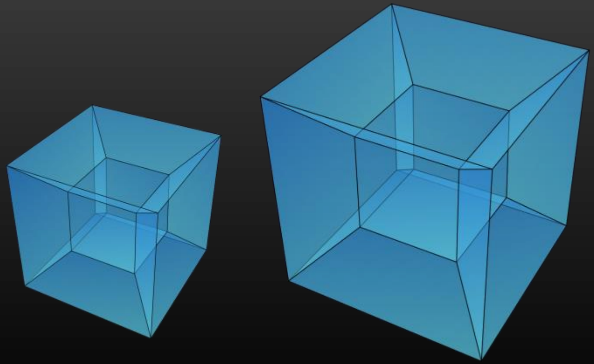
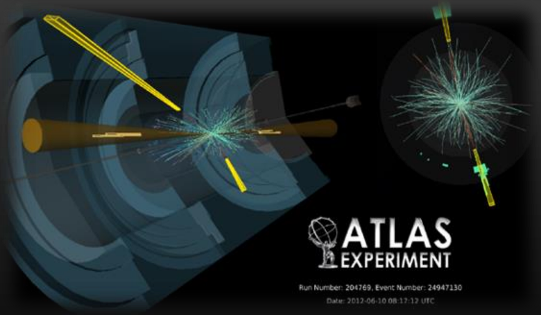
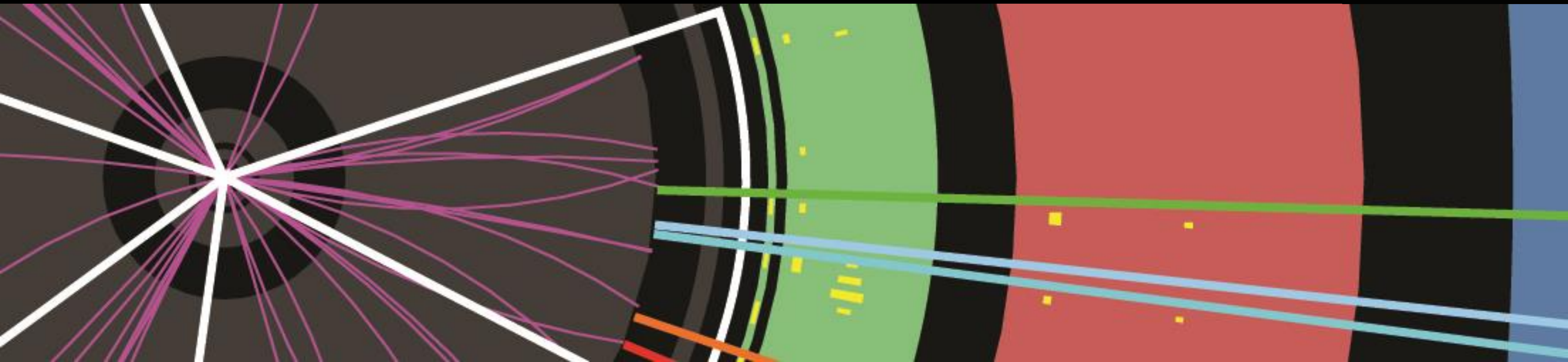




SEARCH FOR EXTRA DIMENSIONS IN THE DI-PHOTON CHANNEL AT THE ATLAS EXPERIMENT AT LHC

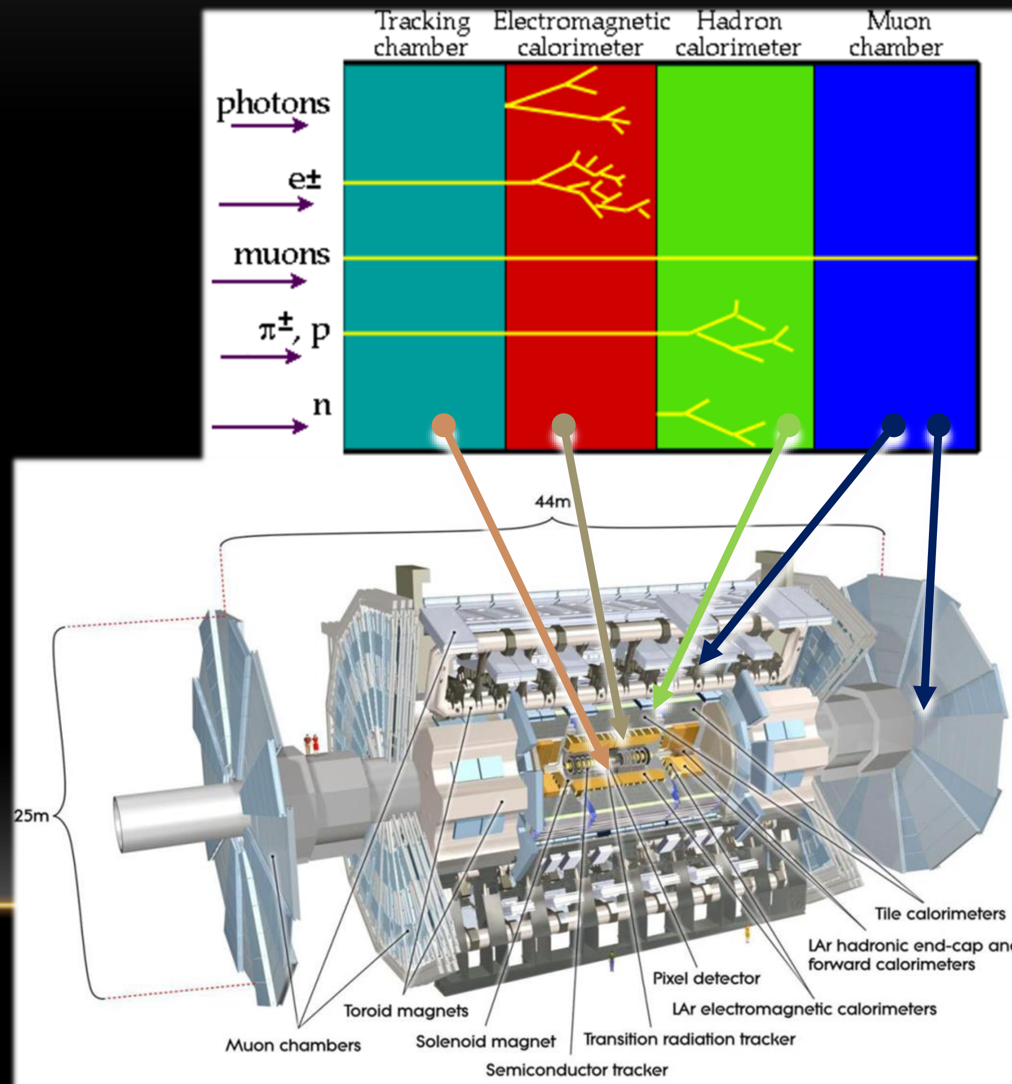
Simone Michele Mazza – Dp. of physics, university of Milan



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

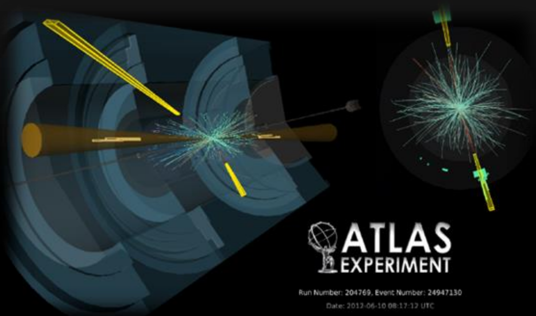
- Three levels of trigger, recordable events/s ~400
  - Trigger level one (hardware)
  - Trigger level two (software)
  - Event filter

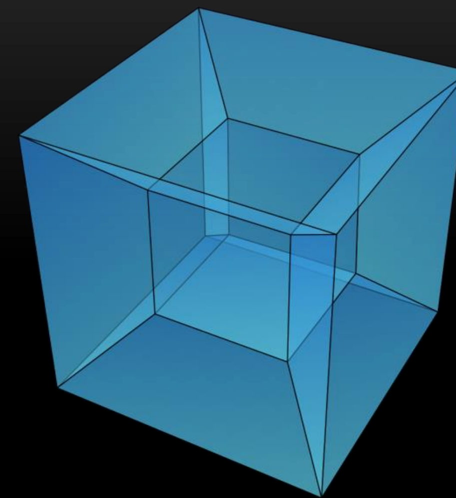
- Object detection based on combination of the detectors' information
  - Object reconstruction
    - Canditades
  - Object identification
    - Photons, electrons, jets etc…



ATLAS EXPERIMENT

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?

10^6

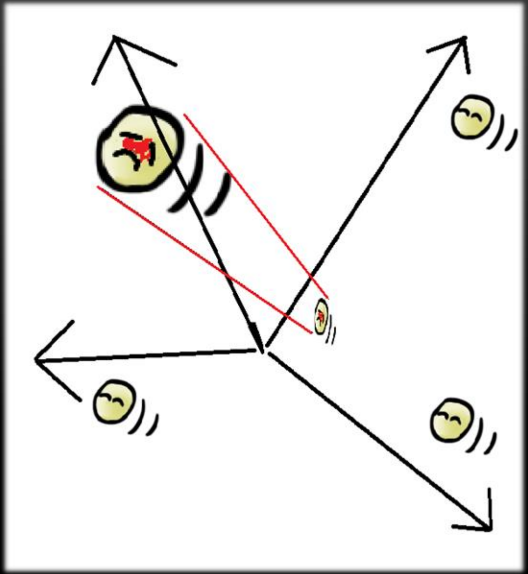
10^{32}

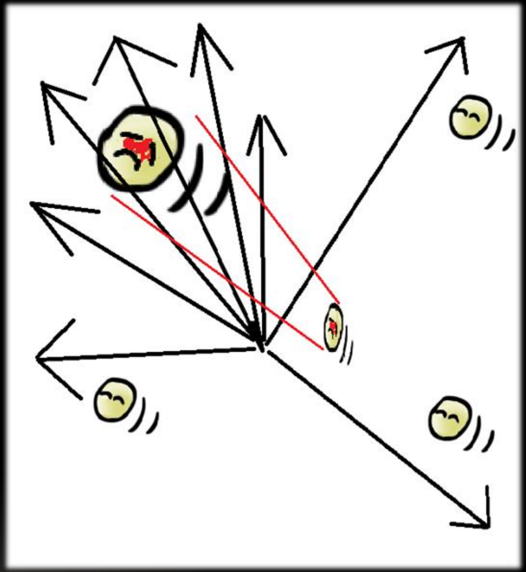
RS AND ADD MODEL

- 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?*

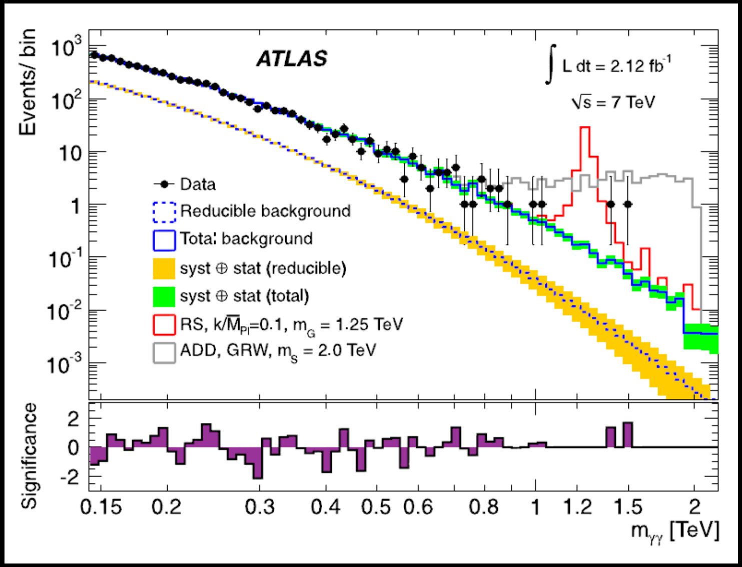


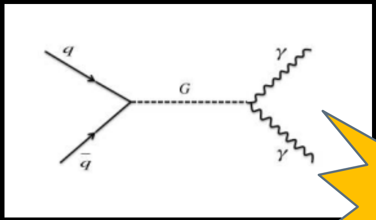


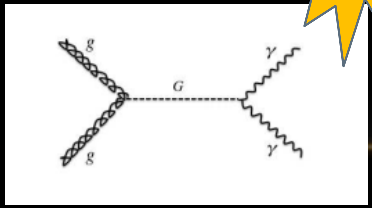
RS AND ADD MODEL

- In particle colliders we can <u>produce and observe the decay of a graviton</u>
  - My analysis tries to detect the Kaluza Klein resonances of the graviton in the additional dimensions in the decay channel with two photons
- Two free parameters
  - Mass of the graviton Mg and coupling k with the SM
- Not an easy analysis:
  - must recognize real diphoton events from <u>reducible background</u> (gamma-jet, dijet) and <u>irreducible background</u>
- Even if we observe a resonance a spin analysis will be needed (could be a Z')

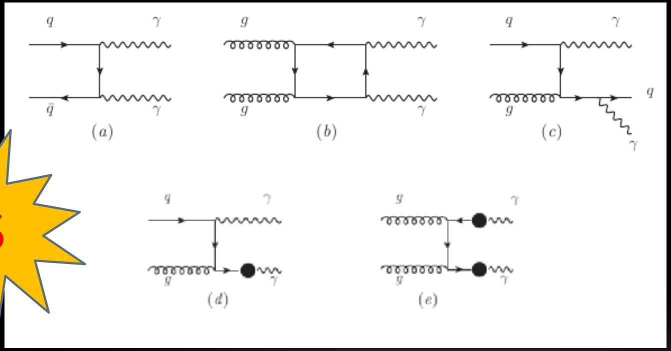
Studying the di-photon invariant mass
RS signature: resonances
ADD signature: non-resonant excess



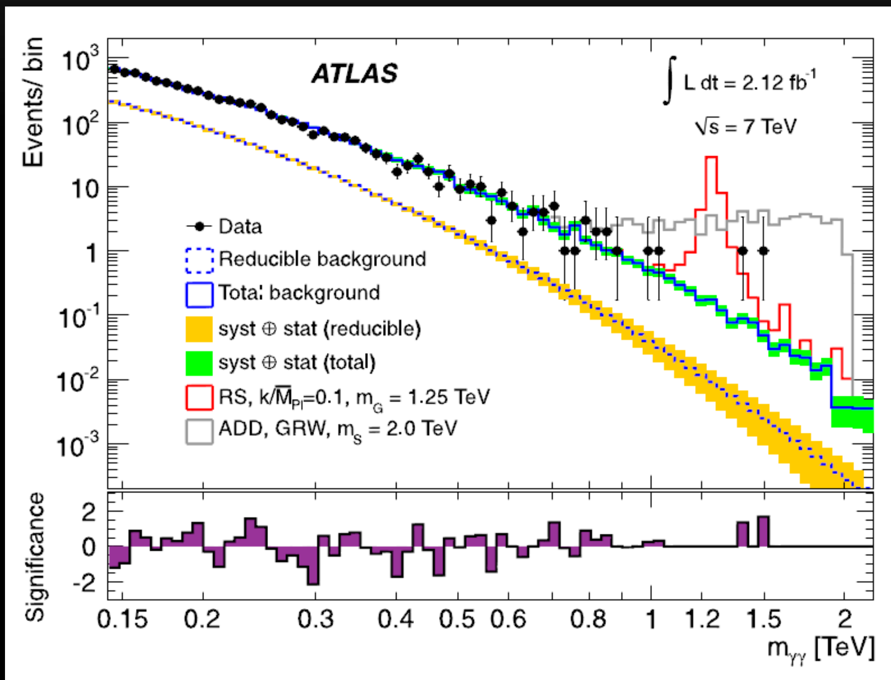


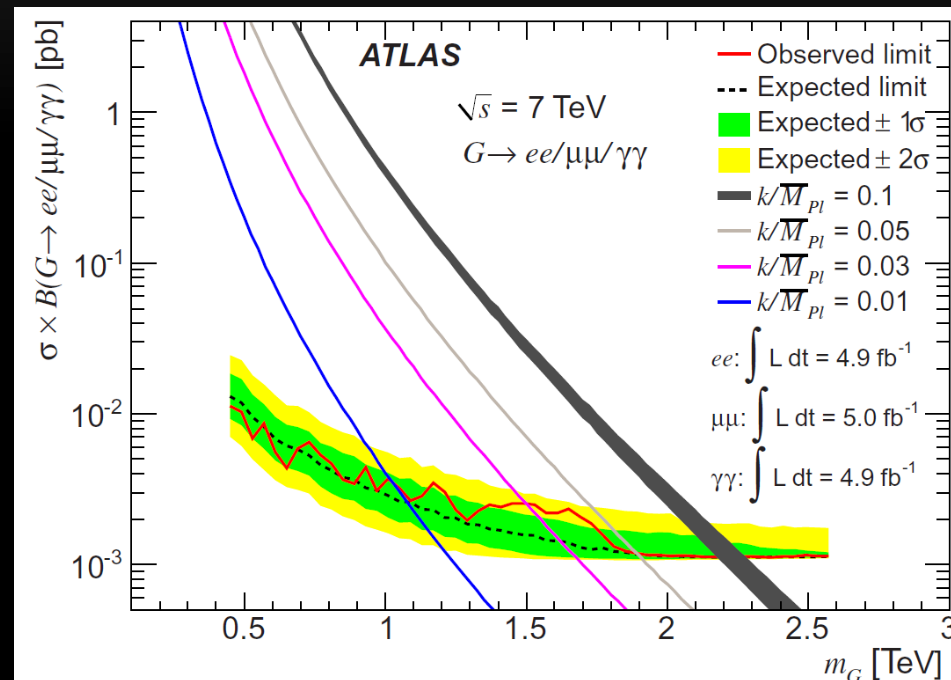


VS



RESULTS UNTIL NOW - EXCLUSIONS





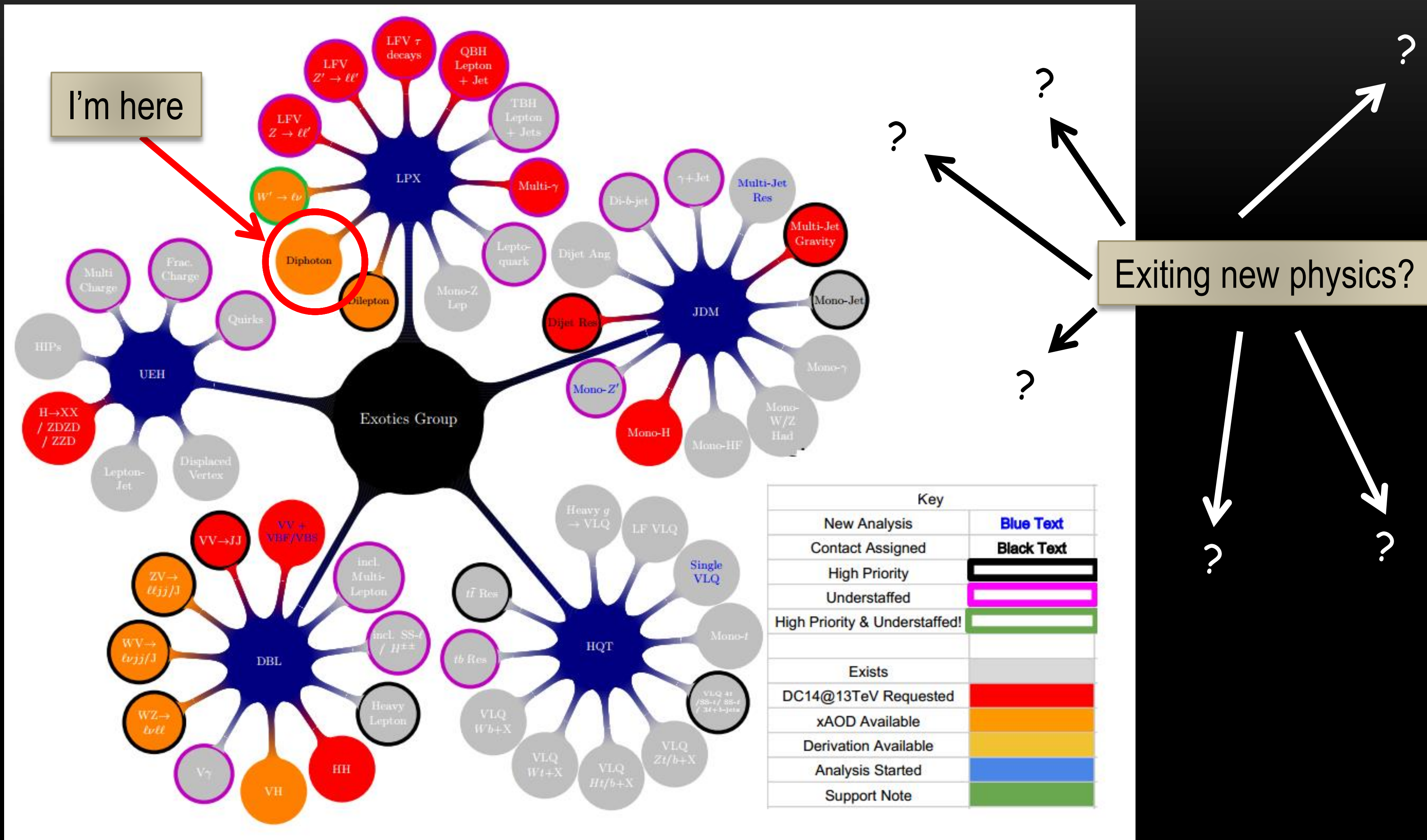
BUT WHO KNOWS WHAT WE'LL FIND IN THE NEXT RUN!?

PREPARING FOR 13 TEV RUN

- Prepare data derivation
- Write analysis
  - Most of the performance tools (photon id, isolation, photon calibration) are work in progress → I'm giving a hand here
- Analyze MC of signal and fit signal model
- Study the background distribution (also from MC) ← I'm around here
- Study systematic errors
- Write Statistics code
- Prepare first projections for 13 TeV run

- Wait for data (May 2015) …
  - Probably L_{int} = 15 fb^{-1} ready for summer (almost the same L_{int} of the whole past run) with 13 TeV of center of mass energy

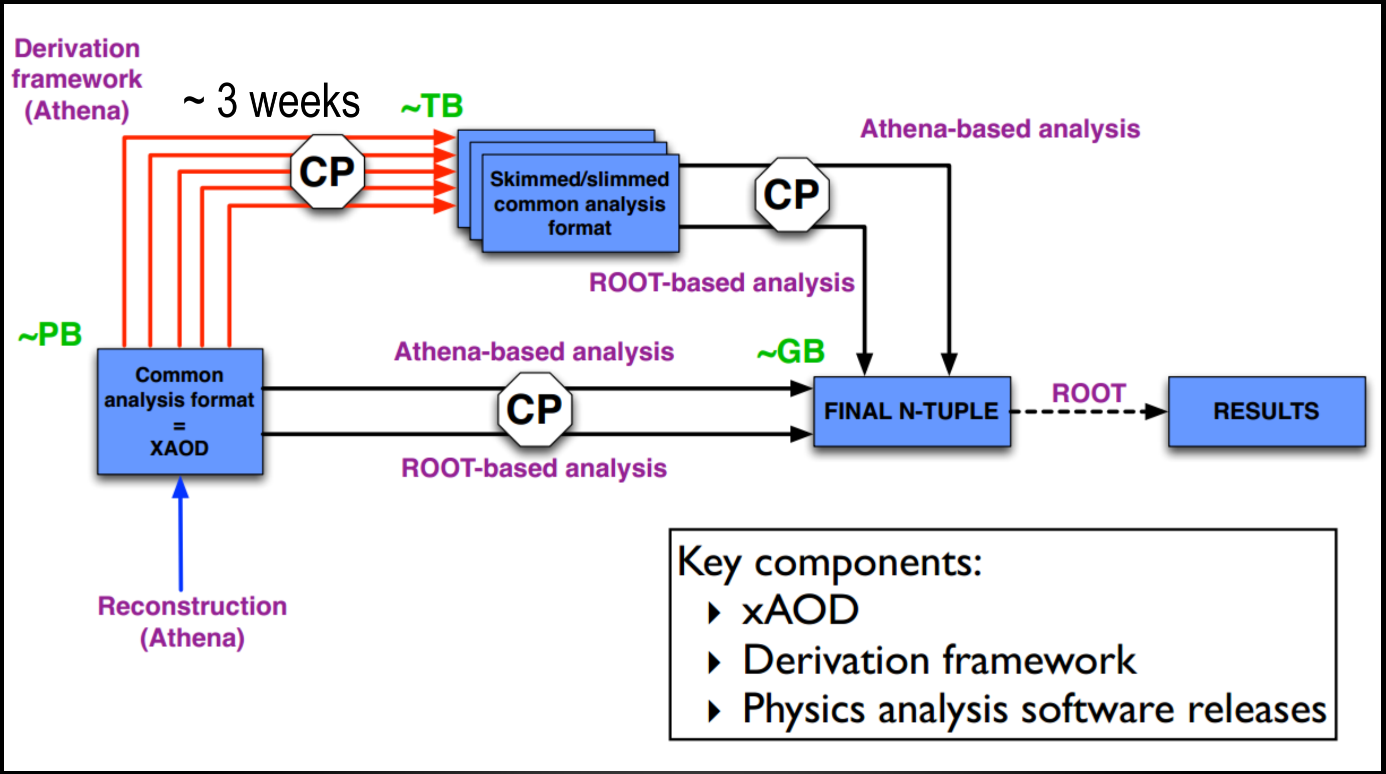
LOTS OF BROTHERS IN THE EXOTICS GROUP!



Maybe there is already a sign of a W'!!! → http://arxiv.org/abs/1405.1994 (ATLAS paper coming soon)

DATA DERIVATION IN ATLAS FOR 14 TEV RUN

- Datasets are HUGE: very important to reduce the size before analyze it in the home institute
  - Keep only certain events and only part of the informations
  - I wrote and currently supporting the derivation for the di-photon exotics group



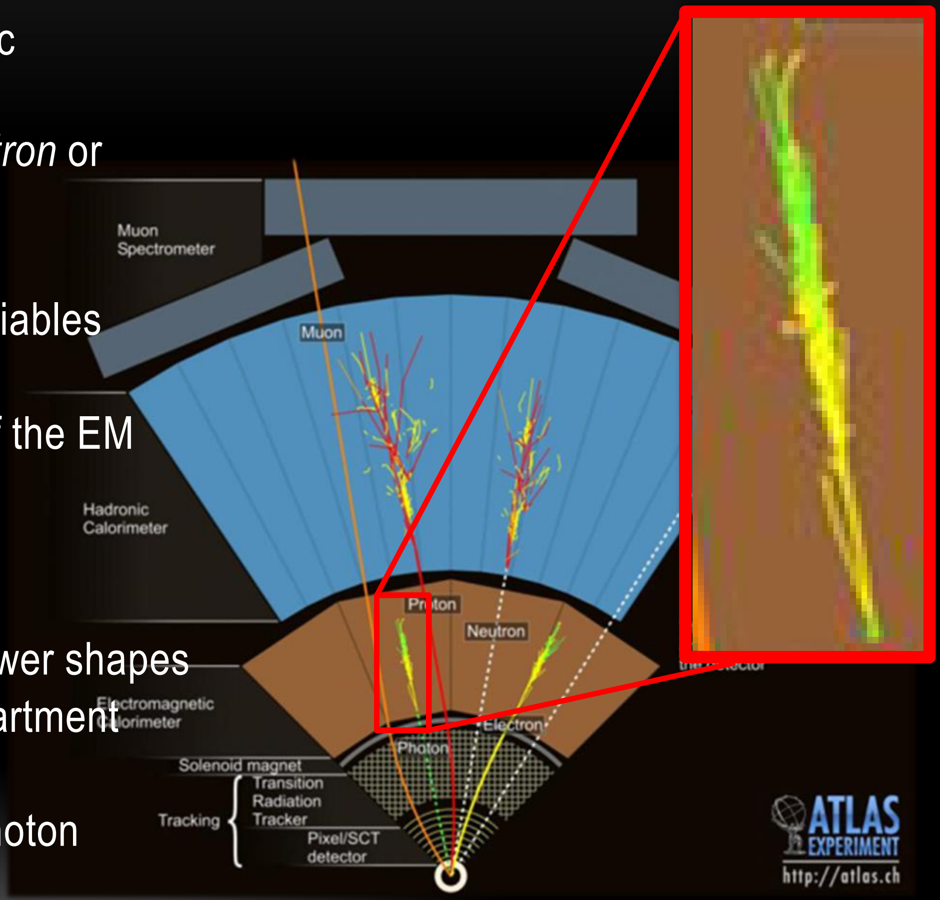
PHOTON RECONSTRUCTION AND IDENTIFICATION IN ATLAS

- 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

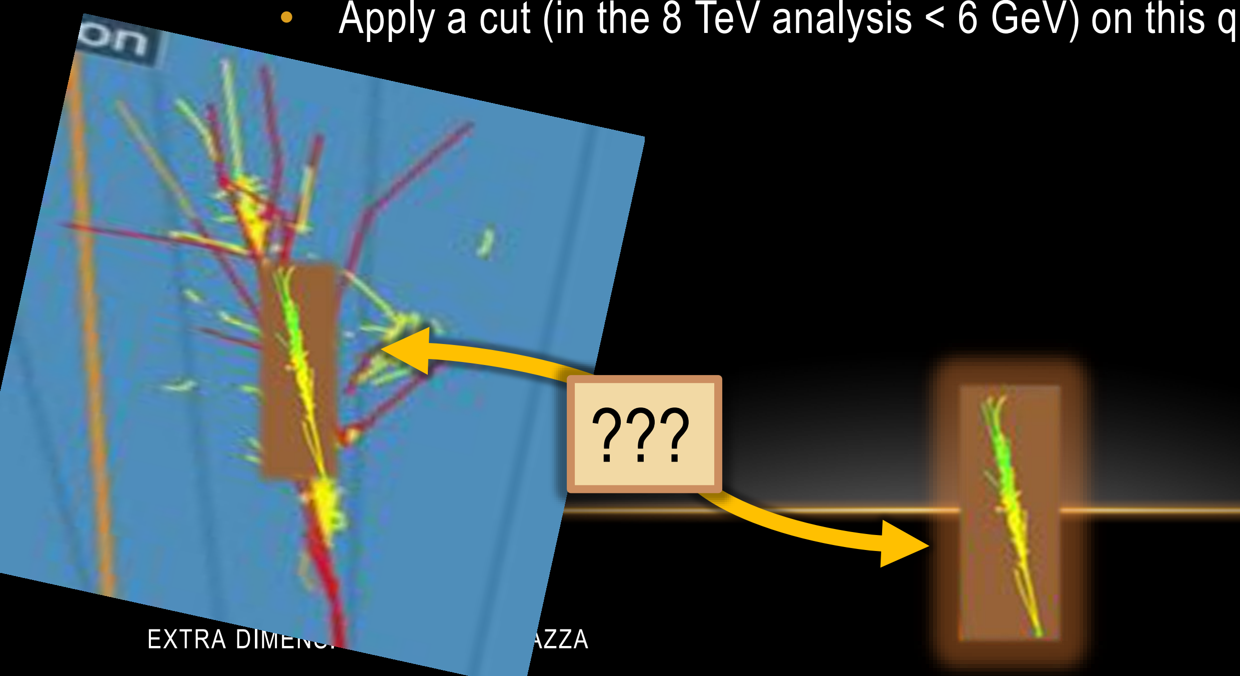
- Two sets of cuts for identification:
  - Loose: leakage + second compartment shower shapes
  - Tight: loose + shower shapes in first compartment

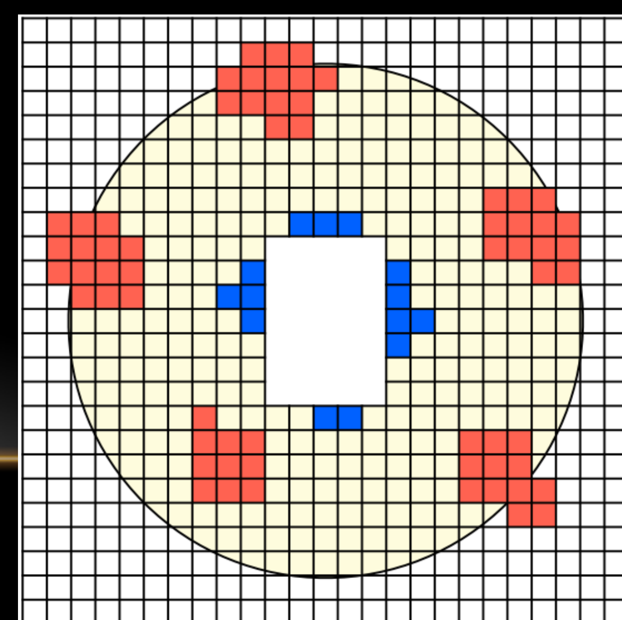
- Isolation variable: energy deposits around the photon



ISOLATION VARIABLE

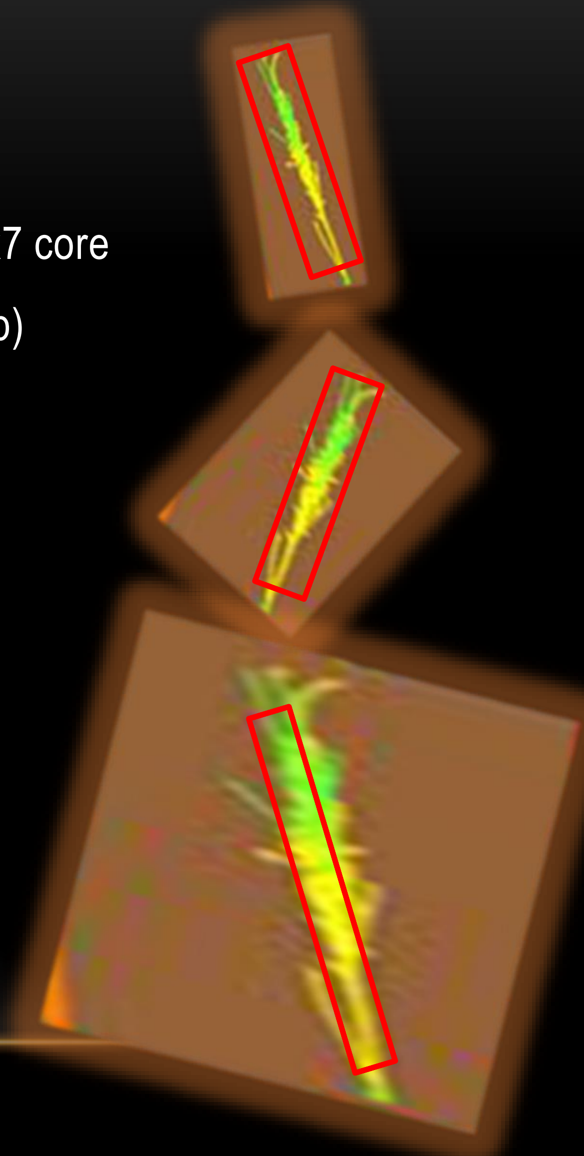
- After the photon identification, how to further identify a real photon from a Jet (or a jet with a prompt (leading) photon?)
  - A Jet faking a photon have lots of other particles around it
- Isolation variable
  - Energy of the *topoclusters* in a cone in the calorimeter of $\Delta R=\sqrt{(\Delta\varphi^2+\Delta\eta^2)}=0.4$ (or 0.2, 0.3) without the central cells (5x7)
  - Corrected for the object energy leakage and pileup/underlying event
    - <u>These corrections are not ready at the moment for the 13 TeV run</u>
  - Apply a cut (in the 8 TeV analysis < 6 GeV) on this quantity





ISOLATION PT LEAKAGE CORRECTIONS

- Currently working in the isolation correction tool
  - Corrections for pt leakage of the e/gamma object outside the 5x7 core
- Analyze a huge dataset of single particle photon and electron (~ 3 Tb)
  - Only *one photon* without pileup
  - to get the distribution of topoclusters energy in the cone, that is completely from pt leakage, vs the photon Et
  - Fit the 2D distribution of Et and topoEtcone in η bins to get the median leakage of the e/gamma object
  - Get the correction factor as a function of (Et, η) and apply it to data/MC in the analysis
- Next step: get pileup corrections



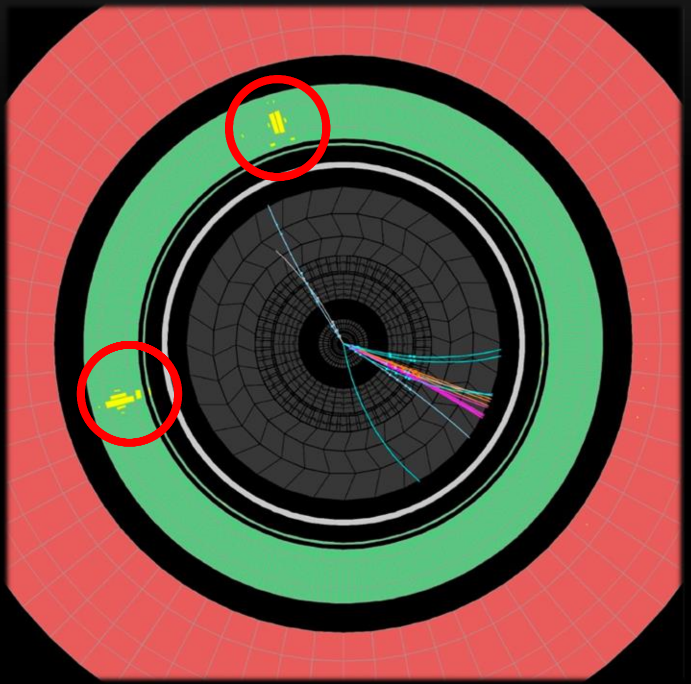
SELECTION OF EVENTS WITH TWO PHOTONS

- Selection for two well reconstructed and isolated photons
  - Pass trigger with 2 photons (E_T of 25,35 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 $|\eta| < 2.37$, $E_T > 25$ GeV
  - Passing loose ID criteria

- Define leading, sub-leading photons (most energetic)
  - Leading photon with $E_T > 40$ GeV
  - Sub-leading photon with $E_T > 30$ GeV
  - Pass tight cut criteria and isolation (calorimeter and tracks)

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



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

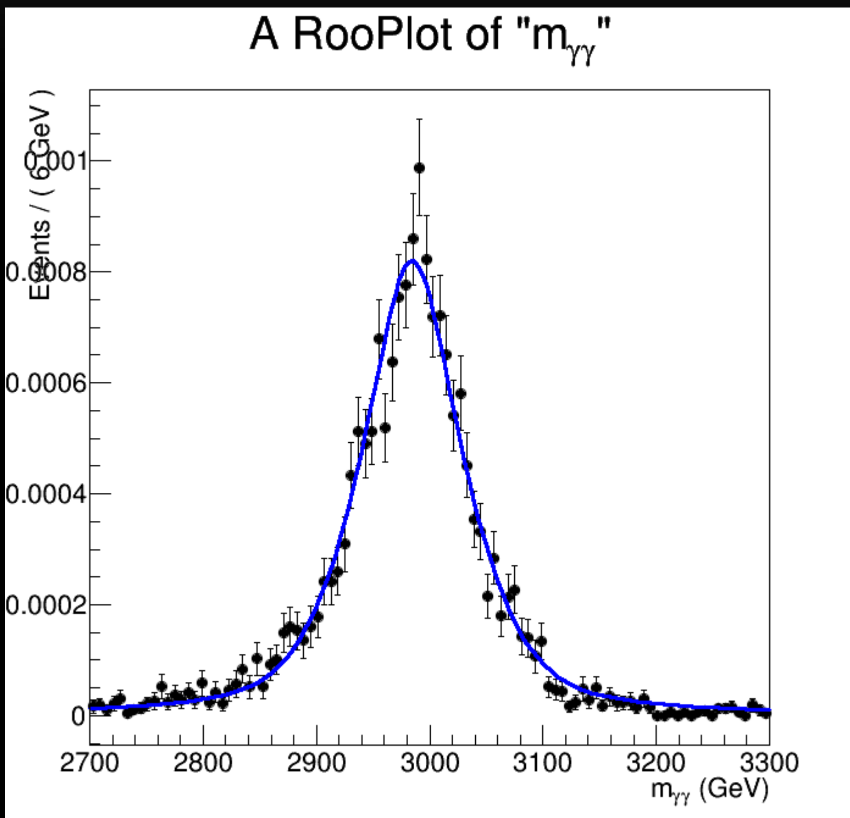
SYSTEMATICS,
SIGNAL AND BACKGROUND MODEL

- Study of the systematic errors
  - Impact on event selection, kinematic variables
  - On photon calibration, isolation, photon identification …

- Using this selection we can re-create the distribution of $M_{\gamma\gamma}$ of MC signal samples
  - Samples of signal of gravitons with different Masses and couplings
  - Fit an analytic function to the signal distribution
- Study the $M_{\gamma\gamma}$ of the background distribution
  - choosing the best analytic function to describe it
  - Fit the chosen background function on data outside the signal region (ex: $M_{\gamma\gamma} < 1$ TeV)

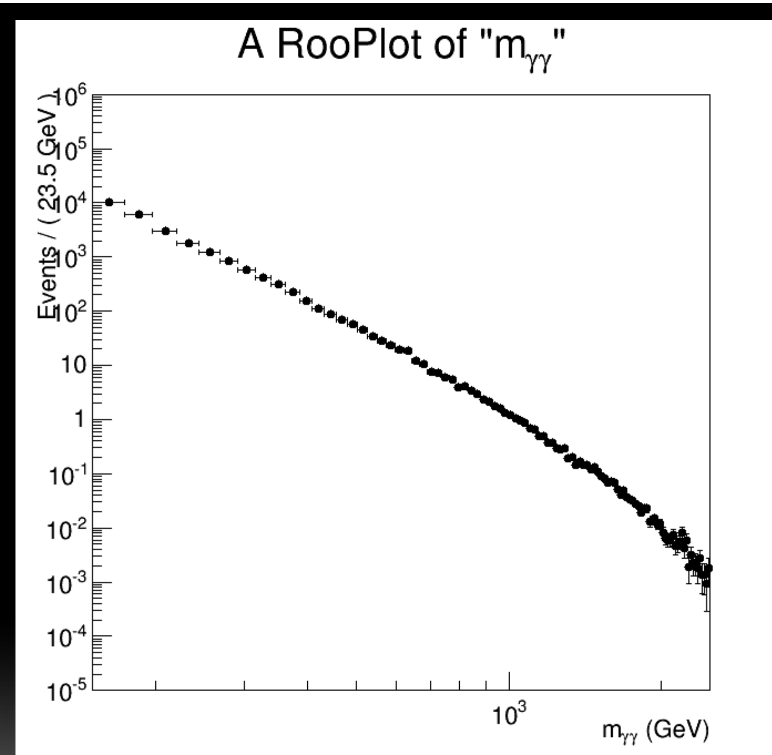
SIGNAL FIT AND BACKGROUND - PRELIMINARY

- Signal model (MC):
  BreitWiegner + Gaussian

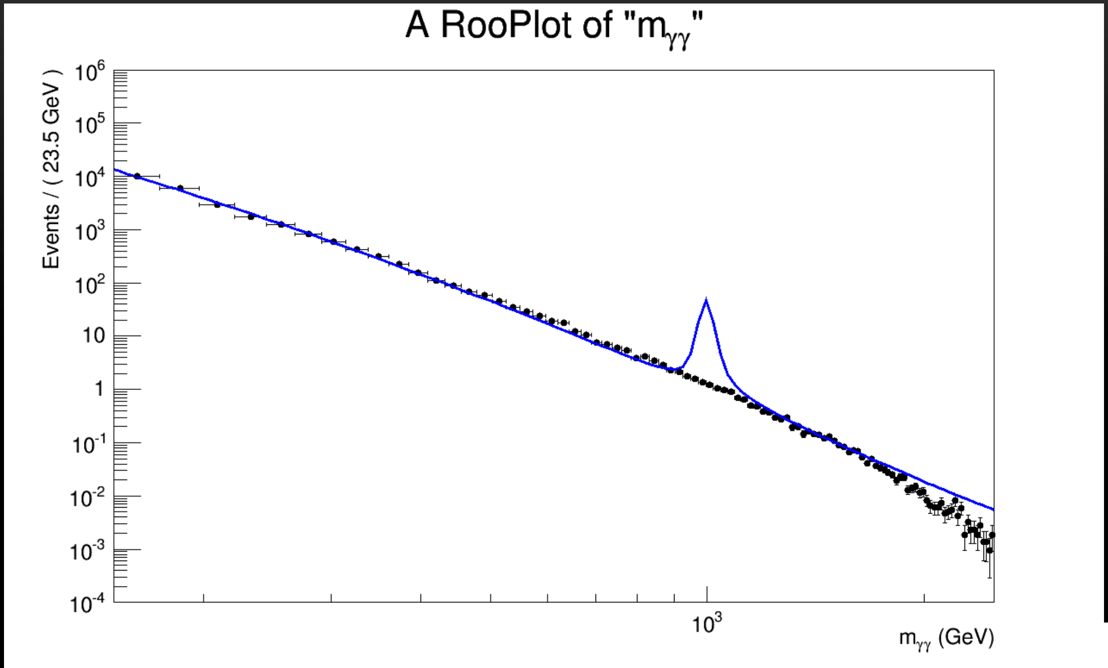


- Background model (MC):

$$x^{k_1\times(1-log(x))} \times x^{k_2\times log(x)} \times \left(1 - \frac{1}{1+e^{(x-k_3)/k_4}}\right)$$

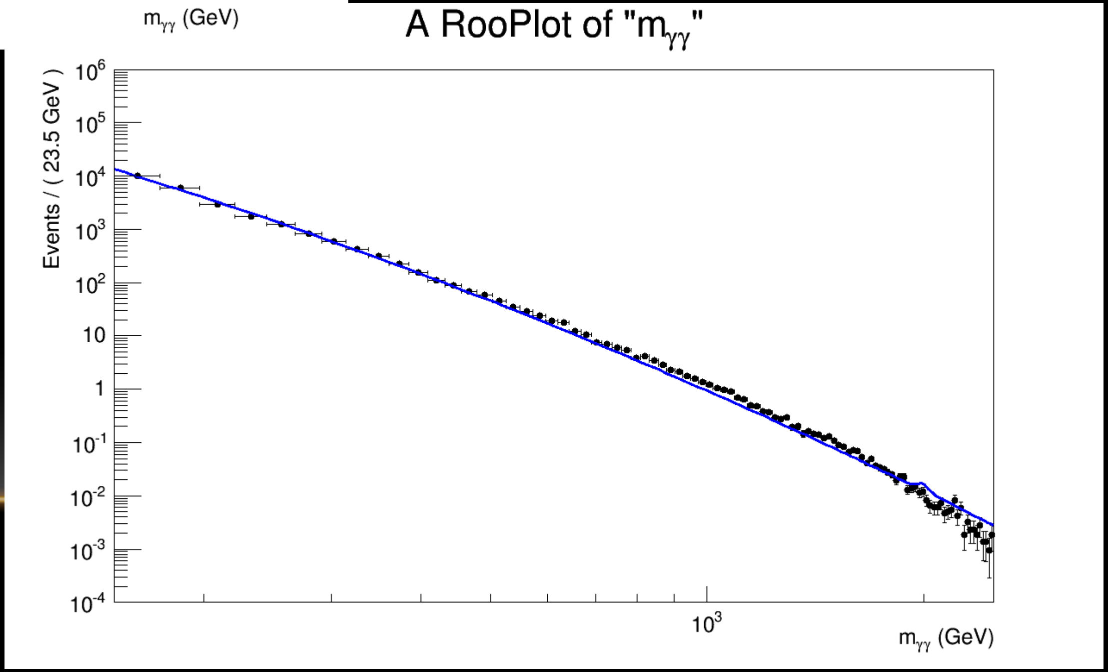


PRELIMINARY RESULTS



Graviton with

Mg = 1 TeV and k = 0.1



Graviton with

Mg = 2.5 TeV and k = 0.1

EXTRAPOLATE STATISTIC RESULTS

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

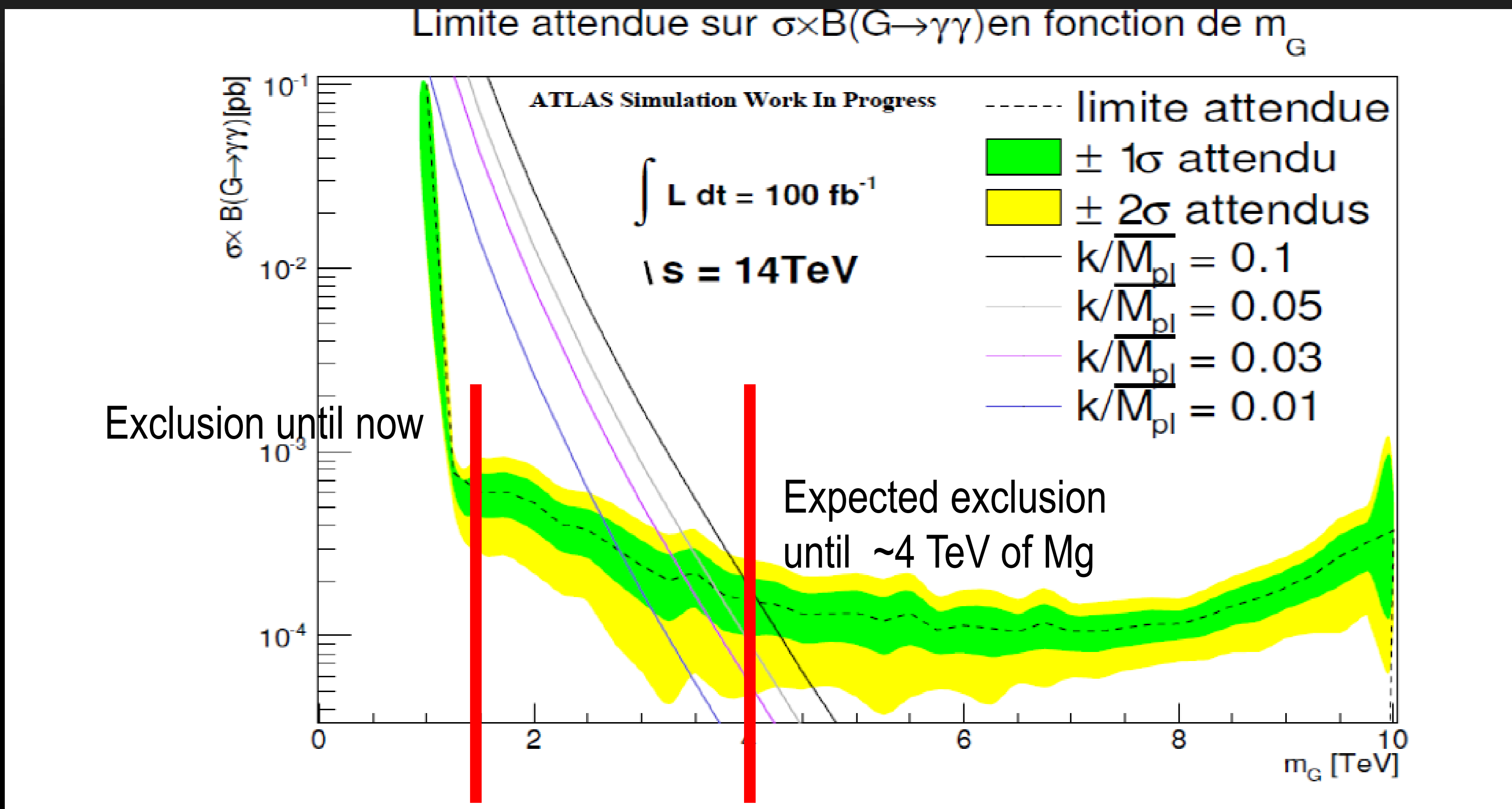
$$E[n_i] = \mu s_i + b_i ,$$
$$s_i = s_{\rm tot} \int_{{\rm bin}\, i} f_s(x; \boldsymbol{\theta}_s)\, dx ,$$
$$b_i = b_{\rm tot} \int_{{\rm bin}\, i} f_b(x; \boldsymbol{\theta}_b)\, dx .$$

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

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

- 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

13 TEV PROJECTIONS FOR 100 FB^{-1}
(COURTESY OF GRENOBLE)



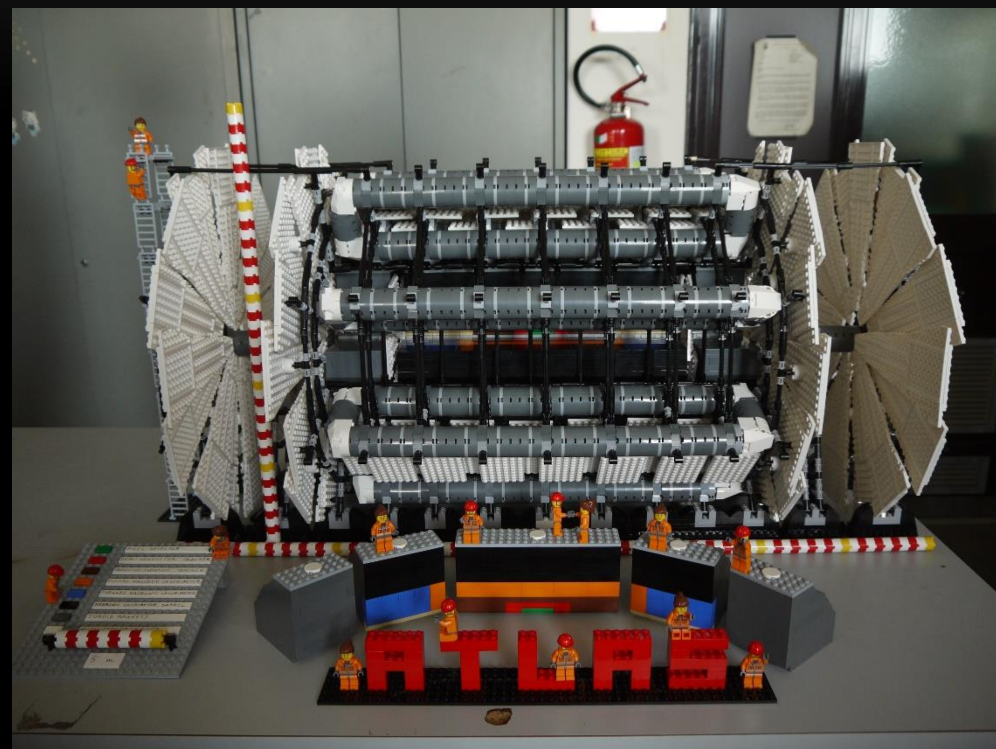
Valeurs de $k/\overline{M_{Pl}}$	0.01	0.03	0.05	0.1
Limites attendues [TeV] (LO)	2.80	3.54	3.39	4.10

MAYBE A SIGNAL WILL SHOW UP?

~~Conclusions~~ → FUTURE PLANS

- Preparation for run 2 data analysis is progressing
  - Performance tool
  - Systematics
  - Statistic
- I am doing my best to meet the data taking re-start
- Looking forward to run2!
- …
- <u>Thank you for your time!</u>

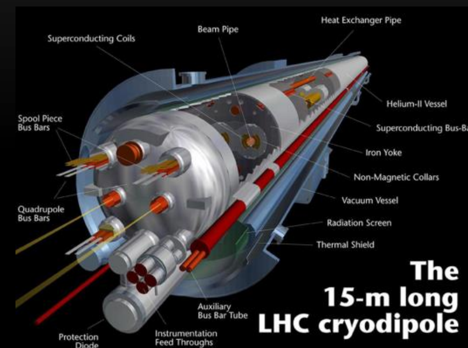
ATLAS EXPERIMENT

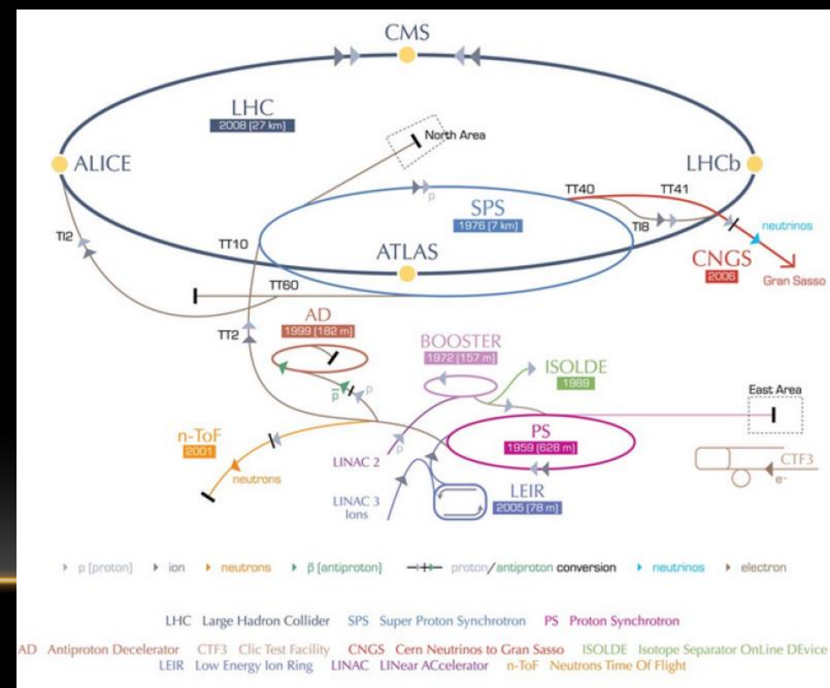


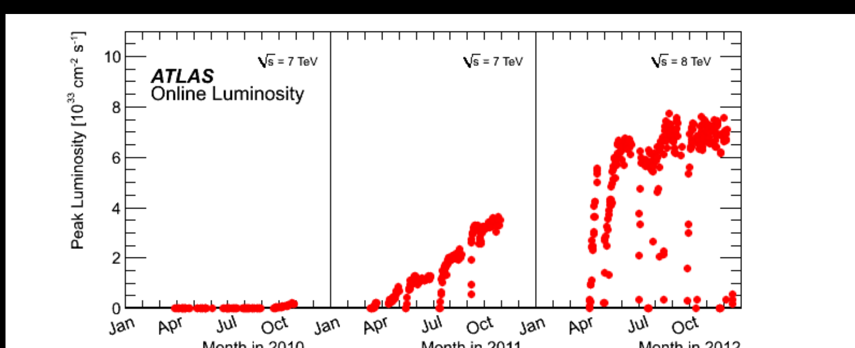
BACKUPS

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 8x$10^{33}cm^{-2}s^{-1}$
  - Bunch spacing: 25ns
- Now in shutdown
  - Will re-open in 2015 with 14 TeV of center of mass energy



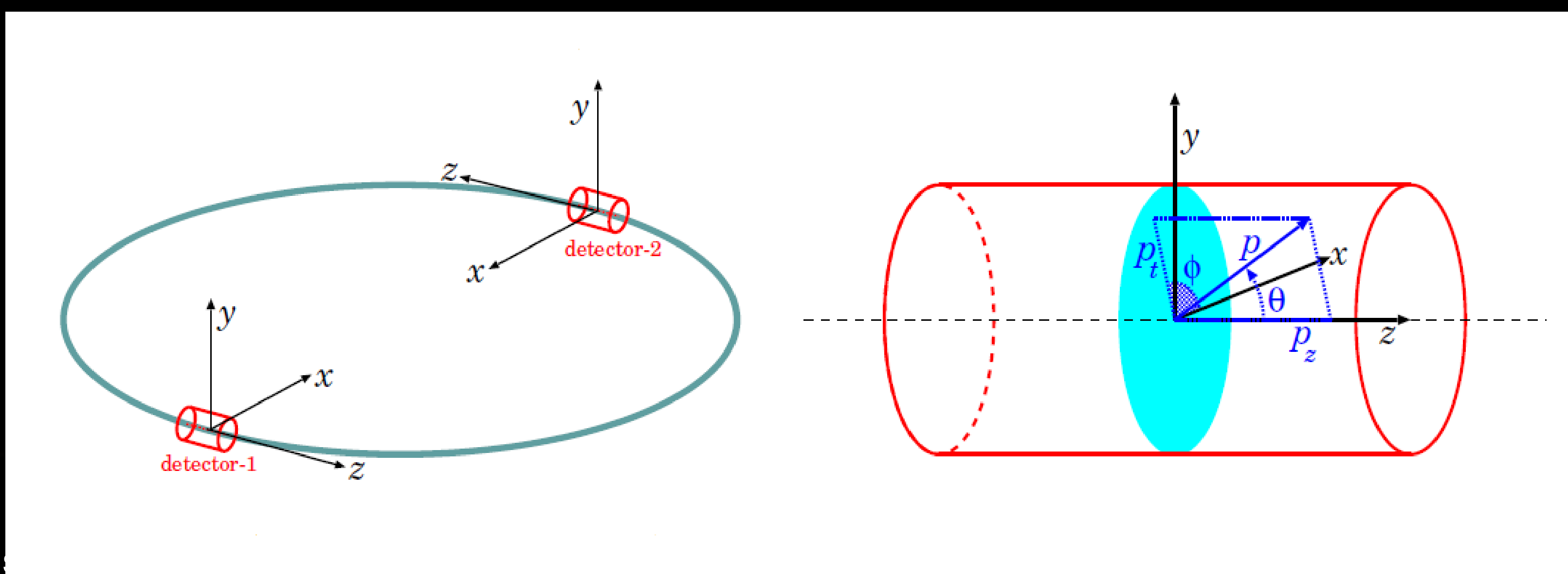




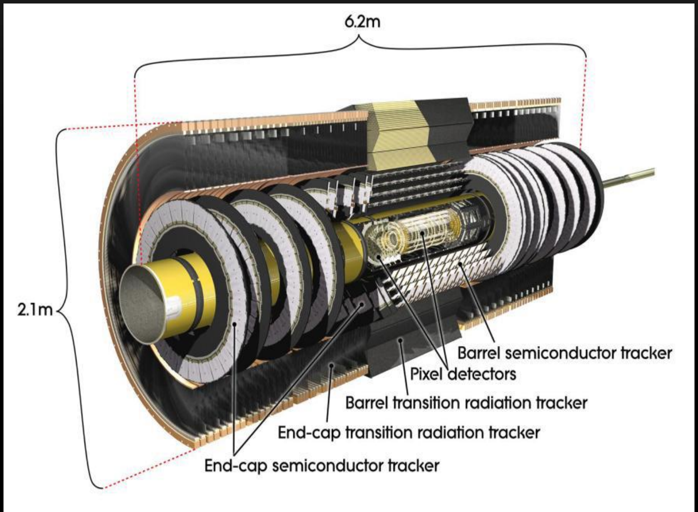
ATLAS COORDINATES SYSTEM

- 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

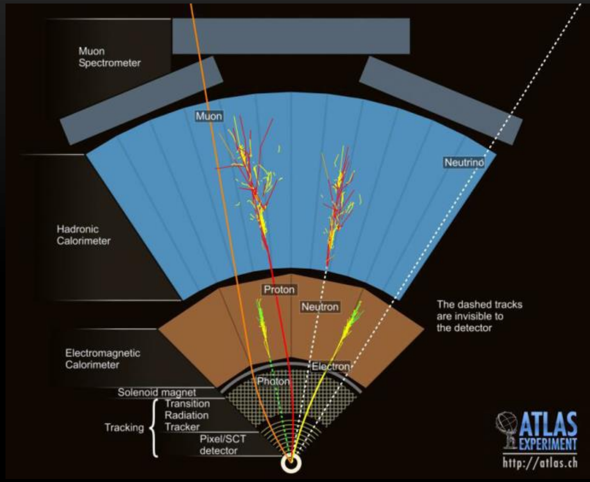


ATLAS DETECTOR STRUCTURE



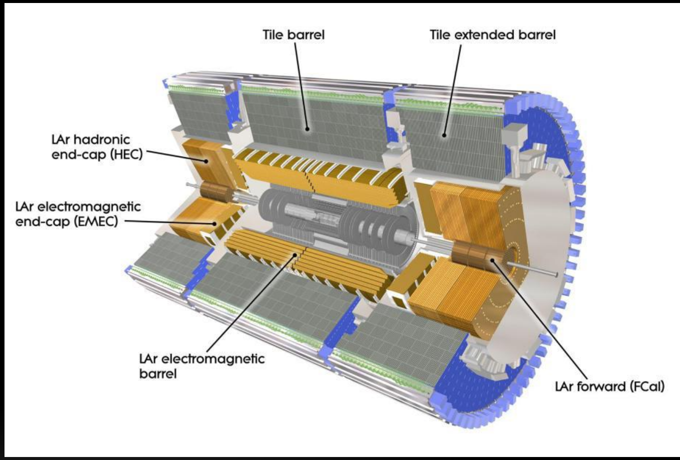
Inner detector

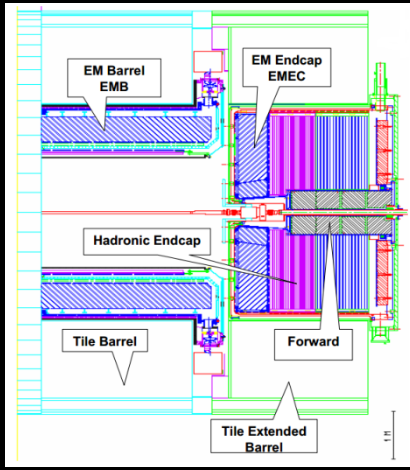
- 7 m long, 2.3 m diameter
- Measure tracks for charged partices
- Detect primary and secondary vertices
- Three layers
  - Semiconductor pixel detectors
  - Silicon microstrip detector
  - Radiation transition detector

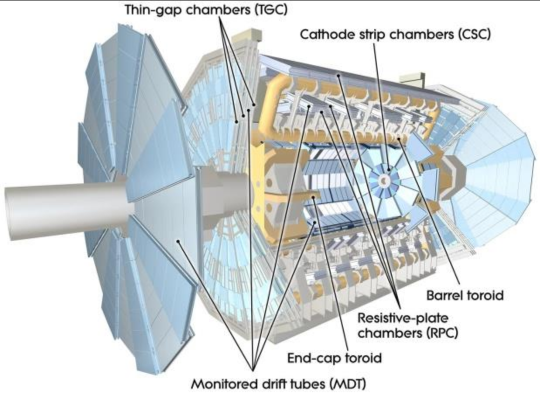


Calorimeters

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



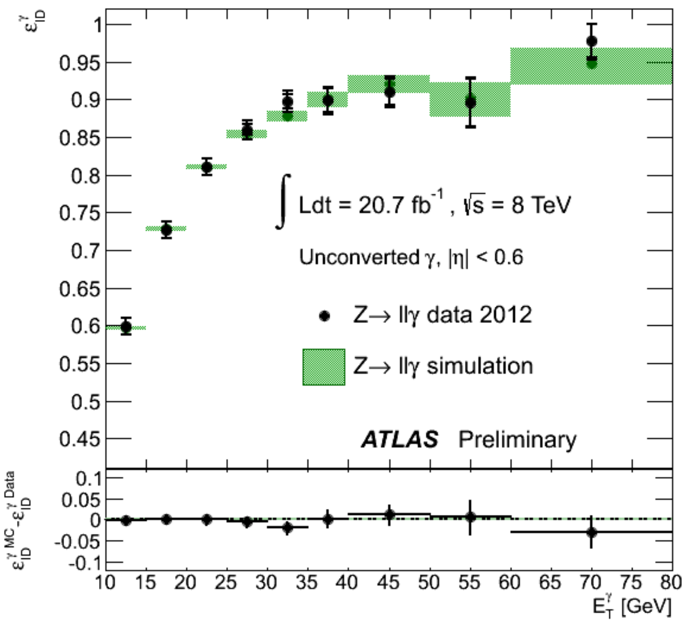


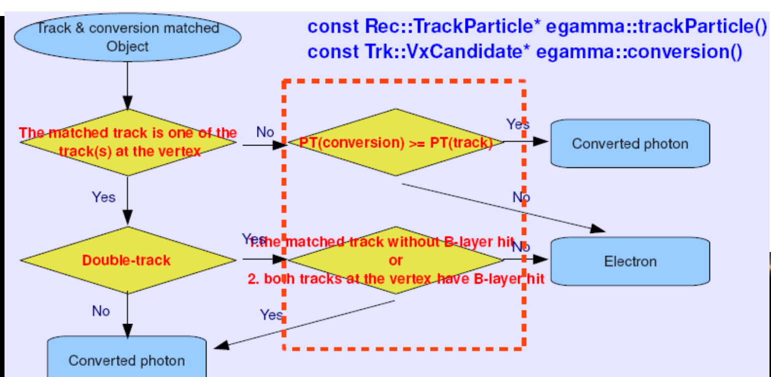


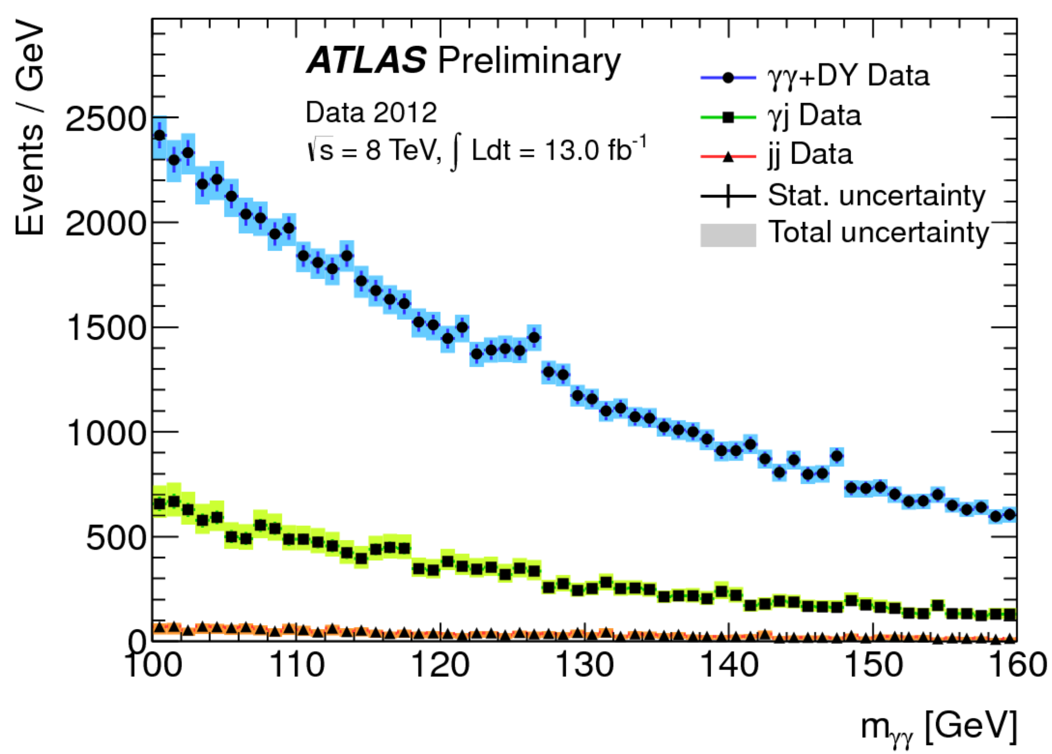
Muon detector

- 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

PHOTON IDENTIFICATION EFFICIENCY
DI-PHOTON COMPOSITION







ATLAS INNER DETECTOR AND ELECTROMAGNETIC CALORIMETER

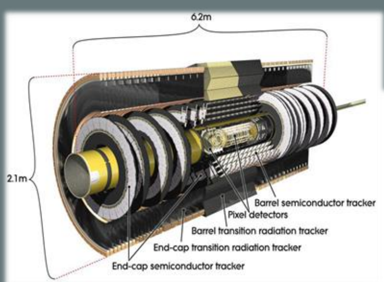
- **Inner detector**
  - **Measure charged particles tracks**
  - **Detect primary and secondary vertices**
- Three levels
  - Semiconductor pixel detectors (±10 μm)
  - Silicon microstrip detectors (±16 μm)
  - Radiation transition detector (±30 μm)

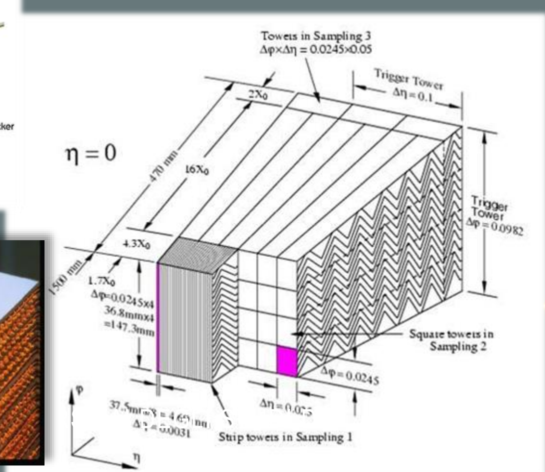
- **Electromagnetic calorimeter**
  - **Detect photons, electrons**
  - Sampling calorimeter of Liquid Argon /Pb
  - Covers pseudorapidy region of |η|<3.2
  - Electrodes and absorbers are bend in a accordion way
- Segmented in three longitudinal segments with different glanularity
- Resolution:

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

- **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