Beyond Standard Model searches by ATLAS and CMS

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TU Dortmund University

on behalf of the ATLAS and CMS Collaborations

ICPPA-2018
October 22-26

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung
FSP 103 ATLAS

Open Questions

DM ?

$m_H \ll \Lambda_P$?

$m_e \ll m_t$?

baryon asym. ?

gravitation?

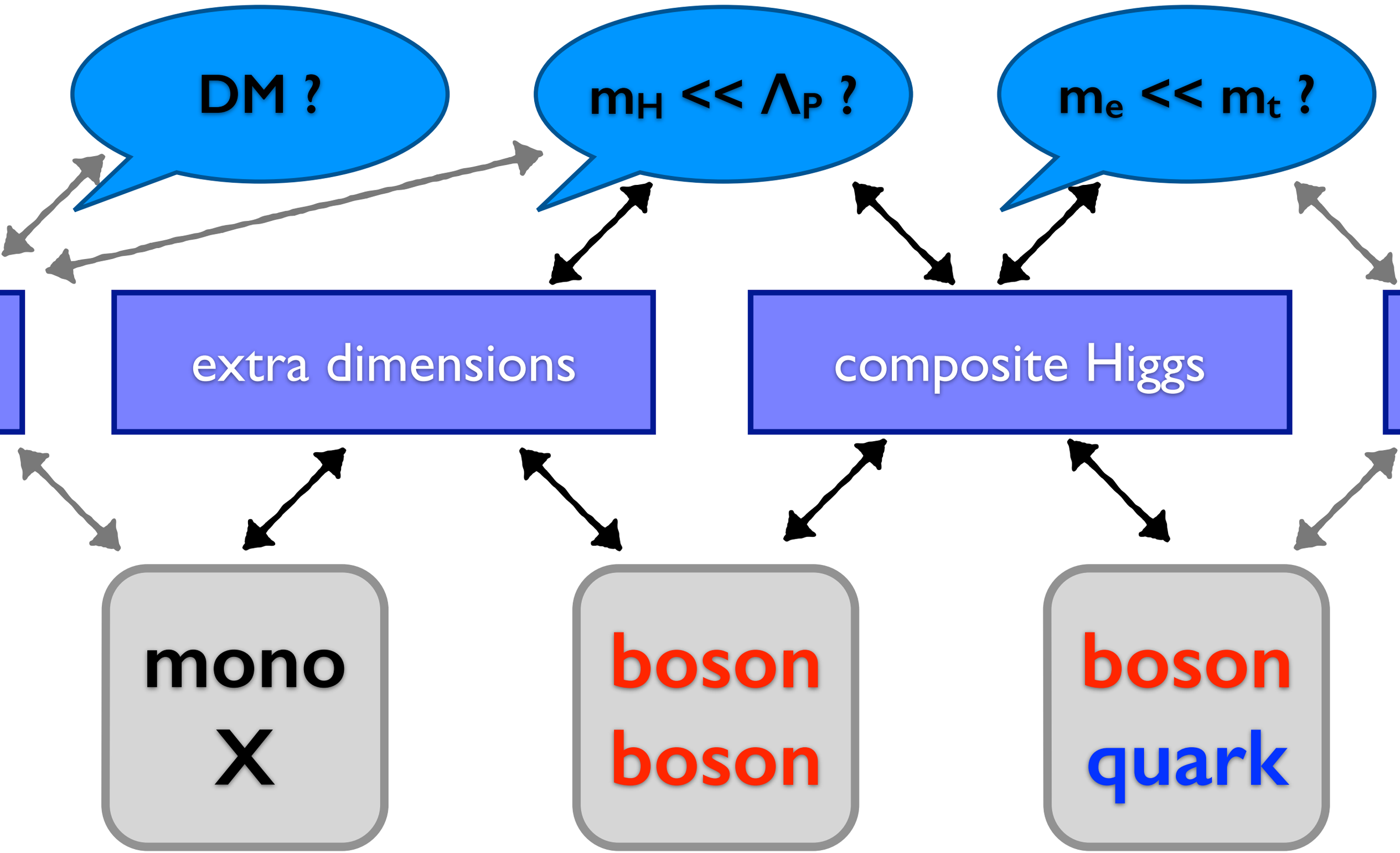
$\alpha=\alpha_W=\alpha_S$?

m_ν ?

3 gen. ?

lepton & quark?

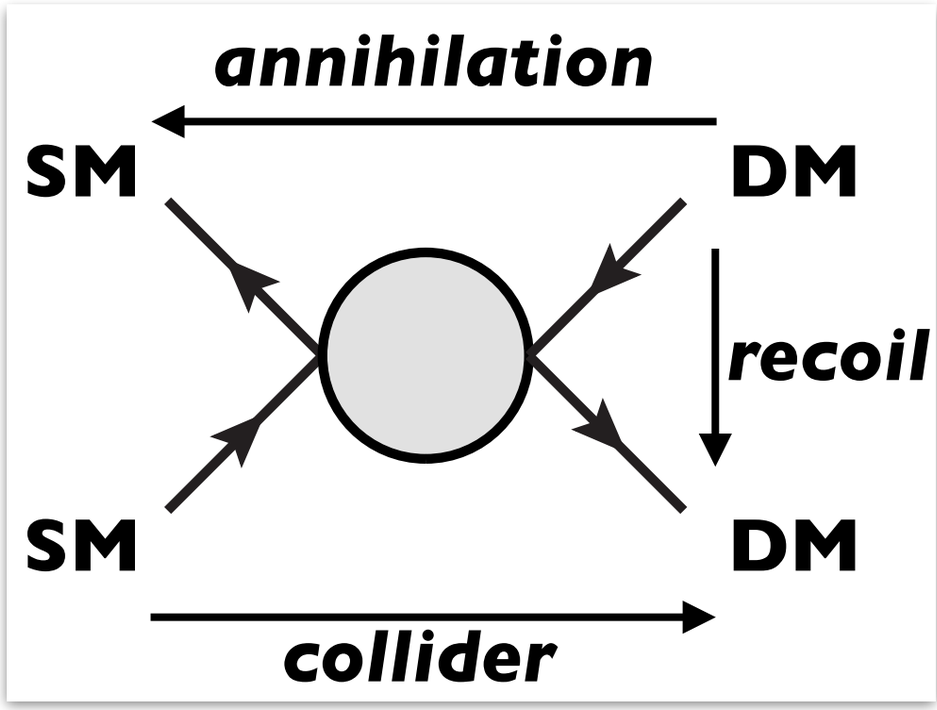
Answers?


DM ?
$m_H << \Lambda_P$?
$m_e << m_t$?
extra dimensions
composite Higgs
mono X
boson boson
boson quark

Searches

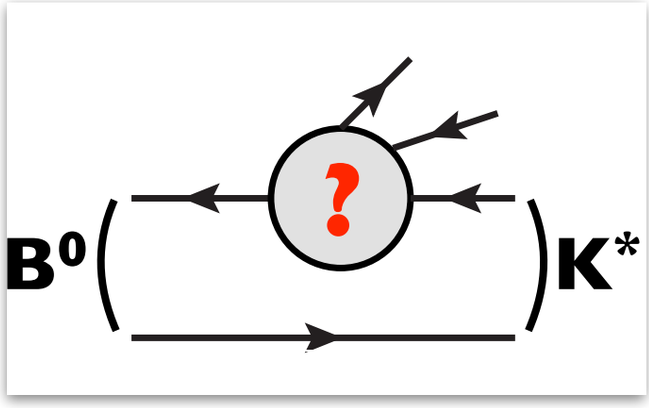
Collider

Non-Collider

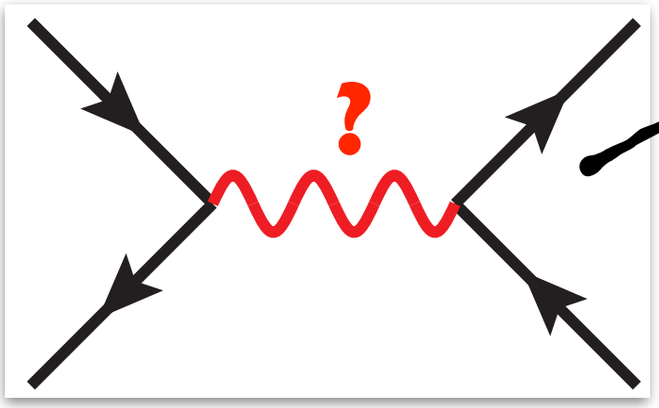


Plenaries 3 & 4 (Tue, Wed)

Indirect



Direct



This summer (≤4 months)

- 20 new results by CMS
- 20 new results by ATLAS

vs.

- 30' time for this talk

Pavel Krokovny (Wednesday)

Tackling New Physics with Distinct Signatures

long-lived

boson
boson

boson
quark

leptons

quark
quark

mono
X

Tackling New Physics with Distinct Signatures

→ *Daniel Teyssier right after this talk!*

long-lived

boson
boson

boson
quark

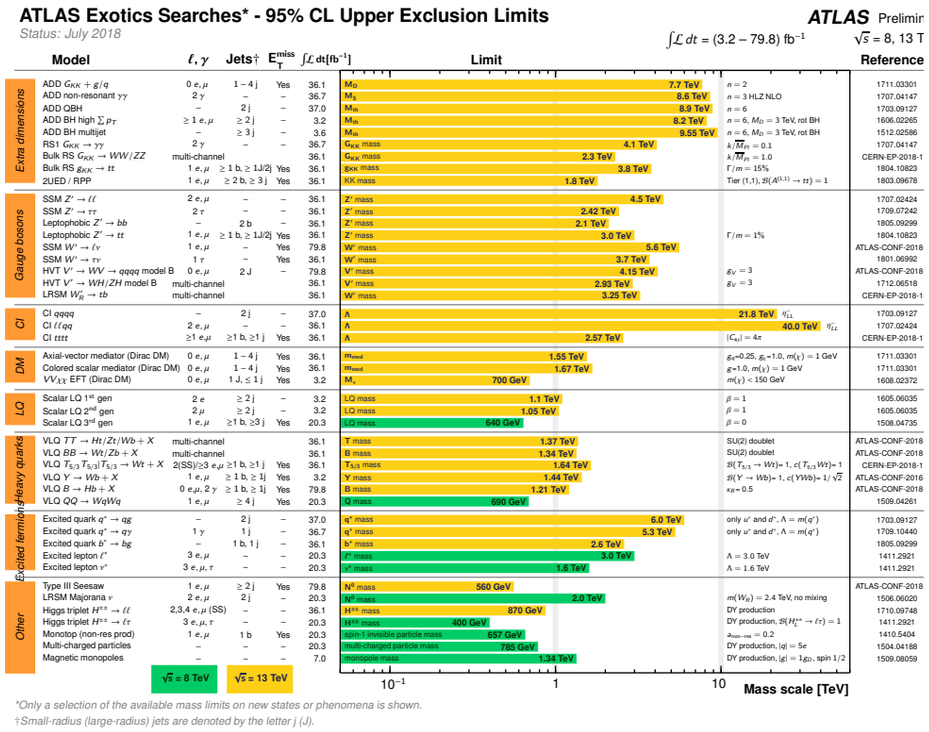
leptons

quark
quark

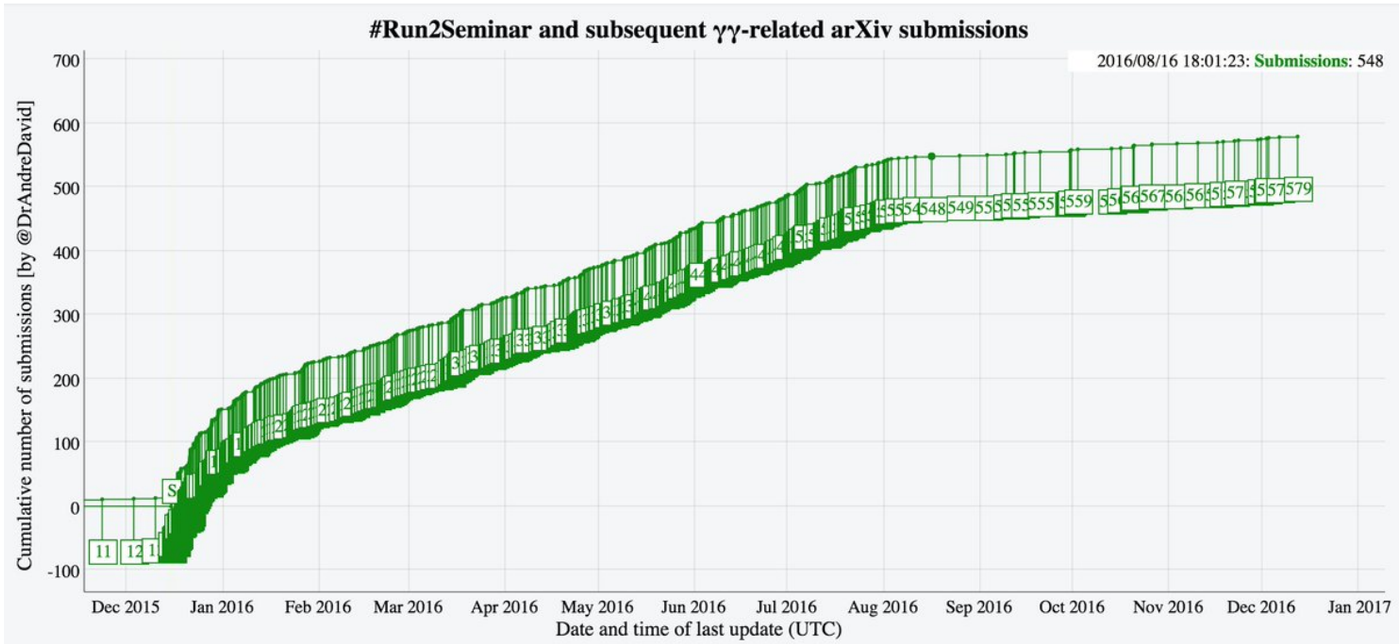
mono
X

Spoiler Alert!

No significant deviations from the SM observed so far.



One single discovery may turn particle physics upside down.



twitter.com/DrAndreDavid

long-lived

boson
boson

boson
quark

leptons

quark
quark

mono
X

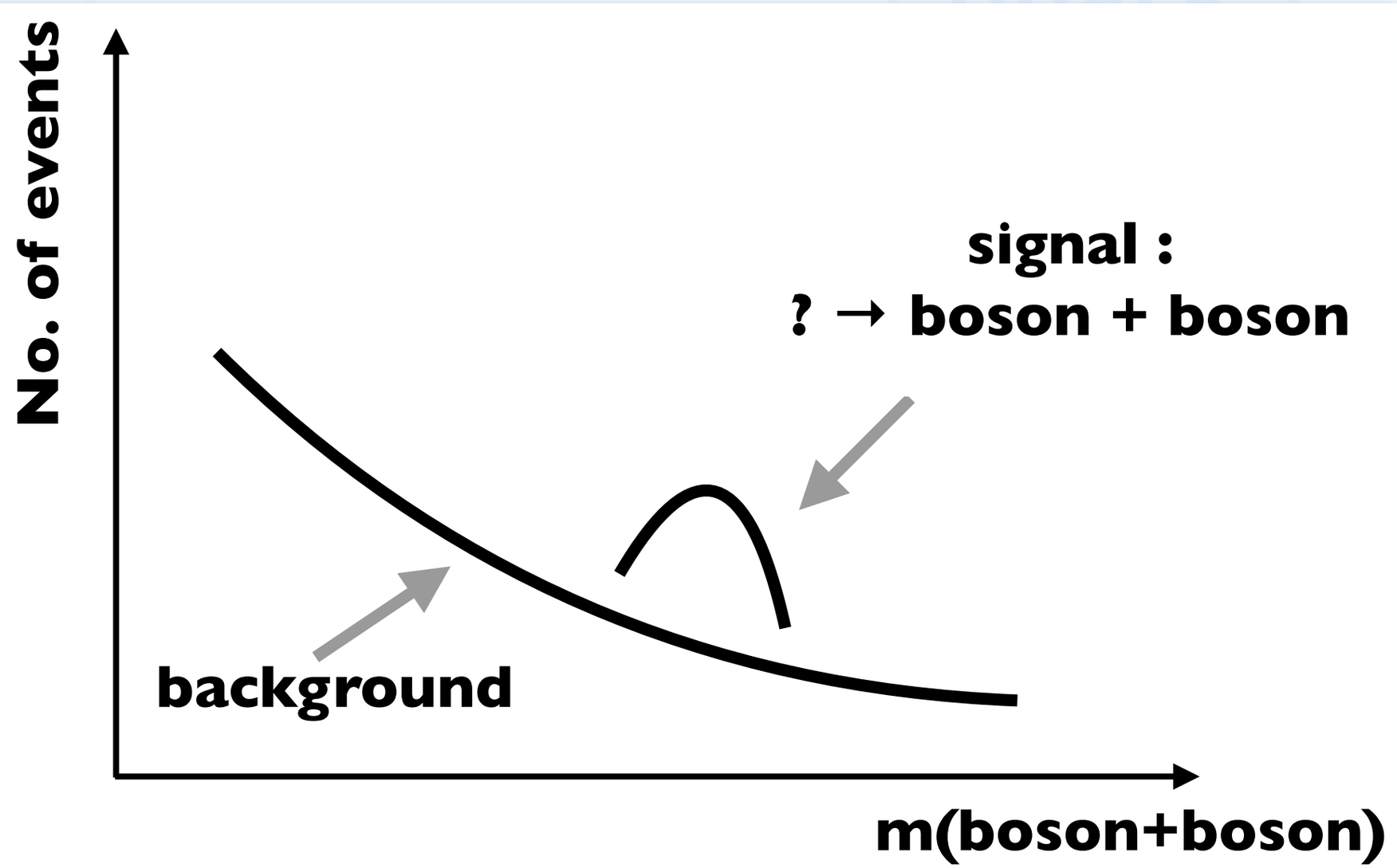
New results

- HH comb.
- HH → 2b2τ
- VV/H comb.
- γ-jets

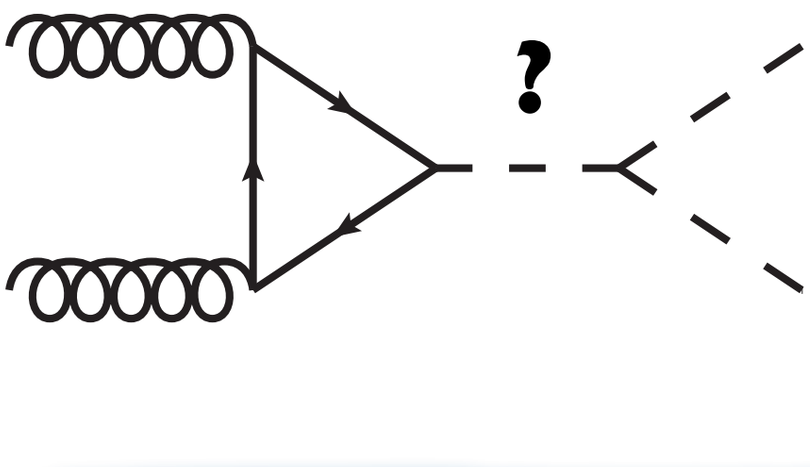
$m_H << \Lambda_P$?

boson

boson



Higgs + Higgs (Combination)

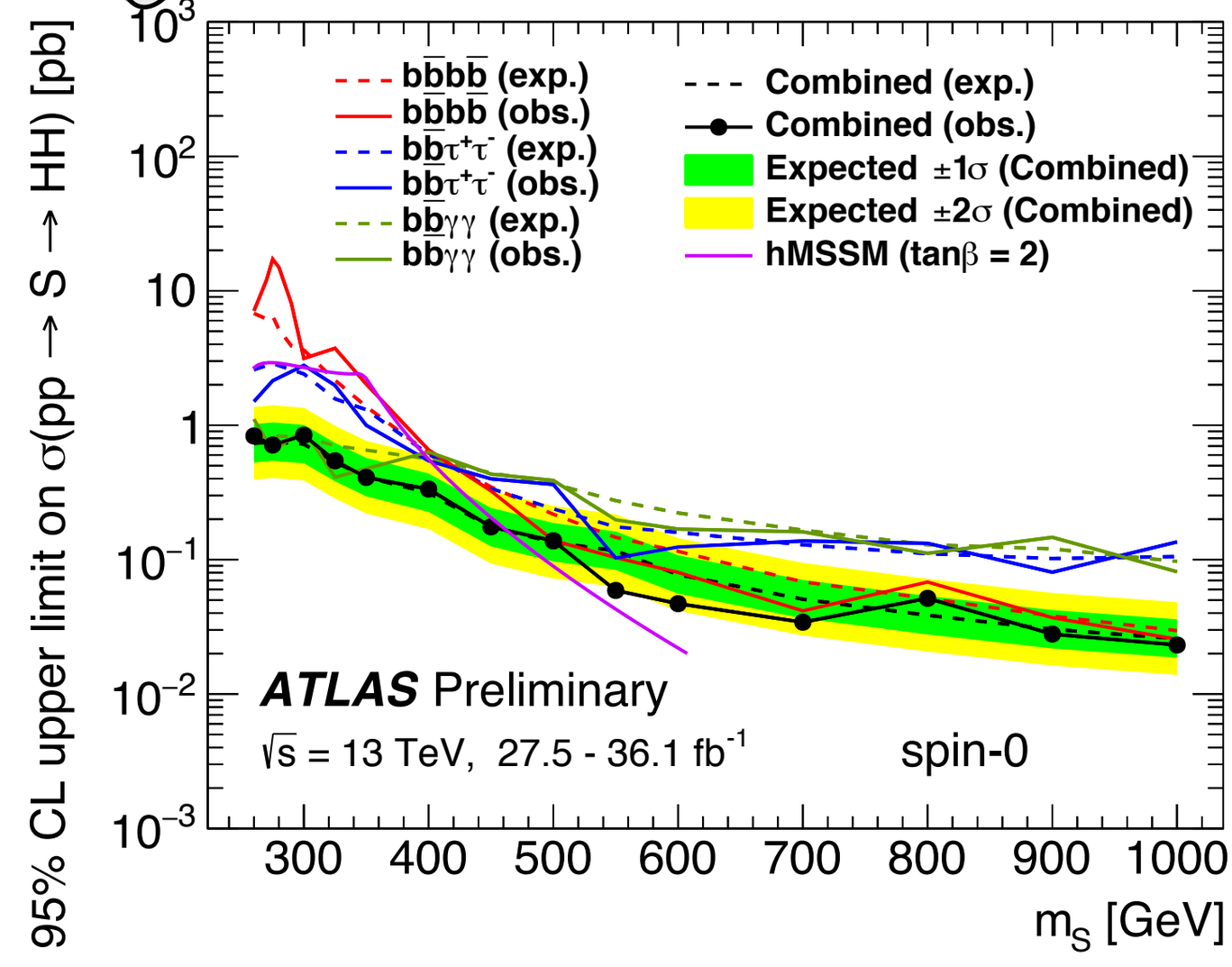


CONF-2018-043

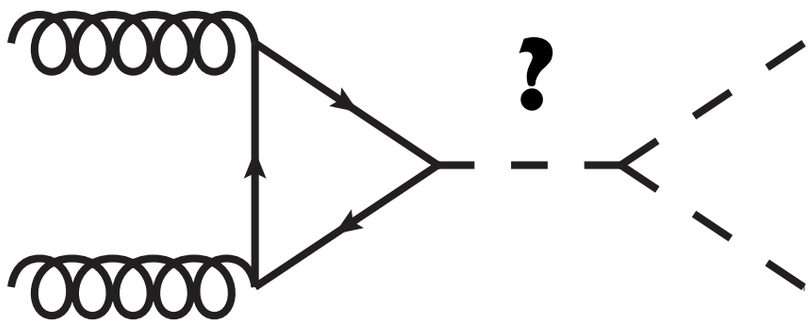
09/18

Three analyses combined

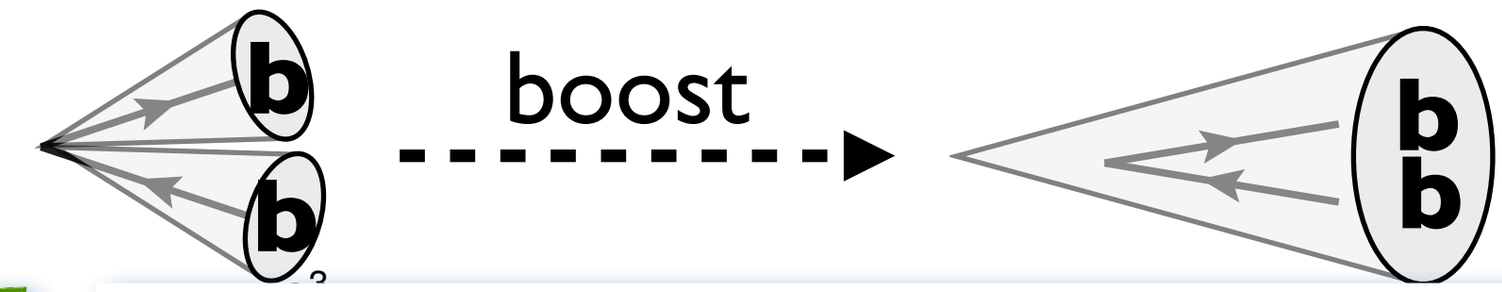
- $b\bar{b}b\bar{b}$
- $b\bar{b}\tau^+\tau^-$
- $b\bar{b}\gamma\gamma$



Higgs + Higgs (Combination)



$H \to b\bar{b}$ or $\tau^+\tau^-$ or $\gamma\gamma$



CONF-2018-043

09/18

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- $b\bar{b}b\bar{b}$
- $b\bar{b}\tau^+\tau^-$
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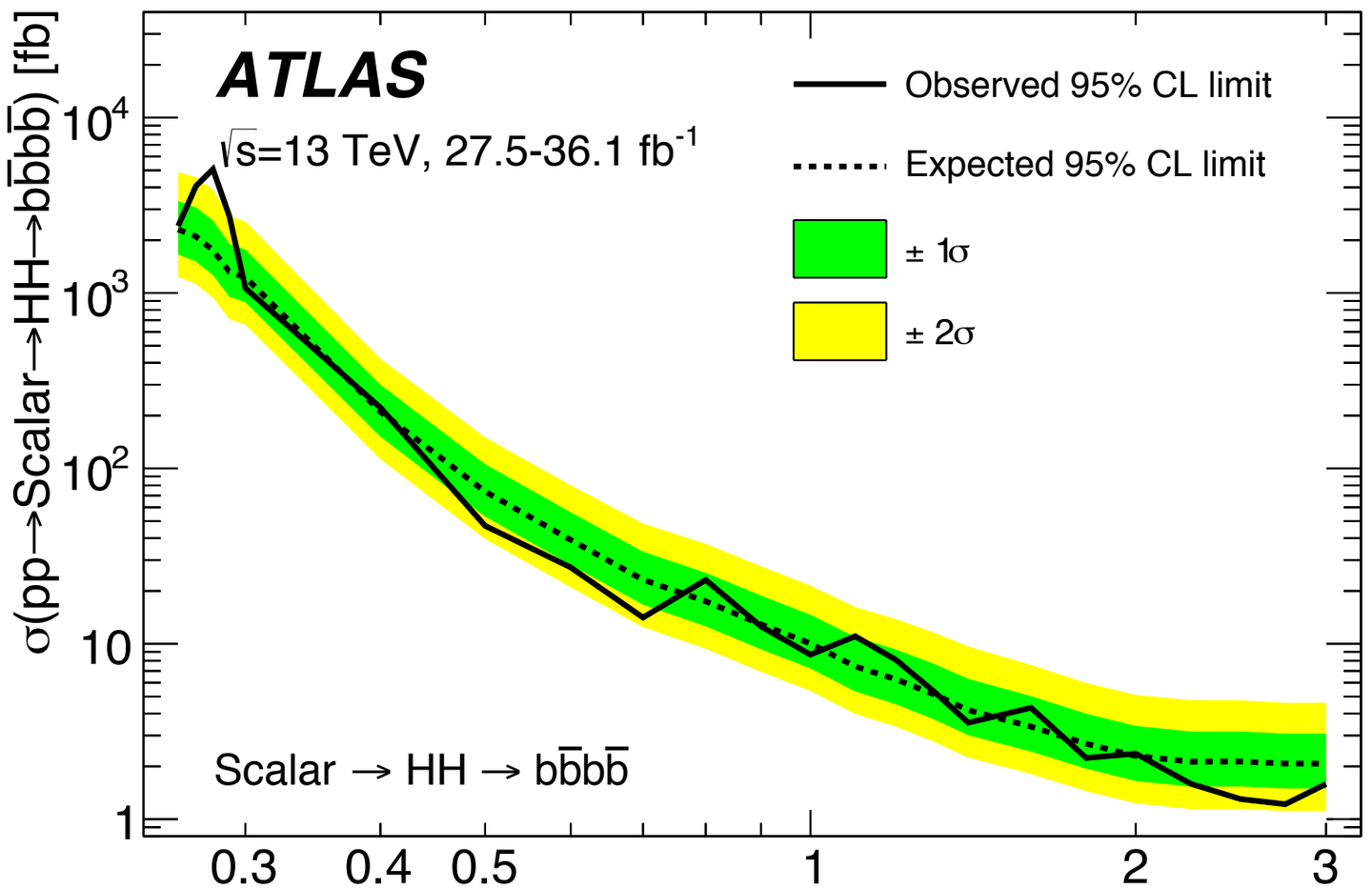


1804.06174

long-lived

boson
boson

boson
quark

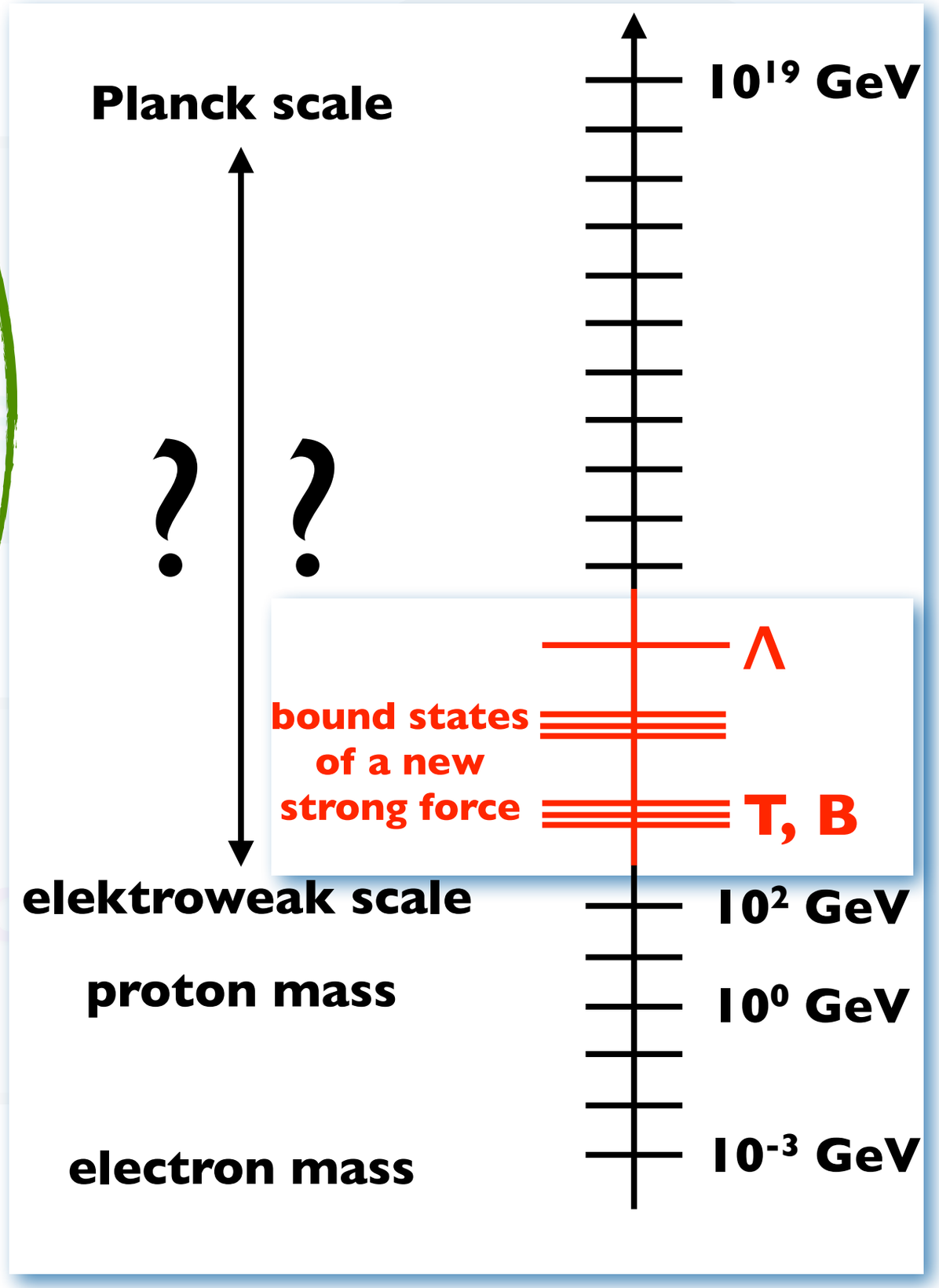
leptons

quark
quark

mono
X

New results

- B → Hb
- X → Wt
- Q → Zq
- All-had.
- Same-sign
- VLQ comb.
- XX



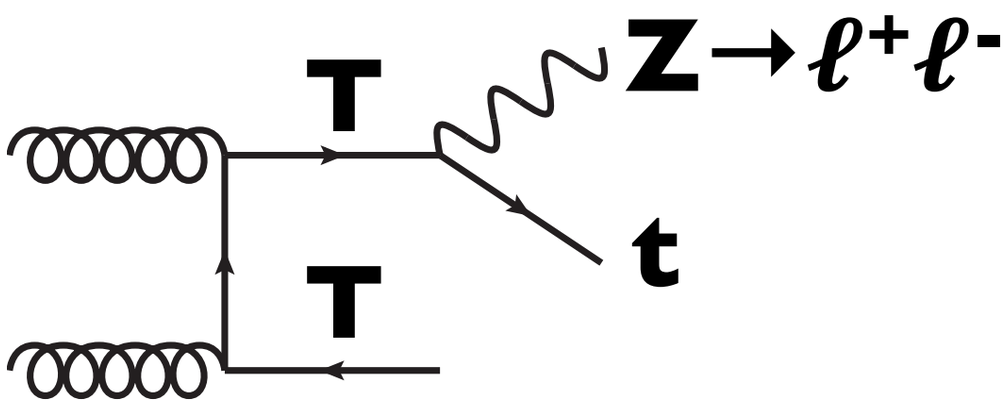
boson

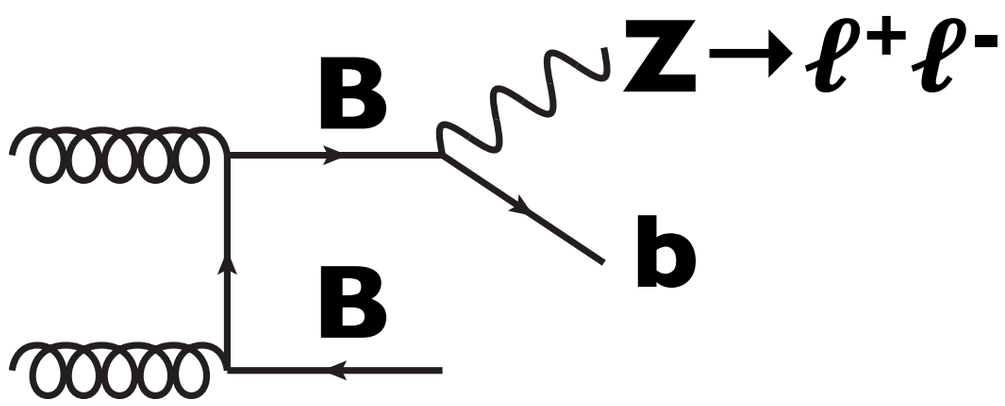
quark

$m_H << \Lambda_P$?

$m_e << m_t$?

≥2ℓ (opposite electric charge)



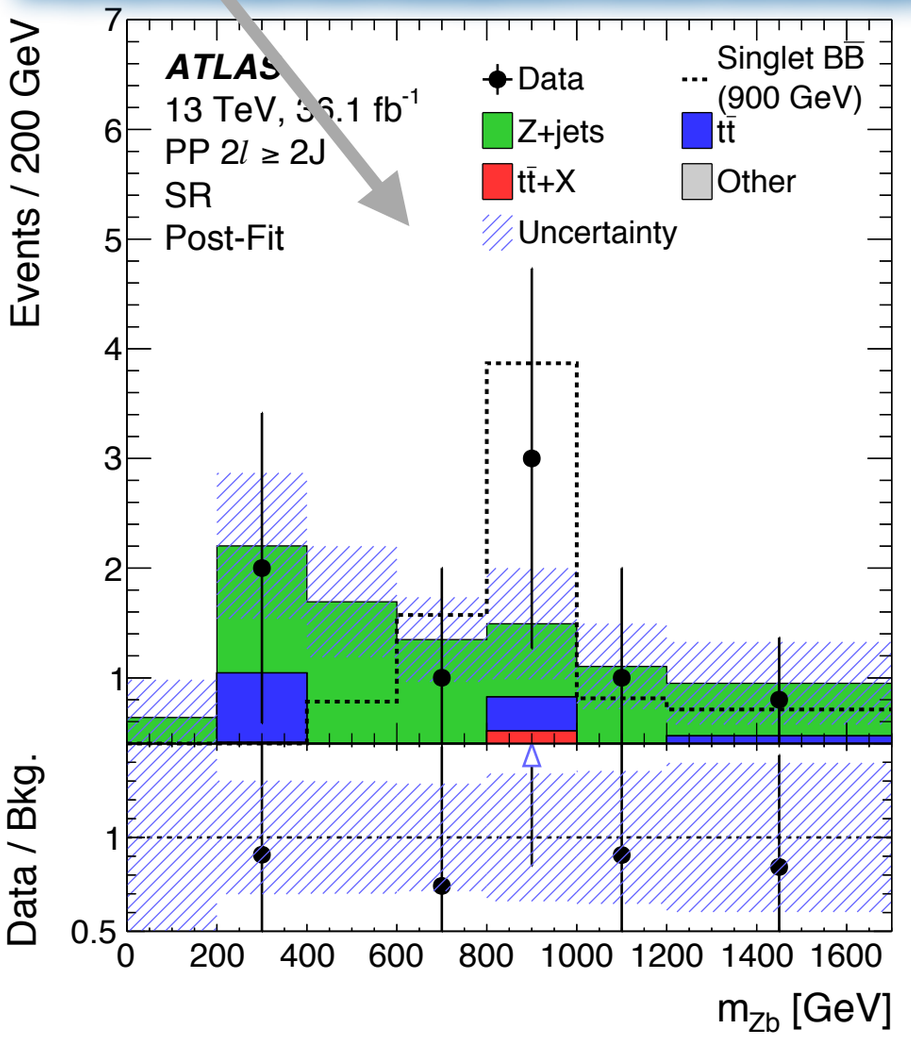


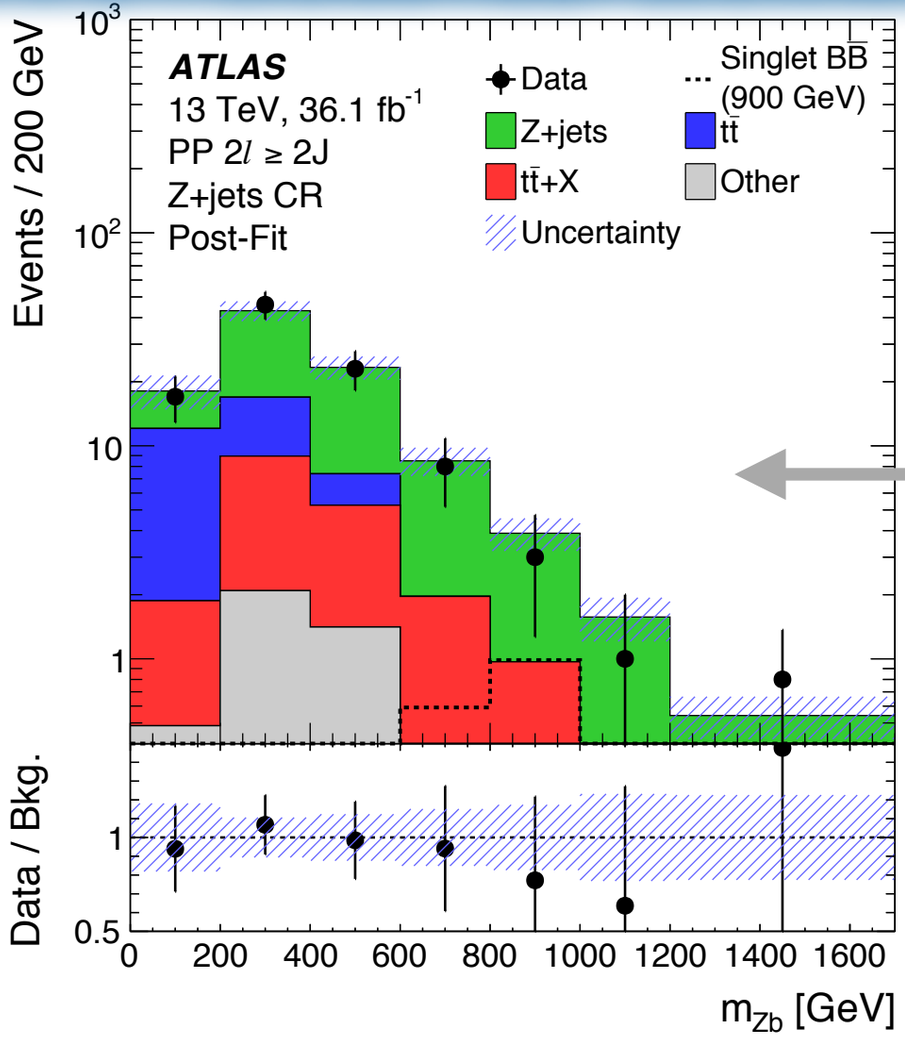
ATLAS EXPERIMENT

1806.10555

06/18

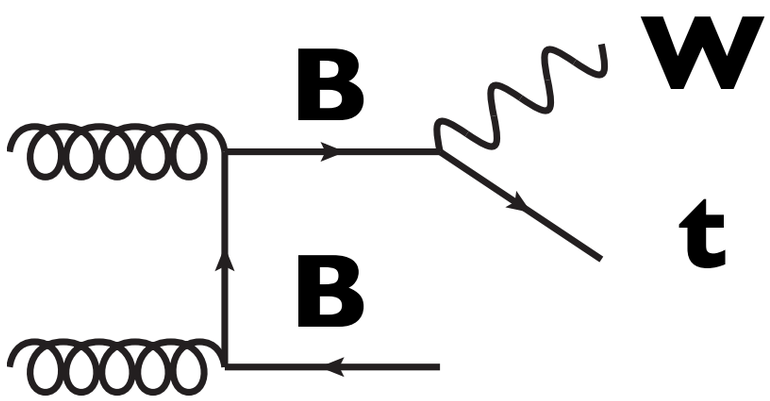
- 2ℓ and ≥3ℓ signal regions; 2ℓ (≥3ℓ) more sensitive to B→Zb (T→Zt)

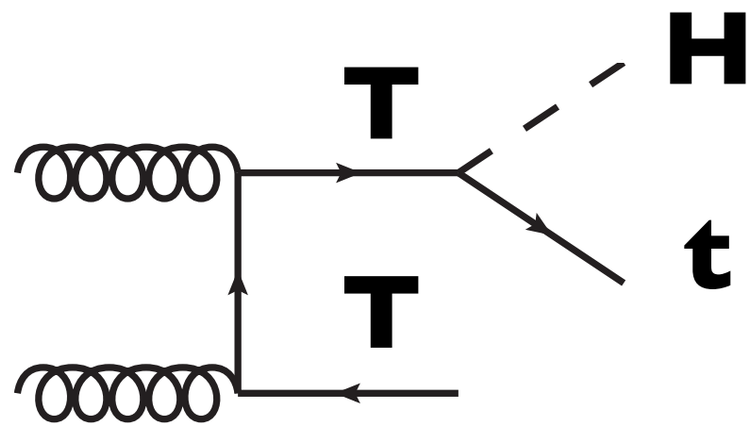




- Modelling of main bkgs. controlled in bkg.-enriched regions

≥2ℓ (same electric charge)



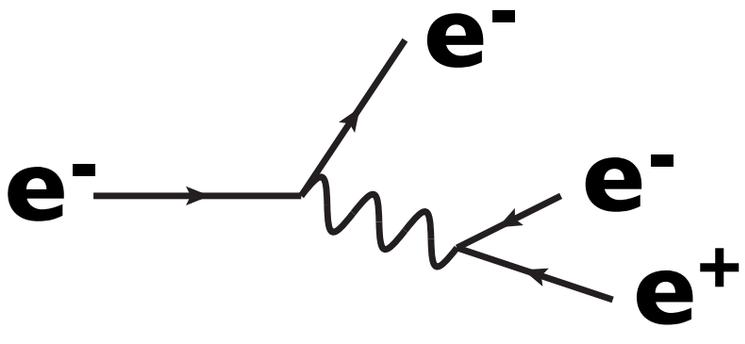


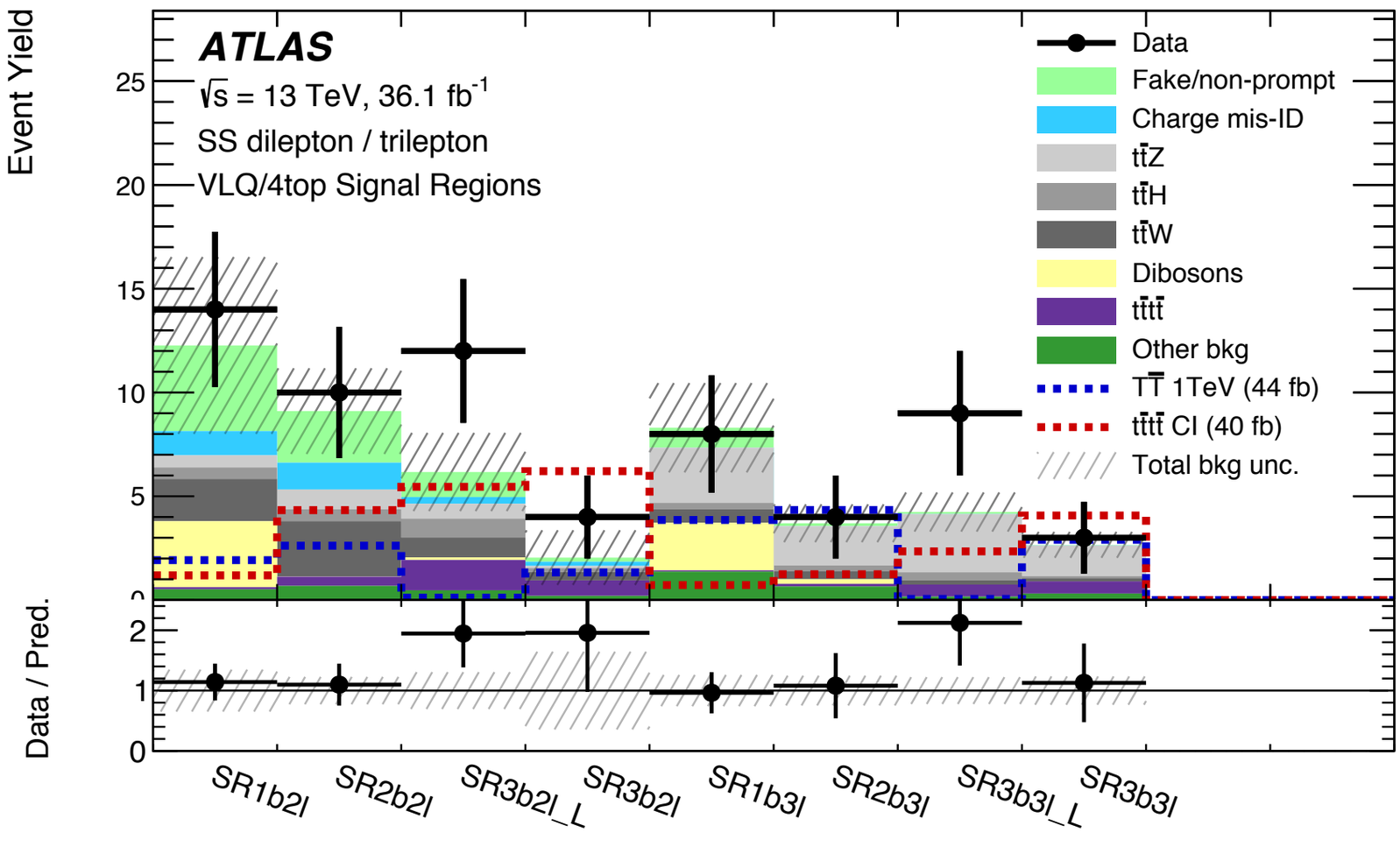
ATLAS EXPERIMENT

1807.11883

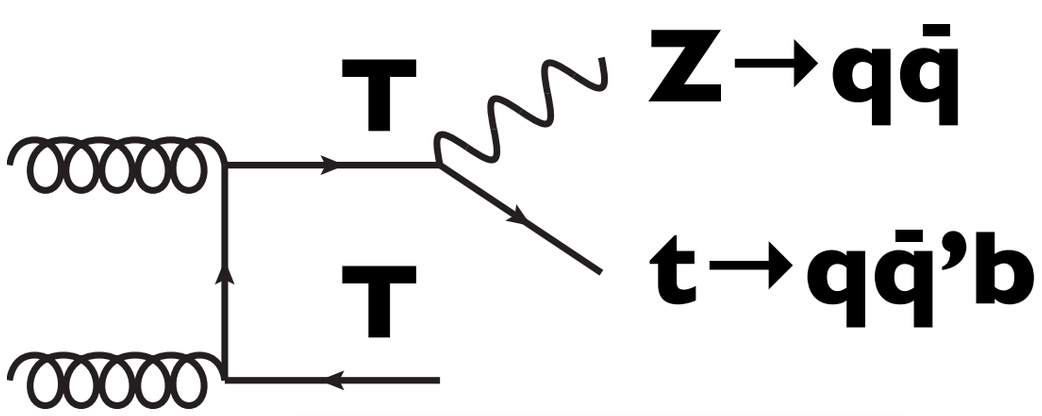
07/18

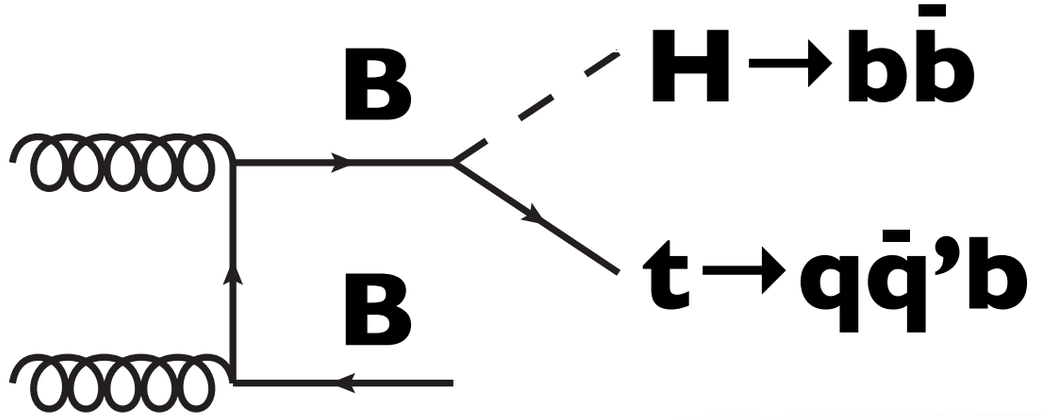
- Counting experiment in 8 regions
- Instrumental bkg. (fake leptons & mis-ID electron charge) estimated from data





All-hadronic



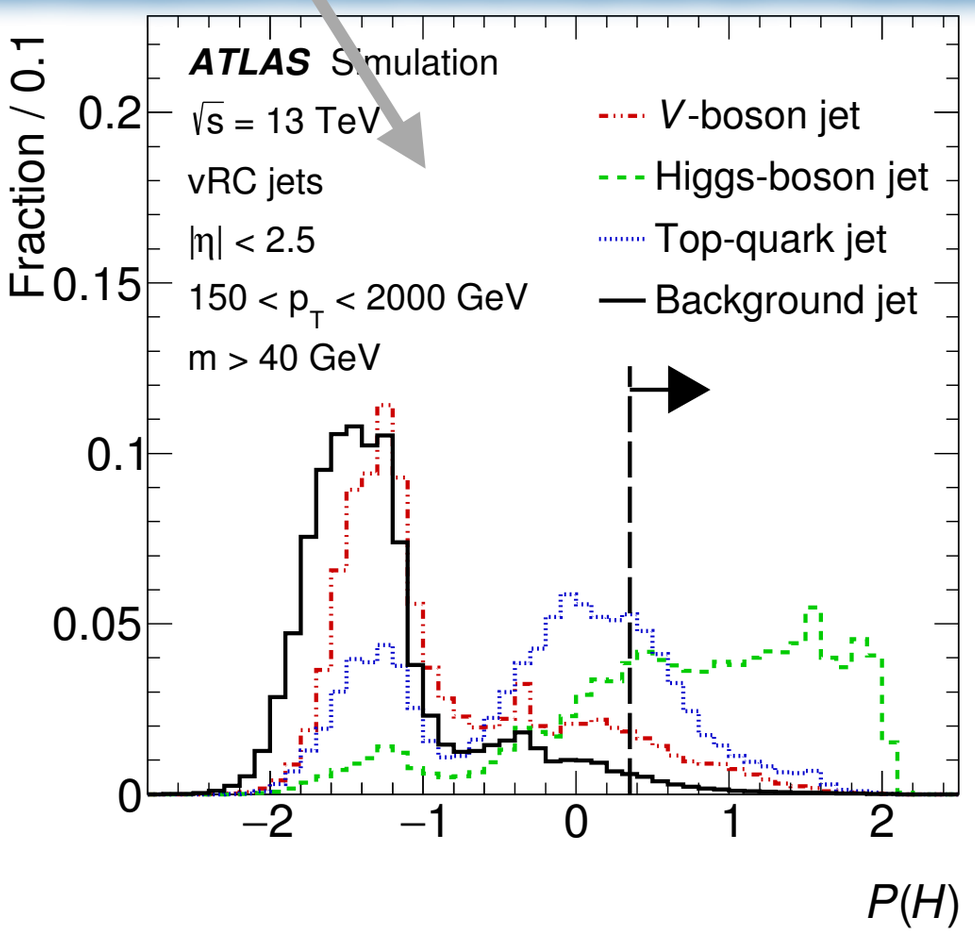


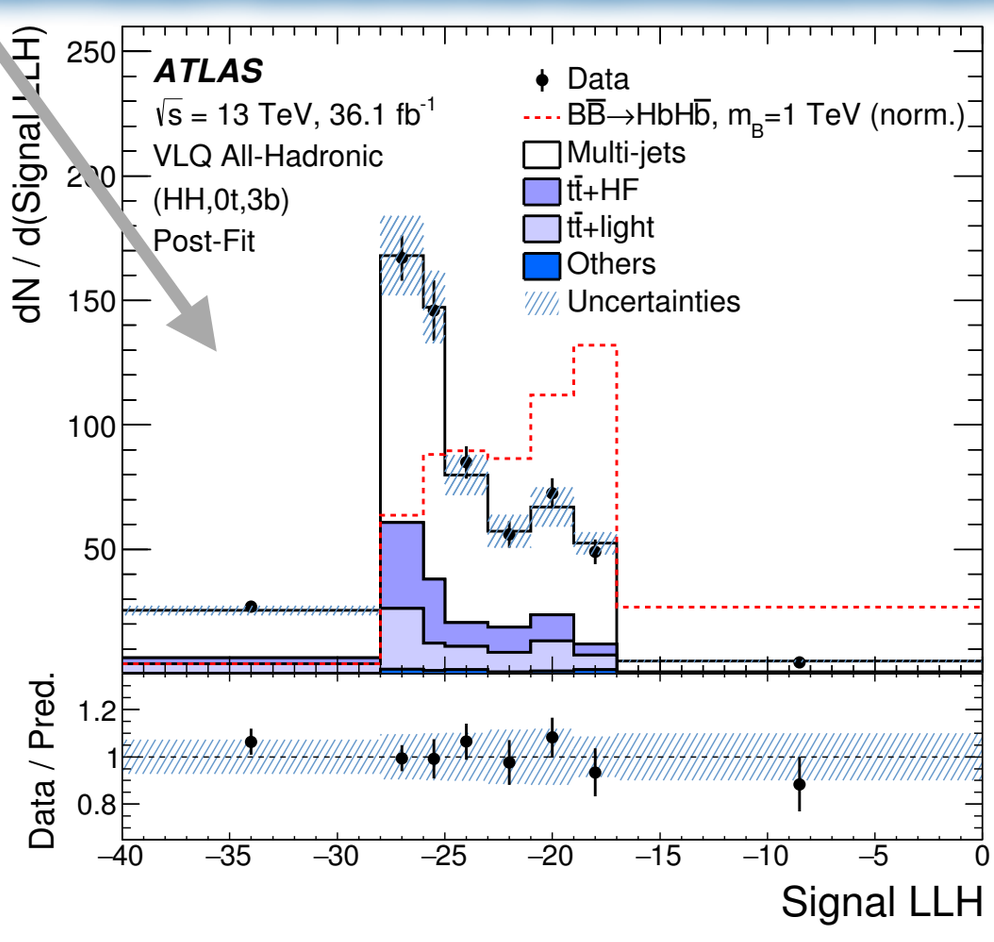
ATLAS EXPERIMENT

1808.01771

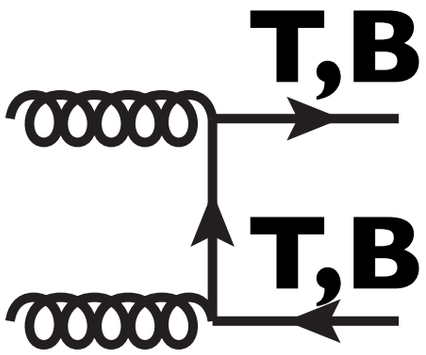
08/18

- Suppression of large multijet background challenging
- Multi-class DNN tagger for hadronic resonances
  - Matrix-element method testing the signal hypothesis



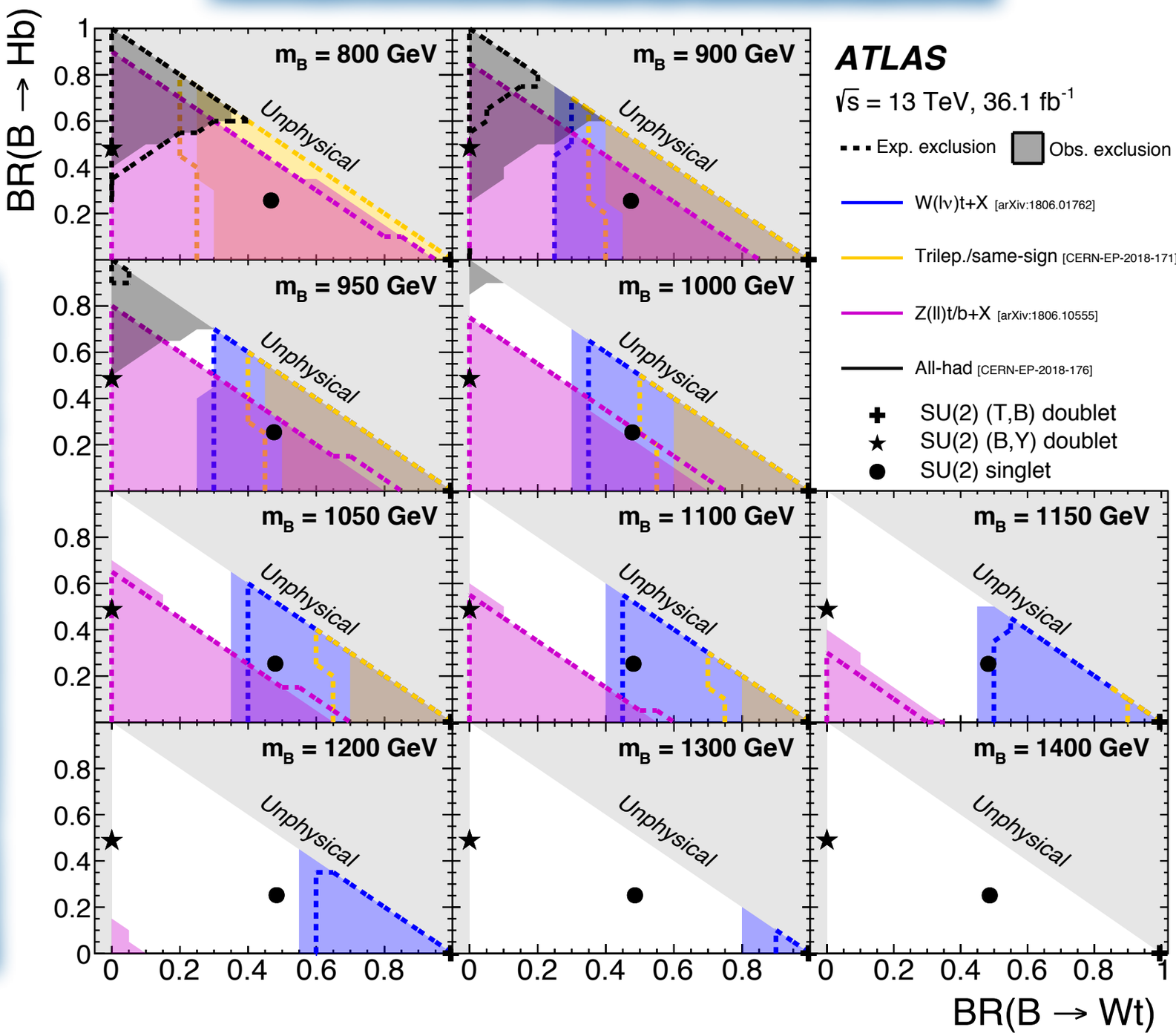


VLQ Combination



BR(Hb) + BR(Wt) + BR(Zb) = 1

- Combination of
  - 6 searches for T
  - 4 searches for B
- Assuming only decays to SM particles: exclude
  - m_T < 1.31 TeV
  - m_B < 1.03 TeV

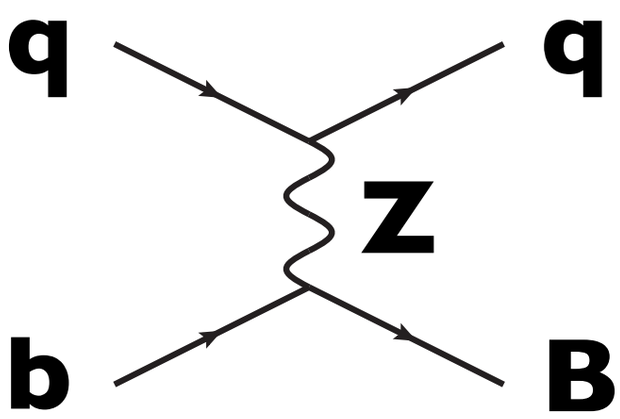


ATLAS EXPERIMENT

1808.02343

08/18

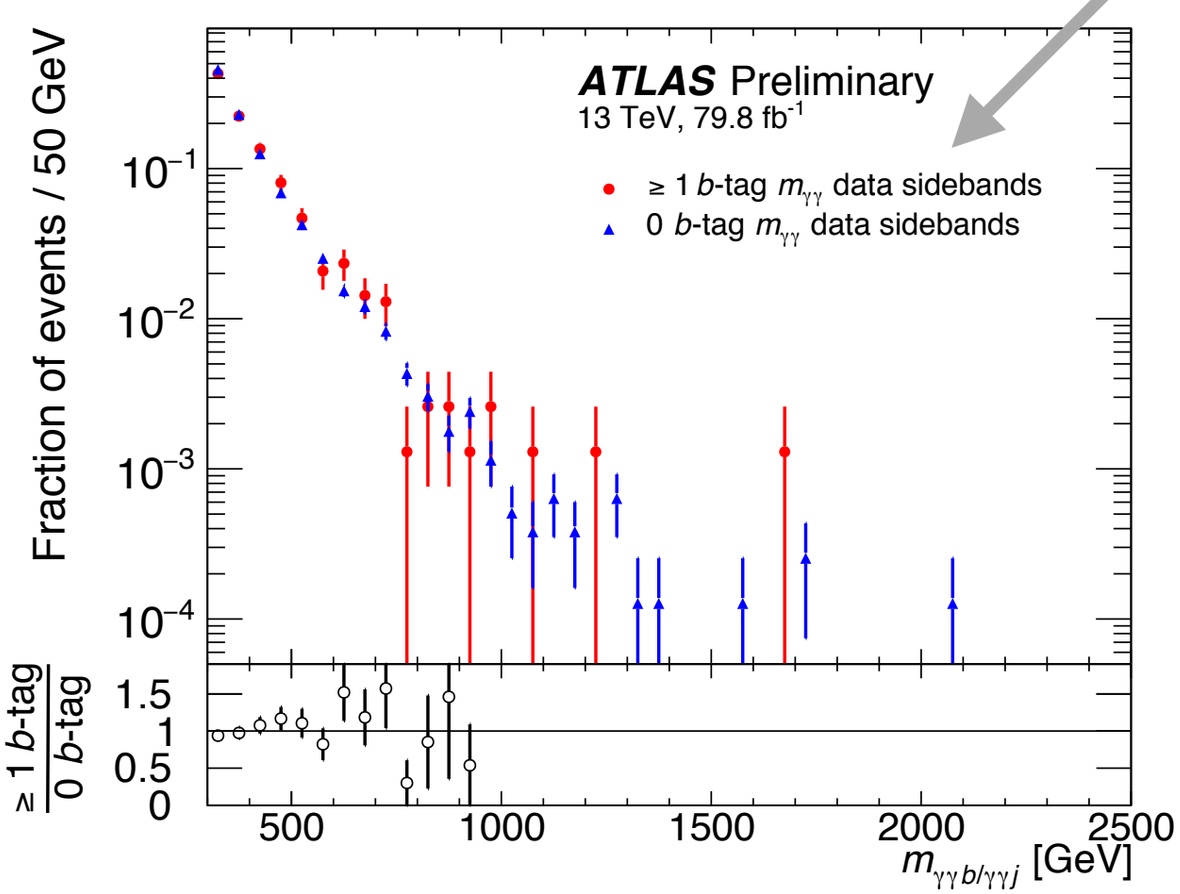
Single Production: B → Hb

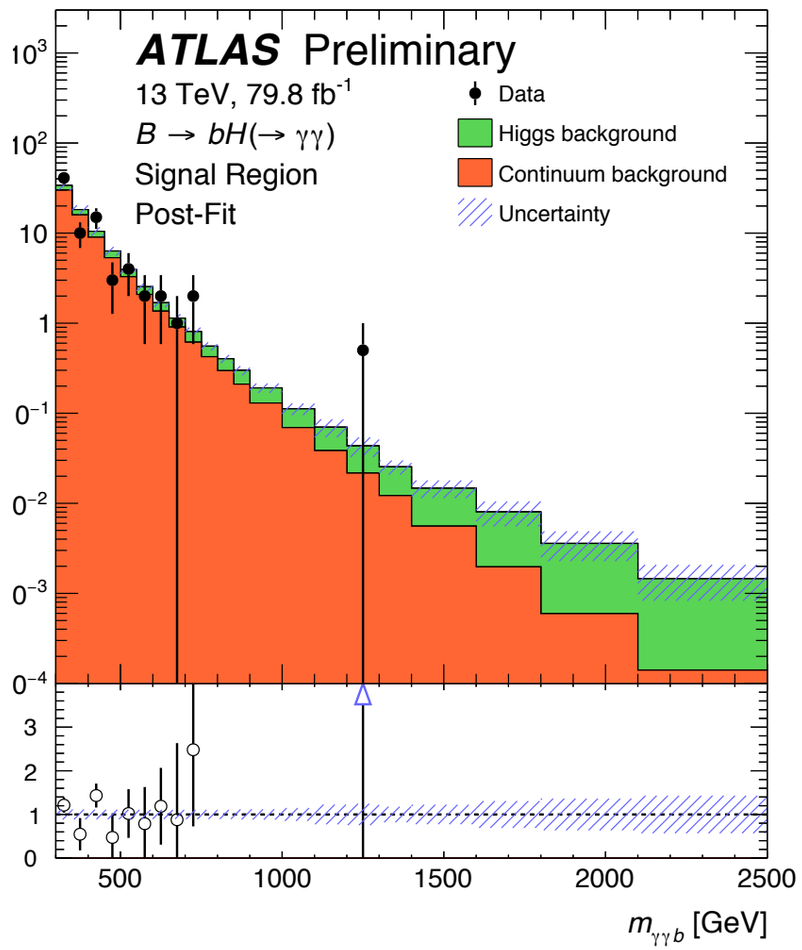


- H → γγ decay
- Loose b-tagging at high p_T
- Continuum γγ bkg. estimated from data in events with $m_{\gamma\gamma}$ in 105-120/130-160 GeV

CONF-2018-024

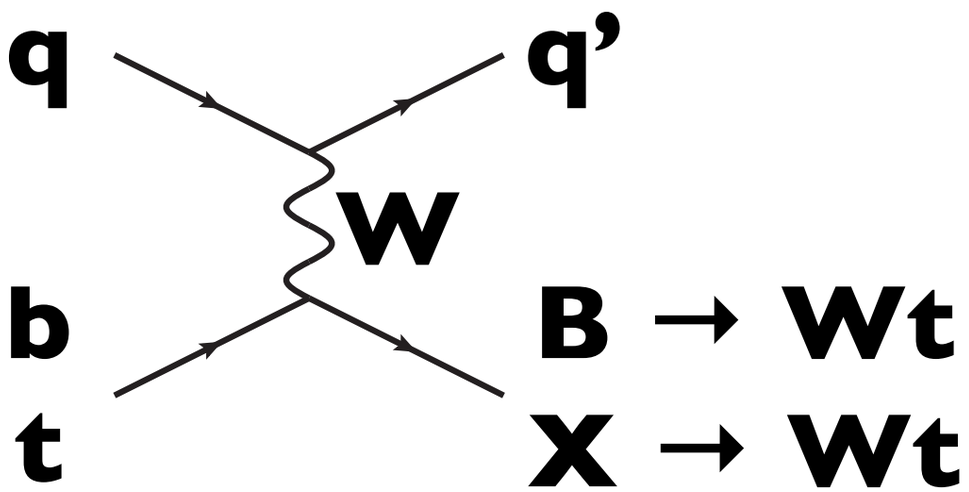
07/18





m_B < 1.21 TeV excluded in doublet model for benchmark coupling value

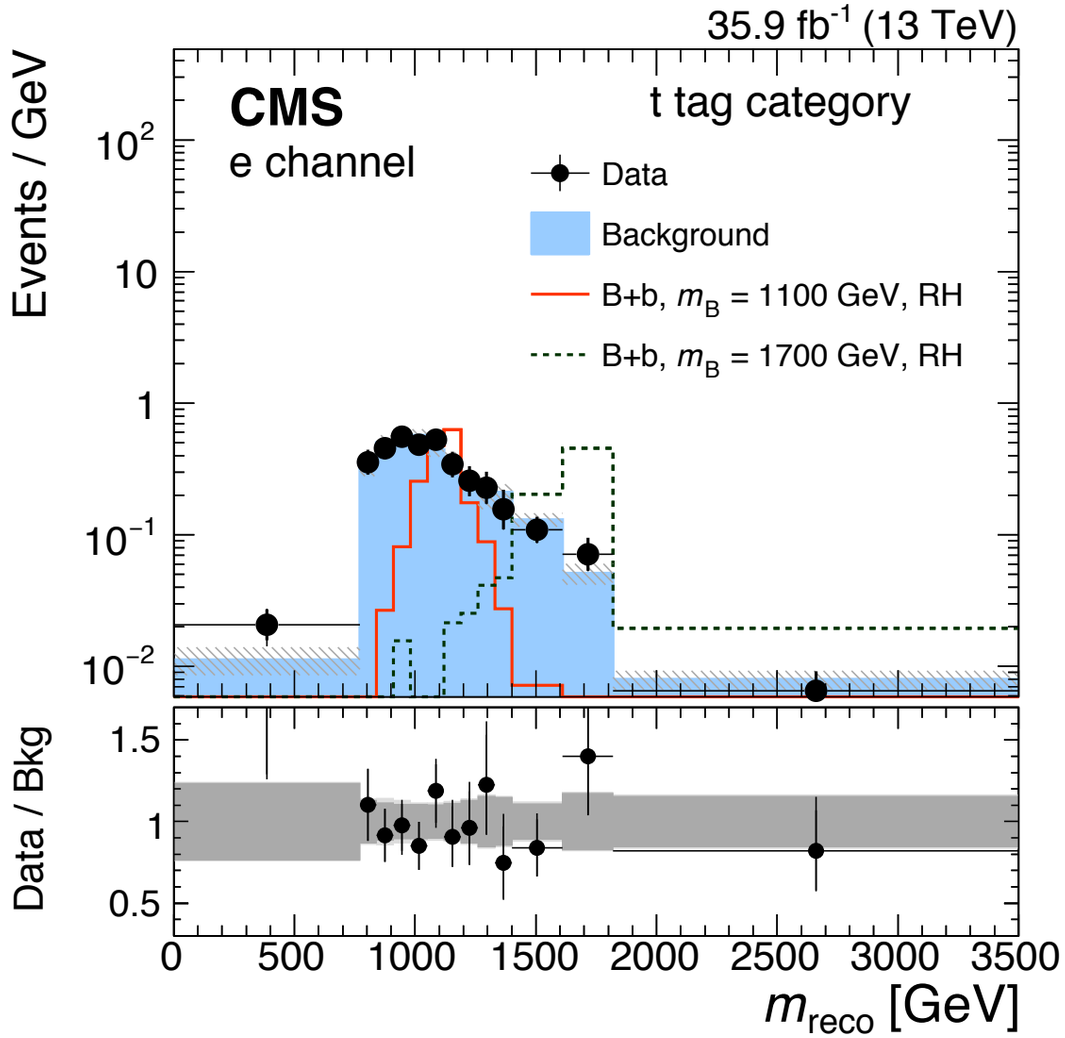
Single Production: B and X → Wt

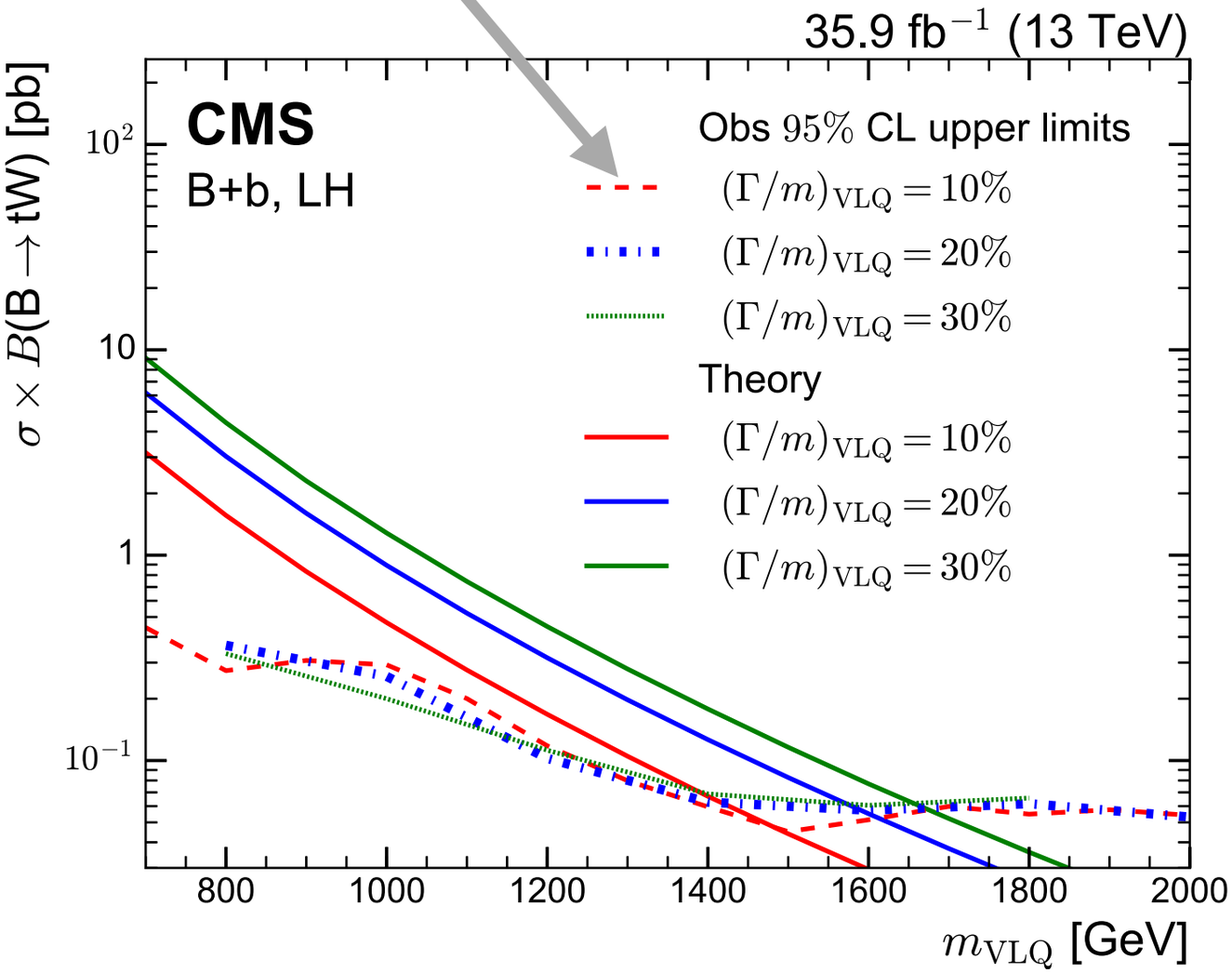


- ℓ+jets channel
- Categories based on top-, W- & b-tags
- Limits depend on width (defined by coupling value)

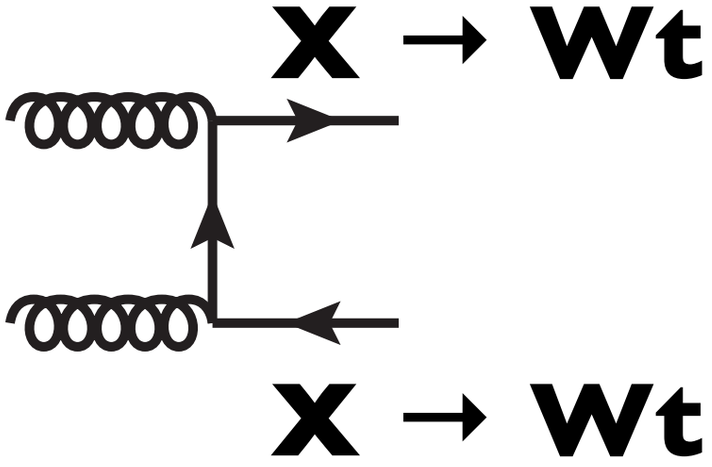
1809.08597

09/18





Pair Production: XX (X → Wt)

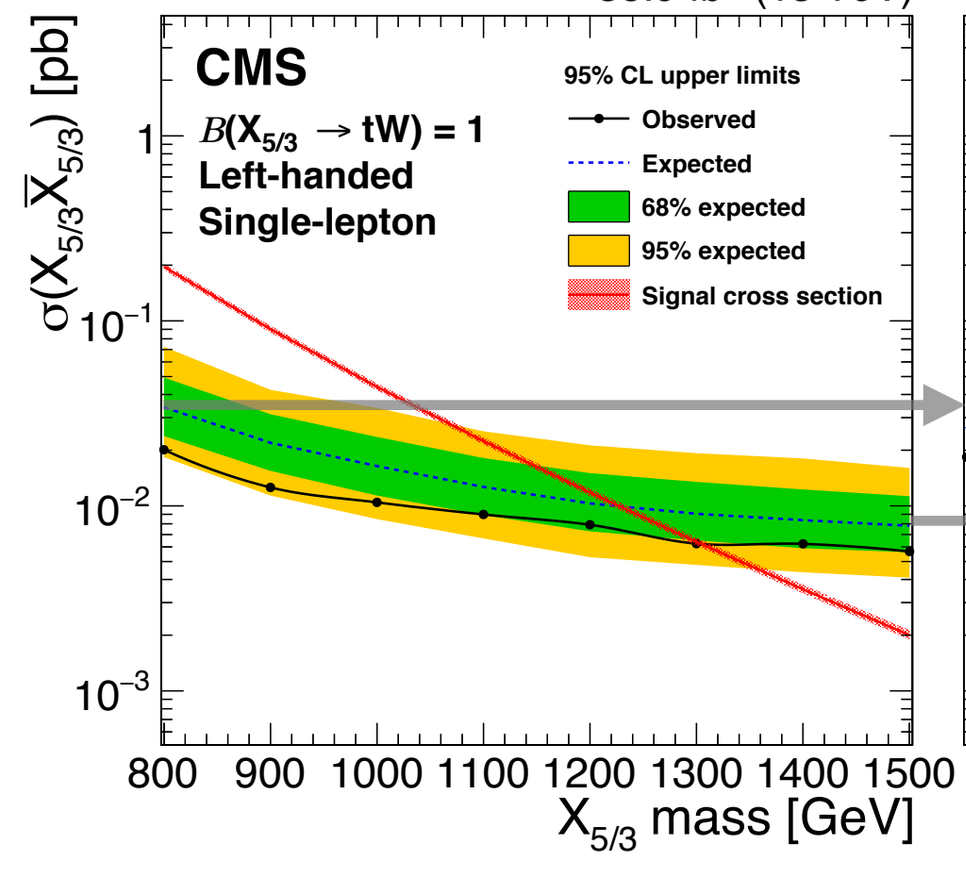


- $\ell^{\pm}\ell^{\pm}$ channel: low background
  - dominates at low m_X
- ℓ+jets channel: high acceptance
  - dominates at high m_X
- Combination improves sensitivity

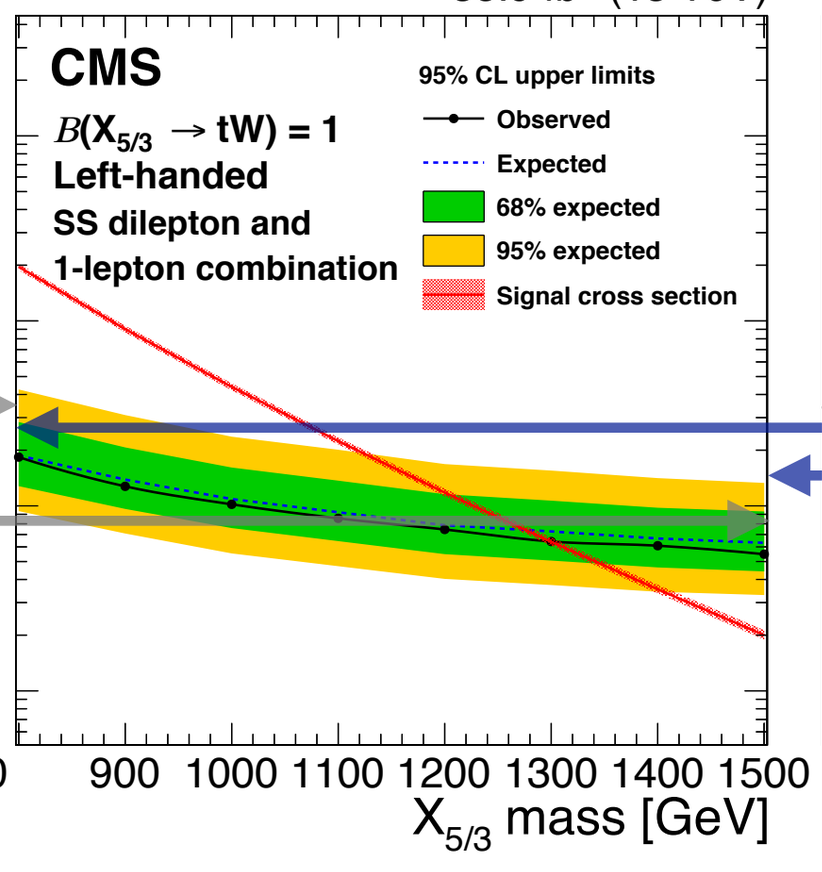
1810.03188

10/18

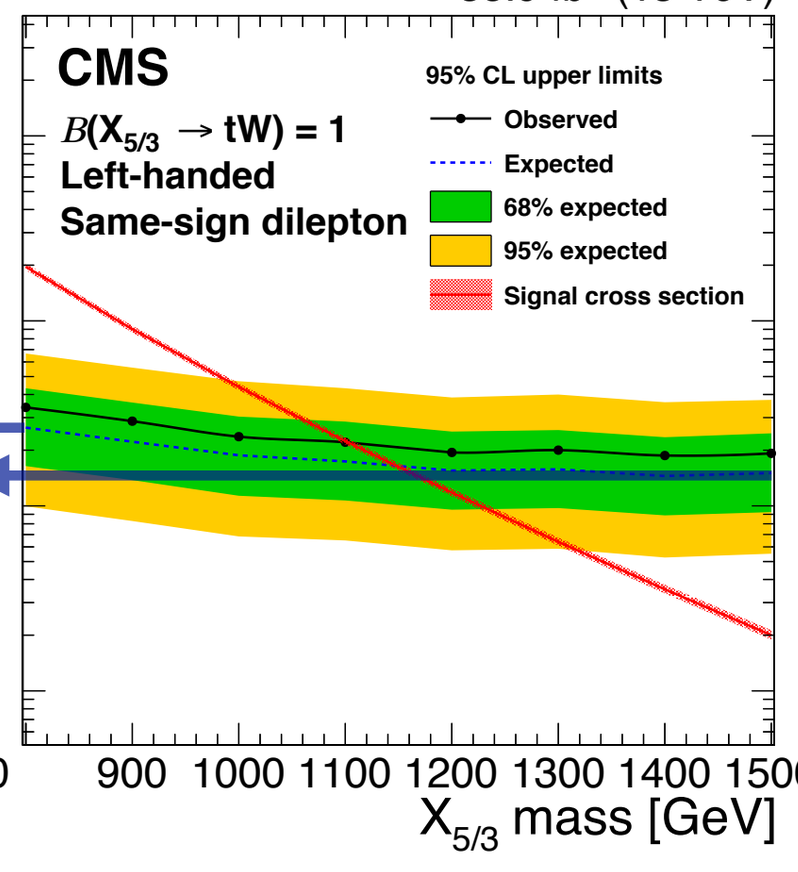
ℓ+jets



combination



$\ell^{\pm}\ell^{\pm}$



long-lived

boson
boson

boson
quark

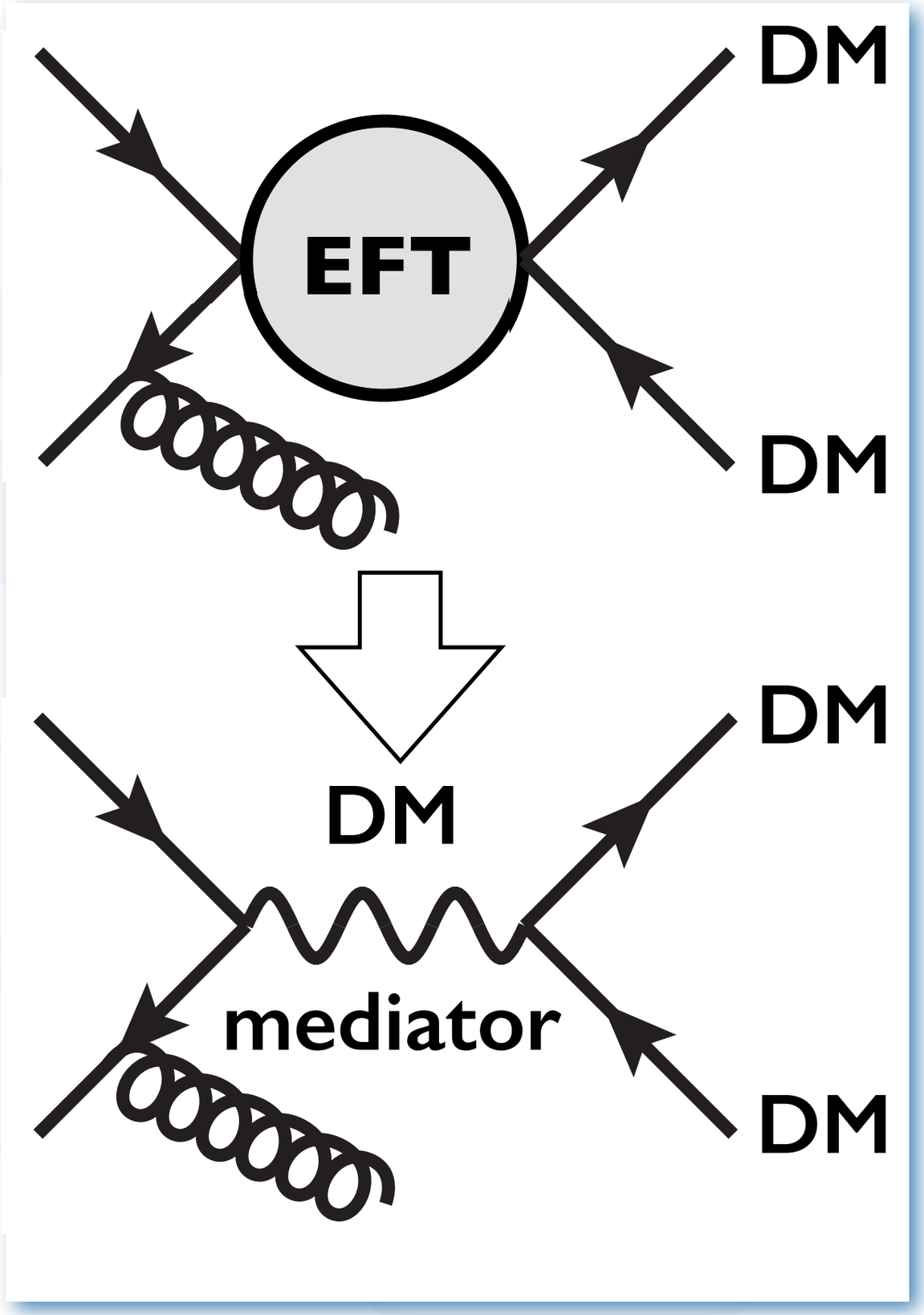
leptons

quark
quark

mono
X

New results

- H + DM
- H + DM
- H → DM
- γ + DM
- t($\bar{t}$) + DM
- Dark E

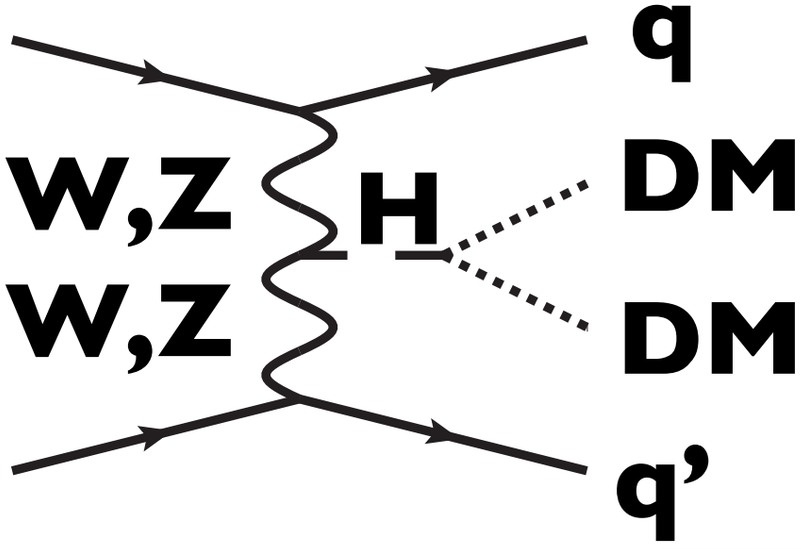


DM ?

$m_H << \Lambda_P$?

mono X

H → DM



- Vector-boson fusion
  → 2 jets with large $\Delta\eta$ & m_{jj}
- large E_T^{miss}

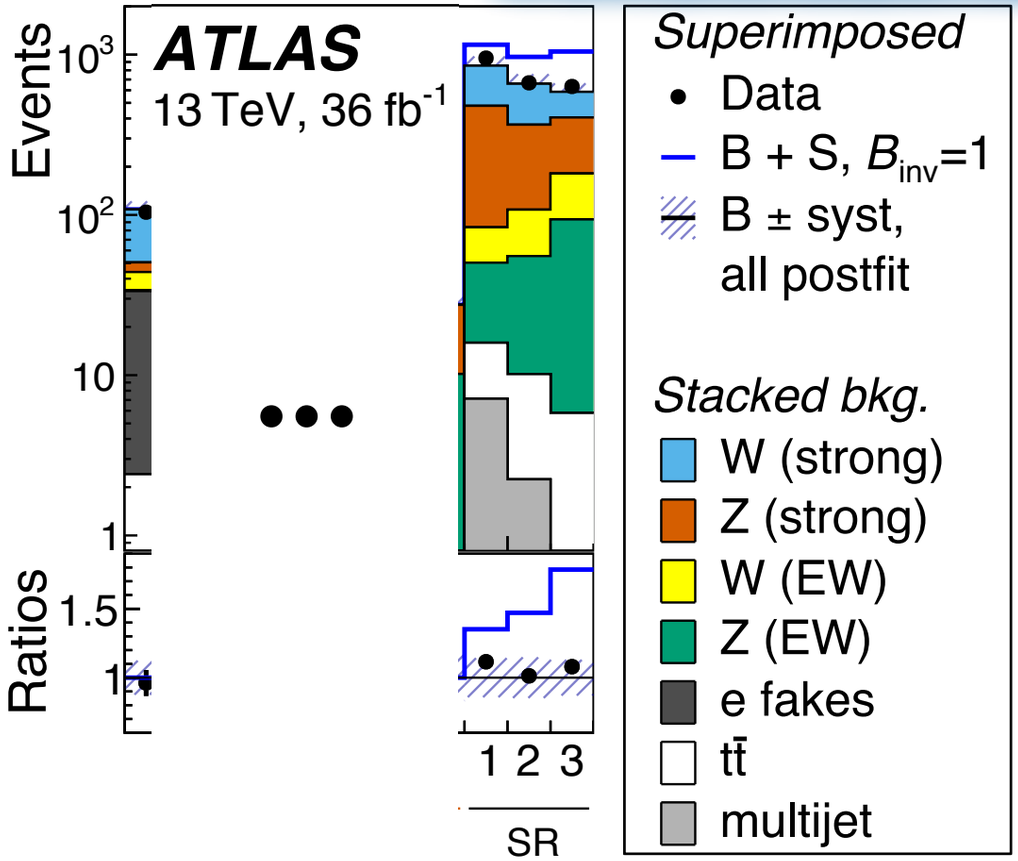
ATLAS EXPERIMENT

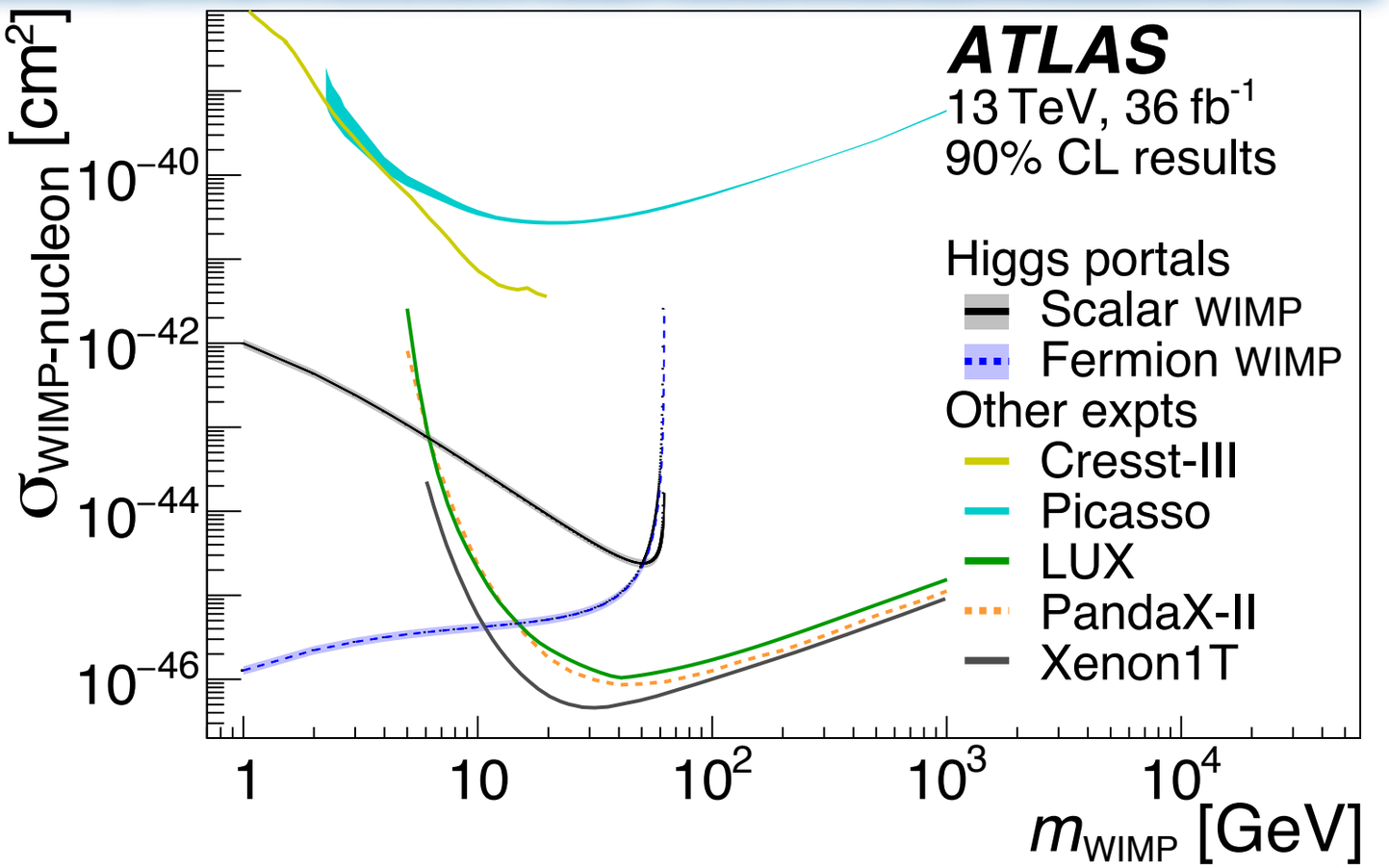
1809.06682

09/18

CMS result:
1809.05937

BR(H→inv.) < 0.32 (90% CL) → limit on $\sigma_{spin\text{-}indep.}$ (Fox et al. 2012)





long-lived

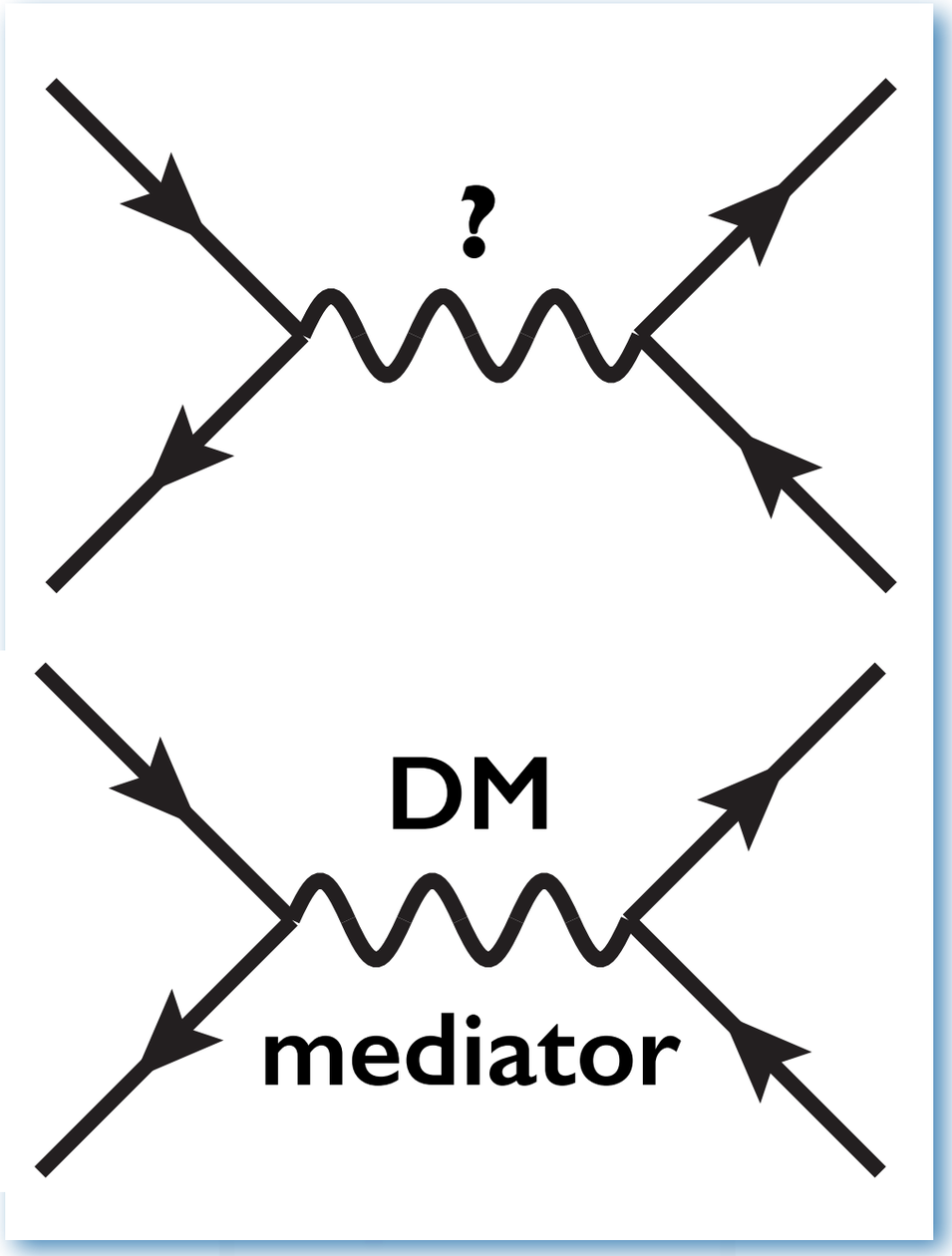
boson
boson

boson
quark

leptons

quark
quark

mono
X



$m_H << \Lambda_P$?

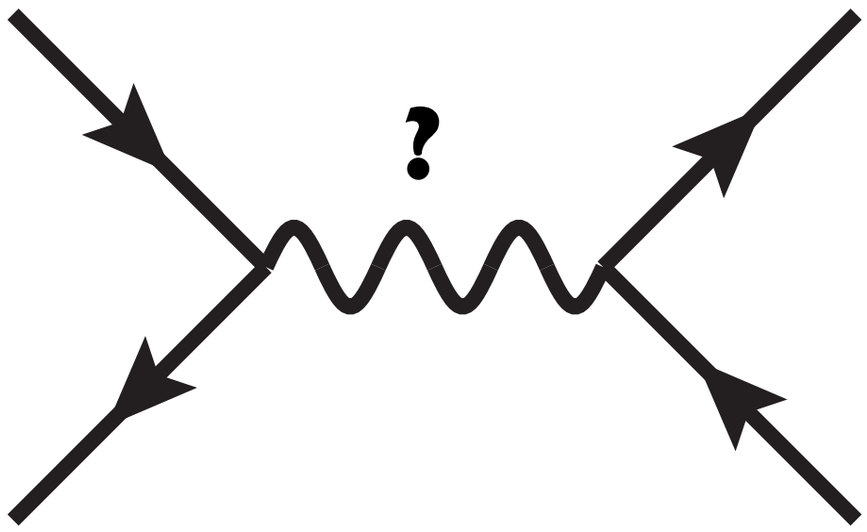
DM ?

quark
quark

New results

- Dijet
- Dijet+ISR
- Trijet
- W' → tb
- Z' → Tt
- W' → Tb

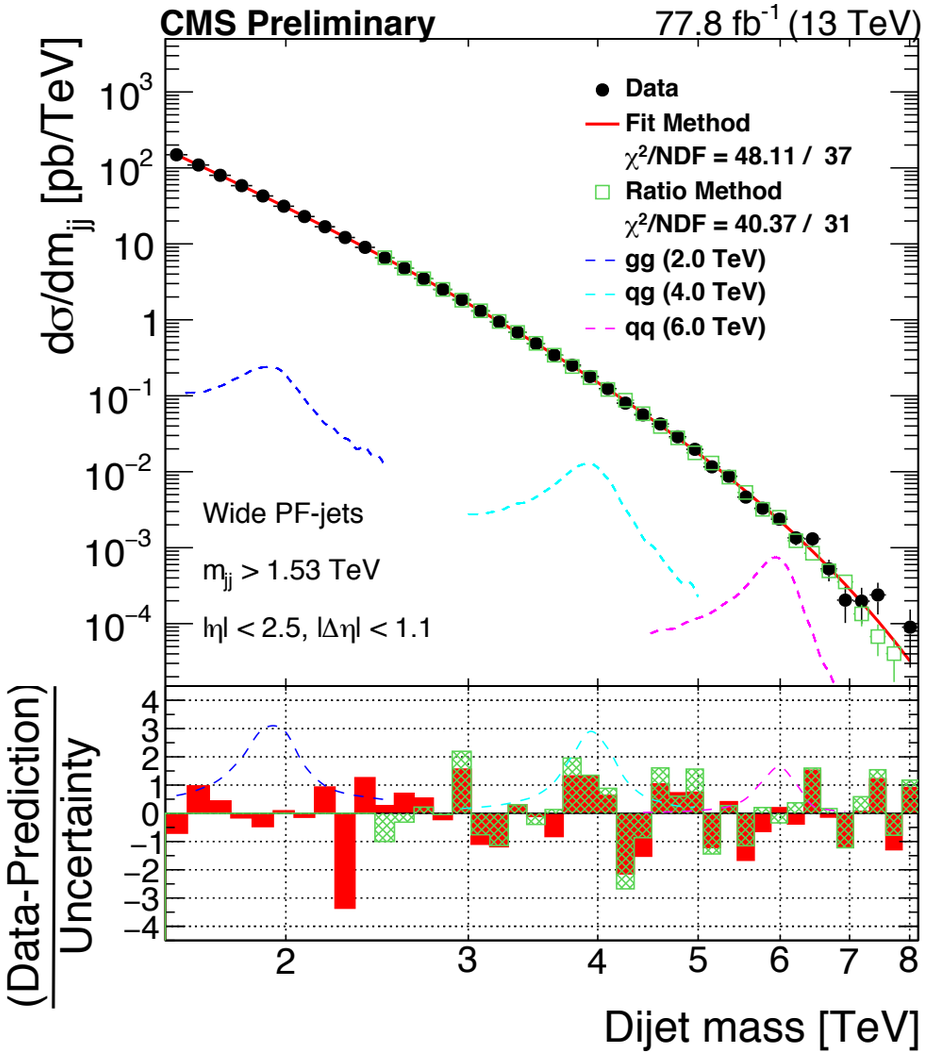
Dijet

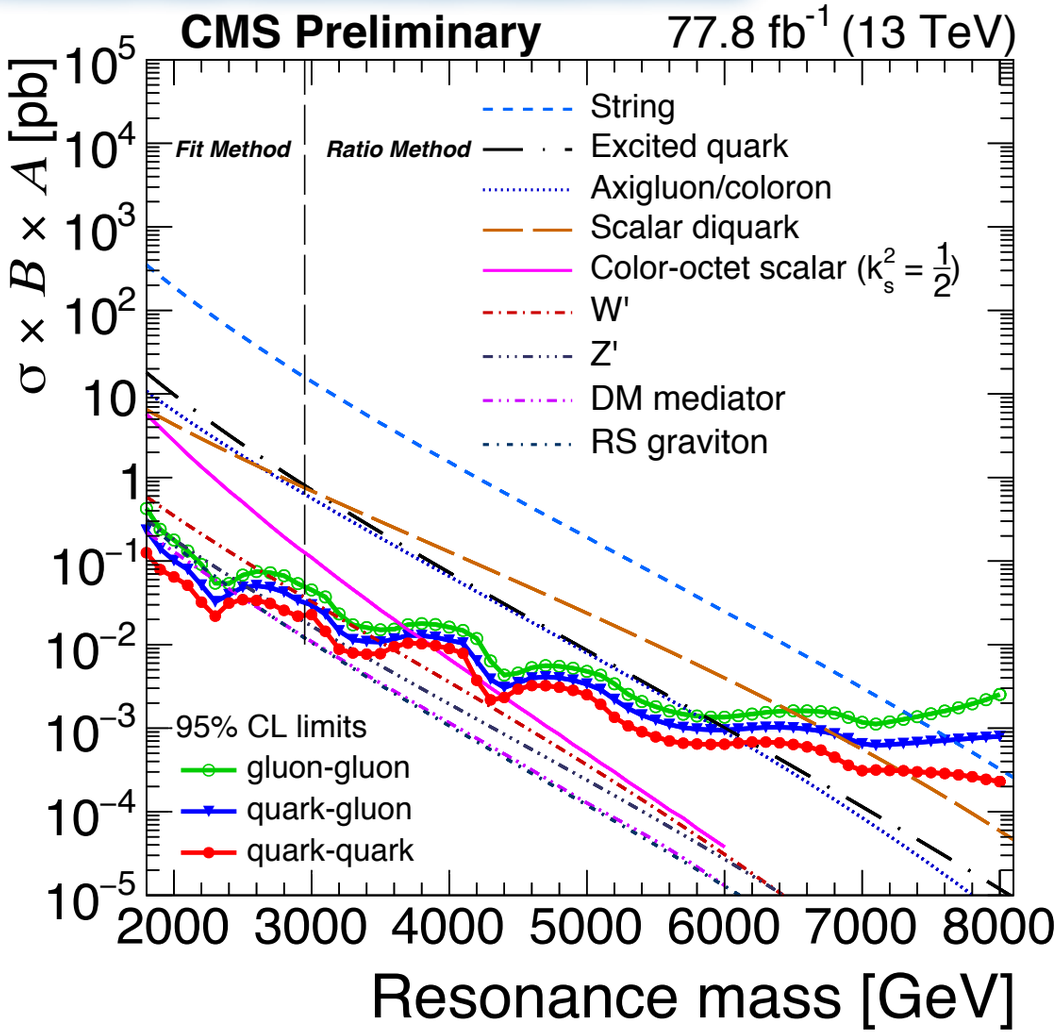


- inv. mass of 2 "wide jets" (= all jets with $\Delta R < 1.1$)
- new bkg. estimate using regions with $|\Delta\eta| > 1.1$

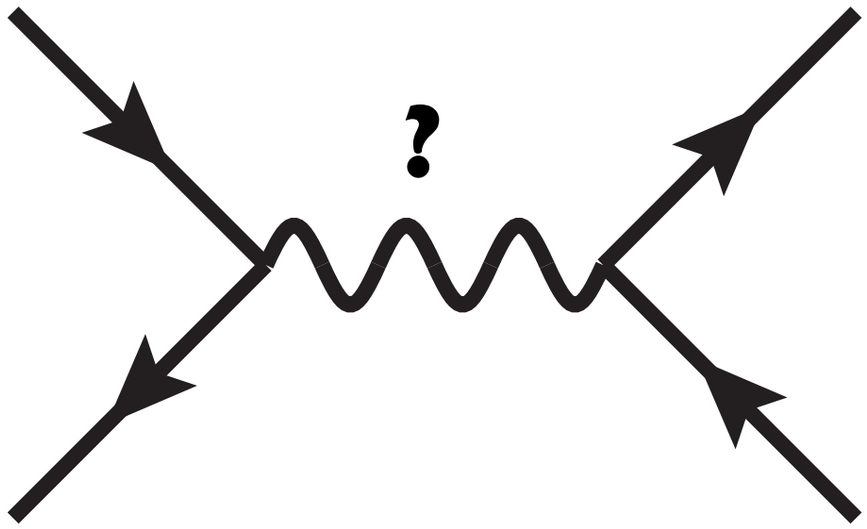
PAS-EXO-17-026

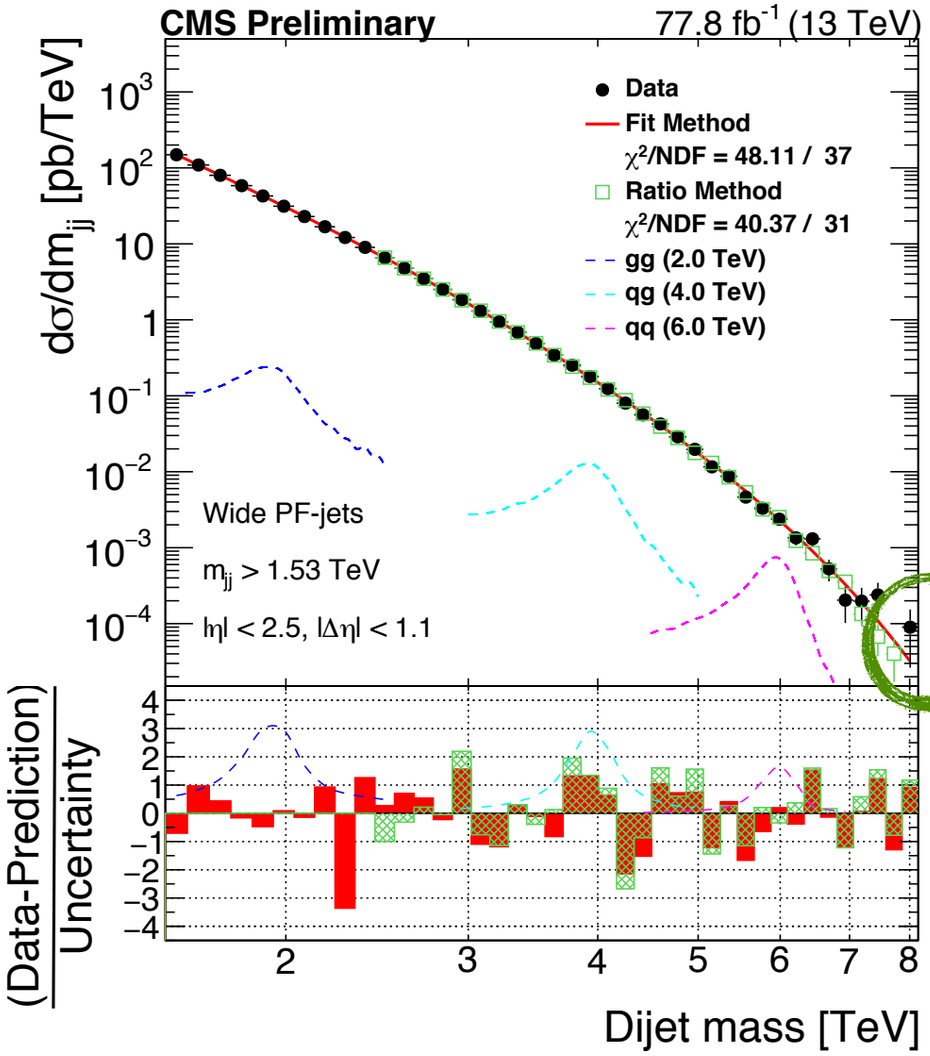
09/18

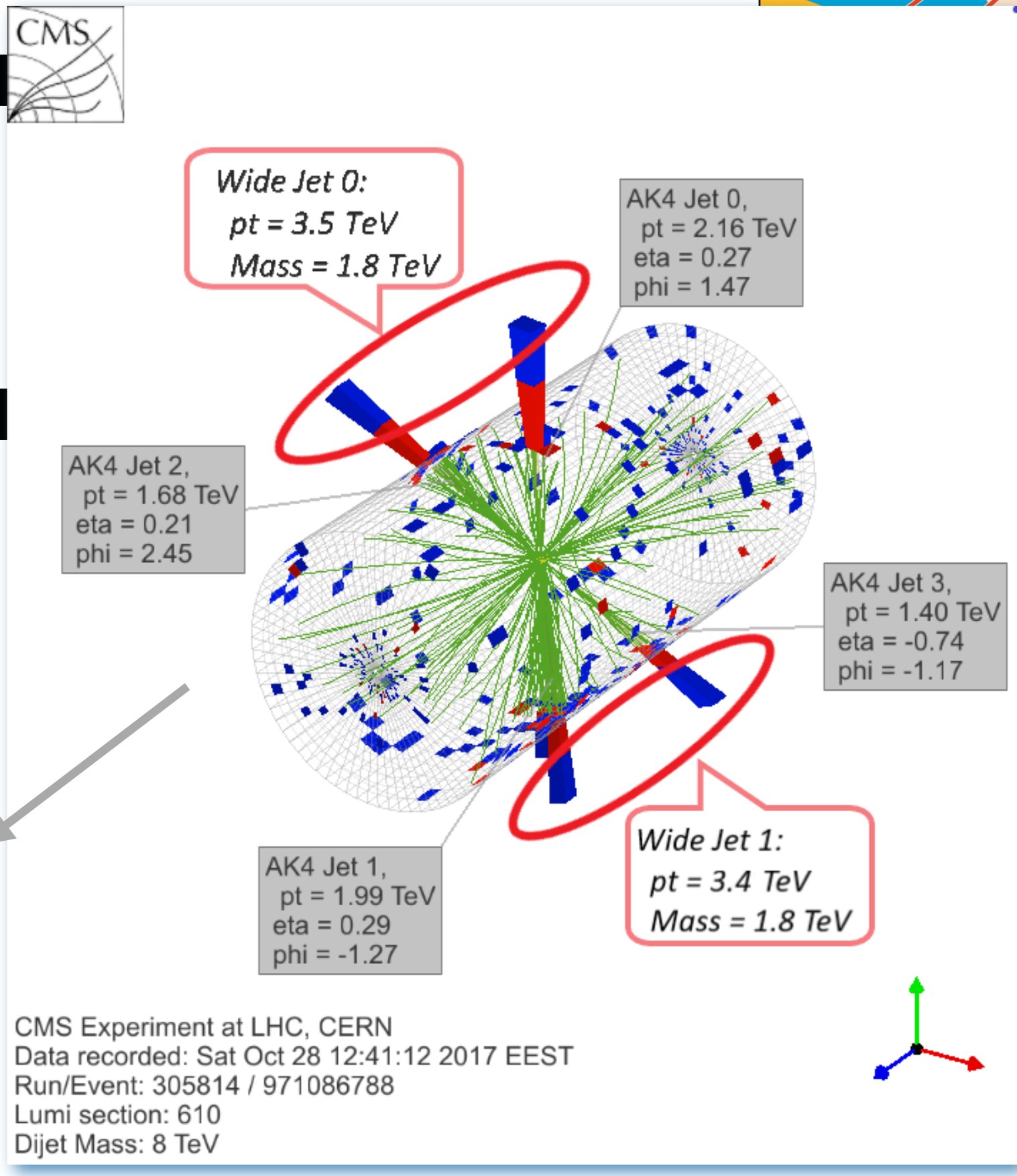




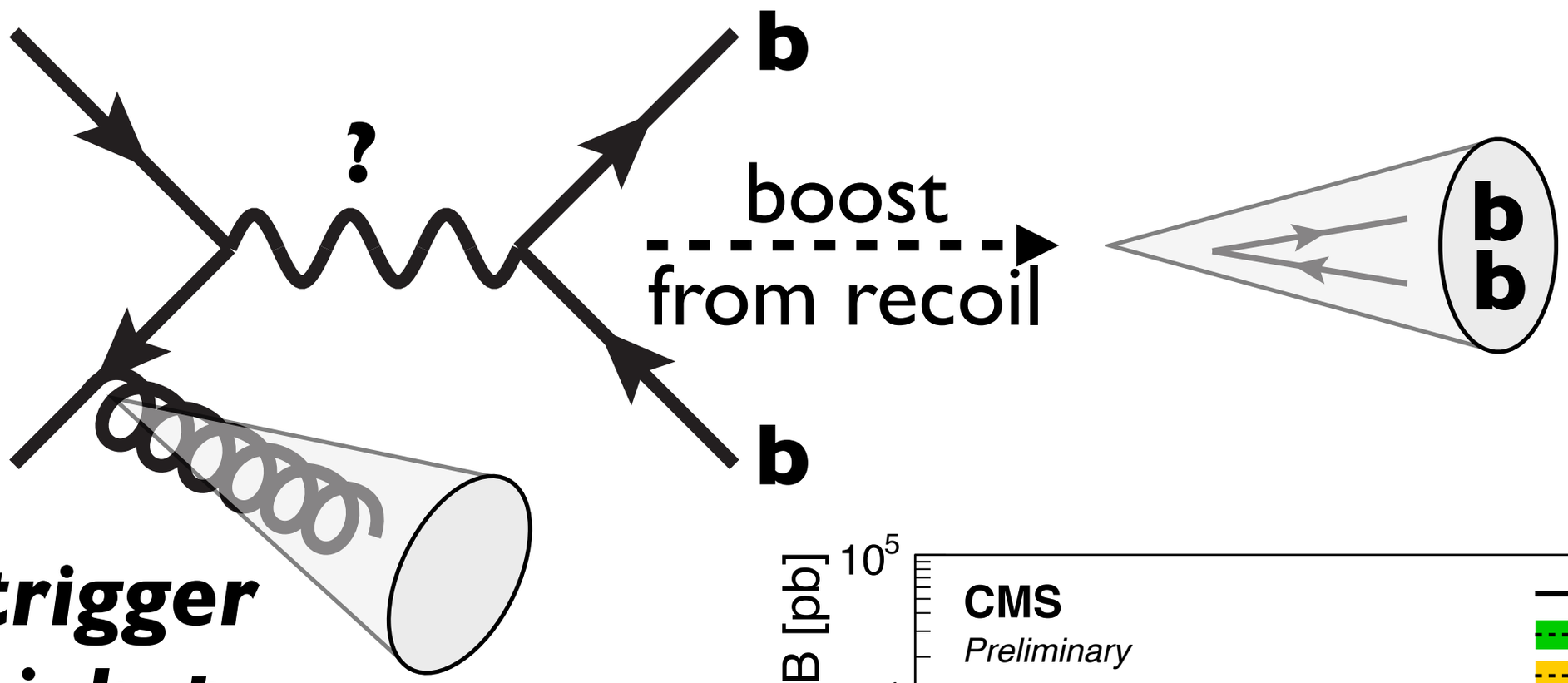
Dijet


q
?
q


CMS Preliminary
77.8 fb-1 (13 TeV)
Data
Fit Method
χ2/NDF = 48.11 / 37
Ratio Method
χ2/NDF = 40.37 / 31
gg (2.0 TeV)
qg (4.0 TeV)
qq (6.0 TeV)
Wide PF-jets
mjj > 1.53 TeV
|η| < 2.5, |Δη| < 1.1
dσ/dmjj [pb/TeV]
(Data-Prediction)/Uncertainty
Dijet mass [TeV]

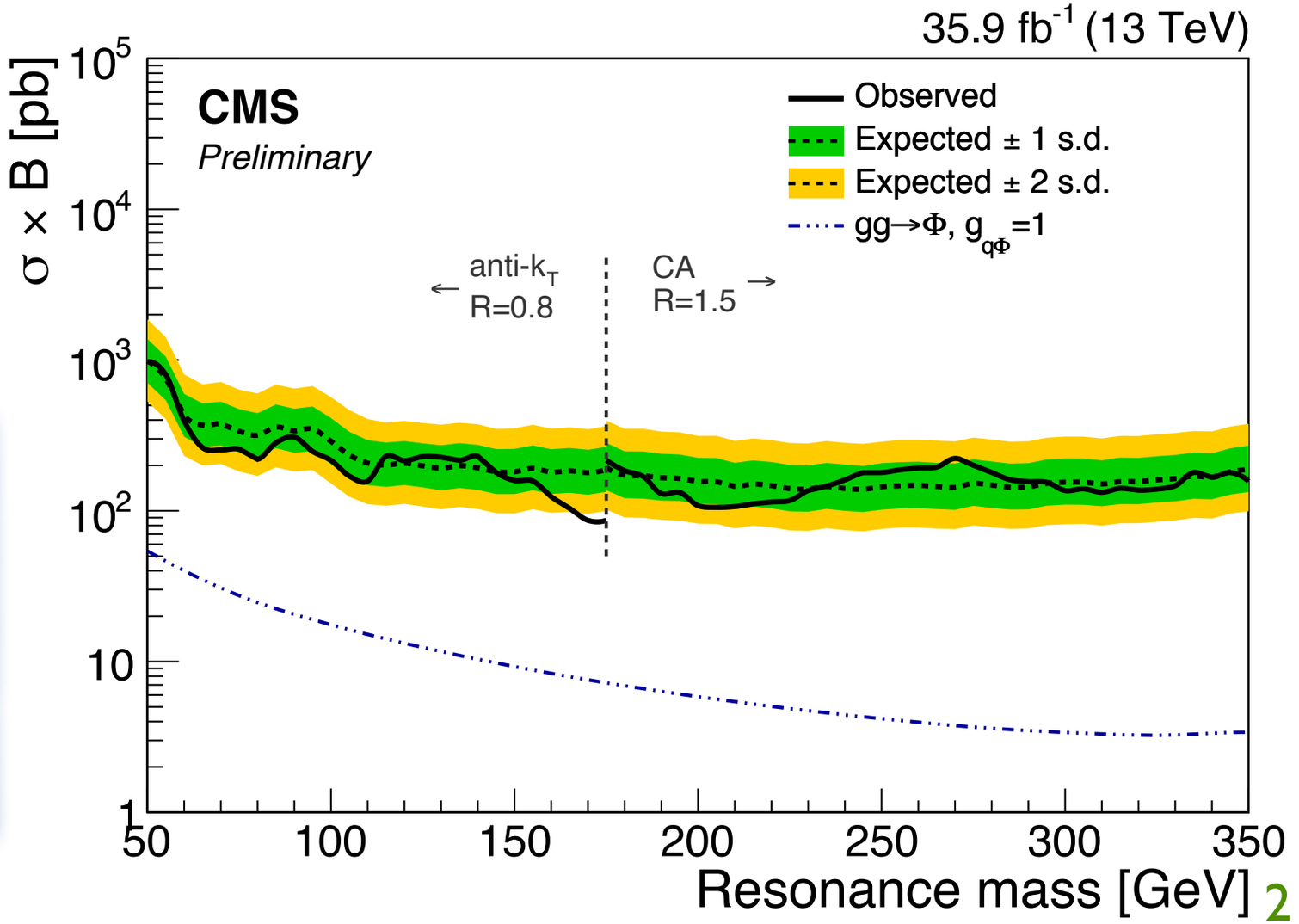

Wide Jet 0:
pt = 3.5 TeV
Mass = 1.8 TeV
AK4 Jet 0,
pt = 2.16 TeV
eta = 0.27
phi = 1.47
AK4 Jet 2,
pt = 1.68 TeV
eta = 0.21
phi = 2.45
AK4 Jet 3,
pt = 1.40 TeV
eta = -0.74
phi = -1.17
AK4 Jet 1,
pt = 1.99 TeV
eta = 0.29
phi = -1.27
Wide Jet 1:
pt = 3.4 TeV
Mass = 1.8 TeV
CMS Experiment at LHC, CERN
Data recorded: Sat Oct 28 12:41:12 2017 EEST
Run/Event: 305814 / 971086788
Lumi section: 610
Dijet Mass: 8 TeV

Di-b-jet + ISR



trigger high-p_T ISR jet

- Large-R jet must be 2-prong-like (DDT)
- Search for bump in large-R jet mass



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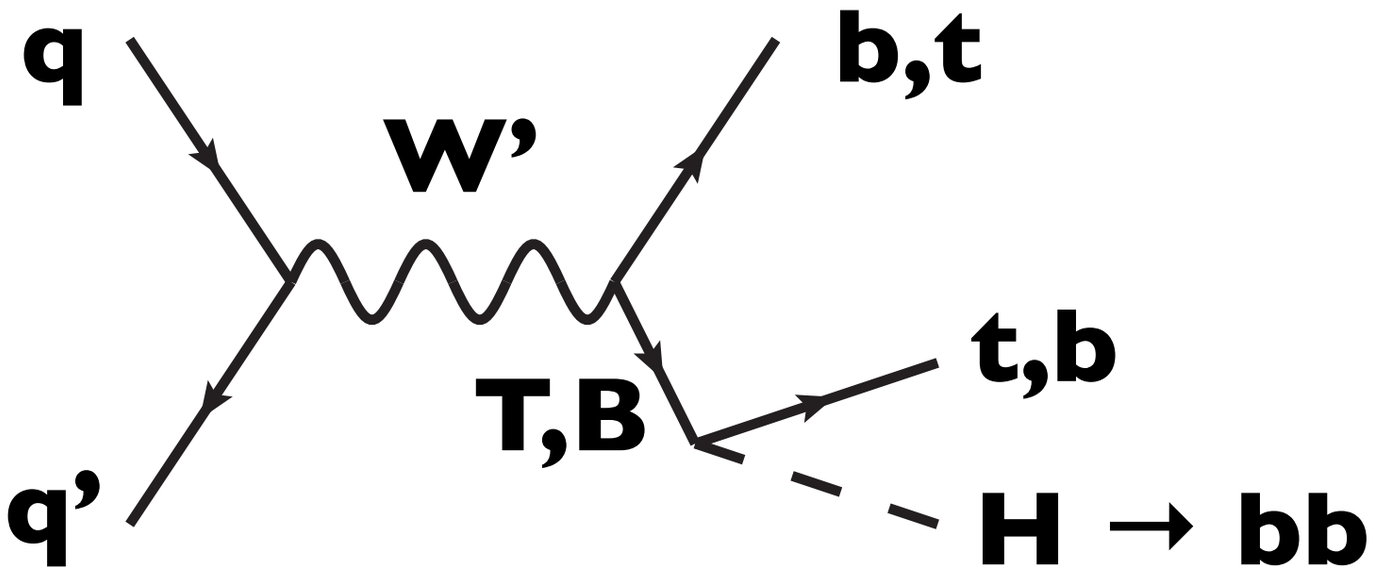
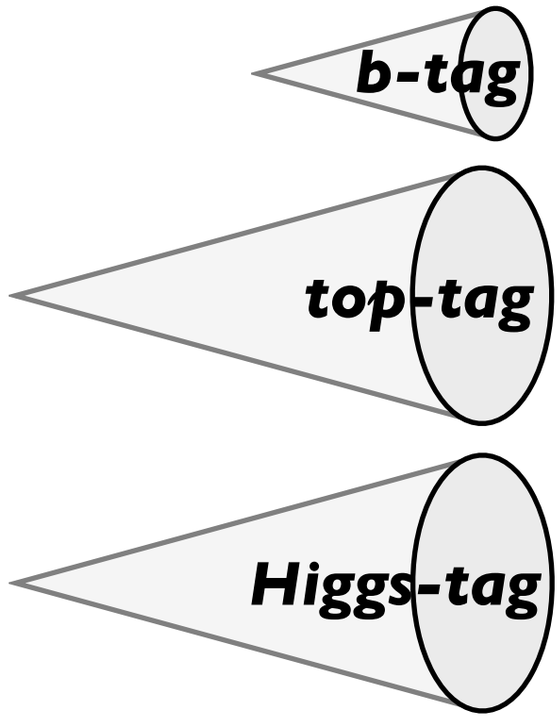
W' → Tb or tB





PAS-B2G-18-001

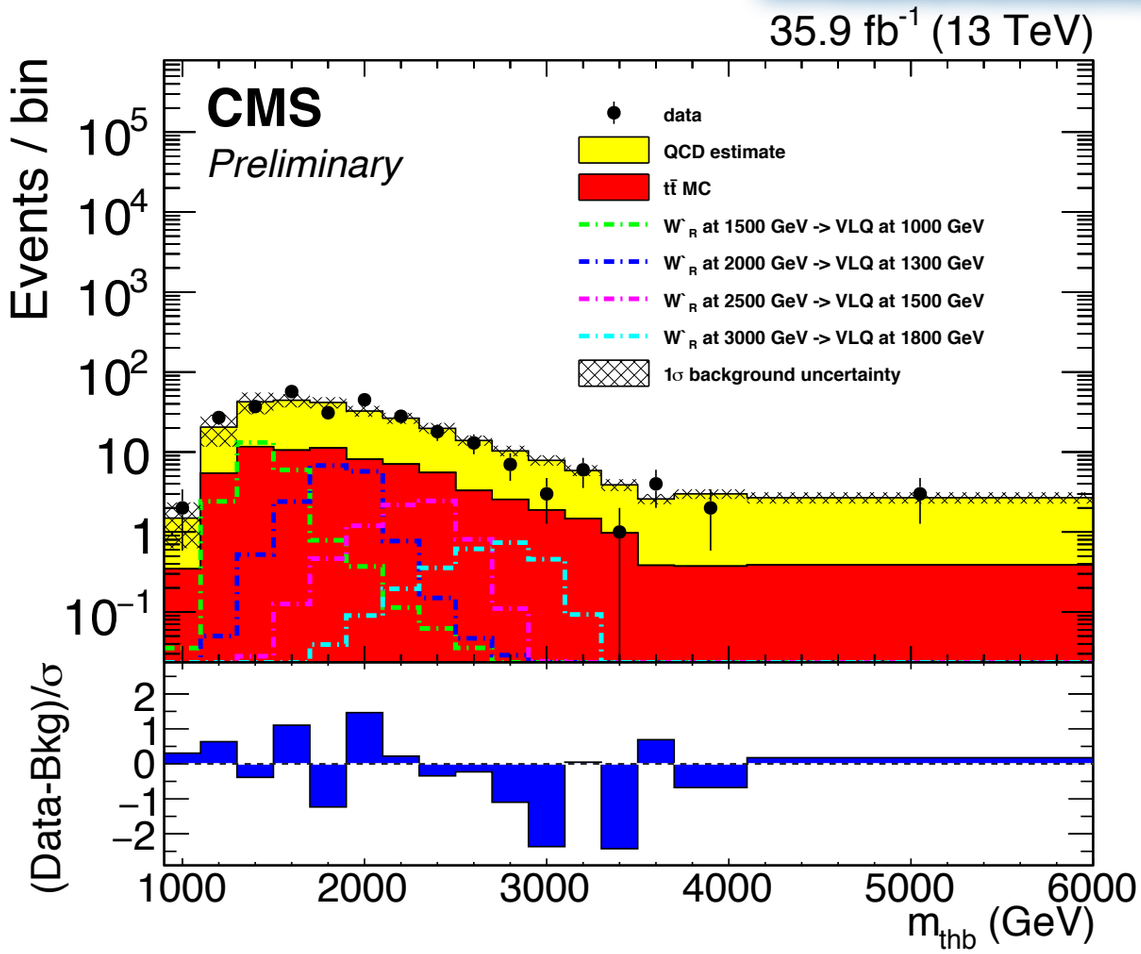
07/18

search in allhadronic final state

Main background: QCD multijet

- Estimated from control regions with inverted Higgs-/top-tagging
- Not (yet) sensitive to benchmark W' model

(specific mixing & BR(Ht/b) = 50%)



long-lived

boson

boson

boson

quark

leptons

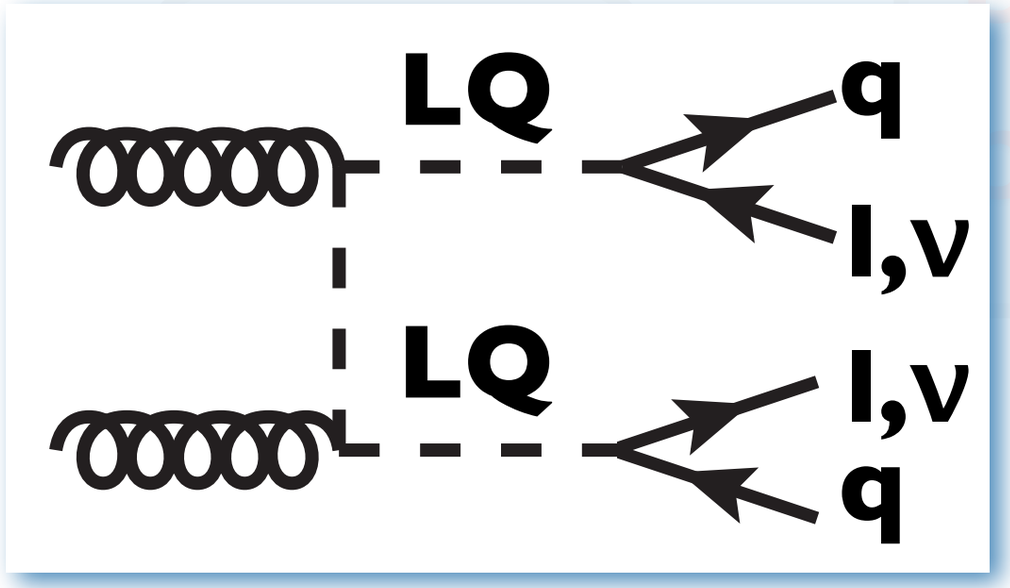
quark

quark

mono

X

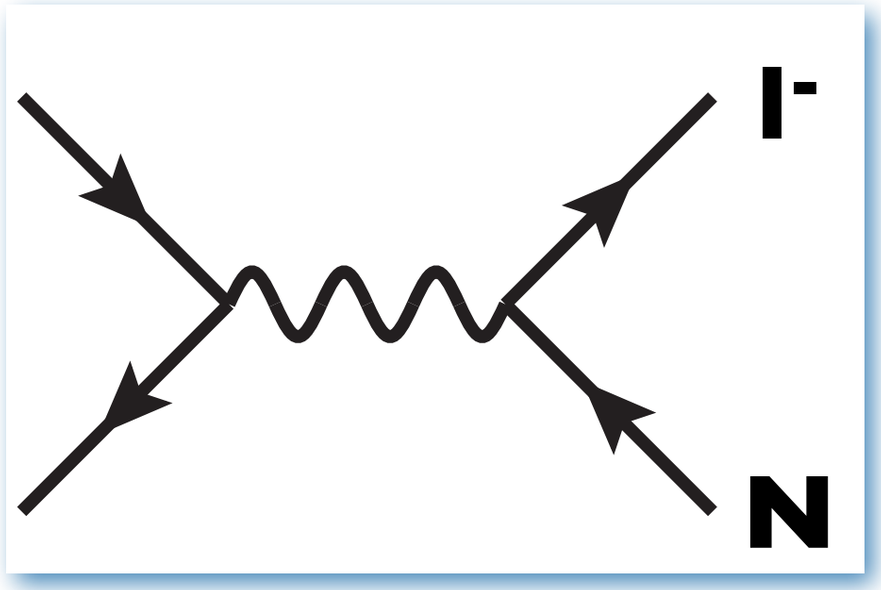
lepton & quark?



New results

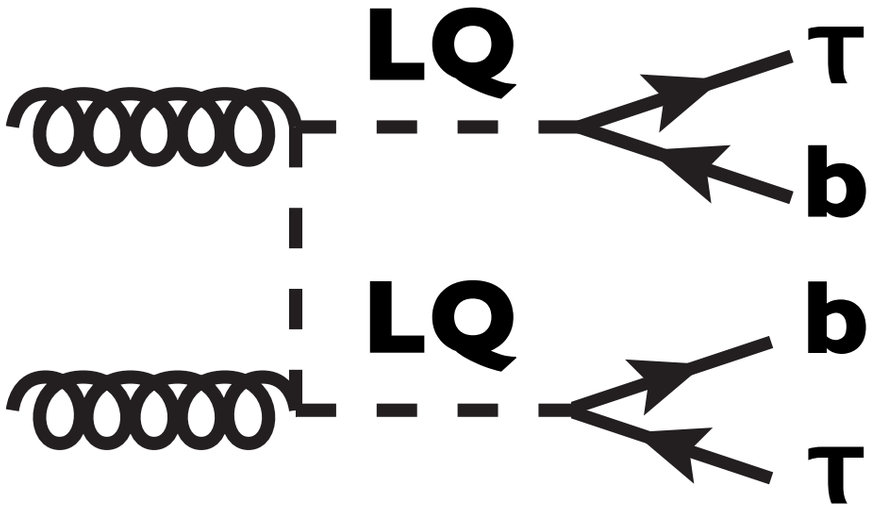
- LQ → q + e
- LQ → b + τ
- LQ → DM
- Heavy ν
- Vector-like ℓ
- $\ell^* \rightarrow \ell\gamma$
- ? → e μ

leptons



m_ν ?

b + τ



Flavor anomalies

- in $B \to D^{(*)} \tau \nu$
- in $B \to K^* \mu \mu$ (e e)

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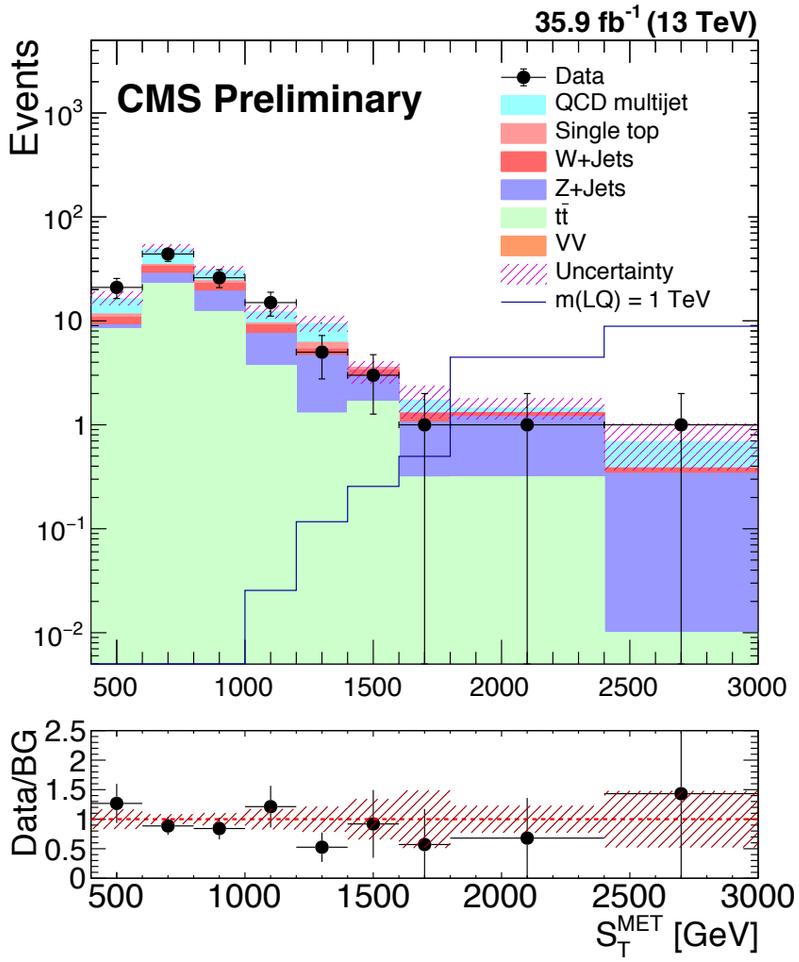
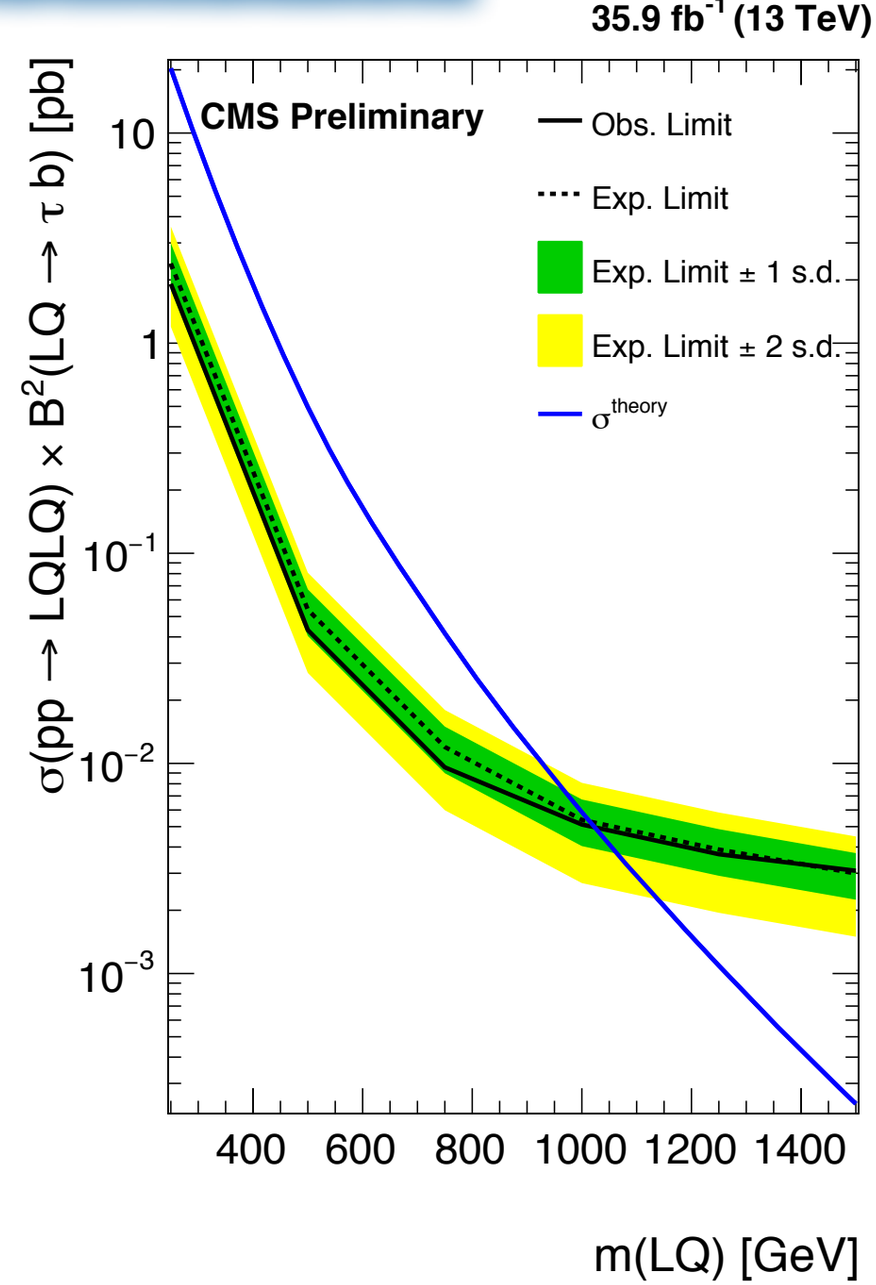
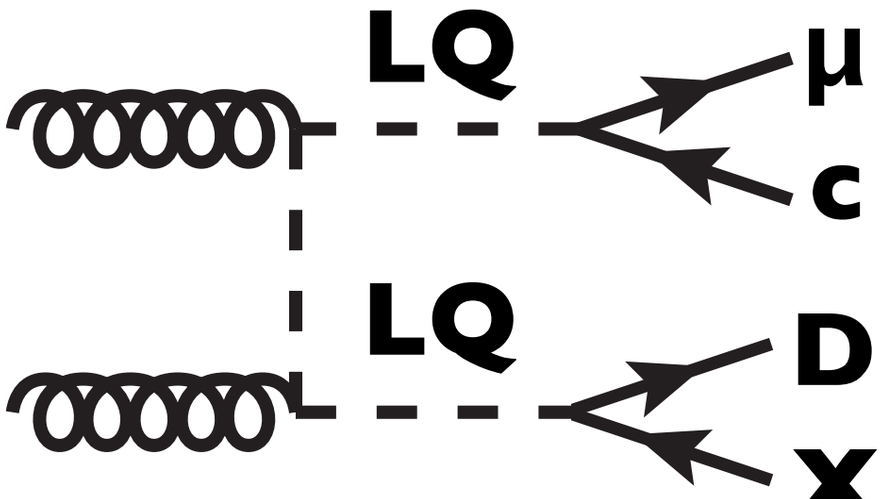
⇒ LQ that preferentially couples to b & τ ?

- 2 hadronically decaying τ
- no b-tagging
- S_T^{MET} = Σ of
  - p_T (τ_1 & τ_2)
  - p_T (j_1 & j_2)
  - E_T^{miss}





LQ → ℓ + DM



- "Mono-LQ" search
- Peak in $m_{\mu j}$ + E_T^{miss}

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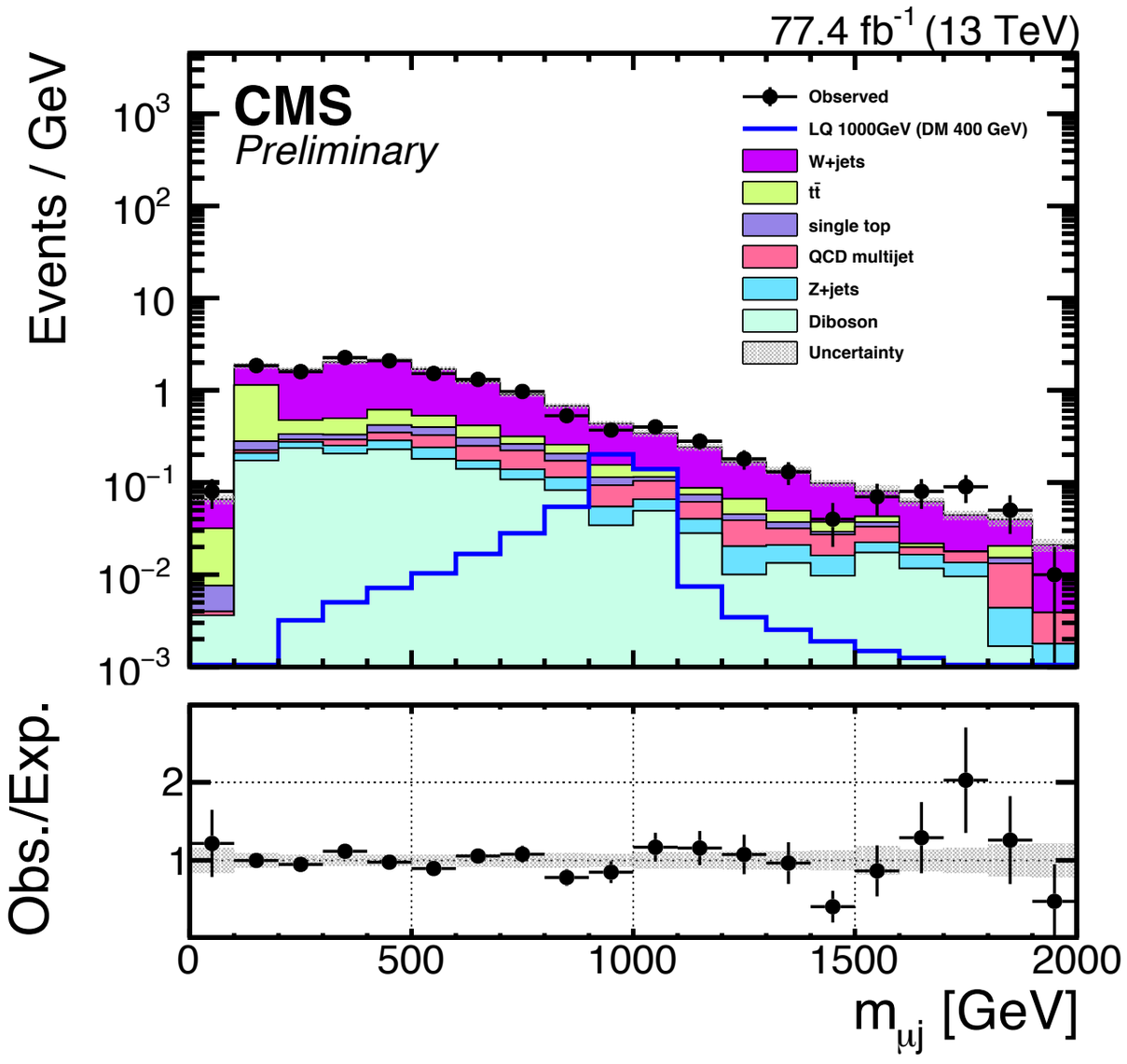
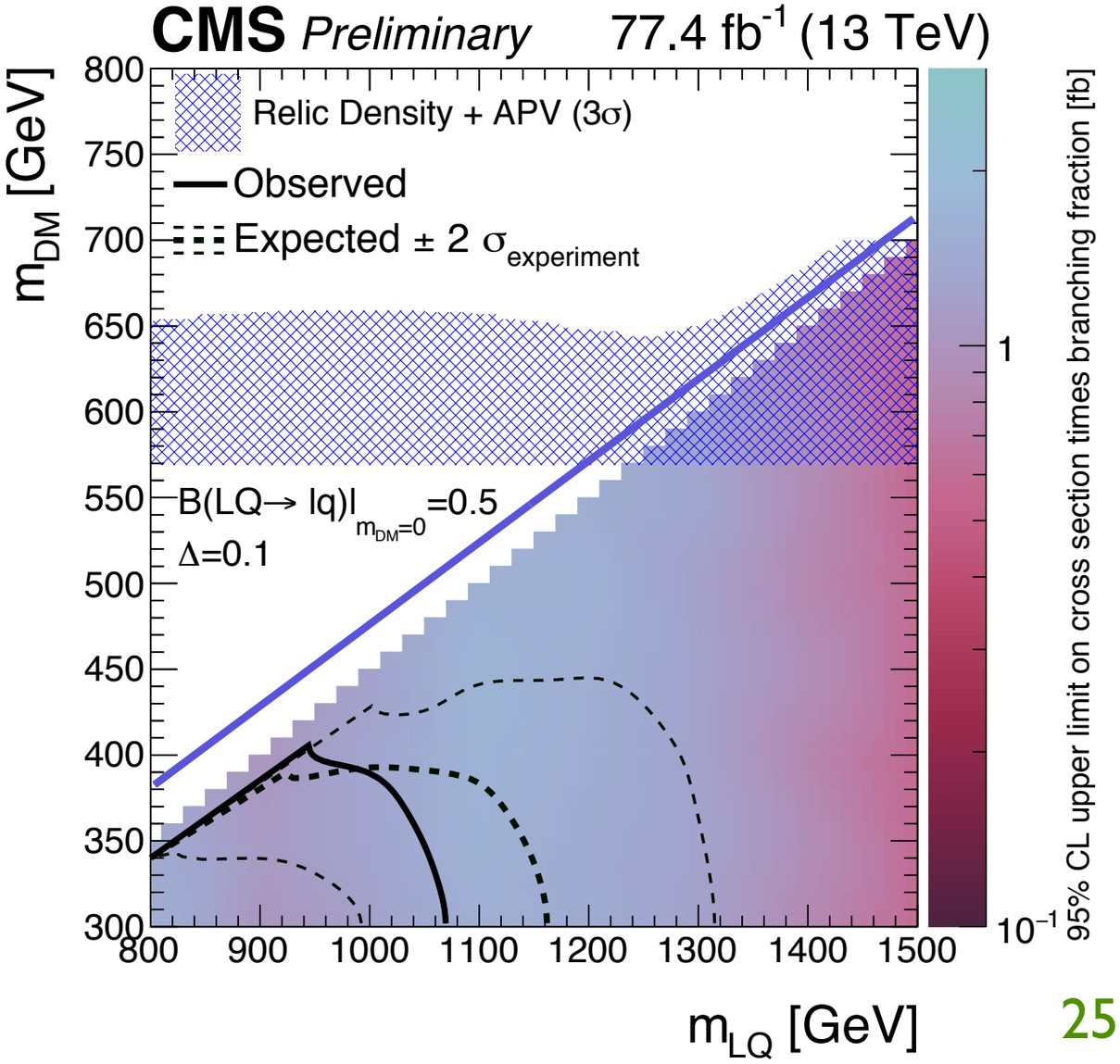
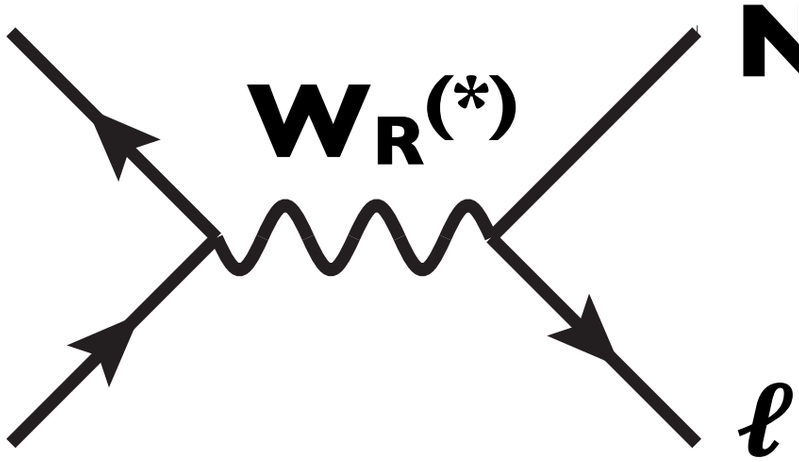
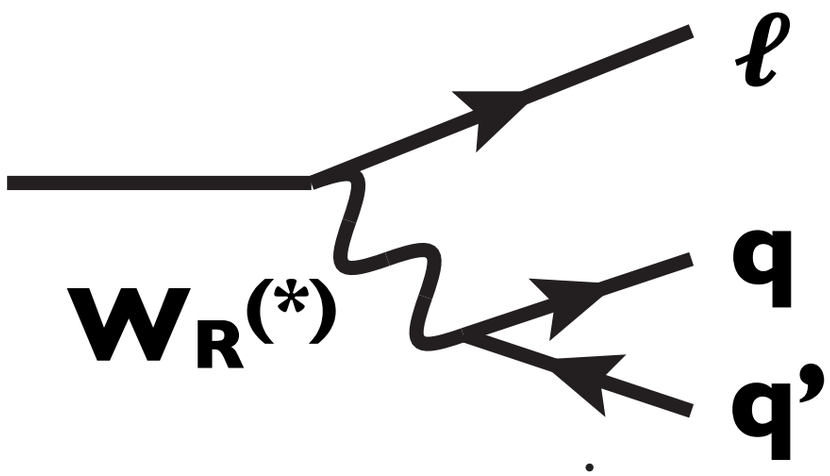
X → DM μ c (soft if small Δm(X,DM))





Heavy Neutrino

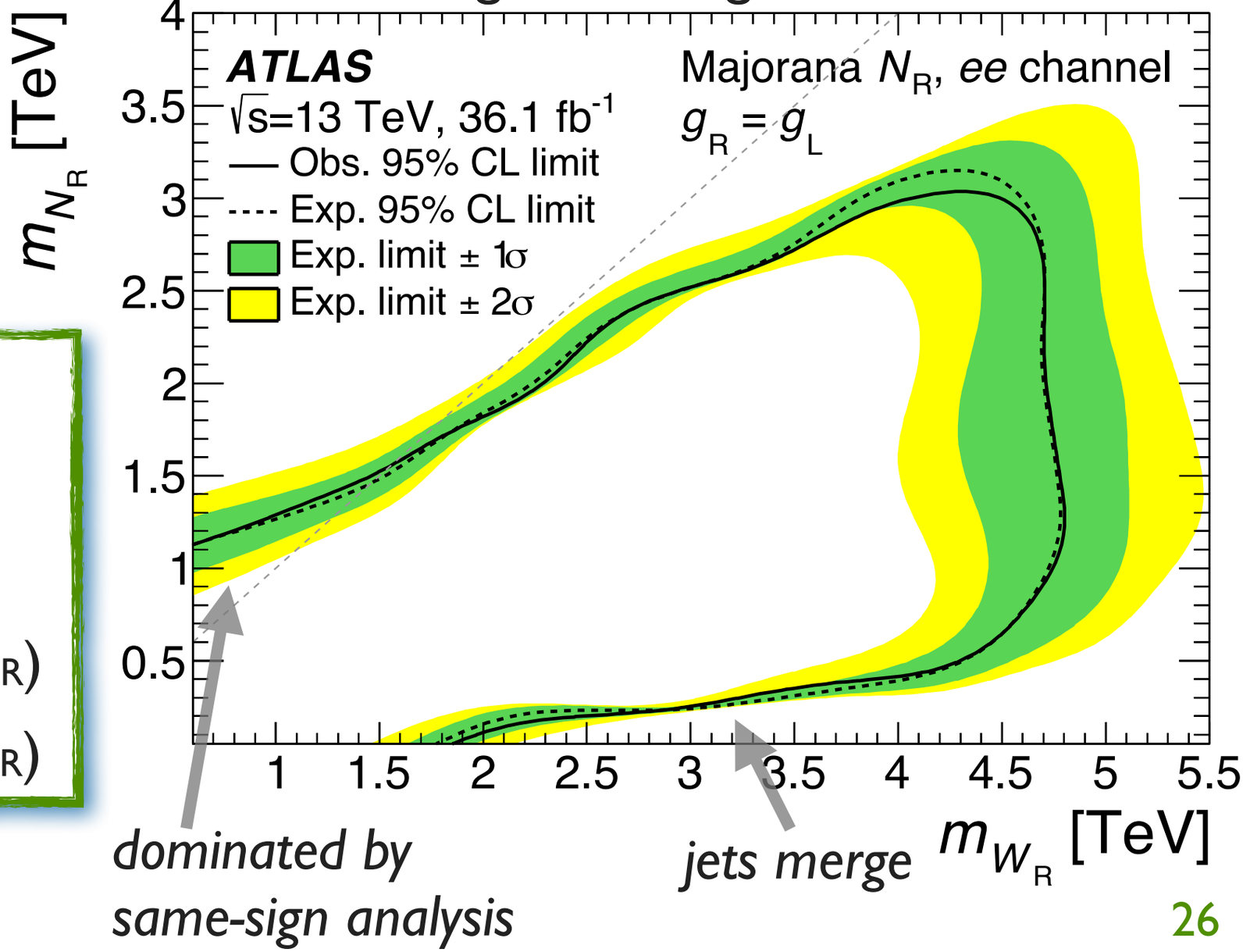




1809.11105

08/18

assuming no mixing between flavors:



Dirac-N_R	→	$\ell^+\ell^-$ only
Majorana-N_R	→	$\ell^\pm\ell^\pm$ & $\ell^+\ell^-$
$m(W_R)>m(N_R)$	→	$m_{llqq} \sim m(W_R)$
else	→	$m_{qq} \sim m(W_R)$

SUSY Signatures

u	c	t	γ	h		$\tilde{u}$	$\tilde{c}$	$\tilde{t}$	$\tilde{\chi}_1^0$	$\tilde{\chi}_2^0$
d	s	b	g	(A)		$\tilde{d}$	$\tilde{s}$	$\tilde{b}$	$\tilde{g}$	$\tilde{A}$
e	μ	τ	Z	(H)		$\tilde{e}$	$\tilde{\mu}$	$\tilde{\tau}$	$\tilde{\chi}_3^0$	$\tilde{\chi}_4^0$
ν_e	ν_μ	ν_τ	$W^\pm$	$(H^\pm)$		$\tilde{\nu}_e$	$\tilde{\nu}_\mu$	$\tilde{\nu}_\tau$	$\tilde{\chi}_1^\pm$	$\tilde{\chi}_2^\pm$

SUSY Signatures

u	c	t	γ	h
d	s	b	g	(A)
e	μ	τ	Z	(H)
ν_e	ν_μ	ν_τ	$W^\pm$	$(H^\pm)$

$\tilde{u}$	$\tilde{c}$	$\tilde{t}$	$\tilde{\chi}_1^0$	$\tilde{\chi}_2^0$
$\tilde{d}$	$\tilde{s}$	$\tilde{b}$	$\tilde{g}$	$\tilde{A}$
$\tilde{e}$	$\tilde{\mu}$	$\tilde{\tau}$	$\tilde{\chi}_3^0$	$\tilde{\chi}_4^0$
$\tilde{\nu}_e$	$\tilde{\nu}_\mu$	$\tilde{\nu}_\tau$	$\tilde{\chi}_1^\pm$	$\tilde{\chi}_2^\pm$

New results

- bbhh + MET
- b-jets+MET(+ℓ)
- τ + jets + MET
- γ + jets + MET
- Razor vars.
- ? → τ + MET
- H(+/-) → τ ν
- ? → W + MET
- t($\bar{t}$) + MET
- γ + ℓ + MET

- Naturally solves hierarchy problem
  if m(top) ~ m(stop)
- Often R-parity conservation assumed
  - Lightest supersymmetric particles (LSP) is DM candidate
  - Large E_T^{miss}

SUSY Signatures

u	c	t	γ	h
d	s	b	g	(A)
e	μ	τ	Z	(H)
ν_e	ν_μ	ν_τ	$W^\pm$	$(H^\pm)$

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$\tilde{d}$	$\tilde{s}$	$\tilde{b}$	$\tilde{g}$	$\tilde{A}$
$\tilde{e}$	$\tilde{\mu}$	$\tilde{\tau}$	$\tilde{\chi}_3^0$	$\tilde{\chi}_4^0$
$\tilde{\nu}_e$	$\tilde{\nu}_\mu$	$\tilde{\nu}_\tau$	$\tilde{\chi}_1^\pm$	$\tilde{\chi}_2^\pm$

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- ? → W + MET
- t($\bar{t}$) + MET
- γ + ℓ + MET

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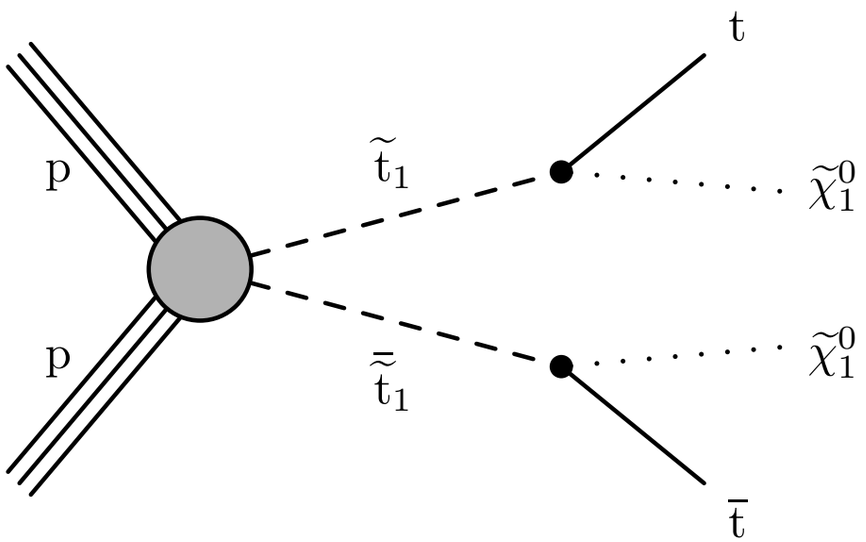
Stop → top + neutralino



- Challenging if $\Delta m(\tilde{t}, \tilde{\chi}_1^0) \approx m(t)$
- M_{T2}: kinematic endpoint for $t\bar{t}$

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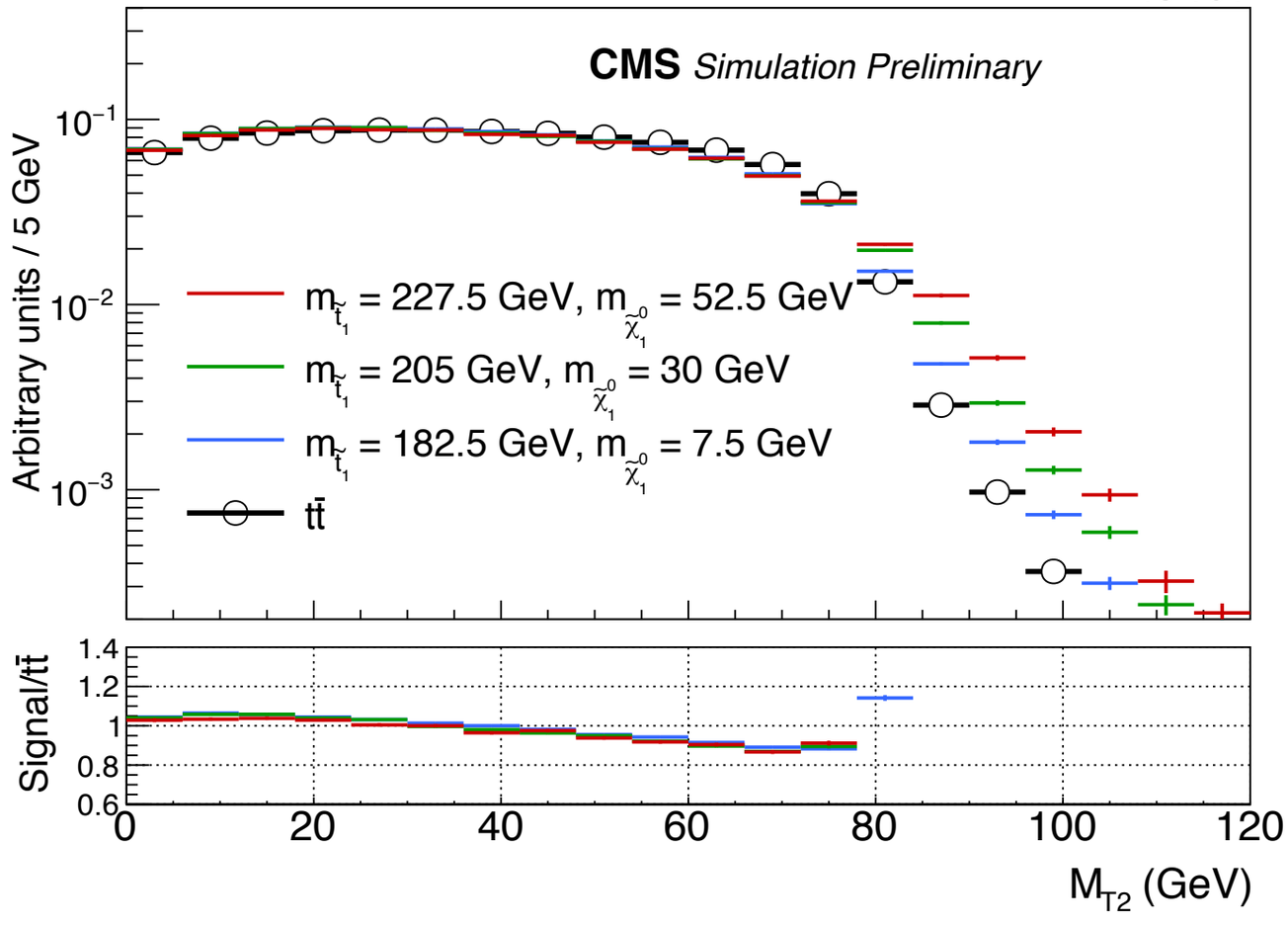
$$M_{T2}^2 = \min_{\vec{p}_{T1}^{\,miss} + \vec{p}_{T2}^{\,miss} = E_T^{miss}} \left(\max \left[m_T^2(\vec{p}_T^{\,\ell 1}, \vec{p}_{T1}^{\,miss}), m_T^2(\vec{p}_T^{\,\ell 2}, \vec{p}_{T2}^{\,miss}) \right] \right)$$

- 1e & 1μ & ≥ 2 jets with ≥ 1 b-tag
- Stop quarks excluded for $m < 210$ GeV if $\Delta m(\tilde{t}, \tilde{\chi}_1^0) = m(t)$



SUSY Signatures

u	c	t	γ	h
d	s	b	g	(A)
e	μ	τ	Z	(H)
ν_e	ν_μ	ν_τ	$W^\pm$	$(H^\pm)$

$\tilde{u}$	$\tilde{c}$	$\tilde{t}$	$\tilde{\chi}_1^0$	$\tilde{\chi}_2^0$
$\tilde{d}$	$\tilde{s}$	$\tilde{b}$	$\tilde{g}$	$\tilde{A}$
$\tilde{e}$	$\tilde{\mu}$	$\tilde{\tau}$	$\tilde{\chi}_3^0$	$\tilde{\chi}_4^0$
$\tilde{\nu}_e$	$\tilde{\nu}_\mu$	$\tilde{\nu}_\tau$	$\tilde{\chi}_1^\pm$	$\tilde{\chi}_2^\pm$

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- τ + jets + MET
- γ + jets + MET
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- ? → W + MET
- t($\bar{t}$) + MET
- γ + ℓ + MET

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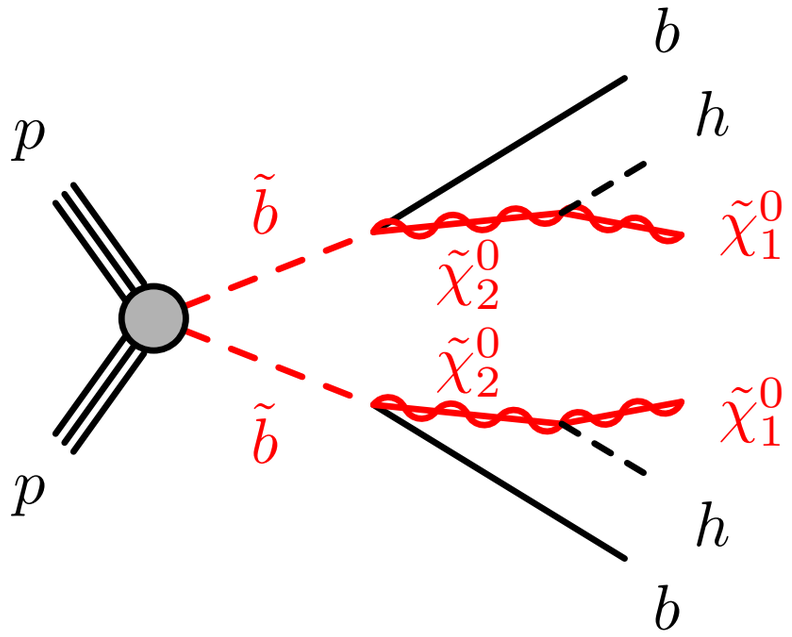
Sbottom → bottom + h + neutralino



If $|\tilde{\chi}_1^0\rangle \approx |\tilde{B}\rangle$ and

$|\tilde{\chi}_2^0\rangle \approx \alpha\,|\tilde{W}_3\rangle + \beta\,|\tilde{h}\rangle$

⇒ large BR of $\tilde{\chi}_2^0$ to h

ATLAS EXPERIMENT

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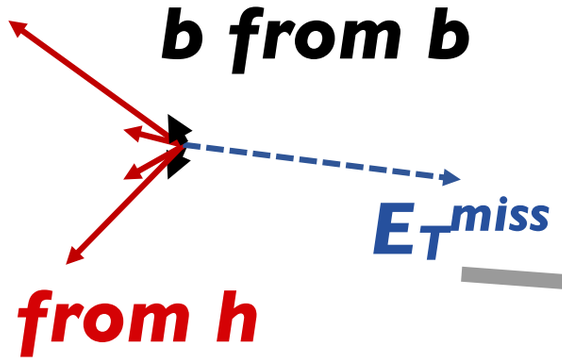
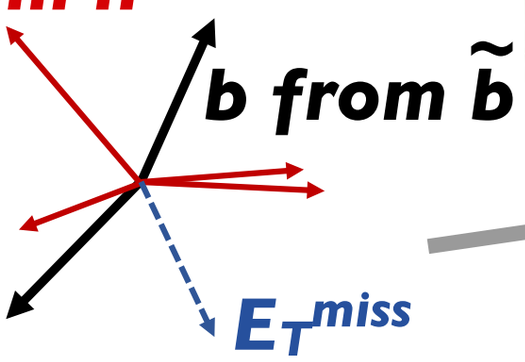
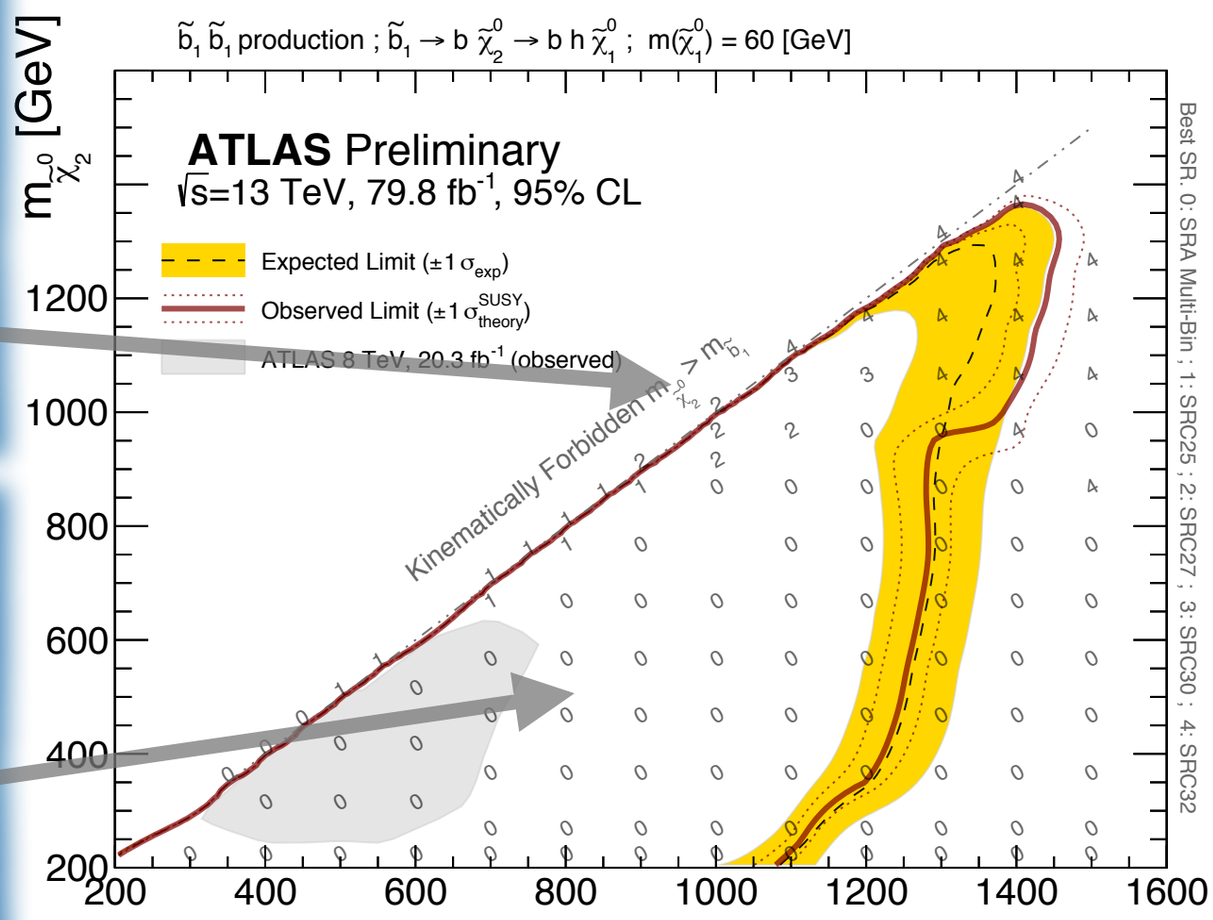
- Case 1: $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$ = 130 GeV
- Case 2: $m(\tilde{\chi}_1^0)$ = 60 GeV

- ≥3 b-jets
- Very large object-based E_T^{miss} significance



- ≥4 b-jets
- large E_T^{miss}
- large Σp_T + E_T^{miss}





SUSY Signatures

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d	s	b	g	(A)
e	μ	τ	Z	(H)
ν_e	ν_μ	ν_τ	$W^\pm$	$(H^\pm)$

$\tilde{u}$	$\tilde{c}$	$\tilde{t}$	$\tilde{\chi}_1^0$	$\tilde{\chi}_2^0$
$\tilde{d}$	$\tilde{s}$	$\tilde{b}$	$\tilde{g}$	$\tilde{A}$
$\tilde{e}$	$\tilde{\mu}$	$\tilde{\tau}$	$\tilde{\chi}_3^0$	$\tilde{\chi}_4^0$
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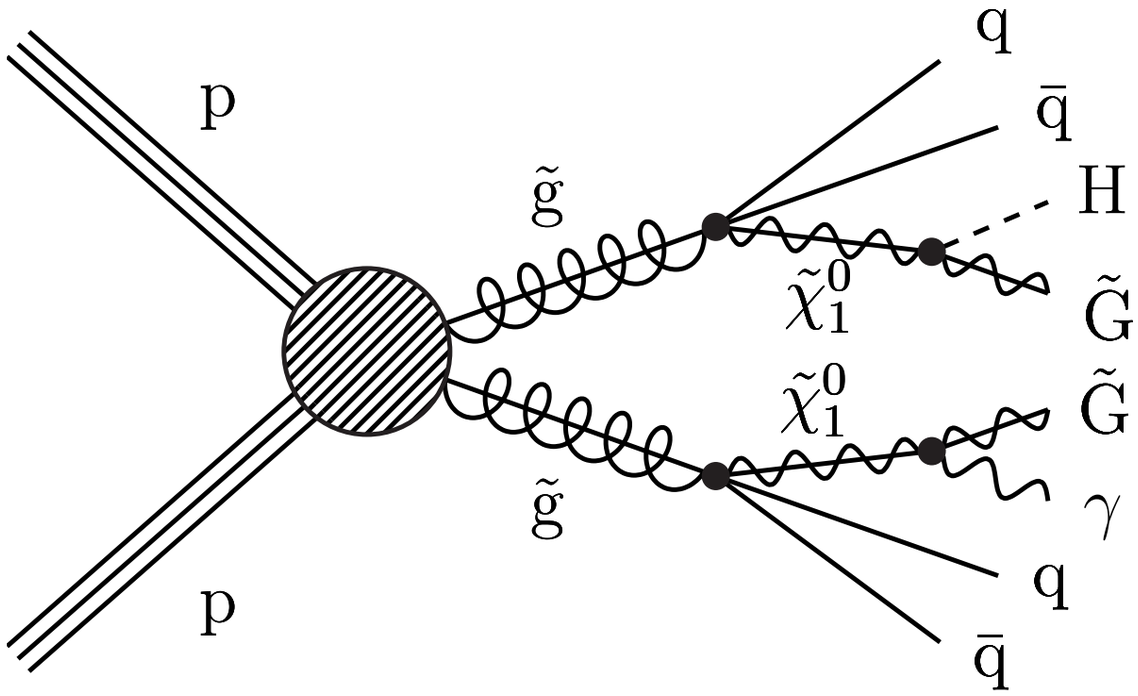
- t($\bar{t}$) + MET
- γ + ℓ + MET

- Naturally solves hierarchy problem if m(top) ~ m(stop)
- Often R-parity conservation assumed
  - Lightest supersymmetric particles (LSP) is DM candidate
  - Large E_T^{miss}

γ + jets + E_T^{miss}

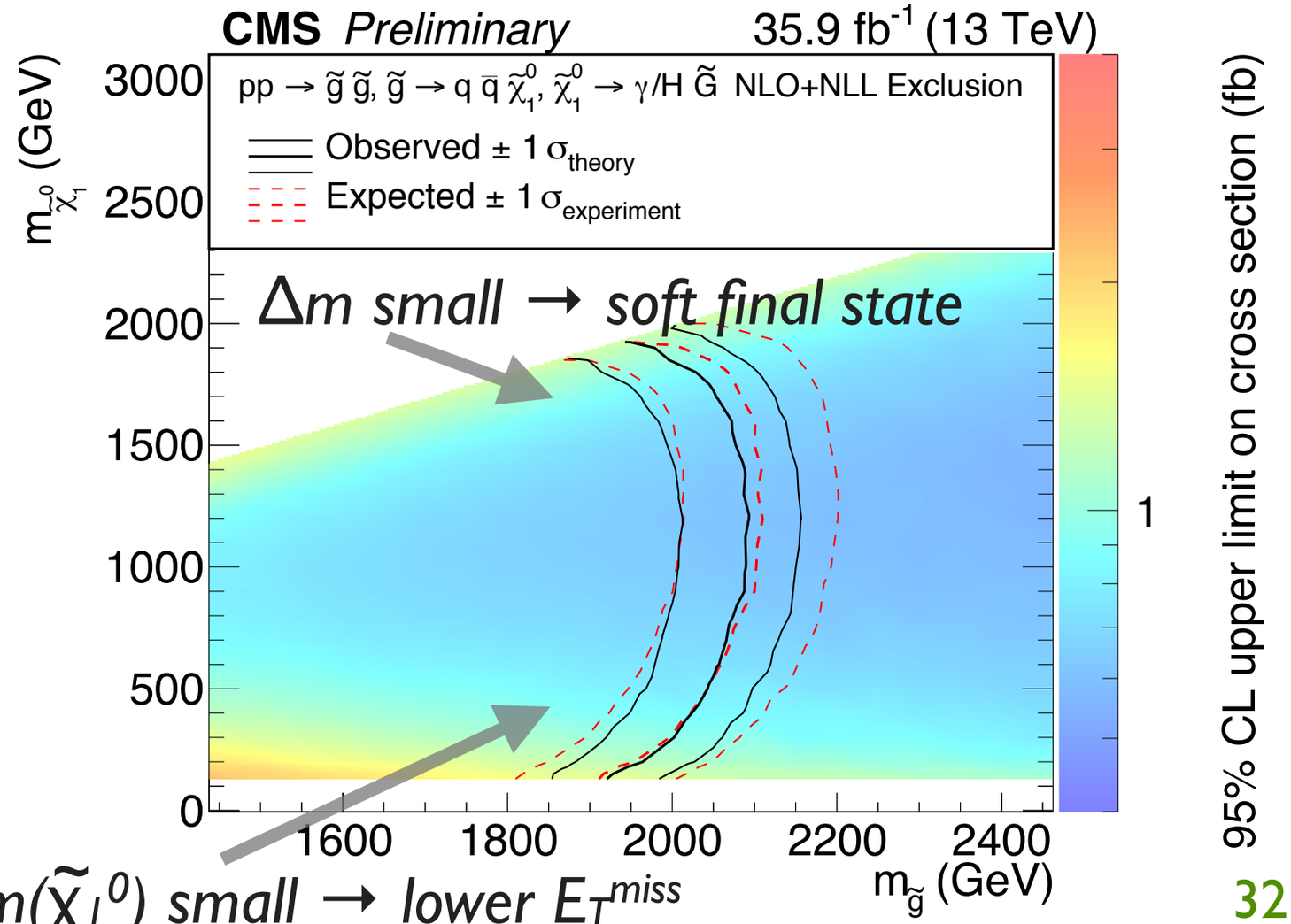


- Gauge-mediated SUSY breaking
- LSP = gravitino
- BR($H\tilde{G}$) = 50%

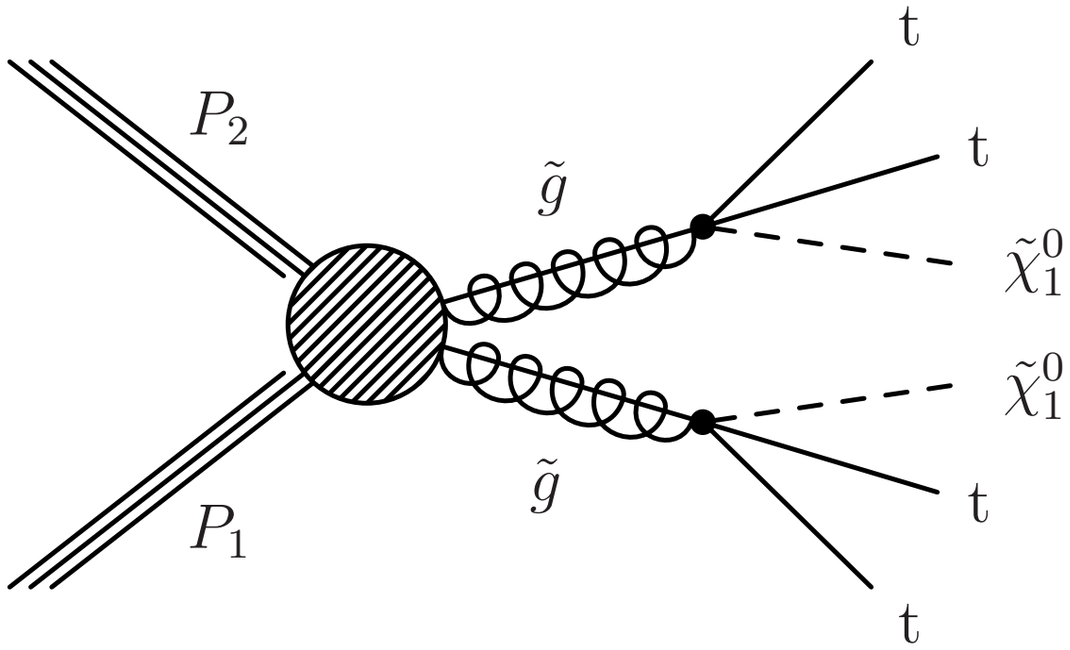
PAS-SUS-18-002

09/18

- $p_T(\gamma)$ > 100 GeV
- ≥ 2 jets
- large E_T^{miss} & Σp_T(objects)
- 25 SRs based on:
  - #jets
  - #b-jets
  - E_T^{miss}



Razor Variables



- Categorized in #ℓ (0/1), #W-tags, #top-tags, #jets, #b-jets

PAS-SUS-16-017

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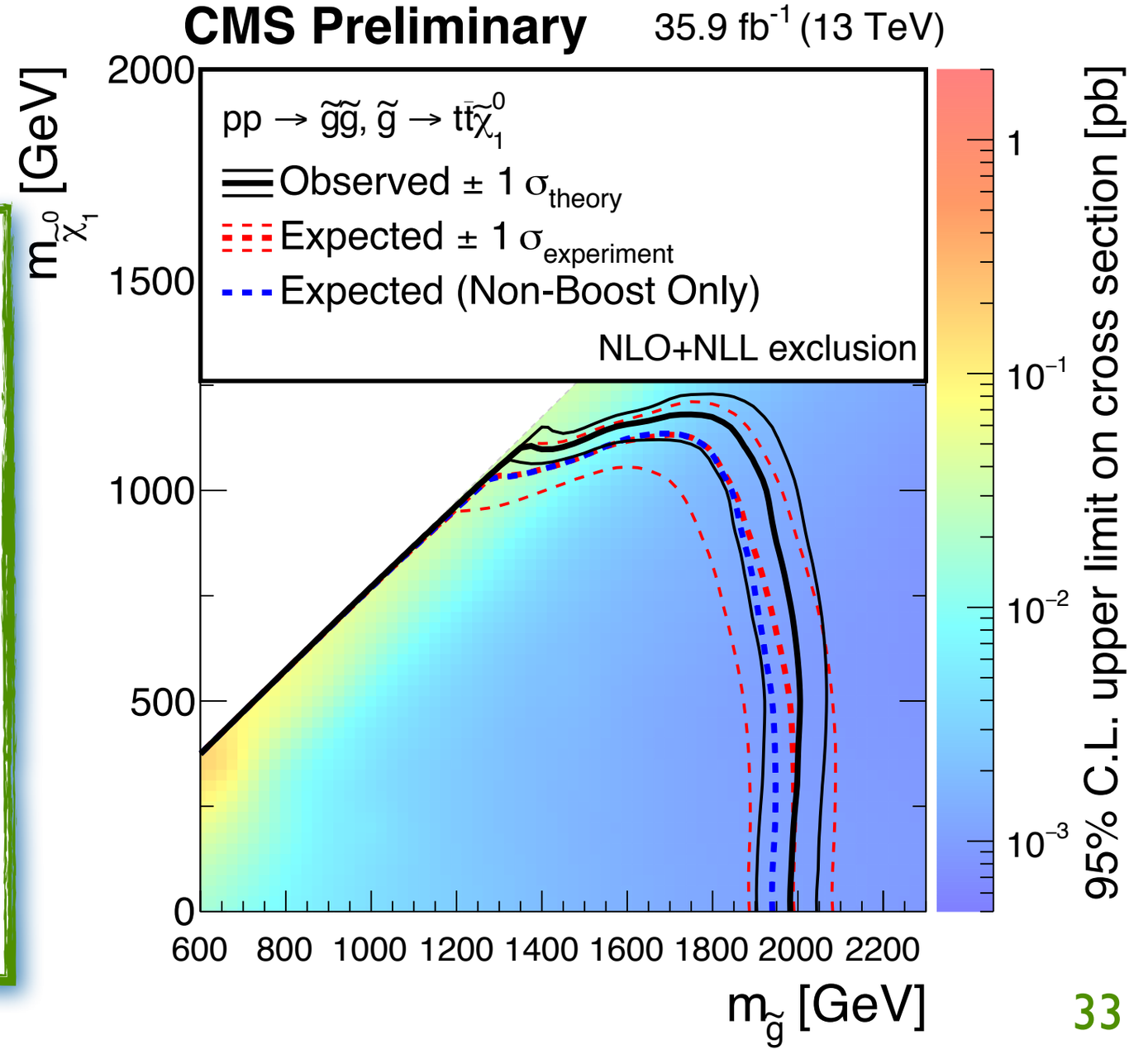
- Generic search for R-parity SUSY
- Using 'razor' variables M_R and R^2
- Bins of M_R and $R^2 = (M_R / M_T^R)^2$:
  - 2 'megajets' (minimizing Σm^2)

$$M_R \equiv \sqrt{(|\vec{p}^{j1}| + |\vec{p}^{j2}|)^2 - (p_z^{j1} + p_z^{j2})^2}$$

$$M_T^R \equiv \sqrt{\frac{p_T^{miss}(p_T^{j1} + p_T^{j2}) - \vec{p}_T^{miss} \cdot (\vec{p}_T^{j1} + \vec{p}_T^{j2})}{2}}$$



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d	s	b	g	(A)
e	μ	τ	Z	(H)
ν_e	ν_μ	ν_τ	$W^\pm$	$(H^\pm)$

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$\tilde{e}$	$\tilde{\mu}$	$\tilde{\tau}$	$\tilde{\chi}_3^0$	$\tilde{\chi}_4^0$
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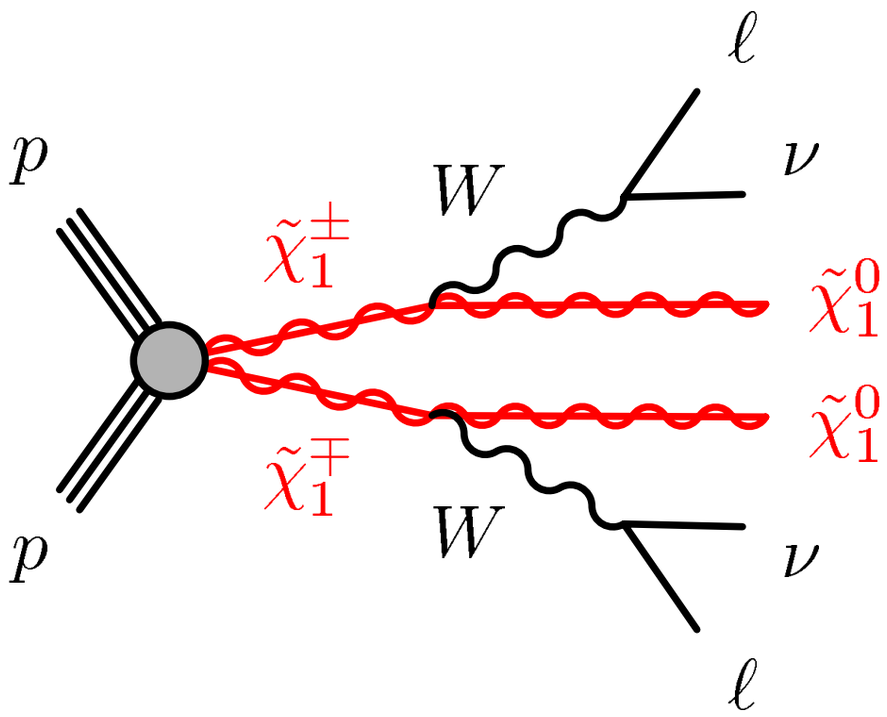
Chargino → W($\ell\nu$) + neutralino



- EW production
- May be first sign of SUSY if gluinos and squarks have very large mass

ATLAS EXPERIMENT

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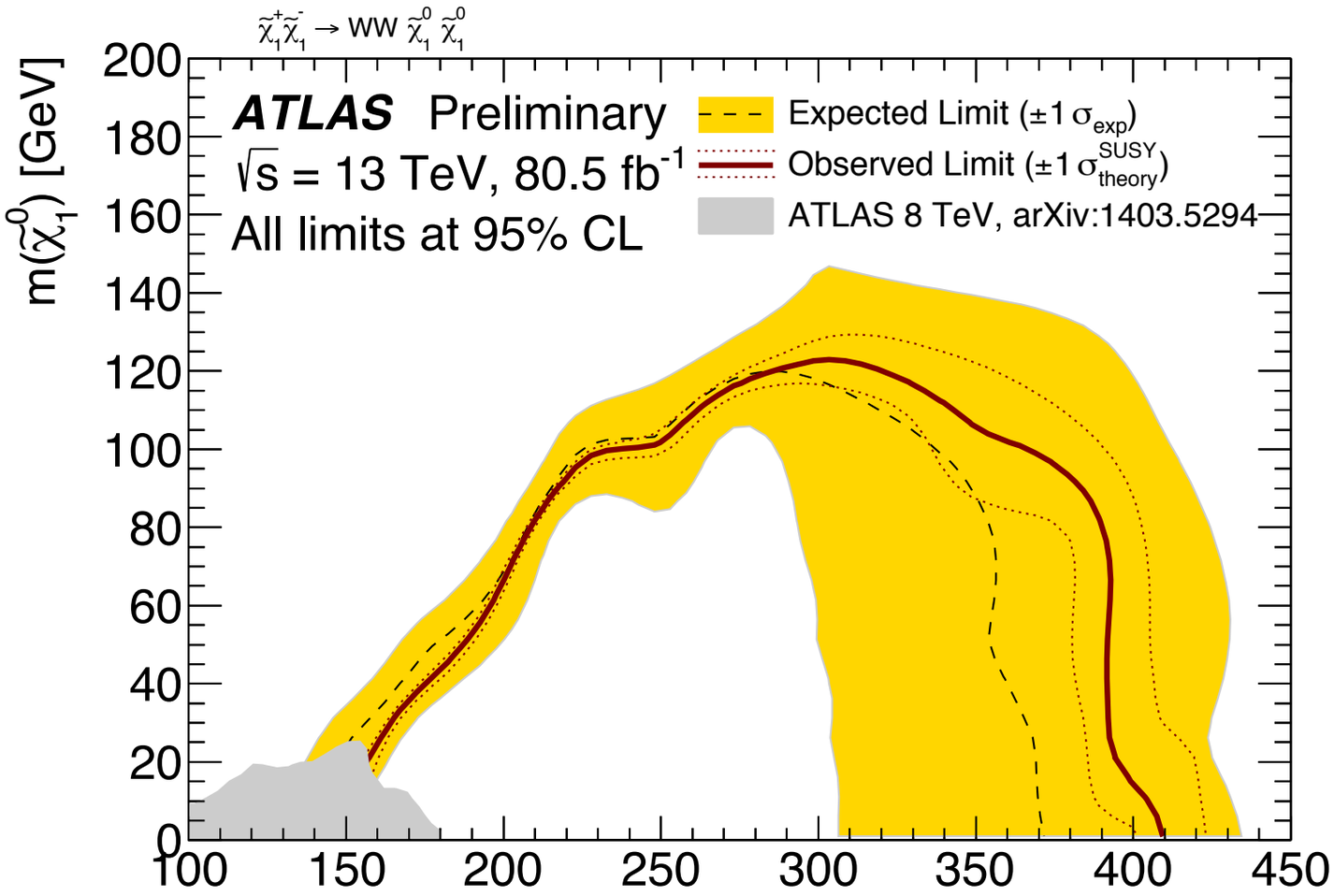
- $\ell^+\ell^-$ and large E_T^{miss}
- Search in M_{T2} bins in 4 different regions:
  - same ℓ flavor, 0 (1) jets
  - different flavor, 0 (1) jets



Conclusions

- Rich search program ongoing
  - Advancements in experimental techniques & strategies
- No significant excess found so far
- Hence, many extensions of the SM strongly constrained
  - Can be reinterpreted in many other models
  - Many searches provided in HEPData for reinterpretation in alternative models