Isfahan University of Technology

Institute for Research in Fundamental Sciences
School of Particles and Accelerators

Search for extra dimensions (ADD) in di-lepton final state

IPMLHC2013: Second IPM Meeting on LHC Physics, 7-12 Oct 2013

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On be half of CMS collaboration

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Overview

- ✓ ADD Model
- ✓ Electron and Muon selections
- ✓ E-μ method for FS backgrounds.
- ✓ Jet estimation using fake rate
- ✓ Di-lepton Mass Spectrum
- ✓ PDF & other uncertainties
- ✓ Cut optimization
- ✓ Limit calculation
- ✓ Limit interpretation
- ✓ Conclusion

SM weaknesses

✓ ***Hierarchy problem.***

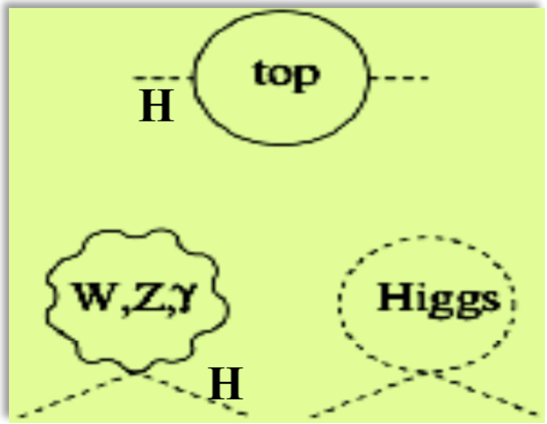
Too many free parameters

Flavor / Family problems and fermion masses problem

Neutrinos mass and oscillations

Dark matter

…



$$\boxed{\Delta m_H^2 = -\frac{y_f^2}{8\pi^2}[2\Lambda^2 + 6m_f^2 \ln(\Lambda/m_f) + ...]}$$

the mass of the Higgs diverges quadratically .

if we suppose that the SM remains valid up to the Planck scale, then Λ = M_{Pl} **and this correction is 10^{30} times** bigger than the reasonable value of the mass-squared of the Higgs, namely $(100GeV)^2$

Major theoretical arguments that motivated the search for extra dimensions.

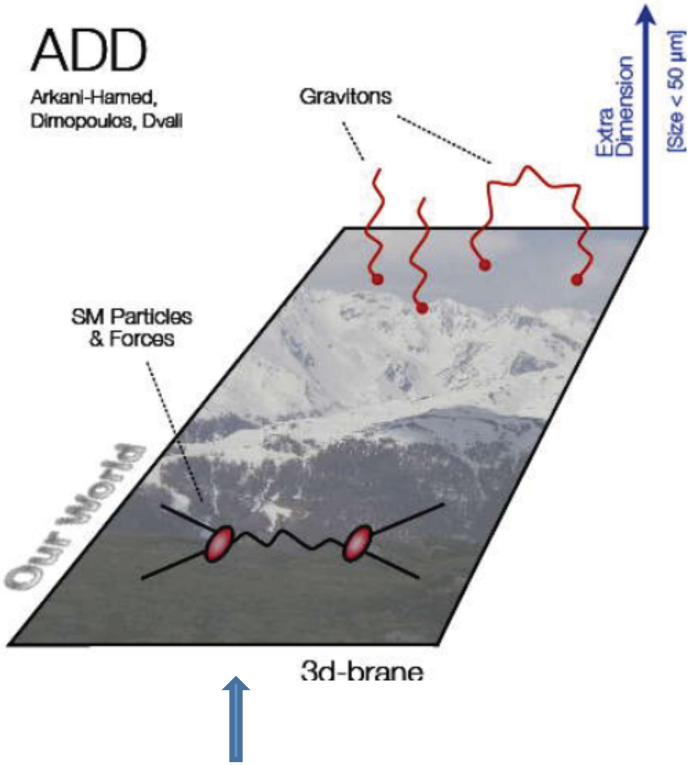
- ✧ Unification of gravity and gauge interactions of elementary particles.
- ✧ Quantization of gravitational interactions.
- ✧ Higgs mass hierarchy problem.
- ✧ Cosmological constant problem.

Extra Dimensions

The original proposal to use Extra Dimension to solve the hierarchy problem without rely on either super- symmetry or Technicolor was proposed by **Arkani-Hamed, Dimopoulos, and Dvali** (**ADD**)

Phys. Lett. B 429 (1998) 263

A scenario whereby the SM is constrained to the the common 3 + 1 space-time dimensions, while gravity is free to propagate through the entire multidimensional space ("bulk").
the gravitational force is effectively diluted, having undergone a Gauss's Law reduction in the flux.



The SM(4-dimension) has been tested up Up to few hundred GeV consistent with Experimental Data so SM fields can not Propagate into the ED .

The fundamental Planck scale, M_D *is therefore related to the apparent (3-dimensional) scale,* M_{Pl} .

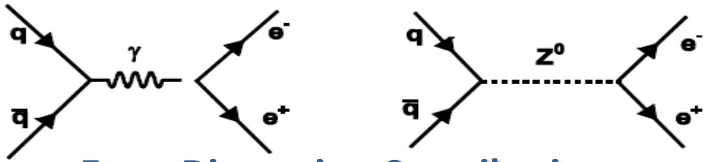
$$M_D^{(n_{\rm ED}+2)} \sim \frac{M_{\rm Pl}^2}{R^{n_{\rm ED}}}$$

-To solve the Hierarchy Problem: $M_D \sim M_{EW}$

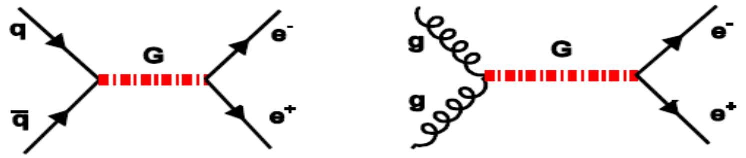
Virtual Graviton Exchange

One of the observable effect is due to a virtual graviton acting as a propagator in Drell-Yan like processes, which result in production of a fermion pair in the final state.

Standard Model

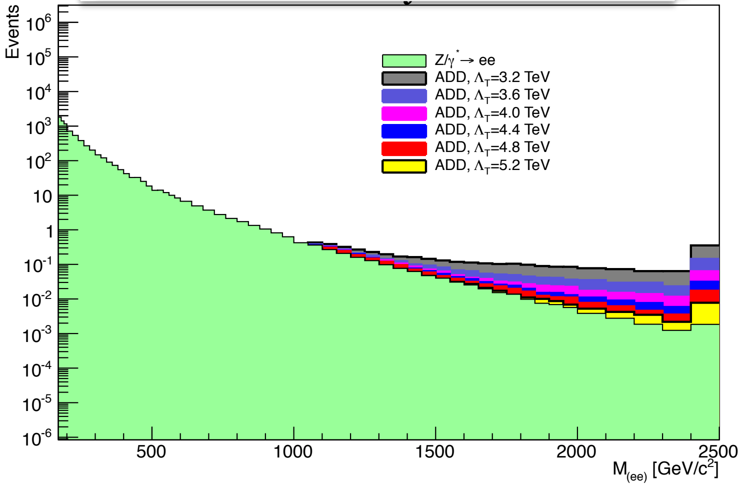


Extra Dimension Contributions



the graviton-induced diagram interferes with the analogous SM diagrams and results in an enhancement of the invariant mass spectrum of the diboson or difermion system, particularly at high masses, where the number of KK excitations contributing to this process is large.

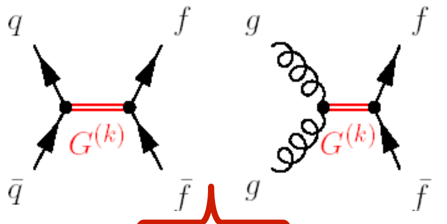
$$\sigma(n_{ED}, M_S) = \sigma_{SM} + A\eta\sigma_{\text{int}} + B\eta^2\sigma_{ED}$$



The gap between the adjacent kk modes is very small and we expect a non-resonant enhancement in the invariant mass spectrum of the di-lepton system, particularly at high masses.

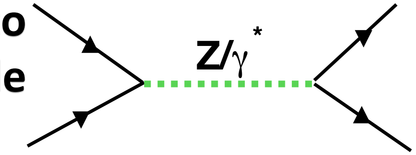
Cross Section and Parameter Conventions

- ❑For virtual graviton processes, the effects of ED are parameterized .
- ❑*Several conventions for F are* used in the literatures.
- ❑HLZ is the only one that has an explicit dependence on the number of ED.



$$\sigma_{total} = \underbrace{\sigma_{DY}} + \underbrace{A \times \eta \sigma_{int}} + \overbrace{B \times \eta^2 \sigma_{ED}}$$

Parameterization of the cross section due to existence of extra dimensions with single Parameter η in the different conventions.



HLZ	$\eta = F/M_s^4$	$F = \begin{cases} \log\left(\frac{M_s^2}{s}\right), & n_{ED} = 2 \\ \frac{2}{n_{ED}-2}, & n_{ED} > 2 \end{cases}$
GRW	$\eta = \dfrac{1}{\Lambda_T^4}$	$\Lambda_T^4 = \dfrac{8\pi\Gamma\left(n_{\mathrm{ED}}/2\right) M_D^{n_{\mathrm{ED}}+2}}{2\pi^{n_{\mathrm{ED}}/2} c_1 \Lambda^{n_{\mathrm{ED}}-2}}$

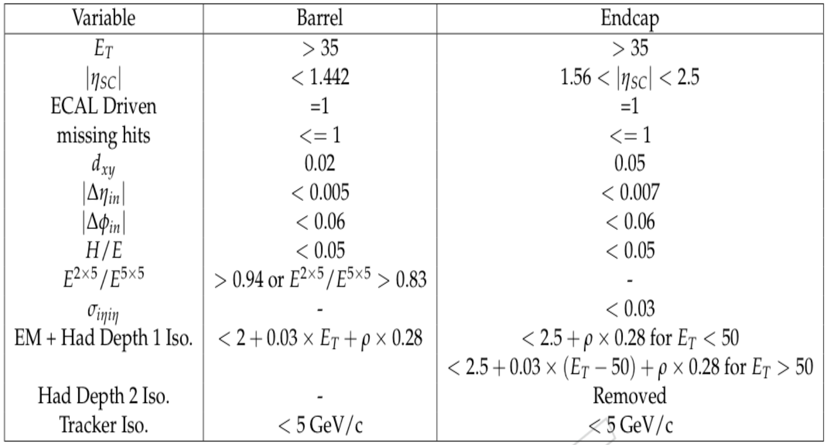
Phys.Rev.D59, 105006 (1999)

$$\boxed{\Lambda_T^4 = \frac{n_{\mathrm{ED}}-2}{2} M^4_{s,\mathrm{HLZ}}}$$

Nucl. Phys.B544, 3 (1999)

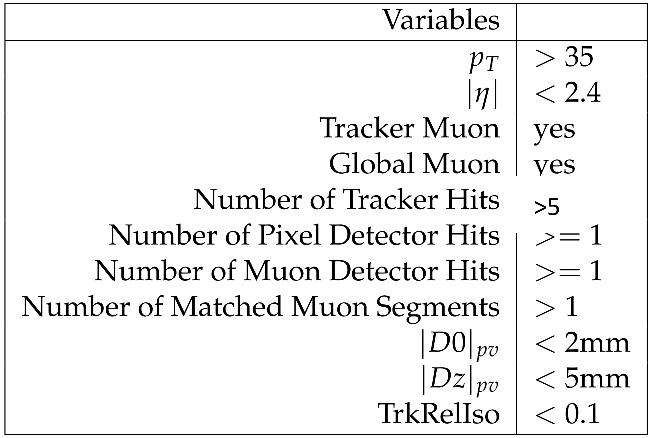
Electron and Muon Selection

Electron selection:



Variable	Barrel	Endcap
E_T	> 35	> 35
$\lvert\eta_{SC}\rvert$	< 1.442	$1.56 < \lvert\eta_{SC}\rvert < 2.5$
ECAL Driven	=1	=1
missing hits	$<= 1$	$<= 1$
d_{xy}	0.02	0.05
$\lvert\Delta\eta_{in}\rvert$	< 0.005	< 0.007
$\lvert\Delta\phi_{in}\rvert$	< 0.06	< 0.06
H/E	< 0.05	< 0.05
$E^{2\times5}/E^{5\times5}$	> 0.94 or $E^{2\times5}/E^{5\times5} > 0.83$	-
$\sigma_{i\eta i\eta}$	-	< 0.03
EM + Had Depth 1 Iso.	$< 2 + 0.03 \times E_T + \rho \times 0.28$	$< 2.5 + \rho \times 0.28$ for $E_T < 50$ $< 2.5 + 0.03 \times (E_T - 50) + \rho \times 0.28$ for $E_T > 50$
Had Depth 2 Iso.	-	Removed
Tracker Iso.	< 5 GeV/c	< 5 GeV/c

Muon Selections:



Variables	
p_T	> 35
$\lvert\eta\rvert$	< 2.4
Tracker Muon	yes
Global Muon	yes
Number of Tracker Hits	>5
Number of Pixel Detector Hits	$>= 1$
Number of Muon Detector Hits	$>= 1$
Number of Matched Muon Segments	> 1
$\lvert D0\rvert_{pv}$	< 2mm
$\lvert Dz\rvert_{pv}$	< 5mm
TrkRelIso	< 0.1

-*dpT/pT*<0.3 for the track used for momentum measurement

-One muon matched to a HLT object muon

https://twiki.cern.ch/twiki/bin/view/CMSPublic/SWGuideMuonId

Signal and Backgrounds

Signal consists of 2 lepton in the final state.

Backgrounds can be divided into 2 categories:

Irreducible :

-Standard Model Drell-Yan with 2 electrons(muons) in the final state.
It is estimated using Monte Carlo Simulated events. POWHEG generator is used to take into account the NNLO.

Reducible :

- Top-Like or Flavor Symmetric backgrounds: Consists of all events with two real electrons(muon) in the final state:

- **Di-Leptonic TTBar and Single Top tW-channel**
- **Di-Boson (WW,WZ)**
- **Z→tau+tau**

This type of background is estimated by using "*e-mu* "method.

-Jet Backgrounds (QCD, W+Jets,γ+Jet) :jets can be miss-reconstructed as electrons
It is not possible to estimate it from MC due to lack of enough statistics. Accordingly, it is estimated from data using "*fake rate*" method.

Top-like (Flavor Symmetric), e/mu-Method

The dominant contribution of di-lepton back grounds in the tail of invariant mass distribution is due to full leptonic ttbar and lower contribution of ww ,tw and wz also some contribution from $Z \rightarrow \tau\tau$ in low invariant region.

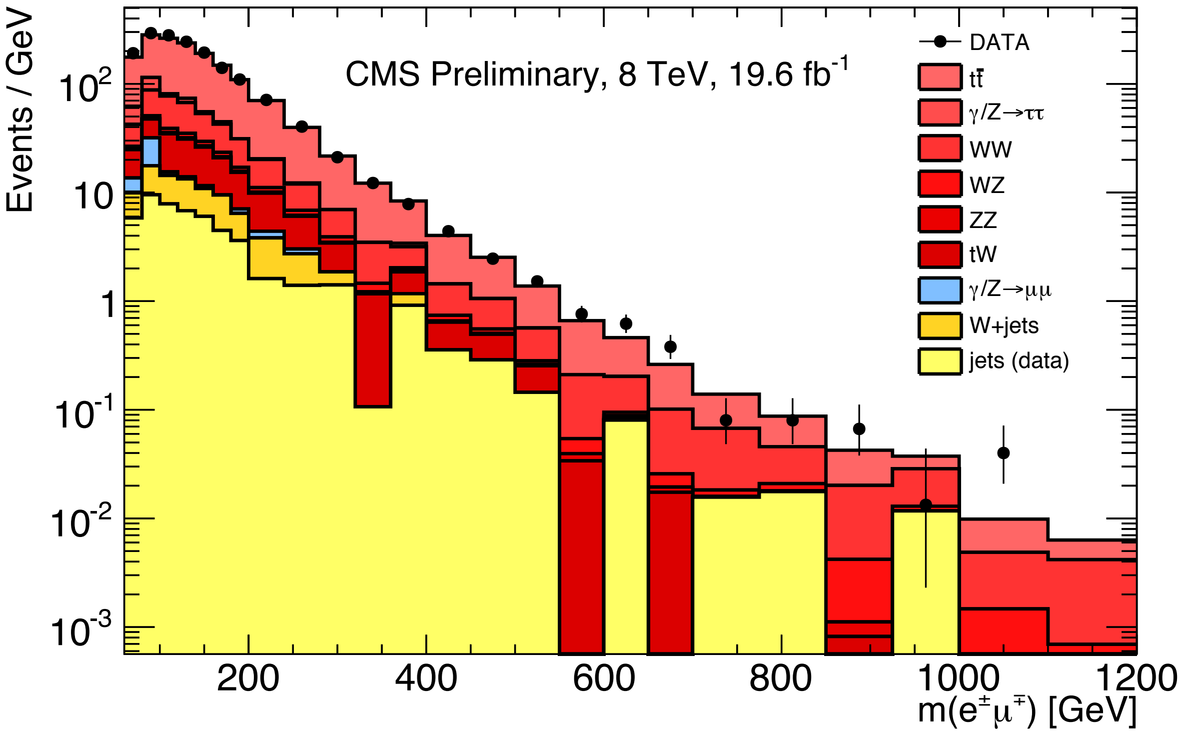
These processes are flavor-symmetric. They have a branching ratio to a pair of leptons of different flavor (e-mu) twice of the branching ratio to ee.

The contribution of these backgrounds to the ee(μμ) spectrum can be estimated using the following:

Electron(muon) efficiency calculated using the tag and probe method for 2 different regions: Z peak region and High mass region

$$\left(\frac{N_{ee}}{N_{e\mu}}\right)_{DATA} = \frac{1}{2}\frac{(\varepsilon_{id}\varepsilon_{rec}A)_{e}}{(\varepsilon_{id}\varepsilon_{rec}A)_{\mu}}$$

eμ Spectrum



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$$\left(\frac{N_{ee(\mu\mu)}}{N_{e\mu}}\right)_{DATA} = \frac{1}{2}\frac{(\varepsilon_{id}\varepsilon_{rec}A)_{e(\mu)}}{(\varepsilon_{id}\varepsilon_{rec}A)_{\mu(e)}}$$

- ✧ Estimation of ee(μμ) spectrum due to flavor symmetric backgrounds from eμ distribution.
- ✧ Cross checked with the Direct MC and good agreement.

M_{ee}

Jet Background Estimation

-The multi-jet events where two jets are mis-reconstructed as electrons and pass the HEEP selection cuts.

-W+jets events with one jet is mis-identified as an electron and passes the HEEP selection cuts.

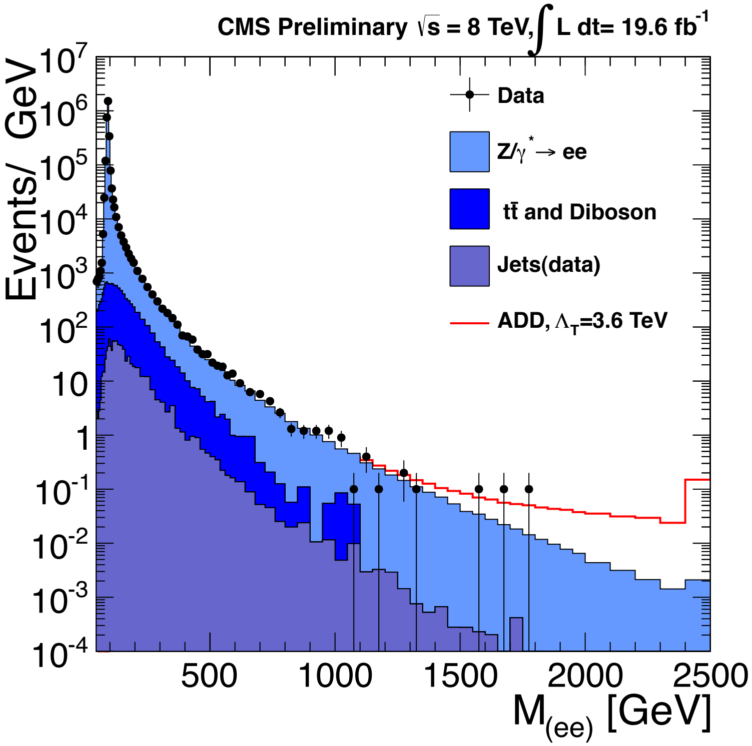
-Photon+jets events where both photon which converts to electrons and jet pass the HEEP selection.

The Fake rate method has been applied to estimate the jet backgrounds :

The fake rate: is defined as the number of HEEP electrons(tight cuts) over the number of Gsf Electrons passing the fake rate pre-selection cuts.

- ✧ Estimate the jet backgrounds by applying the fake rate twice to the Events with 2 GSF electrons which pass the pre-selection criteria but not pass HEEP (in order to reduce the z->ee contributions) selection cuts.
- ✧ Include W+jet and γ+jets contributions.

Di-Electron Invariant Mass



- ✧ 2 electrons in the final state
- ✧ Normalized DY to the data in the window 60-120 GeV.
- ✧ Investigated the impact of considering just EB-EB events.
  - -No significant improvement.
- ✧ Still keep using event with at least one electron in the barrel region.
- ✧ Nice agreement between Data and MC.

- ✧ NO indicate signal.

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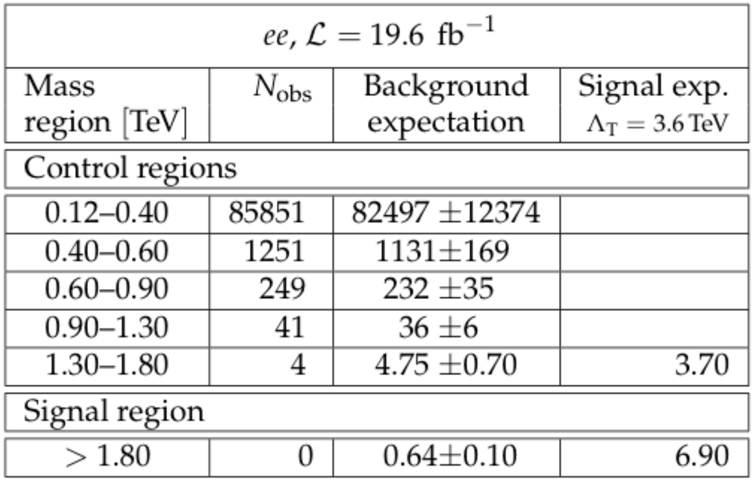
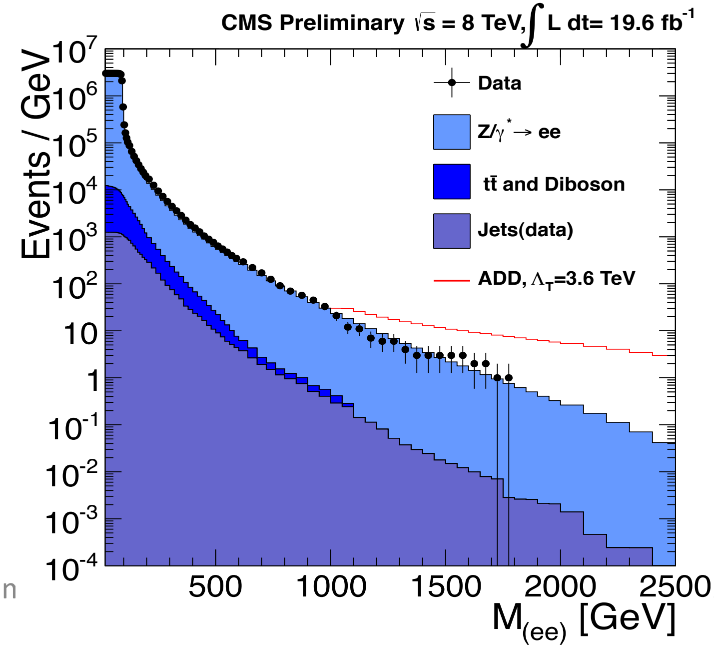
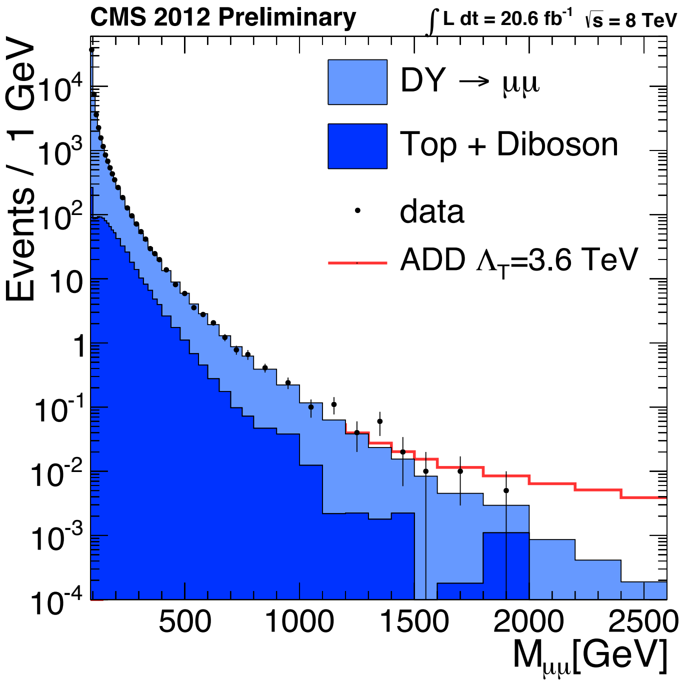


ee, $\mathcal{L} = 19.6$ fb^{-1}			
Mass region [TeV]	N_{obs}	Background expectation	Signal exp. $\Lambda_T = 3.6$ TeV
Control regions			
0.12–0.40	85851	82497 ±12374	
0.40–0.60	1251	1131±169	
0.60–0.90	249	232 ±35	
0.90–1.30	41	36 ±6	
1.30–1.80	4	4.75 ±0.70	3.70
Signal region			
> 1.80	0	0.64±0.10	6.90



Di-Muon Invariant Mass



- $|\eta|<2.1$ for leading muon and $|\eta|<2.4$ for the
- Second muon
- Good agreement between Data and MC.

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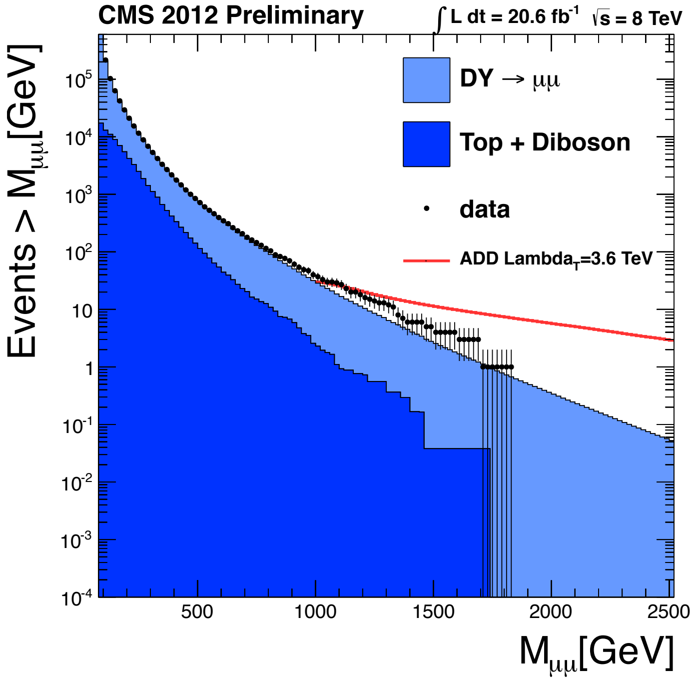
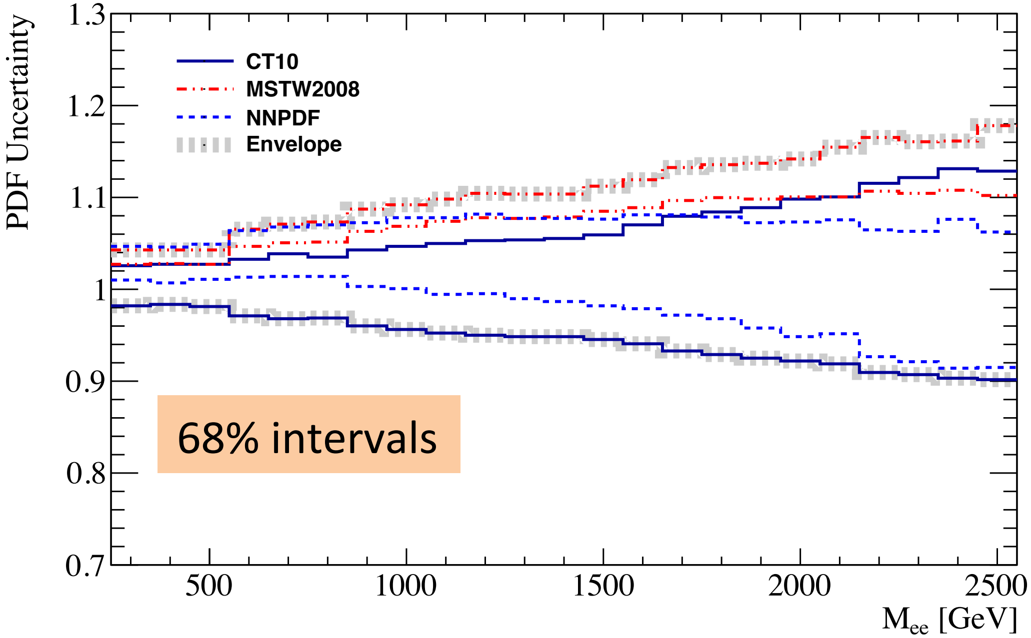
$\mu\mu$, $\mathcal{L} = 20.6$ fb^{-1}			
Mass region [TeV]	N_{obs}	Background expectation	Signal exp. $\Lambda_T = 3.6$ TeV
Control regions			
0.12–0.20	$8.20 \cdot 10^4$	$(7.96\pm0.64) \cdot 10^4$	
0.20–0.40	$1.92 \cdot 10^4$	$(1.87\pm0.15) \cdot 10^4$	
0.40–0.60	$1.42 \cdot 10^3$	$(1.45\pm0.14) \cdot 10^3$	
0.60–0.90	287	282 ± 32	
0.90–1.30	49	44.5 ± 6.6	
1.30–1.80	11	5.74 ± 1.16	3.38
Signal region			
> 1.80	1	0.73 ± 0.21	6.04



PDF uncertainty

- PDF Uncertainties are the leading bkg uncertainty at high masses.
- Main background DY →ee generated with Powheg using the PDF set CT10.
- Followed the recommended of PDF4LHC.
- Calculated the mass dependent uncertainties using re-weighting method with CT10, MSTW2008 and NNPDF sets.



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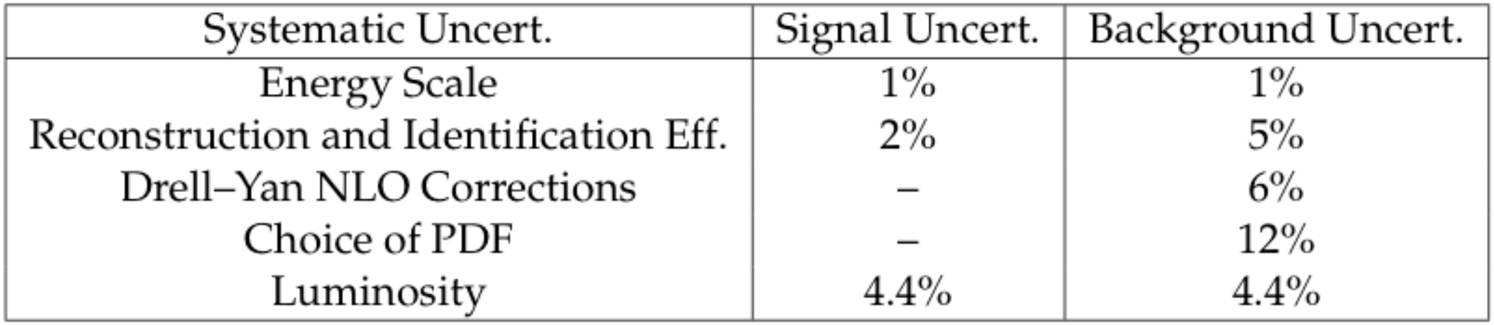
Around 9%uncertainty at 1.5 TeV which grows up to 14% at 2.5 TeV.

Other Uncertainties

Electron :



Systematic Uncert.	Signal Uncert.	Background Uncert.
Energy Scale	1%	1%
Reconstruction and Identification Eff.	2%	5%
Drell–Yan NLO Corrections	–	6%
Choice of PDF	–	12%
Luminosity	4.4%	4.4%

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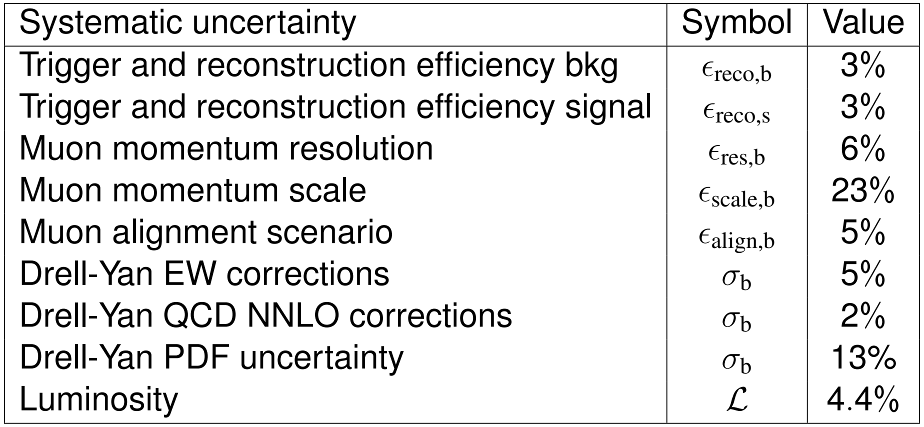
Fake rate uncertainty 40%.EXO-12-061

Muon:

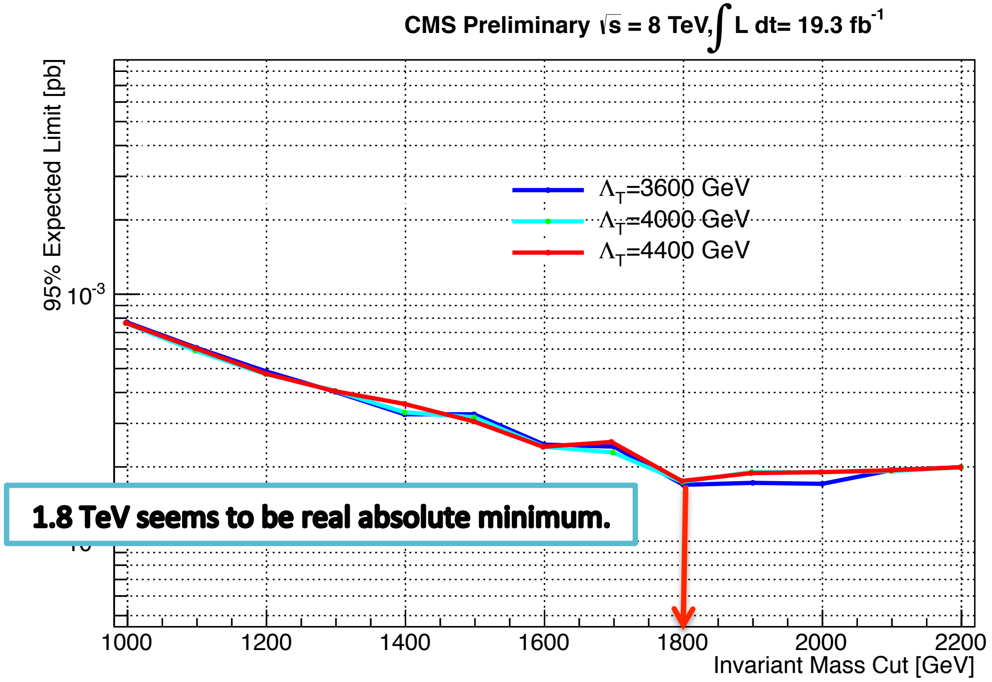


Systematic uncertainty	Symbol	Value
Trigger and reconstruction efficiency bkg	$\epsilon_{\mathrm{reco,b}}$	3%
Trigger and reconstruction efficiency signal	$\epsilon_{\mathrm{reco,s}}$	3%
Muon momentum resolution	$\epsilon_{\mathrm{res,b}}$	6%
Muon momentum scale	$\epsilon_{\mathrm{scale,b}}$	23%
Muon alignment scenario	$\epsilon_{\mathrm{align,b}}$	5%
Drell-Yan EW corrections	σ_{b}	5%
Drell-Yan QCD NNLO corrections	σ_{b}	2%
Drell-Yan PDF uncertainty	σ_{b}	13%
Luminosity	$\mathcal{L}$	4.4%

EXO-12-027

Optimized Invariant Mass

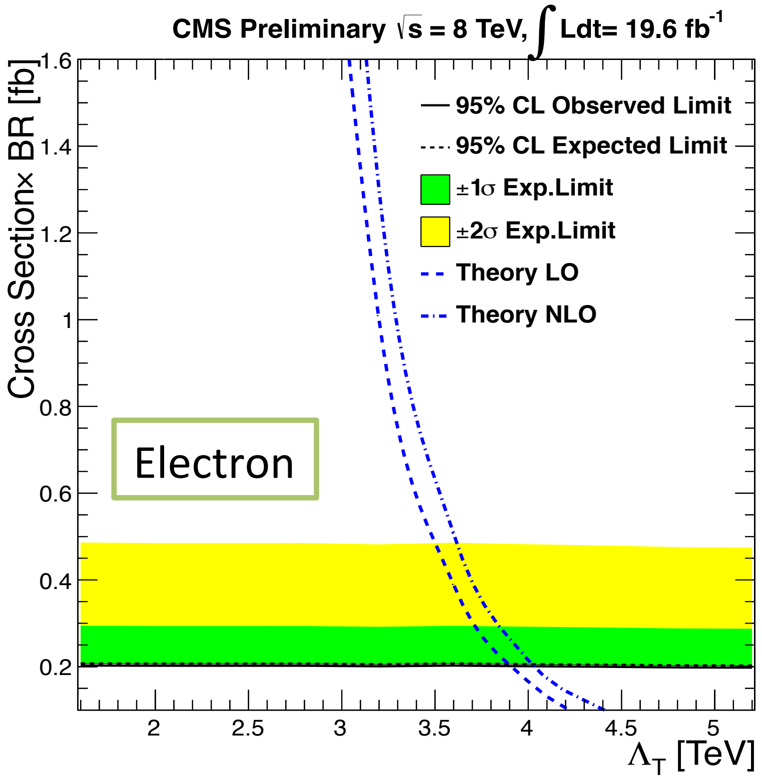
- *To put the limit on the cross section we have to determine the signal region in a way that gives us the maximum sensitivity.*
- *The criteria to optimize the invariant mass cut is to minimize the expected 95% C.L. limit on the cross section for the ADD model or in the other words exclude* ***Λ_T as high as possible.***
- *Expected limit as a function of invariant mass have to become minimize.*



1.8 TeV seems to be real absolute minimum.

- Observed no excess over Standard Model expectation above invariant mass cut.
- Single bin Counting experiment(count number of events above optimized invariant mass cut) considering all systematic is used to calculate exclusion limit on the signal cross section
- Using the bayessian approach.
- Use Higgs tools package.

Limit calculation



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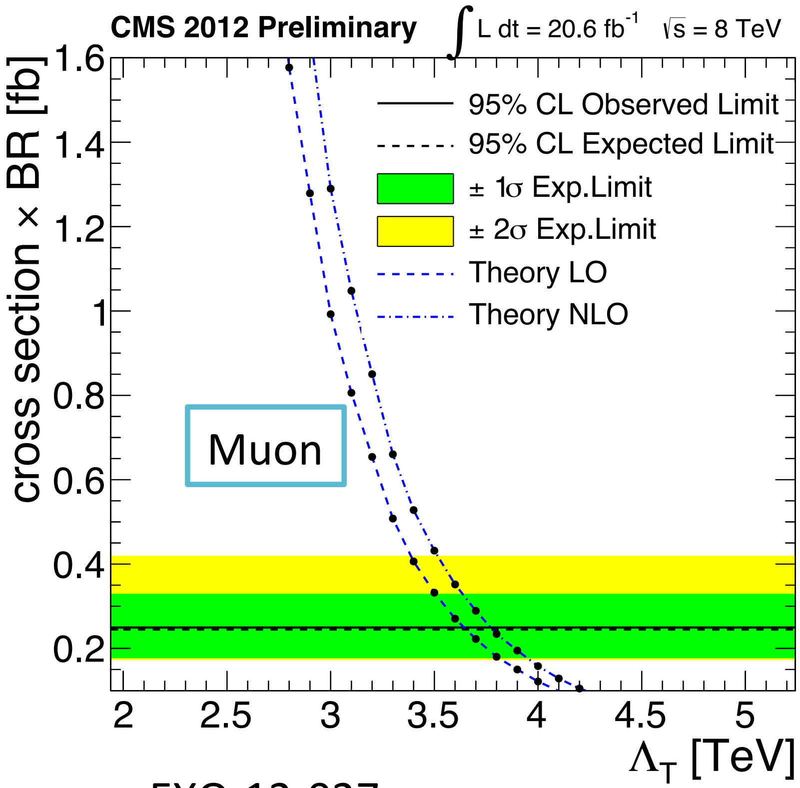
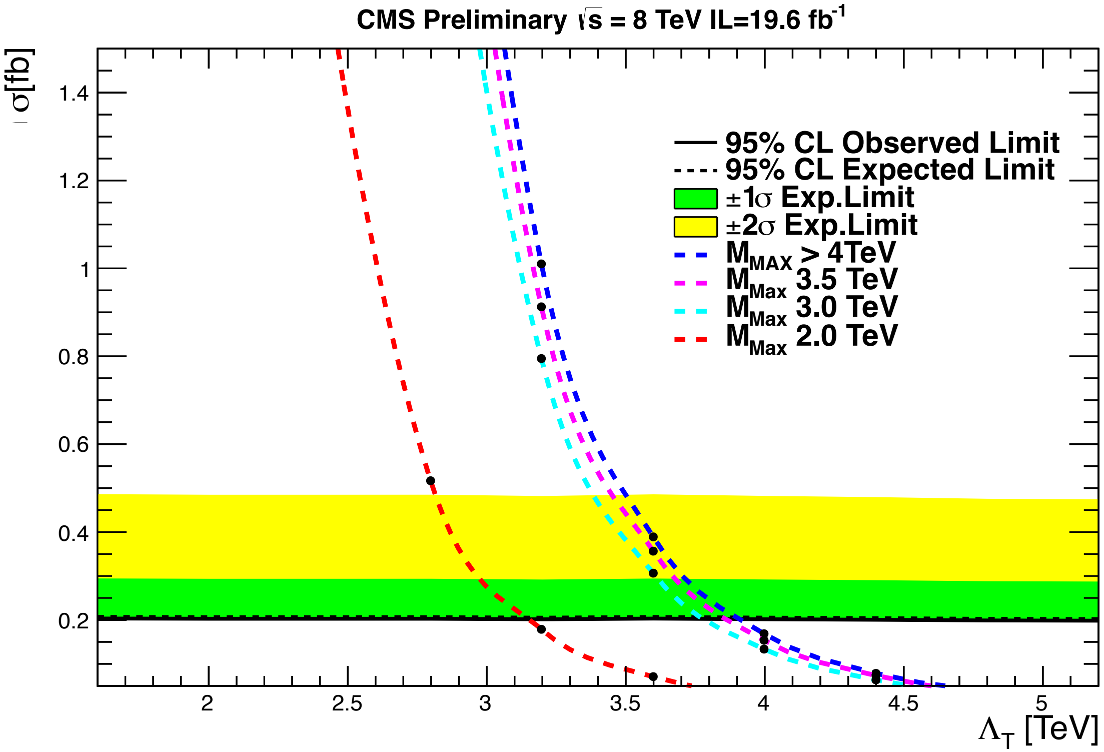


EXO-12-027

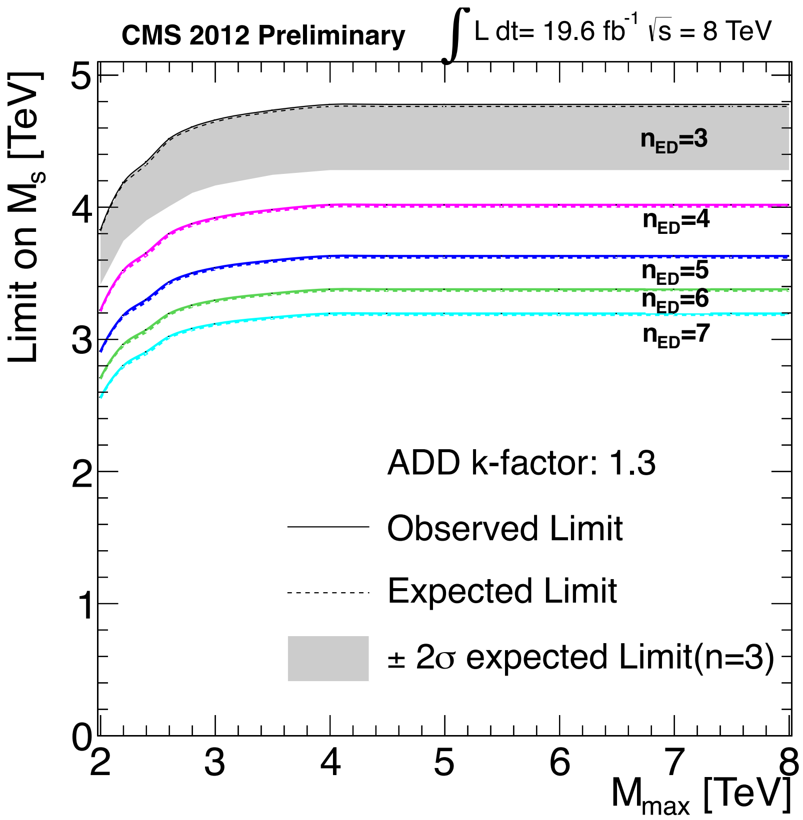
- 95% observed limit on the ADD cross section 0.19(0.25)fb in di-electron(di-muon) channels.
- 95% CL limits on the Λ_T , considering the ADD signal in LO assumption are 3.90(3.64) TeV respectively in Di-electron(Di-muon) channels.

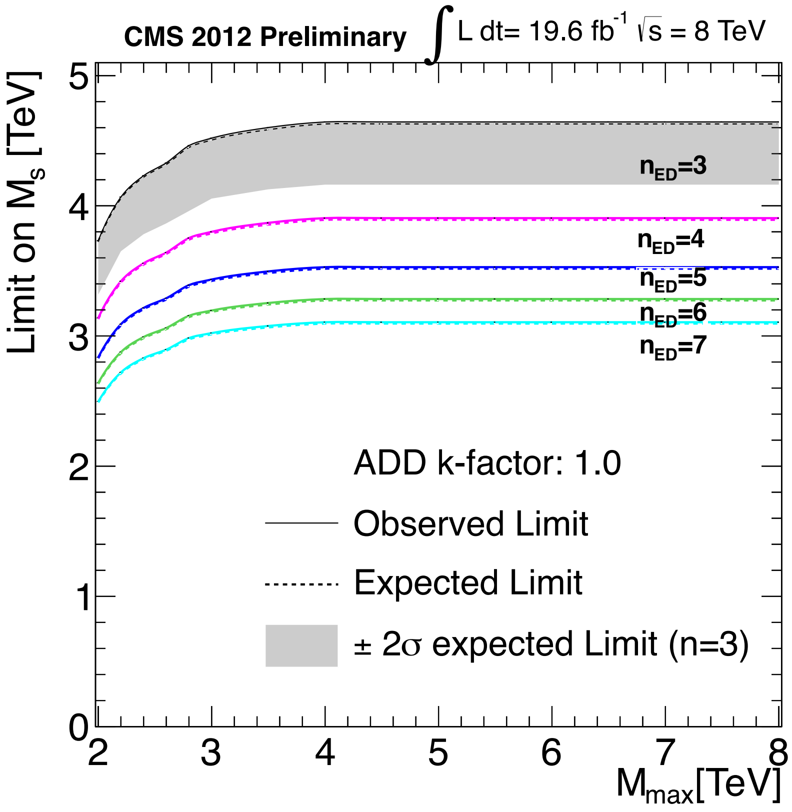
Limit W.R.T different model validity



- ✧ The ADD model itself does not predict the maximum di-electron invariant mass up to which the theory is valid.
- ✧ Depending on maximum validity of the model(ADD), theoretical cross section could be changed. Therefore the limit would be different.
- ✧ LO assumption of the theory is considered.

Translated Limit in HLZ (Electron)





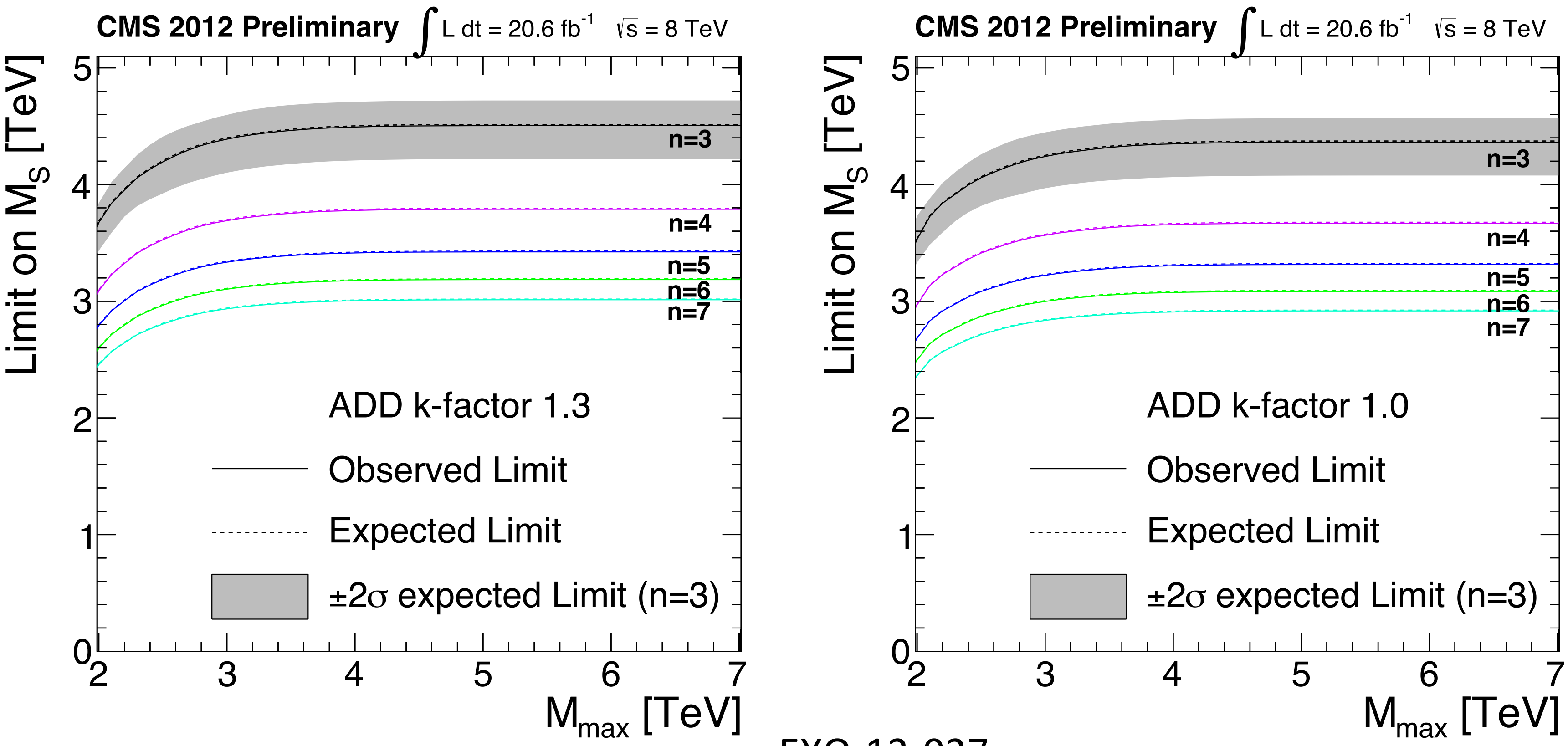
(GRW) converts to (HLZ) →

$$\boxed{\Lambda_T^4 = \frac{n_{\mathrm{ED}} - 2}{2} M_{s,\mathrm{HLZ}}^4}$$

EXO-12-031

- ✧ Limits on the scale M_S for different numbers of extra dimensions VS the validity range of the effective theory.
- ✧ M_s exclude up to 4.59(4.73) TeV in the lowest number of extra dimensions in LO and NLO assumption.

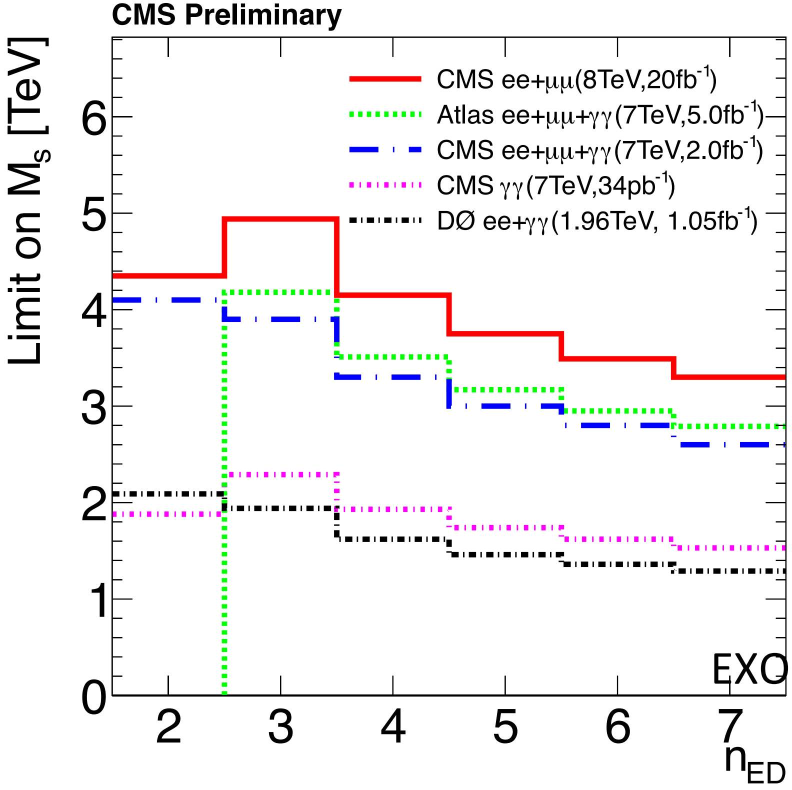
Translated Limit in HLZ (Muon)



EXO-12-027

- Limits on the scale M_S for different numbers of extra dimensions VS the validity range of the effective theory.
- M_s exclude up to 4.33(4.49) TeV in the lowest number of extra dimensions in LO and NLO assumption.

ADD limit improvement 2011-2012



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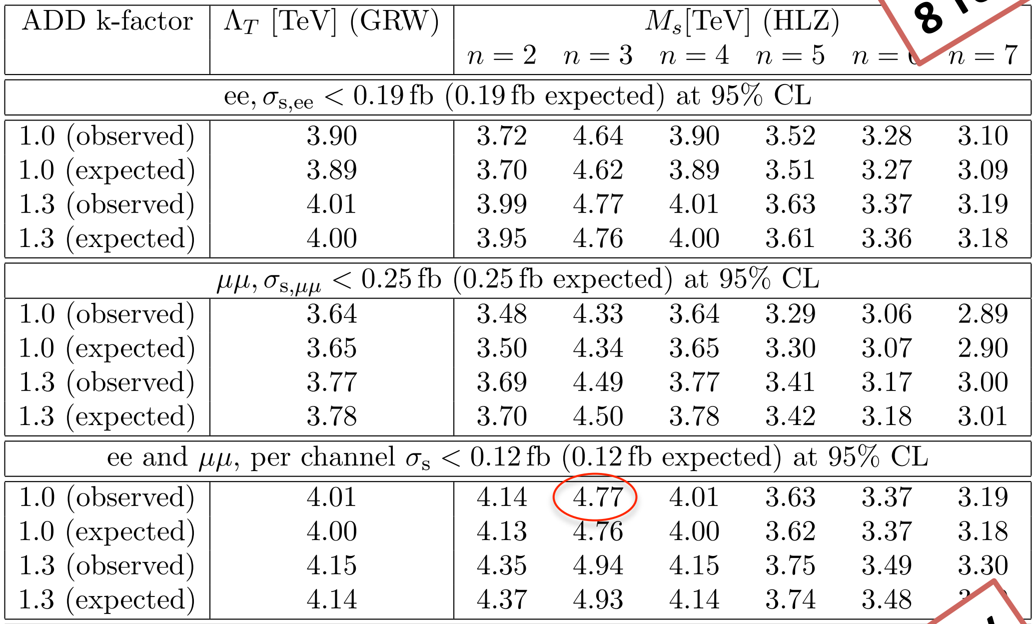
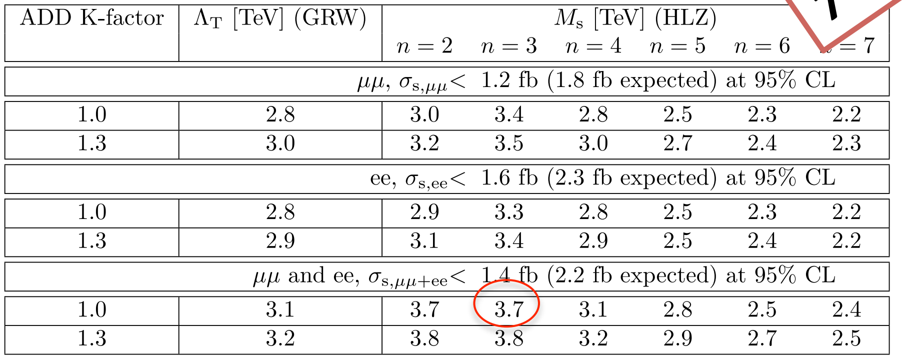
8 TeV



ADD k-factor	Λ_T [TeV] (GRW)	M_s[TeV] (HLZ) $n = 2$	$n = 3$	$n = 4$	$n = 5$	$n = 6$	$n = 7$
ee, $\sigma_{\mathrm{s,ee}} < 0.19\,\mathrm{fb}$ (0.19 fb expected) at 95% CL							
1.0 (observed)	3.90	3.72	4.64	3.90	3.52	3.28	3.10
1.0 (expected)	3.89	3.70	4.62	3.89	3.51	3.27	3.09
1.3 (observed)	4.01	3.99	4.77	4.01	3.63	3.37	3.19
1.3 (expected)	4.00	3.95	4.76	4.00	3.61	3.36	3.18
$\mu\mu$, $\sigma_{\mathrm{s},\mu\mu} < 0.25\,\mathrm{fb}$ (0.25 fb expected) at 95% CL							
1.0 (observed)	3.64	3.48	4.33	3.64	3.29	3.06	2.89
1.0 (expected)	3.65	3.50	4.34	3.65	3.30	3.07	2.90
1.3 (observed)	3.77	3.69	4.49	3.77	3.41	3.17	3.00
1.3 (expected)	3.78	3.70	4.50	3.78	3.42	3.18	3.01
ee and $\mu\mu$, per channel $\sigma_{\mathrm{s}} < 0.12\,\mathrm{fb}$ (0.12 fb expected) at 95% CL							
1.0 (observed)	4.01	4.14	4.77	4.01	3.63	3.37	3.19
1.0 (expected)	4.00	4.13	4.76	4.00	3.62	3.37	3.18
1.3 (observed)	4.15	4.35	4.94	4.15	3.75	3.49	3.30
1.3 (expected)	4.14	4.37	4.93	4.14	3.74	3.48	[illegible]

7 TeV



ADD K-factor	Λ_T [TeV] (GRW)	M_s [TeV] (HLZ) $n = 2$	$n = 3$	$n = 4$	$n = 5$	$n = 6$	$n = 7$
$\mu\mu$, $\sigma_{\mathrm{s},\mu\mu}<$ 1.2 fb (1.8 fb expected) at 95% CL							
1.0	2.8	3.0	3.4	2.8	2.5	2.3	2.2
1.3	3.0	3.2	3.5	3.0	2.7	2.4	2.3
ee, $\sigma_{\mathrm{s,ee}}<$ 1.6 fb (2.3 fb expected) at 95% CL							
1.0	2.8	2.9	3.3	2.8	2.5	2.3	2.2
1.3	2.9	3.1	3.4	2.9	2.5	2.4	2.2
$\mu\mu$ and ee, $\sigma_{\mathrm{s},\mu\mu+\mathrm{ee}}<$ 1.4 fb (2.2 fb expected) at 95% CL							
1.0	3.1	3.7	3.7	3.1	2.8	2.5	2.4
1.3	3.2	3.8	3.8	3.2	2.9	2.7	2.5

About ***1TeV*** improvement from 7 to 8 TeV

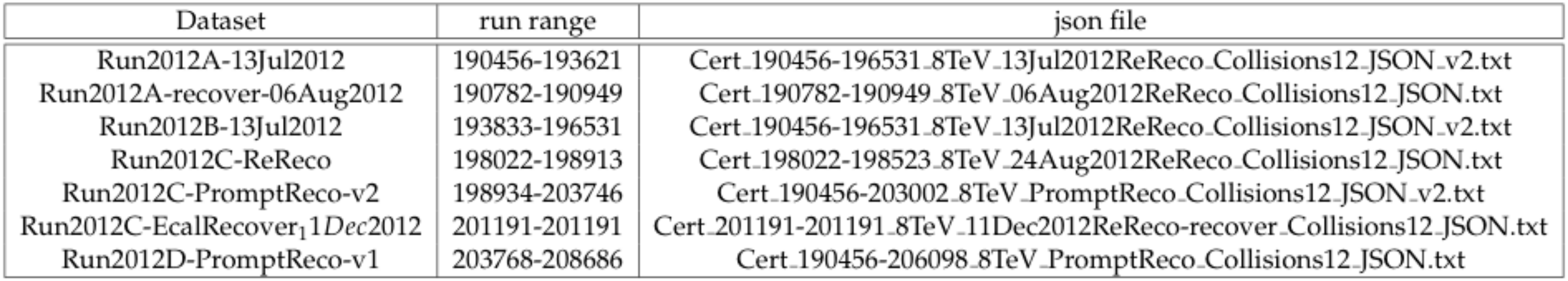
Physics Letters B711,1,2012

Conclusion

- ✧ Presented ADD to di-lepton analysis with ~ 20 fb^{-1} of 2012 CMS data in 8TeV CEM.
- ✧ Data driven methods used to estimate the flavor symmetric and jet backgrounds.
- ✧ Data is in a good agreement with the SM prediction and no indication of signal contribution.
- ✧ Systematic Uncertainties were studied and implemented in the analysis.
- ✧ Combination limit, Exclude Λ_T up to 4.01(4.15) TeV in GRW convention and M_s up to 4.77 (4.94) TeV depending on the number of extra dimensions in the LO and NLO assumption.
- ✧ 1 TeV improvement in the parameters of model M_s limit WRT 7 TeV data of CMS presented as a best limit on the extra dimension cross section in the di-leptonic channel ever.

Back up

Data& Trigger



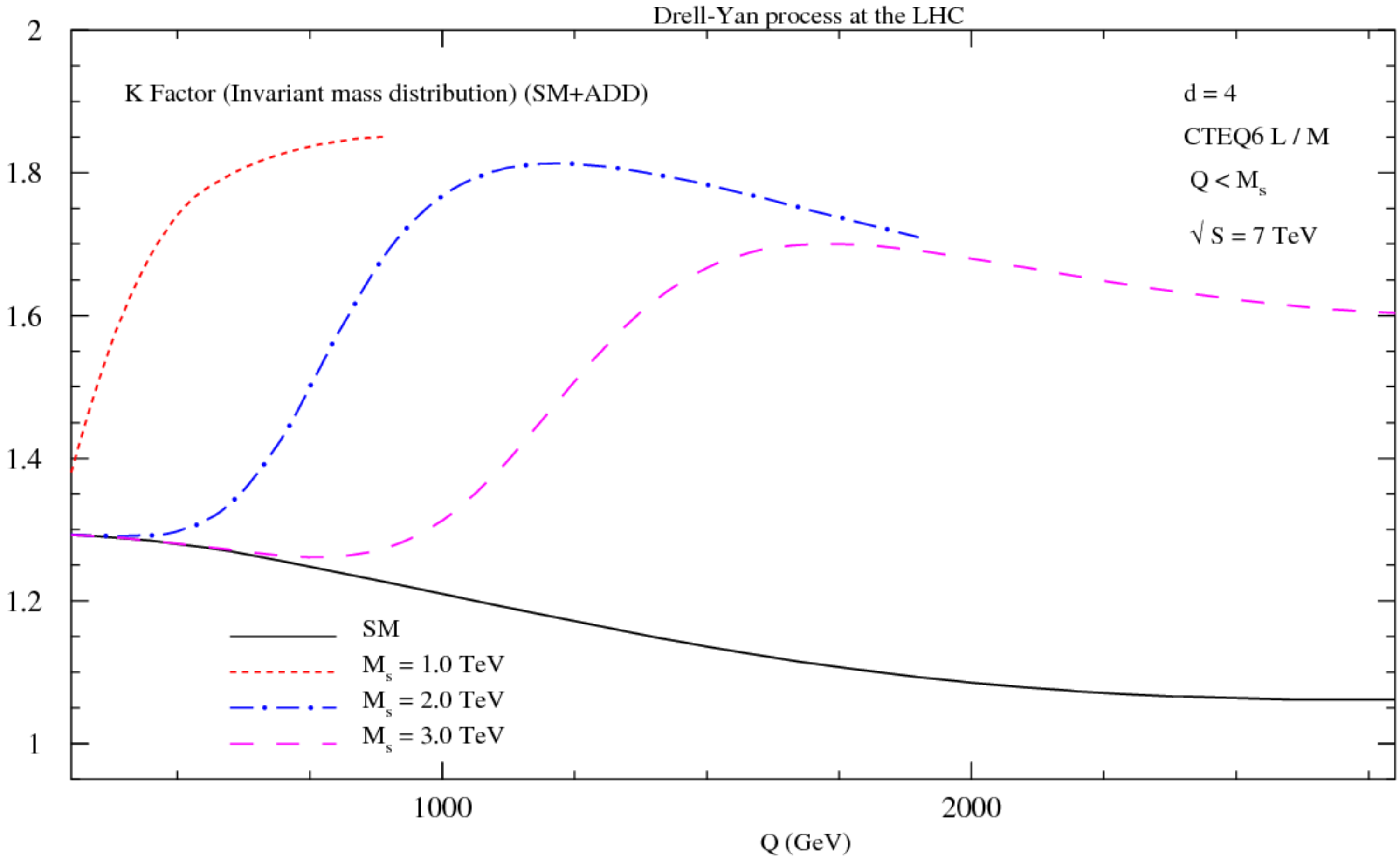
Dataset	run range	json file
Run2012A-13Jul2012	190456-193621	Cert_190456-196531_8TeV_13Jul2012ReReco_Collisions12_JSON_v2.txt
Run2012A-recover-06Aug2012	190782-190949	Cert_190782-190949_8TeV_06Aug2012ReReco_Collisions12_JSON.txt
Run2012B-13Jul2012	193833-196531	Cert_190456-196531_8TeV_13Jul2012ReReco_Collisions12_JSON_v2.txt
Run2012C-ReReco	198022-198913	Cert_198022-198523_8TeV_24Aug2012ReReco_Collisions12_JSON.txt
Run2012C-PromptReco-v2	198934-203746	Cert_190456-203002_8TeV_PromptReco_Collisions12_JSON_v2.txt
Run2012C-EcalRecover$_1 1Dec2012$	201191-201191	Cert_201191-201191_8TeV_11Dec2012ReReco-recover_Collisions12_JSON.txt
Run2012D-PromptReco-v1	203768-208686	Cert_190456-206098_8TeV_PromptReco_Collisions12_JSON.txt

Integrated Luminosity: *19.6 fb*$^{-1}$

Signal, Jet Bck estimation(Fake Rate)	**/Photon +DoublePhotonHighPt**
eμ-Method	**/MuEG**
Tag&Prob	**/DoubleElectron**

Triggers :	
HLT_DoubleEle33_CaloIdL_GsfTrkIdVL HLT_Ele32_CaloIdT_CaloIsoT_TrkIdT_TrkIsoT_SC17_Mass50 HLT_DoublePhoton70	Signal, Tag and Probe Tag and Probe Tag and Probe
HLT_Mu22_Photon22_CaloIdL	Eμ method

NLO Kfactor of ADD signal

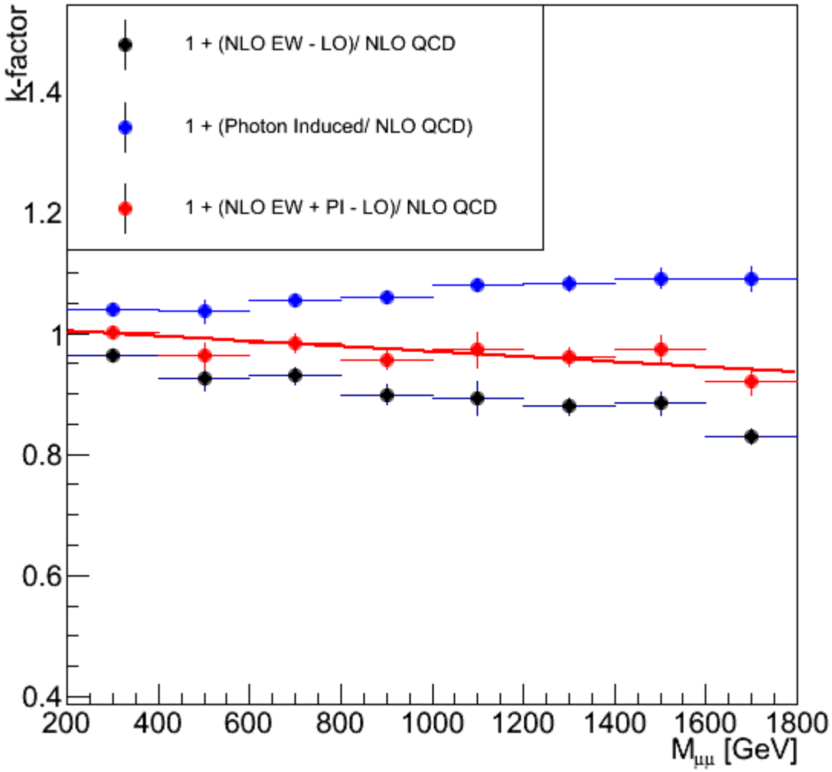


(P. Mathew, V.Ravindran,K.Sridhar et al, "Next-to-Leading Order QCD Corrections to the Drell Yan Cross Section in Models of TeV-Scale Gravity", Nucl.Phys.B 713 (2005))

NLO EW Correction

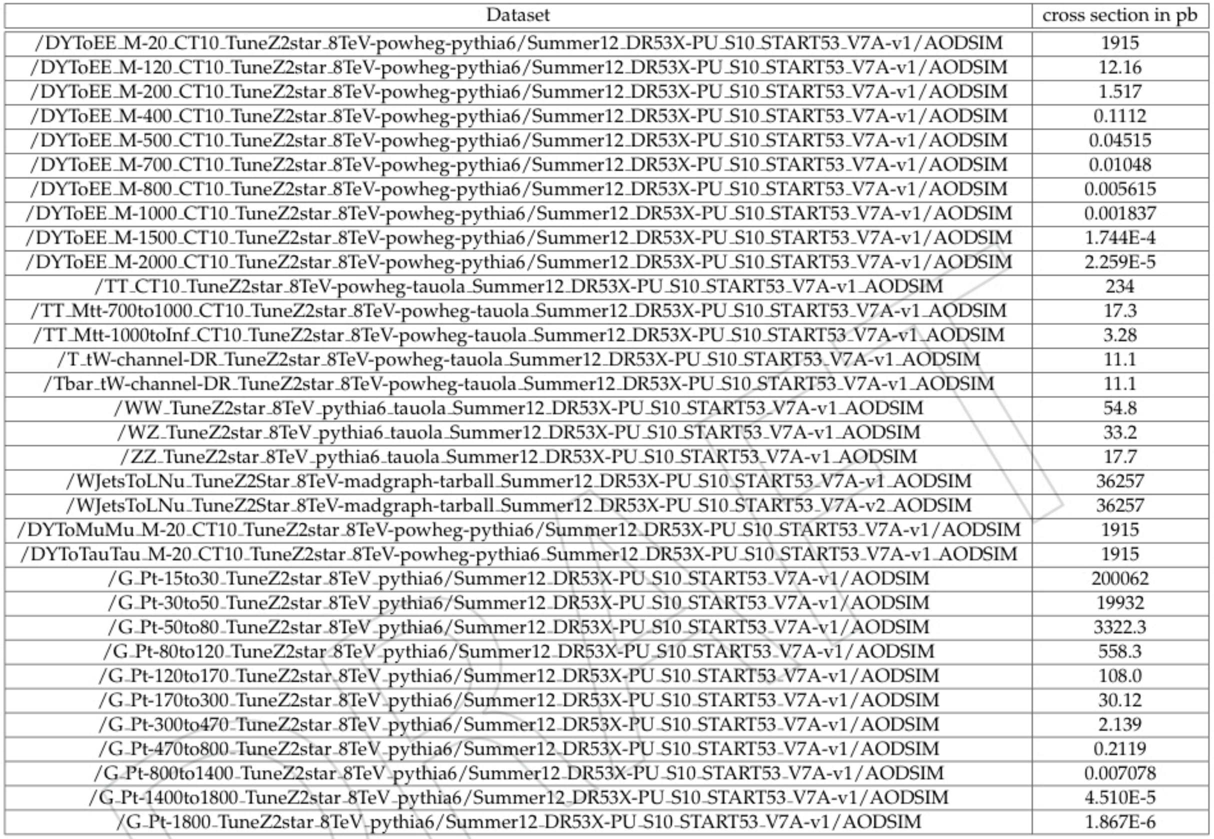
https://twiki.cern.ch/twiki/bin/viewauth/CMS/ADD8TeVDrellYanStudies

Mass Range [GeV]	k1	k2	k3
200 - 400	0.964	1.039	1.002
400 - 600	0.926	1.036	0.962
600 - 800	0.930	1.054	0.984
800 - 1000	0.899	1.058	0.957
1000 - 1200	0.893	1.080	0.973
1200 - 1400	0.879	1.082	0.961
1400 - 1600	0.885	1.090	0.975
1600 - 1800	0.830	1.090	0.920



MC samples

Using 53X Samples , Summer 12
All DY ,Ttbar and single top(tw) samples generated at NLO with POWHEG.
WW, WZ, ZZ ,γ+jet(W+Jet) Pythia(Madgraph).



Dataset	cross section in pb
/DYToEE_M-20_CT10_TuneZ2star_8TeV-powheg-pythia6/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	1915
/DYToEE_M-120_CT10_TuneZ2star_8TeV-powheg-pythia6/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	12.16
/DYToEE_M-200_CT10_TuneZ2star_8TeV-powheg-pythia6/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	1.517
/DYToEE_M-400_CT10_TuneZ2star_8TeV-powheg-pythia6/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	0.1112
/DYToEE_M-500_CT10_TuneZ2star_8TeV-powheg-pythia6/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	0.04515
/DYToEE_M-700_CT10_TuneZ2star_8TeV-powheg-pythia6/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	0.01048
/DYToEE_M-800_CT10_TuneZ2star_8TeV-powheg-pythia6/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	0.005615
/DYToEE_M-1000_CT10_TuneZ2star_8TeV-powheg-pythia6/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	0.001837
/DYToEE_M-1500_CT10_TuneZ2star_8TeV-powheg-pythia6/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	1.744E-4
/DYToEE_M-2000_CT10_TuneZ2star_8TeV-powheg-pythia6/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	2.259E-5
/TT_CT10_TuneZ2star_8TeV-powheg-tauola_Summer12_DR53X-PU_S10_START53_V7A-v1_AODSIM	234
/TT_Mtt-700to1000_CT10_TuneZ2star_8TeV-powheg-tauola_Summer12_DR53X-PU_S10_START53_V7A-v1_AODSIM	17.3
/TT_Mtt-1000toInf_CT10_TuneZ2star_8TeV-powheg-tauola_Summer12_DR53X-PU_S10_START53_V7A-v1_AODSIM	3.28
/T_tW-channel-DR_TuneZ2star_8TeV-powheg-tauola_Summer12_DR53X-PU_S10_START53_V7A-v1_AODSIM	11.1
/Tbar_tW-channel-DR_TuneZ2star_8TeV-powheg-tauola_Summer12_DR53X-PU_S10_START53_V7A-v1_AODSIM	11.1
/WW_TuneZ2star_8TeV_pythia6_tauola_Summer12_DR53X-PU_S10_START53_V7A-v1_AODSIM	54.8
/WZ_TuneZ2star_8TeV_pythia6_tauola_Summer12_DR53X-PU_S10_START53_V7A-v1_AODSIM	33.2
/ZZ_TuneZ2star_8TeV_pythia6_tauola_Summer12_DR53X-PU_S10_START53_V7A-v1_AODSIM	17.7
/WJetsToLNu_TuneZ2Star_8TeV-madgraph-tarball_Summer12_DR53X-PU_S10_START53_V7A-v1_AODSIM	36257
/WJetsToLNu_TuneZ2Star_8TeV-madgraph-tarball_Summer12_DR53X-PU_S10_START53_V7A-v2_AODSIM	36257
/DYToMuMu_M-20_CT10_TuneZ2star_8TeV-powheg-pythia6/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	1915
/DYToTauTau_M-20_CT10_TuneZ2star_8TeV-powheg-pythia6_Summer12_DR53X-PU_S10_START53_V7A-v1_AODSIM	1915
/G_Pt-15to30_TuneZ2star_8TeV_pythia6/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	200062
/G_Pt-30to50_TuneZ2star_8TeV_pythia6/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	19932
/G_Pt-50to80_TuneZ2star_8TeV_pythia6/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	3322.3
/G_Pt-80to120_TuneZ2star_8TeV_pythia6/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	558.3
/G_Pt-120to170_TuneZ2star_8TeV_pythia6/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	108.0
/G_Pt-170to300_TuneZ2star_8TeV_pythia6/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	30.12
/G_Pt-300to470_TuneZ2star_8TeV_pythia6/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	2.139
/G_Pt-470to800_TuneZ2star_8TeV_pythia6/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	0.2119
/G_Pt-800to1400_TuneZ2star_8TeV_pythia6/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	0.007078
/G_Pt-1400to1800_TuneZ2star_8TeV_pythia6/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	4.510E-5
/G_Pt-1800_TuneZ2star_8TeV_pythia6/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	1.867E-6

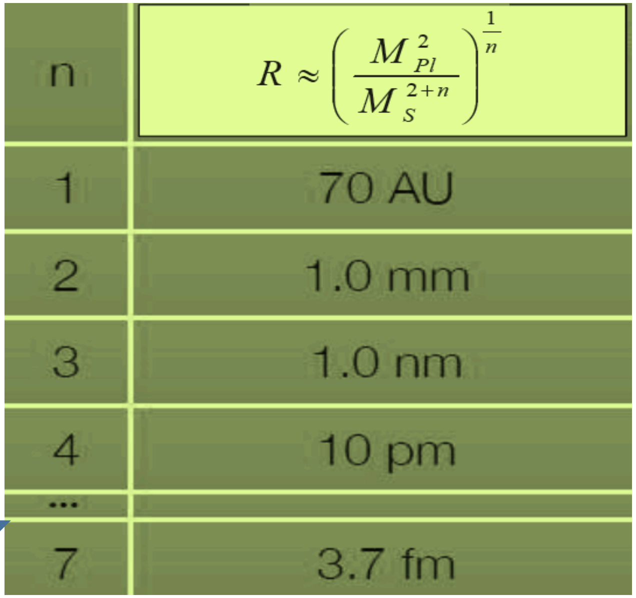
Extra Dimensions

-If Large Extra Dimensions exist the 4-D Planck Scale (**M_{Pl}) is not a fundamental scale**

-The 4+n Planck Scale (**M_S) is the Fundamental** Scale.

-To solve the Hierarchy Problem: $M_S \sim M_{EW}$

Setting Ms = 1 TeV



n	$R \approx \left(\frac{M_{Pl}^{2}}{M_{S}^{2+n}}\right)^{\frac{1}{n}}$
1	70 AU
2	1.0 mm
3	1.0 nm
4	10 pm
…	
7	3.7 fm

Outside the reach of modern measurements of gravity

high-energy colliders, the LHC in particular, are an excellent place to study the effects of Extra Dimension