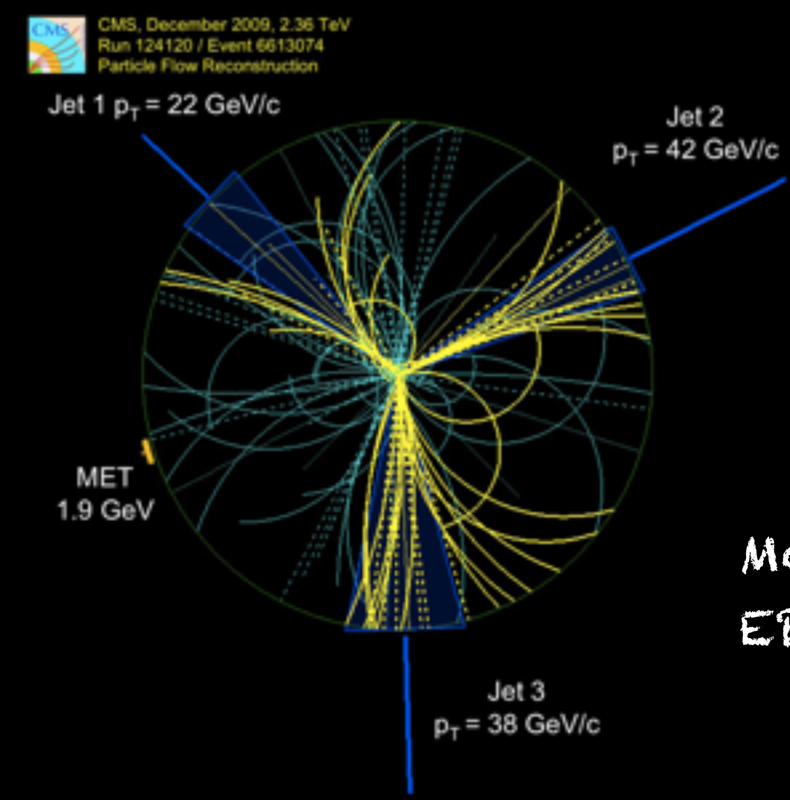
# "Experimental Results from CMS"

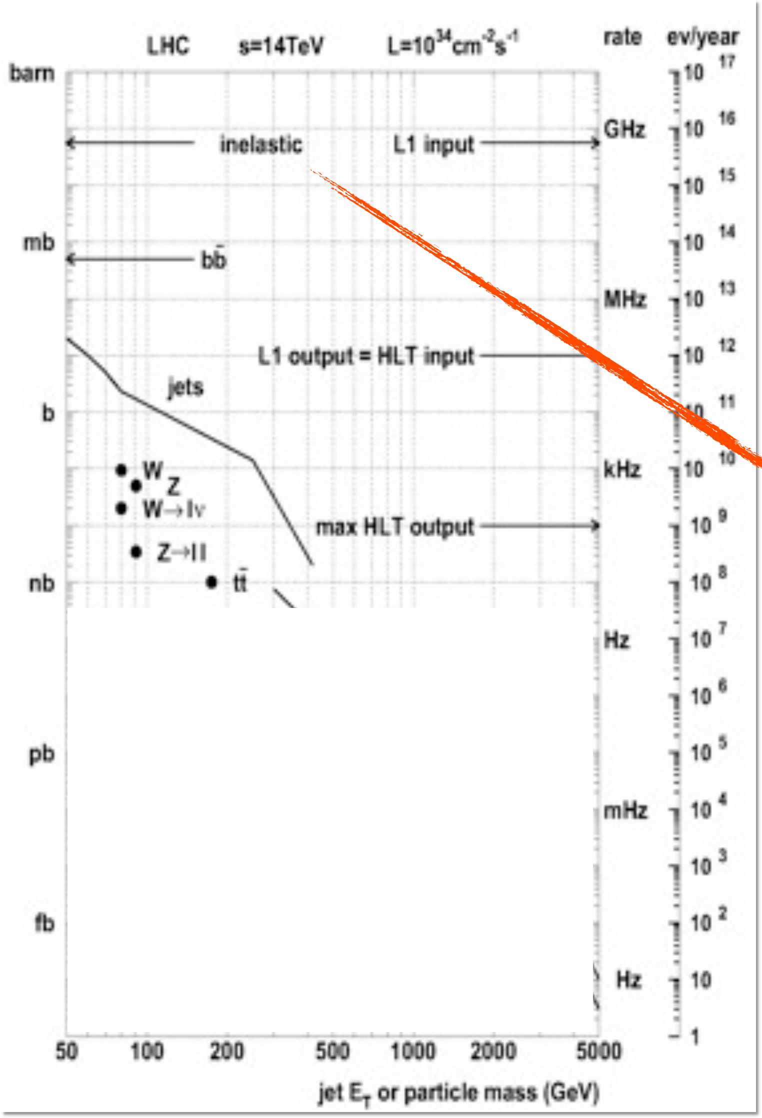



Moratorium on EPS results

Richard Cavanaugh
Fermilab & University of Illinois - Chicago

CTEQ Summer School, Madison Wisconsin
16 July, 2011

# Production Cross Sections at the LHC




- Cross sections and background estimates (measured, calculated) tell us what minimum energy and luminosity we need from the colliding beams and therefore what the detector must be able to handle
- Production dynamics determine the range of energies and angles we need to measure

Inelastic background events produced at a rate of 1 GHz.

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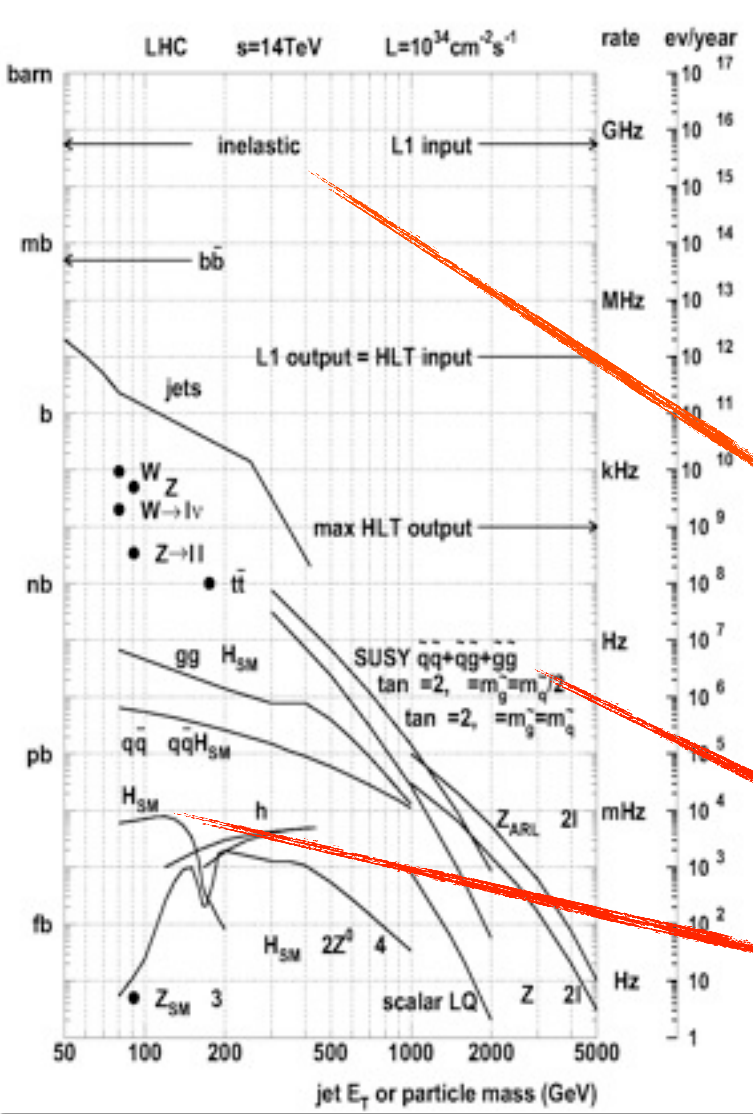


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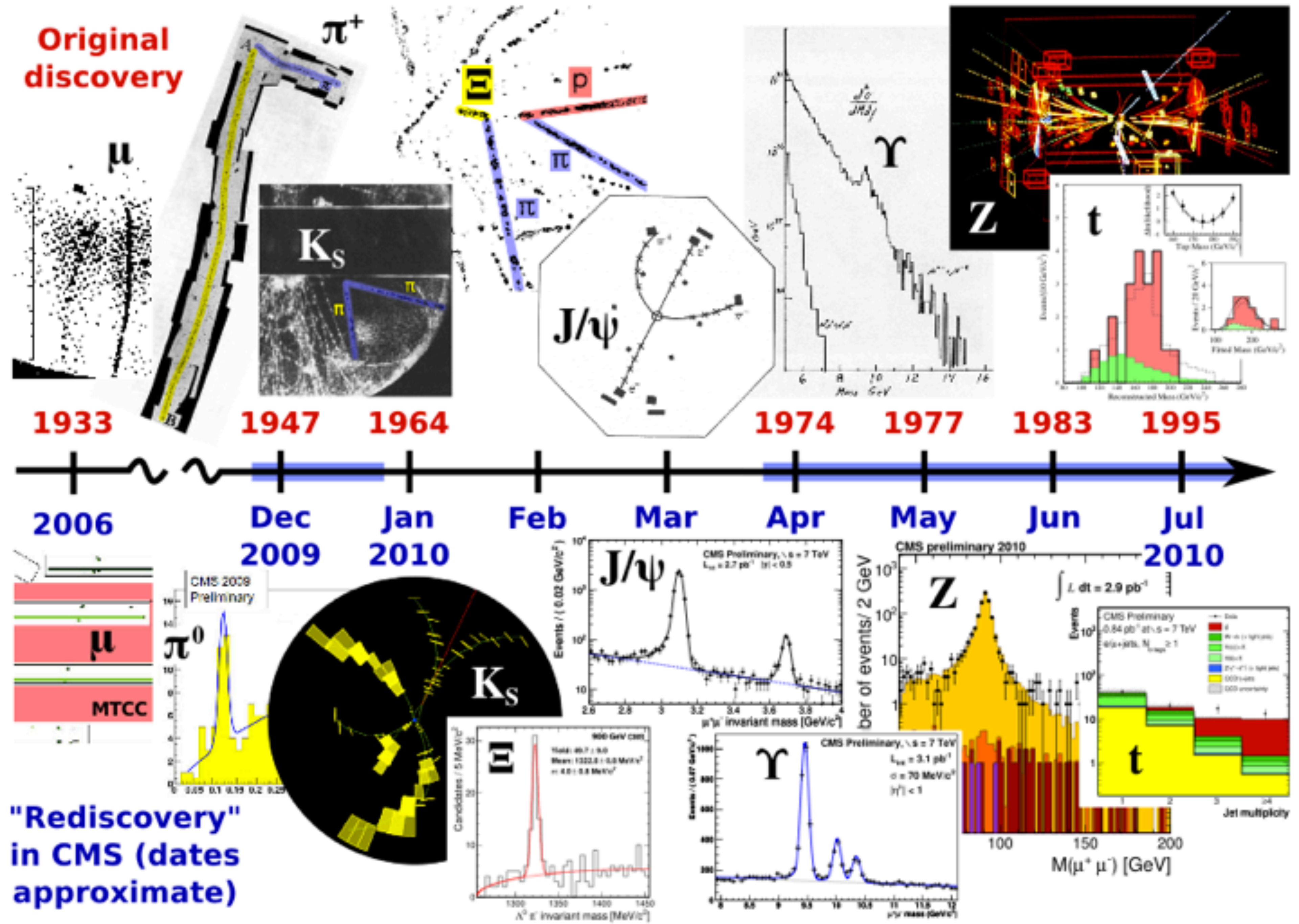
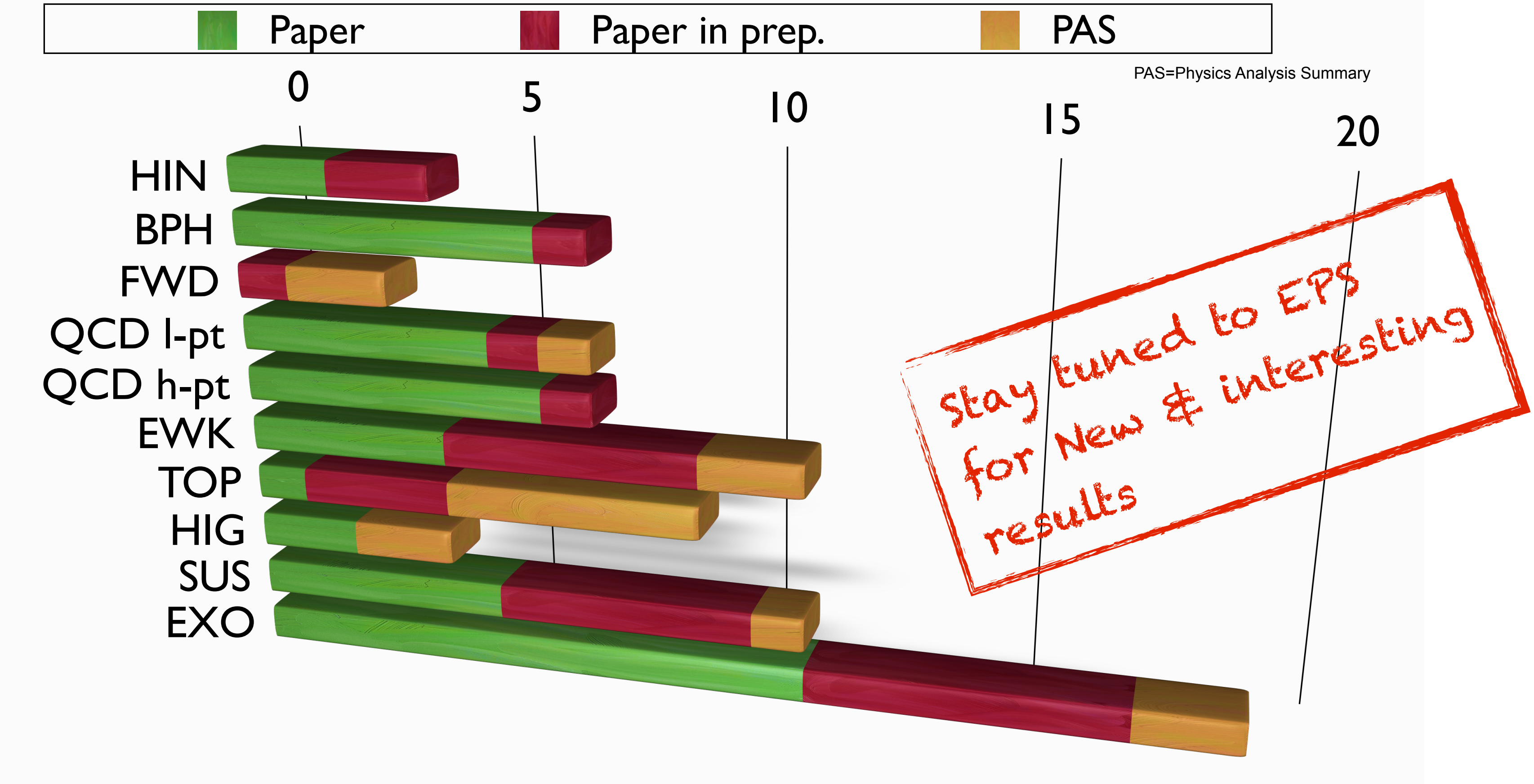
Supersymmetry ~ 1Hz

Detectable Higgs production ~ 1 milliHz


Original discovery
1933
1947
1964
1974
1977
1983
1995
2006
Dec 2009
Jan 2010
Feb
Mar
Apr
May
Jun
Jul 2010
μ
π+
Ks
Ξ
p
π
J/ψ
ϒ
Z
t
MTCC
π0
CMS 2009 Preliminary
CMS preliminary 2010
M(μ+ μ-) [GeV]
Jet multiplicity
"Rediscovery" in CMS (dates approximate)

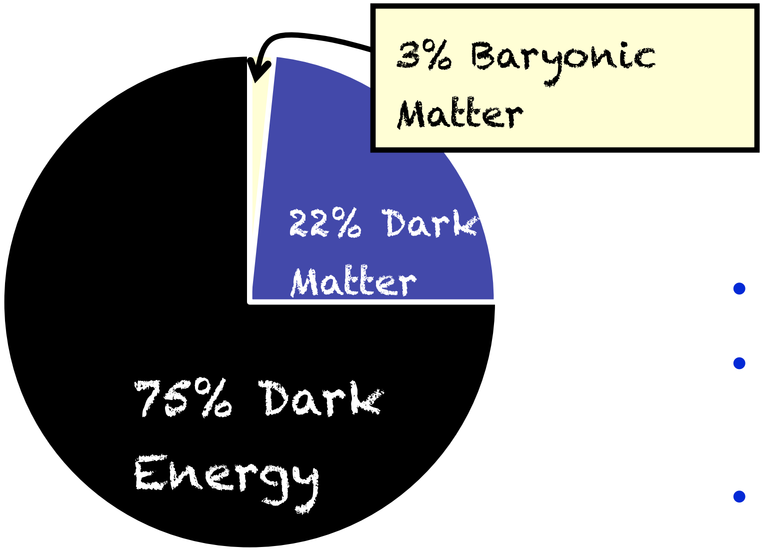
# List of Physics Results

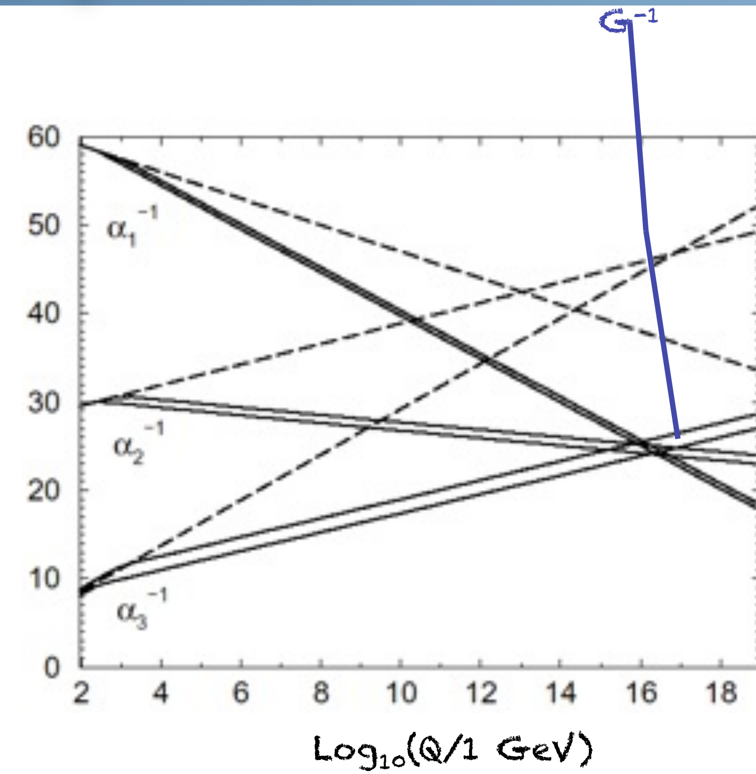



- More than 80 Analyses based on 2010 Data
- More than 50 Papers submitted, 30 in the pipeline
- I will focus on a small subsample of those (2010) today!

# Motivating Themes for SUSY

- Naturally leads to Electro-weak symmetry breaking
- Avoids fine tuning of SM
- Viable Dark Matter Candidate (R-parity conservation)




- Gauge Coupling Unification
- Gravity naturally unifies (roughly) too
- Pre-requisite of String Theory

Of course, some problems too : No experimental evidence, so far!

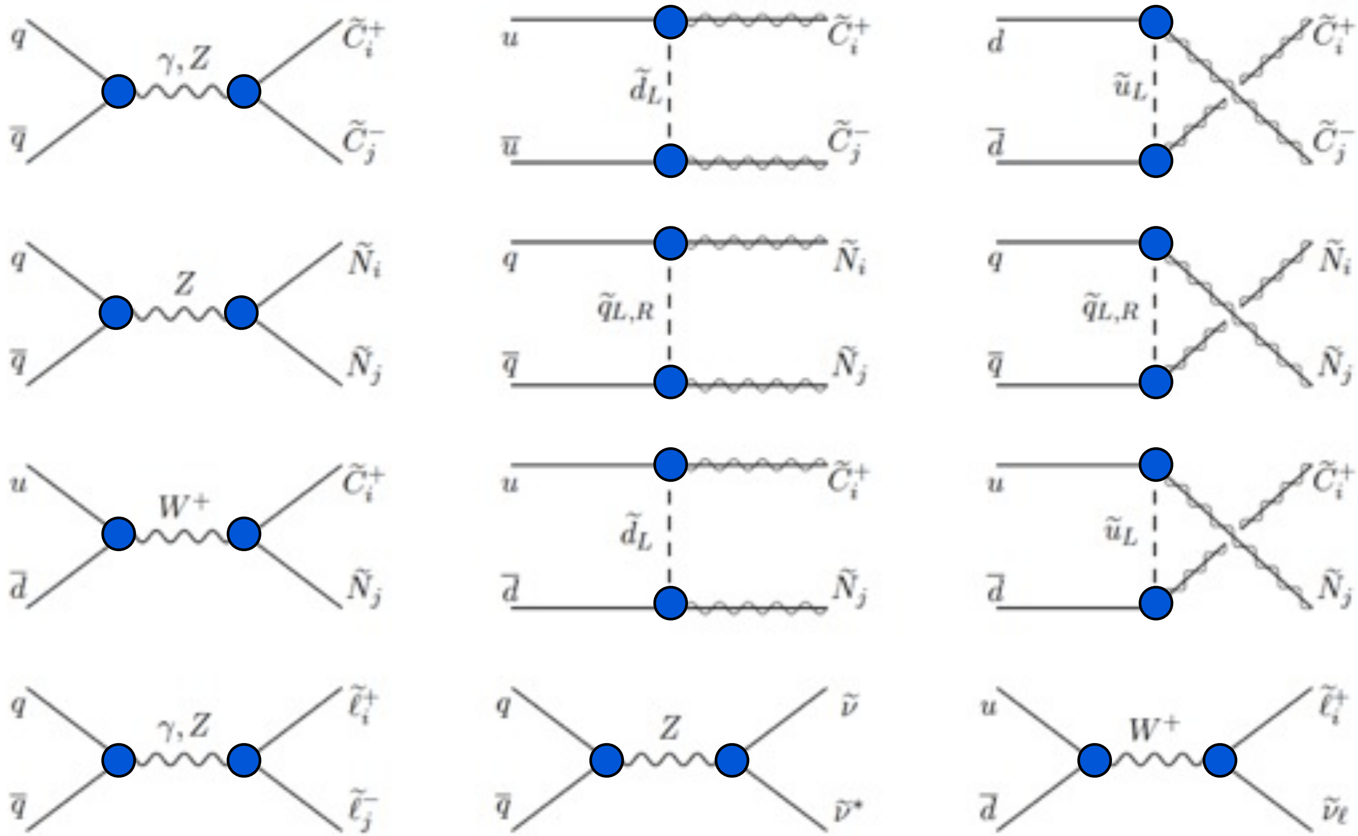
# Supersymmetry

- A symmetry between fermions and bosons

| SM Particles | SUSY Particles | | | |
|---|---|---|---|---|
| quarks: $q$ | $q$ | squarks: $\tilde{q}$ | | |
| leptons: $l$ | $l$ | sleptons: $\tilde{l}$ | | |
| gluons: $g$ | $g$ | gluino: $\tilde{g}$ | | |
| charged weak boson: $W^{\pm}$ | $W^{\pm}$ | Wino: $\widetilde{W}^{\pm}$ | $\tilde{\chi}^{\pm}_{1,2}$ | chargino |
| Higgs: $H^0$ | $H^{\pm}$ | charged higgsino: $\widetilde{H}^{\pm}$ | | |
| | $h^0, A^0, H^0$ | neutral higgsino: $\tilde{h}^0, \tilde{A}^0,$ | $\widetilde{H}^0$ | higgsino |
| neutral weak boson: $Z^0$ | $Z^0$ | Zino: $\widetilde{Z}^0$ | $\tilde{\chi}^0_{1,2,3,4}$ | neutralino |
| photon: $\gamma$ | $\gamma$ | photino: $\tilde{\gamma}$ | | |

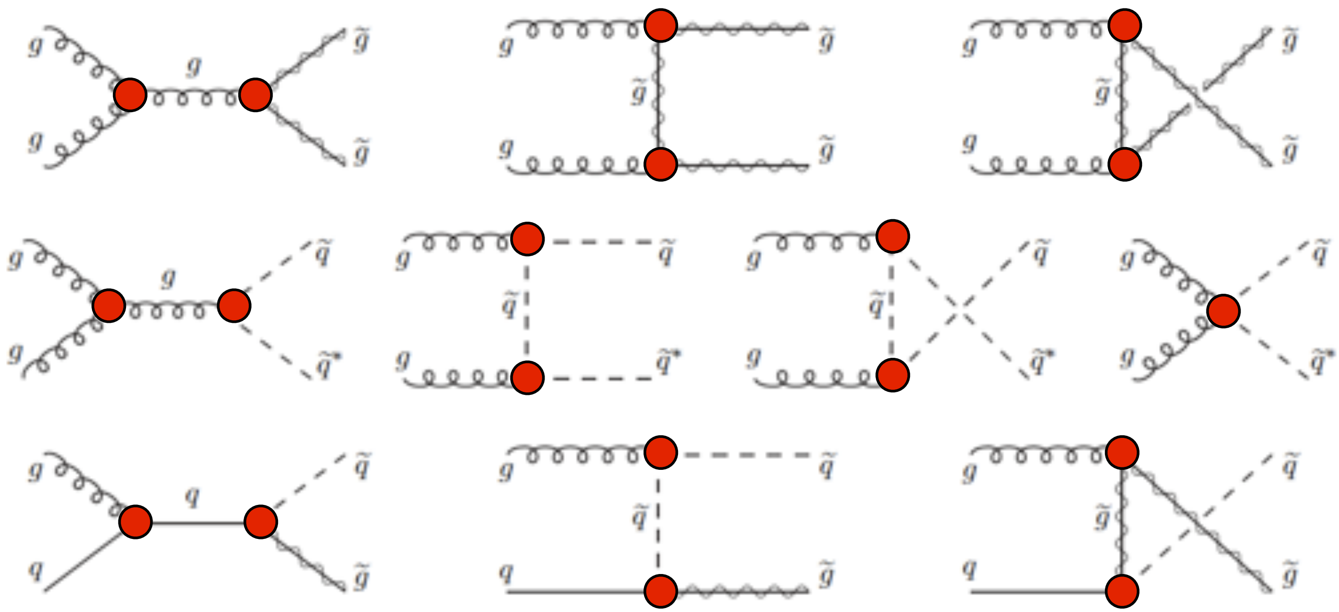
- Generally assume LSP is stable (R-parity conservation)
- SUSY must be broken!
  - mechanism is unknown ⇒ many new free parameters!
- CMSSM (basically mSUGRA):
  - Supergravity inspired model, 5 free parameters:
    - $m_0$, $m_{1/2}$, $A_0$, $\tan\beta$, Sign($\mu$)

# Chargino & neutralino Production



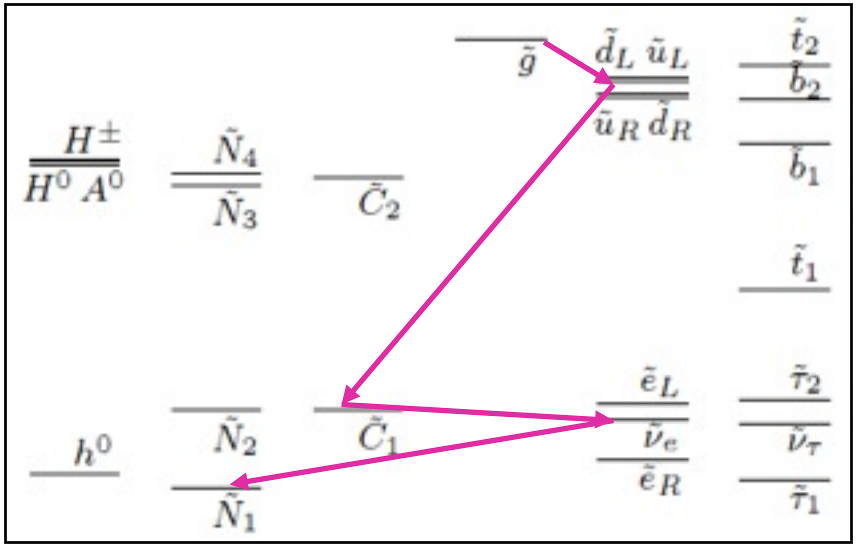

- Most involve only weak couplings

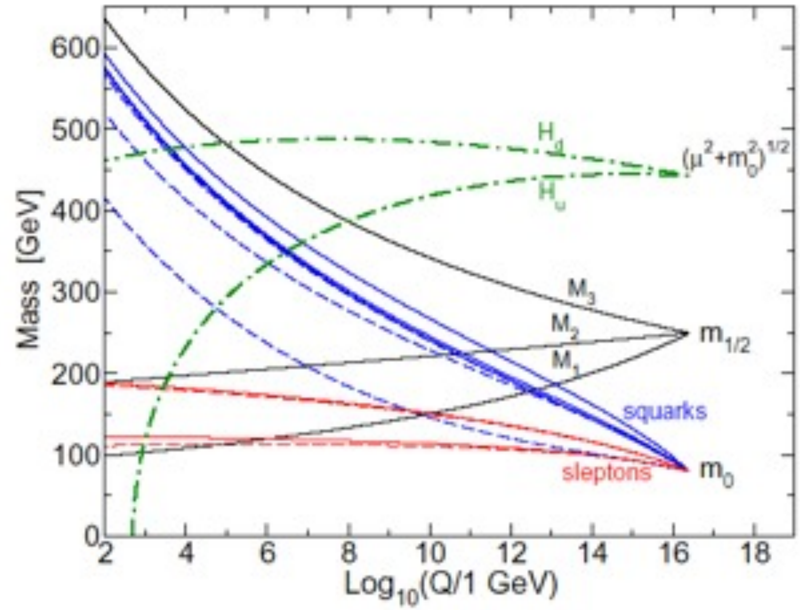
# Squark & gluino production



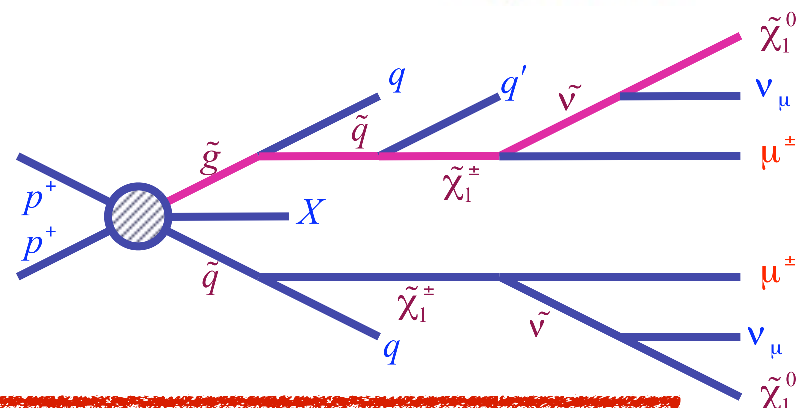
- Involve the strong coupling
- LHC initial state: quarks and gluons!
  - squark & gluino production dominate over chargino & neutralino production
- Thus: Lots of Jets and MET in final state for SUSY events!!

# What does SUSY Look Like?




- Complex decays chains
  - High $P_T$ jets ( q, g )
  - Leptons ( χ, l, W, Z )
  - MET (LSP)




Generic Signature of many New Physics Models!

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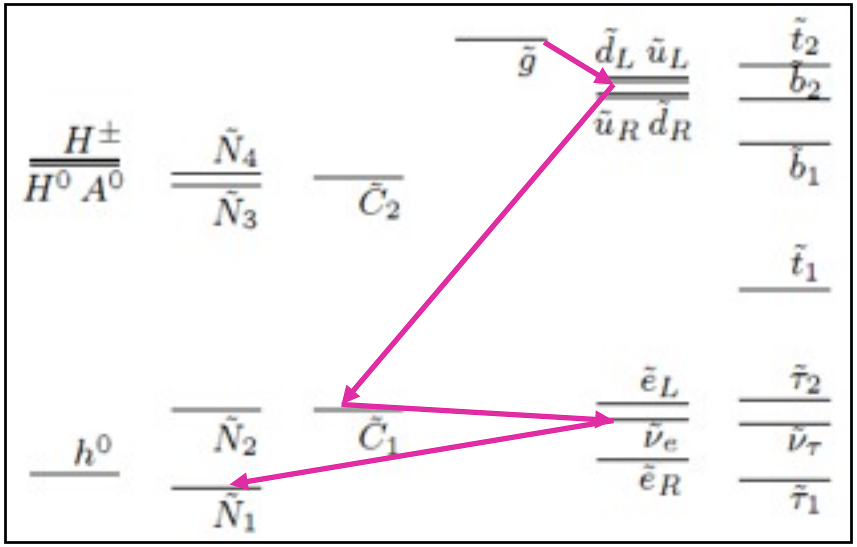


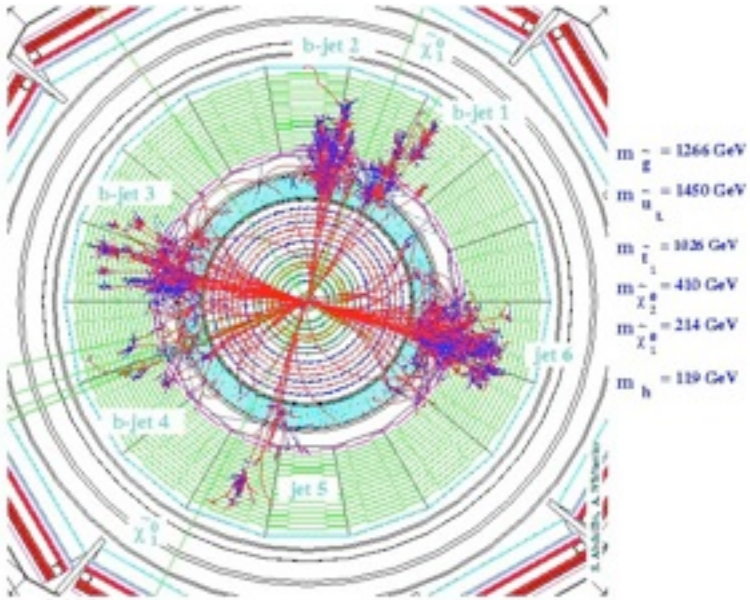


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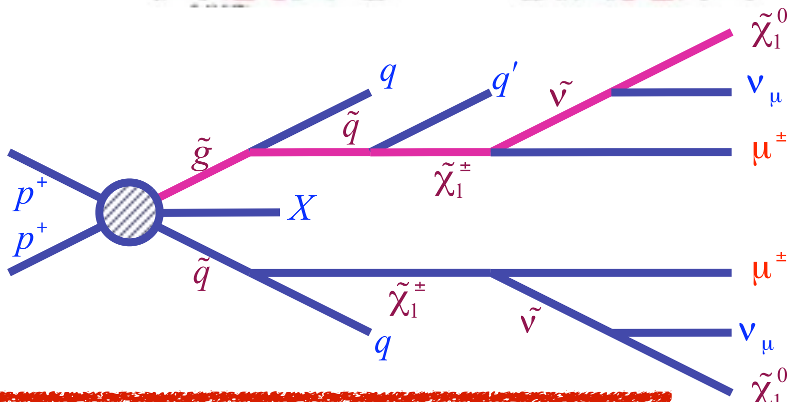


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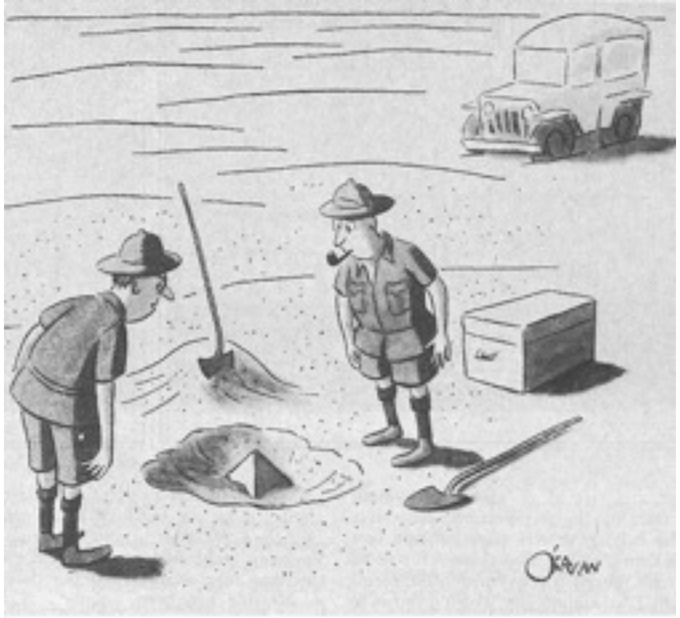

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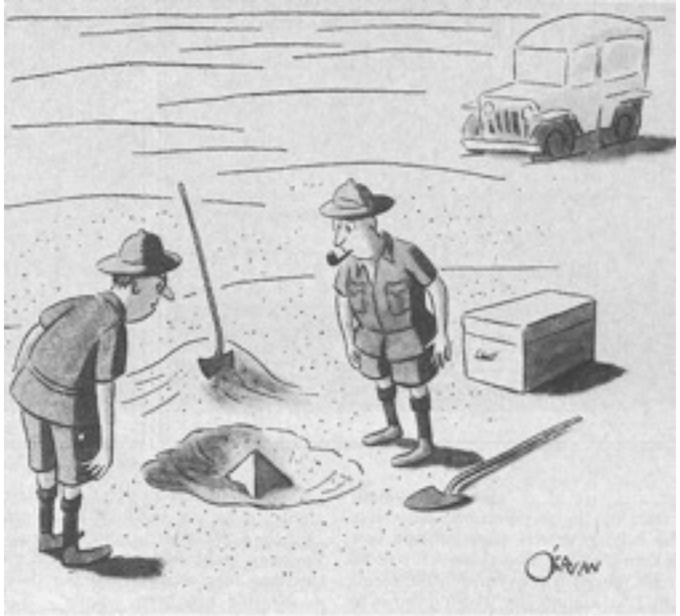

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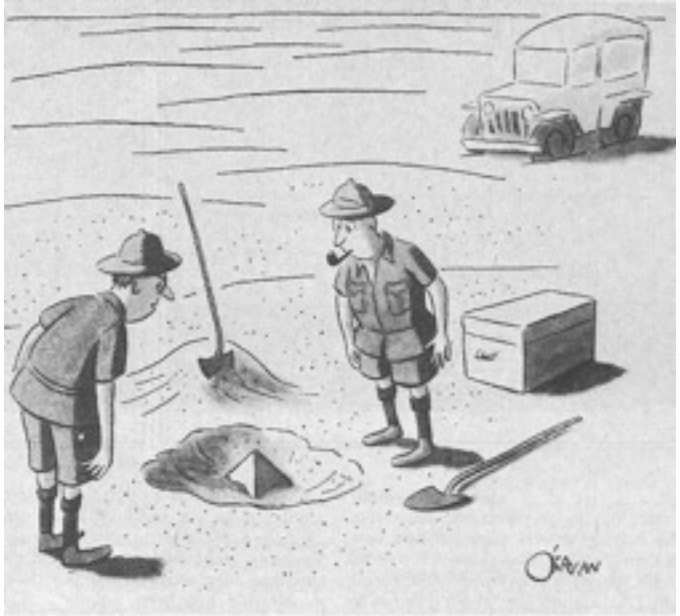

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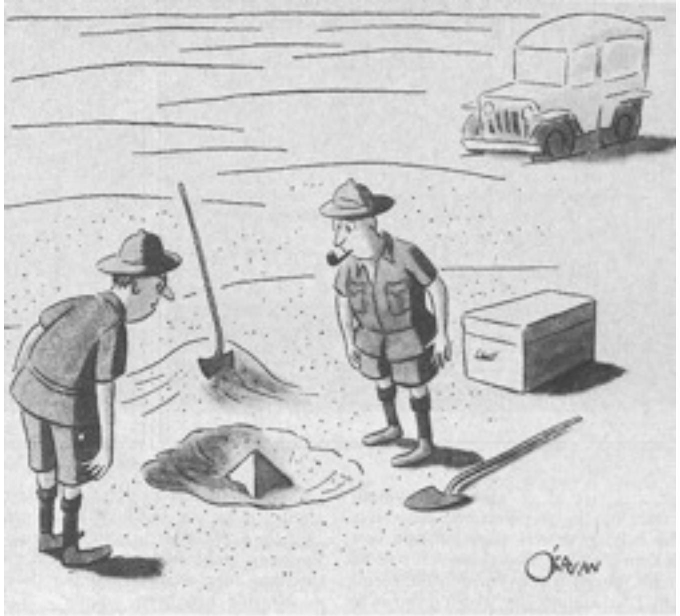

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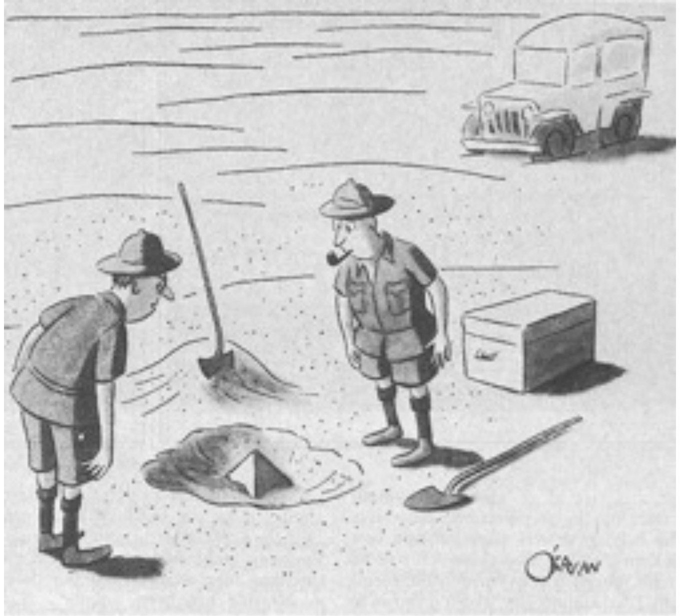

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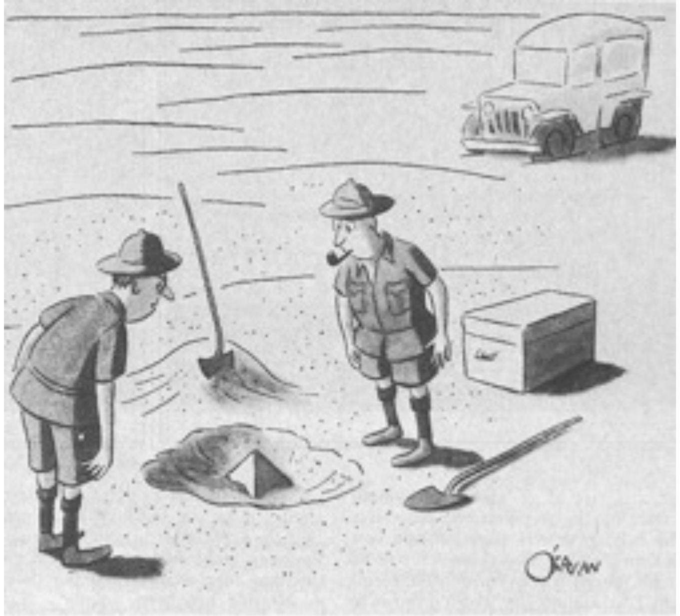

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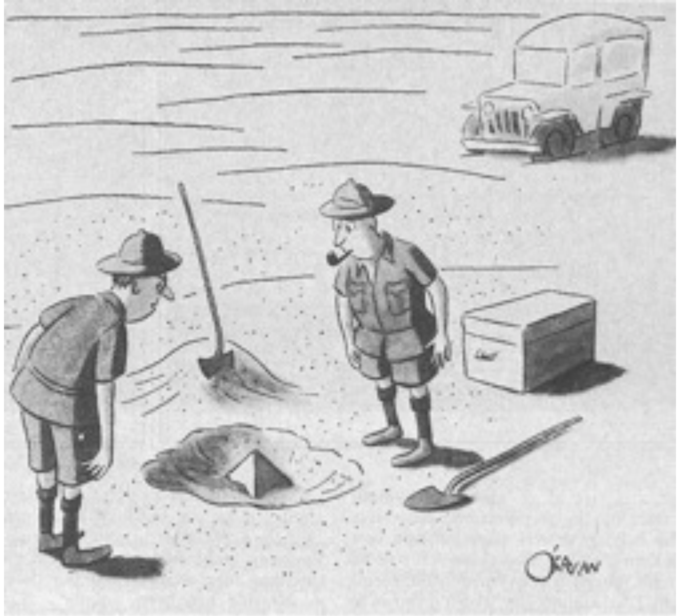

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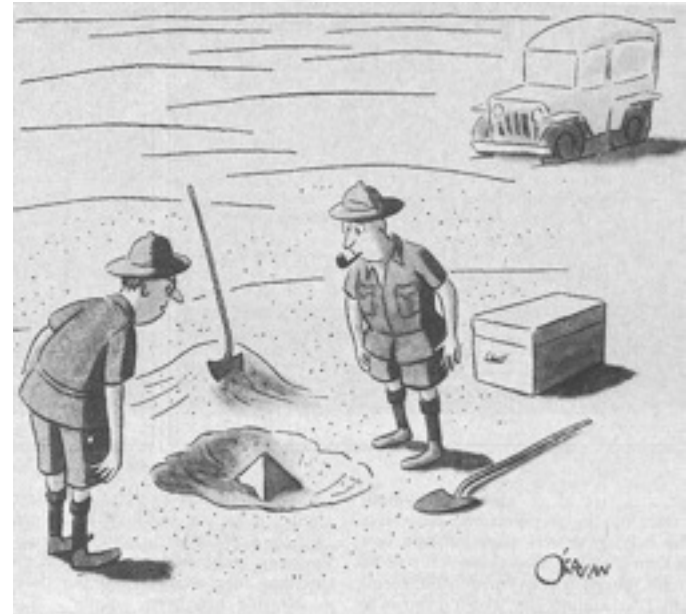
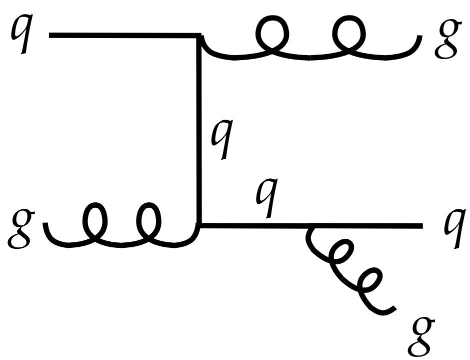


"This could be the discovery of the century. Depending, of course, on how far down it goes."

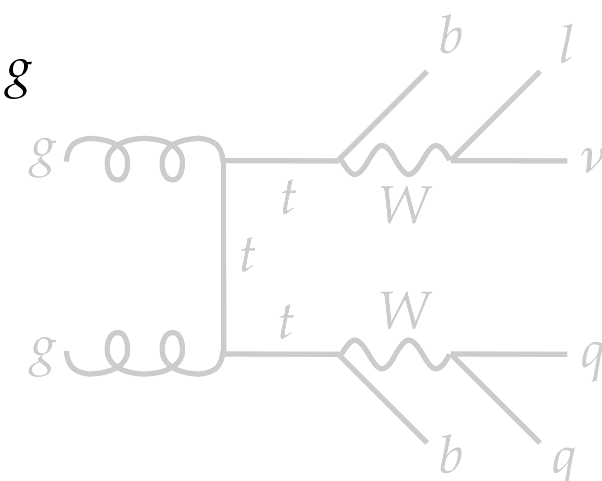
"I think I've found the Higgs boson!"

# Descending* the staircase of the SM…

### QCD + Electroweak




Top



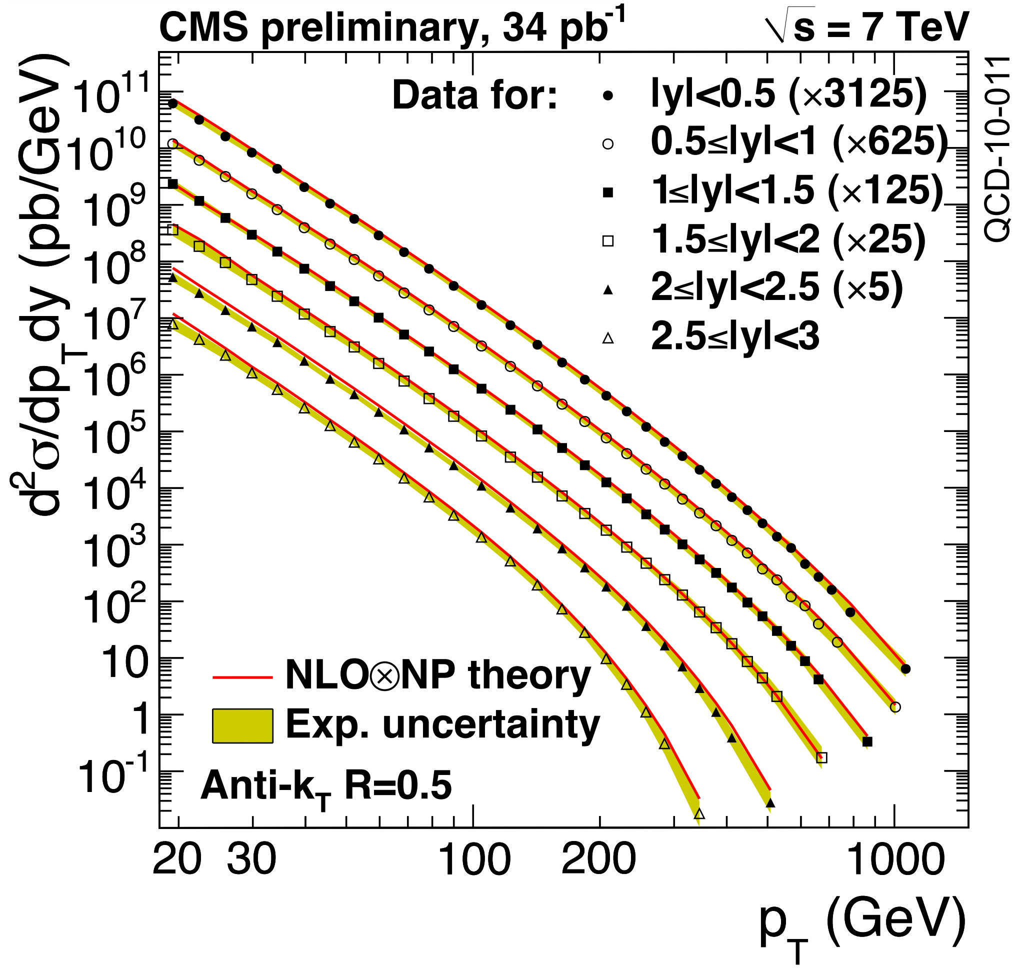

…to New Physics




*Adapted from Michael Peskin

# Inclusive Jets

- From pT = 18 GeV to pT ~ 1 TeV
- Extends to very low pT thanks to particle flow
- JES Uncertainties 3-4%
- Already at particle-level corrected for resolution
- Inclusive Jet pT spectra in good agreement with NLO pQCD predictions



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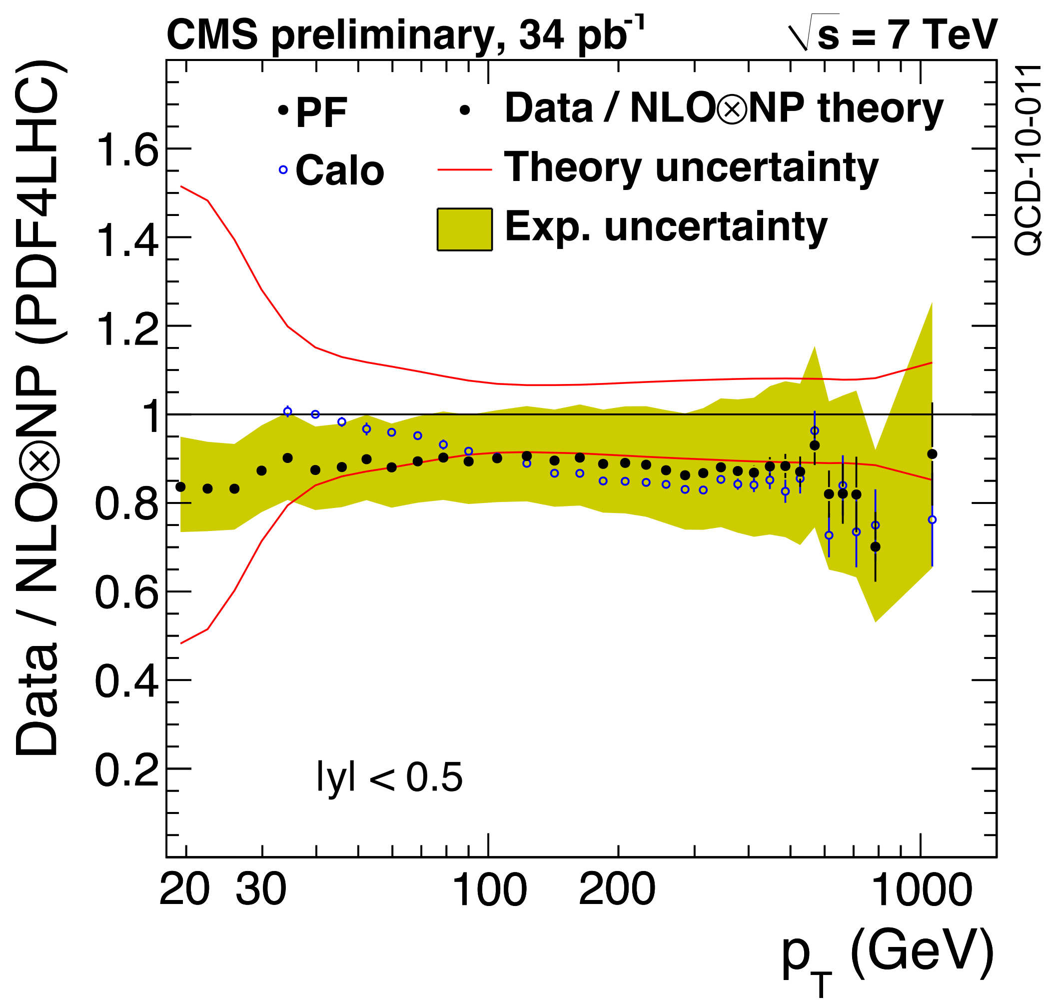
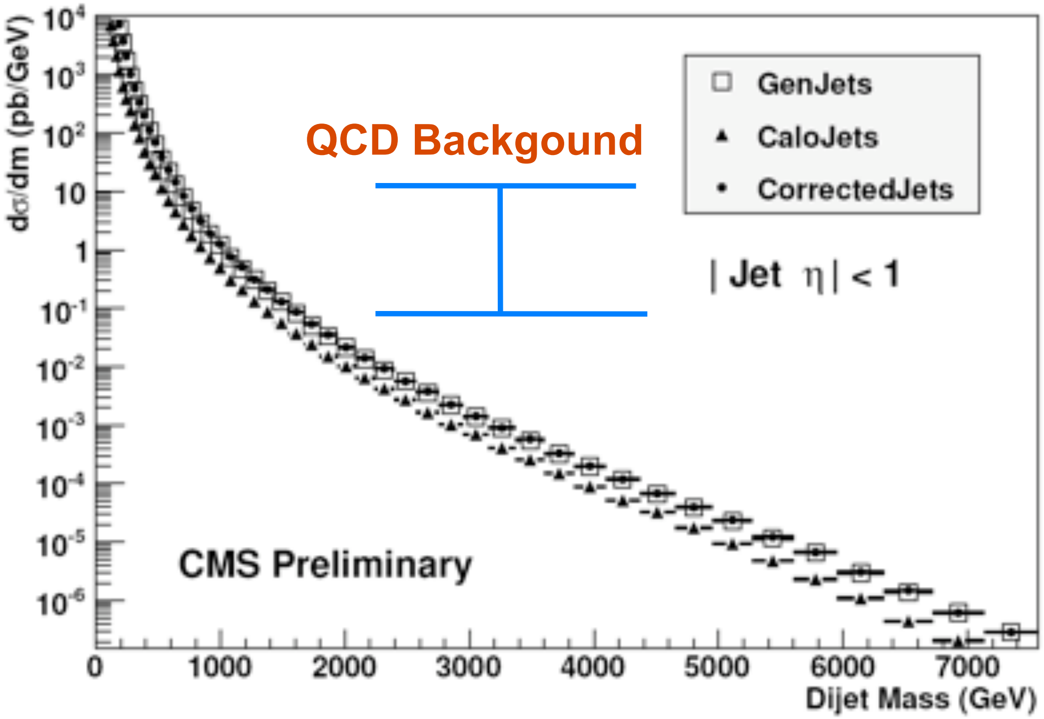
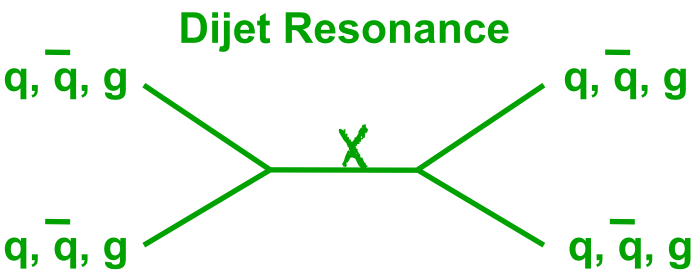


# Dijet Production

- Measure rate vs. corrected dijet mass and look for resonances.
  - Use a smooth parameterized fit or QCD prediction to model background
- Strongly produced resonances can be seen



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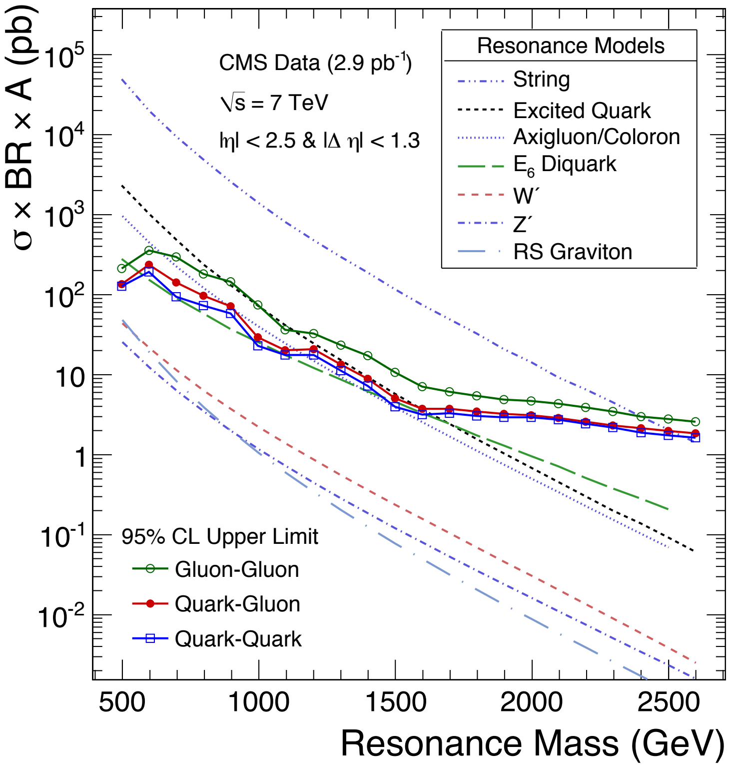


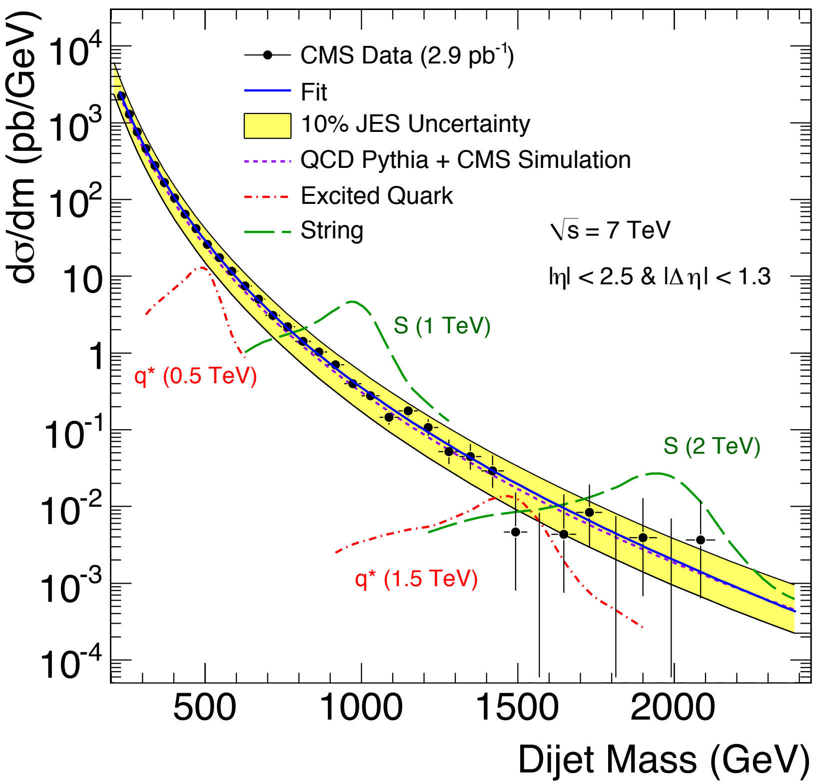

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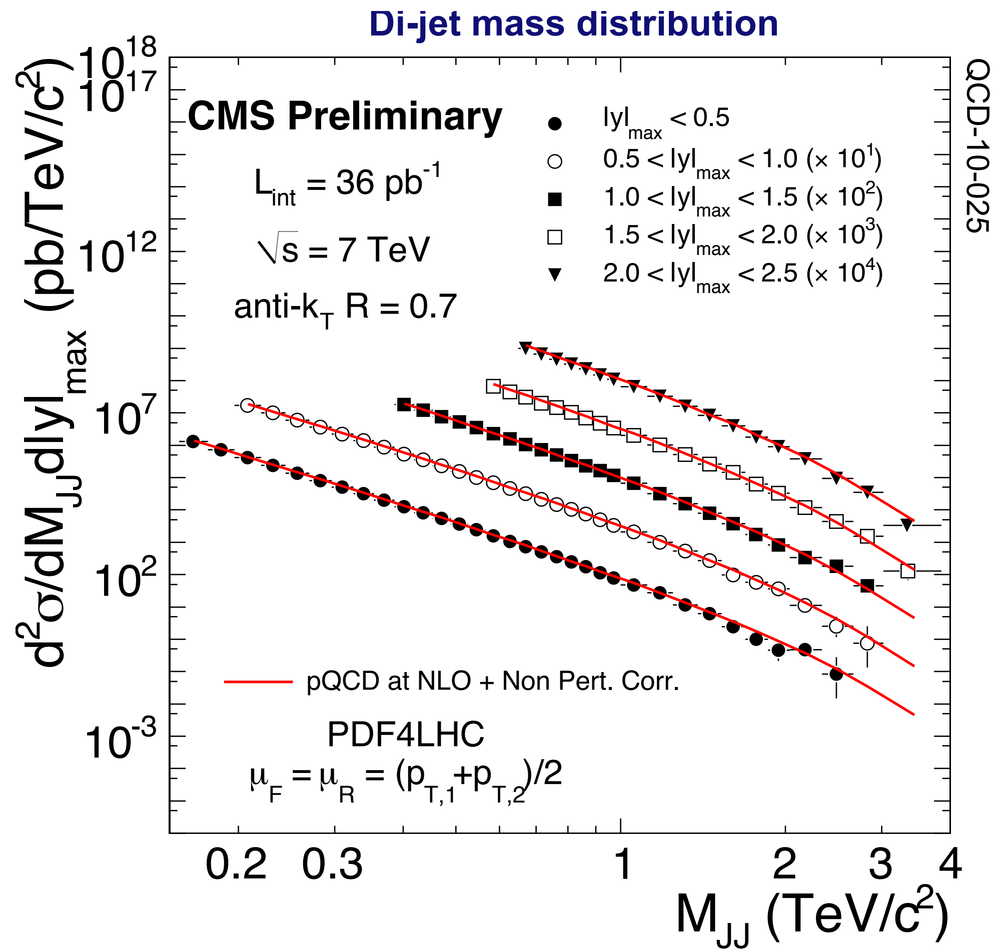
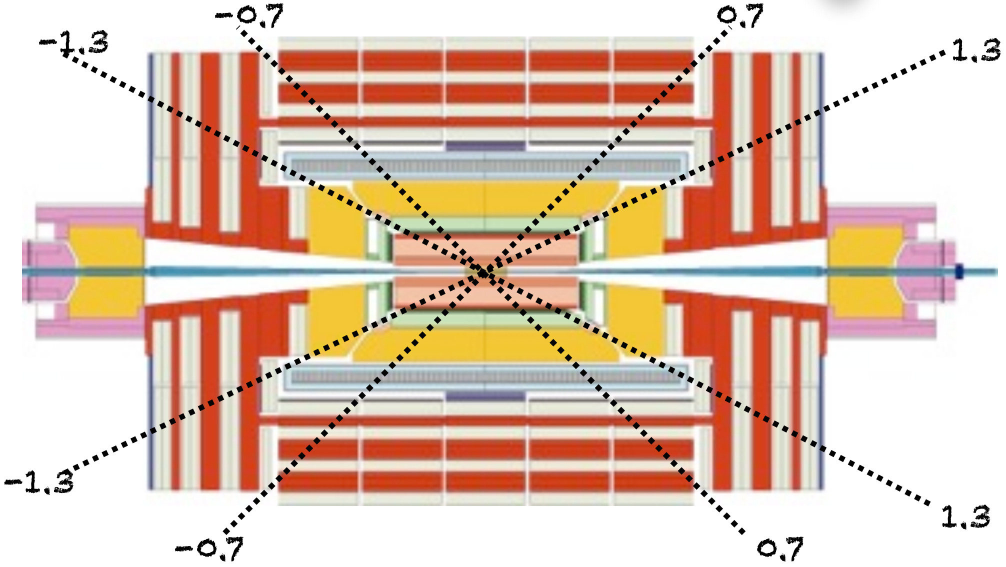
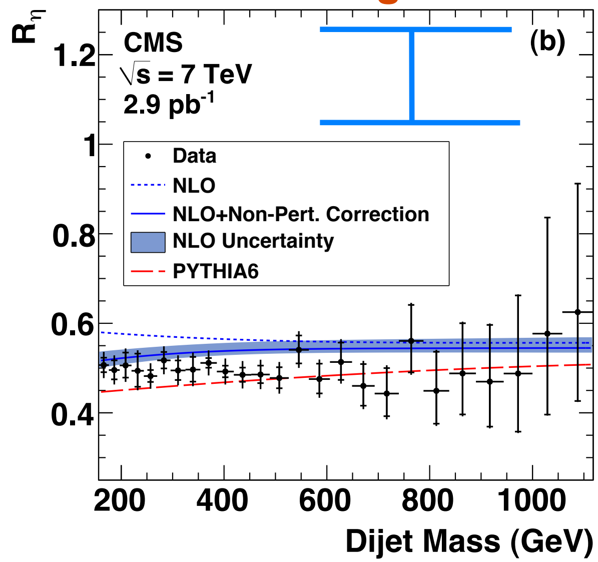


# Dijet ratio

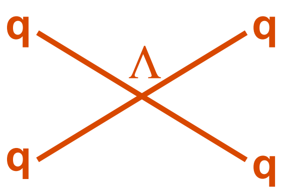



QCD Backgound




- Ratios help keep systematics low
  - many effects cancel
- QCD: roughly no η preference
- Expect NP to appear at high pT
  - hence, central η

Contact Interaction



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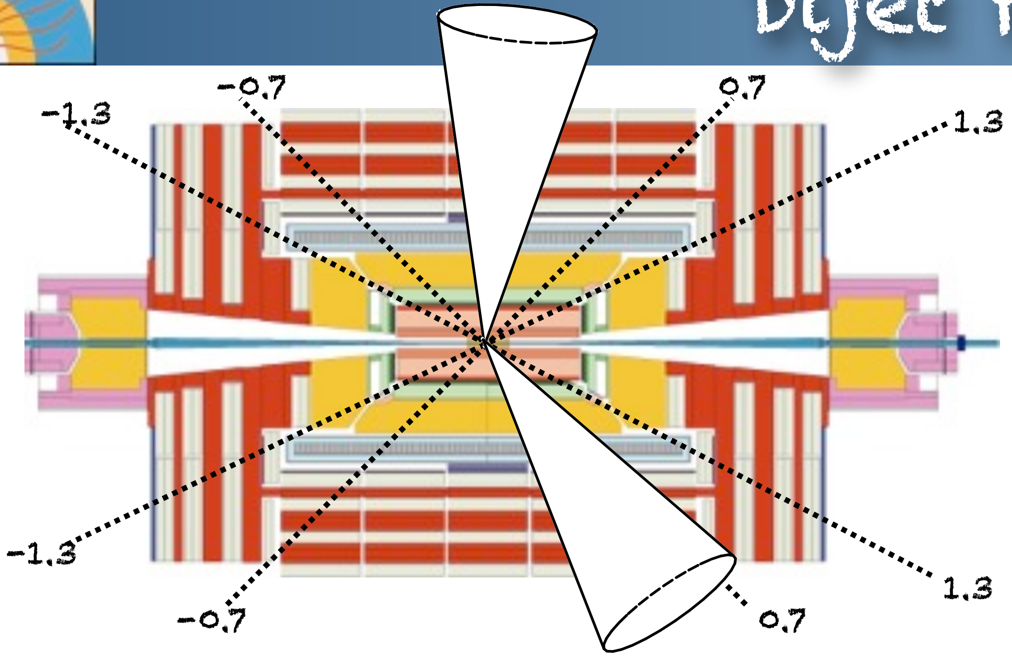


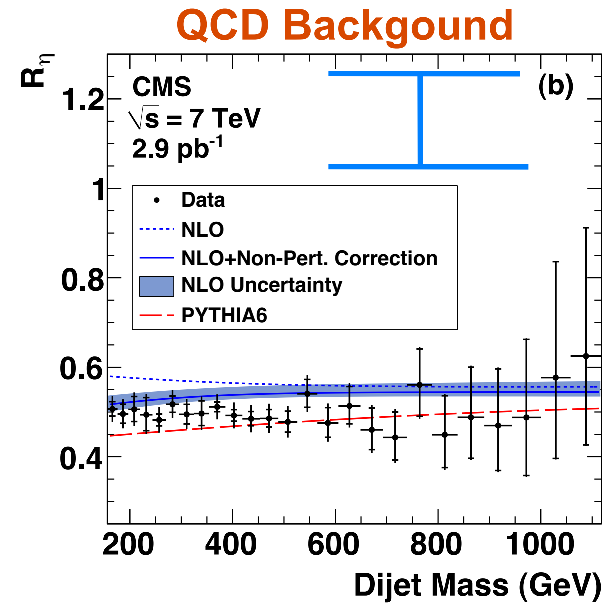


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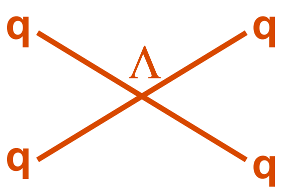

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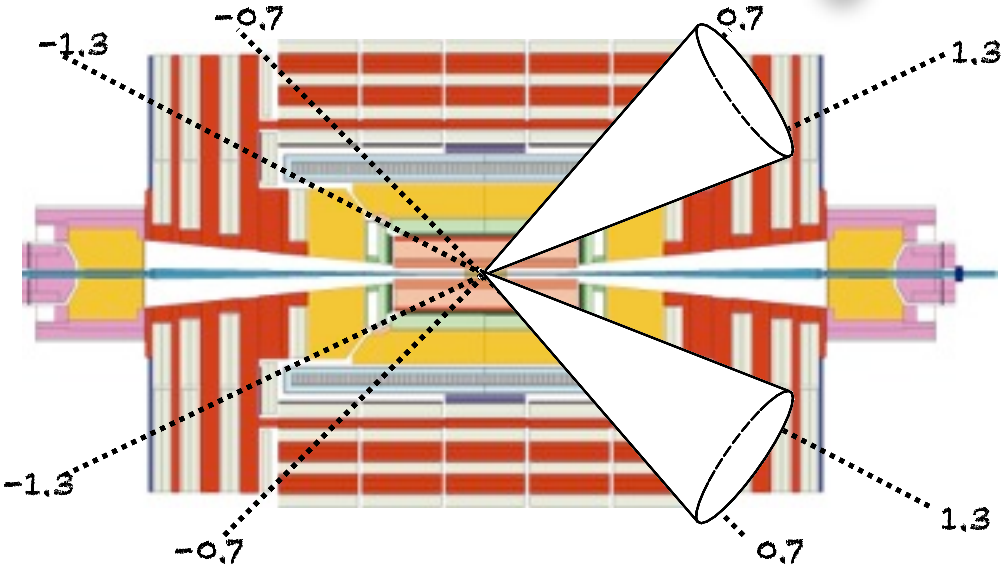


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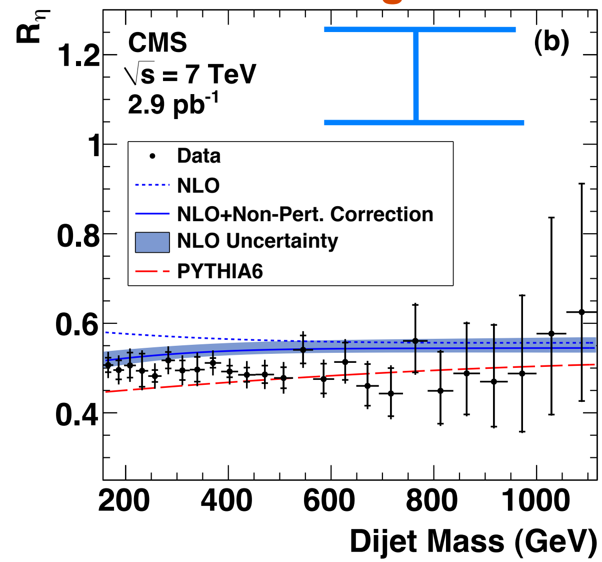


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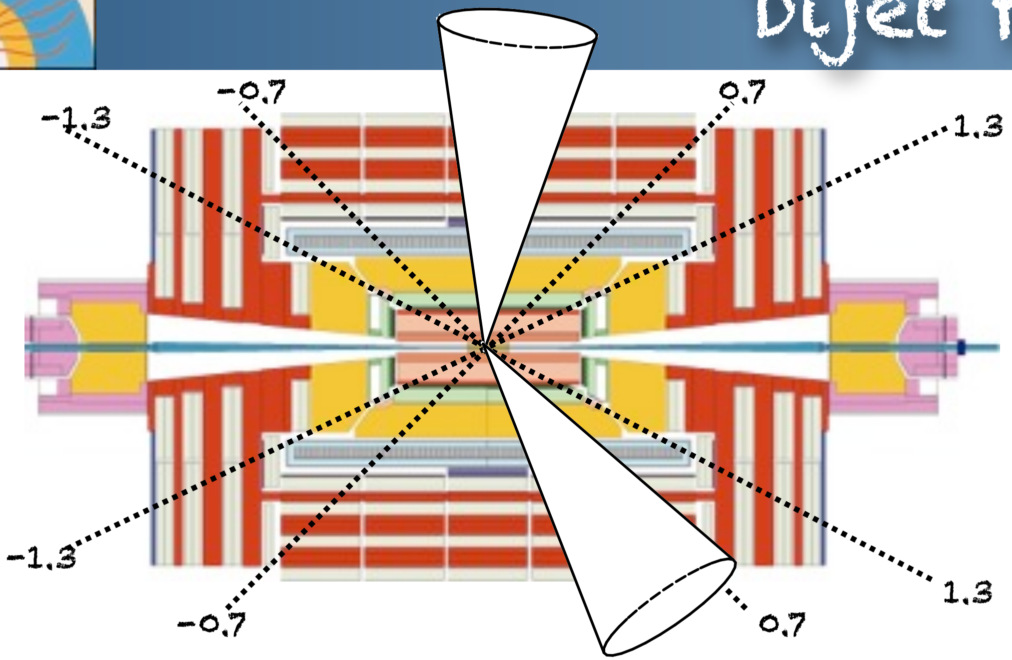


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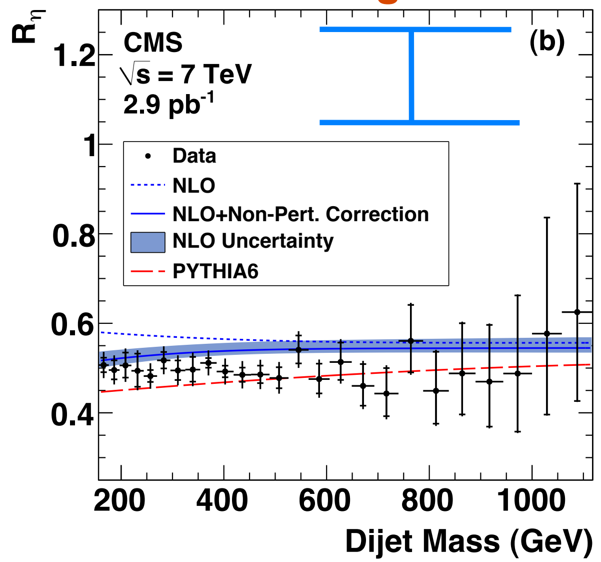


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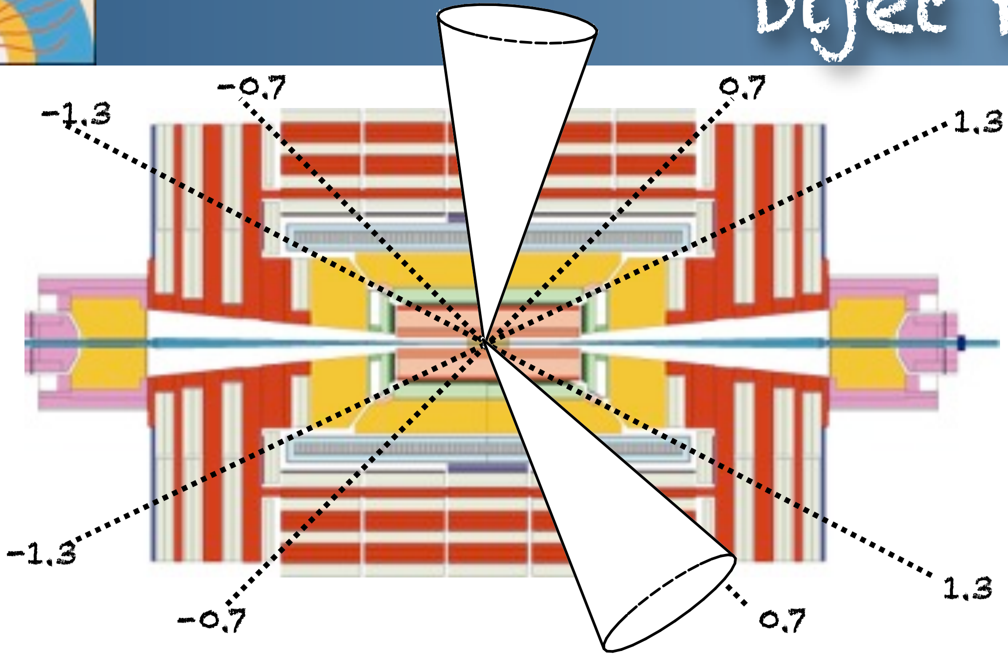


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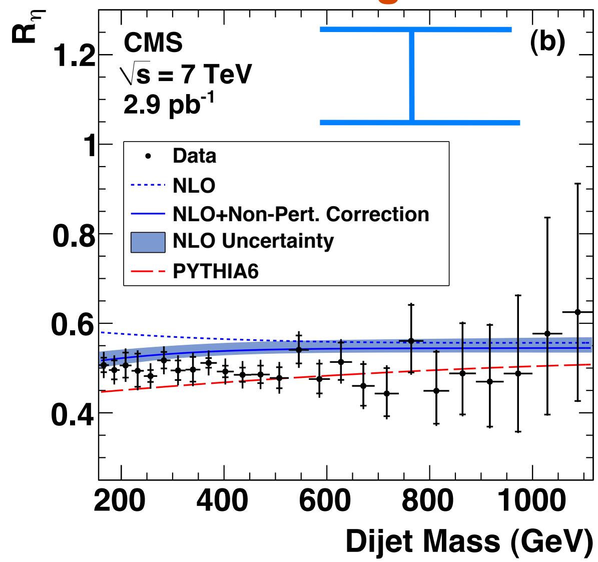


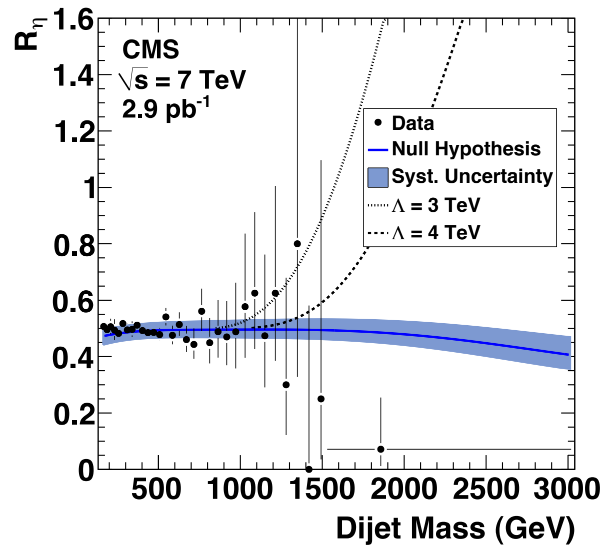


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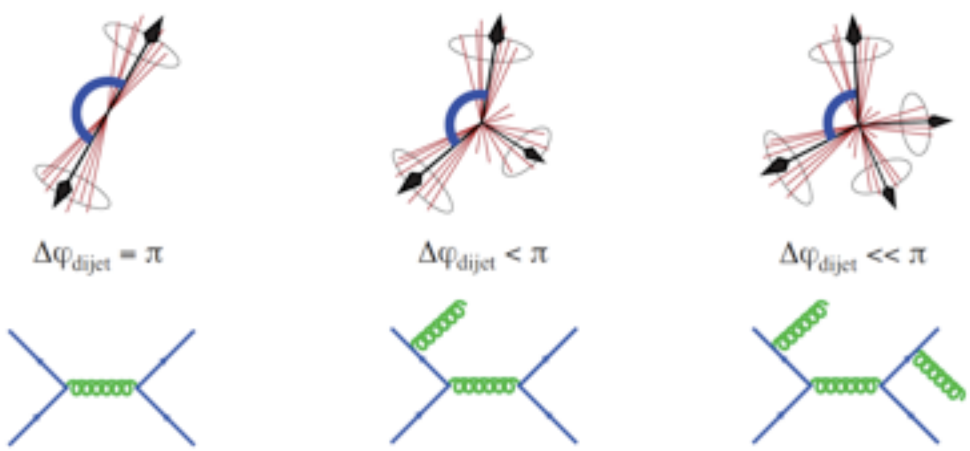
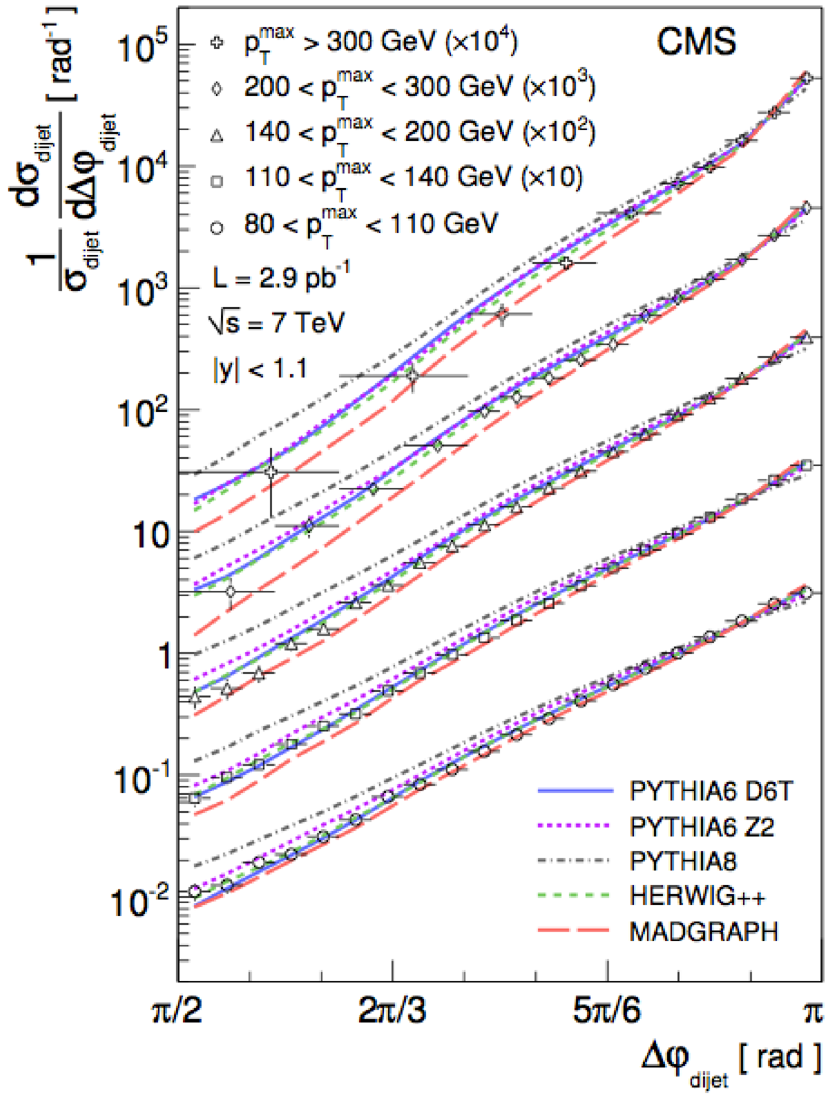
# Multijet production

- leading jets Δφ distribution sensitive to higher order radiation
- w/o explicitly measuring the radiated jets -- no jet counting!
- Particle level distributions
- Corrections are dominated by JES and jet φ resolutions



# Historic Interlude

- Searches for New Physics (NP) at LHC
  - SUSY signatures have large SM backgrounds
  - Several levels of SM pQCD processes must be crossed
- ATLAS showed sometime ago:
  - PYTHIA alone
    - optimistic est. of backgrounds
  - More realistic ME simulations
    - much less S/sqrt(B) discrimination!
- This led to earnest and well intentioned statements from CMS & ATLAS like:
  "We must
  - understand SM before discovery"
  - rely on accurate simulations"

  ...these are non-trivial statements!

Both of these statements have come true!

| | |
|---|---|
| $\sigma_{tot}$ | 100 mb |
| jets with $p_T > 100$ | 1 $\mu$b |
| W/Z | 100 nb |
| $t\bar{t}$ | 800 pb |
| SUSY ($M$ < 1 TeV) | 1-10 pb |

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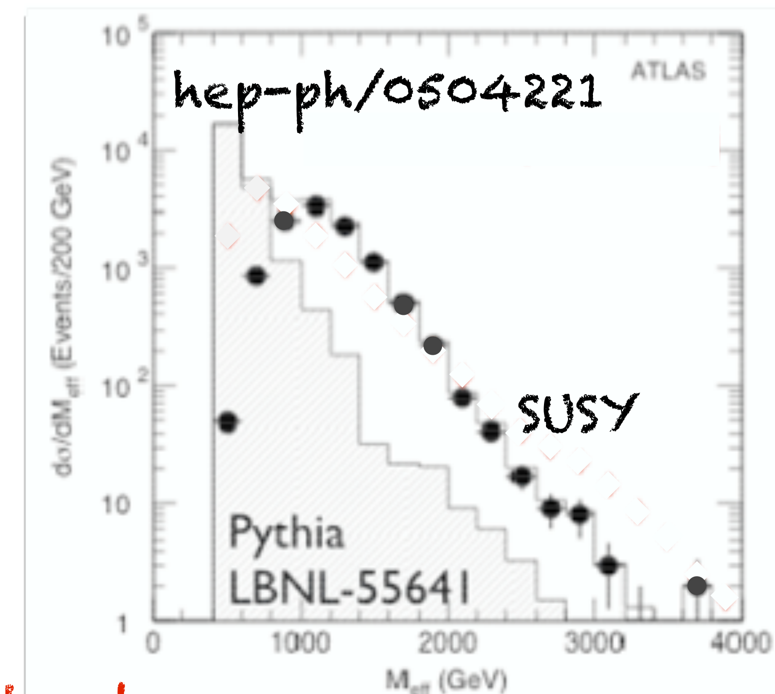
- This led to earnest and well intentioned statements from CMS & ATLAS like:
  "We must
  - understand SM before discovery"
  - rely on accurate simulations"

...these are non-trivial statements!

| | |
|---|---|
| $\sigma_{tot}$ | 100 mb |
| jets with $p_T$ > 100 | 1 $\mu$b |
| W/Z | 100 nb |
| $\bar{t}t$ | 800 pb |
| SUSY ($M$ < 1 TeV) | 1-10 pb |




Both of these statements have come true!

# Historic Interlude



- Searches for New Physics (NP) at LHC
  - SUSY signatures have large SM backgrounds
  - Several levels of SM pQCD processes must be crossed
- ATLAS showed sometime ago:
  - PYTHIA alone
    - optimistic est. of backgrounds
  - More realistic ME simulations
    - much less S/sqrt(B) discrimination!
- This led to earnest and well intentioned statements from CMS & ATLAS like:
  "We must
  - understand SM before discovery"
  - rely on accurate simulations"

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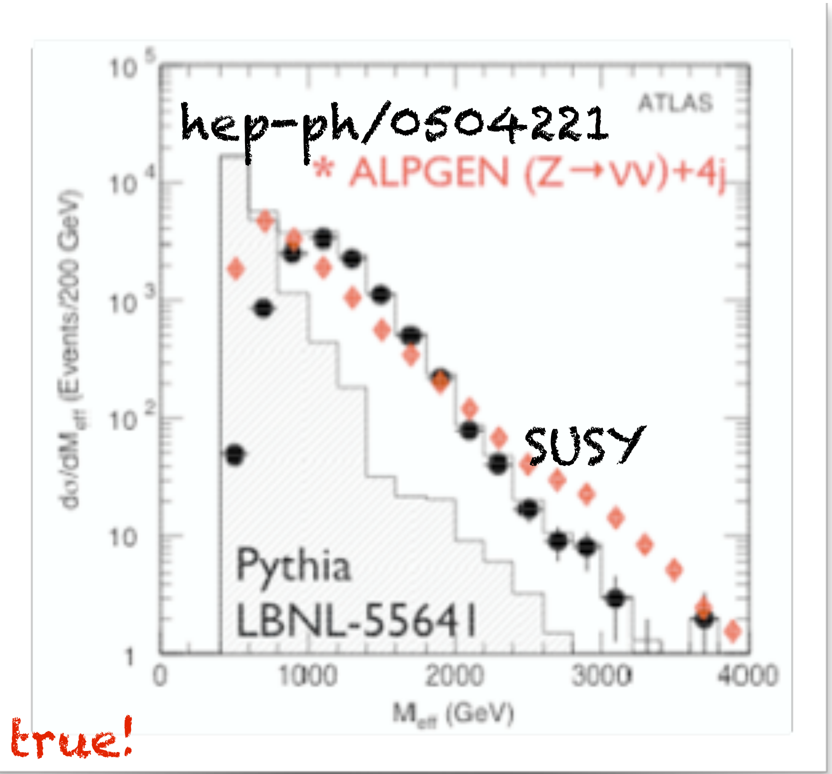


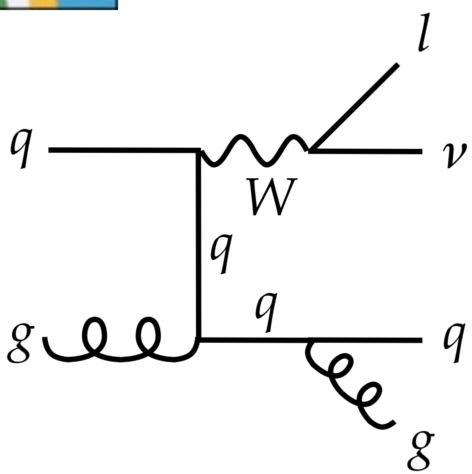

Both of these statements have come true!

# New Heavy Coloured Particles

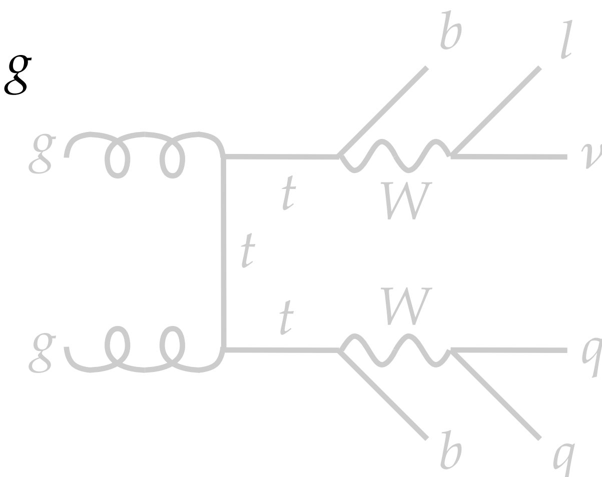
- First convince ourselves we can see
  - old heavy uncoloured particles (W,Z)
- Then convince ourselves we can see
  - old heavy coloured particles (top)
- Then convince ourselves we can distinguish
  - old heavy particles + ISR/FSR jets
- from
  - cascade decays of new heavy particles

# Descending* the staircase of the SM…

## QCD + Electroweak




Top



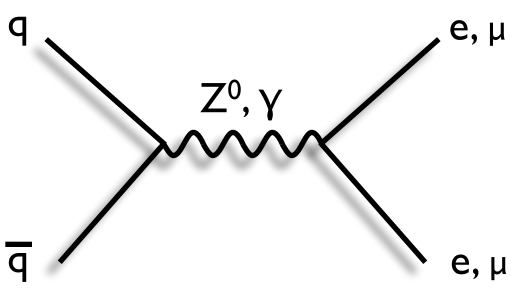

## …to New Physics



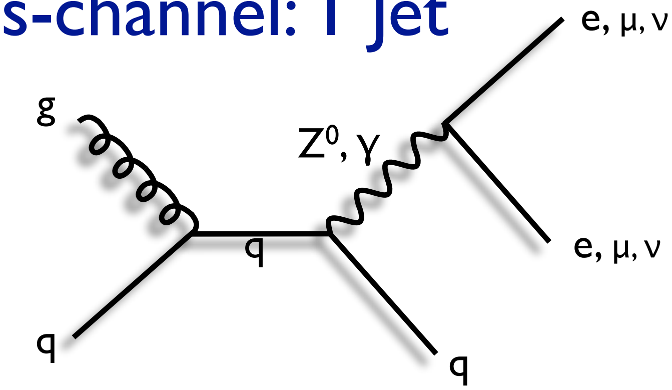

*Adapted from Michael Peskin

# Example of some V+Jets Diagrams

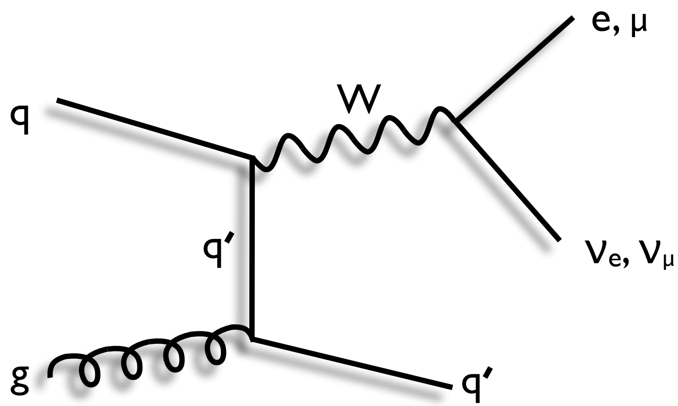
## qq Drell-Yan: 0 Jets



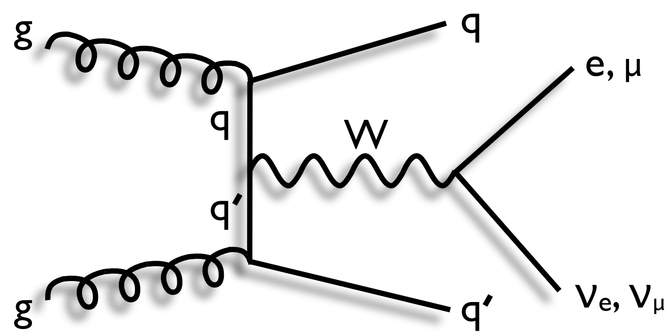

## qg s-channel: 1 Jet




## qg t-channel: 1 Jet




## higher order gg channels: 2 Jets



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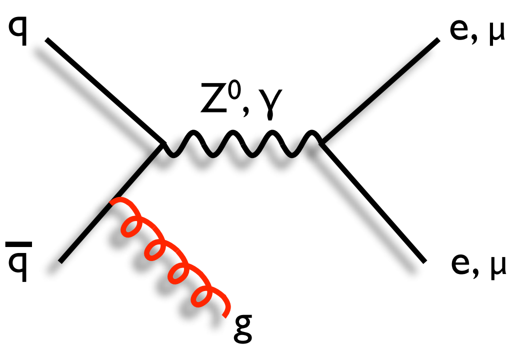


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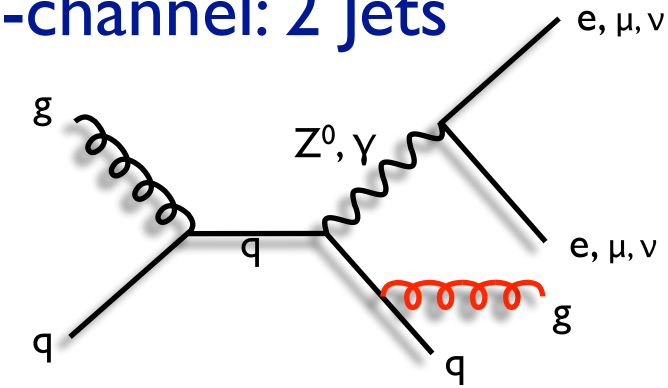


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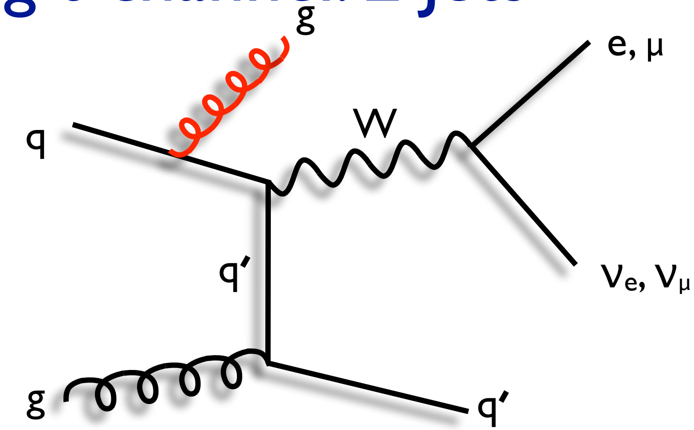
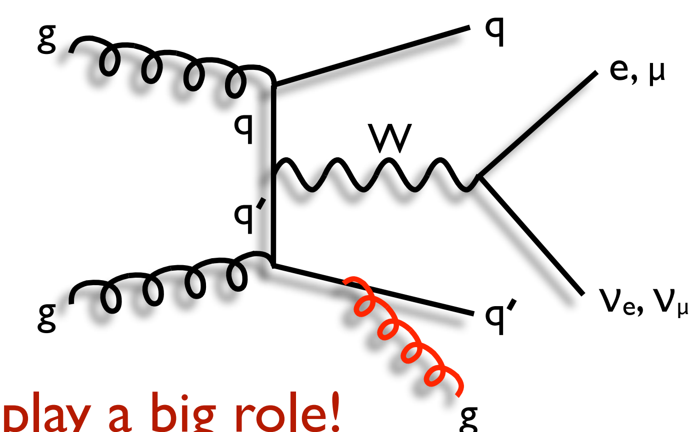



## higher order gg channels: 3 Jets

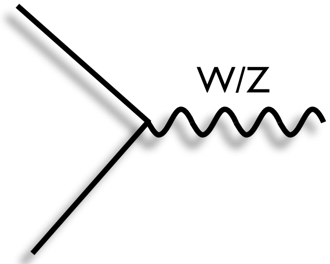



Initial and Final State Radiation play a big role!

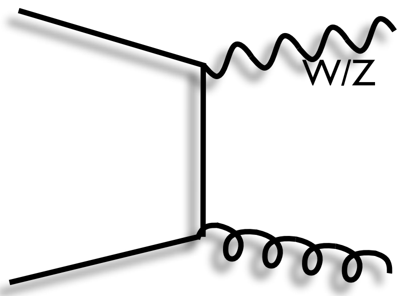
# Unique Properties of LHC

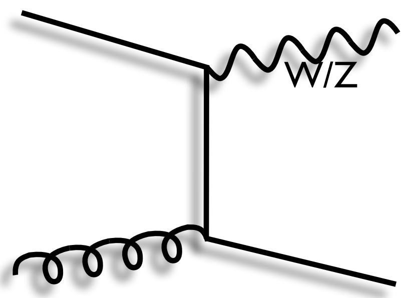
- Production in association with multijets enhanced at LHC (hence pure QCD reason to study V+Jets at LHC)

  - W/Z+0 partons (LO)-> need $\bar{q}$, q
    - valence-valence process at Tevatron
    - valence-sea, sea-sea process at LHC



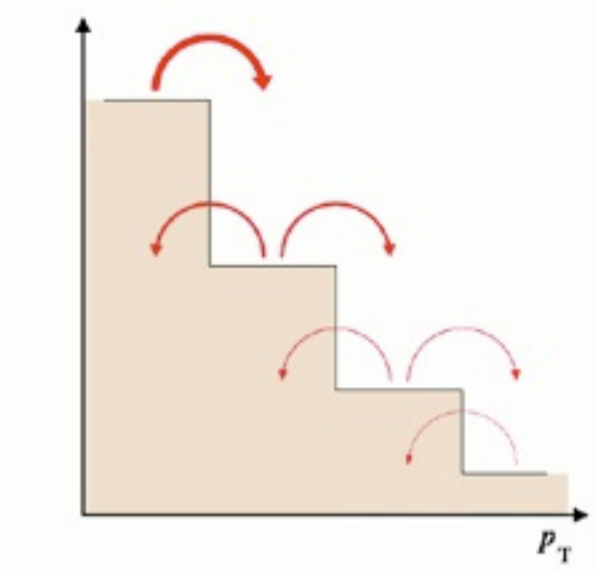

  - W/Z+1 parton:
    - q $\bar{q}$ -> W/Z + gluon (Tevatron)    q g -> W/Z q (LHC)

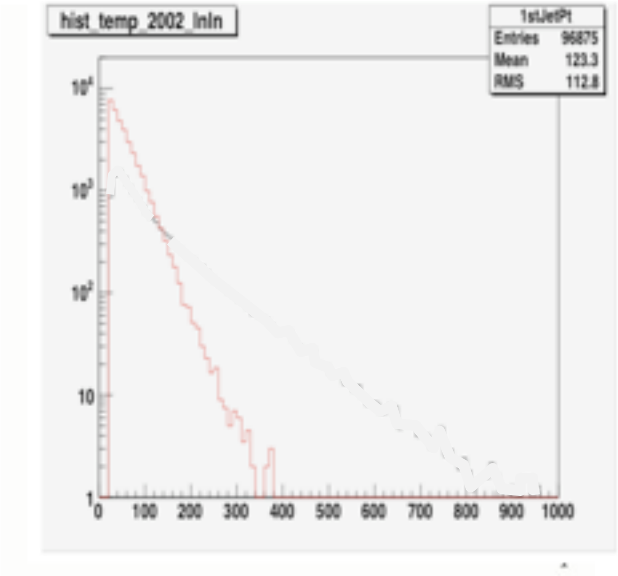


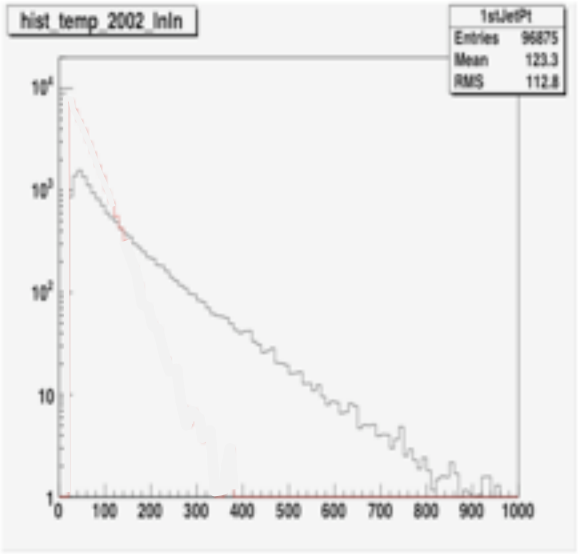

  - W/Z + Jets is enhanced at LHC
    - large gluon contribution, large phase space for additional jets

*slide modified from Maria Fiascaris


$p_T$


hist_temp_2002_lnln
1stJetPt
Entries 96875
Mean 123.3
RMS 112.8
$10^4$
$10^3$
$10^2$
10
1
0 100 200 300 400 500 600 700 800 900 1000

# Correcting for detector effects



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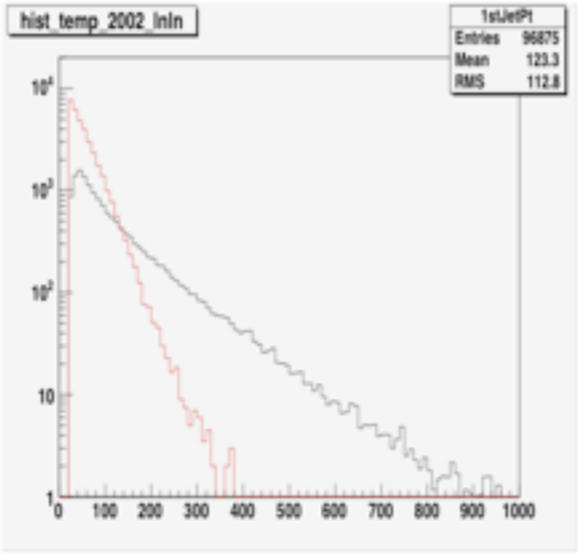
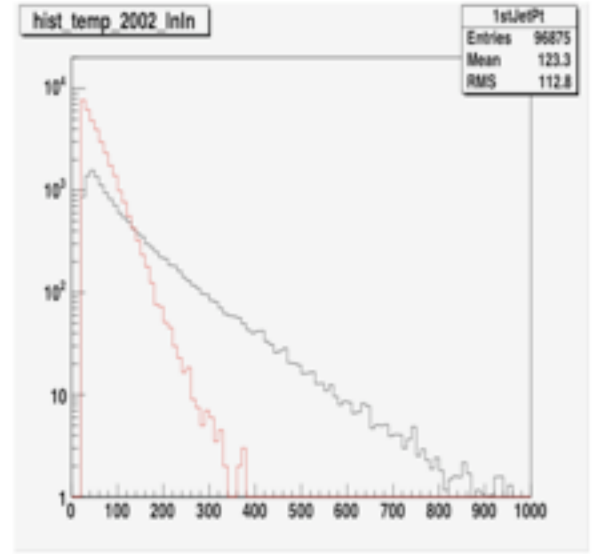


# Correcting for detector effects

- Finite detector resolution on a steeply falling spectrum leads to longer tails
  - Must correct, to compare with Theory



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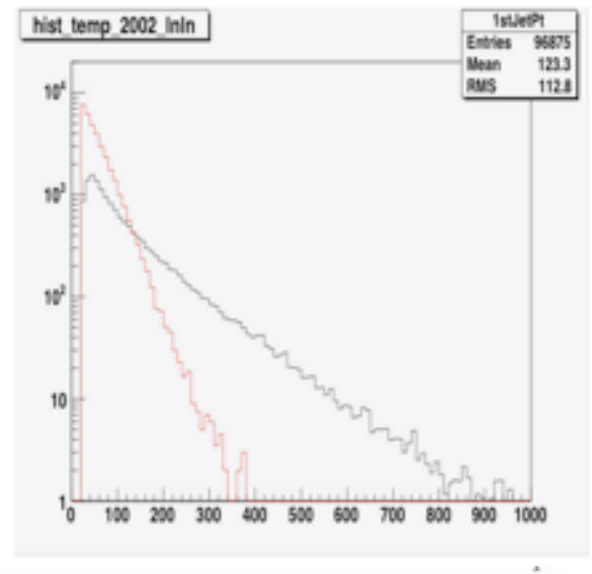

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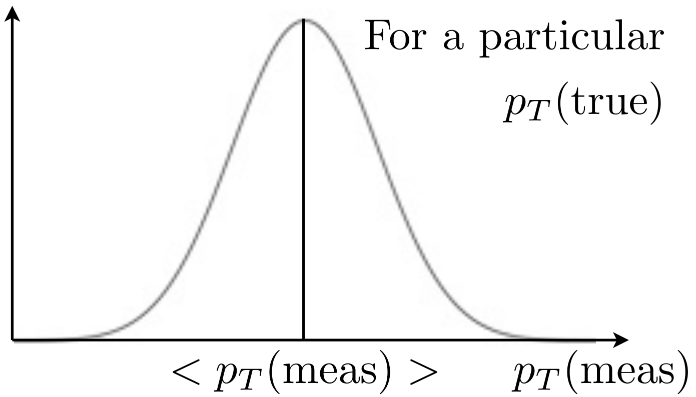
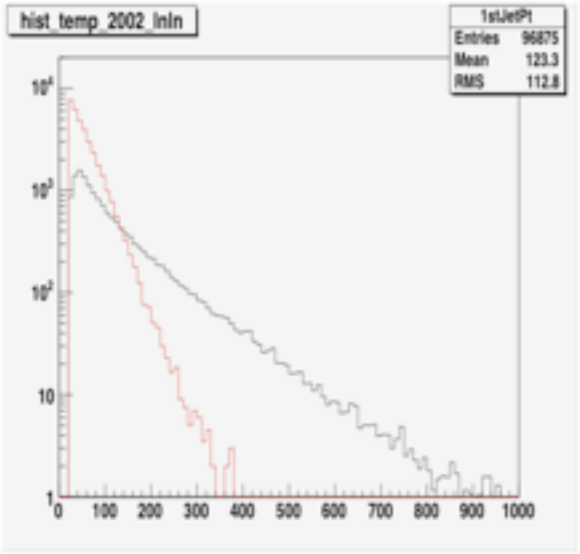



- Invert Probability Matrix and apply to measured pT distribution



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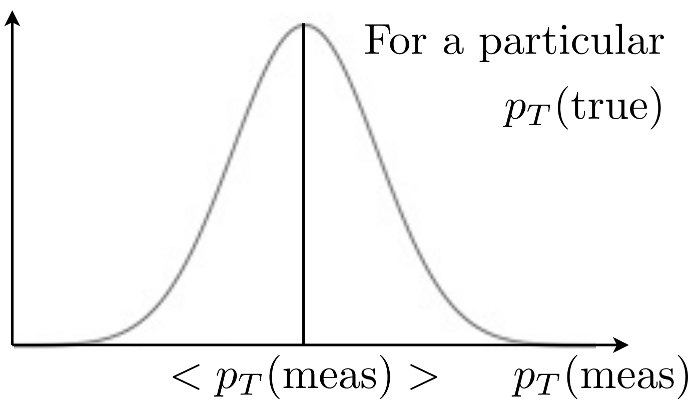


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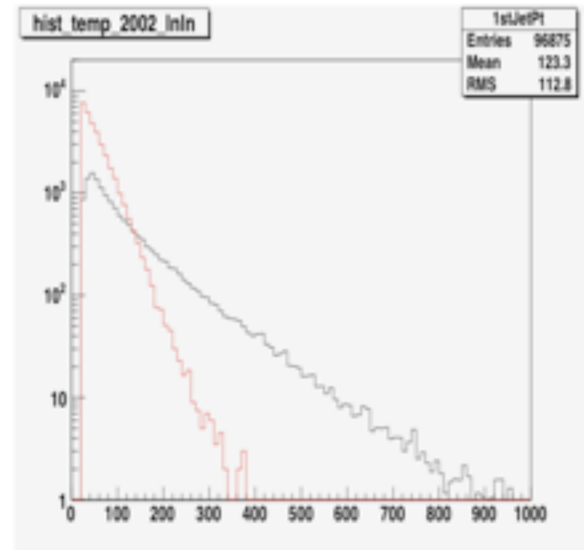
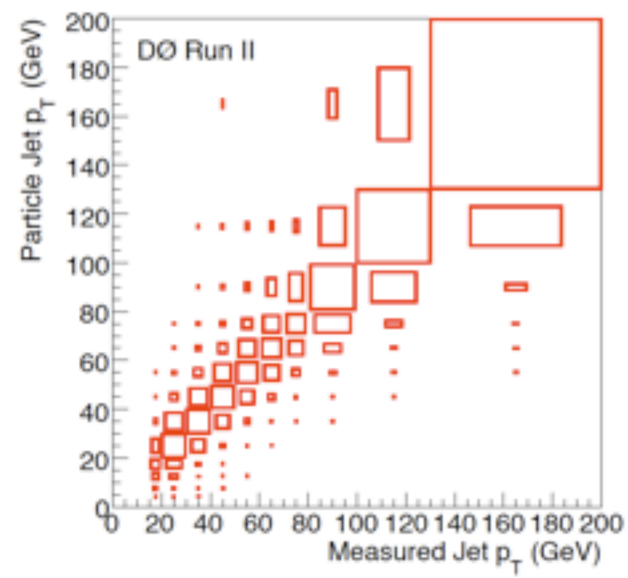
$$\left(\frac{d\sigma}{dp_T(\text{meas})}\right)_{\text{corrected}} = \mathbf{M}^{-1}\left(\frac{d\sigma}{dp_T(\text{meas})}\right)_{\text{uncorrected}}$$



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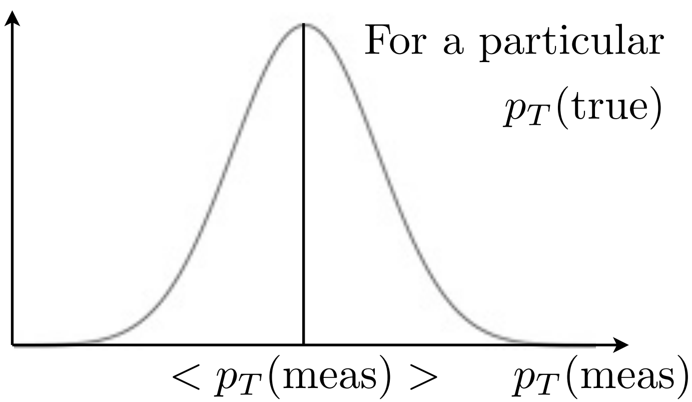


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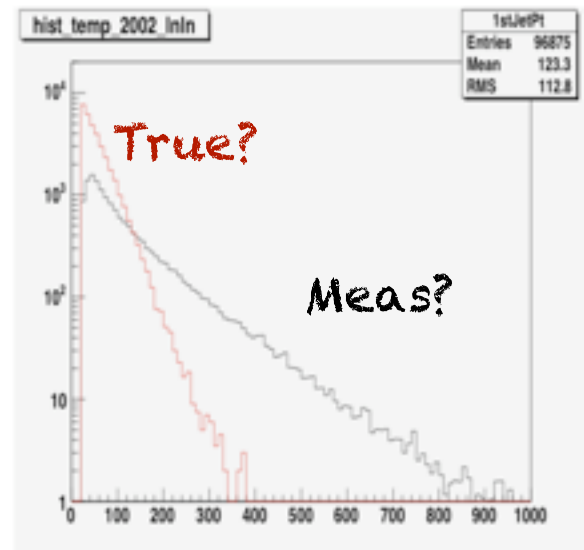


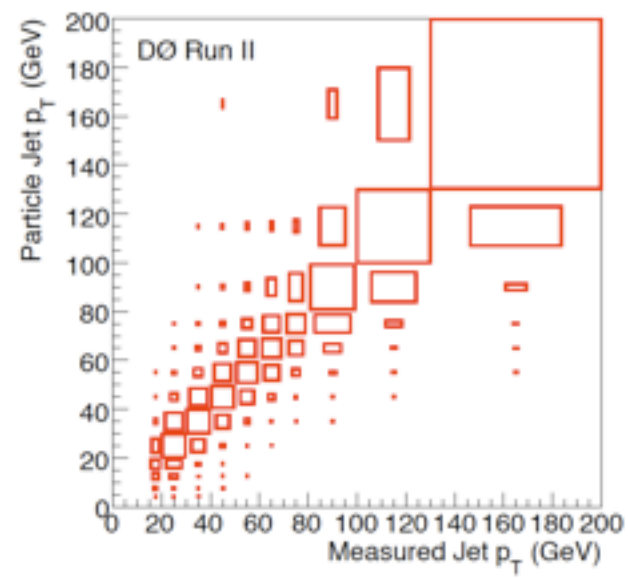

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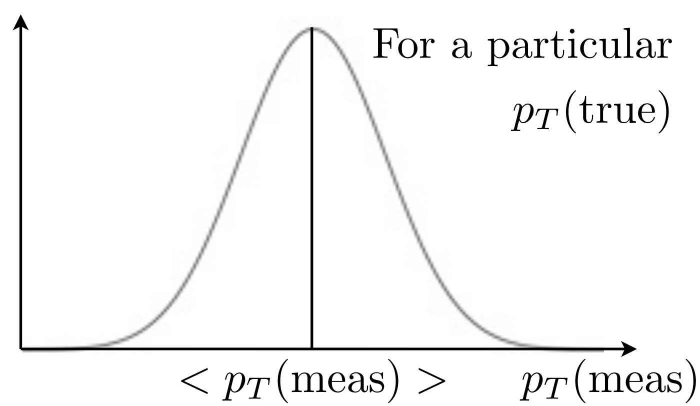


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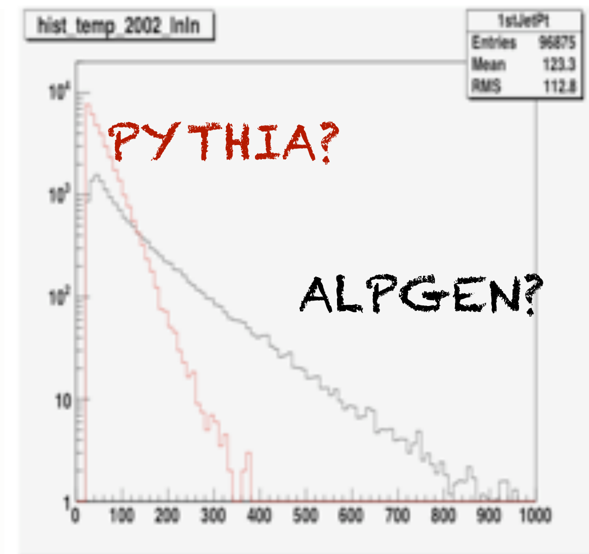
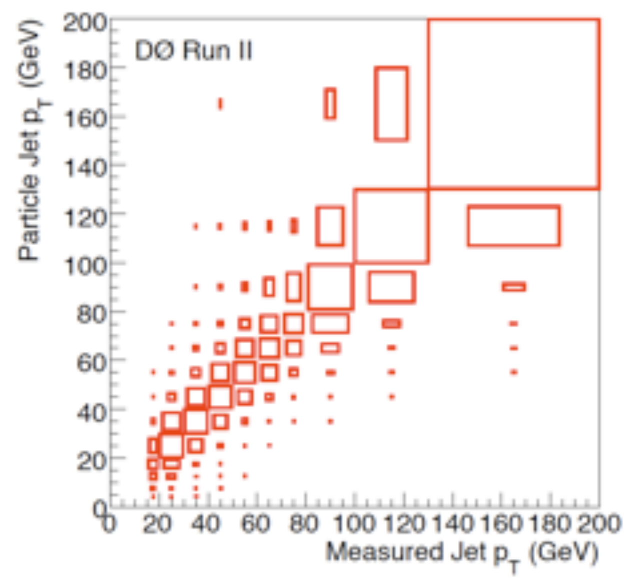
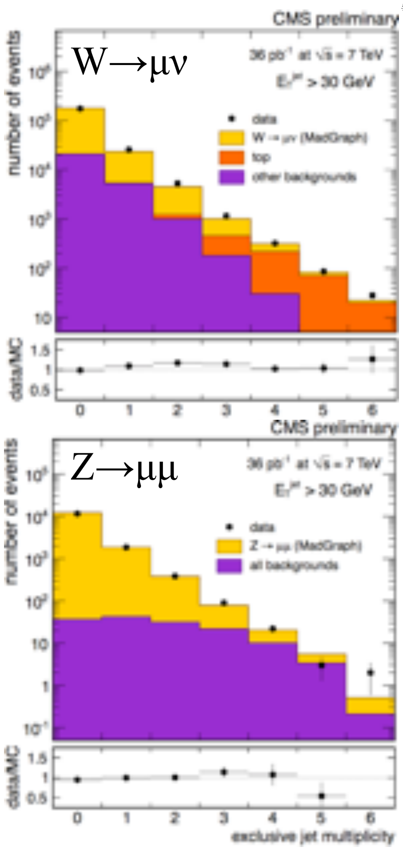


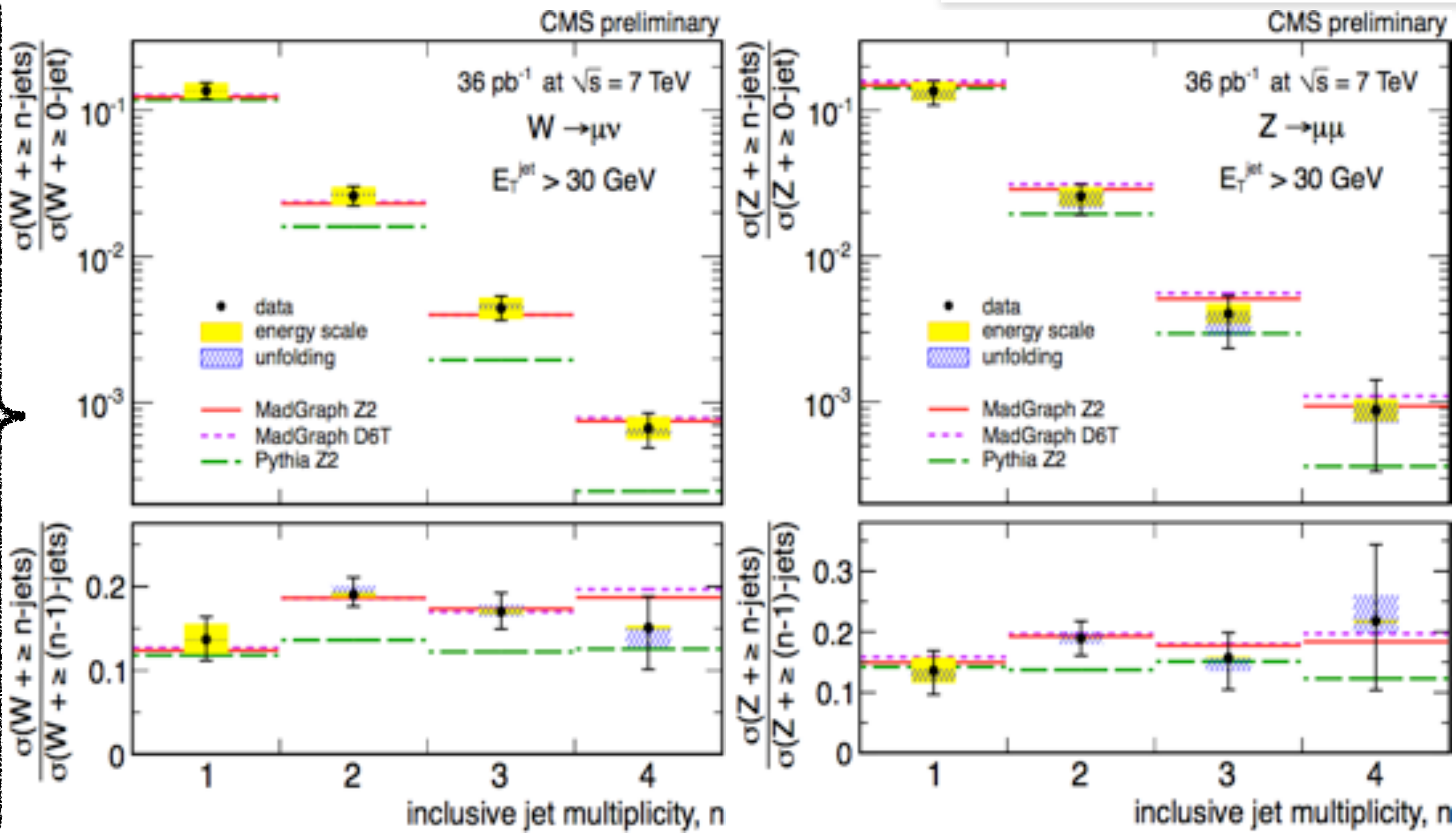



# W, Z + n jets

- Important test of perturbative NLO predictions and background many searches
- Jets reconstructed from Particle Flow using anti-$k_T$ algorithm (R=0.5), $E_T$ > 30 GeV
- Systematics dominates, mainly due to energy scale and unfolding for large *n* (Singular Value Decomposition, assuming MadGraph jet migration from particle-level jets)
- Agreement with MadGraph, discrepancies with Pythia observed

CMS-PAS-EWK-10-012



# W, Z + n jets



- Berends-Giele scaling:

$$\frac{\sigma(V+\geq n-\text{jets})}{\sigma(V+\geq (n+1)-\text{jets})} = \alpha + \beta \times n$$

- Expected ~ constant with n

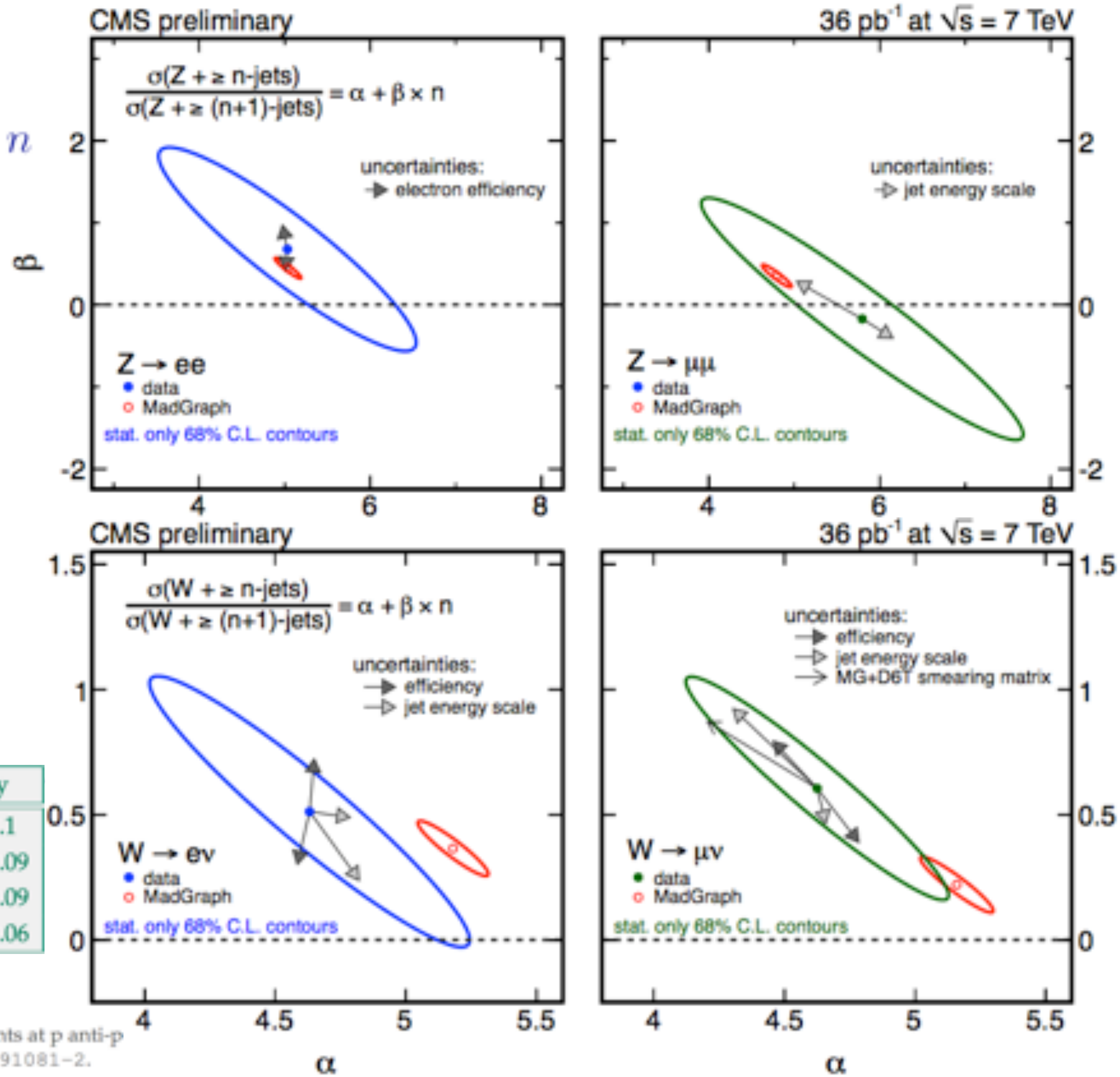
electrons

| | | data | stat | JES | $\epsilon(\ell)$ | Theory |
|---|---|---|---|---|---|---|
| Z | $\alpha$ | 5.0 | ±1.0 | $^{+0.1}_{-0.0}$ | $^{+0.00}_{-0.06}$ | 5.04 ± 0.10 |
| | $\beta$ | 0.7 | ±0.8 | $^{+0.08}_{-0.04}$ | $^{+0.3}_{-0.6}$ | 0.45 ± 0.08 |
| W | $\alpha$ | 4.6 | ±0.4 | $^{+0.2}_{-0.0}$ | $^{-0.05}_{+0.02}$ | 5.18 ± 0.09 |
| | $\beta$ | 0.5 | ±0.4 | $^{+0.0}_{-0.3}$ | ±0.2 | 0.36 ± 0.07 |

muons

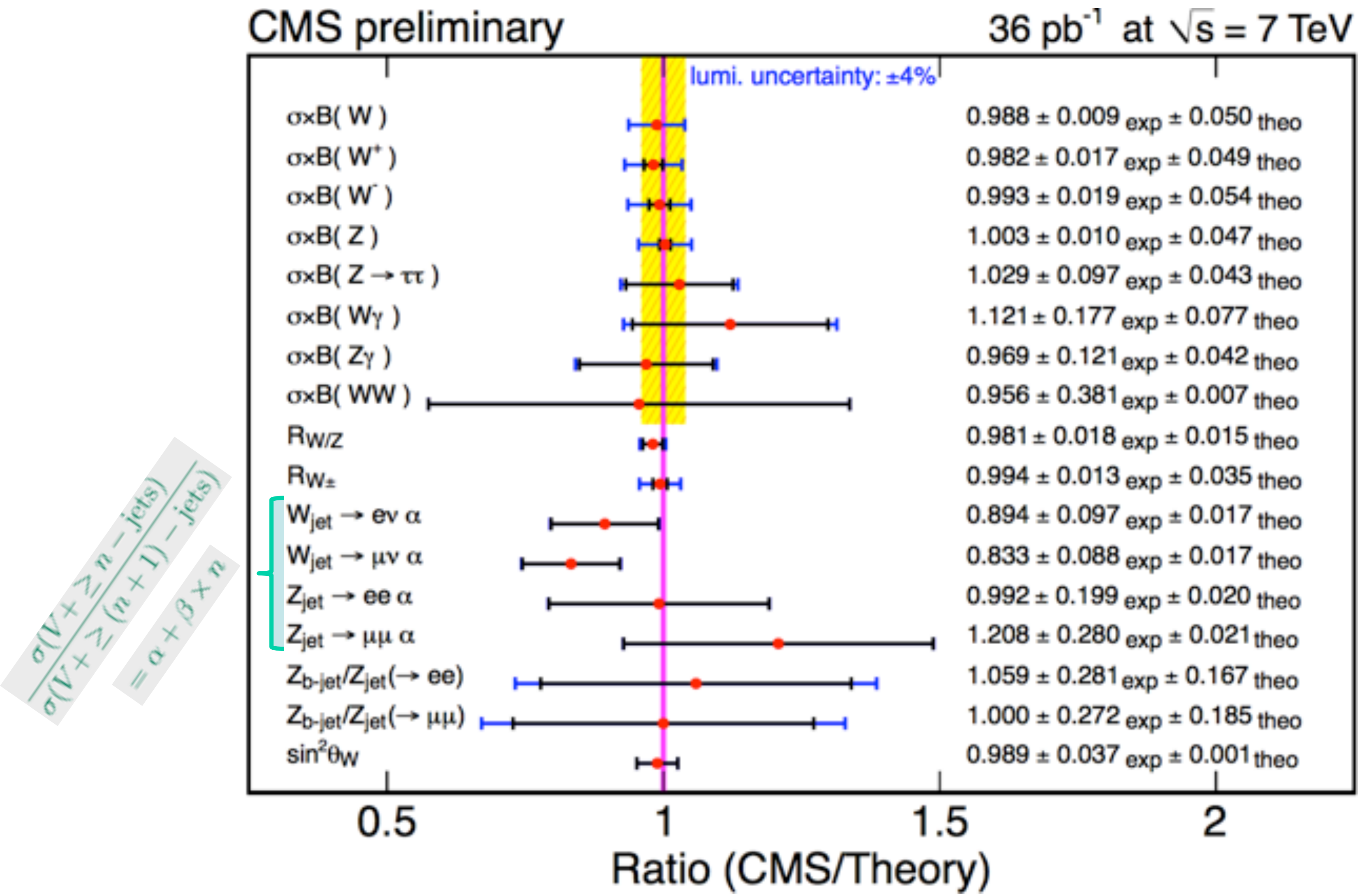
| | | data | stat | JES MC | $\epsilon(\ell)$ | D6T tune | Theory |
|---|---|---|---|---|---|---|---|
| Z | $\alpha$ | 5.8 | ± 1.2 | ±0.6 | ±0.1 | +0.3 | 4.8 ± 0.1 |
| | $\beta$ | -0.2 | ± 1.0 | ±0.3 | ±0.1 | -0.0 | 0.35 ± 0.09 |
| W | $\alpha$ | 4.3 | ±0.3 | ±0.2 | ±0.2 | -0.4 | 5.16 ± 0.09 |
| | $\beta$ | 0.7 | ±0.3 | ±0.2 | ±0.3 | +0.3 | 0.22 ± 0.06 |

CMS-PAS-EWK-10-012



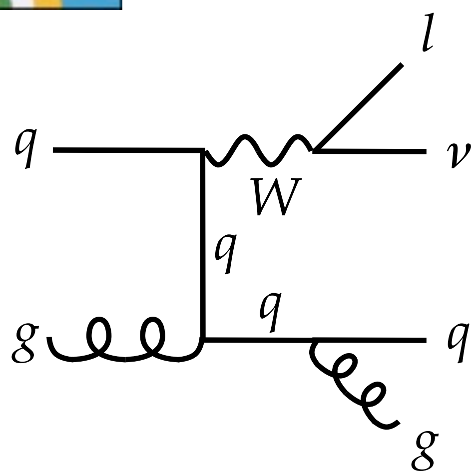

F. A. Berends, W. T. Giele, H. Kuijf et al., "Multi-jet production in W, Z events at p anti-p colliders", *Phys. Lett.* **B224** (1989) 237. doi:10.1016/0370-2693(89)91081-2.

# Summary of CMS EW results

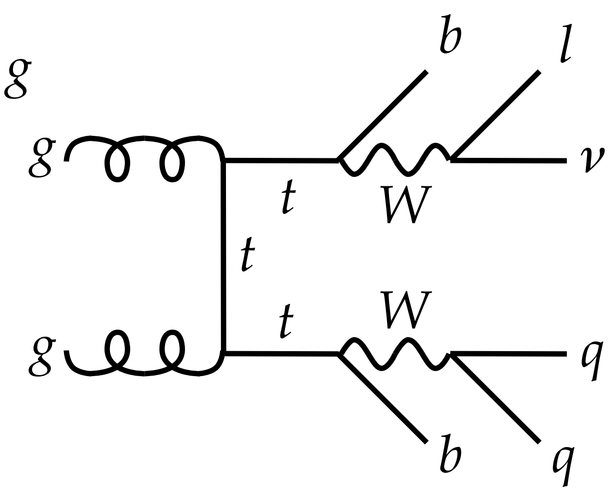


# Descending* the staircase of the SM...

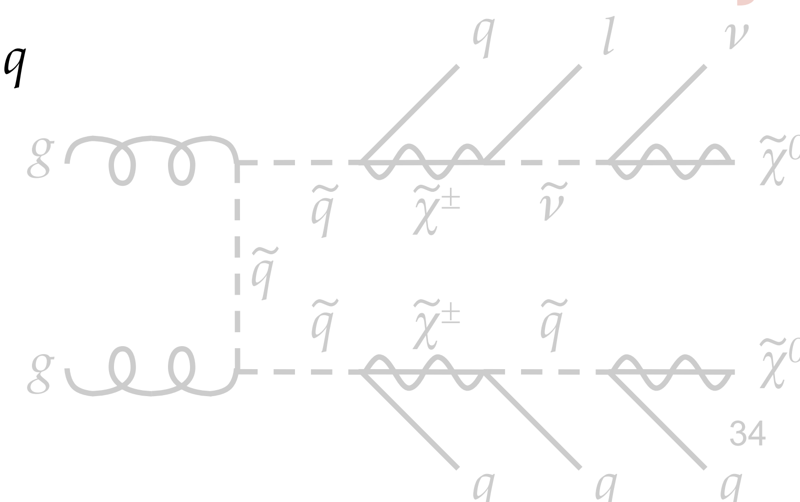
**QCD + Electroweak**




**Top**

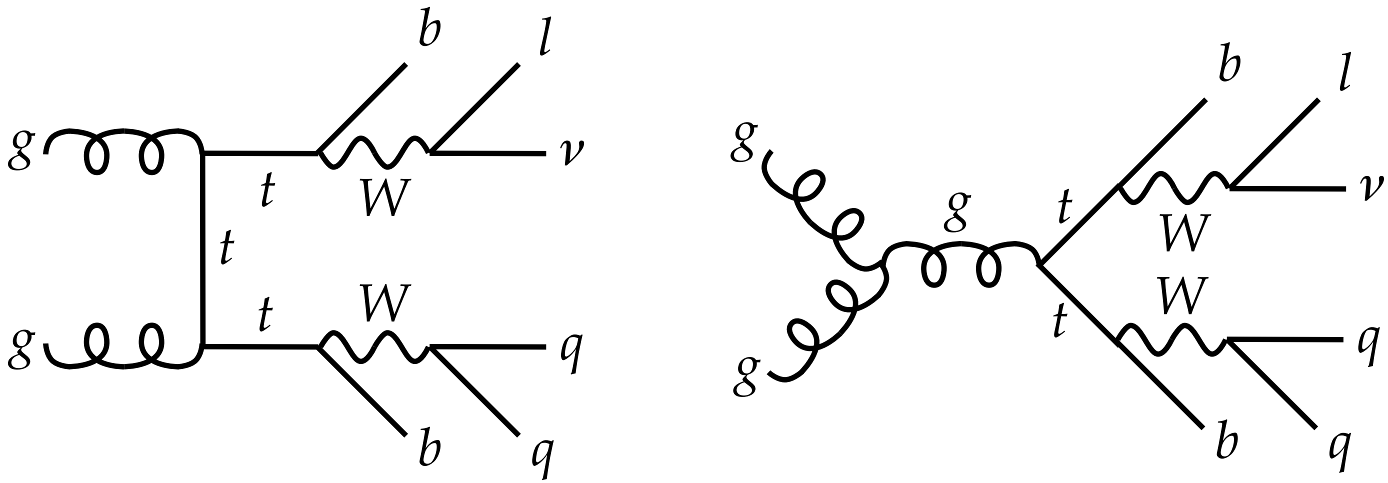



**...to New Physics**

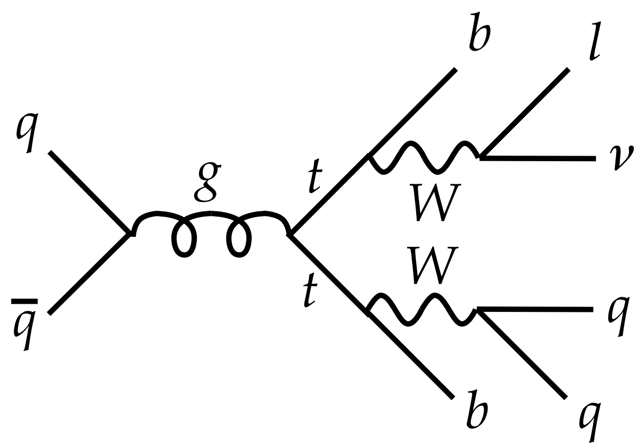



*Adapted from Michael Peskin

# LHC: Tops produced by gluons



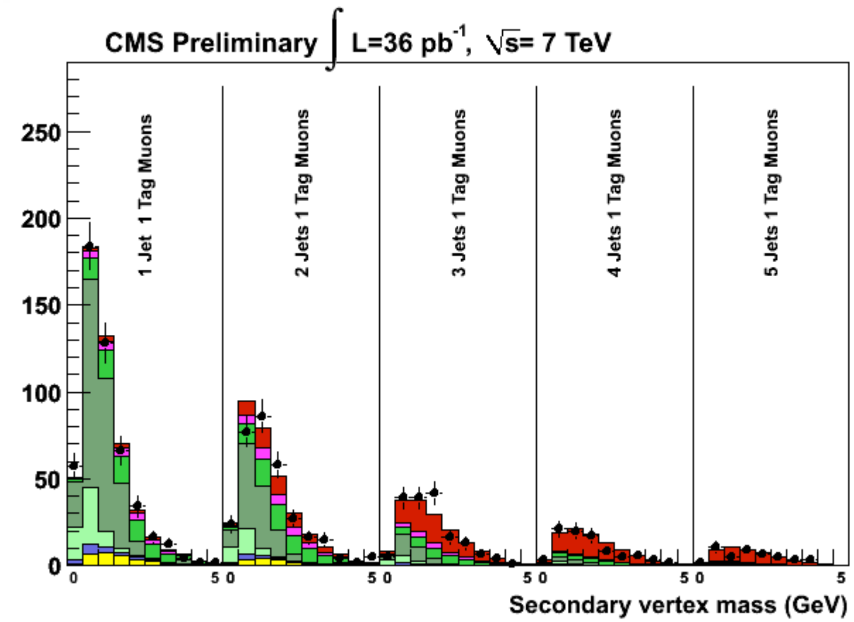

85%

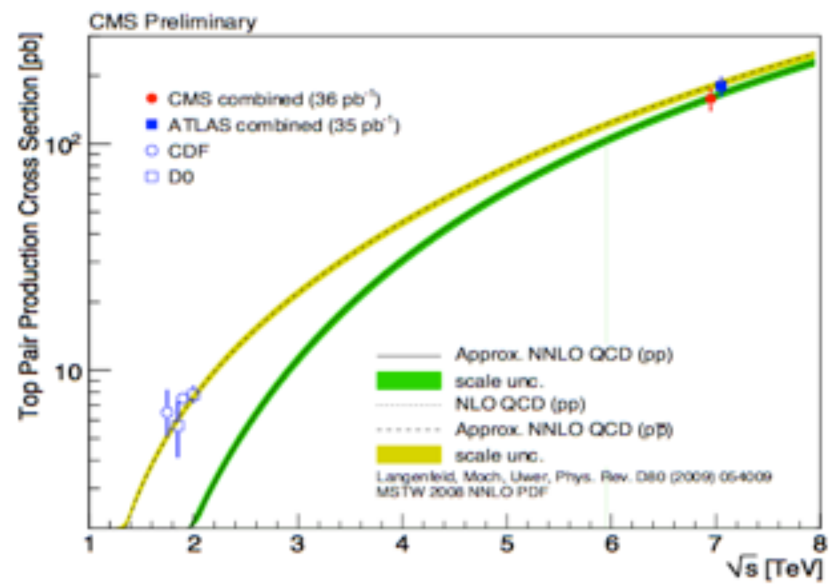



15%

# Top Cross Section

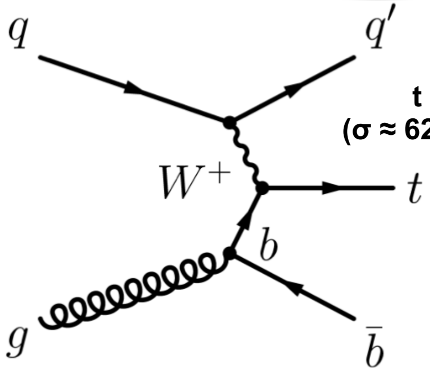
- Divide sample into categories:
  - Njets, Ntags, electrons, muons
- Fit secondary vertex mass distribution
  - across all categories using shapes from simulation
- Let data/MC scale factors (JES, b-tag/miss-tag eff.) also float
- Result:
  - top cross section 11% syst. uncert.
  - scale factors consistent with 1, within fit error



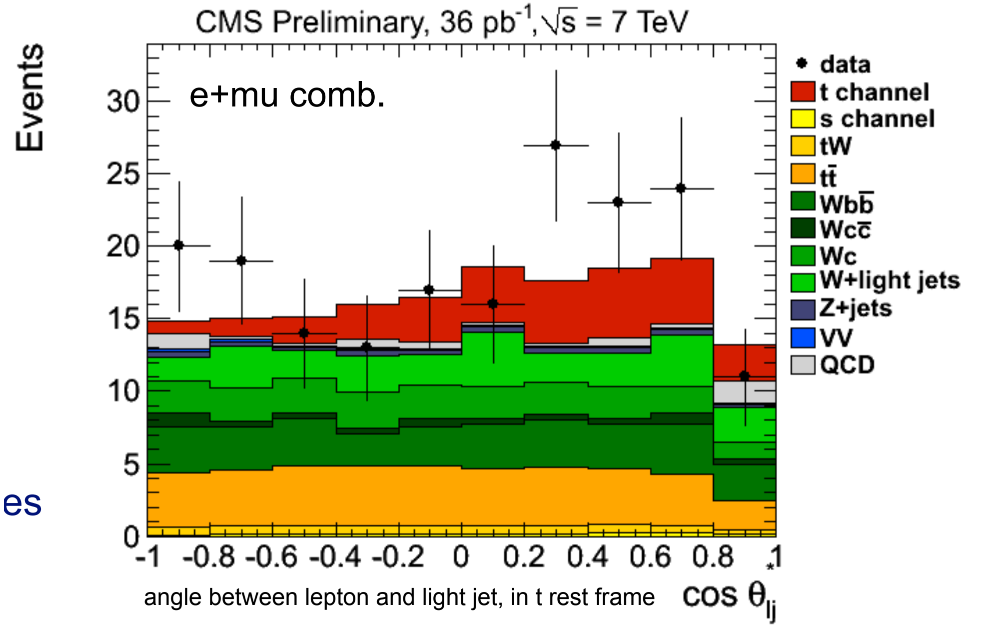
# Single Top Production

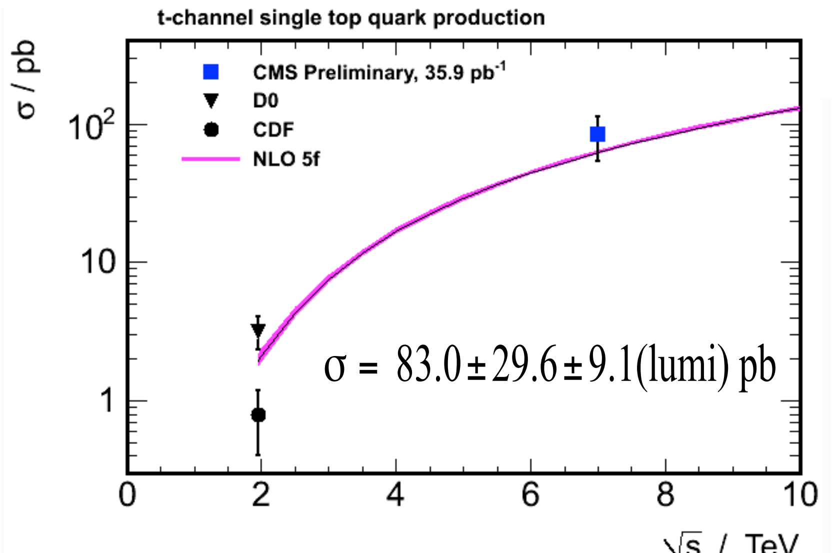





- Example of finding tiny signals with lepton, MET, b-tag and jets
- Two different analyses (cut based and BDT):
  - three different channels.
- Very challenging analysis.

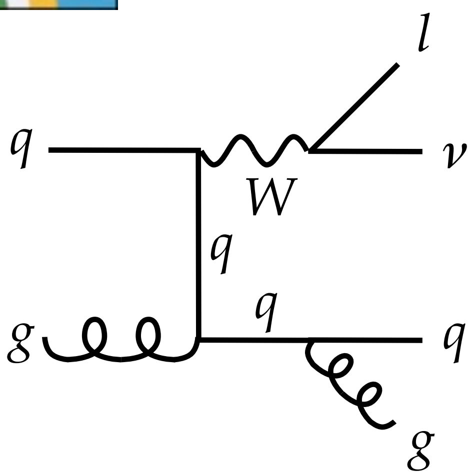
es



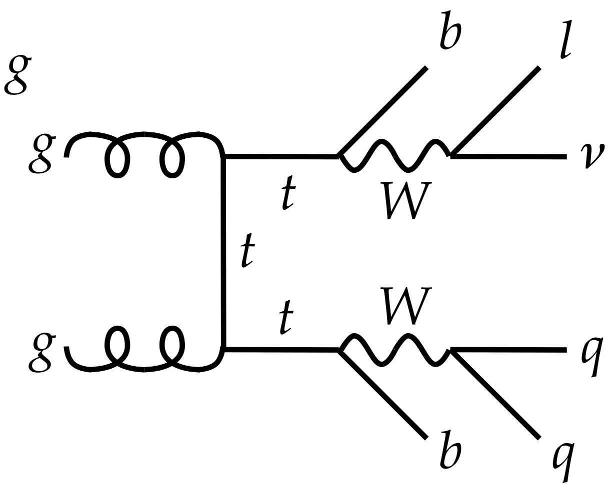



# Descending* the staircase of the SM…

## QCD + Electroweak




## Top

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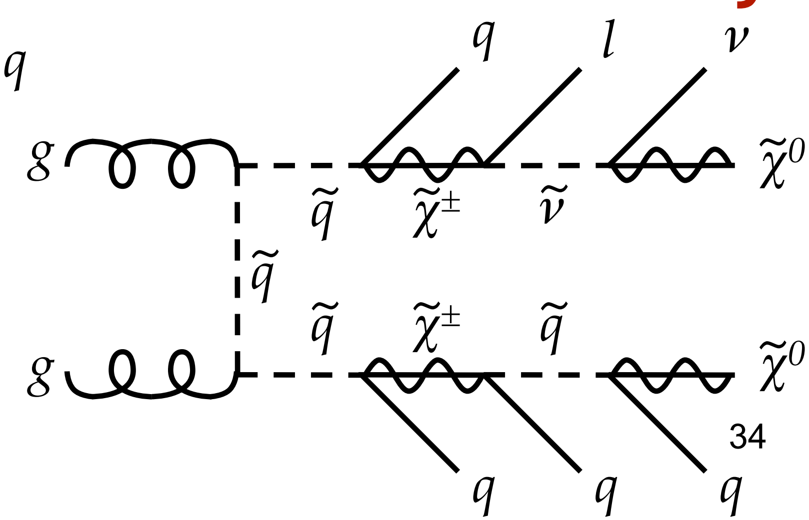
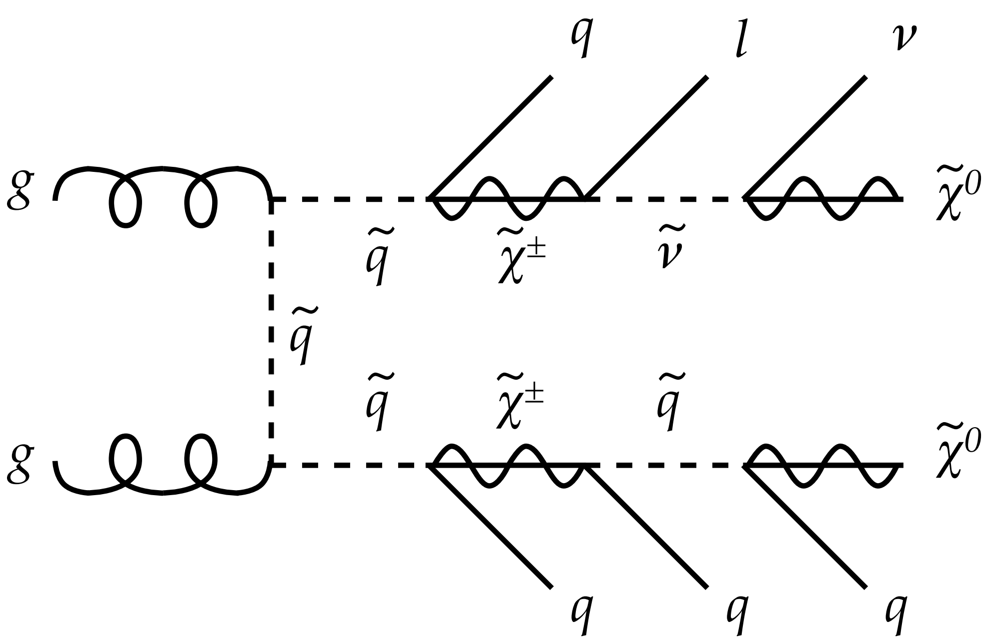



*Adapted from Michael Peskin

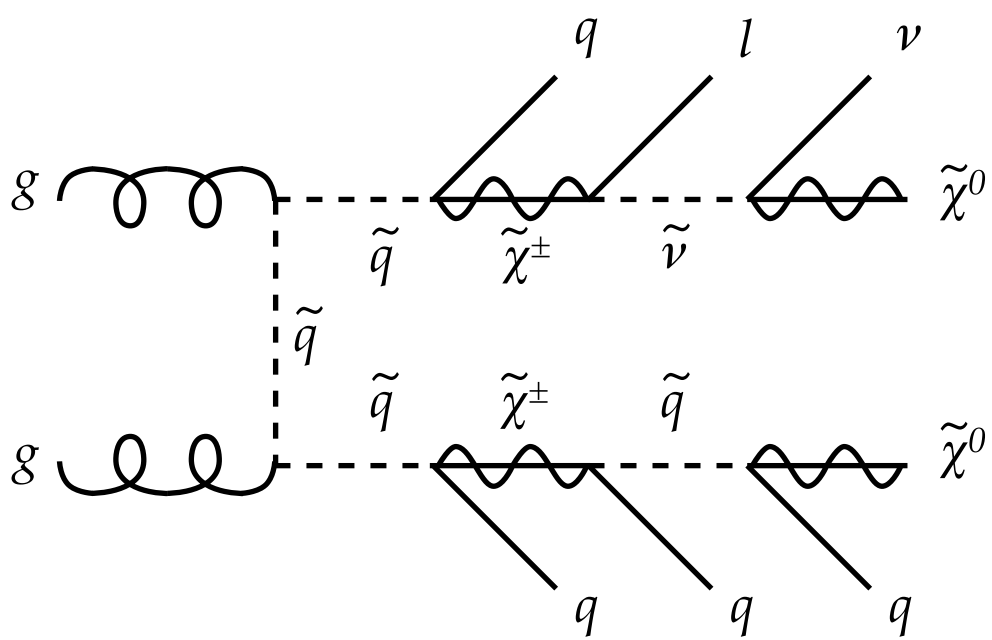
# SUSY: Cascade Decays



# SUSY: Cascade Decays

| 0-leptons | 1-lepton | OSDL | SSDL | ≥3 leptons | 2-photons | γ+lepton |
|---|---|---|---|---|---|---|
| Jets + MET | Single lepton + Jets + MET | Opposite-sign di-lepton + jets + MET | Same-sign di-lepton + jets + MET | Multi-lepton | Di-photon + jet + MET | Photon + lepton + MET |

Modified from G. Dissertori



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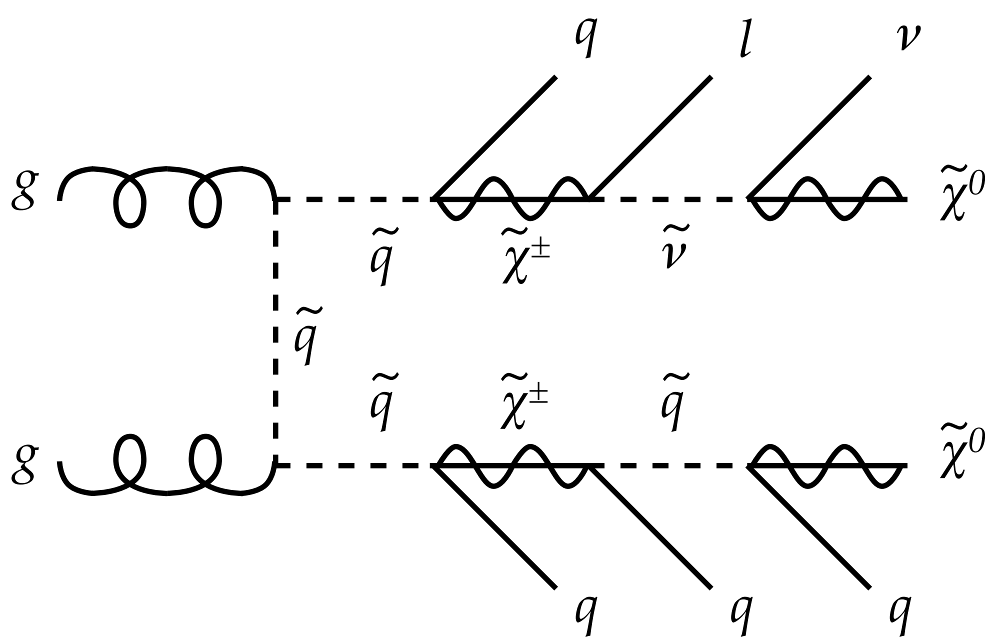
|---|---|---|---|---|---|---|
| Jets + MET | Single lepton + Jets + MET | Opposite-sign di-lepton + jets + MET | Same-sign di-lepton + jets + MET | Multi-lepton | Di-photon + jet + MET | Photon + lepton + MET |

High SM Backgrounds Low

Modified from G. Dissertori



# SUSY: Cascade Decays

| 0-leptons | 1-lepton | OSDL | SSDL | ≥3 leptons | 2-photons | γ+lepton |
|---|---|---|---|---|---|---|
| Jets + MET | Single lepton + Jets + MET | Opposite-sign di-lepton + jets + MET | Same-sign di-lepton + jets + MET | Multi-lepton | Di-photon + jet + MET | Photon + lepton + MET |

High SM Backgrounds Low →

← Discovery Sensitivity

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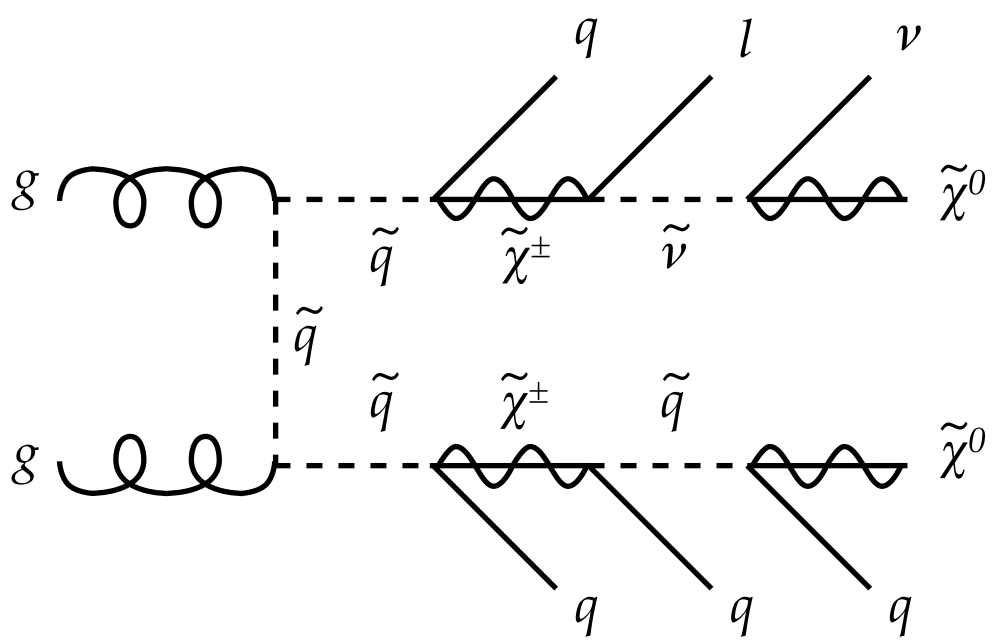

# SUSY: Cascade Decays

Fermilab
UIC University of Illinois at Chicago

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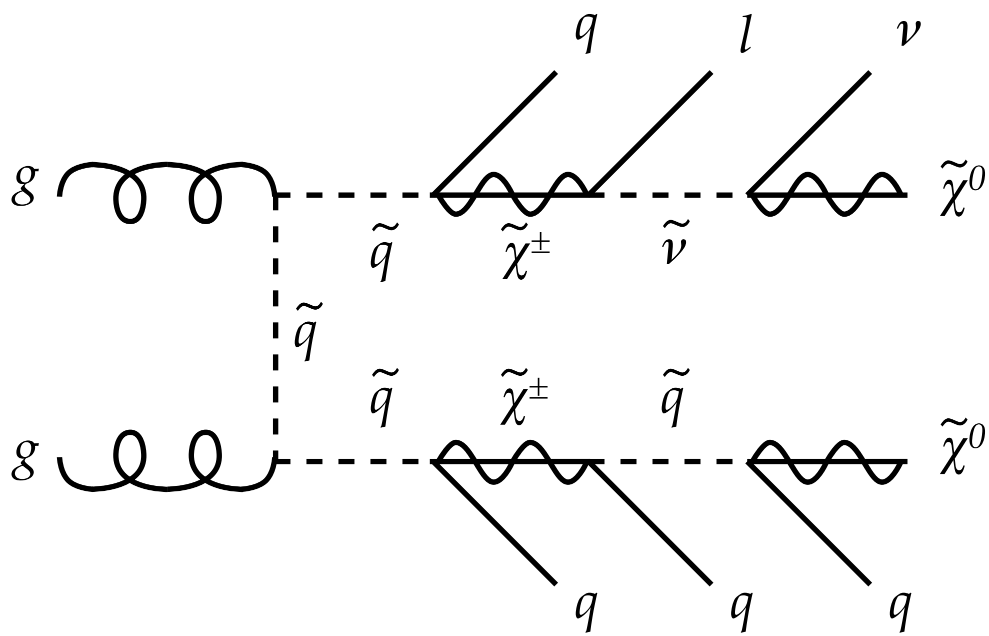
High — SM Backgrounds — Low →

← Discovery Sensitivity

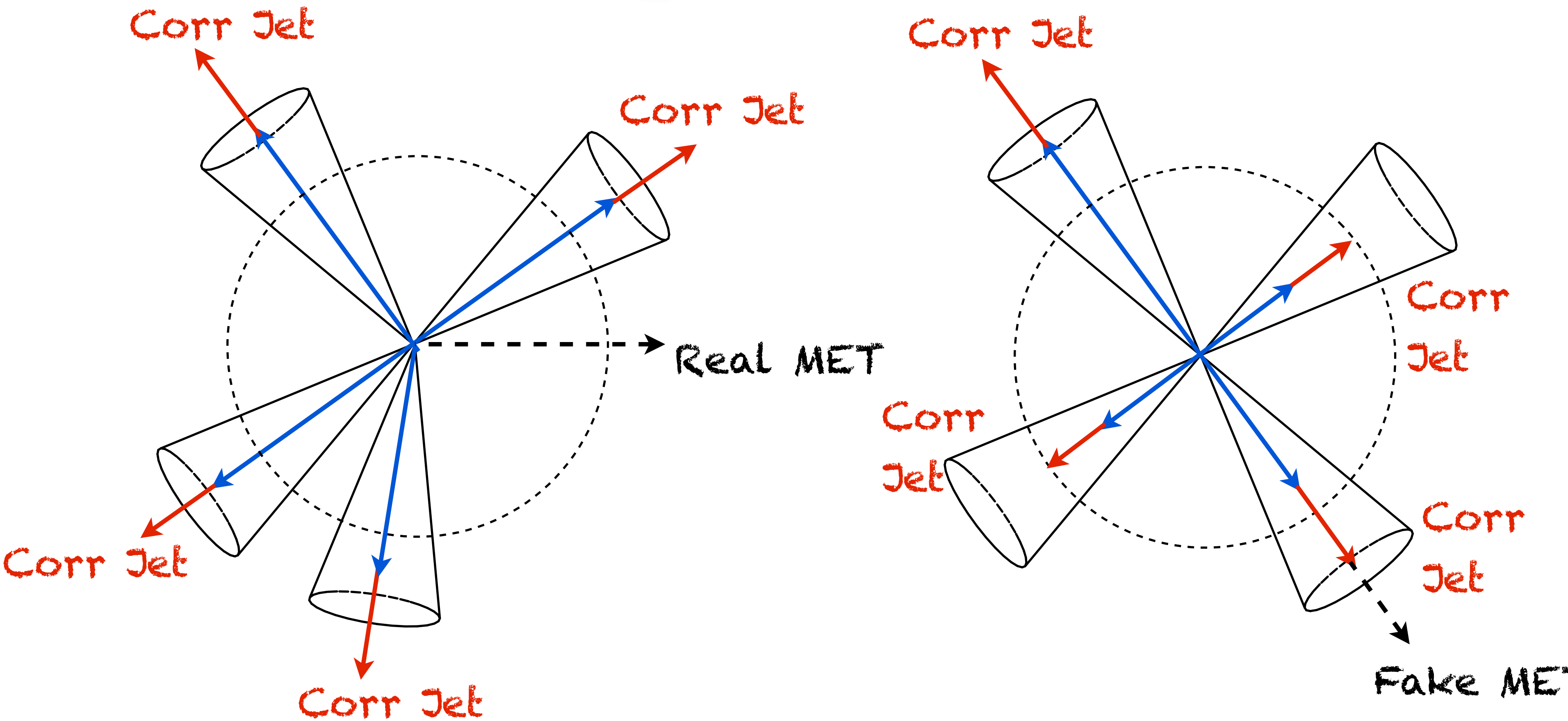
↔ Gauge-mediated SUSY Breaking




Modified from G. Dissertori

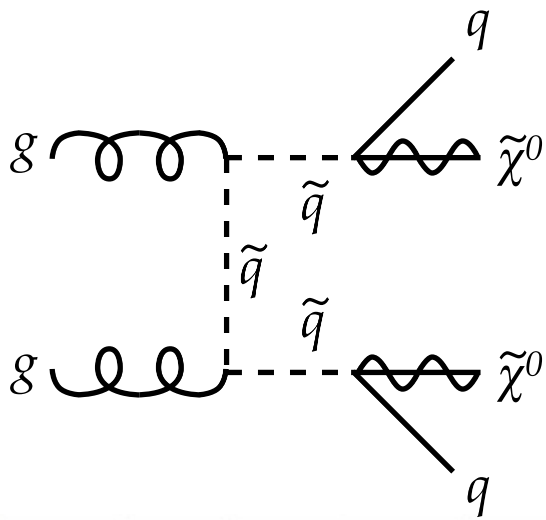
# Cleaning Fake MET

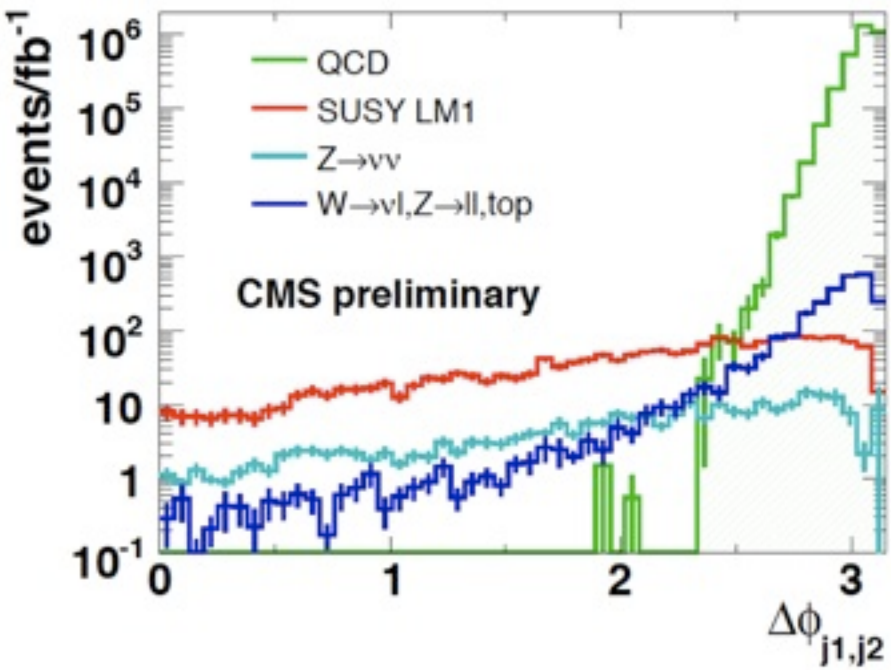


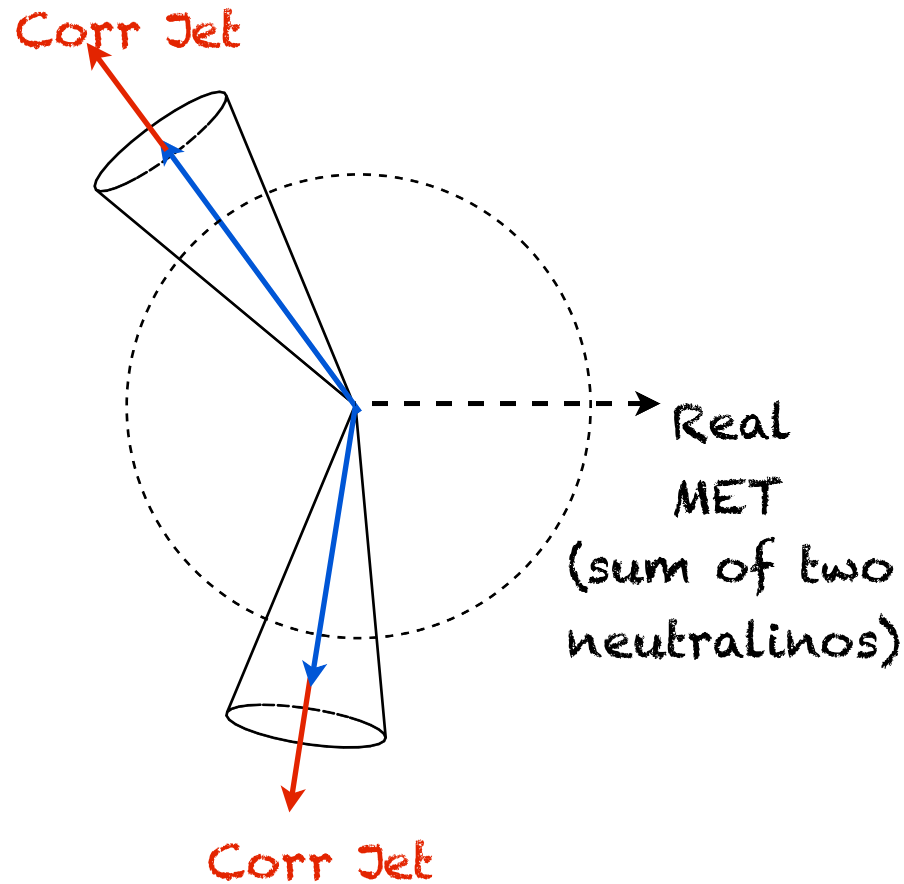



- Real MET is typically "isolated"
  - i.e. does not point in direction of a jet
- Fake MET typically points in direction of 2nd leading jet

# Exclusive dijet + MET



# Exclusive dijet + MET

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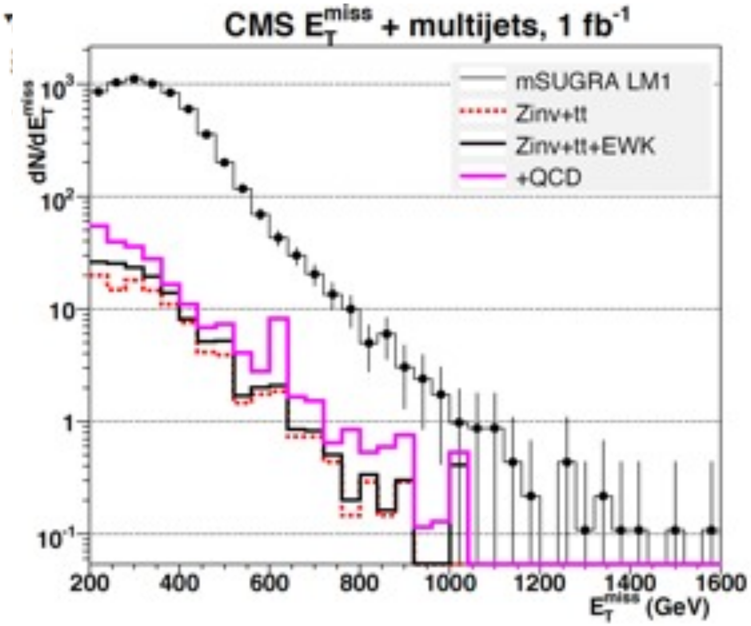
- ...so, try to avoid using it



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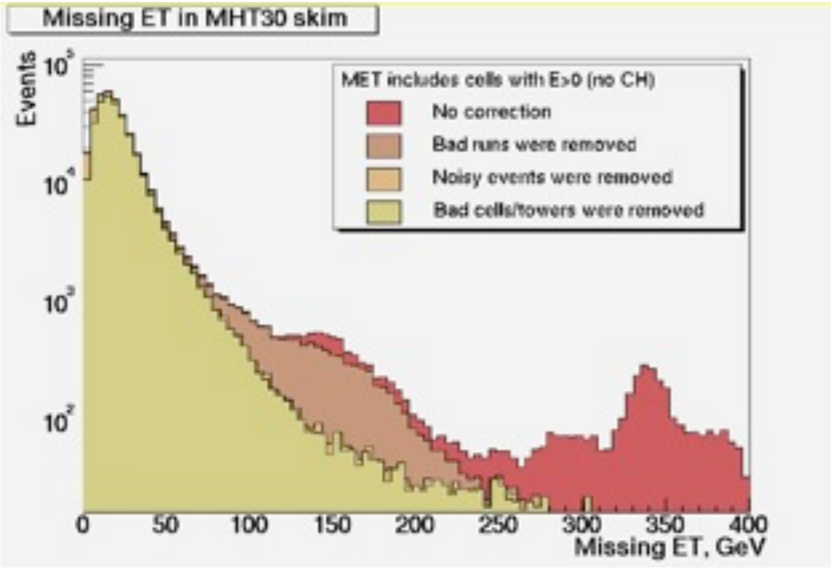

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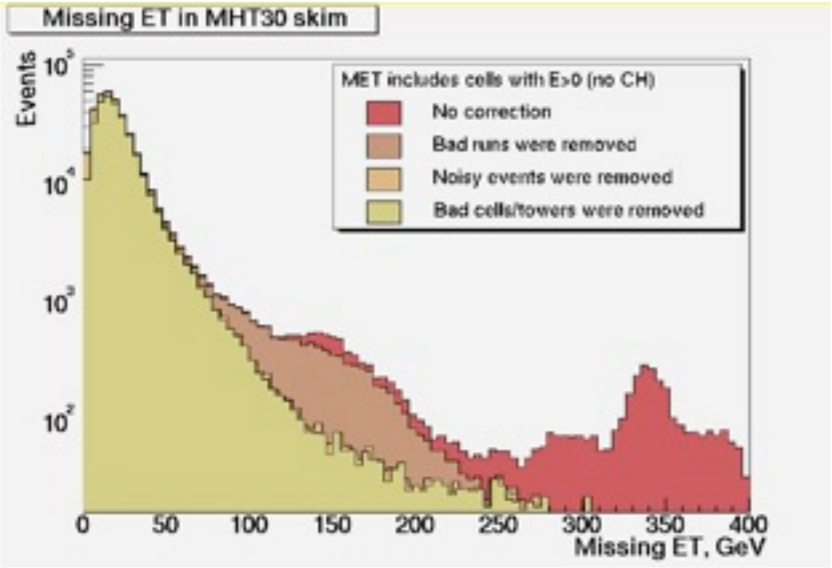
$$\alpha_T = \frac{E_T^{j2}}{\sqrt{2E_T^{j1}E_T^{j2}(1-\cos\Delta\phi)}} = \frac{\sqrt{E_T^{j2}/E_T^{j1}}}{\sqrt{2(1-\cos\Delta\phi)}}$$



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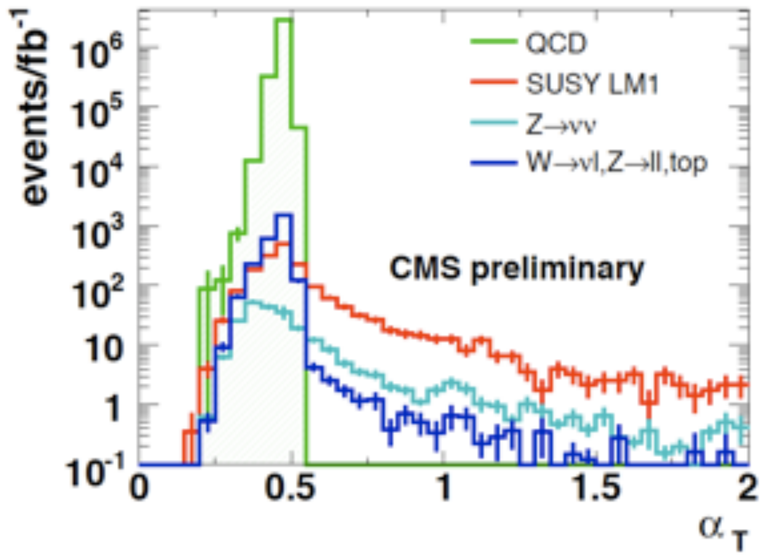

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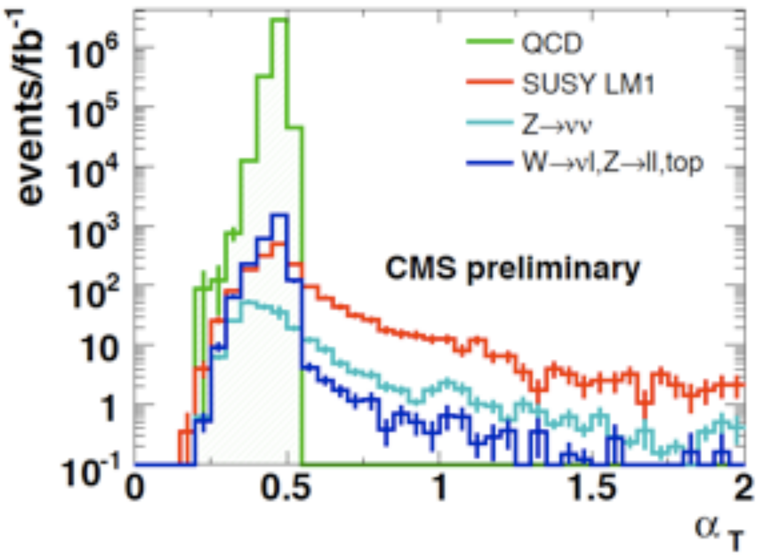


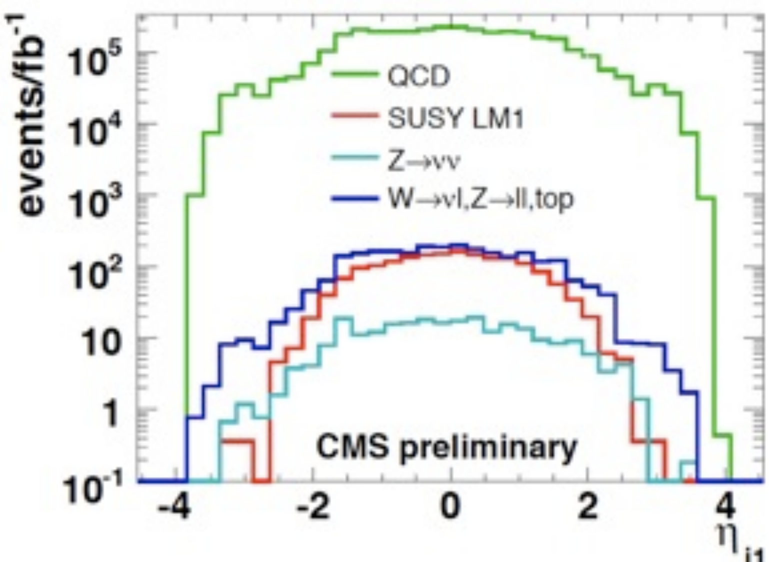

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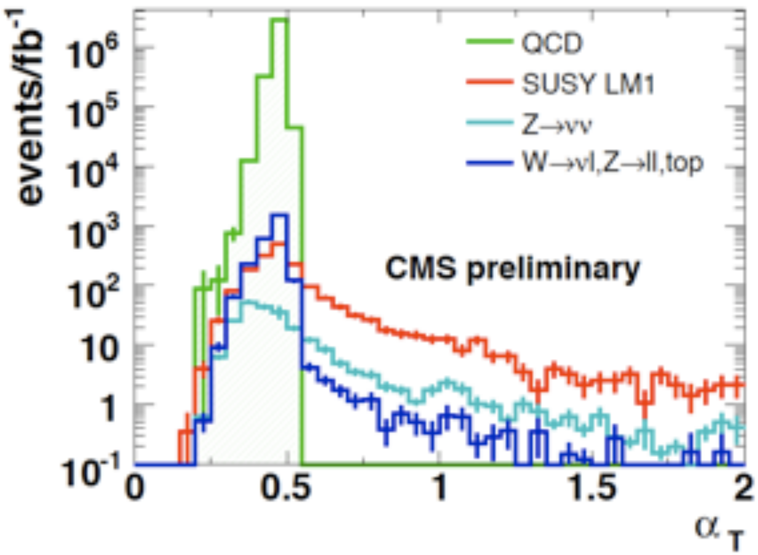
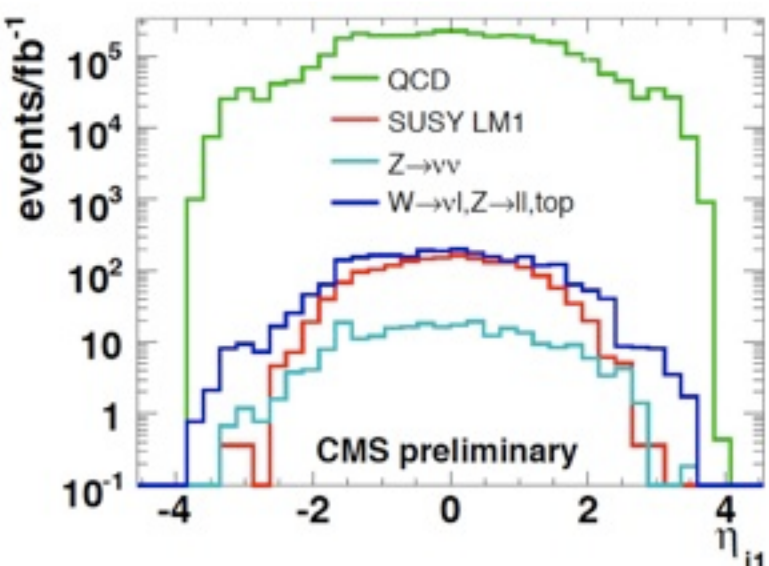
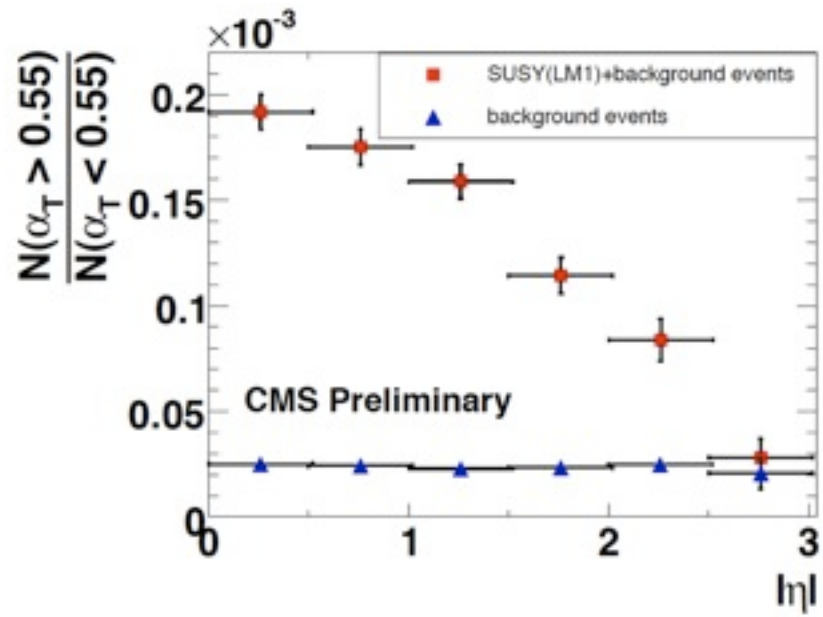


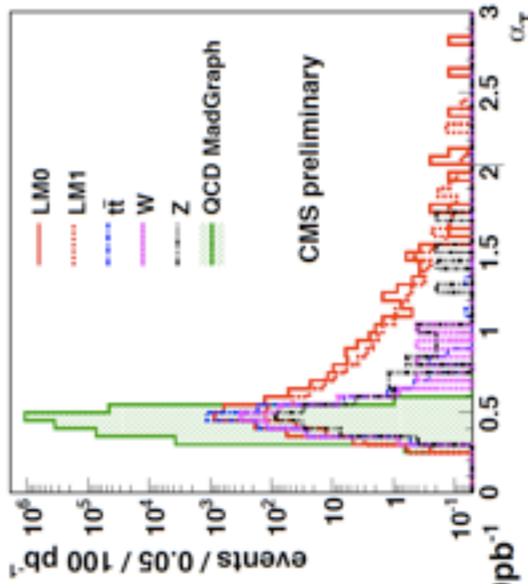



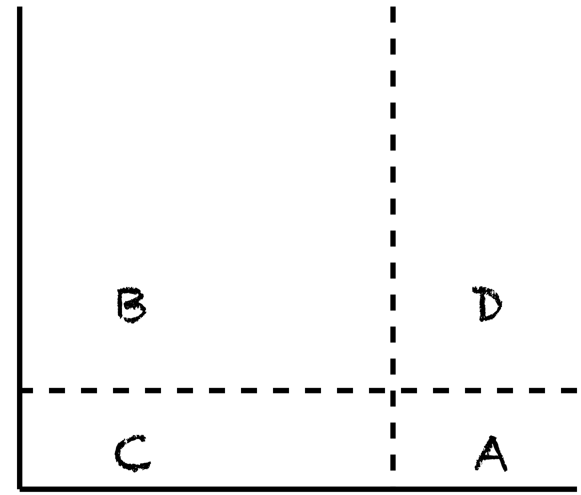



# ABCD/Matrix method



- Estimate bkg from data:
  - Most signal is in "C"
  - Backgrounds are in
    - "A", "D", "B"

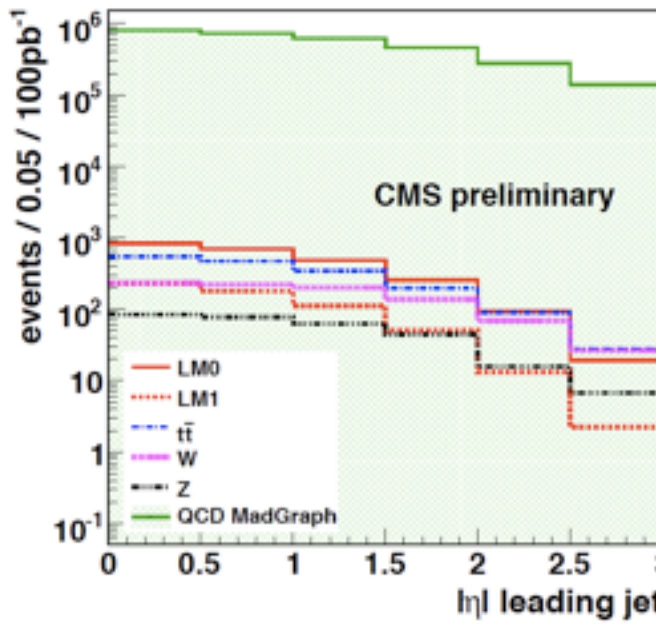


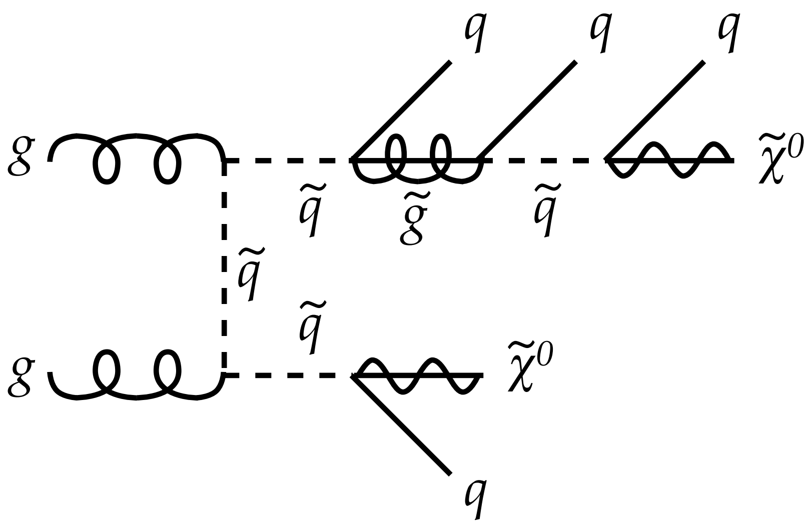

- Assume that for bkg
  - "A" / "D" = "C" / "B"
  - valid if $\alpha_T$ & $\eta$ are uncorrelated

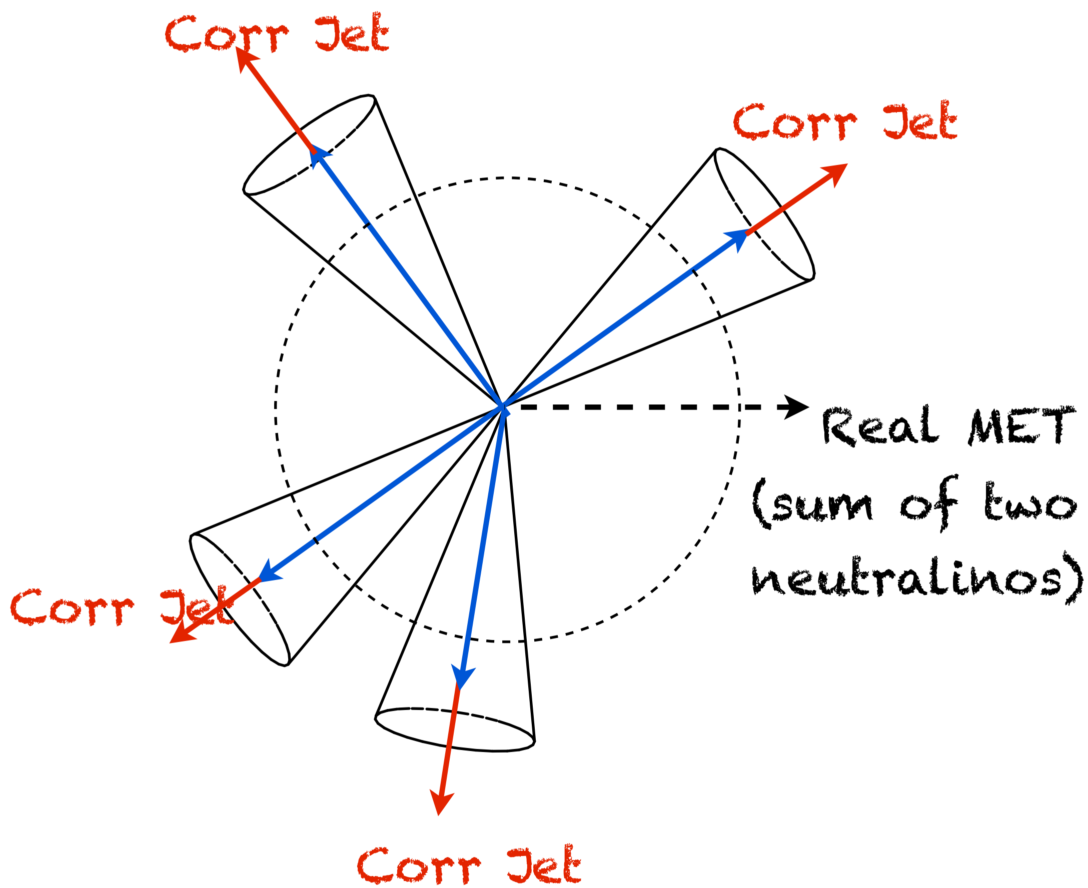
$$N^{\text{bkg}}_{\text{pred}}(\alpha_{\text{T}} > 0.55, |\eta| < 2)$$

$$= R_{\alpha\text{T}}(0.55, |\eta| > 2) \times N^{\text{bkg}}_{\text{meas}}(\alpha_{\text{T}} < 0.55, |\eta| < 2)$$



# Inclusive N-Jets + MET



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- One can indeed generalize to N-Jets
  - basic idea: combine N-Jets into effective 2-Jet system
  - Formula looks a little bit different, but idea is same

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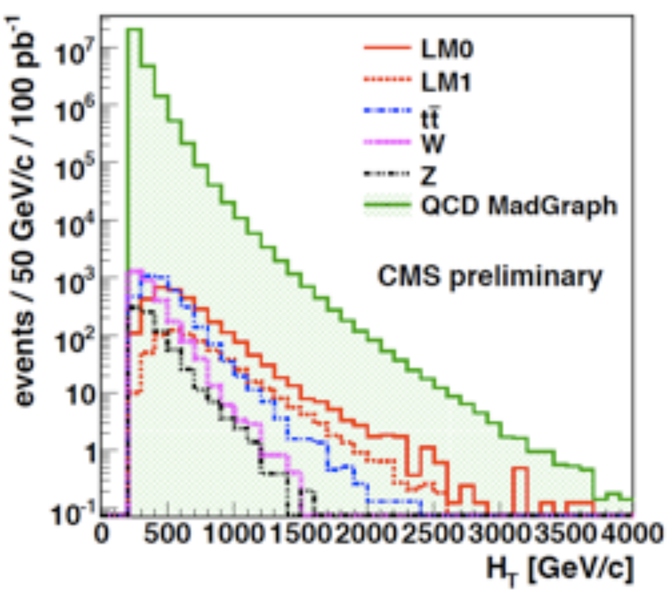
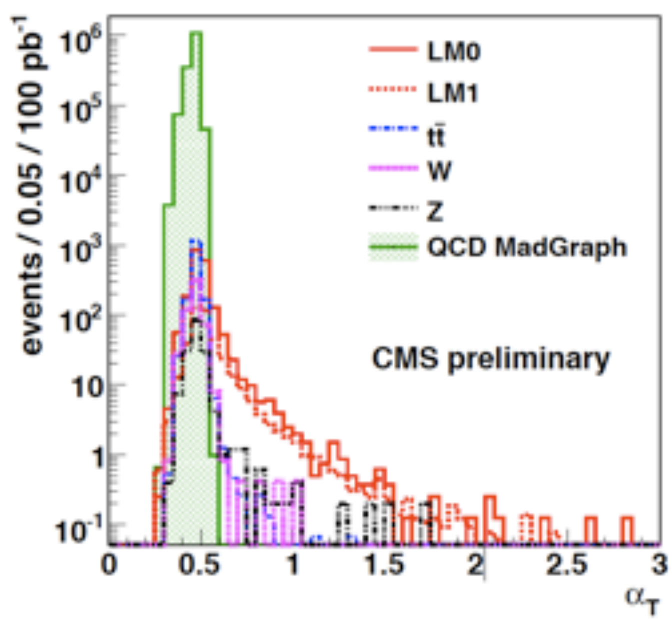
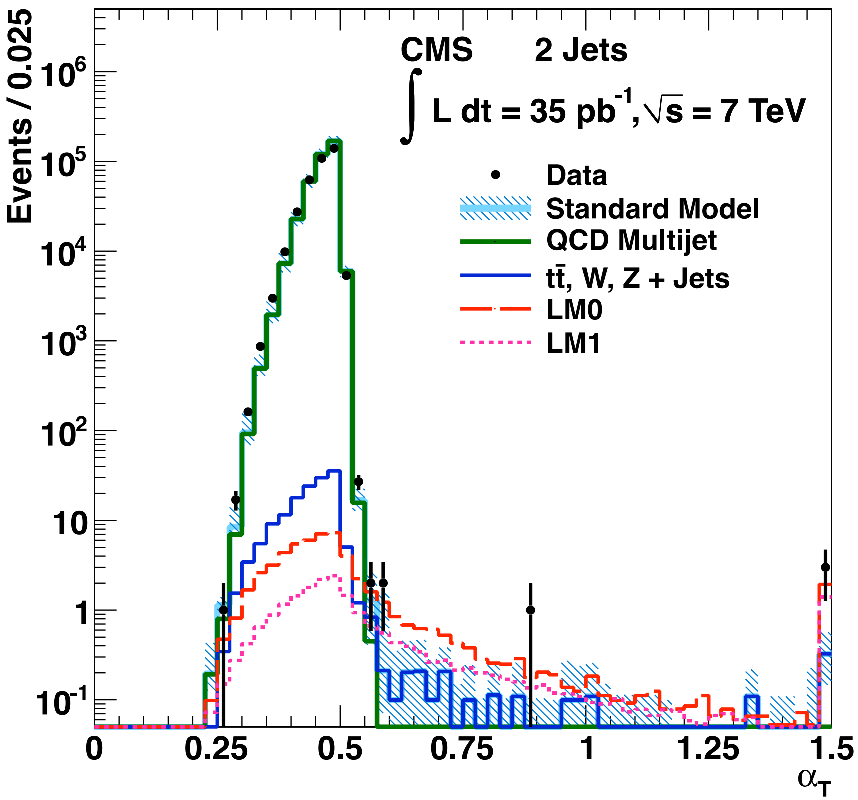
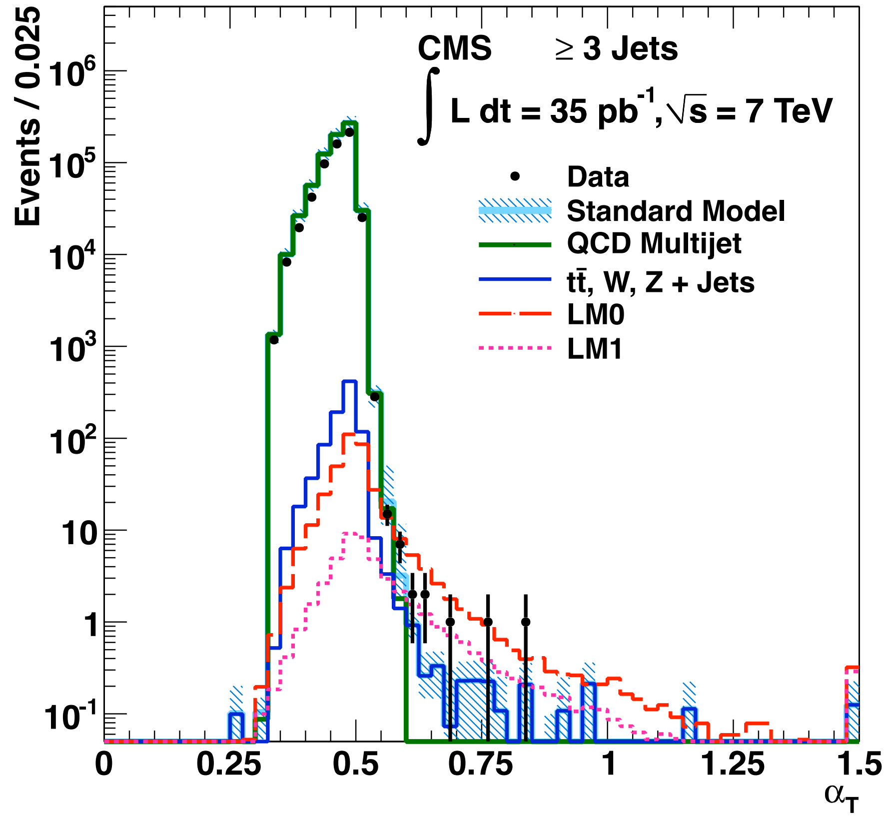


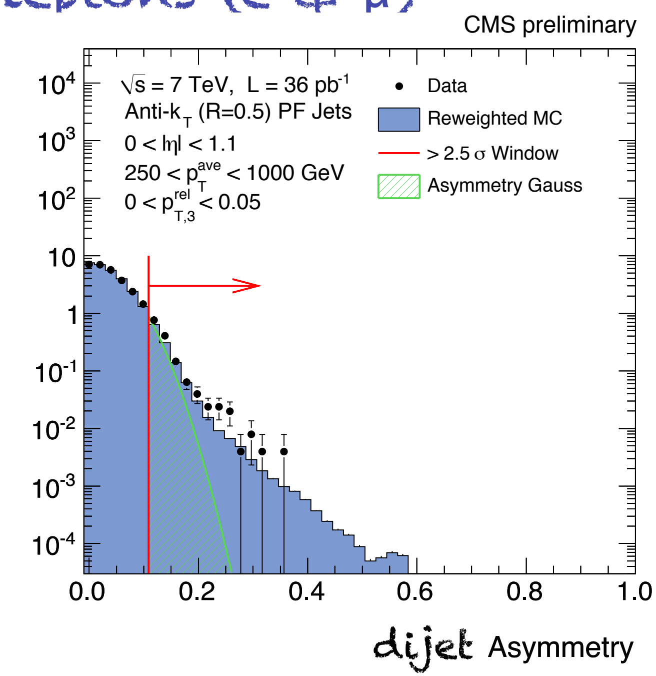


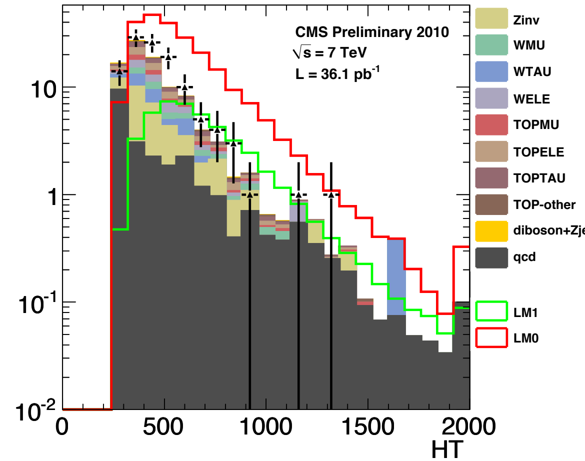



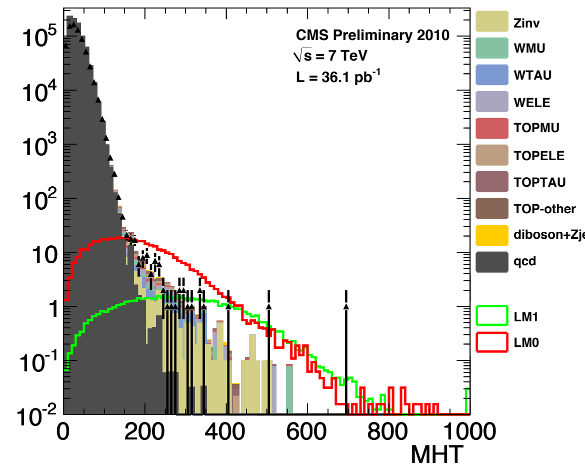

arXiv:1101.1628 PLB 698 (2011) 196

# Full Jets & MET Search

- Analysis based on understanding the detector response in detail
  - Jets + MET in good shape! Use them!
- Complementary to kinematic searches
- baseline selection:
  - at least 3 jets pT > 50 & |η| < 2.5
  - HT > 300 & MHT > 150
  - veto isolated leptons (e & μ)
- Backgrounds:
  - multijet QCD,
  - Z(+jets)->νν,
  - W+jets,
  - ttbar
  - determined from data!

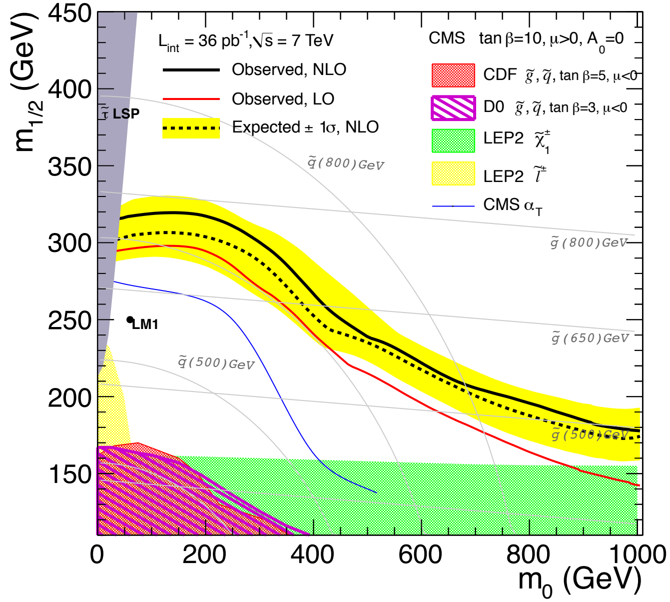


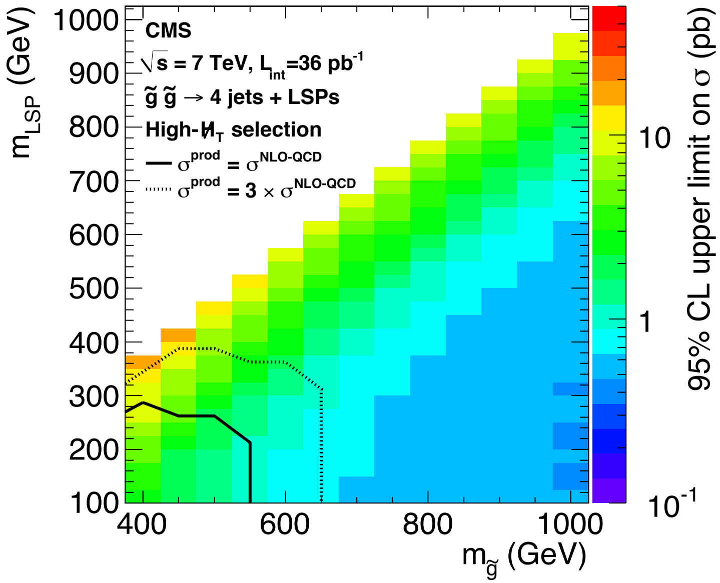



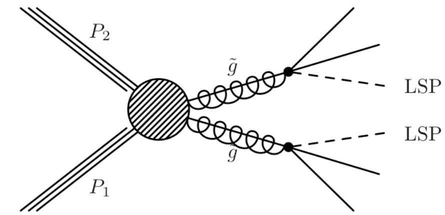



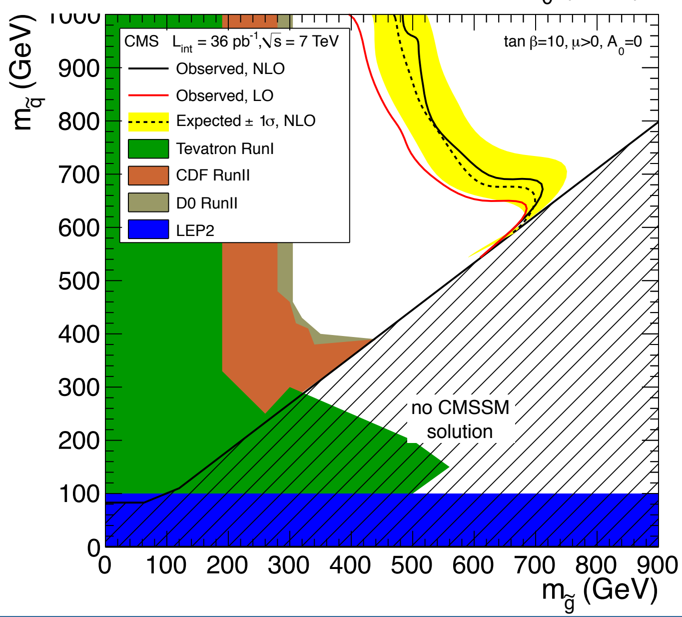

| | Predicted | Observed |
|---|---|---|
| MHT > 250 GeV | 19 ± 3.6 | 15 |

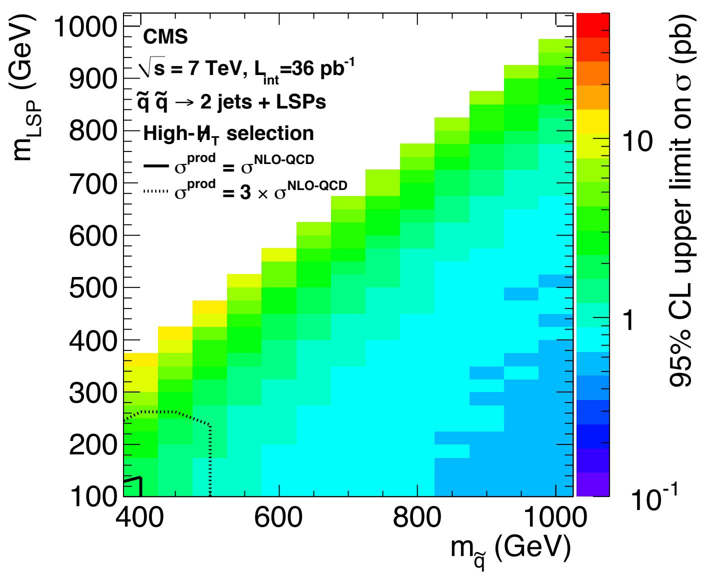
| | Predicted | Observed |
|---|---|---|
| HT > 500 GeV | 43.9 ± 6.1 | 40 |

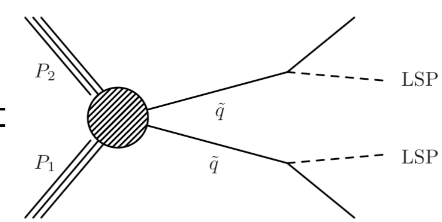

CMS tan β=10, μ>0, A0=0
Lint = 36 pb-1, √s = 7 TeV
Observed, NLO
Observed, LO
Expected ± 1σ, NLO
CDF g̃, q̃, tan β=5, μ<0
D0 g̃, q̃, tan β=3, μ<0
LEP2 χ̃±1
LEP2 l̃±
CMS αT
τ̃ LSP
LM1
q̃(800)GeV
g̃(800)GeV
g̃(650)GeV
q̃(500)GeV
g̃(500)GeV
m1/2 (GeV)
m0 (GeV)


CMS
√s = 7 TeV, Lint=36 pb-1
g̃ g̃ → 4 jets + LSPs
High-HT selection
σprod = σNLO-QCD
σprod = 3 × σNLO-QCD
mLSP (GeV)
mg̃ (GeV)
95% CL upper limit on σ (pb)

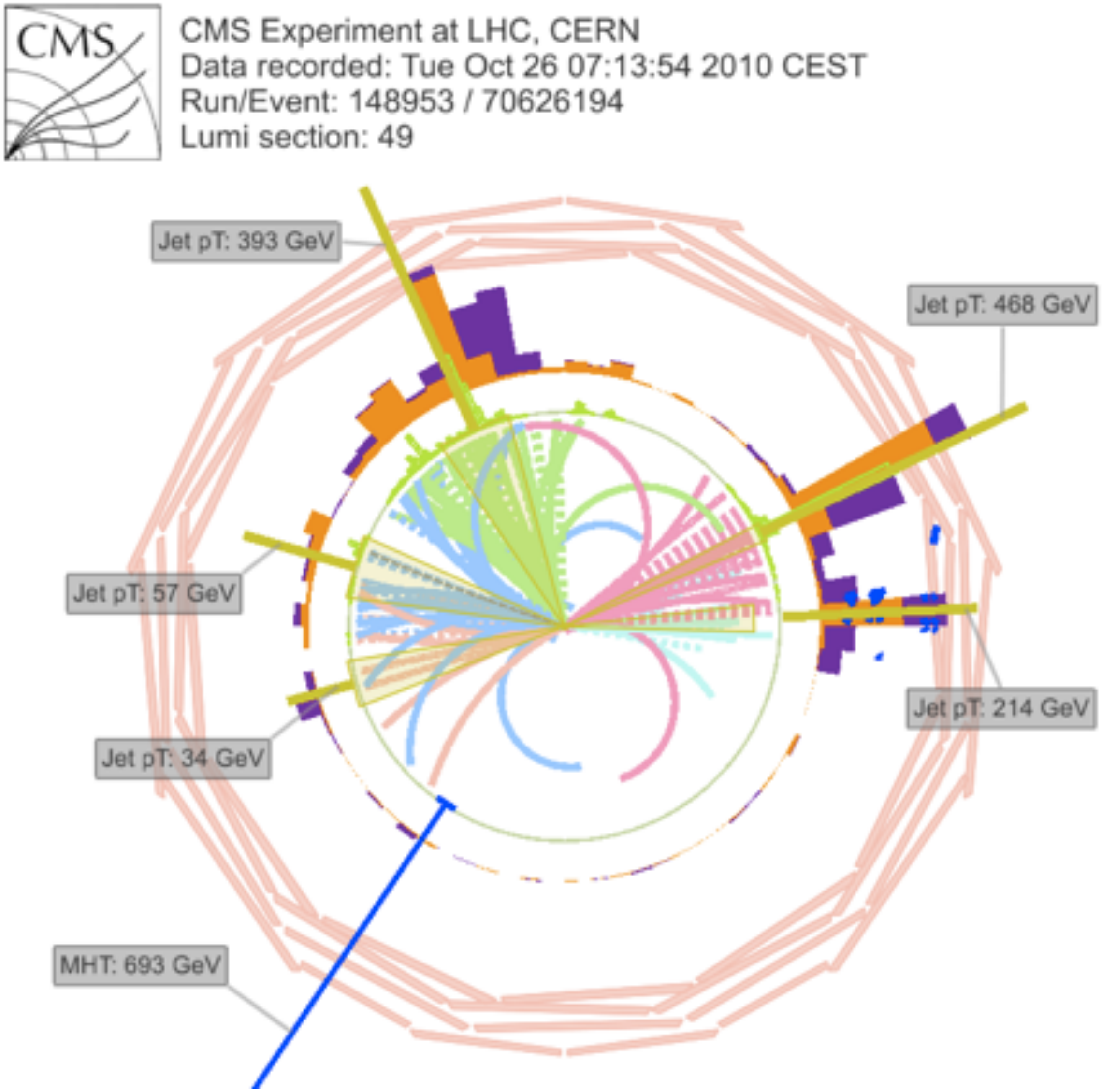

P2
P1
g̃
LSP
LSP


CMS Lint = 36 pb-1, √s = 7 TeV
tan β=10, μ>0, A0=0
Observed, NLO
Observed, LO
Expected ± 1σ, NLO
Tevatron RunI
CDF RunII
D0 RunII
LEP2
no CMSSM solution
mq̃ (GeV)
mg̃ (GeV)


CMS
√s = 7 TeV, Lint=36 pb-1
q̃ q̃ → 2 jets + LSPs
High-HT selection
σprod = σNLO-QCD
σprod = 3 × σNLO-QCD
mLSP (GeV)
mq̃ (GeV)
95% CL upper limit on σ (pb)

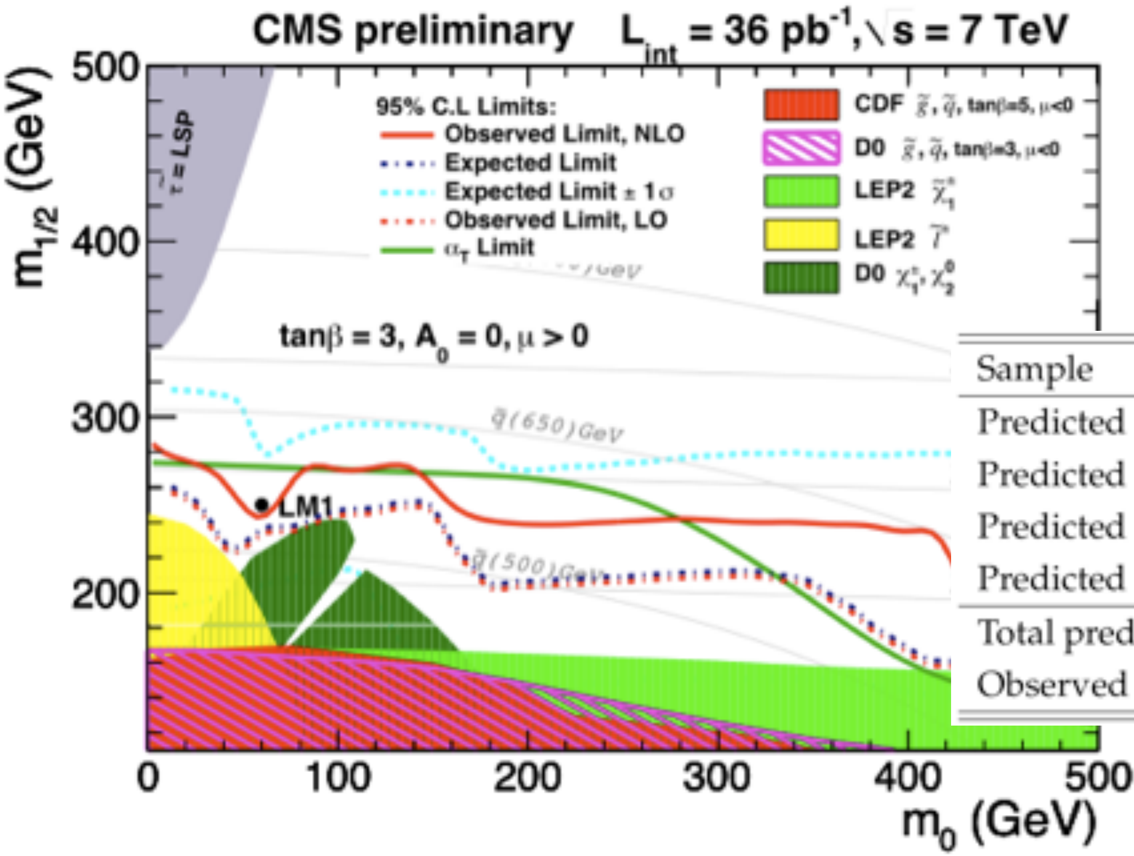

P2
P1
q̃
LSP
LSP

# One nice event…



# Single Lepton Search

- Exactly one isolated e or μ pT > 20 GeV
- At least 4 jets ET > 30 GeV |η| < 2.4
- Background from top and W+jets from simulation, all the rest from data



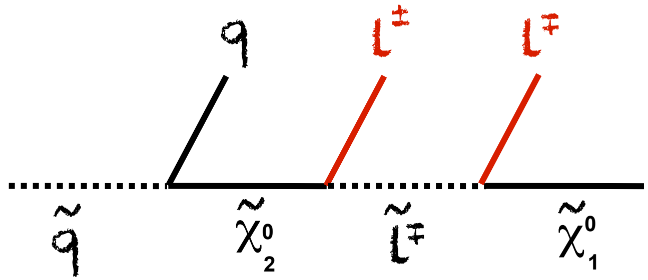

CMS PAS-SUS-10-006

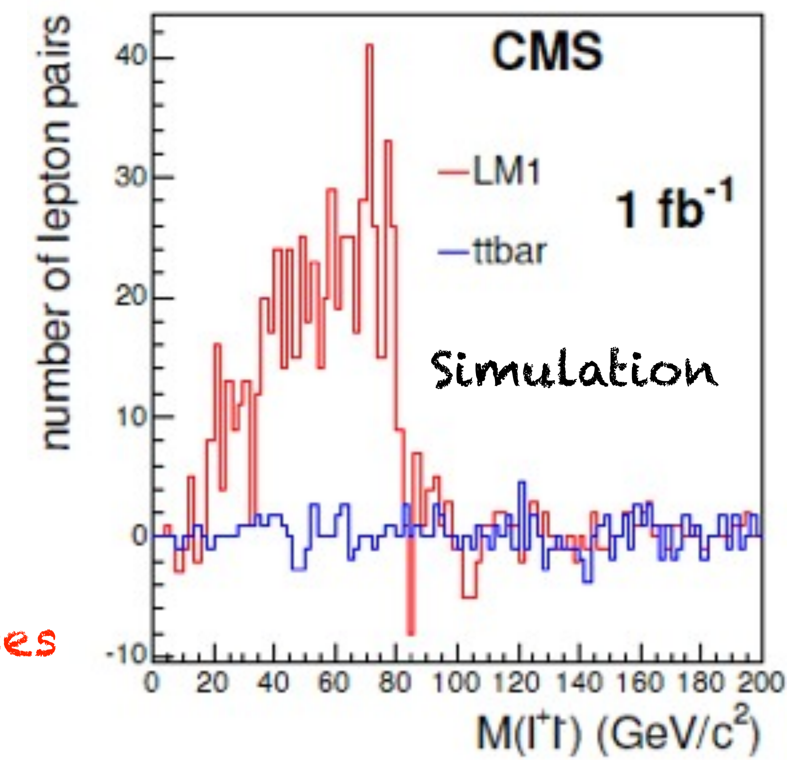
| Sample | $\ell = \mu$ | $\ell = e$ |
|---|---|---|
| Predicted SM 1 $\ell$ | $1.7 \pm 1.4$ | $1.2 \pm 1.0$ |
| Predicted SM dilepton | $0.0^{+0.8}_{-0.0}$ | $0.0^{+0.6}_{-0.0}$ |
| Predicted single $\tau$ | $0.29 \pm 0.22$ | $0.32^{+0.38}_{-0.32}$ |
| Predicted QCD background | $0.09 \pm 0.09$ | $0.0^{+0.16}_{-0.0}$ |
| Total predicted SM | $2.1 \pm 1.5$ | $1.5 \pm 1.2$ |
| Observed signal region | 2 | 0 |

# Opposite-sign Dilepton Search

## WHY INTERESTING? Reconstruct sparticle masses!

- R-Parity -> stable $\chi^0_1$ -> no invariant mass peaks to reconstruct



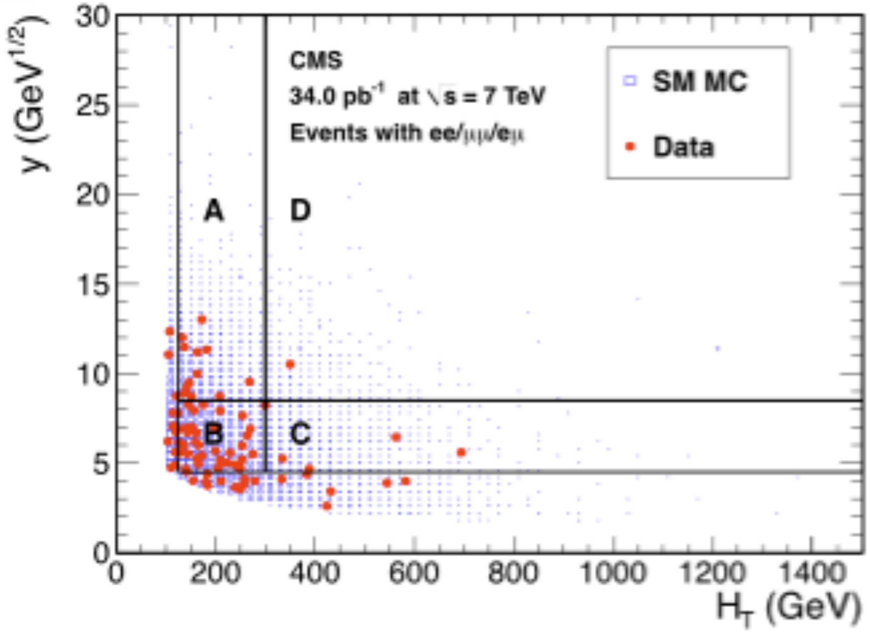



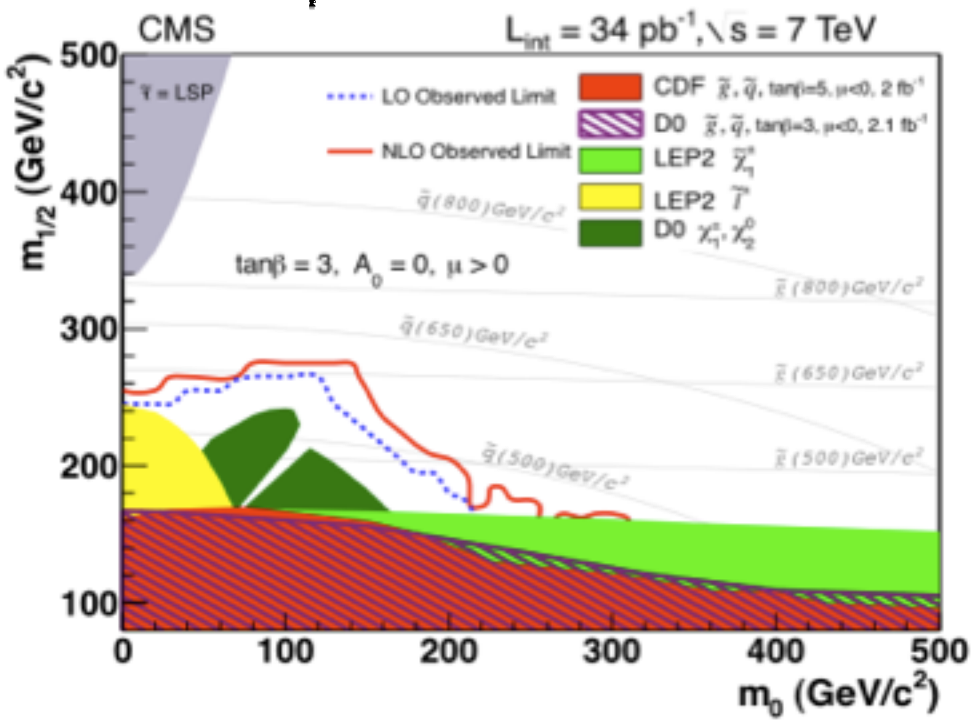

- However, two-body decay of $\chi^0_2$ to $\chi^0_1$ via a right-slepton
  - Sharp opposite-sign same-flavour dilepton invariant mass edge
  - depends on $\chi^0_2$ , $l_R$, and $\chi^0_1$ masses
- Can perform SM & SUSY background subtraction using
  - Opposite Flavour distribution: e+e- "+" μ+μ- "-" e+μ- "-" μ+e-

# Opposite-sign Dilepton Search



- Adding a second lepton rejects W+jets leaving mostly top background
- Estimated from data with ABCD method
- Observed events consistent with SM prediction




arxiv:1103.1348

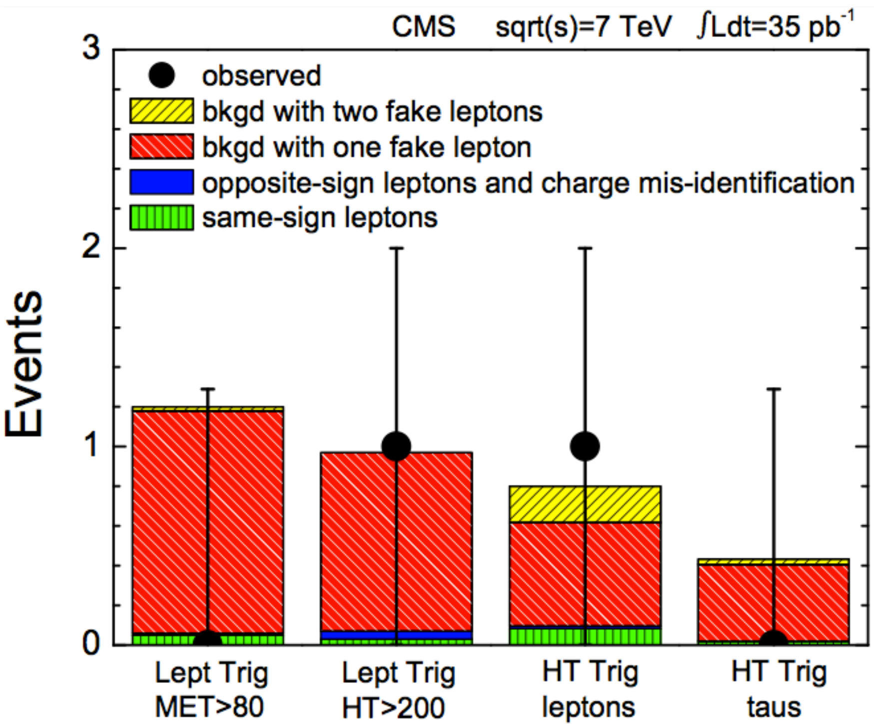
| | Predicted | Observed |
|---|---|---|
| Region D | 1.4 ± 0.8 | 1 |

# Same-Sign Dilepton Search

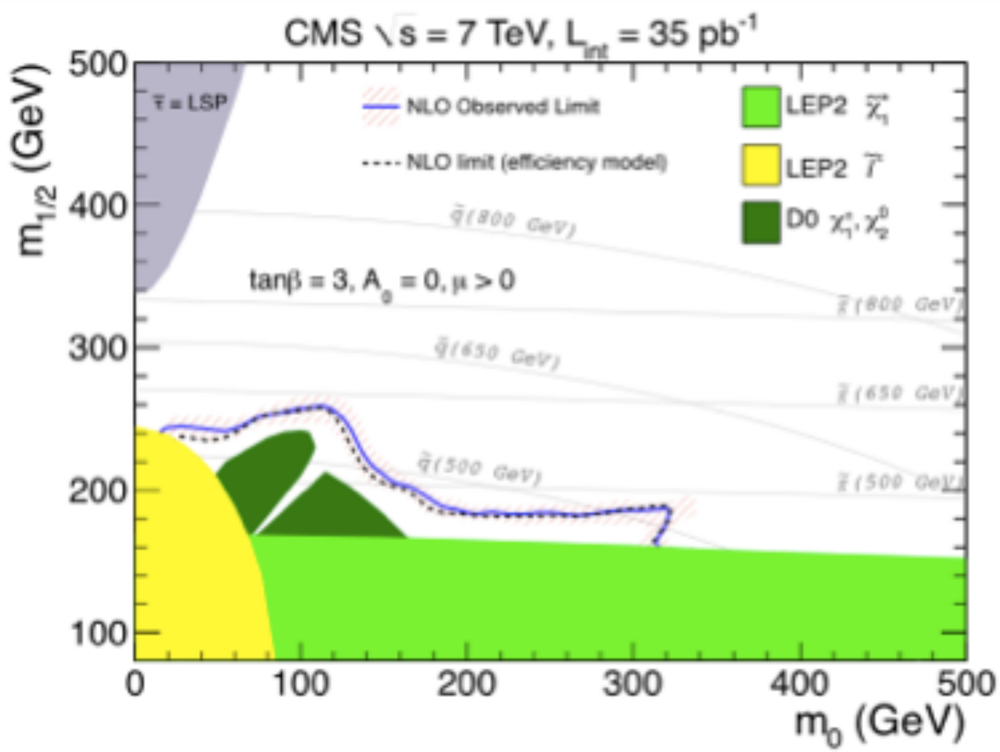
- Essentially absent in the SM (dominant bkgd mis-id leptons)
- Search in all three lepton species and four search regions
- Similar sensitivity as in OS for small tanβ
- Tau not yet included in limit

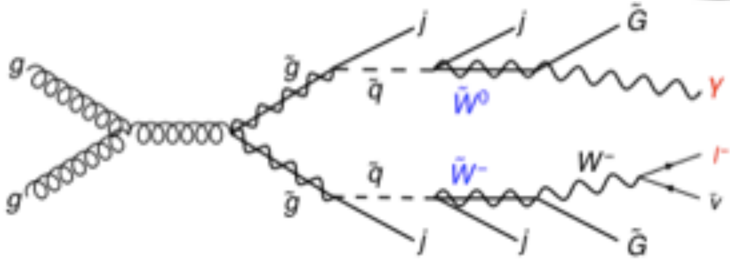
arxiv:1104.3168

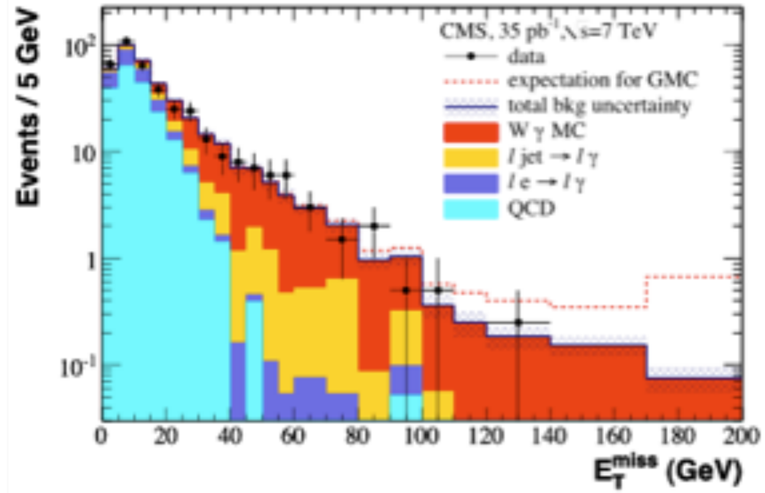
Observed events



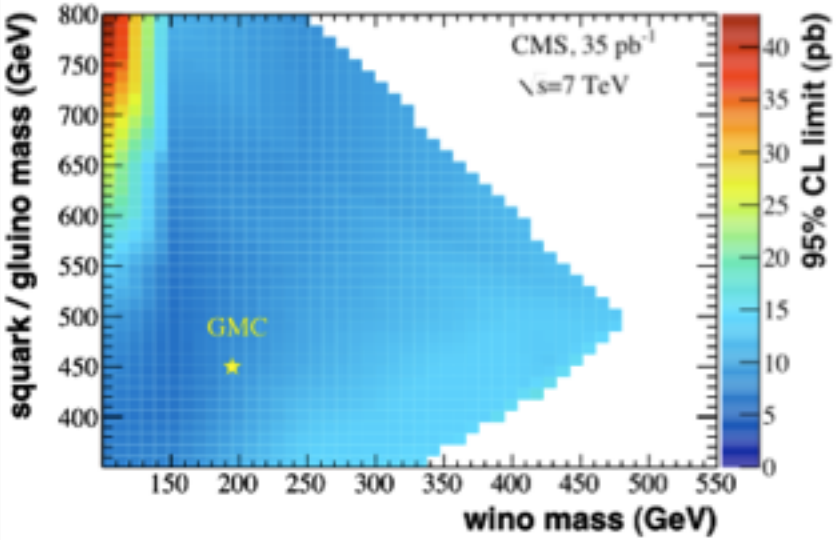

CMSSM exclusion limits






- $\gamma$+l expected when lightest neutral and charged gauginos are mass degenerate
- Main background W$\gamma$ (from MC)
- Other sources estimated from the data



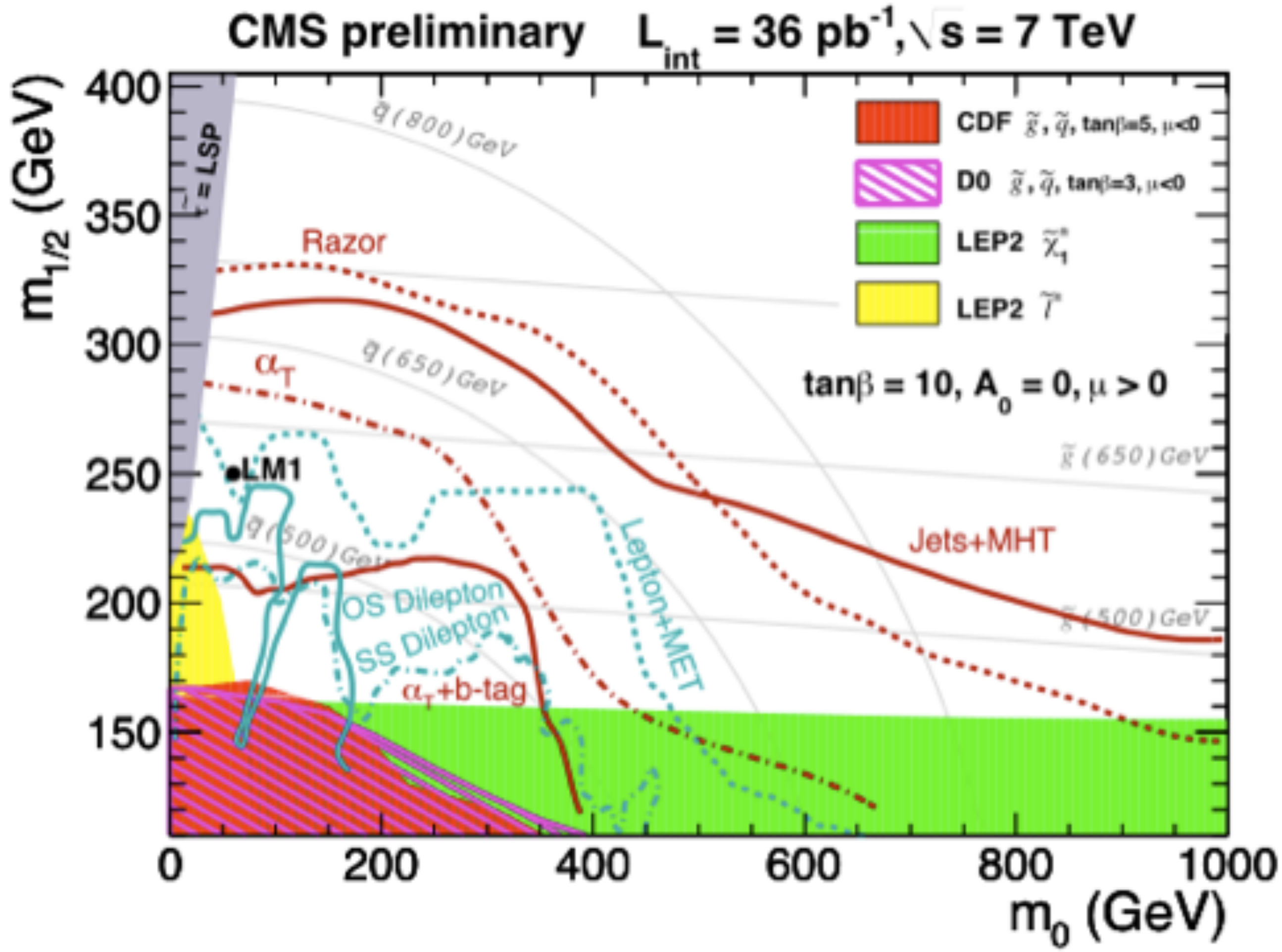

arxiv:1105.3152

95% CL upper limit on the cross section as a function of squark/gluino mass vs wino mass

# Summary of SUSY Searches



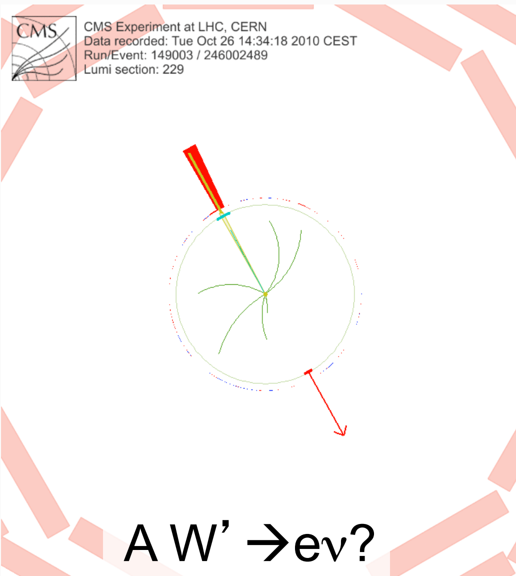
- Observed limits from several 2010 CMS SUSY searches plotted in the CMSSM (m0, m1/2) plane



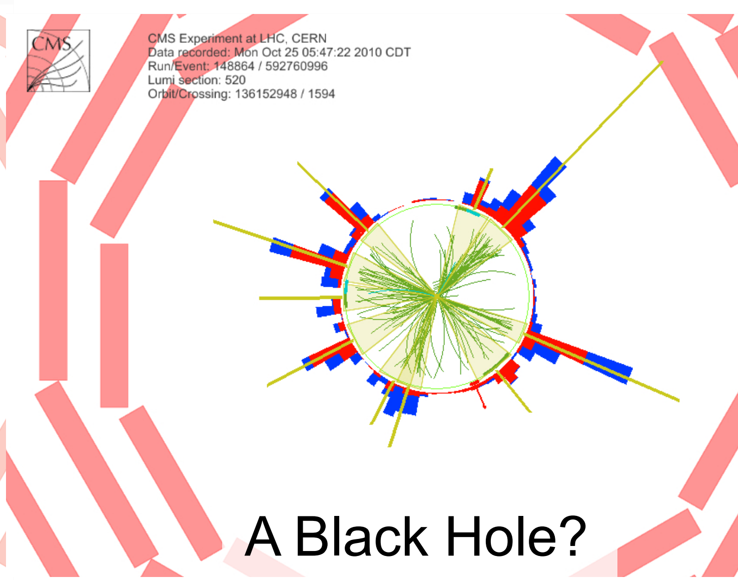
# Conclusion

- For lack of time, did not cover (perhaps) most exciting topic:
  - Higgs! We expect to make strong statements on the existence of the Higgs this year!
  - Exotic Physics: Black Holes, etc
- The LHC & CMS are in exceptional condition
  - delivering high quality data
  - delivering exciting, high quality results
  - providing new insights into nature
- We can only guess what natures has in store!!
  - & we have a good chance to whatever it is!
- Stay tuned!!!

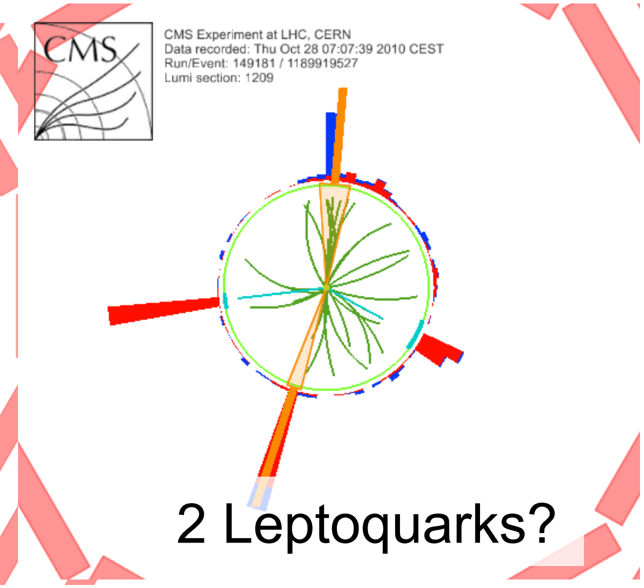
# Exotic Physics? 1 event does not make!



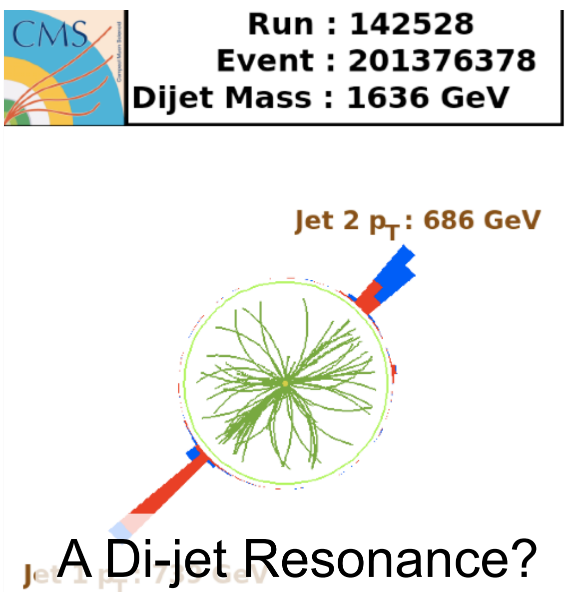

A W' →eν?



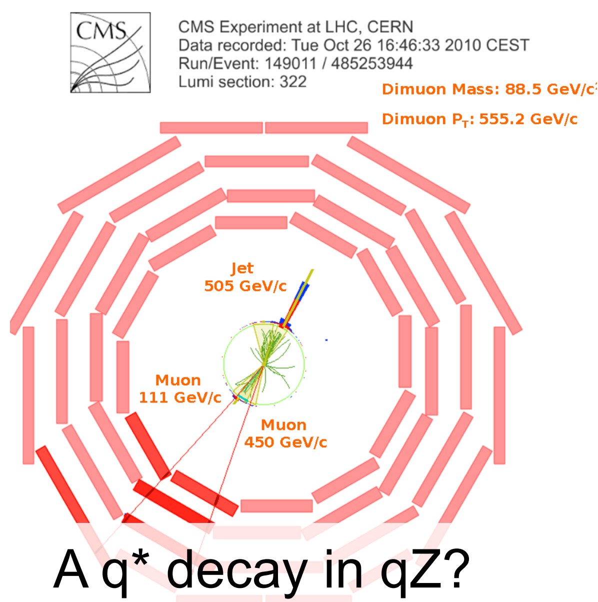

A Black Hole?




2 Leptoquarks?




A Di-jet Resonance?

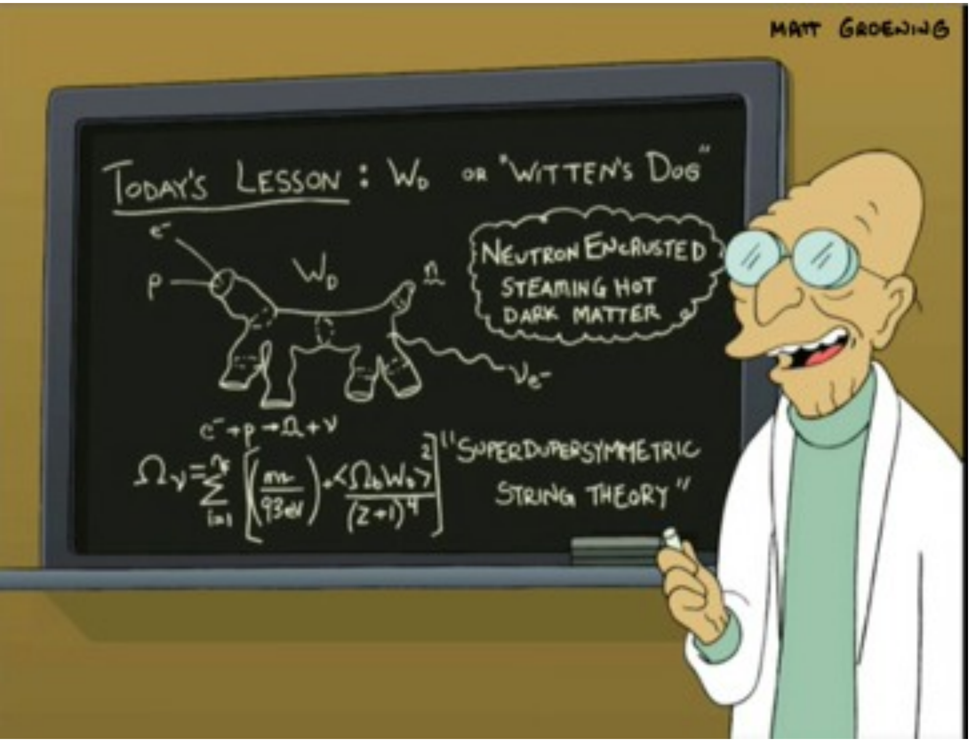



A q* decay in qZ?

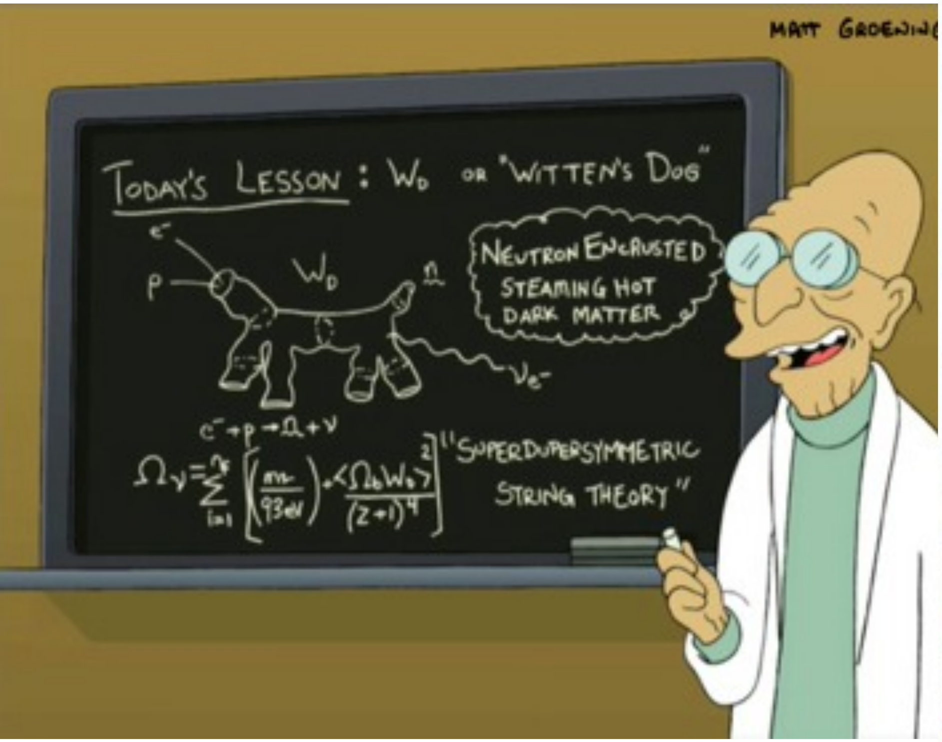
CMS is able to see for and study complex events…

…with enough data, complex events like these might indicate new physics!

## One end of the spectrum...



One end of the spectrum...




...the other end of the spectrum!


At a resolution of $10^{-24}$ metres, isolated clumps of Strange Matter pop briefly out of the quantum foam to debate the possible existence of Particle Physicists.