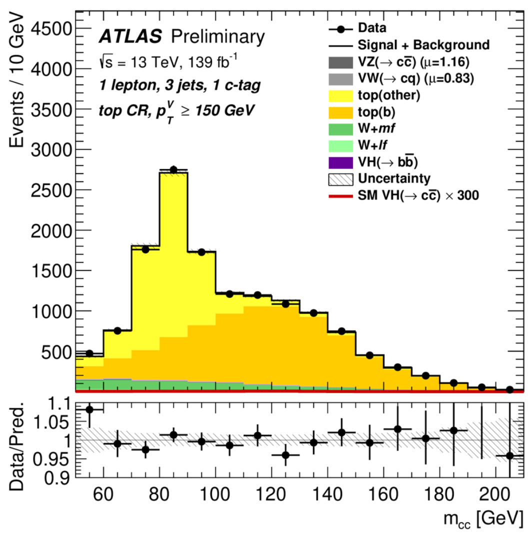
V+jets background



- One CR per SR
- Events with large separation between jets (high ΔR_{cc})

→ Constrain V + heavy flavour jets

Top background



- In 0/1 lepton
- Require ≥ 1 b-tag

→ Constrain ttbar and single top backgrounds

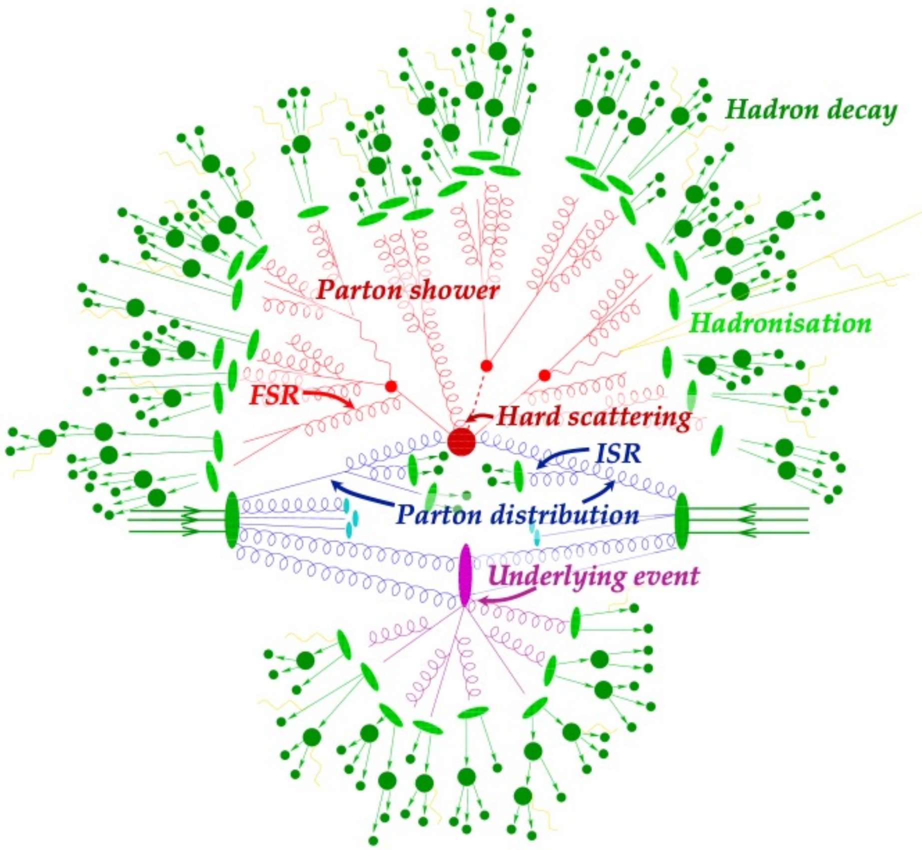
V+jets modelling in ATLAS

arXiv 2112.09588

- Current baseline generator for V+jets in ATLAS is Sherpa 2.2.11 (superseding Sherpa 2.2.1)
    - Several improvements: corrected heavy flavour production fractions, higher order QCD/EW corrections, computational improvements
- Alternative generator for modelling studies is **MadGraph5_aMC@NLO+Pythia8** w/ up to 3 additional partons at NLO, using **FxFx ME and PS merging** prescription

Table 1: Summary of the SHERPA 2.2.1 and 2.2.11 configurations.

Configuration	SHERPA 2.2.1	SHERPA 2.2.11
Generator version	SHERPA 2.2.1	SHERPA 2.2.11
PDF set	NNPDF3.0NNLO	NNPDF3.0NNLO
EW input scheme	Effective	$\sin^2\theta_{\text{eff}}$
QCD accuracy	0–2j@NLO+3,4j@LO	0–2j@NLO+3,4,5j@LO
NLO EW_{virt} corrections	No	Yes
Subtraction scheme	Default	Modified Catani–Seymour
Special treatment for unordered histories	No	Yes
Scale for $\mathbb{H}$-events	STRICT_METS	H'_{T}
Gluon colour/spin exact matching	Yes	No
Core process for K-factor	$2 \rightarrow 4$	$2 \rightarrow 2$
Phase-space strategy	Sliced in $\max(H_{\text{T}}, p_{\text{T}}^{V})$	Analytic enhancement

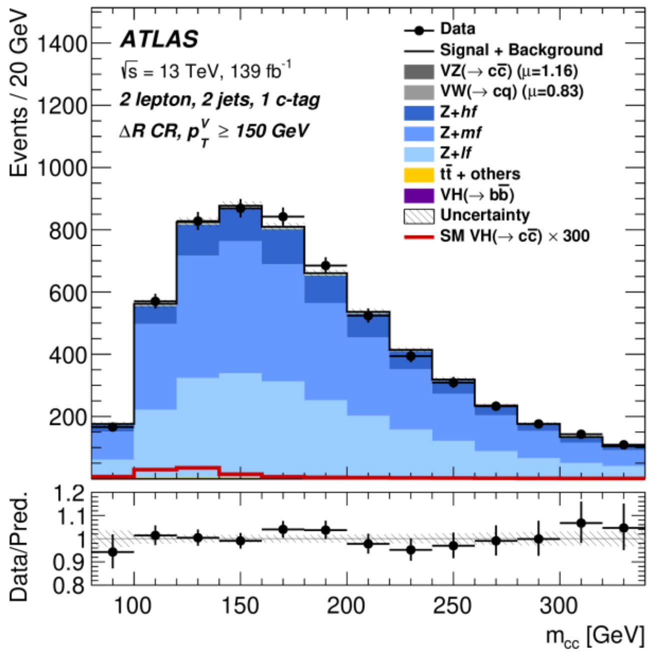


V+jets modelling approach

- Start from **nominal simulated samples**
  - Nominally simulated with **Sherpa 2.2.1 5F MEPS@NLO** (NLO-accurate ME for up to 2 jets, LO-accurate ME for up to four jets)
  - Samples produced in slices of max(H_T, p_T^V) to control phase space sampling
  - Filters are applied to select events with heavy flavour jets
  - More details on generator setup here
- Constrain **normalisations** (and m_{cc} shapes) of V+jets in dedicated control regions, e.g. through selecting events with high ΔR between jets
- Float normalisations based on di-jet flavour:
  - VH(bb): Float V+hf (bb,bc,bl,cc) separately and take remaining components as predicted by simulation + uncertainty
  - VH(cc): Float separately V+hf (bb,cc), V+mf (bc,bl,cl) and V+l

  → In both cases, with uncertainties applied on flavour composition
- Determine floating normalisations with as much granularity as data allows (in different bins of jet multiplicity, p_T of vector boson)

Example of V+jets control region in VH(cc)



V+jets modelling approach

- Derive uncertainties by considering different variations
  - **MadGraph+Pythia8 5F MEPS@LO** (up to 4 partons) → dominant uncertainty
  - Renormalisation/factorisation scale (μ_R, μ_F) variations
- Calculate shape and normalisation effects of each alternative generator
- Group normalisation effects together, to calculate:
  - **Overall normalisation** uncertainties on smaller V+jets components
  - **Extrapolation uncertainties** between different analysis regions and on the **flavour composition** of backgrounds
  - **Shape uncertainties:** Consider also variations on the shapes of kinematic distributions based on the alternative samples, and include shape uncertainties in the analysis

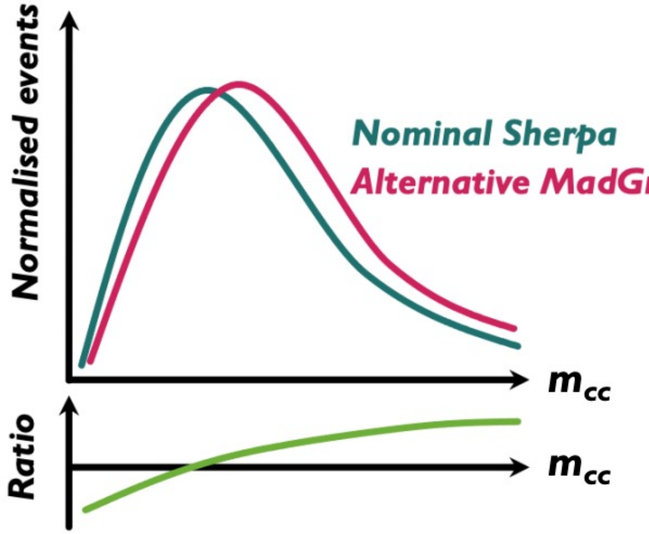
→ directly parametrise the ratio of nominal and alternative generators on m_{cc}

Extrapolation uncertainties calculated from yields n_1 and n_2 from regions 1 and 2 (e.g. SR and CR):

$$Acc.ratio = \sqrt{\sum_i \left(\frac{\left(\frac{n_1}{n_2}\right)_i}{\left(\frac{n_1}{n_2}\right)_{nominal}} - 1 \right)^2}$$

Different sources added in quadrature

Illustration of shape systematics for mass-based fit

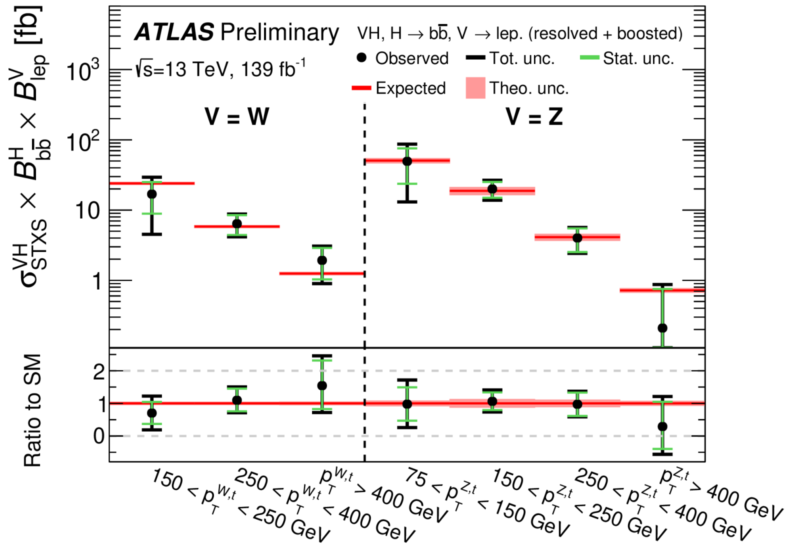


VH, H→bb,cc results

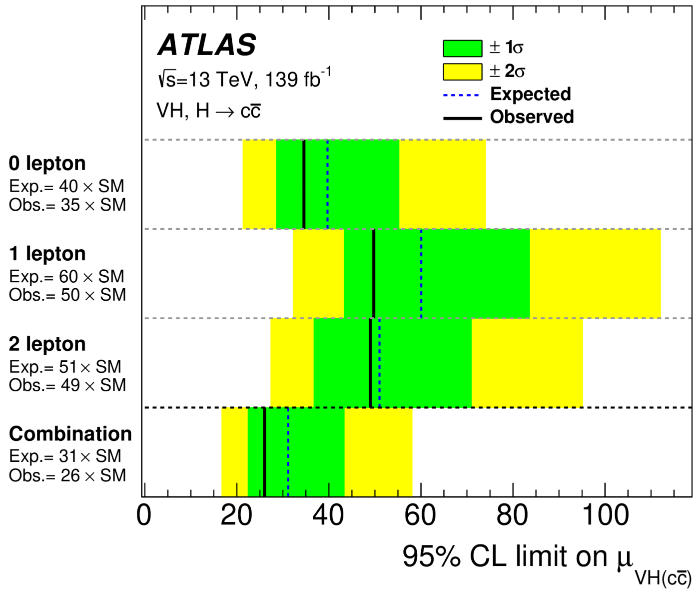
Legacy analysis is a combination of three separate analyses, which have been previously published:

- **Resolved VH(bb):**
  - MVA based analysis following H→bb observation strategy
  - Total significance of 6.7σ, WH/ZH measurement, STXS measurement and EFT interpretation
- **Boosted VH(bb):**
  - Cut-based analysis, first iteration of analysis using boosted reconstruction
  - Total observed significance of 2.1σ, STXS measurement and EFT interpretation
- **VH(cc):** (resolved regime)
  - Cut-based analysis, first iteration of this analysis using Full Run 2 dataset and all three lepton channels)
  - Upper Limit of 26 x SM, first direct constraint on $|\kappa_c|<8.5$

VH(bb) cross-sections



VH(cc) limits



VH(cc) breakdown of uncertainties

- Uncertainty on VH(cc) ~ 15.3
- **Stat** and **systematic** uncertainties of the same order
- Largest contributions to systematic uncertainties:
  - **Z+jets**
  - **Top**
  - **Flavour tagging**
- Knowledge of modelling of main analysis backgrounds is driving the size of the systematic uncertainties

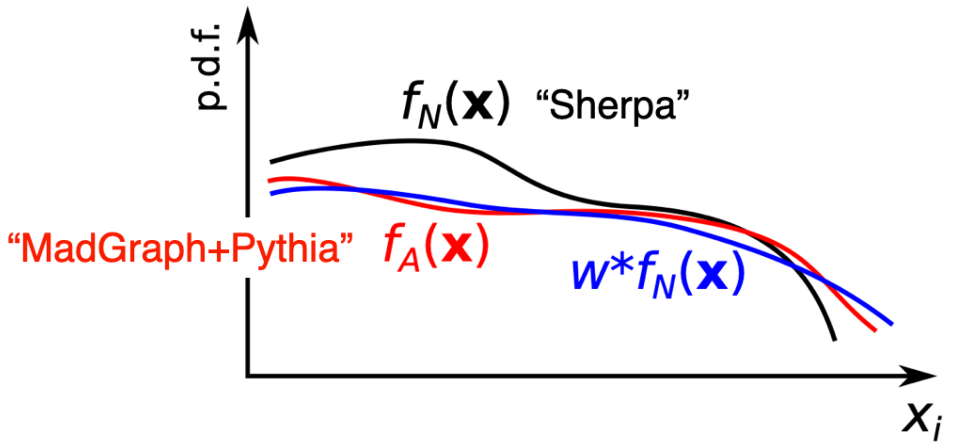
→ Significant improvements necessary on both V+jets and top quark modelling

Set of NPs	Impact
Total	**± 15.3**
Data Stat	**± 10.0**
Data stat only	± 7.9
Float. norm	± 5.1
Full Syst	**± 11.5**
VHcc modelling	± 2.1
Background modelling	± 8.8
W+jets	± 2.9
Z+jets	**± 7.0**
Top	**± 3.9**
Diboson	± 1.00
Multi-jet	± 0.98
Hbb	± 0.78

Experimental Syst (excl FTAG)	± 2.96
Lepton	± 0.49
MET	± 0.18
JET	± 2.84
Pile-up/Lumi	± 0.29
FTAG + TT	**± 4.29**
FTAG (b-jet)	± 1.11
FTAG (c-jet)	± 1.67
FTAG (l-jet)	± 0.35
FTAG (tau-jet)	± 0.33
TT ΔR	± 3.33
DT norm	± 1.74
MC Stat	± 4.23

VH, H→bb,cc analysis improvements

- Several areas of improvement possible for VH, H→bb,cc analyses on the Full Run 2 dataset:
- **Jet flavour tagging:**
  - Definition of a coherent jet flavour tagging strategy for b- and c-jets → Close collaboration with ATLAS jet flavour tagging group
  - Overall improvement in sensitivity of +40% for H→cc decays from flavour tagging improvements
- **Machine learning:**
  - Boosted decision trees used as fit discriminant in all analysis categories → +50% improvement in sensitivity to H→cc decays
- **Background modelling:**
  - ML based approach for estimating theoretical uncertainties (CARL) → reweighting to ensure sufficient statistics in alterative MC samples
  - One of the driving analyses in ATLAS for informing theory/MC generator decisions in ATLAS, close overlap with Standard Model measurements of W/Z boson processes



Ongoing VH, H→bb,cc efforts

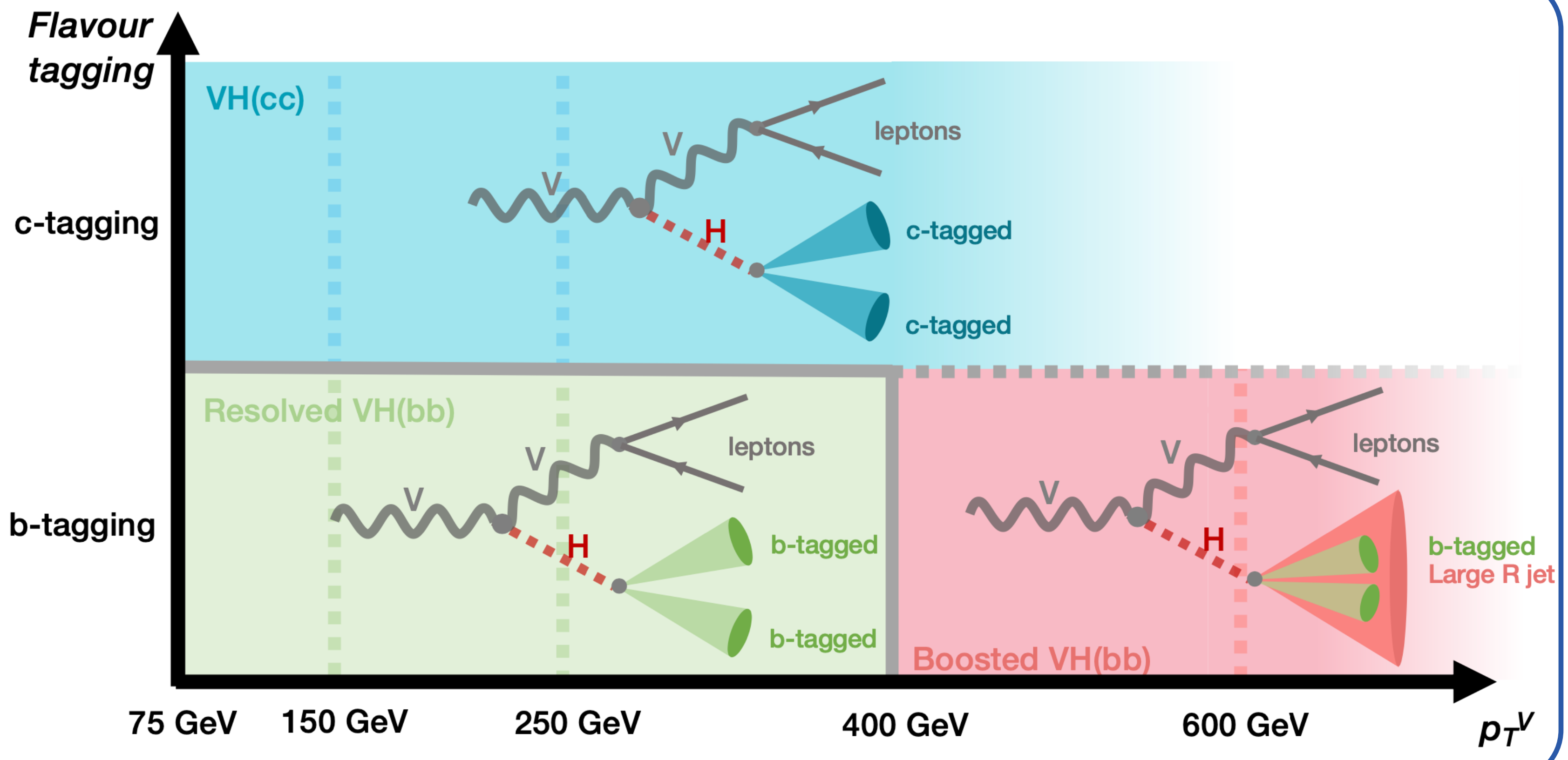
Efforts ongoing to publish a coherent analysis of the entire VH(bb/cc) phase space:

→ Define analysis strategy and treatment of backgrounds optimised for all analyses and improve on analysis results of standalone published analyses

- Separation of VH(bb) and VH(cc) events through flavour tagging
- Separation of boosted and resolved regime by p_T of W/Z

Deliverables:

- Inclusive $\mu_{VH(bb)}$ and $\mu_{VH(cc)}$ signal strengths measurements
- Combined κ_c/κ_b measurements
- STXS cross-section measurement in VH(bb)
- Upper limit on $\mu_{VH(cc)}$
- EFT interpretation

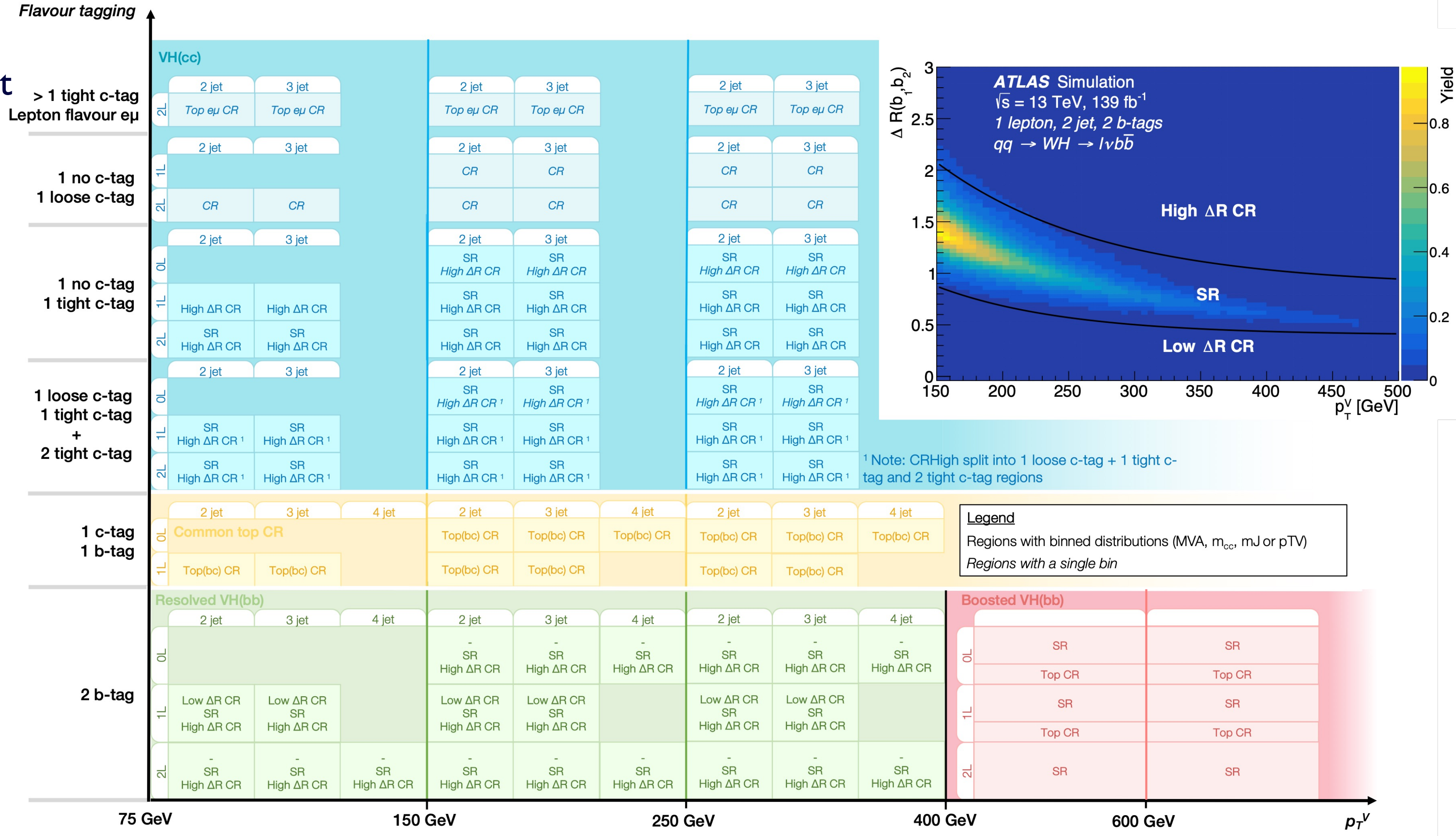


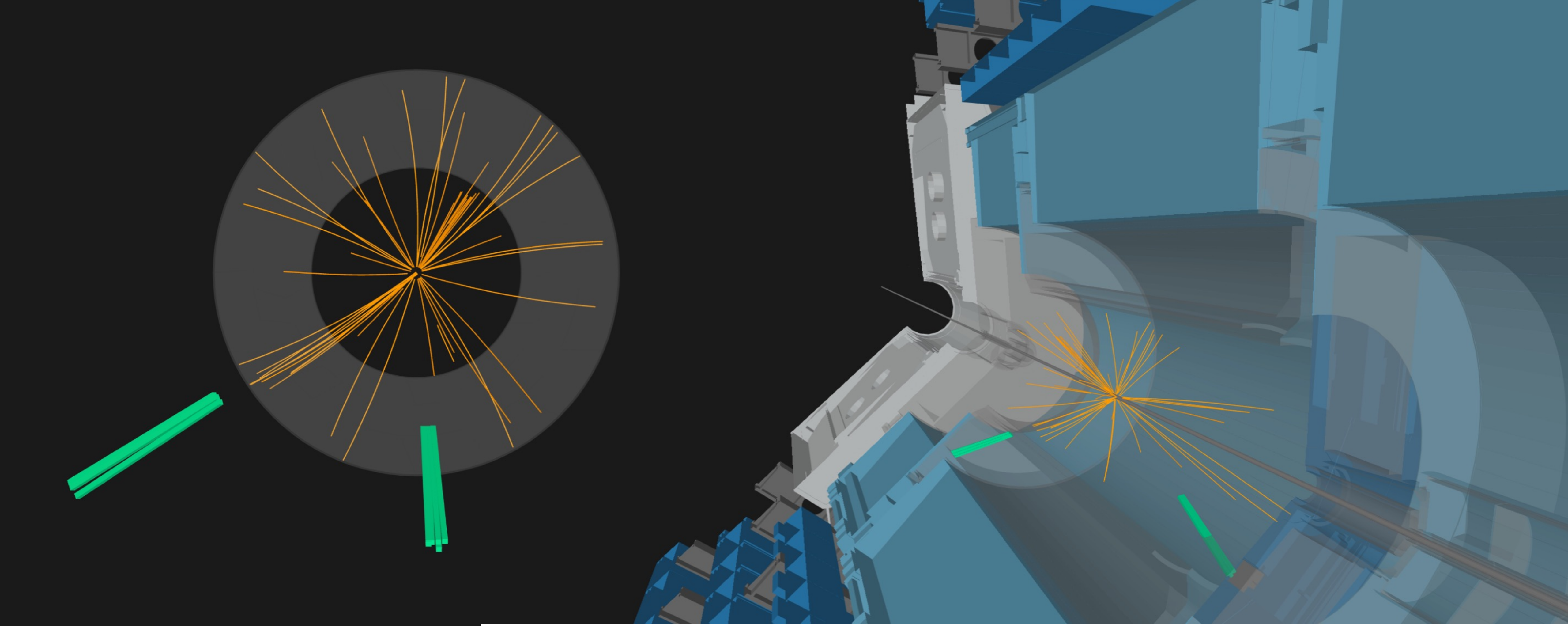
Ongoing VH, H→bb,cc efforts

Given our current MC samples, have to design fit model such that we rely on data-driven estimates of both V+jets and top background

→ **Stay tuned for new VH(bb/cc) results soon**

→ Need to improve generator setup for Run 3



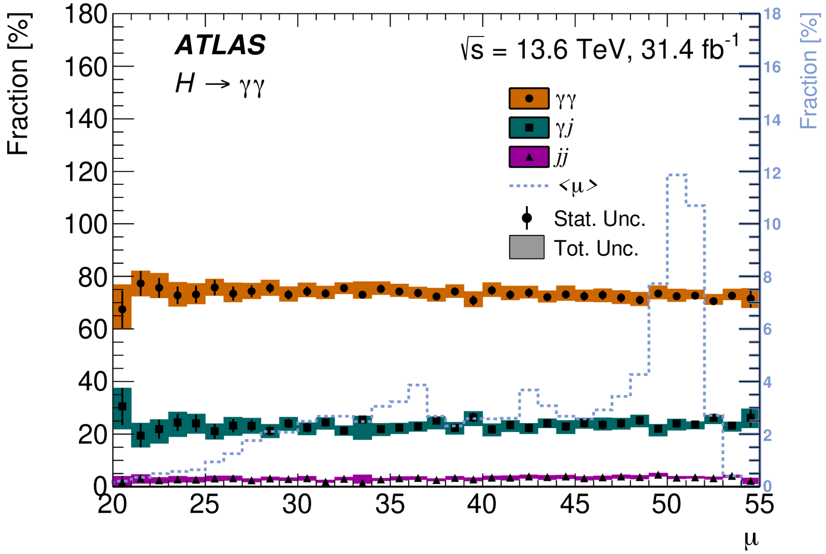


LHC Run 3

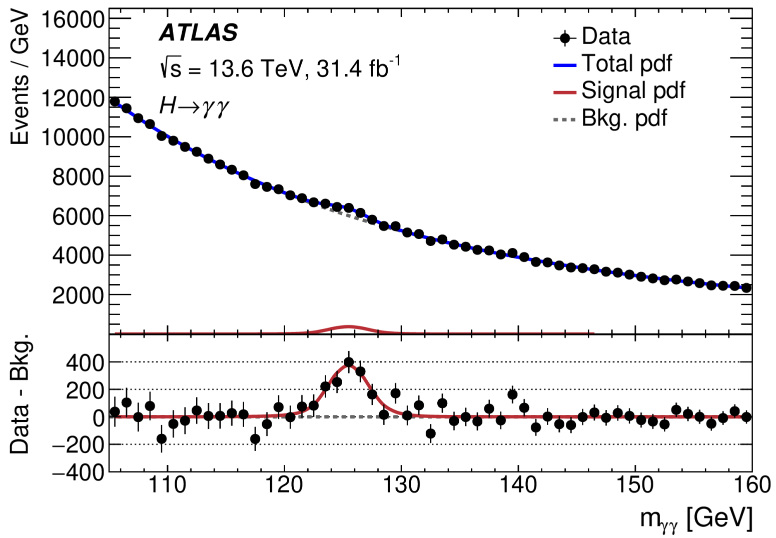
What’s next in Higgs physics?

Run 3 H($\gamma\gamma$/ZZ)

Photon performance in Run 3



H→$\gamma\gamma$ invariant mass spectrum

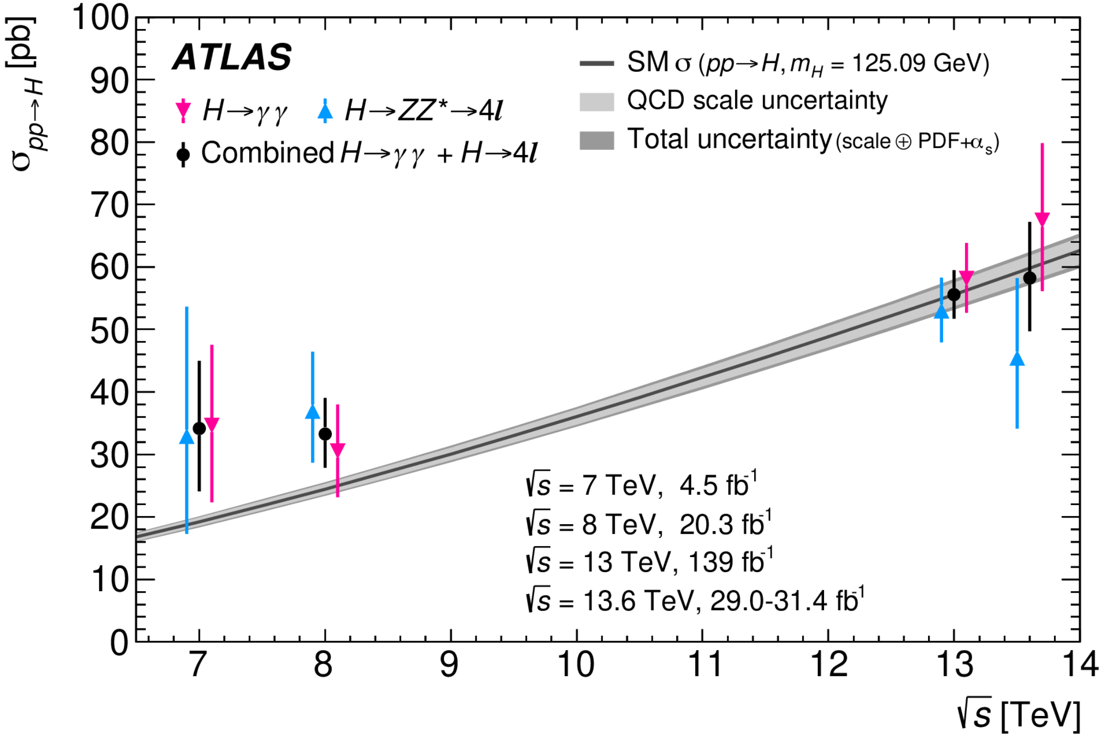


- ATLAS Run 3 datataking is progressing well
- Initial Run 3 analyses have been published
  - W/Z cross-sections, ttbar cross-sections, pp→ZZ
- First Run 3 Higgs results early last year, **using the discovery channels H→$\gamma\gamma$ and H→ZZ**
  - Following Run 2 analysis strategies largely serving as a cross-check of CP calibrations and detector performance
  - Uncertainties largely driven by larger CP uncertainties on physics object due to CP pre-recommendations

Run 3 H($\gamma\gamma$/ZZ)

- Early Run 3 combination of H(ZZ) and H($\gamma\gamma$) also used to measure total pp→H cross-section measurements at 13.6 TeV for the first time: **σ(pp→H) = 59.9±2.6 pb**
- Good agreement with state-of-the art theory calculations, determined at NNLO or better
- Now moving to a more broad Run 3 Higgs physics program, repeating some of the known benchmark channels at the higher center-of-mass energy

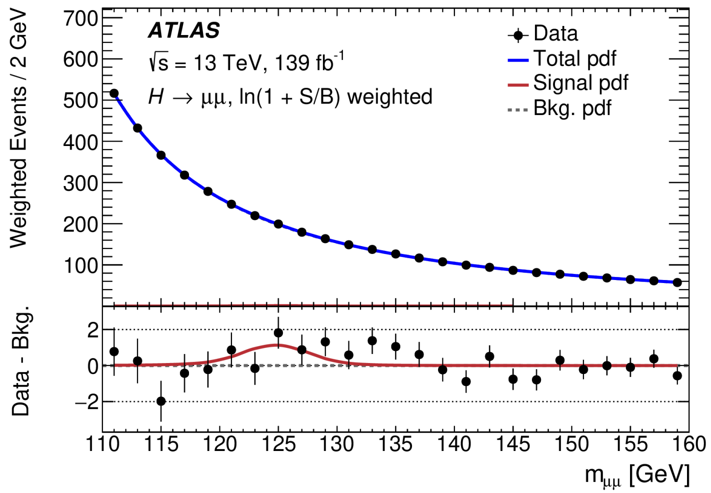
H→$\gamma\gamma$ and H→ZZ cross-sections



Expected Run 3 highlights

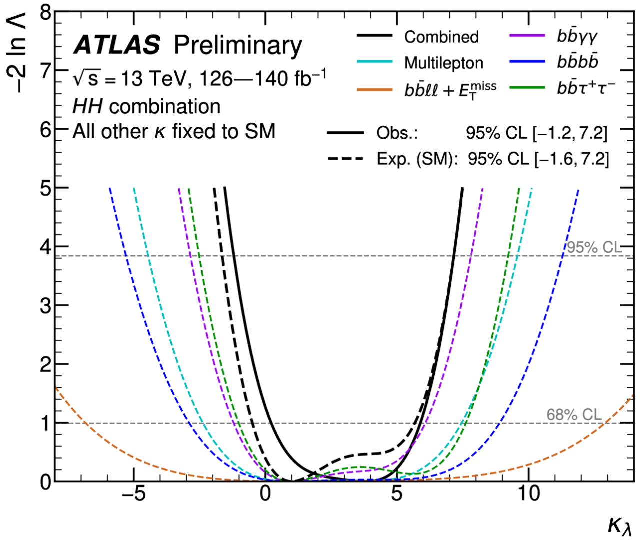
Highlights of Run 3 Higgs physics are expected to include:

- **H→μμ:**
  - Initial Run 3 analysis planned to cross-check muon performance with New Small Wheel
  - Observation at 5σ likely with Full Run 3 dataset and combination with CMS
- **Higgs self-coupling:**
  - Di-Higgs physics program has ramped up significantly during Run 2
  - Unlikely to reach SM precision with Run 3 dataset, but exciting opportunity to test new analysis techniques



Run 2 H→ μμ invariant mass spectrum

Latest Run 2 constraints on Higgs self-coupling

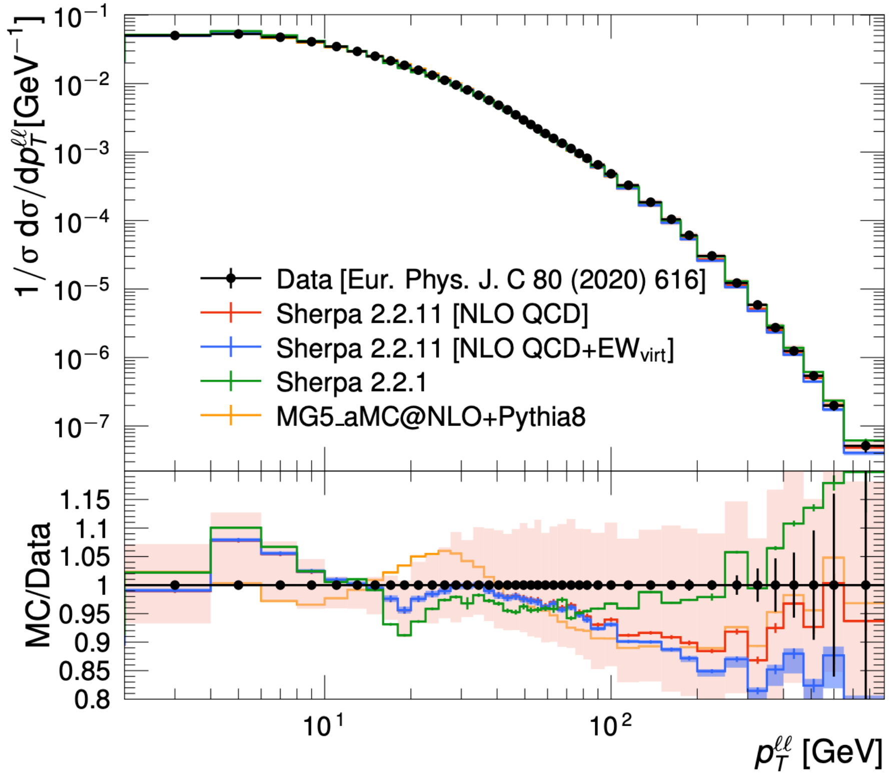


MC predictions for Run 3

- Generally, MC computation is very complicated, and there are several known modelling issues in V+jets
- Would like to provide a better set of MC samples for Run 3, as well as a more coherent definition of systematic uncertainties
- E.g. **known mismodelling of p_T^V spectrum in Sherpa**
  - For Sherpa 2.2.1, see runaway behaviour at high pTV
  - For Sherpa 2.2.11 prediction undershoots data significantly
- Likely **due to updated scale choice in Sherpa 2.2.11**
- Would like to fix this for the Run 3 MC productions, as well as provide a set of theory untertainties that sepearately varies different parts of the theory prediction (ME, PS, PDF etc)

→ almost there with Sherpa, but need to define a dedicated parton shower uncertainty

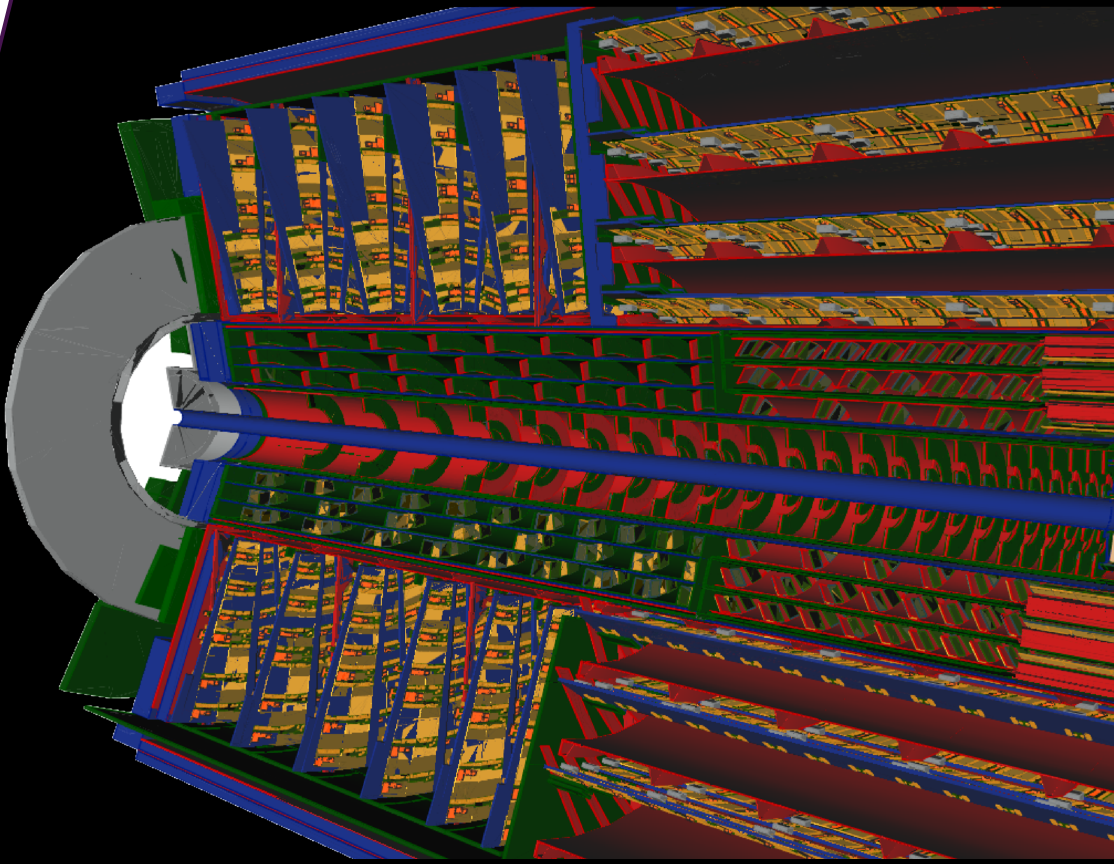
Transverse momentum of vector boson in different MC generators

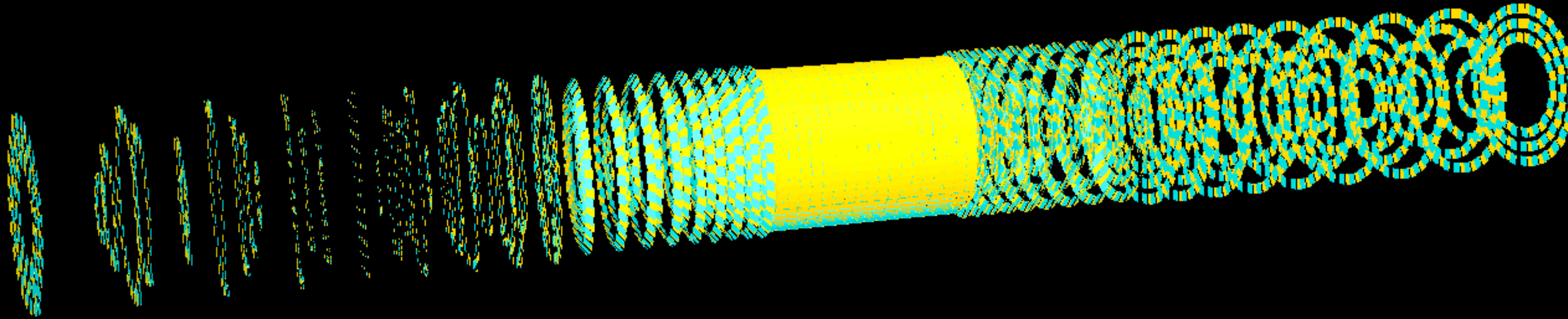


HL-LHC

What do we do with all this data?

And how do we make sure we have a working detector?





HL-LHC extrapolation

ATL-PHYS-PUB-2021-039

- **Planned upgrade to the LHC to High-Luminosity LHC (HL-LHC) to start collecting data in 2028**

→ HL-LHC increased luminosity and pile-up

- Collect 3000 fb^{-1} of data at a center-of-mass energy of 14 TeV over 10 years
- With larger dataset and reduced systematics (factor 2):

  → **Expected upper limit on VH(cc) of 6.4 x SM**

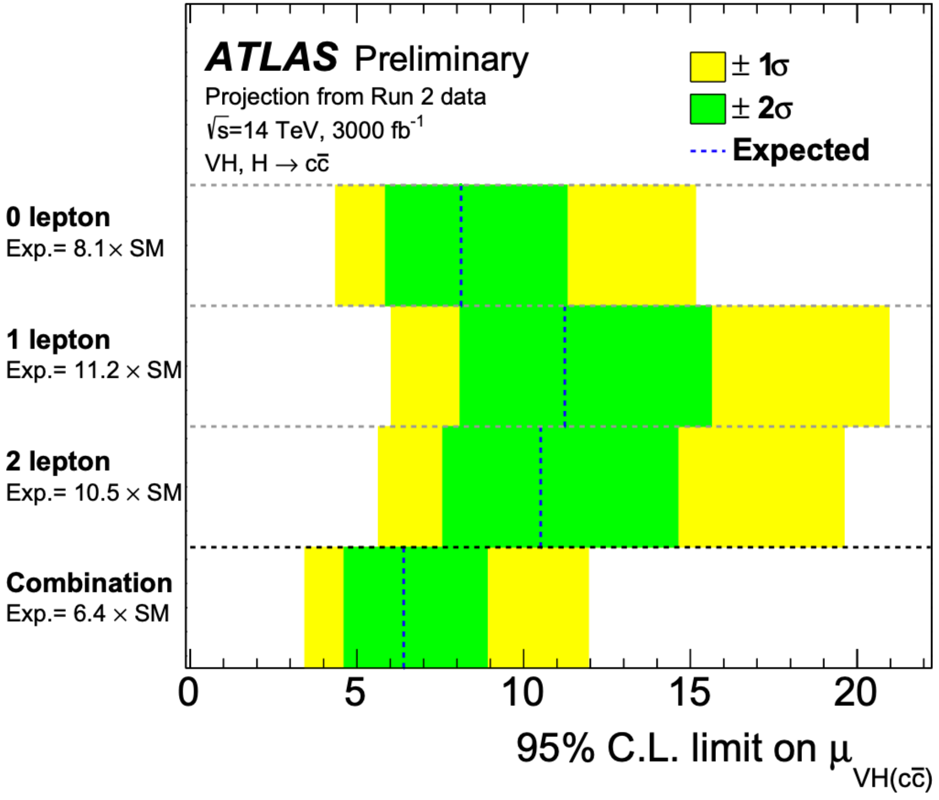
  → Expected constraint on κ_c of $|\kappa_c| < 3.0$

- Combination of VH(→bb) and VH(→cc) analyses allows to constrain more model-independent ratio κ_c/κ_b:

→Expected constraint of $|\kappa_c/\kappa_b| < 2.74$ at 95% CL at HL-LHC

- Extrapolation results based on Full Run 2 analysis → would like to see updated numbers for ECFA within the next year

Expected limits for VH(cc)



HL-LHC

- Will upgrade LHC accelerator to collect a 10 x larger dataset
- Around factor 4 increased number of interactions per collision of proton bunches

→ **High-Luminosity LHC (HL-LHC)**

Places stringent requirements on inner (pixel) detector:

Radiation:

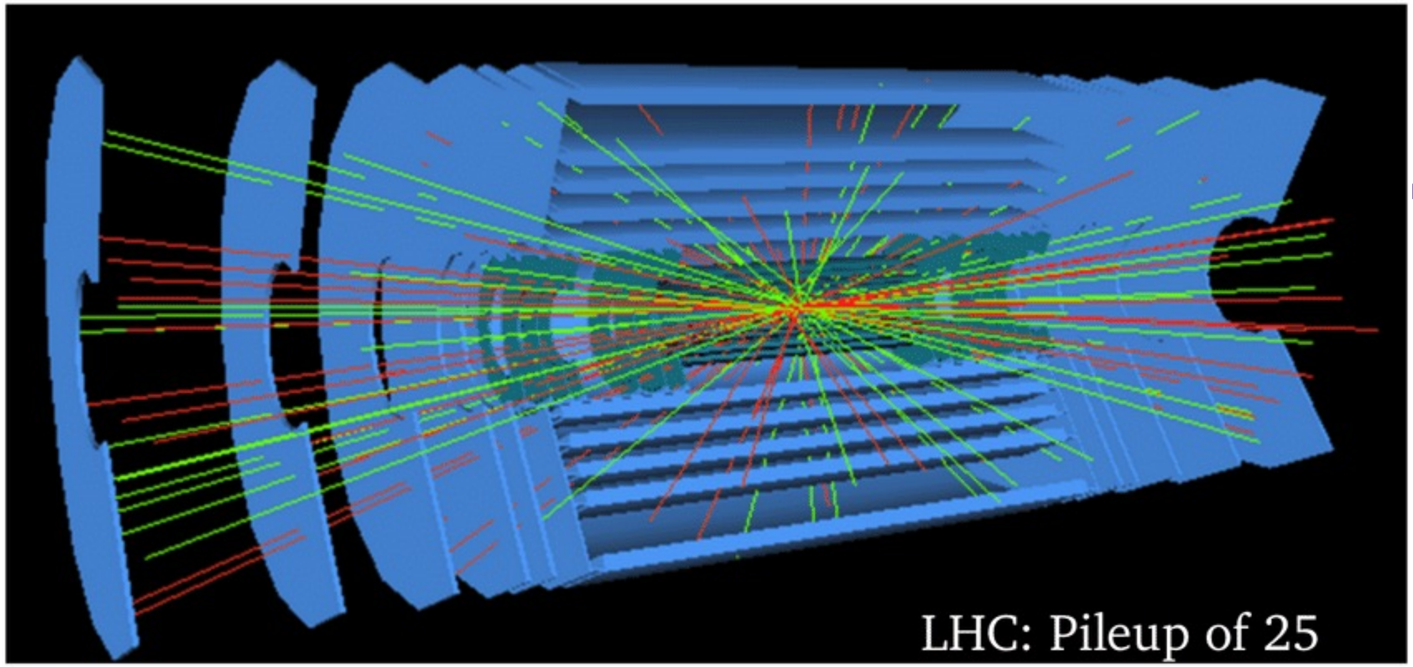
- Expect 4000 fb^{-1}, while current technology and only withstand 400 fb^{-1}

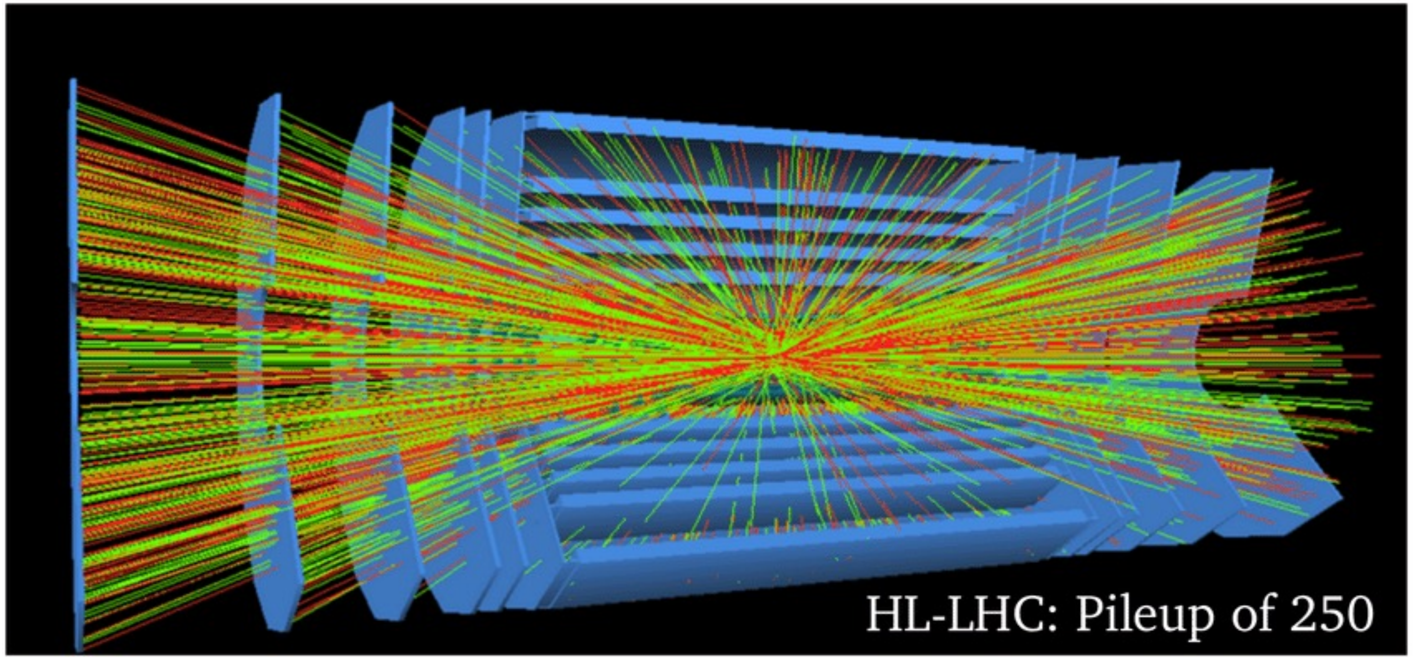
→ Require new sensor and chip technology, radiation tolerant to 1 Grad or 1e16 n_{eq}/cm^2

Granularity:

- Expect up to 200 average collisions per bunch crossing & need to keep occupancy below 1 %

→ Silicon detector with smaller pixels needed





HL-LHC

Performance:

- Improve performance at high p_T
- Reduce/don't increase detector material to reduce multiple scattering
- Increases detector acceptance to $|\eta|=4$

→ New detector layout cover larger area

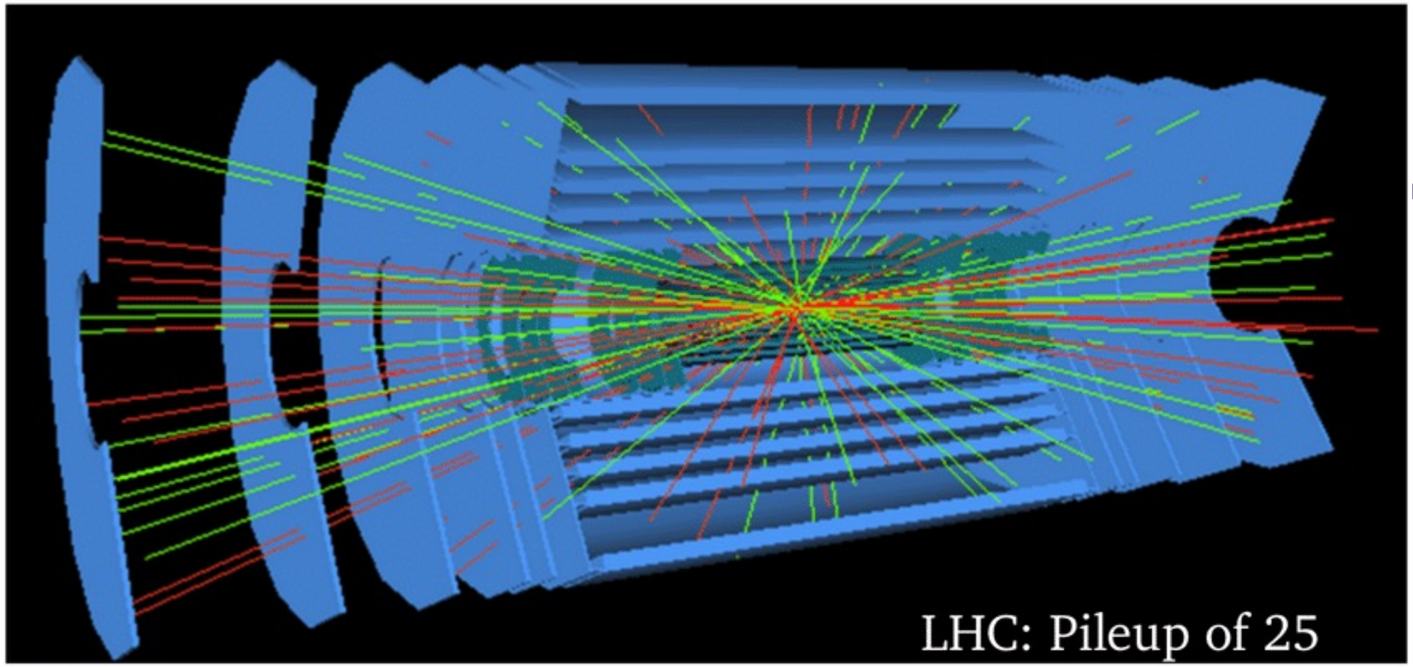
Trigger

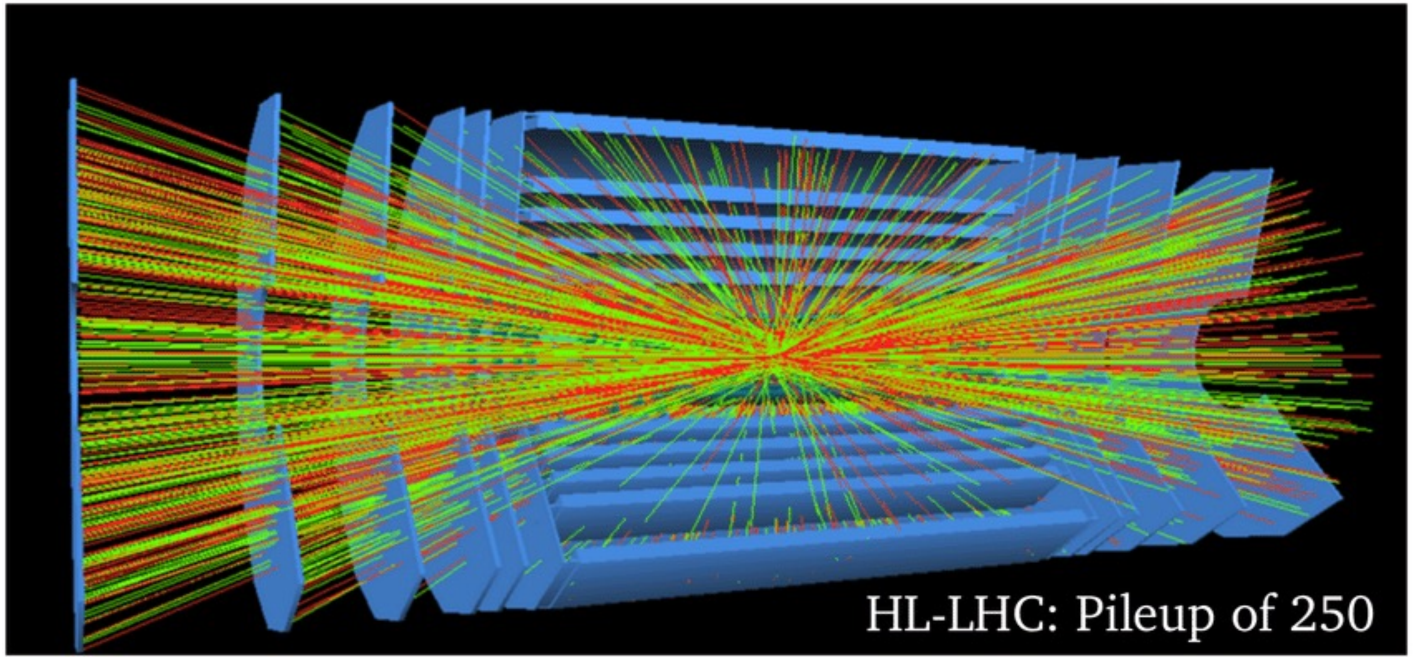
- Increase trigger rate (x10)
- Increase trigger latency (x2)

→ Need high-speed readout electronics, with large buffer memory

→ **Need to utilise new technologies for all detector components (i.e. chip & sensors)**

→ **Build a much larger detector to meet the needs of HL-LHC**





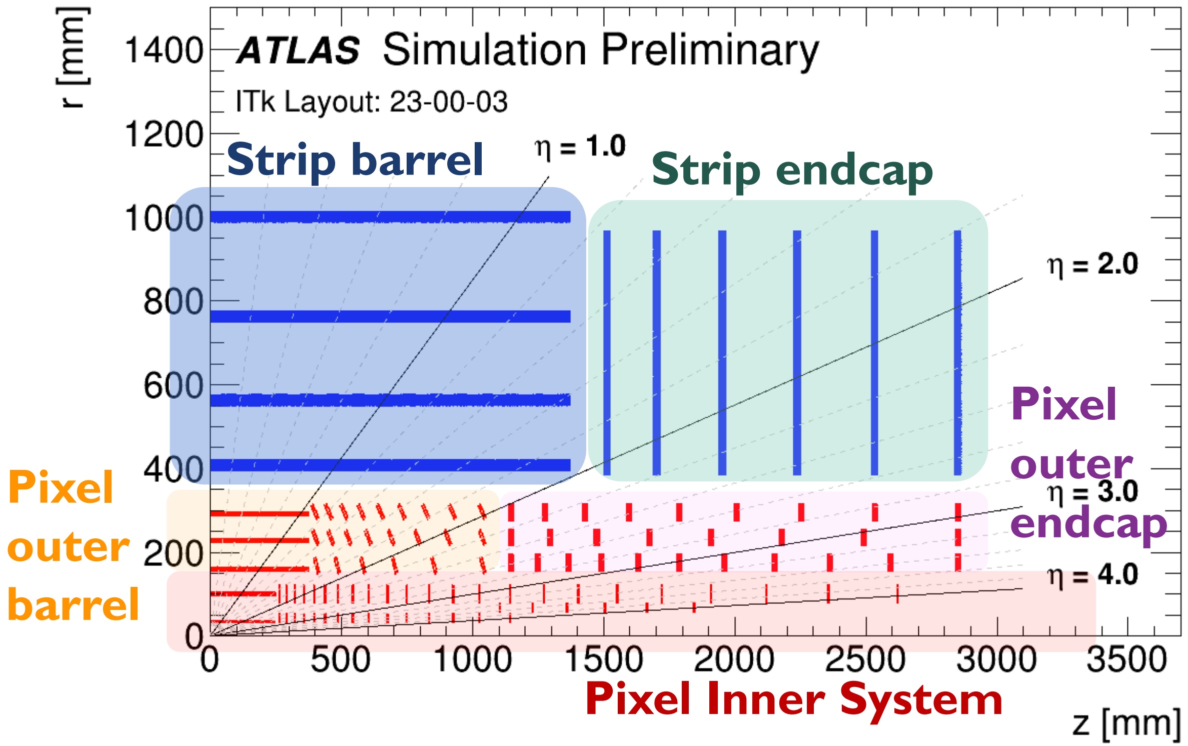
ATLAS ITk Upgrade

- **Upgraded ATLAS Inner Tracker (ITk)**

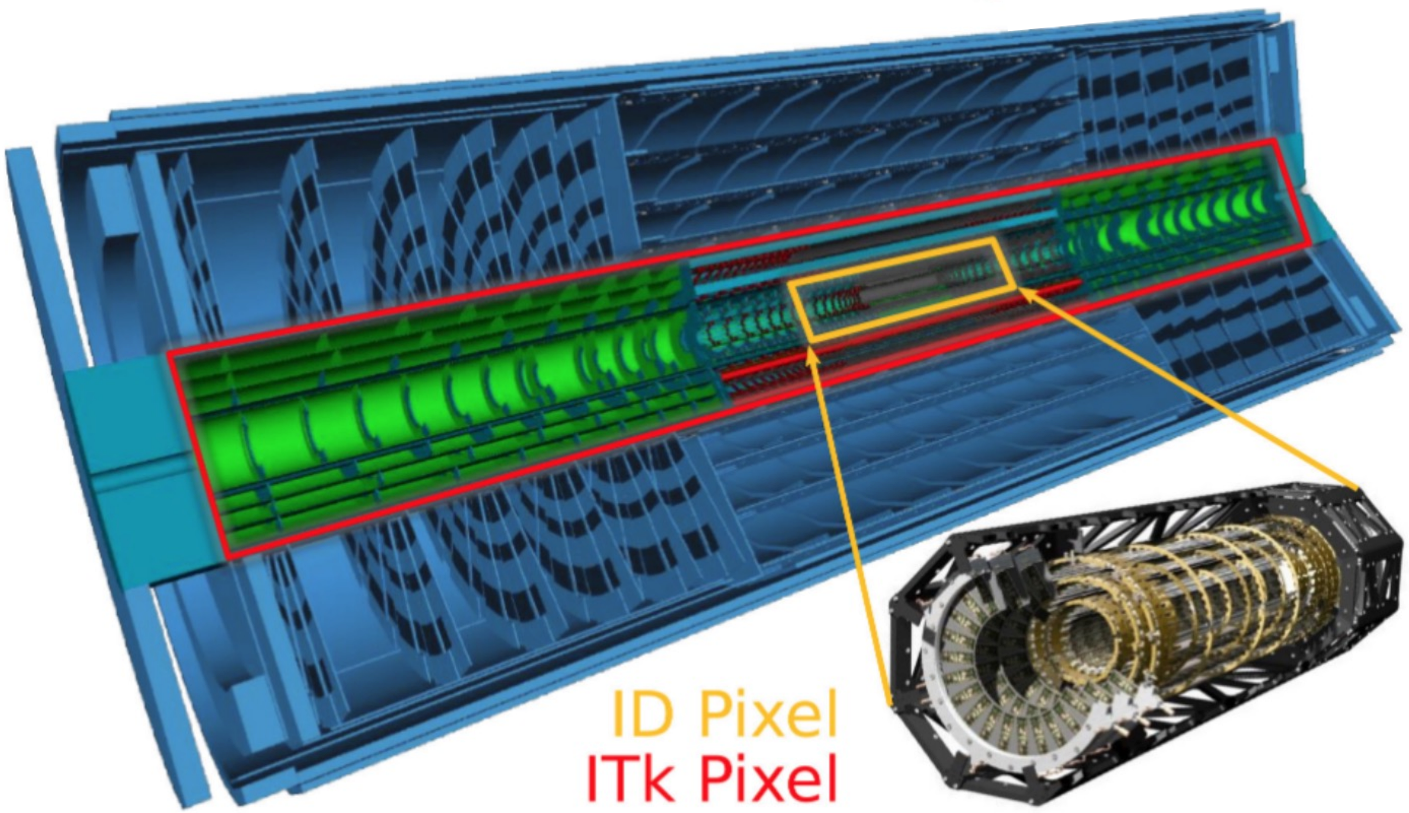
→ Improved resolution and radiation hardness needed & new detector layout

- All silicon tracker:
- ITk Strips system with 4 barrel layers and 6 endcap discs
- ITk Pixel Detector layout consists of 5 barrel layers & endcap rings
- Innermost layer located at r = 33 mm

Planned ITk layout



ITk Pixel Upgrade



All-silicon upgraded tracking detector (ITk) for HL-LHC to cope with increased instantaneous luminosity and pile-up

Upgraded pixel detector:

- Larger silicon area → **6x larger than current tracking detector**
  - ~13 m^2 of active area
  - 9200 pixel modules, 5.1 billion pixels
  - Extended η coverage to $|\eta| \leq 4$
- **Smaller pixel pitch:**

  400 x 50 μm^2 → 50 x 50 μm^2
- **New readout chip** to cope with higher data rates and increased radiation

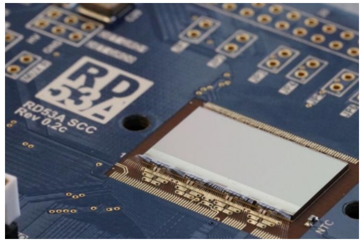
RD53 chip evolution

RD53 collaboration formed

ITK TDR

RD53A submission

RD53A



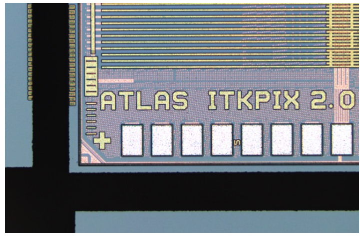
Half size demonstrator

CROC v1 submission

ITkPixV2 submission

CROC v2 submission

ITkPixV2



Production ASIC

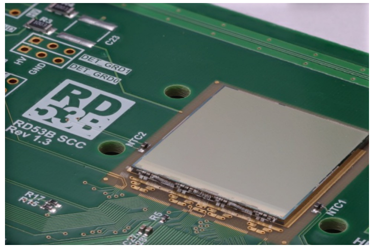
2013 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024

Proto IP | **RD53A** | **RD53B** | **RD53C**

ITkPixV1.0 submission

ITkPixV1.1 submission

ITkPixV1



Pre-production ASIC

- ASICs for ATLAS and CMS pixel detector upgrade have been jointly developed by the RD53 collaboration
- 10 years of ASIC design, development and testing have now concluded
- ITkPixV2 ASIC now fully qualified and in production

ITk Pixel TID damage

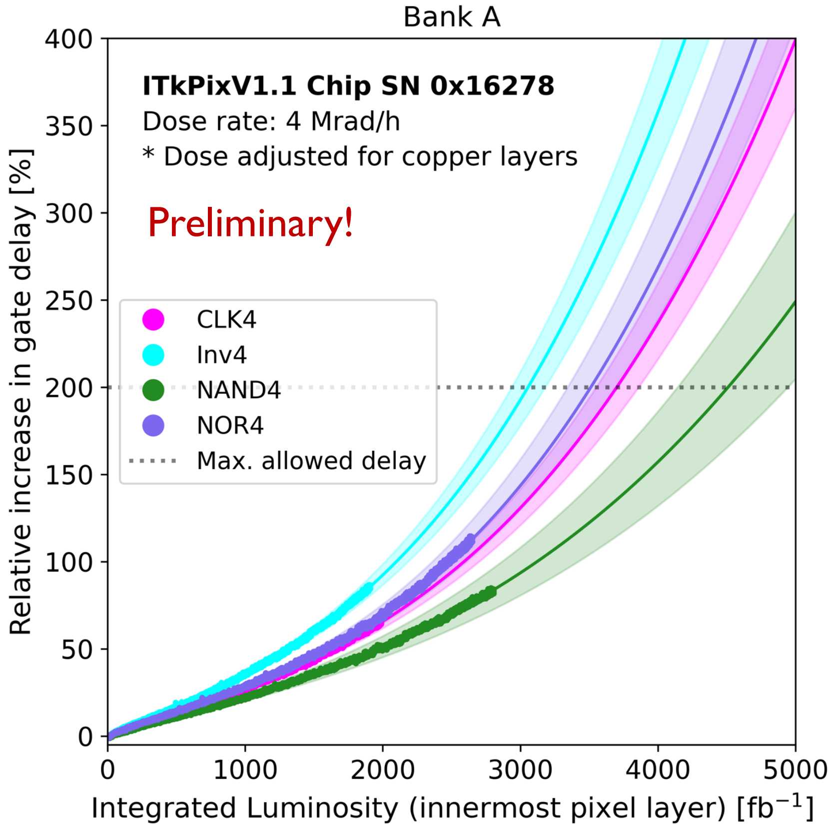
- ITk Pixel ASIC required to withstand 1 Grad of total ionising dose (TID)
- TID damage to the readout electronics depends on both operational settings and dose rate of the delivered radiation

→ difficult to predict, requires dedicated research program to estimate failure point

- Dedicated irradiation program of ITk Pixel ASIC performed using X-rays and radioactive sources

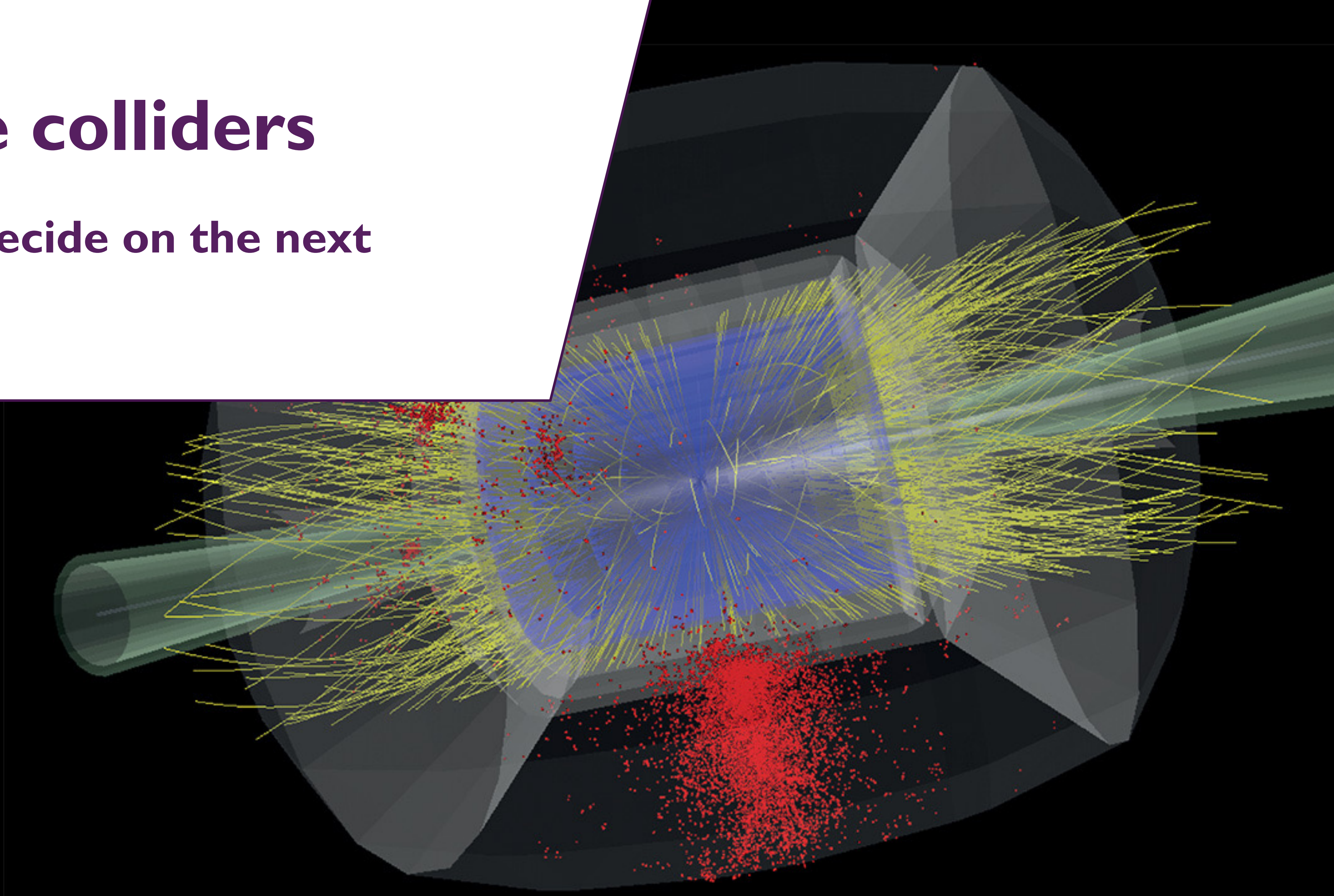
→ **Expected failure point of ITk Pixel ASIC digital logic around 3000 /fb**

	Expected failure point	
Gate	**TID [Grad]**	**Int. Lumi [/fb]**
CLK 4	1.7	3700 ± 160
Inv 4	1.4	3040 ± 120
NAND 4	2.1	4500 ± 370
NOR 4	1.6	3480 ± 180



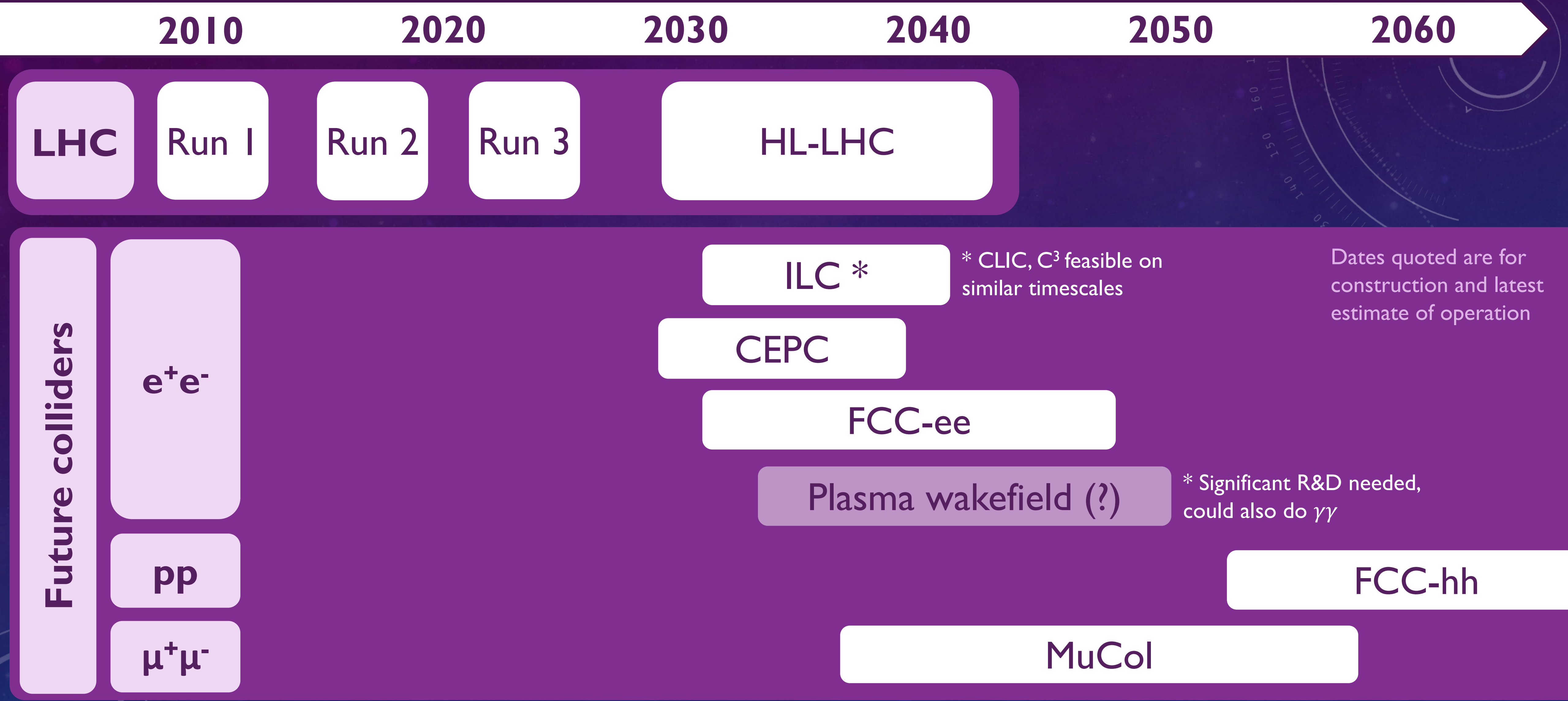
Future colliders

How we decide on the next machine?



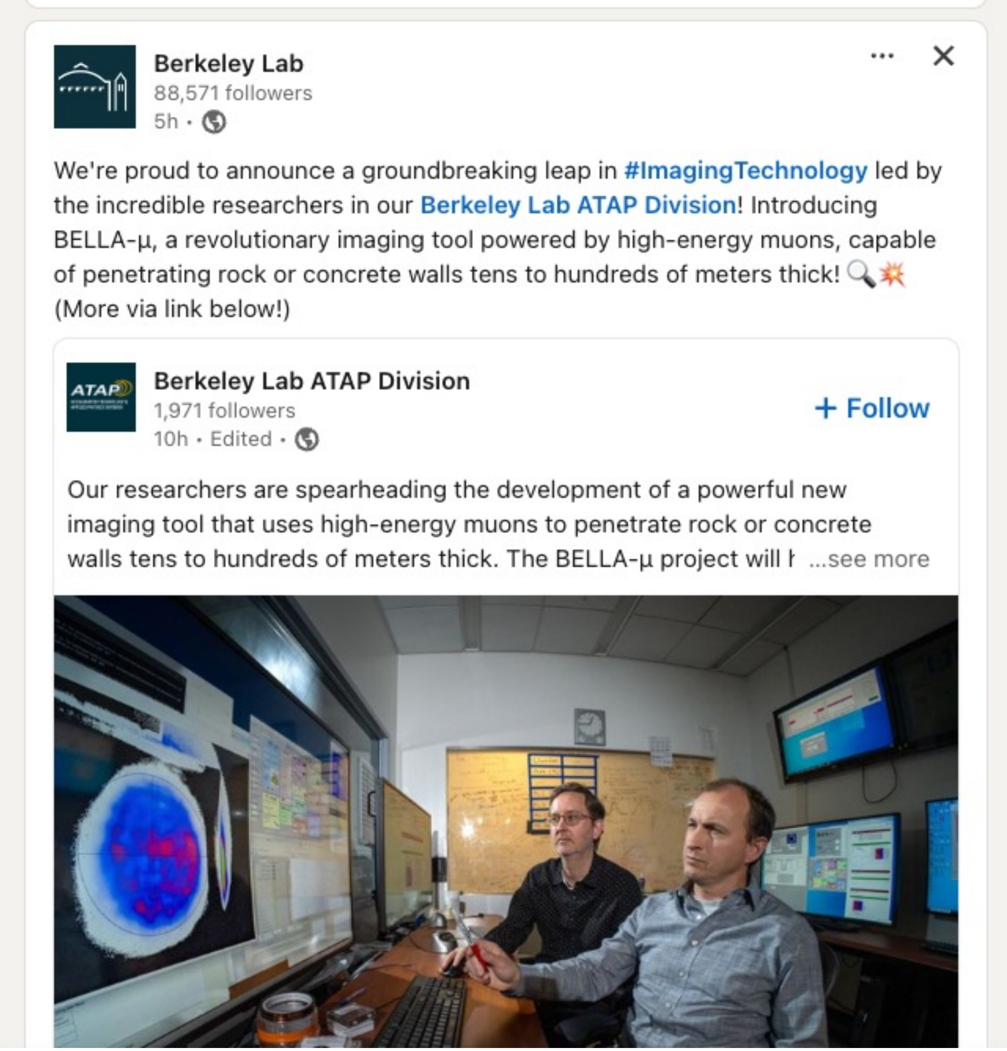
Maria Mironova

Timeline


2010
2020
2030
2040
2050
2060
LHC
Run 1
Run 2
Run 3
HL-LHC
Future colliders
e⁺e⁻
pp
μ⁺μ⁻
ILC *
* CLIC, C³ feasible on similar timescales
Dates quoted are for construction and latest estimate of operation
CEPC
FCC-ee
Plasma wakefield (?)
* Significant R&D needed, could also do γγ
FCC-hh
MuCol

Plasma wakefield acceleration (BELLA-μ)

- Plasma wakefield accelerators provide an exciting opportunity for an alternative to conventional accelerators
- However, significant R&D needed before a possible future accelerator can be defined
- Accelerator R&D currently also ongoing at LBL
- **BELLA-μ project** ongoing as part of that development:
  - DARPA[1]-funded project on muon tomography currently ongoing
  - Use plasma wakefield accelerator to produce beam of electrons, which can be converted into muon
  - Using ITkPix modules & scintillators as muon detectors



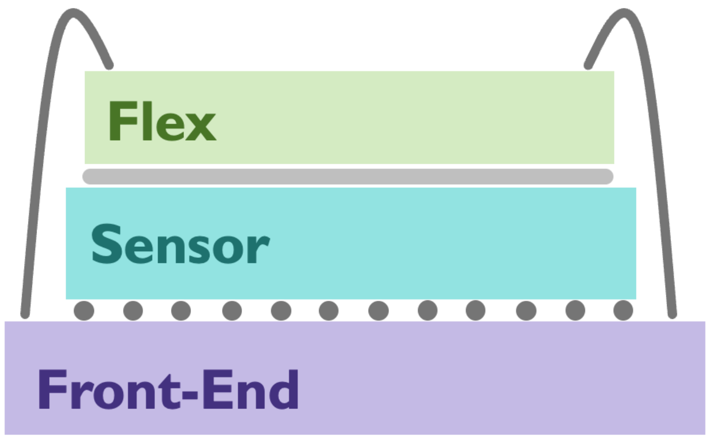
[1] *Defense Advanced Research Projects Agency*

Future Detector R&D

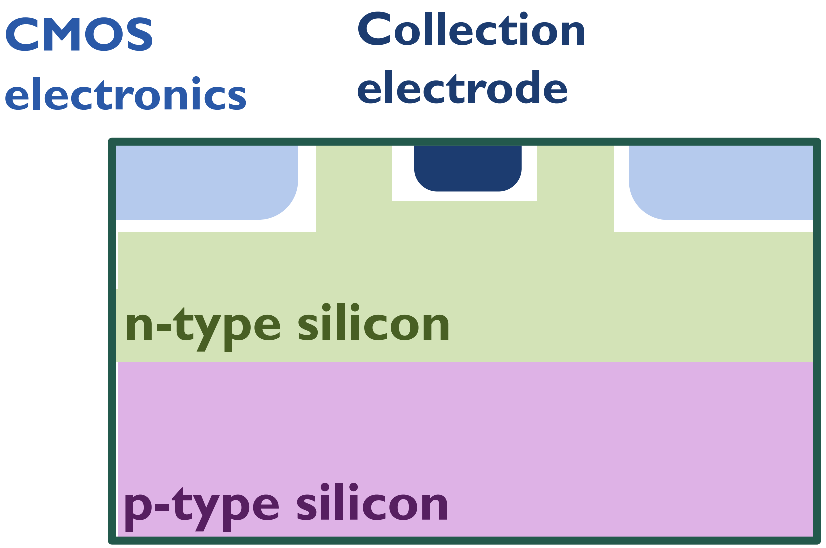
- Future collider discussion also opens opportunities for detector R&D
- Future e^+e^- machine will require tracking detector with:
  - High position resolution and low material
  - Relaxed requirements on radiation hardness and data rate compared to HL-LHC
- Obvious application of monolithic active pixel sensors (MAPS), with active area and readout in the same piece of silicon
- Less developed that current hybrid pixel technology and not as radiation tolerant
- Example of ongoing efforts: **Prototypes in TowerJazz 180 nm technology → (Mini-)MALTA**
- 36.4 x 36.4 μm² pixel size (compared to 50 x 50 μm² in ITk)

JINST 15 (2020) P02005

Hybrid pixel detectors



Monolithic active pixel sensors

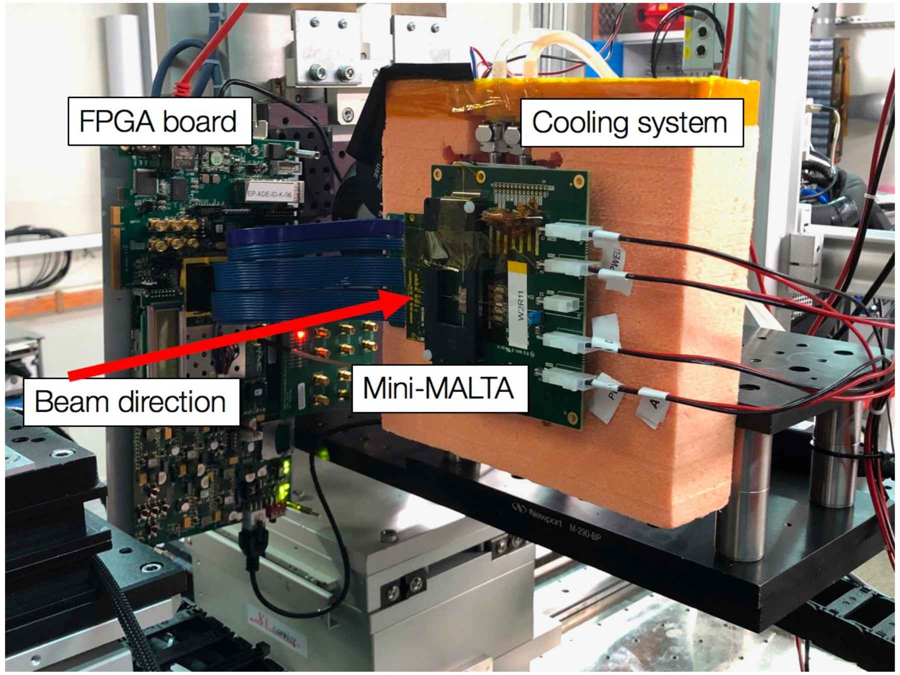


Standard design: Continuous n layer

Future Detector R&D

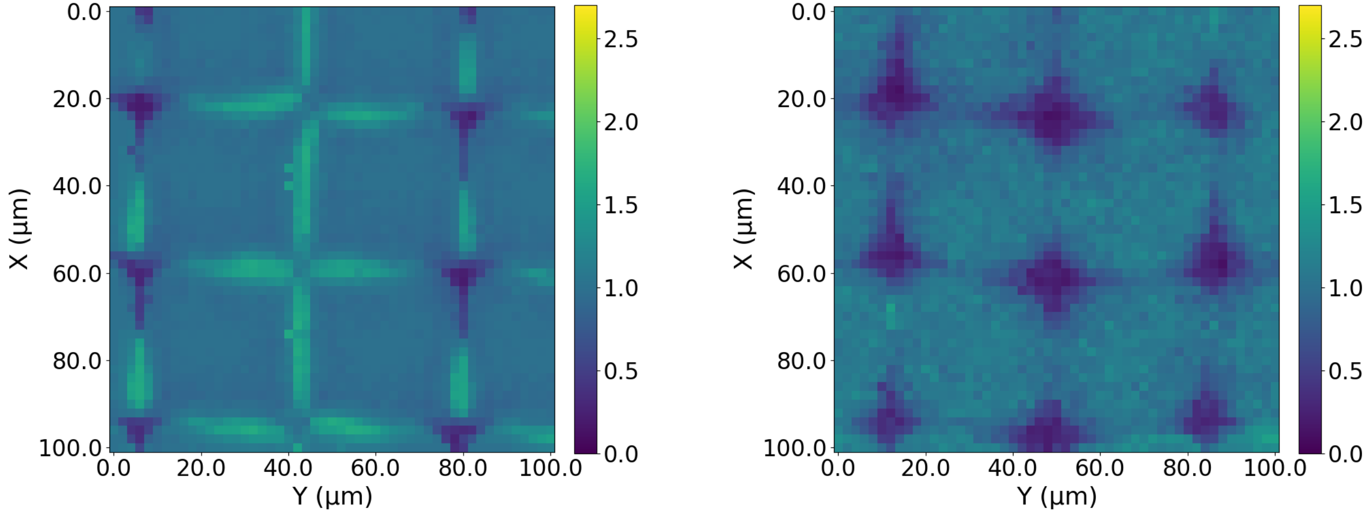
M. Mironova et al, NIM A 956 (2020) 163381

- **MiniMALTA prototype characterised in X-ray testbeam at Diamond Light Source**
- Scan small X-ray beam spot over device to measure pixel response to photons with high precision for samples before and after irradiation
- Clear decrease in pixel response in the pixel corners after irradiation



Standard design: Continuous n layer

Dose unirradiated | 1e15 n/cm^2



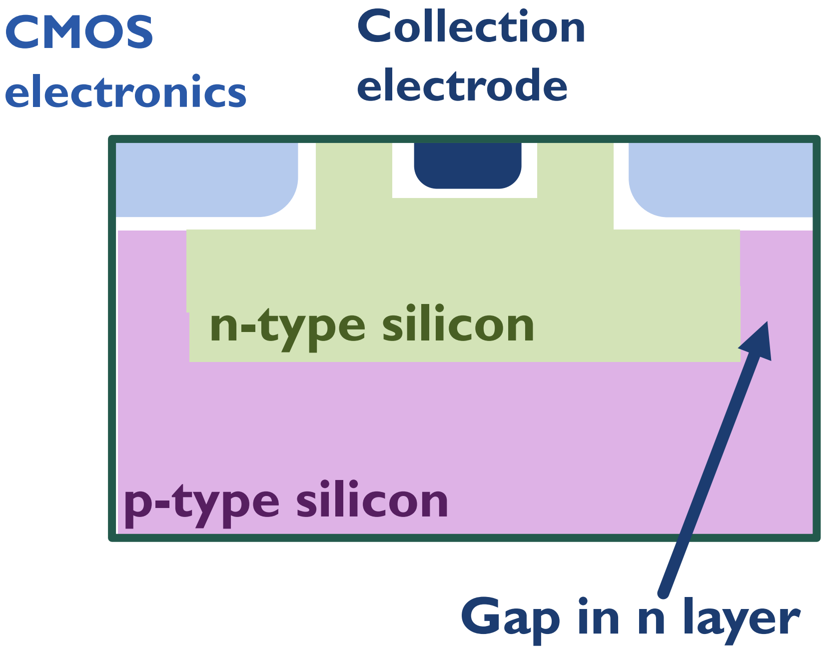
Response: (89 ± 3) % → (77 ± 4) %

Future Detector R&D

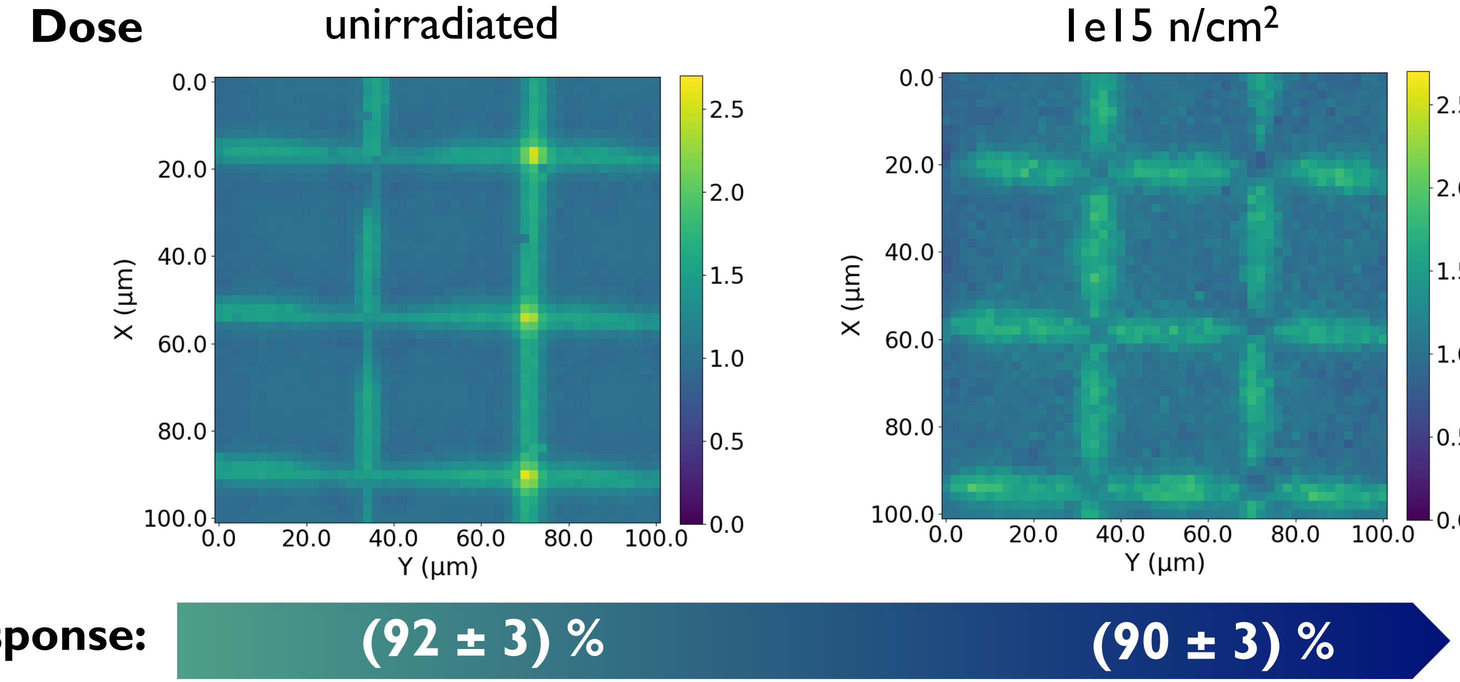
- MiniMALTA prototype includes design modification for better charge collection at the pixel edges

→ **Less decrease of response with irradiation in X-ray testbeam**

→ Further R&D efforts have been ongoing for MALTA chips to improve charge collection and produce larger-scale demonstrators



Modified design: Gap in n layer



Conclusions

- Higgs measurement program at LHC has been highly successful
- As a community we are moving from searching for the Higgs boson to using Higgs as a discovery tool for new physics
- Highest priorities for LHC:
  - Conclude on an HL-LHC timeline and deliver Phase 2 upgrades
  - Define a Higgs physics program which challenges theorists to provide more accurate predictions
- Future colliders:
  - In order to make an informed decision on a future machine, need reliable baseline numbers (HL-LHC) to compare against → European strategy coming up in 2025
  - Significant effort in future colliders still needed to ensure the projected Higgs sensitivities are reliable