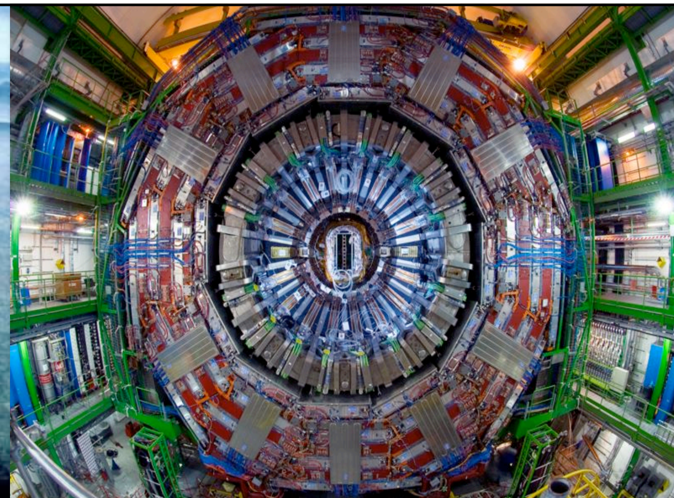

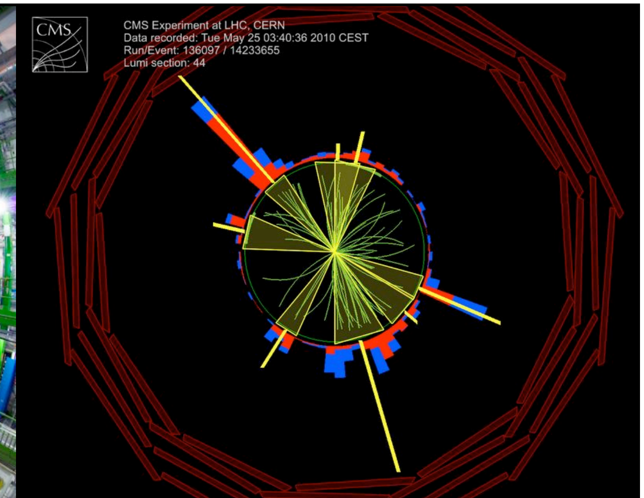

Search for New Physics with Mono-Jet and Missing Transverse Energy in 7 TeV pp collisions at CMS

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on behalf of the CMS collaboration

Division of Particle and Fields 2011: Brown University, RI, USA

Outline

- **Introduction**

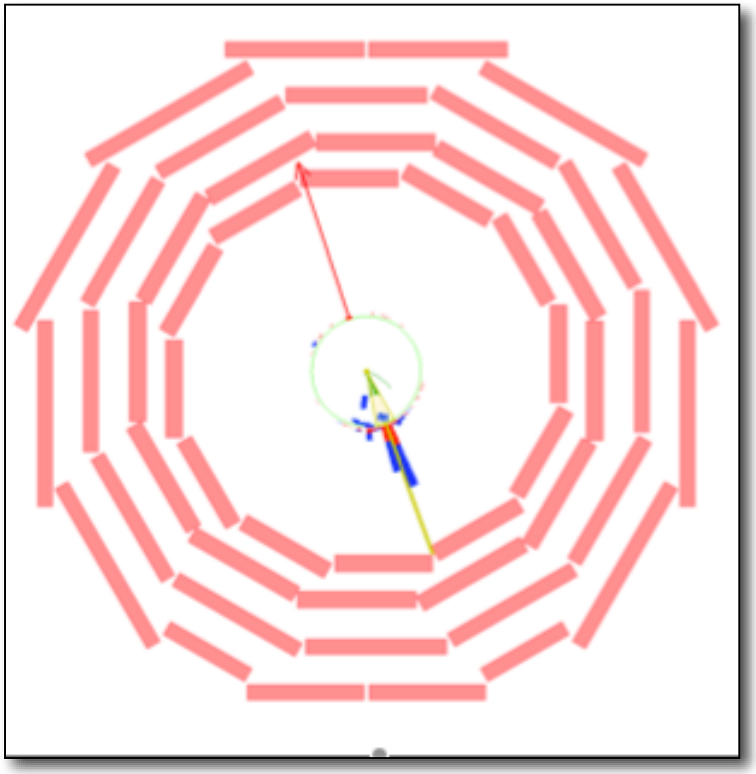
- Motivation : Large Extra Dimensions

- signatures of LED

- **Overview of mono-jet analysis**
- **Data-driven background estimation**
- **Results**
- **Interpretation**

The Signature

- signature : one energetic jet and large missing energy (Met)
- model-independent topology based search
- multitude of new physics scenarios with same signature



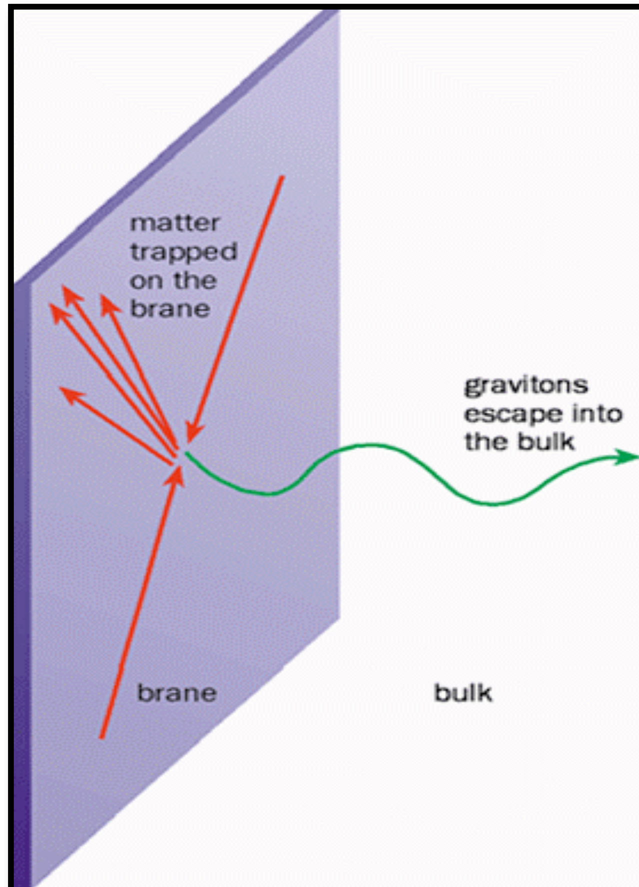
Motivation: Why is gravity so weak?

Force	Particle	Relative strength
Strong	gluon	1
Electromagnetic	photon	10^{-2}
Weak	W^+, W^- and Z	10^{-13}
Gravity	Graviton(?)	10^{-38}

- Gravity is weakest of Standard Model forces.
- Ignore gravity at particle level, many many orders of magnitude smaller than other interactions
- Effects of gravity only becomes important at Planck scale (10^{19} GeV)
- **Hierarchy problem : Why is the electroweak scale so different from Planck scale?**

Motivation: Large Extra Dimensions

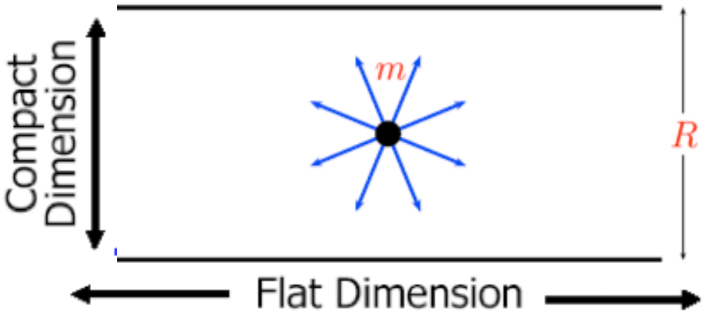
- Large Extra Dimensions proposed as solution for hierarchy problem in late 1990s
- ADD model proposed by Arkani-Hamed, Dimopoulos and Divali
- Phys. Lett. B. 429 (1998) 263
- introduce *n* extra spatial dimensions
- All SM particles confined to our brane
- Gravitons free to propagate in bulk
- gravitational force diluted, appears to be weak



Gravity in Large Extra Dimensions

- Suppose n extra compact spatial dimensions of radius R
- Apply Gauss's law in (4+n) dimensions, gravitational potential between 2 test masses m_1 and m_2 separated by distance r << R:

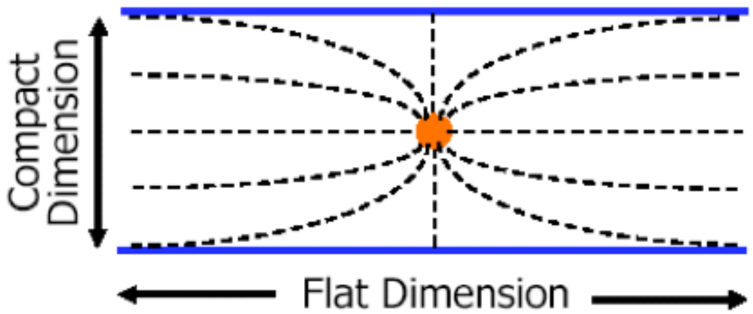
M_D = fundamental Planck scale



$$V(r) \sim \frac{m_1 \times m_2}{M_D^{n+2}} \frac{1}{r^{n+1}}, (r \ll R)$$

- If test masses are separated by r >> R:

$$V(r) \sim \frac{m_1 \times m_2}{M_D^{n+2} R^n} \frac{1}{r}, (r \gg R)$$



- Compared to Newtonian potential:

$$M_{Pl}^2 \sim M_D^{n+2} R^n$$

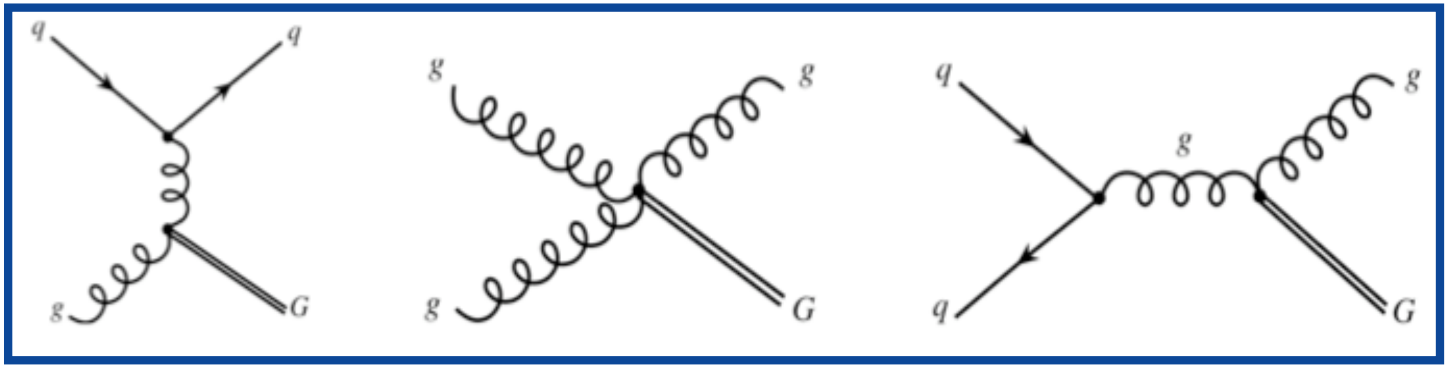
Signatures of Large Extra Dimensions

Setting $M_D \sim 1$ TeV:

For n=1, R ~ 10^{12}m →excluded!

For n =2, R < 10^{-2} cm →same order as direct probes of gravity

For n =6,7, R ~1 fm → only testable at colliders



- Real and virtual production of gravitons
- virtual graviton exchange → signature : di-photon, di-lepton
- direct graviton production $q\bar{q} \to gG$, $qg \to qG$, $gg \to gG$, real graviton emitted in final state → signature: jet +met

Limits on Large Extra Dimensions

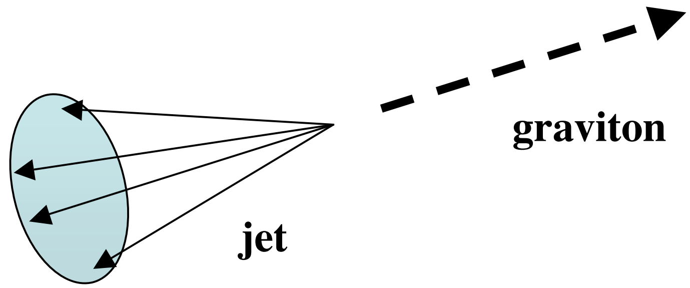
Extra dimensions (n)	Limit on M_D (TeV)		
	D0	CDF	LEP
2	0.921	1.4	1.6
3	0.877	1.15	1.2
4	0.848	1.04	0.94

Measurement strategy

Strategy

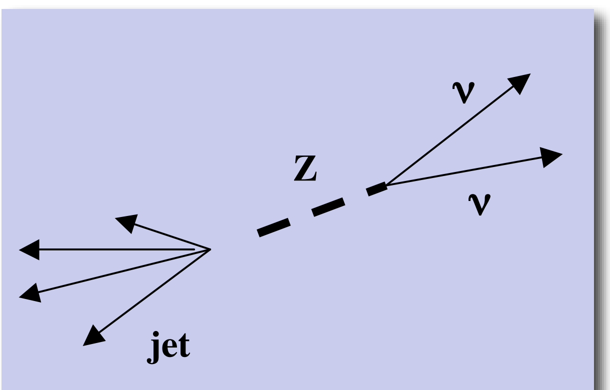
- search for excess above SM
- understanding of backgrounds crucial

Signal

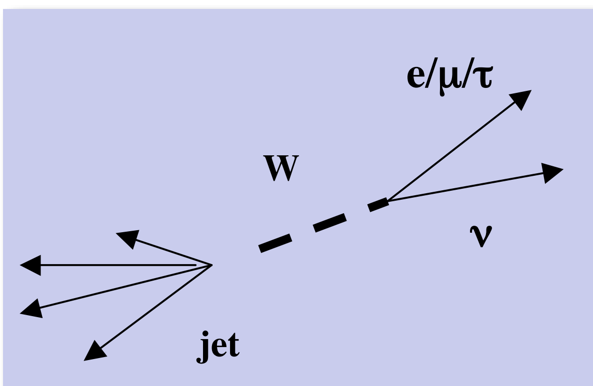


Backgrounds

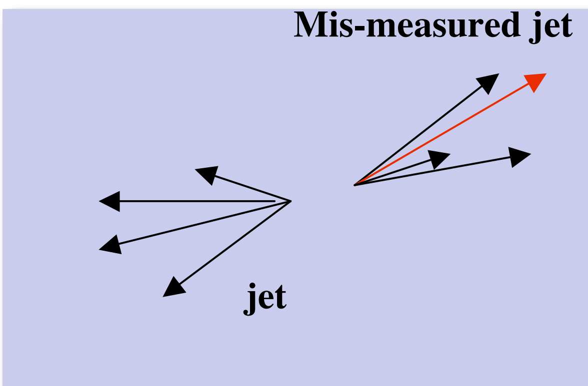
Z→νν +jet, irreducible background, looks just like signal



W+jets, lepton is lost



QCD, jet is mismeasured, producing Met.



Monojet Selection

Select topology

•Use events collected using jet and Met triggers

• one energetic jet, $p_T > 110$ GeV, $|\eta| < 2.4$

• allow one additional jet with $p_T > 30$ GeV

• veto additional jets ($N_{jets} < 3$)

• large missing energy, Met > 150 GeV

Reject background

• QCD

- $\Delta\phi(j1,j2) < 2$

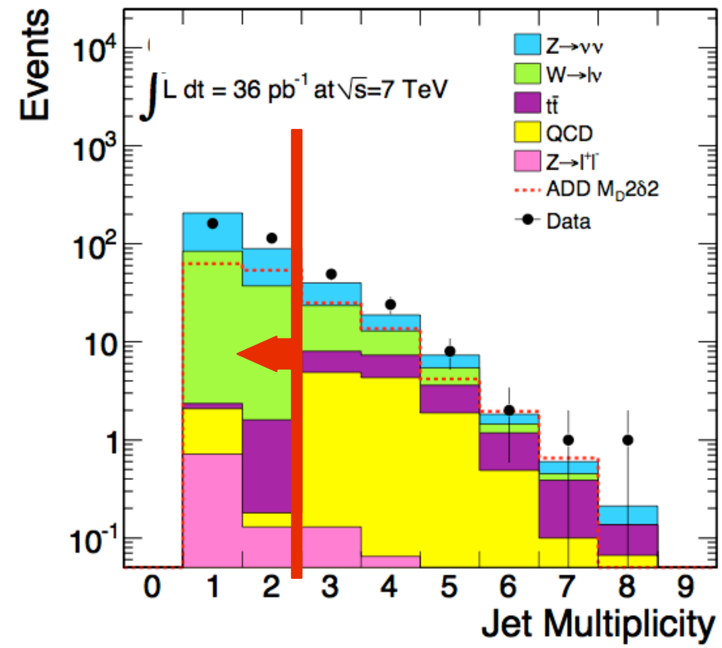
-remove events with back to back jets

• EWK

-lepton veto

-reject events with isolated electrons, muons

-veto events with isolated tracks, removes taus.



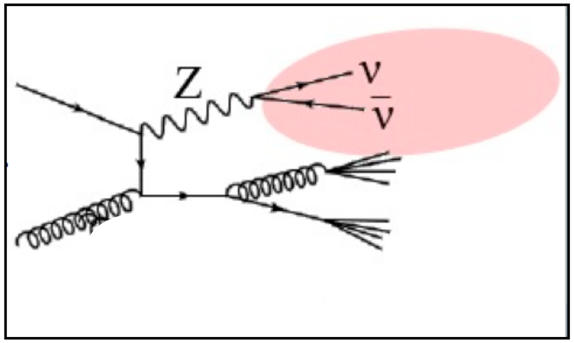
After full selection, largest backgrounds:

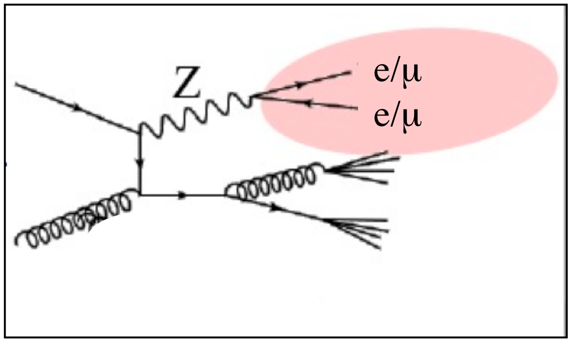
• Z→νν +jet, accounts for ~2/3

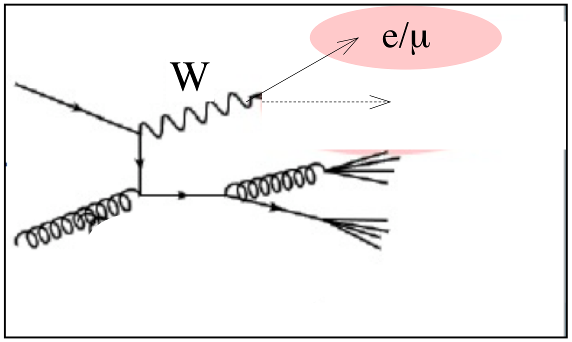
• W+jets, ~1/3

• QCD, ttbar : small.

Estimation of invisible Z background from Z→ll and W→lν







- exploit similar kinematic characteristics of Z→νν, Z→ll and W→lν
- remove leptons from event, interpret as missing energy to model Met in Z→νν events
- potentially 4 statistically independent estimates of background
- Results from muon channel shown, comparable results from electron channel (not discussed here).

Estimation of invisible Z background from $Z \to ll$ and $W \to l\nu$

$Z \to \nu\nu$ from $Z \to ll$

~ 6

$$N(Z \to \nu\nu) = \frac{N_Z^{obs} - N_Z^{bgd}}{A_Z \bullet \varepsilon_Z} \bullet R\left(\frac{Z \to \nu\nu}{Z \to ll}\right)$$

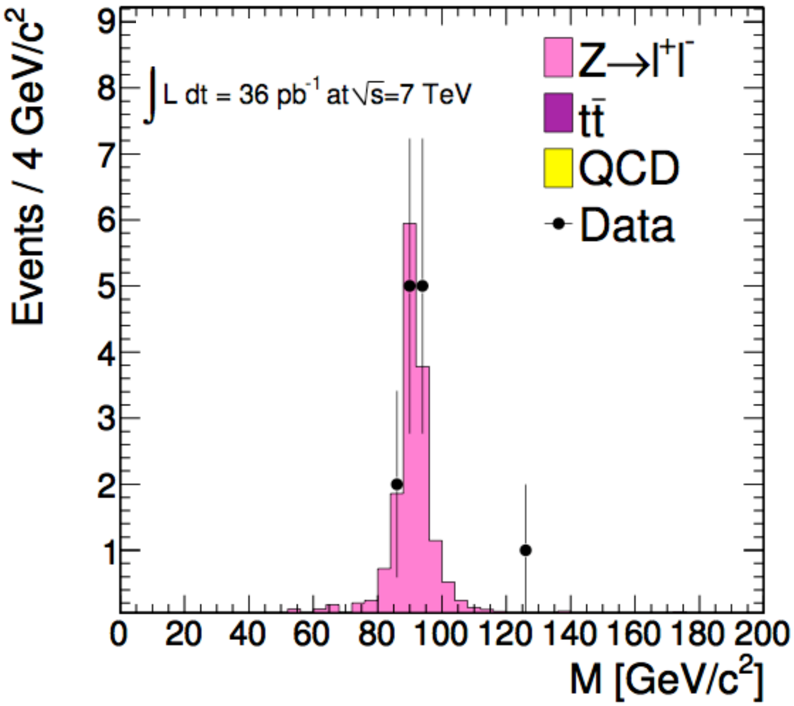
- use same dataset (Jet/Met) as signal region
- select 2 well reconstructed and isolated muons with; $p_T > 20$, $|\eta| < 2.1$, opposite sign charge
- dimuon mass 81-101 GeV
- apply search selection with Met defined as vector sum of p_T of muons
- correct for acceptance and reconstruction efficiencies
- negligible background
- take R from theory

$Z \to \nu\nu$ from $W \to l\nu$

$$N(Z \to \nu\nu) = \frac{N_W^{obs} - N_W^{bgd}}{A_W \bullet \varepsilon_W} \bullet R\left(\frac{Z \to \nu\nu}{W \to l\nu}\right)$$

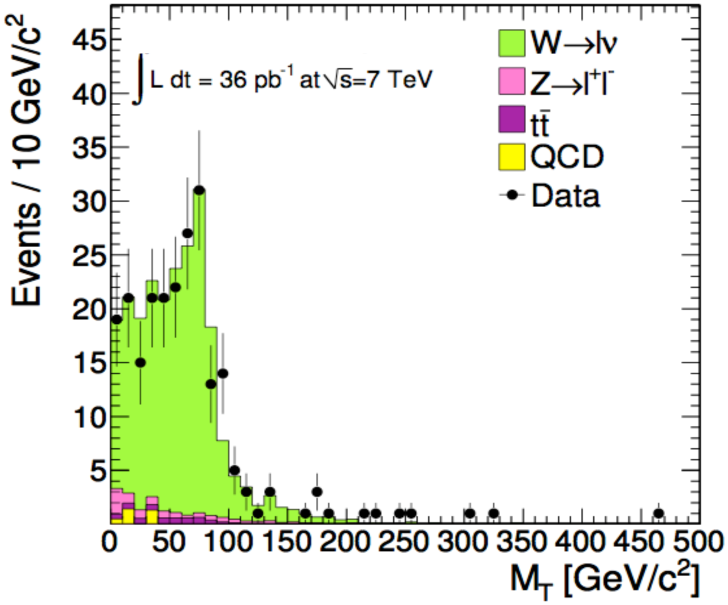
- use same dataset (Jet/Met) as signal region
- select 1 well reconstructed and isolated muon with; $p_T > 20$, $|\eta| < 2.1$
- transverse mass (M_T) 50 - 100 GeV
- apply search selection with Met defined as vector sum of Met and muon
- correct for acceptance and reconstruction efficiencies
- correct for background
- take R from theory, correct for the difference in p_T spectra of bosons at high p_T

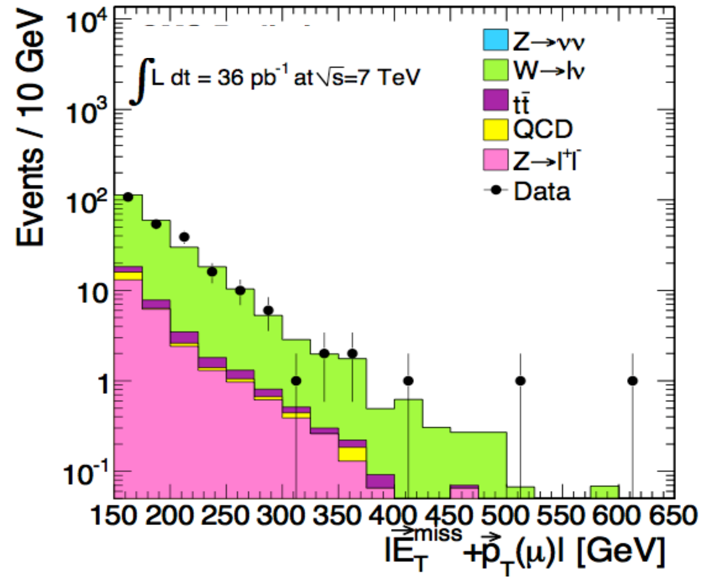
Estimation of invisible Z background from Z→μμ



- 13 Z→μμ events passing selection
- negligible background
- statistically limited
- Z→νν prediction : 162 ± 45

Estimation of invisible Z background from W→μν

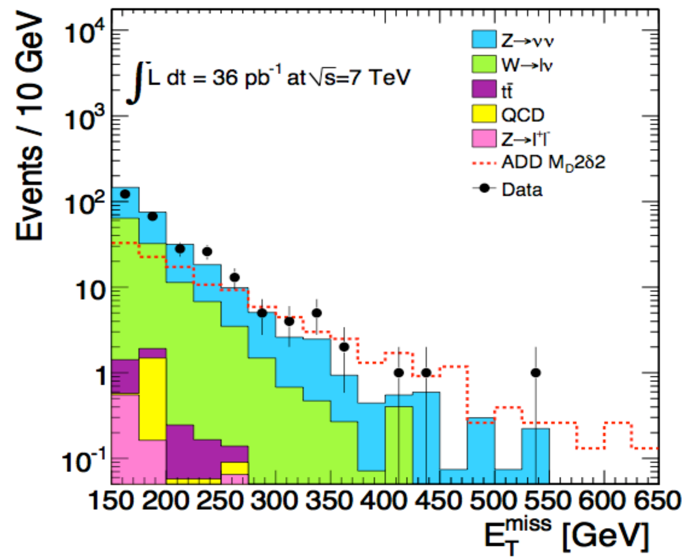


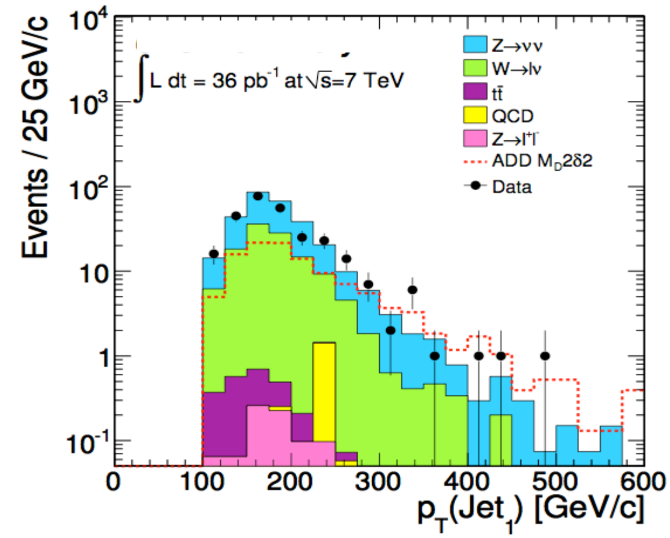


- 113 events in data passing W→μν selection
- shape and yield obtained in data consistent with MC
- background contribution small, use MC for correction, ~ 8%
- correct for acceptance and reconstruction efficiency, 0.42.
- Ratio of Z→νν and W→μν taken from theory, correct for difference in W/Z p_T spectra.
- Z→νν prediction : 176 ± 30, consistent with estimation from Z→μμ
- use data/MC ratio of this sample to predict W+jets background to search selection

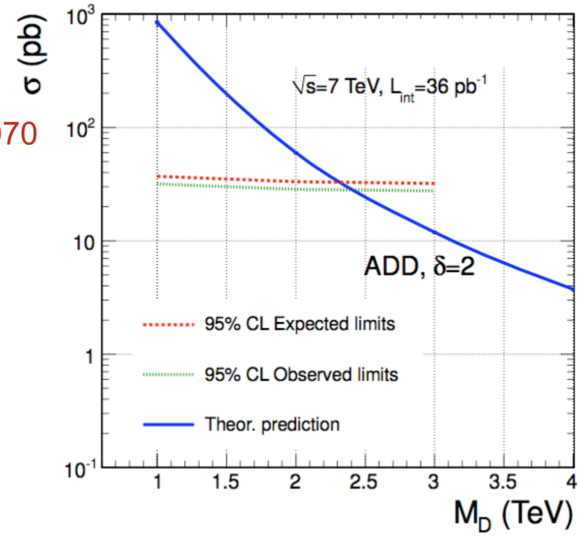
Background	Yields
Z→νν+jets	176
W+jets	117
Z+jets	0.8
$t\bar{t}$	1.7
QCD	1.4
Predicted	297 ± 45
Observed	275

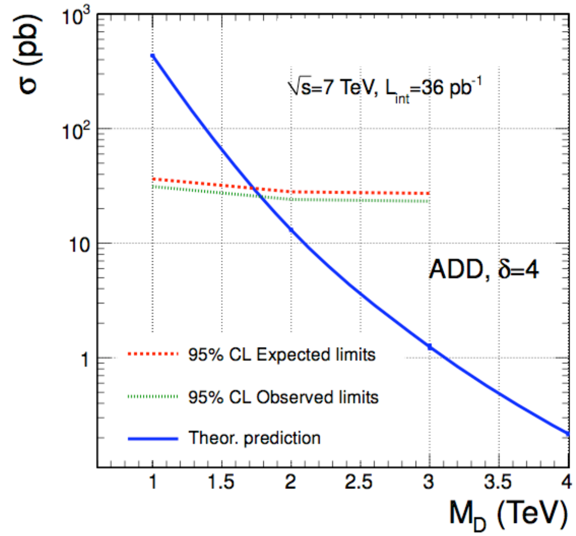
- No excess of events observed
- Set limits





arXiv:1106.4775v1
CMS-EXO-11-003
CERN-PH-EP-2011-070

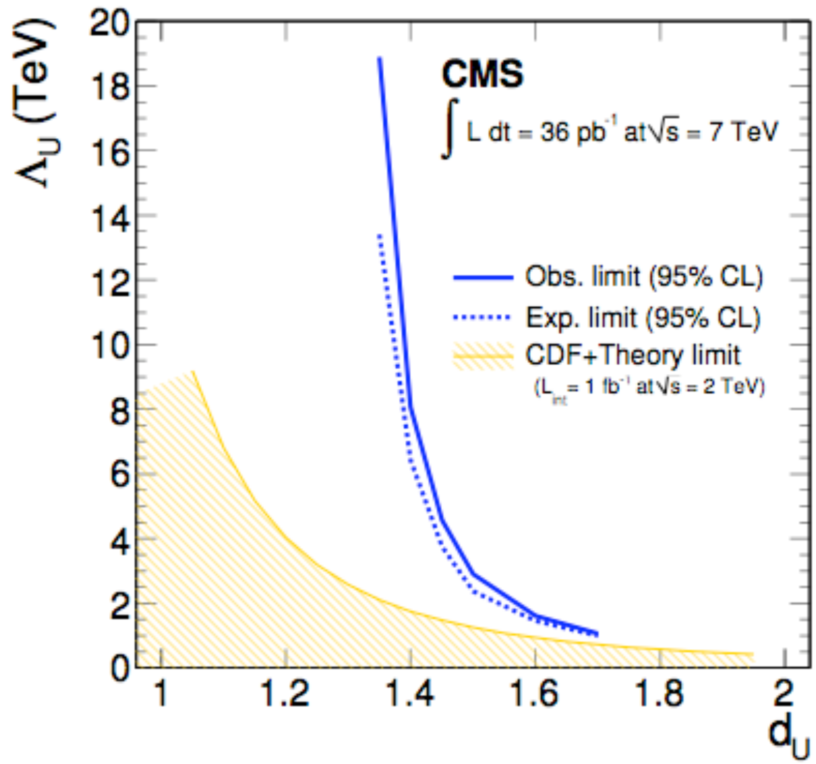




Extra dimensions (n)	Limit on M_D (TeV)		
	CDF	LEP	CMS monojet
2	1.4	1.6	2.29
3	1.15	1.2	1.92
4	1.04	0.94	1.74
5	0.99	0.77	1.65
6	0.95	0.66	1.59

Significant improvement over limits from LEP and Tevatron

- physics originating from a scale invariant sector, coupled to SM through a connector sector at a high mass scale.
- H.Georgi, “Unparticle Physics”, Phys. Rev. Lett. 98 (2007) 221601
- spectrum of invisible, massless and weakly interacting particles
- same signature as ADD
- For unparticles with spin= 0, production cross-sections above 54 pb excluded at 95% confidence level for $d_U = 1.7$ and $\Lambda_U = 1$ TeV
- significant improvement over previous limits



Conclusion

- Searched for new physics in the final state containing one or two hadronic jets and large missing energy using 36 pb^{-1}
- generic search, can be used to constrain many models
- data-driven estimation for dominant backgrounds
- Results consistent with SM predictions, no excess observed
- Limits placed on Large Extra Dimensions model ADD (and Unparticles)
- Significant improvement over limits from LEP and Tevatron
- Much more data on tape, results soon…

BACKUP SLIDES

LHC Limits on ADD

CMS - 36pb^{-1}

δ	K factor	LO Exp.	LO Obs.	NLO Exp.	NLO Obs.
2	1.5	2.17	2.29	2.41	2.56
3	1.5	1.82	1.92	1.99	2.07
4	1.4	1.67	1.74	1.78	1.86
5	1.4	1.59	1.65	1.68	1.74
6	1.4	1.54	1.59	1.62	1.68

ATLAS- 1fb^{-1}

	95% CL limits on M_D for the ADD model	
	HighPt selection	
n	expected [TeV]	observed [TeV]
2	2.98	3.16
3	2.44	2.56
4	2.18	2.27
5	2.03	2.10
6	1.92	1.99

Extra dimensions (n)	Limit on M_D (TeV)		
	CMS (36pb^{-1})	ATLAS (36pb^{-1})	ATLAS (1fb^{-1})
2	2.29	2.3	3.16
3	1.92	2.0	2.56
4	1.74	1.8	2.27
5	1.65	-	2.10
6	1.59	-	1.99

Systematic uncertainties

Signal	Acceptance	JES	PDF
ADD	0.3-2.2%	3-7%	1-2%
Unparticles	0.6-2.9%	7.5-11.5%	3-7%