Search for supersymmetry in the all-hadronic final state with missing transverse momentum, multiple jets and b-tagged jets

Sam Bein, LHC Physics Discussion, 10 July, 2017

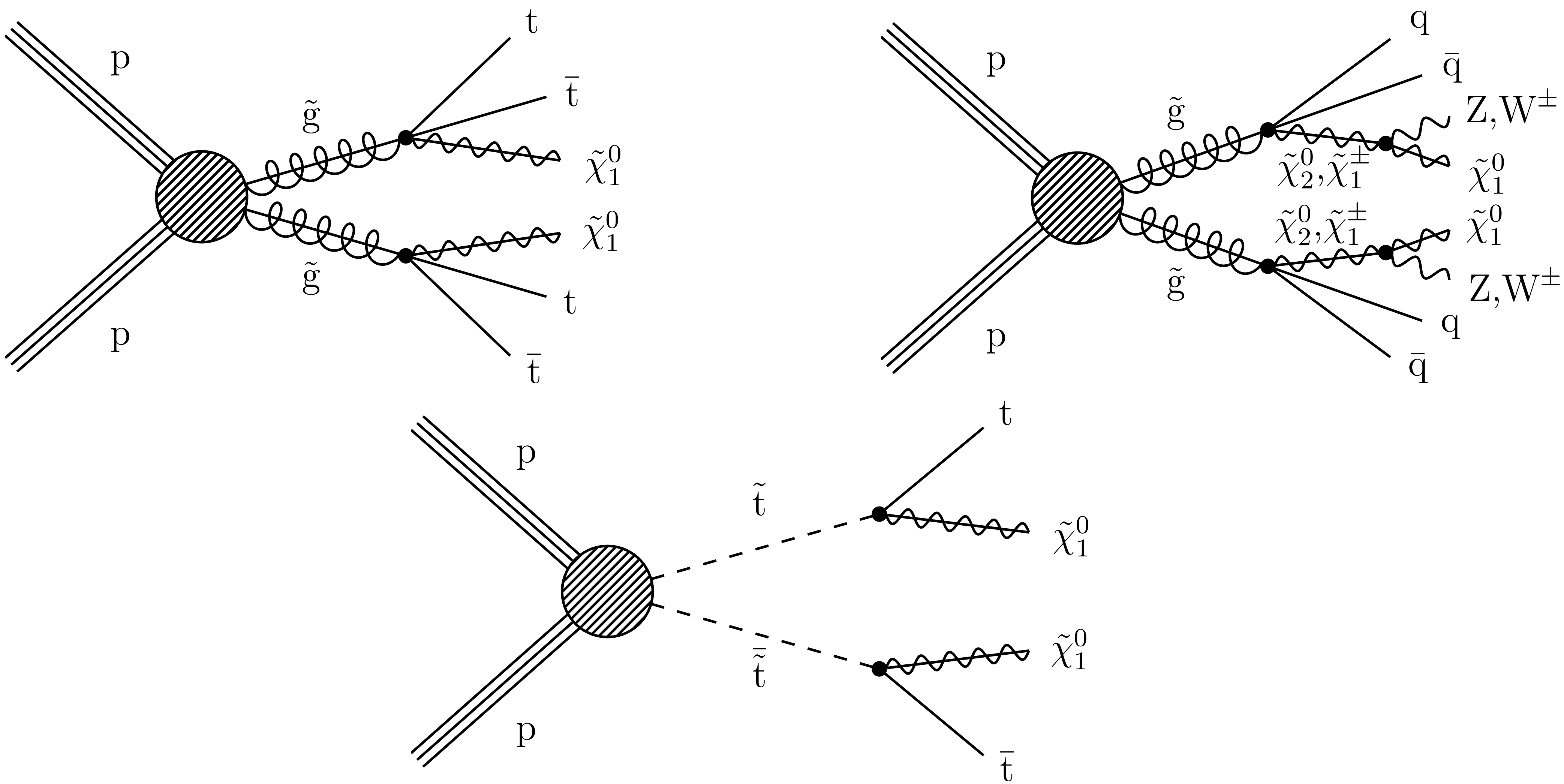
SUS-16-033

Outline

- Motivation for strong SUSY production and all-hadronic analyses
- All-hadronic analysis SUS-16-033
- Standard Model background estimation
- Results of 35.9/fb of observed 13 TeV data and interpretation

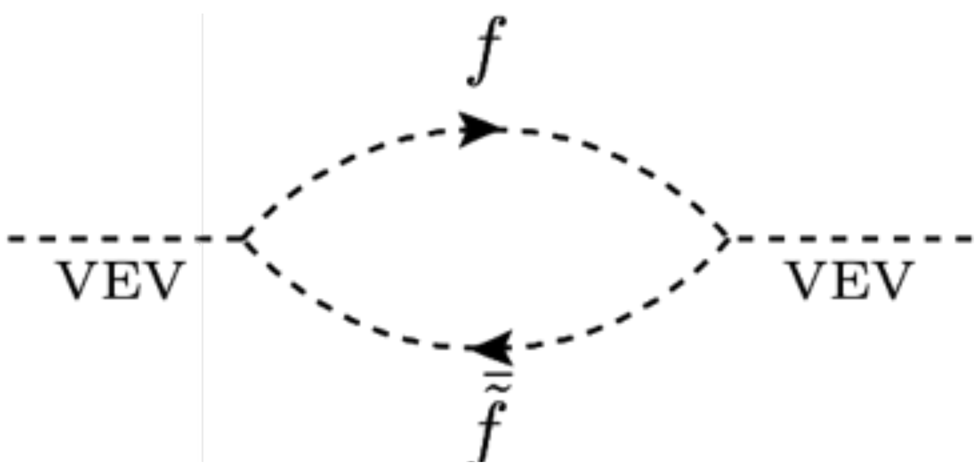
Search for supersymmetry in multijet events with missing transverse momentum in proton-proton collisions at 13 TeV
CMS Collaboration (Submitted on 25 Apr 2017 Phys. Rev. D.)

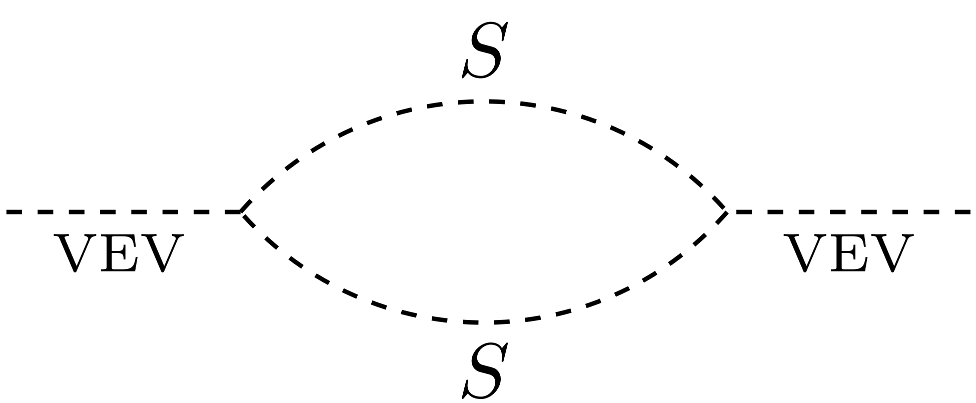
Gluino and squark production



Search for supersymmetry in multijet events with missing transverse momentum in proton-proton collisions at 13 TeV
CMS Collaboration
(Submitted on 25 Apr 2017 Phys. Rev. D.)

SUSY and fine tuning



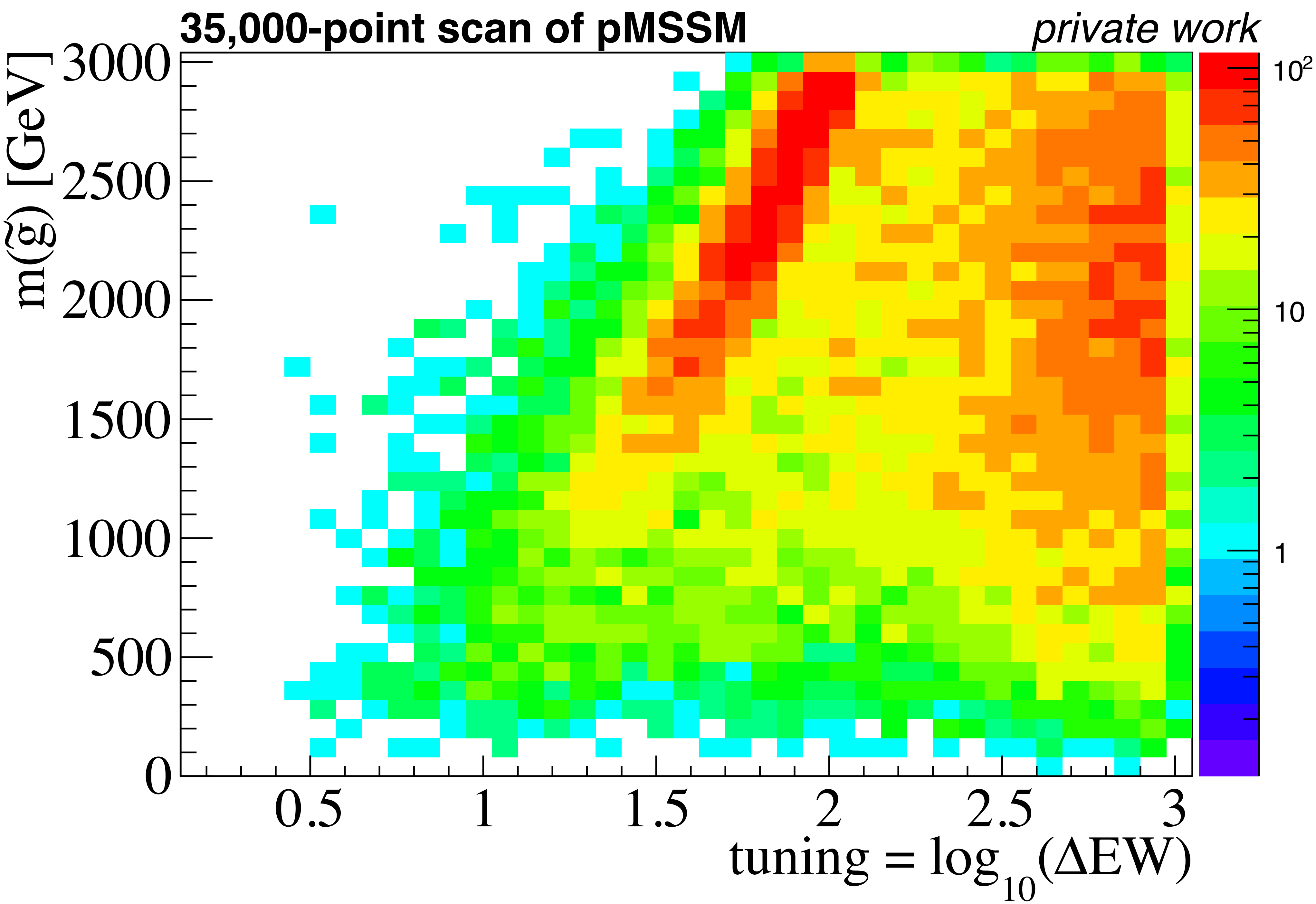


Big hierarchy problem

↓

Little hierarchy problem

Gluino mass vs. fine tuning

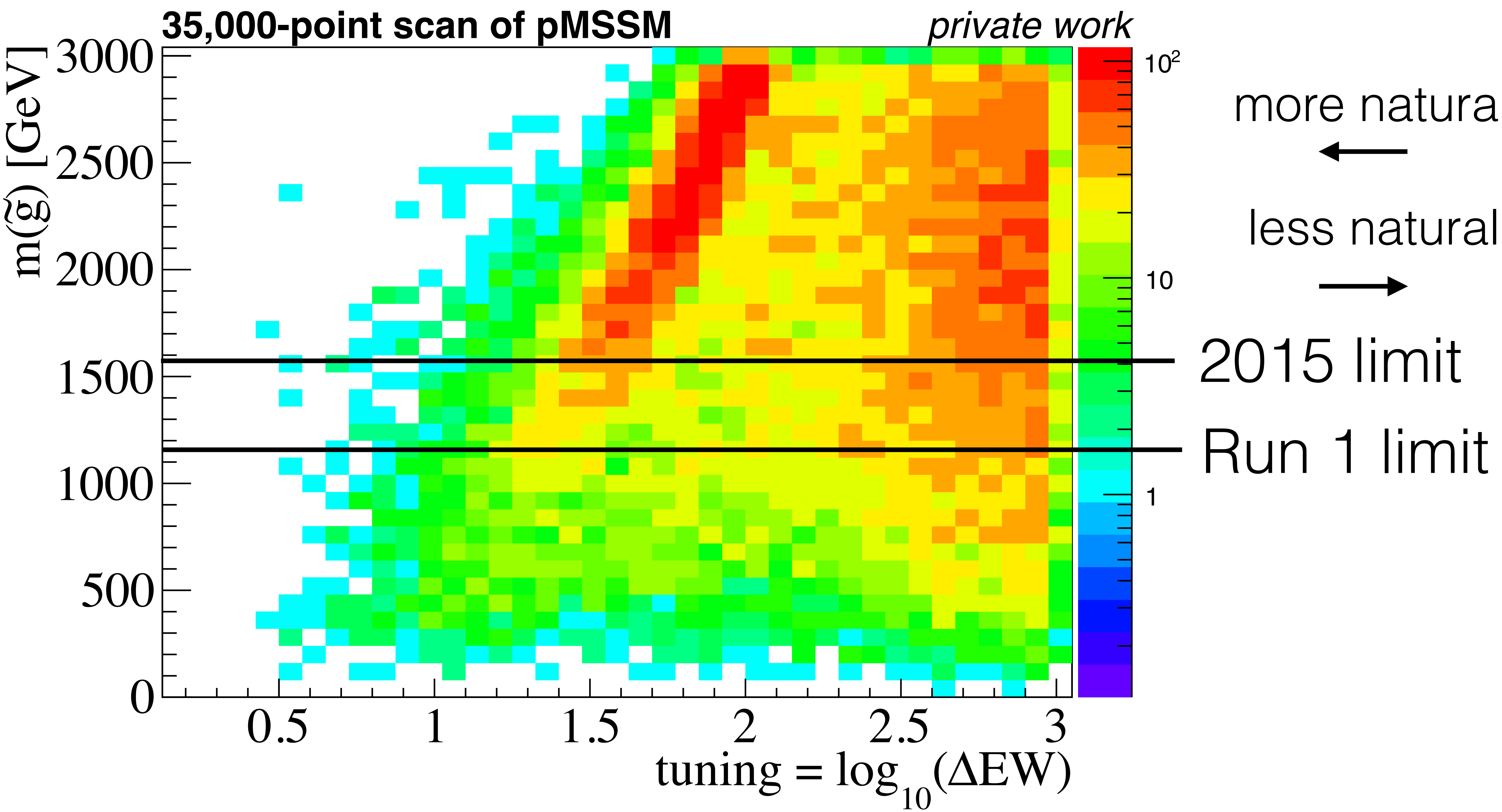


more natural ←

less natural →

Baer, Barger, Kirkland 10.1103/PhysRevD.88.055026, plot from Akshansh Singh

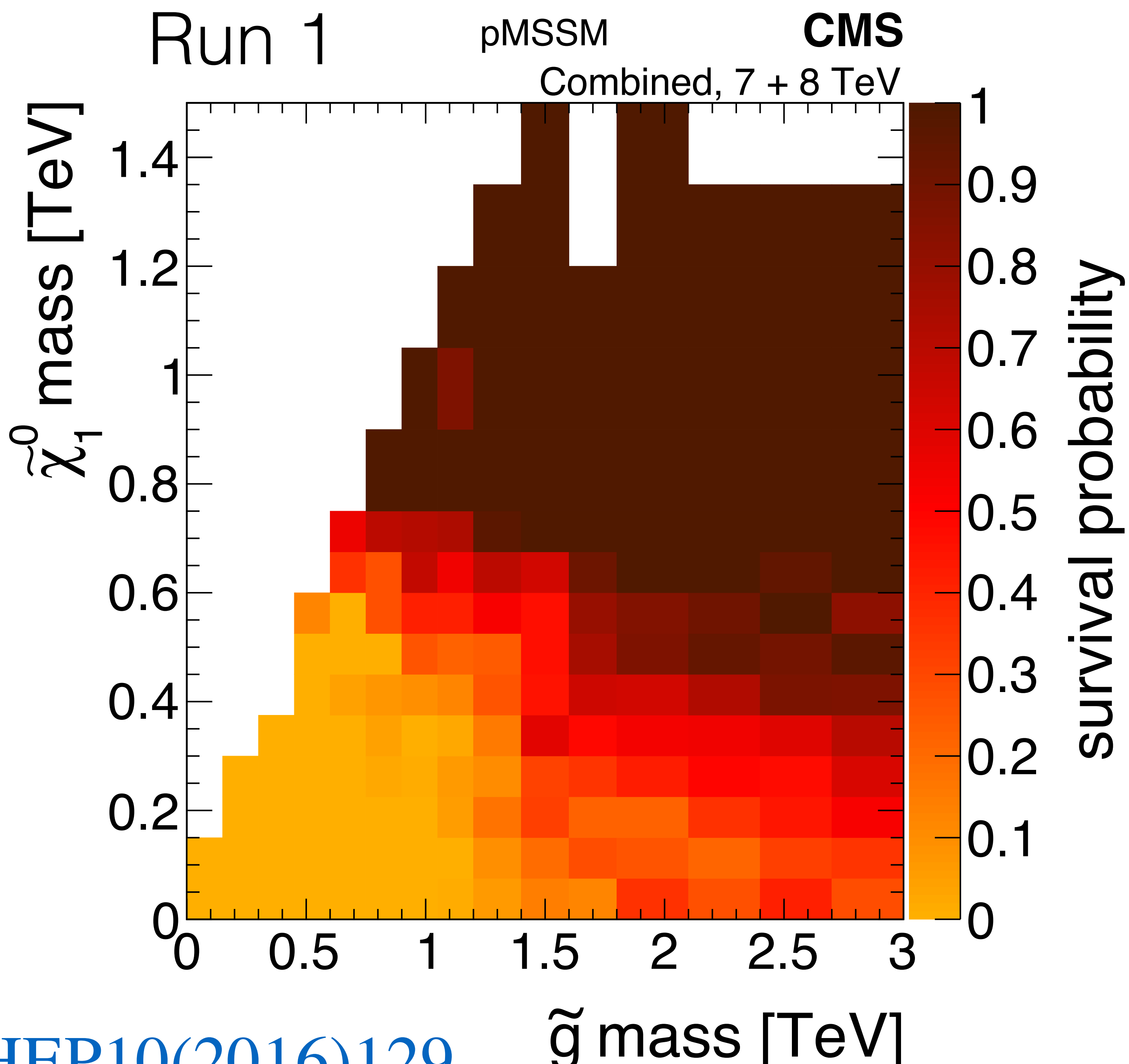
Gluino mass vs. fine tuning



Baer, Barger, Kirkland 10.1103/PhysRevD.88.055026, plot from Akshansh Singh

Run 1 pMSSM Interpretation

- 19-dimensional random scan of 7200 SUSY points within 3 TeV mass box
- Minimal assumptions made on the SUSY-breaking parameters
- Bayesian significance/exclusion interpretation



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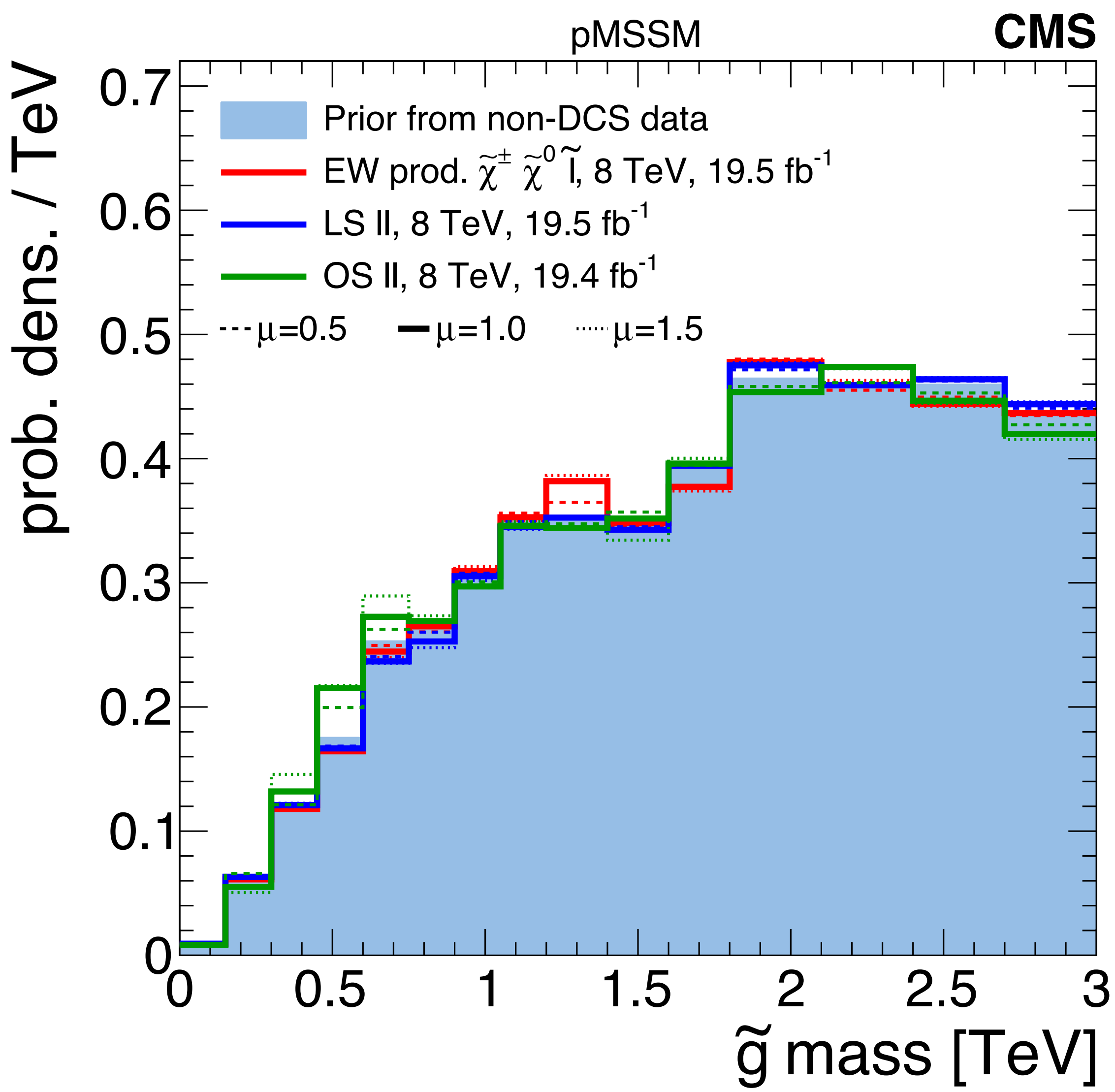
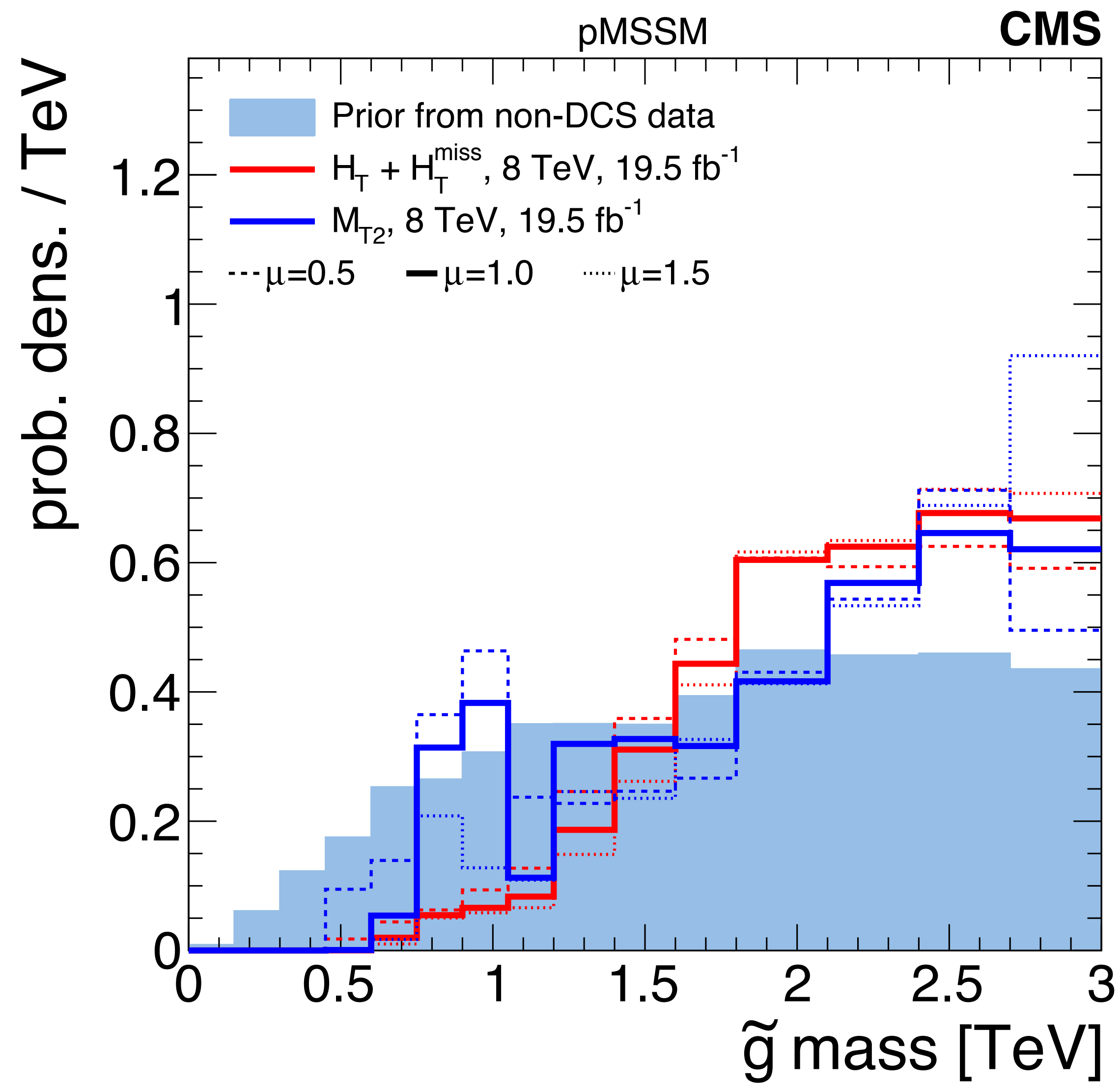
Run 1 pMSSM Interpretation

Leptonic searches



Hadronic searches



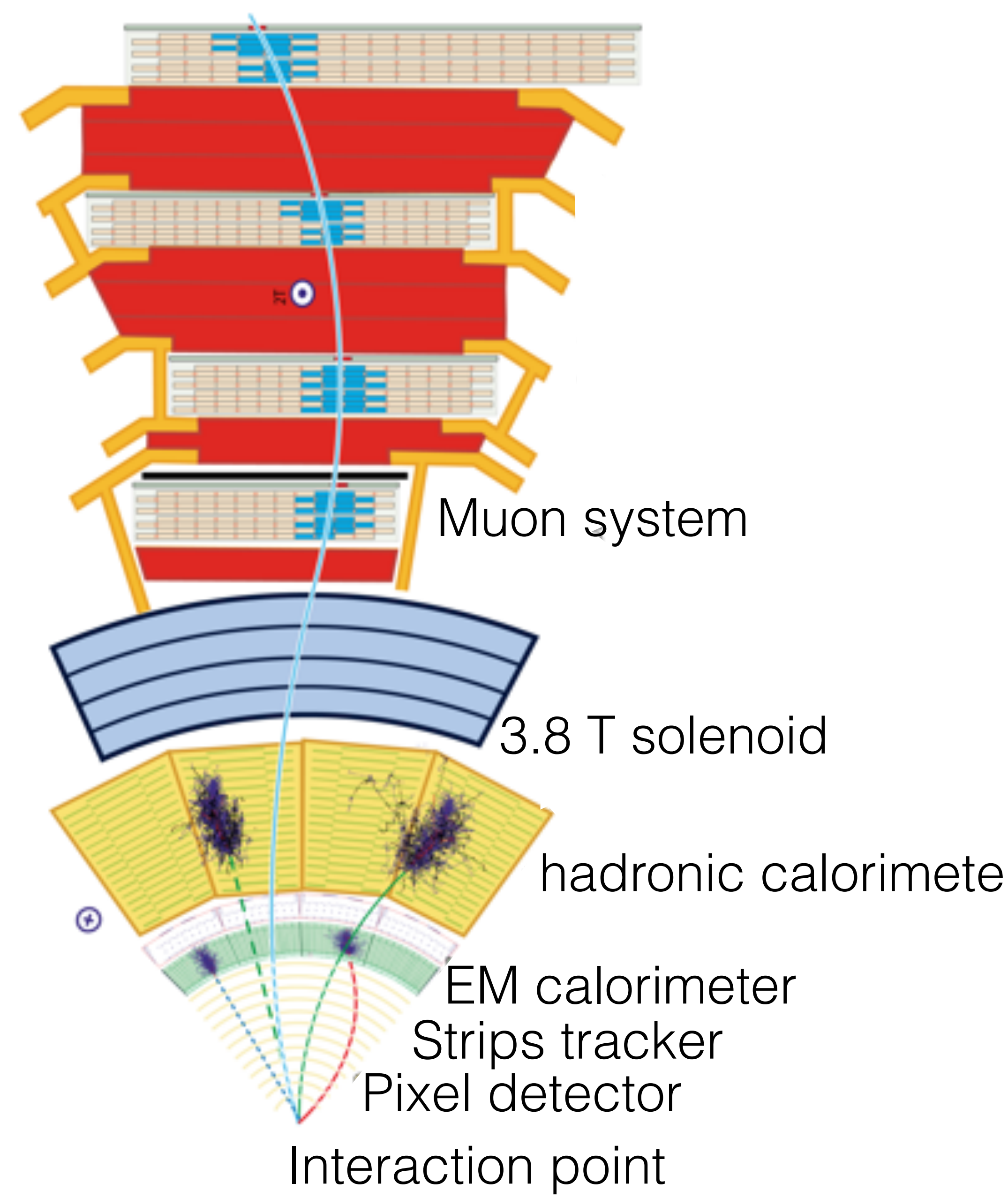
Prior probability density

Object selection

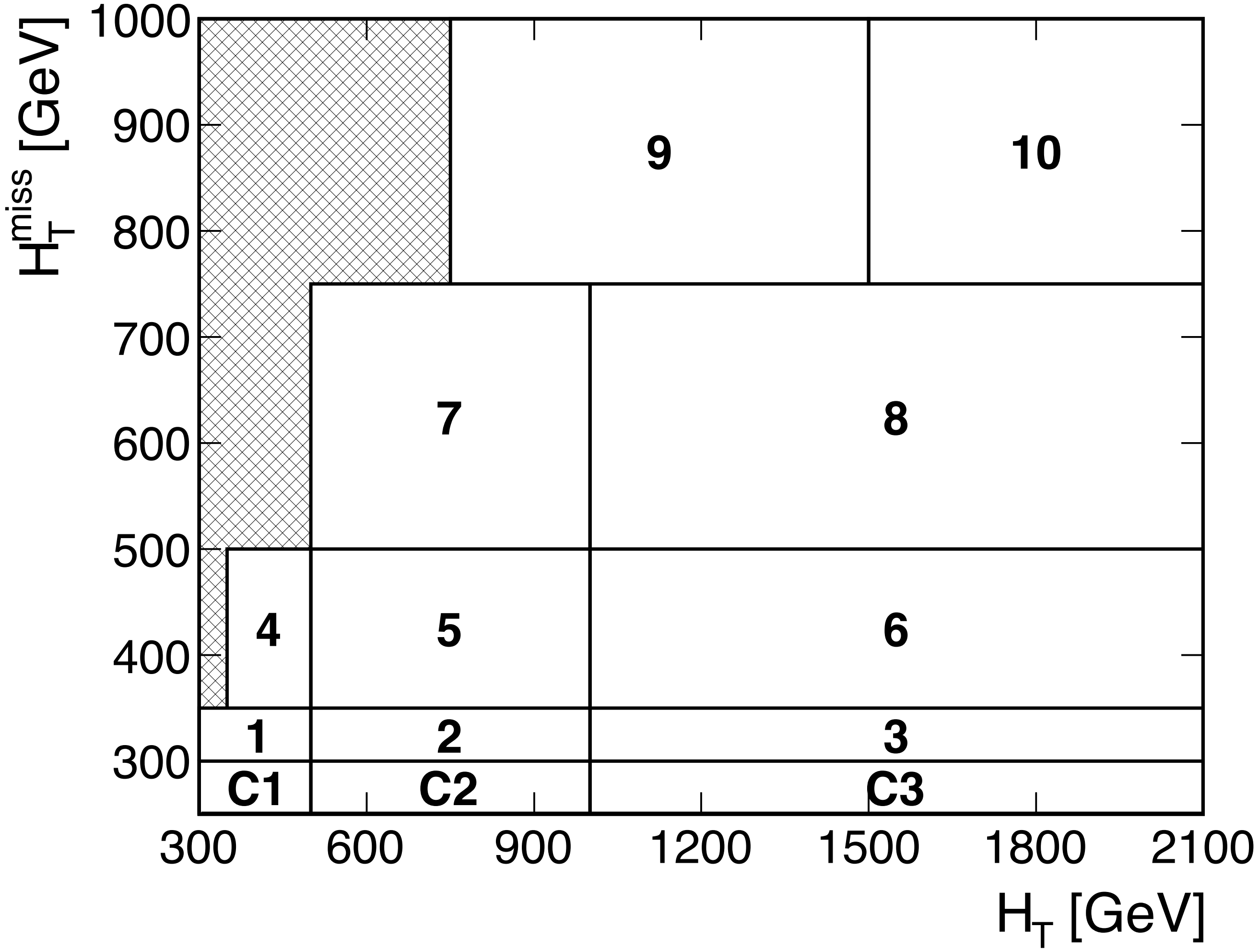
- particle candidates (Particle Flow algorithm)
- jets: anti-KT algorithm, $|\eta| < 2.4\,(\mathrm{H_T}$, n(jets), $\Delta\phi)$, and $|\eta| < 5.0\,(\mathrm{H_T^{miss}})$
- electrons (muons): isolated, $p_\mathrm{T} > 10\,\mathrm{GeV}$, $|\eta| < 2.5\,(2.4)$

Event selection

- trigger: $H_\mathrm{T}^\mathrm{miss}$ and $E_\mathrm{T}^\mathrm{miss} > 100\,\mathrm{GeV}$
- $\mathrm{H_T} = \sum_j (p_\mathrm{T})_j > 300\,\mathrm{GeV}$
- $\mathrm{H_T^{miss}} = |-\sum_j (\vec{p}_\mathrm{T})_j| > 300\,\mathrm{GeV}$
- $\mathrm{n(jets)} \geq 2$
- $\mathrm{n(e)},\ \mathrm{n}(\mu) = 0$
- $\Delta\phi(j1,\ j2,\ j3,\ j4) > (0.5, 0.5, 0.3, 0.3)$
- $\mathrm{n(iso.\,track)} = 0$
- event cleaning, pileup mitigation



Search regions



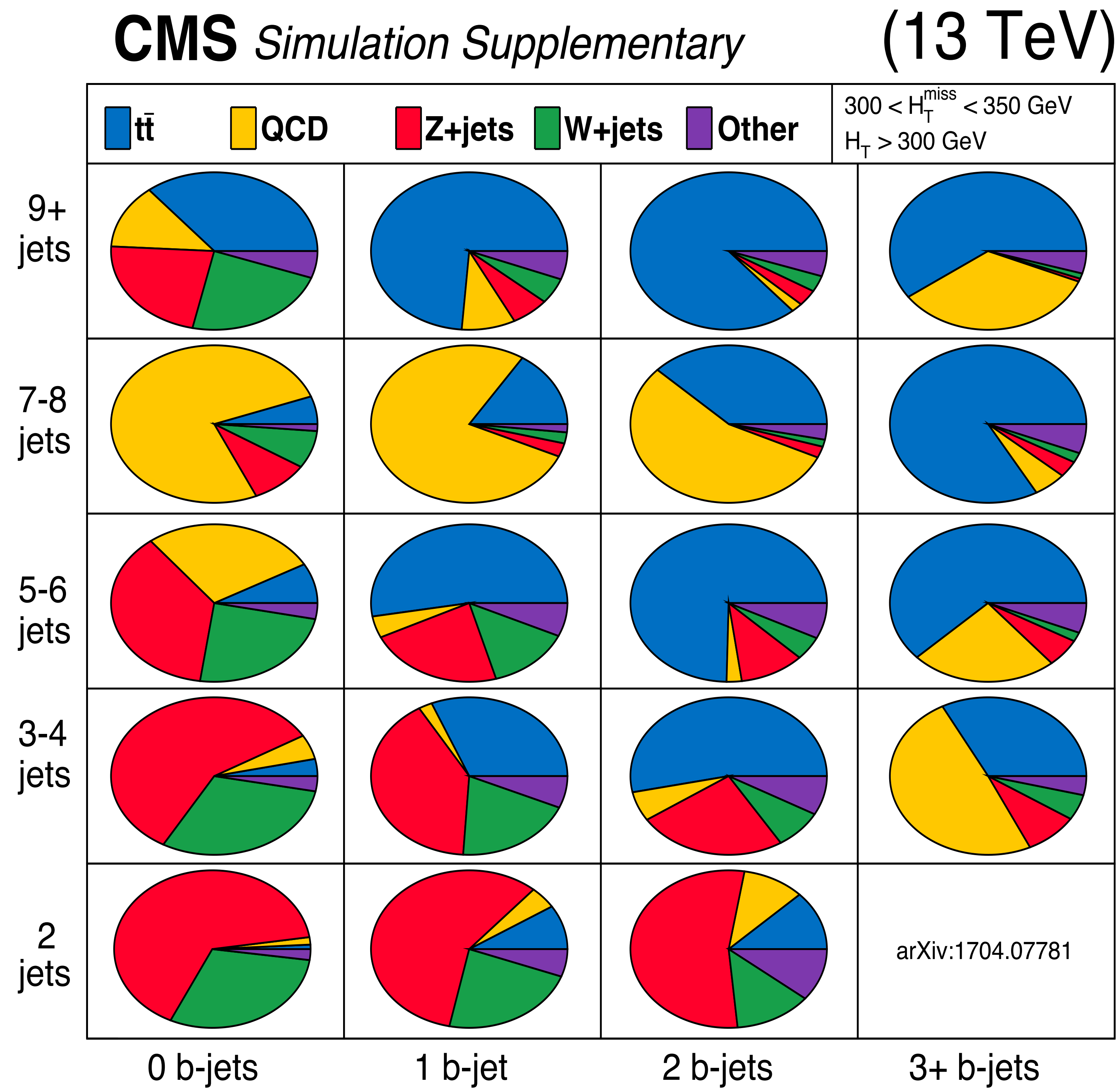
174 search bins

- n(jets) = 2, 3-4, 5-6, 7-8, 9+
- n(b-tags) = 0, 1, 2, 3+

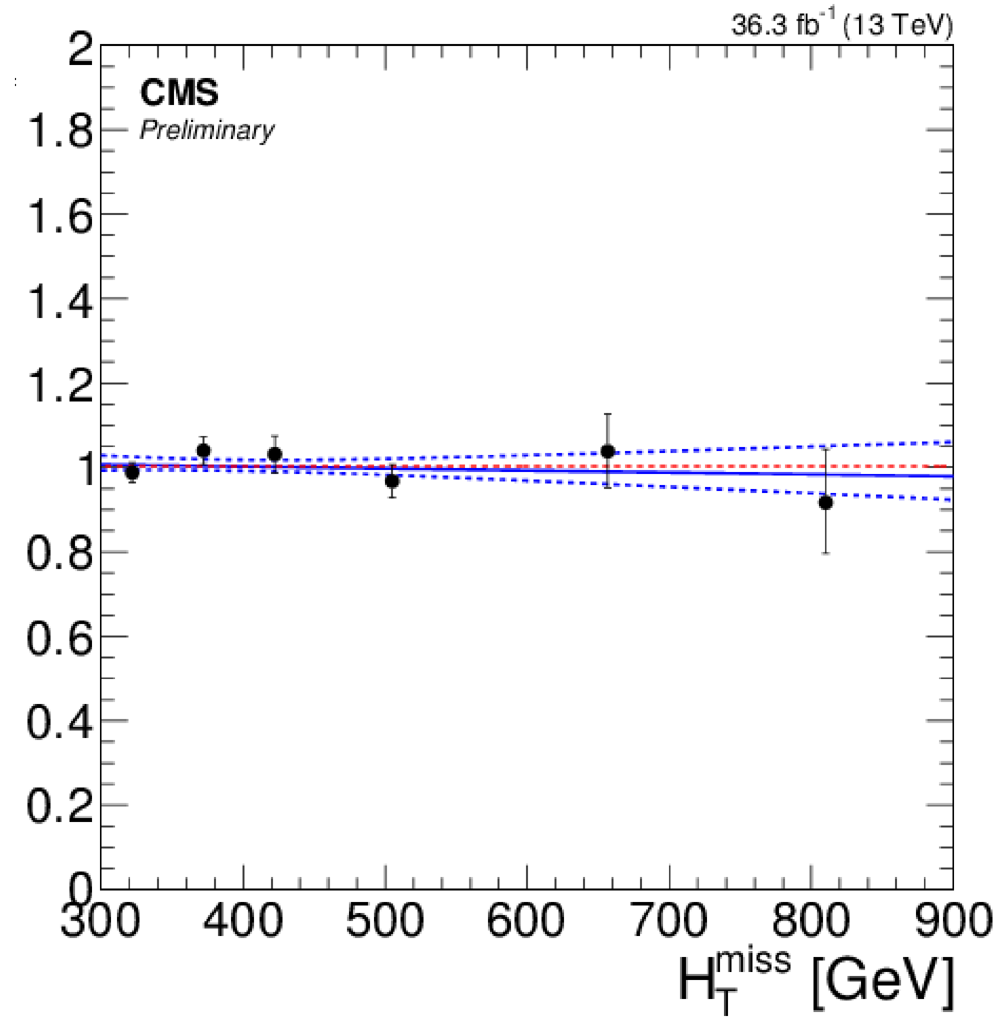
Backgrounds from SM processes

4 sources:

- $Z \to \nu\bar{\nu} + \text{jets}$
- $t\bar{t} + \text{jets}$
- $W \to l^{\pm}\nu + \text{jets}$
- QCD multi-jet



$Z \to \nu\bar{\nu} + \text{jets}$



- Z+jets proxy samples:
  - **photon+jets** sample obtained by applying a single-photon selection to the events, excising photons from events
  - **di-lepton+jets** sample obtained by requiring 2 opposite-sign electrons or muons with an invariant mass consistent with the Z, excising leptons from events
- photon+jets sample transformed by the Z/photon ratio to yield prediction in 0 b-tag category, di-lepton sample used for n(b)>0
- Z/photon ratio obtained from simulation, calibrated using data/simulation scale factor RR

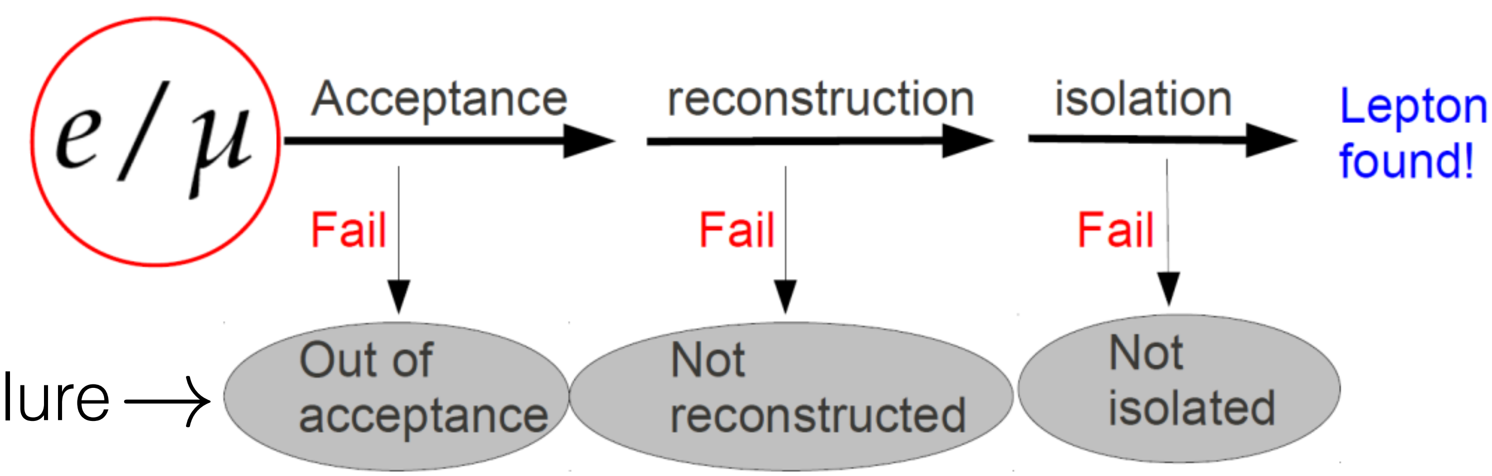
$$\hat{N}_{Z\to\nu\bar{\nu}} = \mathcal{R}\mathcal{R}^{\text{obs}}_{\text{sim}} \cdot \mathcal{R}^{\text{sim}}[Z(\nu\bar{\nu}/\gamma)] \cdot \epsilon \cdot N^{\text{obs}}_{\gamma}$$

(for 0 b-tags)

$W \rightarrow e\nu_e(\mu\nu_\mu) + \text{jets}$

(including Ws from ttbar)

- lost lepton background
  - three possibilities for veto failure $\longrightarrow$



- invert lepton veto to select single-lepton control sample (CS)

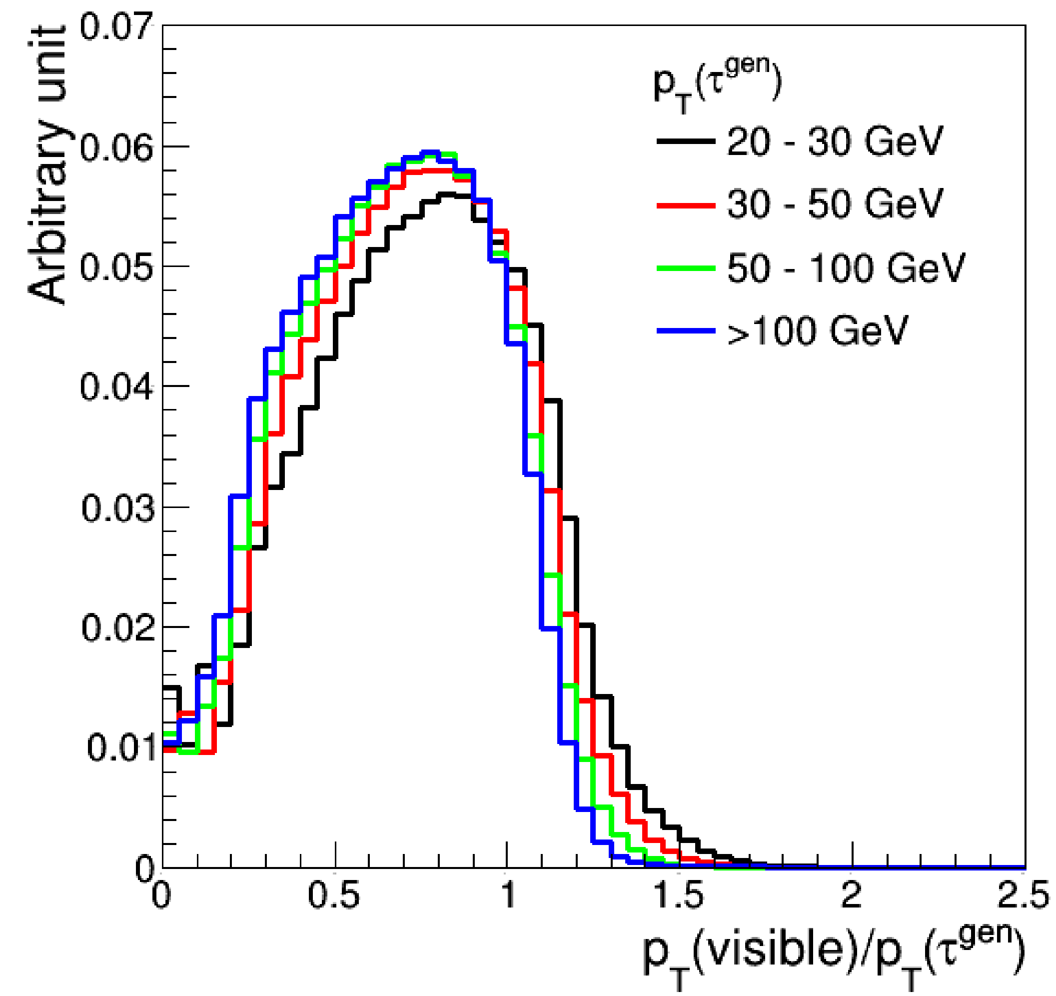
- scale CS counts to the 0-lepton prediction using efficiencies derived in data (reco and iso) and simulation (acceptance)

$$\hat{N}_{0\ell} = (\epsilon\, N_{1\ell}^{\text{obs}})\frac{1-x}{x},\;\; x \equiv P(\text{acc})P(\text{rec}|\text{acc})P(\text{iso}|\text{reco},\text{acc})$$

(+ terms for 2-lepton contamination, iso track veto)

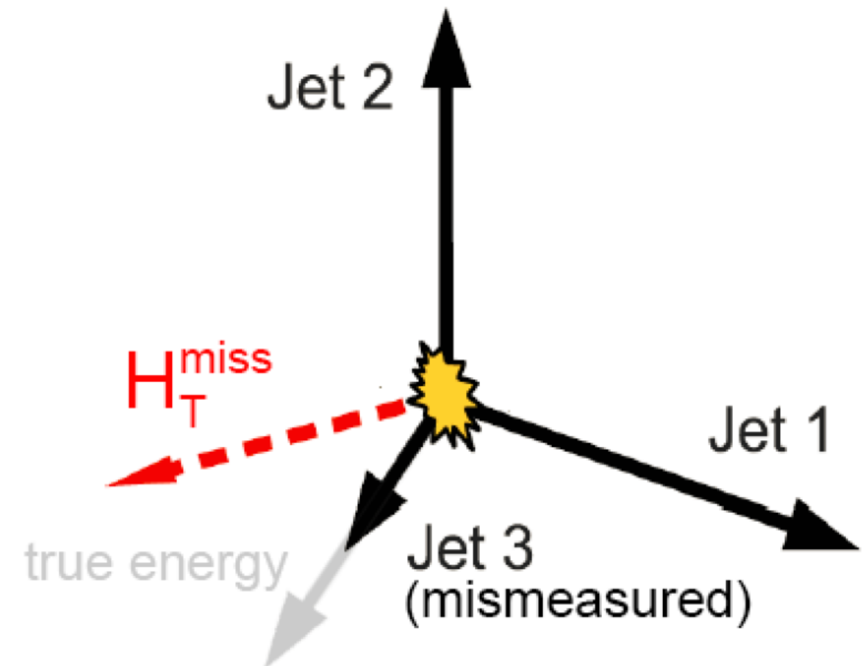
$W \to \tau\nu_\tau + \text{jets}, \ \tau \to \text{hadrons}$

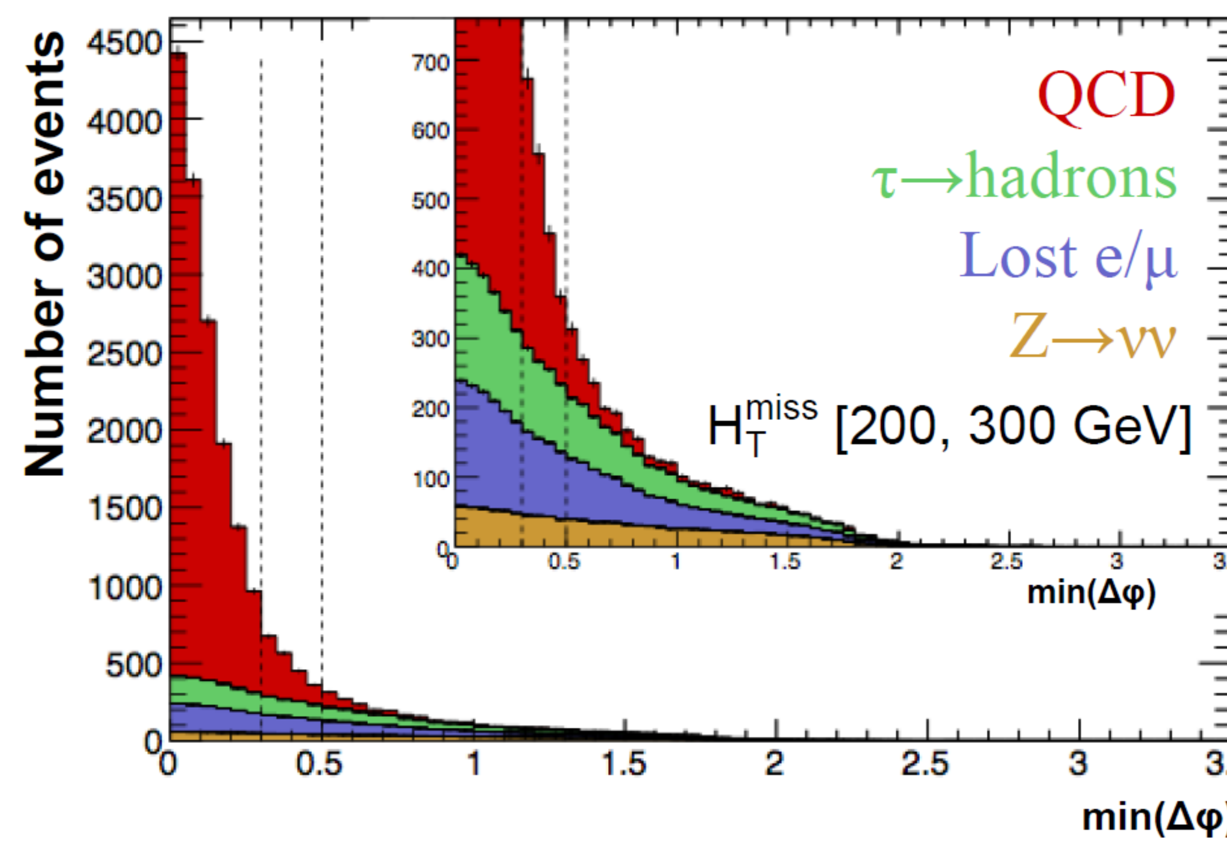
- Hadronically-decaying taus do not trigger the event veto, so this background must be carefully estimated.
    - **single-muon** sample obtained by applying a single-muon selection on events collected with single muon trigger (online pT > 27-30 GeV)
    - muon events are corrected by efficiencies derived from data-corrected simulation; muons are smeared according to tau response templates - *templates derived in simulation*



QCD multi-jet

- Two independent, data-driven QCD estimation methods:
    - *Low-delta phi extrapolation* method
    - *Rebalance and smear* method



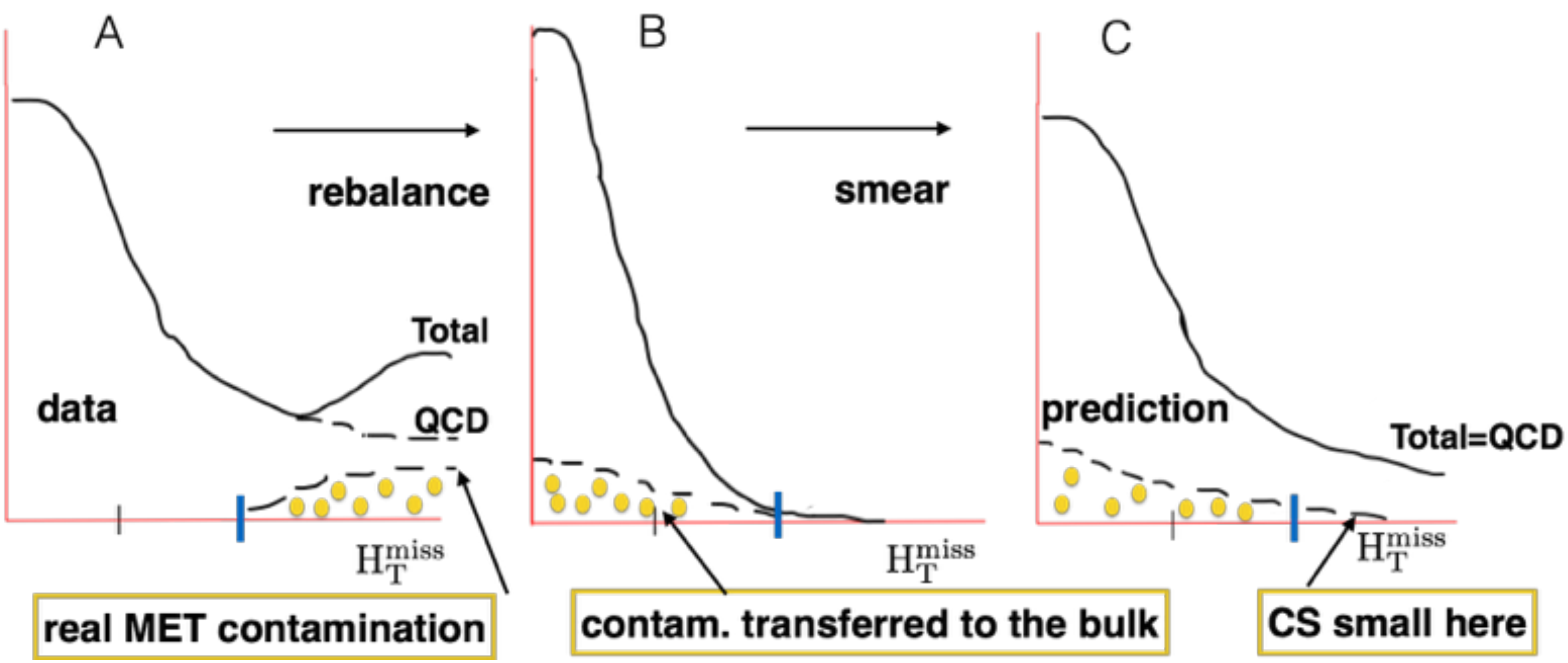


QCD multi-jet

- Remove electroweak contribution from a mostly-QCD control region via a two step process:

1. *rebalance: f*orce all events in the control region into an orientation that resembles QCD events at the particle level (low-MHT);

2. *smear:* rescale the particle-level jets by randomly sampling jet response



Method: *rebalance and smear*

QCD multi-jet

- Rebalance by maximizing the posterior density:

$$\mathrm{P}(\vec{J}_{\mathrm{part}}|\vec{J}_{\mathrm{meas}}) \sim \mathrm{P}(\vec{J}_{\mathrm{meas}}|\vec{J}_{\mathrm{part}}) \cdot \pi(\vec{J}_{\mathrm{part}})$$

reconstructed jet collection

particle-level jet collection

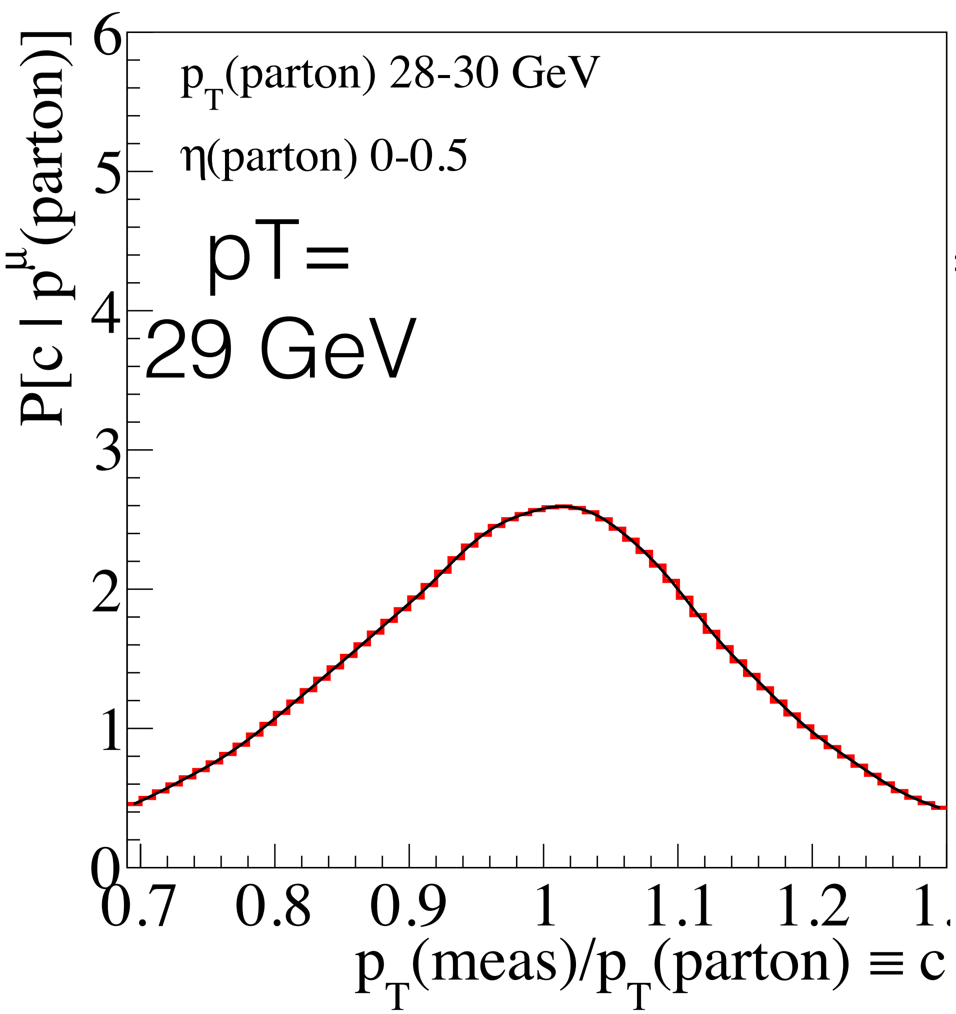
Method: *rebalance and smear*

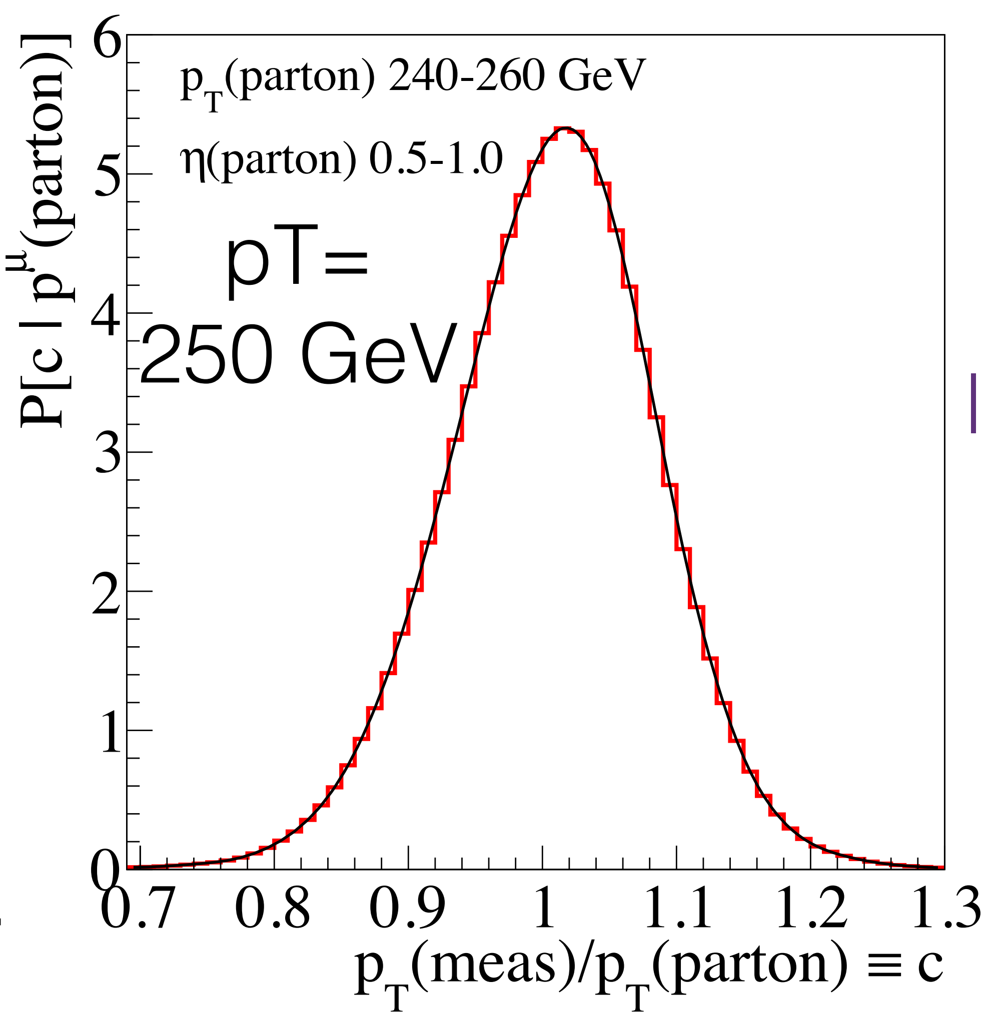
QCD multi-jet

- Rebalance by maximizing the posterior density:

$$\mathrm{P}(\vec{J}_{\mathrm{part}}|\vec{J}_{\mathrm{meas}}) \sim \mathrm{P}(\vec{J}_{\mathrm{meas}}|\vec{J}_{\mathrm{part}}) \cdot \pi(\vec{J}_{\mathrm{part}})$$

$$\mathrm{P}(\vec{J}_{\mathrm{meas}}|\vec{J}_{\mathrm{part}}) = \prod_{i=1}^{n_{\mathrm{jet}}} \mathrm{P}(p^{\mu}_{i,\mathrm{meas}} \mid p^{\mu}_{i,\mathrm{part}}) = \prod_{i=1}^{n_{\mathrm{jet}}} \mathrm{P}(c_i \mid p^{\mu}_{i,\mathrm{part}})$$





likelihood binned in jet eta, pT

Method: *rebalance and smear*

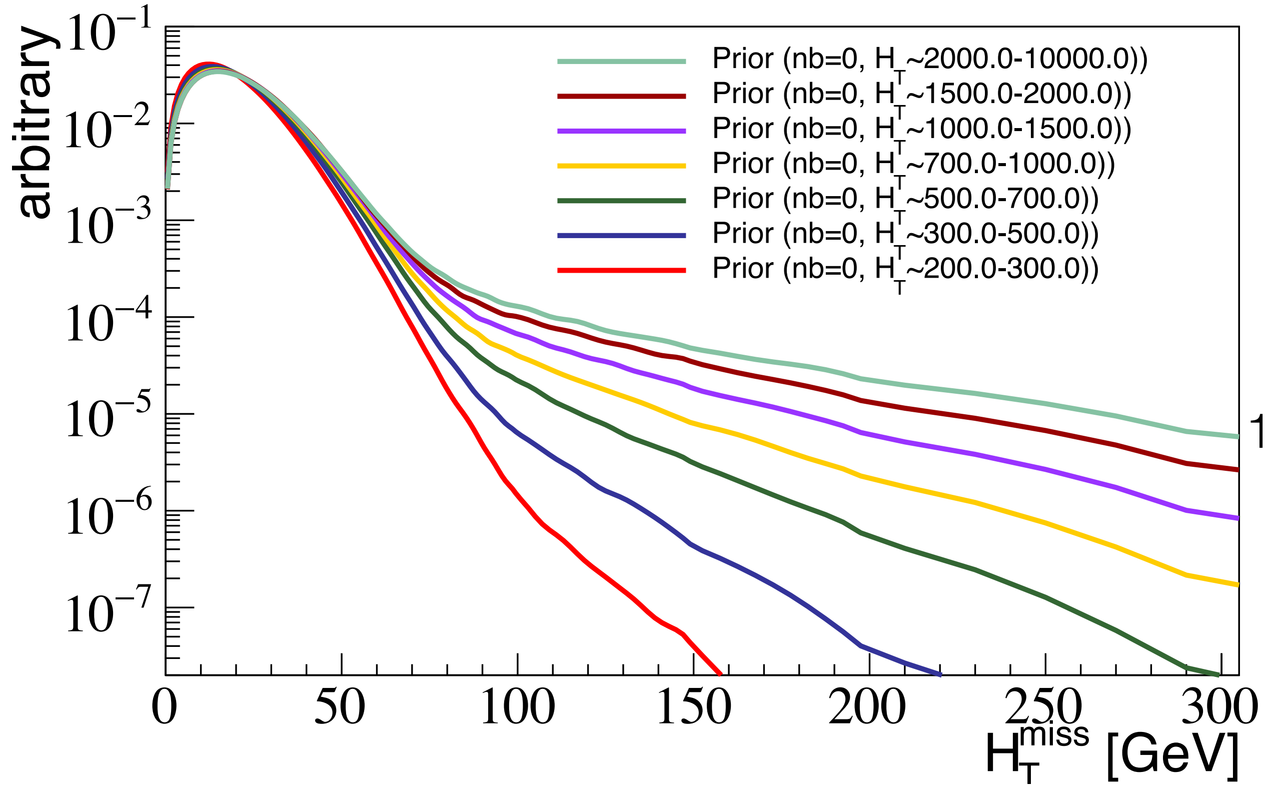
QCD multi-jet

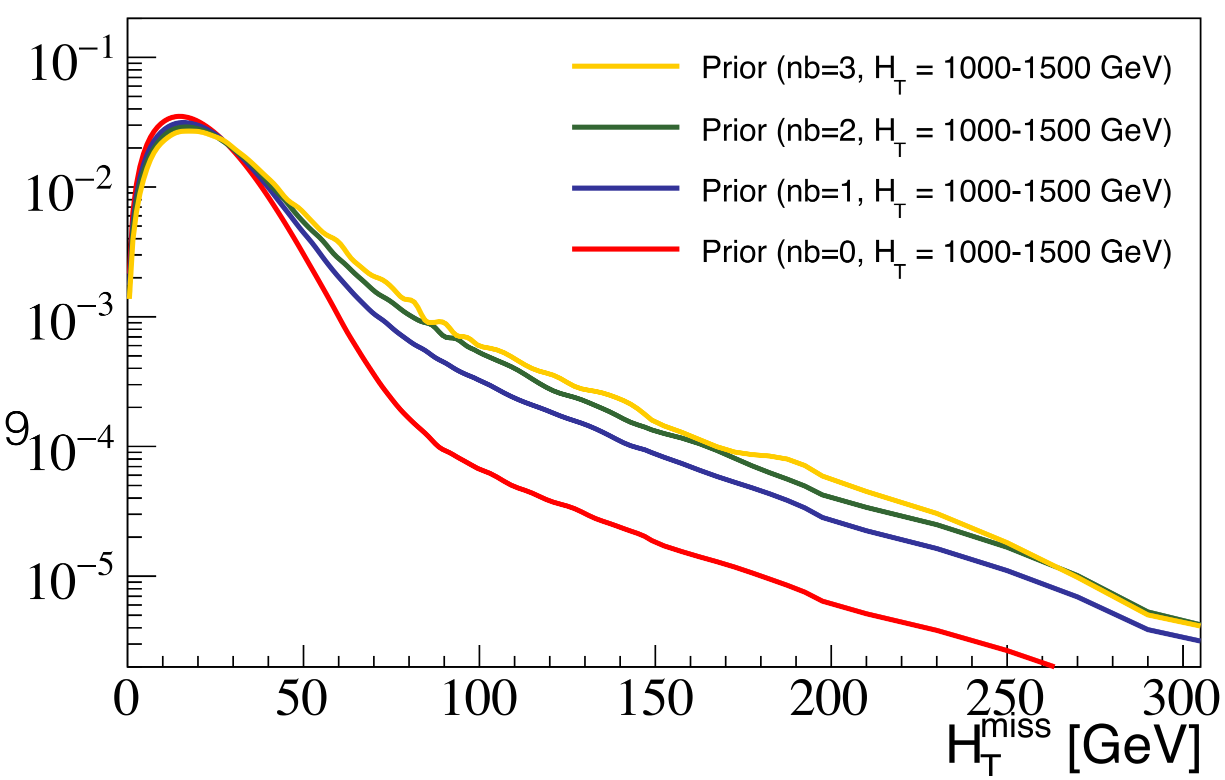
- Rebalance by maximizing the posterior density:

$$\mathrm{P}(\vec{J}_{\mathrm{part}}|\vec{J}_{\mathrm{meas}}) \sim \mathrm{P}(\vec{J}_{\mathrm{meas}}|\vec{J}_{\mathrm{part}}) \cdot \pi(\vec{J}_{\mathrm{part}})$$

gen/sim MHT

Prior binned in HT and n(b-tags)

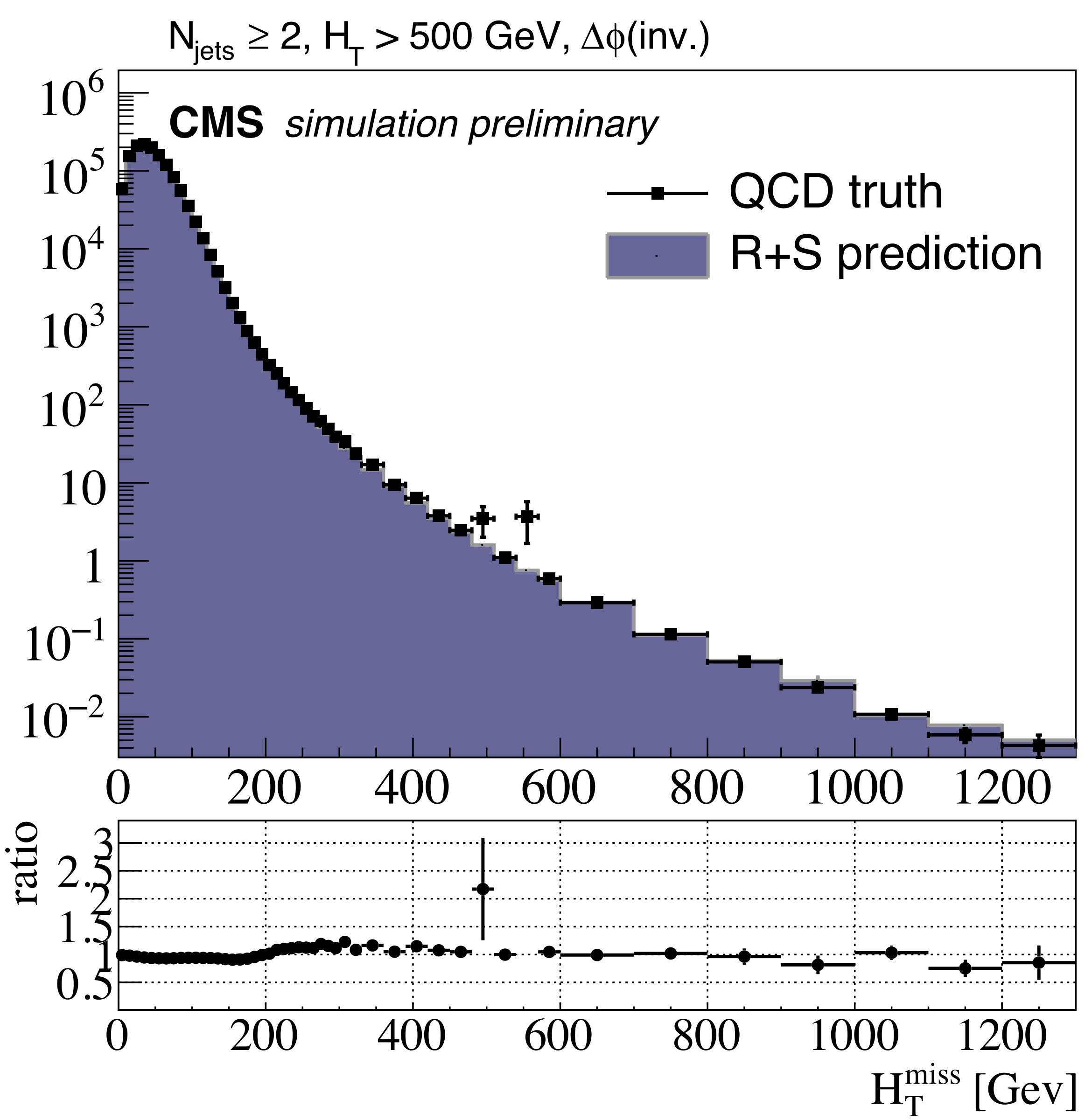


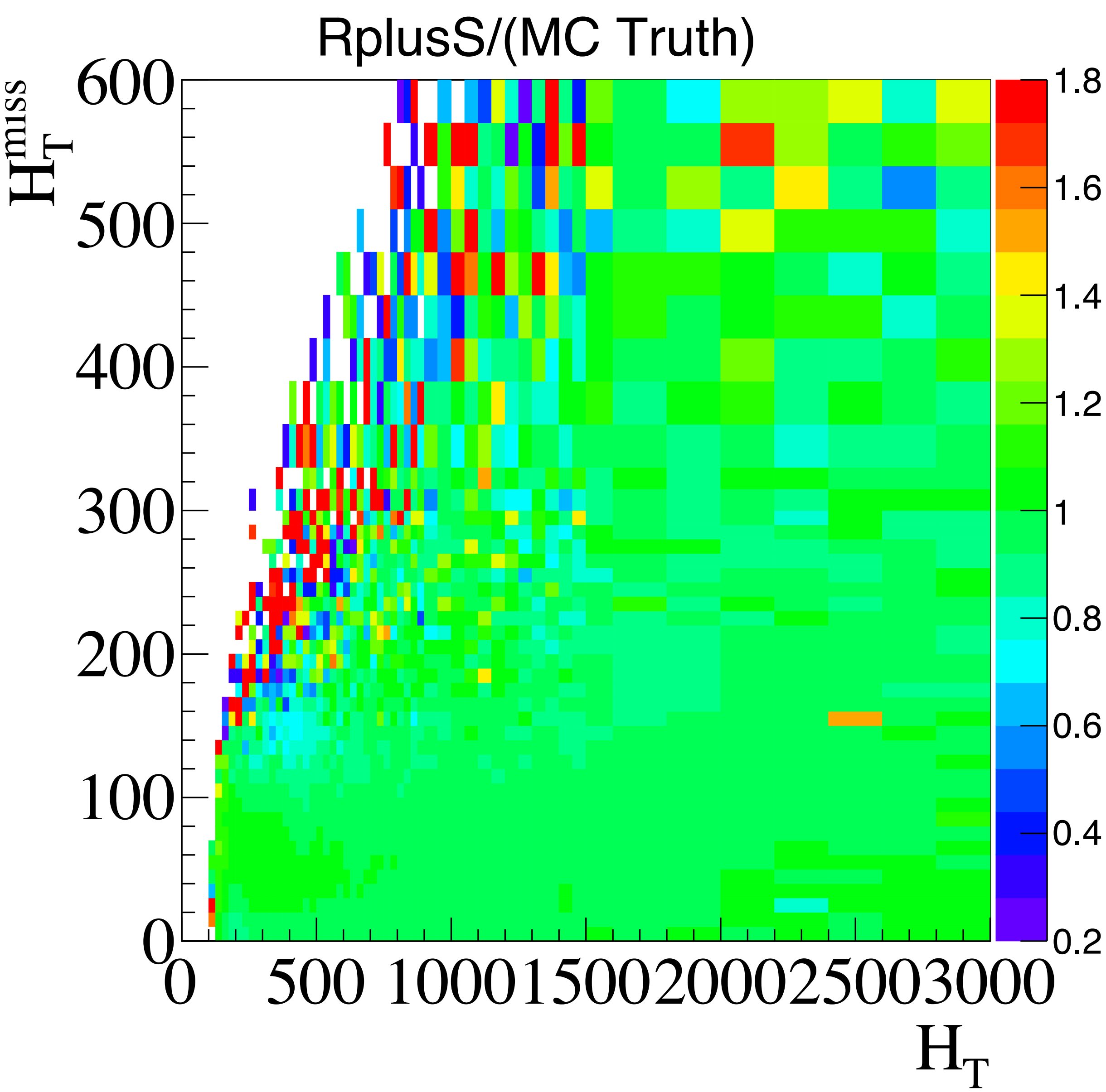


Method: *rebalance and smear*

QCD multi-jet

- Validation: consistency of method performed in simulation:

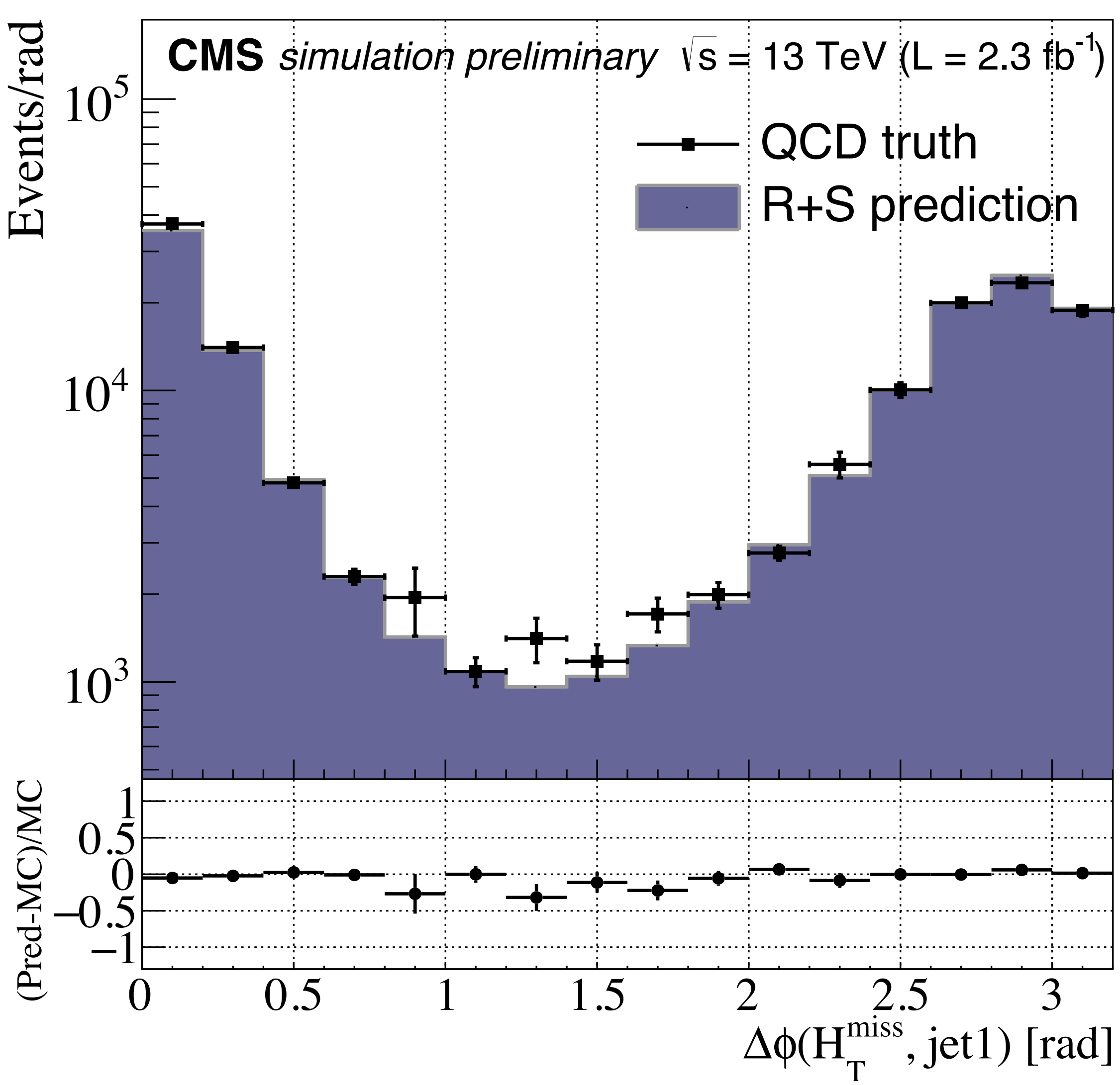


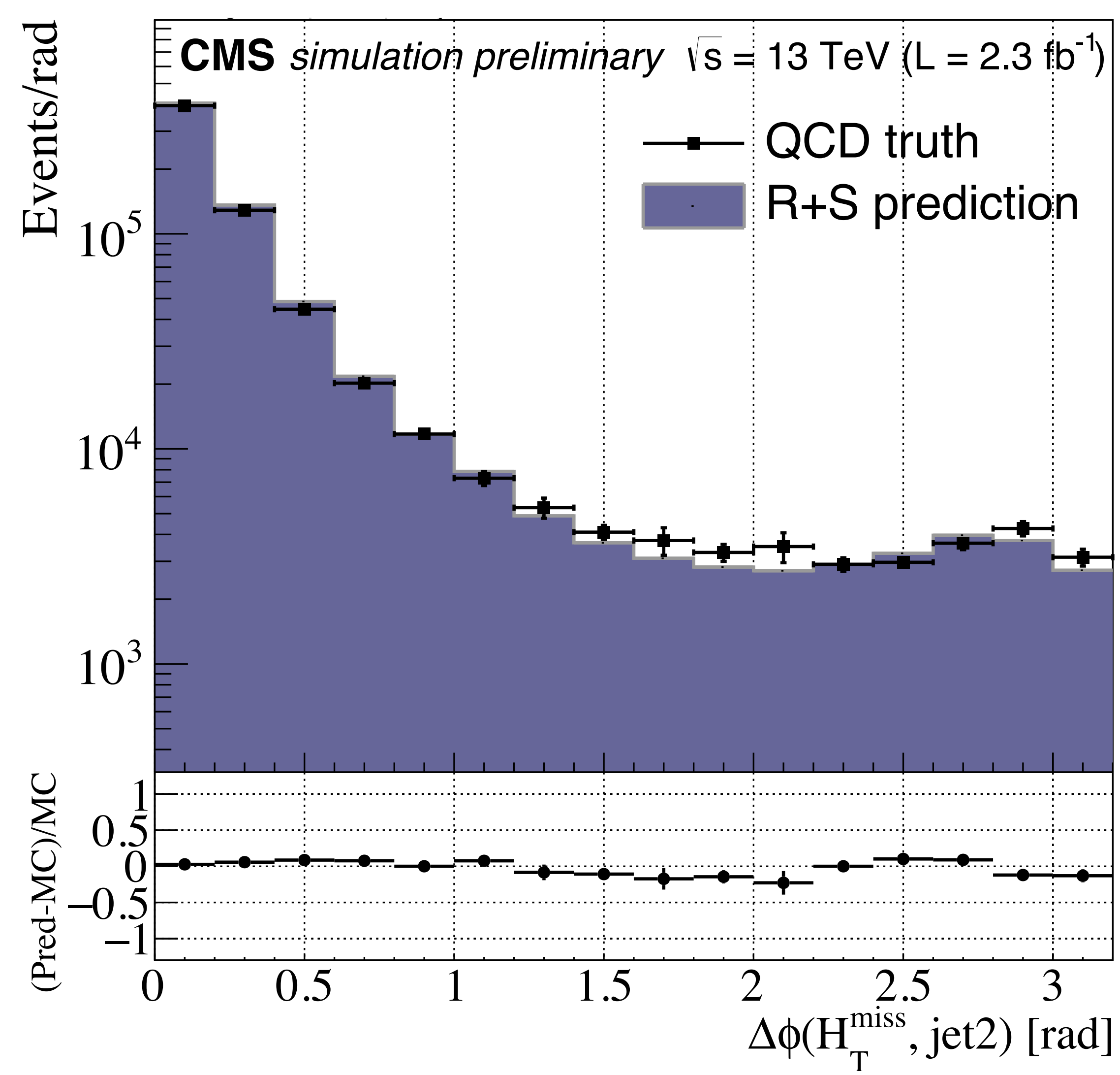


Method: *rebalance and smear*

QCD multi-jet

- Validation: consistency of method performed in simulation:

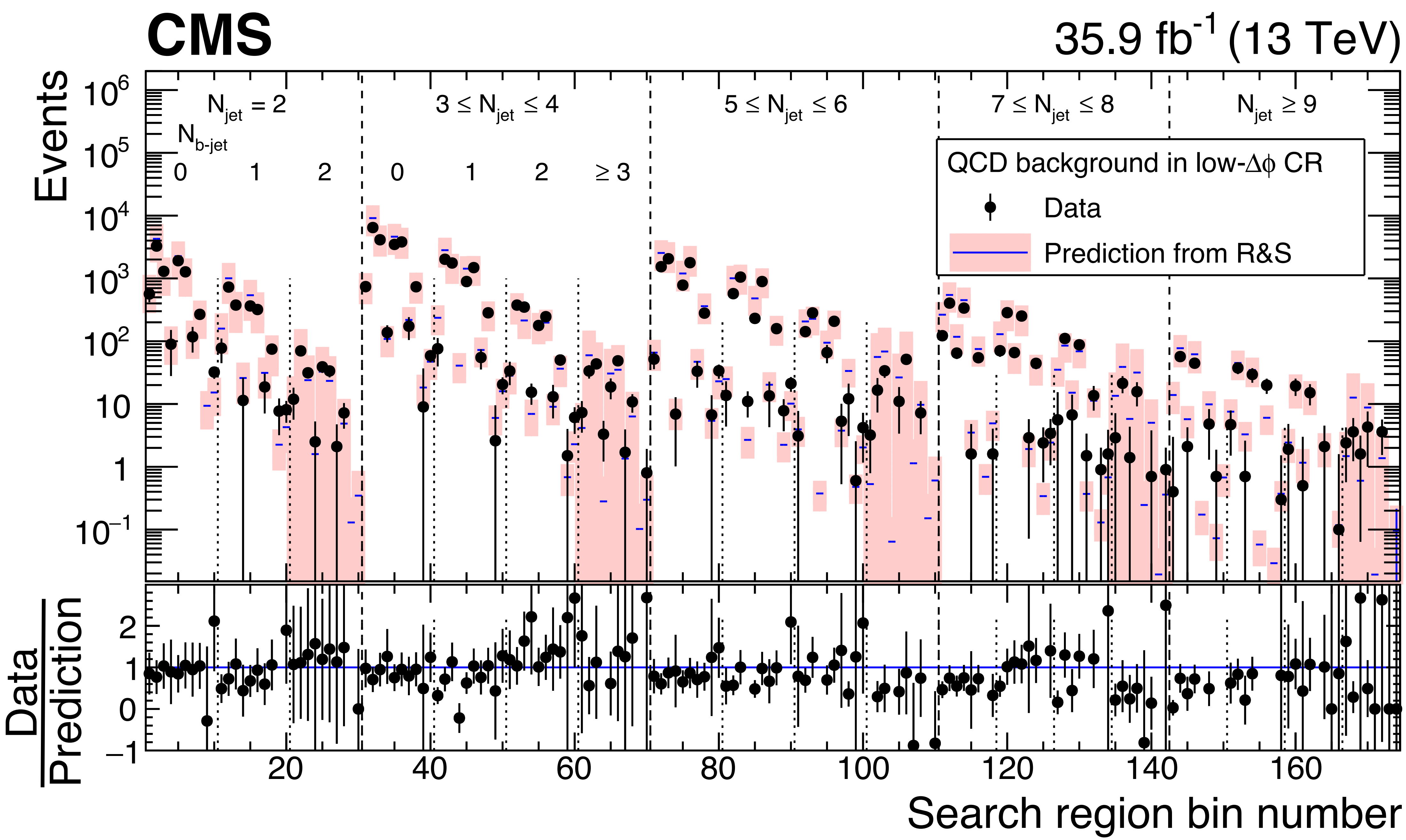




Method: *rebalance and smear*

QCD multi-jet

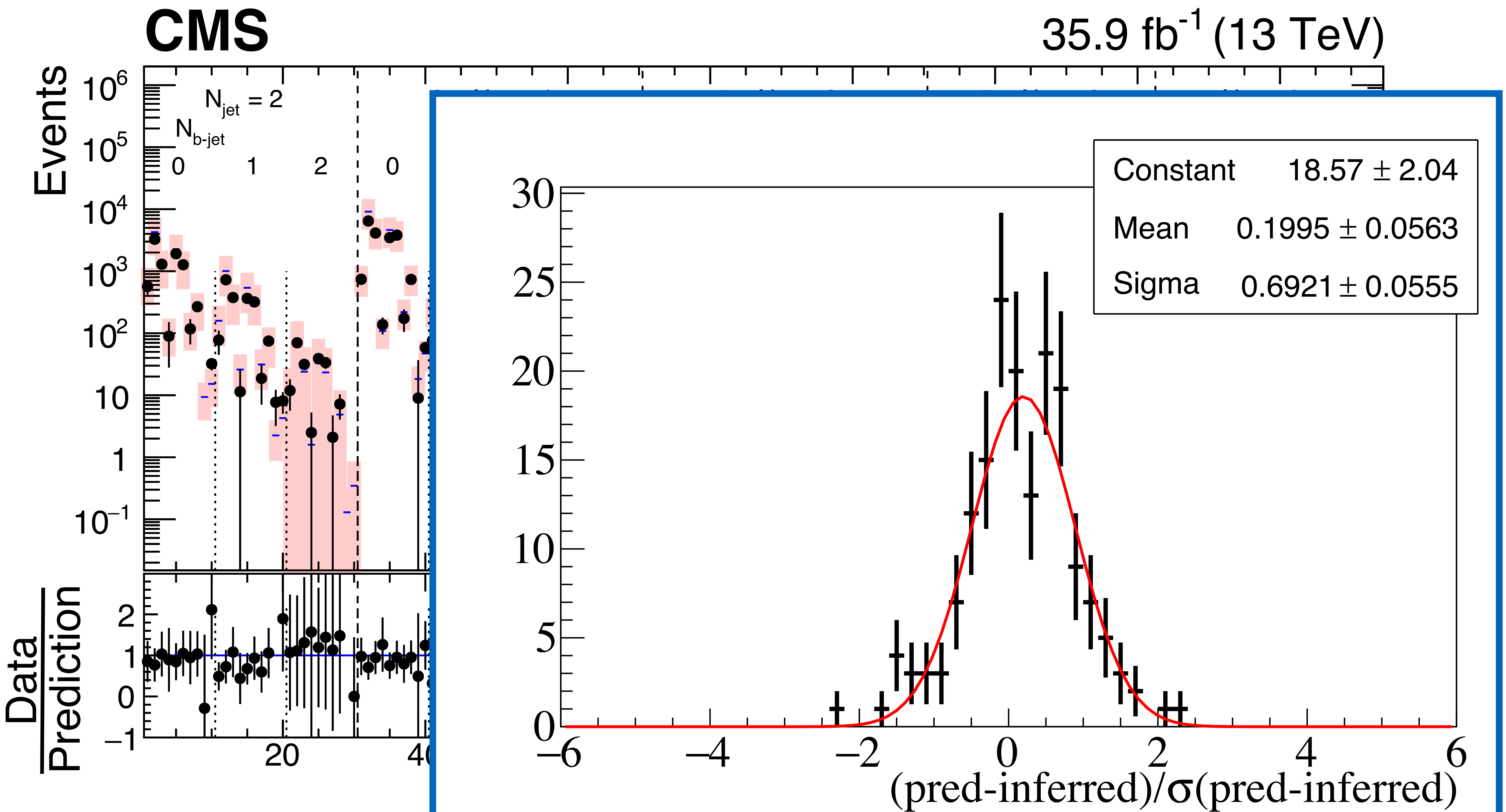
- Validation: consistency between **prediction** and **data** in each LDP search bin

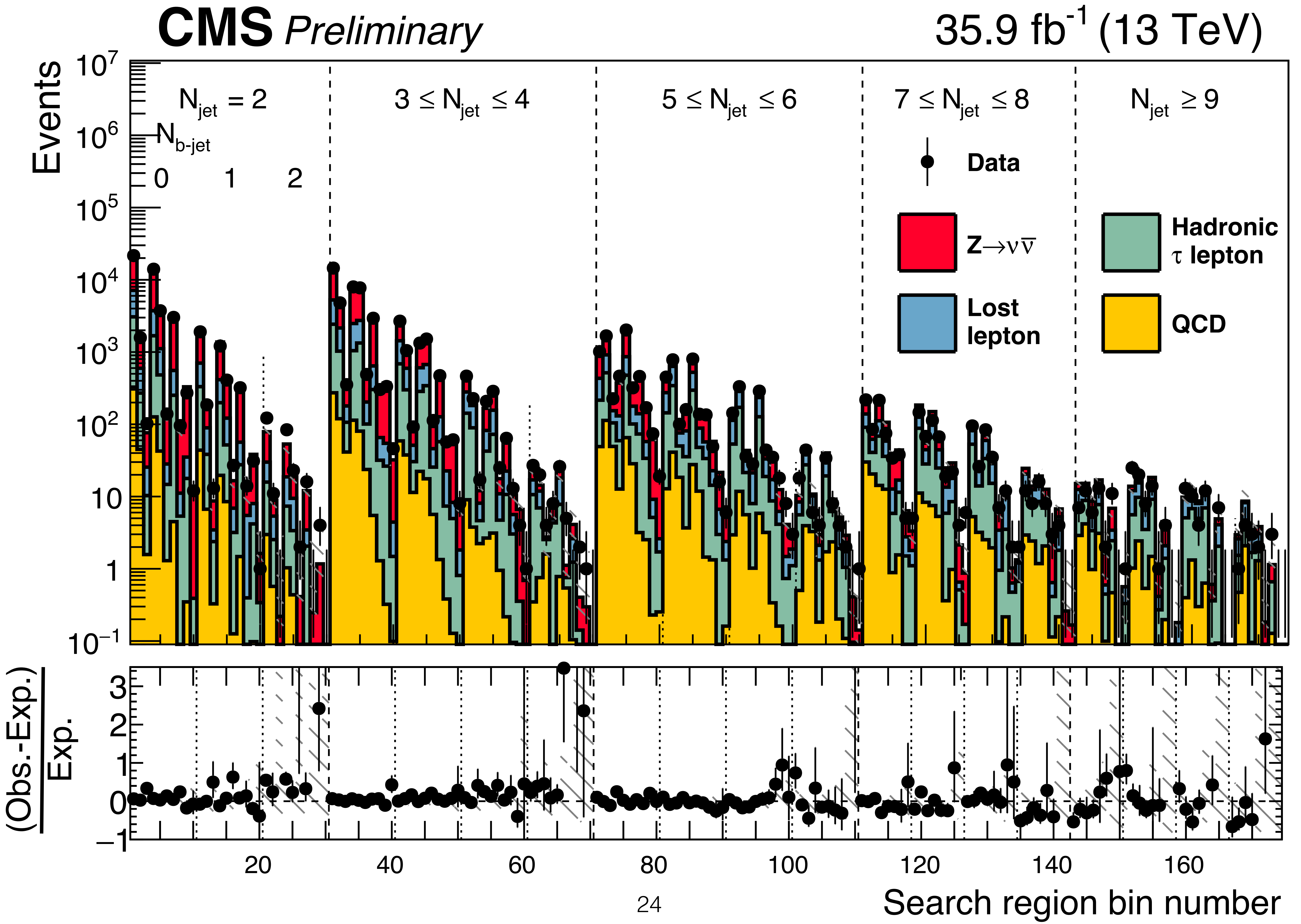


Method: *rebalance and smear*

QCD multi-jet

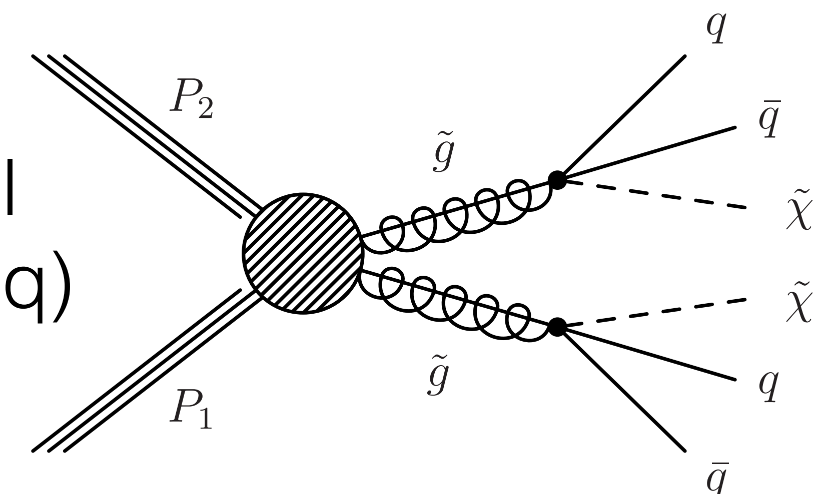
- Validation: consistency between **prediction** and **data** in each LDP search bin

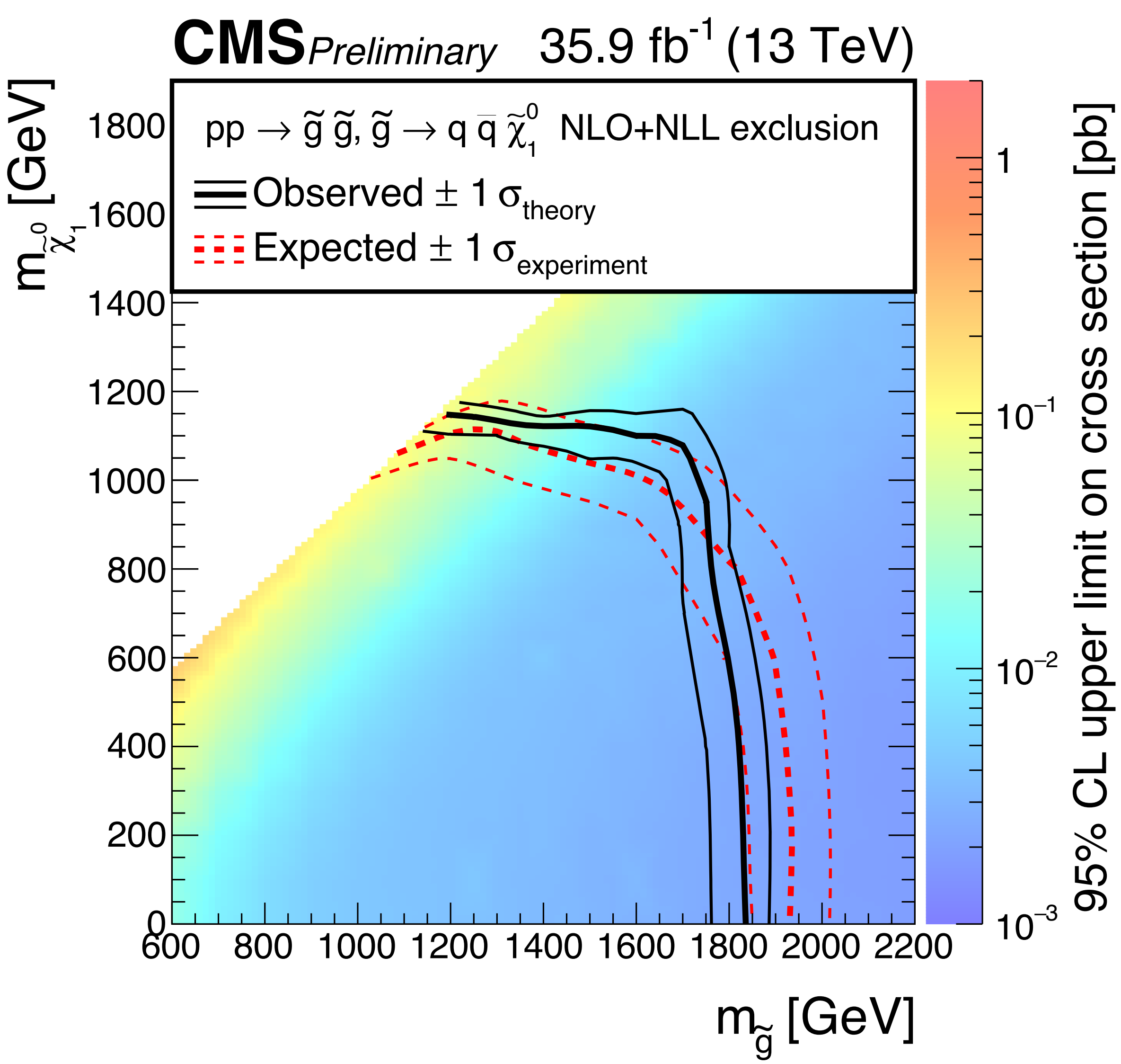



CMS Preliminary
35.9 fb-1 (13 TeV)
Events
N_jet = 2
3 ≤ N_jet ≤ 4
5 ≤ N_jet ≤ 6
7 ≤ N_jet ≤ 8
N_jet ≥ 9
N_b-jet
0 1 2
Data
Z→νν̄
Lost lepton
Hadronic τ lepton
QCD
(Obs.-Exp.)/Exp.
Search region bin number

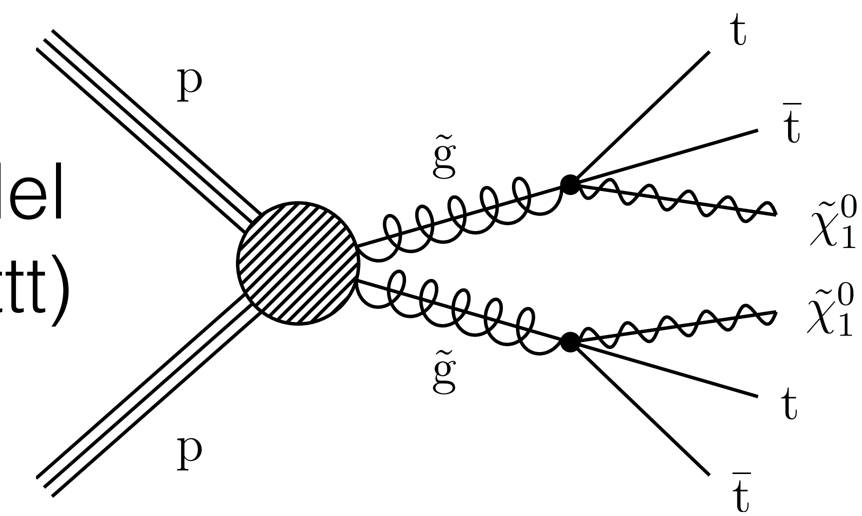
Interpretation

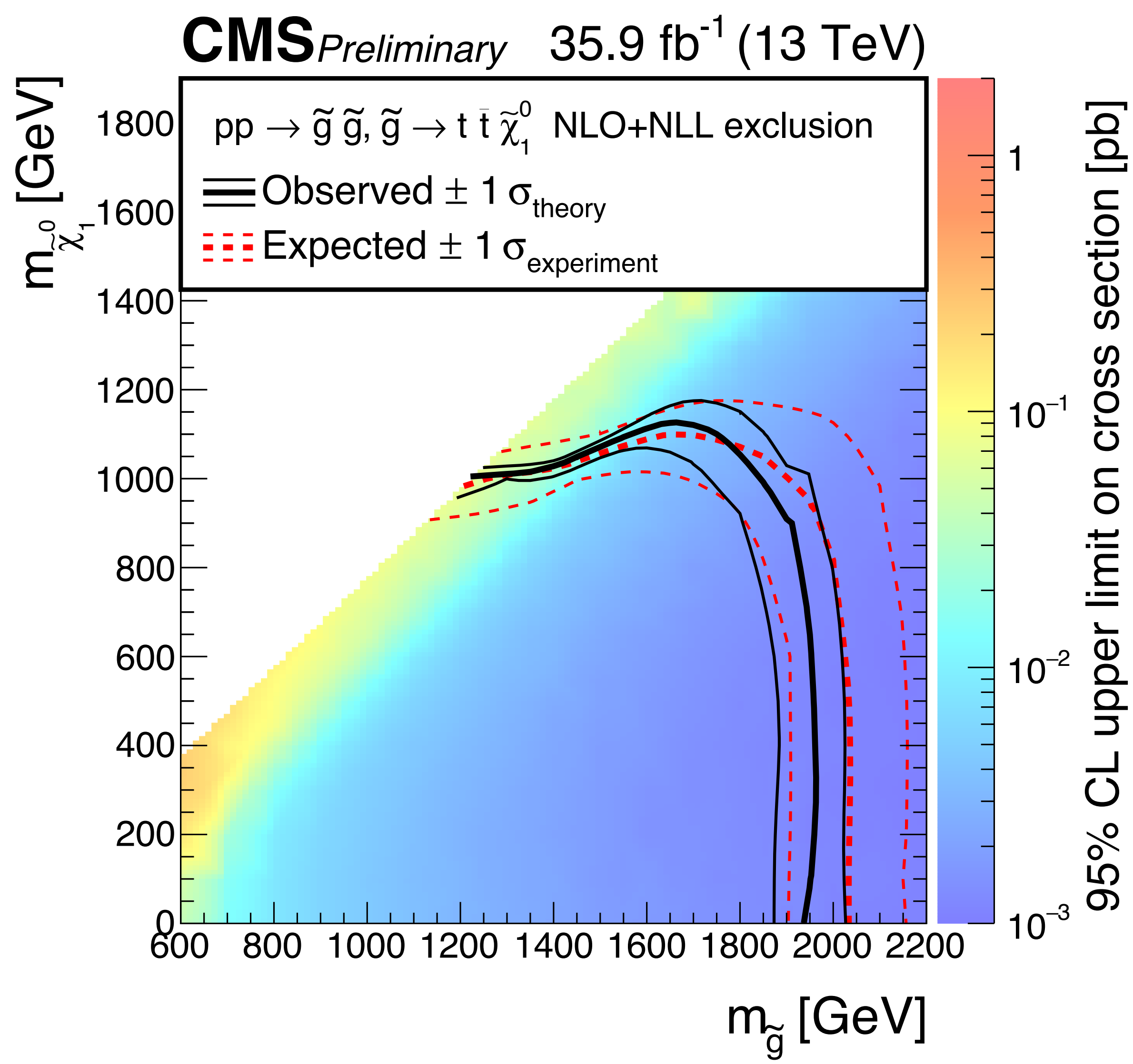
Model (T1qqqq)





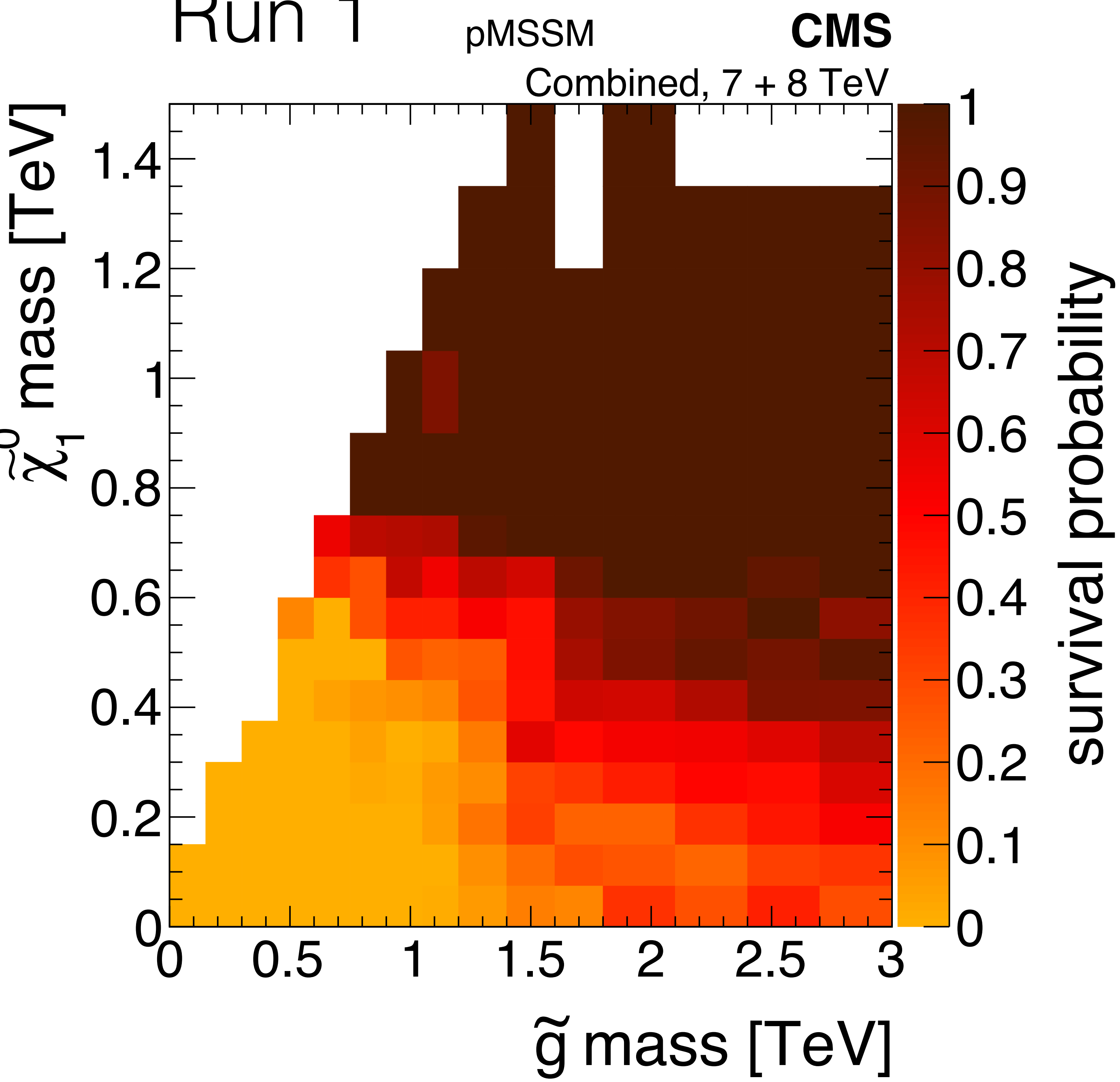
Model (T1tttt)





Interpretation

Run 1



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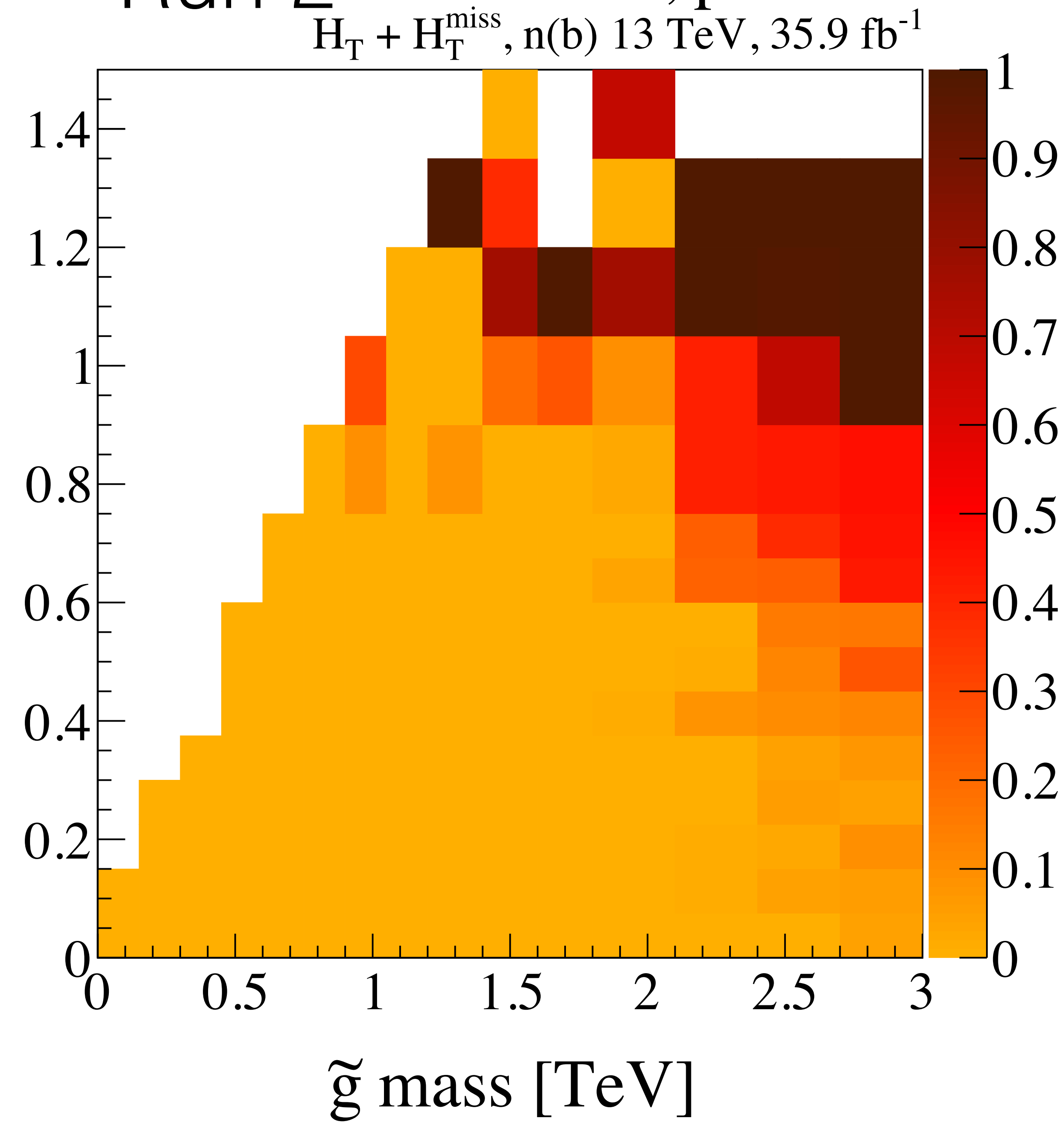
Run 2



private work

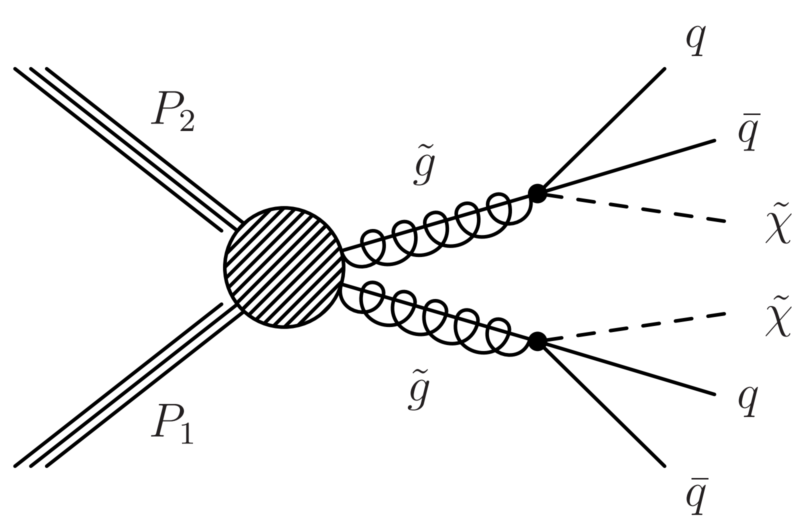
Summary

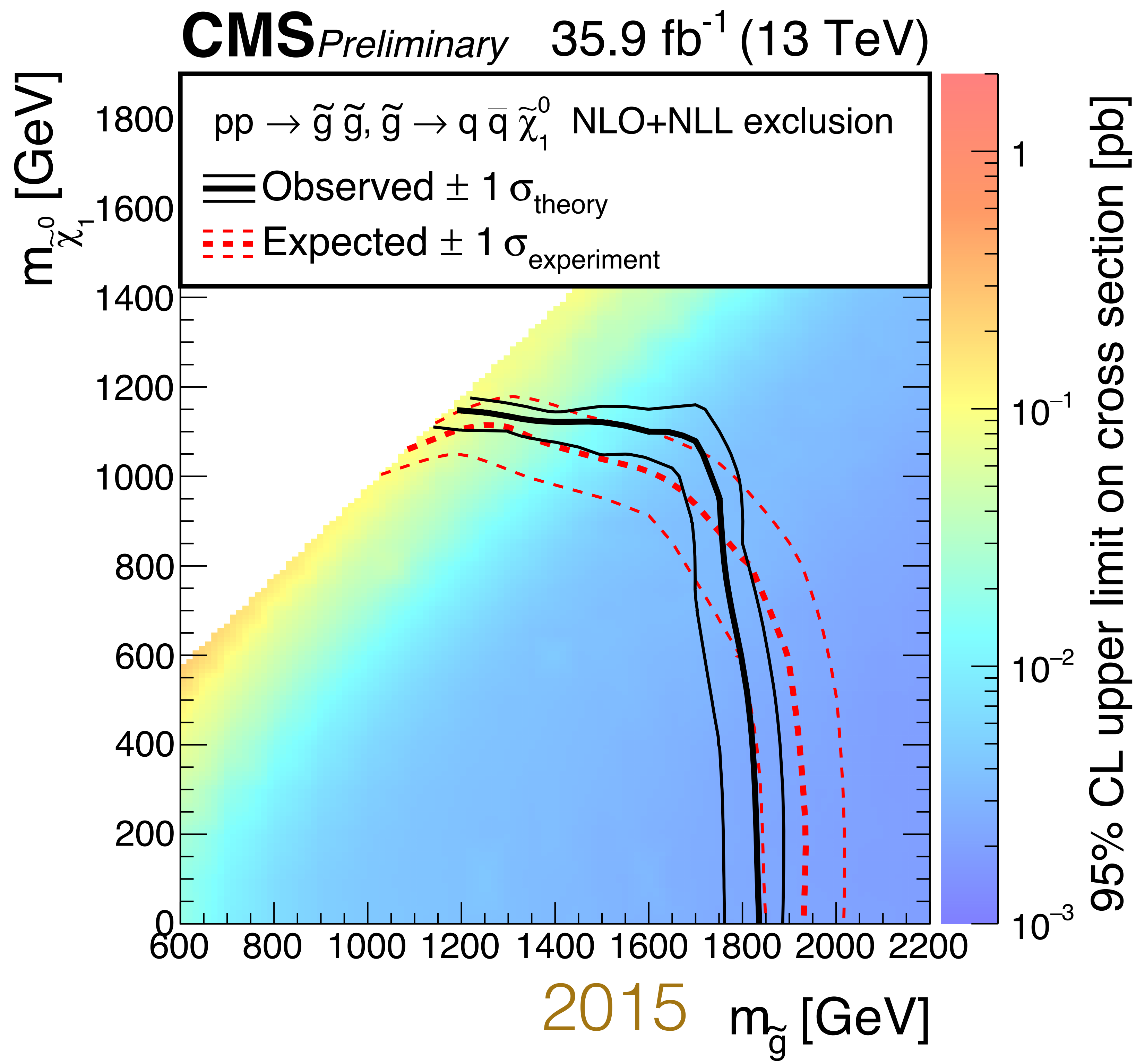
- Data-driven search for supersymmetry in the all-hadronic channel presented
- An absence of significant signal
- Interpretation in terms of simplified models sets an upper limit on the gluino mass of 1800-2000 GeV, depending on the model, assuming a light LSP.
- Wide swaths of the pMSSM parameter space excluded by this 2016 search.

Backup

Interpretation

Model
(T1qqqq)

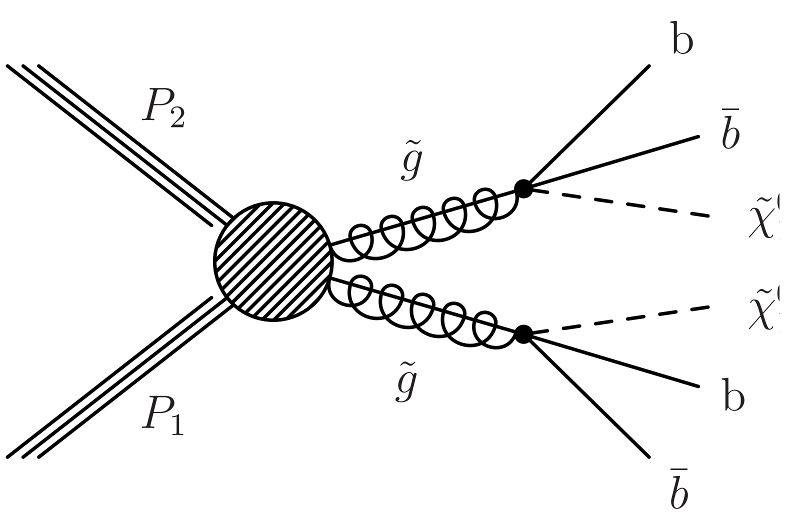


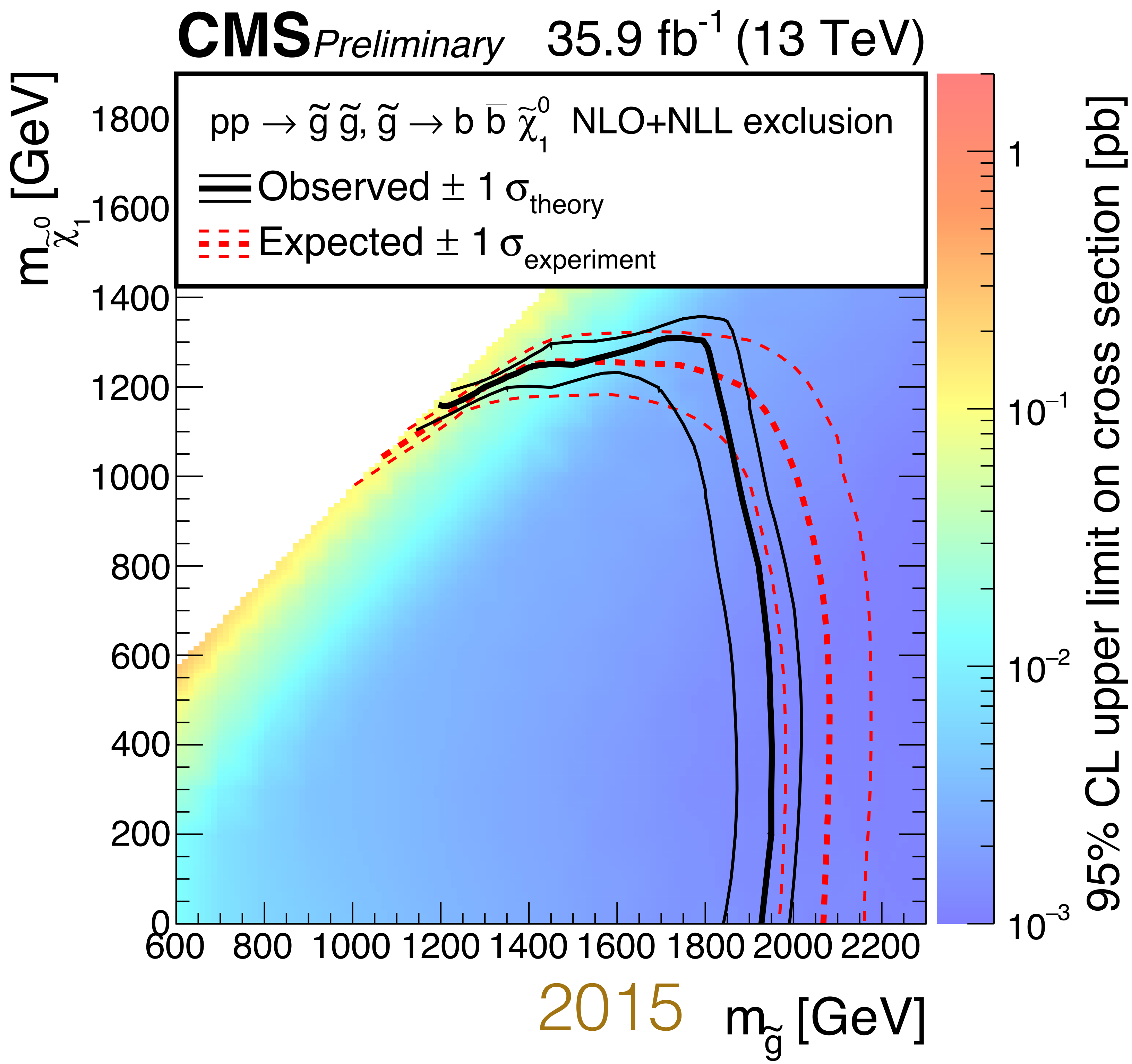


2015

Interpretation

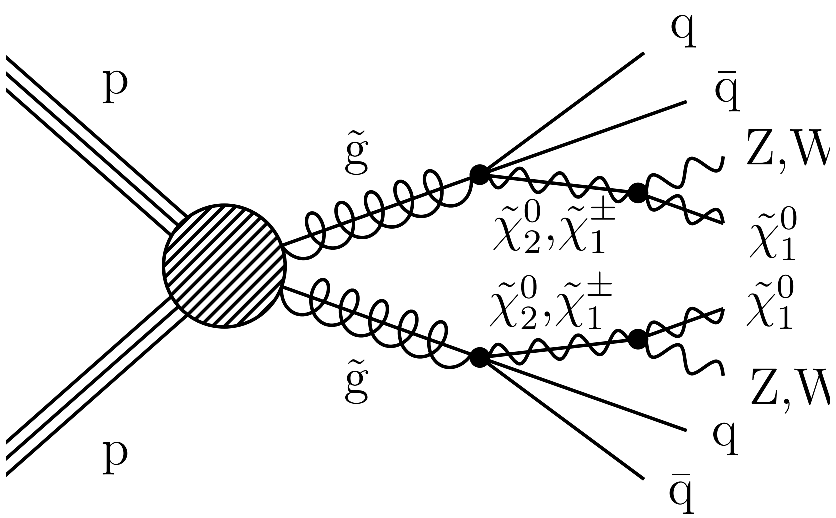
Model
(T1bbbb)

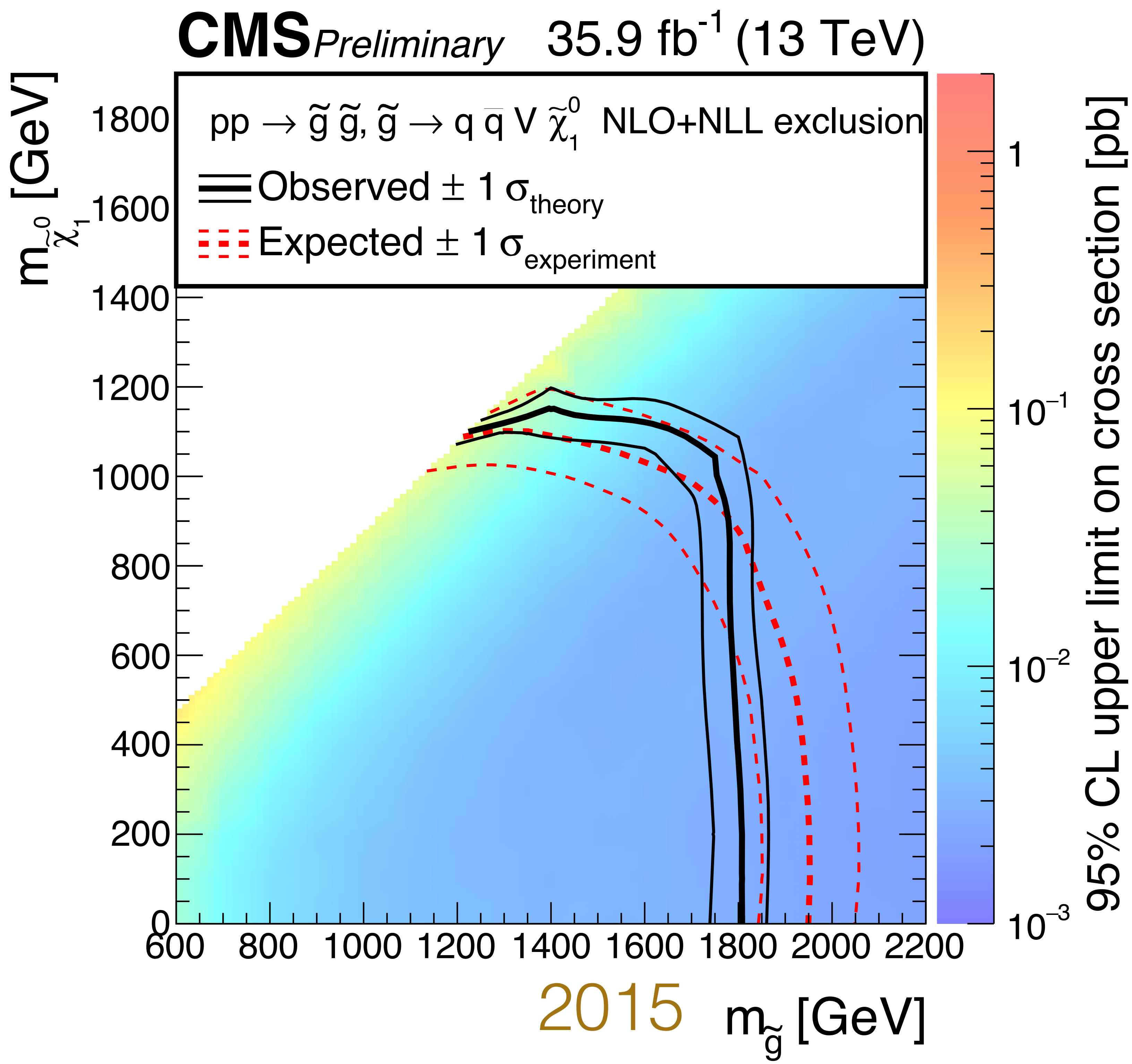




Interpretation

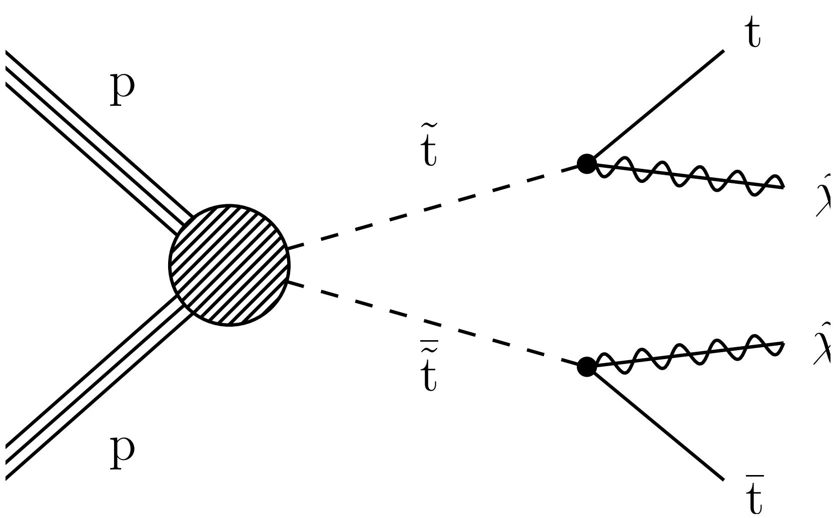
Model
(T5qqqqVV)

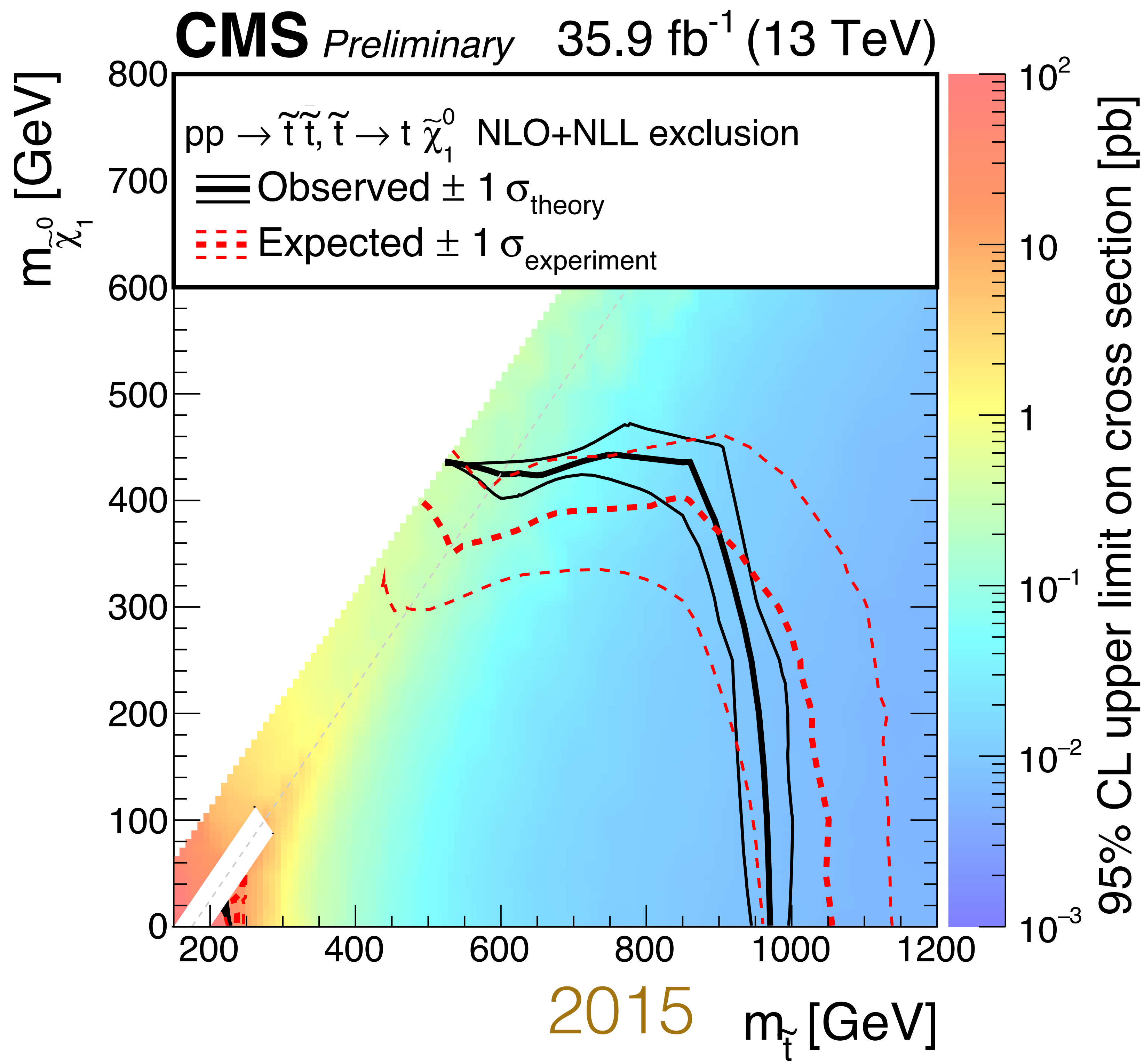




Interpretation

Model
(T2tt)





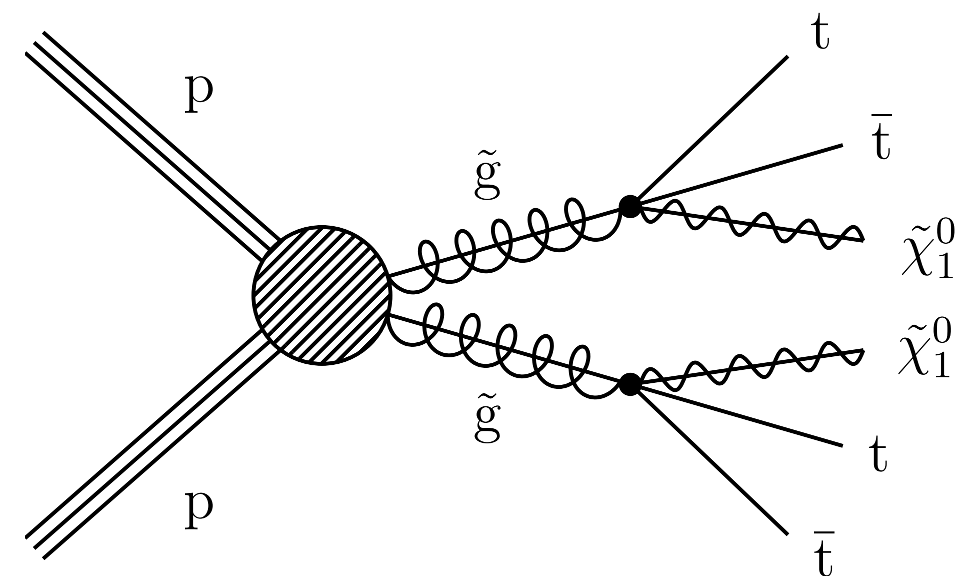
2015

Signal systematics

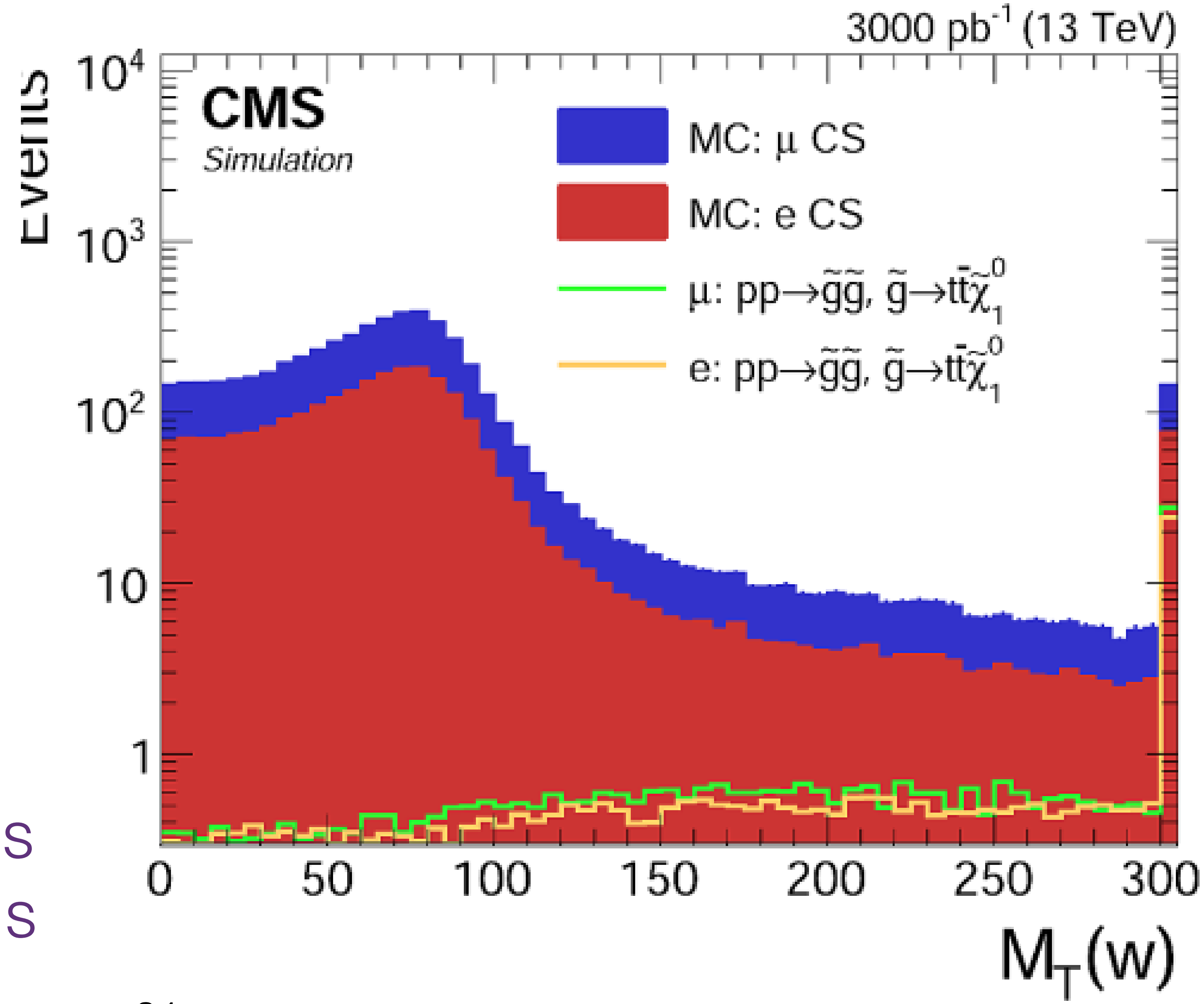
- Luminosity (3%)
- Trigger efficiency (<1%)
- ISR uncertainty (0.1-10.0%)
- Jet energy scale (0.01-1.1%)
- Jet energy resolution (0.01-1.1%)
- Total (3.0-13.0%)

$$W \rightarrow e\nu_e(\mu\nu_\mu) + \text{jets}$$

(including Ws from ttbar)



- SUSY models may abundantly populate the single-lepton control region (SC)
- Ceiling threshold of 100 GeV placed on the transverse mass of the leptons in CR to mitigate potential BSM contamination



SC < 0.1% in most bins
SC ~ 60% in a few bins

$W \to \tau\nu_\tau + \text{jets}, \; \tau \to \text{hadrons}$

- Procedure carried out in a simulated single-muon event sample, and compared with the expected result obtained from a simulated had-tau event sample.
  - Cross check shows agreement within ~15%