Cosmology at the Microscopic Scale

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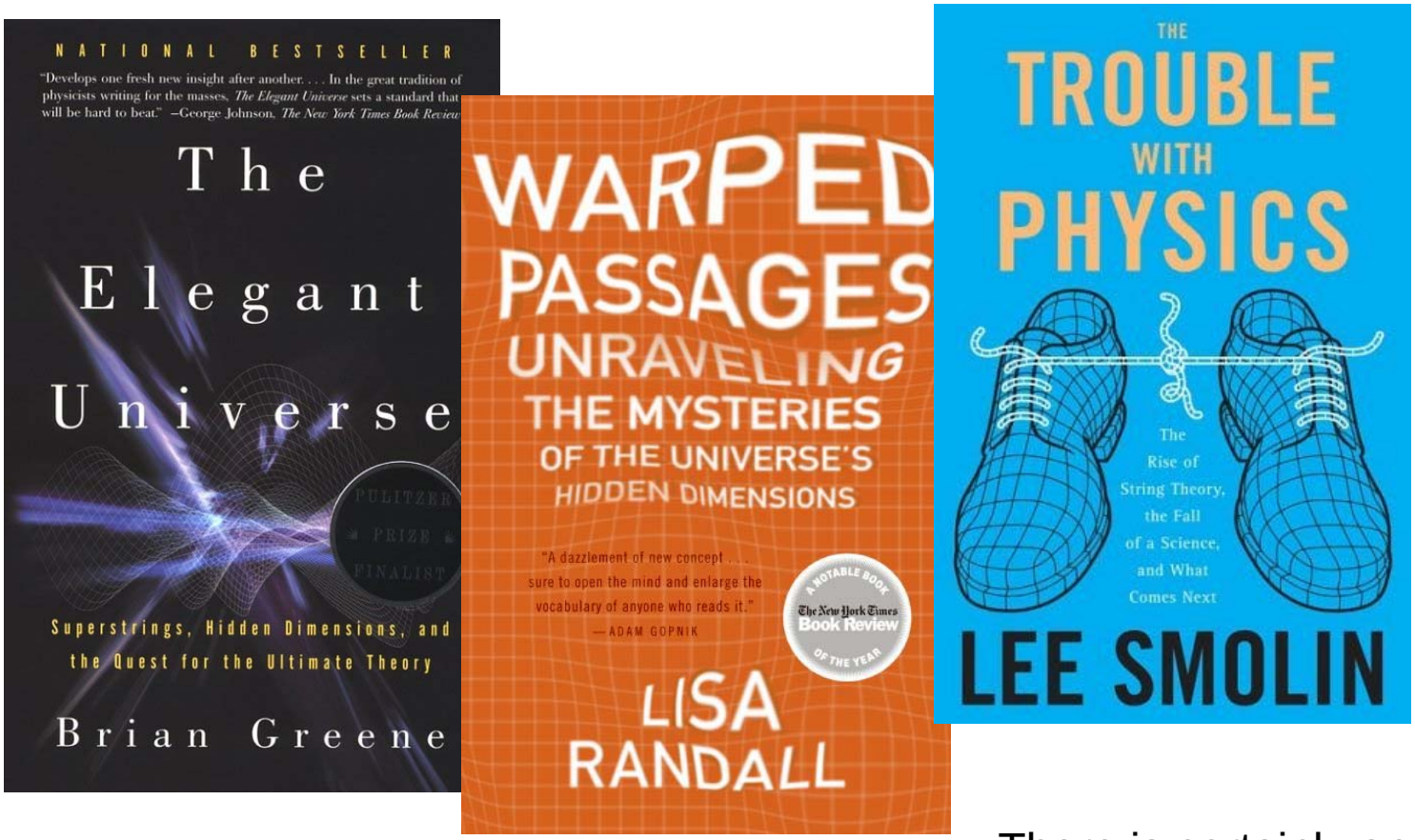
Short Summary

- **Most of the slides are the subset of Paul Padley's talk at the PPC2007**

- **Short (15 min) talk that makes attempt to cover a few interesting topics at the interconnection of Cosmology and Particle Physics such as:**
  - ➔ **Dark Matter**
  - ➔ **Extra Dimensions**
  - ➔ **Black Holes**

- **Current status of the LHC machine and the CMS detector is also presented**

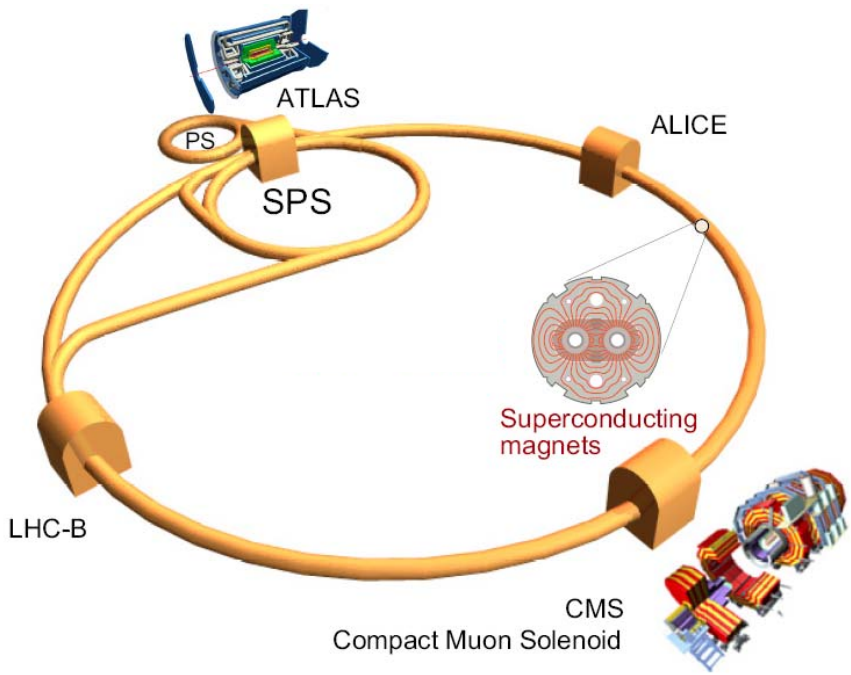
What a Great Time to Be a Physicist



There is certainly an abundance of ideas

What a Great Time to Be an Experimentalist

- The theorists have been generating lots of fascinating ideas
- Unfortunately they have not been well constrained by experiment
- Now the experiments are about to be turned on
- We are going to find some answers

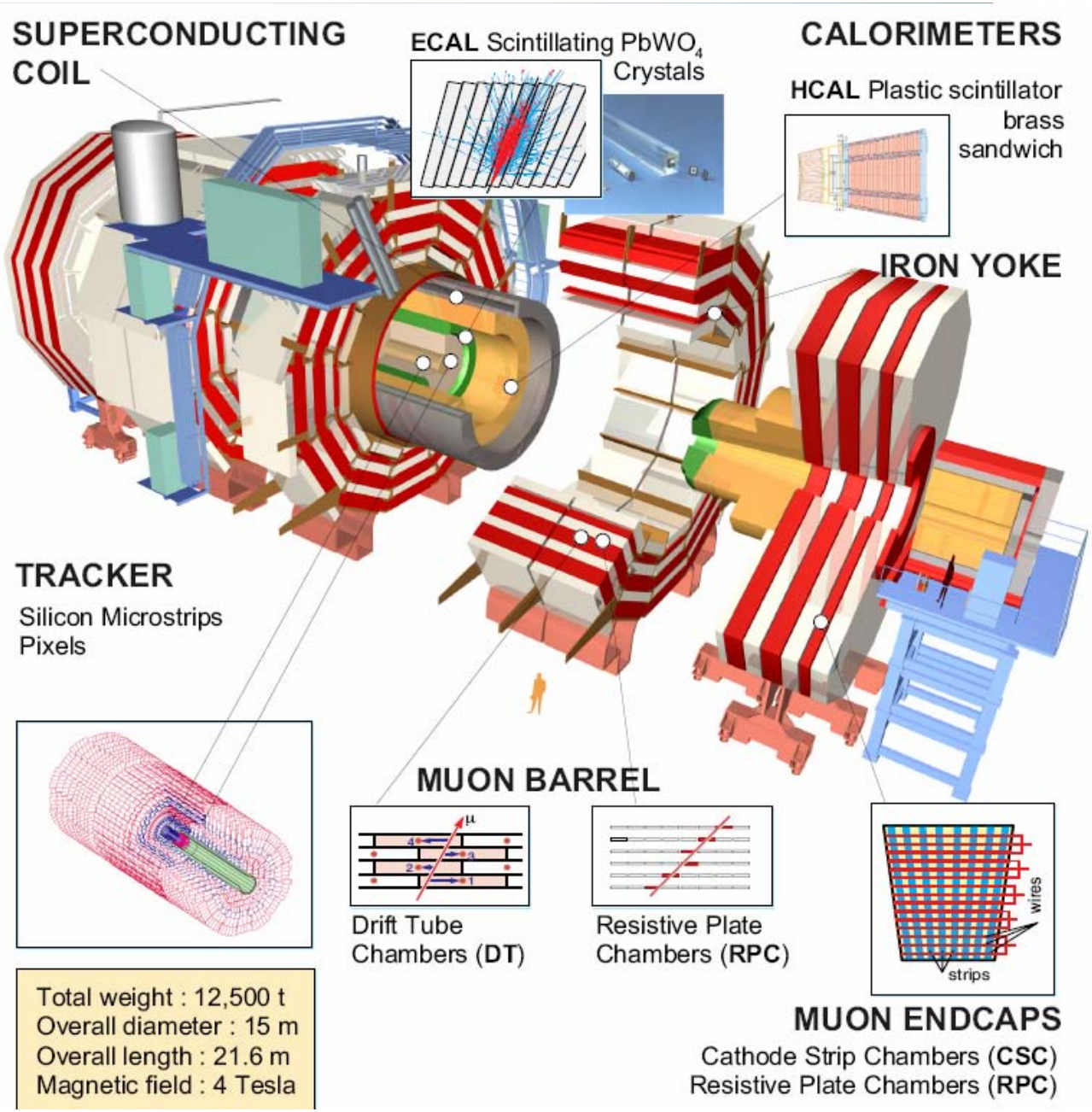


CMS

So lets use a Compact Muon Solenoid (CMS) to look for detector for compact dimensions and other things of cosmological interest

Compact is a Relative Term

- Weighs as much as 30 jumbo jets
- Uses more iron than the Eiffel tower



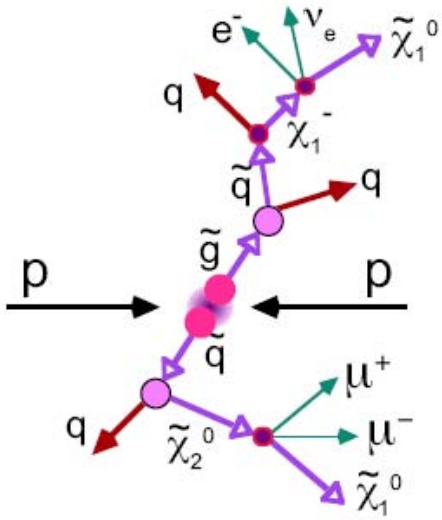
Status

- According to schedule v35.3 CMS is ready for data taking in Nov 2007
- However in light of recent problem with the LHC magnet “it is unlikely that the engineering run can occur at the end of the year but all effort will be made to maintain a physics run in 2008 as foreseen”
- Stay tuned for the new LHC schedule to be published soon

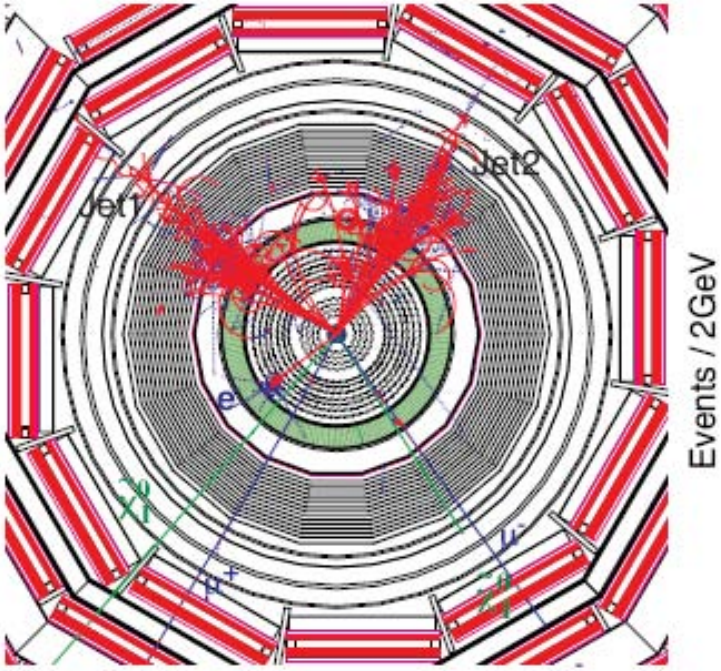
How much data when

- After two years of running it is expected that the LHC will have reached its initial design luminosity of $2x10^{33}cm^{-2}s^{-1}$
- This corresponds to approximately $20fb^{-1}$ per year
- Expect $<5fb^{-1}$ in the first year of running (2008)

SUSY



Seeing events with 3 leptons on one side of the detector and two jets on the other would be exciting – and not too hard to recognize.

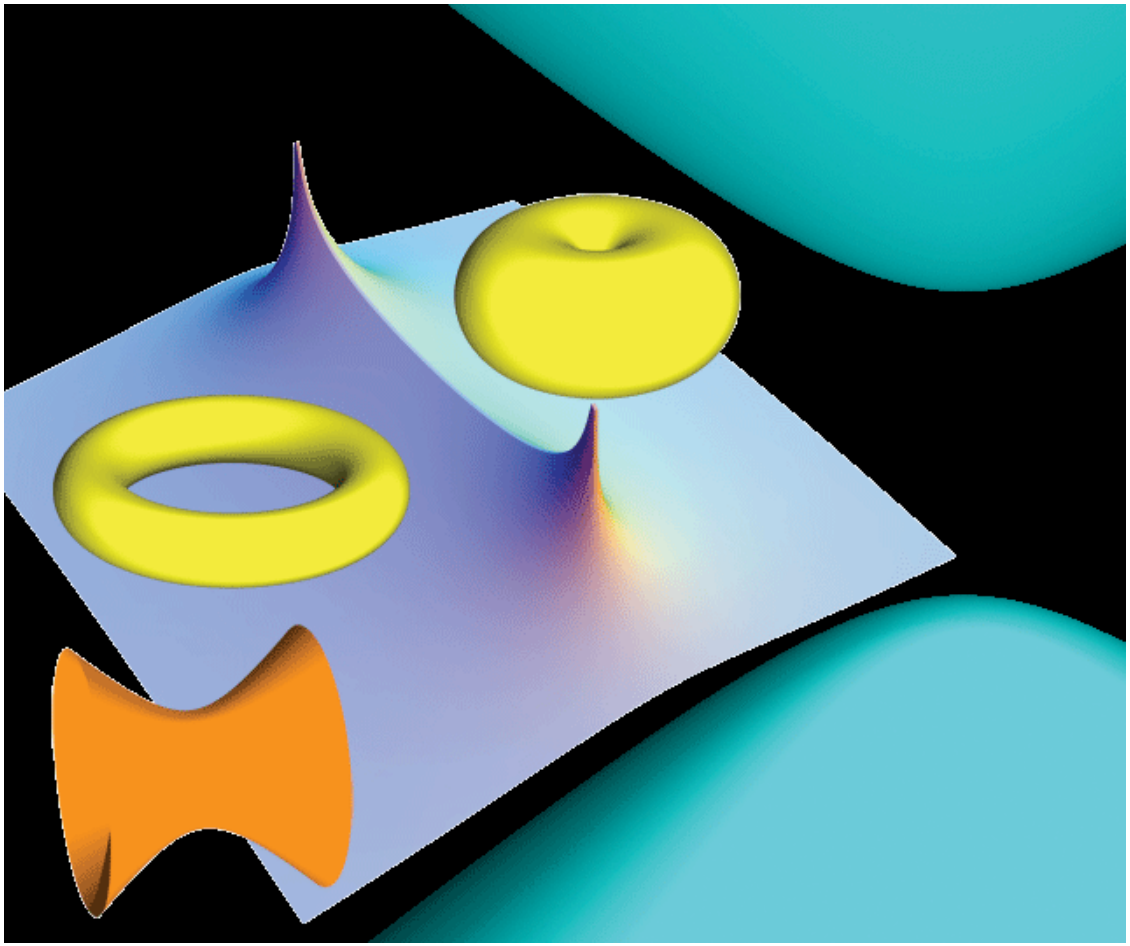


SUSY event with
3 leptons + 2 Jets signature

SUSY

- LSP (neutralino) is one of the best WIMP candidates
- Of course it may prove more difficult to find that the previous page suggests
- A number of different channels have been studied with Monte Carlo data
- Most studies generally predict finding (or excluding) LSP after first year or two of data taking

Extra Dimensions



The purple peaks show the gauge coupling of the Seiberg-Witten theory as a function of the moduli space; the associated tori are shown in yellow. The quantum deformed moduli space of SUSY QCD is shown in turquoise. A slice of anti-de Sitter space is shown in orange.

From Monograph by Terning:
http://particle.physics.ucdavis.edu/modernsusy/index.html

Extra Dimensions

- **ED can easily accommodate the following issues:**
  - ➔ **Dark Matter candidates and other new particles (Kaluza-Klein)**
  - ➔ **TeV scale new physics (hierarchy problem)**
  - ➔ **Quantum Gravity**
  - ➔ **Black Holes**

- **Various ED models have been considered as a potential search candidates including Arkani-Hamed, Dimopoulous, Dvali; Randall-Sundrum; Universal Extra Dimensions**
- **Search strategy: start by looking at simplest things**
  - ➔ **Bumps**
  - ➔ **Overall Spectra Enhancements**

Dielectron

- At CMS we looked at possibility of observing resonance peaks (“bumps”) that are predicted by various models
- These usually are KK excitations of a Graviton and Z boson in several models such as Randall-Sundrum, other ED, etc

Dielectron Sensitivity at CMS

- **Table for significance of discovery for L=30fb^{-1}:**

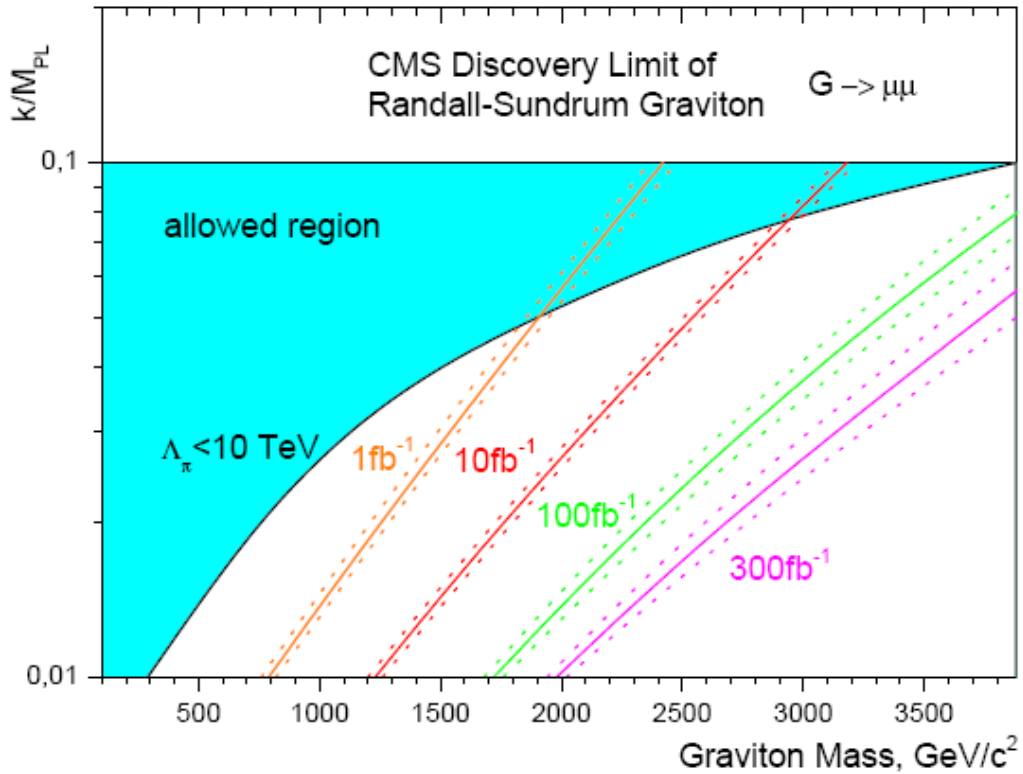
	KK Z		GR, c=.01	GR, c=.1	Z' from SSM	
M, Tev	4	6	1.5	3.5	1.0	5.0
N signal	50.6	1.05	18.8	7.3	72020	0.58
N bcgnd	0.13	0.005	4.16	0.121	85.5	0.025
S	22.5	3.0	6.4	6.8	225	1.63

Dimuon

- As in e+e- case, in RS scenario there are resonances that decay into high mass di-muon states
- G->mu mu in RSI model can be discovered by less than 100fb-1

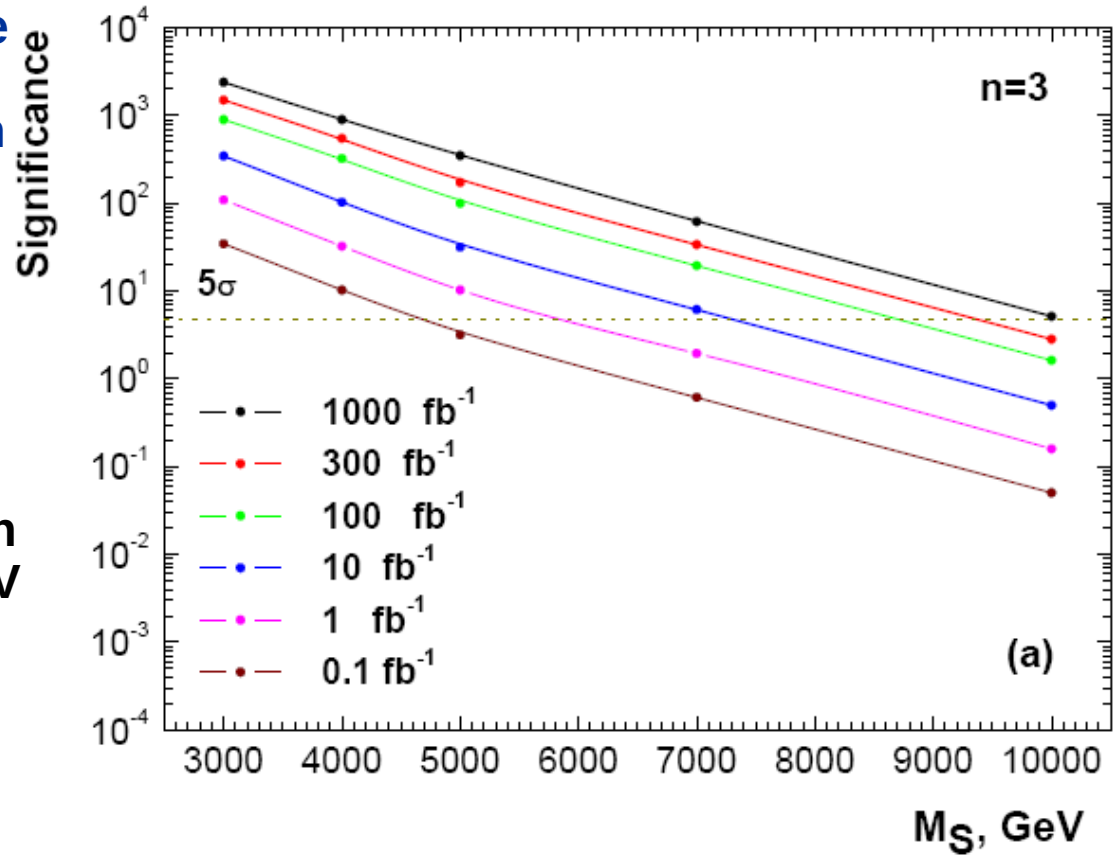
Dimuon “bumps”

Reach of the CMS experiment as a function of the coupling parameter and the graviton mass for various values of integrated luminosity; the left part of each curve is where significance exceeds 5σ



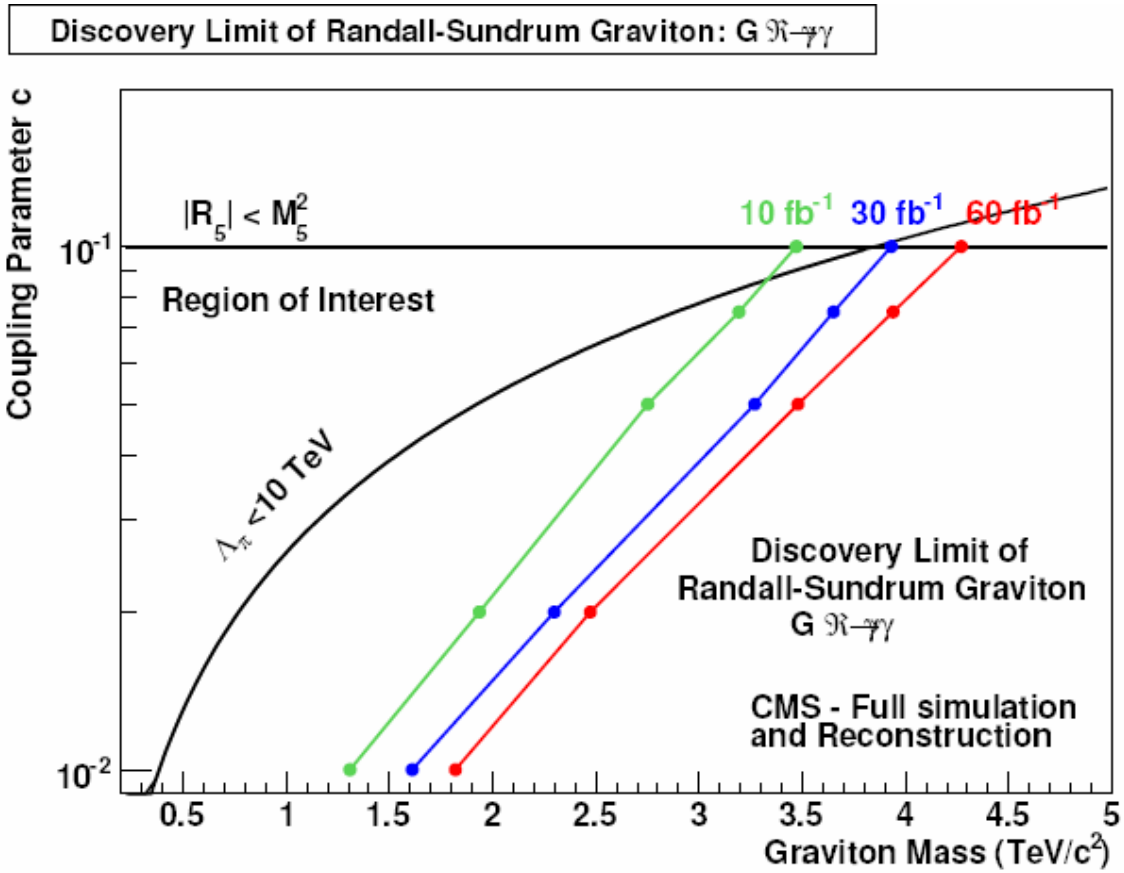
Dimuon spectrum enhancement

- **ADD model is expected to be observed via non-resonant modifications to the di-muon spectrum**
- **Plot to the right is significance as a function of physics scale:**
  - **Even for L=1fb-1 ADD contributions to Drell-Yan process show for M<4TeV**



Diphoton

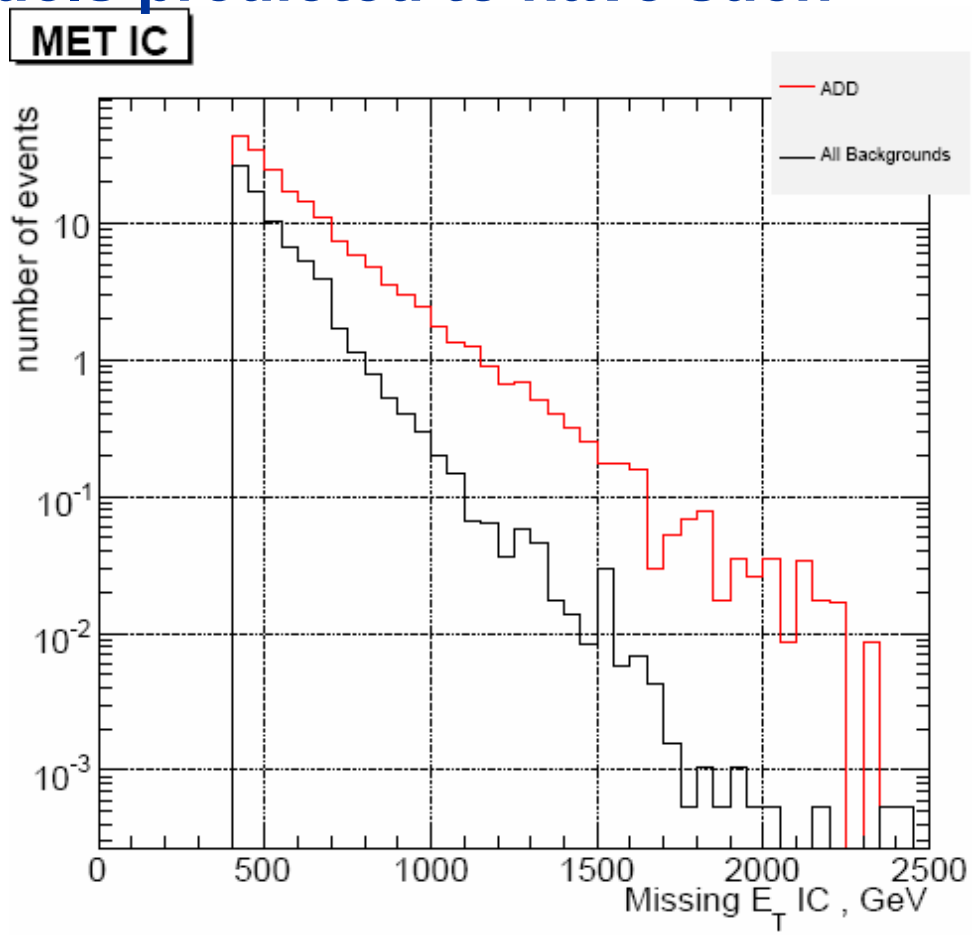
- **Most interesting seems to be Randall-Sundrum graviton decay: GR->γγ**



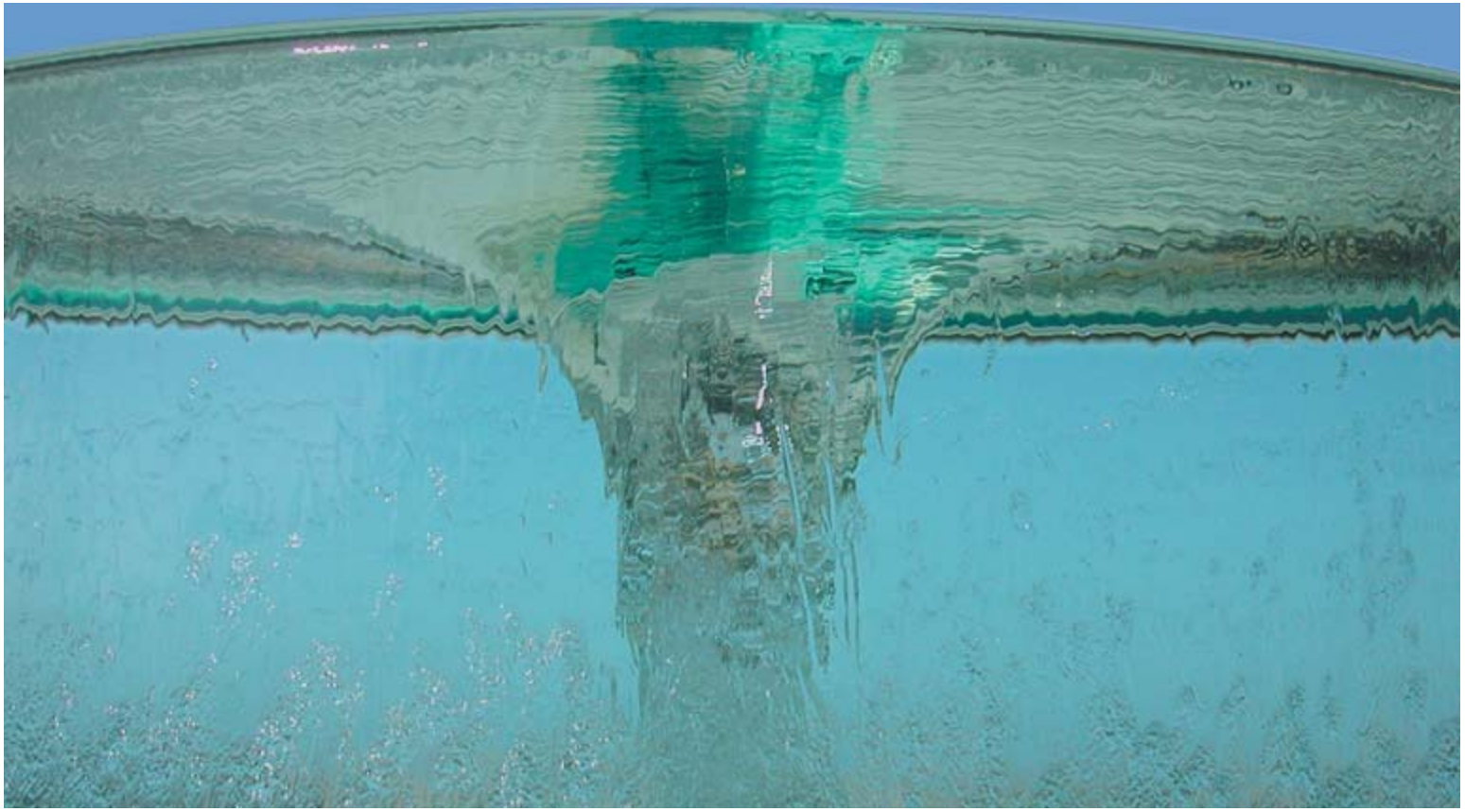
Photon and Missing Et

- **ADD type of ED models predicted to have such signals**

- **MET for 30fb^{-1} in ADD model with n=2**



Black Holes



Water sculpture by William Pye called Charybdis

CHARYBDIS

Χάρυβδις

Also a black hole generator
http://www.ippp.dur.ac.uk/montecarlo/leshouches/generators/charybdis/manual.html

Charybdis (kuh-RIB-dis). Mythological whirlpool off the coast of Sicily that sucked down vast quantities of water three times a day. Together with the monster Scylla, Charybdis was one of twin perils faced by Odysseus. The hero had been warned by Circe that the whirlpool could only be avoided at the cost of passing beneath the cliff harboring Scylla's lair. Sure enough, he timed his passage and steered clear of Charybdis only to lose six sailors to the many-headed Scylla.

Black Holes

- **One of the consequences of large Extra Dimensions is the possibility of Black Hole (BH) production at the LHC**
- **The Schwartzschild Radius of such BH formed in (4+n) dimensional space is given by**

$$r_s = \frac{1}{\sqrt{\pi} M_{(4+n)}} \left(\frac{M_{BH}}{M_{(4+n)}} \left(\frac{8\Gamma((n+3)/2)}{n+2} \right) \right)^{\frac{1}{n+1}}$$

, where $M_{(4+n)}$ is the reduced Planck scale

- **Collision of two partons can result in BH creation if impact parameter is smaller than r_s**
- **Semi-classical approach gives cross-section**

$$\sigma(M_{BH}) = \pi r_s^2$$

Black Holes continued…

- **Higher-dimensional BH decay has significant characteristics such as high sphericity, high multiplicity and high Pt of individual decay products**

- **Due to their relatively large cross-section and distinct signature minimum luminosity needed for BH discovery is fairly small ~ $1fb^{-1}$**

- **BH can only form if $M_{BH} > M_{(4+n)}$ and therefore mass distribution of M_{BH} gives an upper limit of the new Physics scale**

Conclusions

- **There is a bounty of new physics possibilities to be potentially discovered at the LHC that may have significant consequences for the Cosmology**

- **Search strategy most generally involves looking for most obvious things (bumps, enhancements, …) in the beginning**

- **Most of phenomenological models popular today are predicted to have signatures observable in the first few years of the LHC running**