Search for Prompt Production of a GeV scale Dimuon Resonance Using Data Scouting at CMS

Zhangqier Wang

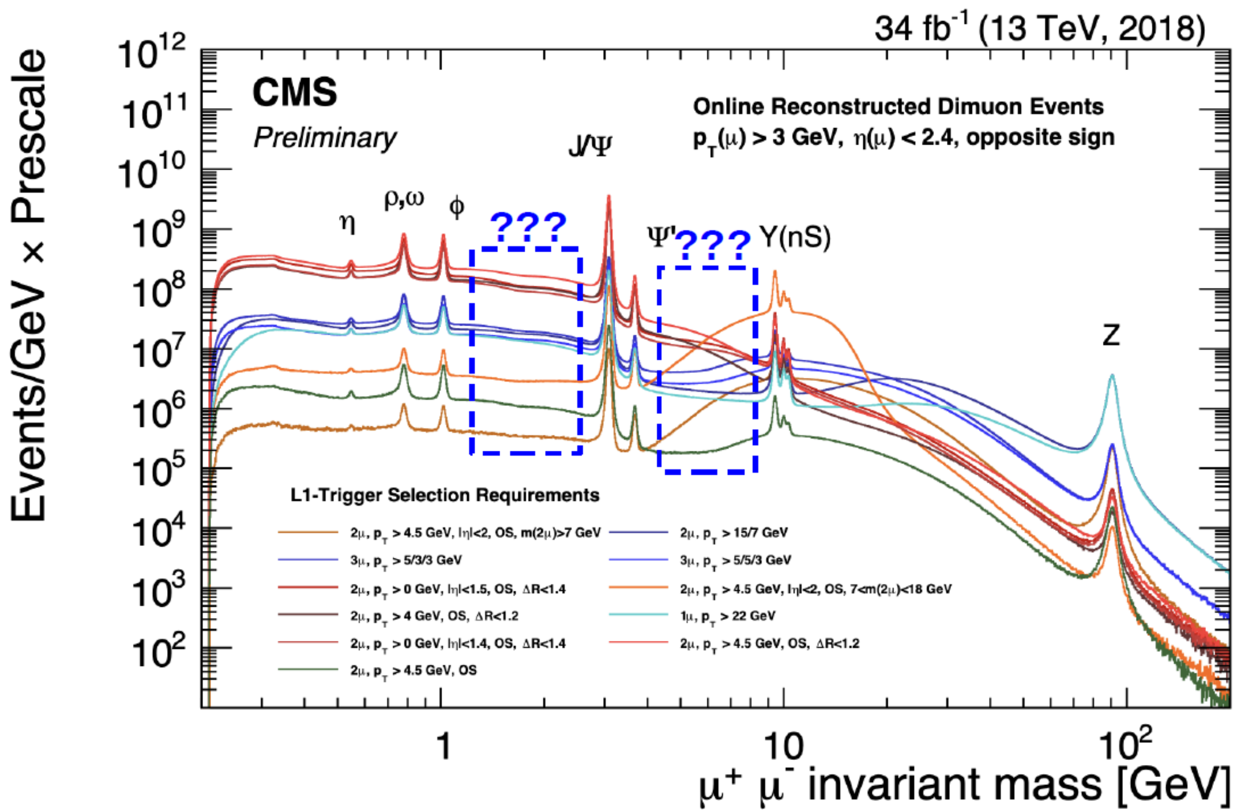
on behalf of the CMS Collaboration

Phenomenology 2023

May 8th 2023

Dimuon Resonances

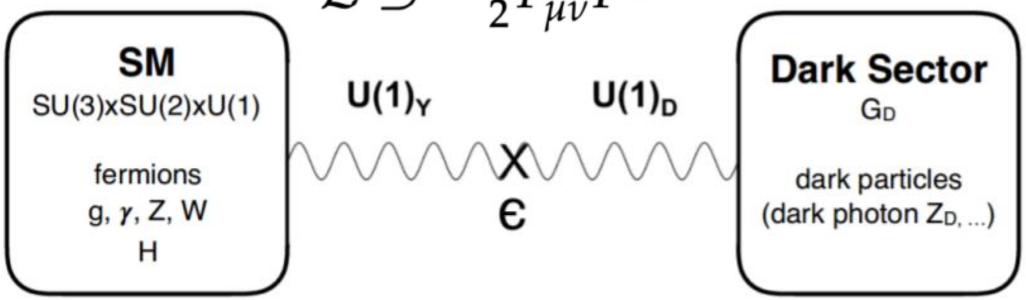
- Historically, several new particles were discovered through the resonant particle pair production
- Search for a narrow dimuon resonance at low mass using Run II scouting data recorded by the CMS

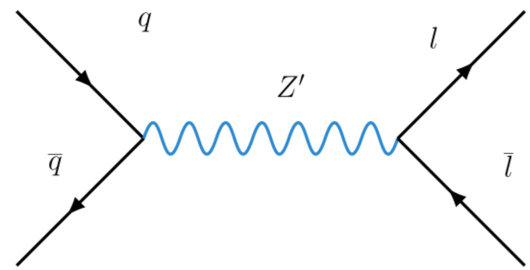


Why GeV Scale ?

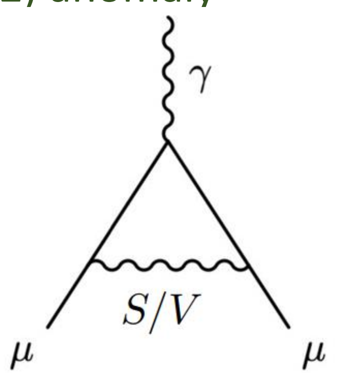
- New states at the GeV scale are motivated from several perspectives.
  - Vector portal interaction in thermal dark matter models

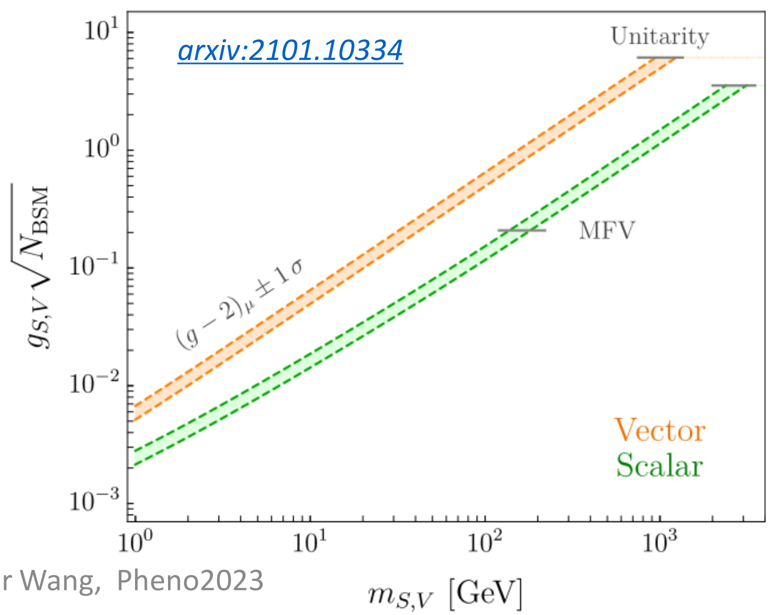
$$\mathcal{L} \supset -\frac{\varepsilon}{2} F_{\mu\nu} F'^{\mu\nu}$$





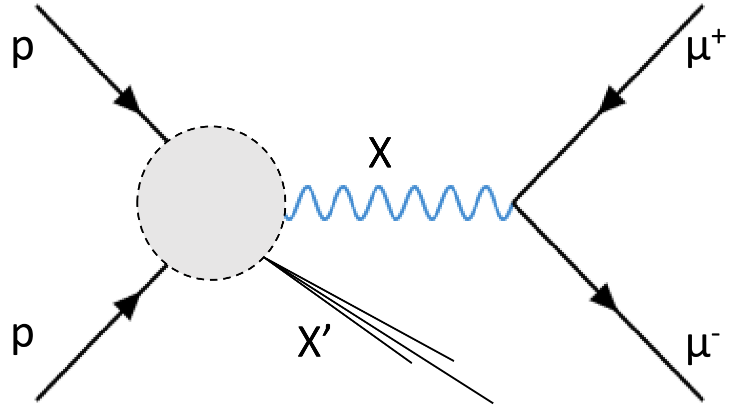
- New scalar or vector coupling to muons could help explain muon (g-2) anomaly





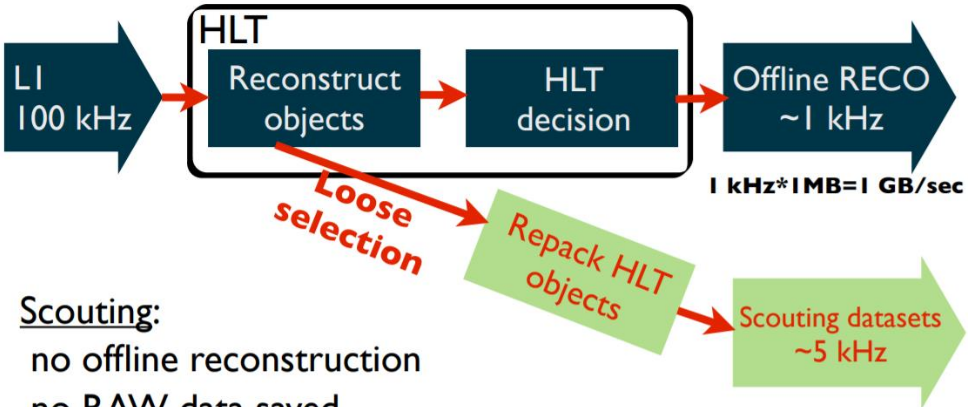
Analysis Strategy

- Searching for a light (1-8 GeV) BSM mediator decaying into a pair of opposite sign muons using Run II scouting data collected by CMS
- Event selection optimized for signal (prompt dimuon resonance)
- Bump hunt on the dimuon mass using analytical signal and bkg. Pdfs
- Measure integrated luminosity, set model independent limit on $\sigma \times B \times \alpha$
- Compute $\sigma \times B \times \alpha$ in specific models to set limits on model parameters

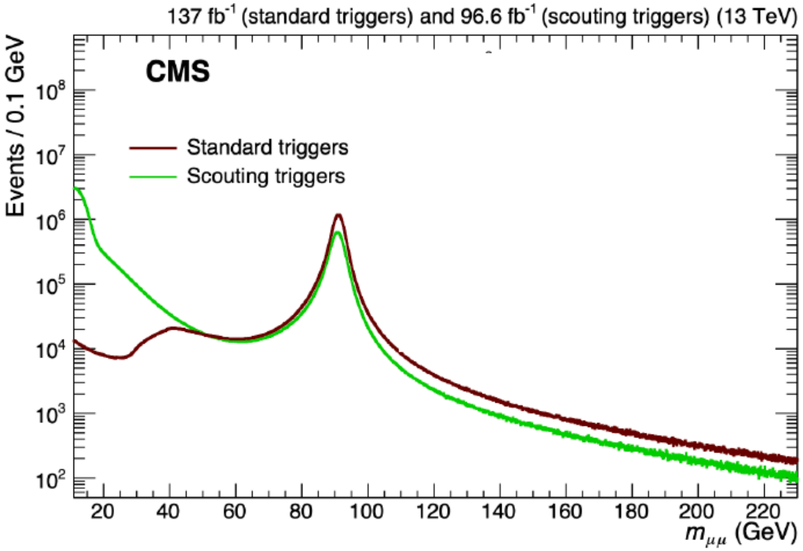


What is “Data Scouting”?

- Di-muon data scouting
  - reconstructed at the high-level trigger (HLT) stage.



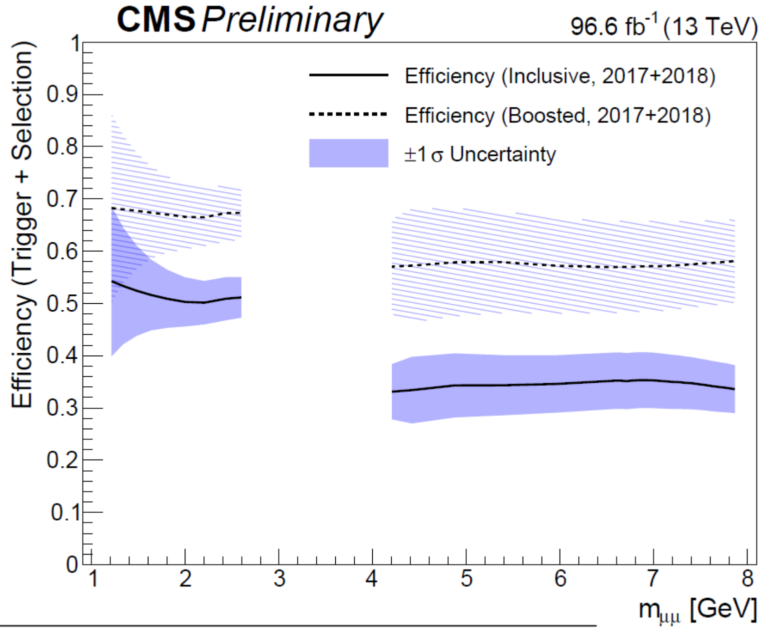
Scouting:
no offline reconstruction
no RAW data saved



Reduced events size by storing only essential information and increasing efficiency for dimuons.

Event Selection

- Target prompt production, require transverse displacement L<0.2cm
  - $p_T^\mu > 4GeV, |\eta^\mu| < 1.9$
- Two signal categories targeting inclusive and boosted production
  - Optimized for different production mechanisms (DY or ggF)
- Two data-driven muon MVA IDs
  - OS J/ψ and Υ events as signal
  - SS events as background

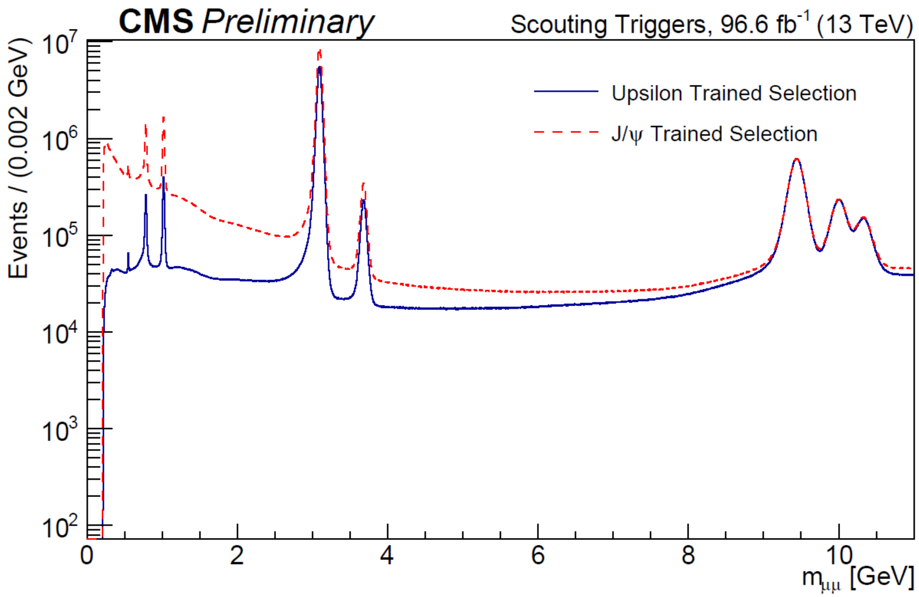


Preselection	$L < 0.2$ cm, $\|\eta^\mu\| < 1.9$, Opposite sign			
Signal	Inclusive		Boosted	
Selection	$m_{\mu\mu} < 4$ GeV	$m_{\mu\mu} > 4$ GeV	$m_{\mu\mu} < 4$ GeV	$m_{\mu\mu} > 4$ GeV
p_T^μ	> 4 GeV		> 5 GeV	
muon ID	J/ψ ID	Υ ID	J/ψ ID	J/ψ ID
Vertex	$L/\sigma_L < 3.5$	$L < 0.015$ cm	$L/\sigma_L < 3.5$	$L/\sigma_L < 3.5$
$p_T^{\mu\mu}$	-	-	> 35 GeV	> 20 GeV

Signal and Background Modeling

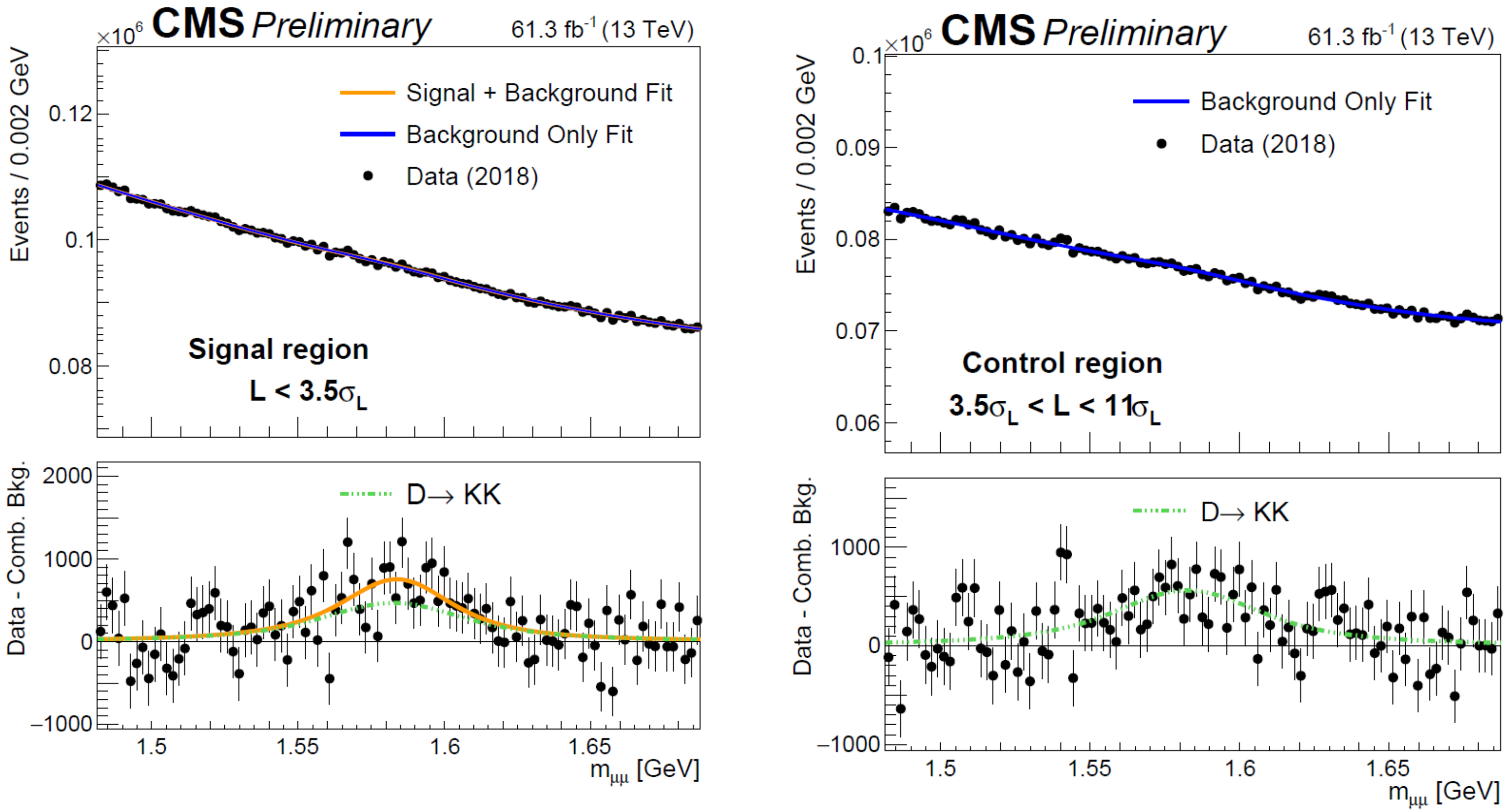
- Pick mass window spanning 5 times the mass resolution around signal
- Signal modeled from fits to SM resonances
  - Double Crystal Ball + Gaussian
  - 20% uncertainty on resolution
- Combinatorial background is modeled using 4th order Bernstein polynomial and other 3 empirical functions (discrete profiling method).
  - checked with toy datasets to have negligible bias

arXiv:1408.6865



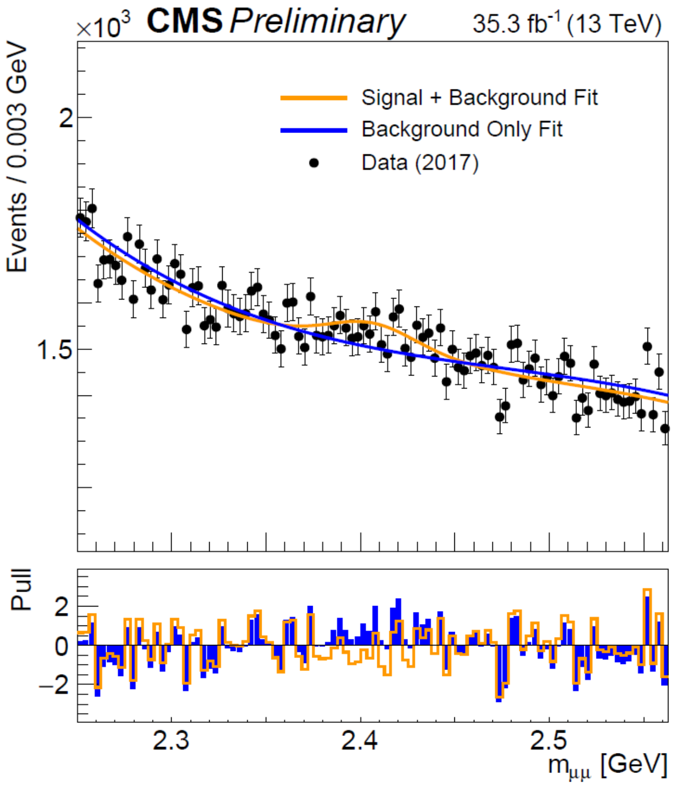
Peaking Backgrounds

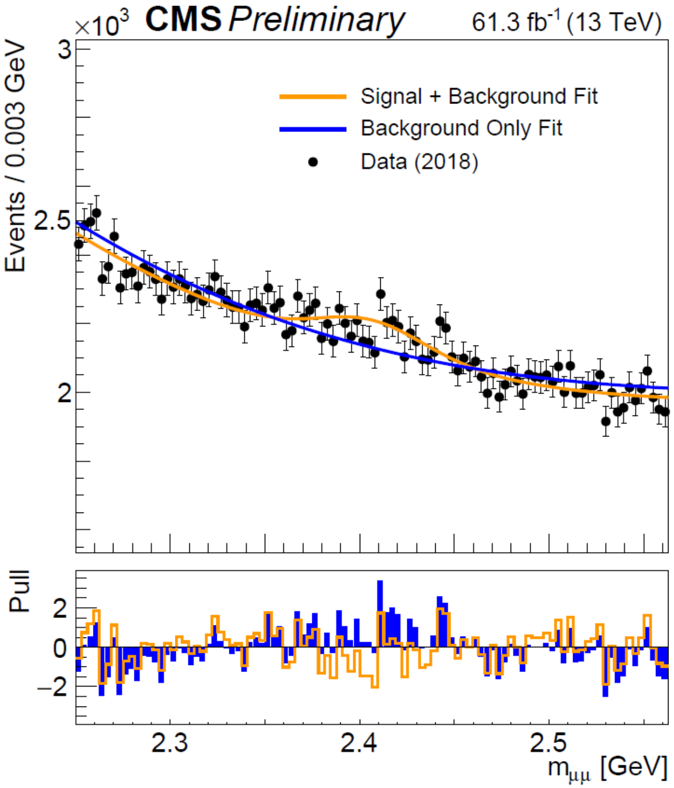
- Peaking backgrounds ($D^0 \to KK, K\pi$) estimated from control regions with inverted L/σ_L selection (transfer factors estimated from simulation)
  - Uncertainty on transfer factors 20-25% estimated using J/Ψ data/MC



Largest Excess

- The largest excess is at 2.41 GeV in the boosted category
  - 3.2σ local significance, 1.3σ global significance
  - Coincides with the 3.1σ local excess at 2.42 GeV in one event category (X+b, 10<pT(X)<20 GeV) from LHCb measurement. *JHEP 10 (2020) 156*

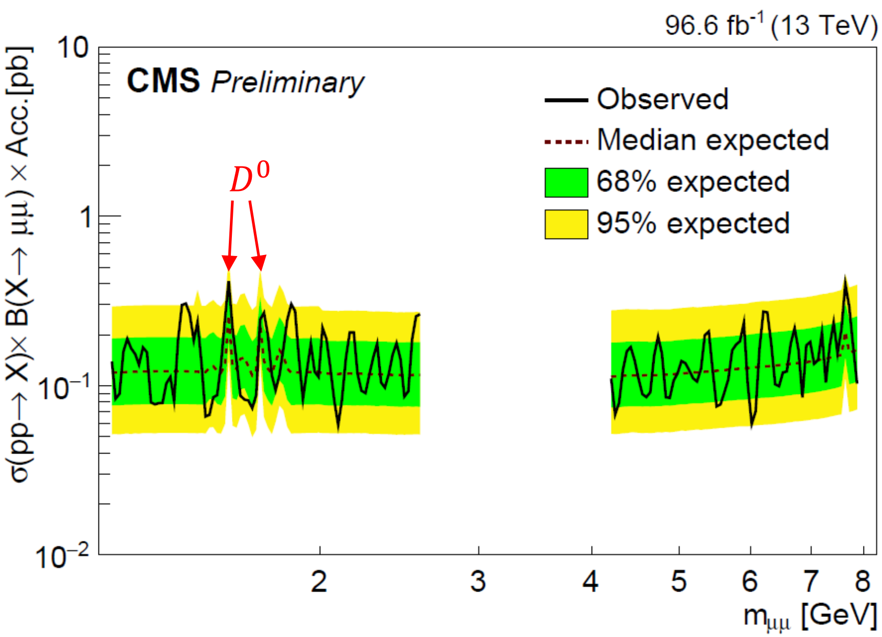




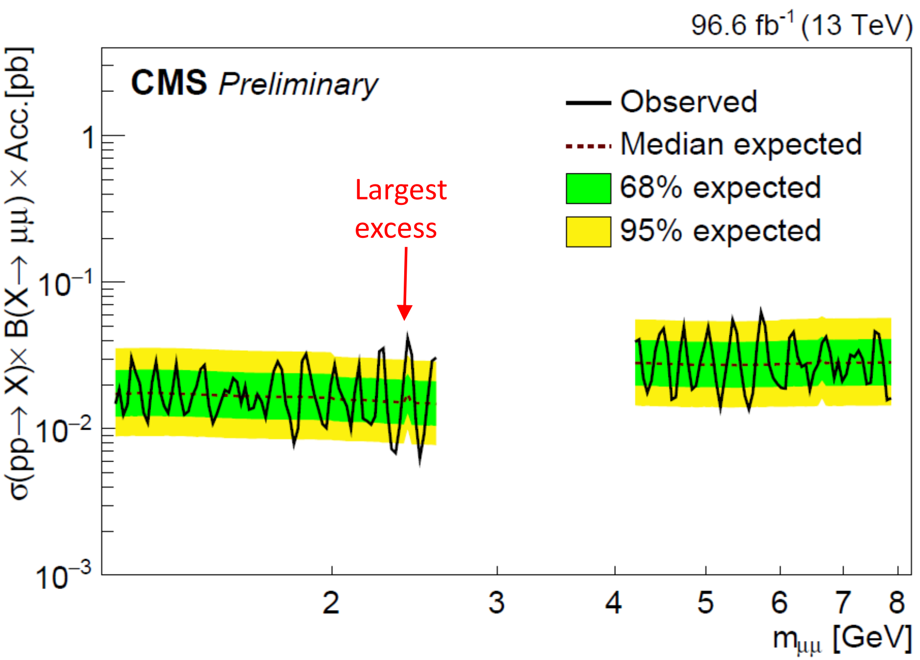
Model Independent Limit

- Main results are model independent limits on $\sigma \times B \times \alpha$ for the inclusive and boosted selections
- Limit calculation includes all experimental uncertainties

Inclusive Selection

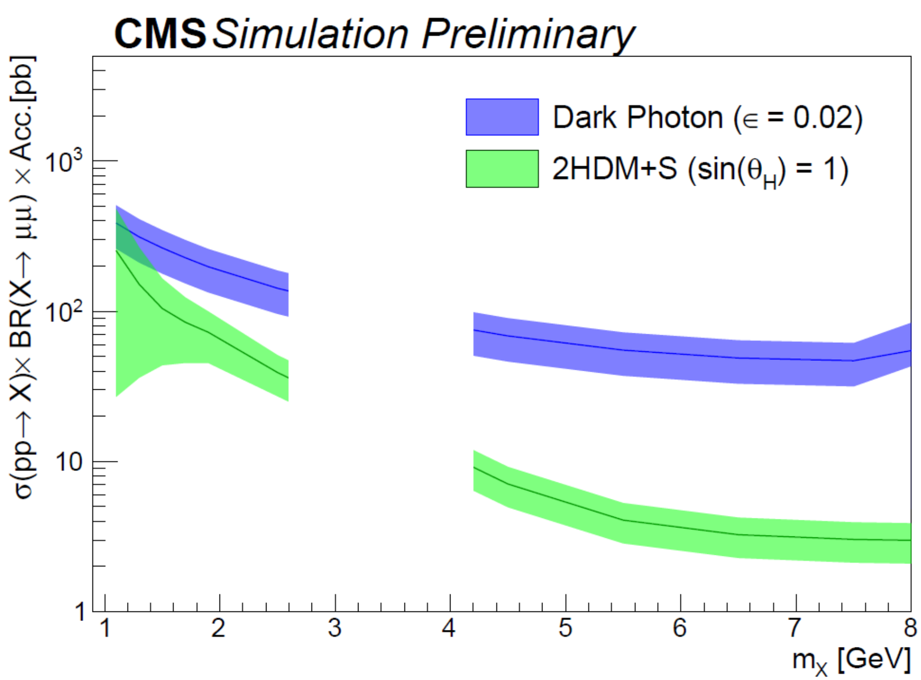


Boosted Selection



Model Dependent Limit

- We choose two specific models to constrain model parameters
  - DY production of vector boson (dark photon)
  - Gluon fusion production of pseudoscalar (2HDM+S)
- Relies on theoretical calculations of cross sections, branching ratio, and experimental acceptance



$$\sigma_{\mathrm{pp}\to \mathrm{Z_D}} \cdot \epsilon^2 \cdot \mathcal{B} \cdot A = \sigma_{\mathrm{limit}}$$

- Dark photon cross section and BR calculated with MadGraph
- NNLO corrections and acceptance from DYTurbo *EPJC 80 (2020) 251*

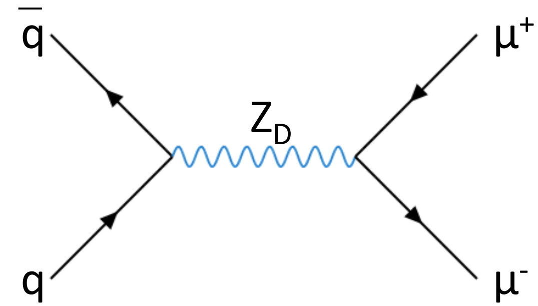
$$\sigma_{\mathrm{pp}\to a} \cdot \sin^2(\theta_{\mathrm{H}}) \cdot \mathcal{B} \cdot A = \sigma_{\mathrm{limit}}$$

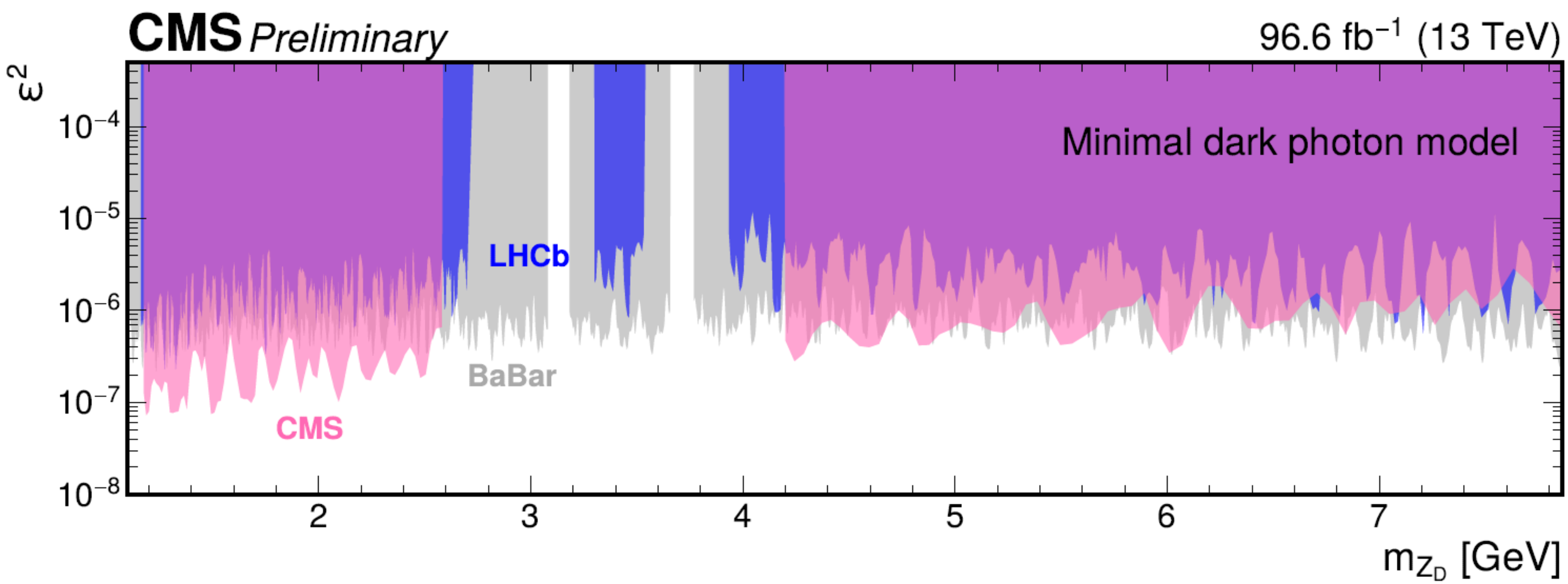
- Gluon fusion cross section from HIGLU, BR from *JHEP 03 (2018) 178*
- Acceptance from MadGraph and Pythia

Dark Photon Interpretation

- Limits on kinetic mixing parameter ε^2 in dark photon model extracted from the inclusive category limits

$$\sigma_{\mathrm{pp}\to\mathrm{Z_D}} \cdot \epsilon^2 \cdot \mathcal{B} \cdot A = \sigma_{\mathrm{limit}}$$





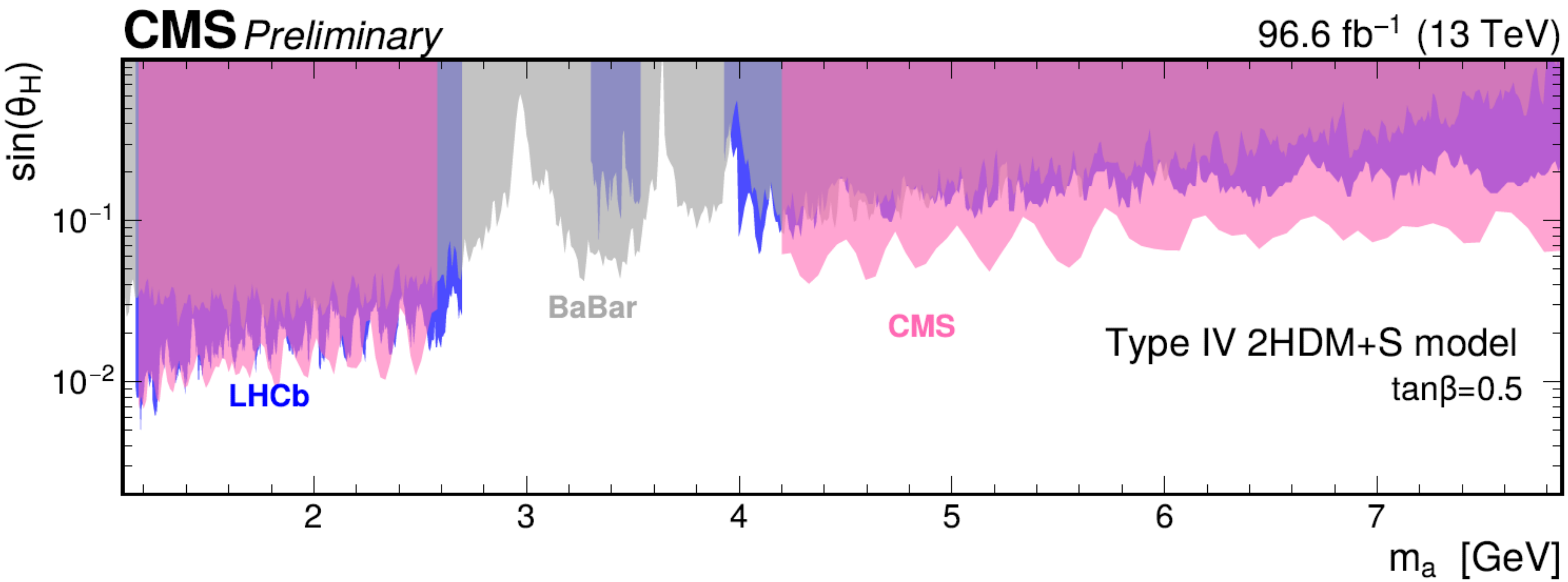
2HDM+S Interpretation

- Limits on mixing angle $\sin(\Theta_H)$ in Type-IV 2HDM+S model ($\tan\beta=0.5$) extracted from the boosted category limits

$$\mathcal{L} \supset -\sum_f \frac{y_f}{\sqrt{2}} i\xi_f^{\mathrm{M}} \bar{f}\gamma_5 f a$$

type	I	II	III	IV
up-type quarks	s_θ/t_β	s_θ/t_β	s_θ/t_β	s_θ/t_β
down-type quarks	$-s_\theta/t_\beta$	$s_\theta t_\beta$	$-s_\theta/t_\beta$	$s_\theta t_\beta$
charged leptons	$-s_\theta/t_\beta$	$s_\theta t_\beta$	$s_\theta t_\beta$	$-s_\theta/t_\beta$

$$\sigma_{\mathrm{pp}\to a} \cdot \sin^2(\theta_{\mathrm{H}}) \cdot \mathcal{B} \cdot A = \sigma_{\mathrm{limit}}$$



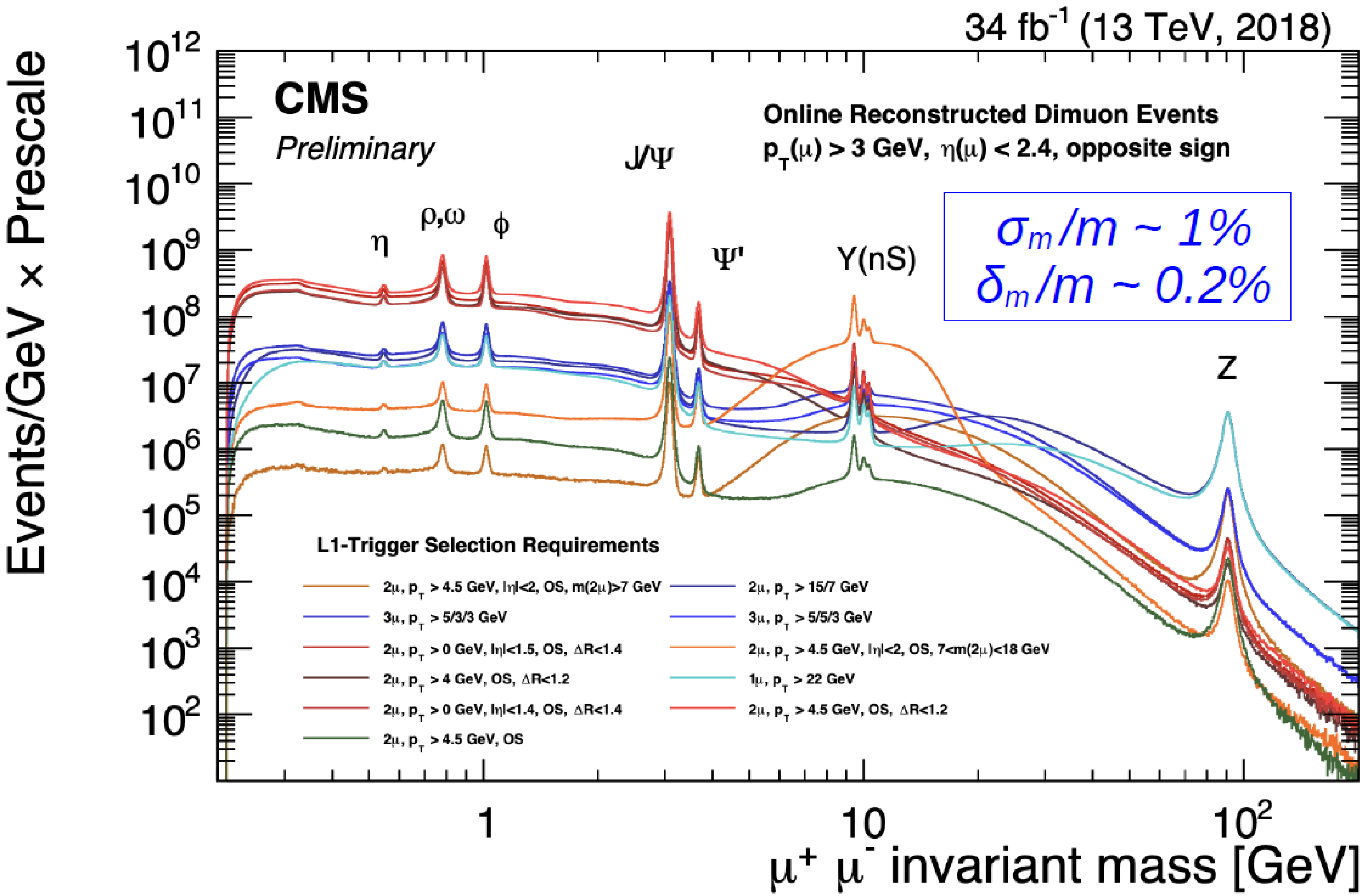
Summary

- Data scouting allows CMS to perform powerful search for dimuon production at GeV scale
  - Impressive sensitivity to dark photon and scalar resonances
- With more statistics from Run 3 data, the result will be further improved.
  - Excesses will be monitored to see if they emerge as new physics
- LHC Run 3 will be FUN!

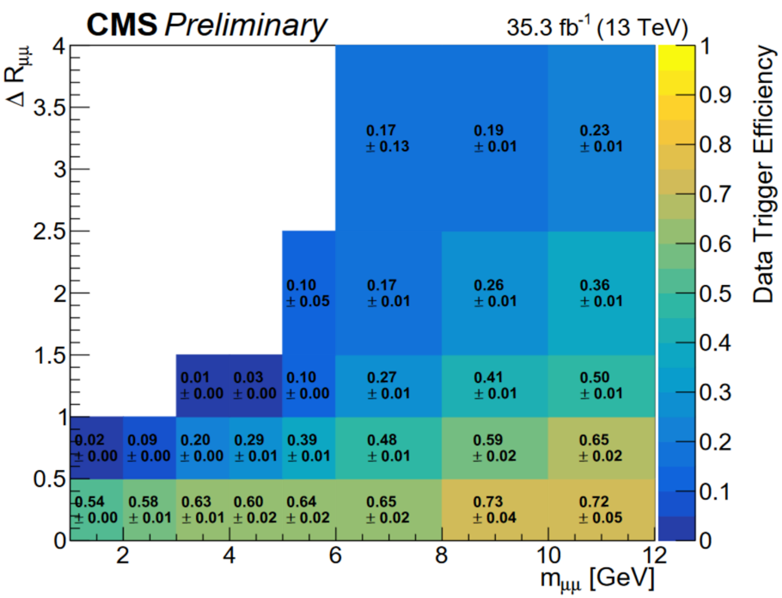
The End

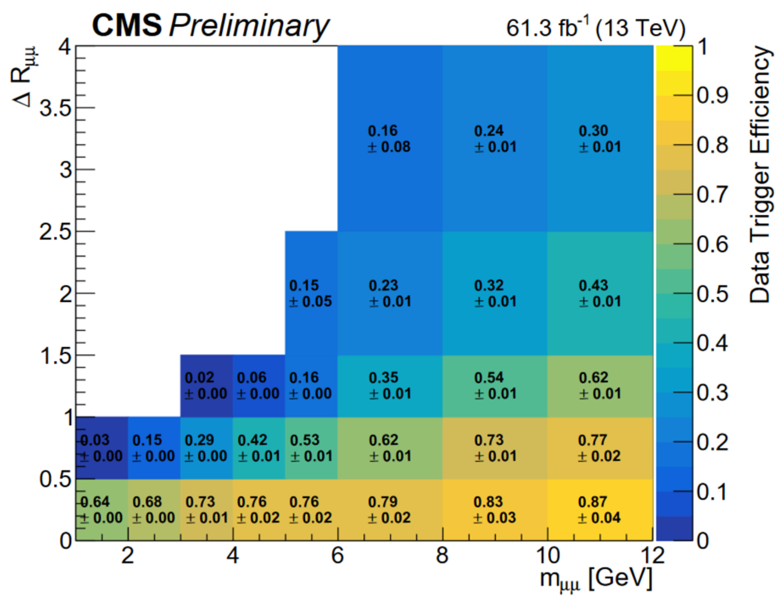
Back up

Scouting Dimuon Mass Distribution



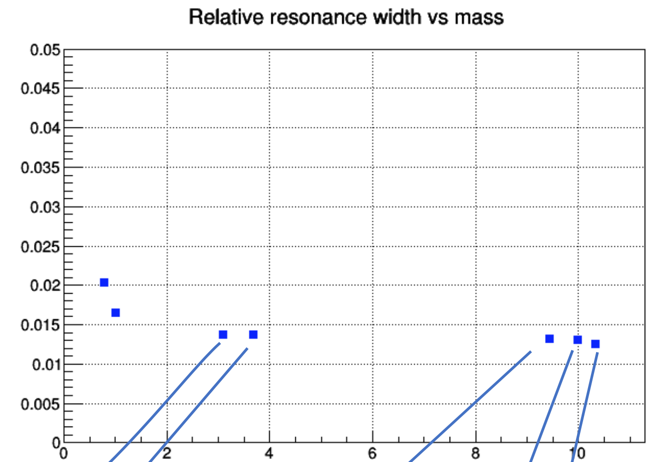
Dimuon Scouting Trigger Efficiency

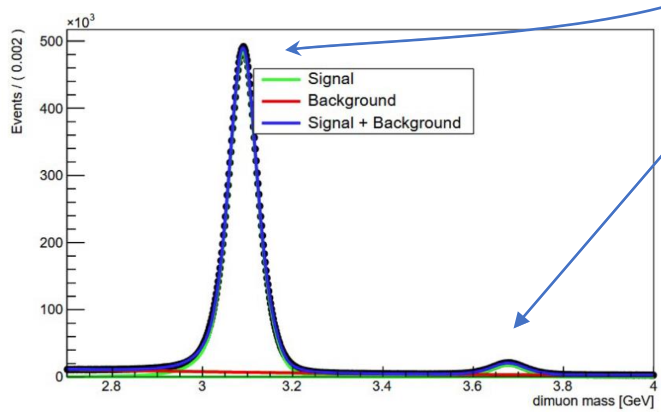


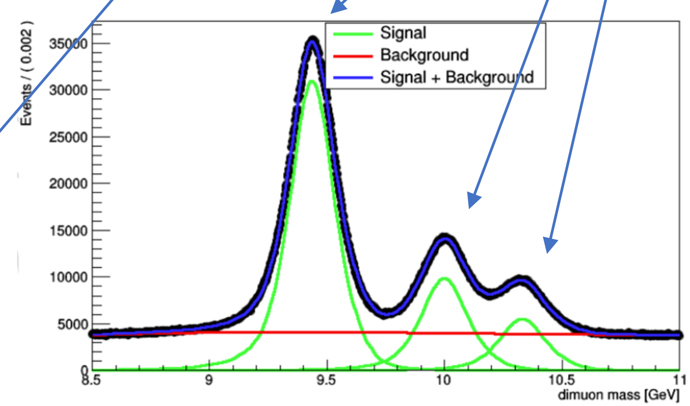


Signal Resolution

- Signal is modelled by a double Crystal Ball function + gaussian with fixed parameters, extracted from fits to SM meson resonances
- Upper plot shows that mass resolution is nearly constant between measured peaks
  - We use a flat value of 1.3%







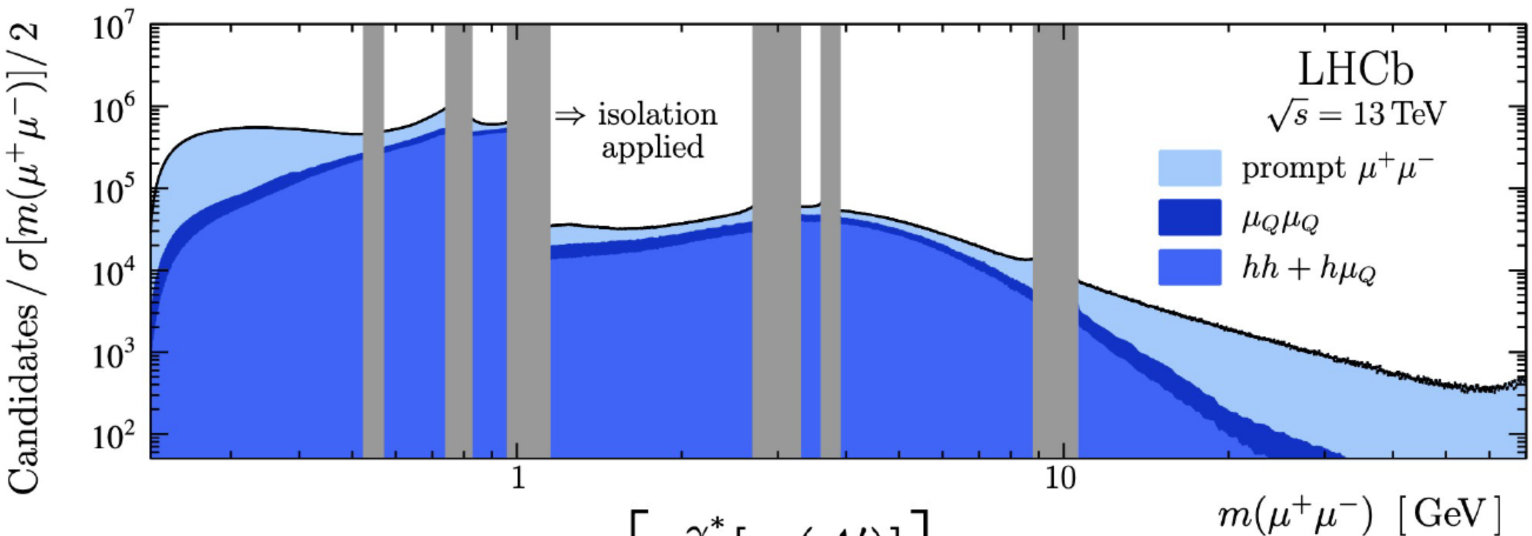
Systematic Uncertainty

Effect	$m_{\mu\mu} < 2.6\,\mathrm{GeV}$	$m_{\mu\mu} > 4.2\,\mathrm{GeV}$
Integrated luminosity	2.3–2.5%	
Mass resolution	20%	
Trigger efficiency	1–20%	
Muon ID efficiency	4–9%	12–20%
Vertex selection	—	3%
Efficiency application	8%	4%
D^0 meson normalization	20–25%	—

LHCb Dark Photon Search

- The mechanism is the same for γ* and dark photon production
- Estimate non-prompt γ* bkg. using SS sample, subtract from observation
- Ratio between the observed γ* yield and signal yield proportional to ε^2

Phys. Rev. Lett. ***124****, 041801*



$$n_{\mathrm{ex}}^{A'}[m(A'),\varepsilon^2] = \varepsilon^2 \left[\frac{n_{\mathrm{ob}}^{\gamma^*}[m(A')]}{2\Delta m}\right] \mathcal{F}[m(A')]$$

Limits with Theory Uncertainties

- Model dependant parameter results, with previously shown ±1σ theory uncertainties added to observed limit