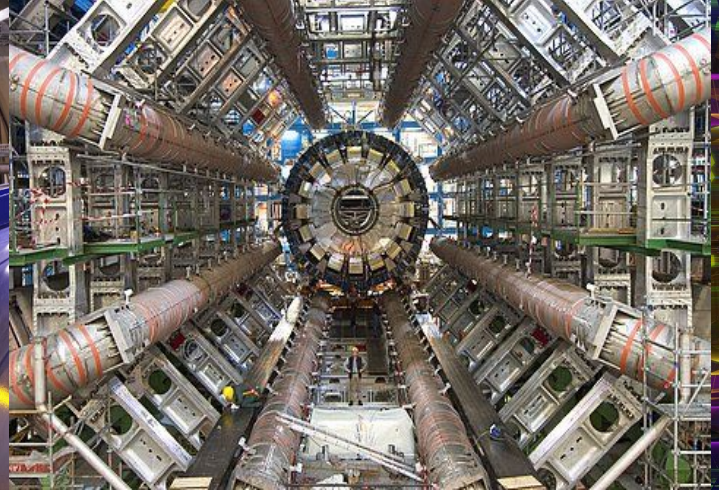
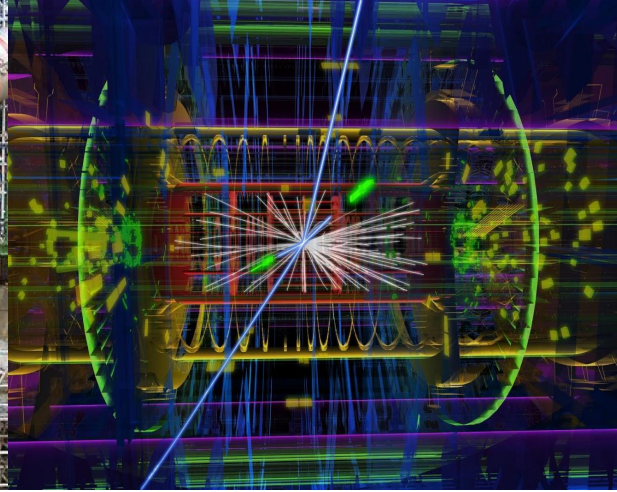




Higgs boson physics and upgrade work

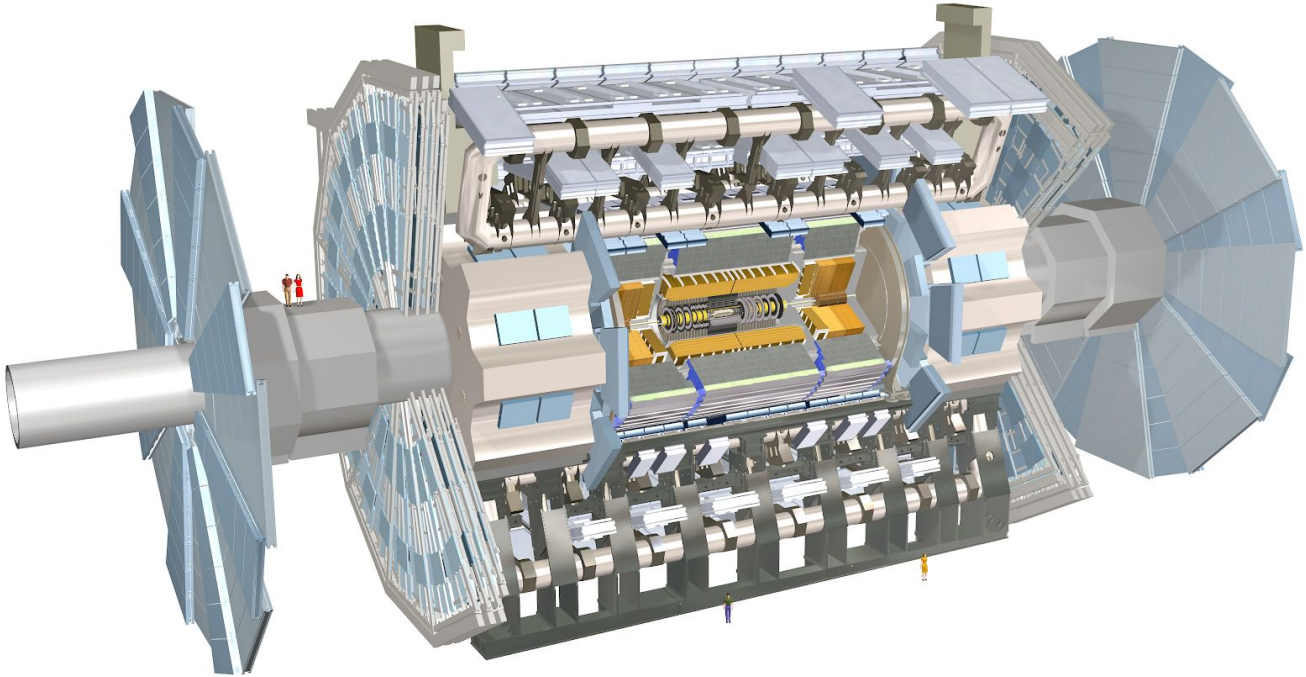
with ATLAS at the Large Hadron Collider

WNPPC 2020 | Banff Alberta | Claire David

YORK UNIVERSITÉ UNIVERSITY

A tour of activities in collider physics

ATLAS, multi-purpose detector



Standard Model measurements

Higgs boson physics

Search of Supersymmetry

Search of Dark Matter

Search of exotic particles

. . .

Electronics design

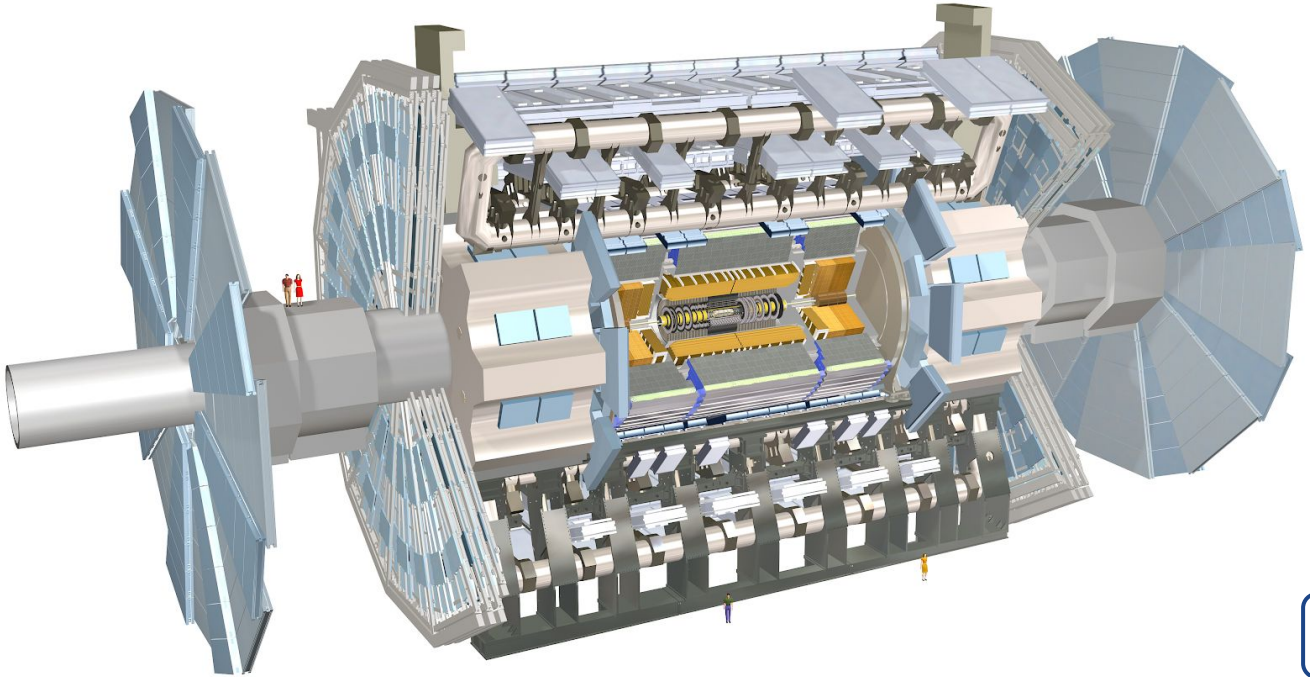
Data acquisition studies

Prototype characterization

. . .

A tour of activities in collider physics

ATLAS, multi-purpose detector



Standard Model measurements

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. . .

The Higgs

The Higgs

- ❑ boson
- ❑ field
- ❑ mechanism

Higgs field

JOURNALISTS It is like snow

a skier (light particle) goes fast and walker sinks (heavy particle)

Higgs field

JOURNALISTS It is like snow

a skier (light particle) goes fast and walker sinks (heavy particle)

THEORISTS The Standard Model is ruled by symmetries ≡ invariances

Mass terms are not invariant unless a scalar field is introduced

⇒ spontaneous 'transition' = Electroweak Symmetry Breaking (EWSB)

The Higgs mechanism generates masses for gauge bosons and fermions

Remaining 'degree of freedom' = scalar Higgs boson

To learn more: "Status of Higgs Boson Physics" in Particle Data Group

Higgs field

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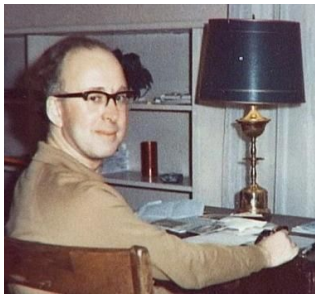
EXPERIMENTALISTS There is a measurable resonance to find (done) and study (now)

Higgs boson timeline

1964

Theoretical formulation



Peter Higgs

François Englert Robert Brout

Tom Kibble Gerald Guralnik Carl Hagen

Higgs boson timeline

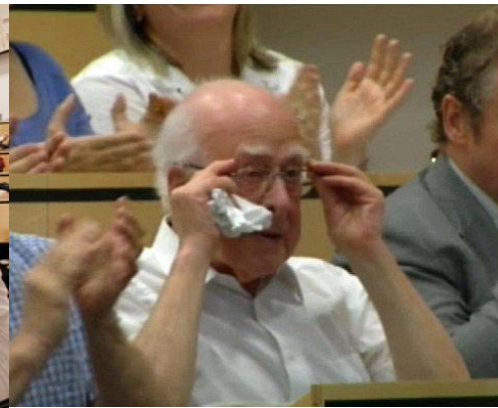
1964 — Theoretical formulation

2012 — discovery!

2020 — ?

"It's really an incredible thing that it's happened in my lifetime"

Peter Higgs



Questions

Are the Higgs boson properties exactly as in the Standard Model?

Are there additional Higgs bosons?

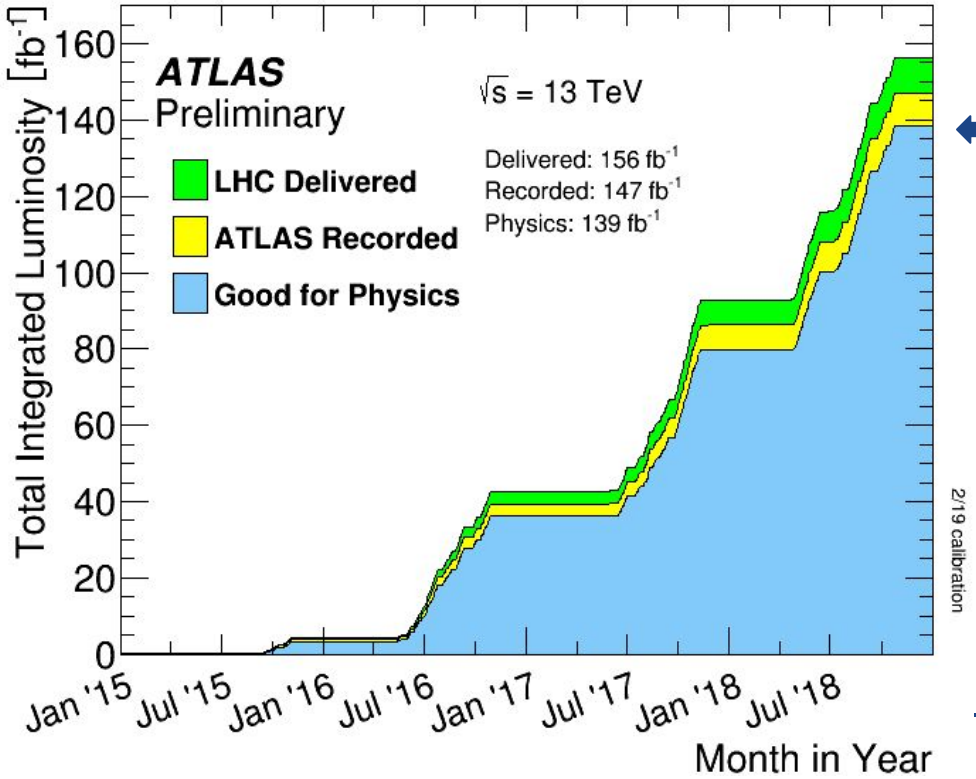
Is the Higgs boson a bridge to the dark matter sector?

Answers

through precise measurements of **Higgs boson properties**

Higgs boson physics: the precision area

inverse femtobarn ≡ 100 trillion (10^{12}) proton-proton collisions



Run 2 dataset 13 TeV

139 inverse femtobarn (fb^{-1})

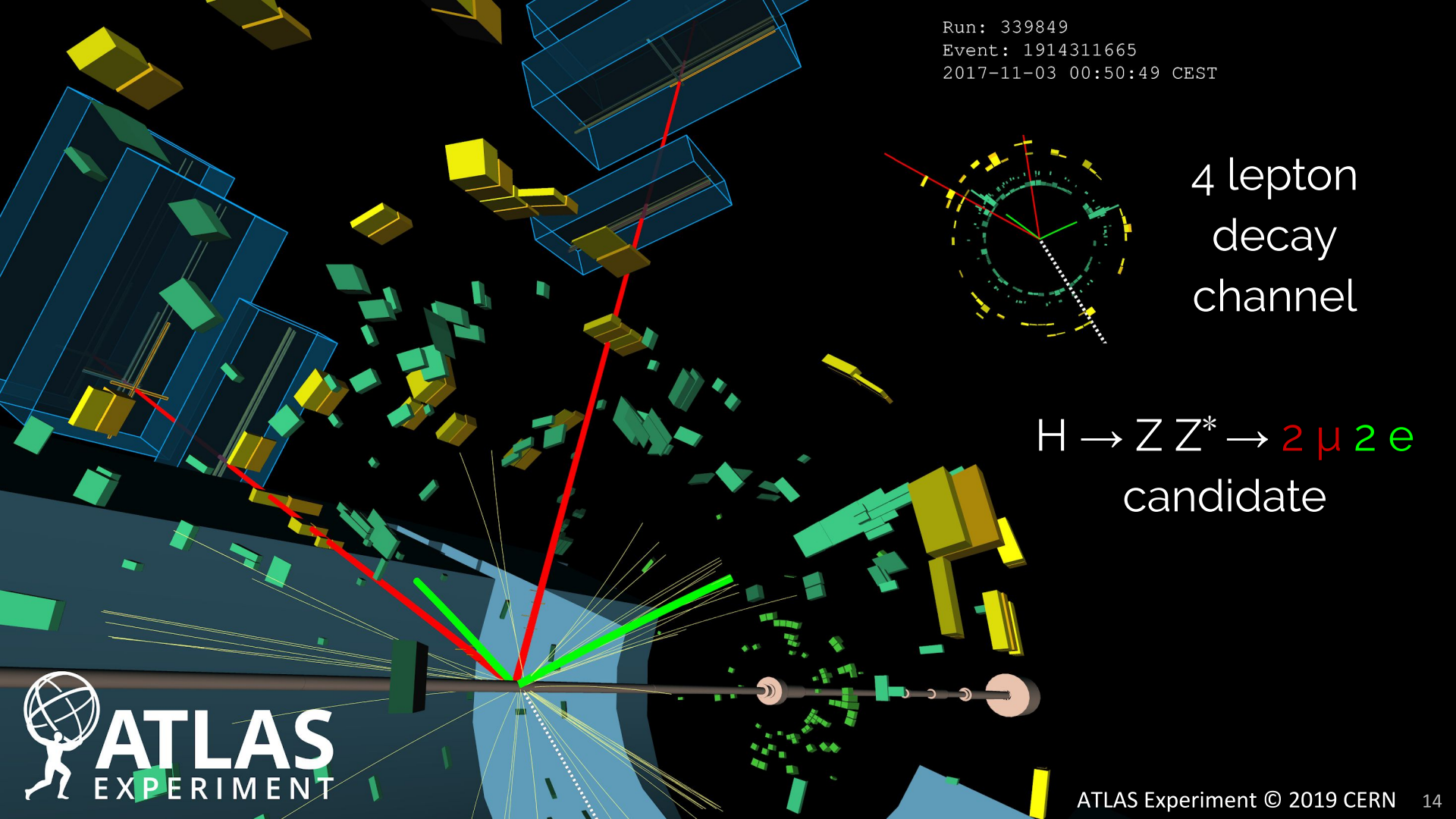
data!

Run 1 dataset 7 and 8 TeV

25 inverse femtobarn (fb^{-1})

Link

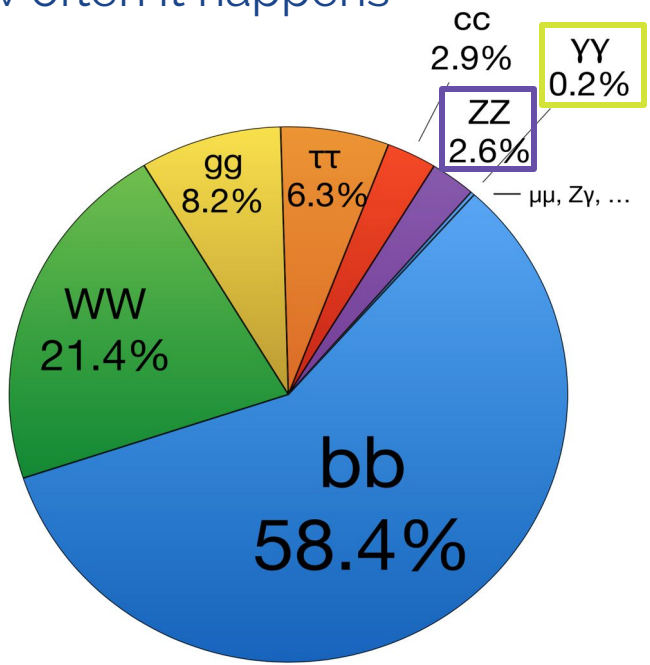
How to measure the Higgs boson?



Higgs boson decay channels

BR = Branching Ratio [in %]

"How often it happens"



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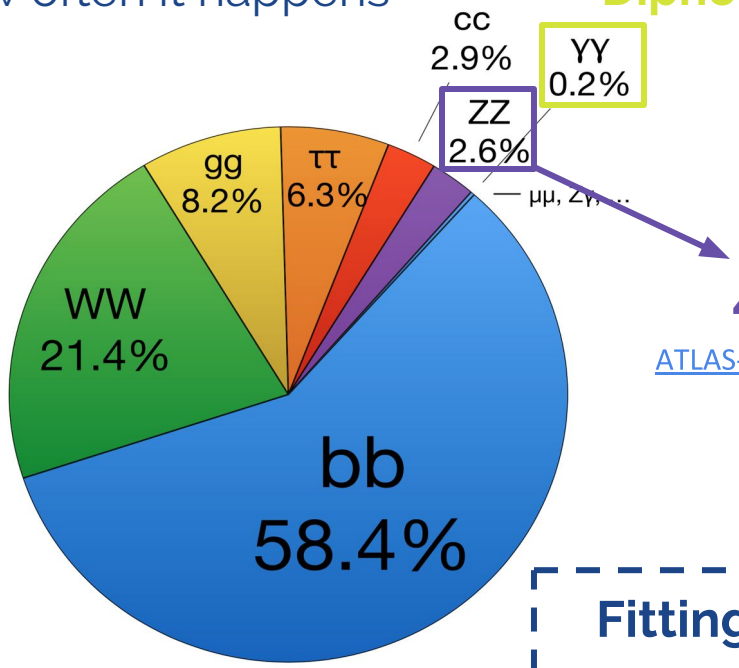

Diphoton

4 leptons

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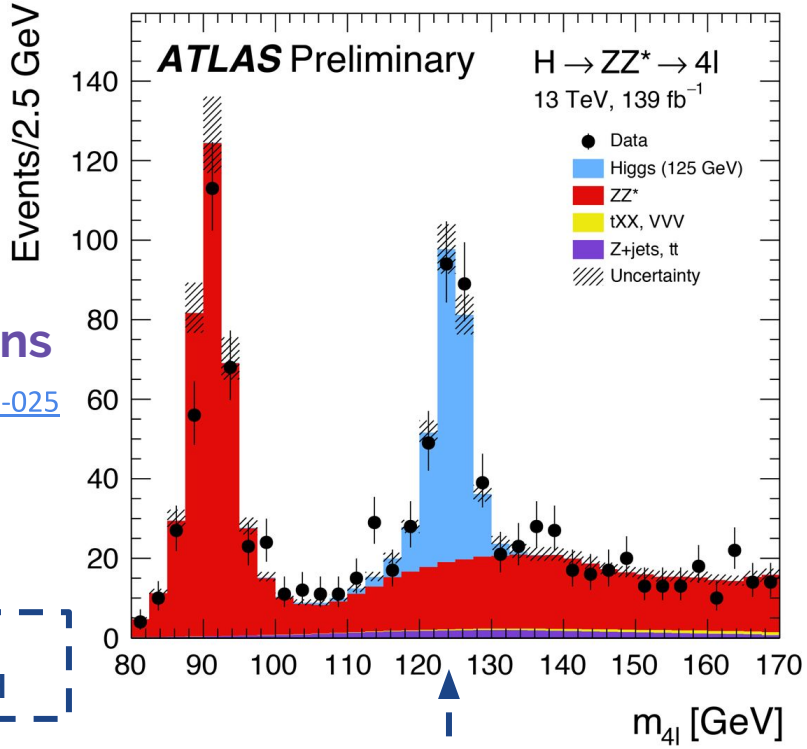
Golden channels → the cleanest



Fitting ⇒ m_H

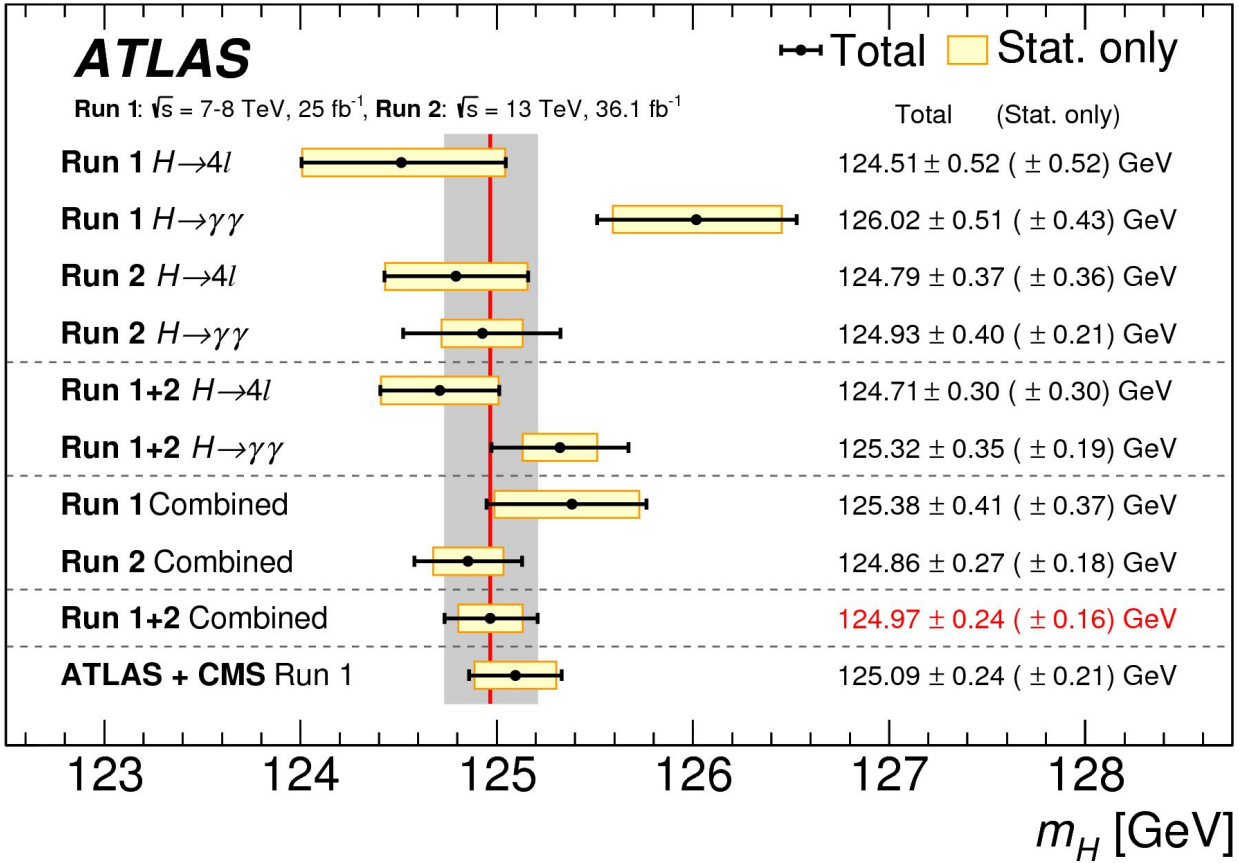
The Higgs mass

more data

reduced uncertainties

ATLAS' most precise result

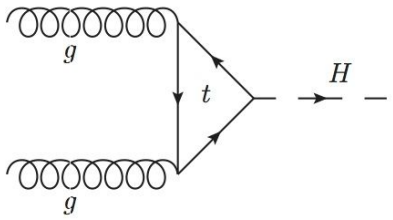
Phys. Lett. B 784 (2018) 345



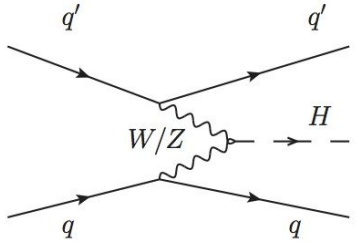
Higgs boson cross-sections

Higgs boson production modes at the LHC

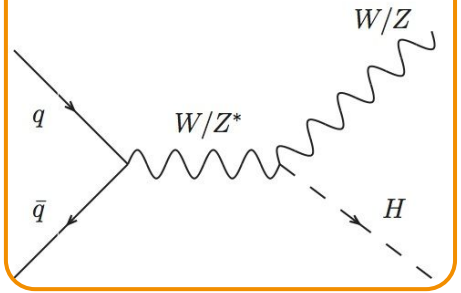
ggF
gluon-gluon Fusion
87%



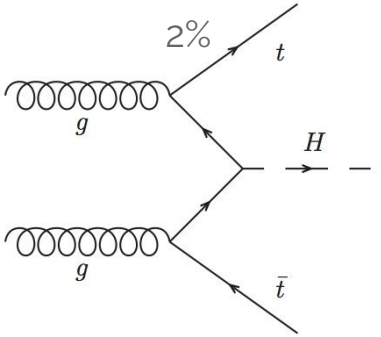
VBF
Vector Boson Fusion
7%

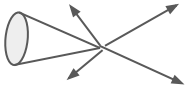


VH
Associated with W or Z
4%

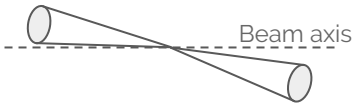


ttH
Associated with ttbar
2%

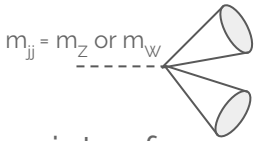




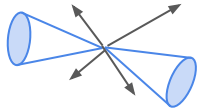
Extra hadronic activity



2 forward jets



2 jets of m_W or m_Z



2 b-jets

Data events assigned to production process using Neural Network

Cross-sections by production mode

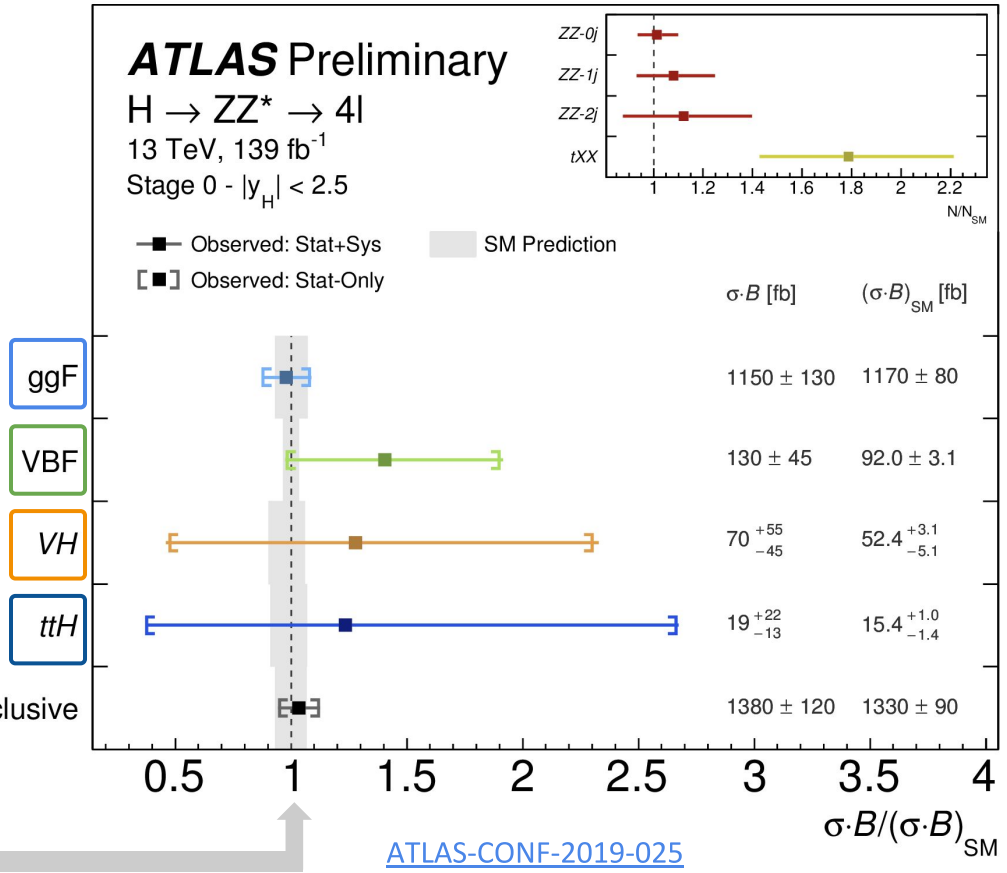
Normalized to Standard Model:

$$\frac{\sigma \cdot \mathcal{B}}{(\sigma \cdot \mathcal{B})_{SM}}$$

Branching ratio: $\mathcal{B}(H \rightarrow ZZ^*)$

20% improvement using Deep Learning Neural Network

results compatible with SM



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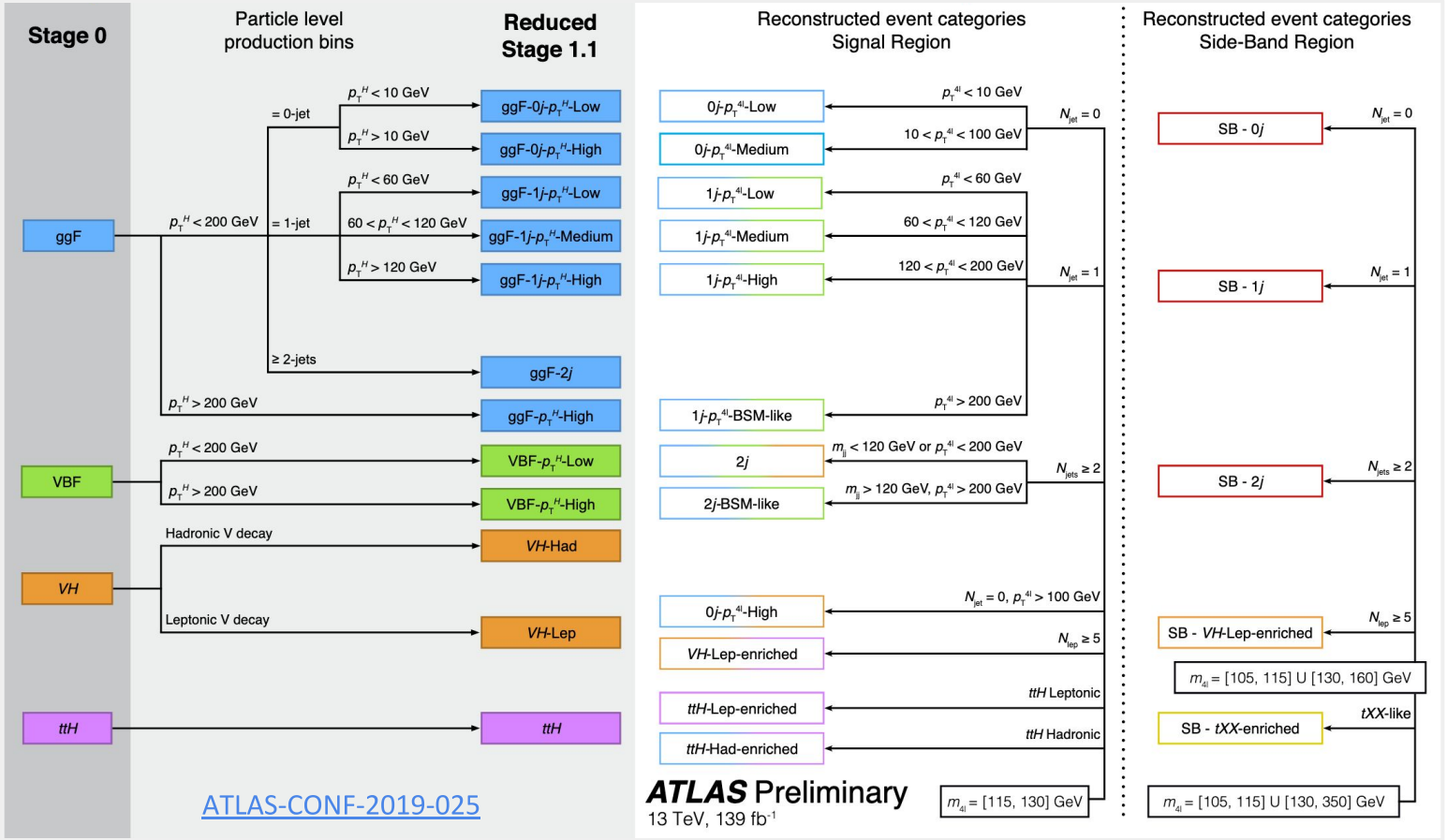
Simplified Template Cross-section "STXS"



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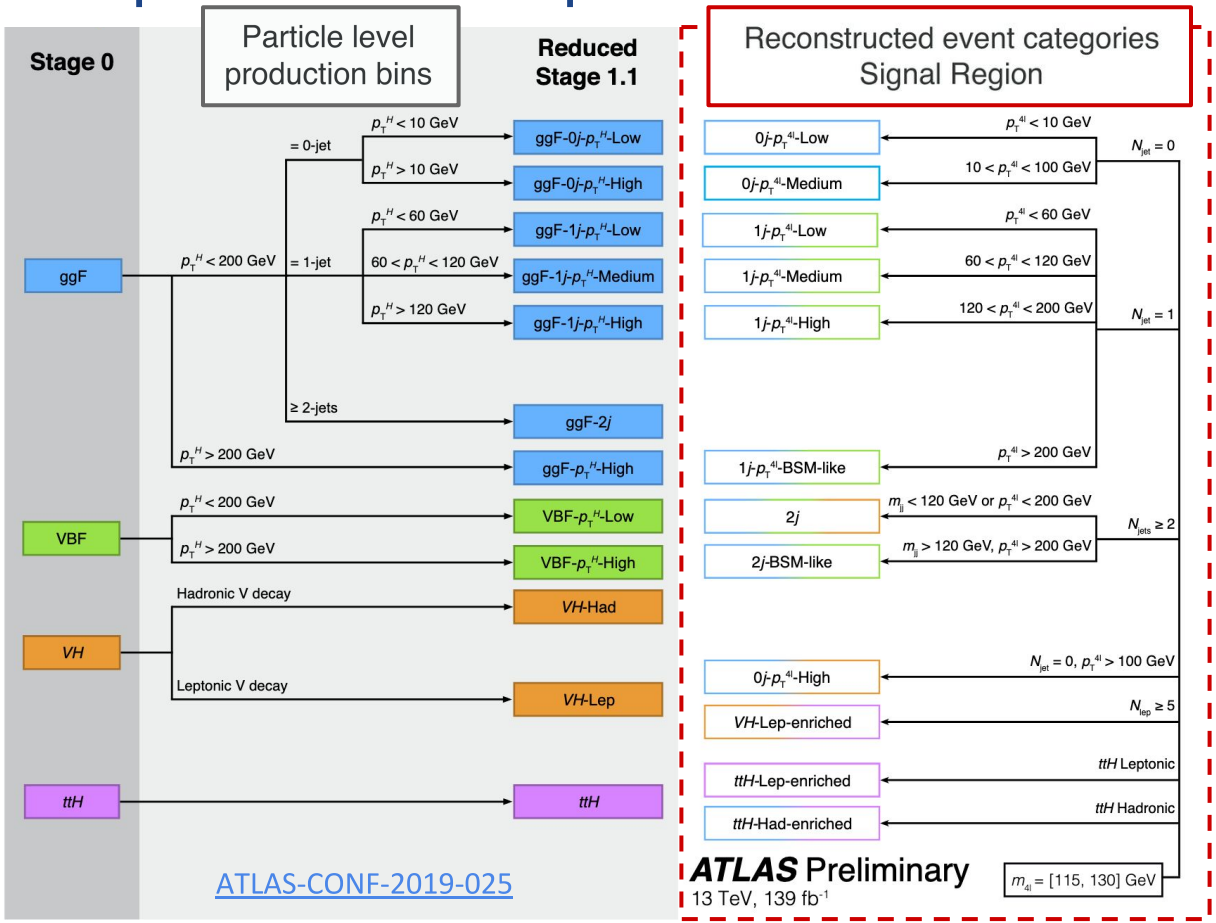
trendy!

Simplified Template Cross-section "STXS"



Phase-space partitioned in production processes

particle - level

↓

dedicated categorization

reco - level

singling out regions with different prospects in terms of theory uncertainty

⇒ **enhanced sensitivity**

Cross-sections re-optimized with STXS binning

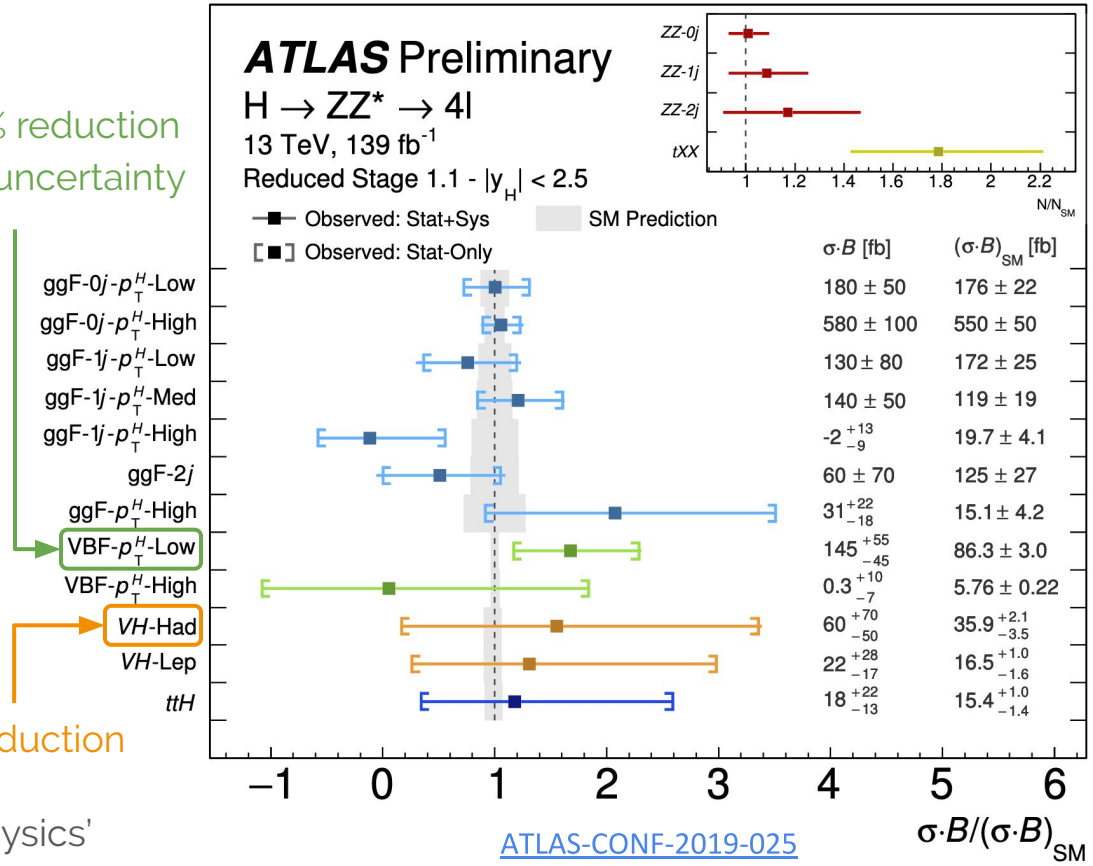
Reduced uncertainties

Pros of STXS framework

- ✓ enhanced sensitivity
- ✓ smaller theoretical uncertainties
- ✓ less model dependance
- ✓ easier to interpret
- ✓ maximize sensitivity to BSM* in dedicated high p_T bins
- ✓ allows machine learning

15% reduction on uncertainty

8% reduction



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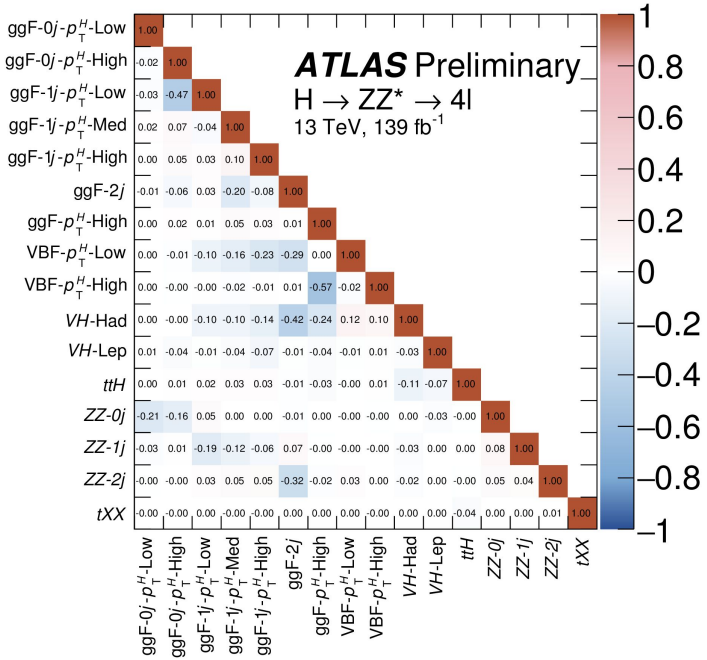
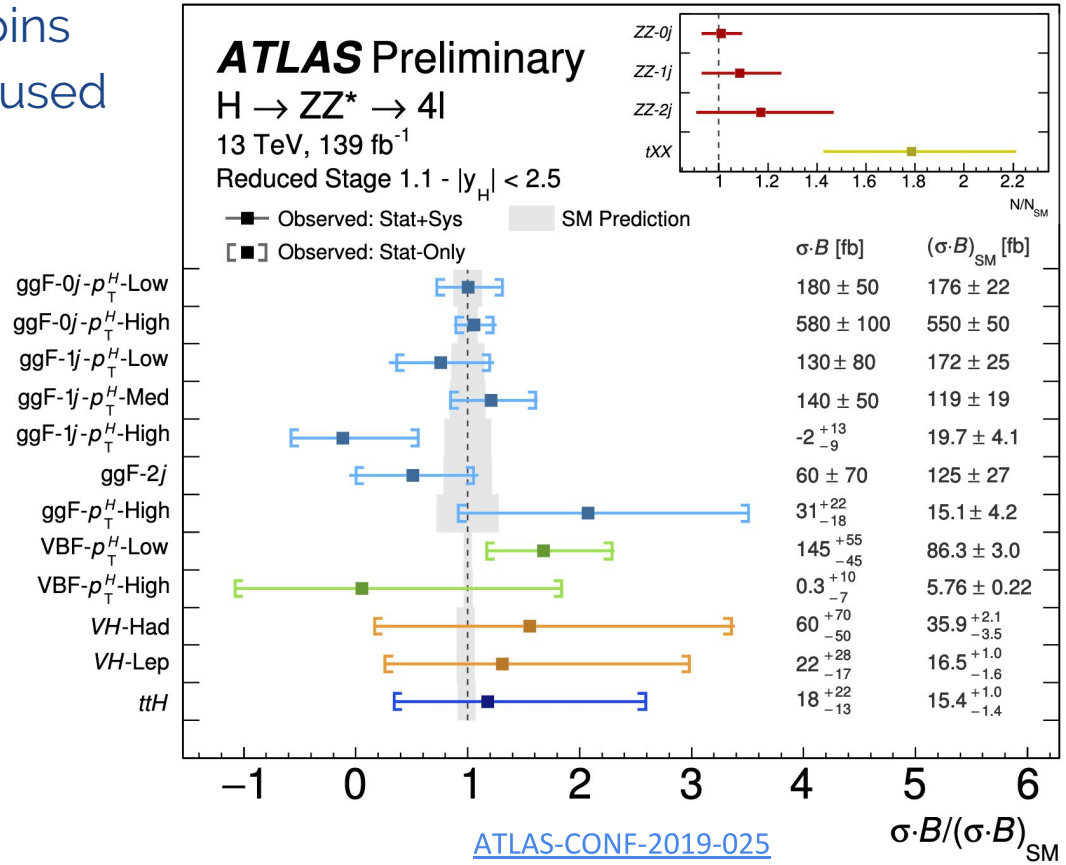
*BSM = Beyond Standard Model, or 'new physics'

Cross-sections re-optimized with STXS binning

Large correlations between STXS bins

⇒ STXS measurements should be used with correlation matrix!





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Differential cross-section

ATLAS-CONF-2019-032

$H \to \gamma\gamma$ + $H \to ZZ^*$ = combined →

Differential cross-section as function of **Higgs boson transverse momentum**

$$p_{T,\,Higgs}$$

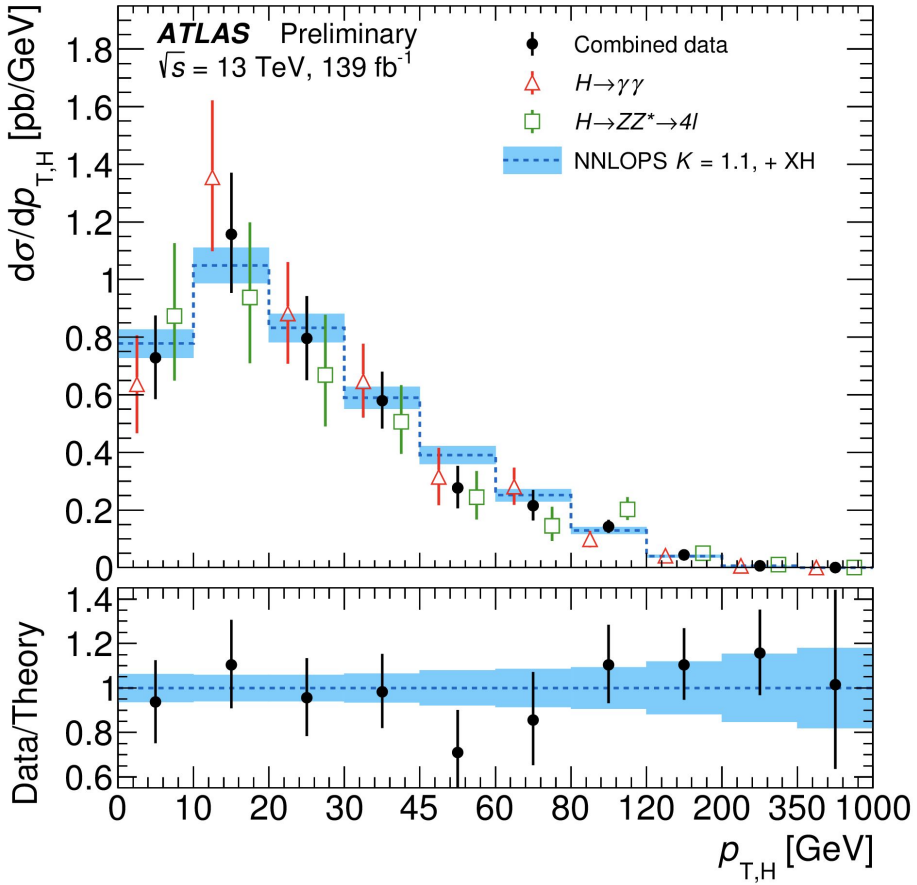
→ variable sensitive to heavy states

→ probing coupling with charm (low p_T)

More: 1606.09253

Compatible results between channels

Agreement with theoretical predictions



Higgs boson couplings to fermions

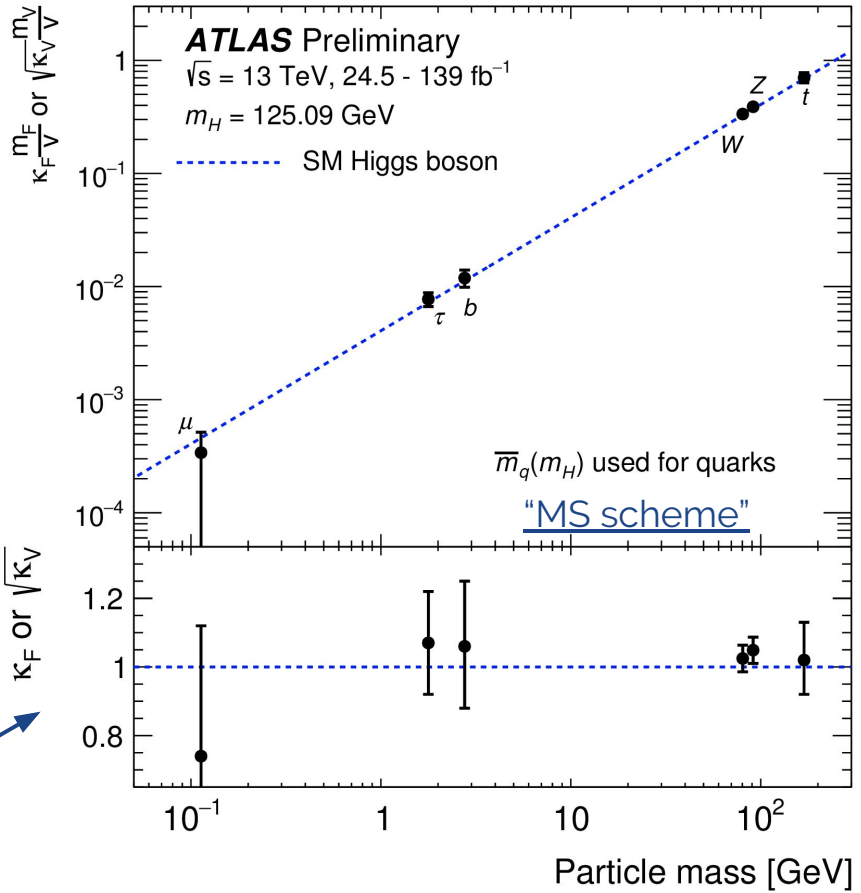
"Yukawa couplings
→ interaction strength

"Kappas"
= coefficients on couplings
SM value = 1

In the Standard Model (SM):
"Couplings are proportional to fermion masses"

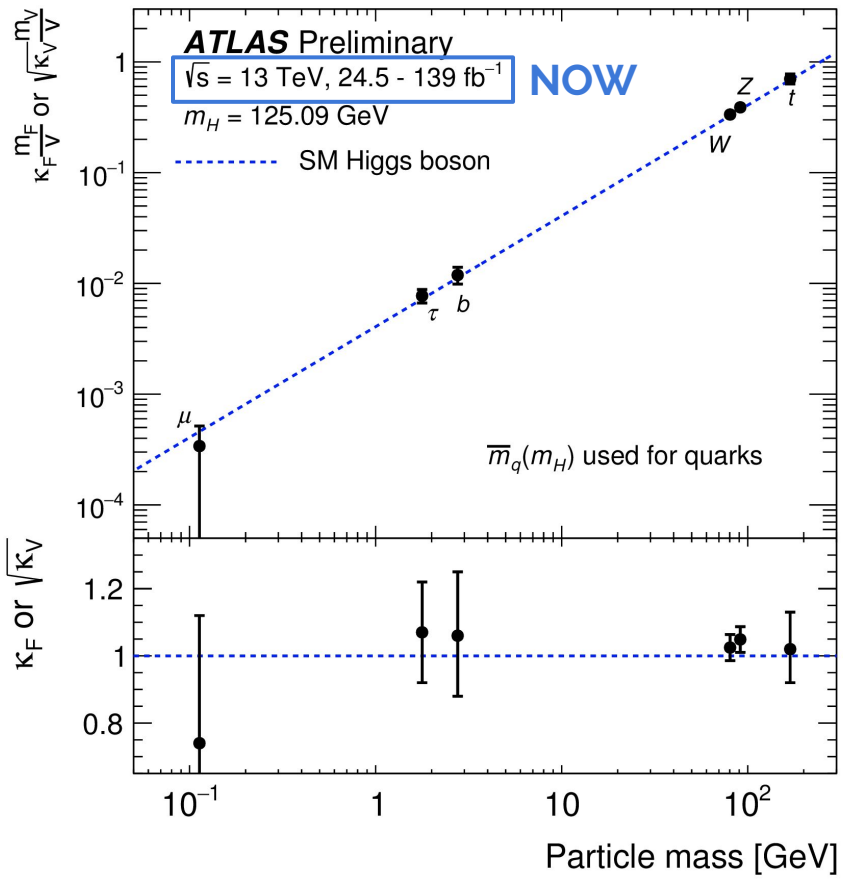
Measuring couplings is a sensitive test to physics Beyond the Standard Model (BSM)
⇒ looking for deviations

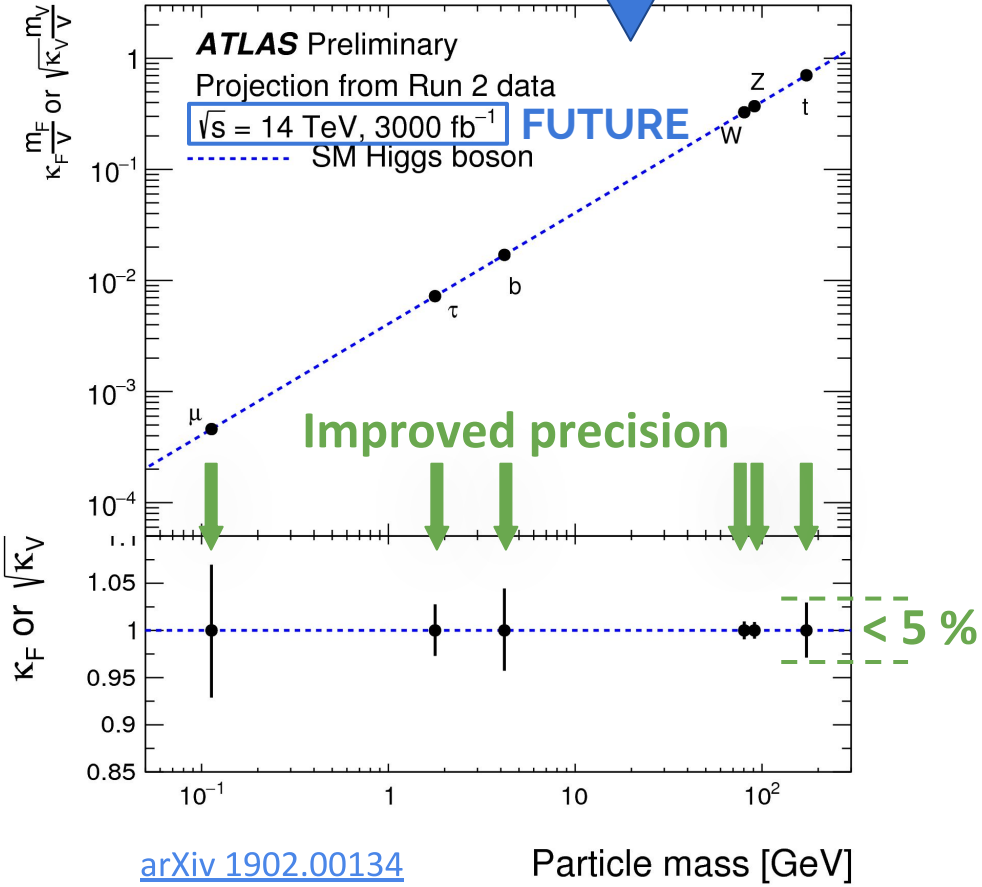
Excellent agreement with theory



Projections with more data

Projections with 20 times more data



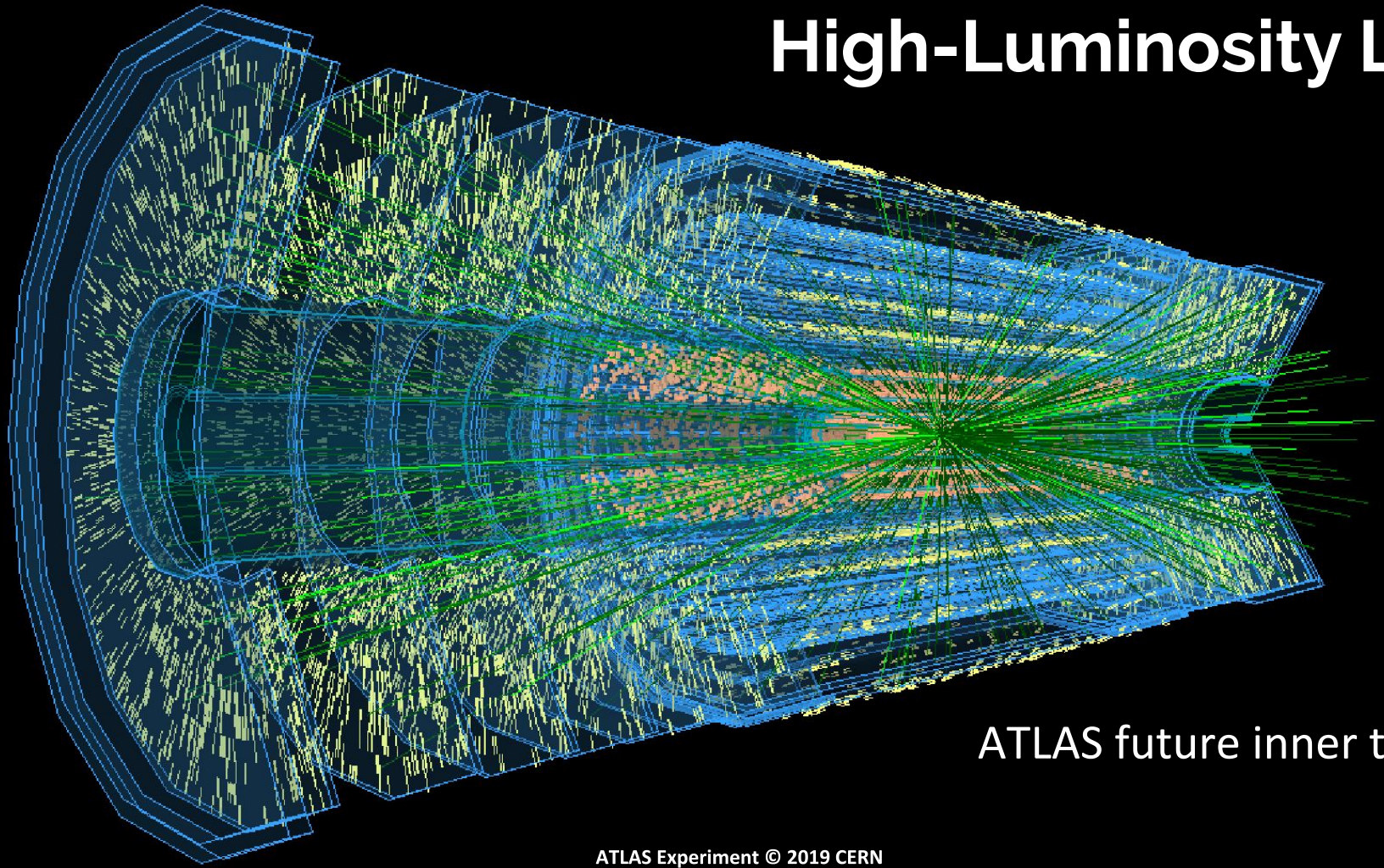


arXiv 1902.00134

We need more data

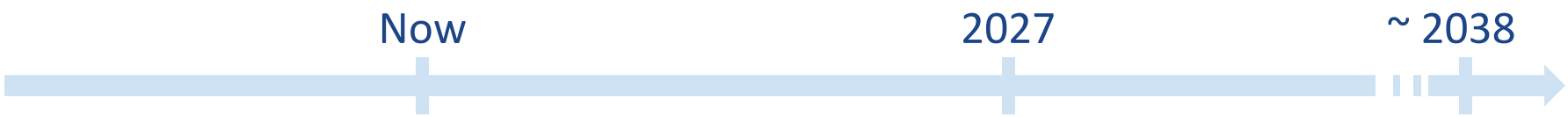
We will get more data

High-Luminosity LHC



ATLAS future inner tracker

The High-Luminosity LHC program

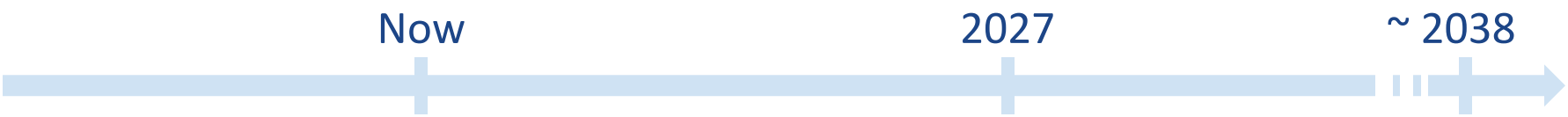


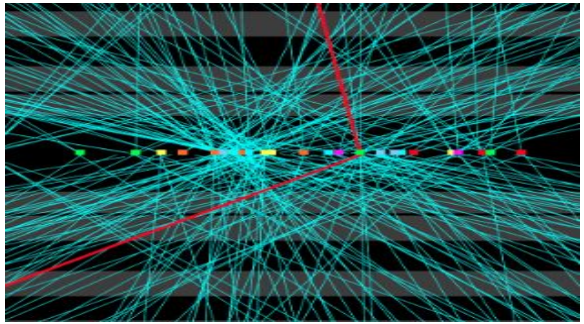
Luminosity: $2 \times 10^{34}\ cm^{-2} . s^{-1}$ ⟶ **up to** $7.5 \times 10^{34}\ cm^{-2} . s^{-1}$

= number of collisions that can be produced in a detector per cm^2 and per second

Improve the discovery potential and precision of measurements

The High-Luminosity LHC program



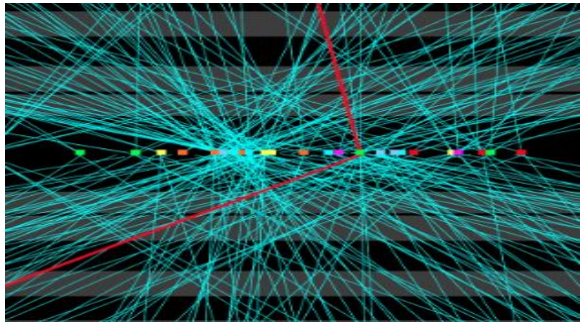


≈ 7 cm

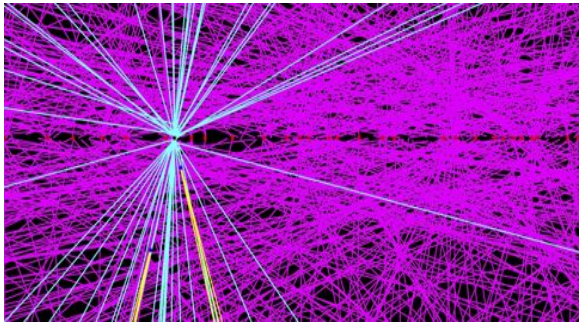
Zoomed view in the beam pipe
at the collision point

The High-Luminosity LHC program

Now — 2027 — ~ 2038



<μ> ≈ 60

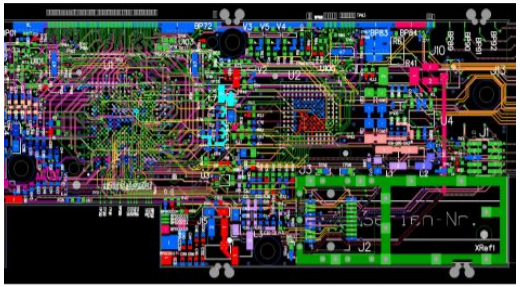


<μ> ≈ 200

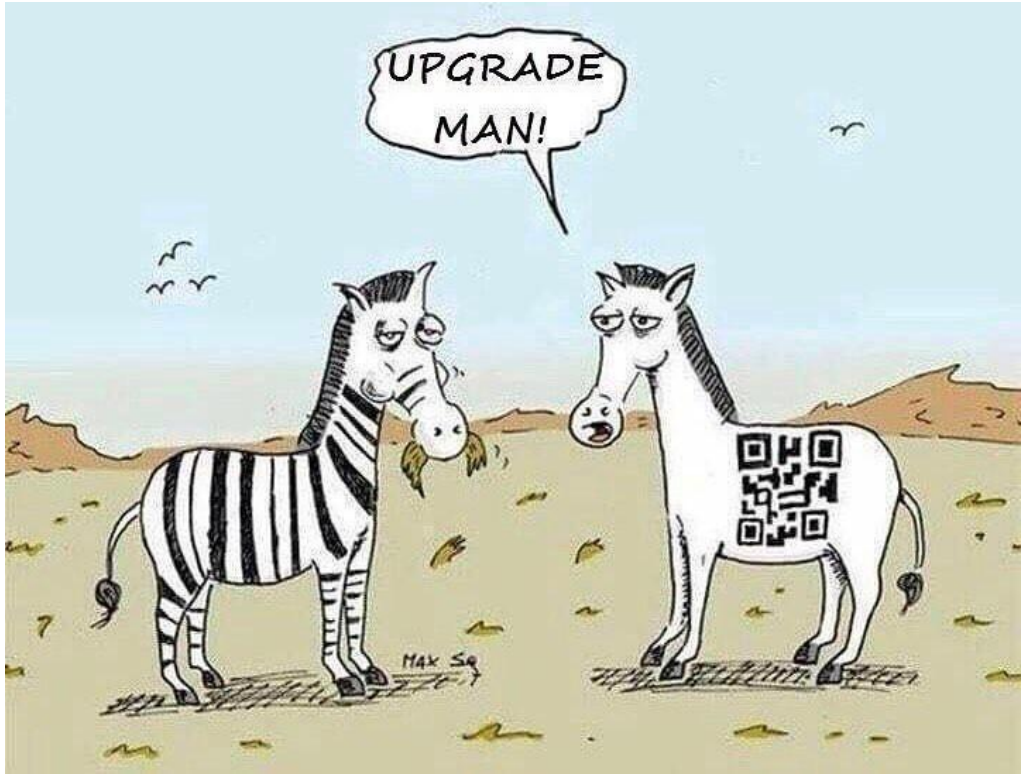
Pile-up = average number of proton-proton interactions per bunch crossing

Requirements

Withstand × 10 higher radiation levels

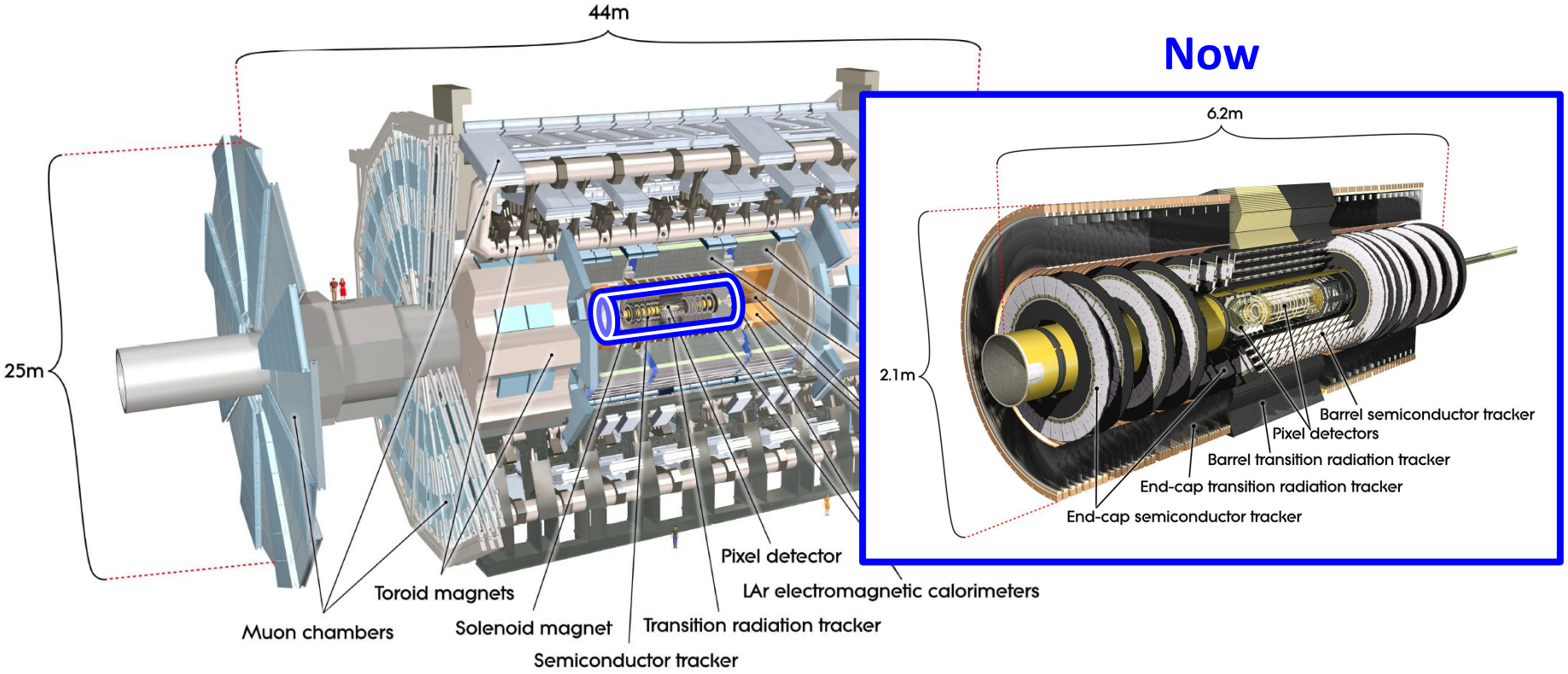


Manage × 7.5 channels

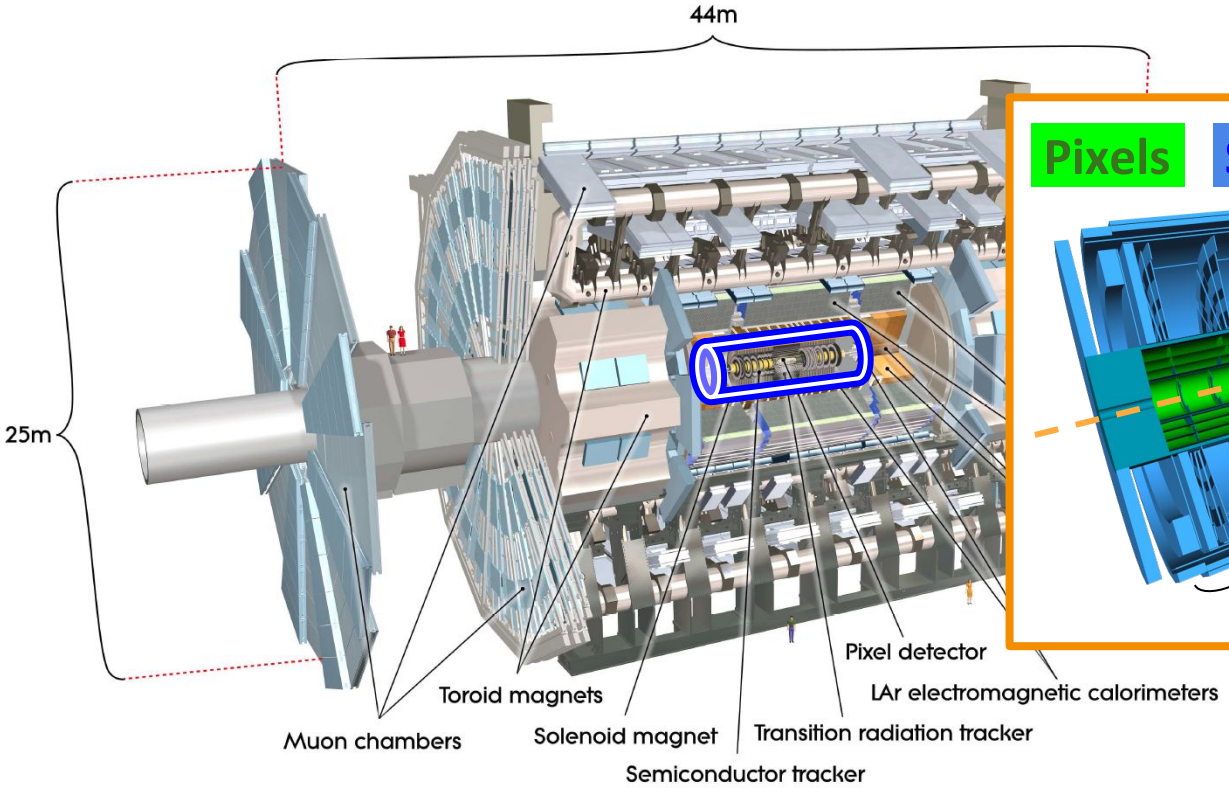


ATLAS current inner tracker

= camera for charged particles



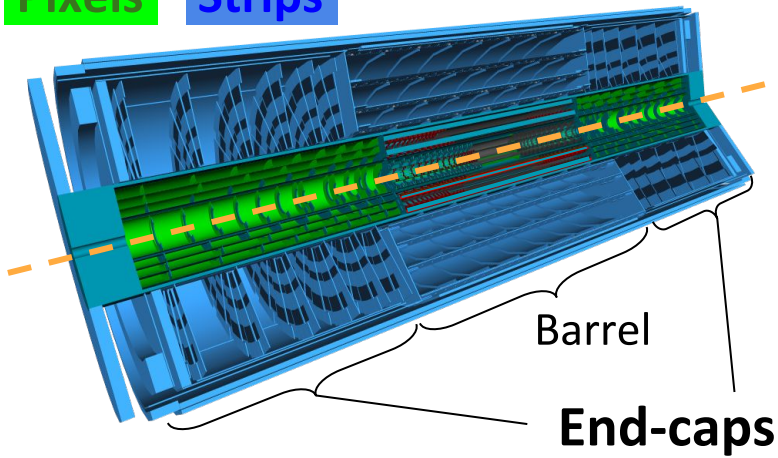
ATLAS current inner tracker

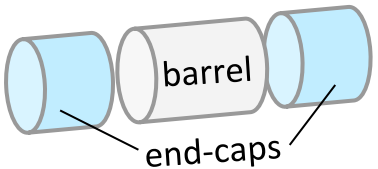


'ITk'

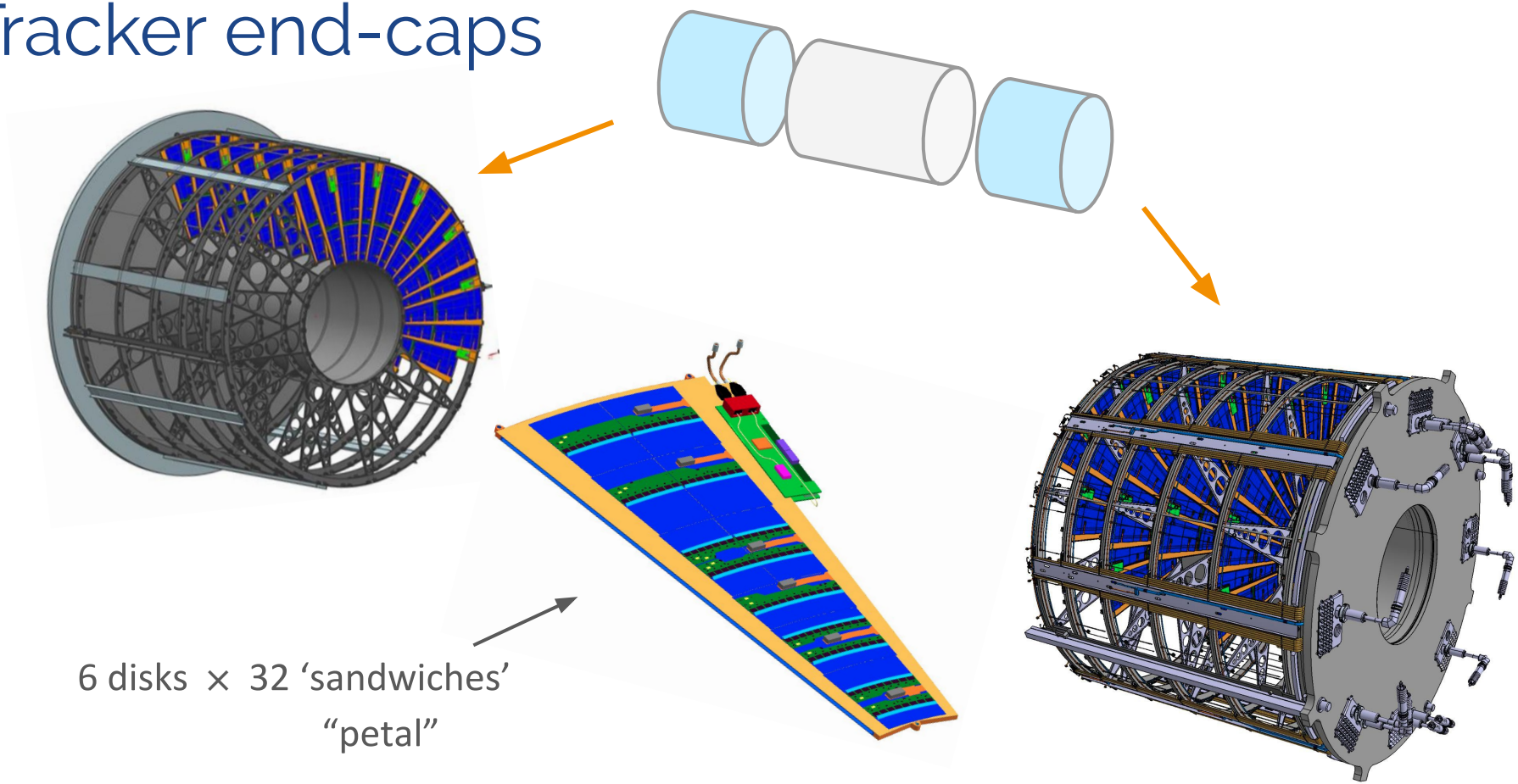
2027

Pixels **Strips** = 'elongated' pixels





Tracker end-caps

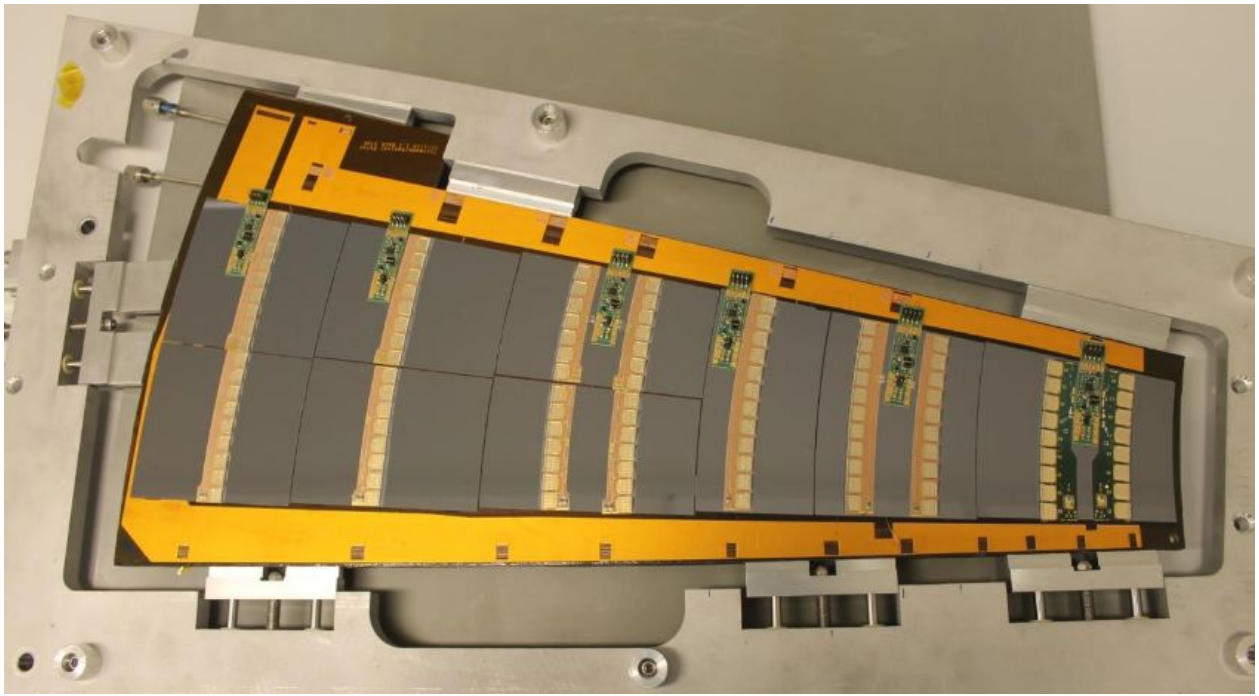


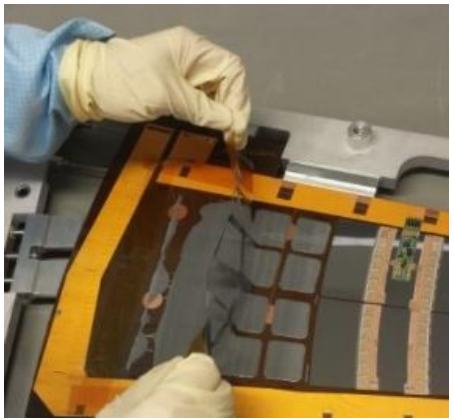
6 disks × 32 ‘sandwiches’

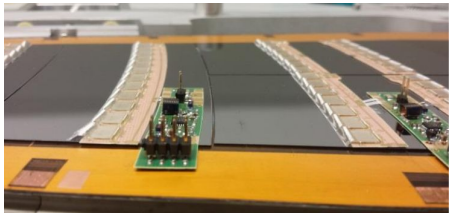
“petal”

Tracker thermo-mechanical prototype

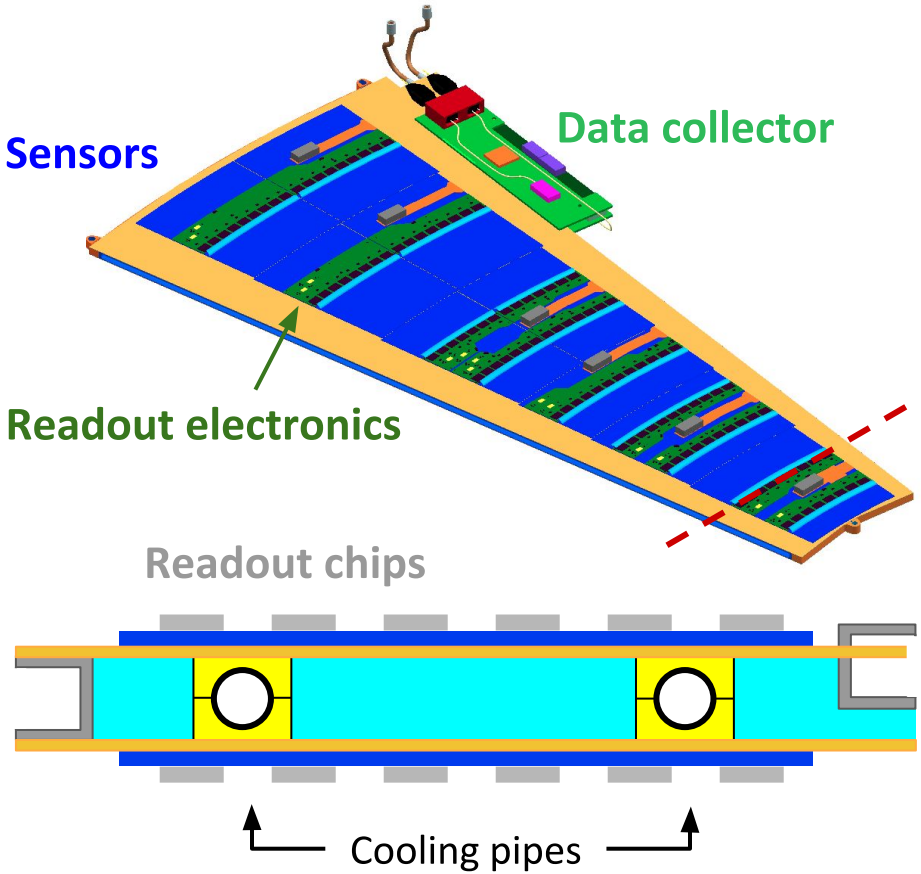
To characterize: → mechanical deformations
→ thermal performance

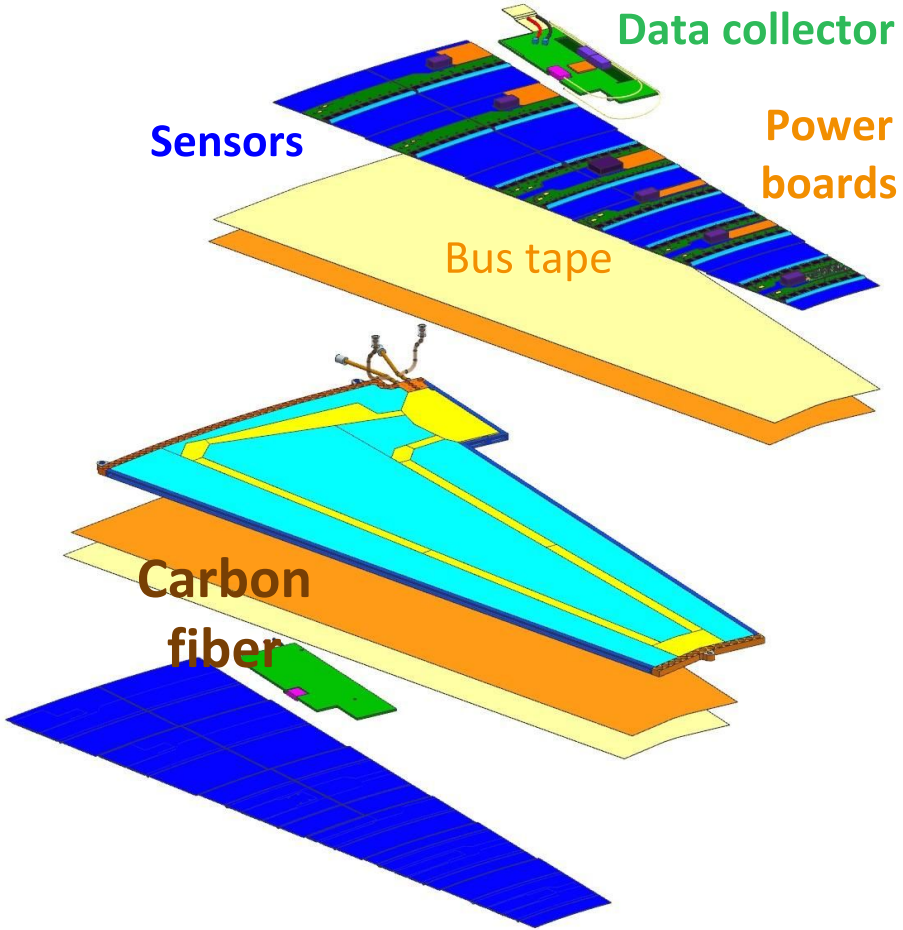




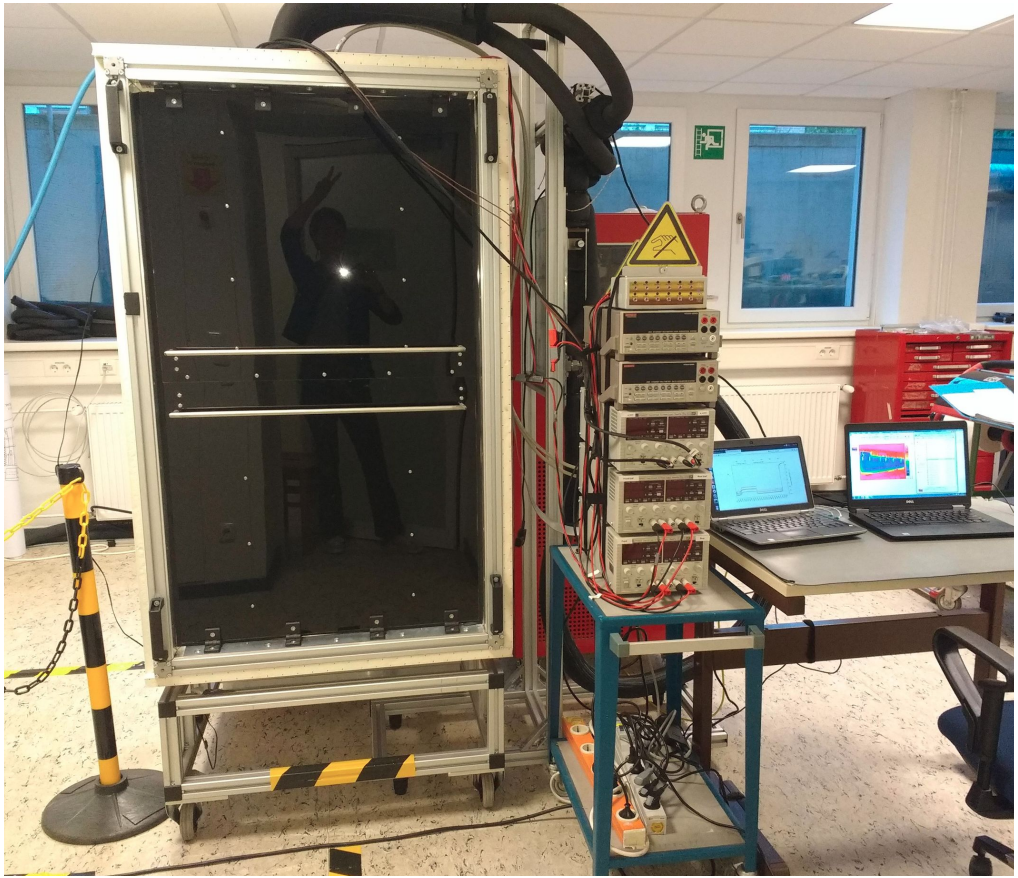


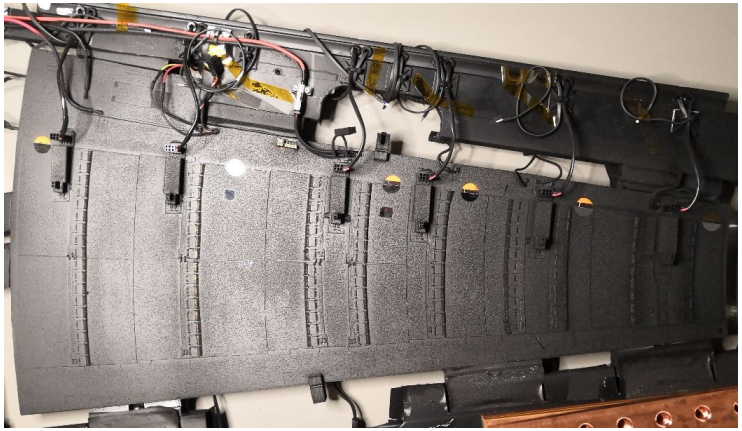
The ITk petal





Experimental setup

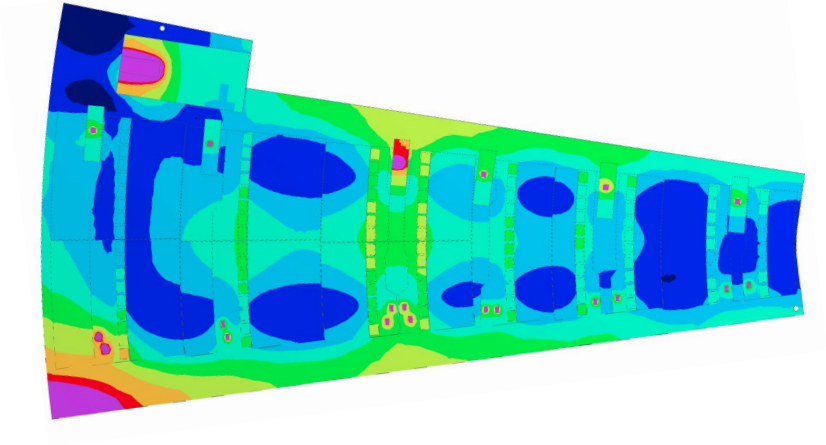




Results: temperature on the sensor surface

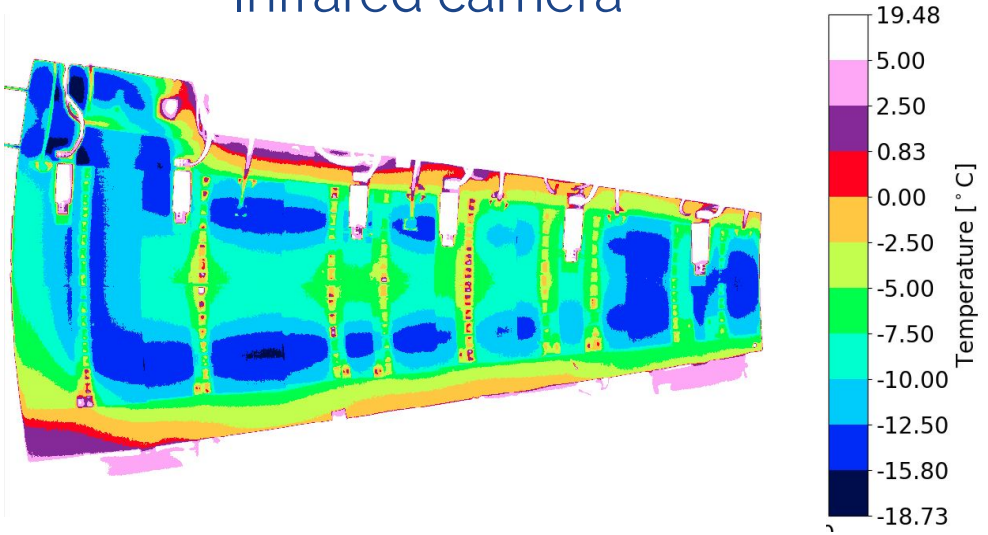
Simulation

Finite Element Analysis (FEA)



Measurements

Infrared camera



✓ Excellent agreement between simulations and experimental measurements

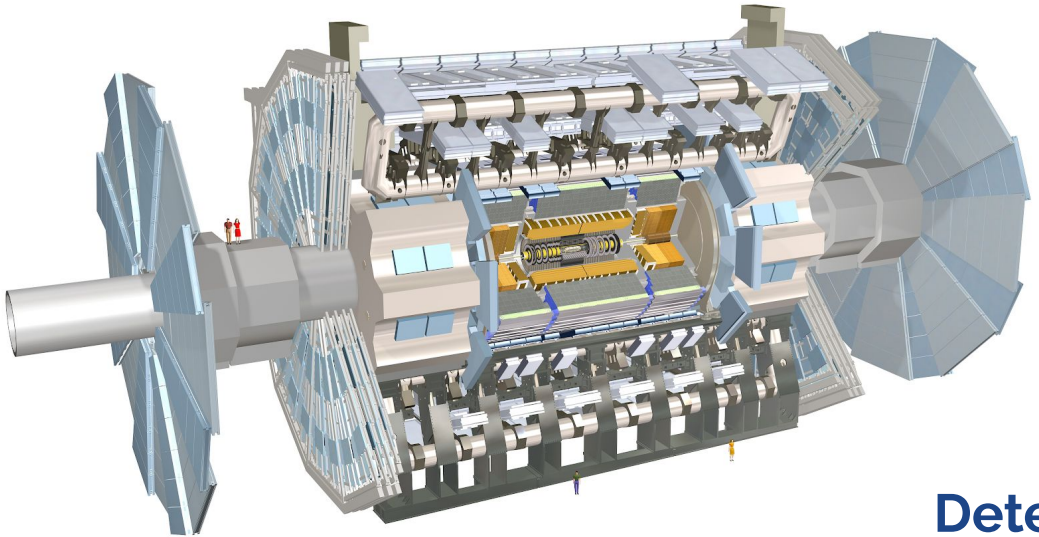
✓ Critical achievement towards the validation of the design

End of ATLAS tour

Higgs boson physics

Area of precision measurements of the Higgs boson properties

Explorations to optimize the results for best sensitivity & interpretation



Detector development

Ongoing hardware work to prepare for the High-Luminosity LHC program

Skills gained in High Energy Physics

Data analysis

Programming, scripting, debugging, git-committing

Machine Learning techniques

Statistical interpretation

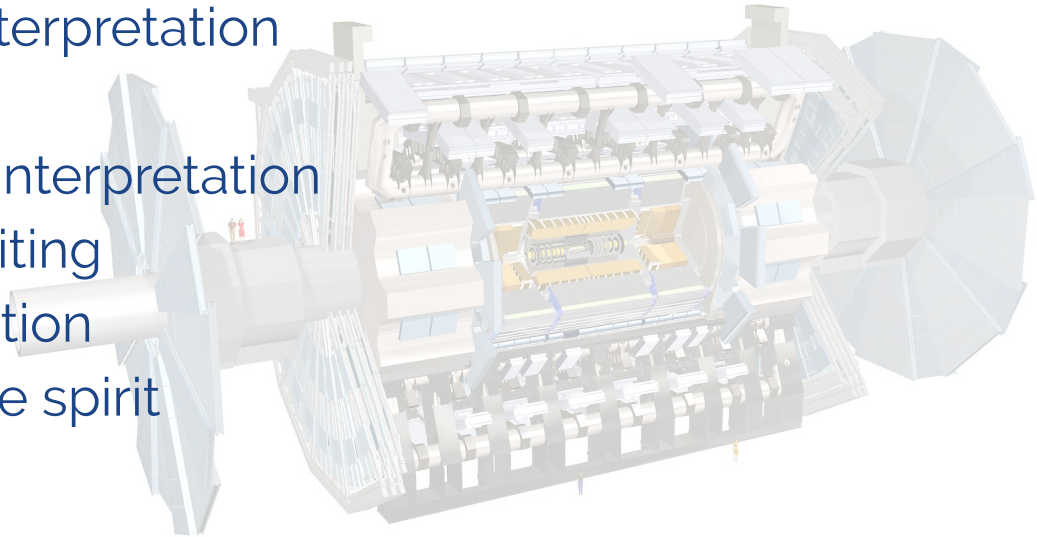
Plotting

Theoretical interpretation

Scientific writing

Communication

Collaborative spirit



Hardware work

Soldering

Test bench setup

Safety regulations

Instrumentation

Data acquisition

Monitoring

Data collection

. . . transferrable in many domains

Questions?

Thank you for your attention

More.

if needed

Cross-section measurements

The data ⇒ only access to reconstructed events (detector level) ⇒ interested in truth level

INCLUSIVE

Extrapolation
from detector acceptance
to full phase space

FIDUCIAL

Restricted to reco-level cuts
Corrected for
→ reconstruction efficiencies
→ stat. & syst. bin migrations

DIFFERENTIAL

inclusive or fiducial

$$\frac{d\sigma}{dx}$$

Measurement with respect to a variable

→ interesting features in distributions [of x]

Examples: η $p_{T,4l}$ $p_{T,Higgs}$

Comparing data to a new model

Extrapolation to repeat
⇒ **need to repeat the analysis**

Defined fiducial volume
⇒ **no need to repeat the analysis**
⇒ Factorization of theoretical & experimental uncertainties