Searches for periodic resonance signals in the dielectron and diphoton channels in ATLAS

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WNPPC

16-Feb-2023

Motivation

- The Standard Model is not complete
- Gravitation? Hierarchy problem? Higgs naturalness problem?
- String theory predicts the existence of the gravitational force carrier – Graviton
- Periodic resonances? Most studies focus on non-periodic resonances

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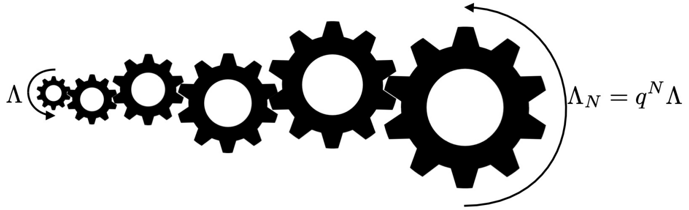
Benchmark Model:

- Clockwork theory is a model-building mechanism to generate fundamental particles
- Clockwork theory suggested graviton with different mass modes and periodic resonances

The full work is recorded at https://cds.cern.ch/record/2754323 (internal only)

Clockwork theory

- Live in warped 5D metric $$ds^2 = e^{\frac{4}{3}k\pi R}(\eta_{\mu\nu}dx^\mu dx^\nu + \pi^2 dR^2)$$
- Provide a mechanism to generate particles in all ranges of scales.



- With a small interaction scale Λ, we can leverage discretely to an exponentially large Λ

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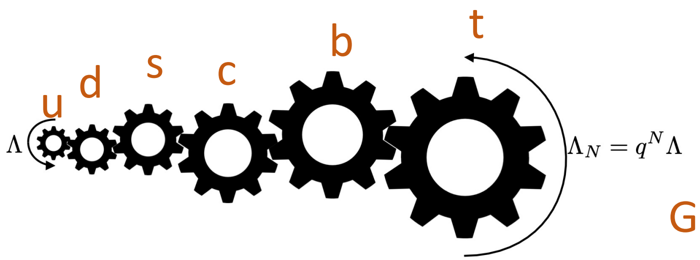

Getting top quark from up quark!

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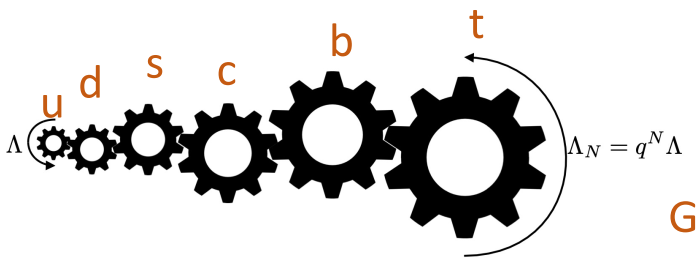


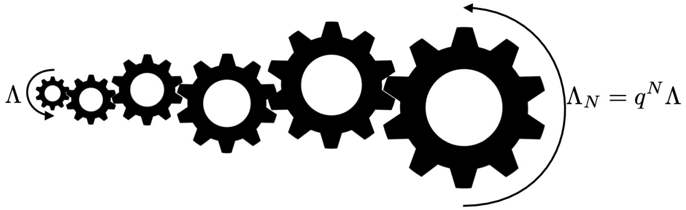
Getting top quark from up quark!

- With a small interaction scale Λ, we can leverage discretely to an exponentially large Λ
- A solution to the Hierarchy problem similar to Little String Theory
- A solution to the Higgs naturalness problem similar to Large Extra Dimension model(LED) and the Randall-Sundrum(RS) model

Undetermined parameters k, M_5 , R

$$ds^2 = e^{\frac{4}{3}k\pi R}(\eta_{\mu\nu}dx^\mu dx^\nu + \pi^2 dR^2)$$

- k Higgs-curvature is a metric parameter, the “spring constant” for the clockwork model
- R is the cut-off range for the high dimension gravitational potential
- M_5 fundamental scale related to Λ , also known as 5D reduced Planck mass



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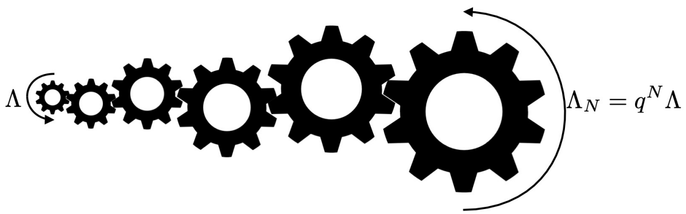


- Related by an equation, where M_p is the 4D(3+1) Planck mass.

$$M_P^2 = \frac{M_5^3}{k}\left(e^{2\pi kR} - 1\right)$$

k, M_5 , R

$$M_P^2 = \frac{M_5^3}{k}\left(e^{2\pi kR} - 1\right)$$

- 4D Planck mass M_p can be obtained by rewriting Newtonian Gravitational potential

$$V(r) = \frac{Gm_1m_2}{r} = \frac{m_1m_2}{{M_p}^2 r}$$

- Extend the potential to 4+n dimensions

$$V(r) = \frac{m_1m_2}{M_n^{2+n}}\frac{1}{r^{1+n}}$$

(in 4+n-Dimensions)

- Make consistent with Newtonian gravity, setting cut off range R so that we get 4D potential at r>>R.

$$V(r) = \frac{m_1m_2}{M_n^{2+n}}\frac{1}{R^n}\frac{1}{r}$$

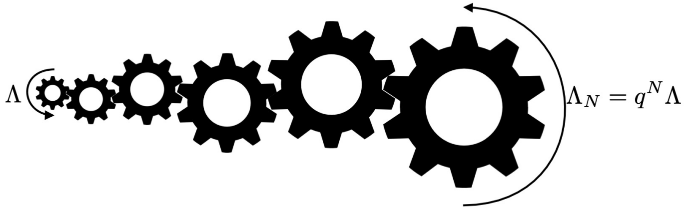
(in 4+n-Dimension but r>>R)

k, M_5 , R

$$V(r) = \frac{m_1 m_2}{M_p^2}\frac{1}{r} = \frac{m_1 m_2}{M_n^{2+n}}\frac{1}{R^n}\frac{1}{r}$$

$$M_n^{2+n} = \frac{M_p^2}{R^n}$$

- n=1 for one extra space $M_5^3 = \frac{M_p^2}{R}$
- Adding in the curved metric effect, we obtain $M_P^2 = \frac{M_5^3}{k}\left(e^{2\pi kR} - 1\right)$



+ $$ds^2 = e^{\frac{4}{3}k\pi R}(\eta_{\mu\nu}dx^\mu dx^\nu + \pi^2 dR^2)$$

Searching Routine

Simulating Physics

Simulating Detector Responses

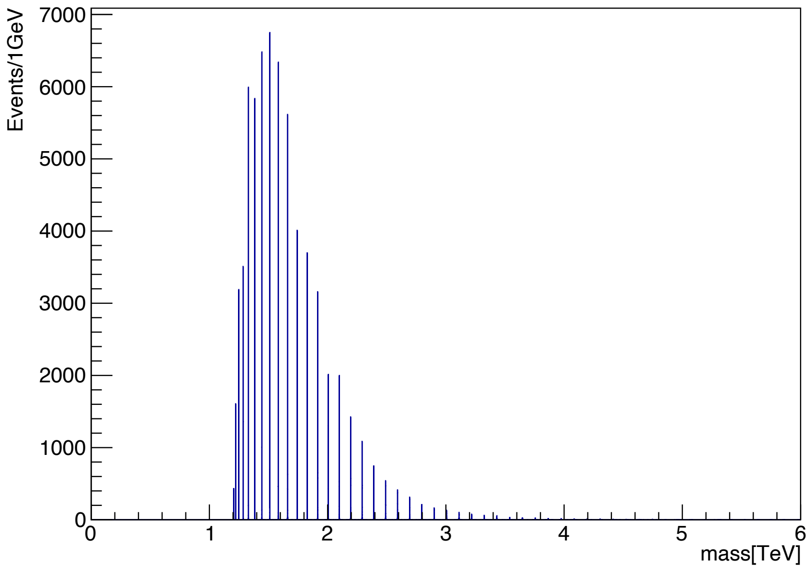
Analyzing responses

Clockwork graviton Physics

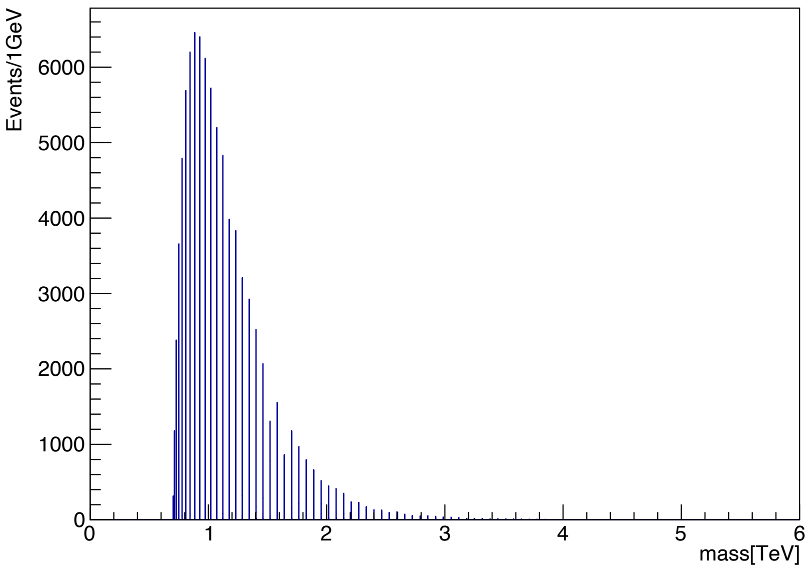
- Clockwork gravitons are predicted to have different mass modes, each having a different mass and interaction strength.
- Br(G→ γγ)=4% Br(G→ee)=2%
- Search the phase space (k, M_5) by simulating clockwork graviton at different (k, M_5)

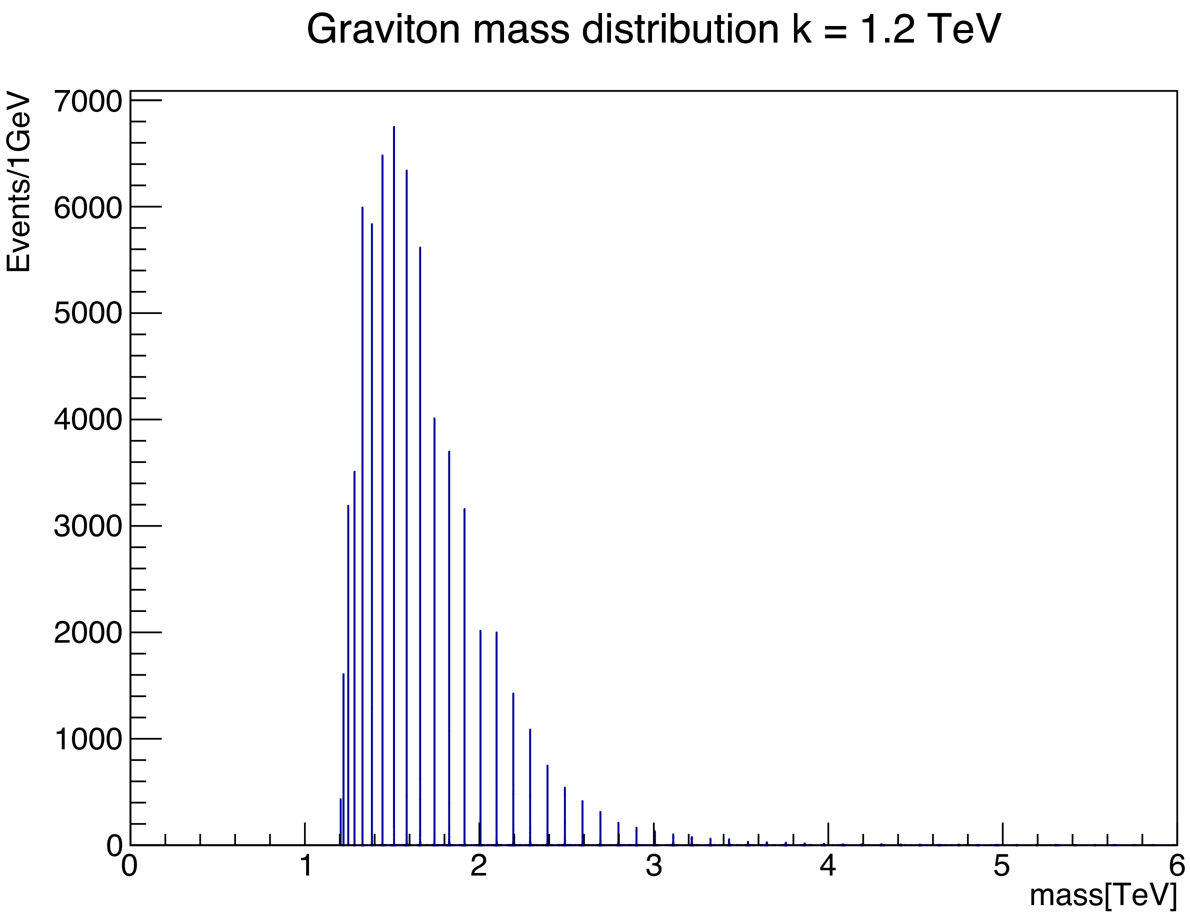
$$m_0 = 0\,, \qquad m_n^2 = k^2 + \frac{n^2}{R^2}\,, \qquad n = 1, 2, 3, \ldots$$

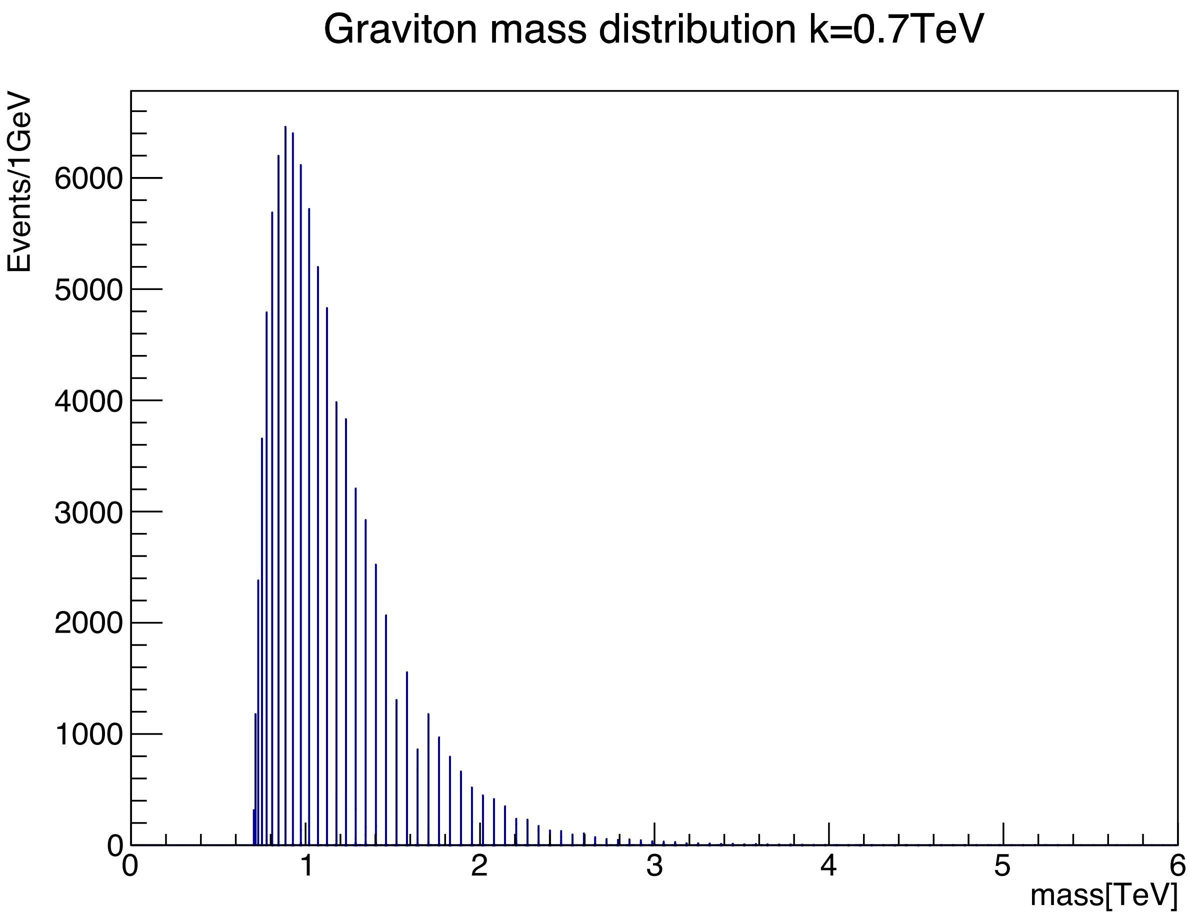
Graviton mass distribution k = 1.2 TeV



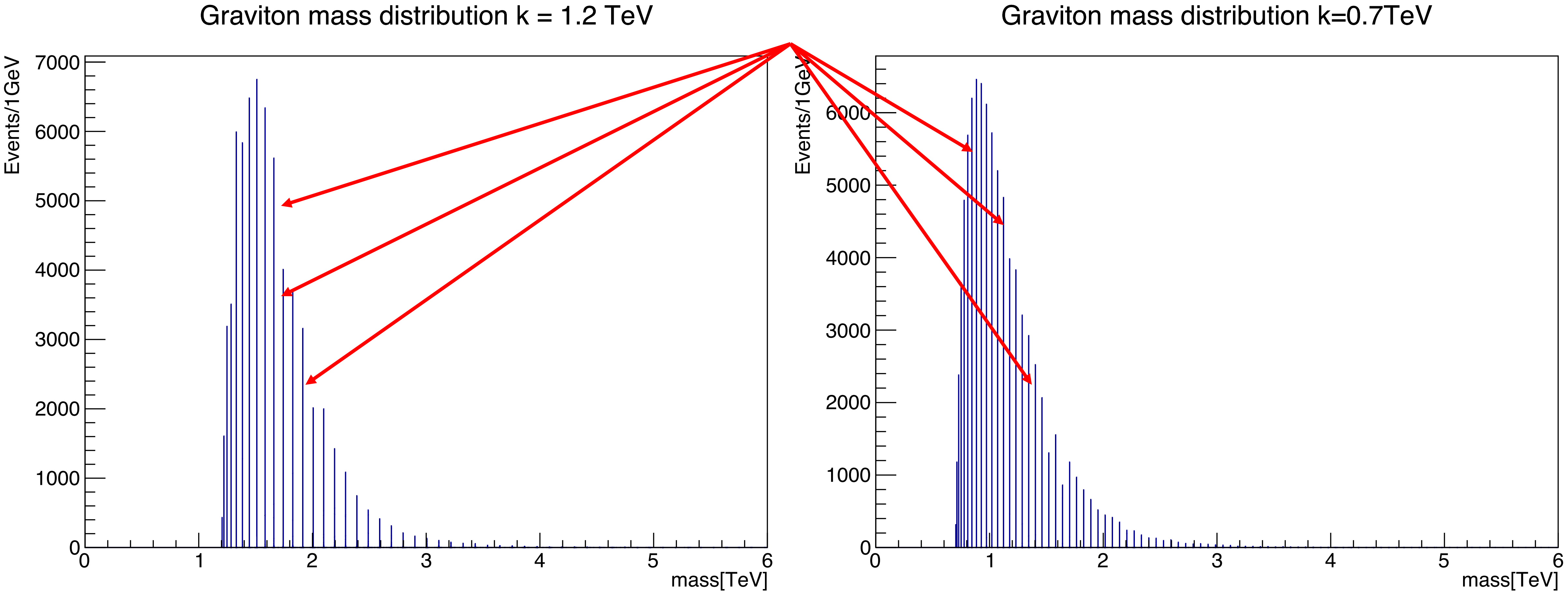
Graviton mass distribution k=0.7TeV



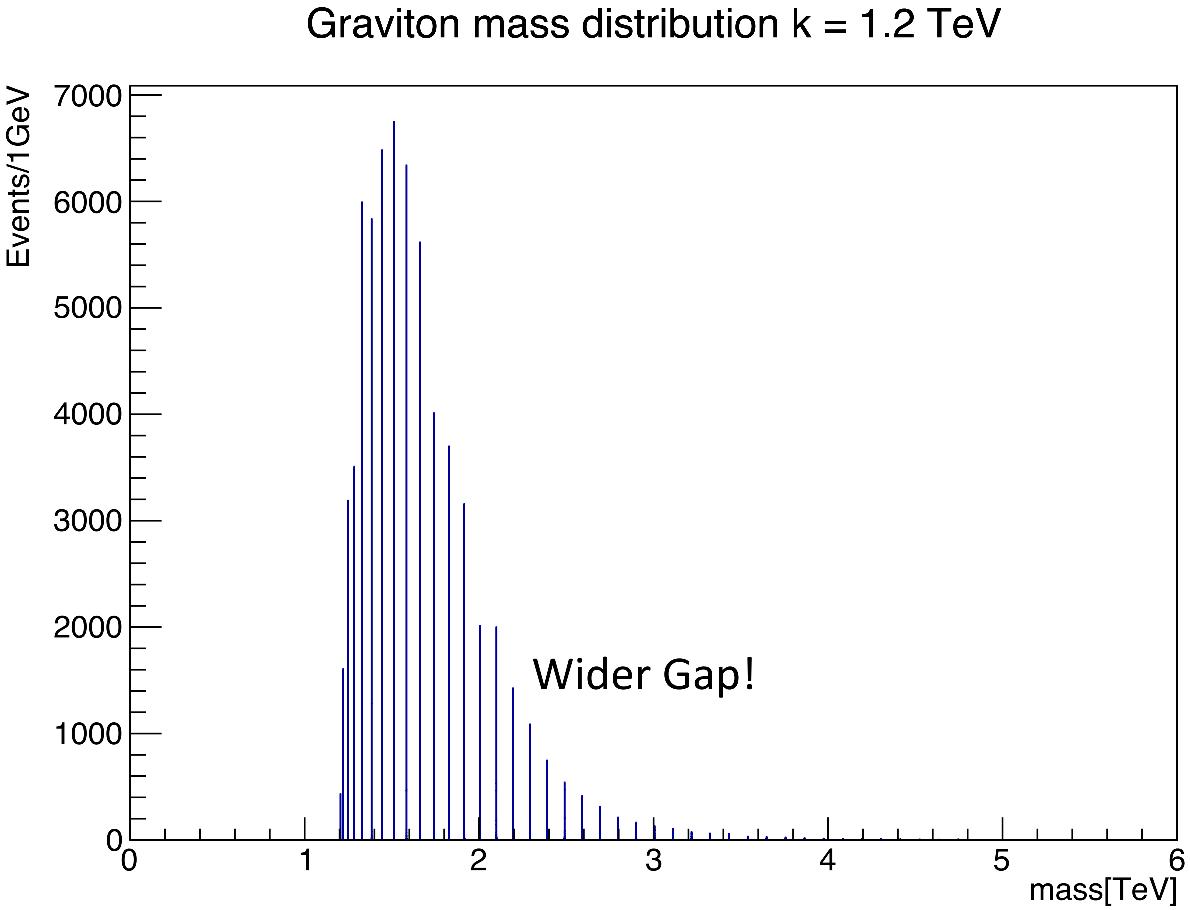


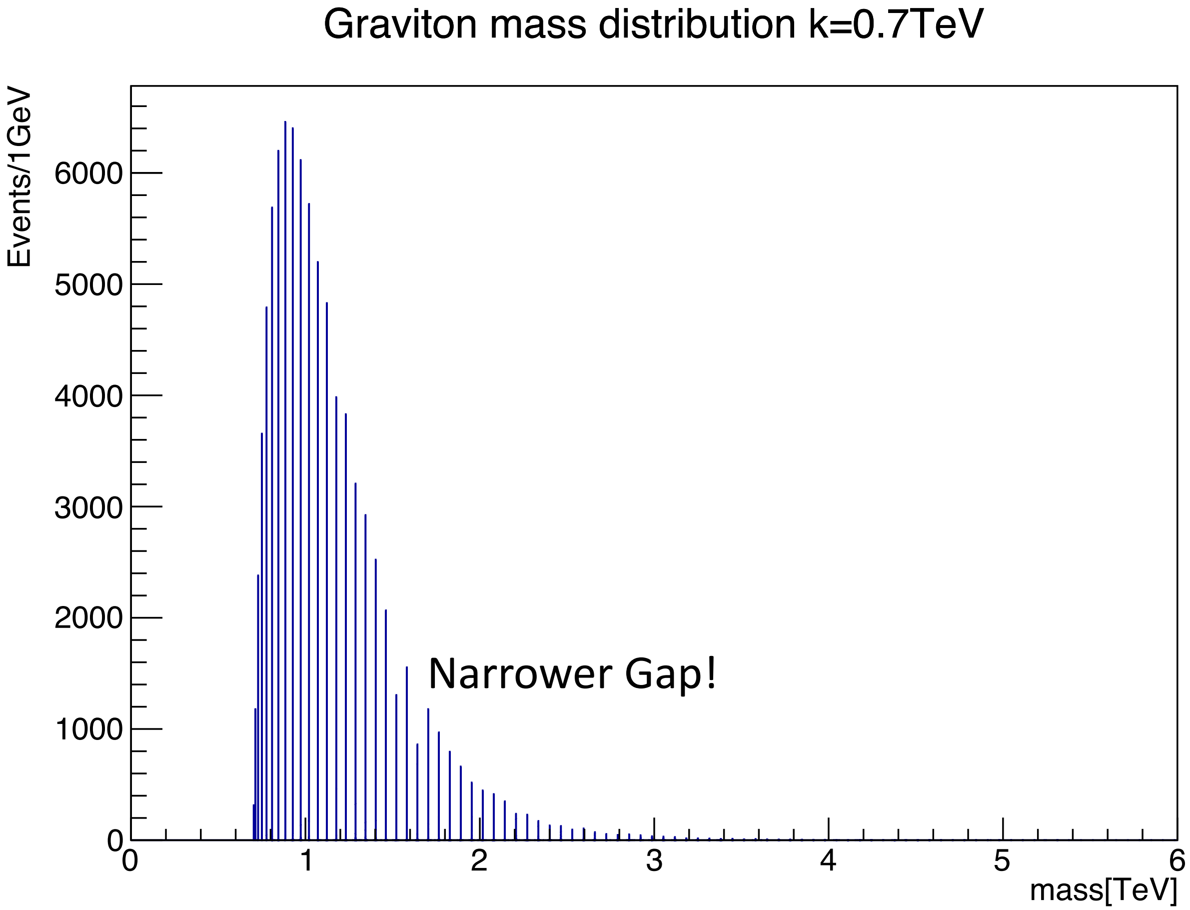


Features	Analysis benefit



Features	Analysis benefit
Many Peaks!	Oscillation!





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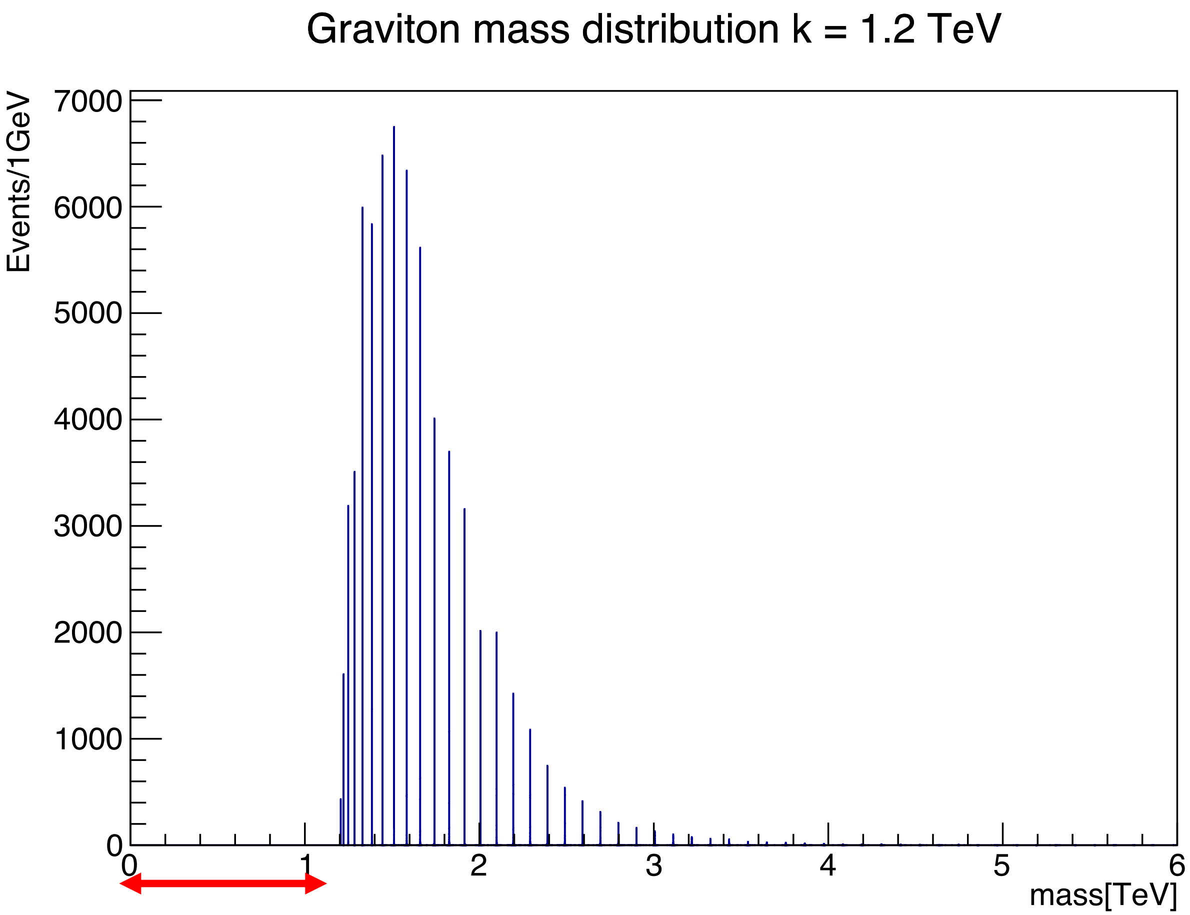
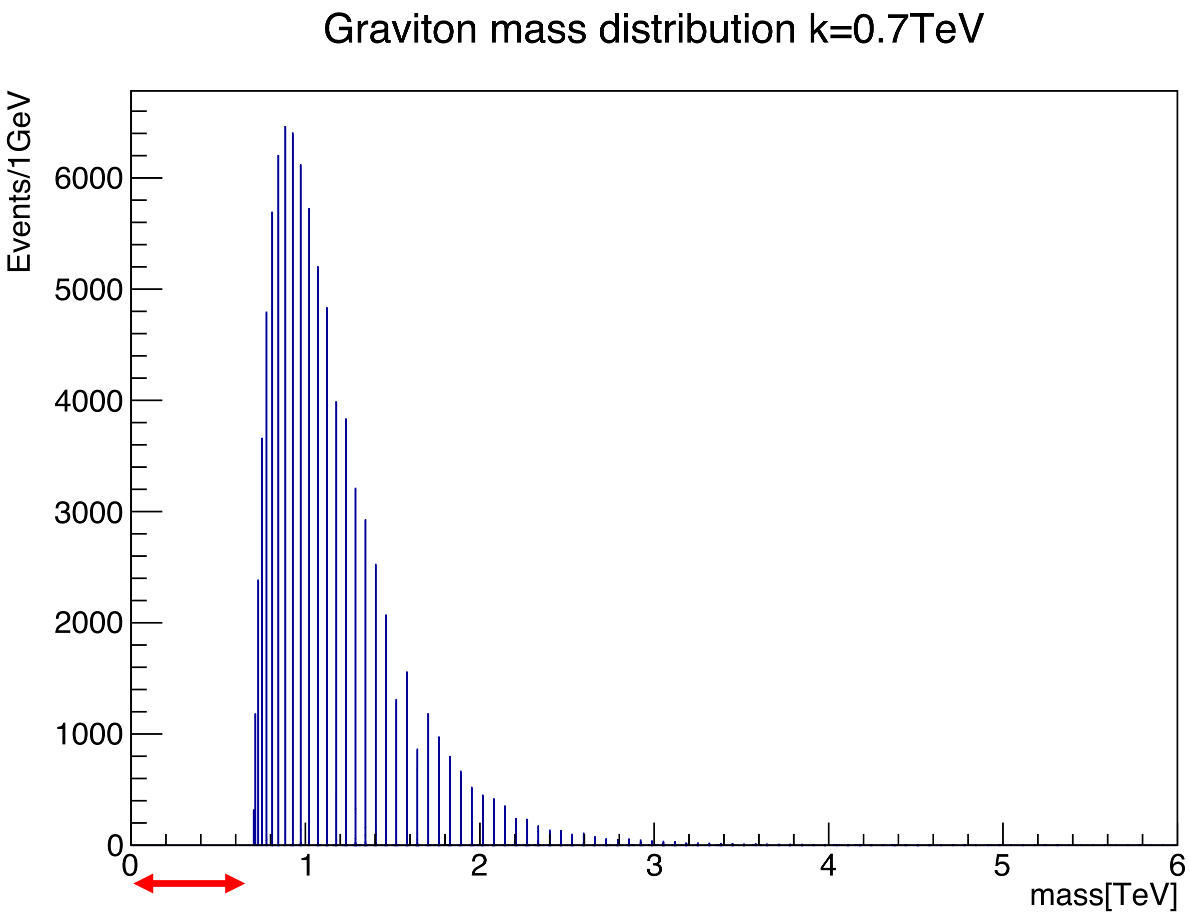
Many Peaks!	Oscillation!
Wide/Narrow gap between peaks!	Unique frequency!

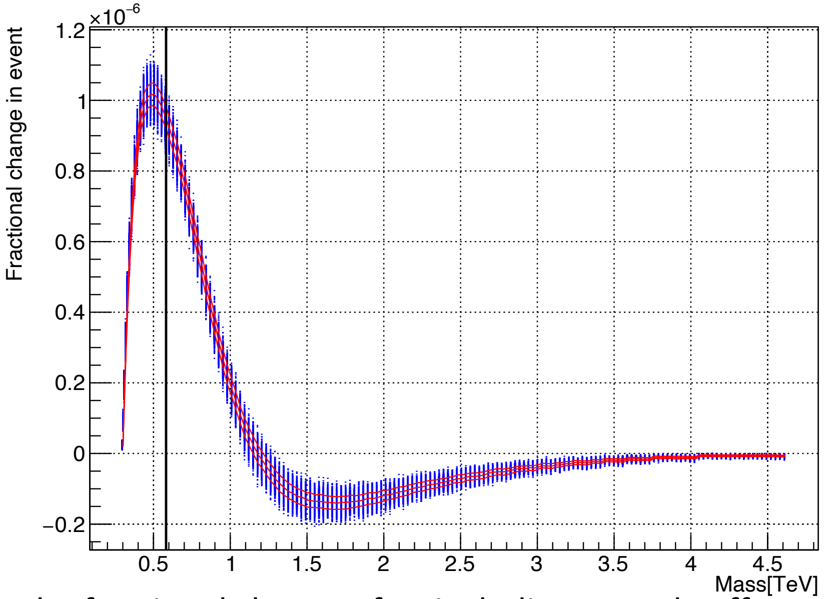




Features	Analysis benefit
Many Peaks!	Oscillation!
Wide/Narrow gap between peaks!	Unique frequency!
Different minimum mass!	Mass range for analysis!

Cascade of decay

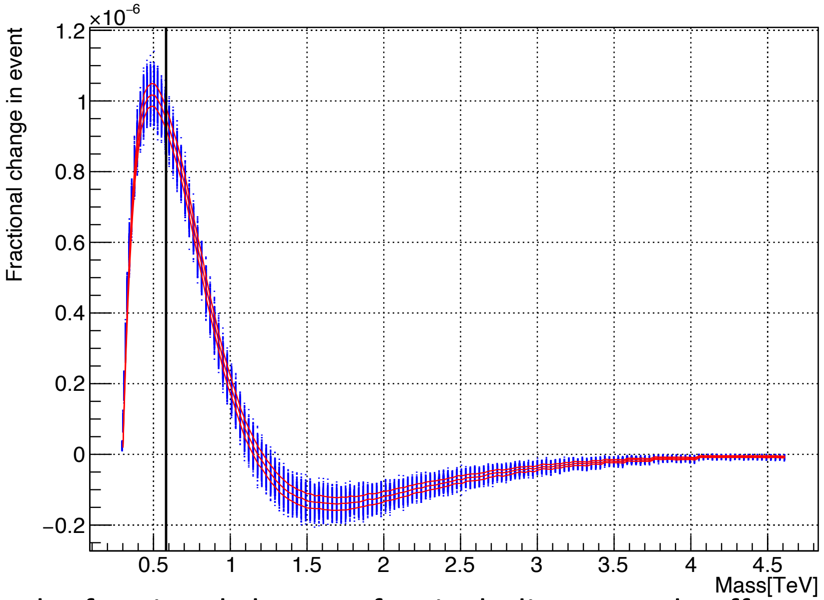
- G(mass mode 40)→G(26)G(14)
- But the daughter G(26) may also decay to G(2)G(1) : G(26)→G(1)G(2)



The fractional change after including cascade effect, k=0.3TeV

Cascade of decay

- G(mass mode 40)→G(26)G(14)
- But the daughter G(26) may also decay to G(2)G(1) : G(26)→G(1)G(2)
- MORE lower-mass gravitons & fewer higher-mass gravitons



The fractional change after including cascade effect, k=0.3TeV

Searching Routine

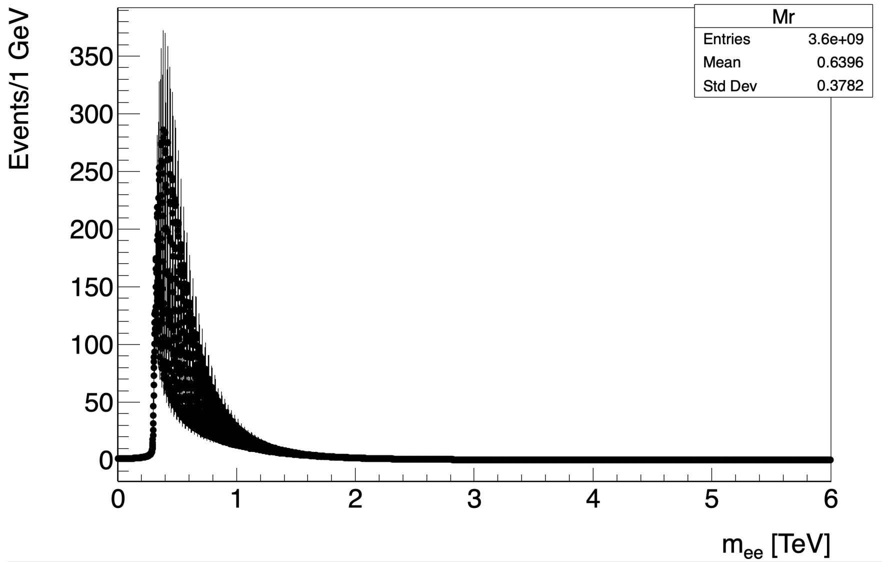
Simulating Physics

Simulating Detector Responses

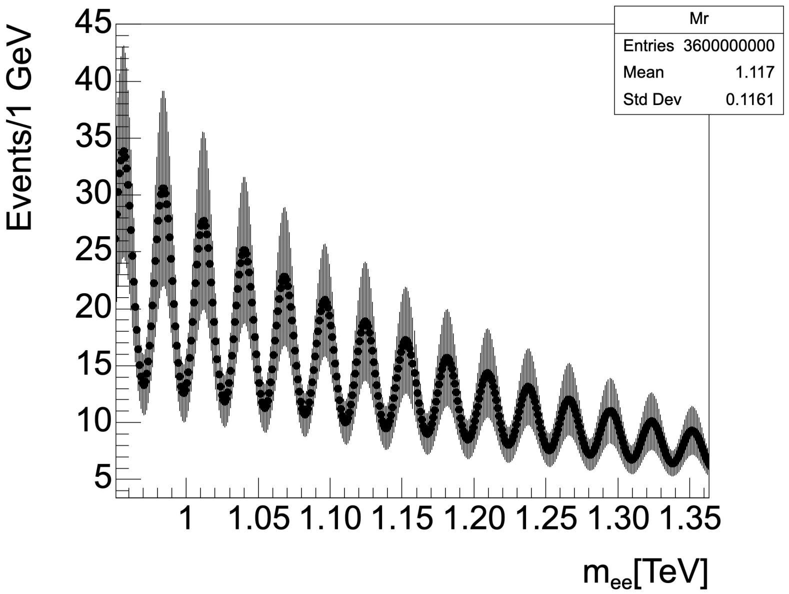
Analyzing responses

From Pythia to Detector responses

- Generating the reconstruction result of the detector.
- Transform/convolution method
- The resolution function for dielectron and diphoton channels are different for ATLAS



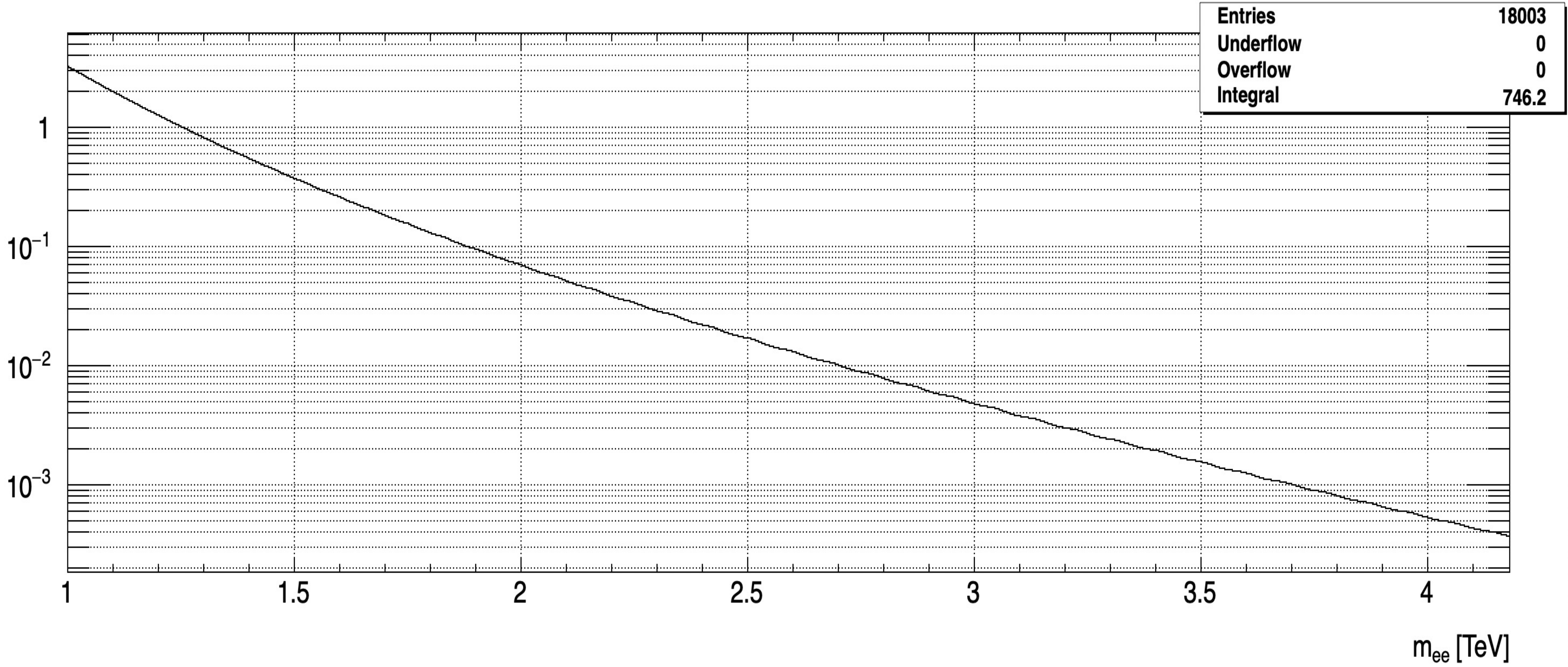
Example plot of transferred result with dielections resolution function k=300GeV



An enlarged version of the left plot to show the oscillation

MC Signal+Background example

Eyes exam: can you see the wiggling?



Searching Routine

Simulating Physics

Simulating Detector Responses

Analyzing Responses

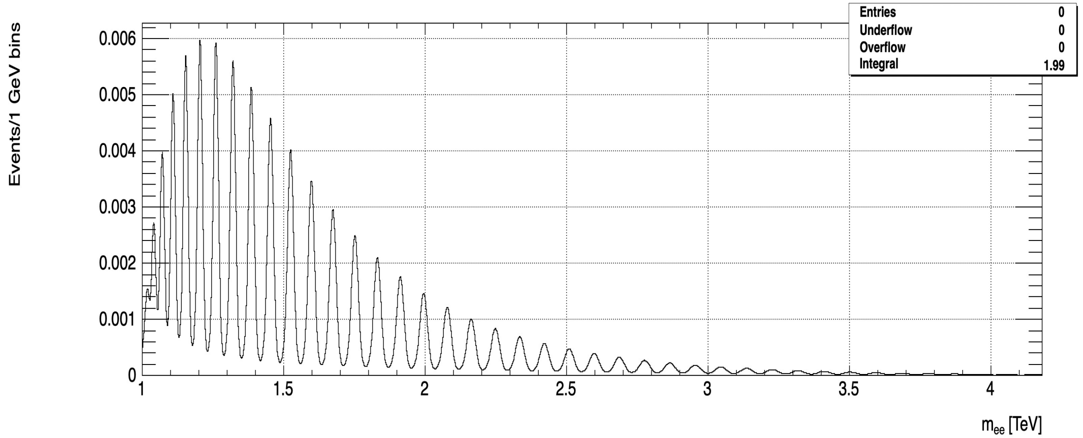
Fourier Transform analysis

- The oscillating spectrum implies the possibility of using Fourier Transform analysis
- We applied discrete Fourier Transform and studied power spectrum P(T)
- In the power spectrum, we define the peak of the spectrum to be our test statistic for the hypothesis test

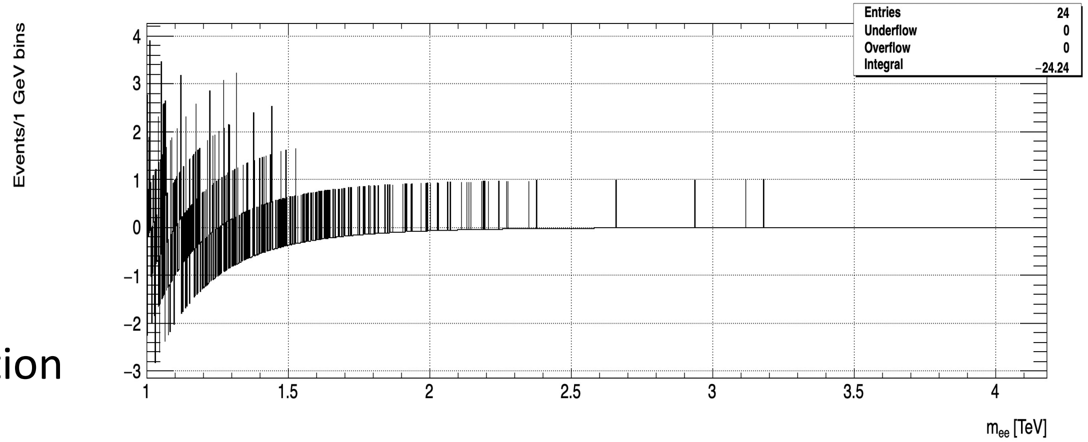
$$P(T) = \left| \frac{1}{\sqrt{2\pi}} \int_{m_{\min}}^{m_{\max}} dm \frac{d\sigma}{dm} \exp\left(i \frac{2\pi\sqrt{m^2 - k^2}}{T} \right) \right|^2$$

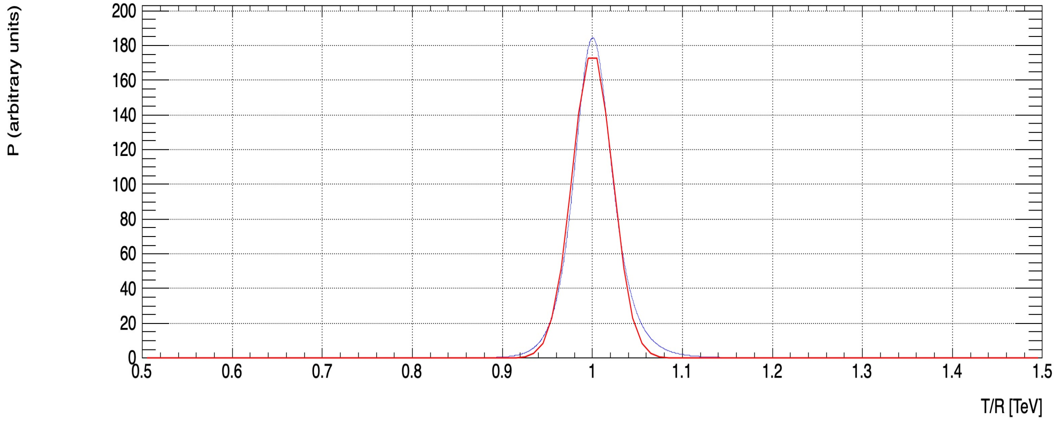
- Background is in appendix

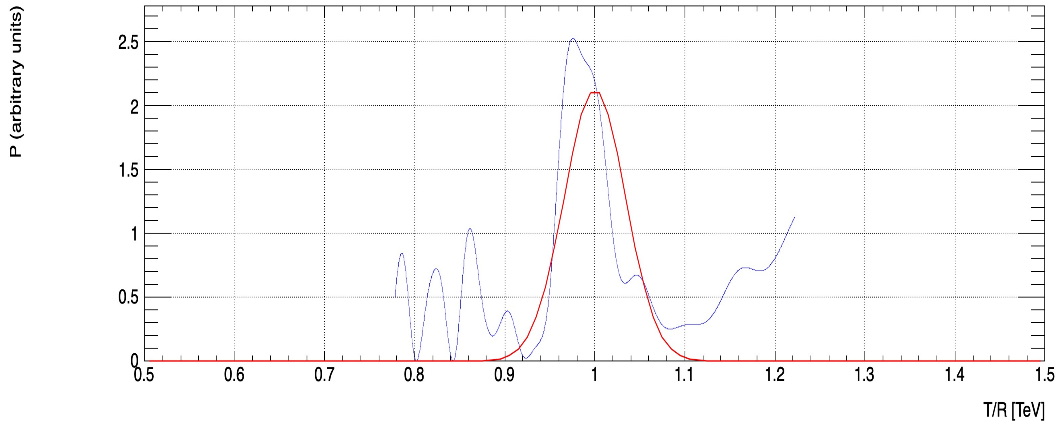
Fourier transform example



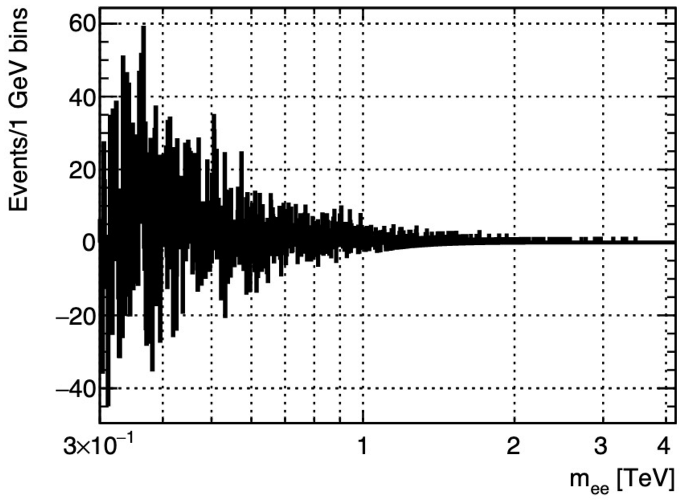
Poisson Fluctuation
➔

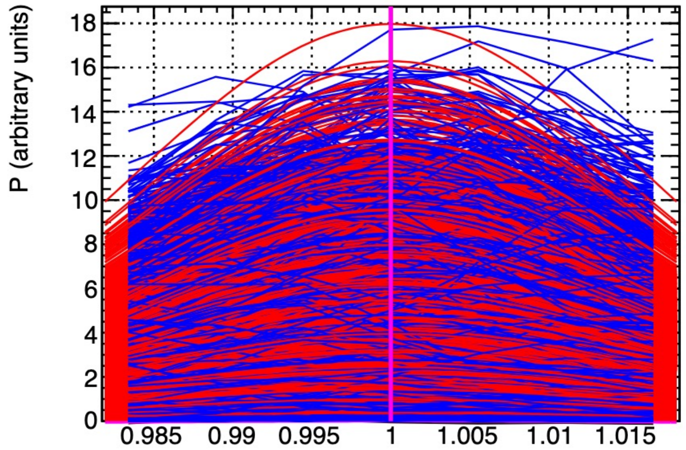






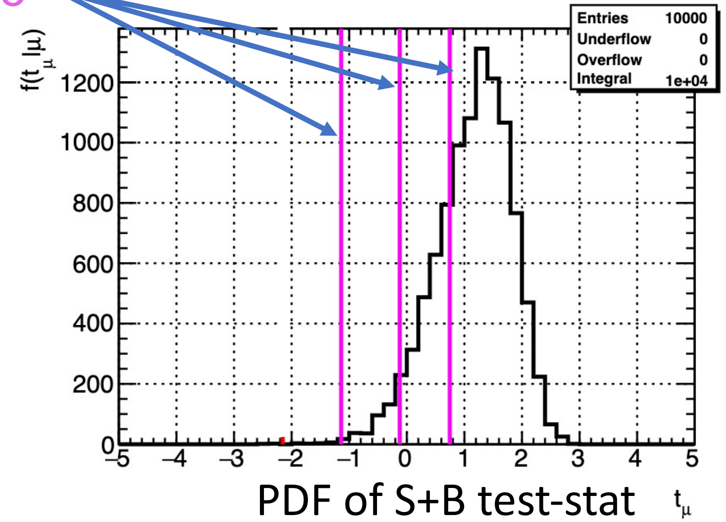
Applying Fourier Transform





10k S+B fitting

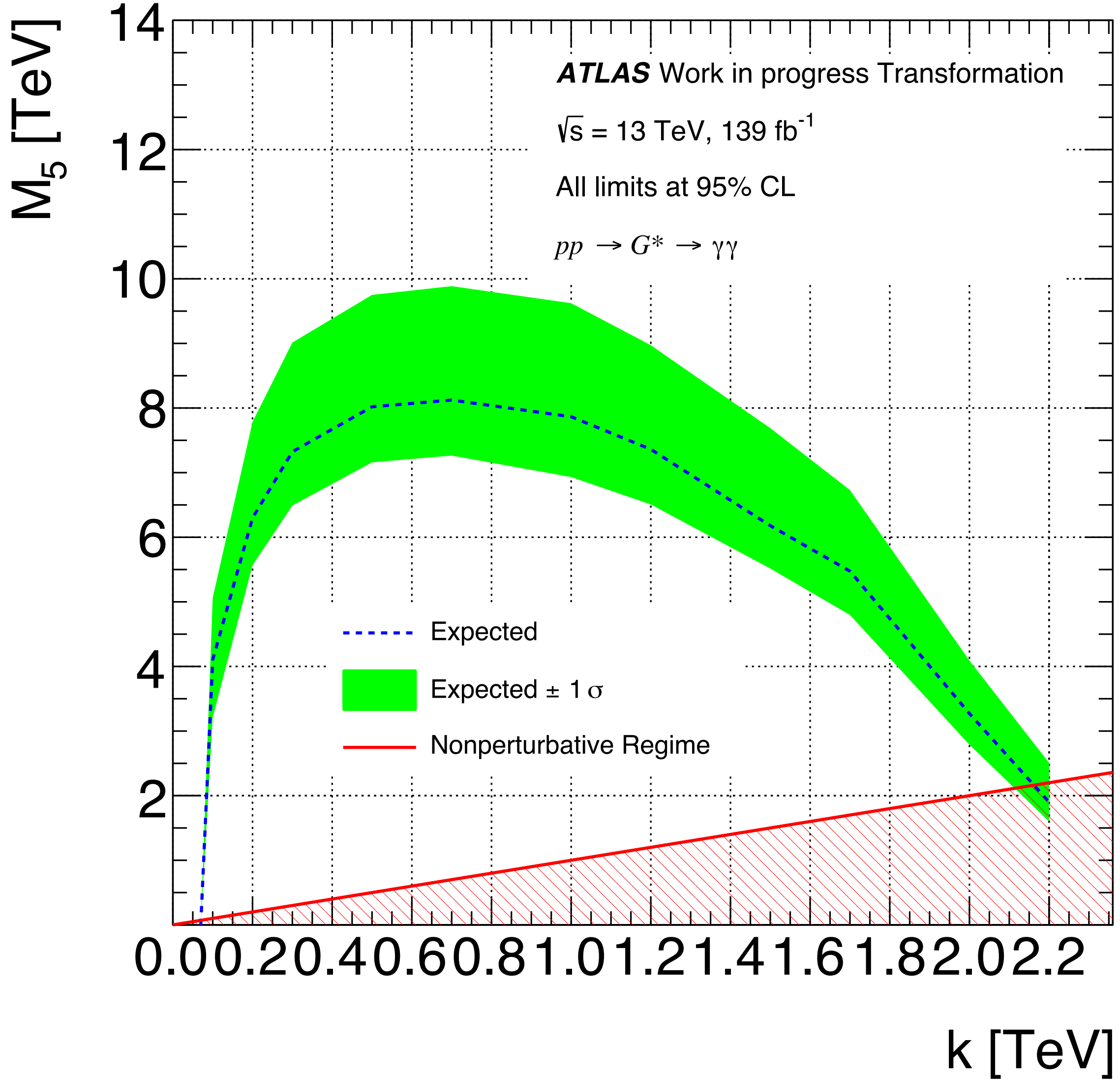
Bkg only test-stat μ±σ

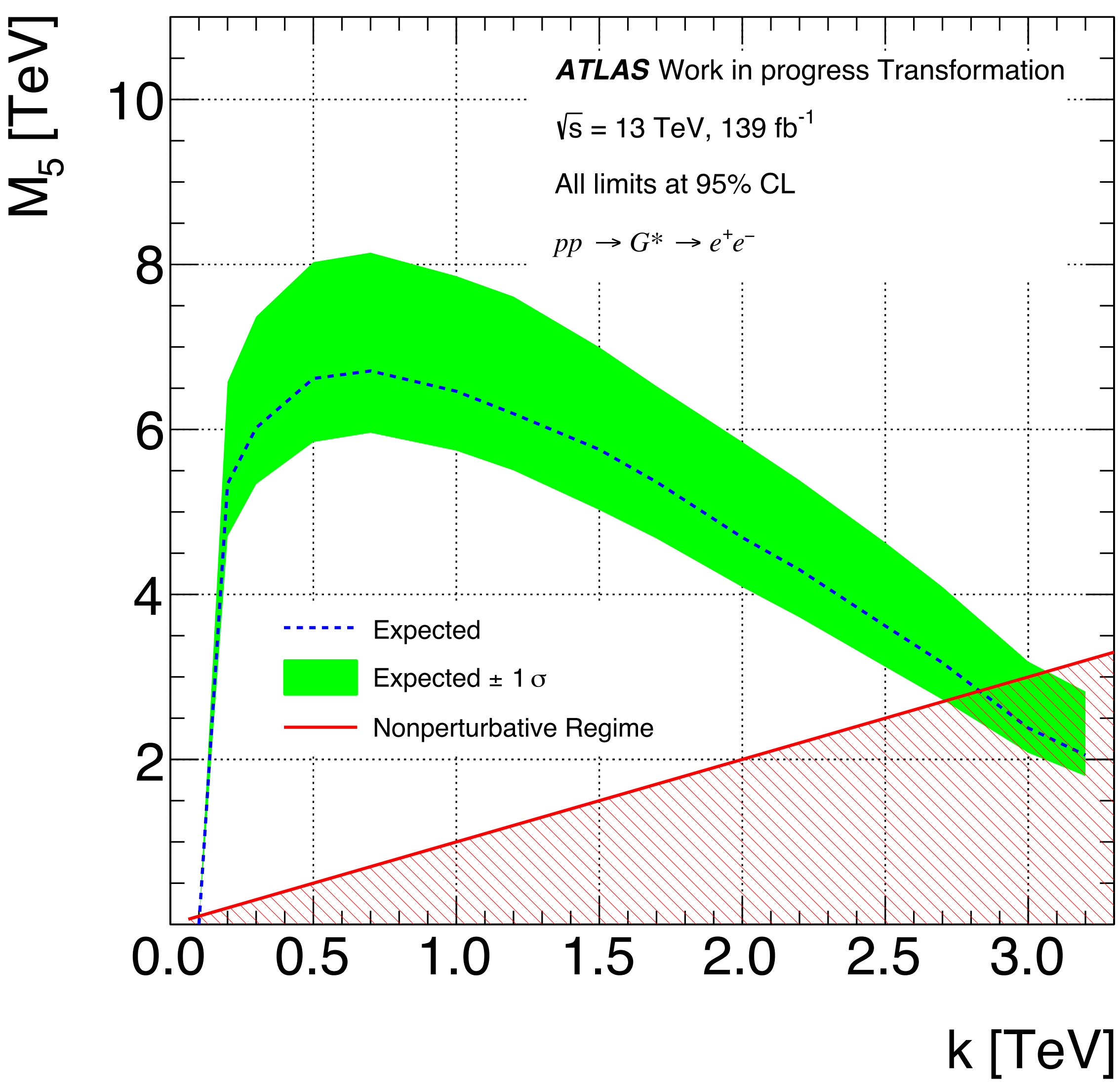


PDF of S+B test-stat

95% LOWER limit plot

$M_5 \propto$ 1/cross-section





Q&A

Thanks for listening

Appendix -- k M_5 R

$$M_P^2 = \frac{M_5^3}{k}\left(e^{2\pi kR} - 1\right)$$

- 3D Planck mass M_p can be obtained by rewriting Newtonian Gravitational potential

$$V(r) = \frac{Gm_1m_2}{r} = \frac{m_1m_2}{{M_p}^2 r}$$

- Fourier transform of 3+n-dimensions gravitational potential

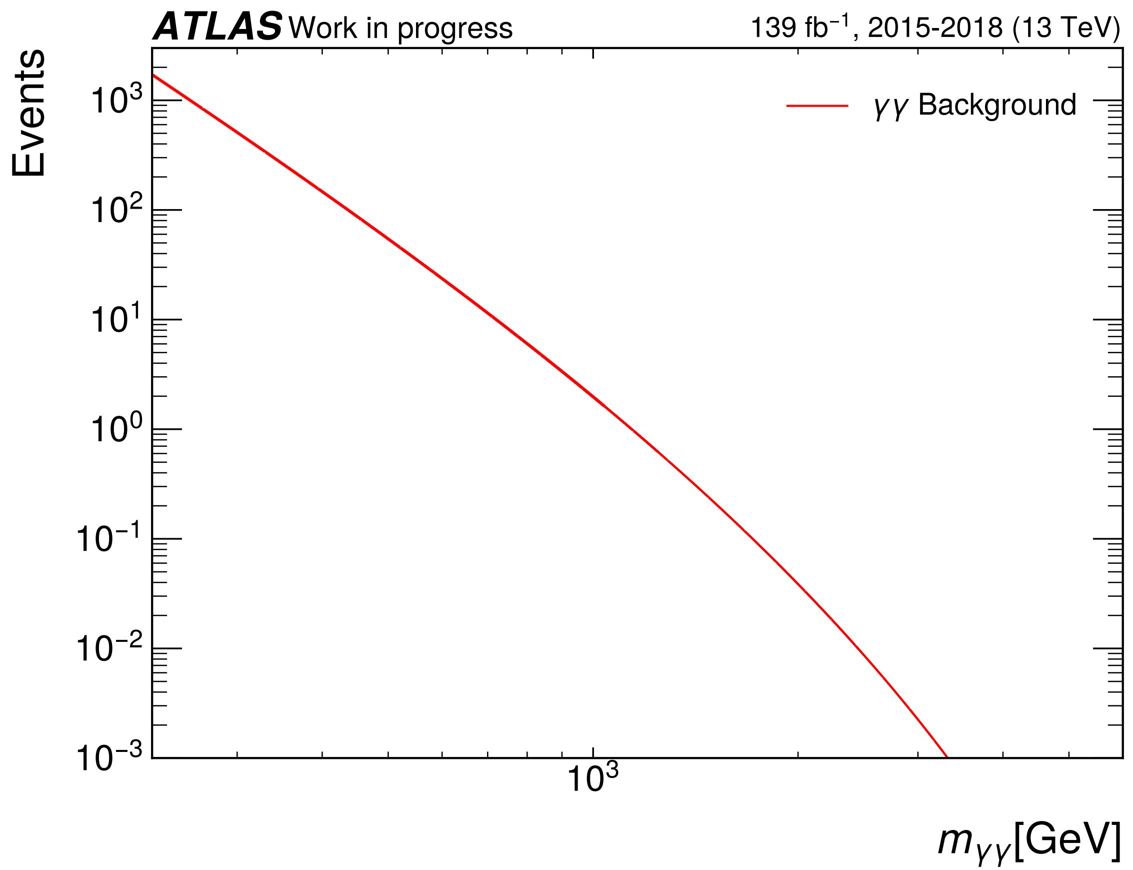
$$V(r) \propto \int d^{3+n}k\, e^{i\vec{k}\cdot\vec{x}} \frac{1}{\vec{k}^2} \propto \frac{1}{r^{1+n}}$$

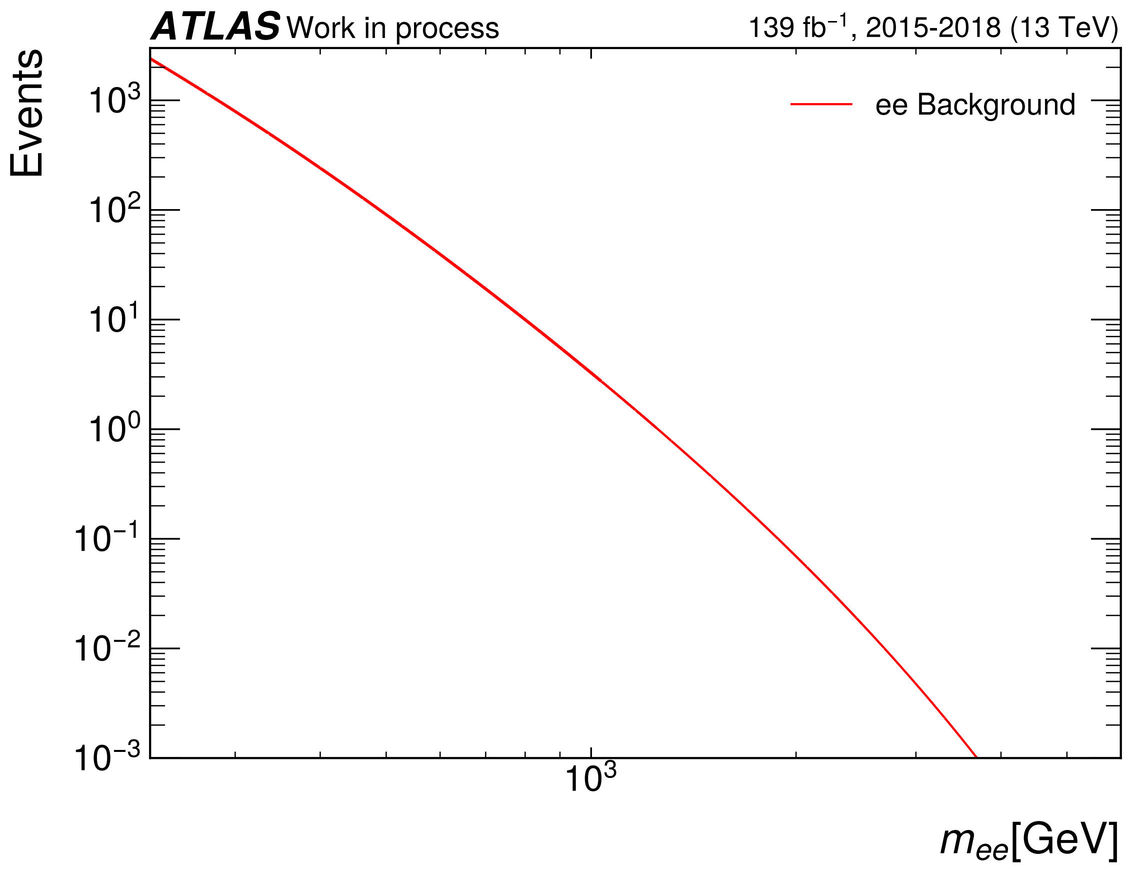
$$V(r) = \frac{m_1m_2}{M_n^{2+n}} \frac{1}{r^{1+n}}$$ (in 3+n-Dimensions)

- Make consistent with Newtonian gravity, setting cut off range R so that we get 3D potential at r>>R.

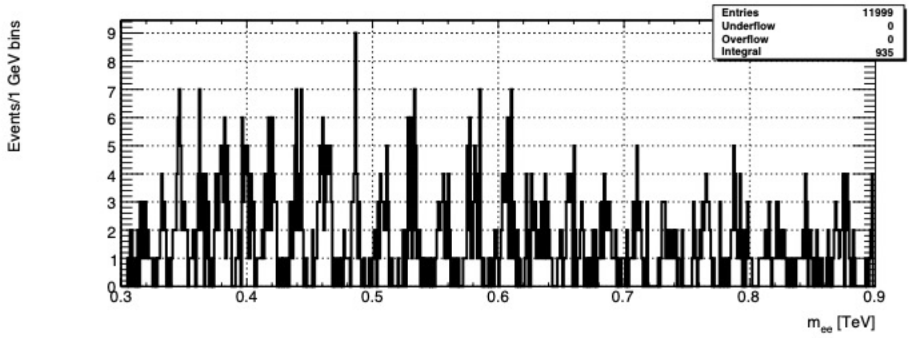
$$V(r) = \frac{m_1m_2}{M_n^{2+n}} \frac{1}{R^n} \frac{1}{r}$$ (in 3+n-Dimension but r>>R)

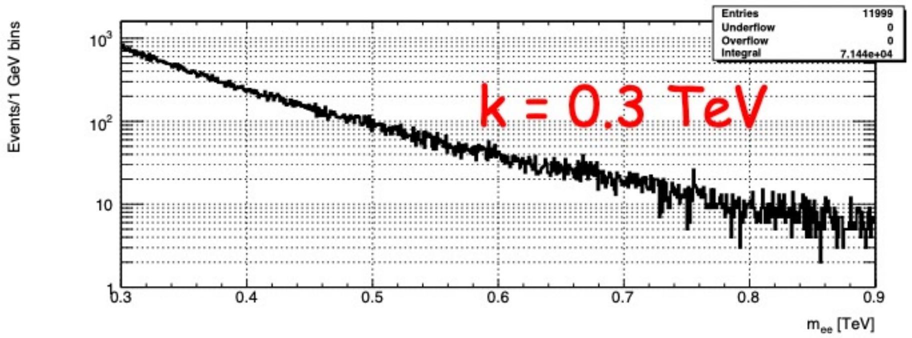
Appendix-Backgrounds

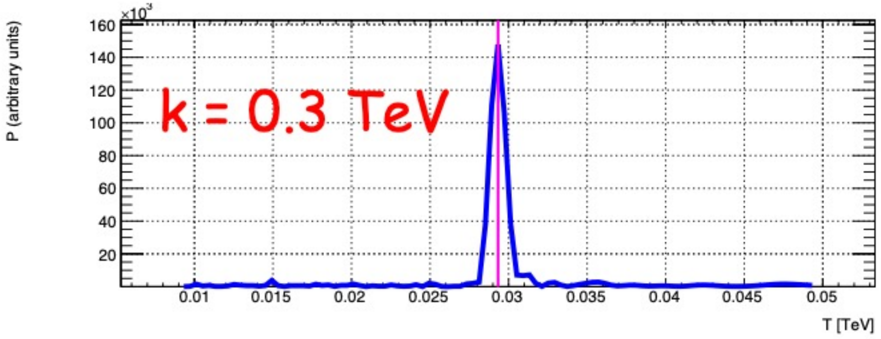


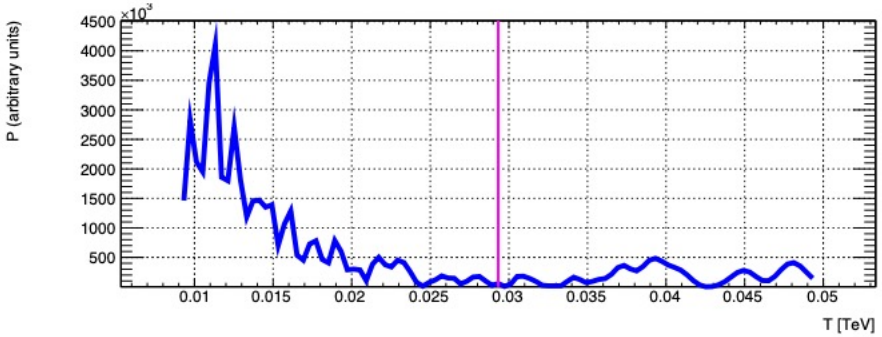


Appendix – FT









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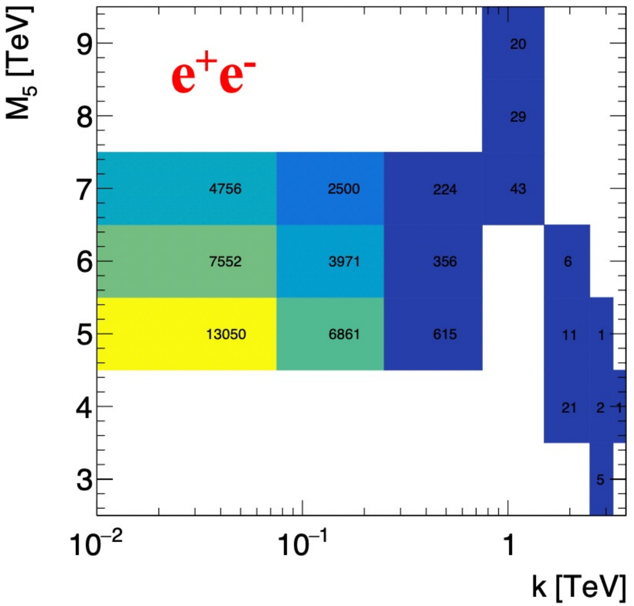
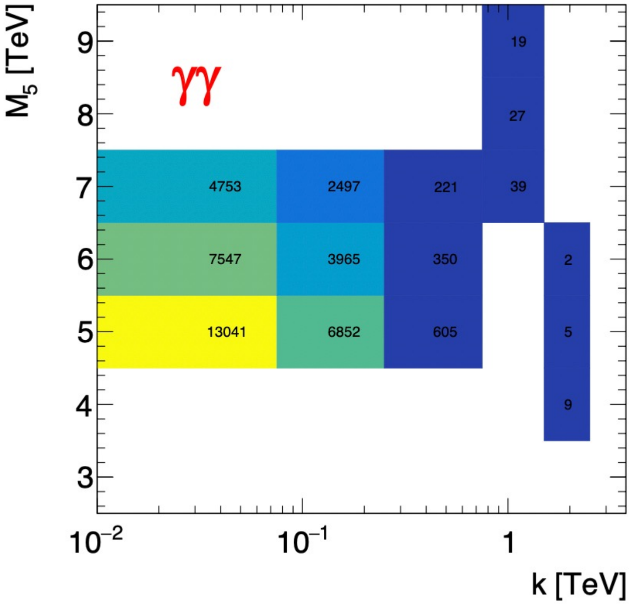
Appendix – Cross-section





Appendix – Decay Width