Early Discovery Channels in CMS

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LHCDM@MCTP: The LHC and Dark Matter

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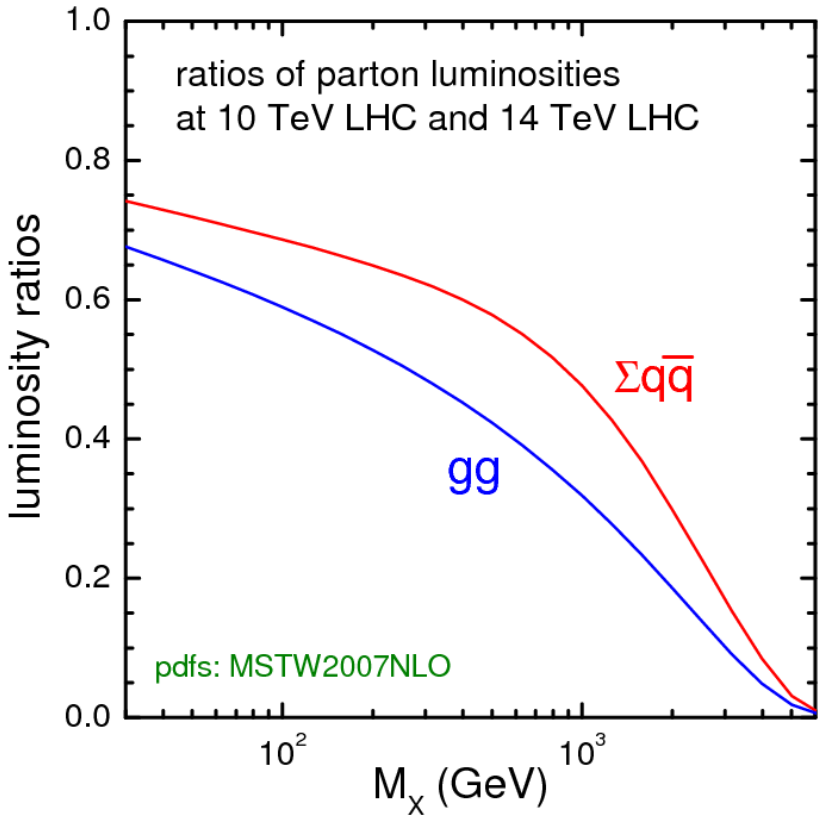
"Early discovery channels"

- Based on recent LHC schedules, we can hope for about 100 pb^{-1} of 10 TeV collisions in 2009
- Full re-analysis at 10 TeV is under study, but most production cross-sections will be reduced by about a factor of 2, depending on mass
- In this talk: 14 TeV analyses reoptimized for 100 pb^{-1}
  - new results, post-Physics TDR
  - roughly what we may see this year

J. Stirling

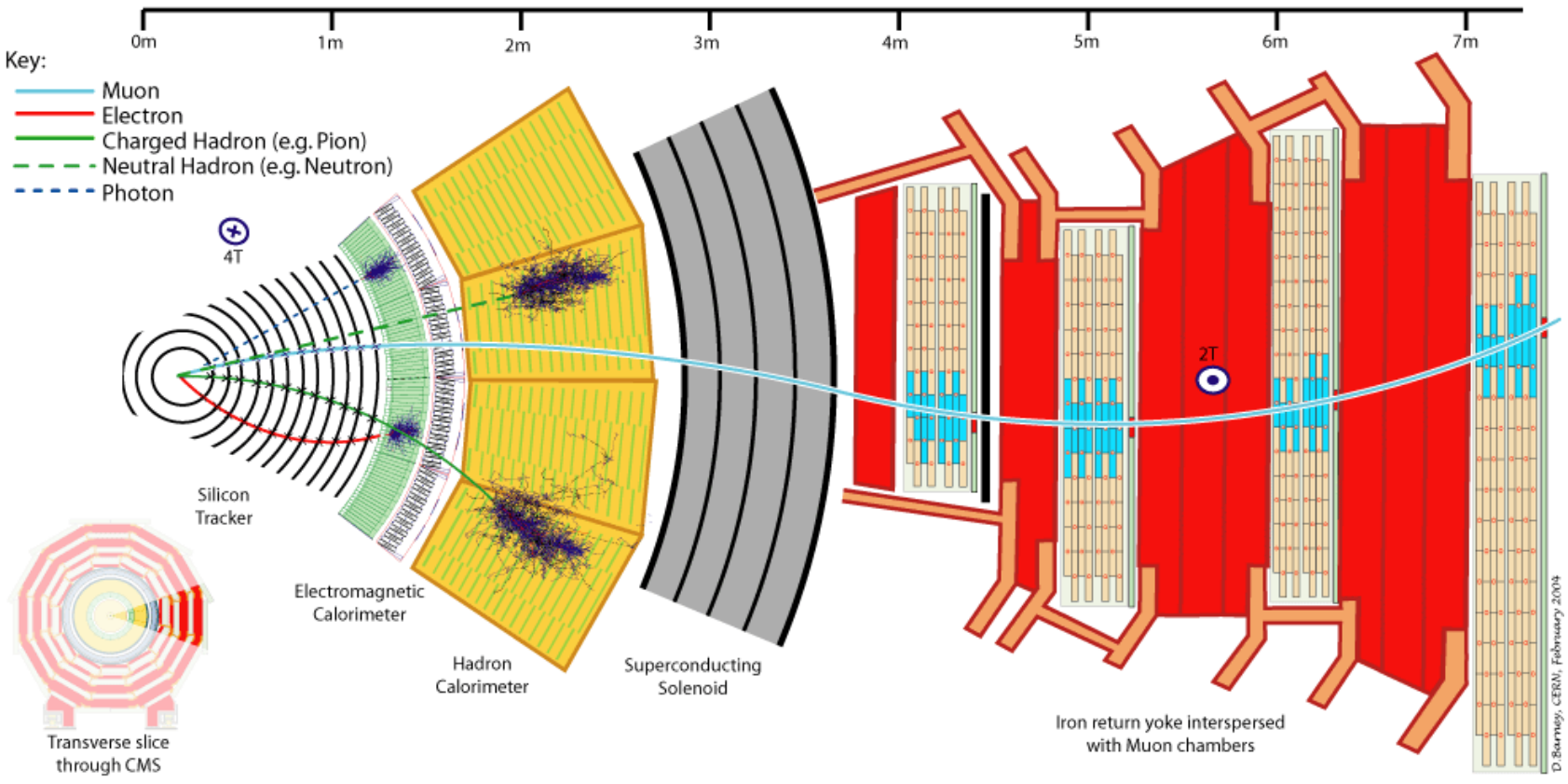


Outline of this talk

1. CMS detector
2. Standard Model: rediscovery, service measurements, and new modes
3. Brief note on SUSY
4. Di-object signature searches: e^+e^-, $\mu^+\mu^-$, jet-jet, jet-$\not\!\!E_{\rm T}$, ...
5. Heavy, long-lived particles and other models

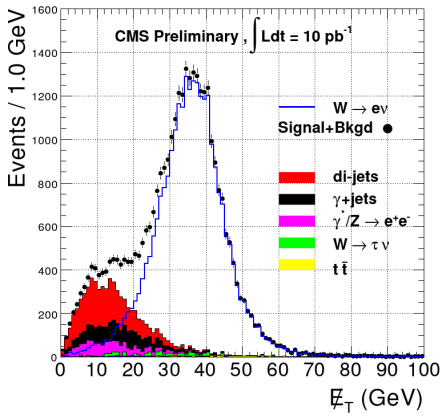
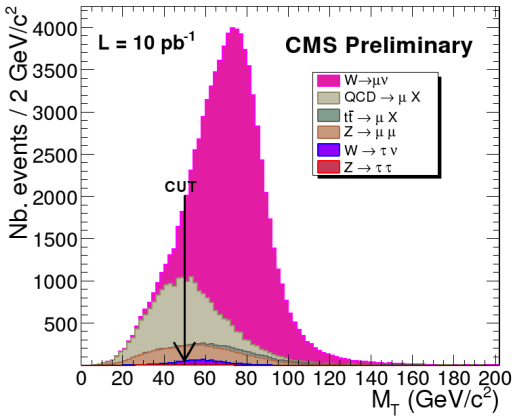
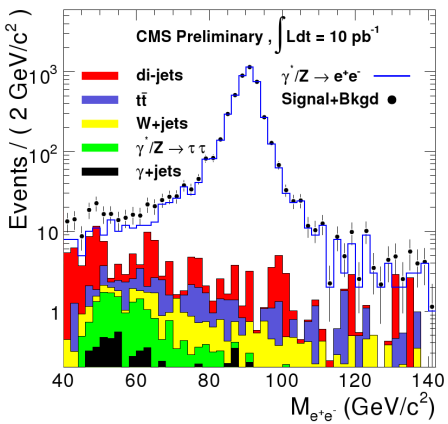
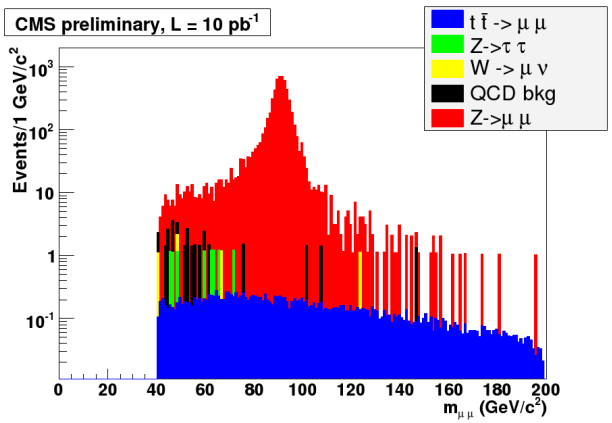
CMS detector

- Nearly 4π general-purpose detector
- All-silicon tracker
- Solenoidal magnetic field
- Highly-redundant muon tracking system (44 muon layers in barrel)



Rediscovering the Standard Model

- Signals and backgrounds at 10 pb^{-1}

	$e^{\pm}\nu$ or e^+e^-	$\mu^{\pm}\nu$ or $\mu^+\mu^-$
$W^{\pm}$	 missing transverse energy	 transverse mass
Z^0	 e^+e^- mass	 $\mu^+\mu^-$ mass

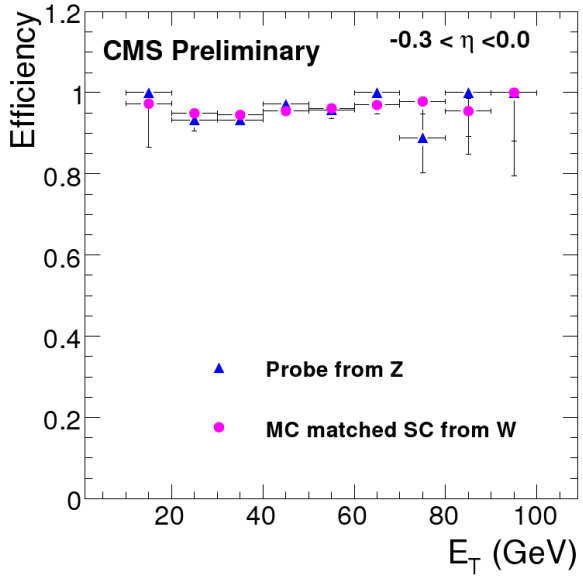
- Top quarks observable with 10–100 pb^{-1} (see Oliver's talk)

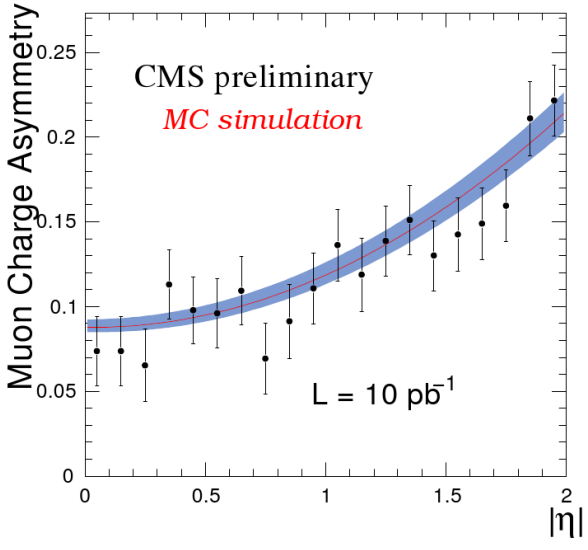
Using the SM for future discoveries

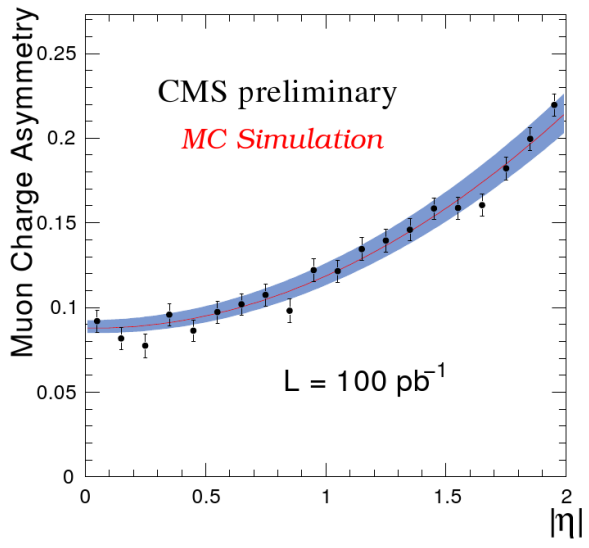
- Determine electron and muon efficiencies by tagging one leg of a $Z \to \ell\ell$, probing the other (right)
- $W^{\pm}$ charge asymmetry (below)

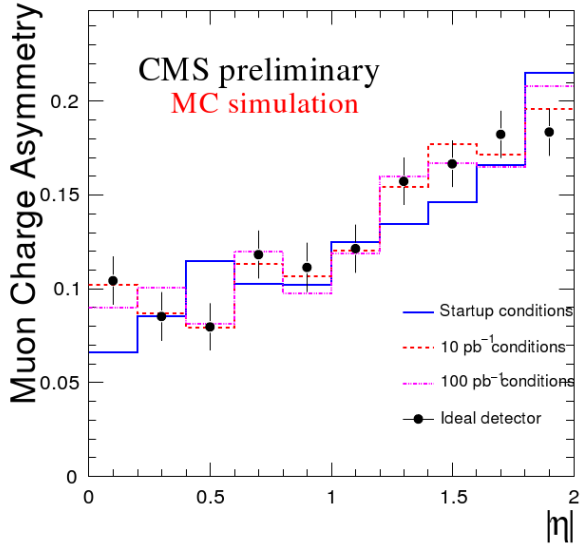
$$A(\eta) = \frac{(d\sigma/d\eta)(W^+) - (d\sigma/d\eta)(W^-)}{(d\sigma/d\eta)(W^+) + (d\sigma/d\eta)(W^-)}$$

  - probes u/d PDFs for other analyses
  - depends only on detector issues that are currently being studied with real data in cosmic ray asymmetry

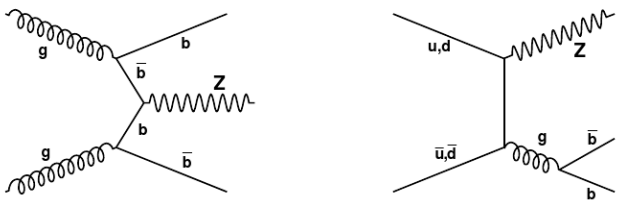




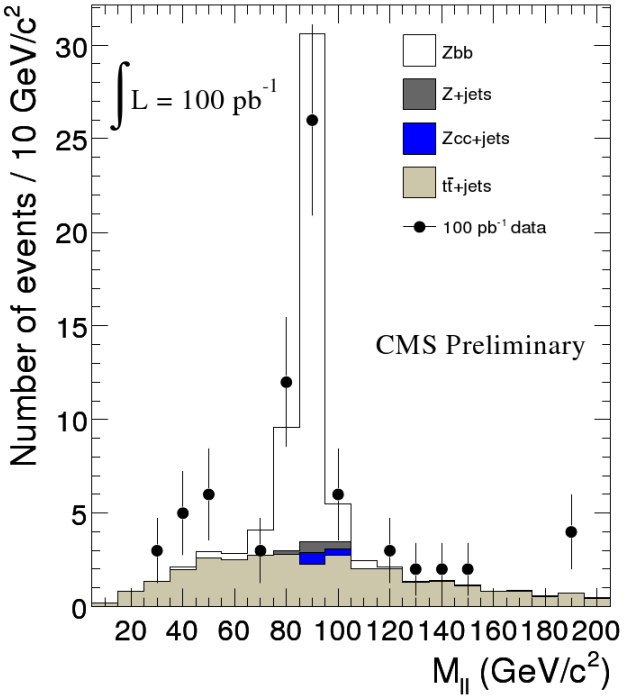


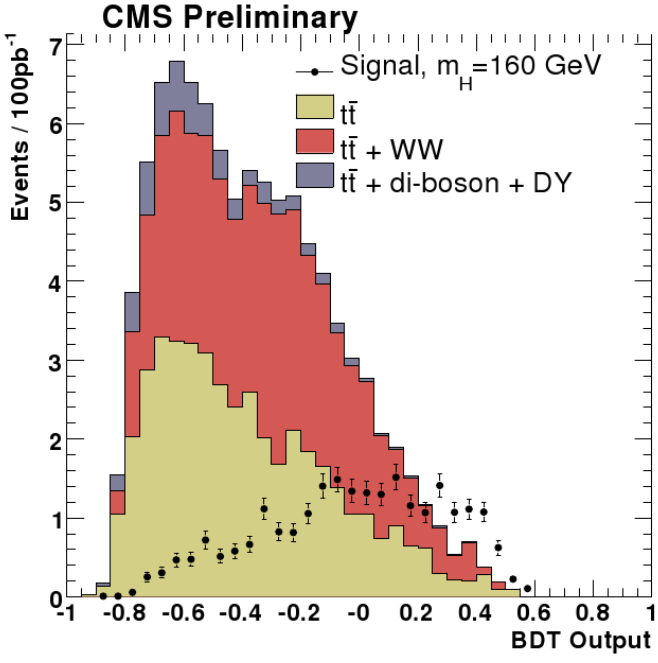


Discoveries in the Standard Model



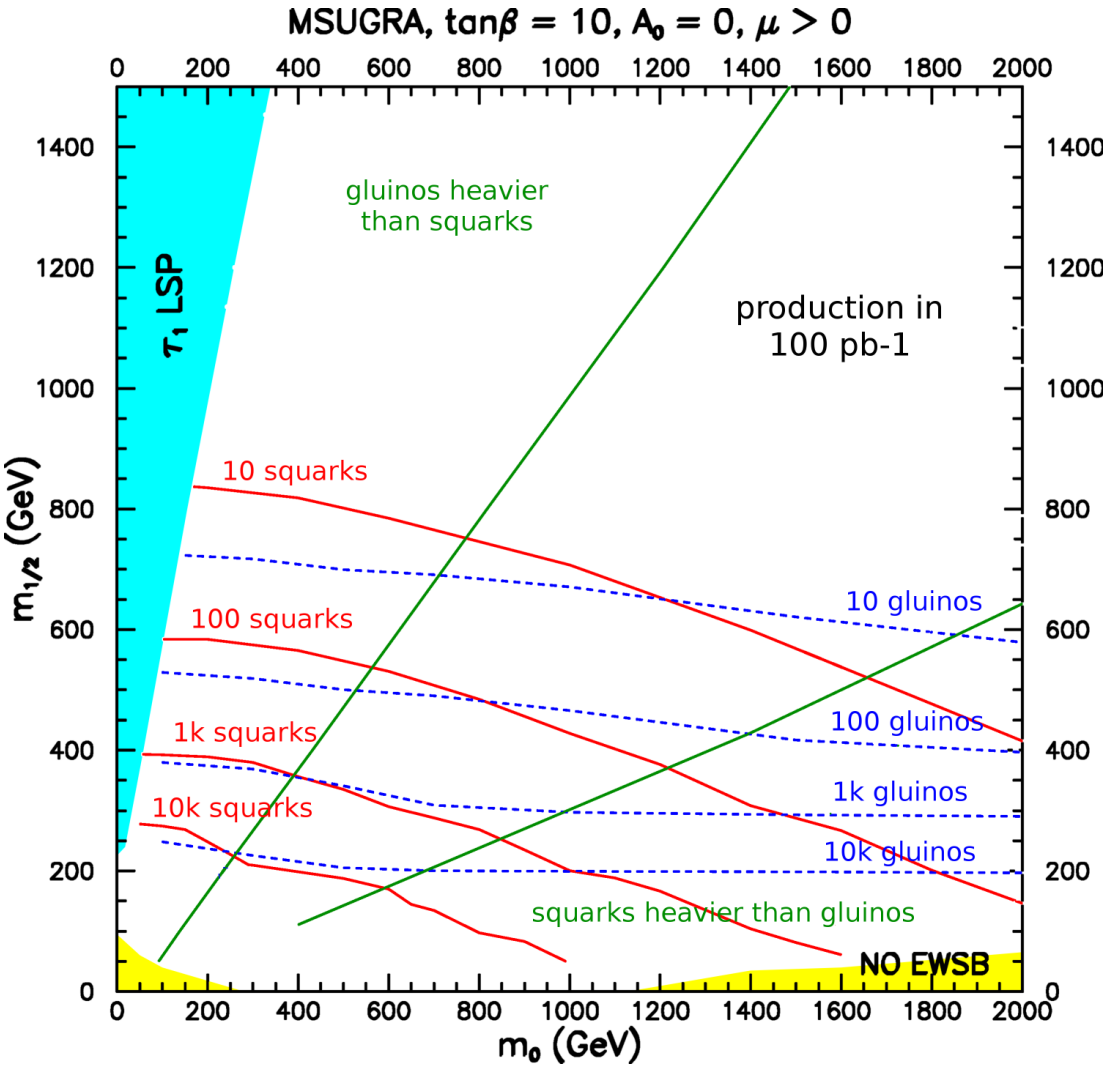
- $Zb\bar{b}$ and ~~di-bosons~~ (re-discovery):
  - background for Higgs searches $H \to ZZ \to 4\mu$, SUSY $H \to 2\tau(\mu)$





- Higgs boson? Even a heavy Higgs?
  - $H \to ZZ$ sensitivity starts at 3 fb^{-1} (for 95% C.L. in $200 < M_H < 400$ GeV)
  - $H \to WW$ has ~10 signal, ~10 background events at 100 pb^{-1} with a boosted decision tree analysis
  - comparable to Tevatron's reach

SUSY at 100 pb^{-1} (briefly)



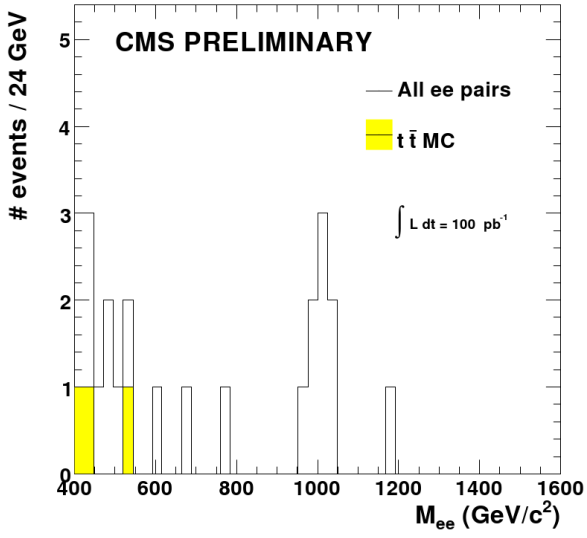
- From the Physics TDR (which focuses on 1 fb^{-1} and above)
- See Oliver and Anwar's talks for more details on SUSY modes

Di-object signature searches

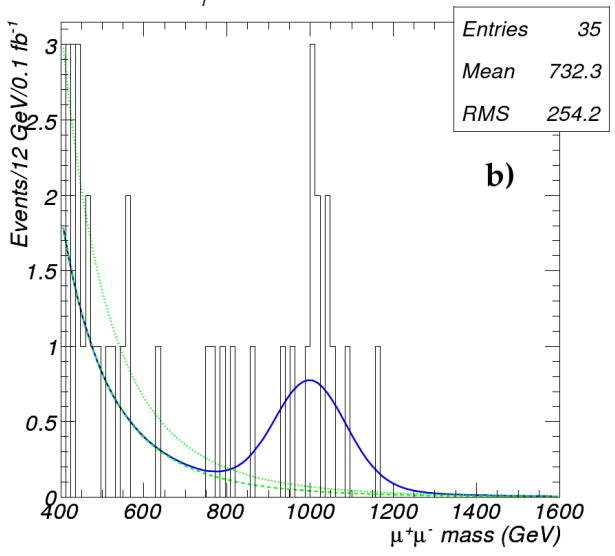
- Look for a (high) mass peak or enhancement in inclusive X-Y pairs, where X and Y are reconstructed "physics objects" like $e^{\pm}$, jet, $\not{E}_{\mathrm{T}}$
- Between a specific-model hunt and completely generic search
  - physics motivation is strong but loosely-specified:
    - di-muon: electroweak couples to leptons, easiest to identify
    - di-electron: electroweak couples to leptons, high-resolution calorimetry at high energy
    - di-jets: new physics may be strongly interacting, high statistics
    - jet-$\not{E}_{\mathrm{T}}$: dark matter shows up as missing energy
    - $t\bar{t}$: new physics will likely be coupled to the third generation *(demands new techniques because W and b jets overlap in boosted tops)*
    - di-tau: new physics will likely be coupled to the third generation
    - $\gamma\gamma$: easy way to identify spin-2 parent
  - small set of simply defined channels (good for low statistics)
- Also help to commission the reconstruction of physics objects for more sophisticated analyses

Di-electrons/muons: Z', RS-1 G^*

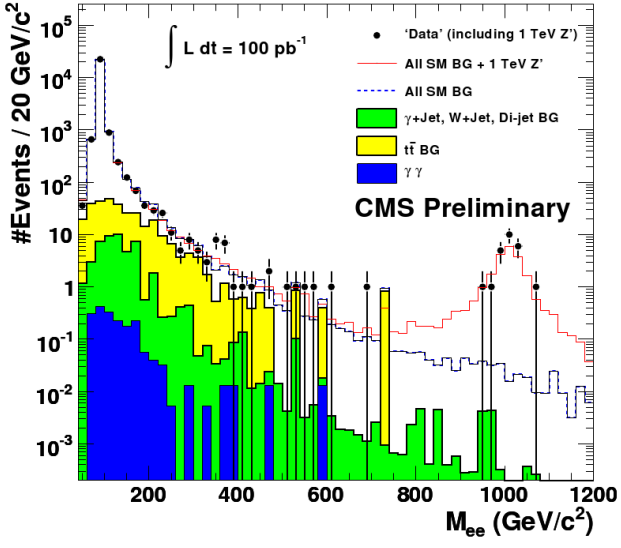
$Z'_\psi \to e^+e^-$

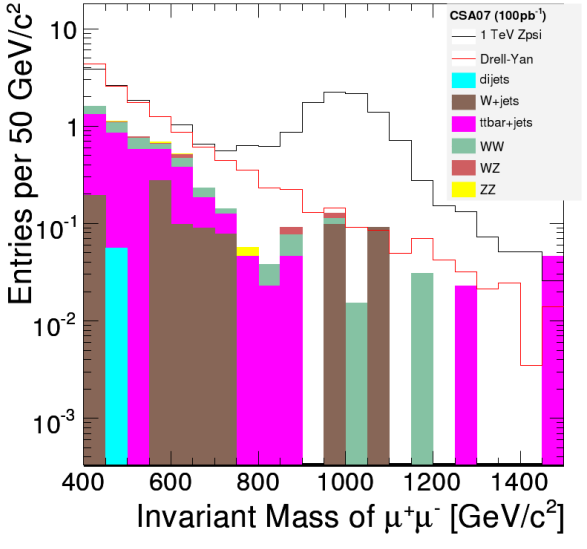


$Z'_\psi \to \mu^+\mu^-$



- Easiest-to-identify signature of new self-adjoint bosons (and therefore a very early analysis)
- Long lever arm in muon tracking system helps to resolve straight tracks and high redundancy helps to distinguish delta rays from TeV muon showering

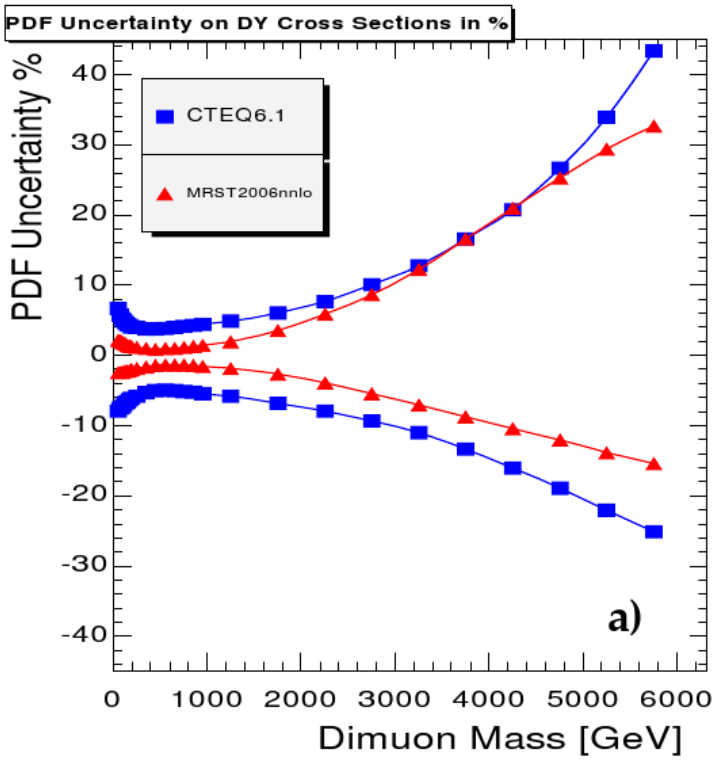




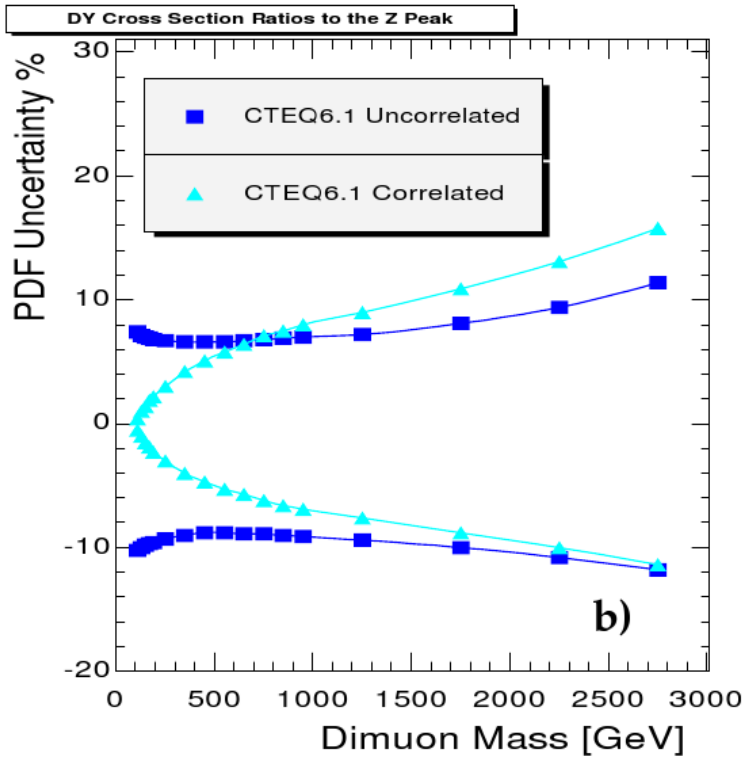
Di-electrons/muons: Z', RS-1 G^*

- Measuring cross-section relative to Z^0 reduces systematic uncertainties:
  - integrated luminosity will only be known to 10–20% in early data
  - PDF uncertainties from $q\bar{q}$ initial states are reduced in the ratio

absolute PDF uncertainty



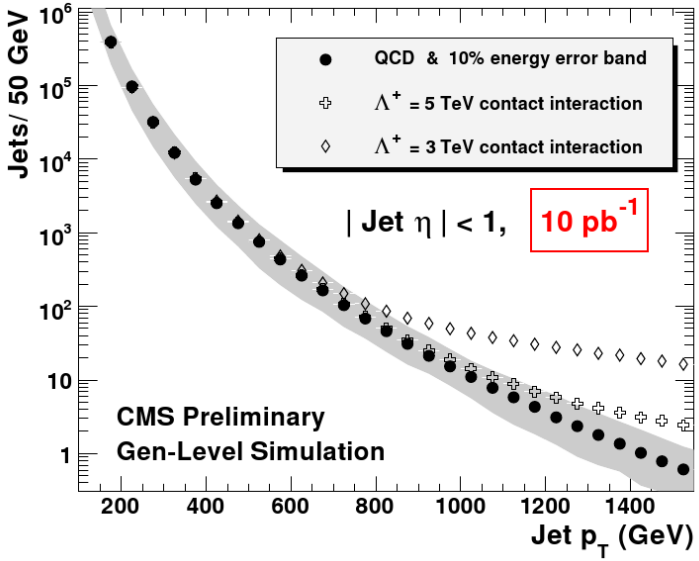
PDF uncertainty relative to Z^0

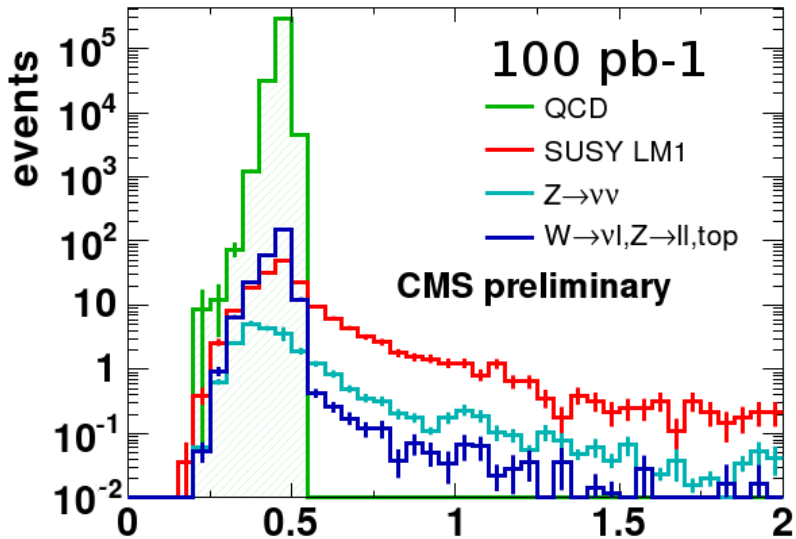


- 95% C.L. upper limit on an unobserved Z_ψ cross-section
  $\approx \left(10\text{–}30 \times 10^{-6}\right) \times Z^0$ cross-section

Di-jets: contact interactions, q^*, SUSY

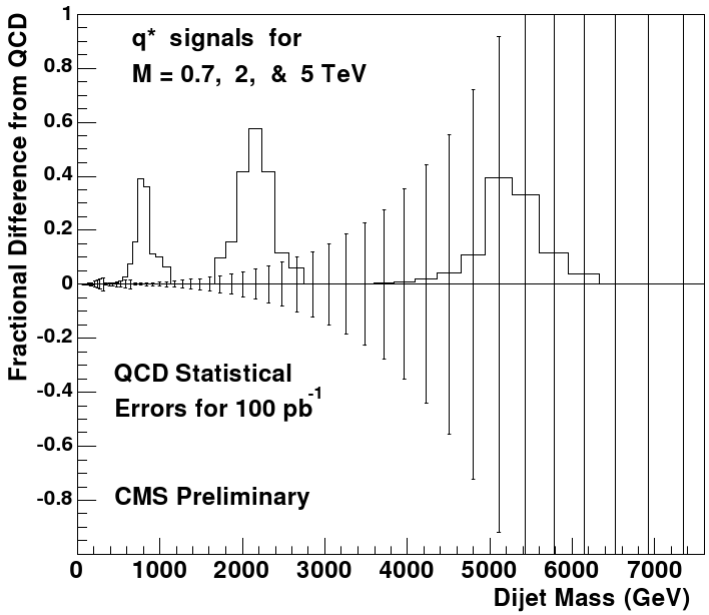
- Enhanced production at high mass (for central $|\eta|$): contact interactions
- Resonance peaks: excited quarks (q^*), new bosons Z', RS-1 G^*
- Angular correlation: direct-decay SUSY e.g. $\tilde{q}\tilde{q} \to q\chi_1^0\, q\chi_1^0$





$\alpha_T = E_T(\text{jet 2})/M_{\text{transverse inv}}(\text{jets 1\&2})$

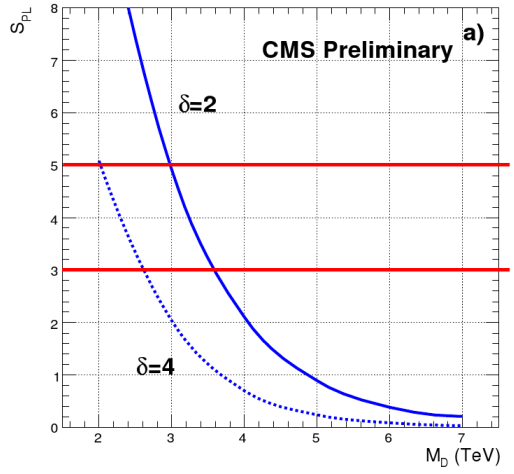
(L. Randall and D. Tucker-Smith arXiv:0806.1049)

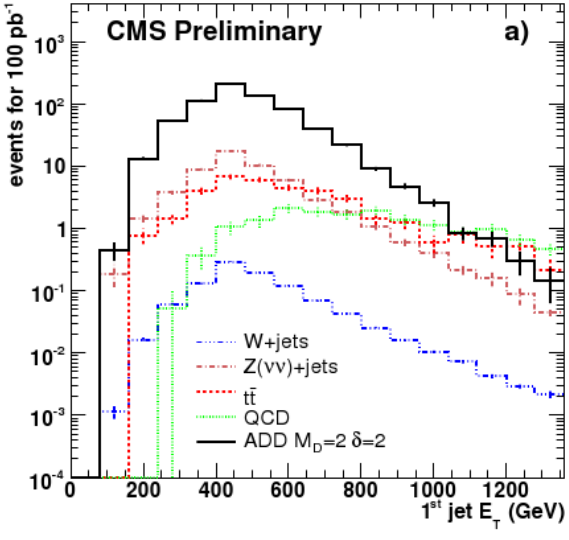


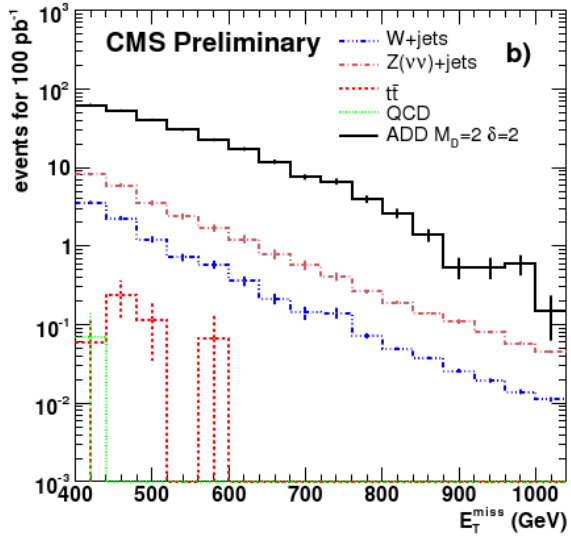
$\not\!\!E_T$ + 1 or more jets: ADD gravitons

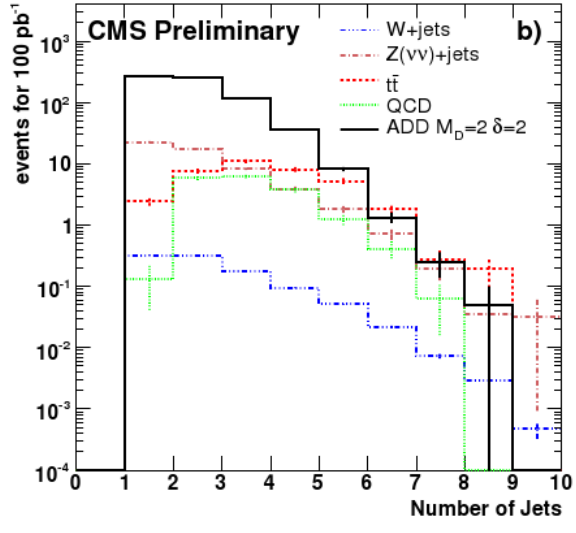
- Simple signature: $\not\!\!E_T$ + 1 jet is the missing energy analogue of a di-object search
- Application: if extra dimensions lower the Plank mass to the TeV scale, real gravitons would be emitted in quark/gluon collisions (ADD model and variations)
- Optimistic case in 100 pb^{-1} pictured below: number of dimensions $\delta = 2$ compactification scale $M_D = 2$ TeV

Significance in 100 pb^{-1}
3 is 99.6% C.L.
5 is a 5σ discovery









$\not\!\!E_T$ commissioning (optional slide)

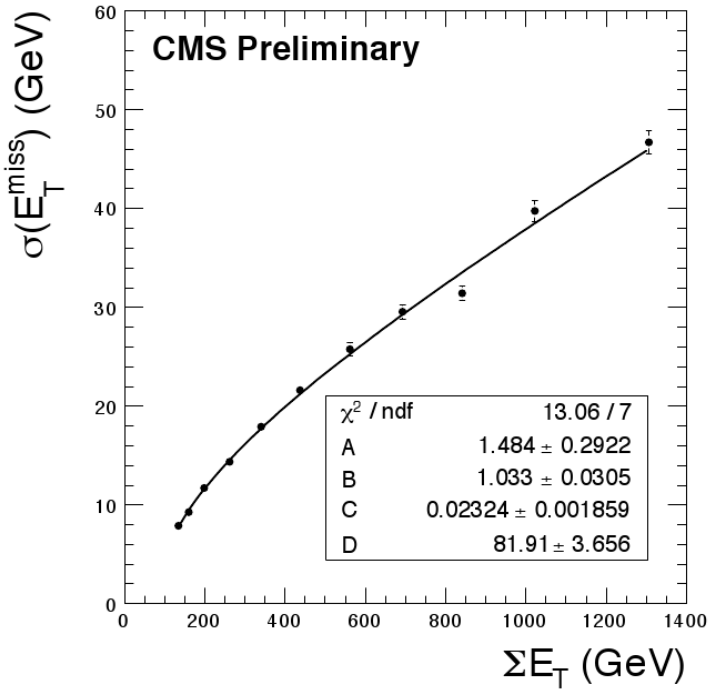
- Missing energy is a physics object commissioned in simple signatures, to be used later in dark matter searches
- Decomposition of $\not\!\!E_T$ resolution (top plot)

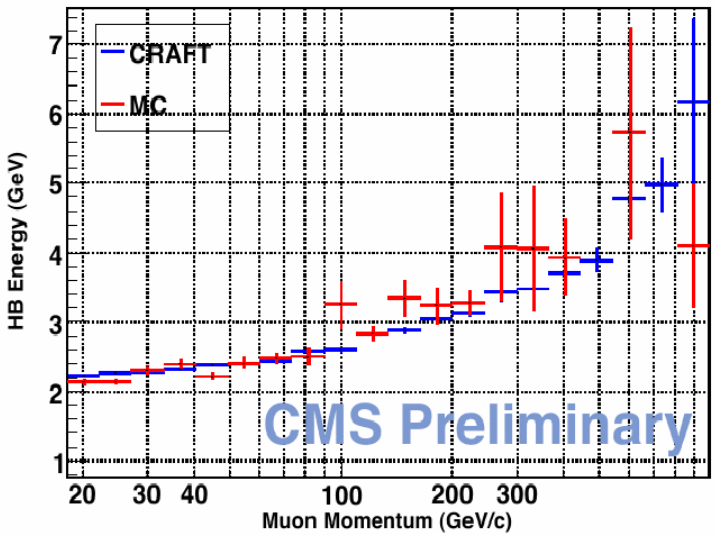
$$\sigma(\not\!\!E_T) = A \oplus B\sqrt{\sum \not\!\!E_T - D} \oplus C(\sum \not\!\!E_T - D)$$

  A. electronic noise, pile-up, underlying event
  B. statistical sampling in calorimeter towers
  C. non-linearities, cracks, dead material
  D. effect of noise, etc. on $\sum \not\!\!E_T$

where $\not\!\!E_T$ = |vector missing momentum|
and $\sum \not\!\!E_T$ = the scalar sum

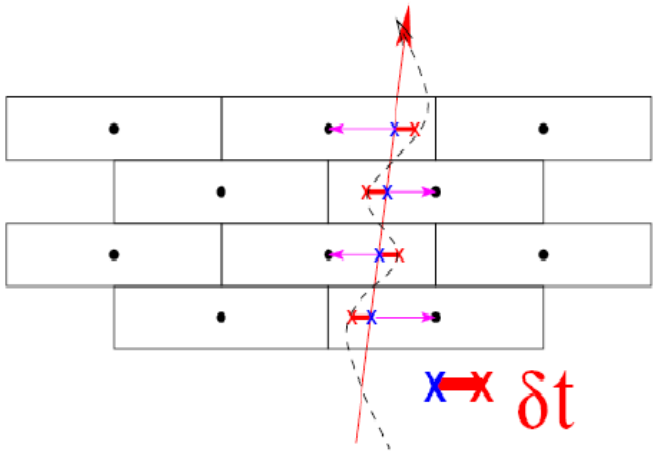
- Snapshot from real data: response of calorimeter towers to muons, a $\not\!\!E_T$ correction, as seen in cosmic rays (bottom plot)
- See James Lamb and Paolo Rumerio's talks for more





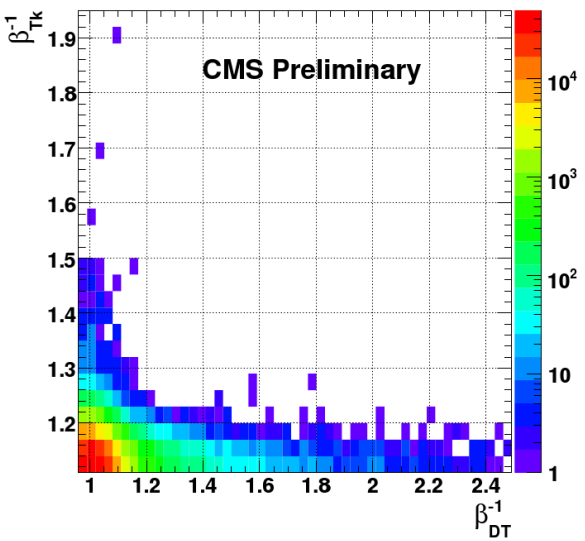
Heavy, long-lived charged particles

- New particles might be charged and live long enough to be detected (split SUSY, part of WIMP sector...)
- Unusual detector signature: would look like a muon with the wrong timing in the CMS drift tubes (top figure) and low-velocity dE/dx in silicon tracker

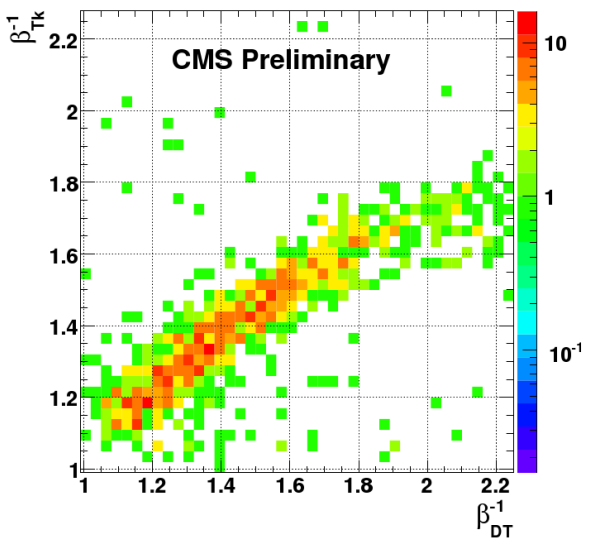


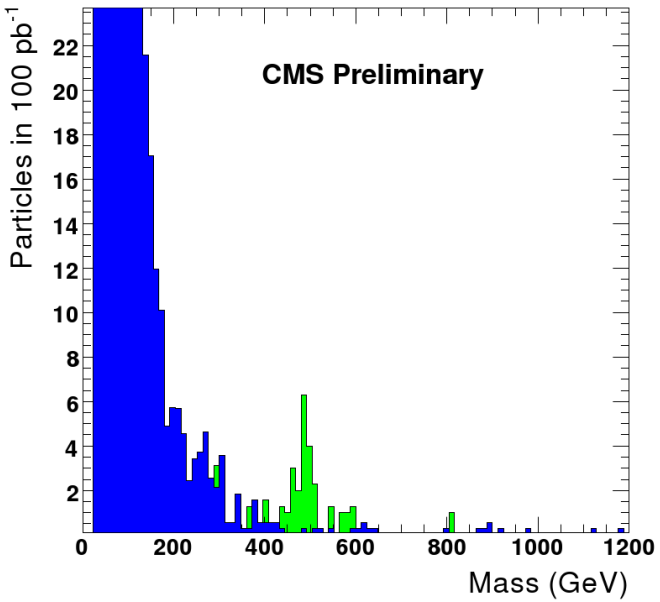
- Requiring a correlation yields low backgrounds at high mass: 500 GeV stop from split SUSY with 100 pb^{-1} shown at bottom-right

background



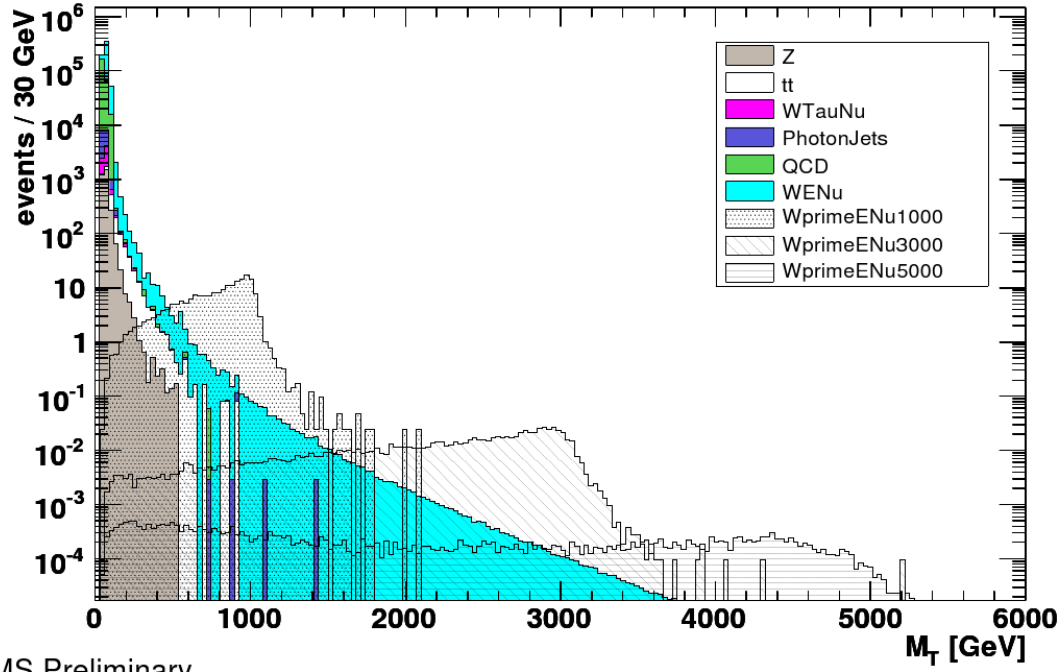
signal





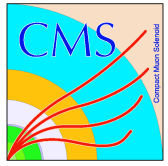
Other new results

- $W' \to e\nu$ (plot at right)
  - enlarged gauge groups usually predict a new W' as well as Z'
  - can also be thought of as an $e+\not{E}_{\mathrm{T}}$ di-object search
- $b'b' \to WWWW\,bb$
  - 1–4 leptons + 2 b-jets
  - 100 pb^{-1} 95% exclusion at the few-pb level up to $M_{b'} = 480$ GeV (well below predicted cross-section for these masses)



- Heavy Majorana neutrino $\to \ell W_R$ with $W_R \to$ jet jet
  - signature 1: dijet mass peak + 2 leptons (produced through W_R)
  - signature 2: dijet mass peak + 1 lepton (produced through Z_R)
- Model Unspecific Search in CMS (MUSiC)
  - 300–400 combinations of e, μ, γ, jet, $\not{E}_{\mathrm{T}}$

Conclusions



- With 100 pb^{-1}, we can do more than "rediscover the Standard Model"
- Di-object searches are a simple way to address broad classes of new physics with small statistics, and at the same time improve our understanding of the detector response
- Understanding the detector with real data will be key to all analyses, early and long-term
- Trigger and pattern recognition are also being made sensitive to unusual detector signatures like long-lived charged particles, *R*-hadrons that stop in the calorimeter or cavern, etc.
- Not everything was included in this talk, I hoped to highlight those analyses which can be performed with low statistics

References (external hyperlinks)

Page	Reference
4	EWK-08-005 *Measurement of the W and Z cross section with electrons*
	EWK-07-002 *Measurement of the W and Z cross section with electrons*
5	EGM-07-001 *Measuring Electron Efficiencies with Early Data*
	EWK-08-002 *W charge asymmetry*
6	EWK-08-001 *Measurement of Z boson production in association with two b-jets*
	From Figure 3.5 (page 54) CMS-TDR-008-2 *CMS Physics TDR: Vol. II*
	HIG-07-001 *Higgs to WW*
7	Relabeling of CMS-TDR-008-2 Figure 13.1 (page 405) for 100 pb^{-1} production
9	EXO-08-001 *Search for* $Z' \to ee$
	SBM-07-002 *Search for* $Z' \to \mu\mu$
10	*Ibid.*
	Pavel Nadolsky *CTEQ PDF developments* at PDF4LHC Workshop, Feb 22, 2008
11	SBM-07-001 *Searches for New Physics using high ET dijet events*
	SUS-08-005 *SUSY search with dijet events* (relabeled for 100 pb^{-1})
12	EXO-08-011 *Search for extra dimensions with monojets*
13	JME-07-001 *Performance of missing ET reconstruction*
	Approved DPG Commissioning Results (internal CMS)
14	EXO-08-003 *Search for Heavy Stable Charged Particles*
15	EXO-08-004 *Search for* $W' \to e\nu$
	EXO-08-009 *Search for a* b'
	CMS NOTE 2006/098 *Heavy Majorana* ν *and right-handed bosons* (internal CMS)
	EXO-08-005 *MUSiC— deviations between data and Monte Carlo simulation*

See https://twiki.cern.ch/twiki/bin/view/CMS/PhysicsResults for more