Search for Large Extra Dimensions at CMS

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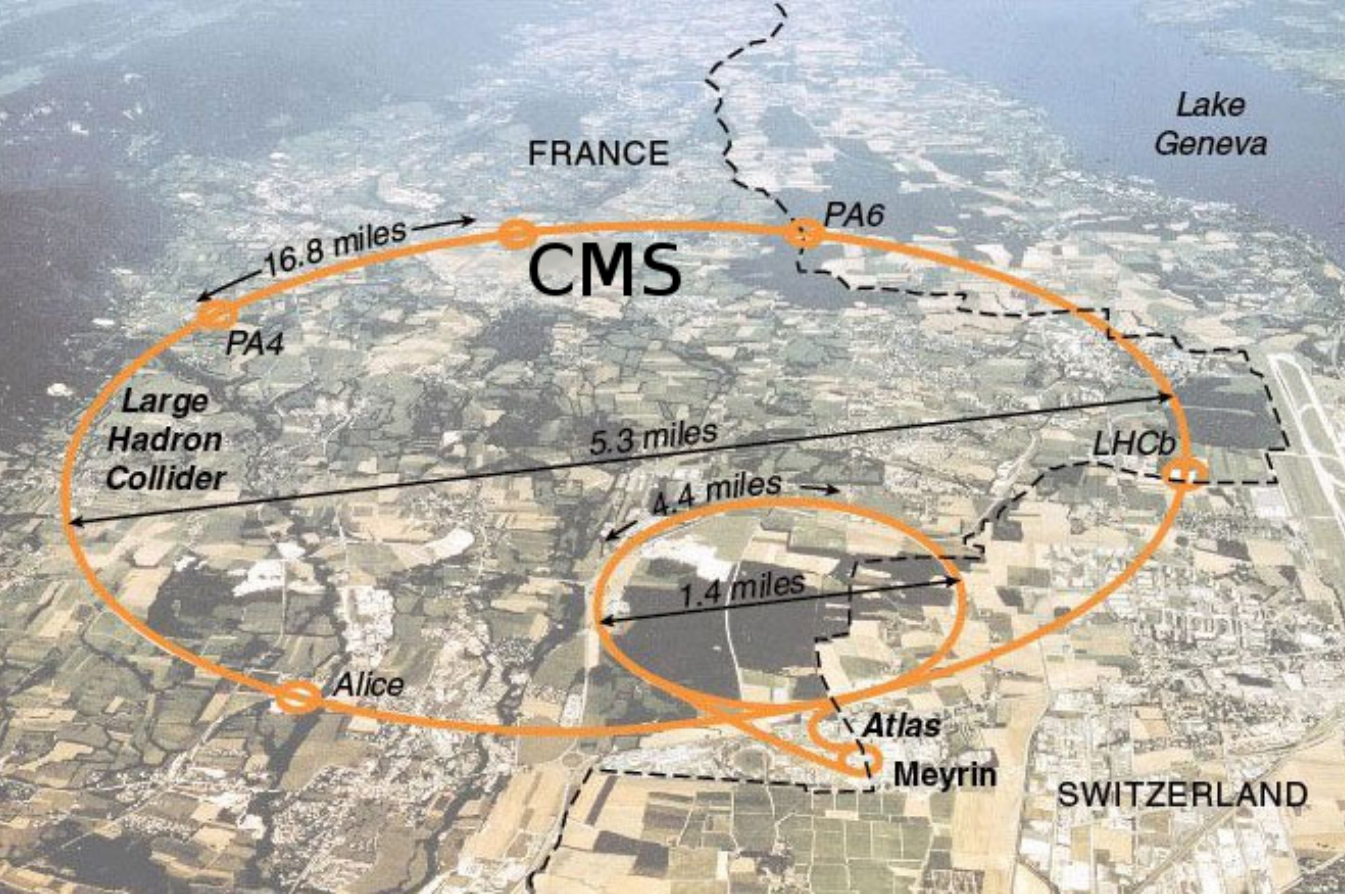
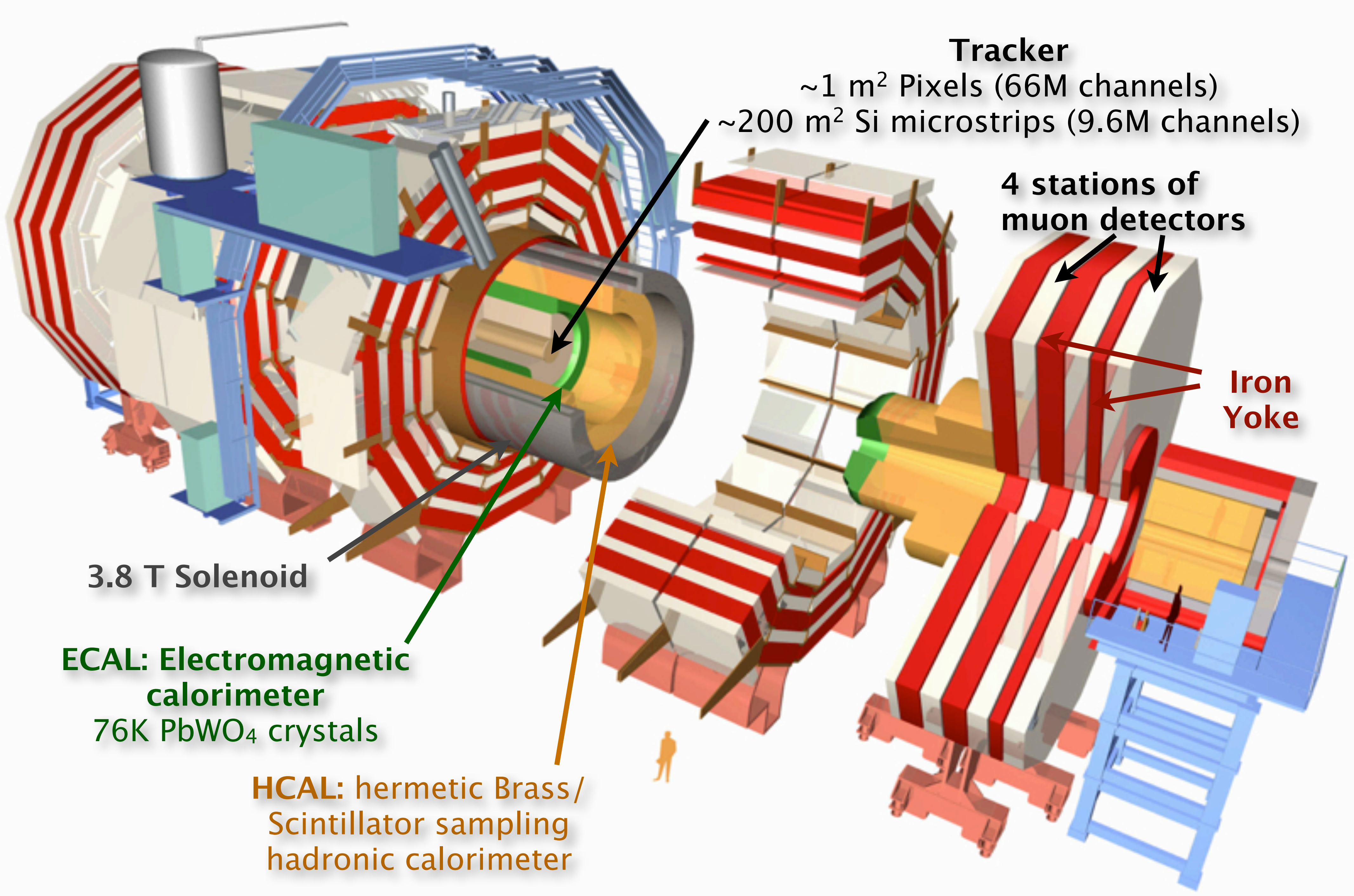
On behalf of CMS Collaboration

PLHC 2011



Large **H**adron **C**ollider *pp* collisions $\sqrt{s}$ = 7 TeV (3.5 + 3.5).
Highest energy particle collider in the world. (design energy 14TeV)



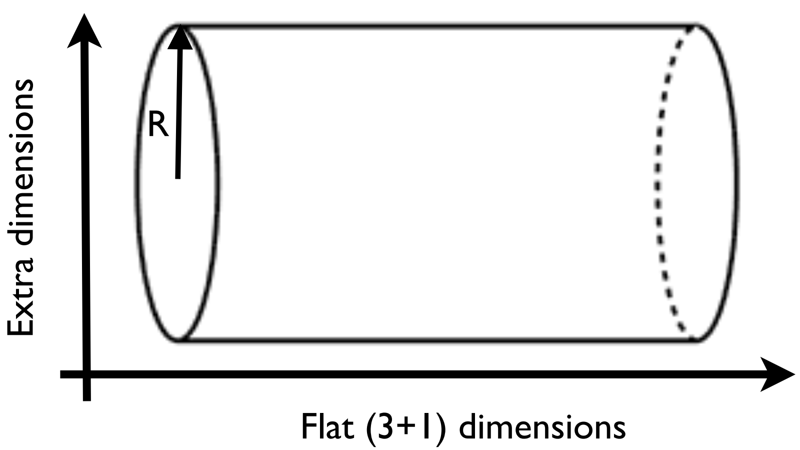
Compact **M**uon **S**olenoid
12500 tons, 21 m long, 15 m diameter

Large Extra Dimensions

- Why gravity is so week?
  - $M_{\mathrm{Pl}} = \sqrt{(\hbar c/G)}$
  - M_{Pl} ~10^{19} GeV
  - M_{EW} ~100 GeV
  - M_{QCD} ~100 MeV
  - **Hierarchy Problem**
- **A**rkani-Hamed, **D**imopoulos, **D**vali

PL **B429** (1998) 263

  - Large extra dimensions - only gravity propagates through the "bulk".
  - Standard model lives on the "brane".
  - Extra dimensions are "curled up" (compactified) in sphere/torus of radius R.
- Gravity in n+1 dimensions
  - $V(r) \sim \frac{1}{M_{\mathrm{D}}^{n+2} r^{n-1}} \xrightarrow{r \gg R} \frac{1}{M_{\mathrm{Pl}}^2 r}$
  - PDG definition $M_{\mathrm{Pl}}^2 = 8\pi R^n M_{\mathrm{D}}^{n+2}$
  - New Planck scale "M_D"



Size of Large Extra Dimensions

- "Large" Extra Dimensions
  - $R > 1/M_D$
  - For M_D = 1 TeV, the size of extra dimensions (R) can be much smaller the 1 mm.
  - Newton's Law has been tested by Modern Cavendish experiments (torsion pendulum) to ~0.1 mm scales.

    Prog. Part. Nucl. Phys 62, 102 (2009)
  - Extra dimensions in sub-millimeter scale are allowed.
  - Gravity can be 10^{38} times stronger (comparable to EW)

M_D = 1 TeV

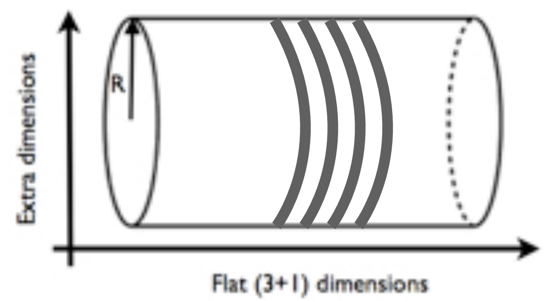
n	R
1	$\sim 10^{12}$ m
2	~1 mm
3	~3 nm
4	$\sim 10^{-12}$ m

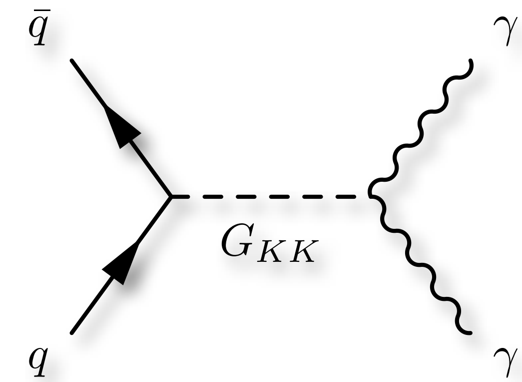
Virtual Kaluza-Klein (KK) Gravitons

- Particle-in-a-box
  - Towers of excitations
  - ΔE ~ 1/R
- Pair Production of dilepton/diboson (at high mass)
  - Non-resonant
  - Continuum excess
- Sum of KK State Diverges
  - UV cutoff at scale M_S
  - Total xsec = SM production + interface effects + extra dimensions effects

$$\sigma_{\rm ADD} = \sigma_{\rm SM} + A\eta_G\sigma_{\rm int} + B\eta_G^2\sigma_{\rm ED}$$

KK Winding Modes





$$R^{-1} = \left(\frac{1}{2\sqrt{\pi}M_D}\left(\frac{M_{Pl}}{M_D}\right)^{2/n_{\rm ED}}\right)^{-1} = \begin{cases} 40\ \text{meV} & \text{if } n_{\rm ED}=2 \\ 80\ \text{eV} & \text{if } n_{\rm ED}=3 \\ 40\ \text{keV} & \text{if } n_{\rm ED}=4 \\ 1\ \text{MeV} & \text{if } n_{\rm ED}=5 \\ 10\ \text{MeV} & \text{if } n_{\rm ED}=6 \\ 100\ \text{MeV} & \text{if } n_{\rm ED}=7 \end{cases}$$

$$\mathcal{F} = 1 \quad \text{(GRW: \textit{Nucl. Phys.} \textbf{B544} (1999) 3)}$$

$$\mathcal{F} = \begin{cases} \log(M_S^2/\hat{s}) & \text{if } n_{\rm ED}=2 \\ 2/(n_{\rm ED}-2) & \text{if } n_{\rm ED}>2 \end{cases} \quad \text{(HLZ: \textit{Phys. Rev.} \textbf{D59} (1999) 105006)}$$

$$\mathcal{F} = \pm\frac{2}{\pi} \quad \text{(Hewett: \textit{Phys. Rev. Lett.} \textbf{82} (1999) 4765)}$$

$$\eta_G = \frac{\mathcal{F}}{M_S^4}$$

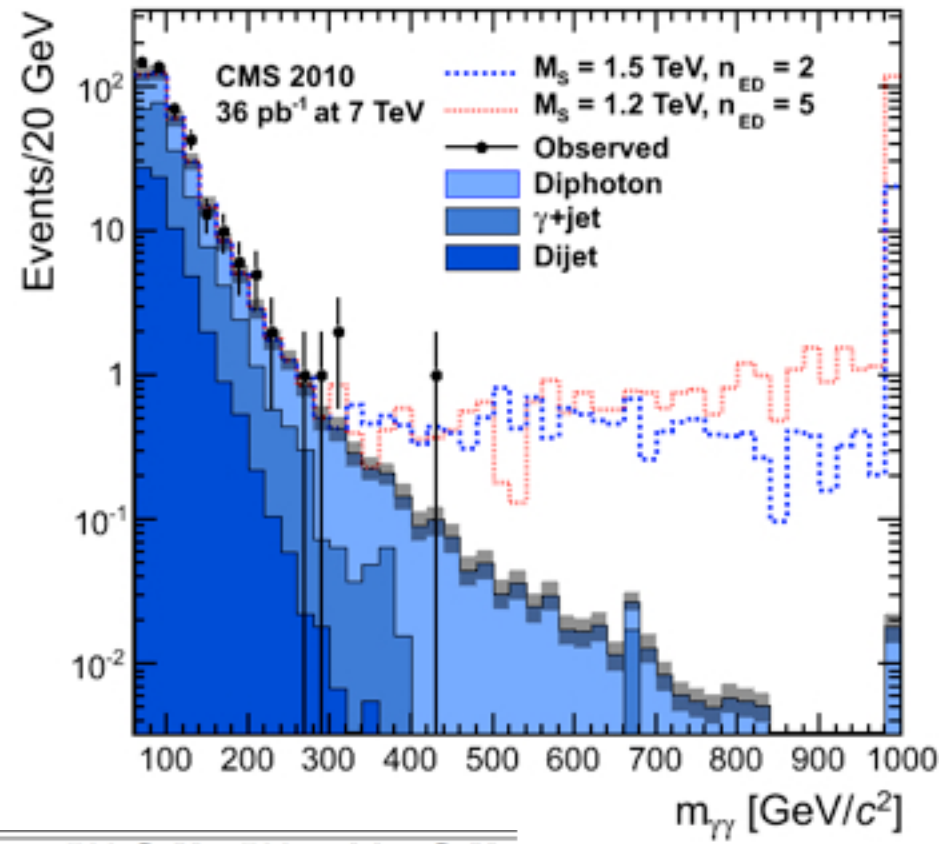
$$N_{TT}^{xy} = (N_{LL}^{xy} f_x f_y) + (-2N_{LL}^{xy} f_x f_y + N_{LT}^{xy} f_x + N_{TL}^{xy} f_y) + (N_{\gamma\gamma}^{xy})$$

Total Bkg. Dijets γ+jets SM γ+γ (MC)

Superscripts: pT of first & second objects
Subscripts: Tight/Lose photon selection

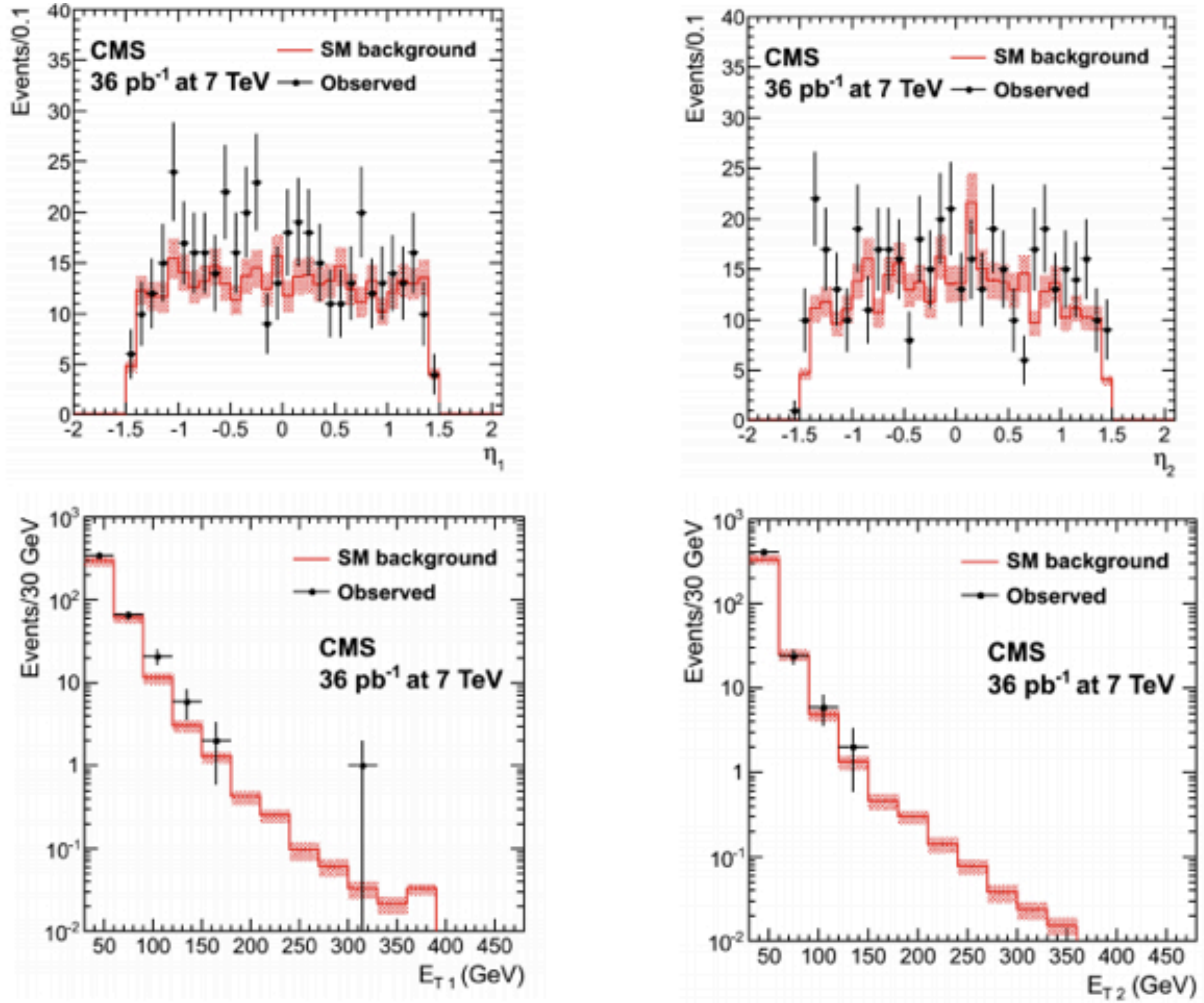
Diphotons Search

- Fake Rate
  - probability to misidentify a non-isolated γ as an isolated one.
- NLO k-factor 1.3 +/- 0.3
- Signal Region: $M_{\gamma\gamma}$ > 500 GeV
  - Optimized in MC for highest sensitivity
  - 60 GeV < Mγγ < 200 GeV (control region)
  - No excess signal



Process	$60 < M_{\gamma\gamma} < 200$ GeV	$200 < M_{\gamma\gamma} < 500$ GeV	$500 < M_{\gamma\gamma}$ GeV
Dijets	70 ± 28	0.5 ± 0.2	0.0009 ± 0.0004
γ+Jets	145 ± 7	2.3 ± 0.3	0.016 ± 0.003
Diphotons	150 ± 35	6.2 ± 1.4	0.286 ± 0.066
Total Backgrounds	365 ± 49	9.0 ± 1.5	0.303 ± 0.066
observed	428	12	0

CMS PAS EXO-10-026
arXiv:1103.4279
Accepted by JHEP



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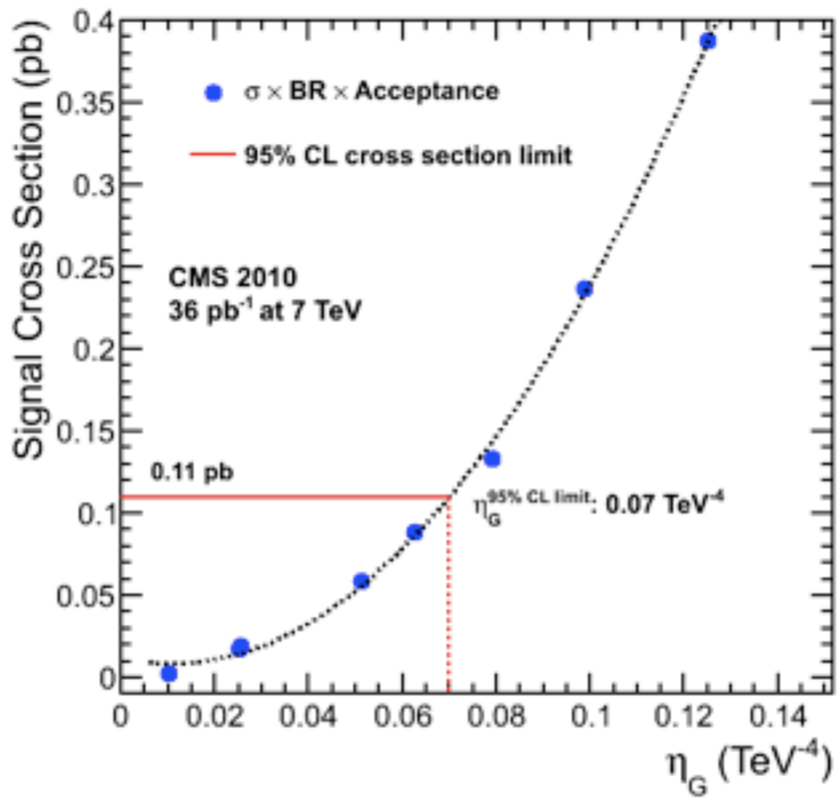
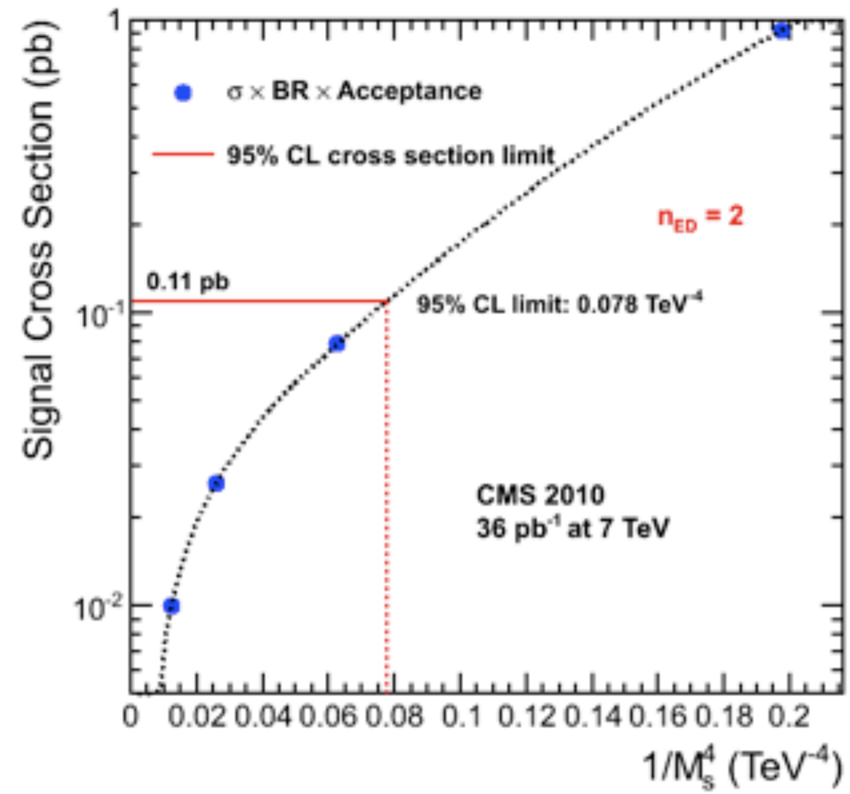
Kinematic Distributions

Diphotons Limits

Table 2: Summary of systematic uncertainties.

	Central Value	Relative Uncertainty
Luminosity	36 pb^{-1}	4.0%
Background diphoton K factor	0.30 Events	23%
Signal Efficiency	77.1%	6.0%
Signal diphoton K factor	1.3	7.7%





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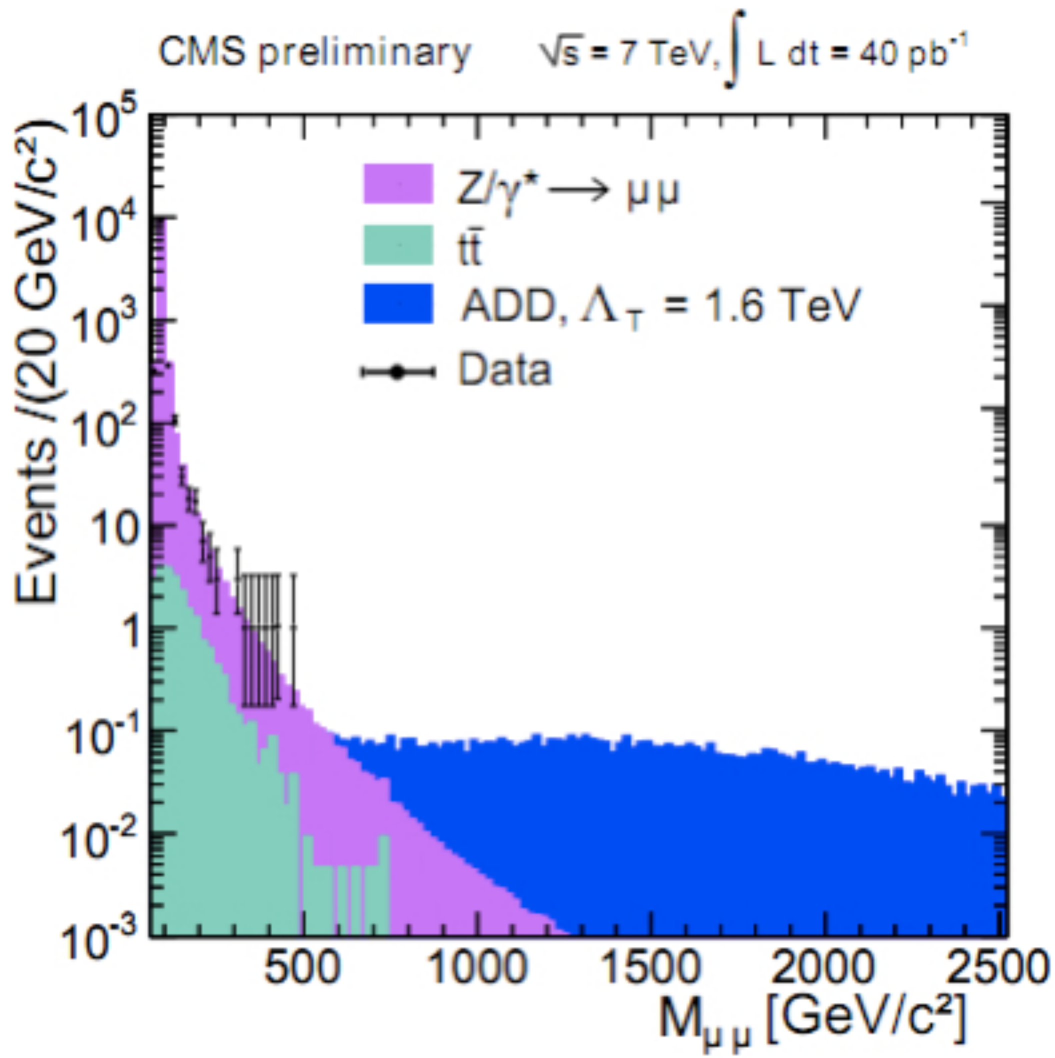
	GRW	Hewett Pos.	Hewett Neg.	HLZ $n_{ED}=2$	HLZ $n_{ED}=3$	HLZ $n_{ED}=4$	HLZ $n_{ED}=5$	HLZ $n_{ED}=6$	HLZ $n_{ED}=7$
Full	1.94	1.74	1.71	1.89	2.31	1.94	1.76	1.63	1.55
$\sqrt{\hat{s}} > M_S$ Trunc.	1.84	1.60	1.50	1.80	2.23	1.84	1.63	1.46	1.31

stringent limits

Dimuons Search

- Signal region: $M_{\mu\mu}$ > 600 GeV
- Background: DY & ttbar
  - DY NLO k-factor
- NNLO k-factor for DY
  - Z-peak (60 - 120 GeV) - 1.4
  - 1.45 @600 GeV
- Normalization to Z peak
- NLO QCD Correction
  - ADD signal - 1.3
- Dedicated studies shows ttbar events agree with simulation. (CMS-TOP-10-001)

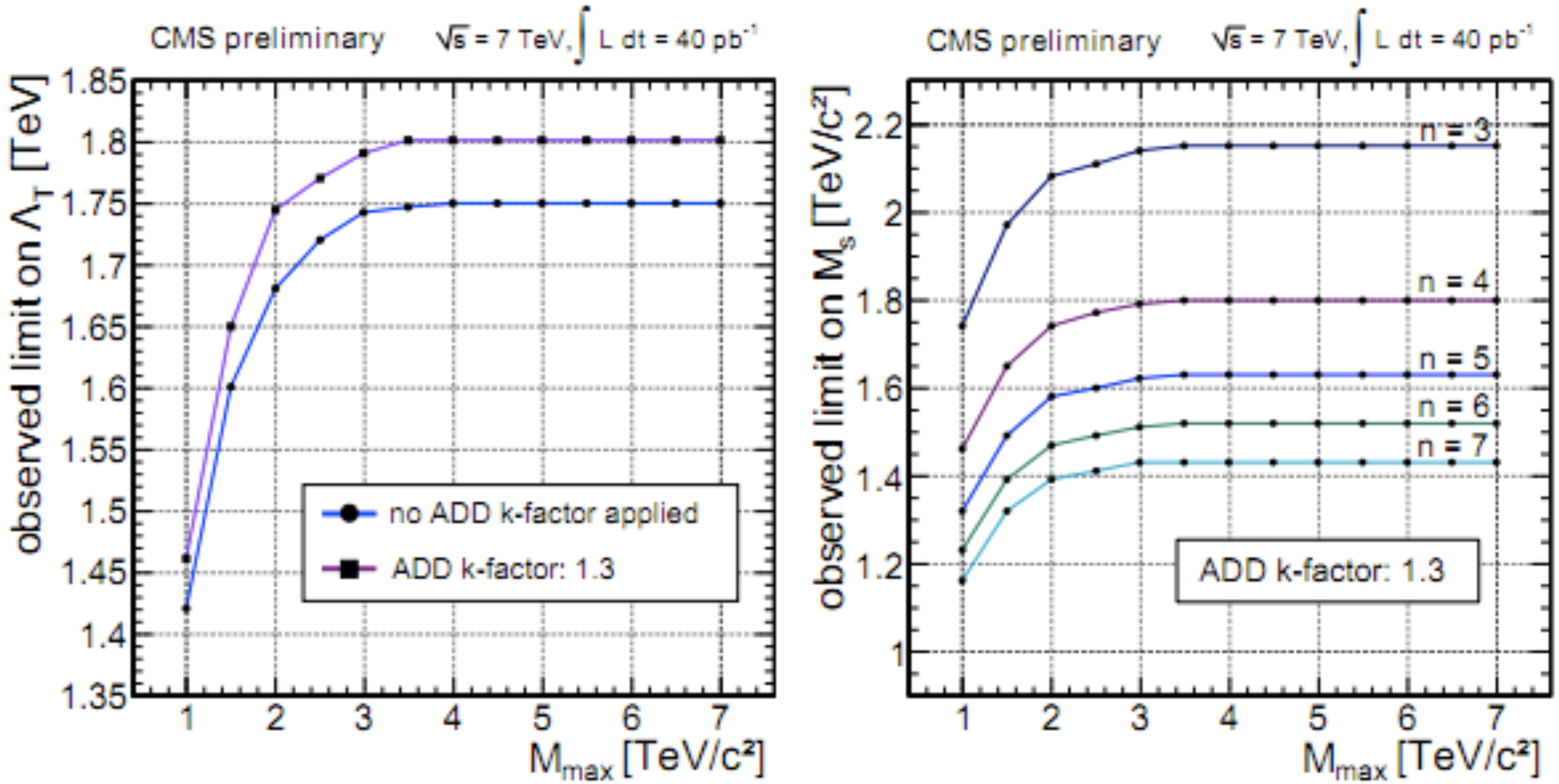


CMS PAS EXO-10-020

stringent limits

Dimuons Limits

	Λ_T [TeV] (GRW)	M_s [TeV/c^2] (HLZ)					
		$n=2$	$n=3$	$n=4$	$n=5$	$n=6$	$n=7$
Full	1.80	1.75	2.15	1.80	1.63	1.52	1.43
Truncated	1.68	1.67	2.09	1.68	1.49	1.34	1.24

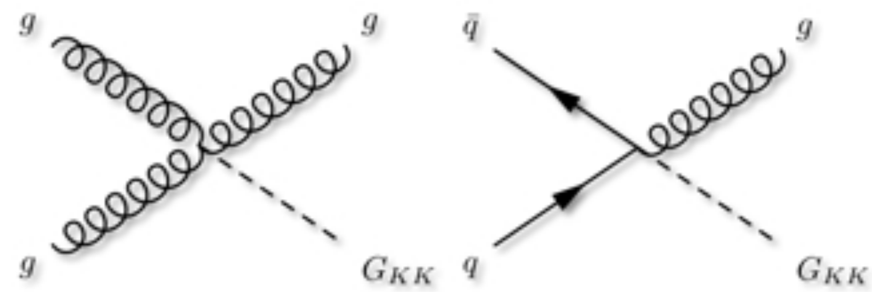


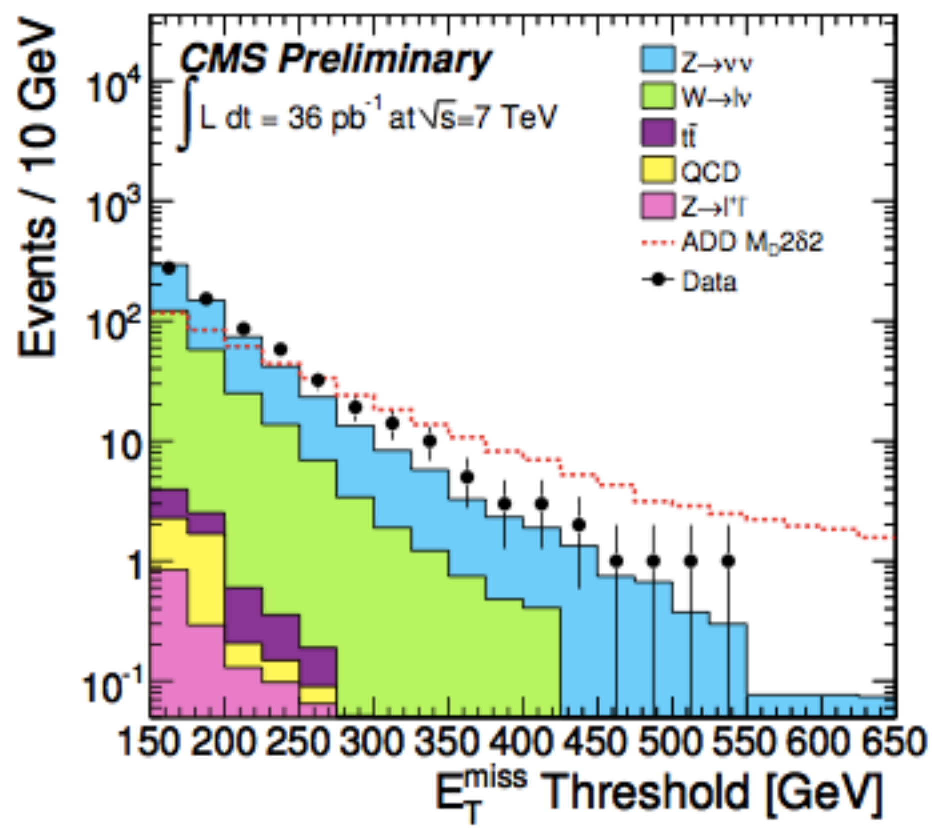
Systematic Uncertainty	Related Parameter	Signal Uncertainty	Background Uncertainty
Trigger and reconstruction efficiency bkg.	$\epsilon_{reco,b}$	—	3%
Trigger and reconstruction efficiency signal	$\epsilon_{reco,s}$	4%	—
Muon momentum resolution	$\epsilon_{res,b}$	—	4%
Drell-Yan higher order corrections	σ_b	—	15%
Drell-Yan PDF uncertainties	σ_b	—	5%
Z normalisation	$\mathcal{L}$	6%	6%
Others		—	1%

CMS PAS EXO-10-020

Direct Graviton (ME_T + Monojet)

- $N_{jet} \leq 2$ and $ME_T > 150$ GeV
  - $pT_1 > 110$ GeV and $|\eta_1| < 2.4$
  - $pT2 > 30$ GeV and $\Delta\varphi_{12} < 2.0$
- W/Z+jets (derived from mu data)
  - one/two (opposite sign) muons
  - 50 GeV < $M_T(l\ \nu)$ < 100 GeV
  - 81 GeV < $M(\mu\ \mu)$ < 101 GeV
- Invisible Z background
  - xsec*BR ratio W+jets/Z(νν)
  - LO MC correction other than W+jets
  - MC kinematic & geometry acceptance
  - efficiency of lepton veto (MC)
  - shape differences of $p_T(W,Z)$ >150 GeV





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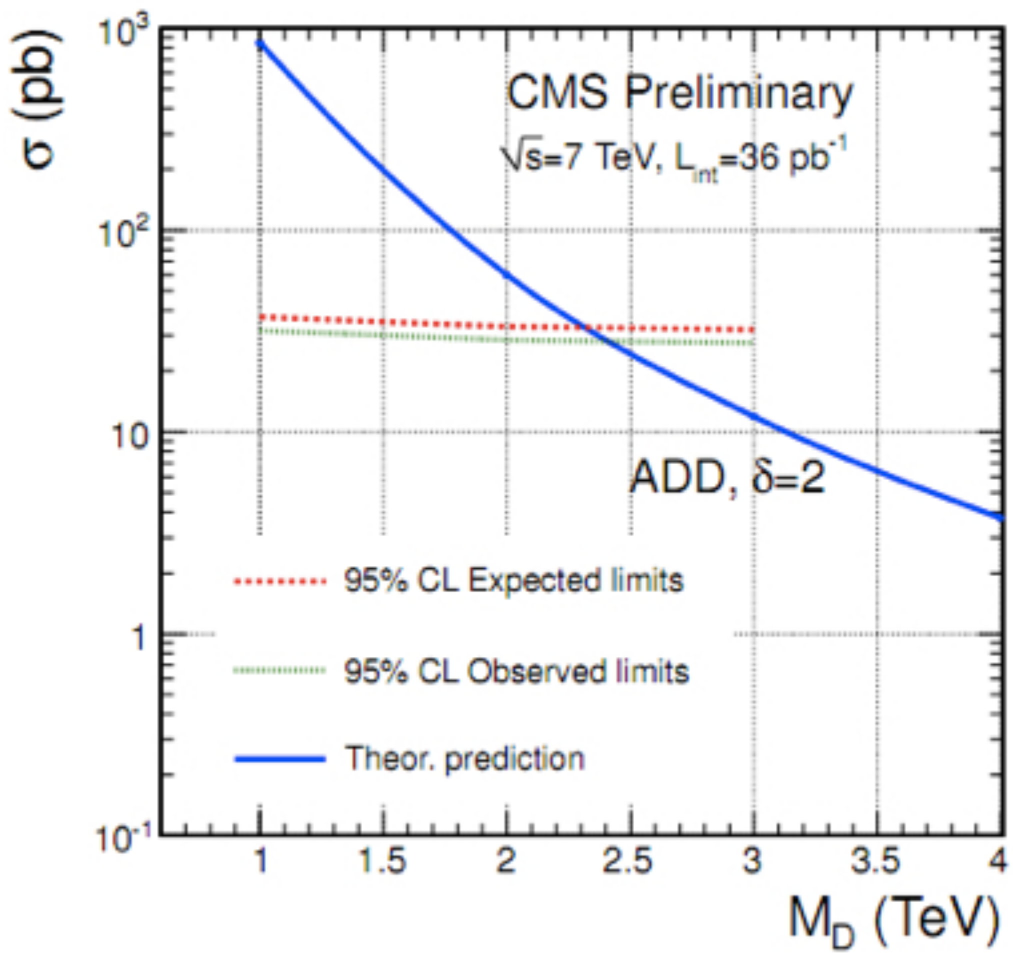
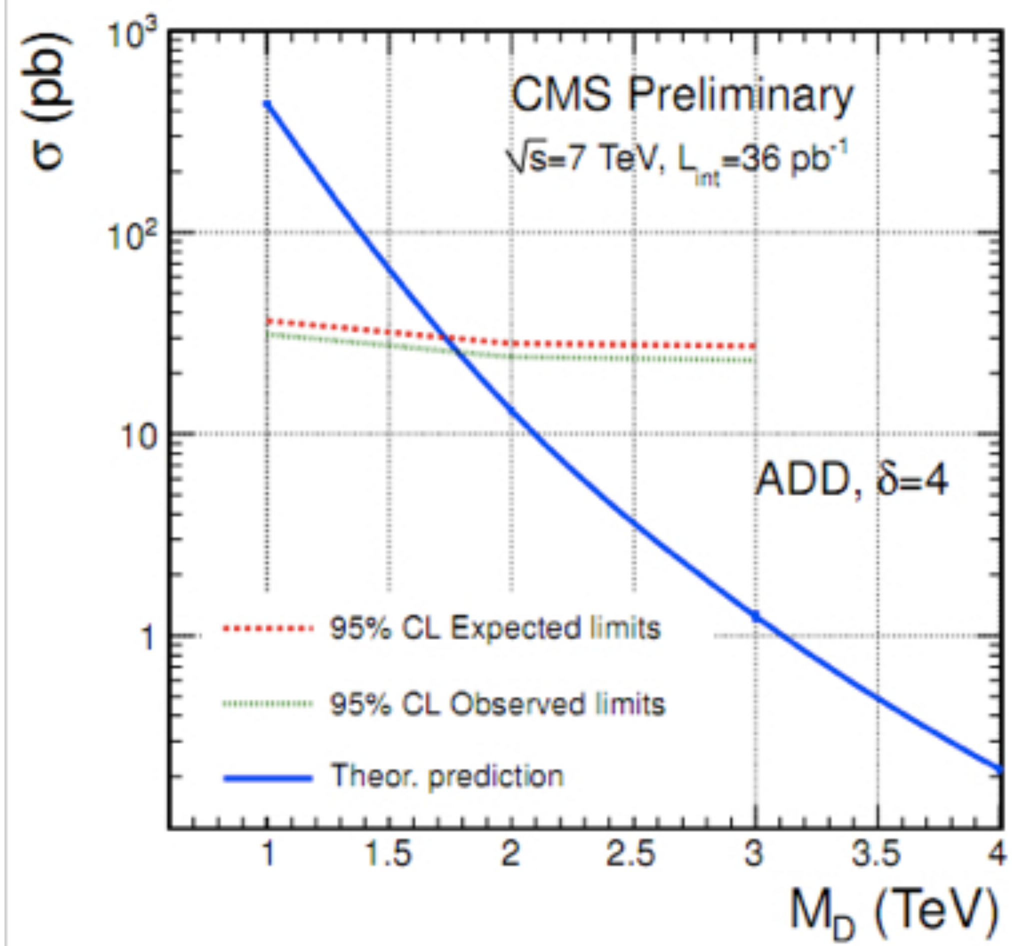
Limits on M_D





LEP: 1.6 TeV D0: 0.921 TeV
CDF 1.4 TeV **CMS: 2.4 TeV**

LEP: 0.94 TeV D0: 0.848 TeV
CDF 1.04 TeV **CMS: 1.75 TeV**

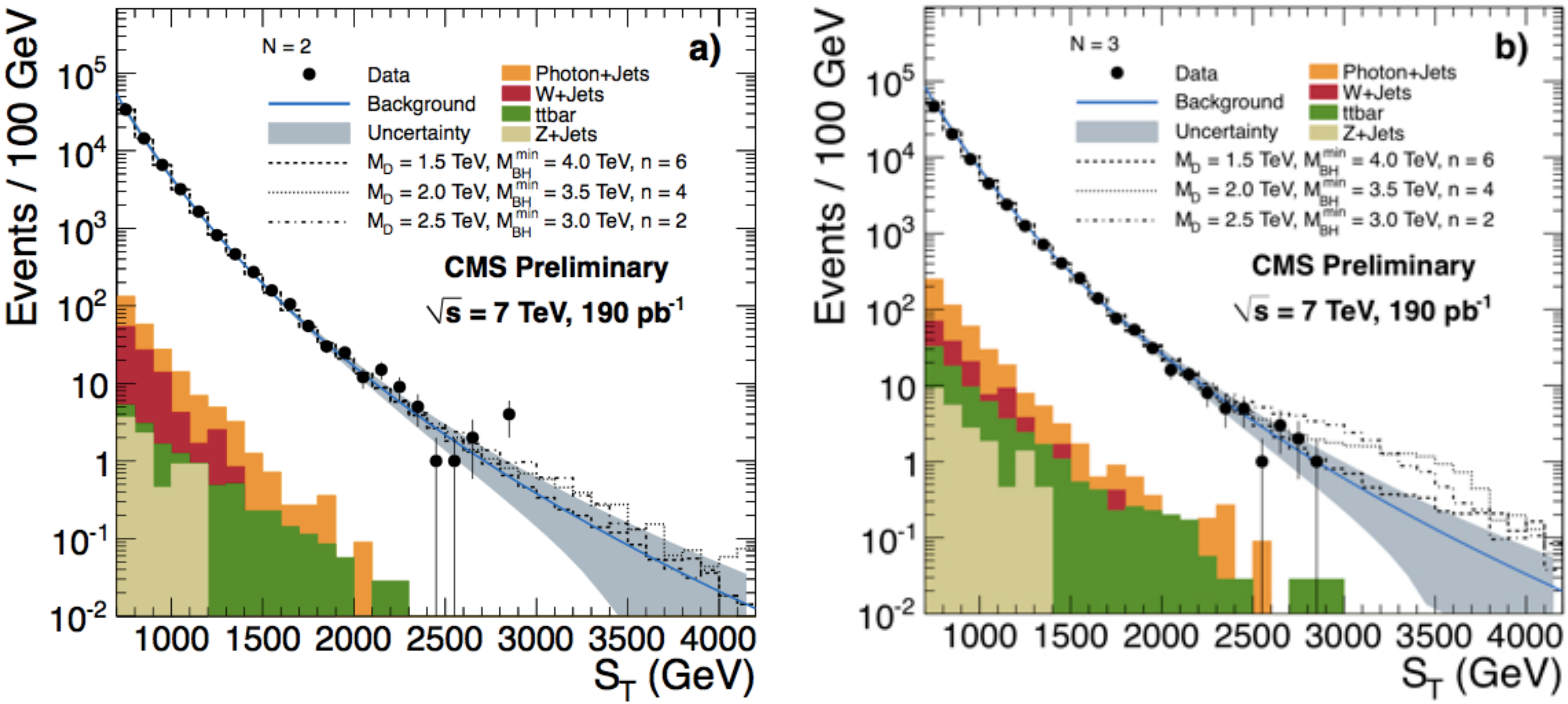
CMS PAS EXO-11-003

Microscopic Black Hole

- Theory
  - $r_s = \frac{1}{\sqrt{\pi} M_D} \left[\frac{M_{BH}}{M_D} \frac{8\Gamma(\frac{n+3}{2})}{n+2} \right]^{\frac{1}{n+1}}$
  - $\sigma = \pi r_s^2$
  - Democratic decay
    - Equal probabilities on SM degree of freedom.
    - Quarks/gluons (~75% jets)
    - Graviton emission is suppressed

- Search
  - $S_T = \sum E_T$, scalar sum of all objects {jet, γ, e, μ} with $E_T > 50$ GeV, including ME_T.
  - ST shape-invariant under object multiplicity.
  - Extract the shape from events with multiplicity N = 2 and 3.
  - Normalize to events with multiplicity $N \geq 3,4,5,6$.

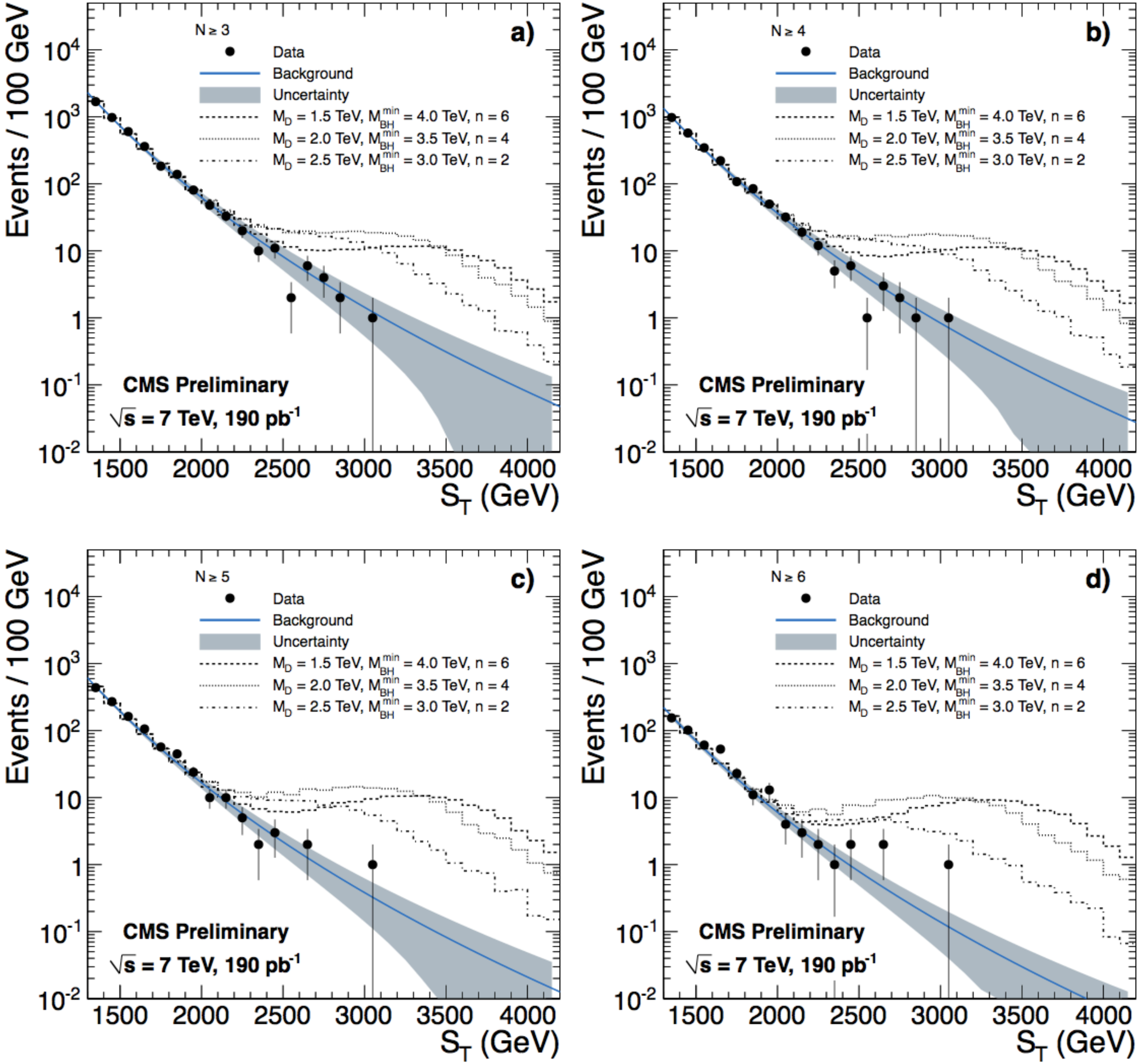
Background Estimation



CMS PAS EXO-11-021

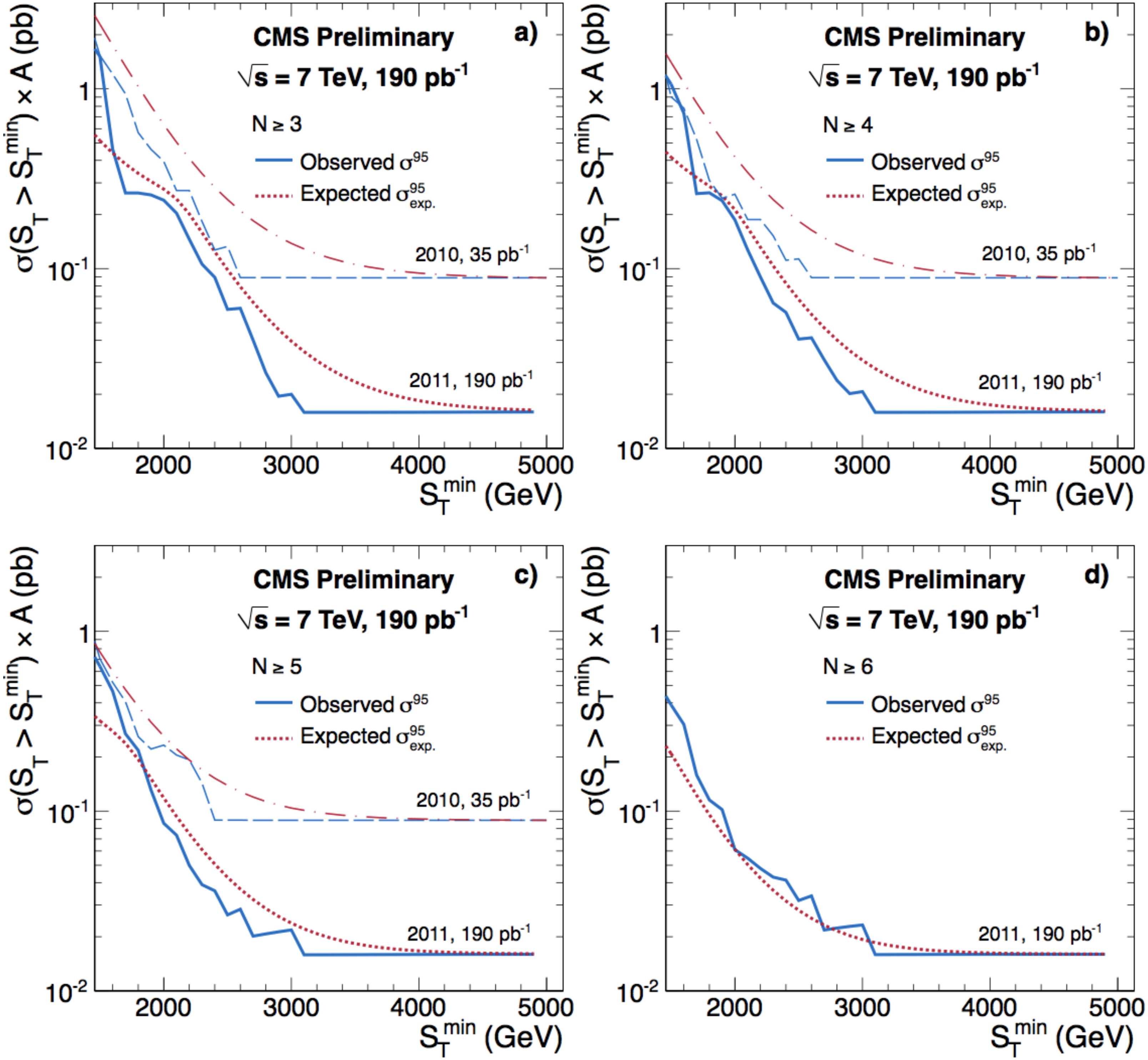
Non-QCD standard model backgrounds are negligible.
No signal contamination in fit/normalization regions.

Search for Microscopic Black Holes



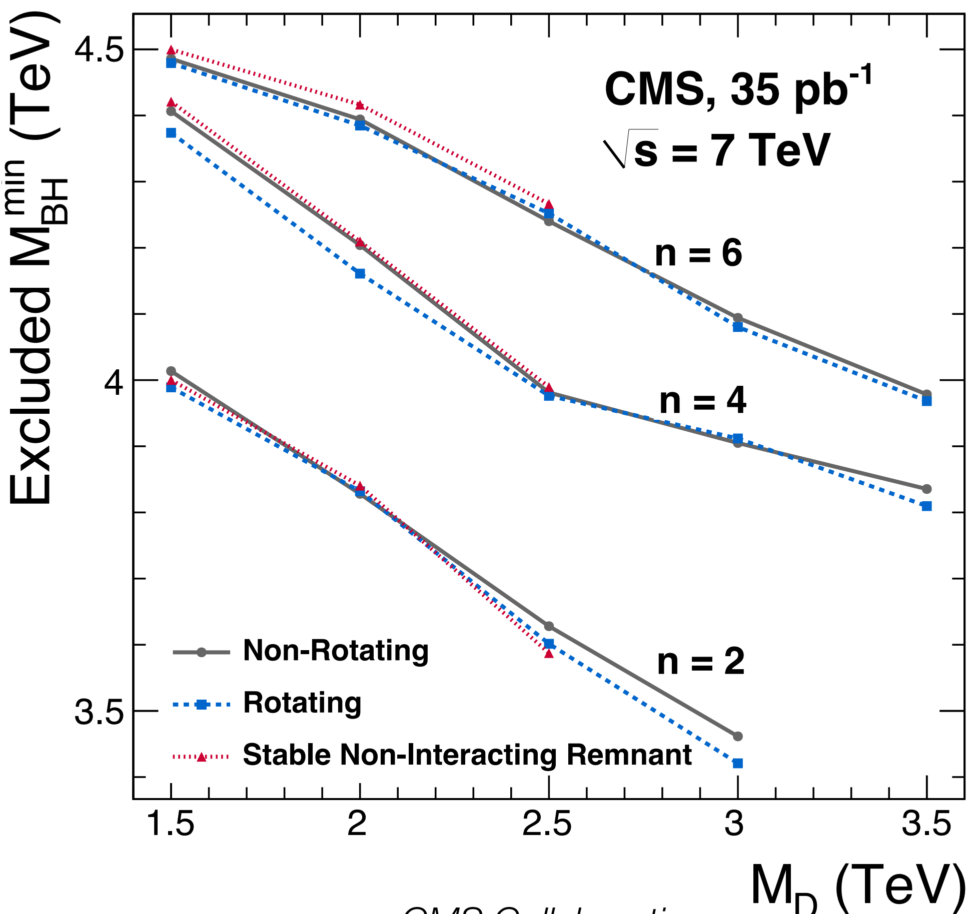
CMS PAS EXO-11-021

Model Independent Limits

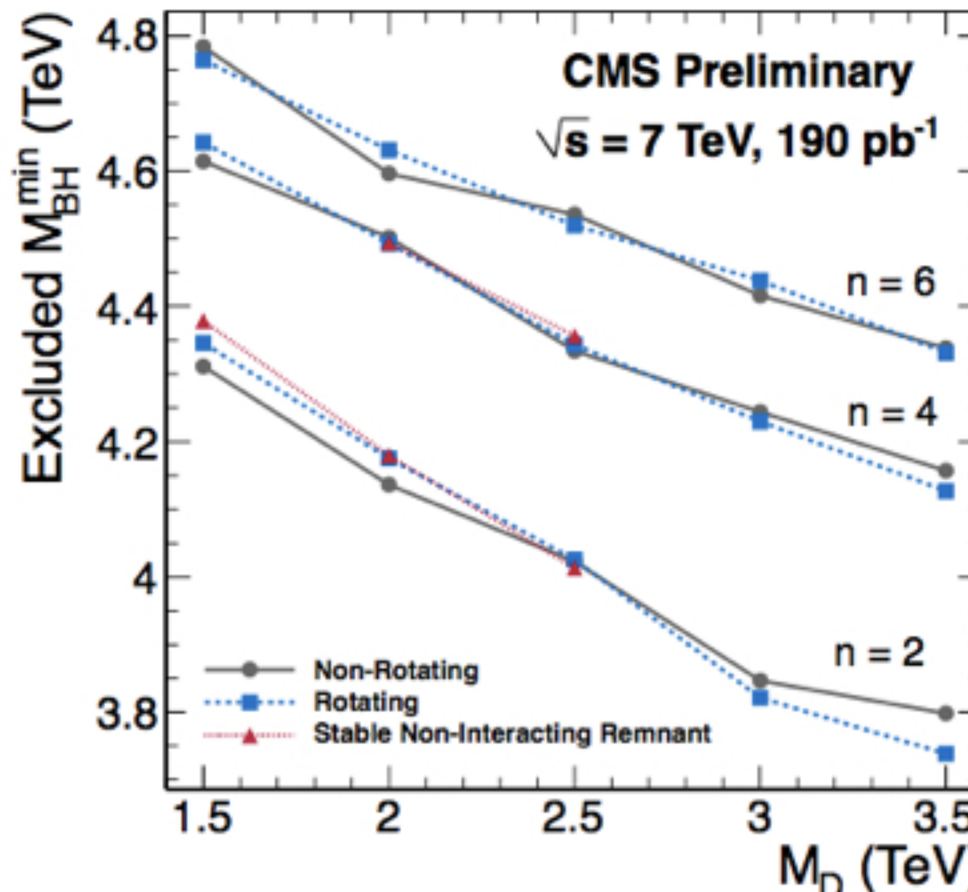


CMS PAS EXO-11-021

Limits on Min. Black Hole Mass



CMS Collaboration
PLB **679**, 434 (2011)



CMS PAS EXO-11-021

~300 GeV better than 2010 data.

Conclusions

- Searches for various of large extra dimensions model
  - Virtual gravitons: diphotons & dimuons (2010 data)
  - Direct gravitons: monojet + ME_T (2010 data)
  - Microscopic black holes (2010 data + updates)
- Most of the models give stringent limits
- Results are publicly available
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO
- Stay tuned!