Masterclasses "Hands on Particle Physics"

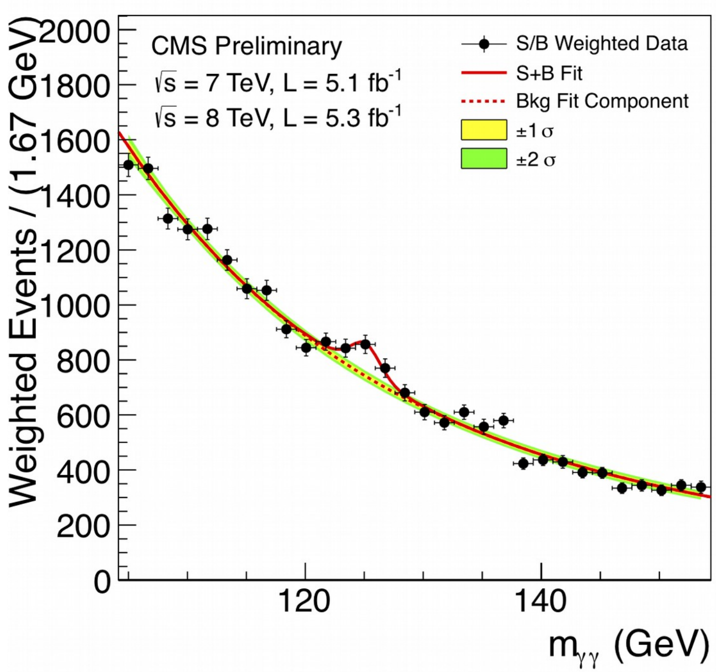
„CERN" Status

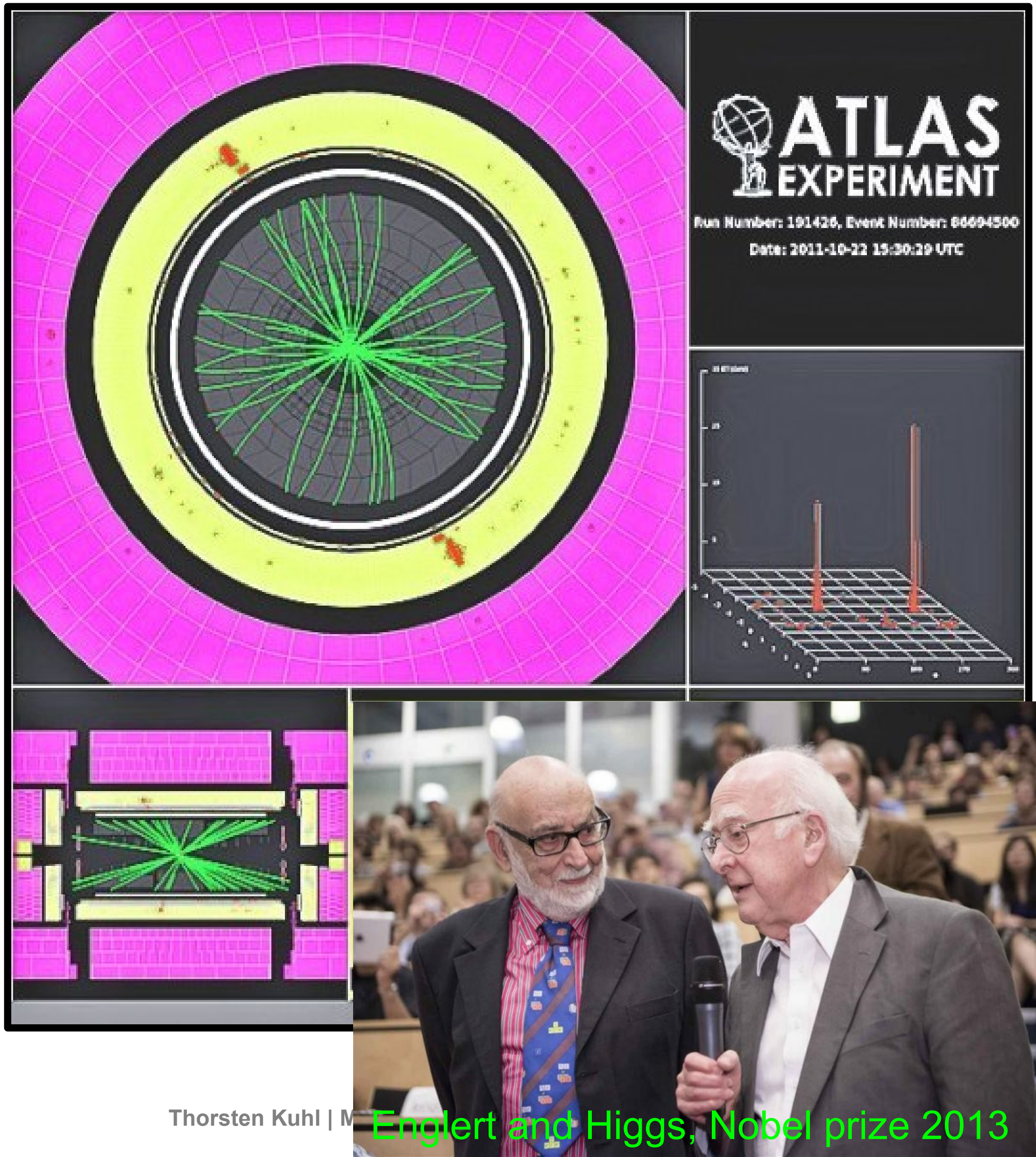
Thorsten Kuhl, 26.02.2016

- Run1: (-2012) → Run2 (2015-)
- Early results
- Future

Higgs discovery 2012

- Discovery of the Higgs Boson in 2012 by ATLAS and CMS
  - $H \rightarrow \gamma\gamma$
  - $H \rightarrow 4Z \rightarrow 4l$
- Both experiments see a significant signal:





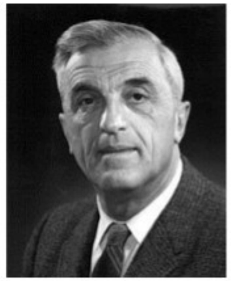
Das CERN

Conseil
Européen pour la
Recherche
Nucléair

Standort	Genf (Schweiz und Frankreich)
Mitgliedstaaten	20 Europäische Nationen
Budget pro Jahr	~ 700 Millionen Euro (davon 20 % aus Deutschland)
Mitarbeiter vor Ort	~ 3.400, weltgrößtes Forschungszentrumg
Beteiligte WissenschaftlerInnen	~8.000 aus 85 Nationen

2015 → 2016 GM Changed


Edoardo Amaldi
1952-1954


Felix Bloch
1954-1955


Cornelis Bakker
1955-1960


John Adams
1960-1961, 1971-1980


Victor Weisskopf
1961-1965


Bernard Gregory
1966-1970


WillibaldJentschke
1971-1975


Léon Van Hove
1976-1980


Herwig Schopper
1981-1988

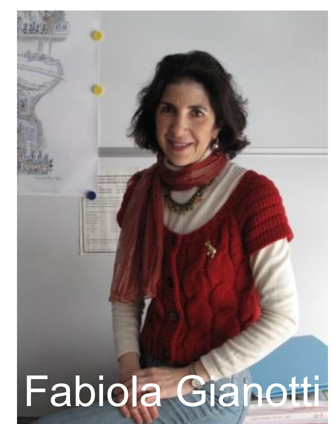

Carlo Rubbia
1989-1993


ıristopher Llewellyn Smith
1994-1998


Luciano Maiani
1999-2003


Robert Aymar
2004-2008


Rolf Heuer
2009-2015



LHC

- Proton-Proton Collider
- Center of mass Energy:
  - 2010-12: 7/8 TeV (achieved)
  - 2014+: 13/14 TeV (design)
- Instantaneous Luminosity:
  - $7 \cdot 10^{33}$ cm^{-2}/s(achieved)
  - $2 \cdot 10^{34}$ cm^{-2}/s (planned, 2016-18)
- Integrated Luminosities:
  - 2011 (7 TeV) : 5 fb^{-1}
  - 2012 (8 TeV) : 20 fb^{-1}
  - 2015-18 : 100 fb^{-1} (~ 3fb^{-1})
  - ~2021-23 : 300 fb^{-1}
  - ~2026+ : 3000 fb^{-1}

LHC and Changes 2012-2015

- LHC moved beam energy from 8 TeV to 13 TeV
  - Time was needed to do the safety changes after the incident 2008:

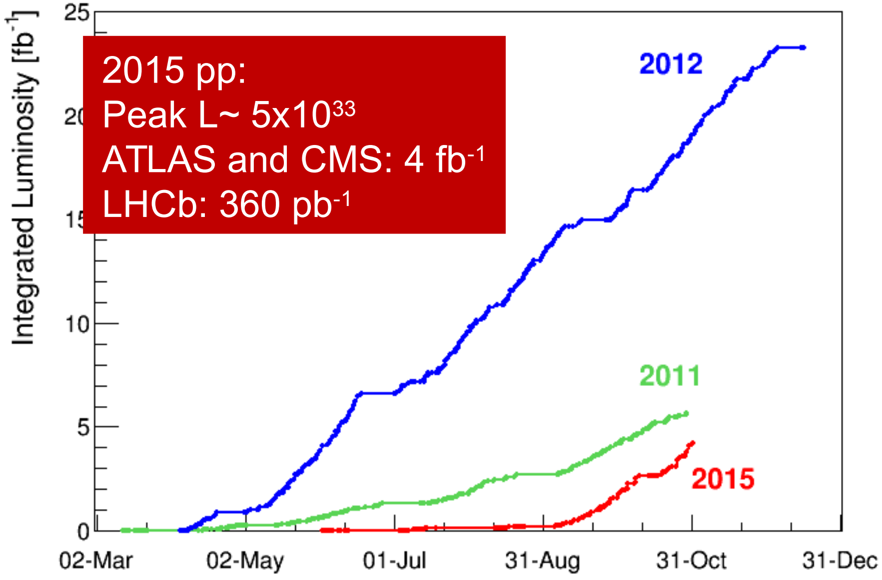
    - much more helium pressure release valves

    - test of all superconducting connections

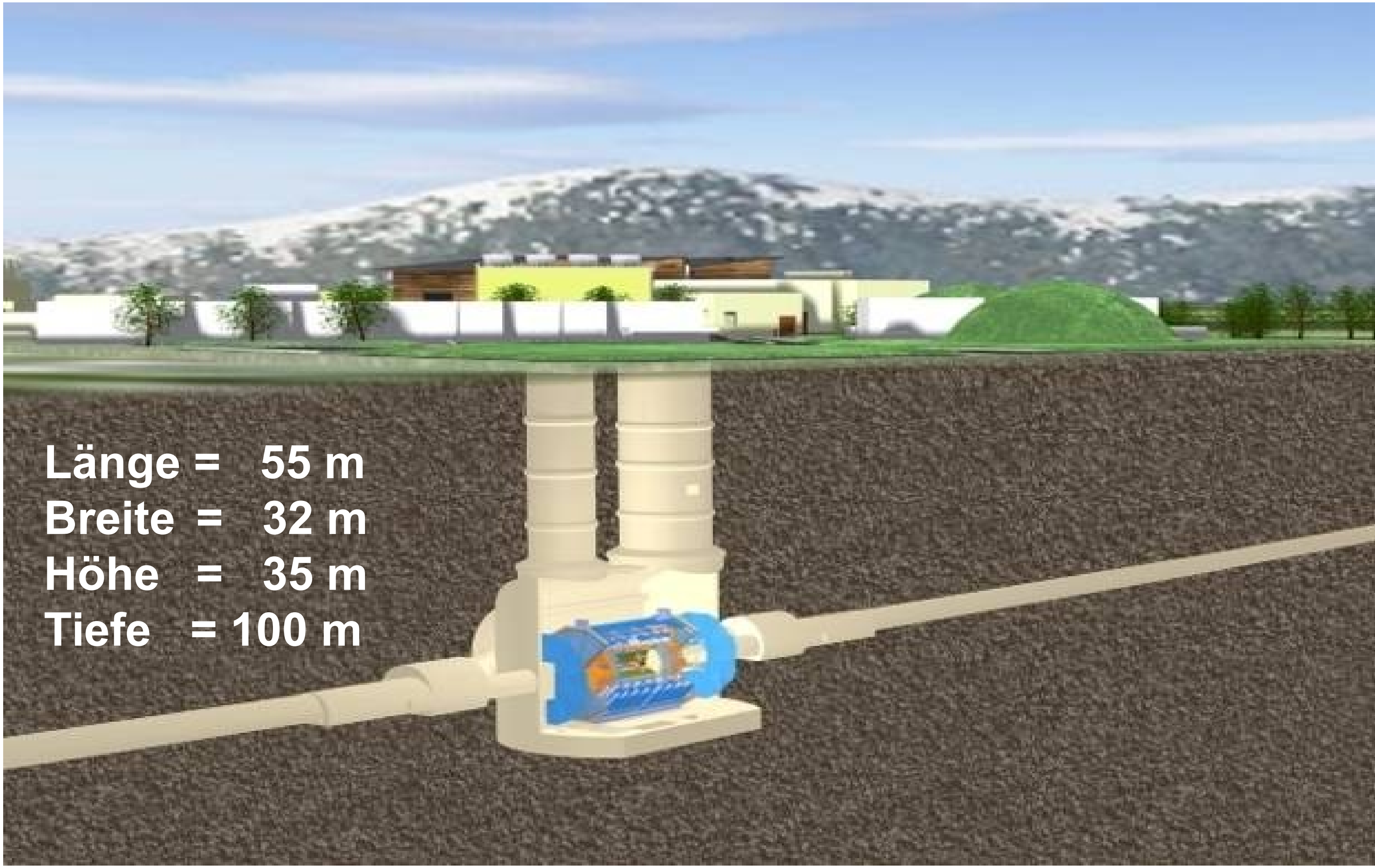
    - training of the magnets

- Some time needed to establish "routine" operation at 6.5 TeV/beam and 25 ns bunch spacing
  - Shorter bunch spacing → huge progress on e-cloud mitigation through scrubbing

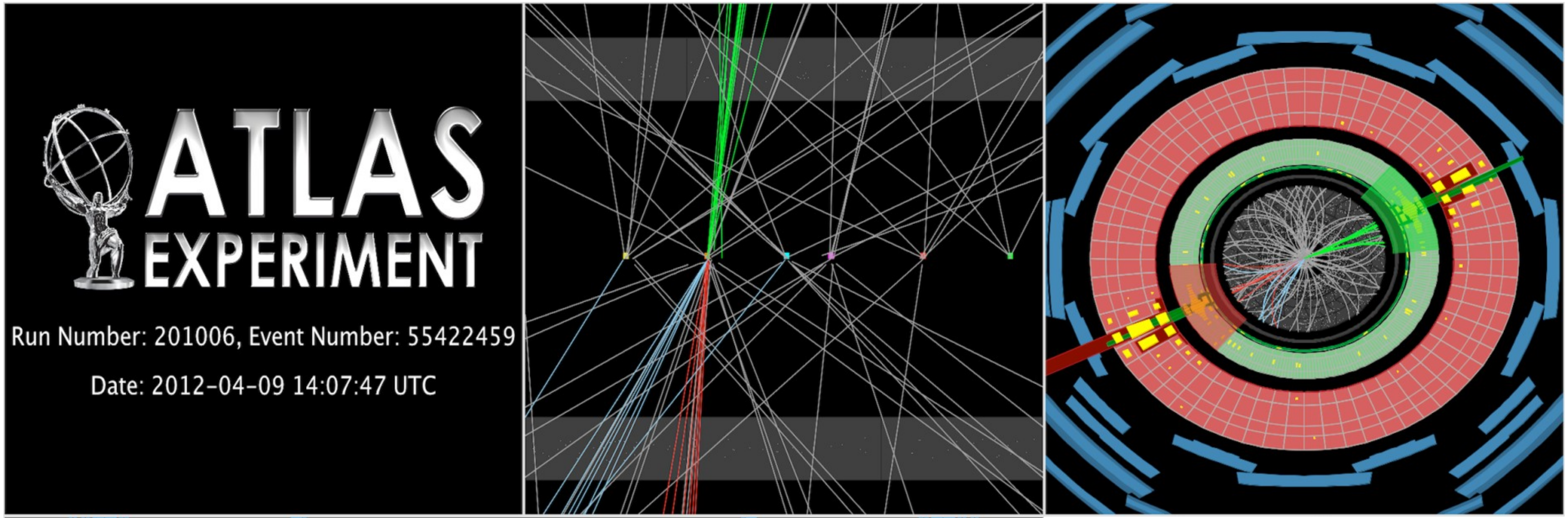
→ Ready for luminosity production in 2016: L ~10^{34} cm^{-2}/s(design), ~30 fb^{-1}/year

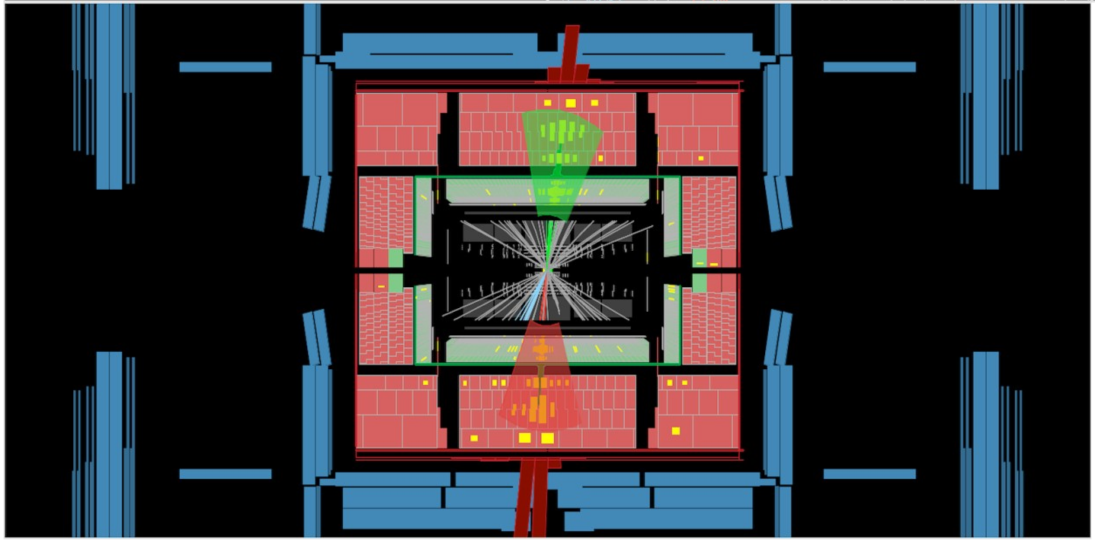


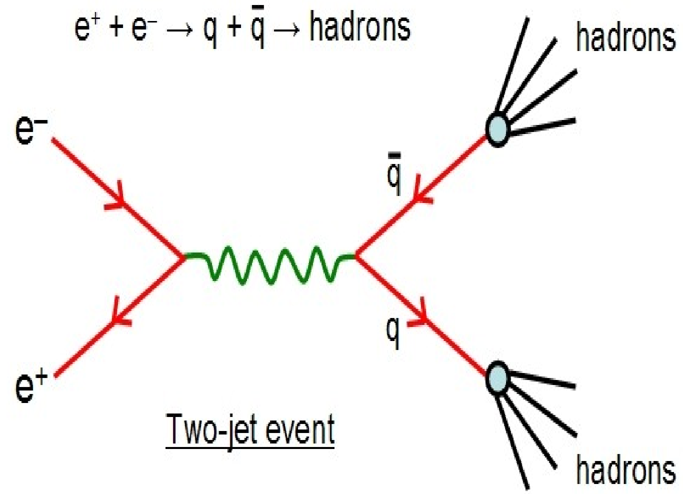
Atlas Detektor



Atlas Detektor

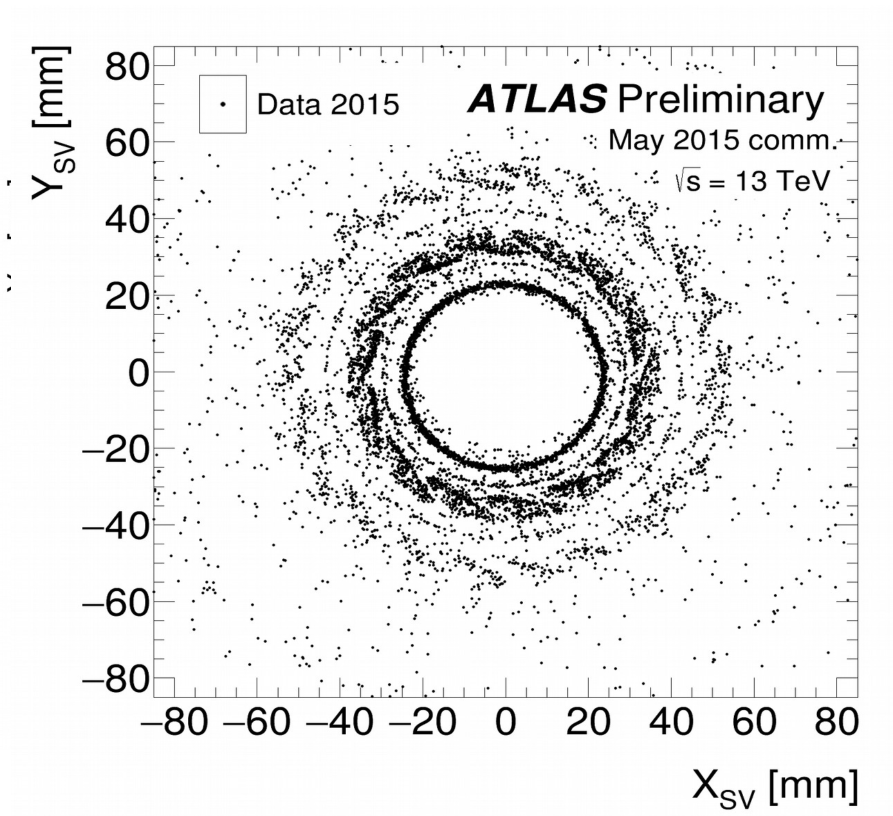


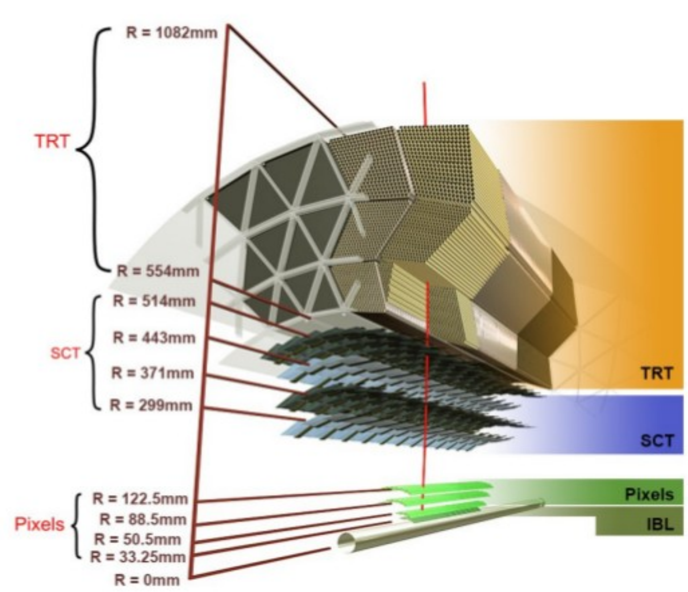




Atlas Detector Improvements

- Added an additional insertable Pixel Layer about 33mm from interaction point:
  - Detector is nearly 100% efficient
  - Huge improvement in impact parameter resolution (b-tagging)





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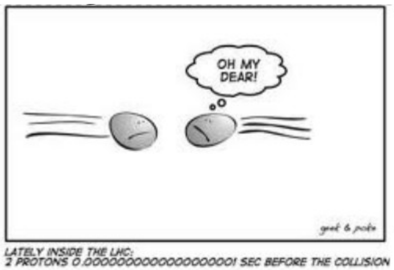
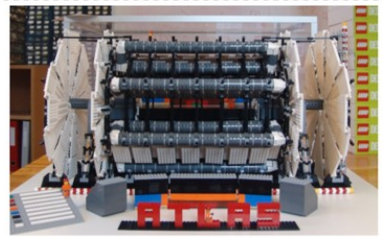
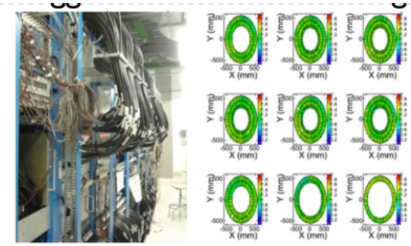
Event data taking and reconstruction

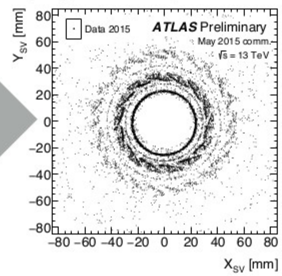


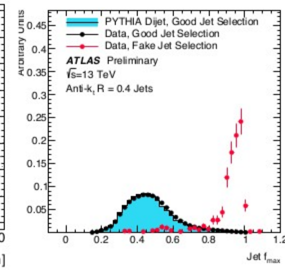




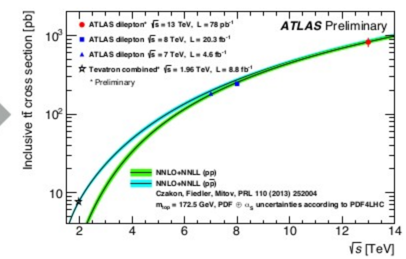
prompt calibration & reconstruction

physics object calibration & uncertainties





measurements & searches

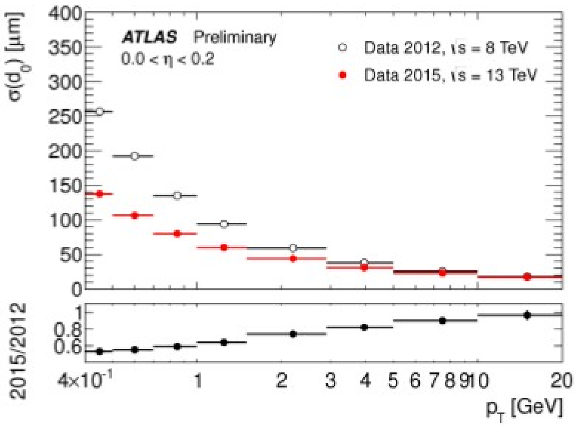


> **Steps necessary for producing a physics results:**

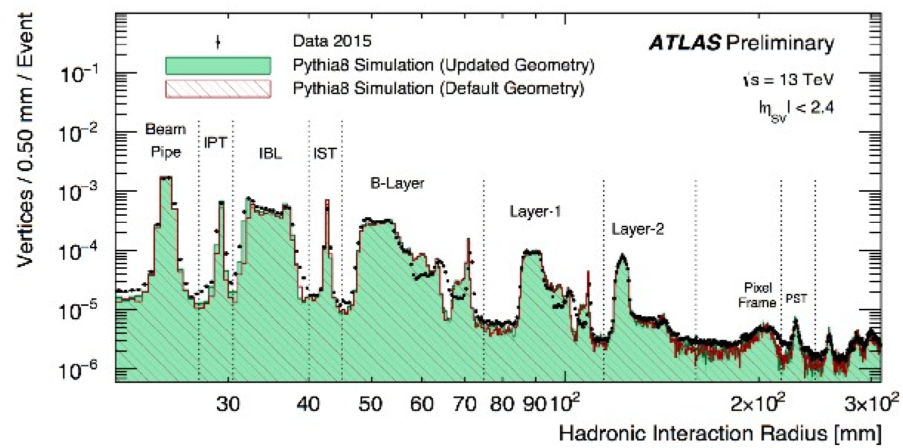
- Data taking, calibration, object reconstruction, unfolding
- On-line reconstruction immediately, first re-calibration ~36h
- First results after a few weeks:
  - Measurement of Standard (Model) Processes
  - Easy to access search signatures

Atlas Detector calibration

IBL: Improved Tracking performance



IBL, new Beam Pipe and Services: Additional material (and main systematic uncertainty for tracking)



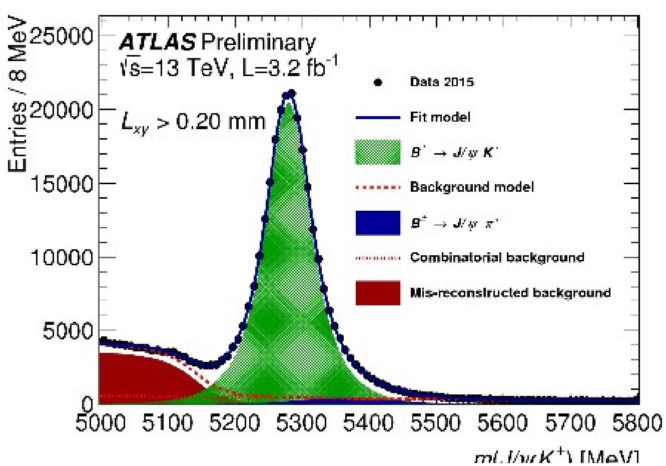
Material studies using hadronic interactions and conversions have led to a new geometry for simulations

Alignment and Tracking Performance check with B± mass

$$B^{\pm} \rightarrow J/\psi K^{\pm}$$

No specific trigger selection

Selection of J/Psi(μμ) and a track (assume Kaon), J/Psi π background from MC



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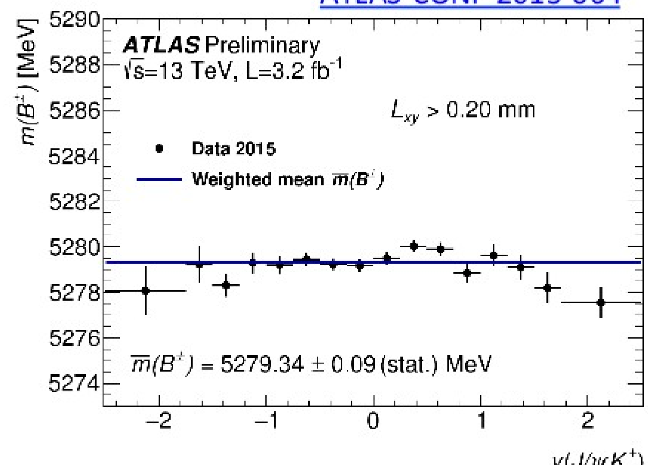
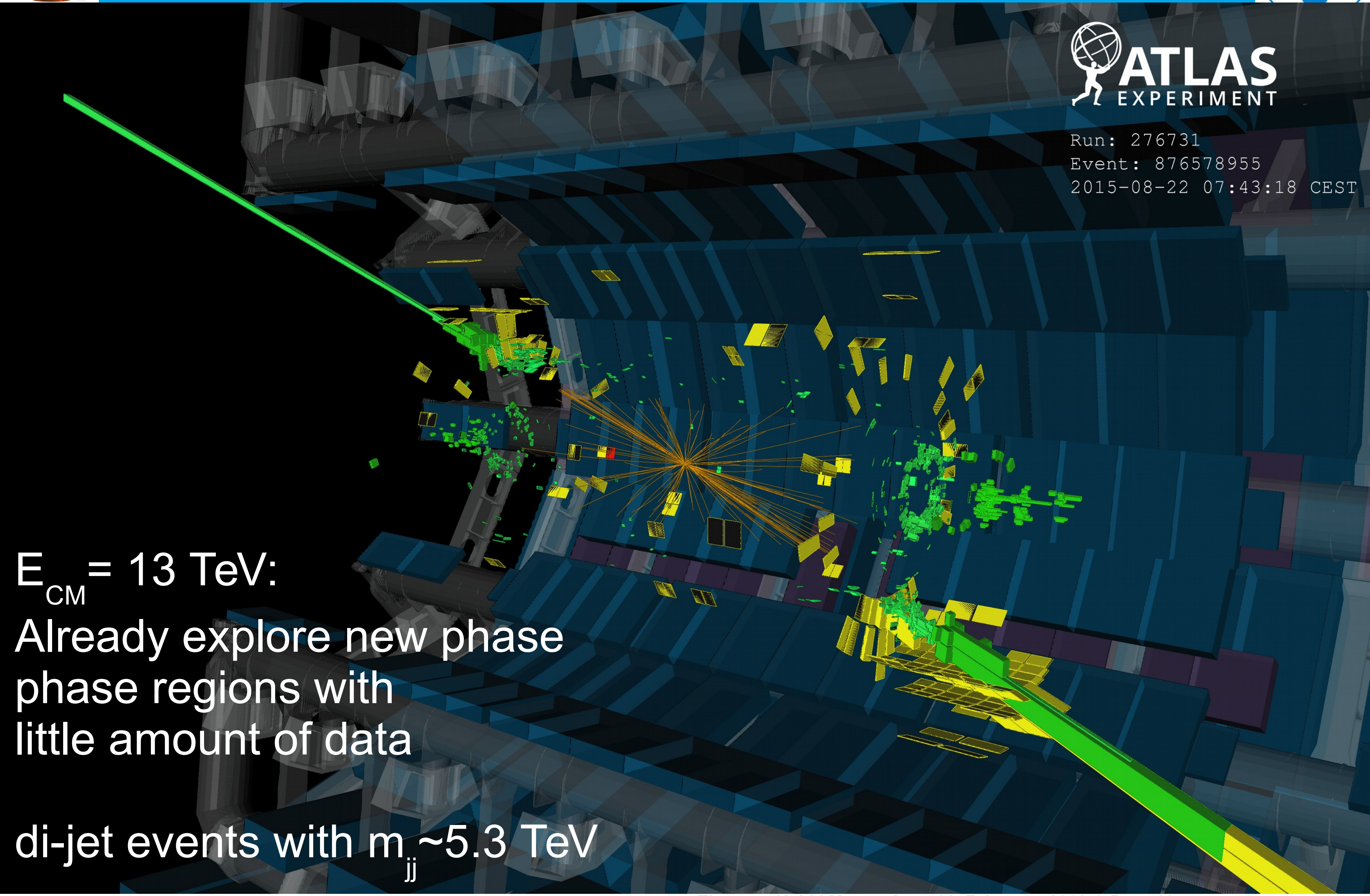


Di-jet event



E_{CM}= 13 TeV:
Already explore new phase
phase regions with
little amount of data

di-jet events with m_{jj}~5.3 TeV

Das Standard Modell

Fundamentale Teilchen:

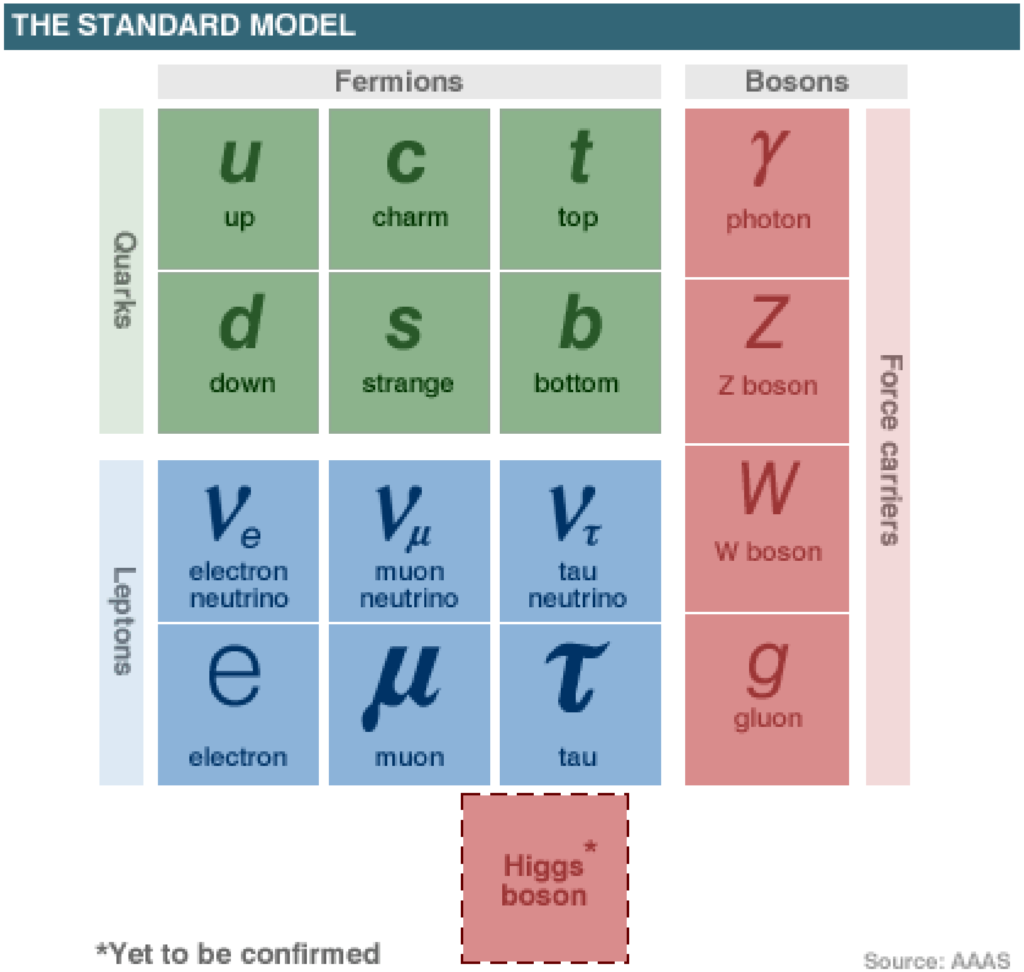
6 Quarks (u, d, c, s, t, b)
6 Leptonen (e, μ, τ, ν_e, ν_μ, ν_τ)

Fundamentale Kräfte:

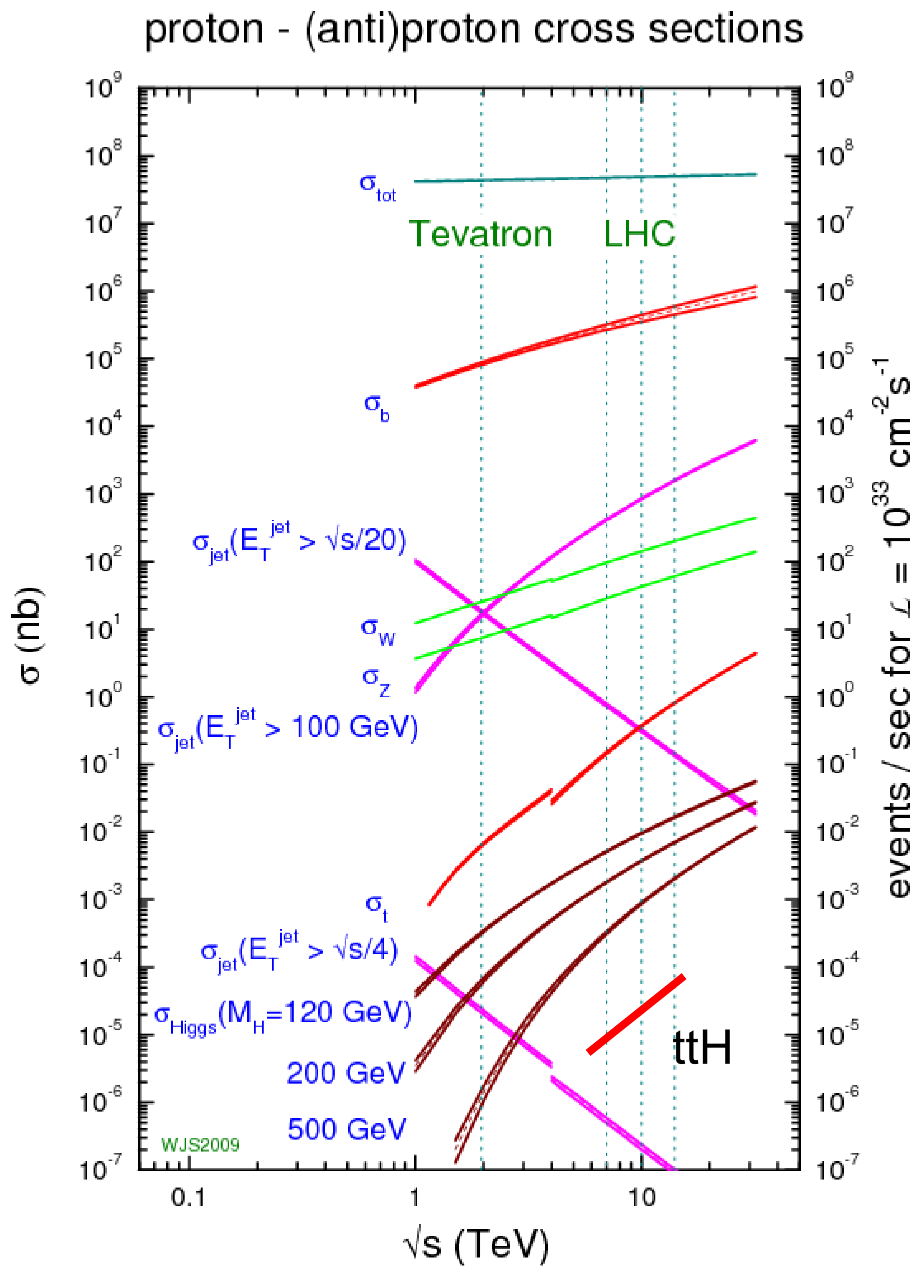
starke Wechselwirkung (g)
schwache Wechselwirkung (W,Z)
elektromagnetische Wechselwirkung (γ)

~1990: Alle bekannt bis auf

- **Top Quark**
- **Higgs-Boson**



Physics Processes at the LHC

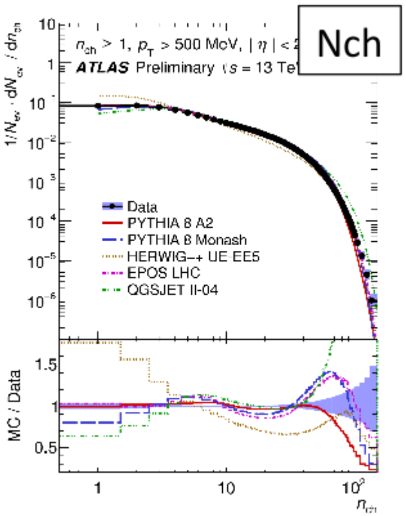


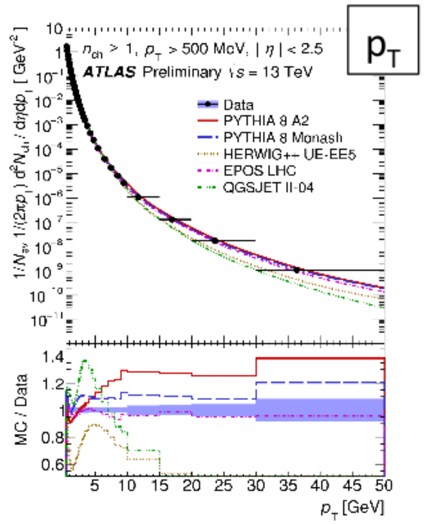
- Total cross section: 100 mb
  - dominant QCD
- Other Standard Model processes $O(10^6\text{-}10^9)$ smaller
- Higgs production: $O(10^{11}\text{-}10^{13})$ smaller
- Rare physic processes profit by increasing energy from 8 TeV to 13 TeV most:
  - W/Z → factor 1.7
  - Top-pairs → factor 3.3
  - ggH → factor 2.3
  - $t\bar{t}H$ → factor 3.9

Standard Model Physics

A2 Minbias tune (for PU)

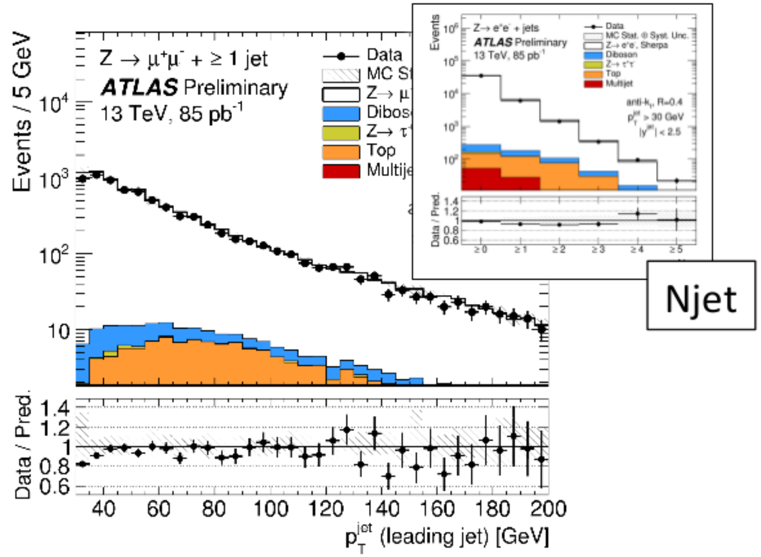
Pythia 6 and 8 (using 7 TeV ATLAS data only)





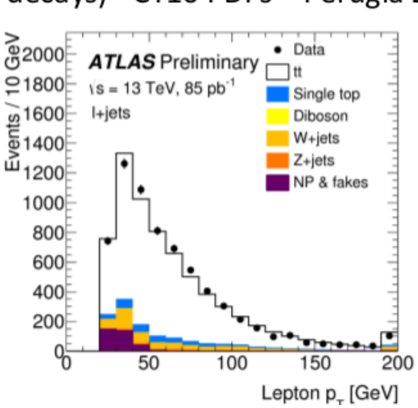
V+Jets , Dibosons, Tribosons

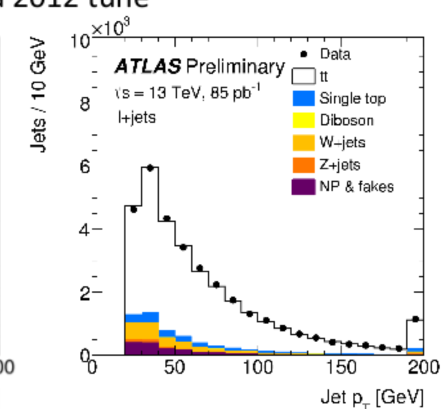
Sherpa NLO (2partons) and LO (up to 4 partons) 2.1.1



Top pair production

Powheg-Box v2 (hdamp =m_t) – Pythia 6.428 – EvtGen (HF decays) - CT10 PDFs – Perugia 2012 tune





Additional samples

(main backgrounds and signals)

e.g. Pythia 8, Sherpa LO, MG5_aMC@NLO

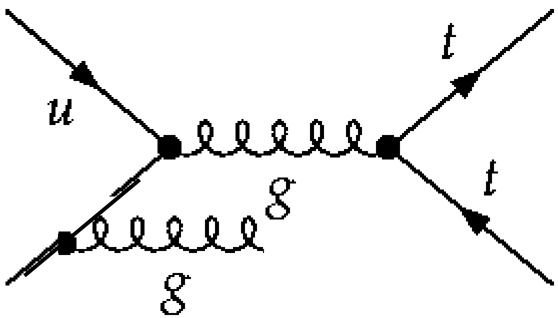
PDFs: CT10, CTEQ6L1, NNPDF3.0

Higher order cross sections used where calculations available

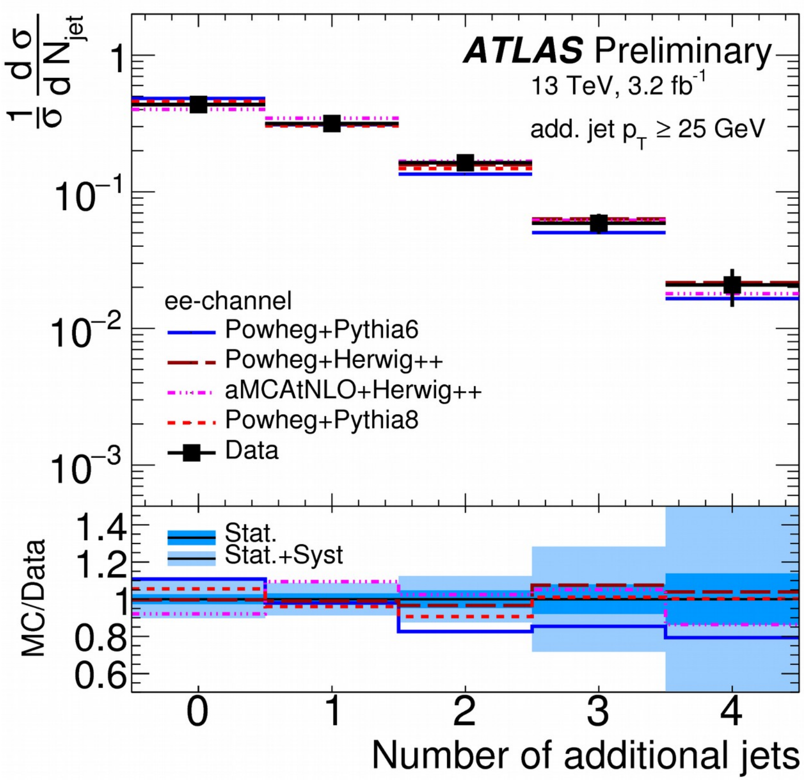
Thanks to the fruitful interactions with theory Community

Jet multiplicity in top-pairs

- Biggest background for ttH is top-pair background with additional jets:

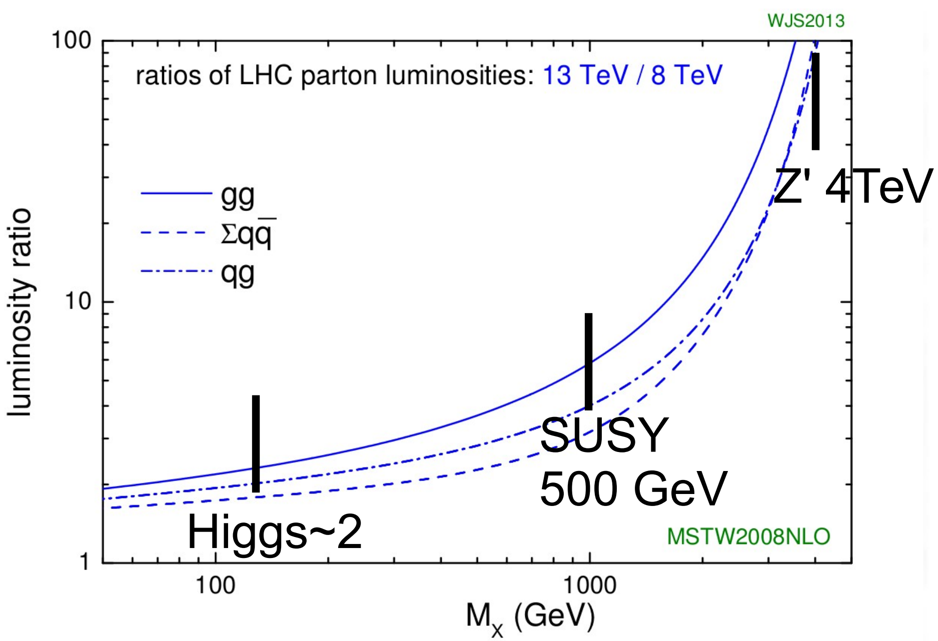


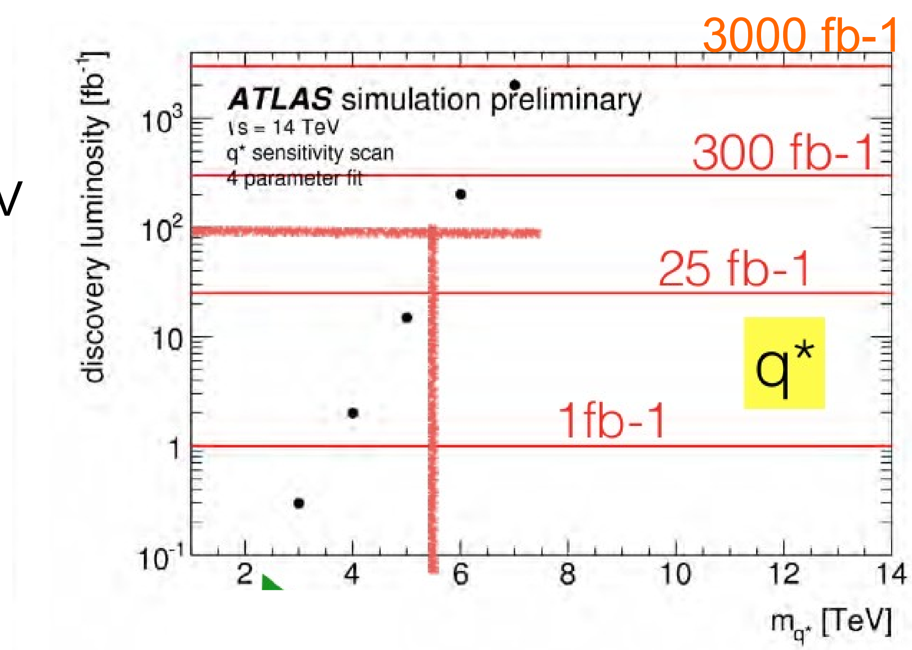
- Di-lepton channel ($t \rightarrow b\ l\nu$), O (10000 events)
- 13 TeV:
  - factor ~3.3+ in x-sections vs 7/8 TeV data taking
  - Established analyses methods:
    → possible in few months of work instead 2-3 years
- Use for Generator development/tuning



Luminosity scaling

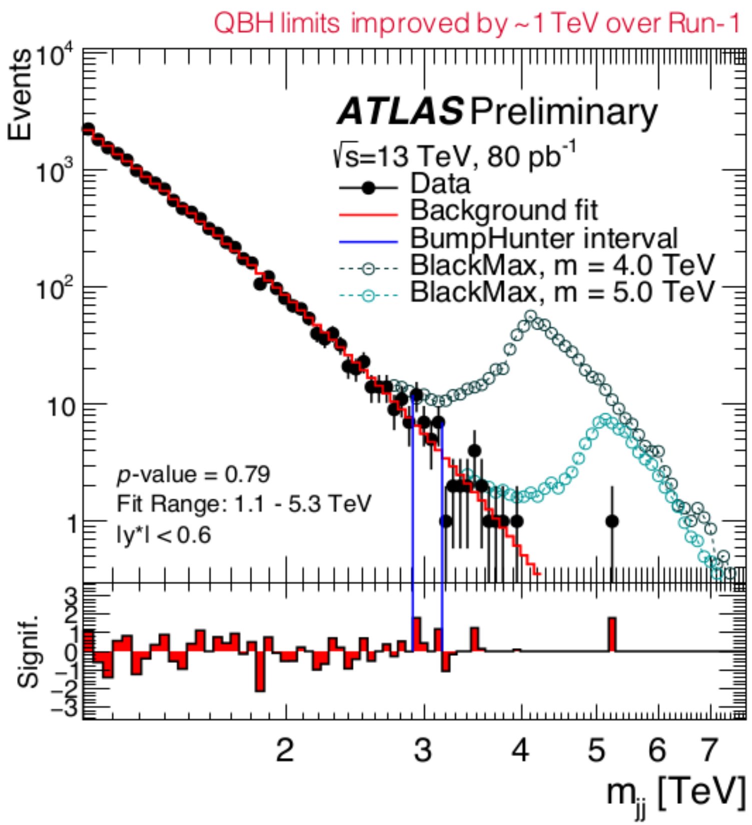
- Most physics happen at a Energy lower then center of mass energy
- Scaling behavior of particle production for a given mass
  - Standard Model: W/Z ~1.7, Top: 3.5
  - Higgs: 2; ttH: 4.5
  - SUSY: 6-50, Heavy exotics particles: up to 1000
- Discovery reach scales with log luminosity
  - Exiting situation in the next months, huge discovery phase space

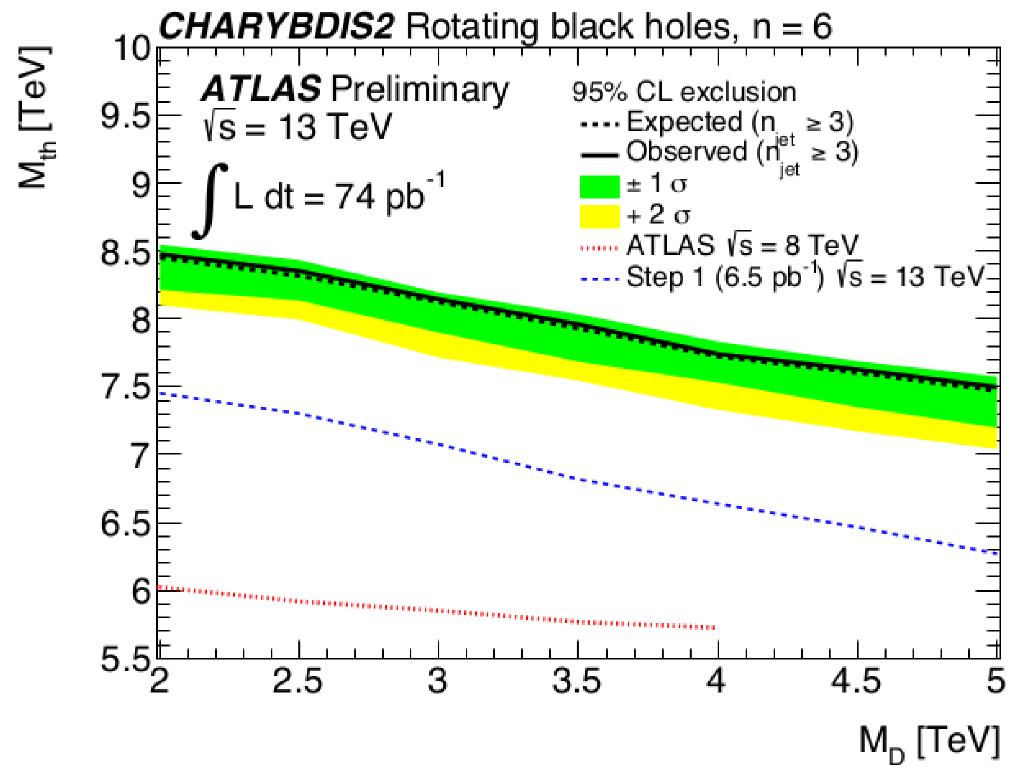




Di-jet measurements and searches

> Jet searches already profit much on additional phase space
  - Improved limits for di-jet signatures vs Run-1 by ~1TeV
  - Huge improvement in multi-jet searches





Measurement of the **Higgs Cross Section** (Combination)

From **Fiducial** to **Total** Inclusive Higgs production cross sections

	13 TeV
Acceptance factor	
$H \to \gamma\gamma$	0.570 ± 0.006
$H \to ZZ^* \to 4\ell$	0.427 ± 0.006
Fiducial cross section [fb]	
$H \to \gamma\gamma$	52^{+40}_{-37}
$H \to ZZ^* \to 4\ell$	$0.6^{+1.3}_{-0.9}$
Total cross section [pb]	
$H \to \gamma\gamma$	40^{+31}_{-28}
$H \to ZZ^* \to 4\ell$	12^{+25}_{-16}
Combination	24^{+20}_{-17} (stat.) $^{+7}_{-3}$ (syst.)
LHC-XS	$50.9^{+4.5}_{-4.4}$

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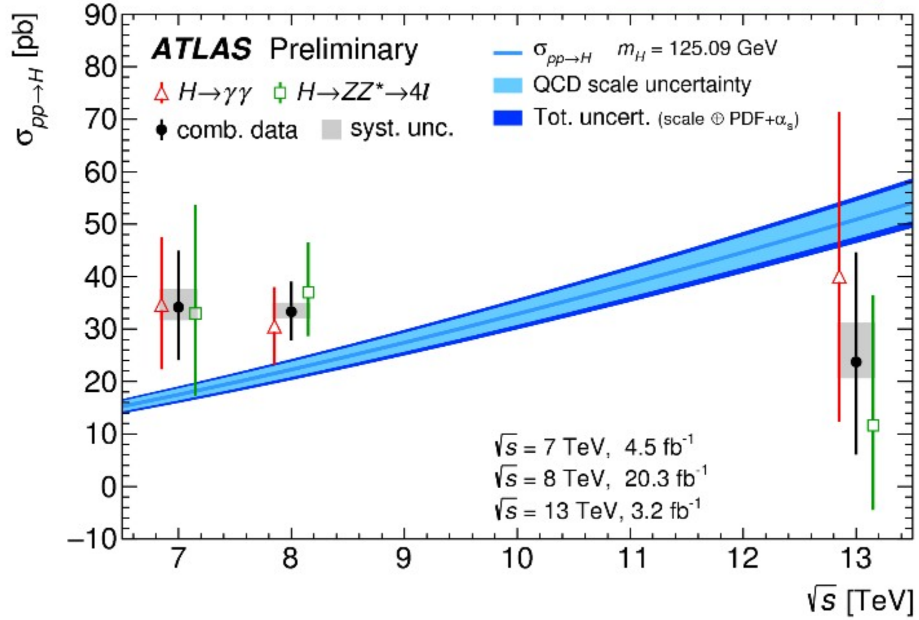
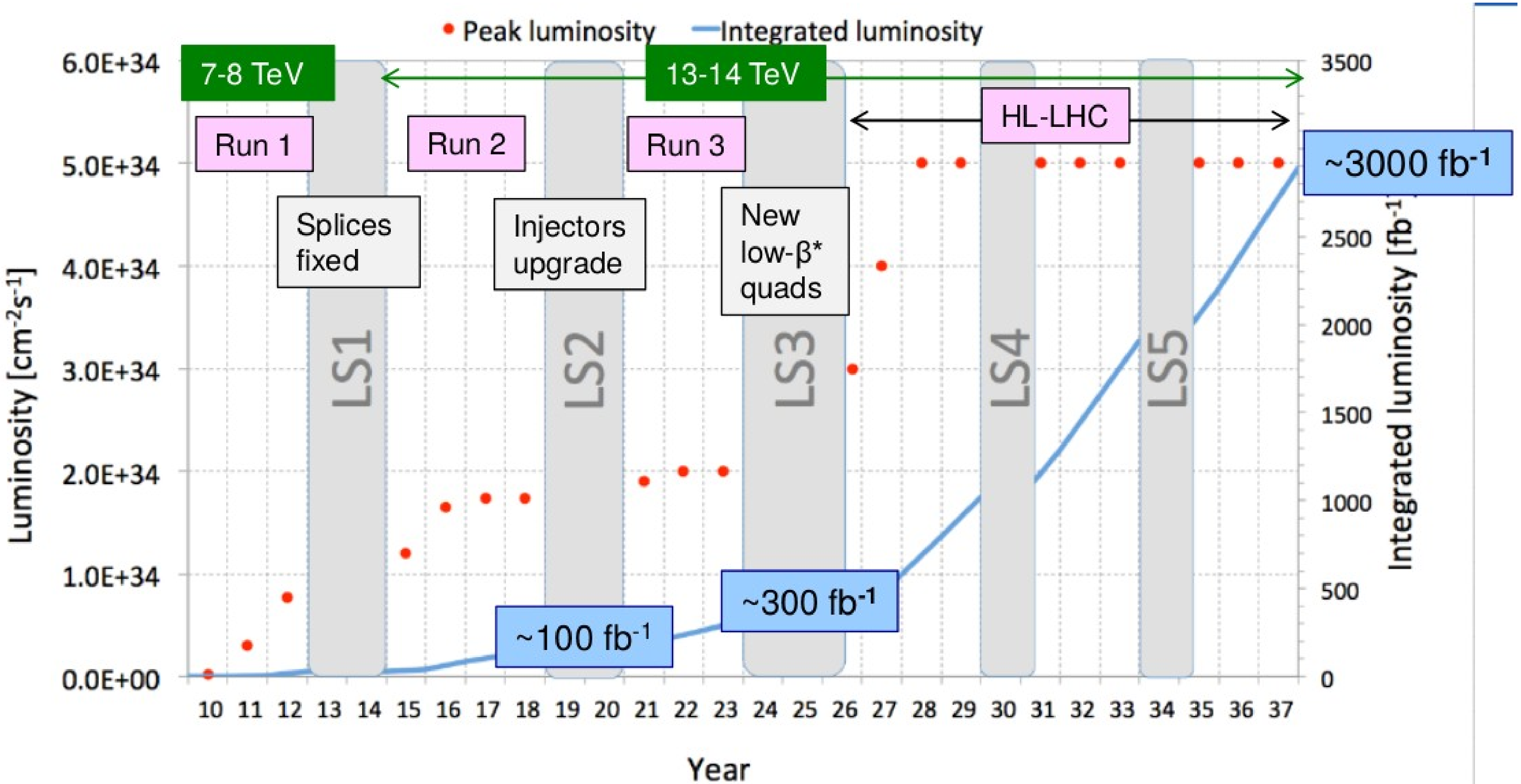


Combined observation significance:

- Expected: **3.4σ**
- Observed: **1.4σ**

Compatibility with SM: **1.3σ**

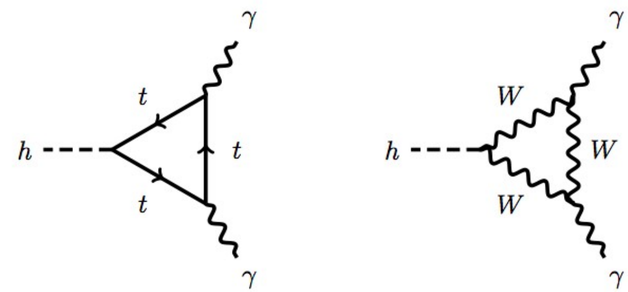
Future of LHC and HL-LHC

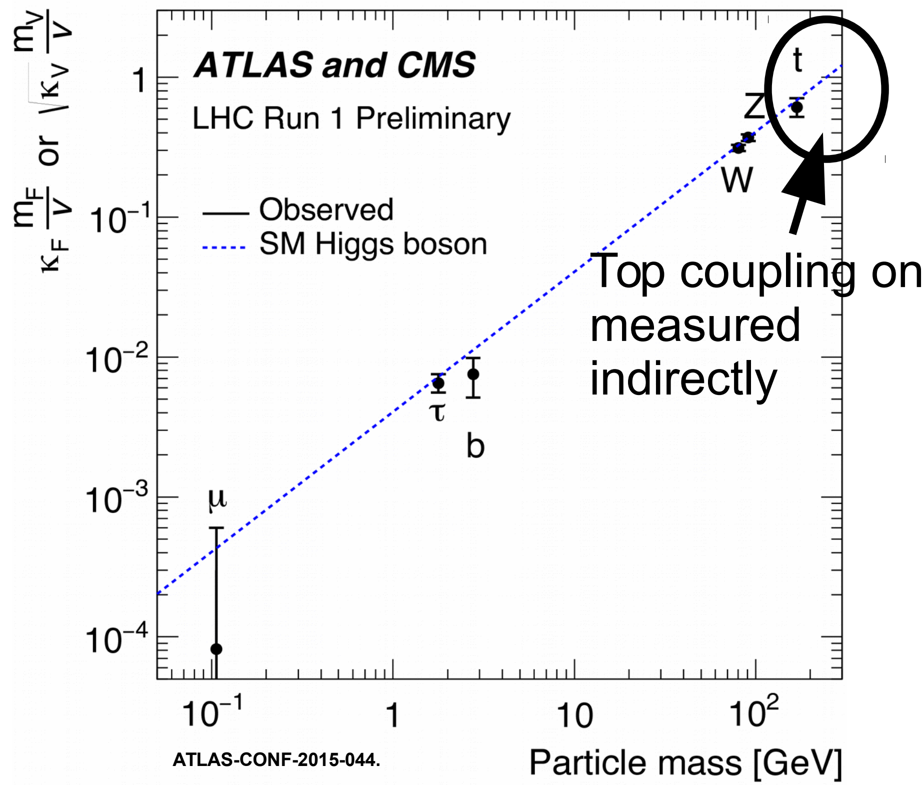


- Program is planned till 2037:
  - Run-2/3: LHC will run an other 3 years, then minor updates of detector, afterwards 3 years of data taking (~300 fb^{-1})
  - LS3: huge changes in detectors and machine for HL-LHC

What do we know about the Higgs

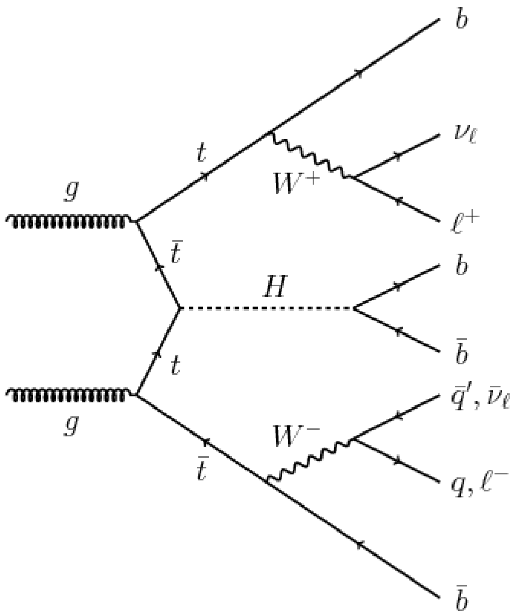
- Mass: 125.5 ± 0.6 GeV
- Spin: 0+ (2+ excluded by 99.9% CL)
- Couplings to bosons:
  - $\mu = \sigma_{measured} / \sigma_{SM}$
- Only one fermionic coupling:
  - New: $\tau\tau$ (4σ evidence)
  - Strong evidence (3σ) for $b\bar{b}$
  - Top coulpling: indirect access via $H \rightarrow \gamma\gamma$
- Missing:
  - Direct measurement of top-coupling (~few 100 fb^{-1})
  - Higgs self coupling



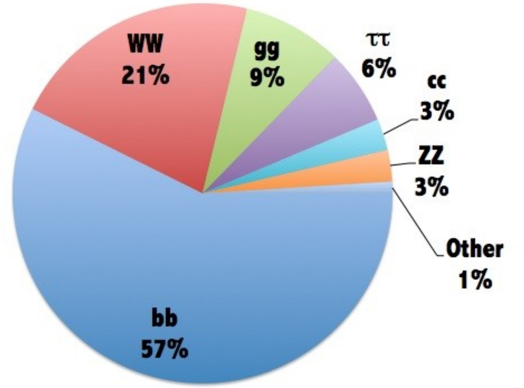


$t\bar{t}H$: Effective (topological) cross section

- Only one fermionic coupling directly measured:
  H → ττ
  → λ_{bH} and λ_{tH} missing to get a complete picture
- λ_{tH} only huge coupling close to 1
  - Why is the difference in couplings that big?
  - Biggest sensitivity for new physics
- In SUSY expect different couplings than SM:
  - $b\bar{b}$ and ττ production bigger at high tanβ
- H → $t\bar{t}$ is not possible because $m_H < 2\, m_{top}$
  - Measurement of λ_{tH} in production via radiation from a top pair



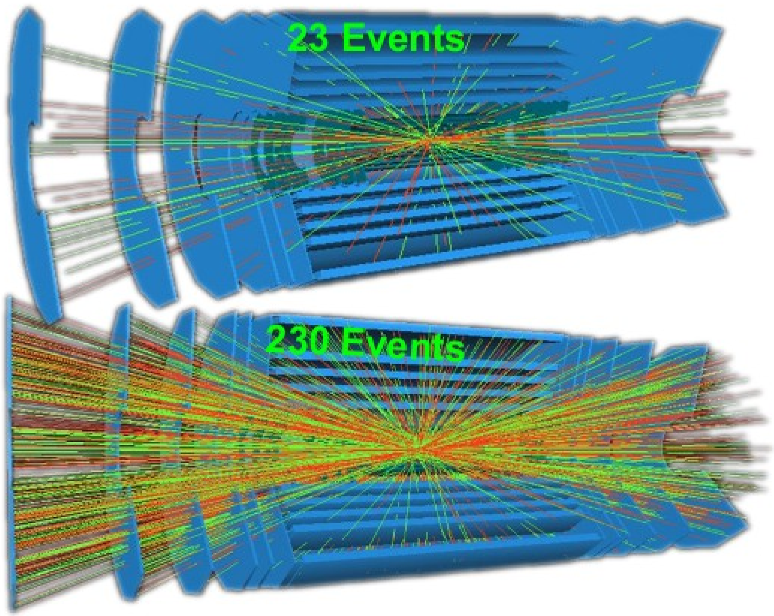
Higgs decays at m_H=125GeV

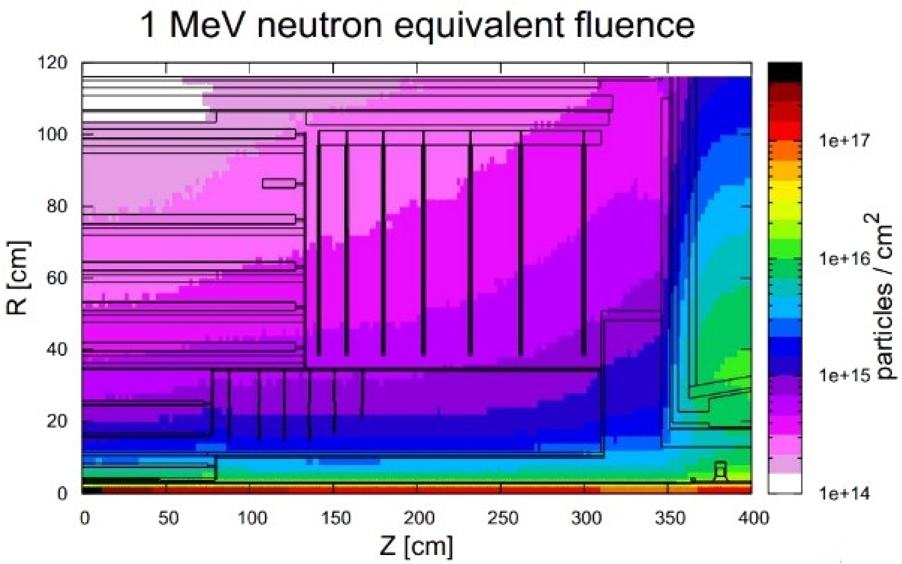


H→ γγ ~10^{-6}

After LS3: High Lumi LHC

- Upgrade the LHC to “High Luminosity (HL)” to gain access to rare processes (very high Energy / low cross section
- “default” LHC to deliver up to ~300 fb^{-1} per experiment until 2023
- HL-LHC from 2026 up to 3000 fb^{-1}
  - extended sensitivity, see Thomas’ talk
  - “Pileup” of <140> events simultaneously to an event of interest
  - Unprecedented levels of radiation (up to 10^{15} neq/cm^2 in the strip det area)

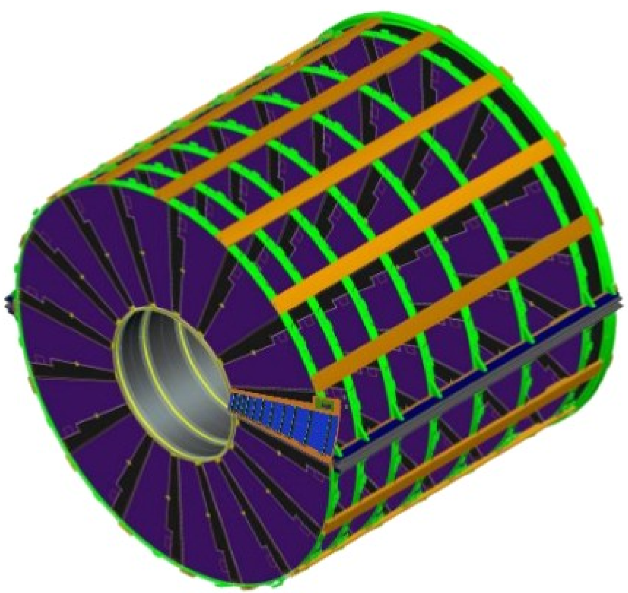


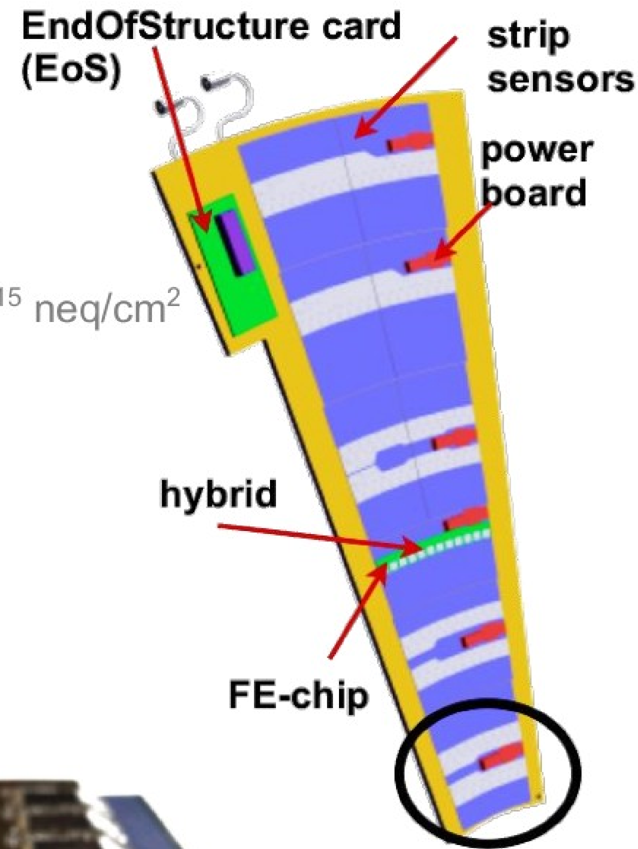


After LS3: Upgrade of Inner Detector

ATLAS tracking detector Upgrade (only Si-strip part here)

- Current Si-strip detector (SCT) manages to
  - measure until ~600 fb^{-1} are reached
  - differentiate pile-up up to ~<60> events
- Does not agree with HL-LHC parameters
- **Strip-tracker-Upgrade** - targets
  - Radiation hardness up to 3000 fb^{-1} resp. $2*10^{15}$ neq/cm^2
  - Granularity about 4x finer than current SCT
  - Track-Trigger, less material, ...





Summary

- LHC: Moved to data taking at a center of mass energy of 13 TeV
  - Few problems related to new running mode (smaller bunch spacing
  - Steep learning curve to the end ~ 4 fb^{-1} delivered
- Atlas:
  - New innermost silicon layer in tracker, phase of understanding the new devices is finished
  - Smooth data taking : recorded ~ 90% of delivered data
  - First results are shown in August, with full dataset in December
  - Many exiting results will come in 2016:

    - precision Higgs physics

    - Searches for more complicated or rare signatures (SUSY)
- Future:
  - Hunt for the new and unexpected
  - ~ 2017/18: first results for ttH
  - Higgs self couplings need HL-LHC