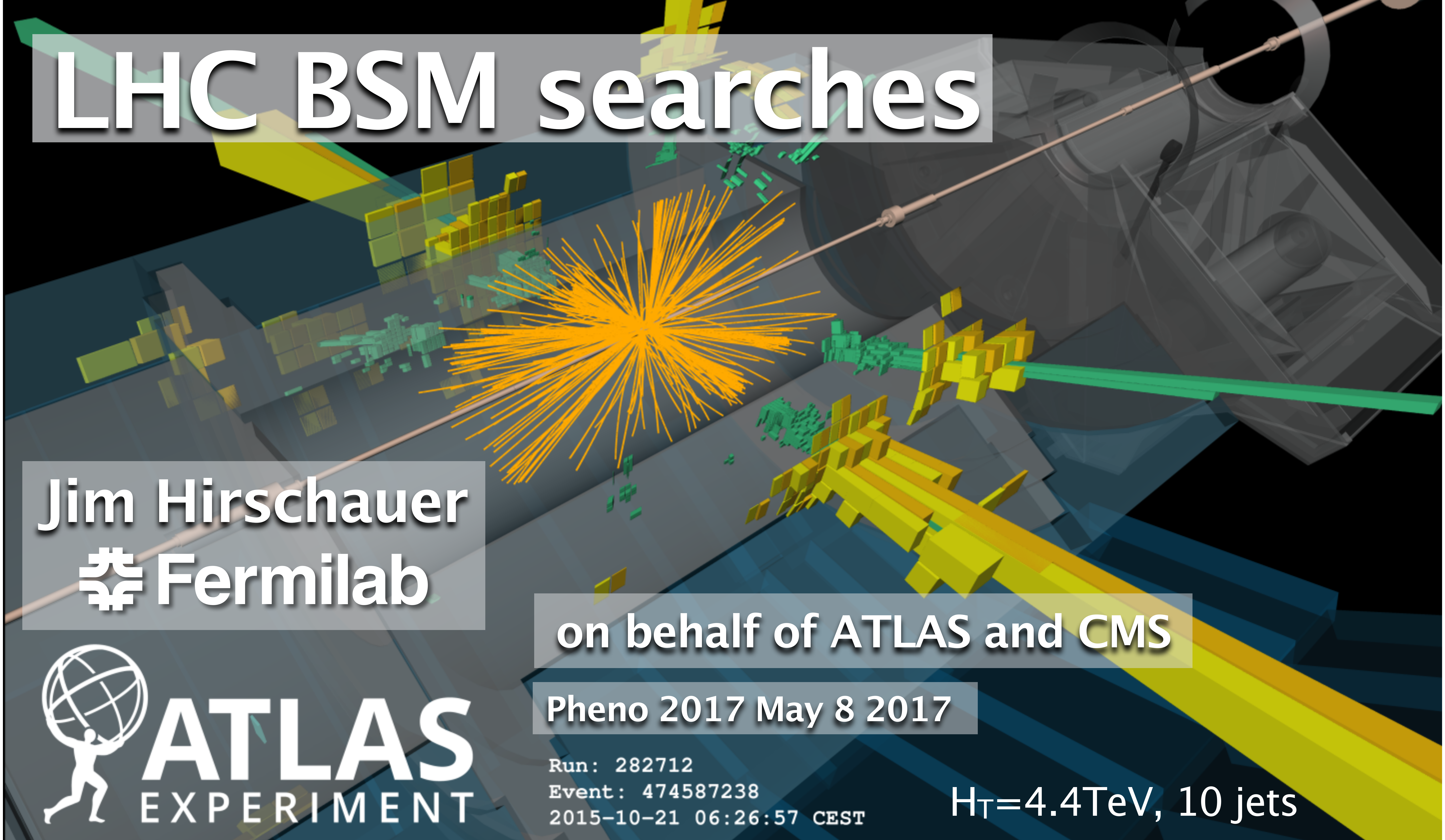
LHC BSM searches

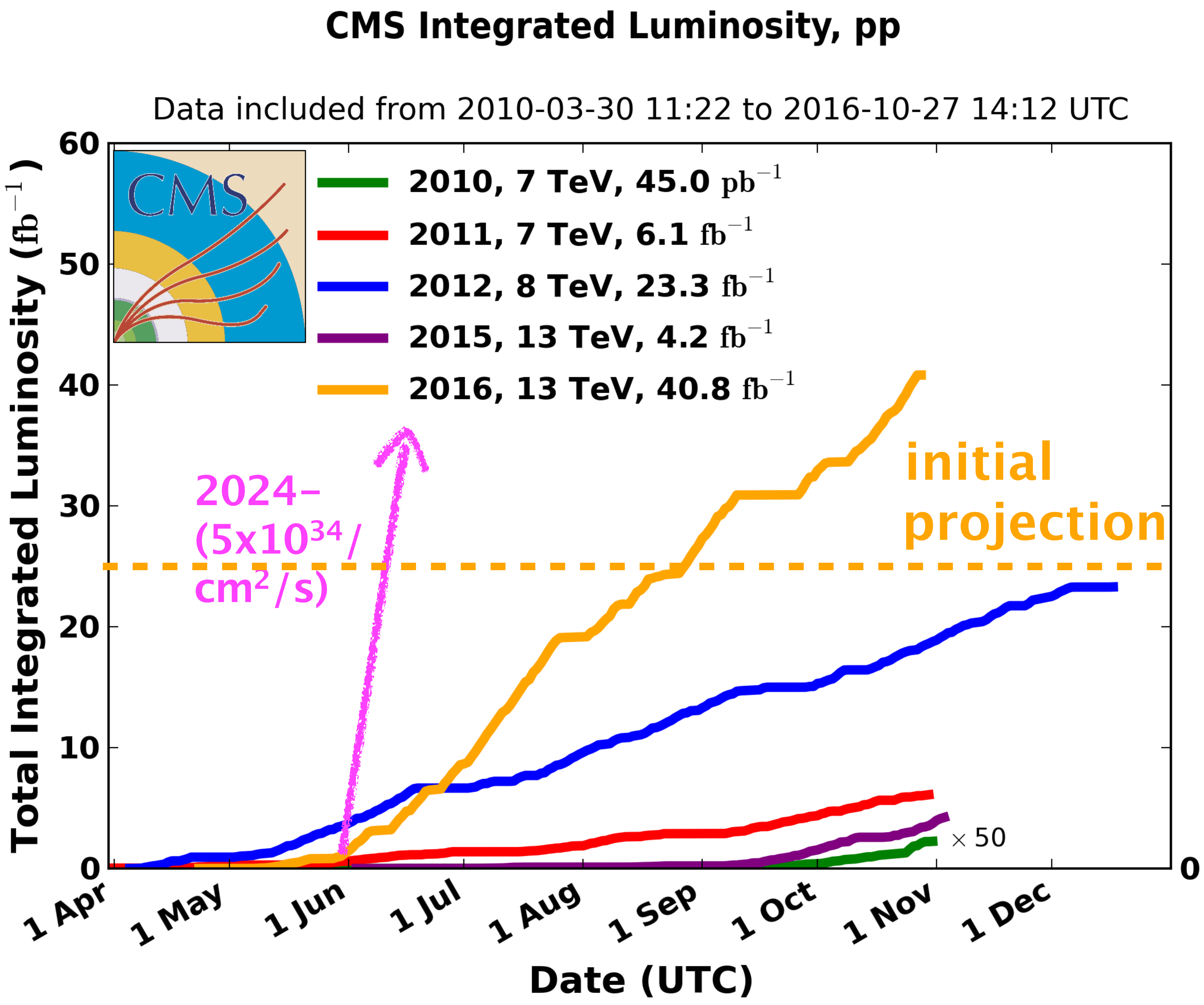
Jim Hirschauer
Fermilab

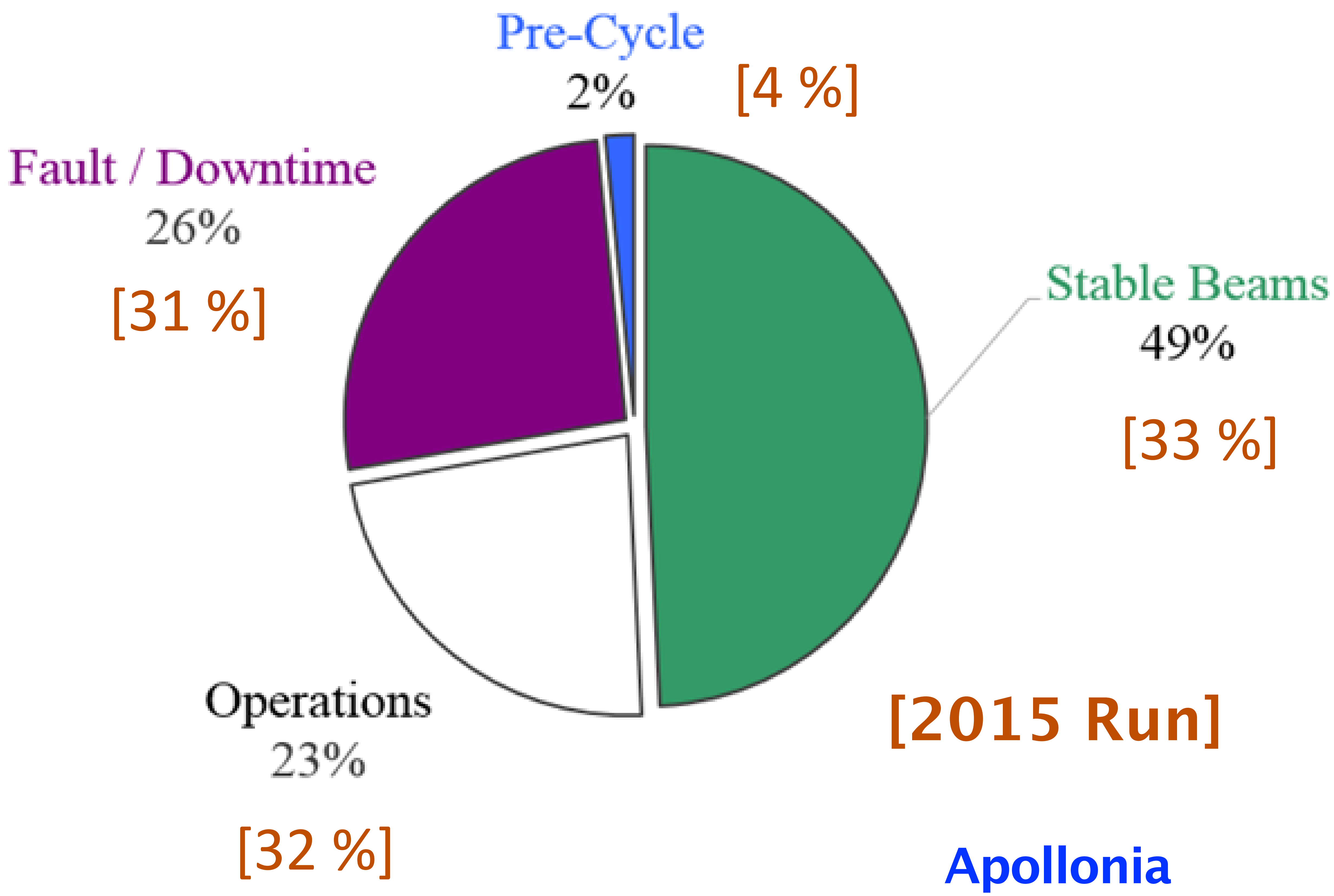
on behalf of ATLAS and CMS

Pheno 2017 May 8 2017



Incredible LHC!





Apollonia
Chamonix 2017

Outline

- Focus on new BSM results from **full 36 fb^{-1} 13 TeV** dataset
  - >50 results from ATLAS and CMS!

- Focus on **tools** and **techniques** for **challenging signatures**
- No roadmap, so we need to look everywhere combining:
  - **signature-based generic searches**
  - **model-driven targeted searches**

- Topics for today:
  - Resonances
  - Dark matter
  - Supersymmetry

  Hiding new phenomena:
  - R-parity violating supersymmetry
  - Long-lived particles

Will not discuss these general categories

- Vector-like quarks

Alice Bean: Search for VLQ (CMS)
Erich Ward Varnes: Search for VLQ (ATLAS)

- Inclusive searches

Deborah Duchardt: Model Unspecific Search (CMS)

- BSM Higgs

Sven Dildick: Light BSM Higgs (CMS)
Roberto Rossin: HH (CMS)
Koji Sato: Neutral/charged BSM Higgs (ATLAS)
Jason Robert Veatch: Exotic Higgs decays and HH (ATLAS)

Note on references

- Results can be found here:

  https://twiki.cern.ch/twiki/bin/view/AtlasPublic

  http://cms-results.web.cern.ch/cms-results/public-results/publications/

- ATLAS preliminary results: **CONF-20YY-XXX**
- CMS preliminary results: **EXO-YY-XXX, SUS-YY-XXX, etc.**

Resonances

- Results from full 36/fb 13 TeV dataset

Dijet resonances

- EXO-16-056
- arXiv:1703.09127

New gauge bosons

- CONF-2017-027 : $Z' \rightarrow \ell^{\pm}\ell^{\pm}$
- CONF-2017-016 : $W' \rightarrow \ell^{\pm}\nu$

Dibosons

- B2G-17-001 : X ➔ VV ➔ JJ

X ➔ VH

- B2G-17-002 : X ➔ VH ➔ qqbb
- CONF-2017-018 : X ➔ VH ➔ qqbb

X ➔ HH

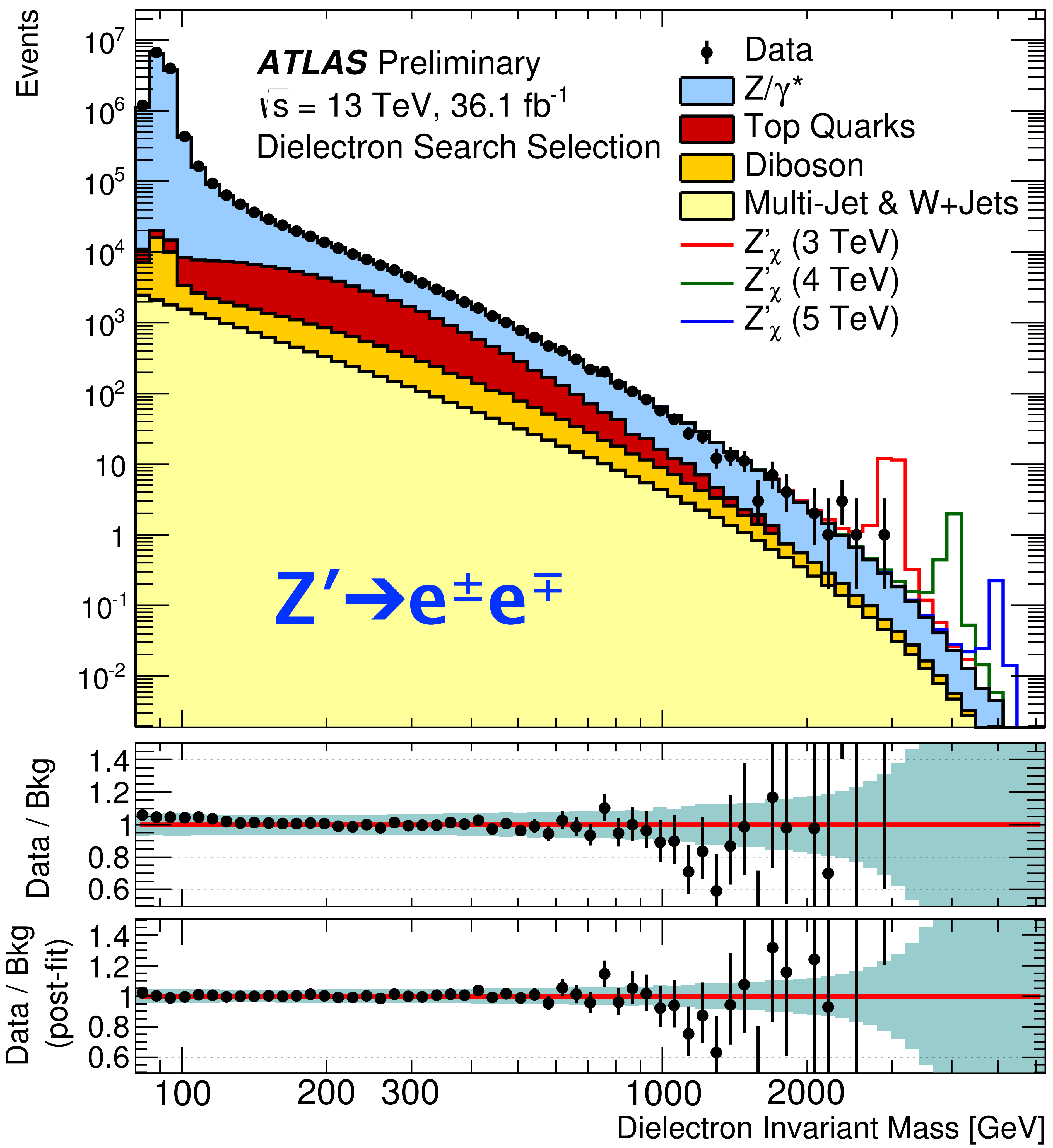
- HIG-17-006 : X ➔ HH ➔ bbWW
- HIG-17-002 : X ➔ HH ➔ $bb\tau\tau$

Parallel talks (CMS/ATLAS):

Jan-Frederik Schulte: Resonances with ℓ, γ, and jets CMS
Sung Won Lee: Resonances with W, Z and H bosons CMS
Petar Maksimovic: Resonances coupling to 3rd gen quarks CMS
Maurice Becker: Multi boson final states ATLAS
Mark Oreglia: VH and HH Resonances ATLAS
Chris Malena Delitzsch: VV/V+gamma Resonances ATLAS

New gauge bosons: X'➔ $\ell^{\pm}\nu$ or $\ell^{\pm}\ell^{\mp}$

CONF-2017-027



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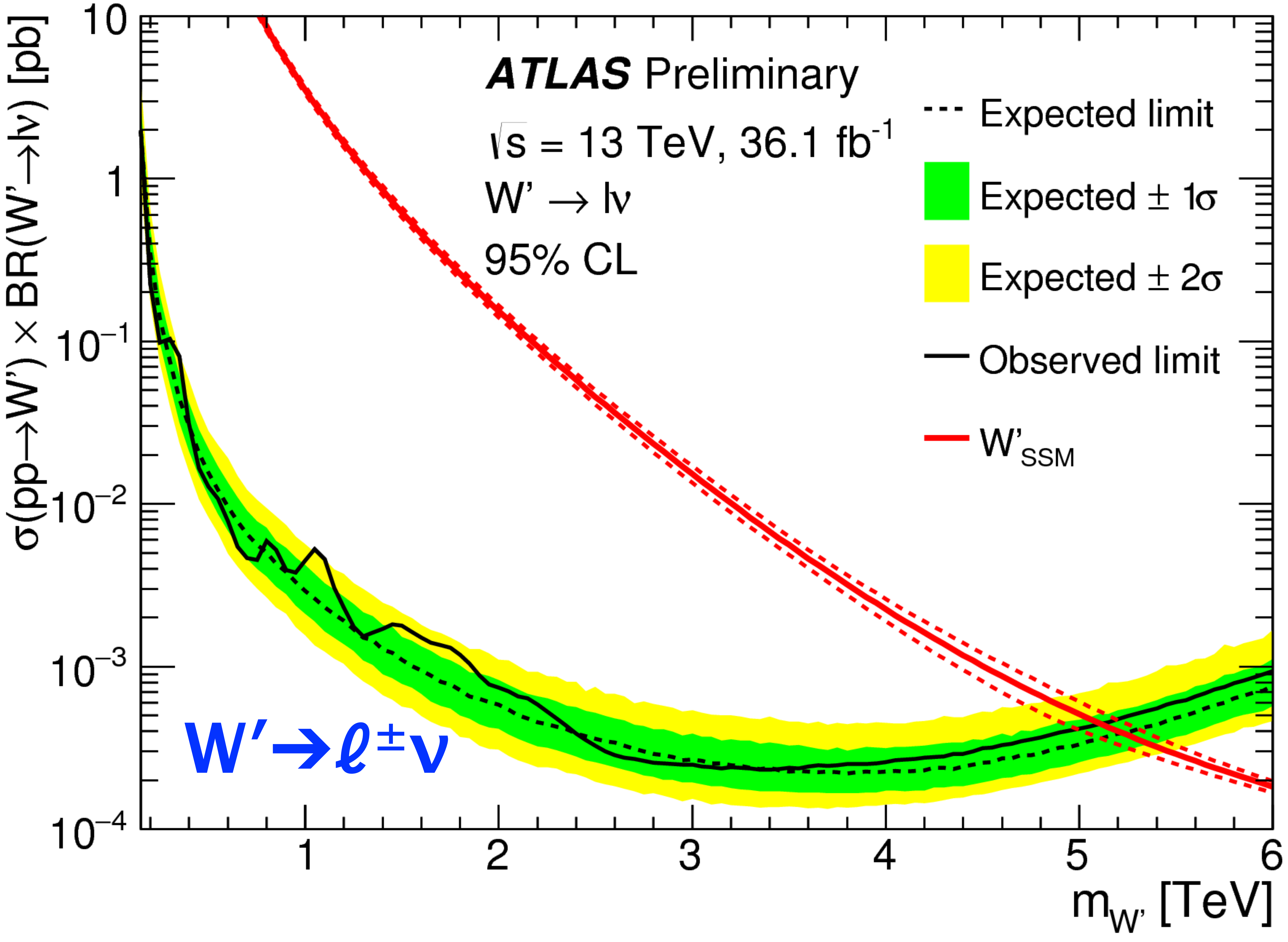


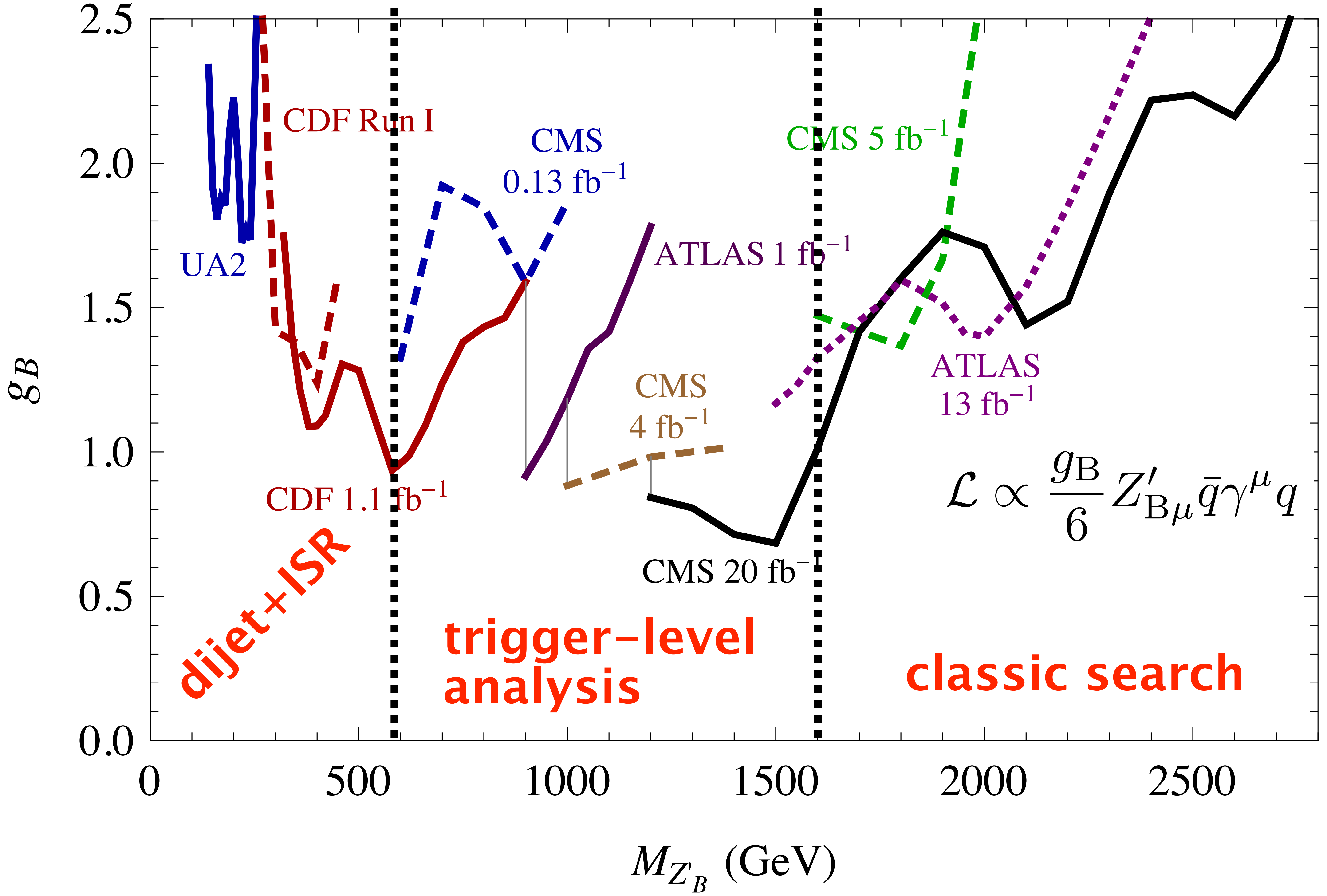
Dijet resonances

- Leptophobic Z′ with couplings to quarks: $\mathcal{L} \propto \frac{g_B}{6} Z'_{B\mu} \bar{q} \gamma^\mu q$
- Unexplored couplings at all Z′ masses
- Challenging to trigger for $M_{Z'}$<1.5 TeV

Techiques:

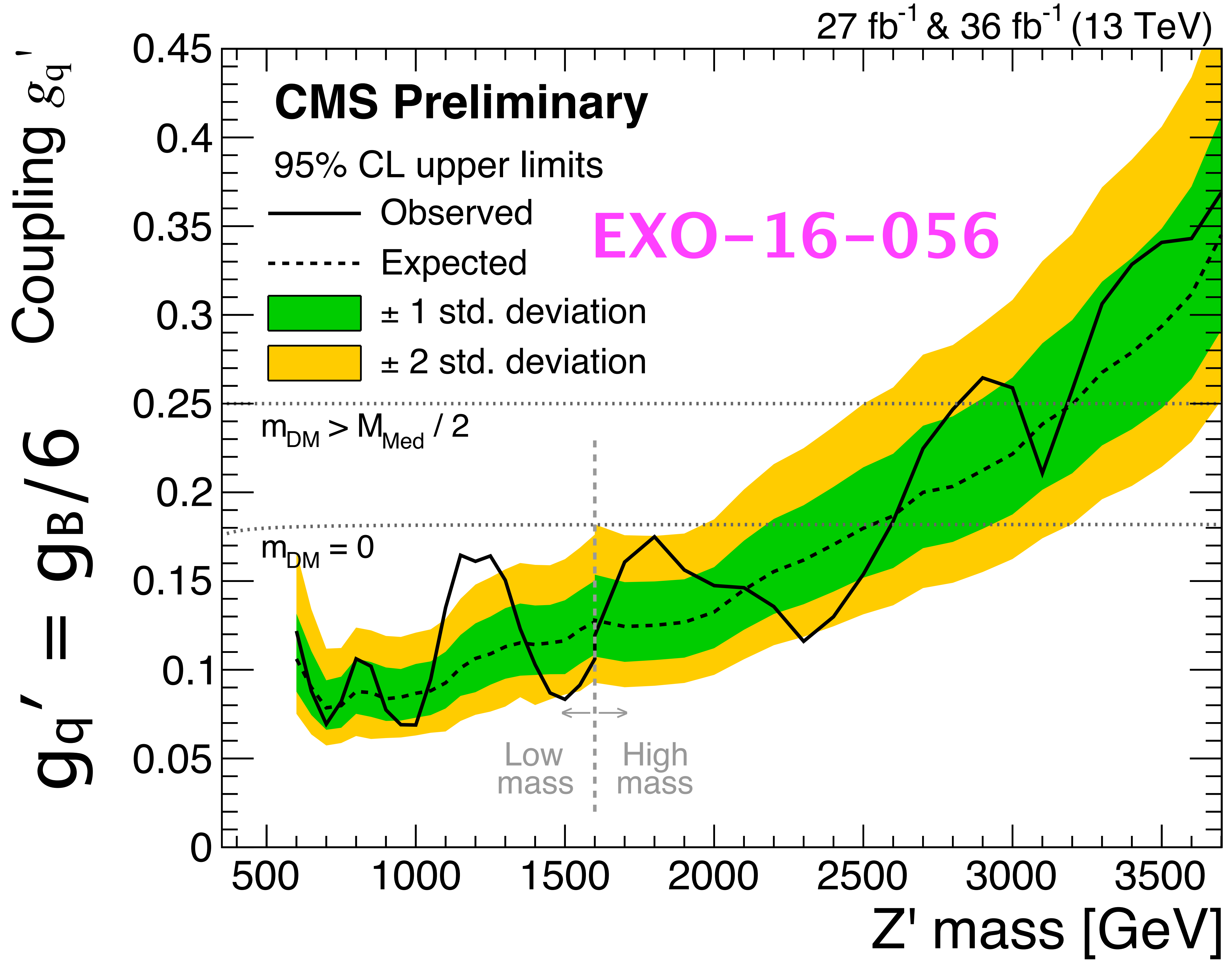
mass range	method
>1500 GeV	classic
600–1500 GeV	trigger–level analysis
250–600 GeV	ISR + resolved dijet
< 250 GeV	ISR + merged dijet

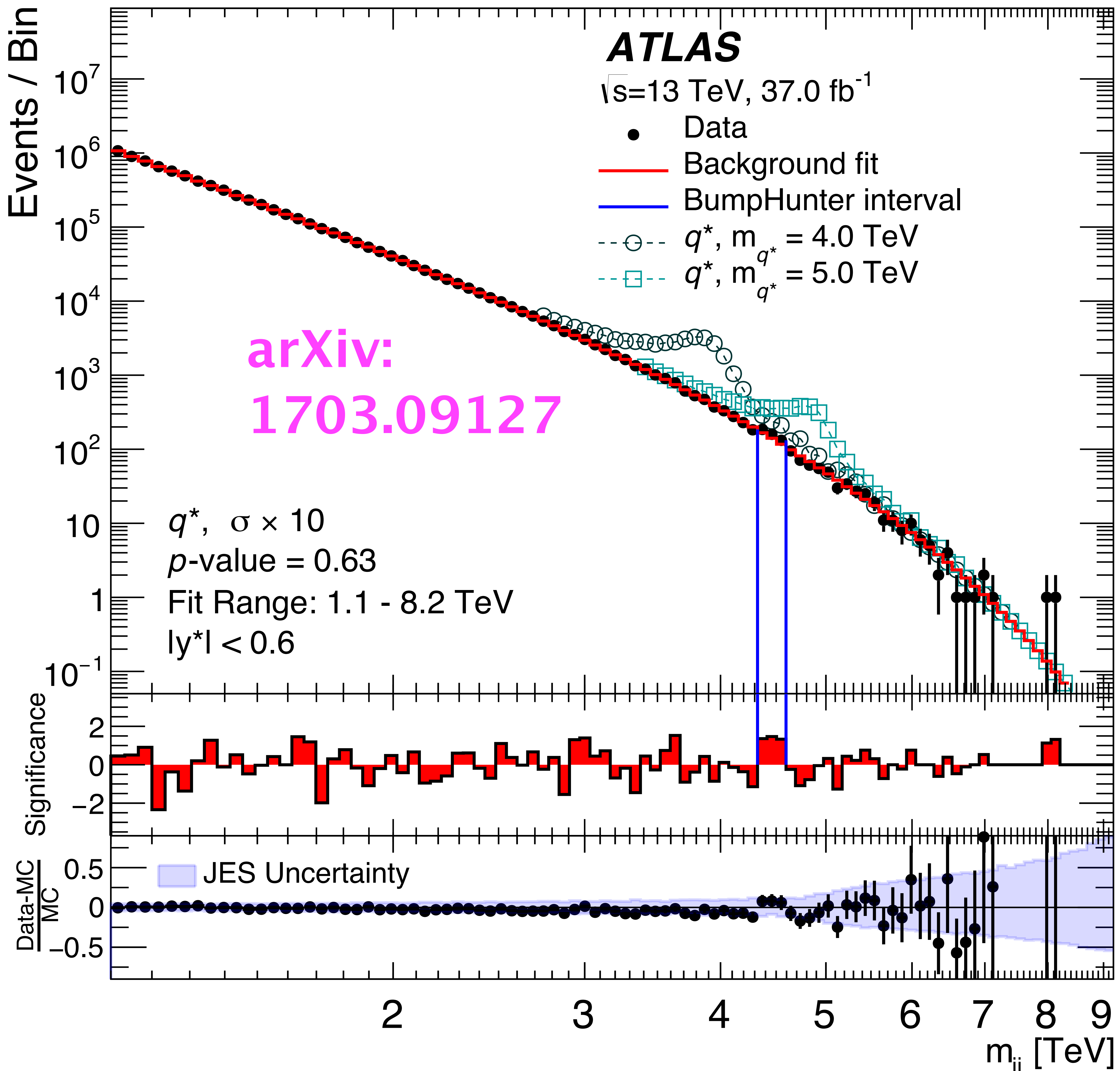
Dobrescu, Yu arXiv:1306.2629



Dijets with M_{jj} > 500 GeV

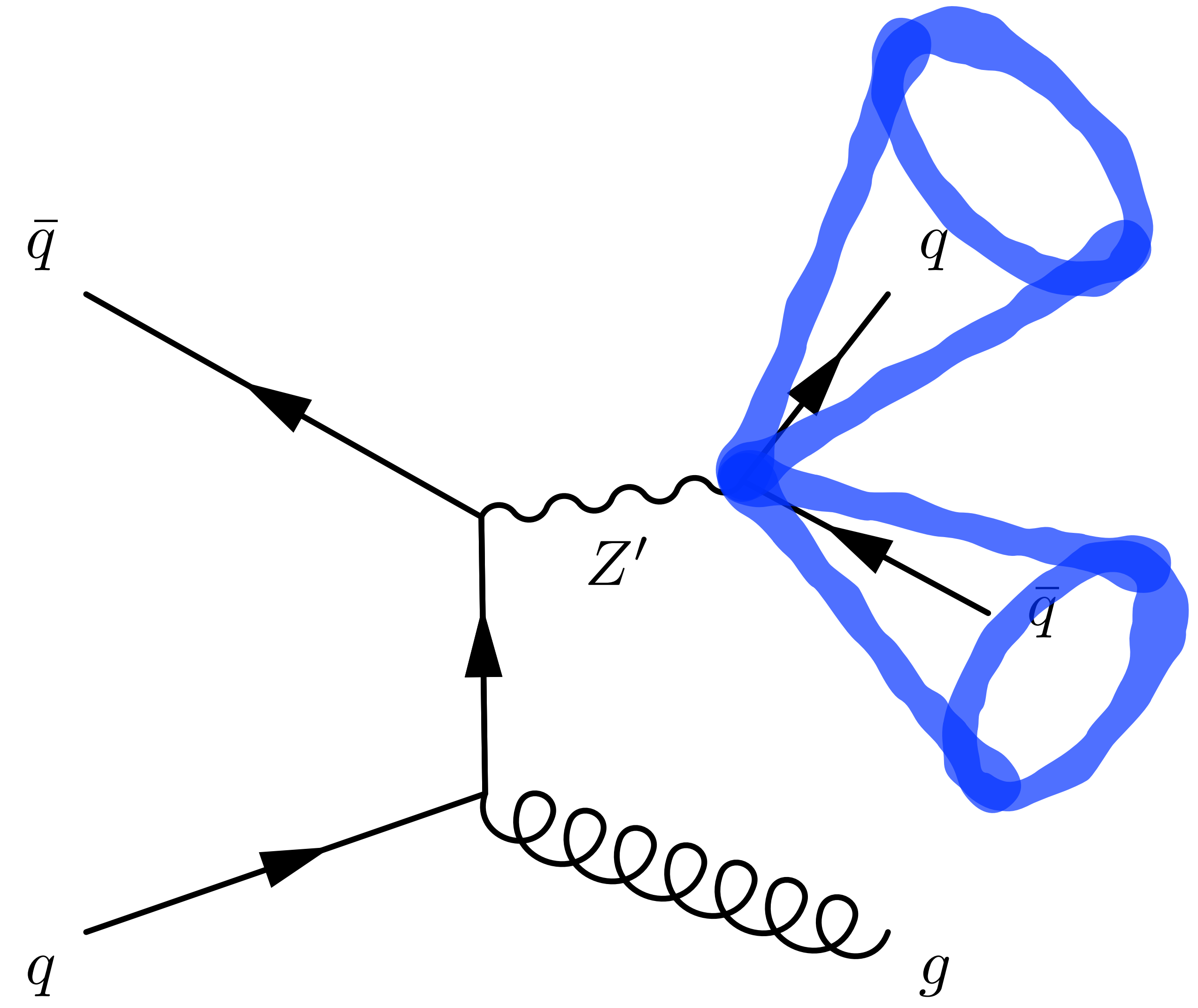
- Classic resonance search for Mjj > 1.5 TeV
- Trigger-level analyses for 500<Mjj<1500 GeV
  - Entire L1 trigger: **1 kHz** @ 1 MB/evt
  - Dijet trigger: **3 kHz** @ 1.5 kB/evt

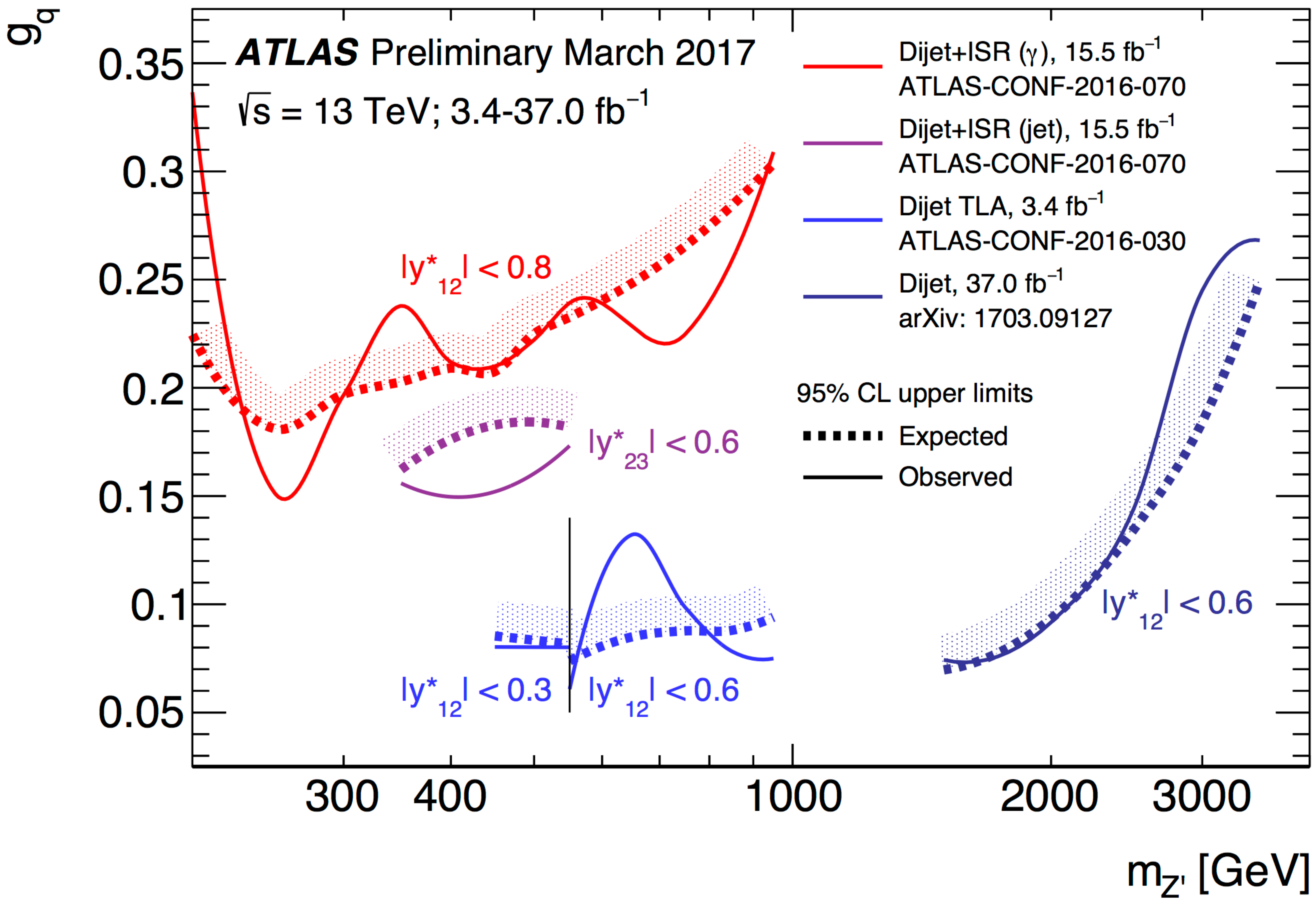




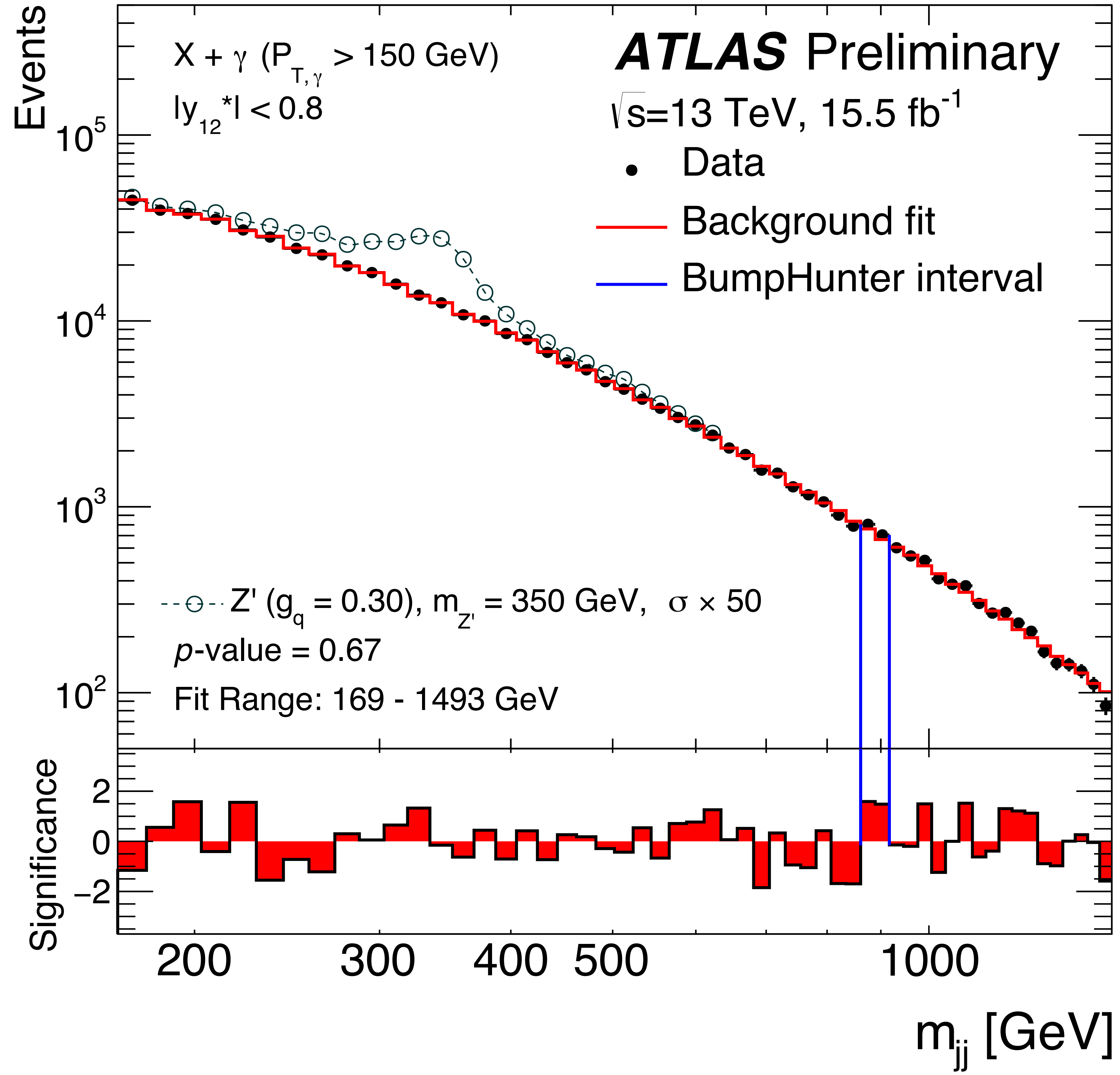
Dijets with $250<M_{jj}<500$ GeV

- **ISR jet + resolved dijet** benefits from high ISR rate
- **ISR γ + resolved dijet** benefits from low threshold and no combinatorial concerns.



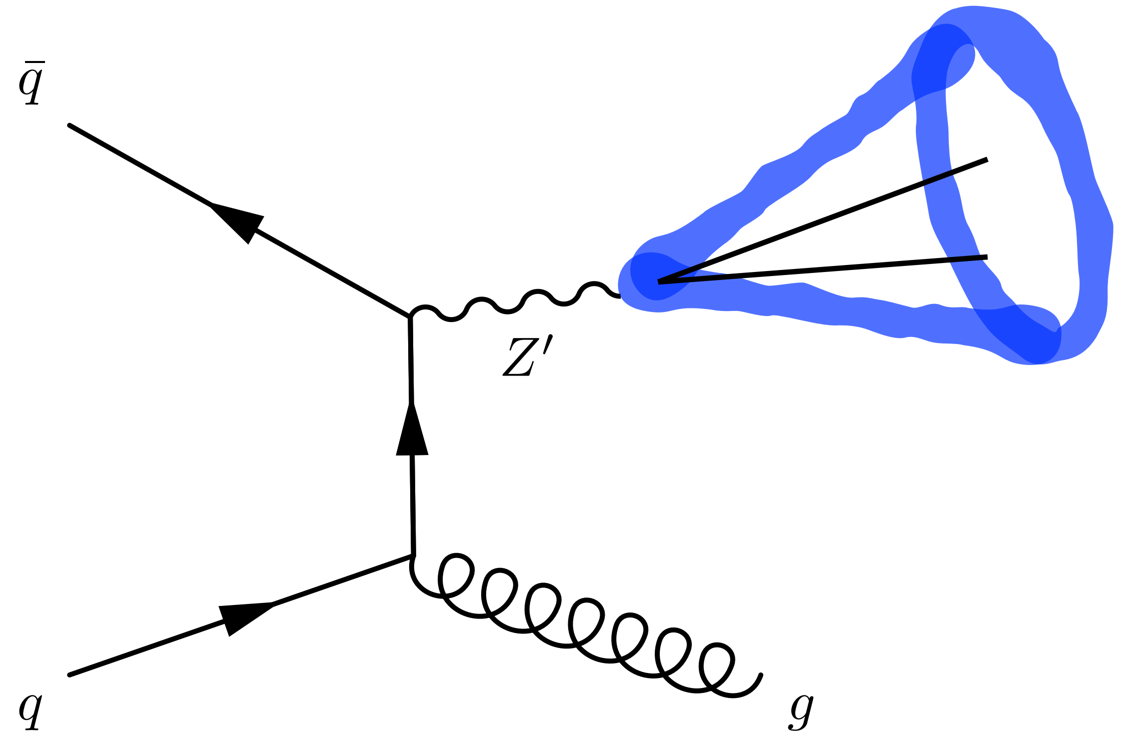


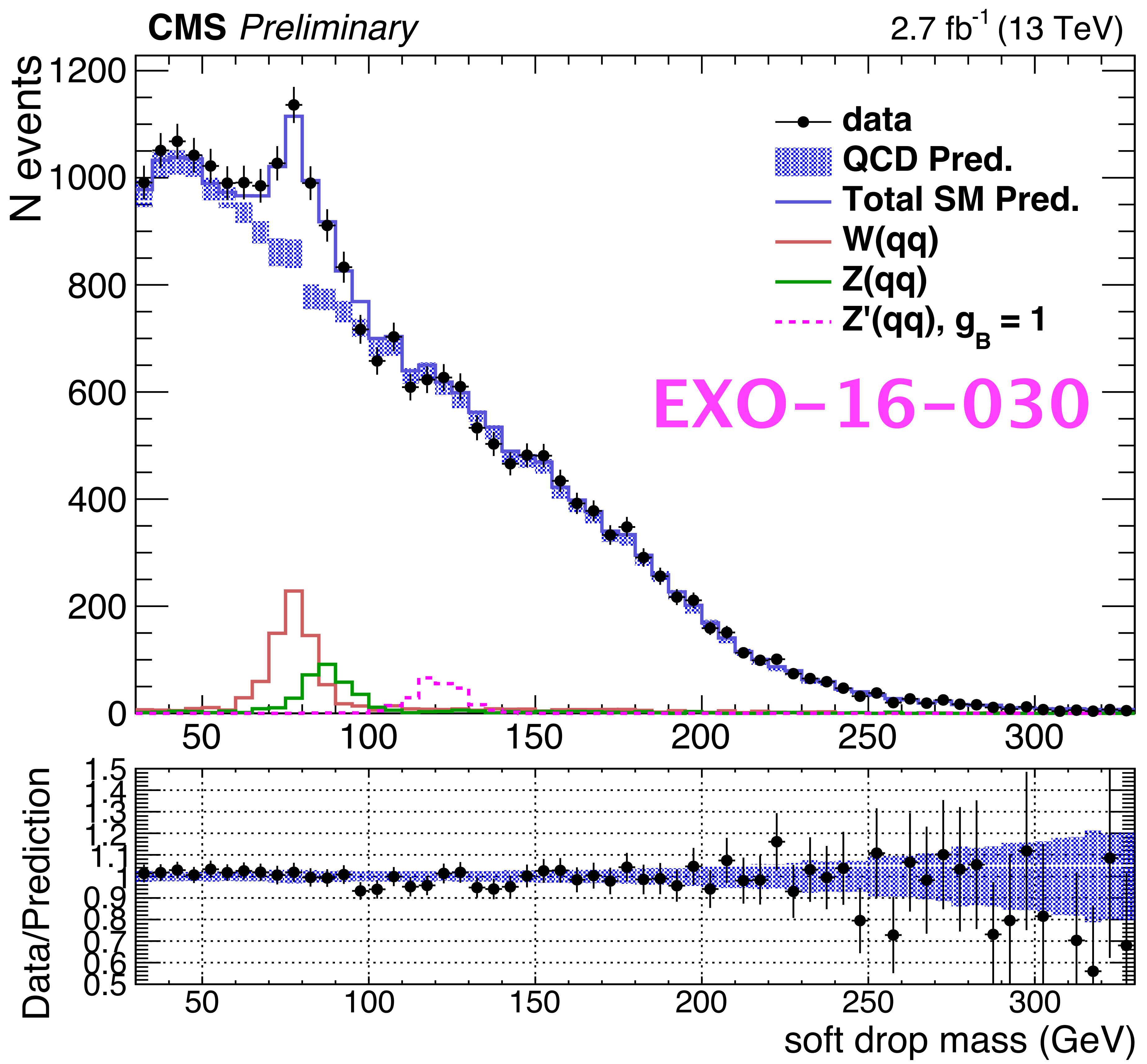
CONF-2016-070

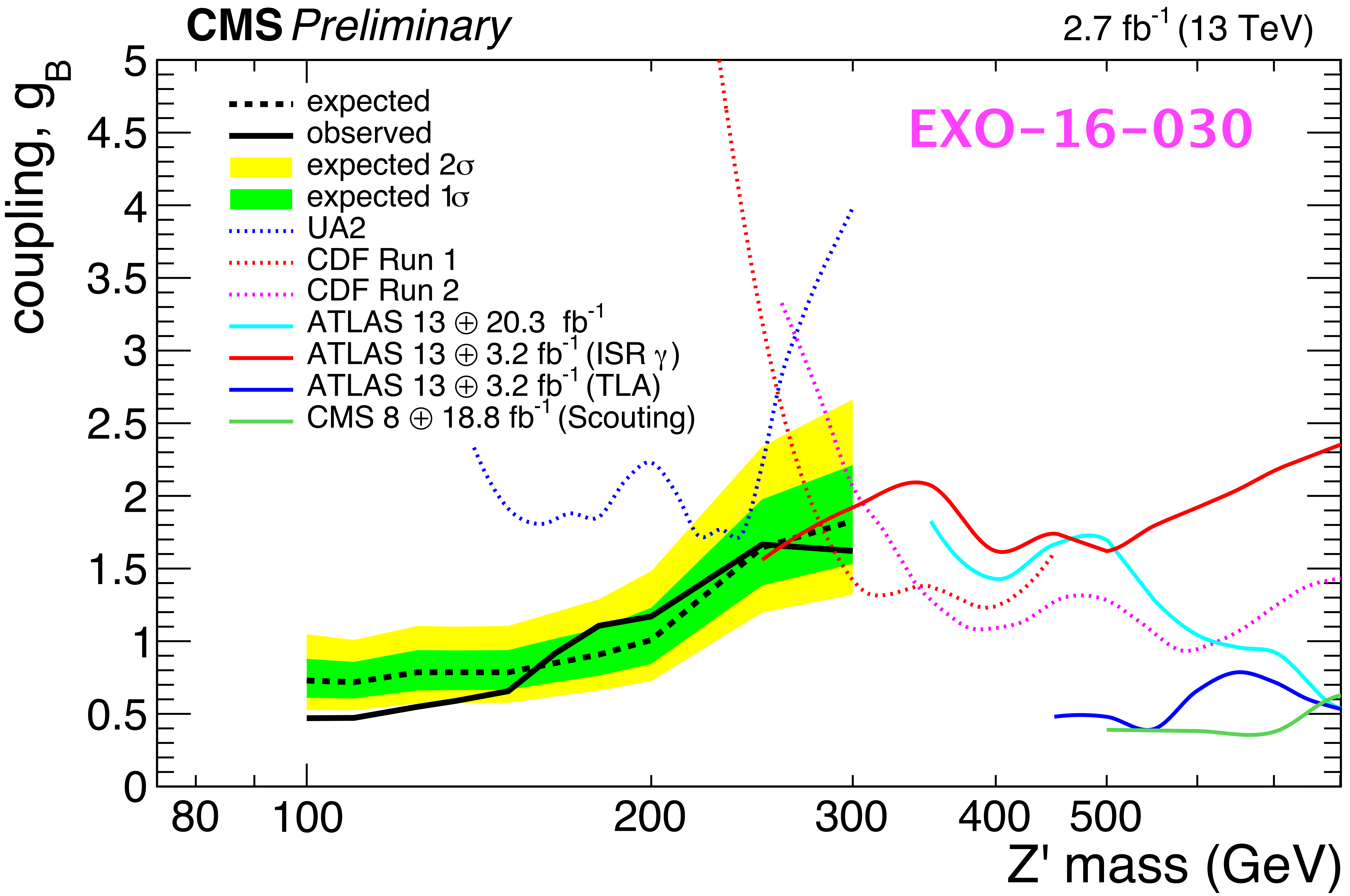


M_{jj} < 250 GeV

- **ISR jet + merged** dijet
- **Challenge**: **substructure** requirements for merged dijet modify mass shape at low mass.
- **Tool**: **Decorrelated substructure and mass** allows prediction of background shape at low mass



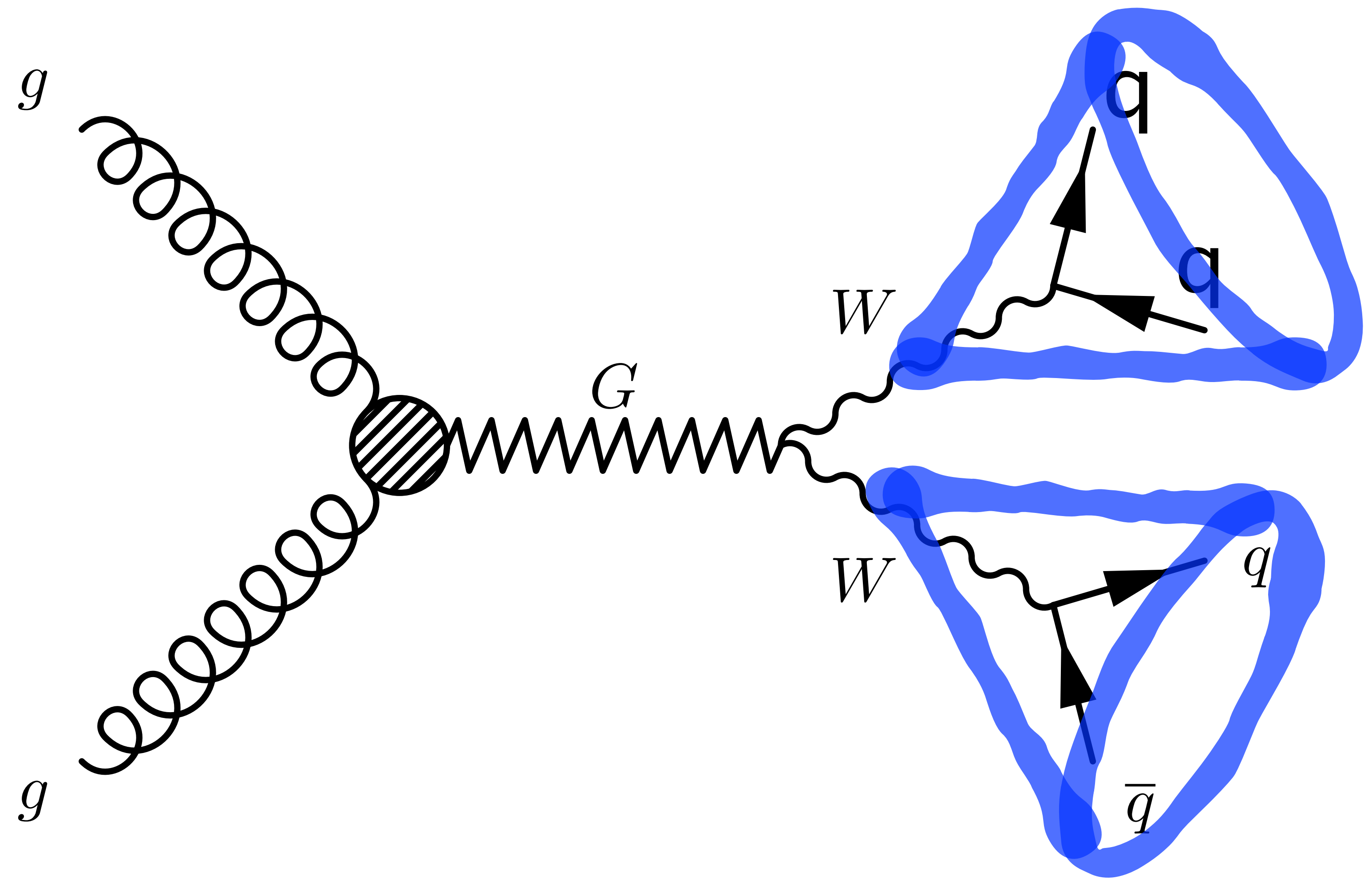




X ➔ VV or VH or HH

Many BSM models predict X➔VV: **RS warped extra dimensions with bulk SM** explain Planck/weak hierarchy and flavor and predict spin-2 graviton ➔ VV. [hep-ph/0701186]

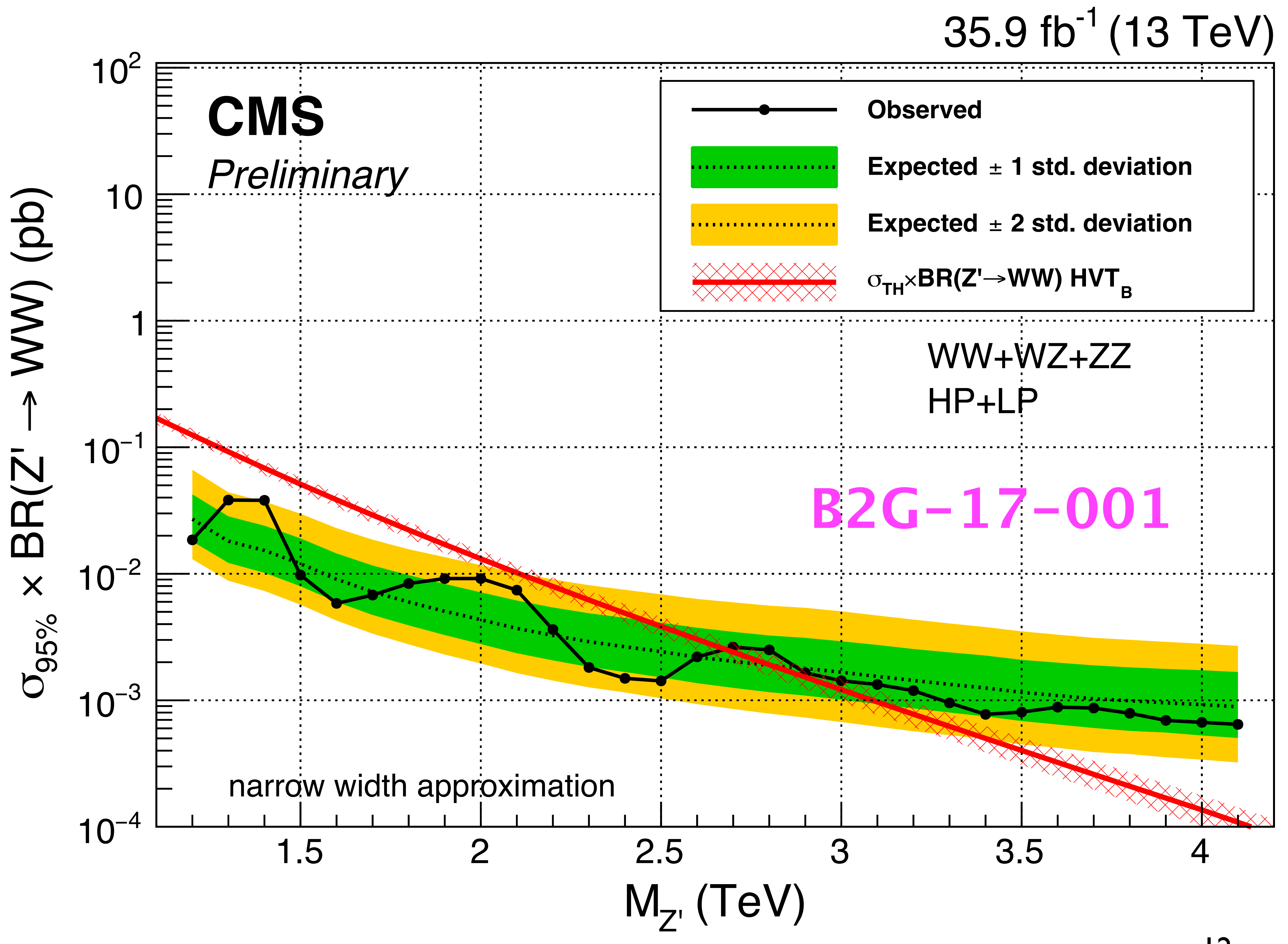
- High mass X ➔ WW/WZ/ZZ/VH/HH
  - V ➔ **single jet for M_X > 1 TeV**.
  - Hadronic final state most sensitive at high mass.
- ATLAS/CMS: same challenges, different **tools and techniques**

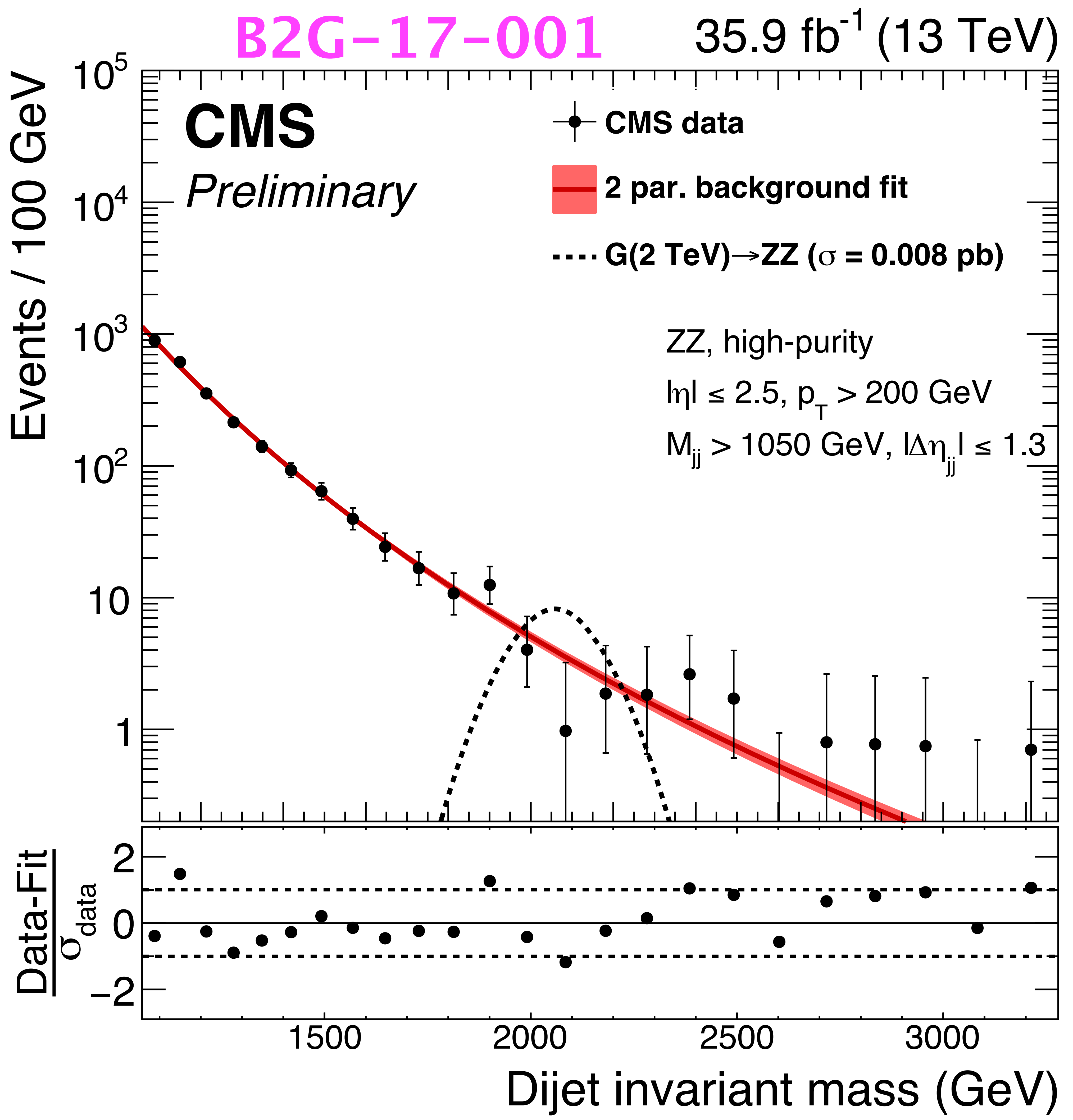


Challenge	ATLAS	CMS
mass measurement	track-assisted mass CONF-2012-065	particle flow PFT-10-001
pileup removal	jet trimming, track-vertex association arXiv:0912.1342, CONF-2012-065	PUPPI arXiv:1407.6013
ISR, UE removal	jet trimming arXiv:0912.1342, CONF-2012-065	soft drop arXiv:1402.2657
substructure identification	D_2 arXiv:1507.03018	N-subjettiness arXiv:1108.2701
merged X➔bb identification	subjet b-tagging CONF-2016-039	global MVA BTV-15-002

X → VV → JJ

- Heavy vector triplet model with couplings representative of composite Higgs.

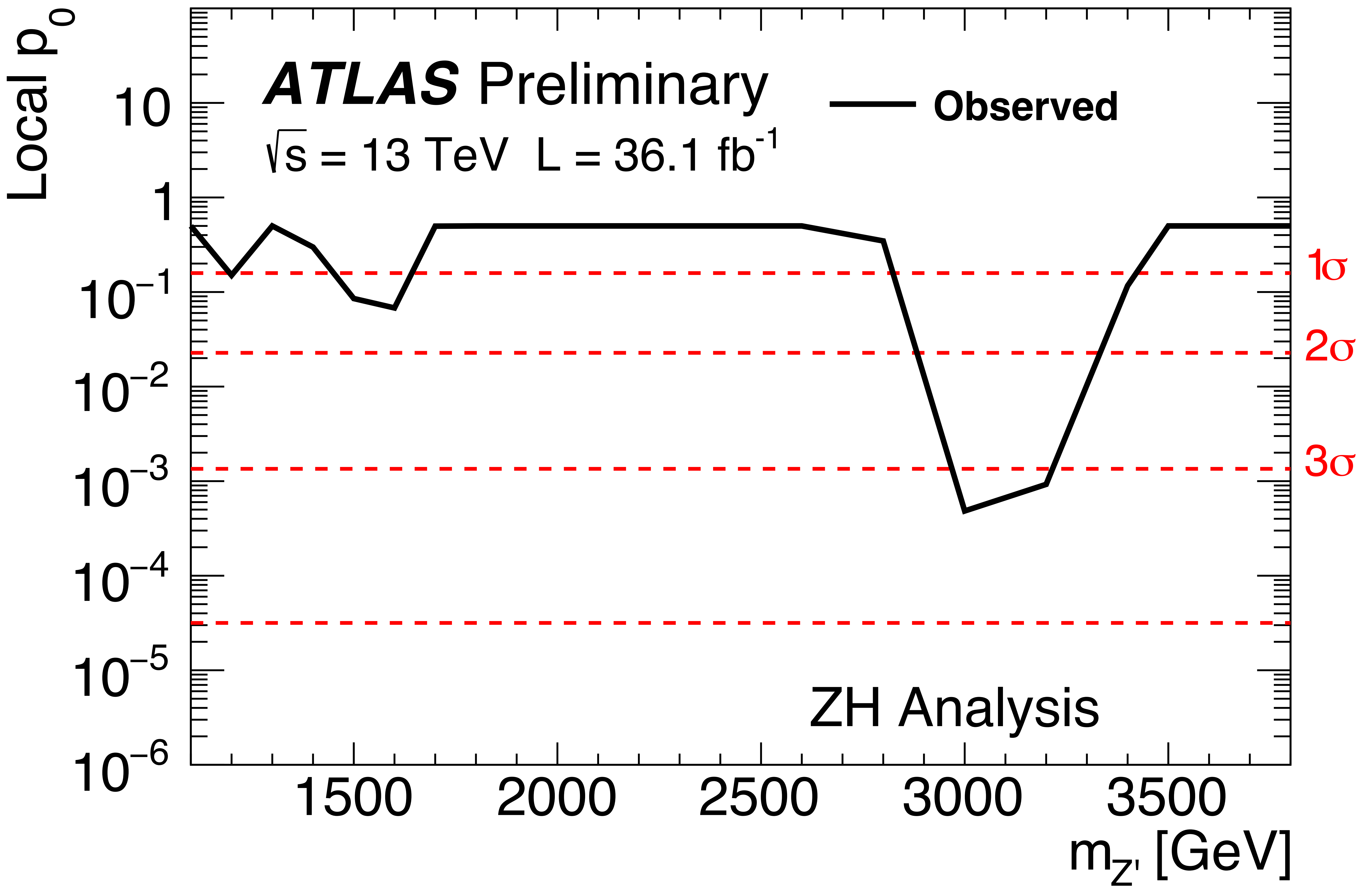


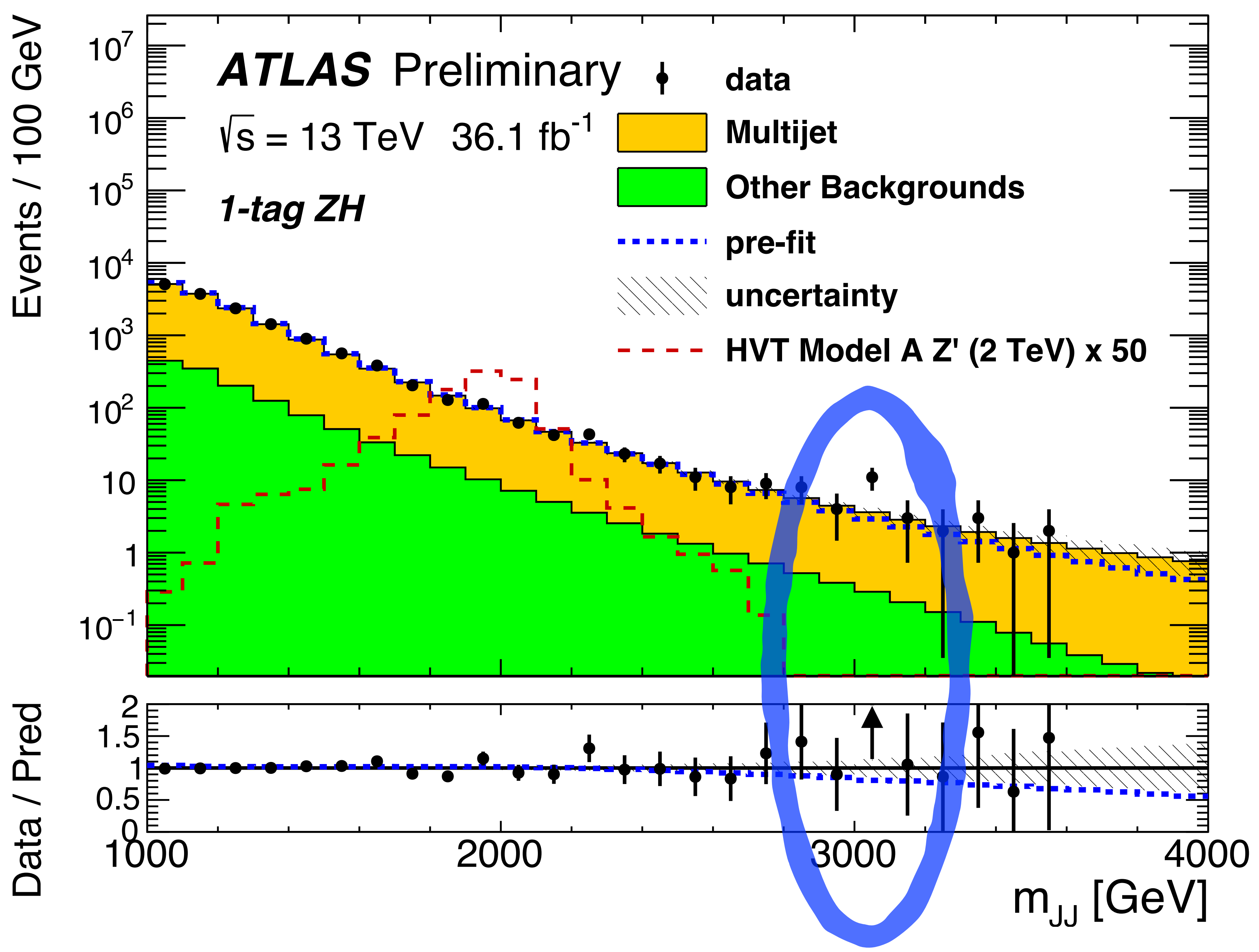


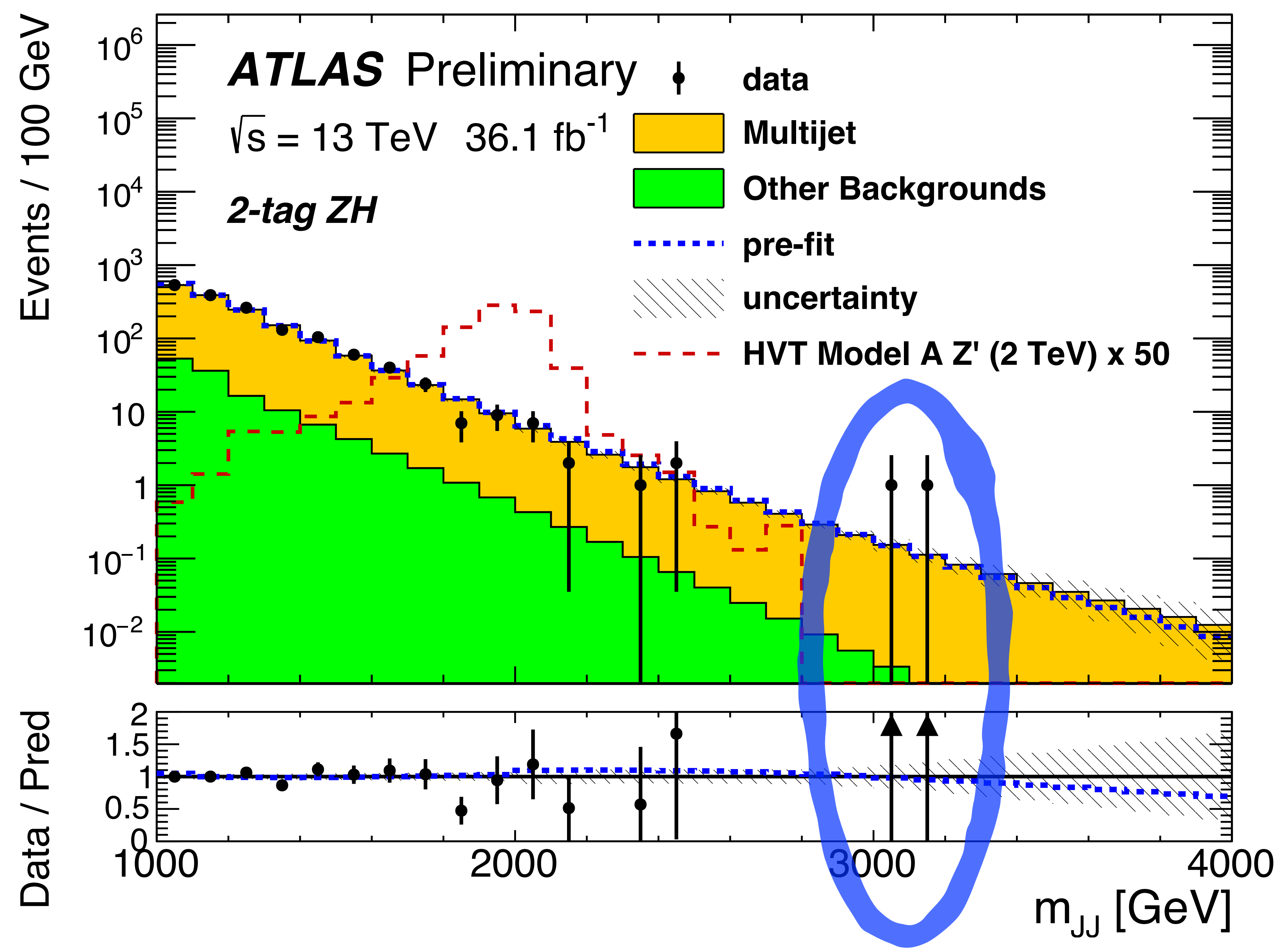
ATLAS X → VH → JJbb

CONF-2017-018

- Coinciding excesses in 1-tag and 2-tags categories.



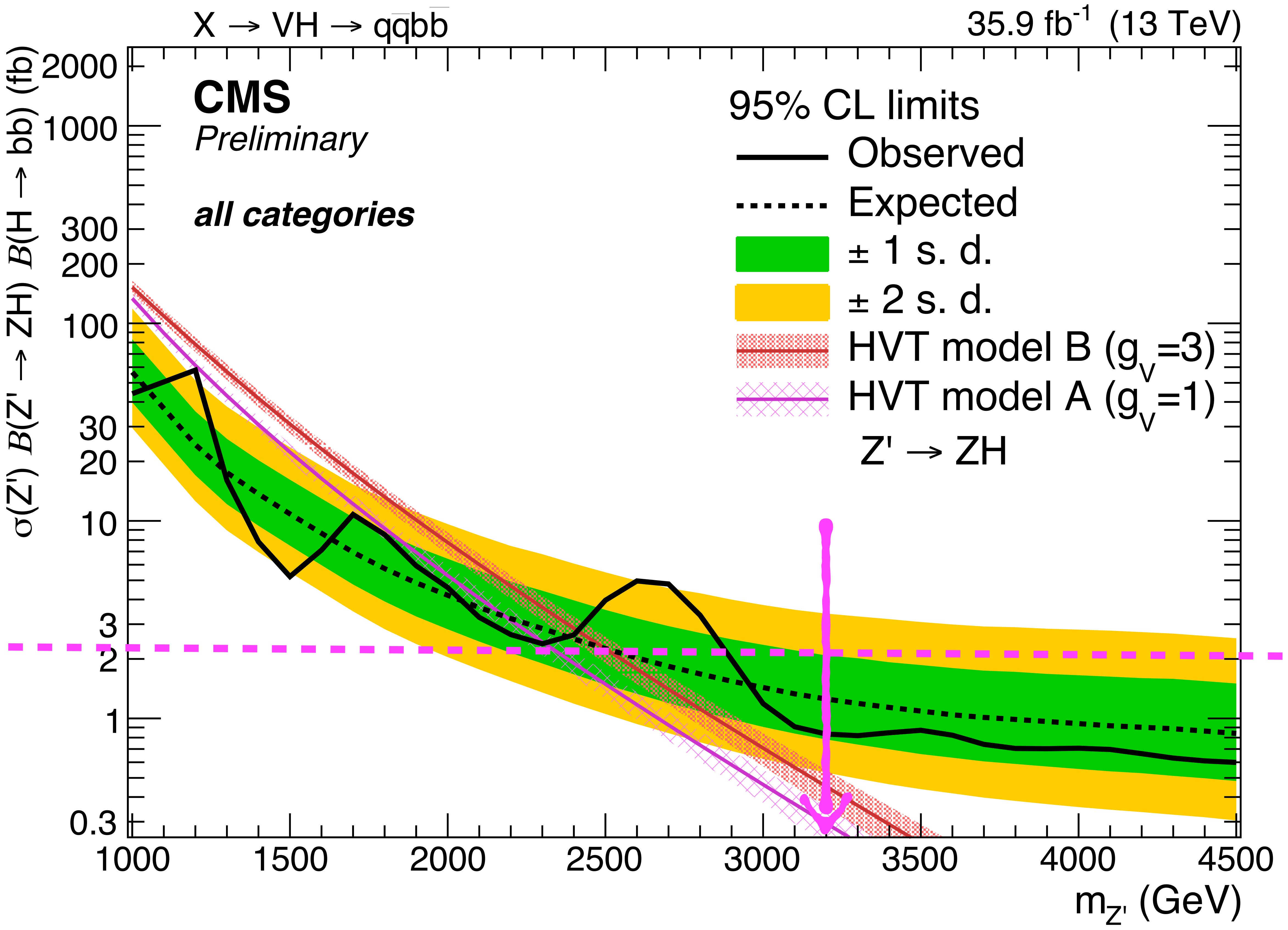




CMS X → VH → JJbb

- No excess at 3 TeV

B2G-17-002



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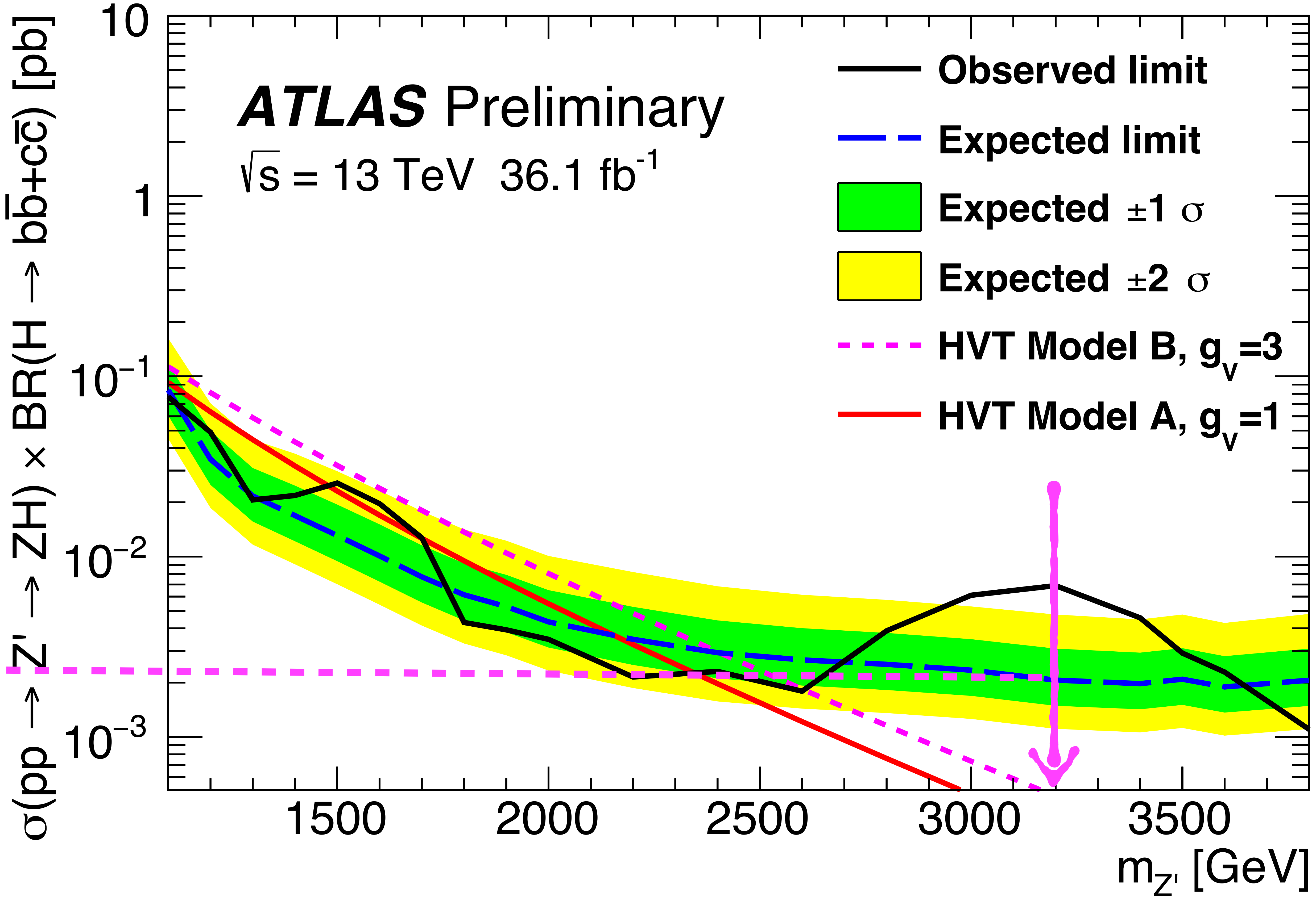
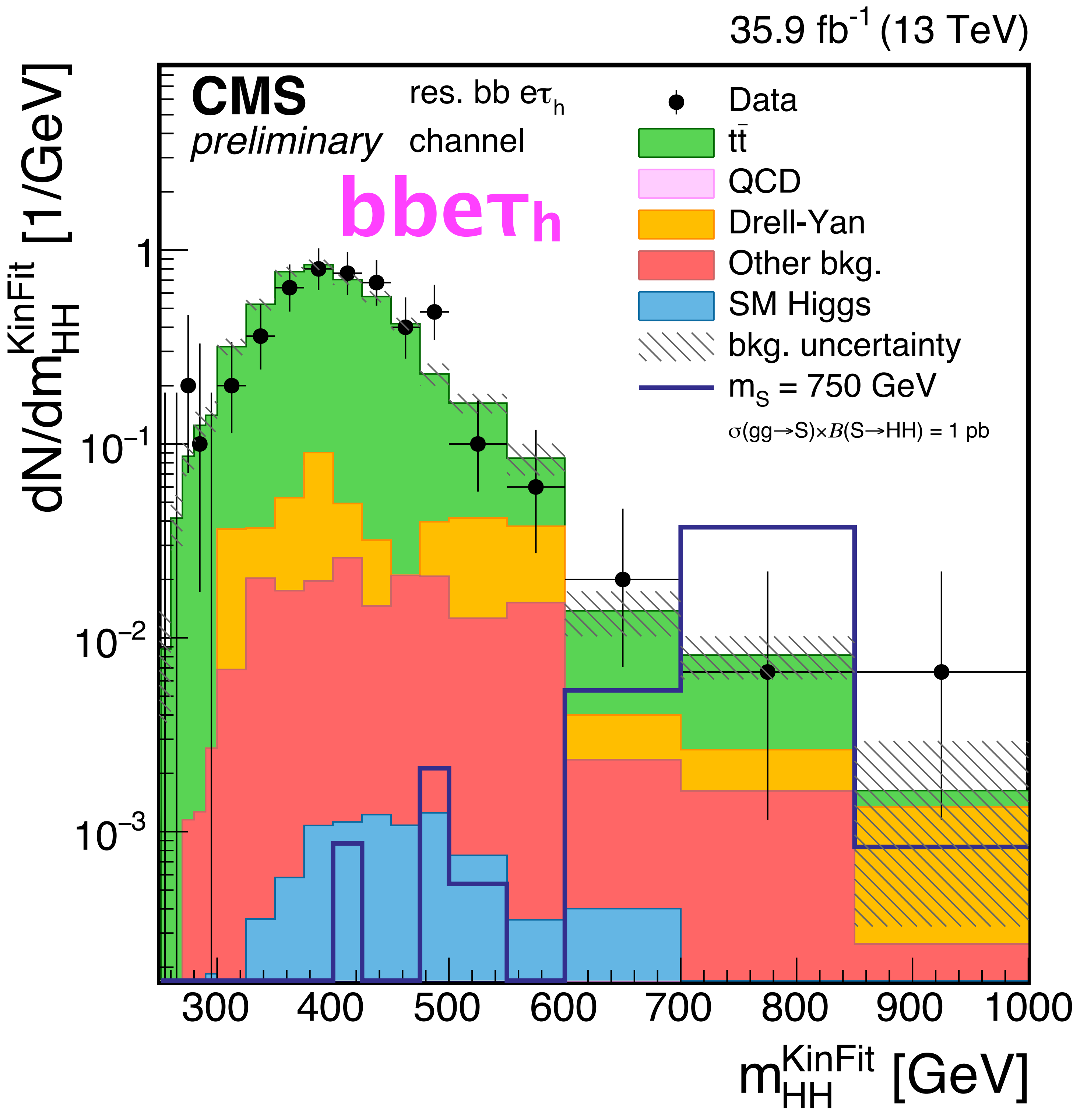


X → HH → bbWW and bbττ

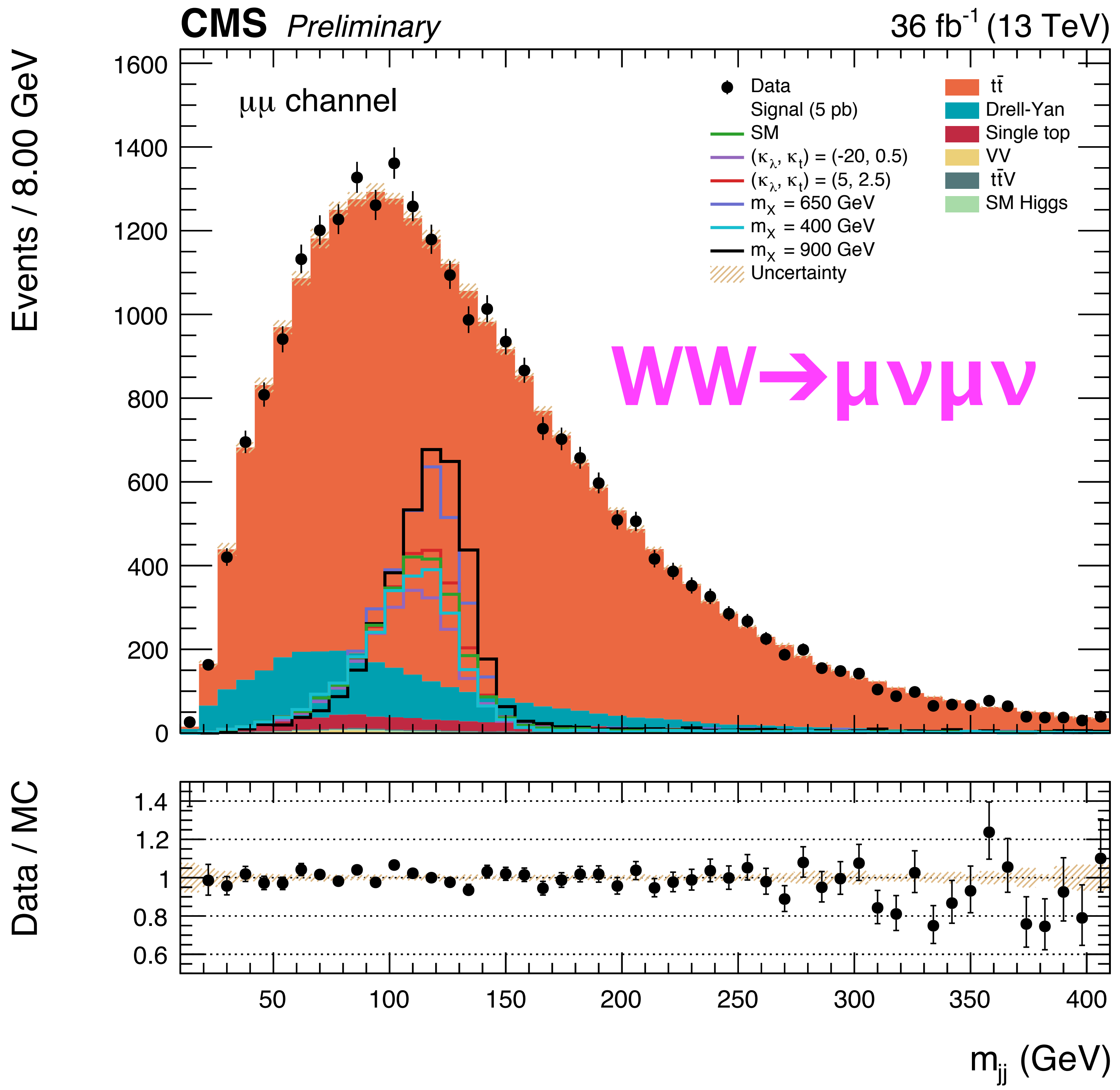
- bbWW → bb+ℓνℓν
- bbττ → bbμτh, bbeτh , bbτhτh

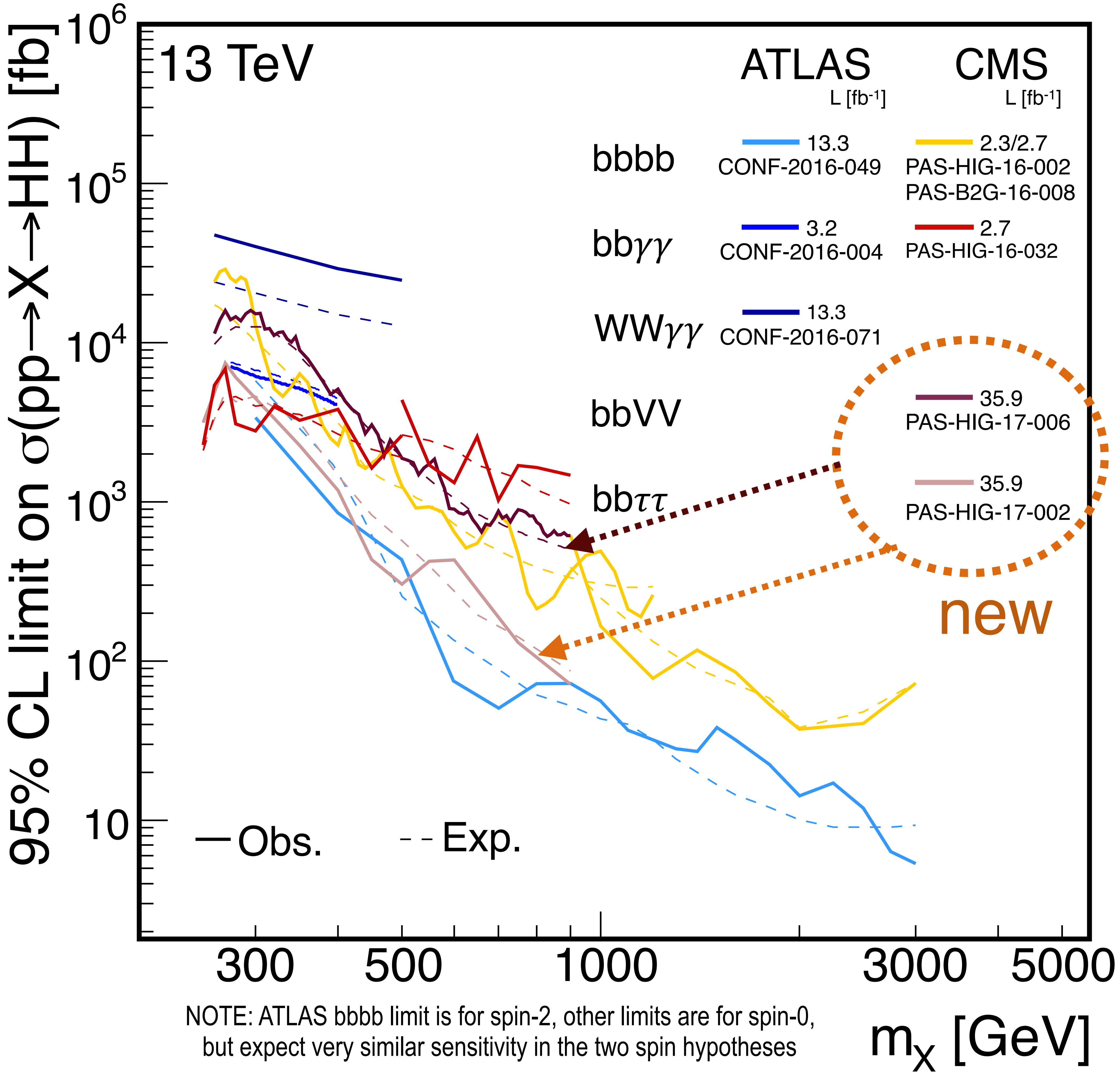
Luca Cadamuro, Moriond EW

HIG-17-002: bbττ



HIG-17-006 : bbWW





NOTE: ATLAS bbbb limit is for spin-2, other limits are for spin-0, but expect very similar sensitivity in the two spin hypotheses

Dark matter

Parallel talk
Marco Cipriani: Searches for dark matter at CMS

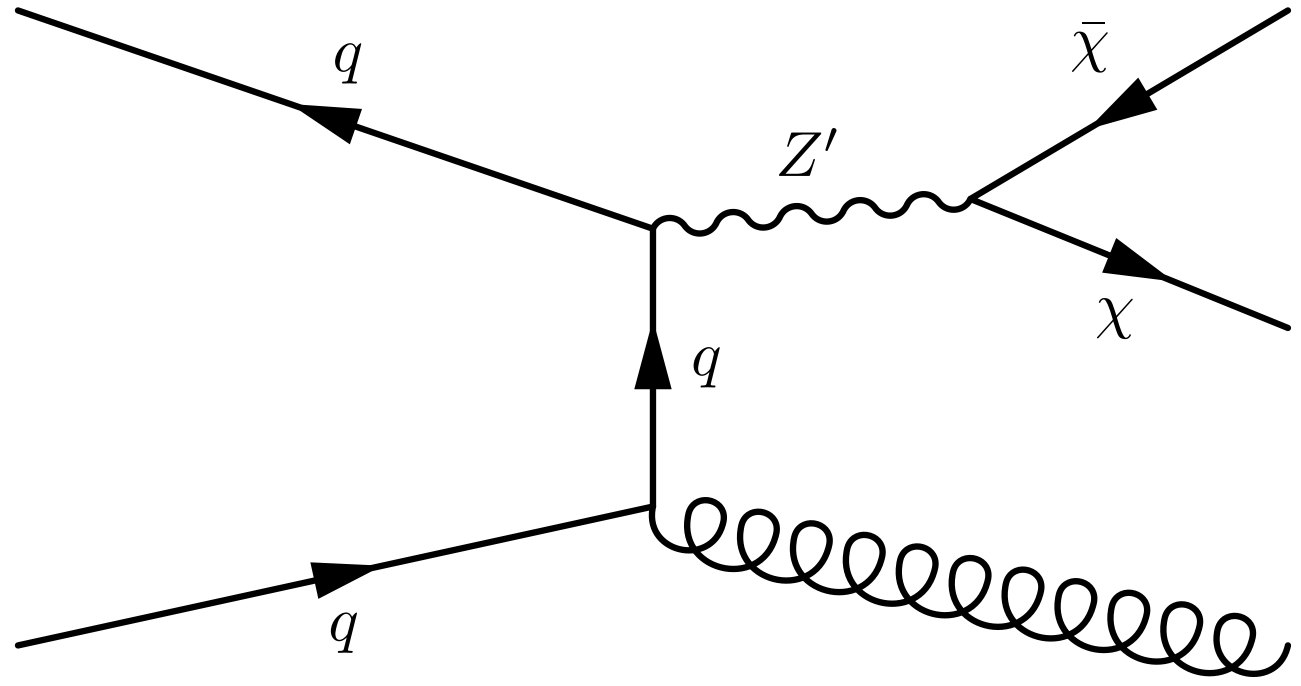
- What if non-interacting dark matter is produced alone in our detectors?
- Trigger on recoil.

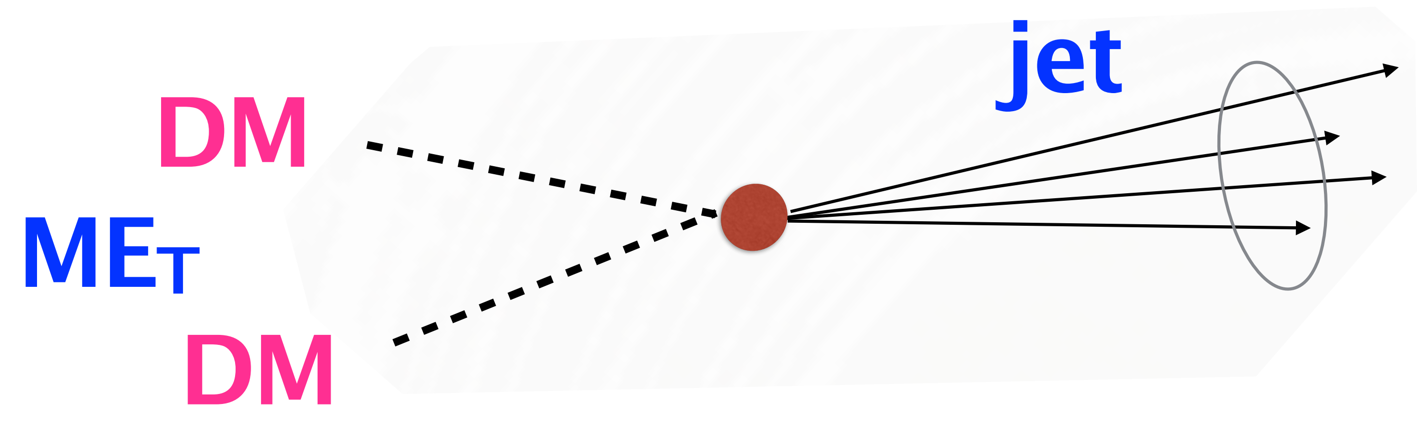
New DM results

- arXiv:1705.03848 : DM + ISR γ
- CONF-2017-024 : DM + H→γγ
- CONF-2017-028 : DM + H→bb

Coincidental recoil with generic DM

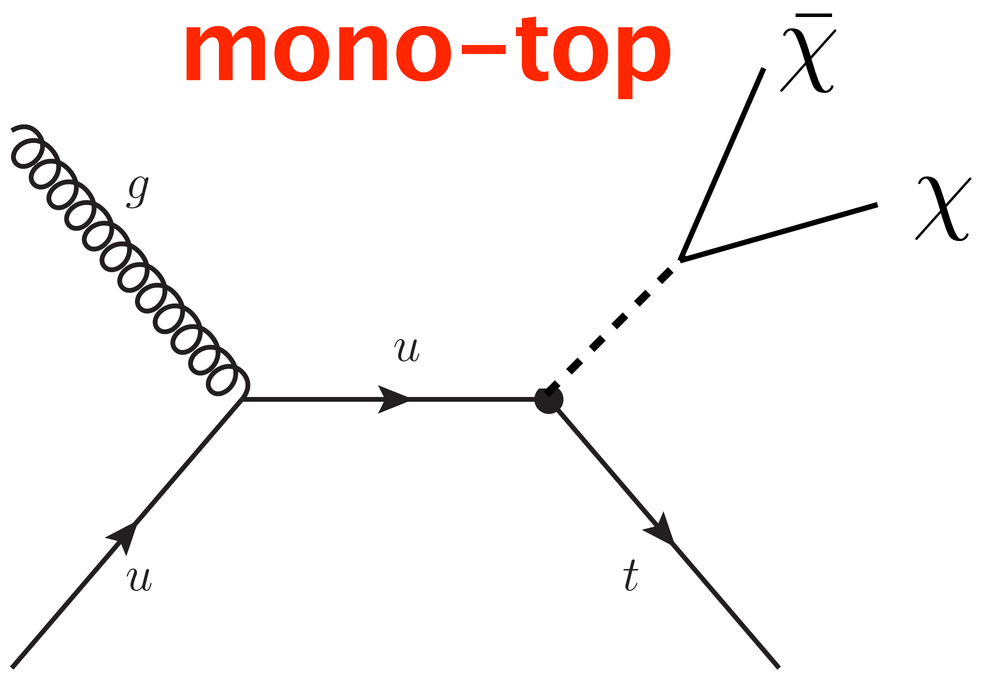
mono-jet, mono-Z, mono-photon



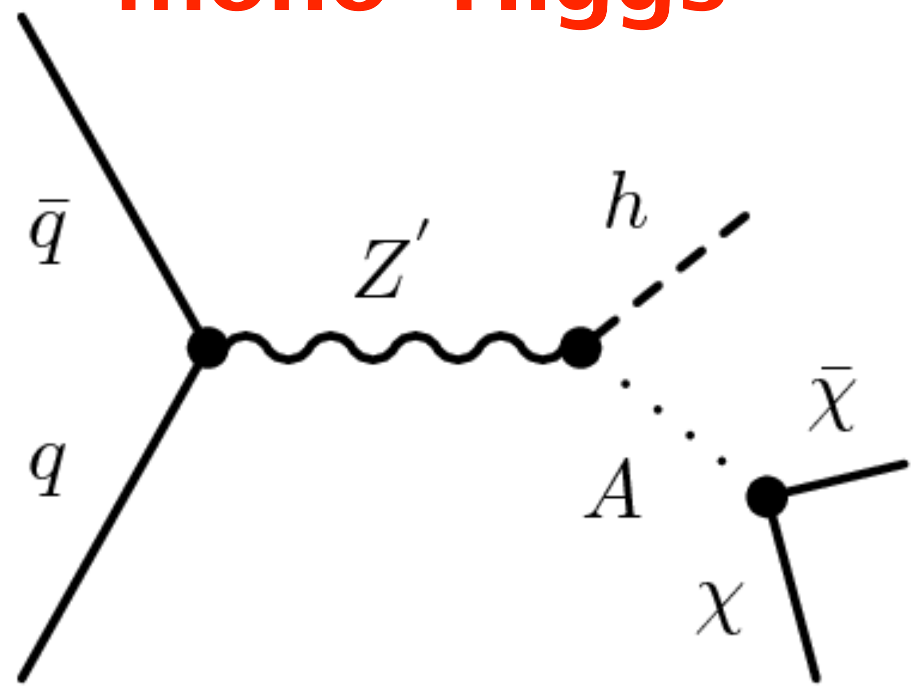


Model-specific recoil

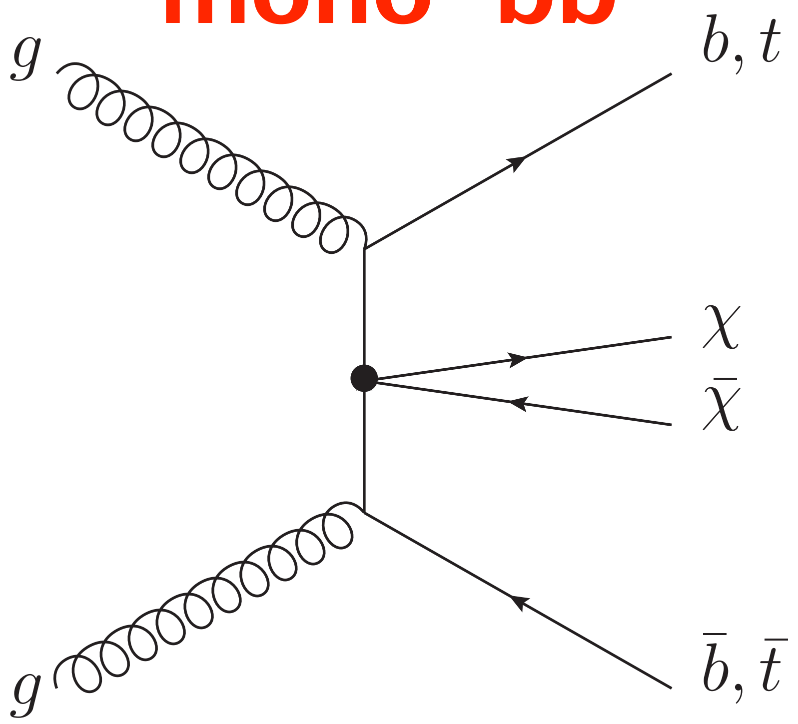
mono-top



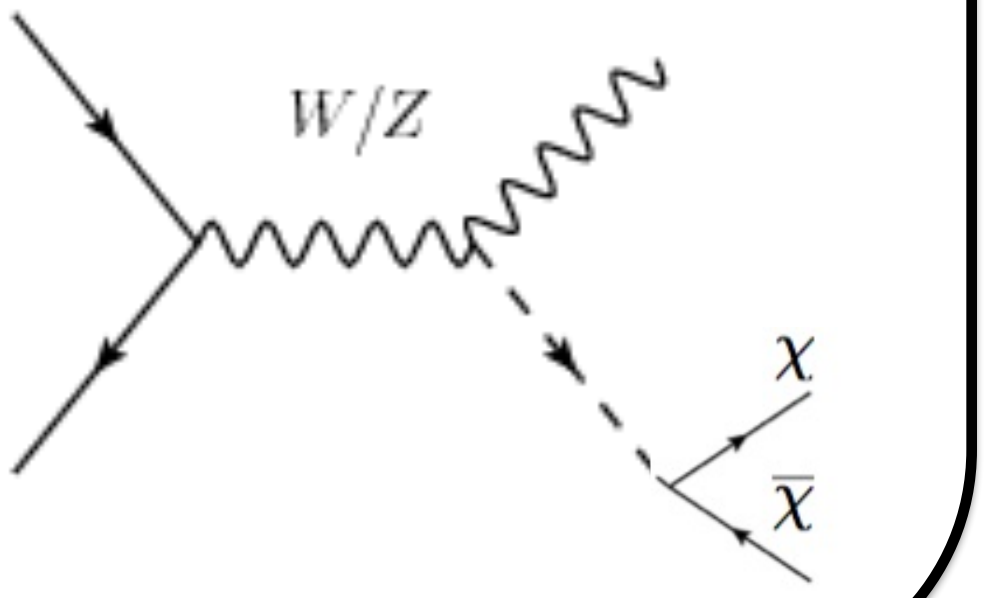
mono-Higgs



mono-tt, mono-bb



H^0 → invisible

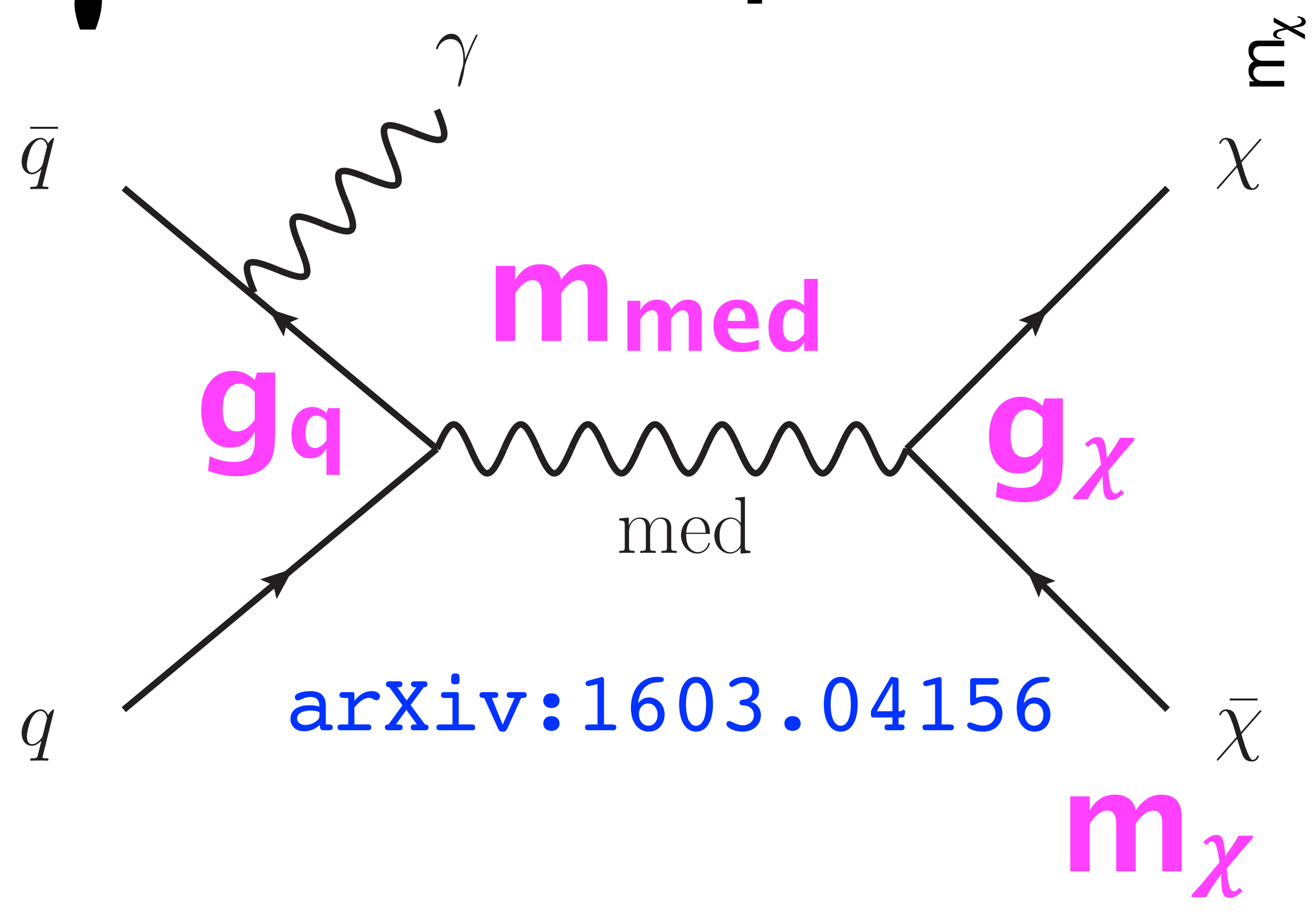


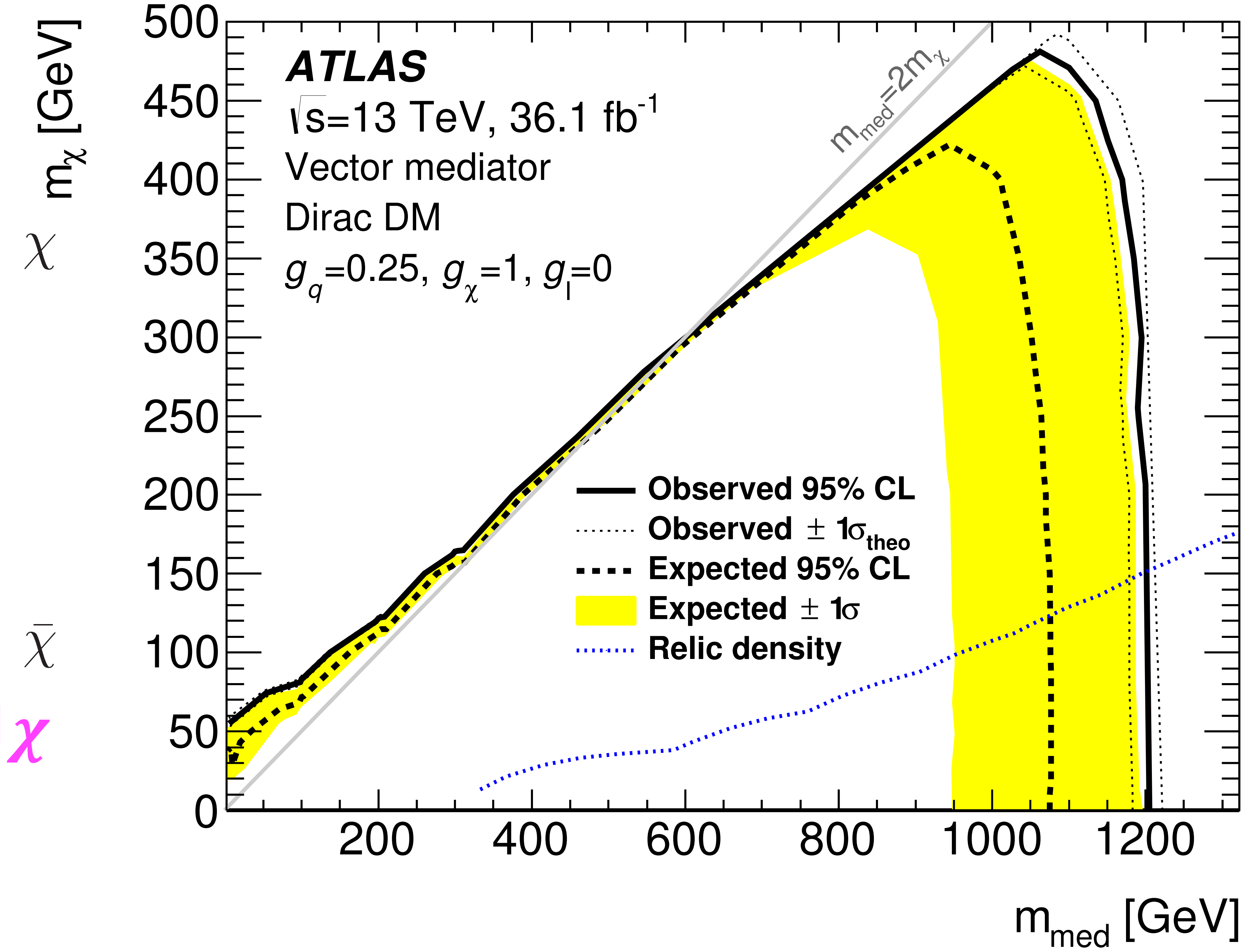
Monophoton: ISR γ + ME_T

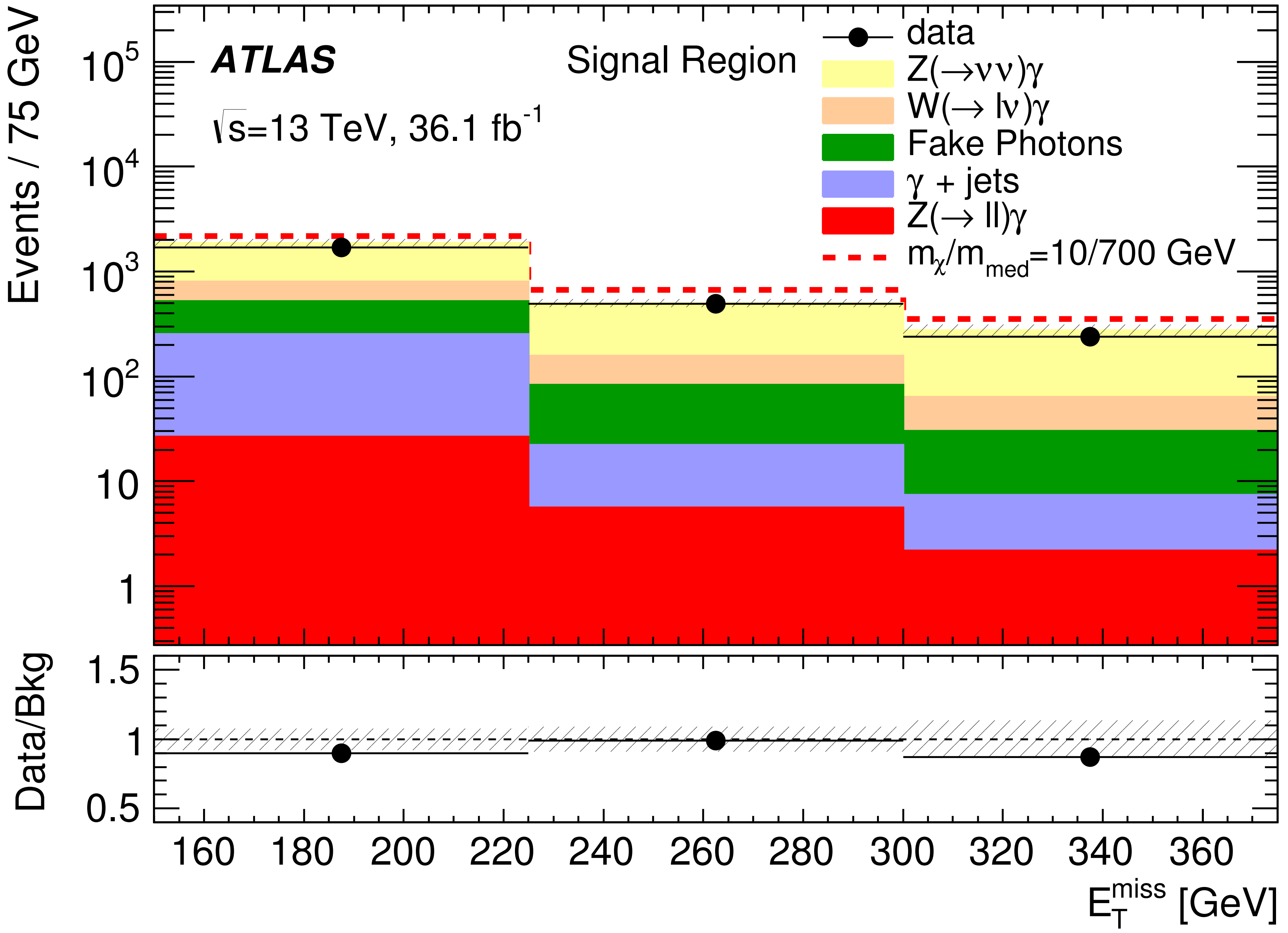
arXiv:1705.03848

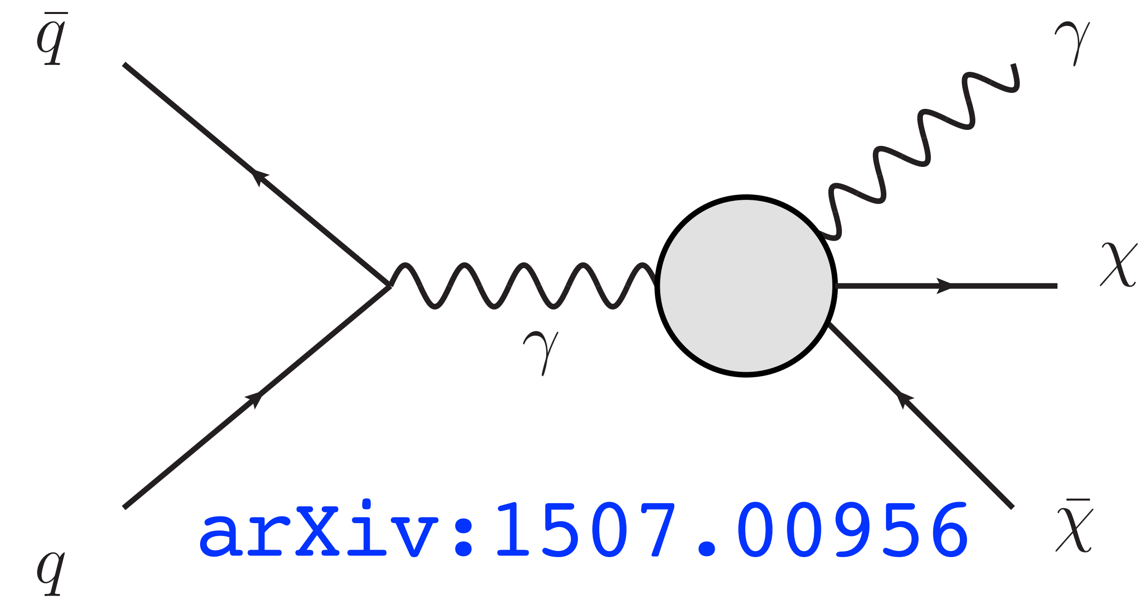
Require

- 1 high-p_T γ
- large ME_T
- $N_j \leq 1$

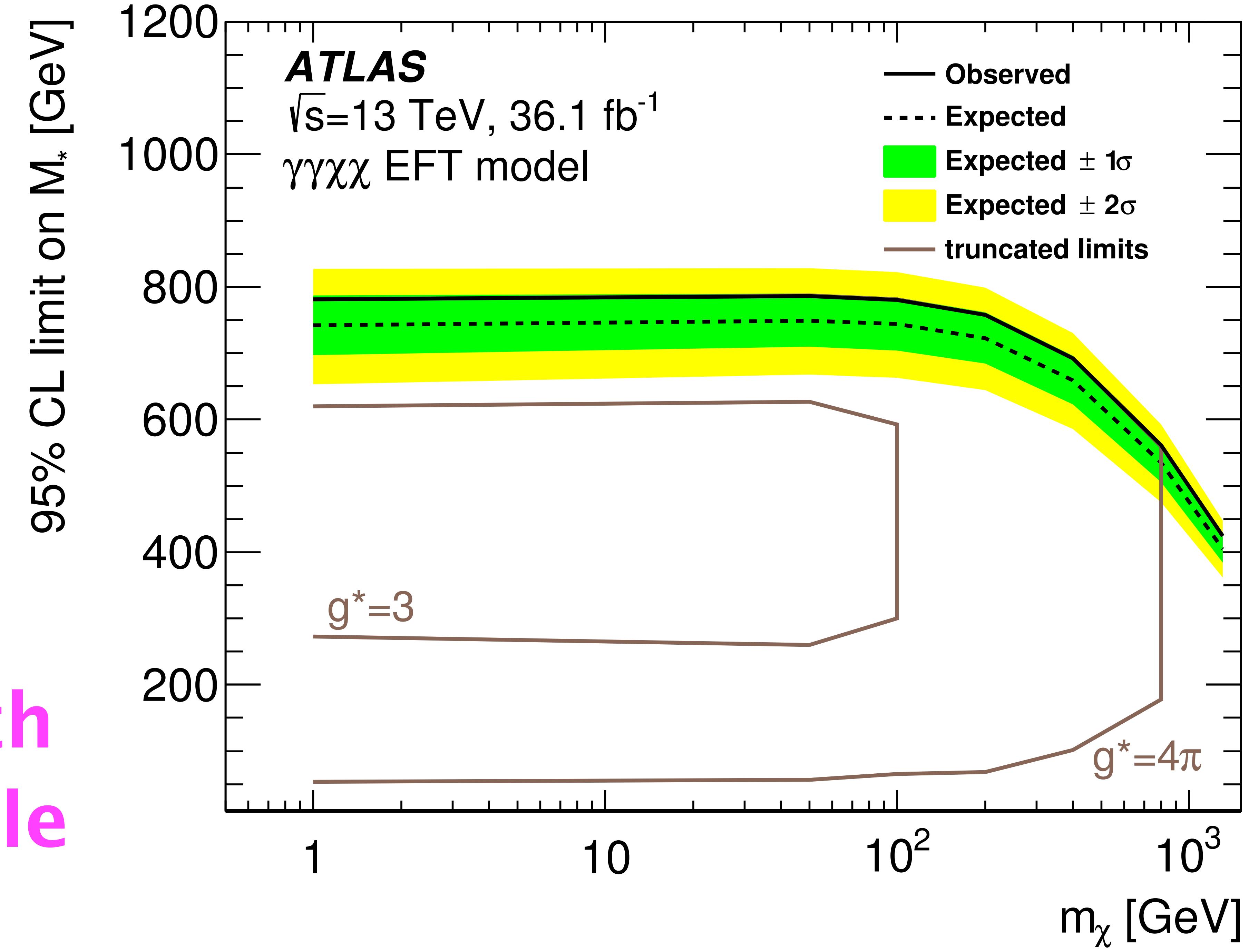








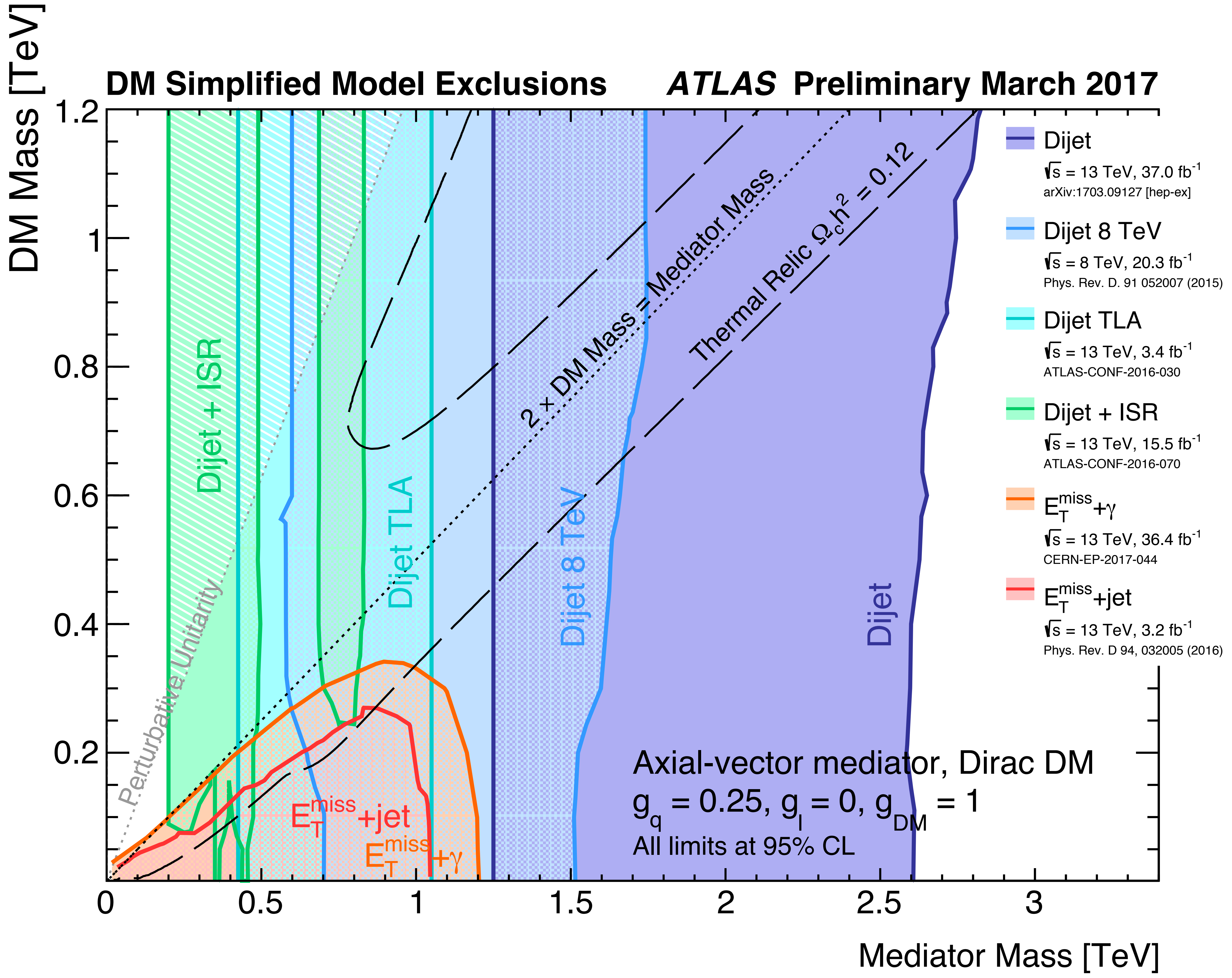
dim-7 operator with M* suppression scale

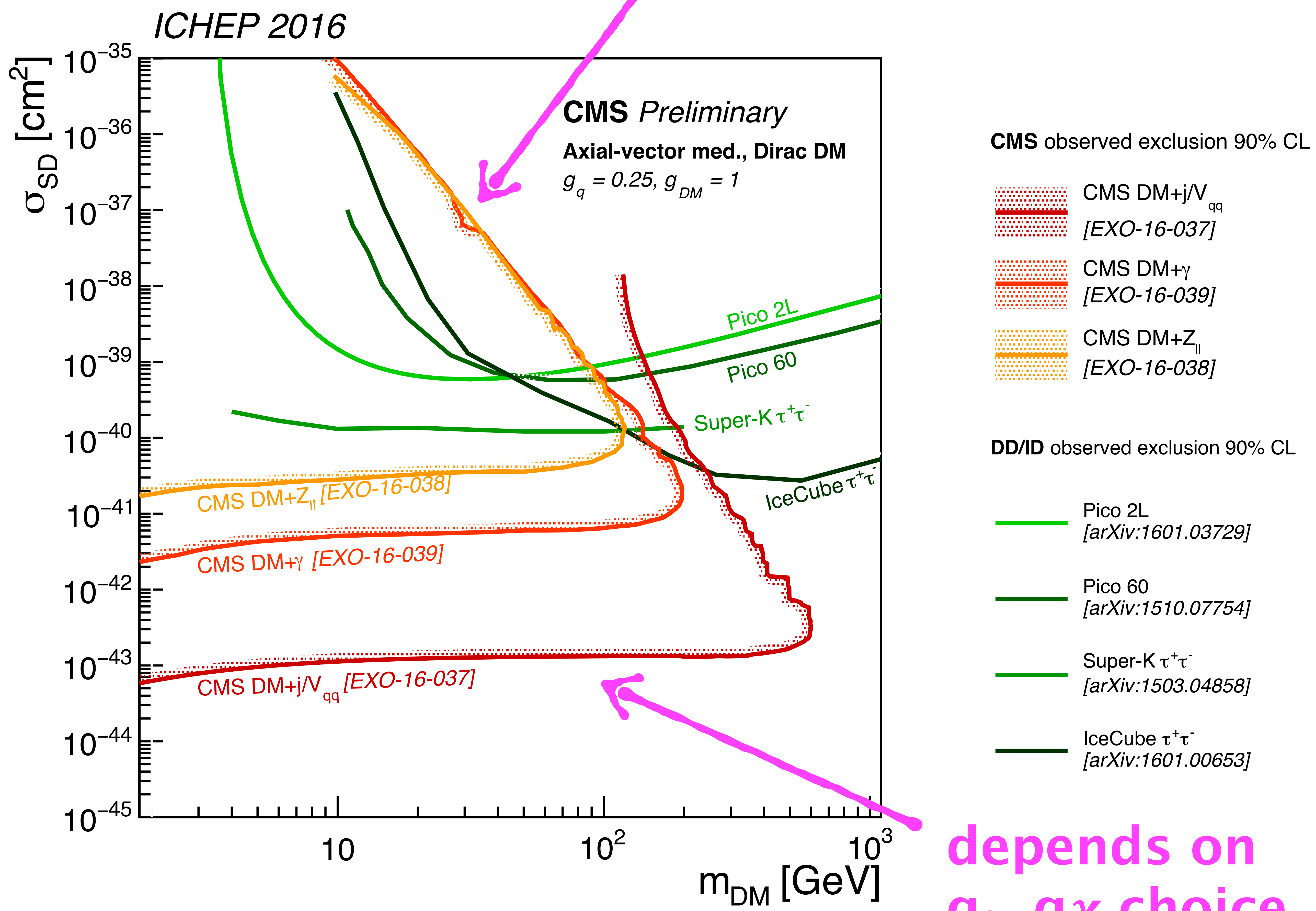


Generic dark matter summary

- Dijet resonance search : **sensitivity to direct mediator production**
- **Complementary with direct detection**: collider searches have good sensivity at low mass and for spin-dependent χ-N coupling.

Mono-X not sensitive where $M_{med}<2M\chi$

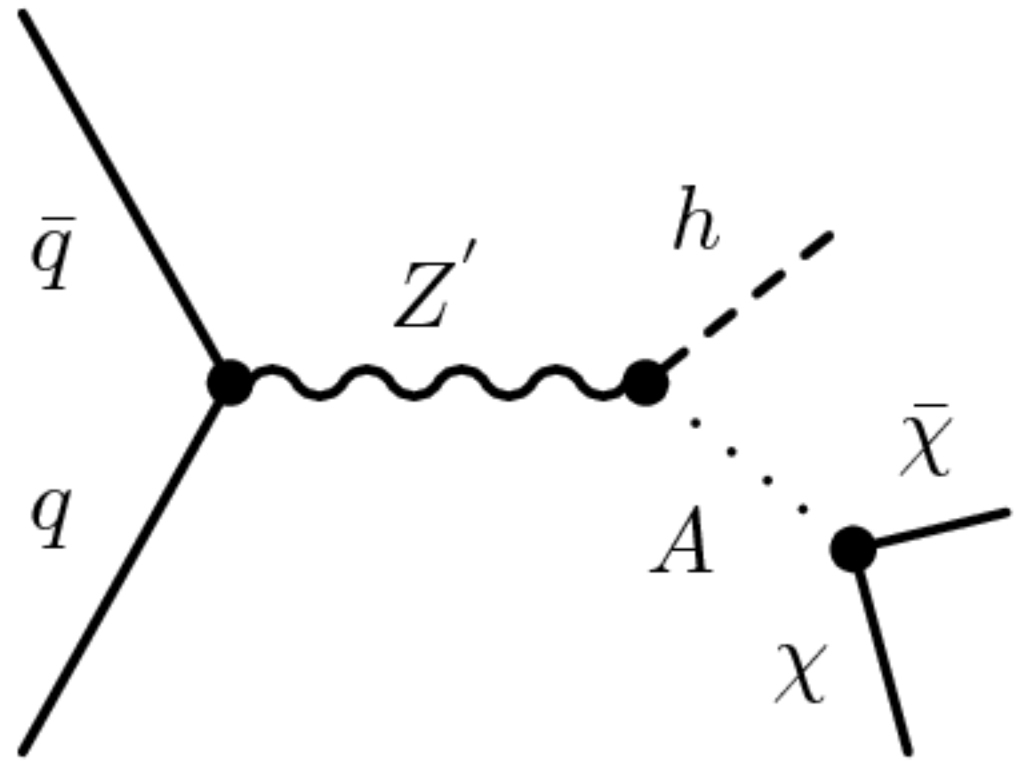




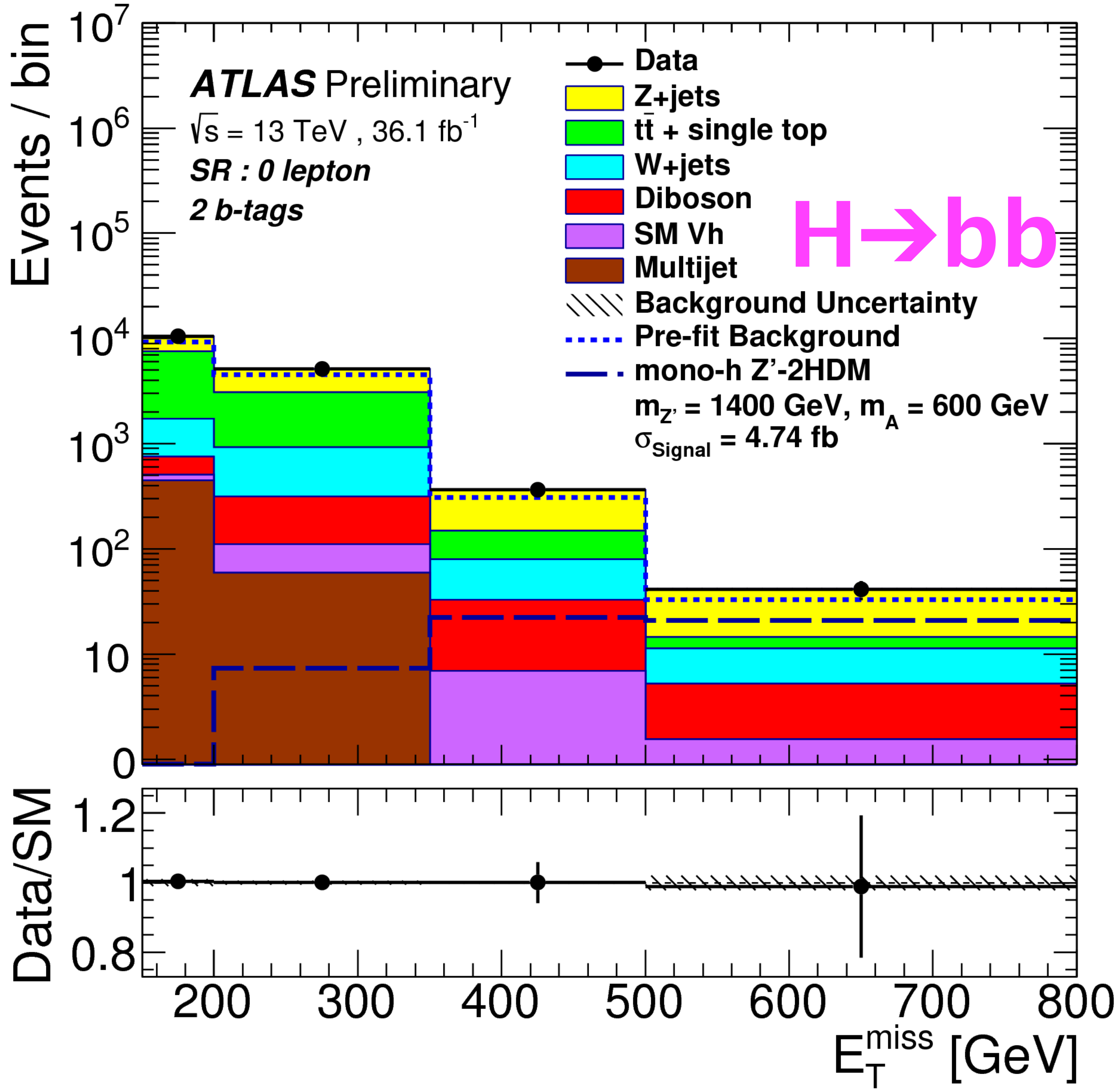
depends on g_q, $g\chi$ choice

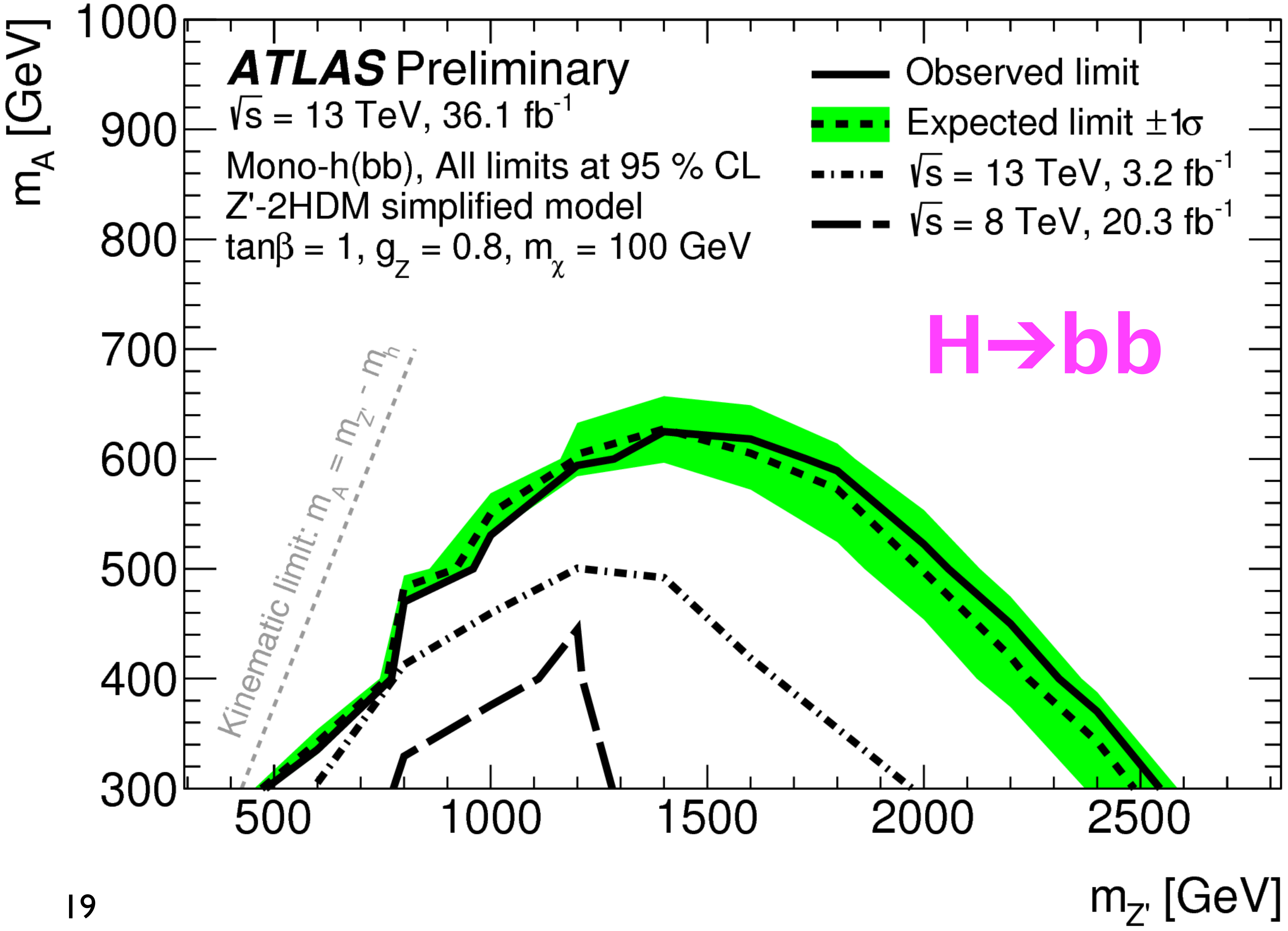
Higgs + ME_T

H→γγ: CONF-2017-024
H→bb: CONF-2017-028



- Important for testing Z′-2HDM
- H→bb : sensitivity in the bulk of m(A) vs m(Z′) space in Z′-2HDM
- H→γγ : sensitivity for m(A) < 300 GeV.





Many new 36 fb^{-1} SUSY results

Gluino / Inclusive

- SUS-16-033 (arXiv:1704.07781) : 0ℓ MH_T
- SUS-16-036 : 0ℓ M_{T2}
- SUS-16-037 : 1ℓ ΣM_J
- SUS-16-042 : 1ℓ $\Delta\varphi$
- CONF-2017-021 : $0\ell+1\ell$ b-jets+ME_T
- CONF-2017-022 : 0ℓ 2-6 jets (recursive jigsaw)

Stop/sbottom

- SUS-16-049 : 0ℓ
- CONF-2017-020 : 0ℓ
- SUS-16-051 : 1ℓ
- SUS-16-032 : sbottom and compressed stop
- CONF-2017-019 : $3\ell1b+1\ell4b$ for stop→ tt+ZH+MET

Electroweakino

- SUS-16-034 : $\ell^{\pm}\ell^{\mp}$ +jets+ME_T
- SUS-16-039 : 3ℓ + ME_T
- SUS-16-048 : 2 soft ℓ

R-parity violating SUSY

- CONF-2017-025 : stop → jj
- CONF-2017-013 : 1ℓ+jets
- EXO-16-029 : stop → jj (low mass)

Long-lived particles

- EXO-16-003 displaced jets
- CONF-2017-026 : displaced vertices
- CONF-2017-017 : disappearing tracks

Parallel talks:

Nadja Strobbe: Fully hadronic final states with CMS
Zhenbin Wu: 3rdt gen squarks with CMS
Minsuk Kim: EWKinos with CMS
Basil Schneider: Dilepton final states with CMS
Menglei Sun: SUSY with photons in CMS
Othmane Rifki: Squarks and gluinos with ATLAS
Fabrizio Miano: 3rd gen squarks with ATLAS
Zara Jane Grout: EWK SUSY with ATLAS

Supersymmetry (SUSY)

	SM particles				SUSY partners			
SM fermions	u	d	e	ν_e	$\tilde{u}$	$\tilde{d}$	$\tilde{e}$	$\tilde{\nu}_e$
	c	s	μ	ν_μ	$\tilde{c}$	$\tilde{s}$	$\tilde{\mu}$	$\tilde{\nu}_\mu$
	t	b	τ	ν_τ	$\tilde{t}$	$\tilde{b}$	$\tilde{\tau}$	$\tilde{\nu}_\tau$
SM bosons	h	A	H^0	$H^\pm$	$\tilde{\chi}^0_1$	$\tilde{\chi}^0_2$	$\tilde{\chi}^0_3$	$\tilde{\chi}^0_4$
	γ	Z^0	$W^\pm$	g	$\tilde{\chi}^\pm_1$	$\tilde{\chi}^\pm_2$		$\tilde{g}$

Why SUSY?

- Explains dark matter
  - **Lightest SUSY particle = LSP**
- Explains hierarchy problem : shields Higgs mass from radiative corrections
- Helps unify forces

For explaining Higgs mass:
- gluino mass < 2 TeV
- stop mass < 1 TeV
- higgsinos < 300 GeV

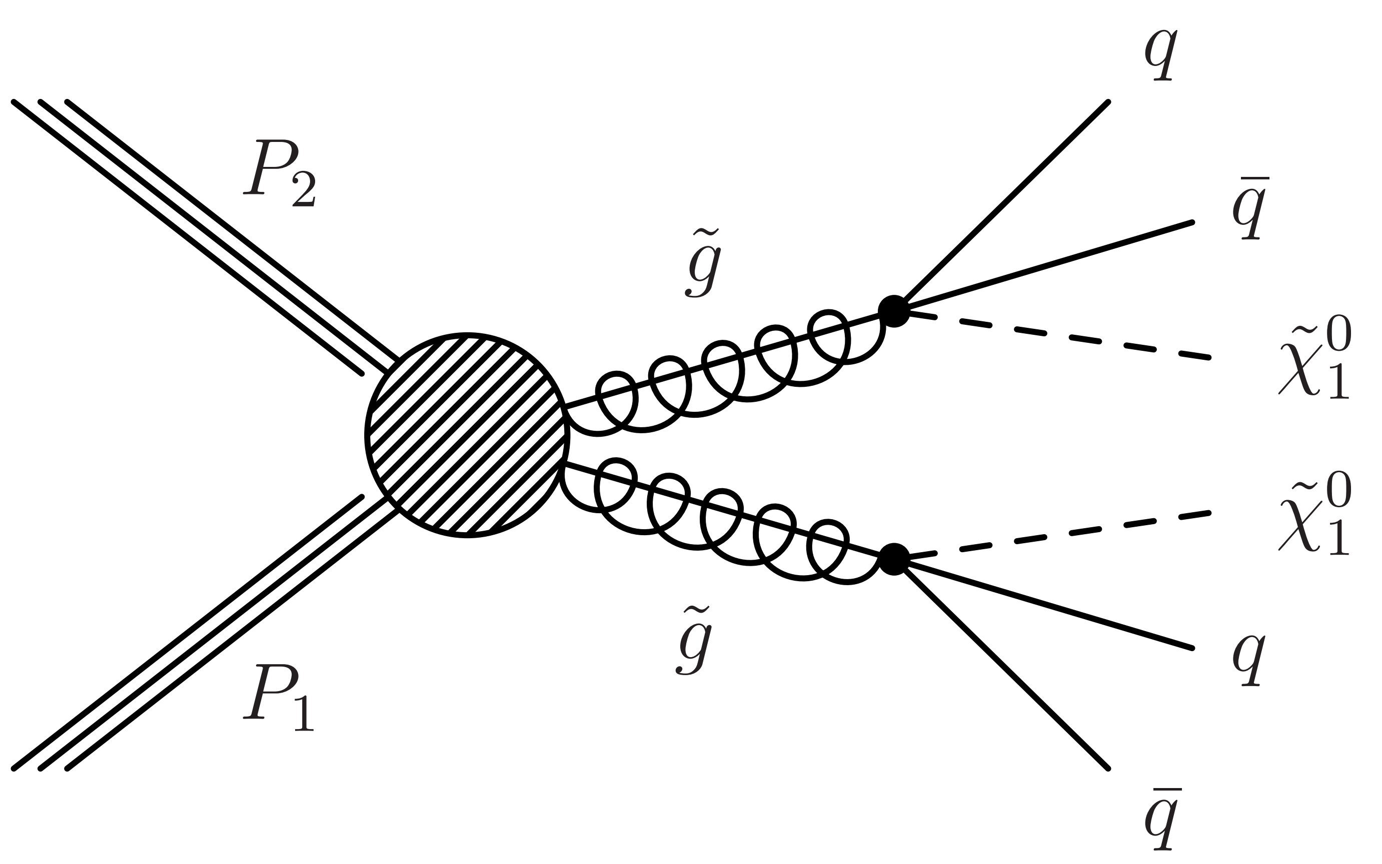
Higgs and gauge boson superpartners mix forming "electroweakinos"

Gluino searches

- presence of $\ell^{\pm}$, b–jets depends on quark flavor
- Hadronic final state most sensitive

ATLAS: optimized for discovery at edge of existing limits

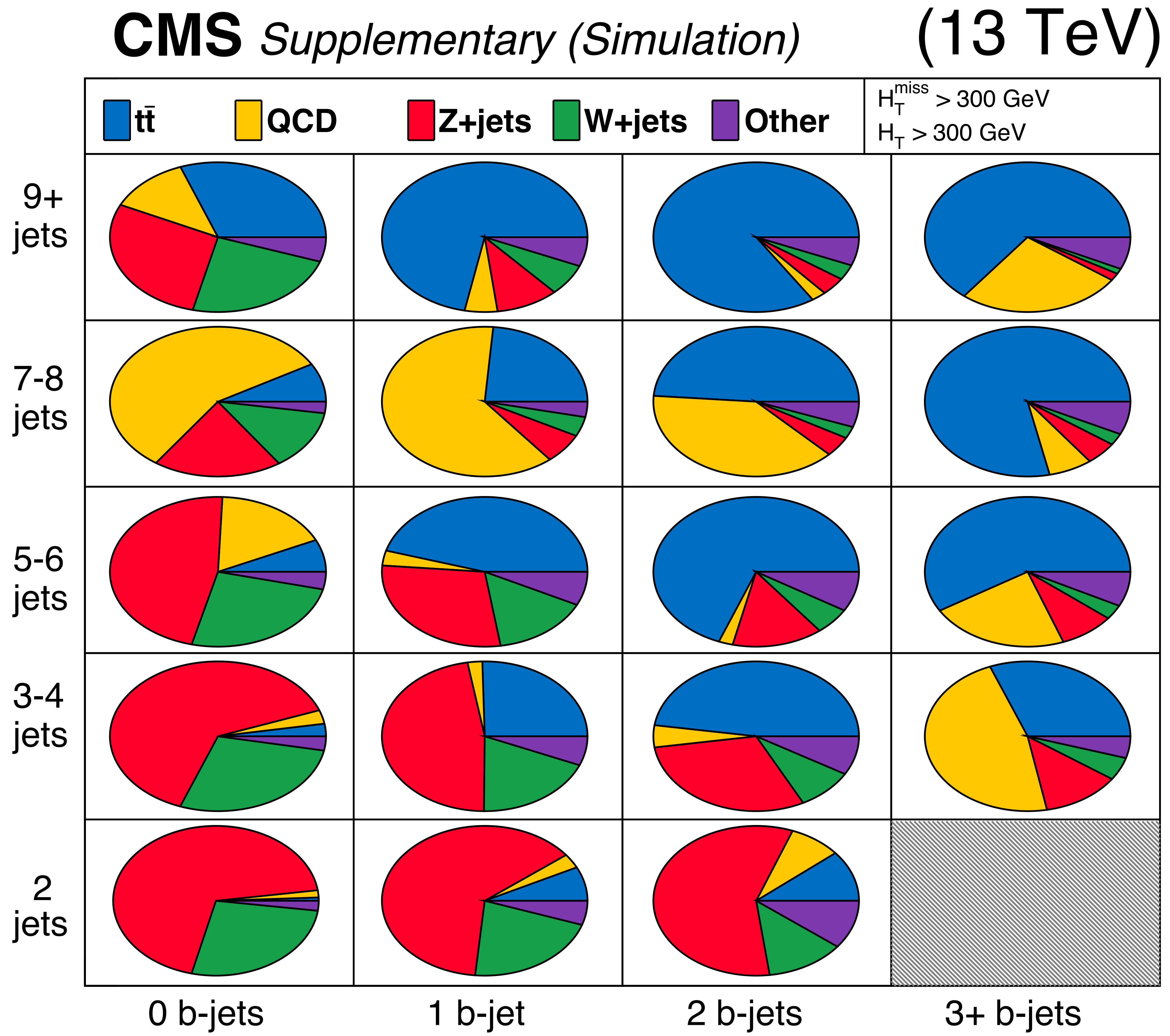
CMS : General search; probe full phase space by combining many bins.



All analyses choose one variable of each type (CMS, ATLAS):

Type	Variables
Energy scale	H_T, M_{T2}, Razor M_R, MHT+Σp_{Tj}, RJR H_{11}^{PP}
Missing energy	ME_T, MH_T, M_{T2}^{CMS}, RJR H_{Tn1}^{PP}
E structure	N_{jets}
Flavor	N_{bjets}
Hybrid	$MH_T/\sqrt{H_T}$ [missing/scale] ΣM_j [scale/structure], Razor R^2 [missing/scale]

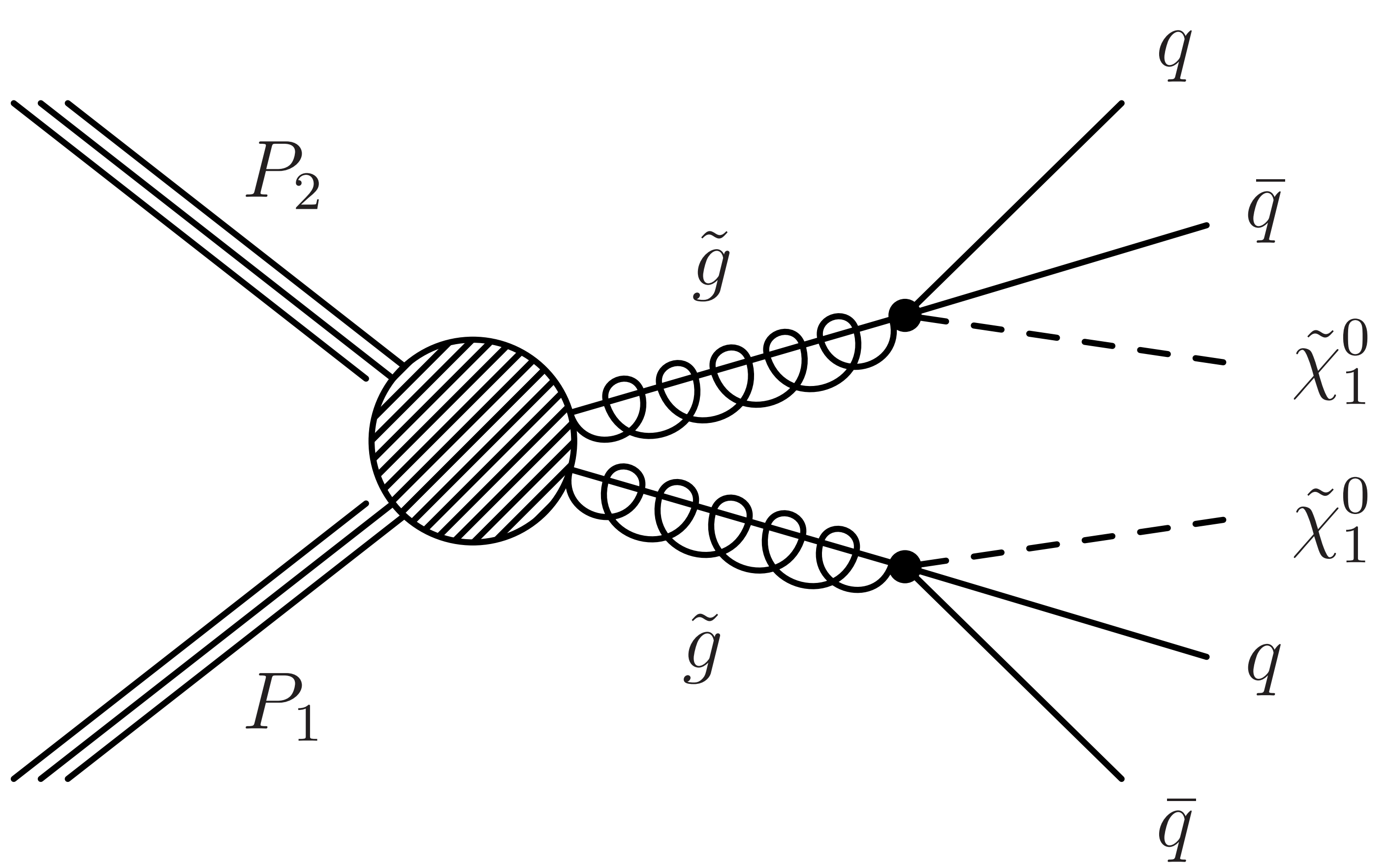
SUS–16–033



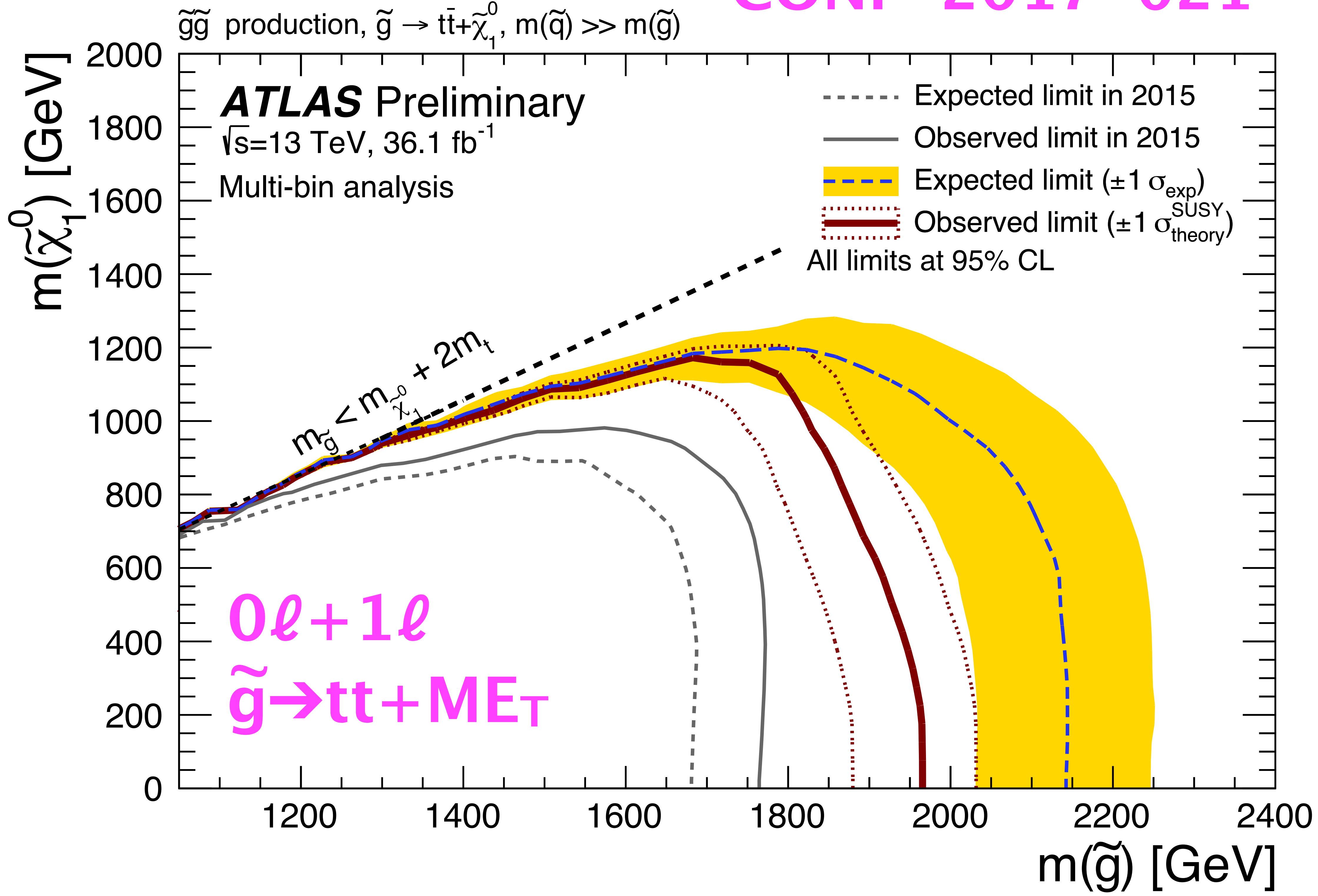
arXiv:1605.01416; Cohen, Dolan, El Hedri, JFH, Tran, Whitbeck

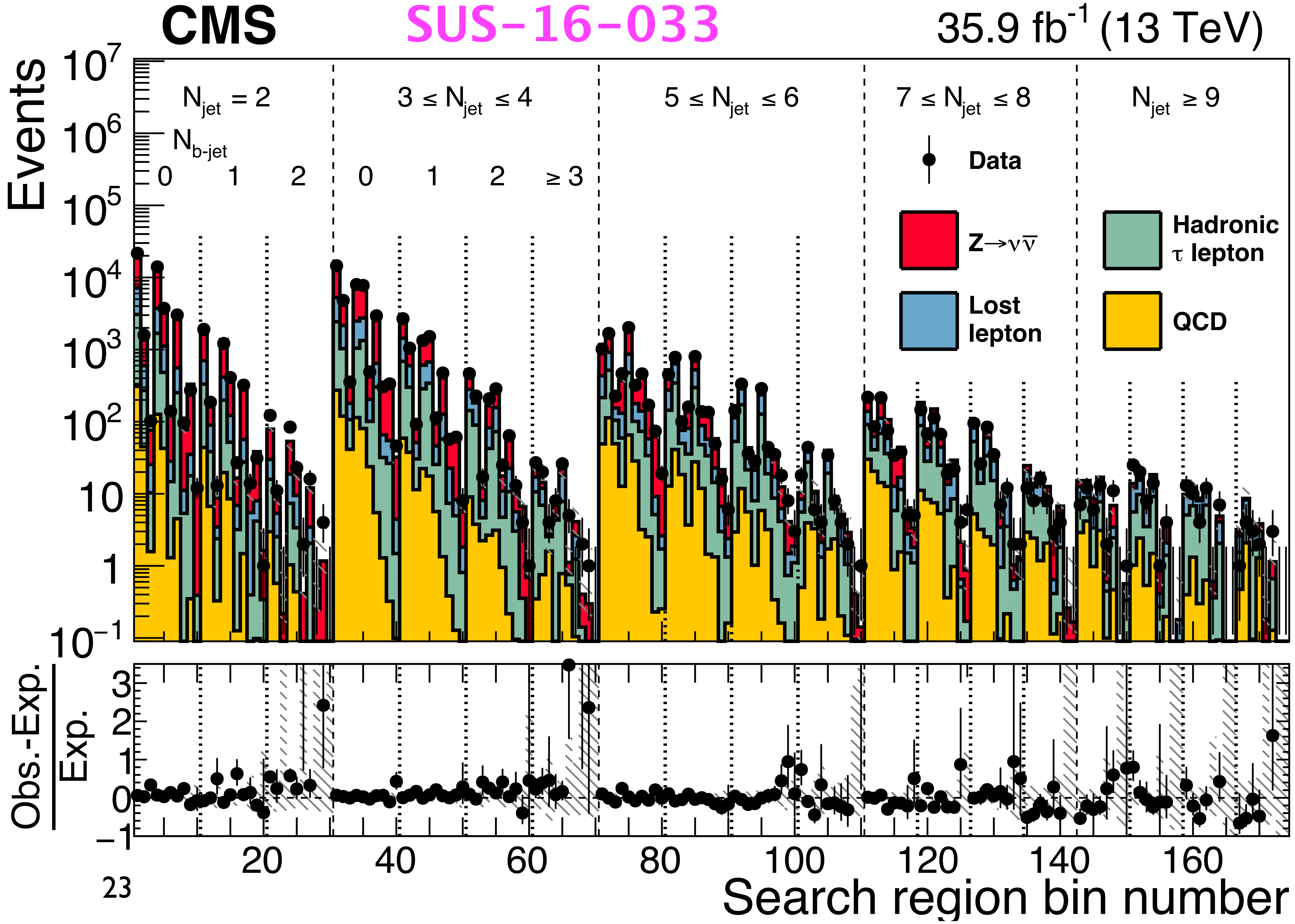
Gluino search results

- simplified model captures kinematic variation in $\Delta m = m(g) - m(\tilde{\chi}_1^0)$
- sensitivity degrades at small Δm where ME_T and H_T are low



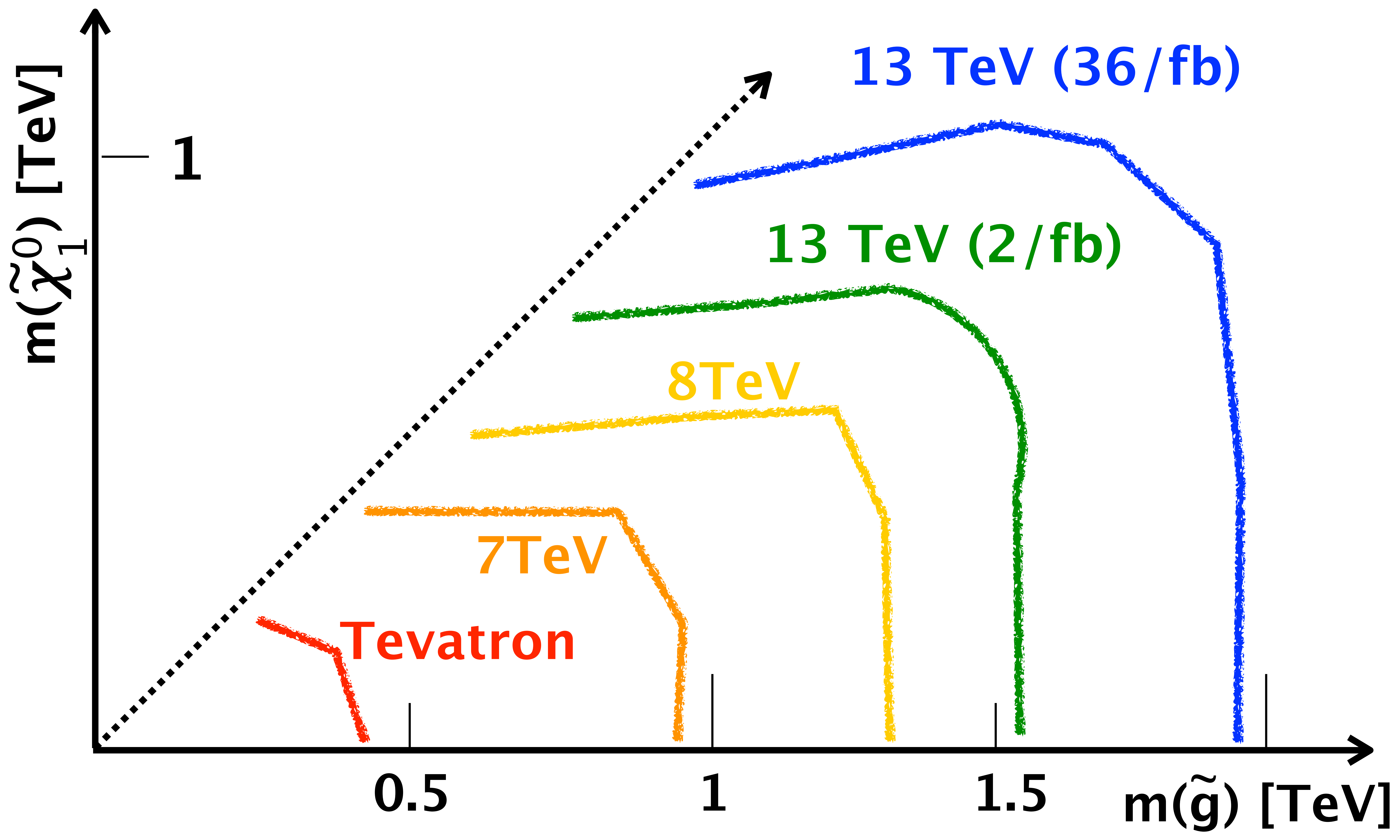
CONF-2017-021





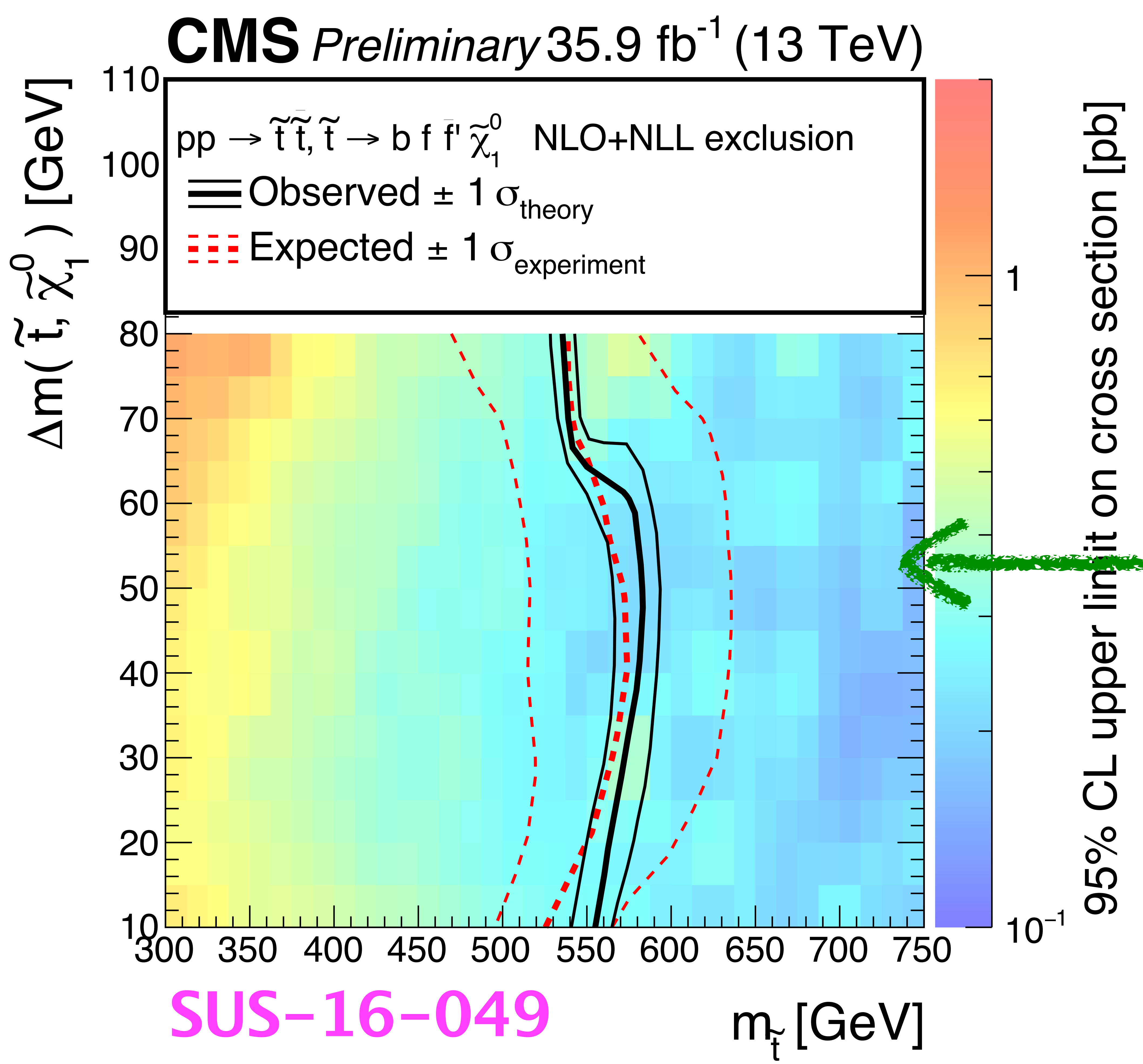
Evolution of gluino sensitivity since 2010

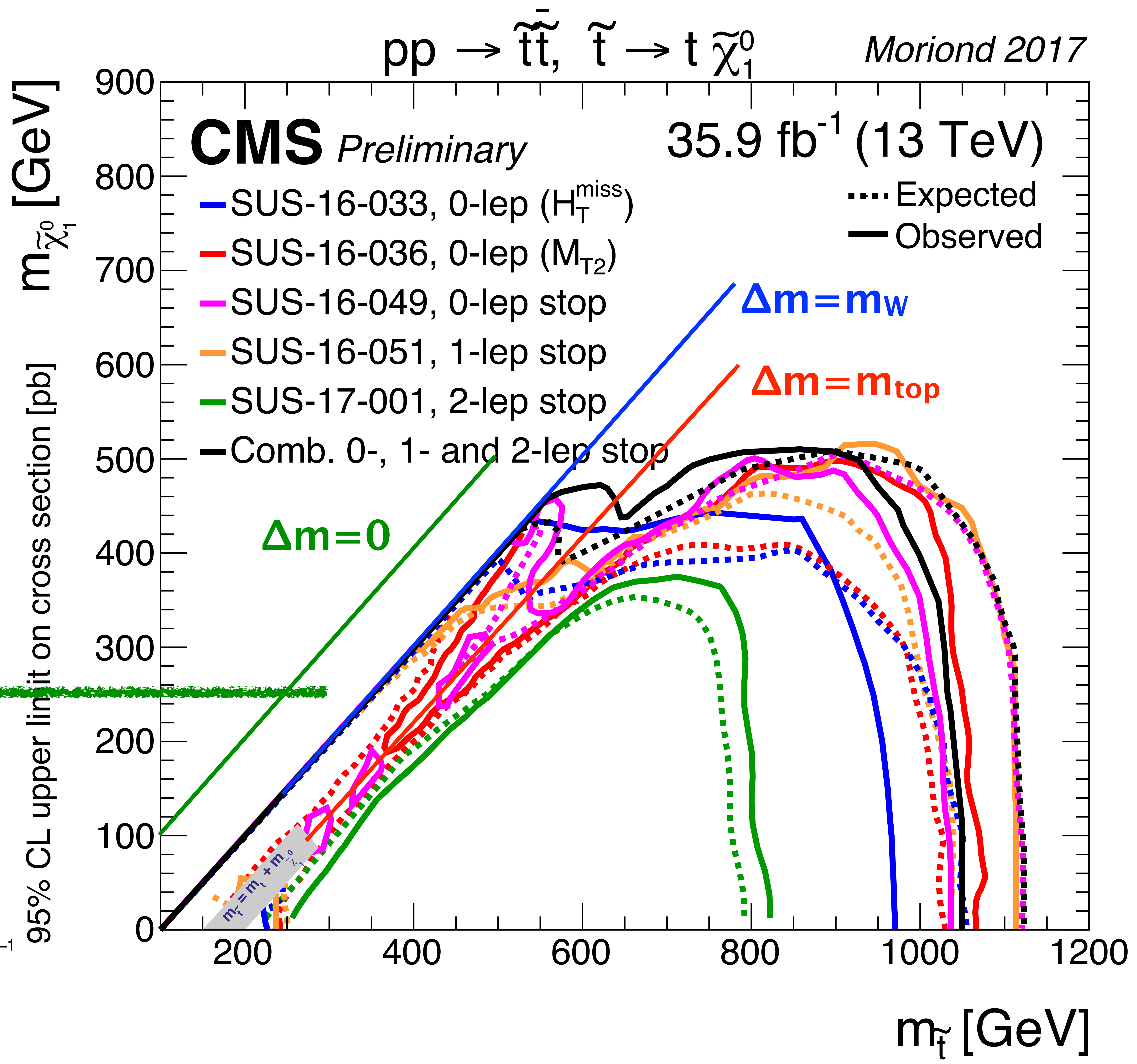
Vast reach of the LHC has taught us much about nature!!



Stop search kinematics

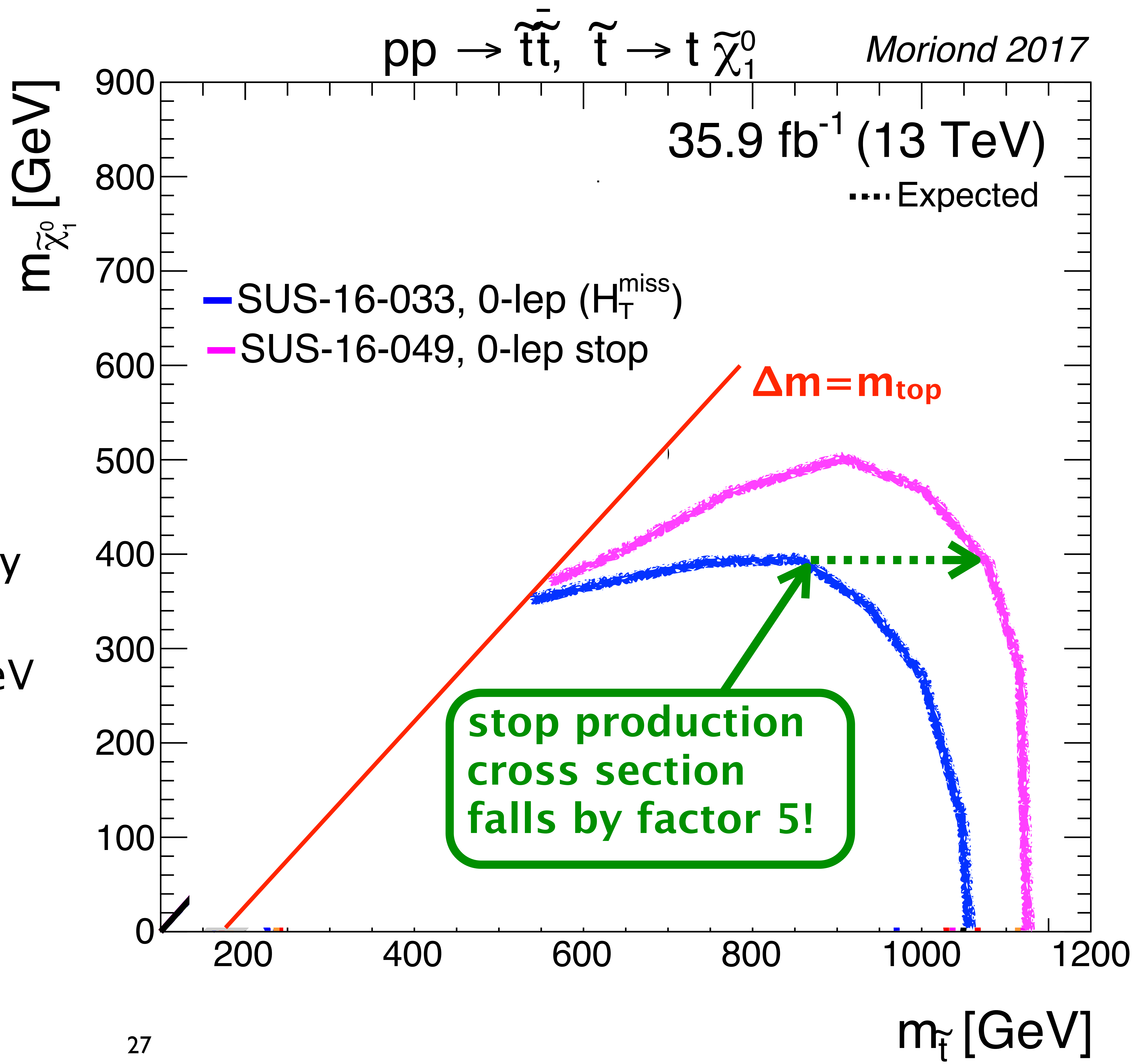
Stop sensitivity





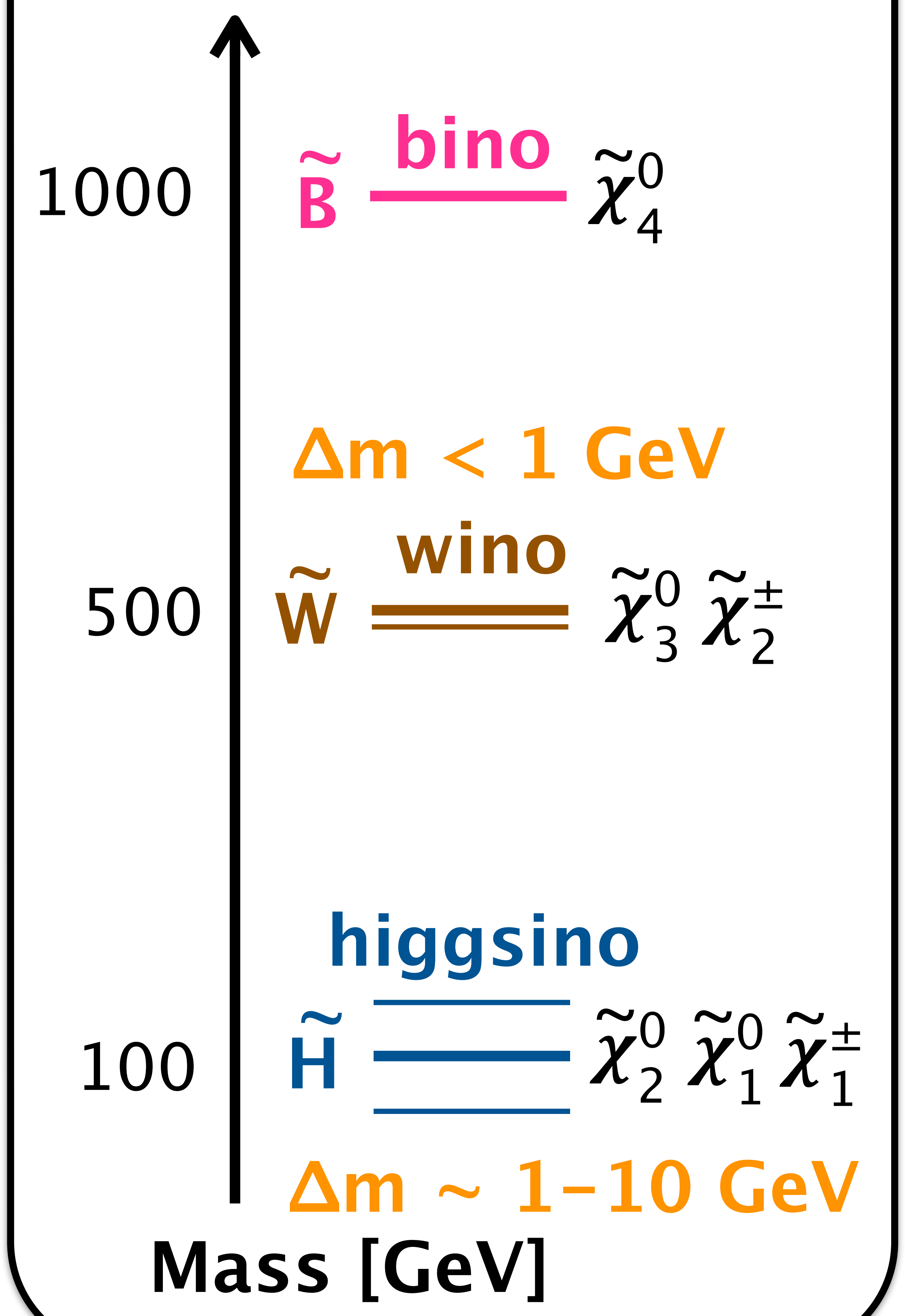
Stop sensitivity

- **General searches** have good sensitivity to top squarks.
- **Targeted searches** use full decay kinematics
  - improve mass reach by 150 GeV
  - critical for potential discovery



Search for EWKino

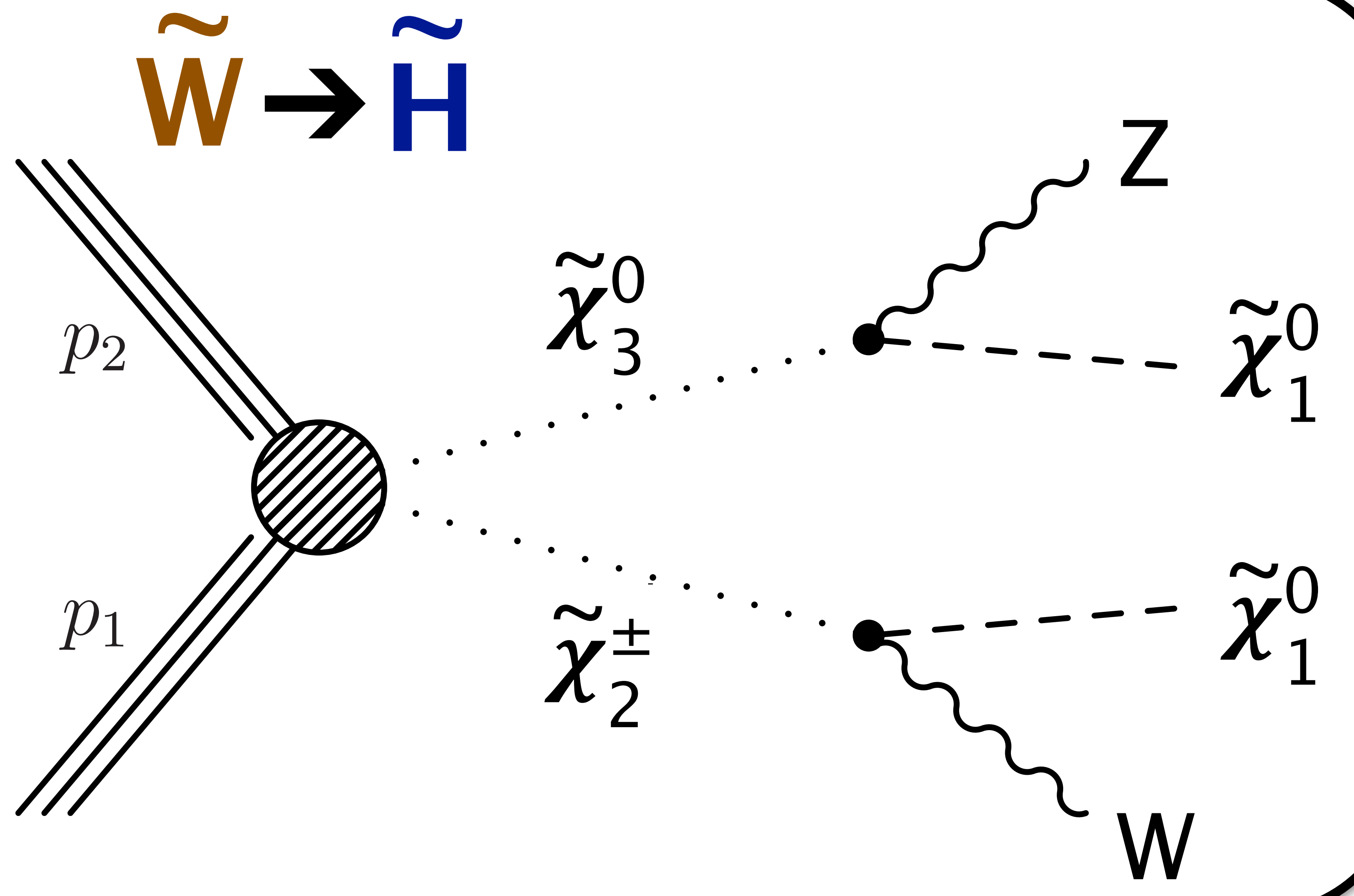
Example spectrum



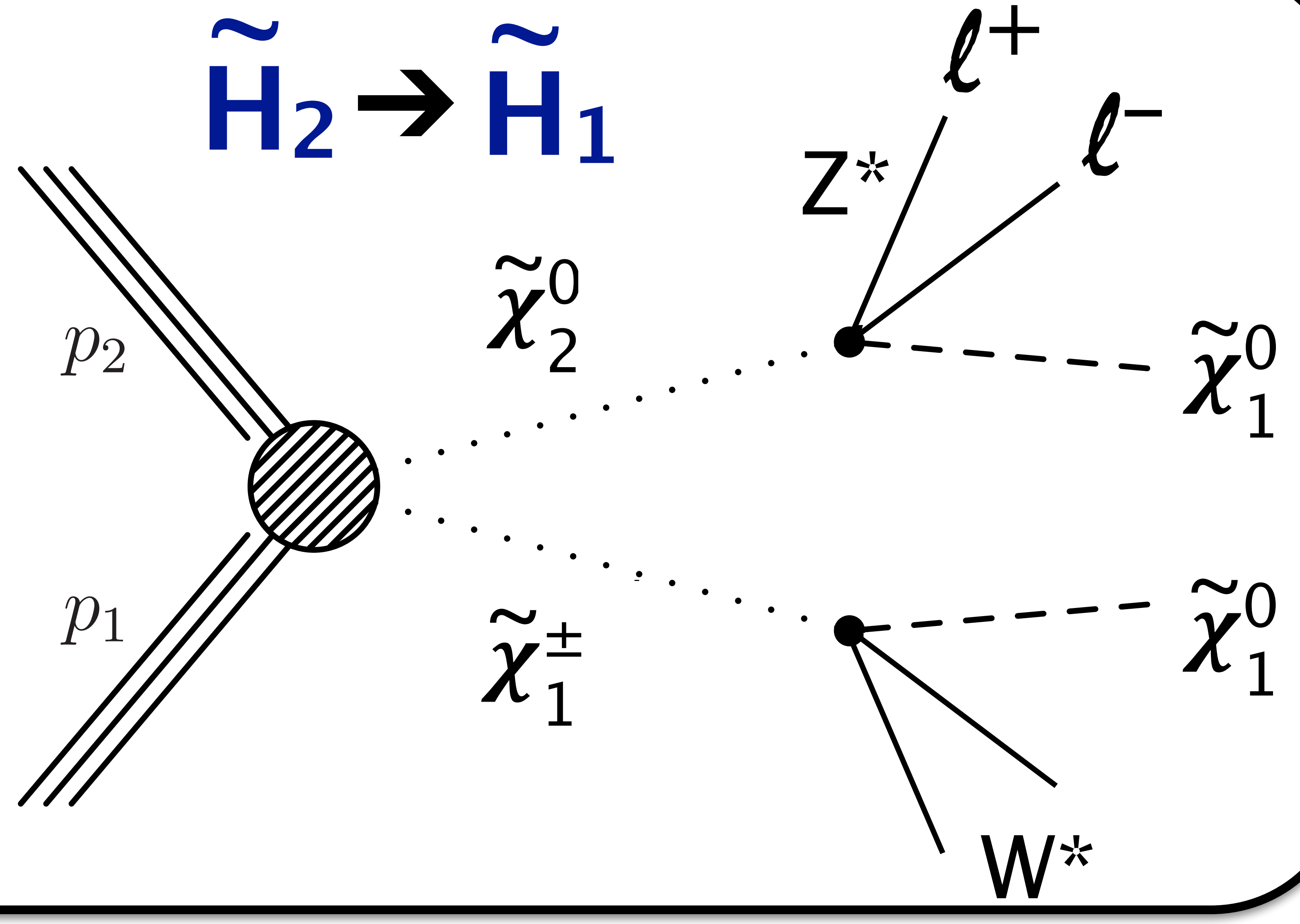
Decays to VV+ME_T expected for all scenarios.

$\Delta m = m_{\tilde{\chi}^0_{2,3}} - m_{\tilde{\chi}^0_1}$

any Δm possible for $\tilde{W} \rightarrow \tilde{H}$



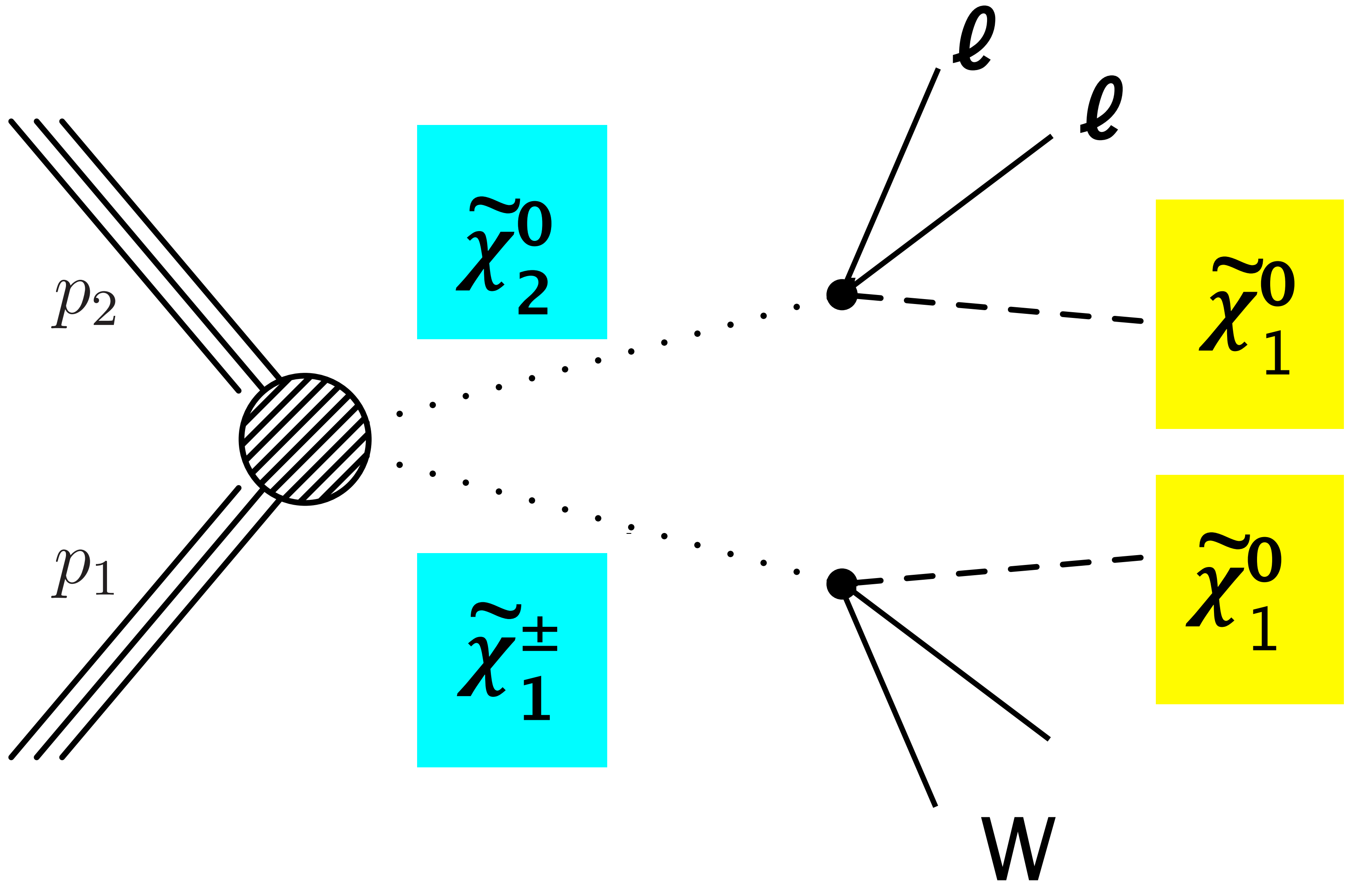
small Δm likely for decays between $\tilde{H}$

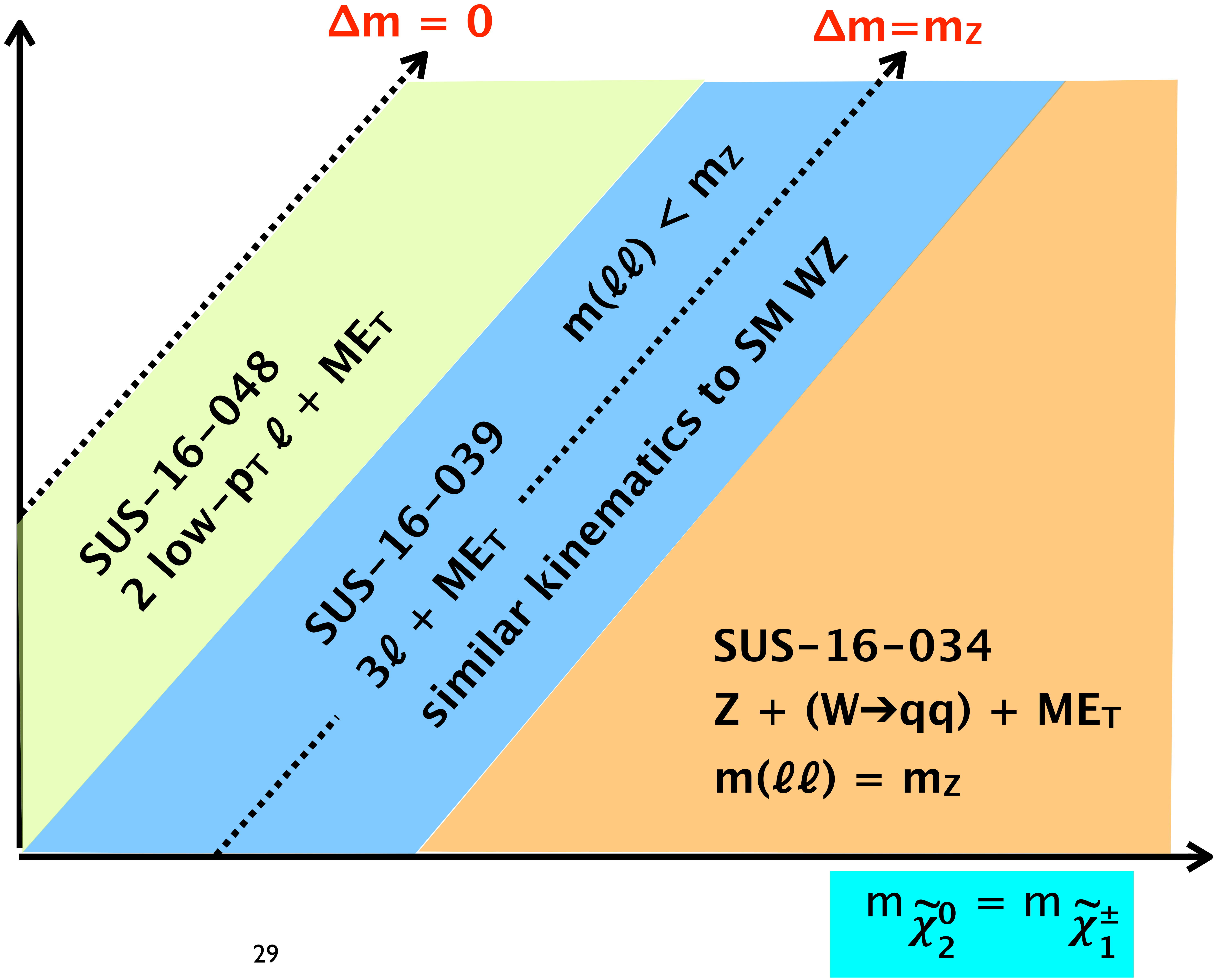


EWKino kinematics

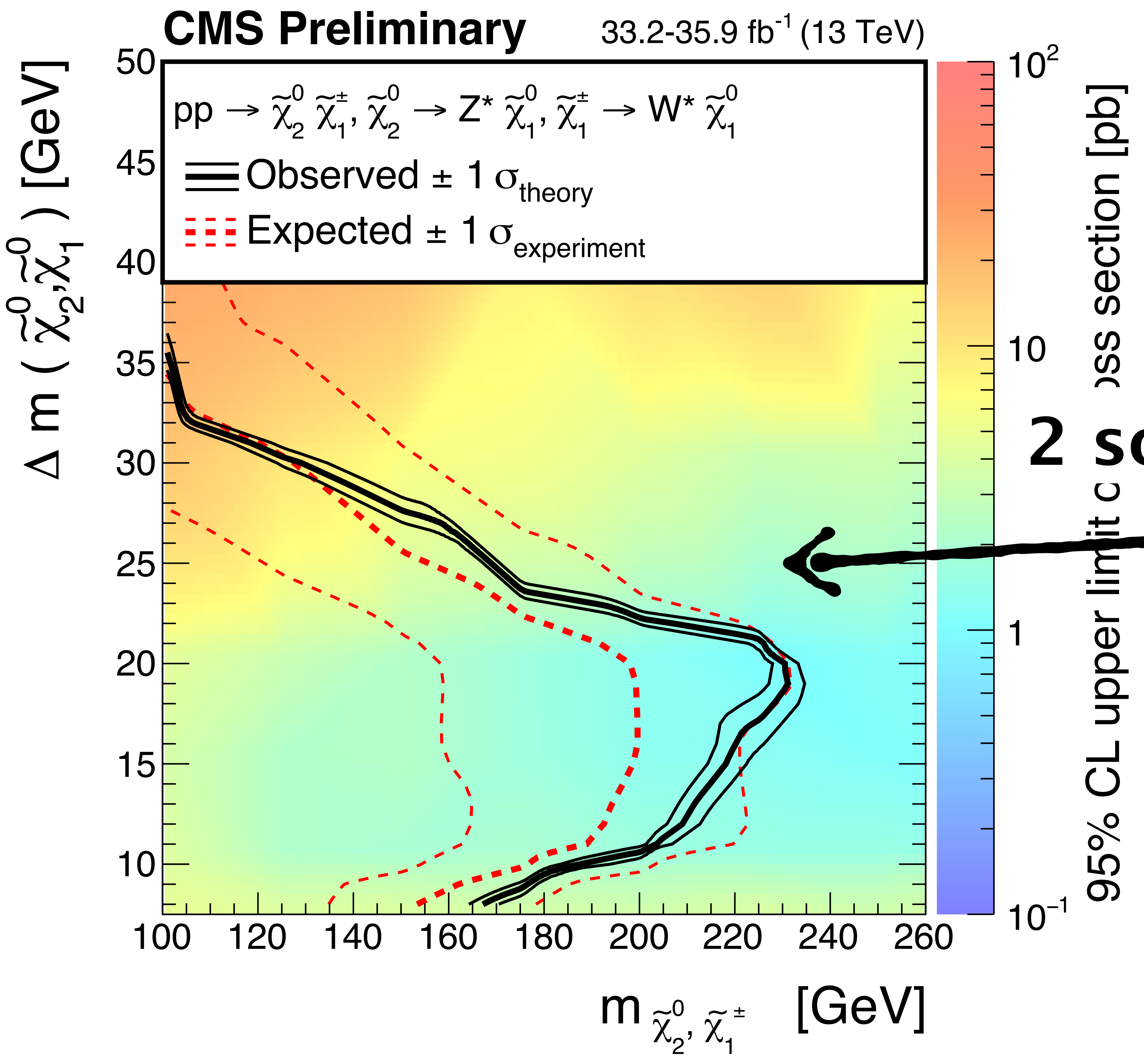
$\Delta m = m_{\tilde{\chi}^0_2} - m_{\tilde{\chi}^0_1}$

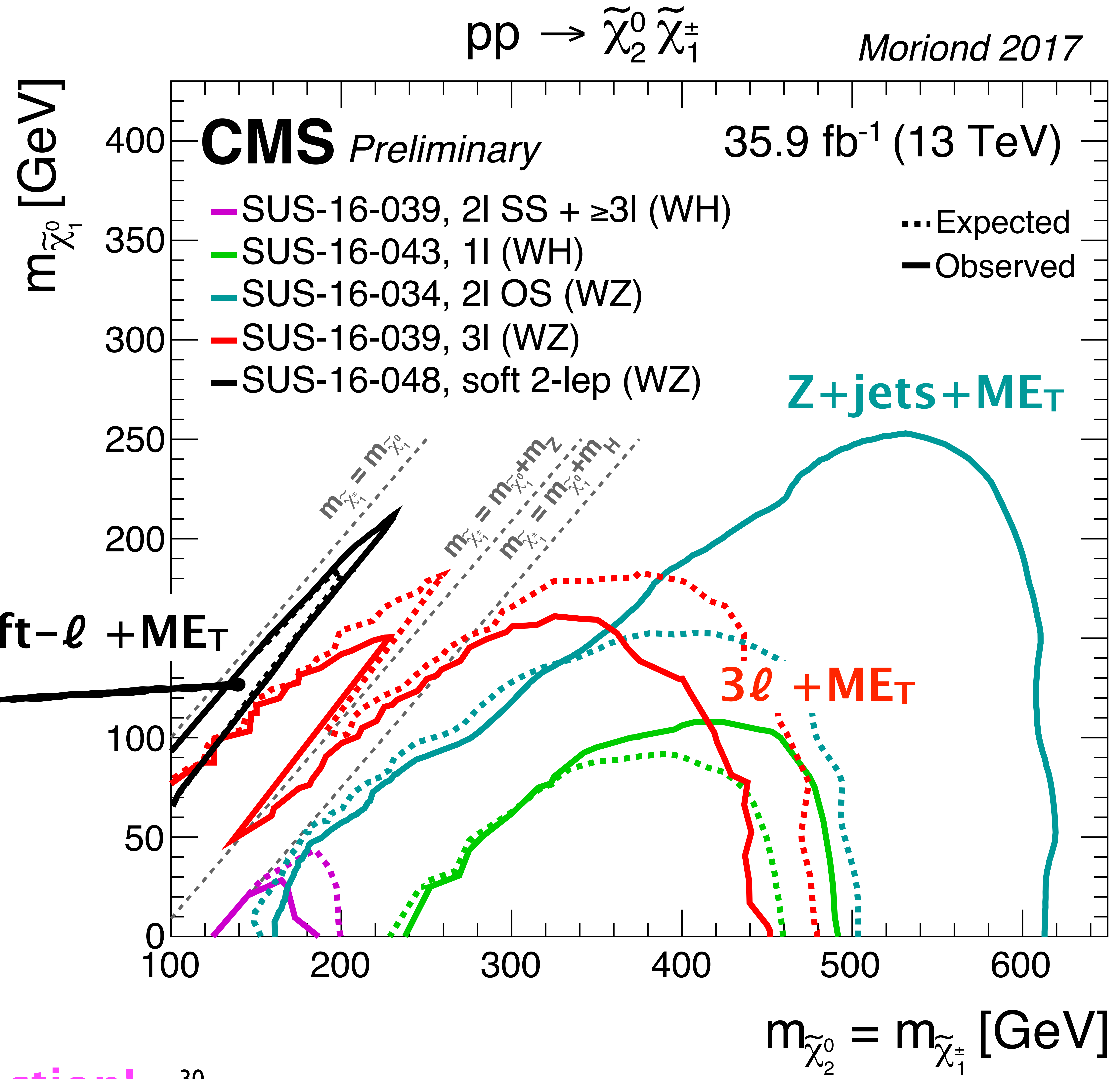
1. $\tilde{W} \rightarrow \tilde{H}$ with large Δm
2. $\tilde{W} \rightarrow \tilde{H}$ with moderate Δm
3. $\tilde{H}_2 \rightarrow \tilde{H}_1$ with small Δm





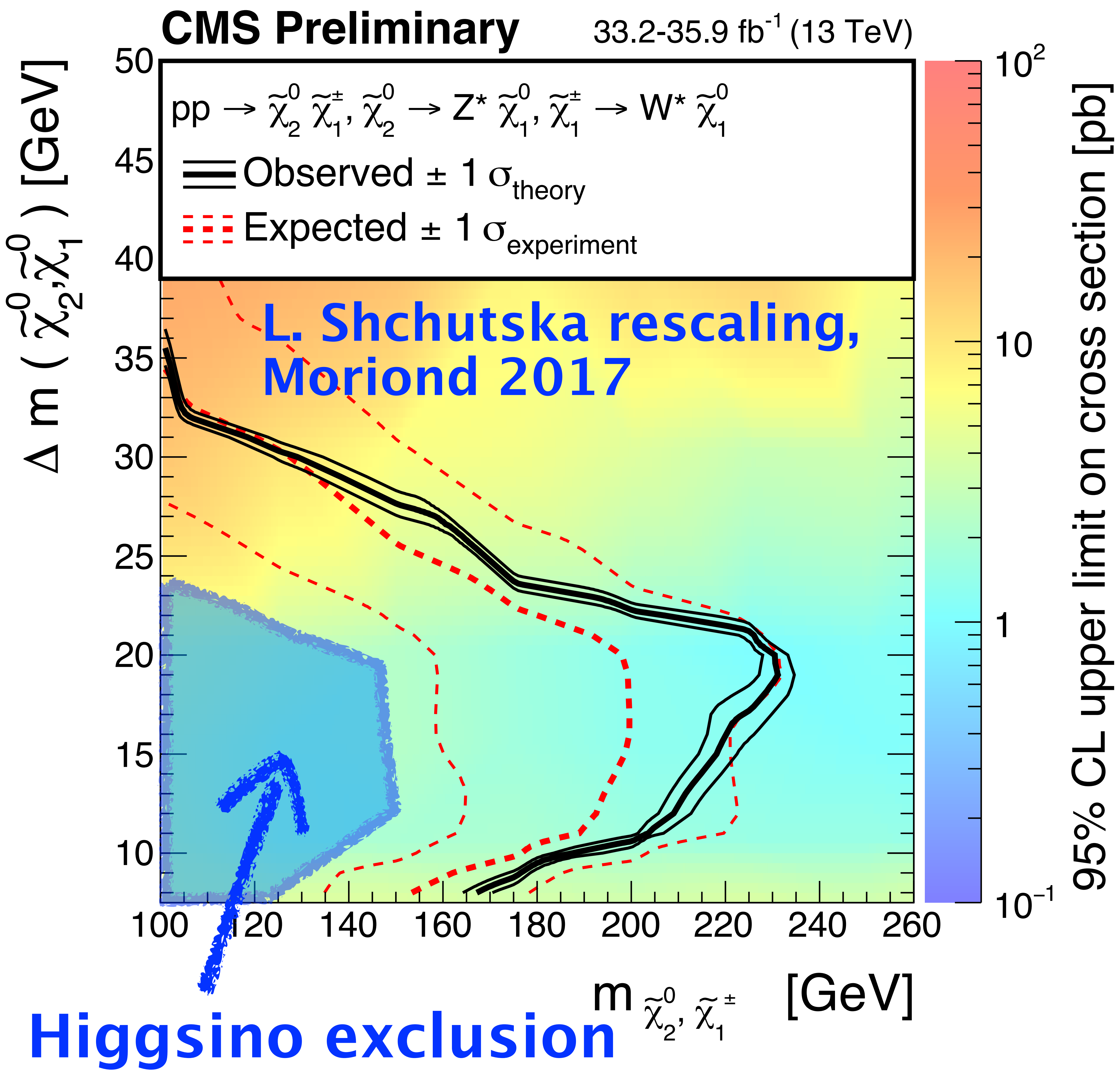
EWKino sensitivity

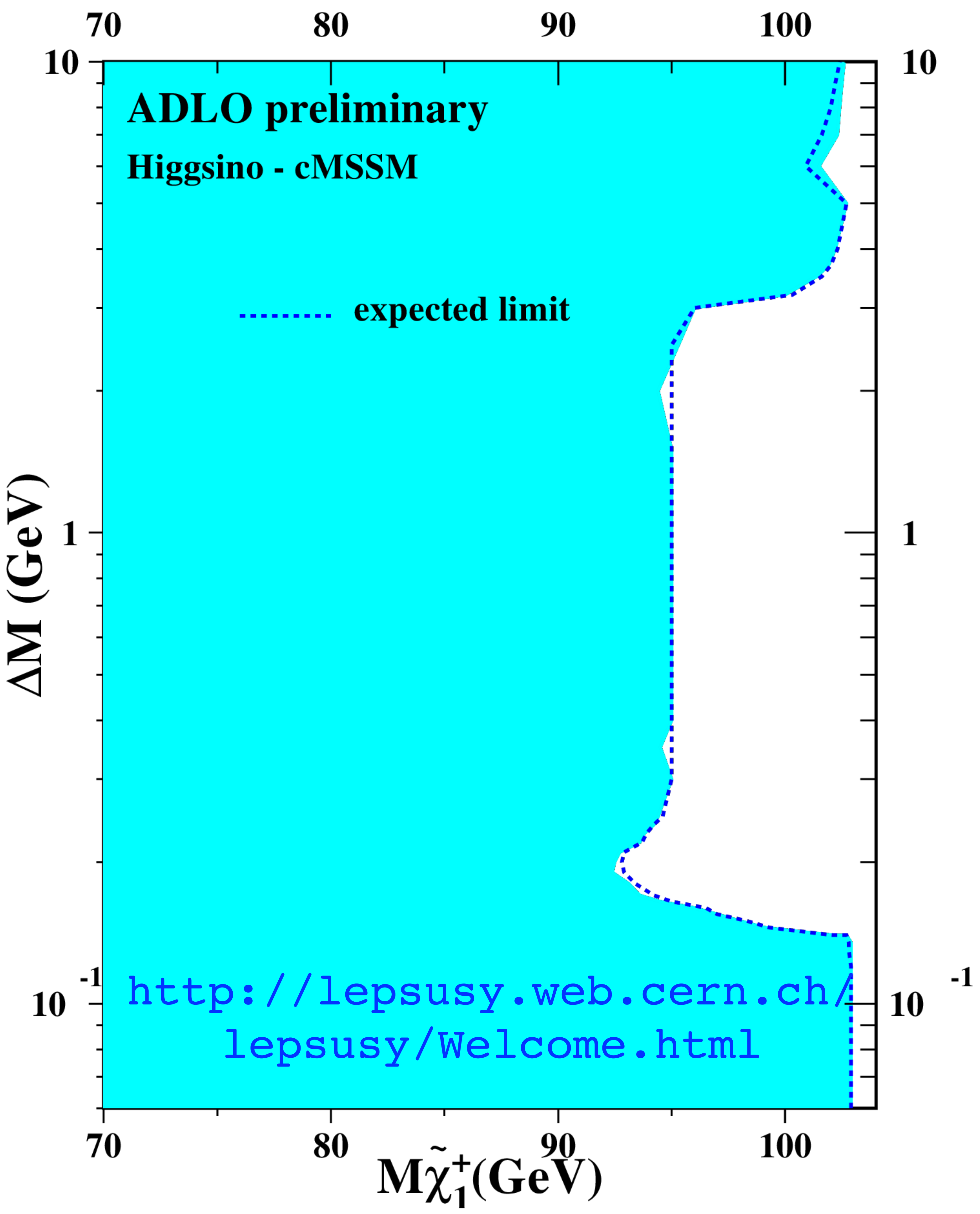




NB: assumes wino-like cross section!

Higgsino sensitivity





At Δm=10 GeV:

- LEP limit is 100 GeV.
- CMS wino limit rescaled to higgsino xsec is 130 GeV.

LHC only now pushing beyond LEP limits!

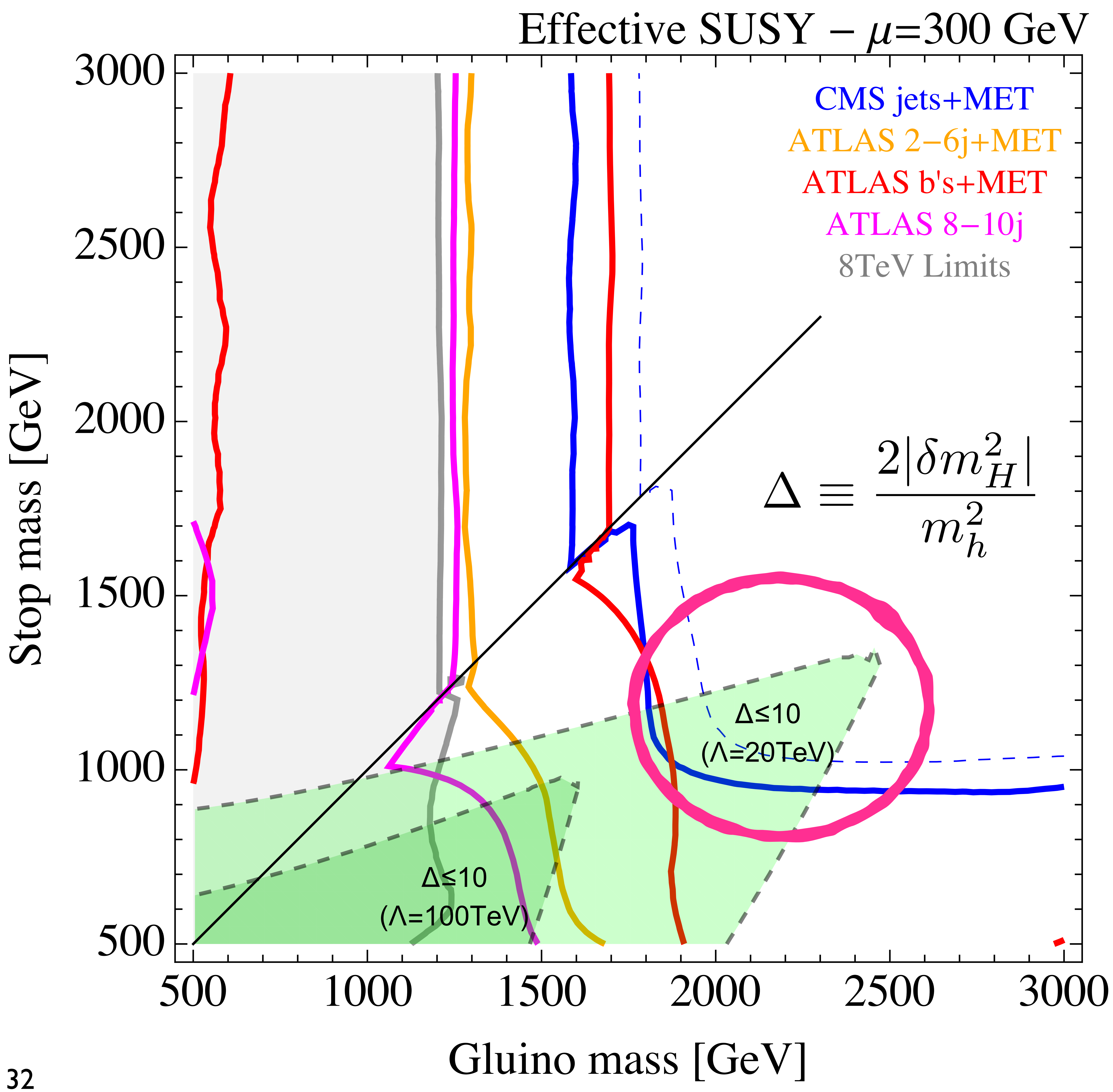
Implication for natural SUSY

Buckley, Feld, Macaluso, Monteux, Shih; arXiv:1610.08059

- Allowed phase space for **10% fine tuning with low Λ=20TeV**.
- Λ=GUT scale implies 0.5% fine tuning.

Options:

- **Denial:** new naturalness metric? H.Baer et al. arXiv:1611.08511
- **Guilt/anger:** Are we sure we are looking in the right places?
- **Depression:** Naturalness mechanism without accessible particles? Twin Higgs?
- **Acceptance:** 0.1% tuning better than 10^{-30}
- **Hope:** Hide SUSY with stealth SUSY, R-parity violation?



R-parity violating SUSY

$$W_{\rm RPV} = \frac{1}{2}\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \frac{1}{2}\lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

$(\Delta L, \Delta B) = (1,0)$ $(\Delta L, \Delta B) = (1,0)$ $(\Delta L, \Delta B) = (0,1)$

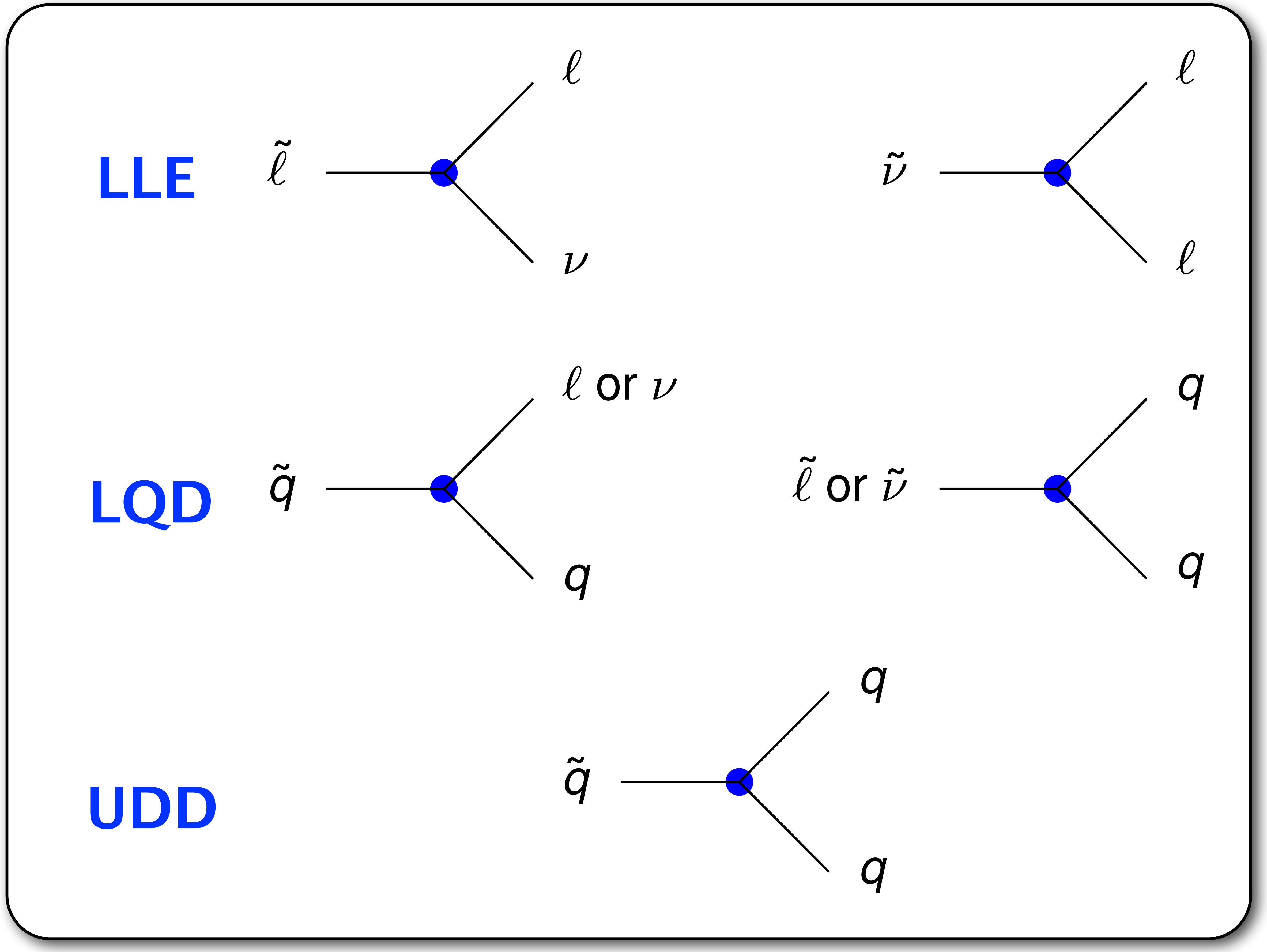
RPV allows decay of LSP ➔ instead of searching with ME_T use

- leptons
- high jet multiplicity

New results

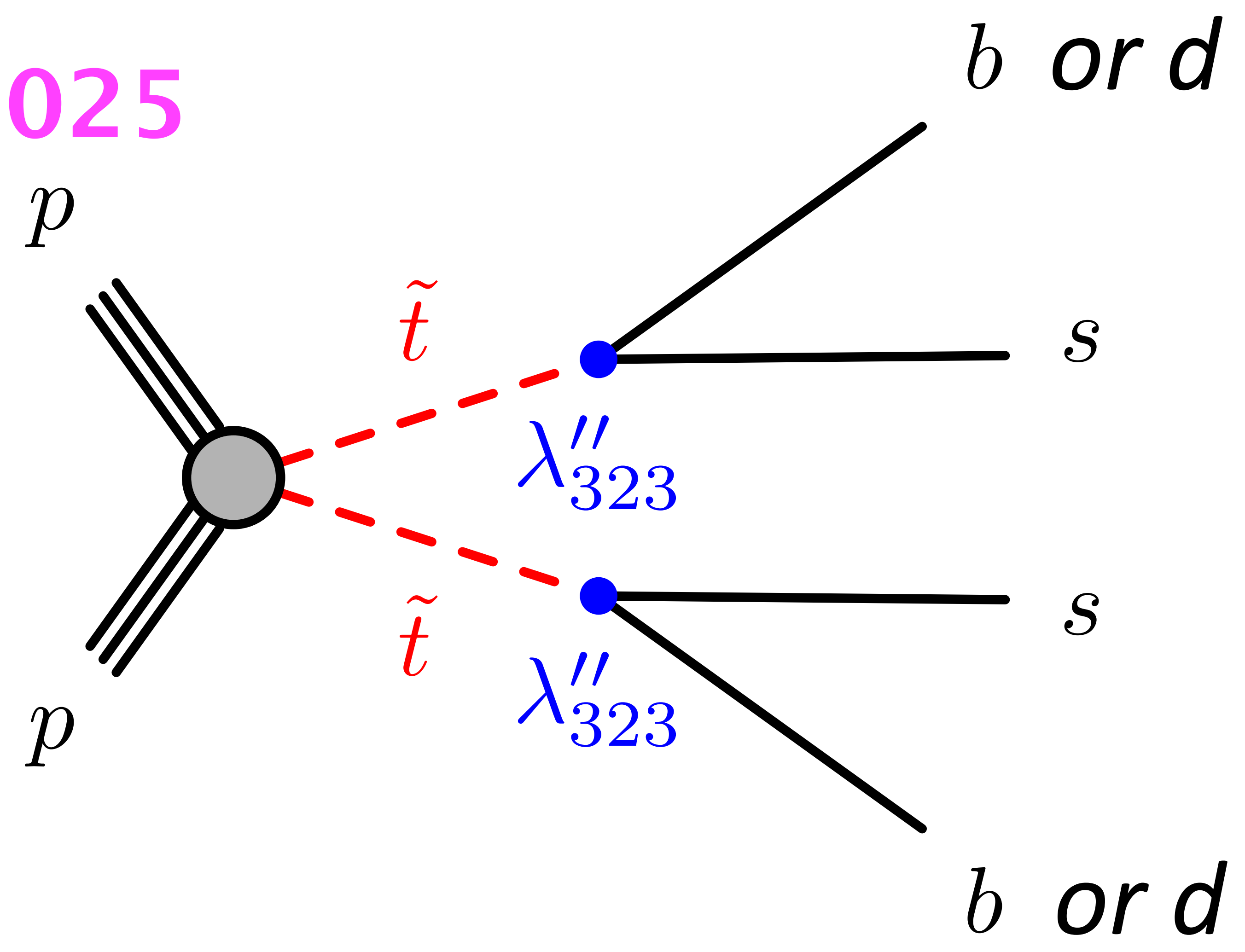
- CONF-2017-025 : stop ➔ jj
- EXO-16-029 : stop ➔ merged jj
- CONF-2017-013 : 1ℓ + many jets

Chihiro Kozakai: Searches for RPV SUSY and long-lived particles with ATLAS

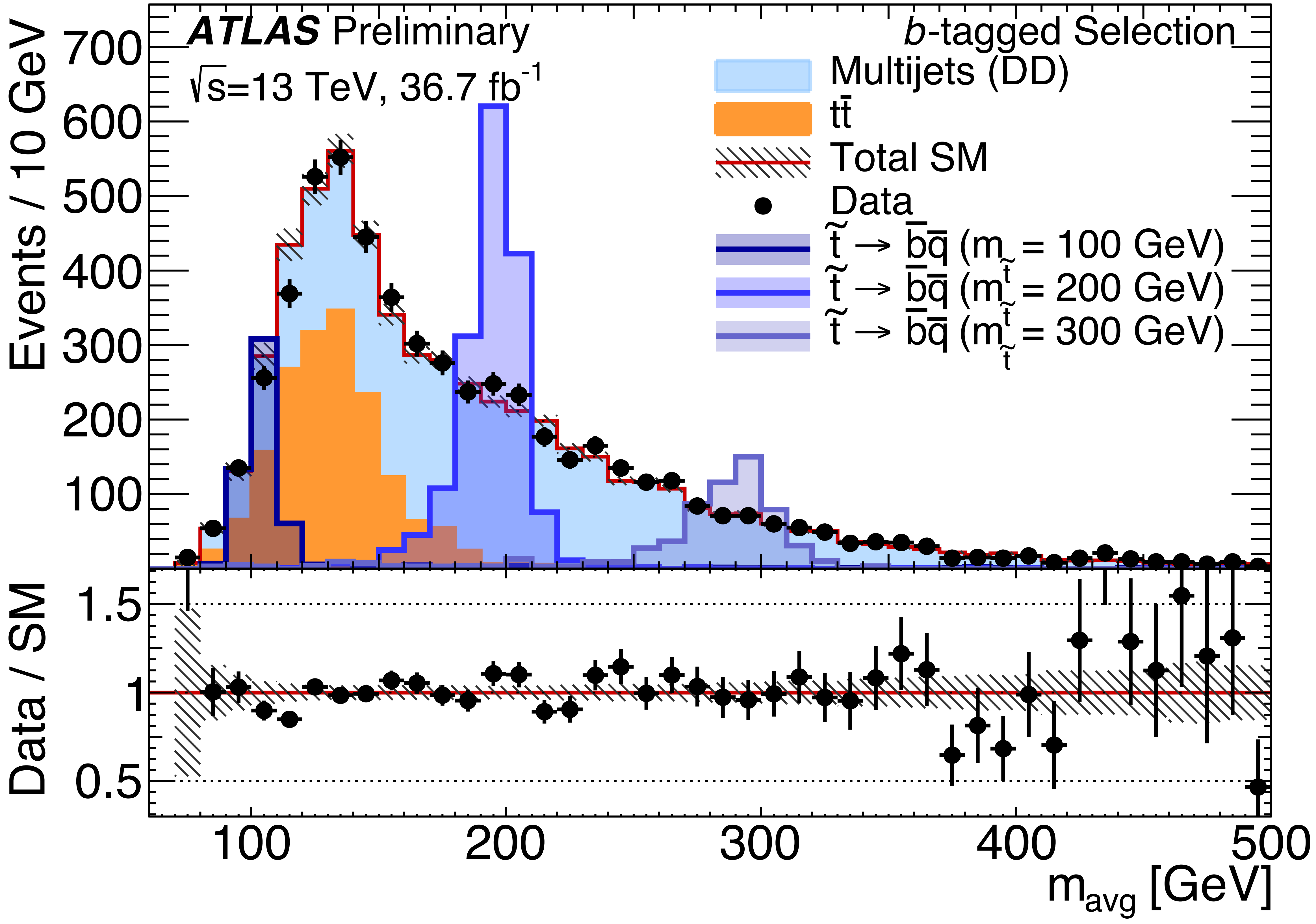


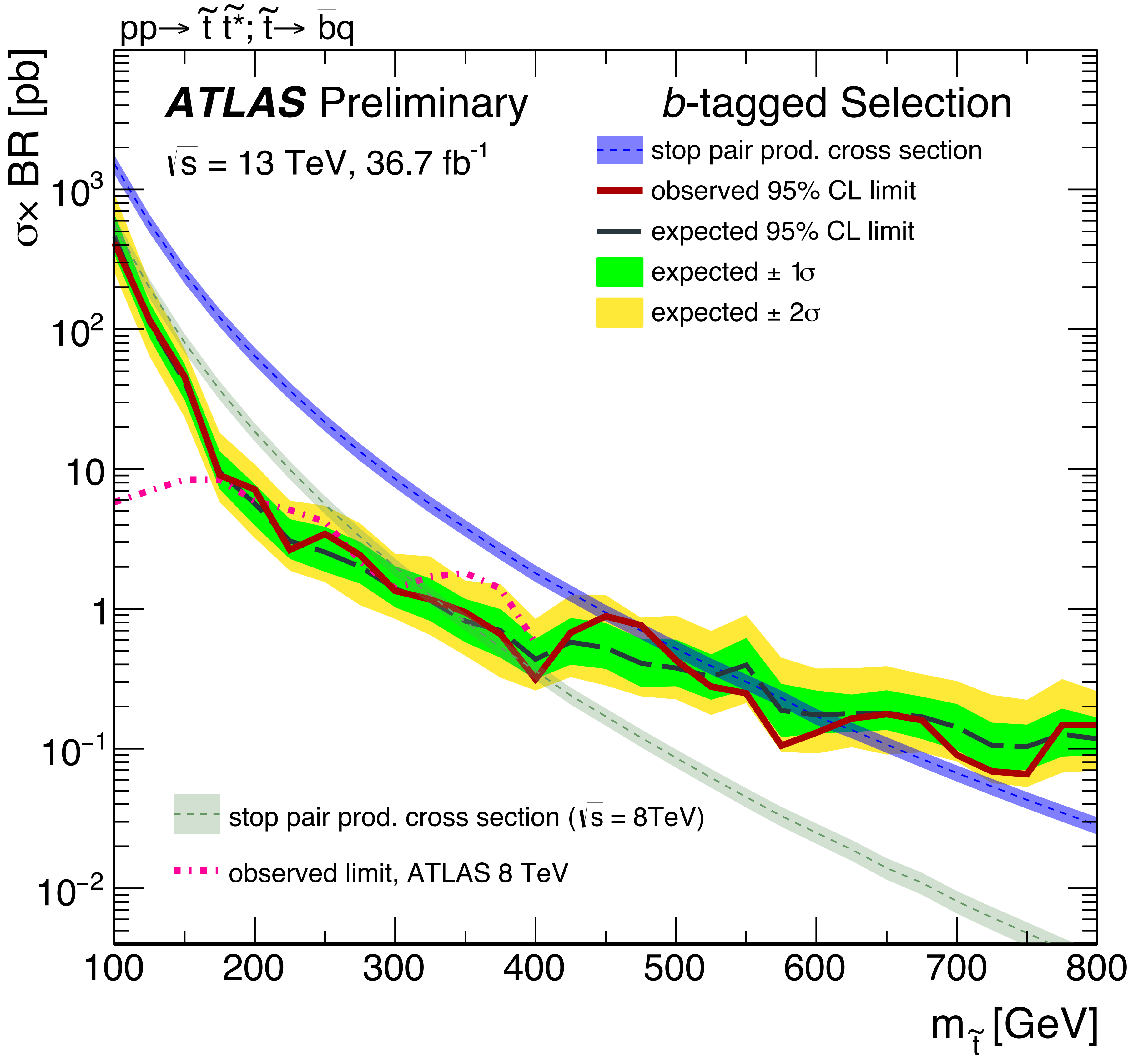
RPV $\tilde{t}\tilde{t} \rightarrow$ (jj)(jj) or (bj)(bj)

CONF-2017-025



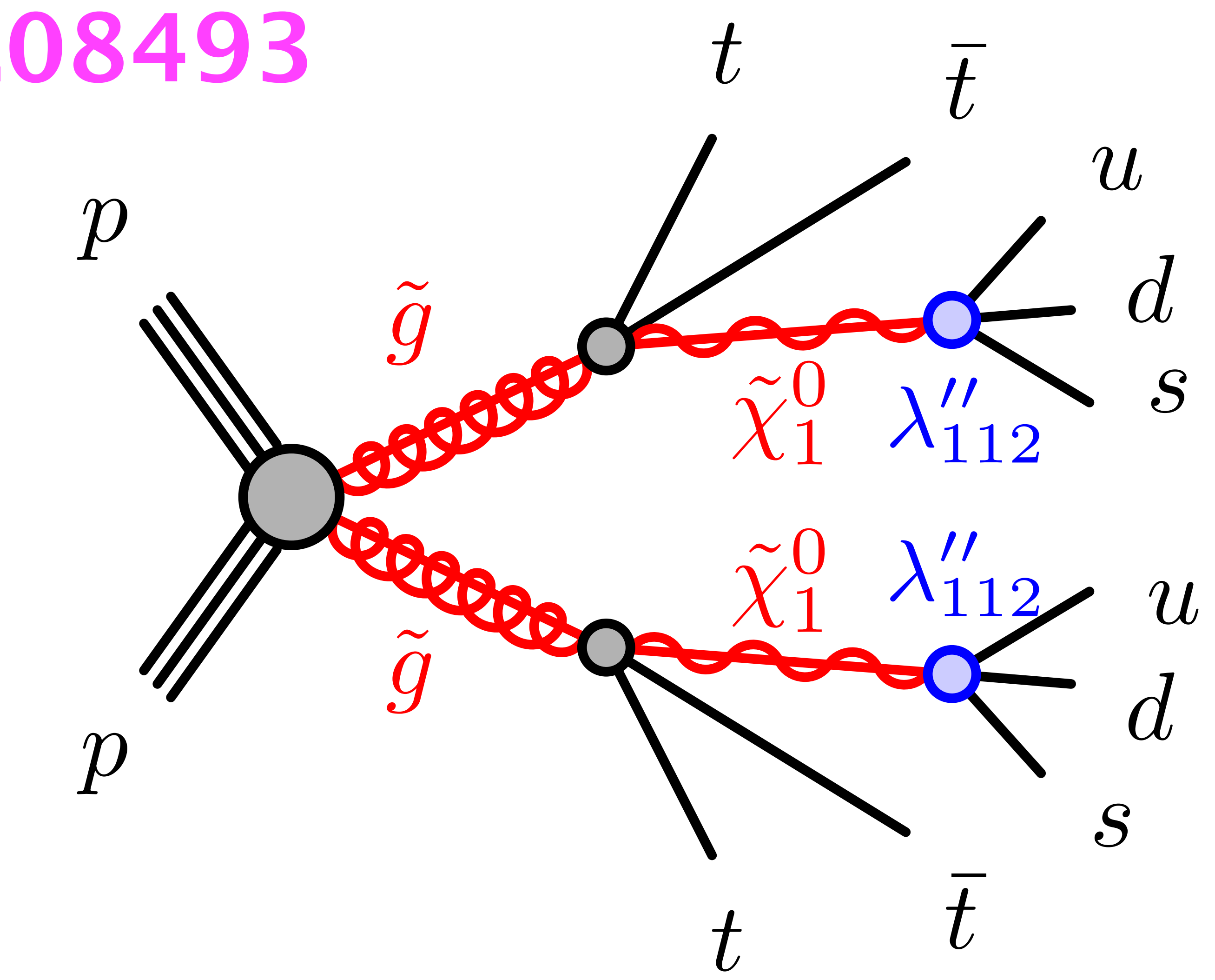
- Background estimated from control samples in $|\cos(\theta^*)|$ and mass asymmetry.

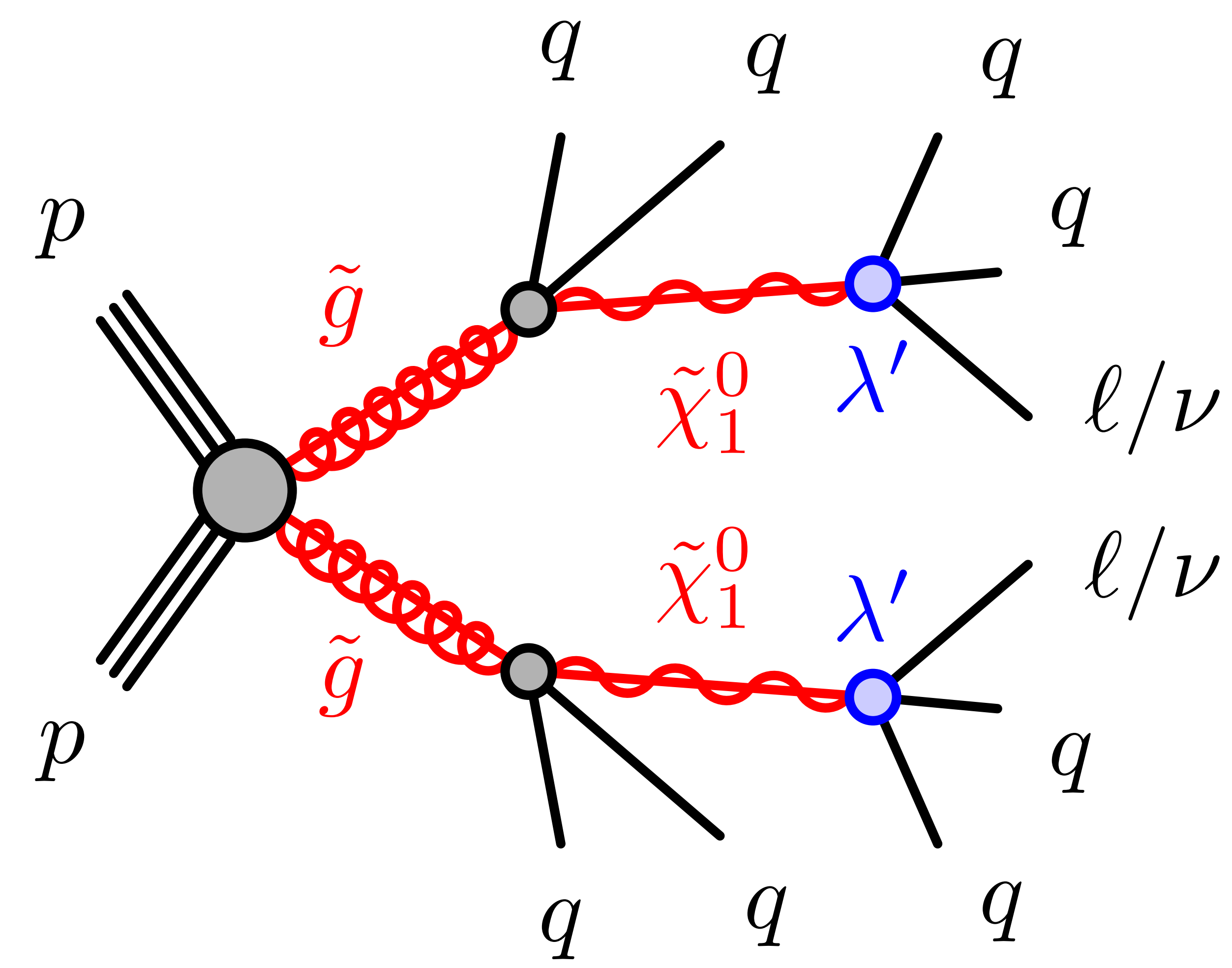




RPV 1ℓ + jets

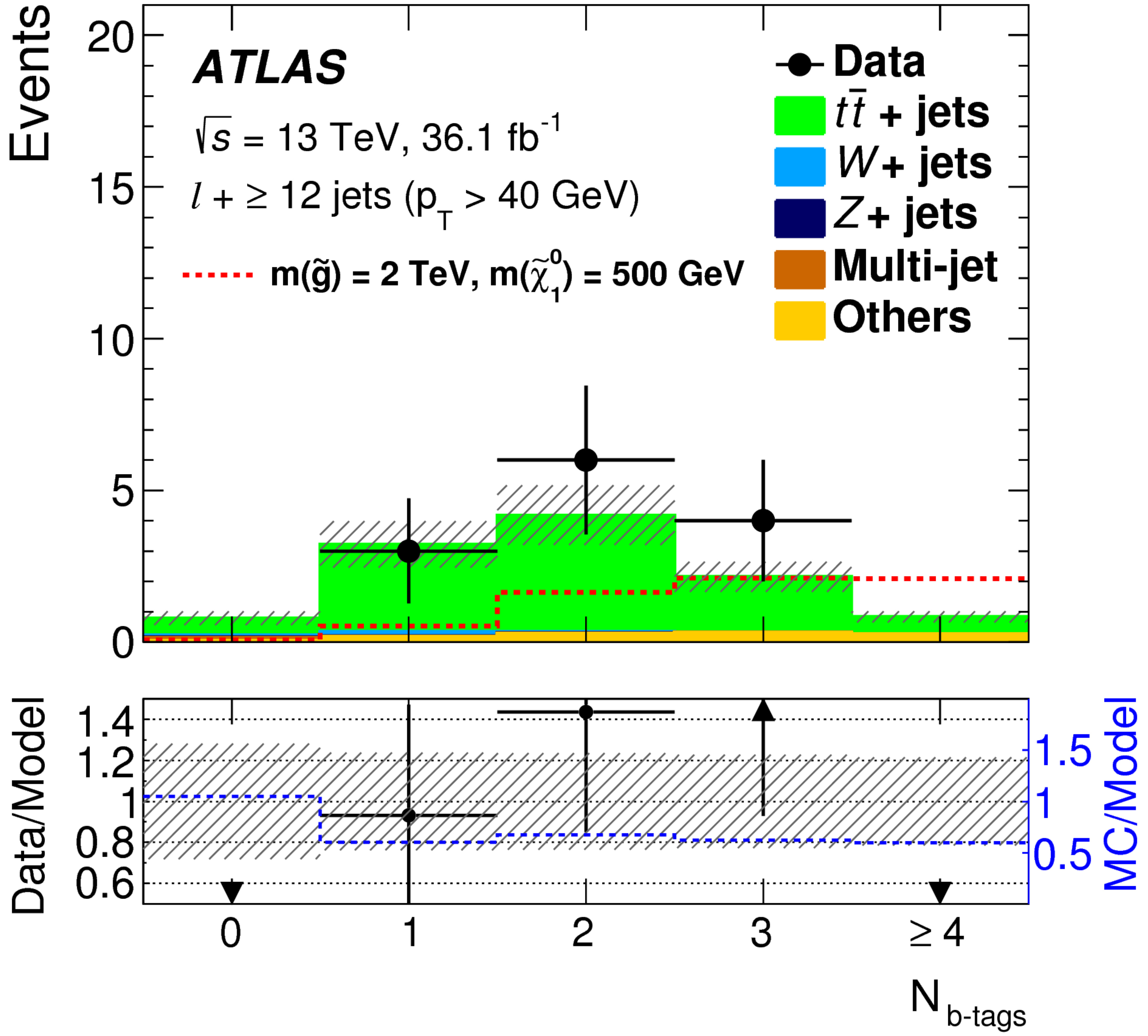
arXiv:1704.08493

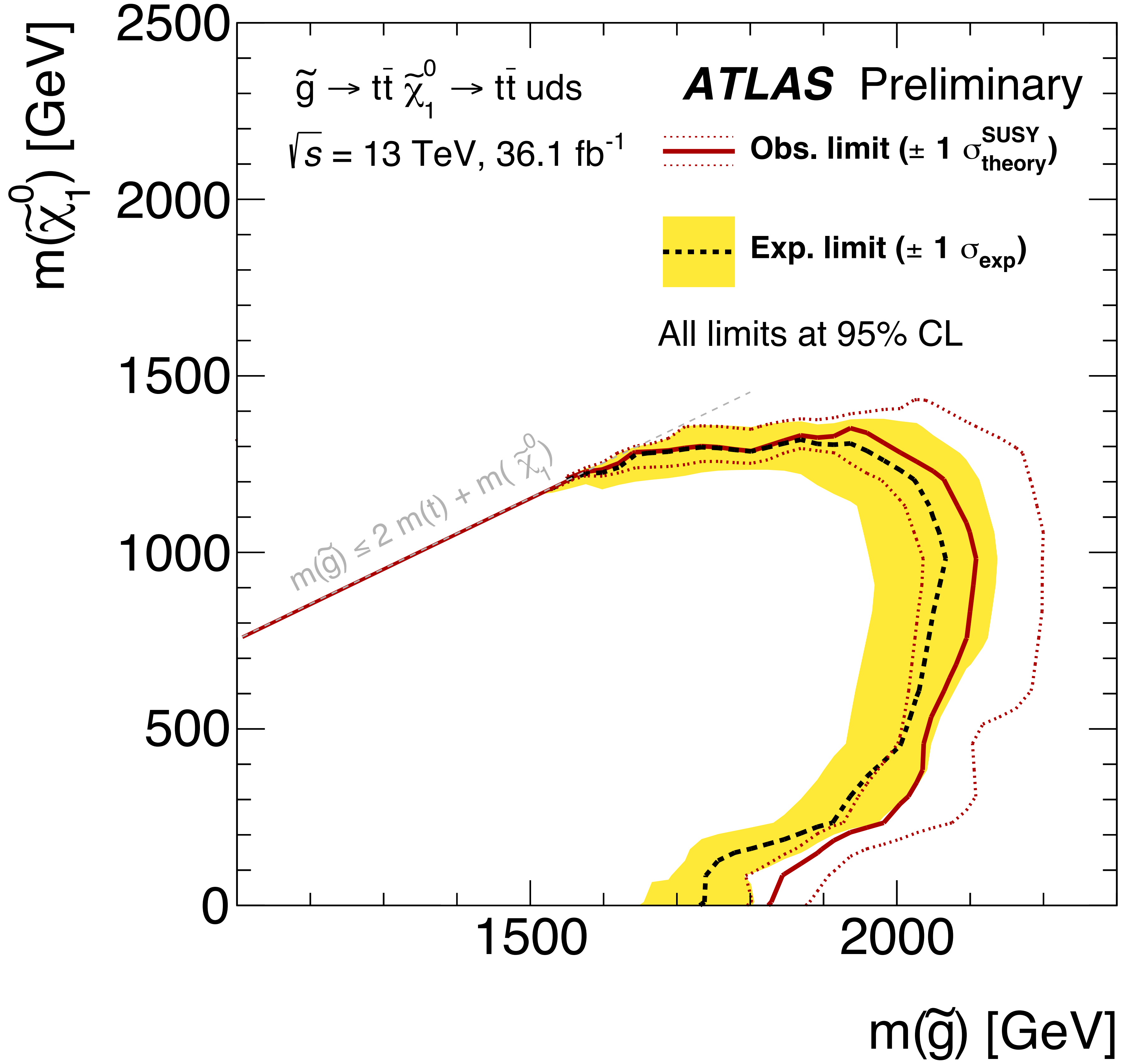




Determine Nj and N_b shapes with parameterized scaling from Nj→Nj+1 in each N_b category.

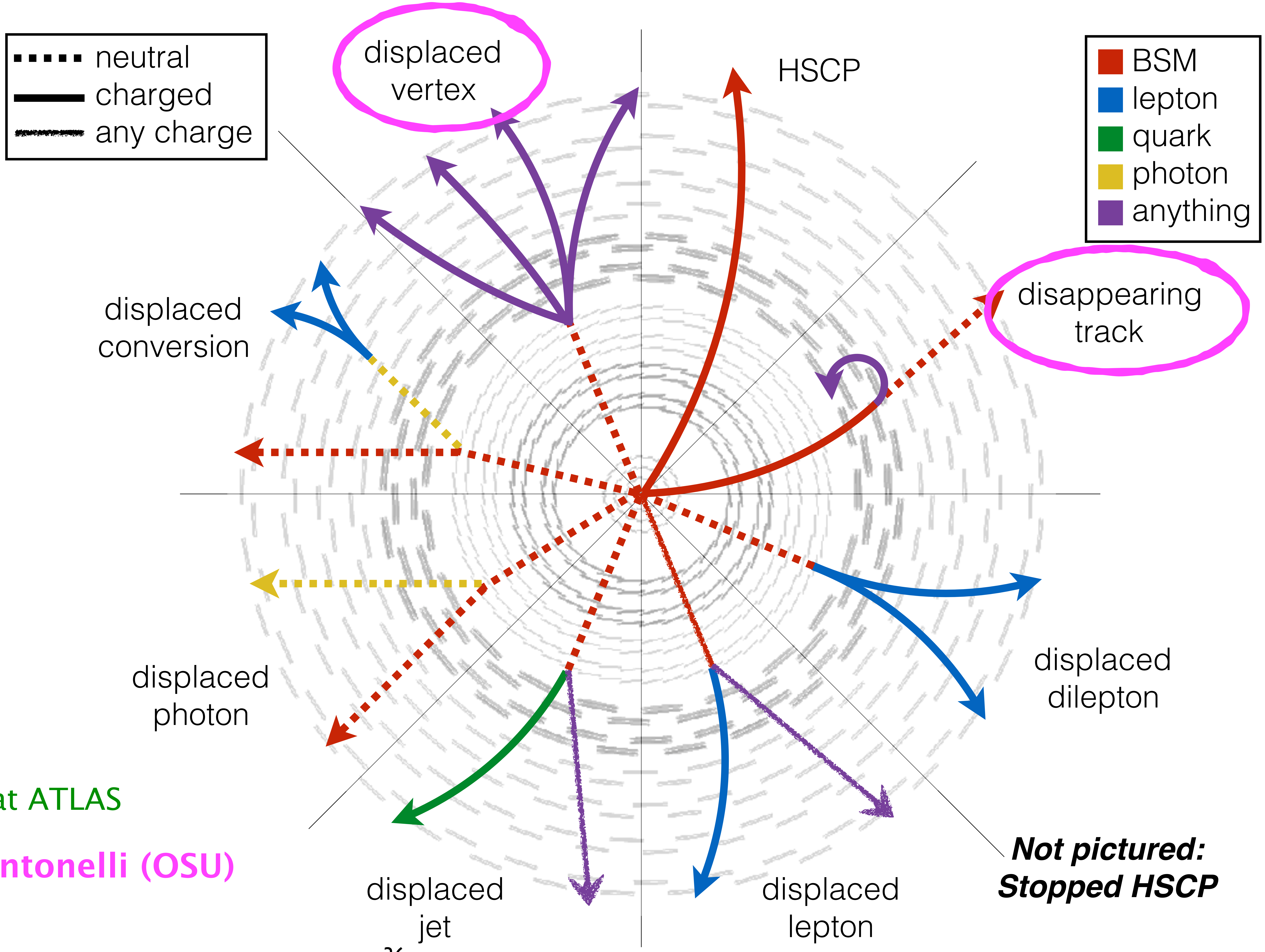
28% uncertainty on number of events with Nj≥12 and Nb≥3.





Long-lived particles

- EXO-16-003 : Displaced jets
- CONF-2017-026 : displaced vertices
- CONF-2017-017 : disappearing tracks



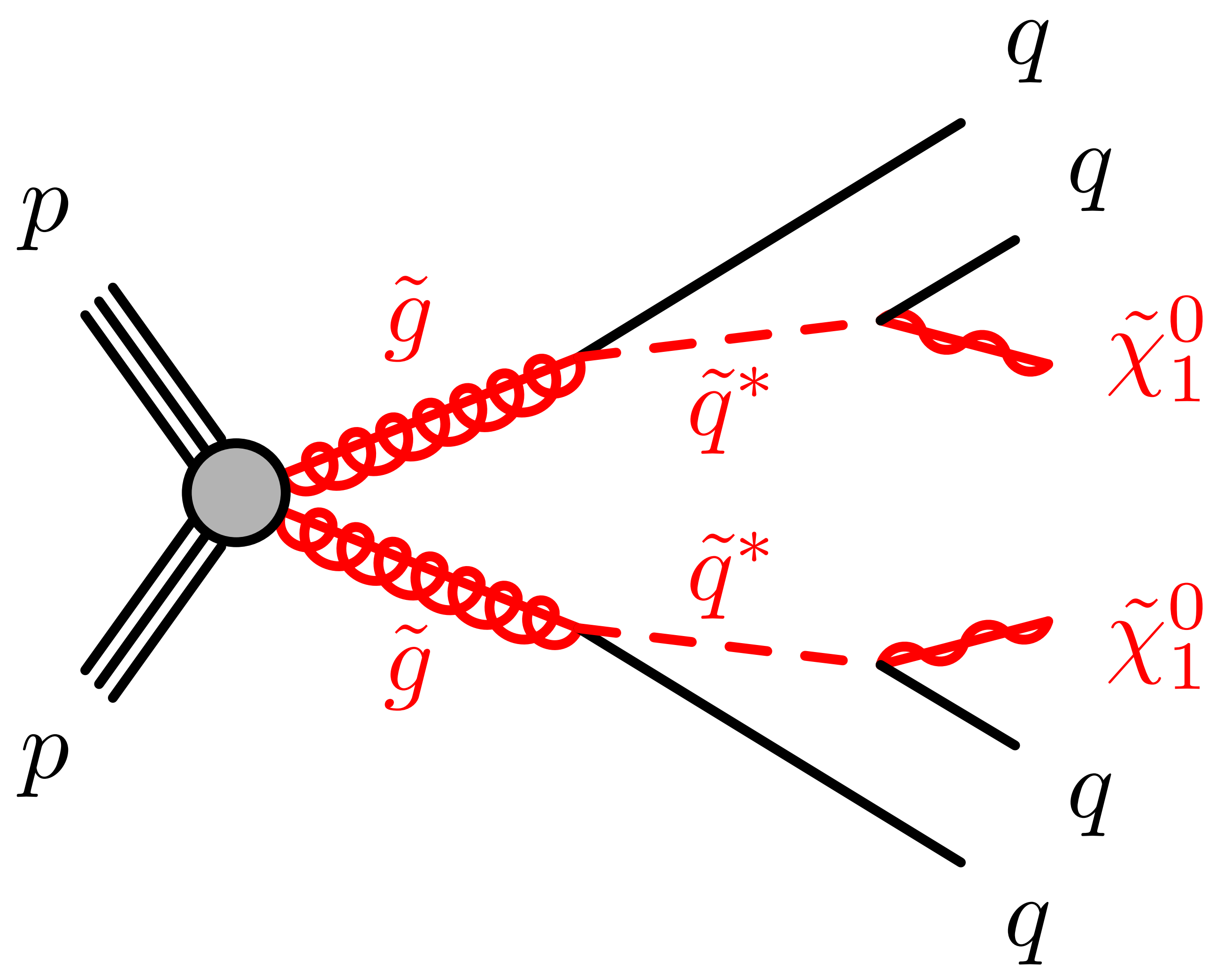
Parallel talks:
GY Jeng: LLP at CMS
C Kozakai: LLP and RPV SUSY at ATLAS

Image: Jamie Antonelli (OSU)

Displaced vertices (DV) + ME_T

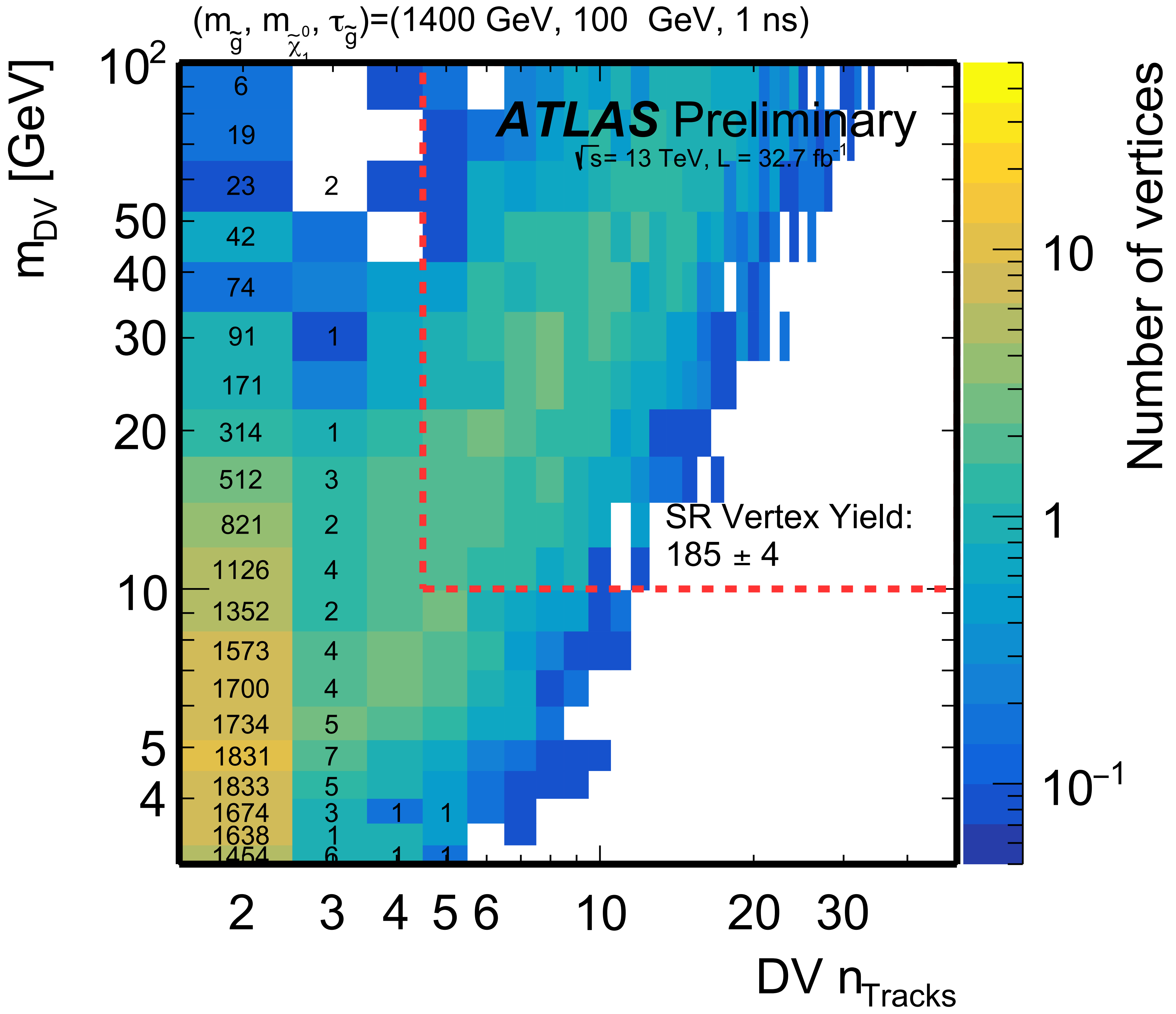
CONF-2017-026

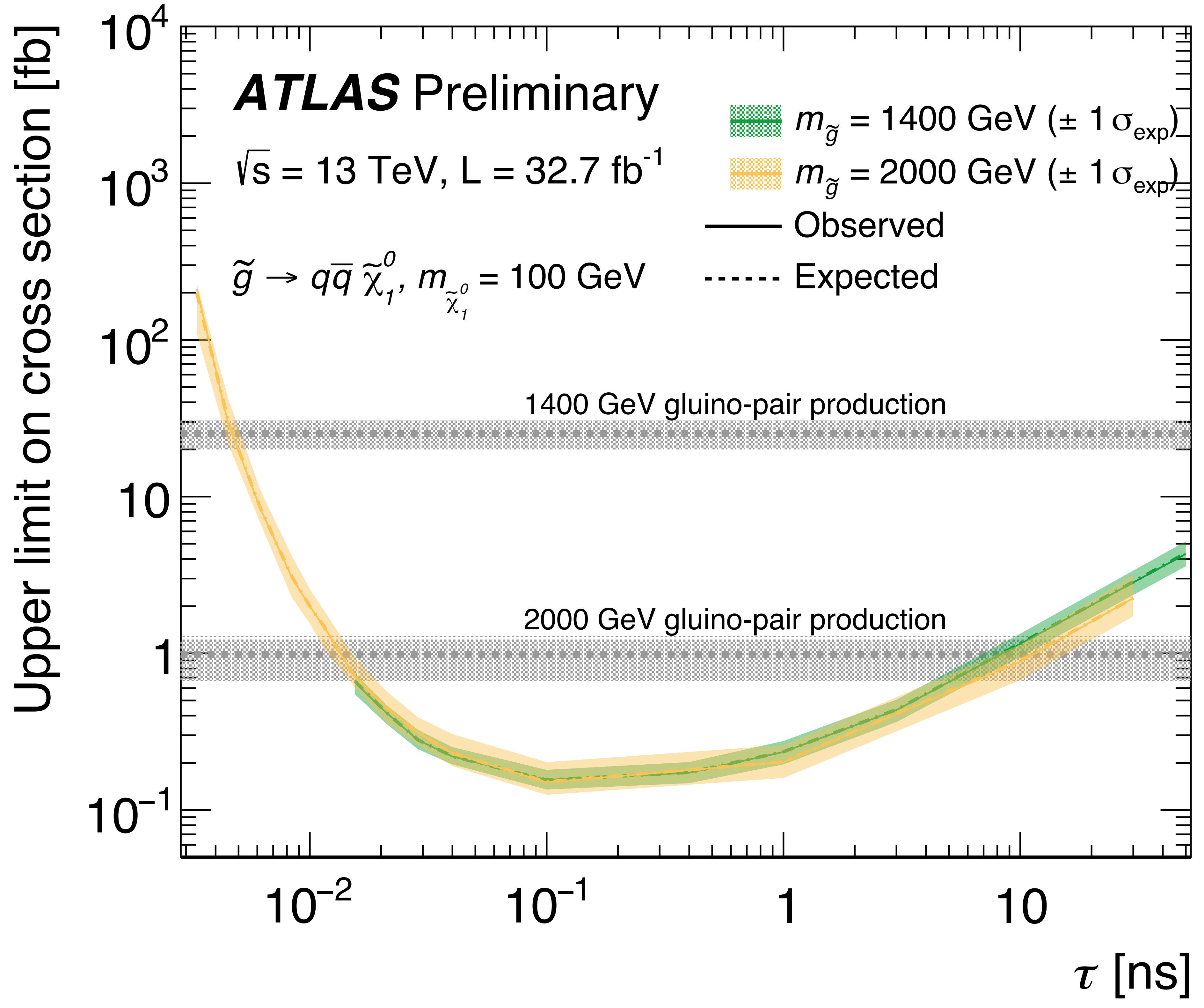
- Long-lived gluino in Split SUSY
- Background from hadronic interactions, merged vertices, accidentical track vertex crossings
- Low background for DV with mass > 10 GeV and ≥5 tracks.



Exp: 0.2±0.2 evts

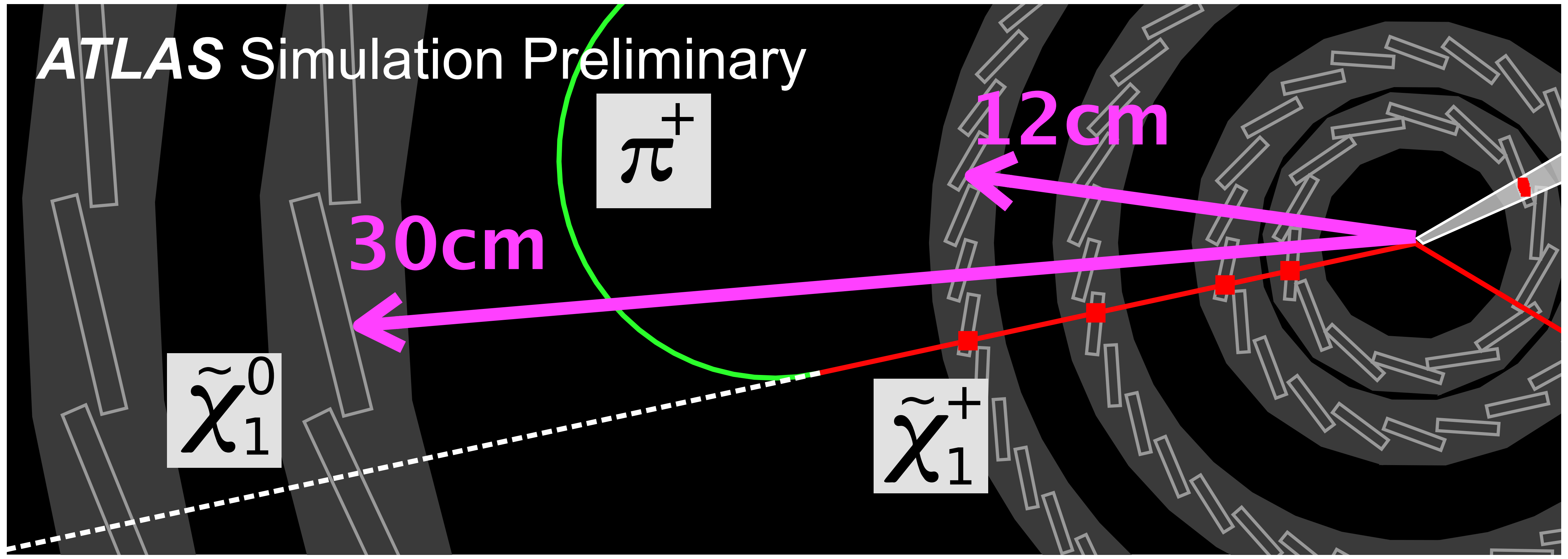
Obs: 0 evts

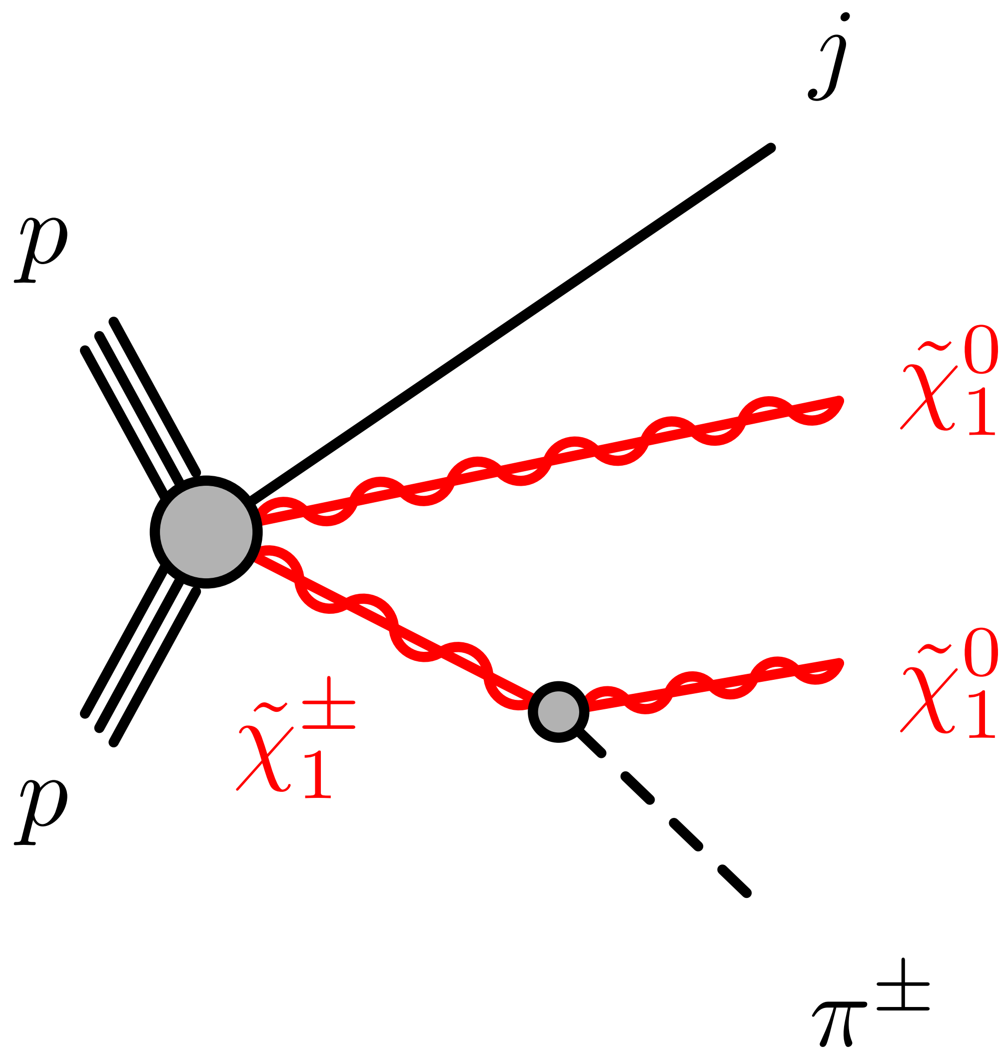


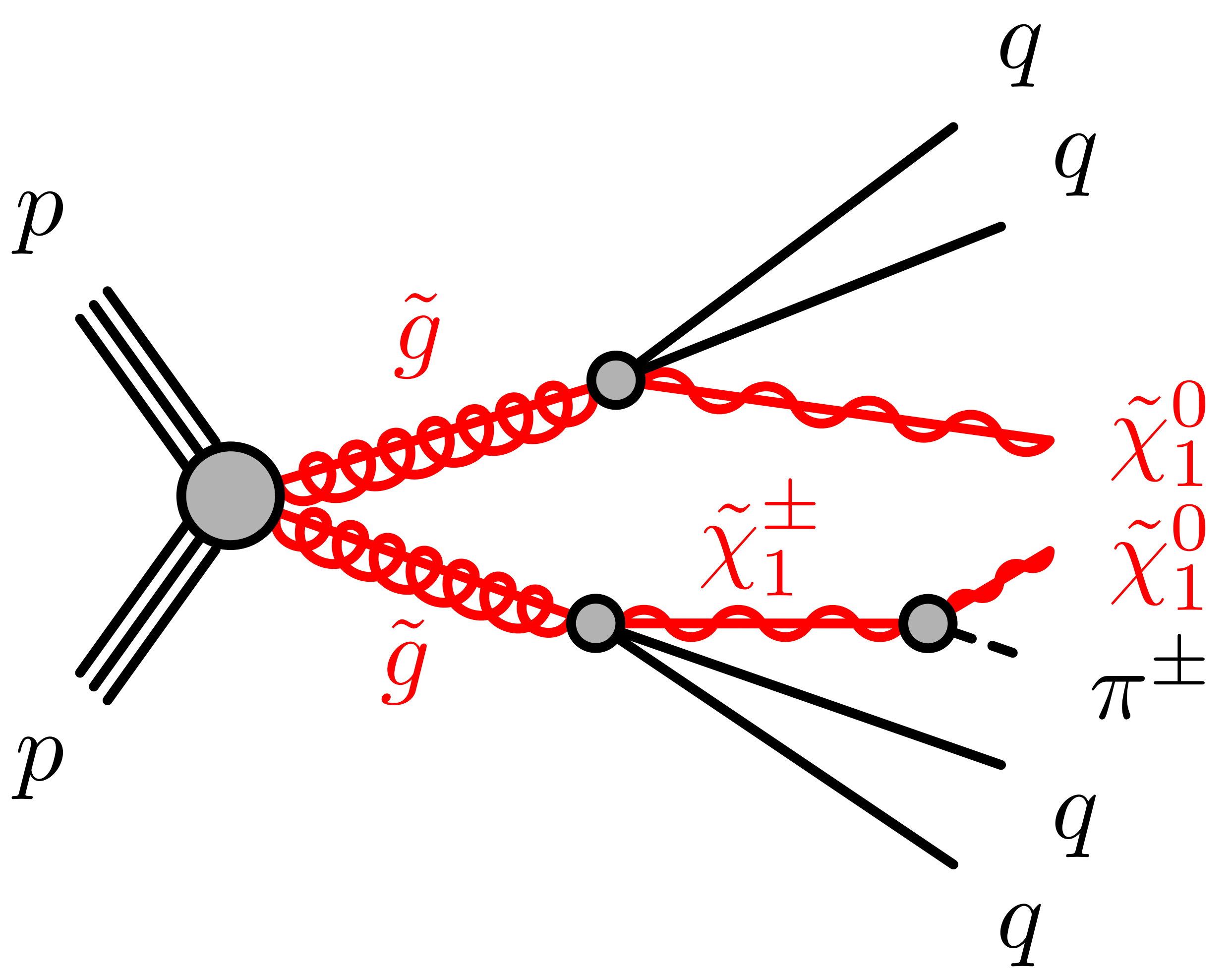


Disappearing tracks

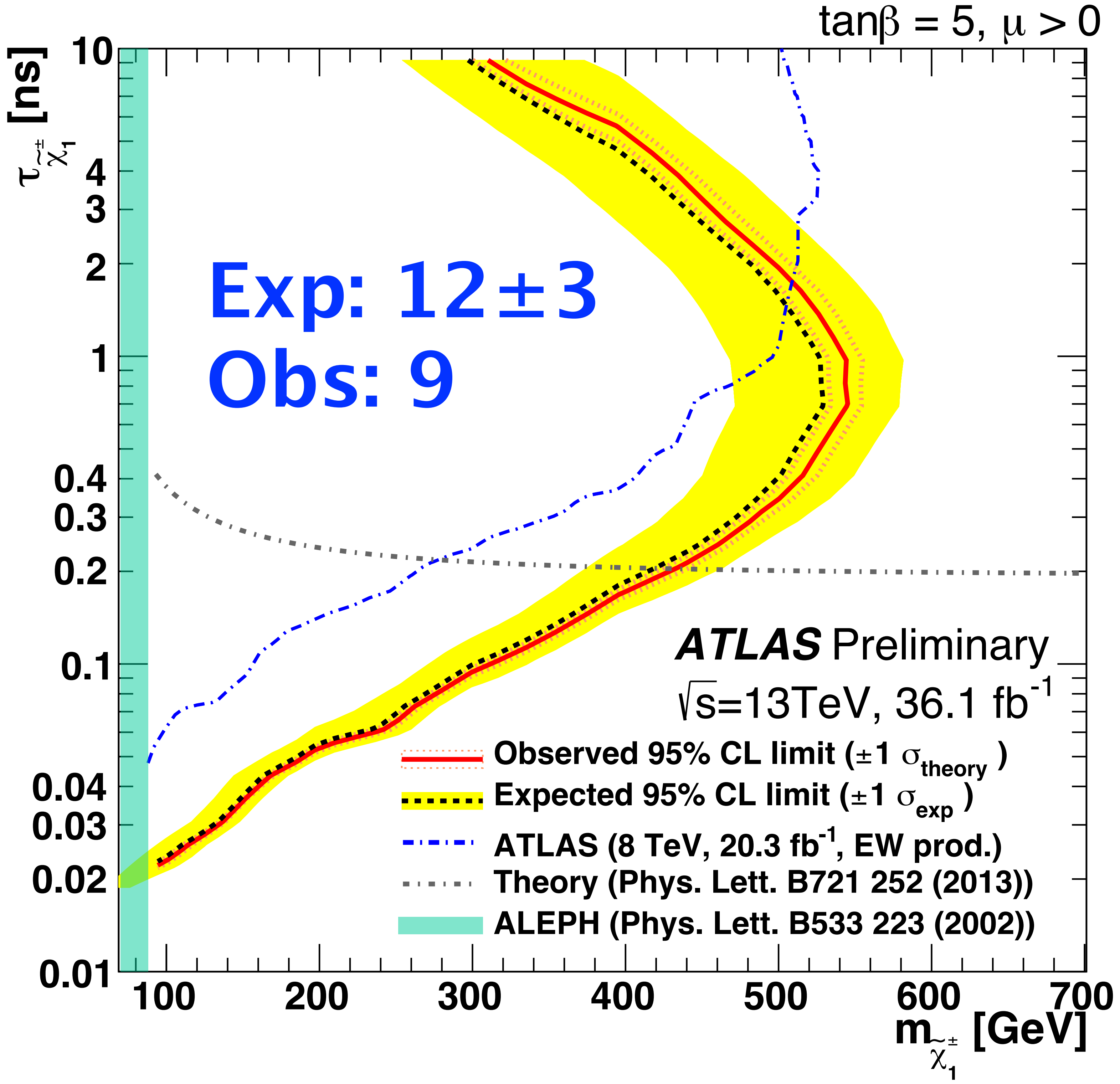
CONF-2017-017

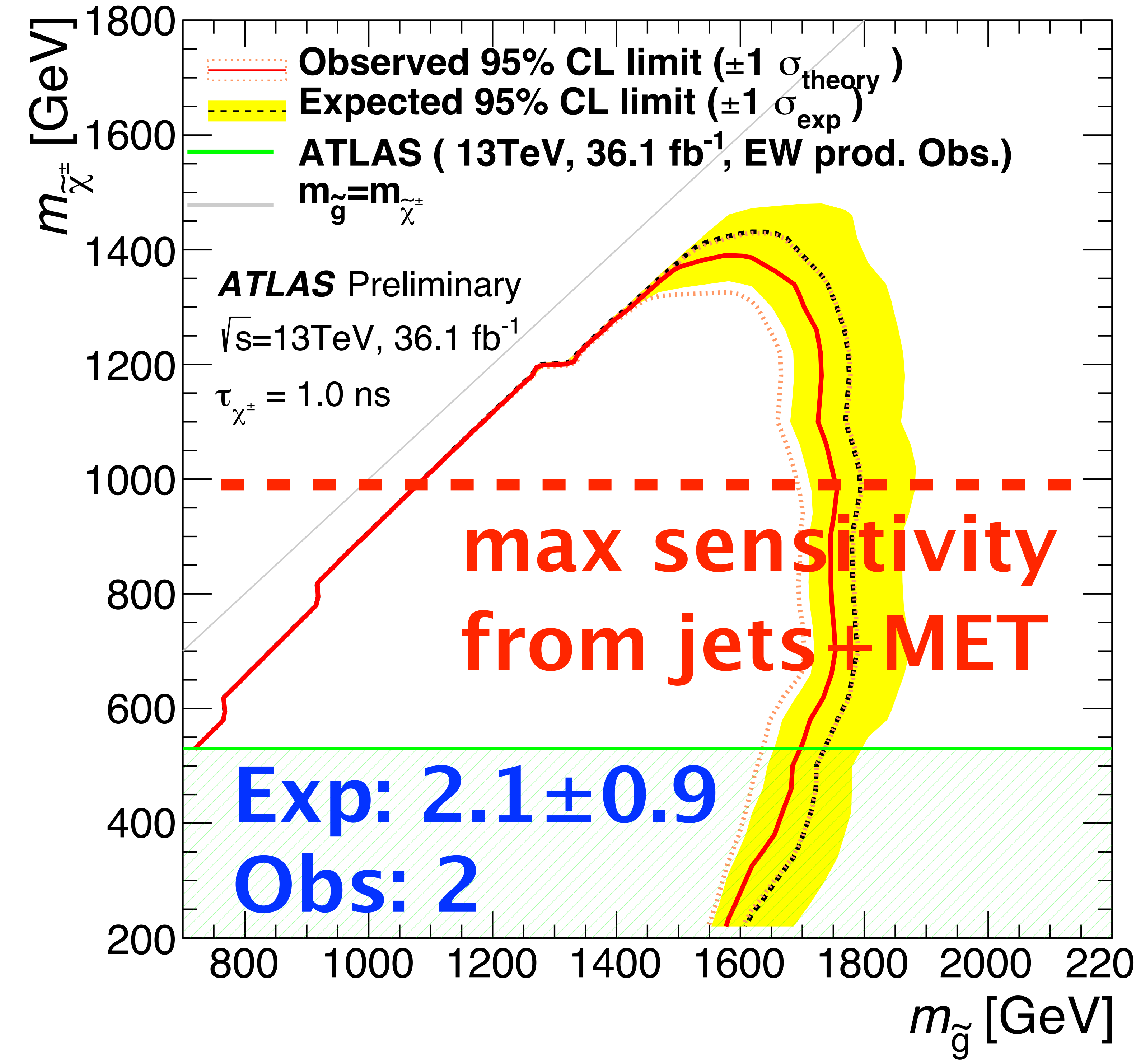




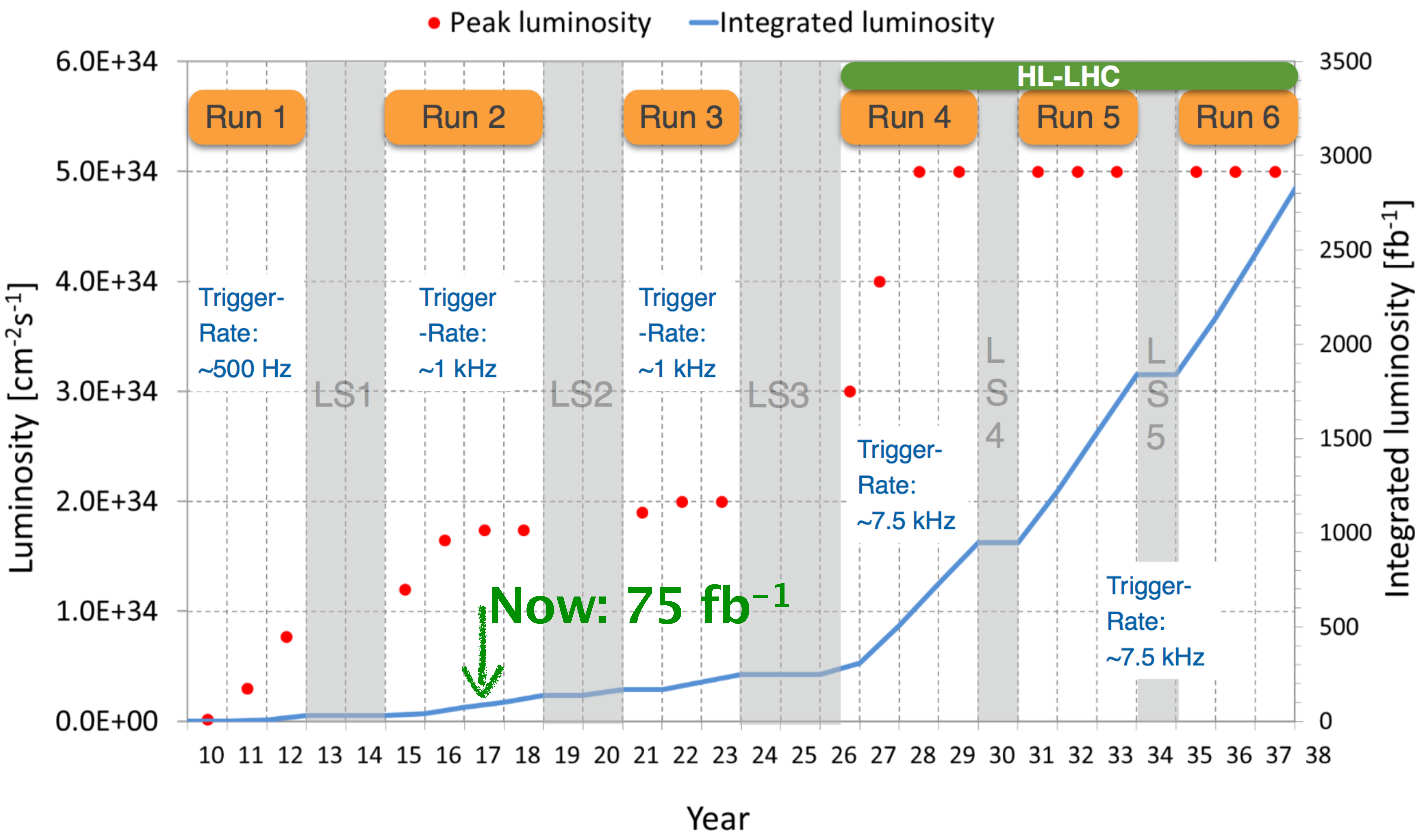


- Small splitting expected in **AMSB SUSY**
- **New pixel layer** allows use of purely pixel tracks — extending reach to shorter lifetimes.
- **Backgrounds** from hadronic interaction, hard brem, random combinations





We are just getting started



Summary

- CMS and ATLAS have so far released **>50 BSM searches** from full 2016 dataset.

- CMS and ATLAS continue to develop **tools** for understanding **challenging signatures and corners of phase space**

- We endeavor to leave no stone unturned with
  - **signature-based generic searches**
  - **model-driven targeted searches**

Additional Material

Parallel Talks

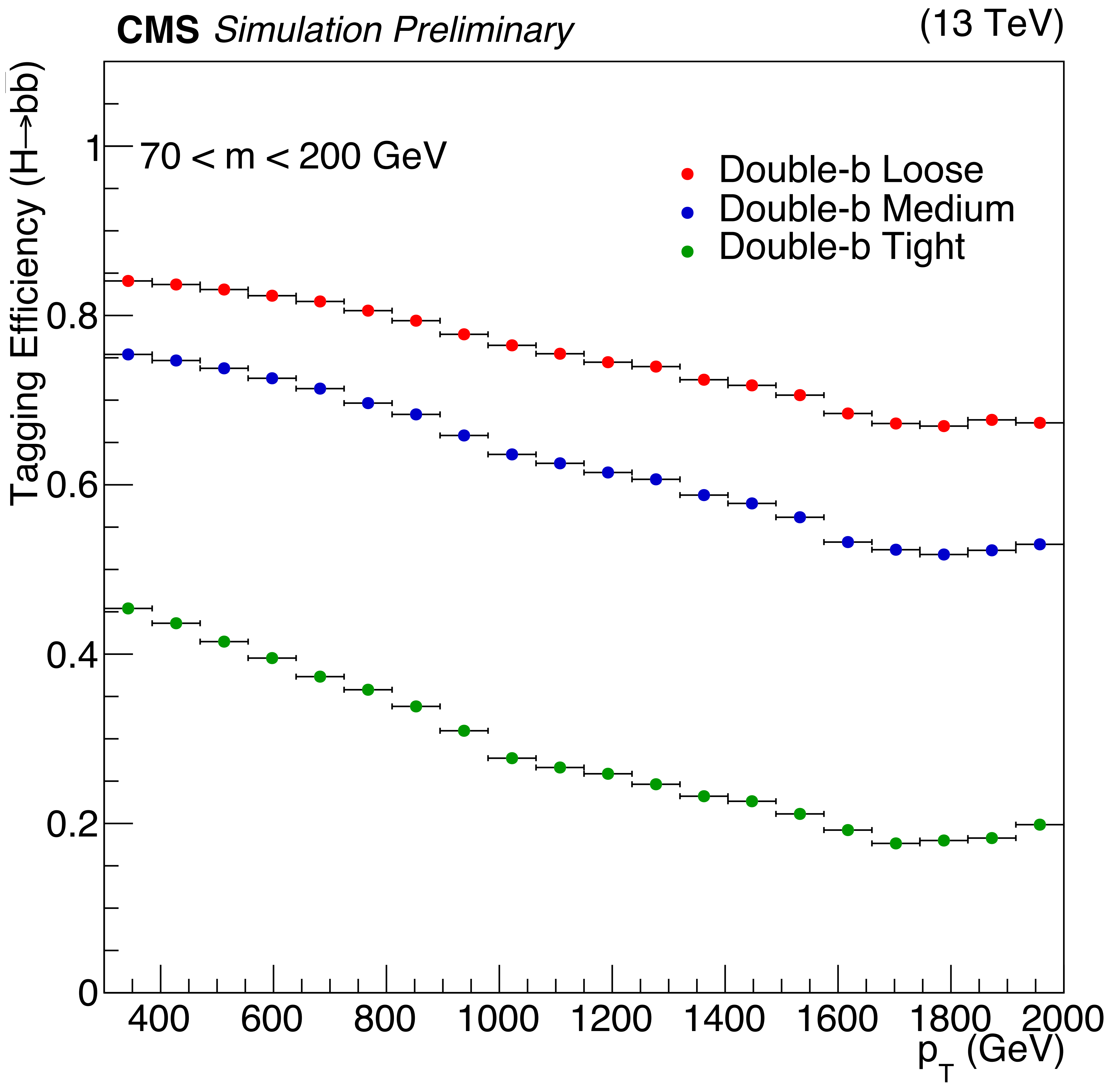
Resonances
Jan-Frederik Schulte: Searches for new heavy resonances with leptons, photons, and jets in CMS
Sung Won Lee: Search for new resonances decaying into W, Z and H bosons at CMS
Petar Maksimovic: Search for new resonances coupling to third generation quarks at CMS
Mark Oreglia: ATLAS Searches for VH and HH Resonances
Chris Malena Delitzsch: ATLAS Searches for VV/V+gamma Resonances
SUSY
Nadja Strobbe: Searches for supersymmetry in fully hadronic final states with CMS
Zhenbin Wu: Searches for third generation squarks with CMS
Minsuk Kim: Searches for electroweak production of SUSY with CMS
Basil Schneider: Searches for supersymmetry in single or opposite-charged dilepton final states with CMS
Menglei Sun: Searches for supersymmetry in final states with photons in CMS
Othmane Rifki: Inclusive searches for squarks and gluinos with the ATLAS detector
Fabrizio Miano: Searches for direct pair production of 3rd gen squarks with the ATLAS detector
Zara Jane Grout: Searches for EWK production of SUSY gauginos/sleptons with the ATLAS detector
Dark Matter
Marco Cipriani: Searches for dark matter at CMS
VLQ
Alice Bean: Search for Vector-like quarks at CMS
Erich Ward Varnes: Search for vector-like quarks at ATLAS
Long-lived
Geng-Yuan Jeng: Searches for long-lived particles and other non-conventional signatures in CMS
Chihiro Kozakai: Searches for SUSY in resonance production, RPV, long-lived particles with ATLAS
BSM Higgs
Sven Dildick: Searches for light BSM Higgs states with CMS
Roberto Rossin: Searches for HH production with CMS
Koji Sato: Search for neutral and charged BSM Higgs Bosons with the ATLAS detector
Jason Robert Veatch: Search for rare and exotic Higgs decays and HH pair production ATLAS
Inclusive
Deborah Duchardt: Model Unspecific Search in CMS

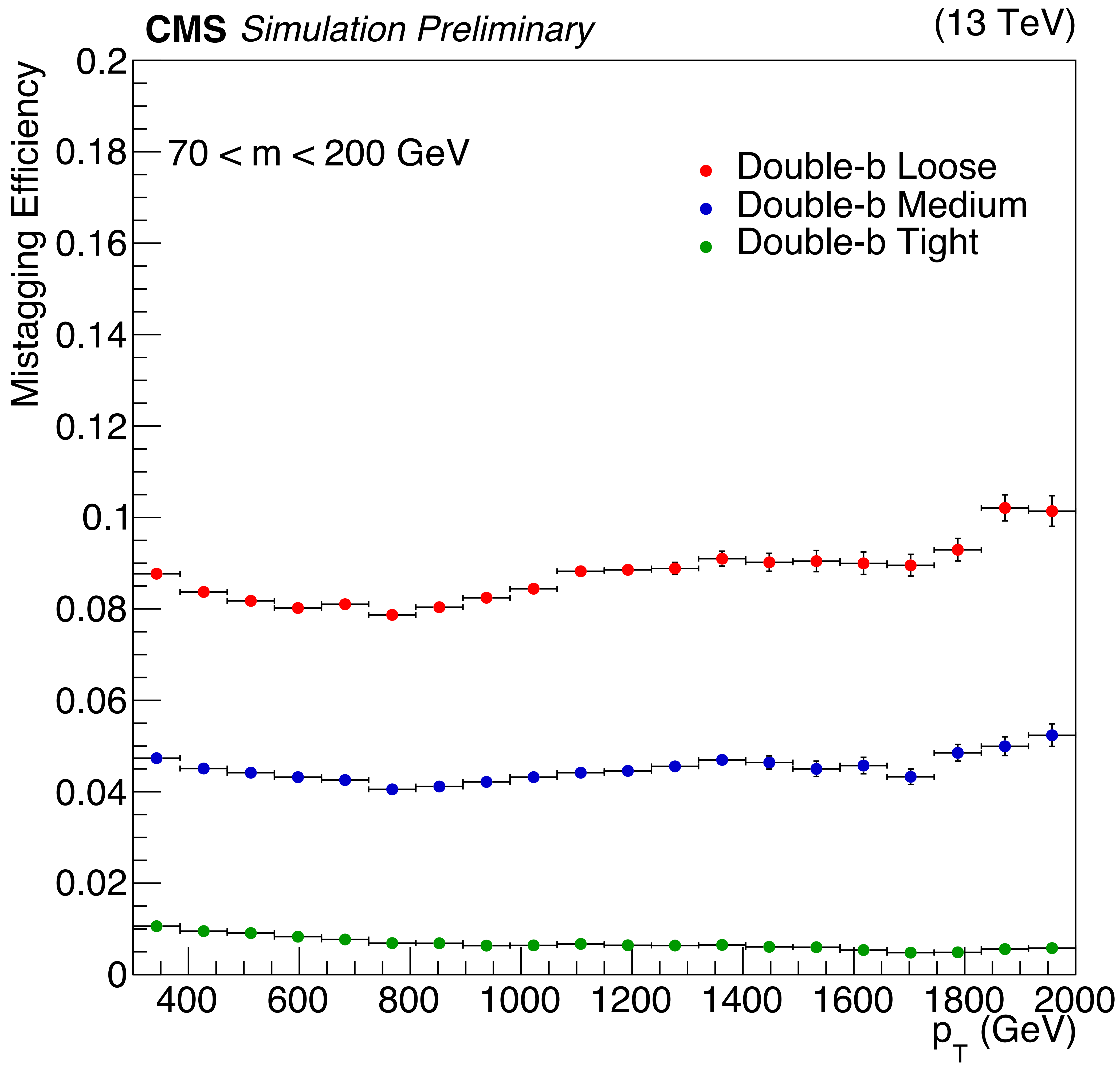
Vector-like quark results

- B2G-17-010 : X➔tb in ℓ+jets
- B2G-17-007 : single vector-like T ➔ Zt
- B2G-16-019 : heavy vector-like Q ➔ SS 2ℓ
- CONF-2017-015 : T ➔ l (Z➔νν)

CMS double b-tagger

BTV-15-002

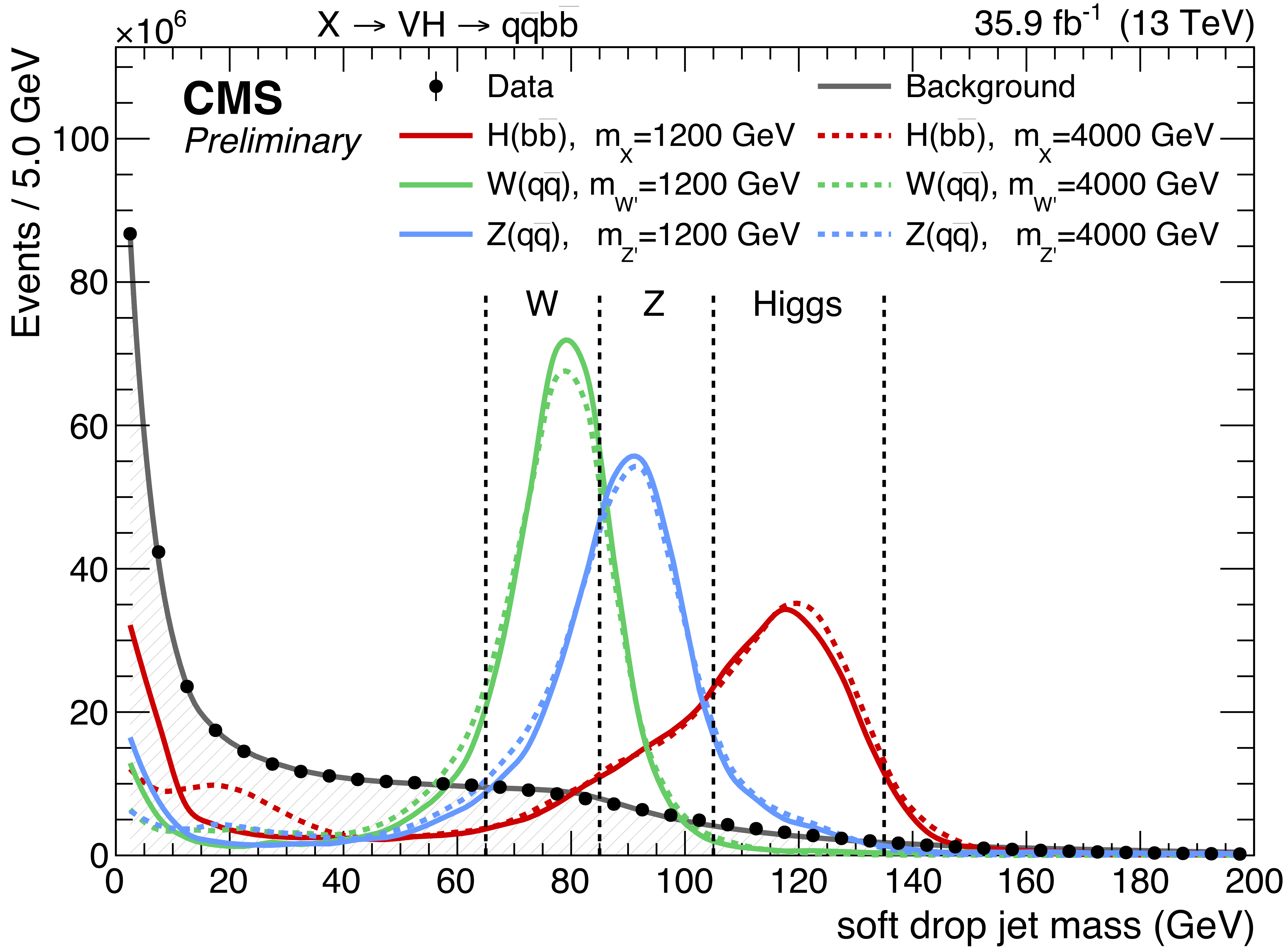




Boosted boson tools

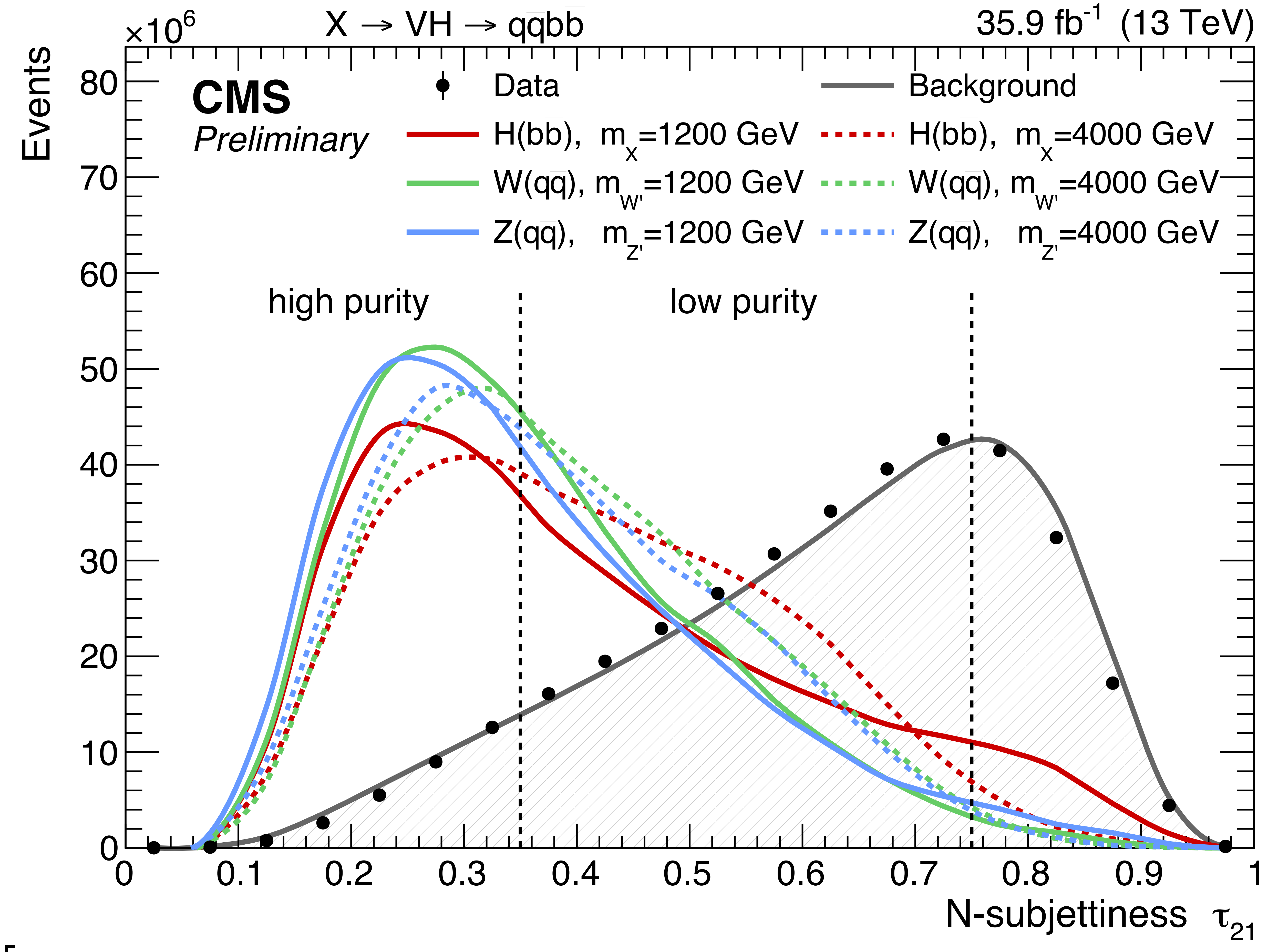
- Optimize mass resolution with **soft drop mass** (similar to trimmed mass).

B2G-17-002



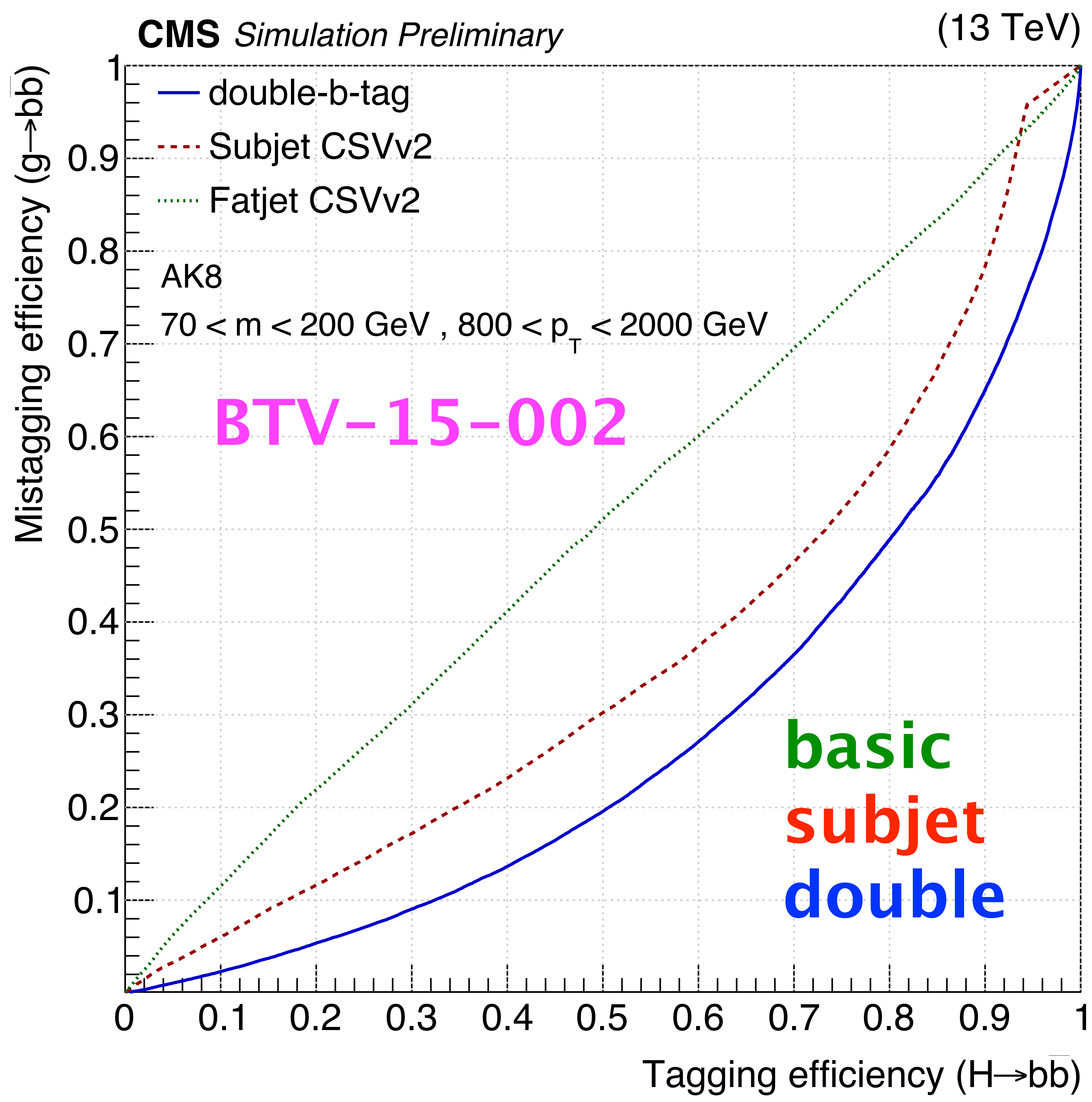
- Identify two subjets with **n-subjettiness τ_{21}** (similar to D_2)

B2G-17-002

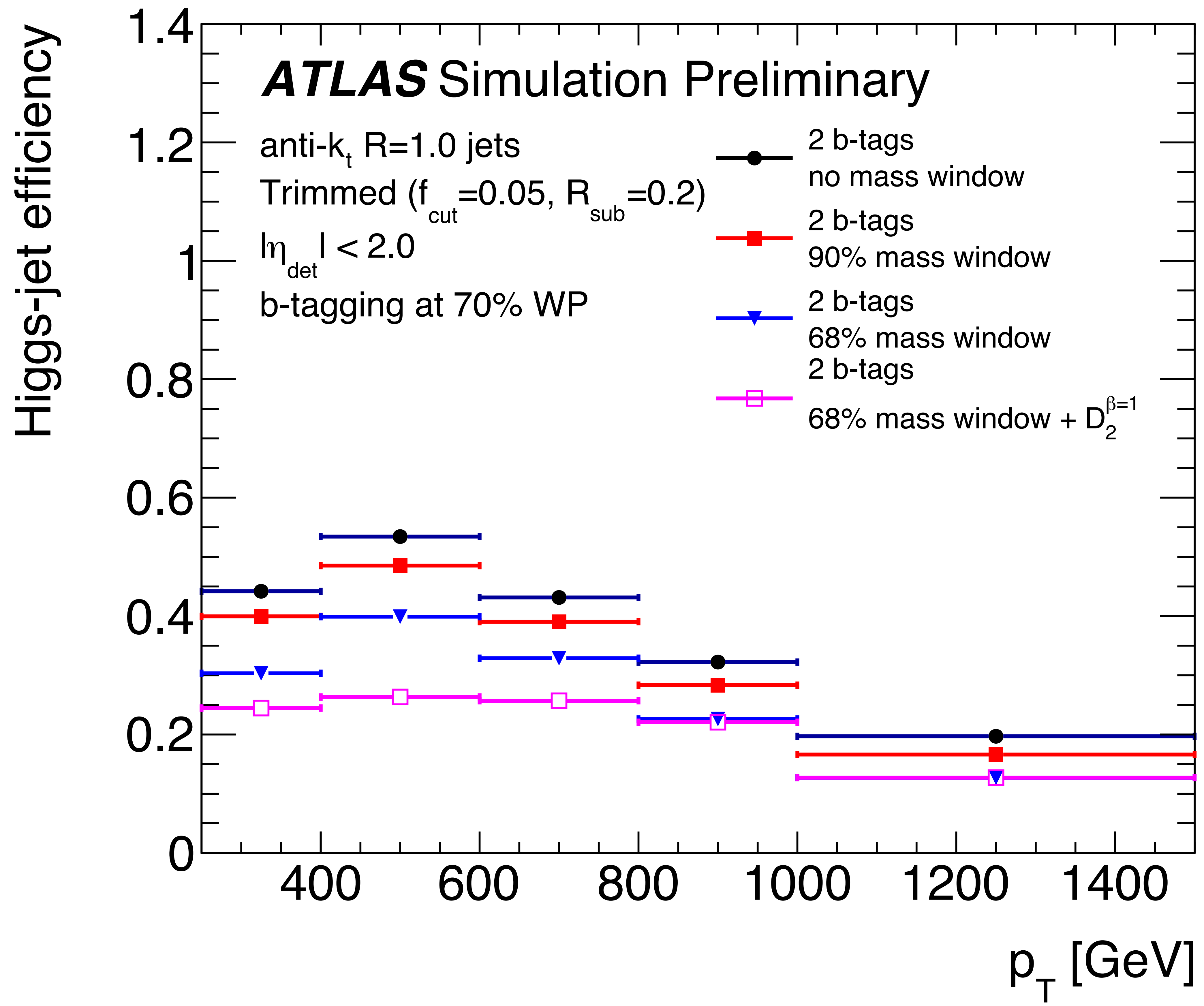


Identifying H➔bb in X➔VH/HH

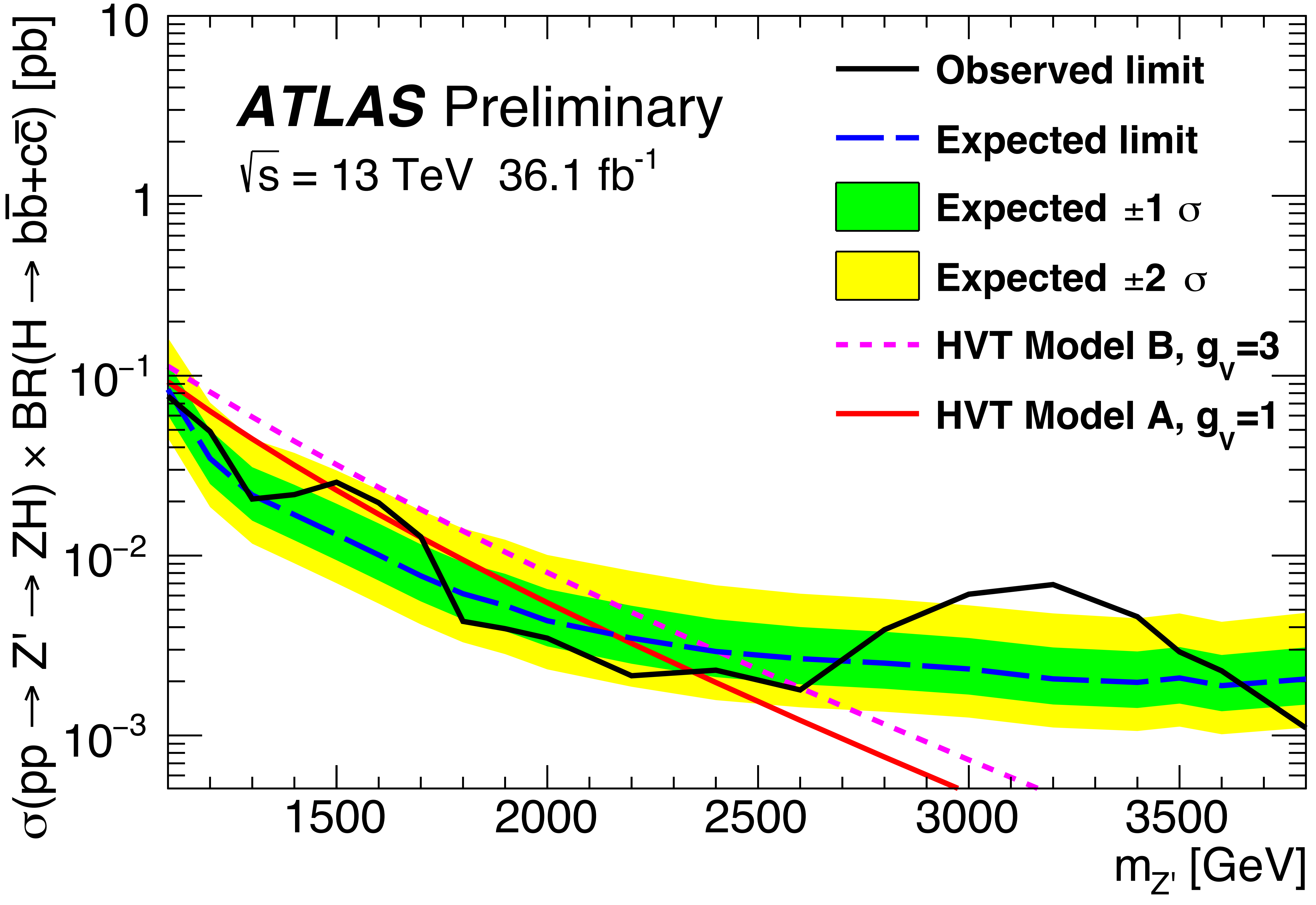
- ATLAS : Identify H➔bb using substructure, mass, and b-tagging of subjets.
- CMS : Identify X➔bb using vertices, tracks, τ-axes, but NOT mass or substructure (to minimize p_T-dependence).

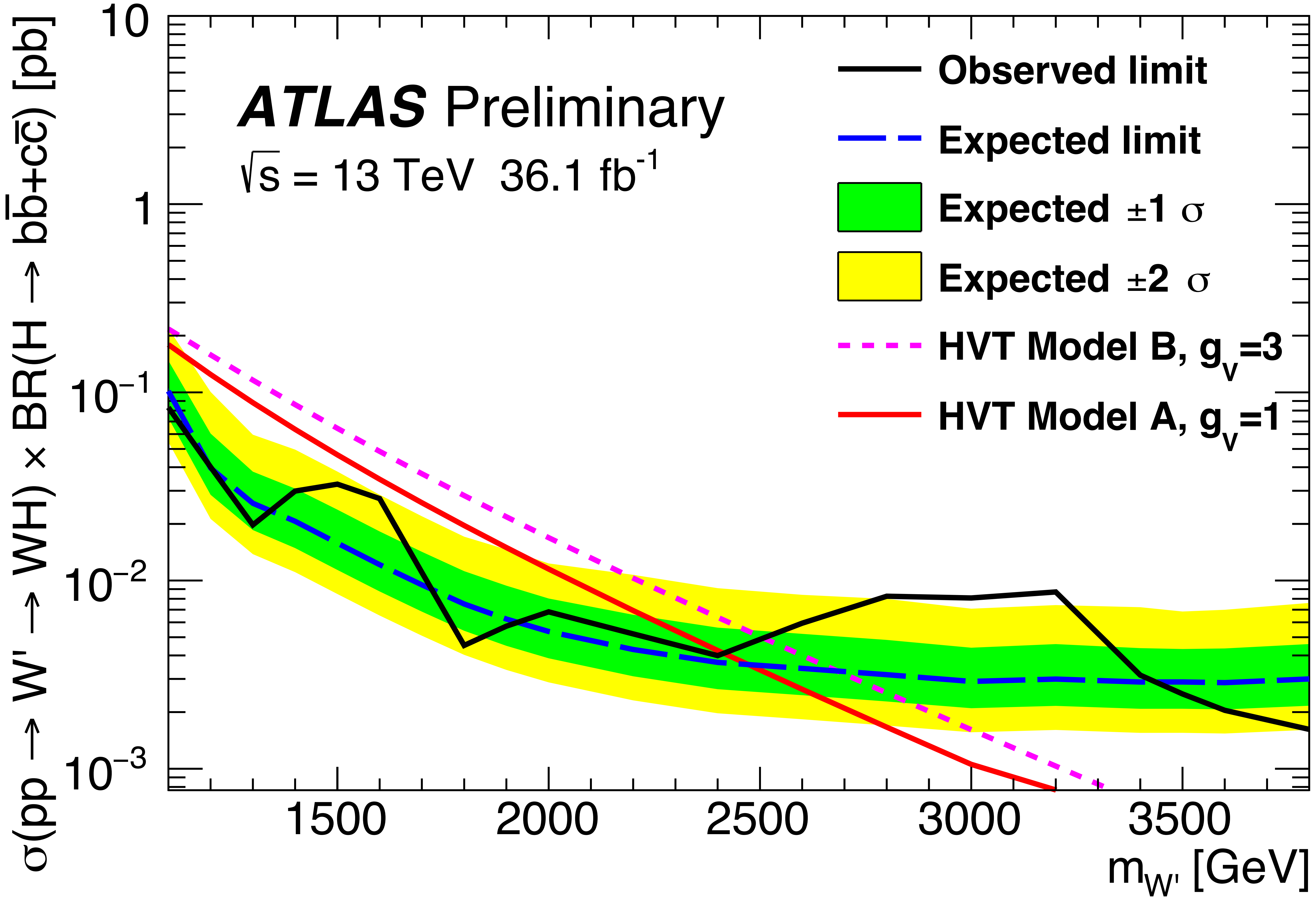


ATL-PHYS-PUB-2015-035



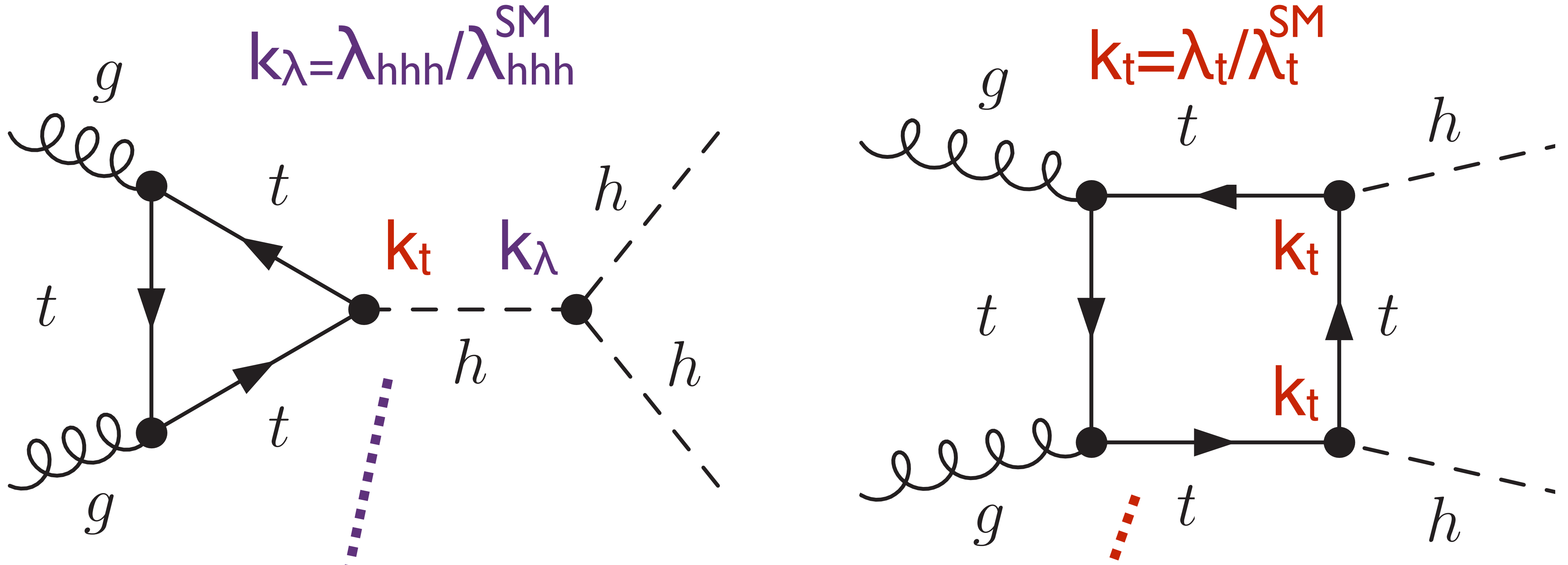
ATLAS X→VH exclusions

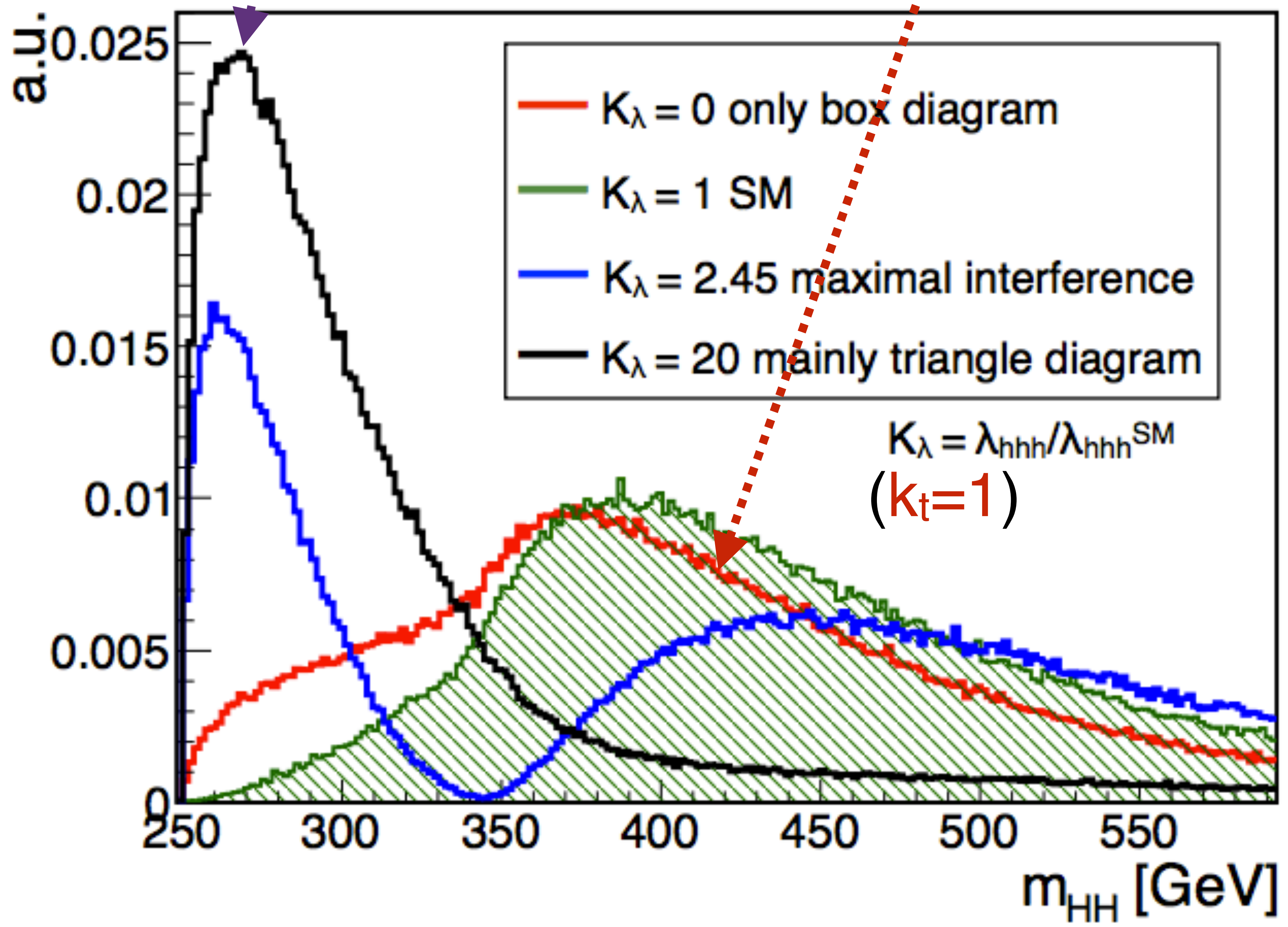


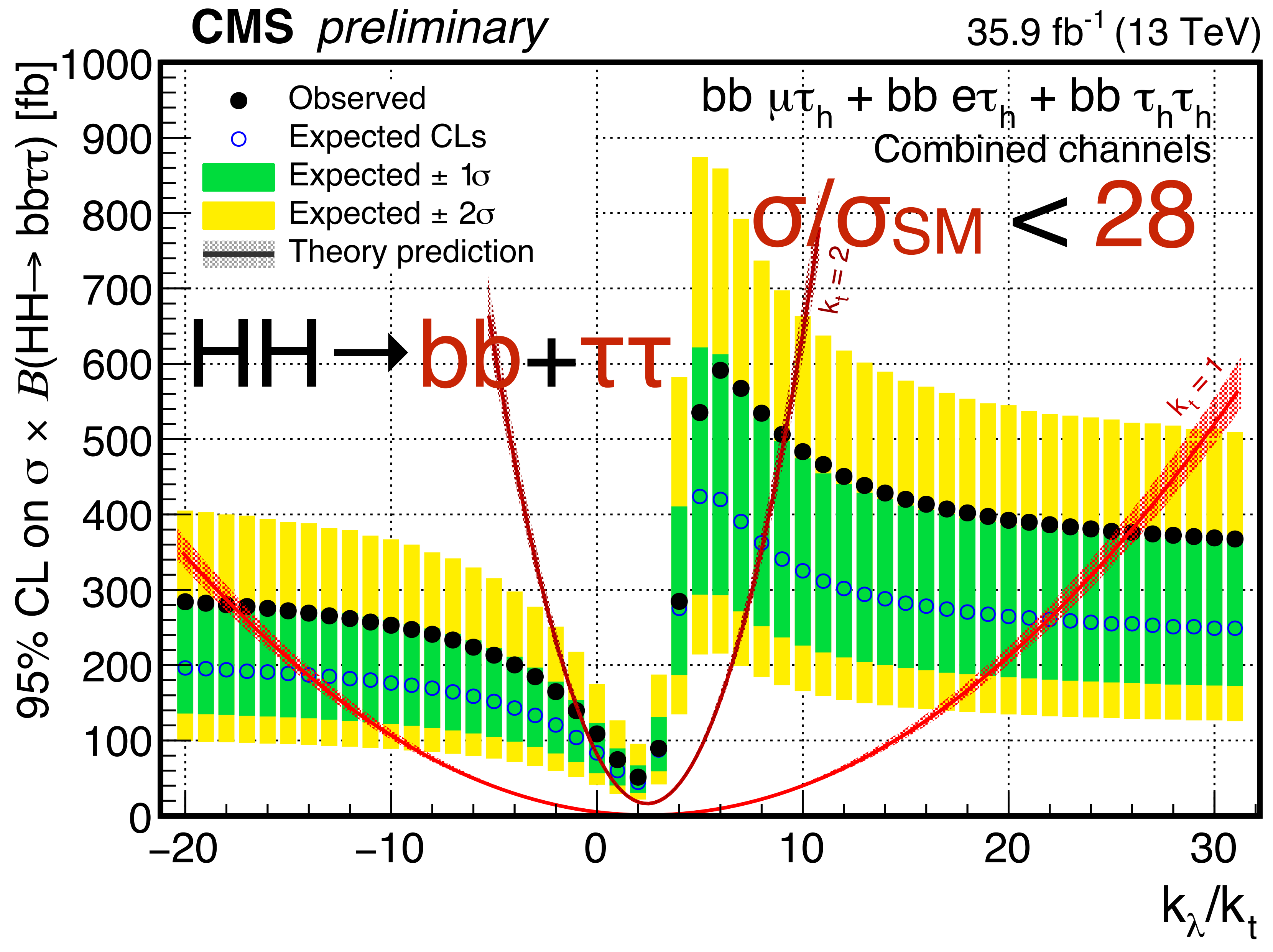


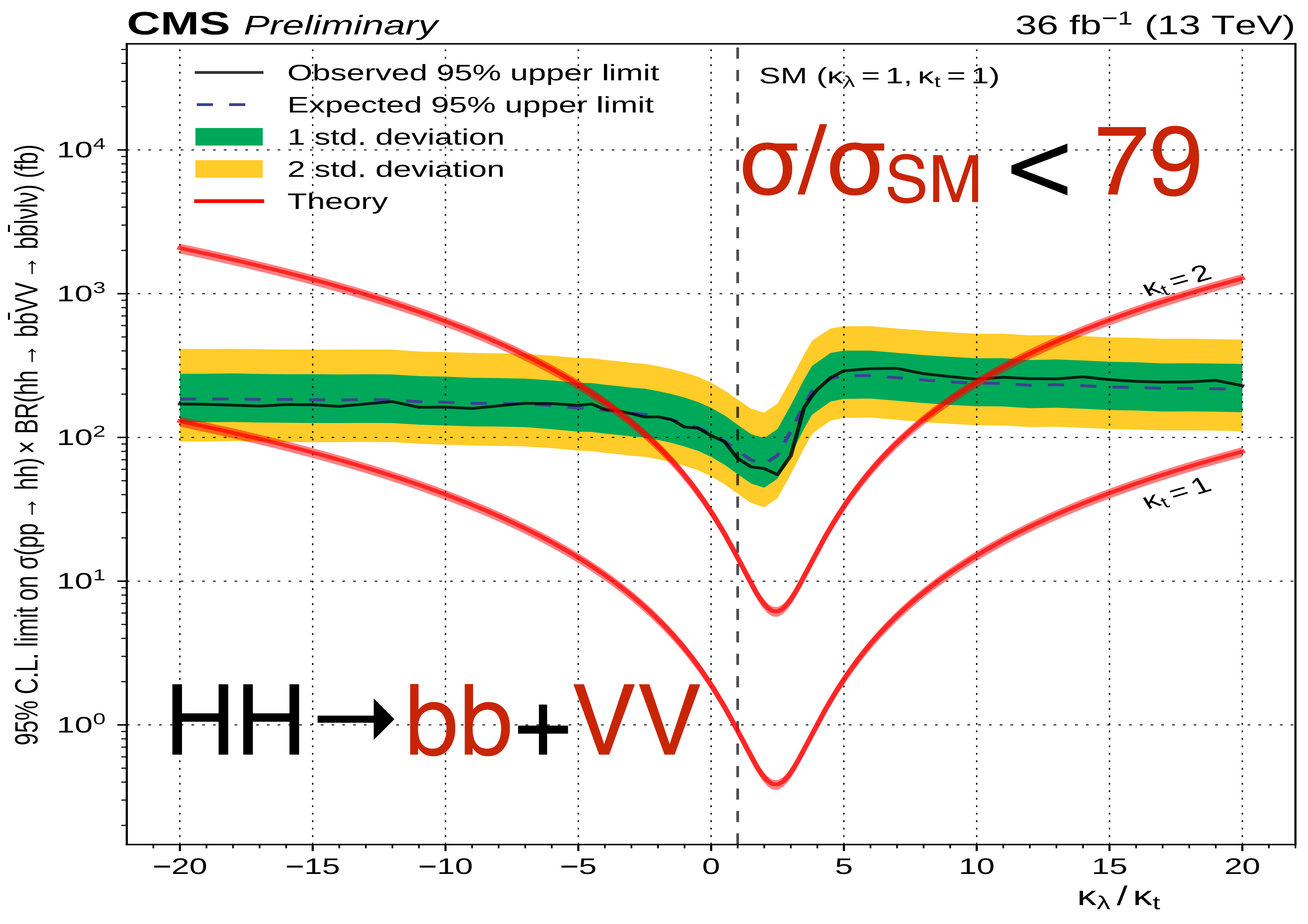
Non resonant HH ➔ bbVV and bbττ

- bbVV ➔ ℓℓbb+MET
- bbττ ➔ $bb\mu\tau_h$, $bbe\tau_h$, $bb\tau_h\tau_h$

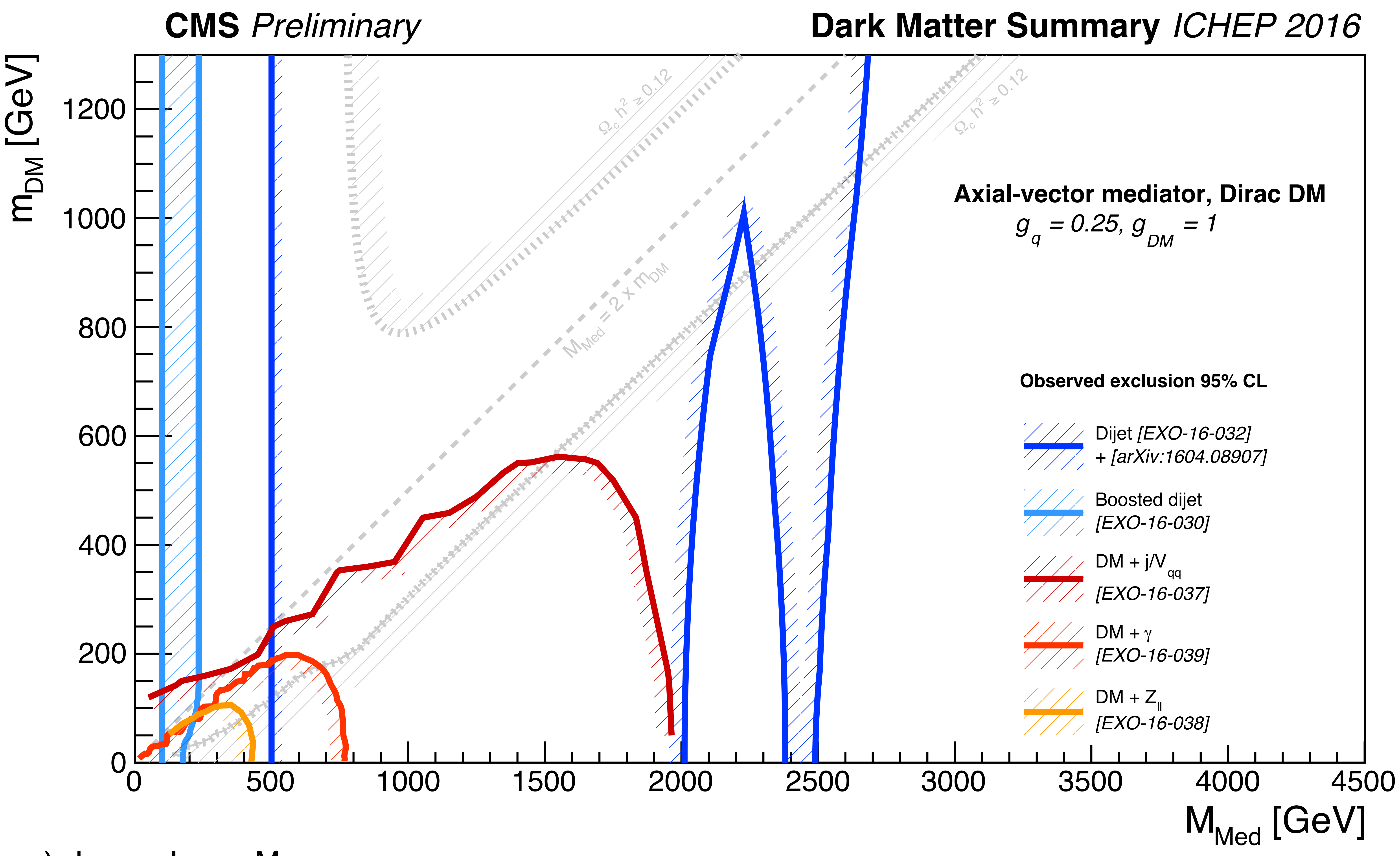








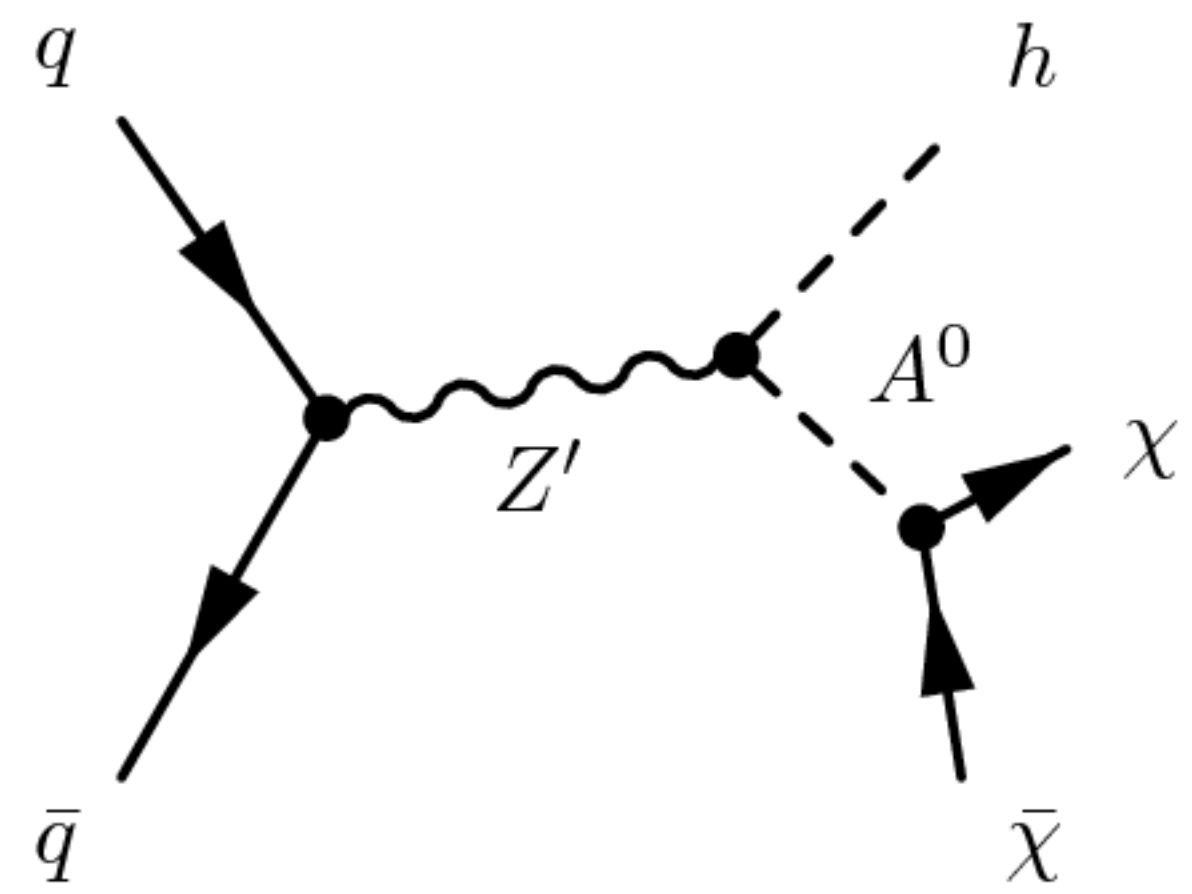
Dark matter mediator exclusions



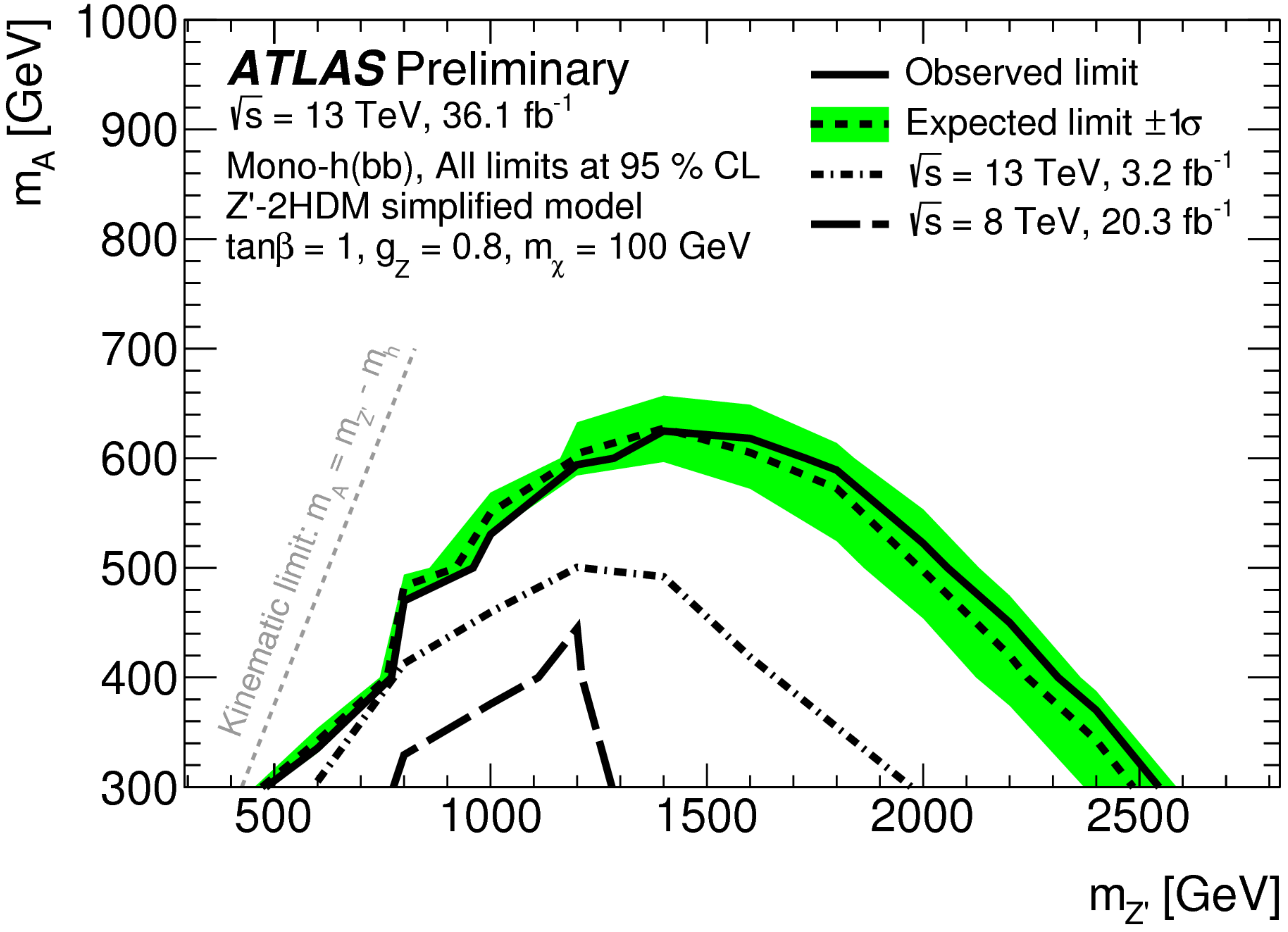
BR(mediator ➔ qq) depends on M_{DM}.
For these couplings:

- $M_{DM} \geq M_{med}$: BR(mediator ➔ qq) = 100%
- M_{DM} = 1 GeV : BR(mediator ➔ qq) = 50%

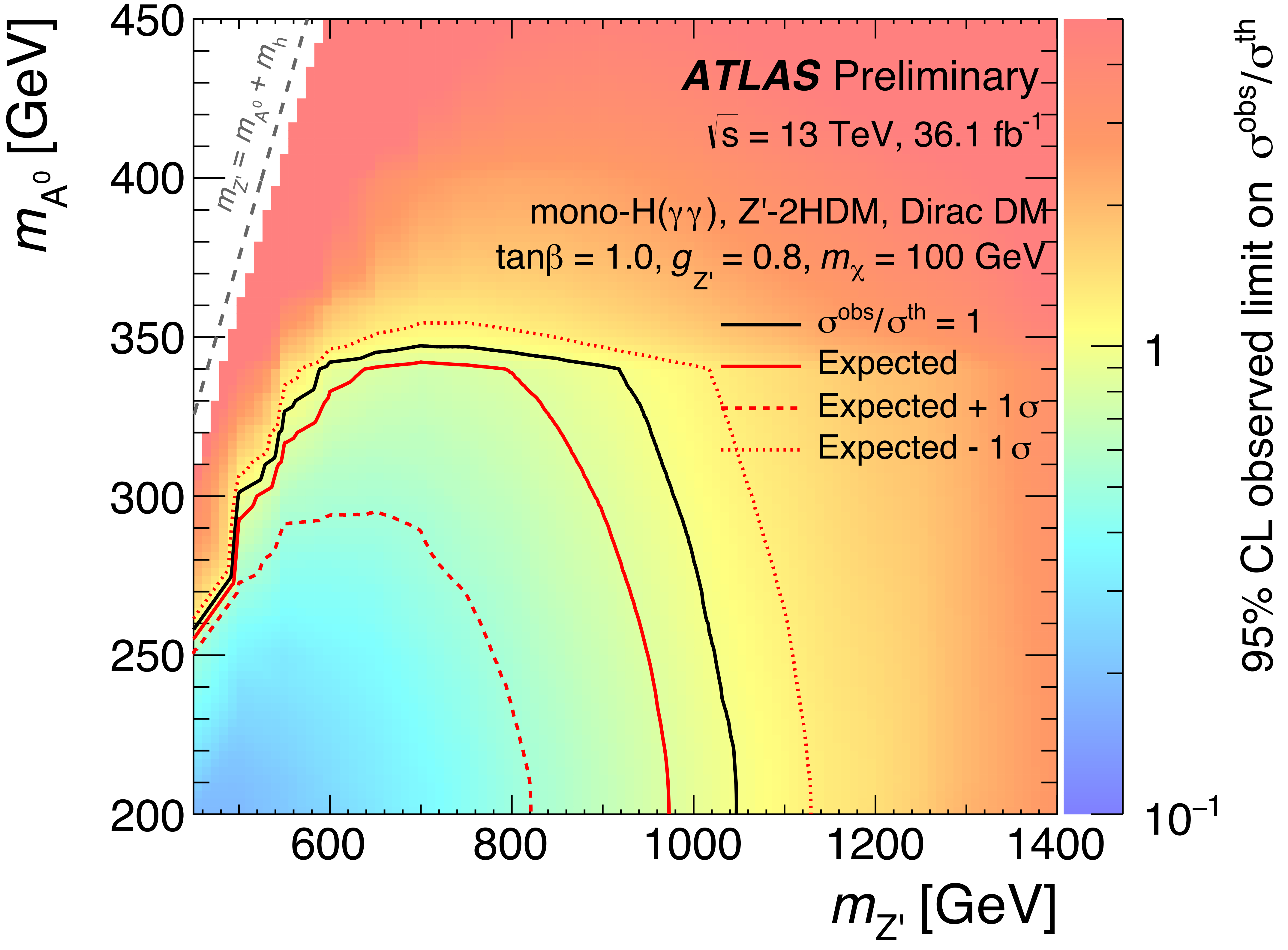
DM+H→γγ vs DM+H→ bb



CONF-2017-028



CONF-2017-024



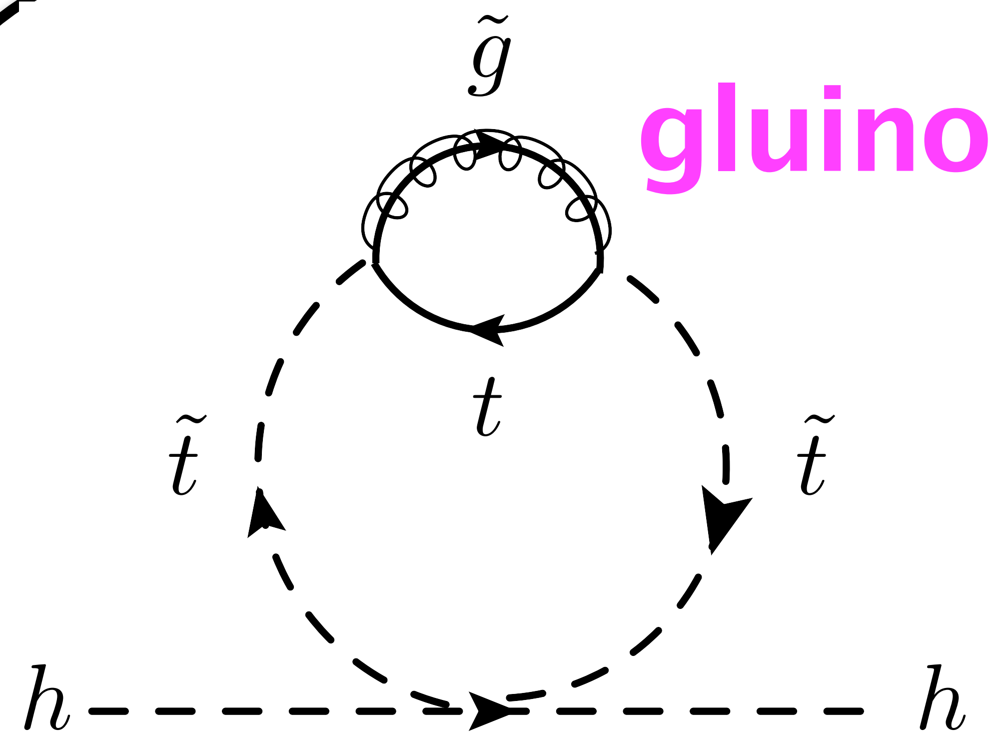
“Natural” SUSY spectrum

$$m_H^2 = (m_H^2)_0 + \delta m_H^2$$

- We measure $|m_H^2|$~100GeV.
- In standard model (SM), $\delta m_H^2 \sim 10^{30}$ GeV.
- In SUSY, δm_H^2 can be small, but depends on sparticle masses.
- Define “natural” spectrum as giving δm_H^2 not » m_H^2.
- Traditional metric: $\Delta \equiv \frac{2|\delta m_H^2|}{m_h^2}$

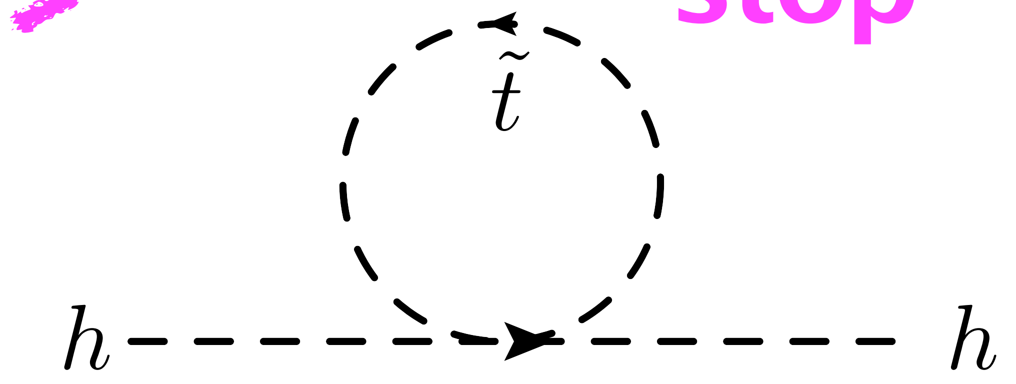
D. Shih

gluino



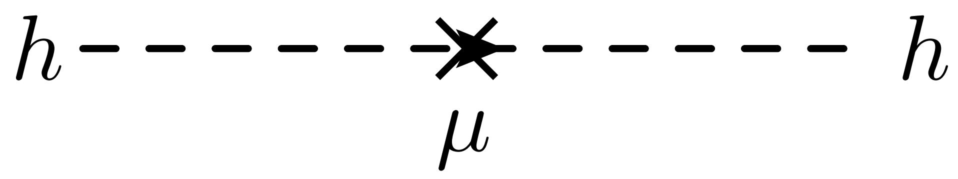
$$\delta m_H^2 \sim -\frac{y_t^2}{\pi^2}\frac{g_3^2}{4\pi^2} M_3^2 \left(\log\frac{\Lambda}{Q}\right)^2$$

stop



$$\delta m_H^2 \sim -\frac{3}{8\pi^2} y_t^2 (m_{Q_3}^2 + m_{U_3}^2) \log\frac{\Lambda}{Q}$$

higgsino



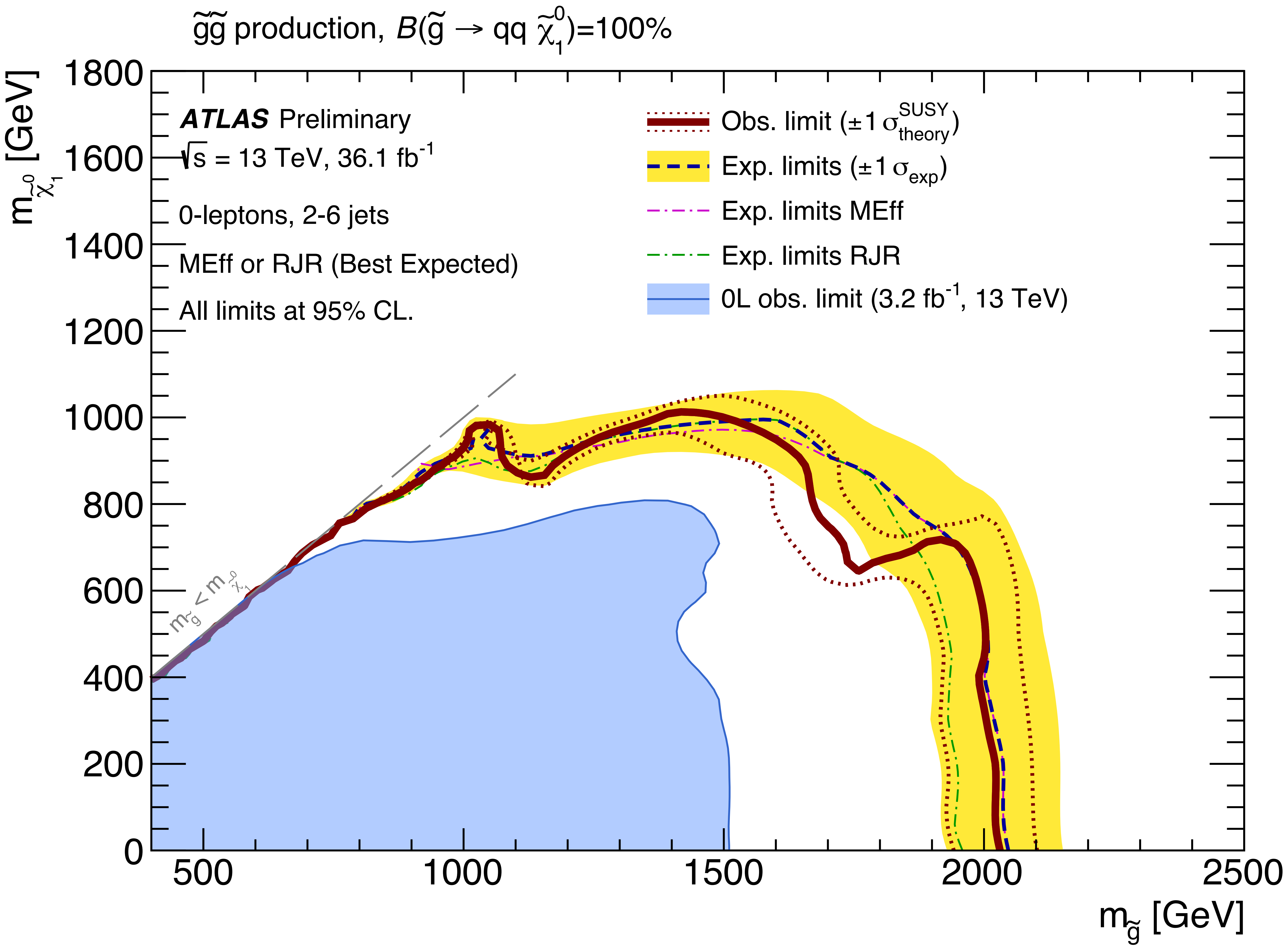
$$\delta m_H^2 \sim |\mu|^2$$

Λ = UV cutoff scale
Q = IR scale appropriate to process

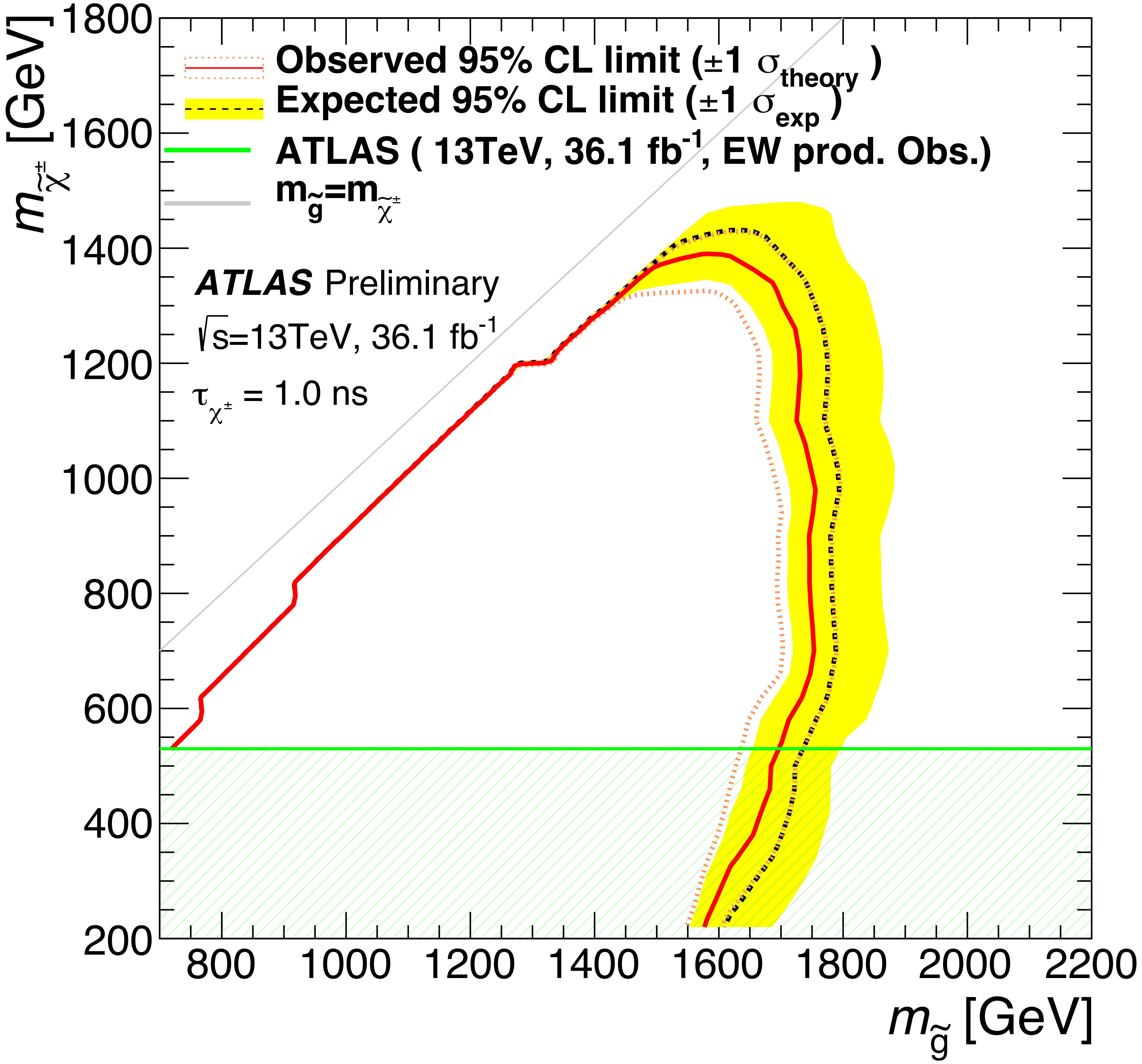
Papucci, Ruderman, Weiler, arXiv:1110.6926
Barbieri, Giudice (1988)
Martin arXiv:hep-ph/9709356

Standard gluino vs. disappearing track

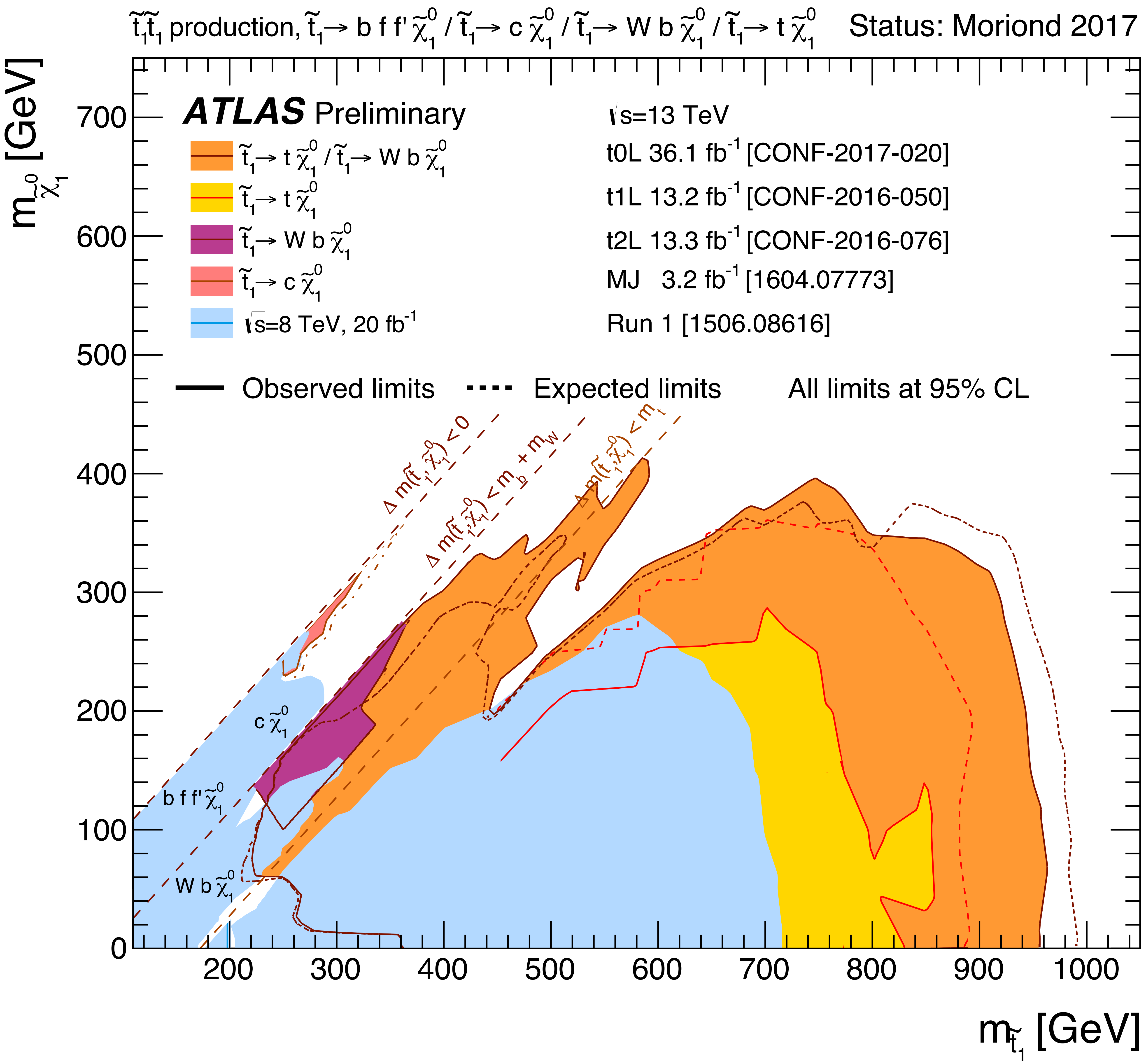
CONF-2017-022



CONF-2017-017



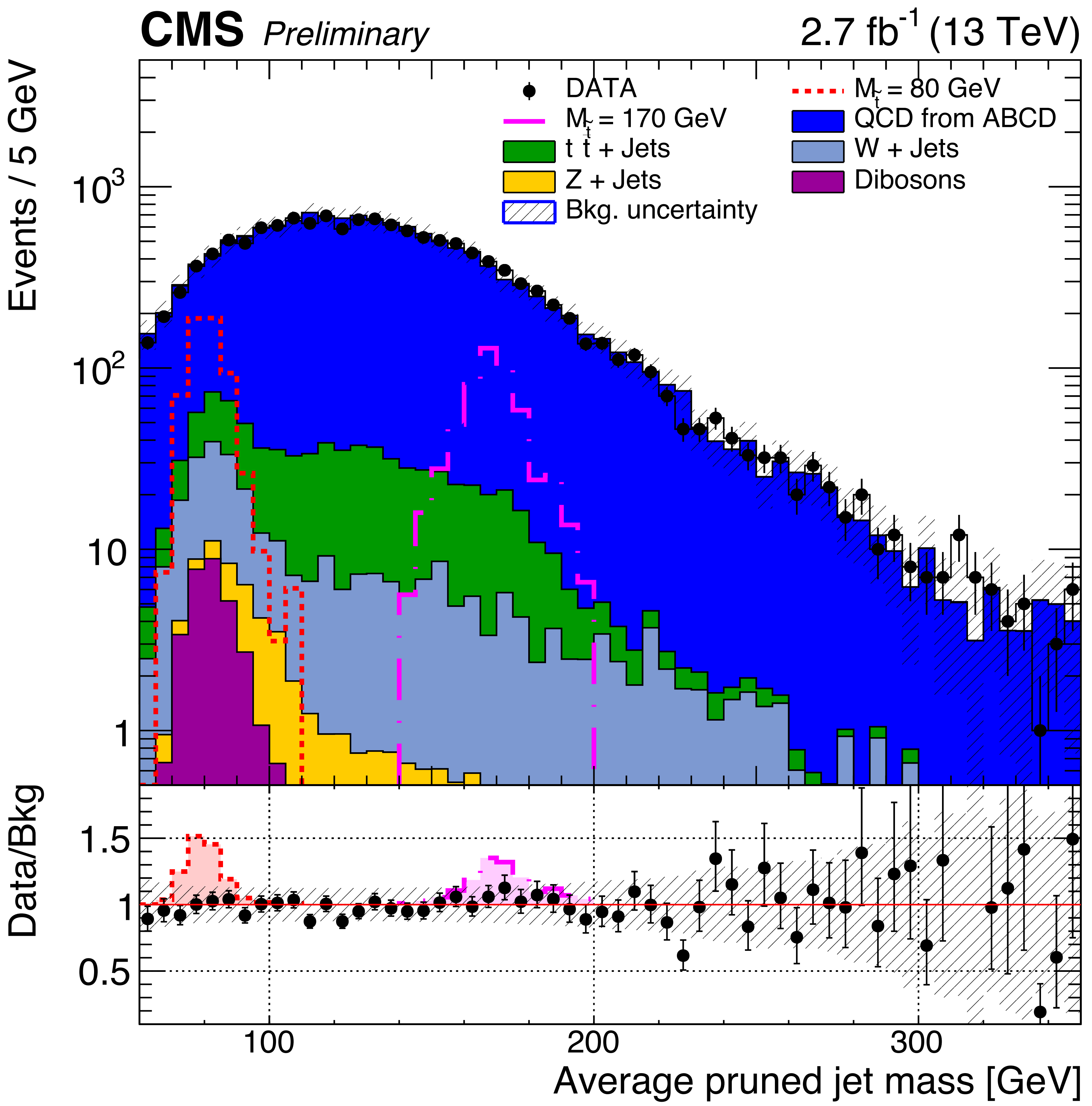
ATLAS stop exclusions

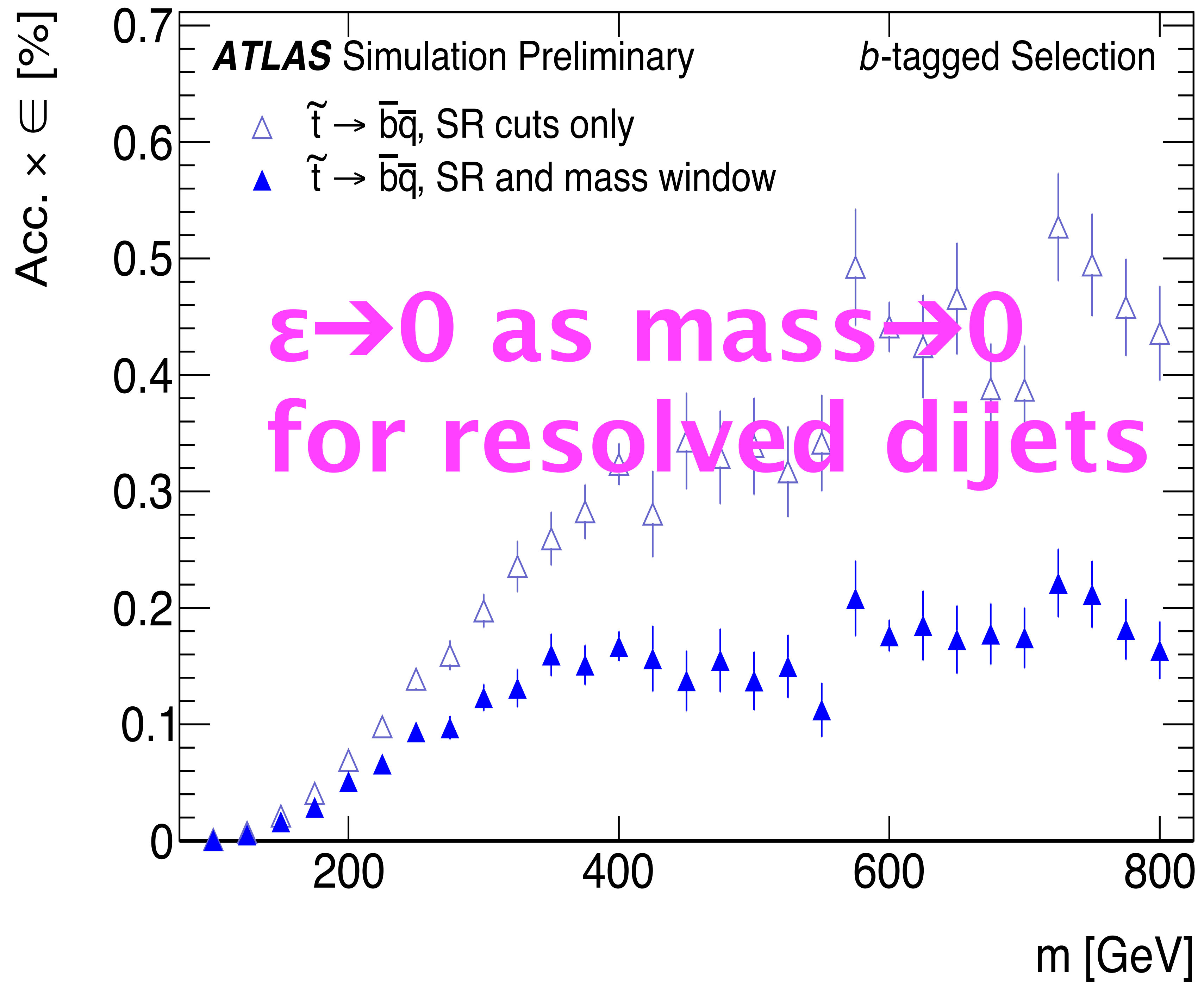


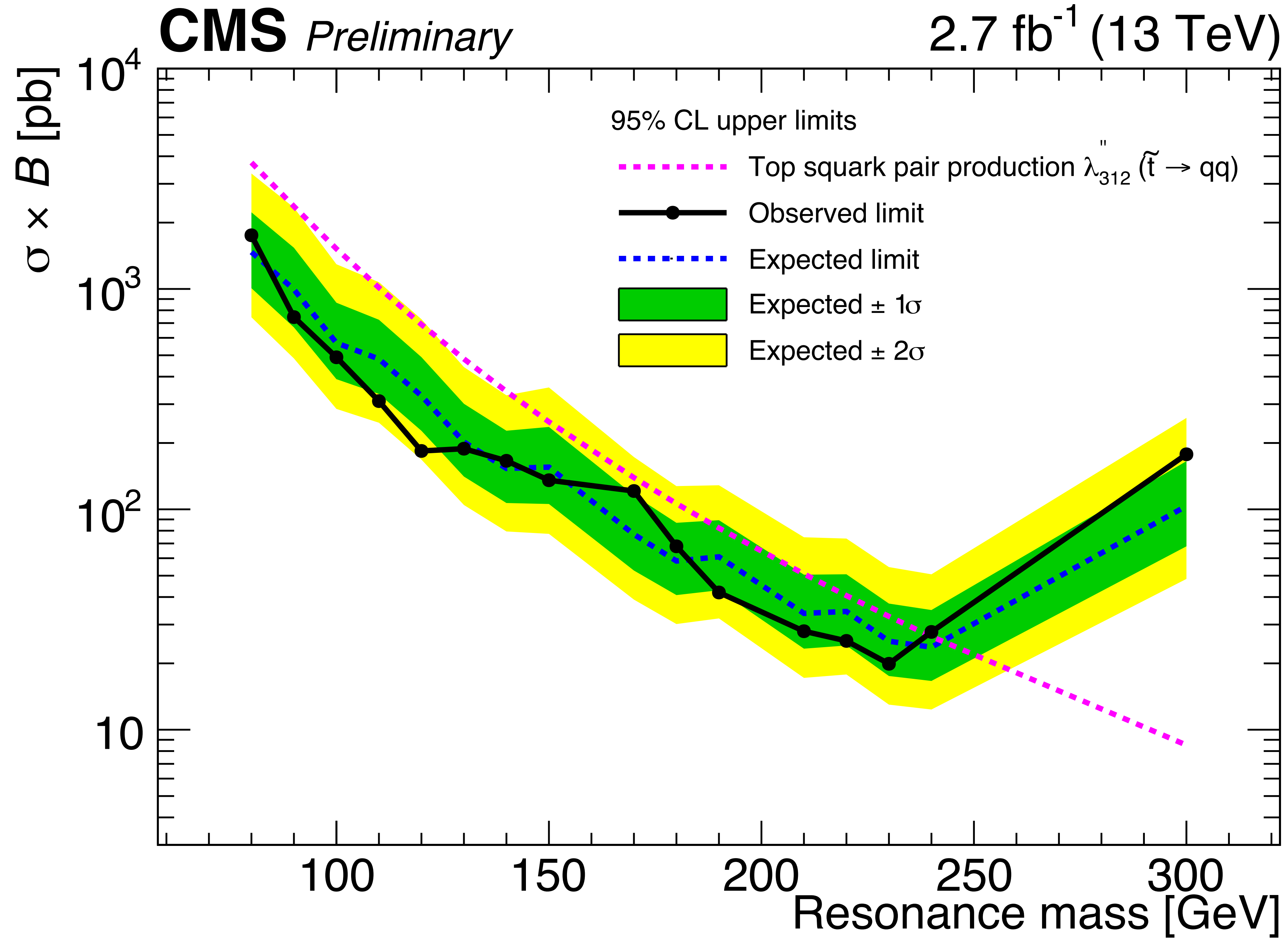
RPV $\tilde{t}\tilde{t}$ → JJ

EXO-16-029

- ε→0 as mass→0 for (jj)+(jj) search
- Special trigger based on H_T + jet mass
- Estimate background in control regions of mass asymmetry and Δη.



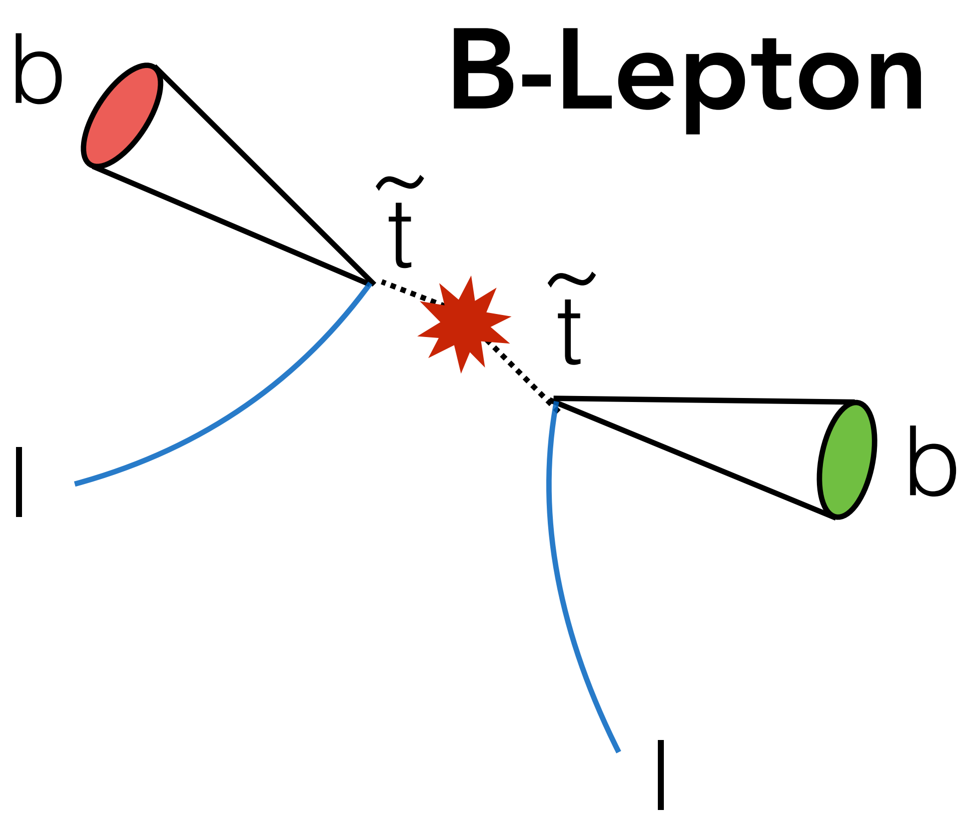


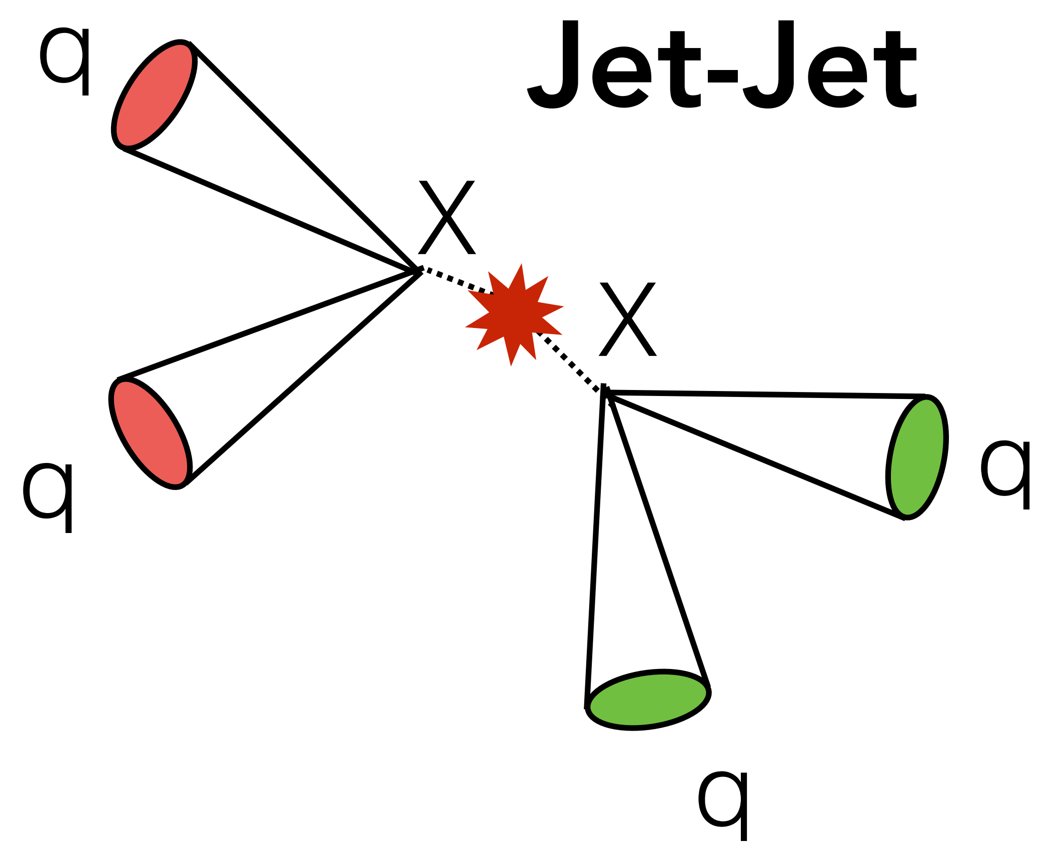


Displaced jets

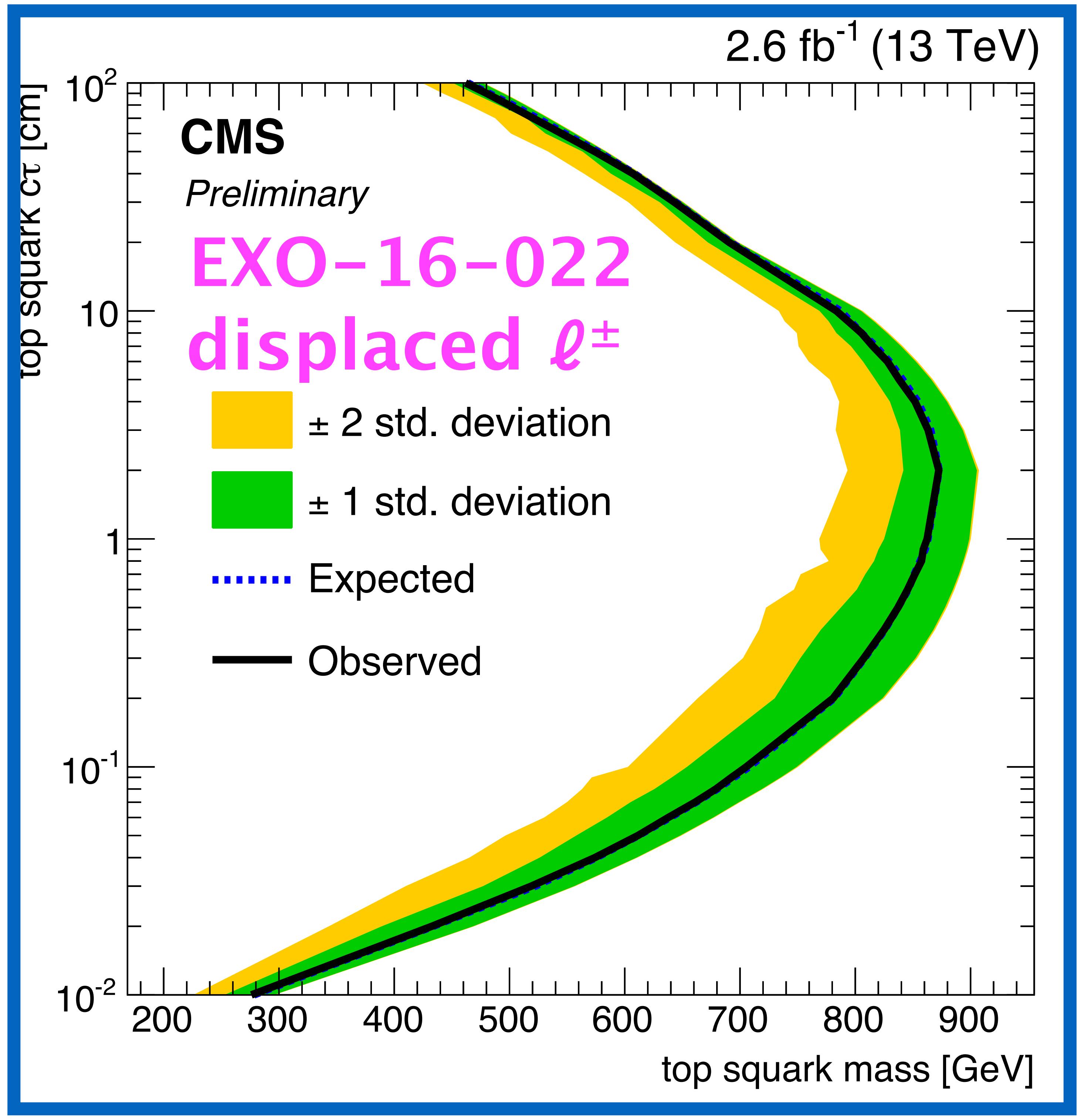
EXO-16-003

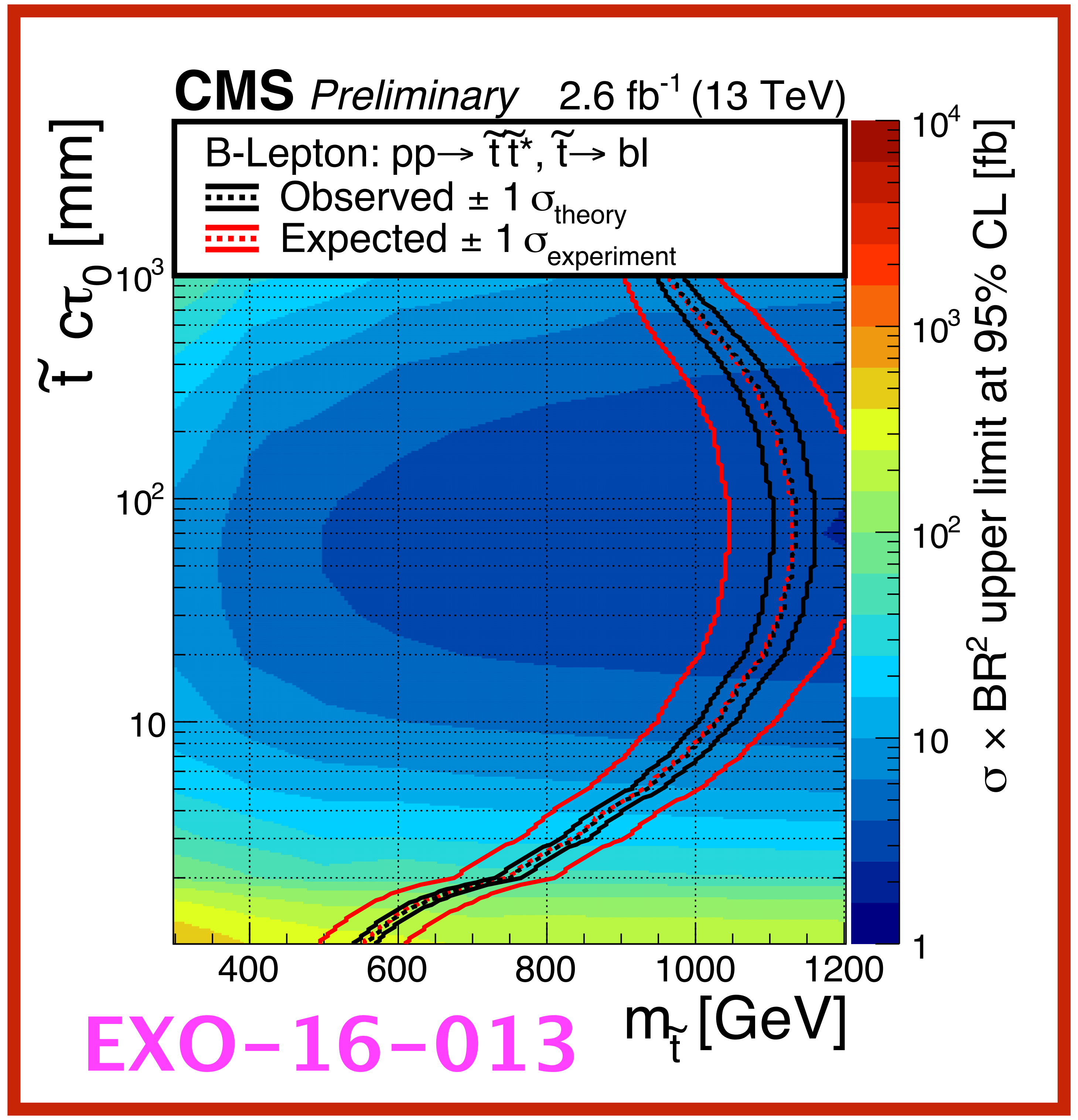
- Special tracking and trigger
- Run 2: analysis based on number of displaced jets (N_{tags}), rather than search for displaced dijet.

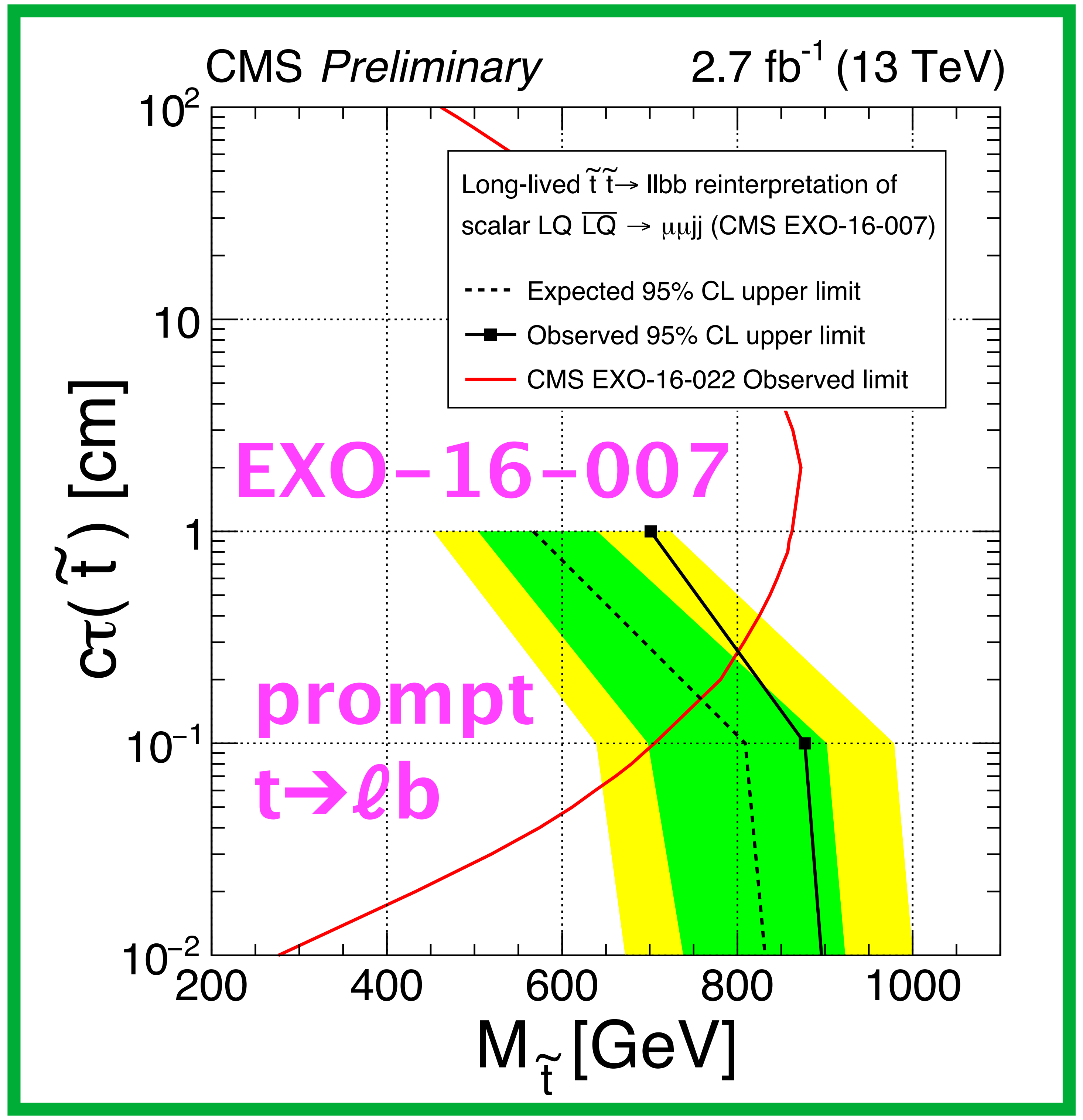




N_{tags}	Expected	Observed
2	1.09 ± 0.16	1
≥ 3	$(4.9 \pm 1.0) \times 10^{-4}$	0







Displaced jets variables

Vertex α : fraction of jet's track p_T to event vertex.

α_{max} : maximum over all vertices

IPsig : median for all tracks in jet of transverse d.o.c.a of track to primary vertex divided by uncertainty

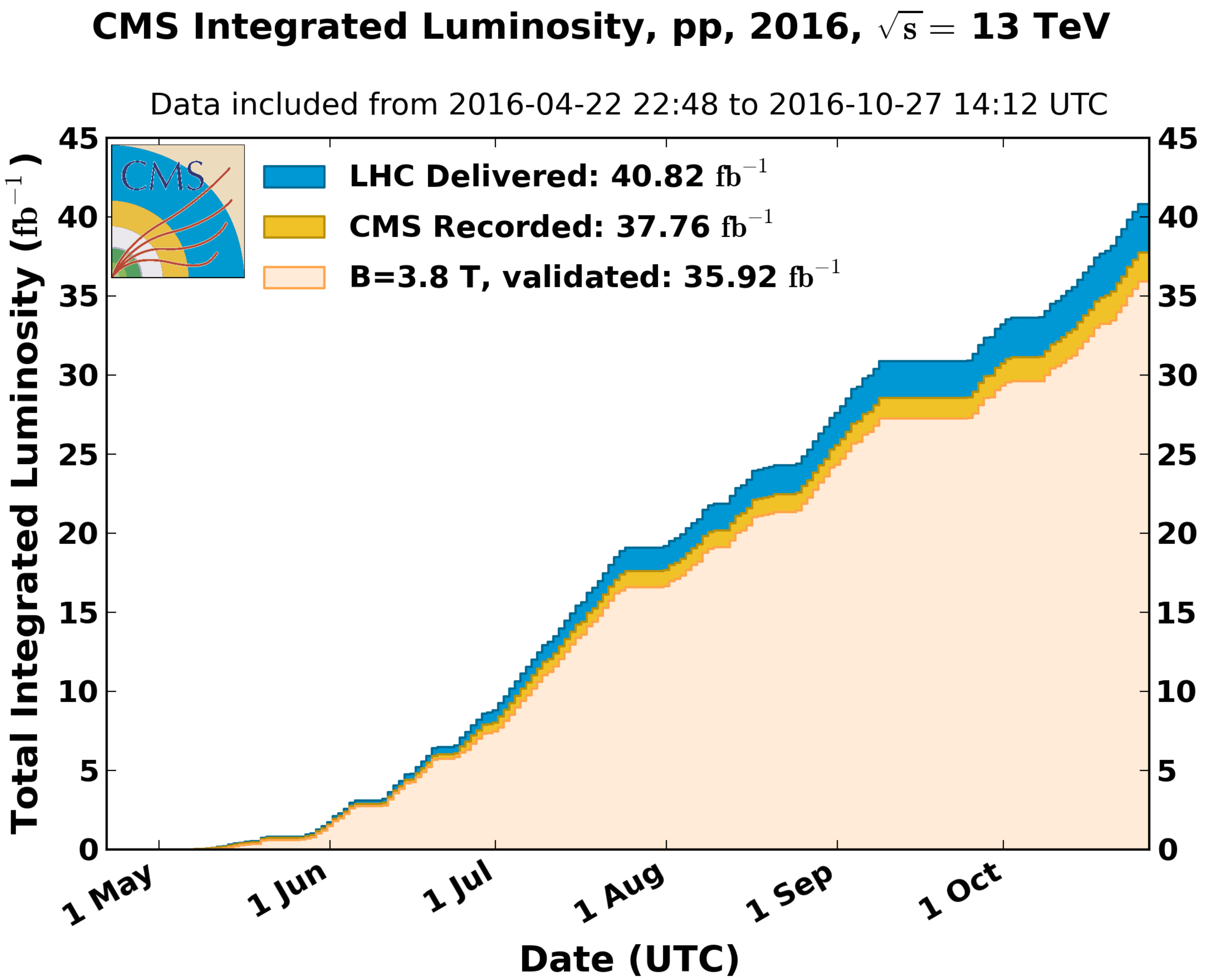
θ2D: median for all tracks in jet of transverse angle between track direction at innermost hit and direction to PV

CMS Detector

CMS 2016 detector performance

- Data taking efficiency ~ 93%
- Data certification efficiency ~ 95%

CMS preliminary results: April 22nd - October 27th 2016								
Tracker		**Calorimeters**			**Muon Spectrometer**			**Operational Issue**
Pixel	SST	ECAL	ES	HCAL	CSC	DT	RPC	Tracker HV ramp
99.9	99.1	99.3	99.7	99.6	99.9	99.9	99.6	99.5
All good for physics: 96%								

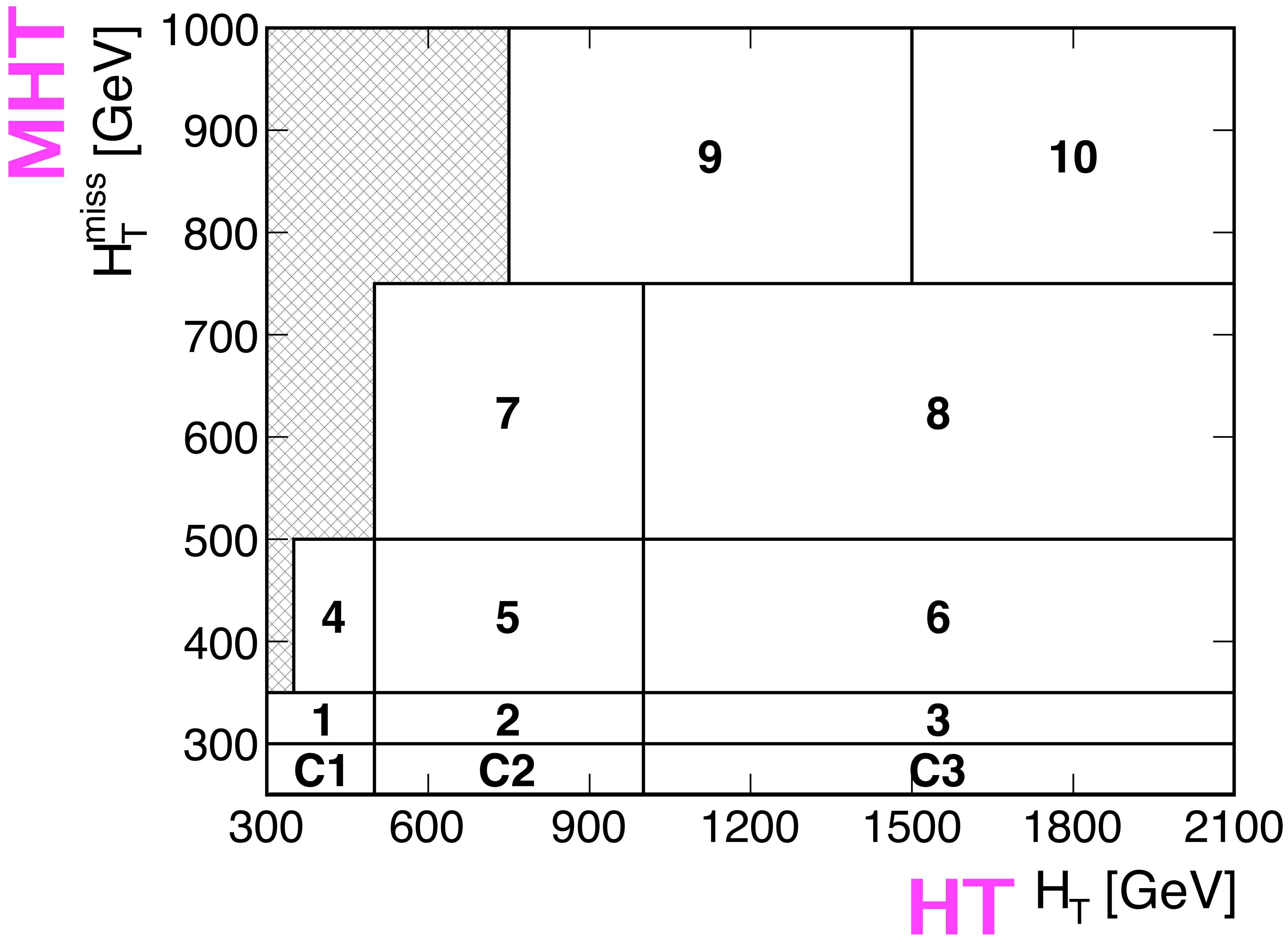


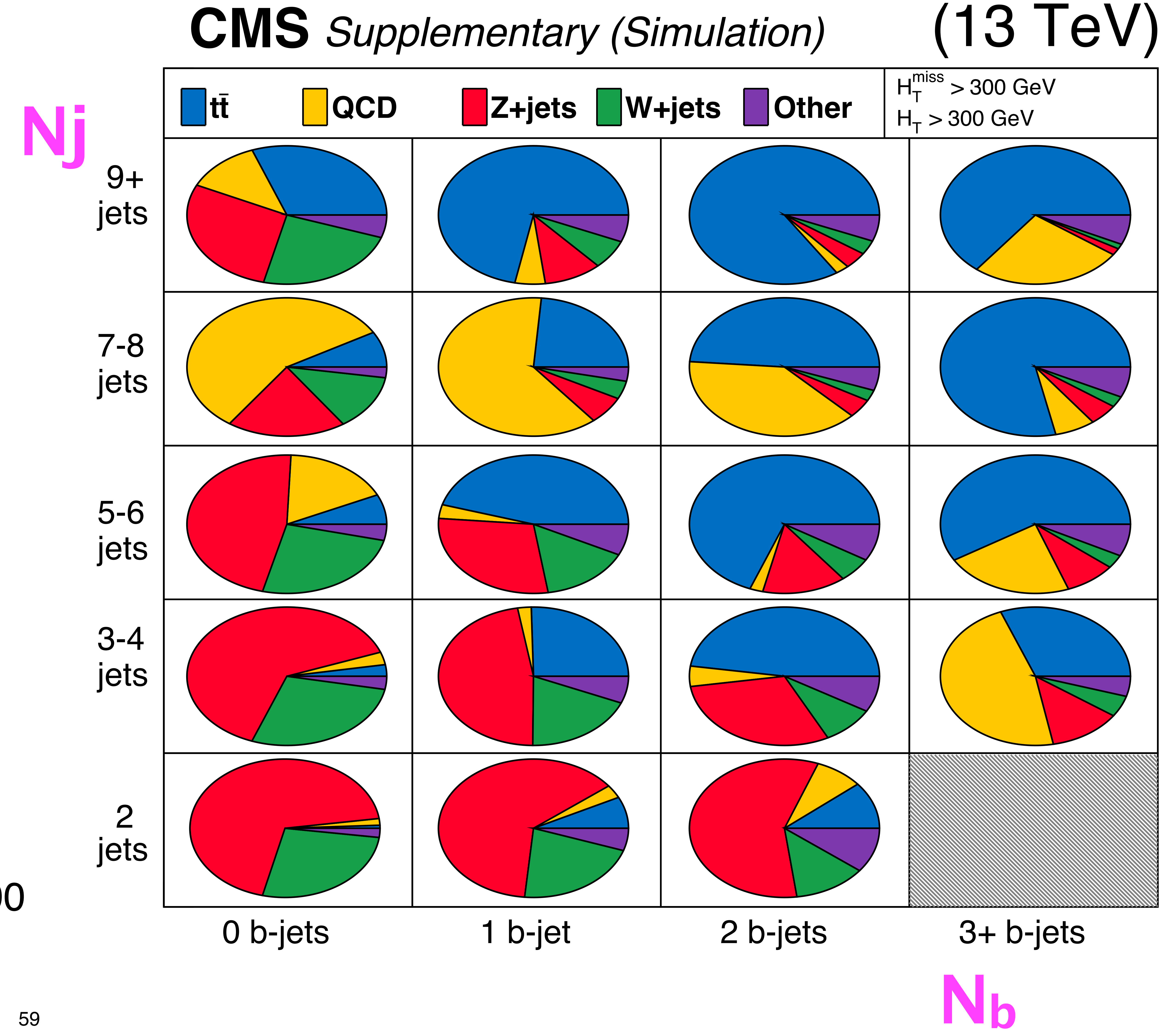
Event categorization

SUS-16-033

174 categories based on

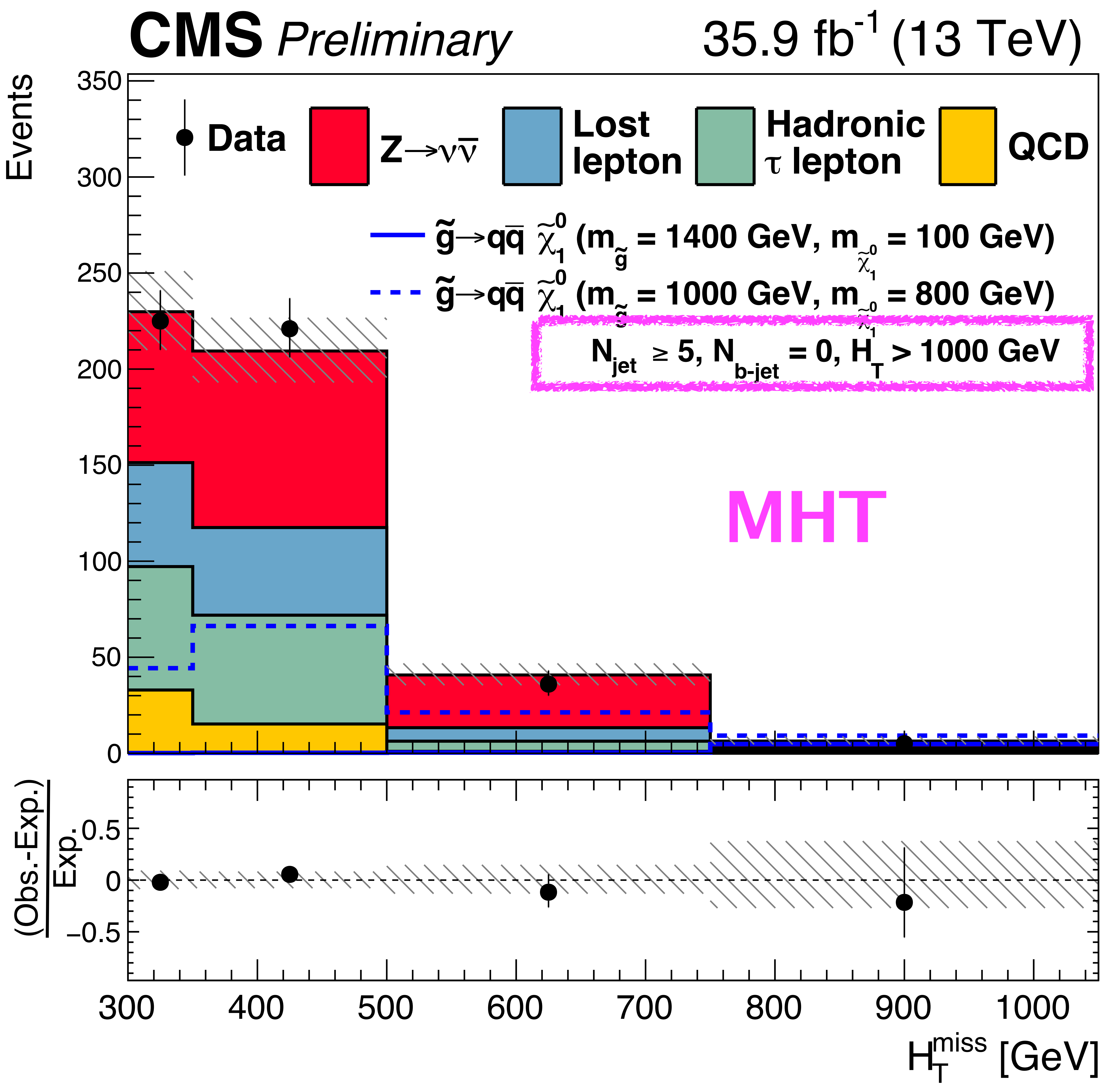
Nj, Nb, MHT, HT

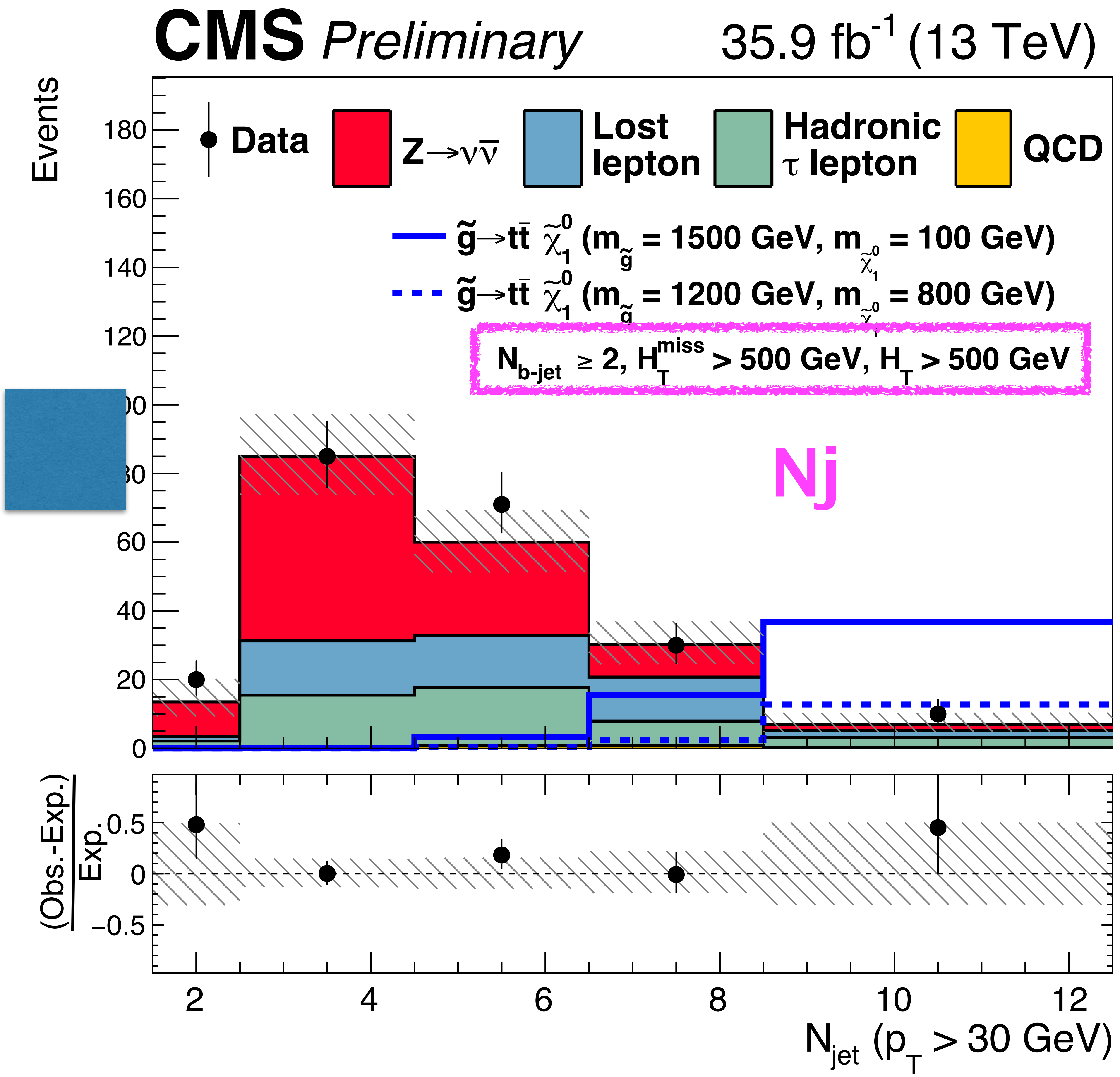




Kinematic distributions

SUS-16-033

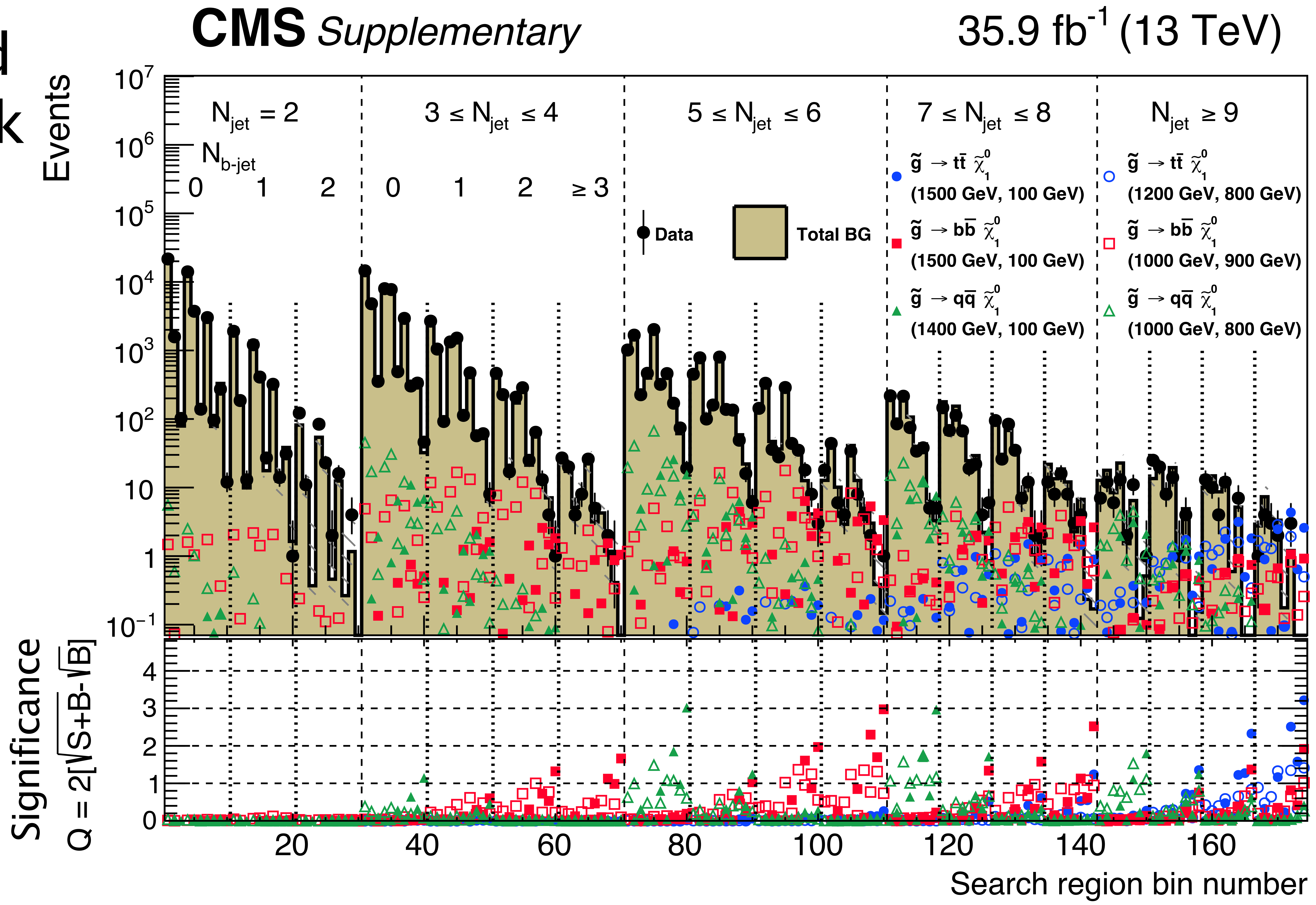




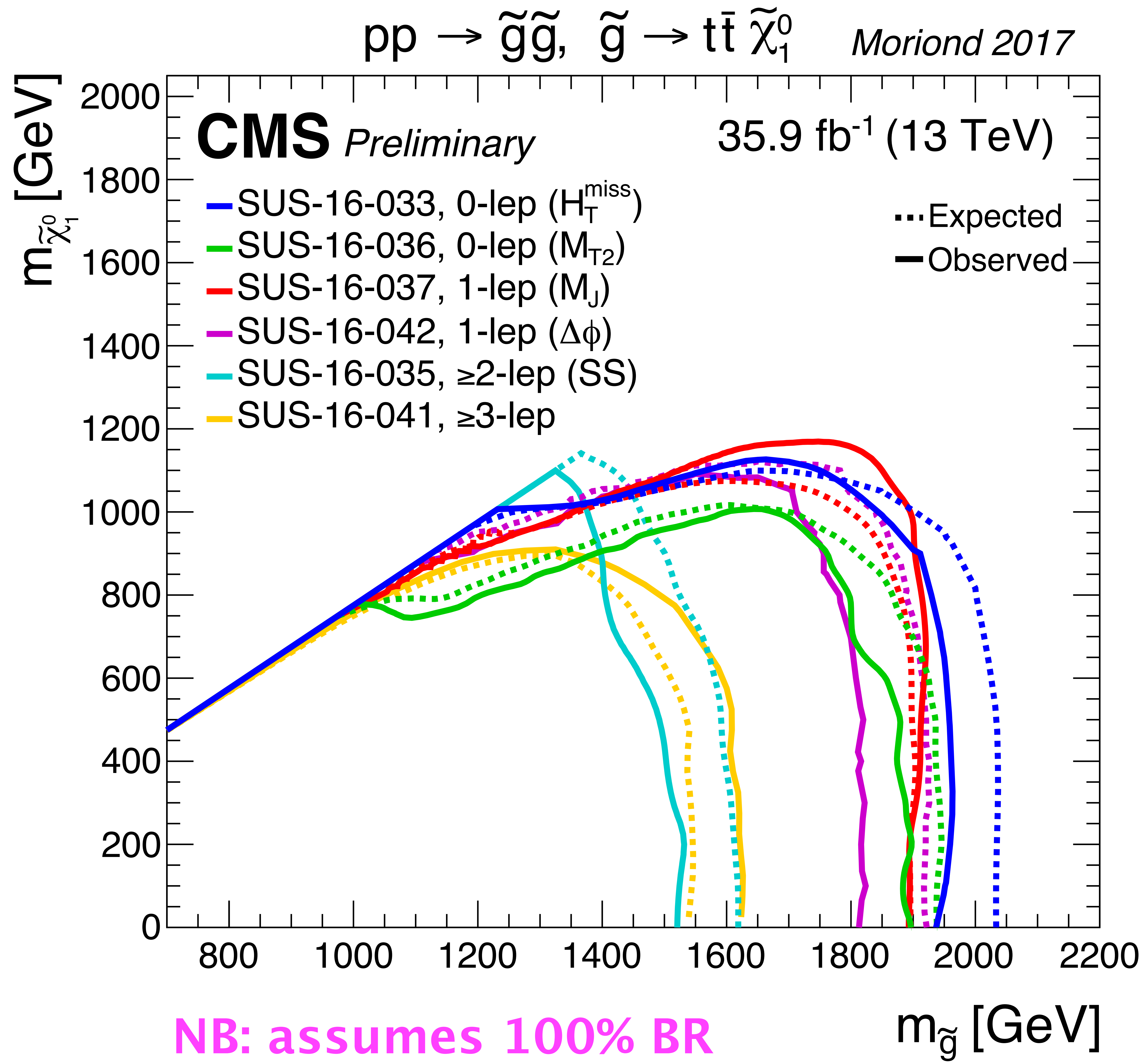
What would a signal look like?

SUS-16-033

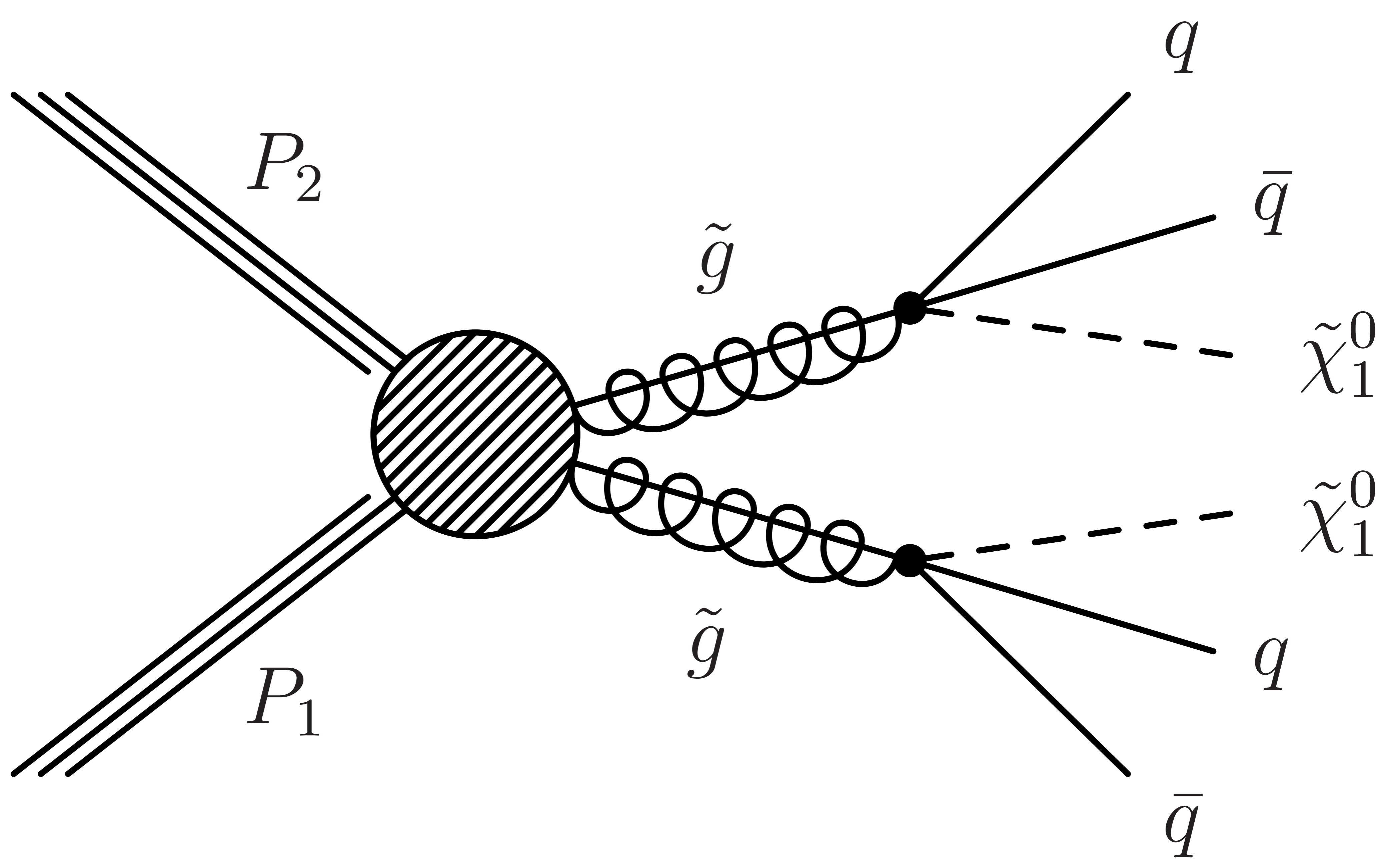
Expect correlated excesses for real signal.



Gluino sensitivity



NB: assumes 100% BR



Identifying top quarks SUS-16-049

1. select candidate **merged tops** (W bosons):

- M_{jet} >110 GeV (50–110 GeV), p_T>400 GeV (200 GeV)

2. identify merged tops (Ws) with **boosted decision tree** (BDT)

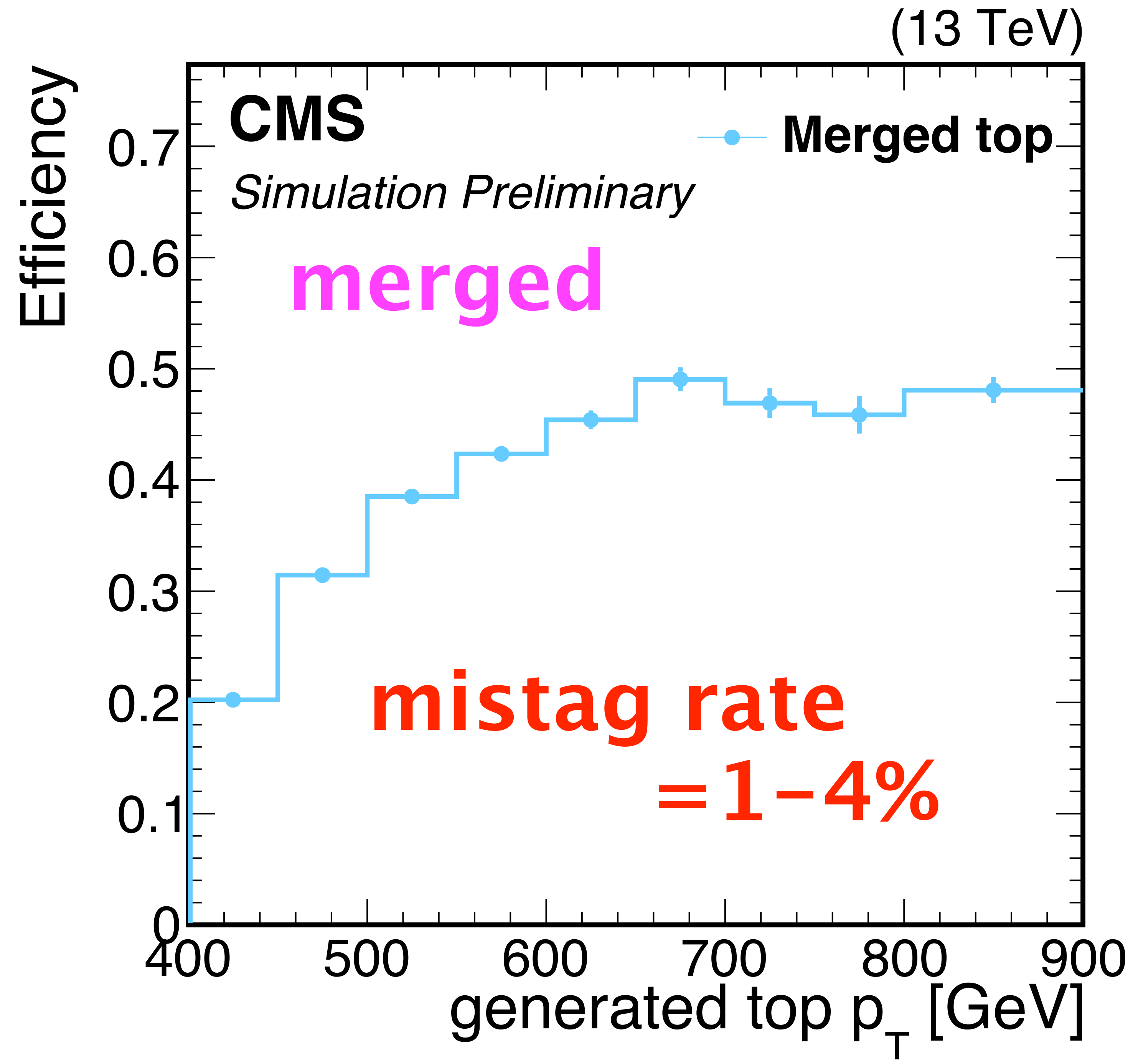
- jet mass corrected for soft radiation effects (soft-drop)
- sub-jet consistency and kinematics (N-subjettiness)
- b-tagging discriminant

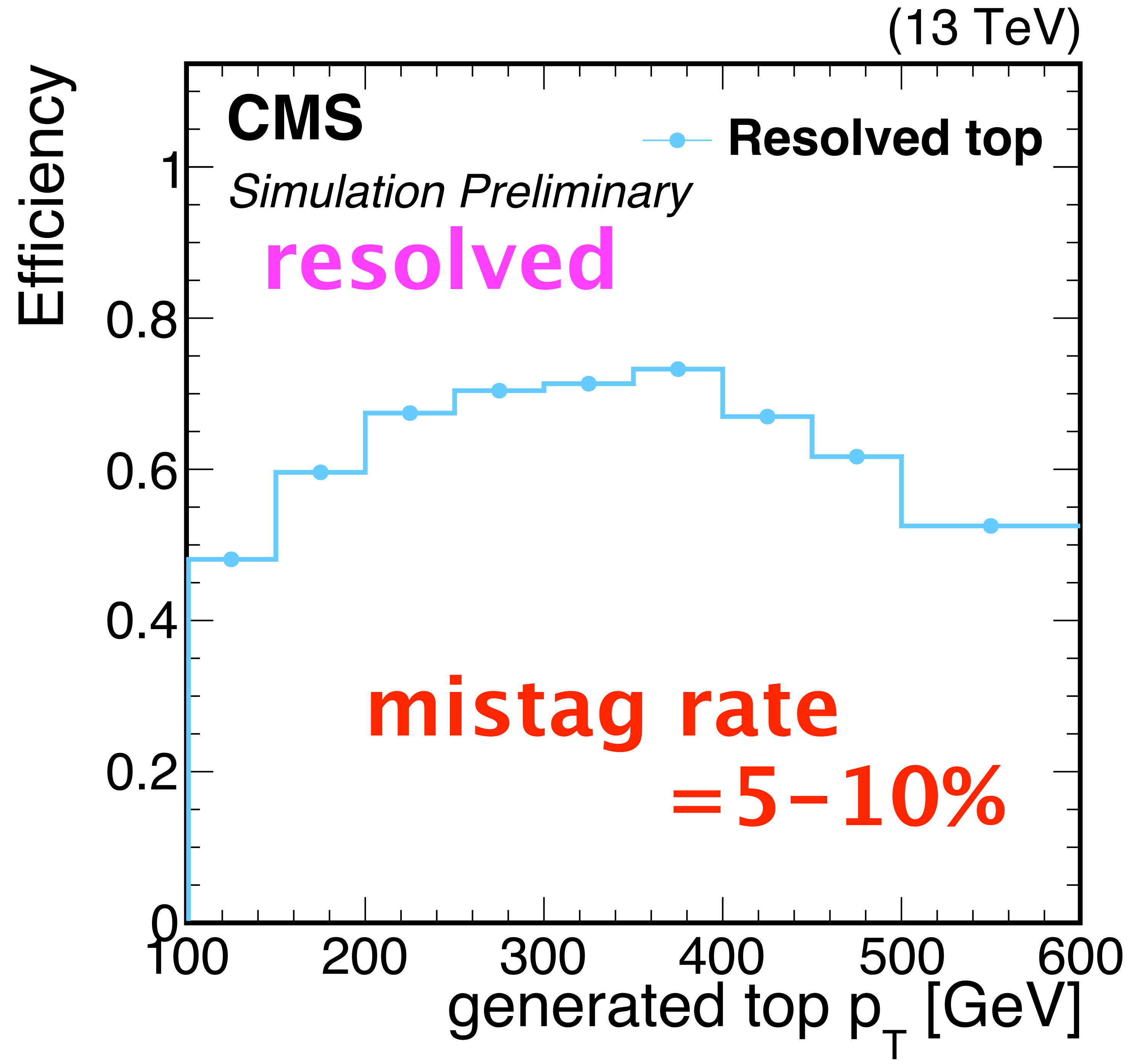
3. select candidate **resolved tops** from remaining jets

- Mass consistent with top

4. identify resolved tops with **BDT** based on
jet 4-vectors and b-tagging discriminant.

- Both **BDTs discriminate between** truth-matched and non-matched tops in tt simulation.





$\Delta m > m_W$ selection

SUS-16-049

Basic selection

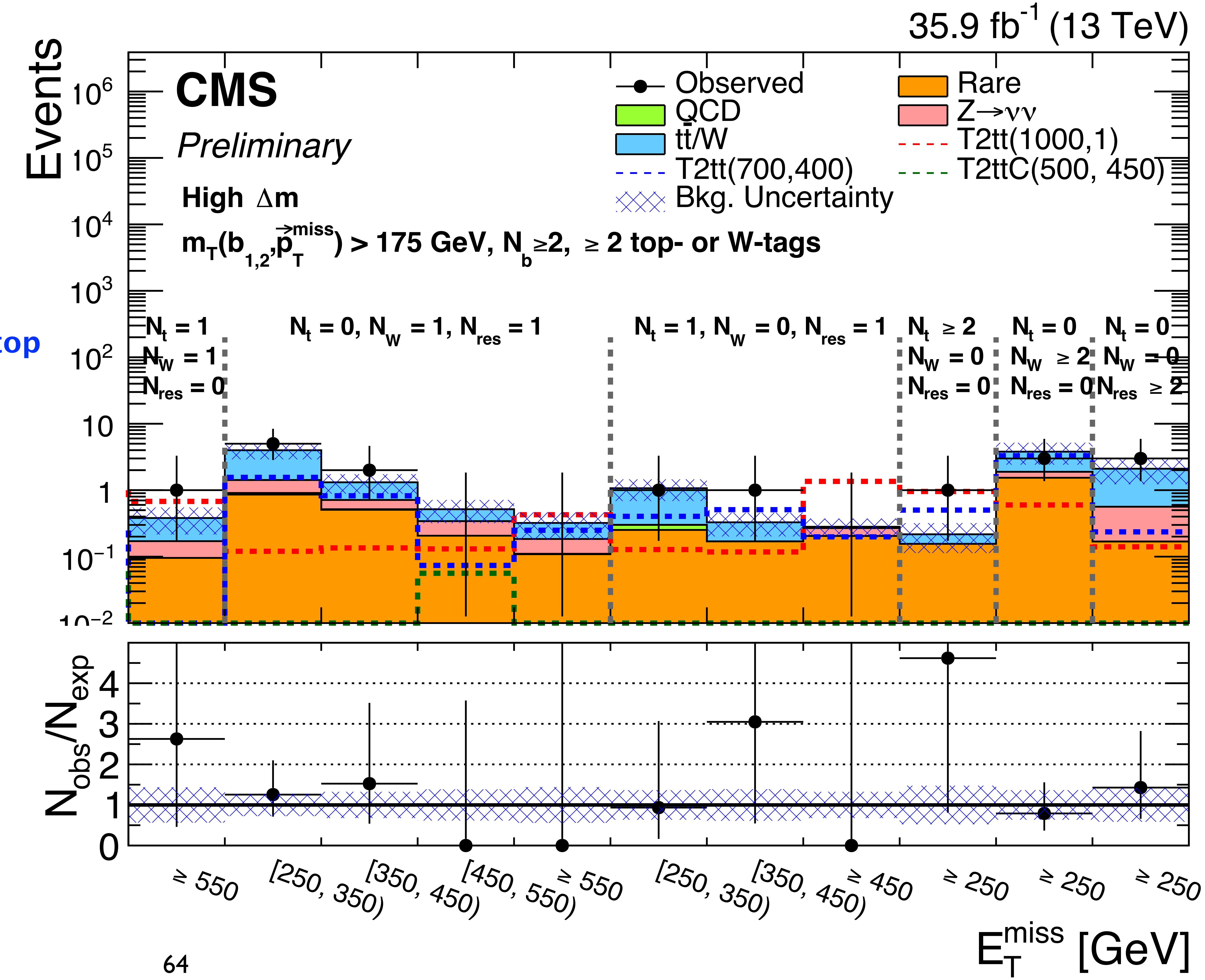
- $N_b \geq 1$, $N_{jets} \geq 5$
- $\Delta\varphi$(jets, MET)>0.5
- MET> 250 GeV

Sample with minimum **m_T^*(b,MET)< m_{top}** is top enriched so also requires

- $N_{jets} \geq 7$
- $N_{resolved} \geq 1$

Classify according to:

- $N_{merged-top}$, $N_{resolved-top}$, N_W, Nj, N_b



* $m_T(q_1, q_2) = 2p_{T1}p_{T2}(1 - \cos\Delta\varphi)$

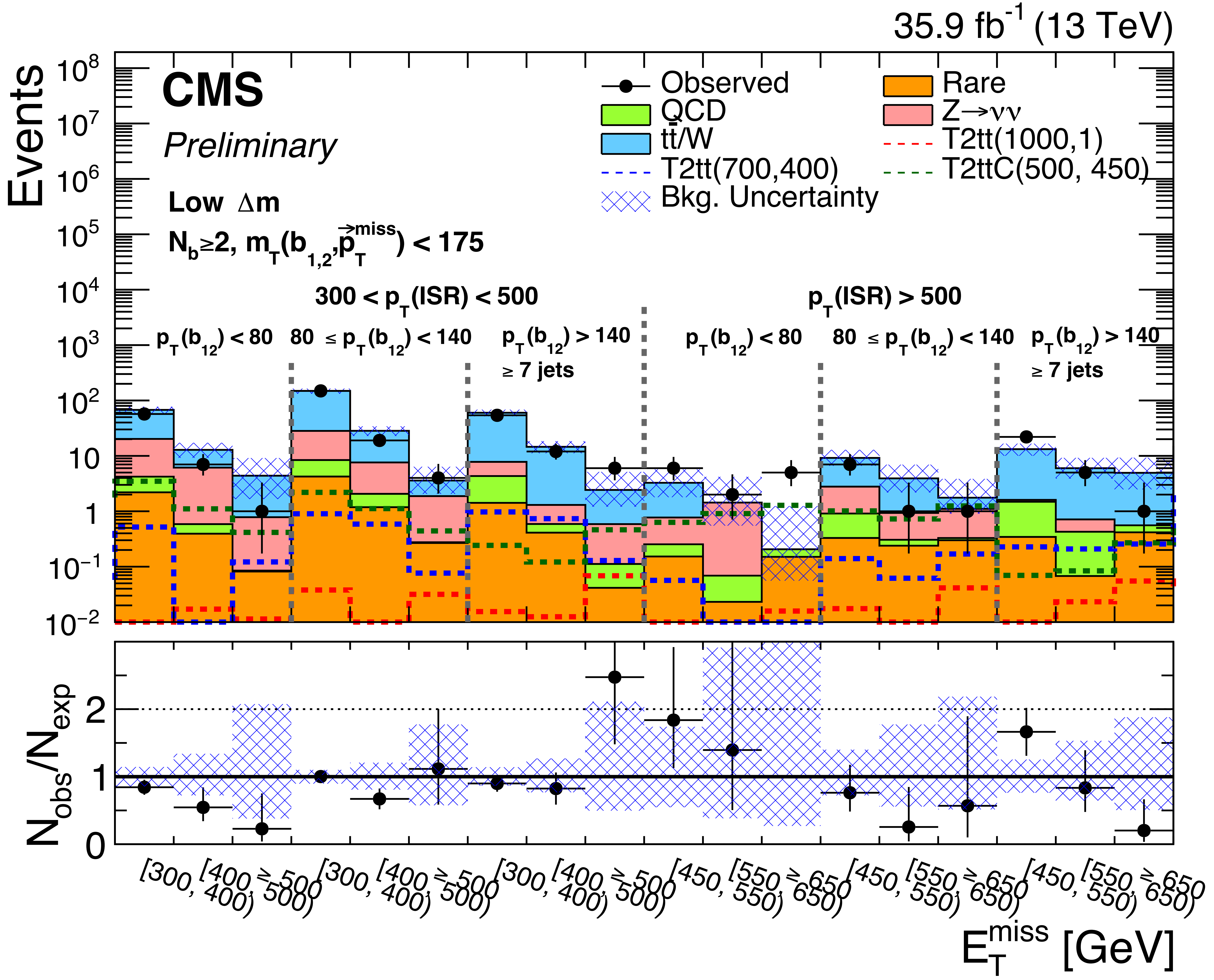
$m_T(q_1, q_2) \leq (q_1+q_2)^2$

$\Delta m < m_W$ selection

SUS-16-049

Basic selection

- $N(\ell) = 0$, $N_j \geq 2$,
- $N_{merged-top} = N_{resolved-top} = N_W = 0$
- MET > 250 GeV
- ISR jet with p_T > 200 GeV
- MET significance > 10 $GeV^{1/2}$
- minimum m_T(b,MET)<175 GeV (for orthogonality with high Δm)



Classify according to:

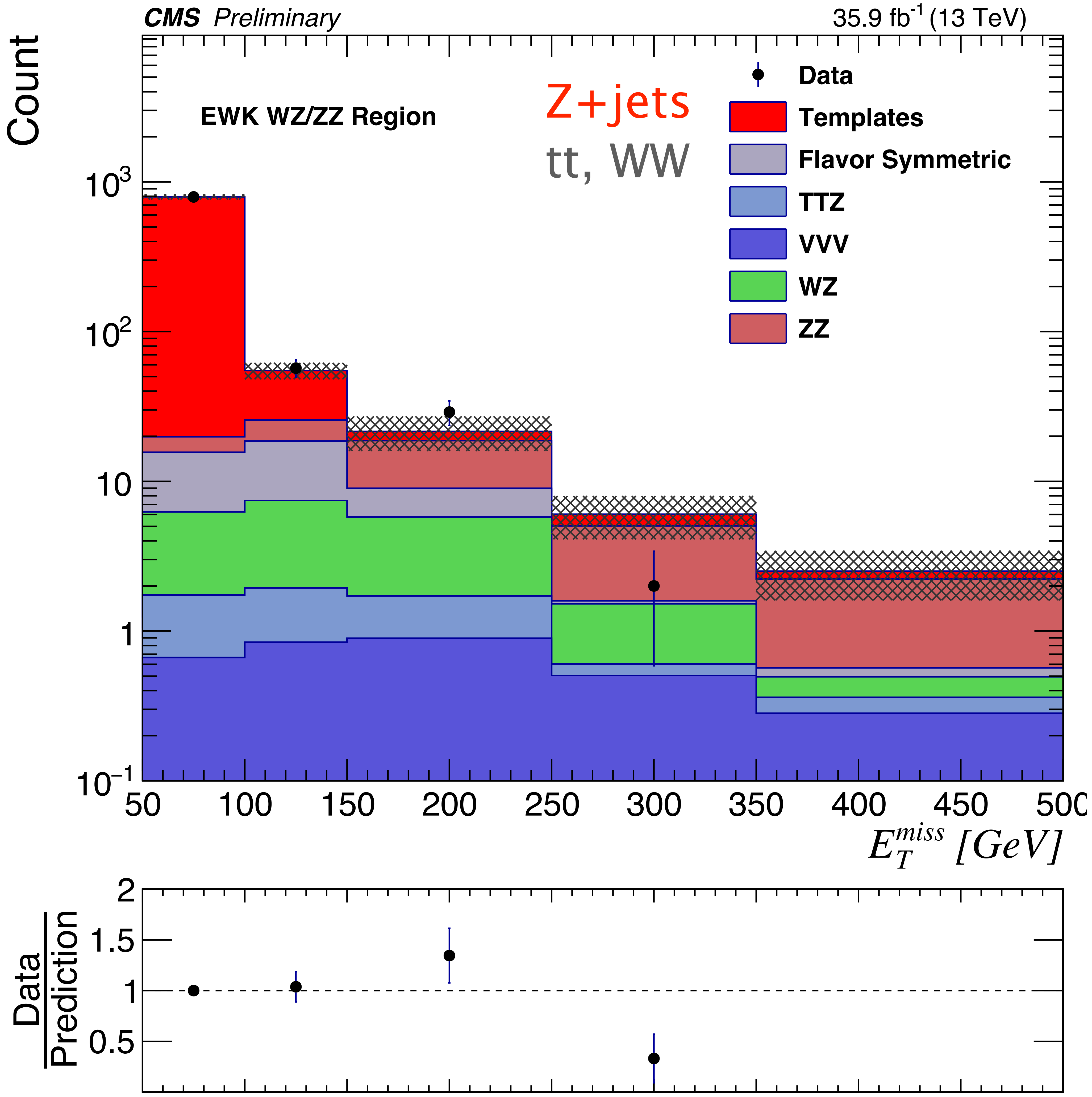
- N_b, Nj
- ISR jet p_T, bjet sum p_T
- number of secondary vertices

Z+jets+MET search ($\Delta m > m_Z$)

SUS-16-034

Selection

	Selection	motivation
Leptons	$e^{\pm}e^{\mp}$ or $\mu^{\pm}\mu^{\mp}$	
MET	>100 GeV	reduce SM
$m(\ell\ell)$	consistent with Z	reduce tt
N_b	0	
$MT2(\ell\ell)$	>80 GeV	
Nj	>=2	reduce Z+jets
m(jj)	< 110 GeV	



Backgrounds

- Z+jets with mismeasured jet
  - MET shape from γ+jets
- VV: simulation estimate validated in 3ℓ & 4ℓ data
- tt + WW : estimate from $e^{\pm}\mu^{\mp}$

SUS-16-039

3ℓ+MET search (Δm~m_Z)

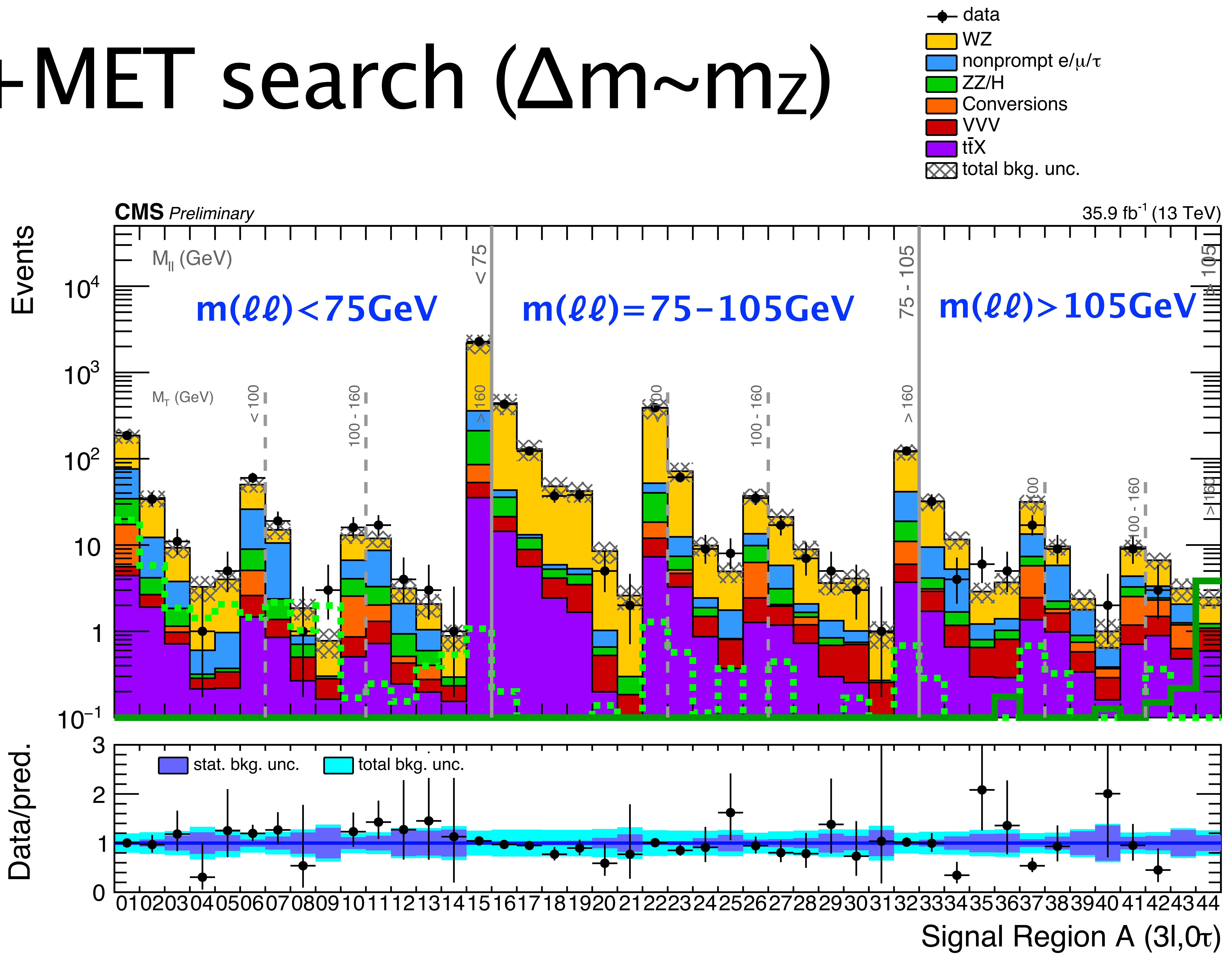
Select

- $e^\pm e^\mp$+ℓ or $\mu^\pm\mu^\mp$+ℓ
- MET > 50 GeV
- N_b=0 suppresses $t\bar{t}$

- Categorize by m(ℓℓ), m_T(ℓ3, MET), MET.

Backgrounds

- WZ estimated with MET<100 GeV sample
- nonprompt ℓ with relaxed ℓ sample



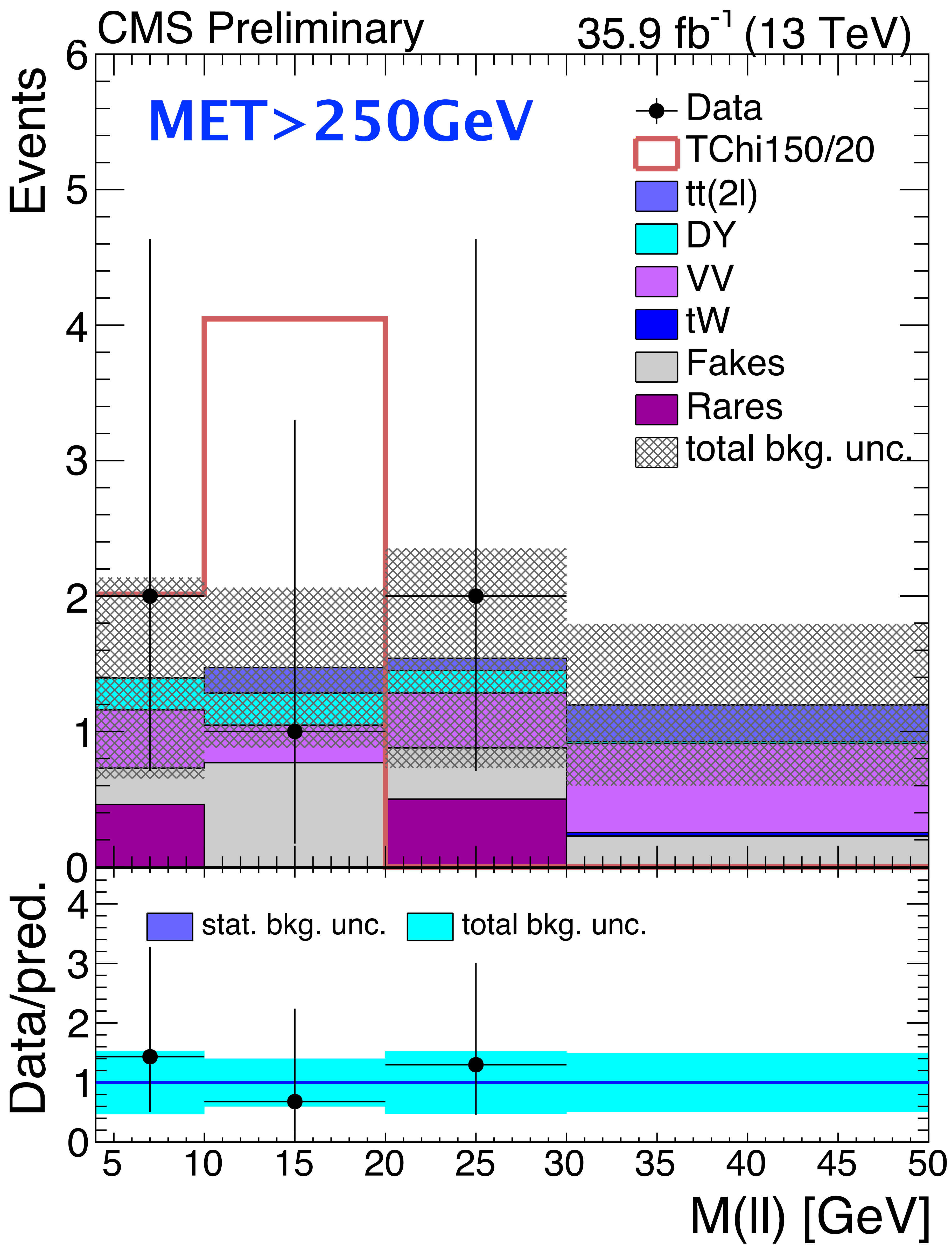
2 low-p_T ℓ + MET (small Δm)

SUS-16-048

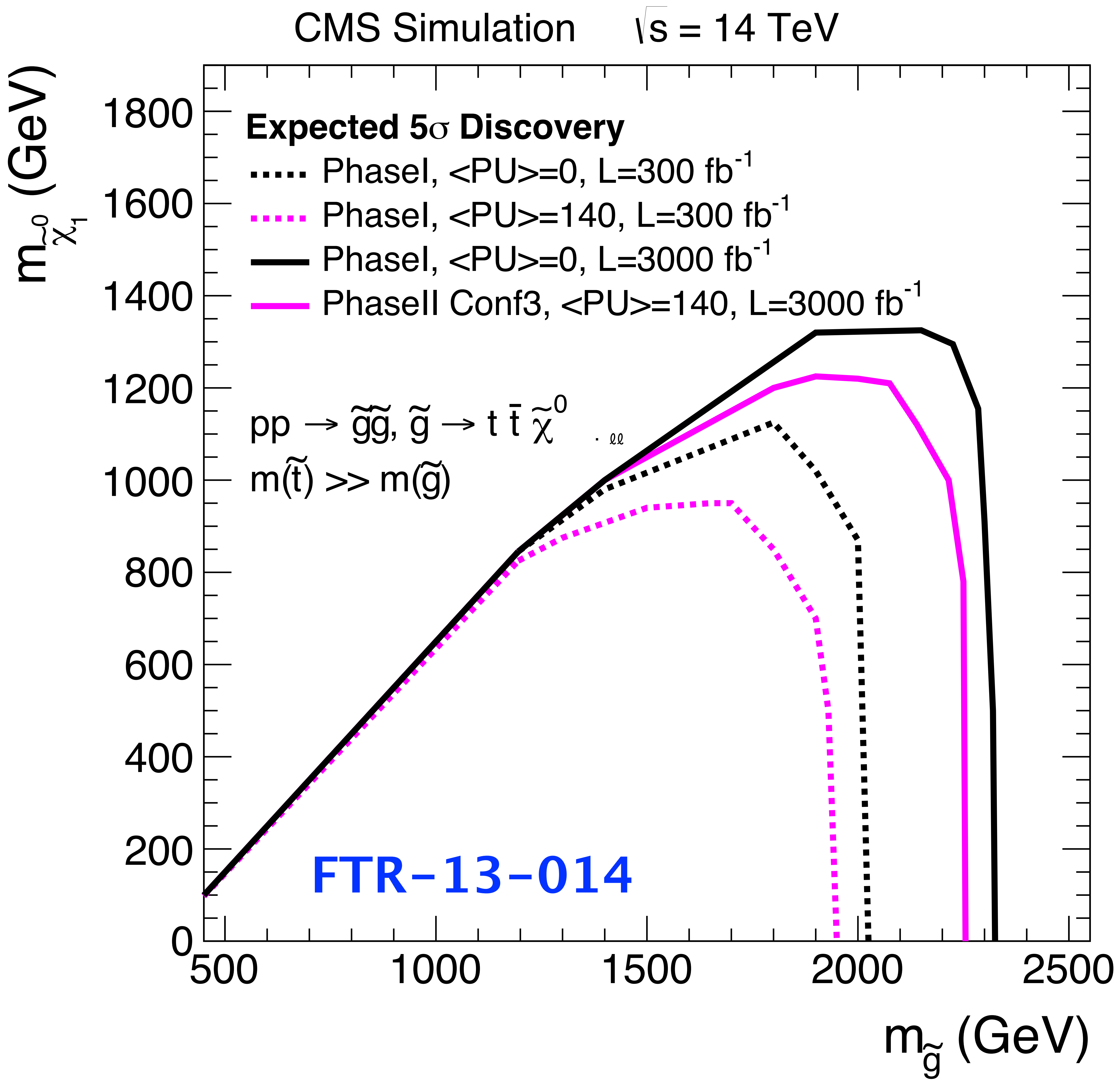
- Special trigger: 2 muons with p_T>3GeV and MET>50 GeV (from ISR boost)

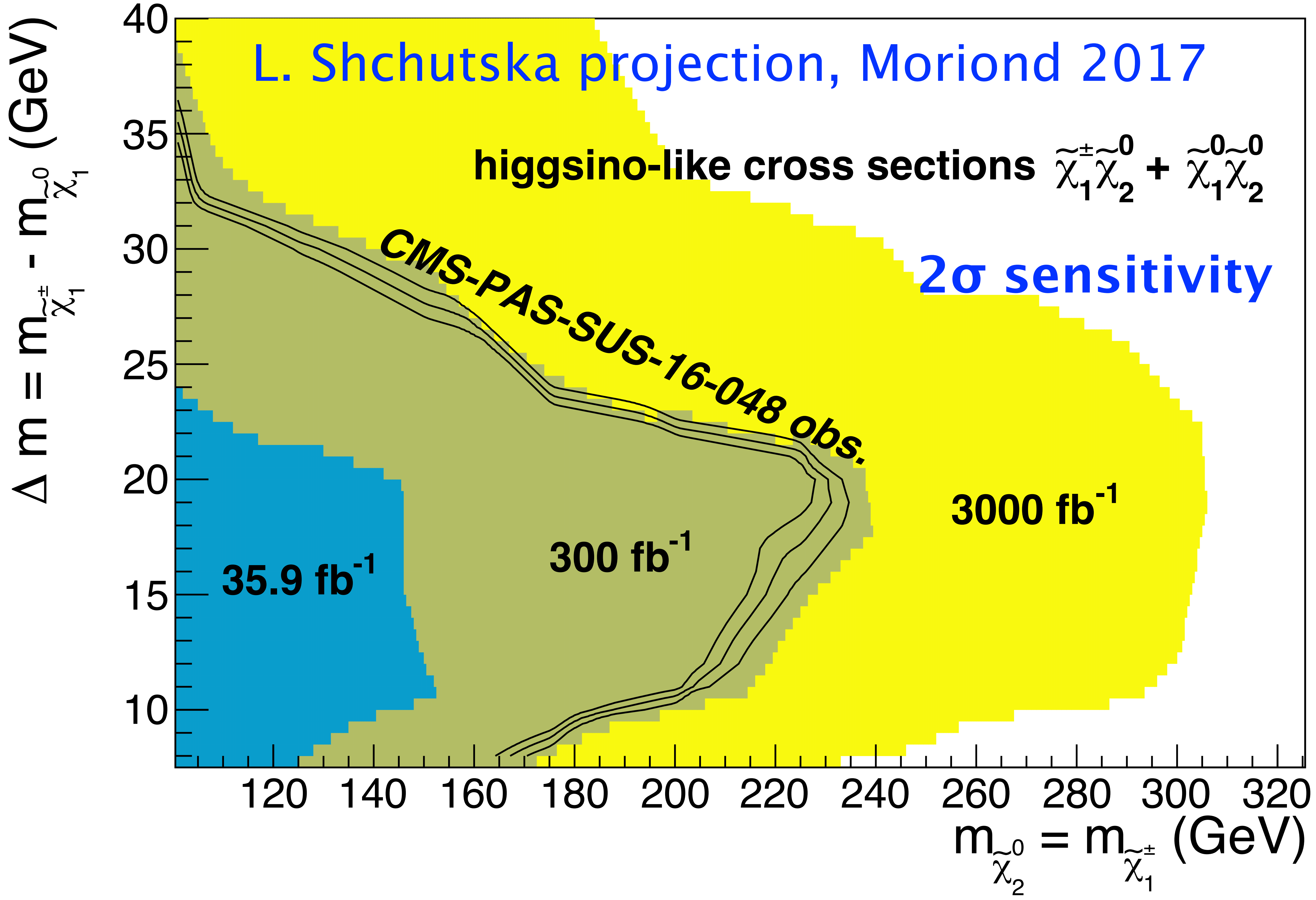
	Selection	motivation
Leptons	$e^{\pm}e^{\mp}$ or $\mu^{\pm}\mu^{\mp}$	
MET	>125 GeV	trigger
Nj (ISR)	≥1	
ℓ p_T	5–30 GeV	reduce tt
N_b	0	
$m_T(\ell$, MET)	< 70 GeV	
MET/HT	0.6 – 1.4	reduce QCD
$m(\ell\ell)$	[4,9], [10.5,50] GeV	reduce SM $\ell\ell$ resonances

- Bkg estimates from data; e.g. VV in m_T ctrl sample
- Categorize based on $m(\ell\ell)$ and MET.



SUSY reach at HL-LHC



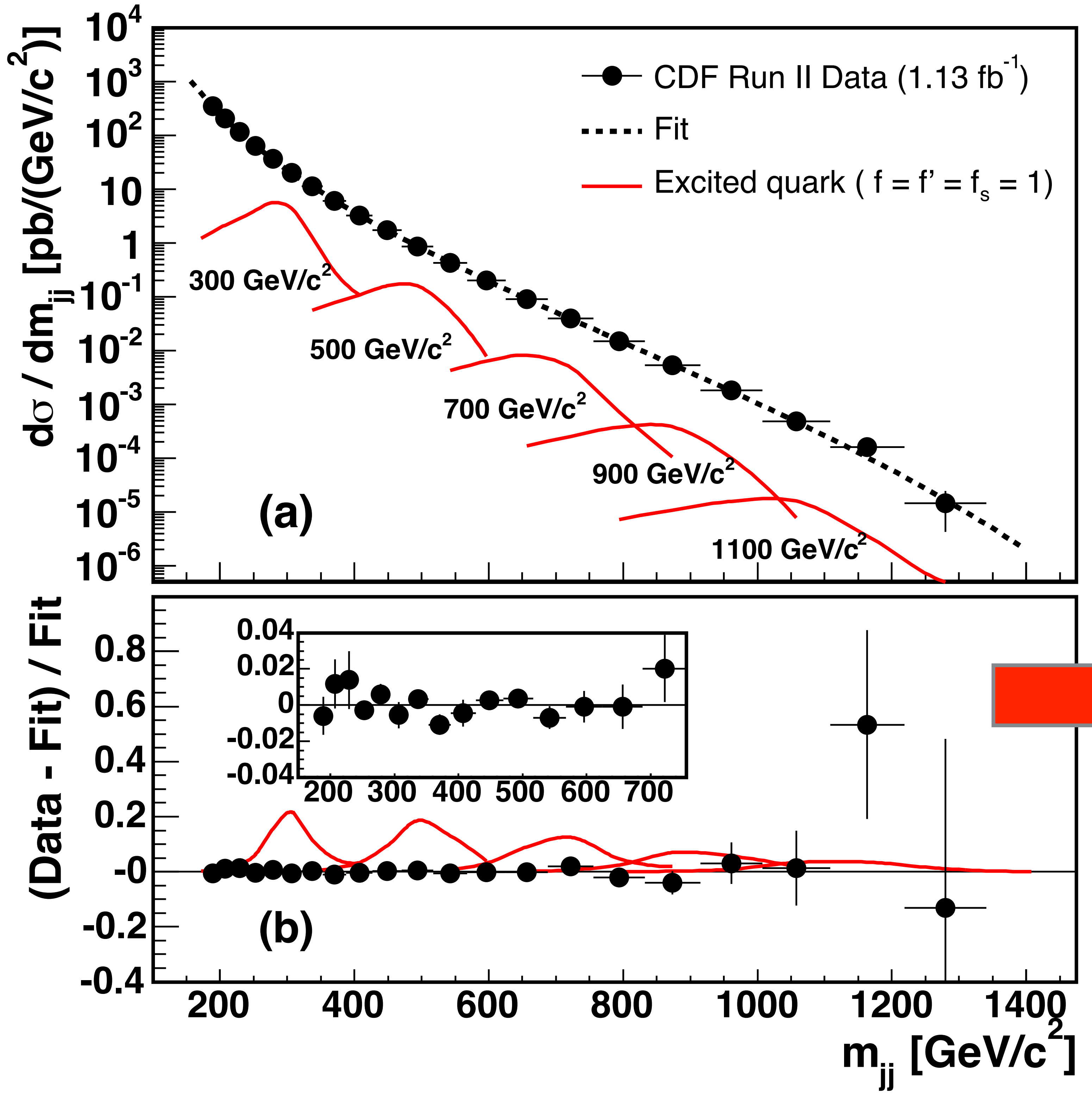


Higgsino reach 230 GeV for small Δm.

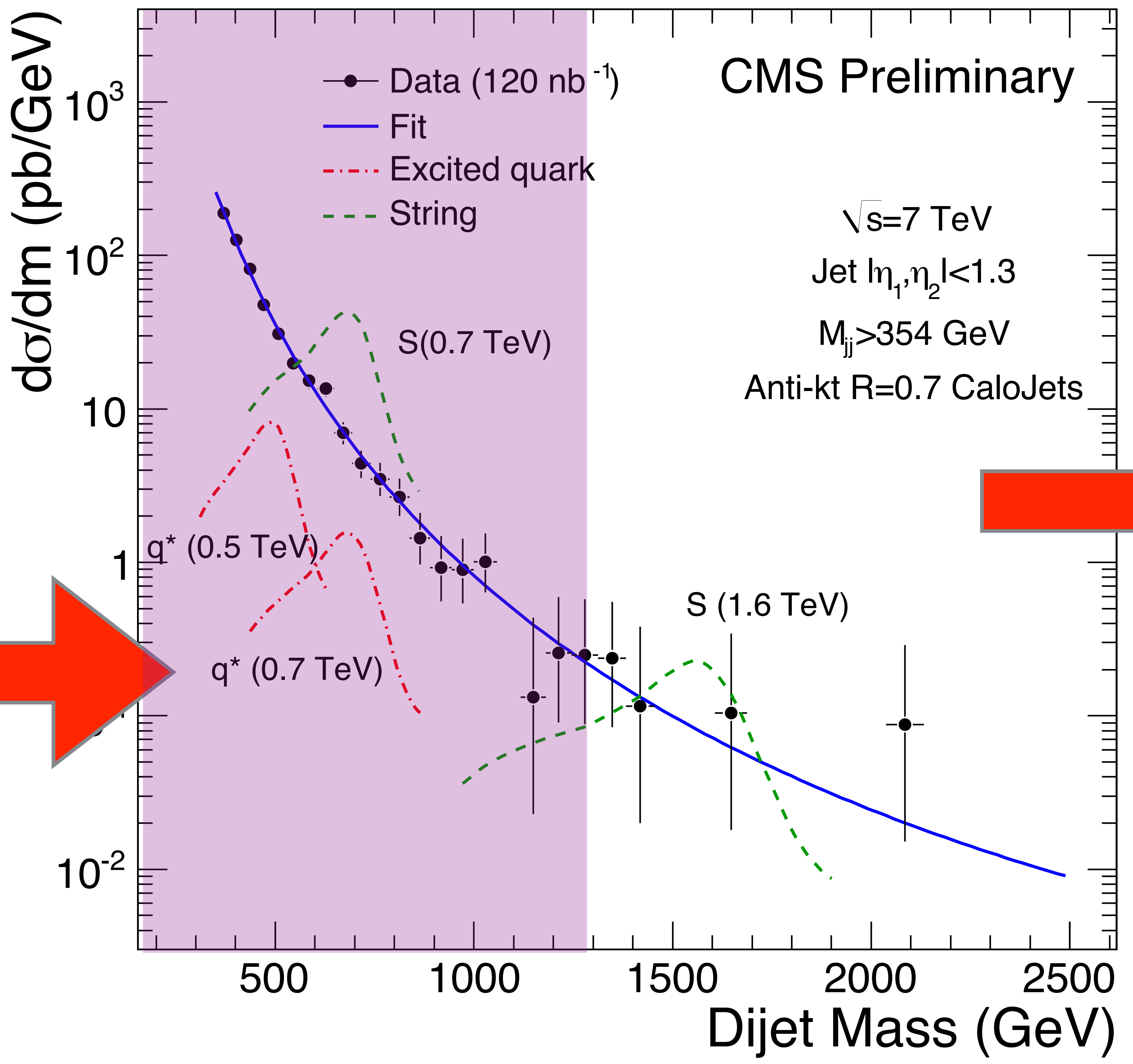
Dijet sensitivity since 2010

Since 2010: 2x energy increase and 30000x luminosity increase!

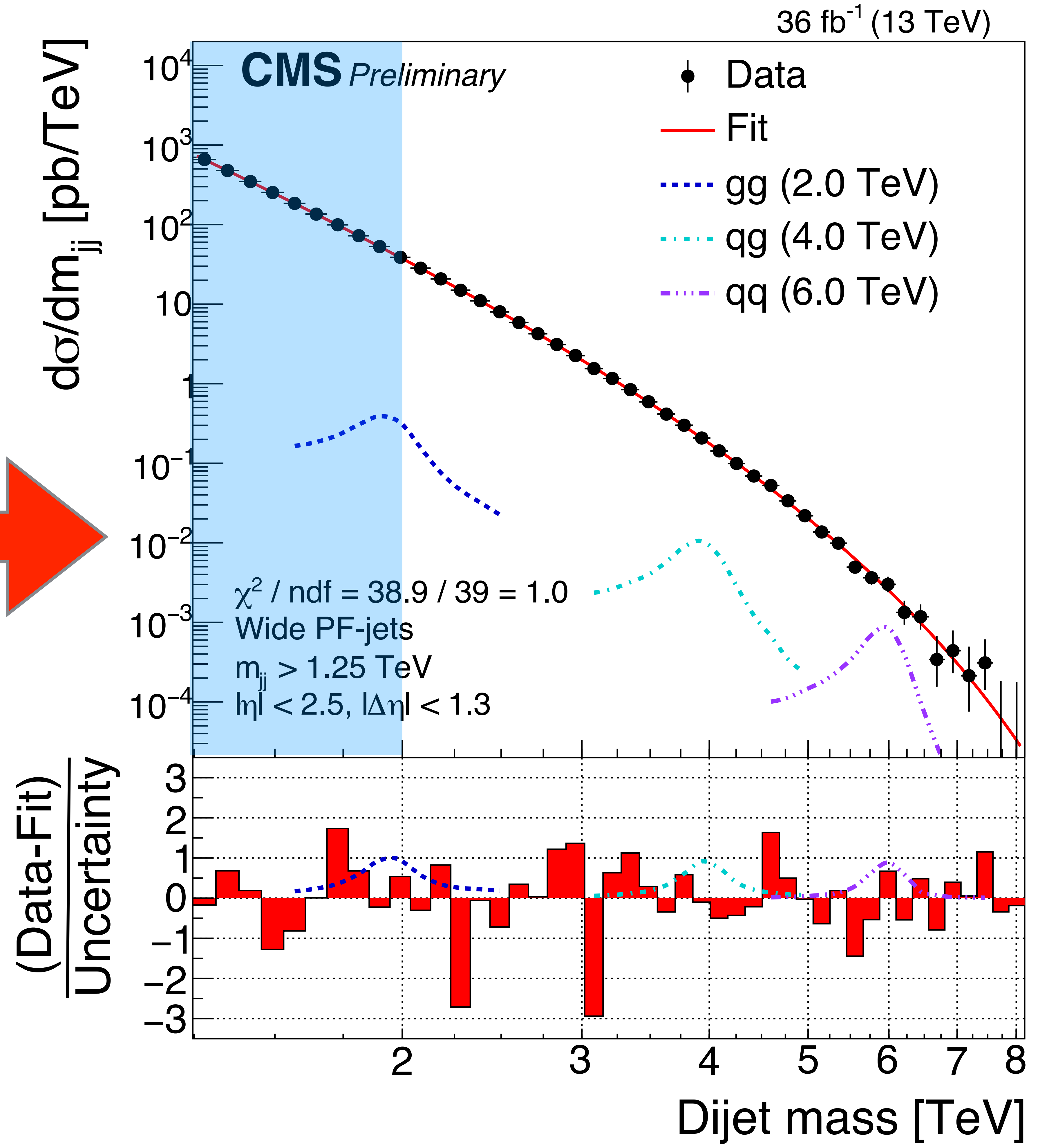
2 TeV : 1.3 fb^{-1} : 2008
arXiv:0812.4036



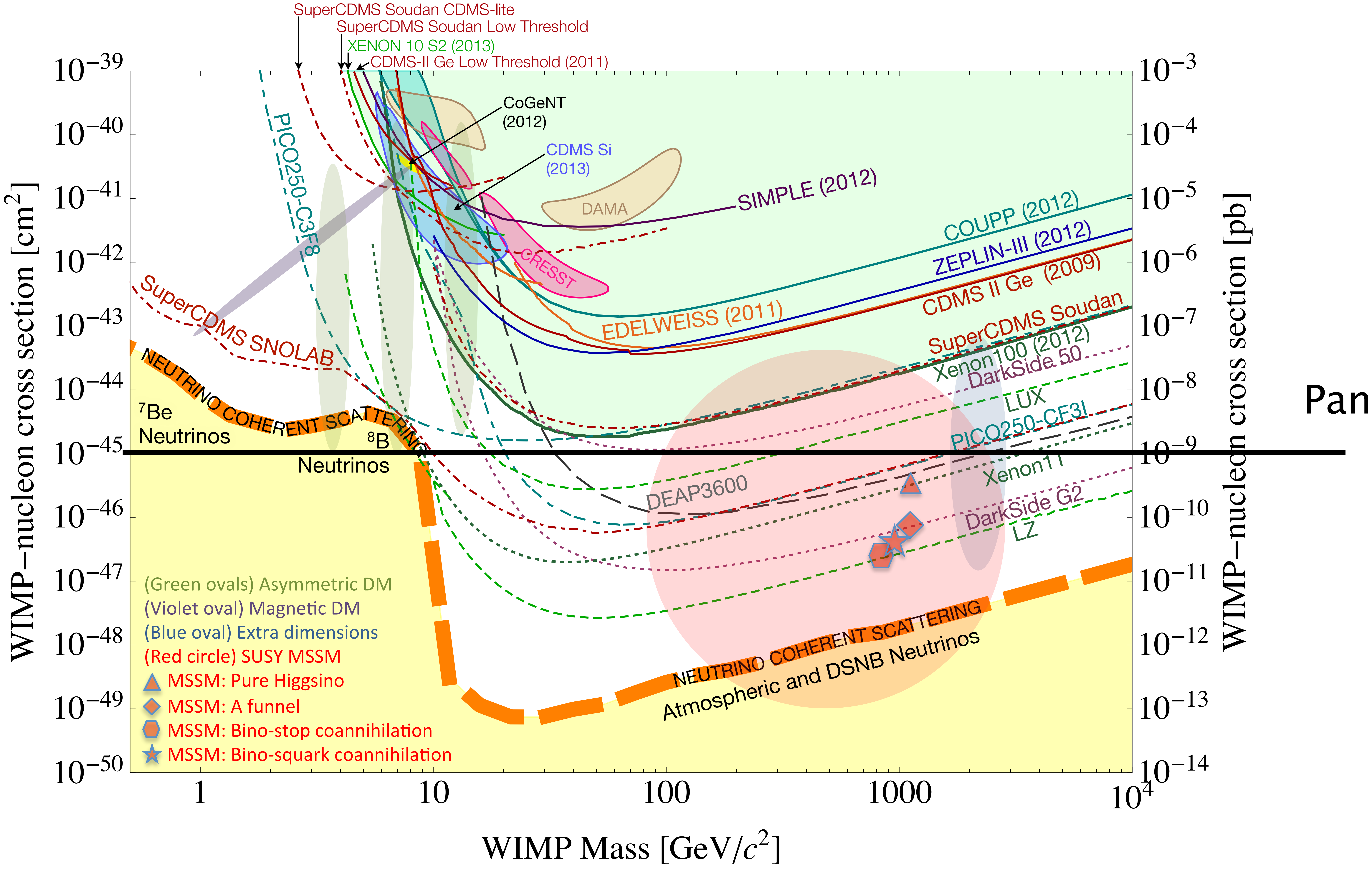
7 TeV : 120 nb^{-1} : 2010
EXO-10-001



13 TeV : 36 fb^{-1} : 2016
EXO-16-056



DM Direct detection



Panda-X limit at 1 TeV