Searches for new heavy resonances and large extra dimensions at CMS

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on behalf of the CMS Collaboration

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Overview

- Introduction
- Search for Narrow Resonances in Dilepton Mass Spectra (EXO-12-061, full 2012 dataset)
- Search for Large Extra Dimensions in Dilepton Events (EXO-12-027, EXO-12-031, full 2012 dataset)
- Search for new physics in monojet events (EXO-12-048, full 2012 dataset)
- Search for Microscopic Black Hole Signatures (EXO-12-009, intermediate 2012 dataset)

(W' results omitted as shown in a dedicated presentation)

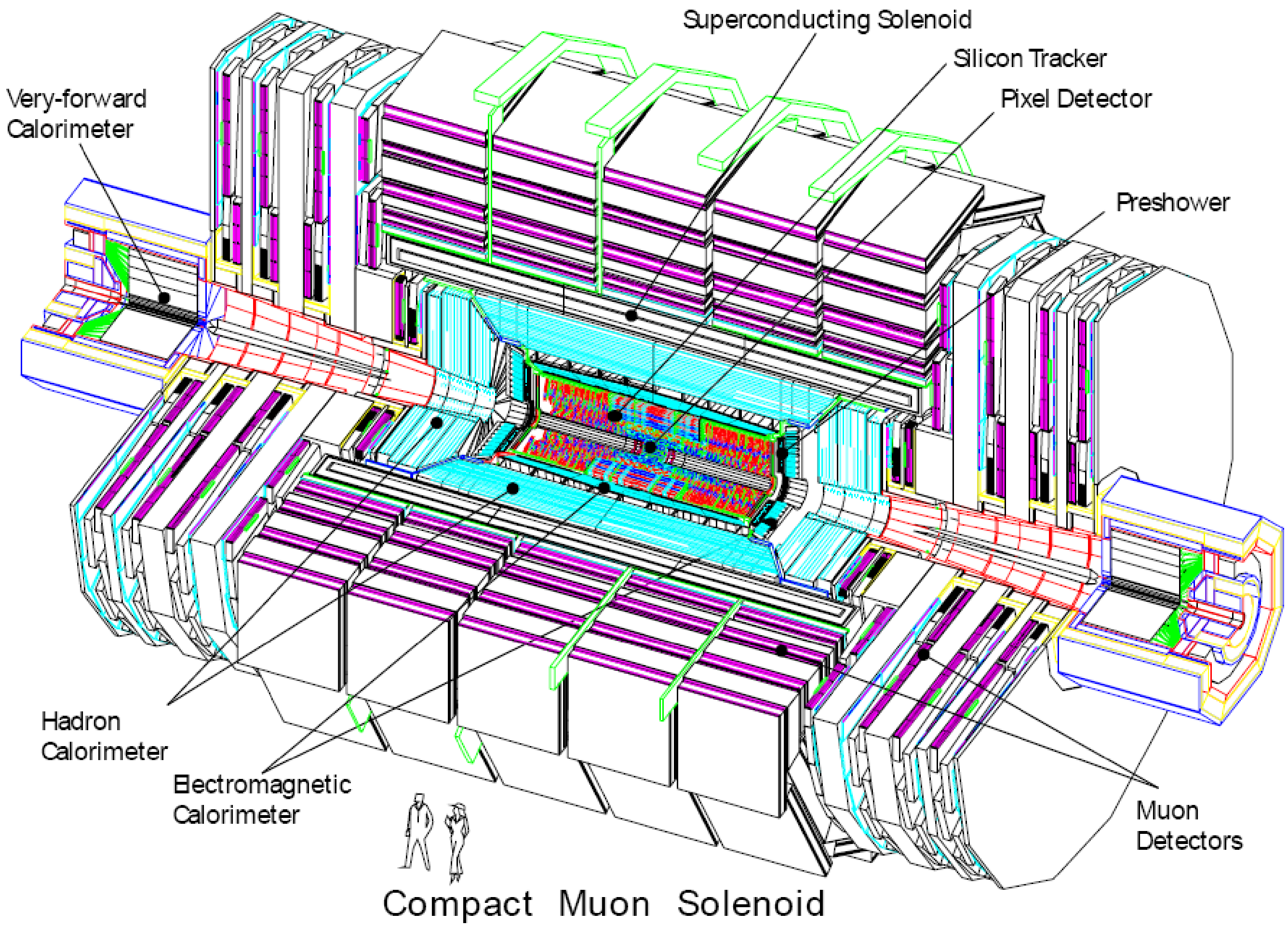
Find these and many more CMS EXO results at:

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

2012 CMS Proton-Proton Data

proton-proton collisions in 2012:

$20\ \mathrm{fb}^{-1}$ of data recorded for analyses at $\sqrt{s} = 8\,\mathrm{TeV}$



Dilepton Resonances

Dielectron Event Selection

- double electron trigger

  $E_T^{cluster} > 33\,\mathrm{GeV}$

- final selection: $p_T^e > 35\,\mathrm{GeV}$

  $|\eta| < 1.44\,(\mathrm{barrel}) \vee 1.56 < |\eta| < 2.5\,(\mathrm{endcap})$

  (at least one barrel electron required)

- isolation requirements in tracker and calorimeter
- track matched to ECAL cluster
- $|d_{xy}| < 0.2(0.5)\,\mathrm{cm}$ in barrel (endcap)
- no opposite sign requirement

Dimuon Event Selection

- single muon trigger $p_T^\mu > 40\,\mathrm{GeV}$
- final selection:

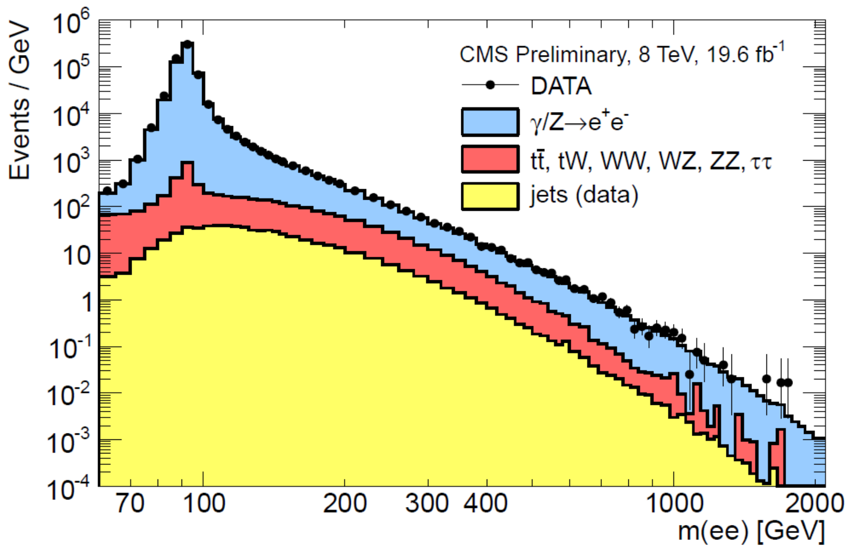
  $p_T^\mu > 45\,\mathrm{GeV}, \; |\eta| < 2.1$, 1st muon

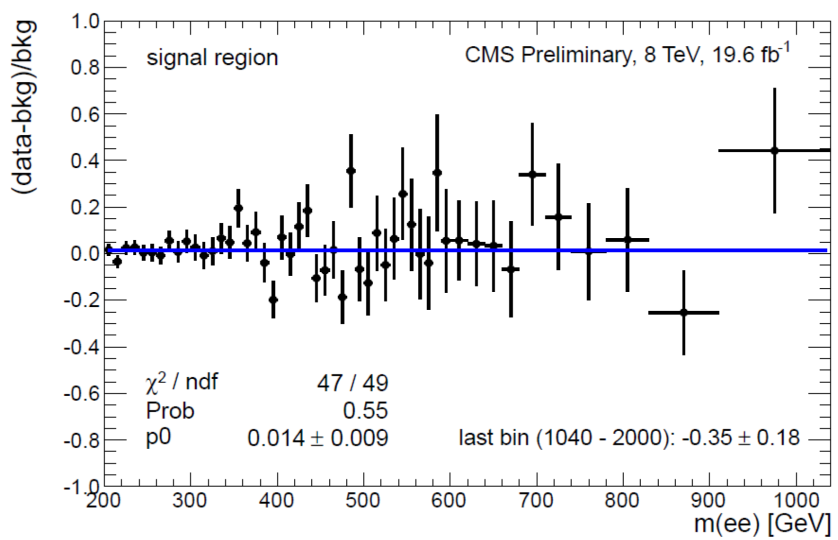
  $p_T^\mu > 45\,\mathrm{GeV}, \; |\eta| < 2.4$, 2nd muon

- muons required to be measured both in tracker and muon system
- tracker isolation
- 5% more data because ECAL isn't used for the event selection
- $|d_{xy}| < 0.2\,\mathrm{cm}$, $|\alpha_{\mu\mu}| < \pi - 0.02$
- opposite sign requirement

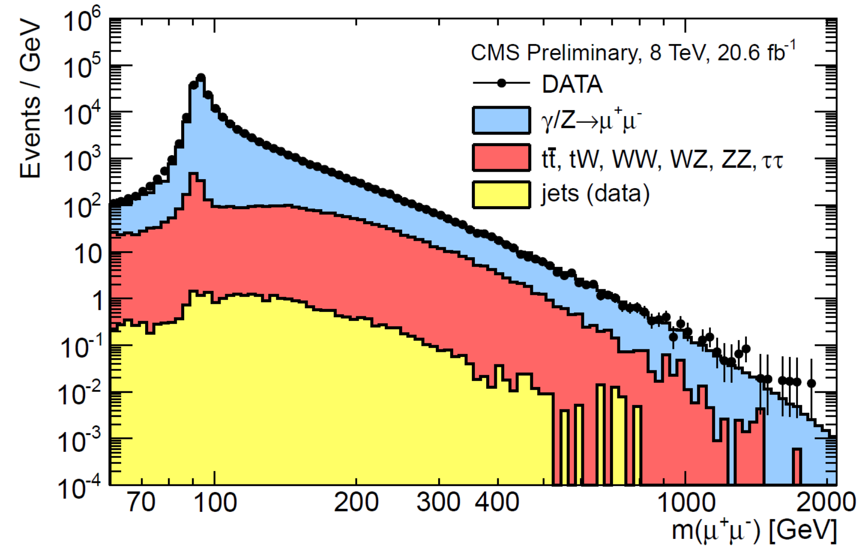
Dilepton Resonances

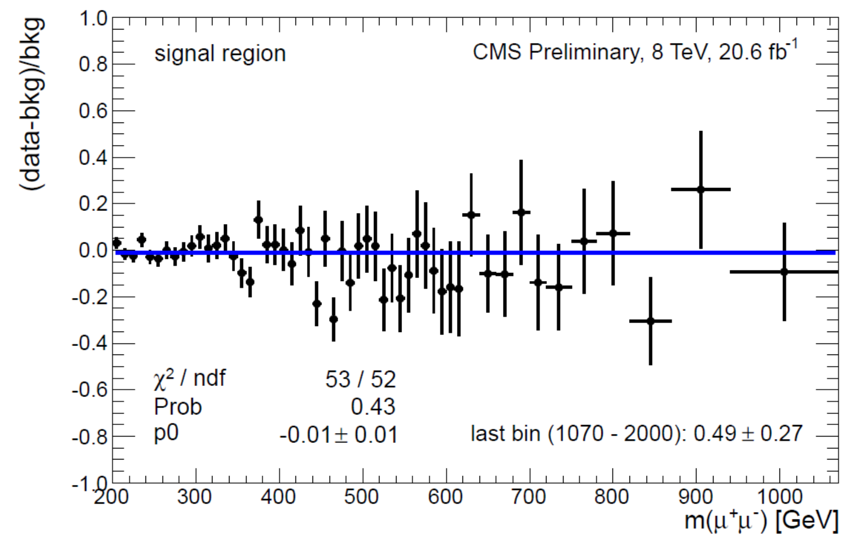
Dielectron Mass Spectrum



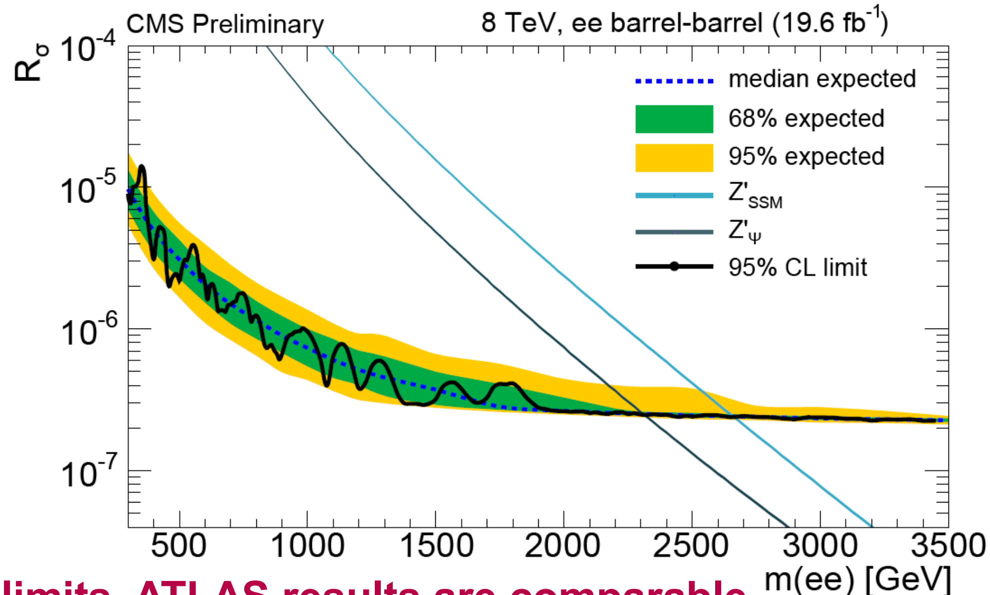


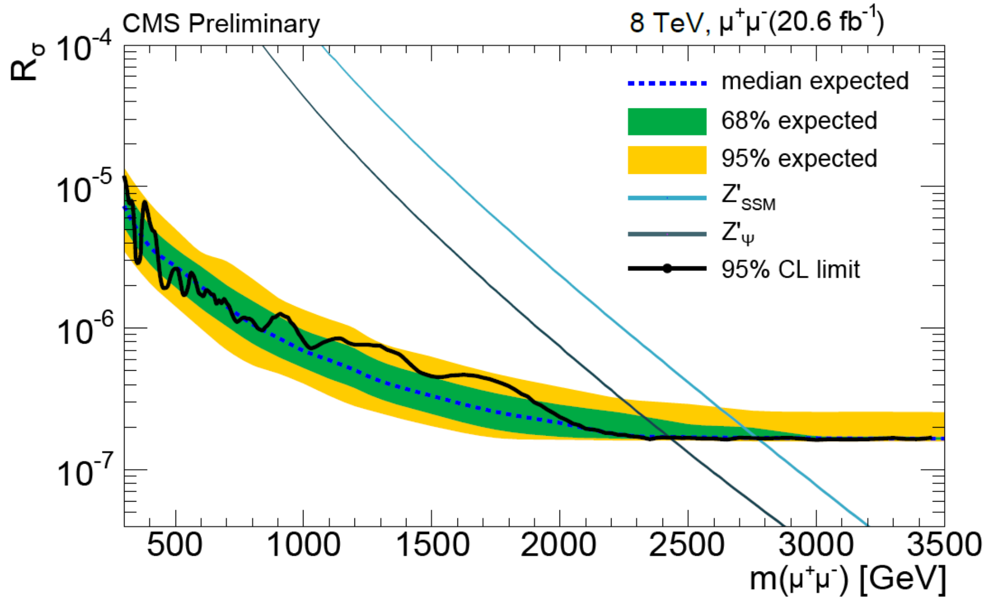
Dimuon Mass Spectrum



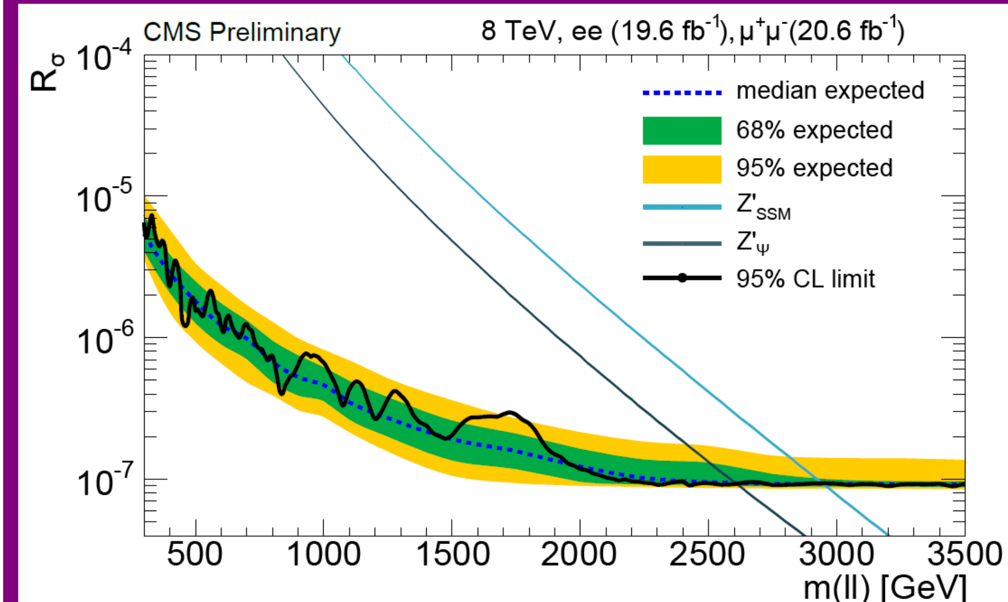


Dilepton Resonances





best limits, ATLAS results are comparable

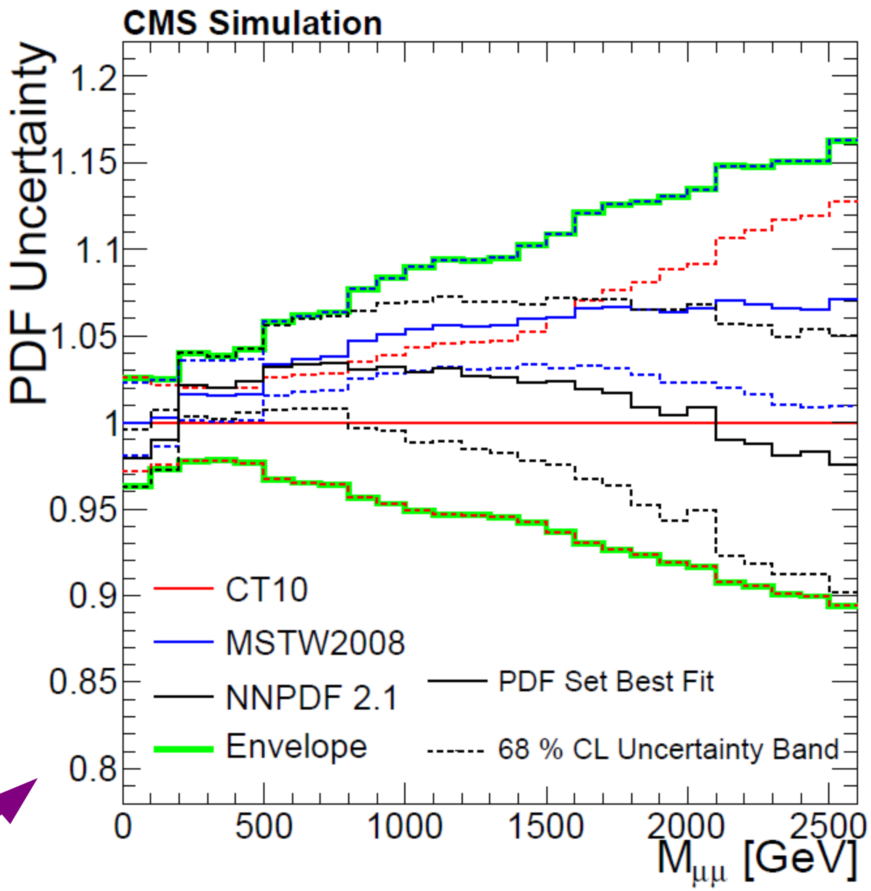


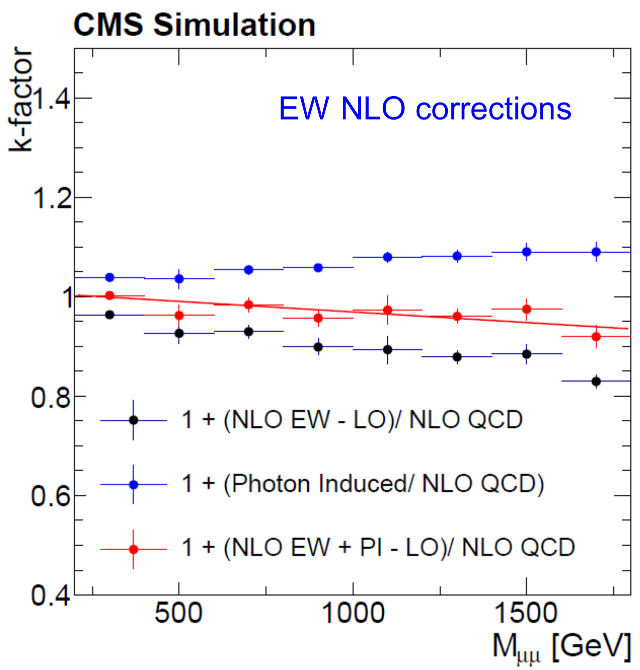
$$R_\sigma = \frac{\sigma(pp \to Z' + X \to \ell\ell + X)}{\sigma(pp \to Z + X \to \ell\ell + X)}$$

- expected shape based on fit to the bkg simulation
- signal width assumed to be dominated by detector resolution (narrow resonance)

Non-Resonant Dilepton Search

- same event selection as resonance search
- try to find inv. mass tail enhancement
- depends more on the bkg simulation
- no unbinned likelihood limits but simple counting experiment with optimized lower mass threshold





Plots shown for the dimuon channel, similar results for dielectron events

Non-Resonant Dilepton Search

$\mu^+\mu^-$ — $\mu\mu$, $\mathcal{L} = 20.6\ \mathrm{fb}^{-1}$

Mass region [TeV]	N_{obs}	Background expectation	Signal exp. $\Lambda_T = 3.6$ TeV
Control regions			
0.12–0.20	$8.20 \cdot 10^4$	$(7.96 \pm 0.64) \cdot 10^4$	
0.20–0.40	$1.92 \cdot 10^4$	$(1.87 \pm 0.15) \cdot 10^4$	
0.40–0.60	$1.42 \cdot 10^3$	$(1.45 \pm 0.14) \cdot 10^3$	
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

ee — ee, $\mathcal{L} = 19.6\ \mathrm{fb}^{-1}$

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

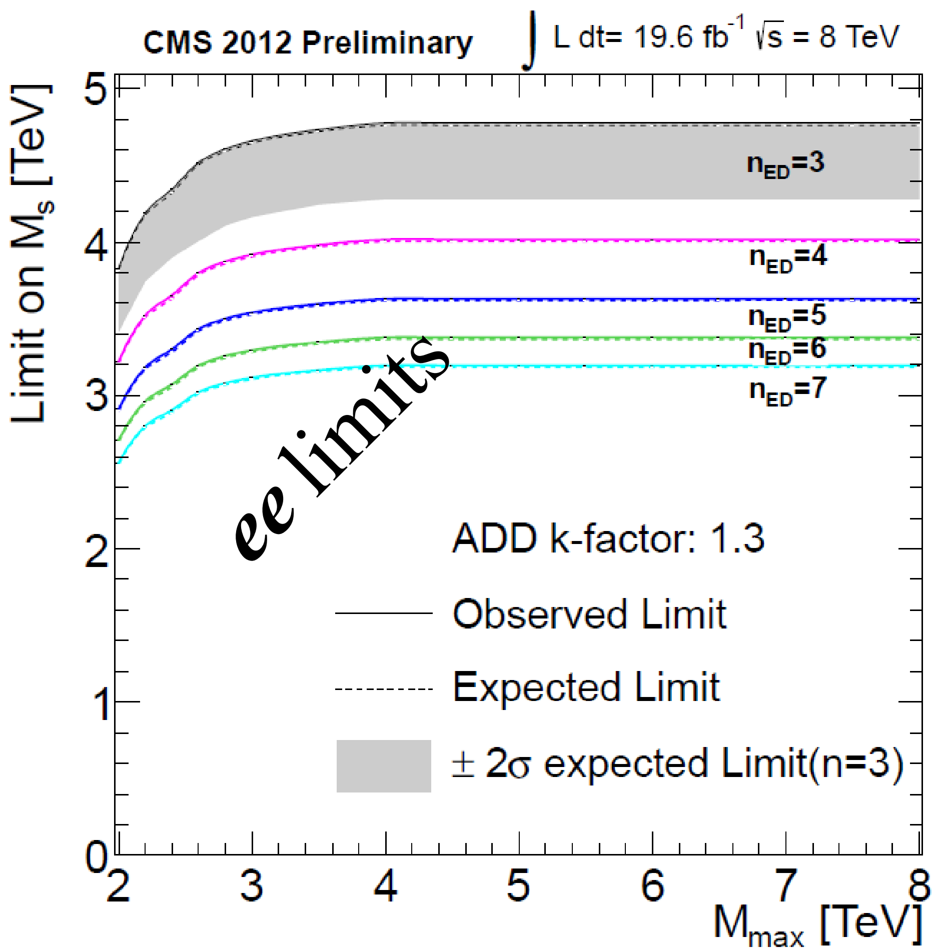
leading systematic uncertainties in the signal region:

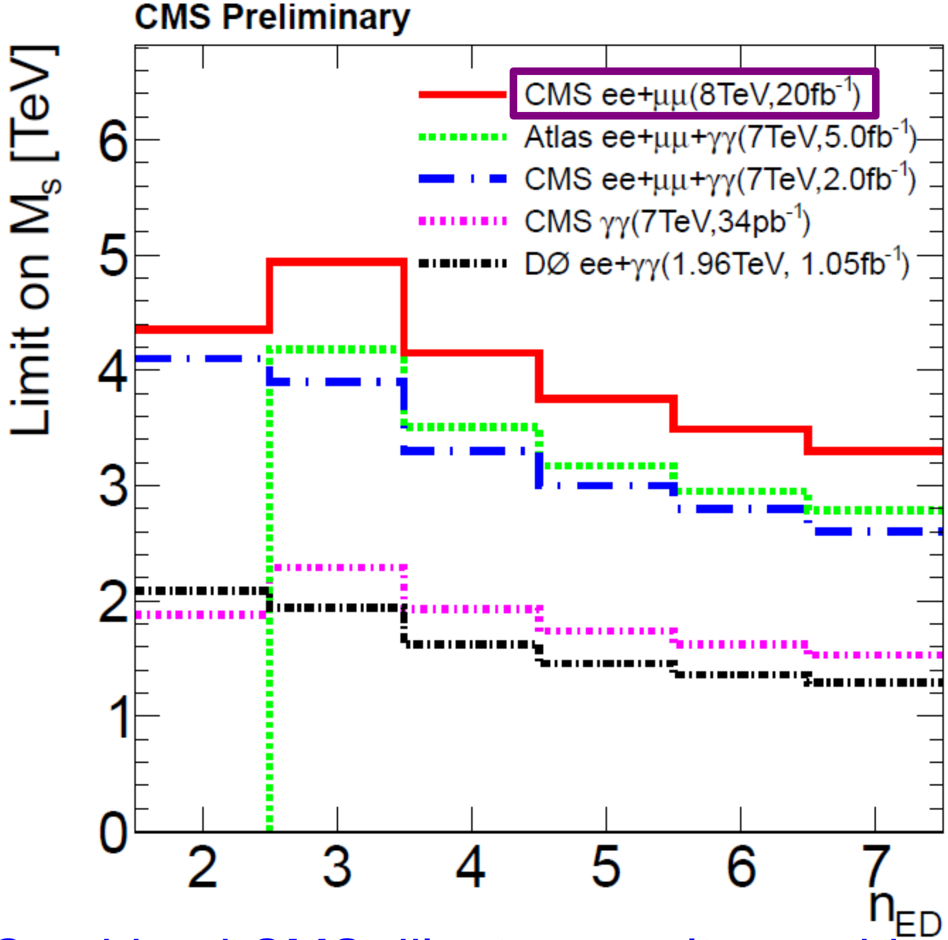
$\mu^+\mu^-$
- muon momentum scale
- PDF uncertainties
- muon mom. resolution
- DY higher order corr.

ee
- PDF uncertainties
- Electron Reco and ID
- DY higher order corr.

Non-Resonant Dilepton Search

Limits on the ADD (Arkani-Hamed, Dimopoulos, Dvali) model





comparable results from the dimuon analysis ...

Combined CMS dilepton results provide the best limits on s-channel graviton exchange

Monojet Search

Trigger:

- $E_T^{miss} > 120\,\mathrm{GeV}$ or
- $E_T^{miss} > 105\,\mathrm{GeV}$, $p_{T,jet} > 80\,\mathrm{GeV}$

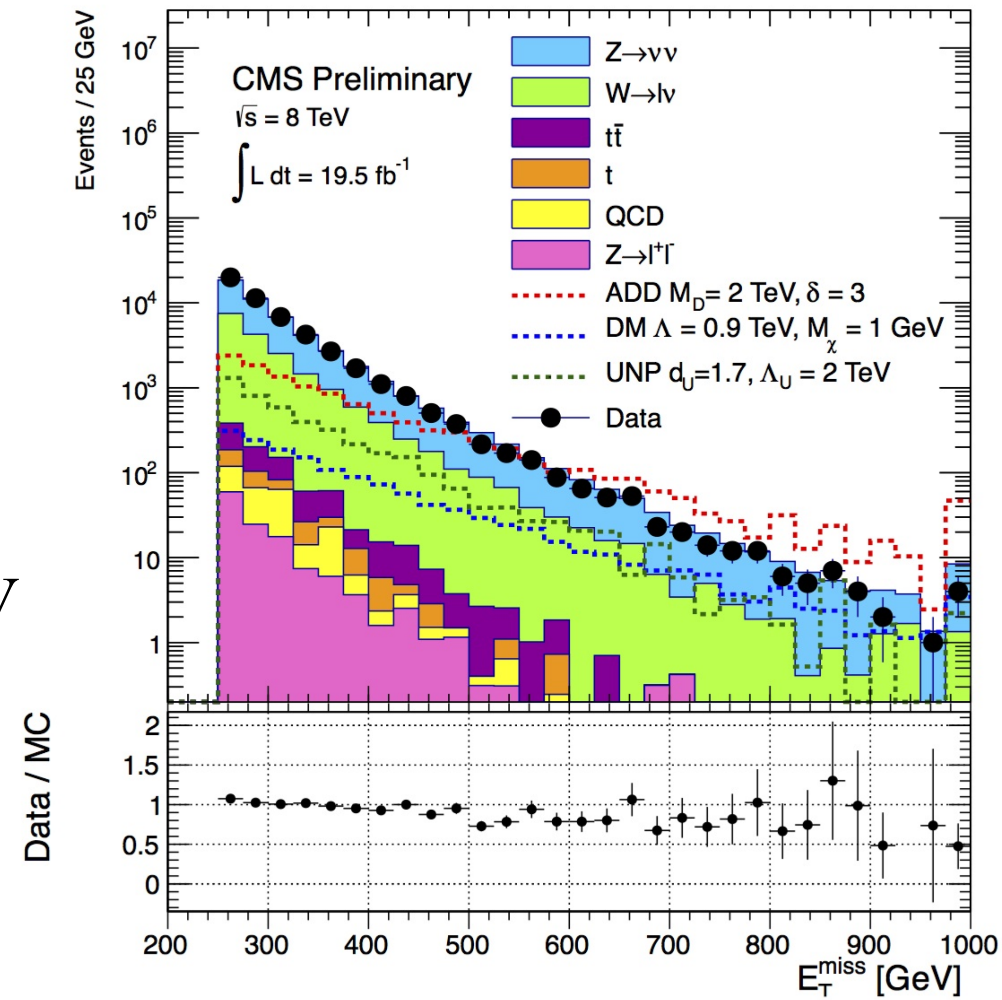
Event Selection:

- jet composition
- veto on isolated muons/electrons
- less than 3 jets with $p_{T,jet} > 30\,\mathrm{GeV}$
- $p_{T,jet\,1} > 110\,\mathrm{GeV}$
- $\Delta\phi_{jet\,1,jet\,2} < 2.5$

Dominant Bkg:

$$Z \rightarrow \nu\nu + \mathrm{Jets}\ ,\ W \rightarrow l\nu + \mathrm{Jets}$$

data compared to simulation



Monojet Search

Data-driven background estimation:

$Z \to \nu\nu + \text{Jets}$
estimated from a dimuon sample

$$N(Z(\nu\nu)) = \frac{N^{\text{obs}} - N^{\text{bgd}}}{A \times \epsilon} \cdot R\left(\frac{Z(\nu\nu)}{Z(\mu\mu)}\right)$$

$W \to l\nu + \text{Jets}$
estimated from a single muon sample

data comapred to
data-driven bkg estimate

E_T^{miss} (GeV) $\rightarrow$	> 250	> 300	> 350	> 400	> 450	> 500	> 550
$Z(\nu\nu)$+jets	30600 ± 1493	12119 ± 640	5286 ± 323	2569 ± 188	1394 ± 127	671 ± 81	370 ± 58
W+jets	17625 ± 681	6042 ± 236	2457 ± 102	1044 ± 51	516 ± 31	269 ± 20	128 ± 13
...							
Total SM	49154 ± 1663	18506 ± 690	7875 ± 341	3663 ± 196	1931 ± 131	949 ± 83	501 ± 59
Data	50419	19108	8056	3677	1772	894	508

Good agreement between SM estimate and data

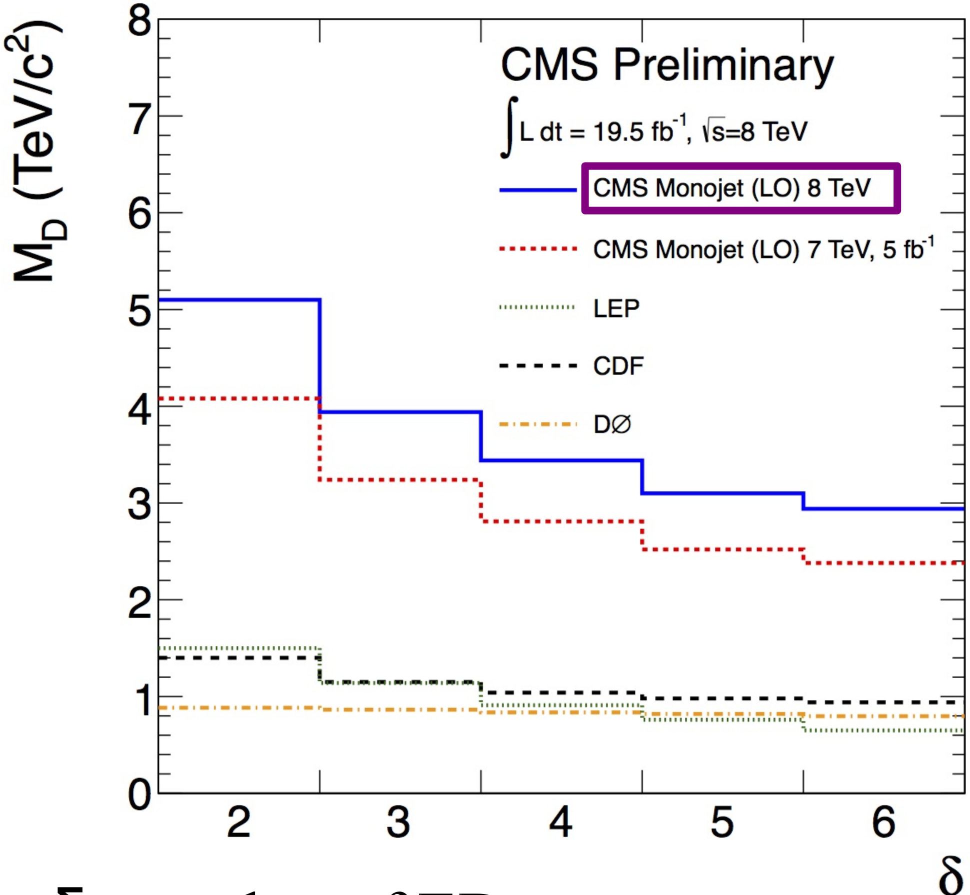
Both statistical and systematic uncertainties are taken into account

overall bkg uncertainty for $E_T^{\text{miss}} > 500\,\text{GeV}$ about $8\,\%$

Monojet Search

Limits on Large Extra Dimensions in the ADD model

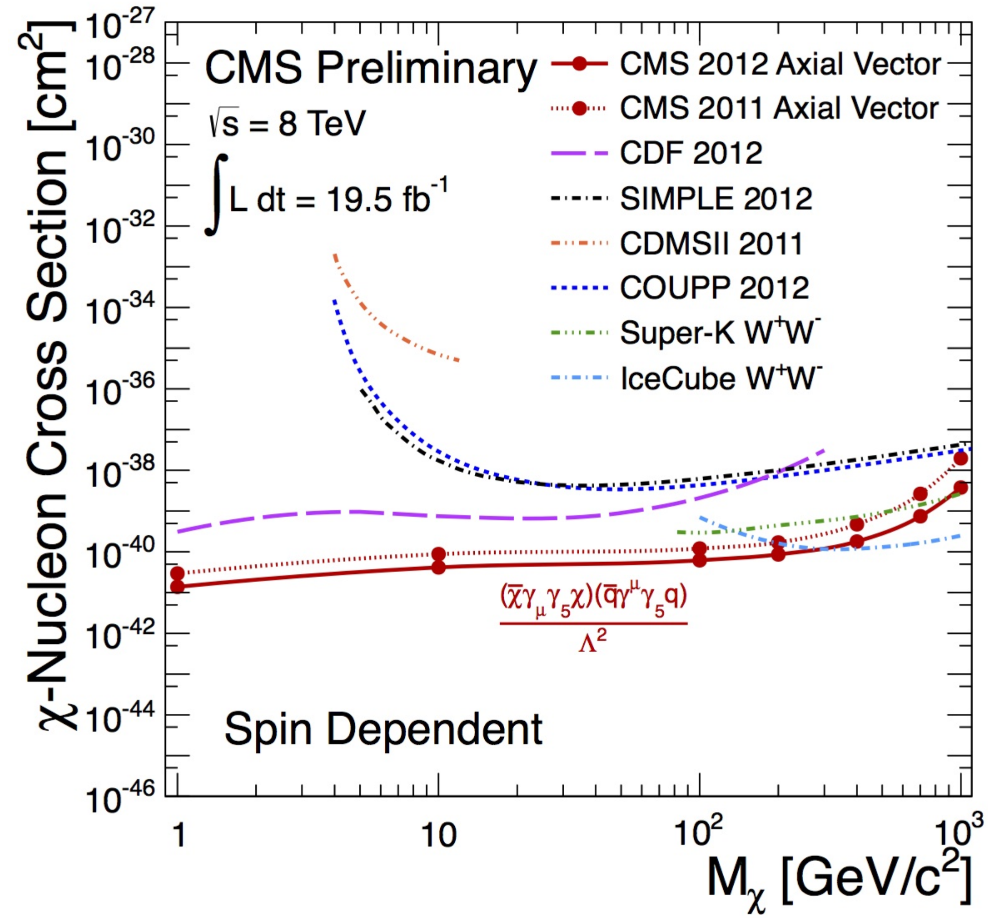
best limits



δ: number of ED

M_D : fundamental Planck mass

Limits on DM Models (shown here: axial vector contact interaction)



M_χ : mass of DM particle

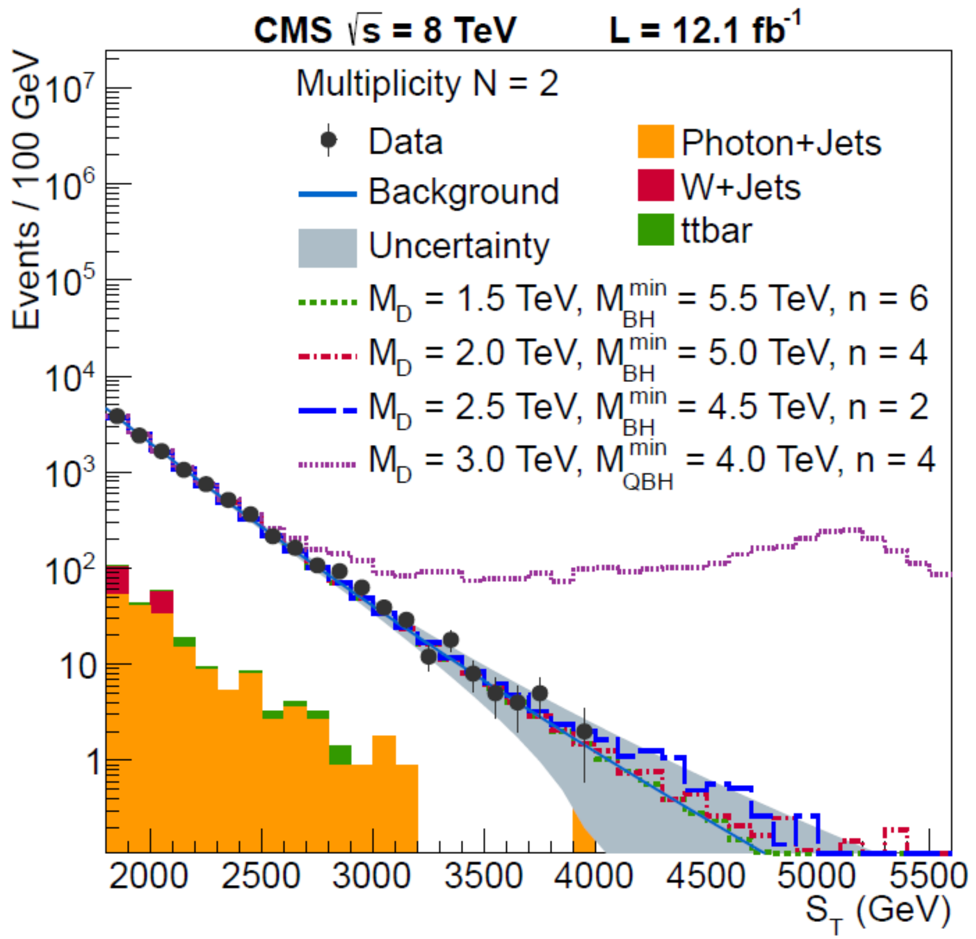
Microscopic Black Holes

trigger:

- based on sum of transverse energies measured in the calorimeter (200-700 GeV, depending on the period of data taking)

selection of physics objects based on Particle Flow:

- jets: $p_T^{jet} > 50$ GeV, $|\eta| < 2.6$
- muons: $p_T^{\mu} > 50$ GeV, $|\eta| < 2.1$
- electrons,photons : $p_T^{e,\gamma} > 50$ GeV
  $|\eta| < 1.44$ (barrel) $\vee$ $1.56 < |\eta| < 2.5$ (endcap)
- missing transverse energy:
  $E_T^{miss} > 50$ GeV



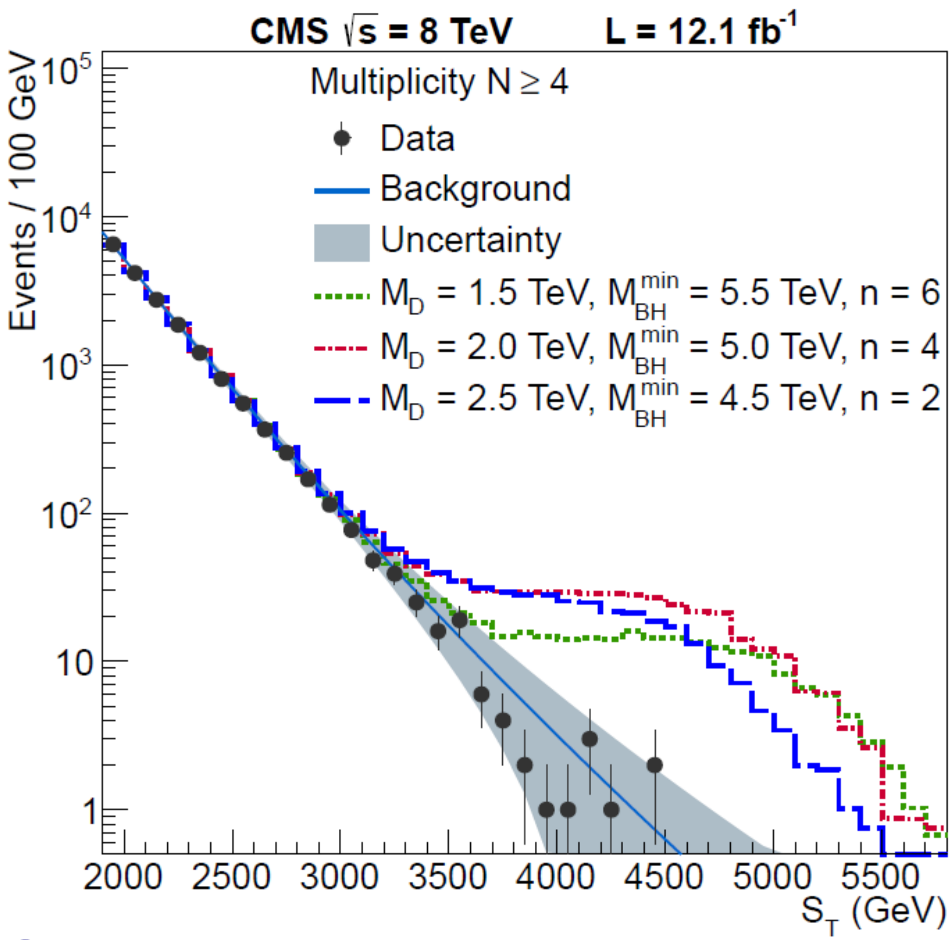
$$S_T = \sum_i p_T^{object\ i} + E_T^{miss}$$

N : number of physics objects (E_T^{miss} not counted)

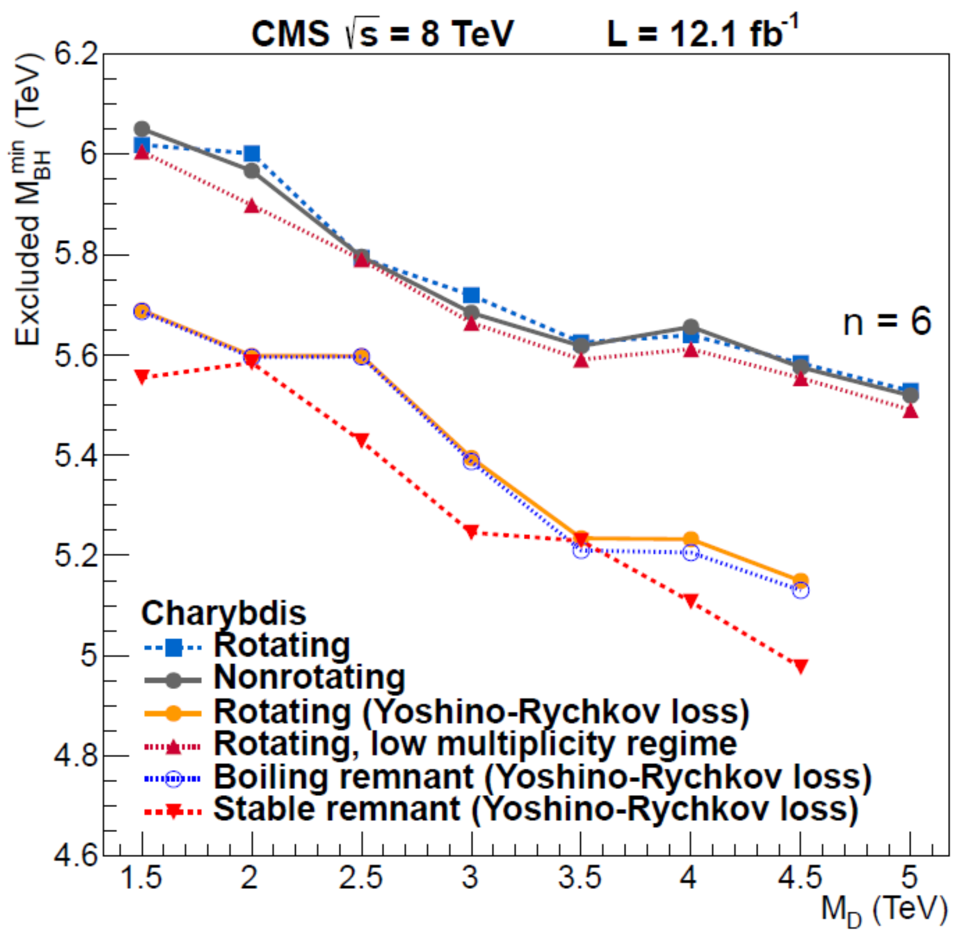
Microscopic Black Holes

Shape estimate for N=2 is applied to higher object multiplicities (inclusive)

example : $N \geq 4$



limits on (semi-classical) micro black hole models simulated with Charybdis



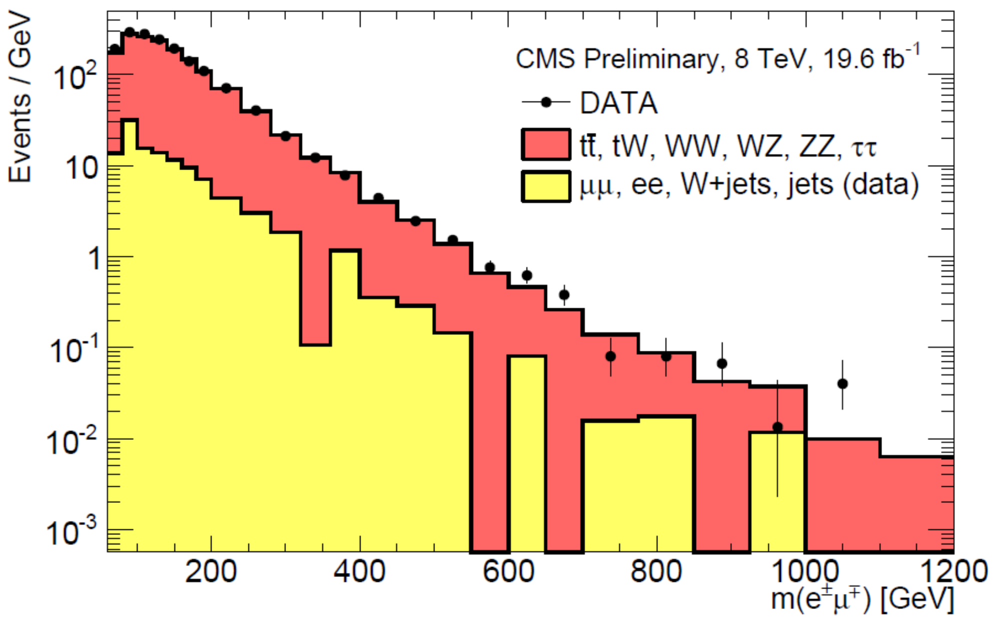
Good agreement between data and SM estimate for $N \geq 2$ to $N \geq 10$

Conclusions

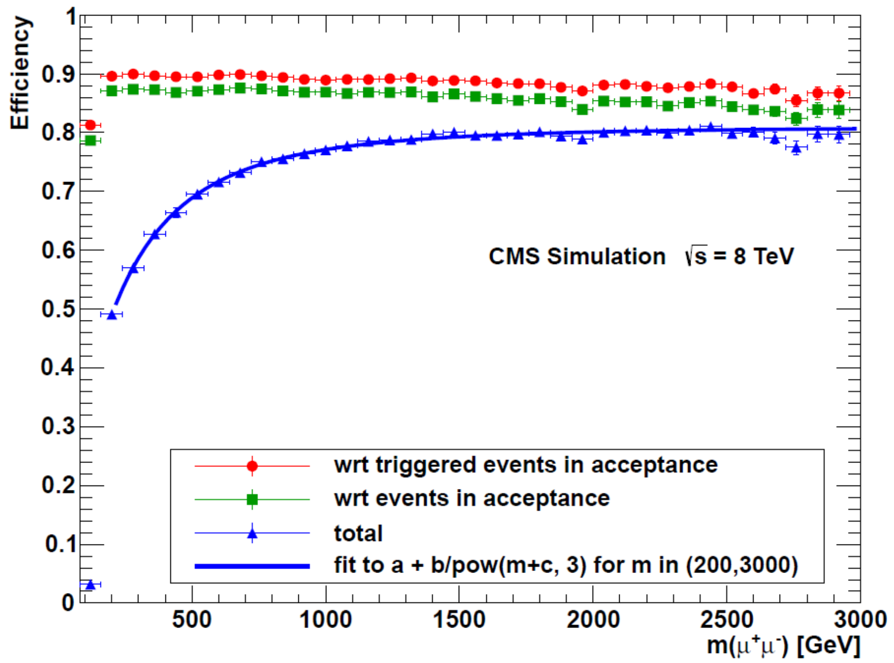
- Presented results from several CMS analyses focusing on searches for heavy dilepton resonances and extra dimensions
- All analyses based on either the full 2012 dataset or a significant part of it
- The measurements are compatible with the standard model expectation and allow to improve the limits on BSM scenarios
- Of course we hope that people outside the CMS collaboration will pick up our results to evaluate implications for additional models

Backup
Figures

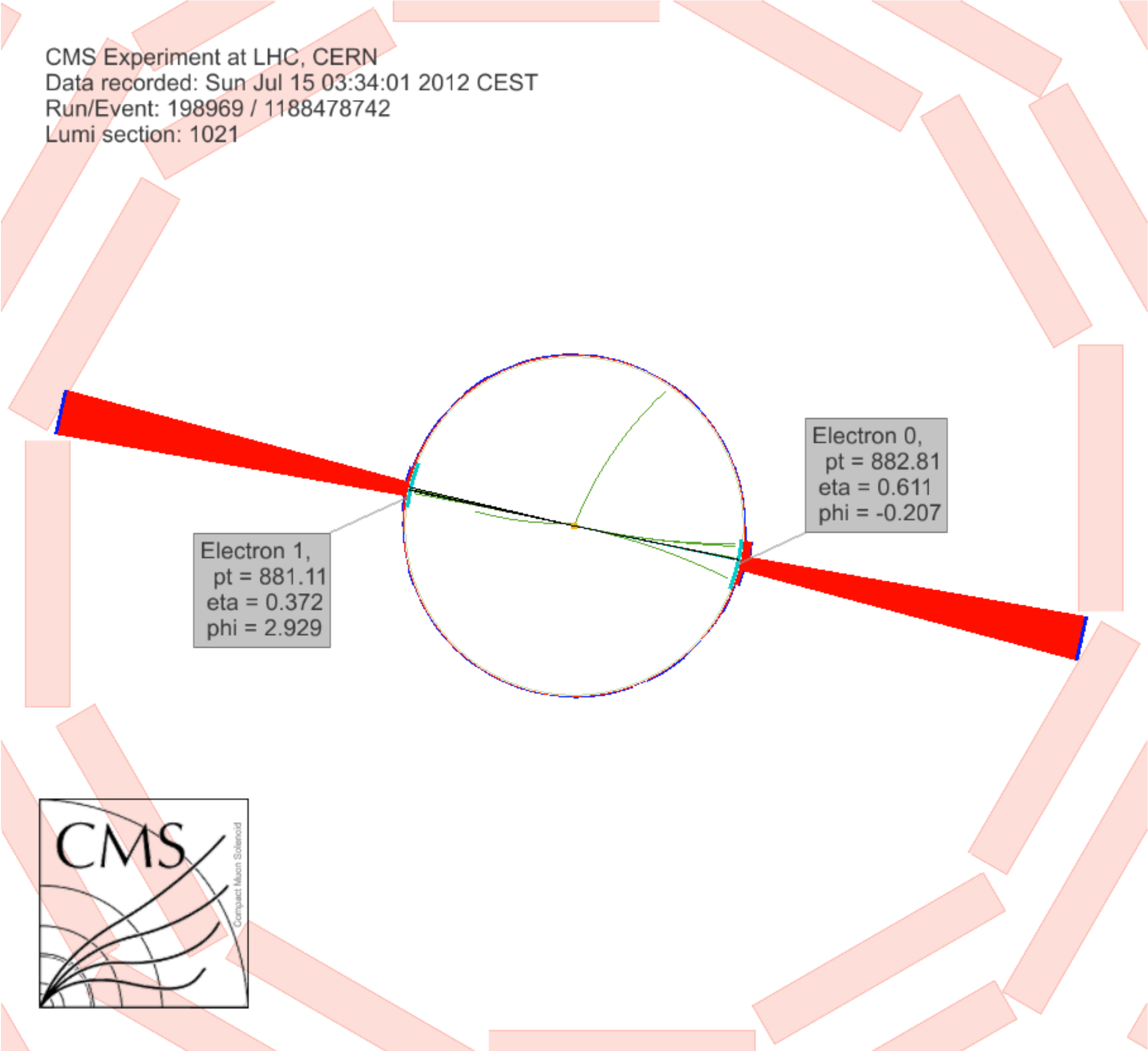
eμ-spectrum



muon efficiency



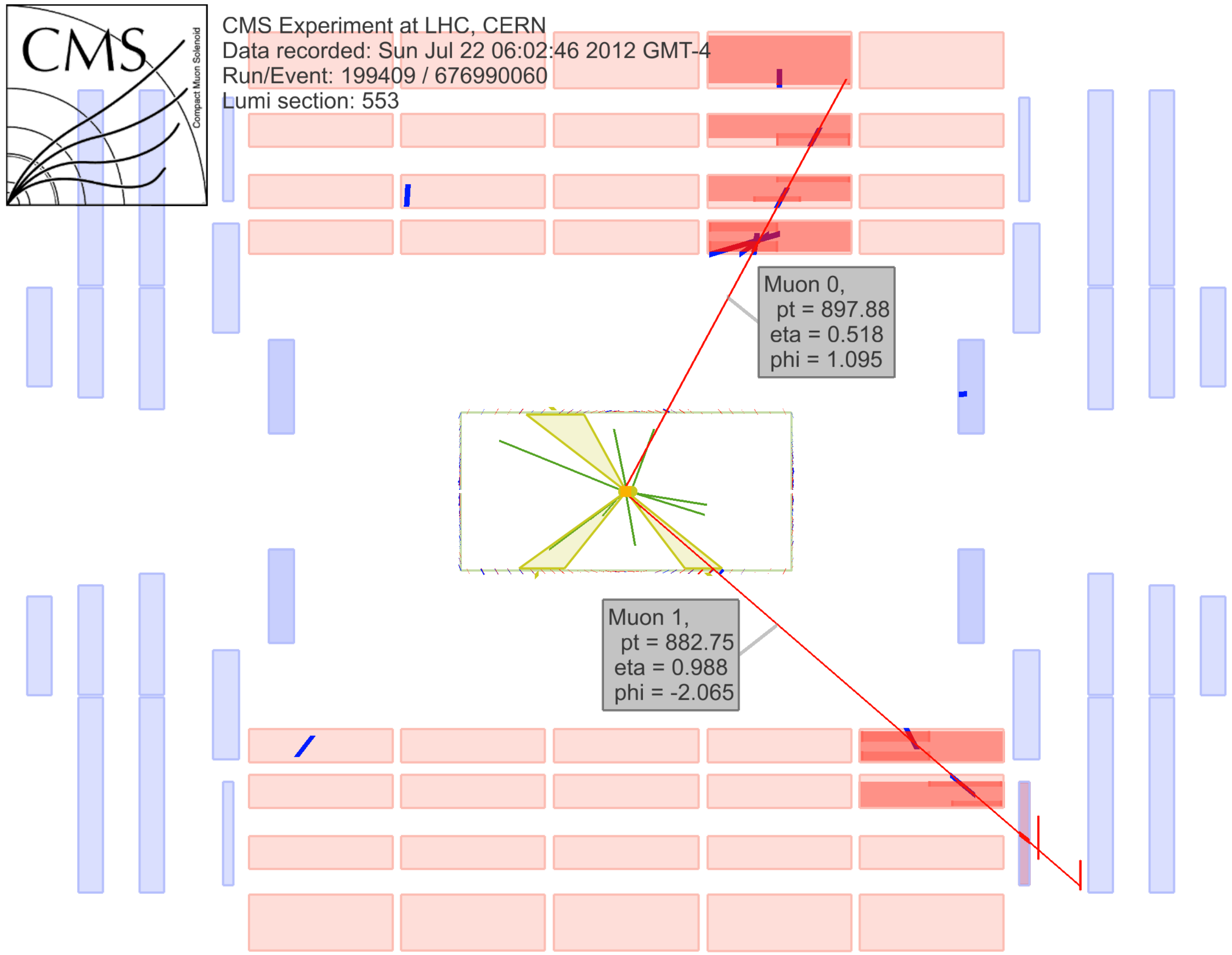
Dilepton Resonances



highest mass dielectron event

$$M_{ee} = 1776 \text{ GeV}$$

Dilepton Resonances

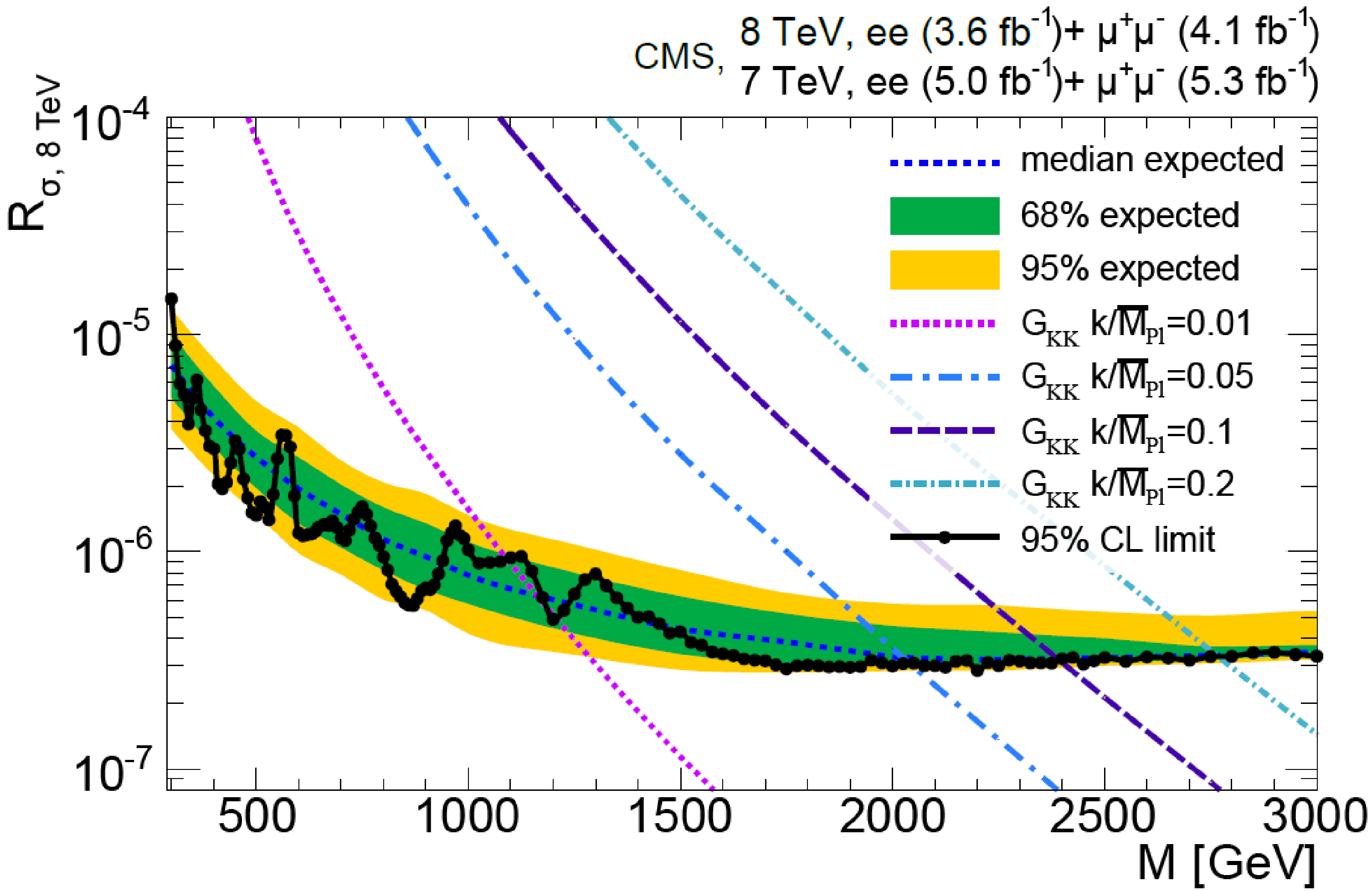


highest mass dimuon event

$M_{\mu^+\mu^-} = 1824\ \text{GeV}$

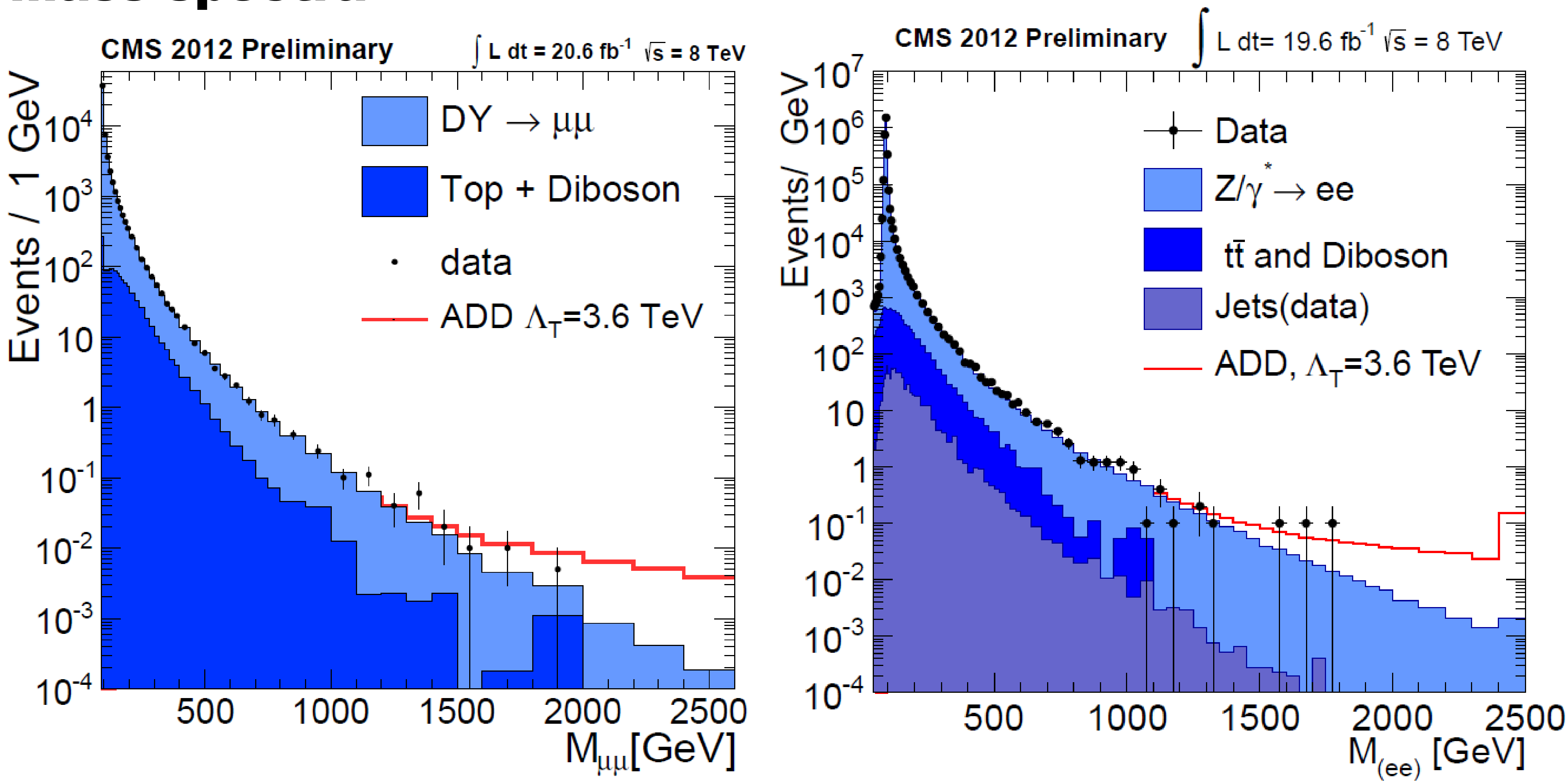
Dilepton Resonances

RS limits with partial 2012 dataset (EXO-12-015)



Non-Resonant Dilepton Search

mass spectra



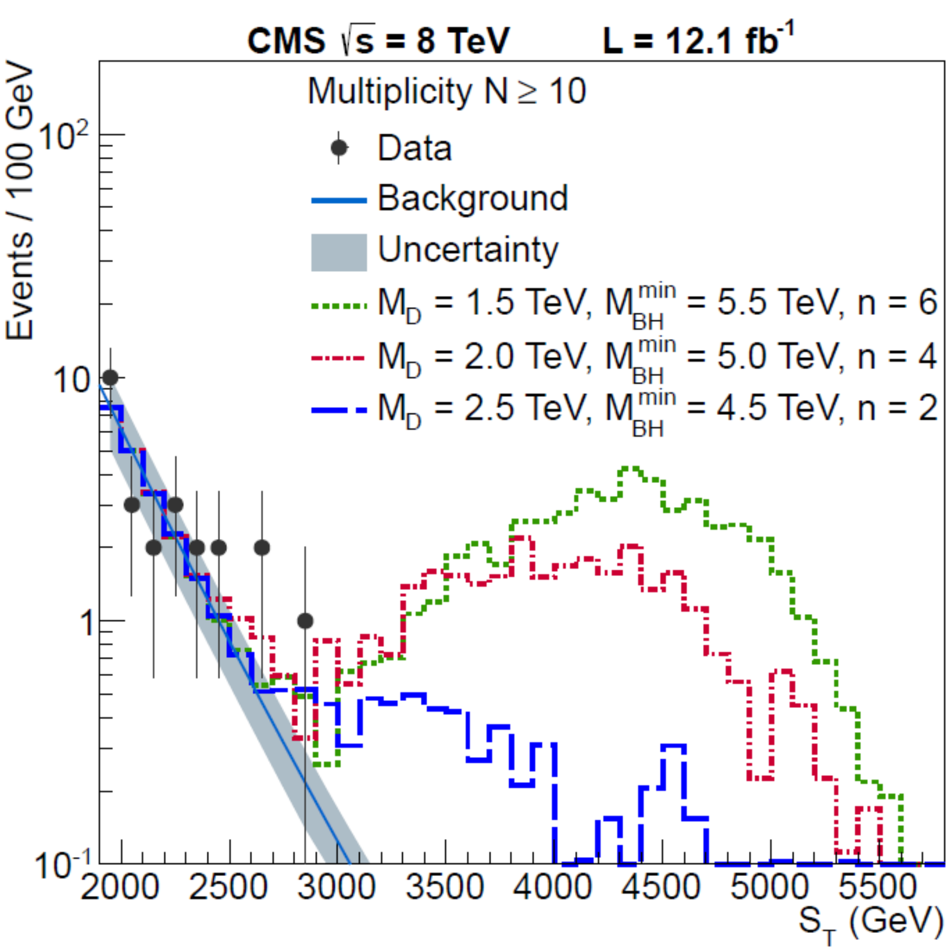
Non-Resonant Dilepton Search

limit table

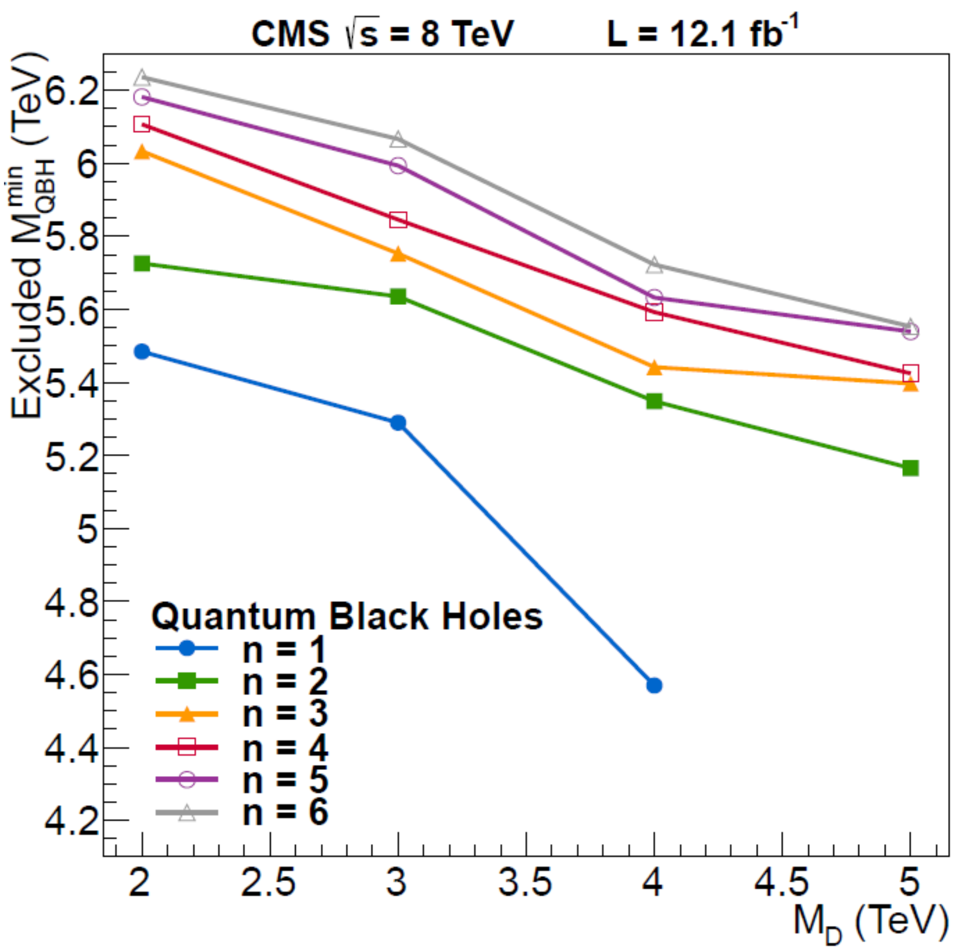
ADD k-factor	Λ_T [TeV] (GRW)	M_s [TeV] (HLZ) $n=2$	$n=3$	$n=4$	$n=5$	$n=6$	$n=7$
$\mu\mu$, $\sigma_{s,\mu\mu} < 0.25\,\mathrm{fb}$ (0.25 fb expected) at 95% CL							
1.0 (observed)	3.64	3.48	4.33	3.64	3.29	3.06	2.89
1.0 (expected)	3.65	3.50	4.34	3.65	3.30	3.07	2.90
1.3 (observed)	3.77	3.69	4.49	3.77	3.41	3.17	3.00
1.3 (expected)	3.78	3.70	4.50	3.78	3.42	3.18	3.01
ee, $\sigma_{s,ee} < 0.19\,\mathrm{fb}$ (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
$\mu\mu$ and ee, per channel $\sigma_s < 0.12\,\mathrm{fb}$ (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	3.30

Microscopic Black Holes

S_T spectrum: $N \geq 10$



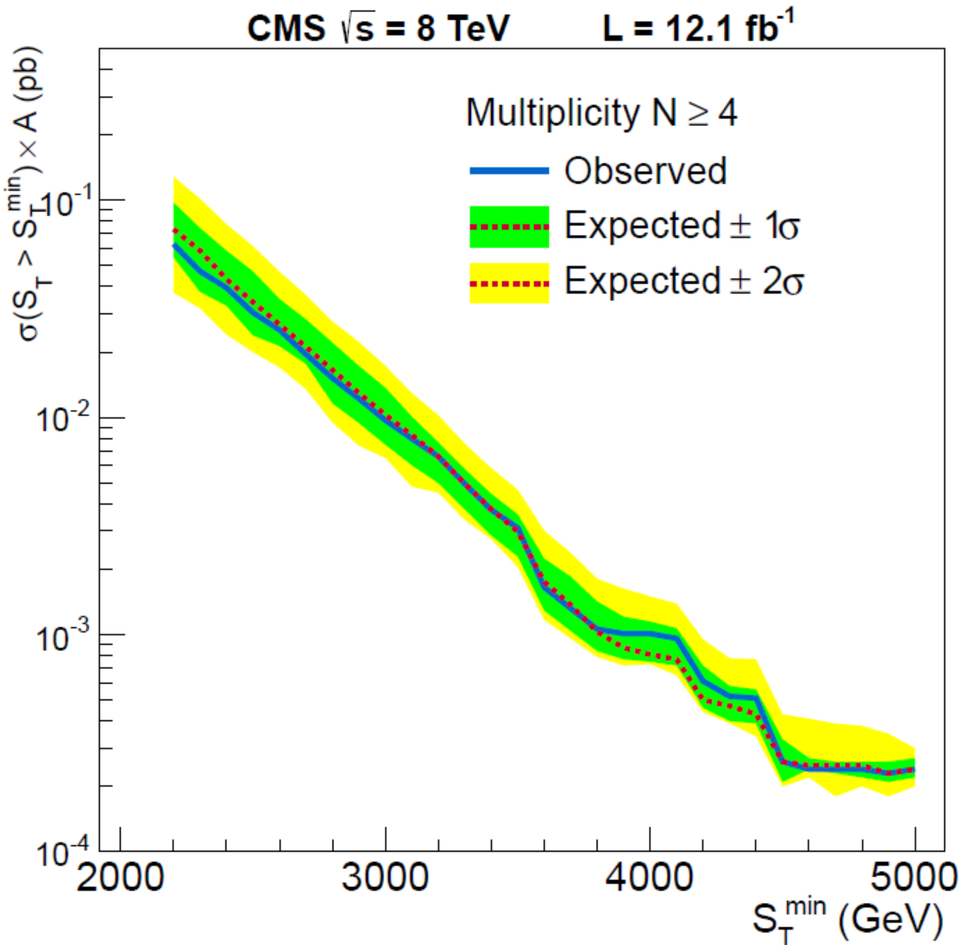
QBH limits



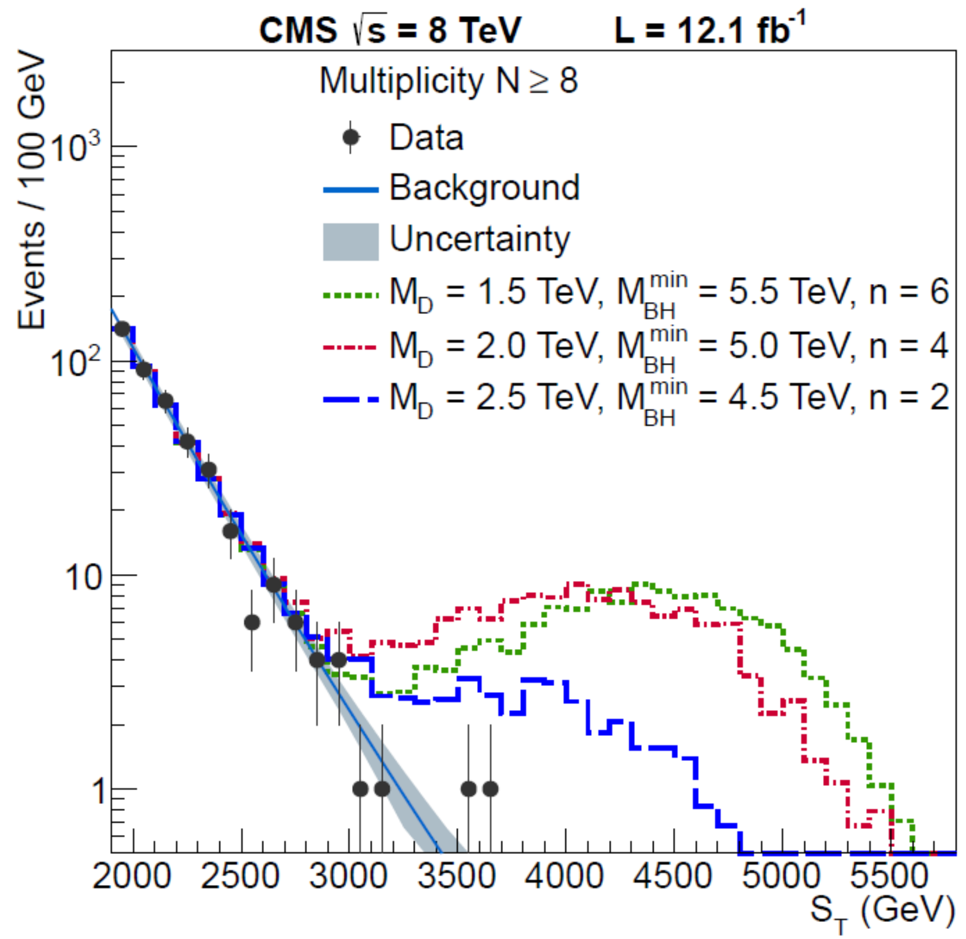
Microscopic Black Holes

model independent limits
on the signal cross section

example: $N \geq 4$

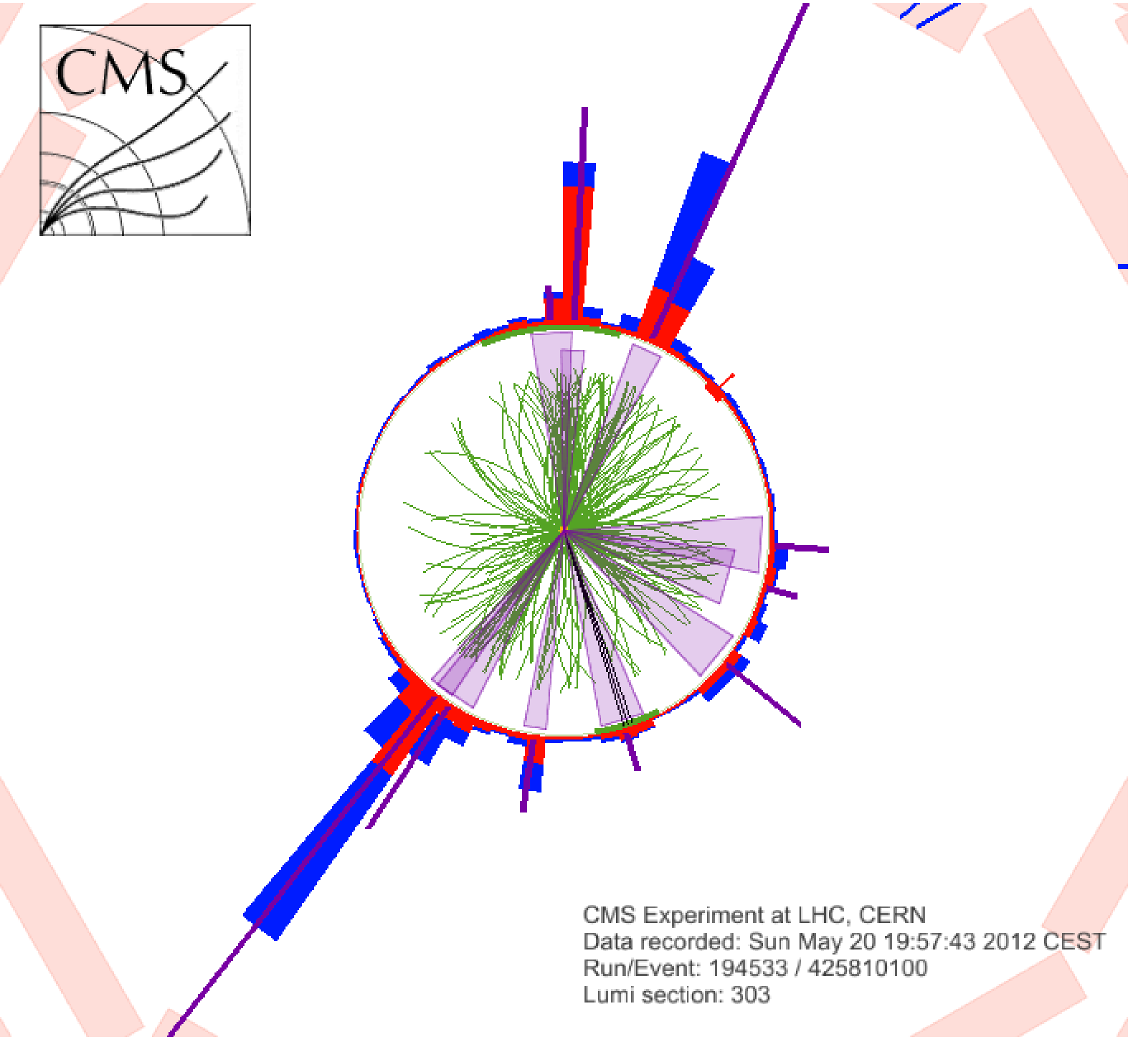


S_T spectrum: $N \geq 8$



Microscopic Black Holes

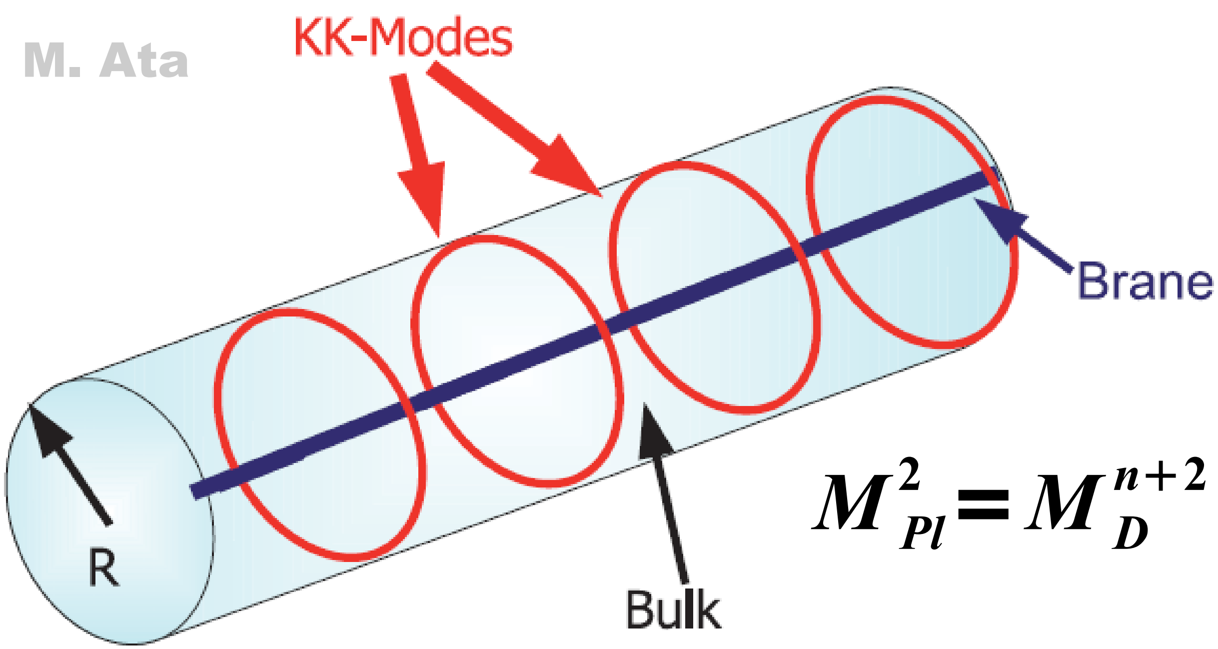
10-jet event



The ADD model

The ADD (Arkani-Hamed, Dimopoulos, Dvali) model leads to an effective field theory based on the ideas of

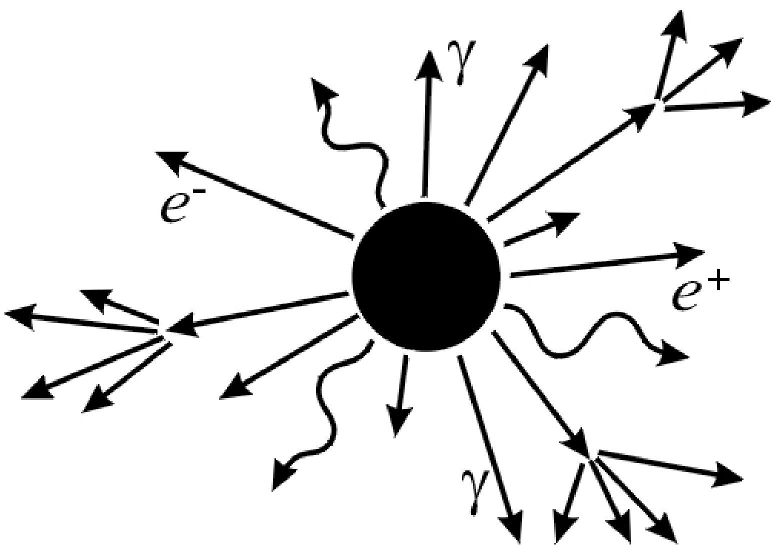
- Compactified Large Extra Dimensions
- Brane Physics



$$M_{Pl}^2 = M_D^{n+2} V_n$$

- The Standard Model (SM) is confined to a brane
- Graviton can propagate in the bulk
- Effective field theory at "low" energies

Microscopic Black Holes



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

simulation of signal events with:
a) BlackMax
b) Charybdis2

Randall Sundrum (RS-1) Scenario

- Slice of AdS_5 space between two 3+1 branes

- "warped" metric

$$ds^2 = e^{-2 k r_c \phi} \eta_{\mu\nu} \, \mathrm{d}x^{mu} \, \mathrm{d}x^{nu} + r_c^2 \, \mathrm{d}\phi^2$$

- resonant diphoton signal from the first KK mode of the Graviton

- **Model parameters:**

graviton mass M_1

coupling parameter $\tilde{k} = k / \mathrm{M}_{\mathrm{Pl}}$