Dark Sector Physics @ LHCb

Mike Williams
on behalf of the LHCb collaboration

Department of Physics & Laboratory for Nuclear Science
Massachusetts Institute of Technology

May 27, 2017

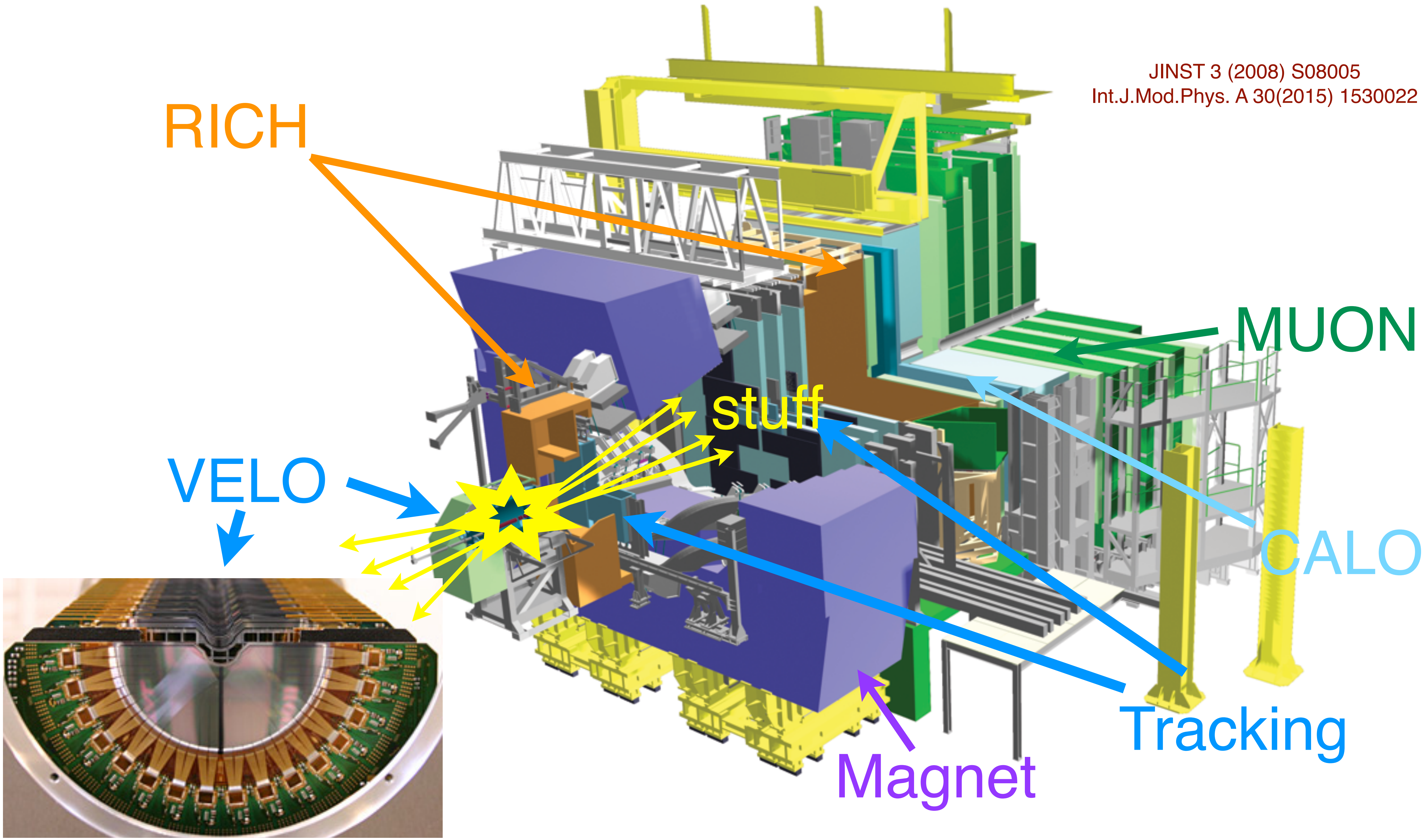

The Large Hadron Collider
LHCb
70 institutes
16 countries
700 physicists
Almost 400 papers!

LHCb Detector

LHCb is a forward Spectrometer ($2 < \eta < 5$)

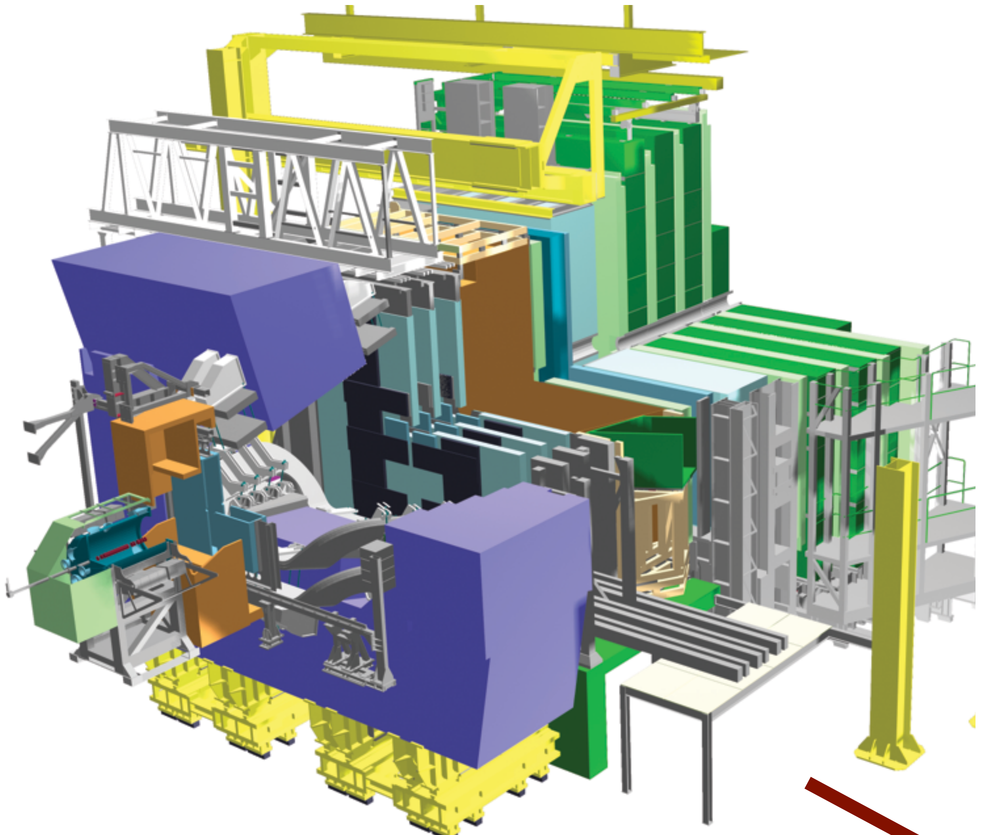
(roughly 1-15^{o})

JINST 3 (2008) S08005
Int.J.Mod.Phys. A 30(2015) 1530022



JINST 8 (2013) P04022

Real-Time Processing



Simple feature-building in custom electronics (e.g. FPGAs) required to reduce the data volume to a transferable rate.

TB/s
(post zero suppression)

Online computing farm processes 250 PB / year, can only persist 1% of this.

50 GB/s

LHCb will move to a triggerless-readout system for LHC Run 3 (2021-2023), and process 5 TB/s in real time on the CPU farm.

Real-Time Processing (Run 2)

1 TB/s ↓ 40 MHz

FPGA-based hardware

50 GB/s ↓ 1 MHz

Real-time reconstruction for all charged particles with p_T > 0.5 GeV.

8 GB/s ↓ 100 kHz

Data buffered on 10 PB disk while alignment/calibration done.

↓

Full real-time reconstruction for all particles available to select events.

→ 3 PB/year (mix of full events & ones where only high-level info kept)

Precision measurements benefit greatly from using the final (best) reconstruction in the online event selection—need real-time calibration. (This also greatly helps BSM searches.)

Final event selection done with access to best-quality data (mostly done during down time between fills).

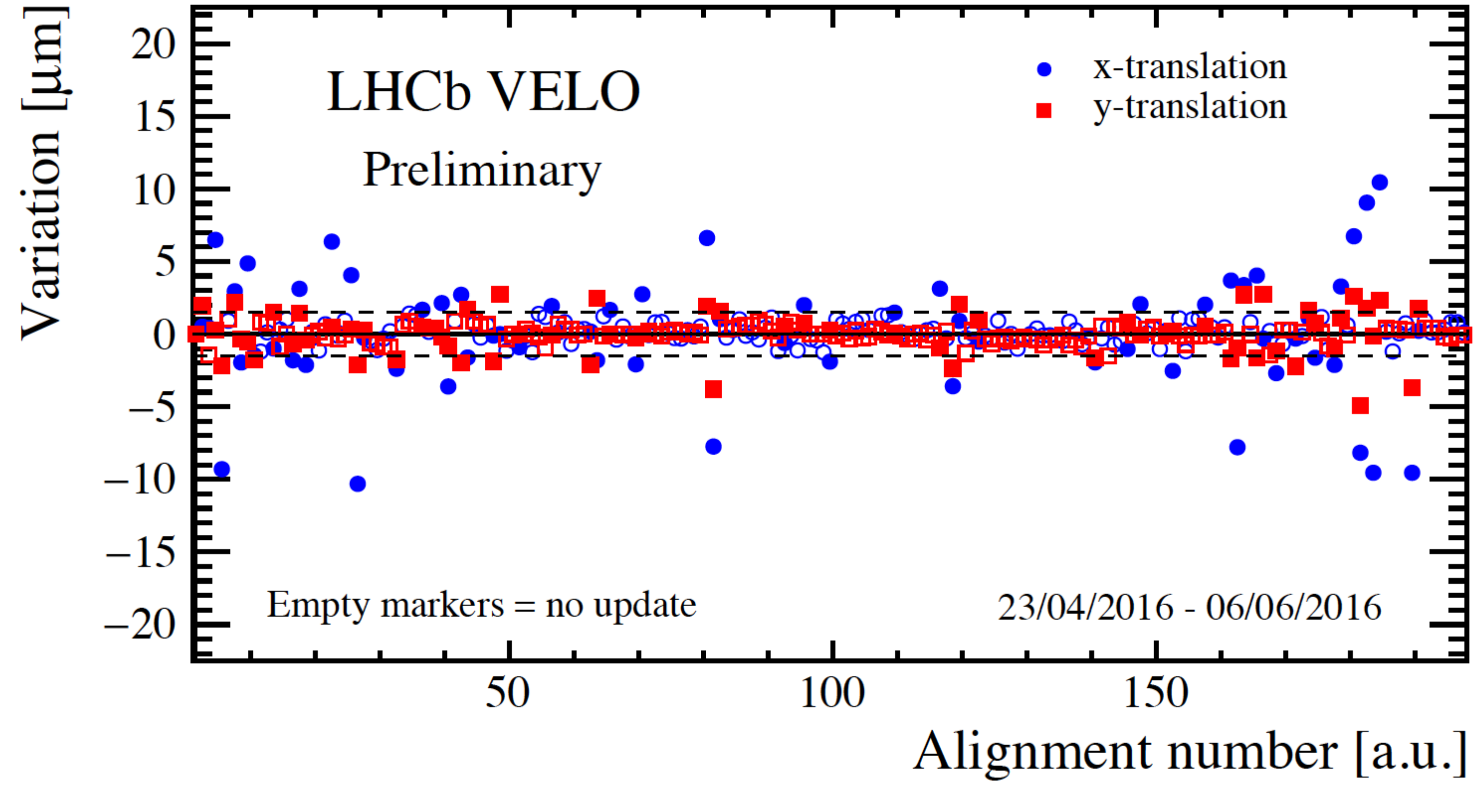
Heavy use of machine learning algorithms throughout the Run 1 and Run 2 trigger.

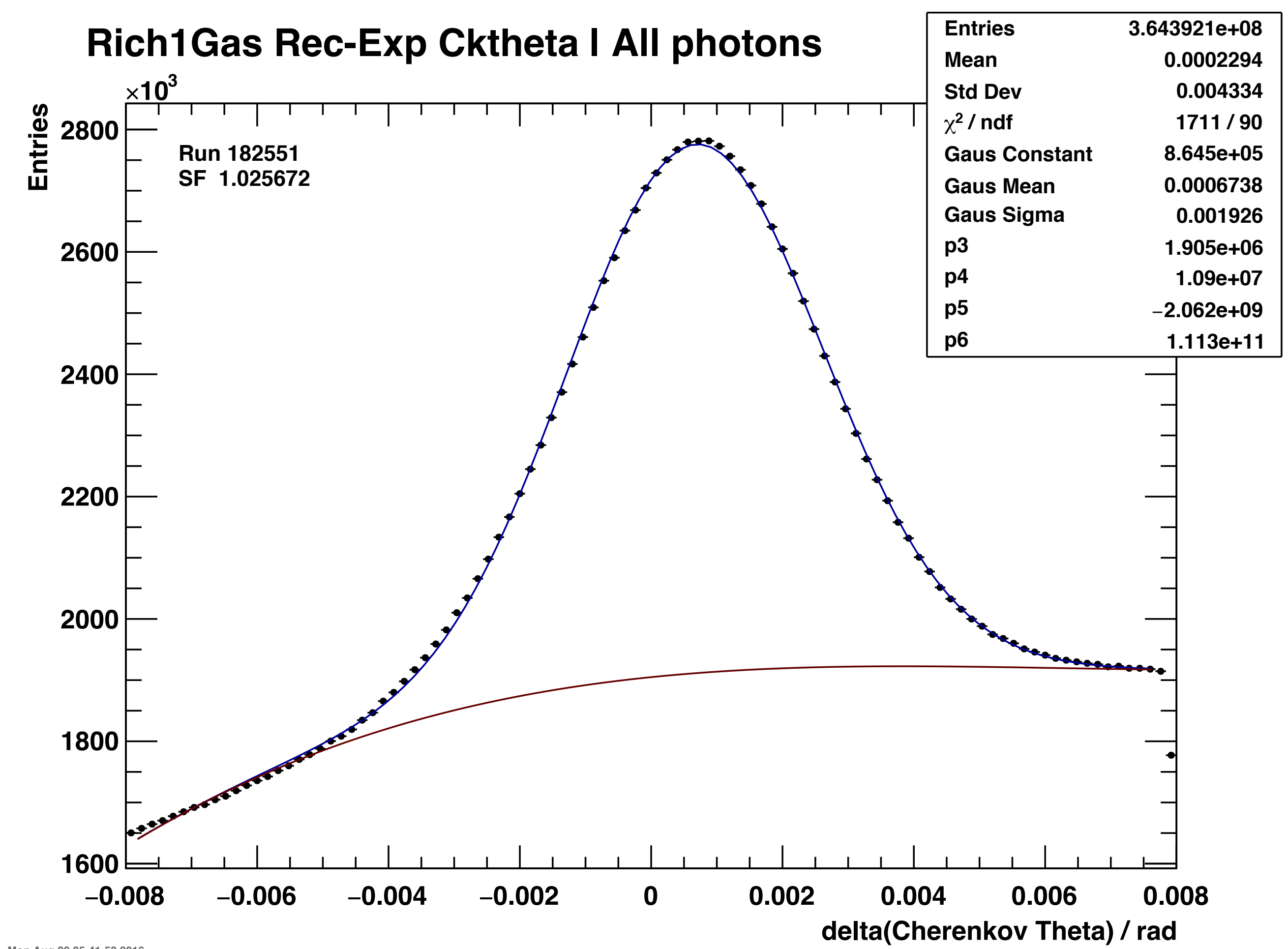
V.Gligorov, MW, JINST 8 (2012) P02013.

Real-Time Calibration

VELO opens/closes every fill, expect updates every few fills. Rest of tracking stations only need updated every few weeks.

RICH gases indices of refraction must be calibrated in real time; requires ~1 min to run, and new calibrations are required for each run.



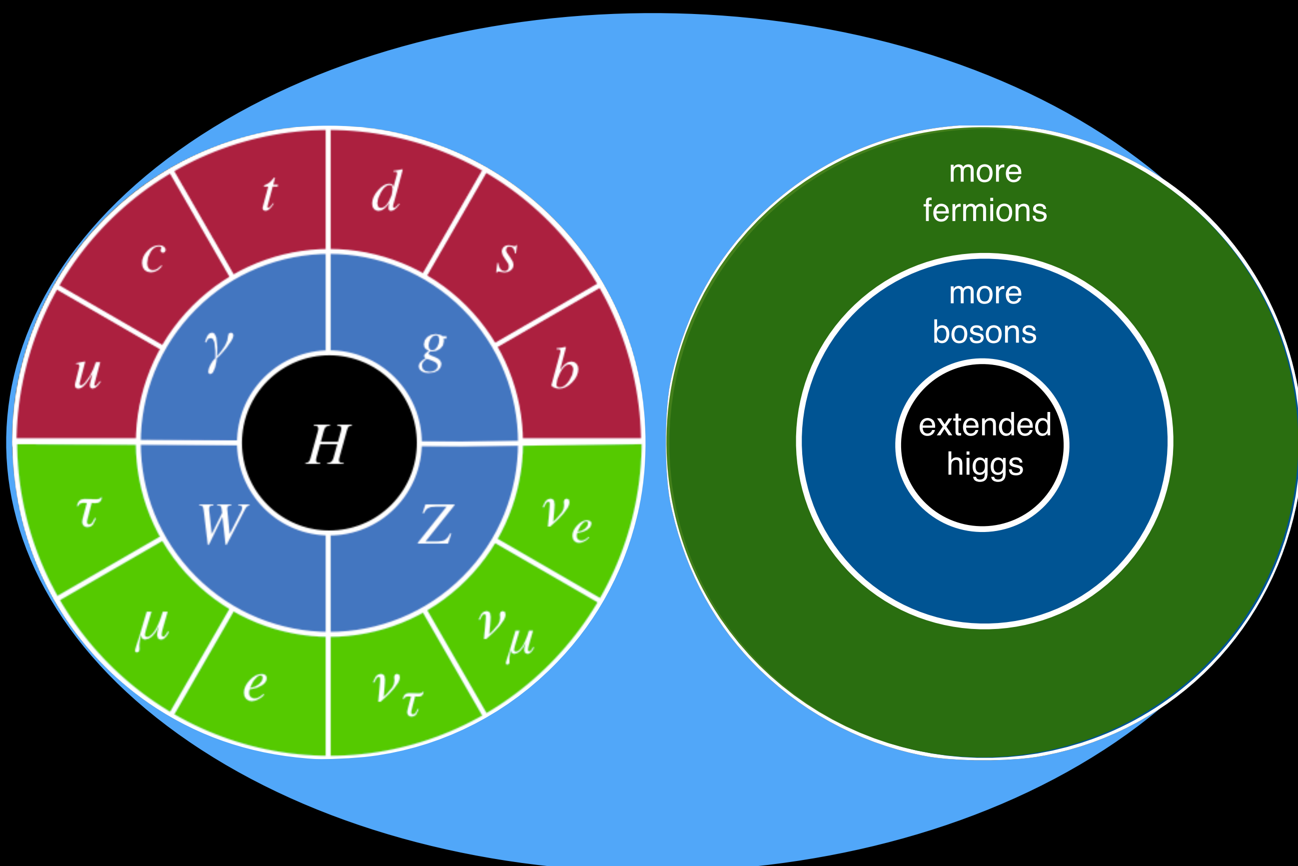


Calibration data is sent to a separate "stream" from the physics data after the first software-trigger stage. This permits running the calibrations on the online farm simultaneously with running the trigger.

(Near) real-time publication: σ(cc)[13TeV] shown @ EPS (2015) within a week of recording the data (measured using online-reconstructed data). We achieved better mass and lifetime resolution online than we had offline in Run 1. LHCb-PAPER-2015-041

Dark Matter Paradigms

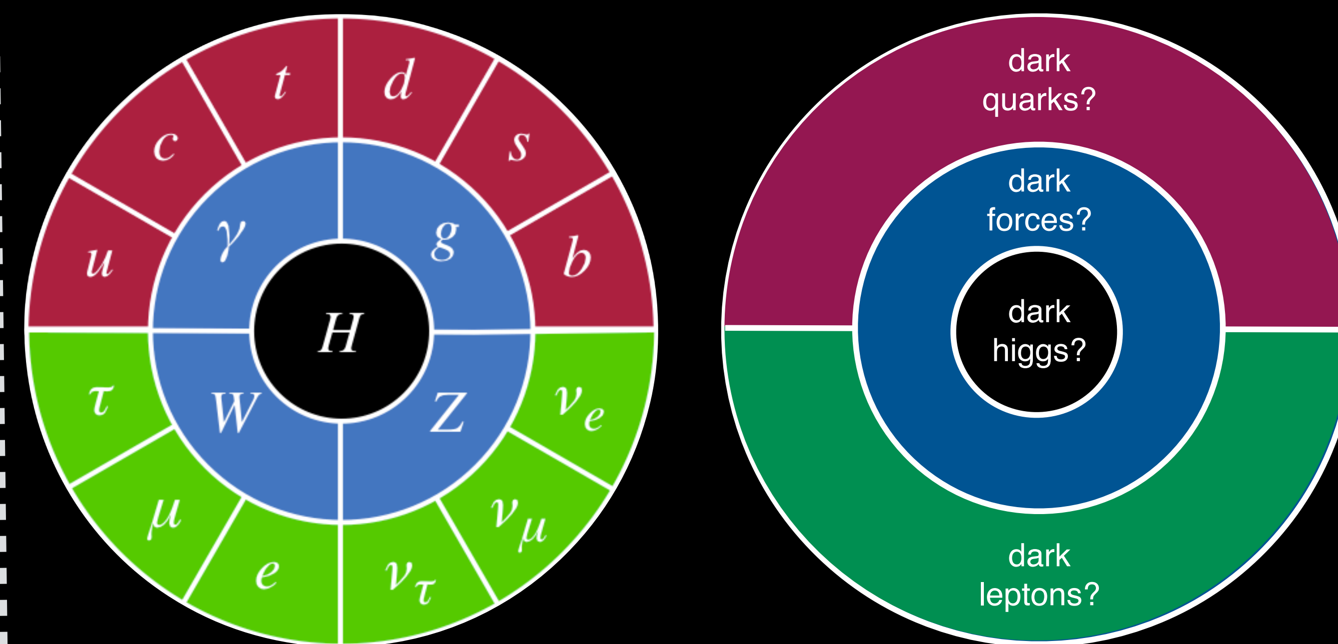
WIMP



SM and DM particles are part of a larger unified theory at the TeV scale.

LHCb searches for indirect evidence of this via quantum effects (flavor physics) — but that's another talk.

Hidden Sector(s)



No direct SM-DM connection, but there could be portals.

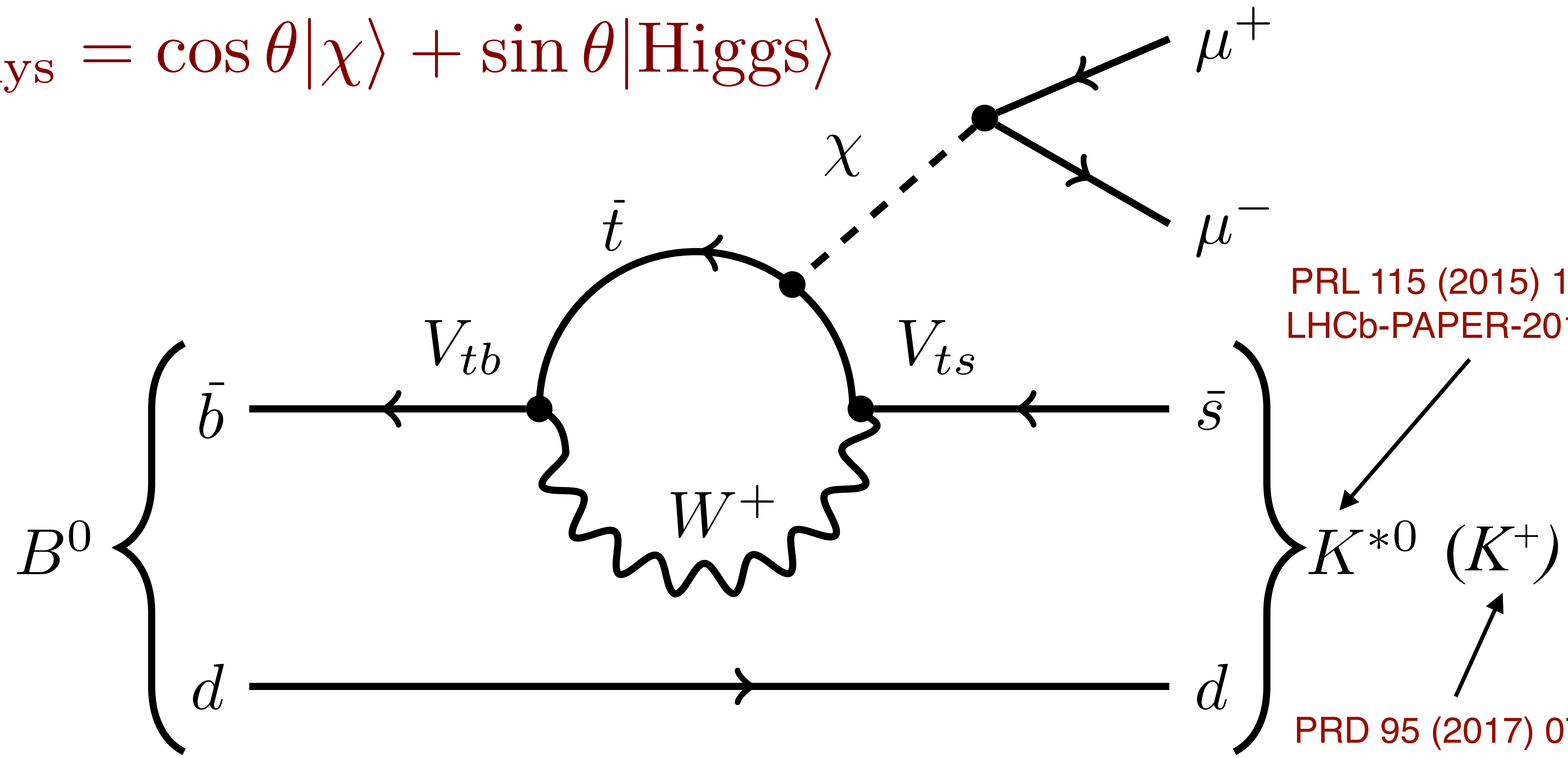
LHCb searches for this directly, and has (or will have) world-leading sensitivity in certain regimes.

Higgs Portal

$b \rightarrow s$ penguin decays are an excellent place to search for low-mass hidden-sector particles (e.g., anything that mixes with the Higgs sector).

$$|\mathrm{Higgs}\rangle_{\mathrm{phys}} = -\sin\theta|\chi\rangle + \cos\theta|\mathrm{Higgs}\rangle$$

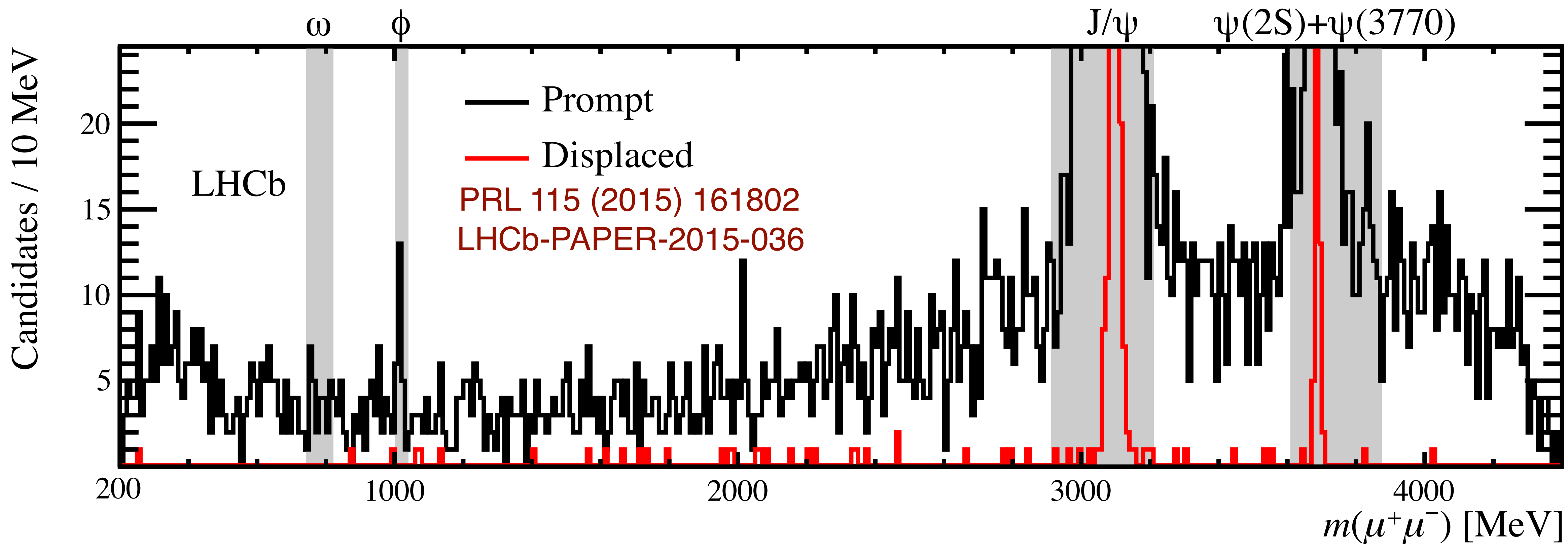
$$|\chi\rangle_{\mathrm{phys}} = \cos\theta|\chi\rangle + \sin\theta|\mathrm{Higgs}\rangle$$

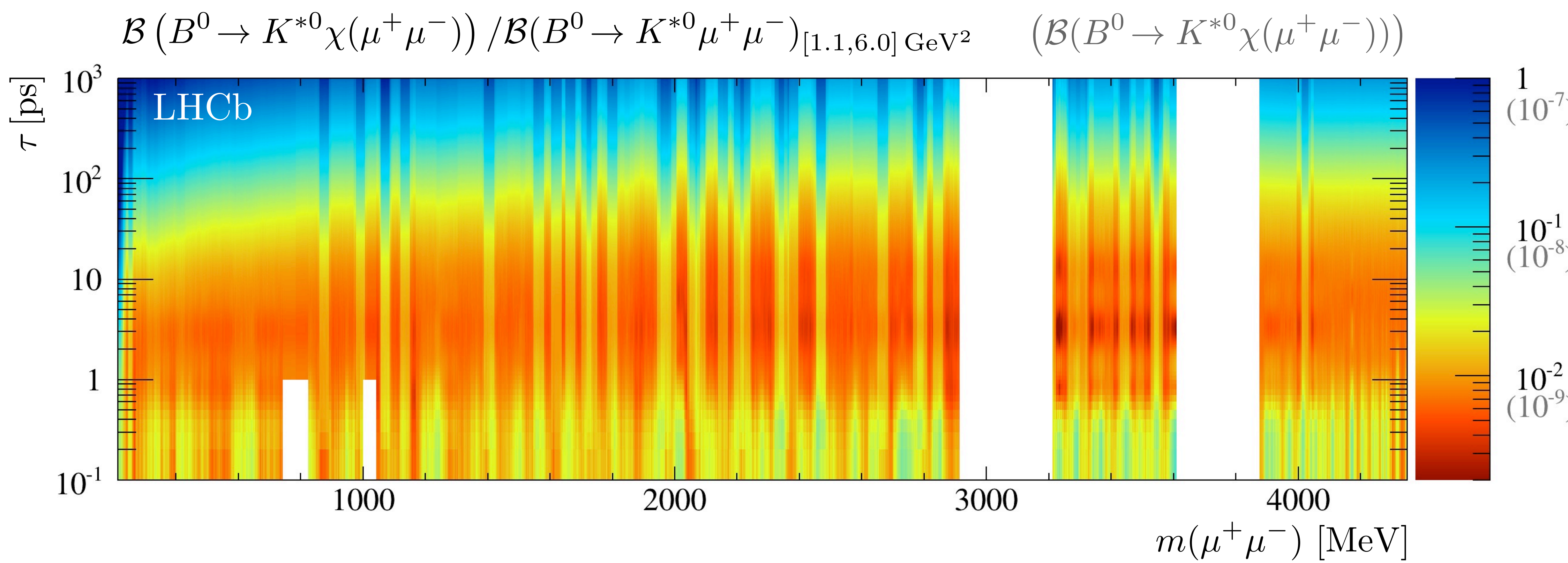


Search strategy handles QCD resonances (MW [1503.04767]), and 2015-036 uses a novel ML algorithm (uBDT) (J.Stevens, MW [1305.7248]).

See also A.Rogozhnikova, A.Bukva, V.Gligorov, A.Ustyuzhanin, MW [1410.4140].

Model-Independent Limits

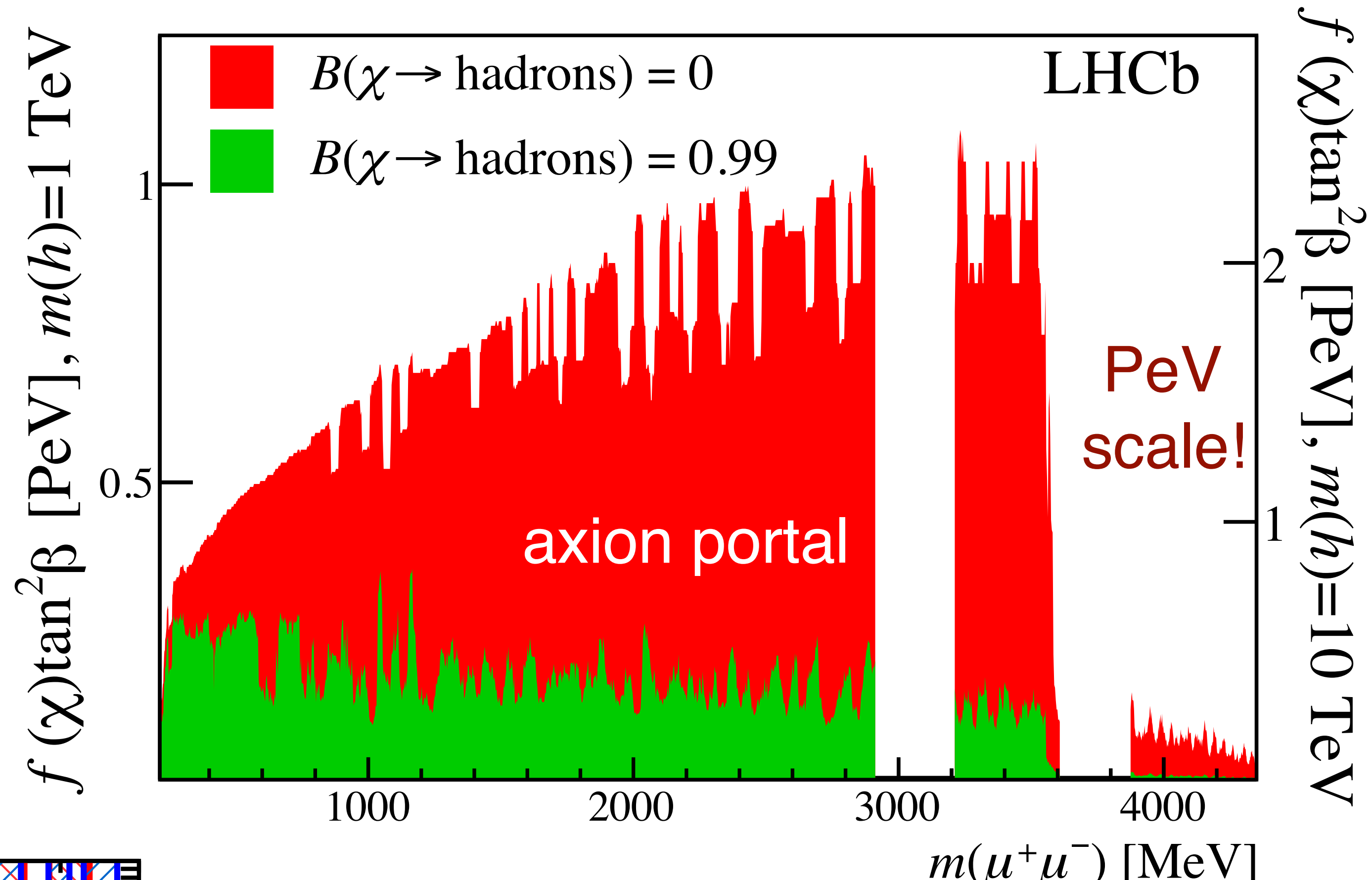


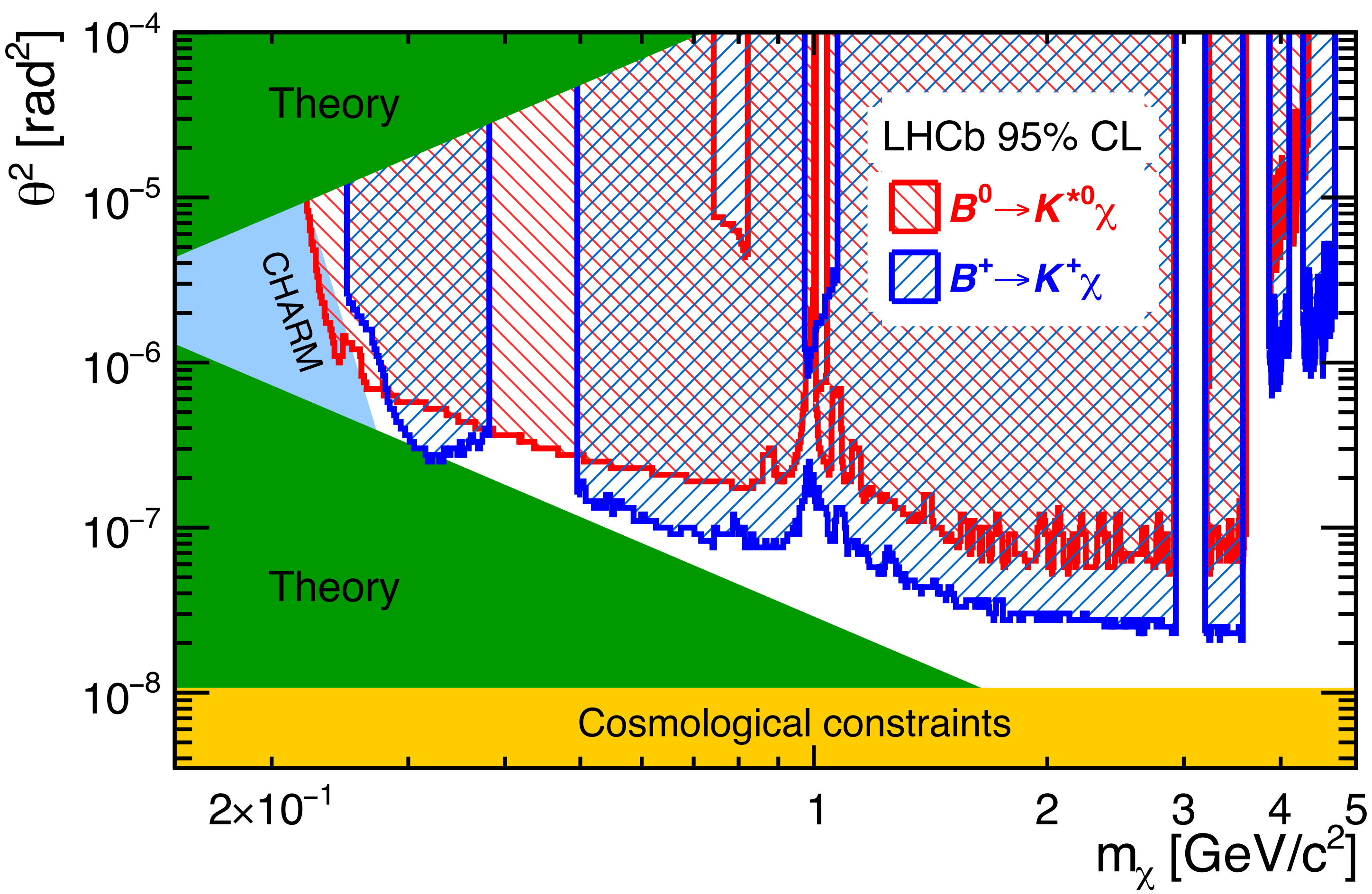


No evidence for a hidden-sector boson; stringent model-independent limits are set.

Benchmark Models

Constraints in the axion portal reach the PeV scale on the axion decay constant in 2HDMs.
[Freytsis,Ligeti,Thaler, 0911.5355]



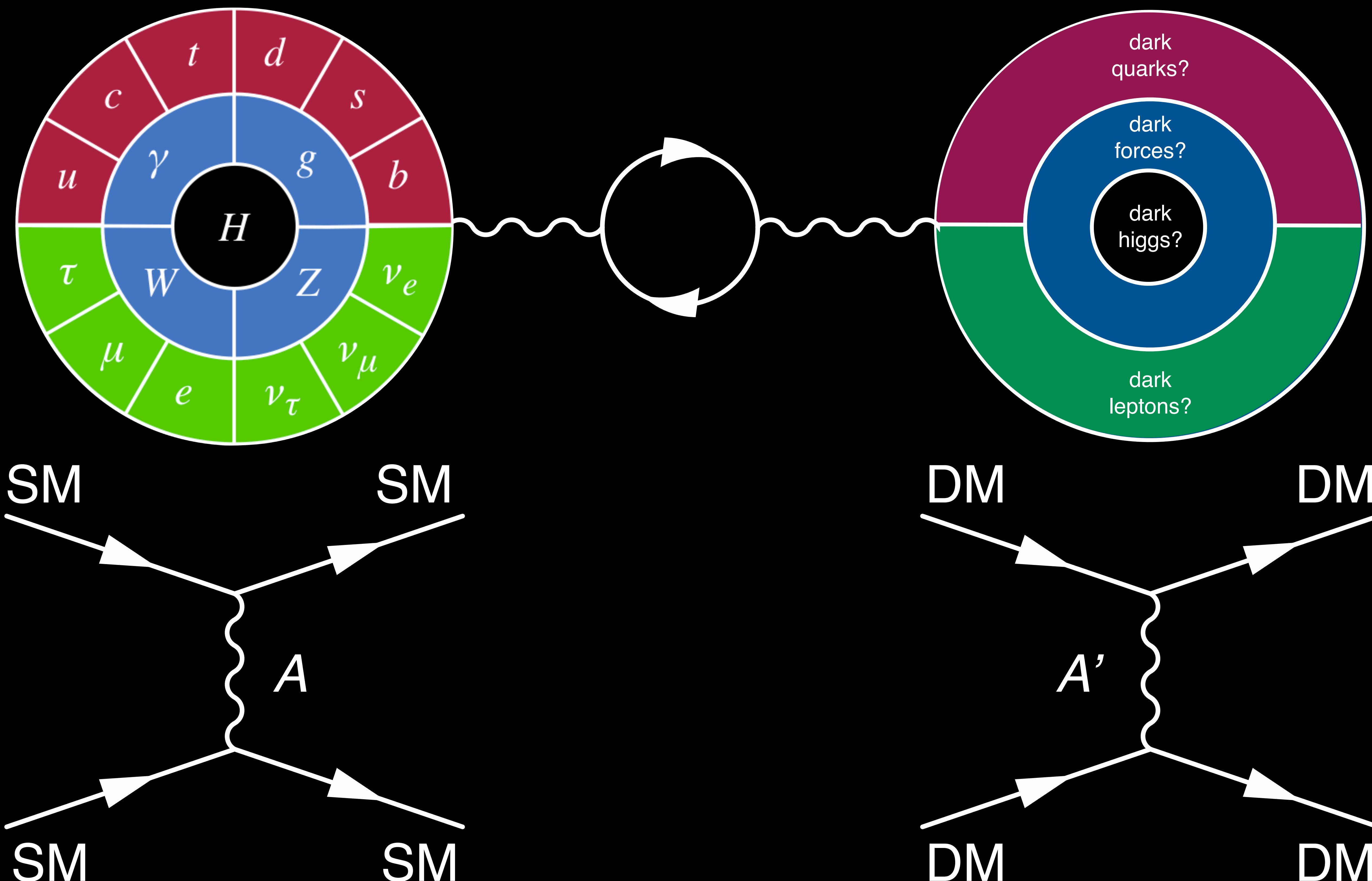


Strongest constraints on a scalar with $2m(\mu)<m<2m(\tau)$ mixing with the Higgs.

Nearly rules out the Inflaton parameter space below $2m(\tau)$ in these models.

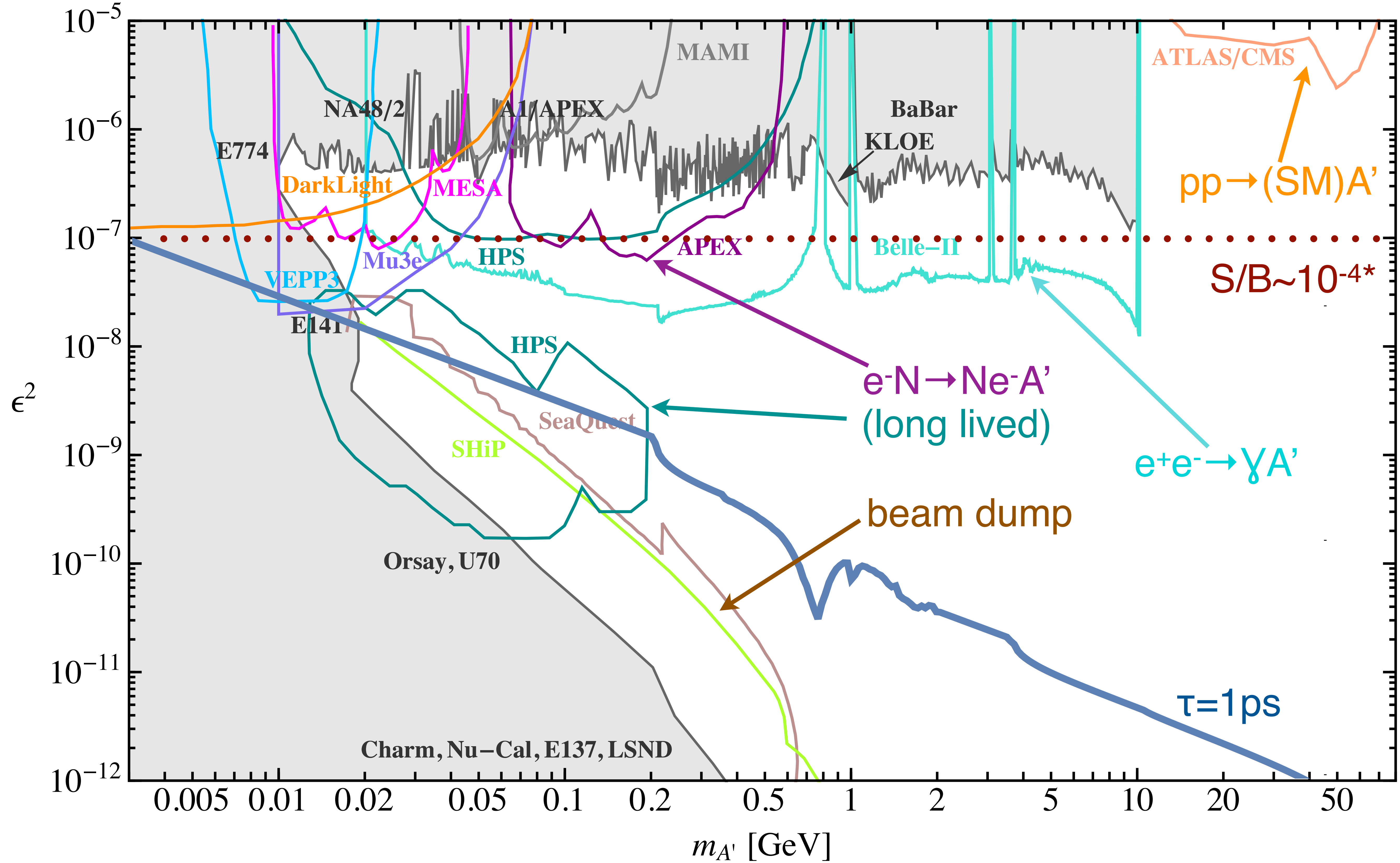
Batell, Pospelov, Ritz [0911.4939];
Bezrukov, Gorbunov [0912.0390,1303.4395]

Dark Photons



Visible A' Decays

Dedicated worldwide effort to search for dark photon decays.



*see MW [1705.03578] for a guide to proper bump hunting.

Dark Photons

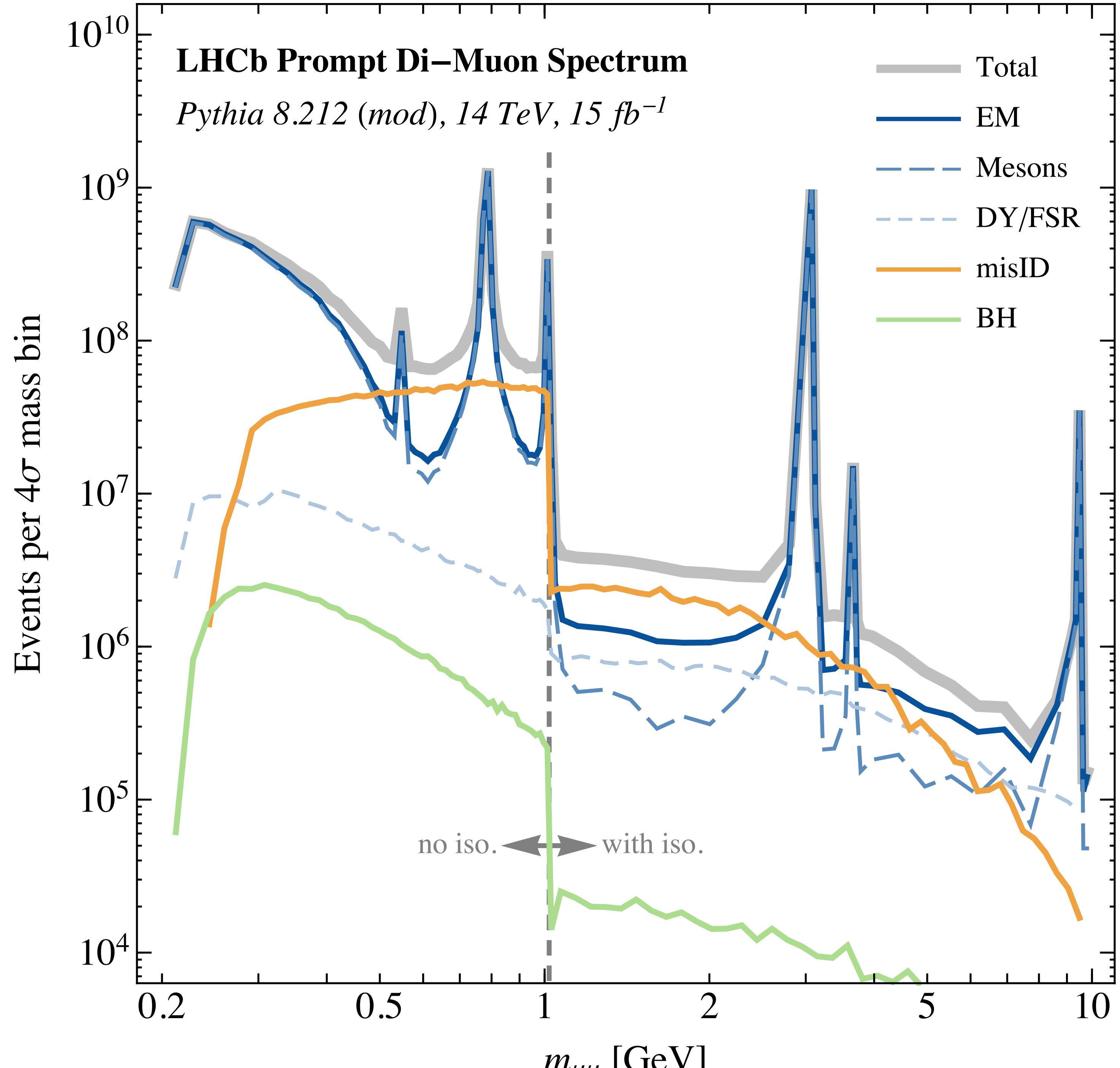
Ilten, Soreq, Thaler, MW, Xue
[1603.08926]

The most experimentally favorable A' decay mode is di-muon. The A' rate can be inferred from the prompt ɣ*→μμ rate making this a **fully data-driven search** at the LHC! $\frac{N(A' \to \mu^+\mu^-)}{N(\gamma^* \to \mu^+\mu^-)} \approx \frac{3\pi}{8} \frac{m(A')}{\sigma(m(\mu\mu))} \frac{\varepsilon^2}{\alpha_{\rm EM}(n(\ell) + \mathcal{R}(\mu))}$

We estimated all contributions to the prompt di-muon spectrum for $p_T(\mu) > 0.5$ GeV, $p(\mu) > 10$ GeV, and $2 < \eta(\mu) < 5$, to permit estimating the possible reach using A'→μμ at LHCb.

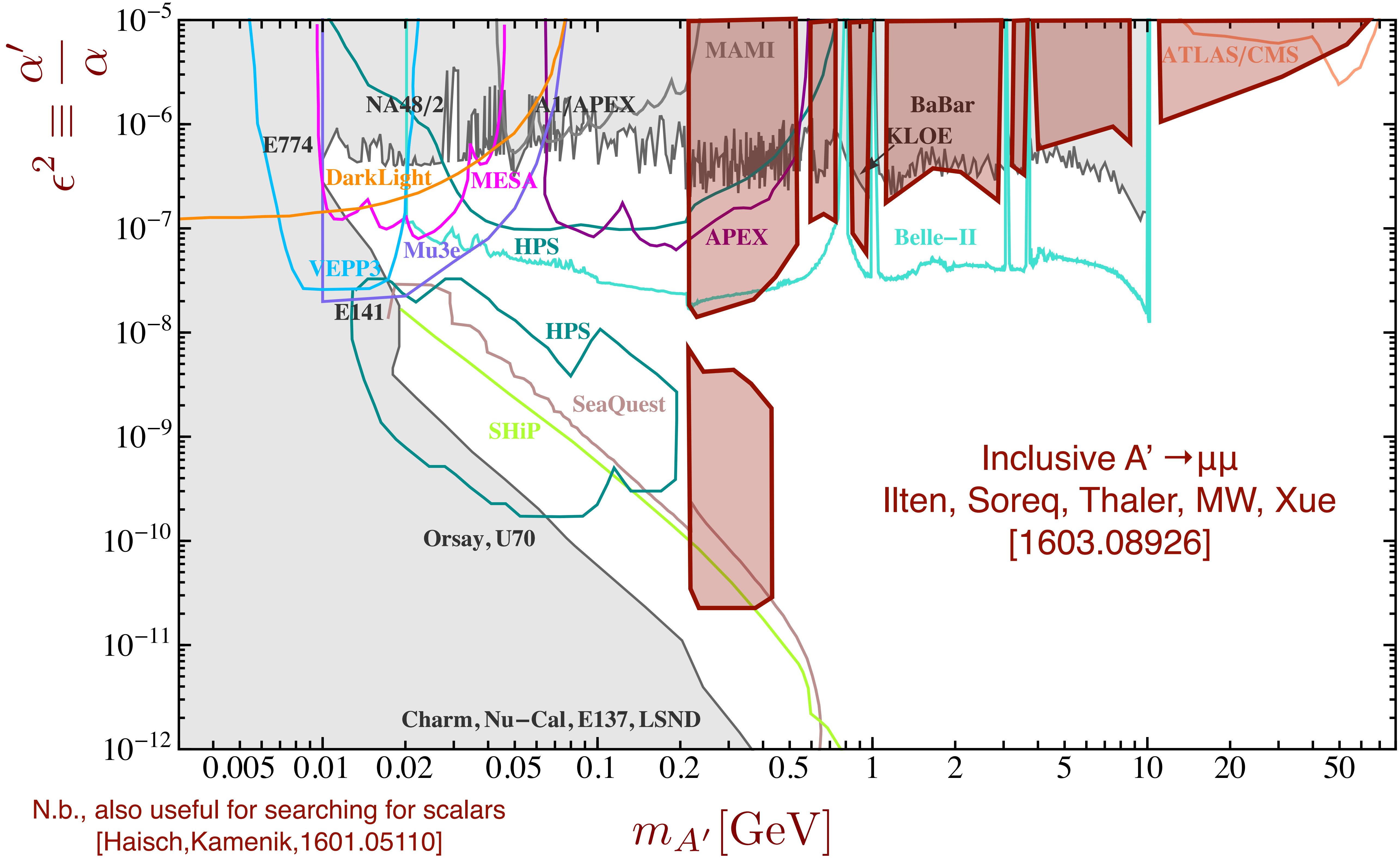
For concreteness, we considered only the 15/fb expected in Run 3 (everything scales as √lumi).

"Mesons" and "DY/FSR" can produce A', "BH" and "misID" cannot.



Dark Photons

Move to a triggerless detector readout in Run 3 will have a huge impact on low-mass BSM searches, including dark photons.

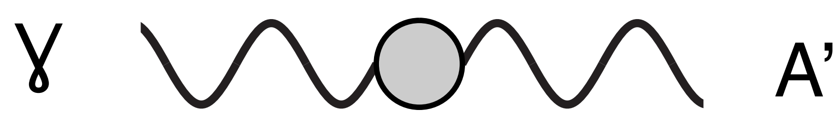


N.b., also useful for searching for scalars
[Haisch,Kamenik,1601.05110]

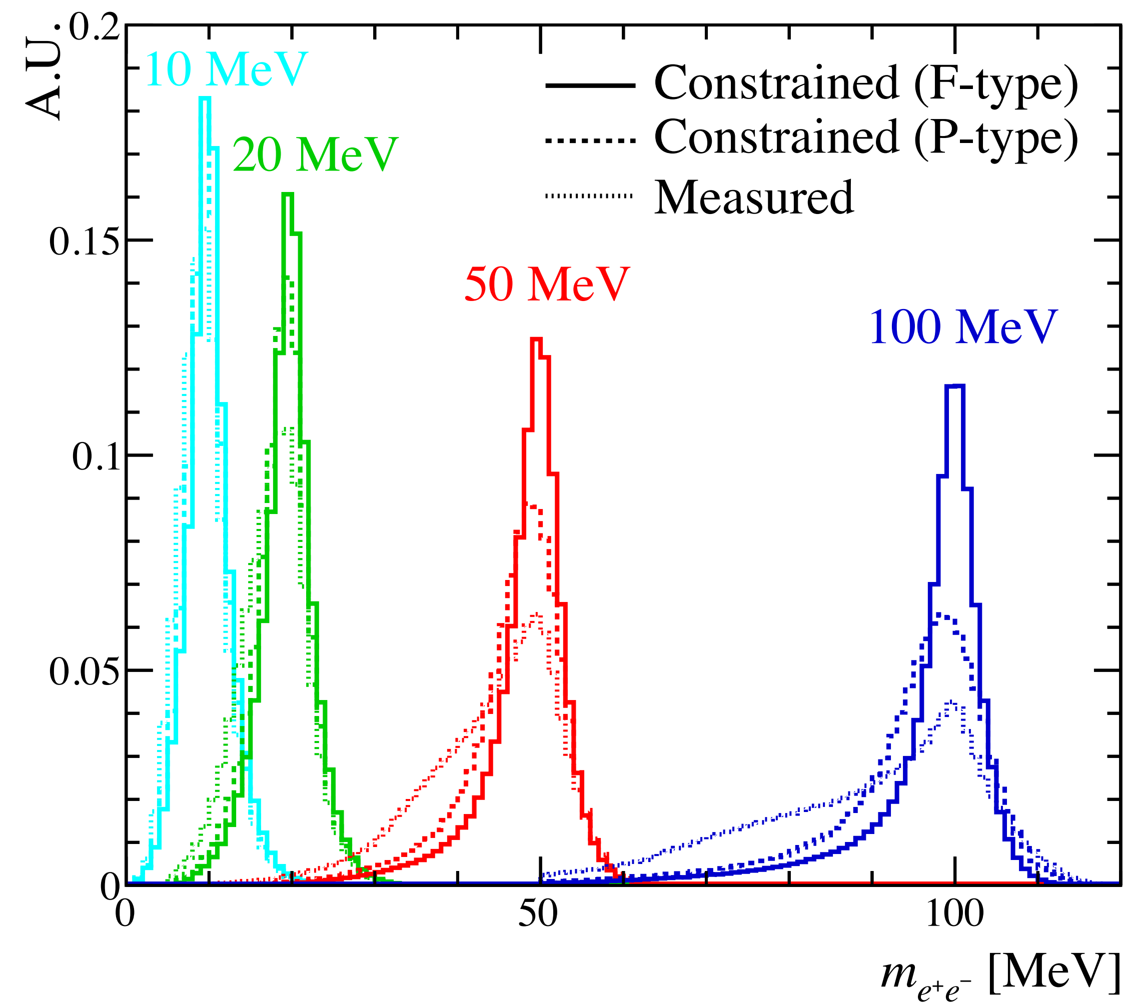
Dark Photons

For the low-mass region, consider the decay $D^{*0} \to D^0 A'(ee)$, which can potentially probe the region 2m(e) to ~142 MeV. The SM decay $D^{*0} \to D^0 \gamma$ will occur within LHCb acceptance at almost 1 MHz in Run 3.

Ilten, Thaler, MW, Xue [1509.06765]



$$\frac{\Gamma(D^{*0} \to D^0 A')}{\Gamma(D^{*0} \to D^0 \gamma)} = \epsilon^2 \left(1 - \frac{m_{A'}^2}{\Delta m_D^2}\right)^{3/2},$$

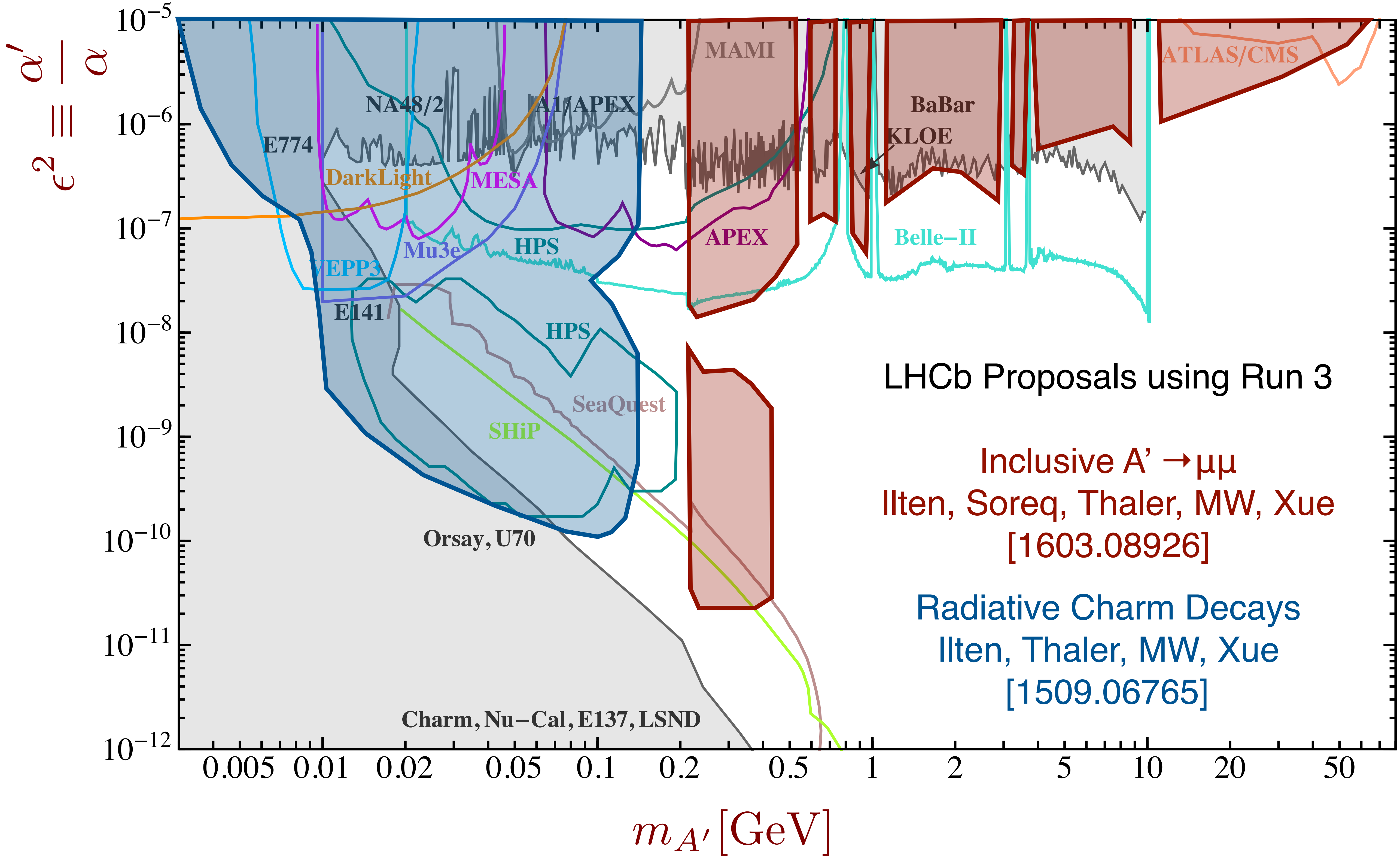


We required A' decays before reaching material to suppress conversions.

Poor m(ee) resolution due to BREM can be greatly improved by performing a mass-constrained fit using known $m(D^{*0})$ and well-measured D^0. Cutting on $m(D^0ee)$ will suppress combinatorial BKGD.

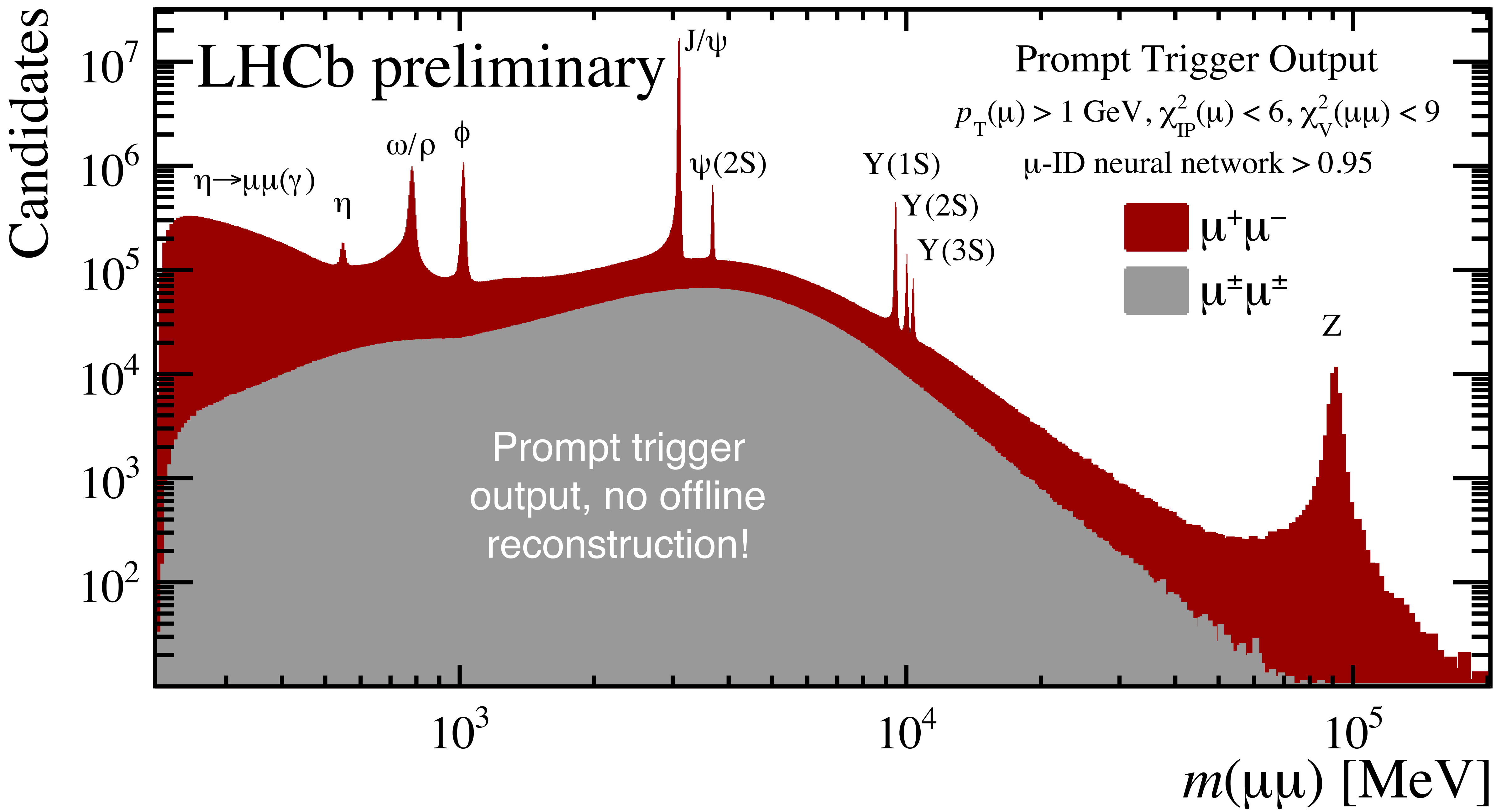
Visible A' Decays

Move to a triggerless detector readout in Run 3 will have a huge impact on low-mass BSM searches, including dark photons.



2016 Data

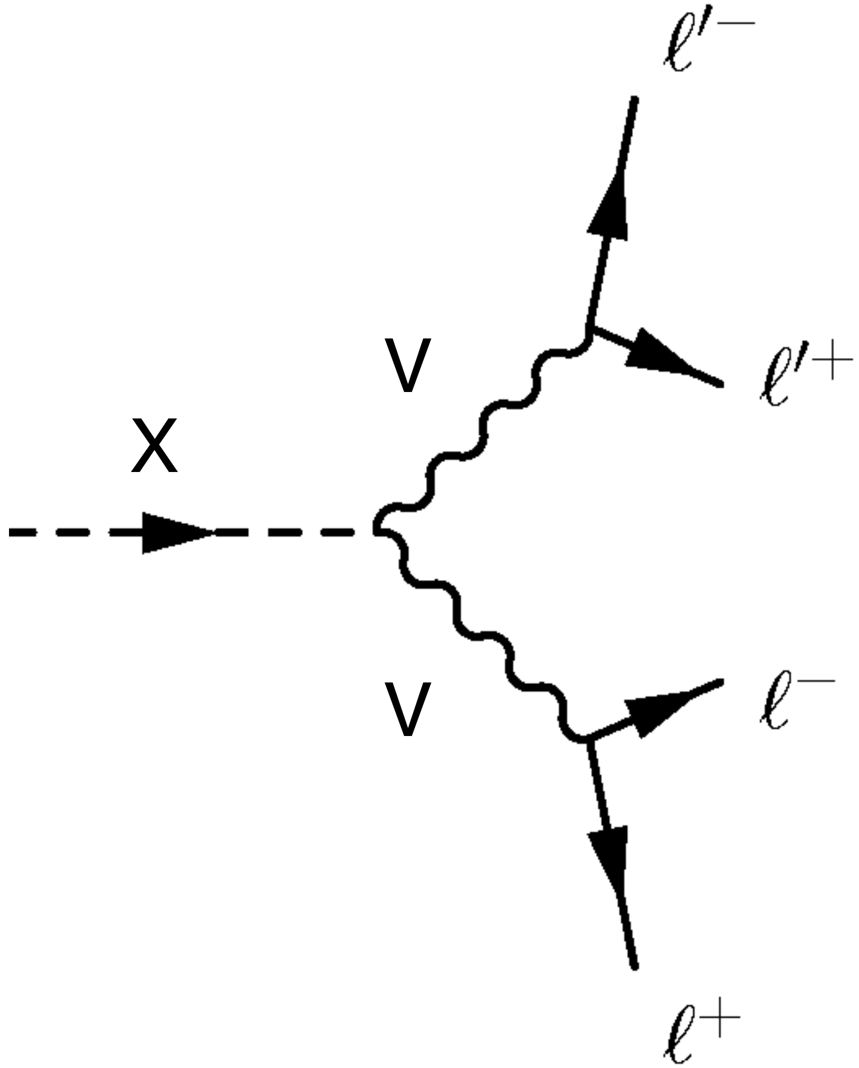
New triggers produced for 2016 to do both the prompt and displaced dimuon searches (rely heavily on advances to the LHCb online system in Run 2).



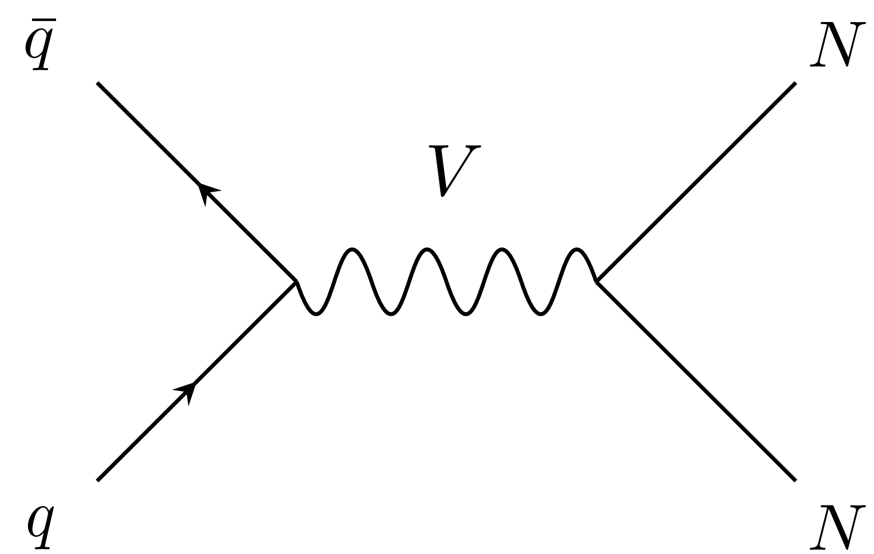
SM rates agree well with our predictions as do backgrounds, which means that the potential A' production rate does too—first search is ongoing!

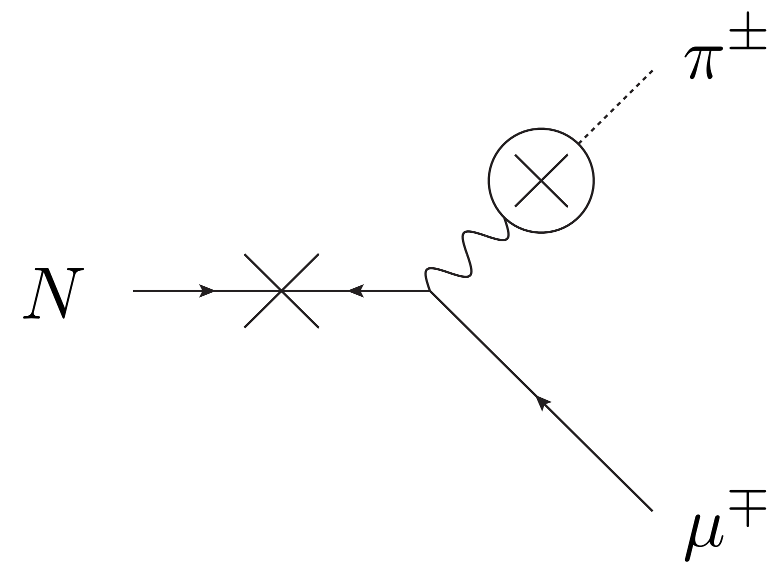
2016 BSM Triggers

Also new triggers added in 2016 for X→4μ with $p_T(\mu)$ > 0.5 GeV, and right-handed neutrino decays to hμ with τ > 1ps (no mass requirements).



Batell, Pospelov, Shuve [1604.06099]





Working on improvements in all 2016 triggers for 2017, and also on additions like inclusive displaced e^+e^- lines, LNV, etc. Searches currently underway.

Real-Time Processing (Run 3)

5 TB/s ↓ 40 MHz

Real-time reconstruction for all charged particles with $p_T > 0.5$ GeV.

↓

Data buffered on disk while alignment/calibration done.

↓

Full real-time reconstruction for all particles available to select events. → 20 PB/year (mostly only high-level info kept, few RAW events to be stored)

Removing the hardware-trigger stage and reconstructing every event will give us unprecedented sensitivity to O(MeV)-O(10 GeV)-scale BSM physics (A', RH nu, etc.), but…

…keeping the vast wealth of physics data will be a challenge. We can't store every event with $\gamma^* \to e^+e^-$ and/or $\mu^+\mu^-$. Autoencoder-based data compression? Moving towards a new era of analysis.

Summary

LHCb is a general-purpose detector in the forward region.