Search for low mass resonances with CMS

Boosted Dijet + ISR at 13 TeV

CMS-PAS-EXO-17-001

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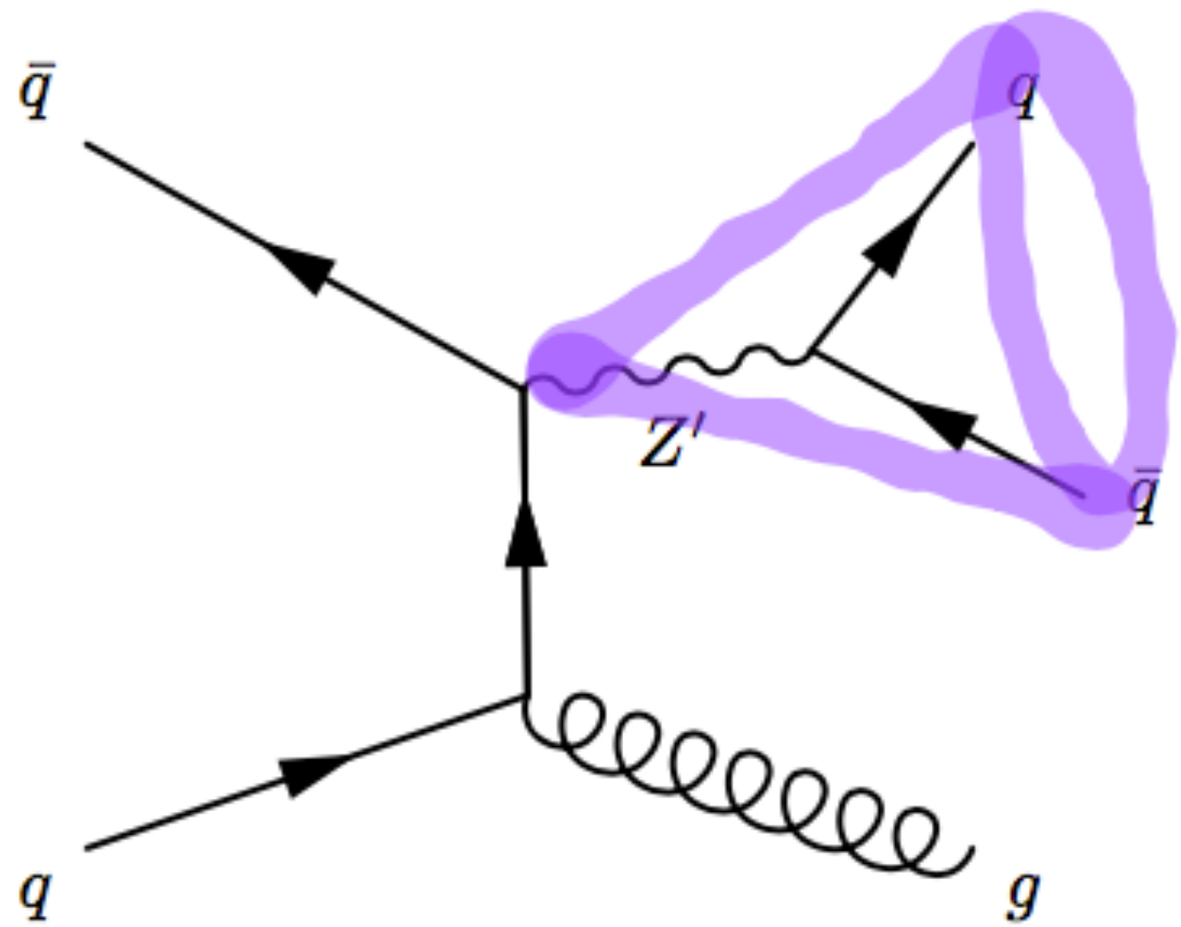
APS DIVISION OF PARTICLES AND FIELDS
FNAL

Low mass hidden resonances?

BOOSTED JET



ISR JET

to get above trigger thresholds

The strategy:

(1) Identify 2-prong signal in the jet

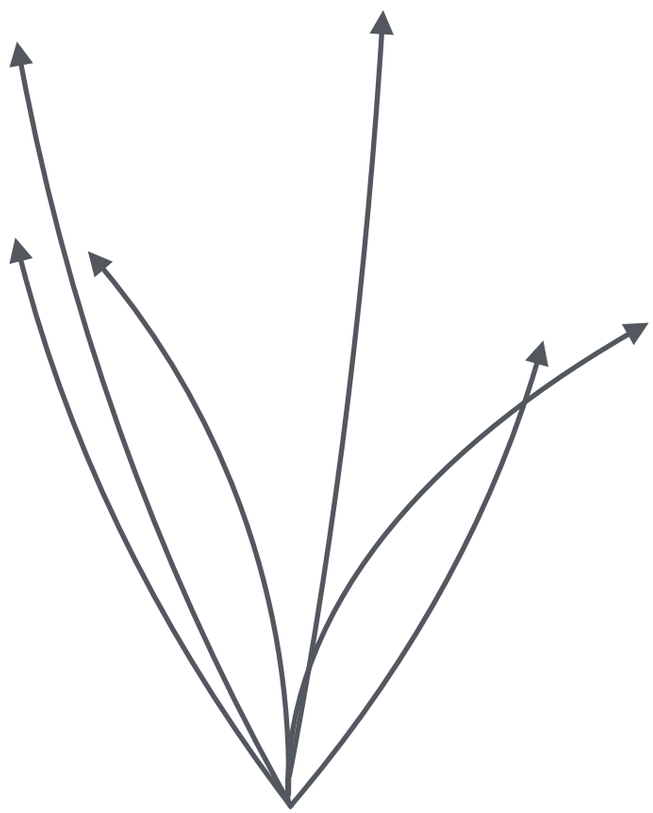
- Jet mass
- Jet substructure: N_2^{DDT}

(2) Estimate background and extract signal

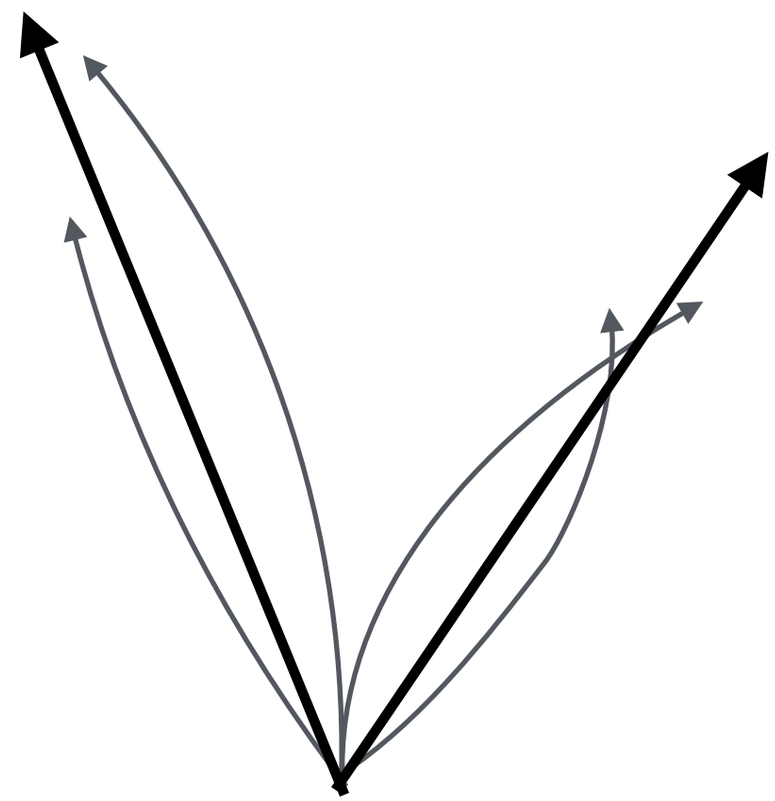
NOT a typical bump hunt

(1) Identify 2-prong signal in the jet

QCD jet



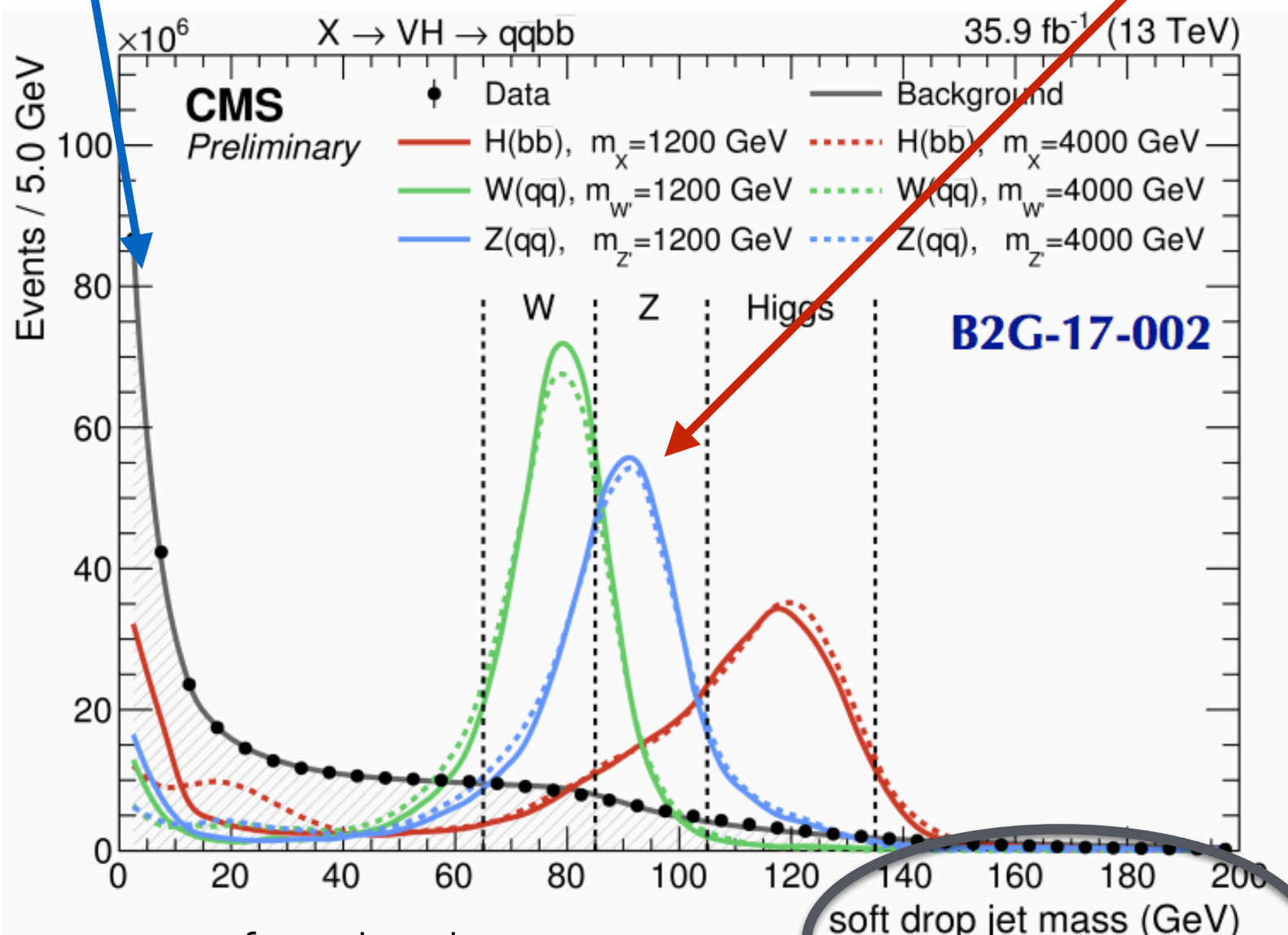
2-prong jet



Jet mass

QCD jet

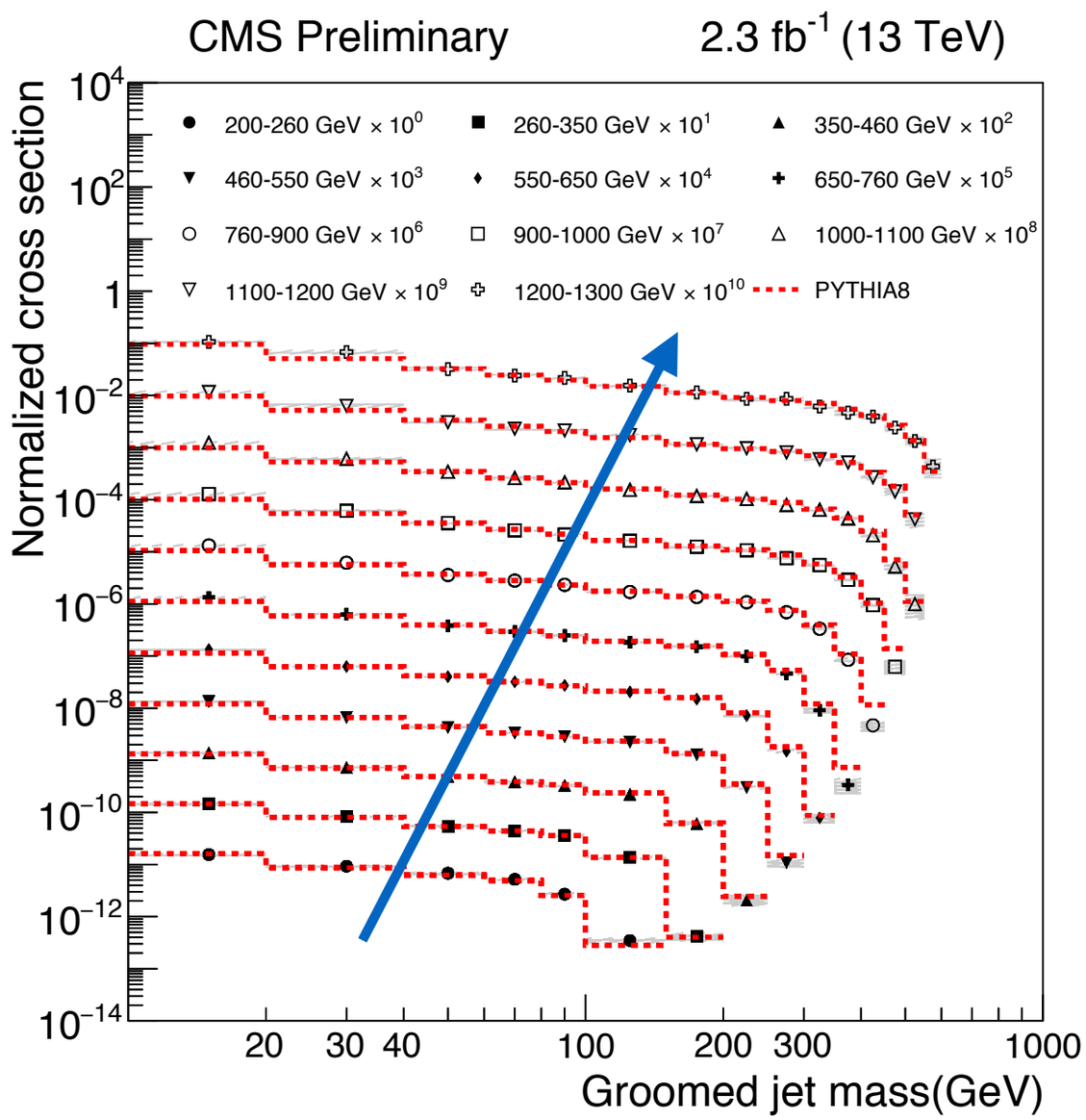
2-prong jet



Grooming removes soft and wide angle radiation

Jet mass

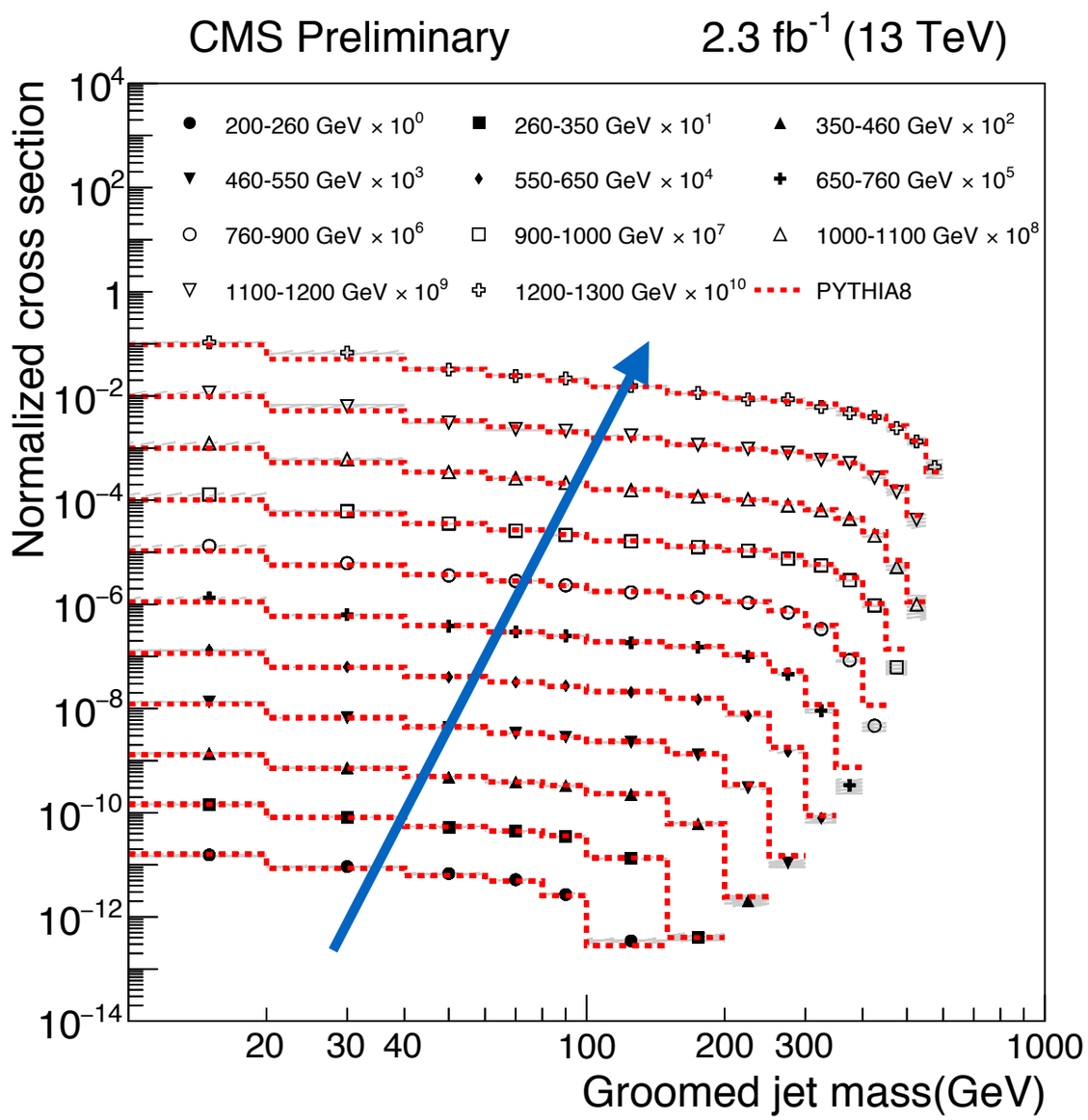
QCD jet



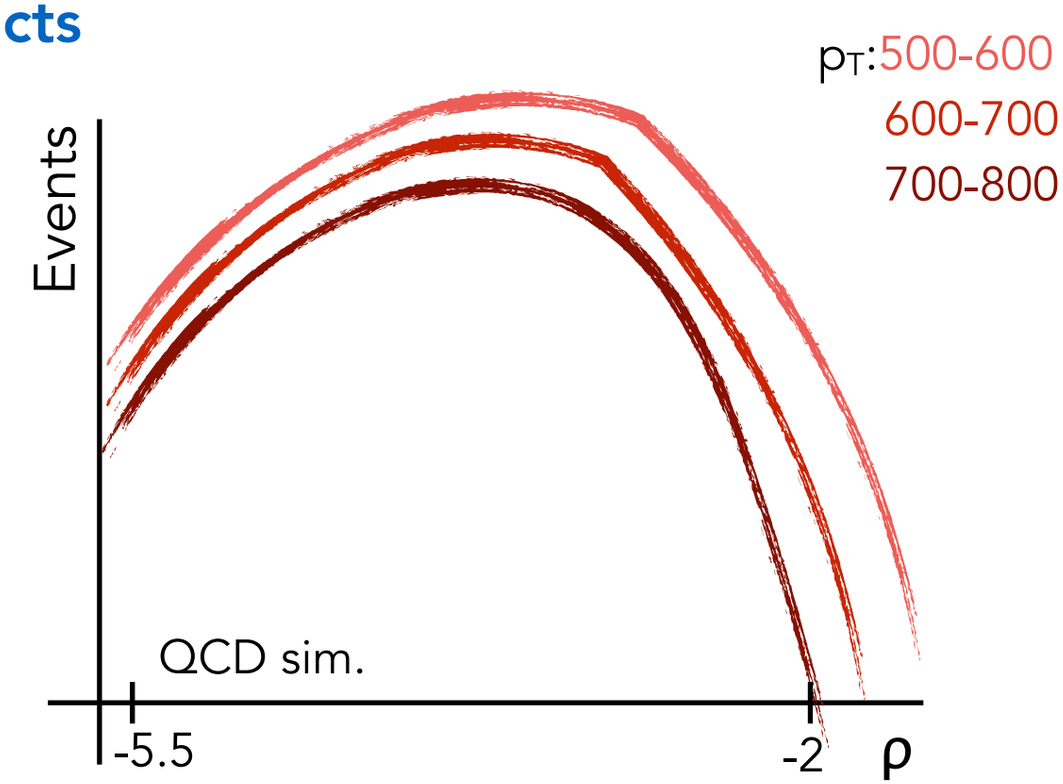
Jet mass depends on jet pT

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: $30<m_{SD}<180$

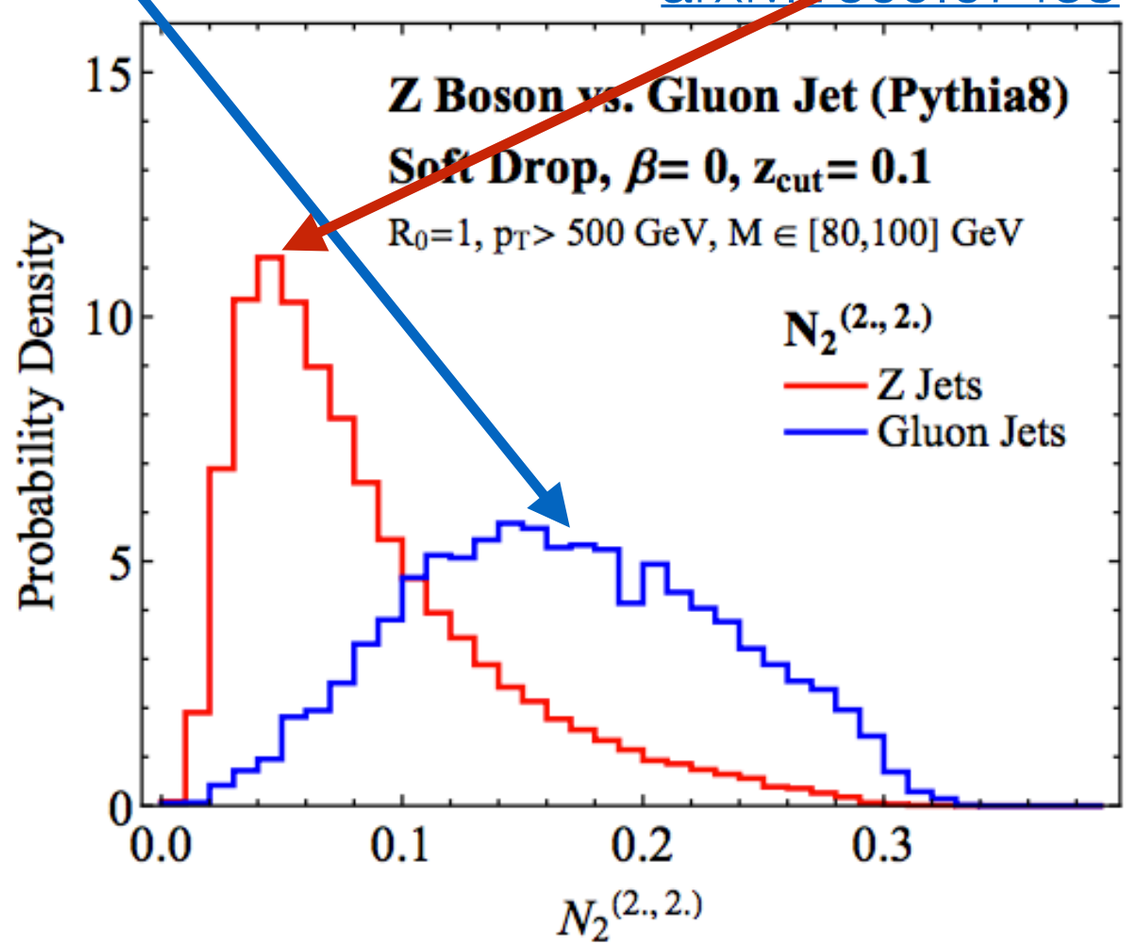
Jet substructure: $N_2(1)$

QCD jet

2-prong jet

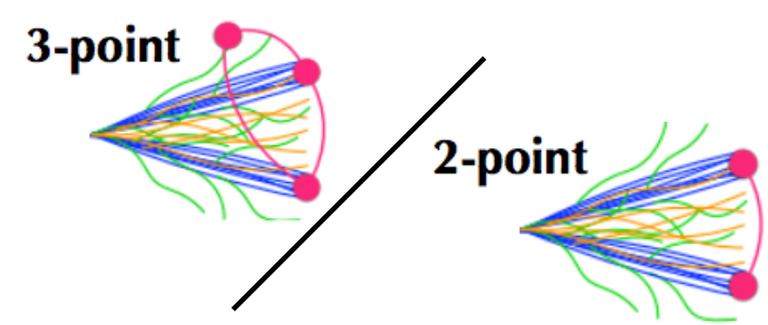
arxiv.1609.07483

We make a selection with 5% background efficiency

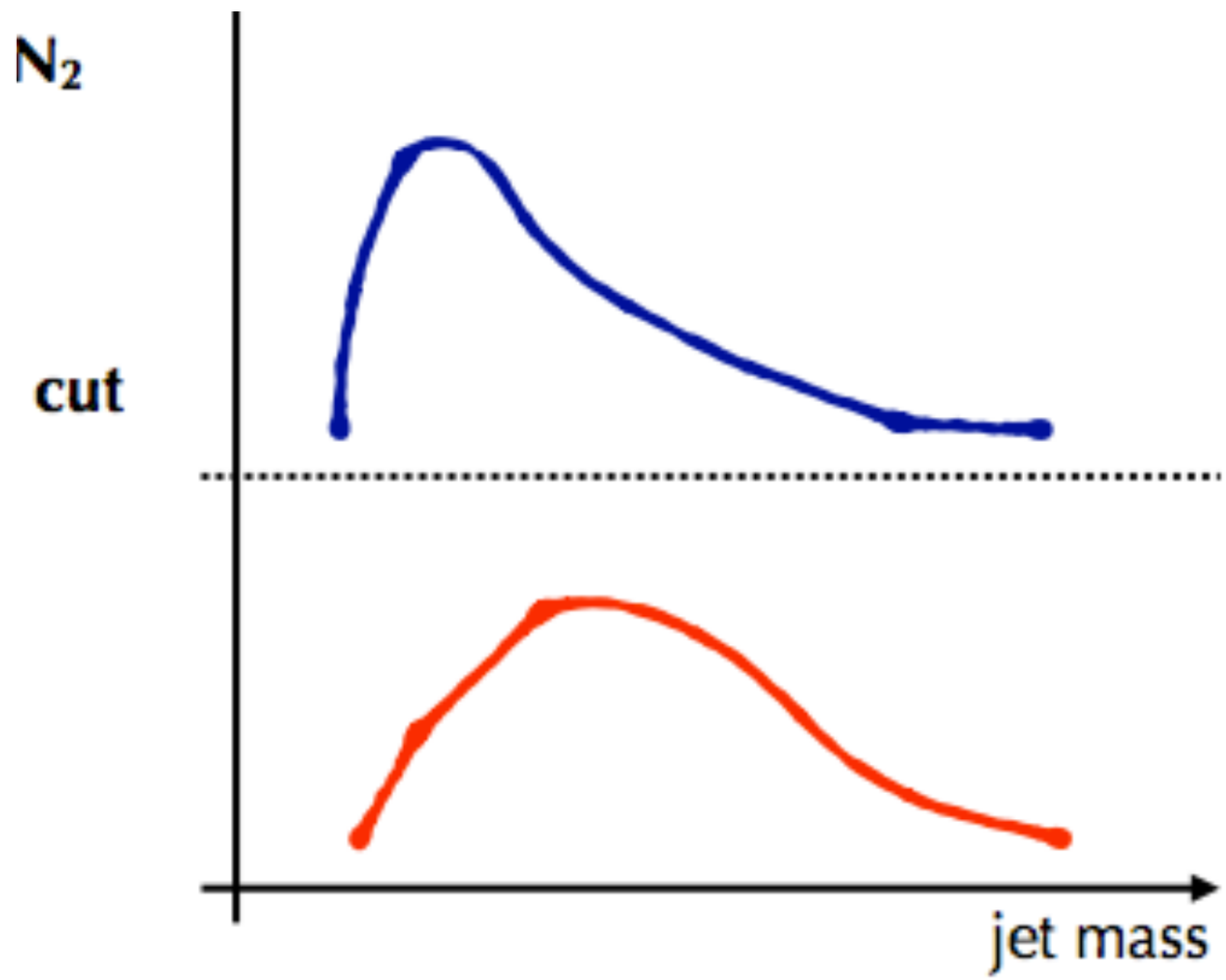


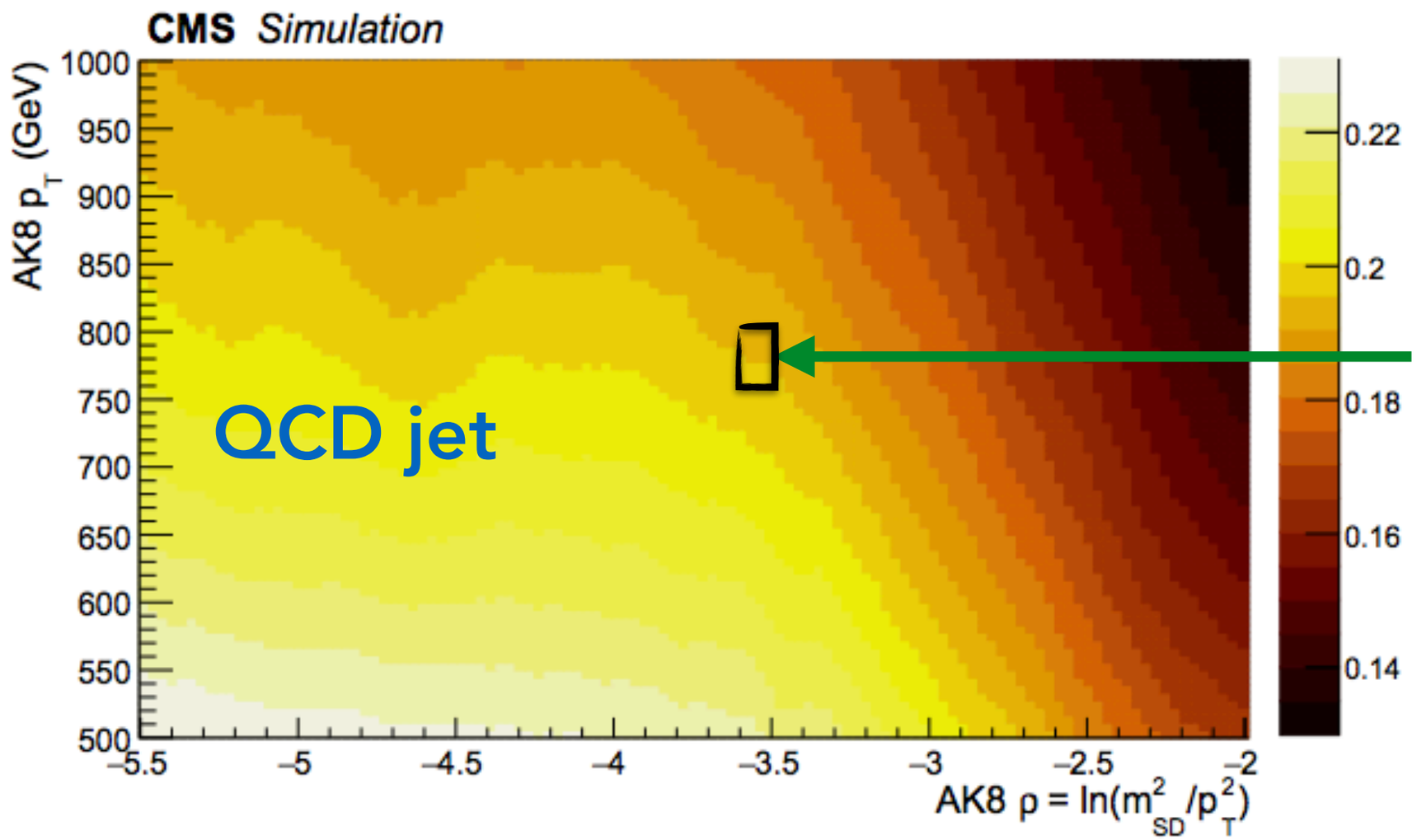
Energy Correlation Functions: correlate particles inside jet

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



- Will sculpt mass distribution after selection



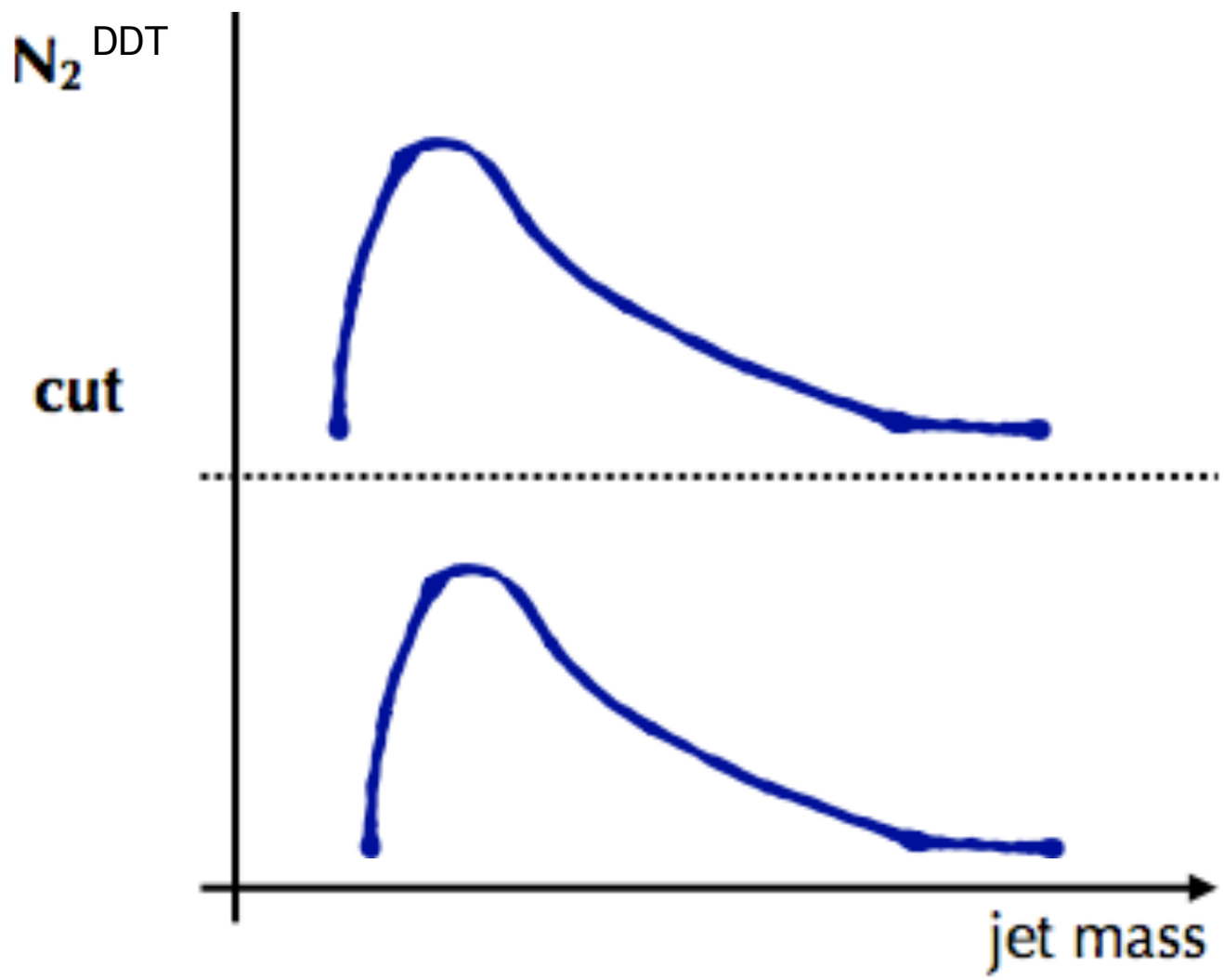


Each bin in pT and ρ:
N_2^1 5% quantile value

Decorrelate from jet mass and pT:

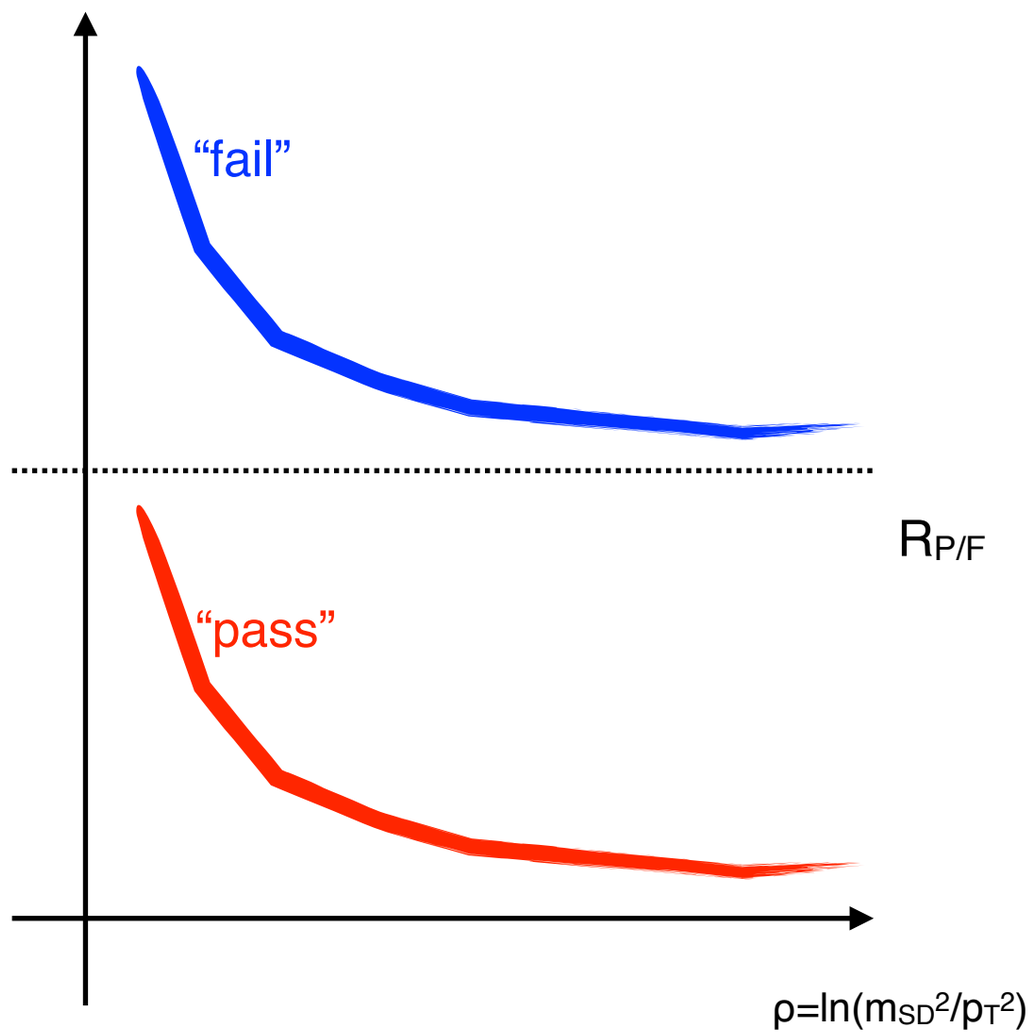
$$N_2^{DDT} = N_2 - N_2(\varepsilon_{QCD})$$

- NO sculpt mass distribution after selection



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

- Defines:



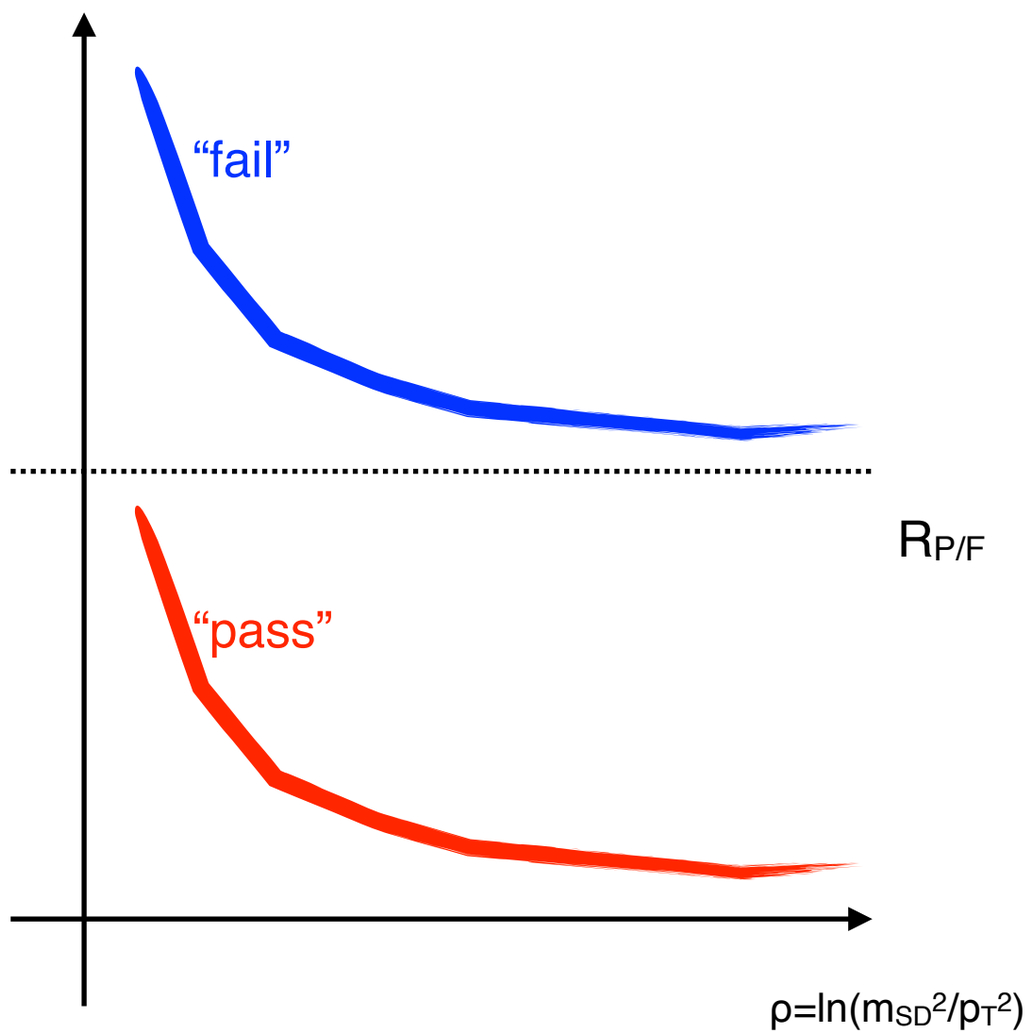
FAIL: $N_2^{DDT} > 0$

PASS: $N_2^{DDT} < 0$

(2) Estimate background and extract signal

- Cutting on a variable gives us another advantage:

$$\mathbf{Pass_{QCD}} = \frac{\mathbf{Pass}}{\mathbf{Fail}} * \mathbf{Fail_{QCD}}$$



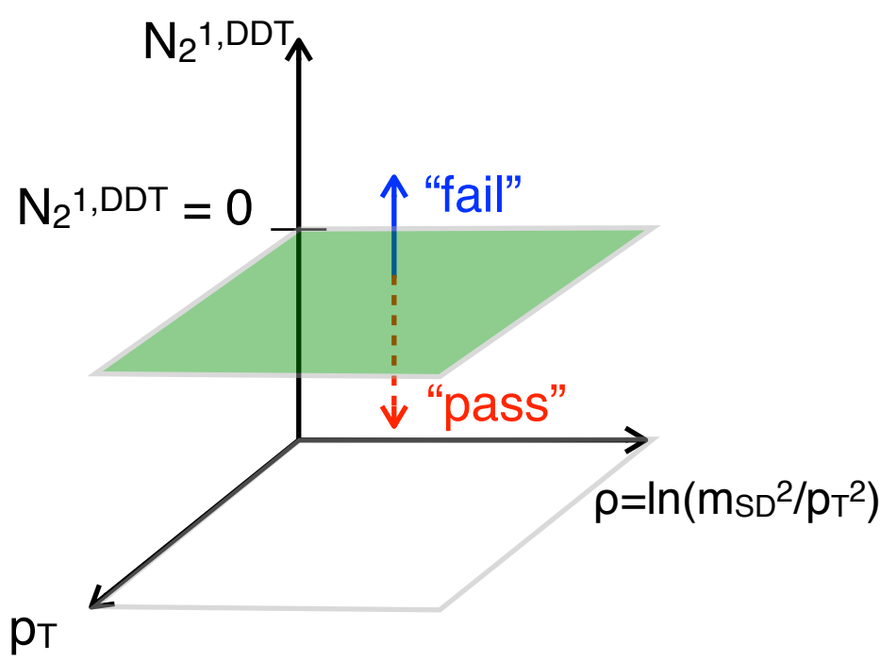
FAIL: $N_2^{DDT} > 0$

PASS: $N_2^{DDT} < 0$

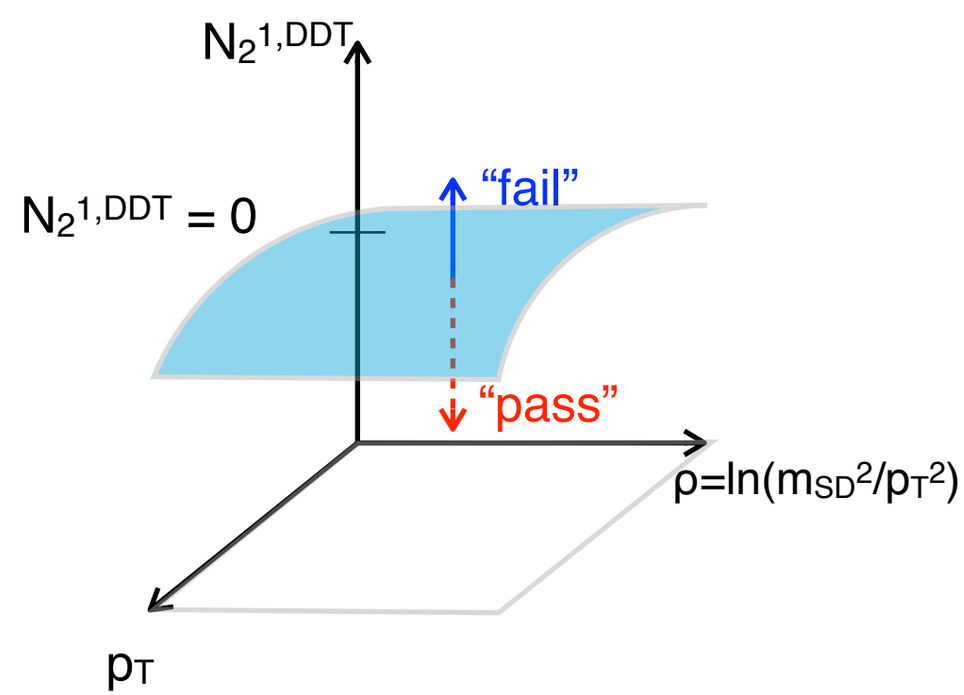
$R_{P/F}$ estimate

- Estimate Pass/Fail ratio $R_{P/F}$

if MC correct:



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



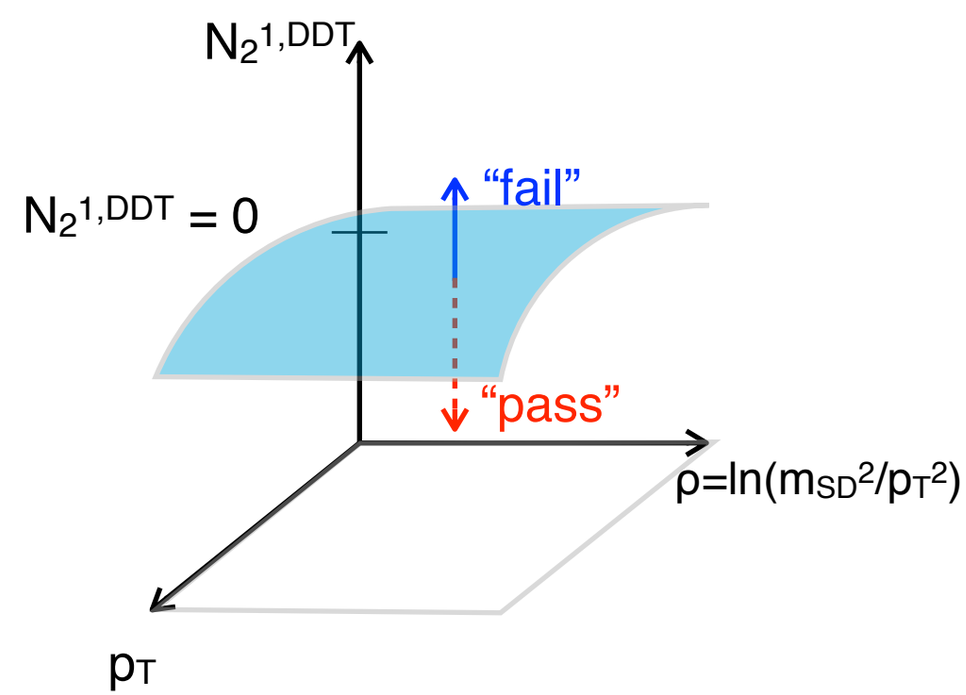
$R_{P/F}$ estimate

- Parametrize discrepancies by surface in ρ and p_T

$$p_{\text{pass}}^{\text{QCD}}(m_{SD}, p_T) = \mathcal{F}(\rho(m_{SD}, p_T), p_T) \times p_{\text{fail}}^{\text{QCD}}(m_{SD}, p_T)$$

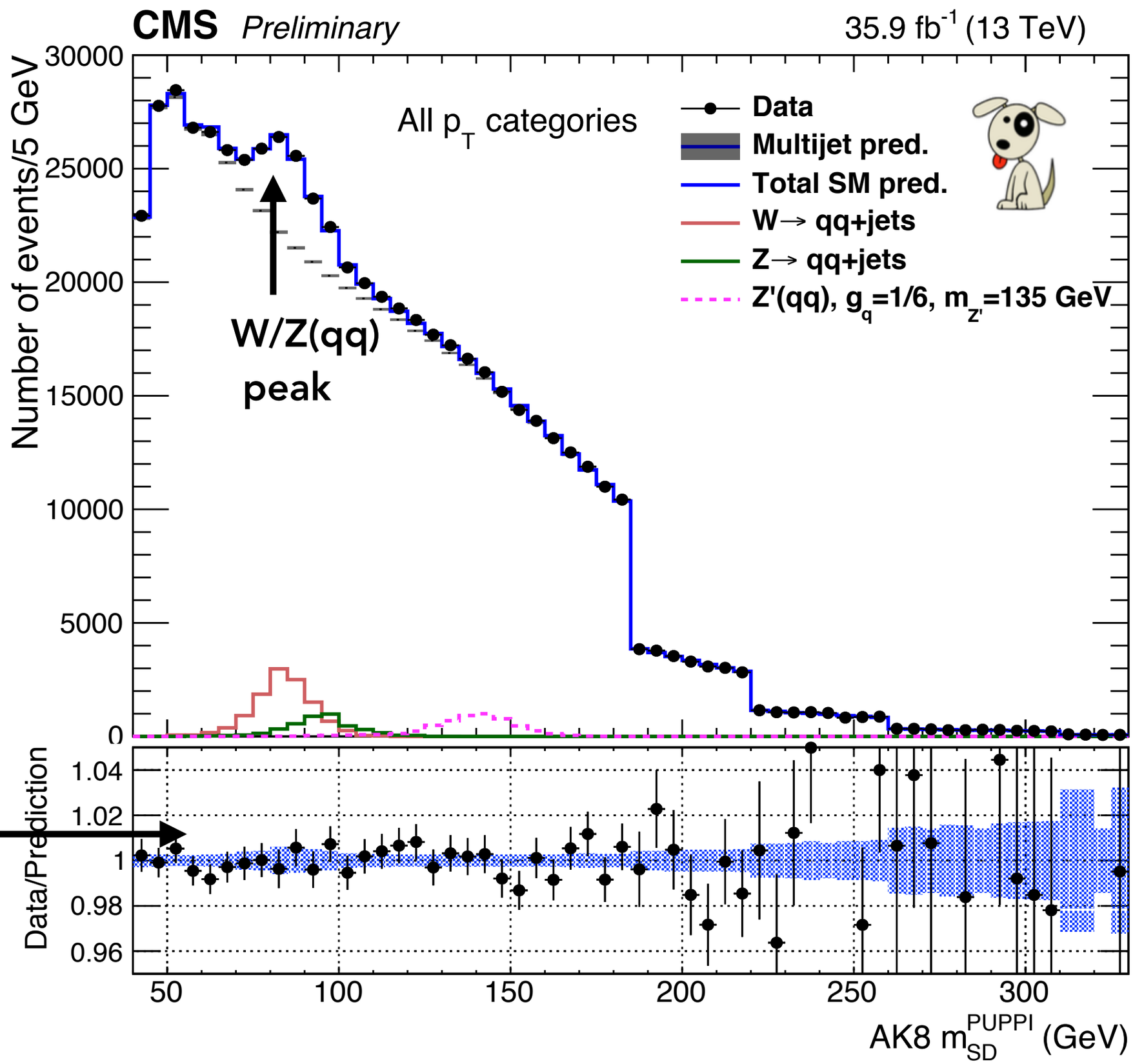
$$\begin{aligned}\mathcal{F}(\rho, p_T) = \epsilon_{\text{QCD}}(1 &+ a_{01}p_T + a_{02}p_T^2 + \cdots \\ &+ (a_{10} + a_{11}p_T + a_{12}p_T^2 + \cdots)\rho \\ &+ (a_{20} + a_{21}p_T + a_{22}p_T^2 + \cdots)\rho^2 + \cdots,\end{aligned}$$

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

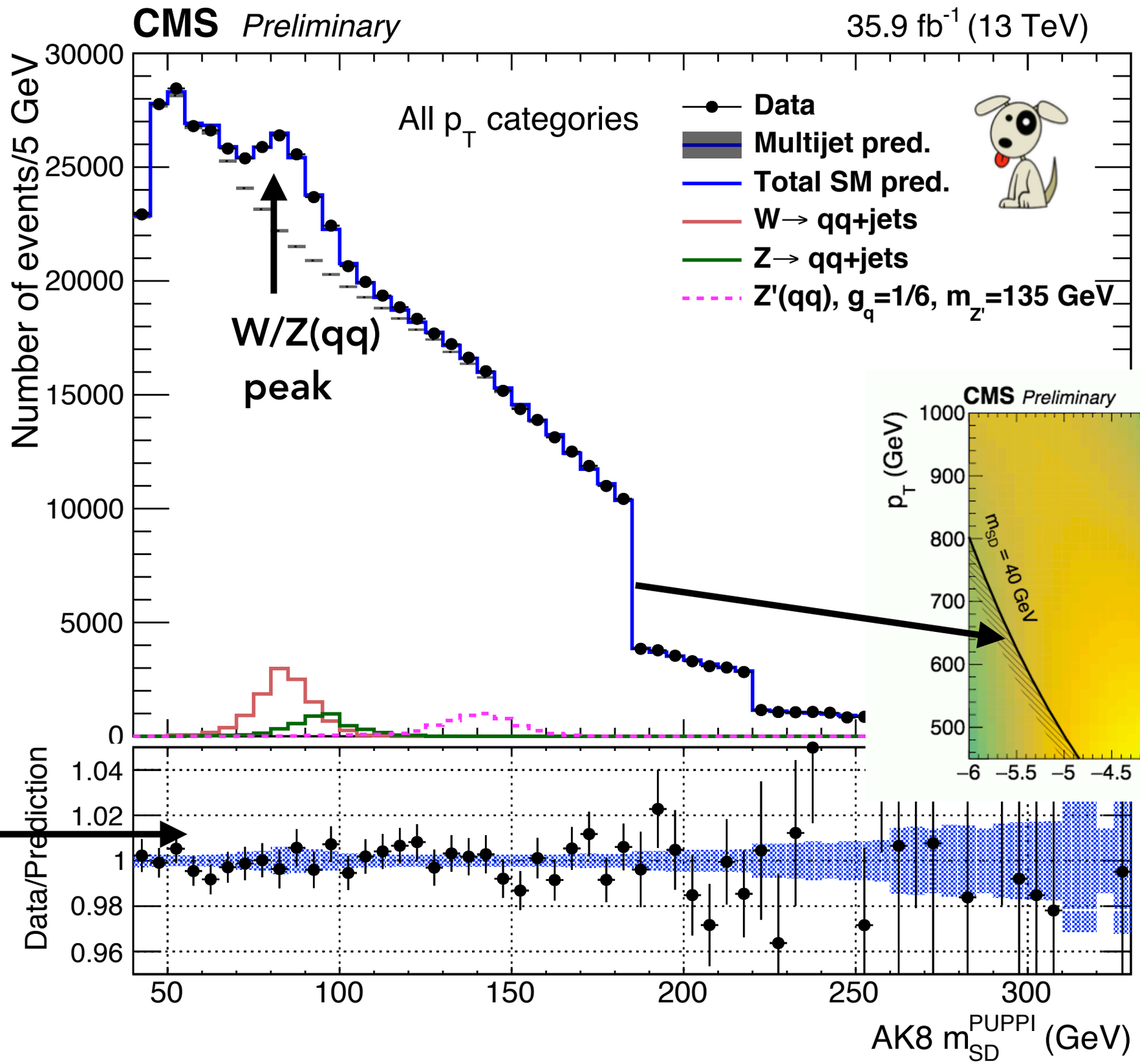


- Using 4th order in ρ and 3rd order in p_T

One simultaneous fit estimates $R_{P/F}$ and performs signal extraction


CMS Preliminary
35.9 fb^{-1} (13 TeV)
All p_T categories
Data
Multijet pred.
Total SM pred.
W→ qq+jets
Z→ qq+jets
Z'(qq), g_q=1/6, $m_{Z'}$=135 GeV
W/Z(qq) peak
Number of events/5 GeV
Data/Prediction
AK8 m_{SD}^{PUPPI} (GeV)

Fit at 7% σ unc.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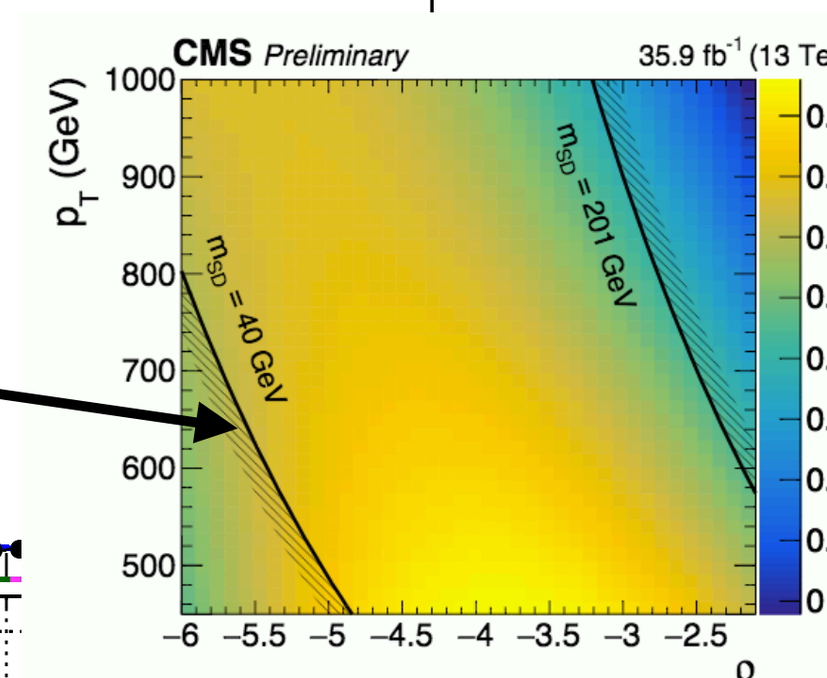
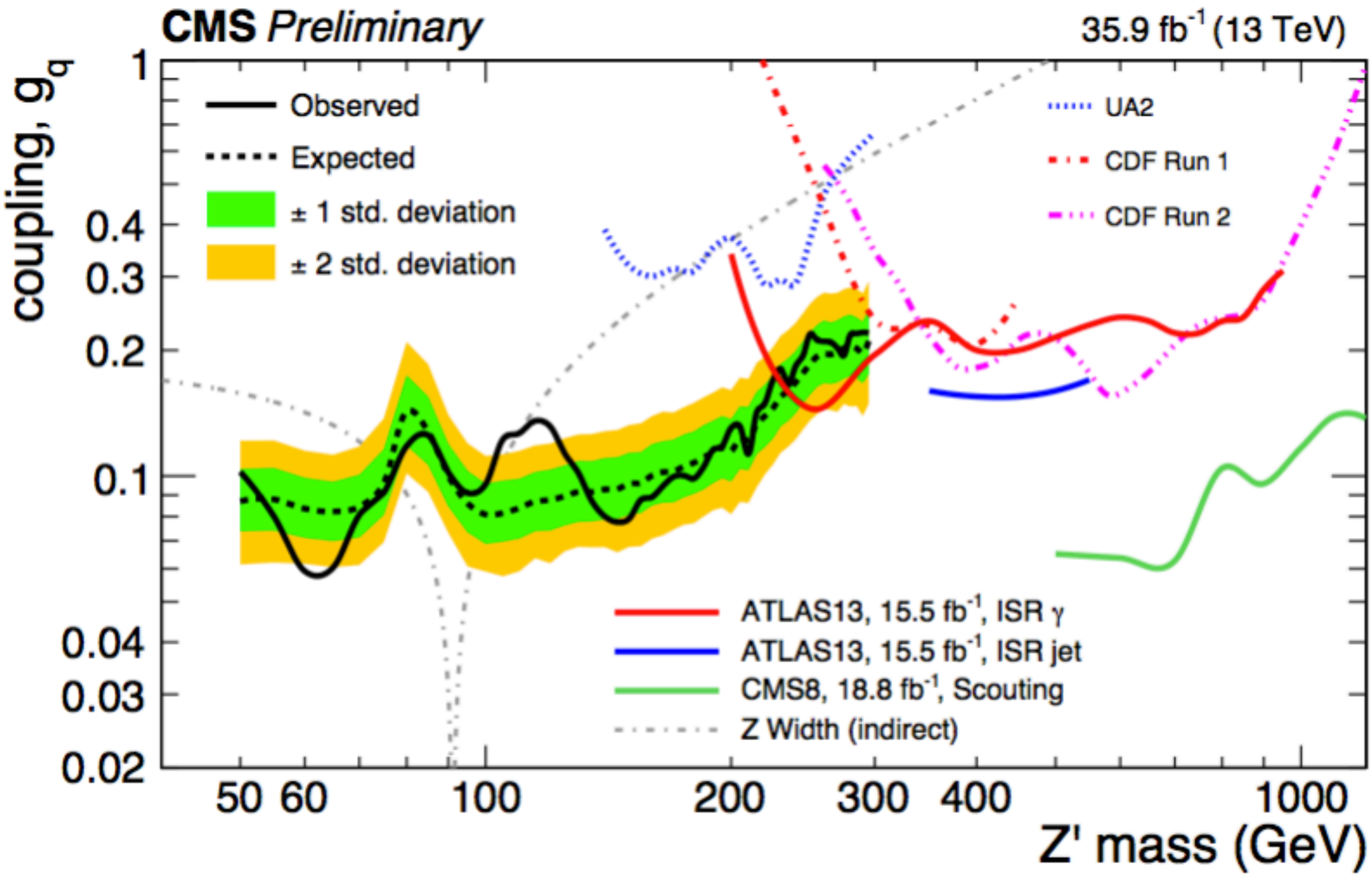
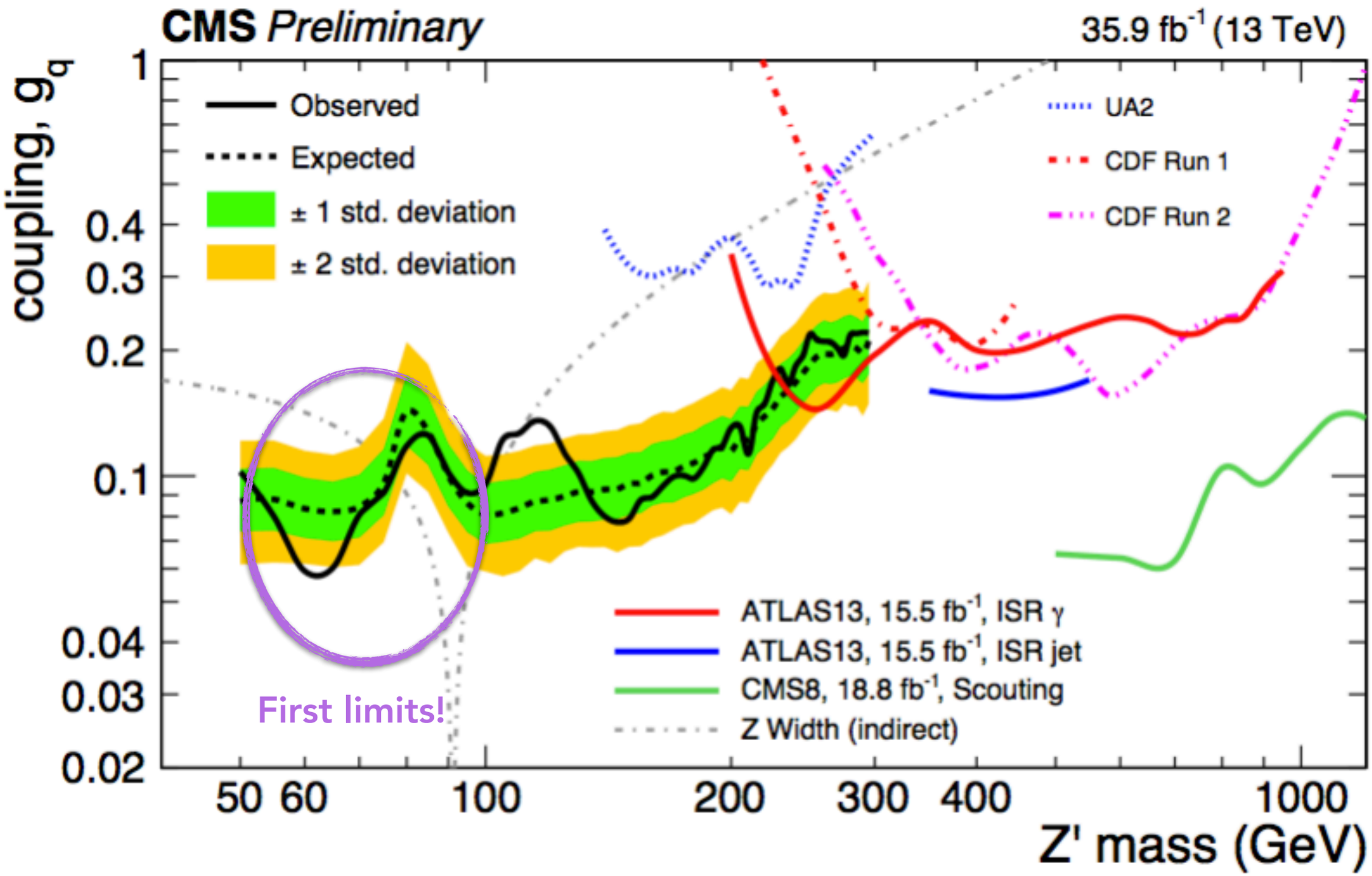

CMS Preliminary
35.9 fb^{-1} (13 Te
p_T (GeV)
m_{SD} = 40 GeV
m_{SD} = 201 GeV

Fit at 7% σ unc.

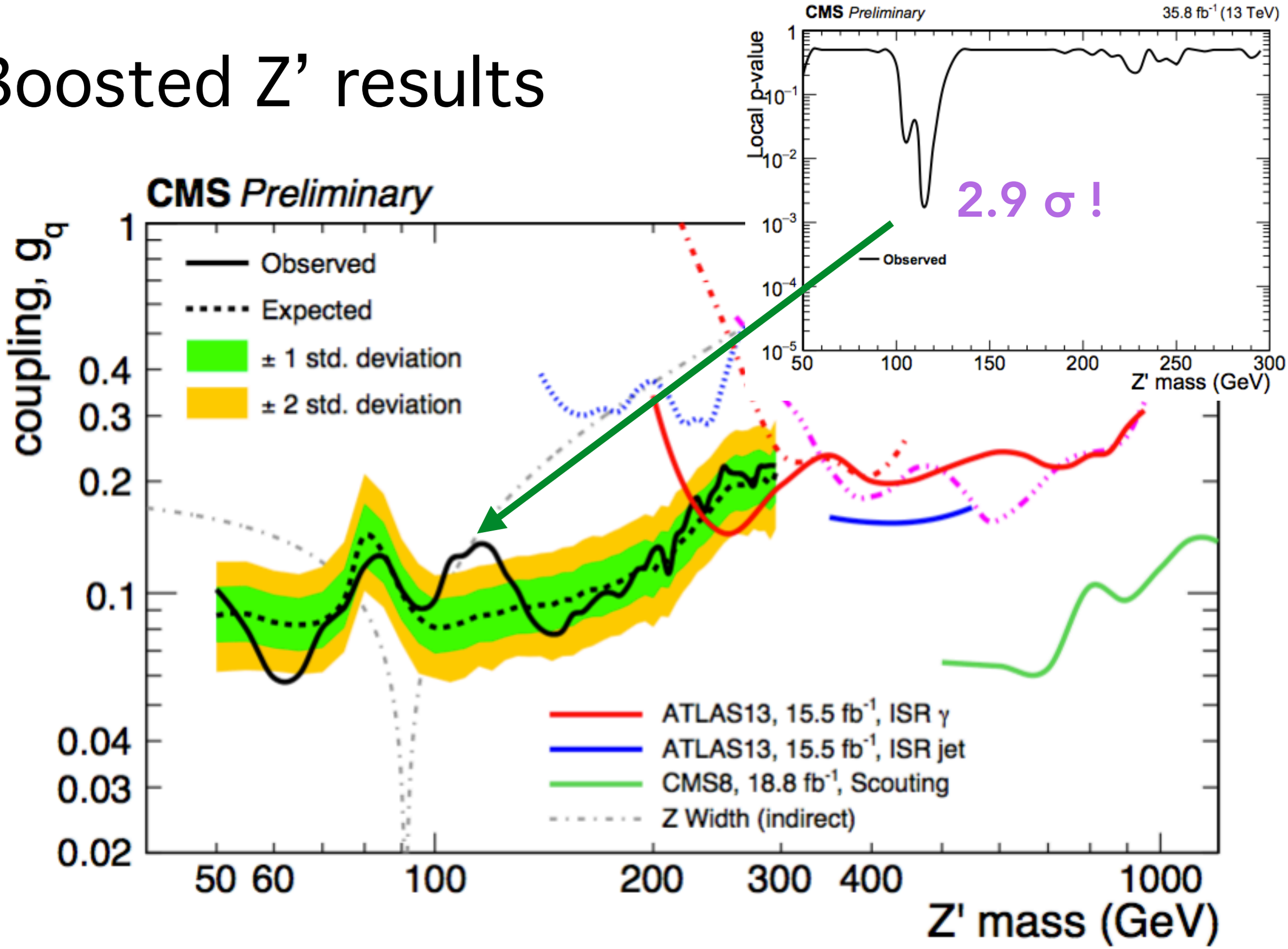
Boosted Z' results



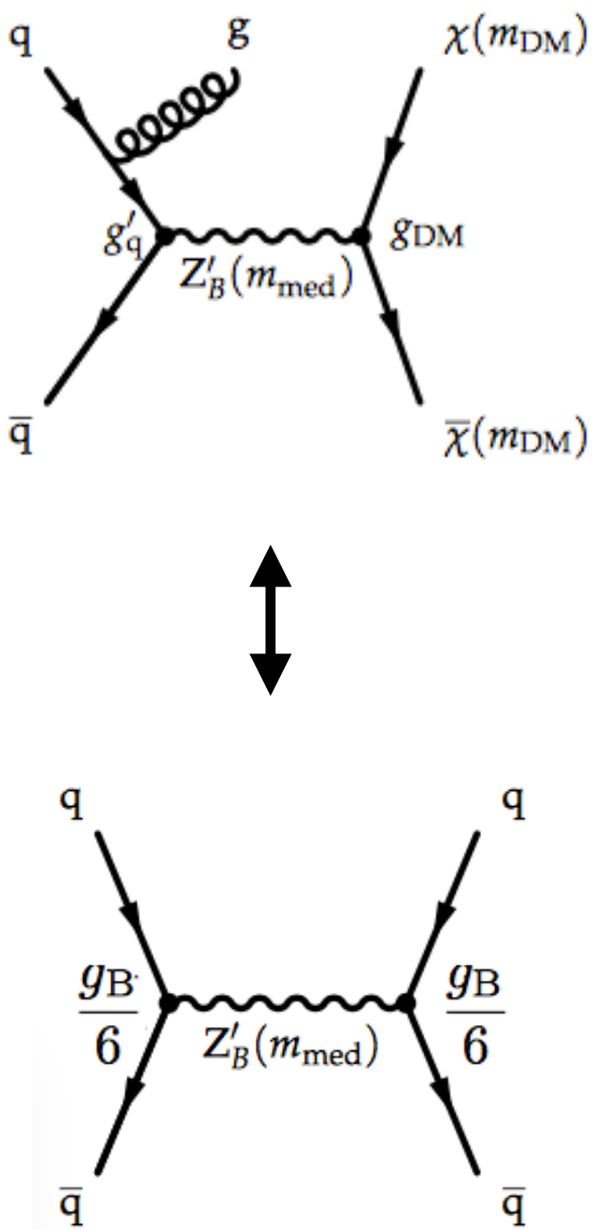
Boosted Z' results

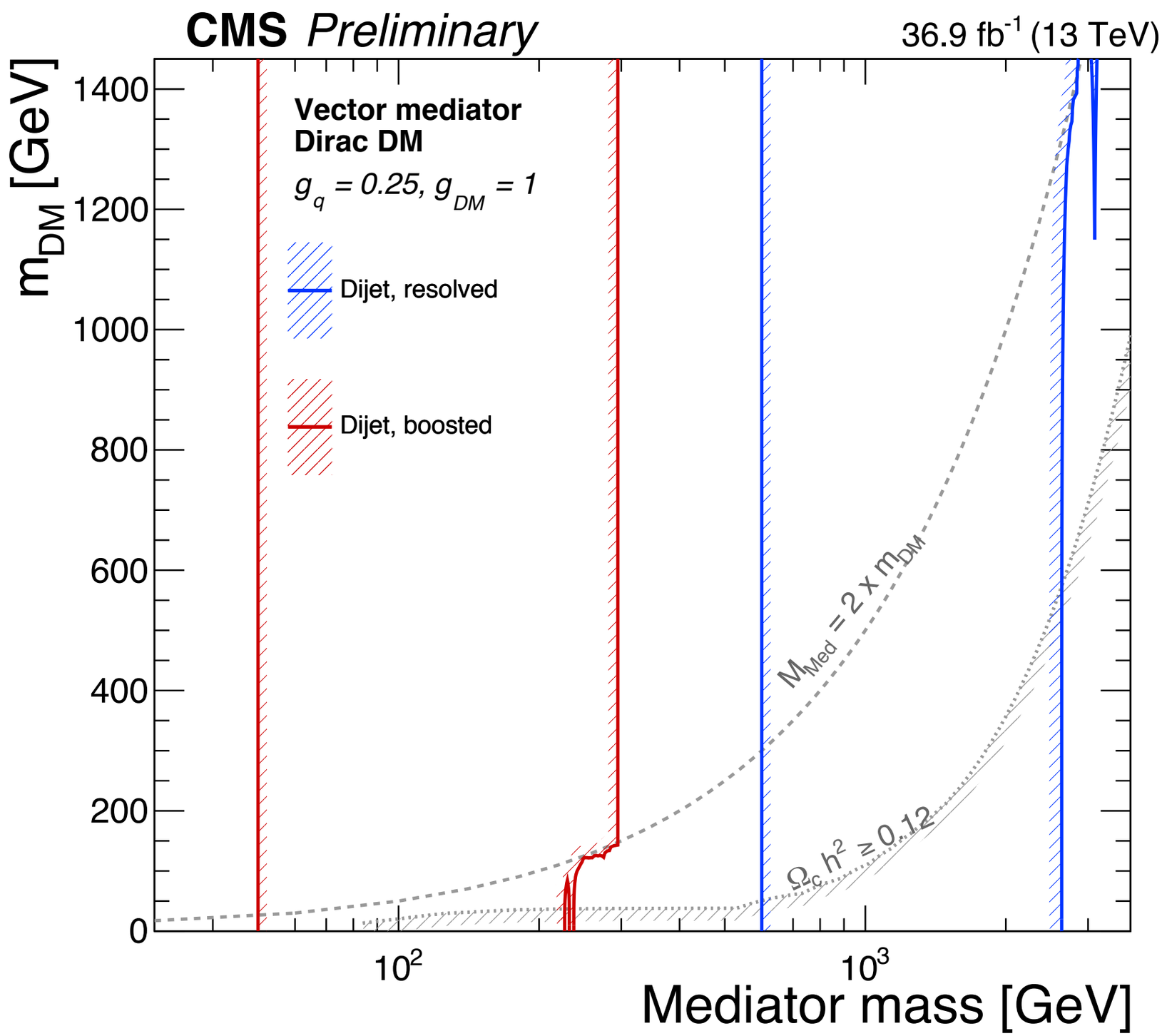


Boosted Z' results



DM connection

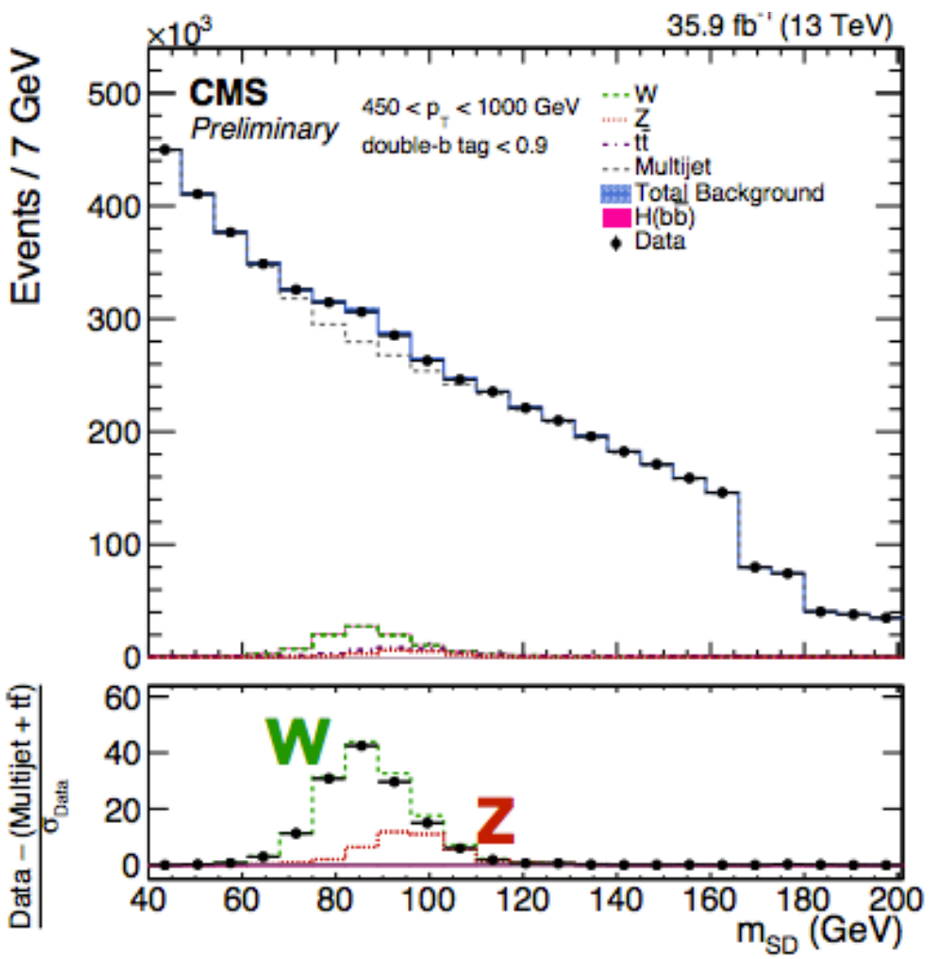


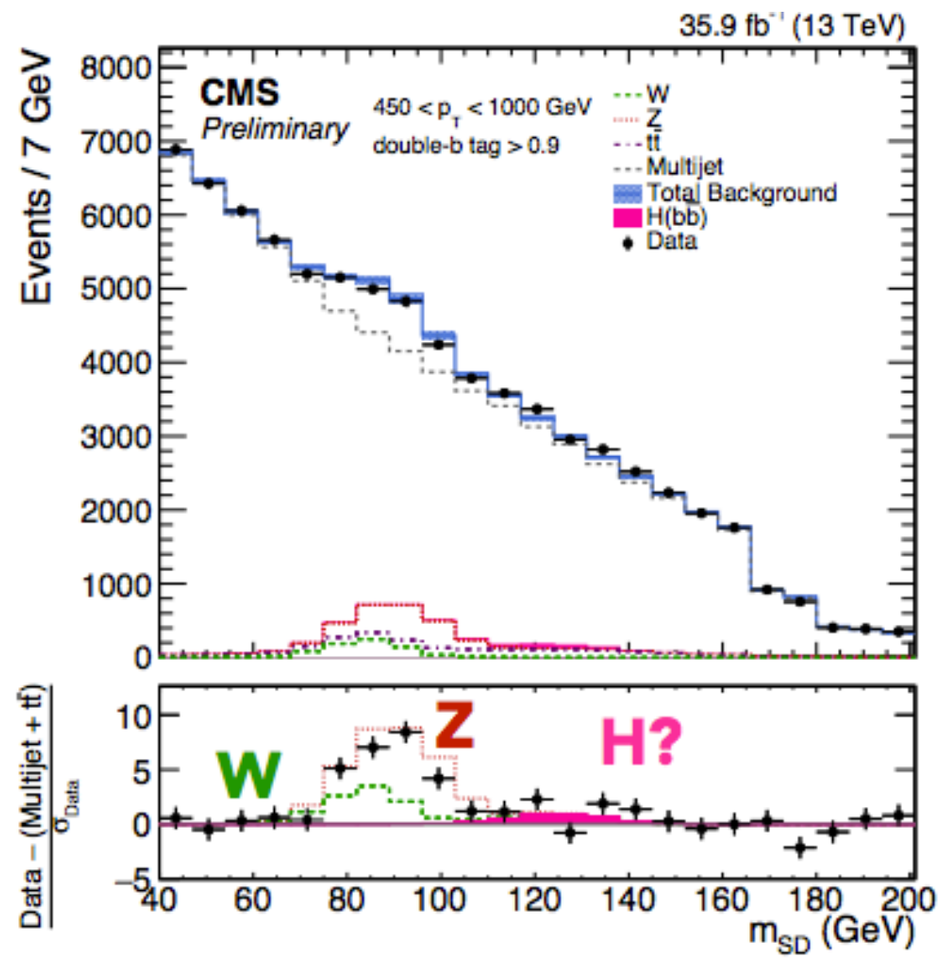


Summary

- Search extended to lower masses (below 100 GeV!)
- Novel background estimate and tagging techniques
- Program can be further extended: See Javier Duarte's slides DPF

CMS-HIG-17-010



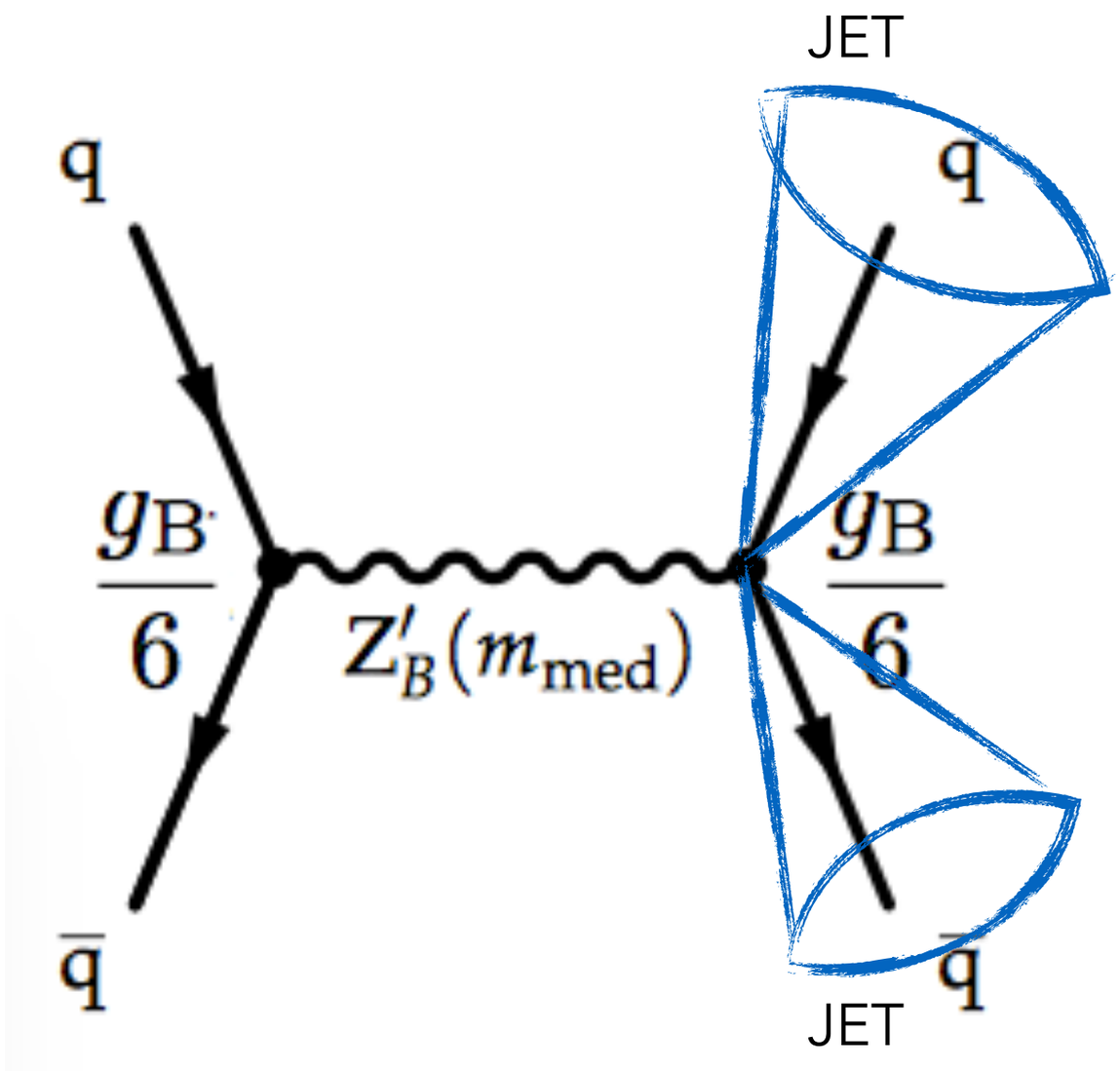


observed H(bb) significance:

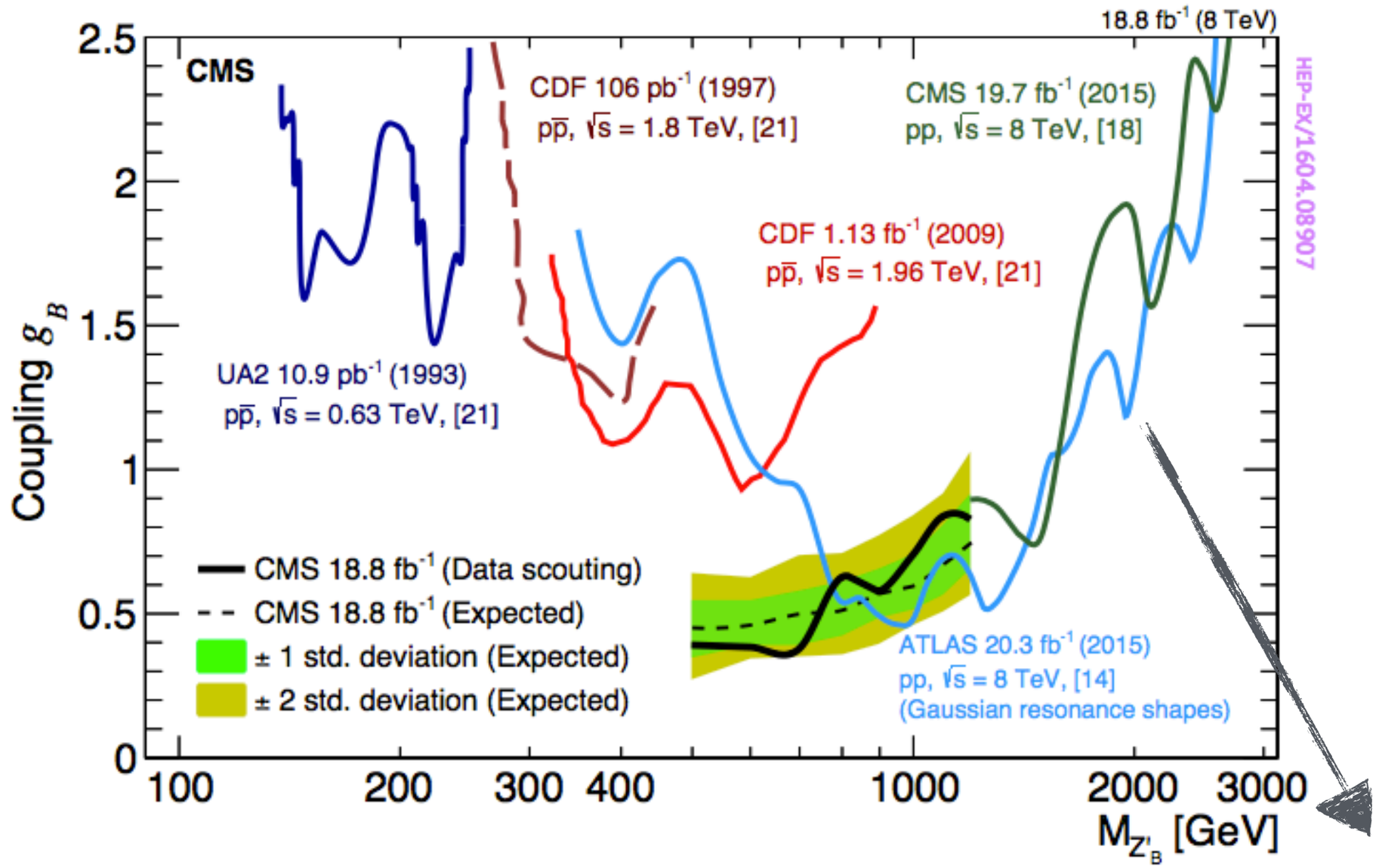
1.5σ, $\mu_H = 2.3^{+1.8}_{-1.6}$

Additional Material

From dijets:

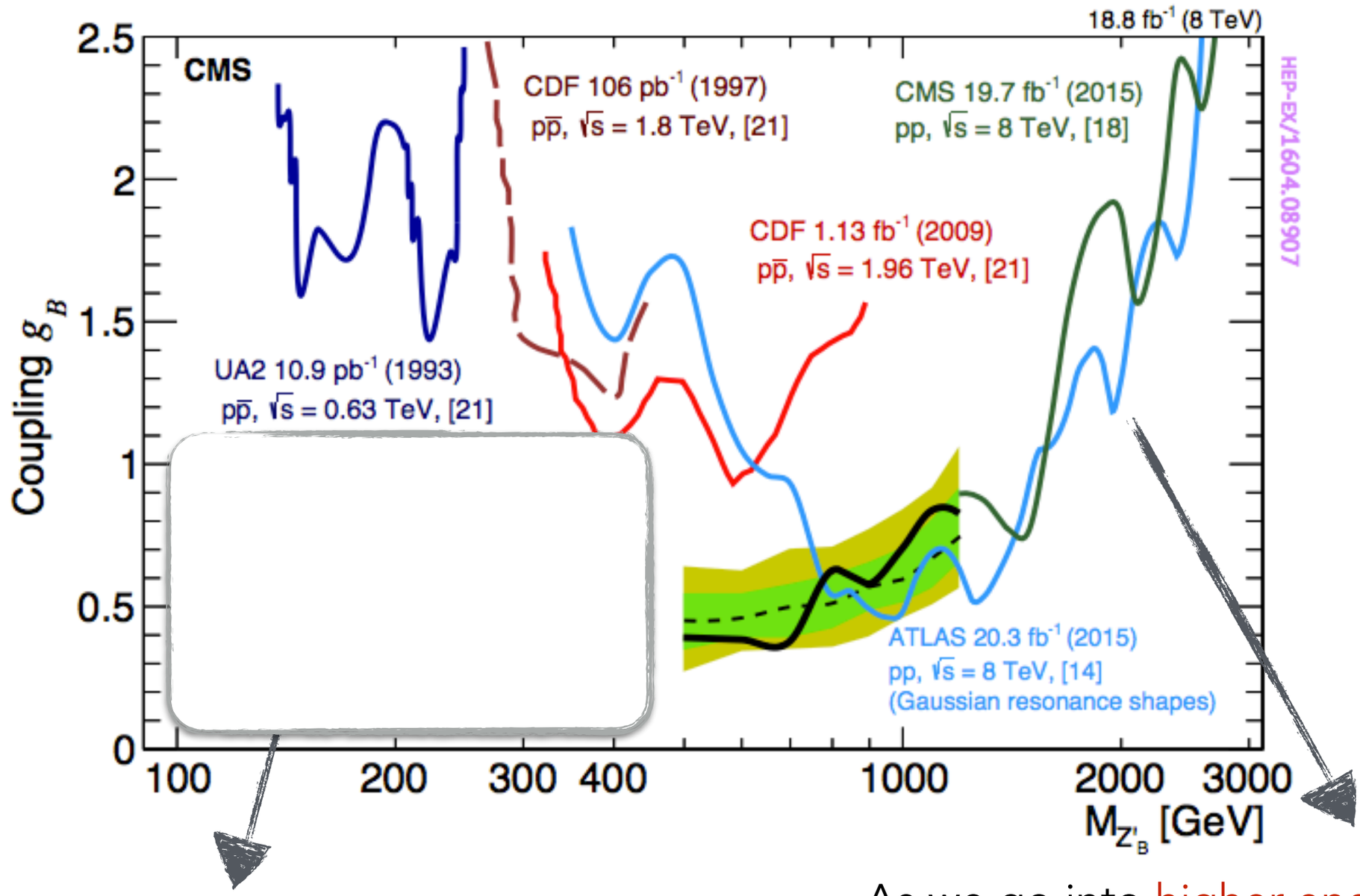


From dijets:



As we go into higher energies
(and more 13 TeV data)
we try to push to higher masses

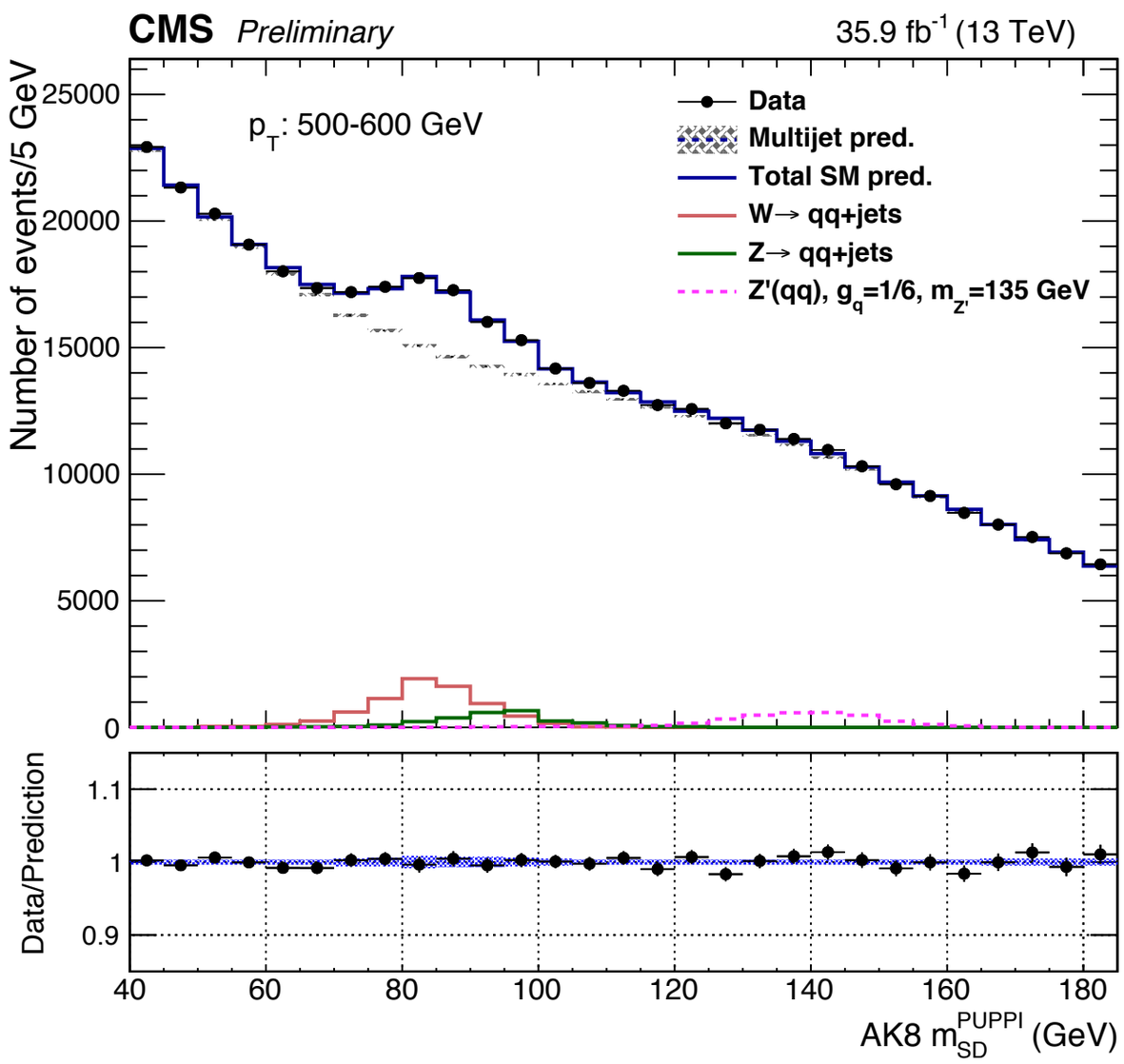
to low mass hidden resonances?

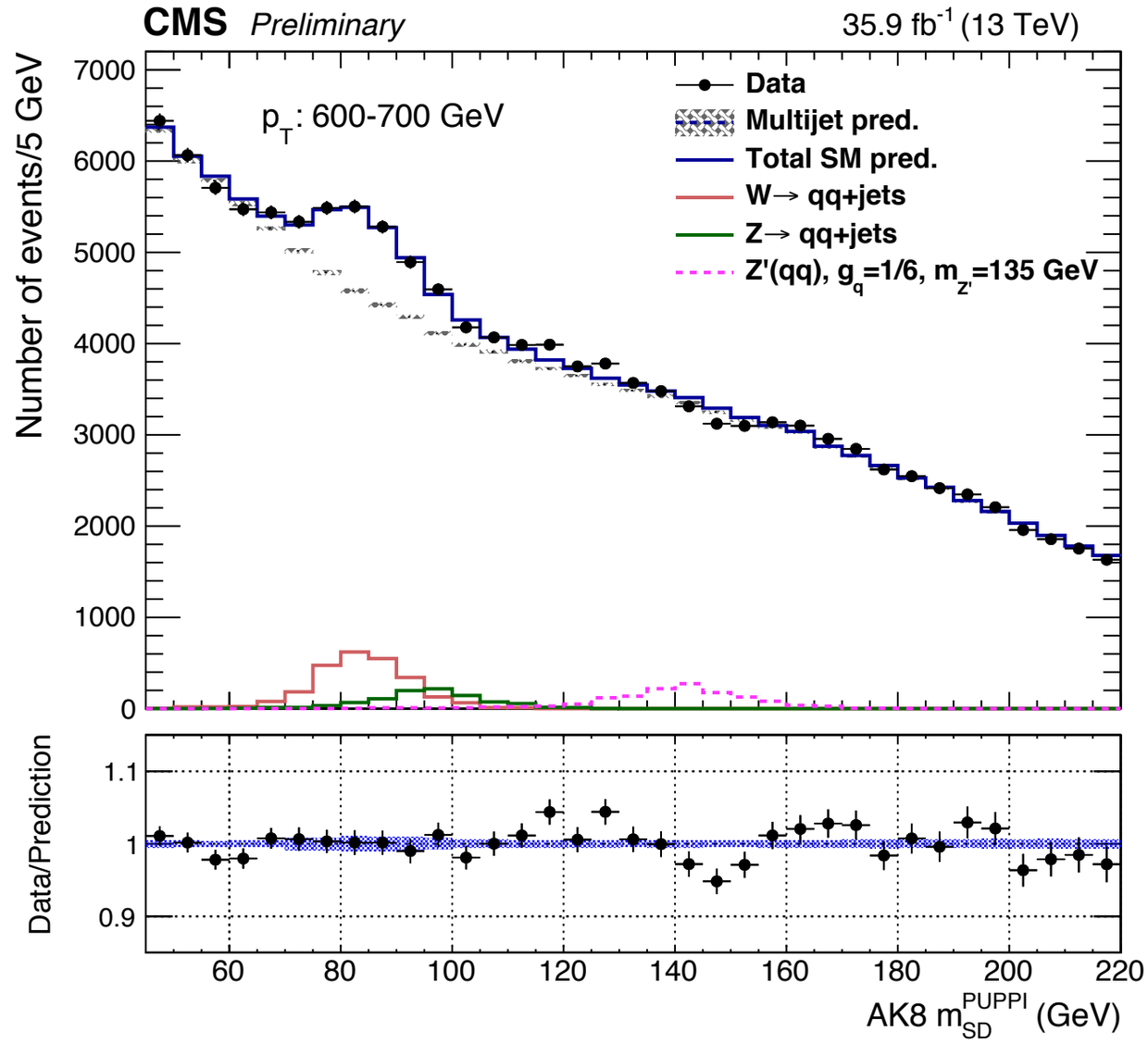


How can we go **lower in mass?**

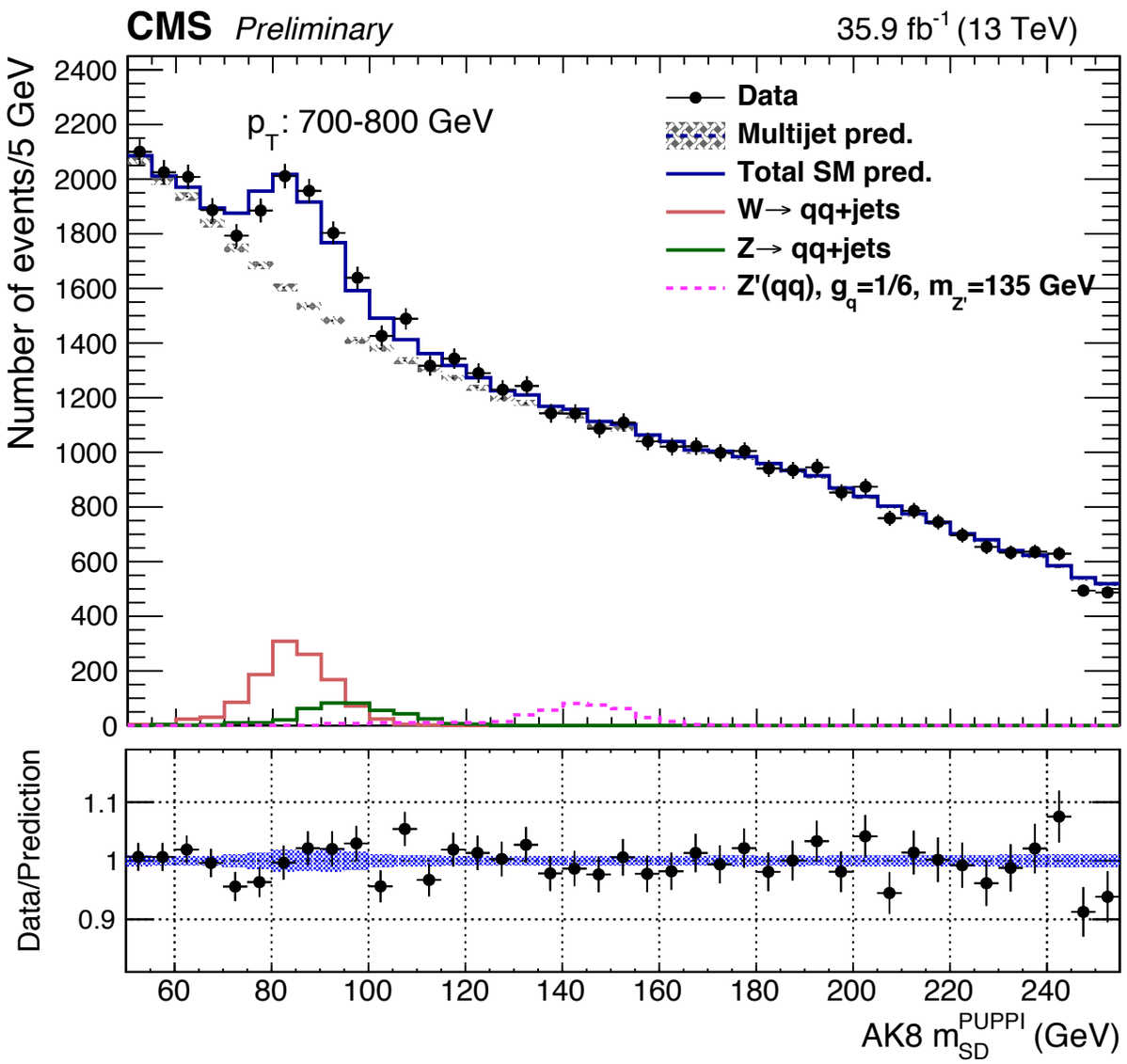
As we go into higher energies
(and more 13 TeV data)
we try to push to higher masses

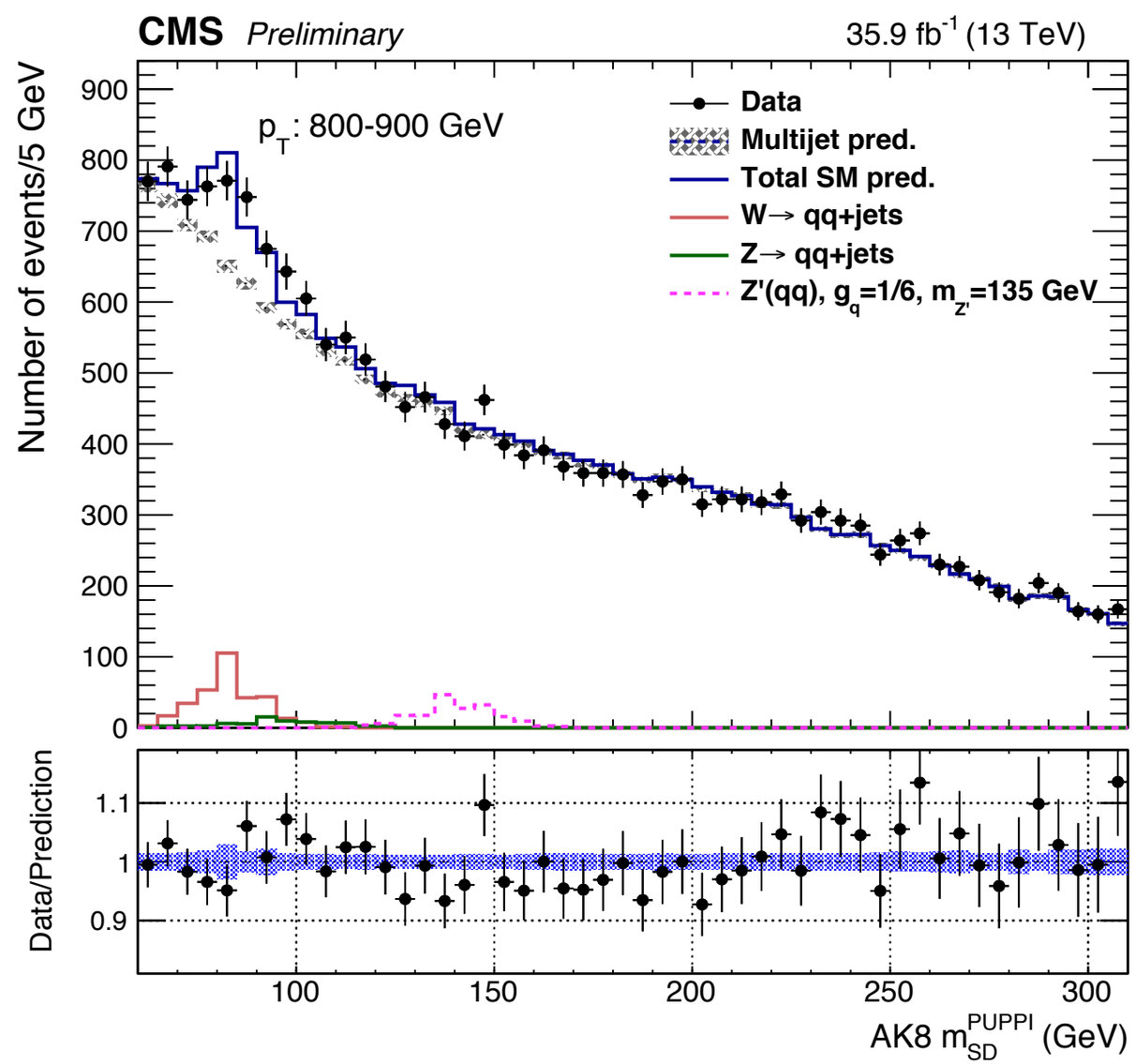
Jet mass by pT categories



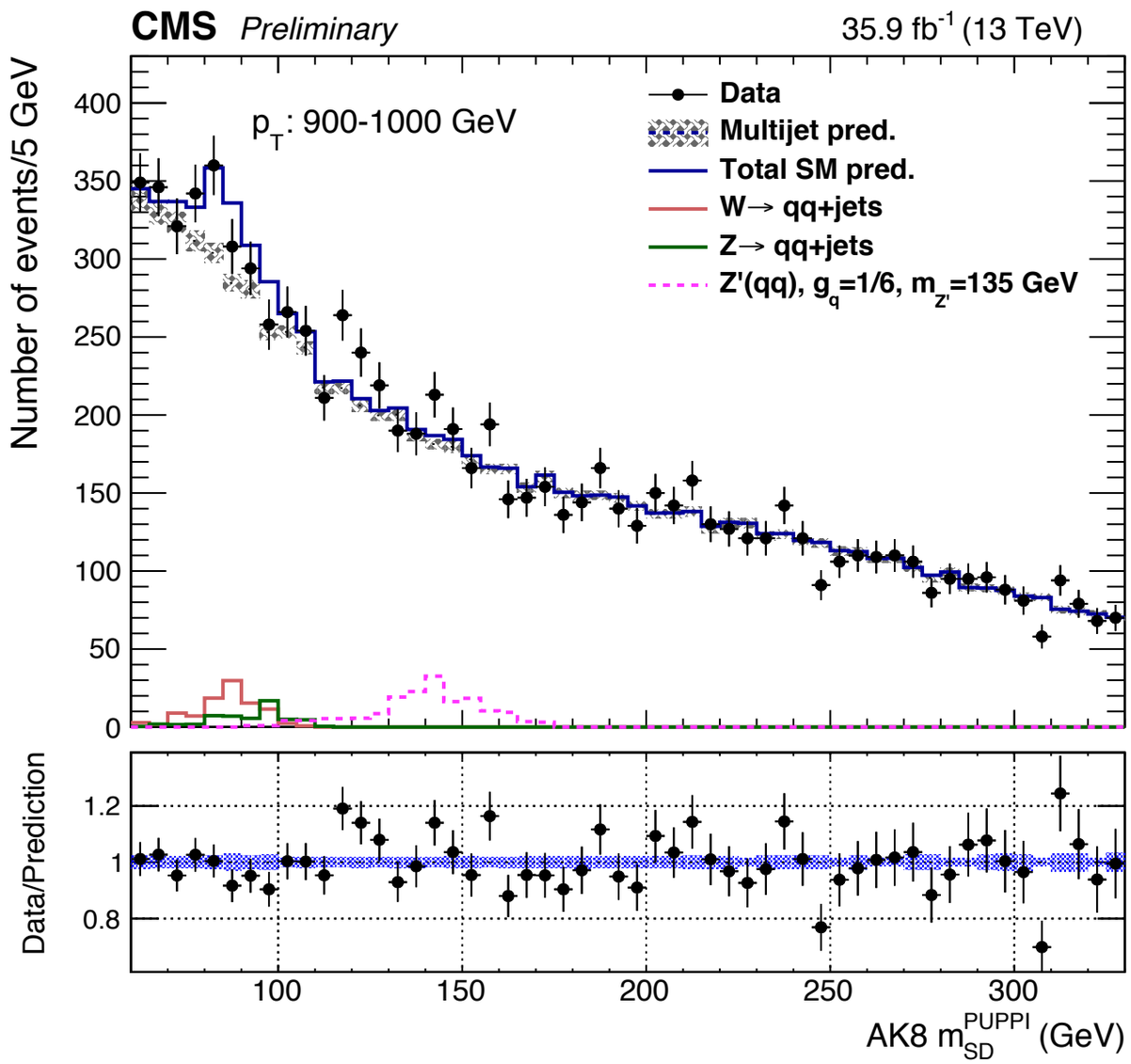


Jet mass by pT categories



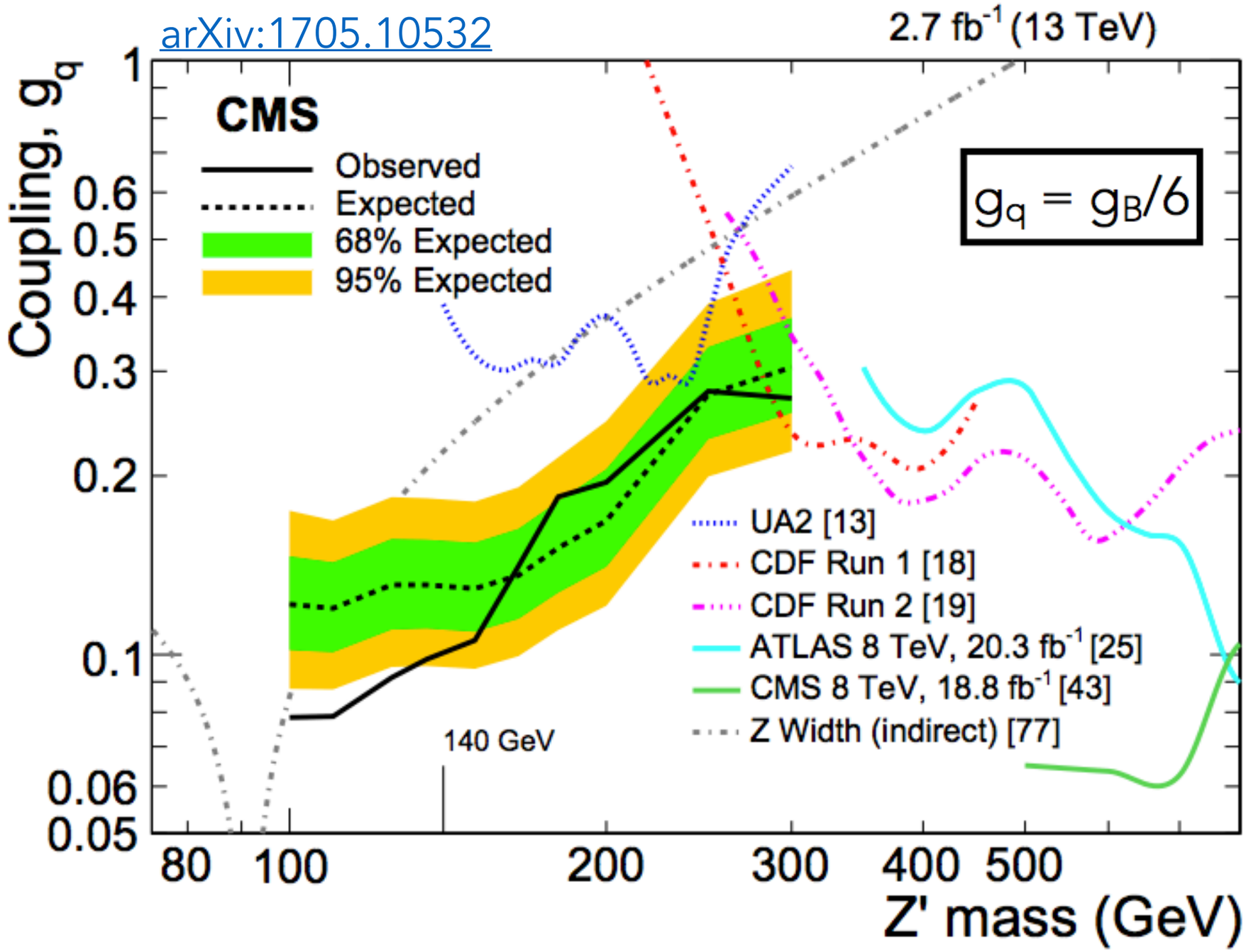


Jet mass by pT categories



BOOSTED Dijet Resonances Program

CMS: FIRST constraint from the LHC below 250 GeV - employed 2015 data (EXO-16-030)



The present search uses 2016 dataset and improved techniques

Systematic Uncertainties

- Background estimation uncertainties:
  - From the parametric uncertainties of the fit

- Systematics for W/Z+Jets, Top and signal

Systematic Effect	SM W/Z and Z′	$t\bar{t}$
W tag ($N_2^{1,deco}$) scale factor	9%	-
NLO QCD p_T corrections	10%	-
NLO EWK p_T corrections$^{\triangle}$	(15%,25%,35%,35%,35%)	-
W/Z ratio NLO p_T corrections$^{\triangle}$	5%	-
jet energy/mass resolution†	10%	-
jet energy/mass scale†	0.5%	-
jet energy/mass scale p_T dependent†	(0.5%,1%,1.5%,2%,2%)	-
luminosity	2.2%	-
trigger	2%	-
lepton veto	0.5%	-
top normalization	-	10%
top mistag rate	-	2%