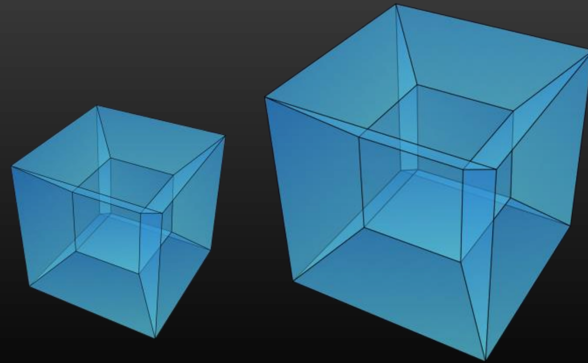
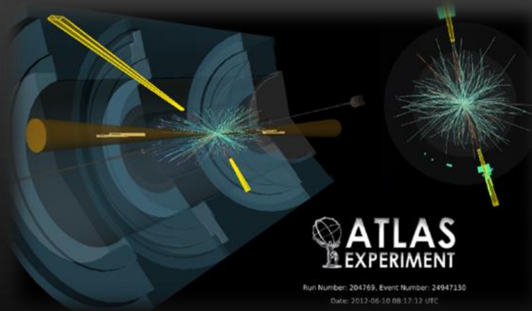
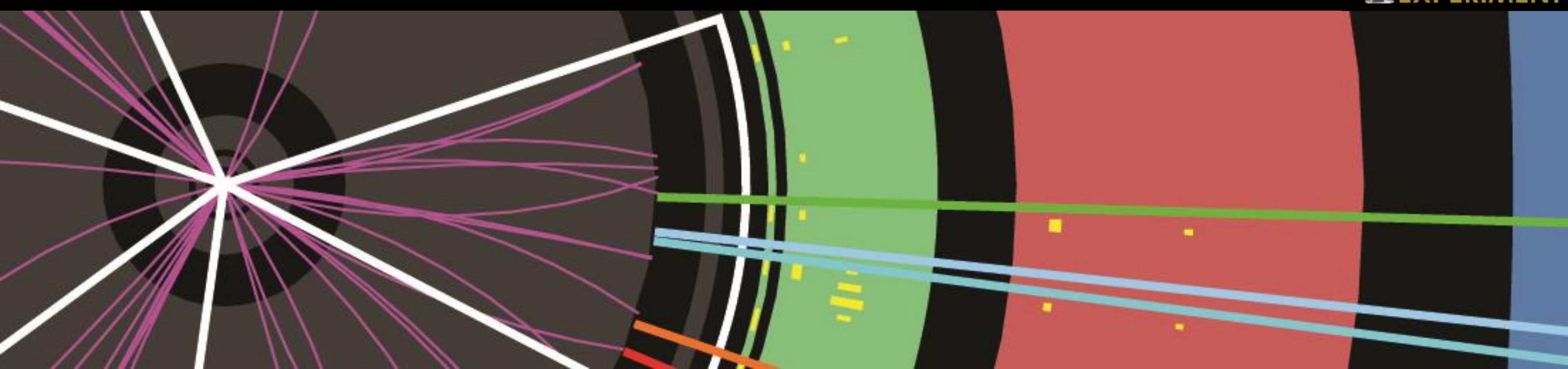




SEARCH FOR EXTRA DIMENSIONS IN THE DI-PHOTON CHANNEL AT THE ATLAS EXPERIMENT AT LHC

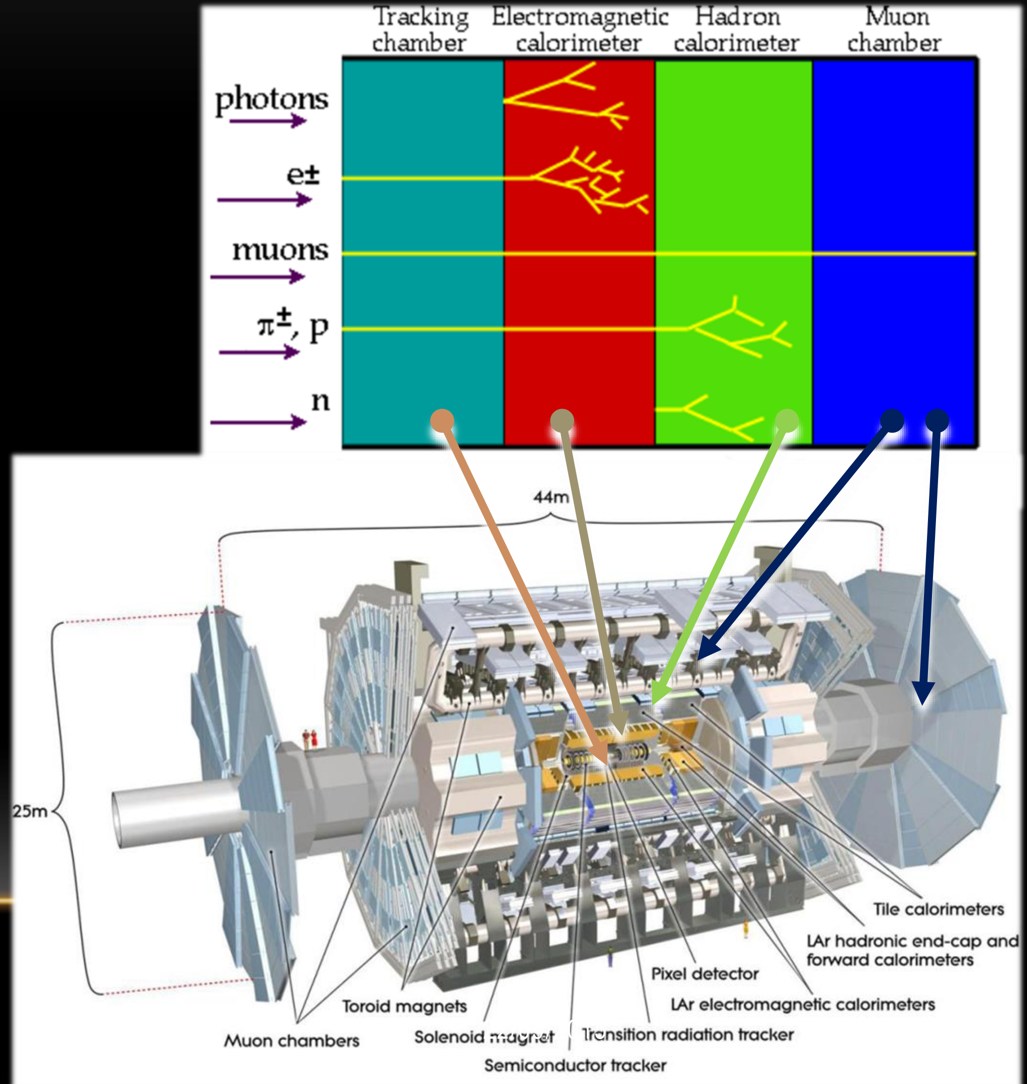
Simone Michele Mazza – Dp. of physics, university of Milan



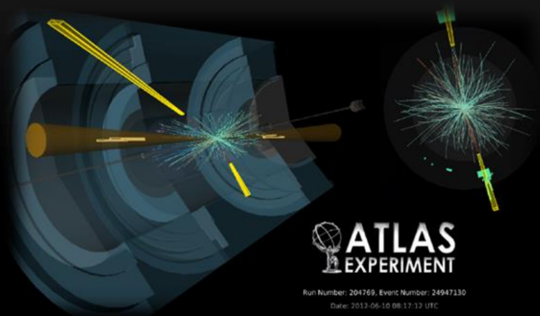
- ATLAS (A Toroidal LHC ApparatuS)
  - 44 m long, 25 m of diameter
  - 4 levels of detectors
    - Inner detector
    - Electromagnetic calorimeter
    - Hadron calorimeter
    - Muon detectors
  - Two magnetic systems (4 magnets)
    - Solenoid, Thoroid

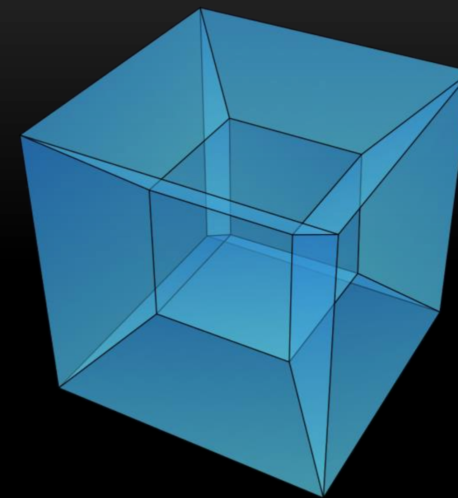
- Three levels of trigger, recordable events/s ~400
  - Trigger level one (hardware)
  - Trigger level two (software)
  - Event filter

- Object detection based on combination of the detectors' information
  - Object reconstruction
    - Candidates
  - Object identification
    - Photons, electrons, jets etc…

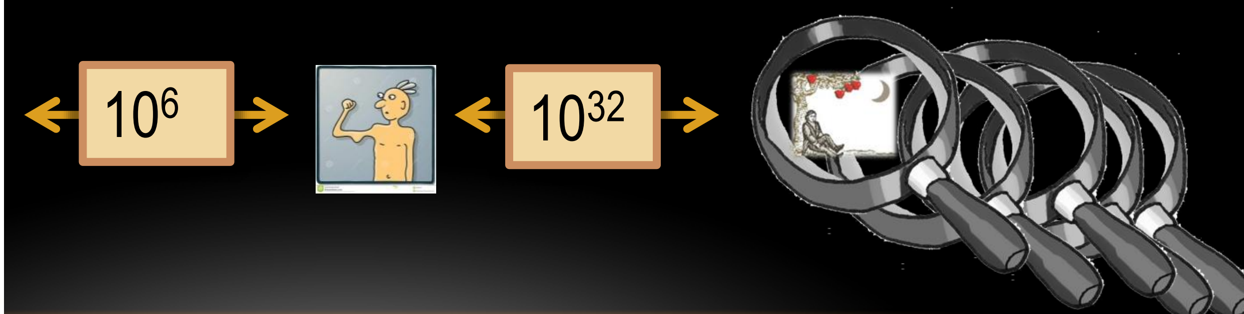


HOW TO GET FROM THIS TO THIS?





- Let me introduce the hierarchy problem
  - There is a large discrepancy between the strong/electroweak force and gravity
  - Why is that so?

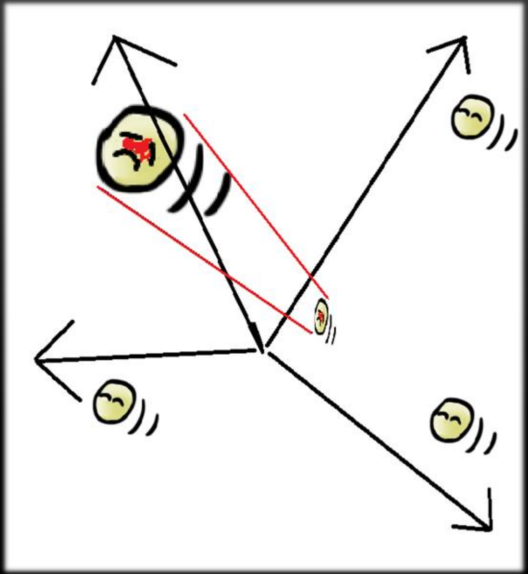


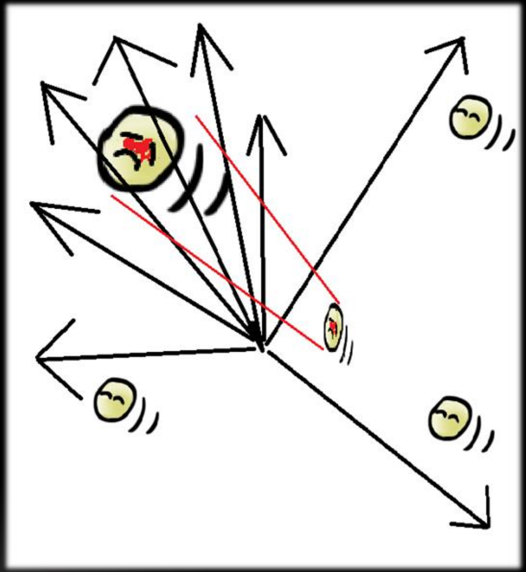
RS AND ADD MODEL

- SM particles are confined in 3-dimension while gravitons can also travel in the additional dimensions
  - Gravity is weak because we can only measure a projection

- There are two theories trying to explain this asimmetry
  - RS model: there is a *fourth dimension that is compactified* *in a* *warped geometry space*
    - $M_d = M_{pl}\, e^{-k\pi r}$
  - ADD: there are *n additional compactified dimensions*
    - $M_d^{n+2} = M_{pl}^{n+2}\, R^{-n}$

- *How can we prove this?*





RS AND ADD MODEL

In particle colliders we can produce and observe the decay of a graviton

- **The analysis tries to detect the Kaluza Klein resonances of the graviton in the additional dimensions in the decay channel with two photons**

Studying the di-photon invariant mass

RS signature: resonances

ADD signature: non-resonant excess

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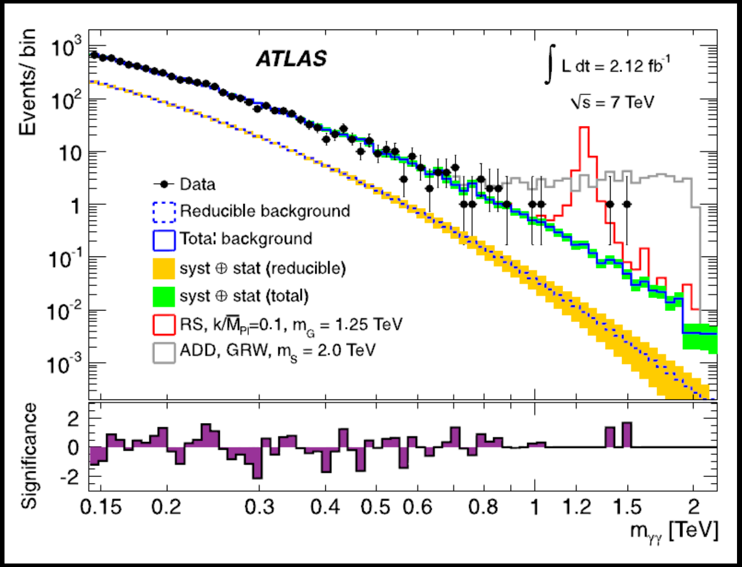
Two free parameters for RS model

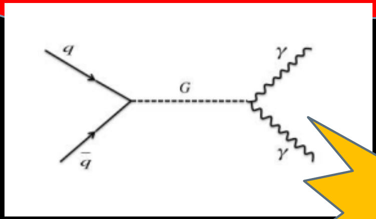
- Mass of the graviton Mg and coupling k with the SM

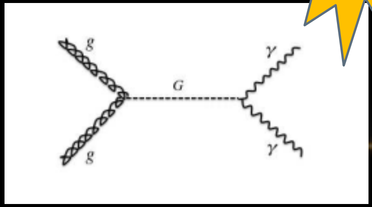


Not an easy analysis:

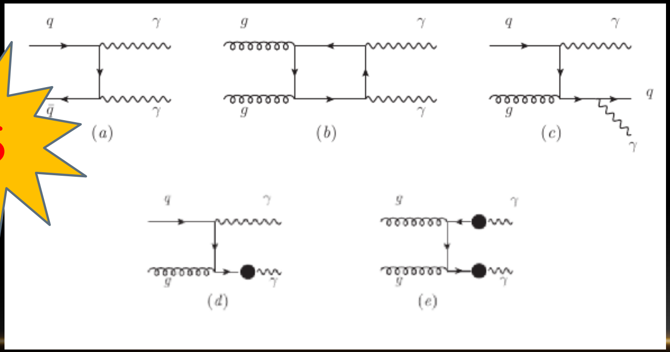
- must recognize real diphoton events from reducible background (gamma-jet, dijet) and irreducible background

Even if we observe a resonance a spin analysis will be needed because **it could be a Z' (in electrons) or another Higgs.**





VS



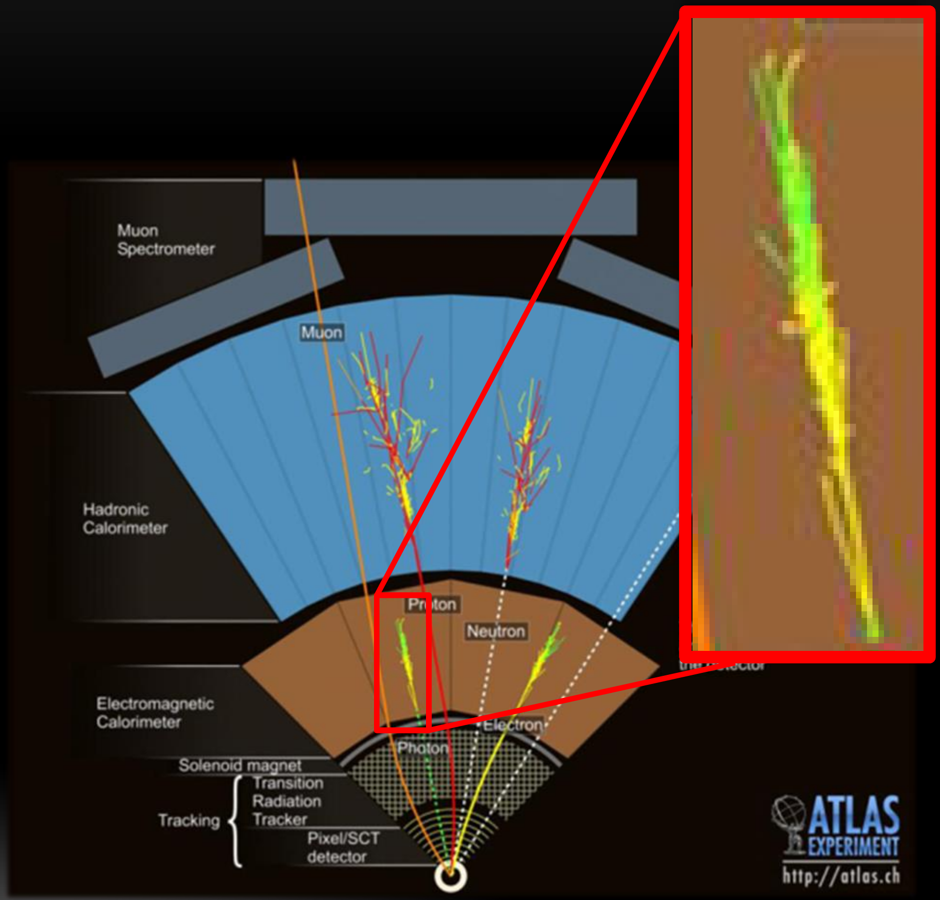
PHOTON RECONSTRUCTION AND IDENTIFICATION IN ATLAS

- Photons reconstruction
  - From energy deposits in the electromagnetic calorimeter <u>with sliding window algorithm</u>
  - Tracks to determine if the candidate is *electron* or *photon converted/unconverted*

- Photon identification based on discriminating variables
  - <u>Energy leakage</u> in the hadronic calorimeter
  - <u>Shower shapes</u> in the three compartment of the EM calorimeter

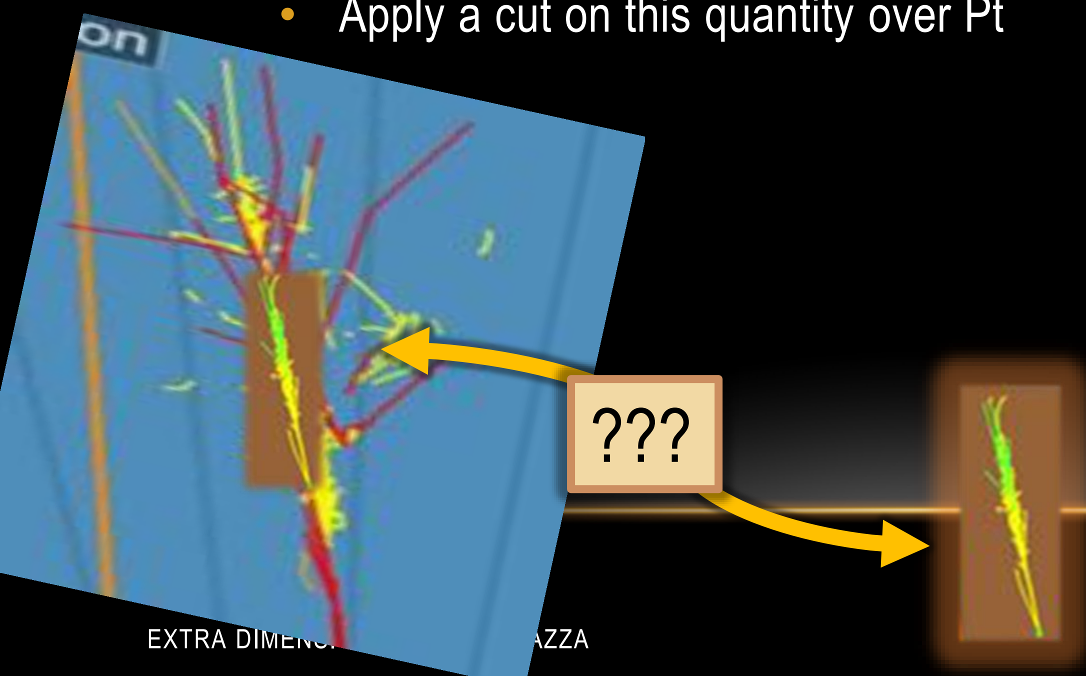
- Two sets of cuts for identification:
  - Loose: leakage + second compartment shower shapes
  - Tight: loose + shower shapes in first compartment

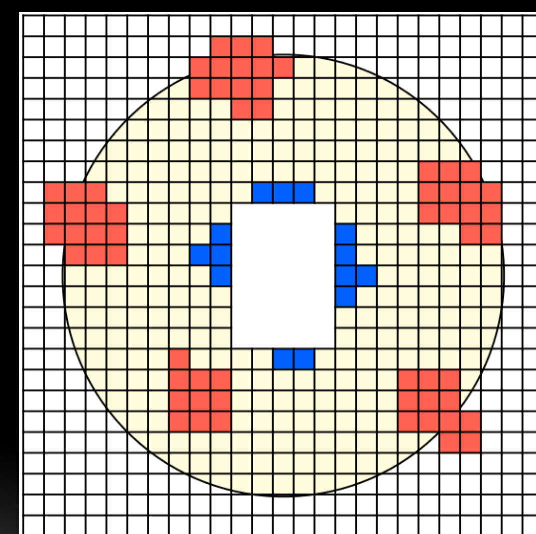
- Isolation variable: energy deposits around the photon



ISOLATION VARIABLE

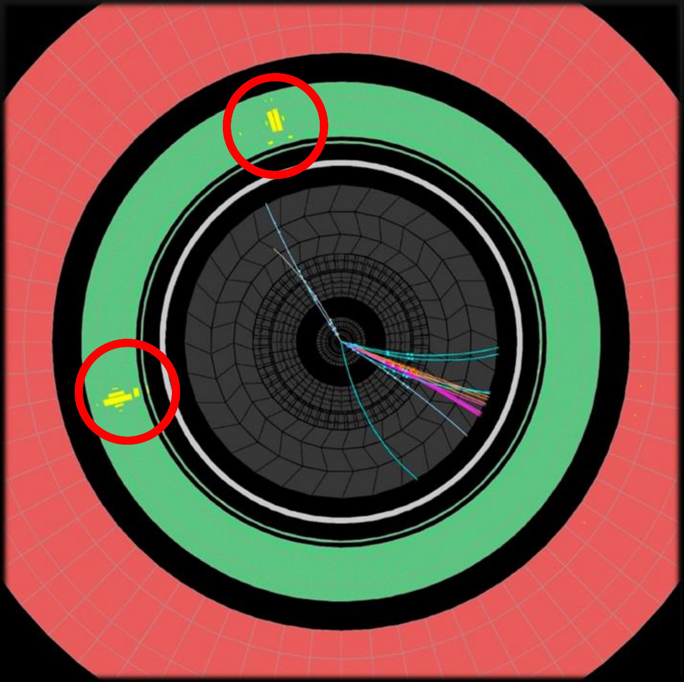
- After the photon identification, how to further identify a real photon from a jet?
  - Jets faking a photons have lots of other particles around it
- Isolation variable
  - Energy of the *topoclusters* in a cone in the calorimeter of $\Delta R=\sqrt{(\Delta\varphi^2+\Delta\eta^2)}=0.4$ (or 0.2, 0.3) without the central cells (5x7)
  - Corrected for the object energy leakage and pileup/underlying event
- The distributions is broader at high energy
  - Apply a cut on this quantity over Pt





SELECTION OF EVENTS WITH TWO PHOTONS

- Selection for two well reconstructed and isolated photons
  - Pass trigger with 2 loose photons (with Et 50 GeV)
  - Pass event selection
    - GRL, event cleaning
  - At least one primary vertex must be reconstructed with two tracks



- Pre-selection: At least two loosely identified photons
  - Within $|\eta| < 2.37$, $E_T > 50$ GeV
  - Passing loose ID criteria

- <u>Define leading, sub-leading photons (most energetic)</u>
  - Leading photon with $E_T > 55$ GeV
  - Sub-leading photon with $E_T > 55$ GeV
  - Pass tight cut criteria and cut on <u>Isolation/Pt</u>

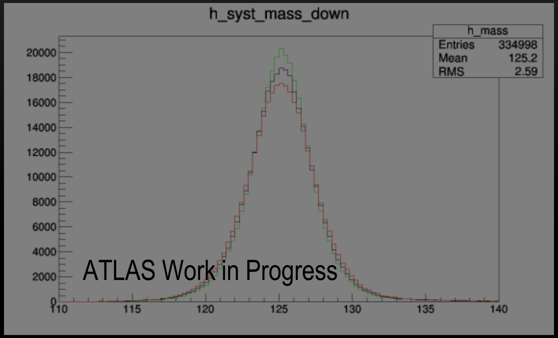
- Invariant mass of the two photons
  - Θ angle between photons

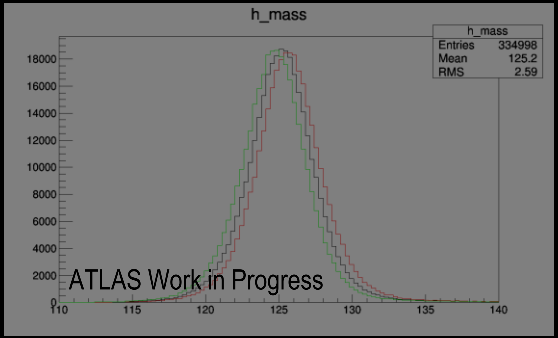
$$m_{\gamma\gamma} = \sqrt{2E_1E_2(1-\cos(\theta))}$$

SYSTEMATICS, SIGNAL AND BACKGROUND MODEL

- Study of the systematic errors
  - Impact on event selection, kinematic variables
  - From photon calibration, identification, isolation. Also from theoretical uncertainty
  - Crucial for the final statistic analysis

- Analysis of MC samples of signal and background
  - MC samples of RS (and ADD) gravitons with different Masses and couplings
  - Flat mass sample: RS graviton resonance with the resonance term removed
  - MC Background of SM di-photon, photon-jet and di-jet





Nominal
Systematic up
Systematic down

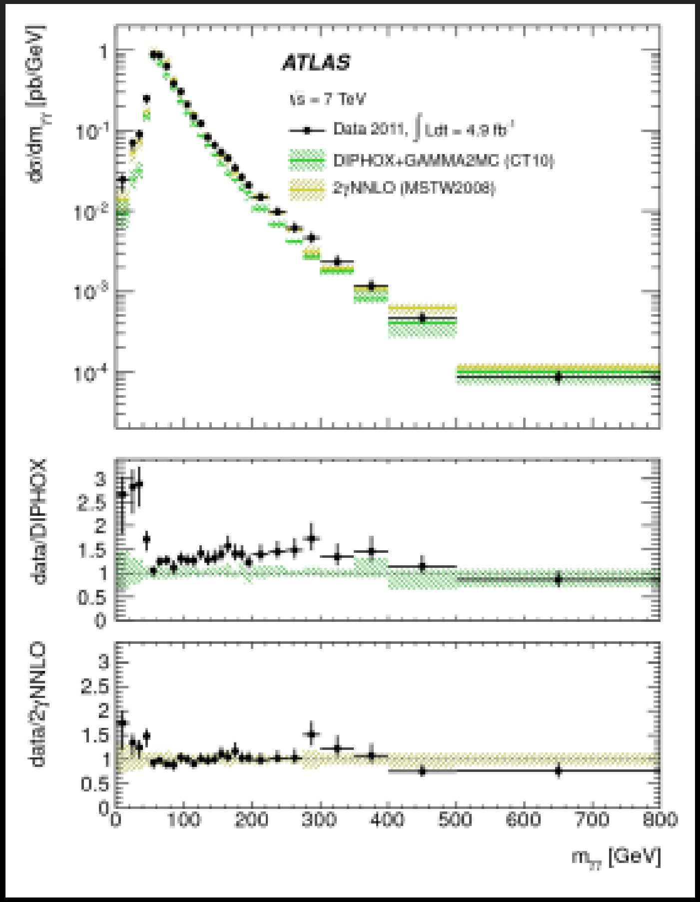
BACKGROUND ESTIMATION

- <u>Crucial point in the analisys:</u> ***Different approaches***

- **Fit on data** with a chosen parametrization (2 ways)
  - Decide a priori a way to discriminate the best function and to evaluate the systematic
  - Use multiple functional forms to the statistic fit and let the fit decide the best one
  - No blinding needed!

- Use **«slices»**
  - Slices around the interested area to evaluate the background.
  - Then move the area.

- Use **MC rescaled on data**
  - **Background composition** (reducible + irreducible) estimated with a **data-driven method** (Isolation template fit)
  - A correction factor from next to leading order (**NLO**) generators (diphox, 2gNNLO) to SM sample at leading order (**LO**) generators (Pythia, Sherpa)
  - <u>This is our baseline</u>



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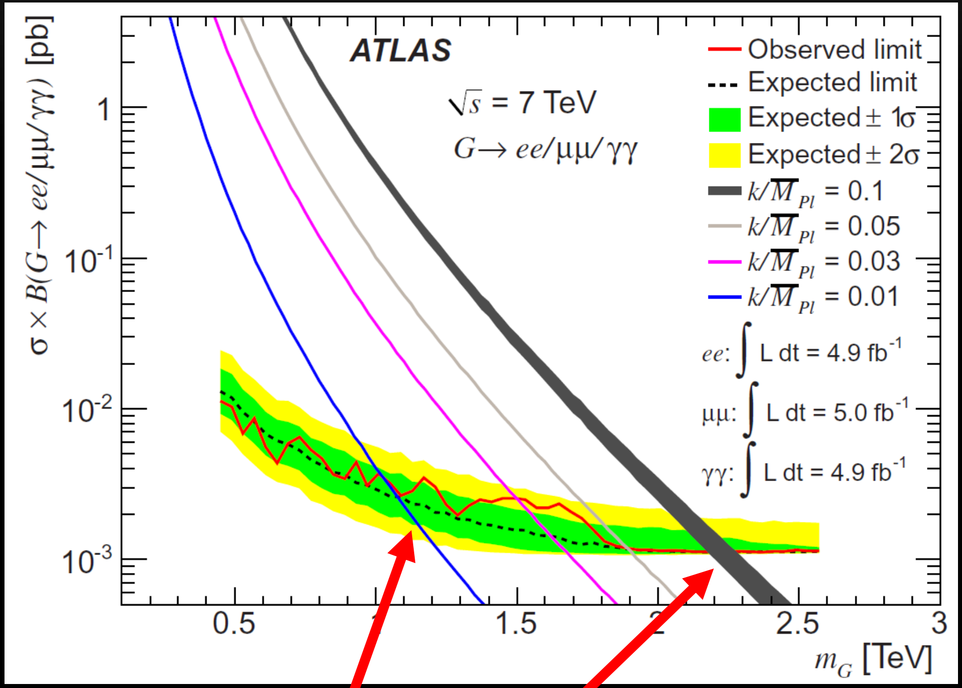
STATISTIC RESULTS

- We have a signal model to test and a well-built background distribution
- Analyze data and study the Mγγ spectrum
  - Compare the model with the observed data using powerful statistic tools
- Using these tools we can find the p_0 (**discovery**) and q_μ (**exclusion**)
  - Exclude the theory (Mg, k) within 2 σ
  - Discover an excess from the expected SM background over 3-5 σ
- On the left: exclusion results from the 7 TeV analysis

The RS graviton hypotesis is tested, each colored curve is a coupling
Dotted line is expected limit
green/yellow bands systematics erros
Red line is the observed limit



Exclusion of Mg < 1.1 TeV for k/Mpl = 0.01 and Mg < 2.3 TeV for k/Mpl = 0.1

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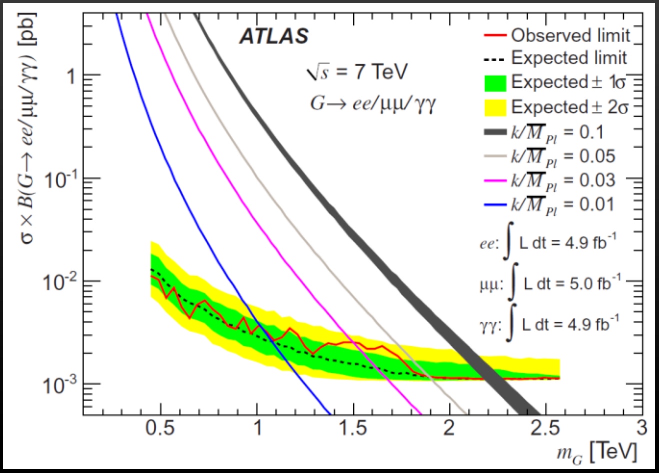


FIRST RESULTS AT 13 TEV ON SIMULATIONS

<u>Preliminary</u> plot of expected limit

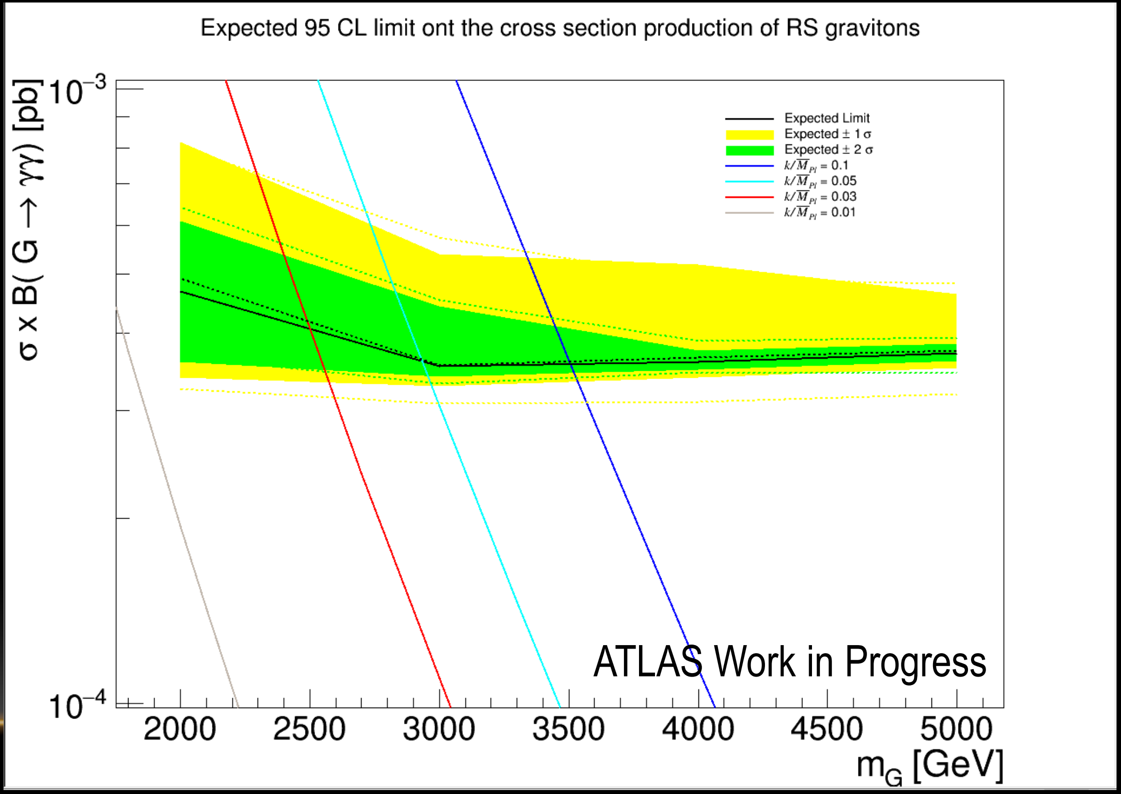
Made using ATLAS MC 2014 samples

- Plot for 20.3 fb-1 (8 TeV luminosity)
- Background correction factor from Diphox
- Limits without (solid) and with (dashed) preliminary systematics included

We can beat run I sensitivity with 1.23 fb-1 of statistic at 13 TeV

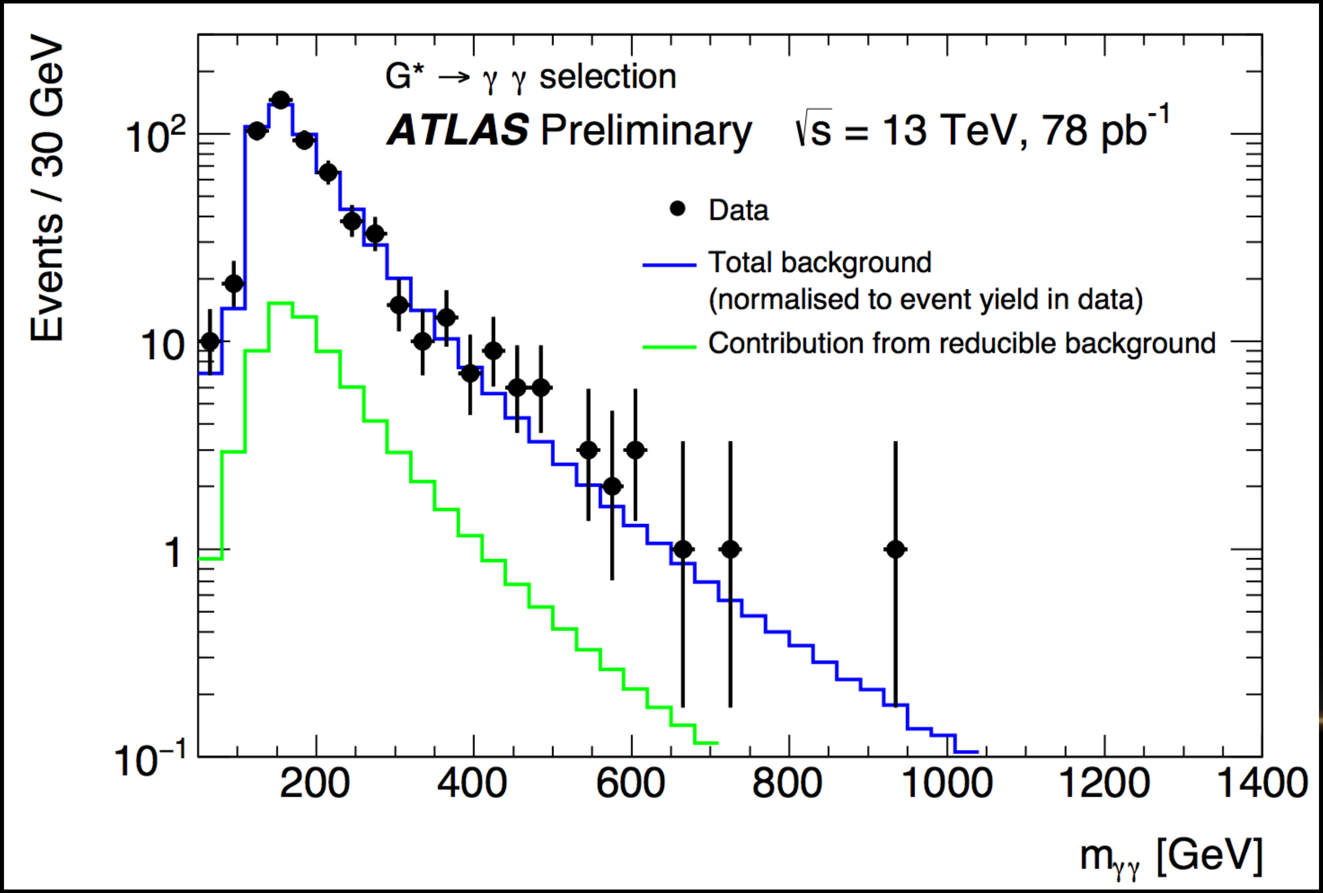
- Using a preliminary signal k-factor of 1.8

Limits made with BAT (Bayesian analysis toolkit)



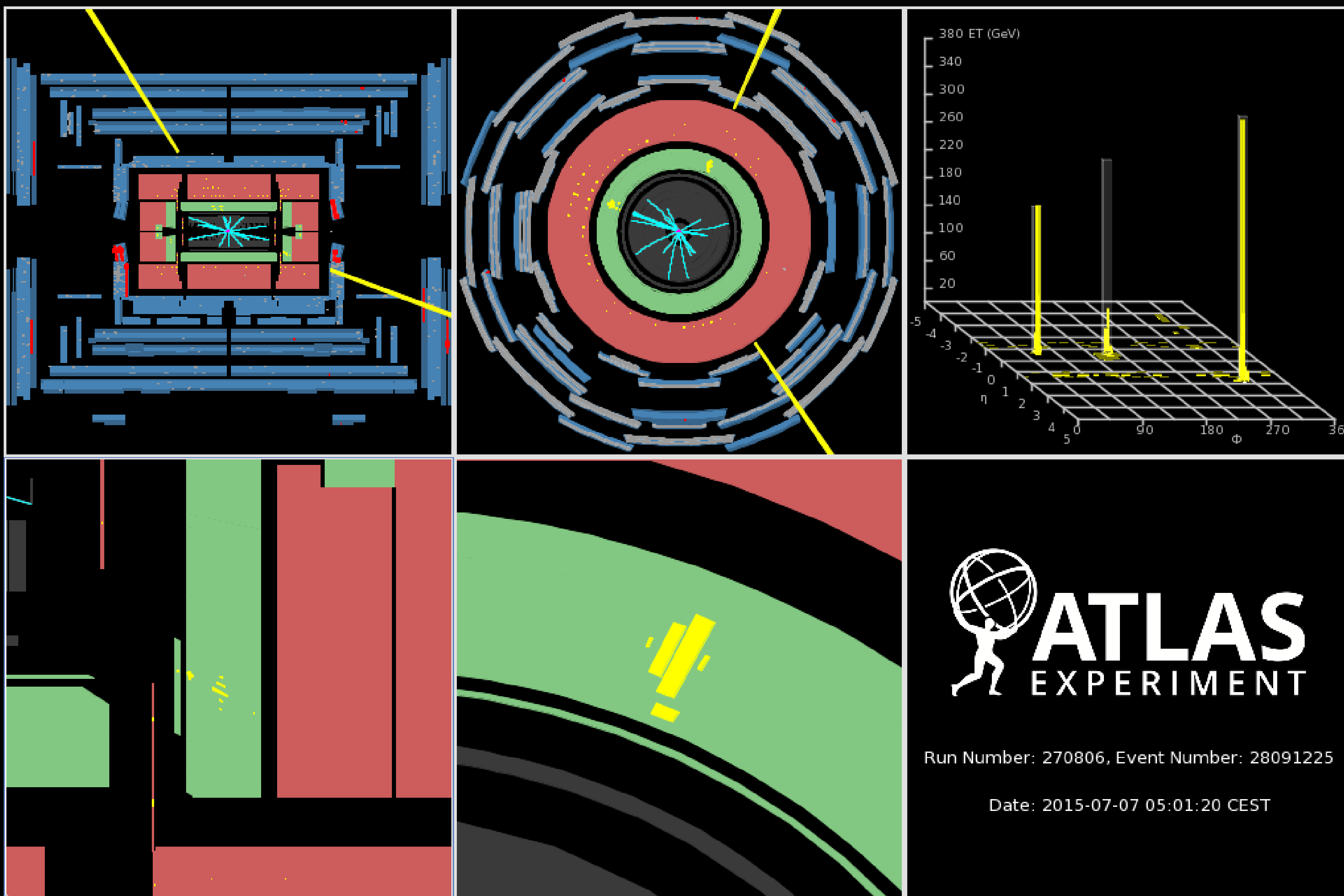
NEW DATA! ATL-COM-PHYS-2015-731

Observed invariant mass spectrum of the selected diphoton candidates (black dots). Superimposed is the SM background prediction (blue histogram). The main background is irreducible: production of pairs of isolated photons via QCD processes. The comparatively small contribution from events with at least one jet being misidentified as a photon is also shown separately (green histogram). The reducible background is estimated using data control samples. The shape of the $m_{\gamma\gamma}$ distribution of the irreducible background is determined using simulation, and it is normalized to the data (after subtraction of the reducible background).



MOST ENERGETIC DIPHOTON EVENT FOR RUN II - ATL-COM-PHYS-2015-731

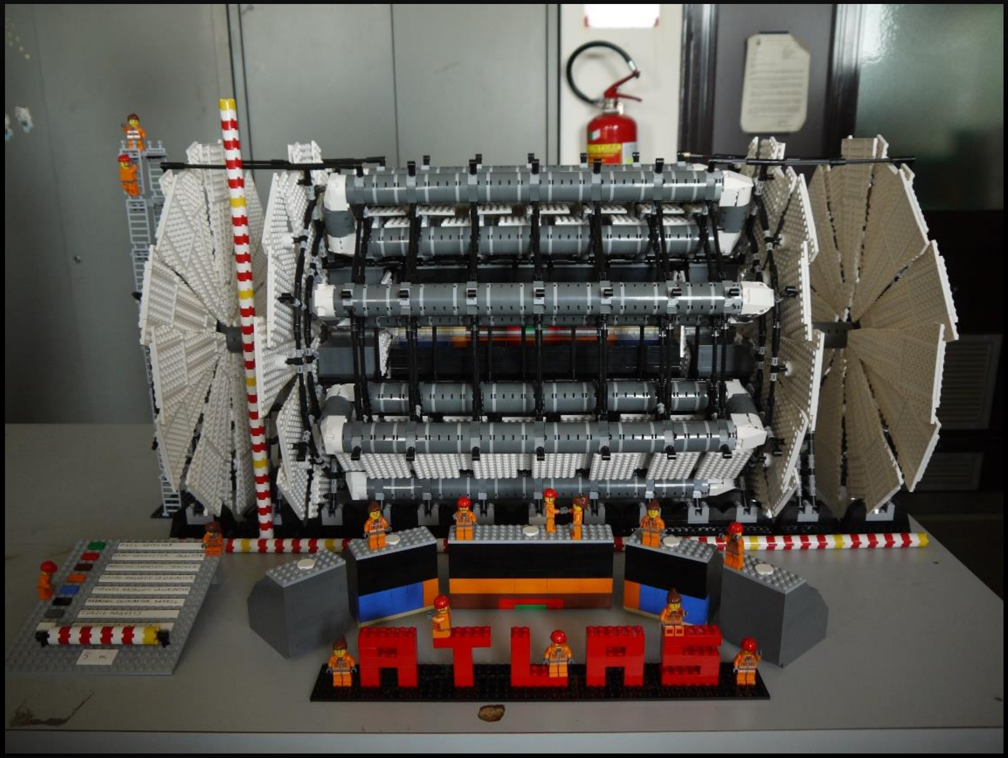
Event display of the highest-mass diphoton event. Event information: Run and event numbers = 270806, 28091225. Invariant mass $m_{\gamma\gamma}$ = 940 GeV, transverse momentum of the diphoton system = 318 GeV. Leading photon E_T, η, ϕ, $E_T$iso = 374 GeV, 1.71, -0.97, 1.54 GeV. Subleading photon E_T, η, ϕ, $E_T$iso = 212 GeV, -0.60, 1.15, -0.08 GeV. The leading photon is converted.



CONCLUSION AND FUTURE PLANS

- Run 1, 7 TeV analysis is public
- Run 1, 8 TeV paper is on its way

- Preparation to finalize run 2 data analysis is progressing
  - The whole machinery is running
  - The paper / CONF note is being written
- We will beat run I with 1.2 fb^{-1} at 13 TeV
  - Right now 600 pb^{-1}
- <u>Thank you for your time!</u>



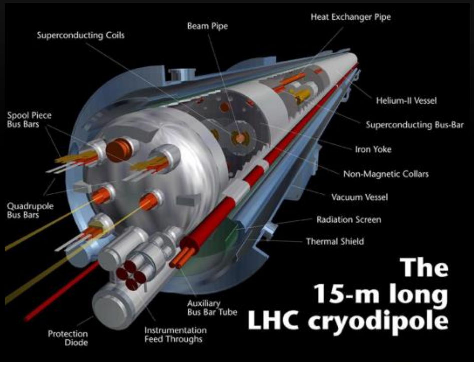
BACKUPS

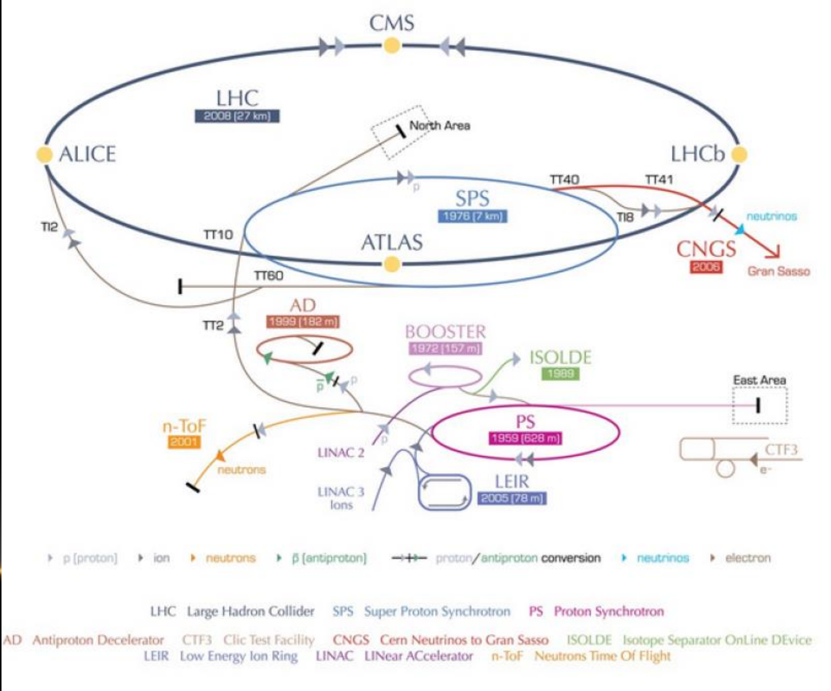
LHC EXPERIMENT AT CERN

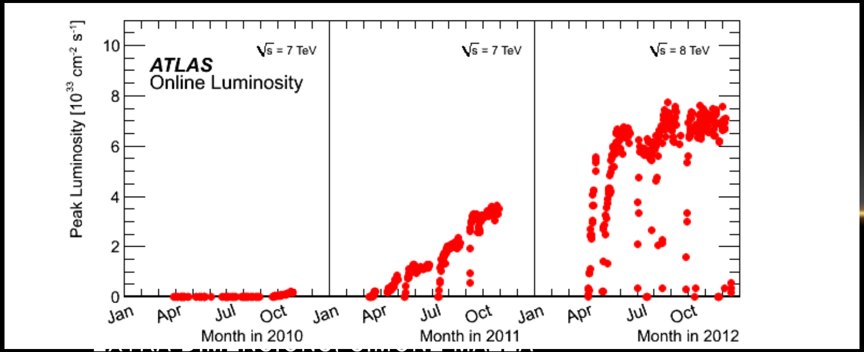
- LHC is a proton-proton collider 27Km long
  - 4 main experiments
    - ATLAS, CMS, ALICE, LHCb

- Current center of mass energy $\sqrt{s}$=8TeV
  - Superconducting magnets 8 T
  - 29fb^{-1} delivered
  - Luminosity peak of 8x10^{33}cm^{-2}s^{-1}
  - Bunch spacing: 25ns

- Now in shutdown
  - Will re-open in 2015 with 14 TeV of center of mass energy



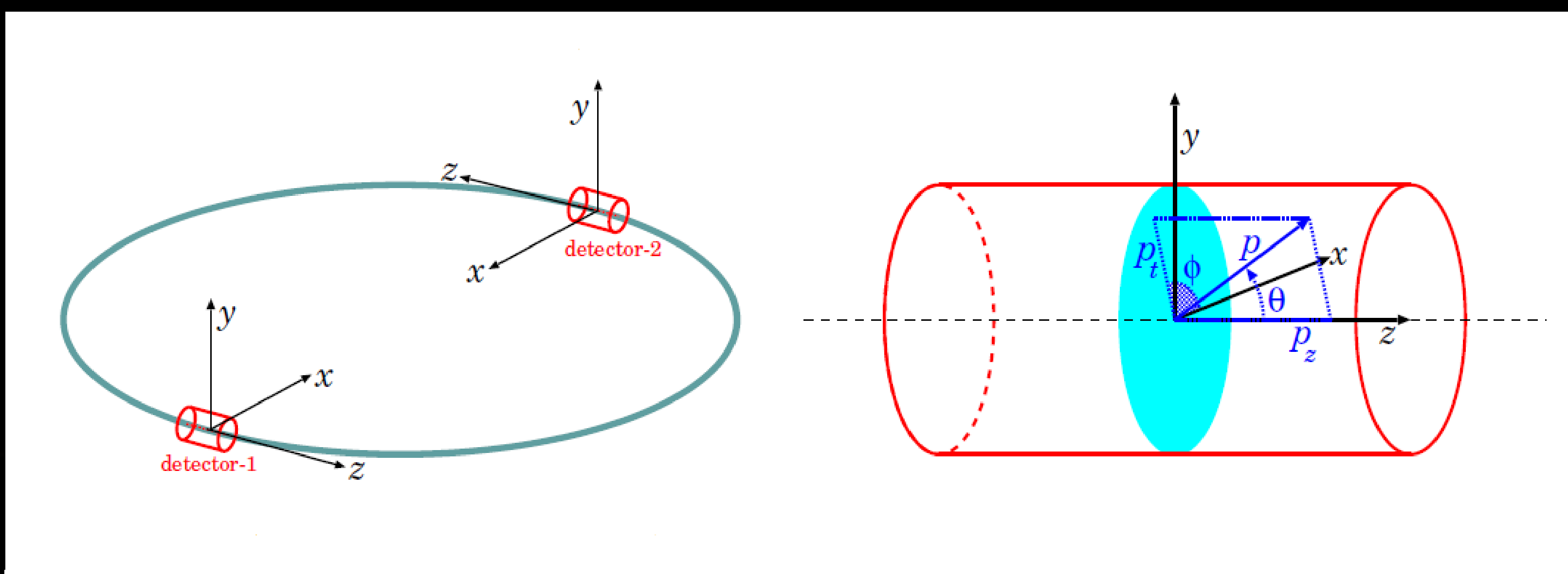




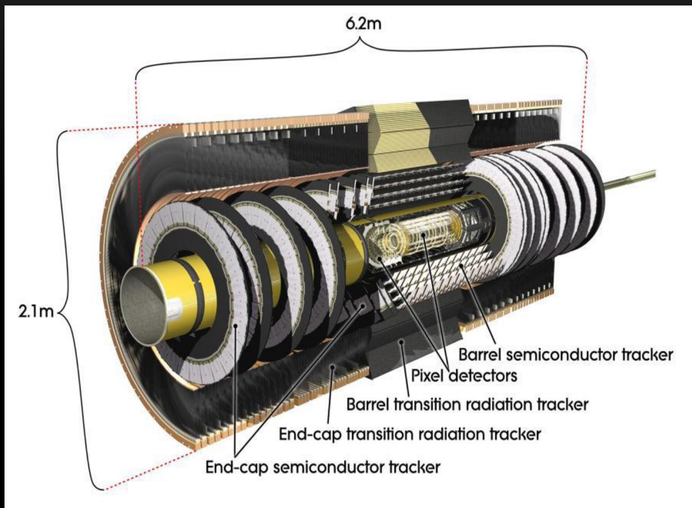
ATLAS COORDINATES SYSTEM

- Coordinates are with Z on the beam axis
  - X,Y is the transverse plane
  - Cylinder coordinates are adopted (z, θ, φ)

- Usually the adopted angular coordinates are **(η,φ)** [η instead of θ]
  - $\eta = -\log(\tan(\theta/2))$ invariant for Lorentz boost on Z
  - $\Delta R = \sqrt{(\eta^2 + \varphi^2)}$ angular distance between two objects

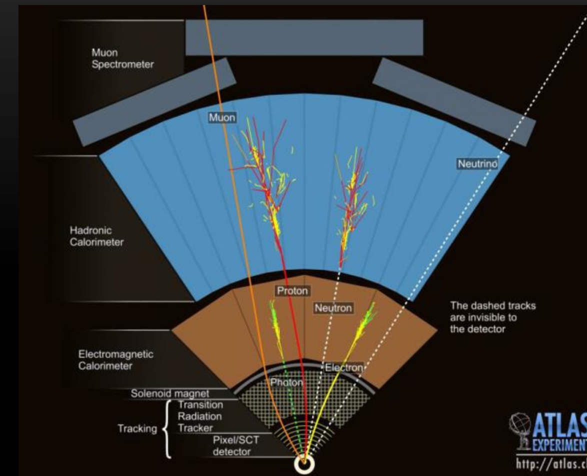


ATLAS DETECTOR STRUCTURE



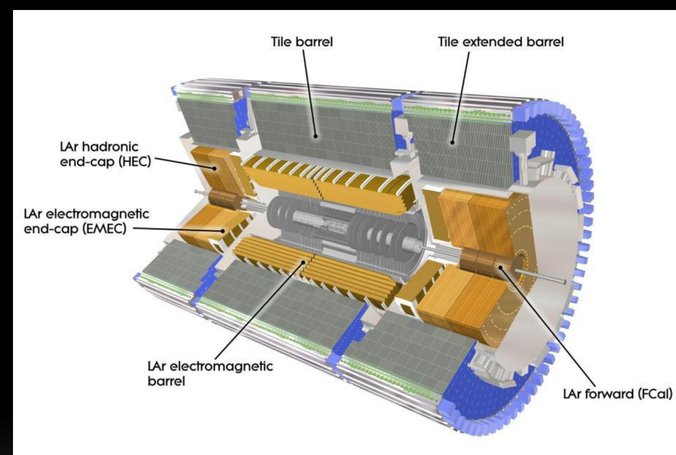
Inner detector

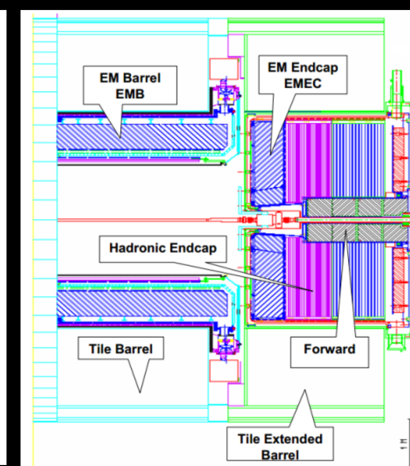
- 7 m long, 2.3 m diameter
- Measure tracks for charged partices
- Detect primary and secondary vertices
- Three layers
    - Semiconductor pixel detectors
    - Silicon microstrip detector
    - Radiation transition detector

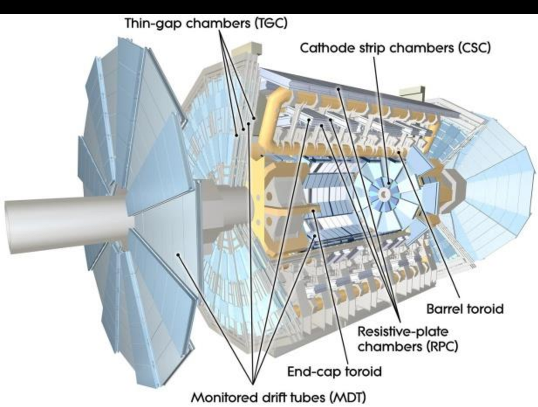


Calorimeters

- Measure position and energy for particles
    - electrons, photons and hadrons
- Electromagnetic calorimeter and Hadronic calorimeter
- Barrel + endcap structure (covering different η regions)







Muon detector

- Outest and largest detector
- Drift tubes in the central region, cathode strip chambers in the forward region
- Muon trigger: resistive plate chambers and thin gap chambers

ATLAS INNER DETECTOR AND ELECTROMAGNETIC CALORIMETER

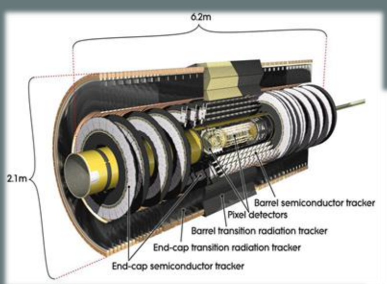
- **Inner detector**
  - **Measure charged particles tracks**
  - **Detect primary and secondary vertices**
- Three levels
  - Semiconductor pixel detectors (±10 μm)
  - Silicon microstrip detectors (±16 μm)
  - Radiation transition detector (±30 μm)

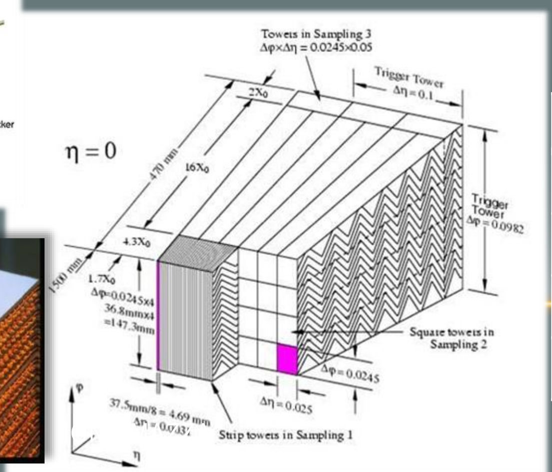
- **Electromagnetic calorimeter**
  - **Detect photons, electrons**
  - Sampling calorimeter of Liquid Argon /Pb
  - Covers pseudorapidy region of |η|<3.2
  - Electrodes and absorbers are bend in a accordion way
- Segmented in three longitudinal segments with different glanularity
- Resolution:

$$\frac{\sigma}{E} = \frac{10-17\%}{\sqrt{E/\mathrm{GeV}}} \oplus 0.7\%$$

- **Hadronic calorimeter**
  - **Detect Jets**
  - Sampling calorimeter of scintillating tiles and Steel
  - Covers pseudorapidy region of |η|<4.9
  - ~11 interaction length
- Granularity: (ηxΦ)=0.1x0.1
- Resolution:

$$\frac{\sigma}{E} = \frac{50-100\%}{\sqrt{E/\mathrm{GeV}}} \oplus 0.3-0.5\%$$





Layer	lenght	Segmentation (ηxΦ)
Presampler	< 1 X_0	0.025x0.1, for |η|<1.8
Strips	~5 X_0	(0.003 - 0.006)x0.1
Middle	~15 X_0	0.025x0.025
Back	~3-4 X_0	0.050x0.025

STATISTIC RESULTS

- Analyze data and study the distribution
  - Now we have a model *of signal and background*
  - Compare the model with the observed data using powerful statistic tools

$$E[n_i] = \mu s_i + b_i \,,$$
$$s_i = s_{\mathrm{tot}} \int_{\mathrm{bin}\, i} f_s(x; \boldsymbol{\theta}_s)\, dx \,,$$
$$b_i = b_{\mathrm{tot}} \int_{\mathrm{bin}\, i} f_b(x; \boldsymbol{\theta}_b)\, dx \,.$$

$$L(\mu, \boldsymbol{\theta}) = \prod_{j=1}^{N} \frac{(\mu s_j + b_j)^{n_j}}{n_j!} e^{-(\mu s_j + b_j)} \prod_{k=1}^{M} \frac{u_k^{m_k}}{m_k!} e^{-u_k} \,.$$

$$\tilde{\lambda}(\mu) = \begin{cases} \dfrac{L(\mu, \hat{\hat{\boldsymbol{\theta}}}(\mu))}{L(\hat{\mu}, \hat{\boldsymbol{\theta}})} & \hat{\mu} \geq 0, \\[2ex] \dfrac{L(\mu, \hat{\hat{\boldsymbol{\theta}}}(\mu))}{L(0, \hat{\hat{\boldsymbol{\theta}}}(0))} & \hat{\mu} < 0 \end{cases}$$

- From λ we can find the q_μ (exclusion) and p_0 (discovery)
  - Exclude the theory (Mg, k) within 2 σ of CL …
  - Or discover an excess from the expected SM background over 3-5 σ of CL

RESULTS UNTIL NOW - EXCLUSIONS

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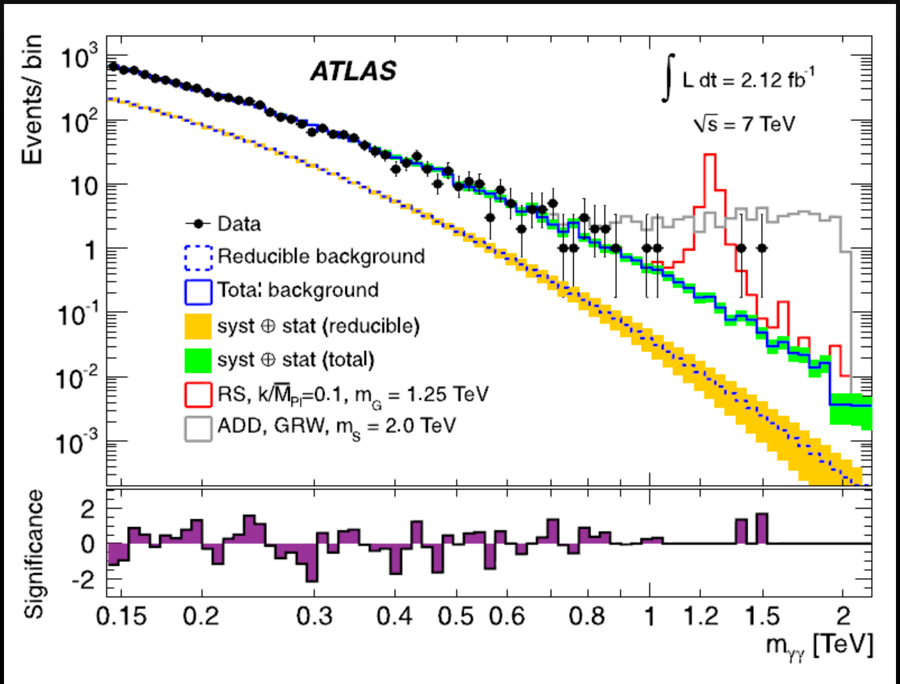

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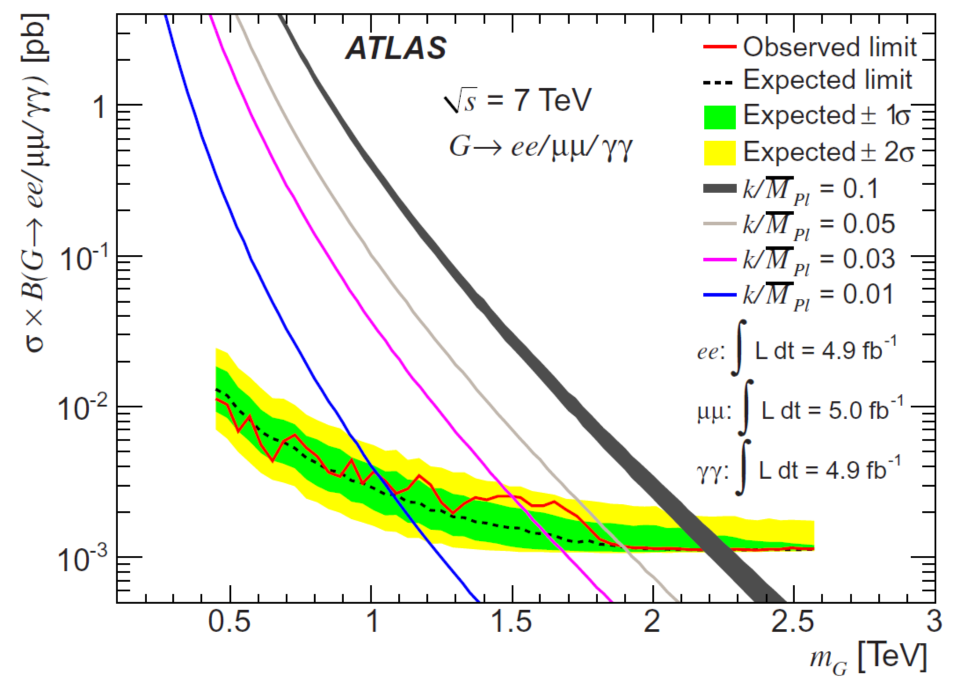

BUT WHO KNOWS WHAT WE'LL FIND IN THE NEXT RUN!?