

Extra Dimensions: CMS

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on behalf of the CMS Collaboration

**Implications of LHC results for TeV-scale physics
2011, CERN**

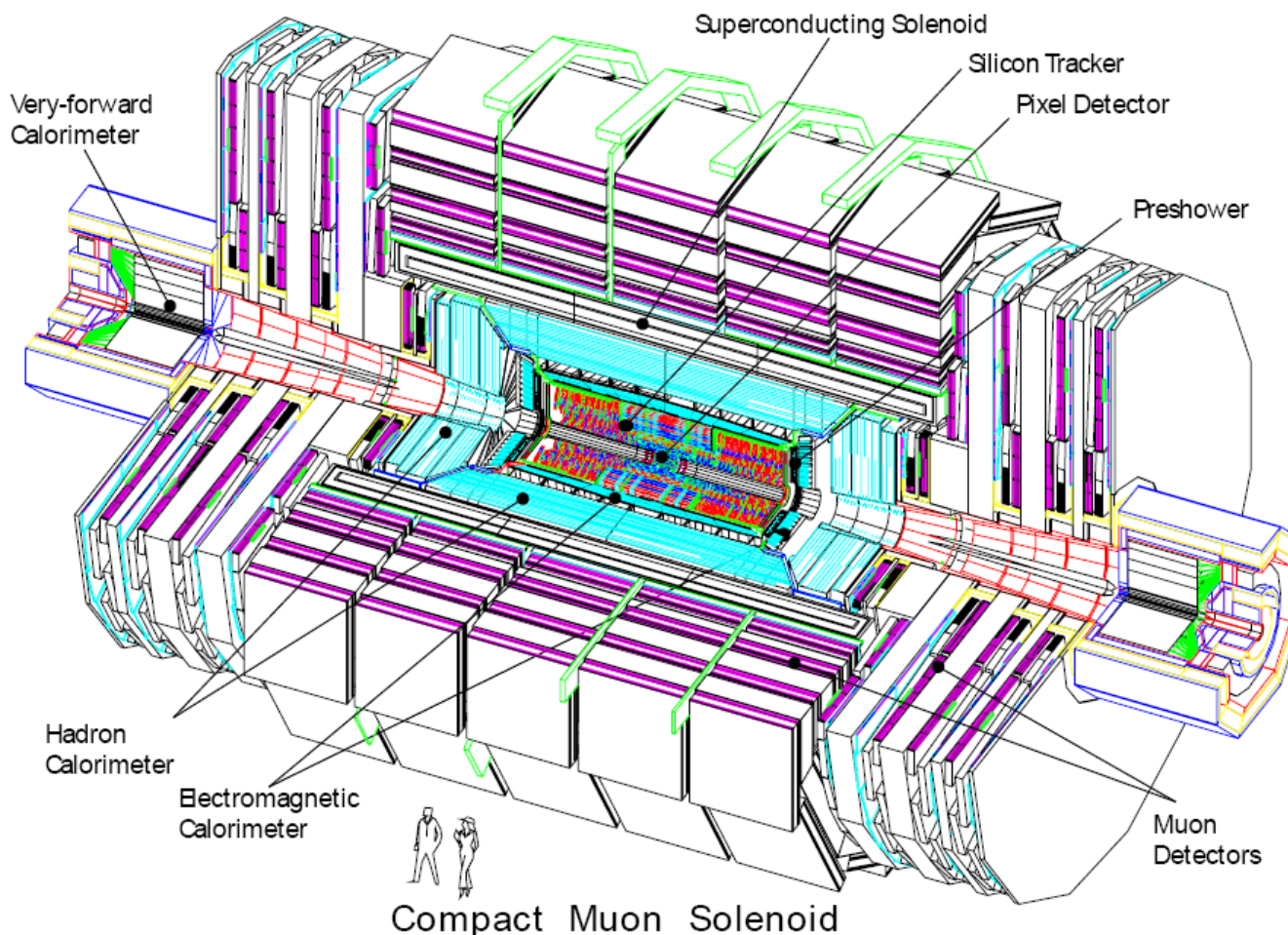
- **Microscopic Black Hole Signatures**
- **Large Extra Dimensions with a Monojet and Missing Transverse Energy**
- **Large Extra Dimensions Using the Monophoton Final State**
- **Large Extra Dimensions in Dimuon Events**
- **Large Extra Dimensions in the Diphoton Final State**
- **Randall-Sundrum Gravitons Decaying into Two Photons**
- **Resonances in the Dilepton Mass Distribution (no details discussed in this presentation)**

All analyses with $>1 \text{ fb}^{-1}$!

CMS: 2011 Data Taking

recorded proton-proton collisions in 2011 (so far):

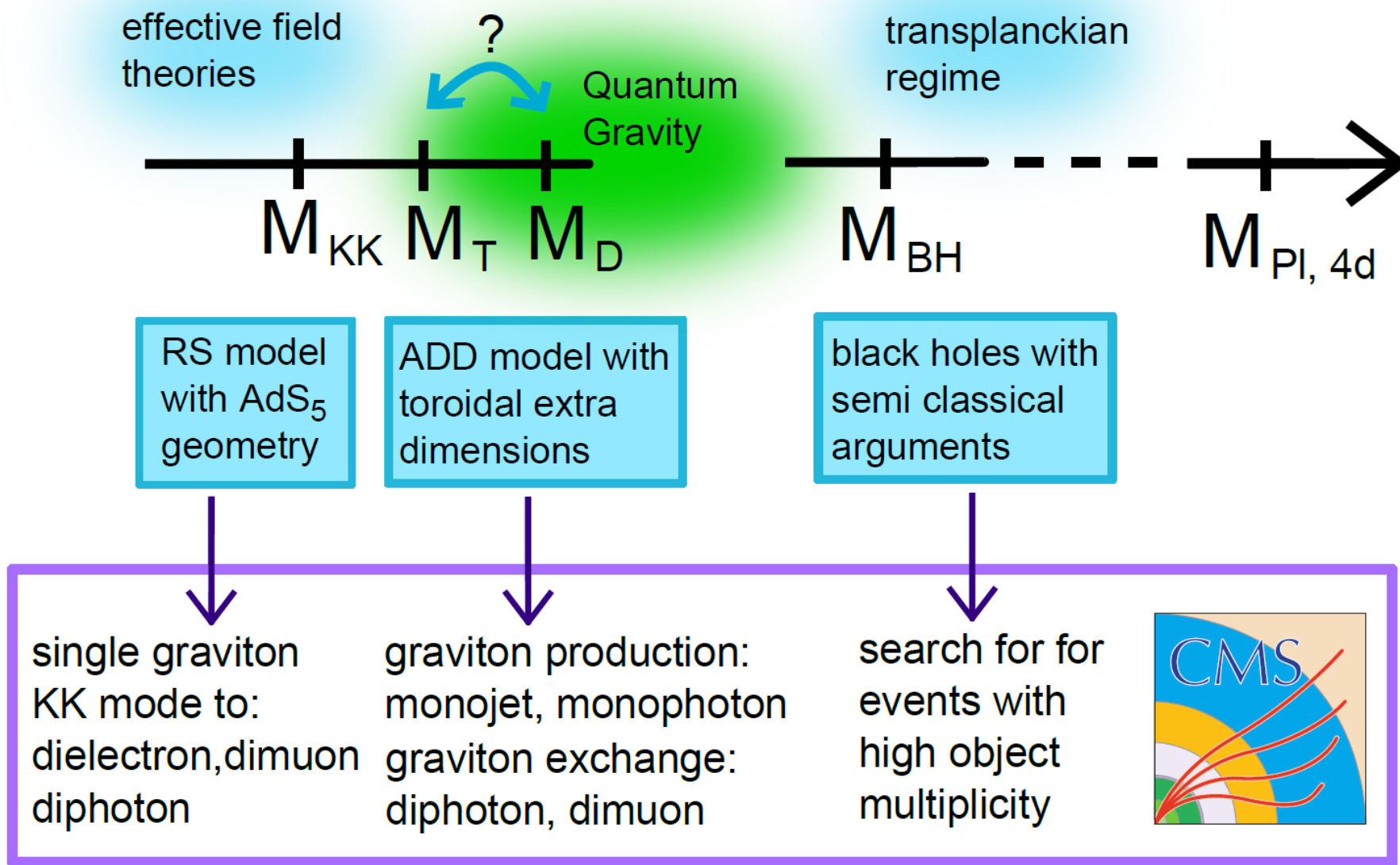
$\sim 2.3 \text{ fb}^{-1}$ of data at $\sqrt{s}=7 \text{ TeV}$



**A Window
towards
Extra
Dimensions?**



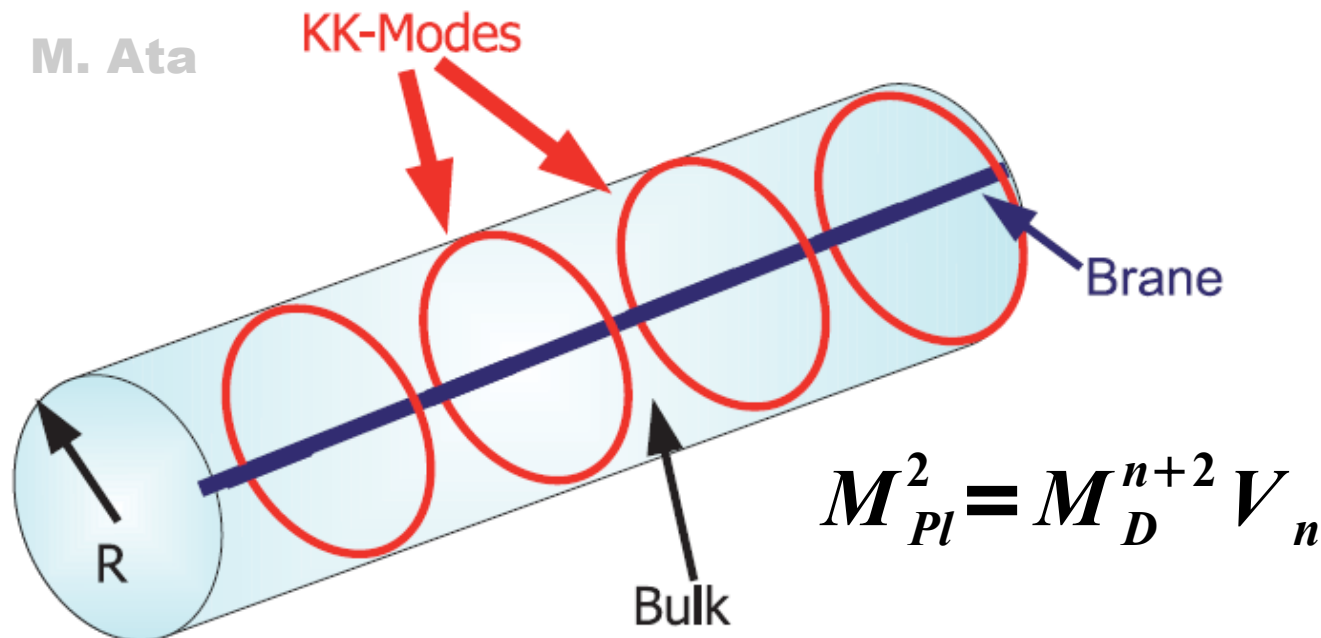
Searches for Extra Dimensions at CMS



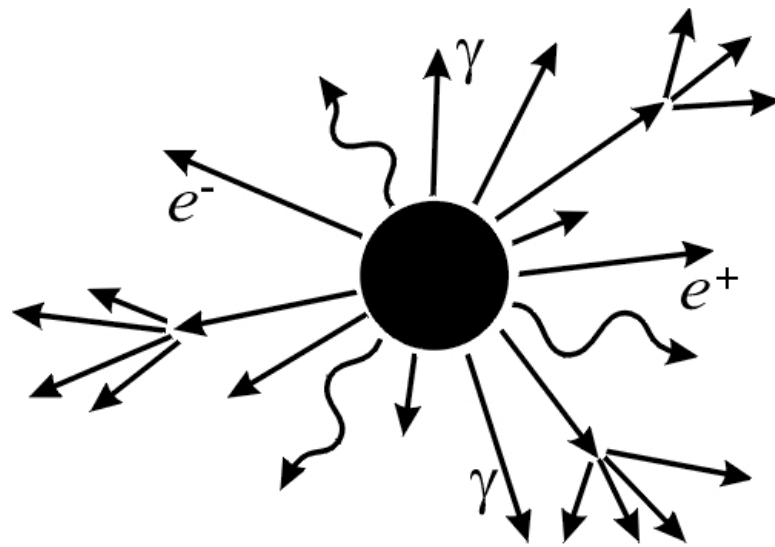
The ADD Model

The ADD (Arkani-Hamed, Dimopoulos, Dvali) model proposes the following setup:

- **Compactified Large Extra Dimensions**
- **Brane Physics**
- The Standard Model (SM) is confined to a brane
- Graviton can propagate in the bulk
- Effective field theories at "low" energies



Microscopic Black Holes



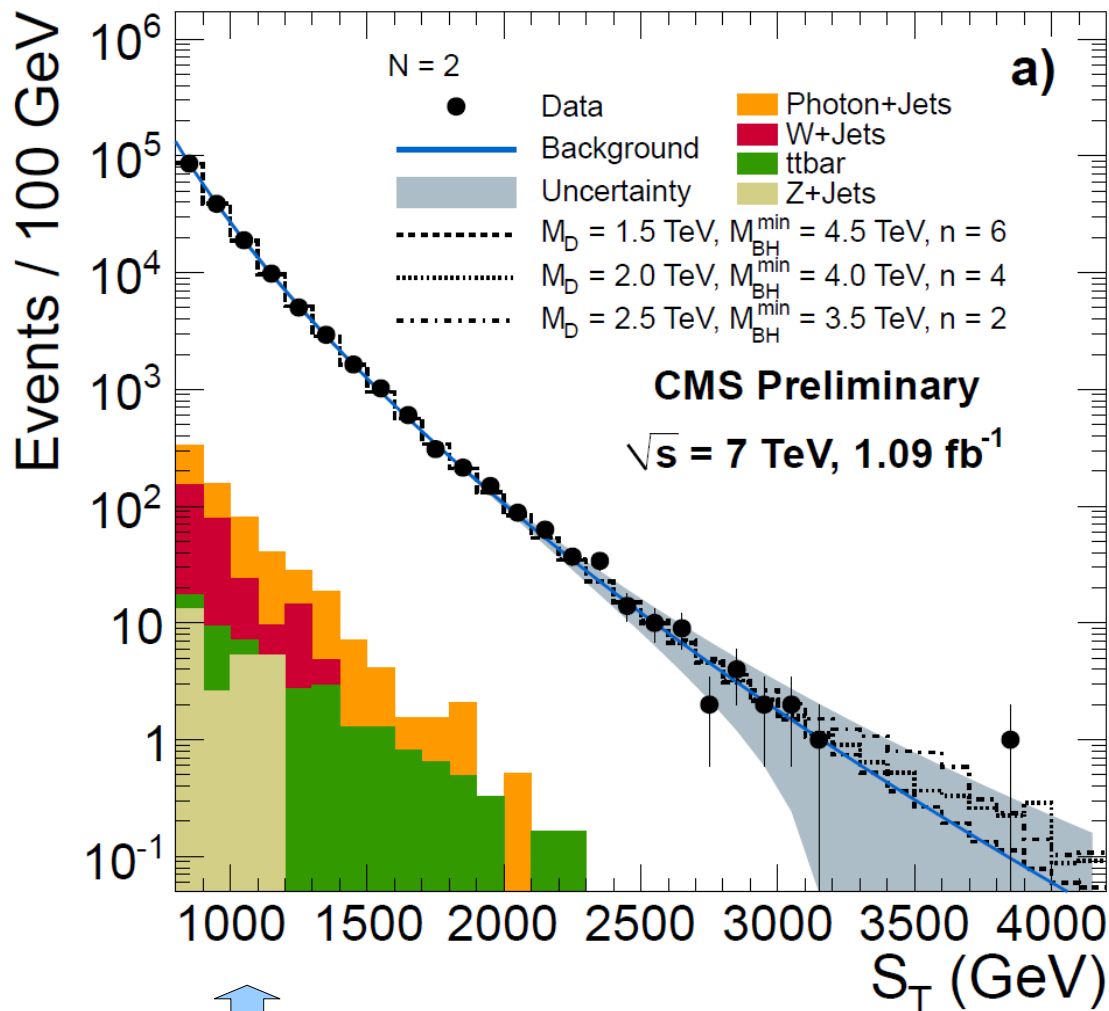
© Sabine Hossenfelder

- Reduced Planck scale due to large extra dimension \rightarrow increased Schwarzschild radius
- Large cross-sections possible $O(100 \text{ pb})$
- Ansatz: $\sigma \sim \pi r_s^2$
- Signature: events with high particle multiplicities and high transversal momentum

simulation of signal events with:

- a) **BlackMax** (no brane tension, **rotating/non-rotating**, no graviton)
- b) **Charybdis2** (rotating, **stable remnant**)

MBH: Background Estimation



↑
 sum of transverse momenta S_T for
 object multiplicity $N=2$

Search variables: S_T, N
 (sum of transverse momenta, object multiplicity)

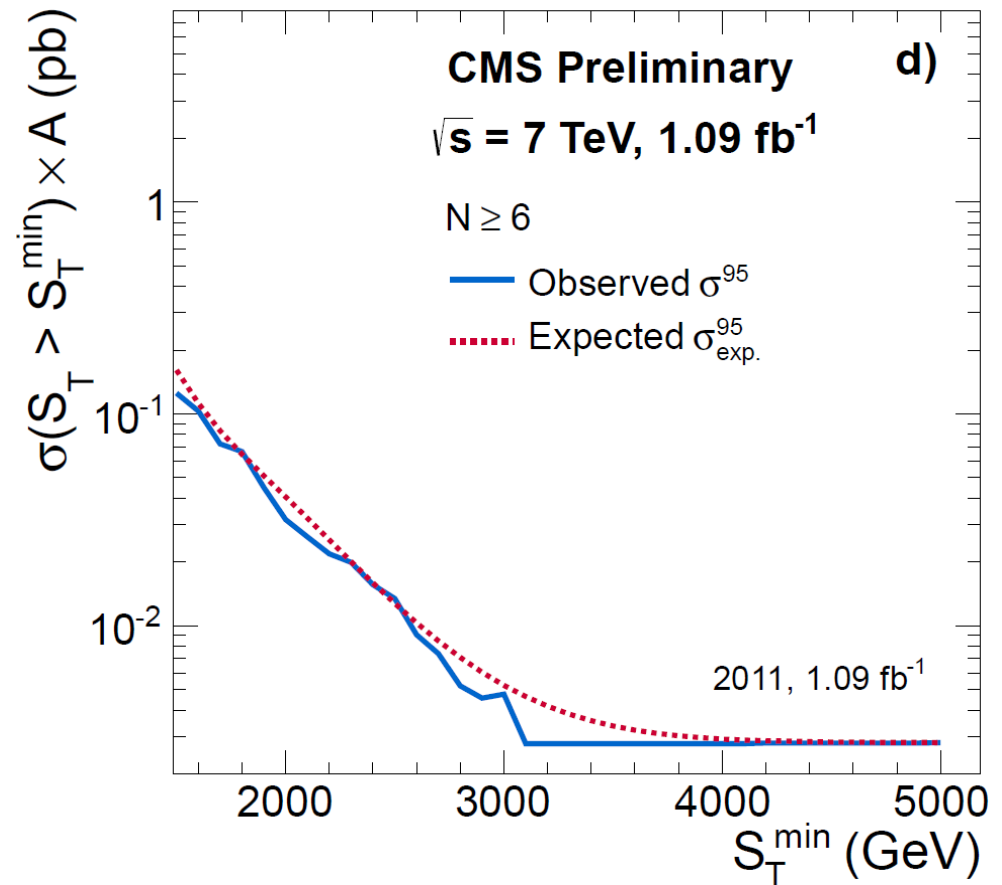
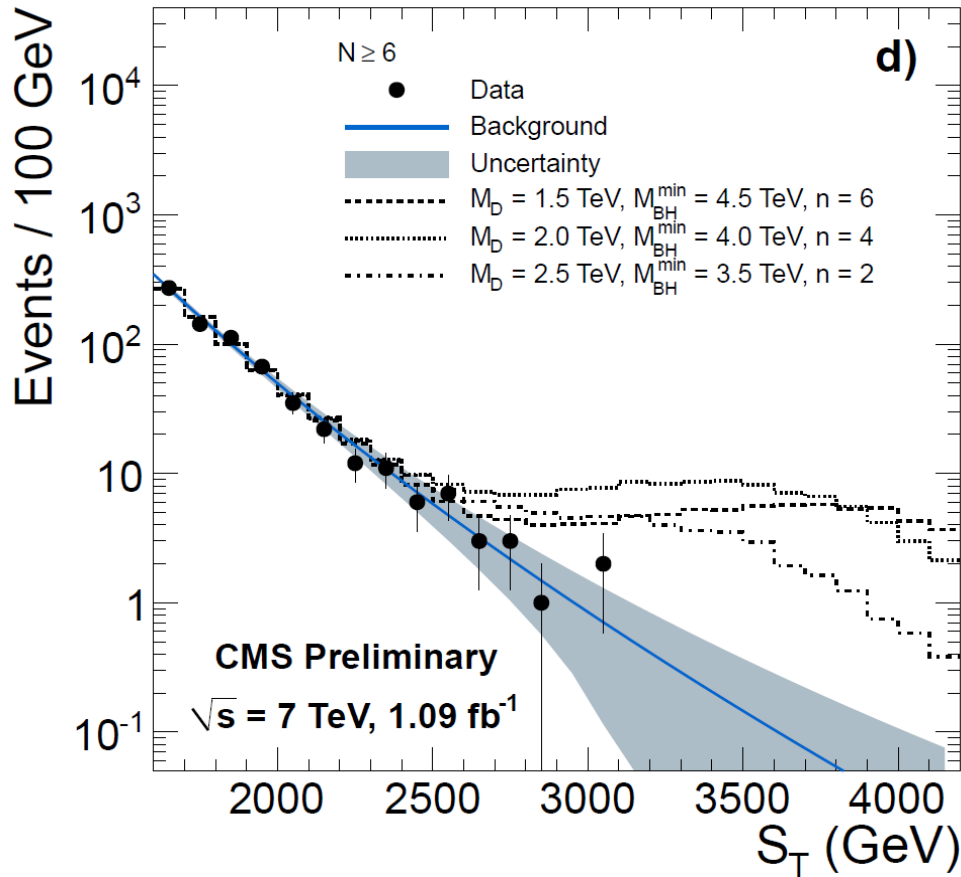
Considered objects:
 (jets, photons, electrons, muons, MET)

Most relevant bkg source:
 - QCD multijet events

QCD multijet bkg from data:

- a) analytic fit for $N=2$ and $N=3$ in signal free region
- b) use that S_T shape is independent of N
- c) normalize fitted shapes in signal free regions to estimate bkg for $N \geq 3 \dots 8$

Model Independent limits (here: $N \geq 6$)



Most relevant systematic bkg uncertainties:

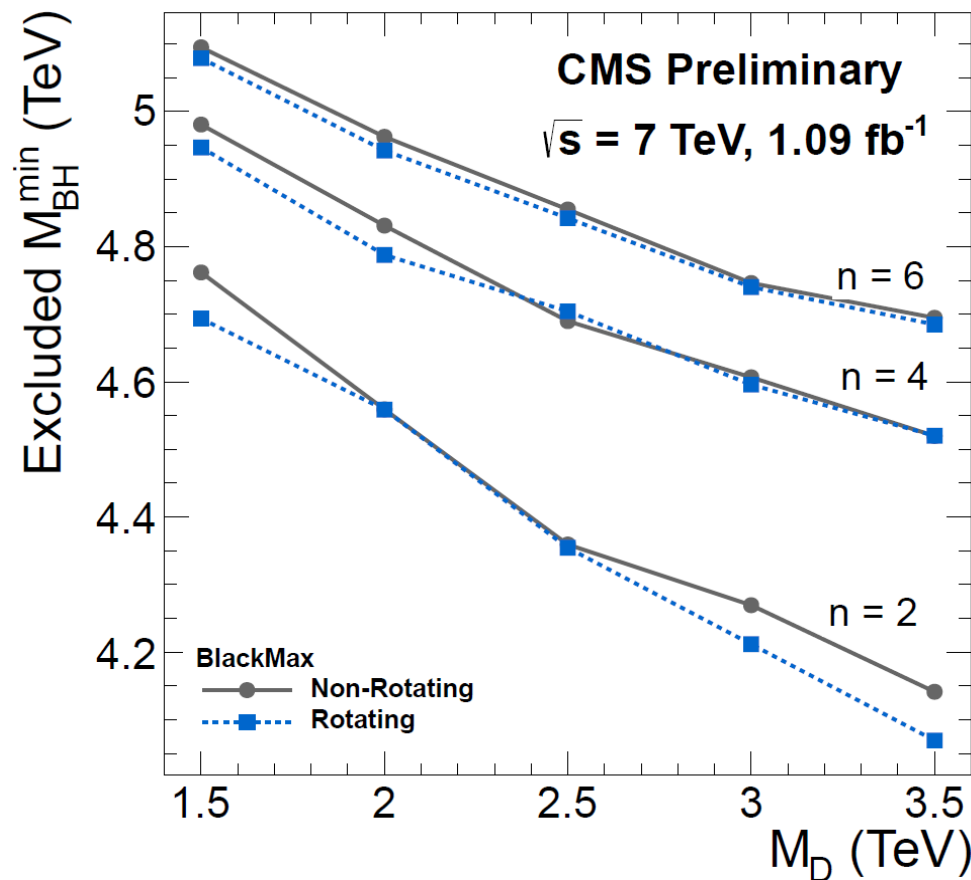
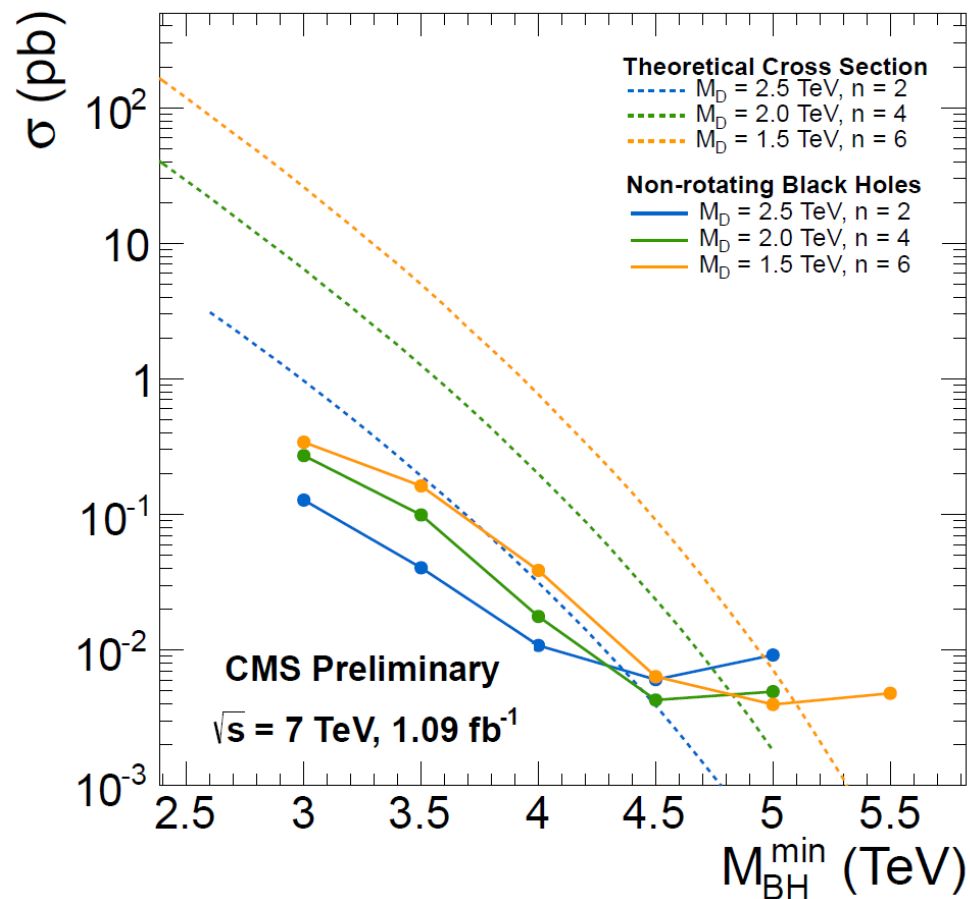
- differences between considered fit functions,
- scale factors for higher multiplicities

Bayesian 95% Upper Limits (Counting Exp.), in dependence on cuts on S_T^{\min} , N

Limits on Microscopic Black Hole Models

Limits for the considered generator models

(naively assuming their applicability for all relevant parameter combinations)



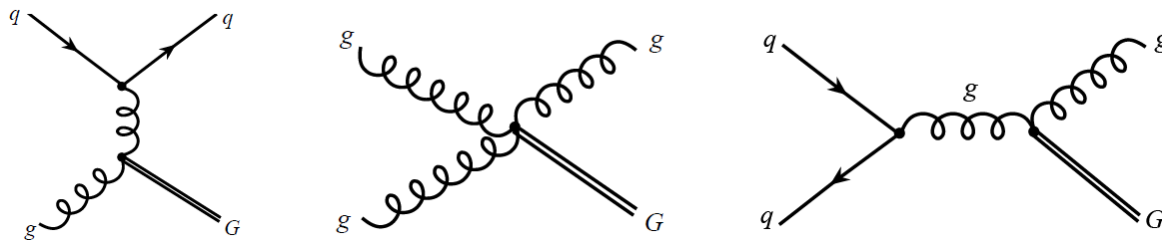
Of course it is important to stay up to date with the progress in the field of Mic. Black Hole Phenomenology

Large Extra Dimensions

- Assume n extra dimensions of equal size compactified on a torus
- The CMS searches are based on two types of signatures in the effective theory:

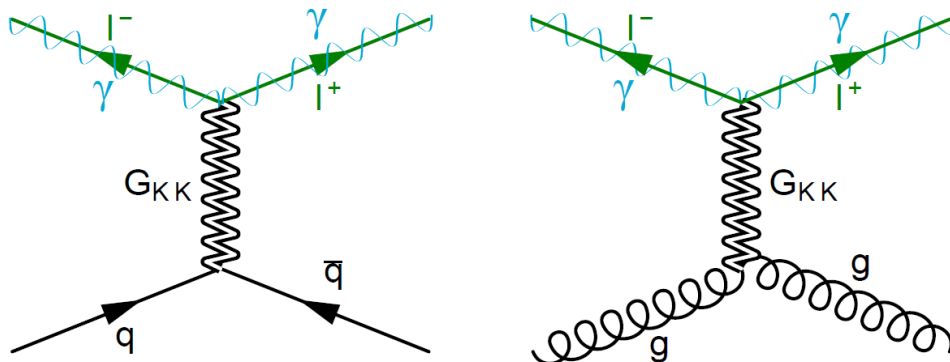
- **Graviton Emission**

limits are set on the effective Planck scale M_D



example graphs:
Jet+Graviton

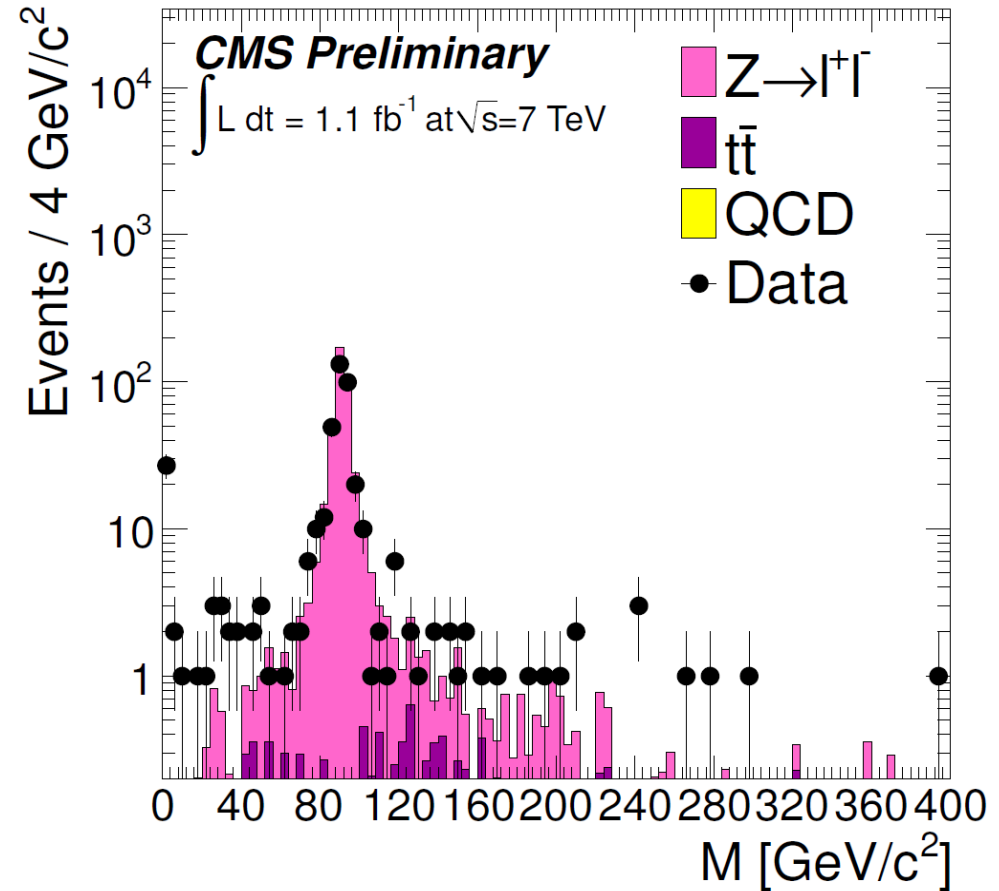
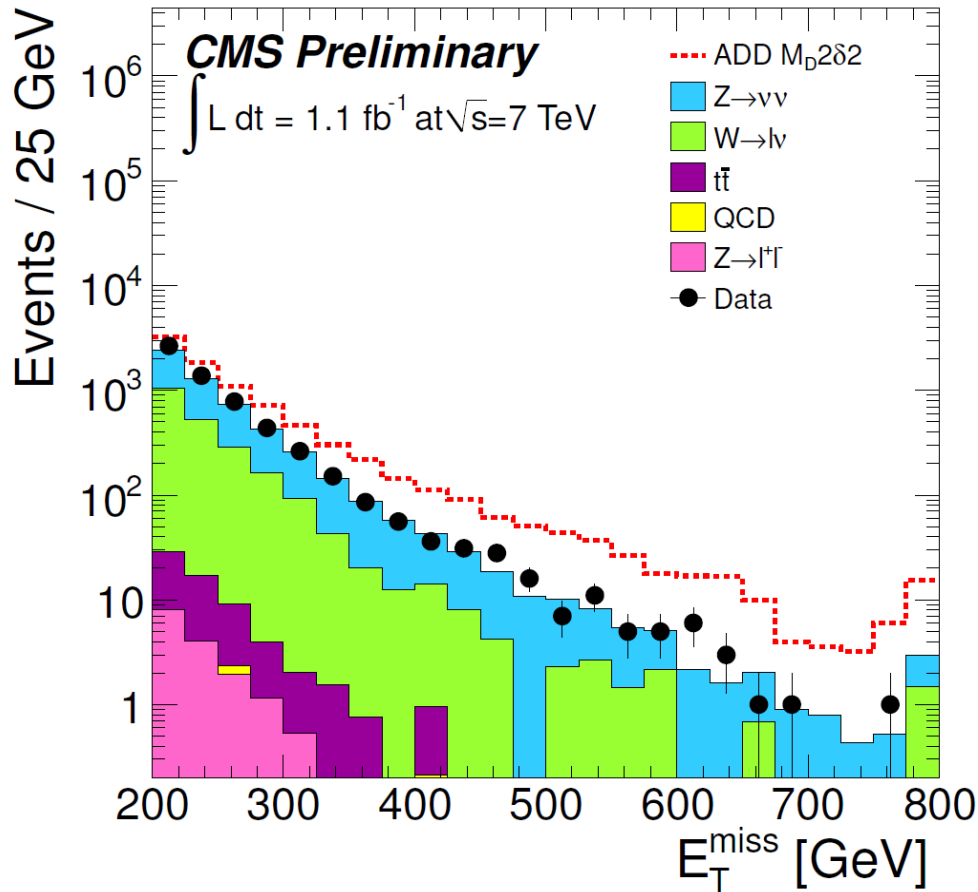
- **Graviton Exchange**



Several parameter conventions

- 1) GRW: G. F. Giudice, R. Rattazzi, J. D. Wells $[\Lambda_T]$
- 2) HLZ: T. Han, J. D. Lykken, R. Zhang $[M_s, n]$
- 3) J. Hewett $[\eta_G]$

ADD Monojet Analysis

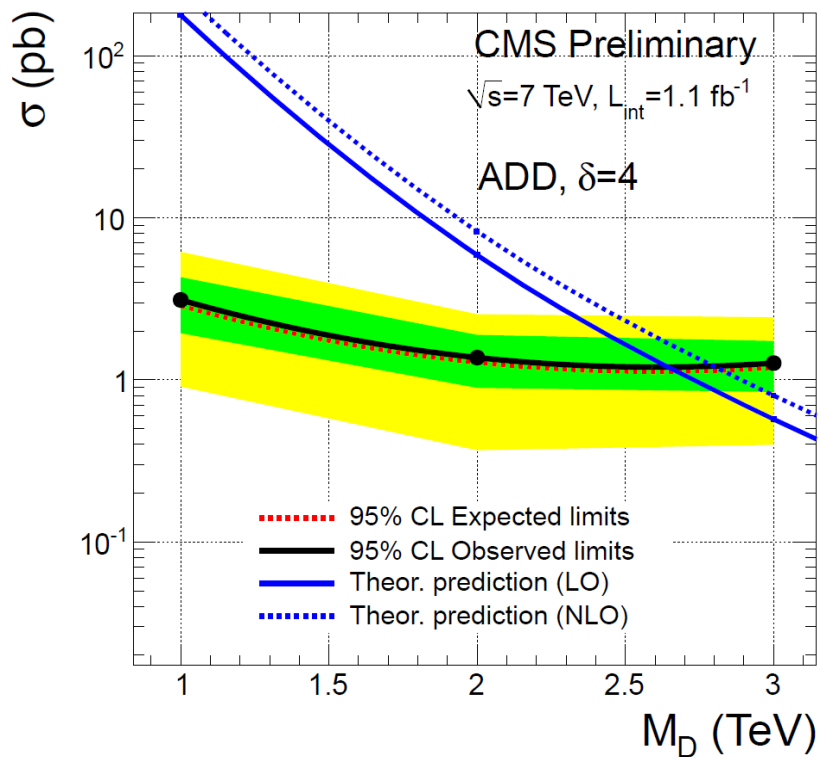


Missing transverse energy for

- veto on isolated lepton
- $p_{T,j1} > 110 \text{ GeV}$

**$Z \rightarrow \mu\mu + \text{jets}$ selection
 for the estimation of
 $Z \rightarrow \nu\nu + \text{jets}$**

ADD Monojets: Results



Dominant bkg sources:

- $Z \rightarrow \nu \nu + \text{jets}$
- $W \rightarrow l \nu + \text{jets}$

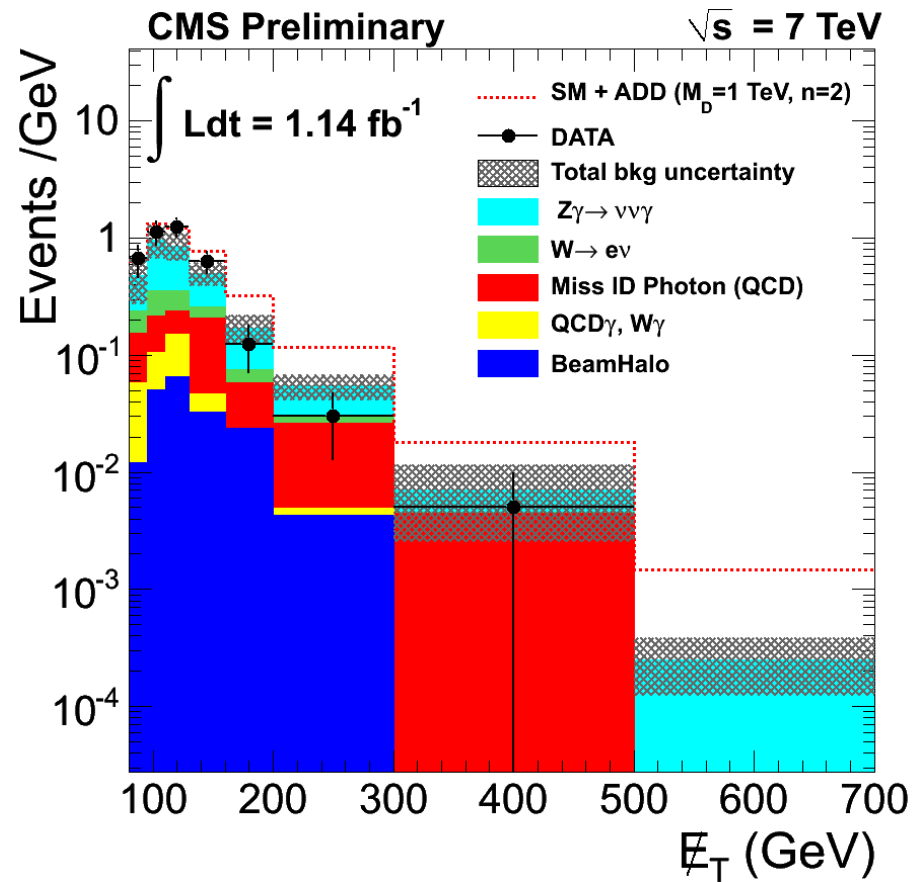
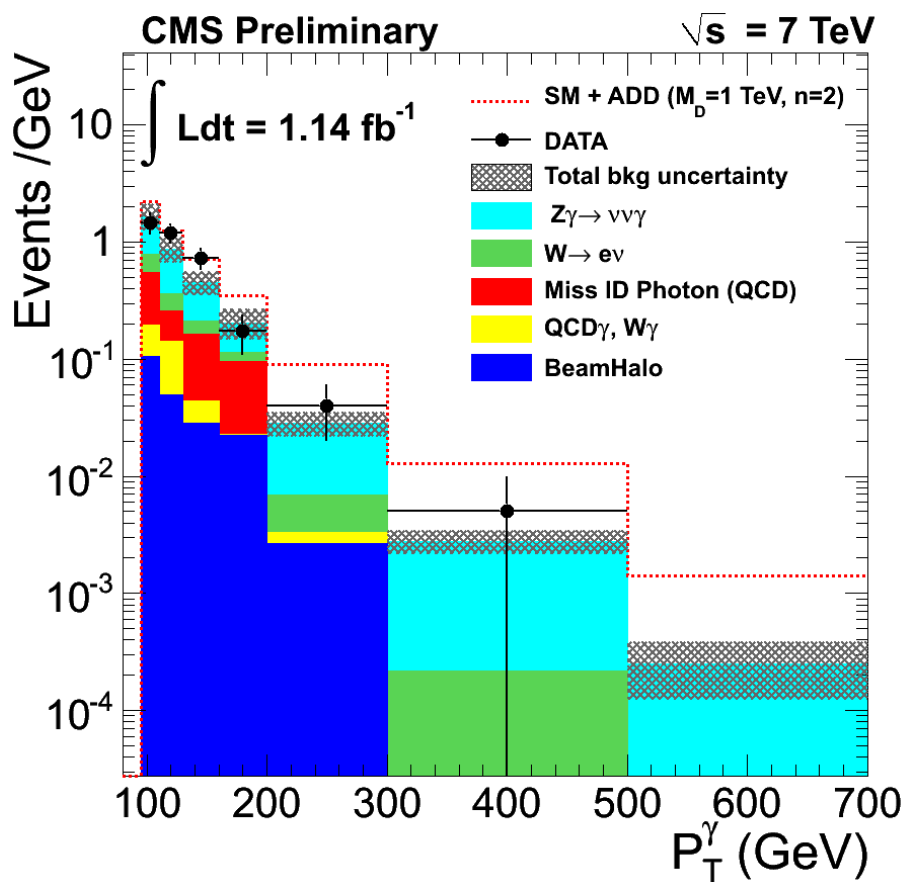
(data driven estimates)

Most important systematic bkg uncertainties:

- jet energy scale
- jet resolution
- PDFs

δ	K factor	CMS 36 pb^{-1}		$E_T^{\text{miss}} > 200 \text{ GeV}$		$E_T^{\text{miss}} > 350 \text{ GeV}$	
		Obs. Limit	Exp. Limit	Obs. Limit	Exp. Limit	Obs. Limit	Exp. Limit
2	1.5	2.56	3.26	3.00	4.10	4.03	
3	1.5	2.07	2.63	2.39	3.25	3.21	
4	1.4	1.86	2.30	2.13	2.83	2.80	
5	1.4	1.74	2.13	1.98	2.57	2.55	
6	1.4	1.68	2.04	1.91	2.39	2.36	

Monophoton Analysis

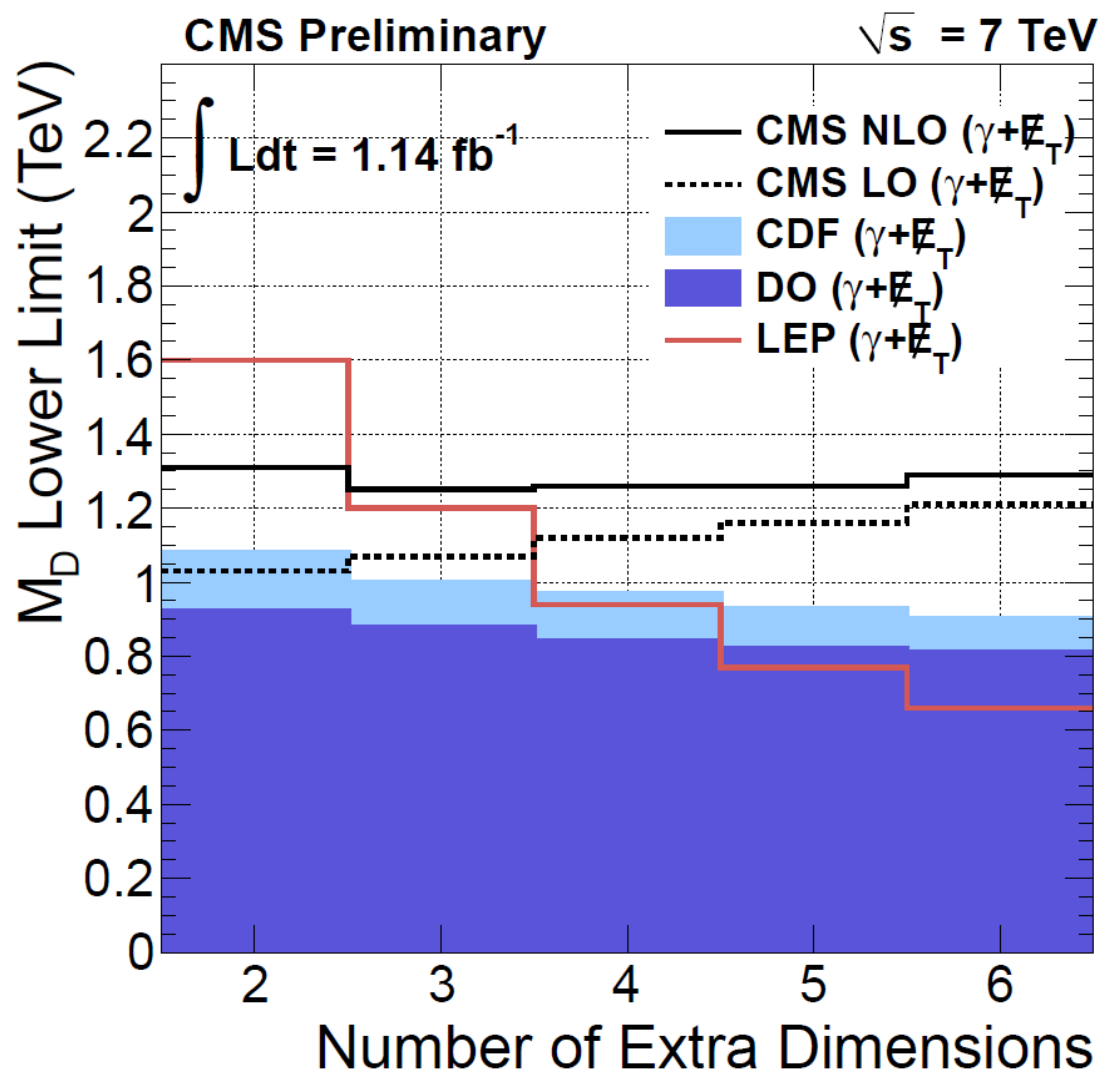


Total Background	67.3 ± 8.4
Total Observed Candidates	80

Most relevant bkg sources:

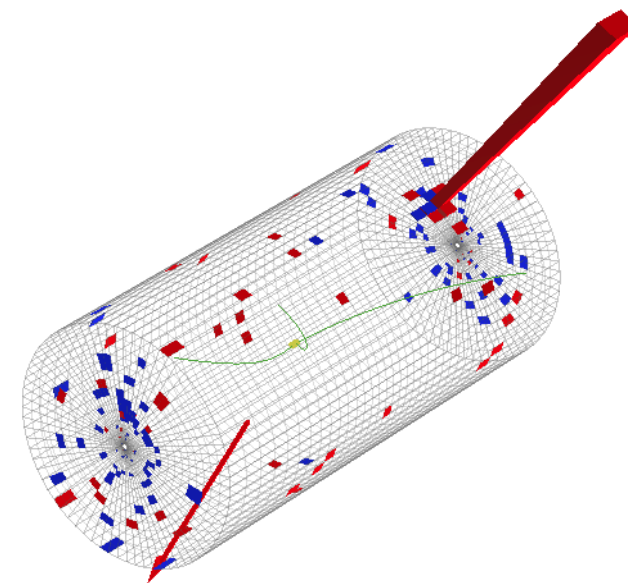
- $Z\gamma \rightarrow \nu\nu\gamma$
- $W \rightarrow e\nu$
- $Jet \rightarrow Miss ID Photon$

Monophoton Analysis



Most relevant systematic bkg uncertainties:

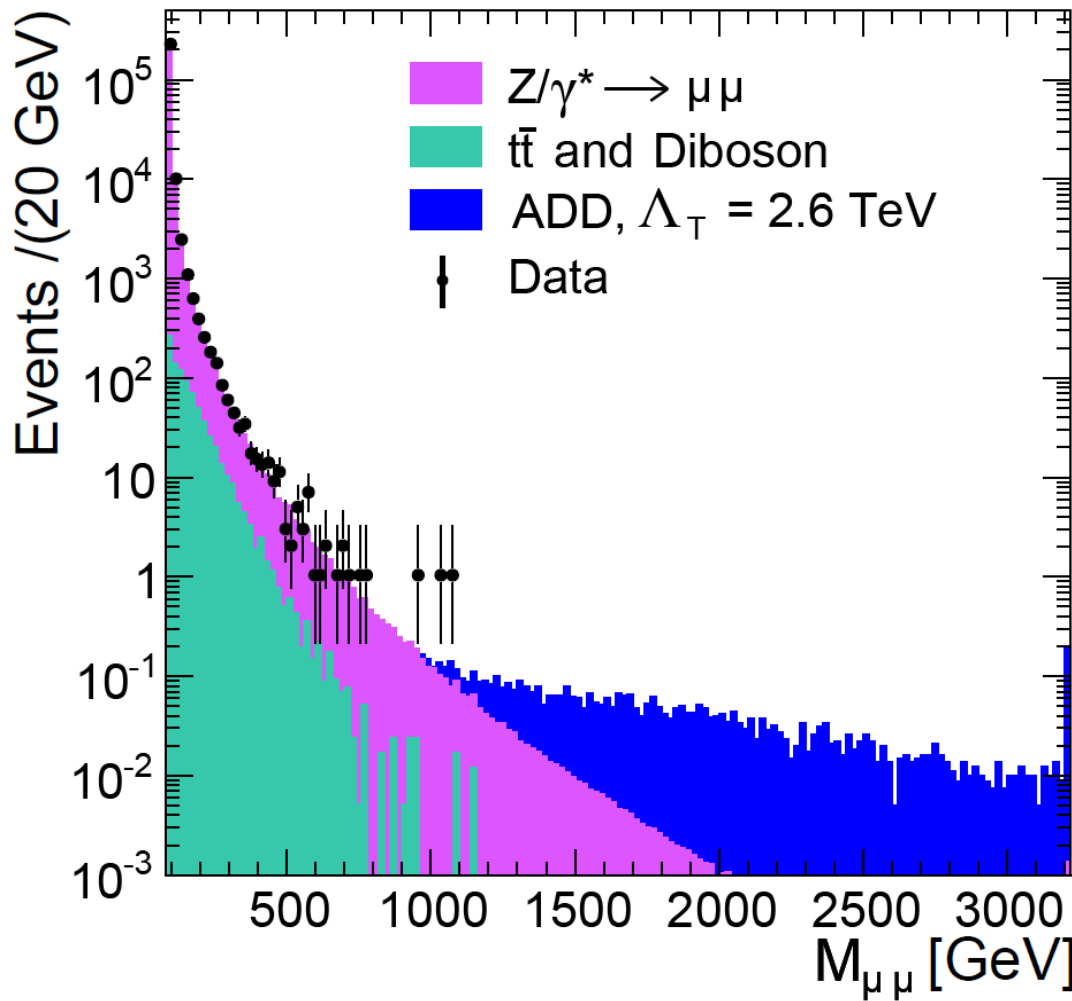
- jet energy / photon / MET scales
- PDFs



CMS Experiment at LHC, CERN
 Data recorded: Sun Apr 24 22:57:52 2011 CDT
 Run/Event: 163374 / 314736281
 Lumi section: 604

Nonresonant Dimuon Analysis

CMS preliminary $\sqrt{s} = 7 \text{ TeV}, \int L dt = 1.18 \text{ fb}^{-1}$

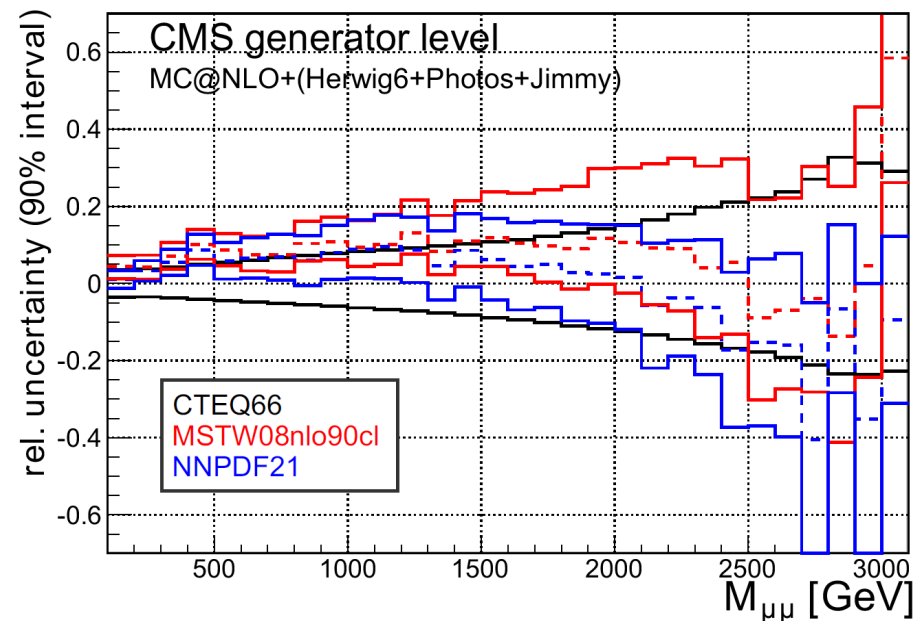


Drell-Yan high mass prediction based on **MC@NLO** (and full CMS simulation) with additional corrections from Horace and **FEWZ**

Dominant bkg sources:

- $Z/\gamma \rightarrow \mu\mu$
- $t\bar{t} \rightarrow \mu\mu + X$

(data driven estimates)



ADD Dimuons: Observed Limits

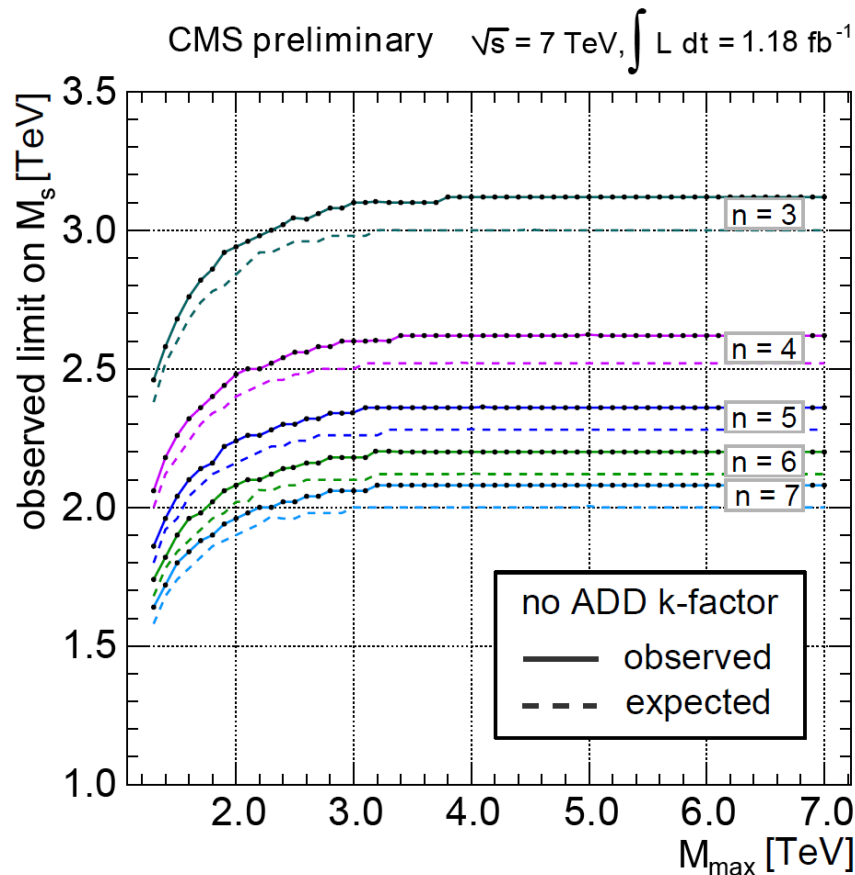
Most important systematic bkg uncertainties:

- PDFs
- higher order corrections

Signal region:

$$M_{\mu\mu} > 1.1 \text{ TeV}$$

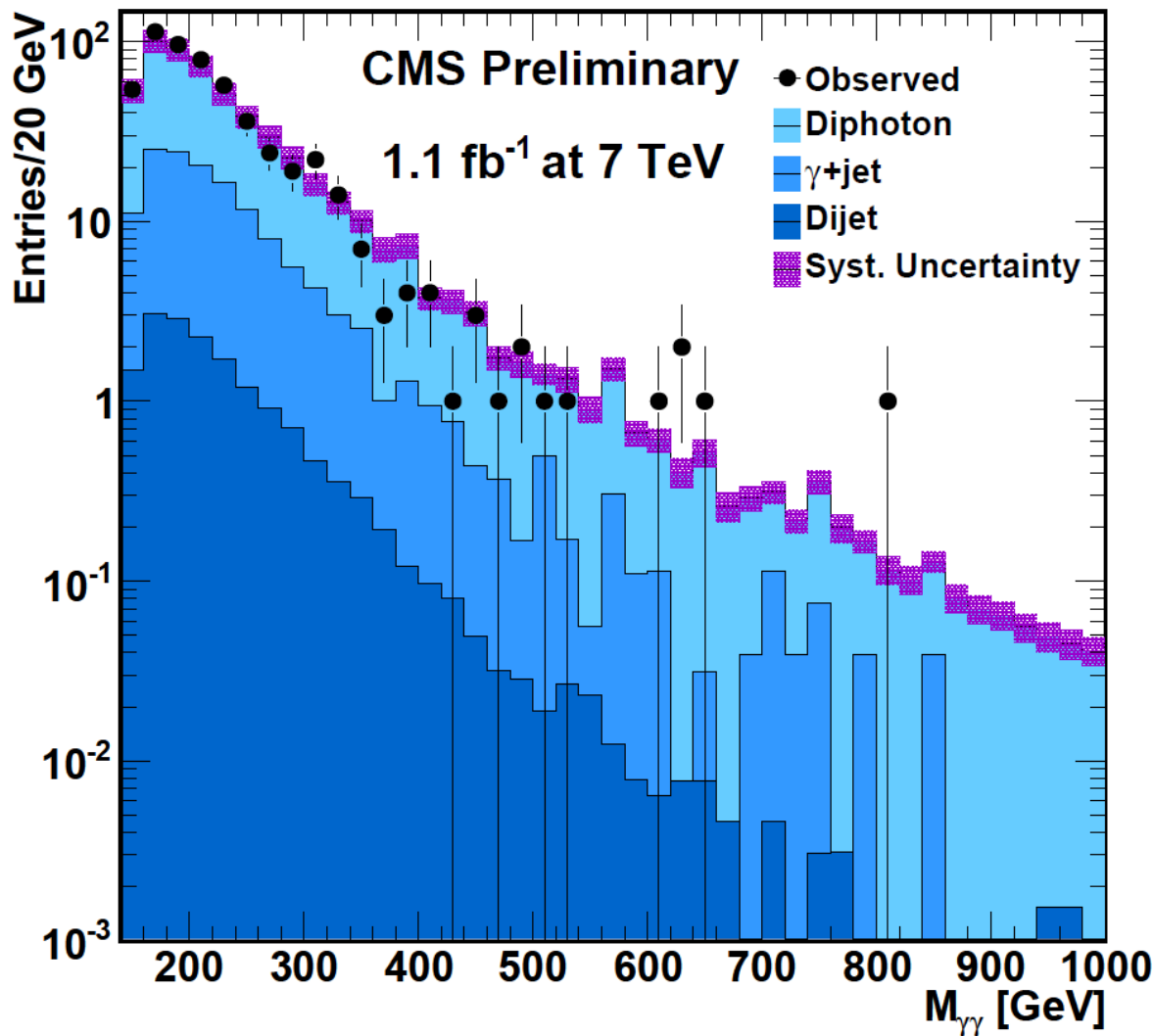
$$|\eta_{\mu}| < 2.1$$



validity range of the effective theory

	Λ_T [TeV] (GRW)	M_s [TeV] (HLZ)					
		$n = 2$	$n = 3$	$n = 4$	$n = 5$	$n = 6$	$n = 7$
ADD k-factor: 1.0							
Full	2.62	2.58	3.12	2.62	2.36	2.20	2.08
Truncated	2.56	2.58	3.10	2.56	2.27	2.09	1.95

ADD Diphoton Analysis



Signal region:

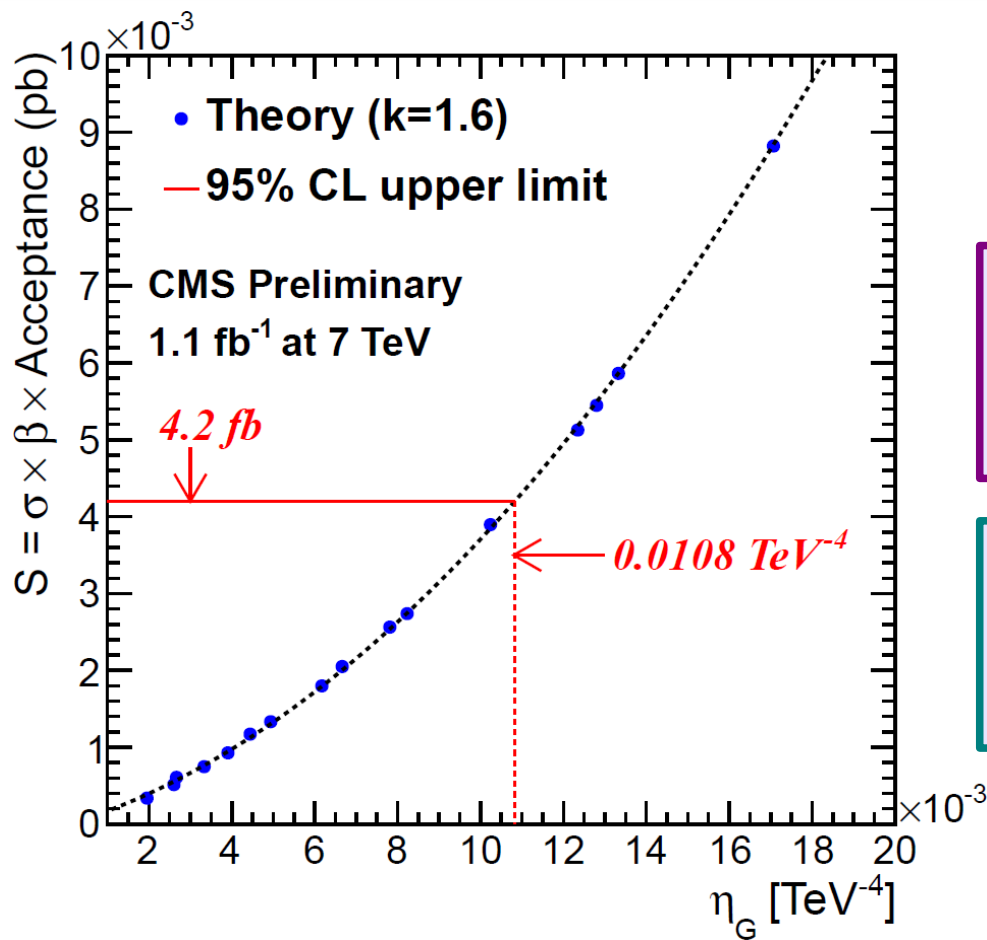
$$M_{\gamma\gamma} > 800 \text{ GeV}$$

$$|\eta_{\gamma}| < 1.4$$

SM background from Diphoton events based on **Pythia** (and full CMS simulation) and NLO corrections from **Diphox+Gamma2MC**

data driven study of **jet → photon fake rate** used to study bkg from dijet and photon+jet events

Results: ADD Diphoton Analysis



Simulation of signal events with **Sherpa**

Dominant bkg sources:

- SM Diphoton Events (from simulation)
- SM Photon+Jet (data driven estimate)

Dominant systematic bkg uncertainties:

- Diphoton k-factor
- PU effects on photon efficiency

Observed limits on M_s for signal truncation at M_s

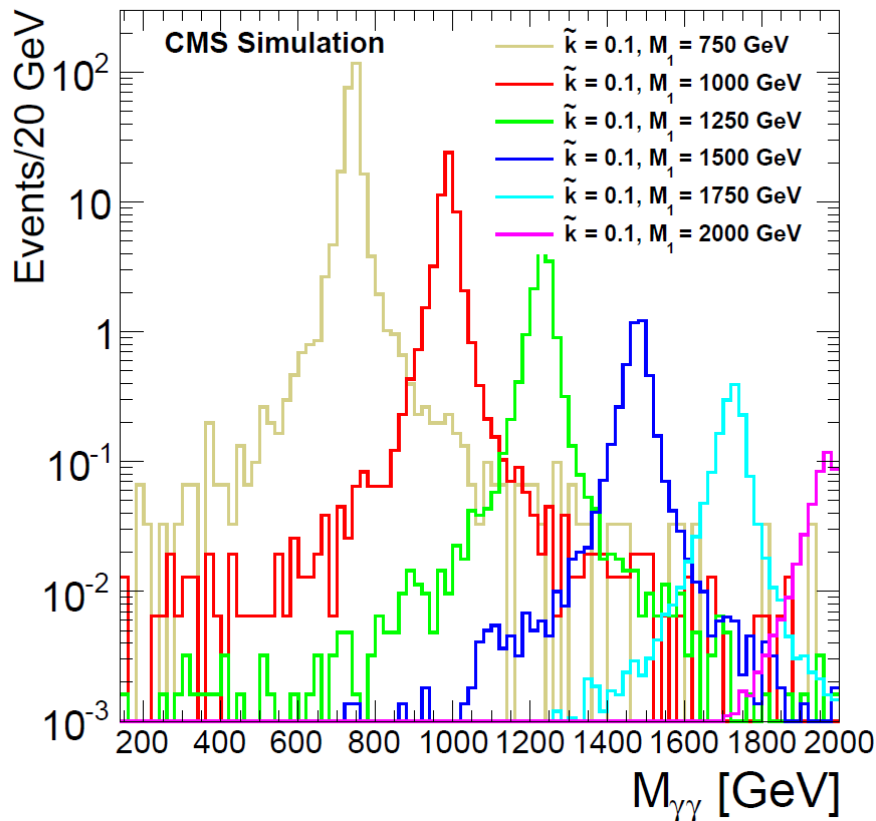
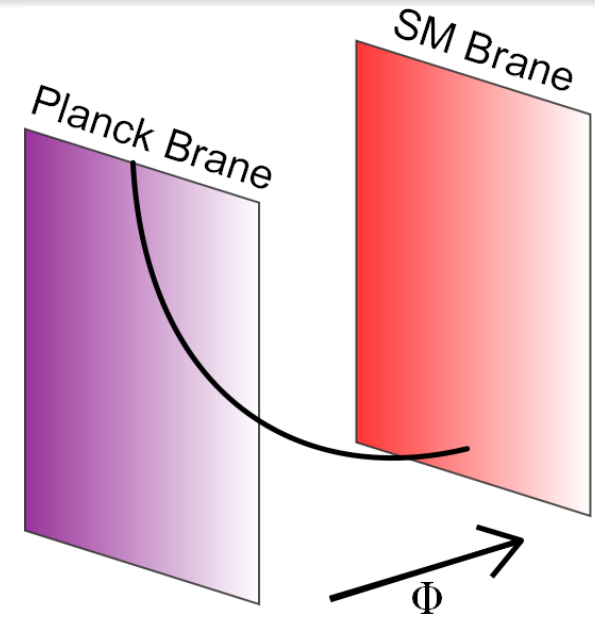
K factor	$n_{\text{ED}} = 2$	$n_{\text{ED}} = 3$	$n_{\text{ED}} = 4$	$n_{\text{ED}} = 5$	$n_{\text{ED}} = 6$	$n_{\text{ED}} = 7$
1.0	3.2	3.4	2.8	2.6	2.4	2.2
1.6	3.5	3.7	3.1	2.8	2.6	2.4

Randall Sundrum (RS-1) Scenario

Slice of AdS_5 space
between two 3+1 branes

"warped" metric

$$ds^2 = e^{-2kr_c\phi} \eta_{\mu\nu} dx^{\mu} dx^{\nu} + r_c^2 d\phi^2$$



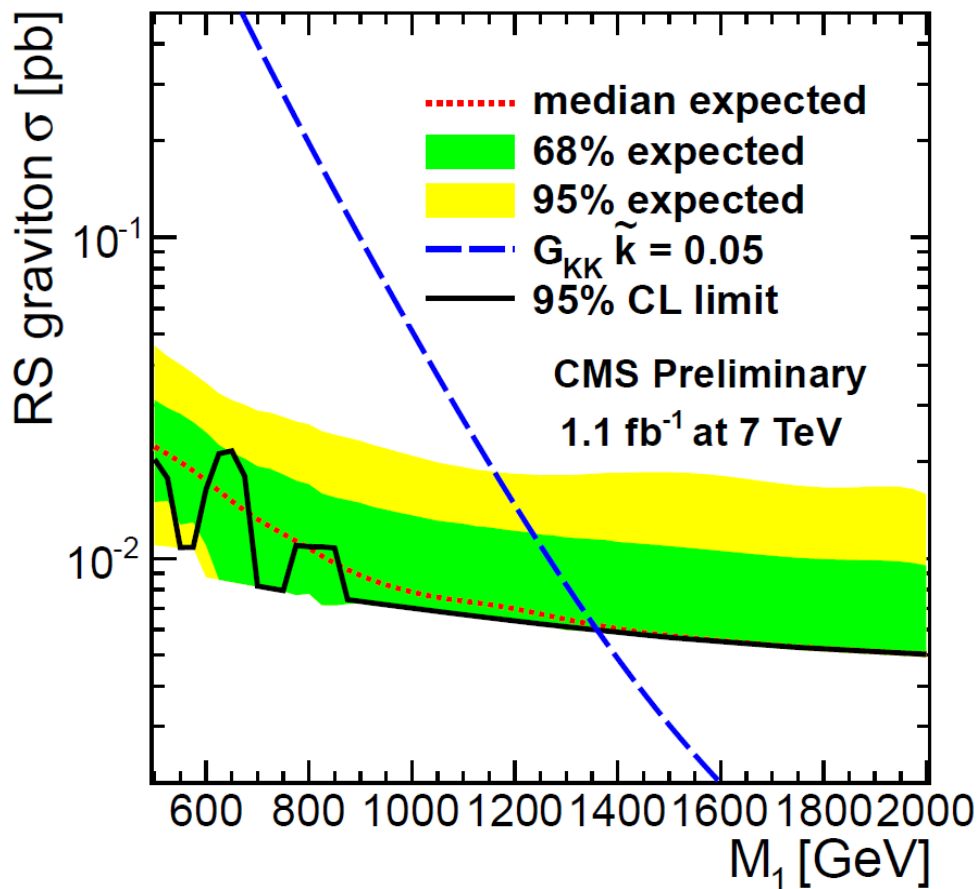
resonant diphoton
signal from the first KK
mode of the Graviton

Model parameters:

graviton mass M_1

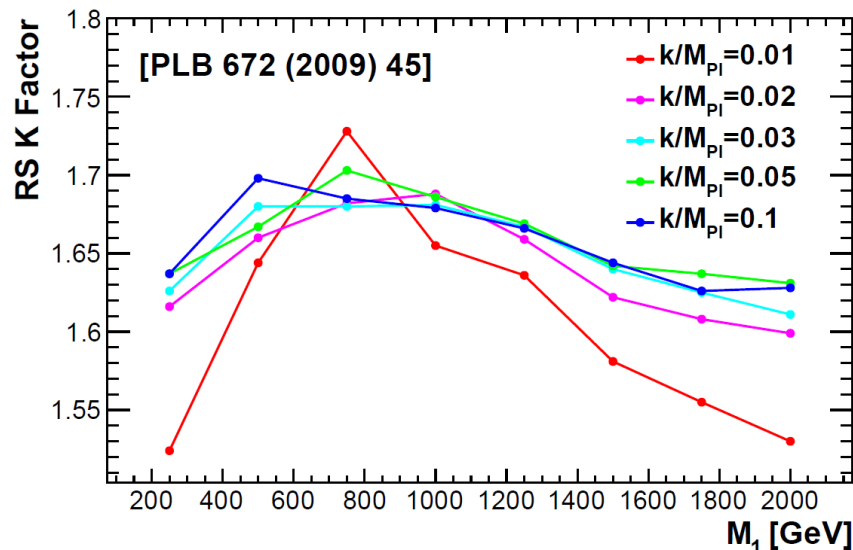
coupling parameter $\tilde{k} = k / M_{Pl}$

Results: RS-1 Diphotons



Limits derived from the Diphoton spectrum as shown on slide 18

simulation of RS-1 signal events with **Pythia6**



95% upper limits in (sliding) mass specific signal window

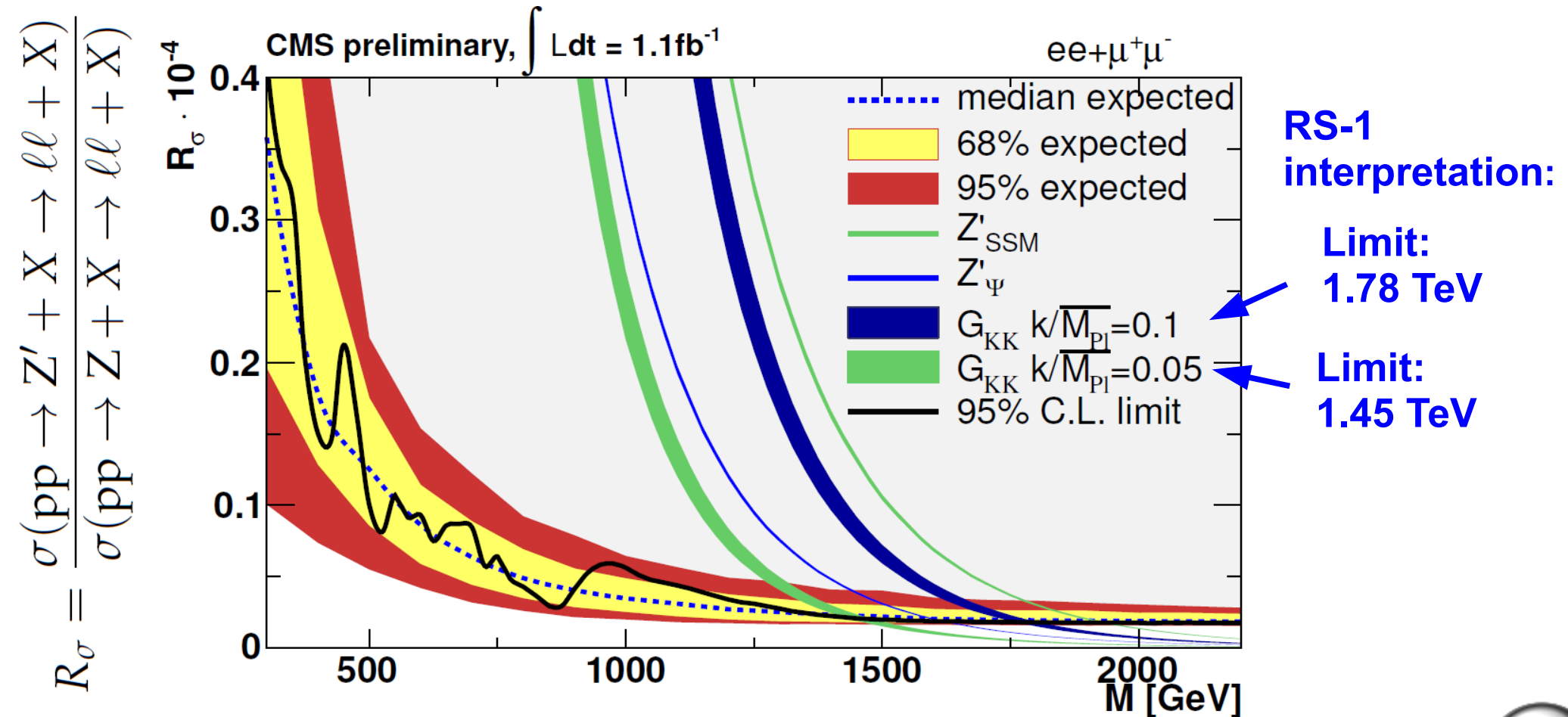
\tilde{k}	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11
M_1 [TeV]	0.77	1.05	1.20	1.31	1.41	1.49	1.57	1.63	1.69	1.74	1.78

Dilepton KK Excitations

Shape based search for a Dilepton excitation in ee and $\mu\mu$ final states



For details on the analysis see the talk given by Sam Harper



Summary

- **Searches for Extra Dimensions at CMS are very active ...**
 - **Many complementary channels are investigated**
 - **Several types of models are considered**
 - **All presented results with $>1 \text{ fb}^{-1}$**
- **Interesting points for discussion ...**
 - **What are the most useful ways of presenting the experimental results?**
 - **Are we missing potentially interesting channels?**
 - **Are there recent developments in the phenomenology of models of Extra Dimensions with implications for LHC searches?**

Link to public CMS result from the EXO group:

<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO>

- Microscopic Black Holes → EXO-11-071
- Graviton Emission: Monojet → EXO-11-059
- Graviton Emission: Monophoton → EXO-11-058
- Graviton Exchange: Dimuon → EXO-11-039
- Graviton Exchange: Diphoton → EXO-11-038
- RS-1 KK Excitation → EXO-11-038
- Dilepton KK excitation → EXO-11-019