Discovering New Physics with Early CMS Data

Greg Landsberg

BROWN UNIVERSITY

CMS

Aspen Winter Conference on Particle Physics

January 20, 2010

Outline

- Why looking beyond the Standard Model?
  - You know the answer!
- Plan of attack
- Discovering new physics with early LHC data*
- Conclusions

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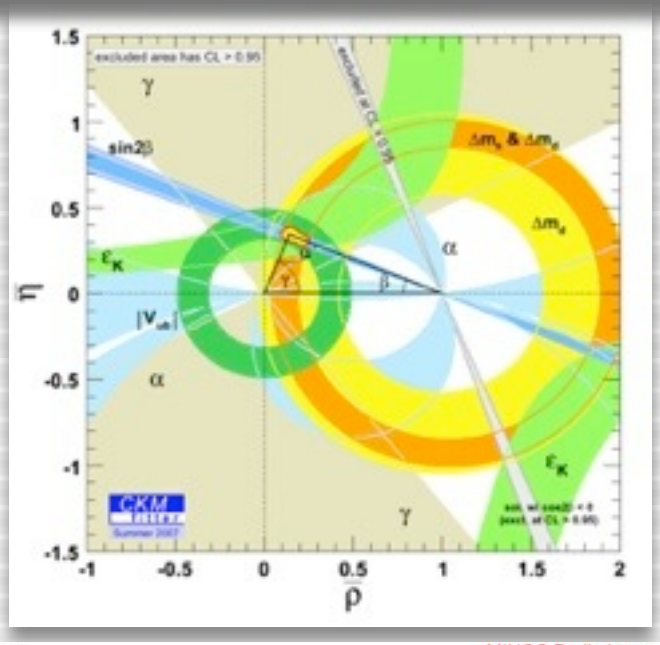
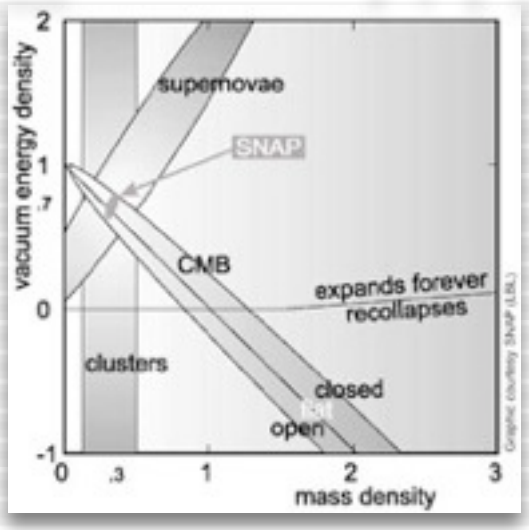
*) Chose to focus on a few characteristic and recent examples, rather than being too inclusive

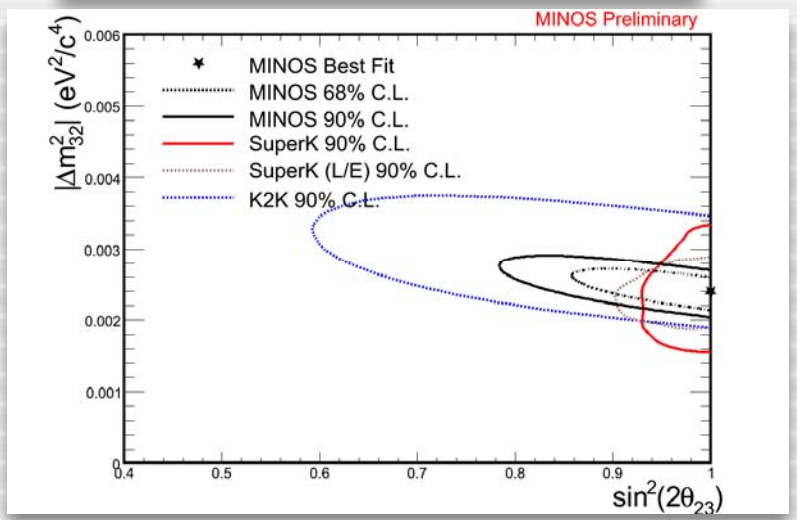
I would like to thank the organizers for a kind invitation and a great conference!

We Live in Precision Times...

	Measurement	Fit	$\lvert O^{meas} - O^{fit} \rvert / \sigma^{meas}$
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02768	
m_Z [GeV]	91.1875 ± 0.0021	91.1874	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959	
σ^0_{had} [nb]	41.540 ± 0.037	41.478	
R_l	20.767 ± 0.025	20.742	
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01645	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481	
R_b	0.21629 ± 0.00066	0.21579	
R_c	0.1721 ± 0.0030	0.1723	
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1038	
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0742	
A_b	0.923 ± 0.020	0.935	
A_c	0.670 ± 0.027	0.668	
A_l(SLD)	0.1513 ± 0.0021	0.1481	
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.399 ± 0.023	80.379	
Γ_W [GeV]	2.098 ± 0.048	2.092	
m_t [GeV]	173.1 ± 1.3	173.2	







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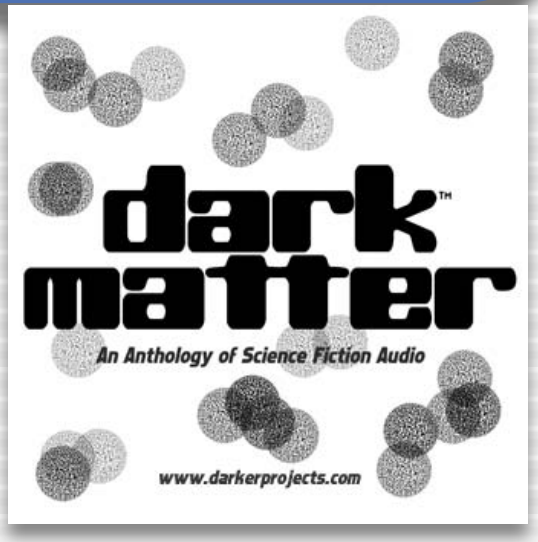

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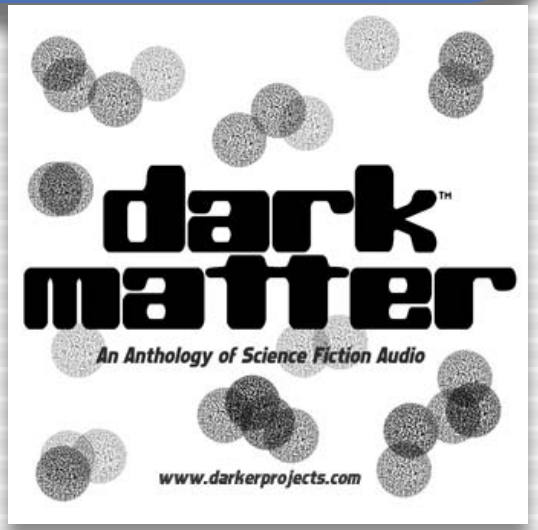

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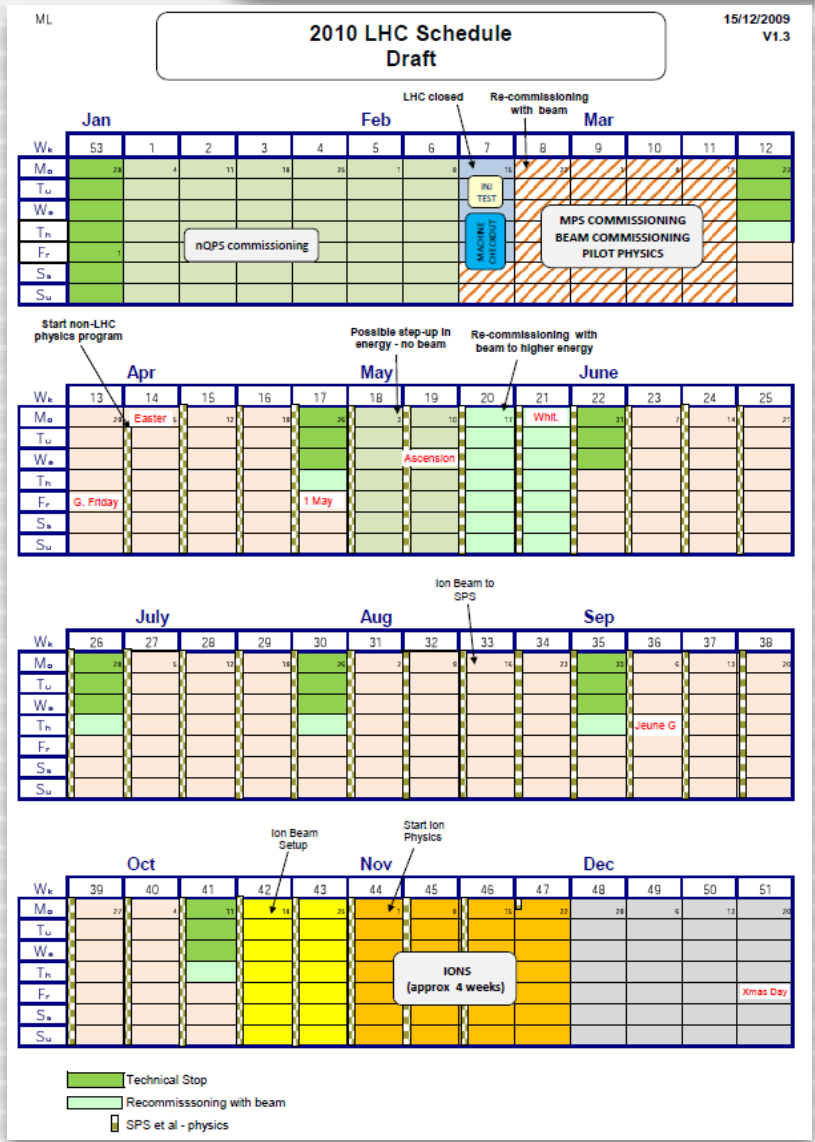
- A lot of dark energy...

The LHC Roadmap 2009-2011

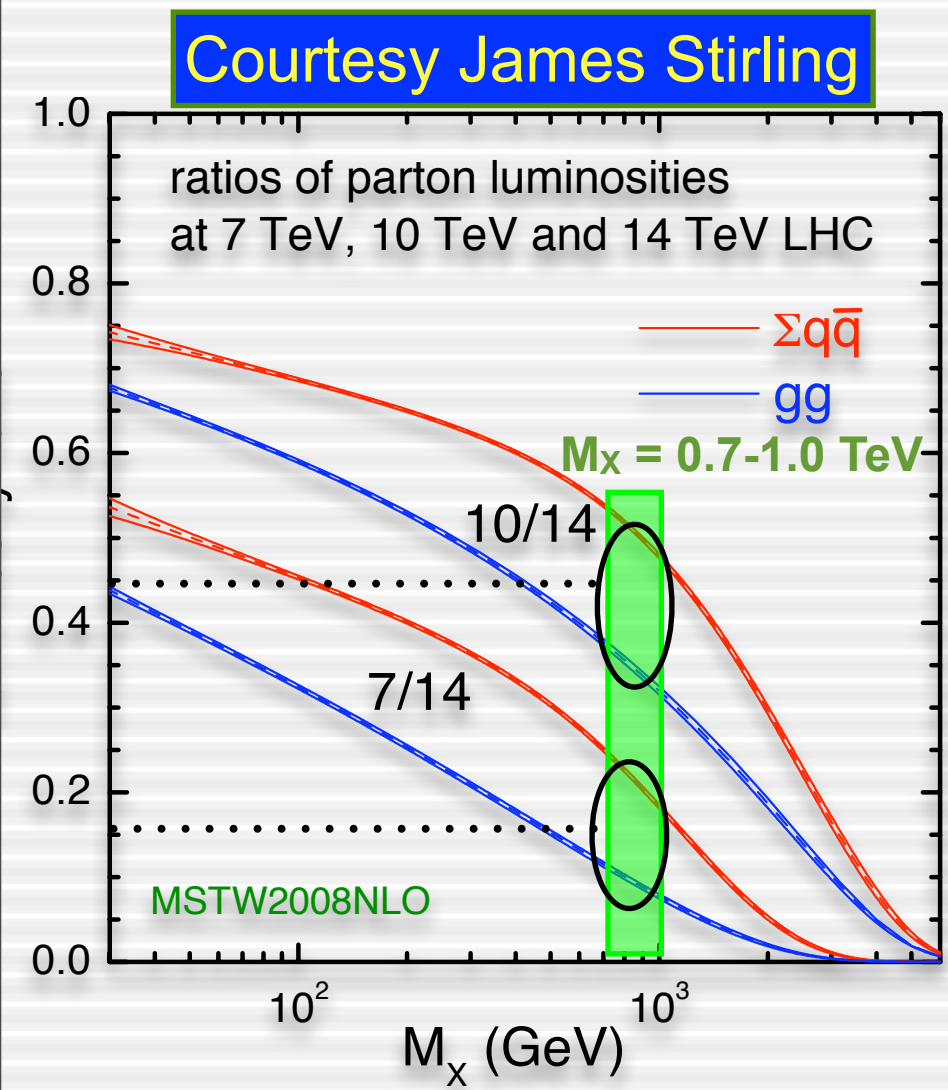
- December 2009 - first collisions at 0.9 and 2.36 TeV
  - Little data, but spectacular detector performance (see Christos Leonidopoulos's talk on Monday, 1/18/10)
- January 2010 - technical stop to commission quench protection system
  - CMS to fix faulty water cooling connectors in the muon system
- February 2010 - LHC turns on
  - Detailed steps to be decided at the Chamonix meeting next week
  - Clear signal from both experiments to go to 7 TeV collisions ASAP
  - Run 2-3 months at 7 TeV; decide on possible higher energy (up to 10 TeV)
- Revised 2010 goal: up to 0.5 fb^{-1} of integrated luminosity
- Possible operation in 2011 at ~10 TeV with ~10x more data

2010 LHC Draft Schedule



- Tentative schedule; to be replaced with the new draft after the Chamonix meeting (next week)
- Proposed 2010 proton physics program:
  - 1 month commissioning and pilot physics
  - 1-2 month @ 7 TeV
  - 1 month Technical Stop
  - 4-5 months @ >7 TeV

Search Sensitivity vs. Energy



- Typical limits for NP from the Tevatron correspond to the c.o.m. energy of ~0.7-1.0 TeV (e.g., LQ's, Z', squark/gluinos)
- For a 1 TeV invariant mass final state one needs roughly 2.5 times the luminosity at 10 TeV than at 14 TeV
- For the 7 TeV running the ratio is approximately 6
  - 7 TeV running requires roughly twice the luminosity of 10 TeV running
- For lighter states (e.g. excited leptons, or pair-produced leptoquarks) the effect is not as large; hence an early discovery is possible even at 7 TeV with O (100 pb^{-1})

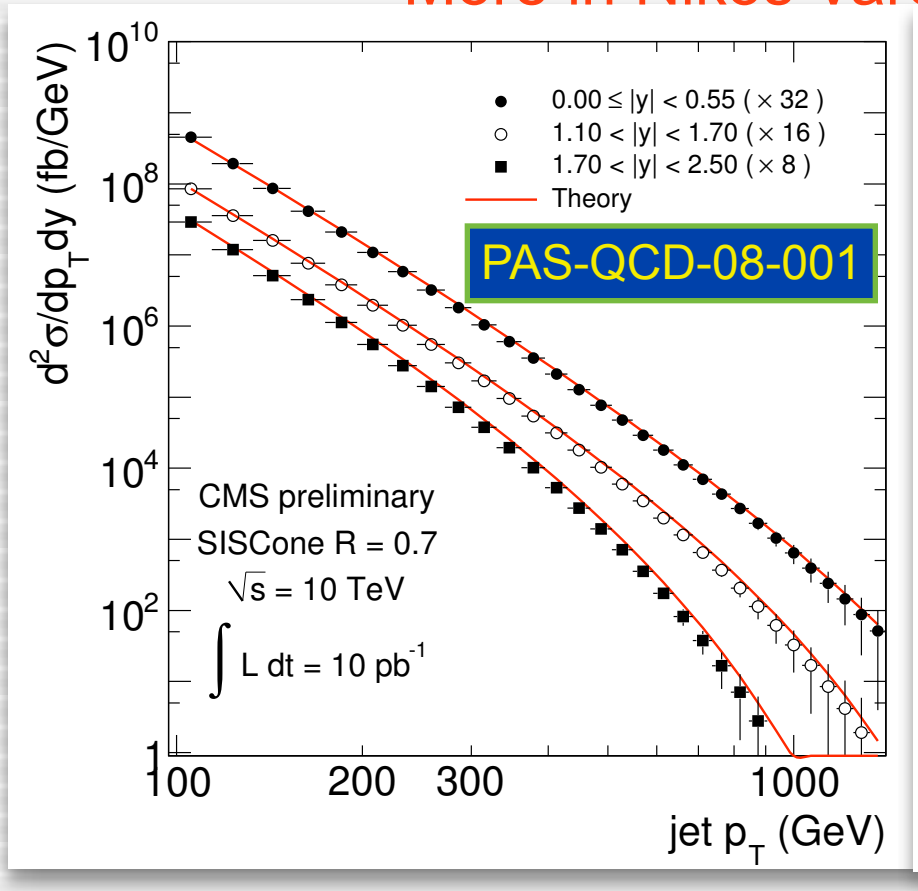
New Physics Analysis Highlights

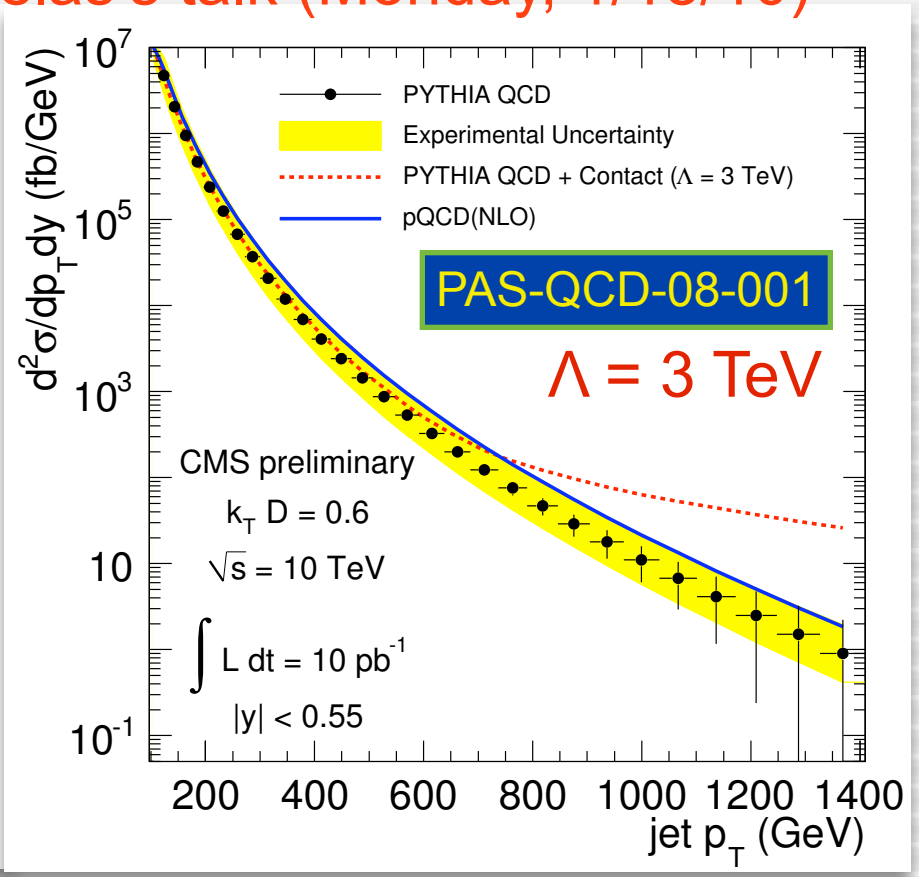
- While it's impossible to cover all the analyses in such a short talk, I'd like to highlight some of the recent results
- Broadly speaking, with the early data (50-500 pb^{-1}) we have sensitivity beyond LEP/Tevatron for:
  - Singly-produced objects with EW couplings (including the propagator)
  - Pair-produced colored objects
- Hence, we want to look for:
  - W′/Z′, KK resonances, compositeness, extra dimensions, black holes, ℓ^*
  - Technicolor, 4th generation quarks, LQ's, low-mass SUSY
  - Stopped gluinos, HSCP's

QCD as an Avenue to New Physics

- Inclusive jet cross section measurement
- Impressive sensitivity for contact interactions

More in Nikos Varelas's talk (Monday, 1/18/10)

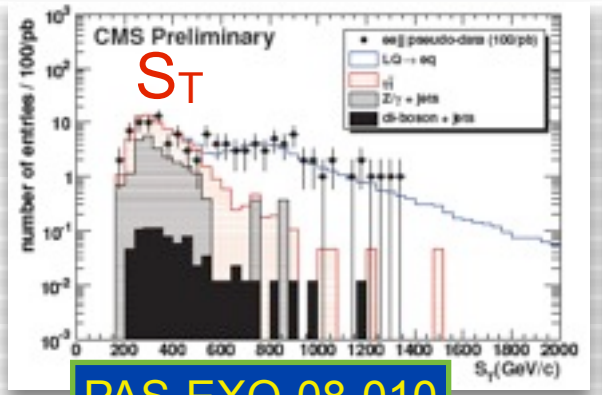


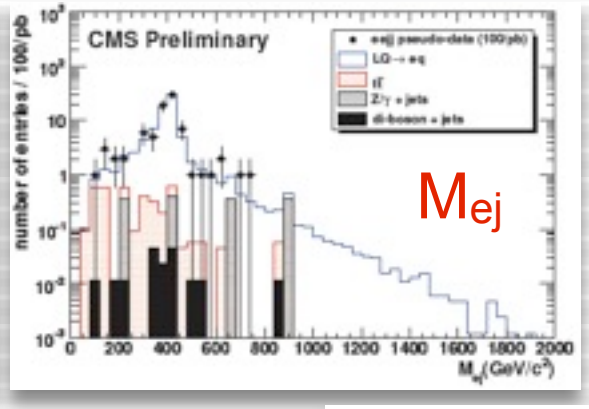


Leptoquarks

- LQ1 → ej: eejj final state
- Simple counting experiment, no mass fit
- S_T (scalar sum of all object E_T's) is the best single variable

- LQ2 → μj: μμjj final state
- Similar analysis
- High sensitivity with early data





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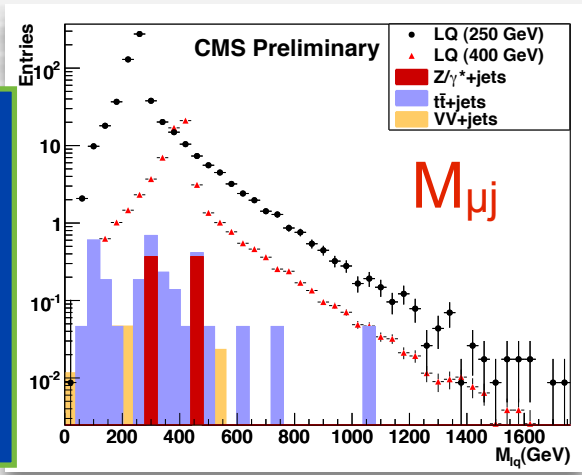

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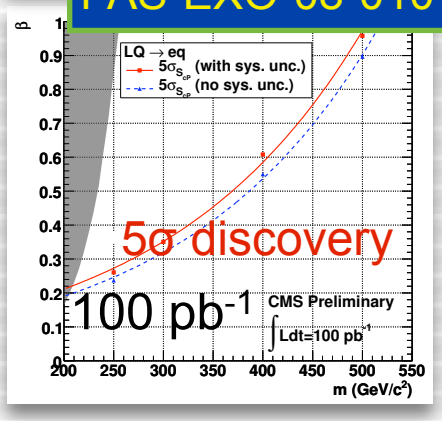
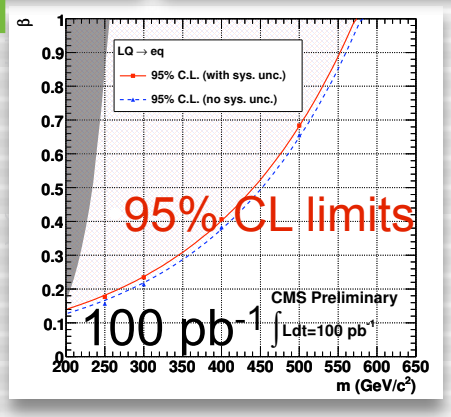
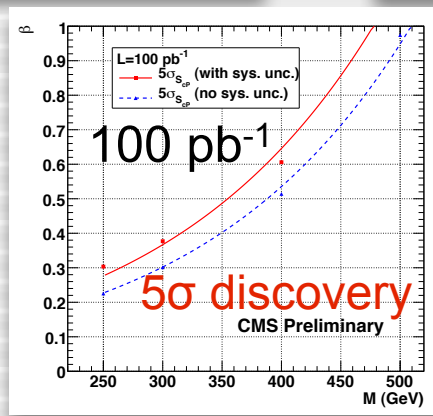
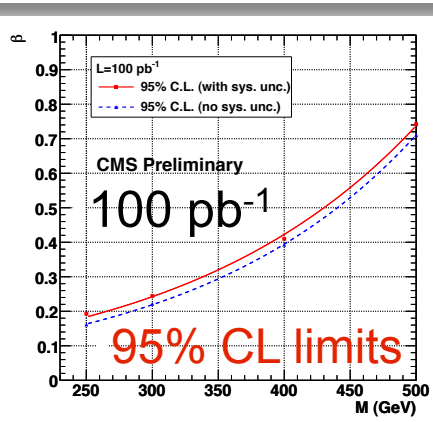




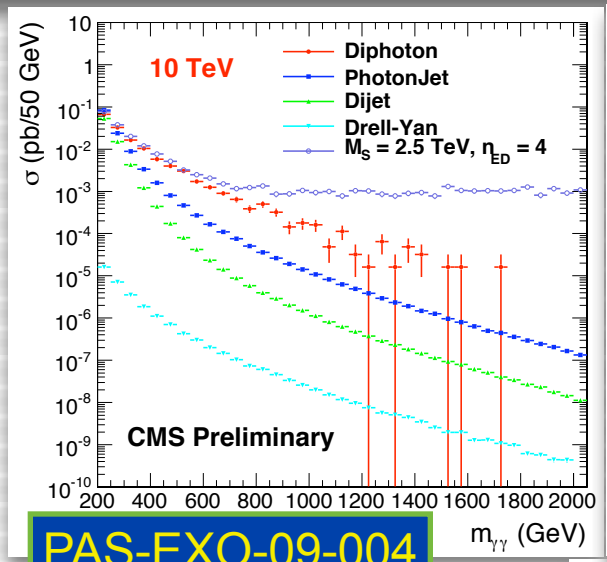


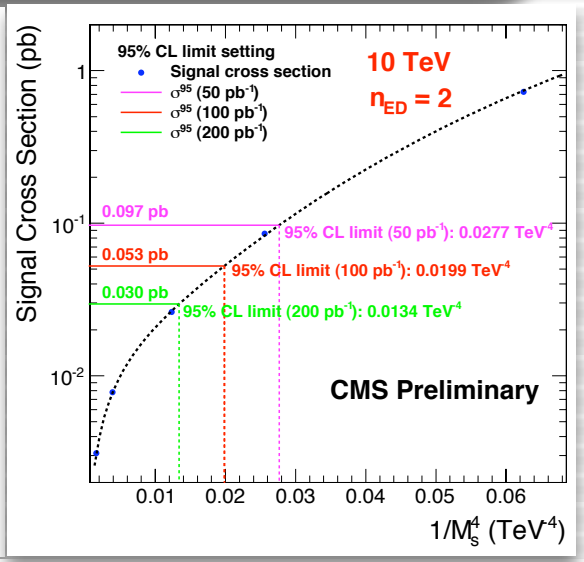


PAS-EXO-09-010

Large Extra Dimensions in $\gamma\gamma$

- Virtual graviton effects in the diphoton channel
- Higher sensitivity than ee or $\mu\mu$
- Generic compositeness-like search for overall enhancement of the $M_{\gamma\gamma}$ spectrum
- Dominant background is due to direct diphotons (obtained by normalizing at low masses)
- Use $M_{\gamma\gamma} > 700$ GeV cut and central photons
  - B = 0.40 events
  - Low background allows for other searches





PAS-EXO-09-004

n_{ED}	95% CL Limit on M_S		
	50 pb^{-1}	100 pb^{-1}	200 pb^{-1}
2	2.5 TeV	2.7 TeV	2.9 TeV
3	3.0 TeV	3.3 TeV	3.5 TeV
4	2.6 TeV	2.8 TeV	3.0 TeV
5	2.3 TeV	2.5 TeV	2.7 TeV
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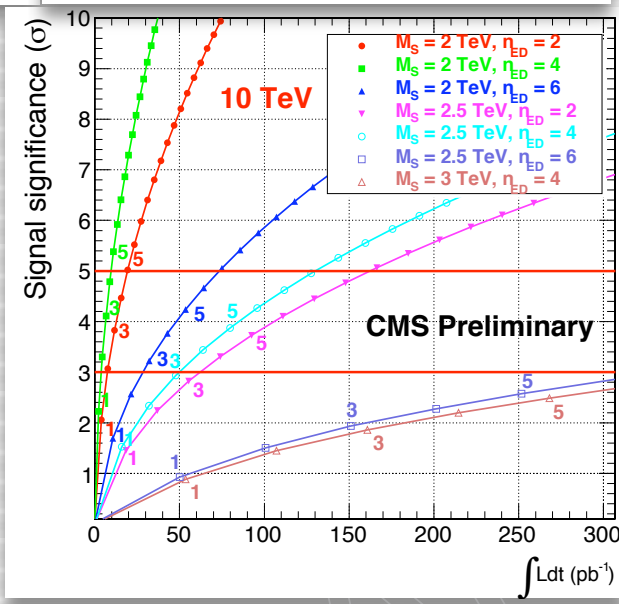
Factor of two higher sensitivity compared to the Tevatron limits!



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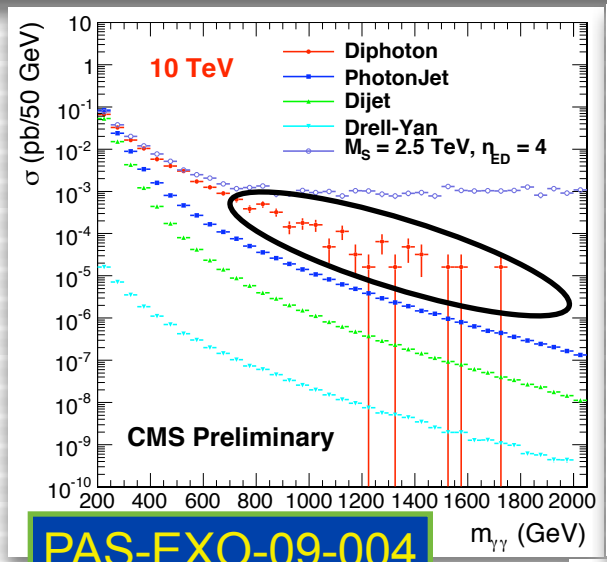

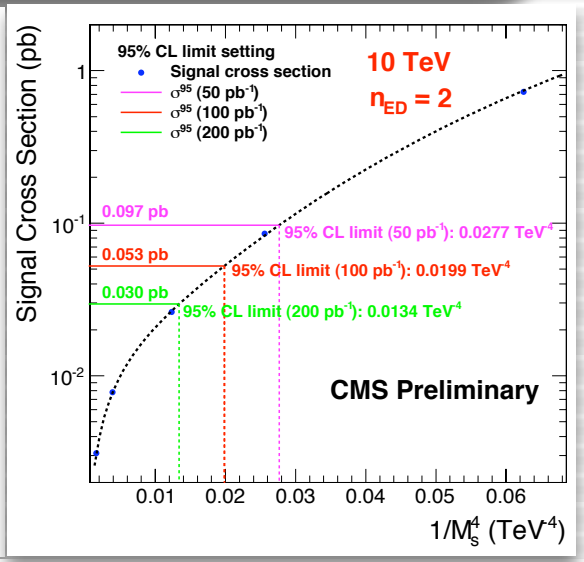

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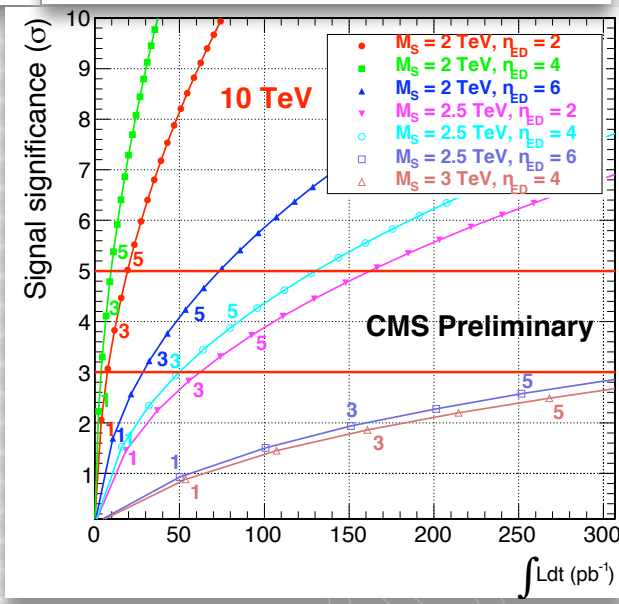

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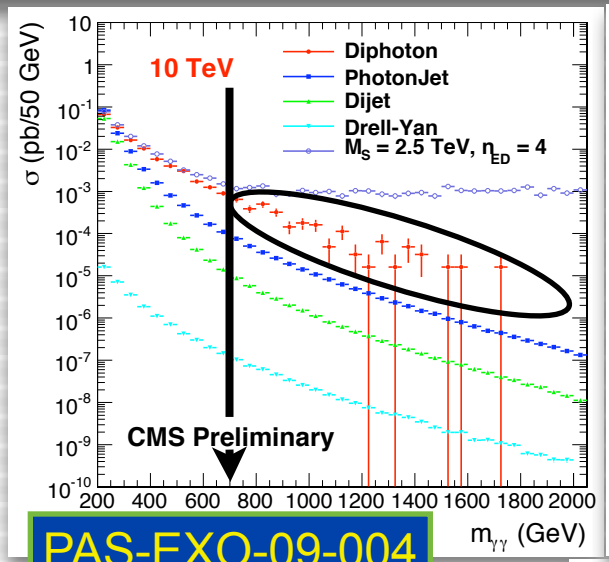

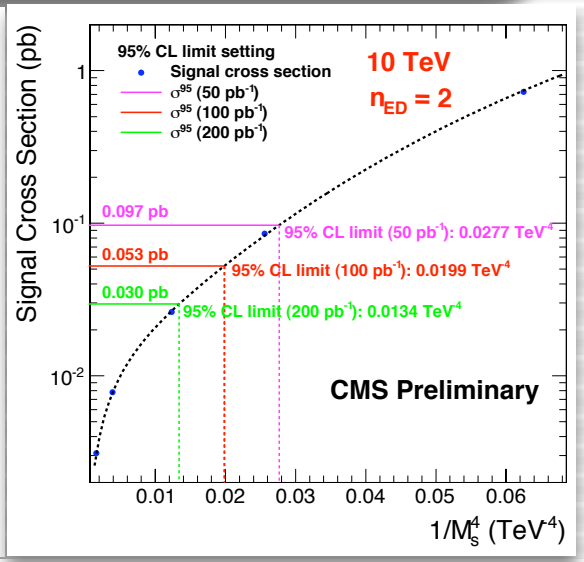

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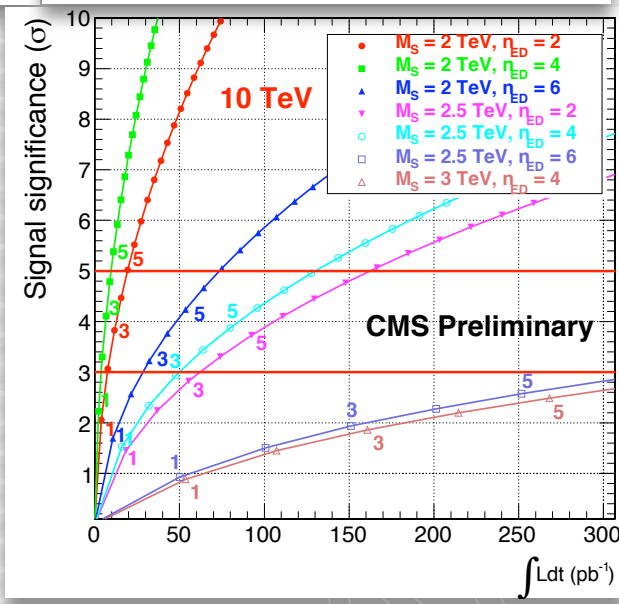

RS Gravitons and Unparticles

- Large ED analysis can be reused in inventive ways:
  - Low background above a certain mass value
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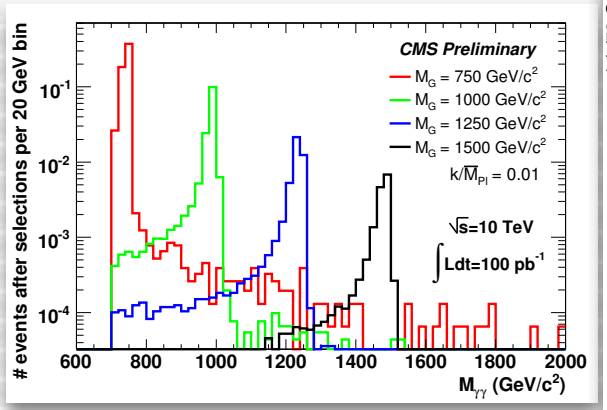
  - Search for other diphoton spectrum enhancements (e.g. due to unparticles)



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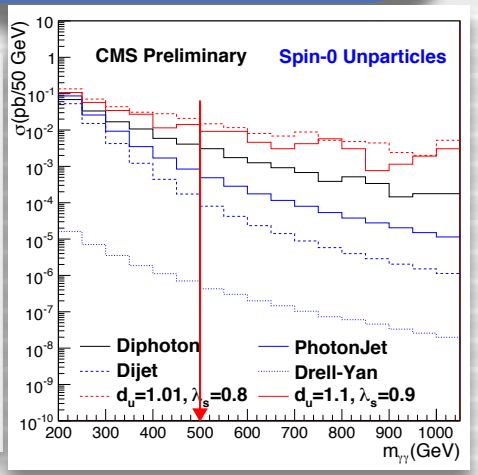

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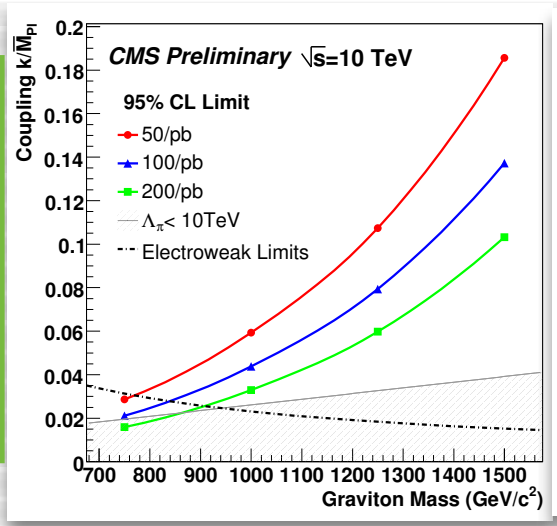

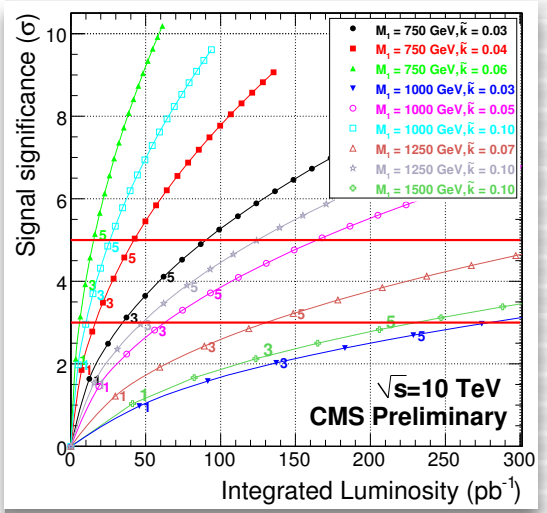

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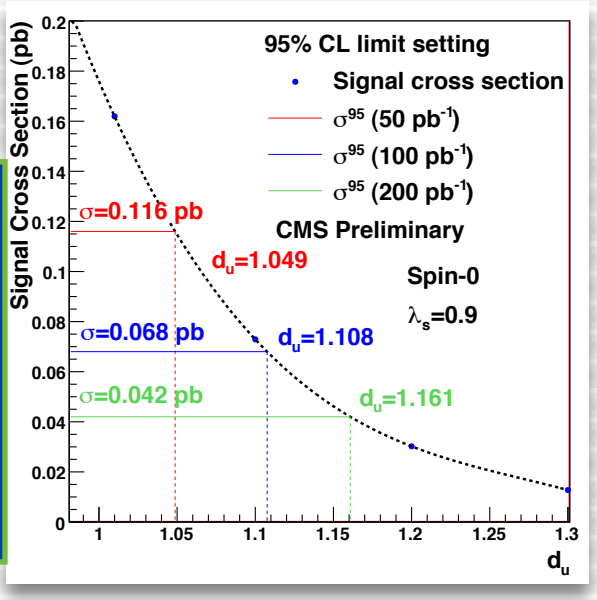

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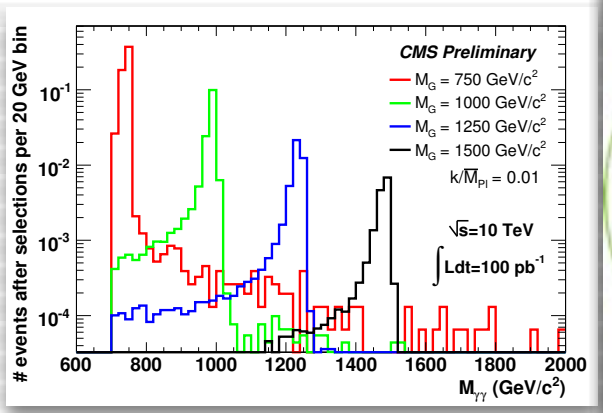

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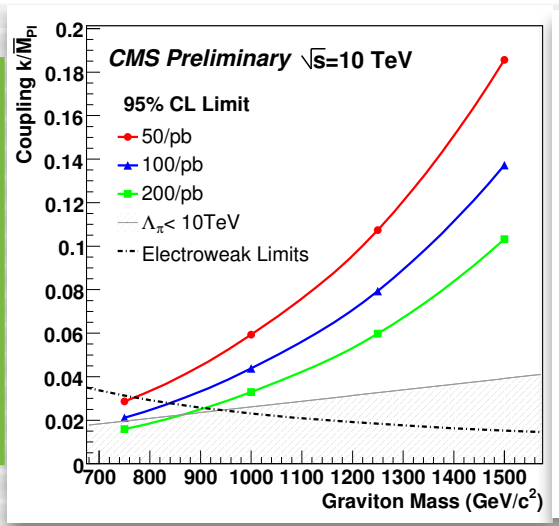

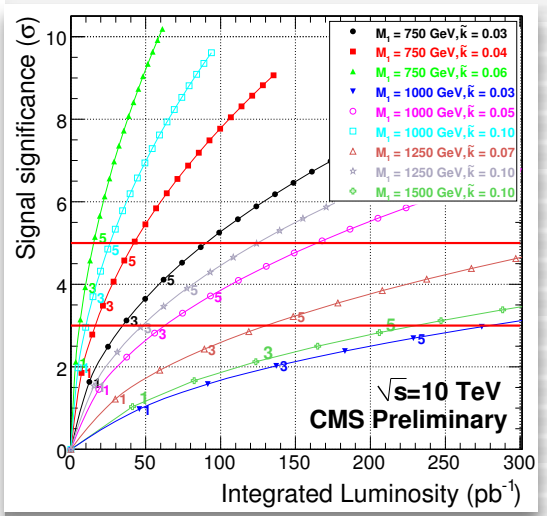

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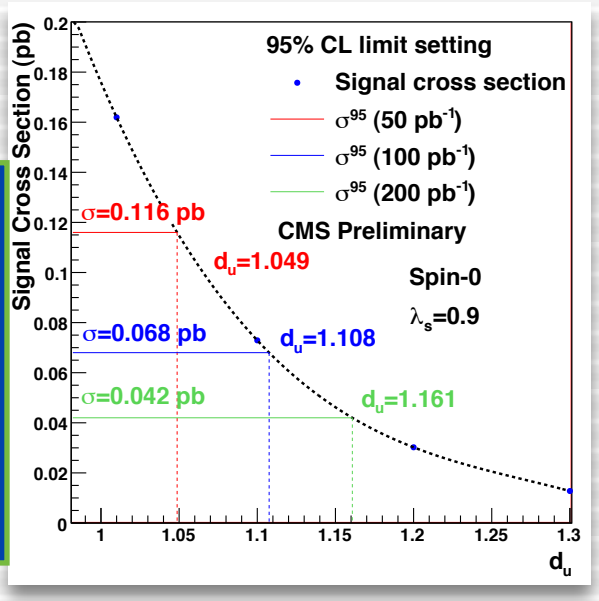
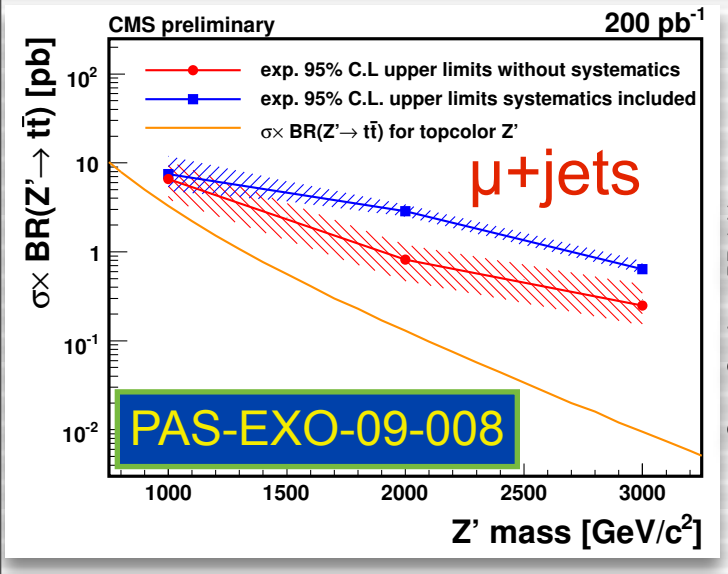
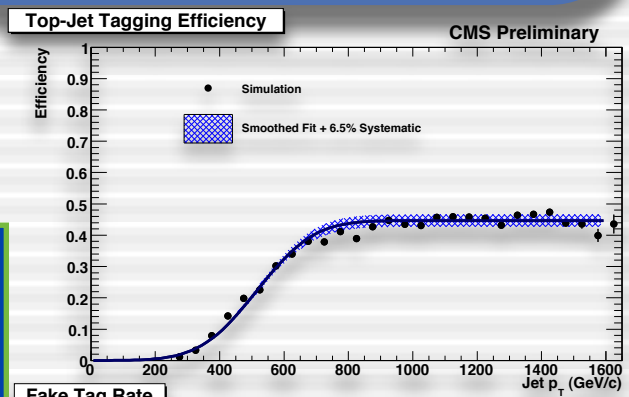


Boosted Top

- Search for high-mass resonances decaying into top pair with high boost
- All hadronic channel (Cambridge-Aachen algorithm)
  - Impressive tagging performance!
  - KK gluons decaying into $t\bar{t}$
- μ+jets channel ($\Delta R_{\mu j}$ and p_T^{rel} cut)
  - Z' decaying into $t\bar{t}$





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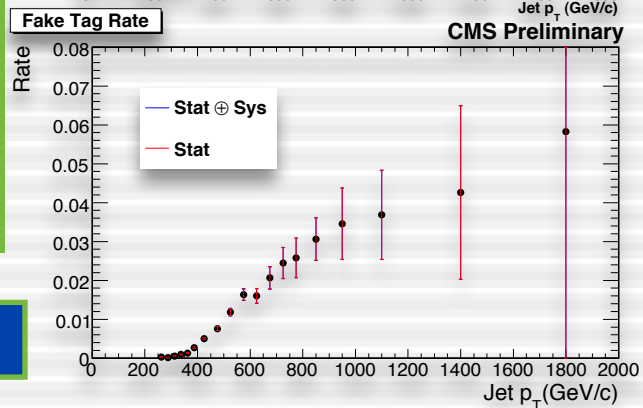

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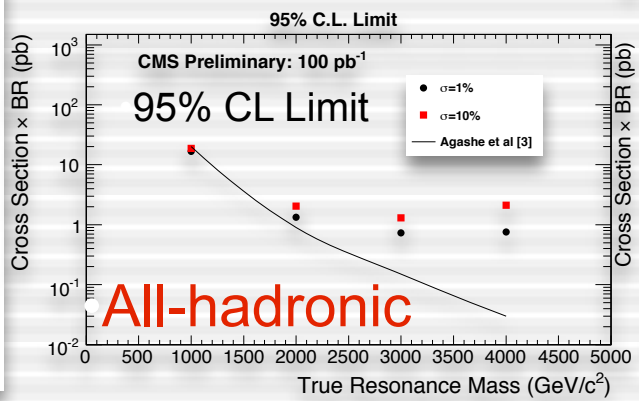

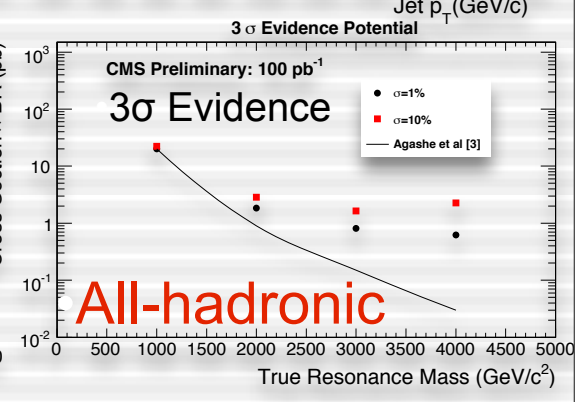

Monojets and Majorana Neutrino

- Complementary way to search for large ED
- High-p_T single jet
- Use Missing H_T > 250 GeV for selection

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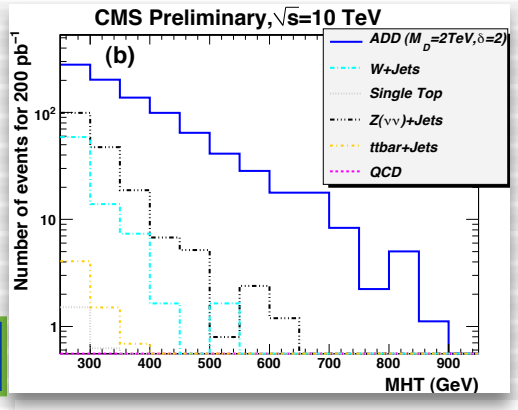
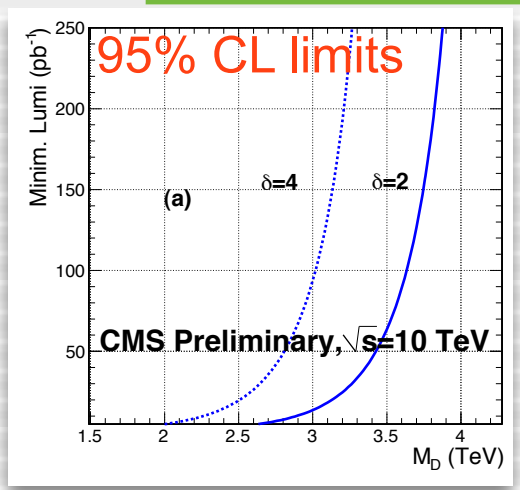
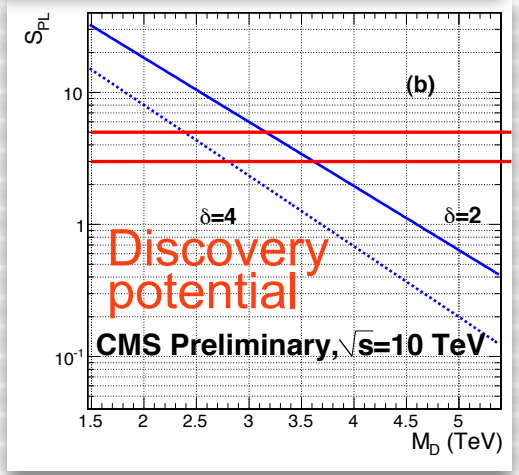
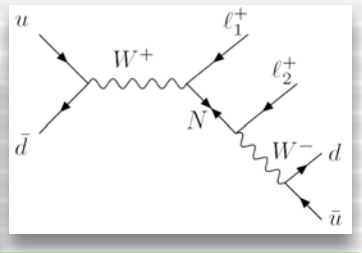


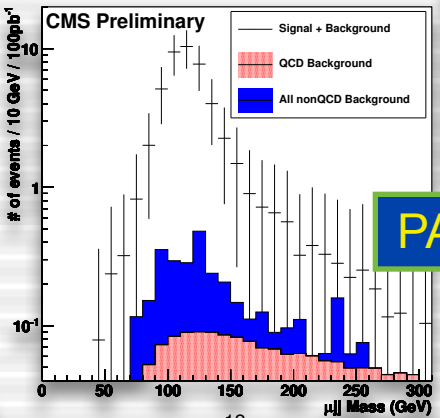


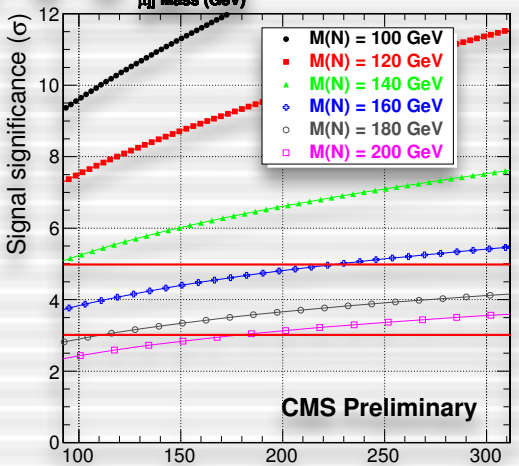


- Majorana neutrino with flavor violation in like-sign dileptons



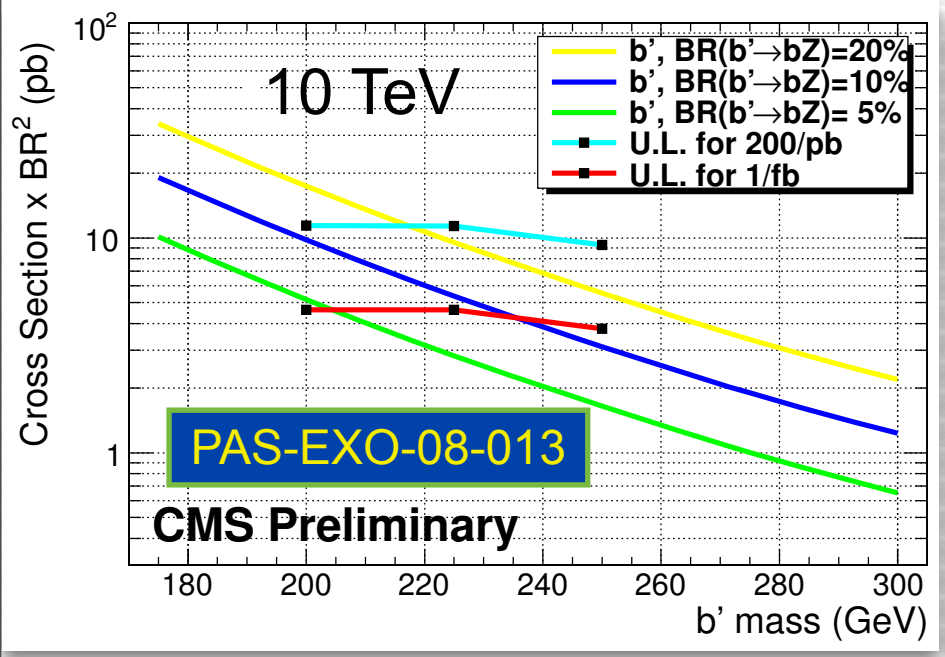
PAS-EXO-09-003

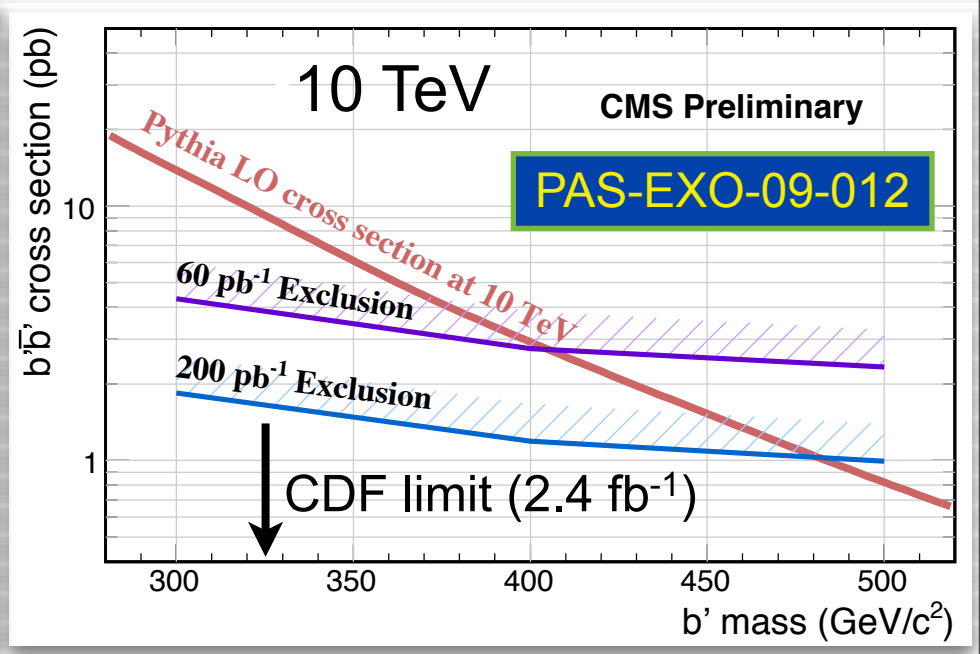




4th Generation Searches

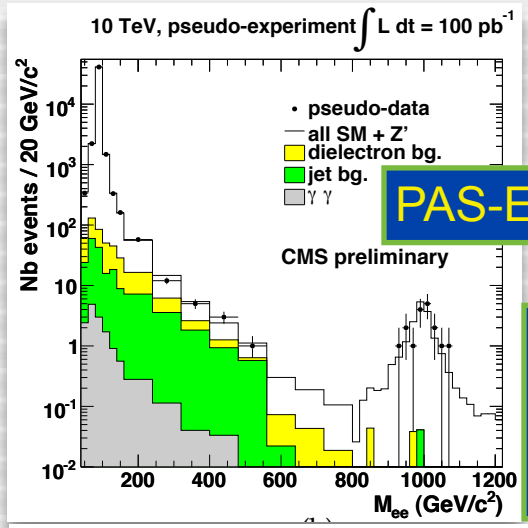
- Two b′ analyses: FCNC bZ and tW decay channels
  - Trilepton and same-sign dilepton final states
  - Relatively low backgrounds; sensitivity exceeds that at the Tevatron with just O(50 pb^{-1})
  - Shy of discovery in the first run, but significant exclusion potential; 3σ evidence up to 400 GeV





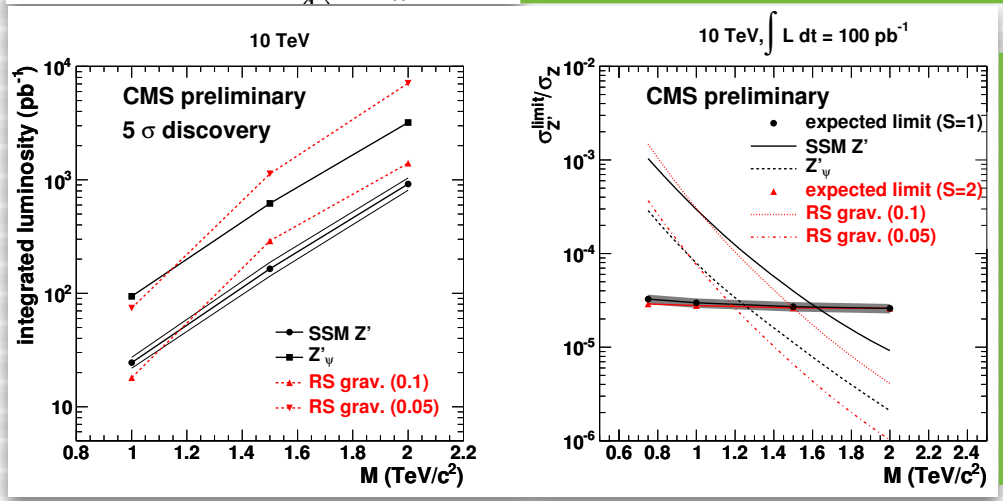
Narrow Resonance Searches

- Z′/G_{KK}(ee)



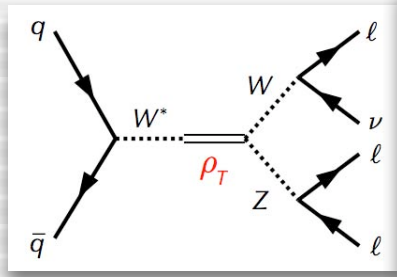
PAS-EXO-09-006

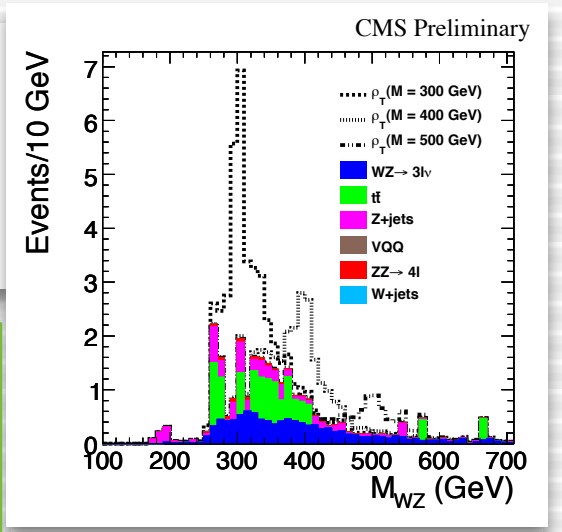
Discovery reach up to 1.2-1.3 TeV for a SM-like Z'



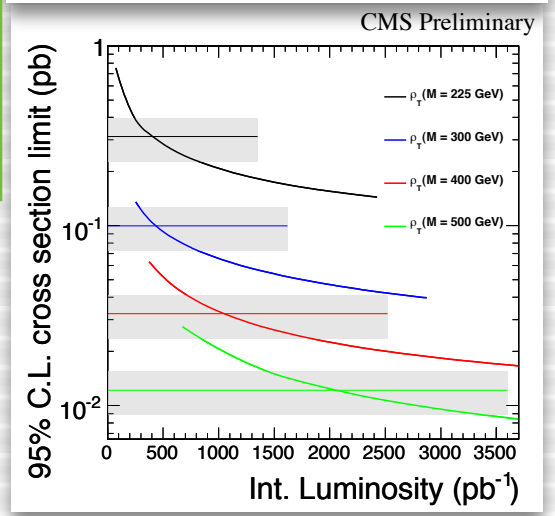
PAS-EXO-09-006

- Technicolor (ρ_T) in WZ



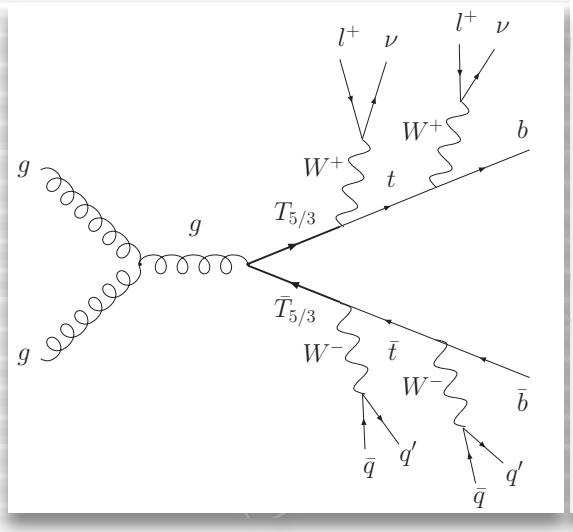


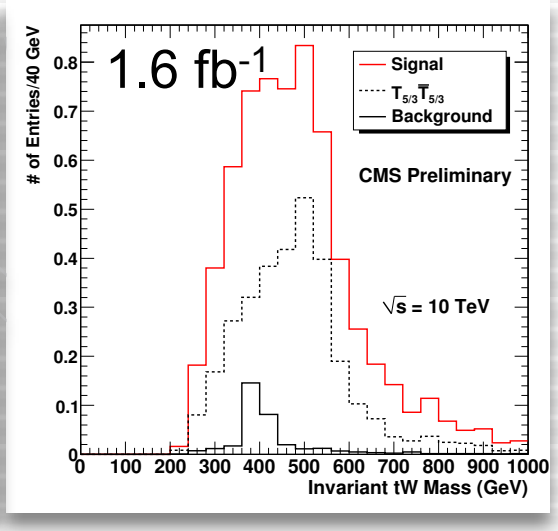
PAS-EXO-09-007

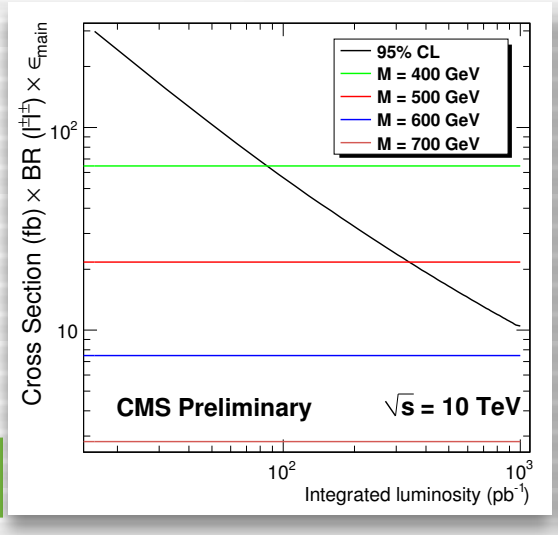


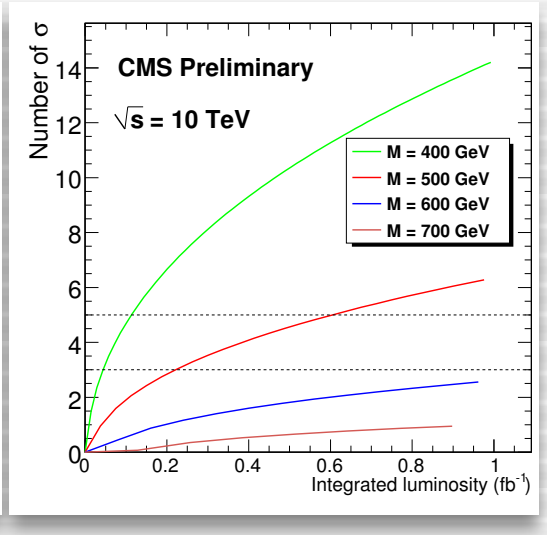
Exotic Top Partners

- Exotic $T_{5/3}$ and B quarks, decaying into t(bW)W
  - Two same-sign leptons and five or more jets
  - Top pair production is the major background
- Discovery potential up to ~400 GeV
- Exclusion up to ~500 GeV





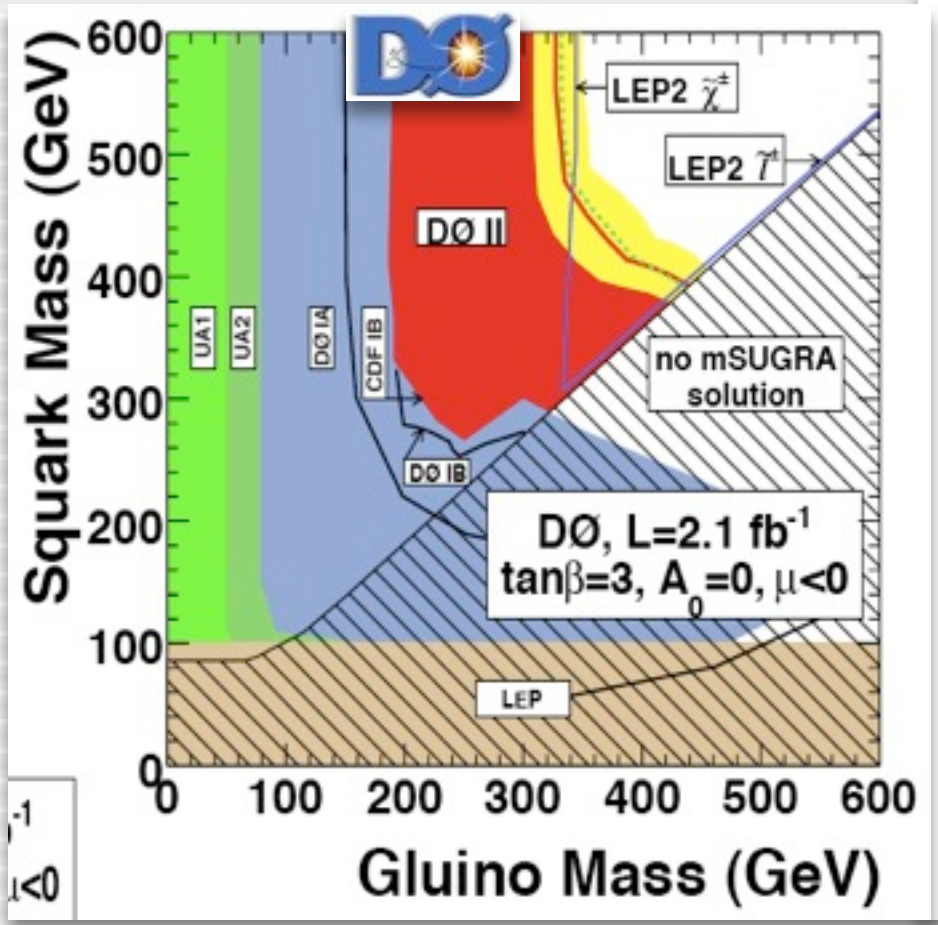


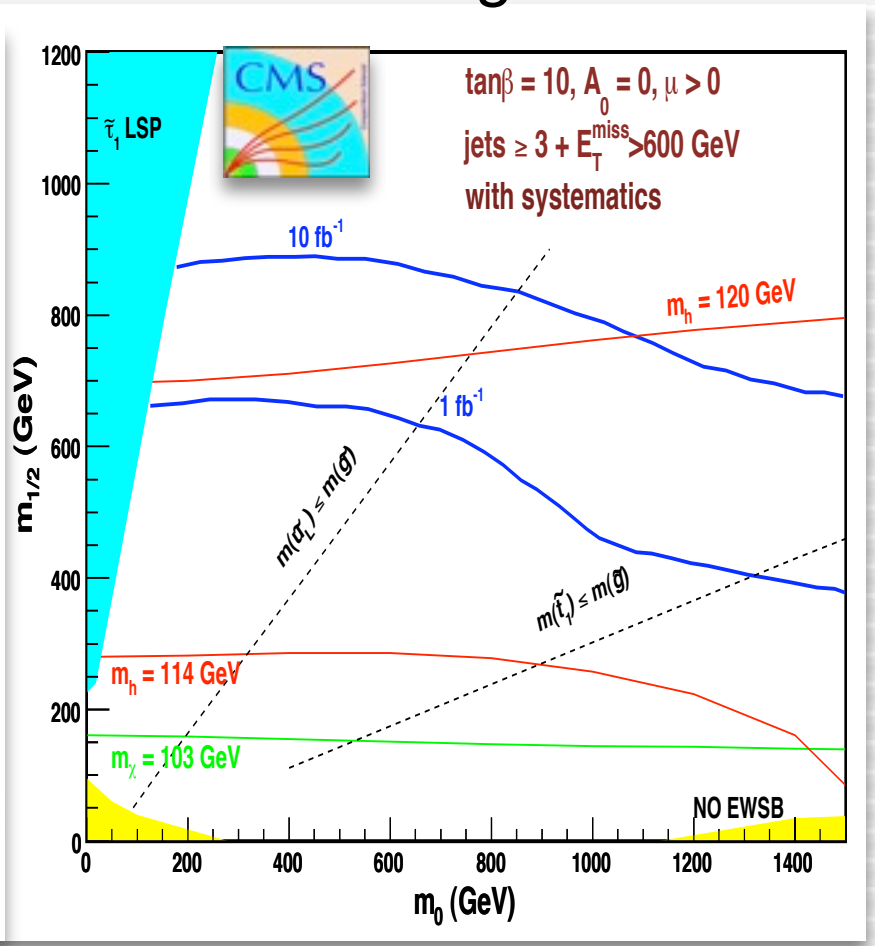


PAS-EXO-08-008

SUSY - an Early Discovery?

- Even with little statistics the reach will be expanded dramatically compared to the Tevatron limits
- The trick is to be able to understand missing E_T





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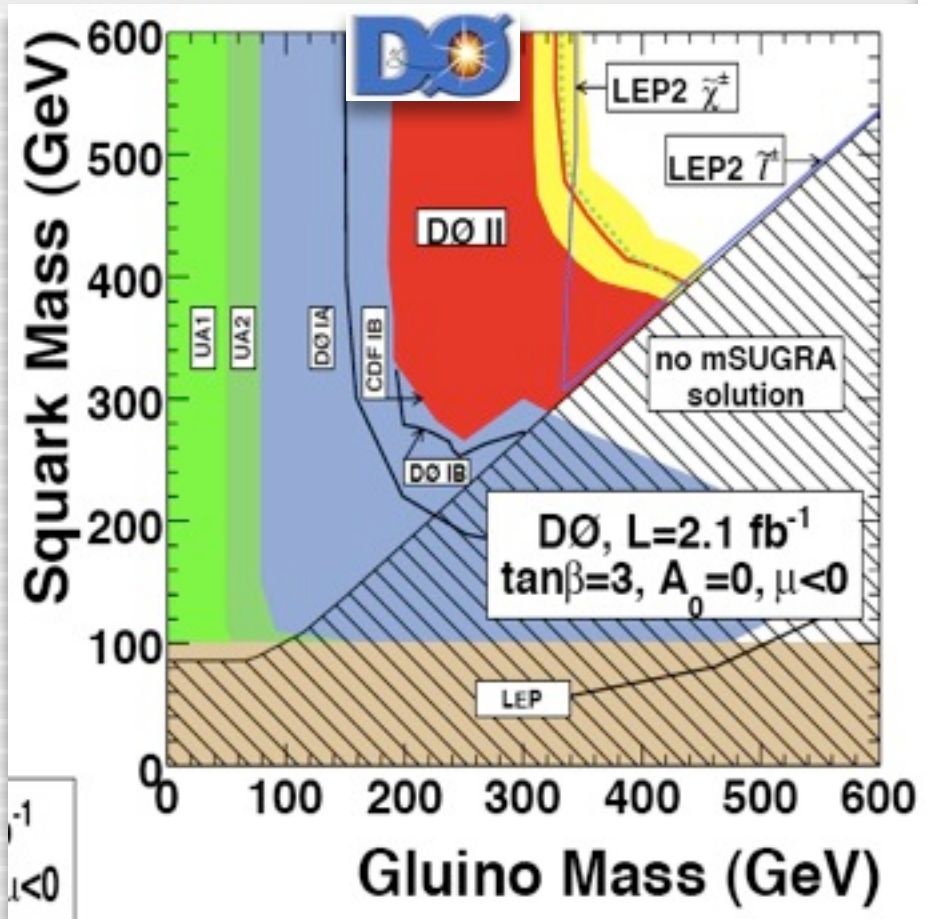
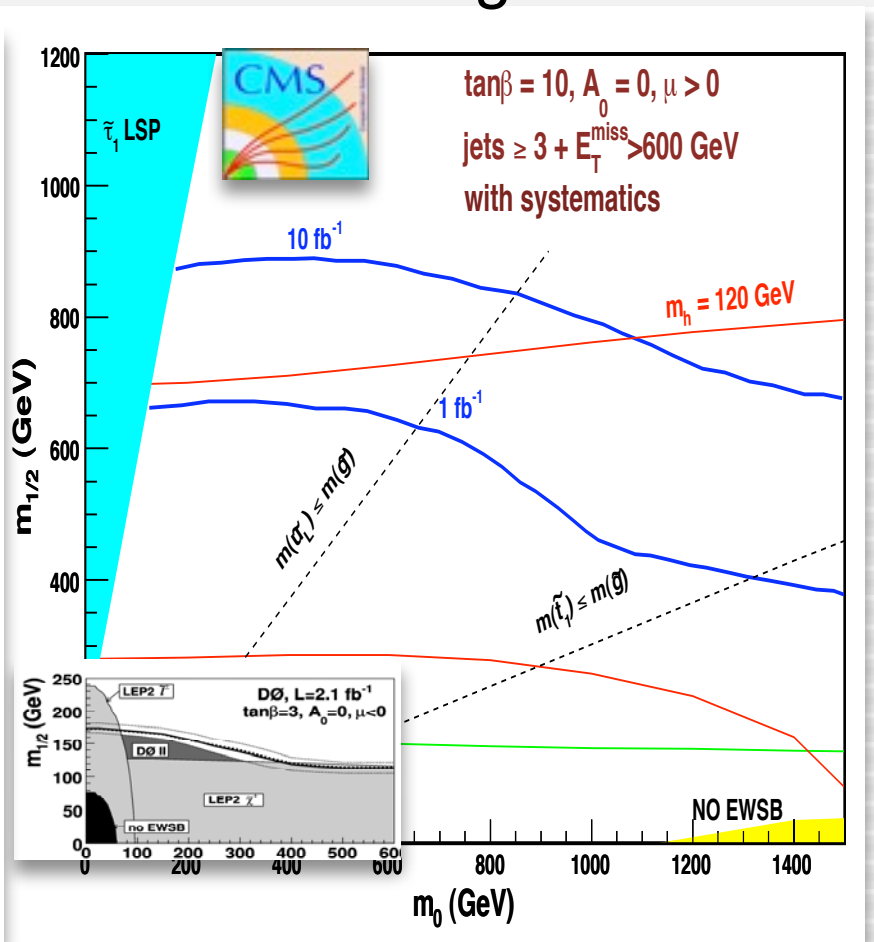
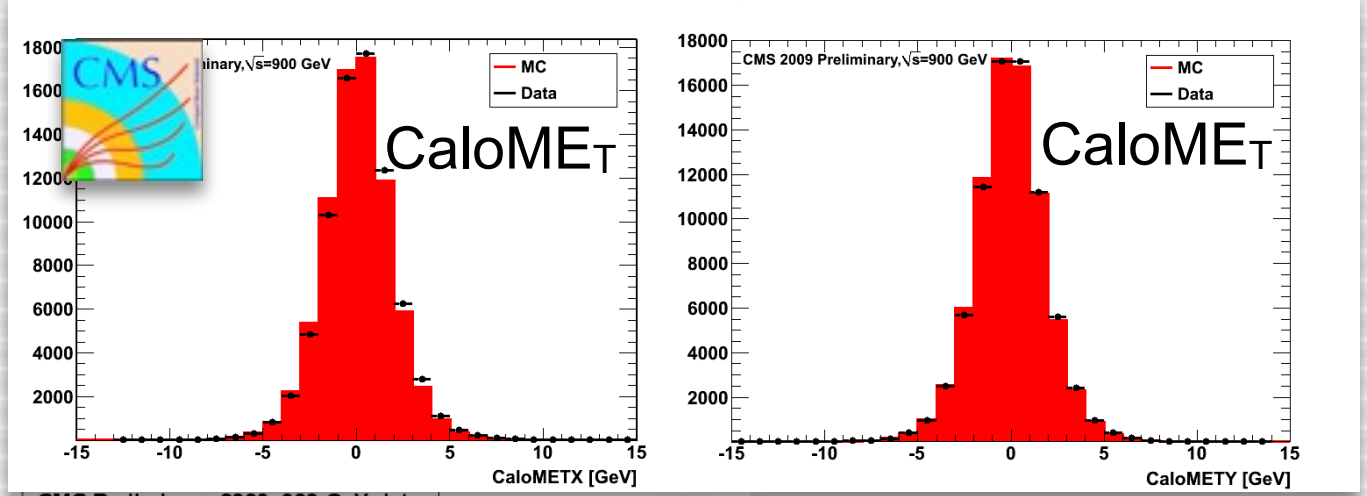
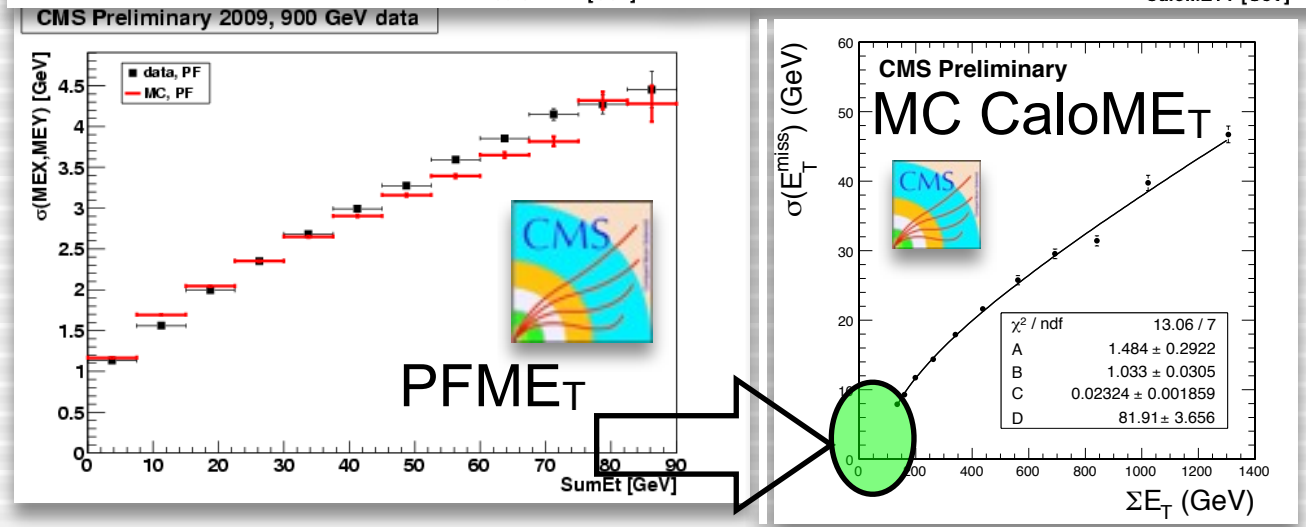




...and We Do (ME_T in Real Data)!

- Very encouraging performance seen in first LHC collision data: both PF and Calorimeter based ME_T



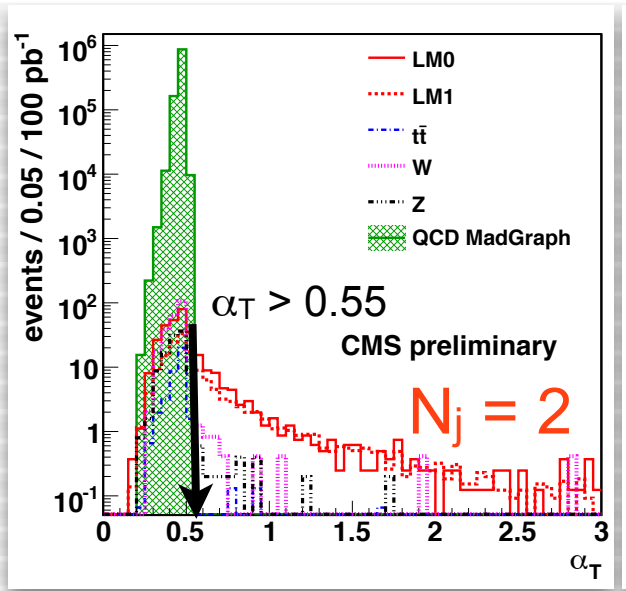


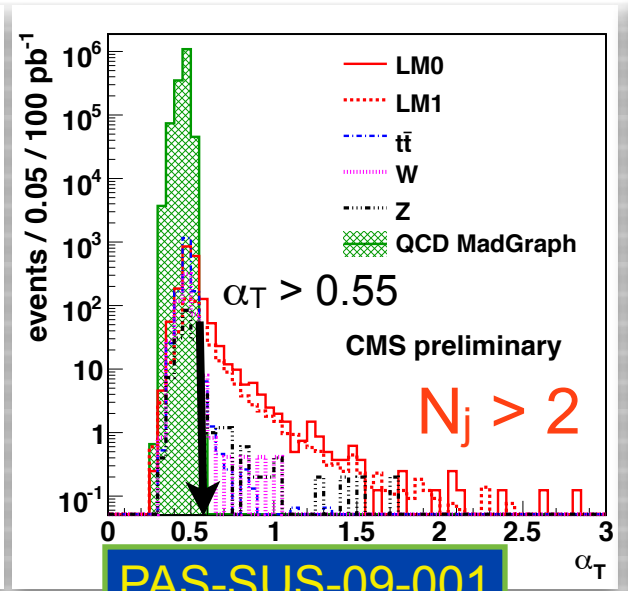
Plan B?

- What if ME_T tails in early data are hard to understand?
  - Still could do hadronic search based on exclusive n-jet events
  - Define the variable: $\alpha_T = E_T^{j2} / M_T$ [a la Randall/Tucker-Smith, PRL **101**, 221803 (2008)], where:

$$M_T = \sqrt{\left(\sum_{i=1}^{n} E_T^{j_i}\right)^2 - \left(\sum_{i=1}^{n} p_x^{j_i}\right)^2 - \left(\sum_{i=1}^{n} p_y^{j_i}\right)^2} = \sqrt{H_T^2 - (H_T^{miss})^2}$$

  - Good separation between QCD background and SUSY signal





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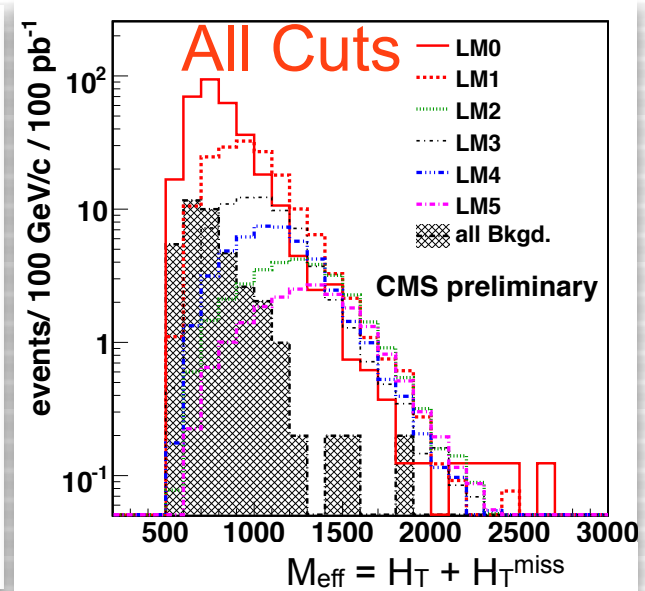
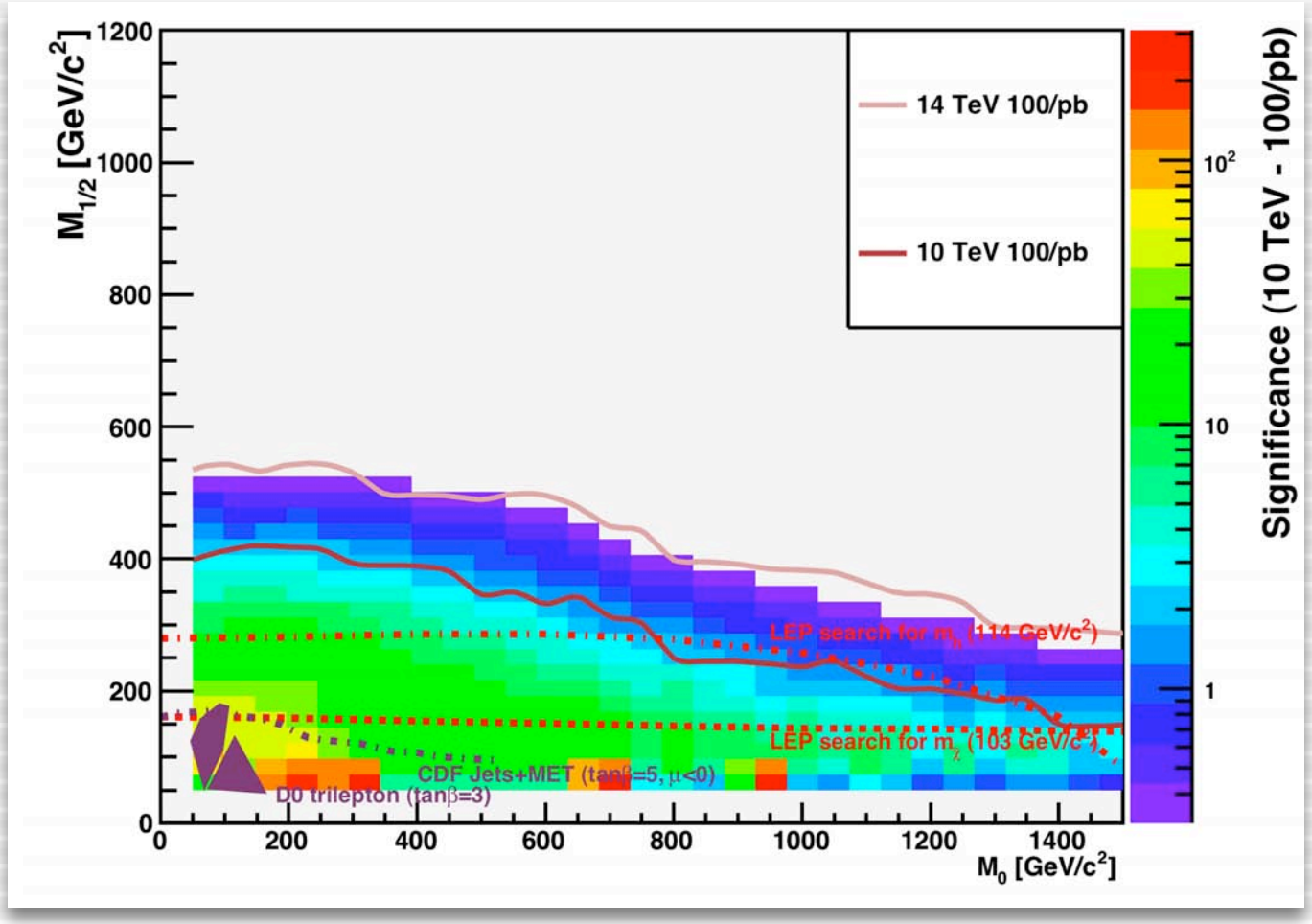


10 TeV Projection

- Detailed studies in several channels are ongoing
- A simple projection from scaling in the all-hadronic channel is available



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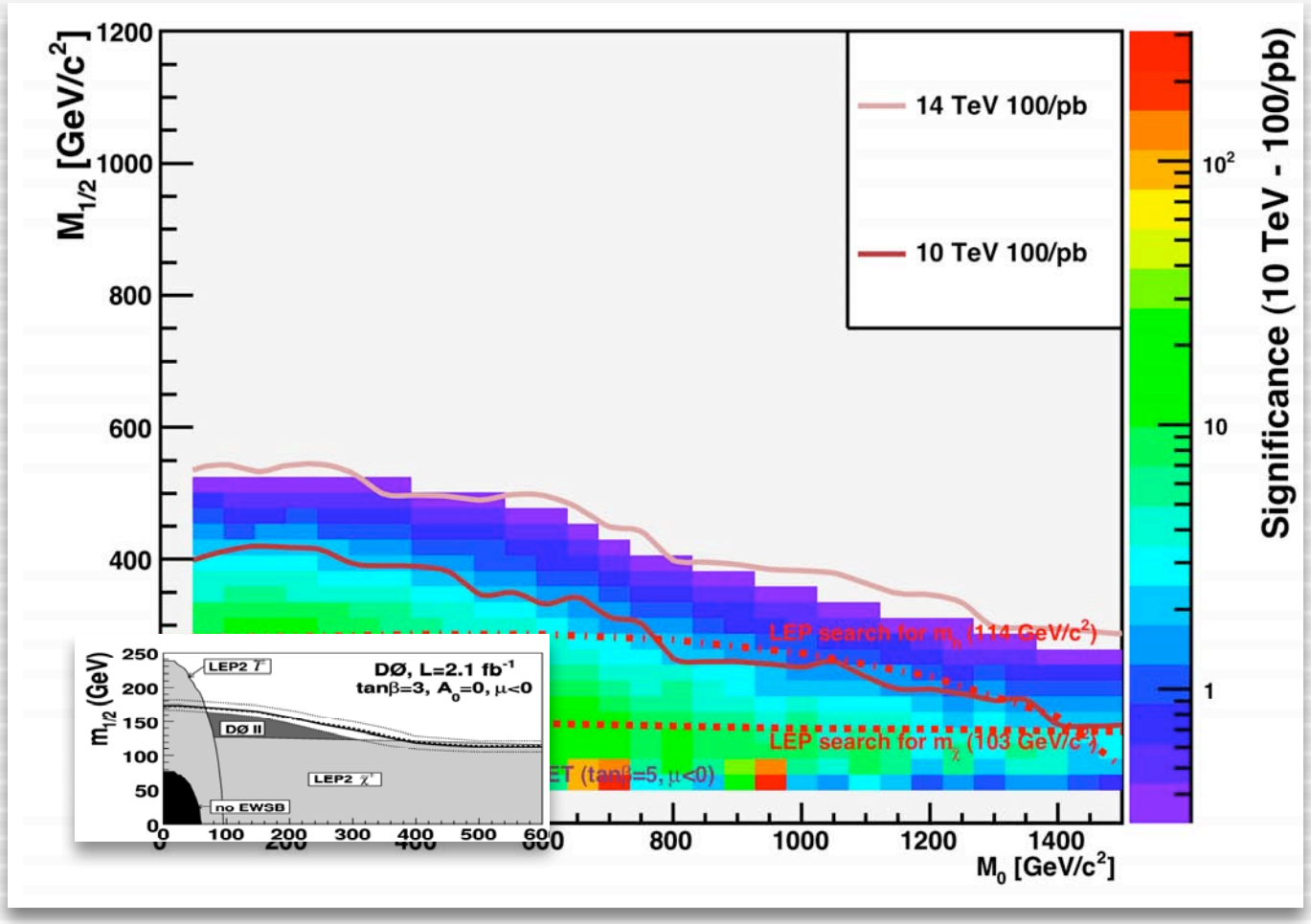
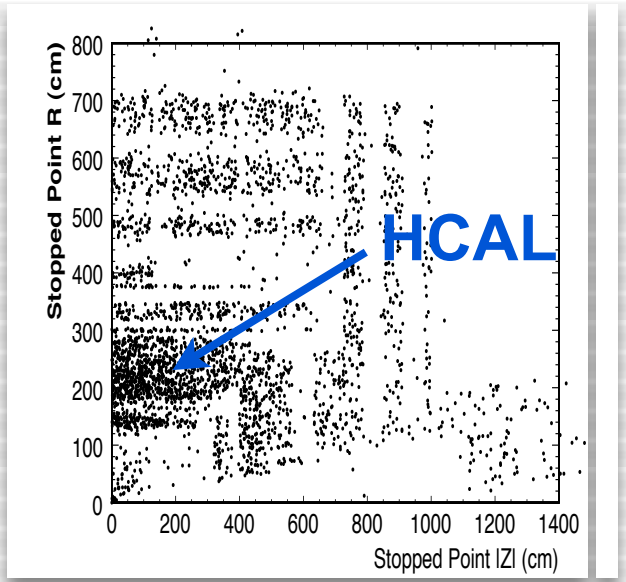
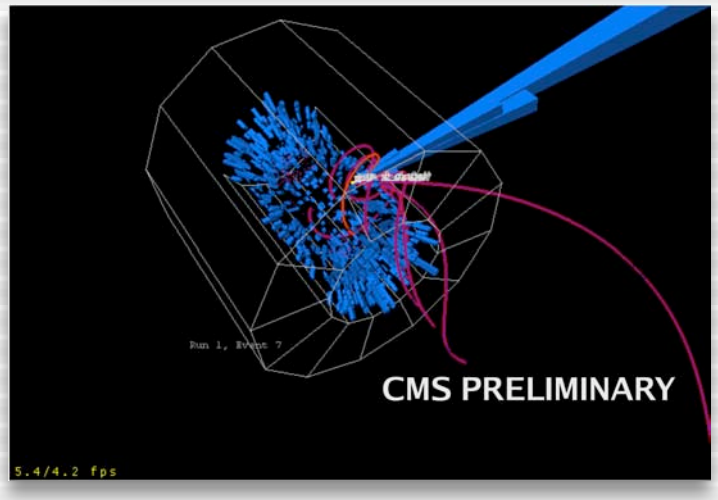


Stopped Gluino Search

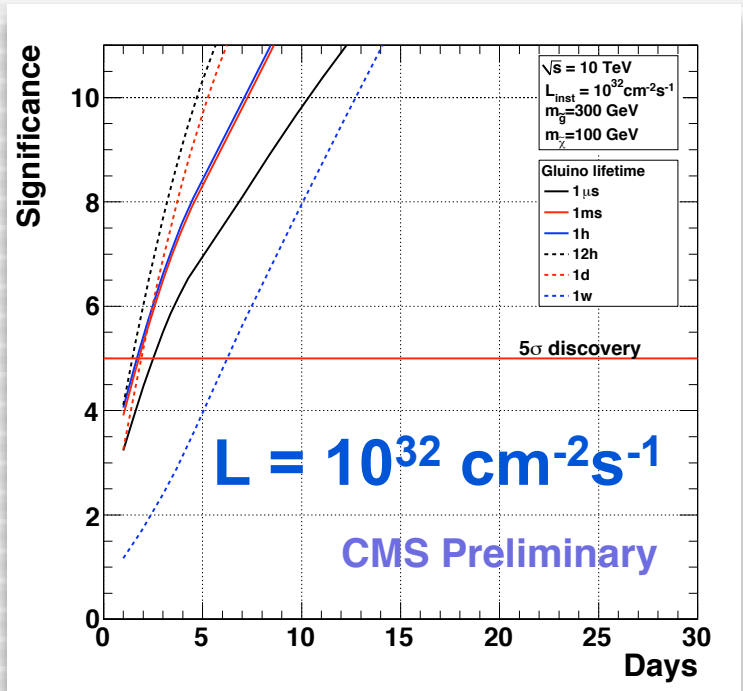
- Long-lived gluinos are predicted in a number of models, e.g., split SUSY
- Strongly produced, they hadronize and eventually stop in the dense detector material (if charged and have low β)
- Decay microseconds to days (or even months!) later
- Look for such decays in HCAL during beam-off time
- Designed and commissioned a special beam-gap trigger

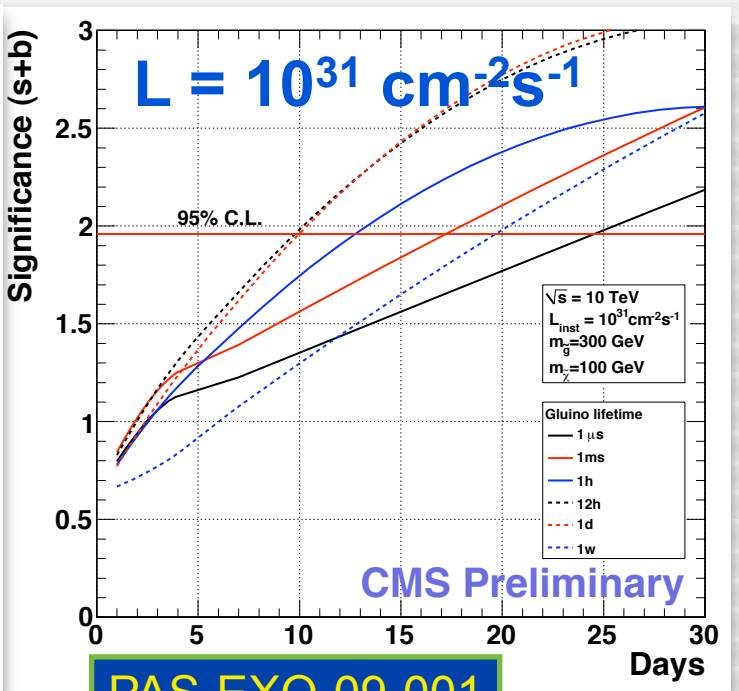




Early Discovery Potential

- Estimated discovery potential for a 300 GeV gluino at L = $10^{31\text{-}32}$ $cm^{-2}s^{-1}$ and a nominal 12-hour LHC operational cycle
- Note that instantaneous luminosity is the key: significance increases only as L x sqrt(t), not usual sqrt(Lt), since the background doesn't depend on L





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Other Topics of Early Interest

- Excited electrons and muons
- W'/W_R searches
- LQ searches with $\beta < 1$
- Searches with taus (including LQ3)
- Searches for highly ionizing slow-moving particles and non-promptly decaying new particles
- Generic deviations from the SM predictions (High-H_T, MUSIC, etc.)
- Search for black holes and string balls
- And of course something COMPLETELY UNEXPECTED!

Black Holes in CMS

Conclusions

- We all hope to see clear peaks ahead (and maybe even some hidden valleys behind)
- 2010 is going to be an exciting year!

... and Watch the CNN!