Search for new resonances decaying two muons in the Bottom Fermion Fusion process

Chang-Seong Moon

Centre for High Energy Physics (CHEP), Kyungpook National University (KNU)

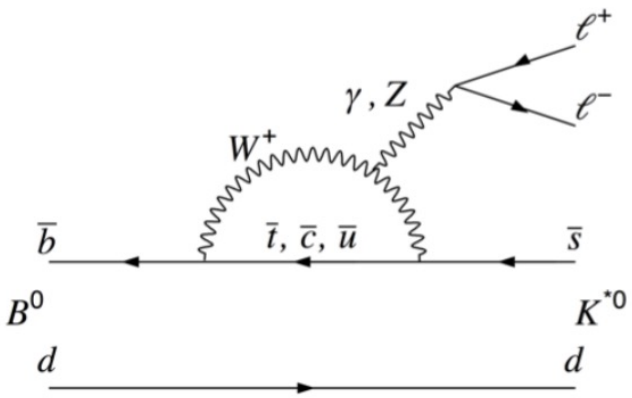
Physics Motivation: B-anomaly

- Anomaly in R_K and R_{K*} observed at LHCb
  - Theory: JHEP 08 (2017) 005, JHEP 1801 (2018) 093
  - LHCb Run 1 result: Phys. Rev. Lett. 113, 151601 (2014)
    JHEP08 (2017) 055

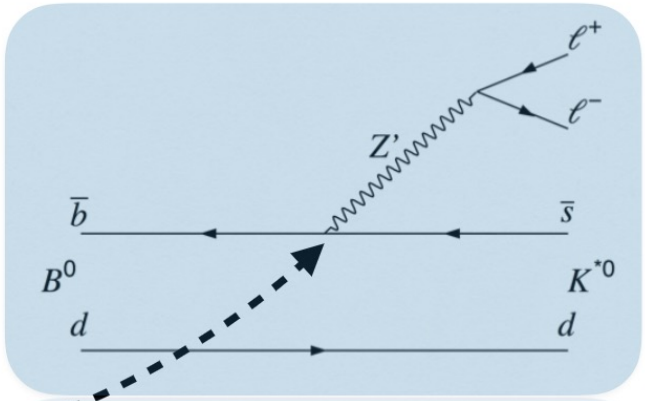
- Deviation at 2.4 – 2.6σ from SM

  → Hint of new Beyond Standard Model

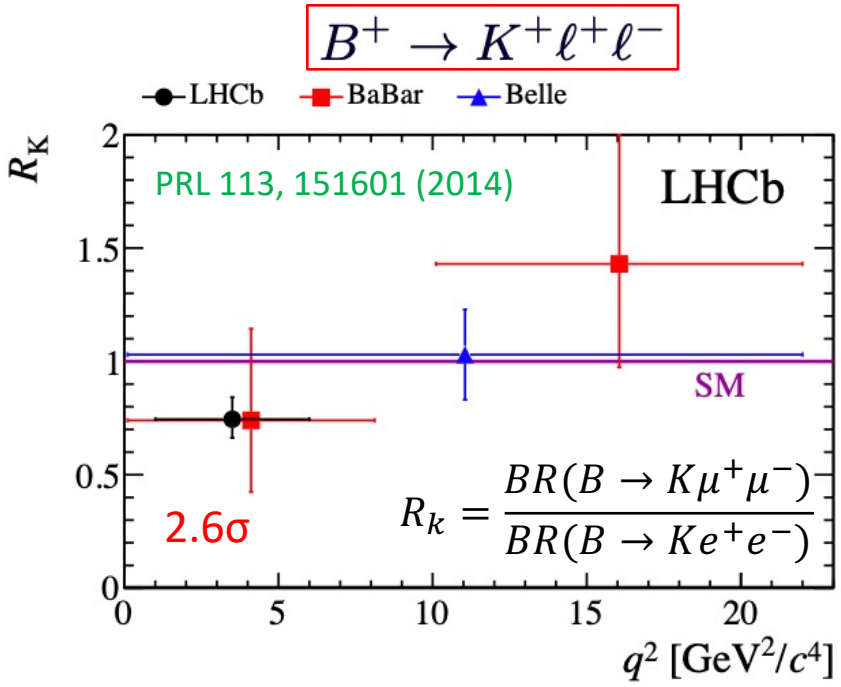
Standard Model (SM)



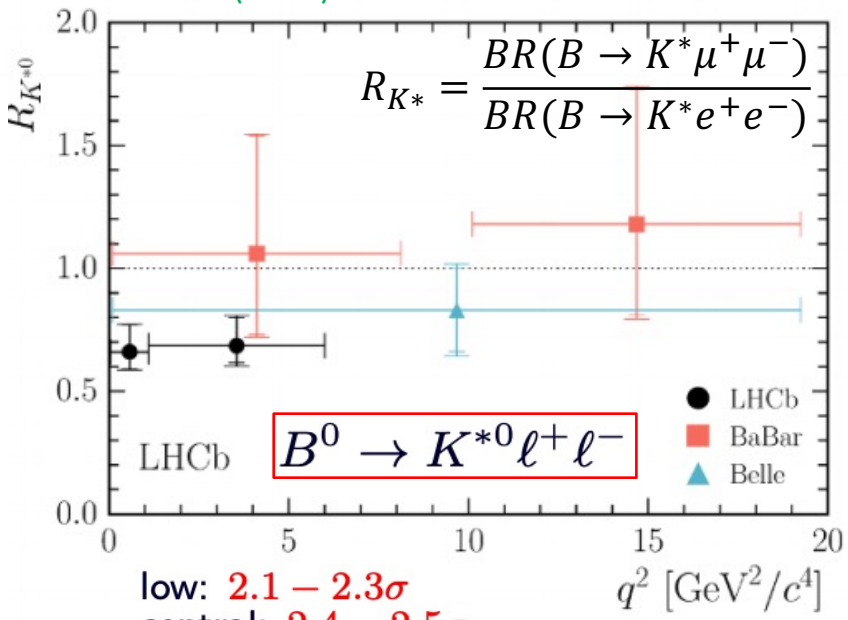
Beyond Standard Model (BSM)



Extra *U(1)*



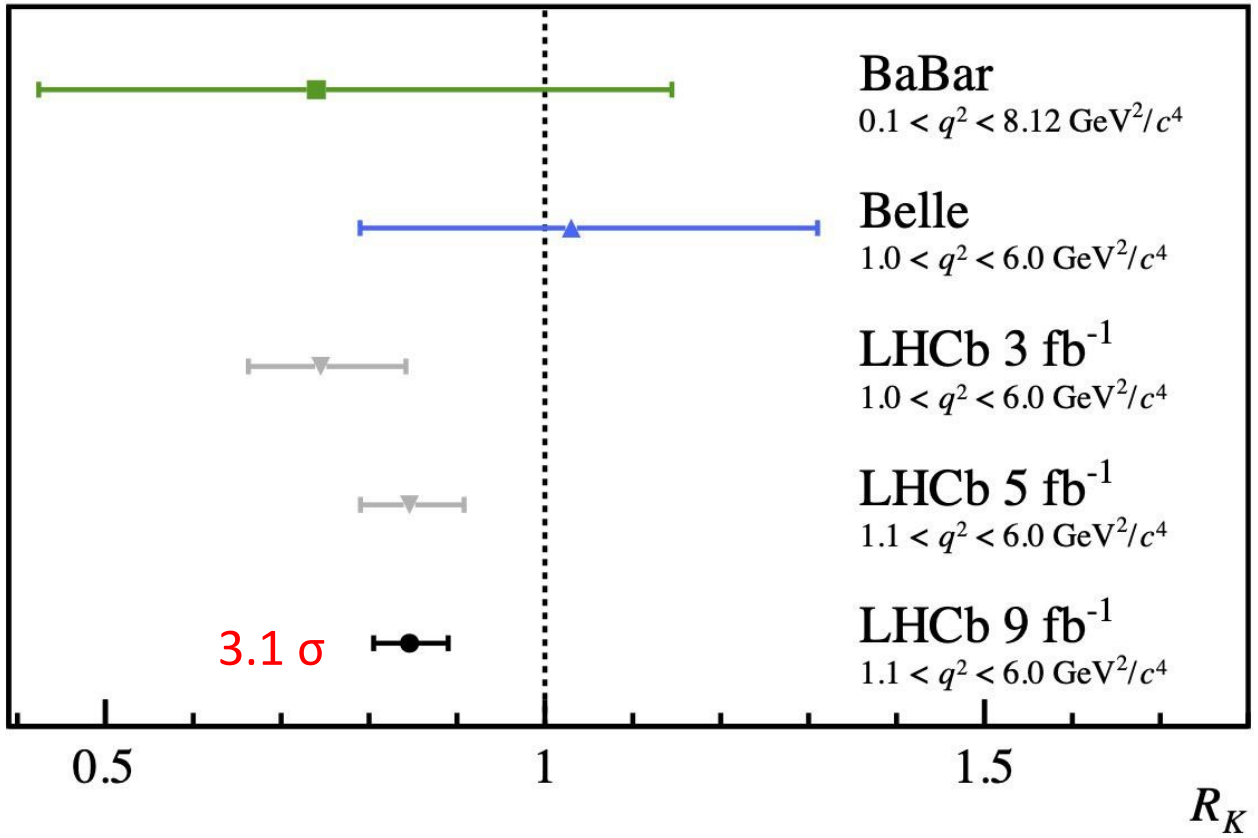
JHEP08 (2017) 055



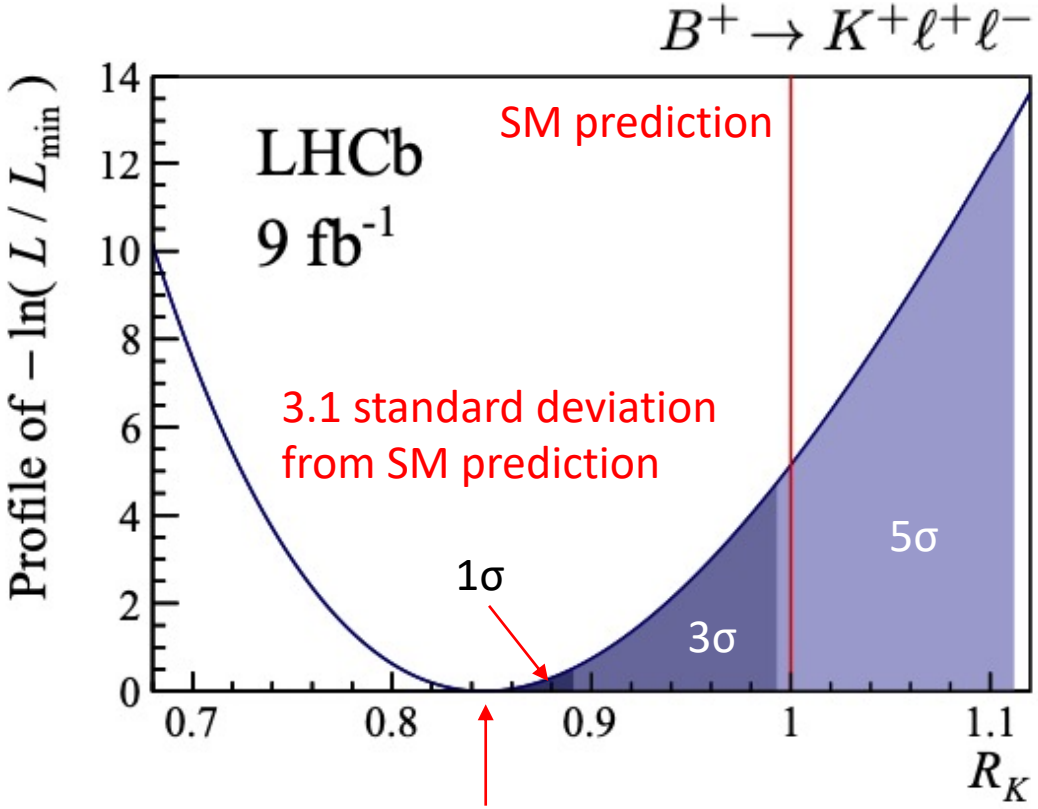
low: $2.1 - 2.3\sigma$
central: $2.4 - 2.5\sigma$

Recent result from LHCb

Comparison between R_K measurements. The measurements by the BaBar and Belle collaborations combine $B^+ \to K^+ \ell^+ \ell^-$ and $B^0 \to K_S^0 \ell^+ \ell^-$ decays. The previous LHCb measurements and the new result, which supersedes them, are also shown.



Likelihood function from the fit to the nonresonant $B^+ \to K^+ \ell^+ \ell^-$ candidates profiled as a function of R_K



$$R_K = 0.846^{+0.044}_{-0.041}$$

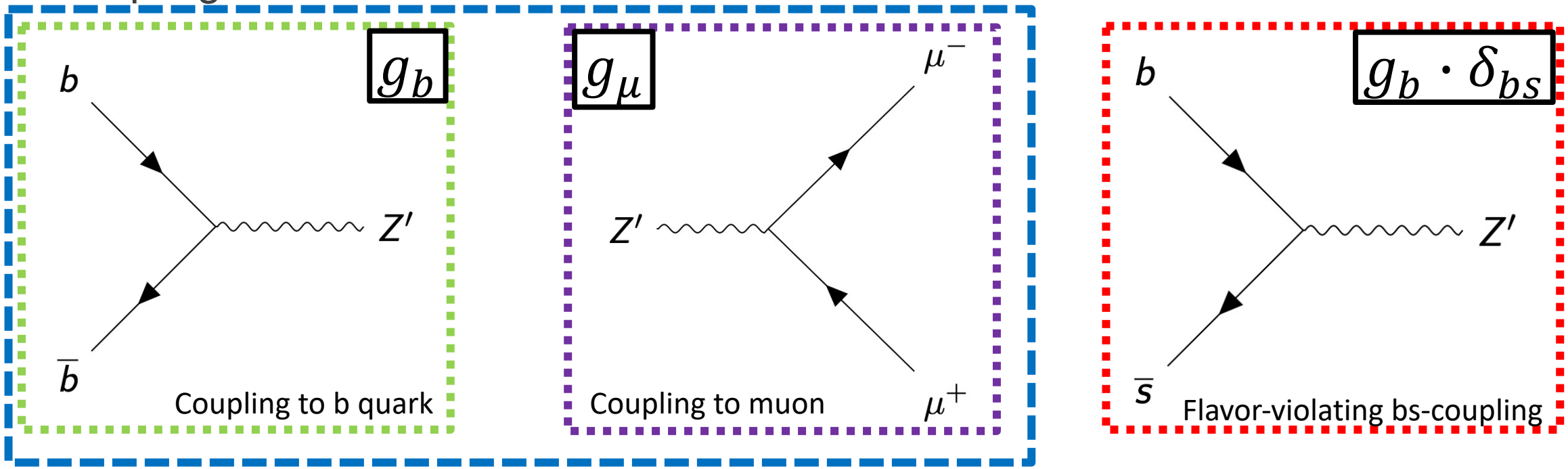
arXiv 2103.11769

A new heavy gauge boson Z'

- We adopt a new heavy neutral gauge boson Z' to explain the anomaly
- **Minimal Lagrangian** PRD 97 (2018) 075035

$$\mathcal{L} \supset Z'_\alpha \left[g_\mu \bar{\mu}\gamma^\alpha \mu + g_b \sum_{q=t,b} \bar{b}\gamma^\alpha P_L q + \left(g_b \delta_{bs} \bar{s}\gamma^\alpha P_L b + h.c. \right) \right]$$

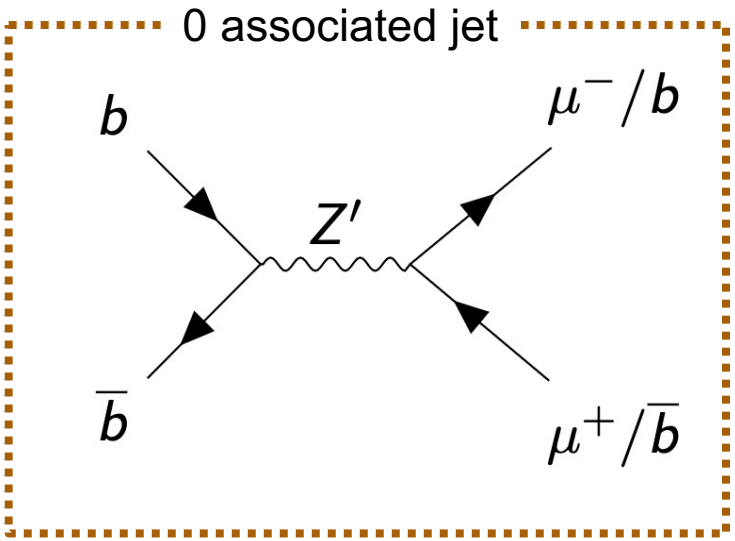
- Couplings

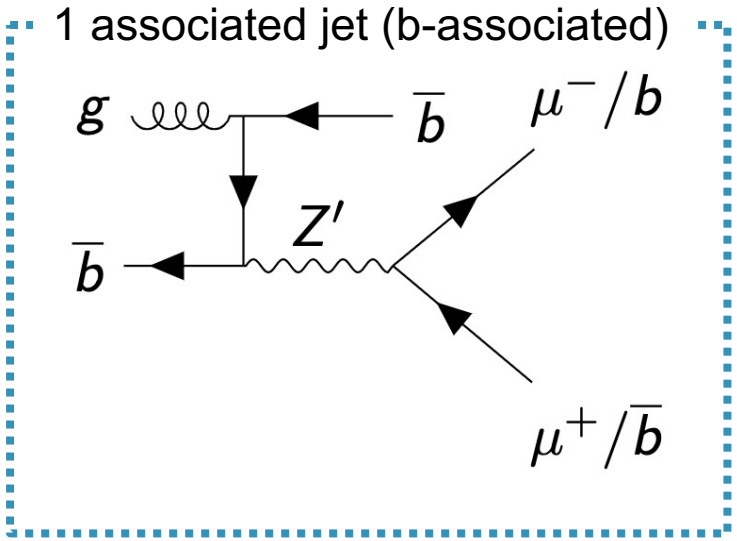


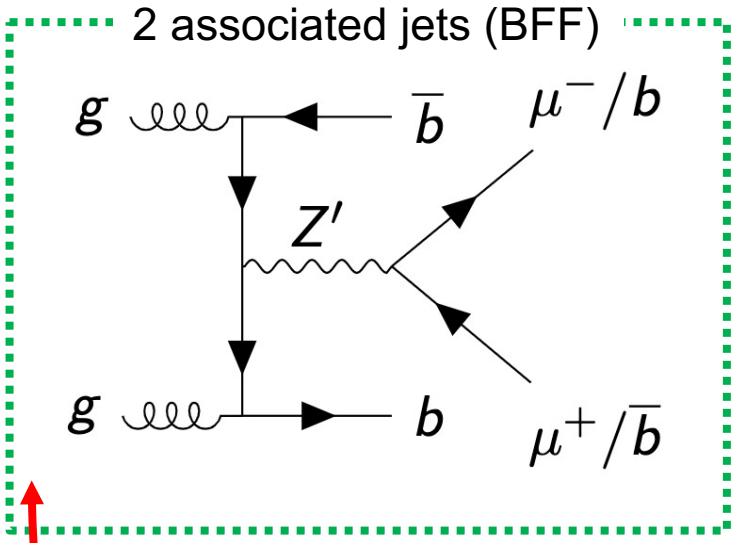
Search new processes with two couplings at CMS

Bottom Fermion Fusion (BFF) Z' Model

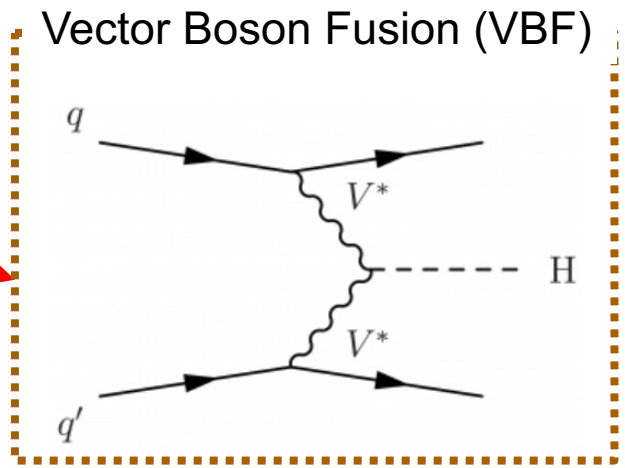
- **Production at the LHC**







Similar form of Feynman diagram!



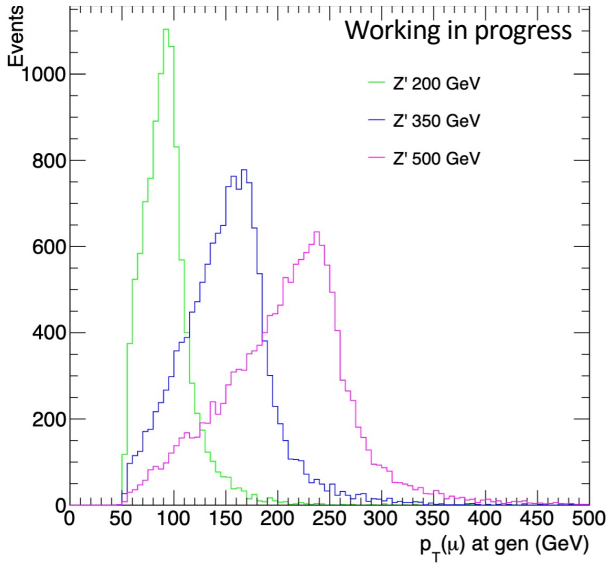
- We call Z' production with 2 associated jets as "Bottom Fermion Fusion" since it looks similar to VBF
- We are generally interested in low mass regions unlikely to other inclusive studies due to:
  - ✓ signal acceptance traded for higher background rejection
  - ✓ b contribution

Signal Kinematics

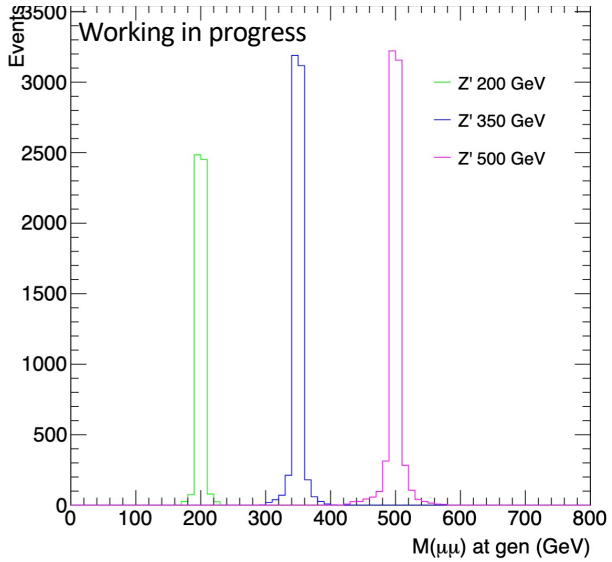
- Low mass Z' region search
- Z' mass points
  - **200**, 250, 300, **350**, 400, 450, **500** GeV
- Generator level & Reco level kinematics
  - Muon p_T
  - Invariant mass of dimuon
- Check signal sample generation
- Higher p_T and invariant mass with higher Z' mass

Generator level

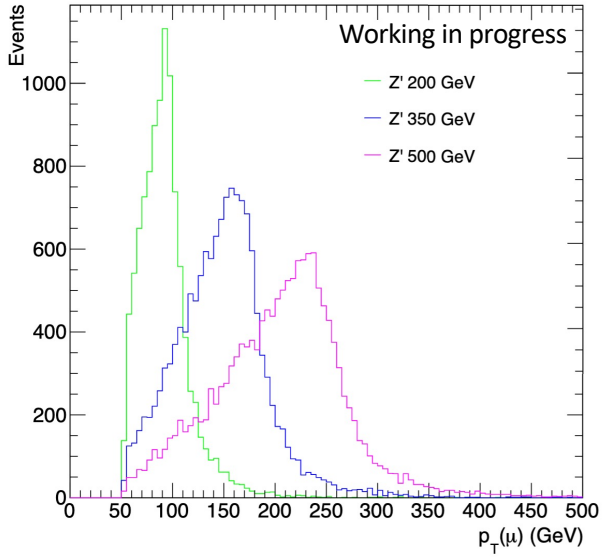
Muon p_T

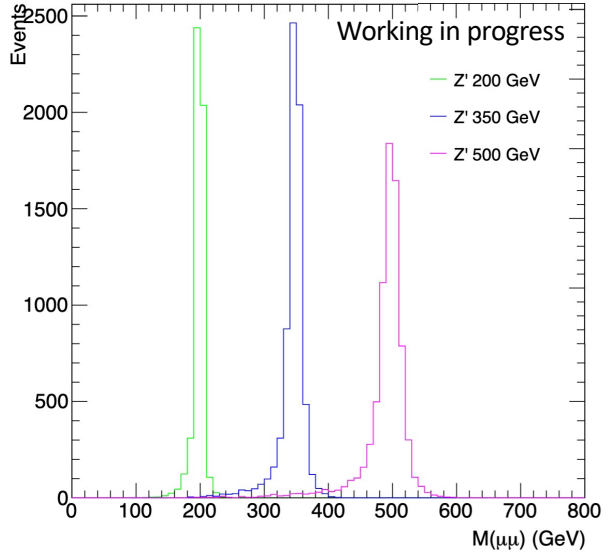


Invariant mass of dimuon



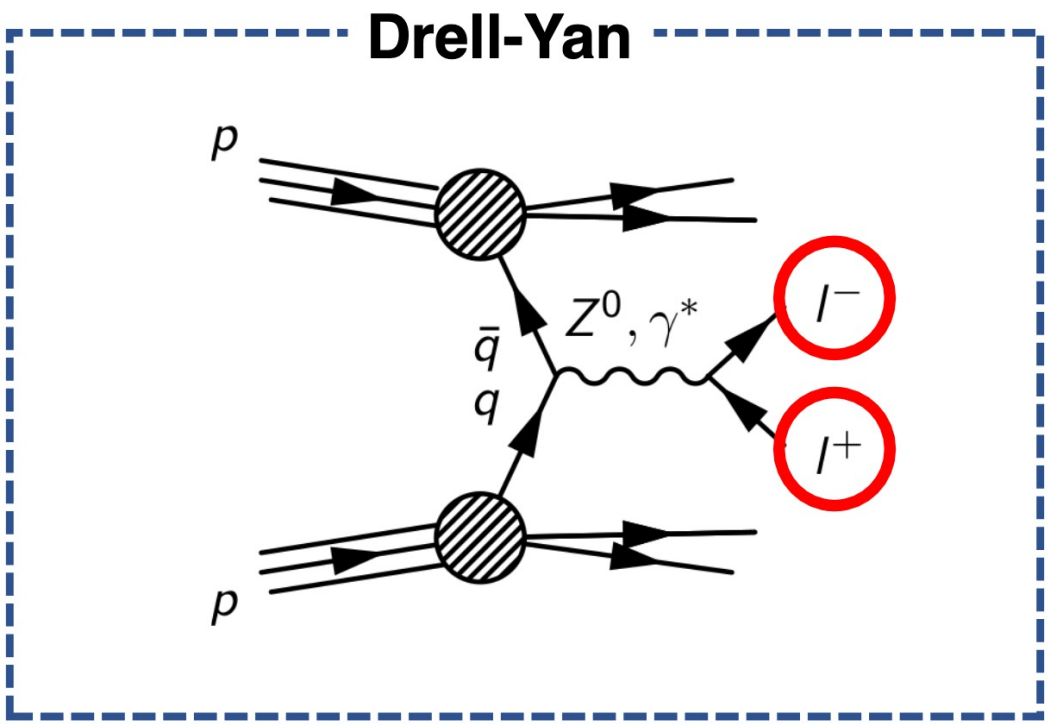
Reco level

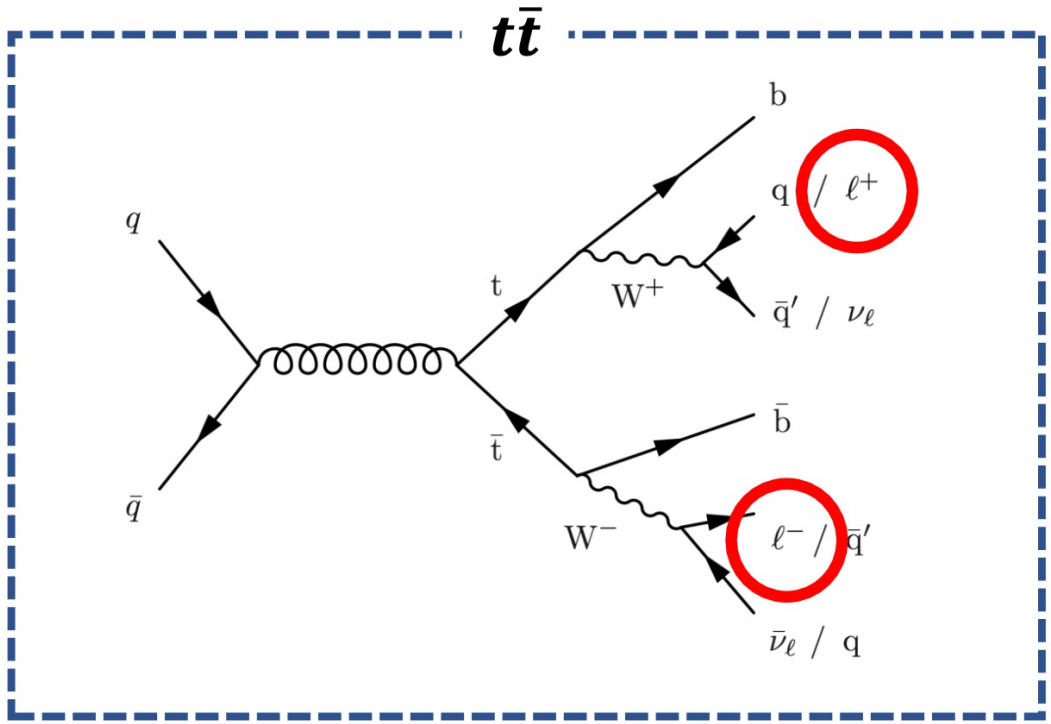




Main Backgrounds

- Possible to generate dimuon signal similar to $Z' \to \mu\mu$ production





Different invariant mass of two leptons

High E_T^{miss}

- We use specialized **kinematic cuts** to reduce backgrounds

Triggers & Physics Object IDs

- **Datasets:** SingleMuon/DoubleEG
- **Triggers:**

	μ
2016	HLT_Mu50 or HLT_TkMu50
2017	HLT_Mu50 or HLT_TkMu100 or HLT_OldMu100
2018	HLT_Mu50 or HLT_TkMu100 or HLT_OldMu100
	ee
2016	HLT_DoubleEle33_CaloIdL_MW or HLT_DoubleEle33_CaloIdL_GsfTrkIdVL
2017	HLT_DoubleEle25_CaloIdL_MW
2018	HLT_DoubleEle25_CaloIdL_MW

- **Physics Object IDs**

Muons	Electrons	Jets
✓ TightID ✓ $p_T > 54$ GeV ✓ $\lvert\eta\rvert < 2.4$ ✓ Tracker Iso < 0.1	✓ HEEP (v7.0) ID (high energy electron identification algorithm) ✓ $p_T > 54$ GeV ✓ $\lvert\eta\rvert < 2.5$ ✓ $\lvert\Delta R(e,\mu)\rvert > 0.1$	✓ Loose jet ID ✓ Tight pileup ID, if $p_T < 50$ GeV ✓ $\lvert\eta\rvert < 5$ ✓ $\lvert\Delta R(jet,\mu)\rvert > 0.4$

+

non-b jets
✓ $p_T > 30$ GeV
b-jets
✓ $p_T > 20$ GeV ✓ DeepCSV medium WP

Signal & Control Regions

- "**ABCD**" method for a data driven background estimation

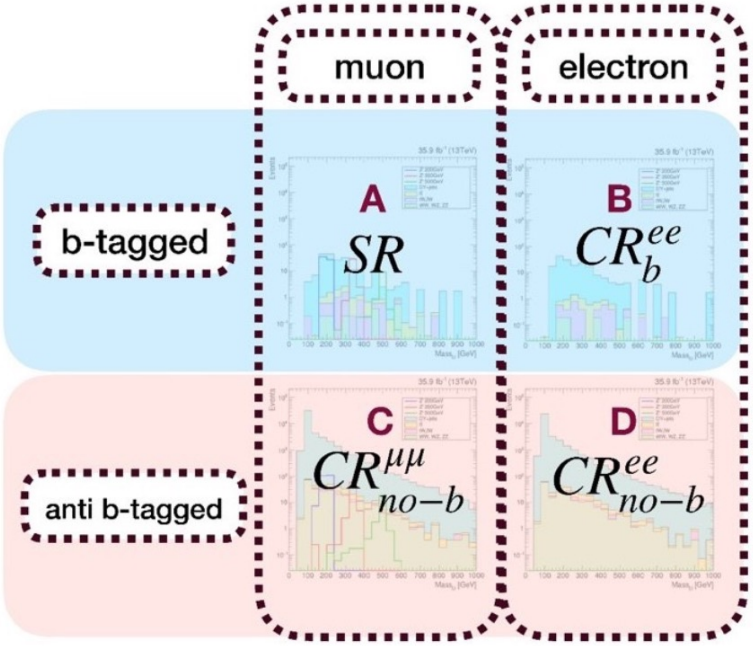
N_b	N_{jets}^{all}	$\mu\mu$	$e\mu$	ee
≥ 1	2	SR($\geq$ 1b,2j)	$CR_{t\bar{t}}$($\geq$ 1b,2j)	$CR_{DY+t\bar{t}}$($\geq$ 1b,2j)
0	2	$CR^{\mu\mu}_{DY+t\bar{t}}$(2j)	$CR_{t\bar{t}}$(2j)	$CR^{ee}_{DY+t\bar{t}}$(2j)
1	1	SR(1b)	$CR_{tW+t\bar{t}}$(1b)	$CR_{tW+DY+t\bar{t}}$(1b)
0	1	$CR^{\mu\mu}_{tW+DY+t\bar{t}}$(1j)	$CR_{tW+t\bar{t}}$(1j)	$CR^{ee}_{tW+DY+t\bar{t}}$(1j)

SR1

SR2

- Background estimation with ABCD
  - Estimate backgrounds in SR
  - SR yield from CR yields ($A = B\frac{C}{D}$)
  - Cross check signal region

$$n_{SR} = n_{CR_b^{ee}} \frac{n_{CR^{\mu\mu}_{no-b}}}{n_{CR^{ee}_{no-b}}}$$

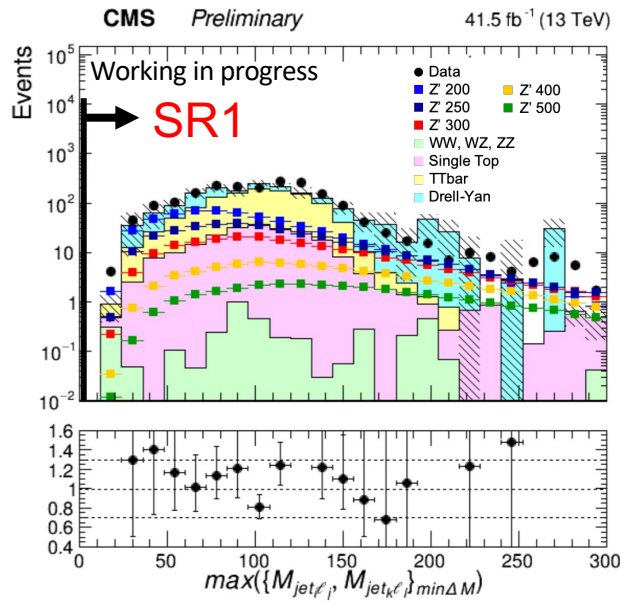


- Selection optimization for each region
  - TMB, normalized MET, $H_T - L_T$
  - PU jet ID & b-tagging WP

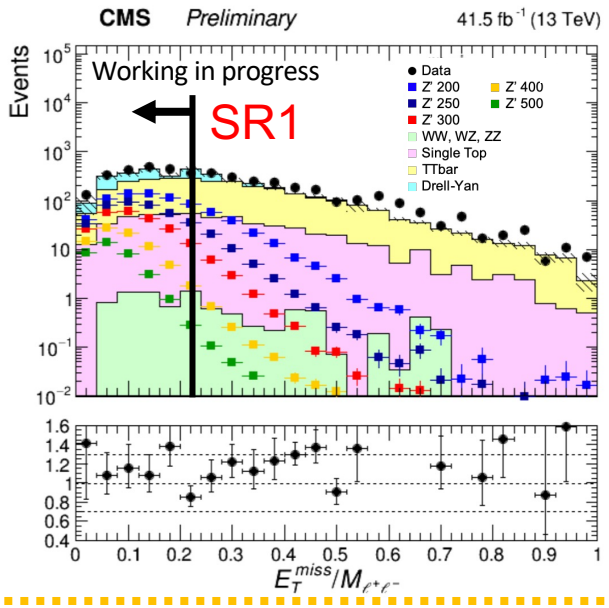
Analysis Strategy: BFF Specialized Kinematic Cuts

- Ask for **two opposite sign muons**
- At least two jets with at least one b-tagged → Help to remove Drell-Yan events
- Apply **top mass bound (TMB)** and **MET** cuts → Reduce top pair contribution
- Select events with **high leptonic activity (H_T v.s. L_T)** $H_T = \sum p_T^{jet}$ and $L_T = \sum p_T^{lepton}$

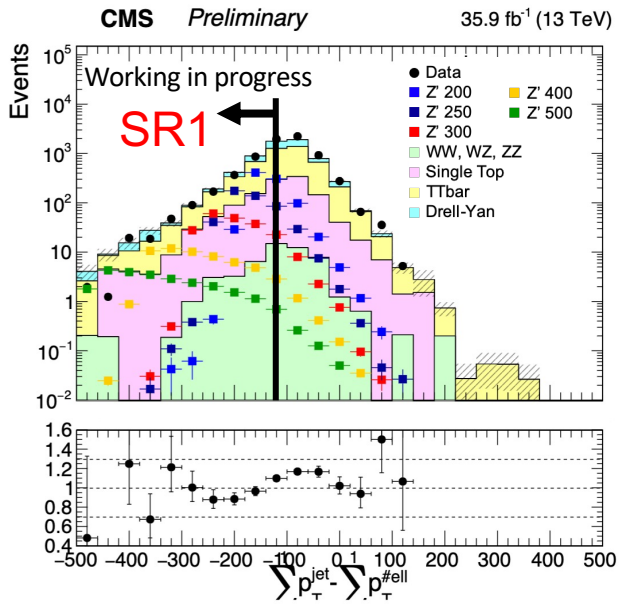
TMB



Normalized MET ($\vec{p}_T^{miss}/m_{\mu\mu}$)



$H_T - L_T$



- Data
- Z' 200
- Z' 250
- Z' 300
- Z' 400
- Z' 500
- WW, WZ, ZZ
- Single Top
- TTbar
- Drell-Yan

- **Signal selection (SR1)**
  - TMB > 0 GeV
  - Normalized MET < 0.22
  - $H_T - L_T$ < -120
- **Signal selection (SR2)**
  - TMB > 170 GeV
  - Normalized MET < 0.22
  - $H_T - L_T$ < -60

PU jet ID & b-tagging WP Optimization

- Drell-Yan, TTbar and Z' sample
- Optimize for:
  - Significance
  - Sufficient statistics

Pileup jet ID

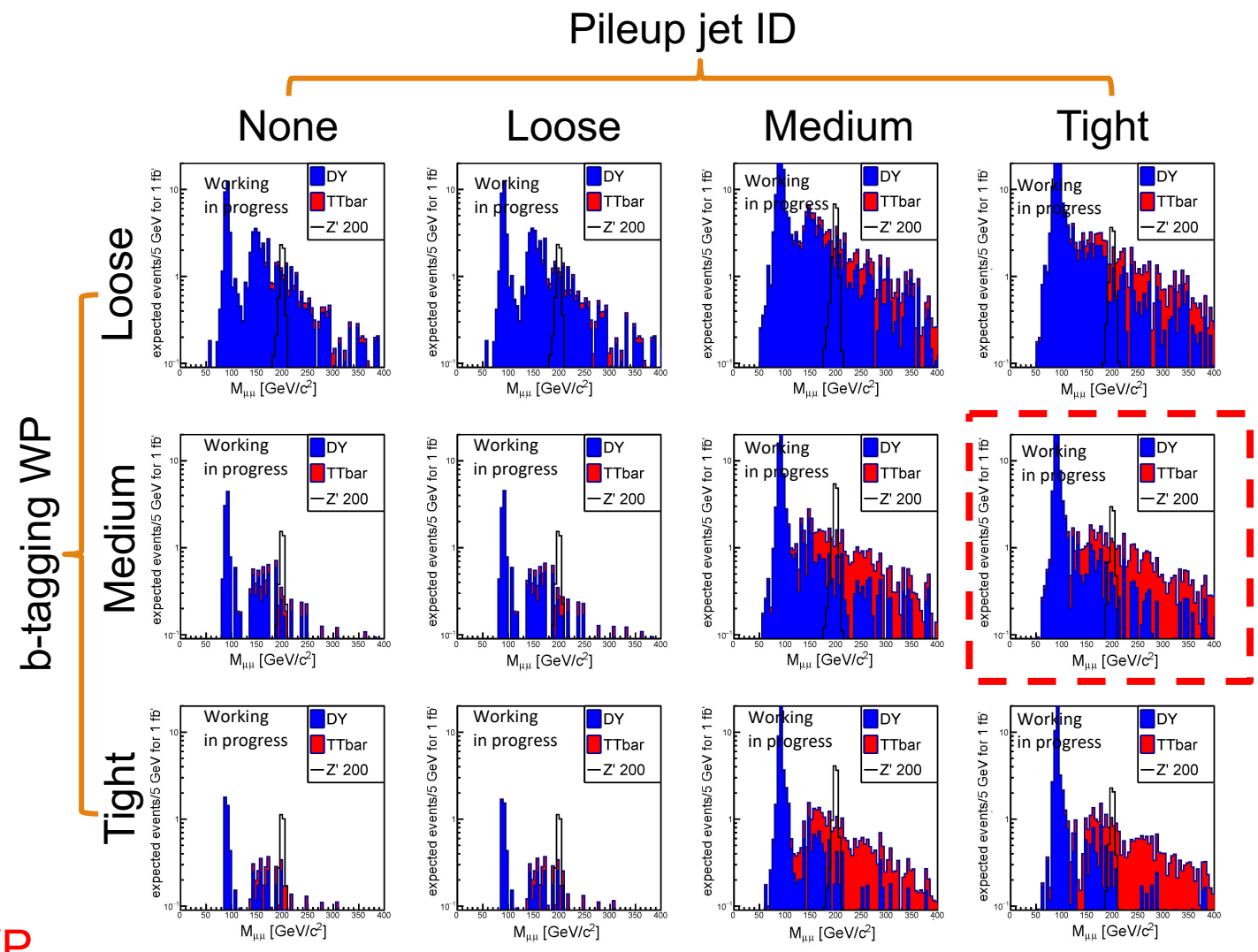
b-tagging WP

	Medium	Tight
Medium	14.9	**17.3**
Tight	12.0	11.1

Table: 1 jet CR/SR in Z' peak region

- Best fit

→ tight PU jet ID & medium b-tagging WP



Dimuon mass distributions in SR(1b + 1b/j)

Summary & Outlook

Summary

- New heavy neutral gauge boson Z' model
  - Anomalies in B meson decays - one of hot topics
  - Can be explained with Z' coupling to b, s and muon
- Background estimation
  - Kinematic cuts optimization
  - Selection optimization
  - MET Filters
  - Testing fits and ABCD predictions
- Systematics are already implemented

Outlook

- Expected limits
- Finalize AN
- Aim to pre-approval

Available on the CMS information server

CMS AN-18-258

CMS Draft Analysis Note

The content of this note is intended for CMS internal use and distribution only

2021/05/21
Archive Hash: eawxw314
Archive Date: 2021/01/21

Search for new resonances produced by bottom fermion fusion in dimuon final state with Run II CMS data

Mykhailo Dalchenko[1], Andrea Delgado[1], Sunil Dogra[2], Ricardo Eusebi[1], Teruki Kamon[1], Daekwon Kim[2], Minsuk Kim[4], Jason Lee[3], Chang-Seong Moon[2], Ryan Mueller[1], Denis Rathjens[1], and Ian James Watson[3]

[1] Texas A&M University
[2] Kyungpook National University
[3] University of Seoul
[4] Helsinki Institute of Physics

Abstract

A search is presented for a new boson decaying into two muons associated with one or more b jets. The analysis is performed using data corresponding to an integrated luminosity of 137 fb^{-1} collected in 2016-2018 with the CMS detector in proton-proton collisions at $\sqrt{s}$ = 13 TeV.