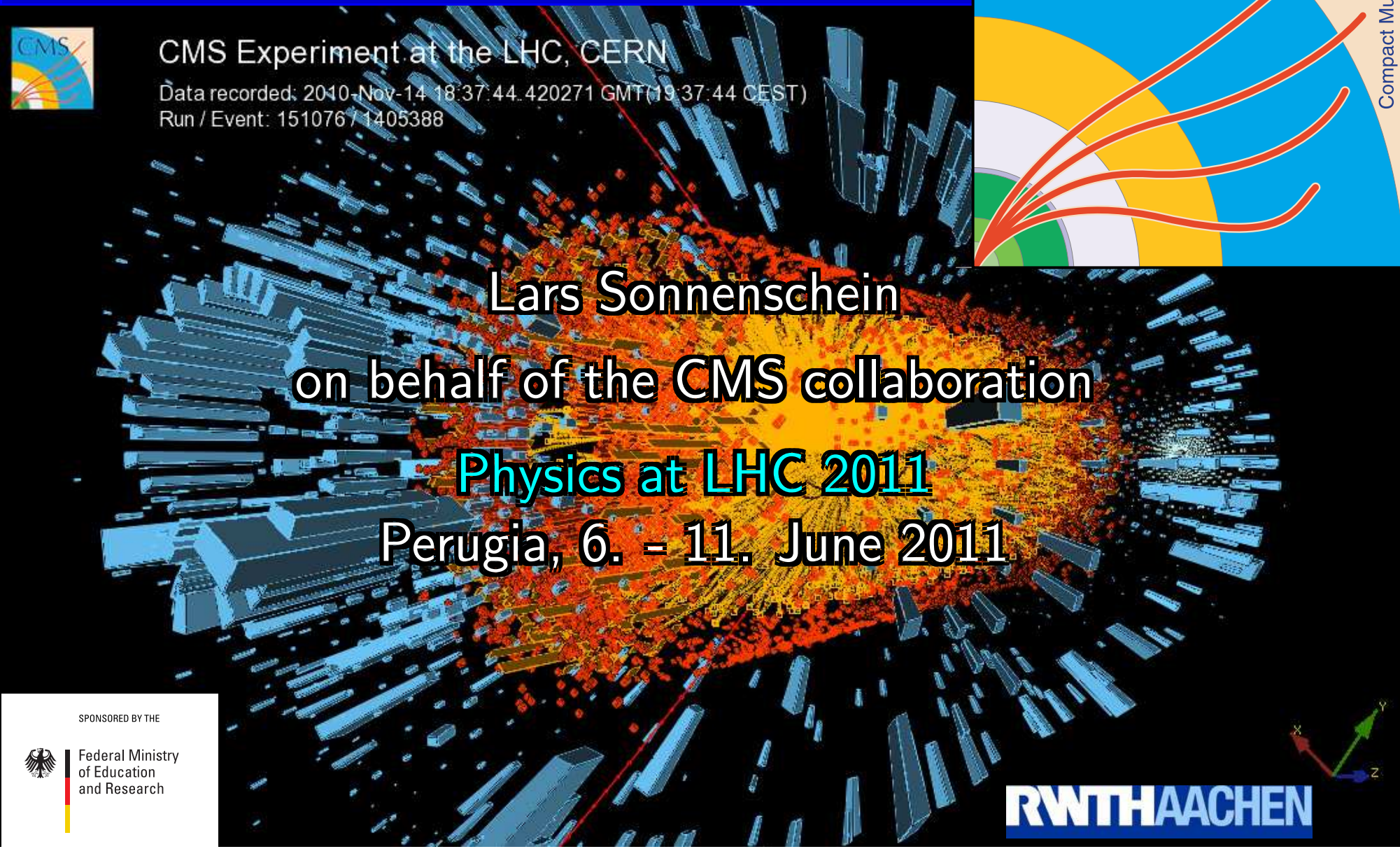
Searches in



CMS

Compact Muon Solenoid

Lars Sonnenschein

on behalf of the CMS collaboration

Physics at LHC 2011

Perugia, 6. – 11. June 2011

SPONSORED BY THE

Federal Ministry of Education and Research

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Outline

Introduction

Searches for supersymmetry (SUSY)

- Opposite-sign dileptons
- Incl. dijets + $\not\!\!E_T$
- Z + jets + $\not\!\!E_T$

Searches for TeV scale gravity (Exotica)

- LED in $\mu\mu$
- Black holes
- RS gravitons $\rightarrow \gamma\gamma$
- LED/Unpart. in Mono-Jet + $\not\!\!E_T$

Searches in lepton production (Exotica)

- highly boosted $Z \rightarrow \mu^+\mu^-$
- Resonant lepton jets
- Inclusive dilepton events
- Excited leptons

Searches in lepton + jets prod. (Exo.)

- 1st gen. scalar Lepto Quarks ($e\nu jj$)
- Heavy b-like quark

Searches in jet production (Exotica)

- Multijet resonances
- Quark comp. in dijet angular dist.

Conclusions

Introduction

Searches for physics beyond the Standard Model

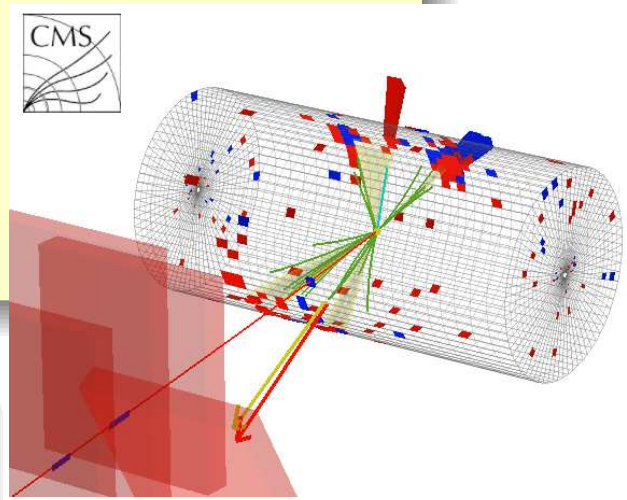
- Some of early new physics searches
- Based on 2010 data ($34 - 40$ pb^{-1} @ 7 TeV) and 2011 data ($190 - 191$ pb^{-1} @ 7 TeV)
- Some of important theories tested
  - New heavy resonances
  - Quark/lepton compositeness
  - Extra dimensions & other exotic signatures
- Many results are published or submitted/accepted for publication:

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

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

Searches for supersymmetry (SUSY)

- Opposite-sign dileptons
- Incl. dijets + $\not{E}_T$
- Z + jets + $\not{E}_T$



For leptonic SUSY searches see talk:
Search for SUSY at CMS in leptonic final states
by Didar Dobur (Higgs and SUSY session 5D)

For hadronic SUSY searches see talk:
Search for SUSY at CMS in all-hadronic final states
by Piet Verwilligen (Higgs and SUSY session 5D)

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Search for SUSY in opposite-sign dilepton events

Event pre-selection

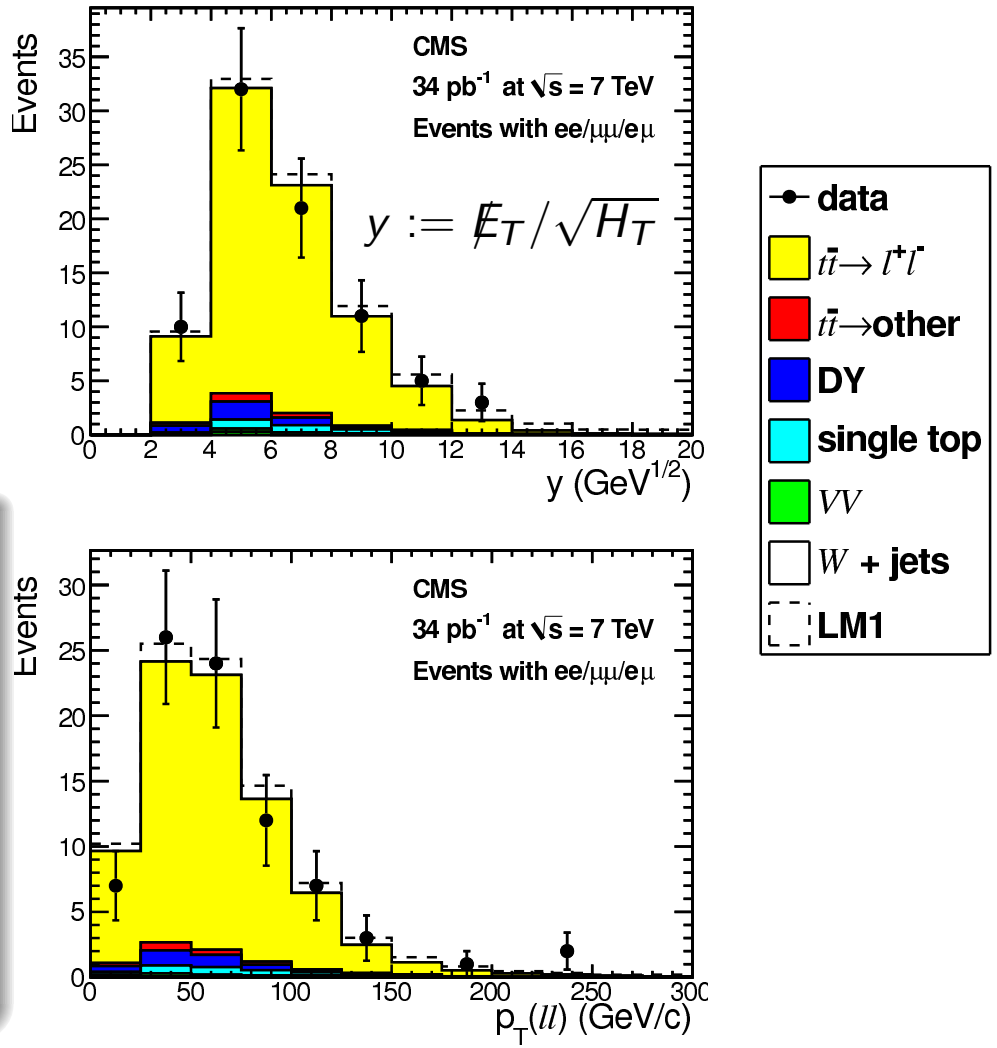
- 2 isol. leptons e^+e^-, $e^\pm\mu^\mp$, $\mu^+\mu^-$
  $p_T^{\ell_1} > 20$ GeV, $p_T^{\ell_2} > 10$ GeV
- Reject: $m_{ee,\mu\mu} < 10$ GeV
  and $76 < m_{ee,\mu\mu} < 106$ GeV (DY)
- $p_T^{\text{jet}} > 30$ GeV (anti-k_T, R=0.5)
  $N_{\text{jets}} \geq 2$
- $H_T := \sum E_T^{\text{jets}}(\text{sel.}) > 100$ GeV
- $\not{E}_T := E_T^{\text{miss}} > 50$ GeV

Modelling, comparison to theory

- Signal: SoftSUSY (particle spectrum)
  PYTHIA 6.4 (+ Prospino NLO)
- Backgrounds (CTEQ 6.6, sig + bkg):
  $t\bar{t}$, W+jets, single top (MADGRAPH)
  DY (MADGRAPH and PYTHIA 6.4, Tune Z2)
  WW, WZ, ZZ (PYTHIA 6.4)

arxiv:1103.1348 [hep-ex], Accepted by JHEP

Search extends Tevatron and LEP limits



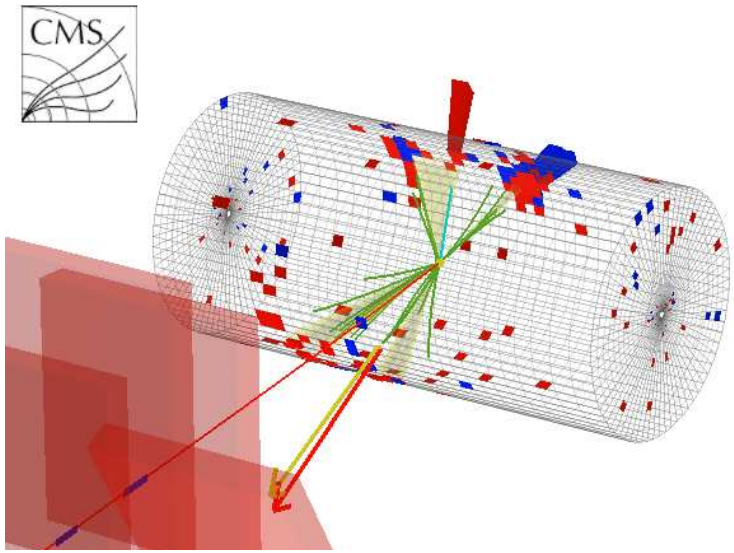
Search for SUSY in opposite-sign dilepton events

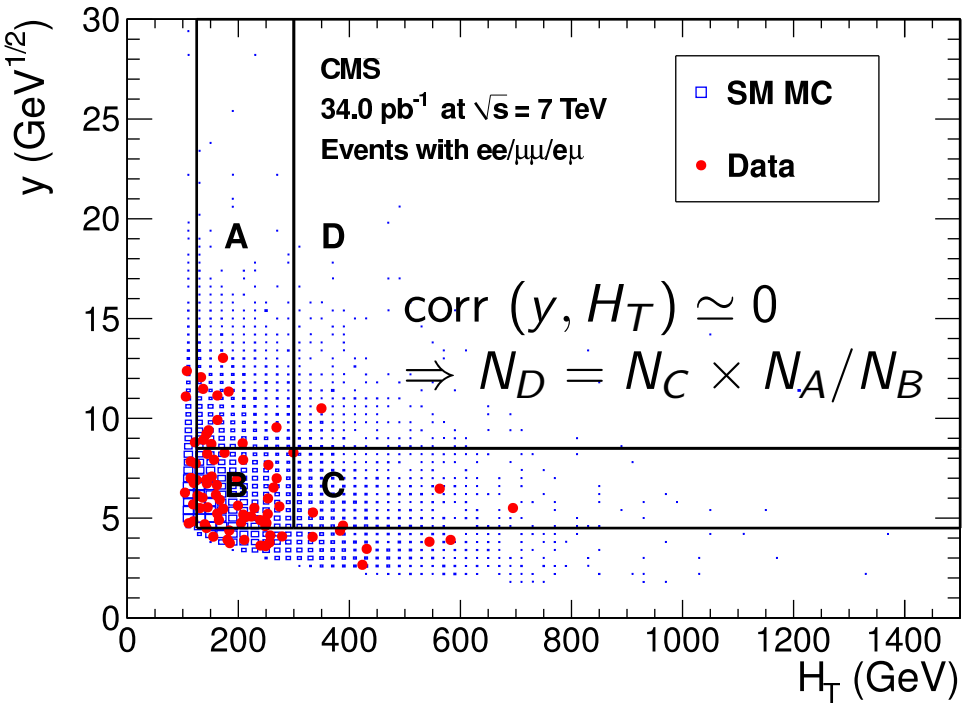
Final event selection

- $H_T > 300$ GeV
- $y := \not{E}_T / \sqrt{H_T} > 8.5\ \sqrt{\text{GeV}}$

Data driven background estimation

- Four (ABCD) regions of uncorr. variables + systematics
- $p_T(\ell\ell)$ method
  $\rightarrow$ modelling $p_T(\nu_\ell \bar{\nu}_\ell) = p_T(\not{E}_T)$ corrected for $\not{E}_T > 50$ GeV and W polarisation
- Non isol. leptons, instrumental background negligible (derived from multi-jet data)





Search for SUSY in opposite-sign dilepton events

Same flavour dilepton search ($ee, \mu\mu$)

BSM decay chains with pair of new heavy particles $\rightarrow$ same ℓ flavours

- Particle flow: leptons, jets, $\not\!\!E_T$
- $H_T > 350$ GeV
- $\not\!\!E_T > 150$ GeV

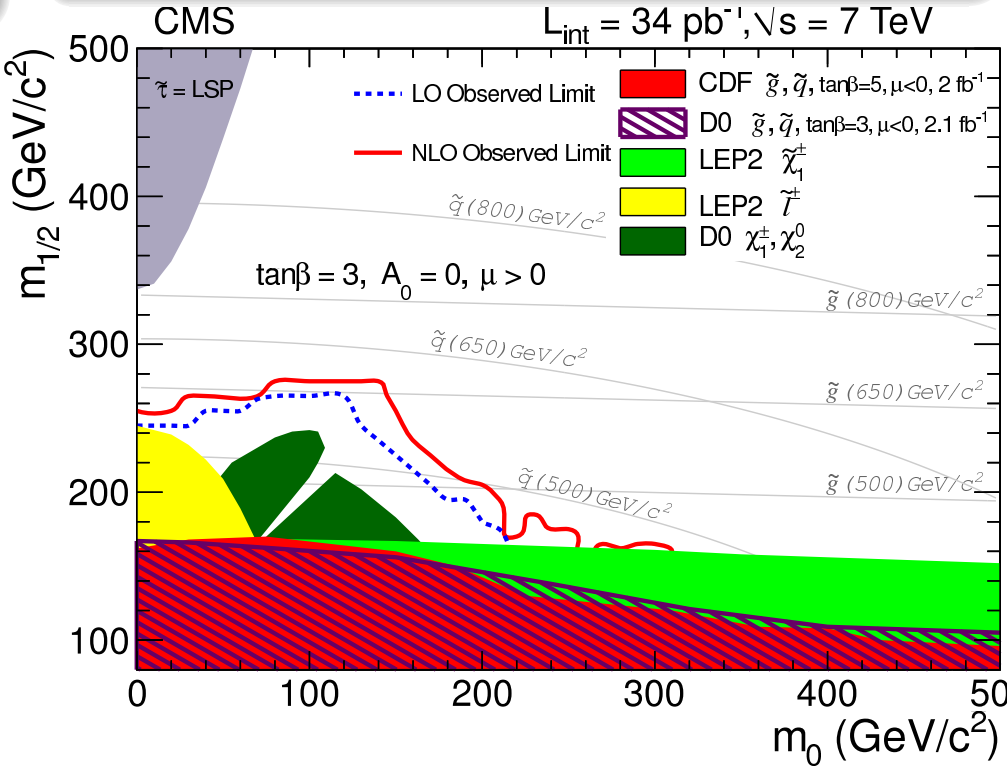
	Signal Region	
Process	ee	$\mu\mu$
$t\bar{t}$ from $e\mu$	$0.4^{+1.0}_{-0.4}$	$0.5^{+1.2}_{-0.4}$
Non-W/Z	0	0
Total predicted	$0.4^{+1.0}_{-0.4}$	$0.5^{+1.2}_{-0.4}$
Total observed	0	0
SM MC	0.38 ± 0.08	0.56 ± 0.07
LM0	3.4 ± 0.2	3.9 ± 0.2
LM1	1.6 ± 0.1	2.0 ± 0.1

LM0,1 = CMS mSUGRA Low Mass benchmark points

Model independent limits

- Bayesian 95% C.L. upper limit on number of non-SM events in signal region is 4.0 ($e\mu$) and 3.0 ($ee, \mu\mu$)

Exclusion limits within CMSSM:



Search for SUSY in incl. dijets + $\not{E}_T$ events

Search extends Tevatron and LEP limits

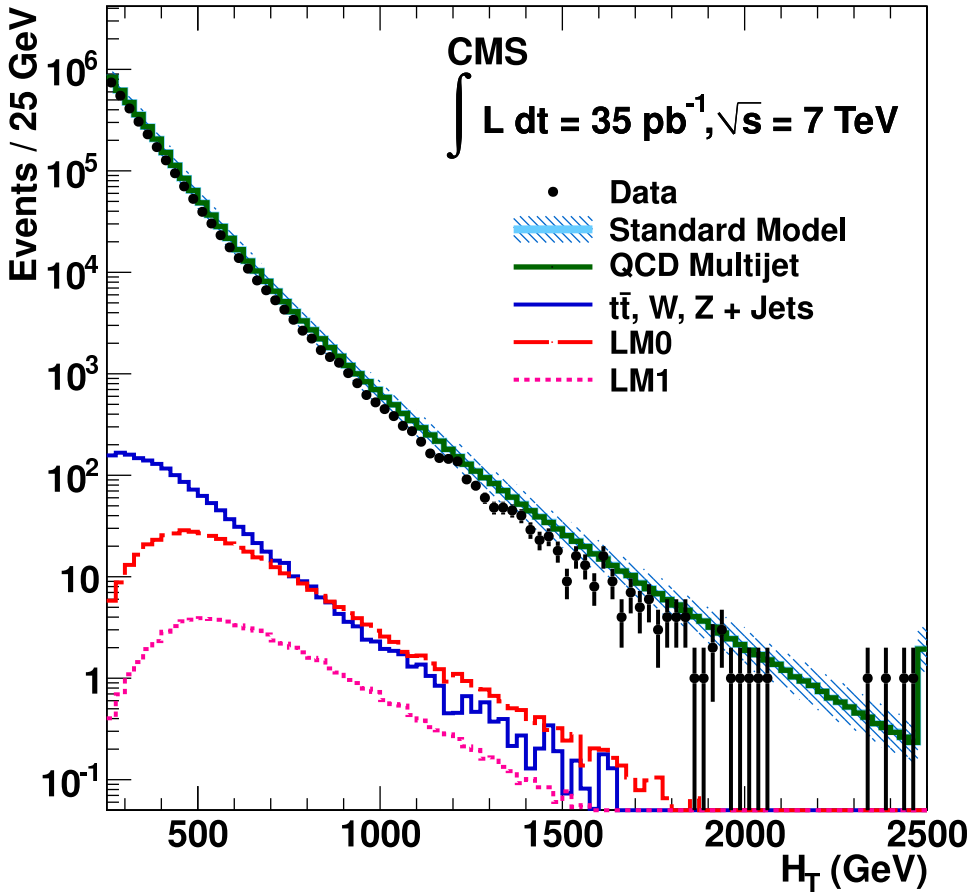
Submitted to Phys. Lett. **B**

Event pre-selection

- $E_T^{\text{jet}} > 50$ GeV, $|\eta| < 3$ (anti-k_T, R=0.5)
- $H_T = \sum E_T^{\text{jets}}(\text{sel}) > 250$ GeV
- $N_j \geq 2$, $E_T^{j_{1,2}} > 100$ GeV, $|\eta_{j_1}| < 2.5$
- Veto: isol. e,μ, $p_T > 15$ GeV
- Veto: isol. γ, $p_T > 25$ GeV

Modelling, comparison to theory

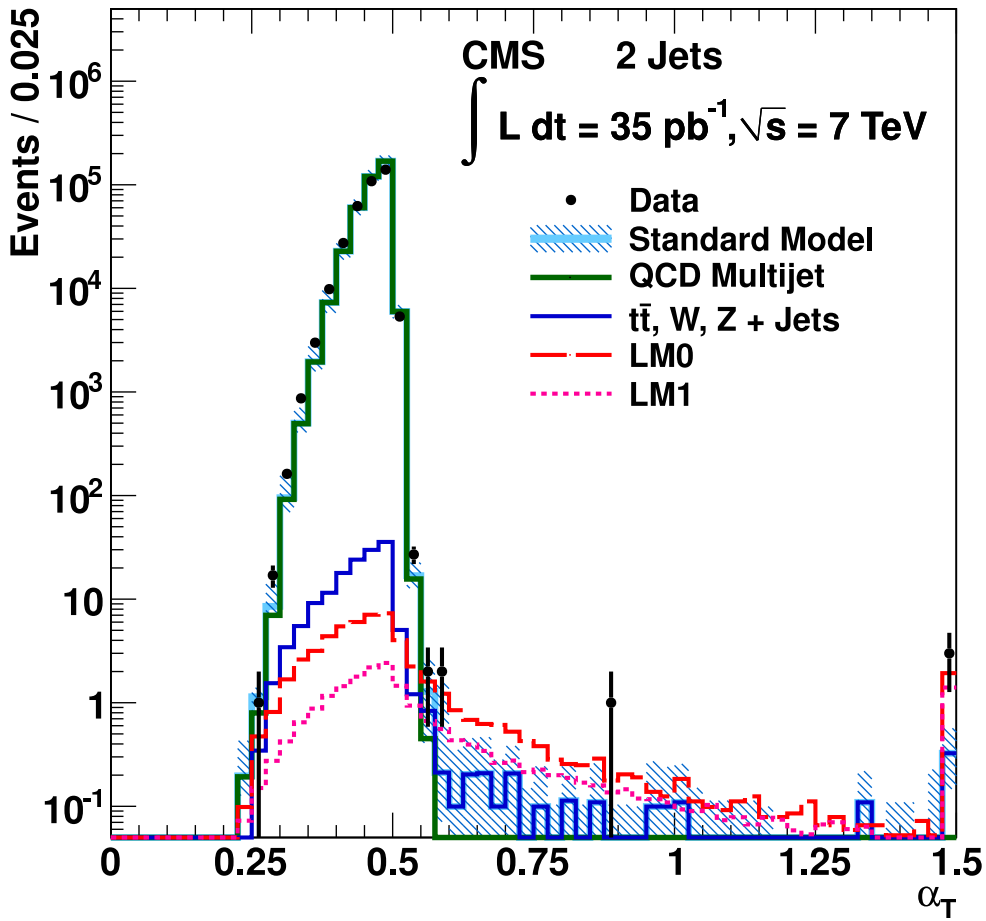
- Signal:
  SoftSUSY (particle spectrum)
  PYTHIA 6.4 (+ Prospino NLO)
- Backgrounds:
  multi-jets (PYTHIA6.4, Tune Z2)
  EW (MADGRAPH, PYTHIA 8.1, Tune 1):
  W+jets, $Z \to \nu_\ell \bar{\nu}_\ell$+jets, $t\bar{t}$+jets



Search for SUSY in incl. dijets + $\not\!\!E_T$ events

Final event selection

- $H_T = \sum E_T^{\text{jets}}(\text{sel}) > 350$ GeV
  - $M_T := \sqrt{(E_T^{j_1}+E_T^{j_2})^2 - (p_x^{j_1}+p_x^{j_2})^2 - (p_y^{j_1}+p_y^{j_2})^2}$
  - $\alpha_T = E_T^{j_2}/M_T \overset{\phi\to\pi, m\to 0}{\longrightarrow} 0.5$
    mismeasured back-to-back jets: $\alpha_T < 0.5$
    not back-to-back jets: $\alpha_T > 0.5$
- $\alpha_T > 0.55$



- $\not\!\!H_T := |-\sum_i \vec{p}_T^{\,j_i}|$, ignore 1 jet
  - $\Delta\phi^* := \min|\Delta\phi(\vec{\not\!\!H}_T, \vec{p}_T^{\,j})|$
- Reject: If $\Delta\phi^* < 0.5$ and
  $\Delta R_{\text{ECAL}}(j, \text{masked region}) < 0.3$
- Reject: $R_{\text{miss}} := \not\!\!H_T/\not\!\!E_T^{\text{calo}} > 1.25$

Search for SUSY in incl. dijets + $\not\!\!E_T$ events

Data driven background estimation

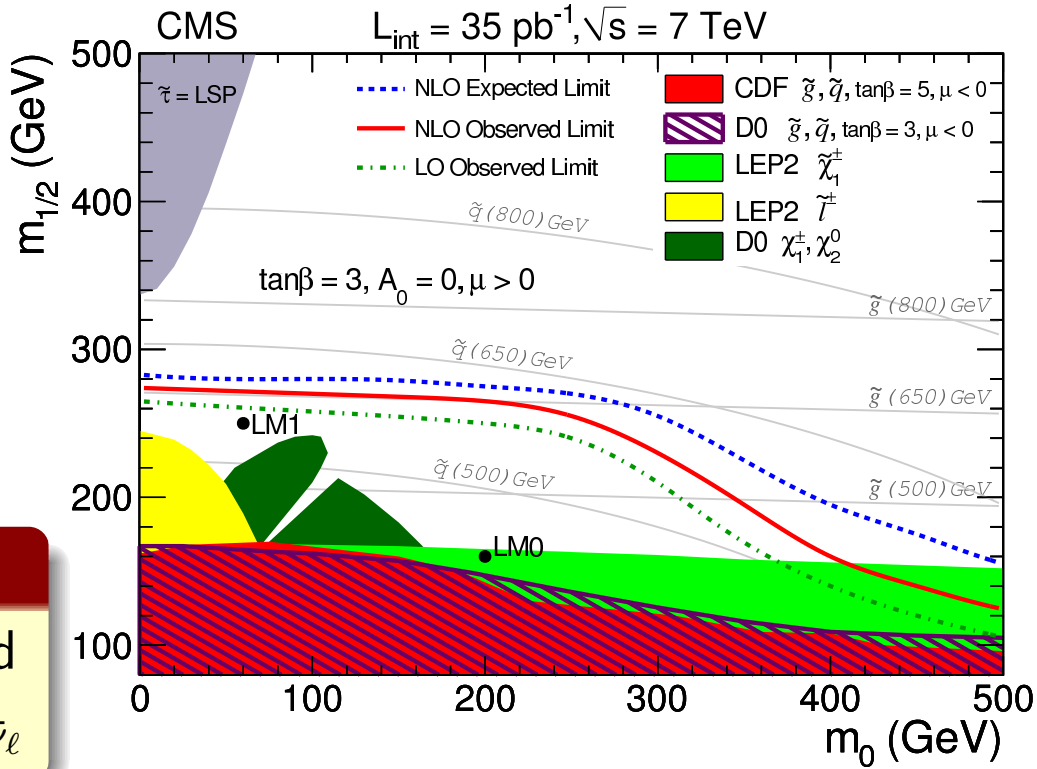
- Total background from 2 control regions: $250 < H_T < 300$ GeV, $300 < H_T < 350$ GeV
- Dominated by SM processes
- $R_{\alpha_T} := \frac{N(\alpha_T > 0.55)}{N(\alpha_T < 0.55)}$
- $R_R = \frac{R_{\alpha_T}(H_T^{300})}{R_{\alpha_T}(H_T^{250})} = \frac{R_{\alpha_T}(H_T^{350})}{R_{\alpha_T}(H_T^{300})} \approx 1$
- Independent bkd. estimation for $W \to \ell\nu_\ell, t\bar{t}$ from $W \to \mu\nu_\mu$ + jets data and for $Z \to \nu_\ell\bar{\nu}_\ell$ from γ + jets data

Limit on signal yield (model indep.)

- Feldman Cousins, Profile Likelihood $L_{\text{tot.}} = L_{\text{signal}} \cdot L_{\text{bkg}}^{\text{incl}} \cdot L_{W,t\bar{t}} \cdot L_{Z\to\nu_\ell\bar{\nu}_\ell}$

Interpretation within CMSSM

- No dedicated optim. for CMSSM
- CMS mSUGRA benchmark points:
  LM0 excluded at 99.99% C.L.
  LM1 excluded at 99.2% C.L.



Search for SUSY in Z + jets + $\not\!\!E_T$ events

Jets $\leftrightarrow$ Z Balance (JZB)

- Signal example: $\tilde{g} \to \bar{q} + \tilde{q} \to \bar{q} + q + \tilde{\chi}_2^0 \to \bar{q} + q + Z + \tilde{\chi}_1^0$
- BSM particle producing $\not\!\!E_T$ has same mother as Z
- JZB $:= \left| -\sum_{\text{jets}} \vec{p}_T \right| - |\vec{p}_T(Z)|$

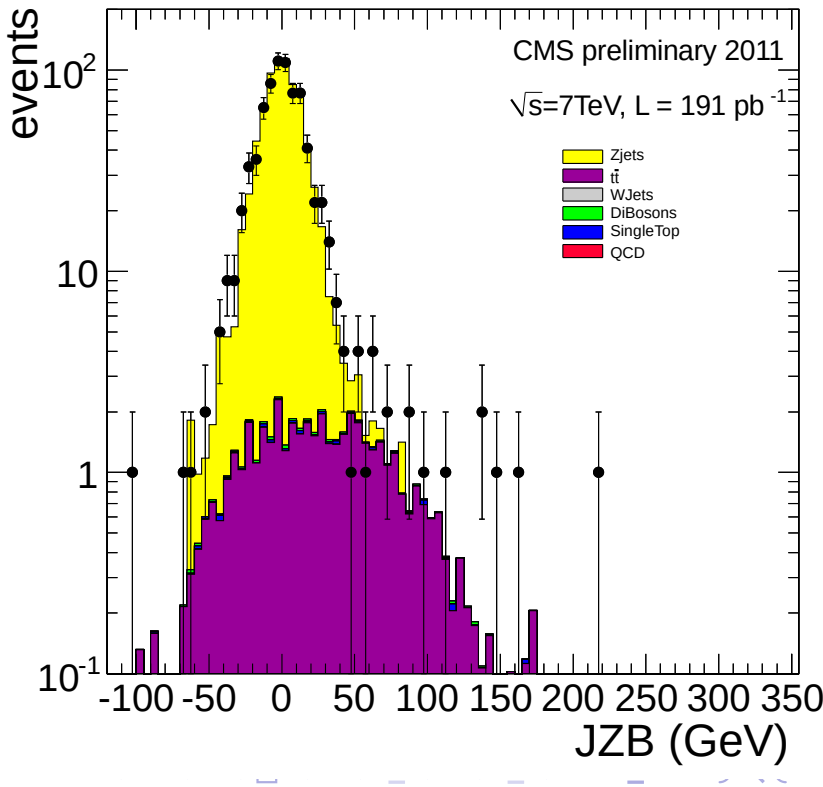
Preliminary, PAS SUS-11-012

Event selection ($Z \to \ell^+\ell^-$)

- isol. e^+e^-, $\mu^+\mu^-$, $e^\pm\mu^\mp$, $p_T(\ell) > 20$ GeV
- $|m_{\ell^+\ell^-} - m_Z| < 20$ GeV
- $\text{JZB}_{\text{ref}} > 50$ GeV, $\text{JZB}_{\text{search}} > 100$ GeV
- Particle-Flow jets (anti-k_T, R=0.5)
  $N_{\text{jets}} \geq 3$, $p_T > 30$ GeV

Modelling, comparison to theory

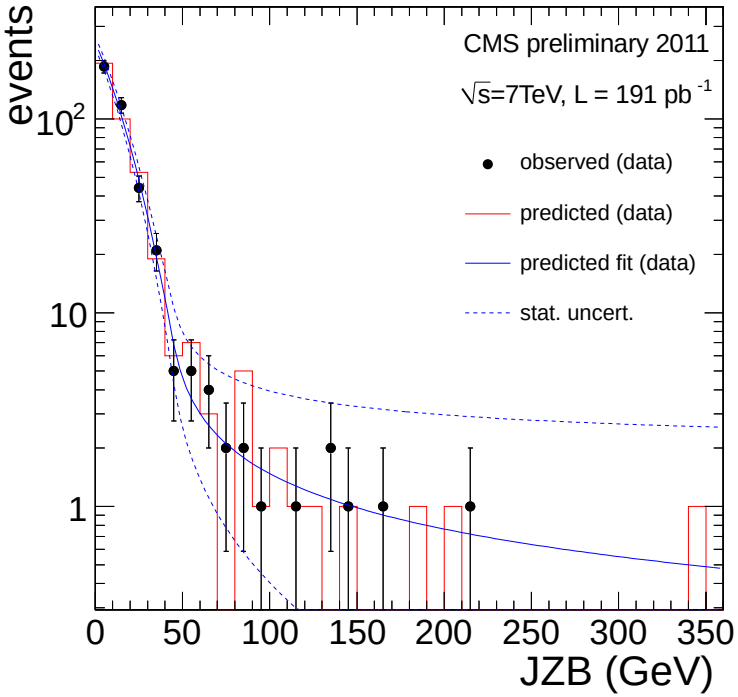
- Backgrounds: DY+jets, $t\bar{t}$
  MADGRAPH 4.4.24, PYTHIA 6.4.22 (Tune D6T)



Search for SUSY in Z + jets + $\not\!\!E_T$ events

Data driven background estimation

- $t\bar{t}$ dilepton opposite-flavour (OF) channel to determine $t\bar{t}$ background
- Consider JZB peak pos. subtracted
- $\mathrm{JZB}^{\mathrm{pred.}}_{\mathrm{bkgd}} = \mathrm{JZB}^{\mathrm{pos}}_{\mathrm{OF}} + |\mathrm{JZB}^{\mathrm{neg}}_{\mathrm{SF}} - \mathrm{JZB}^{\mathrm{neg}}_{\mathrm{OF}}|$



Model independent limits

- Bayesian inference and profile likelihood 95% C.L upper limit on signal events of $14.2^{+7.6}_{-4.6}$ (JZB$>$ 50 GeV) and $8.6^{+4.0}_{-3.5}$ (JZB$>$ 100 GeV)

Upper limits within CMSSM:

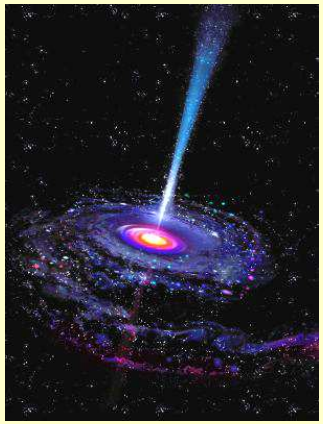
on $\sigma \times \mathrm{BR} \times \mathcal{A}$:

JZB	LM4	LM8
$>$ 50 GeV	0.064	0.067
$>$ 100 GeV	0.040	0.043

Region	Observed events	Background prediction	MC expectation
$JZB > 50\,\mathrm{GeV}$	20	$24 \pm 6(\mathrm{stat}) \pm 1.4(\mathrm{peak})^{+1.2}_{-2.4}(\mathrm{sys})$	16.0 ± 1.2 (MC stat)
$JZB > 100\,\mathrm{GeV}$	6	$8 \pm 4(\mathrm{stat}) \pm 0.1(\mathrm{peak})^{+0.4}_{-0.8}(\mathrm{sys})$	3.6 ± 0.4 (MC stat)

Searches for TeV scale gravity (Exotica)

- LED in $\mu\mu$
- Black holes
- RS gravitons $\rightarrow \gamma\gamma$
- LED/Unpart. in Mono-Jet + $\not{E}_T$



For details see talk:
Search for Large Extra Dimensions at CMS
by Patrick (Ka Vang) Tsang (BSM session 5F)

Large Extra Dimensions in $\mu\mu$ events

$$M_D^{n+2} = \frac{M_{Pl}^2}{(8\pi)L^n}$$

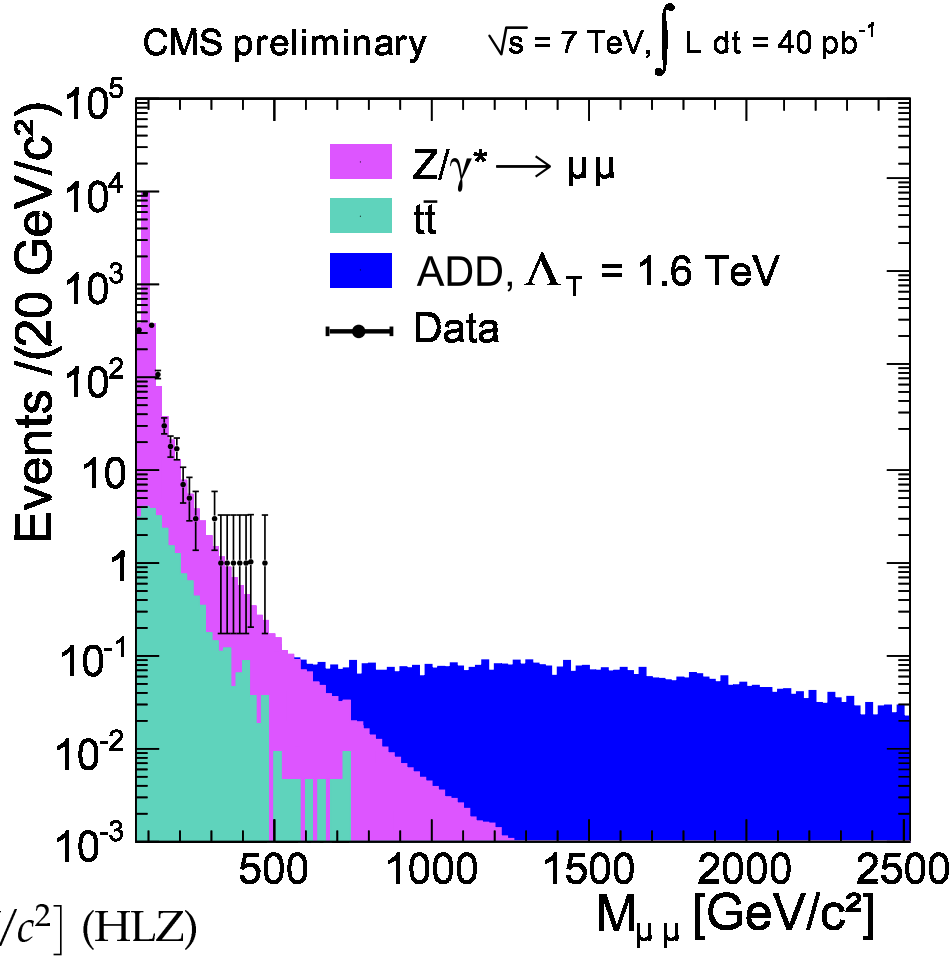
Preliminary, PAS EXO-10-020

Event selection

- 2 isol. muons, $p_T^\mu > 30$ GeV
- $IP_{xy} < 2$ mm (cosmics veto)
- Opening angle $\alpha(\mu,\mu) < \pi - 0.02$

Modelling, comparison to theory

- Signal: Pythia 8.1 (PDF's: CTEQ6L1)
- Dominating backgrounds: DY, $t\bar{t}$
- DY: NLO EW (HORACE), QCD (MC@NLO), NNLO corr. FEWZ
- 95% Bayes upper limits on $\sigma_s(M_{\mu\mu}$=1−7TeV) = 0.088 - 0.098pb



	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

Search for microscopic black hole signatures

For details see LED talk by Patrick (Ka Vang) Tsang (BSM session 5F)

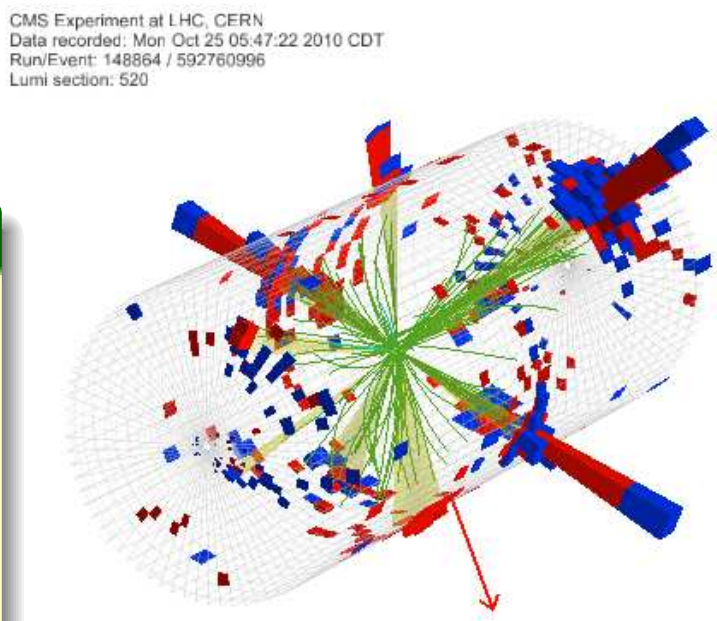
Event selection

- e, γ, μ, jets (anti-k_T (R=0.5)): $p_T > 20$ GeV
- $S_T := \sum p_T^{>50\ \mathrm{GeV}}(e,\ \gamma,\ \mu,\ \mathrm{jet}, \not{E}_T)$

$N(e, \gamma, \mu, j) > N_{\mathrm{min}} = 2, 3, 4, 5, 6$

Preliminary, PAS EXO-11-021

2010 data ($35\mathrm{pb}^{-1}$) already published: Phys. Lett. B **697**, 434 (2011)



10-jet candidate event, $S_T = 1.3$ TeV

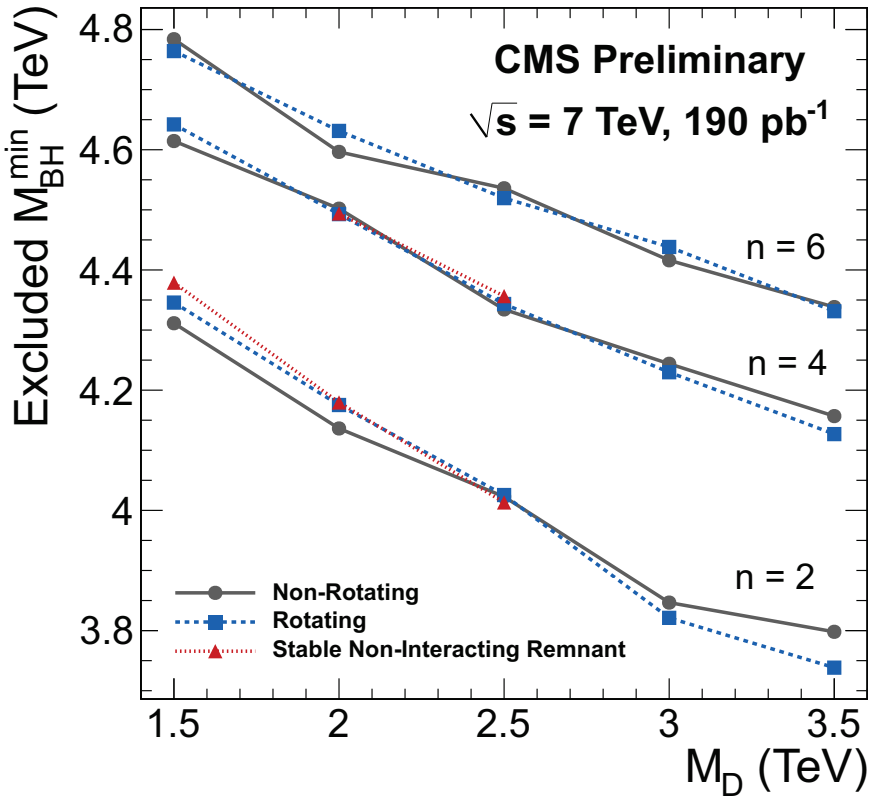
Modelling, comparison to theory

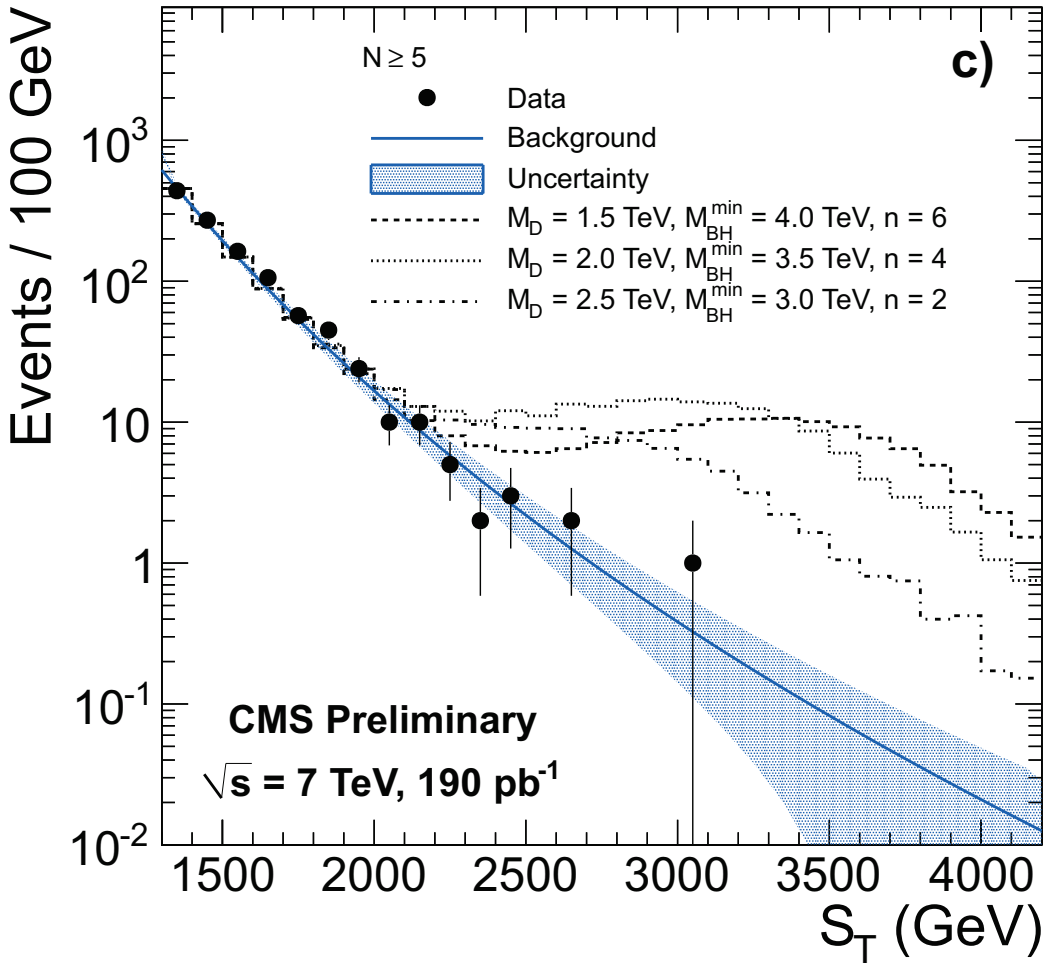
- Black hole signal: BlackMax, CHARYBDIS + PYTHIA 6.420
- Backgrounds:
  Multi-jets from data (S_T reduced sensitivity to ISR, FSR)
  direct γ, W/Z+jets, $t\bar{t}$:
  MADGRAPH + PYTHIA

Search for microscopic black hole signatures

Limits on mass and scale

- Bayesian limit on black hole production at 95% C.L.
- $m^{\text{min}}_{\text{Black Hole}} > 3.9 - 4.8$ TeV
- ADD: $M_D > 3.7 - 4.8$ TeV





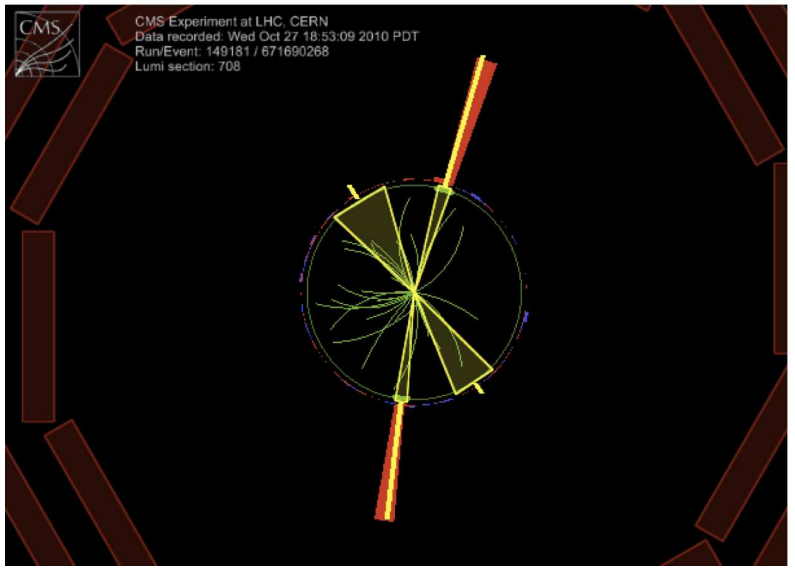
Model independent exclusion limits @ 95% C.L.

- $\sigma(S_T > S_T^{\text{min}}) \times \mathcal{A}$ limits at $\sim$ 15 fb

Search for Randall-Sundrum Gravitons $\rightarrow \gamma\gamma$

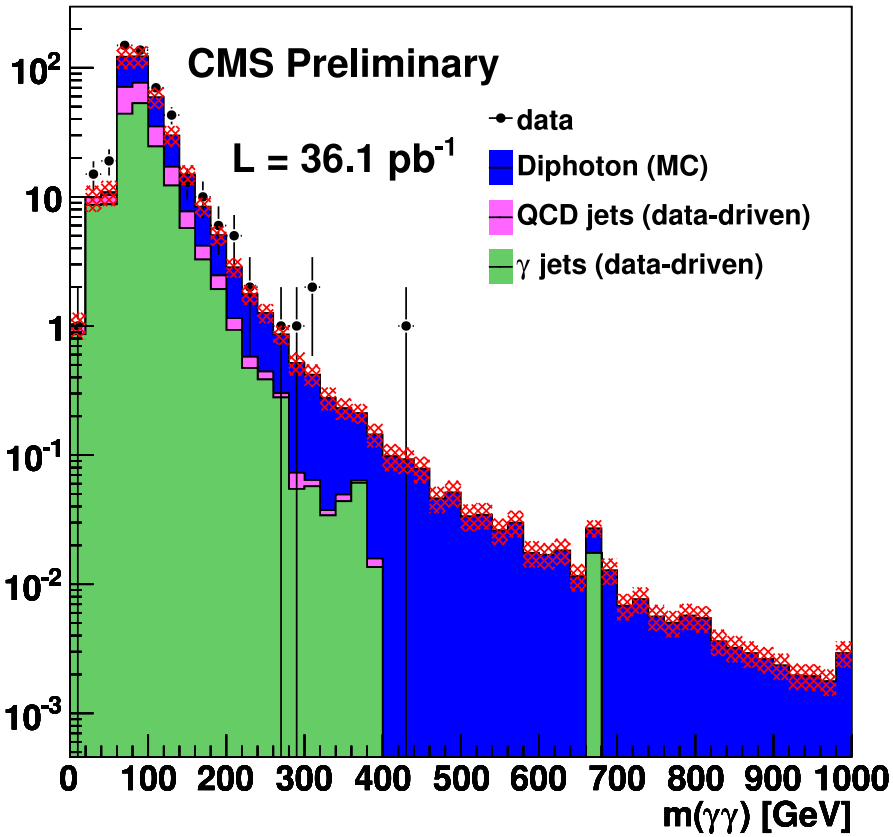
$$\frac{M_{Pl}^2}{8\pi} = \frac{M_5^3}{k}(1 - e^{-2\pi k r_c})$$

Preliminary, PAS EXO-10-019



Event selection

- 2 isol. γ's, $p_T > 30$ GeV, $|\eta| < 1.44$ (barrel)



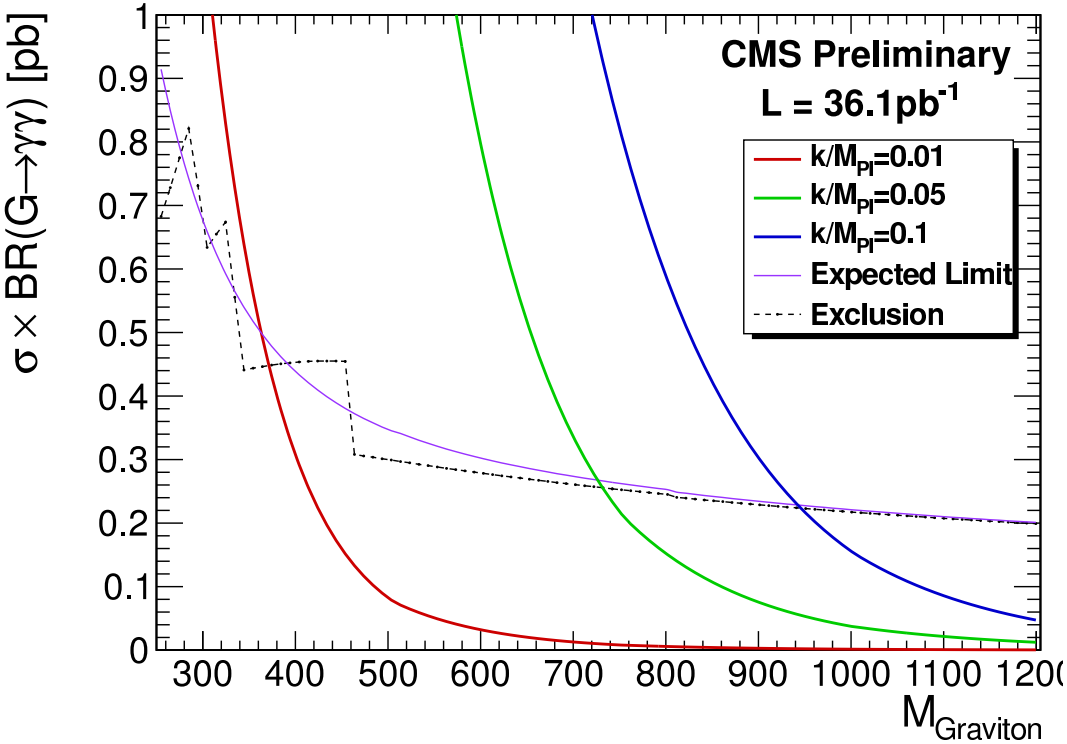
Modelling, comparison to theory

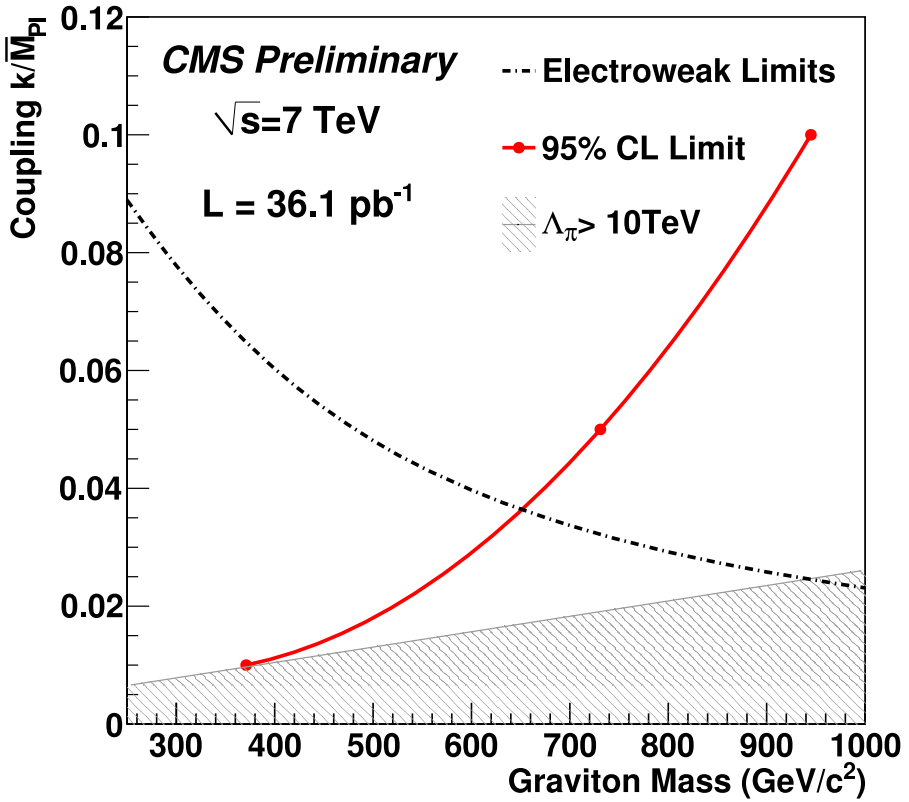
- PYTHIA6: RS-1 graviton, $\gamma\gamma$ (irreducible, NLO $k = 1.3$), γ+jets, di-jets, DY e^+e^-
- S/B endcap worse than barrel ($\rightarrow$ restrict to barrel)
- γ fake rate derived from data

Search for Randall-Sundrum Gravitons $\rightarrow \gamma\gamma$

Exclusion limits

- Bayesian 95% C.L. upper limit on $\sigma \times$ BR in each mass window
- Translating into lower limits on the graviton mass M_1 (as a function of coupling k/M_{Pl})





Search for new physics with a Mono-Jet and $\not{E}_T$

Signature predicted by models: ADD Large Extra Dimensions and Unparticles

$q\bar{q} \to gG(gU)$, $qg \to qG(qU)$, $gg \to gG(gU)$

Event selection

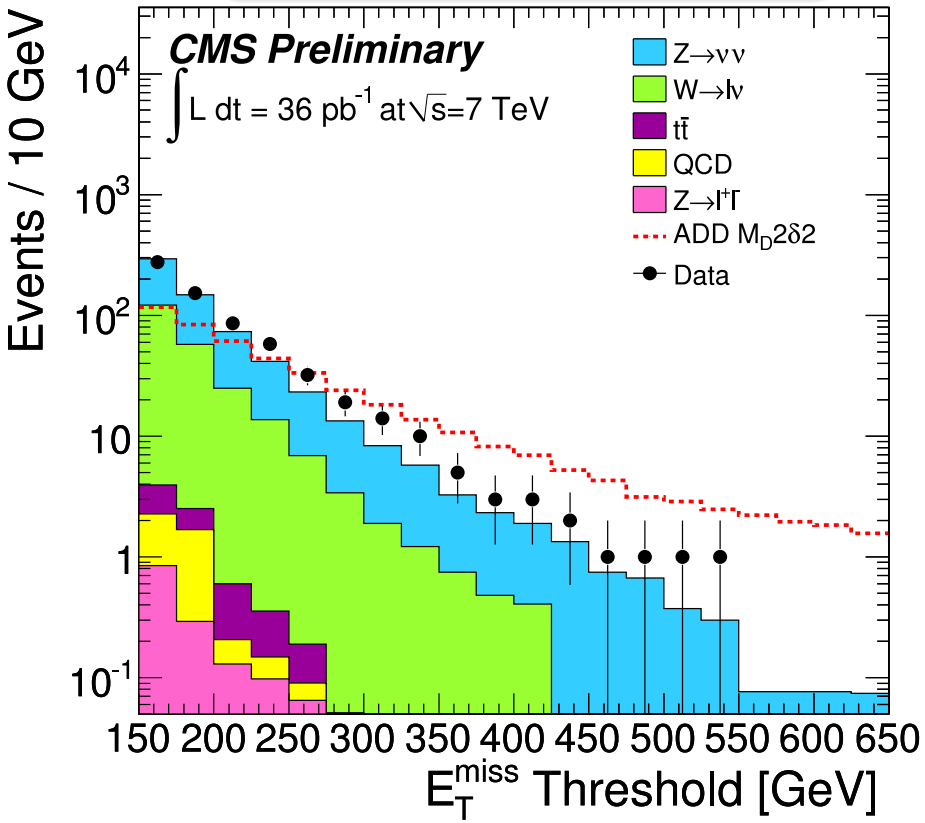
- Particle Flow technique ($\to$ jets, $\not{E}_T$)
- $N_{\text{jets}} = 1, 2$ (anti-k_T, R=0.5)
  $p_T > 30$ GeV, $p_T^{j_1} > 110$ GeV
- No isol. leptons ($p_T > 20$ GeV)
- $\not{E}_T > 150$ GeV

Modelling, comparison to theory

- Signal (ADD, Unparticle): PYTHIA8.130 (CTEQ6.6)
- Backgrounds (V+jets data driven, $t\bar{t}$, multi-jets): MADGRAPH + PYTHIA6.420 (Tune D6T)

Preliminary, EXO-11-003

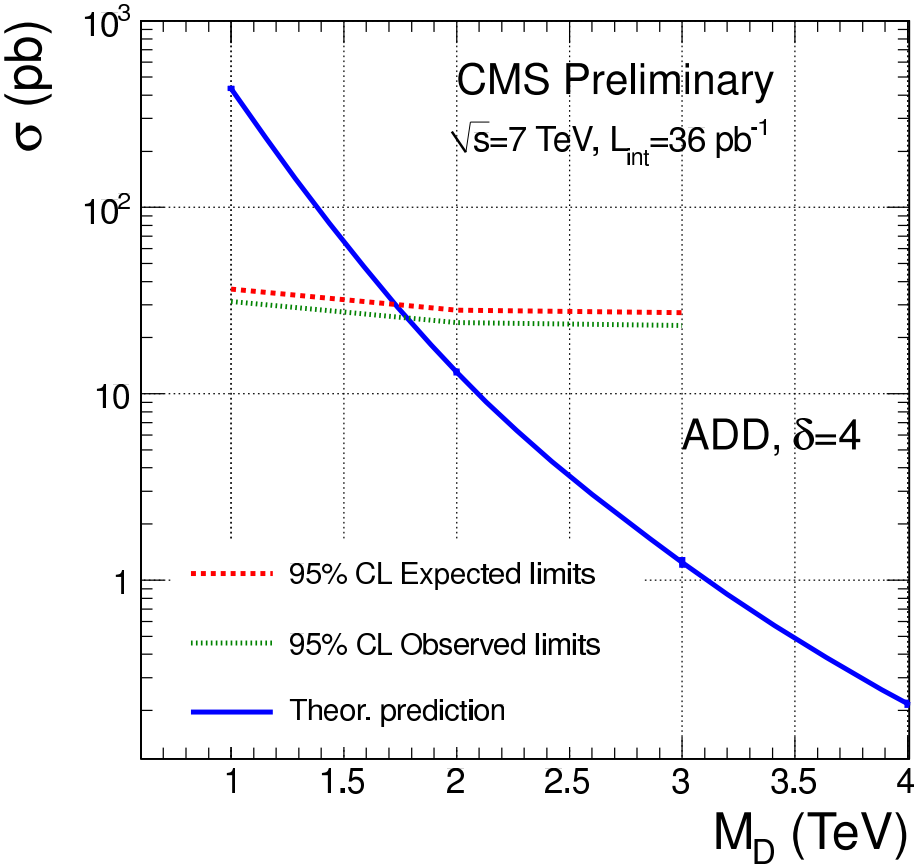
$$M_{Pl}^2 \sim M_D^{\delta+2} R^{\delta}$$

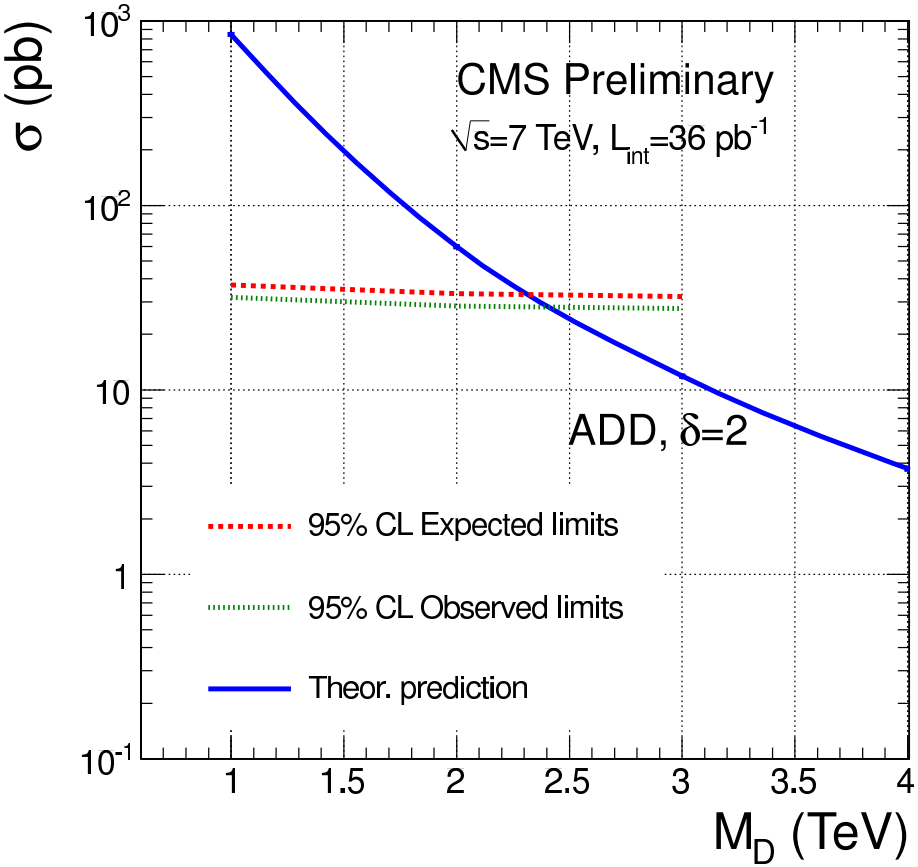


Search for new physics with a Mono-Jet and $\not{E}_T$

Exclusion limits

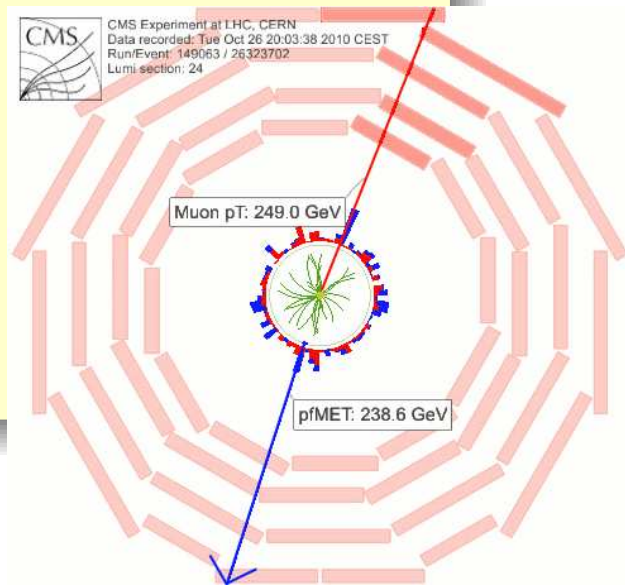
- Bayesian 95% C.L. upper limit on number of non-SM events compatible with measurement (flat prior)
- Translating into limits on model cross sections and parameters





Searches in lepton production (Exotica)

- highly boosted $Z \rightarrow \mu^+\mu^-$
- Resonant lepton jets
- Inclusive dilepton events
- Excited leptons



For details see talk:
Search for leptonic resonances at CMS
by Carmen Diez Pardos (BSM session 5F)

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Search in highly boosted $Z \to \mu^+\mu^-$ events

Optimised for detection of excited quarks $q^* \to qZ \to q\mu^+\mu^-$
Sensitive to compositeness, SUSY, TC, new gauge bosons

Preliminary, EXO-10-025

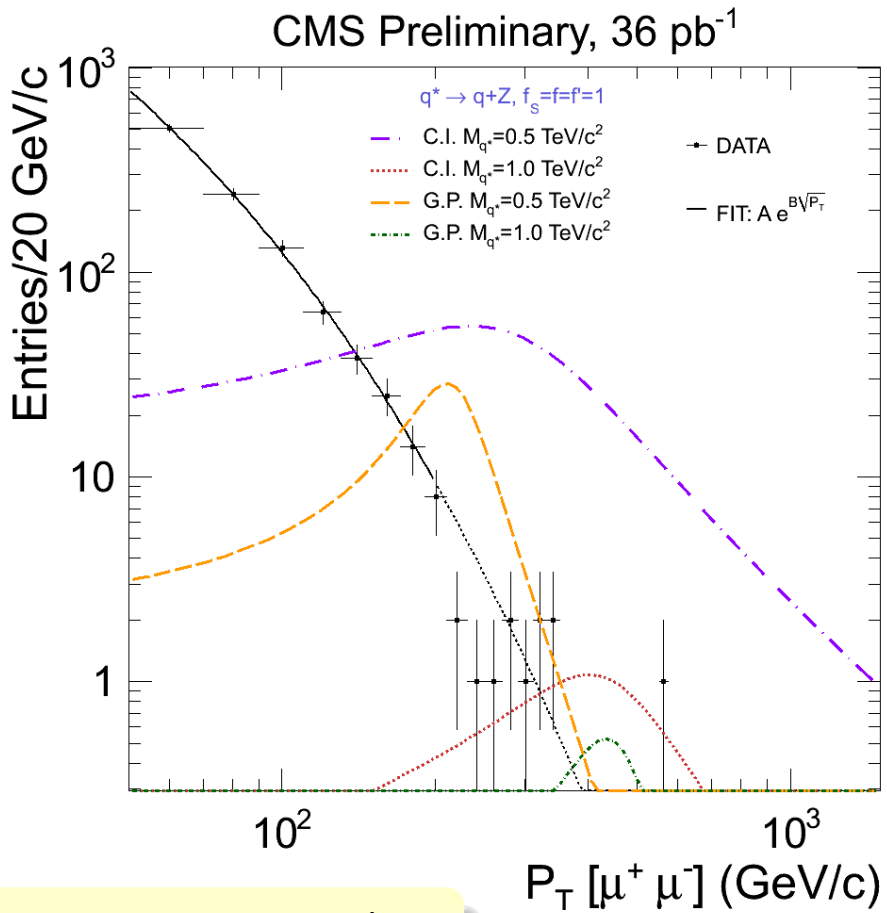
Event selection

- Isol. μ, $p_T^\mu > 20$ GeV
- $N_\mu = 2$, opposite charge
- $60 < m_{\mu^+\mu^-} < 120$ GeV

$$\mathcal{L}_{\text{contact}} = \frac{1}{2}\frac{g_*^2}{\Lambda^2} j^\mu j_\mu$$

Modelling, comparison to theory

- Background processes: $t\bar{t}$+jets, W+jets (MADGRAPH), dibosons, DY (POWHEG + data), multi-jets (data)



Limits: $200 < p_T^{\text{min}}(\mu^+\mu^-) < 400$ GeV

- Bayesian 95% C.L. upper limits ($m_{q^*} = \Lambda$, fermion couplings as SM: $f = f' = f_s = 1$)
- Excluding $m_{q^*} < 911$ GeV (q^* production via gauge production)
- Excluding $m_{q^*} < 1116$ GeV (q^* production via contact interaction)

Search for resonanant lepton jets

Sensitive to broad range of models (e.g. Dark Matter $\gamma_{\text{dark}} \to \mu\mu$)

Preliminary, EXO-11-013

Search extends Tevatron reach significantly!

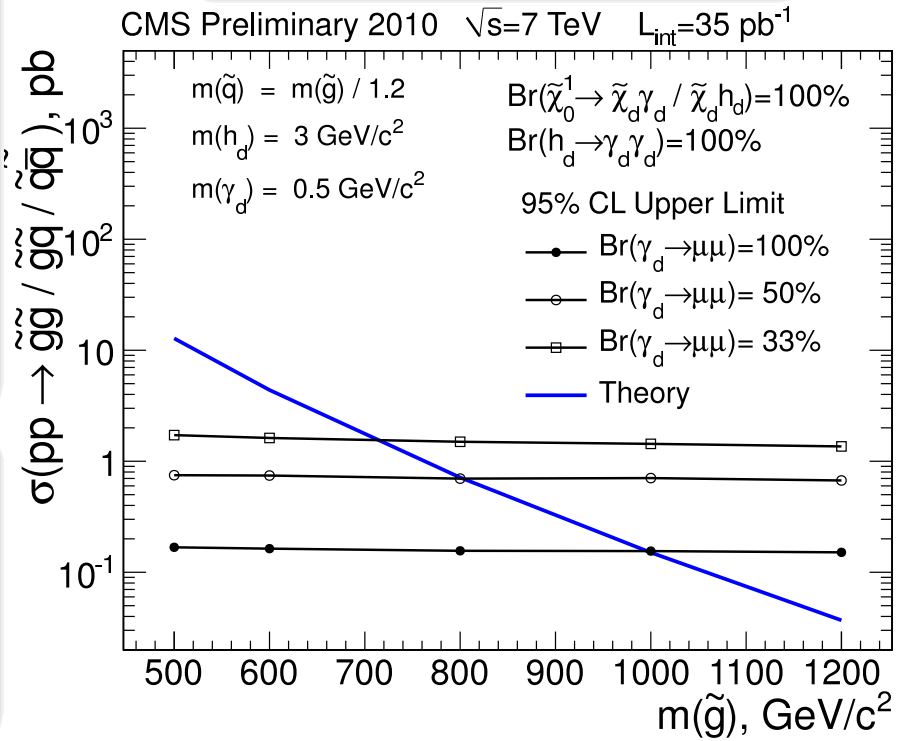
Event selection (muon channel):

- $p_T^{1st}(\mu) > 15$ GeV ($|\eta| < 0.9$), $p_T(\mu) > 5$ GeV
- μ-jet: $m_{\mu\mu} < 9$ GeV (collimated)
- At least one $\mu^+\mu^-$ pair per jet
- Event categories: $R^{N(\mu-\text{jets})}_{n(\mu)_{j_1} n(\mu)_{j_2} \ldots n(\mu)_{j_N}}$
- $p_T^{\mu\mu} > 80$ GeV for R_2^1 (1 jet with 2 muons)

Modelling (data driven)

- Background region to construct templates
- Composition determined from simulation
- Propagated to control and signal region

Dark SUSY model limits



Bayesian 95% C.L. upper limits on new low mass states decaying into muon pairs

- Different event topologies (R_2^1, $R_{2,2}^2$, R_4^1)
- Excl. models with leptonic jet signatures: $\sigma \times \text{BR} \times \alpha_{\text{ideal}}$ range $0.1 - 0.5$ pb

Search in inclusive dilepton events

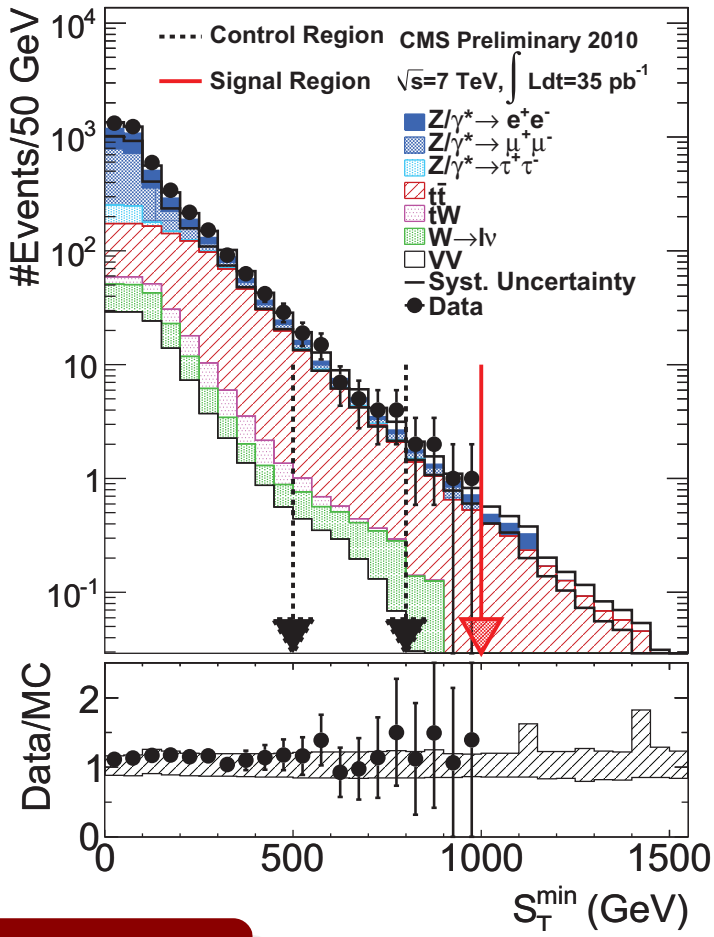
Model independent search

Preliminary, PAS EXO-10-024

Event selection

- Isol. $\ell = e, \mu$, $p_T^\ell > 20$ GeV
- Jets $p_T > 30$ GeV, $|\eta| < 2.5$ (anti-k_T, R=0.5)
- $m_{\ell\ell} > 20$ GeV
- Z region: $e^+e^-, \mu^+\mu^-$, $60 < m_{\ell\ell} < 120$ GeV
- non-Z region: $m_{\ell\ell}{}^{<60\ \text{GeV}}_{>120\ \text{GeV}}$
- $S_T := \sum p_T^{\text{jets}} + \sum p_T^\ell + \not{E}_T$
  control region: $500 < S_T < 800$ GeV
  Z (non-Z) sig. reg.: $S_T > 1000(1200)$ GeV

Cumulative S_T spectrum (non-Z region)



Modelling, comparison to theory

- Background processes (MADGRAPH + PYTHIA): DY, $t\bar{t}$, tW, W+jets, dibosons

Upper limits on $\sigma \times \mathcal{A}$ for Z and non-Z signal regions

- Excl. $\sigma \times \mathcal{A} > 0.14$ pb @ 95% C.L. in both regions

Search for excited leptons

Signal: $\ell\ell^* \to \ell\ell\gamma$, $\ell = e, \mu$ (not considering $\ell^* \to \ell W, \ell Z$)

$$\mathcal{L}_{\text{contact}} = \frac{1}{2}\frac{g_*^2}{\Lambda^2} j^\mu j_\mu$$

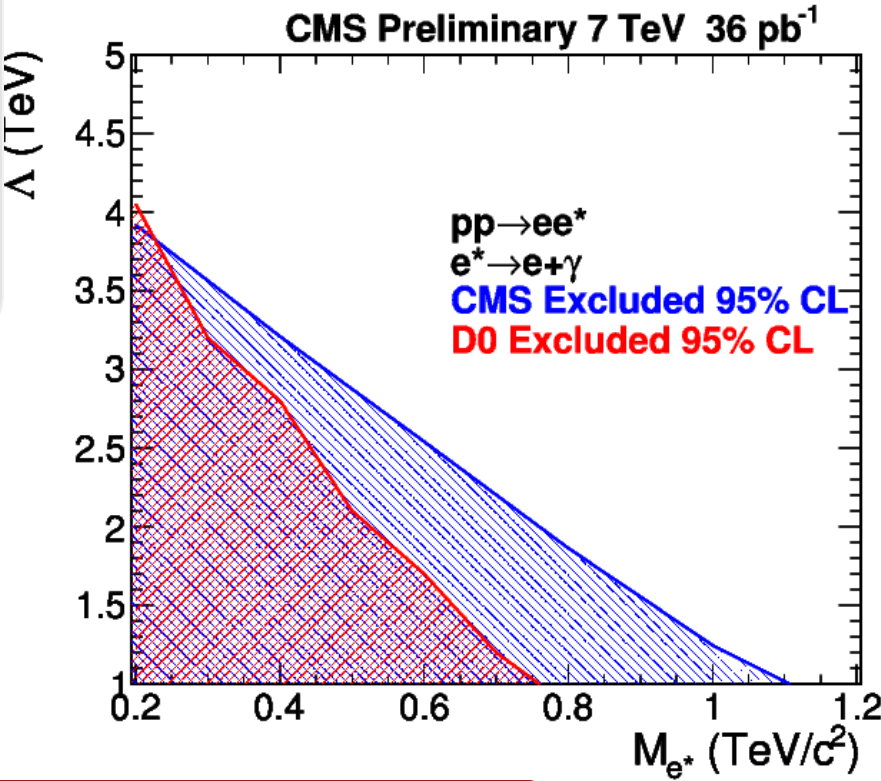
Preliminary, EXO-10-016

Event selection

- Isol $\mu^+\mu^-(e^+e^-)$, $p_T > 20(25)$ GeV
- Isol γ, $p_T > 20$ GeV, $|\eta| < 1.44$
- $m_{\ell\ell} > 60$ GeV
- $m^{\text{max}}_{\ell,\gamma} > 180 - 500$ GeV $(200 < m_{\ell^*} < 1500$ GeV$)$

Modelling, comparison to theory

- signal(compositeness model) + backgrounds PYTHIA6.4 (CTEQ6L1)
- EW: DY MADGRAPH + PYTHIA
- $Z + \gamma$ (data driven)



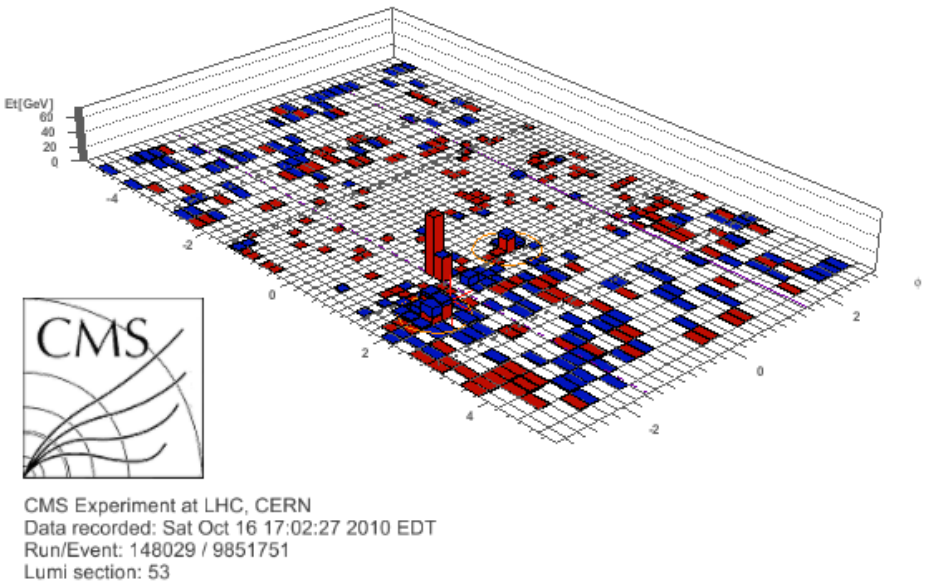
Bayesian 95% C.L. upper limits

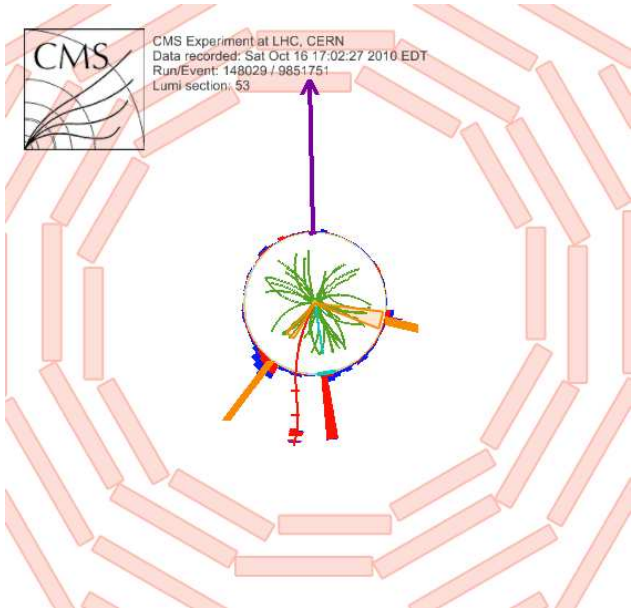
- Excluding at $\Lambda = 2$ TeV: $m_{\mu*} < 785$ GeV, $m_{e*} < 760$ GeV
- Excluding at $\Lambda = m_{\ell^*}$: $m_{\mu*} < 1091$ GeV, $m_{e*} < 1075$ GeV

Searches in lepton + jets prod. (Exo.)

- 1st gen. scalar Lepto Quarks ($e\nu jj$)
- Heavy b-like quark

For details see talk:
Search for leptoquarks and heavy quarks at CMS
by Anne-Fleur Barfuss (BSM session 5F)





AACHEN

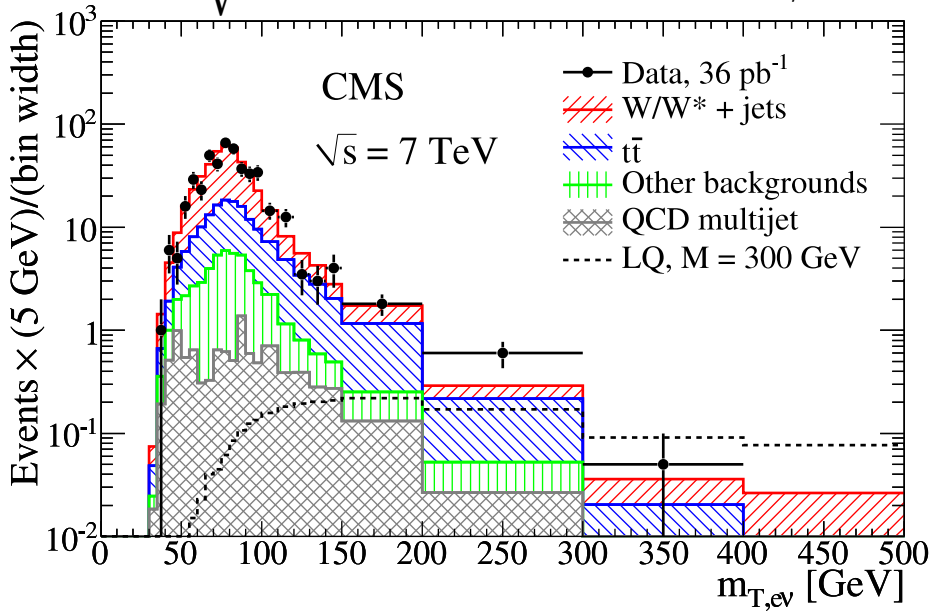
Search for 1st generation scalar leptoquarks ($e\nu jj$ channel)

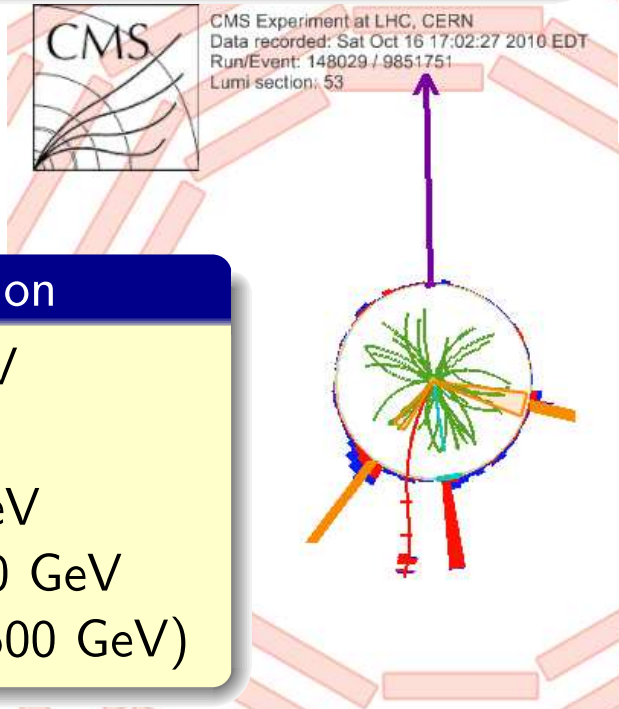
arXiv:1105.5237 [hep-ex], Submitted to Phys. Lett. **B**

Event pre-selection

- $N(e) = 1$, isol., $p_T > 35$ GeV
- $N(\text{jet}) \geq 2$, $p_T > 30$ GeV
- $\not\!\!E_T > 45$ GeV
- $\Delta\phi(\not\!\!E_T, e) > 0.8$, $\Delta\phi(\not\!\!E_T, j_{1st}) > 0.5$
- $S_T = \sum p_T^{\text{jets}} + \sum p_T^{\ell} + \not\!\!E_T > 250$ GeV

$$m_T^{e,\not\!\!E_T} = \sqrt{2 \cdot p_T^e \cdot \not\!\!E_T \cdot (1 - \cos(\Delta\phi_{e,\not\!\!E_T}))}$$





Final event selection

- $p_T(e) > 85$ GeV
- $\not\!\!E_T > 85$ GeV
- $m_T^{e,\not\!\!E_T} > 125$ GeV
- $S_T > 350 - 670$ GeV
  $(200 < m_{LQ} < 500$ GeV)

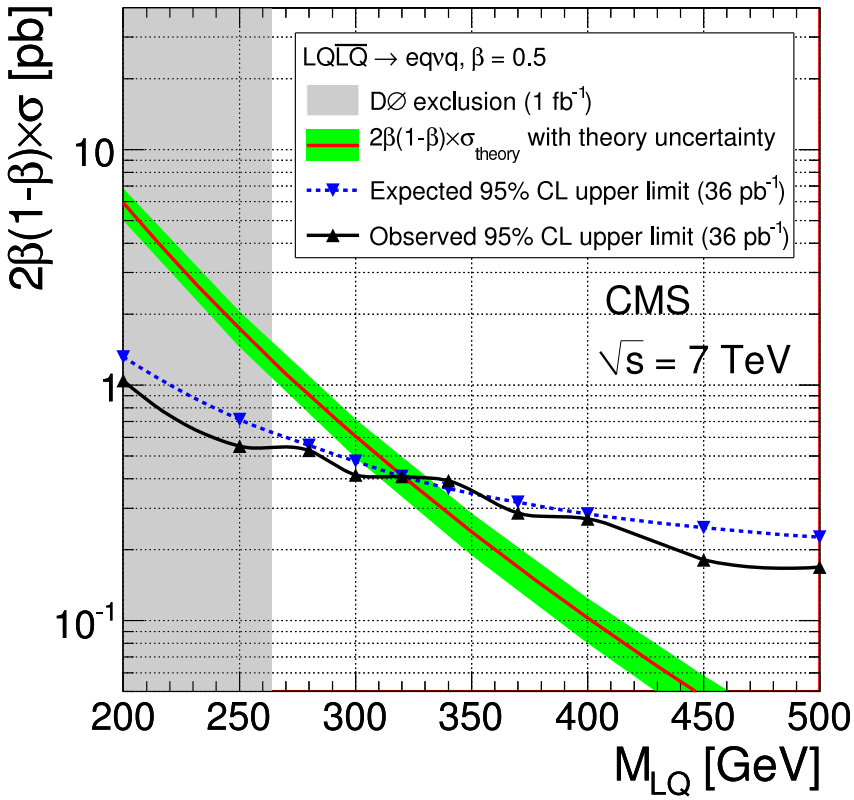
Modelling, comparison to theory

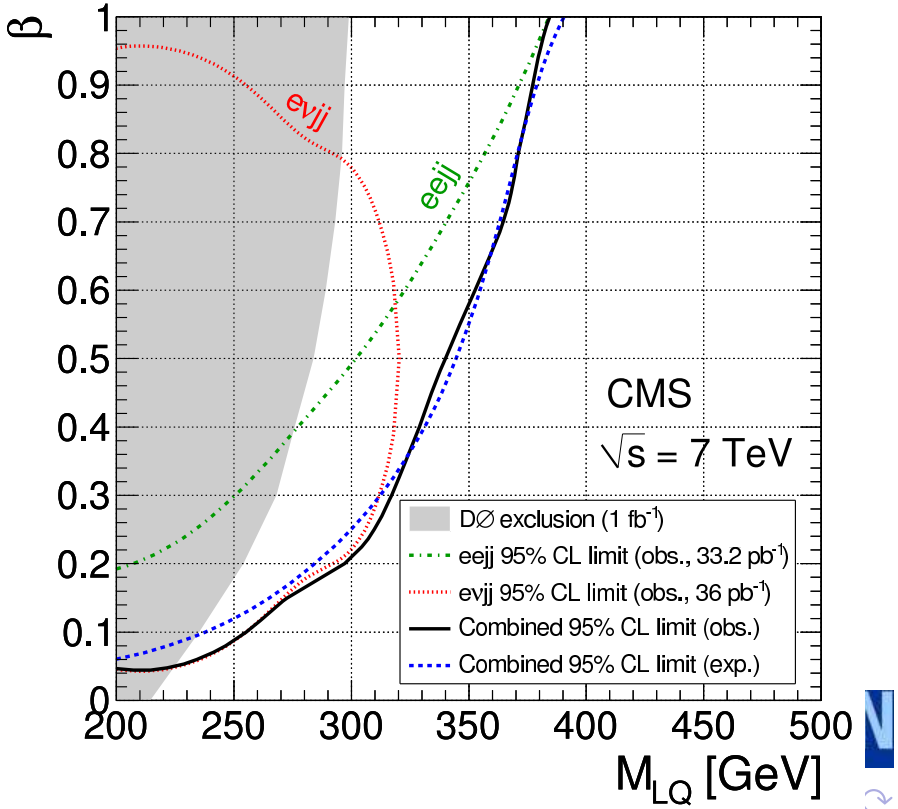
- LQ signal + Dibosons: PYTHIA6.420 (D6T, CTEQ6L1)
- W/Z+jets ALPGEN +PYTHIA
- $t\bar{t}$, single-top, b+jets, γ+jets MADGRAPH + PYTHIA
- Multi-jets (data driven)

Search for 1st generation scalar leptoquarks

Bayesian 95% C.L. upper limits

- LQ production $\sigma \times 2\beta(1-\beta)$ as function of m_{LQ} ($\beta = LQ \to eq$)
- Excluded: $m_{LQ} < 310$ GeV
- Combining with *eejj*-channel. Excl.: $m_{LQ} < 255, 340, 384$ GeV for $\beta = 0.1, 0.5, 1$





Search for heavy bottom-like quark

$b'\bar{b}' \to tW^-\bar{t}W^+ \to bW^+W^-\bar{b}W^-W^+$

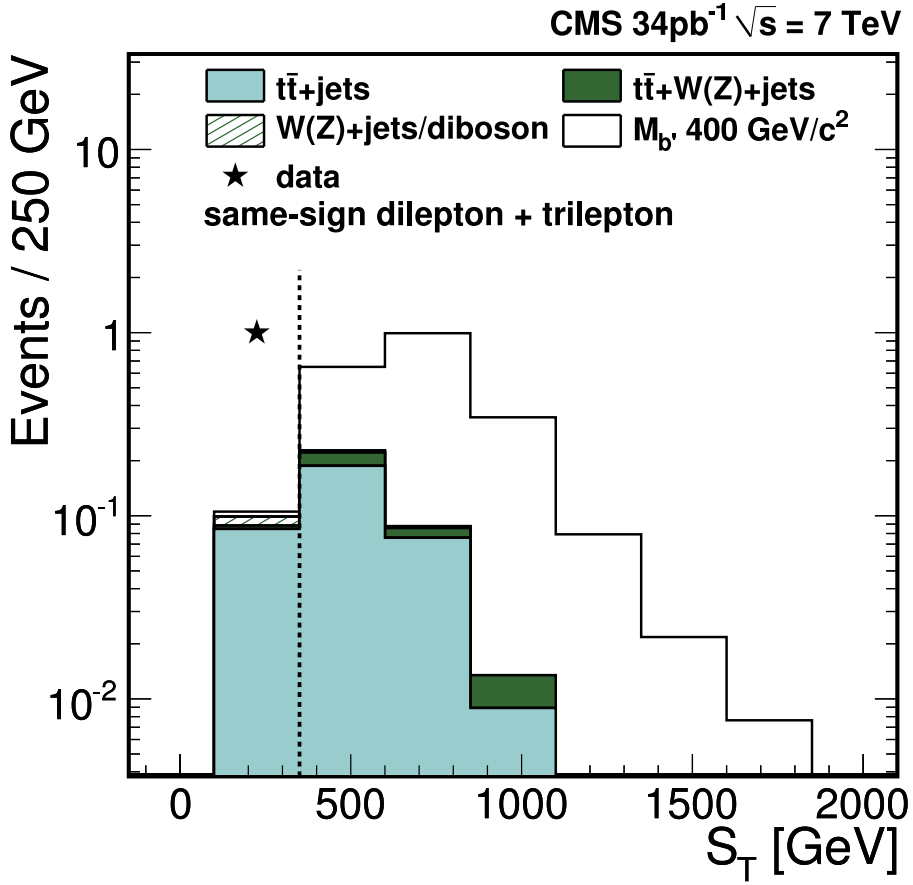
arXiv:1102.4746 [hep-ex], Accepted by Phys. Lett. **B**

Event selection

- Isol. $\ell = e, \mu$, $p_T > 20$ GeV
- $N_\ell = 2(3)$, Exactly 2 ℓ's same-signed
  $\to$ rejecting m_Z candidate events
- p_T(jets) > 25 GeV (anti-k_T, $R = 0.5$)
  $N_{\text{jets}} \geq 4(2)$
- $S_T = \sum p_T^{\text{jets}} + \sum p_T^{\ell} + \not{E}_T > 350$ GeV

Modelling, comparison to theory

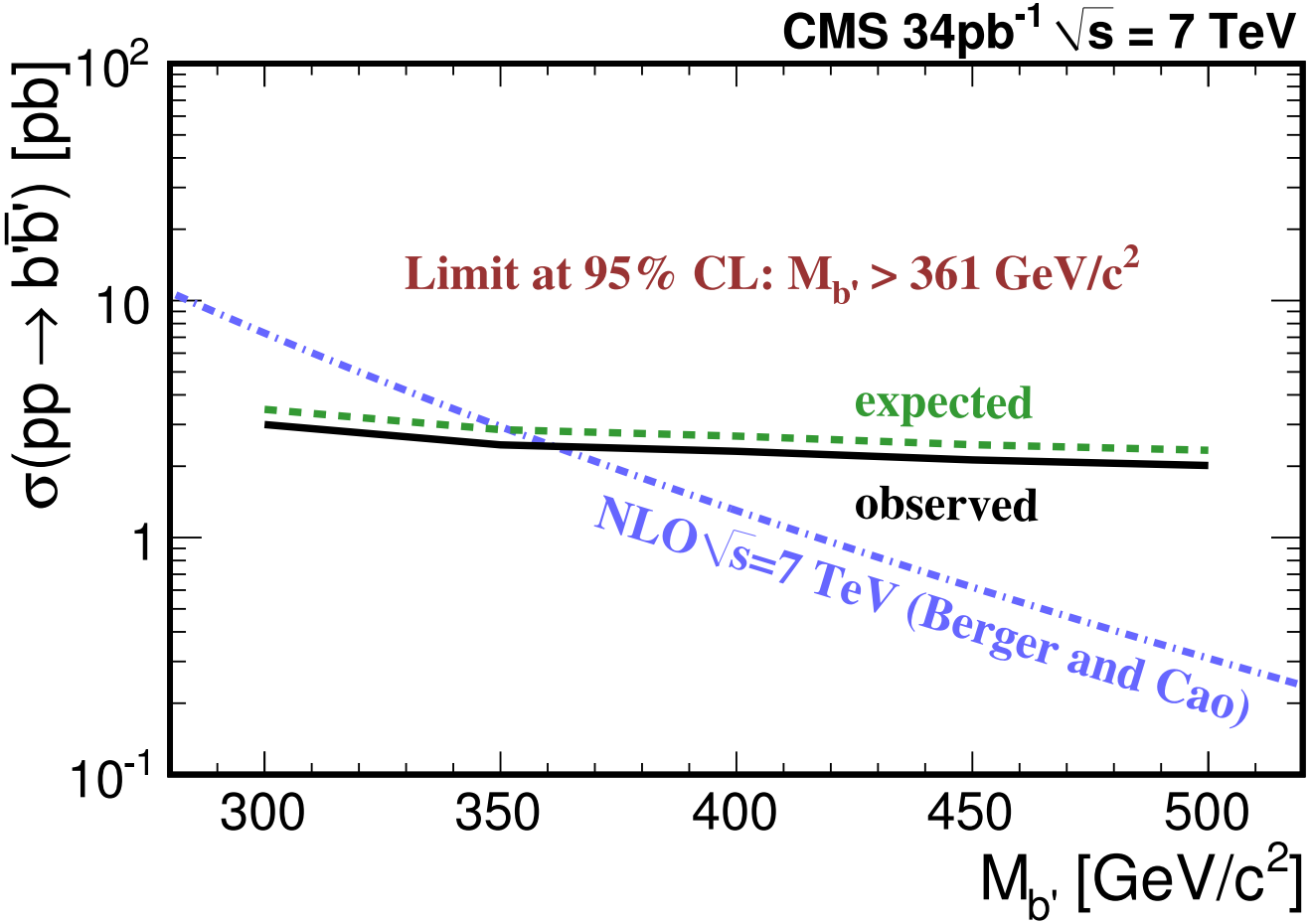
- Signal: MADGRAPH4.4.26 + PYTHIA6.420 (norm. to NLO)
- Background: $t\bar{t}$+jets, W/Z+jets (norm. to CMS)
  Diboson production (NLO, MCFM)
  $t\bar{t} + W/Z$, same-sign $WW + jj$ (MADGRAPH)



Search for heavy bottom-like quark

Exclusion limits on production cross section

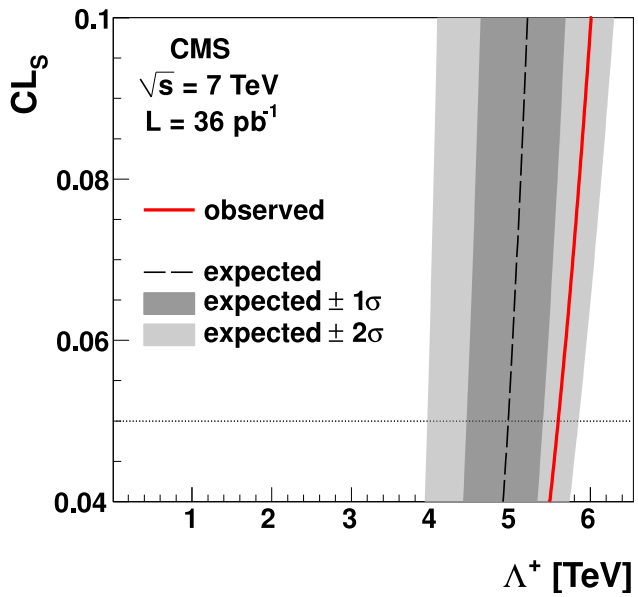
- Zero events selected. No excess over estimated SM background yield
- Bayesian 95% C.L. upper limit on σ as function of $M_{b'}$



Searches in jet production (Exotica)

- Multijet resonances
- Quark comp. in dijet angular dist.

For details see talk:
Search for hadronic resonances at CMS
by Sertac Ozturk (BSM session 5E)



Search for multijet resonances

Preliminary, PAS EXO-11-001

$pp \to \tilde{g}\tilde{g}$, RPV $\tilde{g} \to 3q$

Event selection

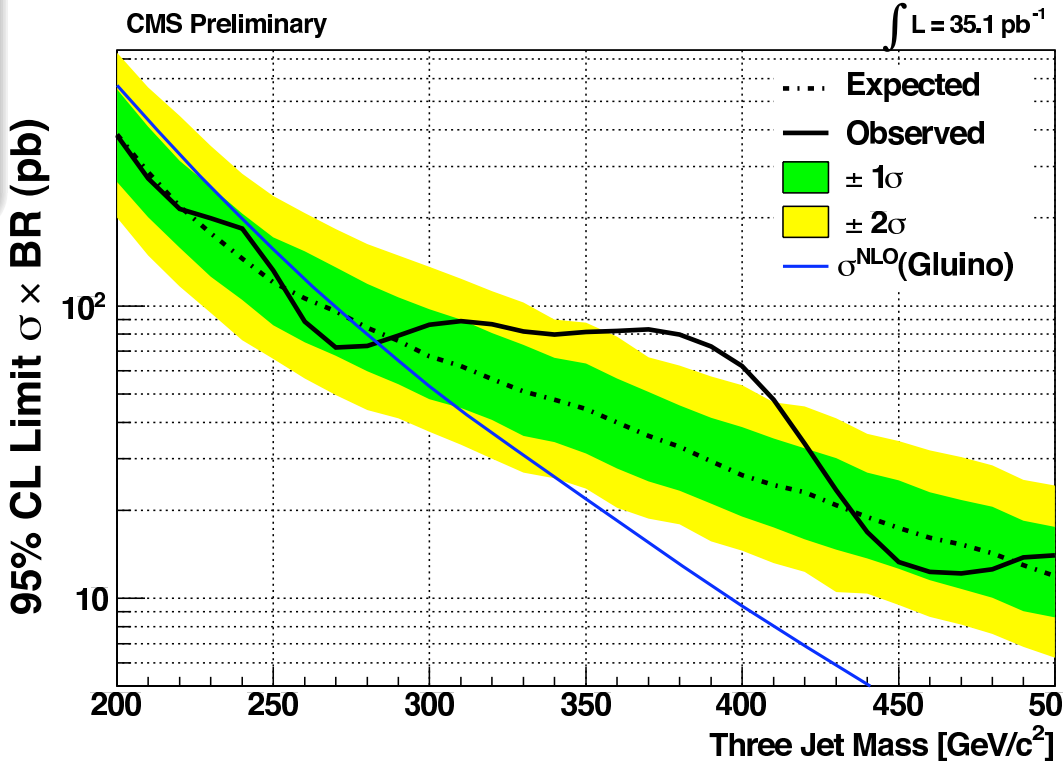
- Particle Flow technique
- $N_{\text{jets}} \geq 6$, $p_T > 45$ GeV ($|\eta| < 3$
- $\sum_{i=1}^{N_{\text{jets}}} p_T^i > 425$ GeV
- $M_{3j} < \sum_{i=1}^{N_{\text{jets}}} p_T^i - 130$ GeV

Modelling, comparison to theory

- Signal: PYTHIA 6.4 (NLO k factor from PROSPINO)
- Background: multijets (from data) and wrong 3-jet combinations

Exclusion limits

- Model independent but $\tilde{g}\tilde{g} \to 6q$ production optimised cuts
- Bayesian 95% C.L. on $\sigma \times$ BR
- RPV uds coupling decaying $\tilde{g}$'s excluded for $200 < m_{\tilde{g}} < 280$ GeV



Dijet angular distributions and search for quark compositeness

- Sensitive to spin of exchanged particle
- No strong dependence on PDF's

EXO-10-009, arXiv:1102.2020 [hep-ex]
Phys. Rev. Lett. **106**, 201804 (2011)

Event selection ($N_{\text{jet}} \geq 2$, anti-k_T, R=0.5)

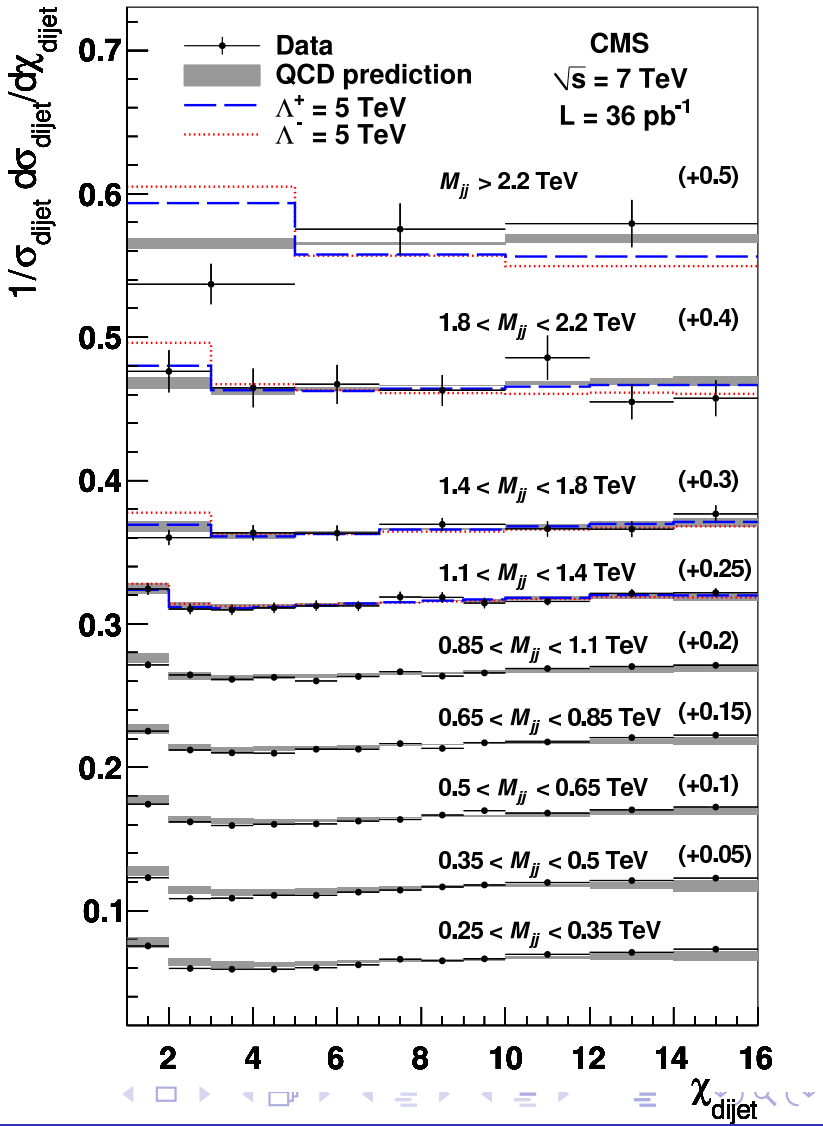
- $\chi_{\text{dijet}} := \exp(|y_1 - y_2|) \overset{m \to 0}{\longrightarrow} \frac{1+\cos\theta^*}{1-\cos\theta^*}$
- $\chi_{\text{dijet}} < 16$
- $y_{\text{boost}} = \frac{1}{2}|y_1 + y_2| < 1.11$
- $M_{jj} > 0.25$ TeV (9 ranges)

Modelling, comparison to theory

- NLO pQCD: from NLOJET++ using FASTNLO, PDF's: CTEQ6.6
- Unfolding: Herwig++2.4.2, PYTHIA6.422 (Tunes D6T & Z2)
- Signal: PYTHIA6.422

Exclusion limits

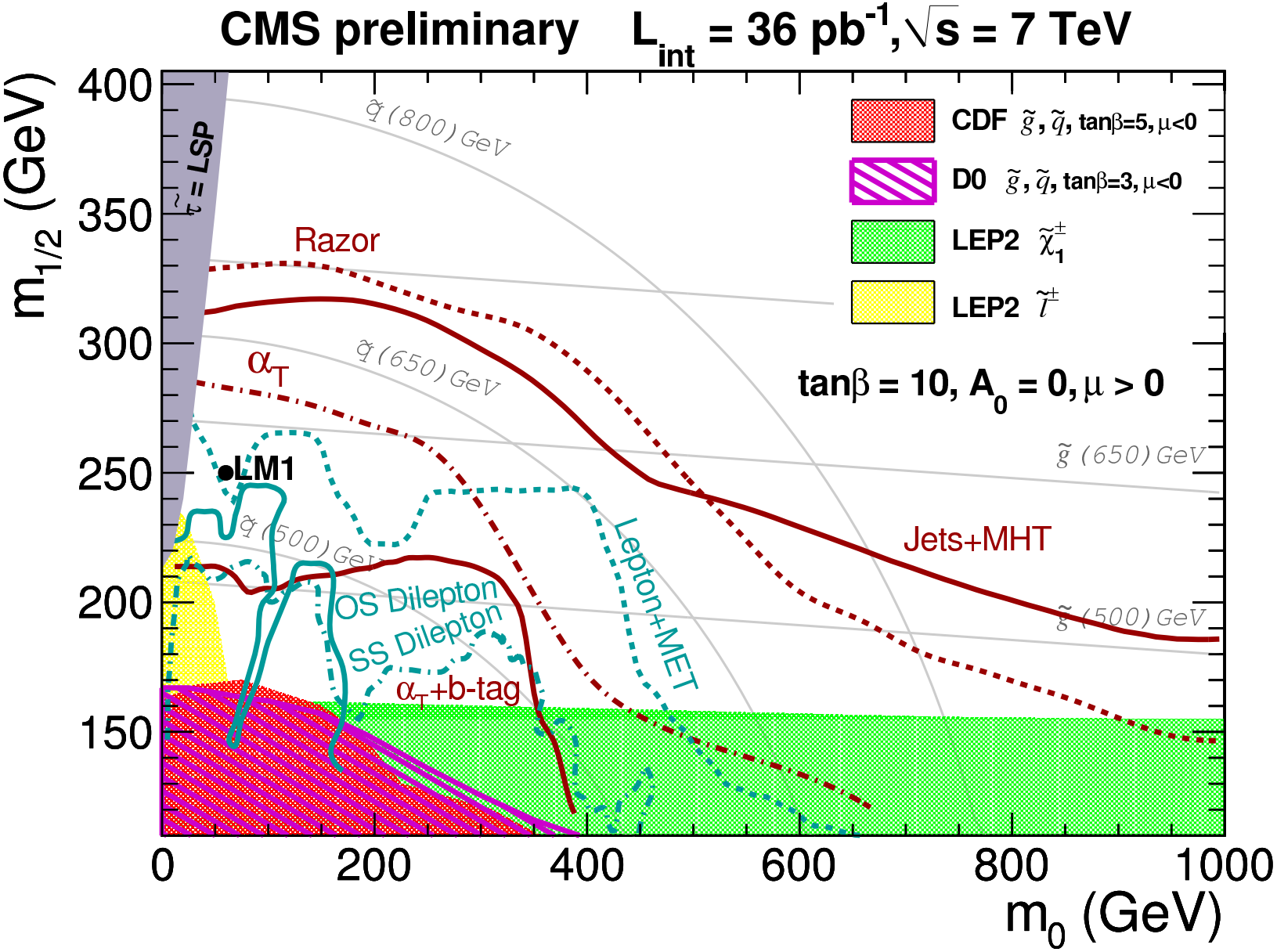
- Modified frequentist approach (CL_s)
- $\Lambda^+ > 5.6$ TeV, $\Lambda^- > 6.7$ TeV @ 95% C.L.



Conclusions

- CMS is searching for evidence of new physics beyond the SM in many channels using early LHC data @ $\sqrt{s} = 7$ TeV
- Already exploring new territory beyond Tevatron
- Only recent results shown here
  - Many new physics searches are underway
- No signals of new physics observed in the early LHC data yet
- More LHC data on the way
  - Analyses progressing with increasing luminosity

SUSY 2010 data combined limits ($\tan\beta = 10$)



Backup slides

Large Extra Dimensions in $\gamma\gamma$ events

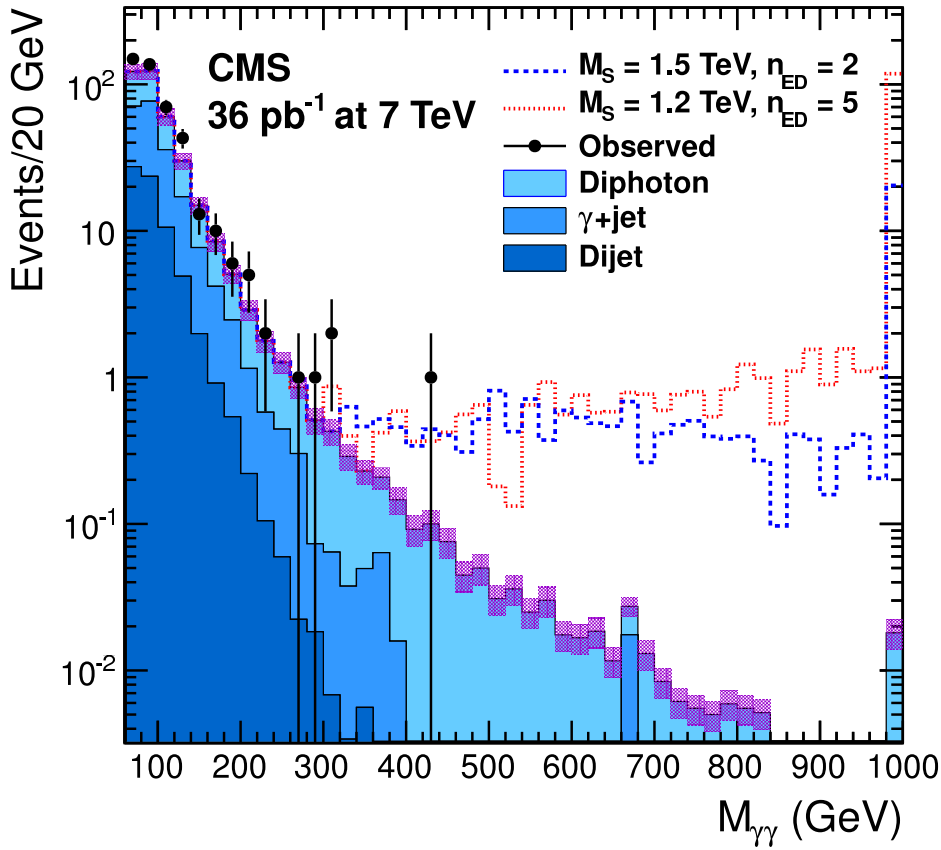
Event selection

- 2 isol. photons, $p_T^\gamma > 30$ GeV
  ECAL fiducial region ($|\eta| < 1.44$)

Modelling, comparison to theory

- Backgrounds: multi-jets + prompt γ's (data driven derived)
- Signal: spin-2 graviton $\rightarrow 2\gamma$'s favoured over decay in fermions
  - ADD model in SHERPA (v1.1.2)
  - k-factor from NLO (DIPHOX)
- 95% C.L. exclusion (Bayes) on $\sigma_s \times \mathrm{Br} \times A = 0.110$ pb

arXiv:1103.4279 [hep-ex], Accepted by JHEP



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

Search for dilepton resonances

Based on shape analyses of dilepton mass spectra

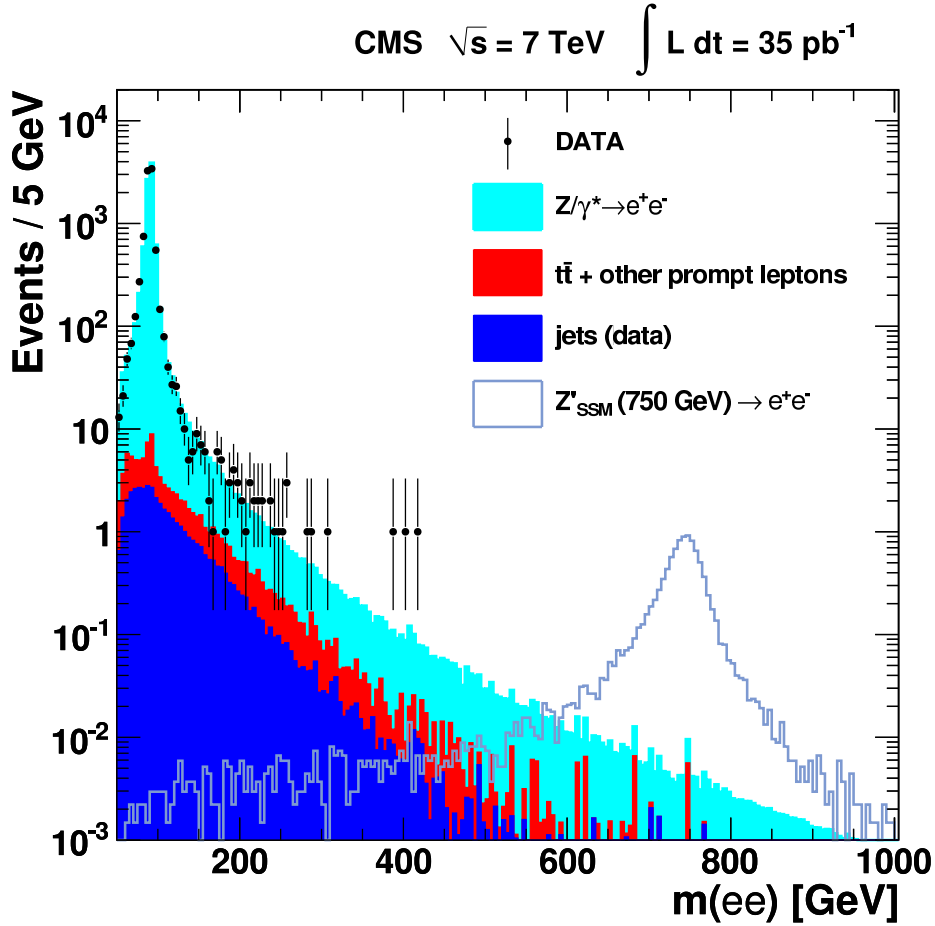
arXiv:1103.0981 [hep-ex], Accepted by JHEP

Event selection

- Isol. $\ell = e, \mu$
- $p_T^\mu > 20$ GeV, $p_T^e > 25$ GeV
- $N_\mu = 2$
  ($\mu^+\mu^-$ or $2e$'s (either charge))

Modelling, comparison to theory

- Background processes:
  DY, $t\bar{t}$, tW, dibosons,
  multi-jets (data driven)
- Event generation (bkg + signal):
  POWHEG (EW), MADGRAPH + PYTHIA6.409 (CTEQ6.1)



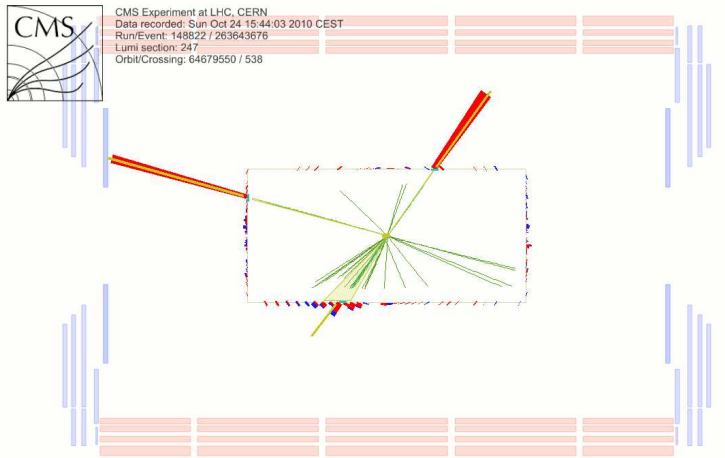
Search for dilepton resonances

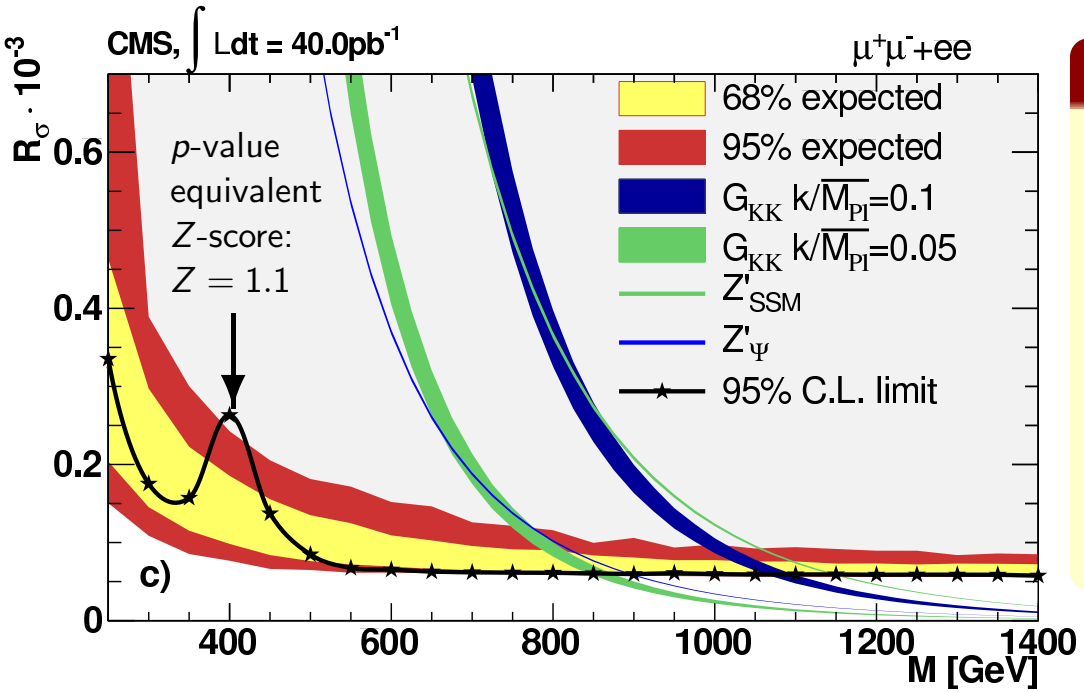
Limits: Bayesian & Frequentist approach

- Ratio reducing many uncertainties:

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

- Extended unbinned likelihood
- 95% C.L. upper limits on σ translated into lower mass limits





Lower mass limits @ 95% C.L.

- Excluding:
  - SM-like Z': $m_{Z'} < 1140$ GeV
  - Superstring Z'_ψ: $m_{Z'_\psi} < 887$ GeV
  - RS G_{KK}: $m_{G_{KK}} < 855(1079)$ GeV for coupling $k/\bar{M}_{Pl} = 0.05(0.10)$
- Improving Tevatron results (and LEP II except for Z')

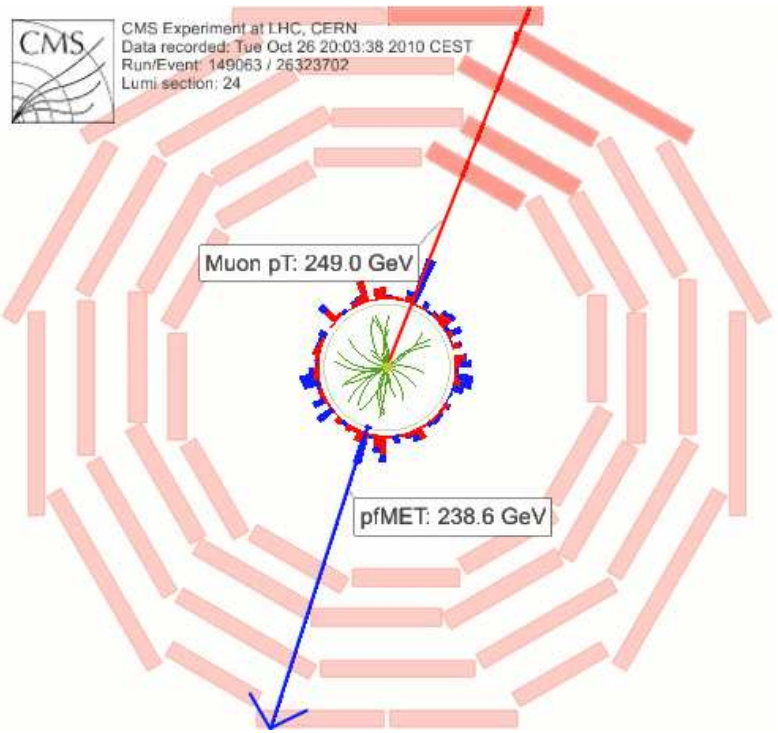
Search for $W' \to \mu\nu_\mu$ production

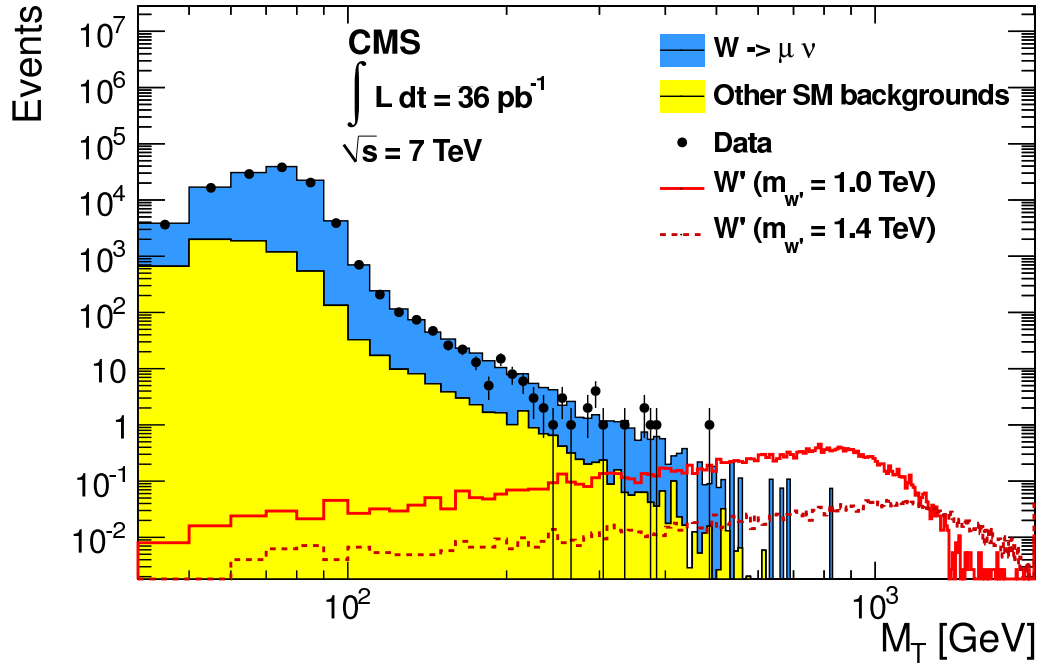
Event selection

- Isol. μ, $p_T > 25$ GeV
- $N_\mu = 1$ (Z, DY)
- $IP_T < 200$ μm (cosmics)
- $0.4 < p_T/\not{E}_T < 1.5$ (signal topology)
- $\Delta\phi(\mu, \vec{\not{E}}_T) > 2.5$
- $M_T > 390$ - 690 GeV ($0.6 < m_{W'} < 2$ TeV)

arXiv:1103.0030 [hep-ex],
Accepted by Phys. Lett. **B**

$$M_T = \sqrt{2 \cdot p|T \cdot \not{E}_T \cdot (1 - \cos\Delta\phi_{\mu,\not{E}_T})}$$





Search for $W' \to \mu\nu_\mu$ production

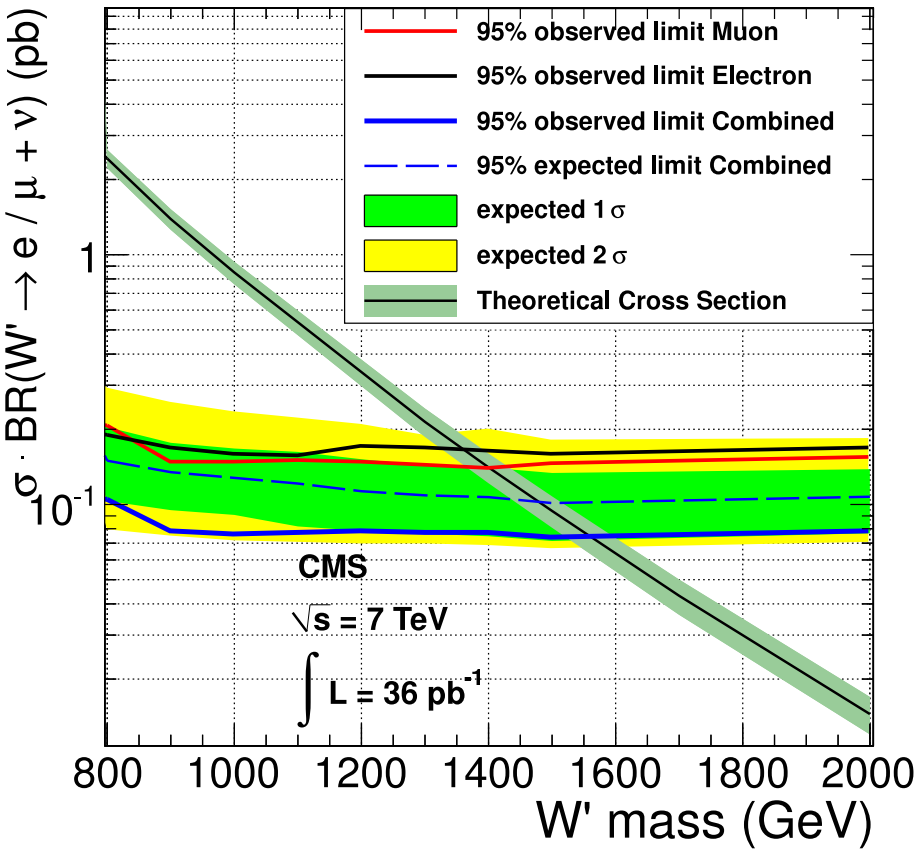
Modelling, comparison to theory

- W' (signal) + diboson, multi-jets PYTHIA6.409 (CTEQ6L)
- EW: W, Z POWHEG + PYTHIA
- $t\bar{t}$ MADGRAPH + PYTHIA
- Background in signal region determined from side band $180 < M_T < 350$ GeV

Limits

- Bayesian approach, flat prior on $\sigma(W')$
- 95% C.L. limit for $\sigma \times$ BR
- translated into $m_{W'}$ limit:
  Excl. $m_{W'} < 1.40$ TeV (observed)
  Excl. $m_{W'} < 1.35$ TeV (expected)
- combined with e channel
  Excl. $m_{W'} < 1.58$ TeV (observed)

e and μ channel combination



Search for $t\bar{t}$ resonances (Exotica)

- Resonances in semilept. $t\bar{t}$ decays

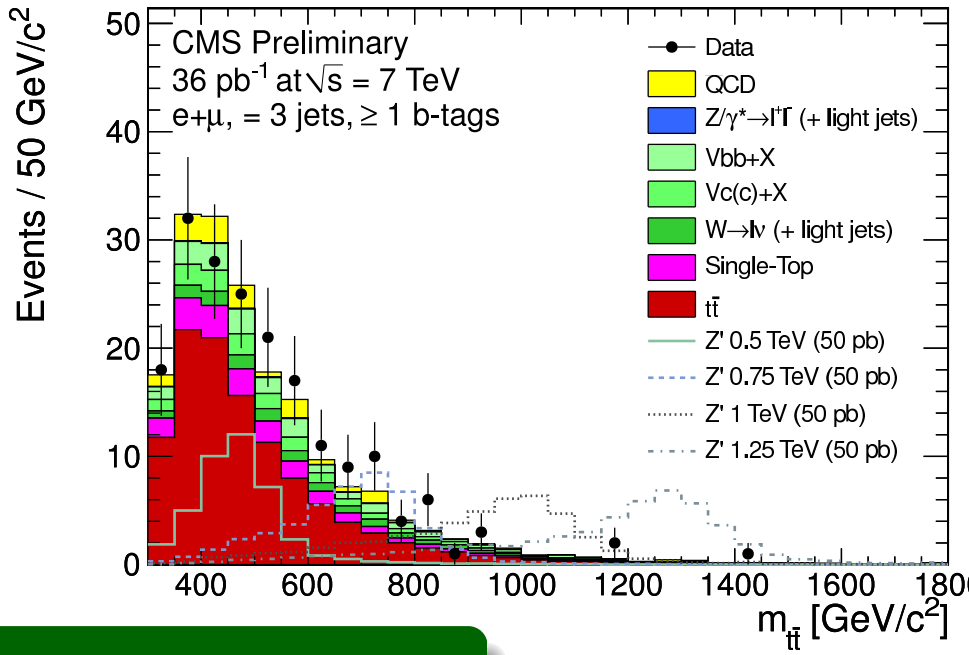
Search for resonances in semileptonic $t\bar{t}$ decays

- Optimised selection for top quarks close to rest & well separated decay products
- Universal reference model: $Z'(\rightarrow t\bar{t})$ with narrow width (1% of mass)

Event selection

- Isol. $\ell = e, \mu$, $p_T^e > 30$, $p_T^\mu > 30$ GeV
- $N(\ell) \equiv 1$
- $\not{E}_T > 20$ GeV
- p_T(jets) > 30 GeV (anti-k_T, $R = 0.5$)
- Secondary Vertex b-jet tagging
- 4 event categories ($\times$ 2 lepton flavours):
  $N_{b-\text{jet}} = 1 \in N_j = 3$,
  $N_{b-\text{jet}} = 0 \in N_j \geq 4$,
  $N_{b-\text{jet}} = 1 \in N_j \geq 4$,
  $N_{b-\text{jet}} \geq 2 \in N_j \geq 4$

Preliminary, PAS TOP-10-007



Modelling, comparison to theory

- Z' signal + W, DY, $t\bar{t}$, single-top background: MADGRAPH + PYTHIA6 and MC@NLO, CTEQ6L PDF's
- Multi-jet background: PYTHIA6 and data driven

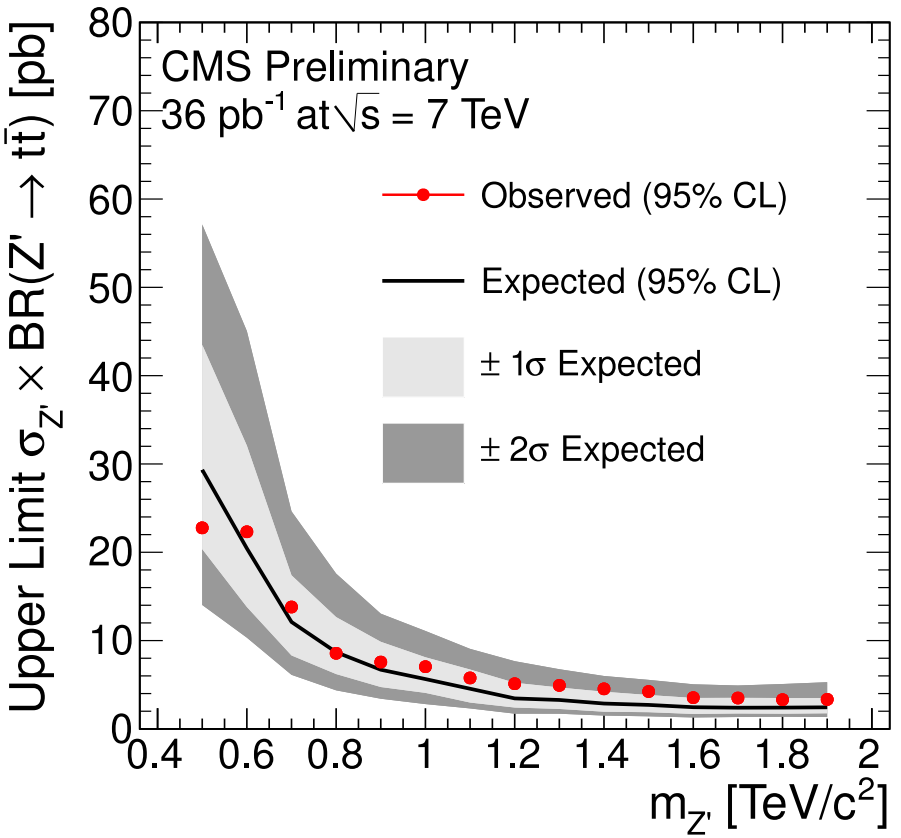
Search for resonances in semileptonic $t\bar{t}$ decays

Event reconstruction

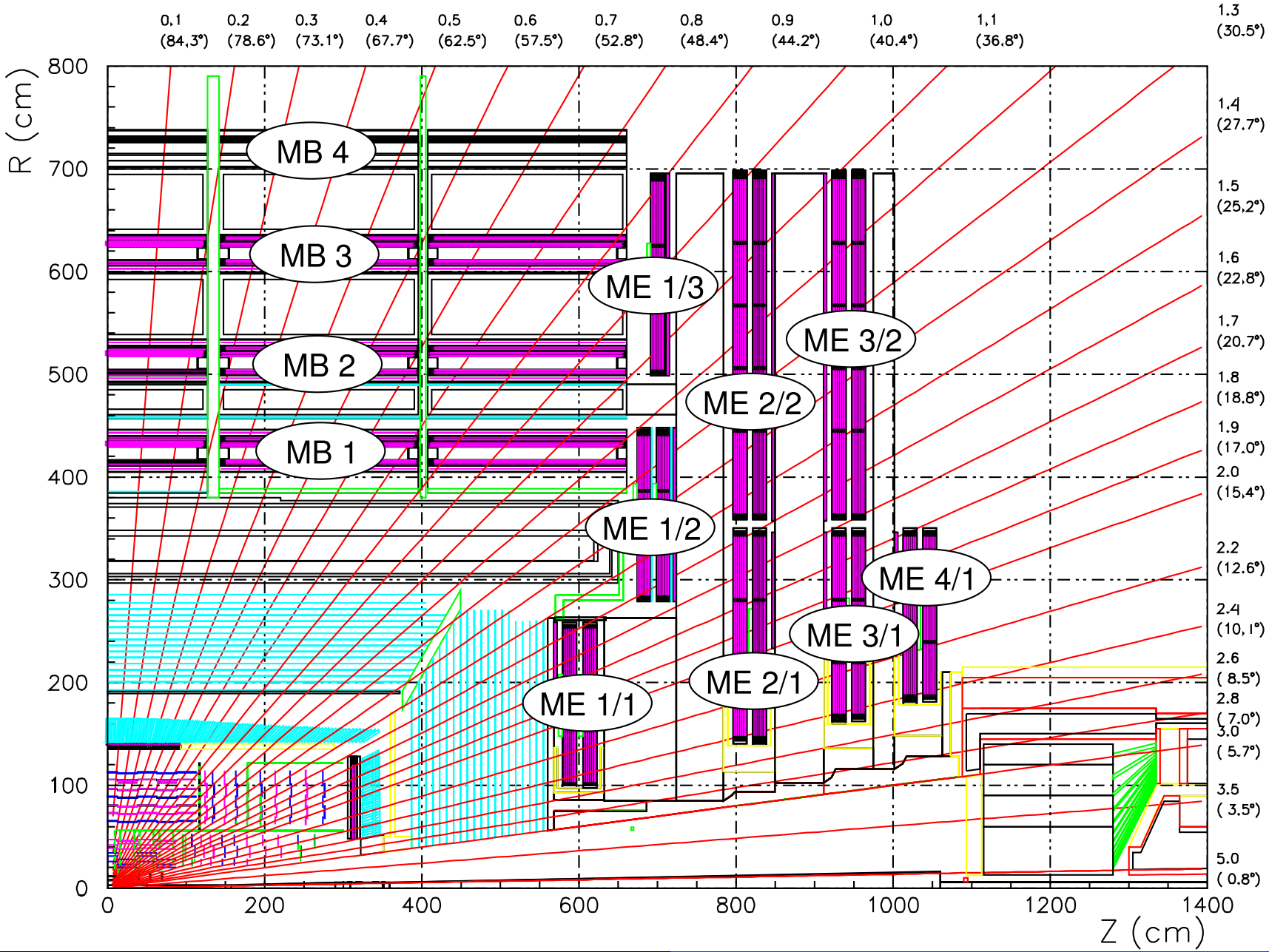
- Reconstructing leptonically decaying W boson $(\ell, \not{E}_T)$
- Associating jets to hadronic W decay and b-jets for all possible comb.
- Choosing best combination + kinematic fit (variation of reco. obj. within res.)

Exclusion limits

- Good agreement between SM prediction and data
- Bayesian 95% C.L on $\sigma(pp \to Z') \times \mathrm{BR}(Z' \to t\bar{t})$
- Assuming Width negligible compared to detector resolution
- Limits competitive with Tevatron
  25 pb for $m_{Z'} = 0.5$ TeV
  7 pb for $m_{Z'} = 1$ TeV
  4 pb for $m_{Z'} = 1.5$ TeV



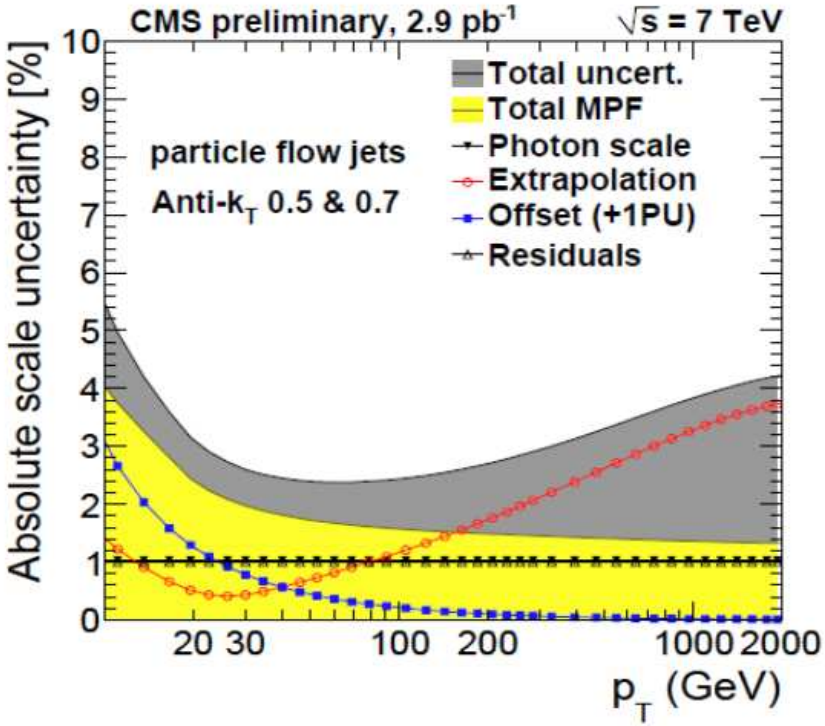
CMS detector and pseudorapidity coverage



Detector and reconstructed object resolutions

Object energy and momentum resolutions

- anit-k_T ($R = 0.5$) energy resolution:
  $\Delta E/E = 100\%/\sqrt{E\,[\text{GeV}]} \oplus 5\%$
- e + unconverted γ's: $p_T > 100$ GeV: $\Delta E/E \lesssim 0.5\%$
  For 2010 data, $E_T > 20$ GeV: barrel(endcap) $\Delta E/E = 1\%(4\%)$
- global muon p_T res.: $1 - 10\%$ up to 1 TeV



Calorimeter transverse energy resolutions

- ECAL ($|\eta| < 3$): $\sim 2\%/\sqrt{E_T}$
- HCAL ($|\eta| < 5$): $\sim 100\%/\sqrt{E_T}$

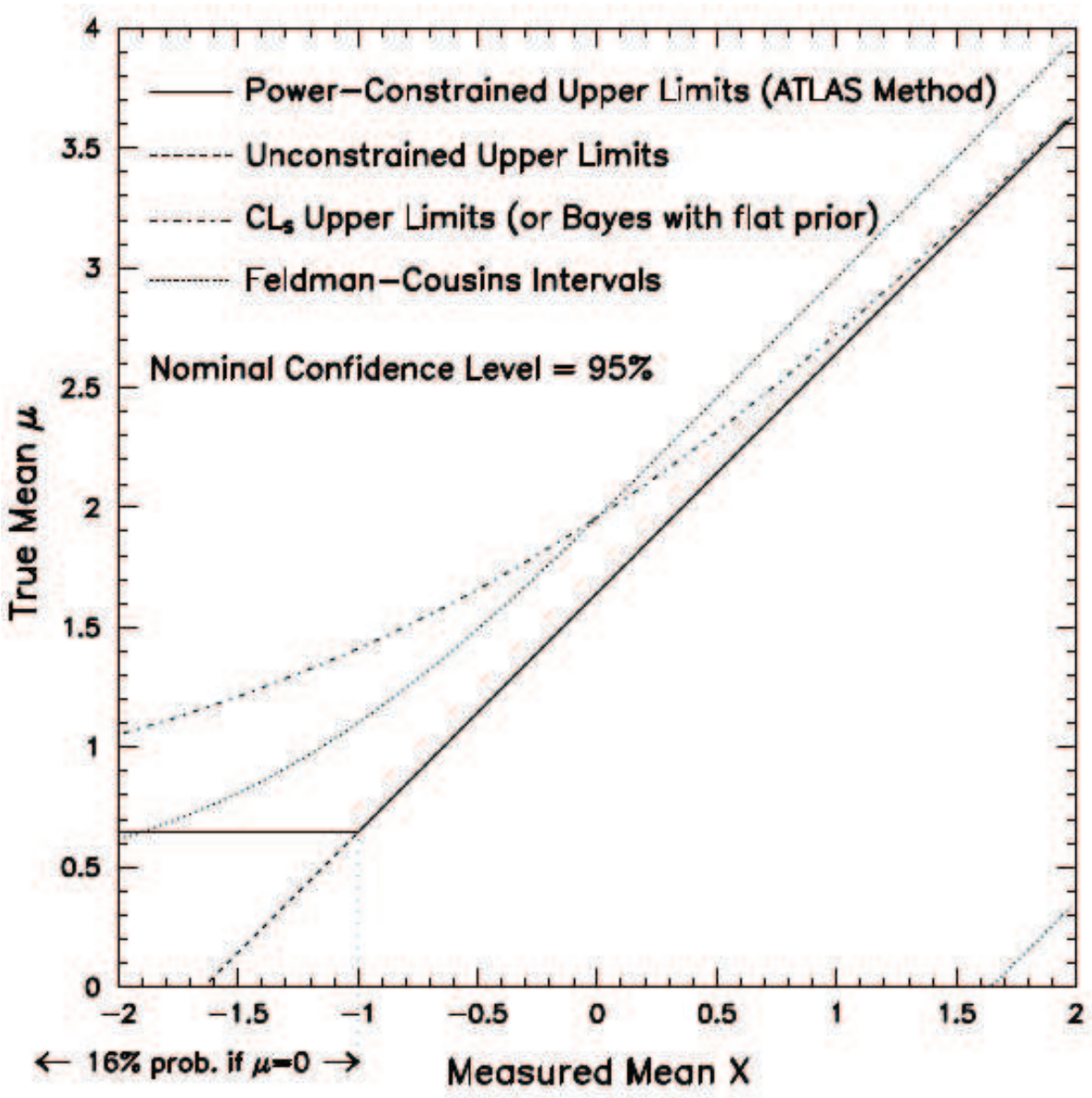
Inner tracker resolutions

- transverse momentum:
  $\text{res}(p_T) = 1.5\%@p_T = 100$ GeV
- impact parameter:
  $\text{res}(IP) = 15\ \mu$m

Intervals and Limits for a Physically Bounded μ

- **Prototype: measurement *x* is unbiased Gaussian estimate of μ. (Let σ=1.) What is 95% C.L. Upper Limit (UL)?**
- **1986: Six methods for UL surveyed by V. Highland (VH) include U.L. = max(0, *x* + 1.64) and U.L. = max(0,*x*) + 1.64.**
- **RPP 1986: Bayesian: uniform prior on the mean μ for $\mu \geq 0$, prior prob = 0 for $\mu < 0$. (VH's other five not mentioned.)**
- **1994,96: 3 ad-hoc frequentist recipes, one using max(*x*,0).**
- **1998: Feldman & Cousins (FC) "Unified Approach" in (Kendall and Stuart) replaces ad hoc frequentist**
- **2002: CL_s from LEP added to Bayesian and FC.**
- **CMS Statistics Committee recommends using (at least) one of the three (red) methods in 2002-present PDG RPP.**
- **ATLAS SC method implies U.L. = max(0, *x* + 1.64) before power constraint (PC), U.L. = max(-1,*x*) + 1.64 after PC.**

Comparison of ATLAS PCL with the three methods in PDG



(Atlas unconstrained U.L. is zero, not null, for x < -1.64)

ATLAS PCL re-opens discussion on use of diagonal line along with ad hoc constraint, out of favor for many years, not recommended by CMS SC.

CMS and ATLAS SC's are reviewing arguments and what has been learned in 25+ years. Academic statisticians have commented as well.

Just tip of iceberg: Poisson example brings in other issues. Nuisance parameters yet more. Choice of test statistic varies.