# Searches for Exotic Phenomena in ATLAS

Johannes Erdmann (TU Dortmund University)
on behalf of the ATLAS Collaboration

Interpreting the LHC
Run 2 Data and Beyond

ICTP Trieste
28.05.2019

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?

$\alpha=\alpha_W=\alpha_S$?

$m_\nu$ ?

3 gen. ?

lepton & quark?

# Open Questions

DM ?

$m_H \ll \Lambda_P$ ?

$m_e \ll m_t$ ?

baryon asym. ?

gravitation?

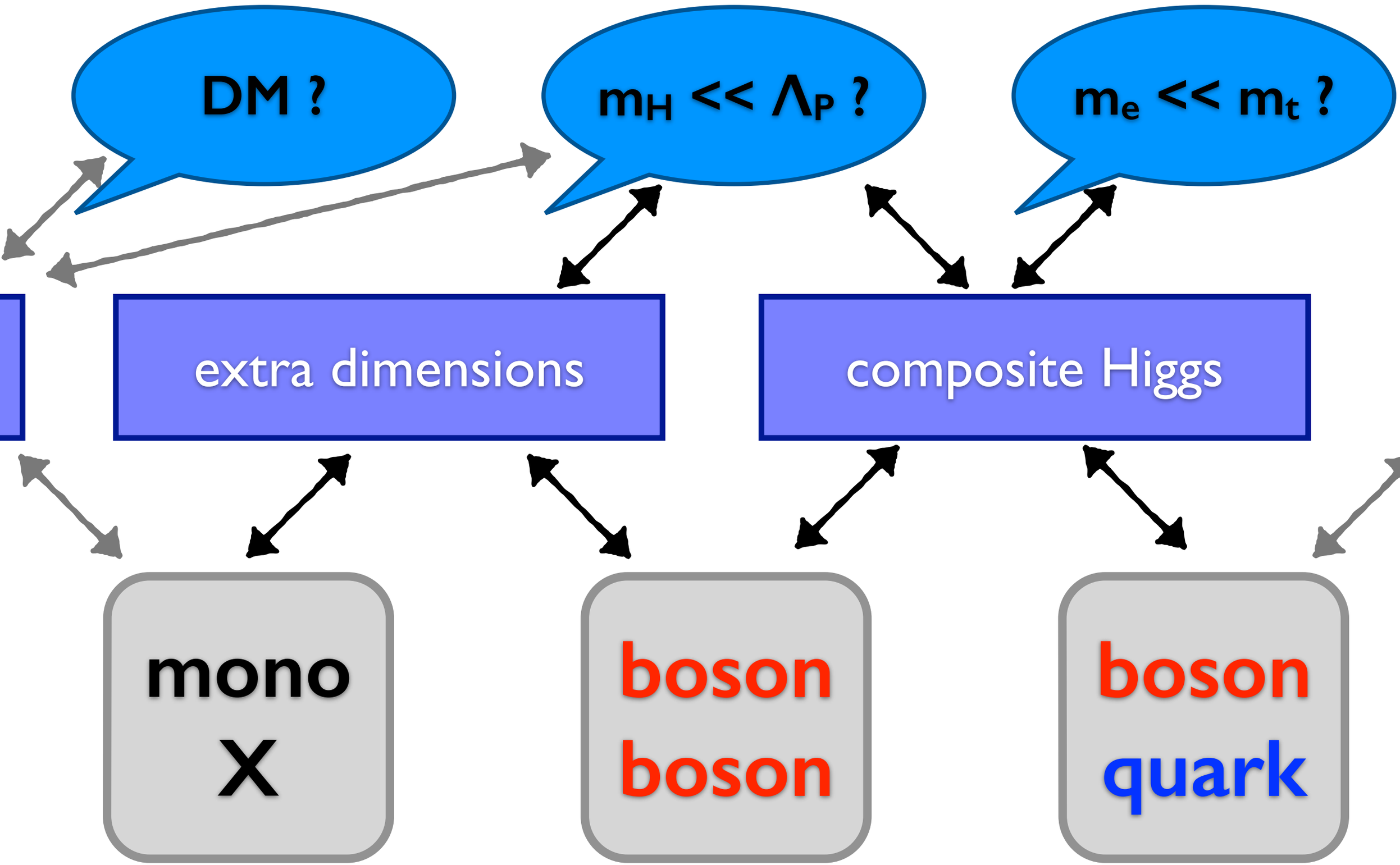
$\alpha=\alpha_W=\alpha_S$?

$m_\nu$ ?

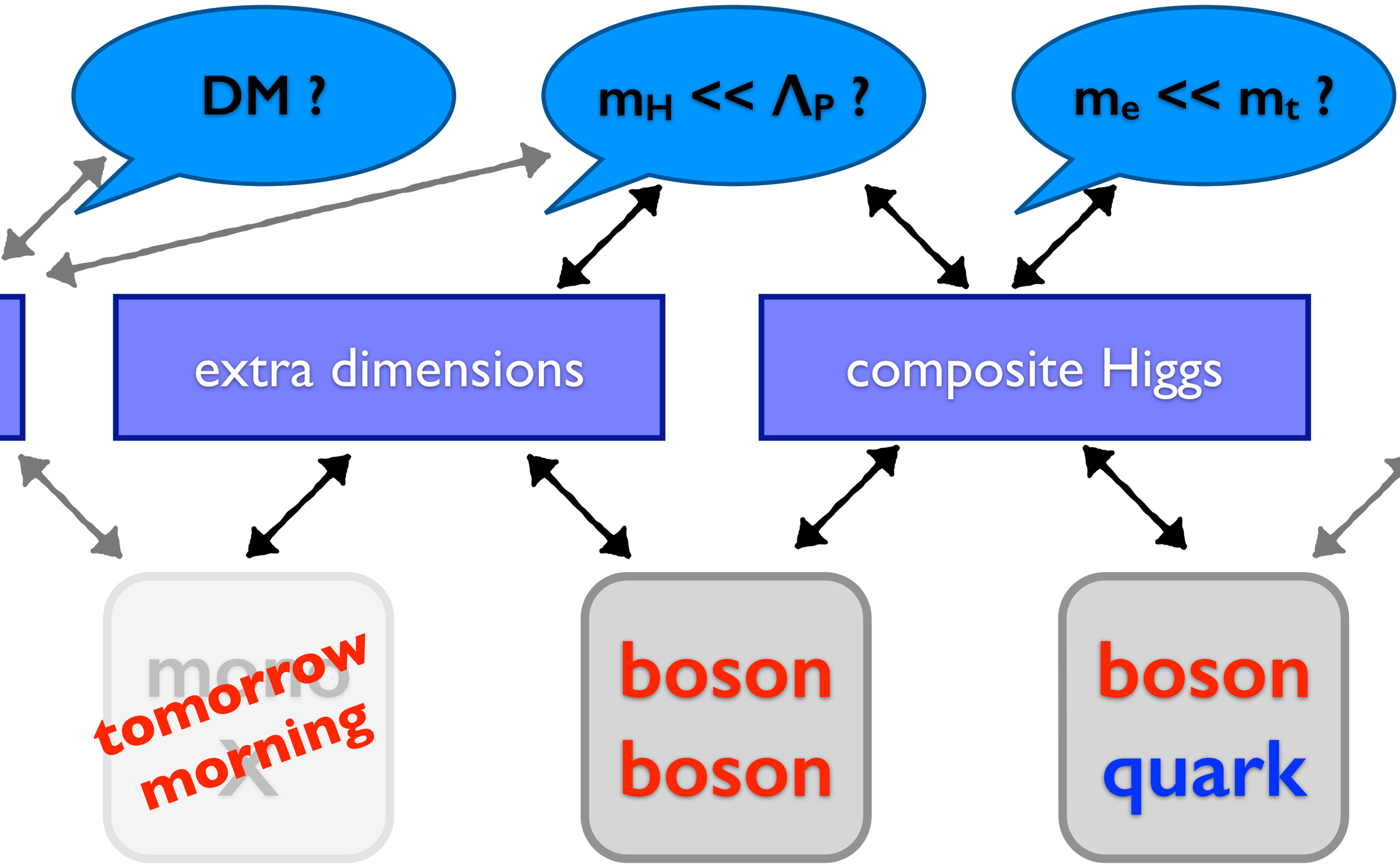
3 gen. ?

lepton & quark?

# Answers?


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

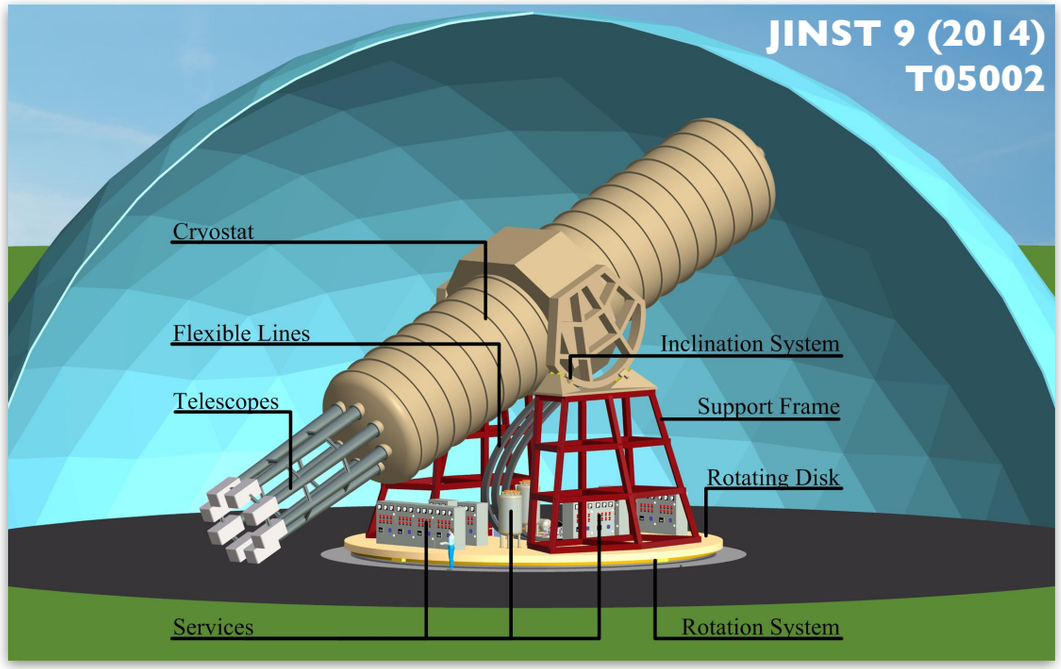
# Answers?


DM ?
$m_H << \Lambda_P$ ?
$m_e << m_t$ ?
extra dimensions
composite Higgs
tomorrow morning
boson boson
boson quark

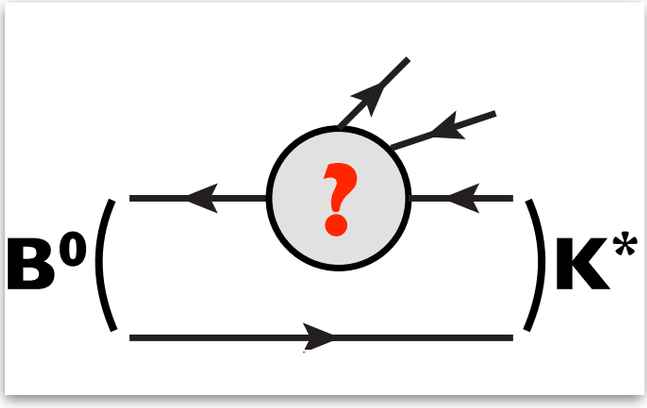
# Searches

## Collider

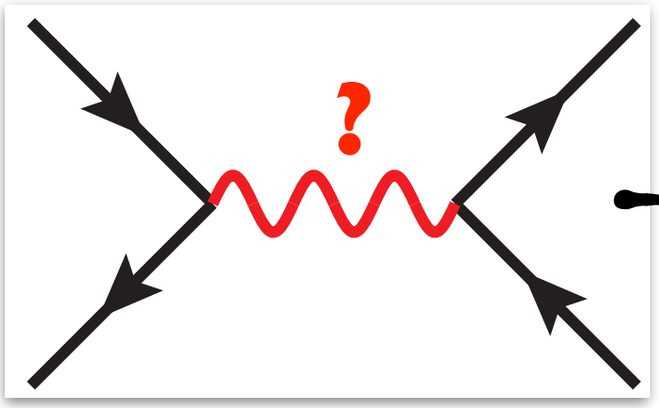

## Non-Collider




## Indirect




## Direct




Wealth of results

- focussing on '$\Delta t < 1$ year'

**Thursday morning session**

# Tackling New Physics with Distinct Signatures

long-lived

boson
boson

boson
quark

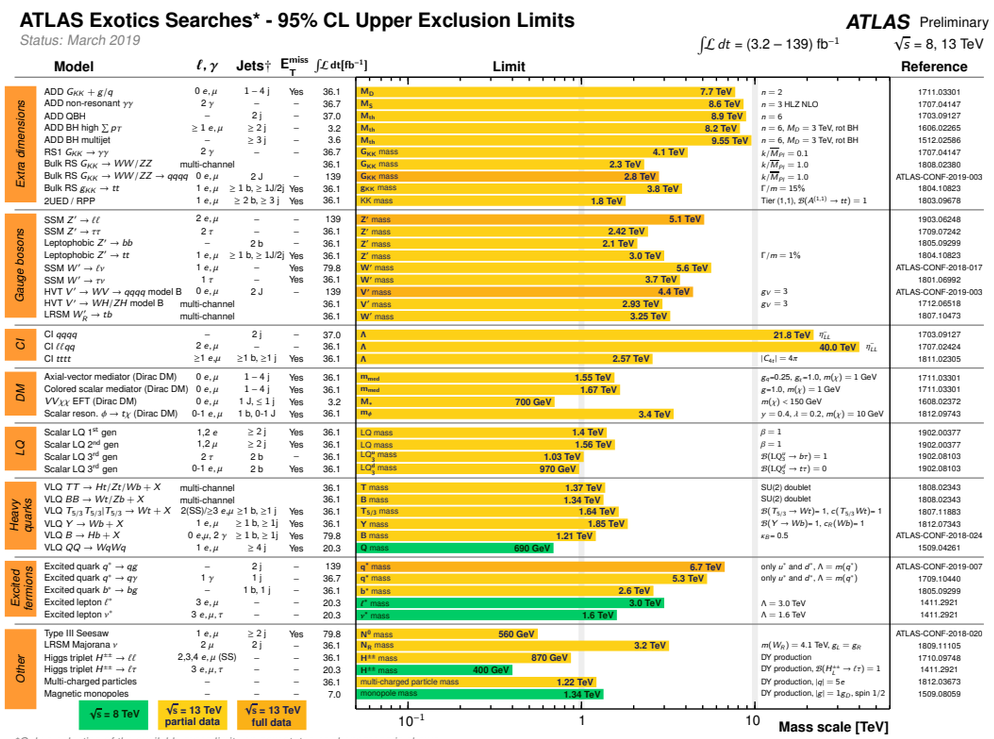
leptons

lepton
quark

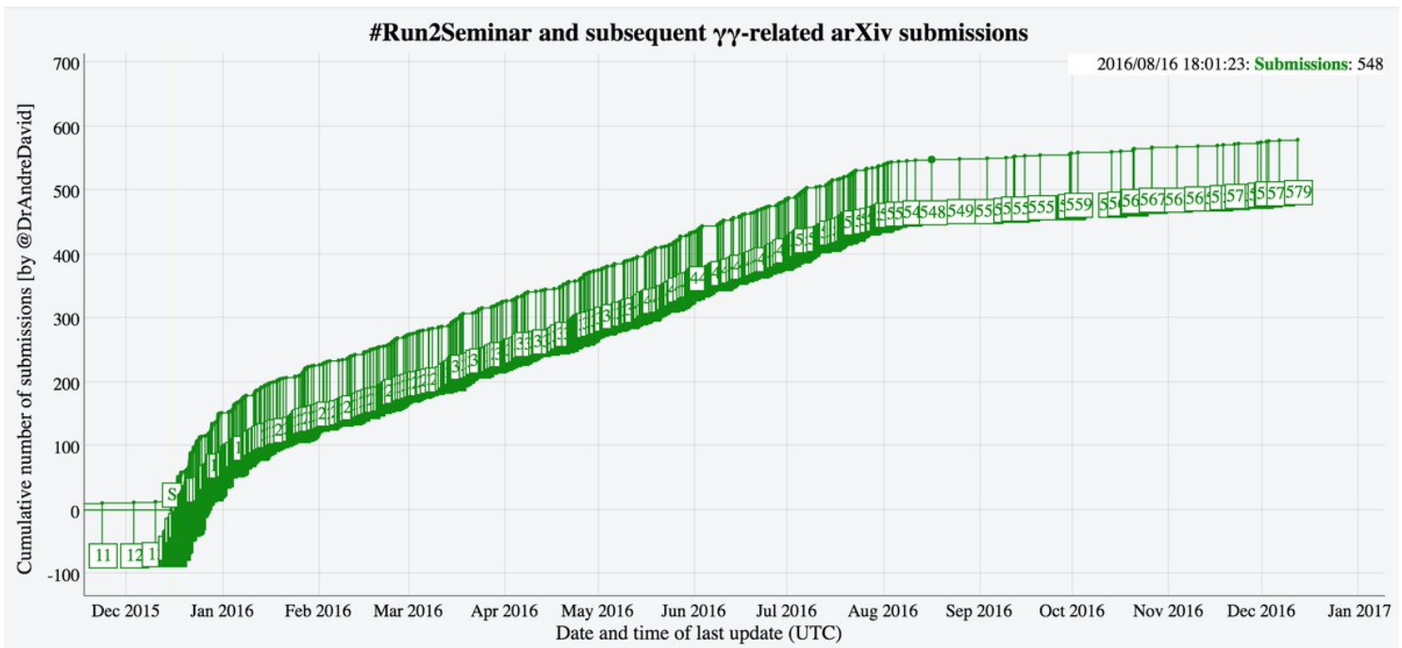
quark
quark

# Spoiler Alert!

*No significant deviations from the SM observed so far.*



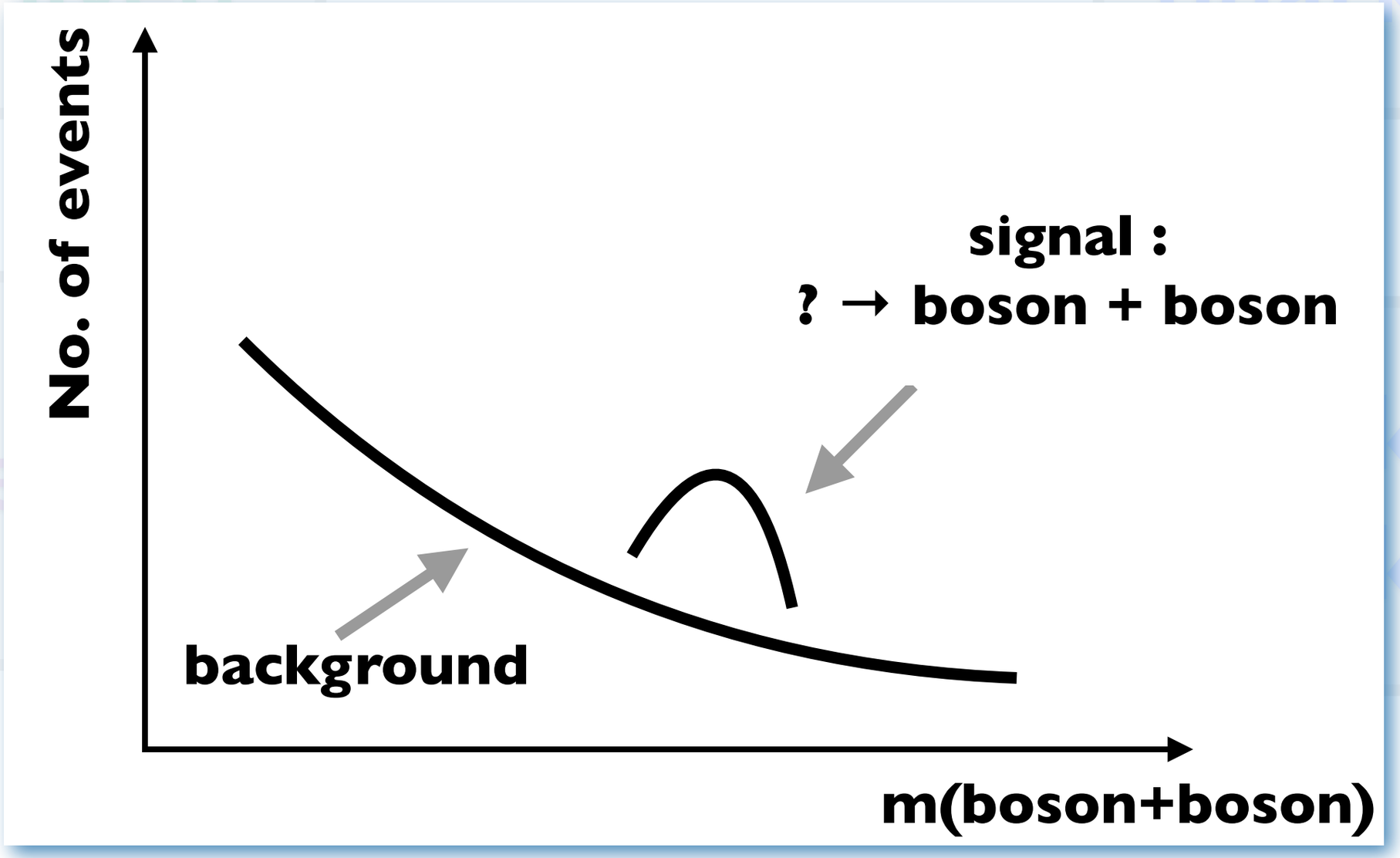

*One single discovery may turn particle physics upside down.*




**twitter.com/DrAndreDavid**

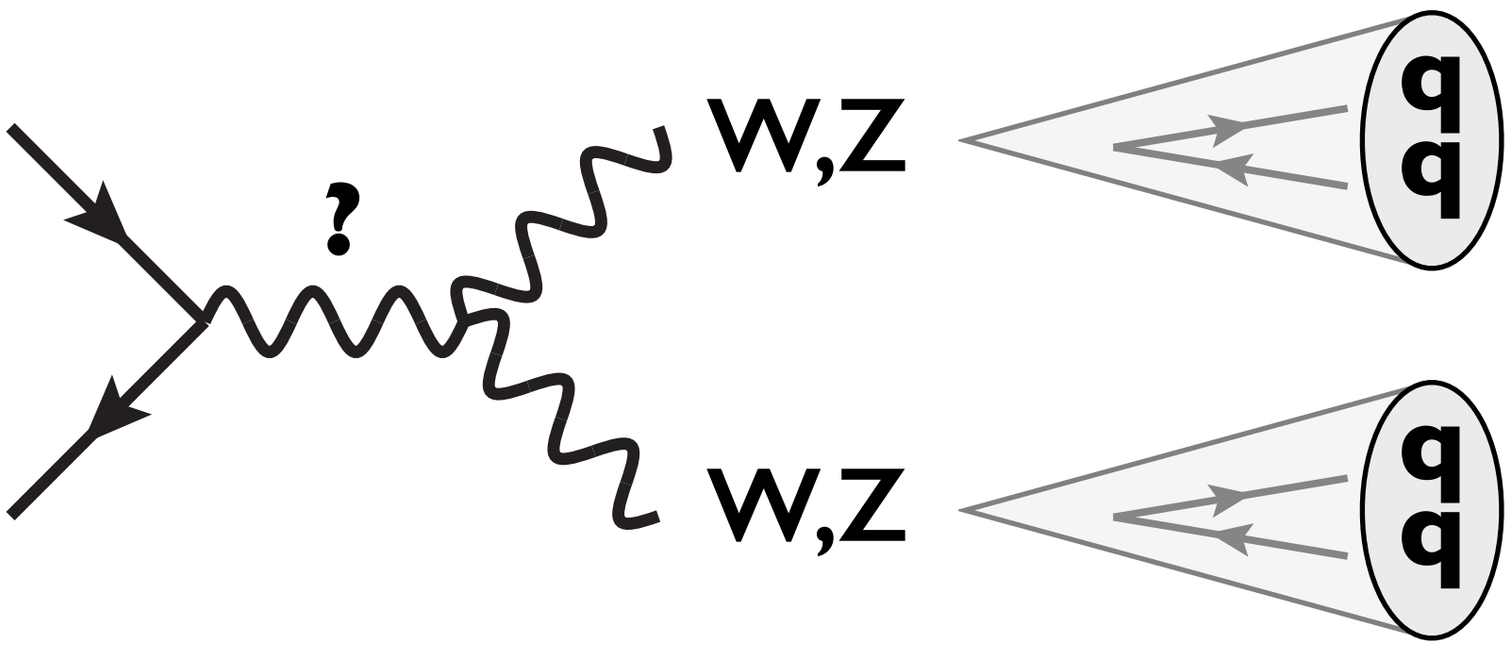
$m_H << \Lambda_P$ ?

**boson**
**boson**



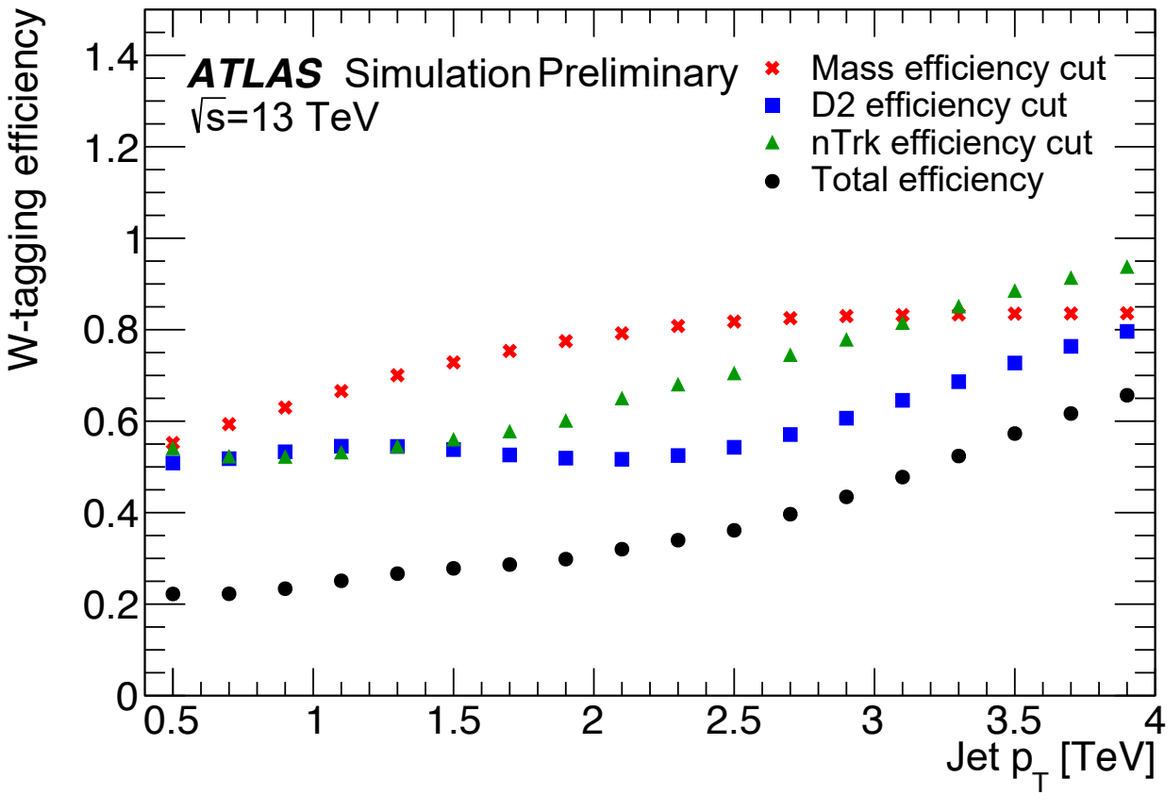
# All-hadronic Di-W/Z

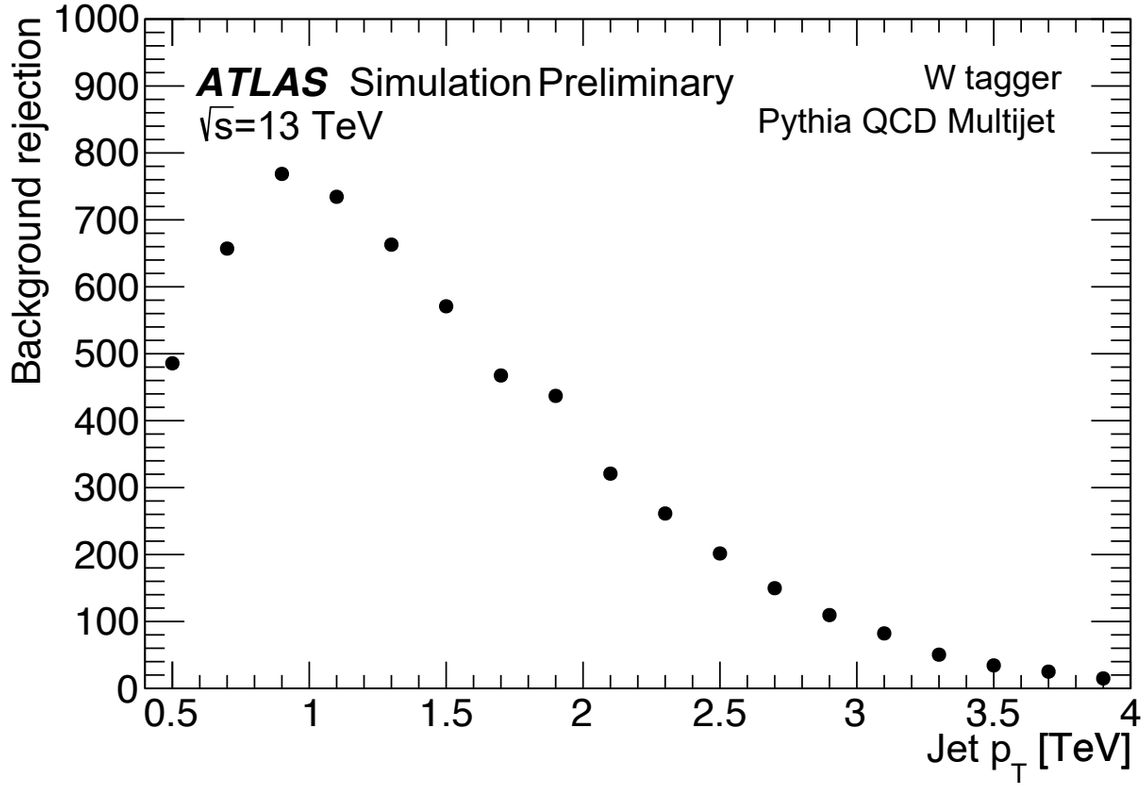





Novel boson tagging

- track-calo clusters:
  up to x2 better $D_2$ res.
- tagger optimized for
  sensitivity ( $\varepsilon/\left(a/2+\sqrt{B}\right)$ )
  in this analysis



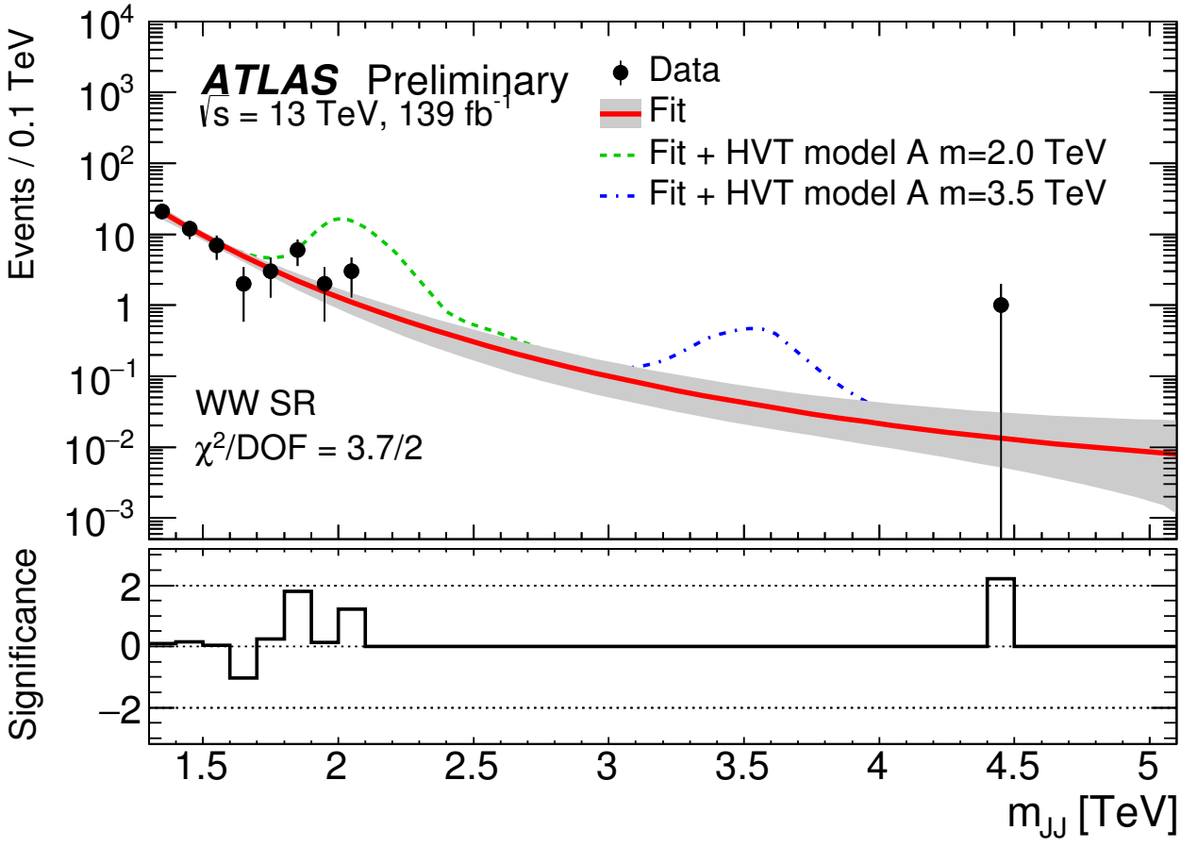



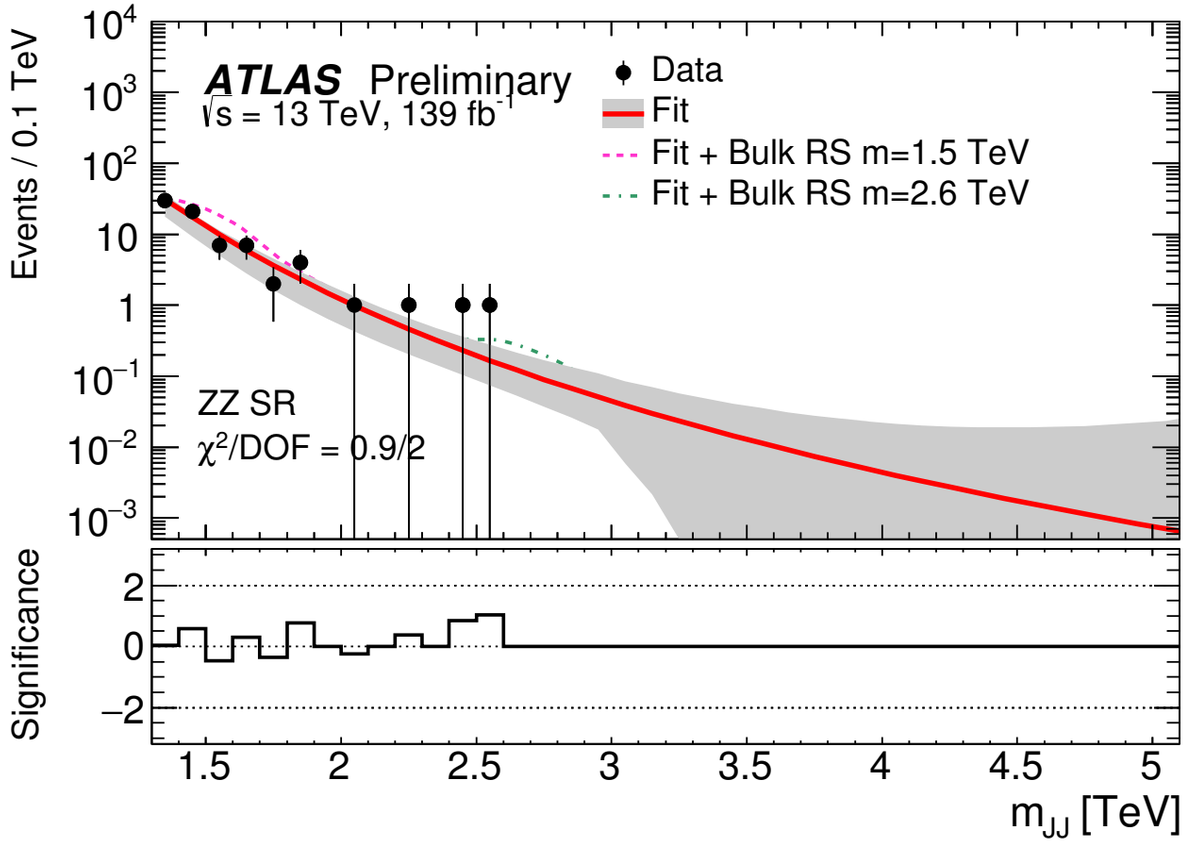
# All-hadronic Di-W/Z



Selection

- 2 boson-tagged large-R jets
- Small $\Delta\eta$
- Good $p_T$ symmetry



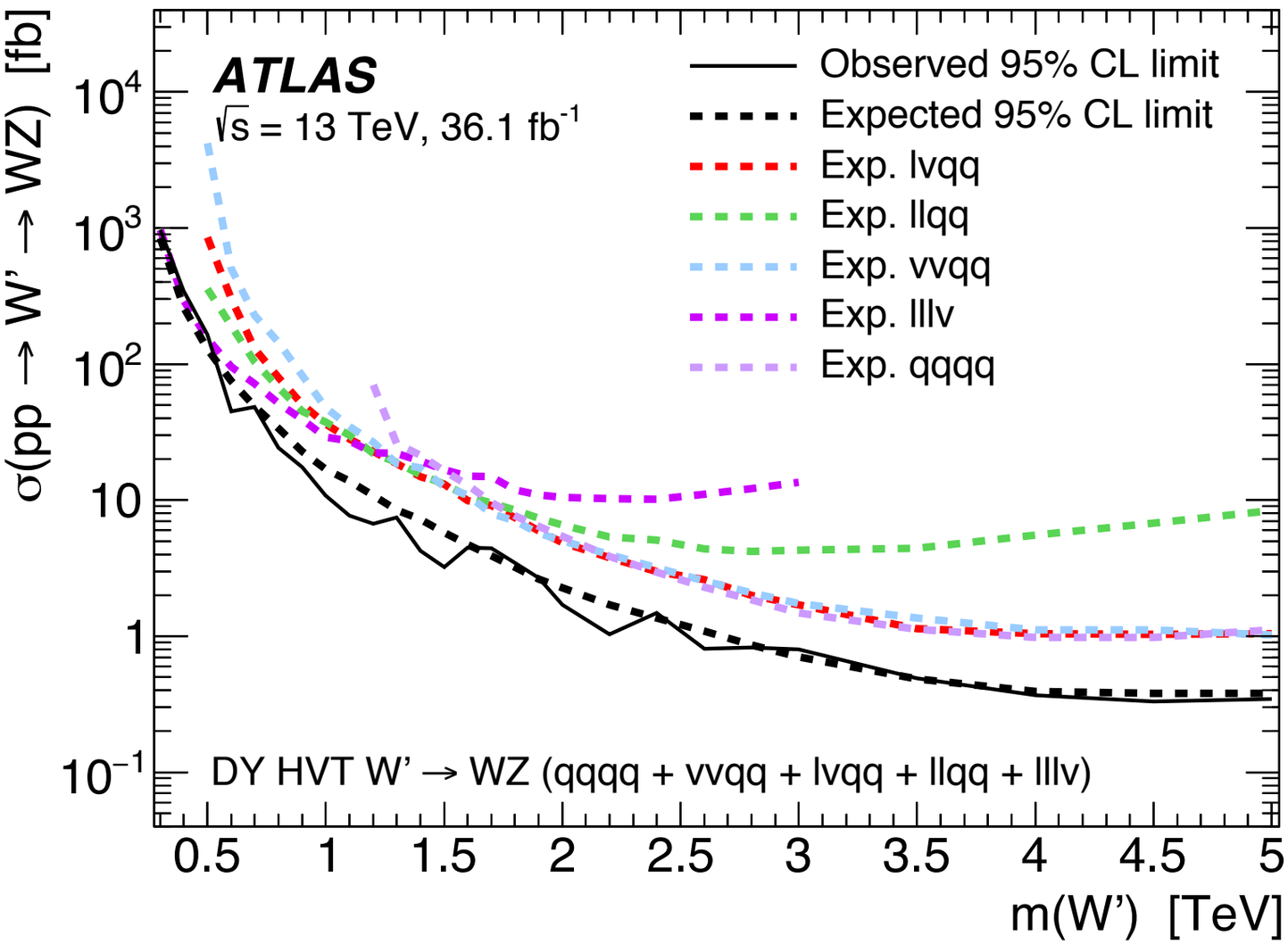



# Diboson Combination



- 12 diboson searches combined
- Various complementary final states
- Including VBF signatures

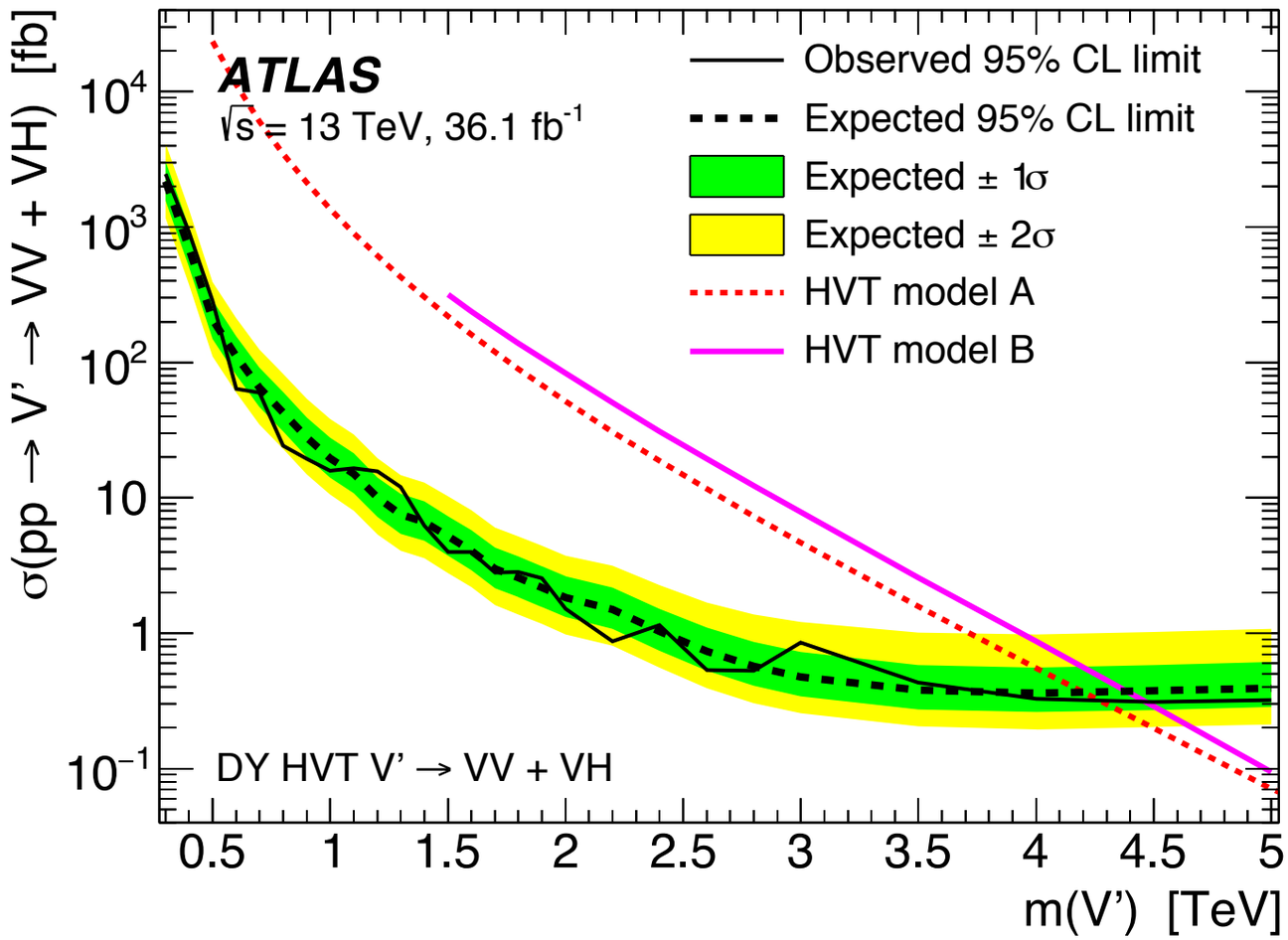
| Channel | Diboson state | Selection | | | | VBF cat. |
|---|---|---|---|---|---|---|
| | | Leptons | $E_{\mathrm{T}}^{\mathrm{miss}}$ | Jets | $b$-tags | |
| $qqqq$ | $WW/WZ/ZZ$ | 0 | veto | 2J | – | – |
| $\nu\nu qq$ | $WZ/ZZ$ | 0 | yes | 1J | – | yes |
| $\ell\nu qq$ | $WW/WZ$ | $1e, 1\mu$ | yes | 2j, 1J | – | yes |
| $\ell\ell qq$ | $WZ/ZZ$ | $2e, 2\mu$ | – | 2j, 1J | – | yes |
| $\ell\ell\nu\nu$ | $ZZ$ | $2e, 2\mu$ | yes | – | 0 | yes |
| $\ell\nu\ell\nu$ | $WW$ | $1e$+$1\mu$ | yes | – | 0 | yes |
| $\ell\nu\ell\ell$ | $WZ$ | $3e$, $2e$+$1\mu$, $1e$+$2\mu$, $3\mu$ | yes | – | 0 | yes |
| $\ell\ell\ell\ell$ | $ZZ$ | $4e$, $2e$+$2\mu$, $4\mu$ | – | – | – | yes |
| $qqbb$ | $WH/ZH$ | 0 | veto | 2J | 1, 2 | – |
| $\nu\nu bb$ | $ZH$ | 0 | yes | 2j, 1J | 1, 2 | – |
| $\ell\nu bb$ | $WH$ | $1e, 1\mu$ | yes | 2j, 1J | 1, 2 | – |
| $\ell\ell bb$ | $ZH$ | $2e, 2\mu$ | veto | 2j, 1J | 1, 2 | – |



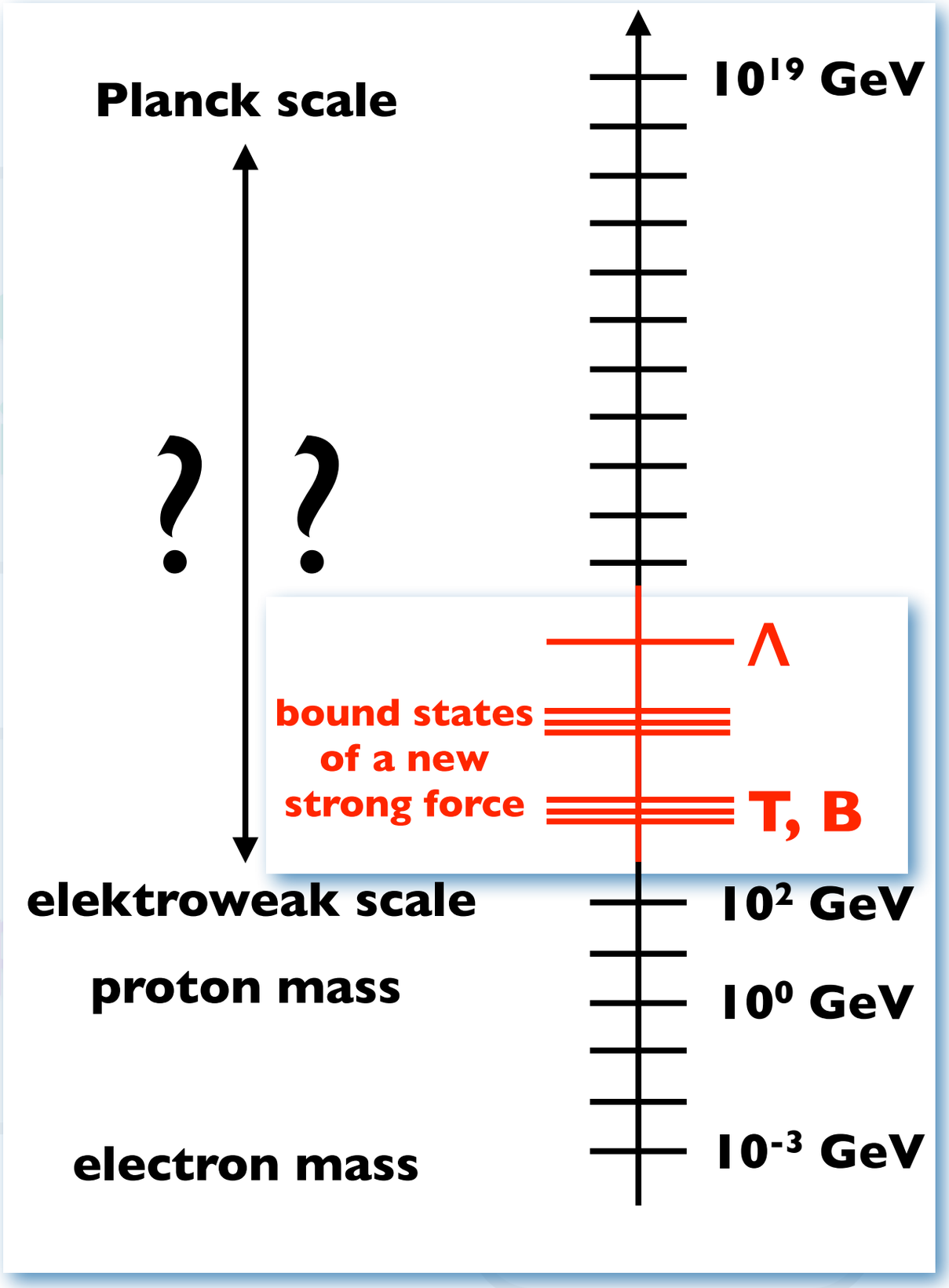
# Diboson Combination



- Large number of interpretations:
  - explicit final states: W' → WZ, …
  - heavy vector triplet models: V' → VV + VH, …




- 2D limits on couplings for given mass
- scalars, KK gravitons, …




boson

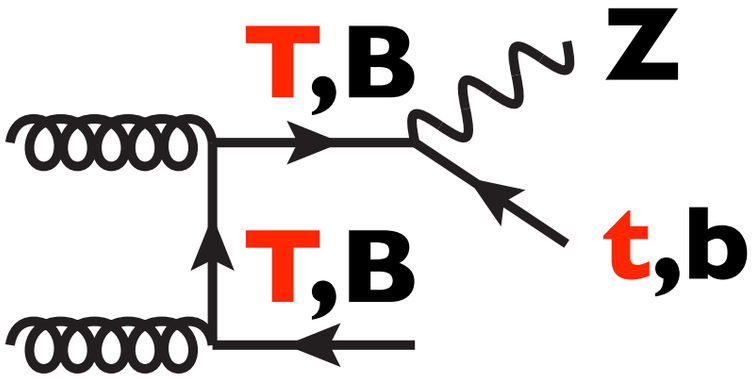
quark

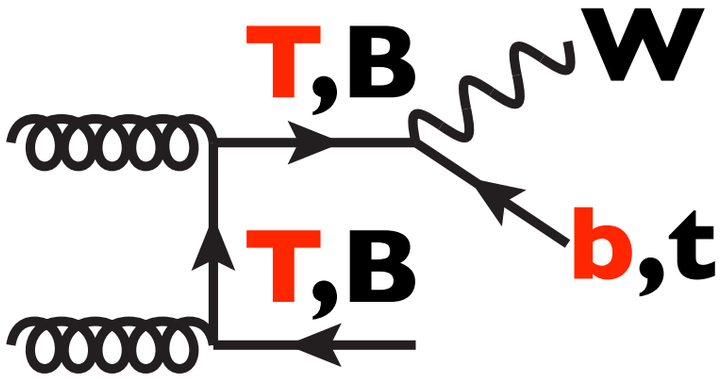
$m_H \ll \Lambda_P$ ?

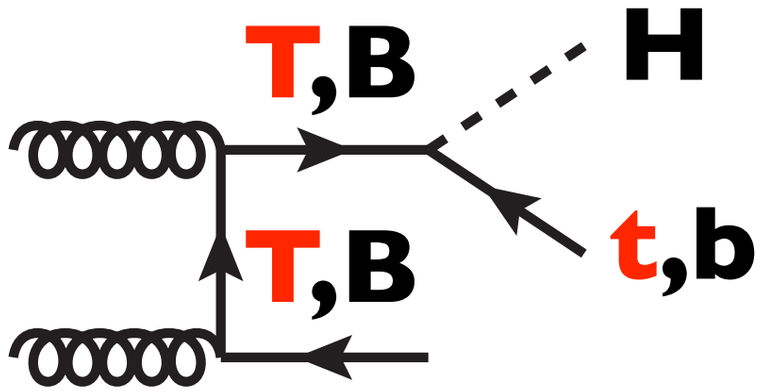
$m_e \ll m_t$ ?

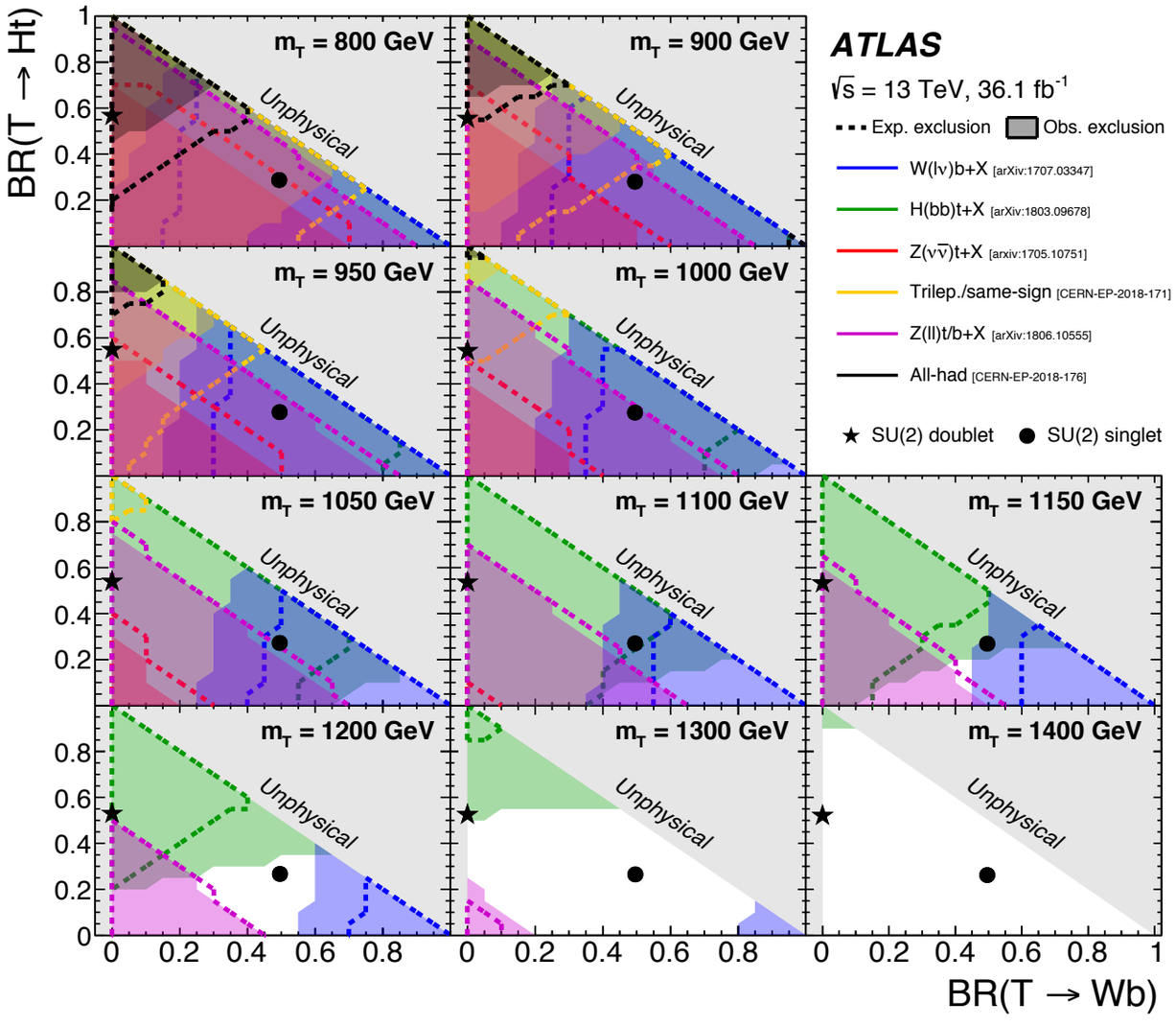
# VLQ Combination

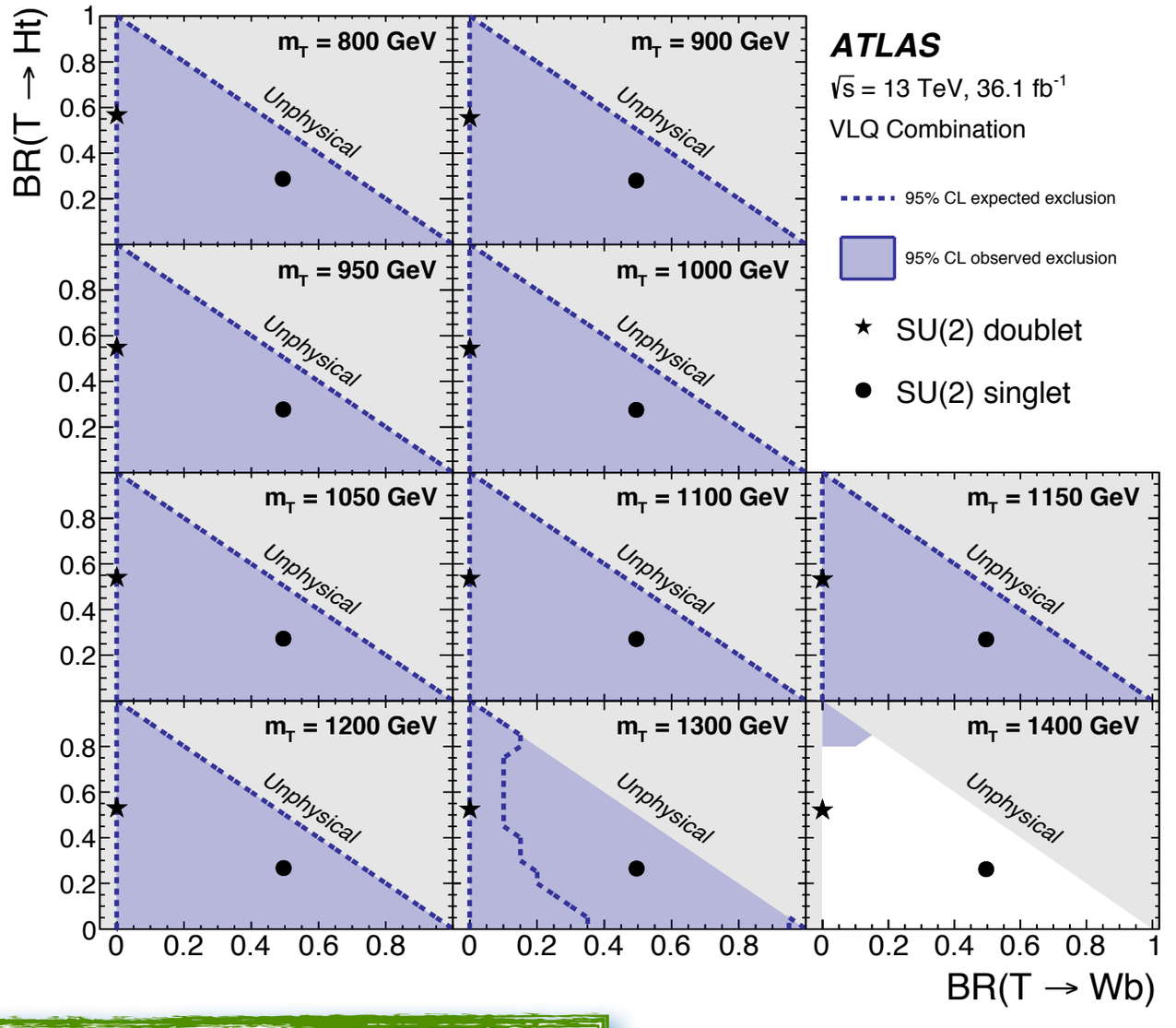




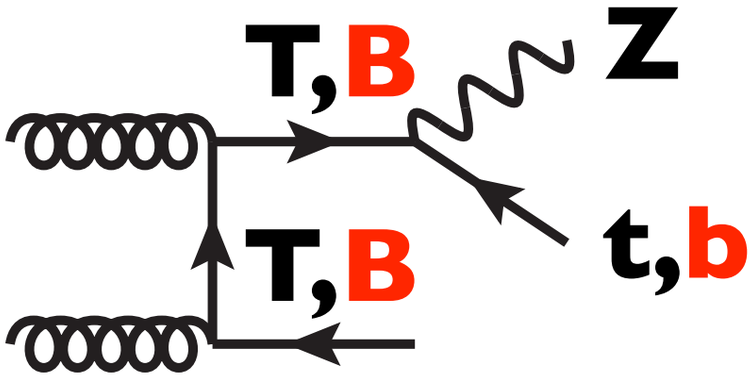



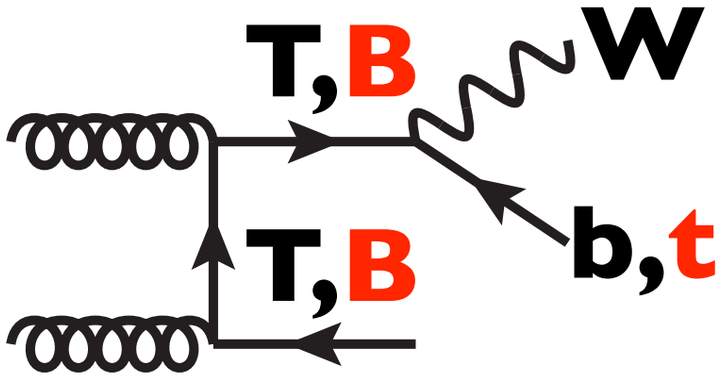



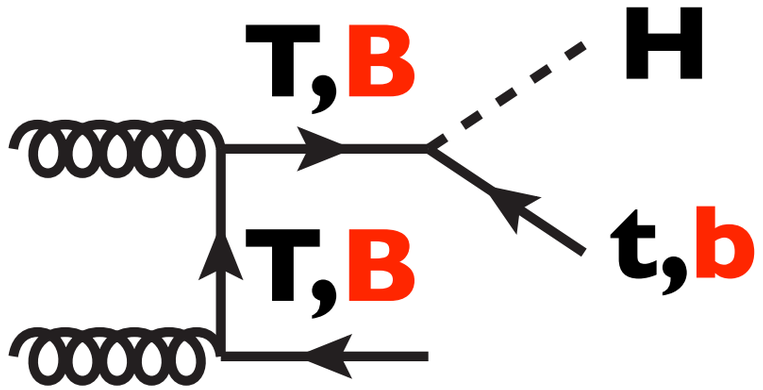

$m_T$ < 1.31 TeV for all BRs into SM particles

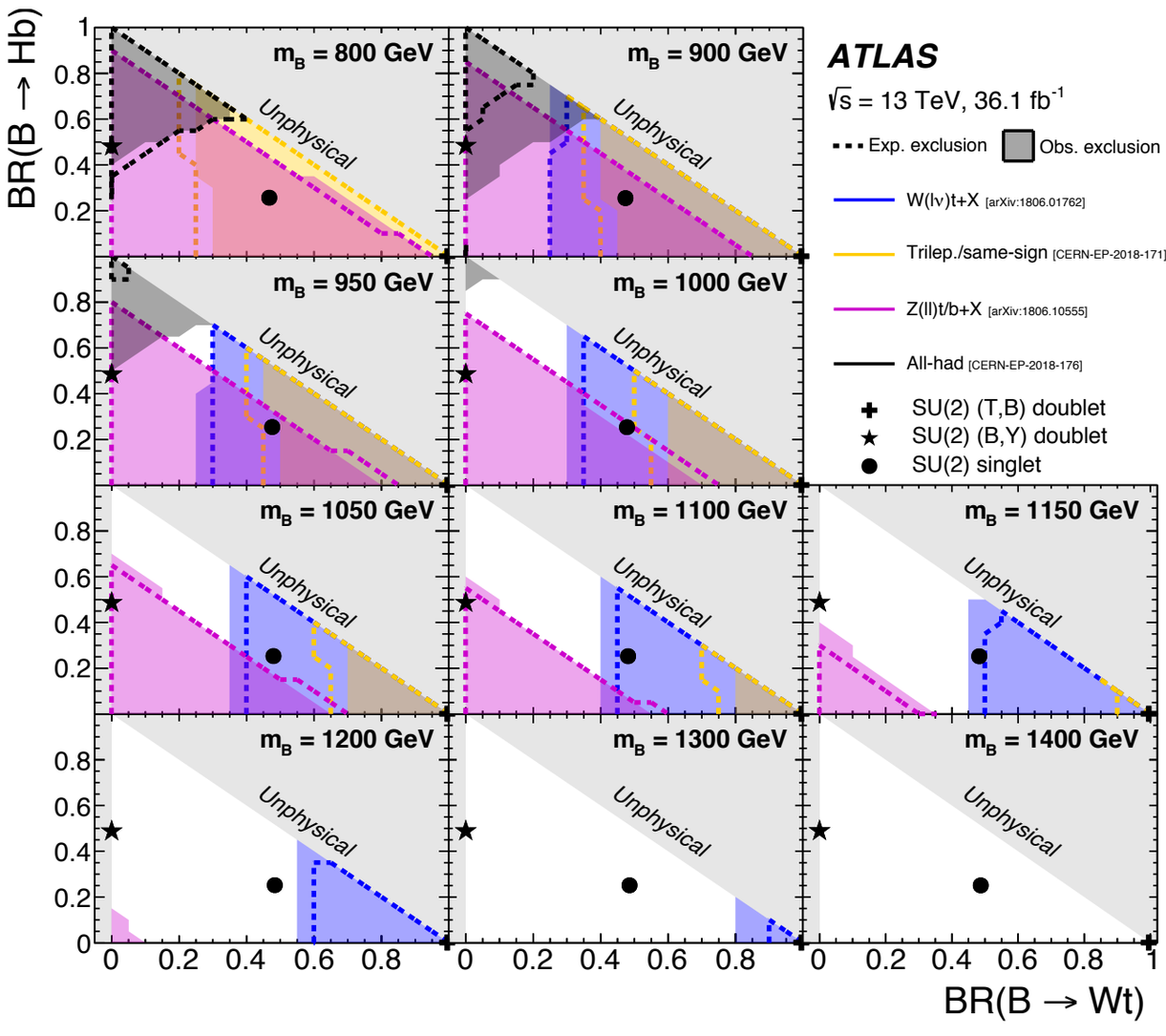
# VLQ Combination

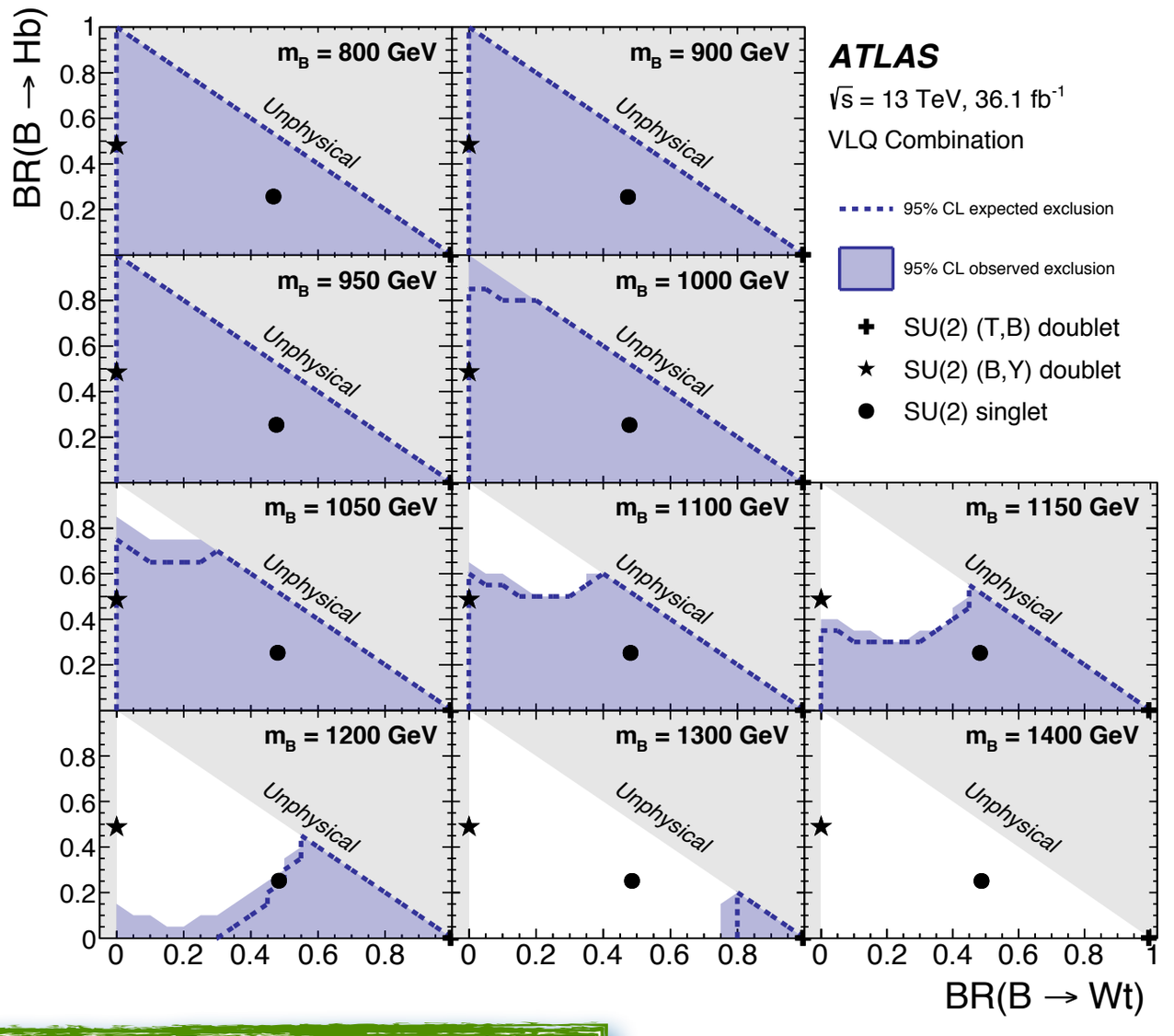




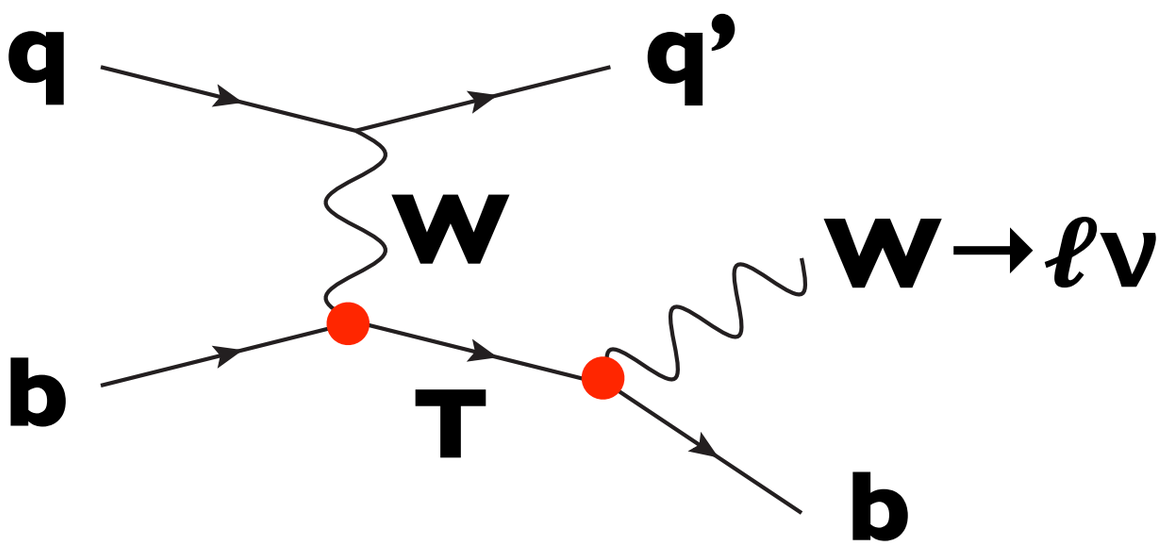



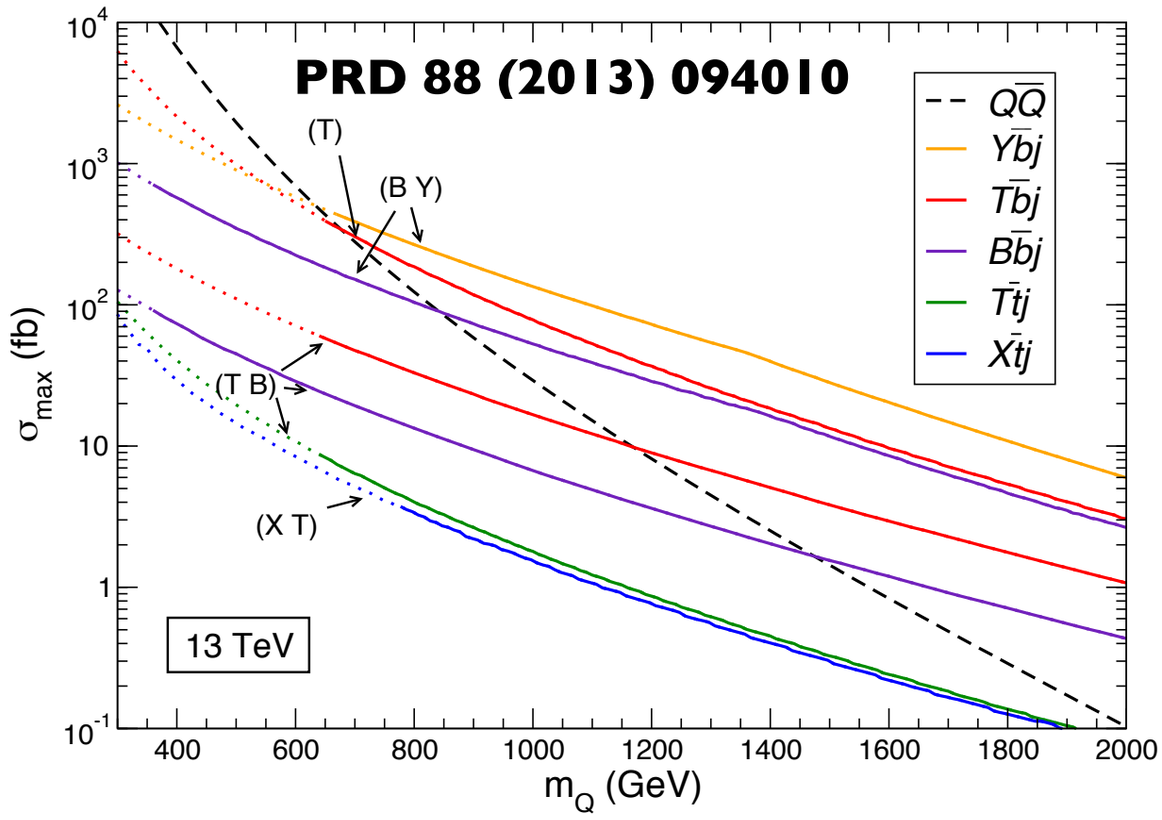

$m_B$ < 1.03 TeV for all BRs into SM particles

arXiv:1812.07343

# Single-VLQ → Wb

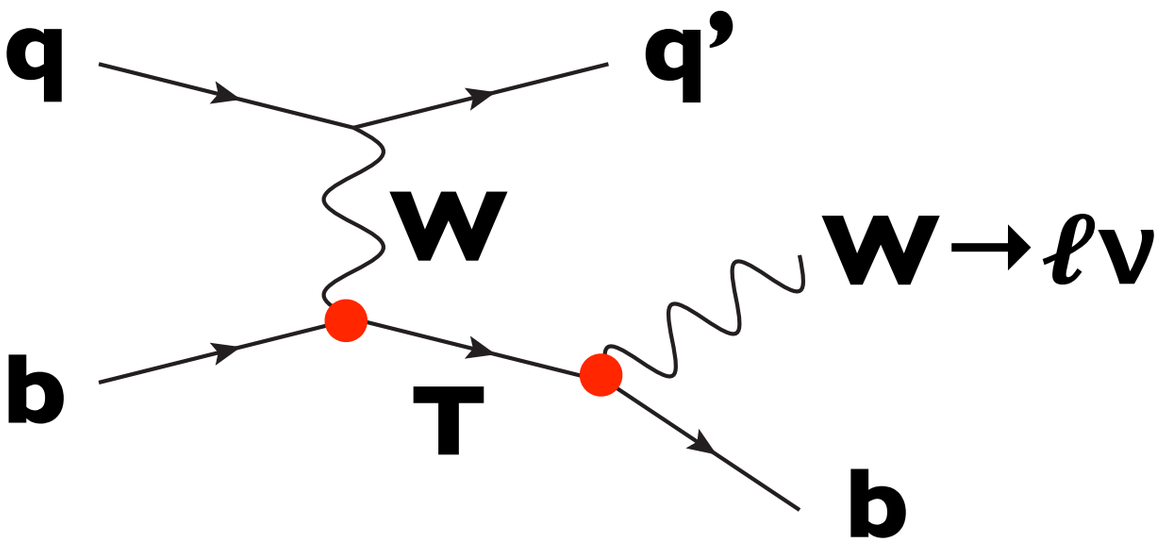
36 fb$^{-1}$

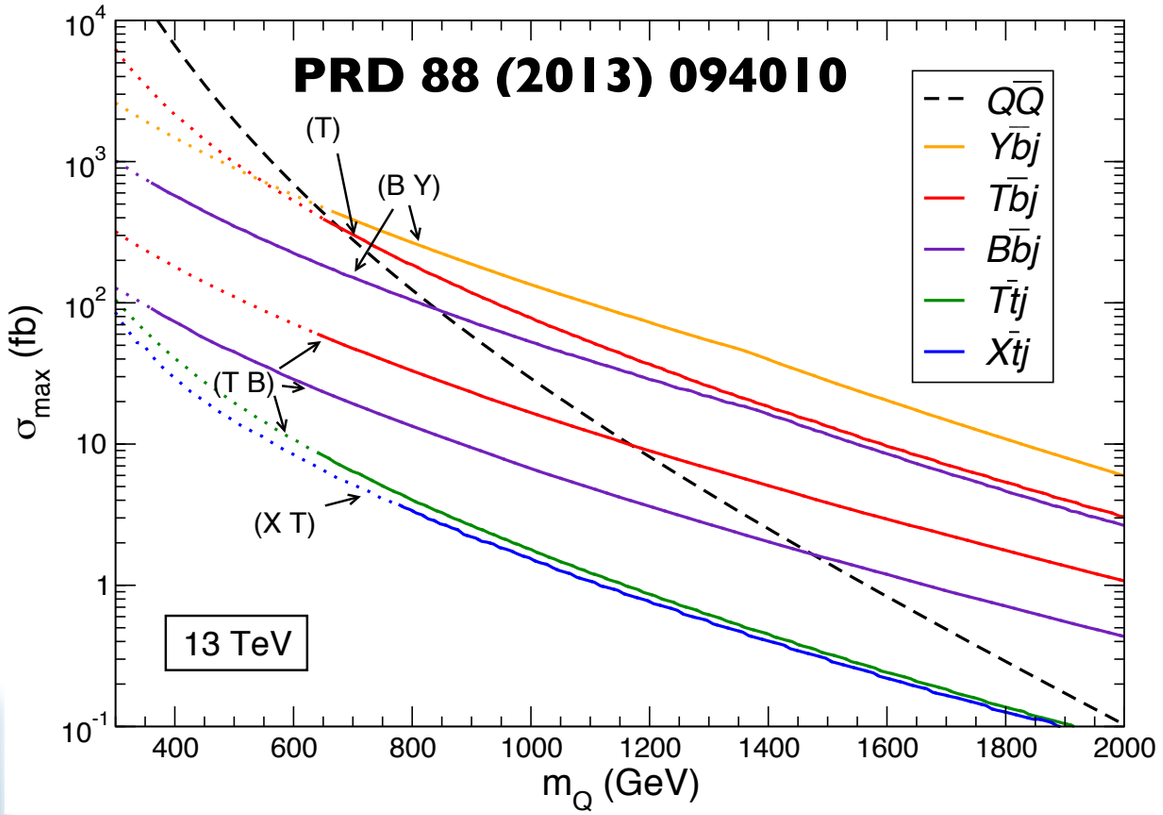


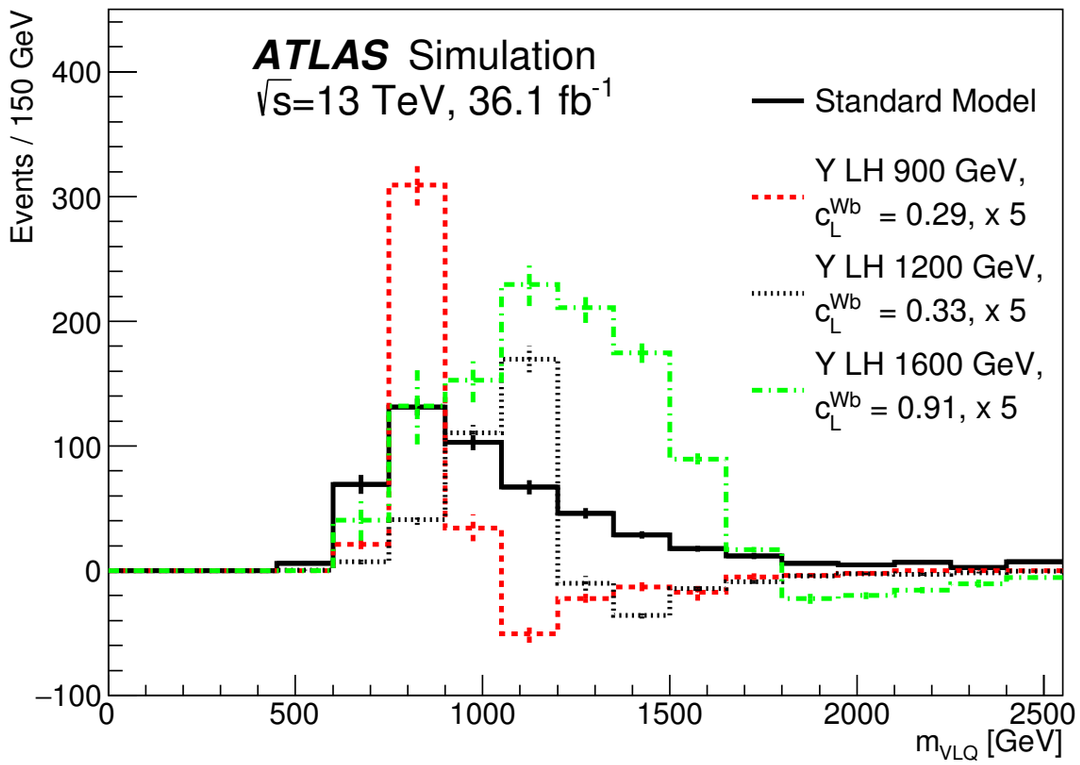
# Single-VLQ → Wb





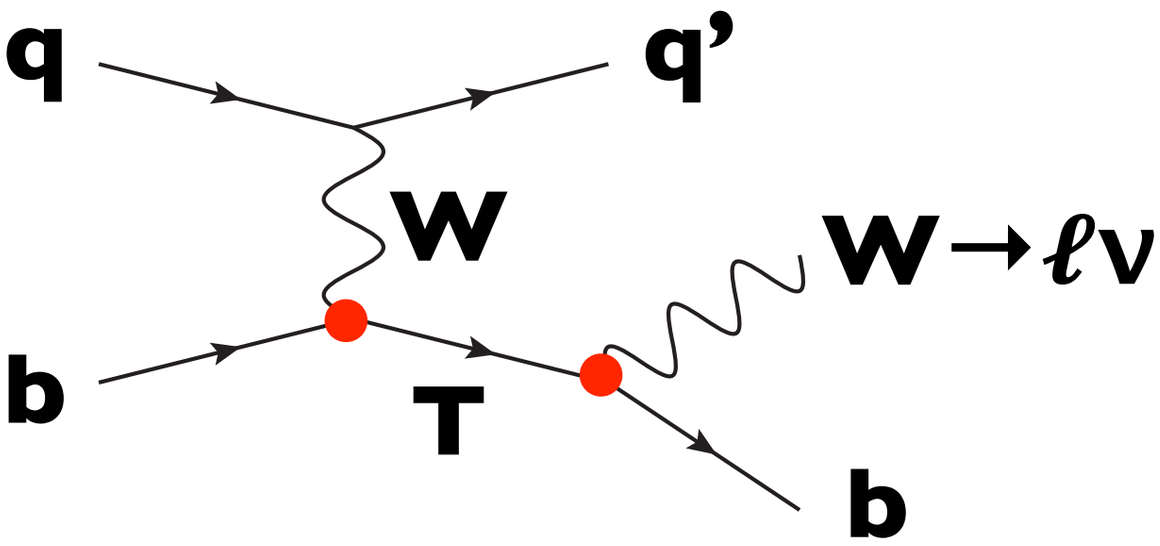



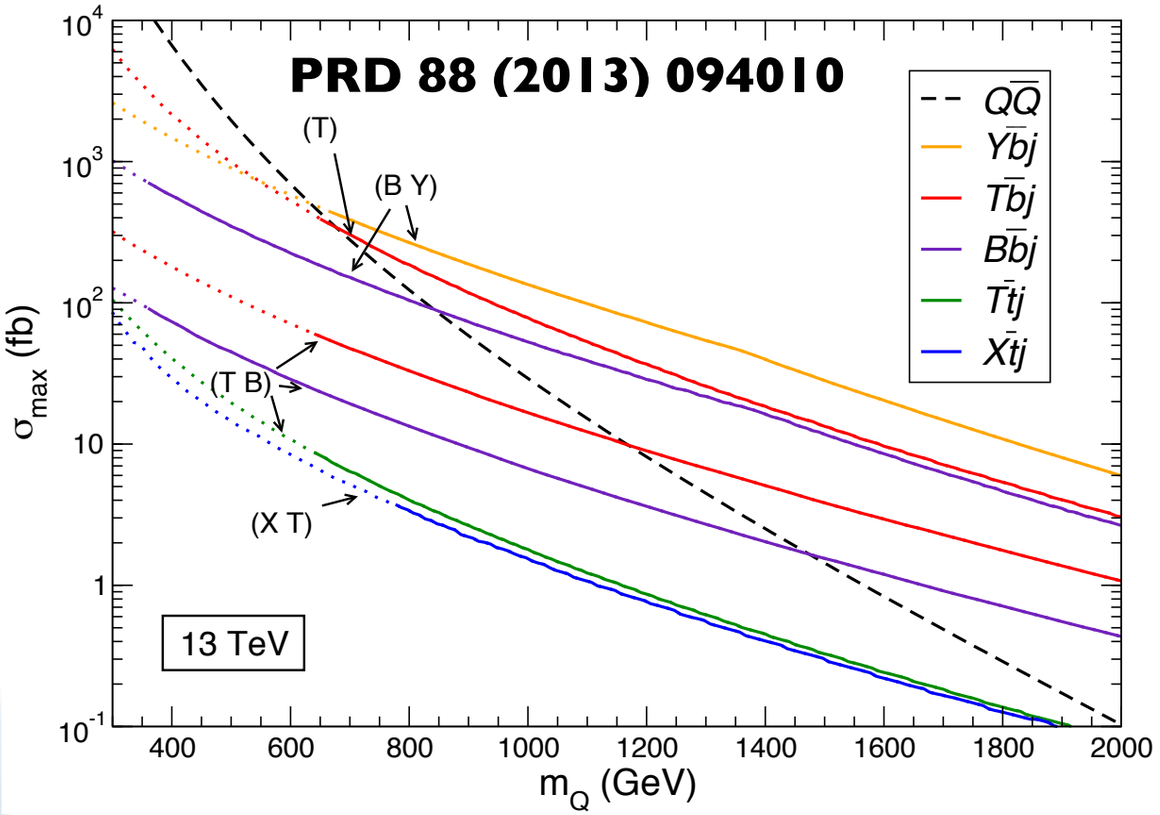

## Interference with W+jets and single top



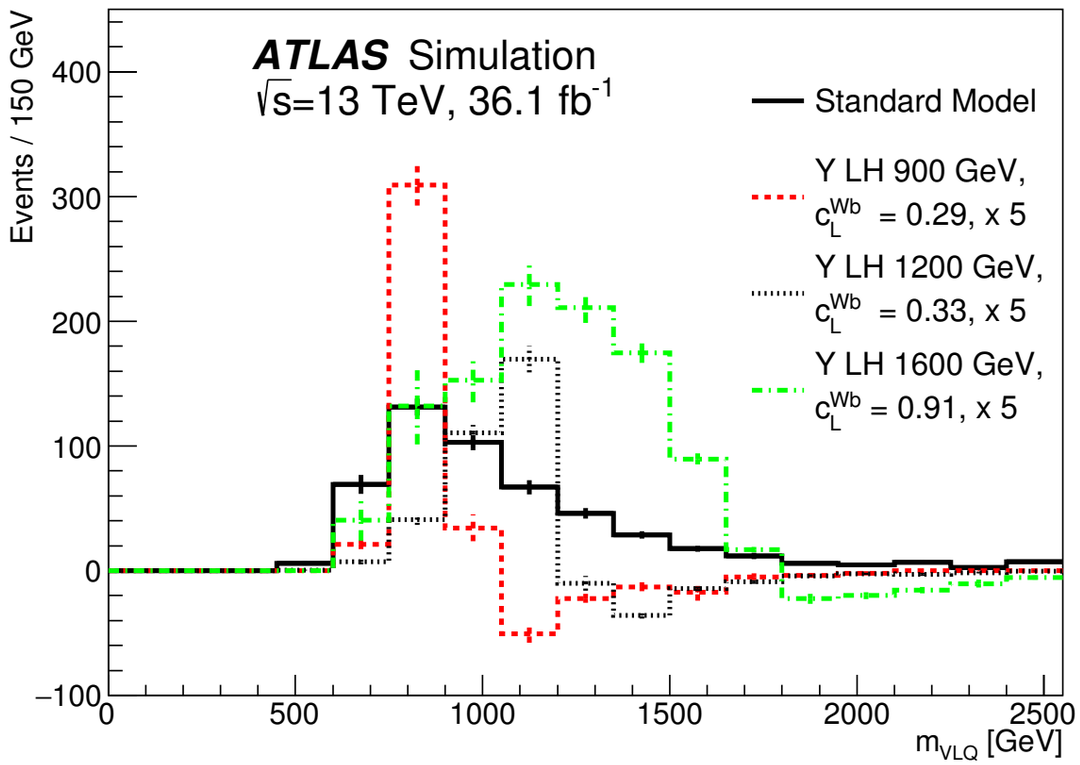
# Single-VLQ → Wb

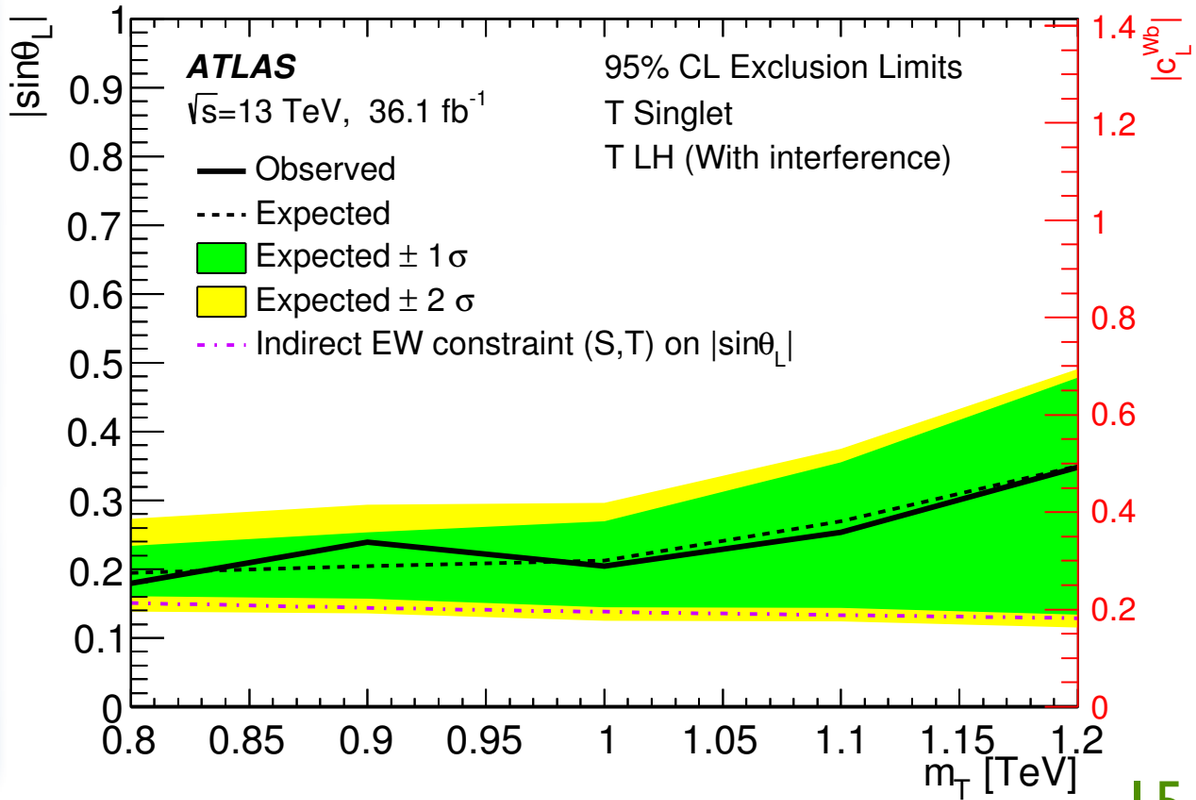





## Interference with W+jets and single top

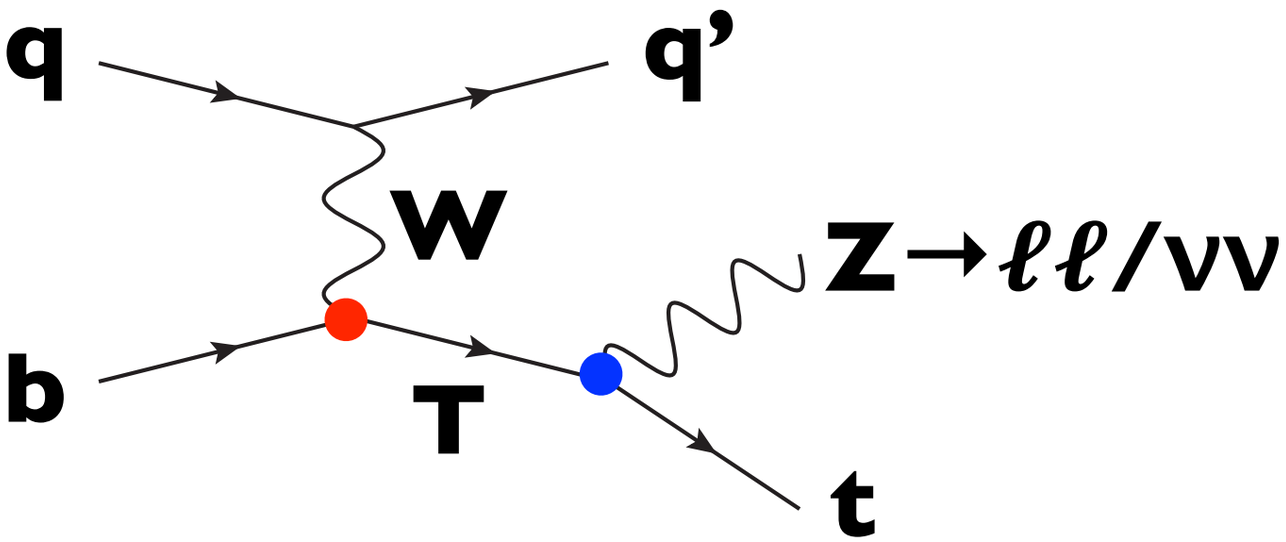


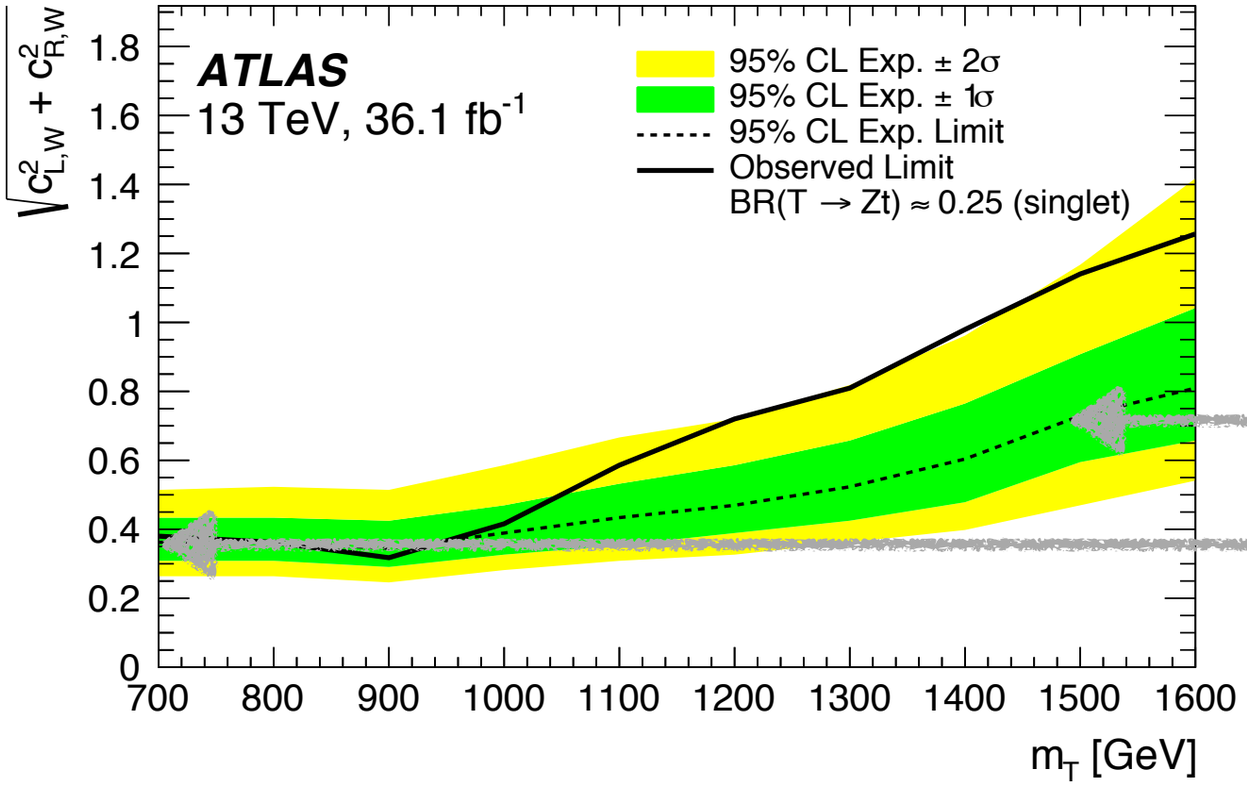
JHEP 05 (2019) 41
PRD 98 (2018) 112010

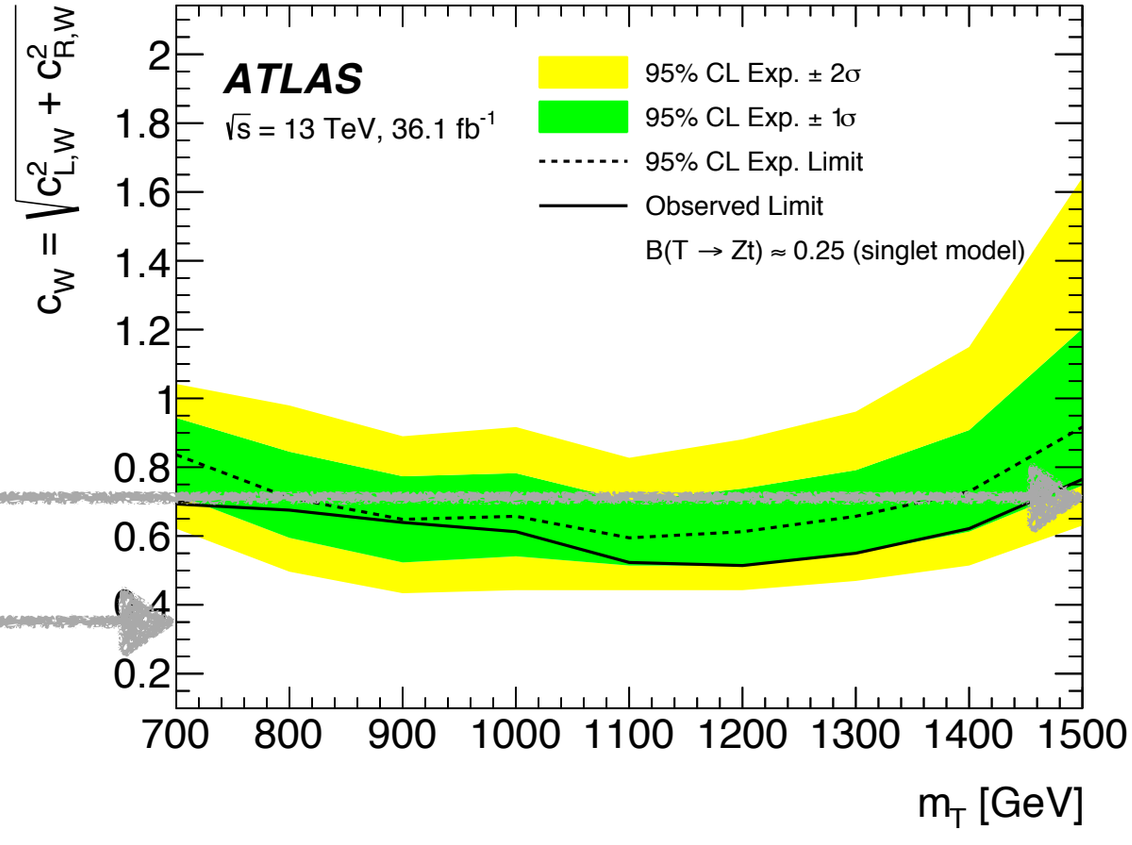
# Single-VLQ → Zt

36 fb$^{-1}$



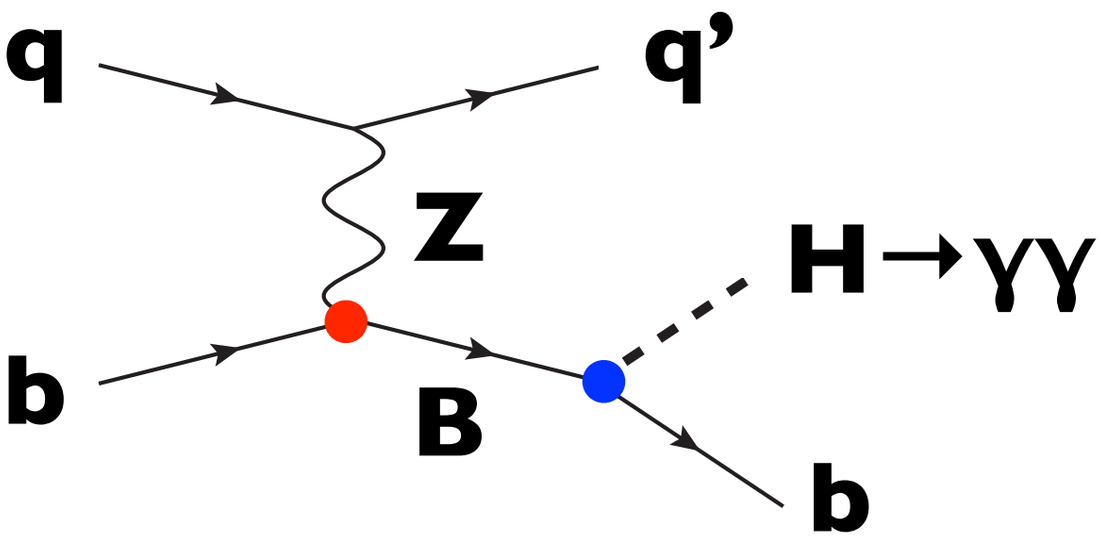

- 3$\ell$ and 2$\ell$ for Z → $\ell\ell$
  - generally more sensitive
- boosted top + $E_T^{miss}$ for Z → νν
  - increases sensitivity at high m



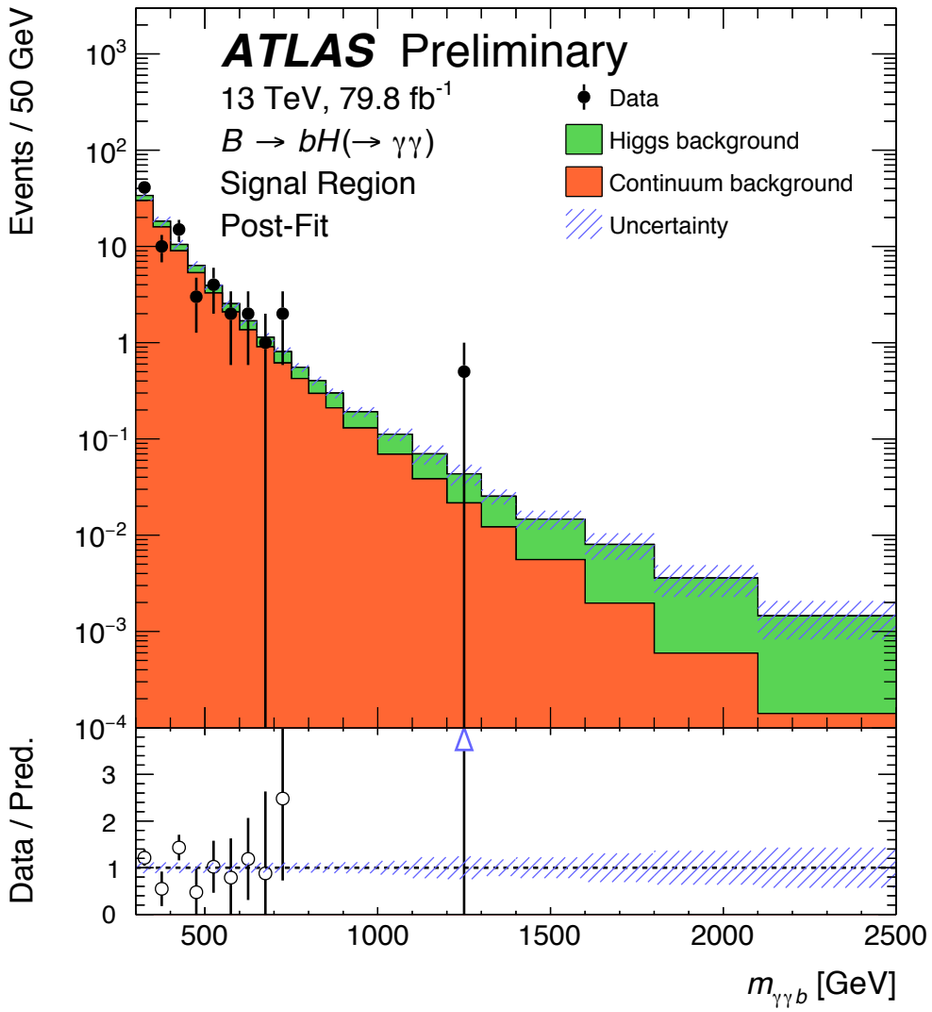



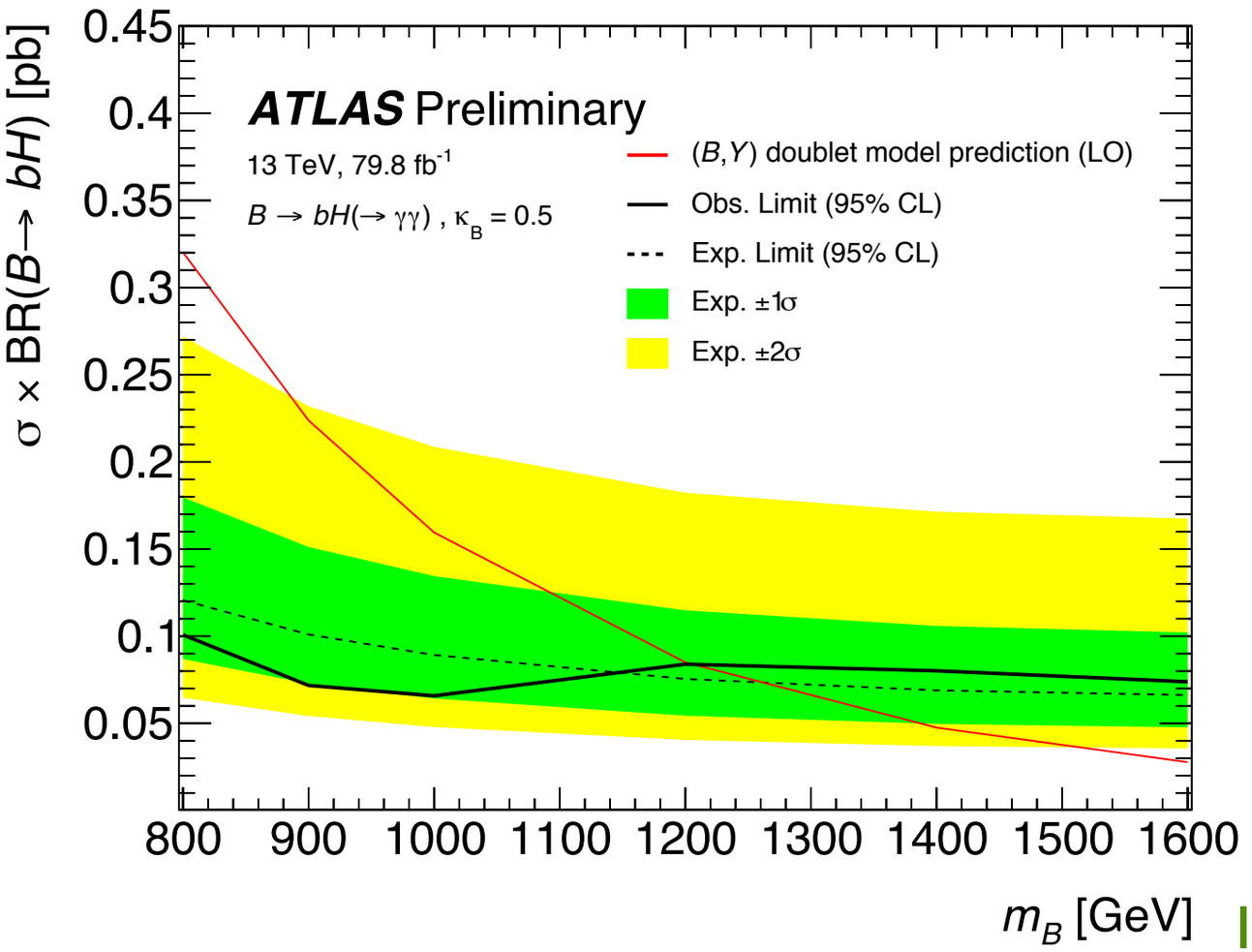
# Single-VLQ → Hb

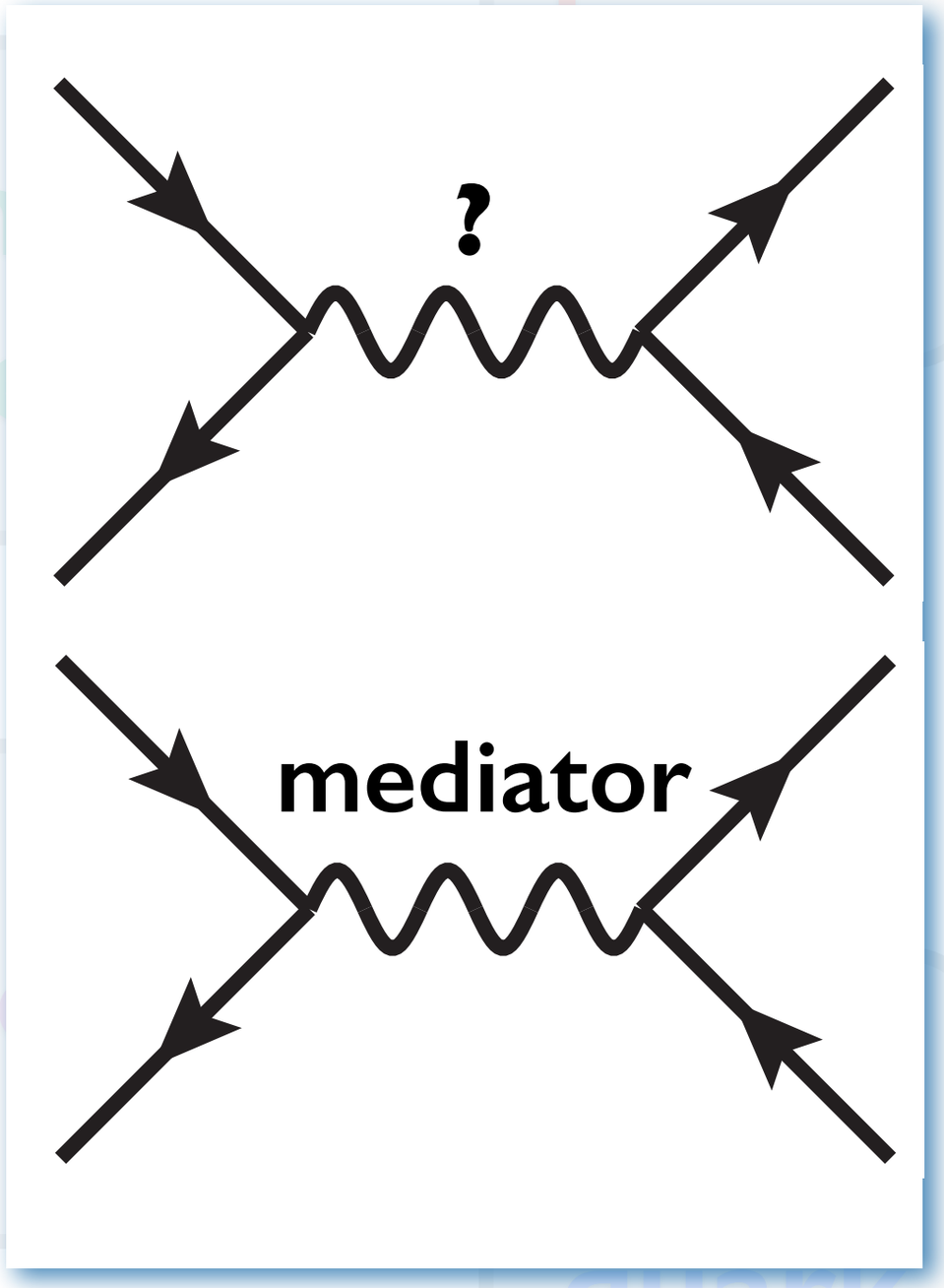





- Low BR, but very low background
- Non-resonant γγ from data sidebands in $m_{\gamma\gamma}$






$m_H << \Lambda_P$ ?

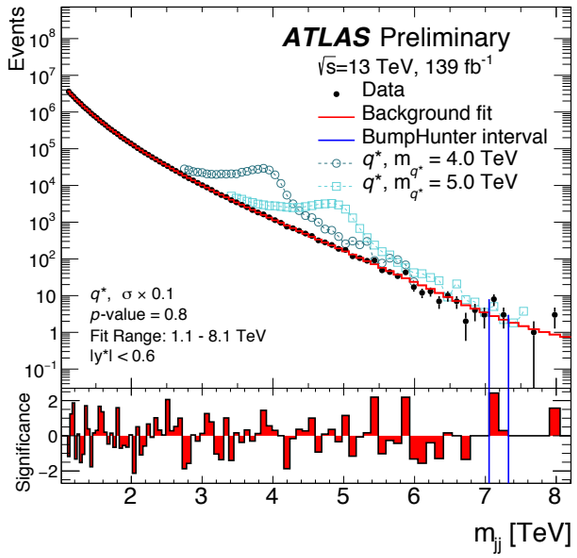
DM ?

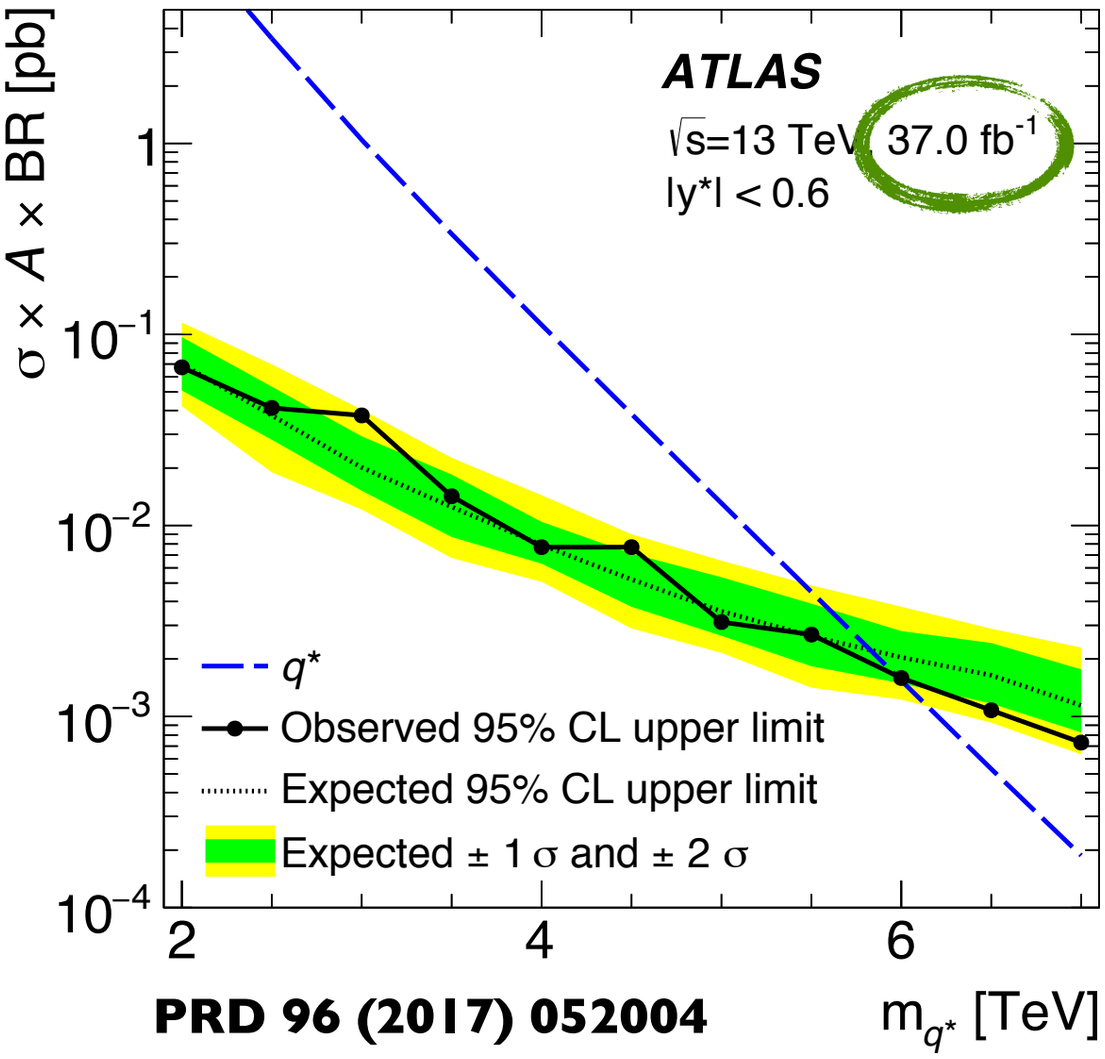
quark
quark

# High-Mass Dijet

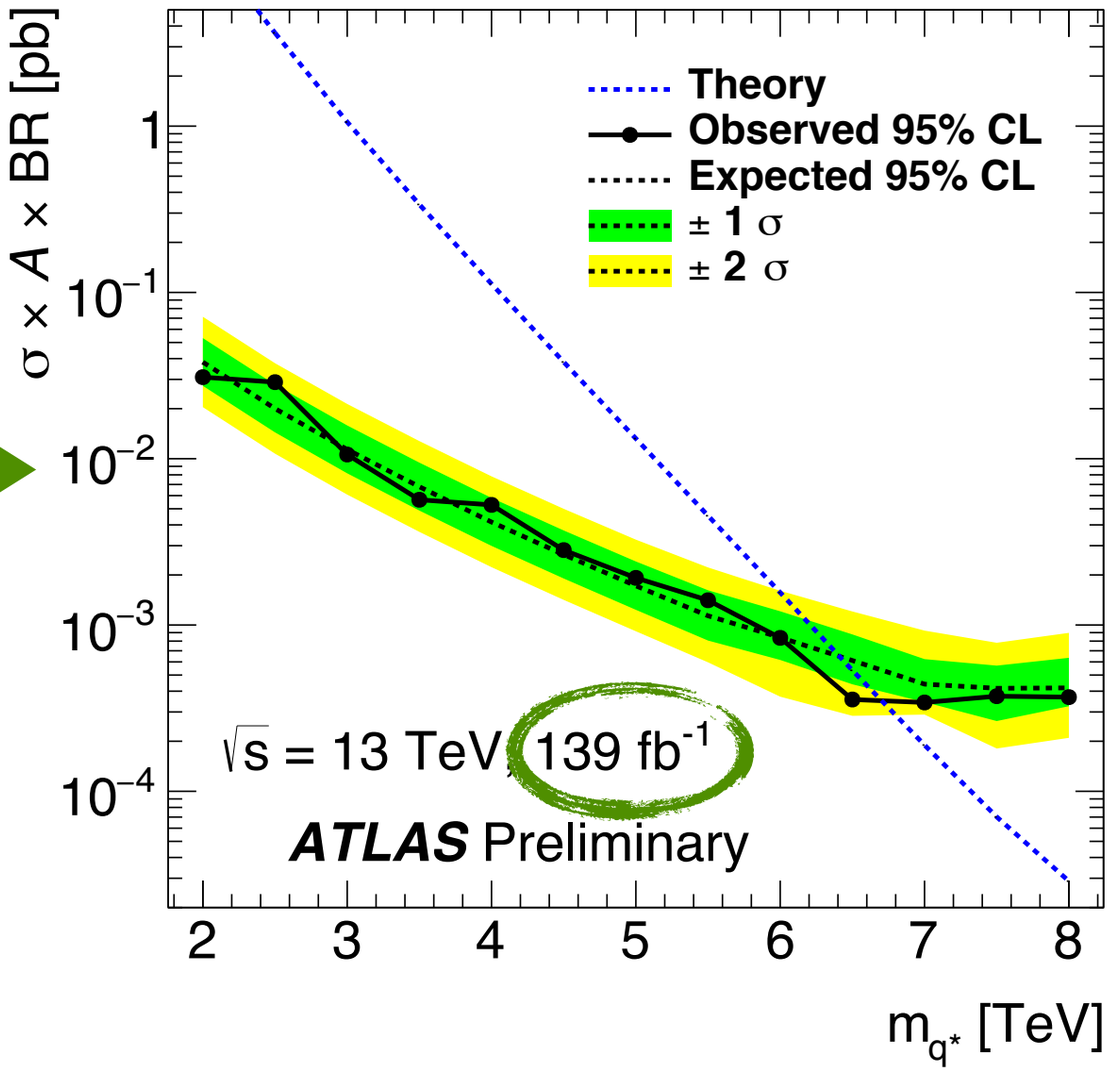


- Background estimate with sliding windows
- Improved sensitivity compared to analysis with 2015/16 data



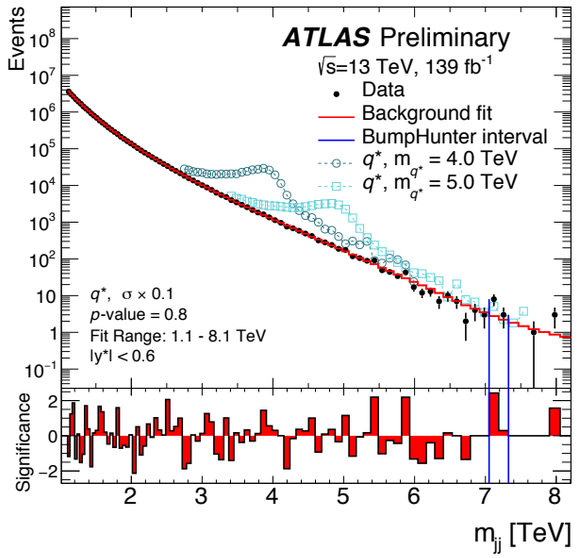

PRD 96 (2017) 052004

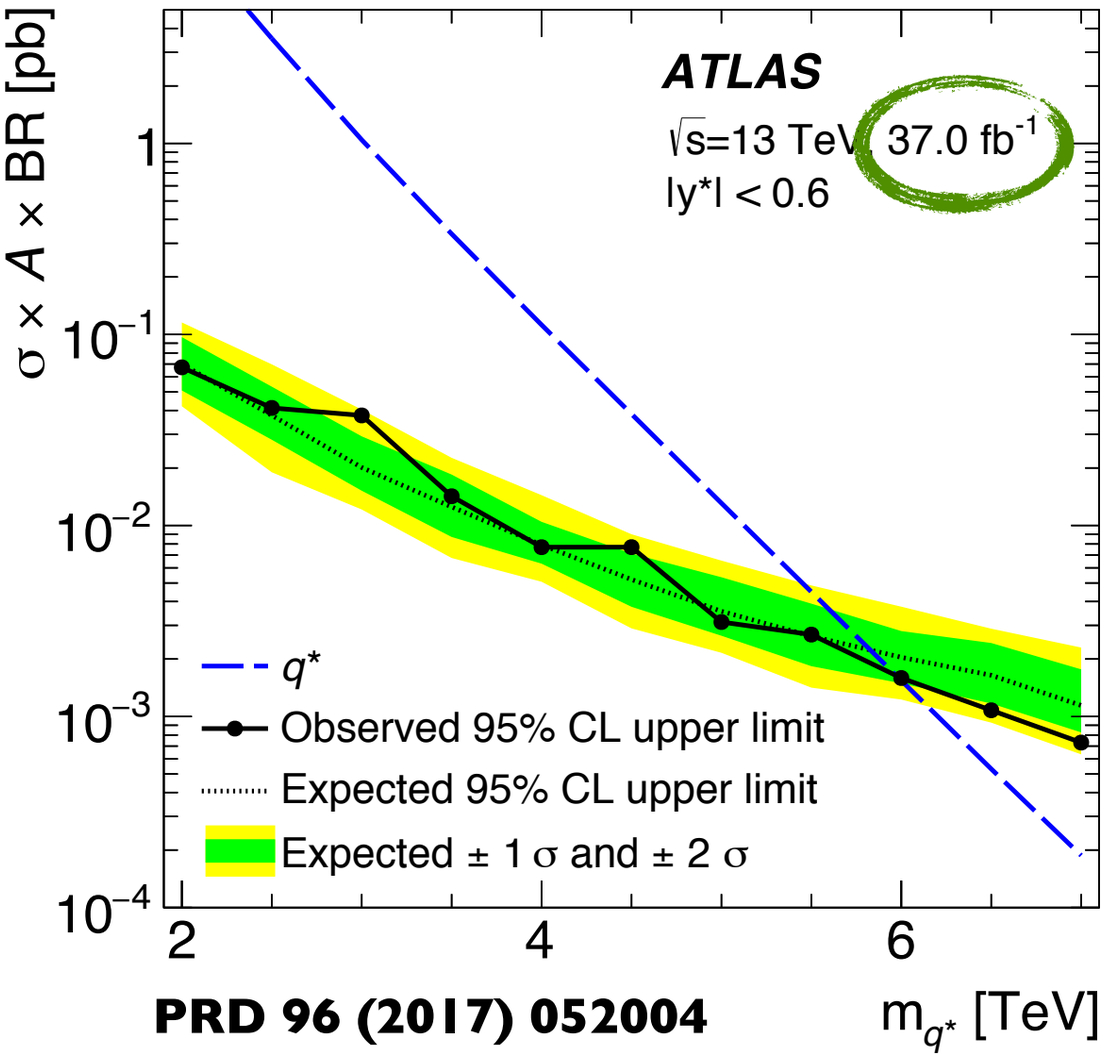


# High-Mass Dijet

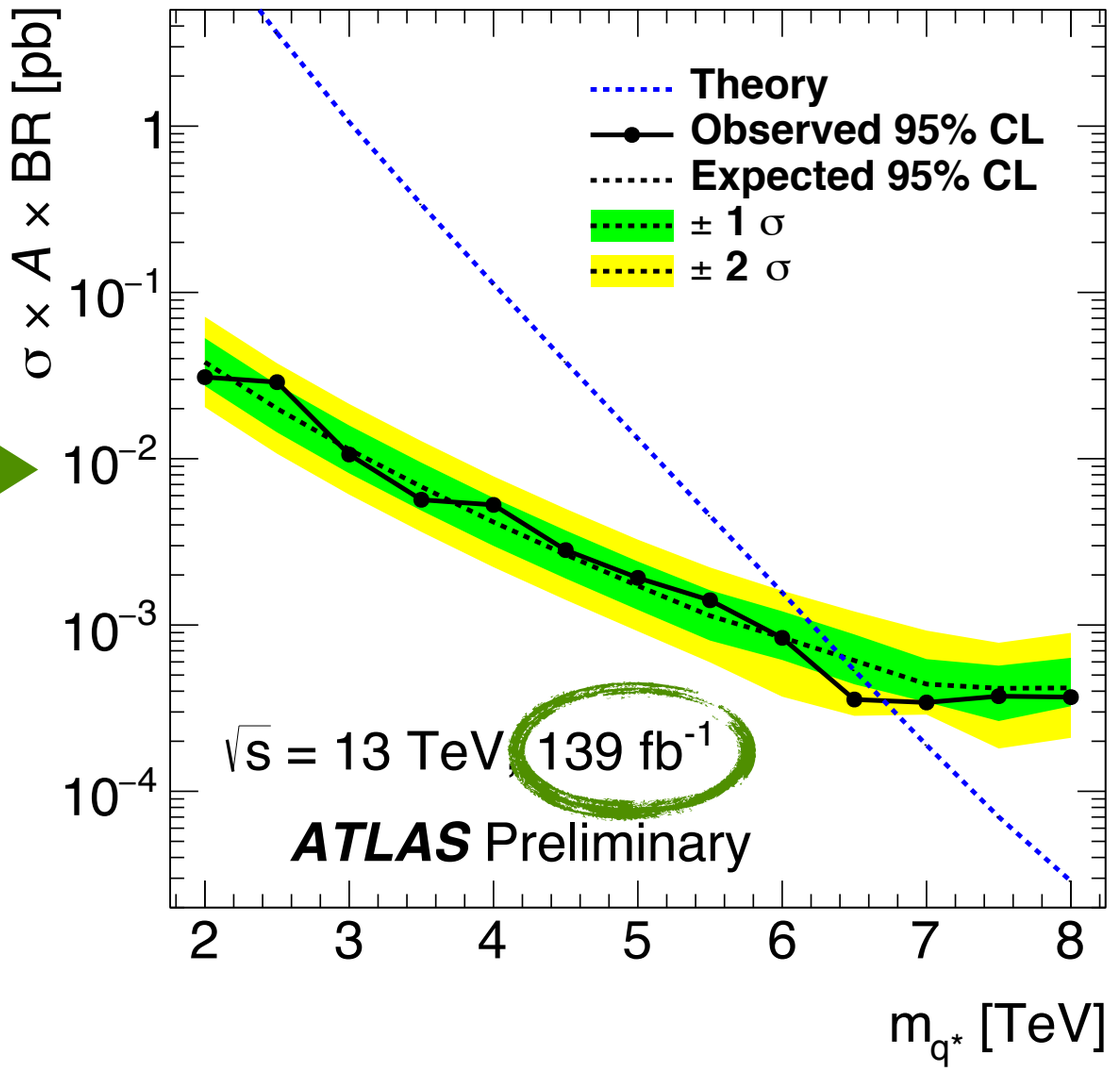


- Background estimate with sliding windows
- Improved sensitivity compared to analysis with 2015/16 data




PRD 96 (2017) 052004




⟹ *talk by Dengfeng Zhang*

# Trigger strategies

Low-mass searches limited by jet-trigger thresholds

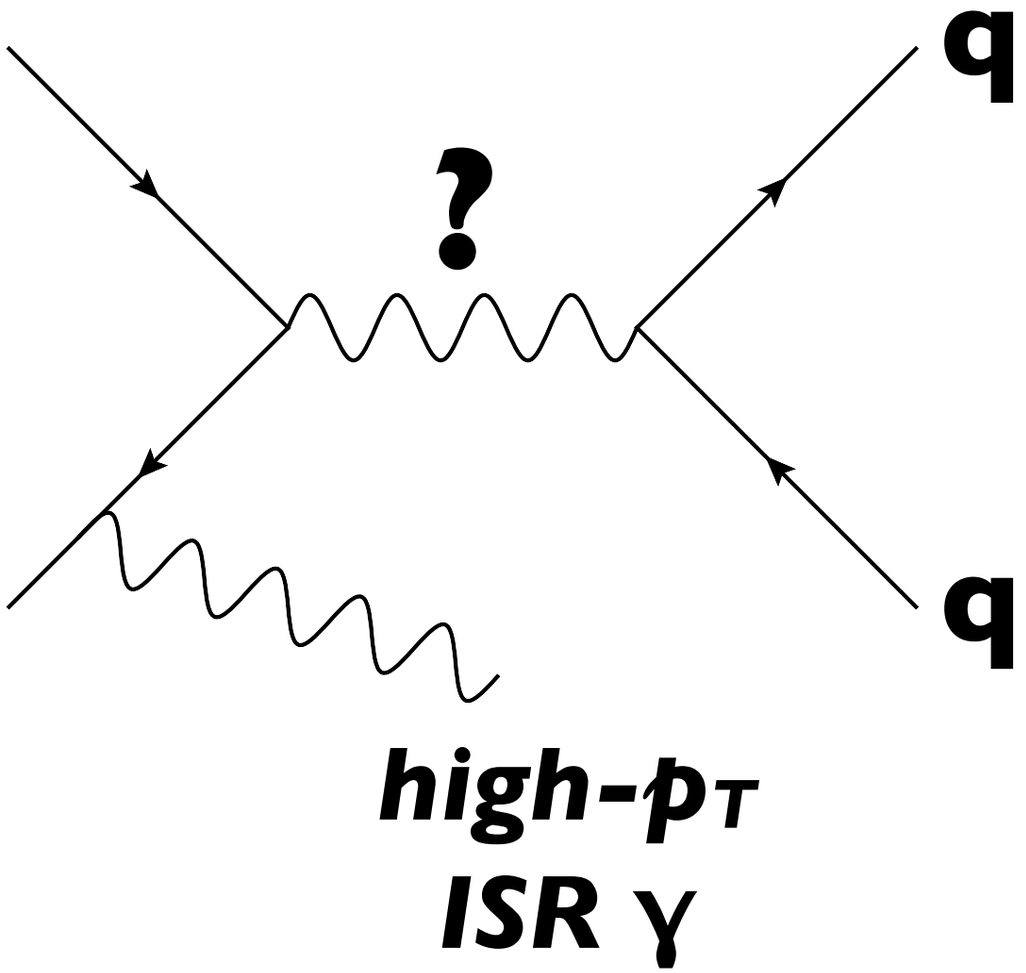
| Trigger | Typical offline selection | Trigger Selection | | Level-1 Peak Rate (kHz) | HLT Peak Rate (Hz) |
|---|---|---|---|---|---|
| | | Level-1 (GeV) | HLT (GeV) | $L = 1.7 \times 10^{34}$ cm$^{-2}$s$^{-1}$ | |
| Single leptons | Single isolated $\mu$, $p_{\mathrm{T}} > 27$ GeV | 20 | 26 (i) | 16 | 187 |
| | Single isolated tight $e$, $p_{\mathrm{T}} > 27$ GeV | 22 (i) | 26 (i) | 26 | 178 |
| | Single $\mu$, $p_{\mathrm{T}} > 52$ GeV | 20 | 50 | 16 | 65 |
| | Single $e$, $p_{\mathrm{T}} > 61$ GeV | 22 (i) | 60 | 26 | 17 |
| | Single $\tau$, $p_{\mathrm{T}} > 170$ GeV | 100 | 160 | 1.2 | 49 |
| Two leptons | Two $\mu$'s, each $p_{\mathrm{T}} > 15$ GeV | $2 \times 10$ | $2 \times 14$ | 2.0 | 30 |
| | Two $\mu$'s, $p_{\mathrm{T}} > 23, 9$ GeV | 20 | 22, 8 | 16 | 42 |
| | Two very loose $e$'s, each $p_{\mathrm{T}} > 18$ GeV | $2 \times 15$ (i) | $2 \times 17$ | 1.6 | 11 |
| | One $e$ & one $\mu$, $p_{\mathrm{T}} > 8, 25$ GeV | 20 ($\mu$) | 7, 24 | 16 | 5 |
| | One $e$ & one $\mu$, $p_{\mathrm{T}} > 18, 15$ GeV | 15, 10 | 17, 14 | 2.0 | 4 |
| | One $e$ & one $\mu$, $p_{\mathrm{T}} > 27, 9$ GeV | 22 (e, i) | 26, 8 | 26 | 2 |
| | Two $\tau$'s, $p_{\mathrm{T}} > 40, 30$ GeV | 20 (i), 12 (i) (+jets, topo) | 35, 25 | 5.1 | 59 |
| | One $\tau$ & one isolated $\mu$, $p_{\mathrm{T}} > 30, 15$ GeV | 12 (i), 10 (+jets) | 25, 14 (i) | 2.1 | 9 |
| | One $\tau$ & one isolated $e$, $p_{\mathrm{T}} > 30, 18$ GeV | 12 (i), 15 (i) (+jets) | 25, 17 (i) | 3.9 | 16 |
| Three leptons | Three loose $e$'s, $p_{\mathrm{T}} > 25, 13, 13$ GeV | $20, 2 \times 10$ | $24, 2 \times 12$ | 1.2 | $< 0.1$ |
| | Three $\mu$'s, each $p_{\mathrm{T}} > 7$ GeV | $3 \times 6$ | $3 \times 6$ | 0.2 | 8 |
| | Three $\mu$'s, $p_{\mathrm{T}} > 21, 2 \times 5$ GeV | 20 | $20, 2 \times 4$ | 16 | 8 |
| | Two $\mu$'s & one loose $e$, $p_{\mathrm{T}} > 2 \times 11, 13$ GeV | $2 \times 10$ ($\mu$'s) | $2 \times 10, 12$ | 2.0 | 0.3 |
| | Two loose $e$'s & one $\mu$, $p_{\mathrm{T}} > 2 \times 13, 11$ GeV | $2 \times 8, 10$ | $2 \times 12, 10$ | 1.6 | 0.2 |
| One photon | One loose $\gamma$, $p_{\mathrm{T}} > 145$ GeV | 22 (i) | 140 | 26 | 46 |
| Two photons | Two loose $\gamma$'s, $p_{\mathrm{T}} > 55, 55$ GeV | $2 \times 20$ | 50, 50 | 2.4 | 6 |
| | Two medium $\gamma$'s, $p_{\mathrm{T}} > 40, 30$ GeV | $2 \times 20$ | 35, 25 | 2.4 | 18 |
| | Two tight $\gamma$'s, $p_{\mathrm{T}} > 25, 25$ GeV | $2 \times 15$ (i) | $2 \times 20$ (i) | 2.4 | 15 |
| Single jet | Jet ($R = 0.4$), $p_{\mathrm{T}} > 435$ GeV | | | | |
| | Jet ($R = 1.0$), $p_{\mathrm{T}} > 480$ GeV | | | | |
| $b$−jets | One $b$ ($\epsilon = 40\%$), $p_{\mathrm{T}} > 235$ GeV | 100 | 225 | 3.4 | 15 |
| | Two $b$'s ($\epsilon = 60\%$), $p_{\mathrm{T}} > 185, 70$ GeV | 100 | 175, 60 | 3.4 | 12 |
| | One $b$ ($\epsilon = 40\%$) & three jets, each $p_{\mathrm{T}} > 85$ GeV | $4 \times 15$ | $4 \times 75$ | 4.9 | 15 |
| | Two $b$'s ($\epsilon = 70\%$) & one jet, $p_{\mathrm{T}} > 65, 65, 160$ GeV | $2 \times 30, 85$ | $2 \times 55, 150$ | 2.7 | 15 |
| | Two $b$'s ($\epsilon = 60\%$) & two jets, each $p_{\mathrm{T}} > 45$ GeV | $4 \times 15$ | $4 \times 35$ | 4.9 | 13 |
| $B$-Physics | Two $\mu$'s, $p_{\mathrm{T}} > 11, 6$ GeV | 11, 6 | 11, 6 (di-$\mu$) | 3.1 | 50 |
| | Two $\mu$'s, $p_{\mathrm{T}} > 6, 6$ GeV, $2.5 < \mathrm{m}(\mu, \mu) < 4.0$ GeV | $2 \times 6$ ($J/\psi$, topo) | $2 \times 6$ ($J/\psi$) | 1.8 | 59 |
| | Two $\mu$'s, $p_{\mathrm{T}} > 6, 6$ GeV, $4.7 < \mathrm{m}(\mu, \mu) < 5.9$ GeV | $2 \times 6$ ($B$, topo) | $2 \times 6$ ($B$) | 1.8 | 7 |
| | Two $\mu$'s, $p_{\mathrm{T}} > 6, 6$ GeV, $7 < \mathrm{m}(\mu, \mu) < 12$ GeV | $2 \times 6$ ($\Upsilon$, topo) | $2 \times 6$ ($\Upsilon$) | 1.5 | 10 |
| Total Rate | | | | 85 | 1550 |

**twiki.cern.ch/twiki/bin/view/AtlasPublic/TriggerPublicResults**

# Trigger strategies

Low-mass searches limited by jet-trigger thresholds

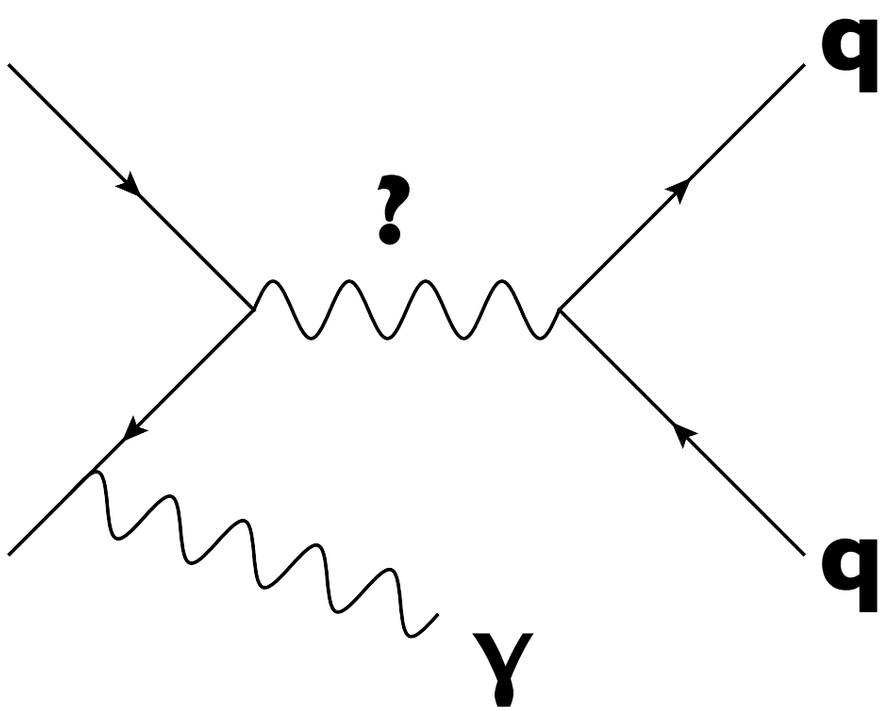
| Trigger | Typical offline selection | Trigger Selection | | Level-1 Peak Rate (kHz) | HLT Peak Rate (Hz) |
|---|---|---|---|---|---|
| | | Level-1 (GeV) | HLT (GeV) | $L = 1.7 \times 10^{34}$ cm$^{-2}$s$^{-1}$ | |
| Single leptons | Single isolated $\mu$, $p_{\mathrm{T}} > 27$ GeV | 20 | 26 (i) | 16 | 187 |
| | Single isolated tight $e$, $p_{\mathrm{T}} > 27$ GeV | 22 (i) | 26 (i) | 26 | 178 |
| | Single $\mu$, $p_{\mathrm{T}} > 52$ GeV | 20 | 50 | 16 | 65 |
| | Single $e$, $p_{\mathrm{T}} > 61$ GeV | 22 (i) | 60 | 26 | 17 |
| | Single $\tau$, $p_{\mathrm{T}} > 170$ GeV | 100 | 160 | 1.2 | 49 |
| Two leptons | Two $\mu$'s, each $p_{\mathrm{T}} > 15$ GeV | $2 \times 10$ | $2 \times 14$ | 2.0 | 30 |
| | Two $\mu$'s, $p_{\mathrm{T}} > 23, 9$ GeV | 20 | 22, 8 | 16 | 42 |
| | Two very loose $e$'s, each $p_{\mathrm{T}} > 18$ GeV | $2 \times 15$ (i) | $2 \times 17$ | 1.6 | 11 |
| | One $e$ & one $\mu$, $p_{\mathrm{T}} > 8, 25$ GeV | 20 ($\mu$) | 7, 24 | 16 | 5 |
| | One $e$ & one $\mu$, $p_{\mathrm{T}} > 18, 15$ GeV | 15, 10 | 17, 14 | 2.0 | 4 |
| | One $e$ & one $\mu$, $p_{\mathrm{T}} > 27, 9$ GeV | 22 (e, i) | 26, 8 | 26 | 2 |
| | Two $\tau$'s, $p_{\mathrm{T}} > 40, 30$ GeV | 20 (i), 12 (i) (+jets, topo) | 35, 25 | 5.1 | 59 |
| | One $\tau$ & one isolated $\mu$, $p_{\mathrm{T}} > 30, 15$ GeV | 12 (i), 10 (+jets) | 25, 14 (i) | 2.1 | 9 |
| | One $\tau$ & one isolated $e$, $p_{\mathrm{T}} > 30, 18$ GeV | 12 (i), 15 (i) (+jets) | 25, 17 (i) | 3.9 | 16 |
| | Three loose $e$'s, $p_{\mathrm{T}} > 25, 13, 13$ GeV | 20, $2 \times 10$ | 24, $2 \times 12$ | 1.2 | $< 0.1$ |
| | Three $\mu$'s, each $p_{\mathrm{T}} > 7$ GeV | $3 \times 6$ | $3 \times 6$ | 0.2 | 8 |
| One photon | One loose $\gamma$, $p_{\mathrm{T}} > 145$ GeV | | | | |
| Two photons | Two medium $\gamma$'s, $p_{\mathrm{T}} > 40, 30$ GeV | $2 \times 20$ | 35, 25 | 2.4 | 18 |
| | Two tight $\gamma$'s, $p_{\mathrm{T}} > 25, 25$ GeV | $2 \times 15$ (i) | $2 \times 20$ (i) | 2.4 | 15 |
| Single jet | Jet ($R = 0.4$), $p_{\mathrm{T}} > 435$ GeV | | | | |
| | Jet ($R = 1.0$), $p_{\mathrm{T}} > 480$ GeV | | | | |
| $b$−jets | One $b$ ($\epsilon = 40\%$), $p_{\mathrm{T}} > 235$ GeV | 100 | 225 | 3.4 | 15 |
| | Two $b$'s ($\epsilon = 60\%$), $p_{\mathrm{T}} > 185, 70$ GeV | 100 | 175, 60 | 3.4 | 12 |
| | One $b$ ($\epsilon = 40\%$) & three jets, each $p_{\mathrm{T}} > 85$ GeV | $4 \times 15$ | $4 \times 75$ | 4.9 | 15 |
| | Two $b$'s ($\epsilon = 70\%$) & one jet, $p_{\mathrm{T}} > 65, 65, 160$ GeV | $2 \times 30, 85$ | $2 \times 55, 150$ | 2.7 | 15 |
| | Two $b$'s ($\epsilon = 60\%$) & two jets, each $p_{\mathrm{T}} > 45$ GeV | $4 \times 15$ | $4 \times 35$ | 4.9 | 13 |
| $B$-Physics | Two $\mu$'s, $p_{\mathrm{T}} > 11, 6$ GeV | 11, 6 | 11, 6 (di-$\mu$) | 3.1 | 50 |
| | Two $\mu$'s, $p_{\mathrm{T}} > 6, 6$ GeV, $2.5 < \mathrm{m}(\mu, \mu) < 4.0$ GeV | $2 \times 6$ ($J/\psi$, topo) | $2 \times 6$ ($J/\psi$) | 1.8 | 59 |
| | Two $\mu$'s, $p_{\mathrm{T}} > 6, 6$ GeV, $4.7 < \mathrm{m}(\mu, \mu) < 5.9$ GeV | $2 \times 6$ ($B$, topo) | $2 \times 6$ ($B$) | 1.8 | 7 |
| | Two $\mu$'s, $p_{\mathrm{T}} > 6, 6$ GeV, $7 < \mathrm{m}(\mu, \mu) < 12$ GeV | $2 \times 6$ ($\Upsilon$, topo) | $2 \times 6$ ($\Upsilon$) | 1.5 | 10 |
| Total Rate | | | | 85 | 1550 |




**twiki.cern.ch/twiki/bin/view/AtlasPublic/TriggerPublicResults**

# Low-Mass Dijet with ISR





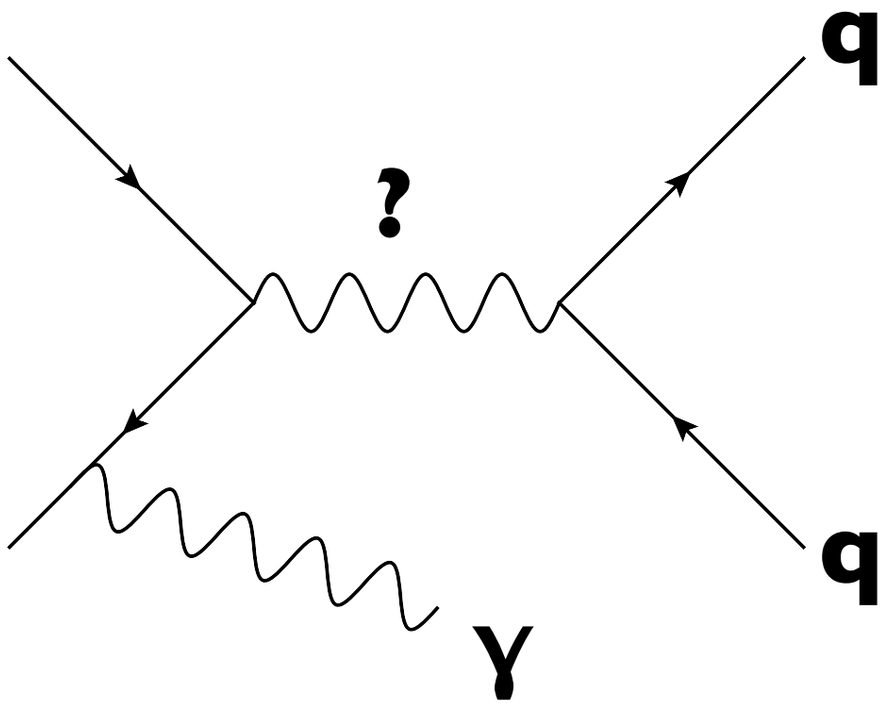

Single-γ or γ+jet trigger

- better at high m (lower γ-$p_T^{min}$)
- worse for low m (higher jet-$p_T^{min}$)

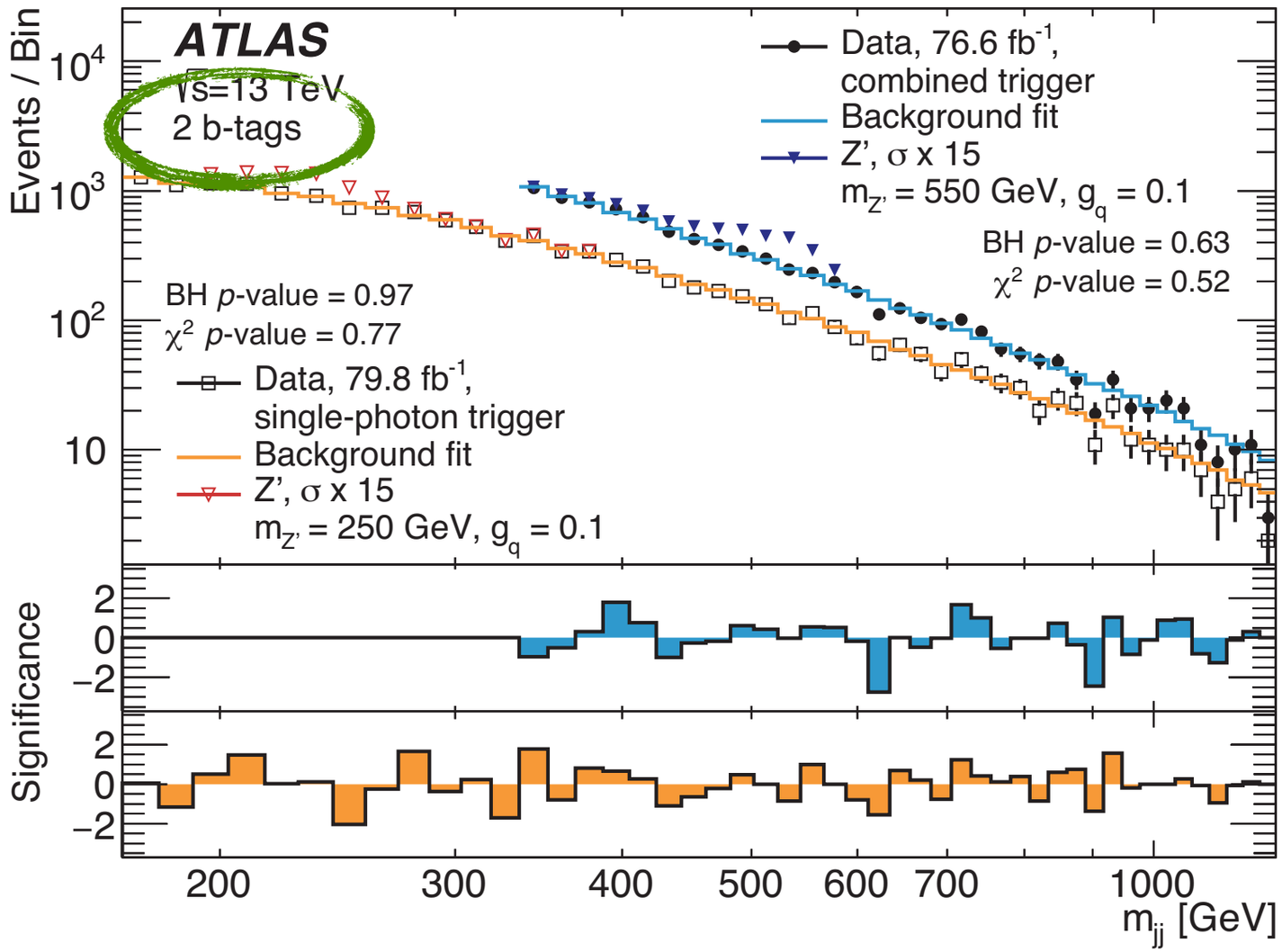
arXiv:1901.10917

# Low-Mass Dijet with ISR

77-80 fb$^{-1}$




Single-γ or γ+jet trigger



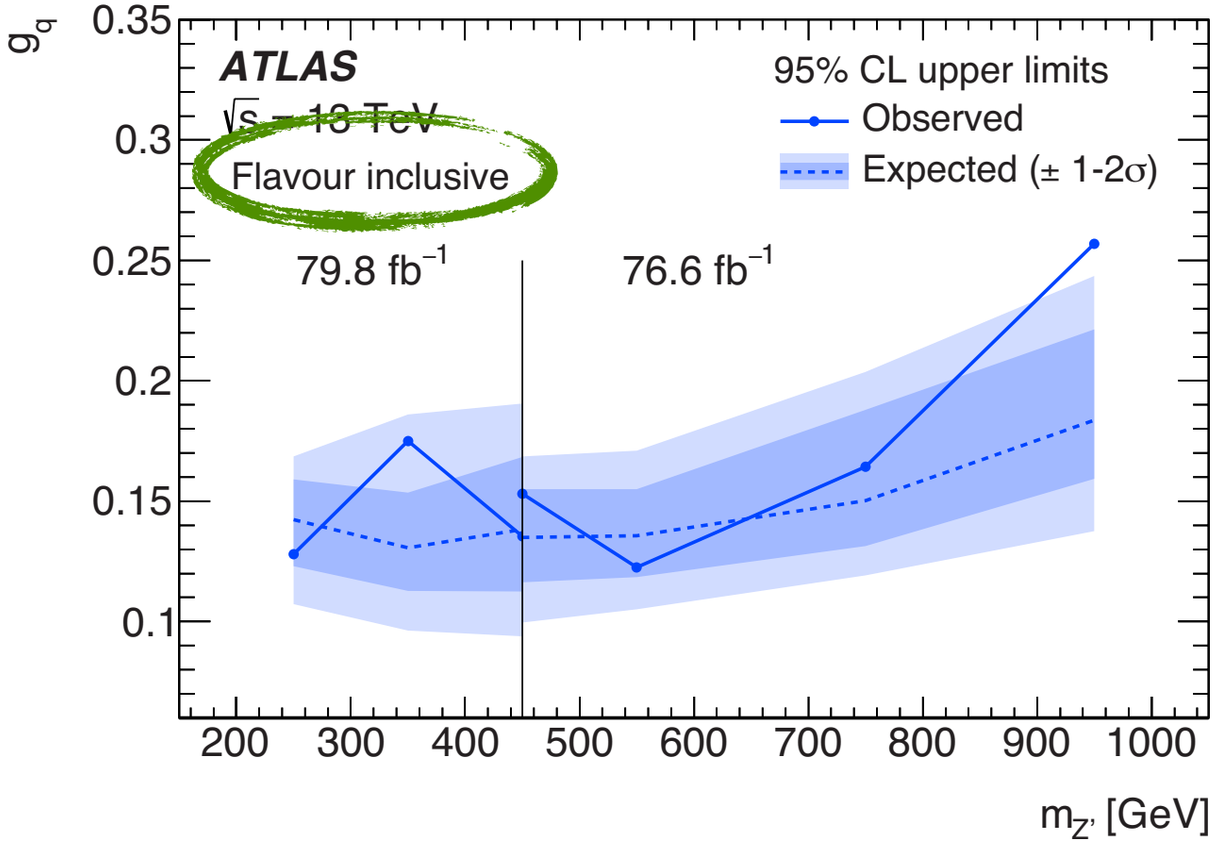

- better at high m (lower γ-$p_T^{min}$)
- worse for low m (higher jet-$p_T^{min}$)

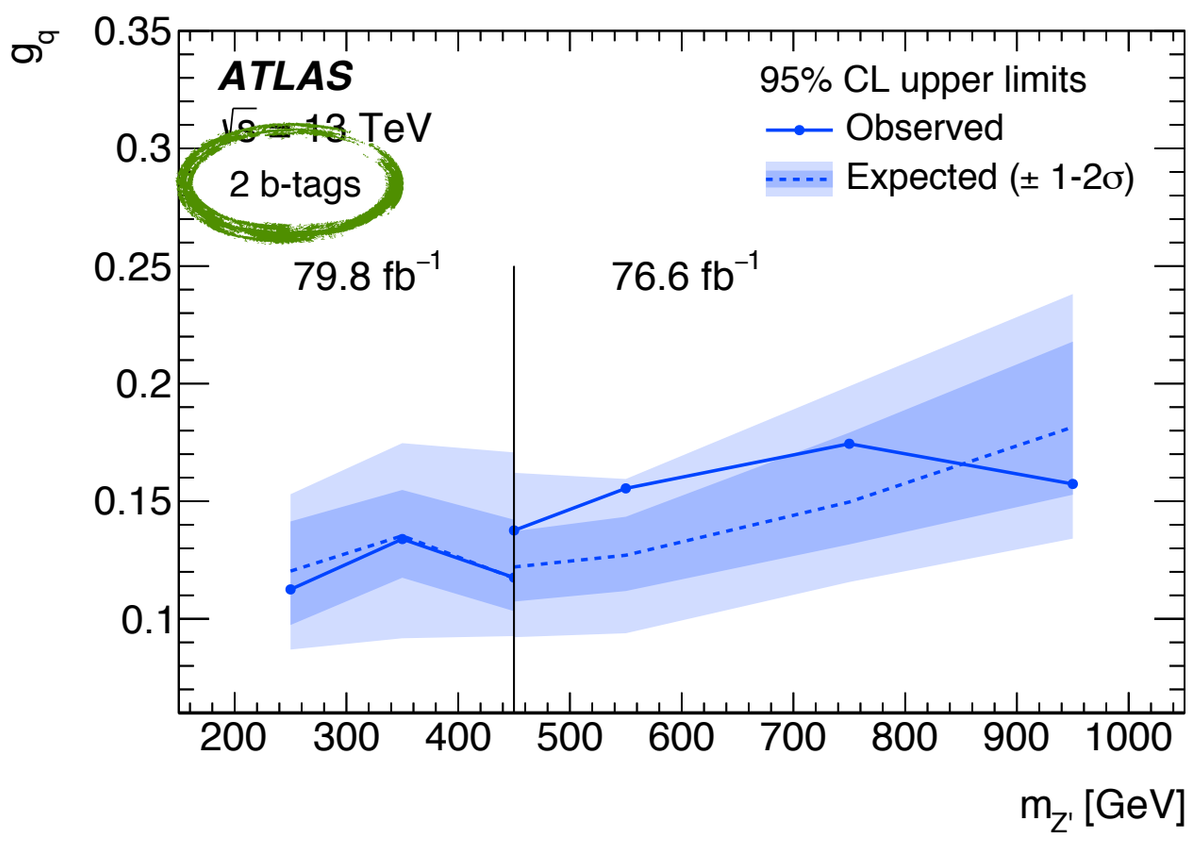
- 2-b-tag selection
- Flavor-inclusive selection

# Low-Mass Dijet with ISR

77-80 fb$^{-1}$

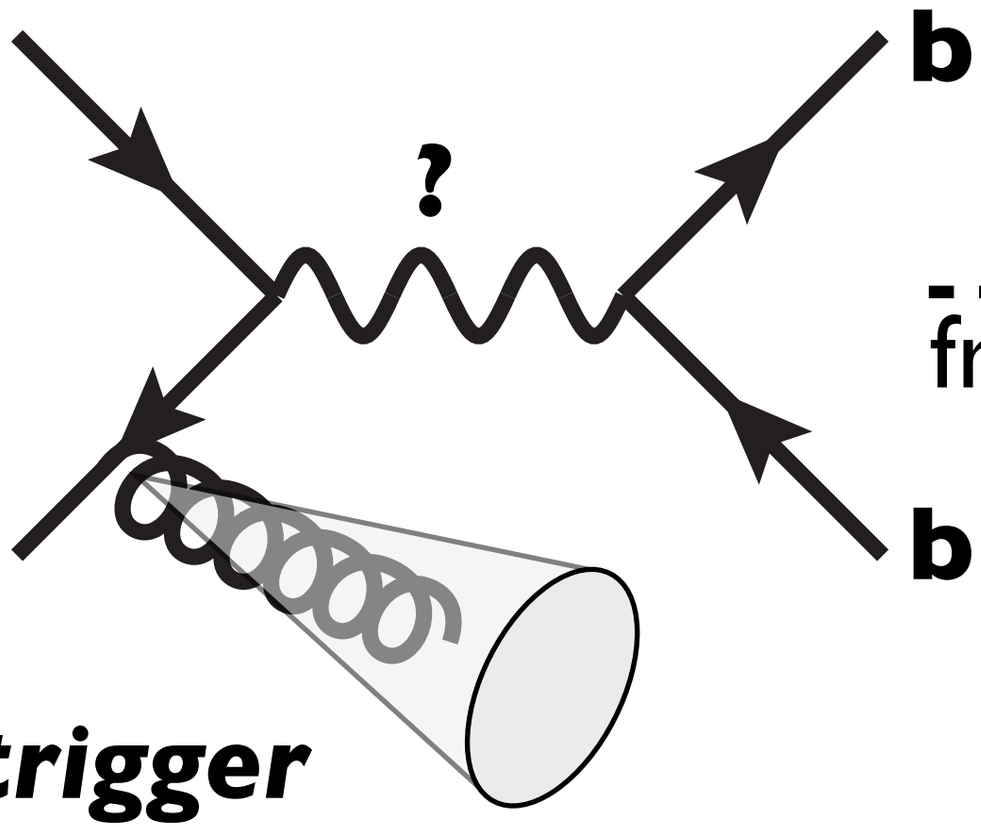
- 2-b-tag selection sensitive to models with enhanced couplings to b-quarks
- 2-b-tag sensitivity to flavour-inclusive couplings even slightly better than flavour-inclusive selection



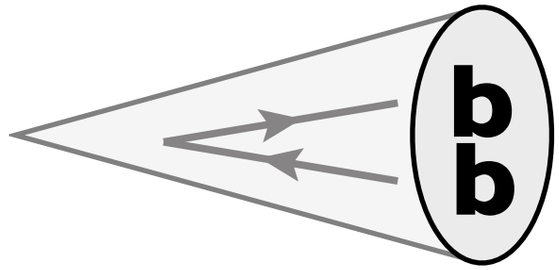



# Low-Mass $b\bar{b}$ with ISR



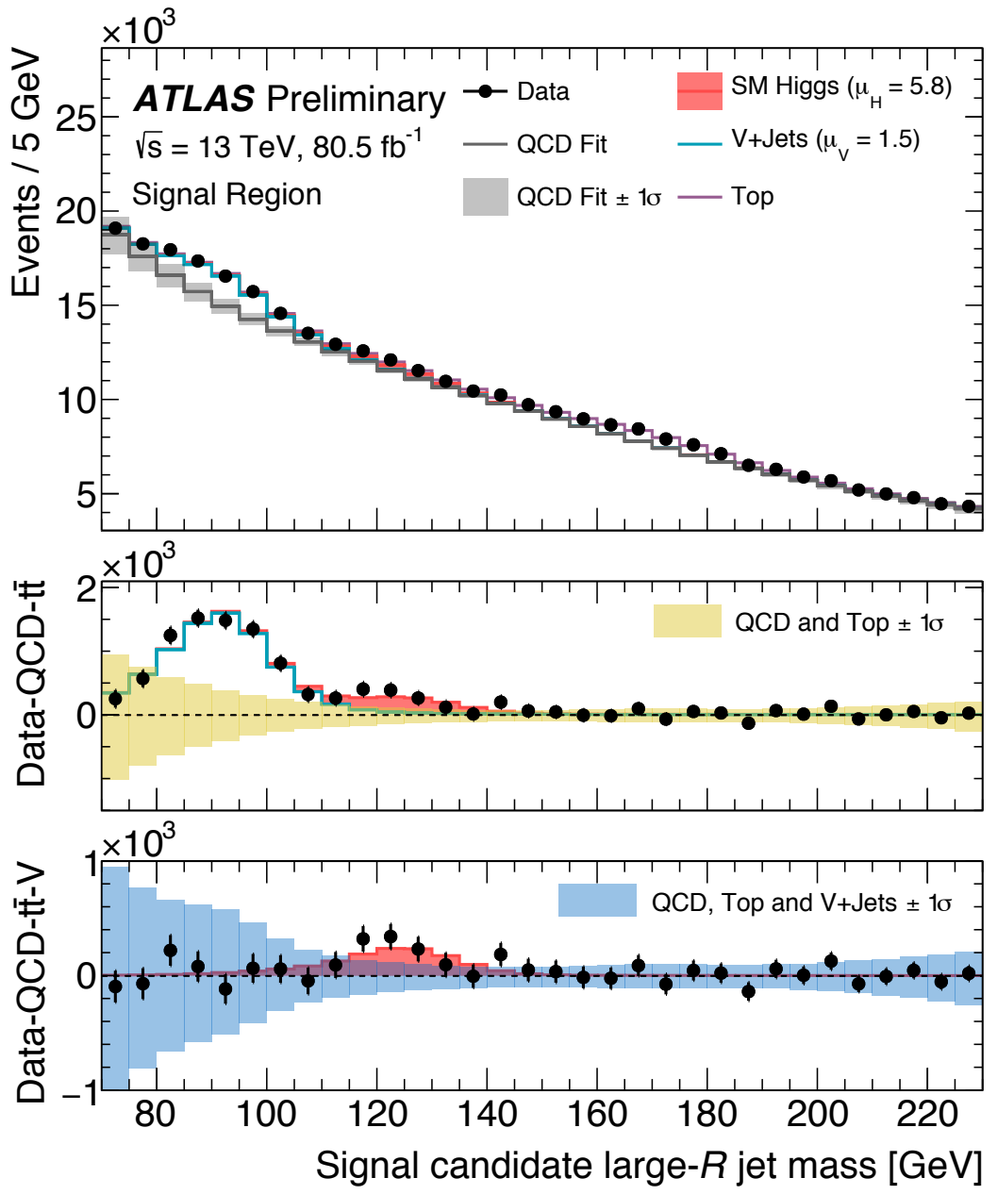



boost from recoil




***trigger high-$p_T$ ISR jet***

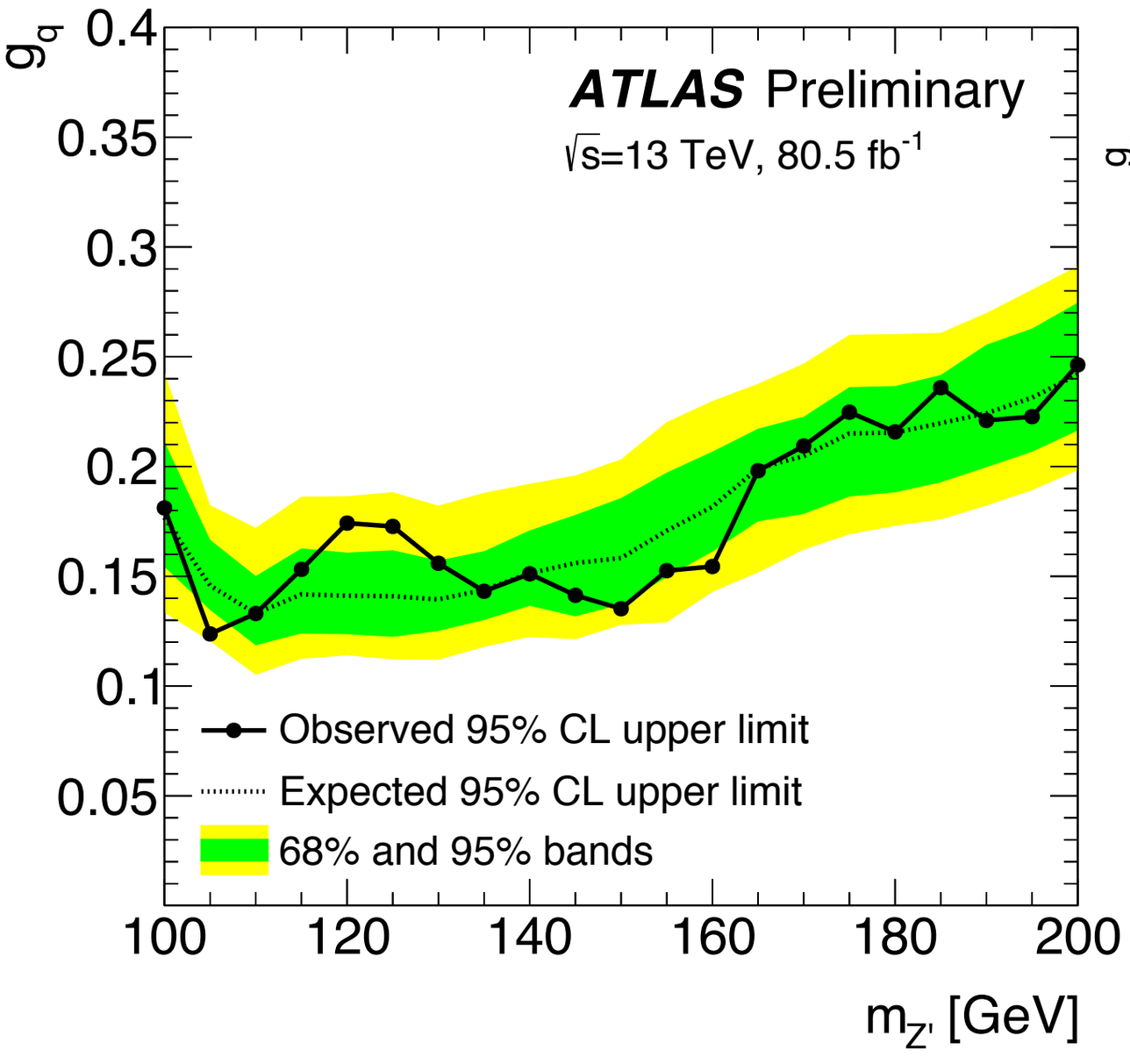
- Candidate jet:
  - $p_T$ > 480 GeV
  - 70 < m < 230 GeV
  - 2 b-tags

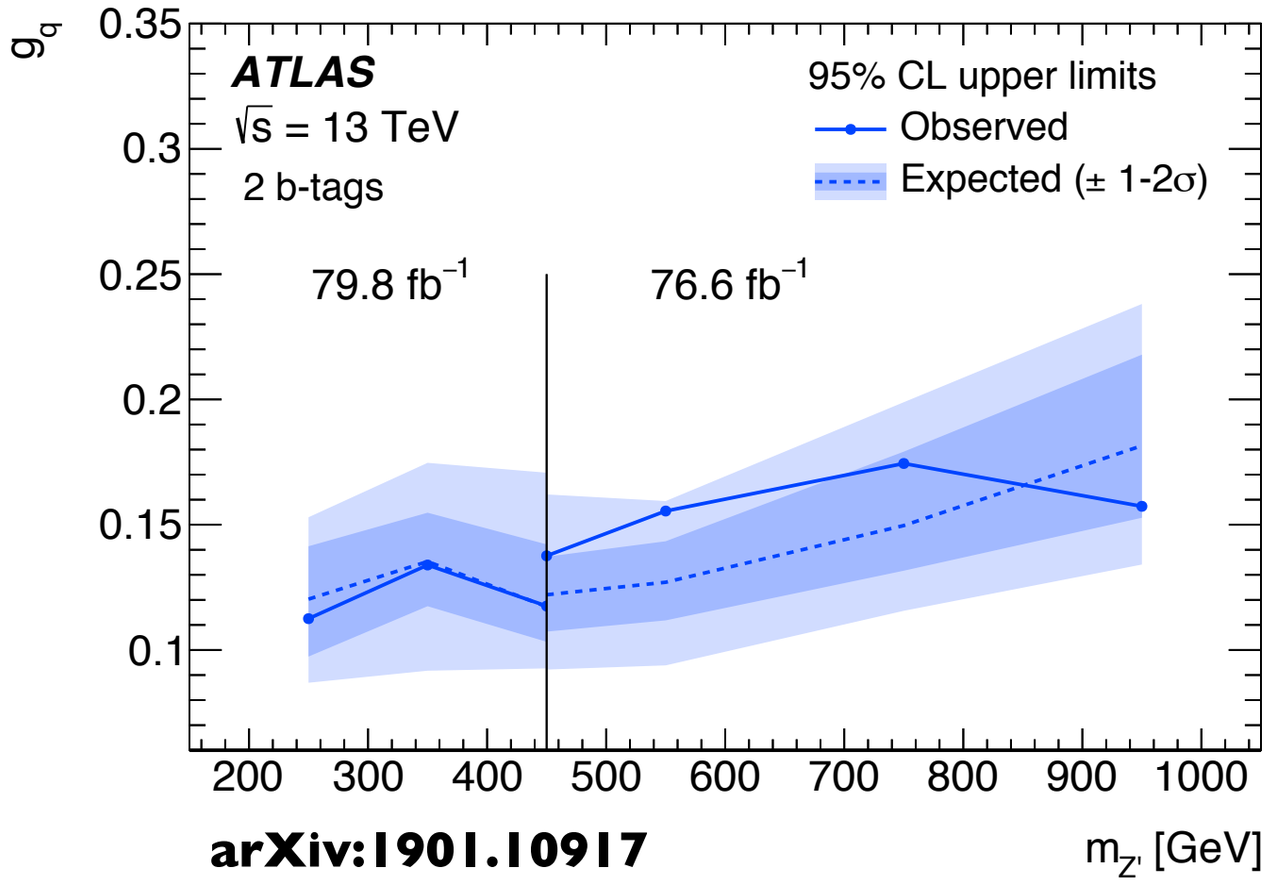


# Low-Mass $b\bar{b}$ with ISR



- Complementary to dijet+γ

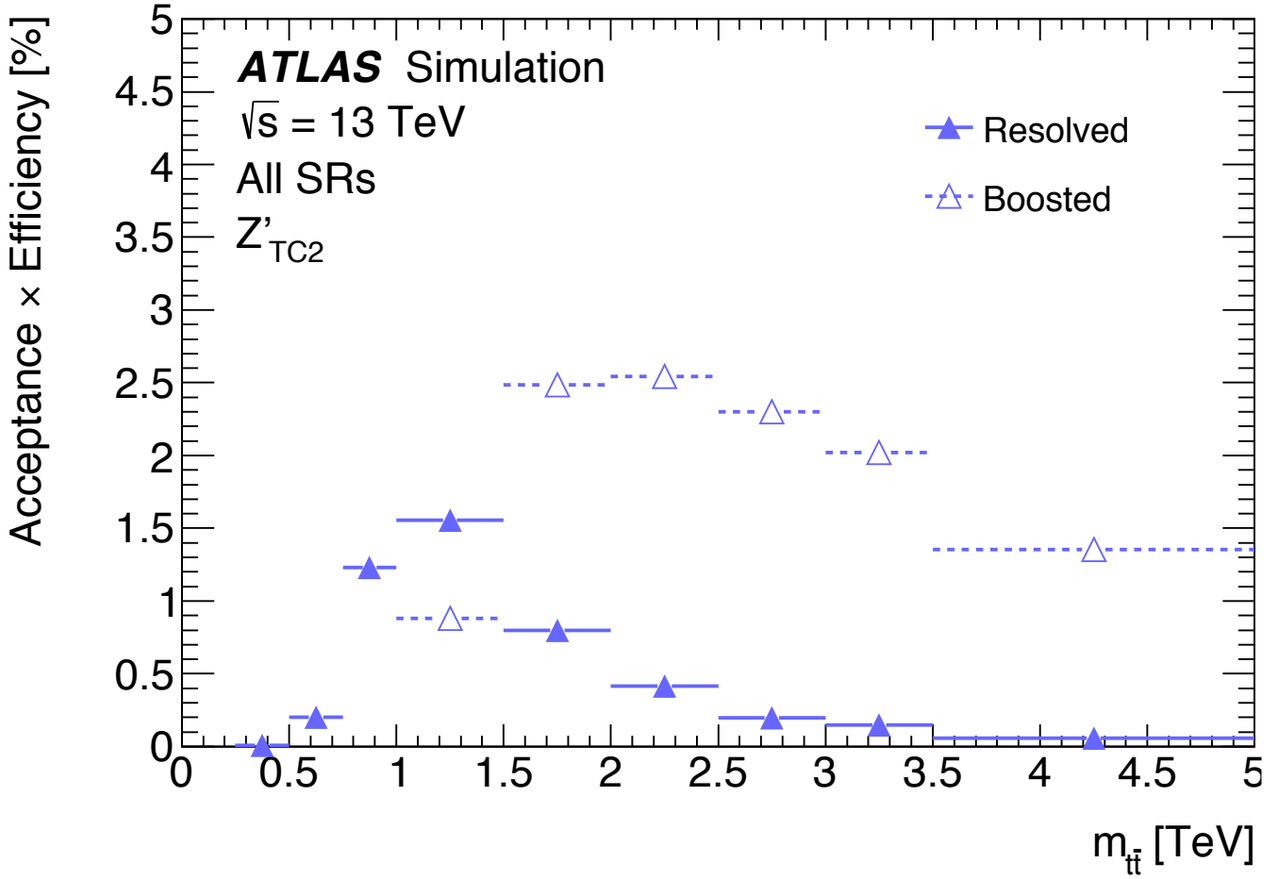


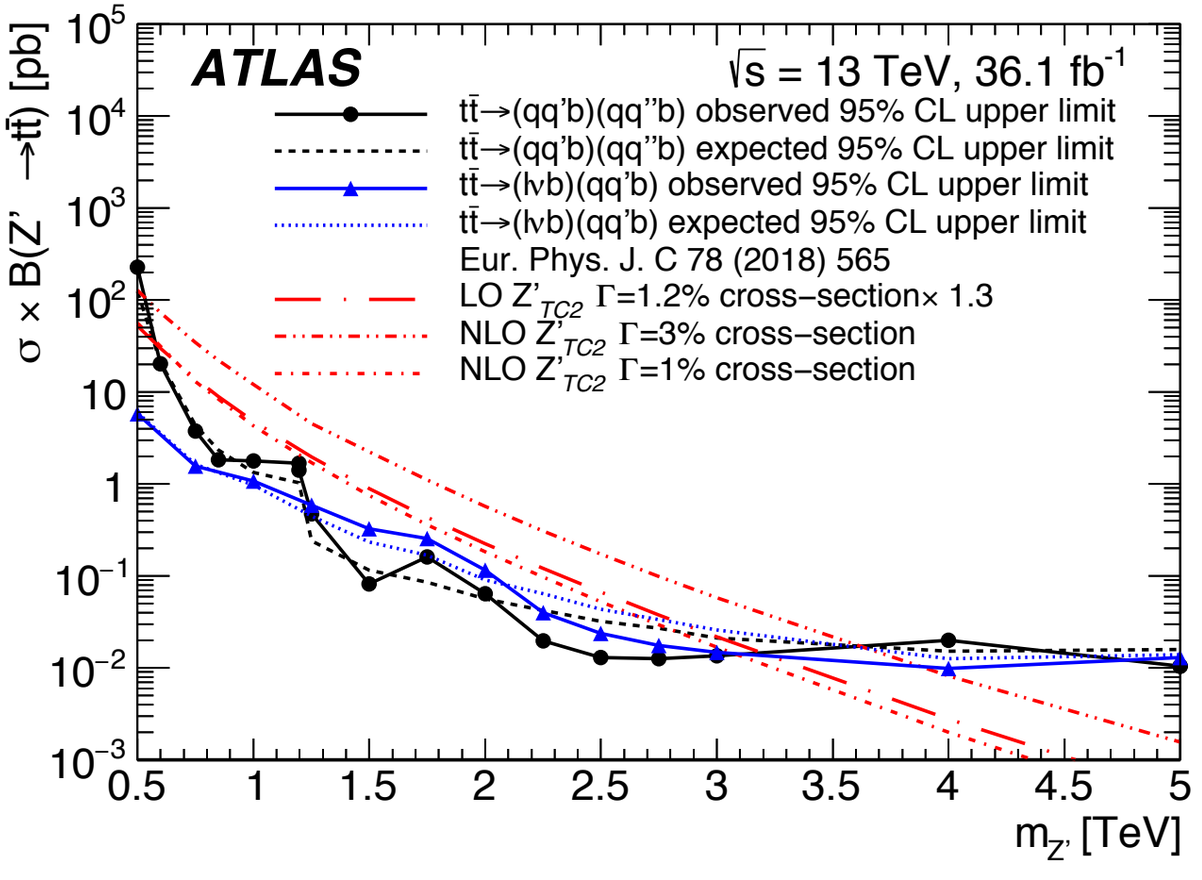



# $t\bar{t}$ (all-hadronic)



- Low mass: multijet final state ("resolved")
  - QCD suppressed by "buckets of tops" + b-tags
- High mass: two large-R jets ("boosted")
  - QCD suppressed by top-tagging + b-tags

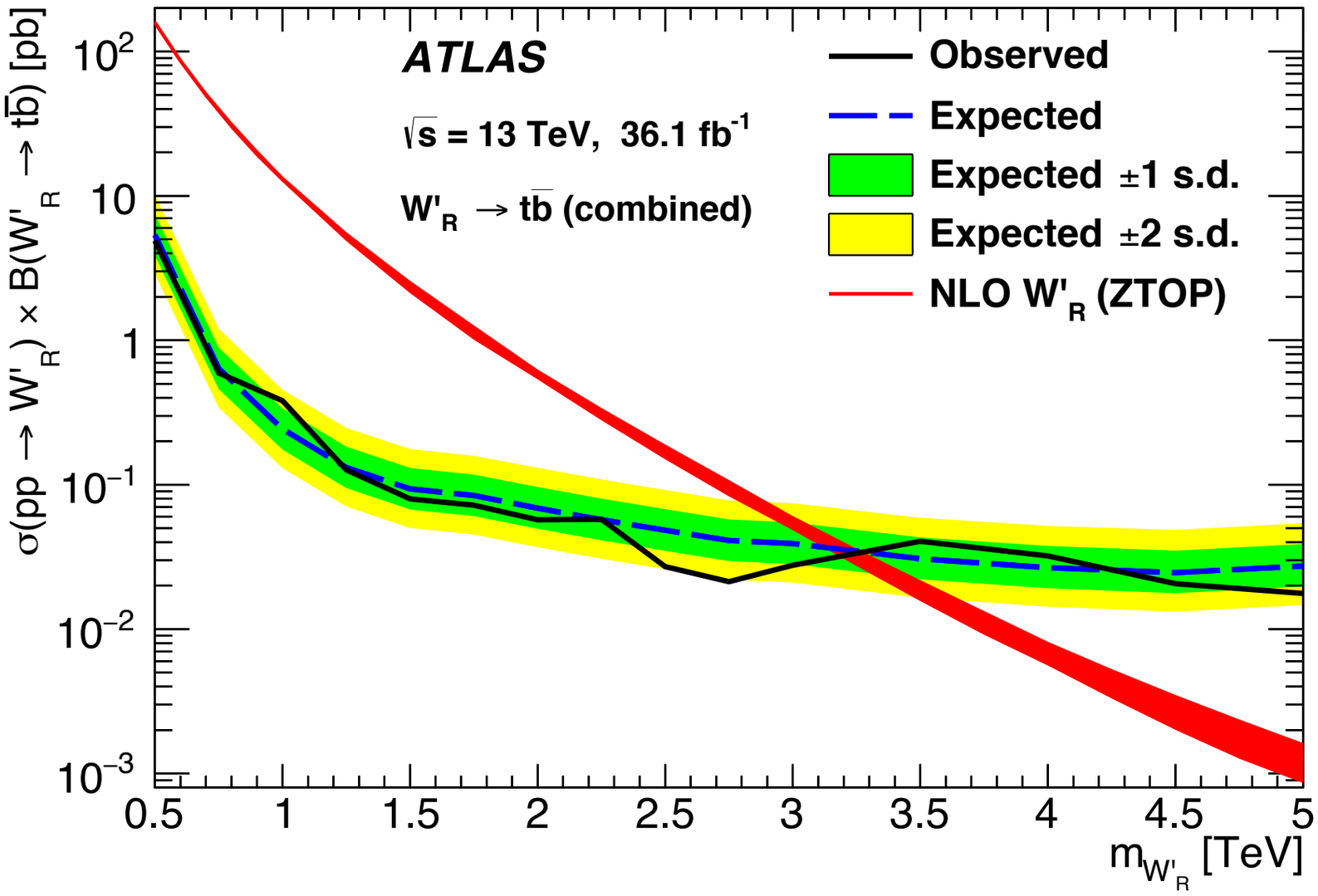


# $t\bar{b}$ ($\ell$+jets)



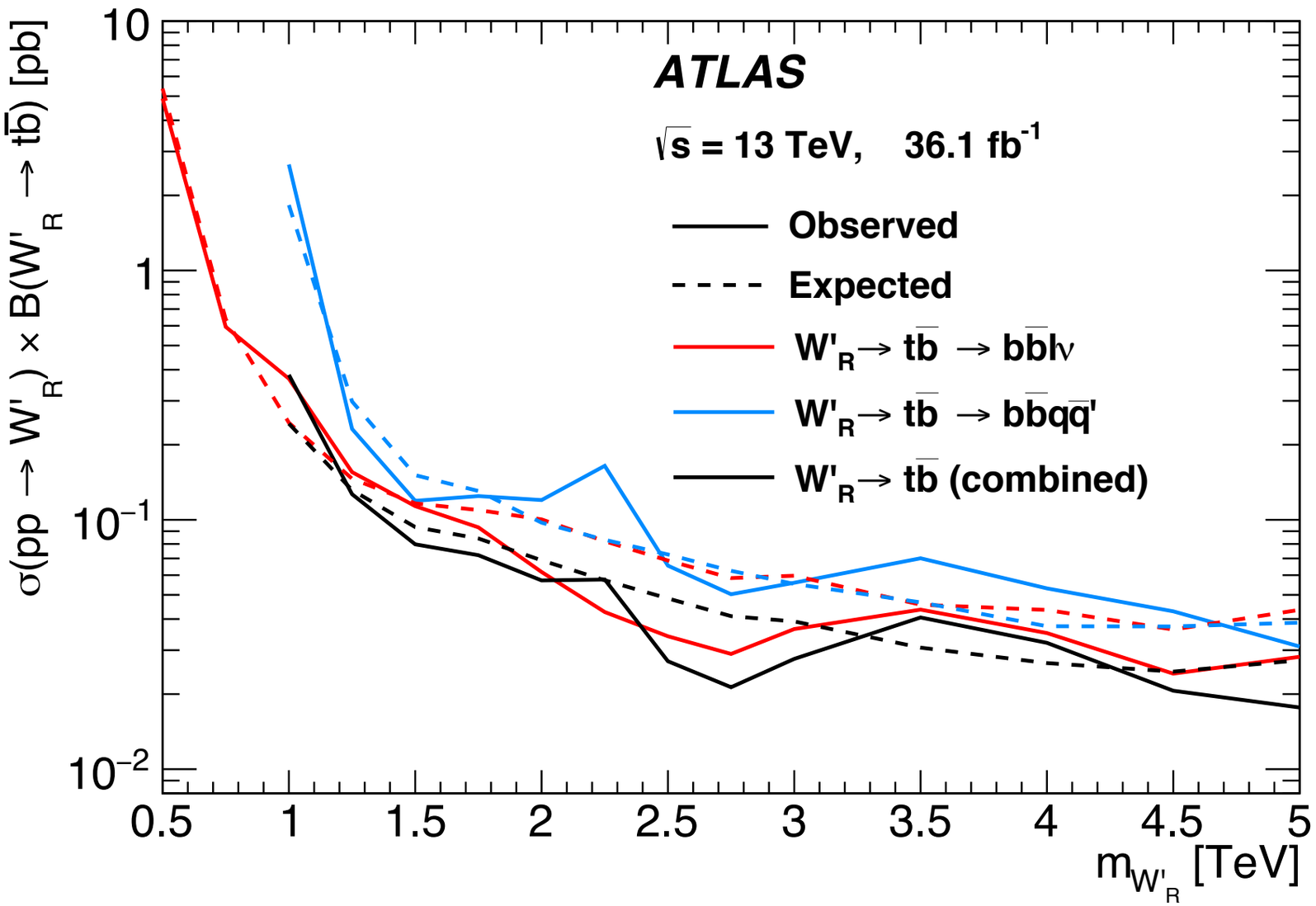
- Focus on right-handed W' (no interference with SM)
- Boosted top ⟹ track isolation for leptons
-



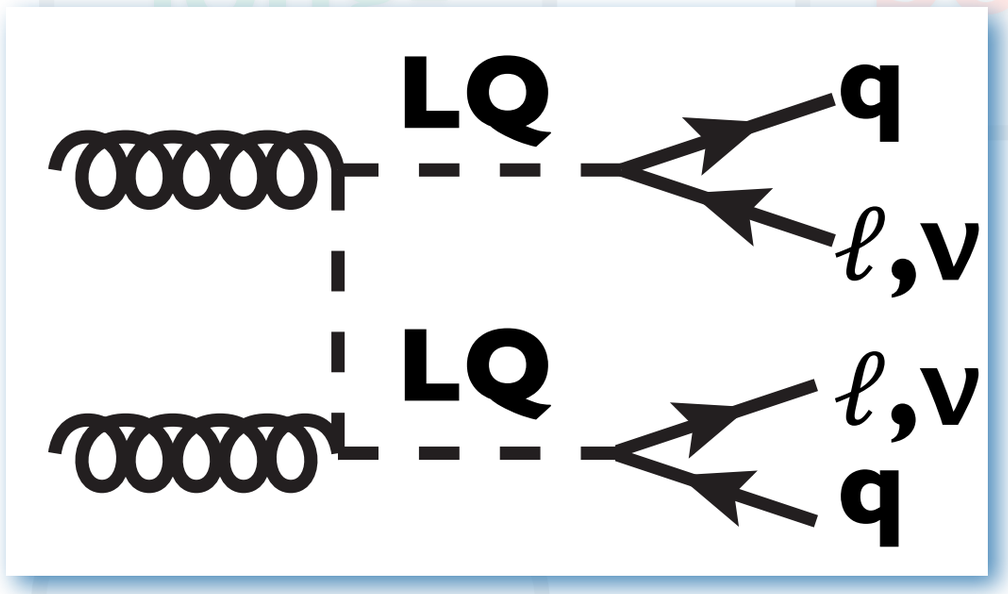
# $t\bar{b}$ ($\ell$+jets)



- Focus on right-handed W' (no interference with SM)
- Boosted top ⟹ track isolation for leptons
- All-hadronic and $\ell$+jets comparable sensitivity for m > 2 TeV



lepton
& quark?




long-

boson

boson

quark

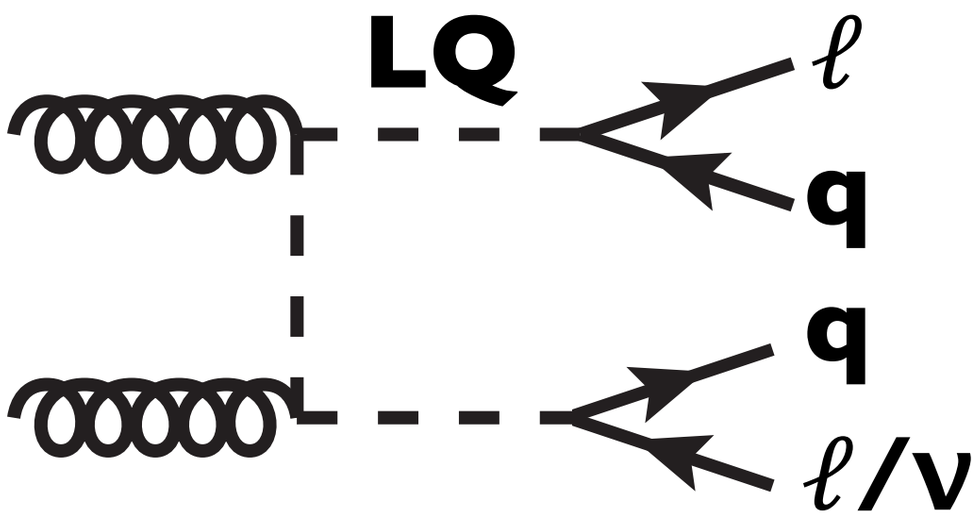
leptons

lepton
quark

quark
quark

# Light Quark + e/μ (neutrino)





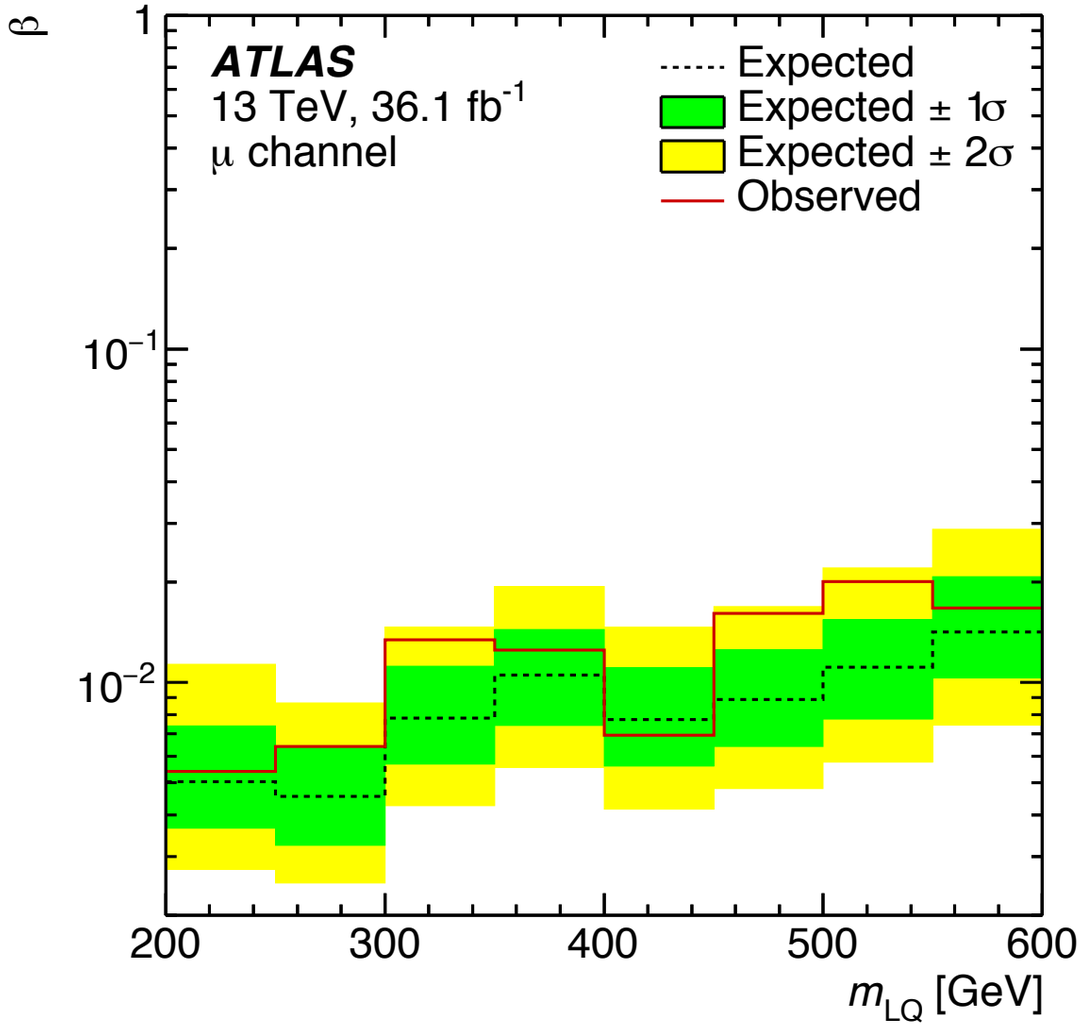

Do LQ explain flavor anomalies?

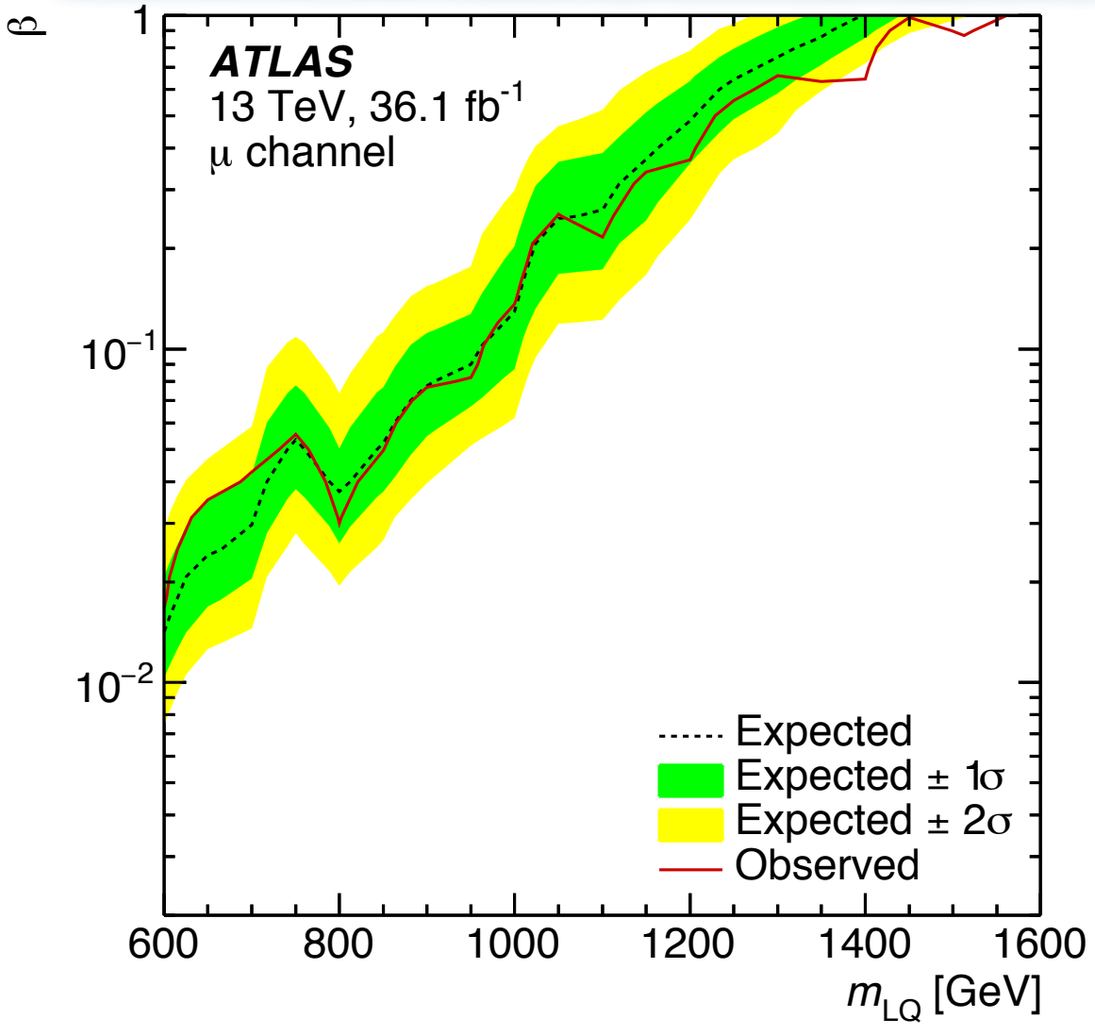
- B → K* μ μ ?

→ 2nd generation couplings?

- Separate BDTs trained for

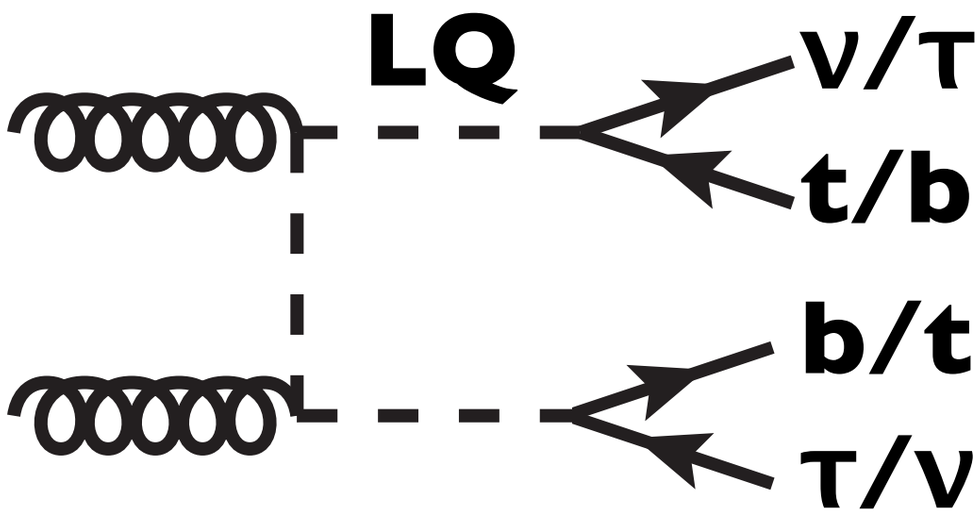
  $\ell\nu qq$ ($\beta \neq 1$) & $\ell\ell qq$ ($\beta = 1$)



# Top/Bottom + Tau (neutrino)



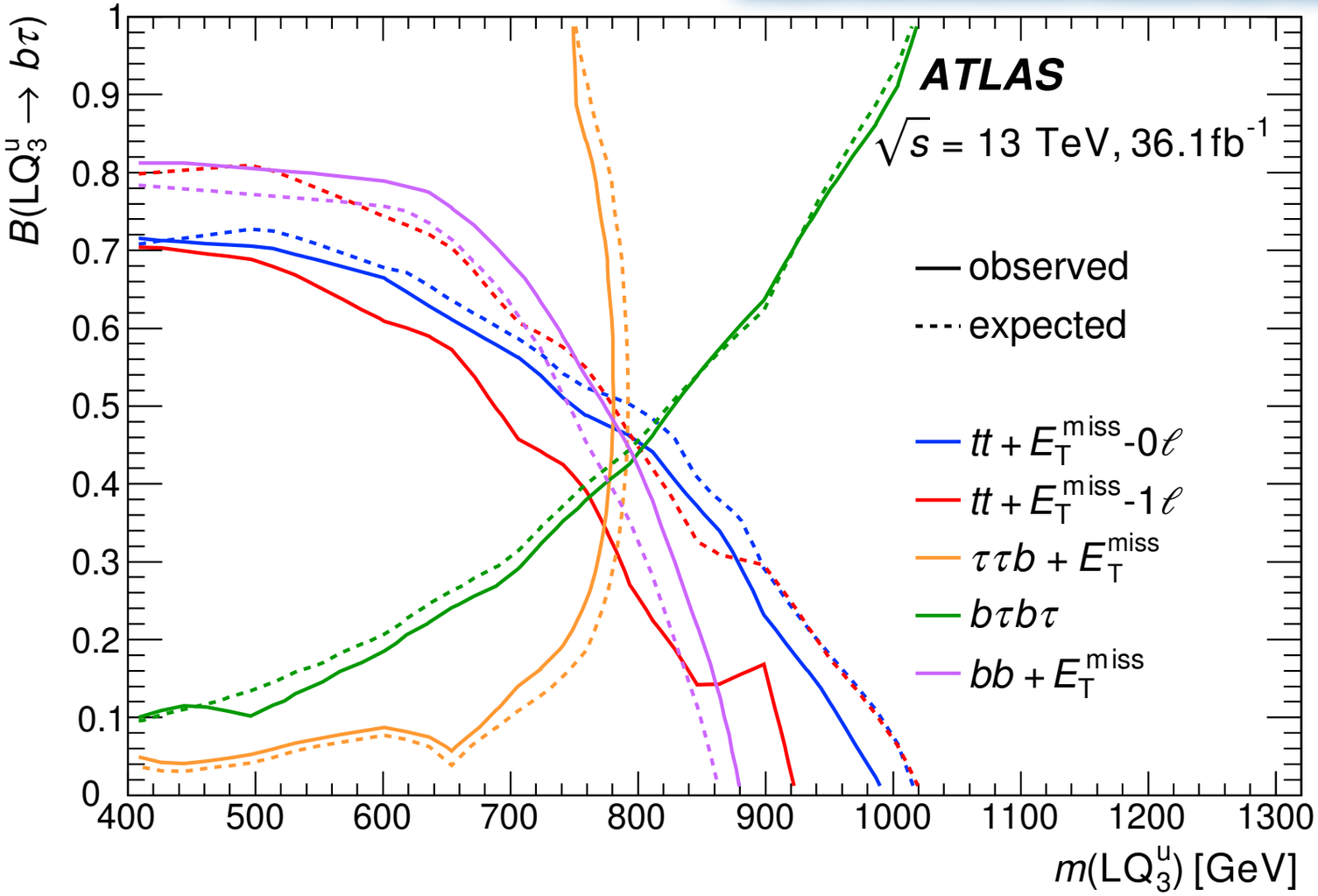



Do LQs explain flavor anomalies?

- B → D* τ ν ?

→ 3rd generation couplings?

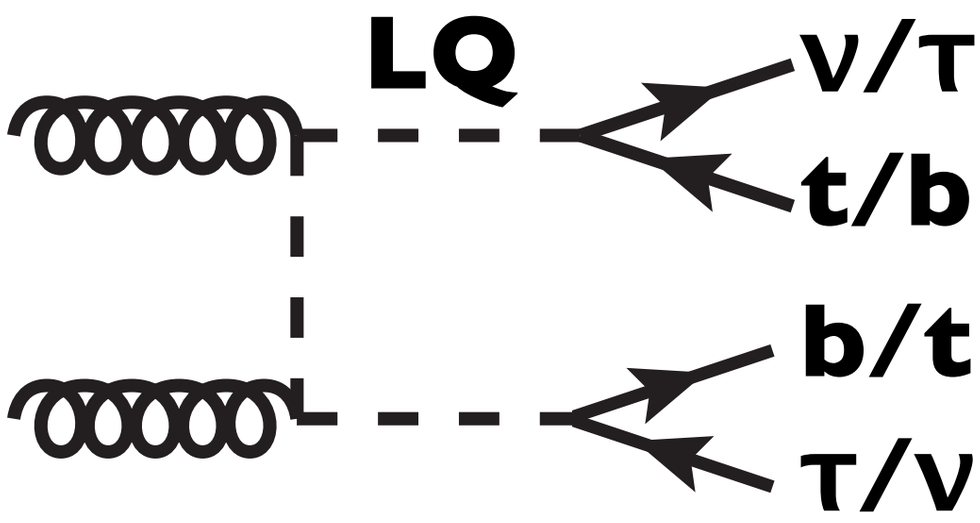
- Reoptimizations/reinterpretations of 5 analyses (HH/SUSY)



arXiv:1902.08103

# Top/Bottom + Tau (neutrino)

36 fb$^{-1}$

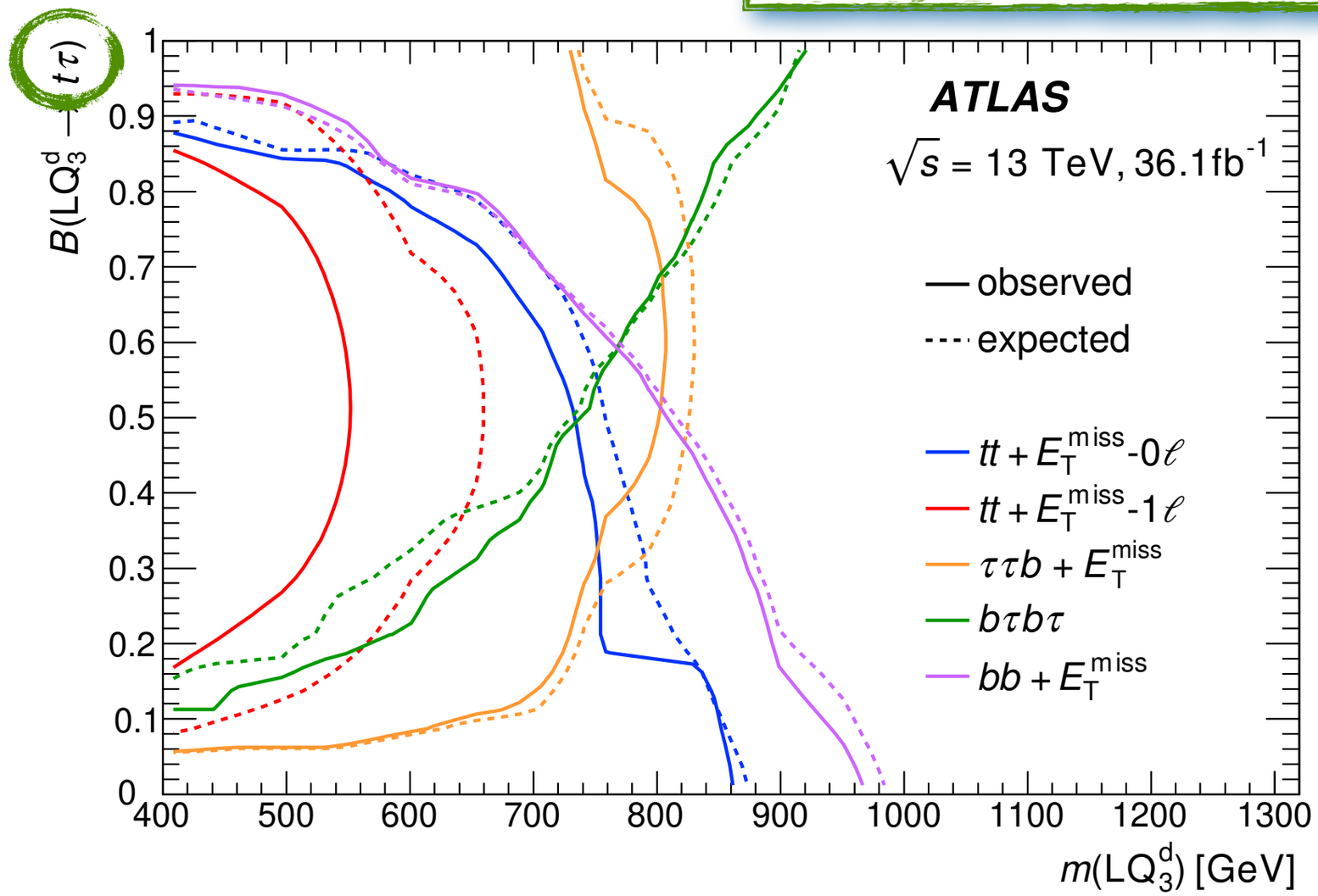



Do LQs explain flavor anomalies?

- B → D* τ ν ?

→ 3rd generation couplings?

- Reoptimizations/reinterpretations of 5 analyses (HH/SUSY)



long-lived

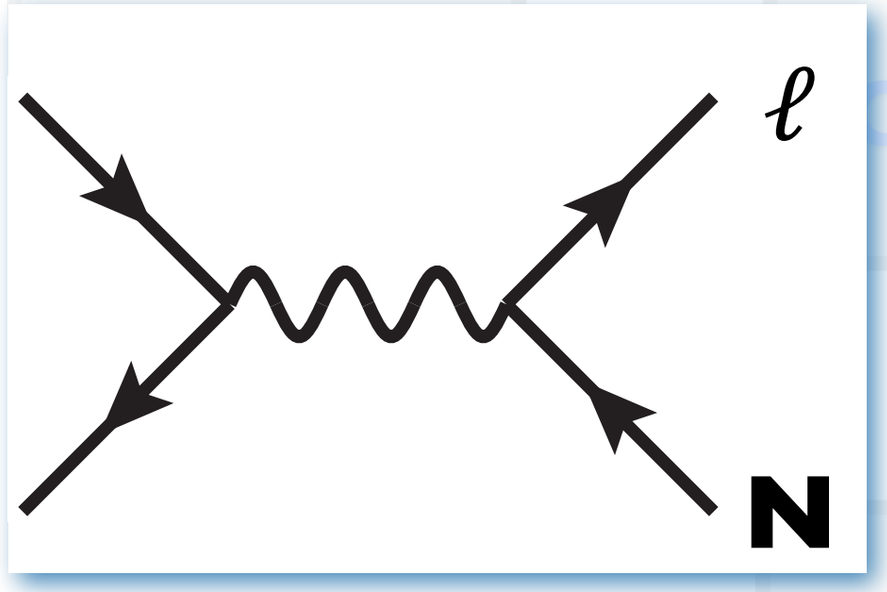
boson

boson

$m_\nu$ ?

boson

quark




leptons

lepton

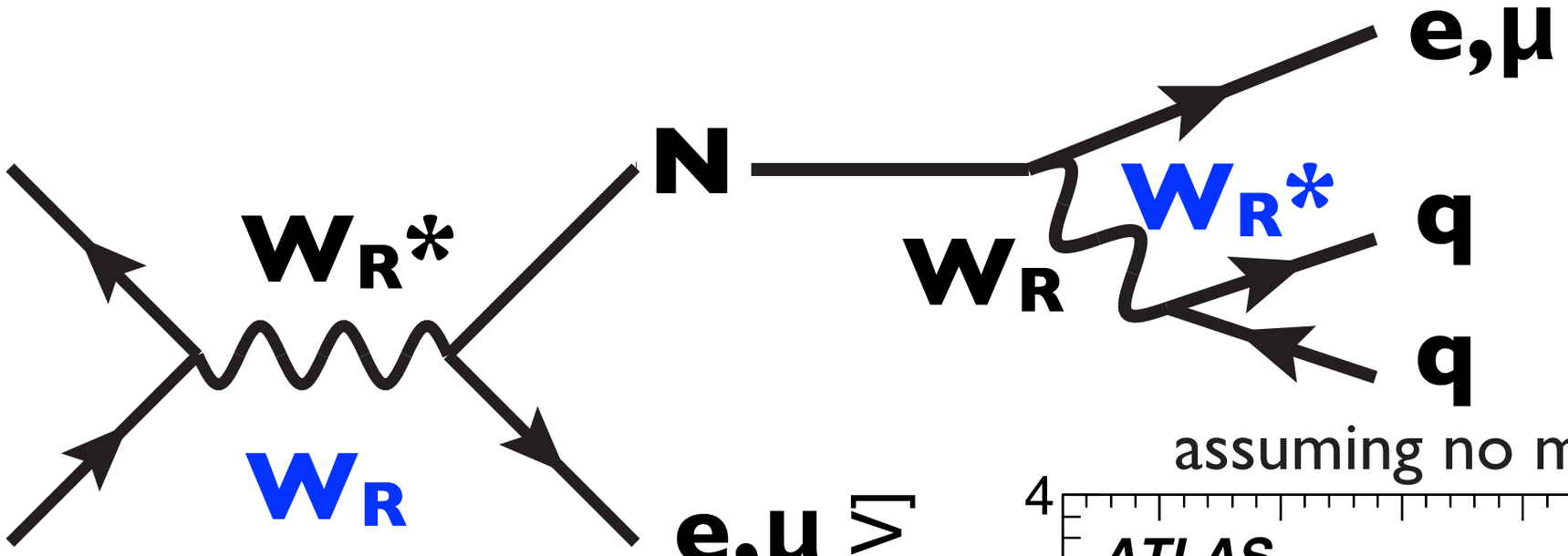
quark

quark

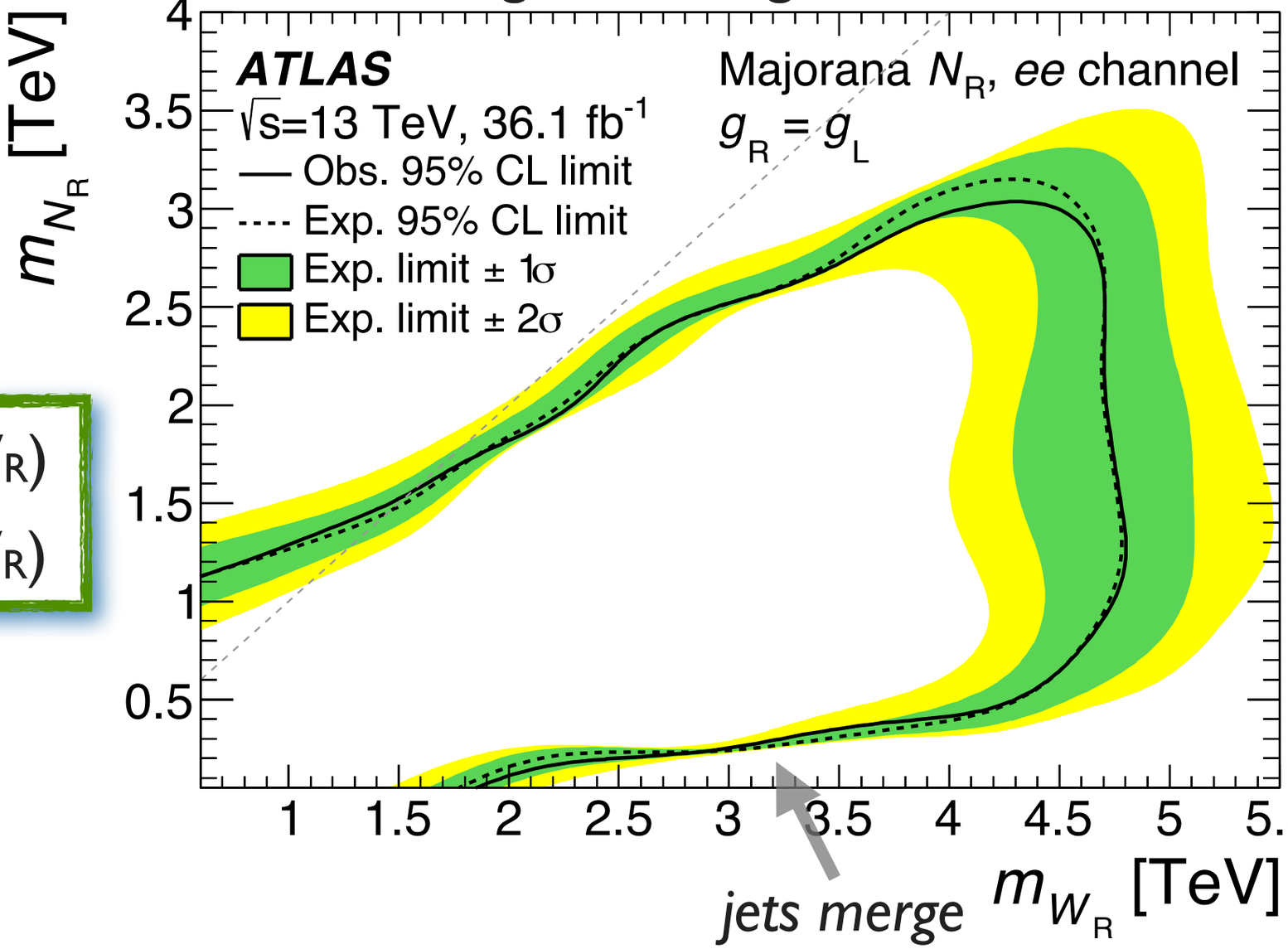
quark

# Heavy Neutrino






assuming no mixing between flavors:

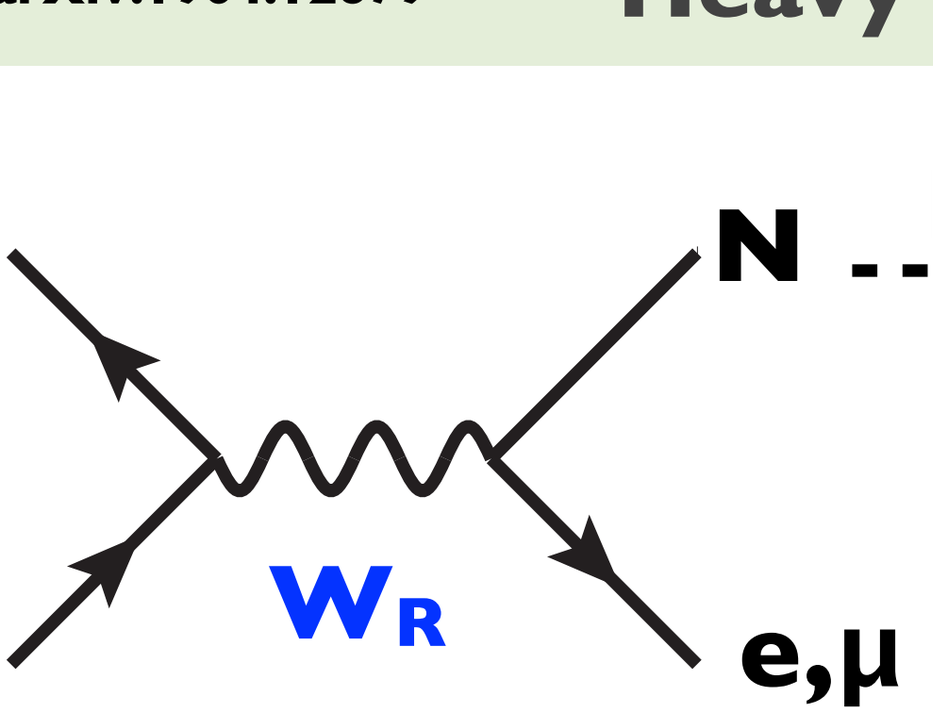


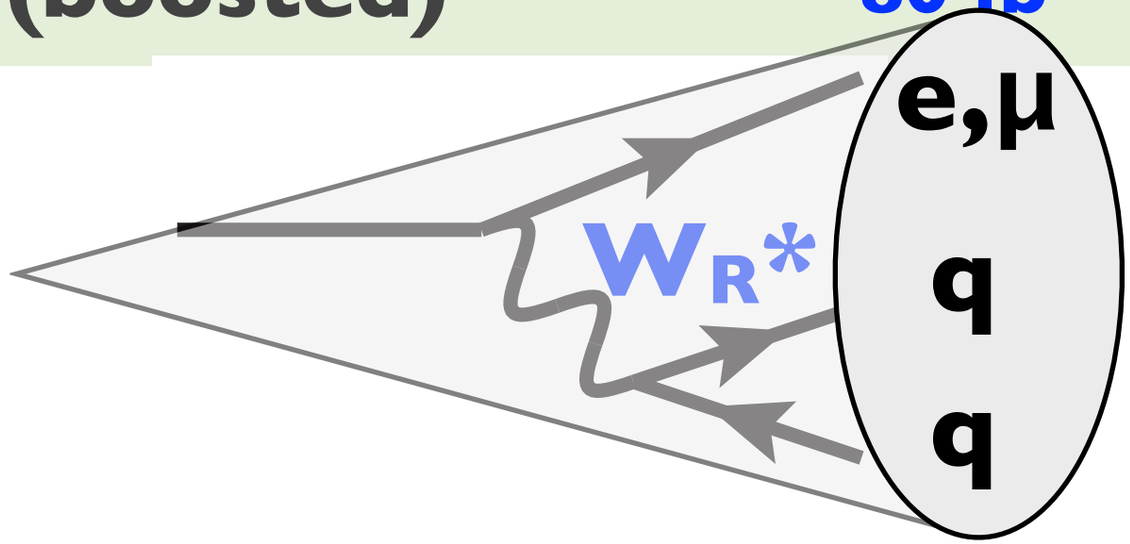

| | | |
|---|---|---|
| $m(W_R) > m(N_R)$ | → | $m_{llqq} \sim m(W_R)$ |
| else | → | $m_{qq} \sim m(W_R)$ |

arXiv:1904.12679

# Heavy Neutrino (boosted)

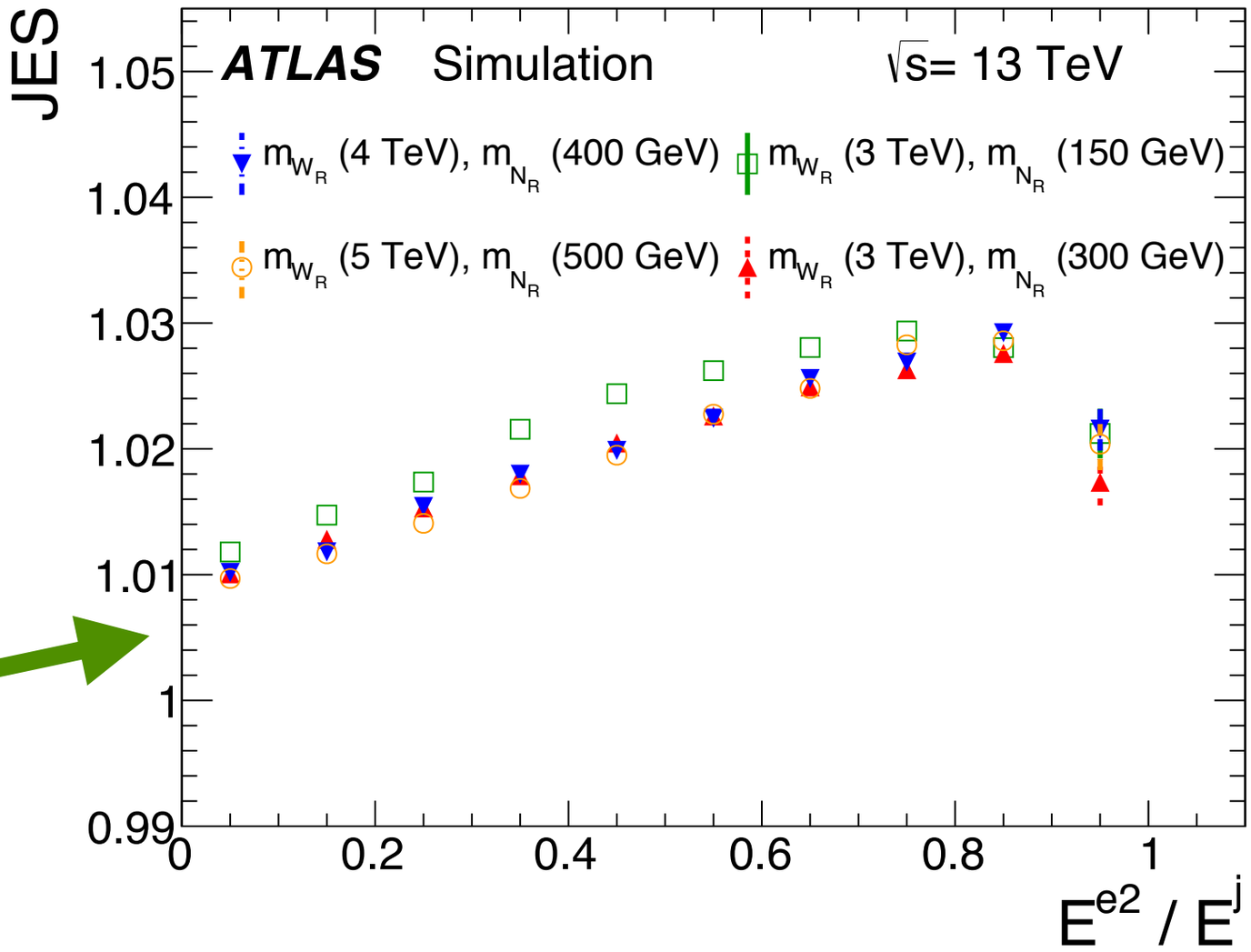
80 fb$^{-1}$




- Lepton in large-R jet and no isolation in 2nd lepton
- Electron as part large-R jet

  ⟹ checks on
  - $e^{\pm}$ efficiency vs. ΔR
  - Jet mass & energy scales

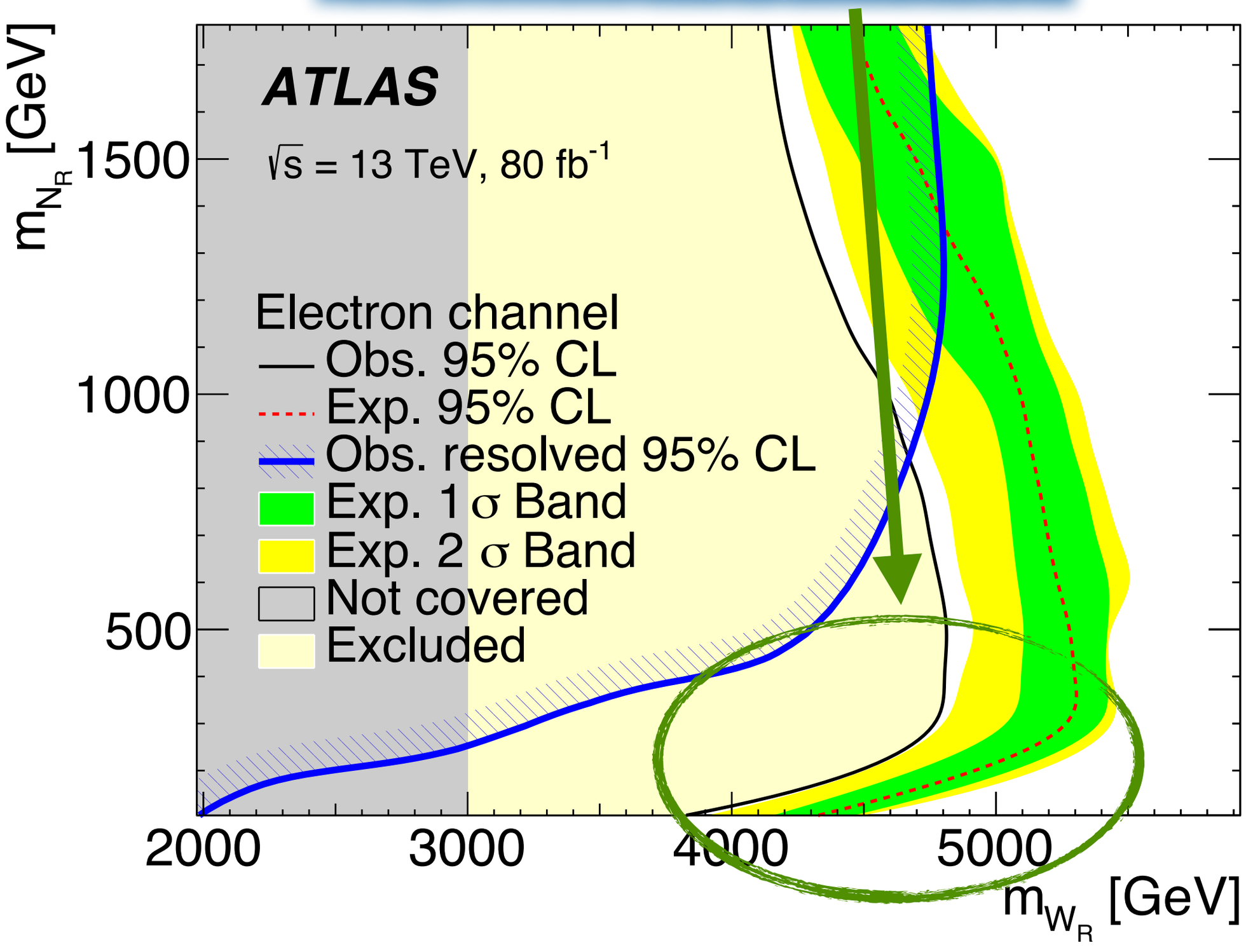


arXiv:1904.12679

# Heavy Neutrino (boosted)

80 fb$^{-1}$

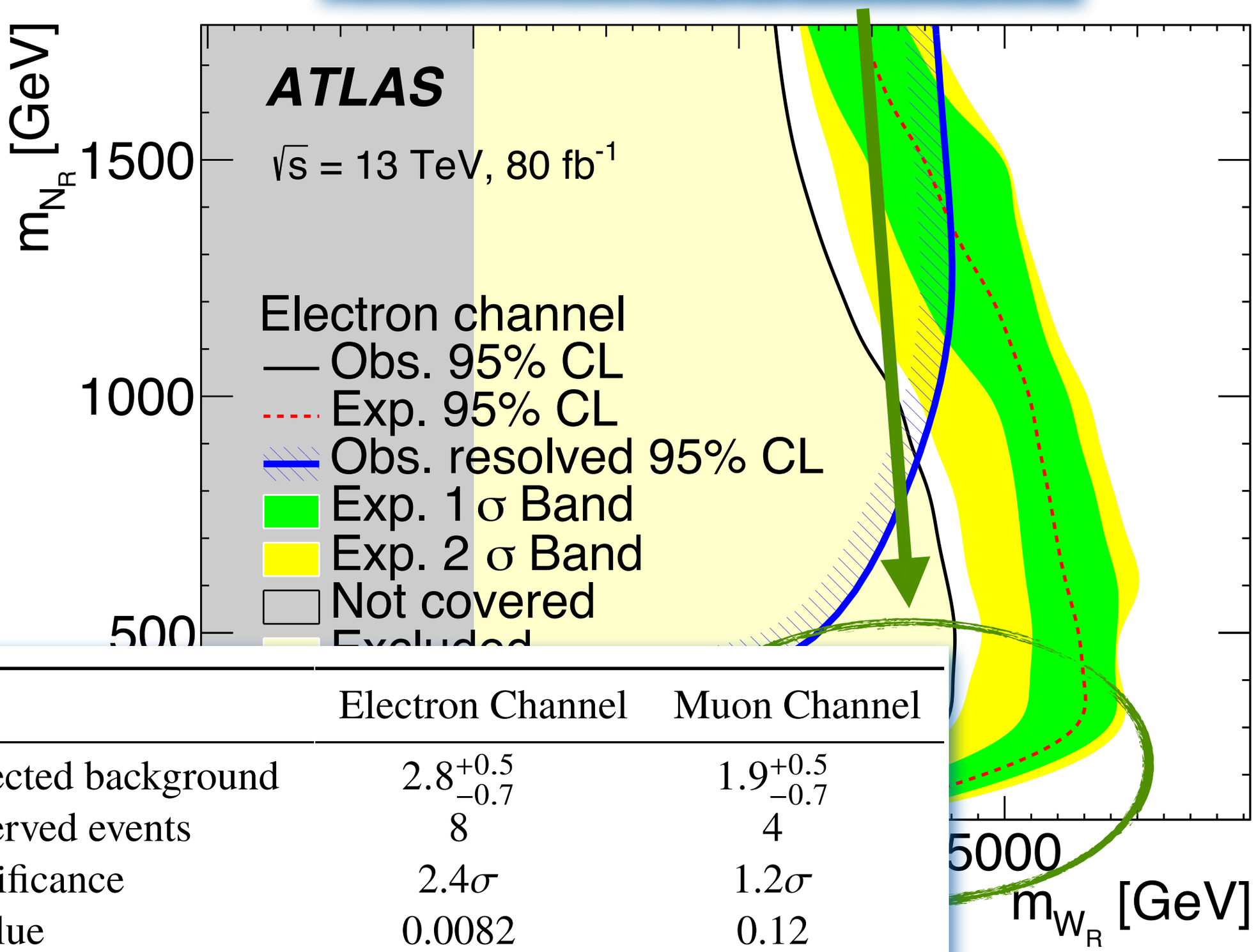
- Improved sensitivity at high boost



# Heavy Neutrino (boosted)



- Improved sensitivity at high boost



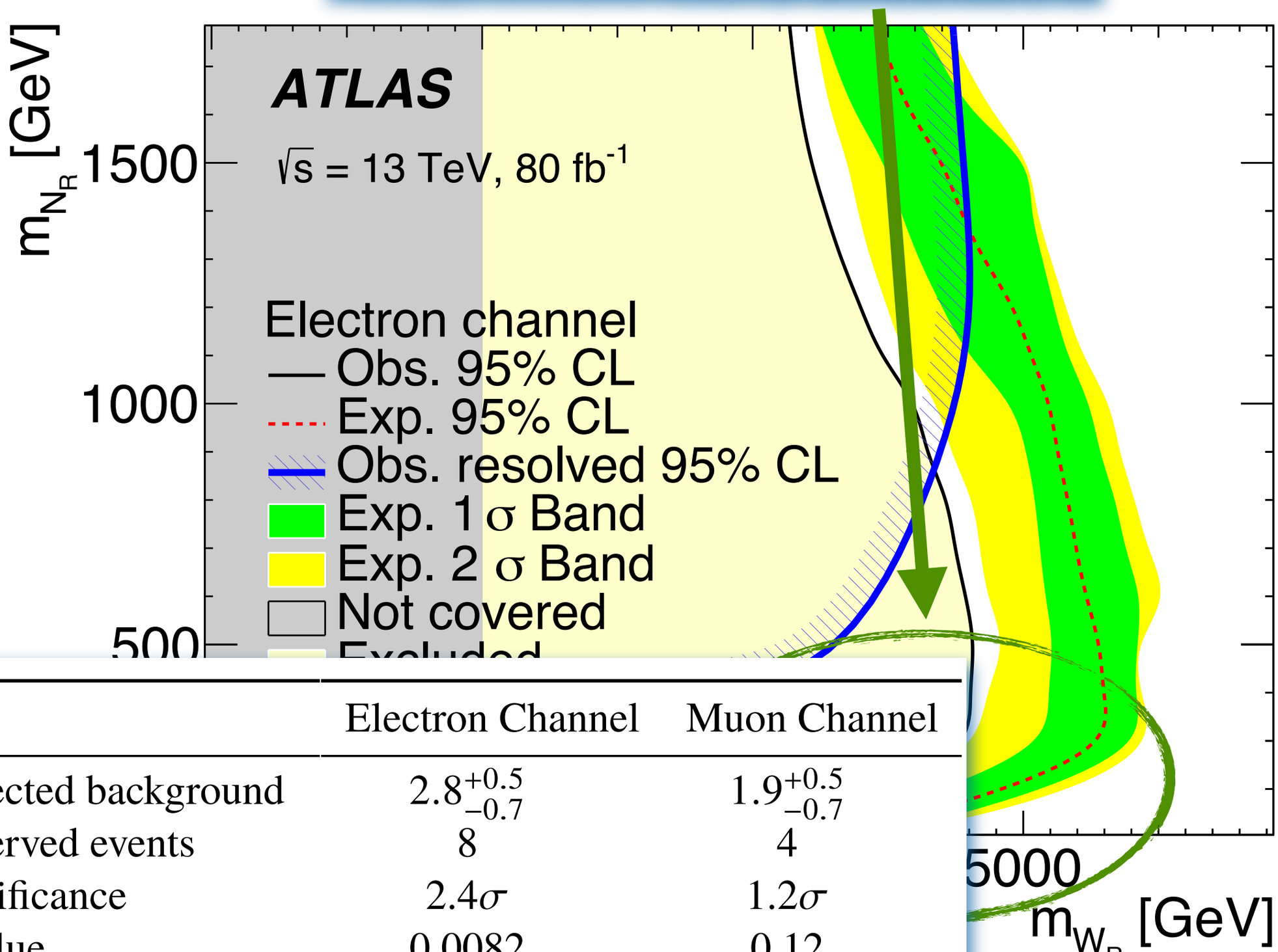

| | Electron Channel | Muon Channel |
|---|---|---|
| Expected background | $2.8^{+0.5}_{-0.7}$ | $1.9^{+0.5}_{-0.7}$ |
| Observed events | 8 | 4 |
| Significance | $2.4\sigma$ | $1.2\sigma$ |
| $p$-value | 0.0082 | 0.12 |

arXiv:1904.12679

# Heavy Neutrino (boosted)

80 fb$^{-1}$

- Improved sensitivity at high boost



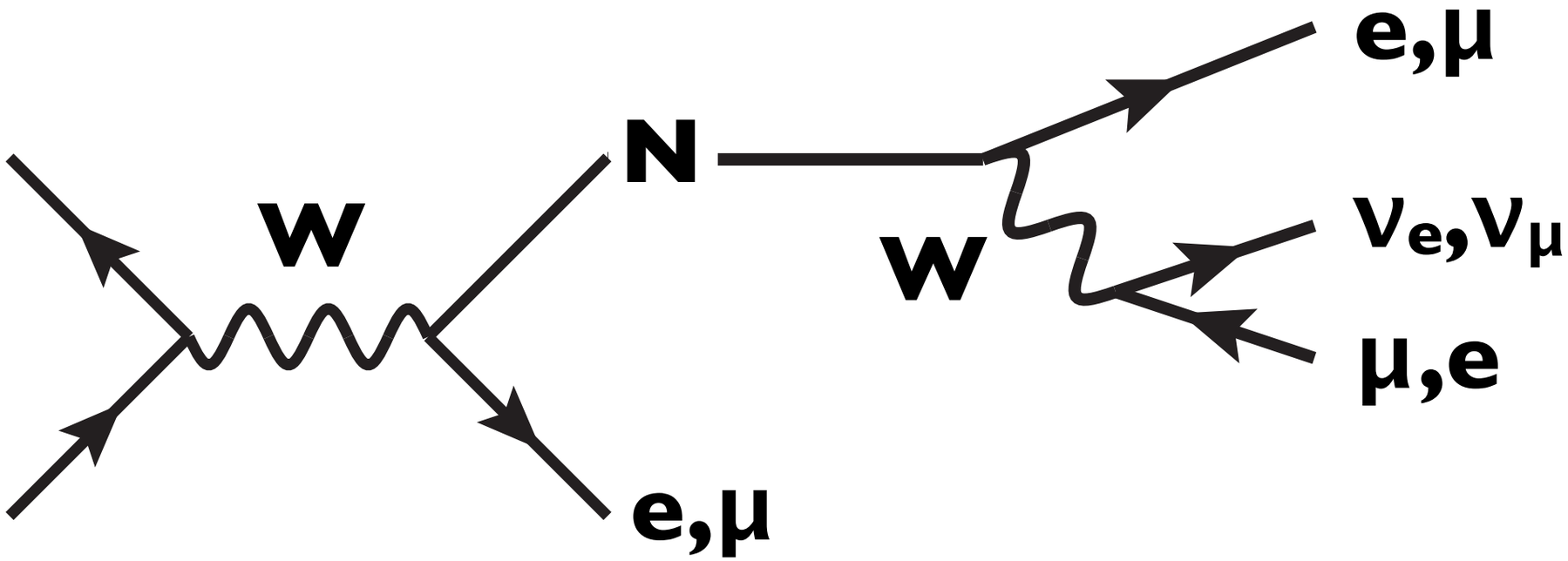

| | Electron Channel | Muon Channel |
|---|---|---|
| Expected background | $2.8^{+0.5}_{-0.7}$ | $1.9^{+0.5}_{-0.7}$ |
| Observed events | 8 | 4 |
| Significance | $2.4\sigma$ | $1.2\sigma$ |
| $p$-value | 0.0082 | 0.12 |

⟹ ***talk by Debarati Roy***

arXiv:1905.09787

# Heavy ν (prompt+displaced)

33-36 fb$^{-1}$




- Prompt search:

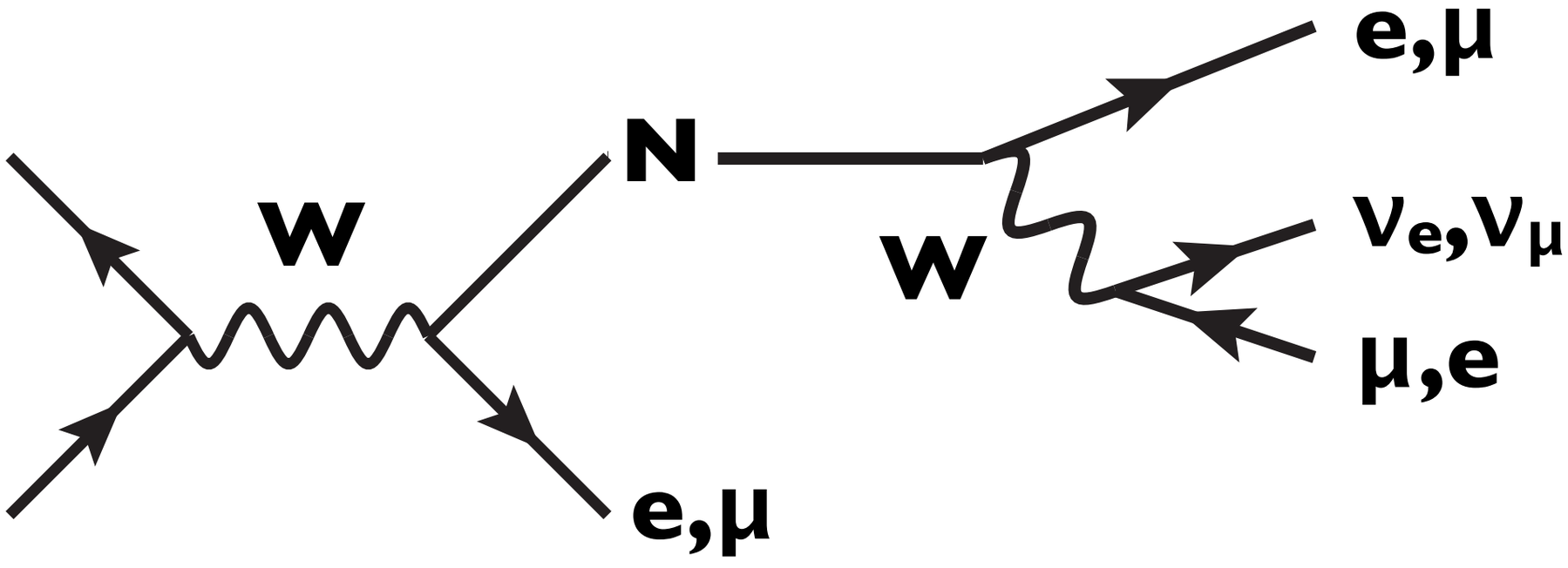
  2e+μ or 2μ+e

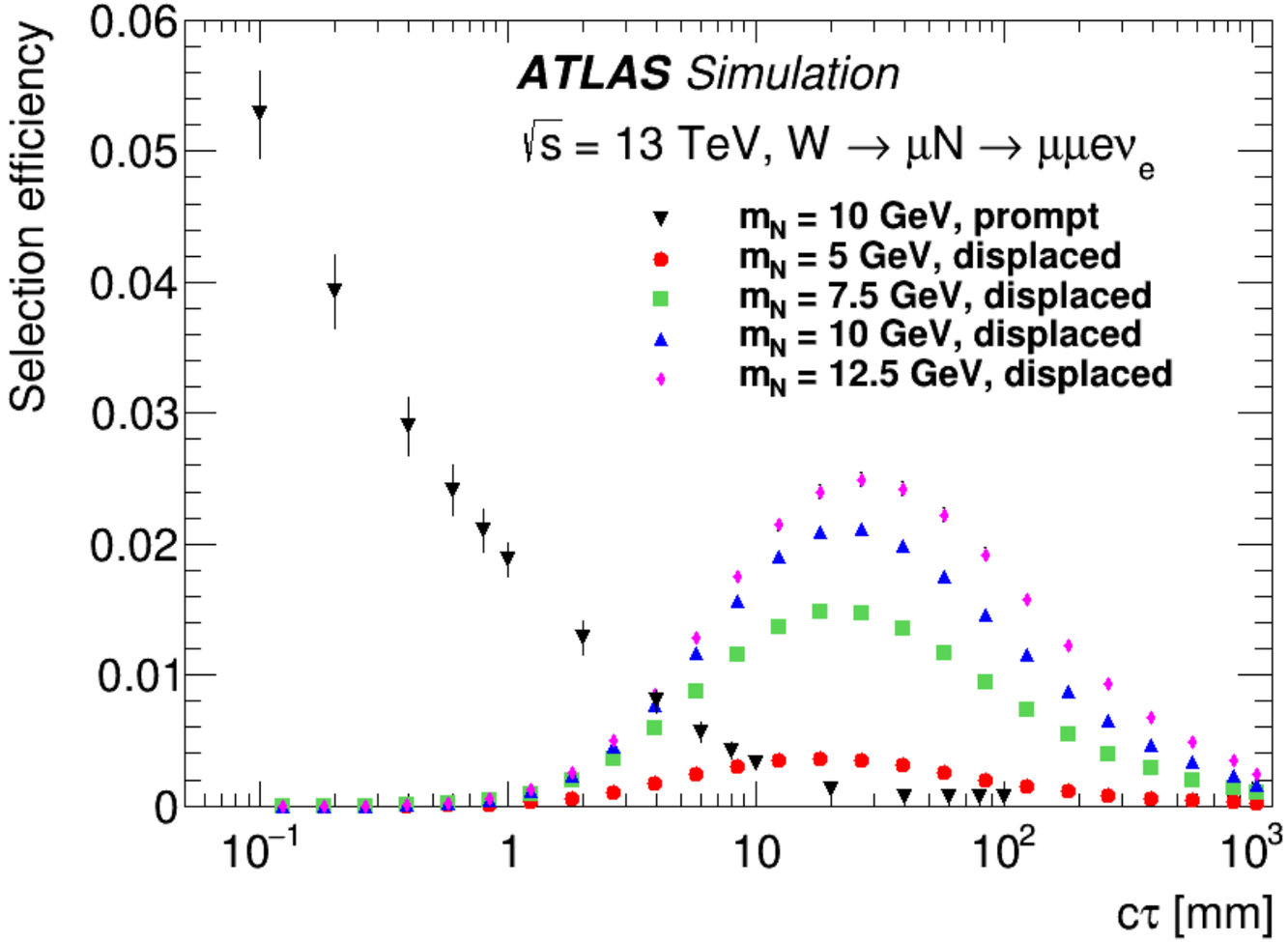
  same charge for same flavor
- Small masses ⟹ long τ
- Displaced-vertex search:
  - μ + displaced vertex with

    d = 4-300mm & m > 4 GeV

# Heavy ν (prompt+displaced)






- Prompt search:

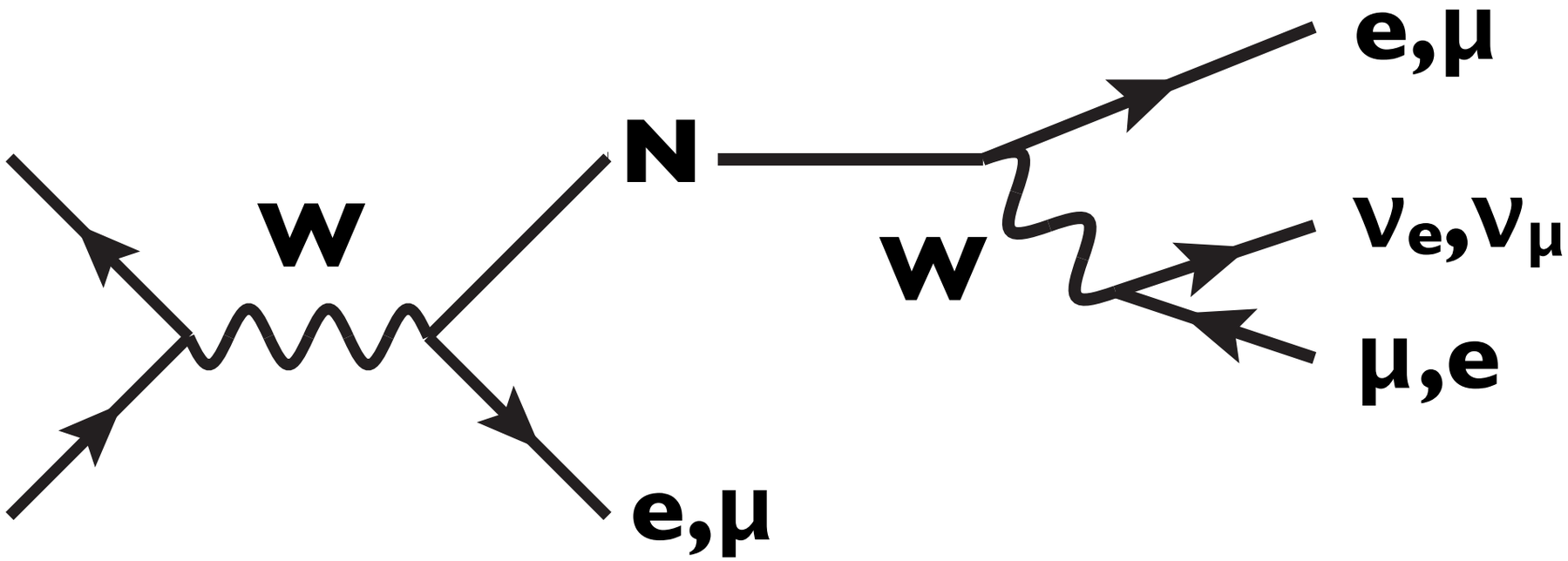
  2e+μ or 2μ+e

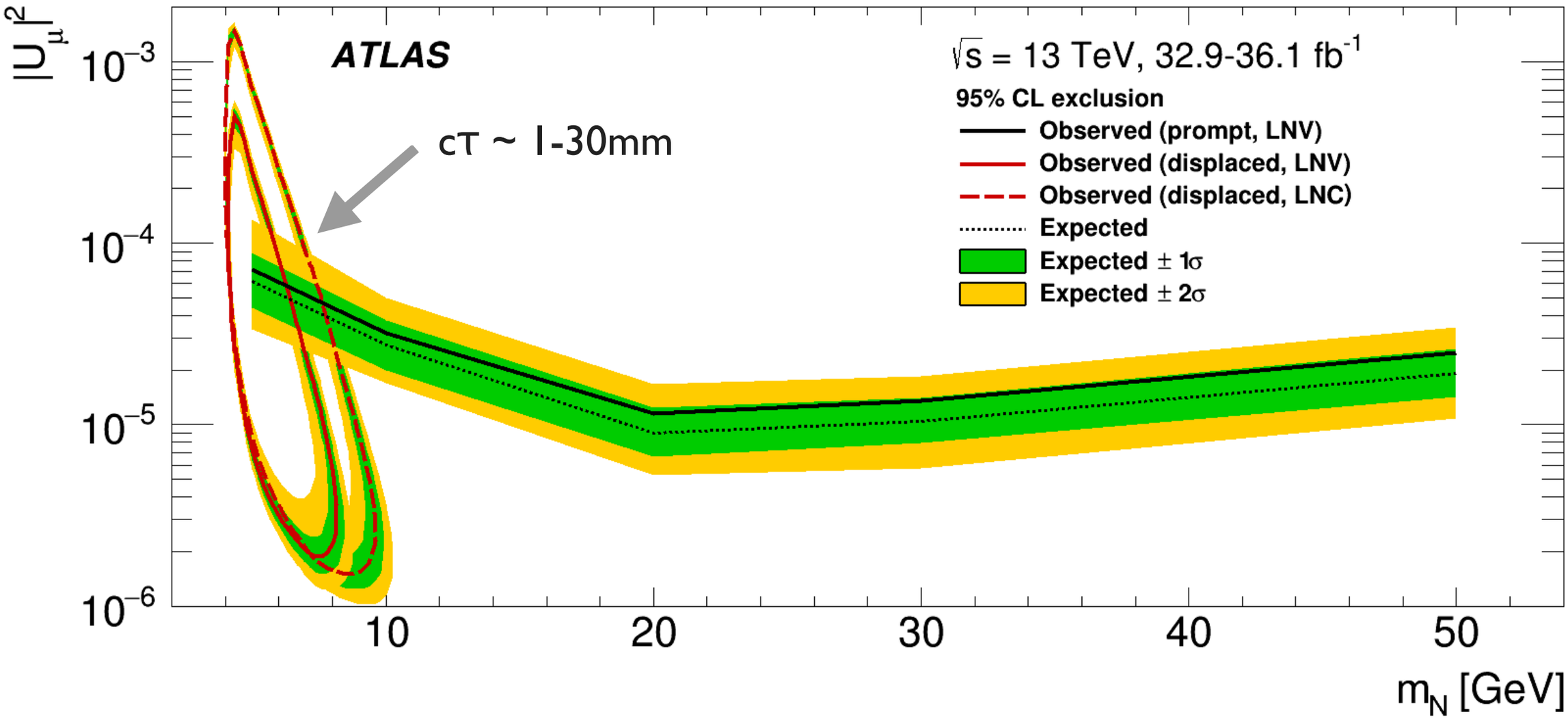
  same charge for same flavor
- Small masses ⟹ long τ
- Displaced-vertex search:
  - μ + displaced vertex with

    d = 4-300mm & m > 4 GeV

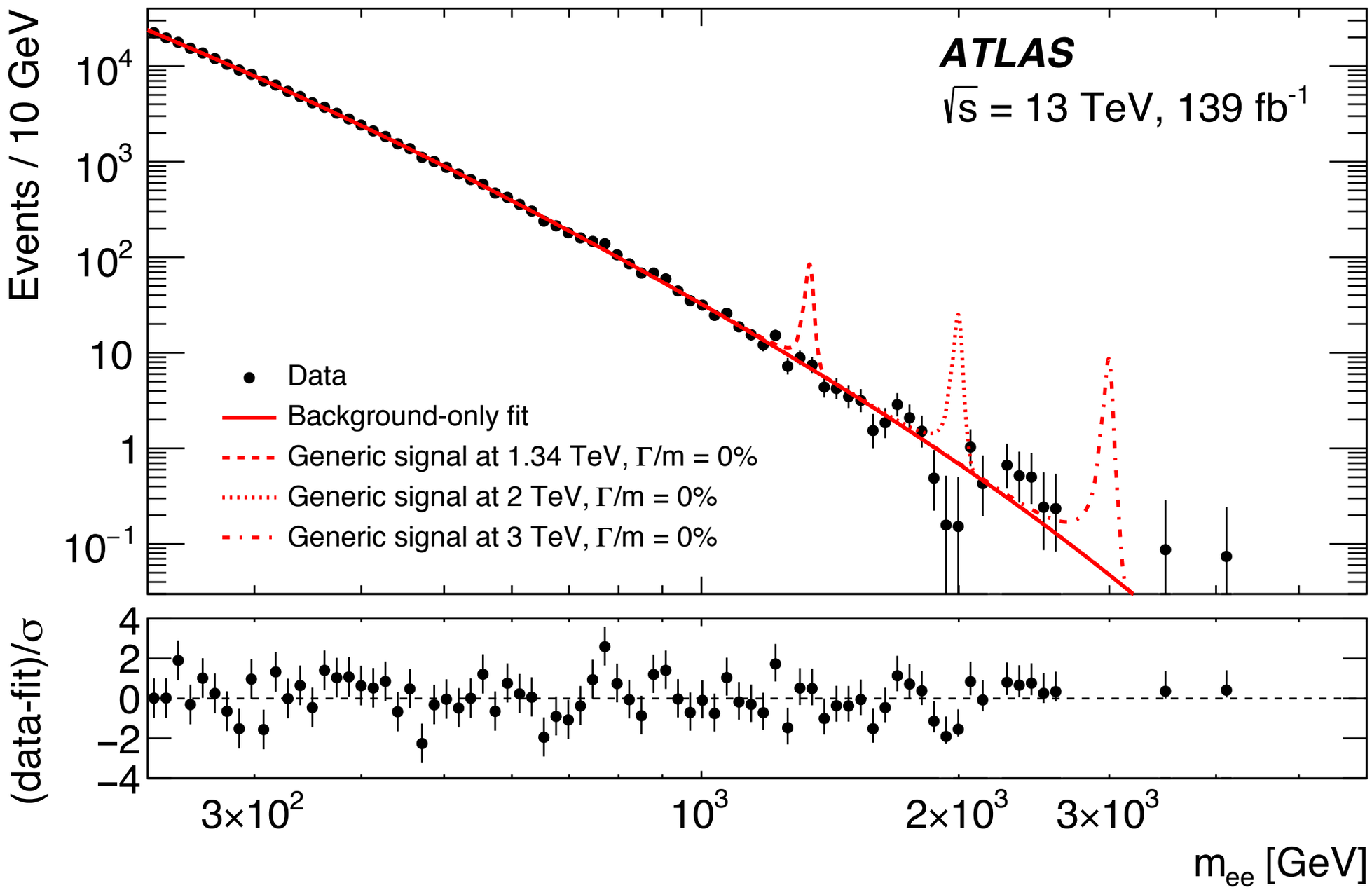
# Heavy ν (prompt+displaced)

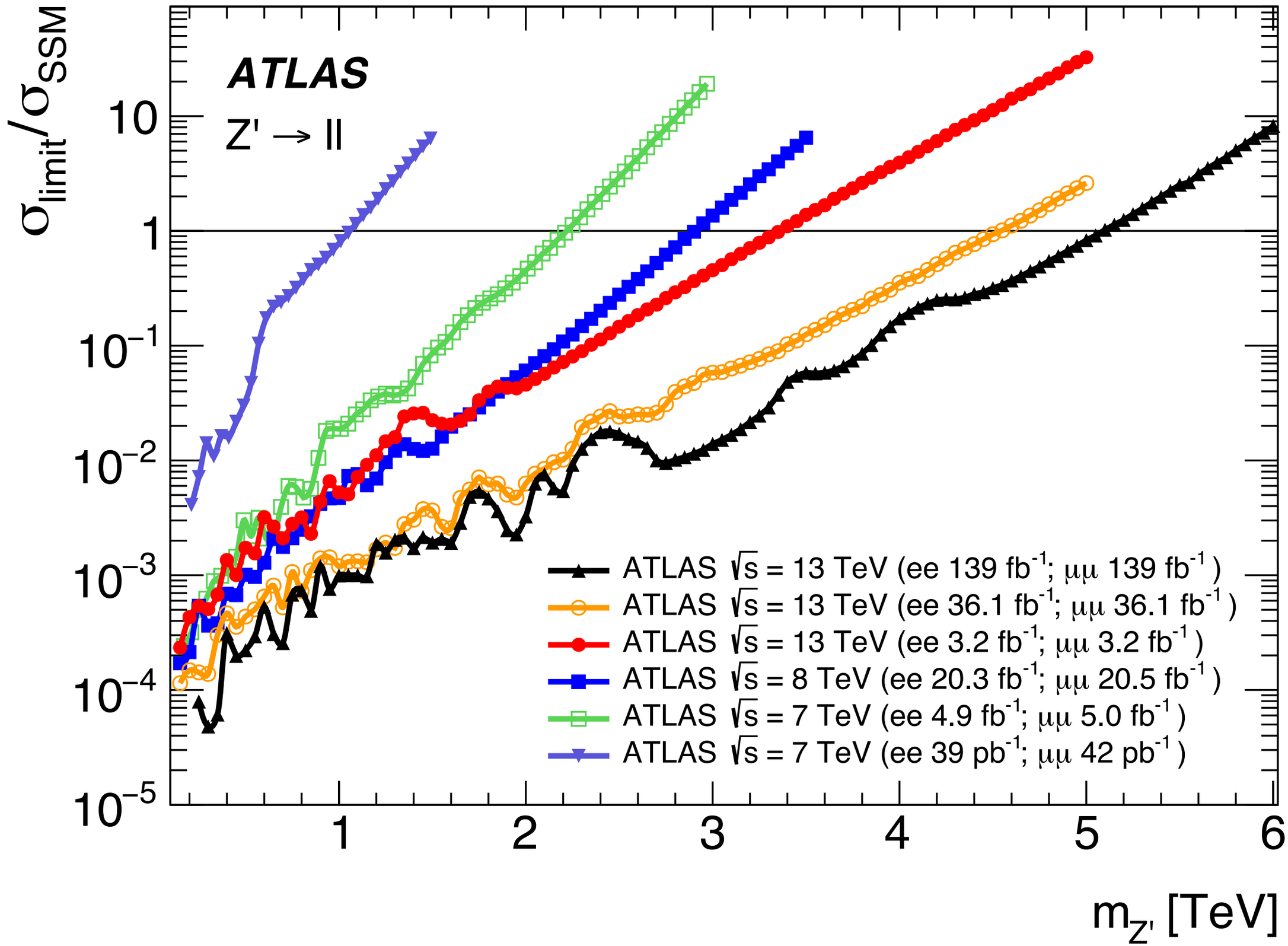




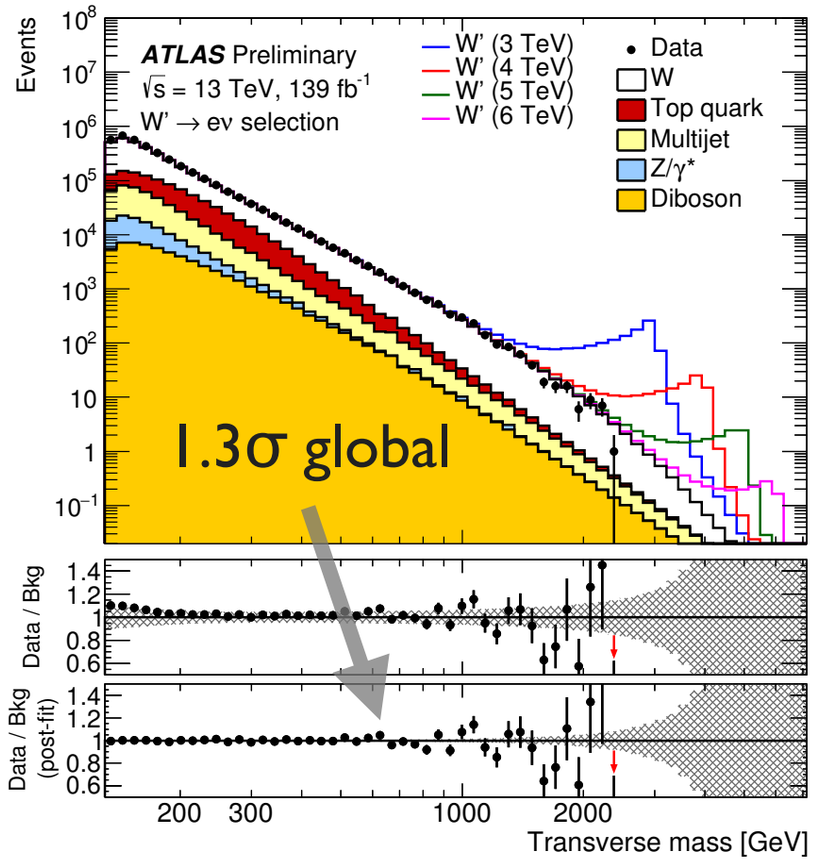



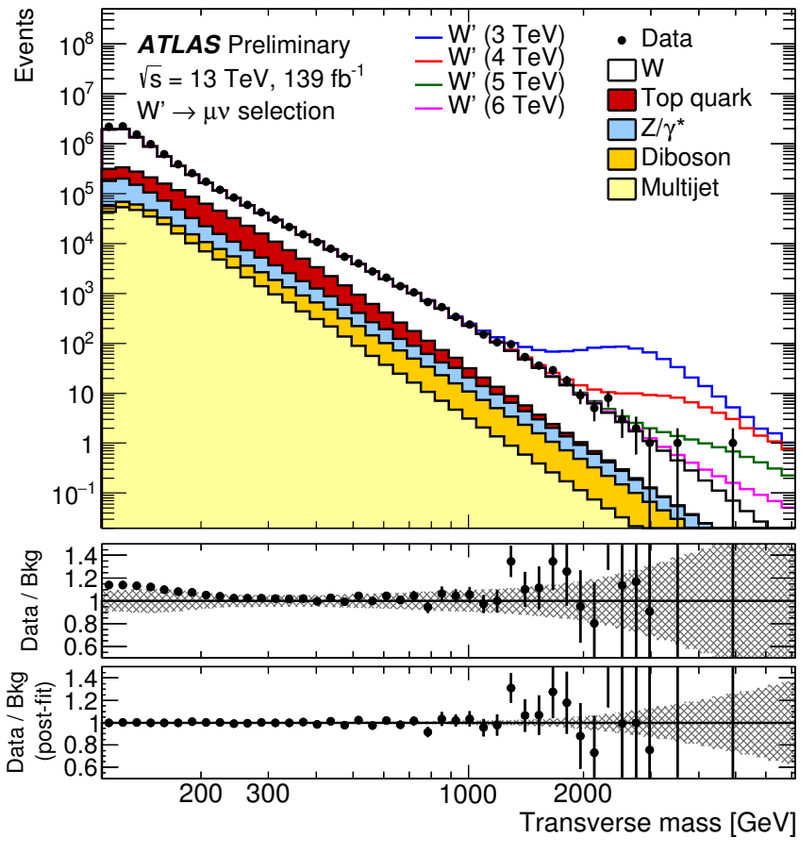
- Convolution of a generic signal BW with resolution
- Interpretation in a variety of models
  - spin-0, -1, -2
  - SSM
  - HVT
  - …

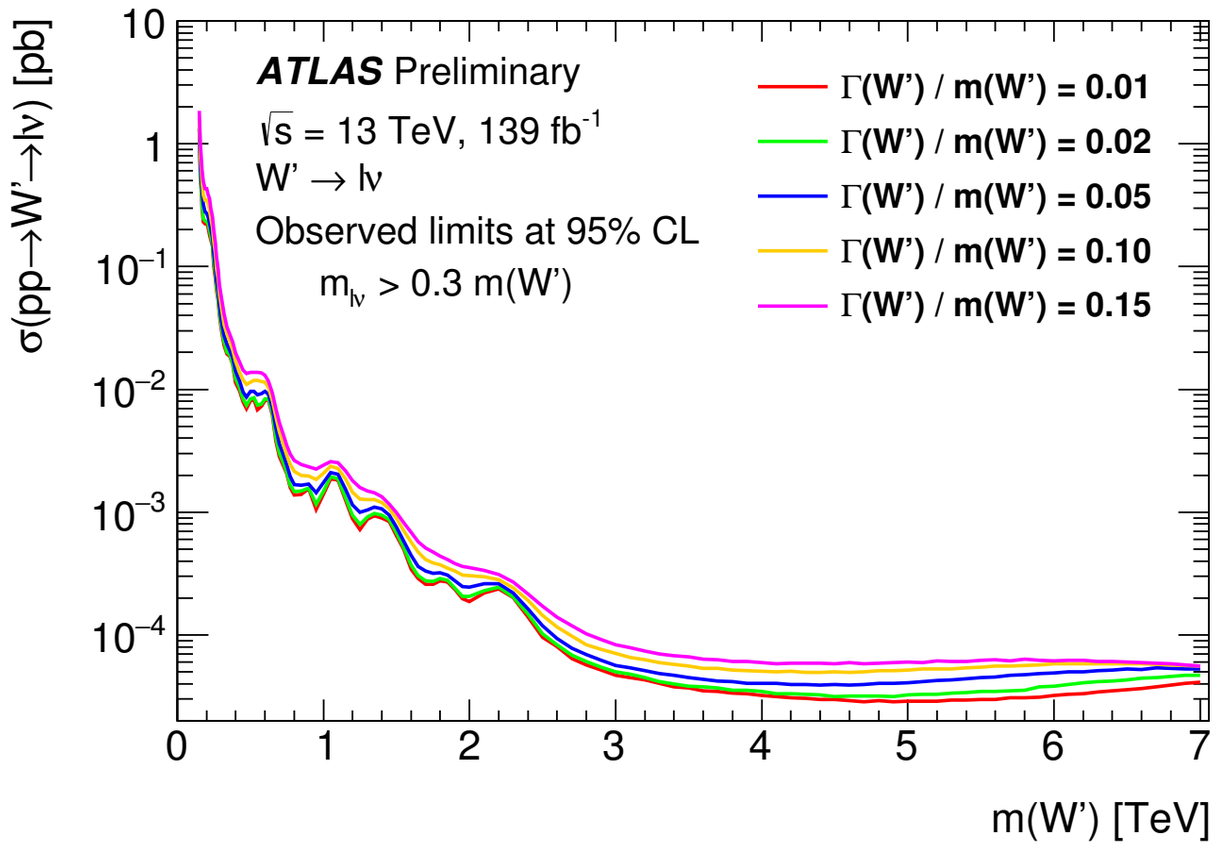



ATLAS
Z' → ll
σlimit/σSSM
10
1
10−1
10−2
10−3
10−4
10−5
1
2
3
4
5
6
mZ' [TeV]
ATLAS √s = 13 TeV (ee 139 fb-1; μμ 139 fb-1 )
ATLAS √s = 13 TeV (ee 36.1 fb-1; μμ 36.1 fb-1 )
ATLAS √s = 13 TeV (ee 3.2 fb-1; μμ 3.2 fb-1 )
ATLAS √s = 8 TeV (ee 20.3 fb-1; μμ 20.5 fb-1 )
ATLAS √s = 7 TeV (ee 4.9 fb-1; μμ 5.0 fb-1 )
ATLAS √s = 7 TeV (ee 39 pb-1; μμ 42 pb-1 )

# EXOT-2018-30 (to be submitted soon) $W' \to \ell\nu$ 139 fb$^{-1}$



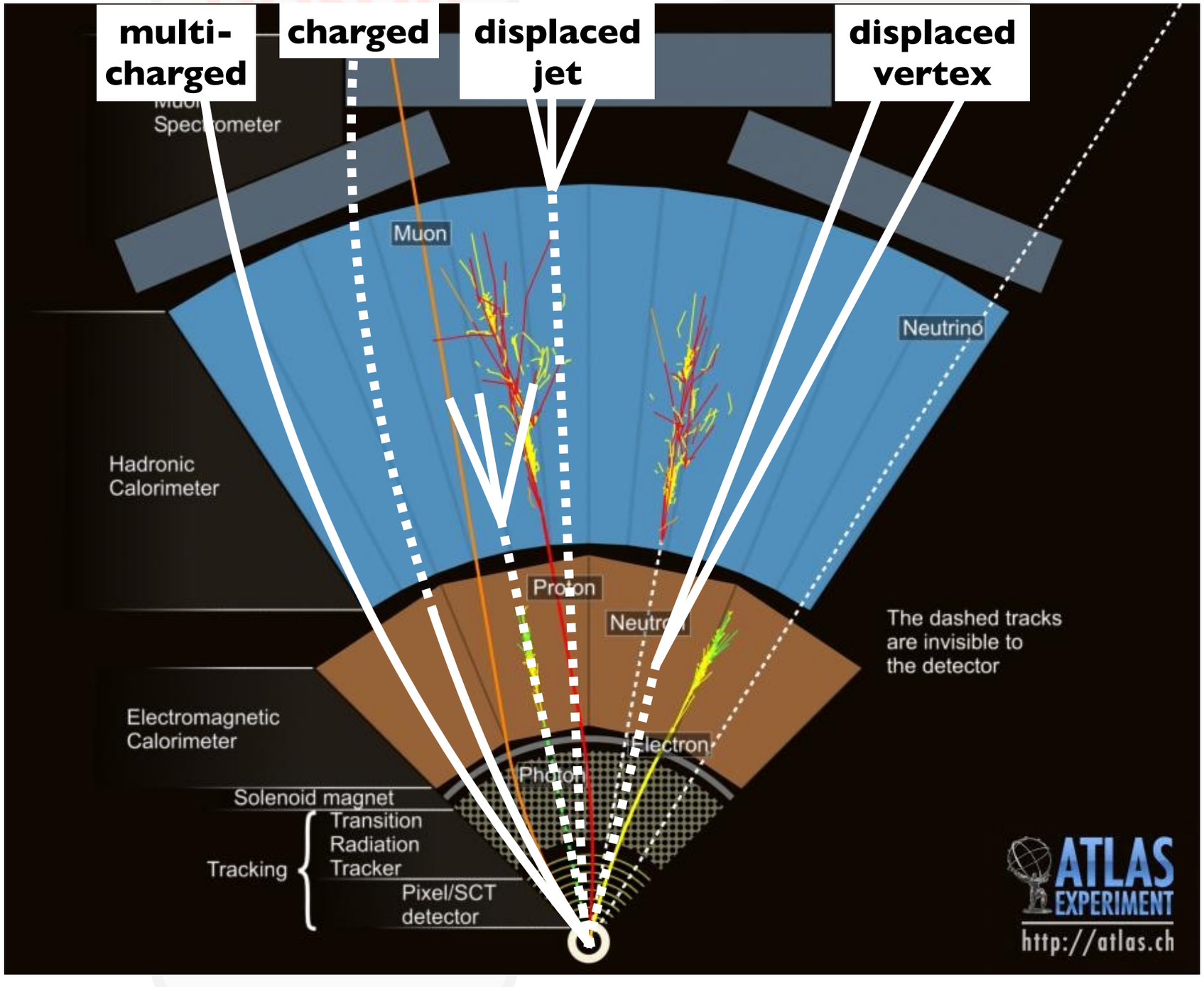



$m_H << \Lambda_P$ ?

DM ?

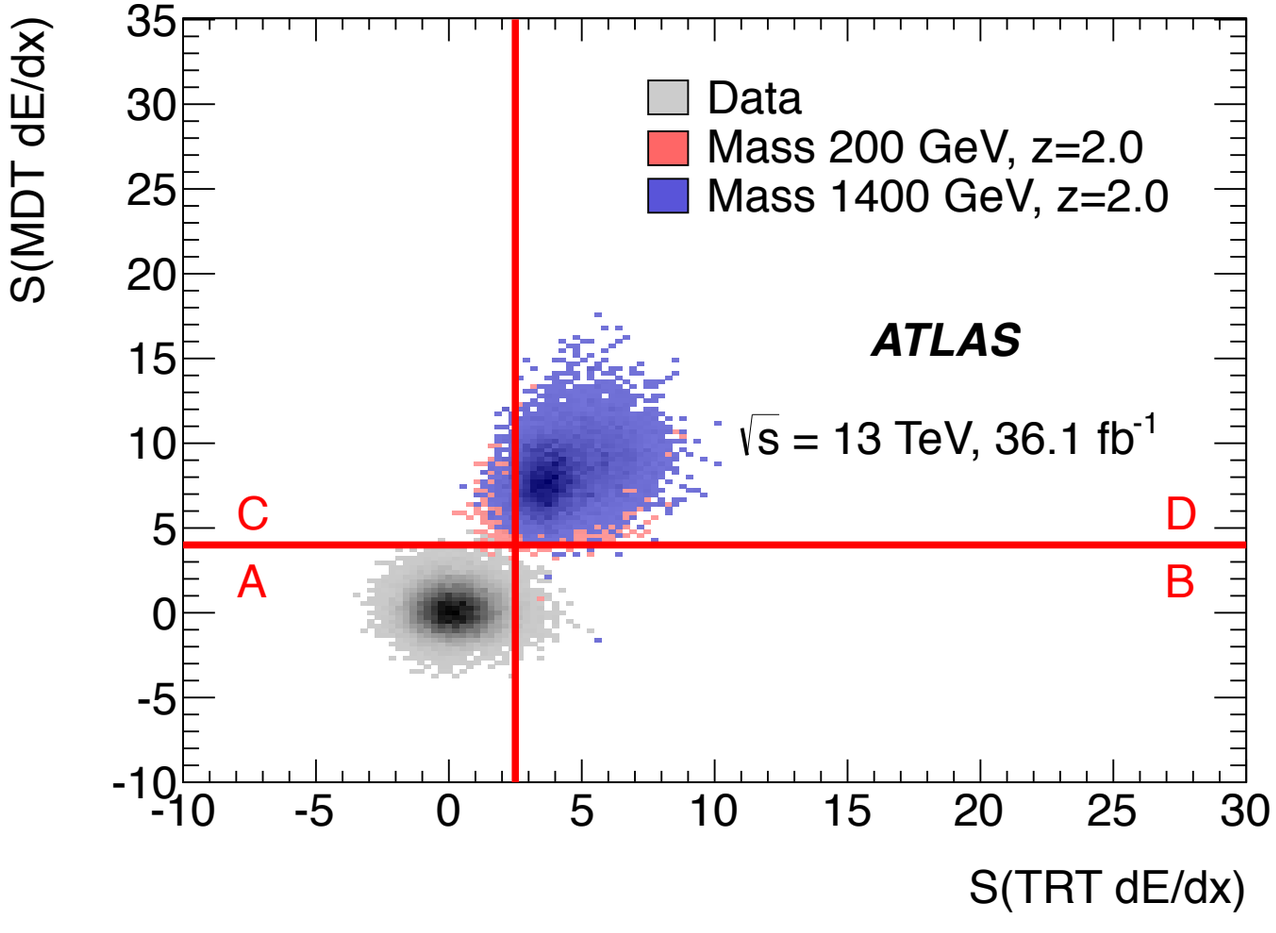
long-lived



# Multicharged



- LLP with q = 2-7e and $\tau \gg L_{ATLAS}/\beta\gamma$
- Signature:
  - μ-like with high dE/dx significance (compared to μ) in Pixel, TRT, MDT

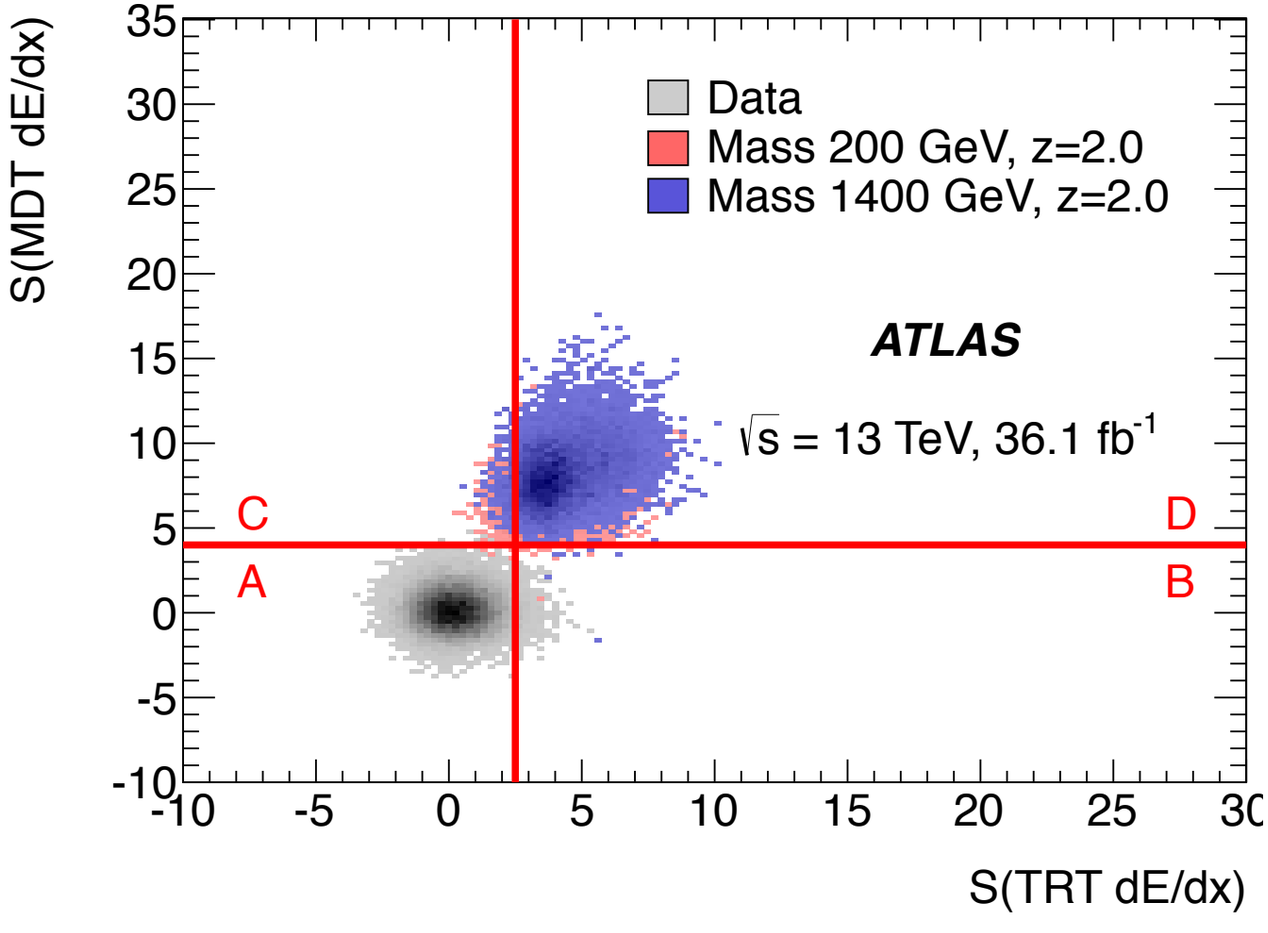


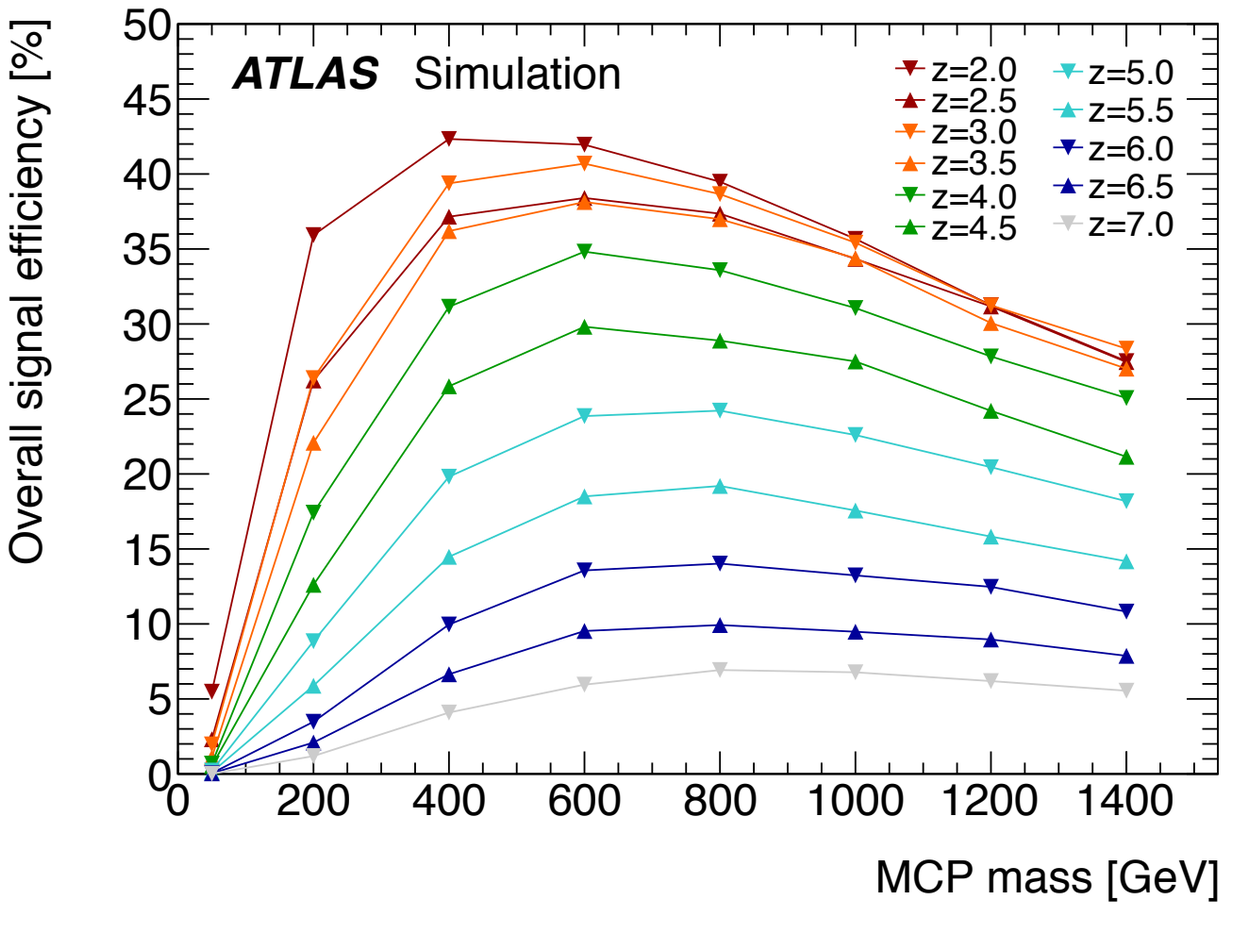
# Multicharged



- LLP with q = 2-7e and $\tau \gg L_{ATLAS}/\beta\gamma$
- Signature:
  - μ-like with high dE/dx significance (compared to μ) in Pixel, TRT, MDT

- At low mass: not always central
- At high q: $p_T > q/e \cdot 50$ GeV
- At high q (and at high mass): dE/dx ⟹ outside trigger window



# Multicharged



- LLP with q = 2-7e and $\tau \gg L_{ATLAS}/\beta\gamma$
- Signature:
  - μ-like with high dE/dx significance (compared to μ) in Pixel, TRT, MDT

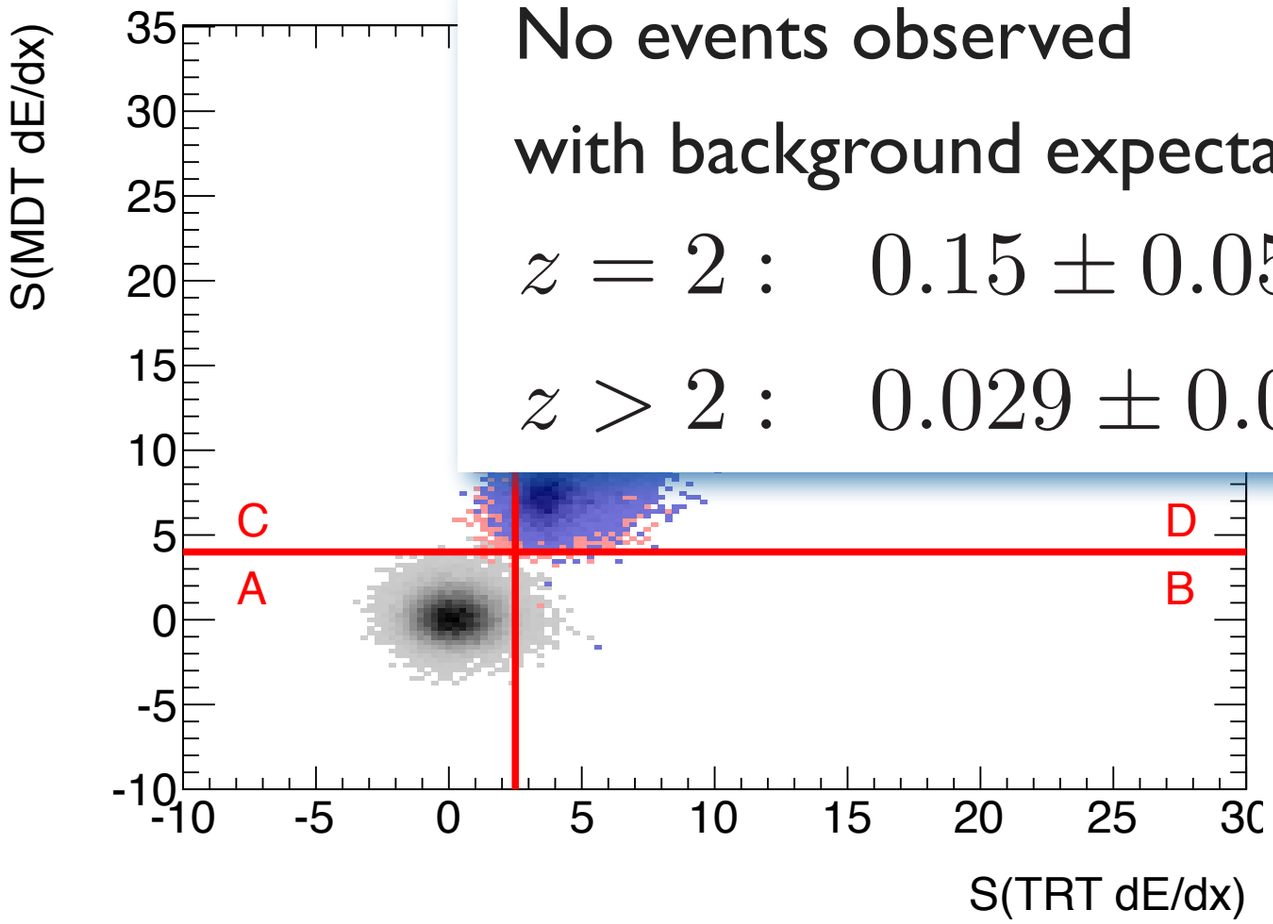
- At low mass: not always central
- At high q: $p_T > q/e \cdot 50$ GeV
- At high q (and at high mass): dE/dx ⟹ outside trigger window

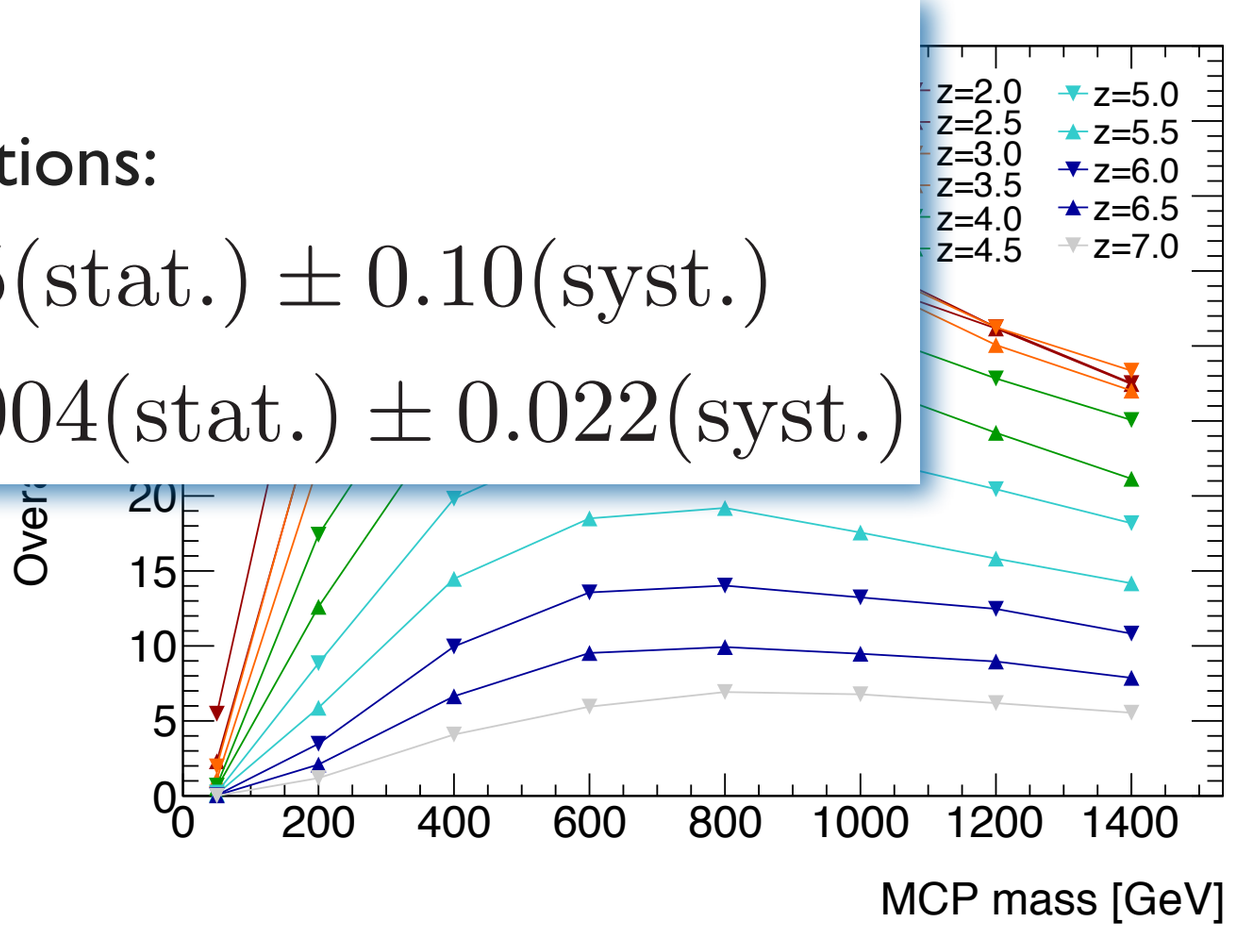
No events observed

with background expectations:

$$z = 2: \quad 0.15 \pm 0.05(\text{stat.}) \pm 0.10(\text{syst.})$$

$$z > 2: \quad 0.029 \pm 0.004(\text{stat.}) \pm 0.022(\text{syst.})$$



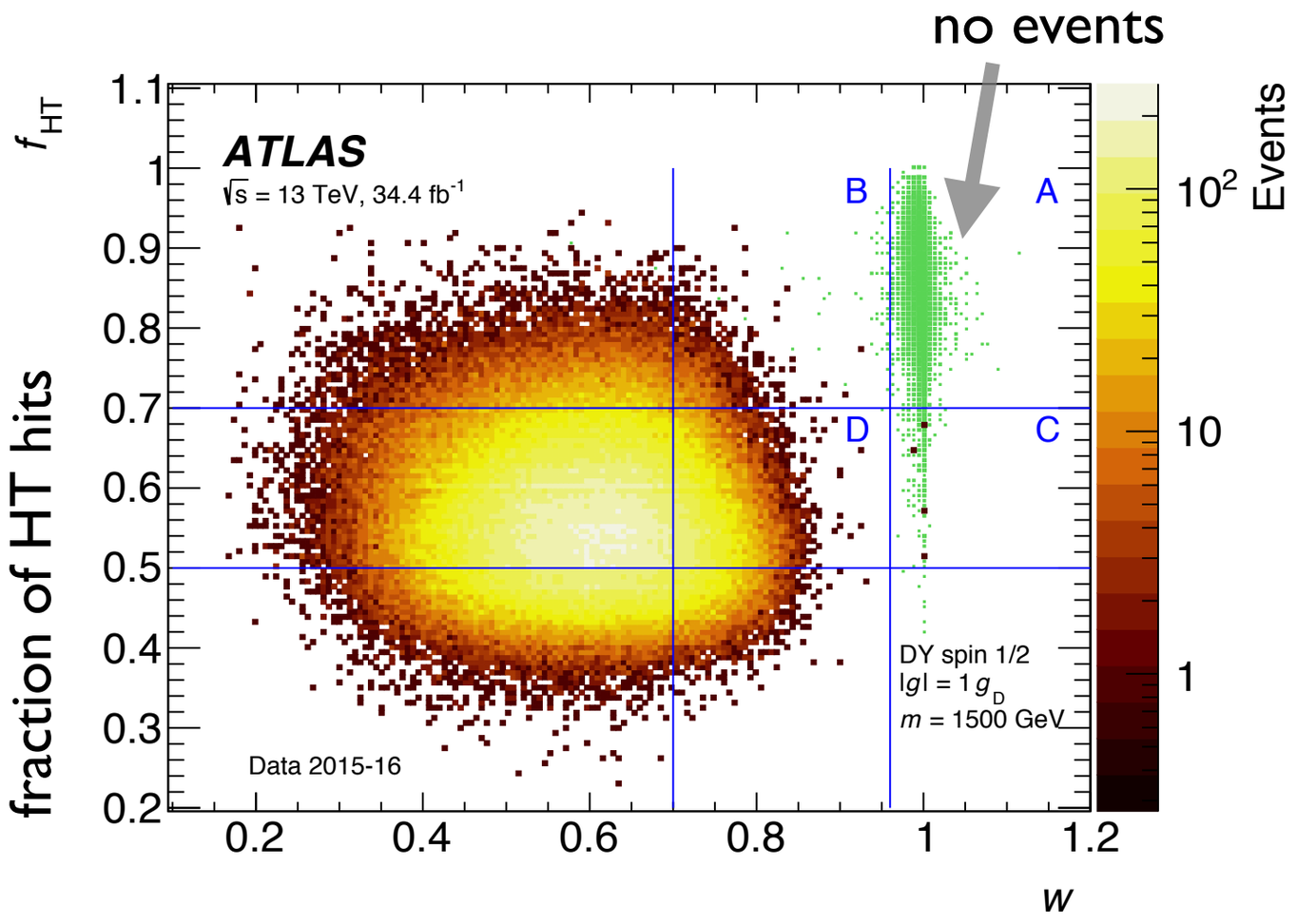



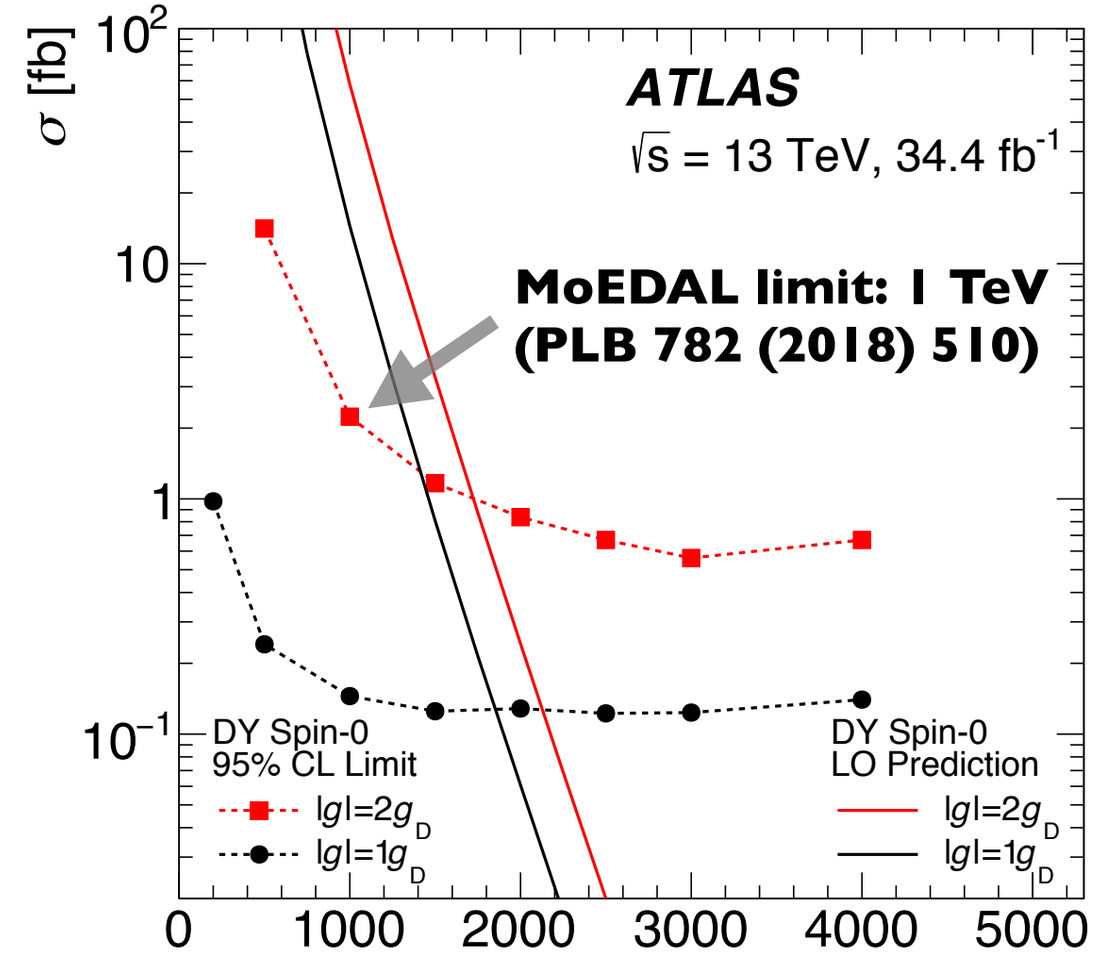
arXiv:1905.10130

# Magnetic Monopoles

34 fb$^{-1}$

- Magnetic monopole ($q = N \cdot q_D \triangleq q = N \cdot 68.5e$) or LLP with $q = 20–100e$
- Large charge $\Longrightarrow$ large dE/dx $\Longrightarrow$ fully absorbed in ECAL
- L1: ECAL + HCAL veto — HLT: high-threshold TRT hits
- Sensitivity limited for high charge (particles stop before ECAL)



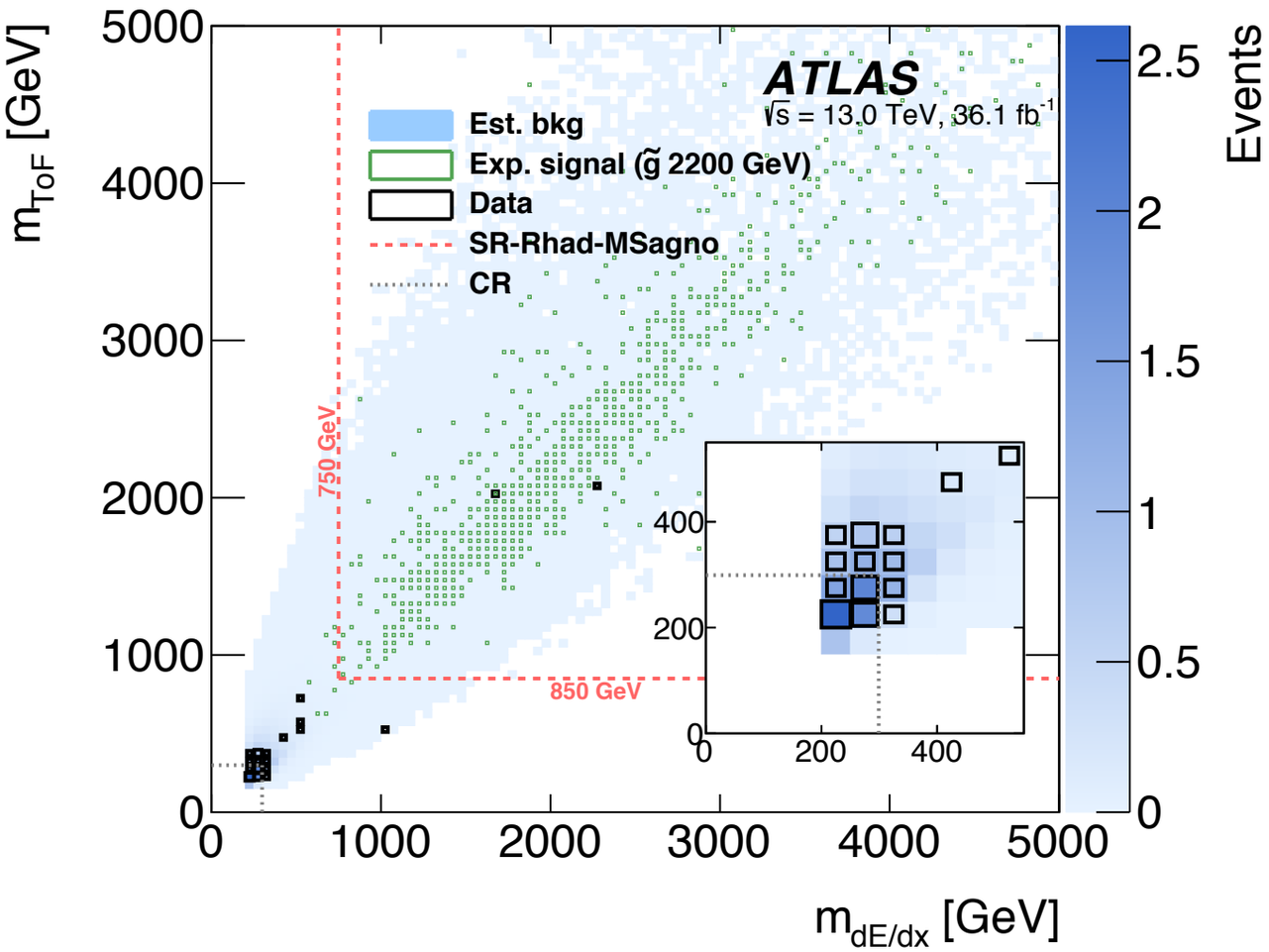




large w = small E dispersion in ECAL

# Heavy Charged



- LLP with large mass & $\tau \geq L_{CALO}/\beta\gamma$
- Signature: large $p_T$ but slow
  - $\beta\gamma$ from Pixel dE/dx
  - $\beta$ from TOF (TILE, MDT, RPC)

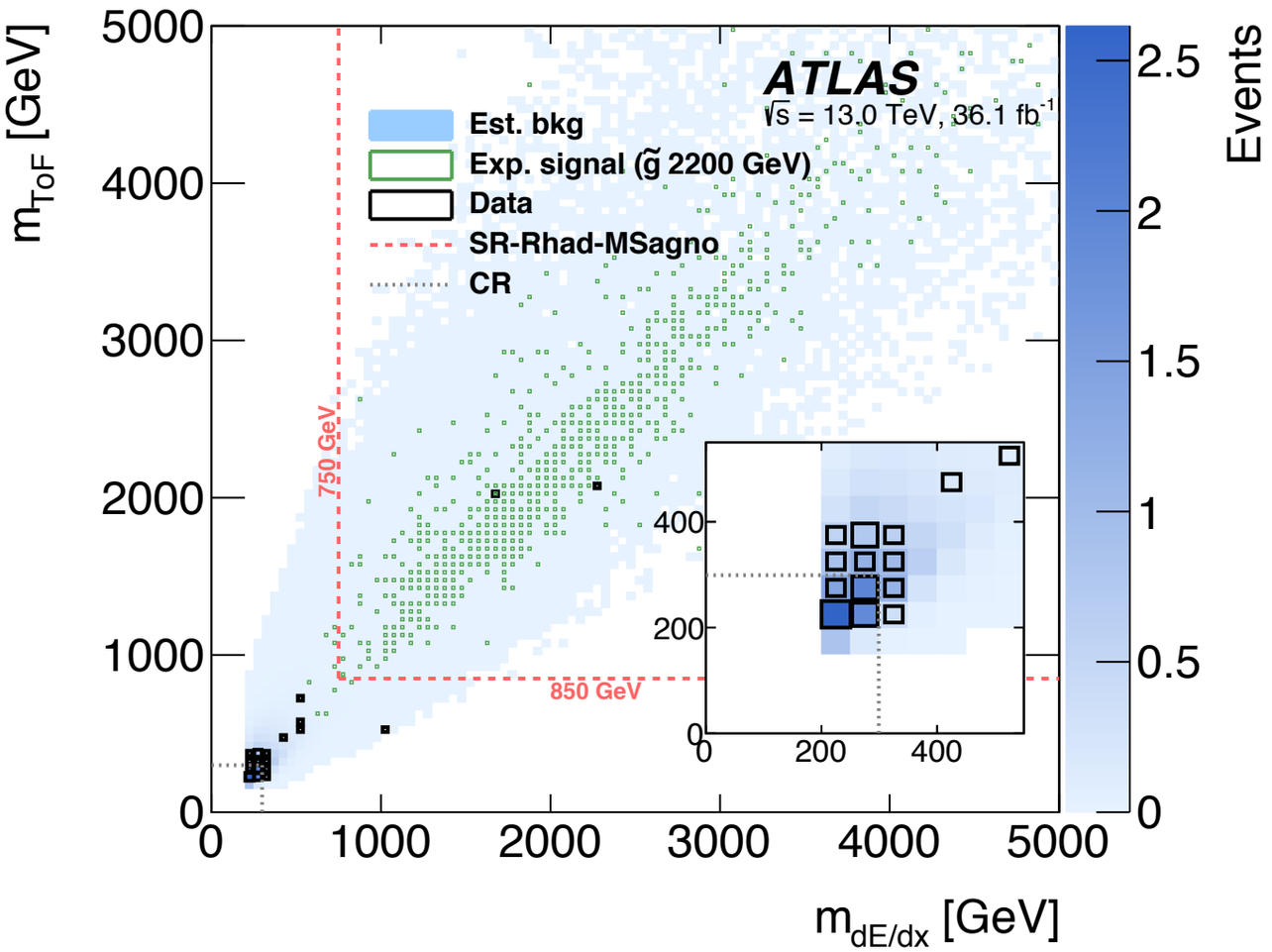


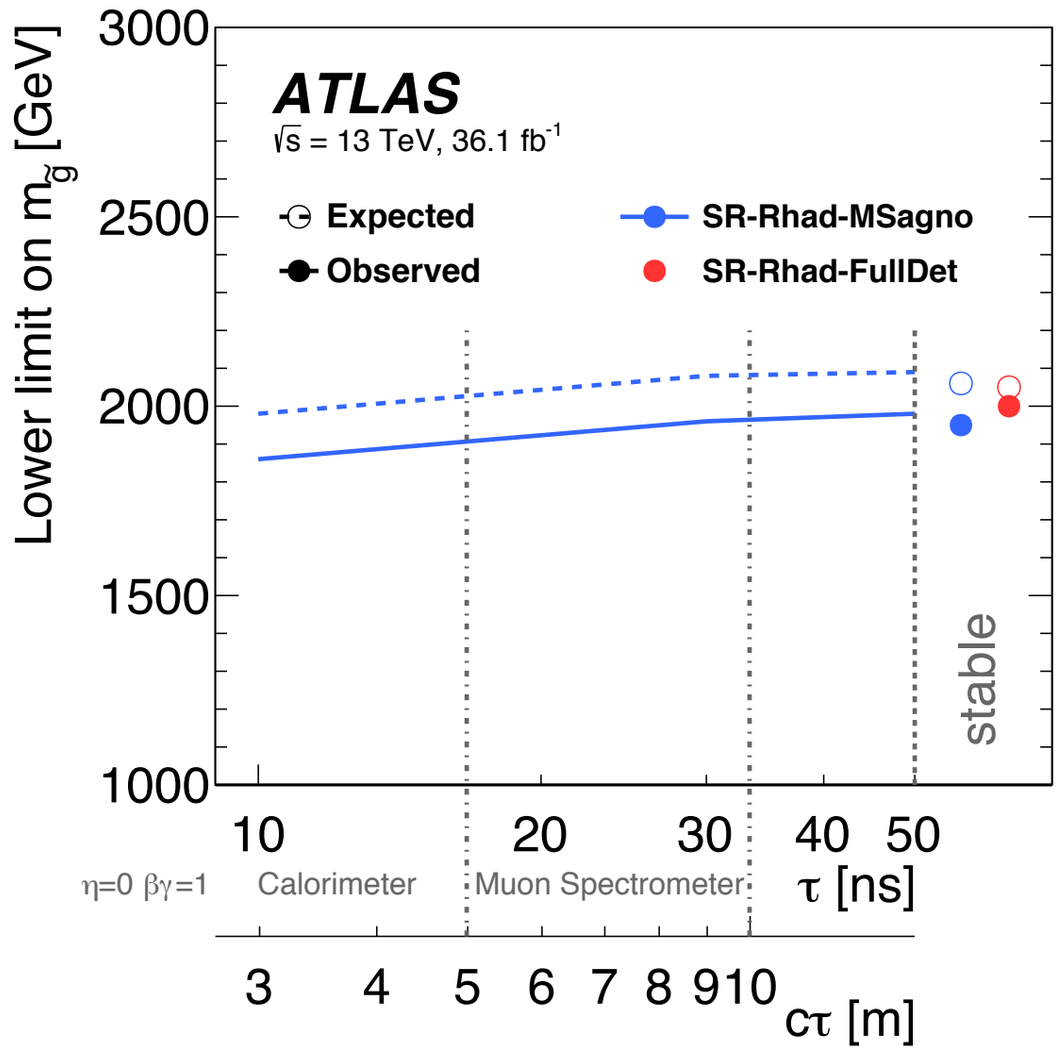
# Heavy Charged



- LLP with large mass & $\tau \geq L_{CALO}/\beta\gamma$
- Signature: large $p_T$ but slow
  - $\beta\gamma$ from Pixel dE/dx
  - $\beta$ from TOF (TILE, MDT, RPC)

- Selections w/ & w/o muon system
- Also sensitive to meta-stable LLP

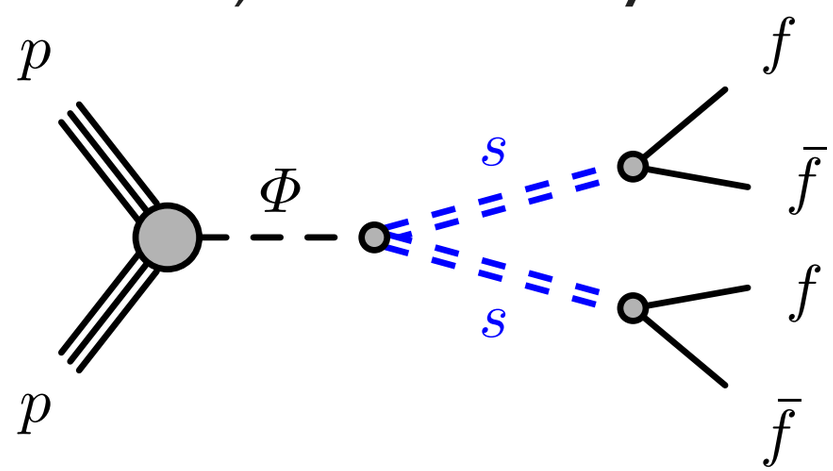


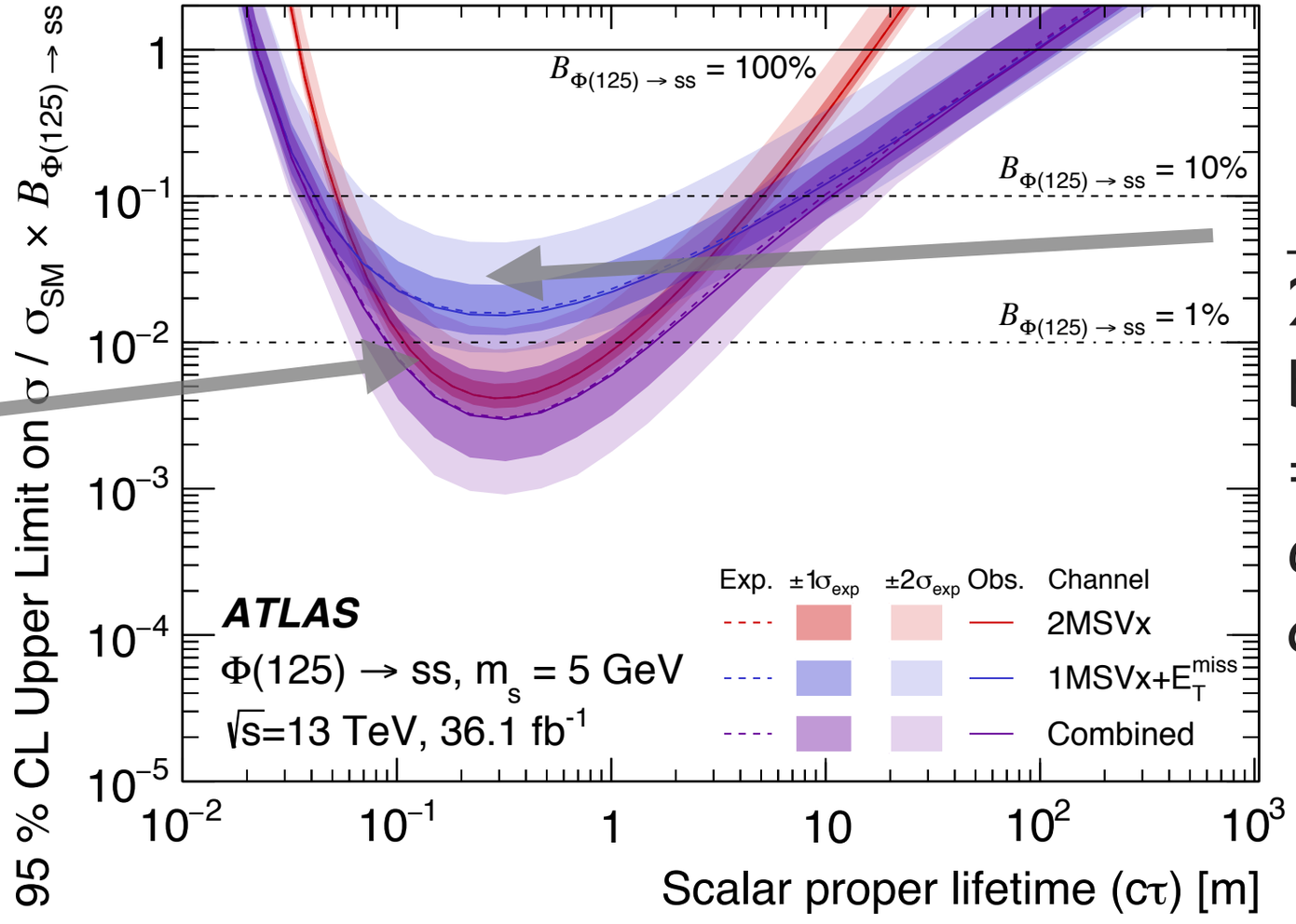
# Displaced Jets (MS)



- Pair-produced neutral LLP that decay in (or just before) the muon system
- Signature:
  - 2 vertices in the muon system
  - isolated from tracks and jets
  - high multiplicity (many hits)




**2 isolated vertices**
*obs.: 0*
*exp.: 0.027±0.011*

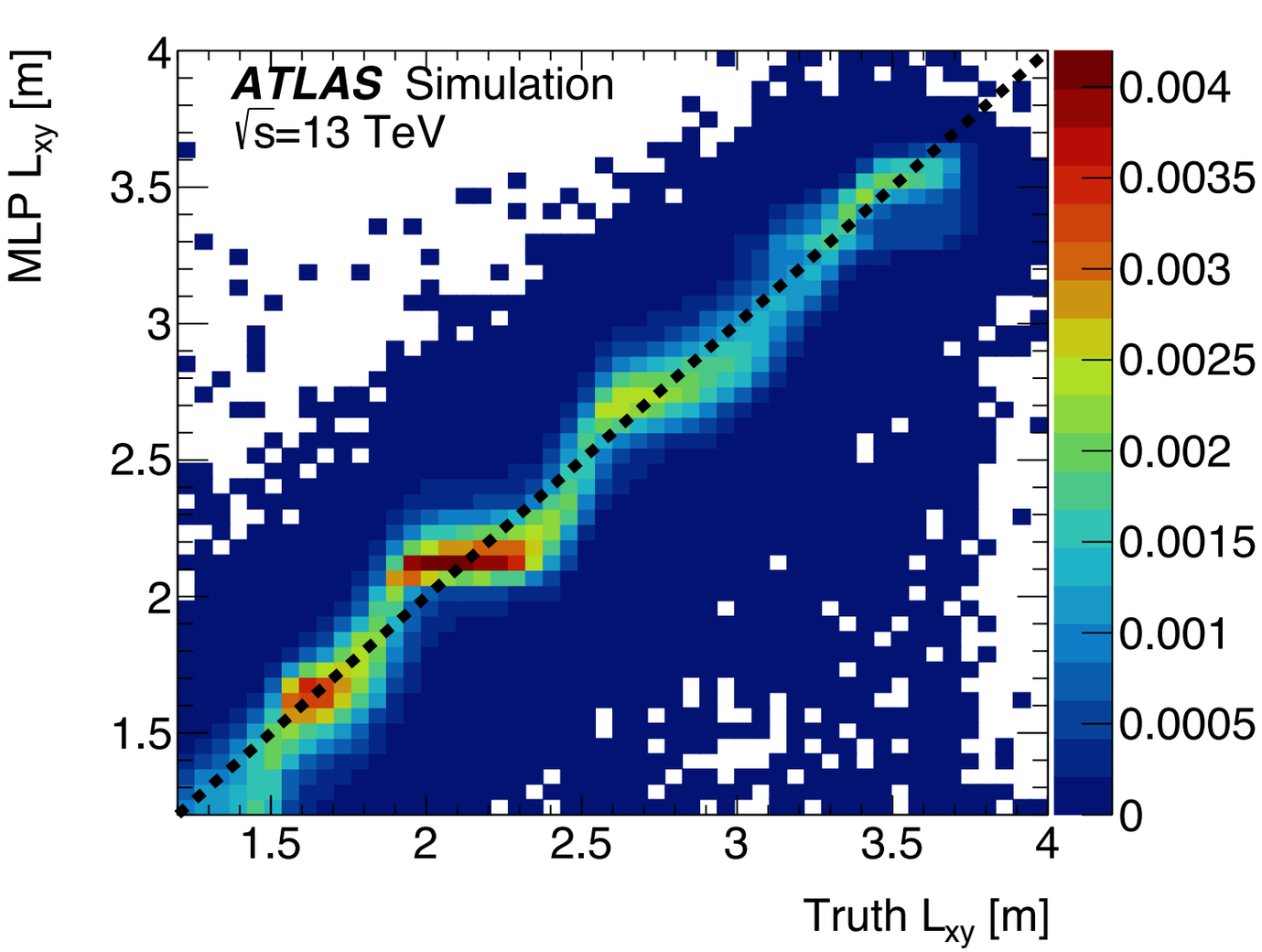


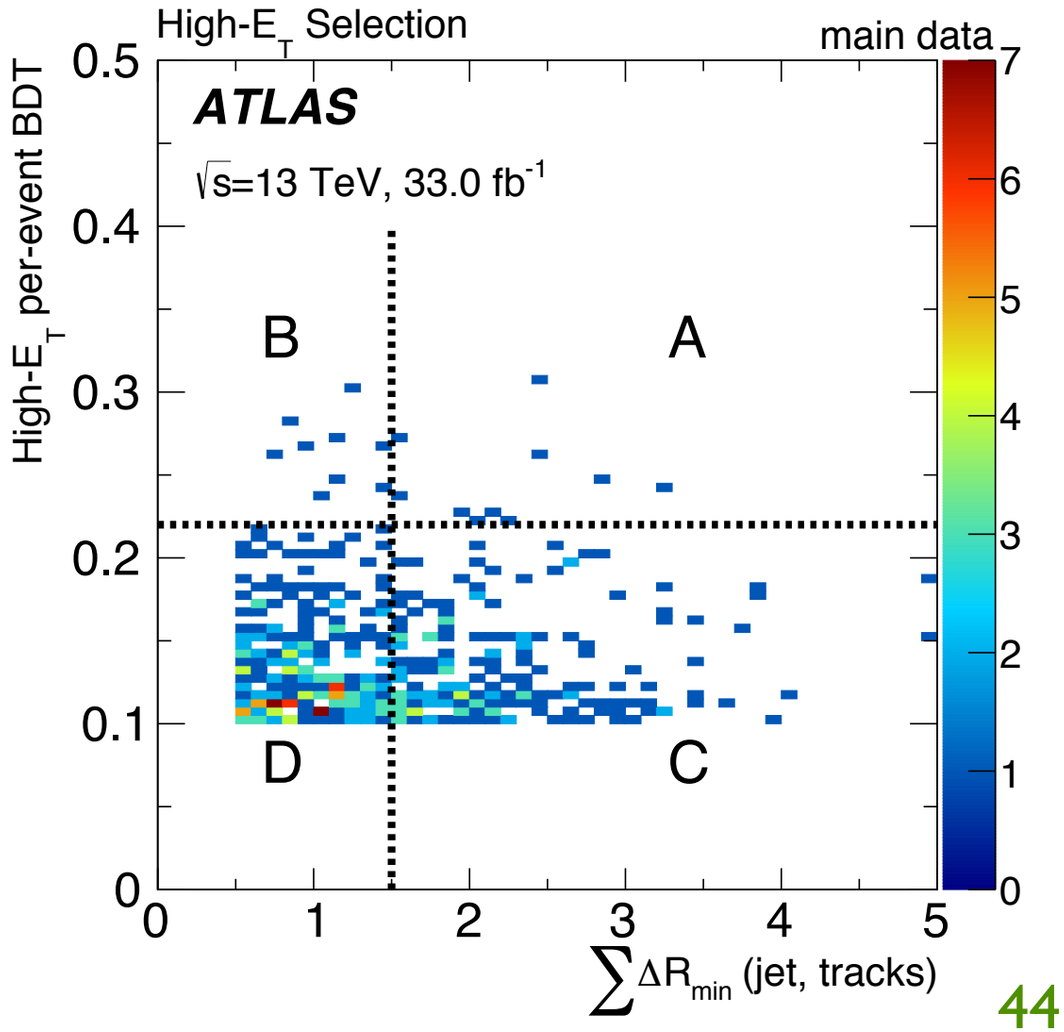

**1 vertex + $E_T^{miss}$**
2nd LLP decays before MS
$\Longrightarrow$ small $\Delta\Phi$
*obs.: 711*
*compatible w/ bkg.*

# Displaced Jets (HCAL)



- Pair-produced neutral LLP that decay in (or just before) the HCAL
- Signature: 2 jets with
  - no tracks
  - large E(HCAL)/E(ECAL)
  - narrow jet shapes
- NN regression for decay vertex
- BDTs vs. QCD & BIB



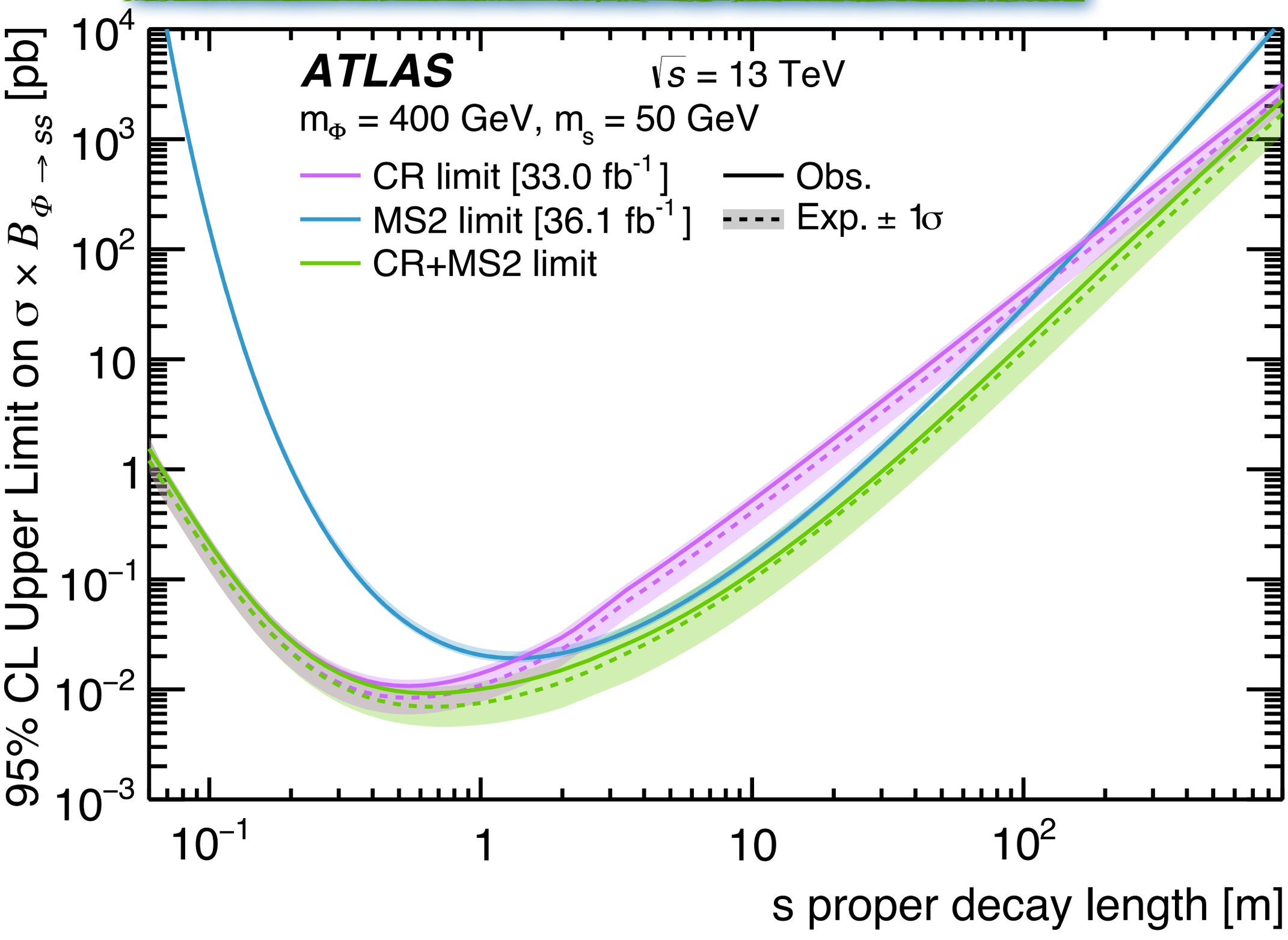



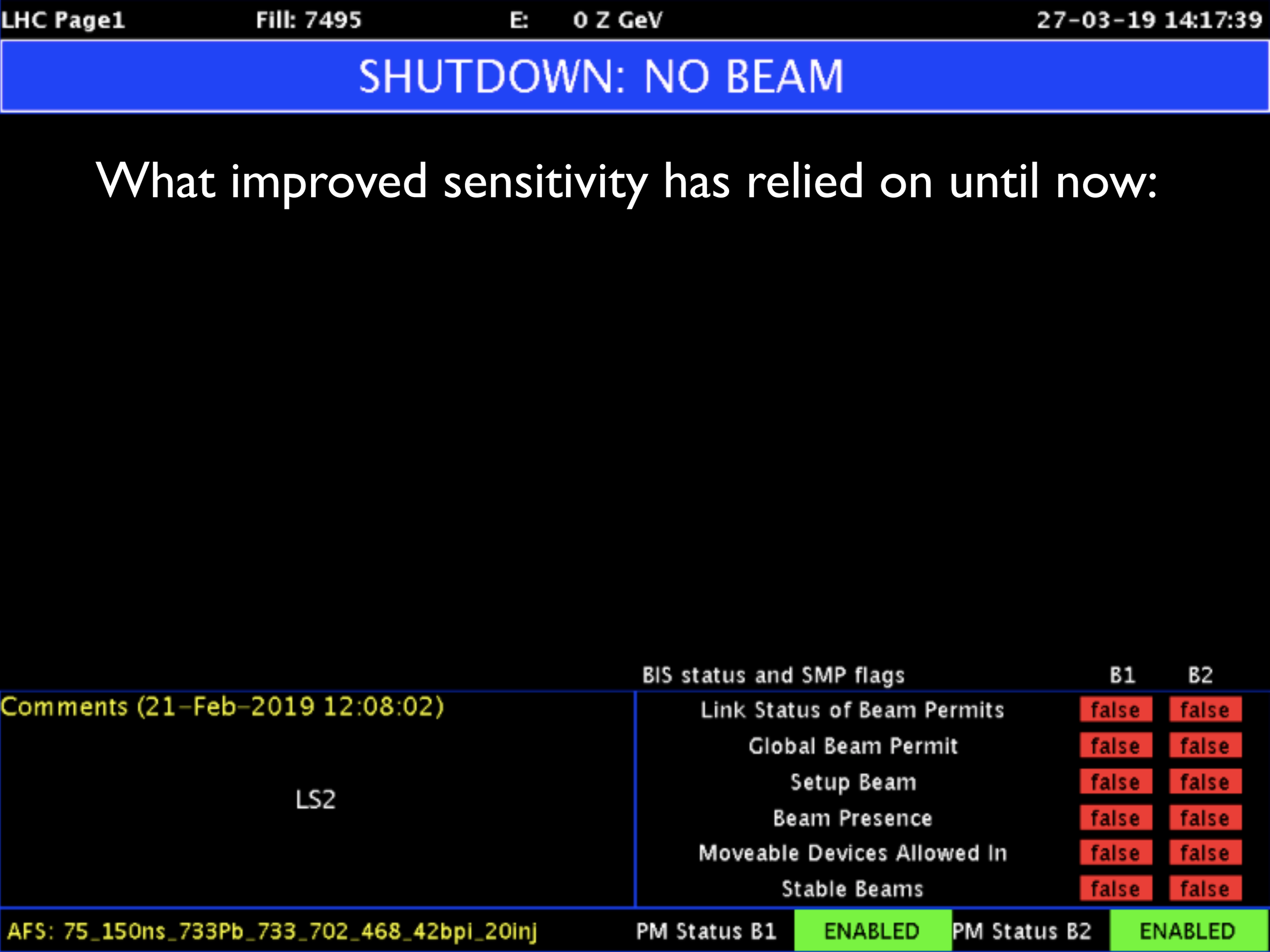
PRD 99 (2019) 052005
arXiv:1902.03094

# Displaced Jets

11-36 fb$^{-1}$

Combination of the two displaced-jet searches



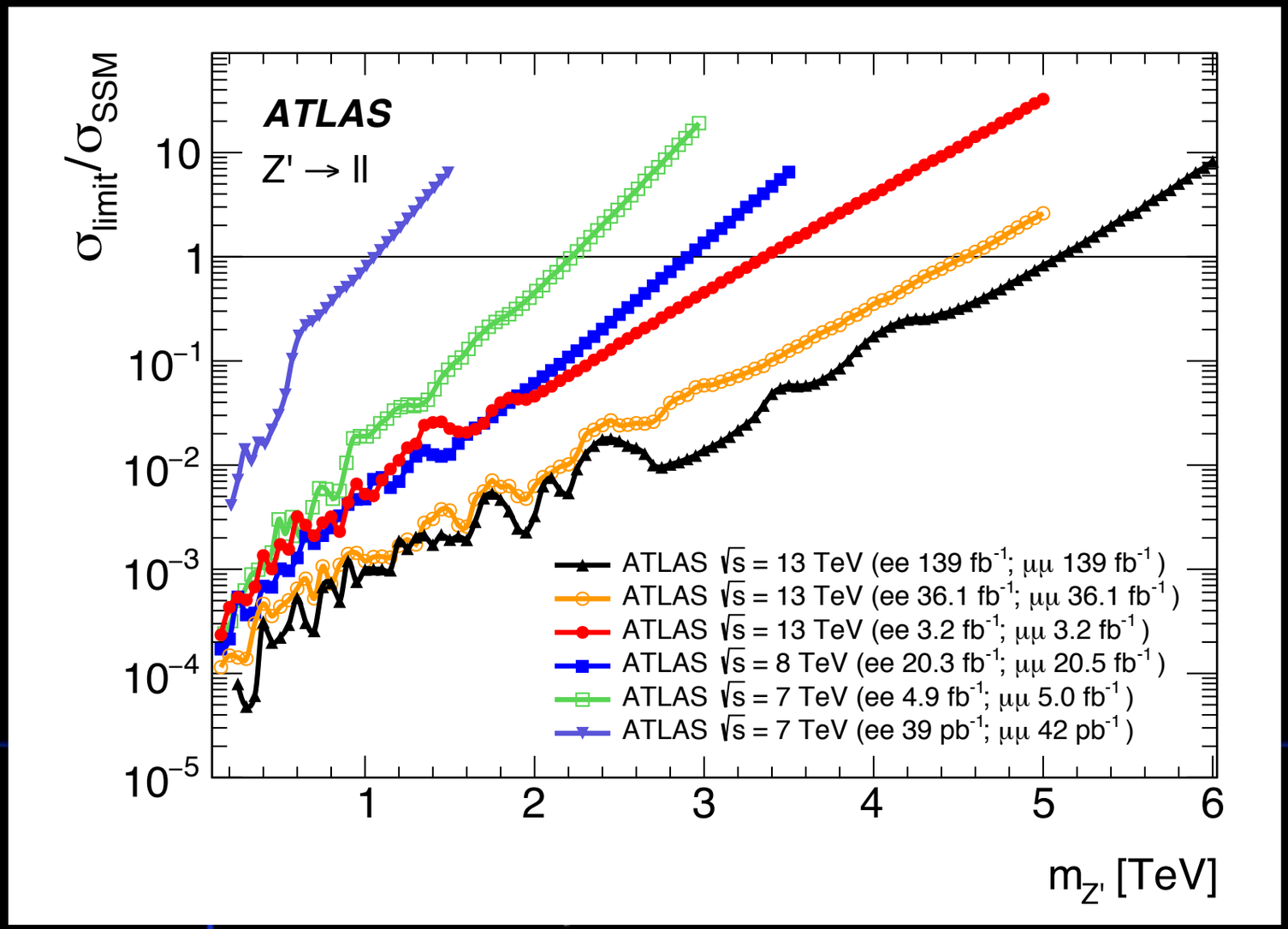

LHC Page1
Fill: 7495
E: 0 Z GeV
27-03-19 14:17:39
SHUTDOWN: NO BEAM
What improved sensitivity has relied on until now:
BIS status and SMP flags
B1
B2
Comments (21-Feb-2019 12:08:02)
LS2
Link Status of Beam Permits
false
false
Global Beam Permit
false
false
Setup Beam
false
false
Beam Presence
false
false
Moveable Devices Allowed In
false
false
Stable Beams
false
false
AFS: 75_150ns_733Pb_733_702_468_42bpi_20inj
PM Status B1
ENABLED
PM Status B2
ENABLED

LHC Page1 Fill: 7495 E: 0 Z GeV 27-03-19 14:17:39

SHUTDOWN: NO BEAM

# What improved sensitivity has relied on until now:

- Larger $\sqrt{s}$
- Larger $L_{int}$




Comments (21-Feb-2019 12:08:02)

LS2

| | | |
|---|---|---|
| Beam Presence | false | false |
| Moveable Devices Allowed In | false | false |
| Stable Beams | false | false |

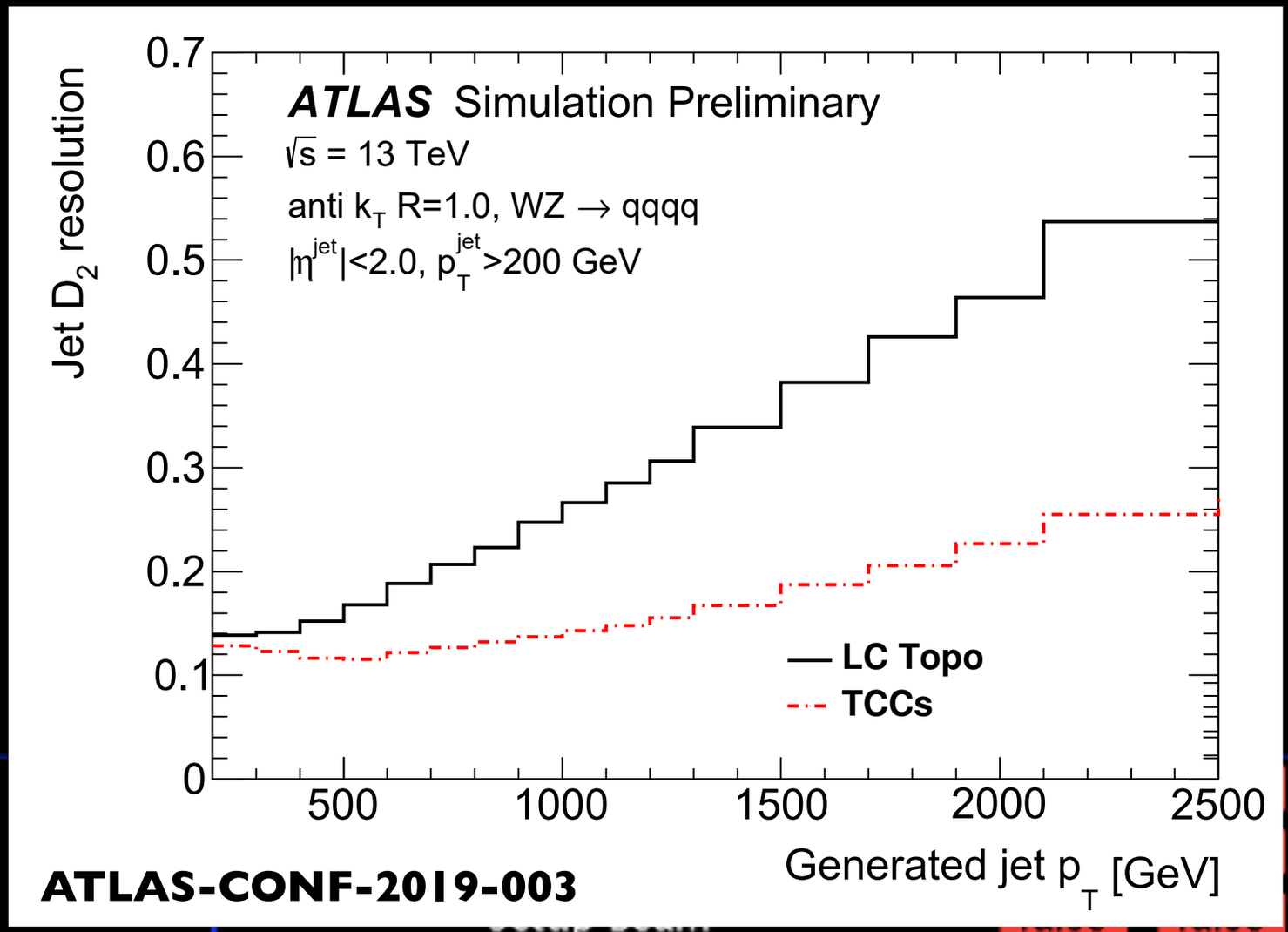
AFS: 75_150ns_733Pb_733_702_468_42bpi_20inj PM Status B1 ENABLED PM Status B2 ENABLED

LHC Page1 Fill: 7495 E: 0 Z GeV 27-03-19 14:17:39

SHUTDOWN: NO BEAM

# What improved sensitivity has relied on until now:

- Larger $\sqrt{s}$
- Larger $L_{int}$
- Better reco.




ATLAS-CONF-2019-003

Comments (21-Feb-2019 12:08:02)

LS2

| | | |
|---|---|---|
| Beam Presence | false | false |
| Moveable Devices Allowed In | false | false |
| Stable Beams | false | false |

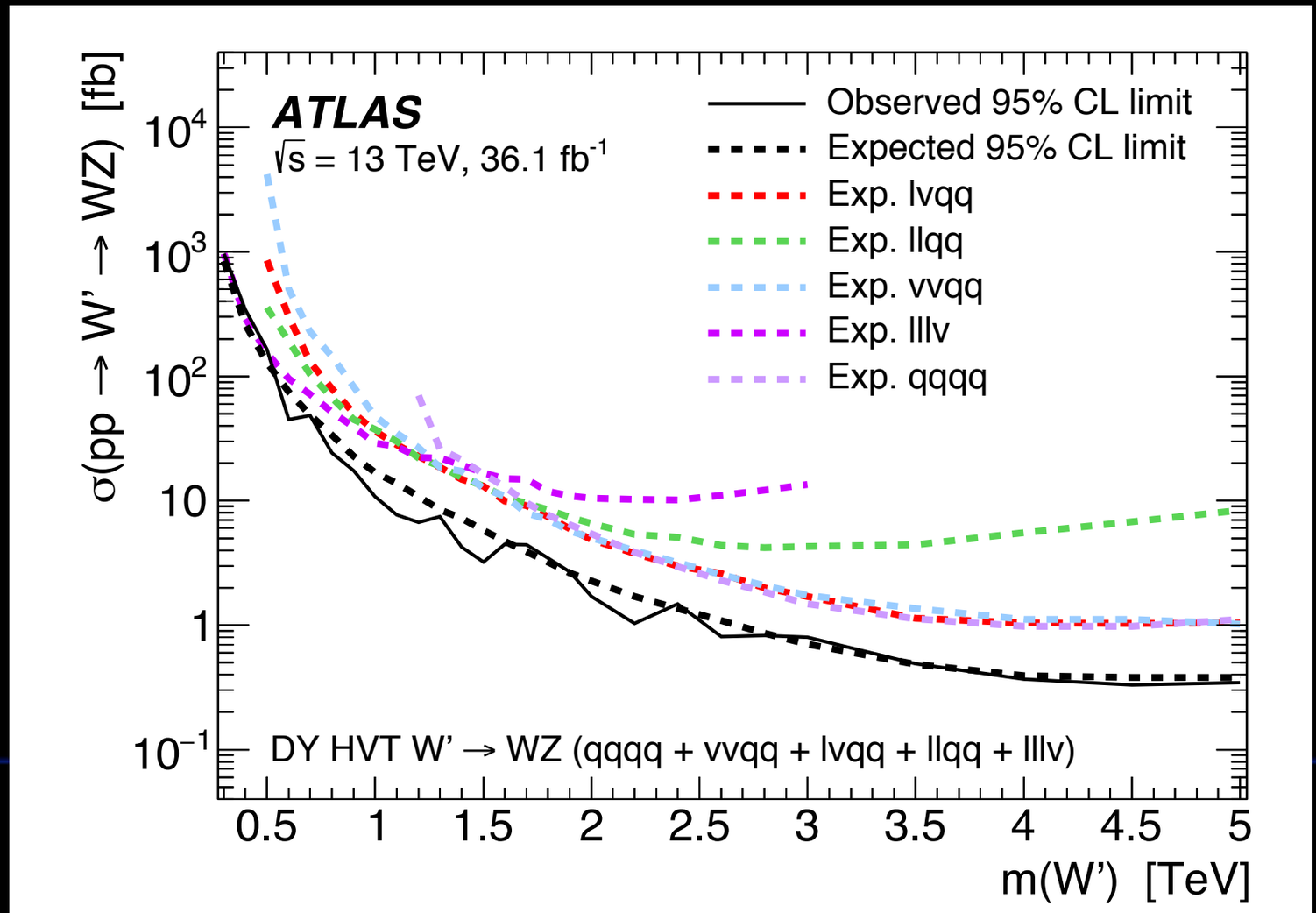
AFS: 75_150ns_733Pb_733_702_468_42bpi_20inj PM Status B1 ENABLED PM Status B2 ENABLED

LHC Page1 Fill: 7495 E: 0 Z GeV 27-03-19 14:17:39

SHUTDOWN: NO BEAM

# What improved sensitivity has relied on until now:

- Larger $\sqrt{s}$
- Larger $L_{int}$
- Better reco.
- Combinations




Comments (21-Feb-2019 12:08:02)

LS2

| | | |
|---|---|---|
| Beam Presence | false | false |
| Moveable Devices Allowed In | false | false |
| Stable Beams | false | false |

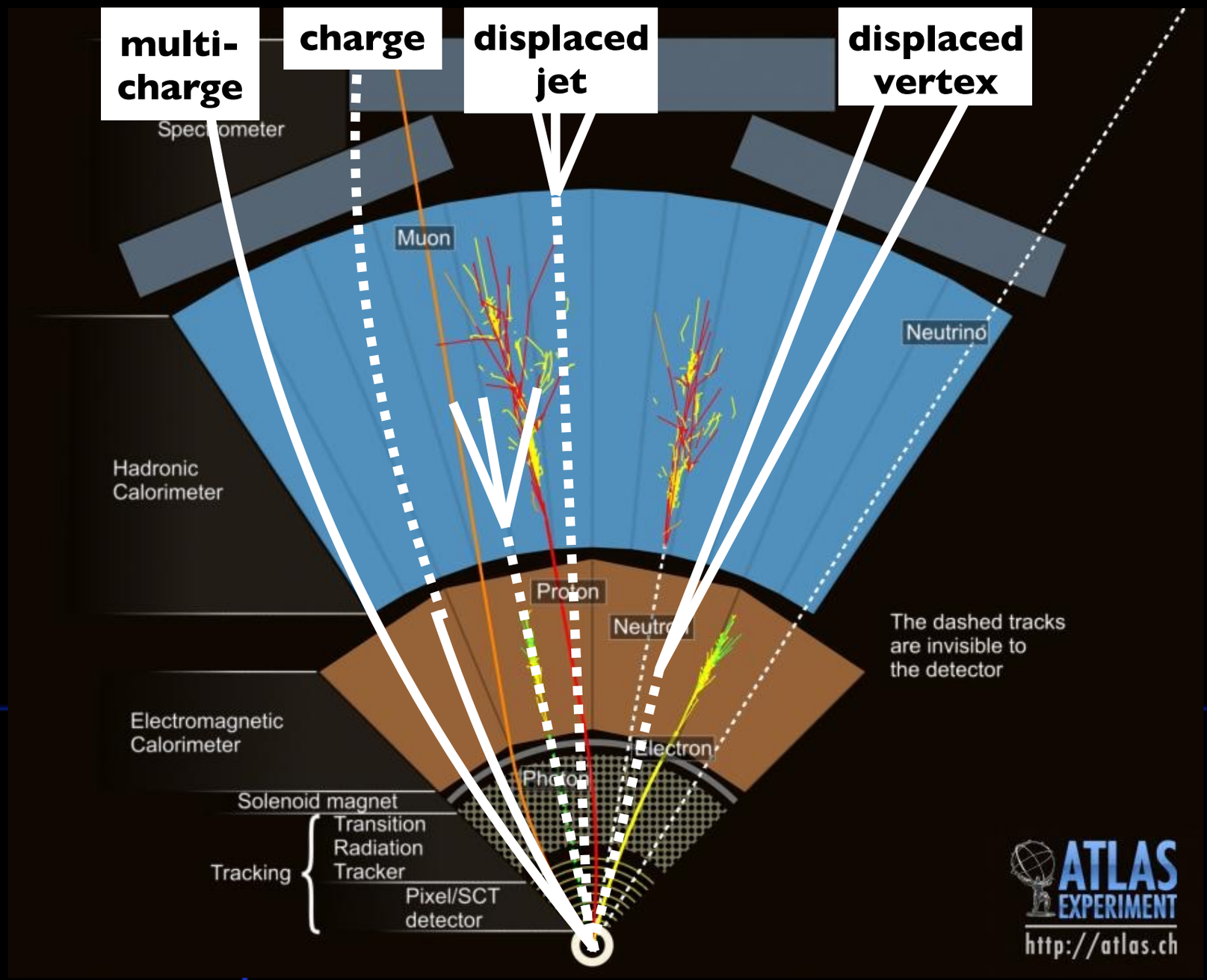
AFS: 75_150ns_733Pb_733_702_468_42bpi_20inj PM Status B1 ENABLED PM Status B2 ENABLED

LHC Page1 Fill: 7495 E: 0 Z GeV 27-03-19 14:17:39

SHUTDOWN: NO BEAM

# What improved sensitivity has relied on until now:

- Larger $\sqrt{s}$
- Larger $L_{int}$
- Better reco.
- Combinations
- New signatures




Comments (21-Feb-2019 12:08:02)

LS2

Stable Beams false false

AFS: 75_150ns_733Pb_733_702_468_42bpi_20inj PM Status B1 ENABLED PM Status B2 ENABLED

LHC Page1 Fill: 7495 E: 0 Z GeV 27-03-19 14:17:39

SHUTDOWN: NO BEAM

What improved sensitivity has relied on until now:

- Larger $\sqrt{s}$
- Larger $L_{int}$
- Better reco.
- Combinations
- New signatures

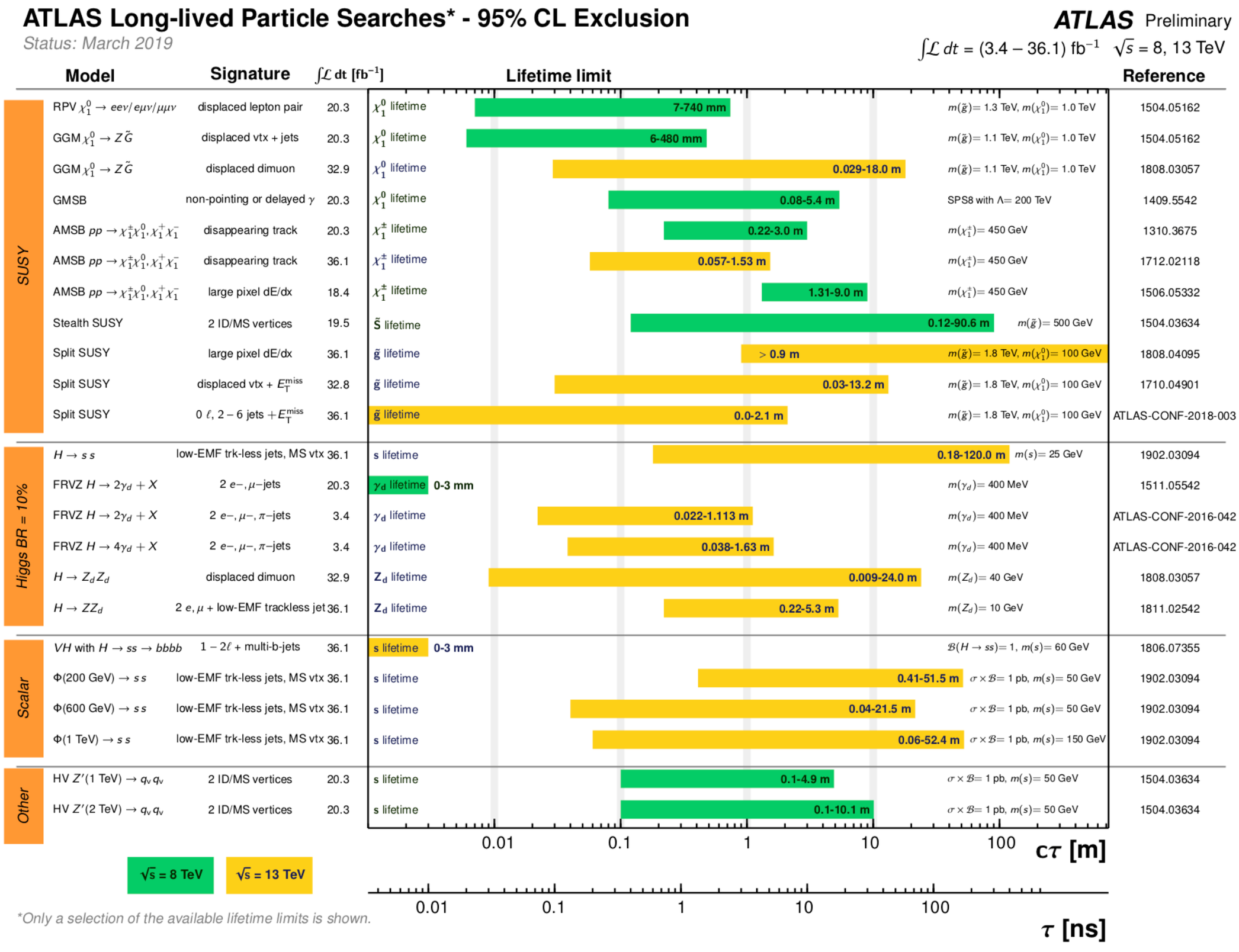
Thanks for your attention!

| Comments (21-Feb-2019 12:08:02) | BIS status and SMP flags | B1 | B2 |
|---|---|---|---|
| LS2 | Link Status of Beam Permits | false | false |
| | Global Beam Permit | false | false |
| | Setup Beam | false | false |
| | Beam Presence | false | false |
| | Moveable Devices Allowed In | false | false |
| | Stable Beams | false | false |

AFS: 75_150ns_733Pb_733_702_468_42bpi_20inj PM Status B1 ENABLED PM Status B2 ENABLED

# BACKUP

# LLP Summary Plot




**atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/EXOTICS**

arXiv:1904.12679

# Heavy Neutrino (boosted)

80 fb$^{-1}$