The ATLAS Detector
- Data Analysis -

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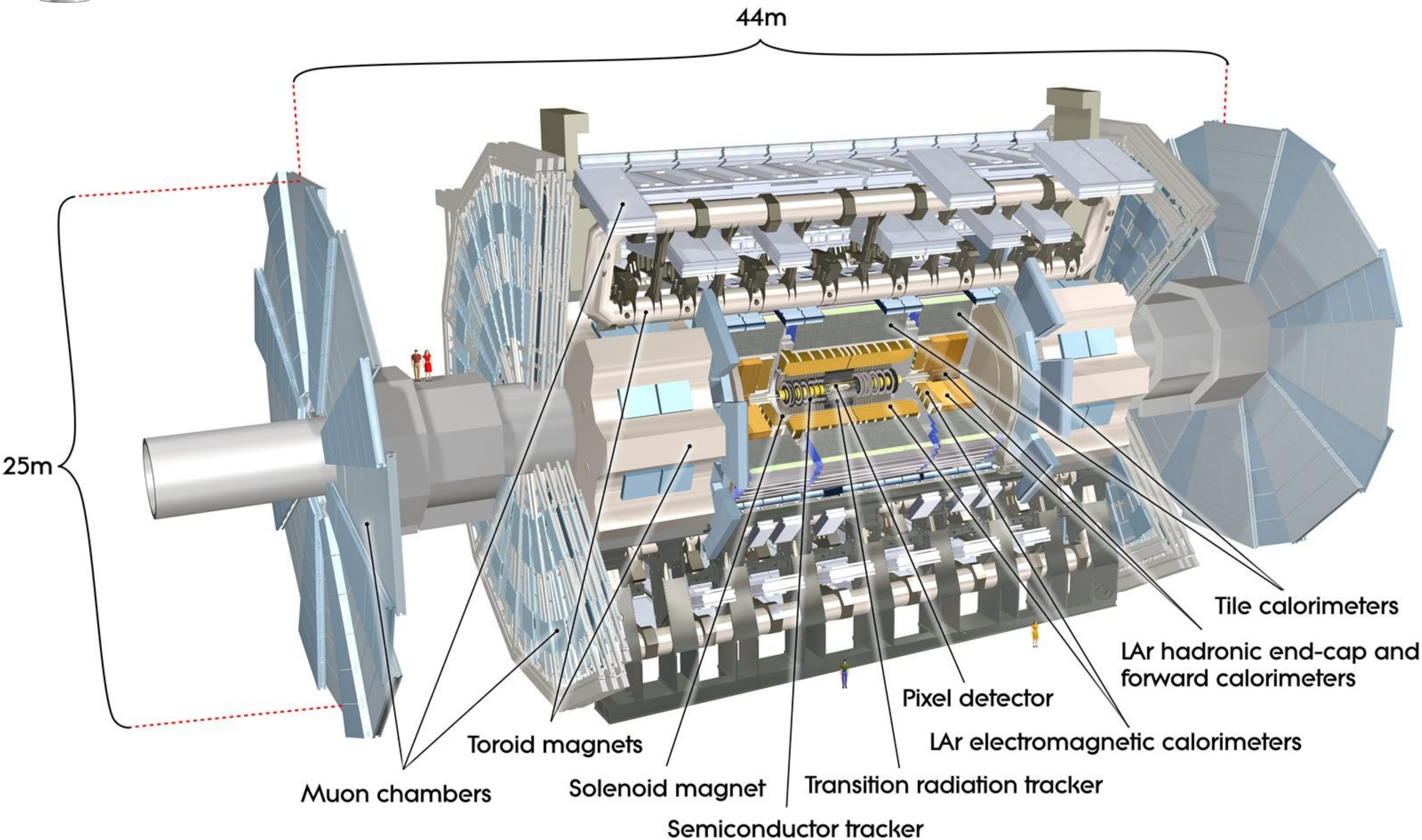
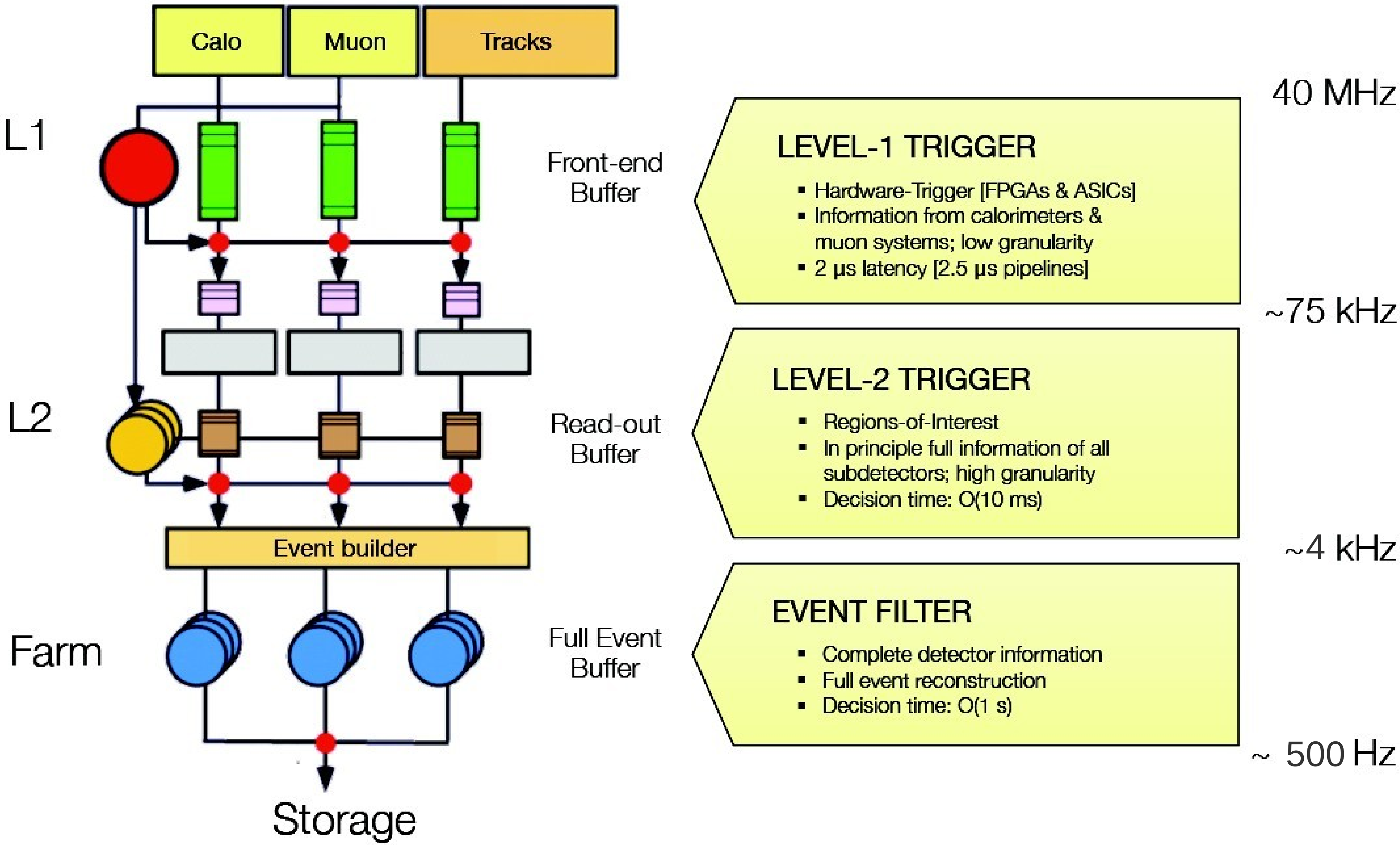
Outline: 1st lecture: The Detector
2nd lecture: The Trigger
3rd lecture: The Analysis (mine)

Reminder



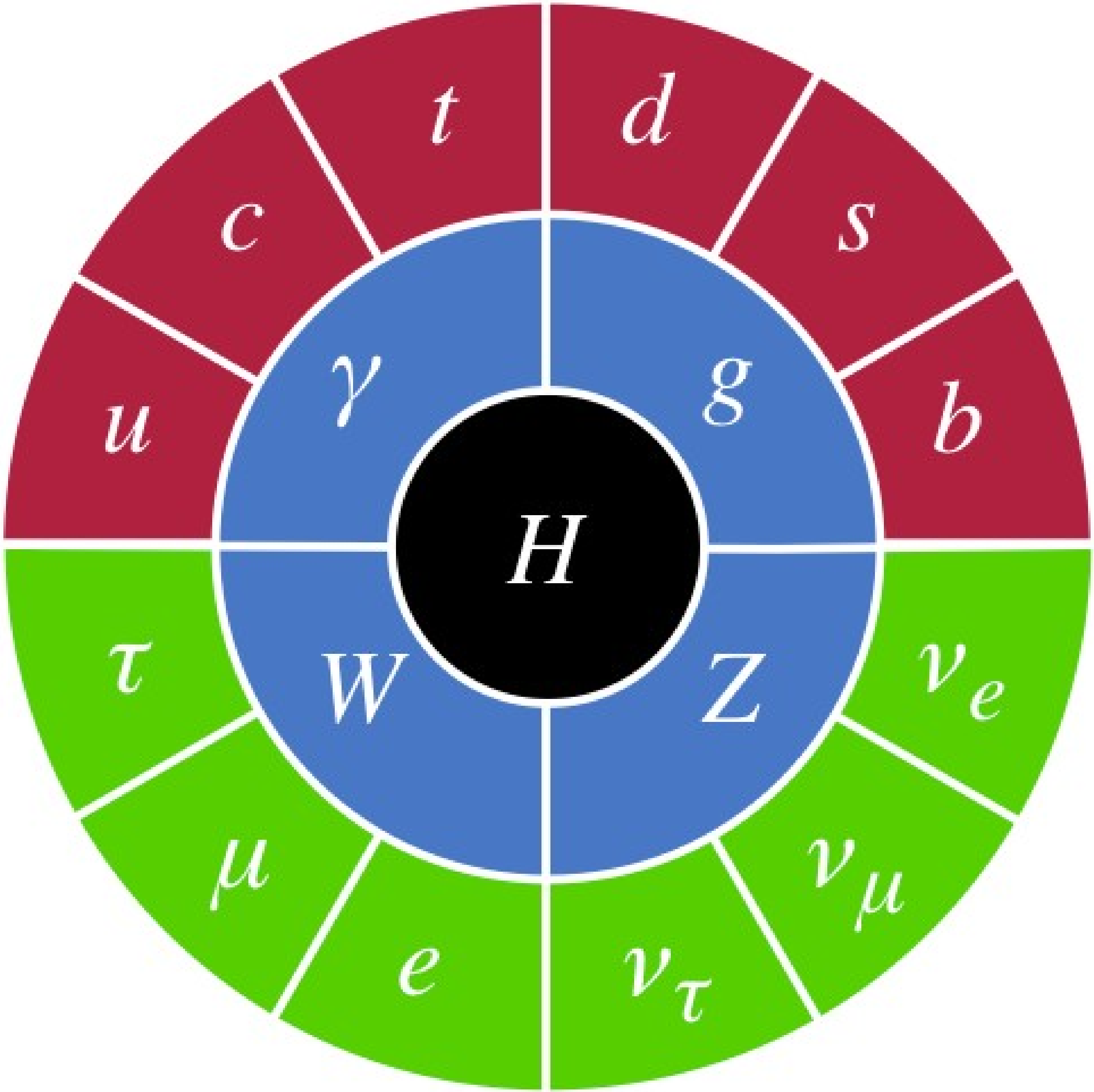
44m
25m
Tile calorimeters
LAr hadronic end-cap and forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Transition radiation tracker
Solenoid magnet
Muon chambers
Semiconductor tracker

Reminder



Calo
Muon
Tracks
L1
Front-end Buffer
L2
Read-out Buffer
Event builder
Farm
Full Event Buffer
Storage
40 MHz
LEVEL-1 TRIGGER
▪ Hardware-Trigger [FPGAs & ASICs]
▪ Information from calorimeters & muon systems; low granularity
▪ 2 µs latency [2.5 µs pipelines]
~75 kHz
LEVEL-2 TRIGGER
▪ Regions-of-Interest
▪ In principle full information of all subdetectors; high granularity
▪ Decision time: O(10 ms)
~4 kHz
EVENT FILTER
▪ Complete detector information
▪ Full event reconstruction
▪ Decision time: O(1 s)
~ 500 Hz

Standard Model of Particle Physics



particlefever.com

Standard Model of Particle Physics

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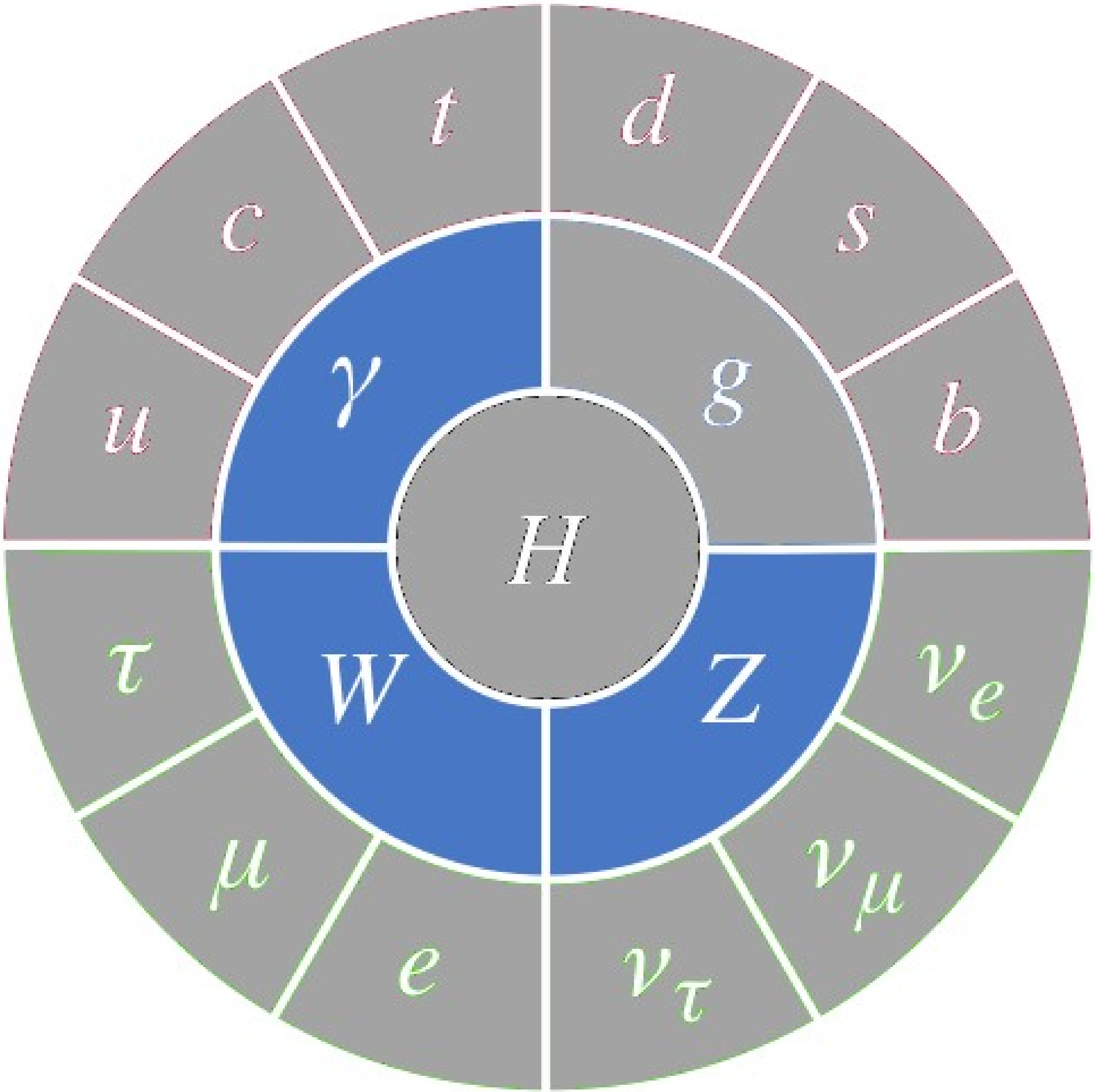


particlefever.com

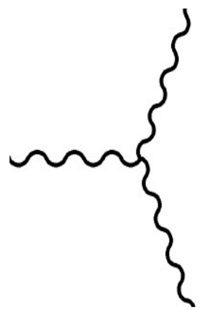
Electroweak Sector

- Based on $SU(2)_L$ x $U(1)_Y$ gauge group (non-Abelian)

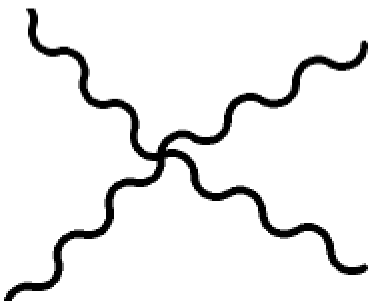
→ weak vector bosons carry charge and interact

- EW gauge boson self-coupling occurs through trilinear and quartic vertices:

trilinear gauge boson vertex



quartic gauge boson vertex

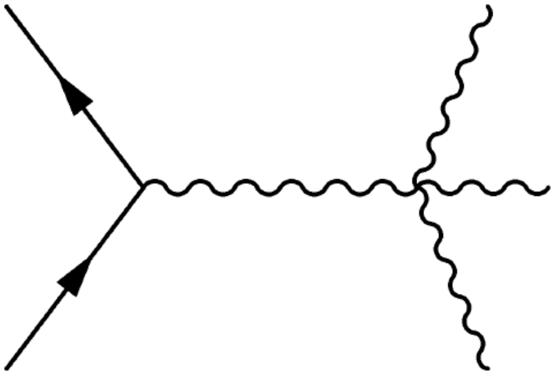


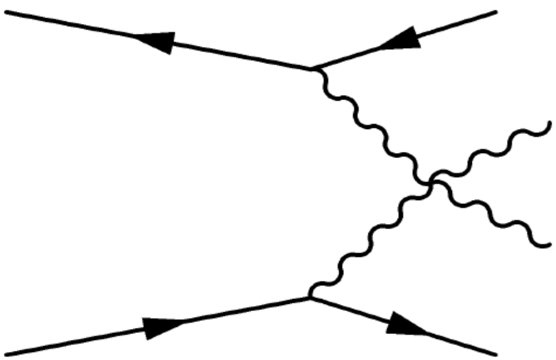
- Self-coupling fully described by the Standard Model

→ measuring these provides direct test of SM

Quartic Gauge Couplings

- quartic gauge couplings can be studied in two or three boson final states





- anomalies in quartic couplings (aQGC) would increase probability for this vertex

→ would manifest in increased boson production

Anom. Quartic Gauge Couplings

aQGCs usually described by effective Lagrangian

- add higher dimensional (dim. 6 or 8) operators to SM Lagrangian $\mathcal{L}$:

$$\mathcal{L}^{\mathrm{aQGC}} = \mathcal{L}^{\mathrm{SM}} + \mathcal{L}^{\mathrm{highDim}}$$

$\mathcal{L}^{\mathrm{highDim}} = \Sigma$ (coupling parameter) * (higher dim. Operator)

coupling parameters e. g. a_C^W, a_0^W, f_{T0}, ...
→ used to set limits on

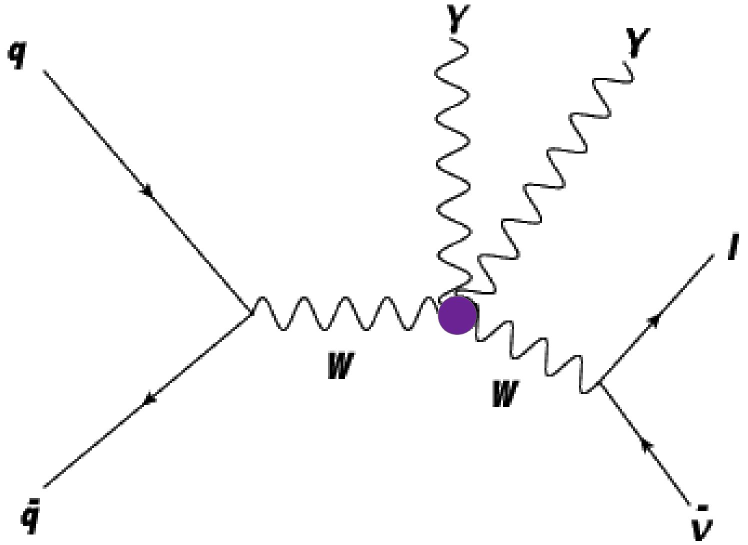
→ Model independent

Quartic Gauge Couplings

- not many aQGC results due to high multiplicity final states
  → need a lot of data

- possibility to find processes that have never been observed!

  e.g. $W\gamma\gamma$ final states



Wγγ Production

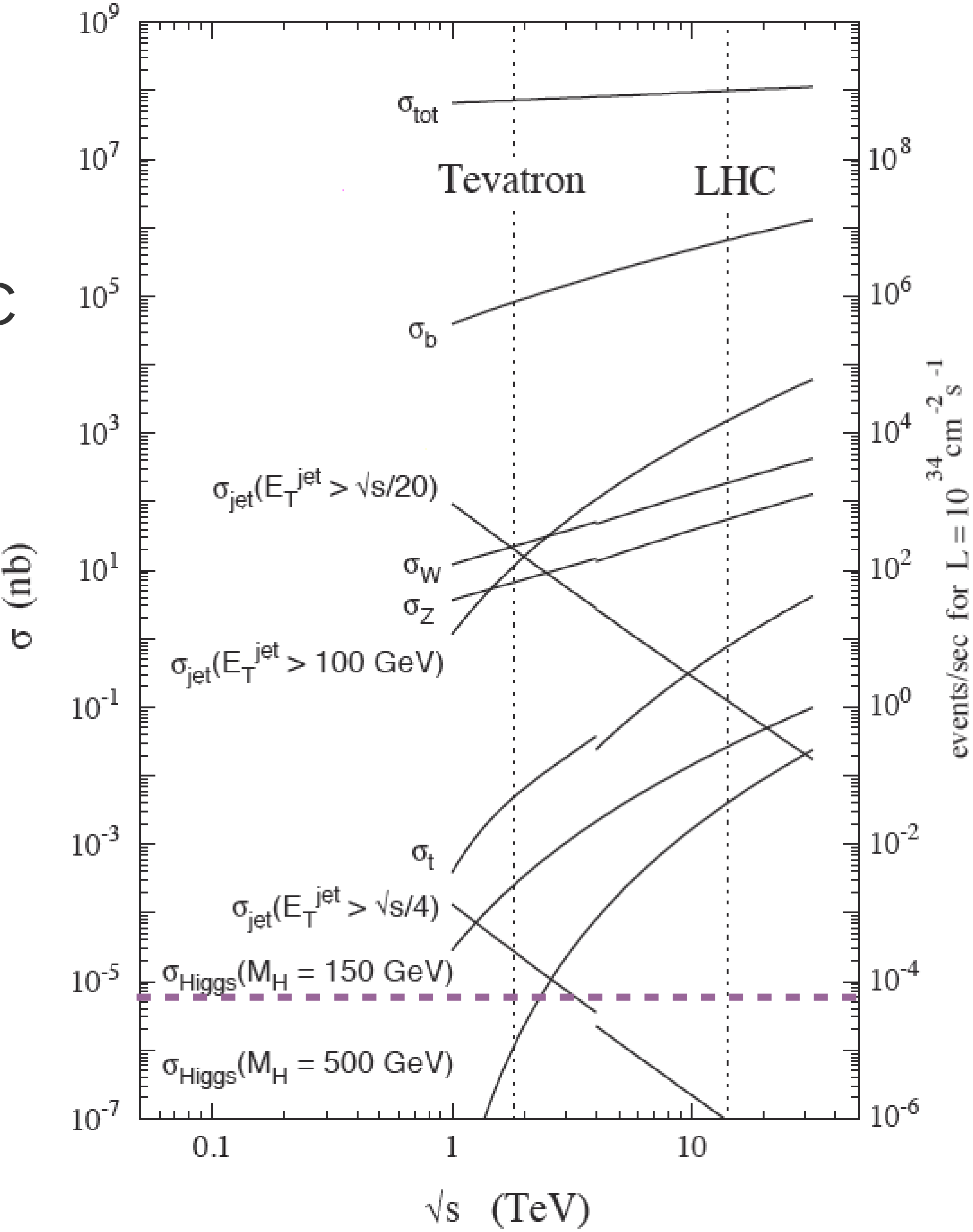
- among first three-boson final states measurable at the LHC
- expectation: (5.76 ± 0.04) fb

  → with $\mathscr{L}$ = 20.3 fb^{-1} in 2012

  ca. 100 signal events

- challenge:

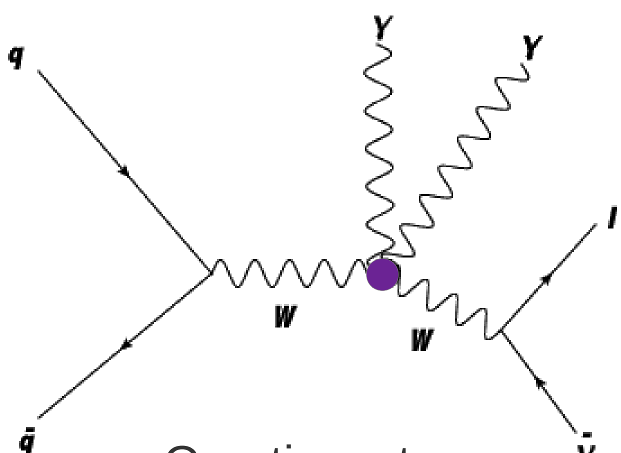
  Dig out these events



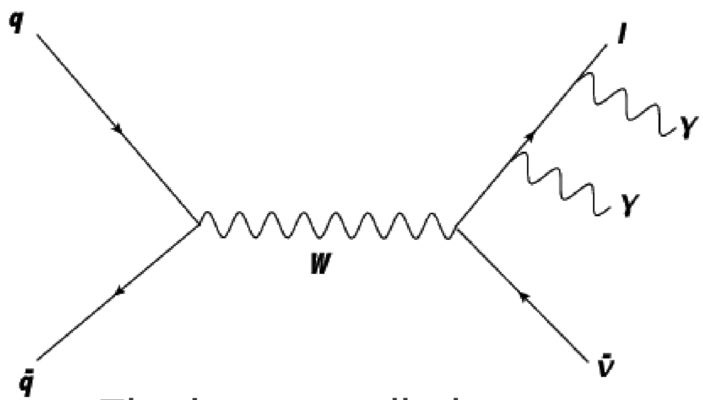
Wγγ Production

- sensitive to the WWγγ coupling

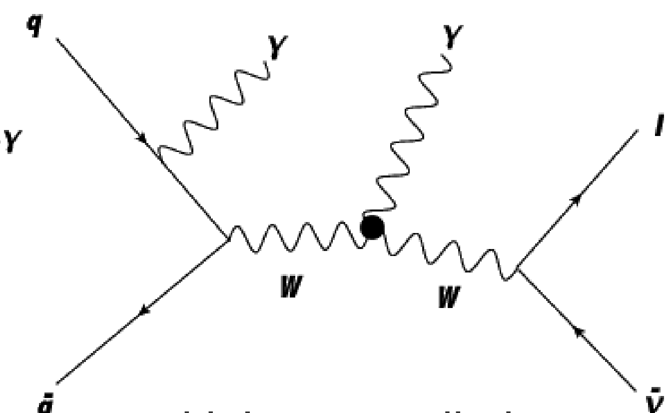
- sensitive to anomalies in this quartic gauge coupling



Quartic vertex



Final state radiation

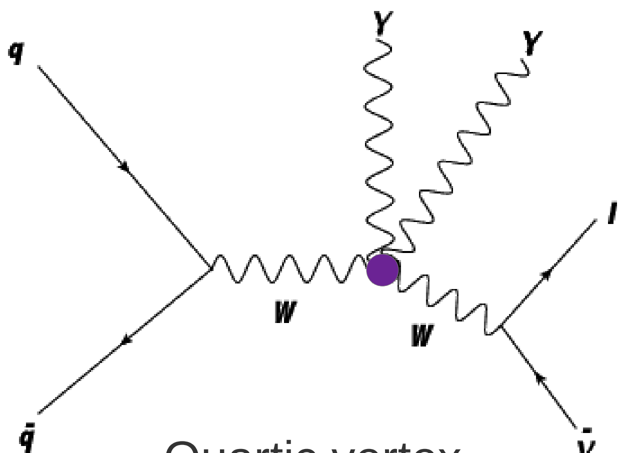


Initial state radiation

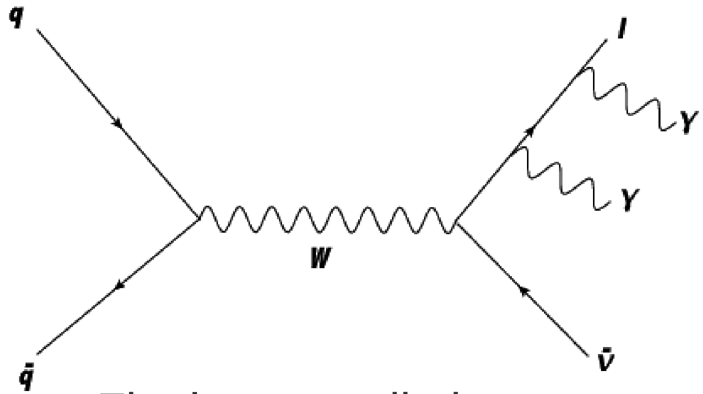
Wγγ Production

- sensitive to the WWγγ coupling
  → measure cross-section

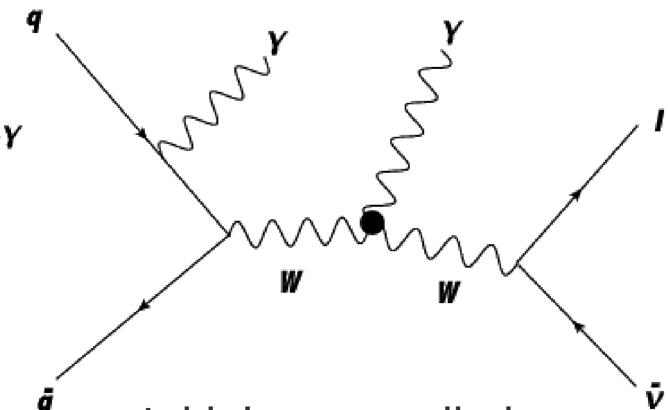
- sensitive to anomalies in this quartic gauge coupling
  → set limits on aQGCs



Quartic vertex



Final state radiation



Initial state radiation

Cross-Section Measurement

$$\sigma_{W\gamma\gamma} = \frac{N}{\int \mathcal{L} dt}$$

N: Observed signal events, $\mathcal{L}$: Luminosity

Cross-Section Measurement

$$\sigma_{W\gamma\gamma} = \frac{N}{\int \mathcal{L} dt}$$

N: Observed signal events, $\mathcal{L}$: Luminosity

Fiducial region (signal region): Restricted phase space and geometric region in which the signal events are counted

$$\sigma^{fid}_{W\gamma\gamma} = \frac{N^{obs} - N^{bkg}}{\int \mathcal{L} dt \times C}$$

C: Correction factor – Measure for detector acceptance and reconstruction efficiency

Wγγ Selection

Leptonic or hadronic final states?

- Hadronic:

  + Gain in W branching ratio

  - Increased amount of background (dijets)

- Leptonic:

  + Clean final state

  - less events compared to hadronic channel

Leptonic final states:

- 1 W-Boson:
  - 1 lepton (e/μ), p_T > 20 GeV
  - E_T^{miss} > 25 GeV
  - m_T > 40 GeV

    $m_T = 2p_T^{lep}E_T^{miss}(1 - \cos\Delta\varphi)$

- 2 isolated photons
  - E_T > 20 GeV

Backgrounds

Ideal case: define signal region without background (signal only)

- requires variables that discriminate signal from background

→ not always possible

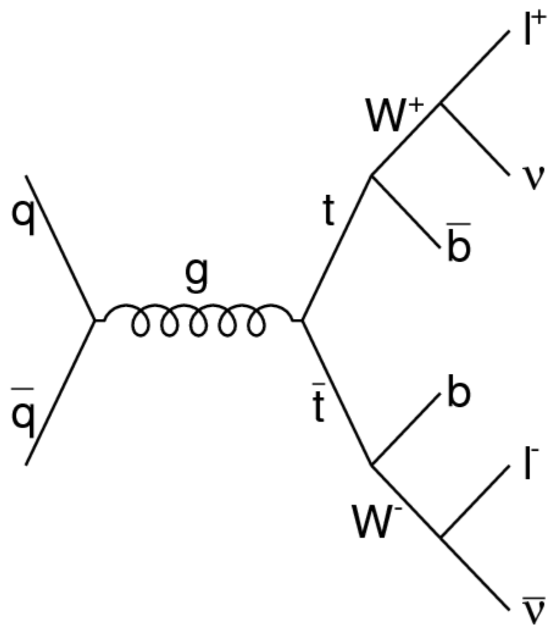
Precise background knowledge needed for good sensitivity

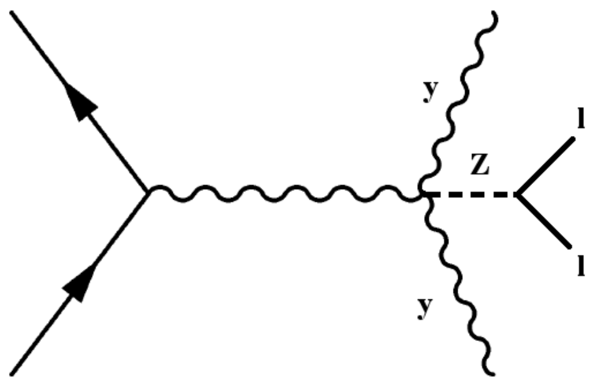
→ work out techniques to estimate background

Monte Carlo not always best estimate → use data

Wγγ Backgrounds

- physics processes with similar signature:
  - top-antitop
  - multi-boson production: Zγγ, WW, ...





→ well described in simulation

Wγγ Backgrounds

- physics processes with similar signature:
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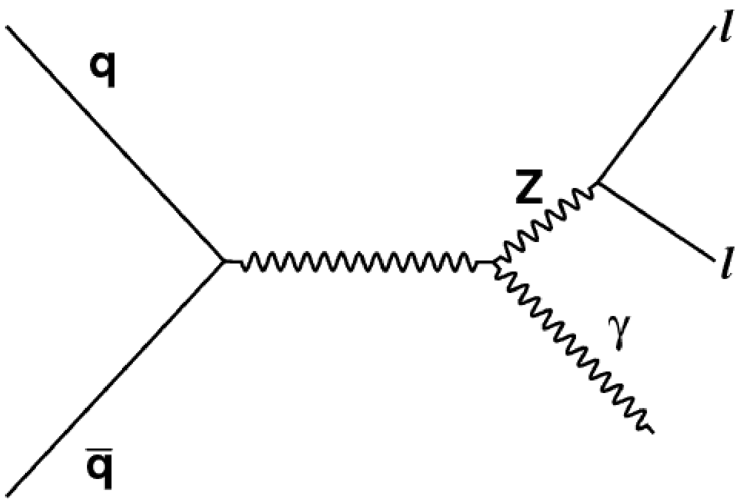
  - multi-boson production: Zγγ, WW, ...

- misidentified electrons:
  - fake photon: Zγ + jets



→ fake object usually not a problem,
but important in low statistics analysis

→ simulation describes this well enough (cross checked with data)

Wγγ Backgrounds

- physics processes with similar signature:
  - top-antitop
  - multi-boson production: Zγγ, WW, ...
- misidentified electrons:
  - fake photon: Zγ + jets
- misidentified jets: → not so well described in simulation
  - fake photon: W/Zγ + jets, W/Z + jets
  - fake lepton: γγ + jets

Wγγ Backgrounds

- physics processes with similar signature:
  - top-antitop
  - multi-boson production: Zγγ, WW, ...
- misidentified electrons:
  - fake photon: Zγ + jets

Estimated using Monte Carlo

- misidentified jets:
  - fake photon: W/Zγ + jets, W/Z + jets
  - fake lepton: γγ + jets

Estimated using data

$W\gamma\gamma$ Backgrounds

- physics processes with similar signature:
  - top-antitop
  - multi-boson production: $Z\gamma\gamma$, WW, ...
- misidentified electrons:
  - fake photon: $Z\gamma$ + jets

Estimated using Monte Carlo

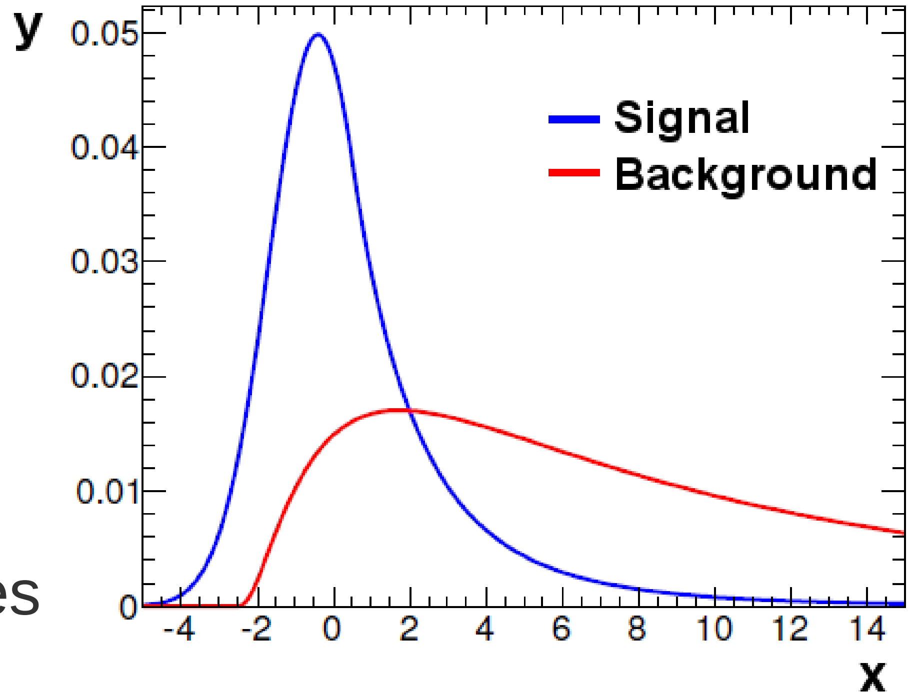
- misidentified jets:
  - **fake photon: W/Zγ + jets, W/Z + jets**
  - fake lepton: $\gamma\gamma$ + jets

Estimated using data

Template Fit Method

Idea: Signal and background distribution differ for specific variable, simple cutting would discard too much signal

→ fit measured distribution with signal and background templates



Challenges:

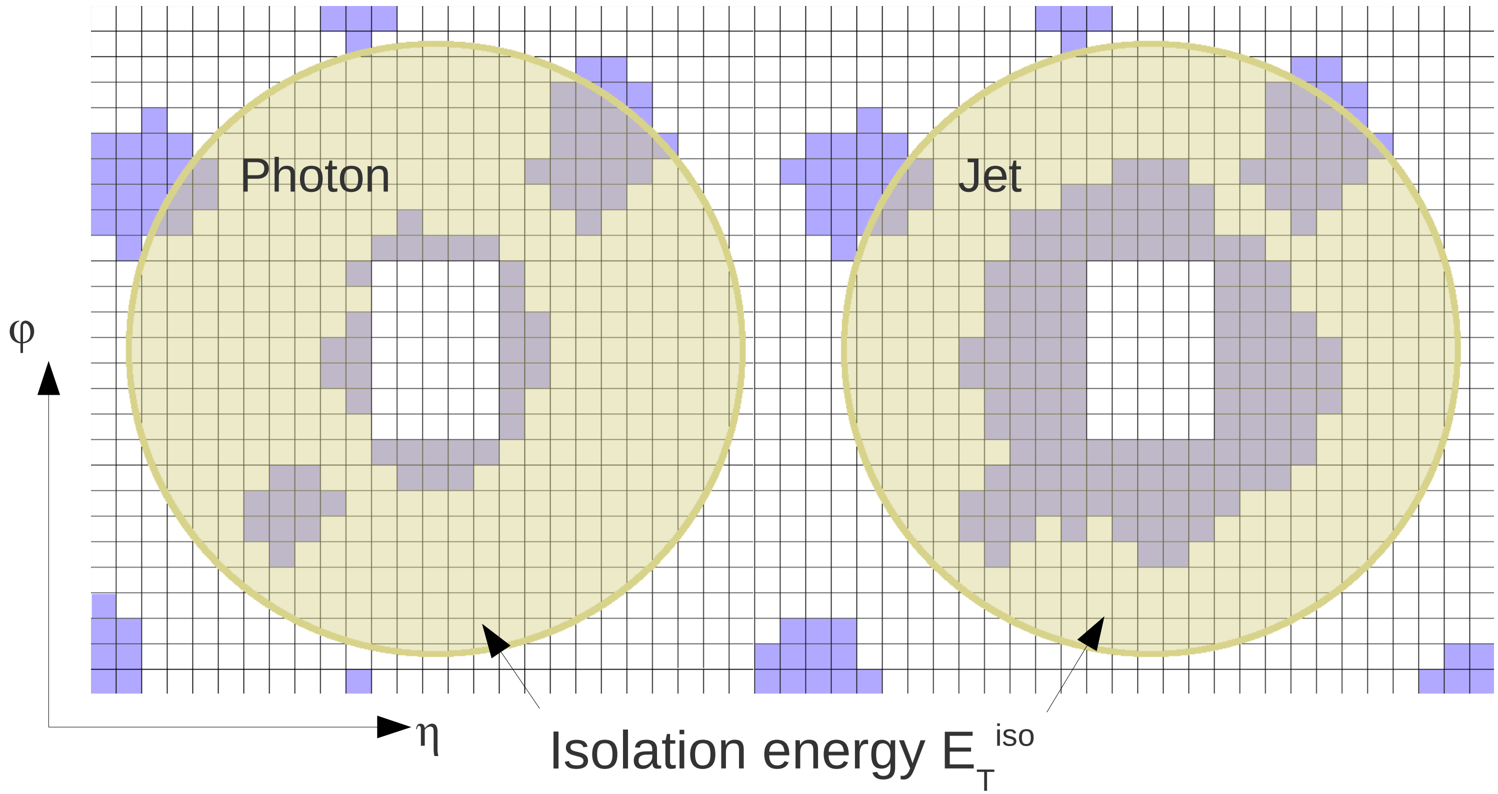
- Finding appropriate variable
- Obtaining templates: requires pure signal and background samples

Fake Photon Background

Estimate number jets that are wrongly identified as photons

- Discriminating variable: E_T^{iso} of the objects

  E_T^{iso} : energy of topological clusters in $\Delta R = \sqrt{(\Delta\varphi^2 + \Delta\eta^2)} < 0.4$



Fake Photon Background

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Templates from different regions:

- real photon template using MC:
  - All cuts except on E_T^{iso}
- fake photons from data:
  - Inverted photon shower shape criterion
  - use single muon trigger

Fake Photon Background

- Templates from different regions
- use normalised distributions as fit templates
- extended max. likelihood fit

Peculiarity: $W\gamma\gamma$ has 3 background components:

- only leading photon from jet
- only subleading photon from jet
- both photons from jets

} 3 background control regions depending on photon identification

Fit isolation of both photons simultaneous (2D)

$$E_T^{iso} = C_{\gamma\gamma} T_{\gamma\gamma} + C_{\gamma j} T_{\gamma j} + C_{j\gamma} T_{j\gamma} + C_{jj} T_{jj}$$

fit parameter

fit template

Wγγ Backgrounds

- physics processes with similar signature:
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- misidentified electrons:
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Estimated using Monte Carlo

- misidentified jets:
  - fake photon: W/Zγ + jets, W/Z + jets
  - fake lepton: γγ + jets

Estimated using data

Results

- Combination of all background estimates gives number of signal events
- Expect ~ 100 events
- Detector acceptance and reconstruction efficiency reduces number of events

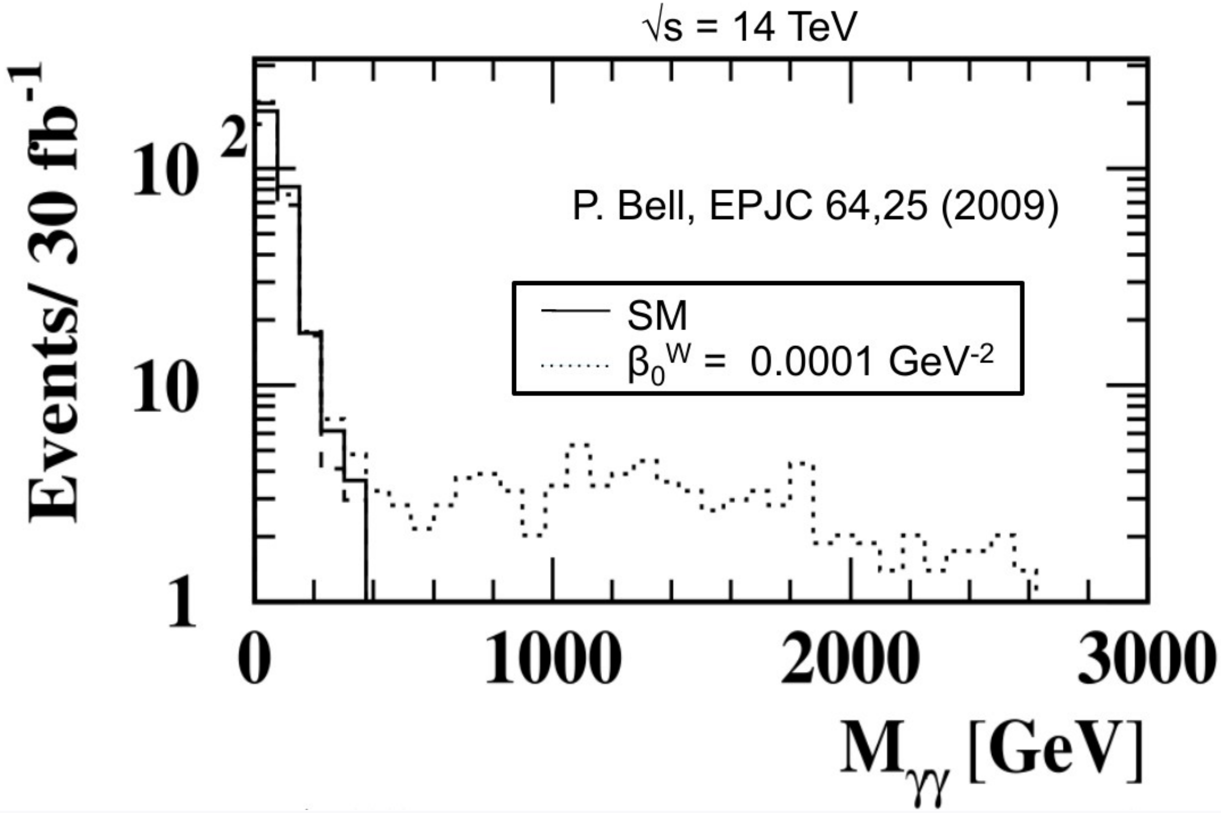
→ calculate cross-section

aQGC limits

Anomalous quartic gauge couplings would manifest at high di-photon invariant masses $m_{\gamma\gamma}$

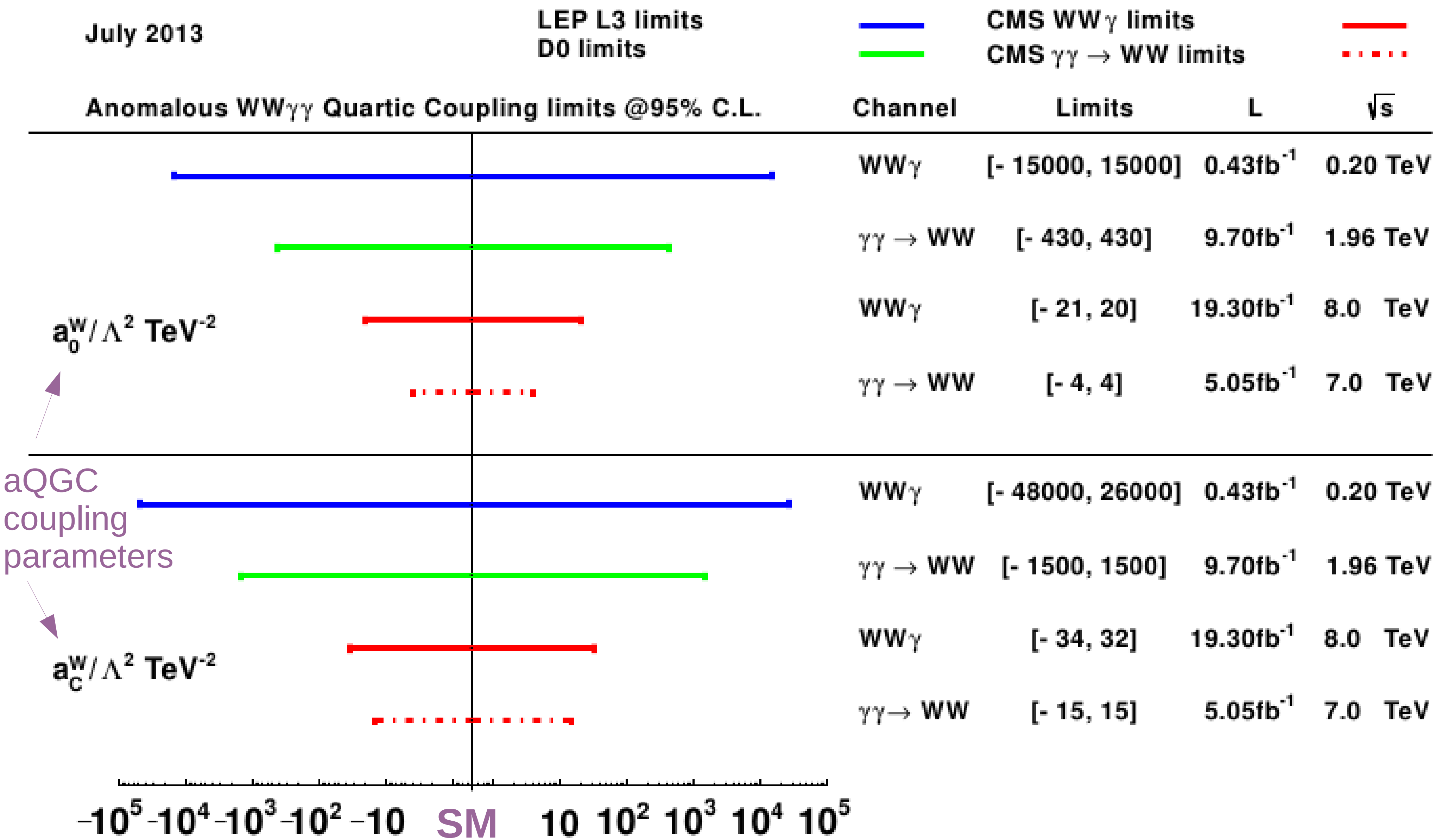
→ cut on $m_{\gamma\gamma}$ to increase sensitivity

→ set limits on coupling constants



State of the Art in aQGC

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMPaTGC



Summary

- Measuring $W\gamma\gamma$ production cross-section feasible for first time with current data set from LHC
  - test of the standard model
  - search for additional couplings

- Using data for background estimation helps to overcome shortcomings of Monte Carlo
  - e.g. use E_T^{iso} distribution for fake photon estimation

This is just one of many interesting results of ATLAS

Thank you!

Sources

- Dissertation of Veit Scharf

  http://www.kip.uni-heidelberg.de/Veroeffentlichungen/details.php?id=2994

ATLAS SM Wirkungsquerschnitte

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/SM/