Developments in Multiboson Physics

BUE dark matter workshop

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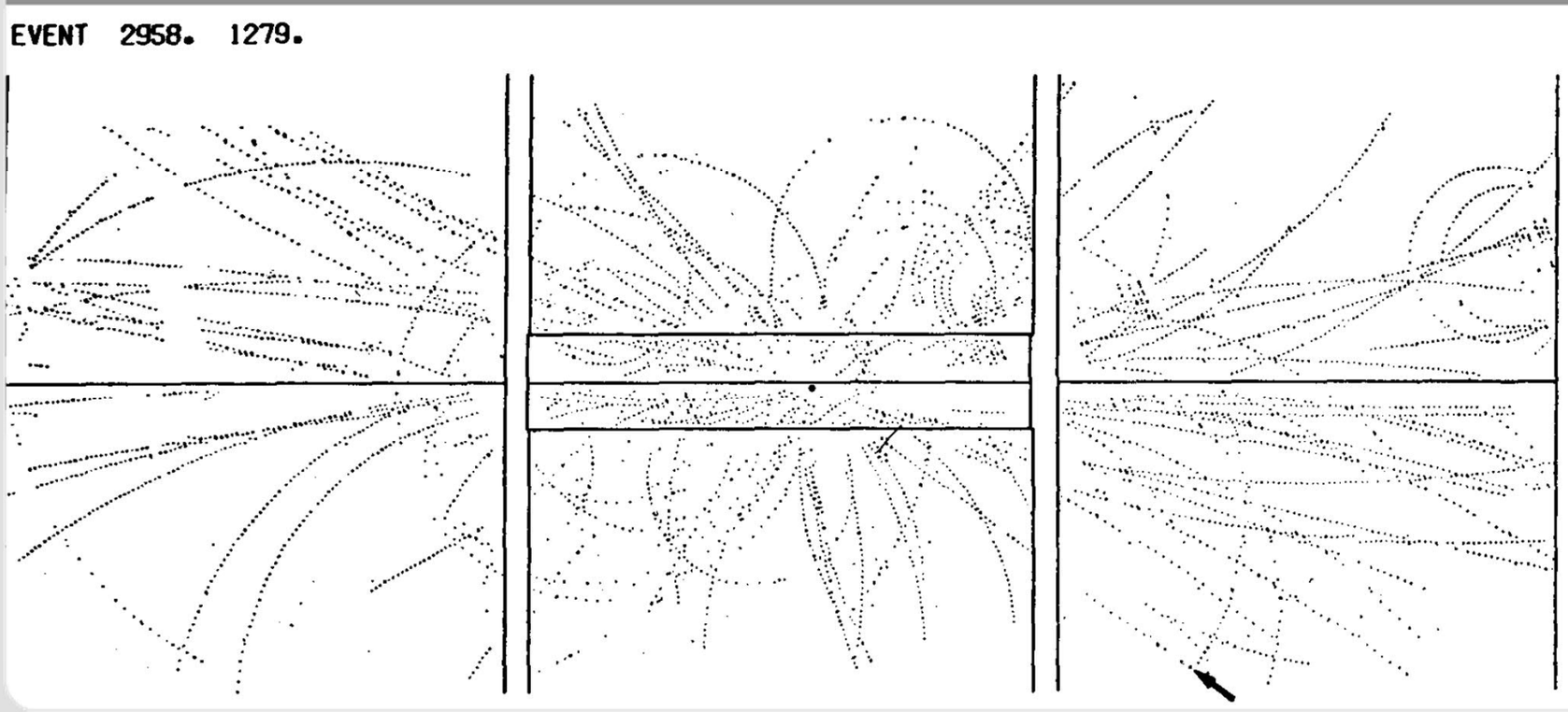
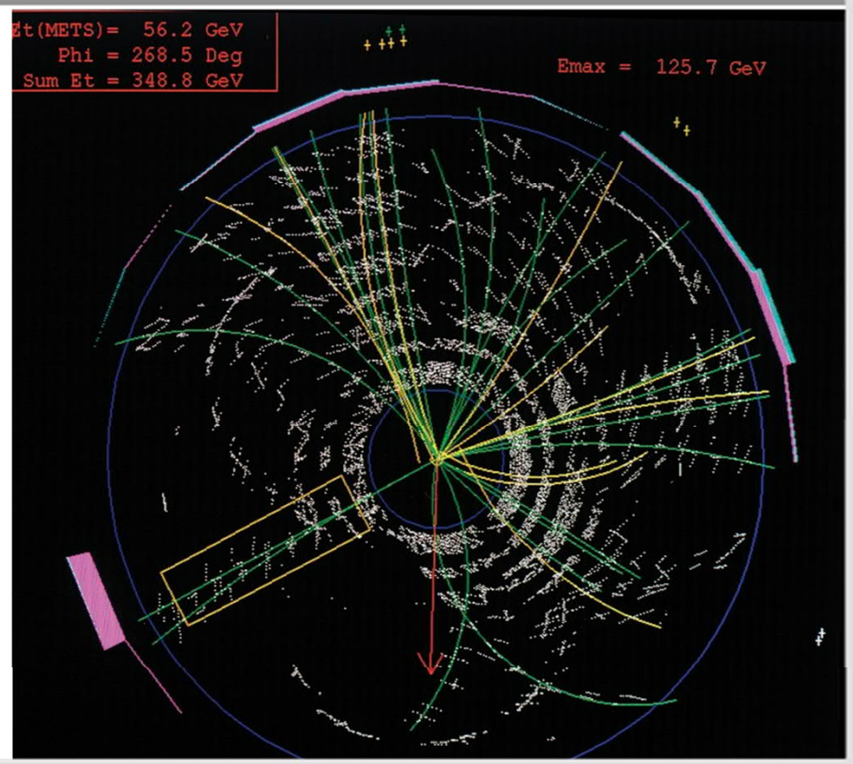
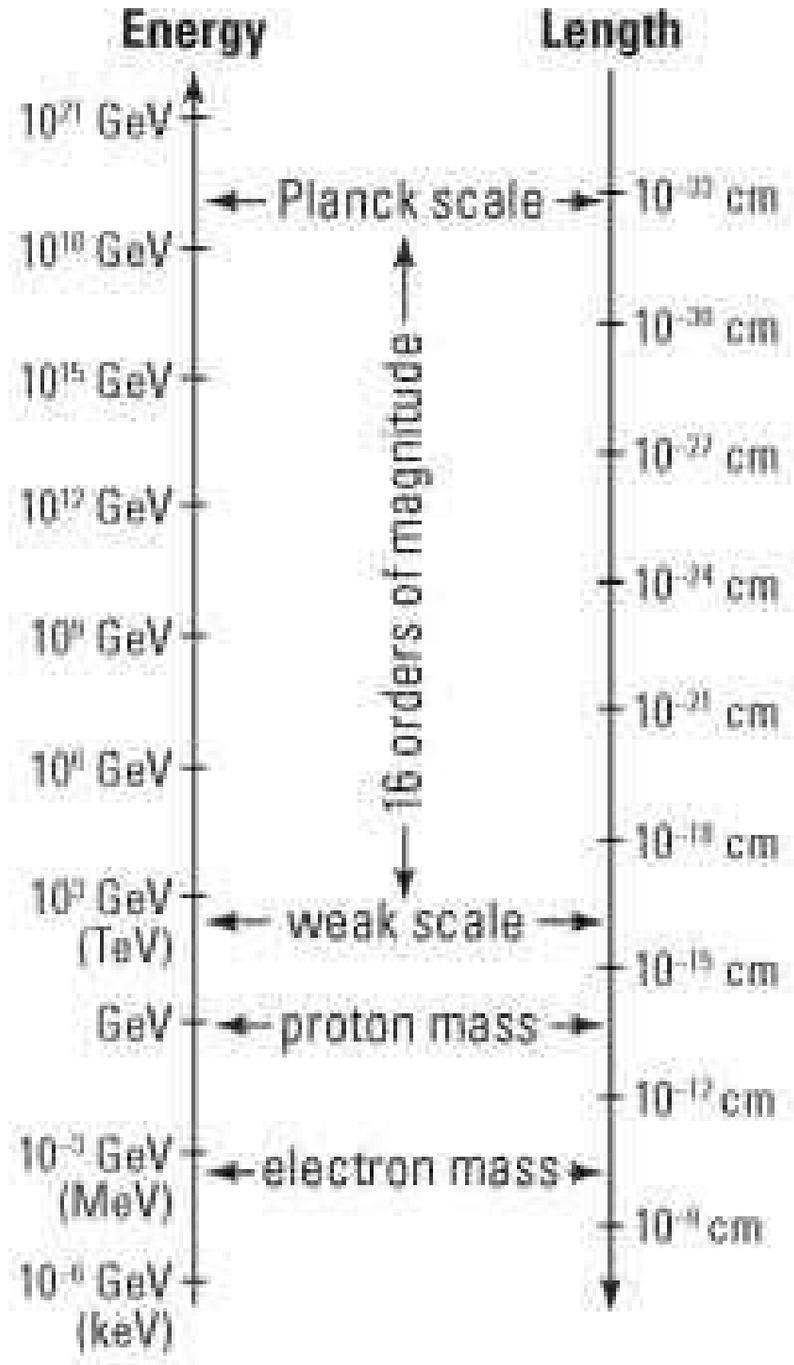




Why even bother?

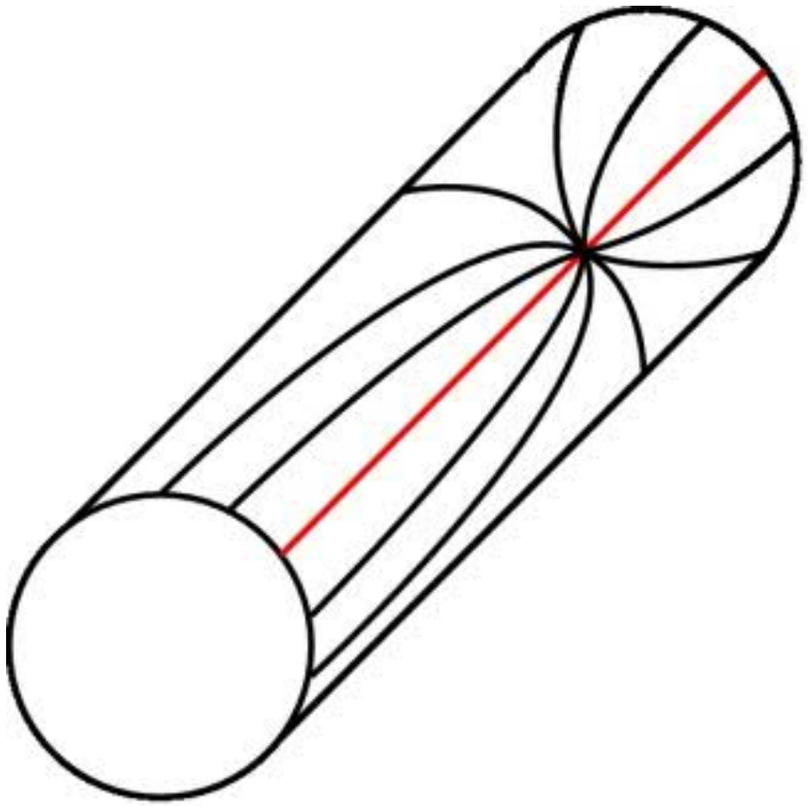
- Hierarchy Problem
- Large difference between electroweak and Planck scales
- Whatever the solution: electroweak bosons likely to be involved
- Hard to reach at previous accelerators

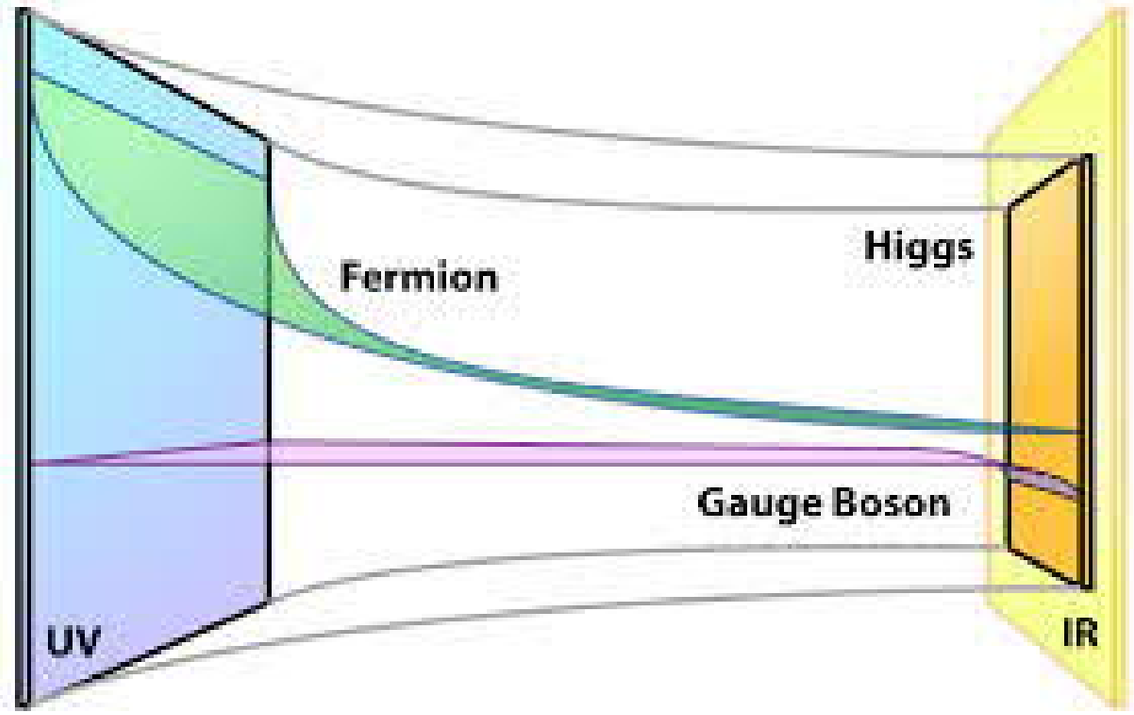


- Search for:
  => new resonances
  => deviations from SM in precision measurements

Potential Solution

- Extra Dimensions





Gravity “diluted” in extra-dimension / by space-time-curvature-factor

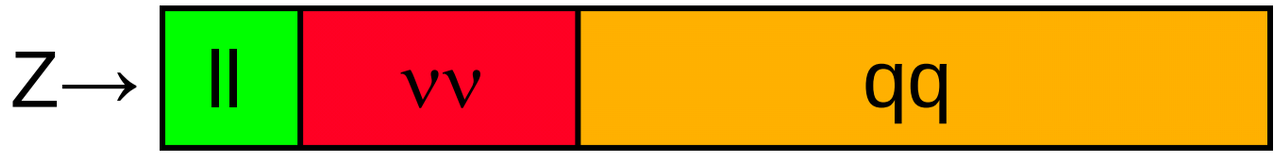
=> expect Kaluza-Klein excitations of the graviton

=> can couple to Vector bosons

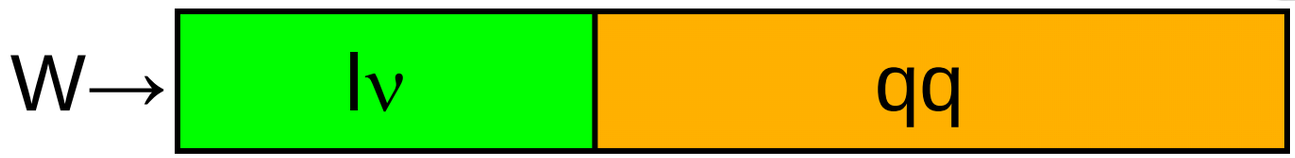
Promising Channels

- Searches largely driven by signal acceptance at high masses
  => prefer hadronic decays

- Hadornic decays difficult
  => high background
  => poor resolution
  => overlapping final state jets for energetic bosons



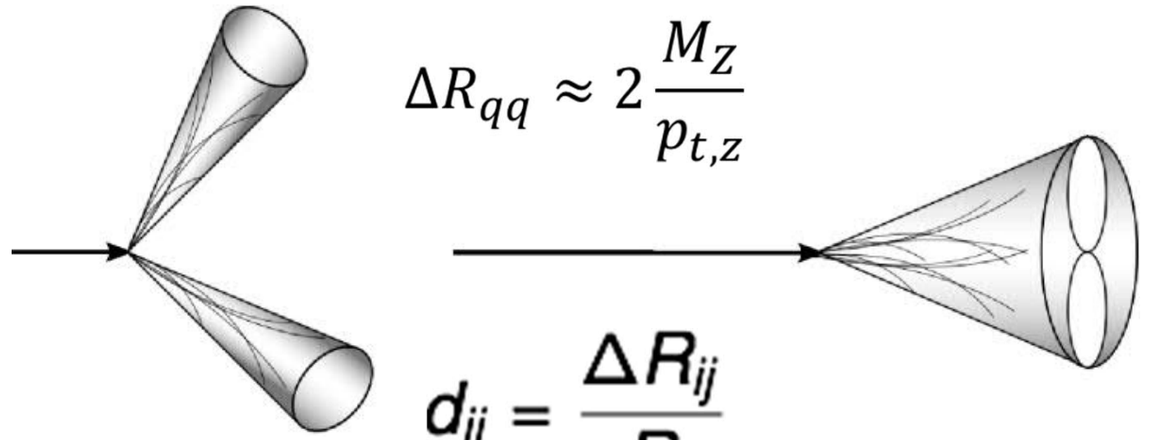
2 leptons: golden channel
- Easy to find
- High precision kinematics
- Low branching fraction



lν channel preferred
- Distinctive lepton signature
- Neutrino not measured

Jet Substructure Methods

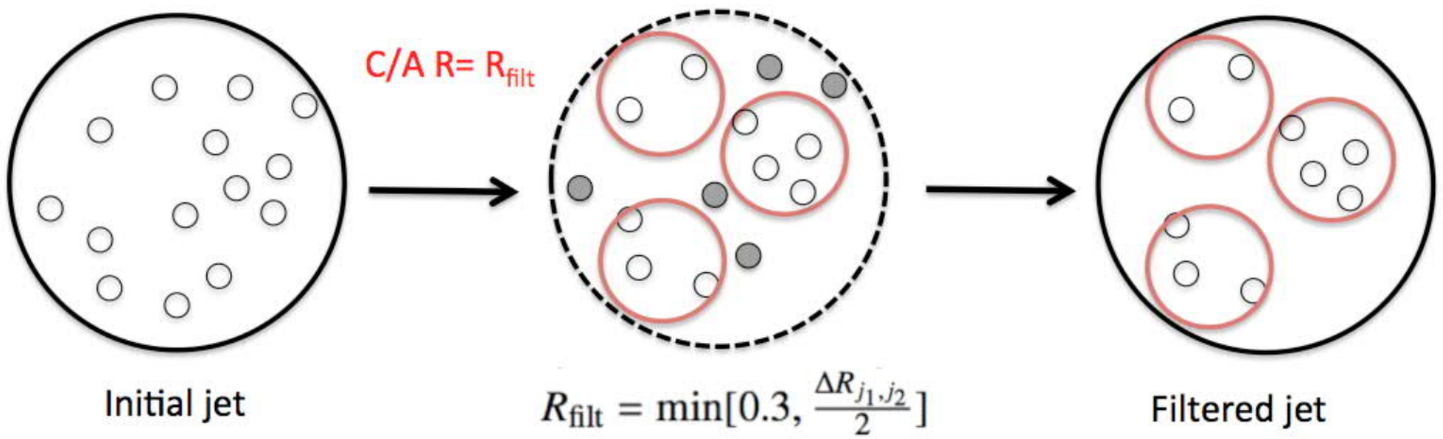
- Highly boosted bosons:
  jets overlap, reconstruced
  as single fat jet



ΔR > jet radius

ΔR < jet radius

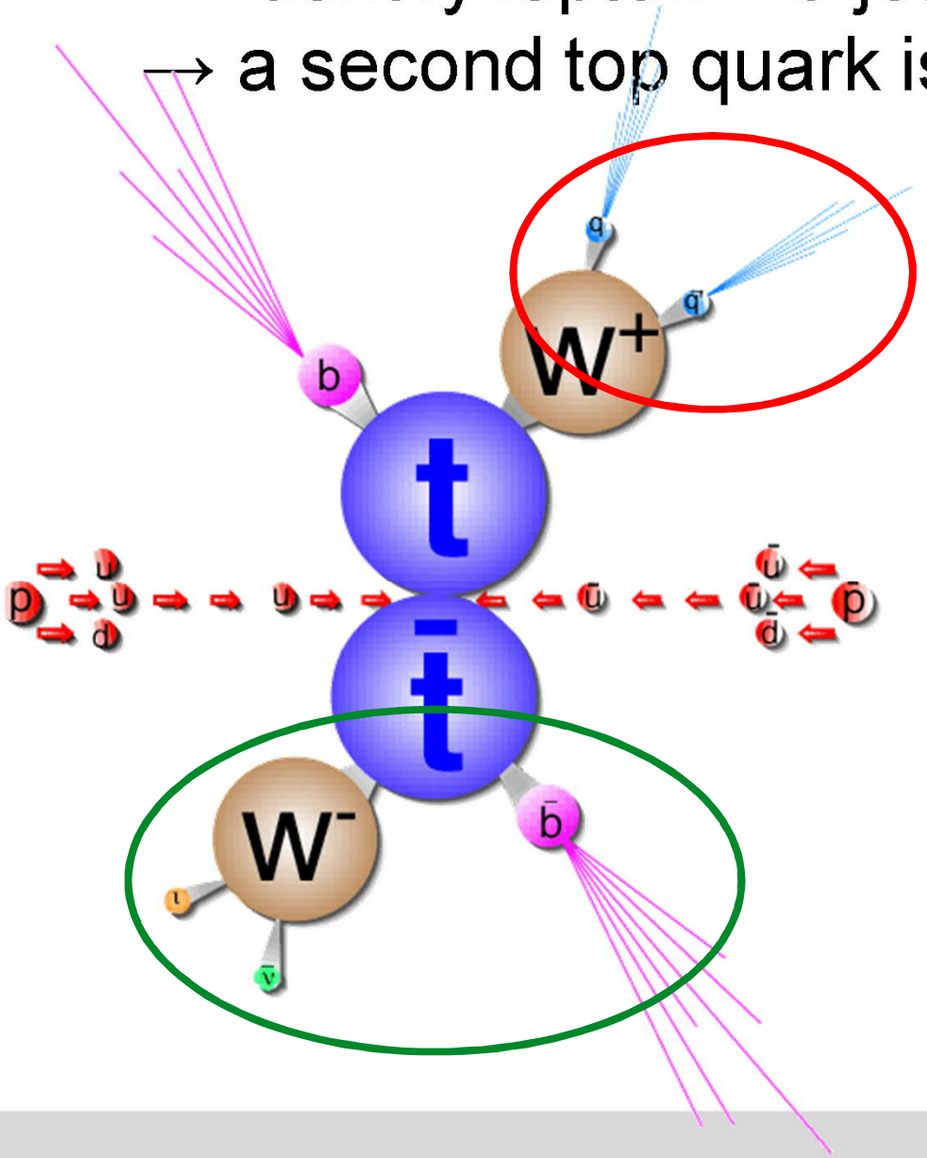
- Identify boosted decays by:
  => jet mass
  => two prong substructure

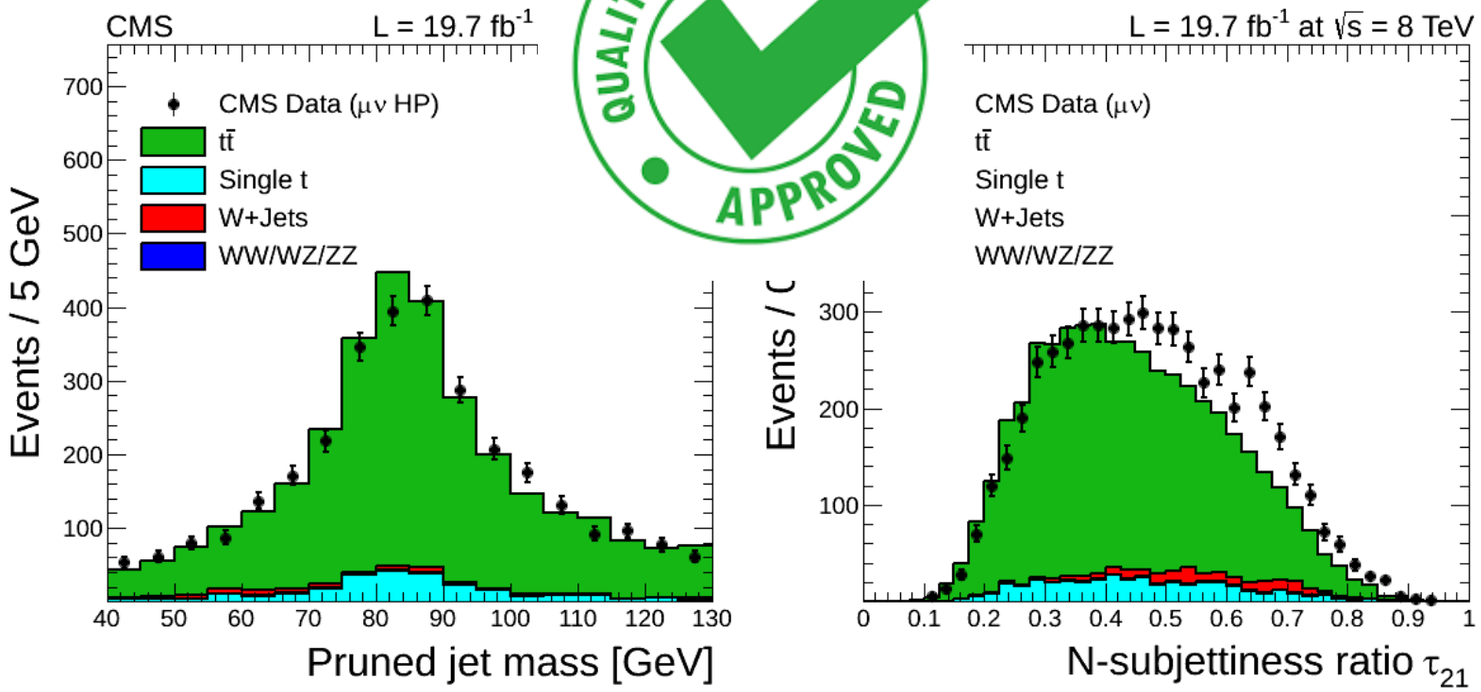


Does that really work?

- How to find hadronic W decays for validation?

- Look at top quark pairs
  → identify lepton + b-jet
  → a second top quark is likely in the event





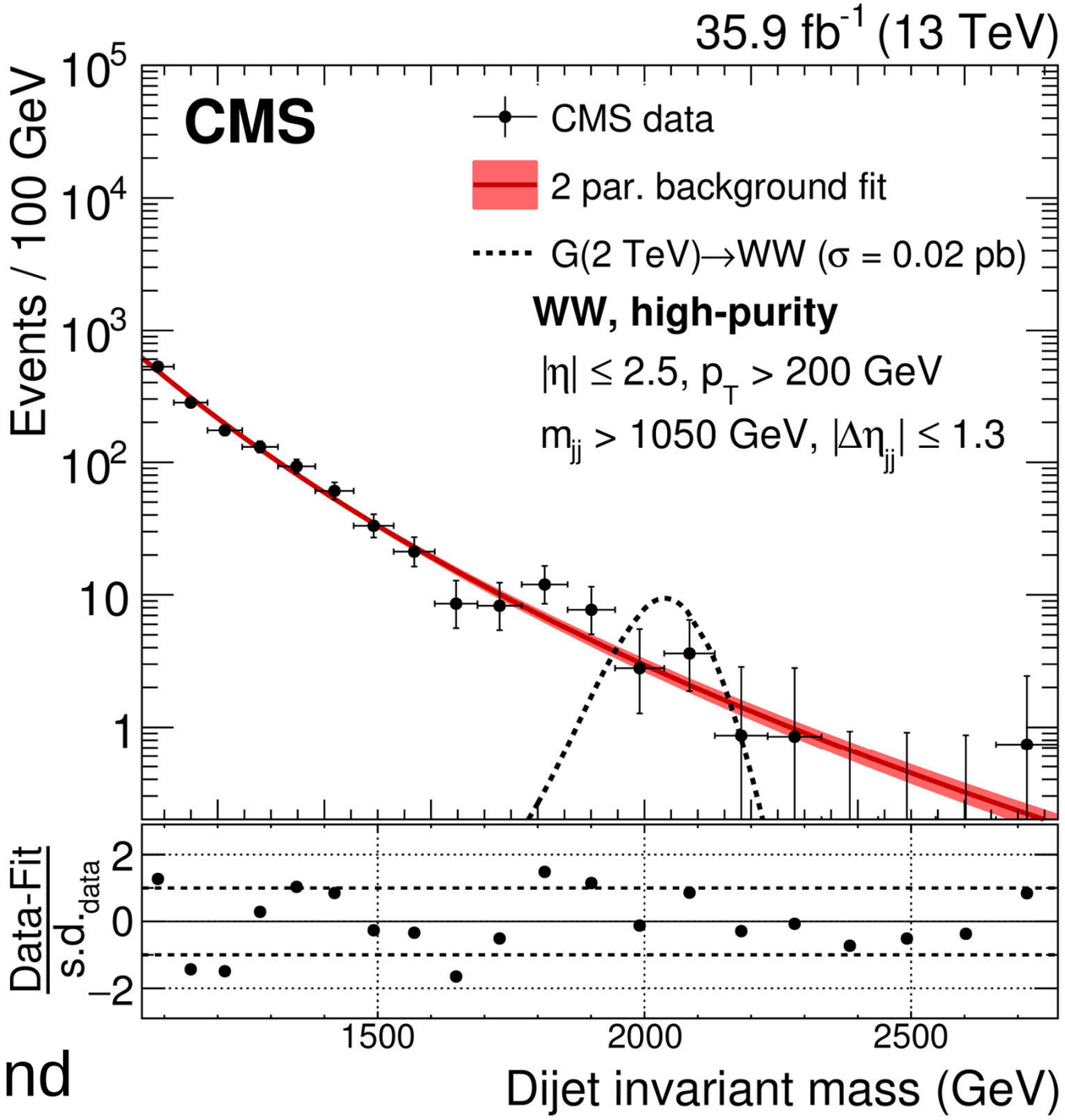
[JHEP 1408 (2014) 174]

Example Analysis

- Straight forward:
  => select two fat-jets
  => look for bumps on smoothly falling dijet mass spectrum

- No resonance found:
  => currently best limit on Bulk Graviton

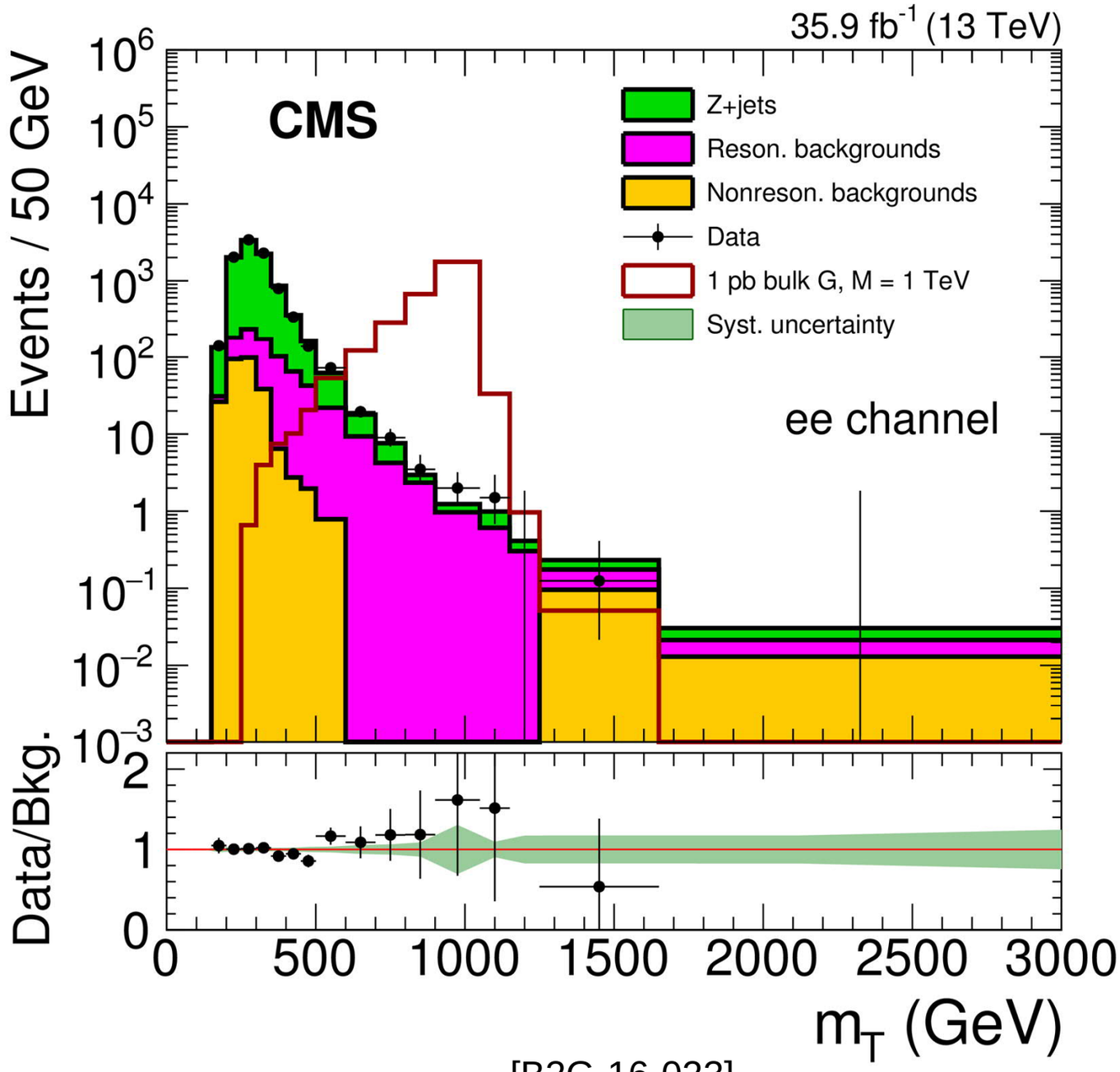
- Background from analytics fit to data:
  => more difficult with more data
  => trying to improve background estiamte for 2017



[B2G-17-001]

Another Example

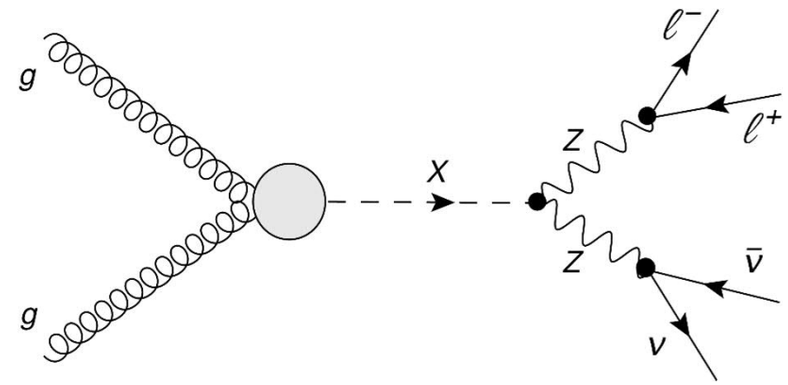
- Looking for ZZ→llνν
- Good BR from νν, but ll part limits acceptance
- High purity compared to hadronic channels
- Using MT distribution to find resonance
- Fake MET background particularly difficult

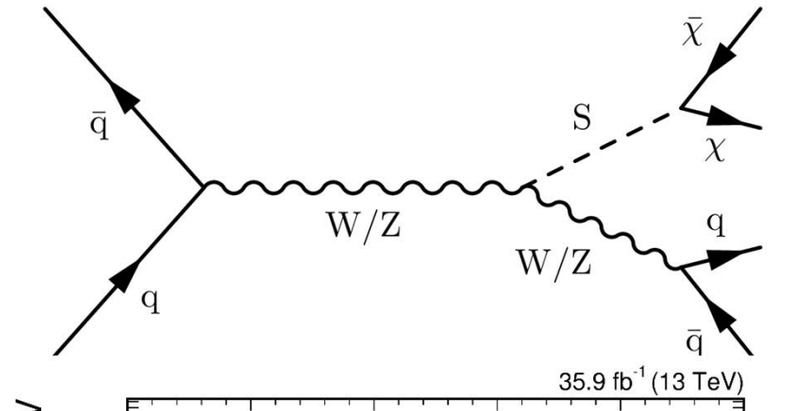


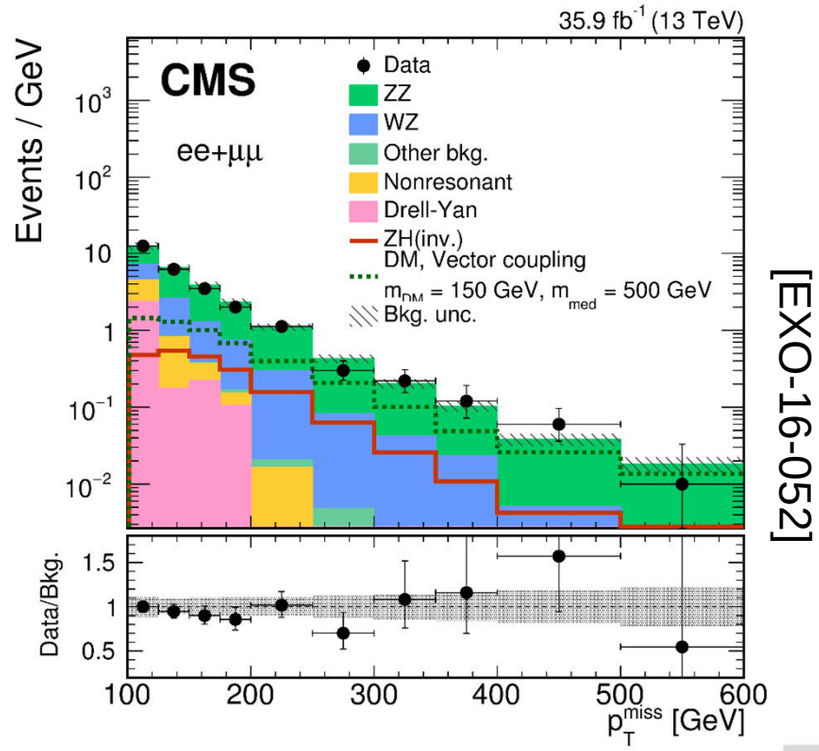
[B2G-16-023]

DM Interpretation

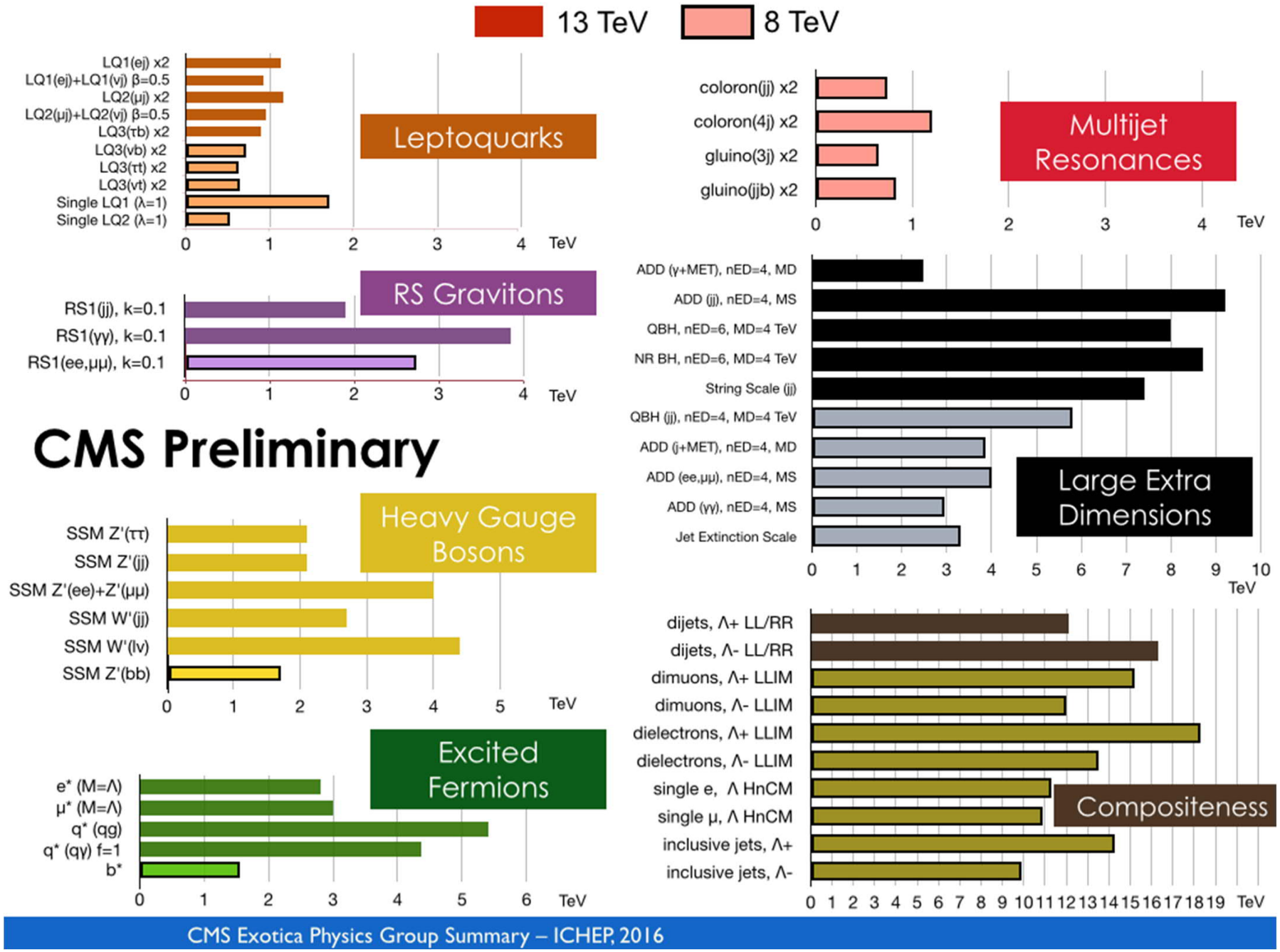
- Z→νν is not observed
  => only pt_Z (=MET) known
- Could be anything else:
  => DM mediator particle
- Very similar analysis can be repurposed to search for DM
  => mostly sensitive to models with weakly coupled mediator
- Kinematics largely independent of DM particle mass
  => important parameters are mediatior properties



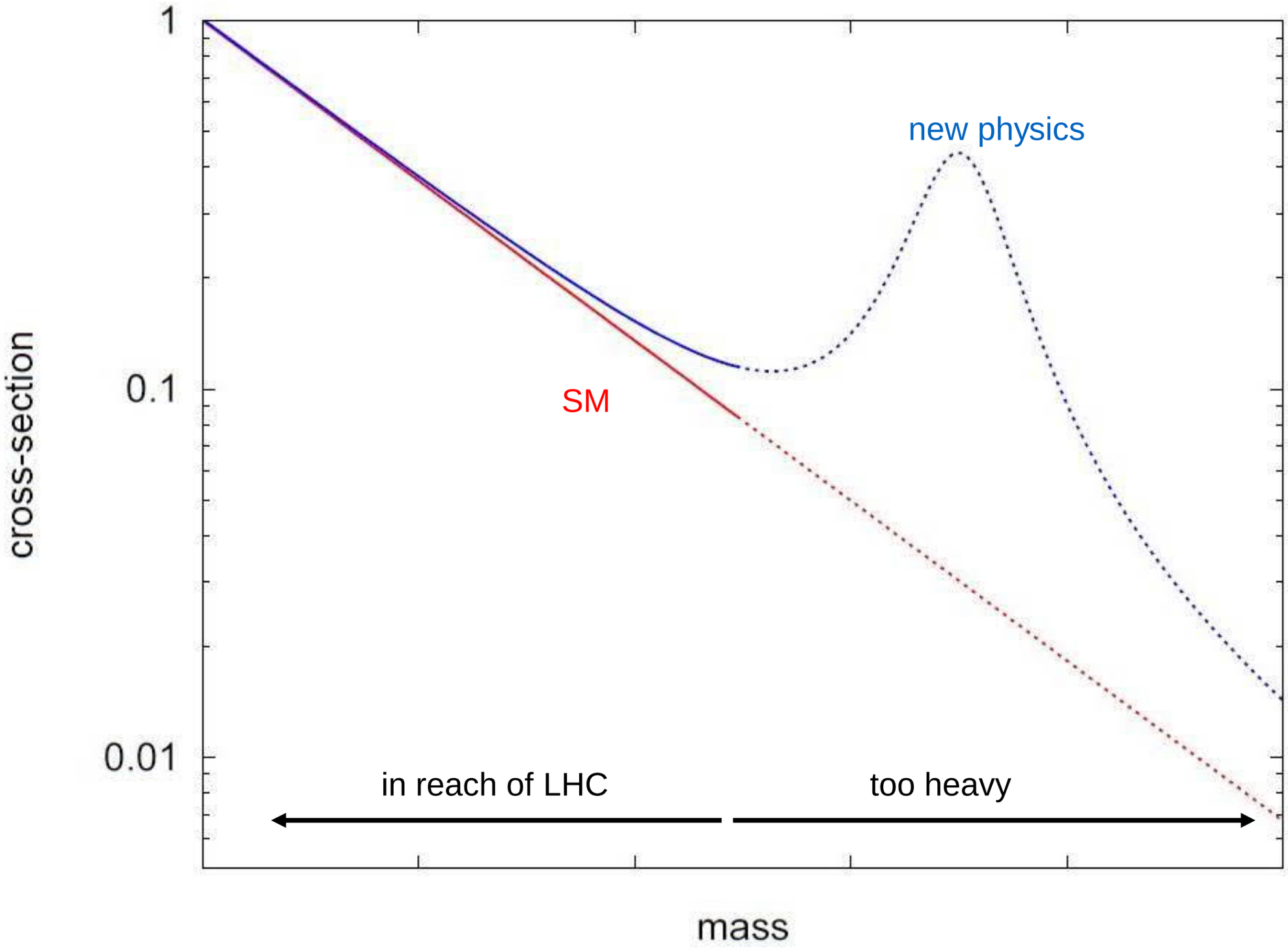




Results


13 TeV
8 TeV
LQ1(ej) x2
LQ1(ej)+LQ1(νj) β=0.5
LQ2(μj) x2
LQ2(μj)+LQ2(νj) β=0.5
LQ3(τb) x2
LQ3(νb) x2
LQ3(τt) x2
LQ3(νt) x2
Single LQ1 (λ=1)
Single LQ2 (λ=1)
Leptoquarks
RS1(jj), k=0.1
RS1(γγ), k=0.1
RS1(ee,μμ), k=0.1
RS Gravitons
CMS Preliminary
SSM Z'(ττ)
SSM Z'(jj)
SSM Z'(ee)+Z'(μμ)
SSM W'(jj)
SSM W'(lν)
SSM Z'(bb)
Heavy Gauge Bosons
e* (M=Λ)
μ* (M=Λ)
q* (qg)
q* (qγ) f=1
b*
Excited Fermions
coloron(jj) x2
coloron(4j) x2
gluino(3j) x2
gluino(jjb) x2
Multijet Resonances
ADD (γ+MET), nED=4, MD
ADD (jj), nED=4, MS
QBH, nED=6, MD=4 TeV
NR BH, nED=6, MD=4 TeV
String Scale (jj)
QBH (jj), nED=4, MD=4 TeV
ADD (j+MET), nED=4, MD
ADD (ee,μμ), nED=4, MS
ADD (γγ), nED=4, MS
Jet Extinction Scale
Large Extra Dimensions
dijets, Λ+ LL/RR
dijets, Λ- LL/RR
dimuons, Λ+ LLIM
dimuons, Λ- LLIM
dielectrons, Λ+ LLIM
dielectrons, Λ- LLIM
single e, Λ HnCM
single μ, Λ HnCM
inclusive jets, Λ+
inclusive jets, Λ-
Compositeness
TeV
CMS Exotica Physics Group Summary – ICHEP, 2016

Indirect Measurements



Effective Field Theories

- Assume new physics at some scale Λ
- Parameterize new physics at lower scales by developing as power series in Λ^{-1}
- Adds new higher Dimension parameters to the Lagrangian

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \frac{1}{\Lambda}\mathcal{L}_1 + \ldots$$

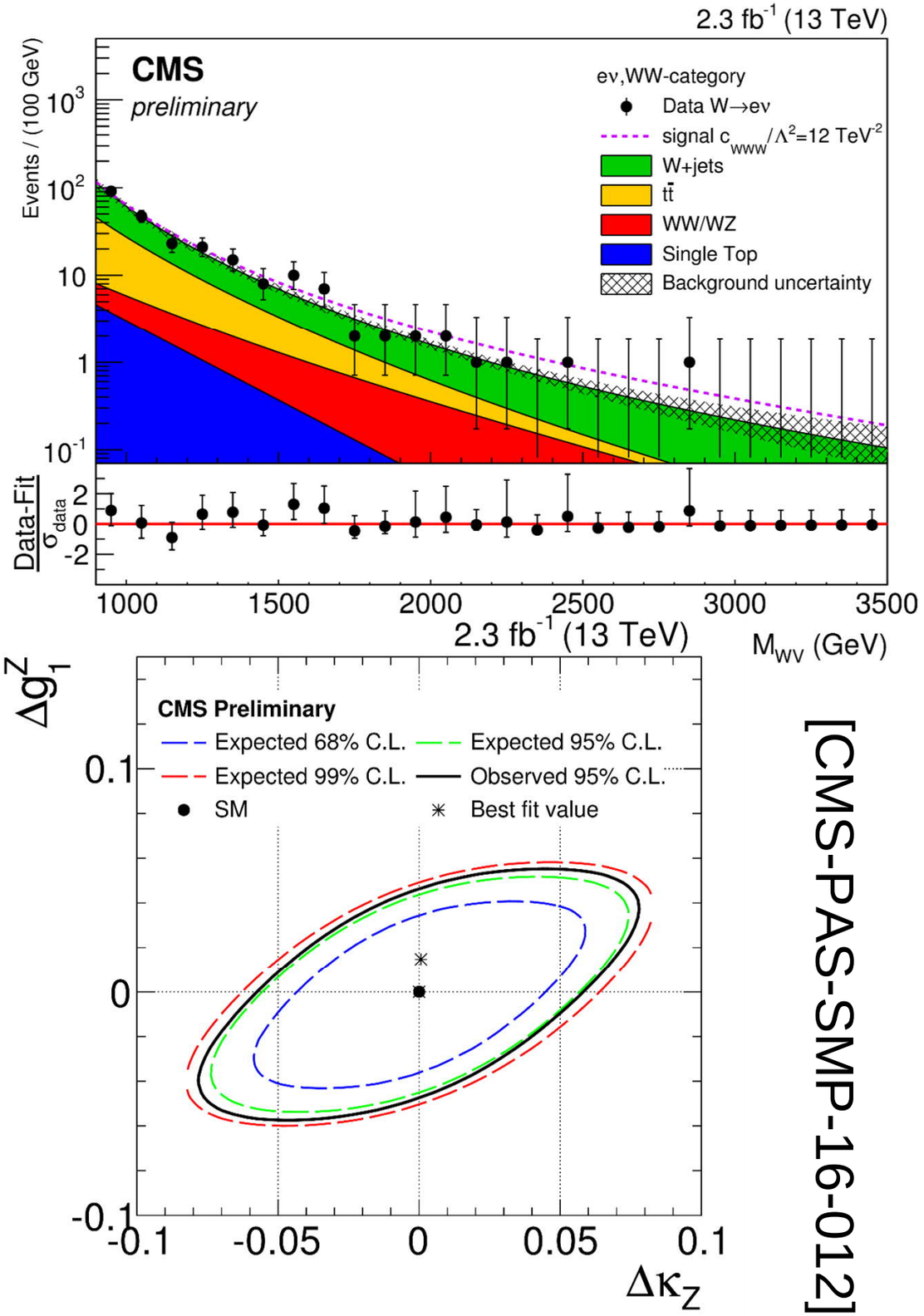
- SM covers all dim. 4 operators
- Dim. 5 violates lepton number (of interest for neutrino masses)
- Dim. 6: includes triple gauge couplings
- Dim. 8: includes quartic gauge couplings

Example

- Typical analysis similar to resonance search
  => biggest difference is signal model

- Generally cannot simulate signal separately from SM diboson processes:
  => significant interference effects

- Results:
  no deviation from SM found

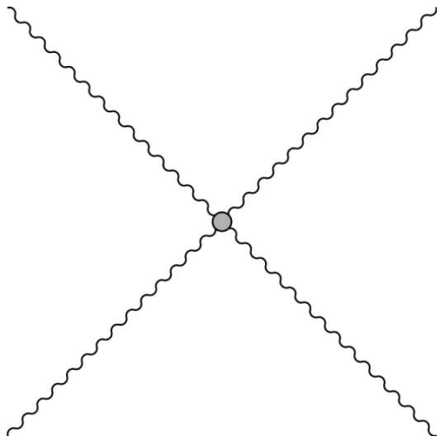


A Closer Look

$$
\begin{aligned}
L \quad = \quad & (D_\mu \phi)^\dagger (D_\mu \phi) - \frac{1}{4} W_{\mu\nu} W^{\mu\nu} - \frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i \bar{l'}_{il} \not{D} l'_{il} \\
& i \bar{q'}_{il} \not{D} q'_{il} + i \bar{u'}_{iR} \not{D} u'_{iR} + i \bar{d'}_{iR} \not{D} d'_{iR} \\
& + L_{\mathrm{yukawa}} + \mu^2 (\phi^\dagger \phi) - \lambda (\phi^\dagger \phi)^2
\end{aligned}
$$

EWK Boson Interactions

$$\frac{1}{4} W_{\mu\nu} W^{\mu\nu}$$

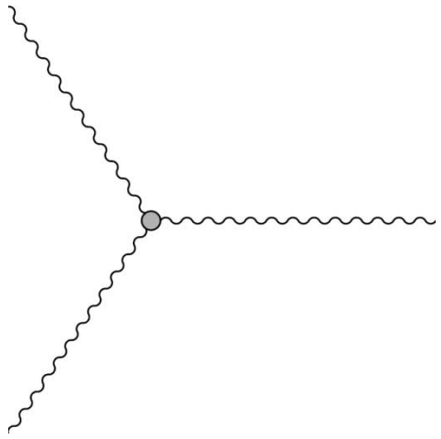


QGC

W,W,W,W

W,W,Z/γ,Z/γ

~~Z/γ,Z/γ,Z/γ,Z/γ~~



TGC

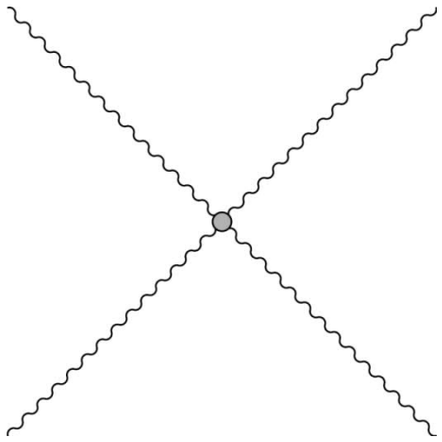
W,W,Z/γ

~~Z/γ,Z/γ,Z/γ~~

Propagator

EWK Boson Interactions

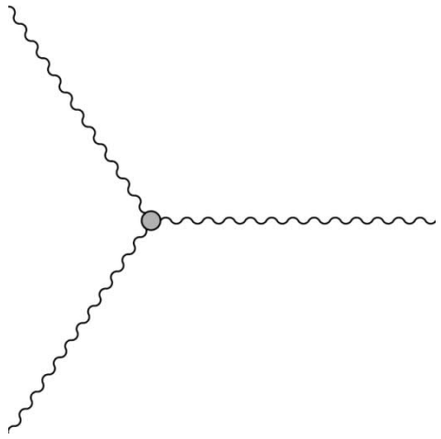
$$\frac{1}{4} W_{\mu\nu} W^{\mu\nu}$$



QGC

W,W,W,W

~~Z/γ,Z/γ,Z/γ,Z/γ~~



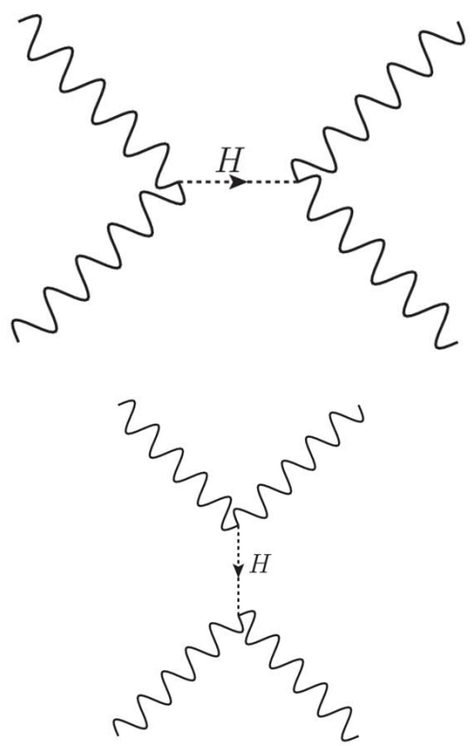
TGC

W,W,Z/γ

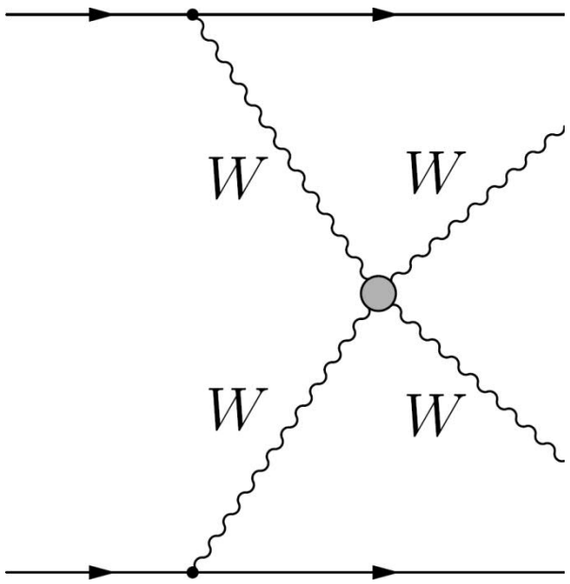
~~Z/γ,Z/γ,Z/γ~~

Propagator

- Cross section rises with cms-energy
  => non-unitary scattering matrix
- In SM, unitarized by negative interference with Higgs diagrams
- Potentially large effects for non-SM Higgs scenarios
- Insight into ewk symmetry breaking

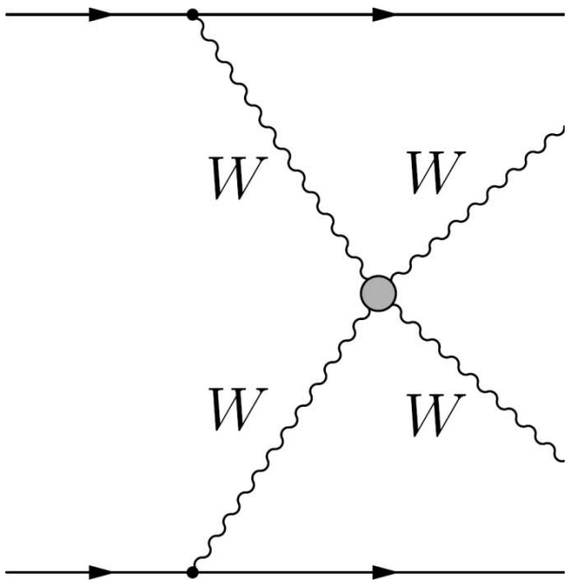


Vector Boson Scattering

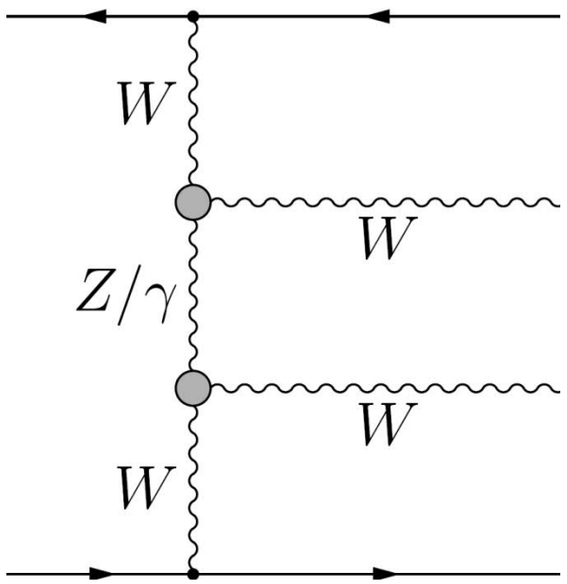


QGC

Vector Boson Scattering



QGC



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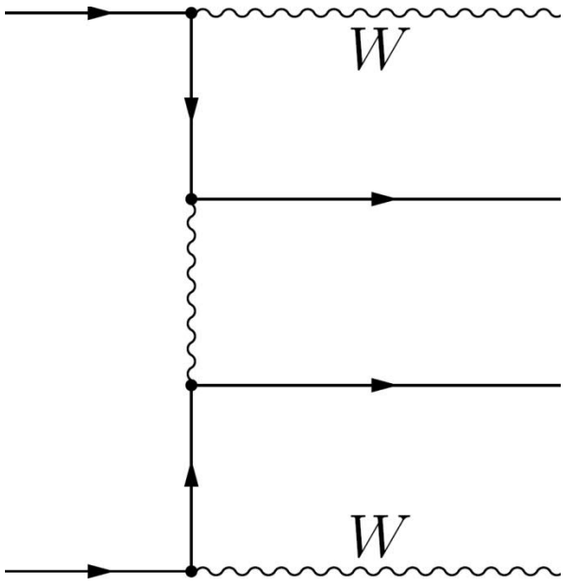
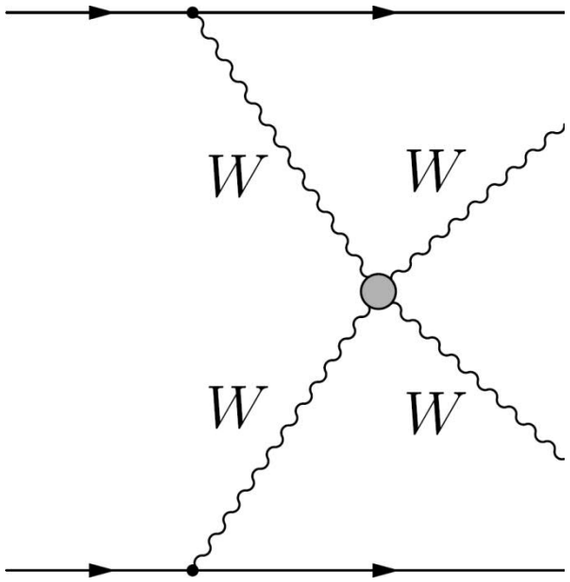


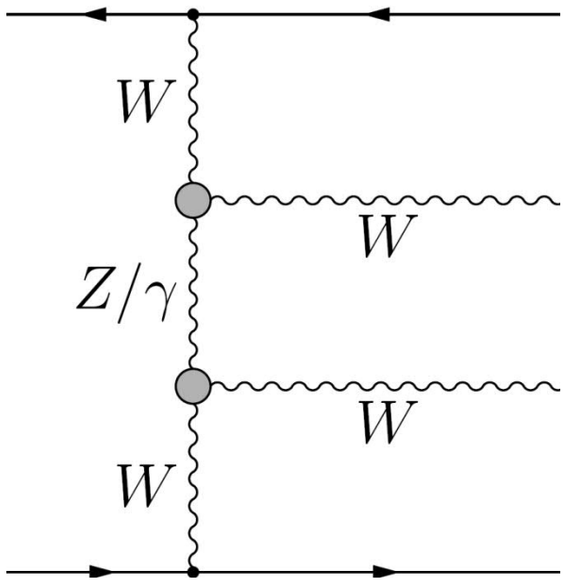
Double Brem

+ … (other α^6)

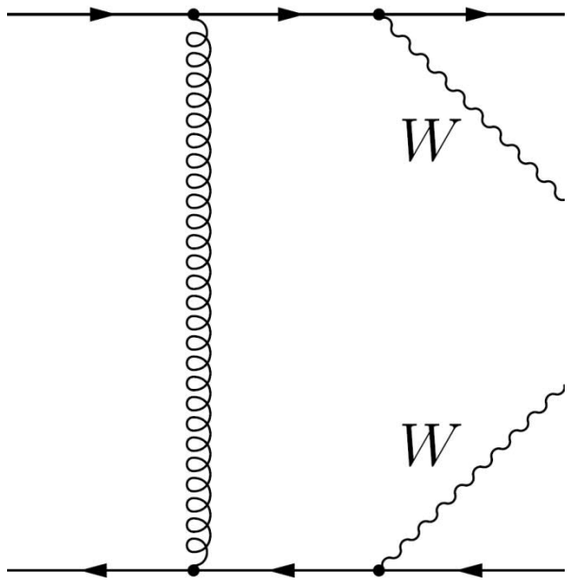
Vector Boson Scattering

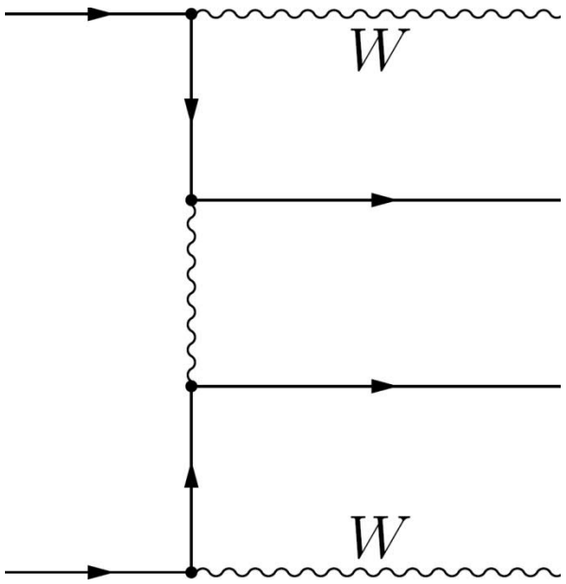


QGC



TGC





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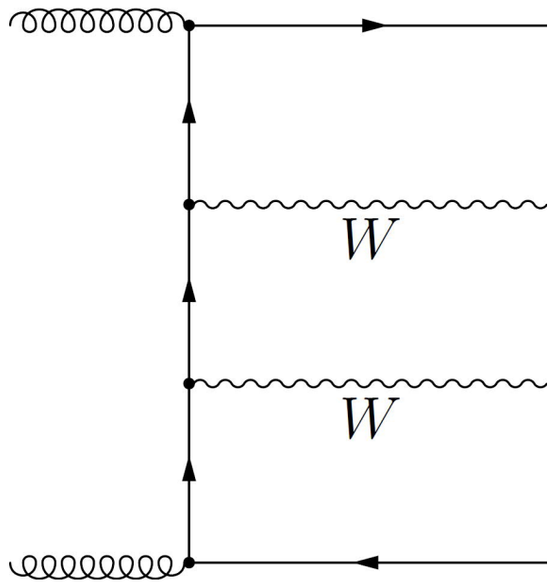
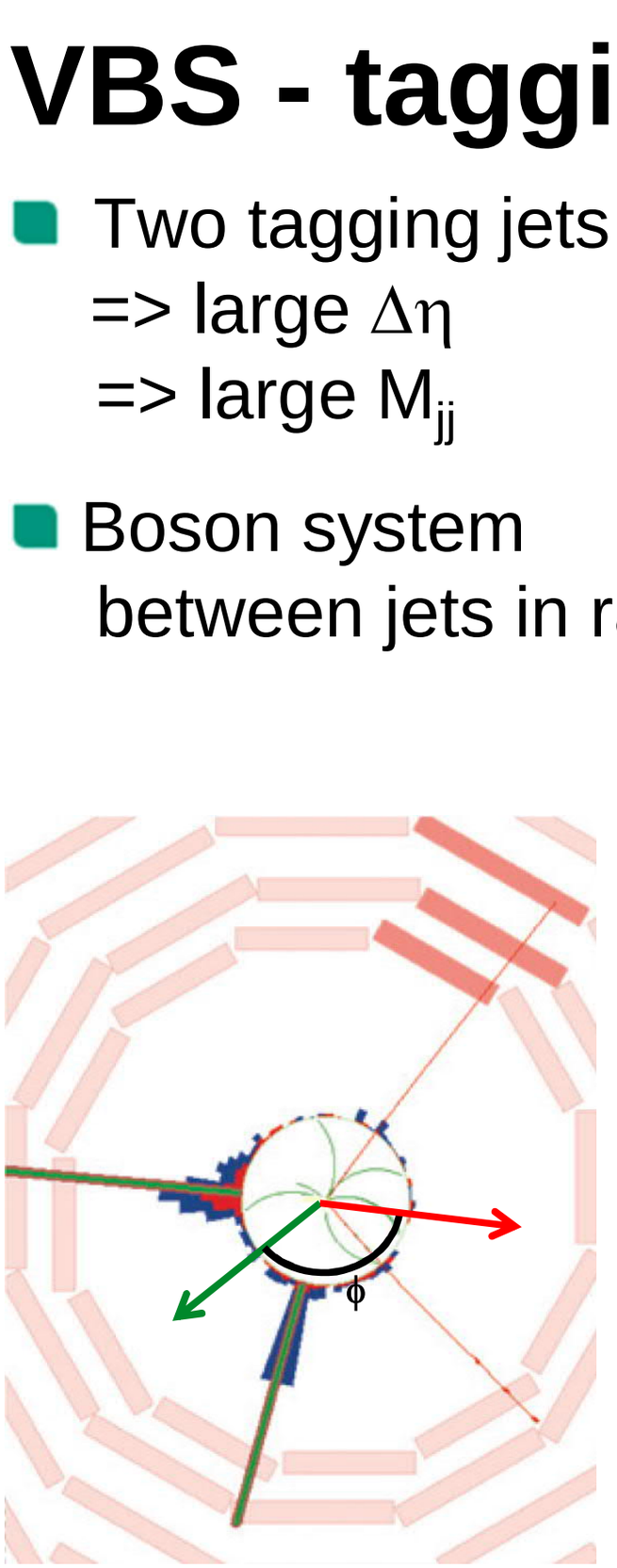
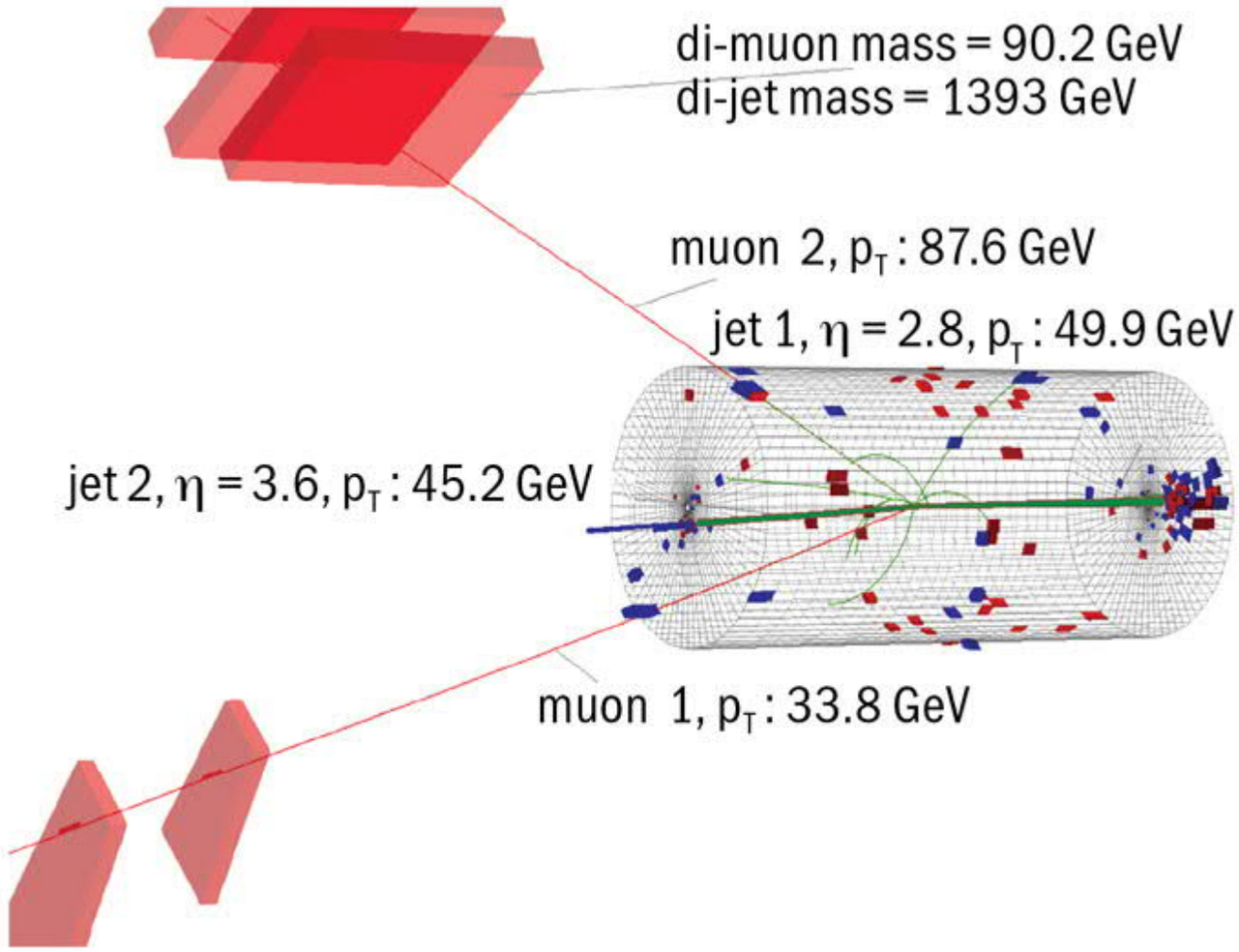


+ … (other $\alpha^4\alpha_s^2$)

VBS - tagging

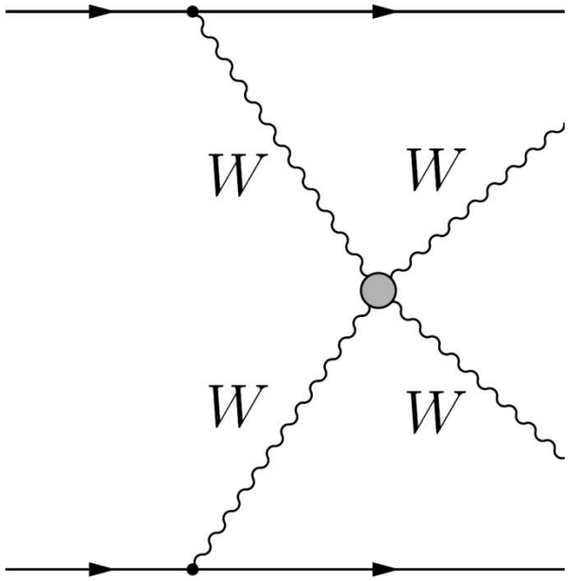
- Two tagging jets
  => large $\Delta\eta$
  => large M_{jj}
- Boson system
  between jets in rapidity



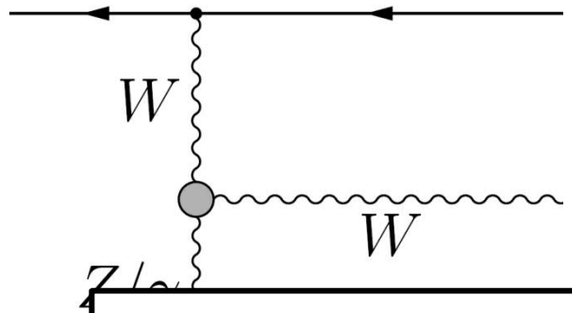


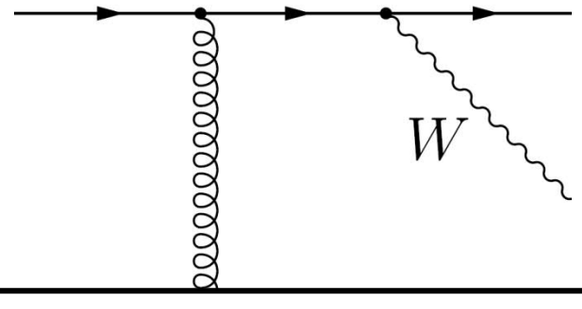
- Angle between dijet and EWK system

Same Sign WW



QGC

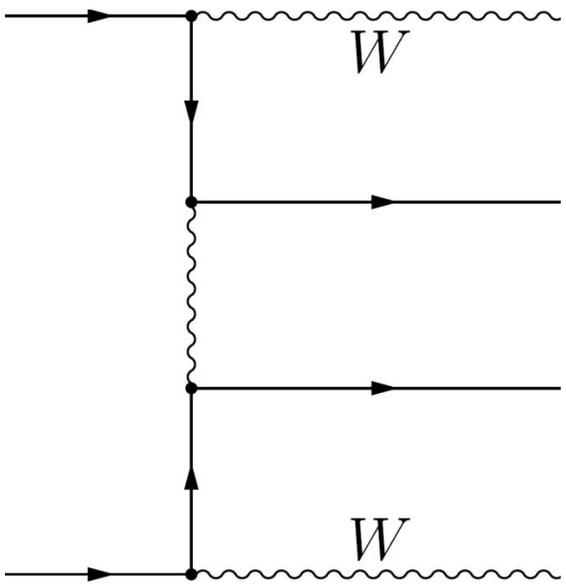




No gluon induced processes at LO

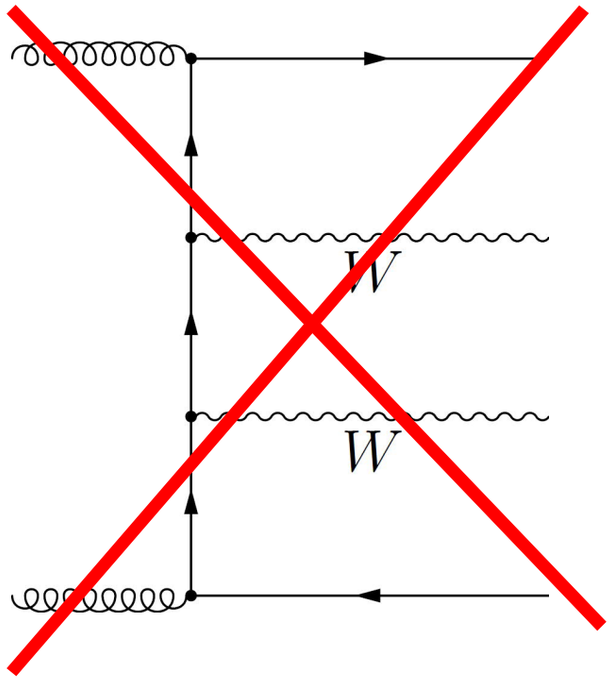
⇩

High purity



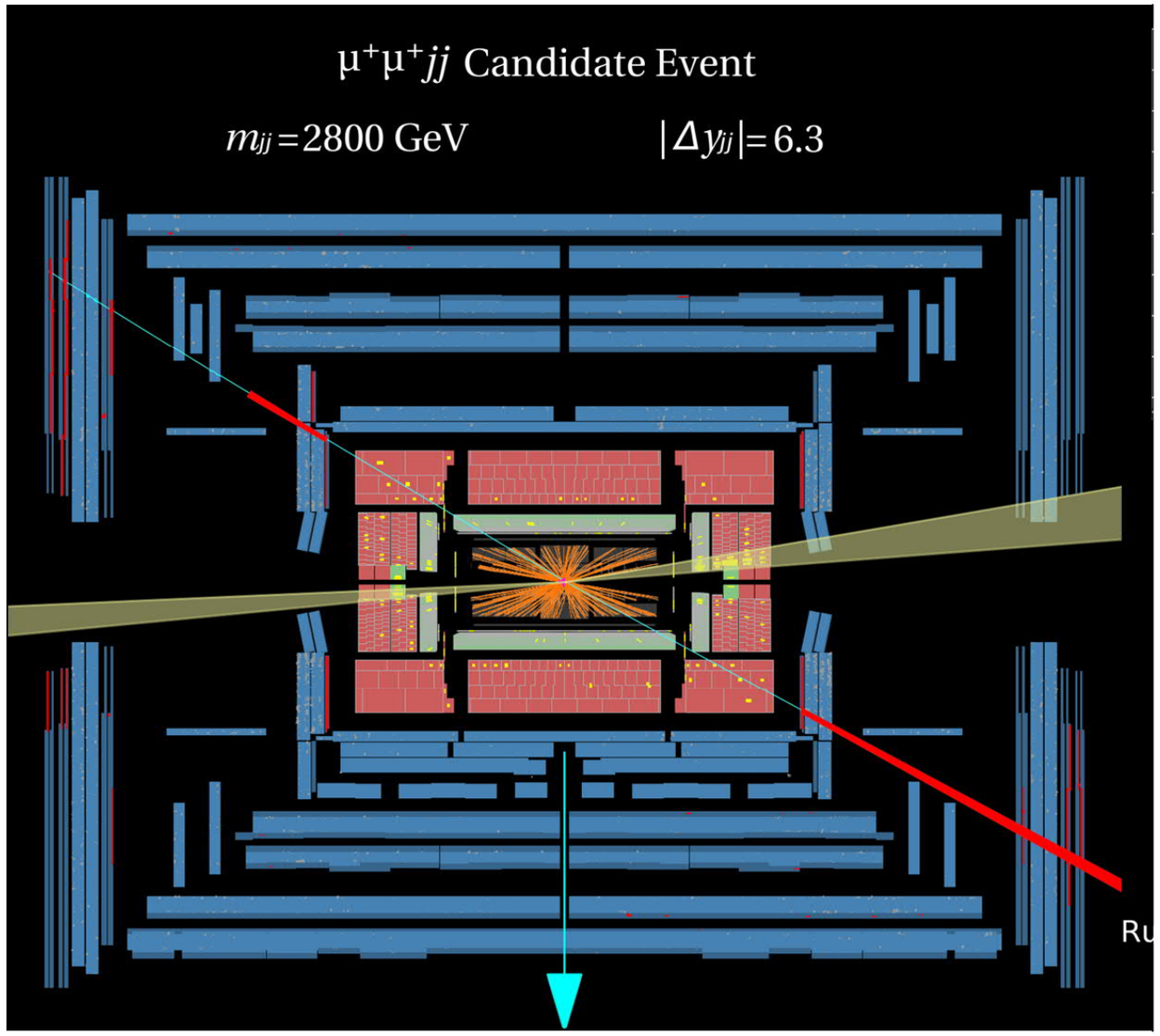
Double Brem

+ … (other α^6)

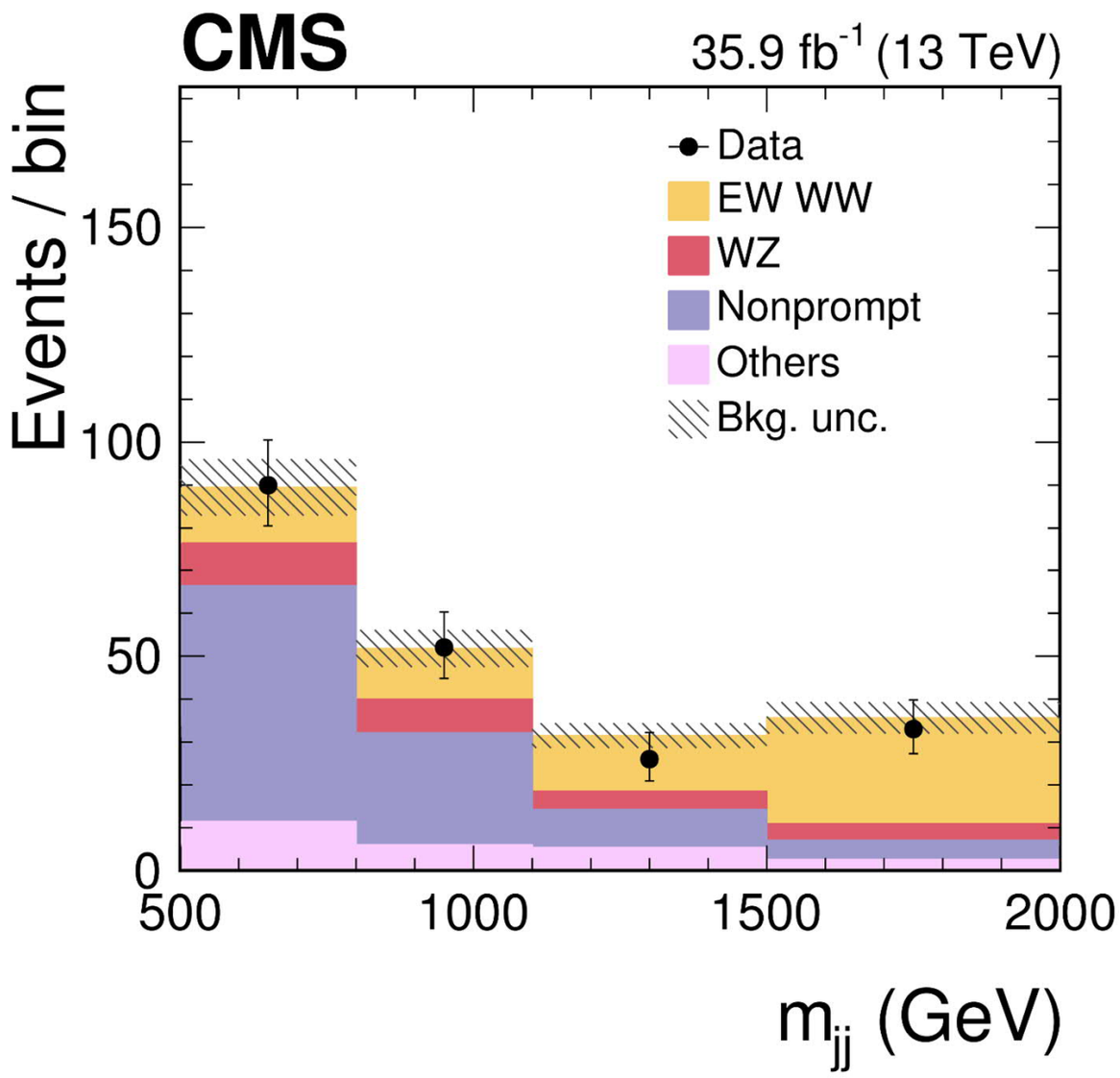


+ … (other $\alpha^4\alpha_s^2$)

Results



[Atlas-CONF-2014-013]



[CMS-SMP-17-004]

Summary

- Multi-Boson processes offer door to new physics at the LHC
  => few measurements from older acceleratorse
  => expect to see effects in weak bosons when answering hierarchy problem

- Many interesting topologies:
  => resonances
  => anomalous couplings
  => vector boson scattering

- Still everything compatible with SM