# Probing low mass resonances with boosted jets

**Boosted Dijet + ISR at 13 TeV search at CMS**

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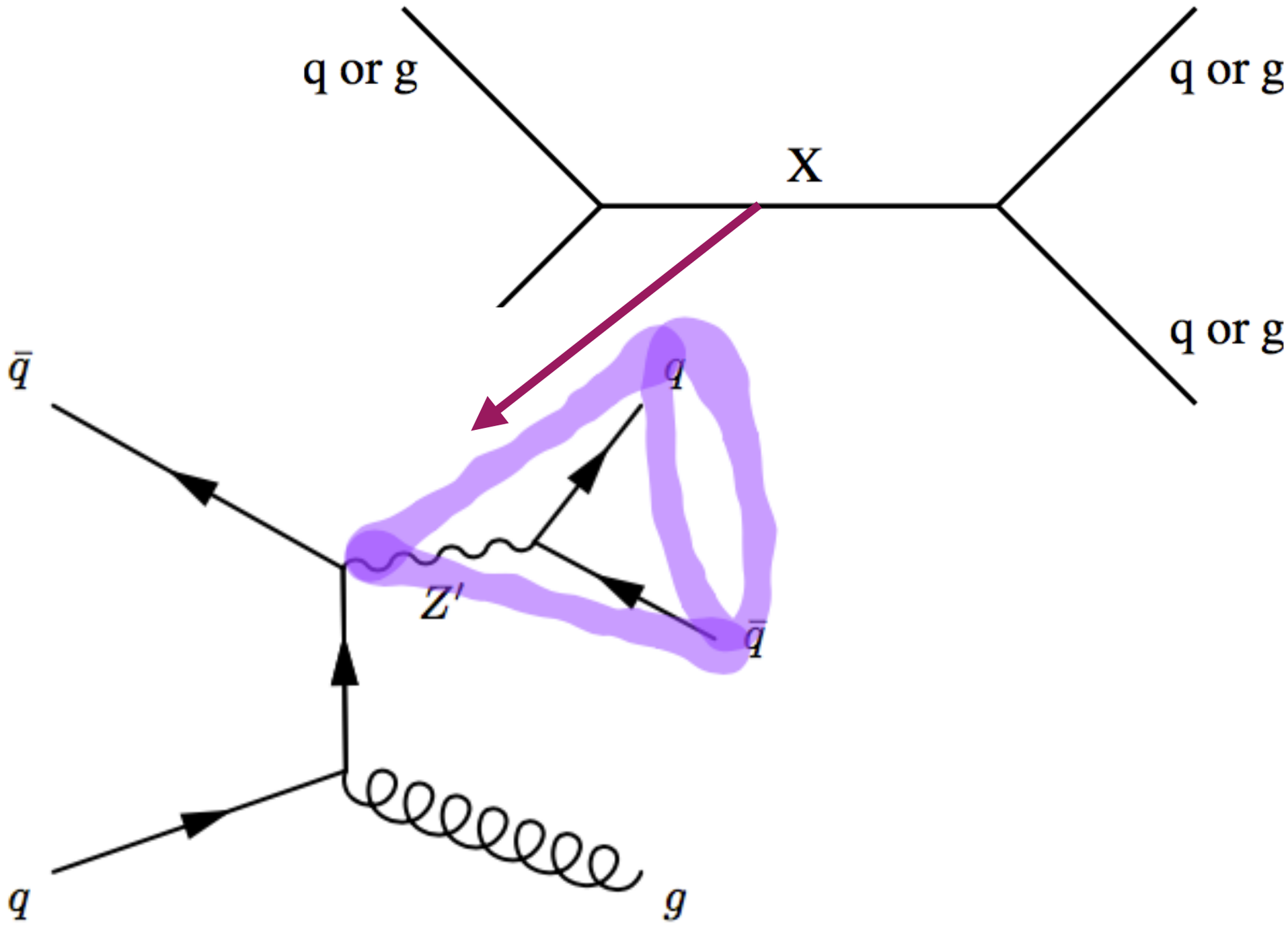
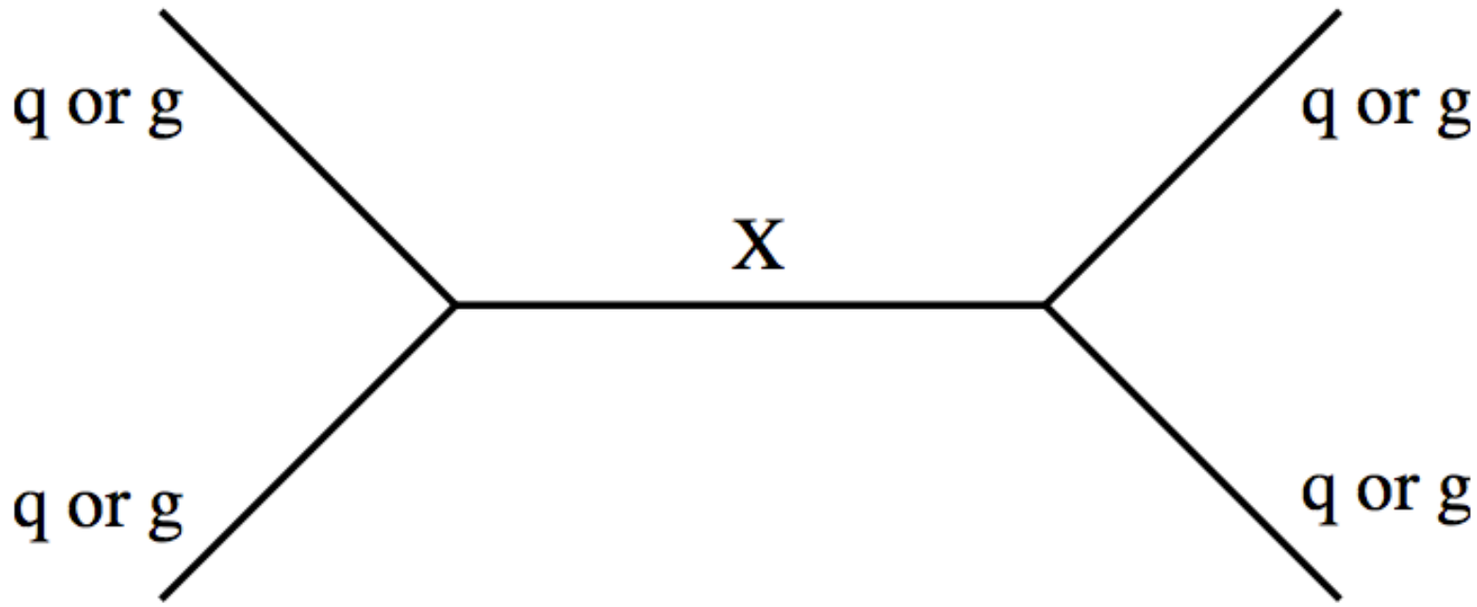
USLUA LHC

A new Z'(qq) particle — low mass (50-300 GeV) — in a single jet.

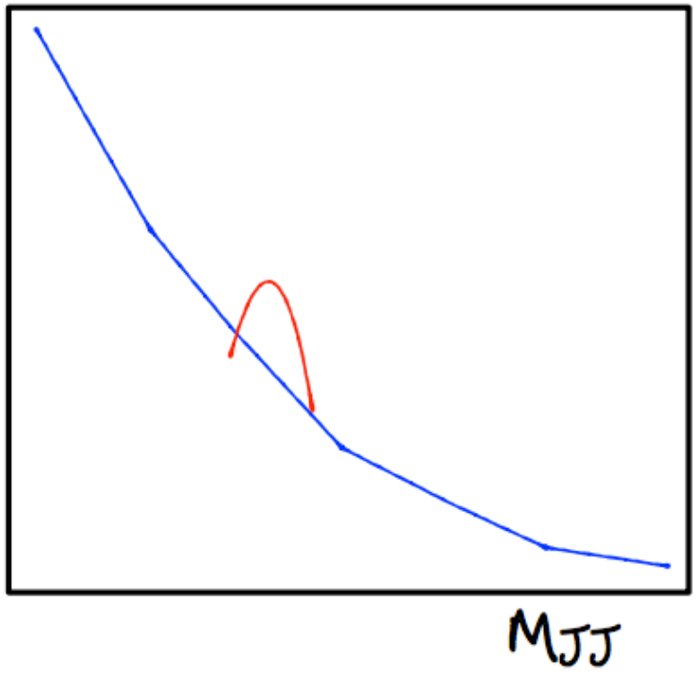


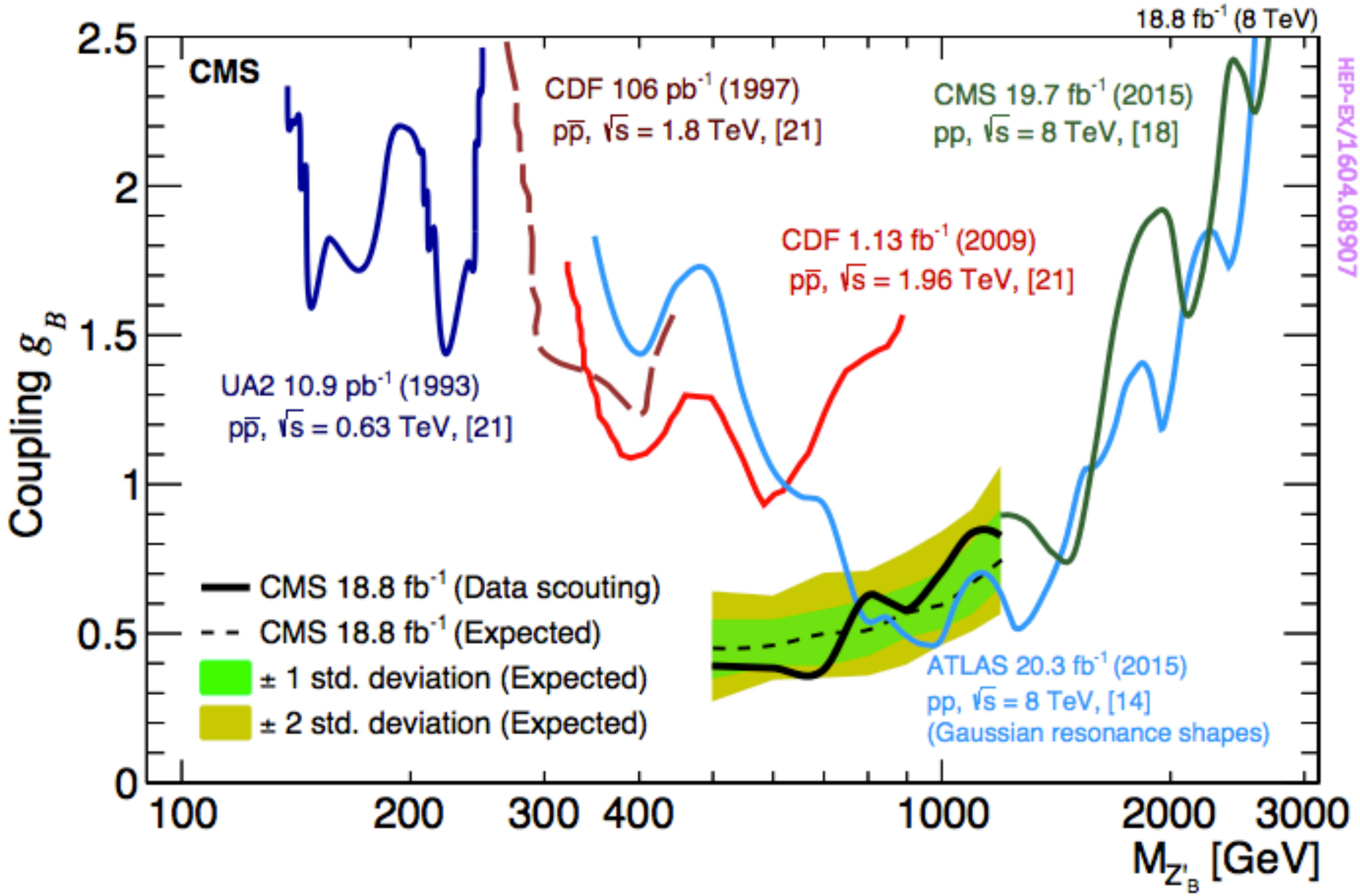
# Dijet searches:

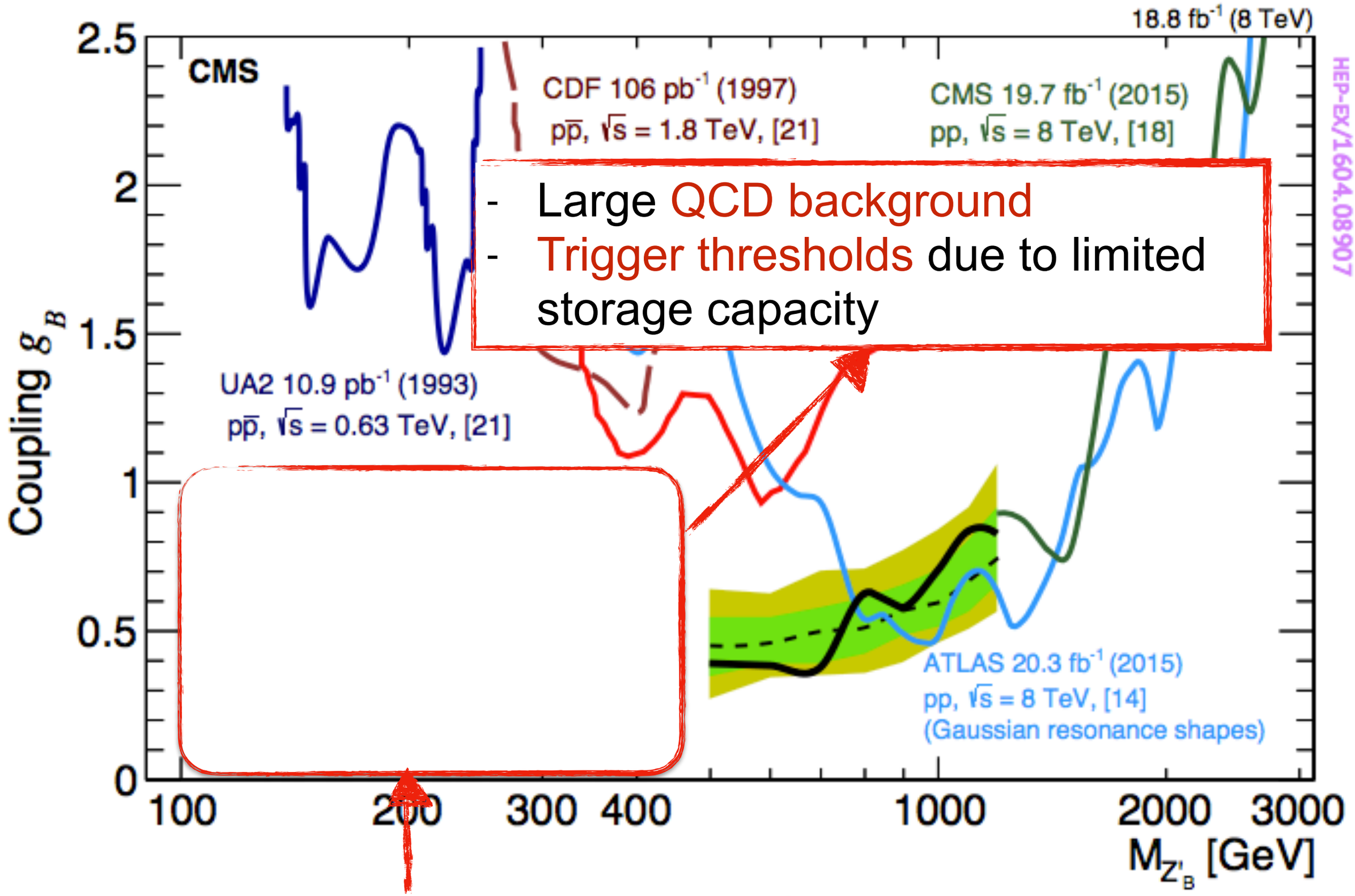



Powerful and generic search at the LHC

- Collect (lots of) data with a trigger based on hadronic activity
- Select events based on jet properties
- Search for a bump over a smoothly falling dijet mass spectrum



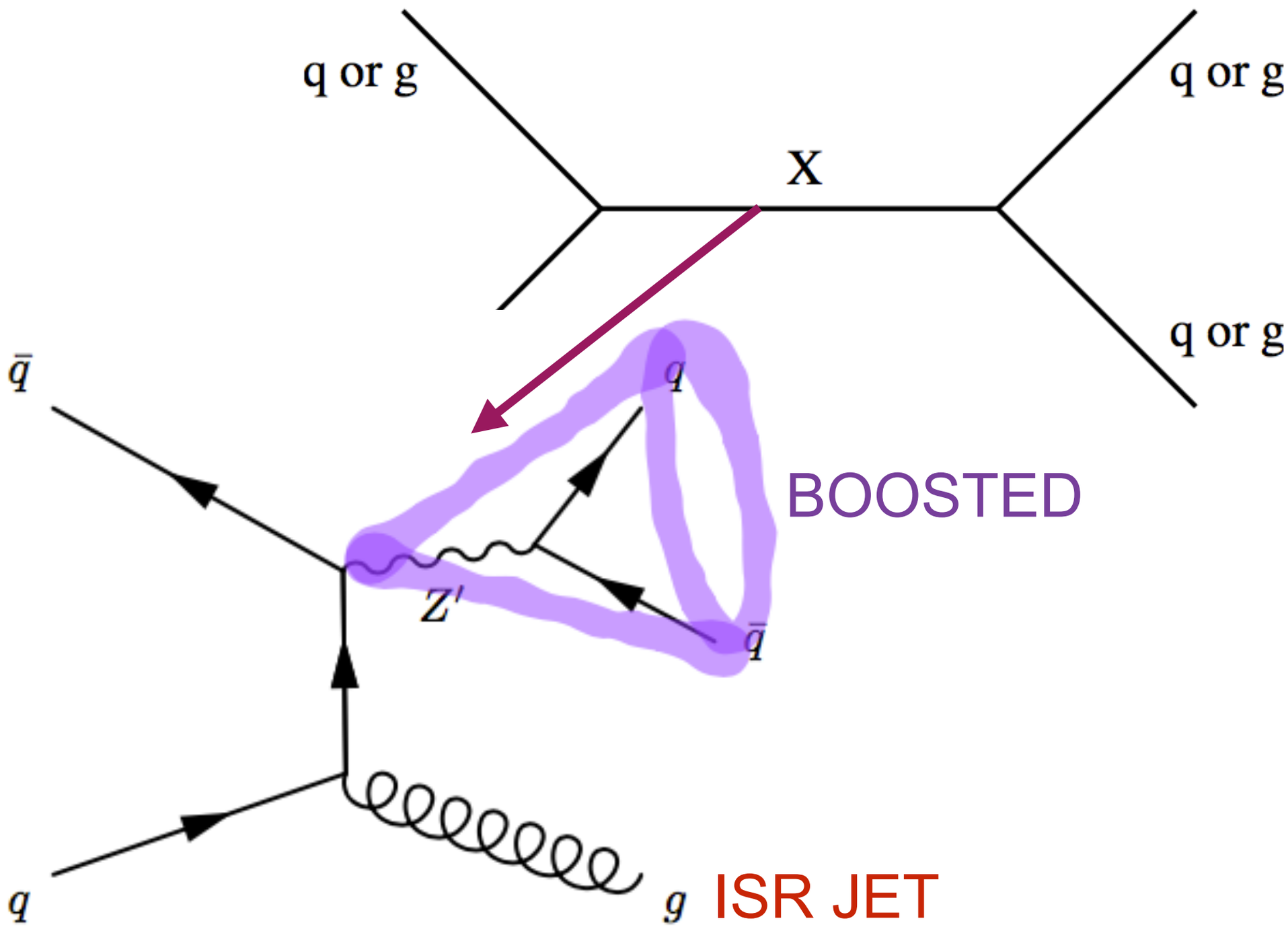

18.8 fb$^{-1}$ (8 TeV)
CMS
CDF 106 pb$^{-1}$ (1997)
$p\bar{p}$, $\sqrt{s}$ = 1.8 TeV, [21]
CMS 19.7 fb$^{-1}$ (2015)
pp, $\sqrt{s}$ = 8 TeV, [18]
CDF 1.13 fb$^{-1}$ (2009)
$p\bar{p}$, $\sqrt{s}$ = 1.96 TeV, [21]
UA2 10.9 pb$^{-1}$ (1993)
$p\bar{p}$, $\sqrt{s}$ = 0.63 TeV, [21]
CMS 18.8 fb$^{-1}$ (Data scouting)
CMS 18.8 fb$^{-1}$ (Expected)
± 1 std. deviation (Expected)
± 2 std. deviation (Expected)
ATLAS 20.3 fb$^{-1}$ (2015)
pp, $\sqrt{s}$ = 8 TeV, [14]
(Gaussian resonance shapes)
HEP-EX/1604.08907
Coupling $g_B$
$M_{Z'_B}$ [GeV]
0
0.5
1
1.5
2
2.5
100
200
300
400
1000
2000
3000




- Large QCD background
- Trigger thresholds due to limited storage capacity

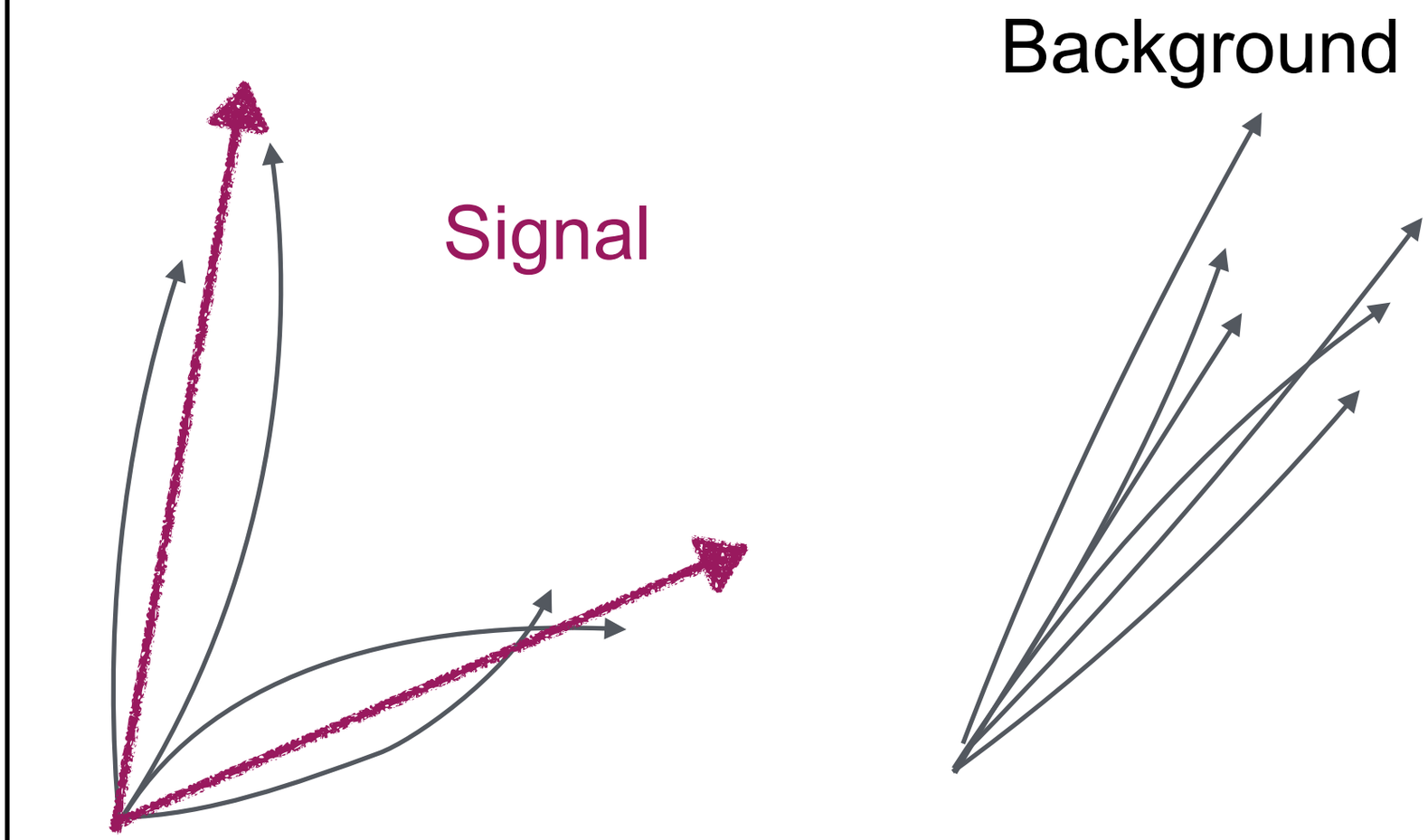
Why no low mass constraints?

# Use ISR jet to get above trigger thresholds



Kinematic Selection:

- High pT (> 500 GeV)
- Trigger: high energy
  - HT 800 GeV




Backgrounds:

- QCD
- W/Z+Jets
- Top

ISR jet

Kinematic Selection:

- High pT (> 500 GeV)
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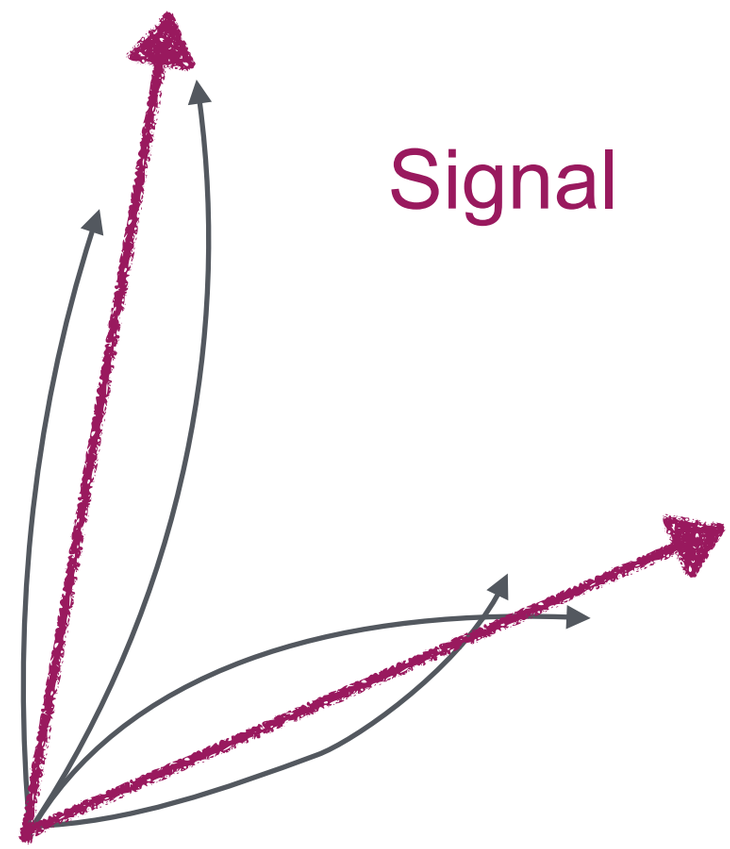
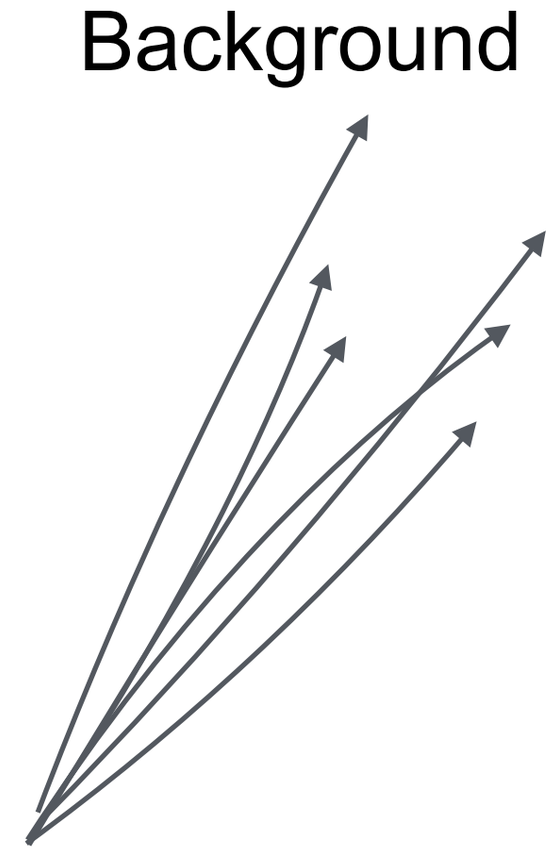
  - HT 800 GeV




Backgrounds:

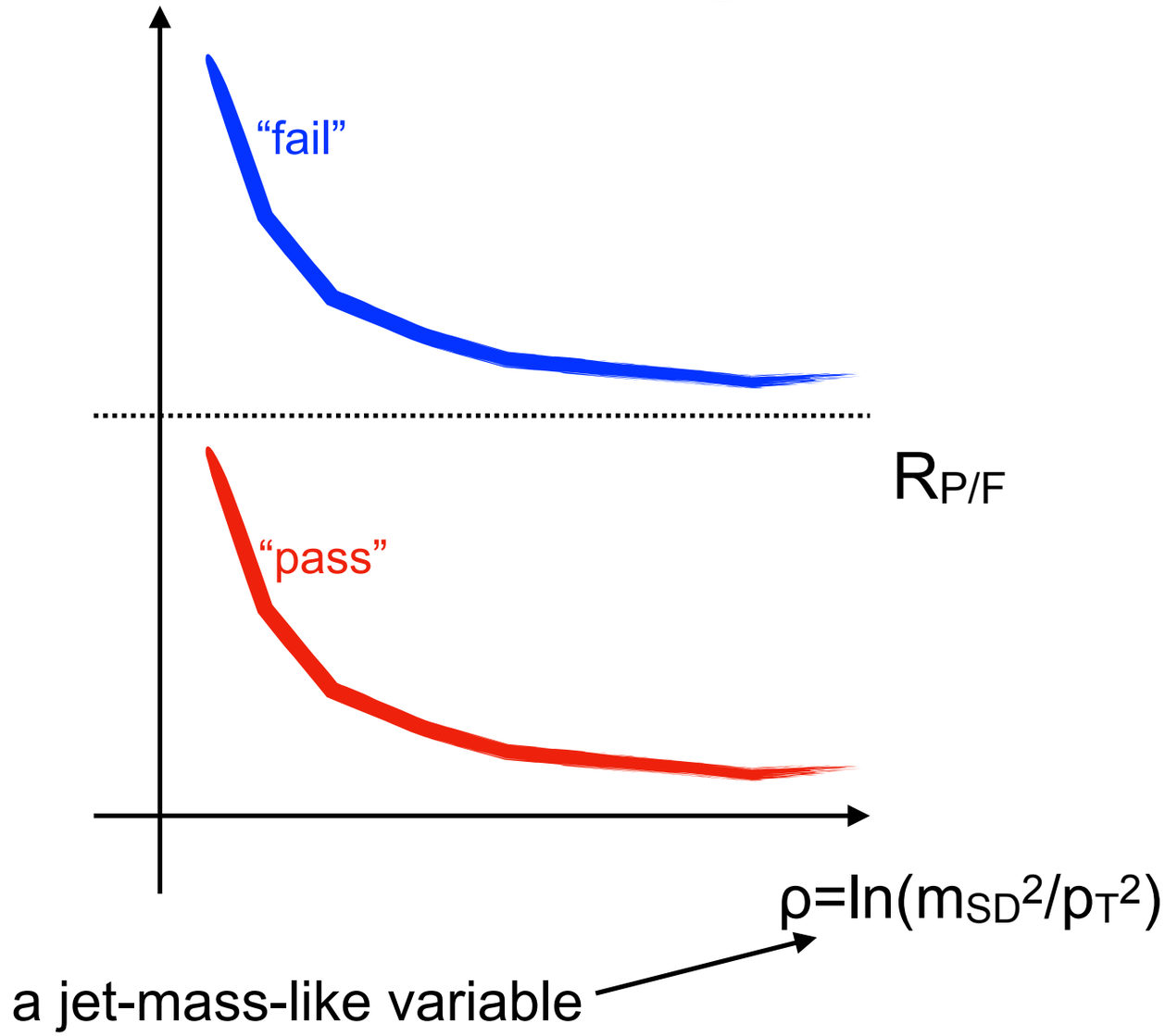
- QCD
- W/Z+Jets
- Top

ISR jet

Substructure selection:

- Jet mass
- "2-prong": $N_2^{DDT}>0$
  - 5% background efficiency
  - Preserves jet mass shape after selection

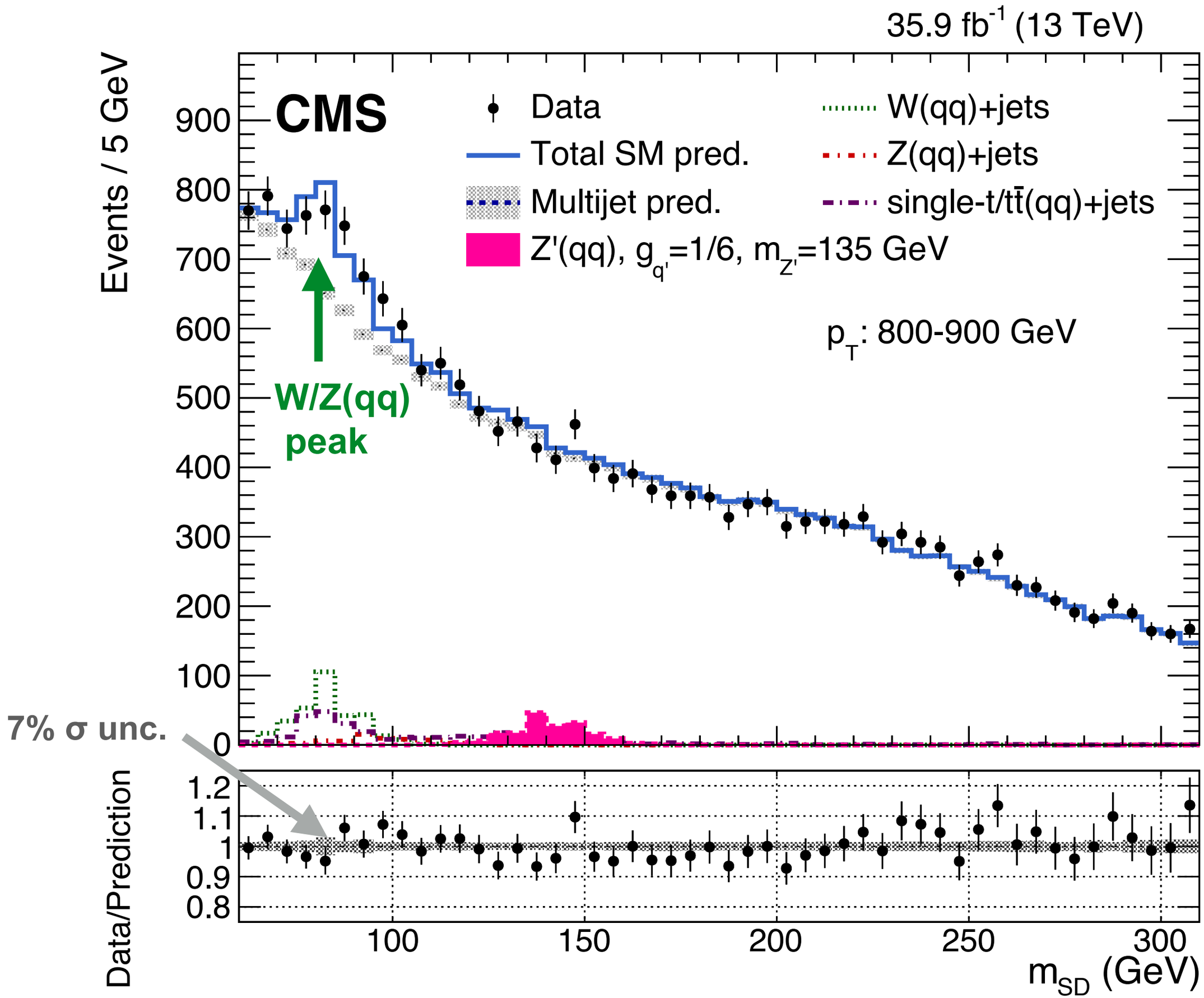
- Cutting on a variable <u>(independent on jet mass, $p_T$)</u> gives us another advantage:

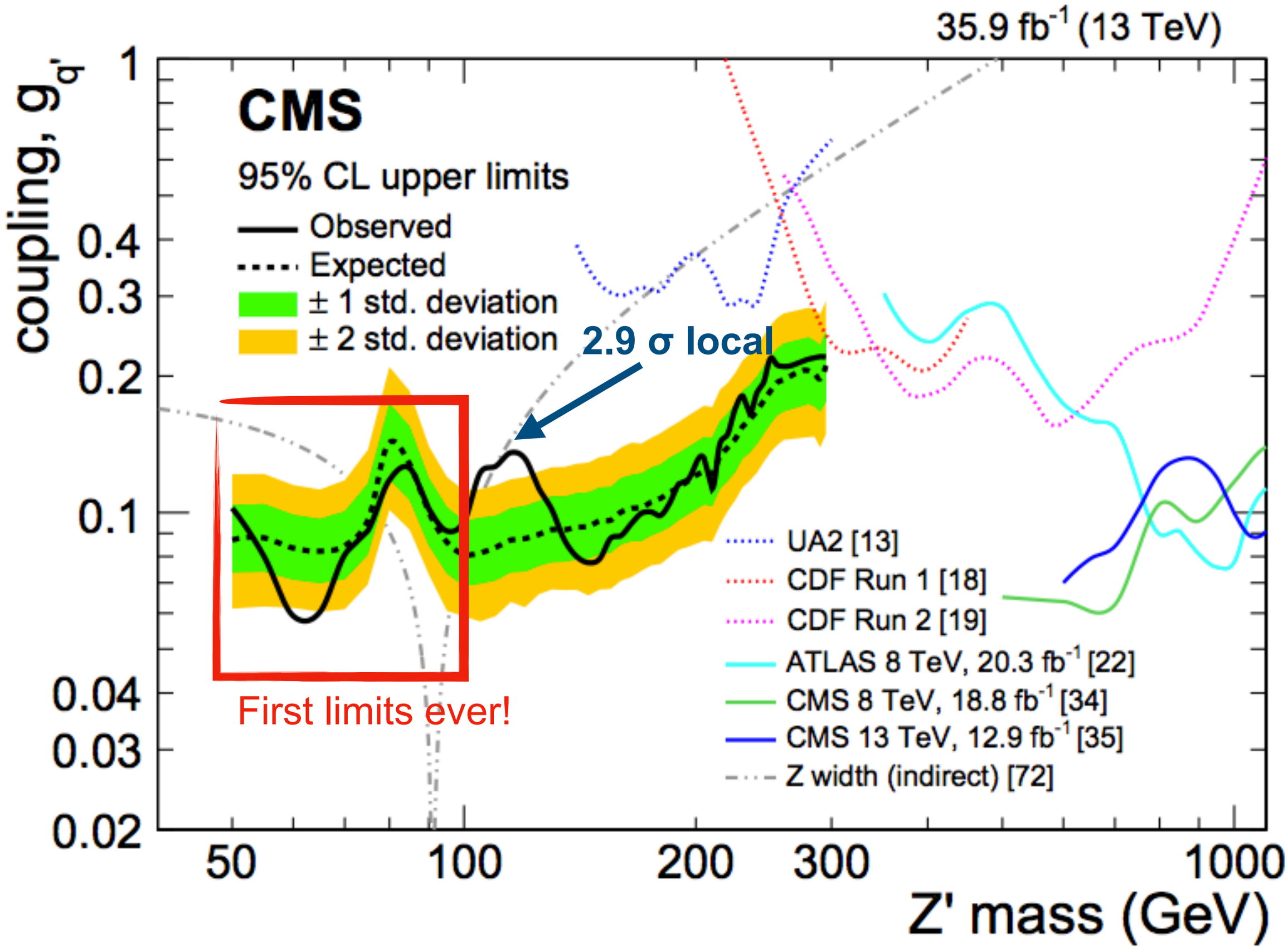



FAIL: $N_2^{DDT} > 0$

PASS: $N_2^{DDT} < 0$

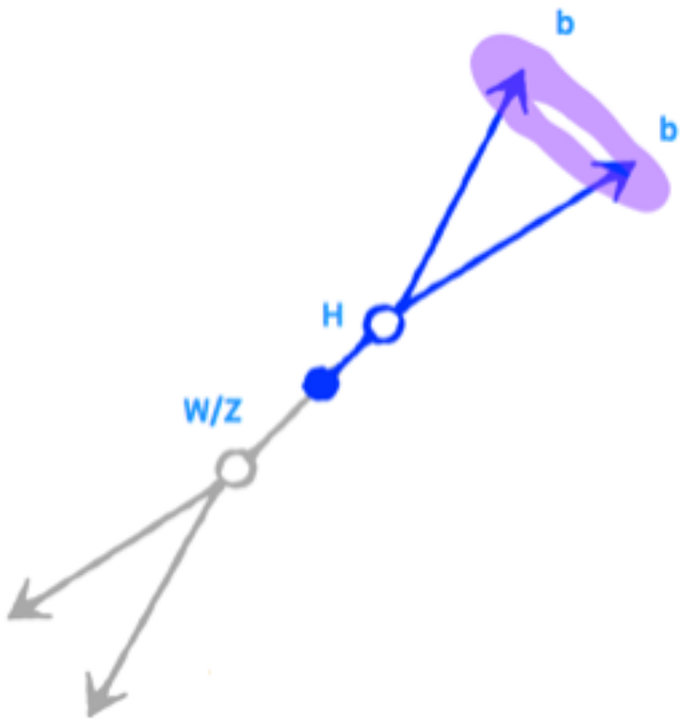
- Data-driven QCD estimate: $\mathbf{Pass_{QCD}} = \frac{\mathbf{Pass}}{\mathbf{Fail}} * \mathbf{Fail_{QCD}}$
- Simultaneously fit pass and fail


35.9 fb$^{-1}$ (13 TeV)
CMS
Data
Total SM pred.
Multijet pred.
Z'(qq), $g_{q'}$=1/6, $m_{Z'}$=135 GeV
W(qq)+jets
Z(qq)+jets
single-t/$t\bar{t}$(qq)+jets
$p_T$: 800-900 GeV
W/Z(qq) peak
7% σ unc.
Events / 5 GeV
Data/Prediction
$m_{SD}$ (GeV)


35.9 fb$^{-1}$ (13 TeV)
CMS
95% CL upper limits
Observed
Expected
± 1 std. deviation
± 2 std. deviation
2.9 σ local
First limits ever!
UA2 [13]
CDF Run 1 [18]
CDF Run 2 [19]
ATLAS 8 TeV, 20.3 fb$^{-1}$ [22]
CMS 8 TeV, 18.8 fb$^{-1}$ [34]
CMS 13 TeV, 12.9 fb$^{-1}$ [35]
Z width (indirect) [72]
coupling, $g_{q'}$
1
0.4
0.3
0.2
0.1
0.04
0.03
0.02
50
100
200
300
1000
Z' mass (GeV)

# Summary

- Search extended to lower masses (below 100 GeV!)
  - EXO-17-001 (arxiv:1710.00159)
- Novel background estimate and tagging techniques
- Program can be further extended:
  - Boosted Higgs(bb) search using same tagging and background estimate.
  - HIG-17-010 (arxiv:1709.05543)
  - Probing gluon vs quark coupling



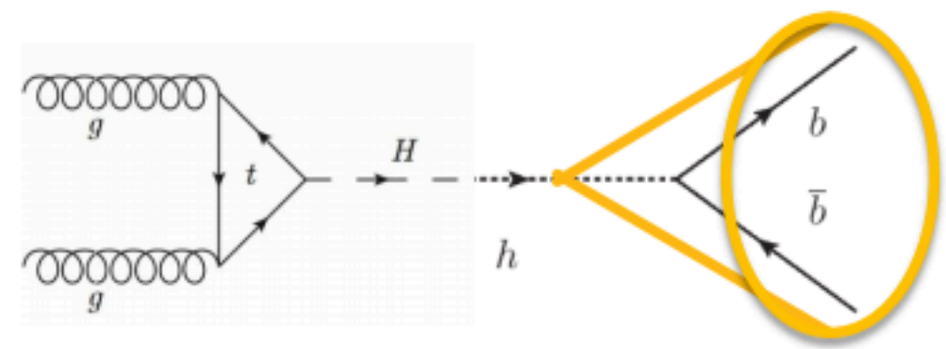
Questions?

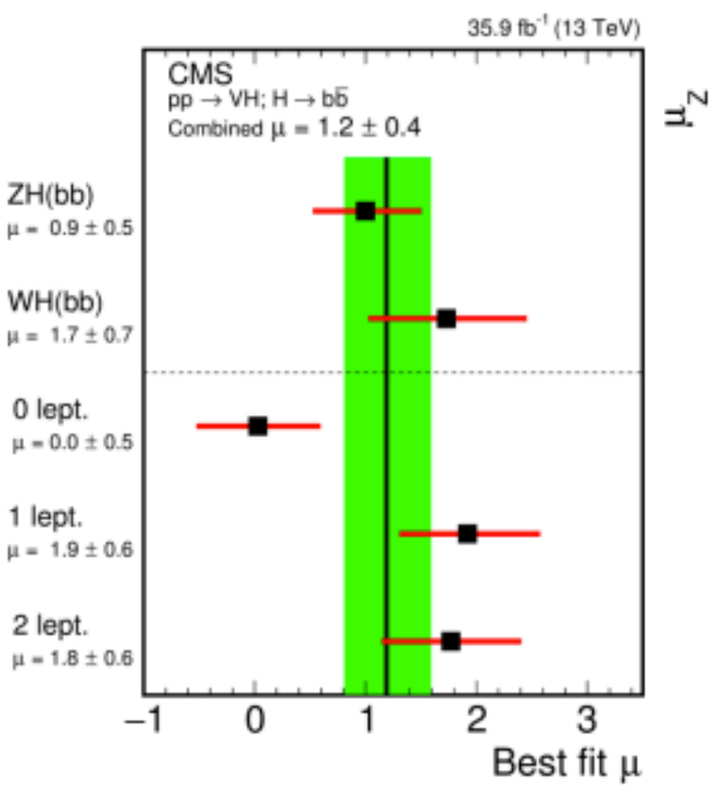
# Joe Pastika's Slides

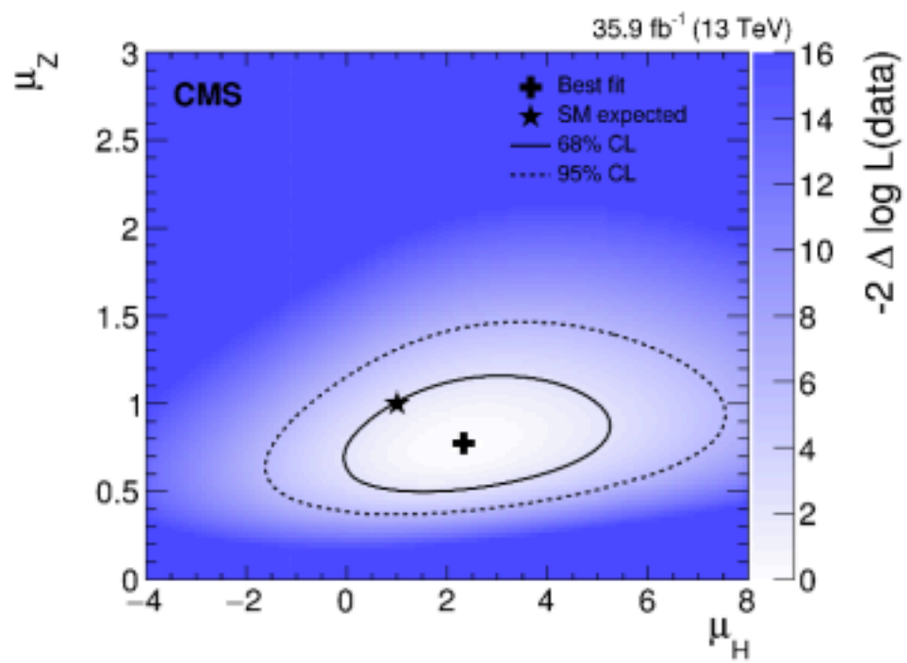
## Boosted Higgs to bb

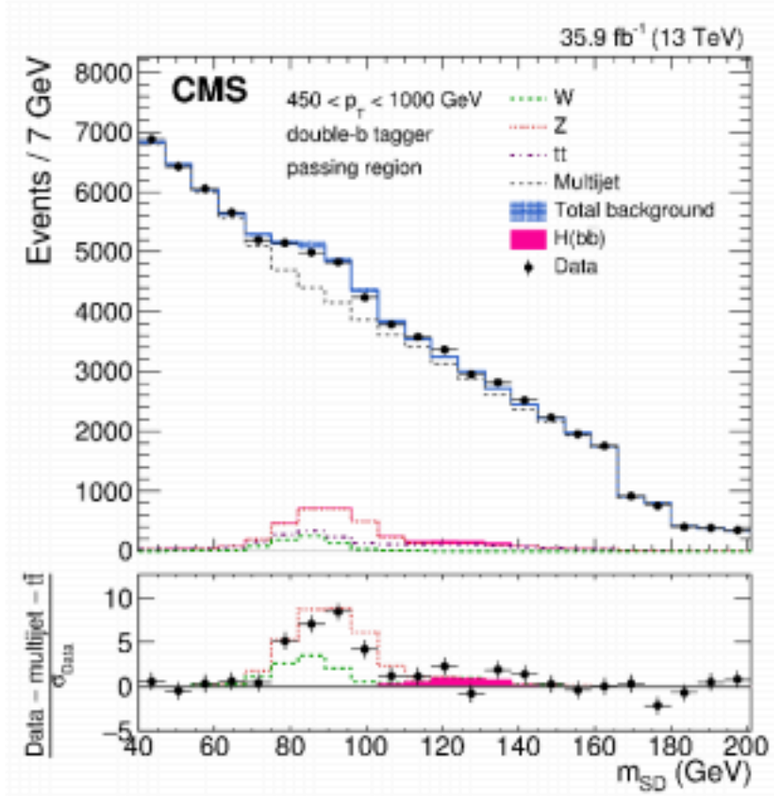
http://arxiv.org/abs/1709.07497
http://arxiv.org/abs/1709.05543

- Traditional $H \to bb$ search shows good agreement between SM and observations ($3.3\sigma$) at 13 TeV
- Dedicated search for events where boosted Higgs decay products end up in a single fat-jet
- Boosted channel significance of $1.5\sigma$



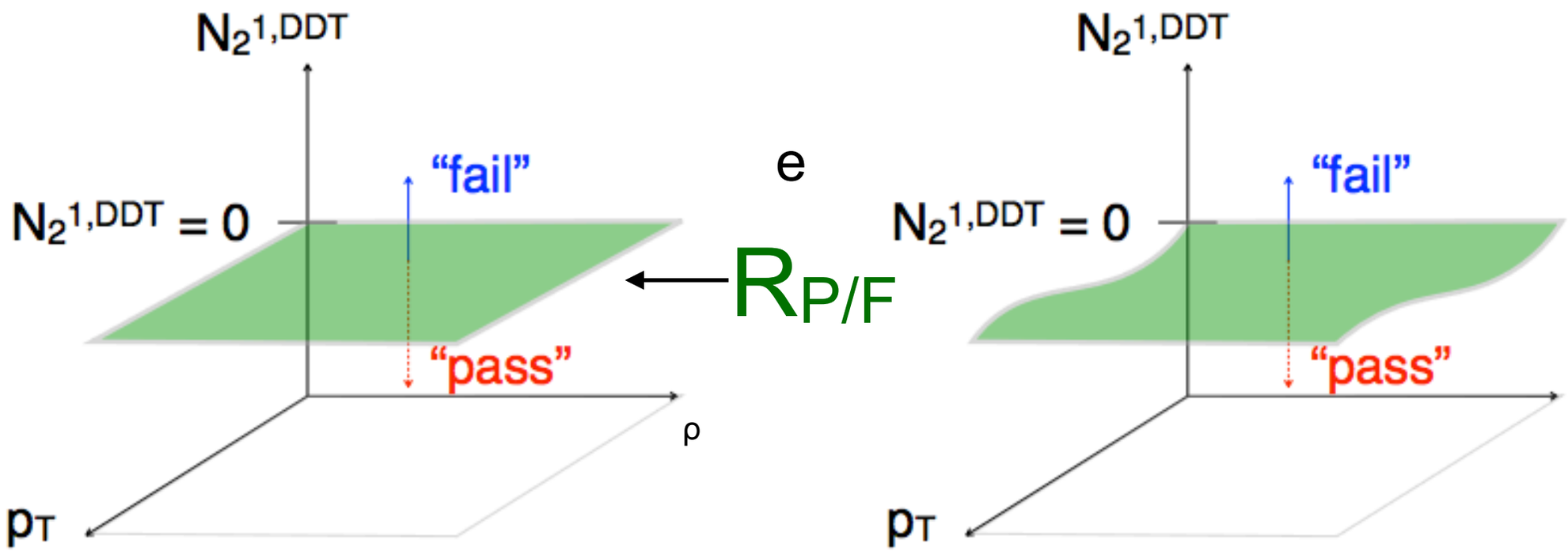



# QCD Estimate

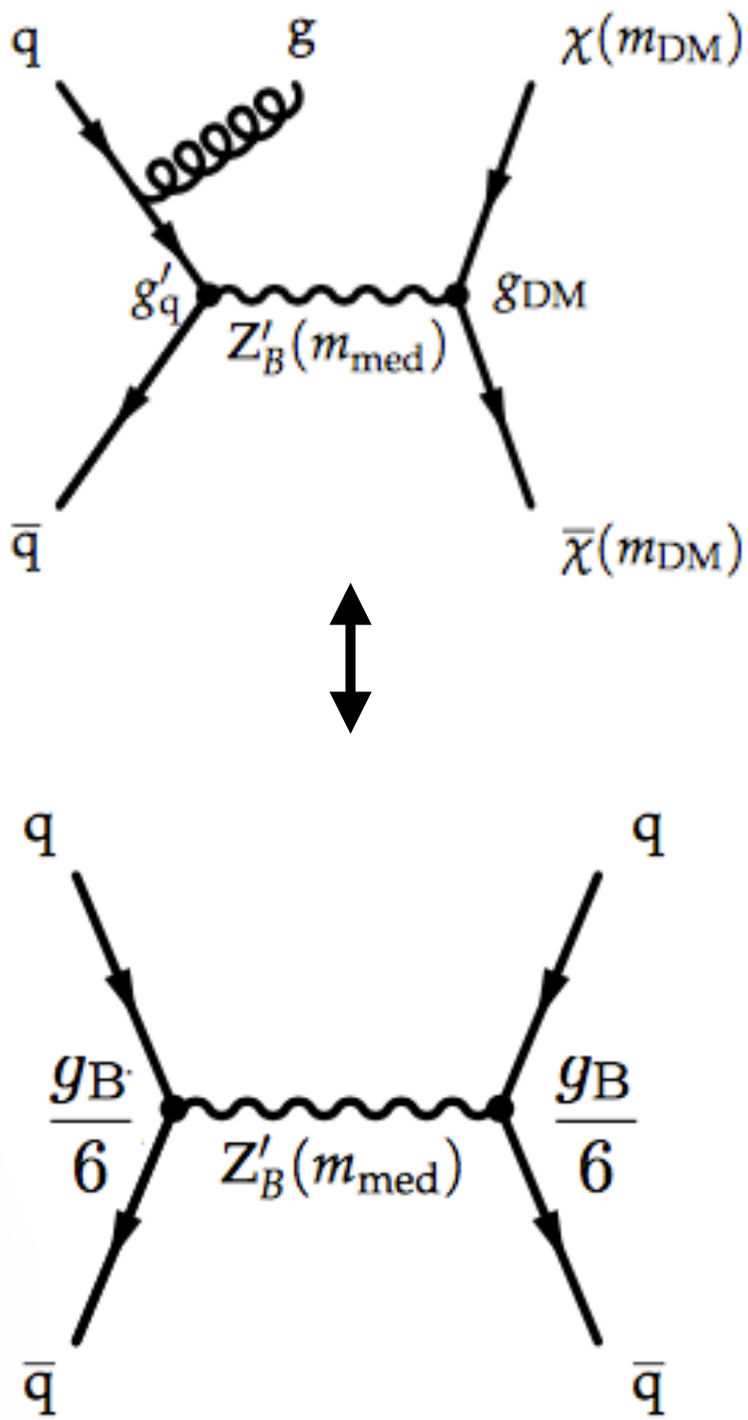
if MC correct:

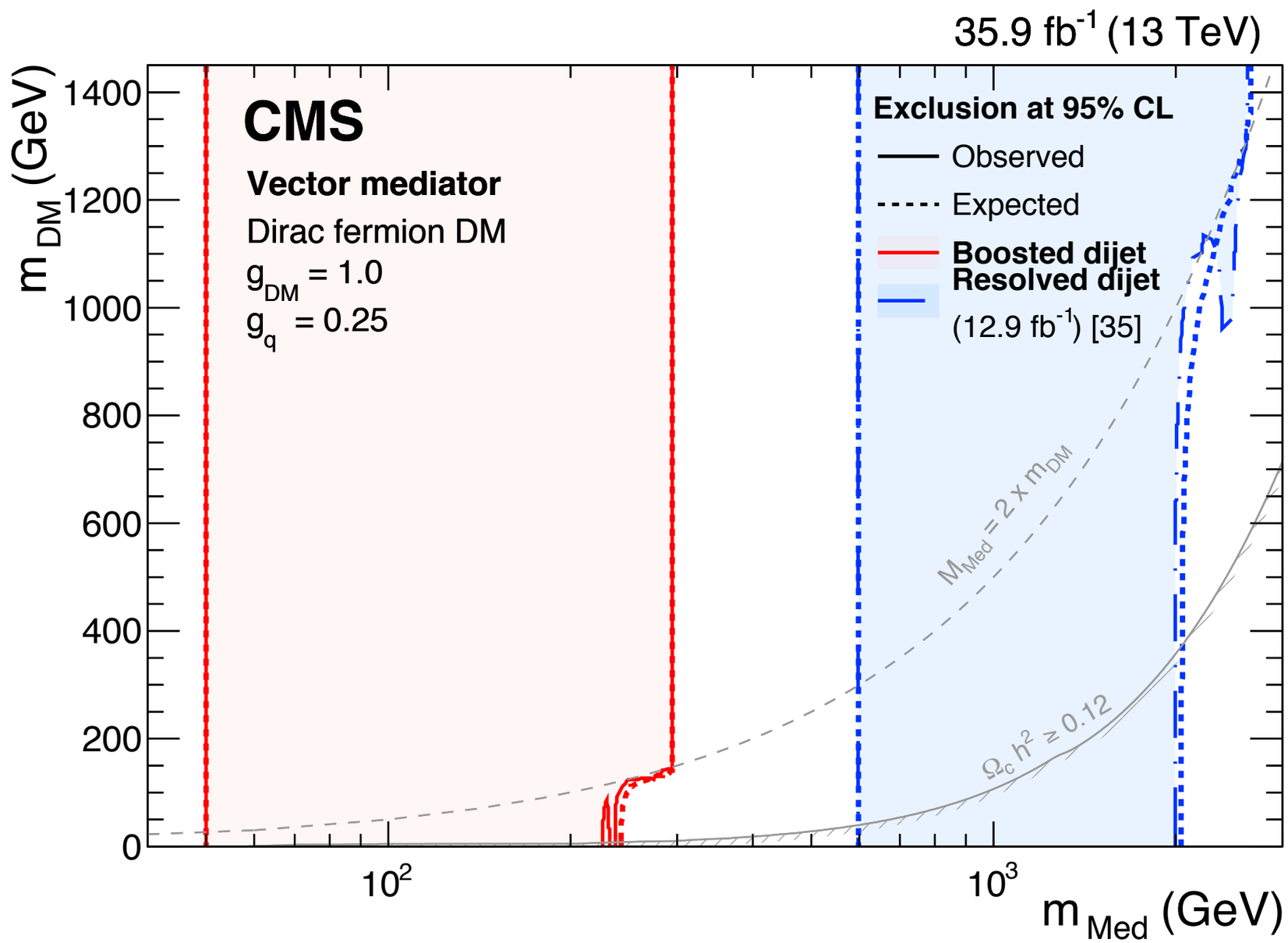
$R_{P/F}$ models Data/MC discrepancies:

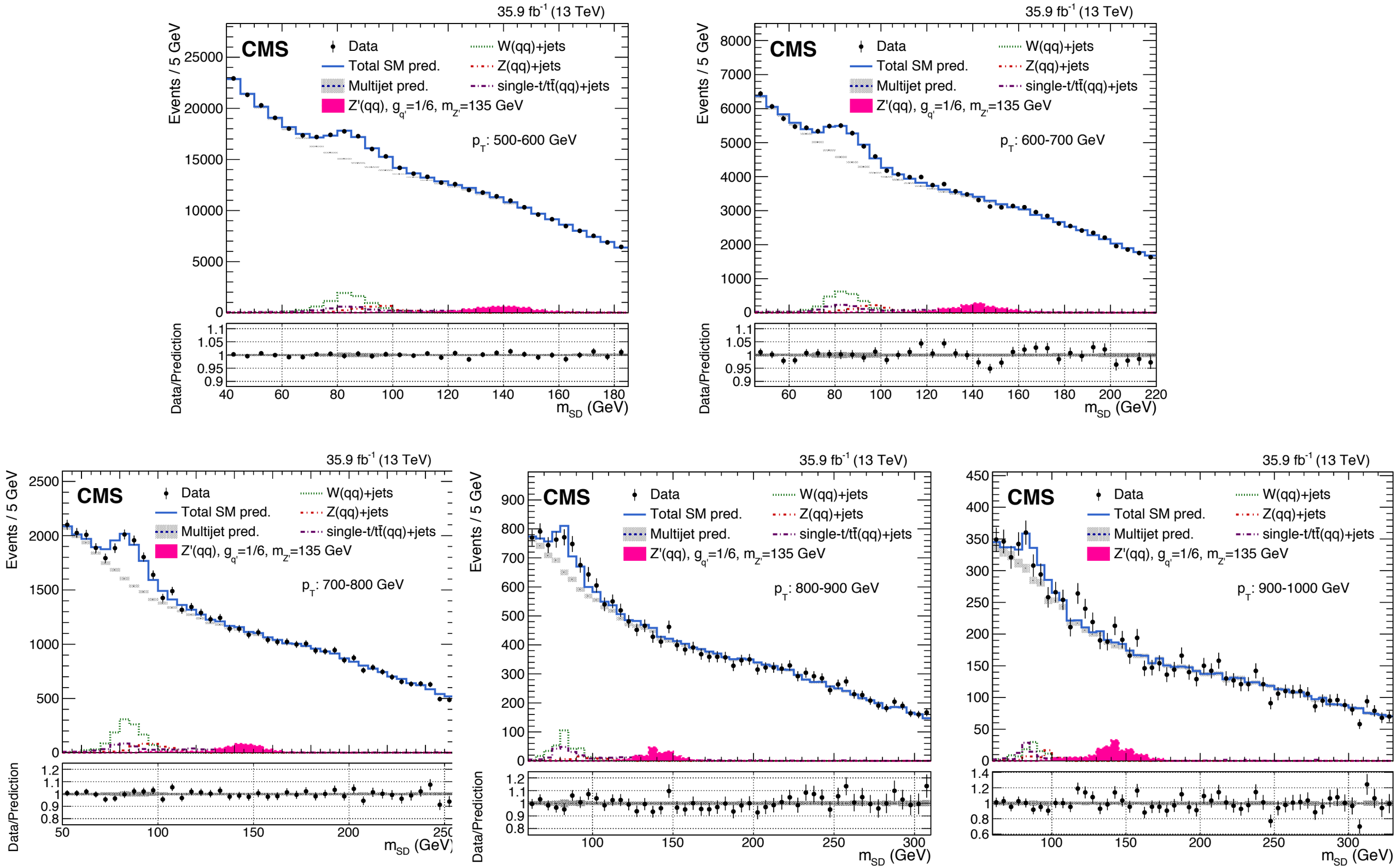



Parametrize discrepancies with polynomial and fit to data.

# Dark Matter constraints

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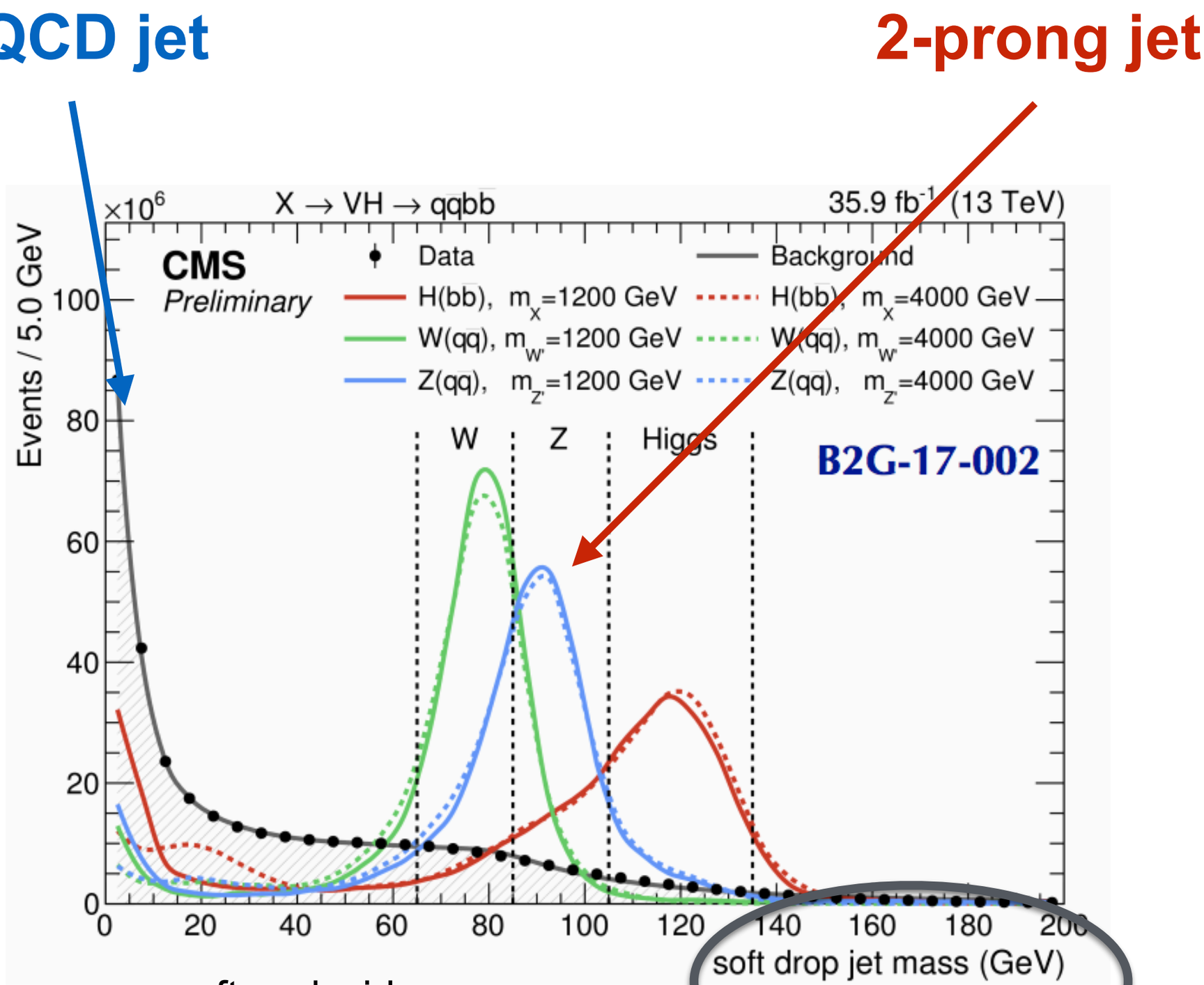
Z(qq)+jets
single-t/$t\bar{t}$(qq)+jets
$p_T$: 500-600 GeV
$p_T$: 600-700 GeV
$p_T$: 700-800 GeV
$p_T$: 800-900 GeV
$p_T$: 900-1000 GeV
Events / 5 GeV
Data/Prediction
$m_{SD}$ (GeV)

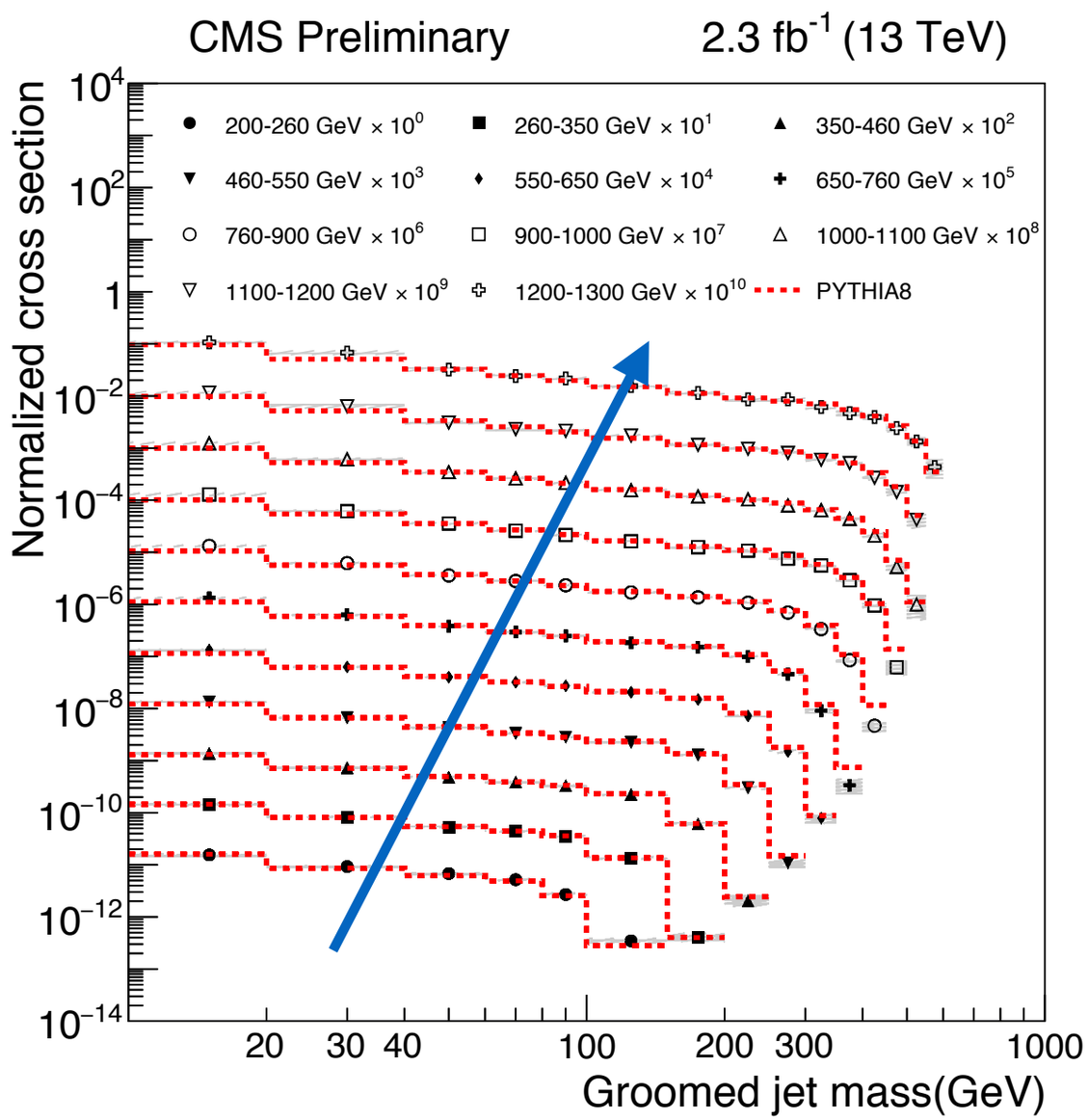
# Jet mass



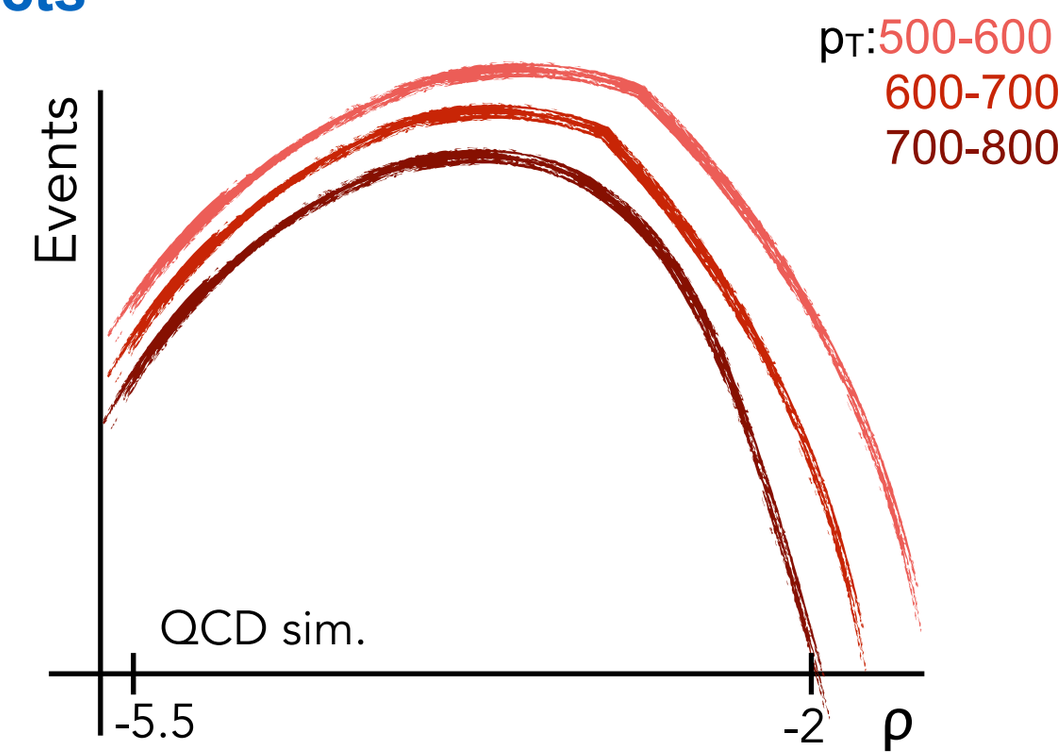

**Grooming** removes soft and wide angle radiation

# Jet mass

## QCD jet




**non-perturbative effects**




**Use QCD scaling variable:**
**Jet $\rho = \ln(m_{SD}^2/p_T^2)$**

We select: **$-5.5 < \rho < -2$**

e.g for a 500 GeV pT bin: $30<m_{SD}<180$

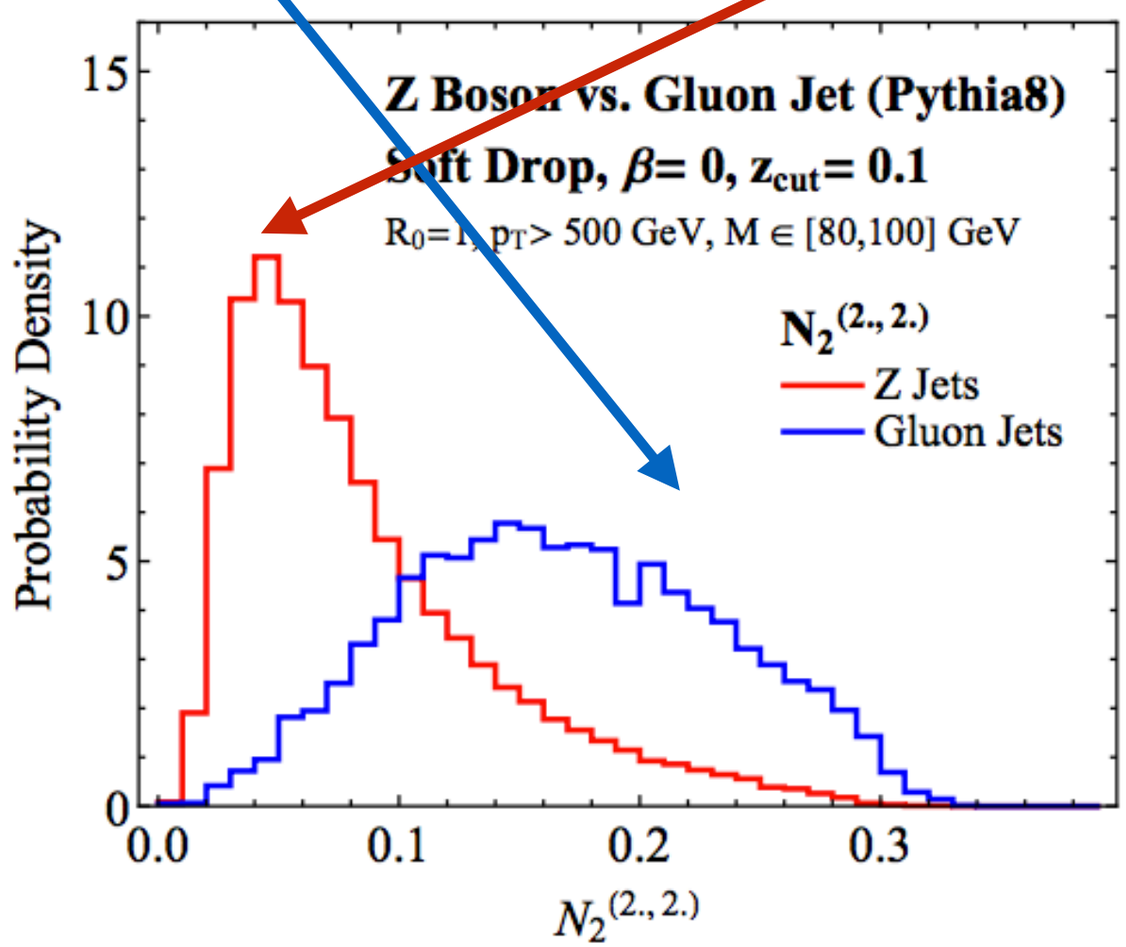
# Jet substructure: $N_2(1)$

**QCD jet**

**2-prong jet**

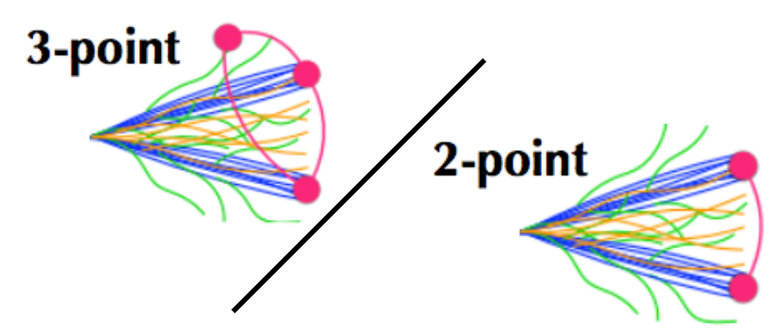
arxiv.1609.07483

**We make a selection with 5% background efficiency**

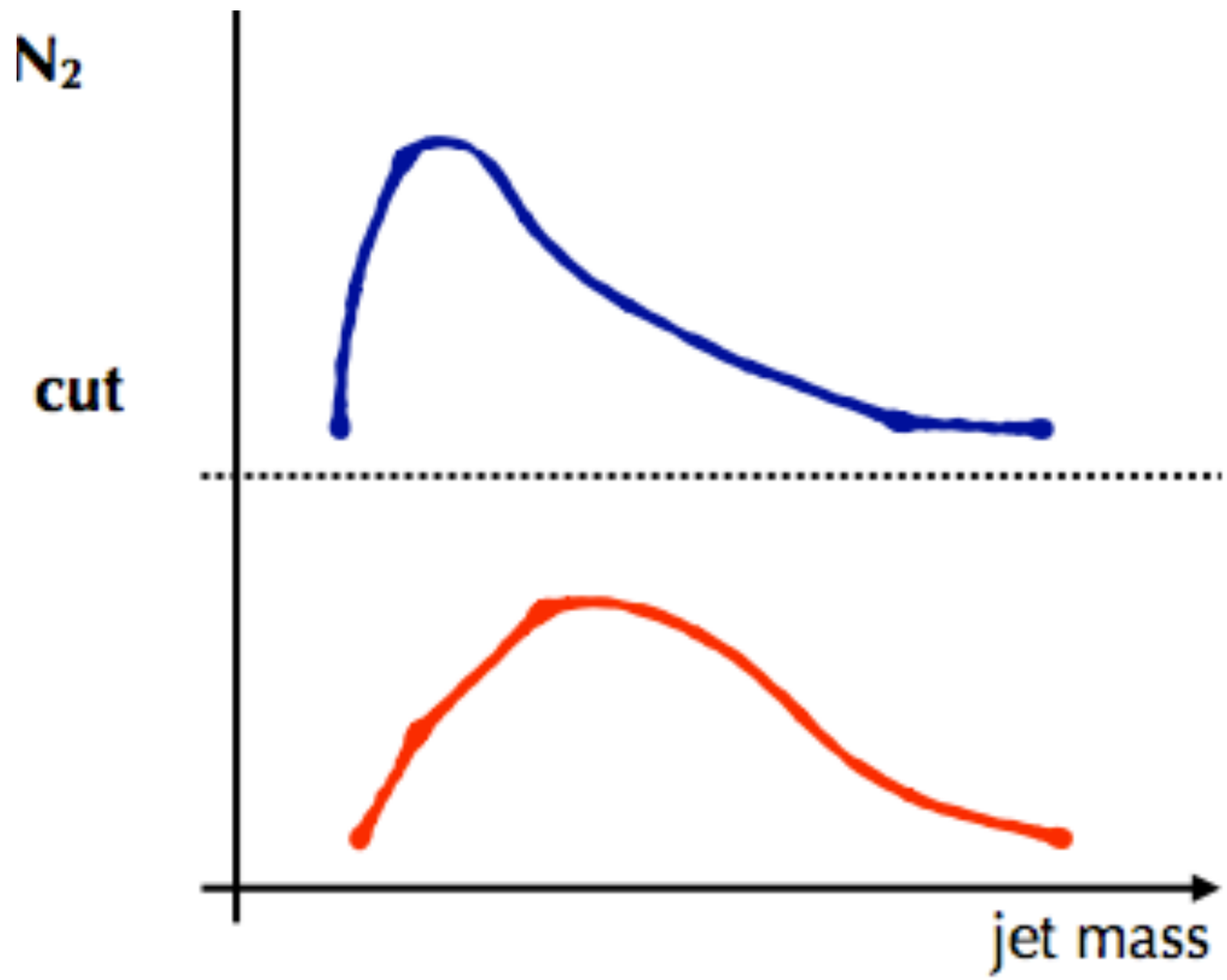


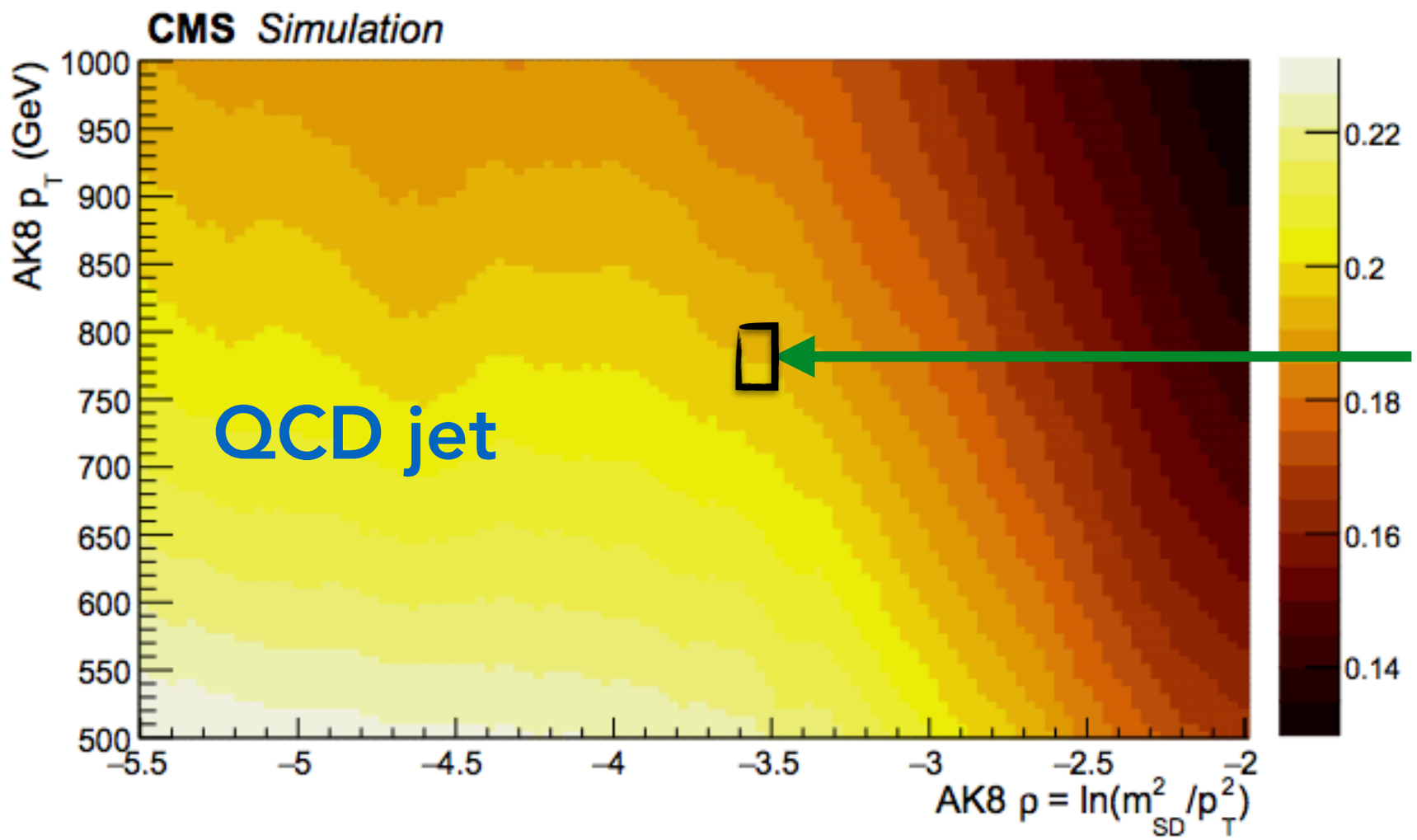

**Energy Correlation Functions:** correlate particles inside jet

$$N_2(\beta) = \frac{{}_2e_3^{\beta}}{(e_2^{\beta})^2}$$



- Will sculpt mass distribution after selection



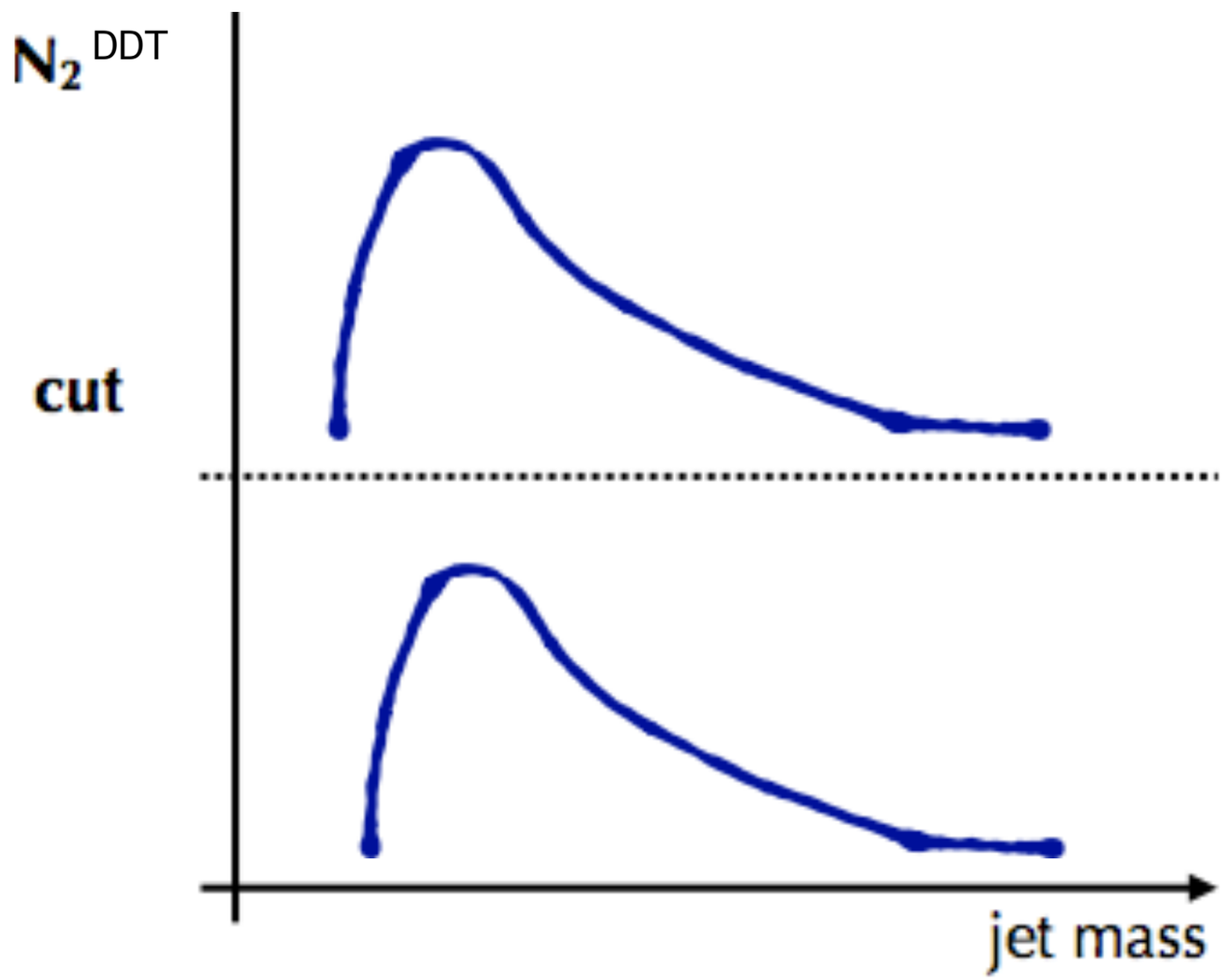



Each bin in pT and ρ:
$N_2^1$ 5% quantile value

Decorrelate from jet mass and pT:

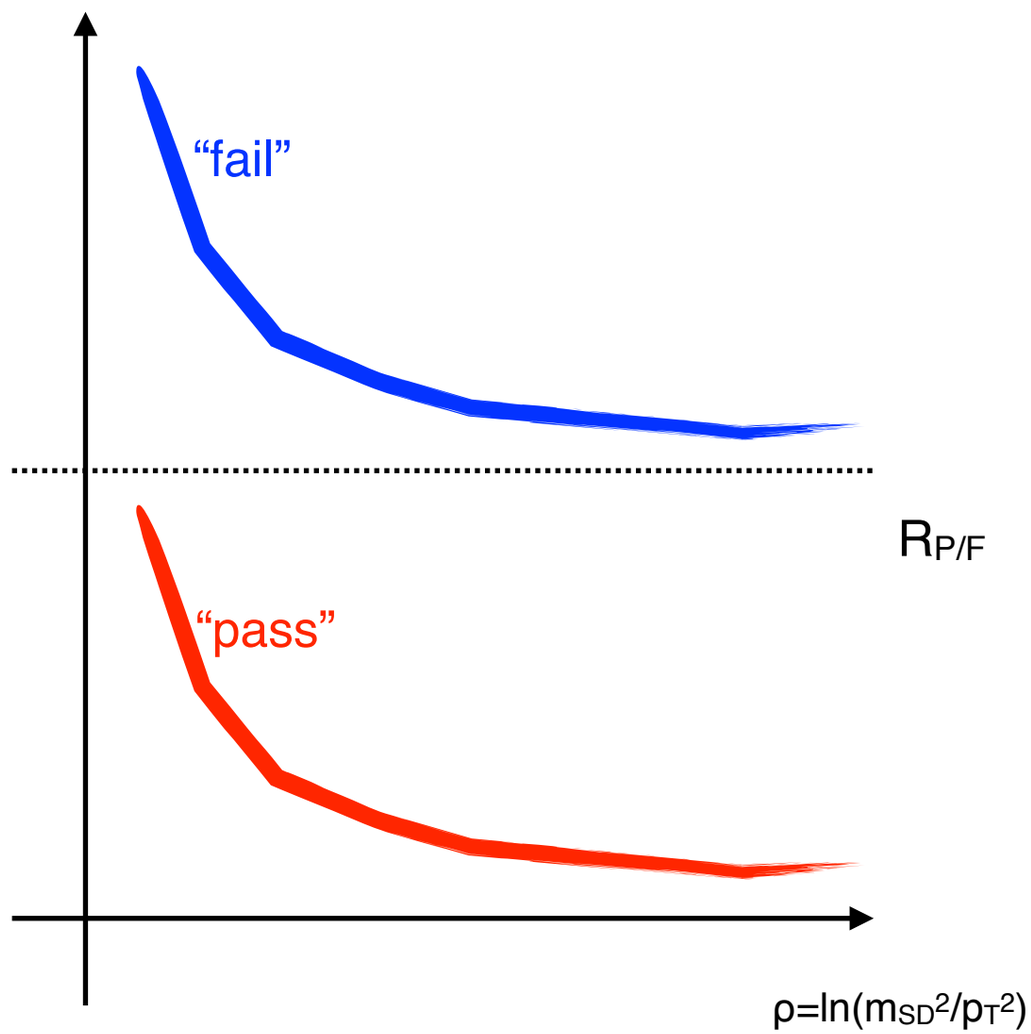
$$N_2^{DDT} = N_2 - N_2(\varepsilon_{QCD})$$

- NO sculpt mass distribution after selection



# Jet substructure: $N_2(1)^{DDT}$

- Defines:




FAIL: $N_2^{DDT} > 0$

PASS: $N_2^{DDT} < 0$