Latest Exotica Results with Jets in the Final State from the CMS Experiment

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On behalf of the CMS Collaboration

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“LHC Now”
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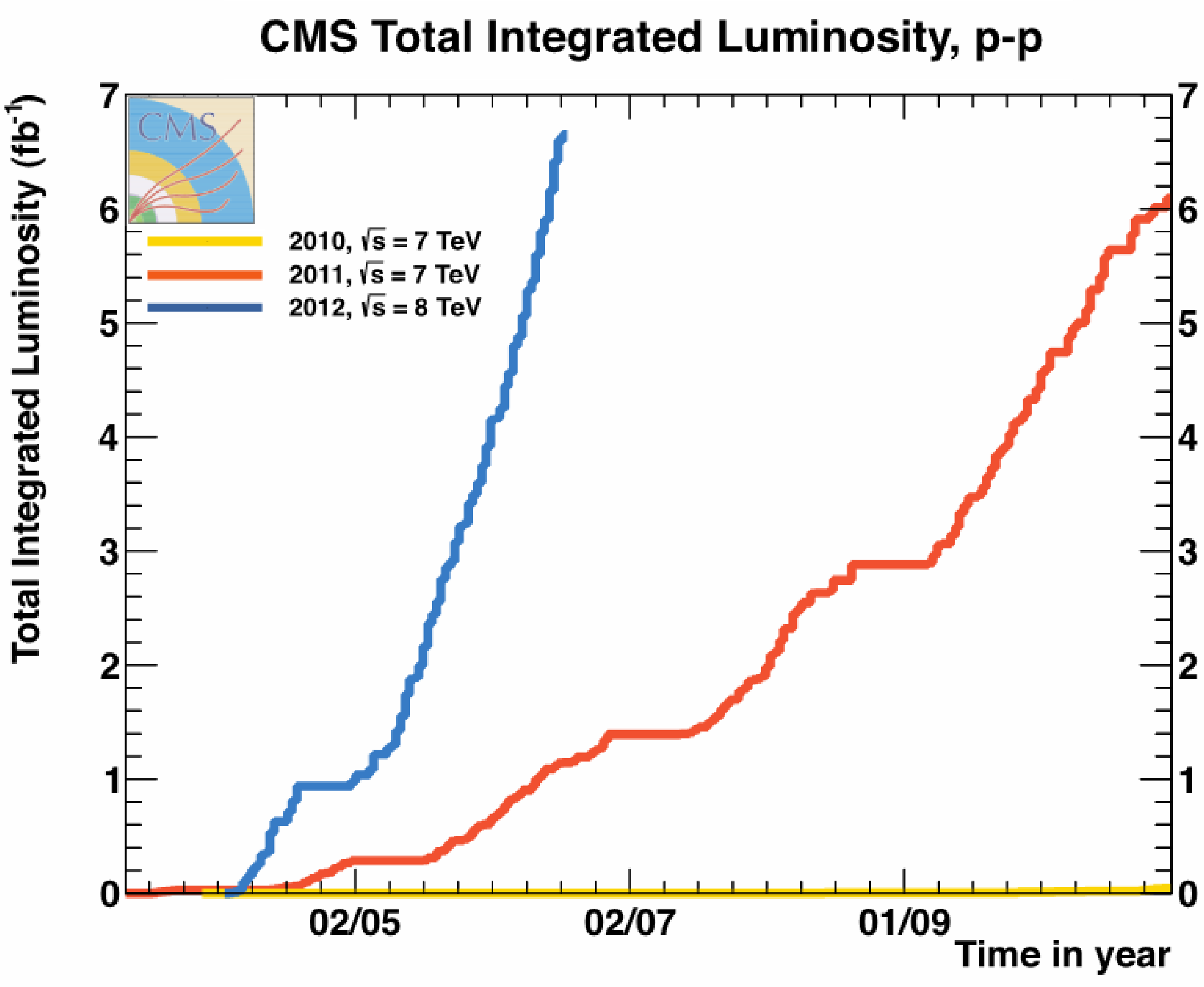
Introduction and Overview

- Hadronic final states experimentally challenging at hadron colliders
- At the same time, sensitive to many extensions of the standard model
  - Strong production of new particles provides potential for early discovery
  - Hadronic final states can outperform the corresponding semileptonic final states (due to increased branching ratios combined with recently developed jet substructure techniques)
- This talk will present some of the latest results from hadronic Exotica searches
  - Most results based on the full 2011 data sample at 7 TeV (with a few based on the latest 8 TeV data)
  - Results presented by increasing final-state multiplicity

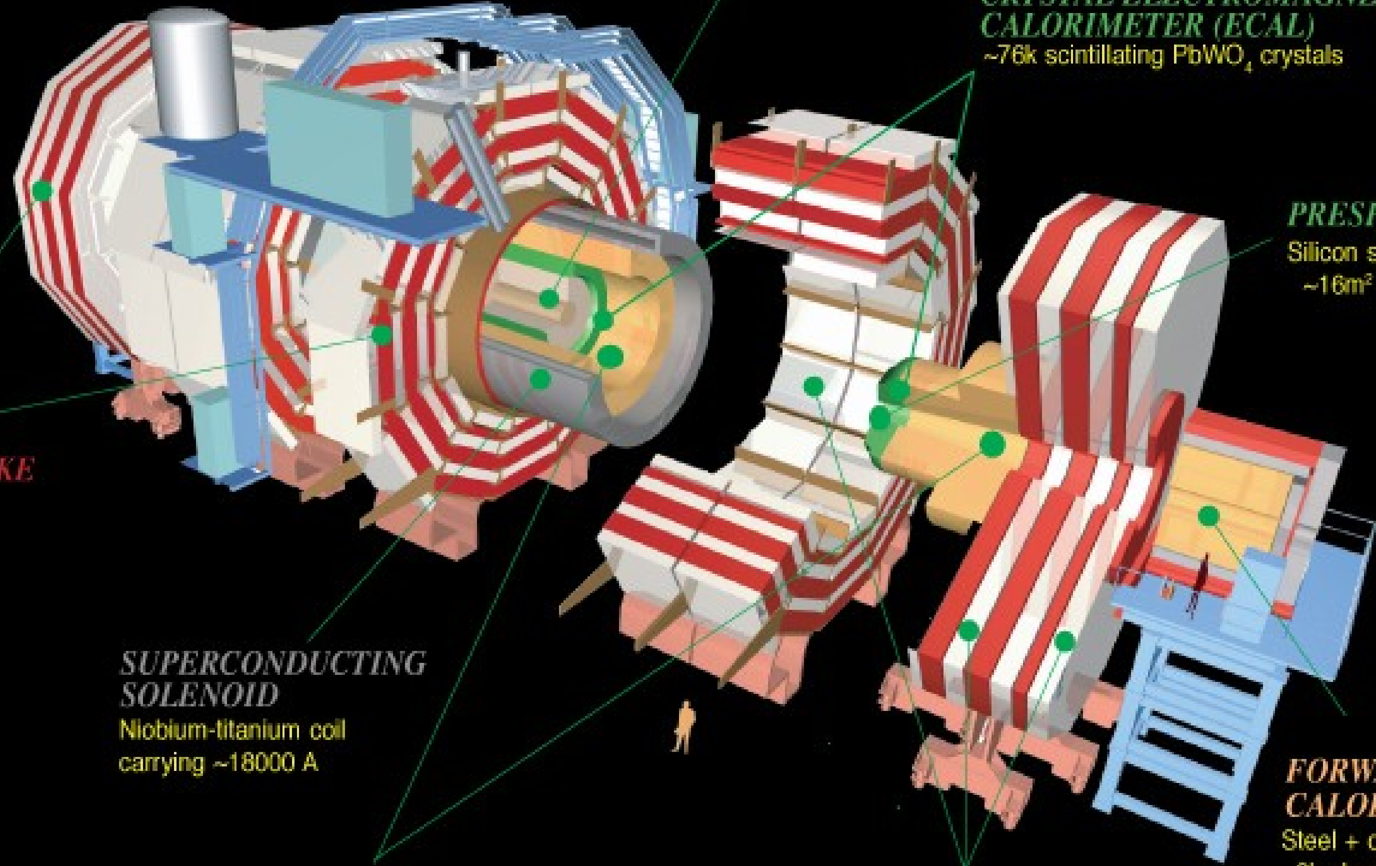
LHC Performance: 2010, 2011, 2012



- Excellent performance
- Made it possible for experiments to deliver significant physics results on relatively short time scales

CMS Detector

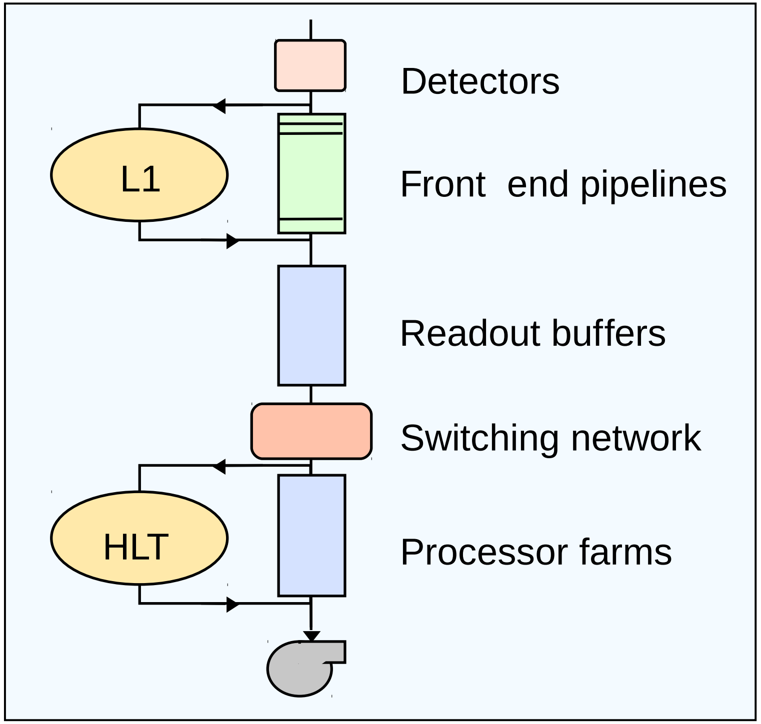
Pixels
Tracker
ECAL
HCAL
Solenoid
Steel Yoke
Muons



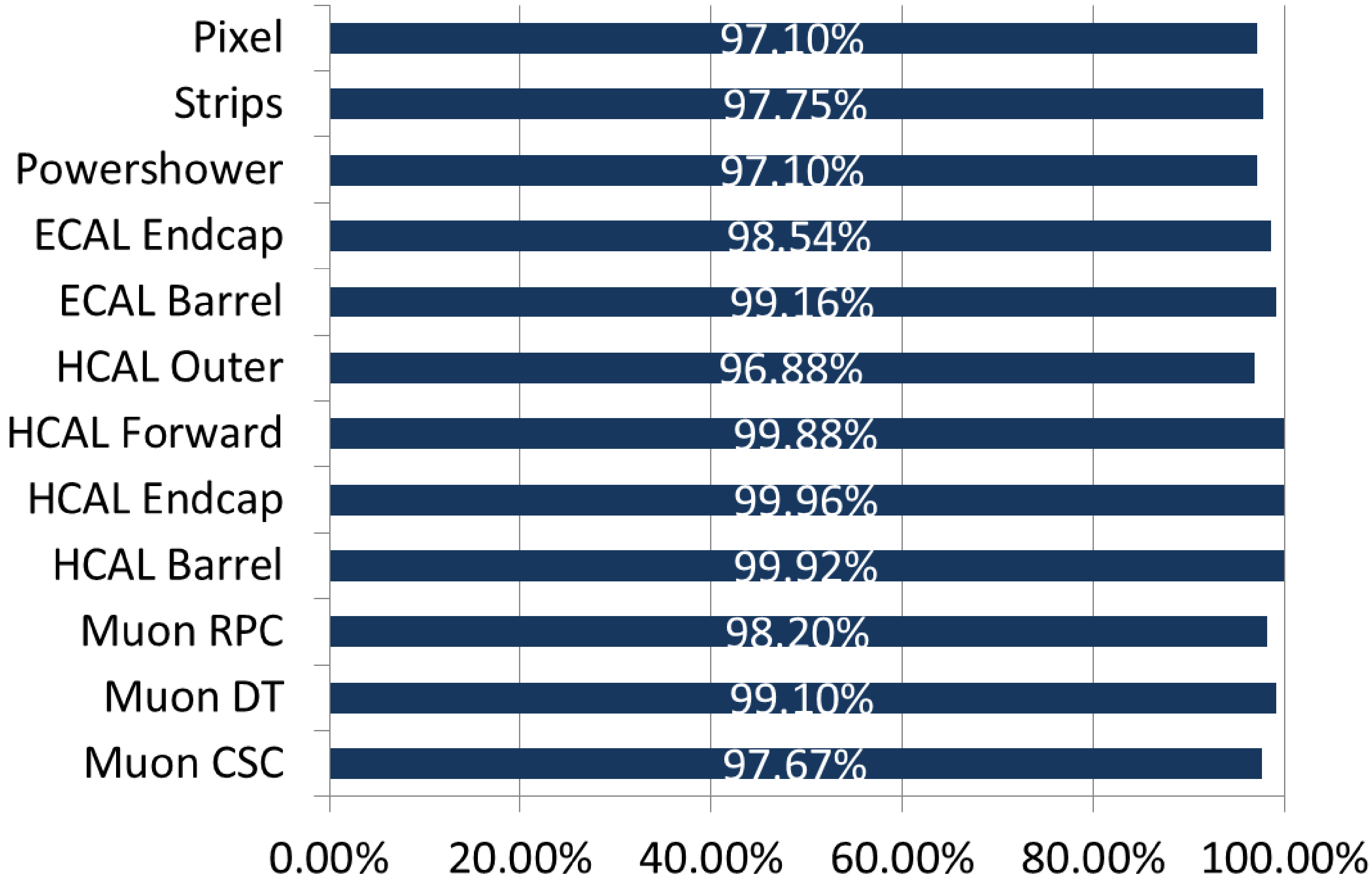
Total weight	**: 14000 tonnes**
Overall diameter	**: 15.0 m**
Overall length	**: 28.7 m**
Magnetic field	**: 3.8 T**

CMS Trigger System

- CMS has a two-tiered trigger system:
  - Level-1 (L1) trigger:
    - Consists of custom-designed fast electronics
    - Designed to reduce the event rate from 40 MHz to 100 kHz
  - High-Level Trigger (HLT):
    - Consists of a farm of commercially available CPUs running reconstruction code optimized for fast processing
    - Reduces event rate from 100 kHz to *O*(300) Hz

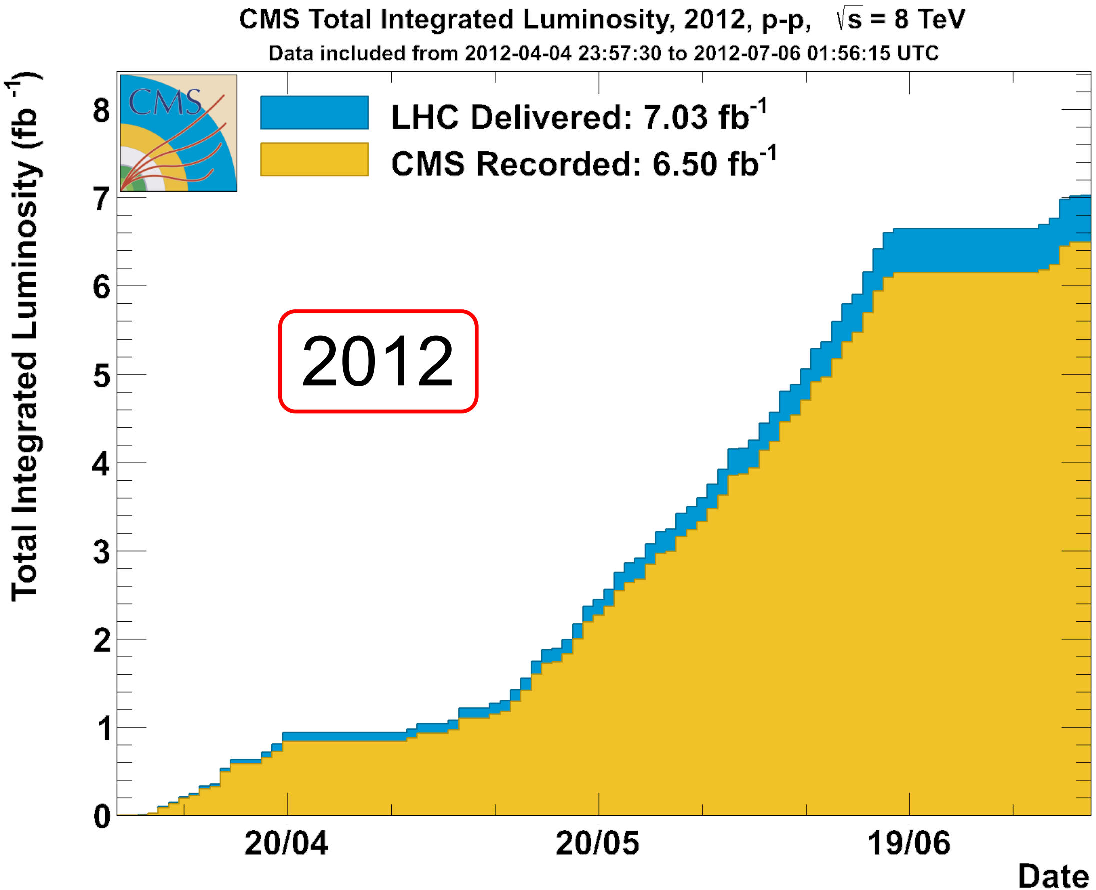


CMS Operational Status*

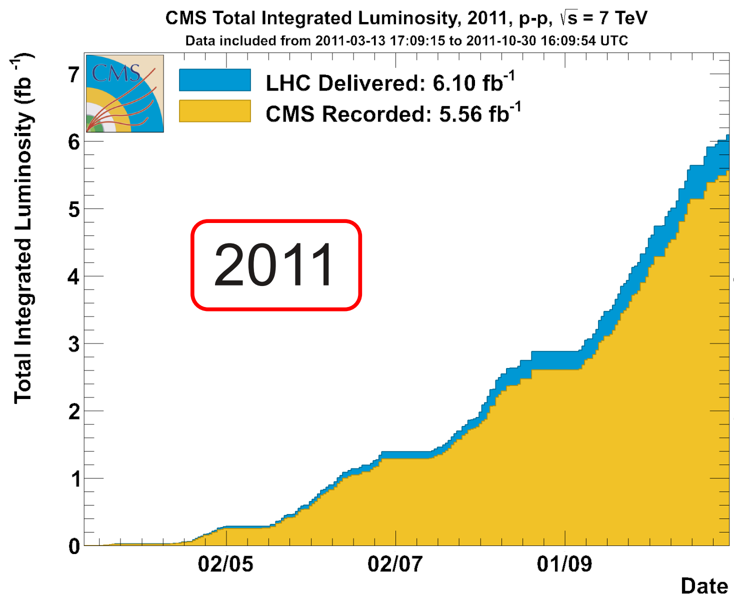


*As of June 15, 2012

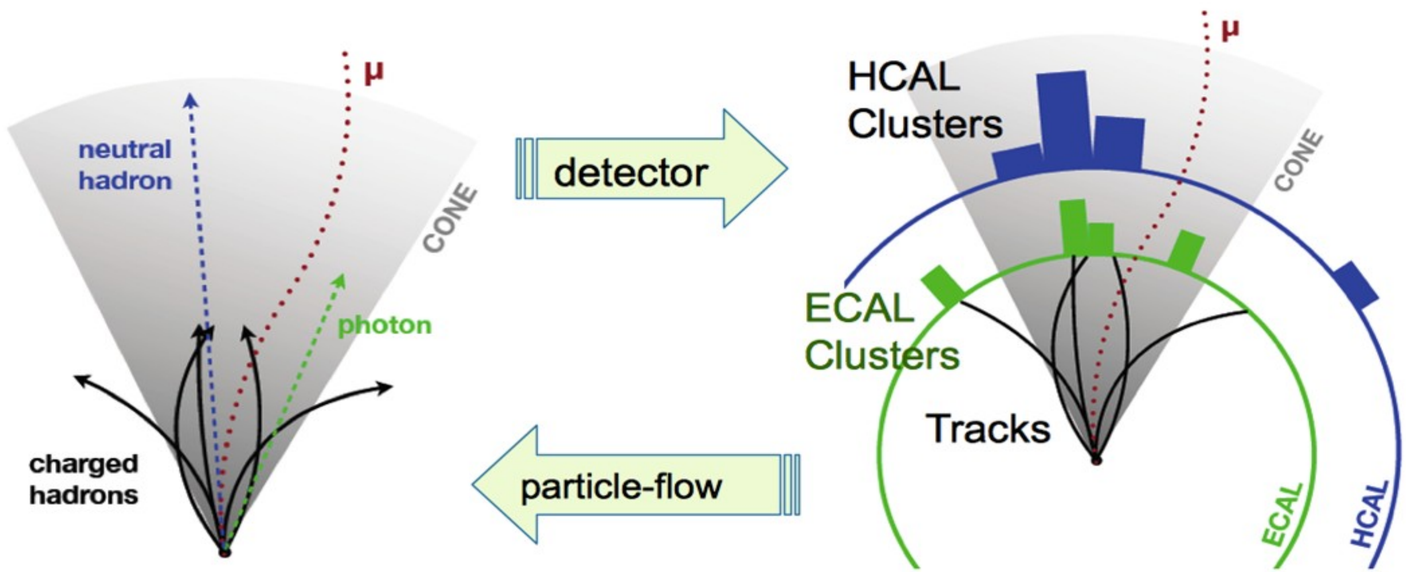
CMS Operational Status (cont'd)



- 2012 data-taking efficiency: ≈92.5%
    - Similar to 2011 data-taking efficiency (≈91.1%)



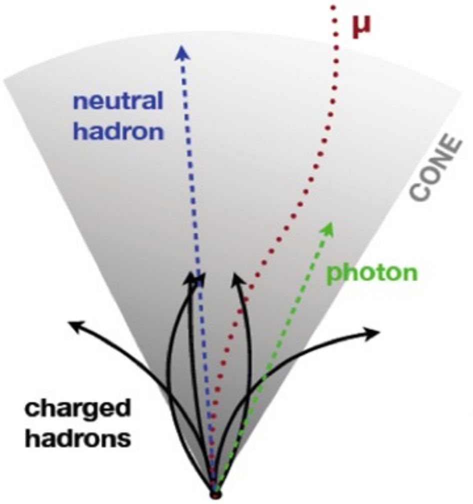
Global Event Description (Particle Flow)

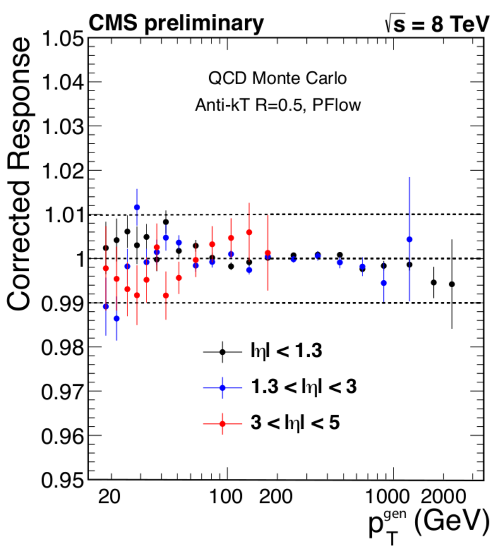


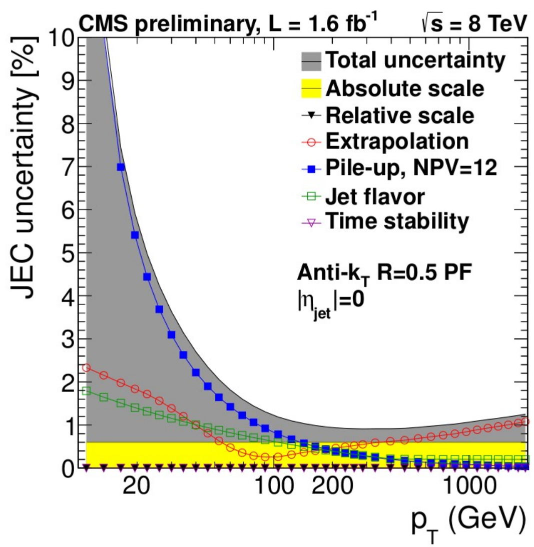
- Particle-flow algorithm combines information from all CMS subdetectors
- Returns a list of reconstructed long-lived particles:
  - e, μ, γ, charged and neutral hadrons
  - Used as building blocks for other higher-level objects
- Made possible by the granularity of the CMS detector and high magnetic field

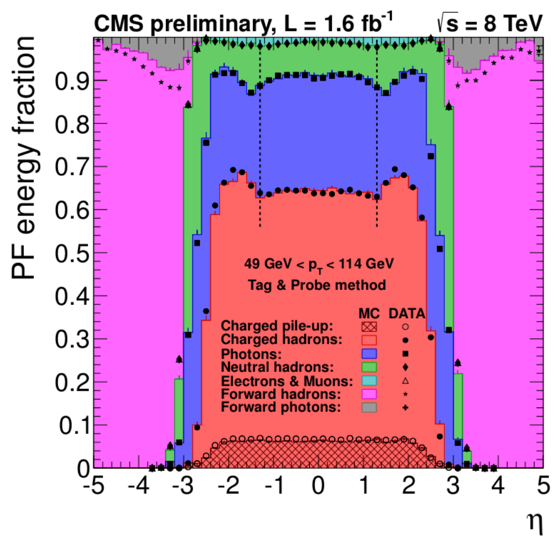
Jet Reconstruction in CMS

- Particle-flow jets clustered from reconstructed particle candidates
- Default jet clustering algorithm: Anti-k_T with R=0.5 and 0.7
- Jet energy scale calibrated using jet energy corrections
  - Account for extra energy from pile-up on an event-by-event basis using jet area
  - Jet calibration vs η better than 1%
  - Jet energy scale uncertainty: ≈1% for p_T>150 GeV, jet energy resolution: 10% at p_T=100 GeV

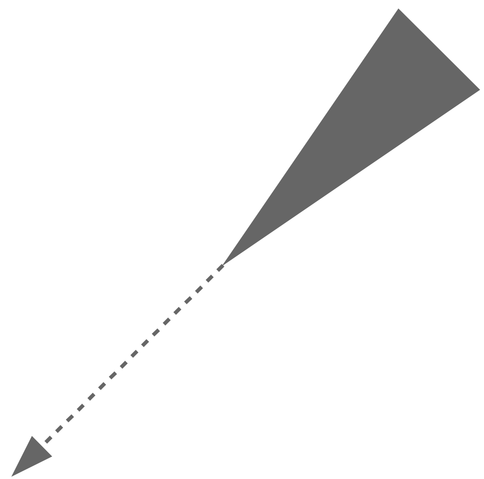








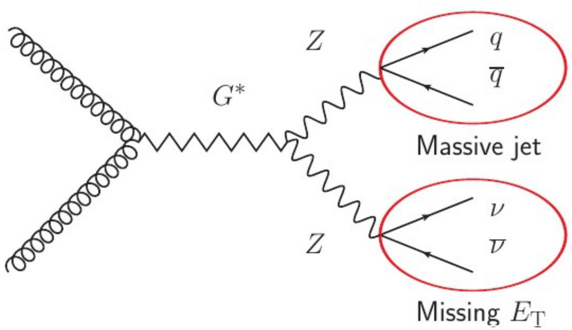
Monojets

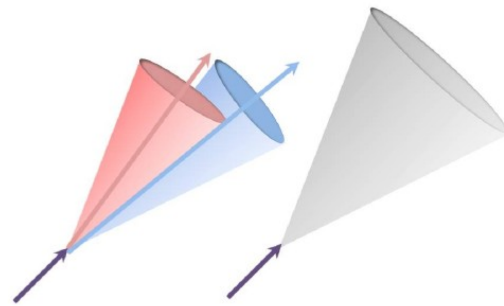


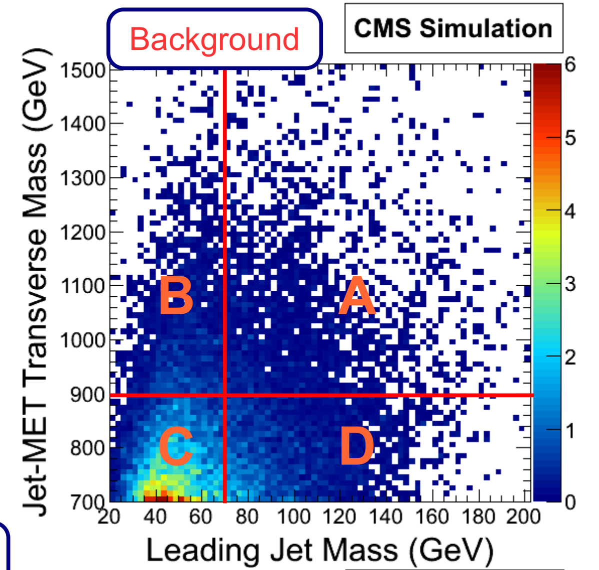
RS Graviton into Jet+MET

EXO-11-061

- Searching for heavy resonances in jet+MET final state
- Benchmark model: RS graviton $G^* \rightarrow ZZ \rightarrow q\bar{q}\nu\bar{\nu}$







- Event selection:
  - Jet p_T>300 GeV and |η|<2.4, MET>300 GeV
  - No isolated e, μ, tracks
  - No more than 2 jets with p_T>30 GeV and |η| <2.4 (if exactly 2, require ΔΦ<2.8)
  - m_j>70 GeV
  - M_T^G>900 GeV

$$M_T^G = \sqrt{2\, p_T^{\text{jet}}\, \not{E}_T \left[1 - \cos\Delta\phi(\text{jet}, \not{E}_T)\right]}$$

Data-driven bkg estimation:

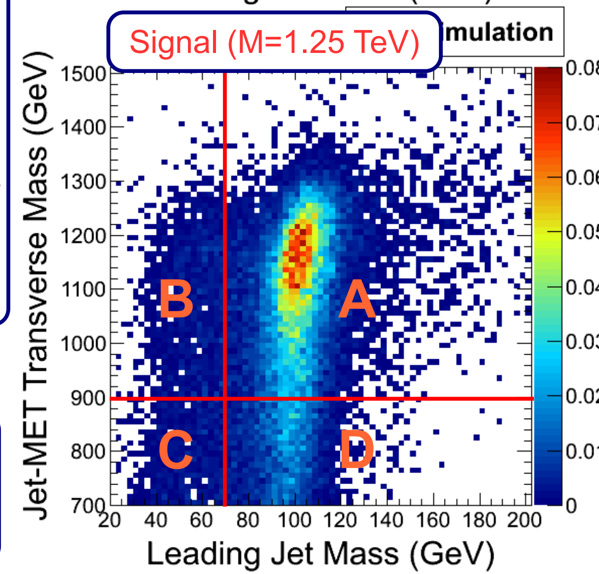
$$A_{\text{est}} = D \cdot \frac{B}{C} \cdot \frac{1}{\rho}$$

ρ = correction factor

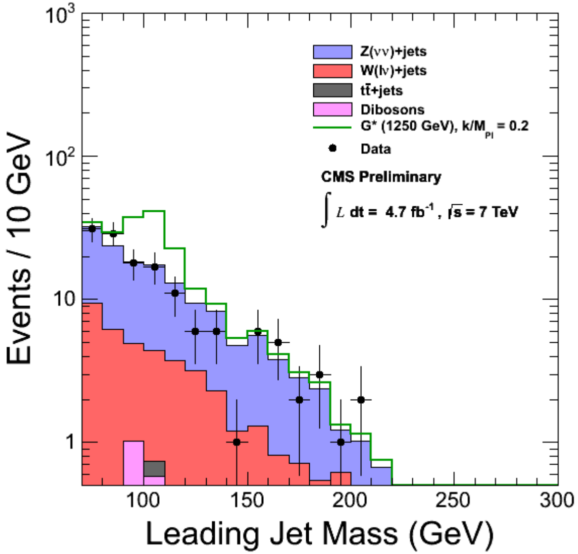
A_{est}=153±29, A_{obs}=138

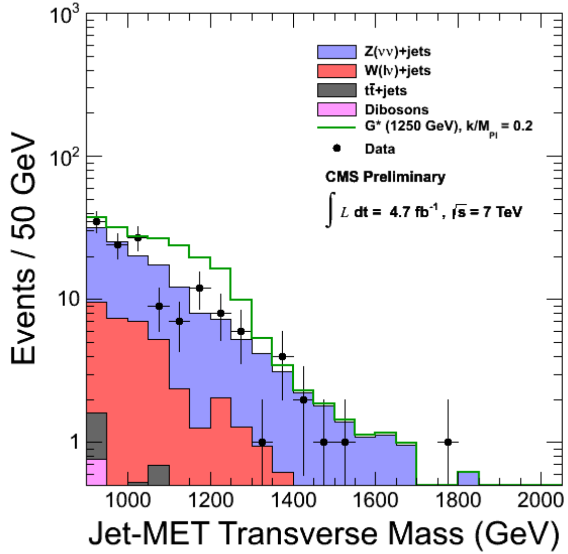
$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$

$$\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

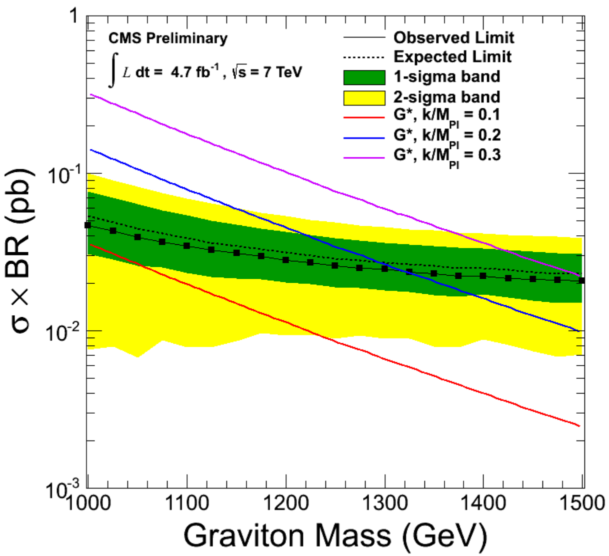


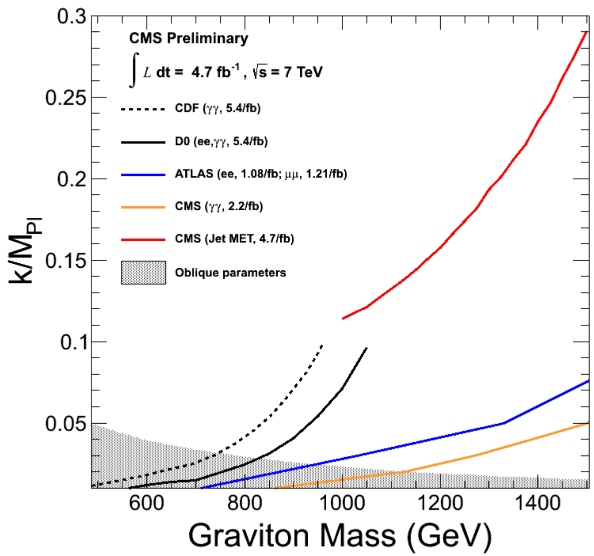
RS Graviton into Jet+MET (cont'd)





- Good agreement between data and background-only prediction



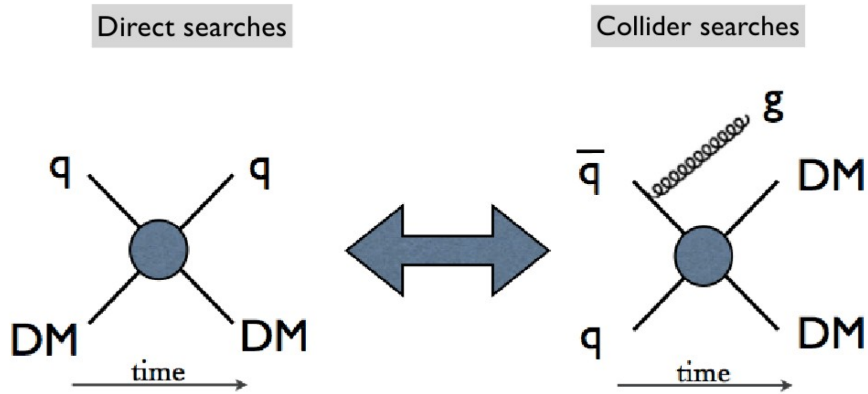


- For resonance masses in the range [1000,1500] GeV, σ×BR>[0.047,0.021] pb or, in the context of the RS model, k/M_{Pl}>[0.11,0.29] excluded at 95% CL

Dark Matter and LED

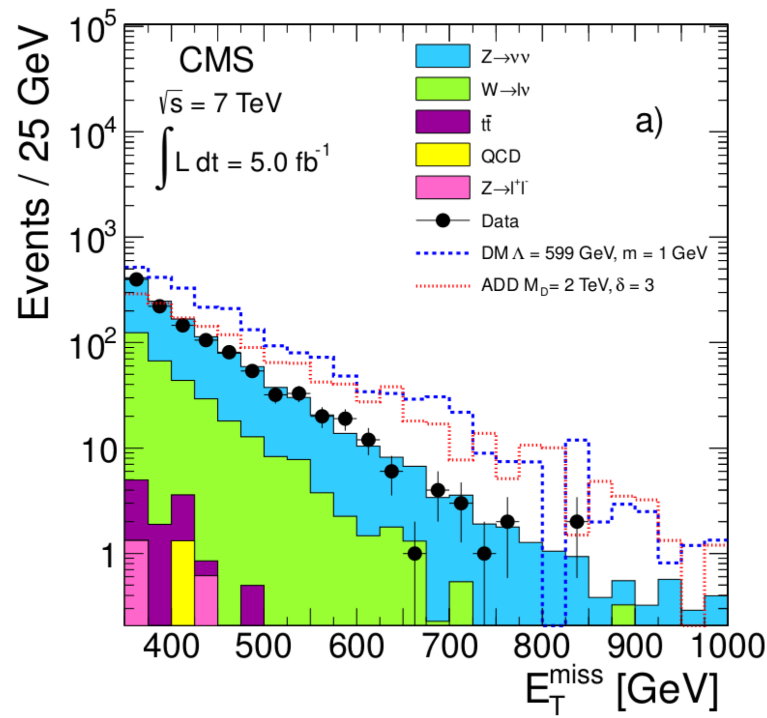
EXO-11-059

- Using monojet+MET events to search for dark matter and ADD graviton production

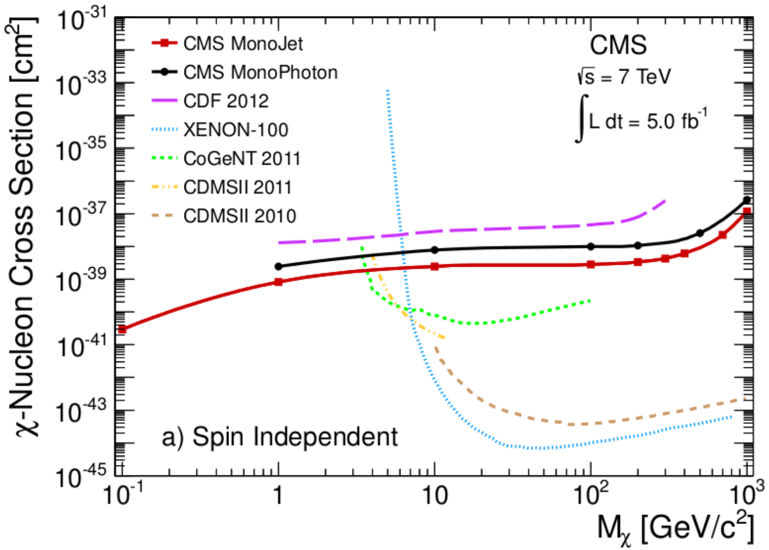


- Collider searches for DM complementary to direct searches
- Mediator particle assumed to be heavy → Contact interaction between DM and SM particles

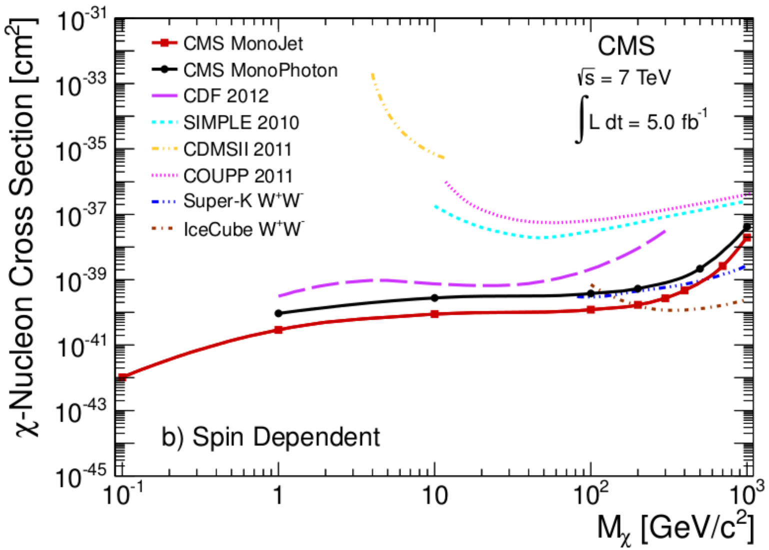
- Event selection:
  - Jet p_T>110 GeV and |η|<2.4, MET>350 GeV
  - No isolated e, μ, tracks
  - No more than 2 jets with p_T>30 GeV (if exactly 2, require ΔΦ<2.5)
- Dominant backgrounds ($Z \rightarrow \nu\bar{\nu}$, $W \rightarrow l\nu$) estimated using data-driven methods
- Data consistent with the standard model prediction → No evidence for dark matter or graviton production



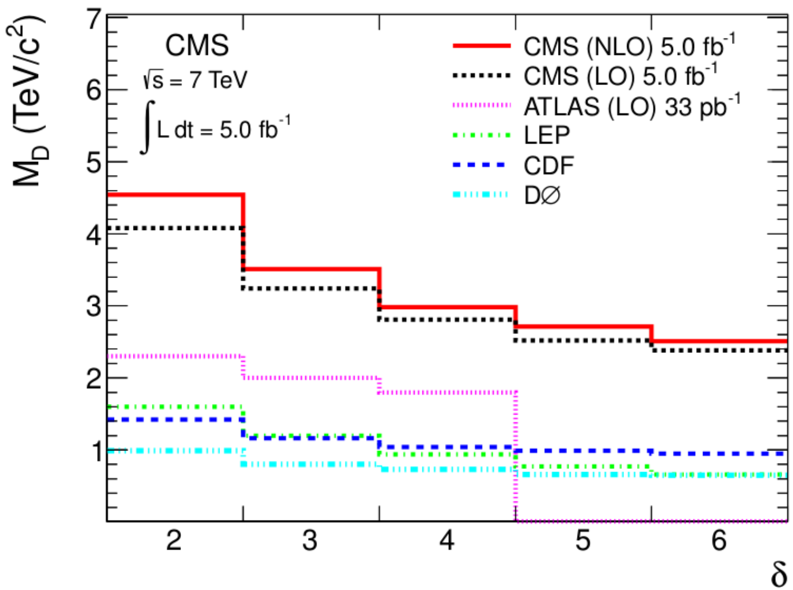
Dark Matter and LED (cont'd)



← Dark matter limits



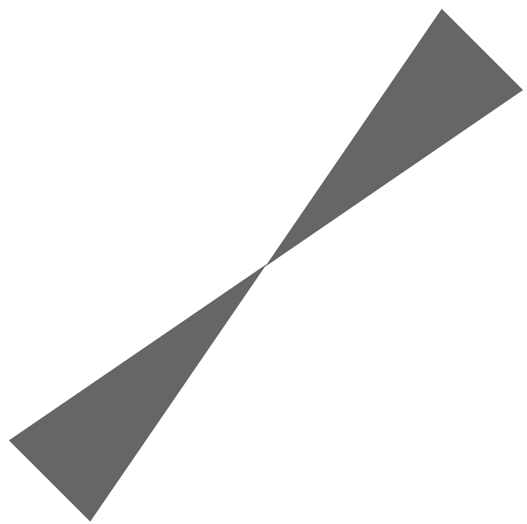
ADD limits →



M_D = Multidimensional Planck scale

δ = Number of extra dimensions

Dijets

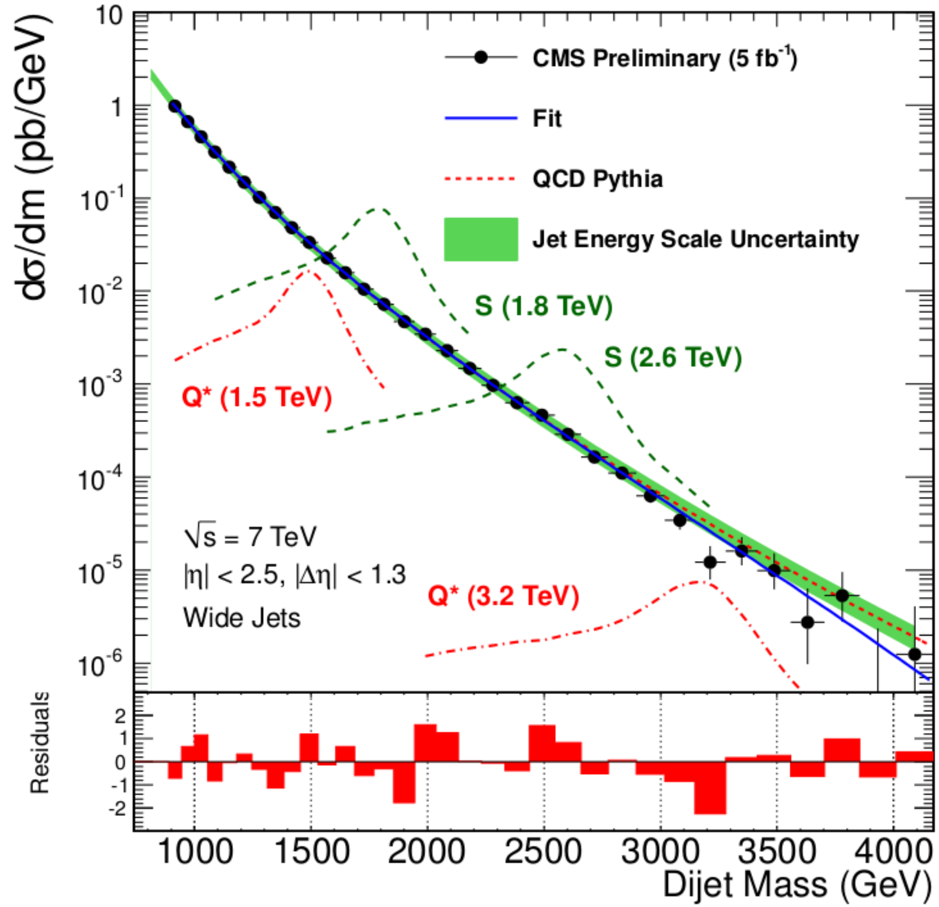


Dijet Resonances (2011)

EXO-11-094

- Searching for resonant structures in smoothly falling dijet mass spectrum
- Using "wide jets" that cluster all other AK5 jets with p_T>30 GeV and |η|<2.5 within ΔR<1.1 around the 2 leading AK5 jets (collects final-state radiation and improves dijet mass resolution)
- Events selected if wide jet |η|<2.5 and |Δη|<1.3
- Using H_T and dedicated dijet mass triggers → Minimum dijet mass of 890 GeV driven by trigger thresholds
- Data well described by PYTHIA6 MC + CMS simulation
- Background estimated from a smooth parameterization fit

$$\frac{d\sigma}{dm} = \frac{P_0(1-m/\sqrt{s})^{P_1}}{(m/\sqrt{s})^{P_2+P_3\ln(m/\sqrt{s})}}$$

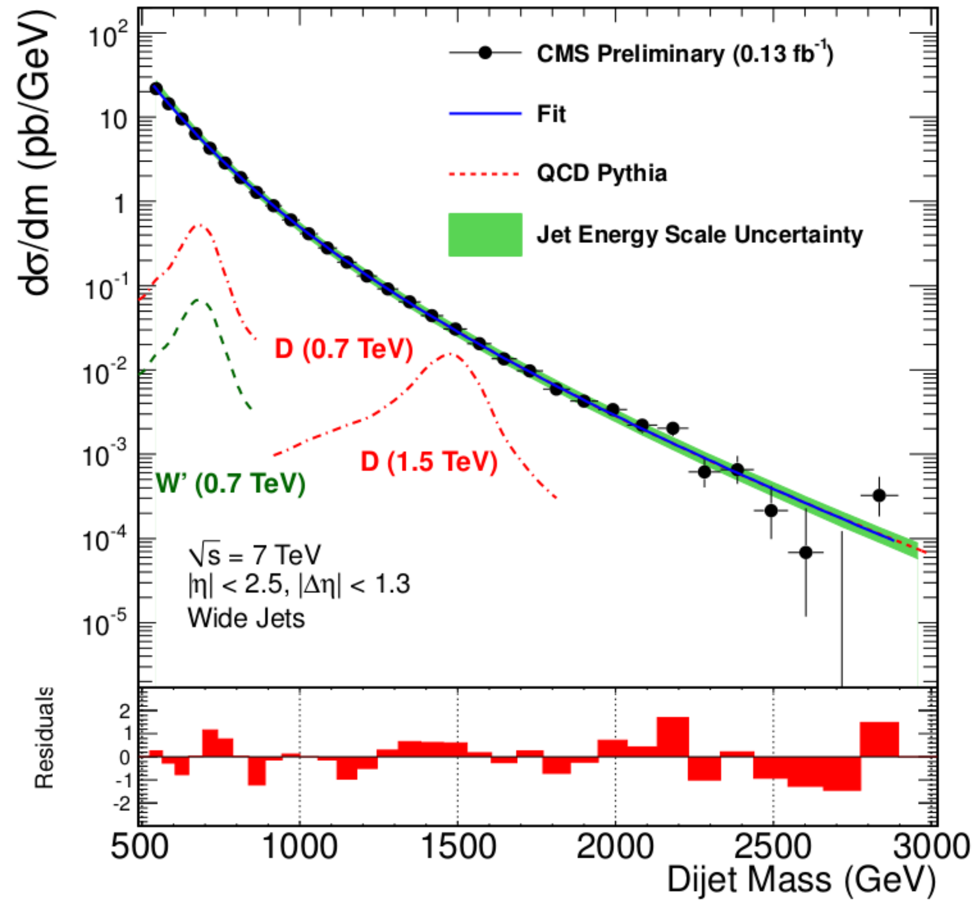


$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$

$$\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

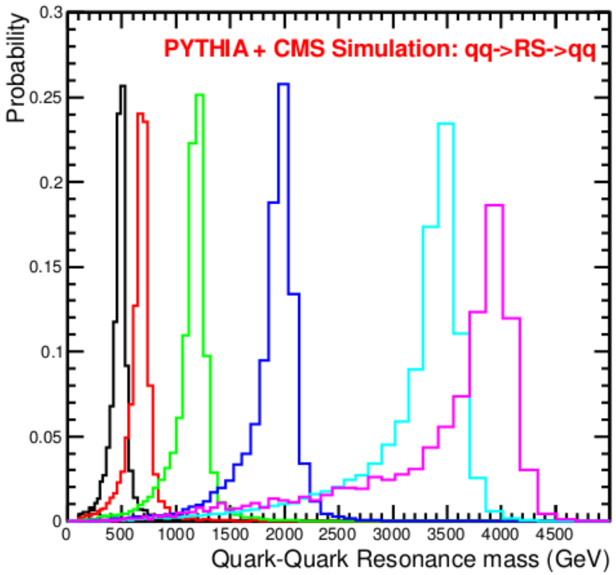
Dijet Resonances (2011) (cont'd)

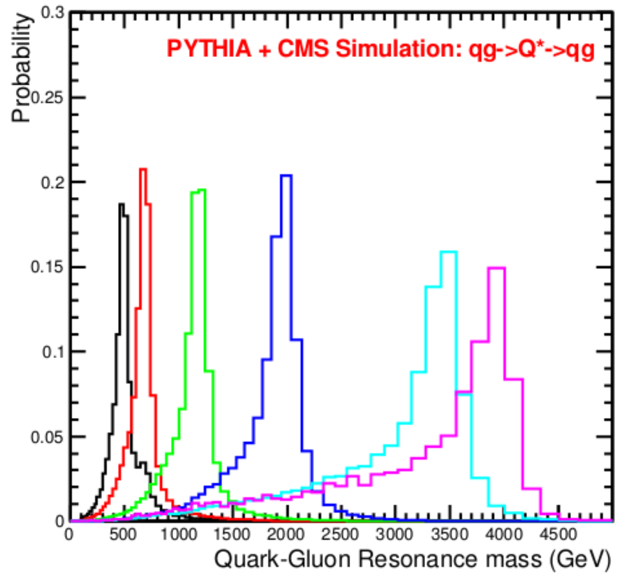
- Complementary low mass search performed using novel triggering and data acquisition strategy introduced in the last few fills of the 2011 run
- Lower trigger thresholds lead to higher event rate → Storing reduced data format (HLT jets) in order to keep the total used bandwidth under control
- CMS uses this same strategy for "data scouting" of regions of phase space inaccessible to standard analyses because of trigger thresholds

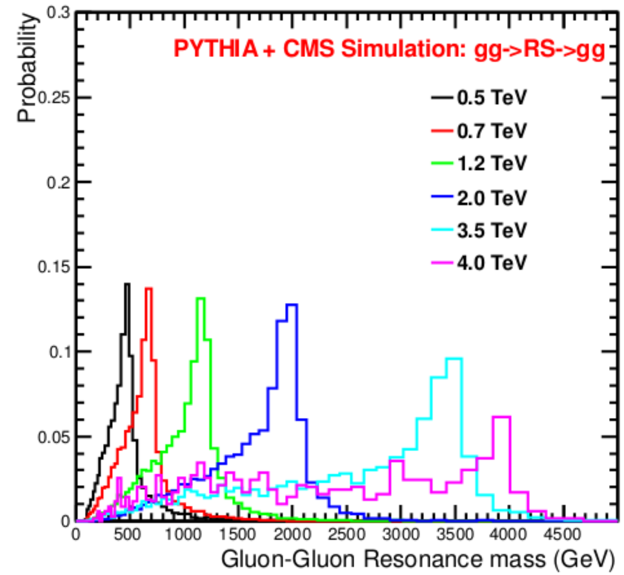


No evidence for new particle production in low and high mass searches

Dijet Resonances (2011) (cont'd)



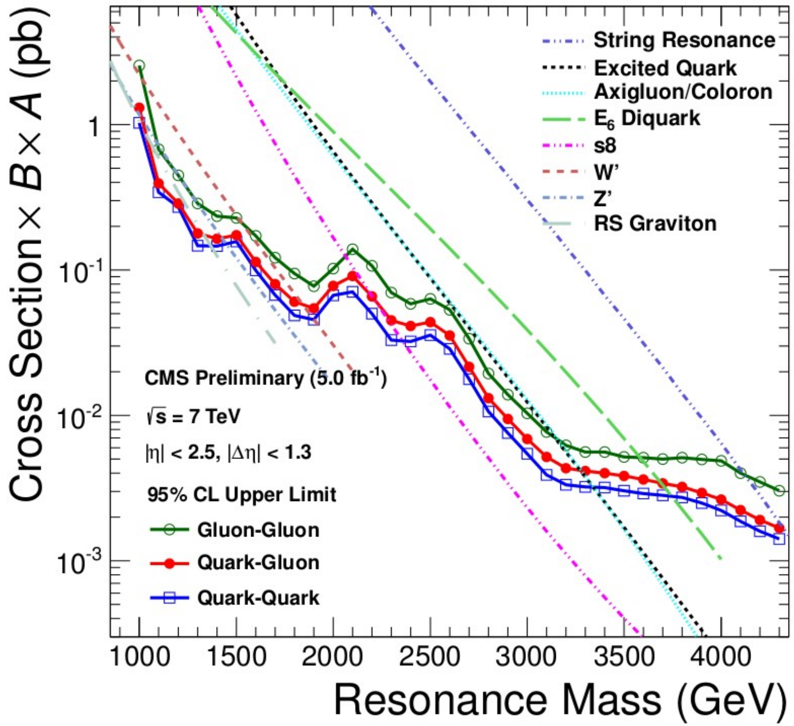


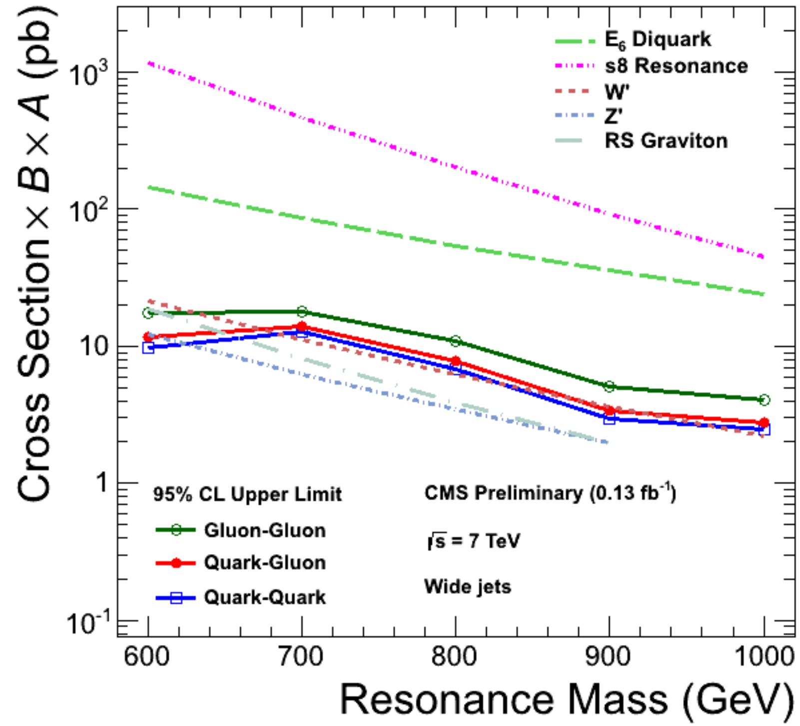


- Signal modeling:
  - Narrow resonances with intrinsic width small compared to the CMS dijet mass resolution
  - Separate resonance shapes for 3 different parton pairings:
    - $q\bar{q}$ (or qq) (from PYTHIA6 G → $q\bar{q}$)
    - qg (from PYTHIA6 q* → qg)
    - gg (from PYTHIA6 G → gg)
  - These shapes together with the measured dijet mass spectrum and the smooth background fit used to set limits

Gaussian core from jet energy resolution and low mass tail from QCD radiation

Dijet Resonances (2011) (cont'd)



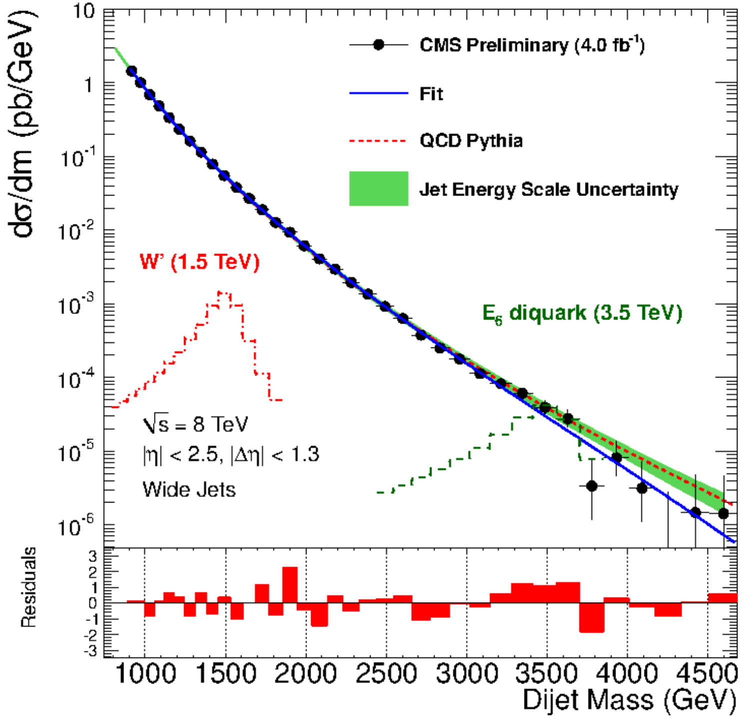


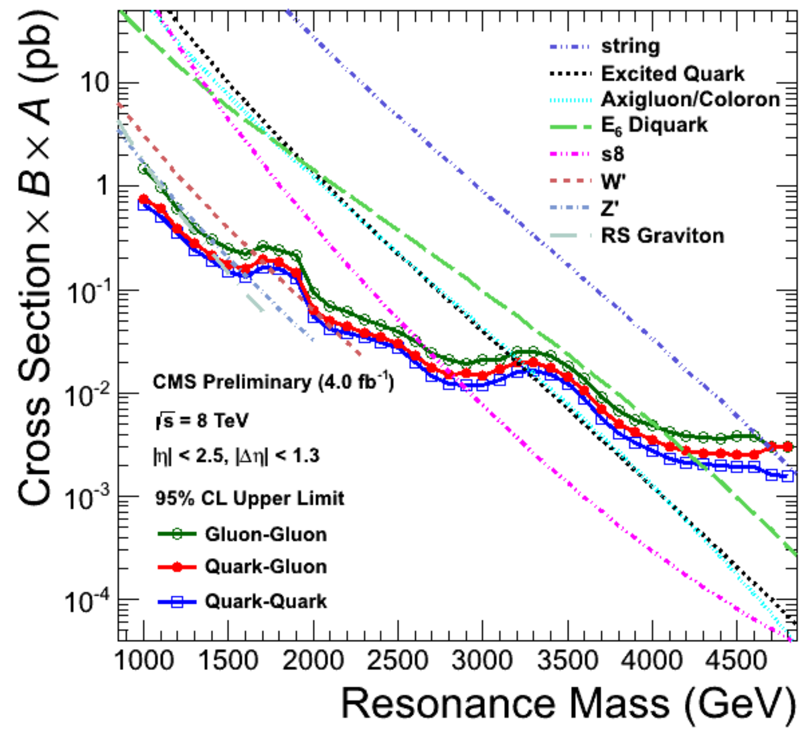
- Model-independent limits set on qq, qg, and gg resonances
- Limits also set on a variety of benchmark models

Model	Final State	Obs. Mass Exclusion [TeV]	Exp. Mass Exclusion [TeV]
String Resonance (S)	qg	[0.6, 4.32]	[0.6,4.28]
Excited Quark (Q*)	qg	[0.6, 3.27]	[0.6,3.05]
E_6 Diquark (D)	qq	[0.6, 3.75]	[0.6,3.72]
Axigluon (A) / Coloron (C)	$q\bar{q}$	[0.6, 3.34]	[0.6,3.17]
s8 Resonance (s8)	gg	[0.6, 2.07]	[0.6,2.25]
W′ Boson (W′)	$q\bar{q}$	[0.60, 0.69]	
		[0.82, 0.96]	[0.60, 0.88]
		[1.0,1.90]	[1.0, 1.77]
Z′ Boson (Z′)	$q\bar{q}$	[1.0, 1.45]	[1.0,1.44]

Dijet Resonances (2012)

EXO-12-016





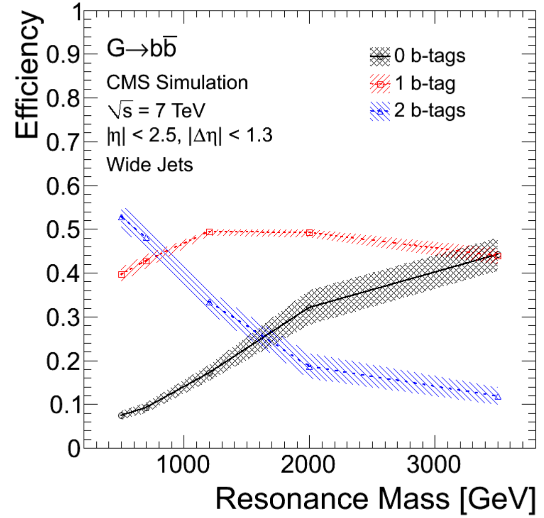
- Increased center-of-mass energy leads to enhanced signal cross sections
- Compared to 2011 results, mass limits extended for most benchmark models

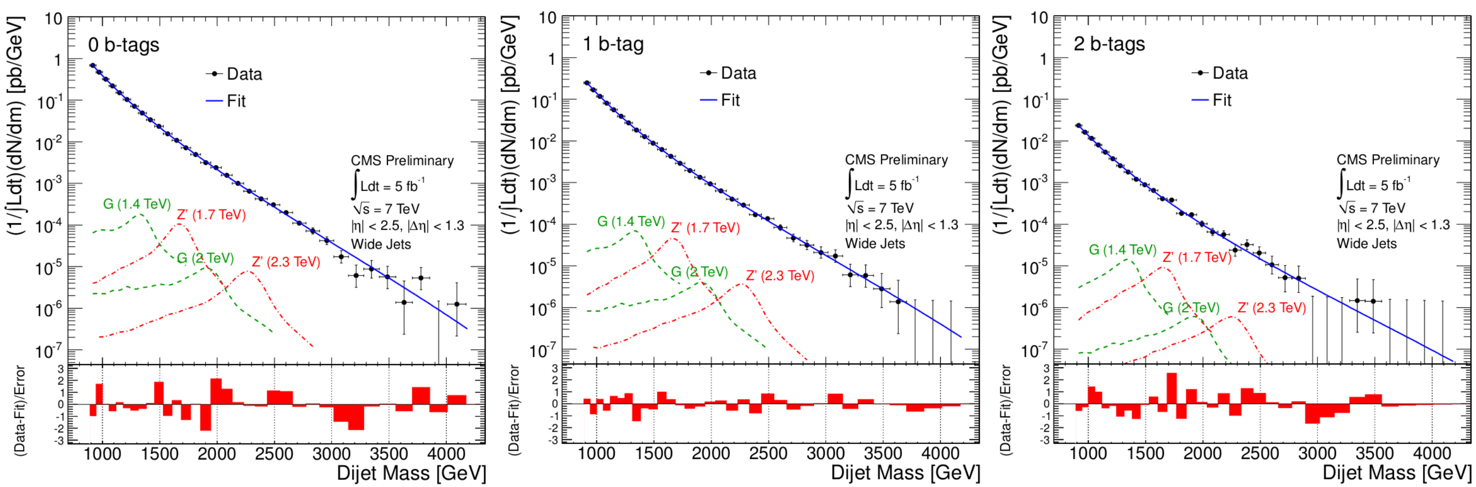
Model	Final State	Obs. Mass Excl. [TeV]	Exp. Mass Excl. [TeV]
String Resonance (S)	qg	[1.0, 4.69]	[1.0,4.64]
Excited Quark (Q*)	qg	[1.0, 3.19]	[1.0,3.43]
E_6 Diquark (D)	qq	[1.0, 4.28]	[1.0,4.12]
Axigluon (A)/Coloron (C)	$q\bar{q}$	[1.0, 3.28]	[1.0,3.55]
s8 Resonance (s8)	gg	[1.0, 2.66]	[1.0,2.53]
W′ Boson (W′)	$q\bar{q}$	[1.0, 1.74] [1.97, 2.12]	[1.0,1.92]
Z′ Boson (Z′)	$q\bar{q}$	[1.0, 1.60]	[1.0,1.50]
RS Graviton (RSG)	$q\bar{q}$+gg	[1.0, 1.36]	[1.0,1.20]

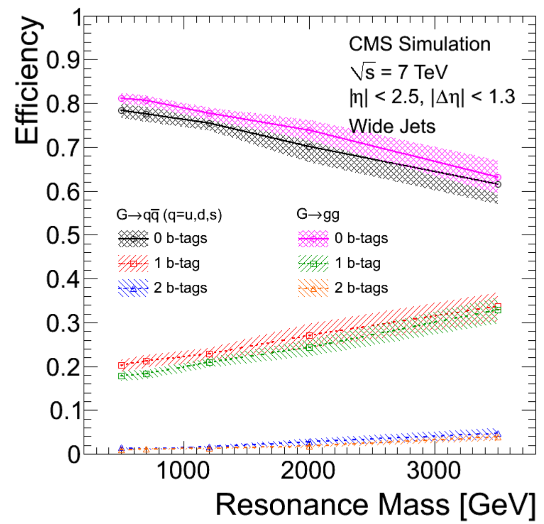
Dijet Resonances with b-tagging

EXO-11-008

- Extension of the standard dijet resonance search
- Considering information on possible presence of a secondary vertex within the jet → Increased sensitivity to resonances preferentially decaying to b-jets
- Only 2 leading jets considered for b-tagging → Events grouped into 3 exclusive categories: 0, 1, and 2 b-tags
- Search performed in all 3 categories simultaneously



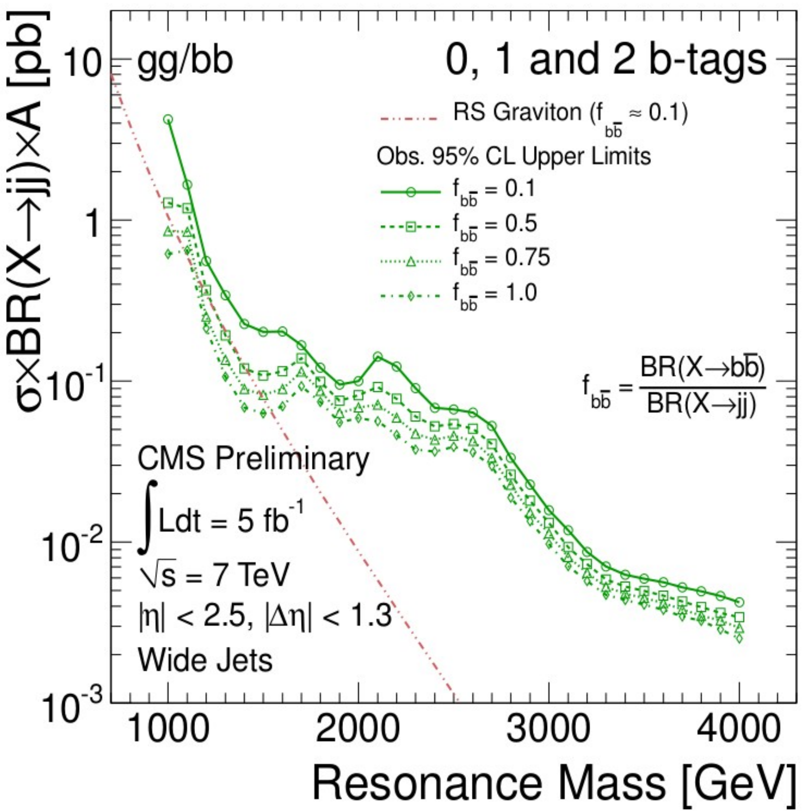


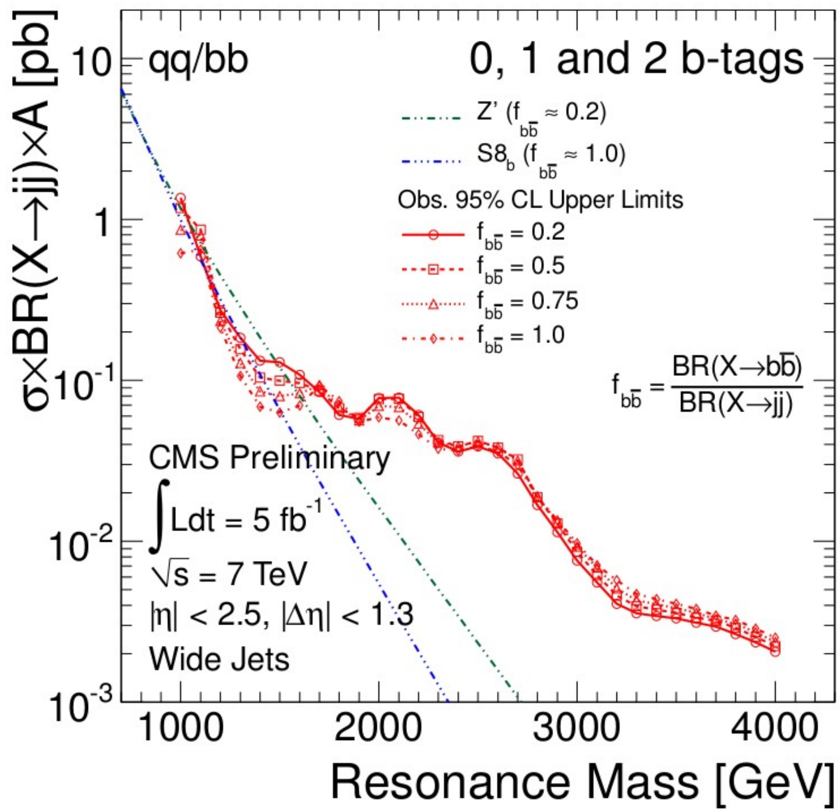


Dijet Resonances with b-tagging (cont'd)

- Set model-independent limits as a function of the $b\bar{b}$ jet fraction

$$f_{b\bar{b}} = \frac{BR(X \to b\bar{b})}{BR(X \to jj)}$$

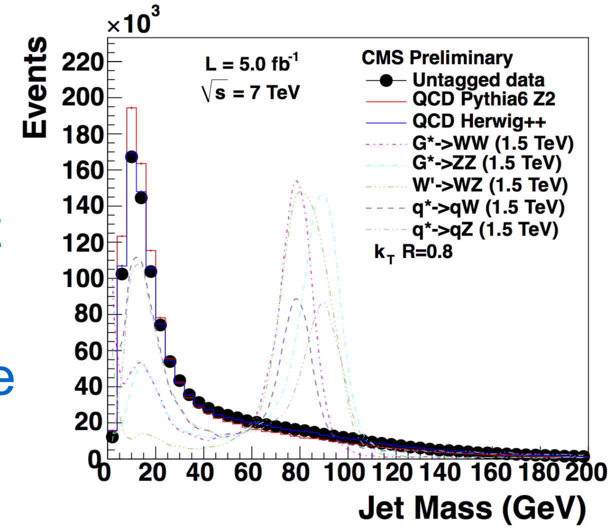


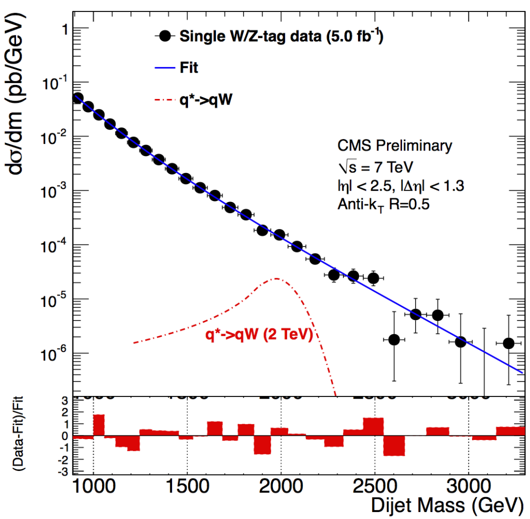


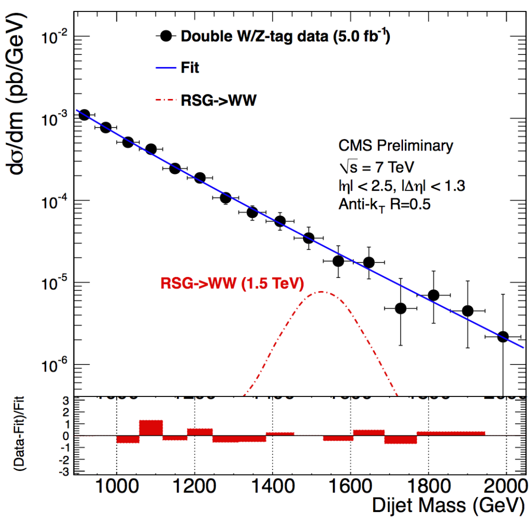
Dijet Resonances with W/Z-tagging

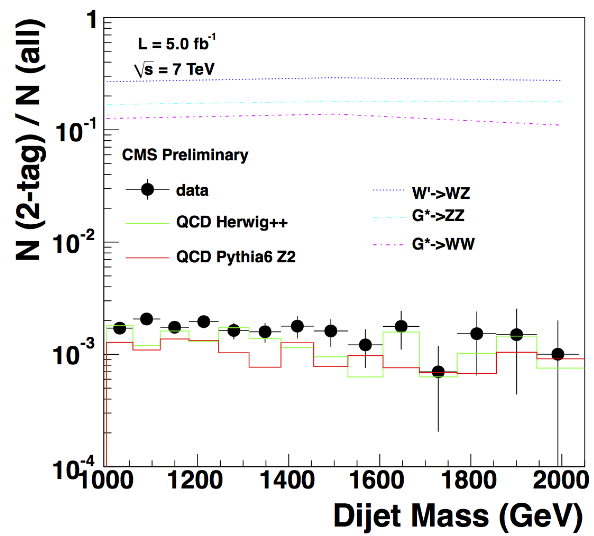
EXO-11-095

- Searching for heavy resonances decaying into boosted hadronic W/Z
- Making use of the jet substructure techniques to tag boosted hadronic W/Z (tagging based on the pruned jet mass, mass drop and the number of subjets)
- AK5 jets used for event selection and reconstructing the dijet invariant mass. Pruned Cambridge-Aachen R=0.8 jets used for W/Z-tagging



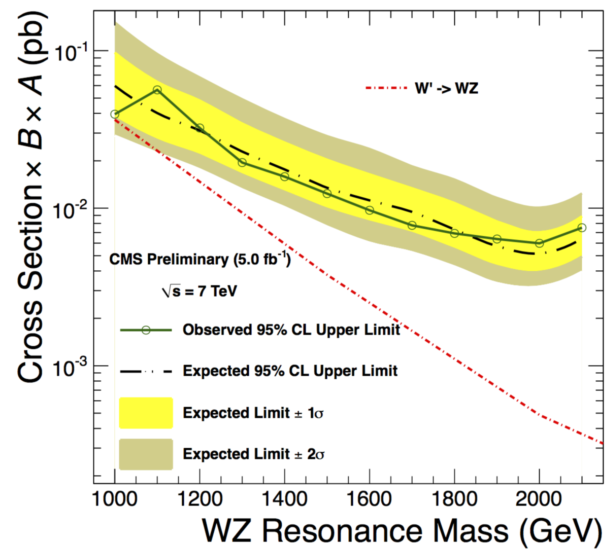


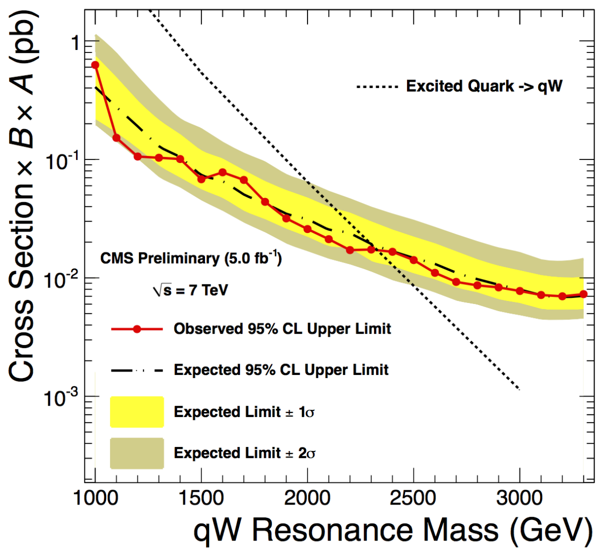


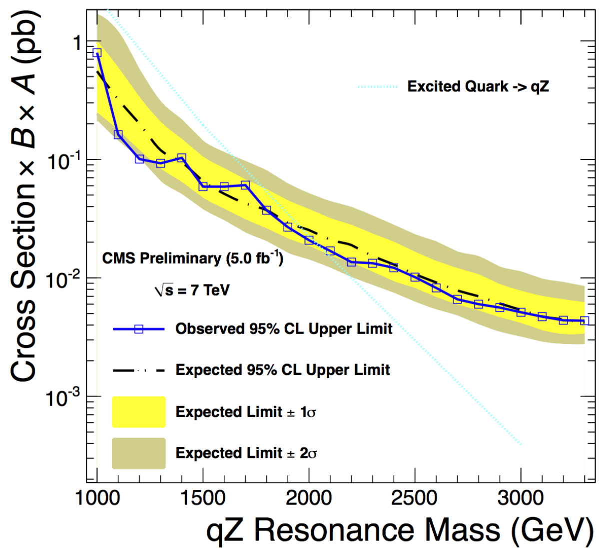


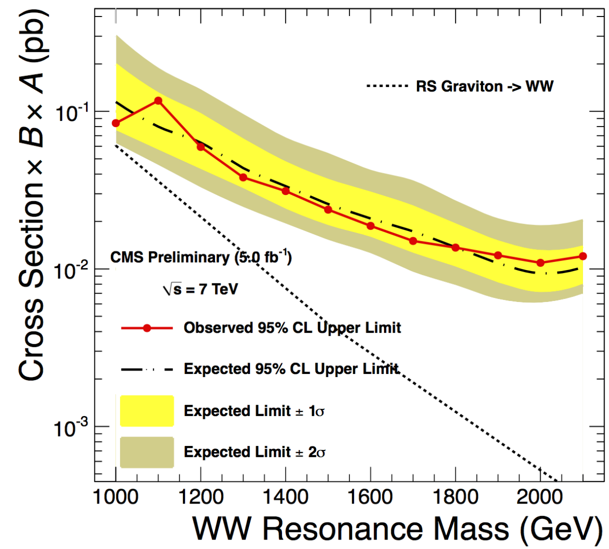
Dijet Resonances with W/Z-tagging (cont'd)

- Limits on qW/qZ resonances set in single-tagged sample
  - Extend mass limits from corresponding semi-leptonic searches
- Limits on WW/WZ/ZZ resonances set in double-tagged sample









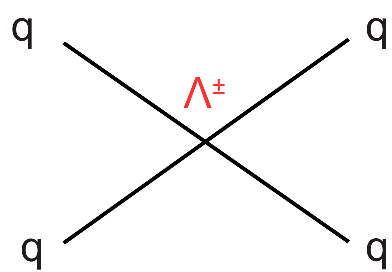
Quark Compositeness

EXO-11-017

- Well bellow the compositeness scale Λ, quark compositeness manifests itself as a four-fermion contact interaction (CI)

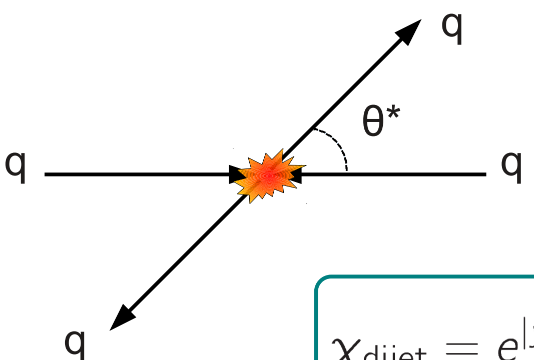
$$L_{qq} = \frac{2\pi}{\Lambda^2}\left[\eta_{LL}(\bar{q}_L\gamma^\mu q_L)(\bar{q}_L\gamma_\mu q_L) + \eta_{RR}(\bar{q}_R\gamma^\mu q_R)(\bar{q}_R\gamma_\mu q_R) + 2\eta_{RL}(\bar{q}_R\gamma^\mu q_R)(\bar{q}_L\gamma_\mu q_L)\right]$$

$$\Lambda = \Lambda^{\pm}_{LL} \text{ for } (\eta_{LL},\eta_{RR},\eta_{RL}) = (\pm1,0,0)$$
$$\Lambda = \Lambda^{\pm}_{RR} \text{ for } (\eta_{LL},\eta_{RR},\eta_{RL}) = (0,\pm1,0)$$
$$\Lambda = \Lambda^{\pm}_{VV} \text{ for } (\eta_{LL},\eta_{RR},\eta_{RL}) = (\pm1,\pm1,\pm1)$$
$$\Lambda = \Lambda^{\pm}_{AA} \text{ for } (\eta_{LL},\eta_{RR},\eta_{RL}) = (\pm1,\pm1,\mp1)$$
$$\Lambda = \Lambda^{\pm}_{(V-A)} \text{ for } (\eta_{LL},\eta_{RR},\eta_{RL}) = (0,0,\pm1)$$



$\Lambda^+ \rightarrow$ Destructive interference between CI and QCD
$\Lambda^- \rightarrow$ Constructive interference between CI and QCD

- Contact interactions affect the angular distribution of the scattered partons



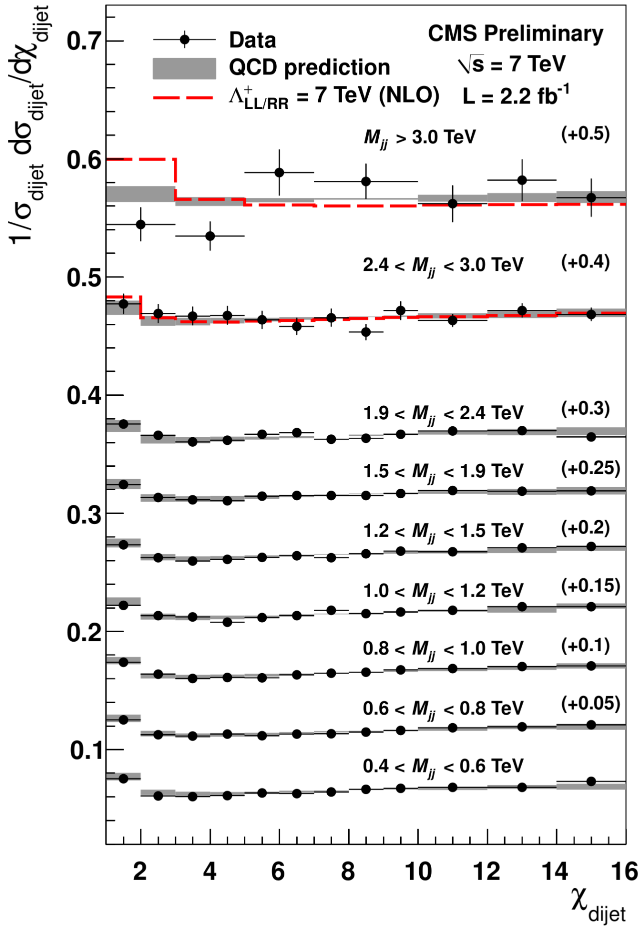
$$\text{Angular dist.} \equiv \frac{1}{\sigma_{\text{dijet}}}\frac{d\sigma_{\text{dijet}}}{d\chi_{\text{dijet}}}$$

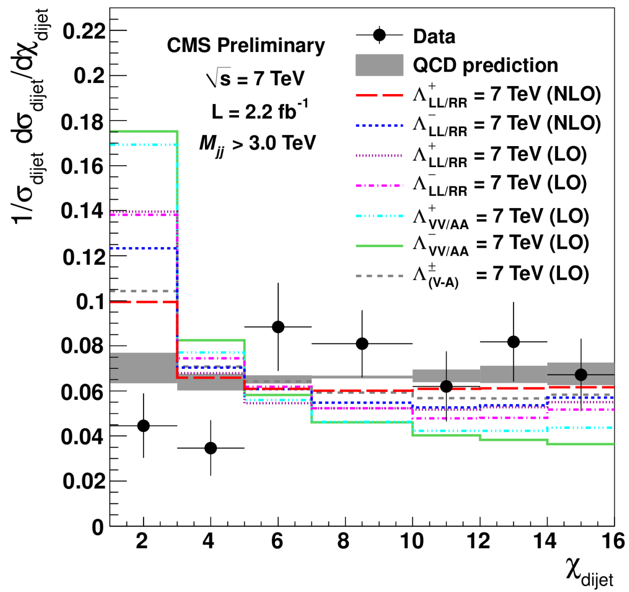
Flat for Rutherford scattering, approximately flat for QCD, peaking at low values of χ_{dijet} for CI models

$$\chi_{\text{dijet}} = e^{|y_1-y_2|} \xrightarrow[m\to0]{} \frac{1+|\cos\theta^*|}{1-|\cos\theta^*|},\ y = \frac{1}{2}\ln\left(\frac{E+p_z}{E-Pz}\right),\ y_{\text{boost}} = \frac{1}{2}(y_1+y_2)$$

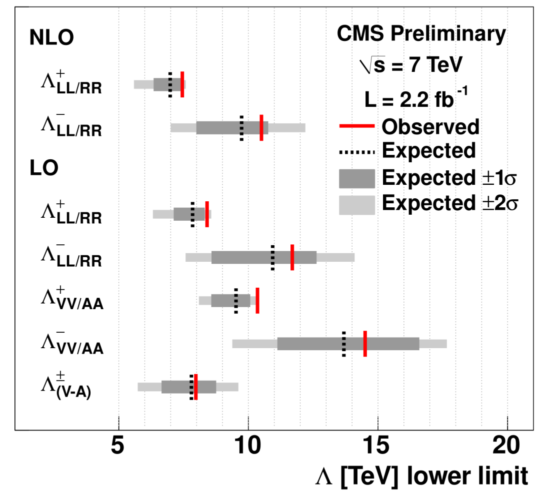
Quark Compositeness (cont'd)

- Event selection: ≥2 jets with χ_{dijet}<16 and $|y_{boost}|$<1.11 (effectively restricts $|y_1|$ and $|y_2|$ to <2.5)
- Angular distribution measured in multiple dijet mass bins



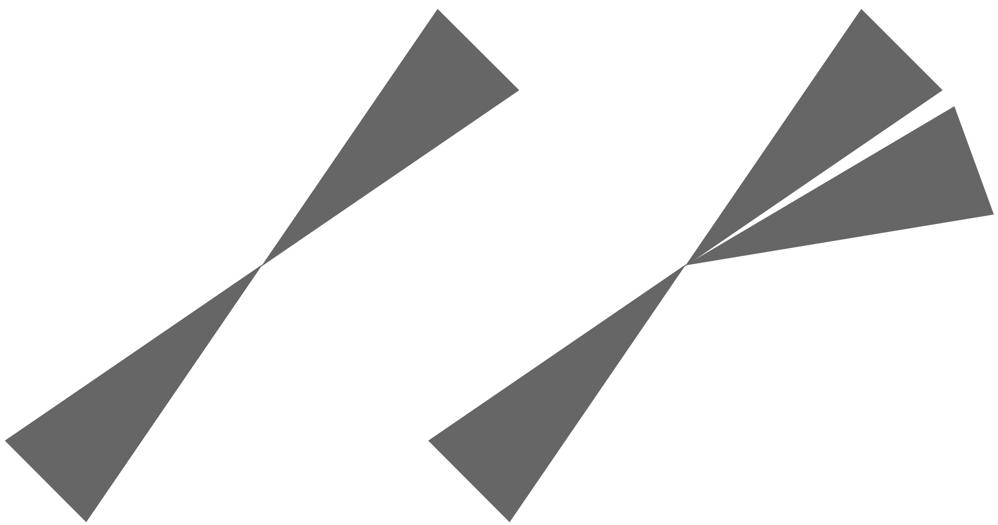


- Results:



CI model	Observed limit (TeV)	Expected limit (TeV)
NLO $\Lambda^+_{LL/RR}$	7.5	$7.0^{+0.4}_{-0.6}$
NLO $\Lambda^-_{LL/RR}$	10.5	$9.7^{+1.0}_{-1.7}$
LO $\Lambda^+_{LL/RR}$	8.4	$7.9^{+0.5}_{-0.7}$
LO $\Lambda^-_{LL/RR}$	11.7	$10.9^{+1.7}_{-2.4}$
LO $\Lambda^+_{VV/AA}$	10.4	$9.5^{+0.5}_{-1.0}$
LO $\Lambda^-_{VV/AA}$	14.5	$13.7^{+2.9}_{-2.6}$
LO $\Lambda^\pm_{(V-A)}$	8.0	$7.8^{+1.0}_{-1.1}$

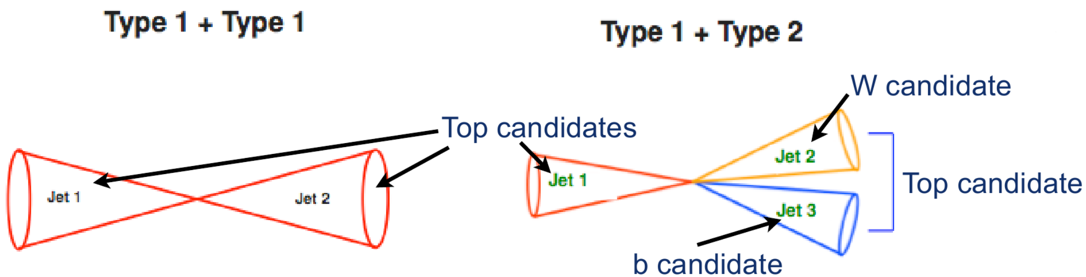
Dijets+Trijets



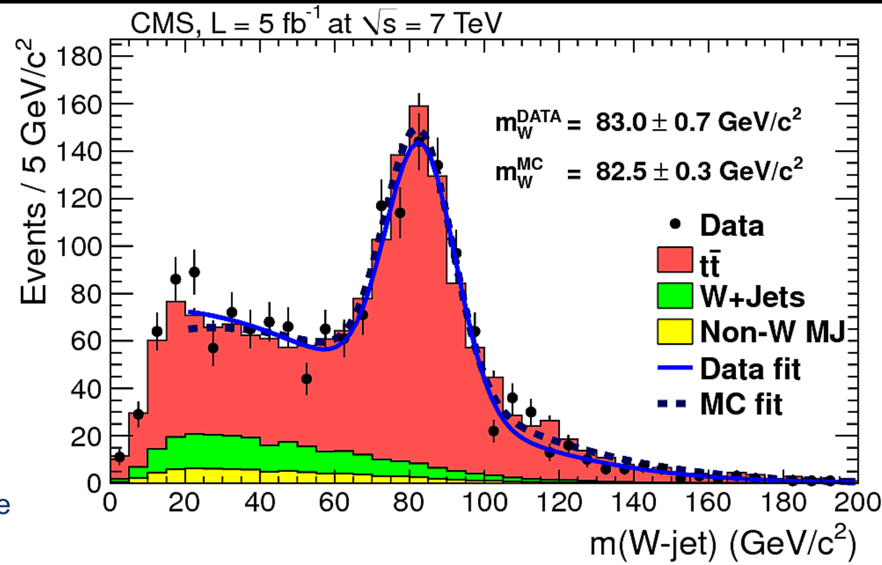
Boosted Tops

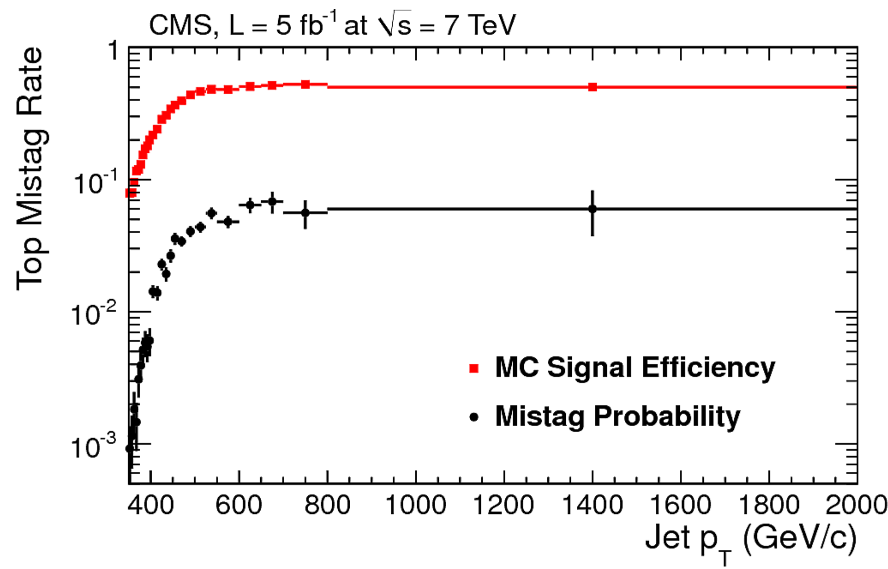
EXO-11-006

- Searching for heavy resonances (m>1 TeV) decaying into boosted $t\bar{t}$ pairs in all-hadronic final state
  - Fully merged and partially merged topologies

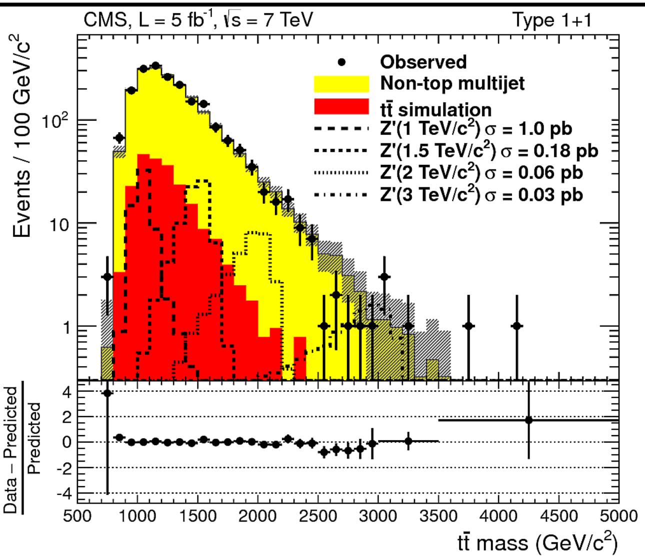


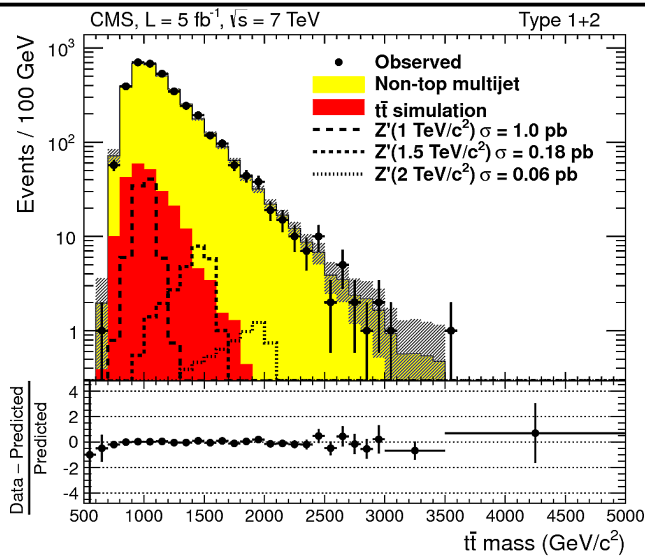
- Using Cambridge-Aachen jets with R=0.8 to tag:
  - Top jets
  - W jets





Boosted Tops (cont'd)

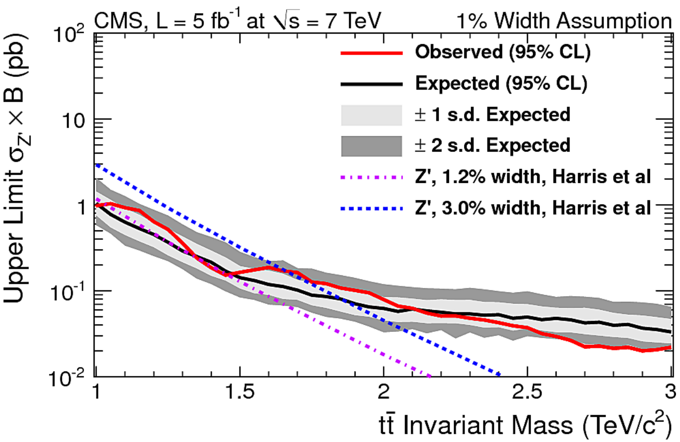


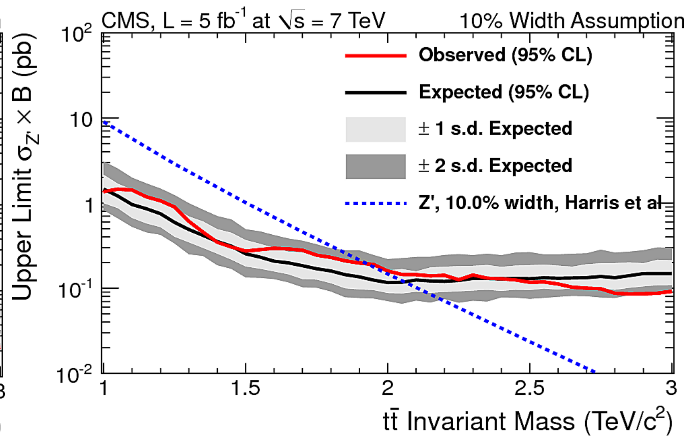


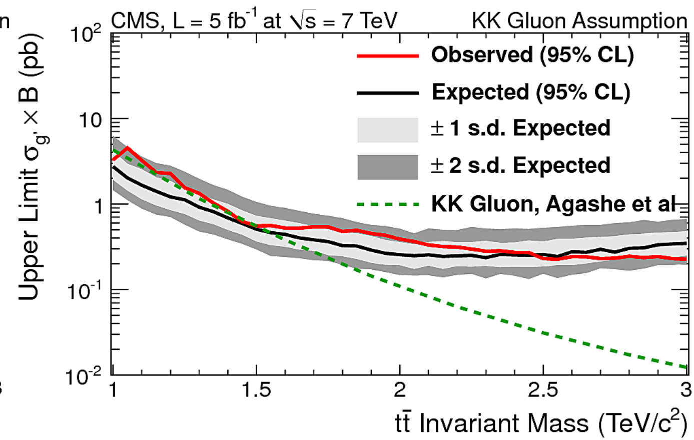
- Data consistent with background-only prediction
- Limits set on:
  - Topcolor Z'
  - RS Kaluza-Klein gluon
  - Enhanced $t\bar{t}$ cross section at high mass

$$\mathcal{S} = \frac{\int_{m_{t\bar{t}}>1\,\mathrm{TeV}/c^2} \frac{d\sigma_{SM+NP}}{dm_{t\bar{t}}} dm_{t\bar{t}}}{\int_{m_{t\bar{t}}>1\,\mathrm{TeV}/c^2} \frac{d\sigma_{SM}}{dm_{t\bar{t}}} dm_{t\bar{t}}}$$

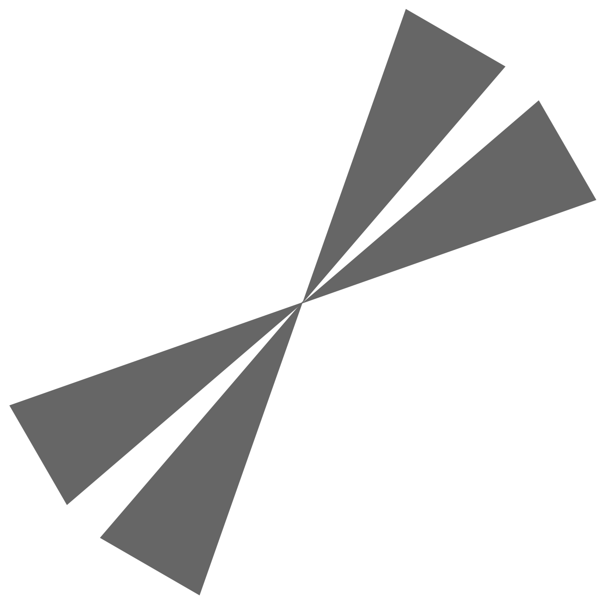
$\rightarrow \mathcal{S} < 2.6$







Paired Dijets



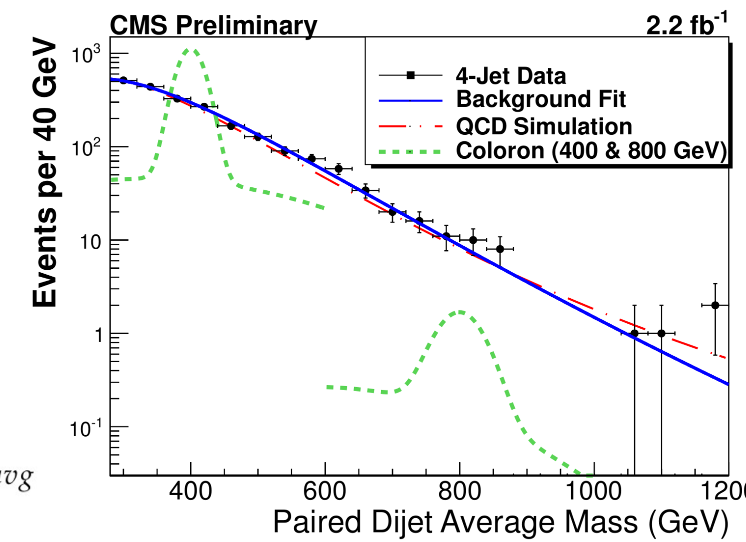
Paired Dijet Resonances

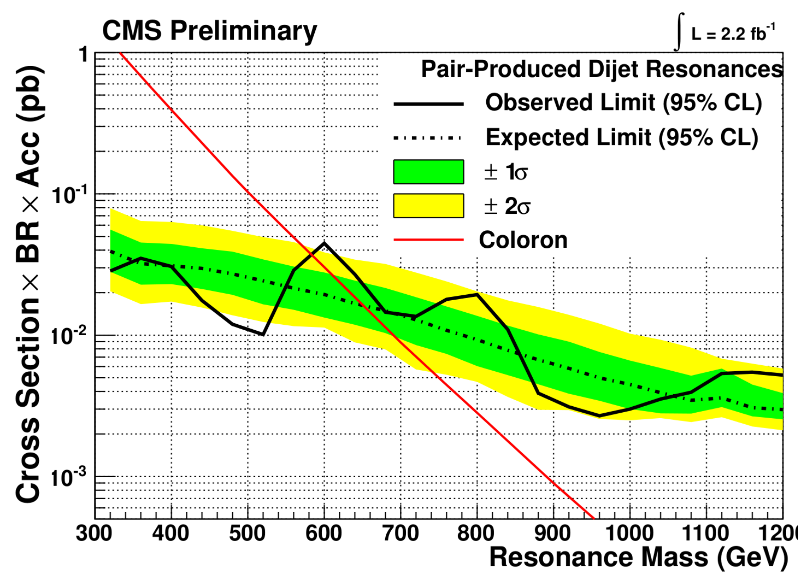
EXO-11-016

- Searching for pair production of new colored particles decaying into dijets
- Search performed in the average dijet mass spectrum of the dijet pair with smallest $\Delta m/m_{avg}$ formed from the 4 leading jets
- Event selection:
  - $\geq$4 jets with $|\eta|<2.5$ and $p_T>150$ GeV
  - $\Delta R_{jj}>0.7$, $\Delta m/m_{avg}<0.15$, $\Delta>25$ GeV

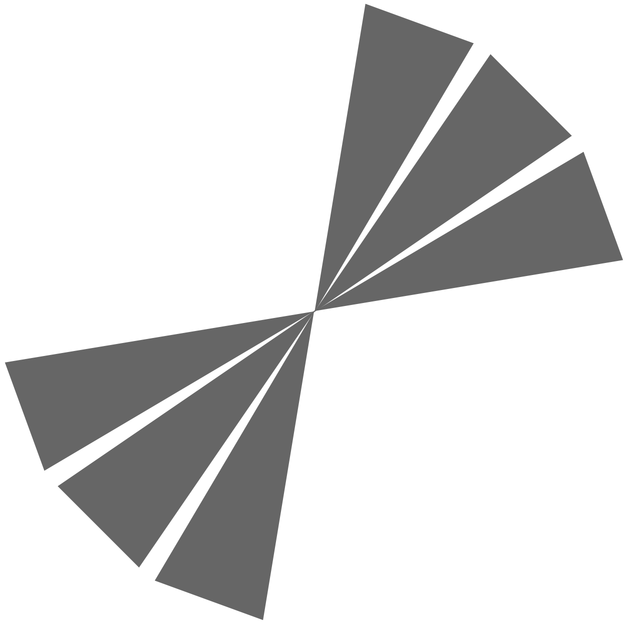
$$\Delta = \sum_{i=1,2} (P_T)_i - m_{avg}$$

- Benchmark model: pair production of colorons decaying into $q\bar{q}$ pairs (acceptance varies from 3% for m=300 GeV to 13% for m=1000 GeV)
- Measured average dijet mass spectrum smoothly falling → No evidence for new particle production
- Observed 95% CL exclusion 320<m<580 GeV (320<m<650 GeV expected)





Paired Trijets



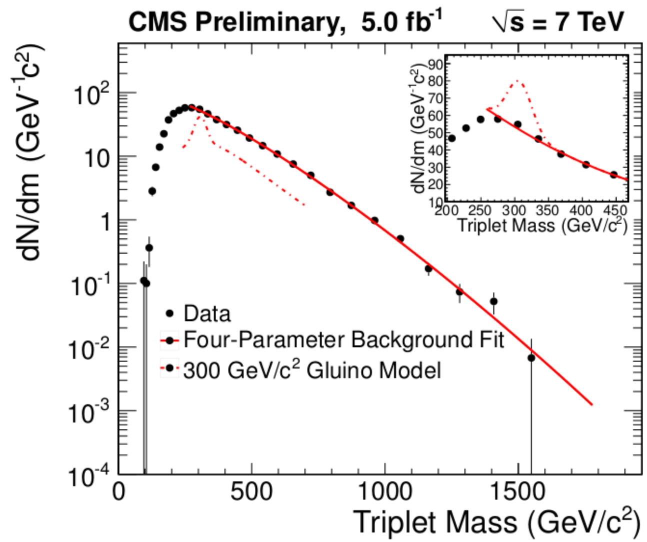
Three-jet Resonances

EXO-11-060

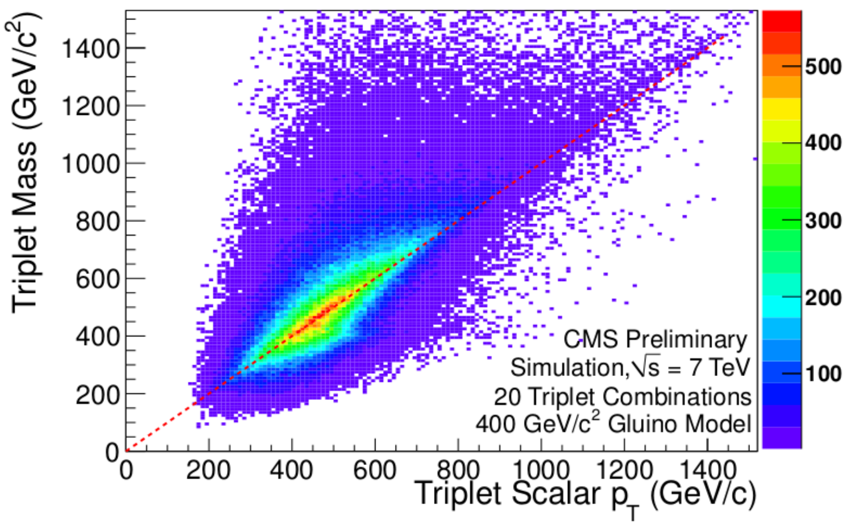
- Searching for pair production of massive colored particles decaying into 3 jets
- Search performed in the triplet mass spectrum using the jet ensemble technique
- Event selection:
  - ≥6 jets with $|\eta|<3.0$, $p_T>70$ GeV and $H_T>900$ GeV
  - 6 leading jets combined into all possible unique triplet combinations → 20 combinations

$$M_{jjj} < \sum_{i=1}^{3} |p_T|_i - \Delta$$

Δ=160 GeV



- Benchmark model: pair production of gluinos with RPV decays into 3 quarks (acceptance varies from 0.25% for m=250 GeV to 2.6% for m=1500 GeV)



Three-jet Resonances

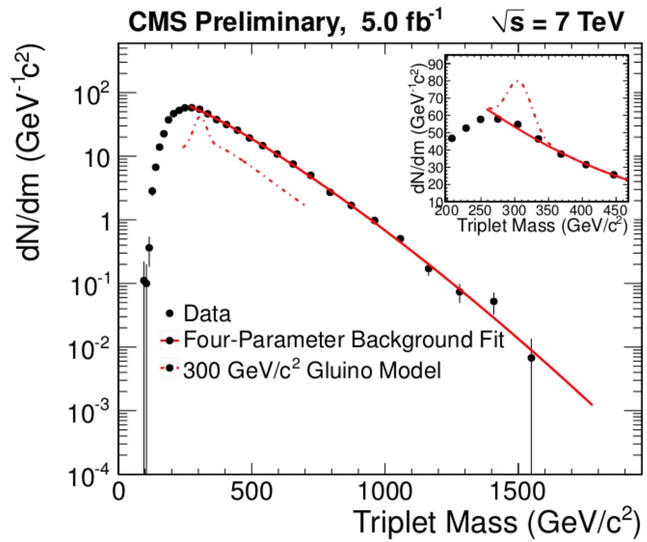
EXO-11-060

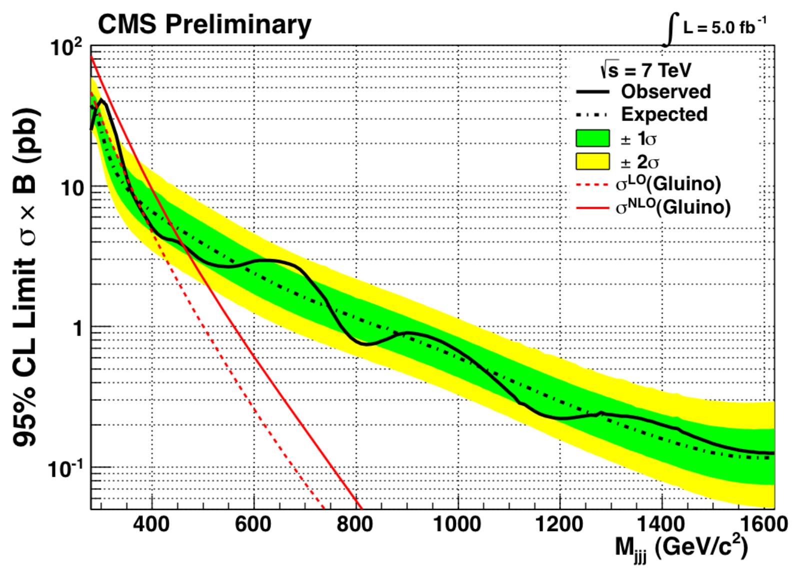
- Searching for pair production of massive colored particles decaying into 3 jets
- Search performed in the triplet mass spectrum using the jet ensemble technique
- Event selection:
  - ≥6 jets with $|\eta|<3.0$, $p_T>70$ GeV and $H_T>900$ GeV
  - 6 leading jets combined into all possible unique triplet combinations → 20 combinations

$$M_{jjj} < \sum_{i=1}^{3} |p_T|_i - \Delta$$

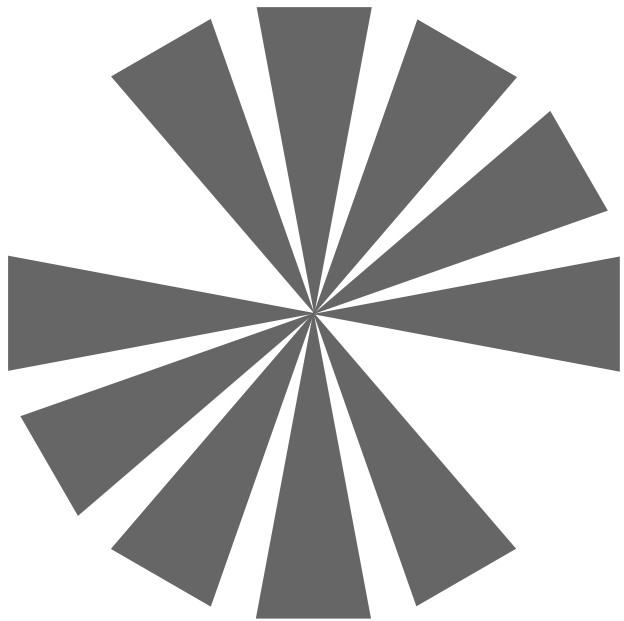
Δ=160 GeV

- Benchmark model: pair production of gluinos with RPV decays into 3 quarks (acceptance varies from 0.25% for m=250 GeV to 2.6% for m=1500 GeV)
- Measured triplet mass spectrum smoothly falling → No evidence for new particle production
- Observed 95% CL exclusion 280<m<460 GeV extends the previous CMS exclusion 200<m<280 GeV





Multijets

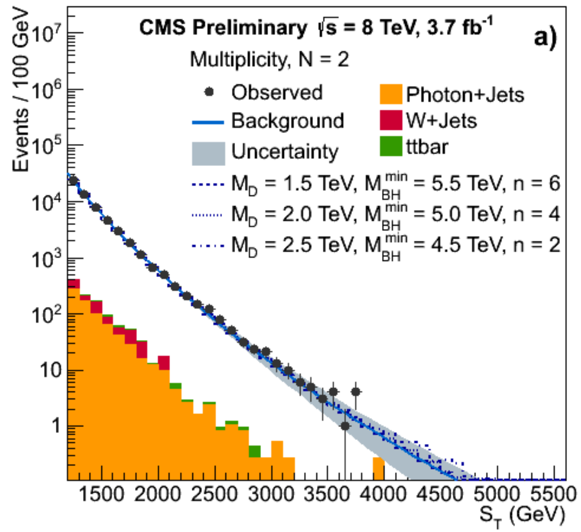


Microscopic Black Holes

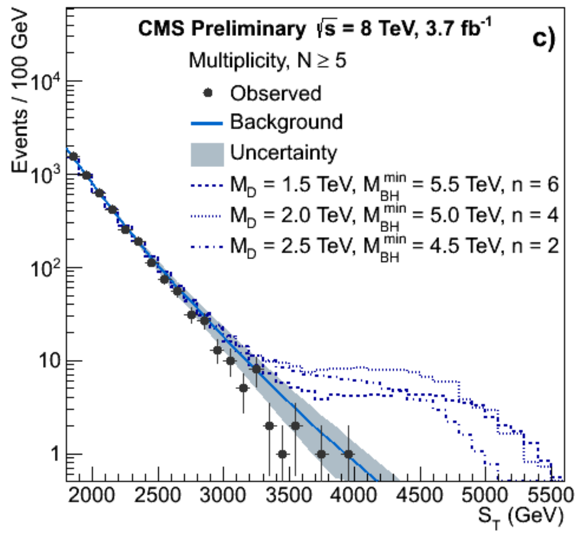
EXO-12-009

- Possible production of microscopic black holes at the LHC is one of the spectacular predictions of low-scale quantum gravity
- BHs evaporate into many high-p_T final state particles (dominated by quarks and gluons at ~75%)
- Search performed in S_T distribution in different final-state multiplicity bins

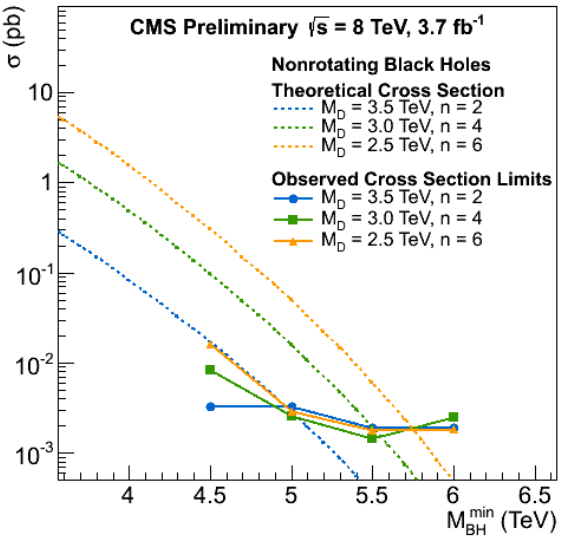
$$S_T = \sum_{j,e,\mu,\gamma}^{N} p_T \ (\text{if } p_T > 50 \text{ GeV}) + \text{MET} \ (\text{if MET} > 50 \text{ GeV})$$

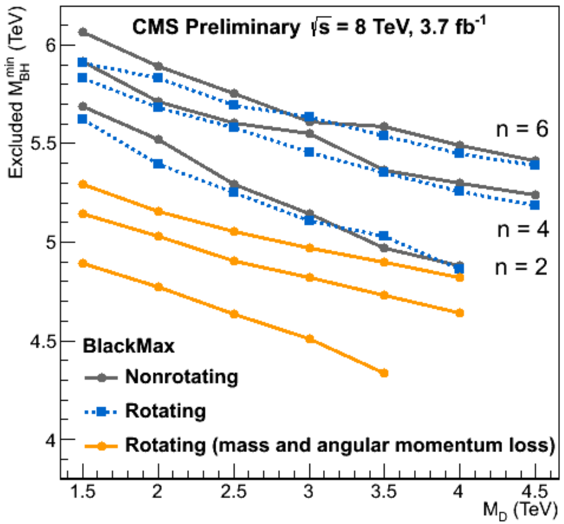


- Main background, QCD multijets, determined from data
  - Based on phenomenological observation that the shape of S_T is independent of the final-state multiplicity
  - Shape determined from fit to S_T in signal-free region (N=2)
  - Background normalization determined for each multiplicity bin separately in signal-free range $1800<S_T<2200$ GeV
- Data consistent with background-only prediction → No evidence for production of microscopic black holes

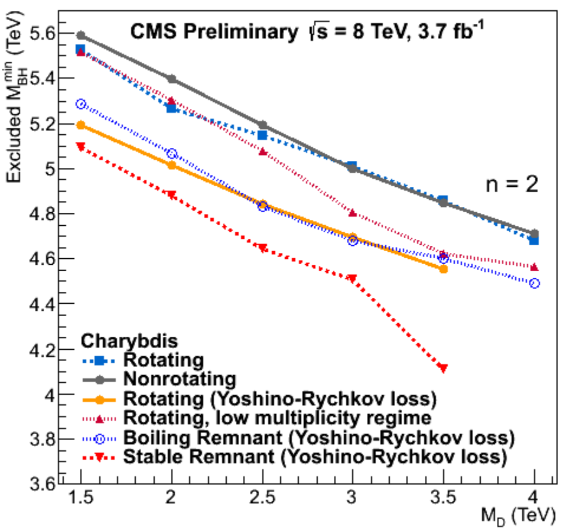


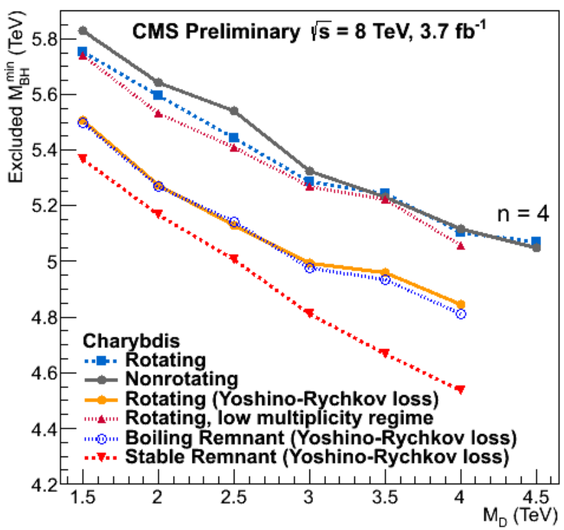
Microscopic Black Holes (cont'd)

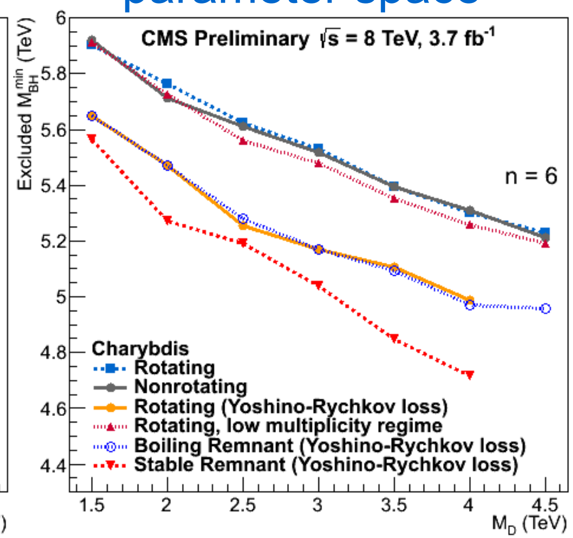




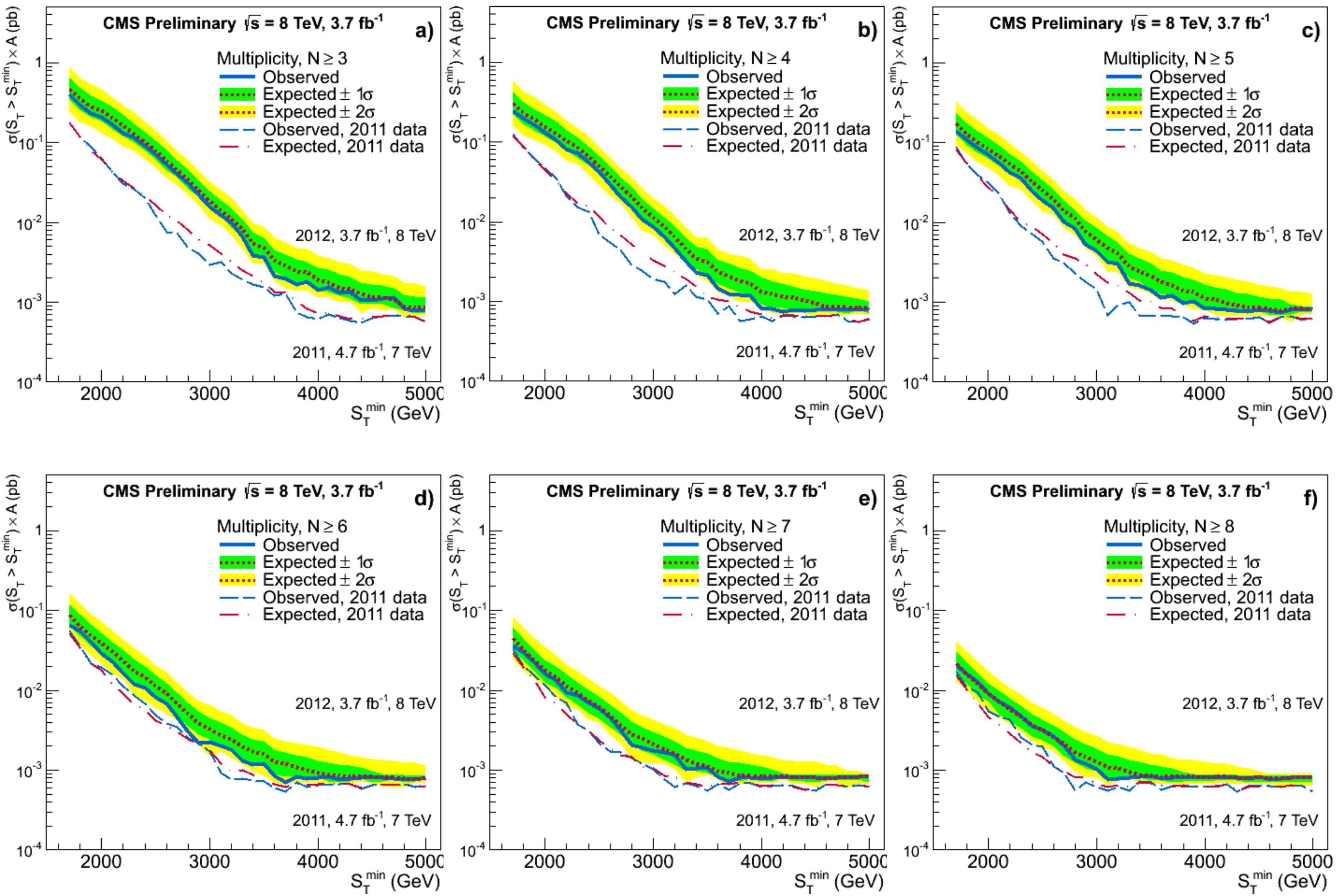
- Model-specific limits set on the parameters of the ADD model
  - Production of semiclassical black holes with the minimum mass from 4.1 to 6.1 TeV for $M_D \leq 4.5$ TeV and $n \leq 6$ excluded at 95% CL (these limits extend those from 2011 data)
- BH production and decay patterns have a significant model dependence → Impractical to scan the entire parameter space







Microscopic Black Holes (cont'd)

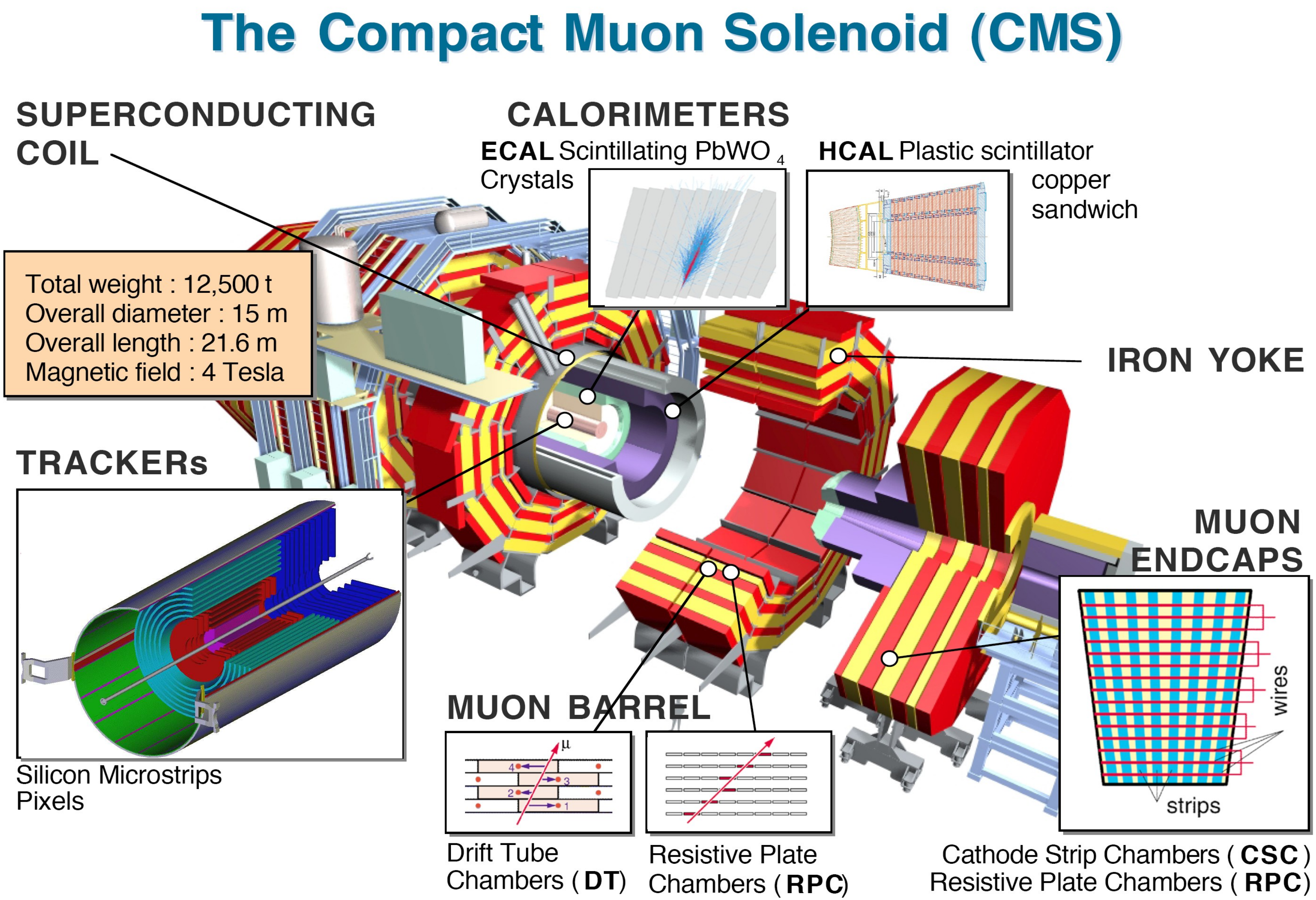


Generic, model-independent limits

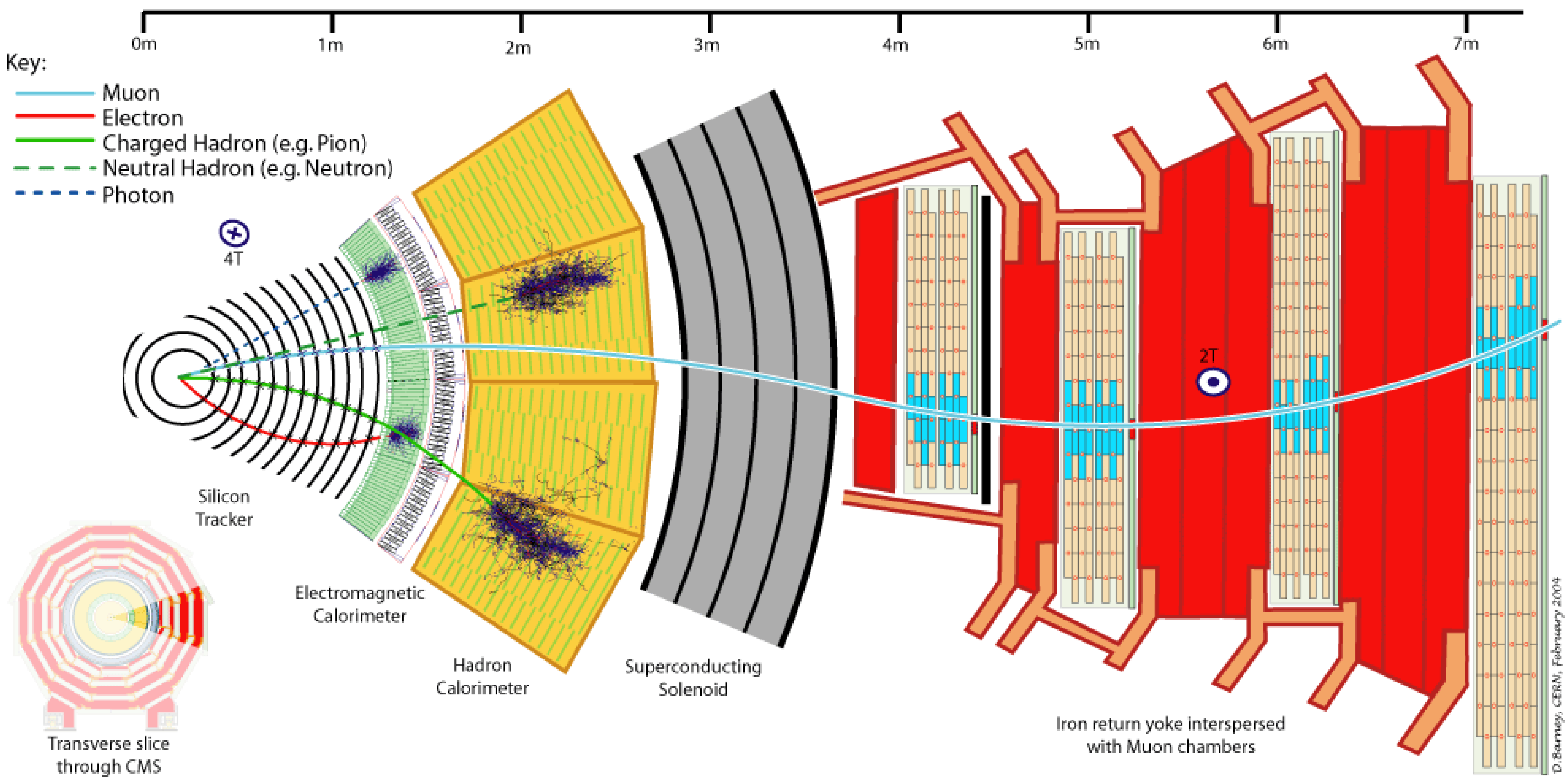
Summary and Outlook

- Hadronic final states are a fertile environment for searches for new physics
- CMS has a rich program of searches in hadronic final states
- So far, no significant deviations from SM predictions found → Stringent limits set on several benchmark models of new physics (some of the set limits are model-independent)
- Focus steadily switching from 7 TeV to 8 TeV data
  - Early 8 TeV analyses produce more stringent limits with less data than 7 TeV analyses (due to increased production cross sections)
  - At the end of 2012 run, expect at least 3 times more data (probably more) than in 2011
- All approved results and documentation linked from: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

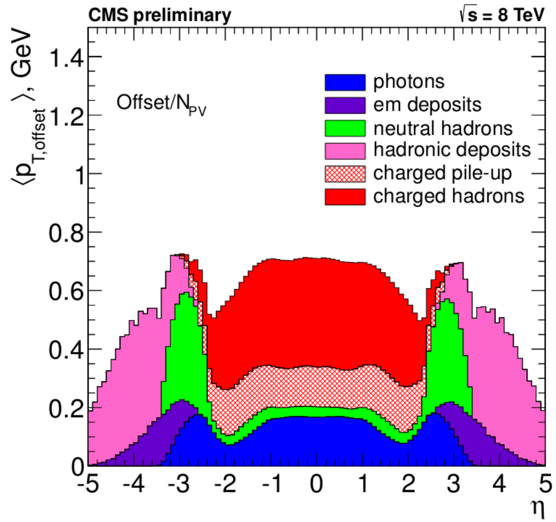
Backup Slides

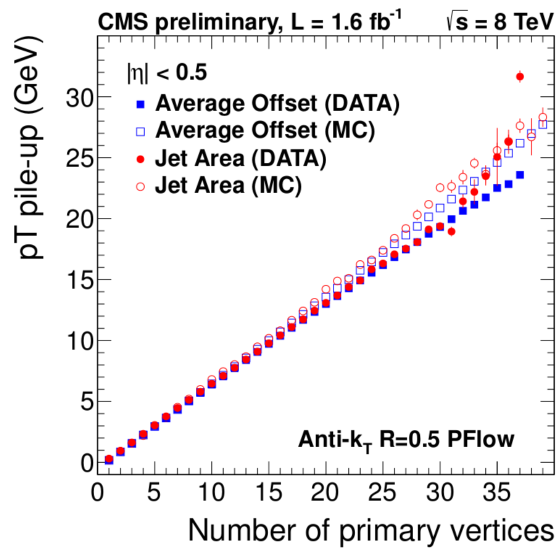

The Compact Muon Solenoid (CMS)
SUPERCONDUCTING COIL
CALORIMETERS
ECAL Scintillating PbWO4 Crystals
HCAL Plastic scintillator copper sandwich
Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla
IRON YOKE
TRACKERs
Silicon Microstrips
Pixels
MUON ENDCAPS
wires
strips
MUON BARREL
Drift Tube Chambers (DT)
Resistive Plate Chambers (RPC)
Cathode Strip Chambers (CSC)
Resistive Plate Chambers (RPC)

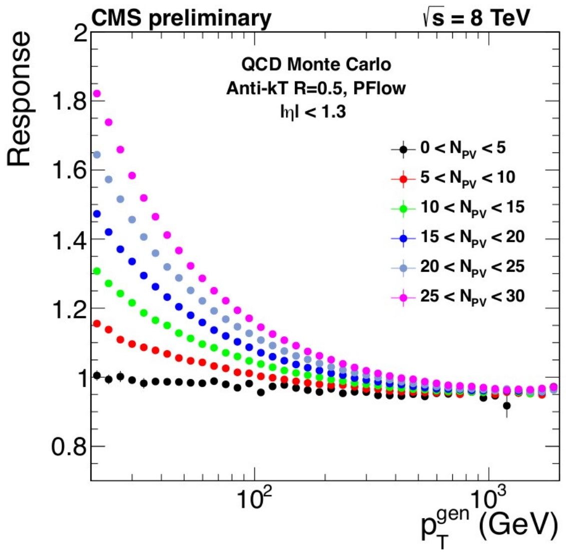
CMS Detector

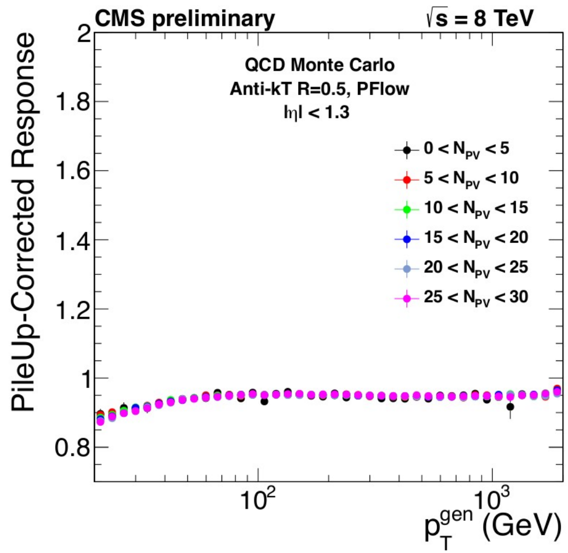


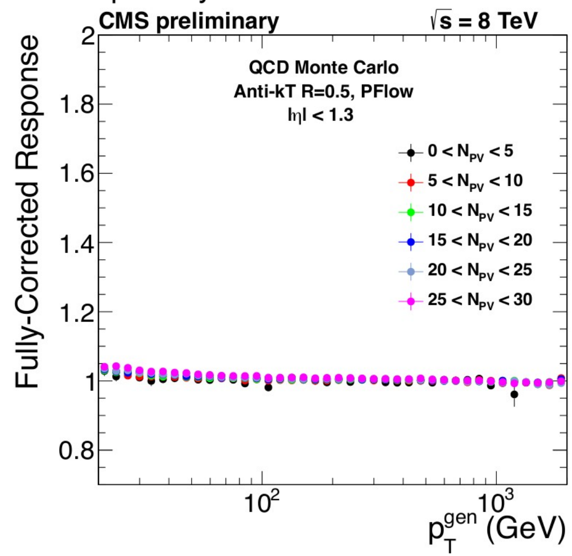
Jet Reconstruction in CMS



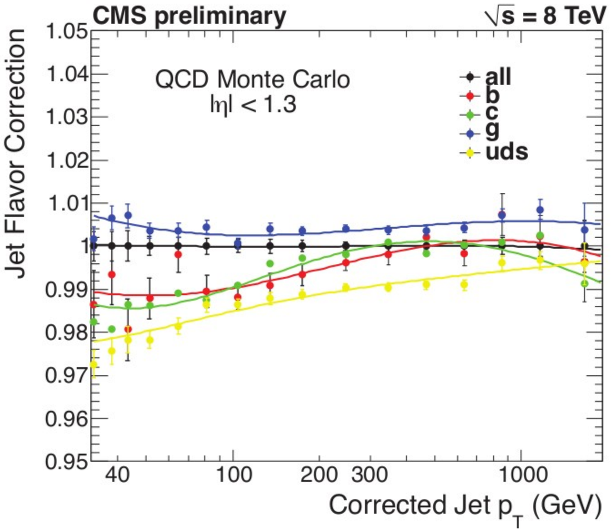


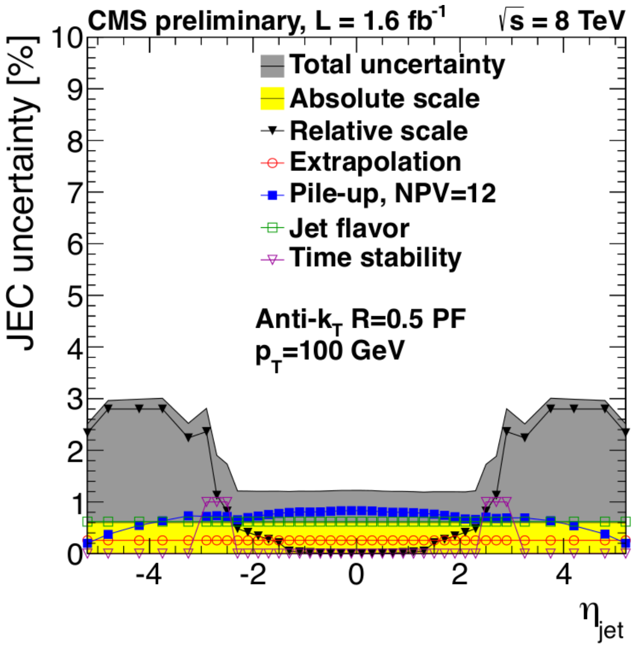


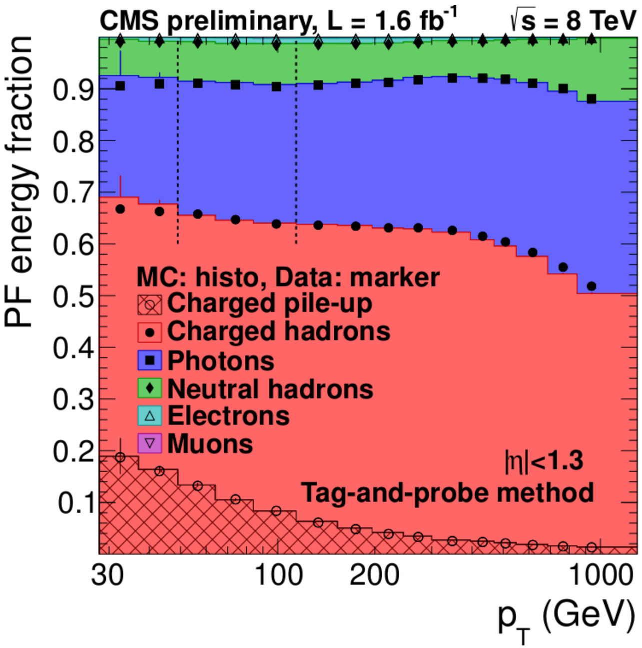




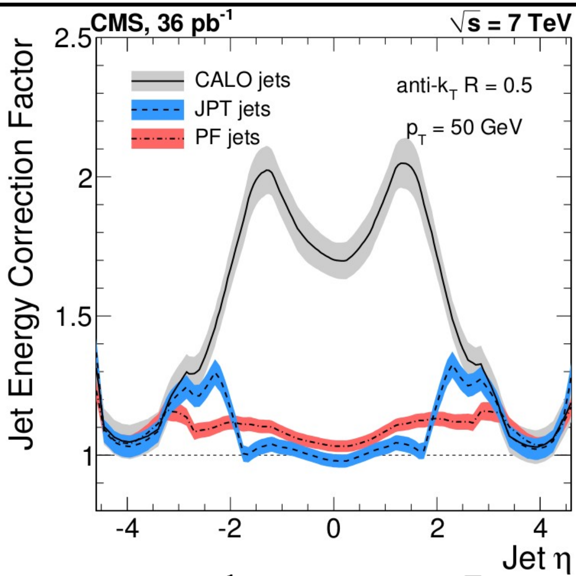
Jet Reconstruction in CMS (cont'd)

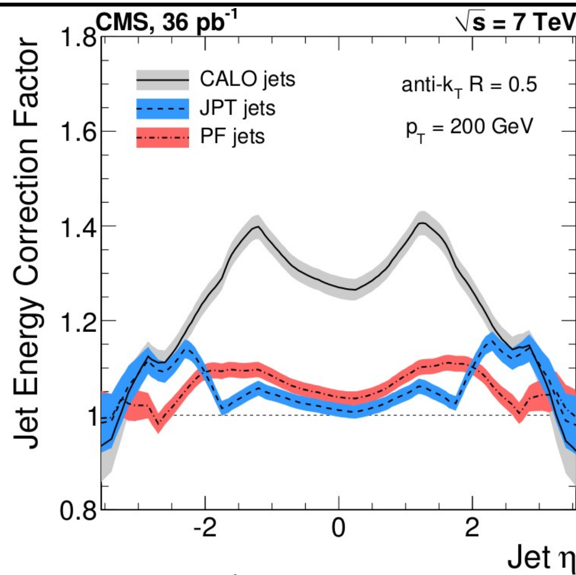






Jet Energy Corrections





$$p_{\mu}^{\rm cor} = \mathcal{C} \cdot p_{\mu}^{\rm raw}$$

$$\mathcal{C} = C_{\rm offset}(p_{\rm T}^{\rm raw}) \cdot C_{\rm MC}(p'_{\rm T}, \eta) \cdot C_{\rm rel}(\eta) \cdot C_{\rm abs}(p''_{\rm T})$$

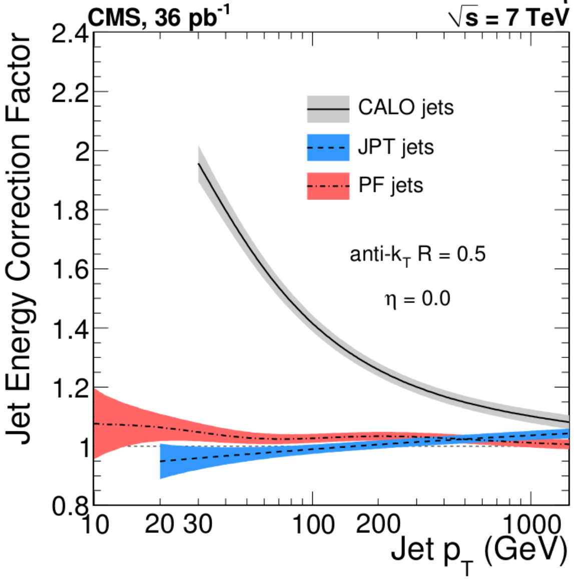
$\mathcal{C}$ - Overall correction factor

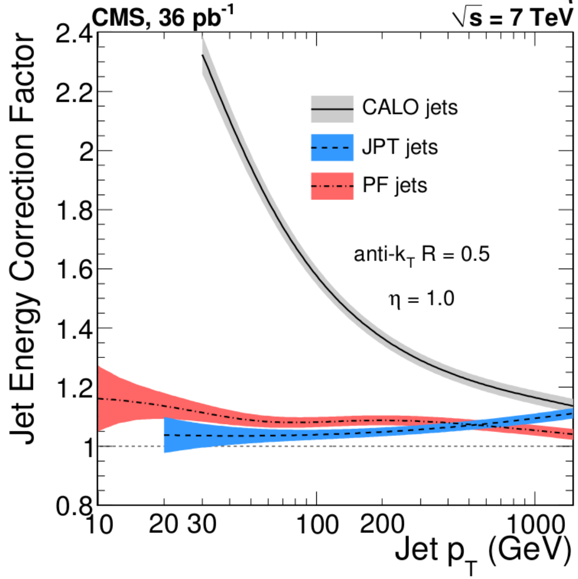
$C_{\rm offset}$ - Offset correction factor

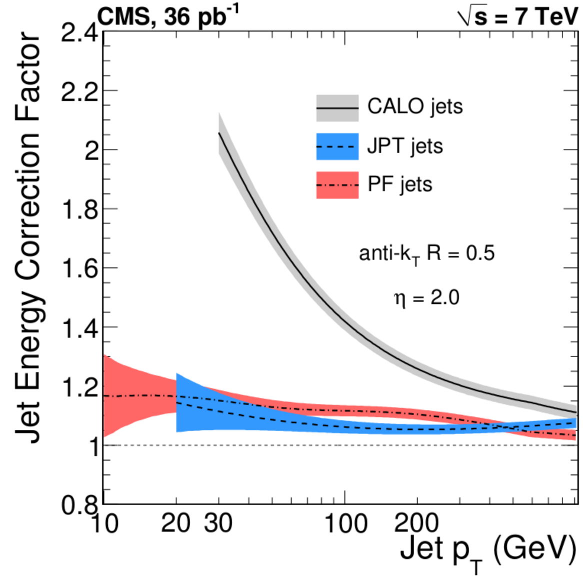
$C_{\rm MC}$ - MC calibration factor

$C_{\rm rel}$ - Residual relative calibration factor

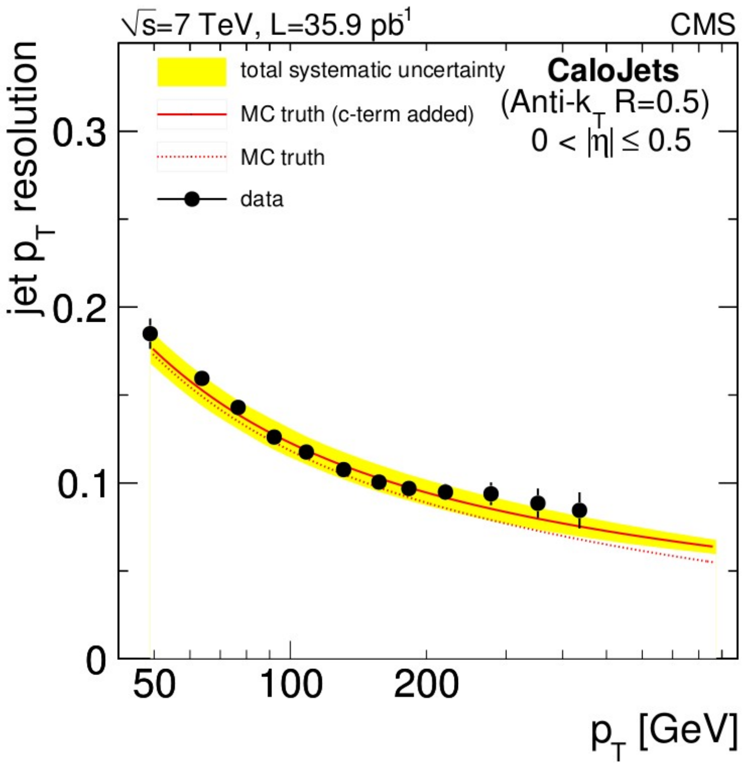
$C_{\rm abs}$ - Residual absolute calibration factor

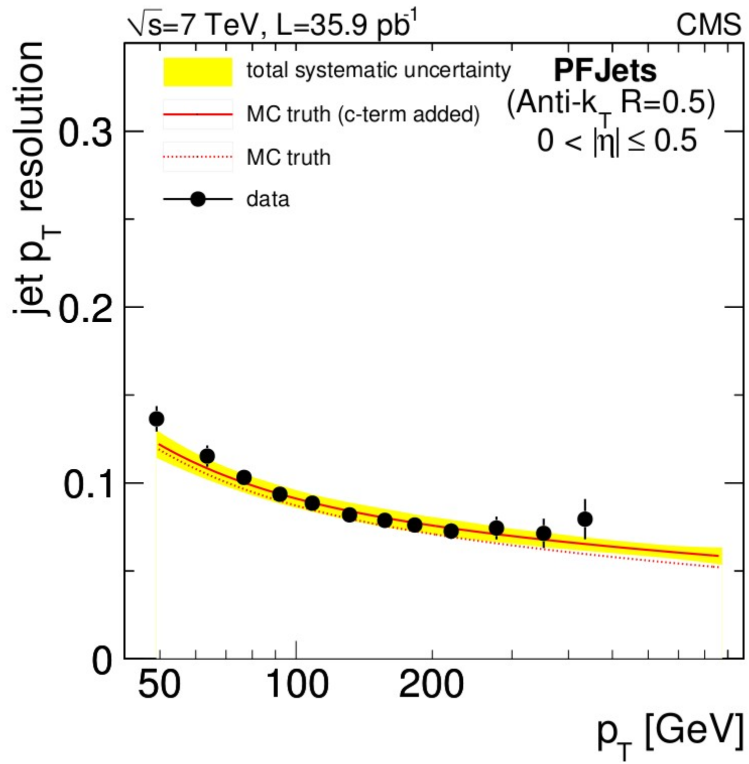






Jet p_T Resolution





$$\frac{\sigma(p_T)}{p_T} = \sqrt{\mathrm{sgn}(N) \cdot \left(\frac{N}{p_T}\right)^2 + S^2 \cdot p_T^{(M-1)} + C^2}$$

N - Noise term

S - Stochastic term

C - Constant term

Dijet Resonances

Properties of some resonance models

Model Name	X	Color	J^P	$\Gamma/(2M)$	Chan
Excited Quark	q^*	Triplet	$1/2^+$	0.02	qg
E_6 Diquark	D	Triplet	0^+	0.004	qq
Axigluon	A	Octet	1^+	0.05	$q\bar{q}$
Coloron	C	Octet	1^-	0.05	$q\bar{q}$
RS Graviton	G	Singlet	2^+	0.01	$q\bar{q}$, gg
Heavy W	W′	Singlet	1^-	0.01	$q\bar{q}$
Heavy Z	Z′	Singlet	1^-	0.01	$q\bar{q}$
String	S	mixed	mixed	0.003 – 0.037	qg, $q\bar{q}$, gg

$F(\cos\theta^*) \equiv d\hat{\sigma}/d\cos\theta^*$

arXiv:1110.5302

- *E_6 diquark, color octet scalars:* $F(\cos\theta^*) = \text{const.}$
- *excited quark:* $F(\cos\theta^*) \sim 1 + \cos\theta^*$, which becomes $F(|\cos\theta^*|) = \text{const.}$ (odd in $\cos\theta^*$).
- *axigluon, coloron, W', Z':* $F(\cos\theta^*) \sim 1 + \cos^2\theta^*$.
- *RS gravitons:* $F(gg \to G \to q\bar{q}) = F(q\bar{q} \to G \to gg) \sim 1 - \cos^4\theta^*$, $F(gg \to G \to gg) \sim 1 + 6\cos^2\theta^* + \cos^4\theta^*$, and $F(q\bar{q} \to G \to q\bar{q}) \sim 1 - 3\cos^2\theta^* + 4\cos^4\theta^*$

CMS dijet mass resolution (wide jets):

qq :

$$\frac{\sigma}{M} = \frac{1.31}{\sqrt{M[GeV]}} + 0.018$$

$\approx 8\%\,(M = 0.5\text{ TeV}), \approx 4\%\,(M = 2.5\text{ TeV})$

qg :

$$\frac{\sigma}{M} = \frac{1.56}{\sqrt{M[GeV]}} + 0.027$$

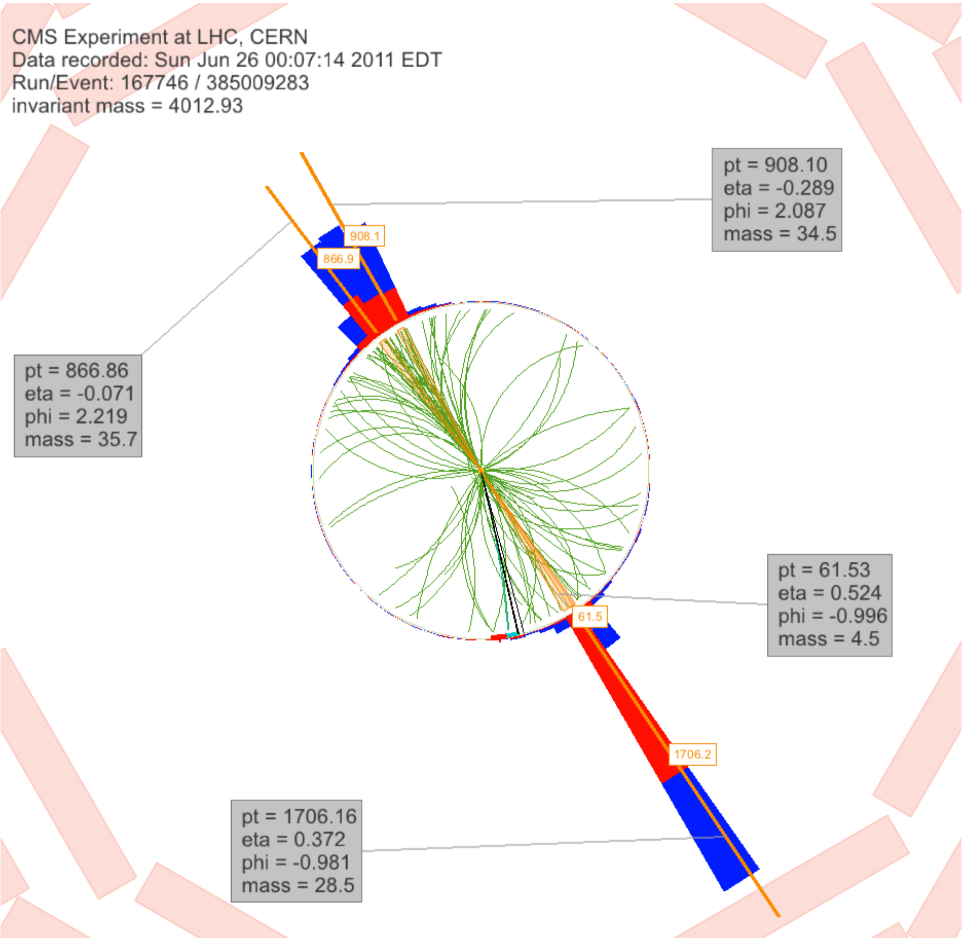
$\approx 10\%\,(M = 0.5\text{ TeV}), \approx 6\%\,(M = 2.5\text{ TeV})$

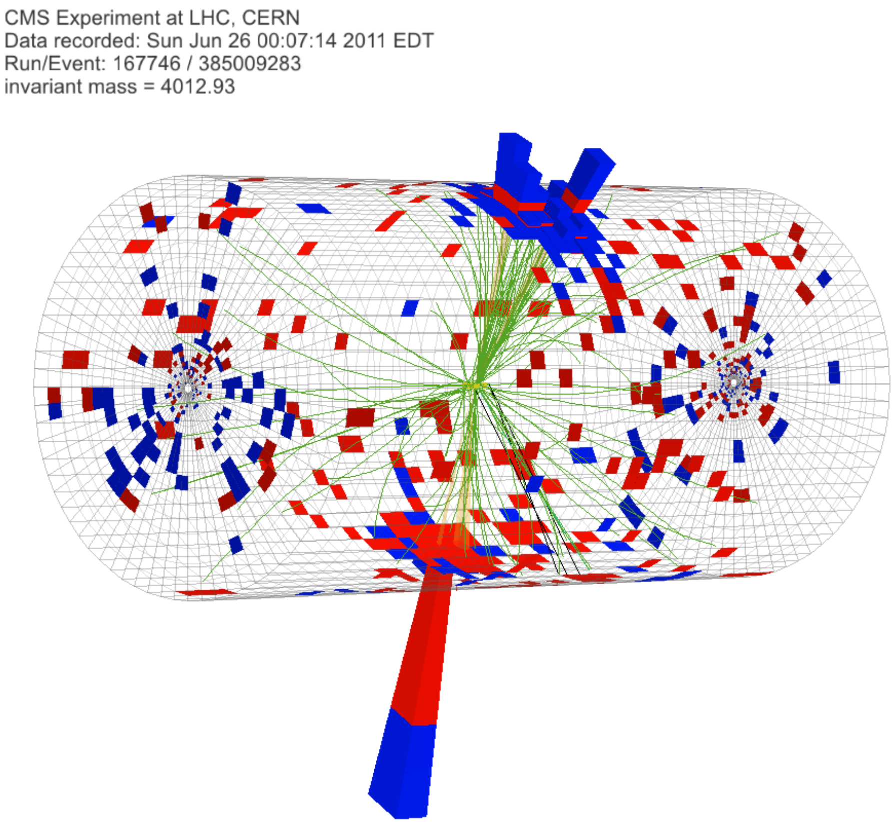
gg :

$$\frac{\sigma}{M} = \frac{2.09}{\sqrt{M[GeV]}} + 0.015$$

$\approx 11\%\,(M = 0.5\text{ TeV}), \approx 6\%\,(M = 2.5\text{ TeV})$

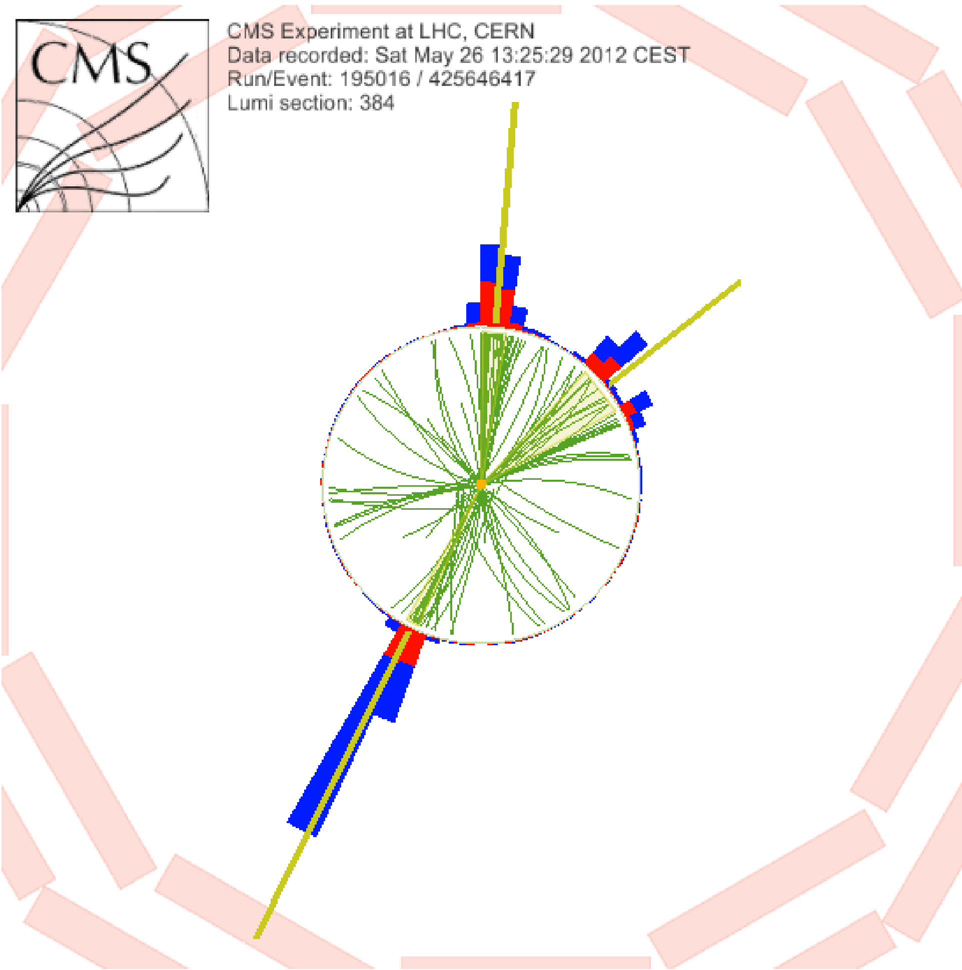
Dijet Resonances (2011)

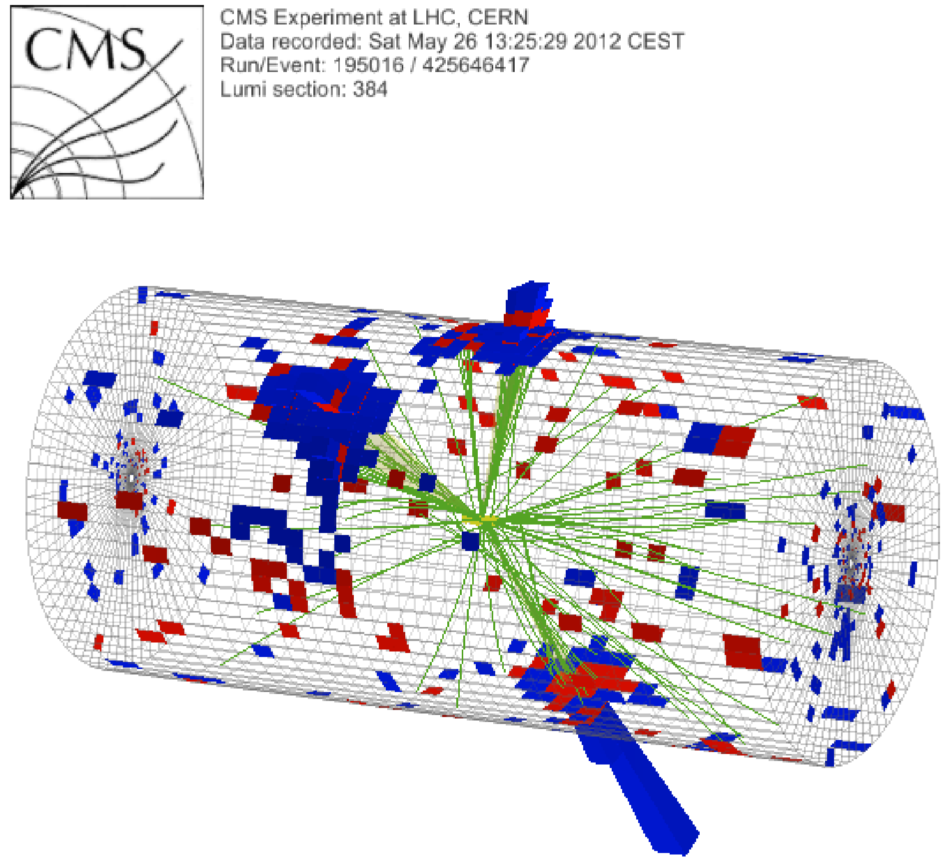




Highest dijet mass event (~4 TeV)

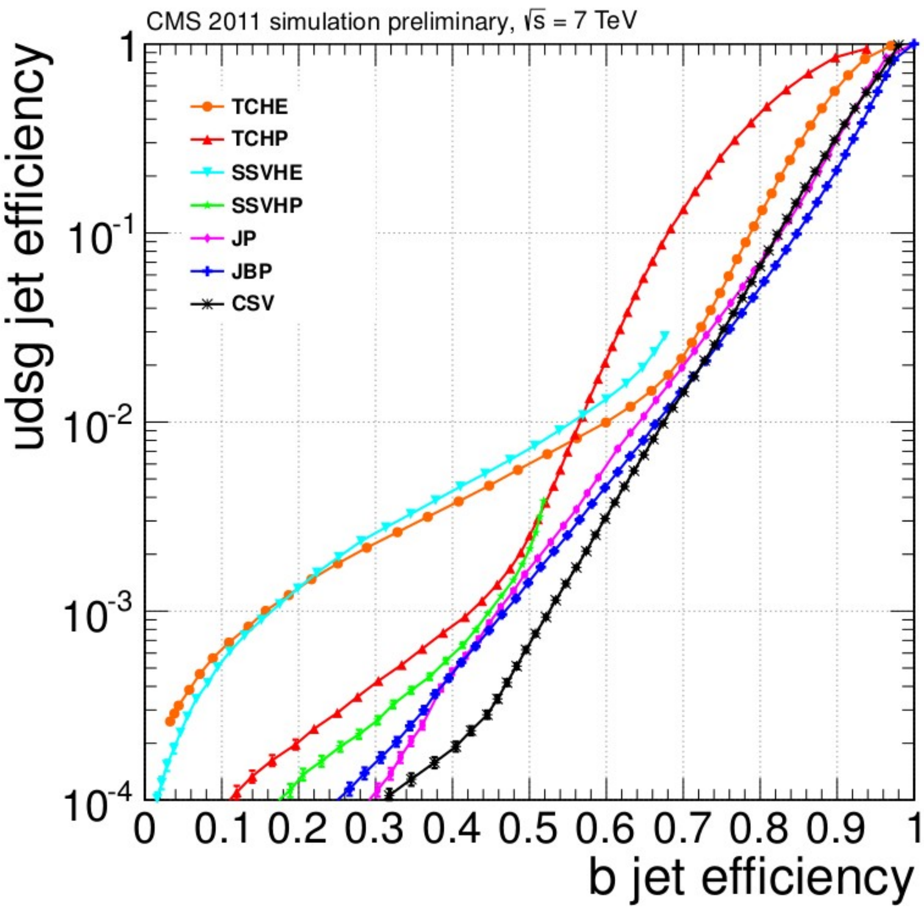
Dijet Resonances (2012)

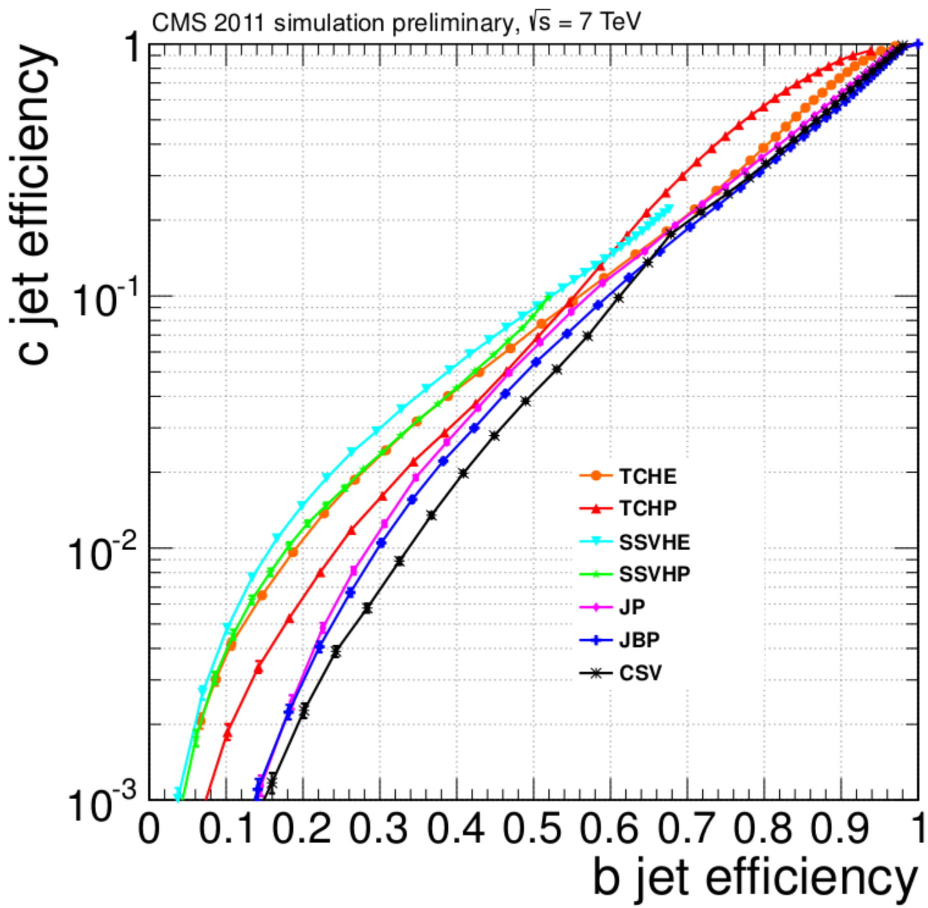




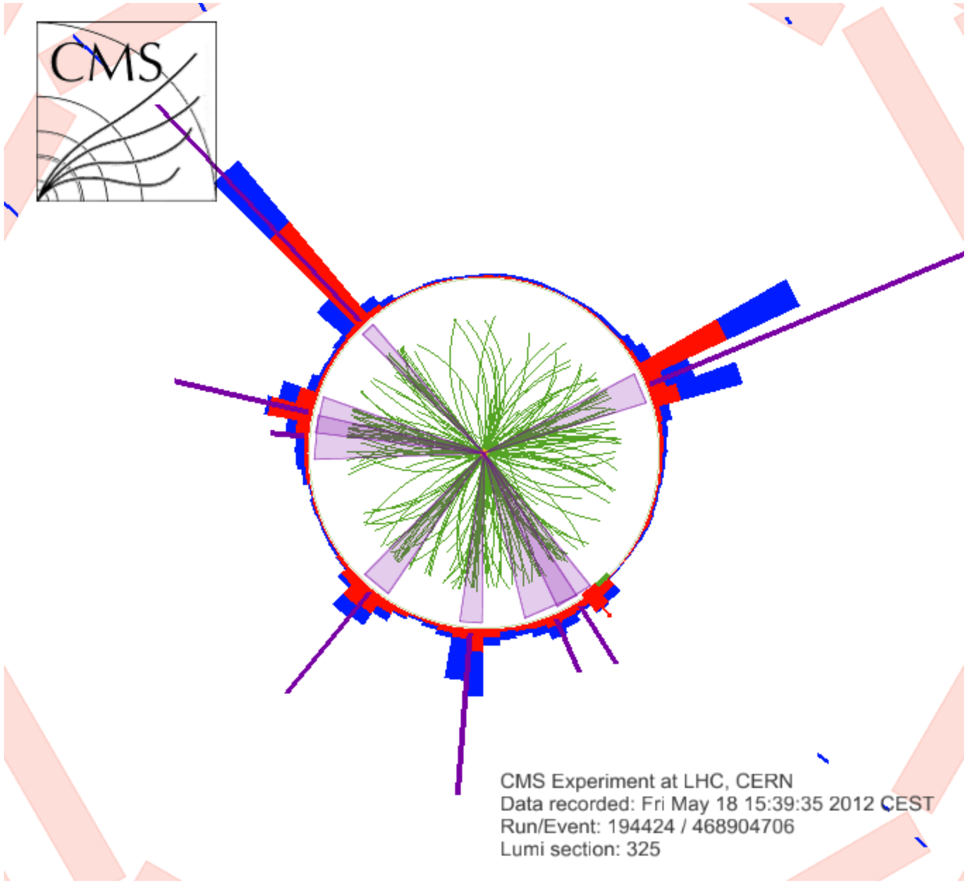
Highest dijet mass event (~4.5 TeV)

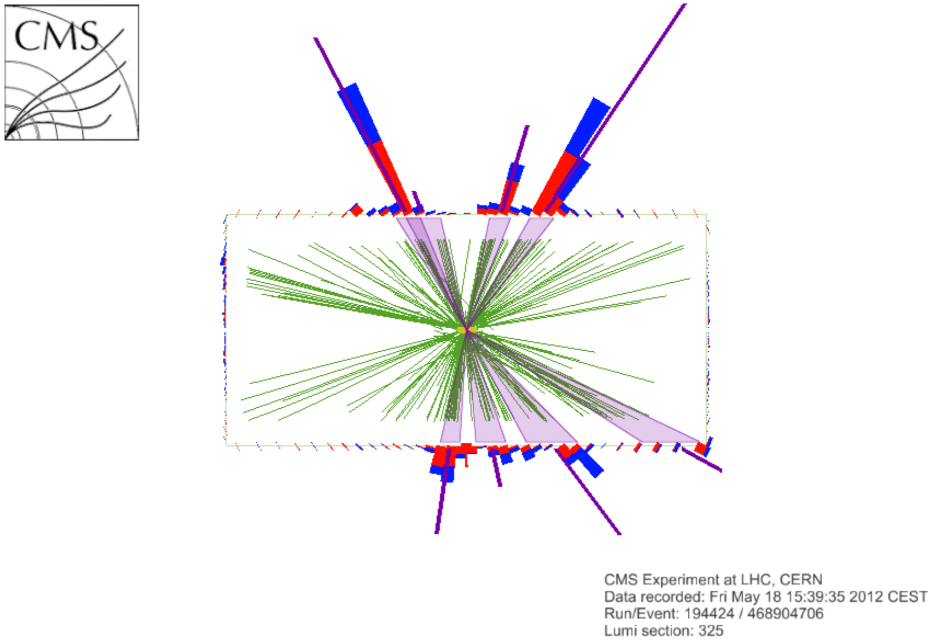
b-tagging Algorithms in CMS





Microscopic Black Holes





8-jet event (S_T=3 TeV)