The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

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Beyond the Standard Model: Results with the 7 TeV LHC Collision Data

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Search for Dijet Resonances at CMS

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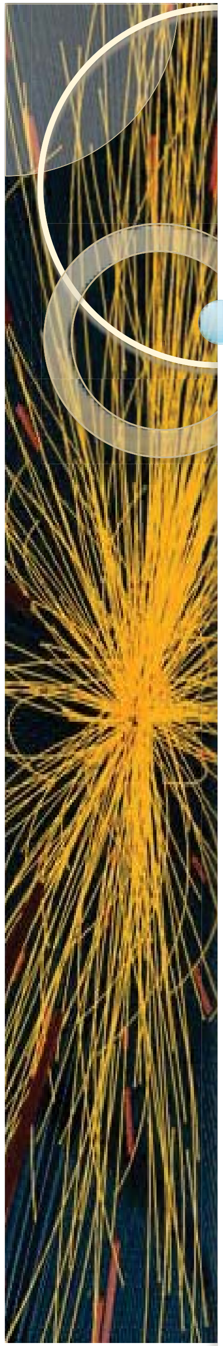

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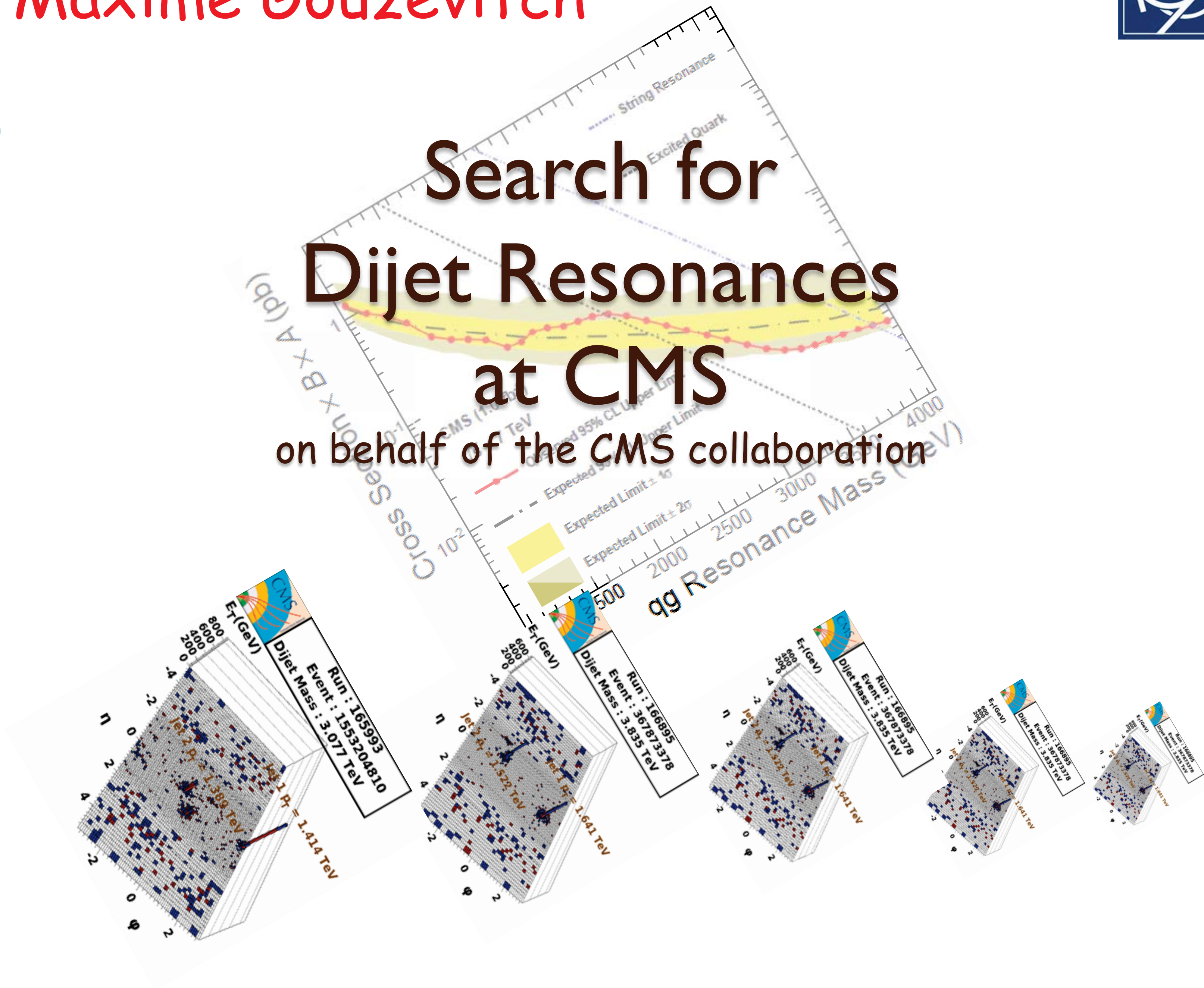
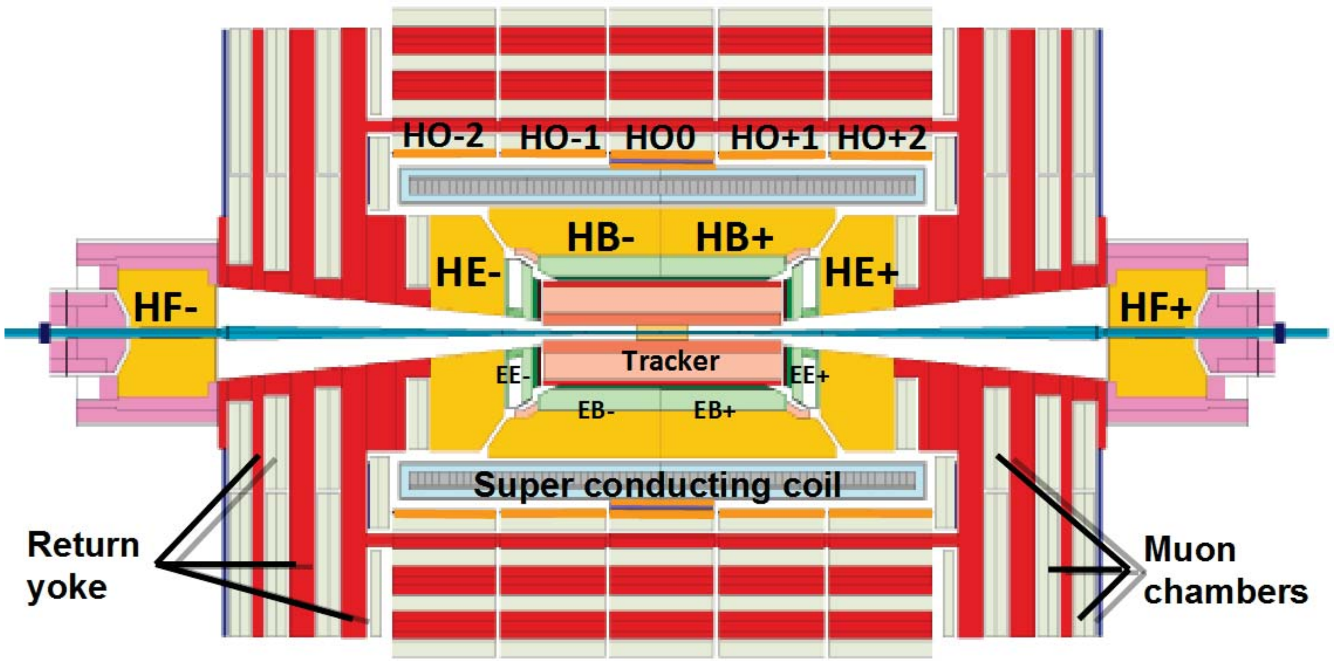


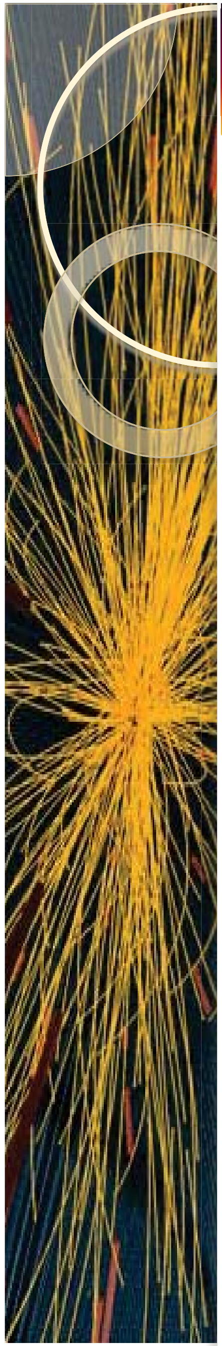
on behalf of the CMS collaboration

0) Where do we stand

CMS detector have collected 3 fb^{-1} @ 7 TeV (1 fb^{-1} in July).

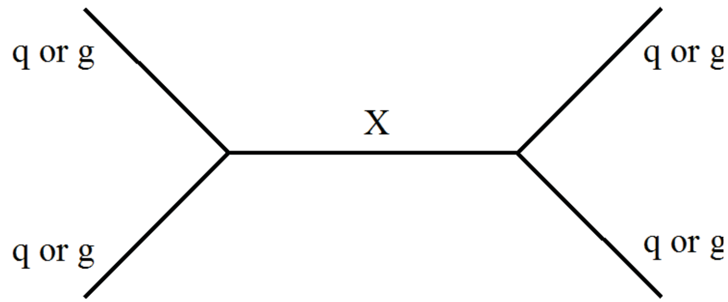
1. Dijet final state provide a "simple" and robust handle to new physics at high mass O(TeV).
2. CMS detector perfectly adapted for high p_T jets ~ O(0.1 TeV) physics.
3. Search for Contact Interactions (CI).
4. Generic Search for Narrow Resonances.



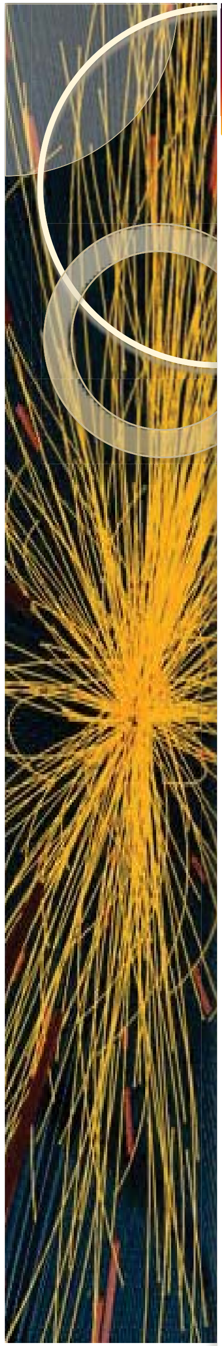


1) What are we looking for

- Search for Heavy Resonances ($M_X \sim O(\text{TeV})$) : qq (Z',W',Axigluon), qg (Q*), gg (RS Graviton).
- Search for Contact Interactions.
- Sensitive mainly to strongly coupling interactions due to the large QCD cross section:
  - Very robust channel not affected by any EW background → first EXOTICA analysis published when new data comes.
  - Large background.
  - Quickly rising trigger thresholds

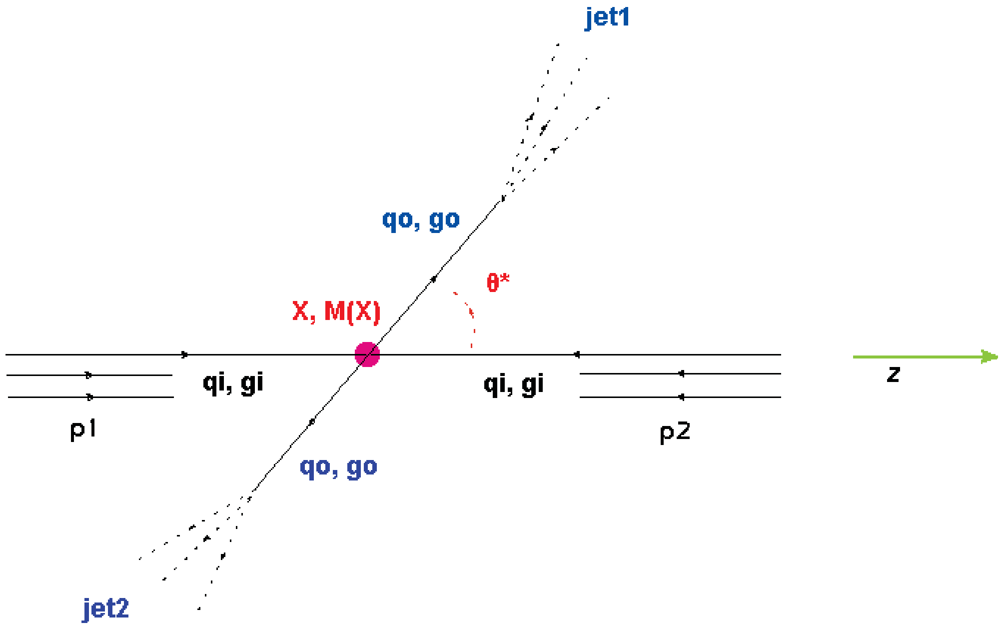


2.1) The phase-space: Di-jet kinematics.



Final state described by 2 variables

Those variables are nearly uncorrelated



$$M_X = M_{12}$$

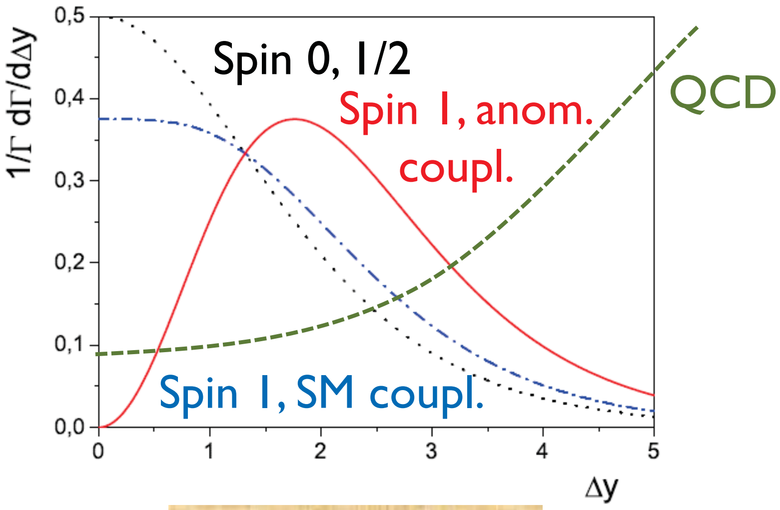
- X mass estimated out of 2-jets invariant mass.

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

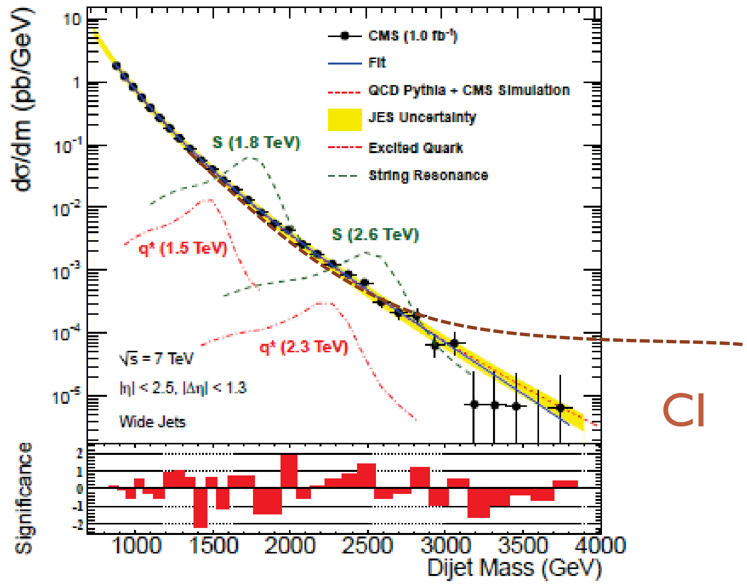
- θ* angle in X rest frame wrt to pp axis
- Linked to $\Delta\eta_{12}$ which is easy to measure
- Distribution dependant of X spin.

2.2) The phase-space: definition.

1. $|\eta_{jet}| < 2.5$: Low – Resonance and CI; Large – QCD.
   - Corresponds to the tracker acceptance: best resolution and jet id.
2. $|\Delta\eta_{12}| < \Delta\eta_{max}$: Low – Resonances and CI; Large – QCD.



arXiv:1010.2648

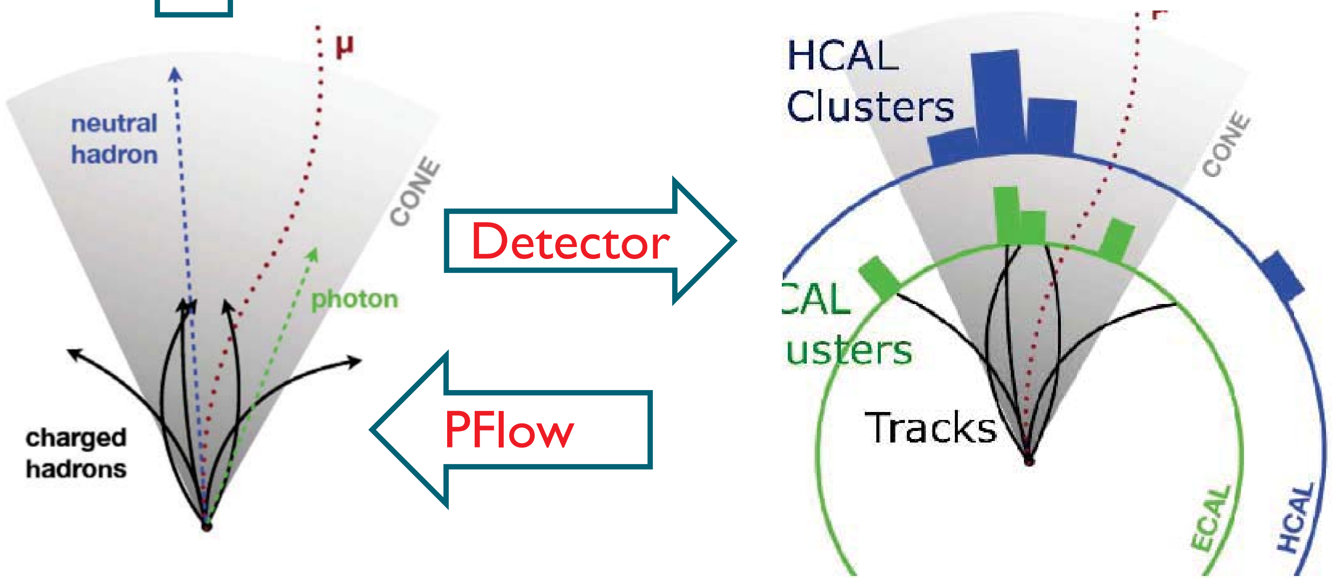


3. $M_{12} > M_{min}$: Bump – Resonance; Excess at Large Mass – CI.
   - M_{min} depend on the trigger turn on curve.
     Instantaneous luminosity * 10 $\rightarrow M_{12,\,min} * 1.5$

3) Jets reconstruction: different methods

PF jets
made of Reco PF Particles

Calo jets
made of Calorimeter towers



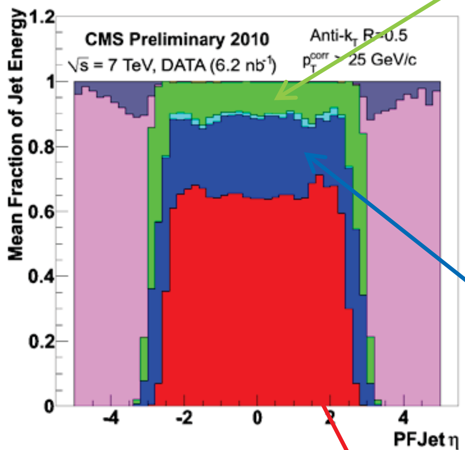
Gen Particles
Reco PF Particles

Clusters and tracks

3) Jets reconstruction: Particle Flow algorithm

- Using the combination of all available detectors to reconstruct and indentify particles (π, γ, K_0, μ, e)
- Low p_T π: precision dominated by the tracker.
- High p_T π: precision dominated by calorimeters.

PAS-PFT-10-003



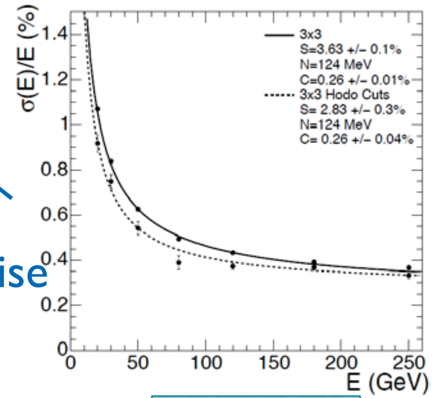
Precise

Precise

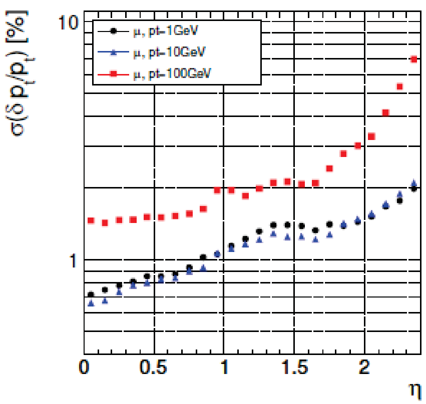
HCAL:

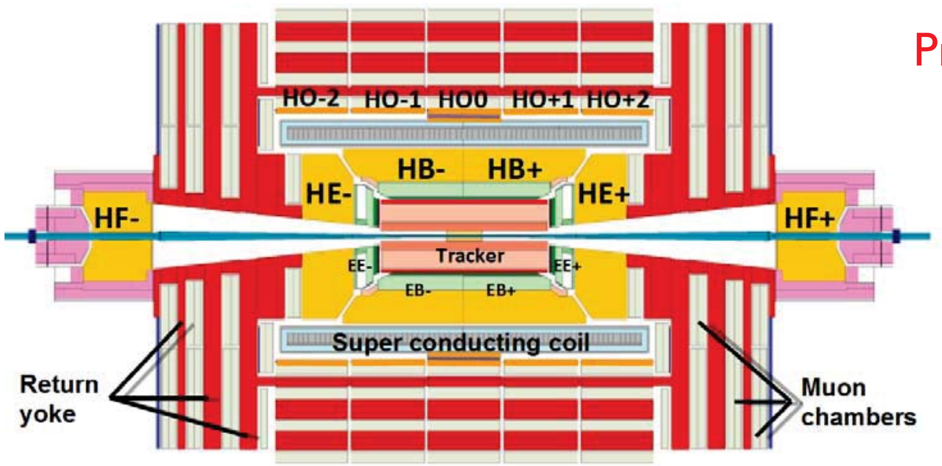
120%/ $\sqrt{E}$ + 6.9%

ECAL



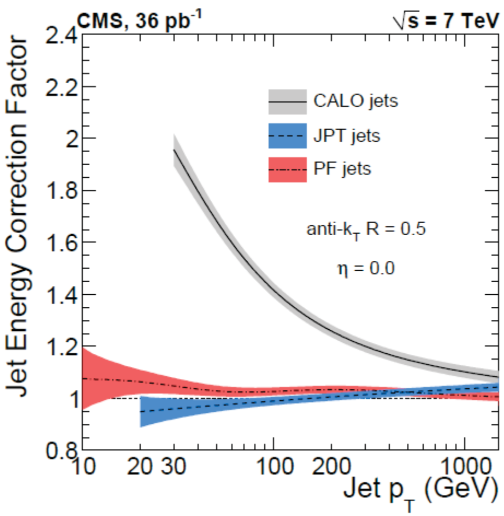
Tracker

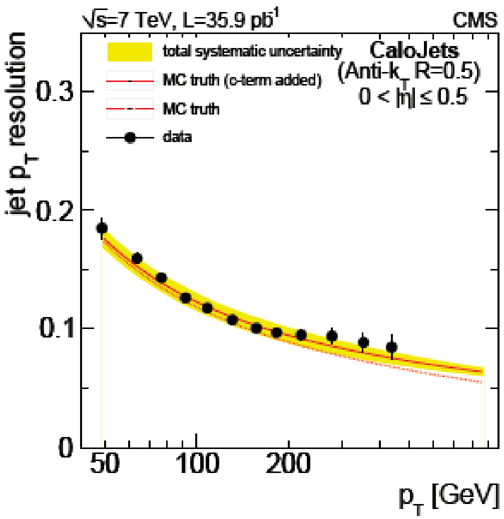


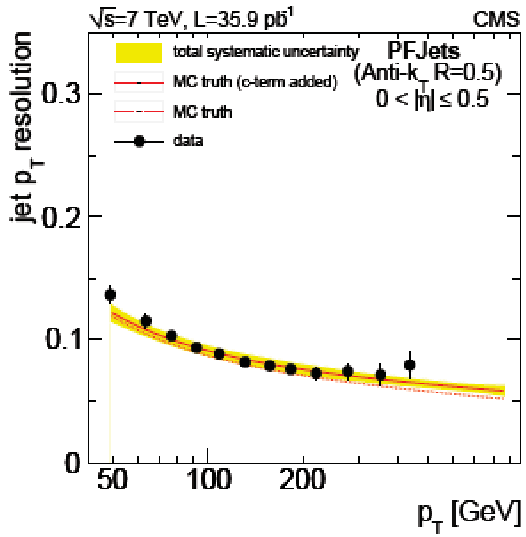


3) Jets reconstruction: Performances

- Particle Flow approach brings Reco jets close to Gen jets.
- Give access to jets with p_T > 10 GeV.
- Keep the JER better than 15%: JER uncertainty – 10%.
- Jet energy scale: JES uncertainty – 2.2%.







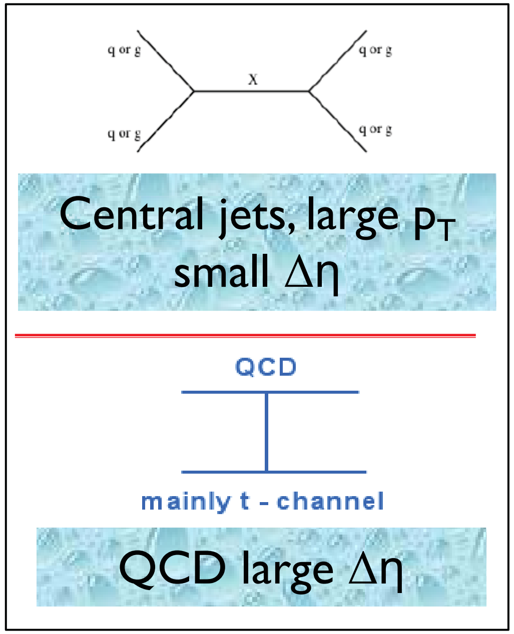
arXiv:1107.4277

4.1) Search for Contact Interactions

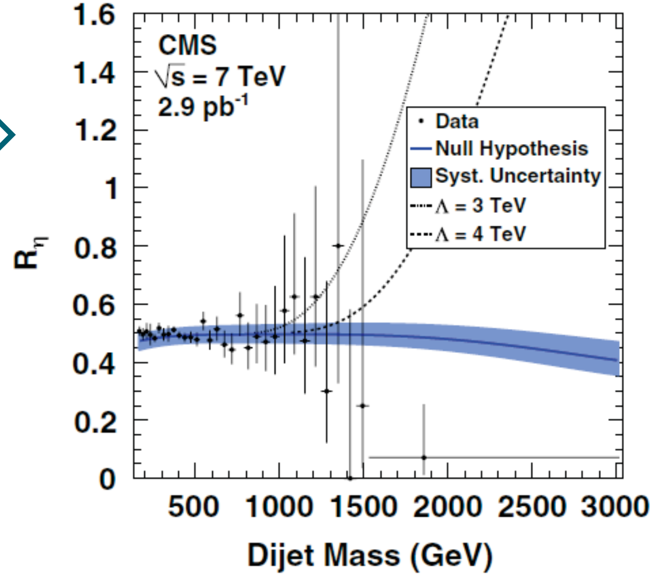
- A non-renormalizable dimensional coupling g.
- Suppressed by a large scale Λ reflecting the physics at a new scale.

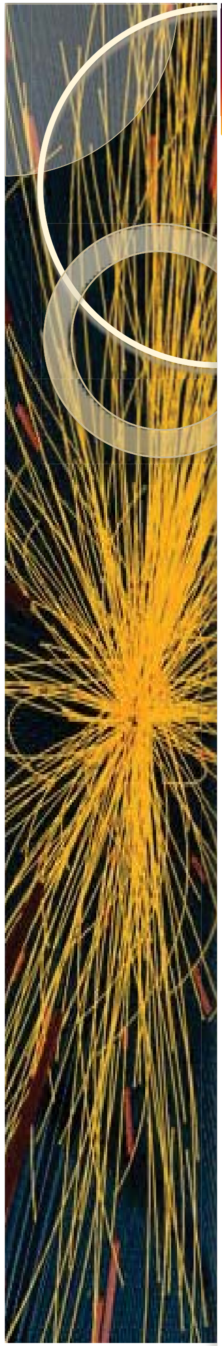
$$L_{qq} = \frac{g^2}{2\Lambda^2}\left[\eta_{LL}(\bar{q}_L\gamma^\mu q_L)(\bar{q}_L\gamma_\mu q_L) + \eta_{RR}(\bar{q}_R\gamma^\mu q_R)(\bar{q}_R\gamma_\mu q_R) + 2\eta_{RL}(\bar{q}_R\gamma^\mu q_R)(\bar{q}_L\gamma_\mu q_L)\right]$$

- CI expected at low $\Delta\eta_{12}$ and large M_{12}.
- QCD at large $\Delta\eta_{12}$ and low M_{12}.



$$R = \frac{N_{evt}(|\eta_{jets}| < 0.7)}{N_{evt}(0.7 < |\eta_{jets}| < 1.3)}$$

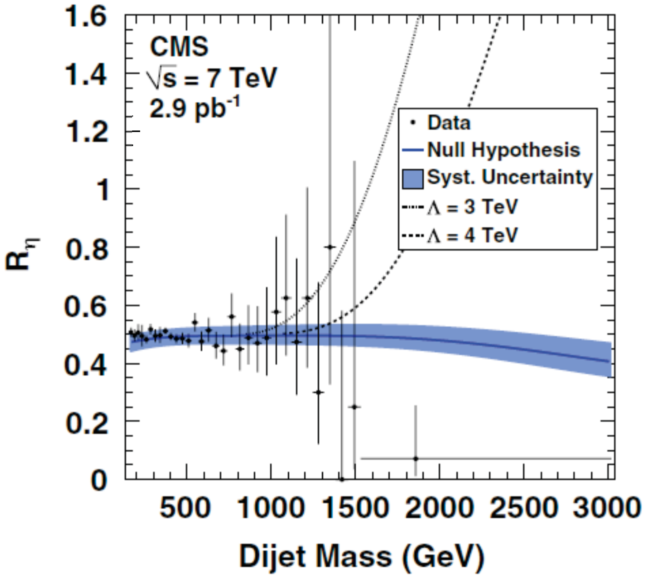




4.2) Search for Contact Interactions

- Cancellation of systematic unc. In the Ratio:
  - Total exp. unc. (JER, JES): 3-5%
  - Total theory unc. (NLO, PDF, Model): 2-7%
- No excess observed.
- We use Bayesian formalism to establish exclusion limits. Bkg. Hypothesis shape from NLO calculations or PYTHIA. Normalization factor taken from data at low mass: M_{12} < 790 GeV.

$$R = \frac{N_{evt}(\,|\eta_{jets}| < 0.7)}{N_{evt}(0.7 < |\eta_{jets}| < 1.3)}$$



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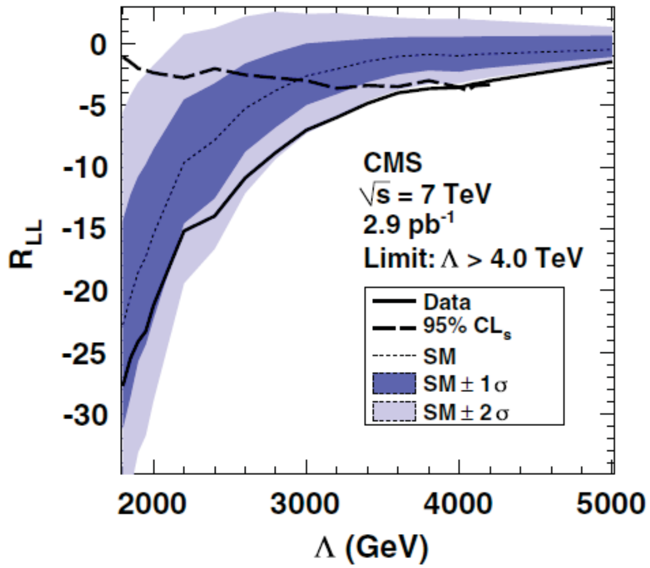
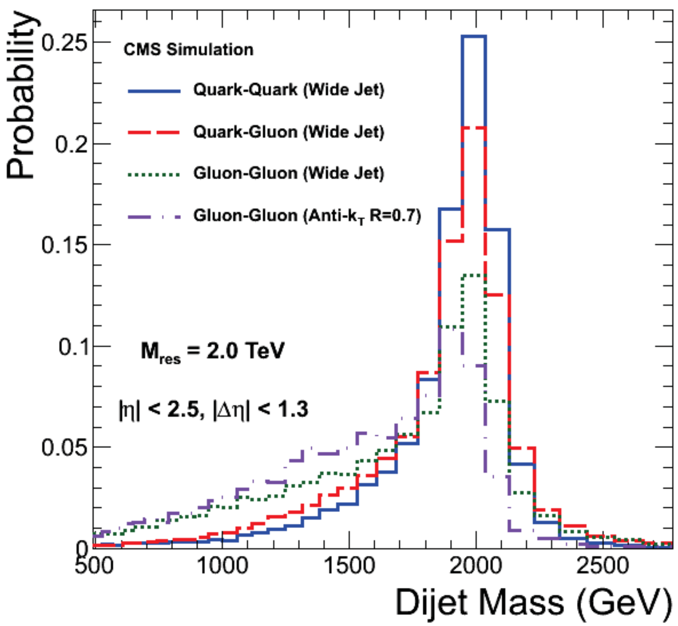
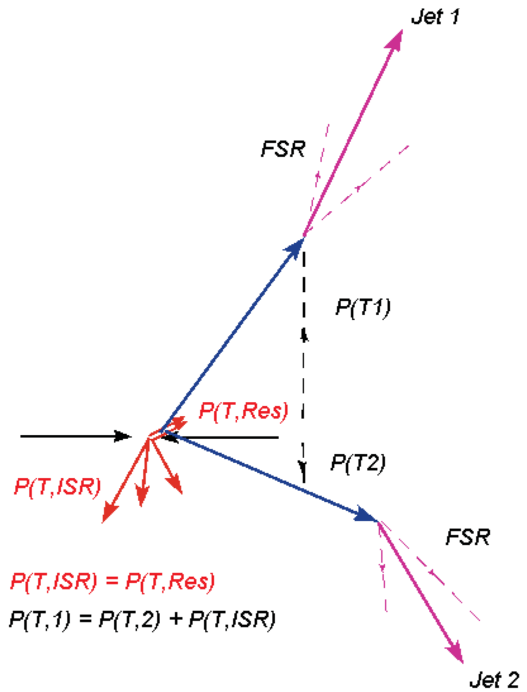


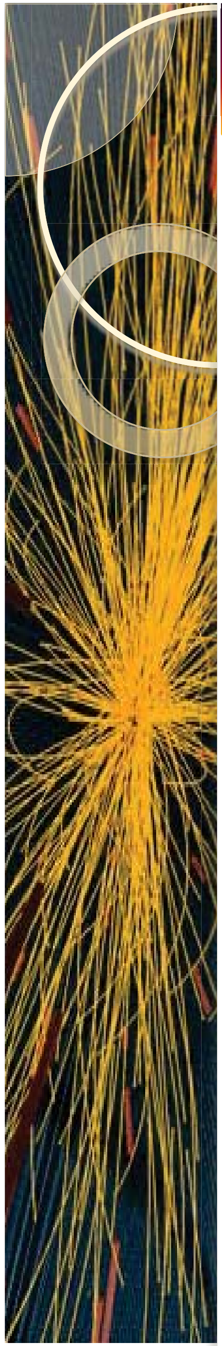
Λ_{LL} < 4 TeV excluded

5.1) Search for heavy resonances

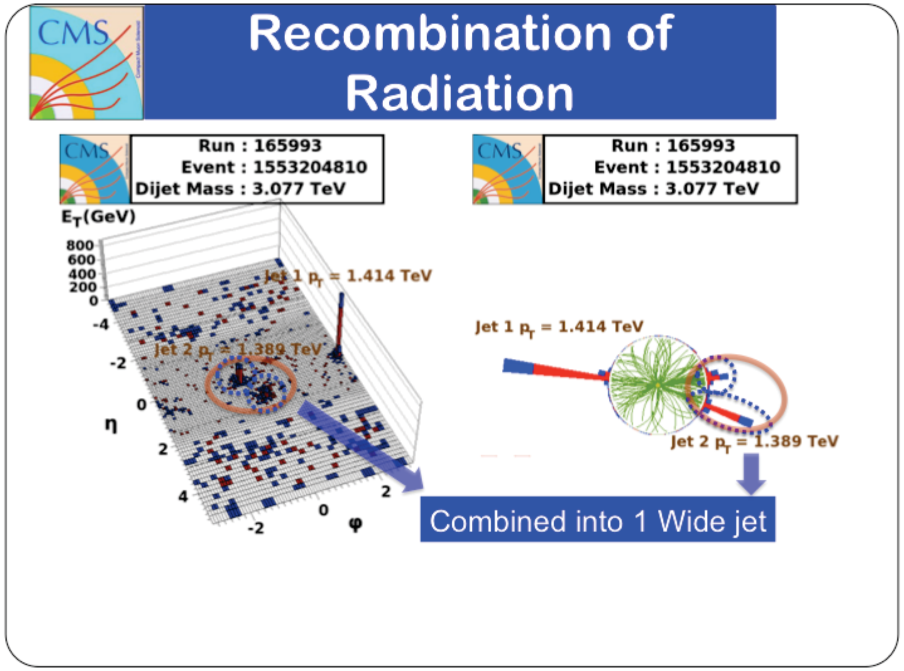
- “Generic” search for narrow heavy resonances - O(1-10GeV).
- Reconstructed mass shape is initially a B-W. Deformed by:
  - Partons luminosity (low mass tail).
  - Loss of Final State Radiation: low mass tail, central gaussian.
  - Catch Initial State radiation: large mass tail, central gaussian.
  - Experimental resolution: central gaussian.





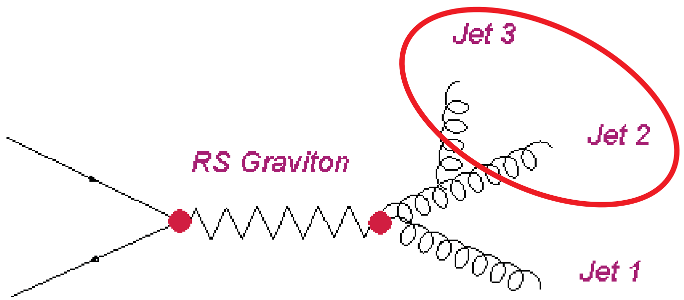


5.2) Search for heavy resonances: Wide jets

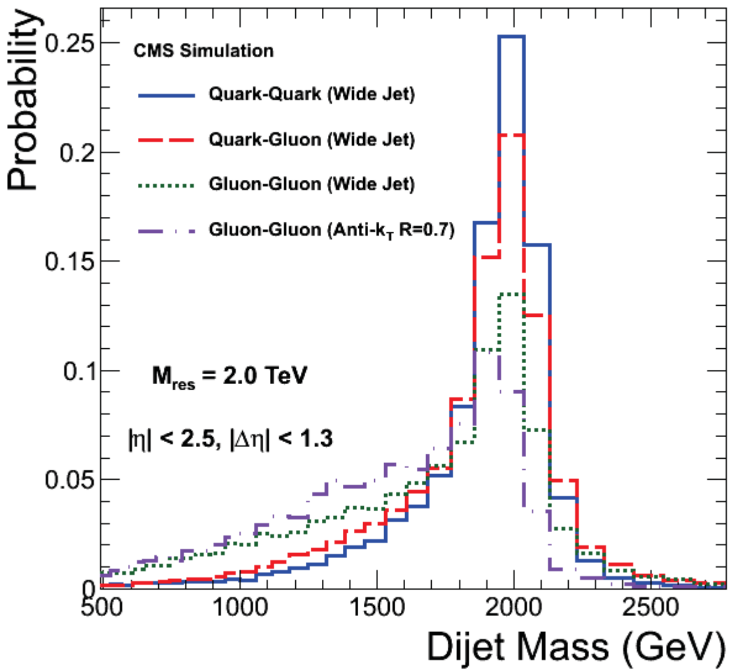


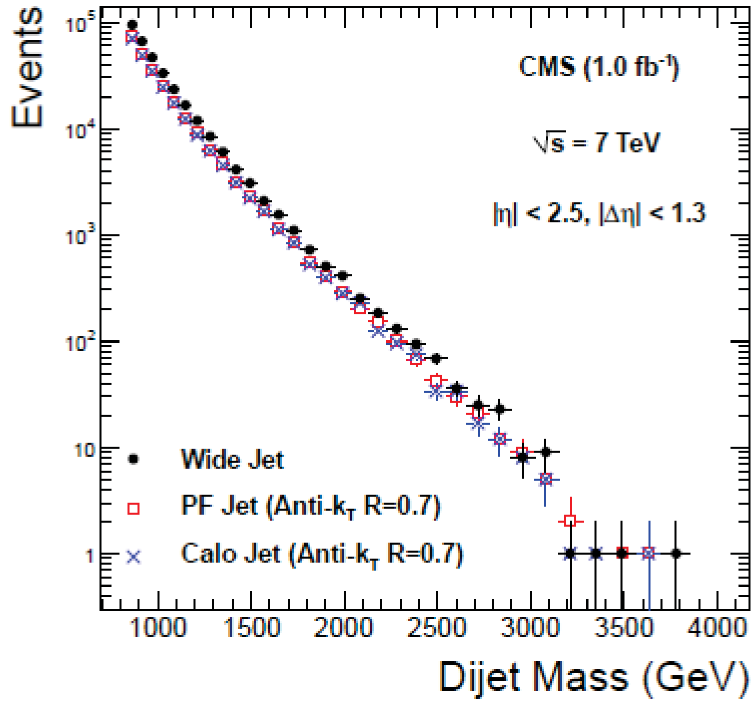
<u>Fat Jets algorithm</u>

- Select 2 leading AK5 PF jets.
- For AK5 PF jets j from 3 to n:
  - Require:
    - $p_{T,j} > 10$ GeV
    - $|\eta| < 2.5$
  - If $\Delta R_{j1} < R_{Fat}$ and ΔR_{2j}.
    - Add j to Fat Jet 1.
  - If $\Delta R_{j2} < R_{Fat}$ and ΔR_{1j}.
    - Add j to Fat Jet 2.



5.3) Search for heavy resonances: Wide jets

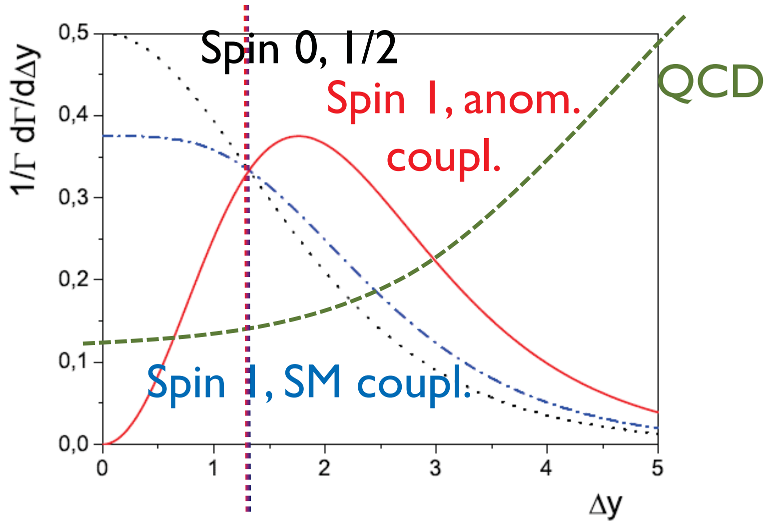




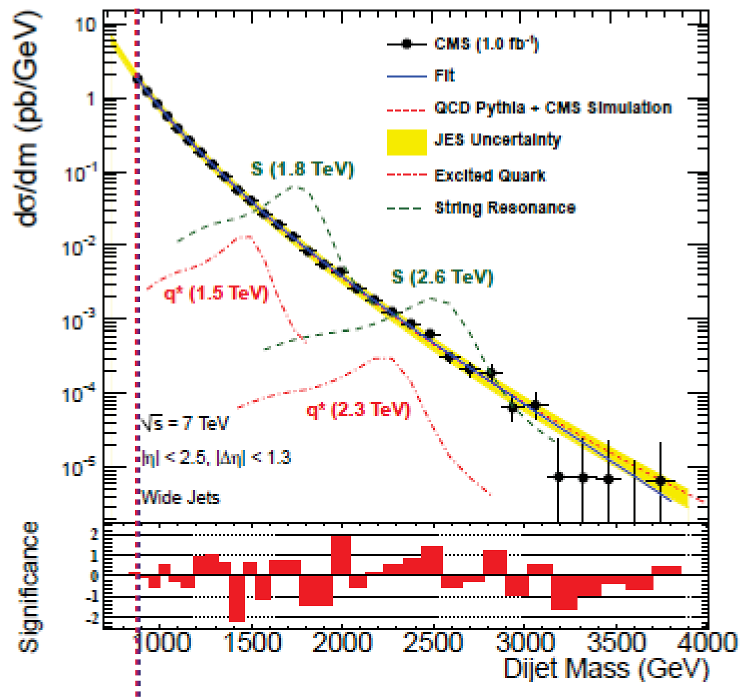
- Large Radius collect most of FSR, but also more ISR and increase the background.
- Usually M_X ↑, R_{opt} ↑.
- Optimal Radius found R_{Fat}=1.1, looking for optimal S/√B.

5.4) Search for heavy resonances: Analysis

1) Fit data with a smooth function (fine for PYTHIA QCD spectrum).
2) Look for excess which looks like generic mass shapes: qq, qg, gg.



$\Delta\eta_{12} < 1.3$

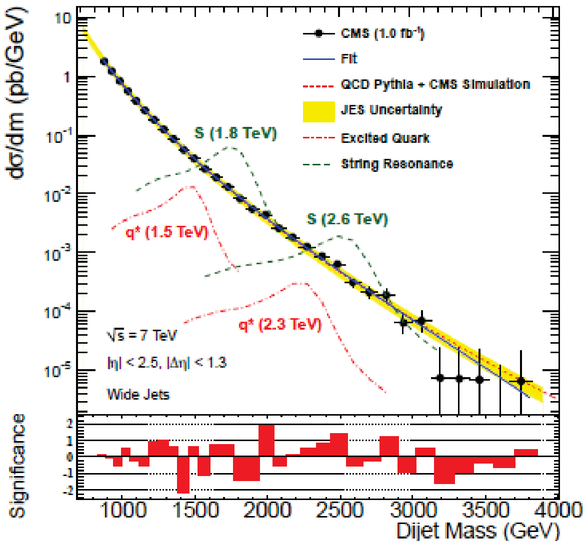


$M_{12} > 838$ GeV

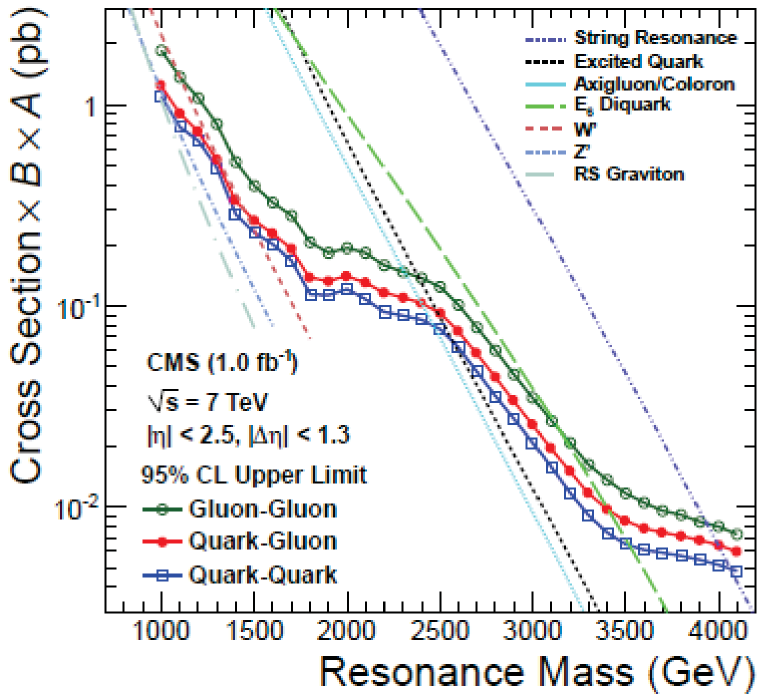
- Phase space:
  - $M_{min} > 838$ GeV : Lowest unprescalled trigger.
  - $\Delta\eta_{12} < 1.3$: optimal $S/\sqrt{B}$ for Q*.
- L=1.1 fb^{-1} (Full July data sample). Lumi uncertainty: 4%
- JES (2.2% on each jet): 15% effect on cross section.
- Different fit functions used to estimate shape systematics.

5.5) Search for heavy resonances: Results

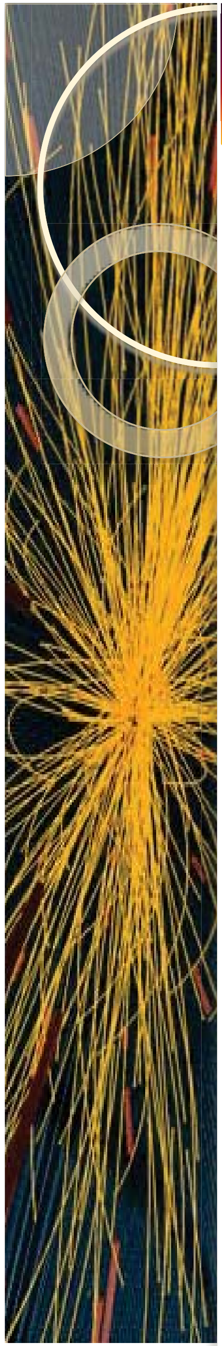
- No significant excess observed.
- We use Bayesian formalism to establish exclusion limits with $CL_{95\%}$.
- Benchmark models written as function of qq, qg, gg final state.
- Exclude strongly coupled benchmark models below 2.5 TeV.
- First EW coupled model: W' excluded below 1.5 TeV.



Model	Excluded Mass (TeV)	
	Observed	Expected
String Resonances	4.00	3.90
E_6 Diquarks	3.52	3.28
Excited Quarks	2.49	2.68
Axigluons/Colorons	2.47	2.66
W′ Bosons	1.51	1.40



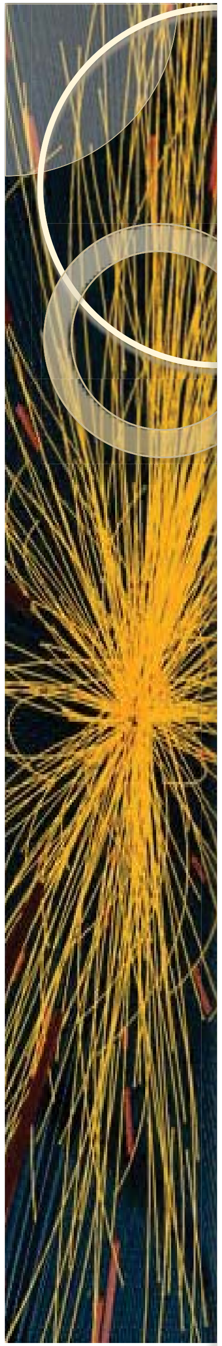
arXiv:1107.4771



We sail in the unknown land

- With the Dijet observable we are in the bulk of the unknown ocean of the TeV physics.
- We exclude above 2.5 TeV many strongly coupling models.
- The Contact Interactions are excluded above 4 TeV.
- W' model with the SM couplings is the first EW "victime" of the Dijet search.
- Need alternative strategies to stay sensitive to Z', RS Gravitons: kill QCD bkg, specific triggers.
- Santa Maria is sailing in the ocean, no land on the horizon.

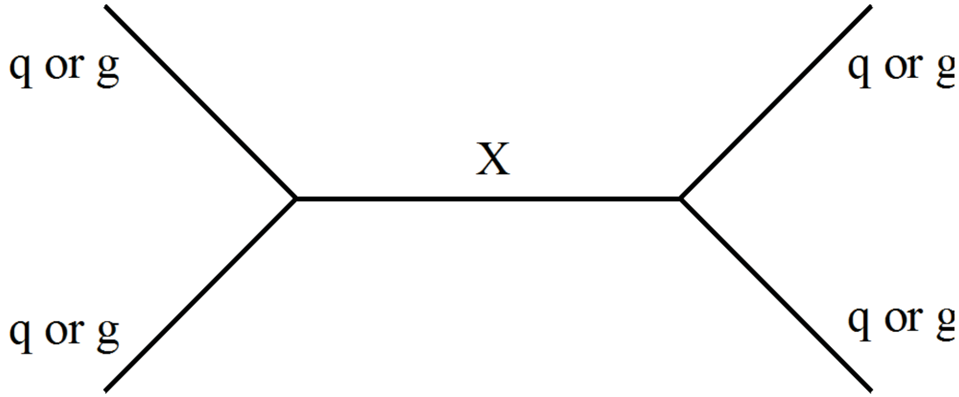
But we believe that we can reach India!!!



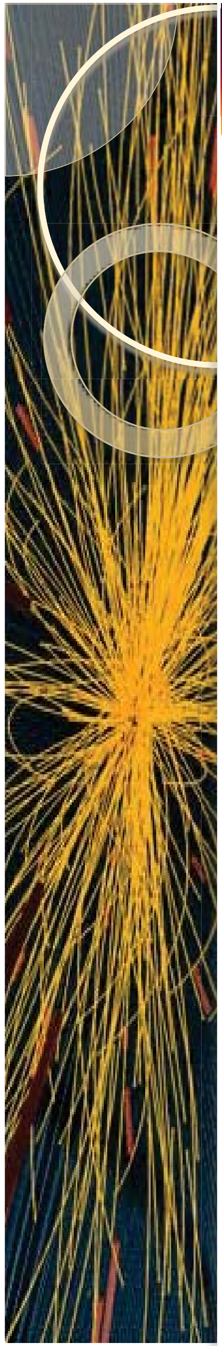
BACKUP

1) Spectrum formula

$$\frac{dR}{dt} = \frac{dL}{dt} * \int_{Mth}^{7TeV} \frac{d\sigma}{dM} dM \propto \frac{dL}{dt} * M_{th}^{-6}$$

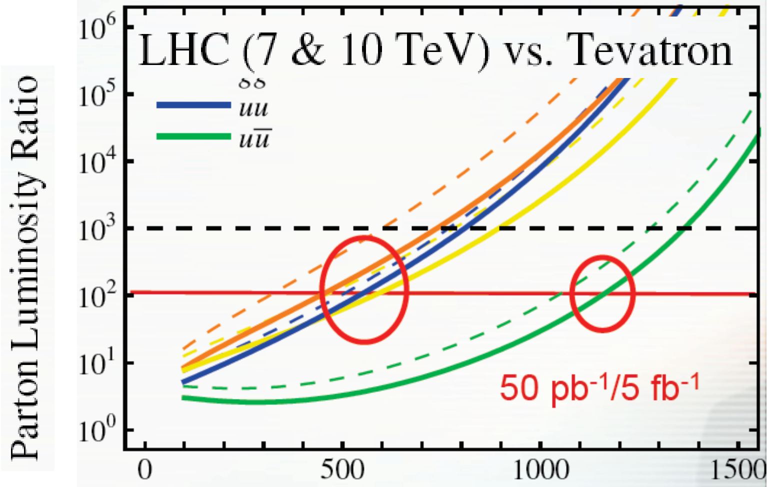


$M_{12} \sim 2p_T\,(1+\Delta\eta^2/8)$



0) Sail direction

- Counting experiments:
  - Raw Generic searches.
- Resonances search:
  - Few assumptions about mass shapes.
- Exclusive searches:
  - Rely on topological details.
- Try to use when possible the in-situ background measurement background. Otherwise rely on MC.



Bauer et al., Phys. Lett. B **690**, 280 (2010)

LHC strategy in 2010:

Parton Lumi > Lumi(Tvt)/Lumi(LHC)
- for all quark, gluon initial state @ 0.6 TeV.
- for quark – antiquark initial stat @ 1.2 TeV