Prospects from the general purpose detectors at the LHC

Beyond the Flavour Anomalies III
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On behalf of the CMS Collaboration

University of Zurich UZH

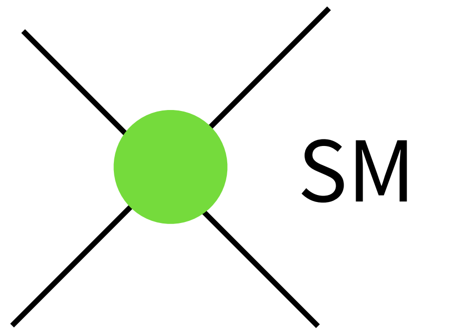
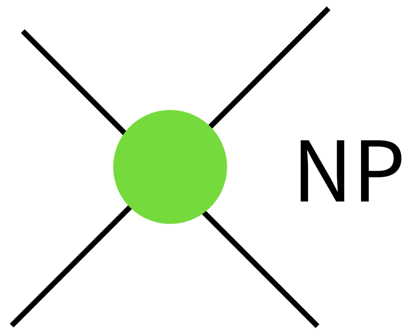
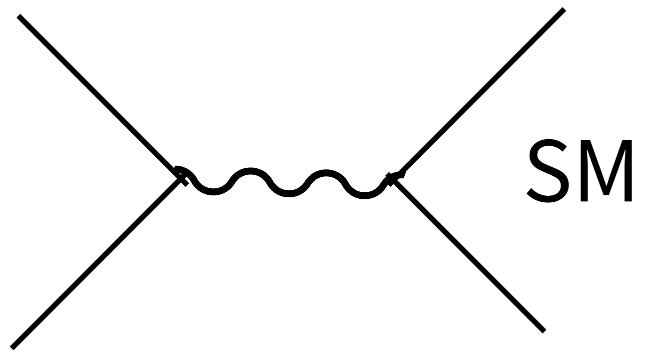
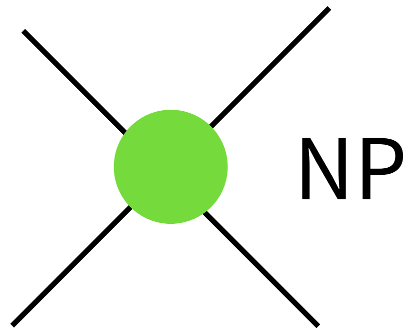
Reference: https://cms-results-search.web.cern.ch/

Role of the Energy-Frontier experiment

Directly probe new physics at high-q^2

Hopefully, we can **produce** new physics via mass on-shell ($q^2 > m_{NP}^2$) and reveal its properties

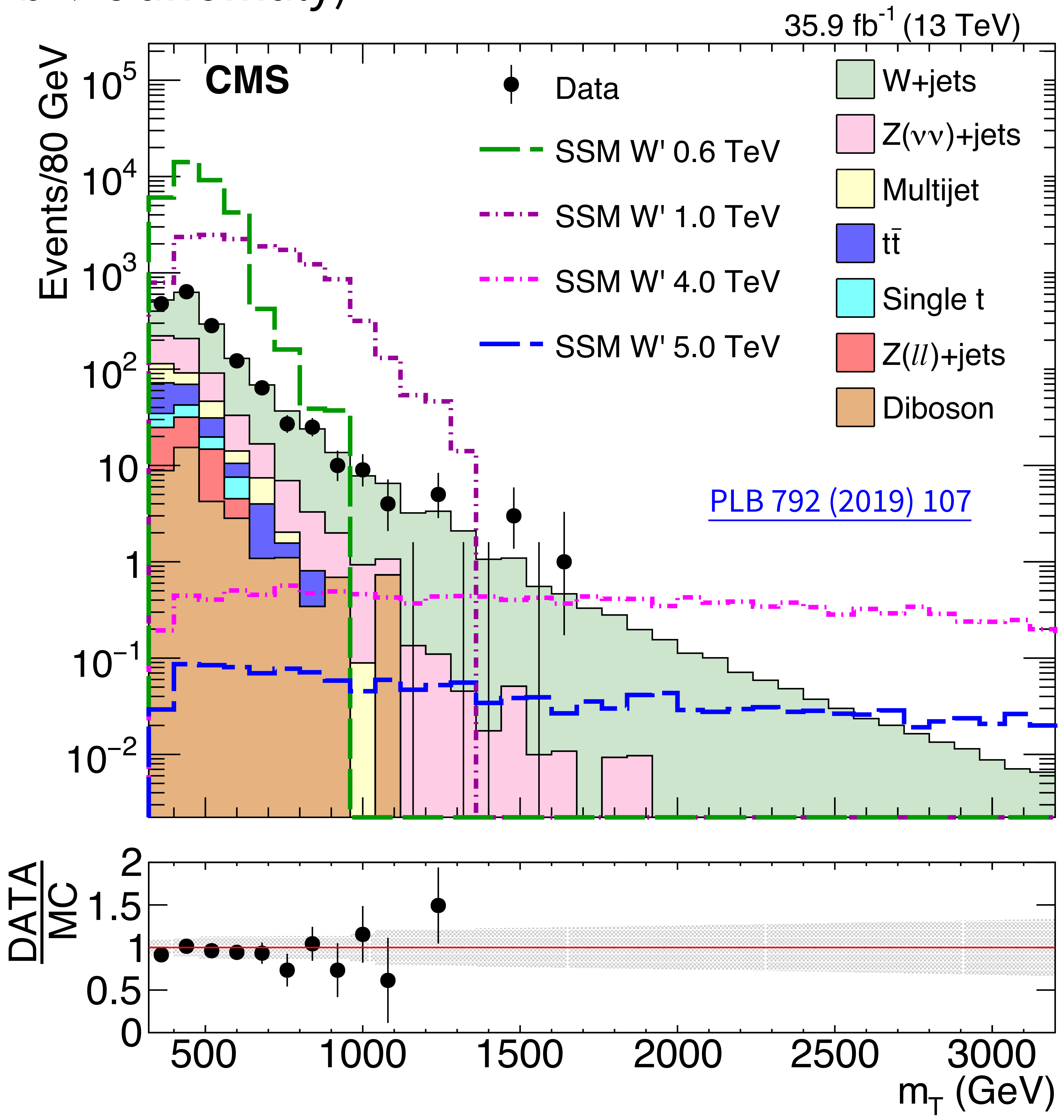
But even if it is not i.e. mass off-shell ($q^2 < m_{NP}^2$), we can provide **significant** constraint on possible new physics scenario

	Background	Signal
B-physics ($q^2 \sim m_B^2$)		
	$\sim G_F^2$	$\sim (G_F^{NP})^2$
Off-shell searches at CMS ($m_B^2 \ll q^2 < m_{NP}^2$)		
	$\sim \frac{(G_F m_{W/Z}^2)^2}{\hat{s}}$	$\sim (G_F^{NP})^2 \times \hat{s}$

→ test new physics with much better s/b !

W' → τν search (motivated by b → c anomaly)

1 τ_h + missing E_T with back-to-back topology ($\Delta\phi > 2.4$ rad)



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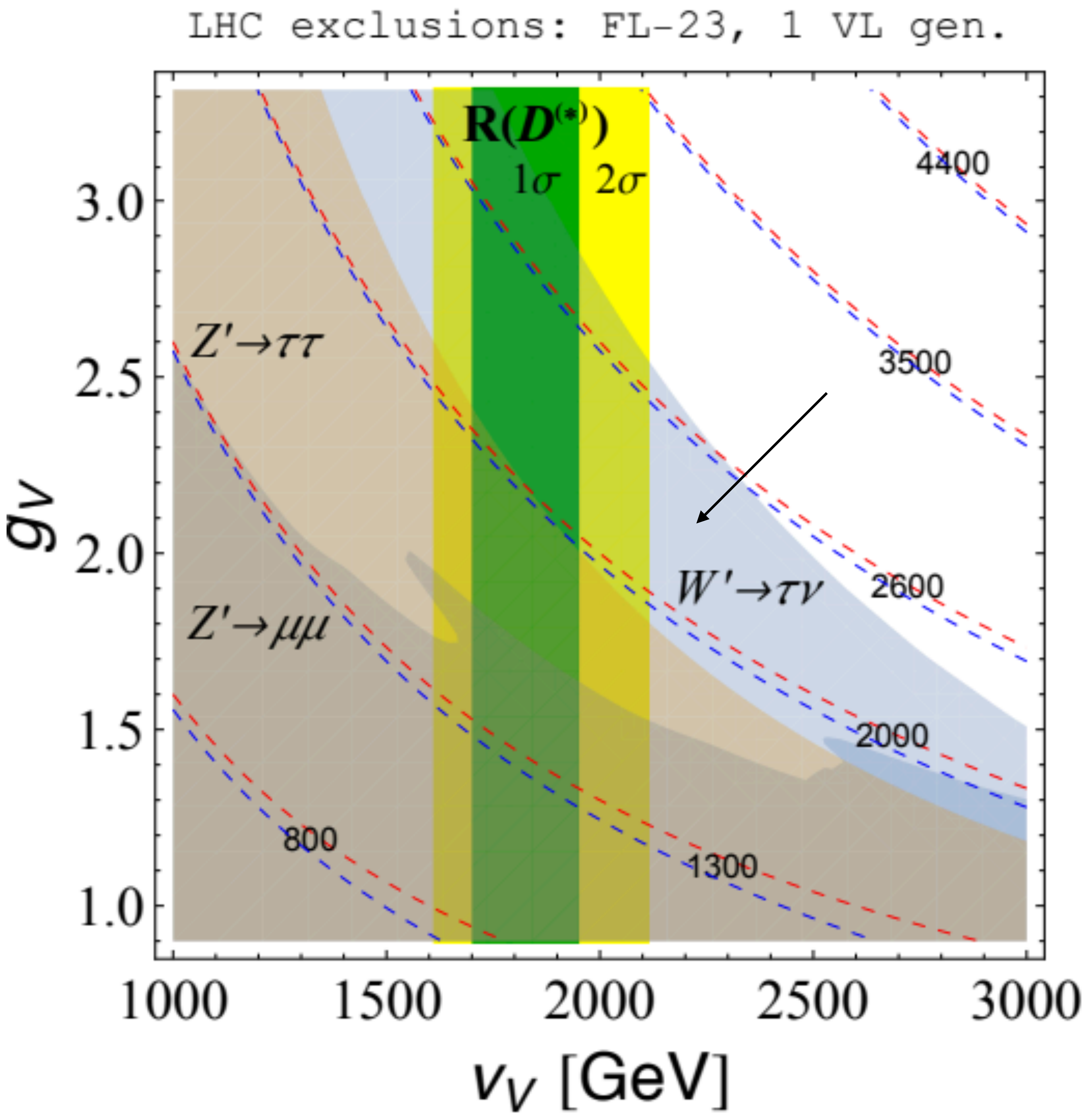
Assume only minimum couplings arXiv:1804.04642

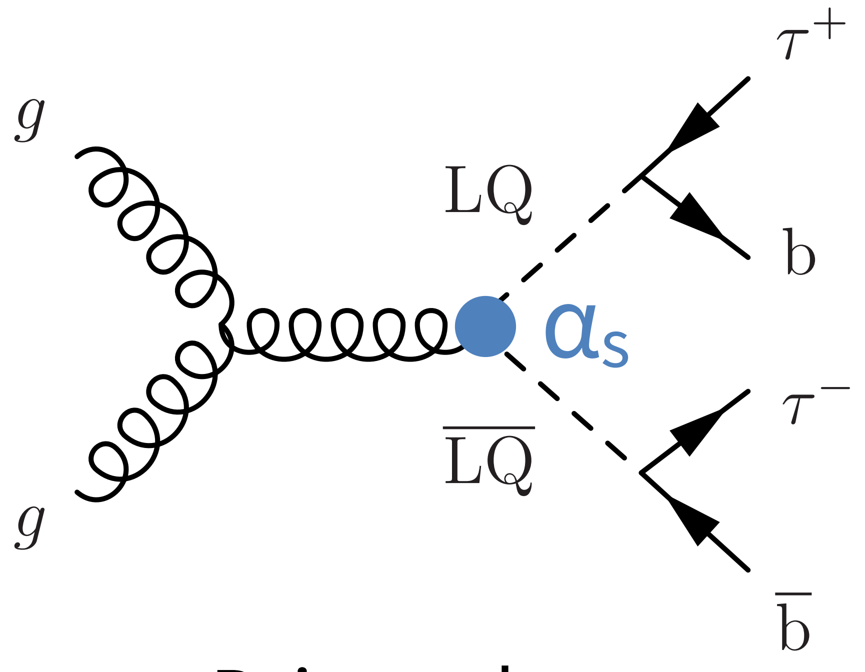


Today's talk

- Highlight relevant high-q^2 searches of new physics that can potentially explain B-physics anomalies
- Describe our B-physics programs as well as its future prospects
- Conclusion & discussions

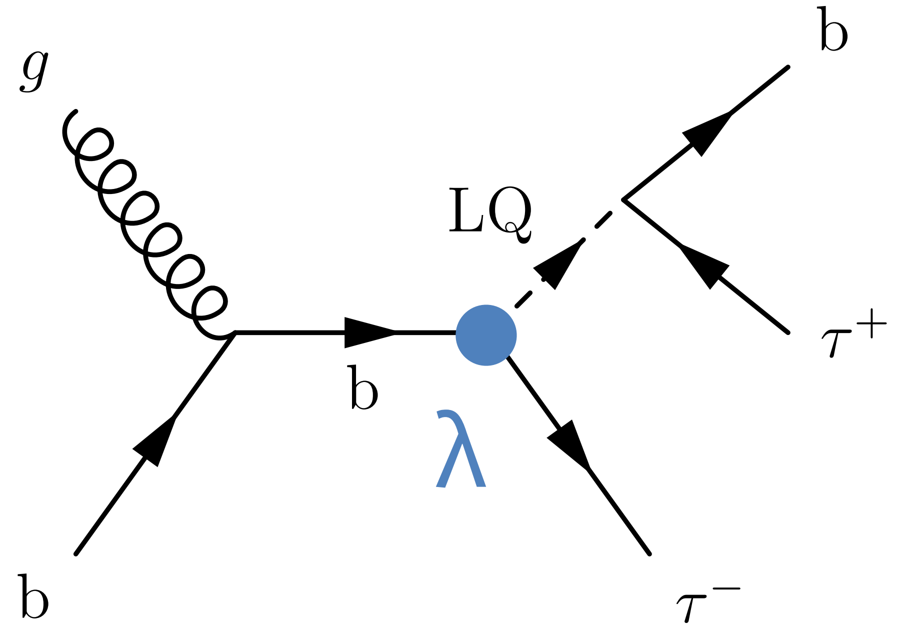
Note: only focus on CMS results but similar results also obtained by ATLAS

Leptoquark searches



Pair prod.

- Large cross-section
- Model-independent

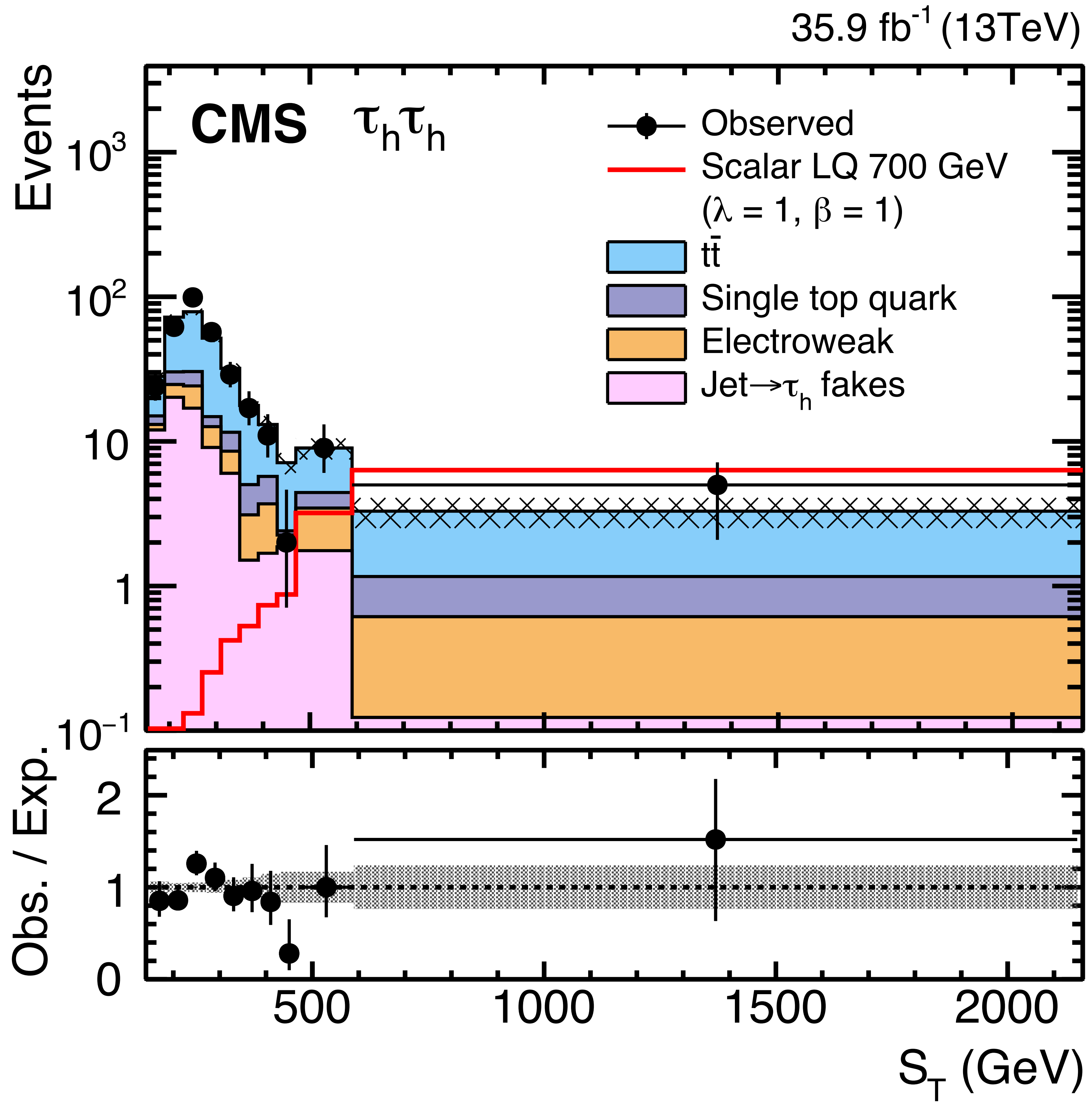


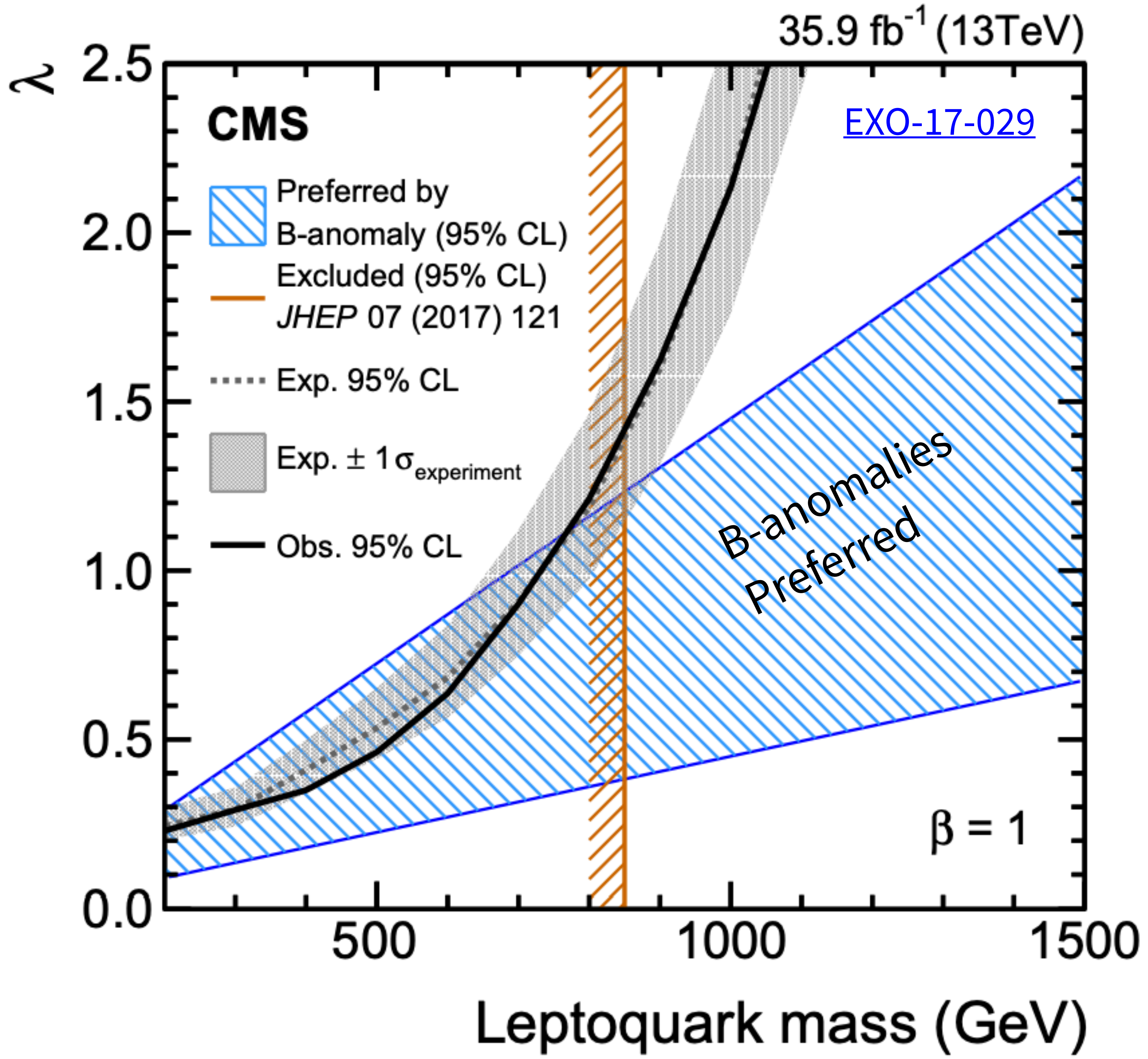
Single prod.

- cross-section ∝ λ^2 (model dependent)

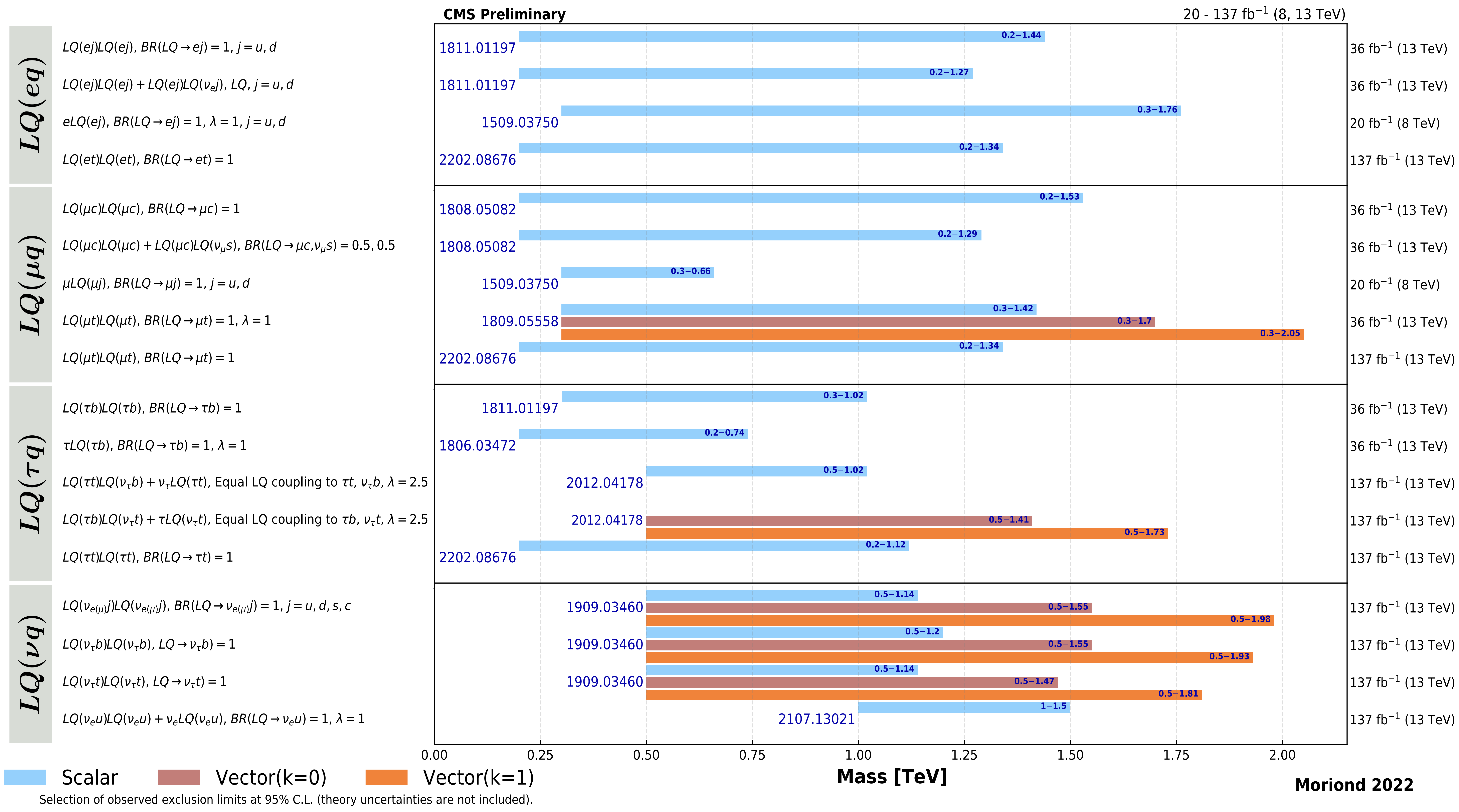
General strategy:

- Require final state particles and use ΣE_T as final discriminant
- Fit the distribution with signal templates with various mass assumption and do hypothesis testing





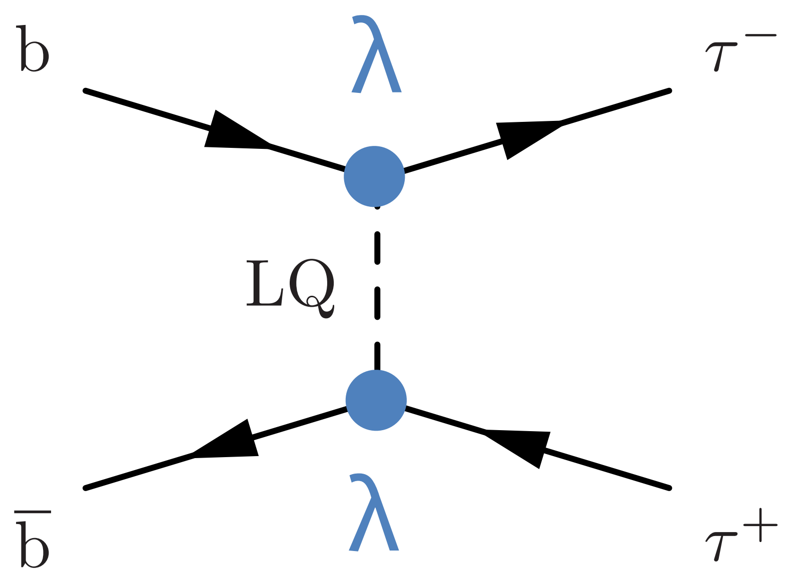
- Many final states examined (e, μ, τ, ν) x (u/d/c/s-jet, b, t)



https://twiki.cern.ch/twiki/bin/view/CMSPublic/SummaryPlotsEXO13TeV#Leptoquark_summary_plot

- No indications of new physics (yet)
- **Less gain expected in the future (sensitivity only scales by squared root of Integrated luminosity)**

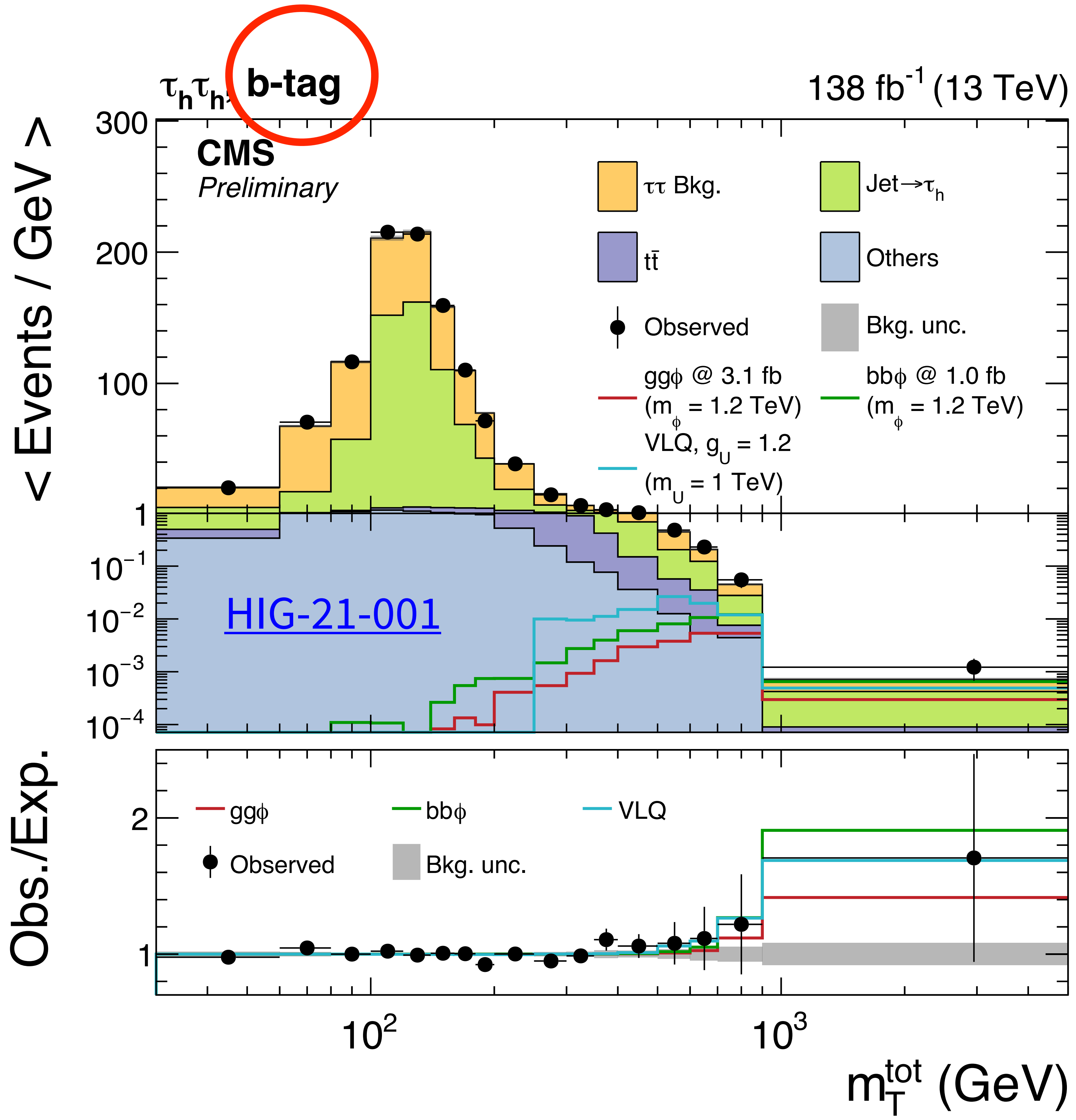
Search for non-resonant signals

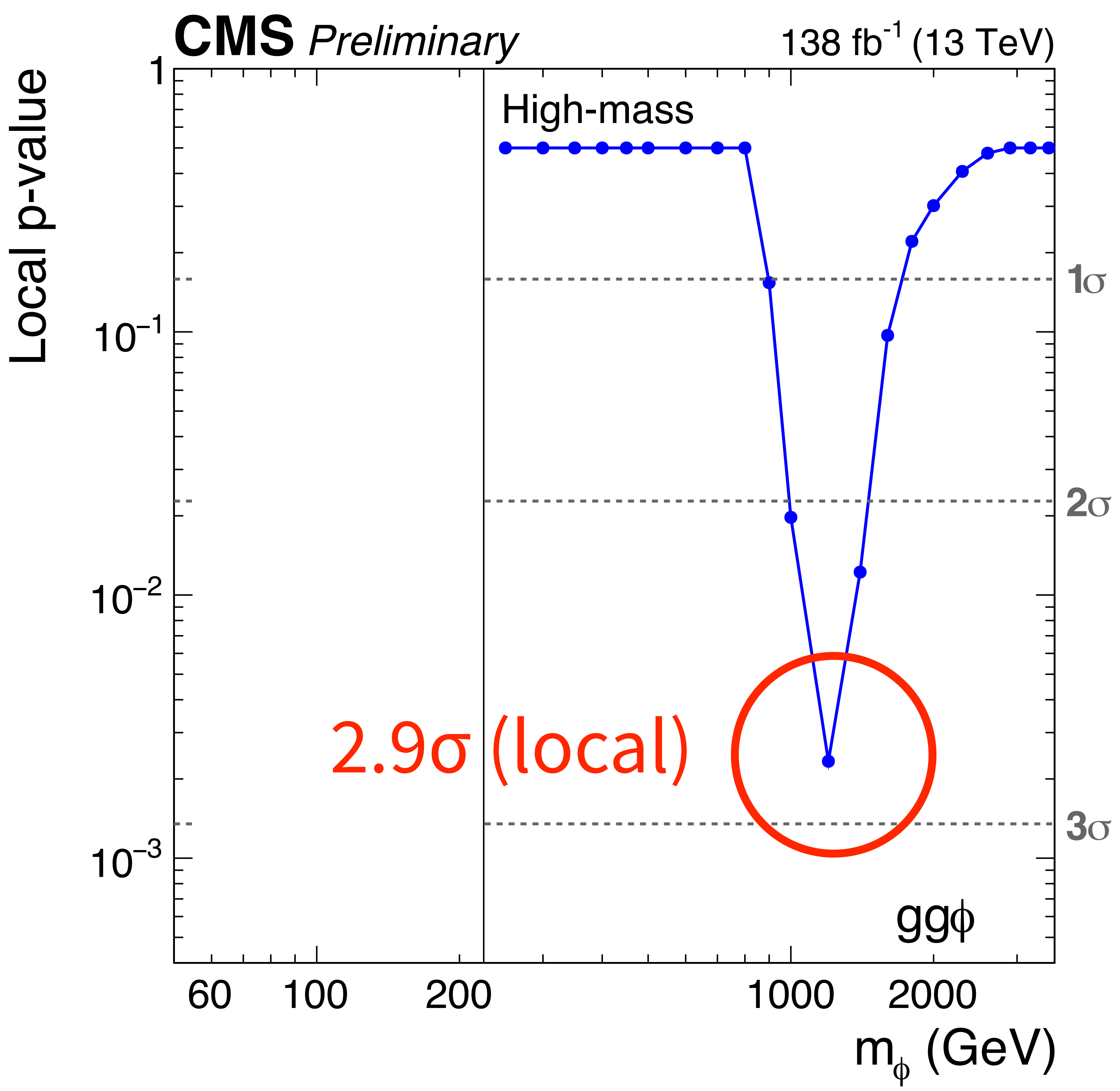


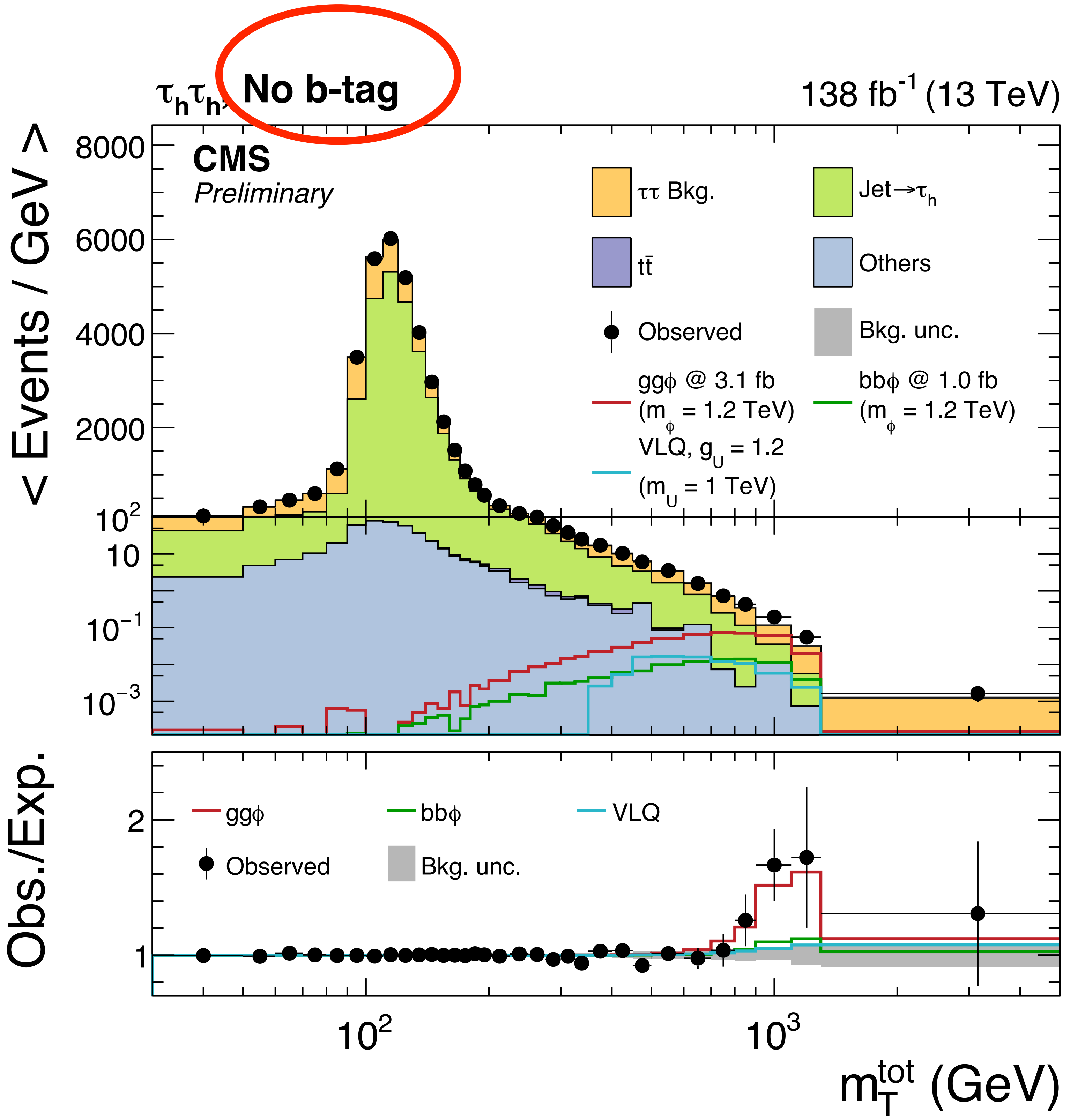
Non resonant

- Cross-section ∝ λ^4
- This is THE process where we first expect anomalies if the B-physics anomalies are real
- Difficult: no clear resonance — Looking at the excess at the tail of m(ττ)

Note1: no b-tag category also saw excess (LQ signal with exclusive bτ coupling would be small)



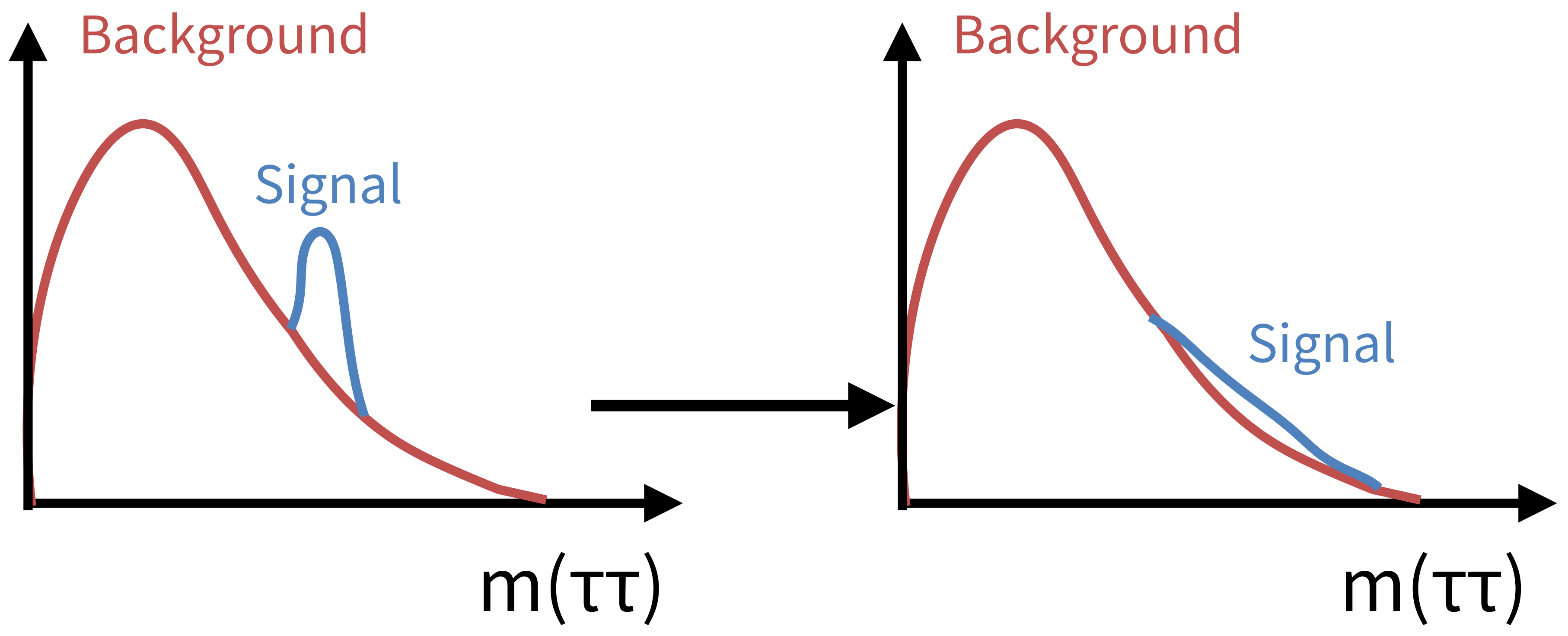




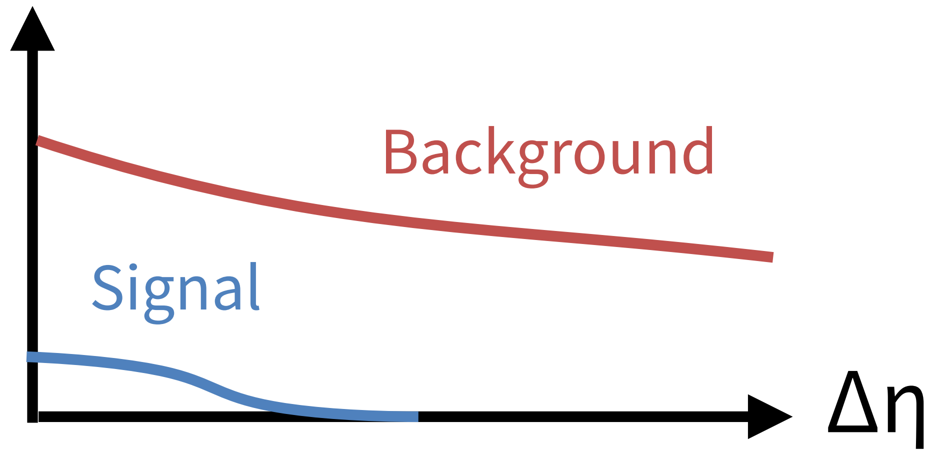
Note2: ATLAS didn't see corresponding excess at 1TeV

Dedicated search for non-resonant ττ signals

Standard method of using ττ invariant mass distribution m(ττ) won't work so well



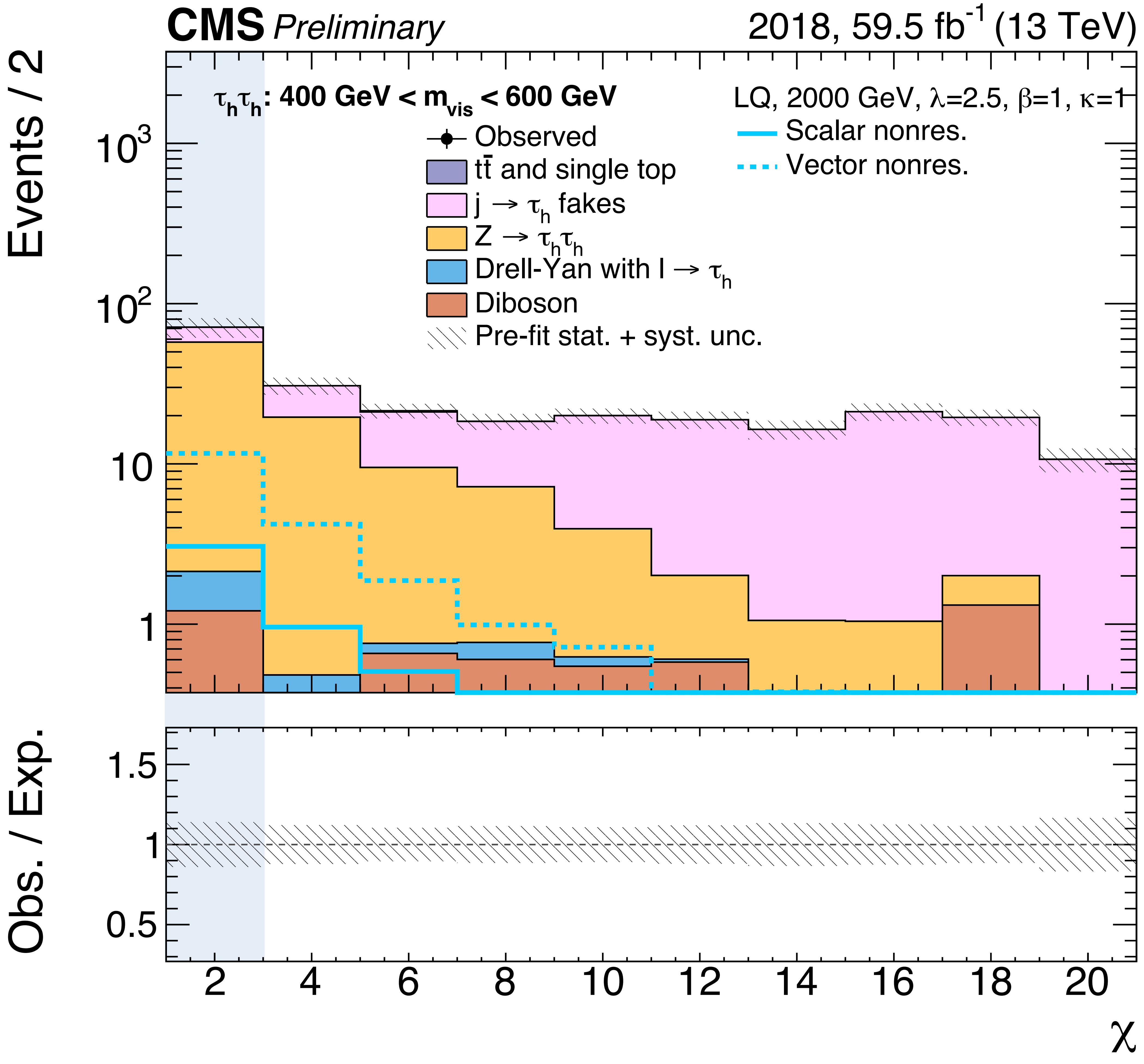
Idea: look at angular correlations between two taus, Δη(τ, τ)



I. Neutelings

[EXO-19-016]

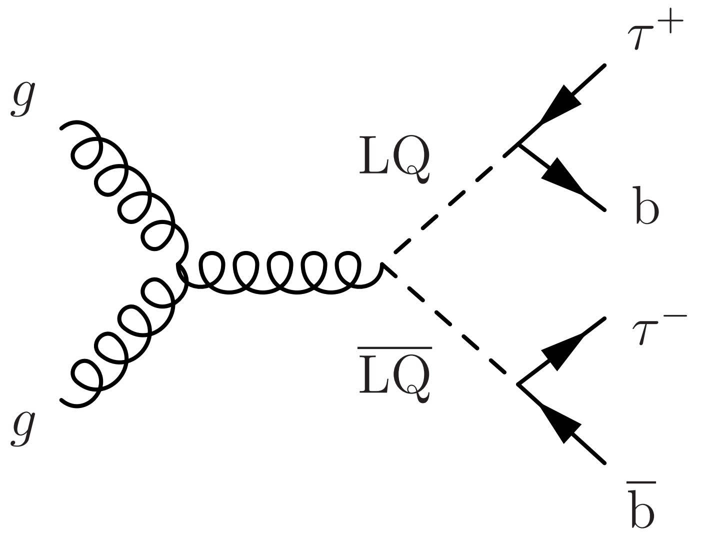
- We almost completed Run-2 analysis



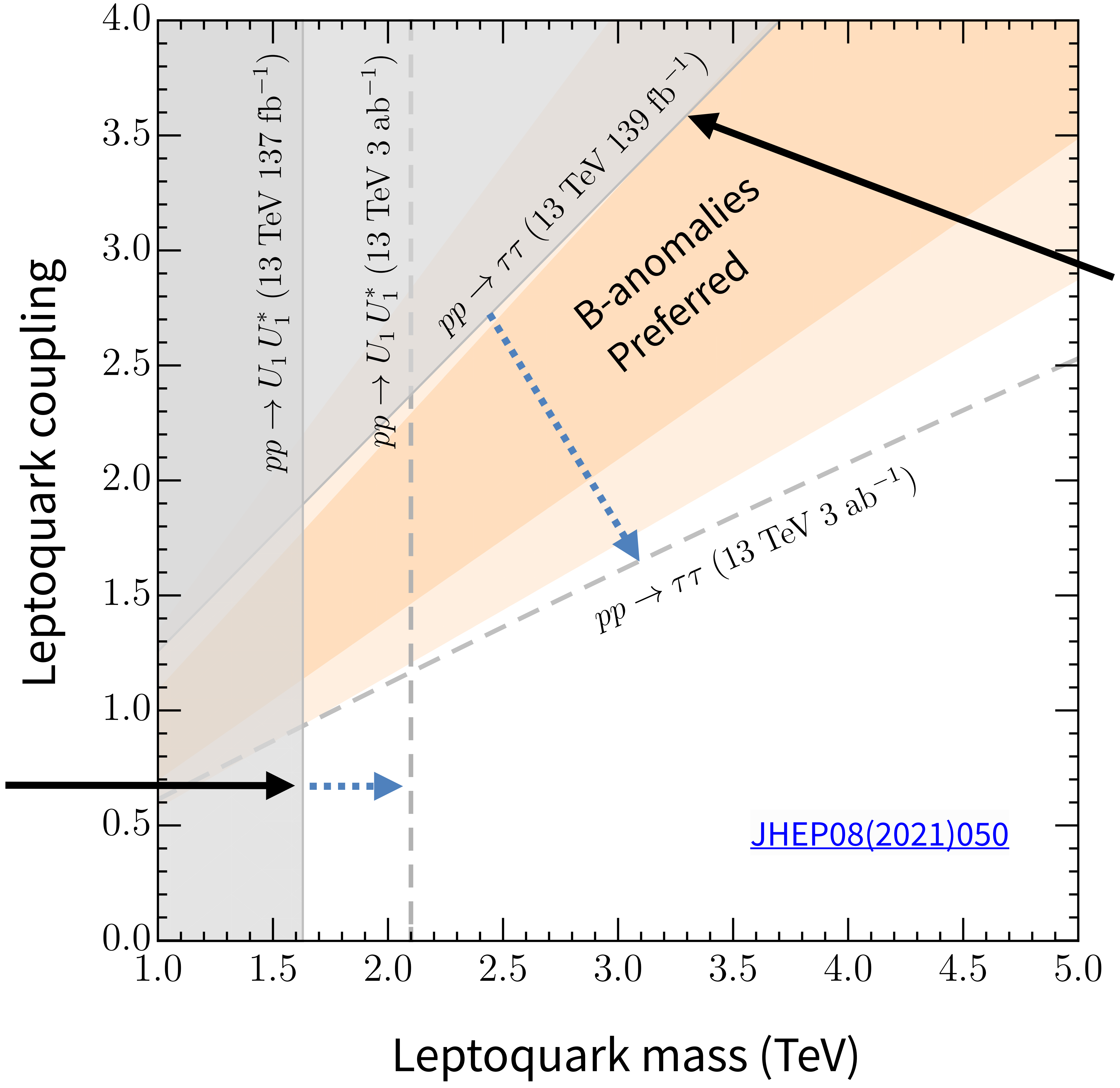
- We observed "**some excess**" that is compatible with m(ττ) method
- Publish soon!

Future Prospect

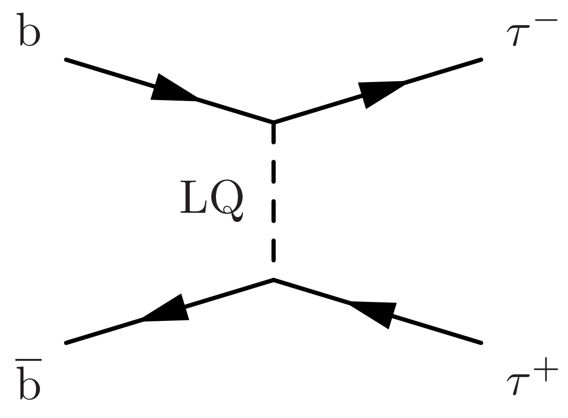
It is this type of off-shell analyses that can strongly constrain new physics models explaining B-physics anomalies

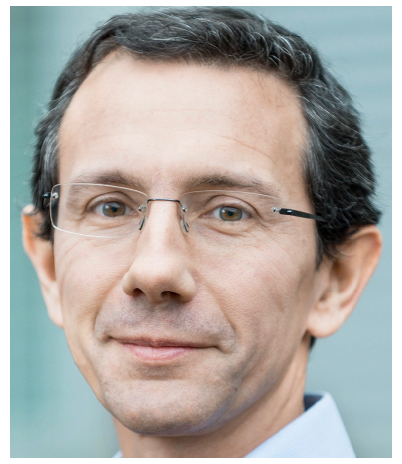


On-shell search



Off-shell search using data we have now




G. Isidori

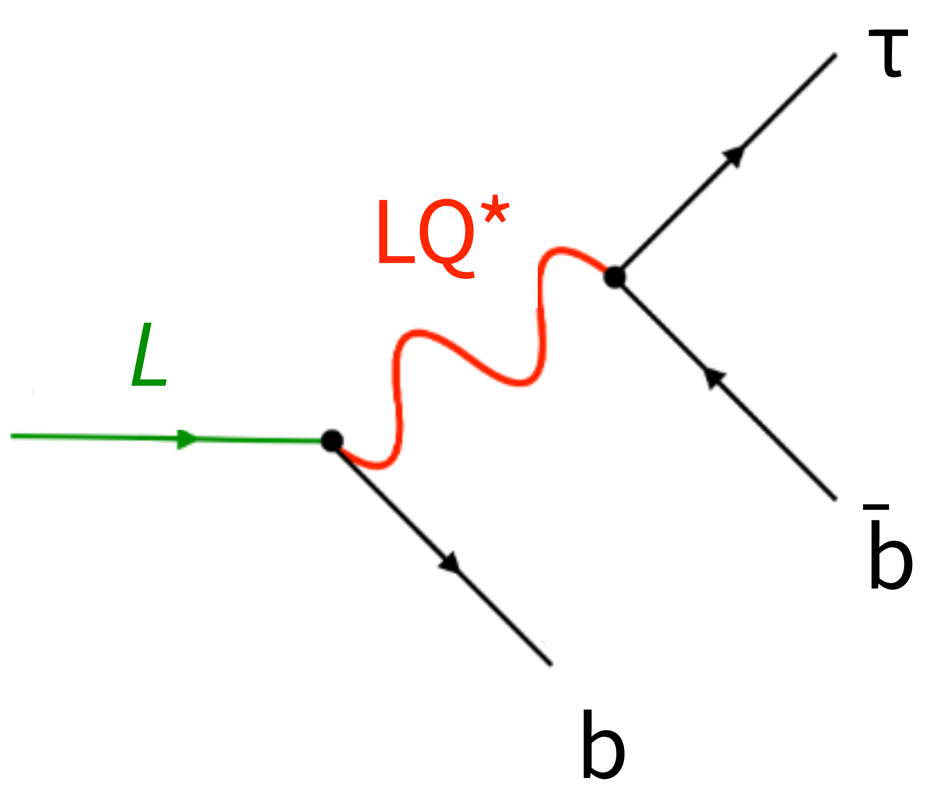

J. Martin

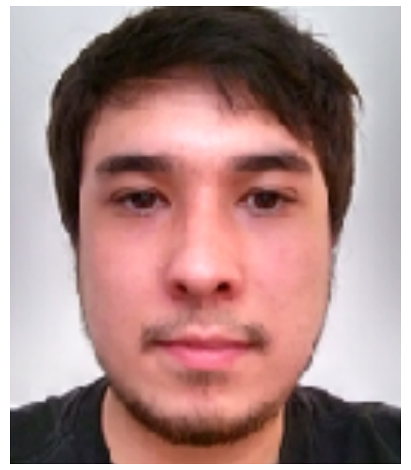

D. Faroughy

Other ideas under discussions (examine tau polarization for those events that showed excess, detect interference pattern between off-shell ττ resonance and Standard model DY Z → ττ). More ideals/inputs welcome!

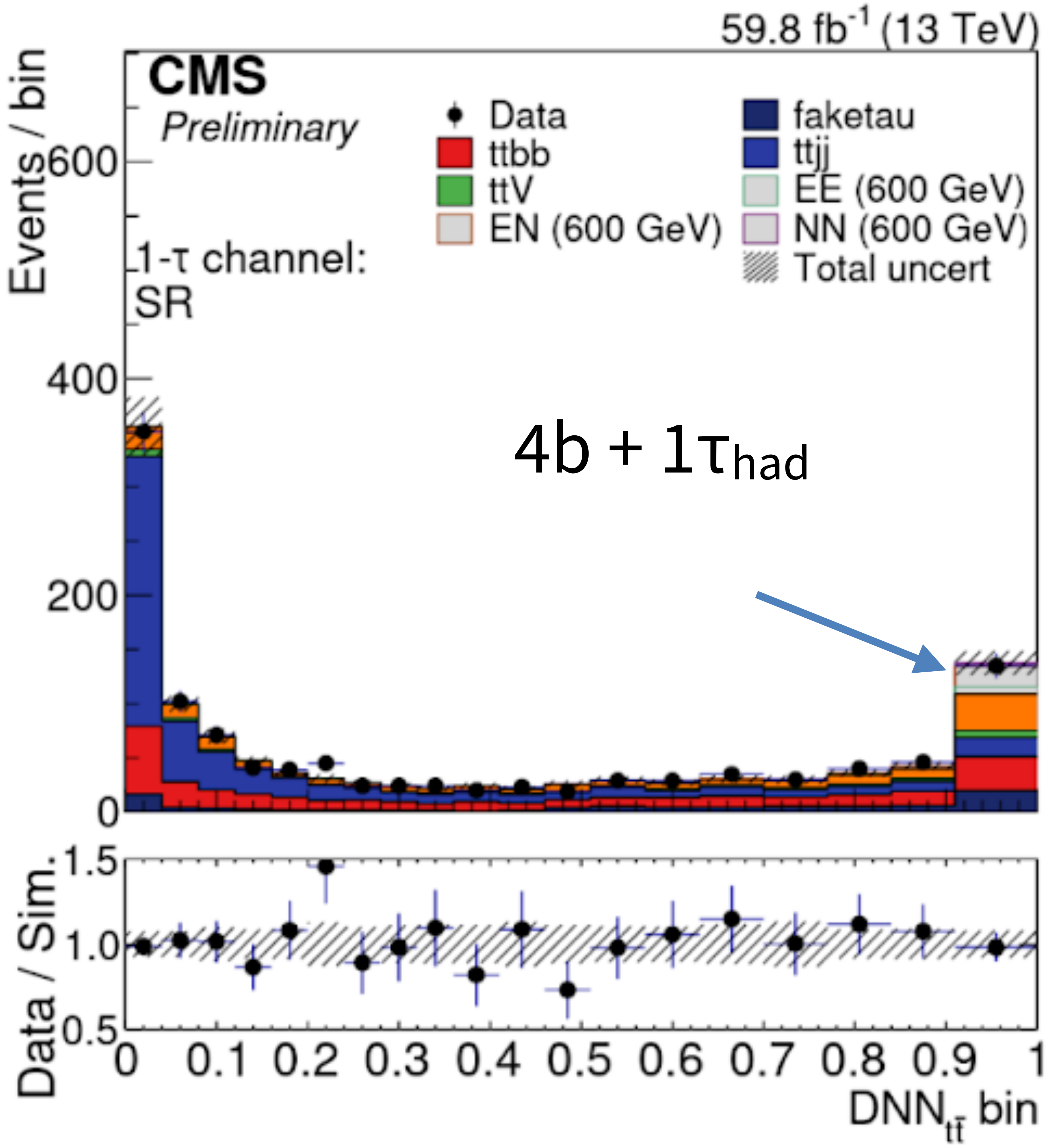
Vector-like lepton search

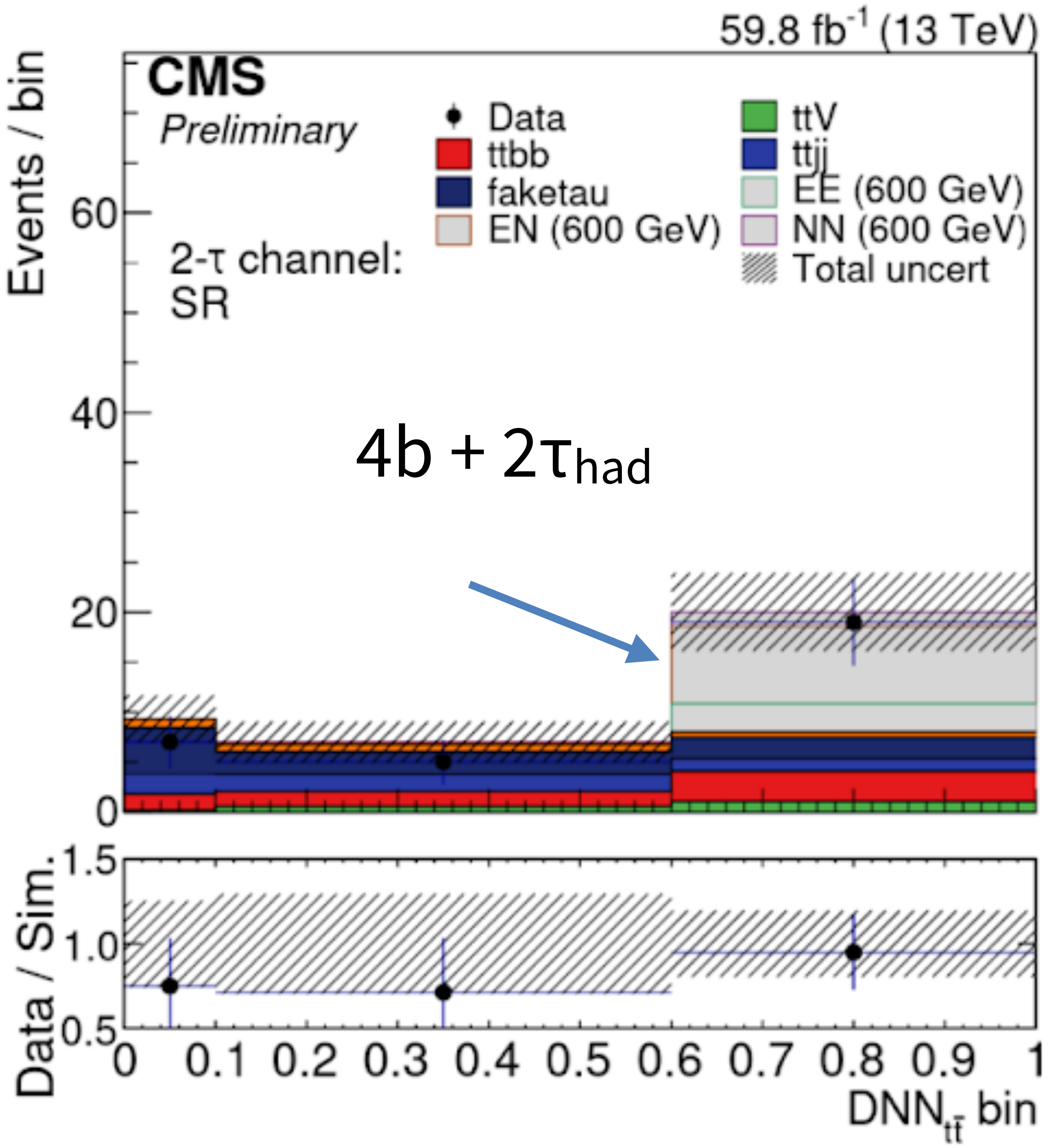
- Leptoquark won't be stand-alone (cf: $W_L W_L \rightarrow W_L W_L$ scattering violates unitarity → necessitate Higgs boson)
- Some model (e.g. 4321) predicts new families of **Vector-Like Lepton that couples to LQ**





V. Mikuni





~3σ excess!
Intriguing result that can also support B-physics anomalies
→ We are looking at other ττ final states

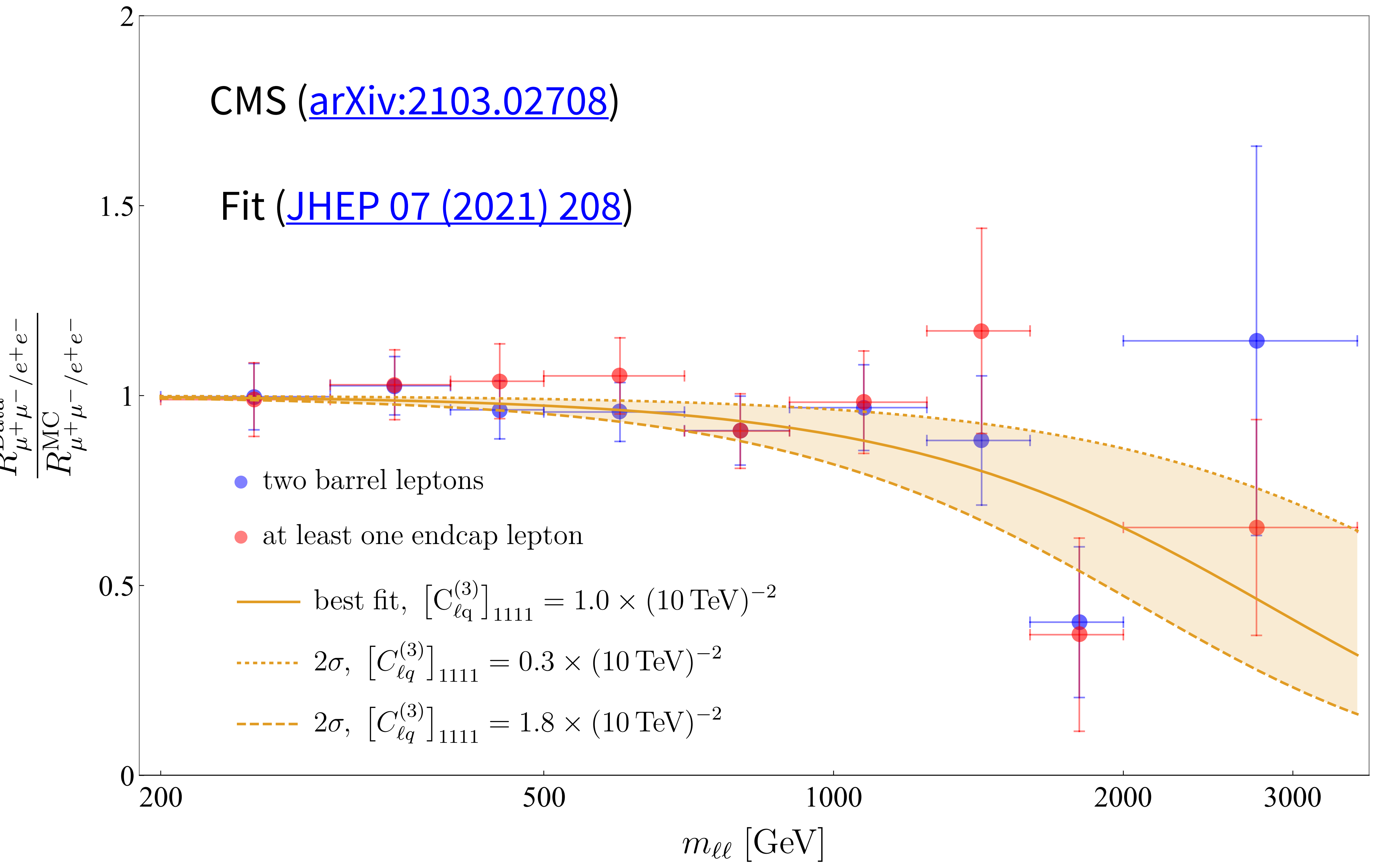
B2G-21-004

LFU test at high-p_T

New physics that created "anomalies" in B-physics experiment can create LFU violation at high-q^2 too → complementary input!

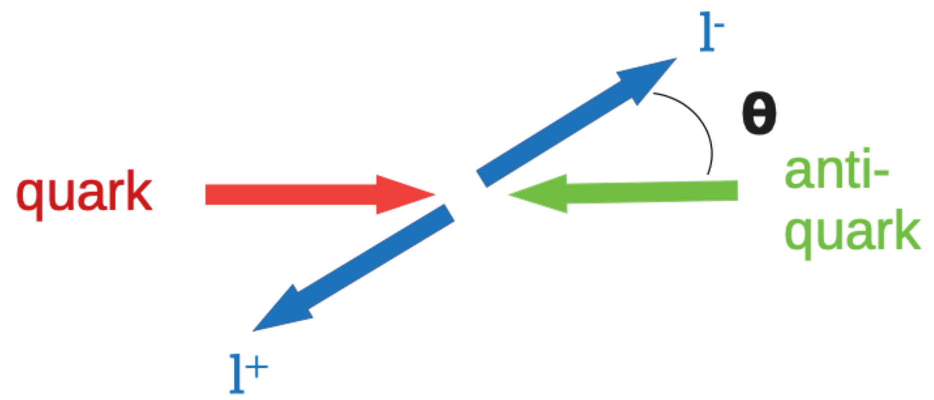
N(ee) v.s. N(μμ) as a function of m(ll)

Binning in m(ll) will enhance sensitivity to new physics at high energy scale

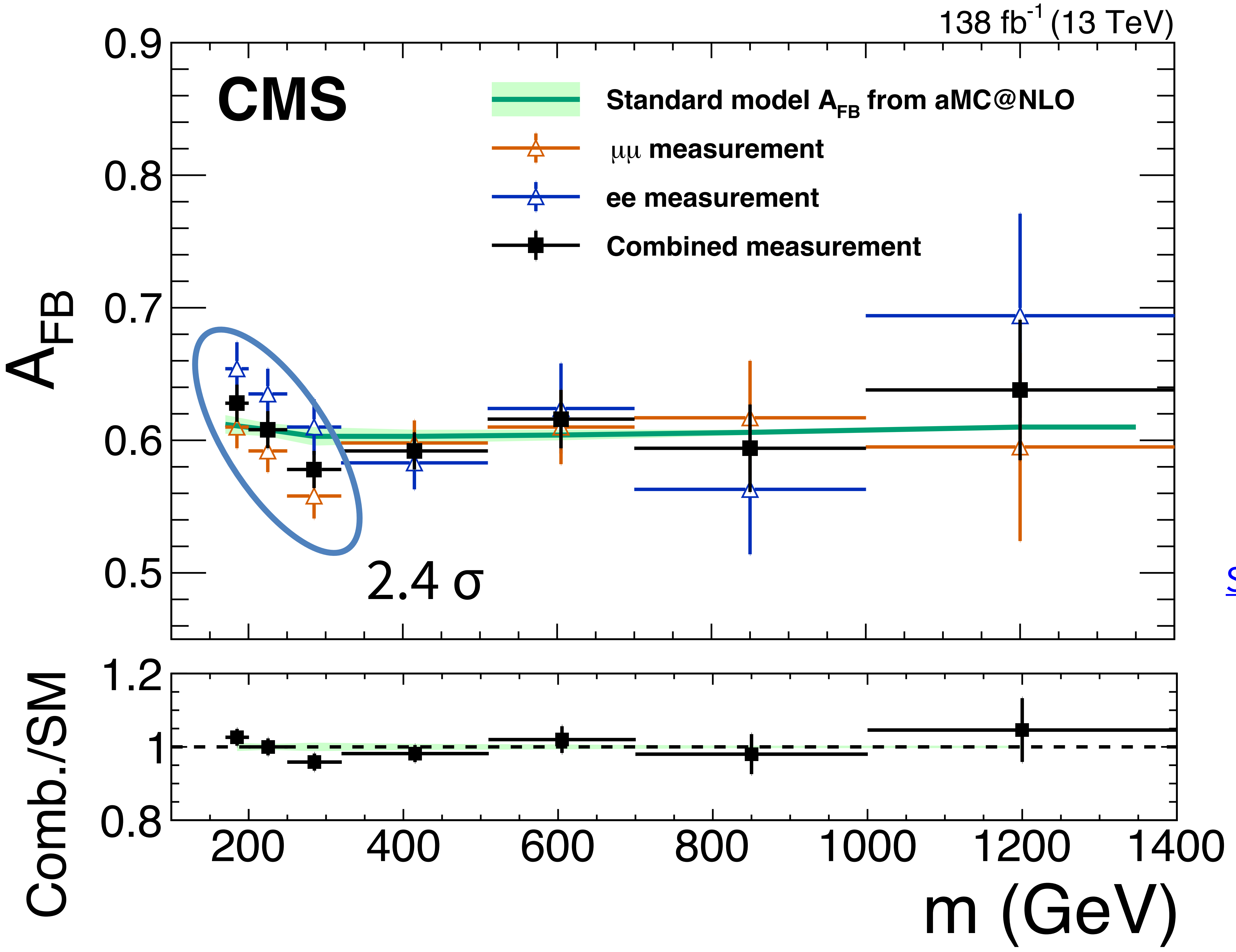


Forward-backward asymmetry (ee v.s. μμ)

$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$



Forward: cosθ > 0, Backward: cosθ < 0



SMP-21-001

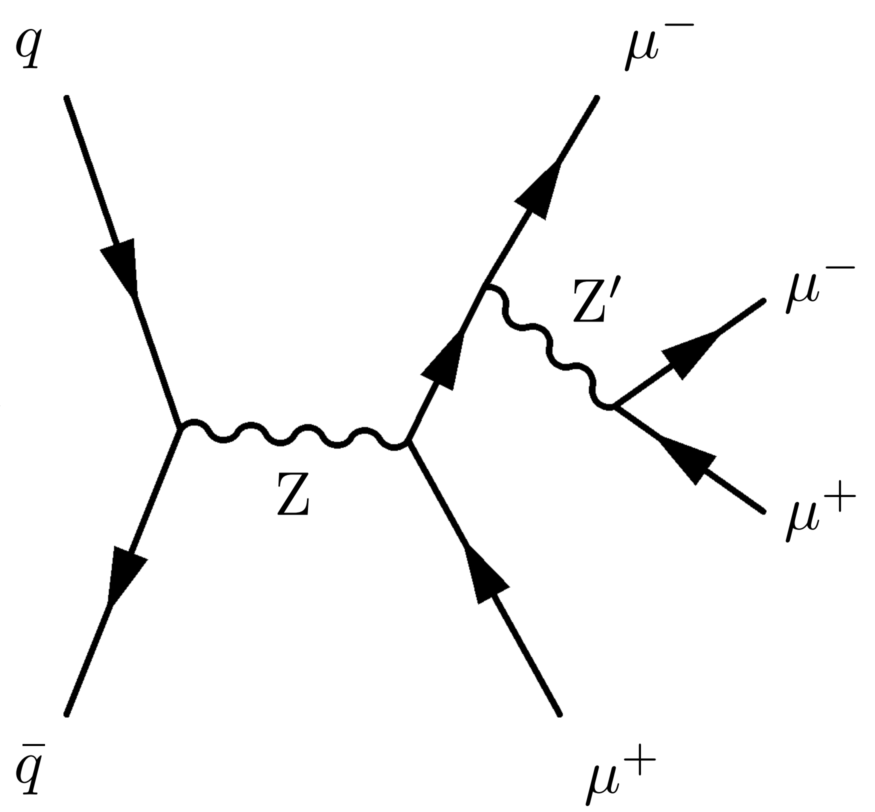
Q: What about μμ v.s. ττ? With more data?

Flavoured Z’ search

We put **minimum** assumptions:

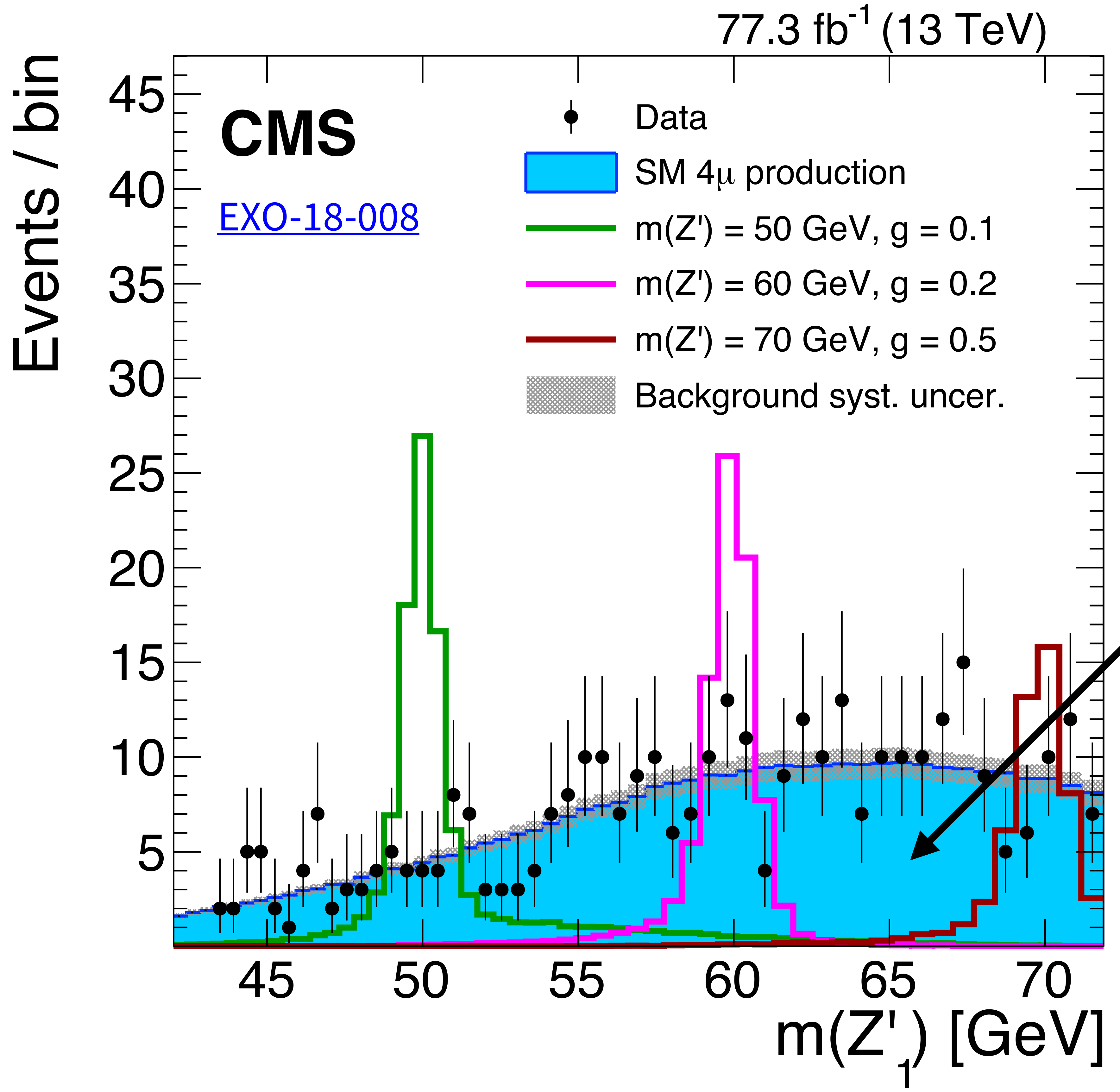
- Z’ exists and explain b → sμμ anomaly
- Z’ only couples to μ and τs (e.g. Lμ - Lτ model)

Search for

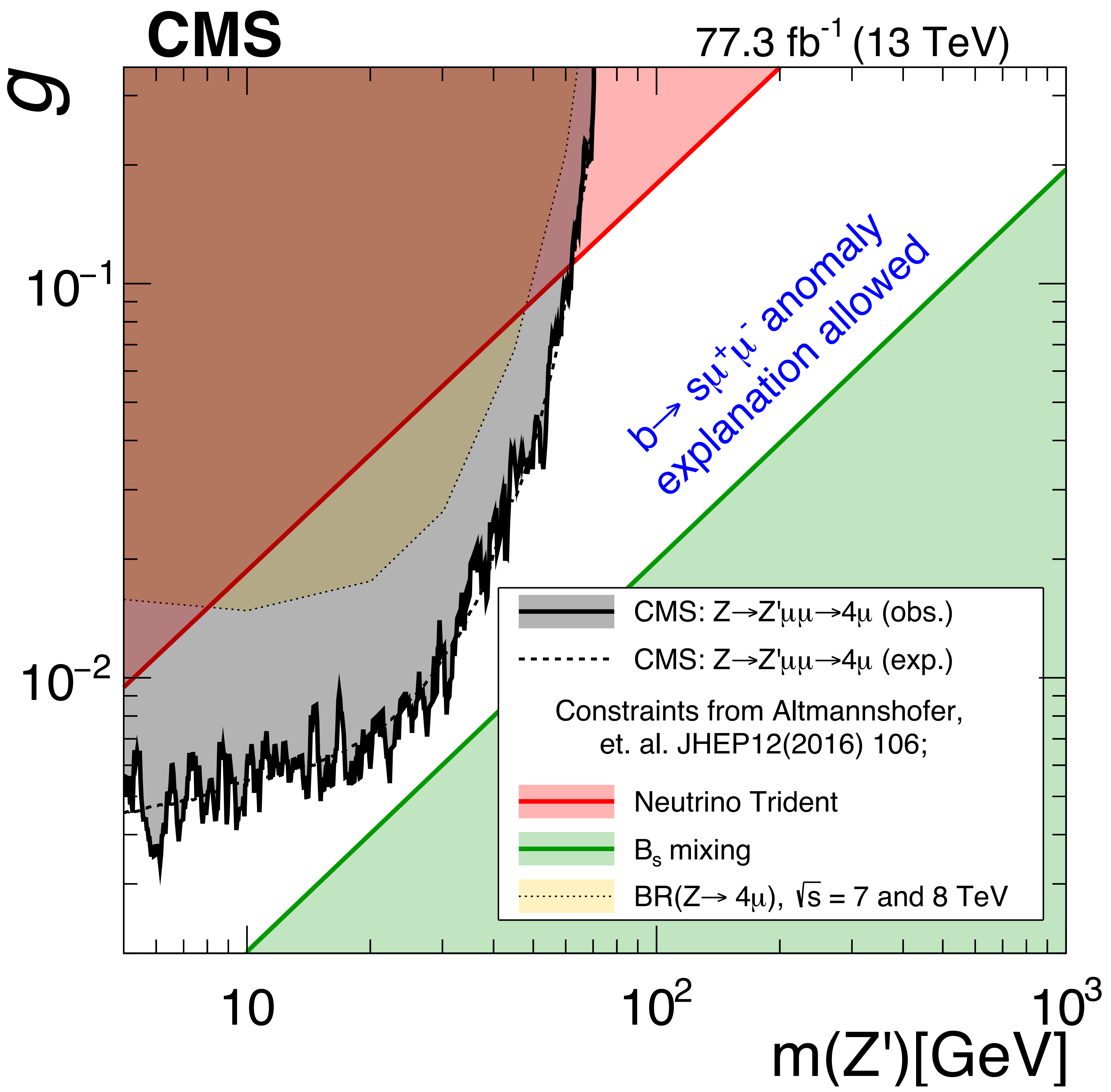


Event selection:

- m(4μ) ~ m_Z
- Choose 2 muons, that, most probably come from Z’



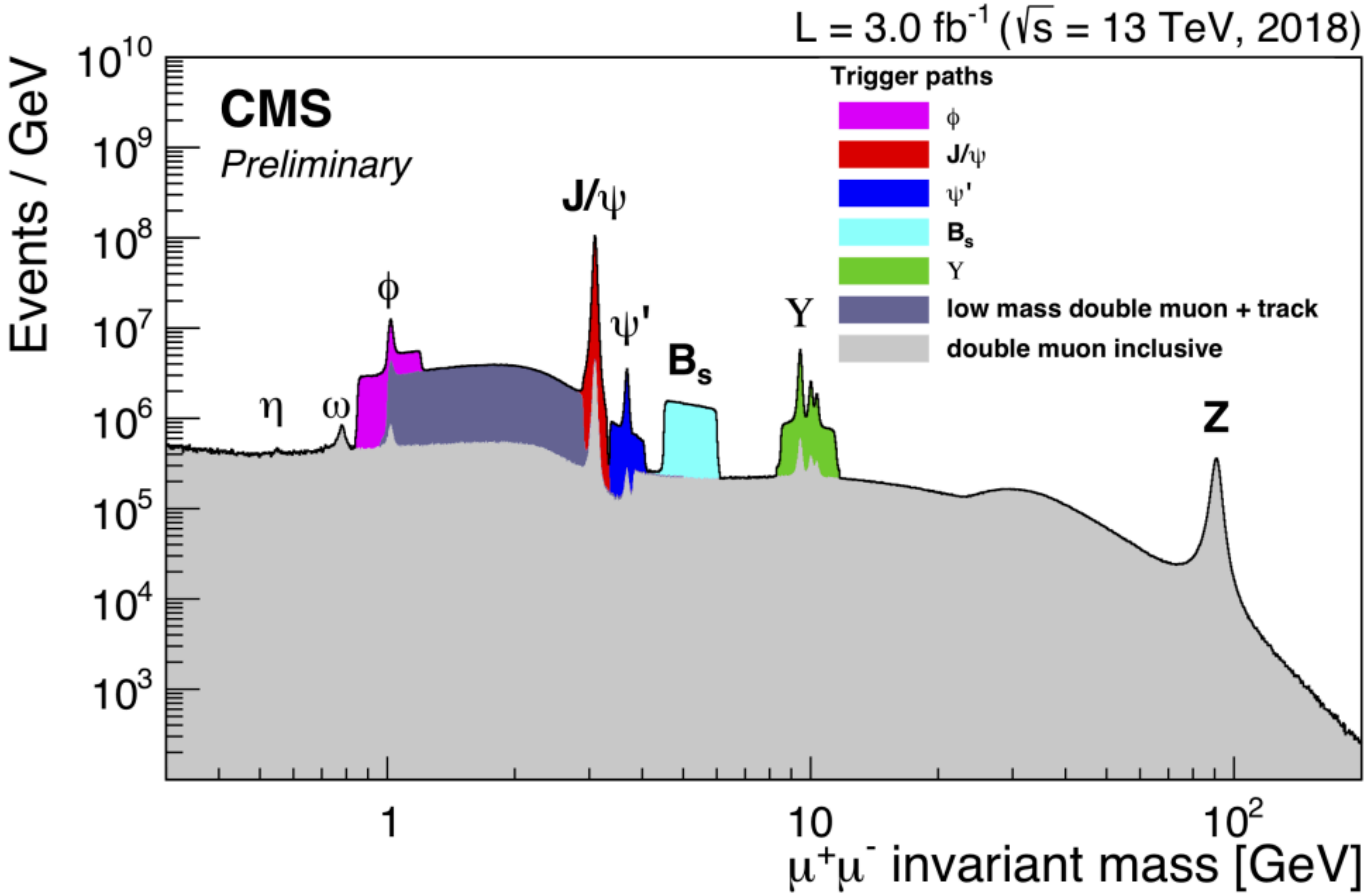
Main BG:
Z → γ*μμ → 4μ evaluated by simulation



Similar analysis with **μμττ** final state on-going!

B-physics program at CMS

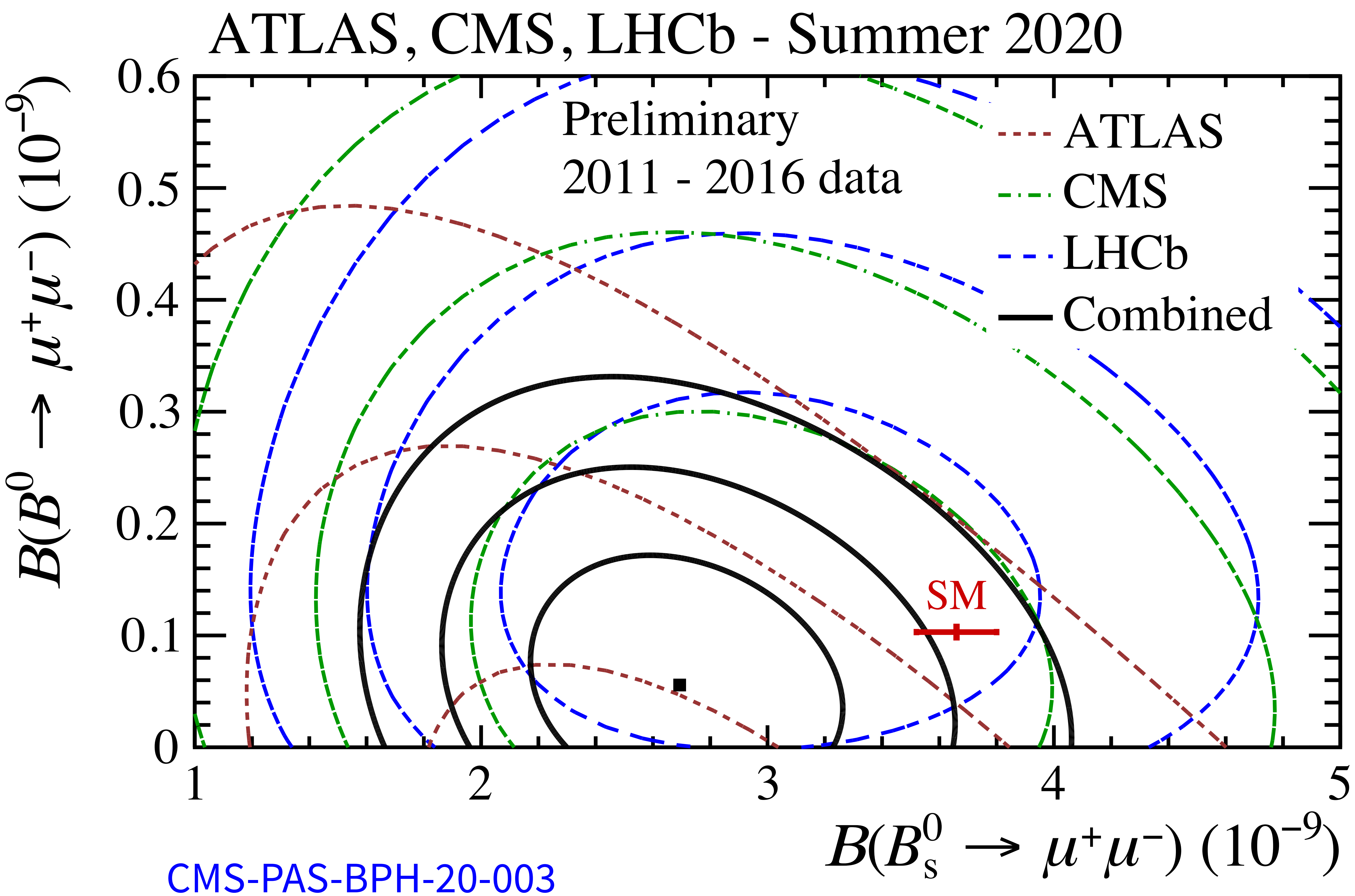
- Unlike LHCb, we operate our detector at **high** instantaneous luminosity and a lot of trigger bandwidths have been allocated to high-p_T physics programs (e.g. Higgs, BSM searches)
- We do B-physics with the final state that has low rate enough to fit the overall trigger budget → **μμ** final states **(~100Hz out of 1kHz total budget)**



CMS-DP-2018-036

Br($B_s \to \mu\mu$) measurement

- Doubly suppressed in the SM (FCNC + Helicity suppression)
  - Br($B_s^0 \to \mu\mu$) = (3.66 ± 0.14) x 10^{-9}
- In conjunction with small theoretical uncertainty (**4%**), perfect testing ground for detecting small NP contributions

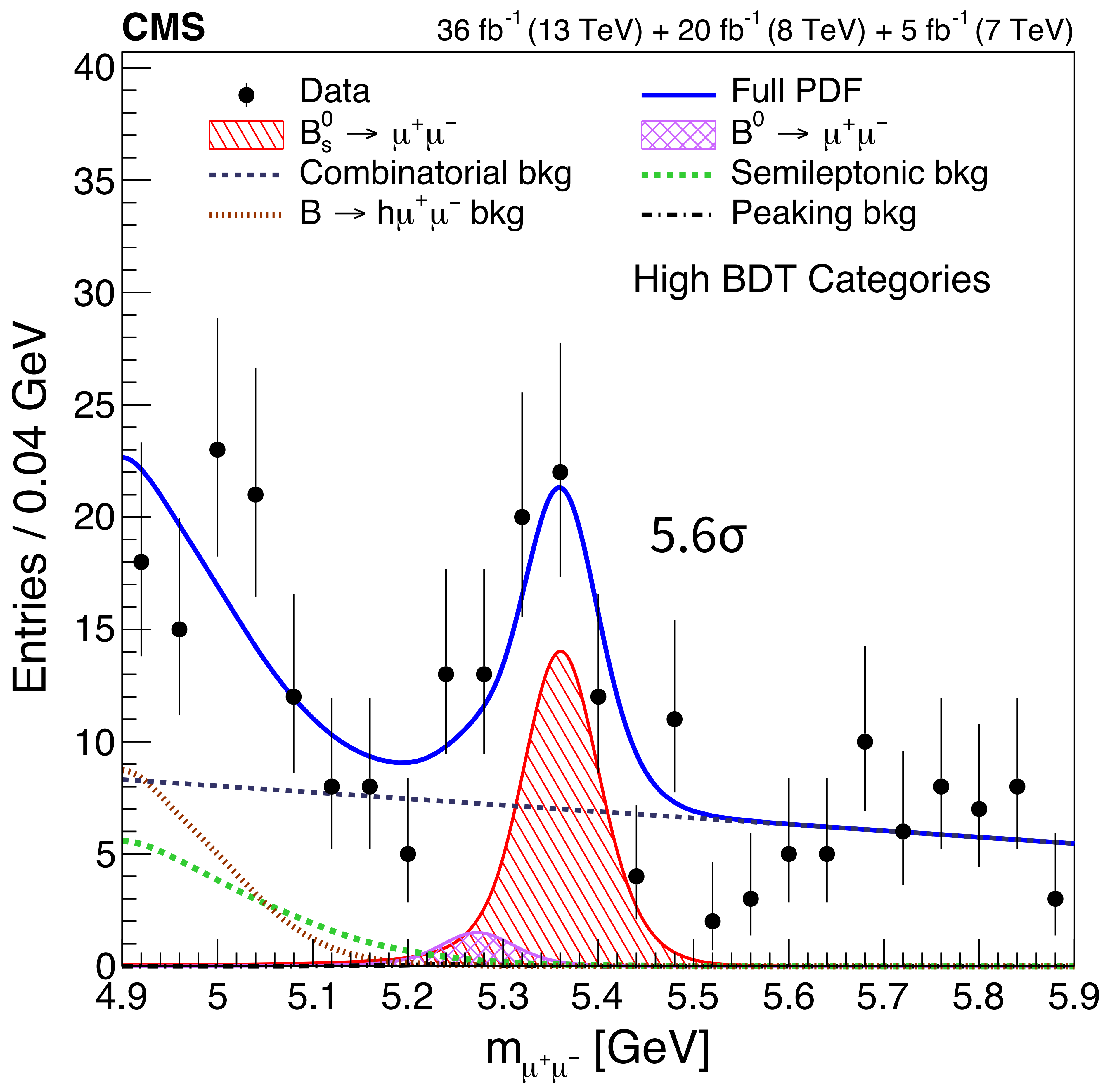


CMS-PAS-BPH-20-003

Run-1 + 2016 data:

Br($B_s \to \mu\mu$) = (2.9 ± 0.7) x 10^{-9}

→ 24% rel. uncertainty (**stat. limited**)



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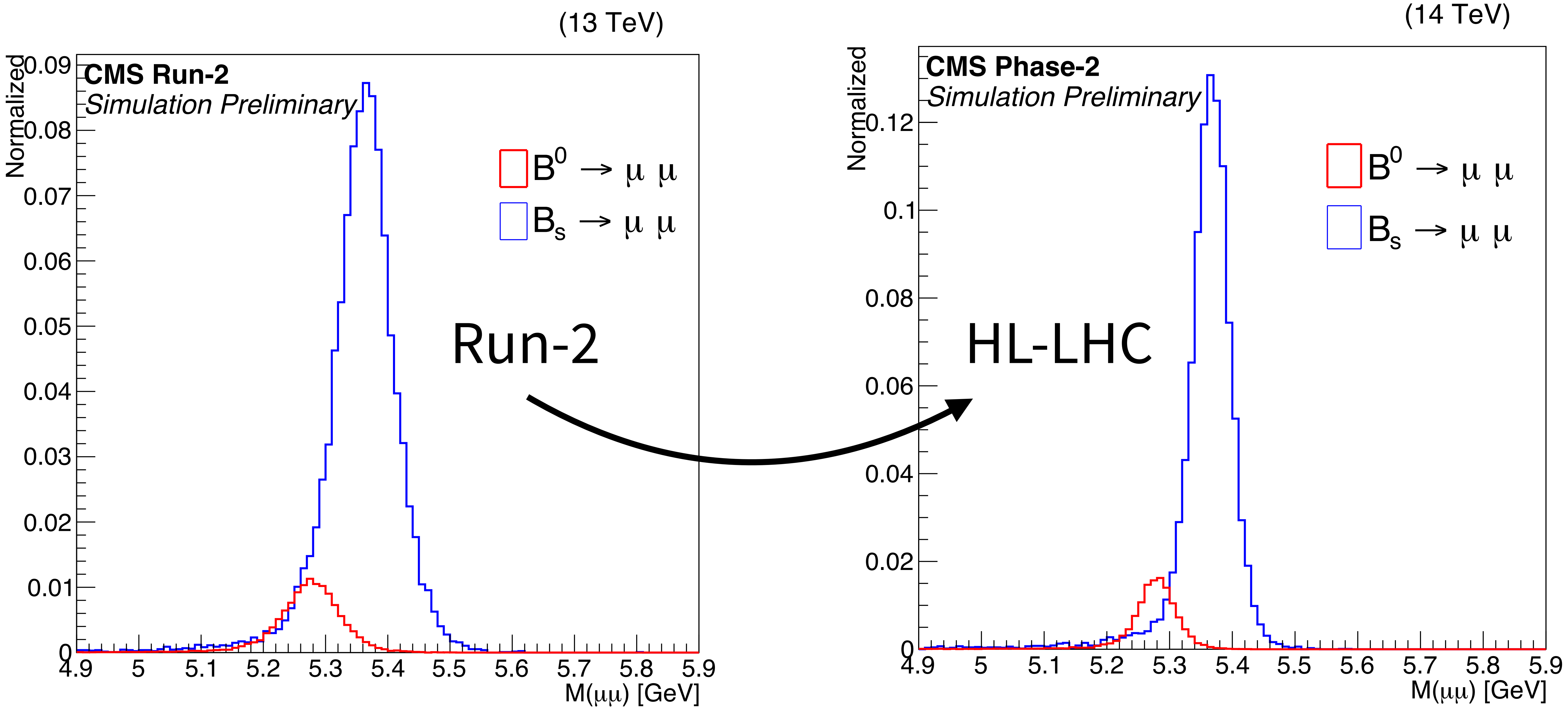
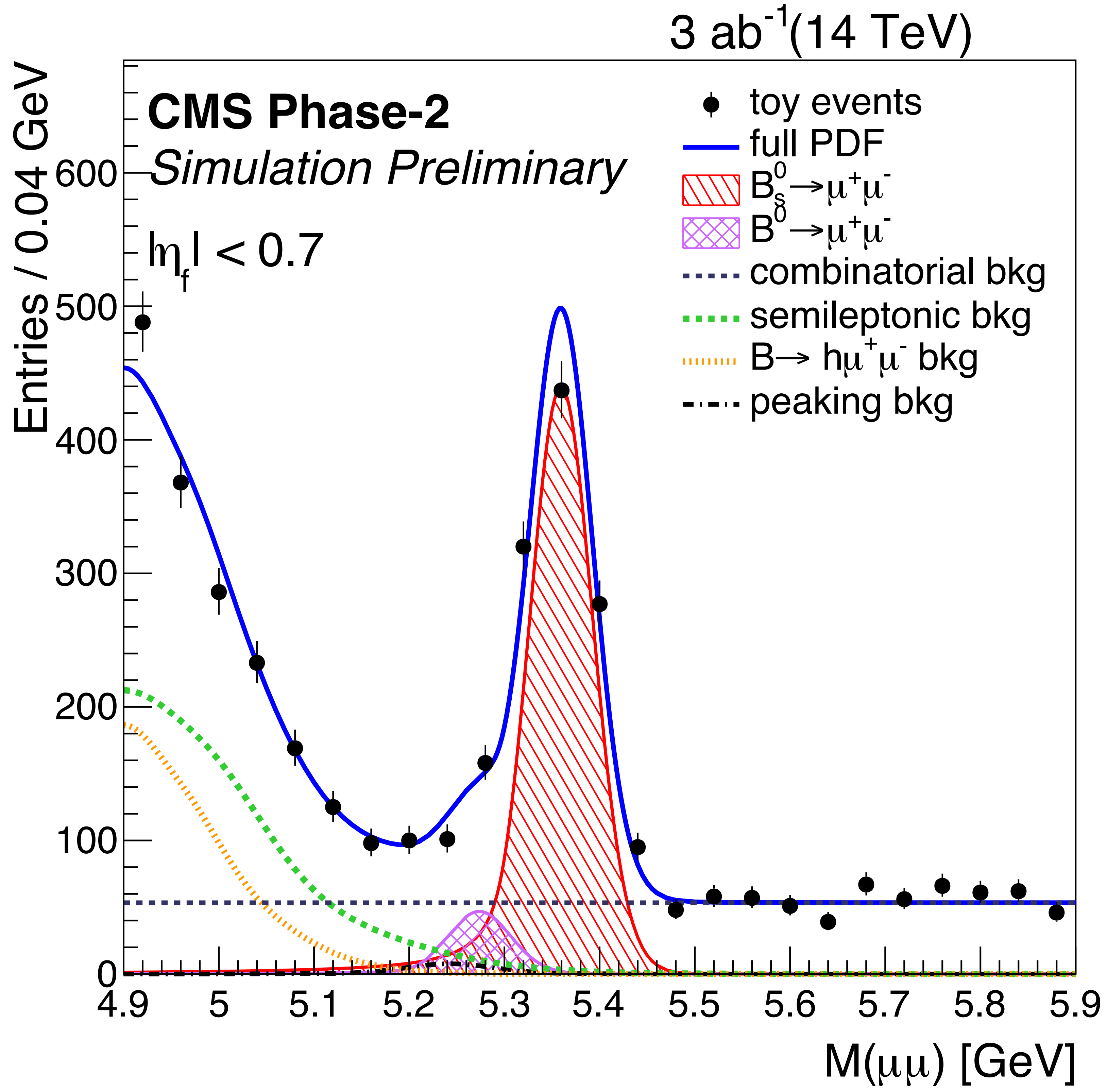
Future prospects of the $B_{s/d} \to \mu\mu$ decay

CMS-PAS-FTR-18-013

- **Updating with full Run-2 statistics (coming soon) —** achieved improvement beyond luminosity scale
- We are also developing a new trigger for Run-3
- Future projection towards HL-LHC





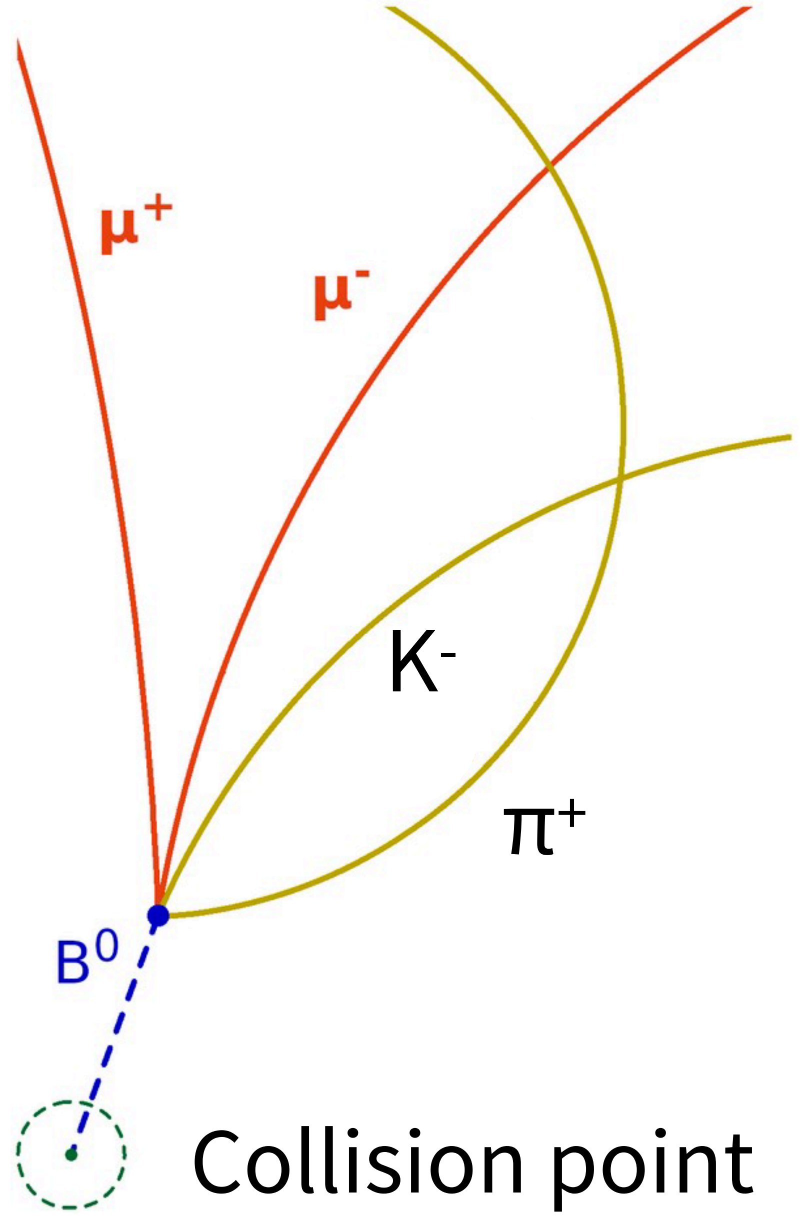
Improved μμ mass resolution
thanks to reduced material budgets
+ smaller silicon sensor pitch

$\mathcal{L}$ (fb^{-1})	$N(B_s)$	$N(B^0)$	$\delta\mathcal{B}(B_s \to \mu\mu)$	$\delta\mathcal{B}(B^0 \to \mu\mu)$	$\sigma(B^0 \to \mu\mu)$
300	205	21	12%	46%	$1.4 - 3.5\sigma$
3000	2048	215	7%	16%	$6.3 - 8.3\sigma$

P5' analysis in $B^0 \rightarrow K^{*0}\mu\mu$ decay

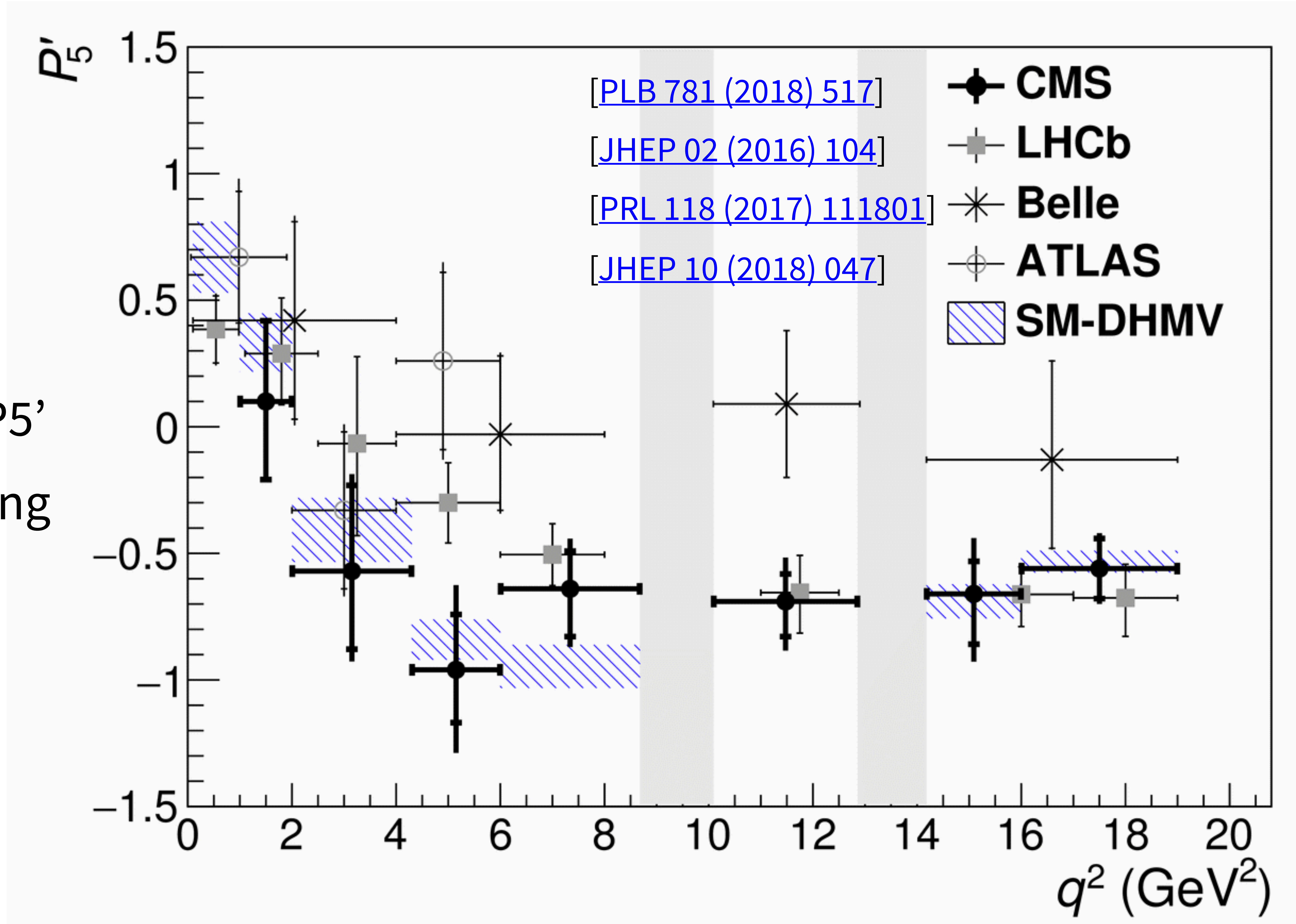
$K^{*0} \rightarrow$ vector (3 polarisation states)

Allows to access $C_7^{(')}$, $C_9^{(')}$, $C_{10}^{(')}$, $C_{S,P}^{(')}$



Run-1 result

Due to limited statistics, P1 and P5' are extracted among 8 parameters



- Triggered by displaced μμ
- ID of kaon and pion according to which combination results in a K* mass closer to PDG (892 MeV)

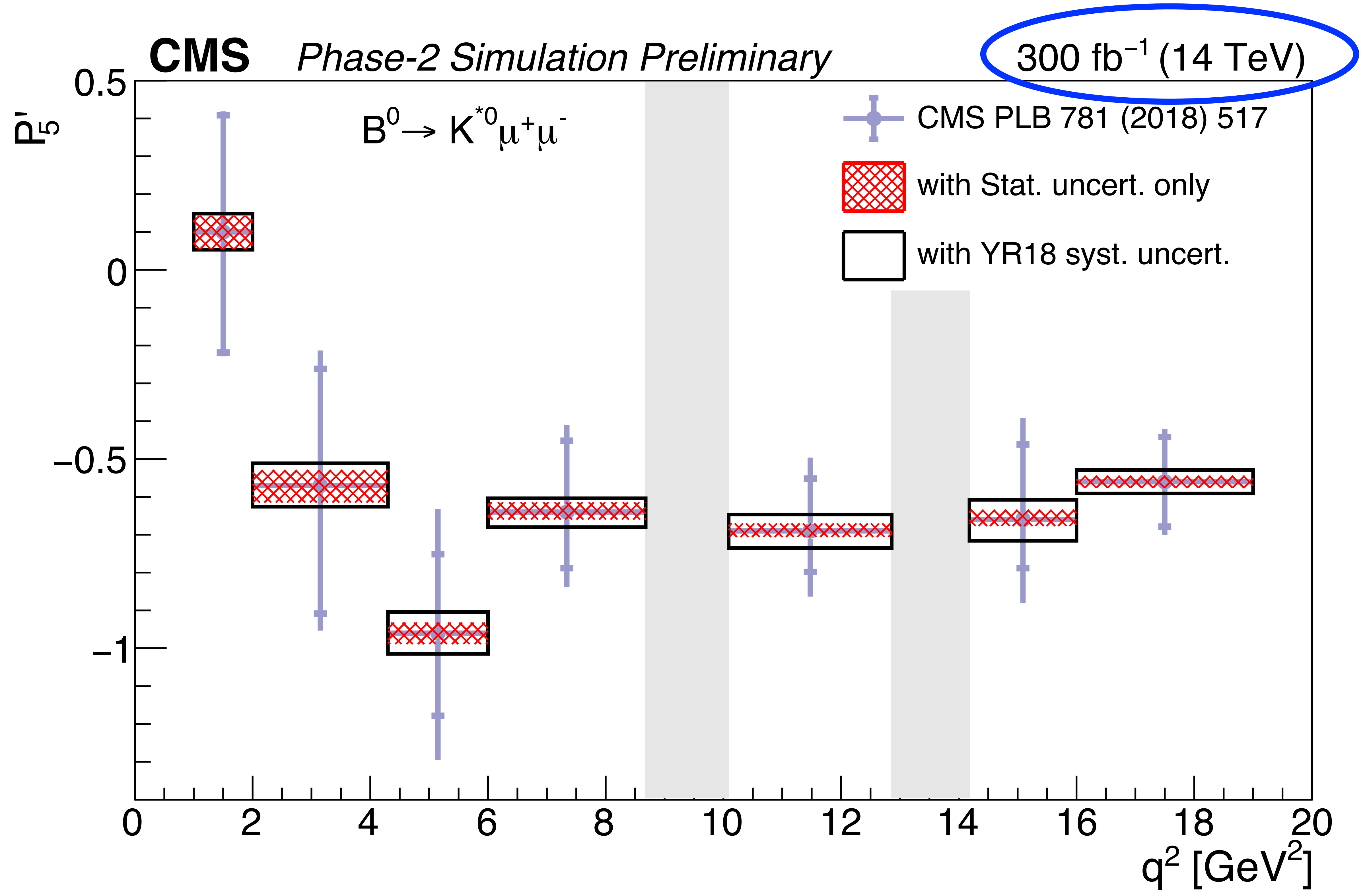
PLB 781 (2018) 517—541

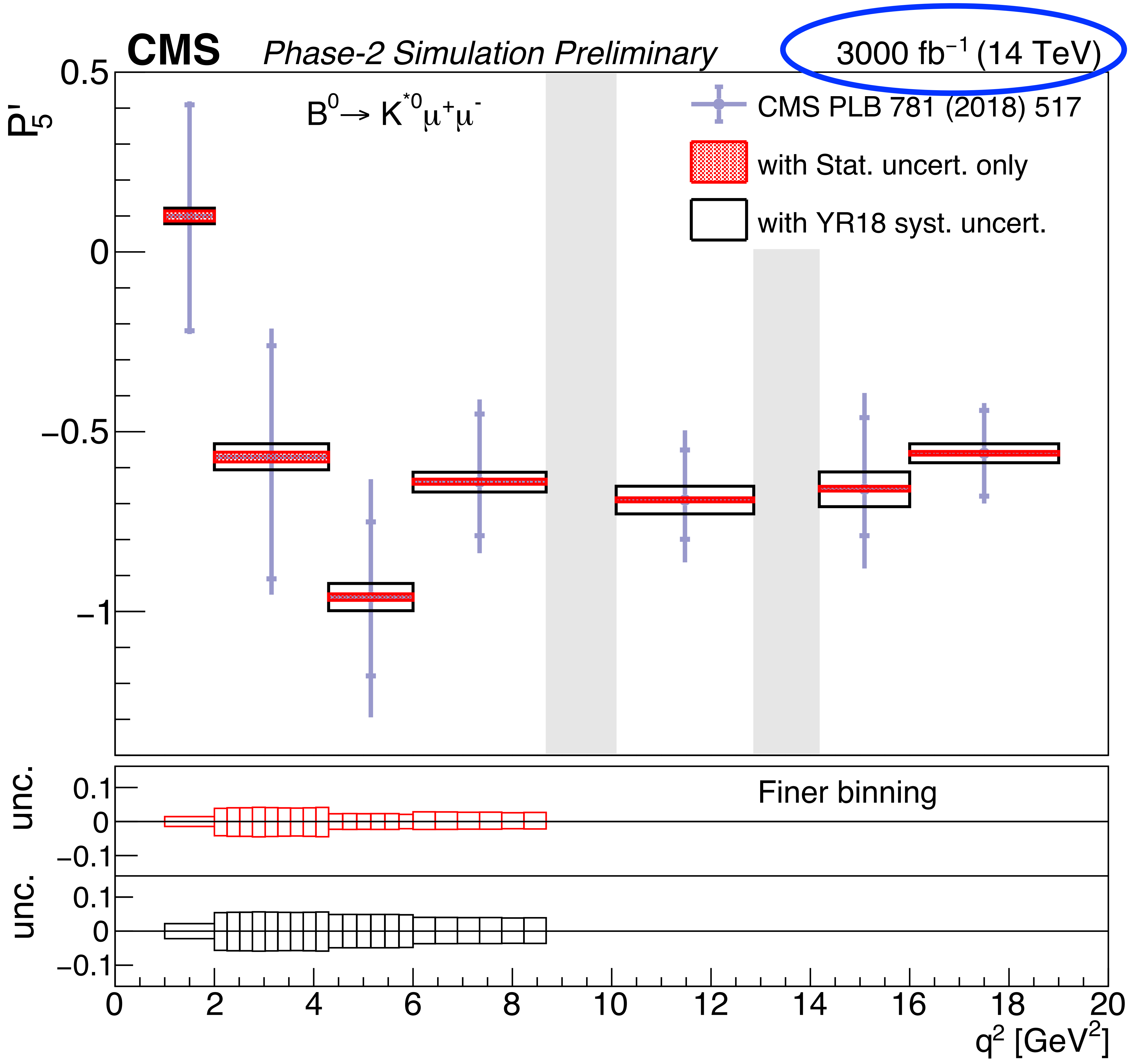
- We are close to complete full Run-2 analysis (x8 more stat. than Run-1)
  - Large improvements in stat. uncertainty (the result start to be systematically dominated)
  - Plan to extract **full set of 8 angular parameters**

Future projections to HL-LHC

CMS-PAS-FTR-18-033

- Starting from Run-1 result, we scaled statistical uncertainty, including the systematics that are based on the data control region
- No improvements in the analysis strategy nor in the trigger performance

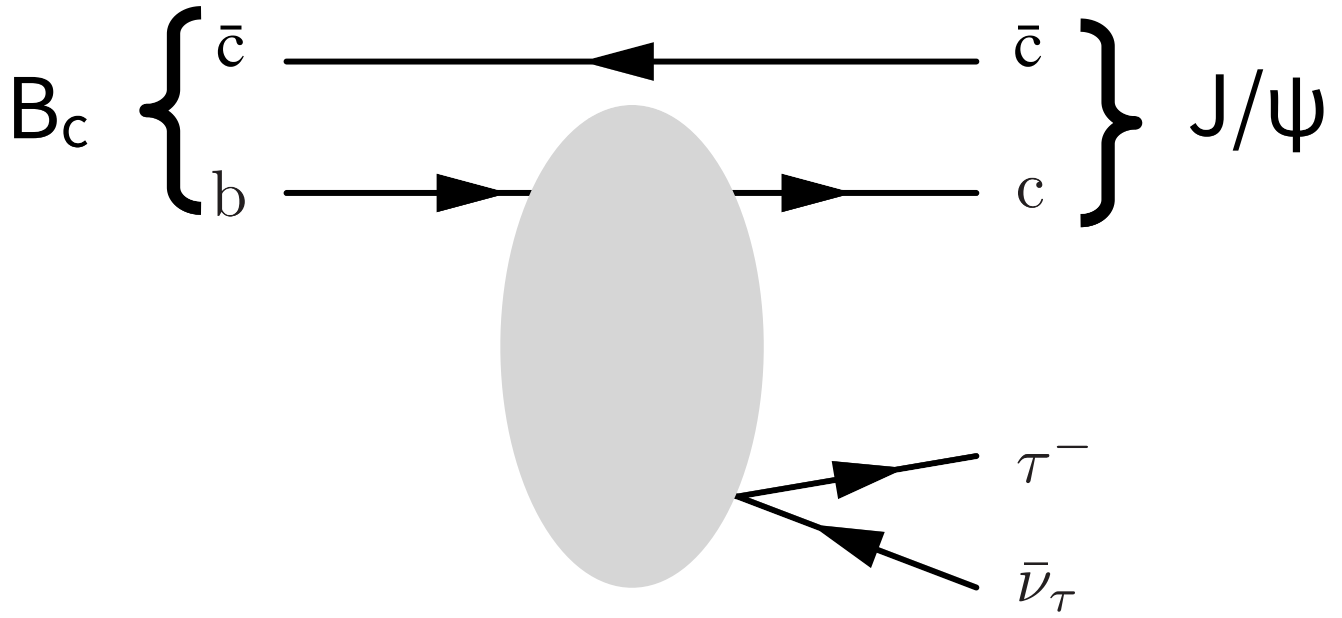




With 3000/fb, one can further split q^2 range in finer bins

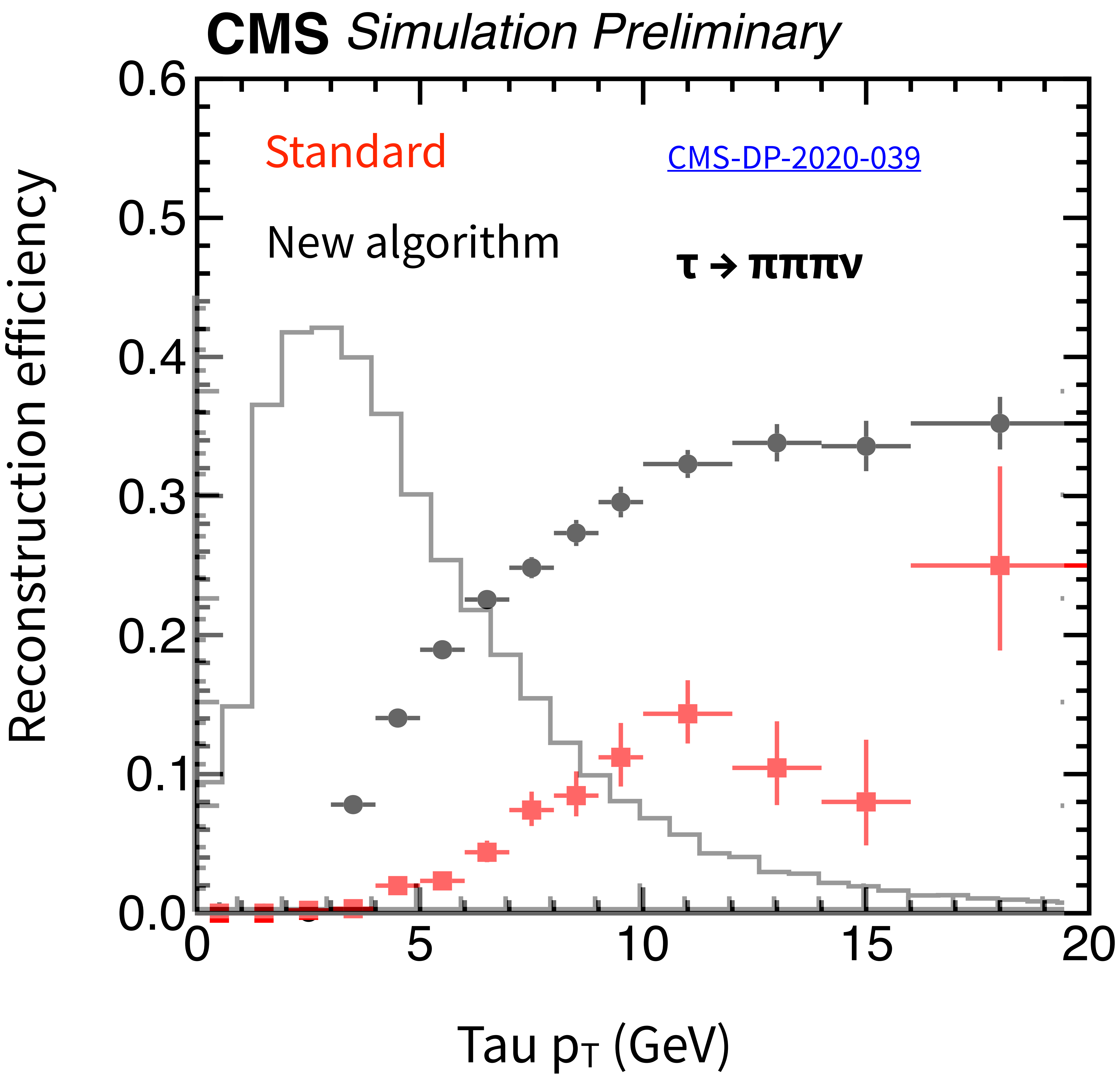
R(J/ψ) analysis

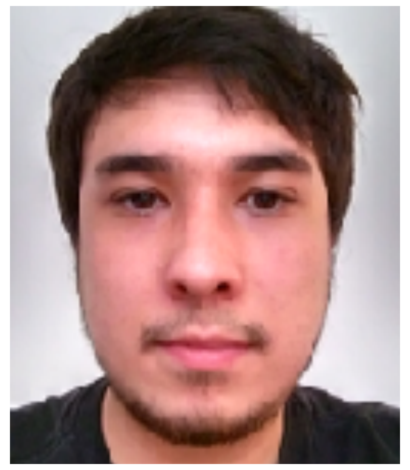
Decay rate measurement of Bc → J/ψτν



- We can do a good job, because CMS collected many events with J/ψ (by utilizing J/ψ → μμ decay)
- Huge statistics

Exploiting both leptonic and hadronic tau decays
→ Challenging: τ lepton has low-momentum (< 10 GeV) → it's very difficult to identify





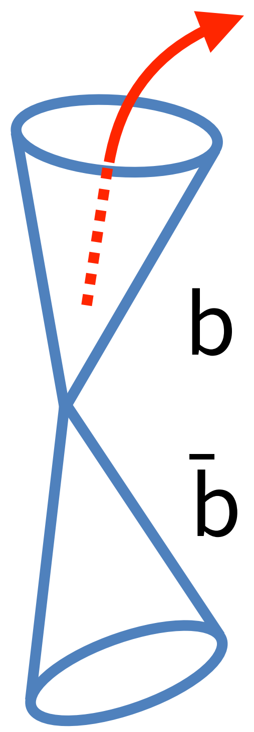
V. Mikuni (ML postdoc @ Berkeley)

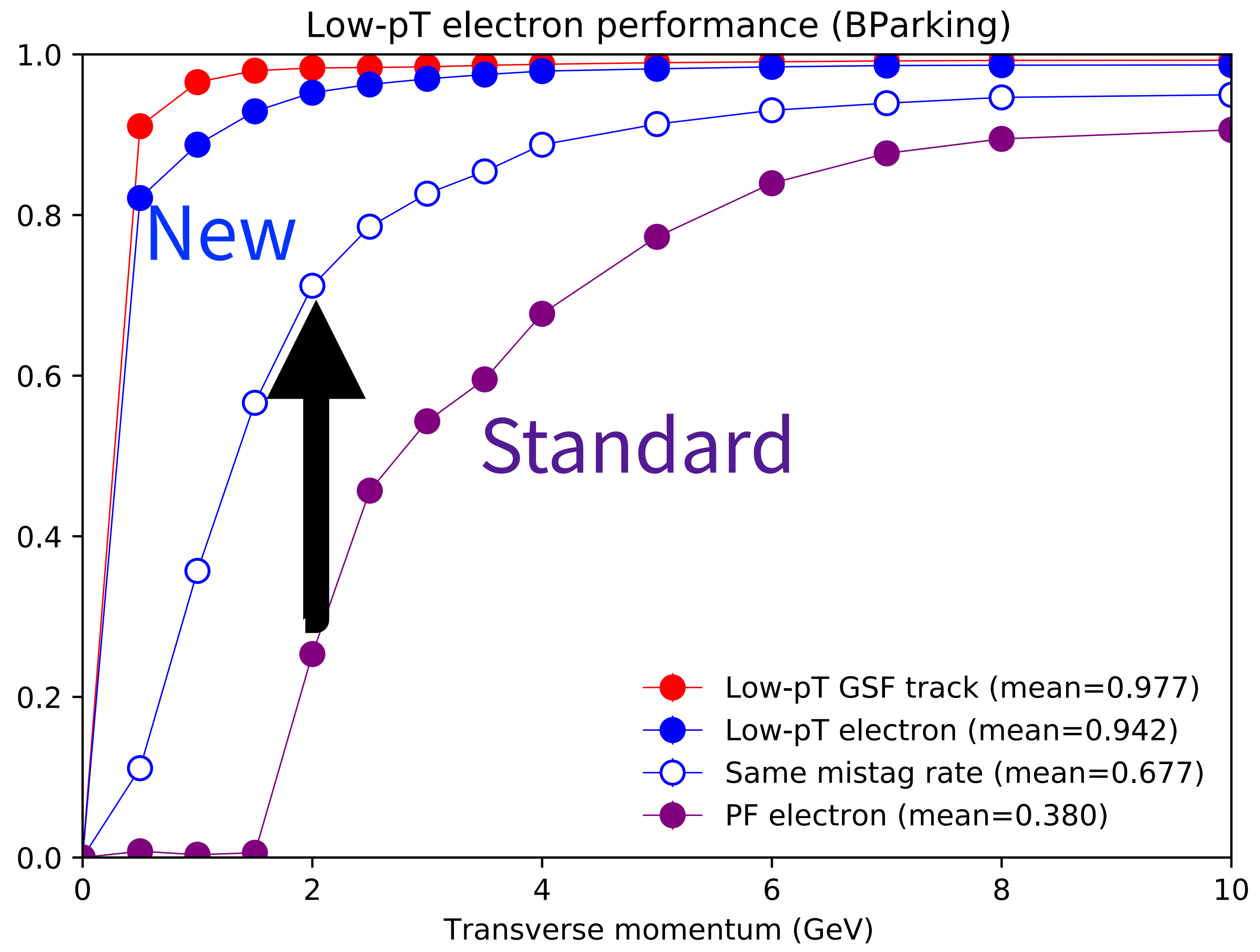
C. Galloni

Expect world-best sensitivity (**targeting summer conference this year**)

Extending our B-physics programs beyond μμ final state

- In 2018, we've collected **10 billion** $B\bar{B}$ events by aggressively triggering on events that have single displaced muon



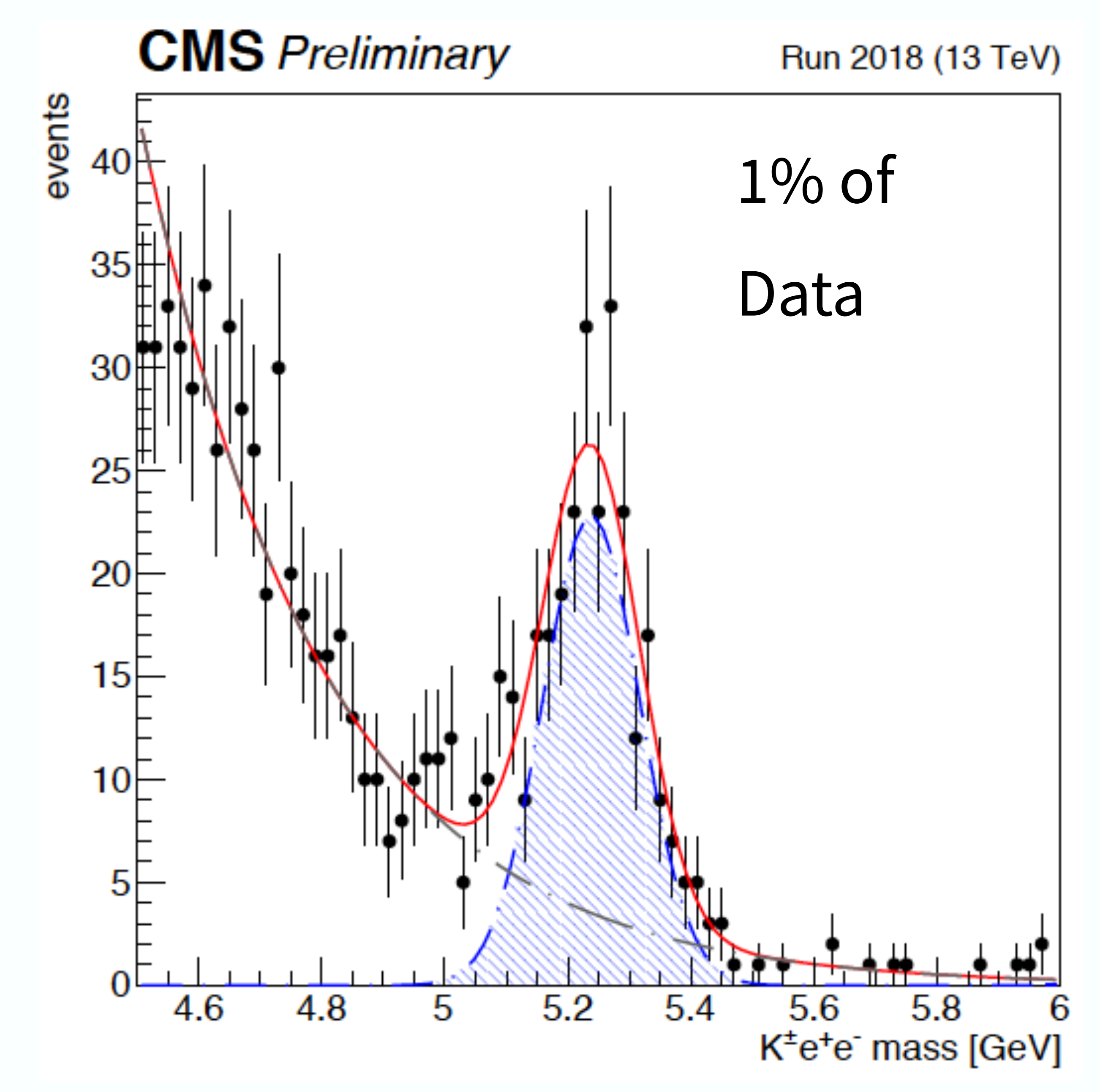


CMS-DP-2019-043

Electron p_T (GeV)

- We are performing **many** B-physics measurements together with newly developed low-p_T electron [CMS-DP-2019-043] and tau [CMS-DP-2020-039] reco. that are applicable down to **a few GeV**

- For Run-3, we are in preparation for even more ambitious triggers!



B → J/ψ (→ ee) K

First observation

at CMS

Conclusion

- B-physics anomalies have been providing us many clues:
  – e.g. which new physics to be searched for? Which phase space to look at?

- Many efforts have been spent both in high-q2 and low-q2 physics

- Some of them seem to support B-physics anomalies but future updates with Run-3 and HL-LHC data will be crucial

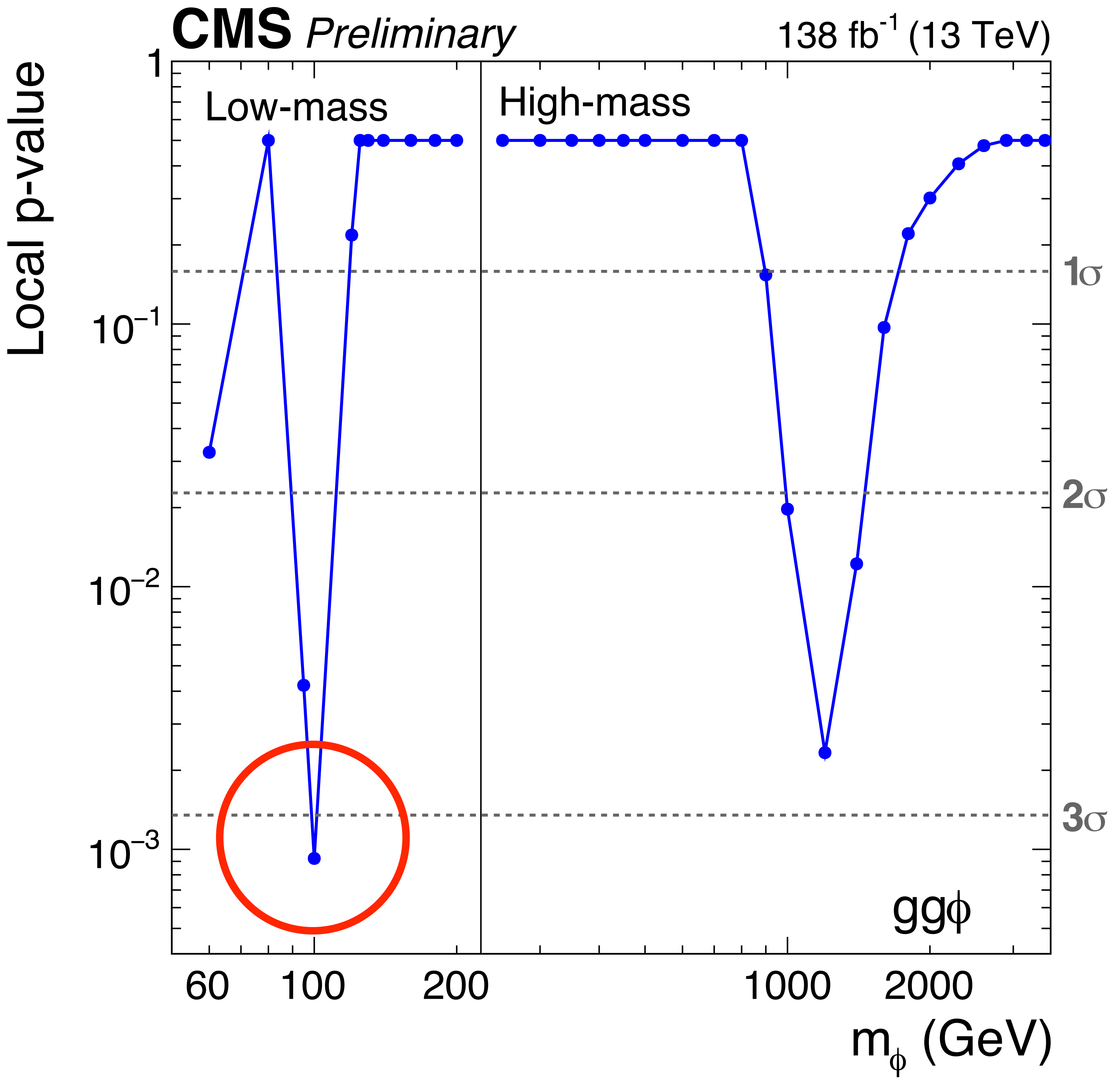
- Since 2018, CMS has been extending B-physics effort by allocating more trigger bandwidth. We plan to further expand this effort in Run-3

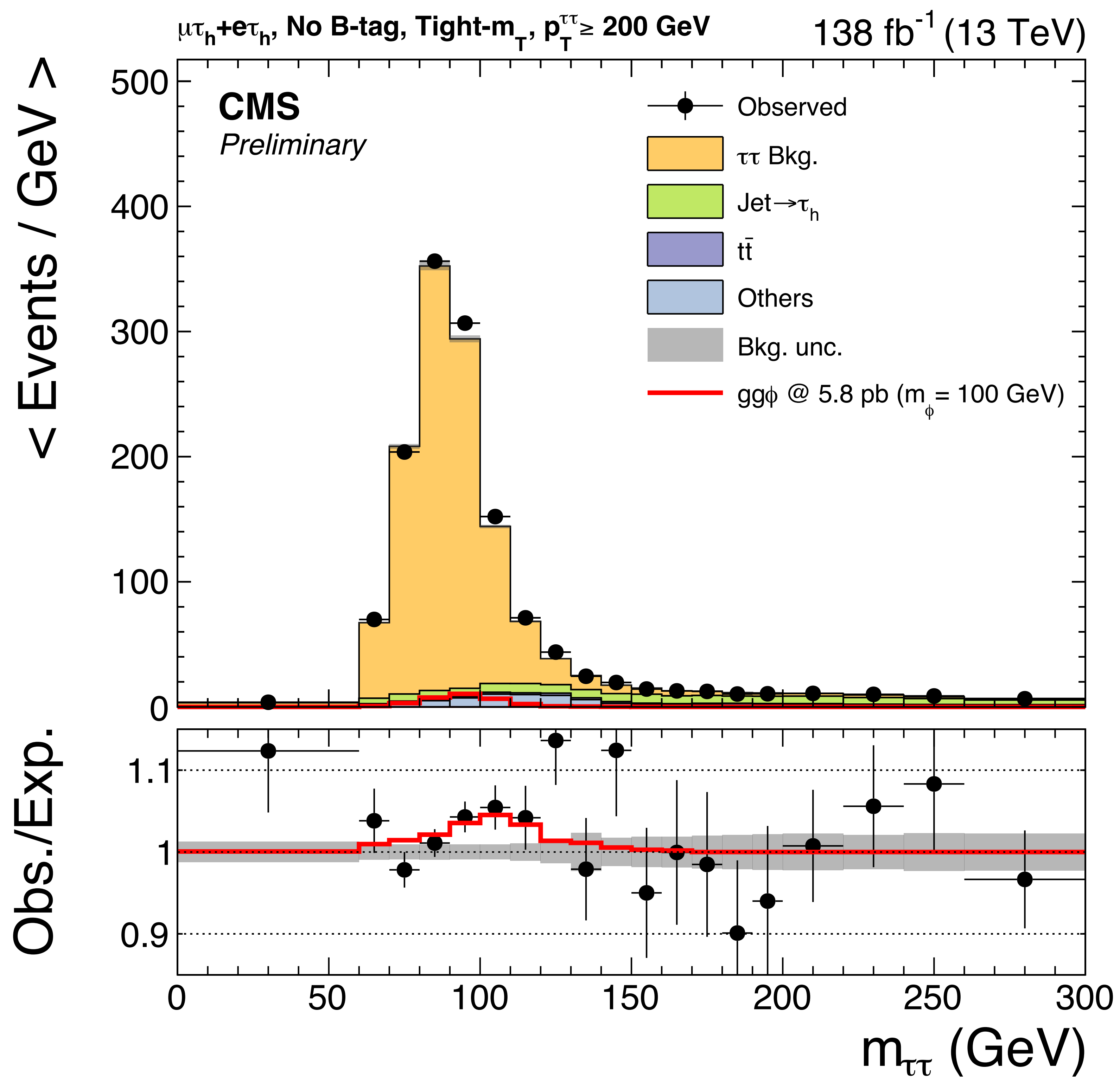
- General-purpose detector will keep providing competitive input to the resolution of flavour anomalies

Discussions

During the course of "ττ excess" search, we found 3σ excess (local) at 100 GeV

(ATLAS has no corresponding measurement; they only look at > 200 GeV)





Apart from this …

any uncovered topics/signatures?

Missing information

on HEP data?

Any connection w.r.t B-physics anomalies?

If this is real, what signatures we should additionally look at?