Maxime Gouzevitch

Search for Hadronic Resonances in CMS

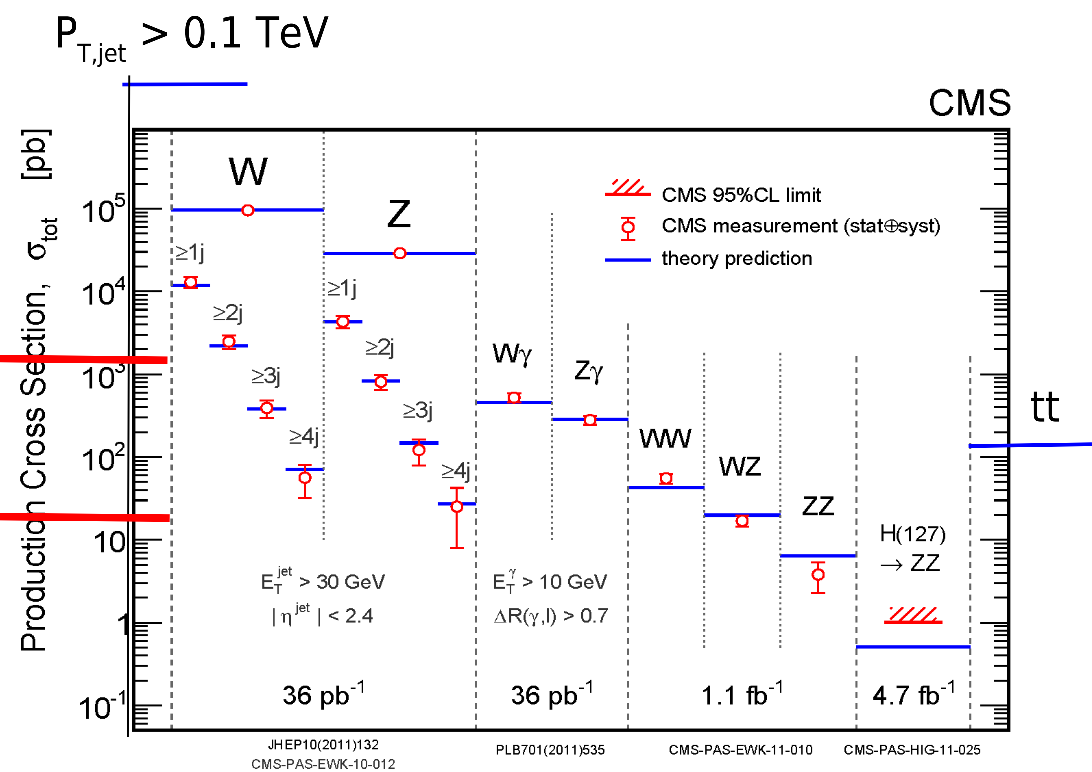
(On behalf of the CMS collaboration)

1) General scope.
2) S-channel searches.
3) New trigger strategies for low mass regime.
4) General concepts of the paired production.
5) Boosted production and substructure.
6) Paired production at rest.
7) Pushing toward high multiplicities.

0.1) Classes of models we are looking for

« QCD like » models :
Axigluon (0.6 TeV)

« EW like » models :
W' (0.6 TeV)



- "QCD like" models: q*, Axigluon, Colorons, s8, E6 Diquarks, Hyperpions...

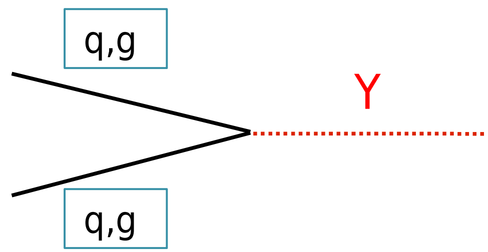
- "EW like" models : W', Z'...

- RS Gravitons.

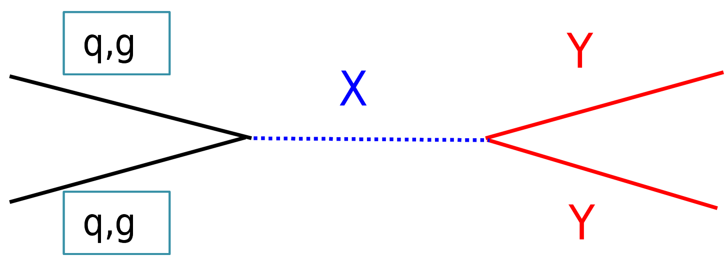
0.2) Channels to be considered

- We look for heavy resonances in the tails of SM in the narrow width approximation (Width << Jet resolution).
- Single production: mainly S-channel, "easy to explore" when possible.
- Paired production: if a conservation law forbids S-channel or S-channel already explored: paired production used. Less background but usually low production cross section.

S-channel production

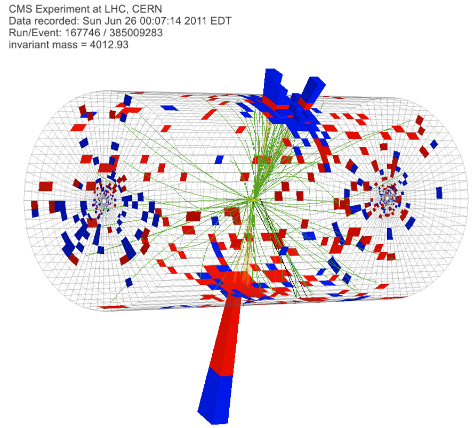


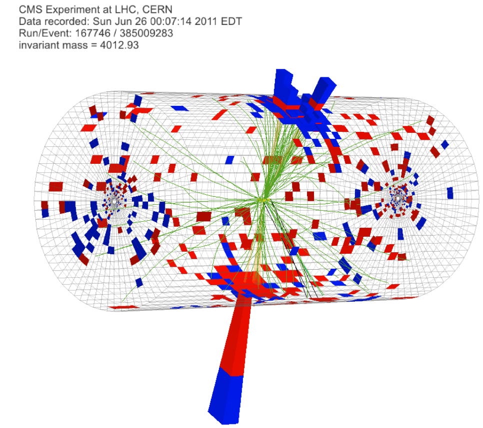
Paired production



Y : new resonance

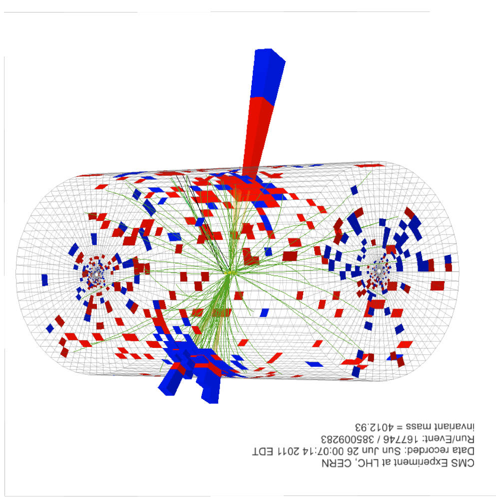
X: new boson or gluon

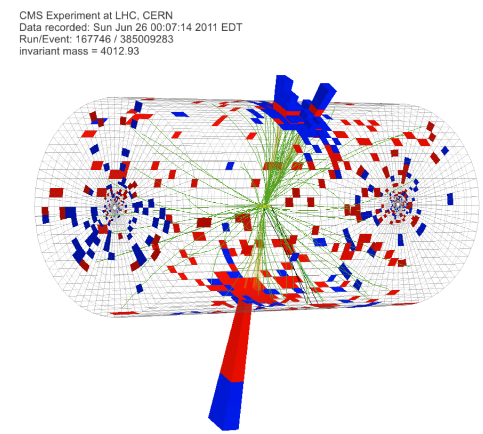




I

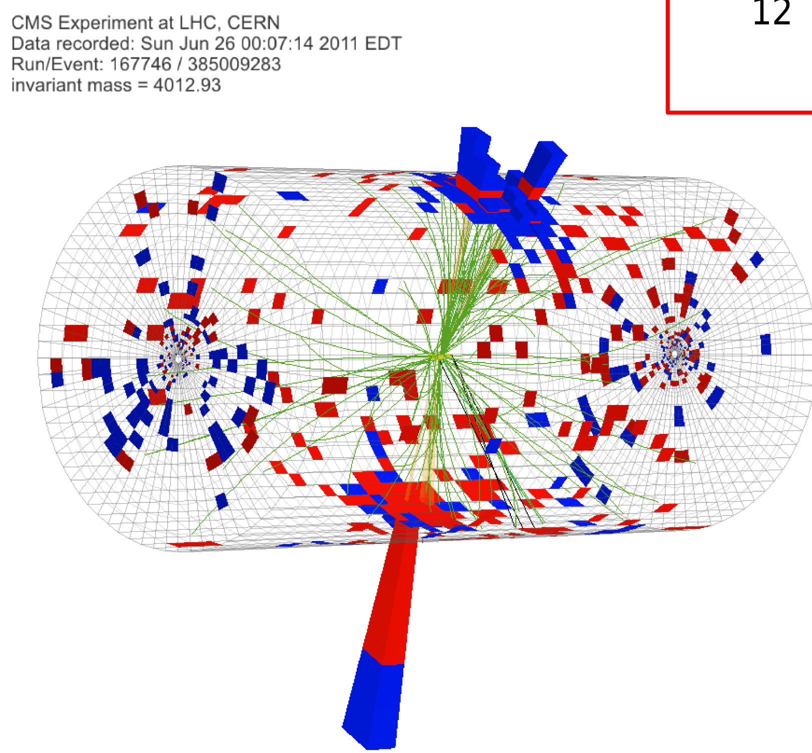
S-channel searches





1.1) S-channel dijet production

M_{12} = 4 TeV
2011

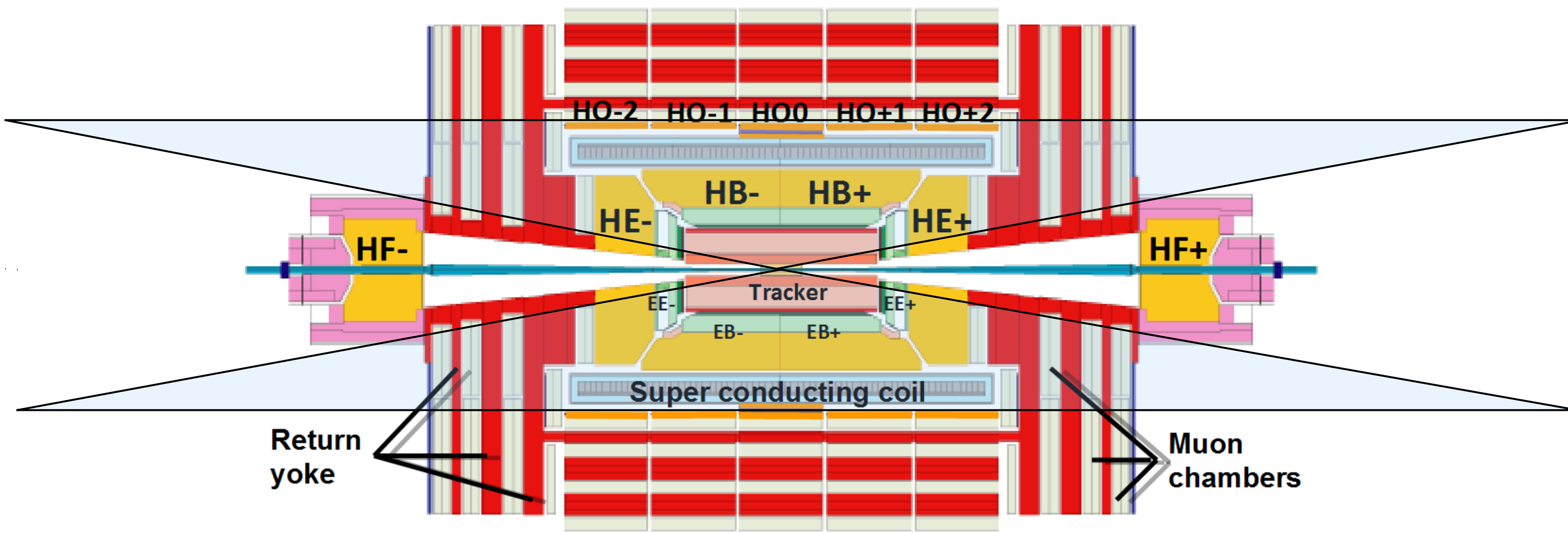


Let's say a few words about the jet reconstruction and explain why:

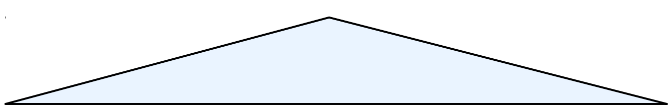
- Jet Energy Scale is known to 1-2%
- How we manage to mitigate the Pile-Up even with 30 PU events.

1.2) Jets reconstruction: Particle Flow algorithm

CMS Calorimeter (ECAL+HCAL) - Very hermetic (>10λ in all η, no projective gap)

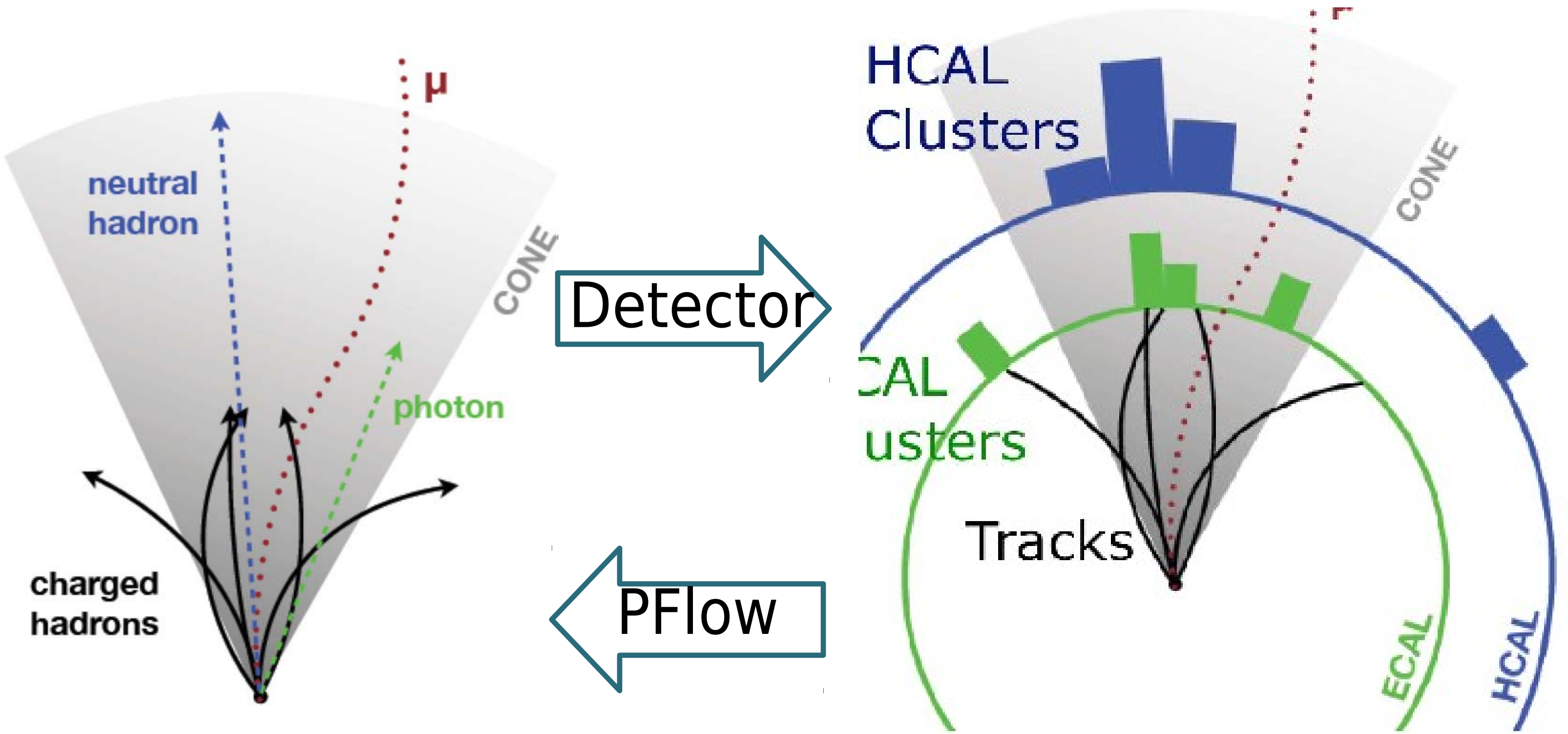


HB Brass Absorber (5cm) + Scintillator Tiles (3.7mm) Photo Detector (HPD) |η| 0.0 ~ 1.4
HE Brass Absorber (8cm) + Scintillator Tiles (3.7mm) Photo Detector (HPD) |η| 1.3 ~ 3.0
HO Scintillator Tile (10mm) *outside of solenoid* Photo Detector (HPD) |η| 0.0 ~ 1.3
HF Iron Absorber + Quartz Fibers Photo Detector (PMT) |η| 2.9 ~ 5.2



Tracker acceptance : $|\eta| < 2.5$
Zone interesting for exotic searches

1.3) Global event description approach (Particle Flow)

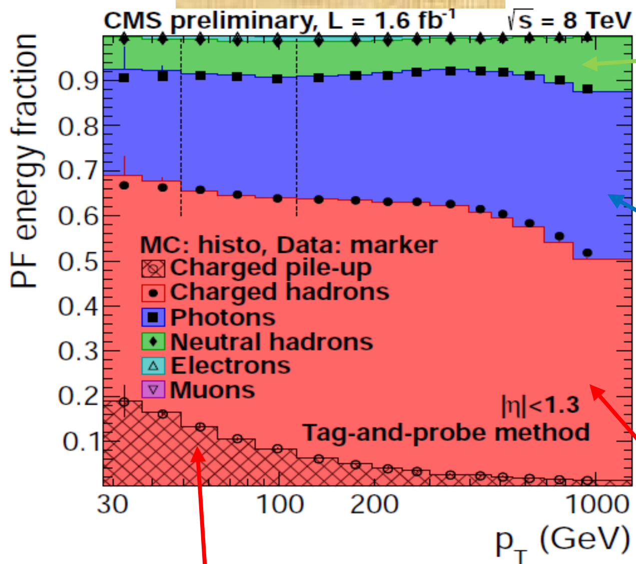


Particles

Clusters and tracks

1.3) Global event description approach (Particle Flow)

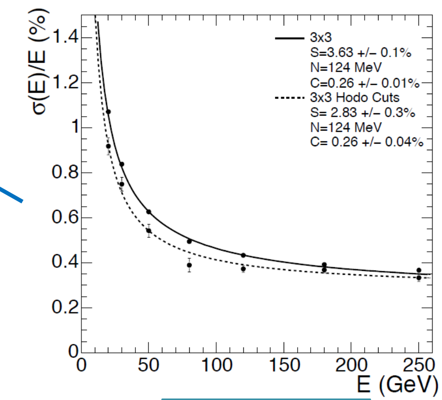
DP-2012/012



HCAL:
$120\%/\sqrt{E} + 6.9\%$

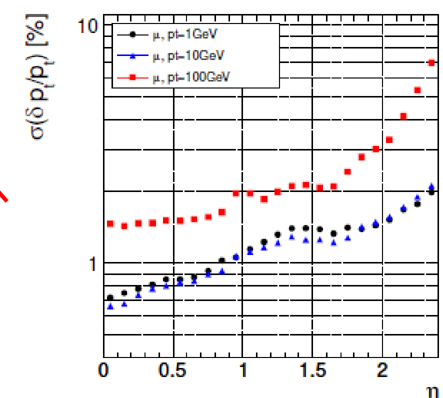
Precise

ECAL



Precise

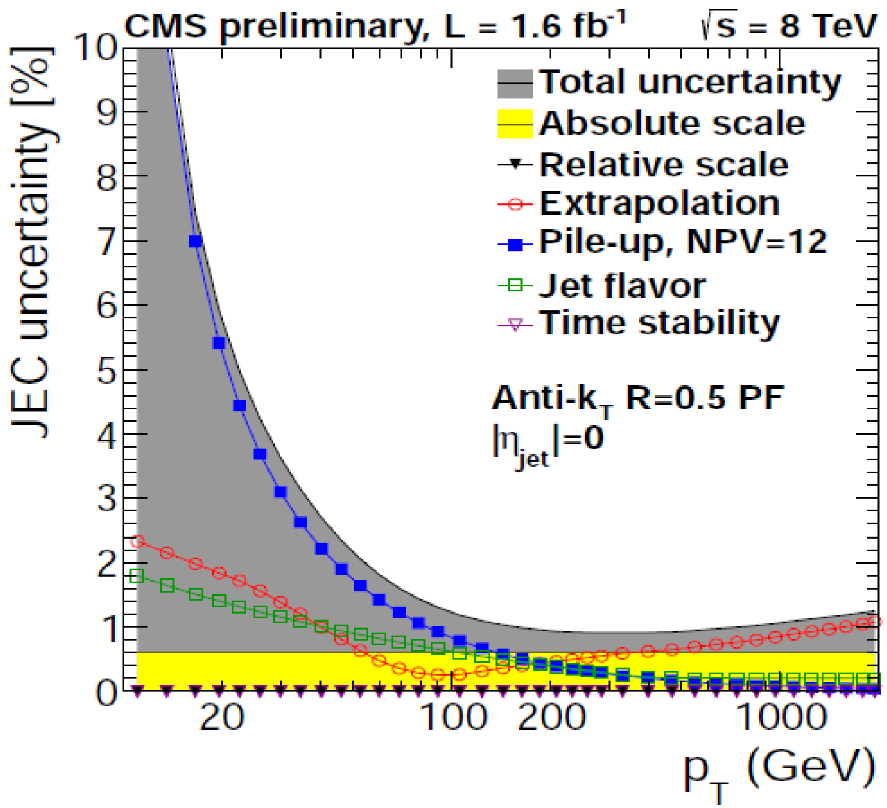
Tracker



- 60% of PU mitigation using charged hadrons attached to secondary tracks.
- Remaining mitigation using jet area.

1.4) Jet energy scale uncertainty

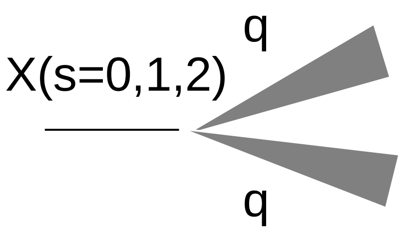
DP-2012/012

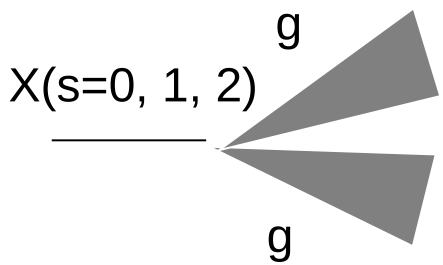


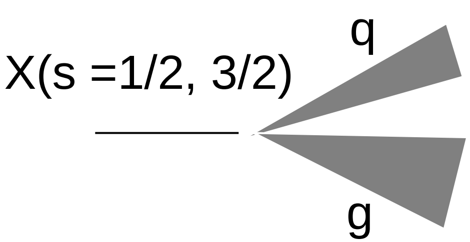
Jet Energy Scale uncertainty is the systematic to remember

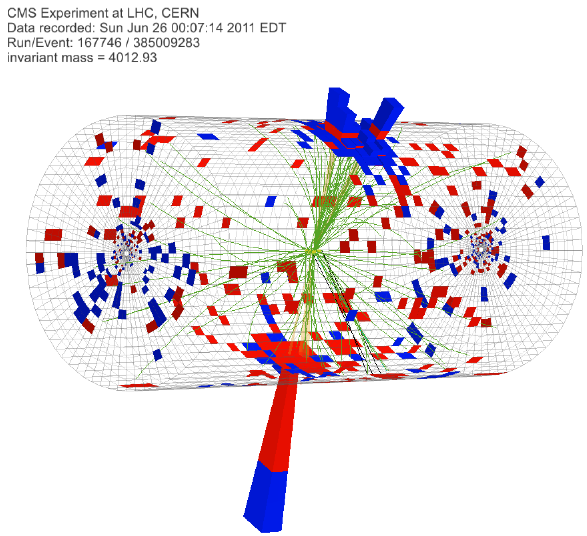
- The exact knowledge of the Jet Energy Scale is good: ~2%.
- But due to quickly falling QCD spectra induce lots of migrations: systematics ~10-20% on the excluded cross sections.

1.5) S-channel dijet production





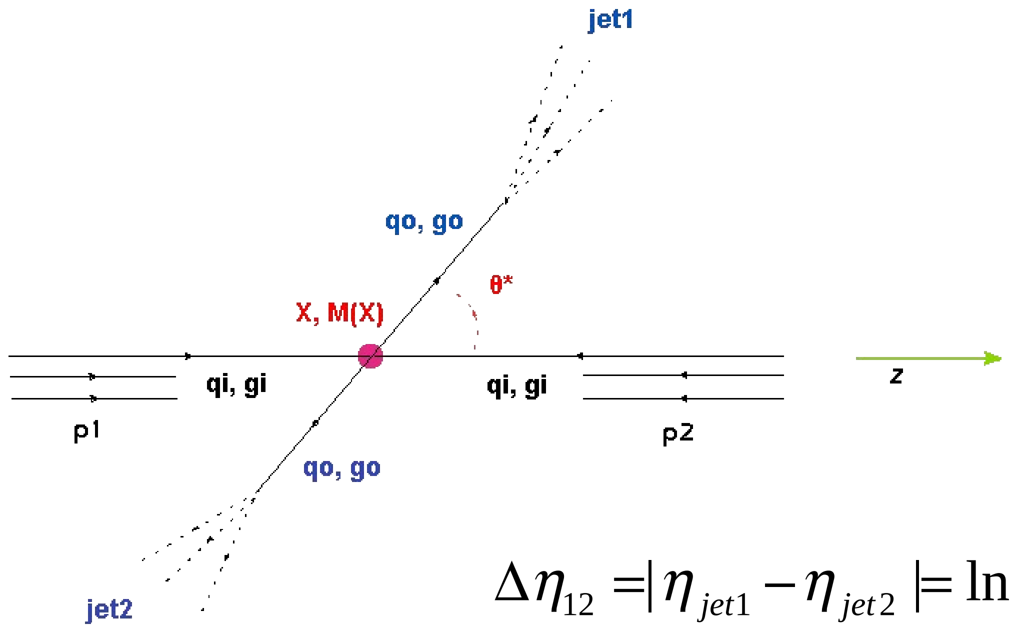




- The first observable to considered with new data:
    - Simple phase space.
    - Jets are easy to identify: localized flux of any number particles.
    - Minimal requirements to remove calorimetric noise.
- QCD jets production background for all others channels.
- Looking mainly for strongly coupling models with large cross section expected.

1.6) The phase-space: Di-jet kinematics.

Final state described by 2 variables



$$M_X = M_{12}$$

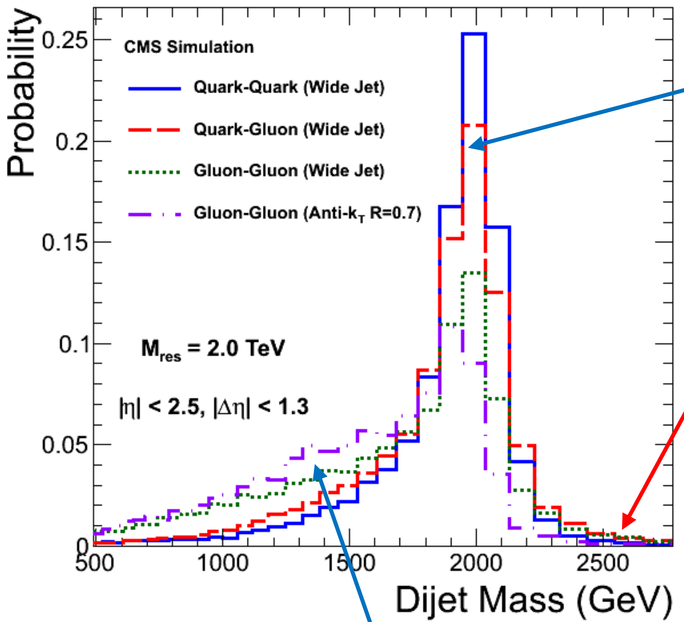
$$\Delta\eta_{12} = |\eta_{jet1} - \eta_{jet2}| = \ln \frac{1 + |\cos\theta^*|}{1 - |\cos\theta^*|}$$

- Mass of X estimated out of 2-jets invariant mass.

- θ* angle in X rest frame wrt to pp axis measured out of 2-jets $\Delta\eta_{12}$.
- Distribution dependent of X spin.

- <u>Resonance search</u>:
  coarse binning in $\Delta\eta_{12}$, fine binning in M_{12}.
- <u>Contact Interaction search</u>:
  fine binning in $x=\exp(\Delta\eta_{12})$, coarse binning in M_{12}.

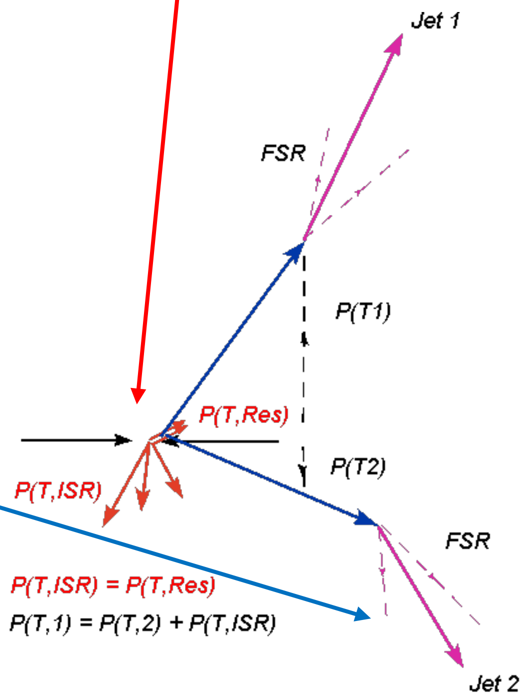
1.7) Search for heavy resonances



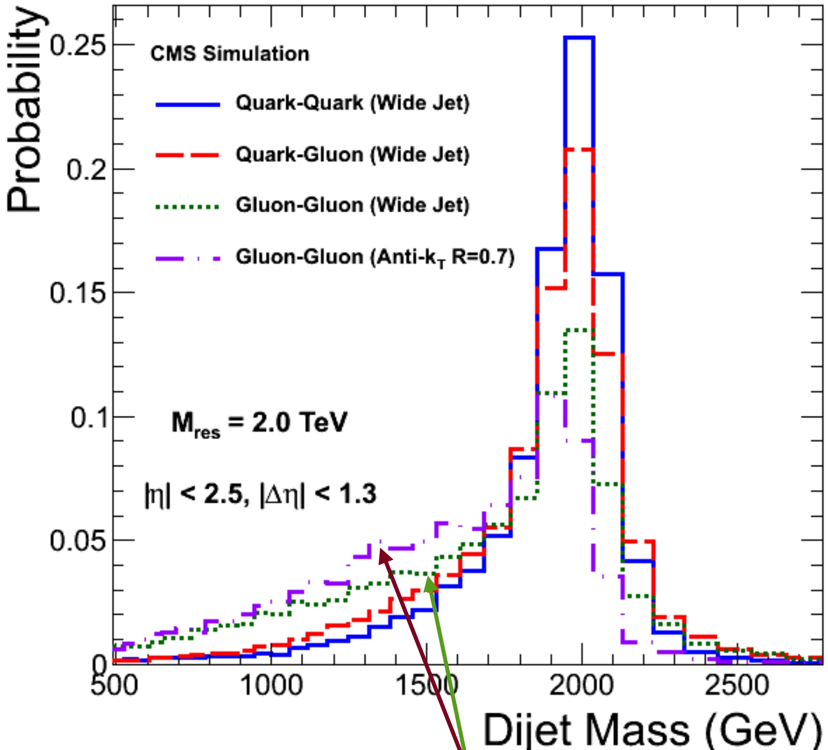
- Narrow width approximation (< 10%).
- Dijet mass resolution: 5-10%.

High mass tail: catch ISR

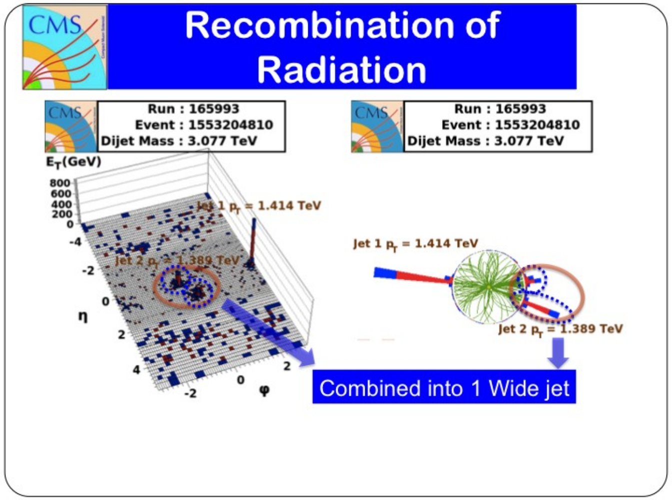
Low mass tail:
- increasing PDF luminosity.
- loss due to the FSR especially for gluons.

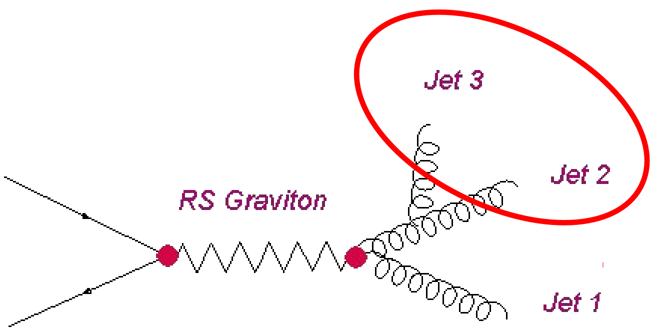


1.8) Search for heavy resonances



Effect of
Wide jets on the tail

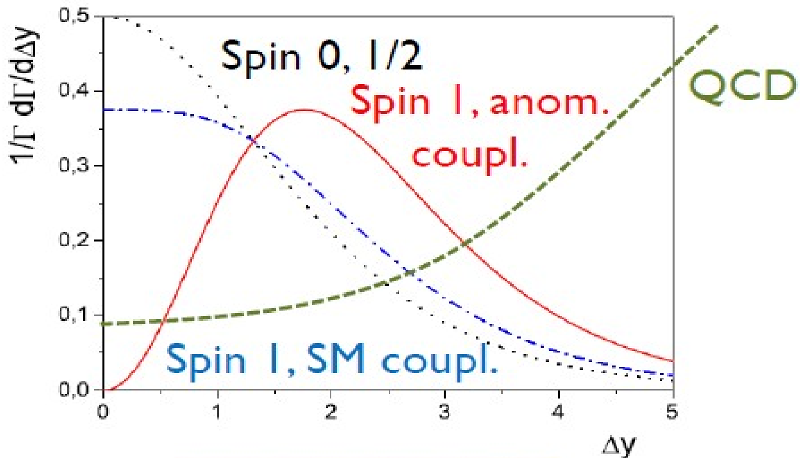




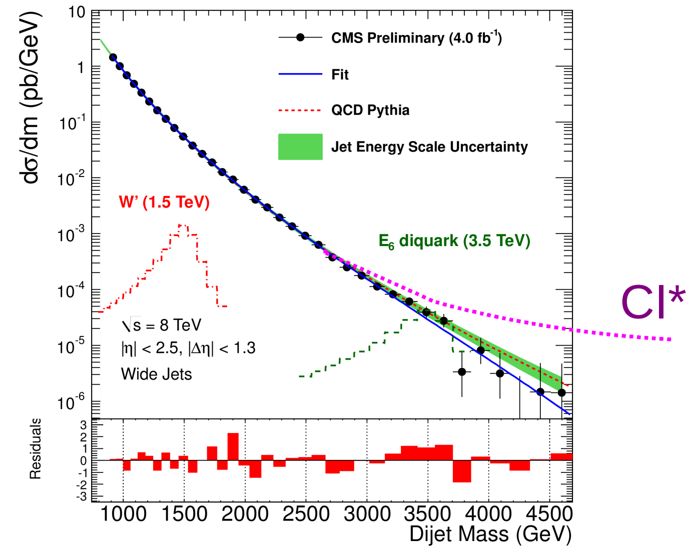
- We developed a specific “FSR recovery” algorithm: Wide jets.
  - Take 2 calibrated leading jets (anti-k_T) R = 0.5.
  - Collect calibrated jets with p_T > 30 GeV with R = 1.1.
  - Improve the signal shape reconstruction but increase background.

1.9) Dijet searches

EXO-12-016 : 2012



arXiv:1010.2648



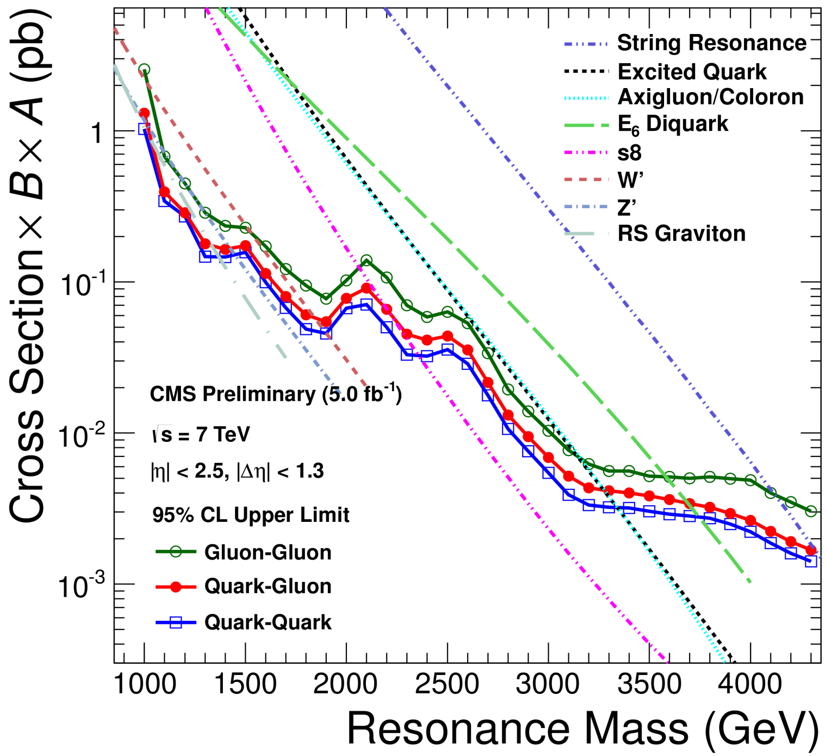
* The line shape driven is for constructive interference QCD and CI.

- Phase-space : M_{min} > 838 GeV (trigger) && $\Delta\eta_{12} < 1.3$ (topology)
- QCD background only matters. Two strategies :
  - Fully data driven : CTEQ inspired parametric functions

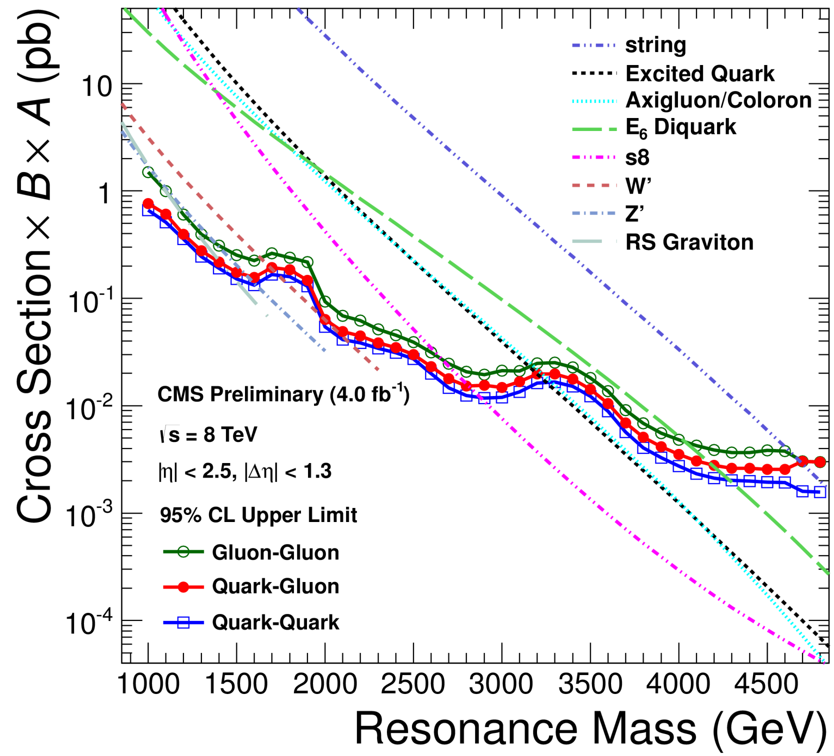
$$\frac{d\sigma}{dm} = \frac{P_0(1 - m/\sqrt{s})^{P_1}}{(m/\sqrt{s})^{P_2 + P_3 \ln(m/\sqrt{s})}}$$

  - Using our QCD knowledge : LO+PS (or NLO) + normalization from data (shown later).

1.10) Dijets mass bump search: Results



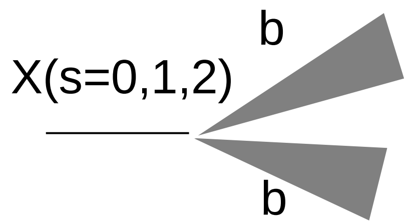
EXO-11-094 : 2011

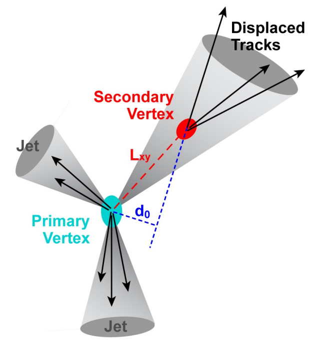


EXO-12-016 : 2012

- Resolution: gg > qg > qq. Limits more stringent for: qq > qg > gg.
- Limit on any dijet decaying model may be estimated from those generic limits.

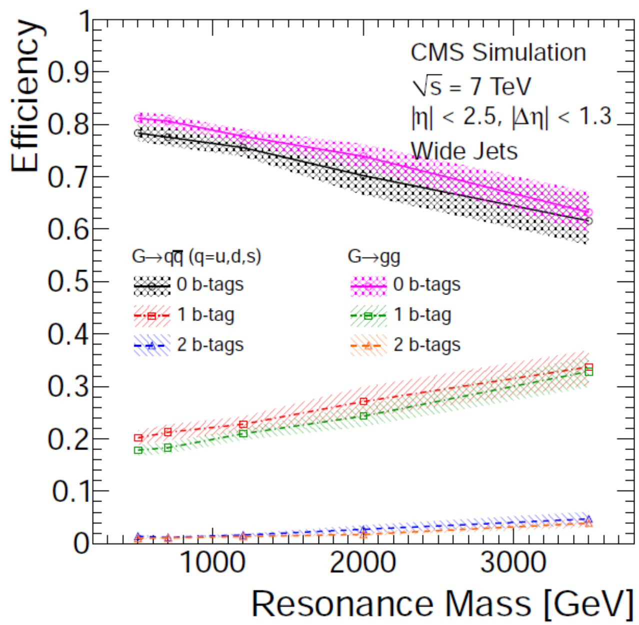
1.11) How can we go further: b-jets final state.

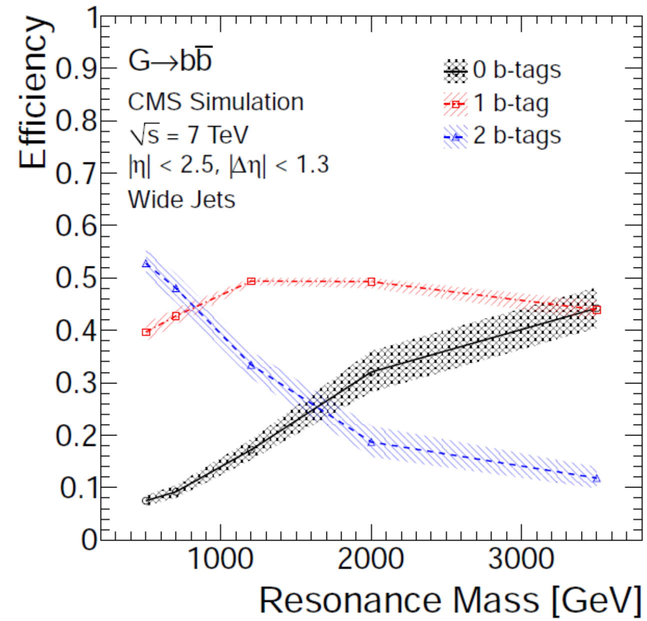




EXO-11-008 : 2011

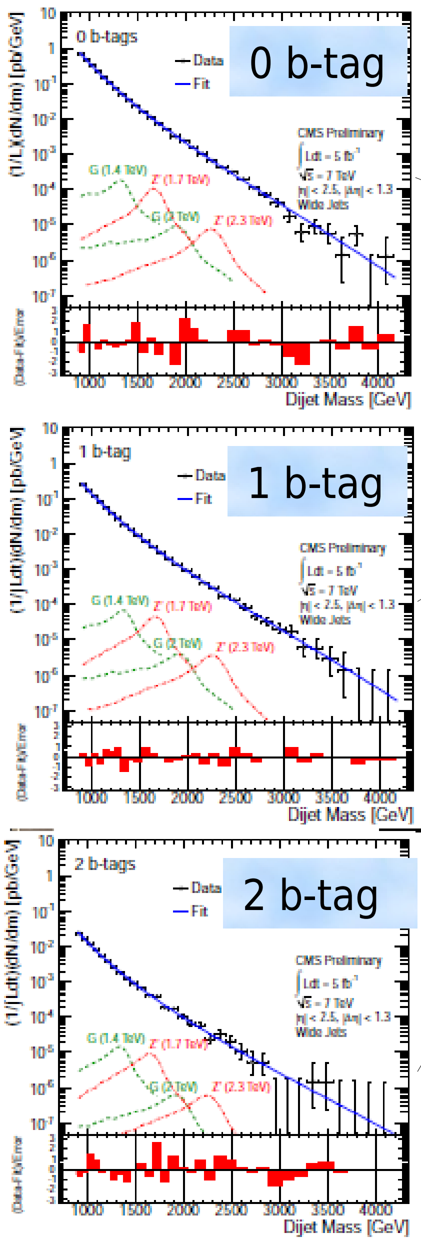
B-tagging concept



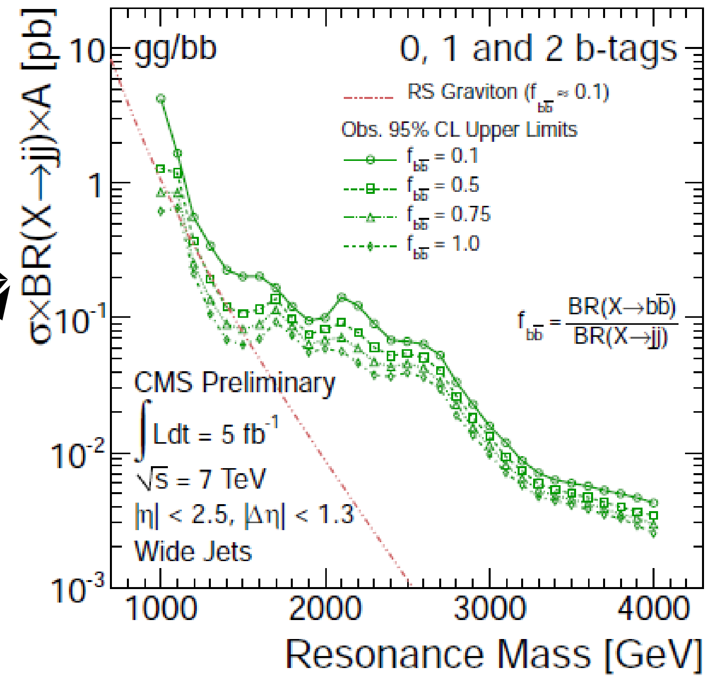


- Each b-tag divides by 5 the QCD background.
- Signal efficiency in 2 b-tags channel is around 30% at 1 TeV.
- Above 2 TeV: signal efficiency reduces and fake rate rises.

1.12) How can we go further: b-jets final state.



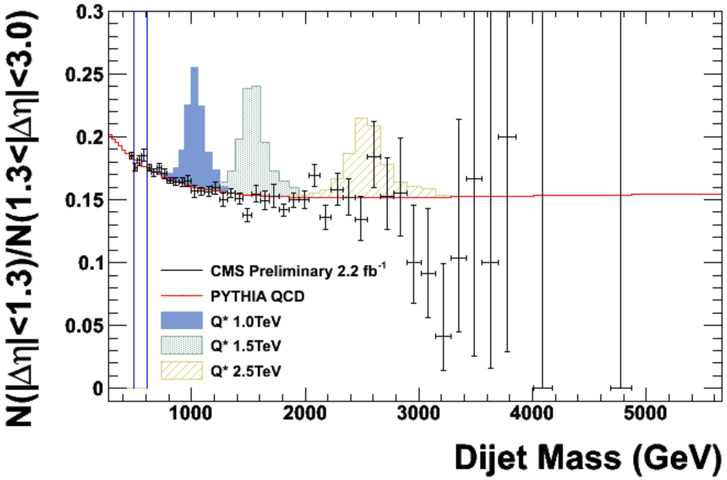
EXO-11-008 : 2011

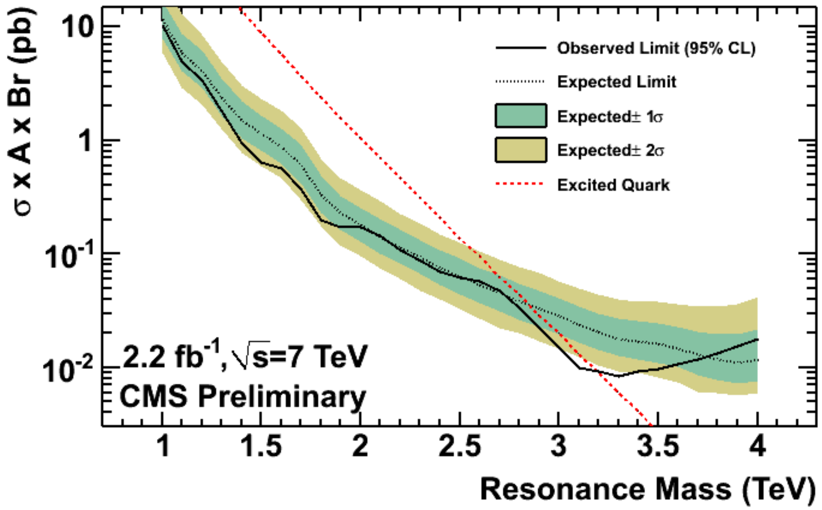


- The limits from 0 b-tag, 1 b-tag and 2 b-tags are combined.
- The analysis improves the sensitivity to resonances decaying into b-quarks below 2 TeV. But you pay the price of the branching fraction.
- Above 2 TeV it converges to the standard dijet analysis.

1.13) Dijet centrality ratio: use QCD prediction

$$\frac{\text{Signal region : } |\eta| < 1.3}{\text{QCD region : } 1.3 < |\eta| < 3.0}$$



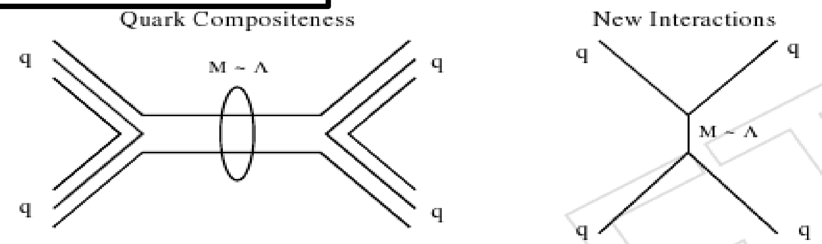


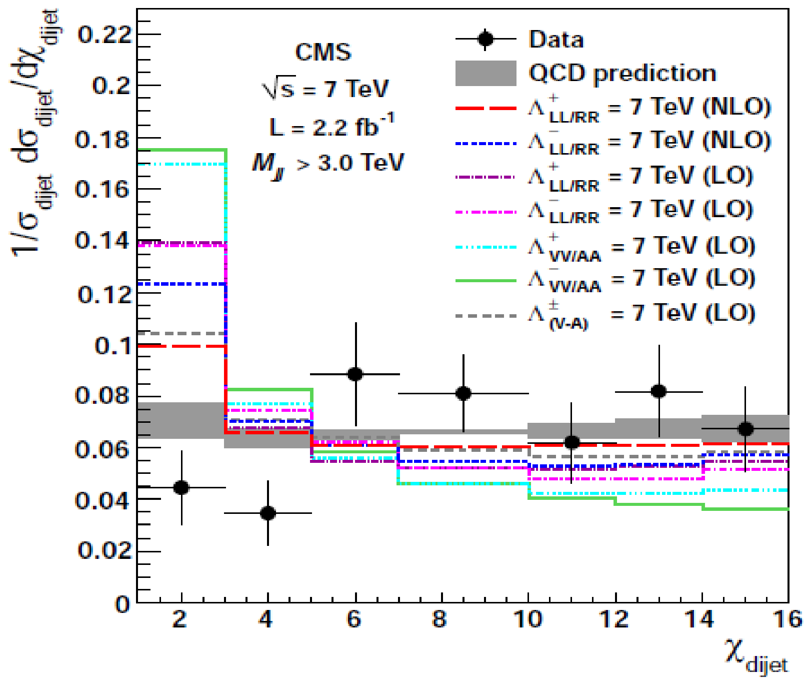
- Background is estimated using QCD LO+PS and NLO to estimate the QCD background normalized to data in signal free region.
- Experimental and theory systematics canceled in the ratio.
- Results compatibles with bump searches.

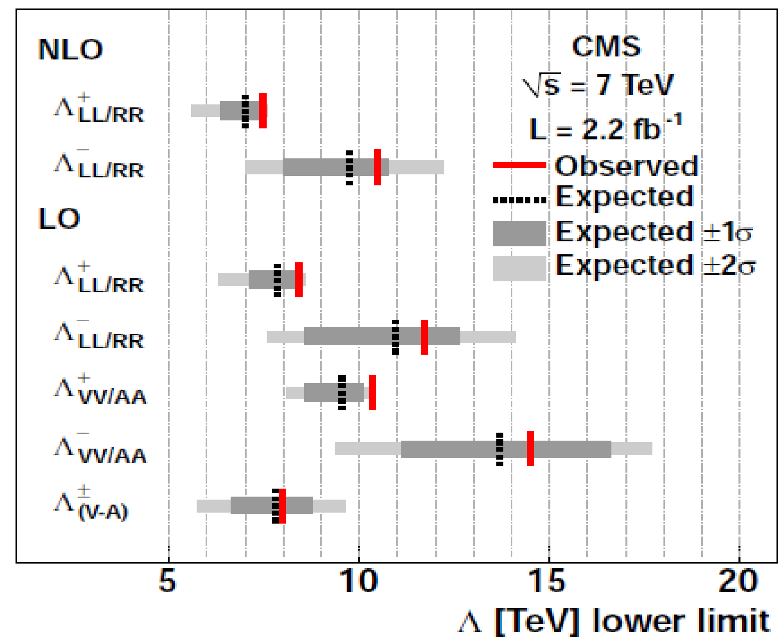
EXO-11-026

1.14) Search for Contact Interactions

EXO-11-017
arXiv:1202.5535





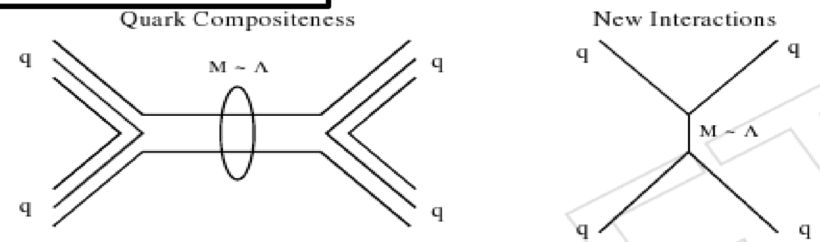


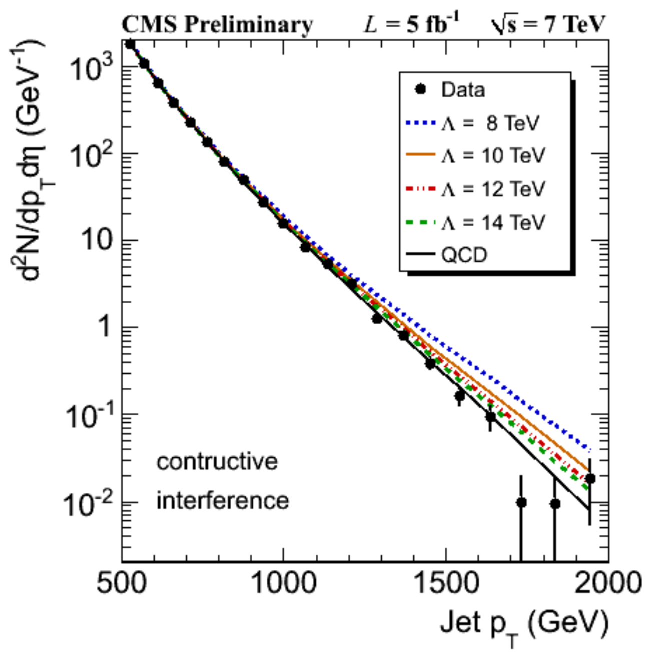
- Fine binning in $\chi = \exp(|\Delta\eta|)$ in coarse regions of Mjj.
- It is a real QCD measurement with unfolding!

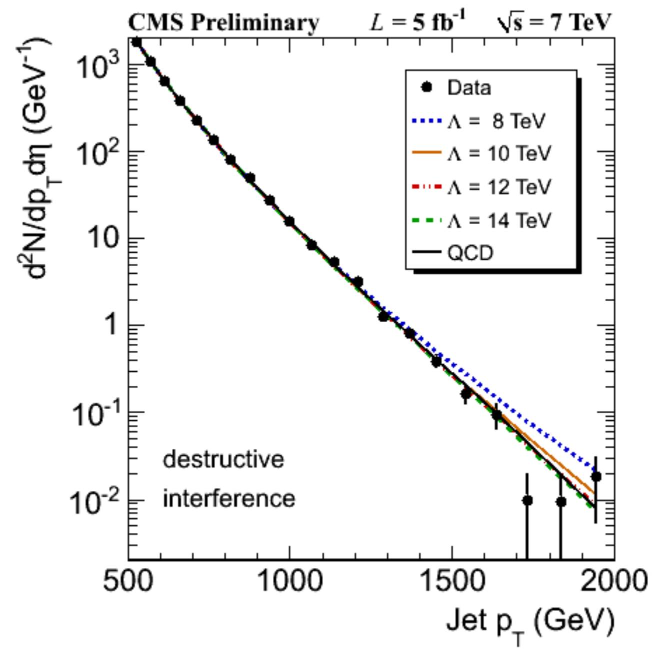
We look on deviation wrt to QCD@NLO in the signal region: low χ and high Mjj.

1.14) Search for Contact Interactions

EXO-11-010







- I do not resist to the pleasure to show fresh out of press results from Contact Interactions in the inclusive jets.
- The constructive are excluded below ~14.5 TeV and destructive below ~9.7 TeV !!!

1.15) Intermezzo

---- Important features of the hadronic searches to remember -----

1.1) S-channel jets searches are dominated by the JES uncertainty.

1.2) The mass shapes are deformed by QCD radiation and parton luminosity.

1.3) The QCD is by far the dominant background:

- either estimated by a smooth CTEQ inspired fit function.
- either taken from QCD calculations with normalization to data.

--------- Results from searches in the S-channel --------

2.1) Strongly coupling models in S-channel are excluded from 0.5 to 3-4 TeV.

2.2) We just start to be sensitives to the weakly coupling models in the jets final state excluding them between 1-1.5 TeV.

2.3) The Contact Interactions are excluded below 7 TeV.

II

New trigger strategies for low mass regime

2.1) Why do we need specific trigger strategies

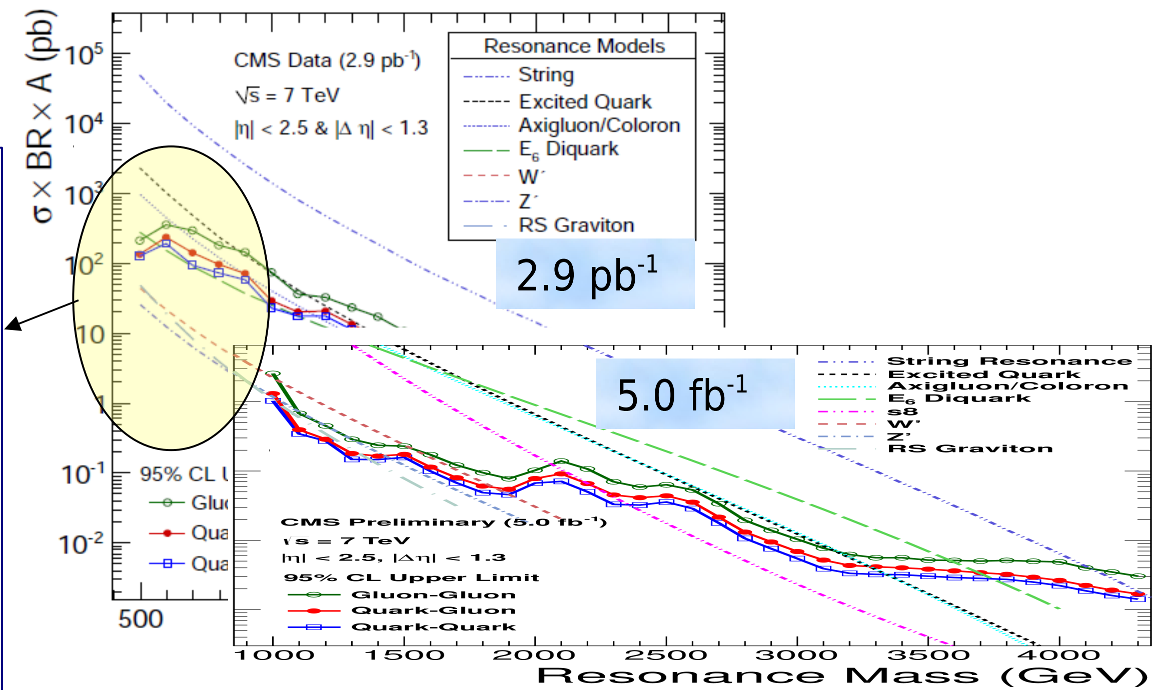
<u>Current situation with triggers</u>

- For hadronic searches we use:
  - Dedicated triggers: 2-jets, 4-jets, 6-jets
  - Generic HT or Single Jet triggers.
- Particle Flow is used online and pile-up removal applied.

Analyses thresholds stable between 2011 and 2012.

Region left behind since 2010.
- Strongly coupling models mainly excluded.
- Weakly coupling models still allowed

Not expected to be fully covered by the Tevatron.



2.2) Why do we need specific trigger strategies

We need an alternative trigger strategy to the default one we use.

1) Standard strategy – 300-350 HZ:

L1 $\rightarrow$ HLT $\rightarrow$ Data acquisition $\rightarrow$ Immediate Reconstruction

2) Data parking – 300-350 Hz:

L1 $\rightarrow$ HLT $\rightarrow$ Data acquisition $\rightarrow$ Reconstruction 2013

- Complementary/extension of the main program

With looser or new triggers.

3) Data scouting – 1000 Hz:

L1 $\rightarrow$ HLT $\rightarrow$ Reduced event content

- Store only few objects reconstructed at HLT level

Jets, Muons...

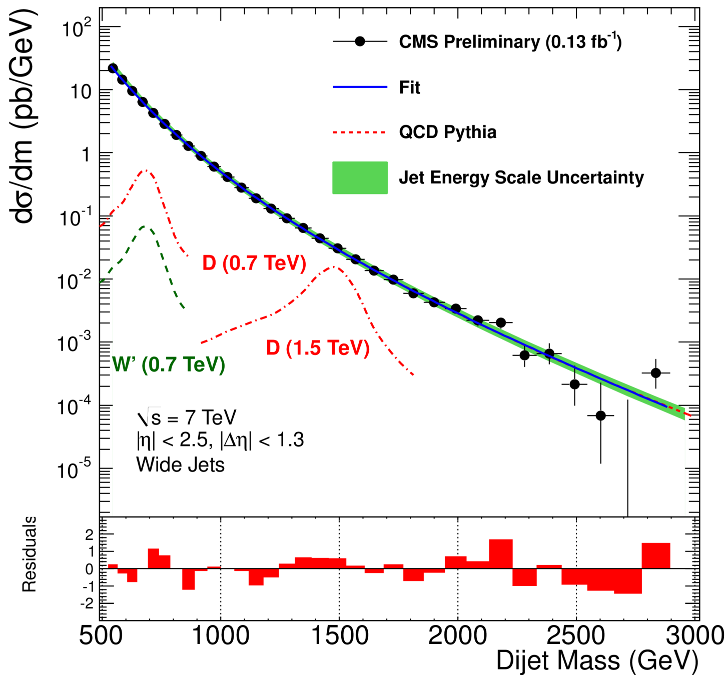
- For now used: HT > 250 GeV
  - Covers low mass hadronic physics.

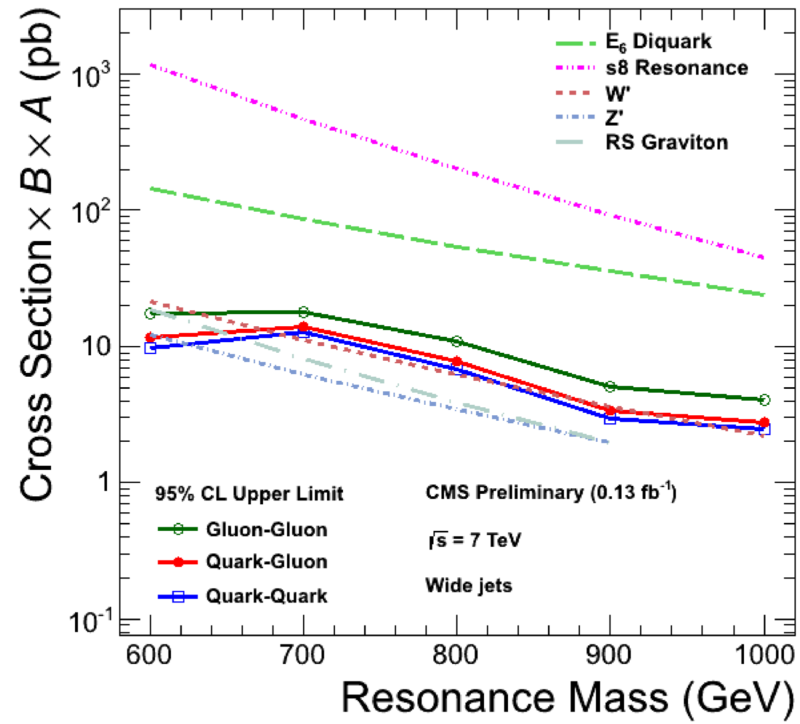
Tested in 2011 with 130 pb^{-1}.

CMS DP-2012/022 (soon on CDS)

CMS Experiment at the LHC, CERN

2.3) First results: dijet searches





EXO-11-094 : 2011

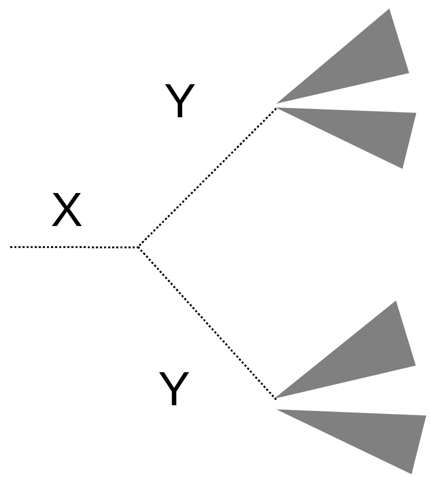
- We successfully tested the data scouting in 2011 filling some gaps in strongly coupling models.
- Start to be sensitive to weakly coupling models.
- In case of an interesting signal a dedicated standard trigger would be mount-up.
- Much more data in 2012 (> 15 fb^{-1}).

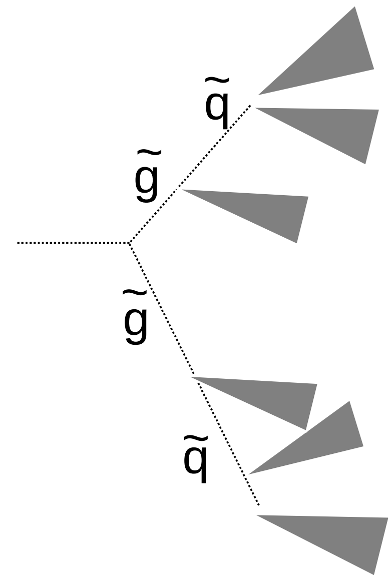
III

General concepts of the paired production

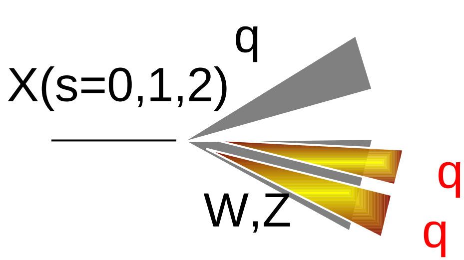
3.1) Paired production channels you all know

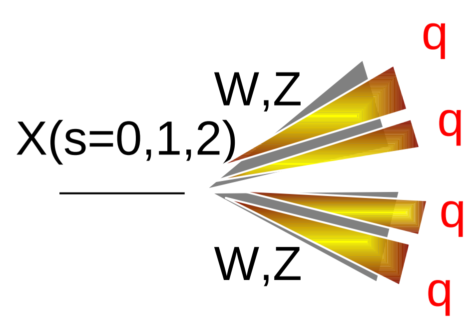
- For some resonances due to a symmetry the s-channel production is disfavored:
colorons produced by a gluon decays; RPV SUSY - paired production of gluinos.





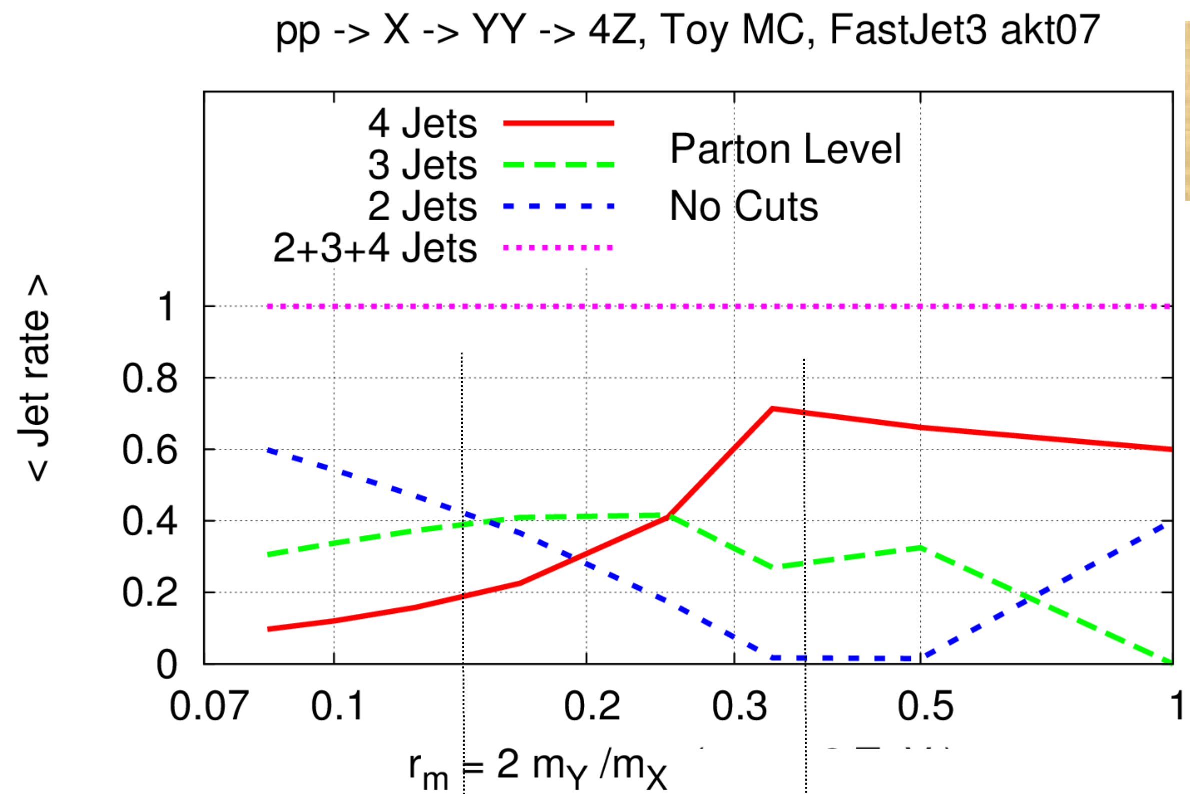
- Heavy resonances produced in S-channel but decaying into a heavy SM object: W, Z or now Higgs boson.

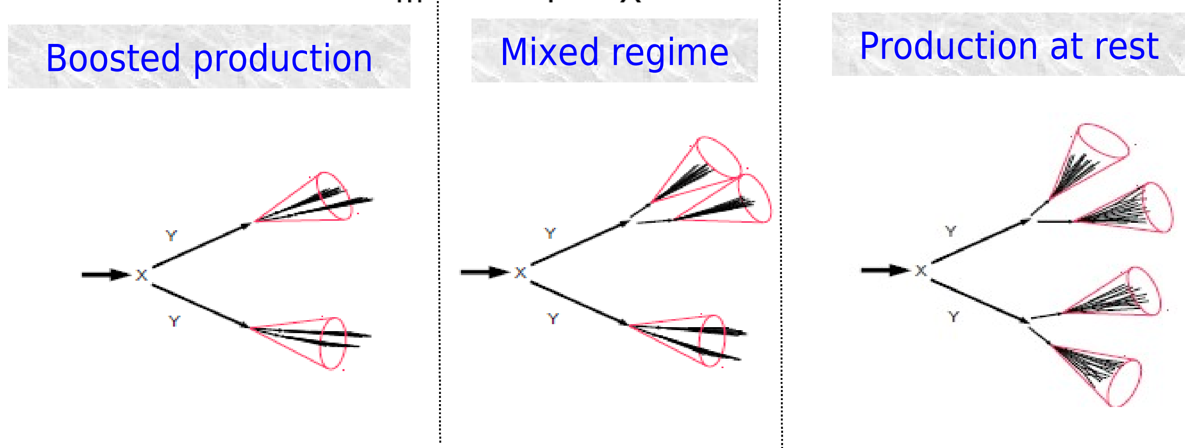




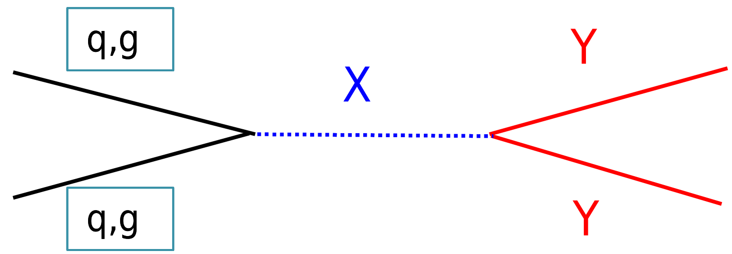
3.2) Generic phase space of pair production process

J. Rojo,
M. Gouzevitch
G. Salam

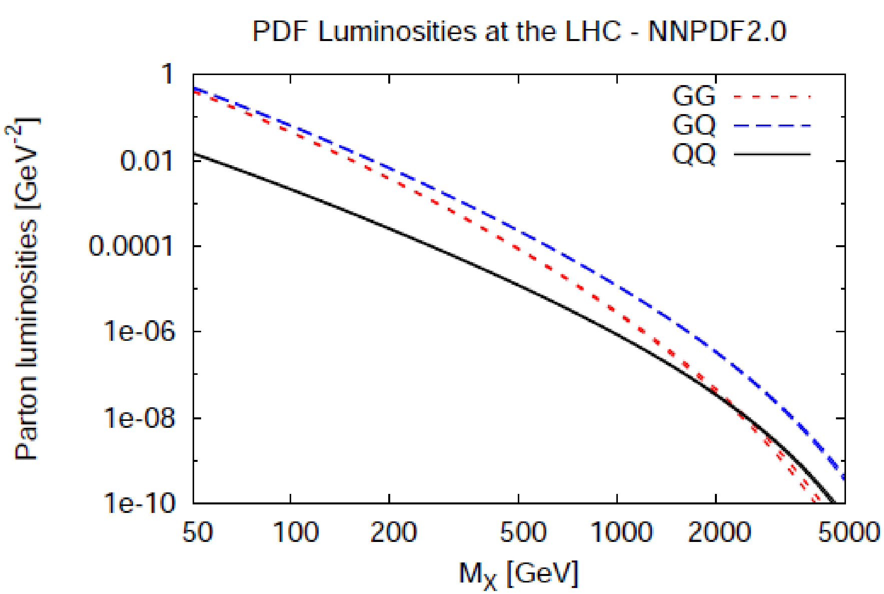


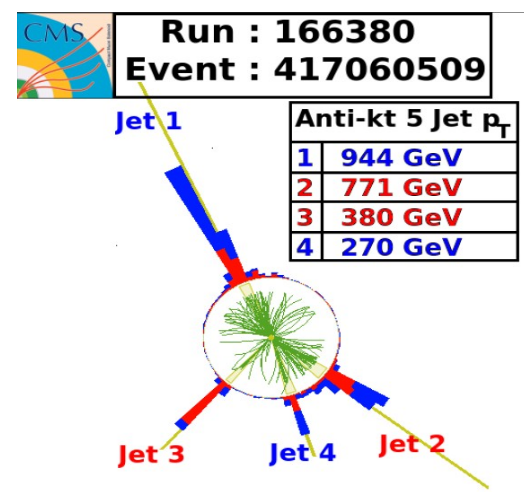


3.3) Non-resonant production

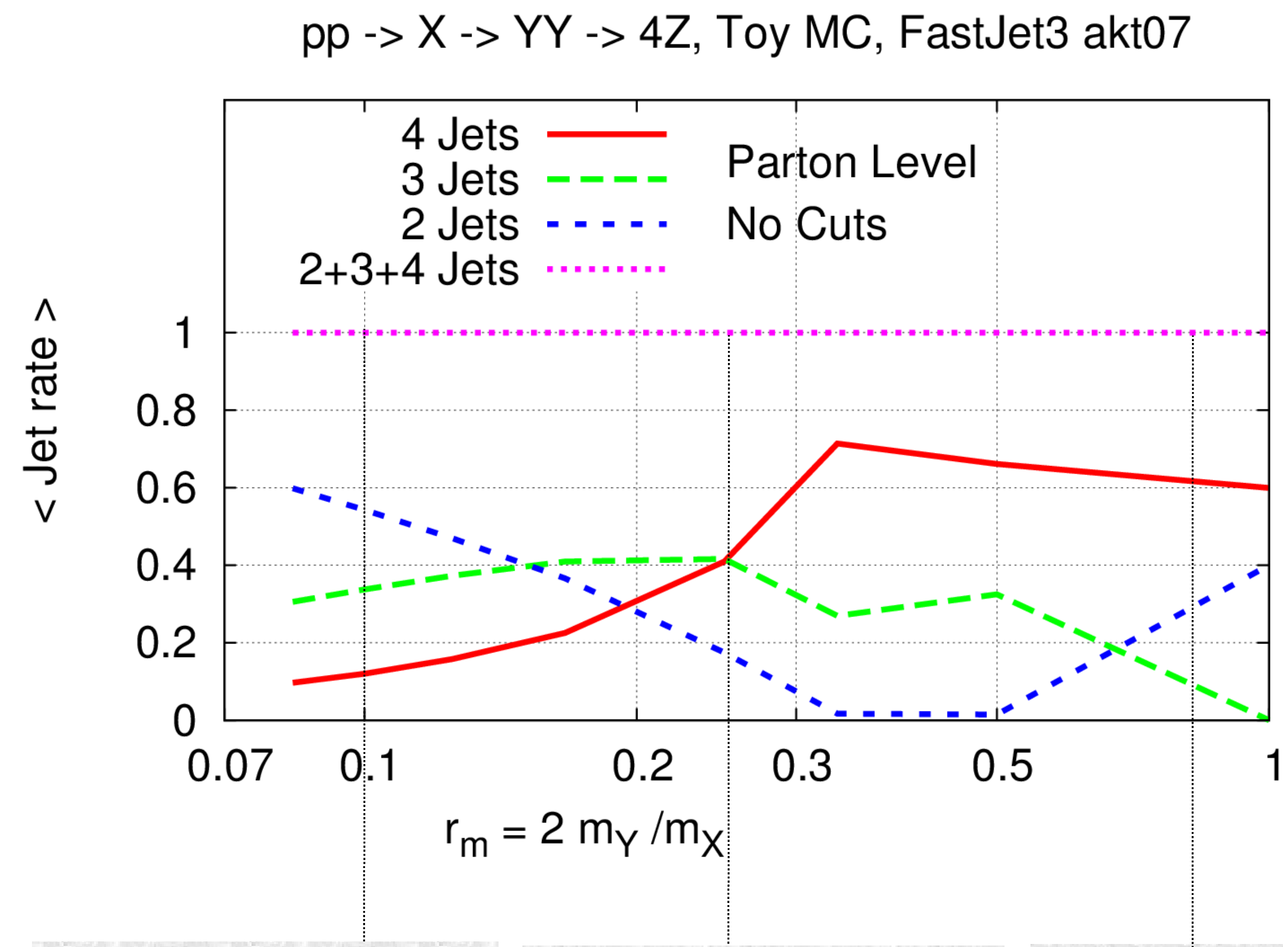


- If X = gluon* we have a non-resonant production.
- Due to the PDF luminosity Y is produced mostly at rest $M_{gluon} \sim 2{*}M_Y$.





3.4) Models localization in the phase-space



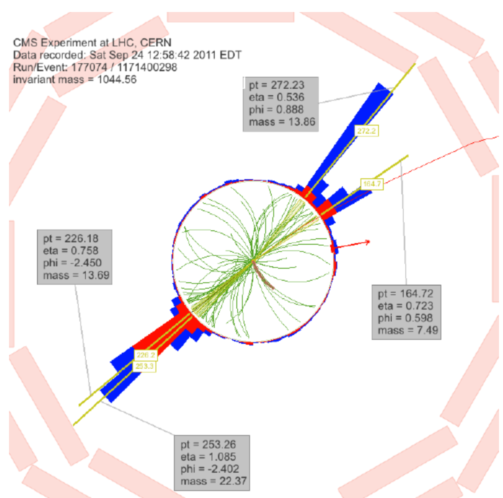
RSG (2TeV) → WW→ 2J
RSG (2TeV) → WZ → 2J
RSG (2TeV) → ZZ → 2J

Radion (1TeV) → 2 Higgs

Gluon → 2 Colorons

IV

Boosted production and substructure

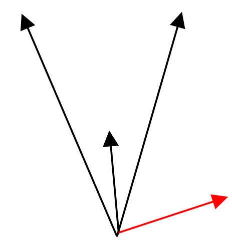


4.1) Pruning algorithm to tag boosted jets

$$z_{ij} = \frac{\min(p_{\mathrm{T}i}, p_{\mathrm{T}j})}{p_{\mathrm{T}i+j}} < z_{\mathrm{cut}}$$

$$\Delta R_{ij} > D_{\mathrm{cut}} = \alpha \times \frac{m_J}{p_{\mathrm{T}J}}$$

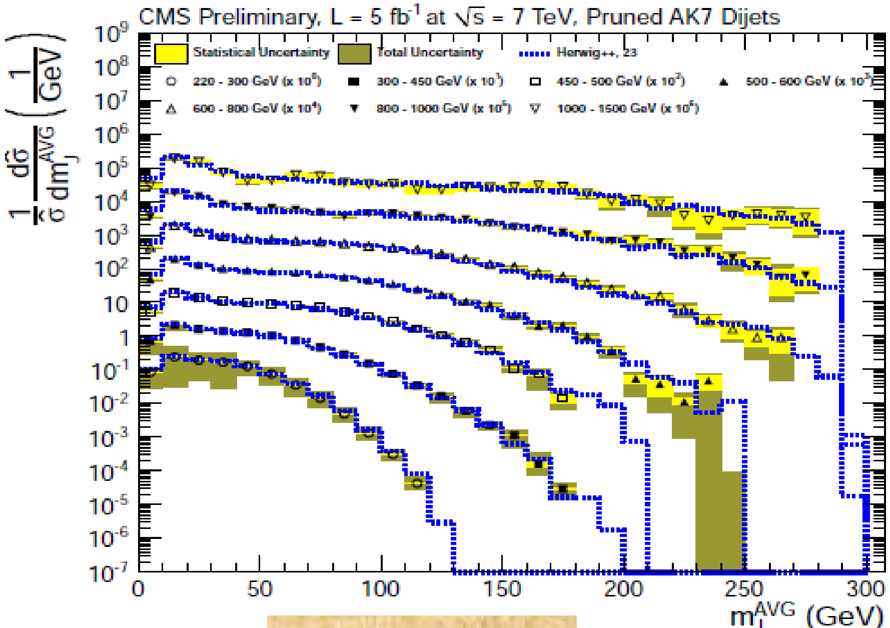
$z_{cut} = 0.1, \alpha = 0.5$



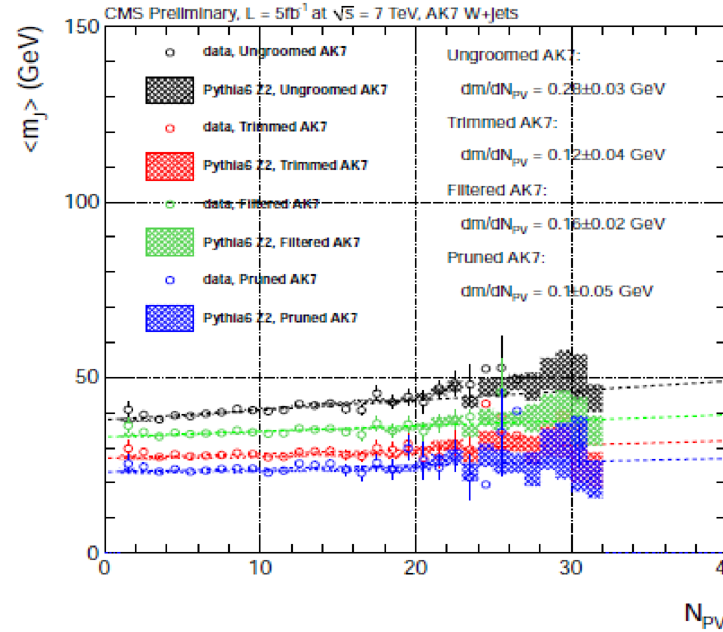
Prunning

- Start with our preferred algorithm (anti-k_T with R=0.5 or 0.7). Reclustered with Cam.-Aach. R=0.8 more sensitive to substructure.
- Reject particles with large angle and low p_T.
- It does not affects much the jet p_T, but much more the jet Mass.

4.2) Does the QCD describe the prunned jets



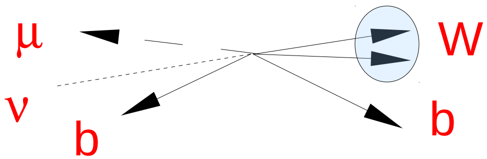
SMP-12-019

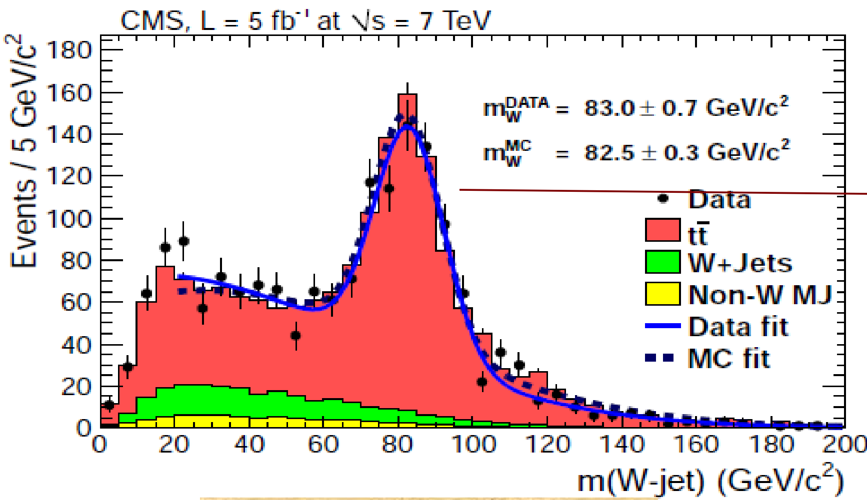


- The pruning algorithm is quite well understood by the LO+PS event simulators.
- It removes also the PU particles and reduces the impact of the PU on the jet mass.

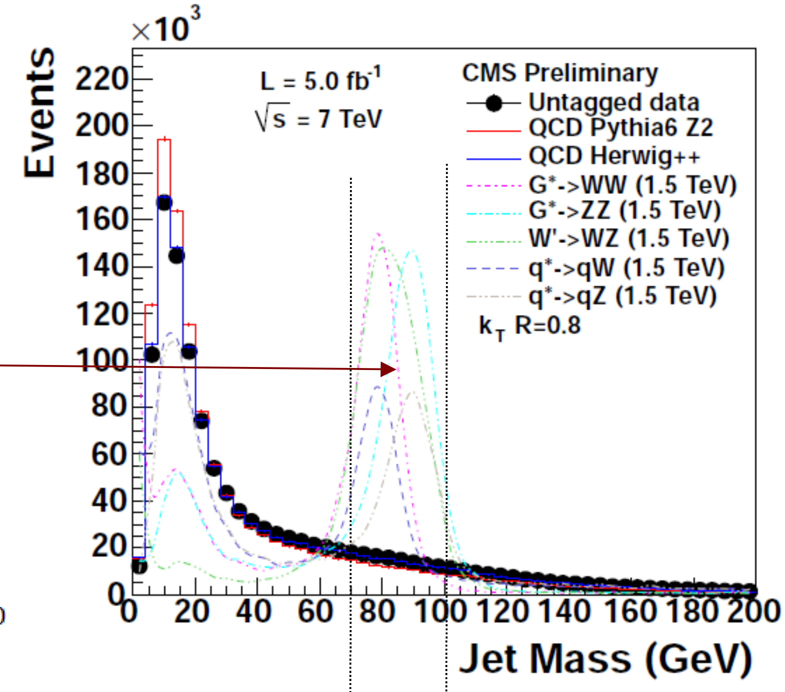
CMS Experiment at the LHC, CERN

4.3) Mass measurement





EXO-11-006
arXiv:1204.2488



EXO-11-095

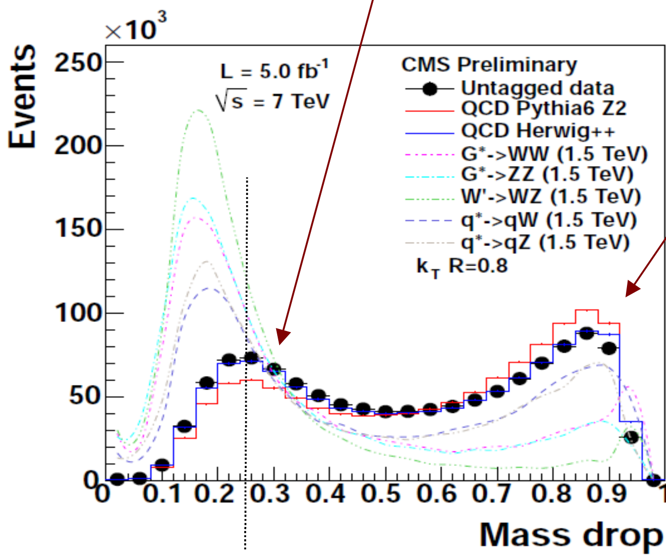
- We request pruned mass around W, Z mass: hard to disentangle W from Z due to resolution. May be one day looking on jet charge...

- Tested in semi-leptonic ttbar.
  - Resolution: 10-15%
  - Scale known at 1%.

4.4) Mass drop

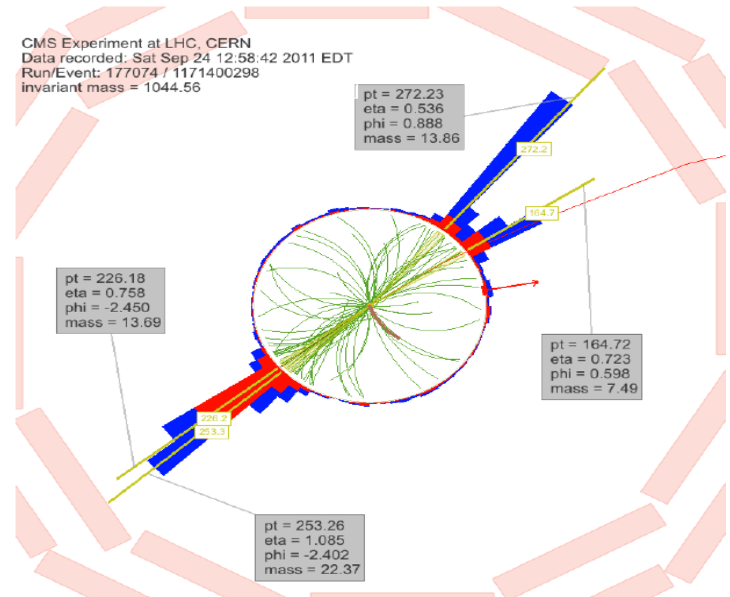
Symmetric splitting

Soft QCD radiation

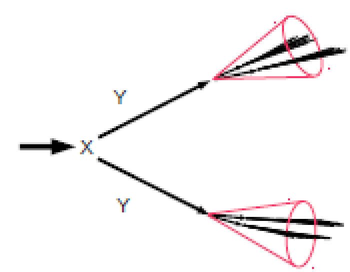


$$\frac{m_1}{m_{\rm jet}} < 0.25$$

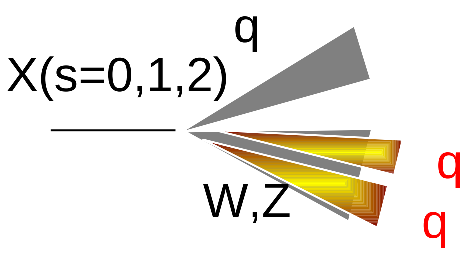
EXO-11-095

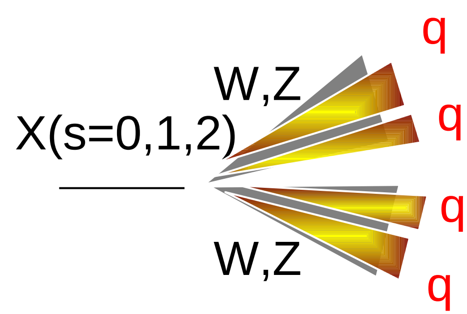


- We request 2 subjets with small mass wrt to W, Z mass.
- Removes QCD background except symmetric splitting.

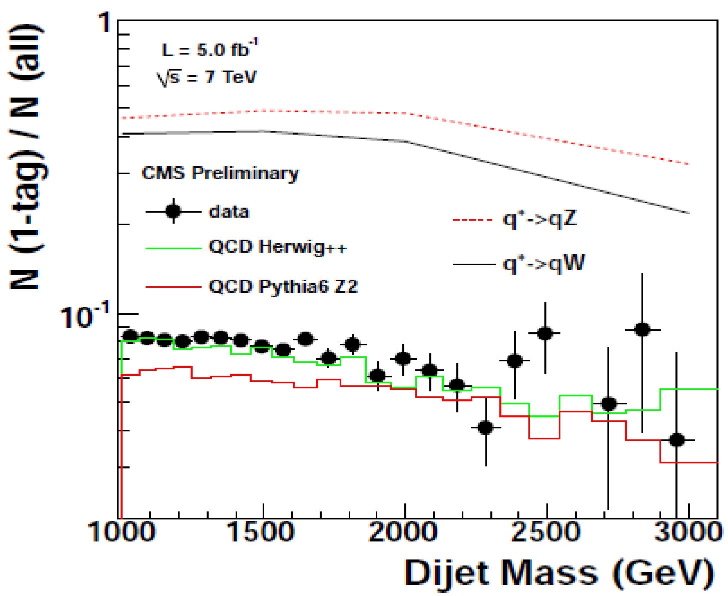


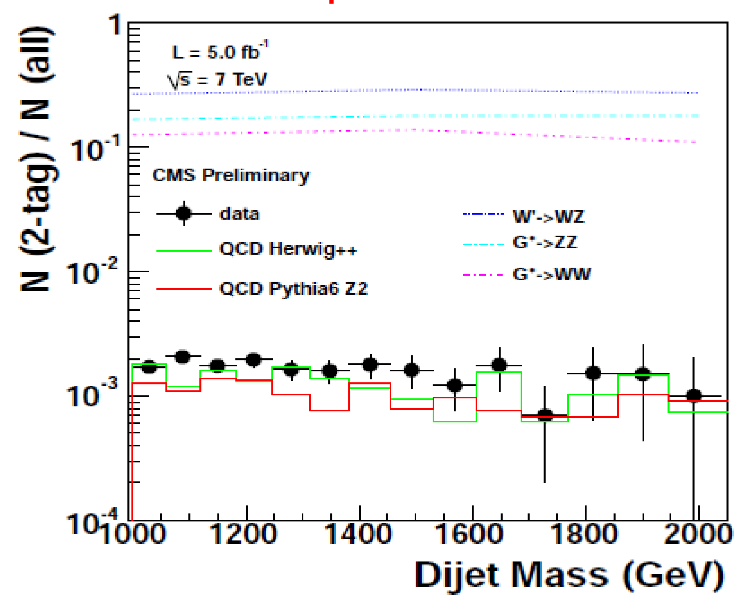
4.5) Search for resonances decaying into boosted V





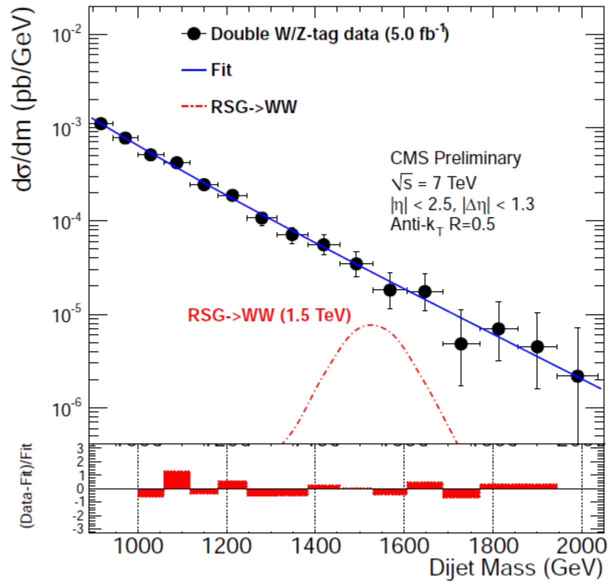
EXO-11-095





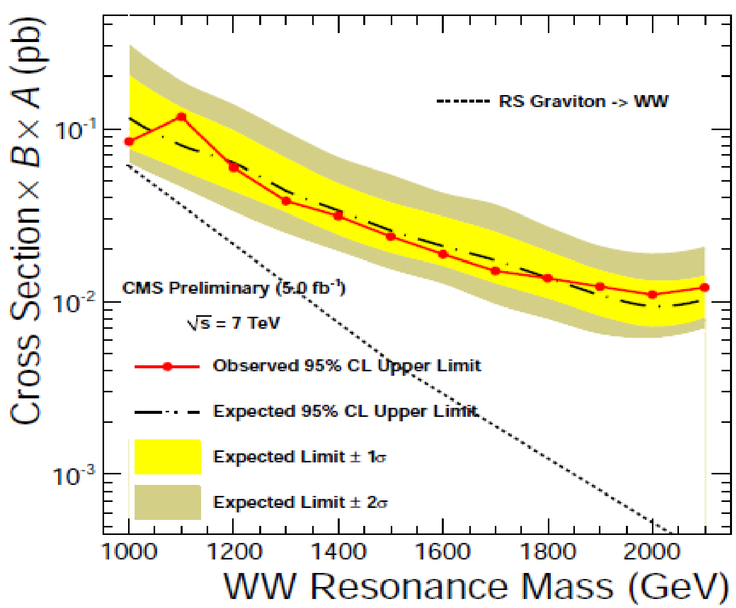
- W, Z tagging reduces background by a factor 15. This is equivalent to the reduction due to the isolated lepton.
- Experimentally high mass jet tag transform QCD search into an EW search.

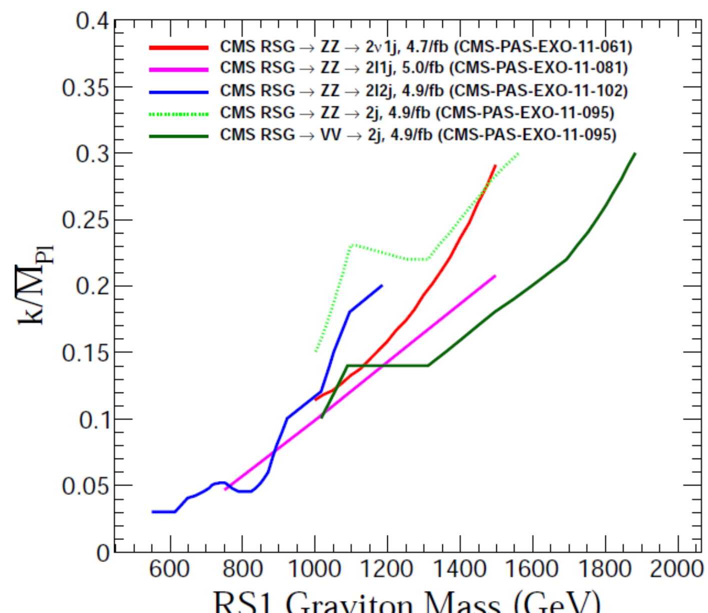
4.6) Search for resonances decaying into boosted V



- Double tagged spectrum well described by generic dijet function.
- Start to be sensitive to the graviton to VV.
- Complementary to the other searches.

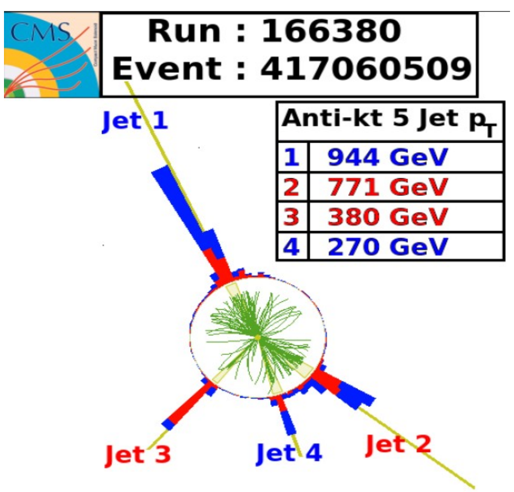
EXO-11-095

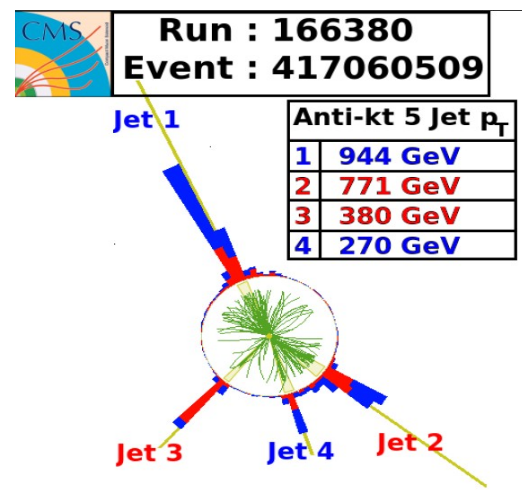




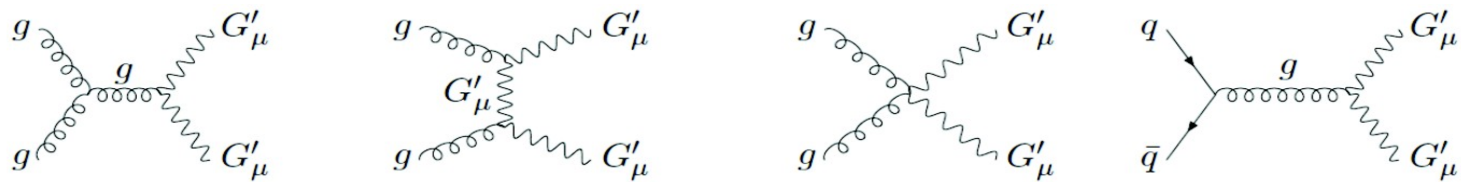
V

Paired production at rest



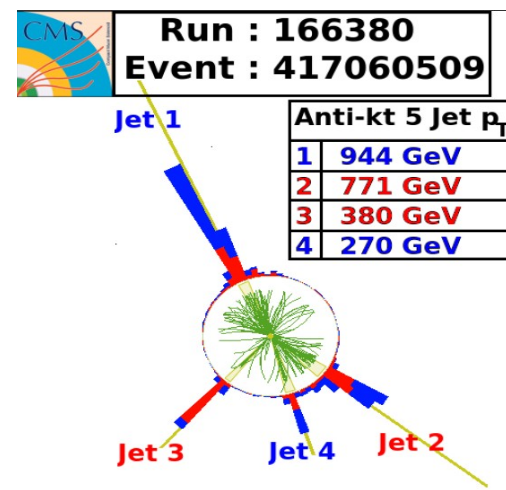


5.1) Paired dijet search



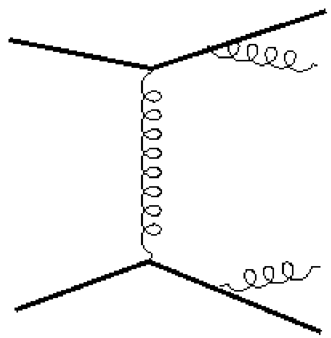
- Typical signal: paired production of colorons with unknown mass (different from V production).
- Selection: try all 6 pairing combinations. Keep the one with minimal ΔM. In the example below: M_{14}, M_{23}, $M_{ave} = (M_{14}+M_{23})/2$.
- Keep the event if

$$p_{T,4} > 150 \text{ GeV}$$
$$\Delta M/M_{ave} < 15\%$$

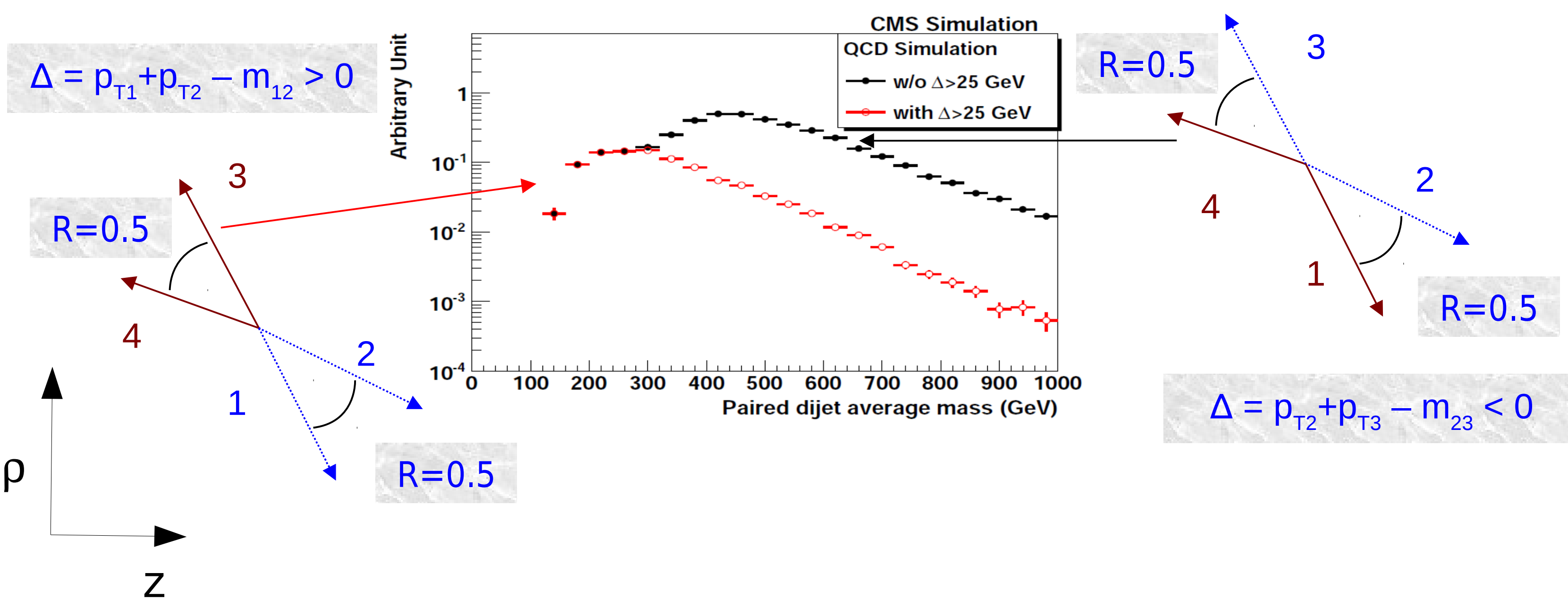


5.2) Paired production at rest

EXO-11-016

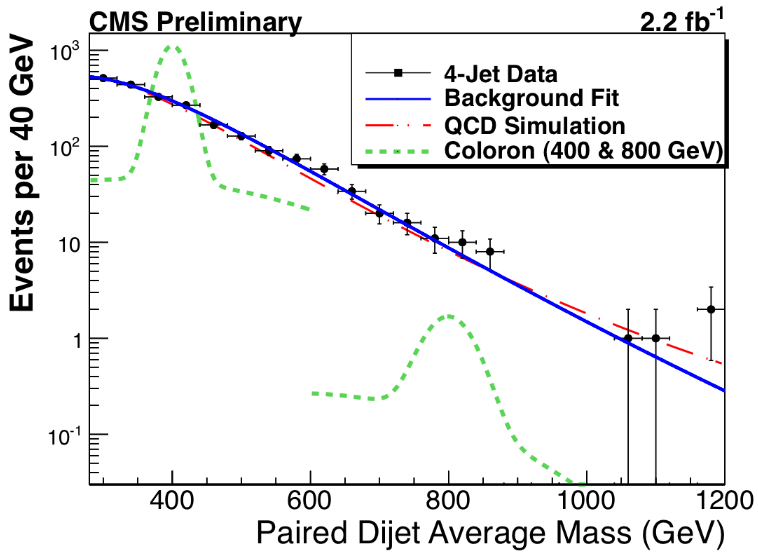


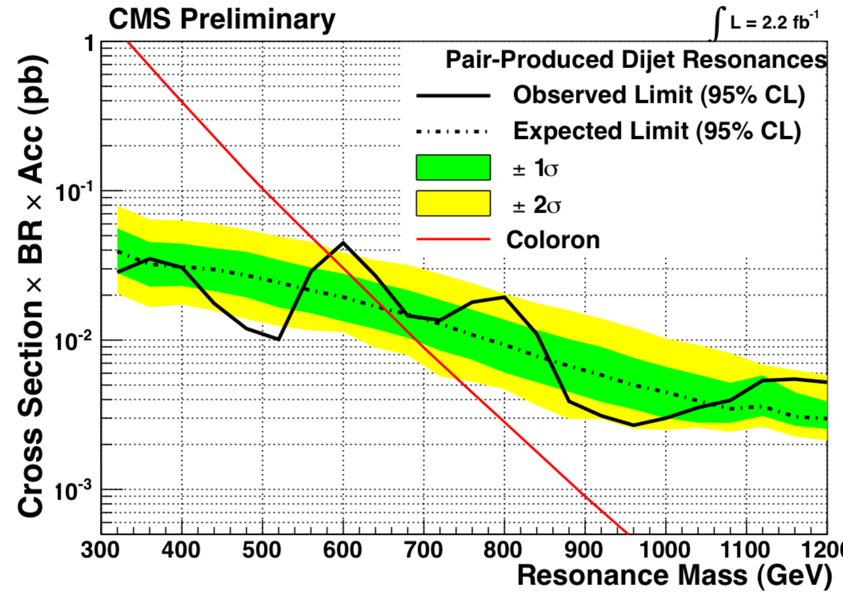
- QCD singularities:
  - t-channel production.
  - Collinear emission:
    large number of jets with $\Delta R=0.5$
  - If jets 3-2, 1-4 are paired important secondary peak.
- « Diagonal cut » Δ_{cut} > 25 GeV remove the secondary peak and improve $S/\sqrt{B}$.



5.3) Paired dijet search

EXO-11-016

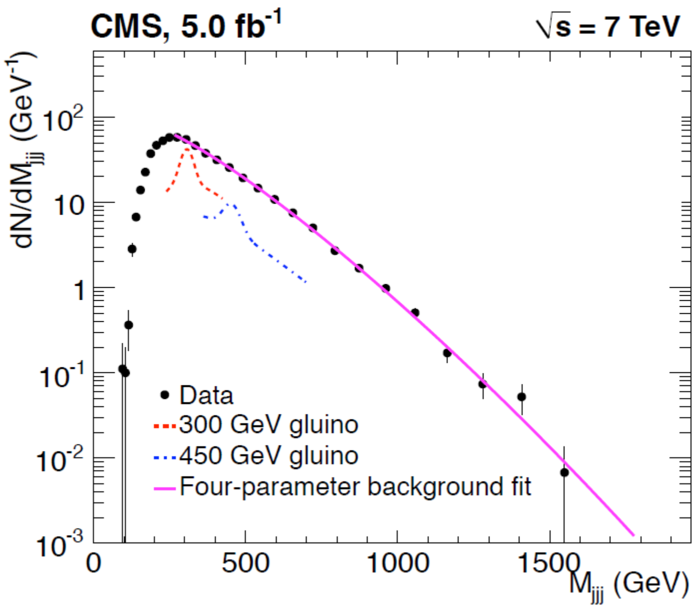


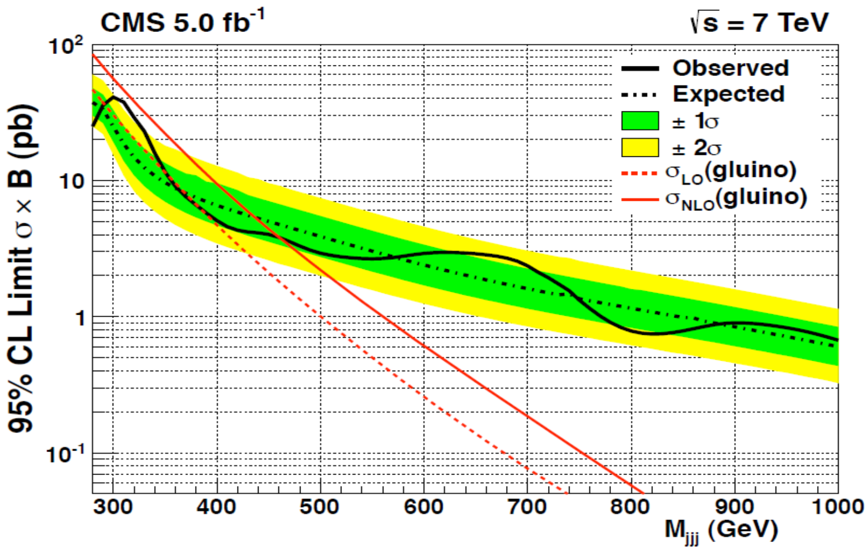


- Well described in shape by PYTHIA and fitted with same background function than dijets.
- Coloron model coupling to gluons excluded up to 560 GeV in the paired production.
- Good candidate for new trigger strategies to cover the region below 300 GeV.

5.4) Paired 3-jets search

EXO-11-060
arXiv:1208.2931

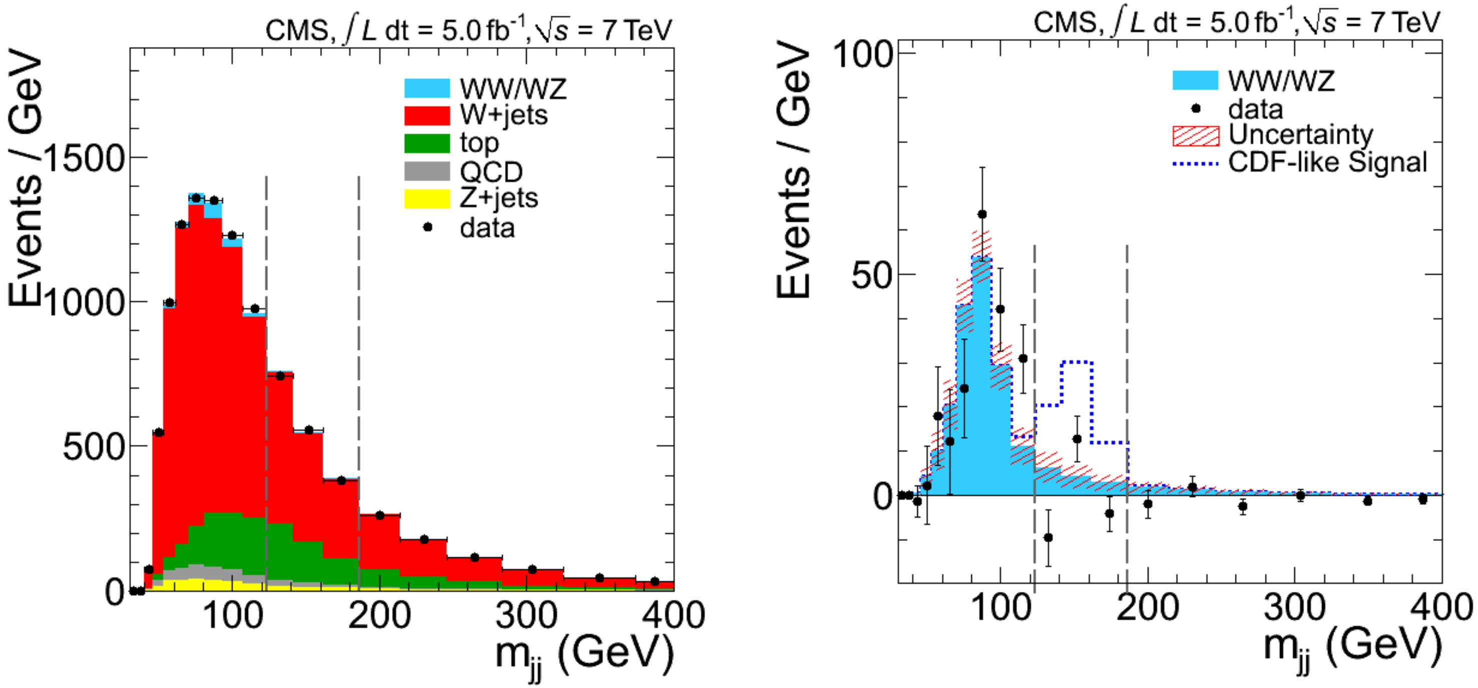




- The paired 3-jets search is similar in principle to the dijet search:
  - Reconstruct the triplets of particles and remove the collinear singularities with the diagonal cut.
- Benchmark model: RPV SUSY.

5.5) Intermezzo

EWK-11-017
arXiv:1208.3477

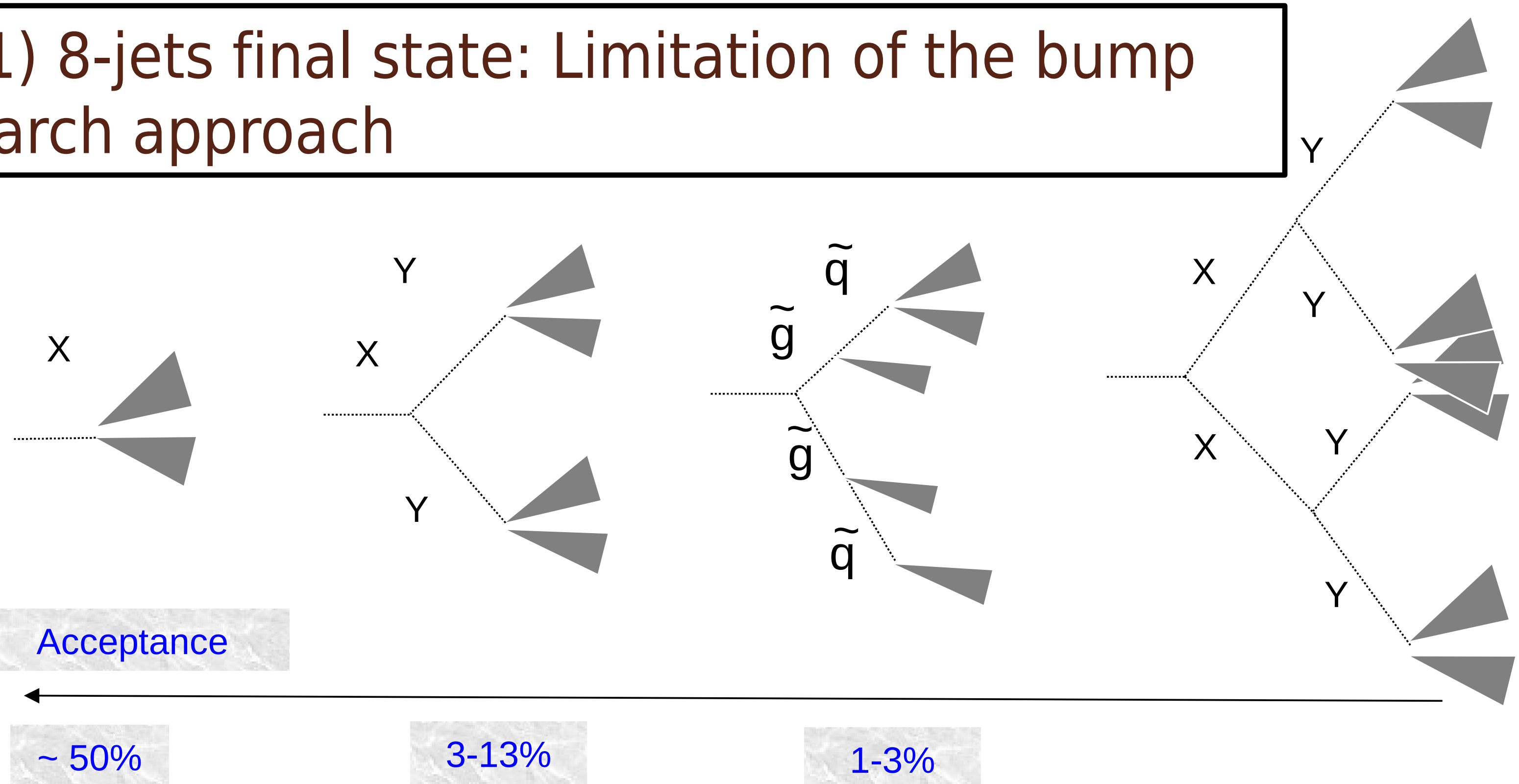


- Search for the pair production $W+X \rightarrow l\nu jj$
inspired by recent CDF results (arXiv:1104.0699), not confirmed by D0 collaboration (arXiv:1106.1921) and Atlas collaboration (ATLAS-CONF-2011-09).
- No evidence of a signal compatible with CDF results is observed.
- Limits set on leptophobic Z' or technicolor.

VI

Pushing toward high multiplicities

6.1) 8-jets final state: Limitation of the bump search approach

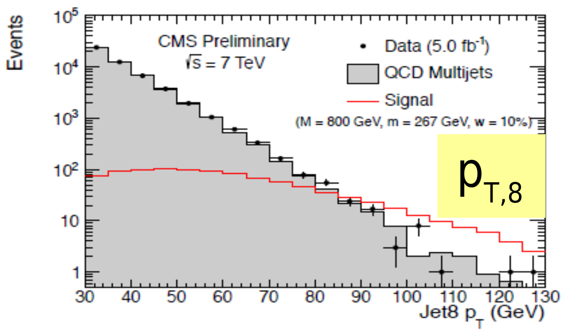


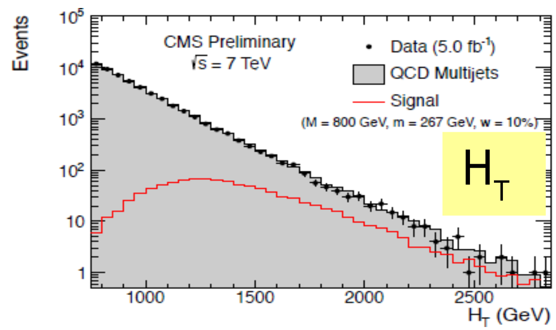
- ISR/FSR contamination: In 50% of cases 4-th jet is not matched to a signal parton but ISR.
- Bump search is mainly sensitive to the central gaussian: combinatorics, trigger thresholds, mismatching move events out of the peak or remove them from the sample.

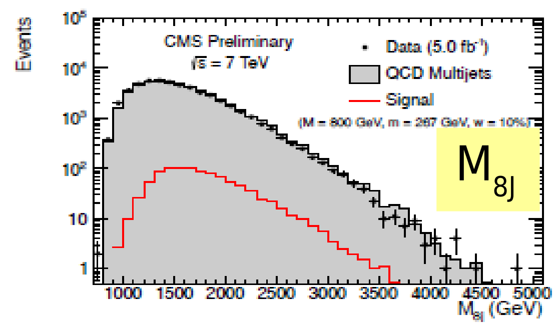
8-jets is the transition point for search strategy

6.2) Extraction of the signal using Neural Network

- In the new approach the phase-space is defined by jets selection ($p_{T,min}$ and η) and the min HT cut: acceptance 20-100%.
- Use MVA approach (Neural Network): 6 kinematic variables each one giving a small sensitivity.







p_T of the 8 leading jets

Signal : Democratic distribution.

QCD : Strong hierarchy.

Centrality of the jets :

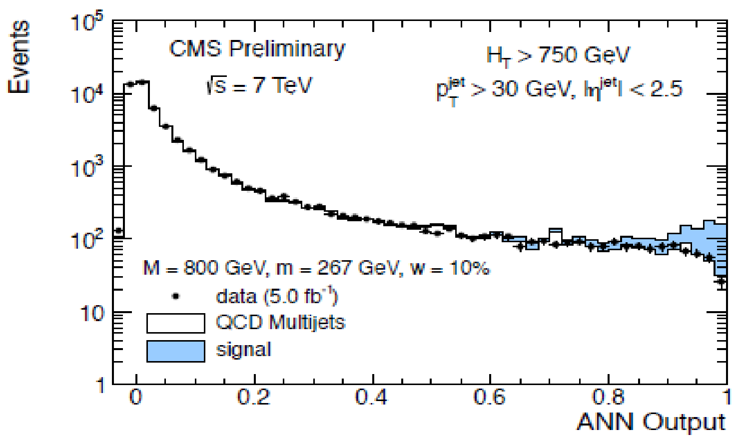
Signal central production : M8j >~ HT

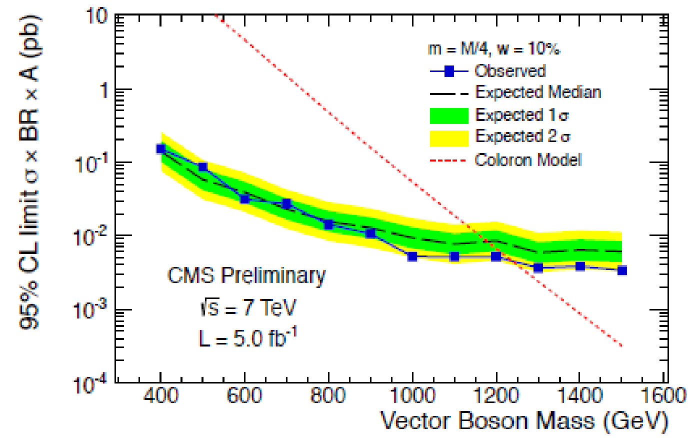
QCD more forward production: M8j >> HT

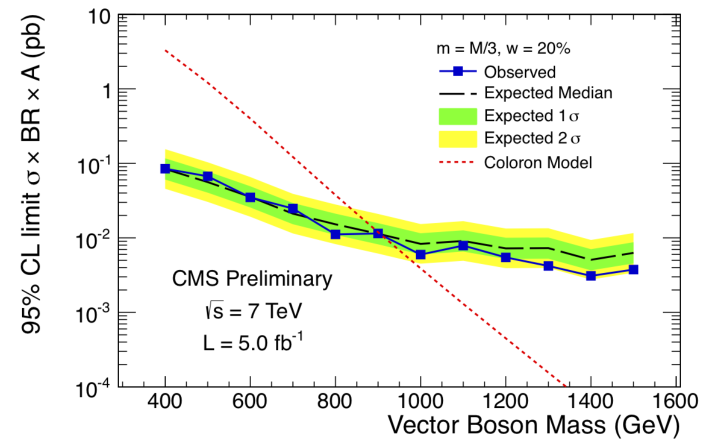
EXO-11-075

6.3) 8-jets search: results

EXO-11-075



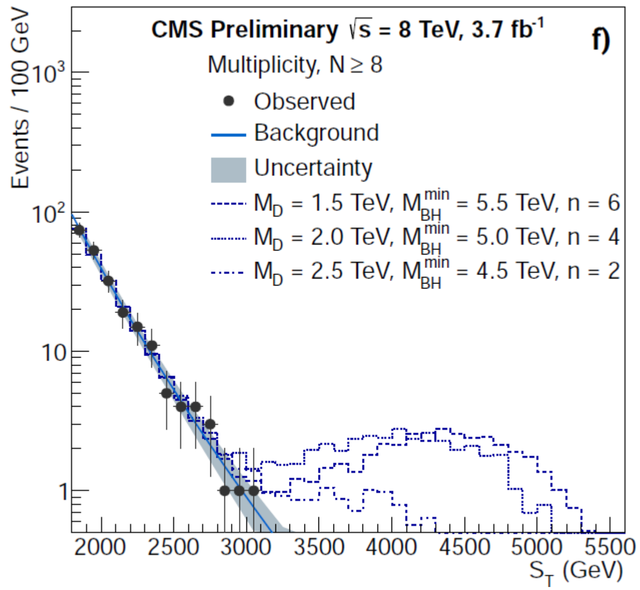


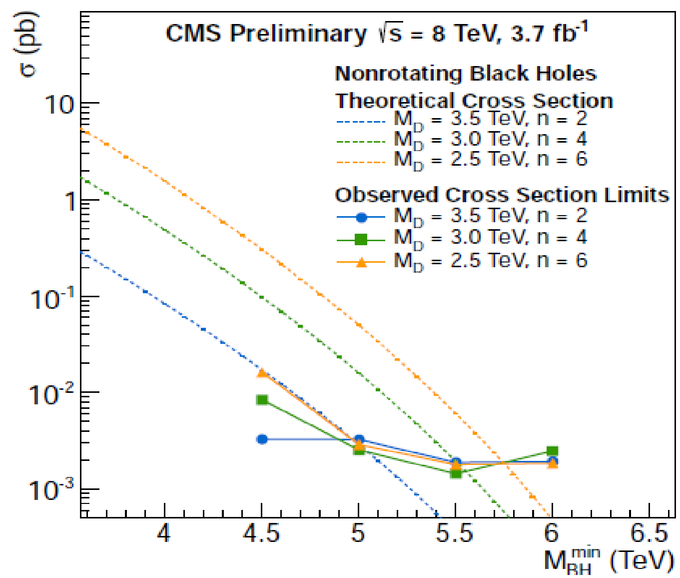


- Fit of Signal and background templates to the data NN output.
- Set limits of the decay chain for different ratio of MY/MX and MX width.

6.4) Black holes thermal evaporation

2011 : arXiv:1202.6396
2012 : EXO-12-009



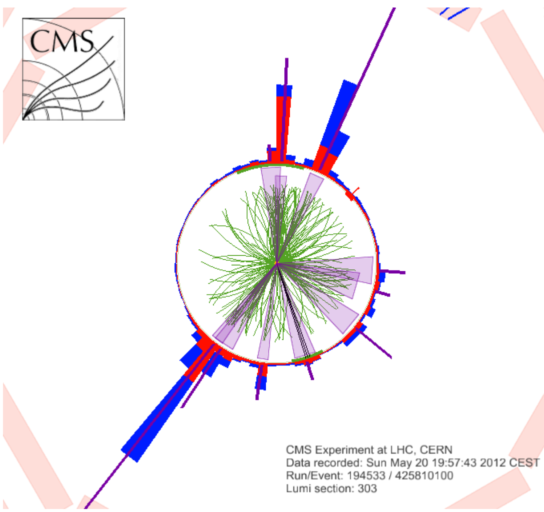


- Semi-classical black holes with extra dimensions: Hawking evaporation. Generic example of high multiplicity final states: the number of particles and spectra not well known.
- The main variable insensitive to the exact details of « splitting » is

$$S_T = H_T + P_T(\text{leptons, photons}) + ME_T$$

- Background fitted with Bump Search function.
- Counting experiment in the tails above an optimized $S_{T,min}$.

10 jets, ST = 2.7 TeV



SUMMARY I

---- Important features of the hadronic searches to remember -----

1.1) Hadronic final state searches are dominated by the JES uncertainty.

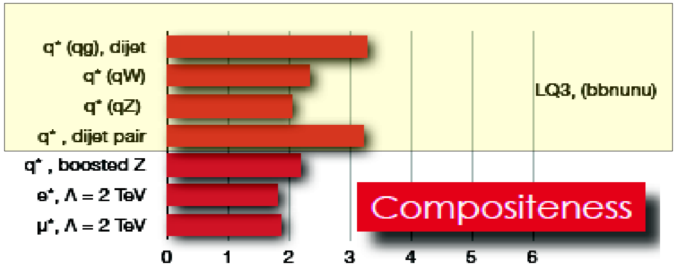
1.2) The QCD radiation limit the reach of the bump searches at energies above $\sqrt{s}/2$ and at high multiplicities (more than 6 jets).

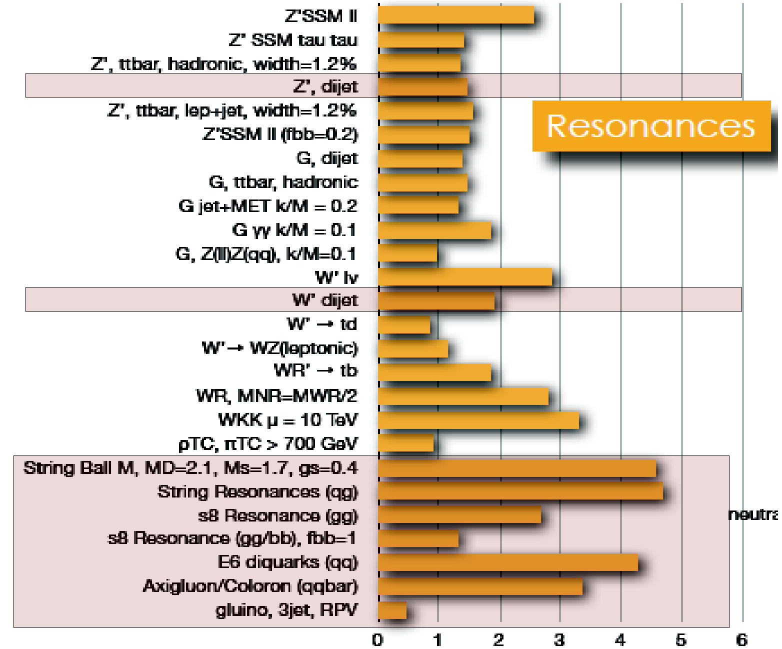
1.3) For high multiplicities alternative MVA based strategies shows up.

1.4) The QCD is the by far dominant background :
- either estimated by a smooth CTEQ inspired fit function.
- either taken from QCD calculations with normalization to data.

1.5) The b-tagging or the substructure techniques extends the sensitivity to the new class of models.

SUMMARY II





2.1) Strongly coupling models (depending on the model):

- in S-channel are excluded from 0.5 to 3-4 TeV.
- Contact interactions excluded up to 7 TeV.
- In paired production from 0.3 to 0.6 TeV.

2.2) Weakly coupling models (jets final state):

- Exclude W' or Z' them between 1-1.5 TeV.
- Develop b-tagging, substructure tools and low mass triggers to increase out sensitivity for this channel

2.3) Extra-dimensions, Gravitations:

- Just start to be sensitive to RS Graviton
- Black holes excluded between 4 and 6 TeV depending on the model.

Backup

1.4) How things happens in reality

Our approach is

« Final state » driven

- O(100) channels.
- Reconstruct objects:
  - <u>Leptons</u>: e, μ, ν=MET, tau.
  - <u>Quarks</u>: q,g=jets, top.
  - <u>Bosons</u>: W, Z, γ.
- Estimate Backgrounds: Data driven methods
- Estimate efficiencies/uncertainties
- Unfold if necessary
- Converts SM measurements into Exotic searches.

- A group combine and pilot individual channels.
- Analyses more « Model driven »

« Theories considered as strategic»

Higgs, SUSY

Benchmark models are set up.

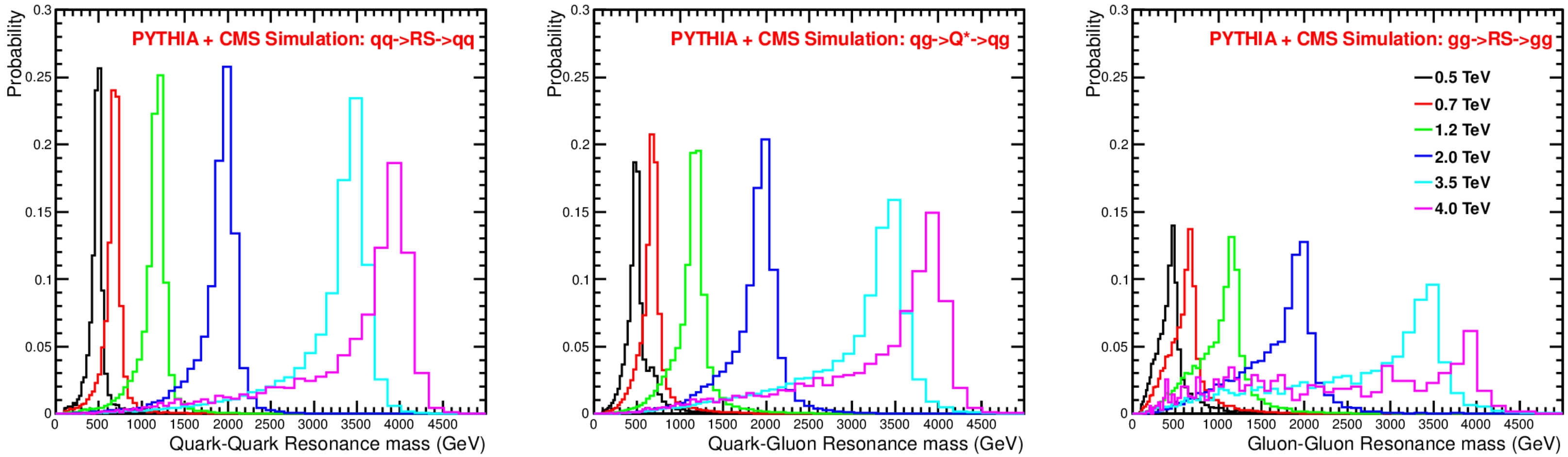
Most of analyses try to stay « model independent »

Typical benchmark models :

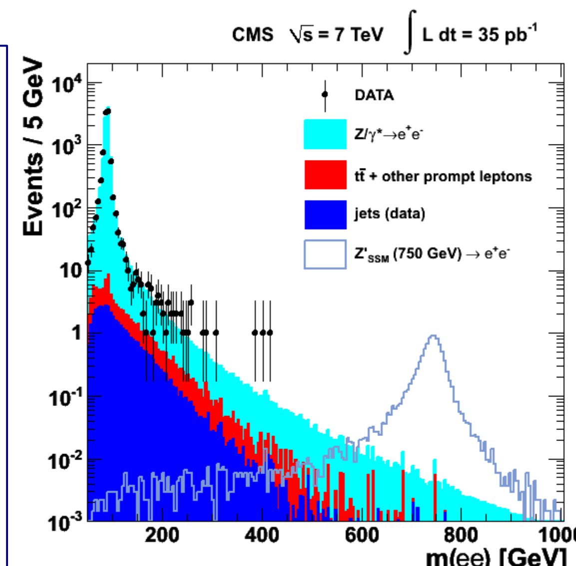
Resonance Mass vs Width

« Other Theories zoology »

1.5) Search for strongly coupling bosons: Dijets



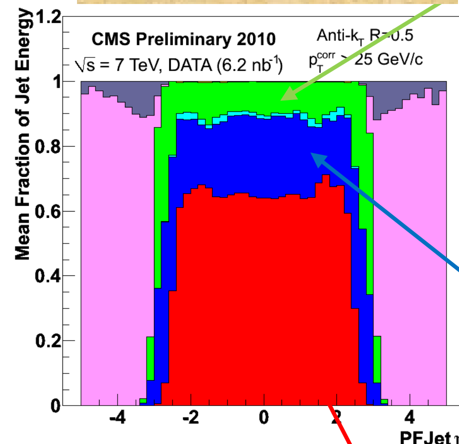
- Two jets with |Δη|<1.3.
- The only background which matters is QCD: use empiric function.



1.3) Jets reconstruction: Particle Flow algorithm

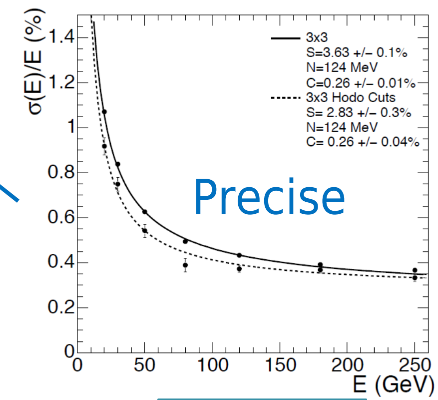
- Using the combination of all available detectors to reconstruct and identify particles (π, γ, K0, μ, e)
- Low p_T π: precision dominated by the tracker.
- High p_T π: precision dominated by calorimeters.

PAS-PFT-10-003



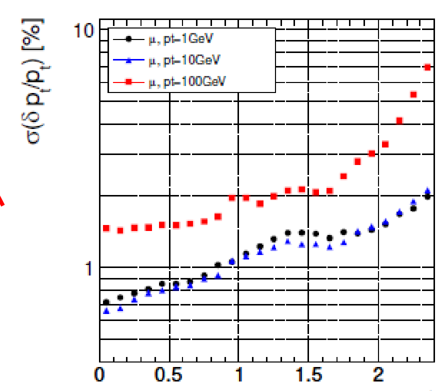
HCAL:
120%/ √E + 6.9%

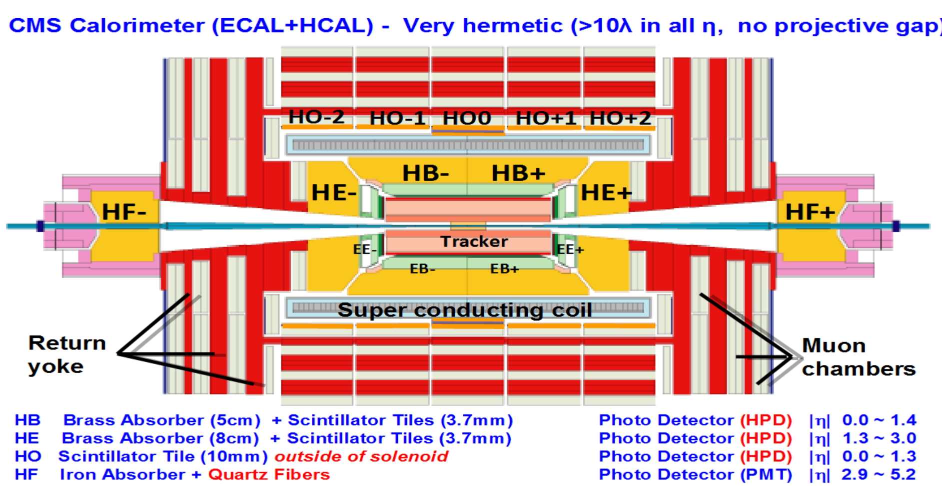
ECAL



Precise

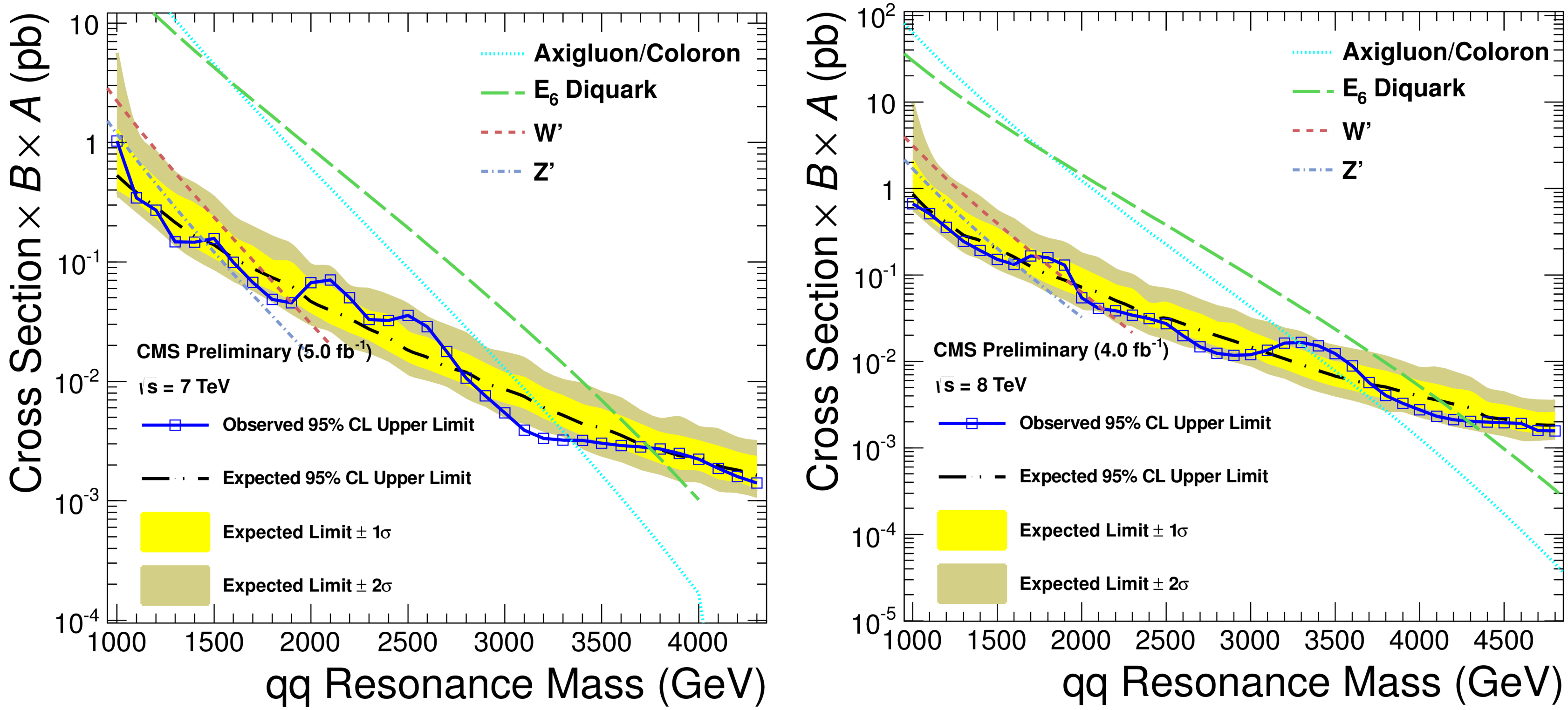
Tracker





Precise

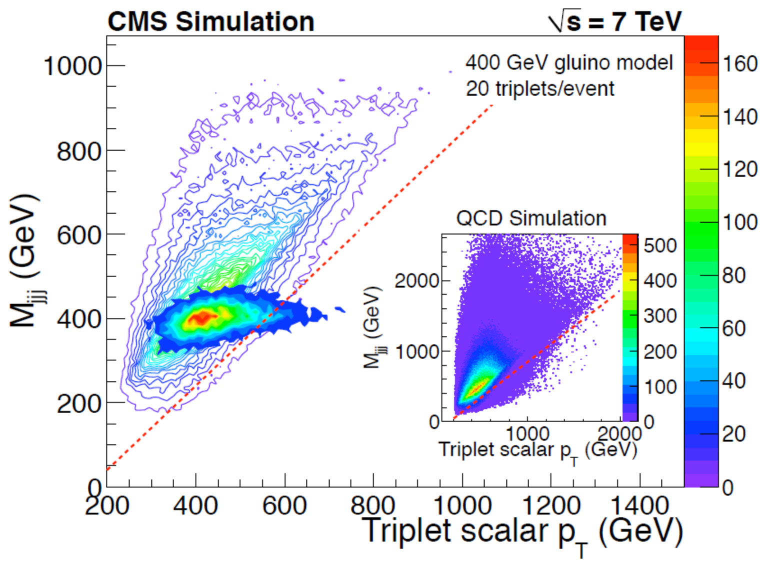
1.8) Search for strongly coupling bosons: Dijets

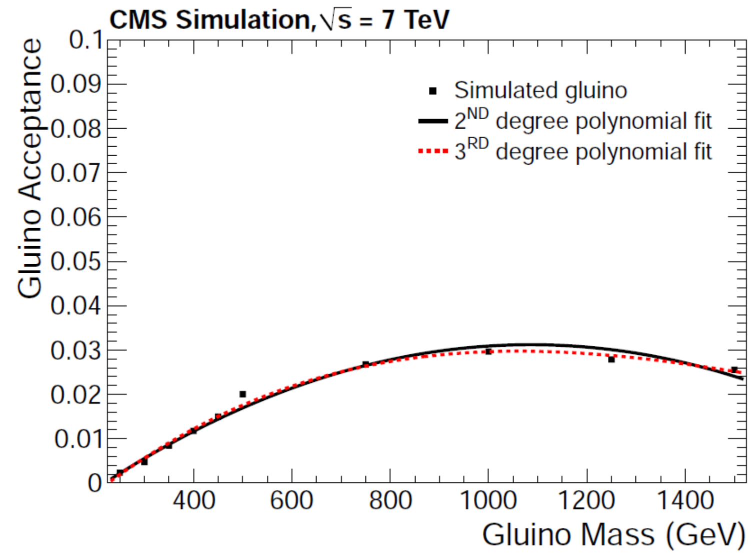


- Two jets with $|\Delta\eta|<1.3$.
- The only background which matters is QCD: use empiric function.

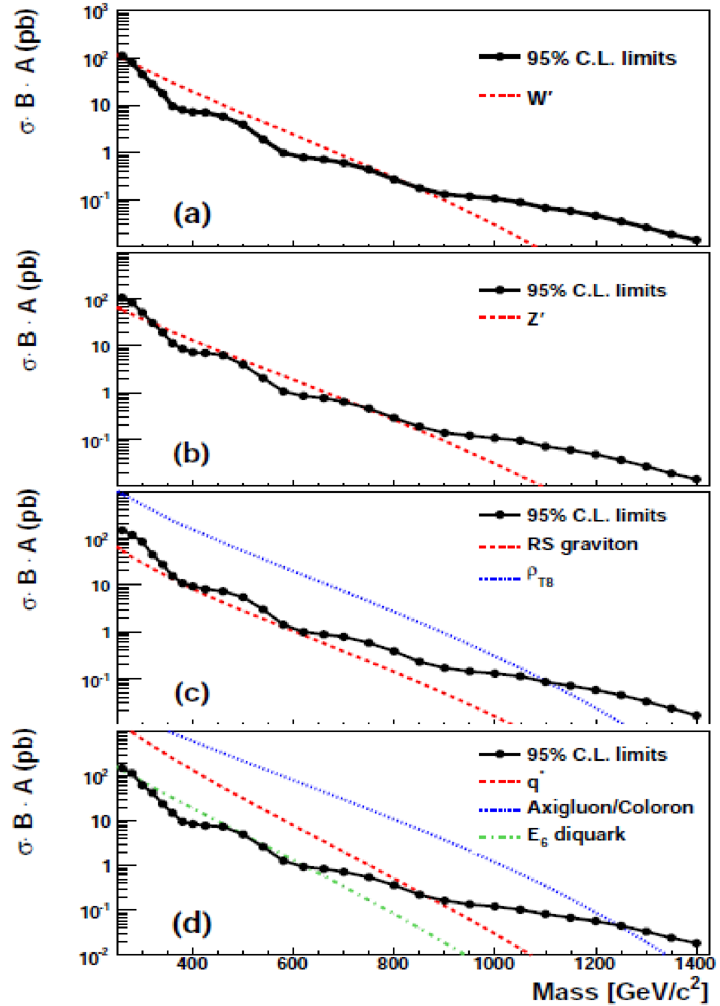
3.7) Paired 3-jets search

- Pair production:

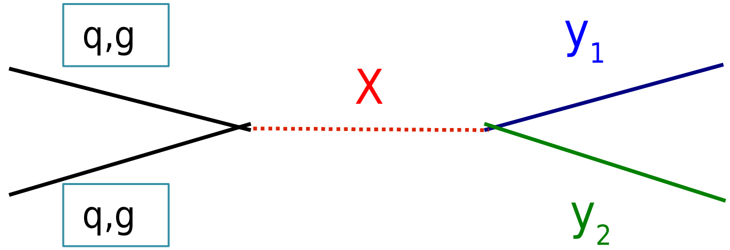




CDF limits at 1.12 fb-1



0.2) The way we work: example of S-channel



$X \to y_1 y_2$ channel
M(X), S_T

<u>Need a width hypothesis</u>

1) "Narrow width hypothesis":
Width < Reso.
2) Scans for different width hypotheses.

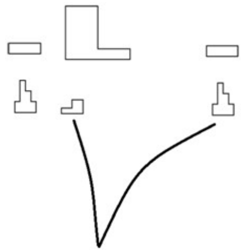
Set « model independant » limits

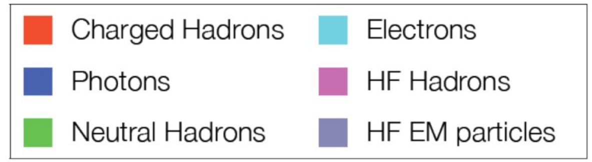
<u>Correct for $Br(X \to y_1 y_2)$</u>

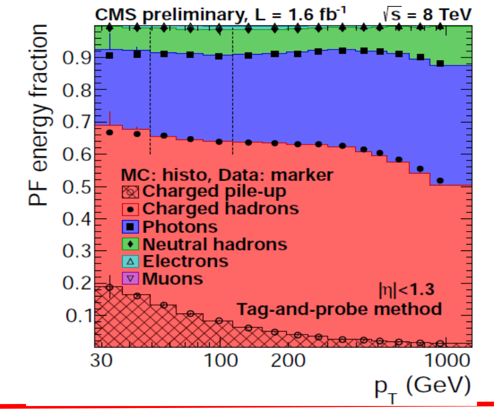
1) Br fixed by the Gauge group and coupling: axigluons.
2) Br a free parameter: W', Z'
- One can mimic the standard model.
- Take indirect constraint from loops.

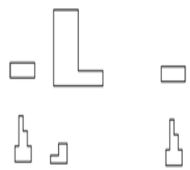
Set model production limits

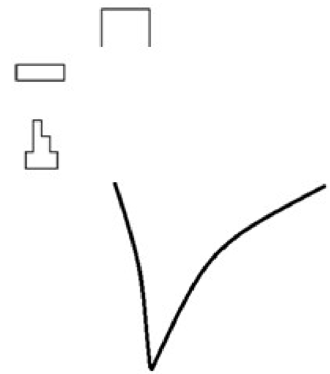
1.3) Jets energy scale and resolution

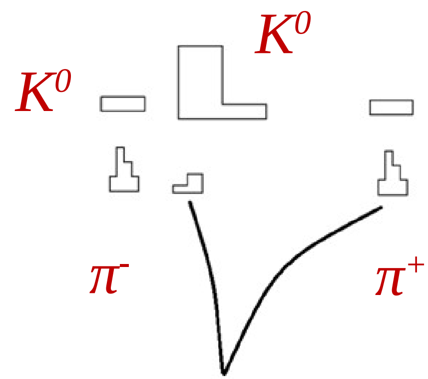












Calo towers jet

- Large corrections: nonlinearity of the response to hadrons. Bended $\pi^{\pm}$.

Jet + Tracks

- Add bended $\pi^{\pm}$.
- Replace for $\pi^{\pm}$ average E(calo) by P(tracks).

PF jets

Remove fluctuations for $\pi^{\pm}$ measurement

$\sigma(\%) \sim f\, \sigma_{\pi\pm,K0}/E_{gen}$

$\sigma(\%) \sim \sigma_{\pi\pm,K0}/E_{gen}$

$\sigma(\%) \sim \sigma_{K0}/E_{gen}$

Core Physics and Data Parking at CMS

- The "core" proton-proton (pp) physics program of CMS at $\sqrt{s}$=8 TeV is realized using collision data collected at an average event rate of 300-350 Hz [corresponding to a peak (average over-the-fill) LHC instantaneous luminosity of approximately 7×10^{33} (4×10^{33}) $cm^{-2}\ s^{-1}$]
- The core data are promptly reconstructed at CERN Tier0 and are generally available within 48 hours for physics analysis

- Extra **300-350 Hz of "parked" data** are collected to **extend the physics program:** standard model measurements and searches for new physics
- The triggers defining the parked datasets are either a looser version of the core physics triggers (for instance with reduced p_T thresholds on the reconstructed objects) or brand-new triggers with small overlap with the rest
- These data are temporarily "parked", waiting to be reconstructed towards the end of the 2012-13 data taking (or earlier, if computing resources are available)
- This provides a complementary set of collision events to perform new physics analyses or improve the existing ones (thanks to the increased acceptance) during the 2013-14 LHC shutdown

Data Parking Triggers (1)

Trigger Selection for Data Parking	Main Physics Motivation	Average Rate (Hz) over typical LHC fill	Tighter / complementary version in the "core" trigger menu
M_{jj}>650 GeV , $\|\Delta\eta_{jj}\|$>3.5	Generic final state produced via Vector Boson Fusion (VBF)	130	QuadJet75_55_38_20: 1 b-jet + 2 "VBF" jets
At least 4 jets with p_T>50 GeV (QuadJet50)	Pair production of stops → top (hadronic decay) + neutralino in models with small mass splitting between stop and neutralino	75	QuadJet60 + DiJet20 OR QuadJet70
R^2*M_R>45 GeV + R^2>0.09	Extend SUSY hadronic searches with "razor" variables (M_R,R^2): compressed mass spectra and light stop searches	20	R^2*M_R>55 GeV + R^2>0.09 + M_R>150 GeV
H_T>200 GeV , α_T>0.57	Extend SUSY hadronic searches with α_T variable	10	H_T>250 GeV , α_T>0.55 H_T>250 GeV , α_T>0.57 H_T>300 GeV , α_T>0.53 H_T>350 GeV , α_T>0.52 H_T>400 GeV , α_T>0.51
Dimuon: $p_T(\mu_1)$ > 13 GeV , $p_T(\mu_2)$ > 8 GeV	PDF constrains using Drell-Yan events at low $M_{\mu\mu}$	10	$p_T(\mu_1)$ > 17 GeV $p_T(\mu_2)$ > 8 GeV
DiTau: $p_T(\tau_{1,2})$ > 35 GeV, $\|\eta(\tau_{1,2})\|$<2.1, isolation, $N_{trk}(\Delta R<0.15)$<5	Include 3-prong tau decays. $h\rightarrow\tau\tau$ measurements: i.e. spin, parity, CP measurement	25	1-prong decay (N_{trk}<3) OR "same" but $p_T(\tau_{1,2})$>30 GeV + 1 jet p_T>30 GeV

3

Data Parking Triggers (2)

Trigger Selection for Data Parking	Main Physics Motivation	Average Rate (Hz) over typical LHC fill	Tighter / complementary version in the "core" trigger menu
$\mu^+\mu^-$: $p_T(\mu\mu)$>5 GeV, |y($\mu\mu$)<2.5|, ΔR<2 , $m_{\mu\mu} \approx m_{\Psi'}$ → [3.35,4.05] GeV	Quarkonium physics (polarization, χ_c, χ_b, exotic states, etc..)	5	Dimuon triggers $p_T(\mu_{1/2})$ > 17/8 GeV (high p_T Ψ')
$\mu^+\mu^-$: $p_T(\mu\mu)$>8 GeV, |y($\mu\mu$)<2.5|, ΔR<2 , $m_{\mu\mu} \approx m_{J/\Psi}$ → [2.8,3.35] GeV	As above	35	Dimuon triggers (high p_T J/Ψ) or displaced triggers for J/Ψ from B decays
$\mu^+\mu^-$: $p_T(\mu\mu)$>5 GeV, |y($\mu\mu$)<2.5|, ΔR<2 , $m_{\mu\mu} \approx m_{\Upsilon}$ → [8.5,11.5] GeV	As above	10	$p_T(\mu^+\mu^-)$>7 GeV
$\mu^+\mu^-$: $p_T(\mu)$>3.5 GeV, |$\eta(\mu)$<2.2|, $p_T(\mu\mu)$>6.9 GeV, displaced vertex wrt beam, $m_{\mu\mu}$ = [1.0,4.8] GeV	Rare B decays with low mass dimuons (displaced)	20	$p_T(\mu)$>4 GeV $m_{\mu\mu} \approx m_{J/\Psi}$ → [2.9,3.3] GeV
1 jet + 1 muon: p_T(jet)>20 (60) GeV, $p_T(\mu)$>4 GeV, $\Delta R(\mu$,jet)<0.4 ***Prescale = 300 (30)***	Select unbiased sample of signal (hadronic decays of D's, B's) using the recoil of a triggered b-jet	10 (5)	2 jets + 1 muon: p_T(jet)>20,40,70 GeV $p_T(\mu)$>5 GeV, $\Delta R(\mu$,jet)<0.4 , larger prescale