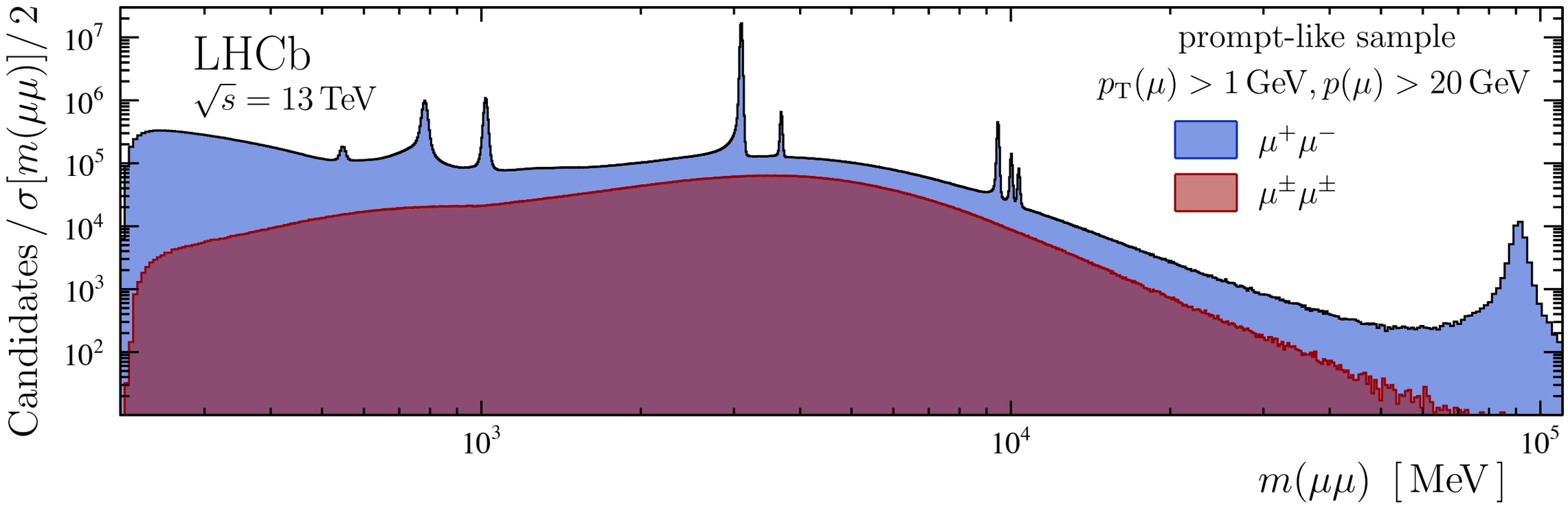


Physics at the LHC - WS 2021-2022

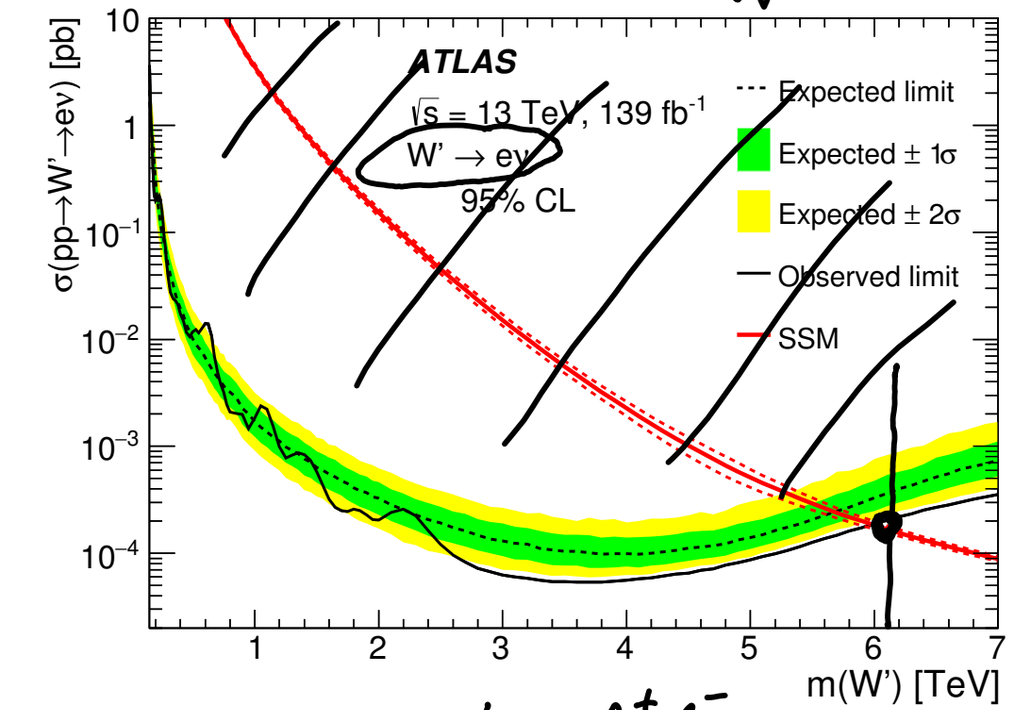
Real time analysis and searches at the intensity frontier at LHCb

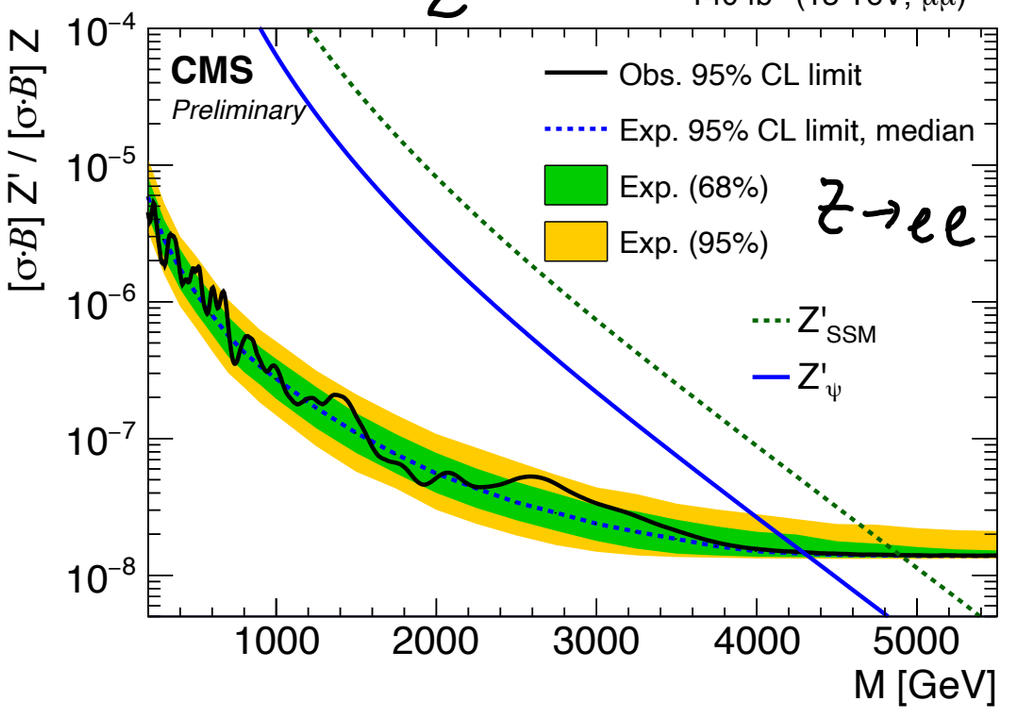
Martino Borsato

Lecture 4/4 - Friday Feb 4th 2022

The energy frontier

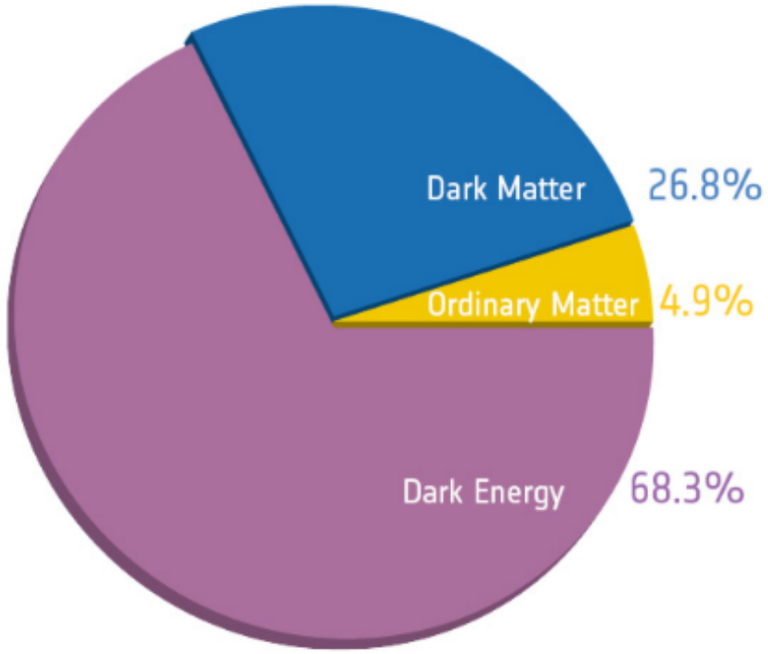
- **Energy frontier exploration** has greatly advanced particle physics
  - Often guided by indirect signs in lower energy processes
  - Example: CPV → third family
- The LHC is our front runner
  - **Discovery of the Higgs**
  - Exploration of the multi-TeV range
  - So far no hint of new heavy objects
  - Lower limits up to several TeV
- **What if the new particles have smaller couplings to the SM?**



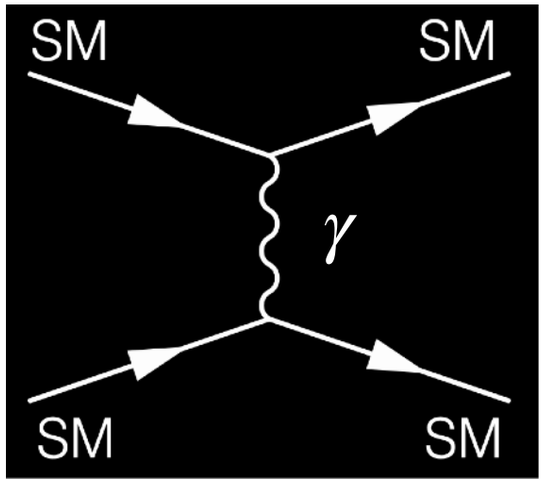


Dark Forces

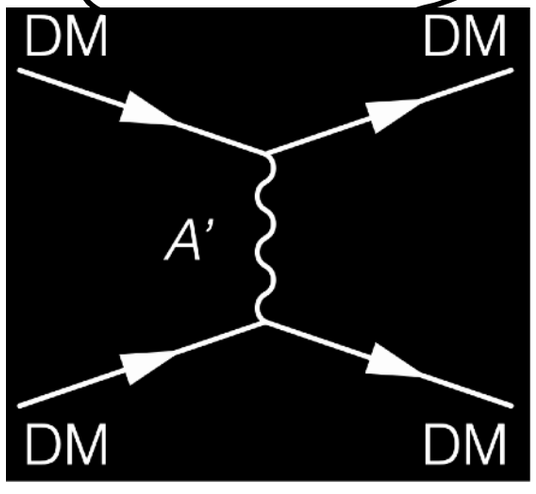
- Astrophysics + Cosmology → there must be Dark Matter
  - Dark = only gravitational effect detected → does not interact e.m. or strongly
  - No candidate particle in the SM
- The weak solution:
  - Dark Matter interact via the weak force
  - Then its mass should be above the weak scale (100 GeV)
- Alternative solution:
  - Dark Matter interacts via new force
  - Couples indirectly to ordinary matter (through quantum loops)
  - **Very small couplings, lighter masses**



Photon



Dark photon

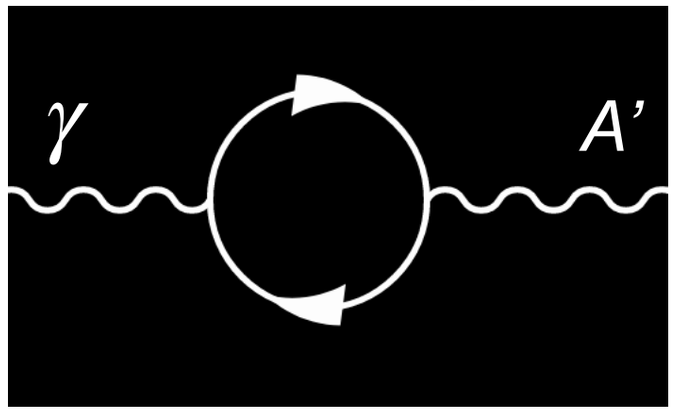


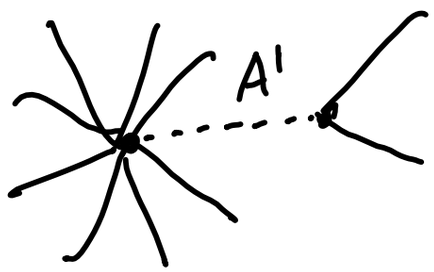
Dark Forces

- **Small coupling**
  - Small cross section
  - Need high luminosity
  - Could have escaped previous experiments (intensity frontier)
- **Lighter mass**
  - Cheap to produce at LHC
  - Production mostly in the forward region
  - Comes with large background of SM particles
- **Small coupling + Light mass**
  - Can have sizeable lifetime!
  - Displaced vertex signature

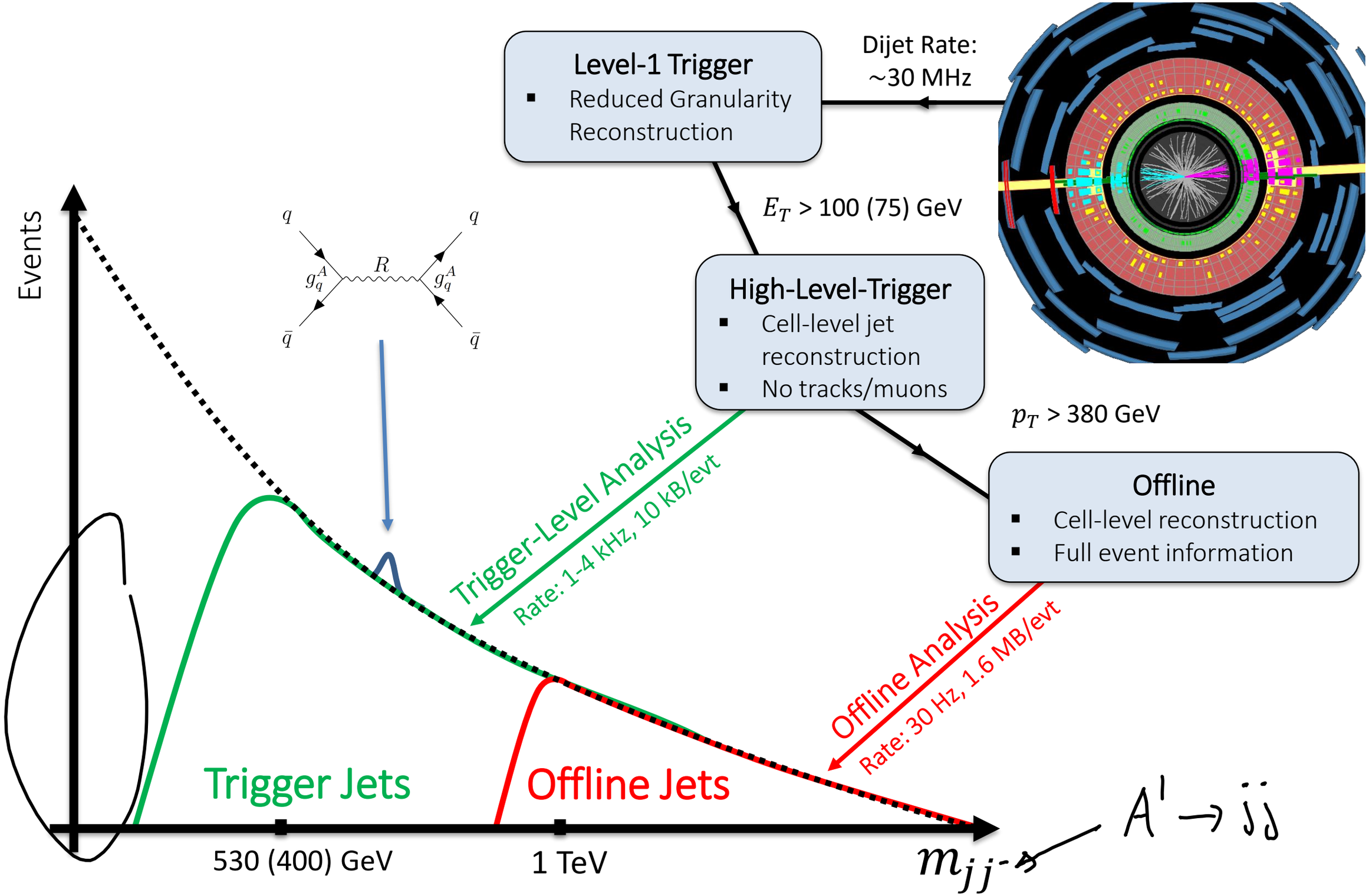
$$\text{Rate} = \sigma \cdot \mathcal{L}$$

Kinetic mixing

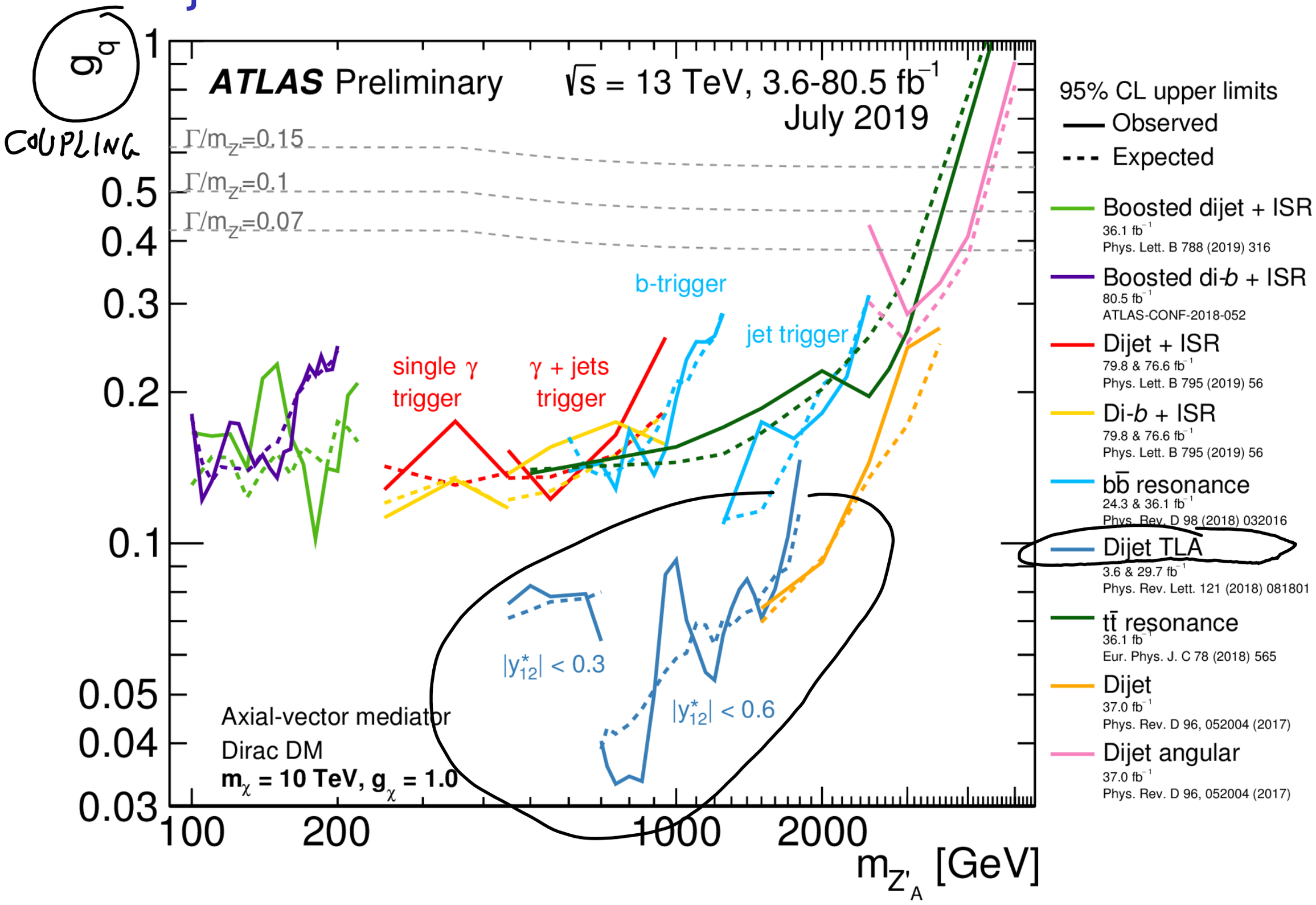




Dijets : TLA spectrum

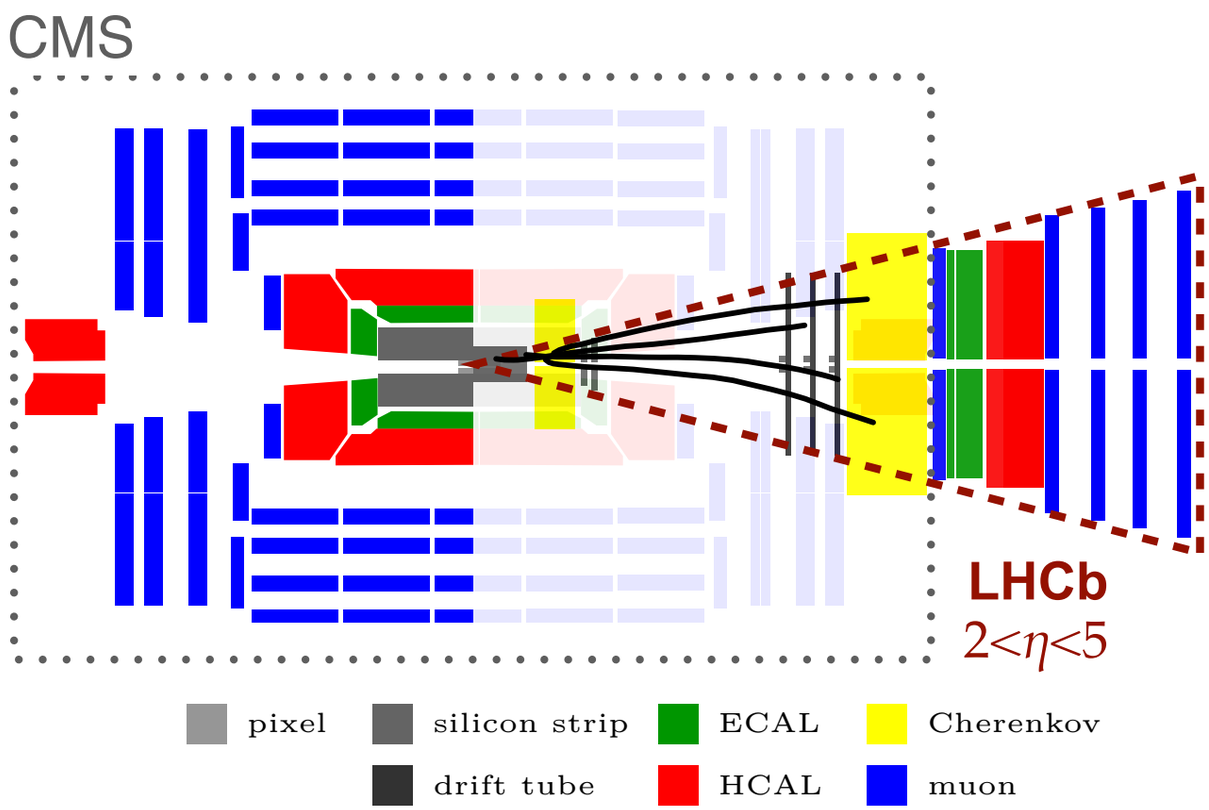


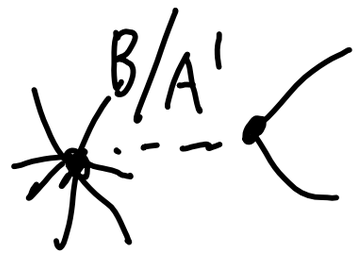
All dijet searches



LHCb vs ATLAS/CMS

- **Lower luminosity** (low pile-up)
  - ~1/8 of ATLAS/CMS in Run 1
  - ~1/20 of ATLAS/CMS in Run 2
- **Capable of very soft triggers!**
  - At hardware level (L0):
    - Muons with $p_T > 1.5\,\text{GeV}$
    - Calo deposits with $E_T > 3\,\text{GeV}$
  - At Software level (HLT):
    - Displaced vertex triggers
  - Real-time calibration in Run 2:
    - Allowed "real time analysis" i.e. keep only interesting part of event

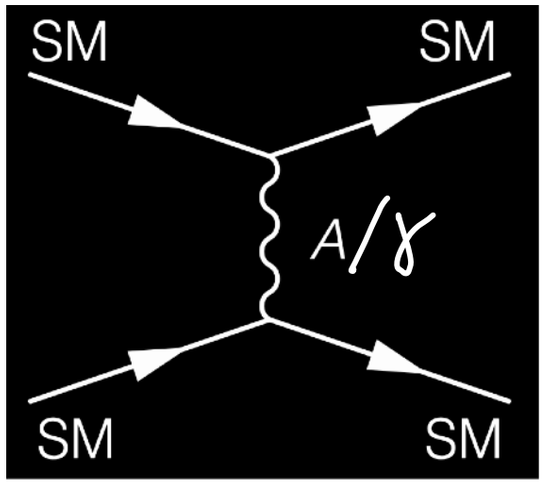


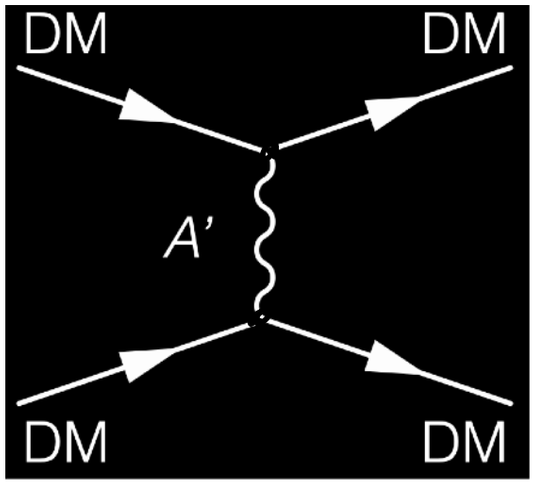


Dark photon search

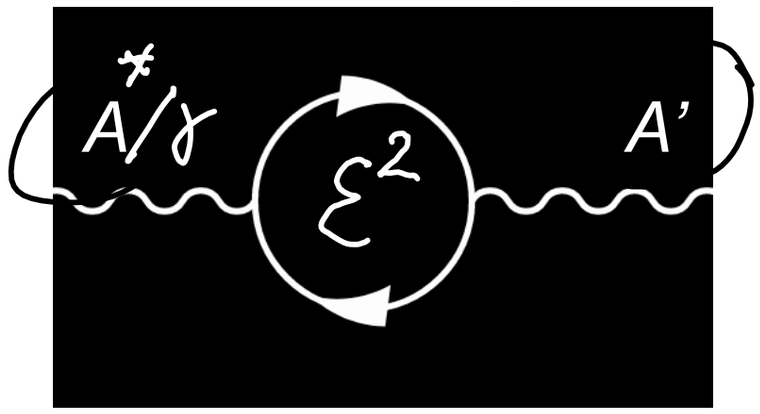
at LHCb

Dark photons phenomenology

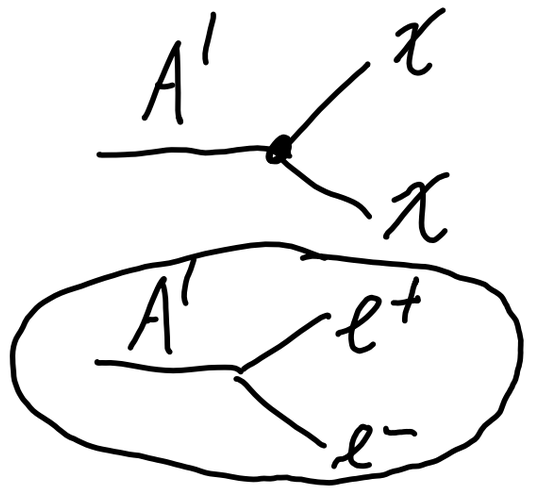




Kinetic mixing

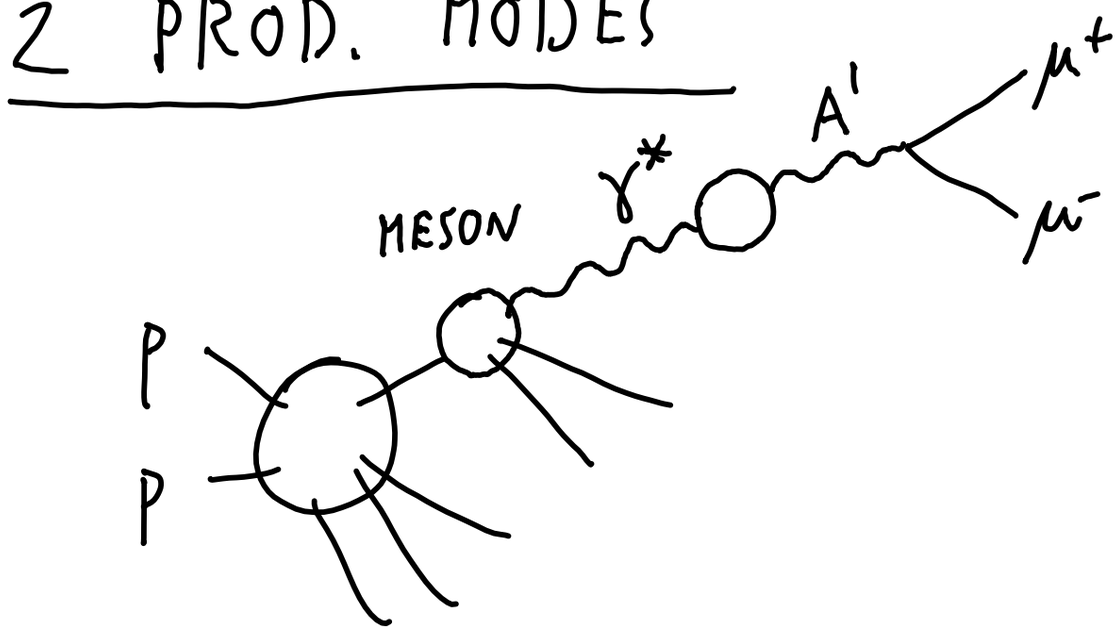


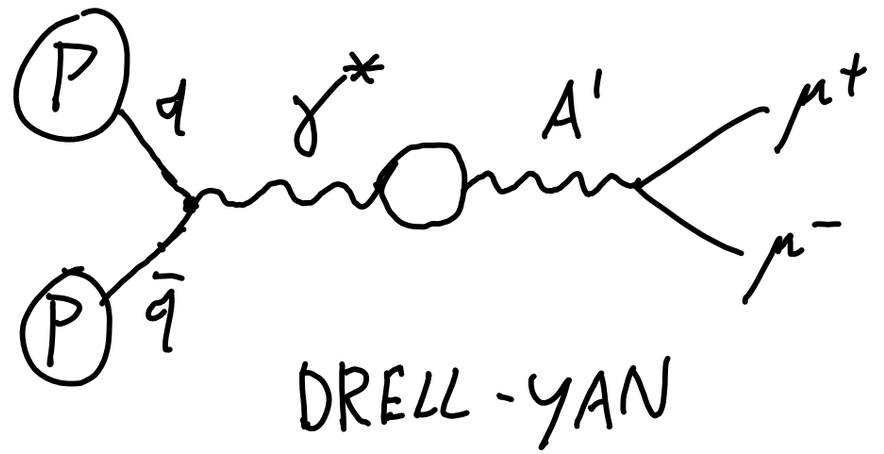
- Dark photon (A') mediates dark matter (χ) interaction
  - If $m(A') > 2m_\chi$ then **invisible decay** $A' \to \chi\chi$ dominant
  - If $m(A') < 2m_\chi$ then **visible decay** $A' \to \ell^+\ell^-$ dominant
- Production from mixing with virtual photon
  - Can oscillate to a dark photon with probability ϵ^2
- Dark photon lifetime proportional to $1/(\epsilon^2 m_{A'})$
  - Light, rarely produced dark photons are displaced



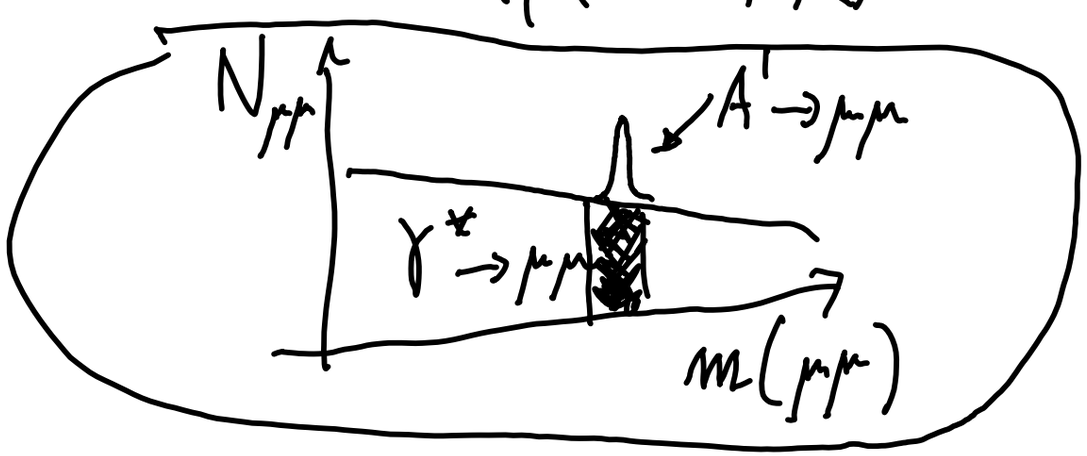
Visible $A' \rightarrow$ LHCb

2 PROD. MODES

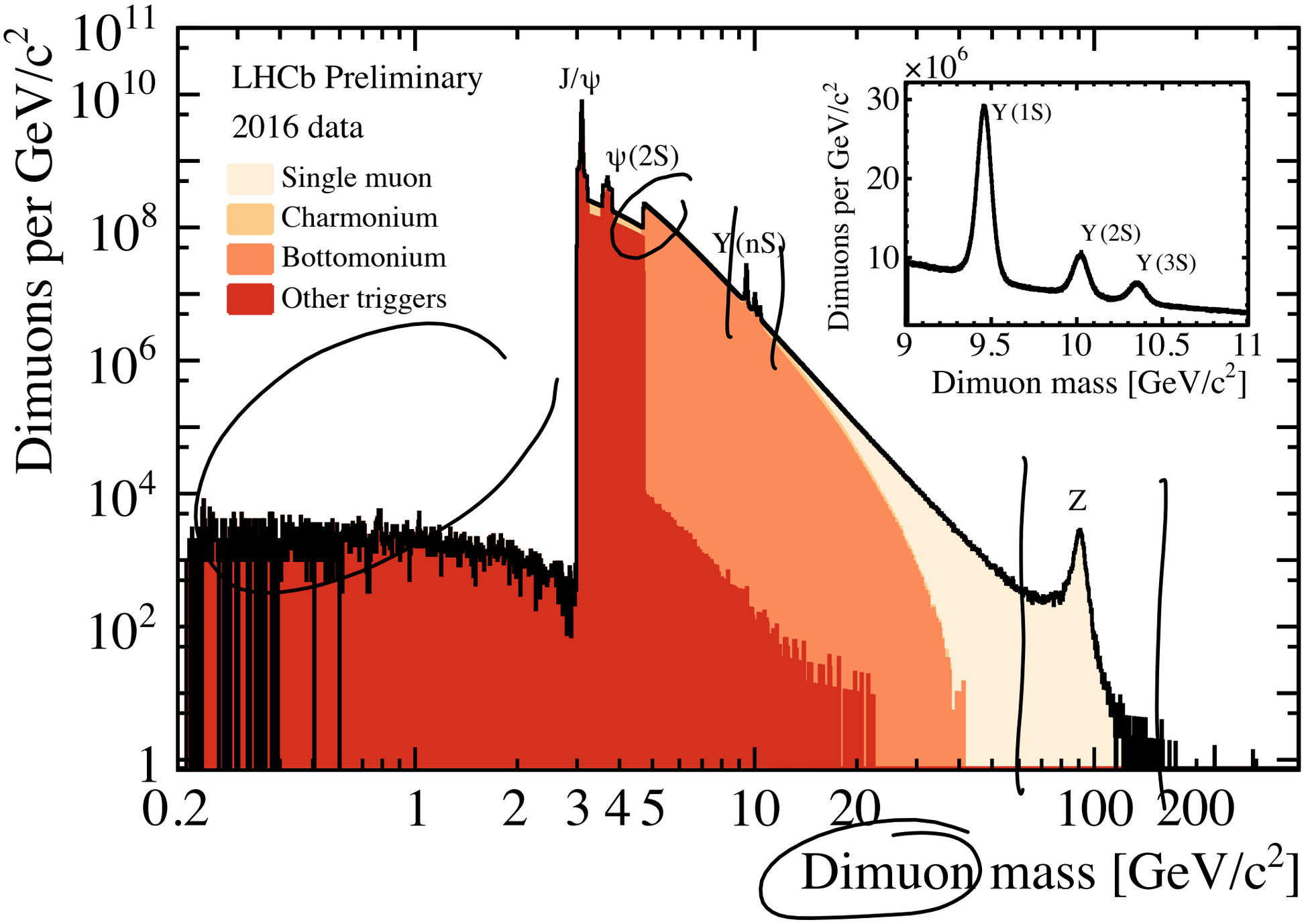




expected $N^{A'}(m_{A'}, \varepsilon) = N^{\gamma^*}(m_{A'}) \cdot \varepsilon^2 \frac{\text{eff}(A' \to \mu\mu)}{\text{eff}(\gamma^* \to \mu\mu)}$

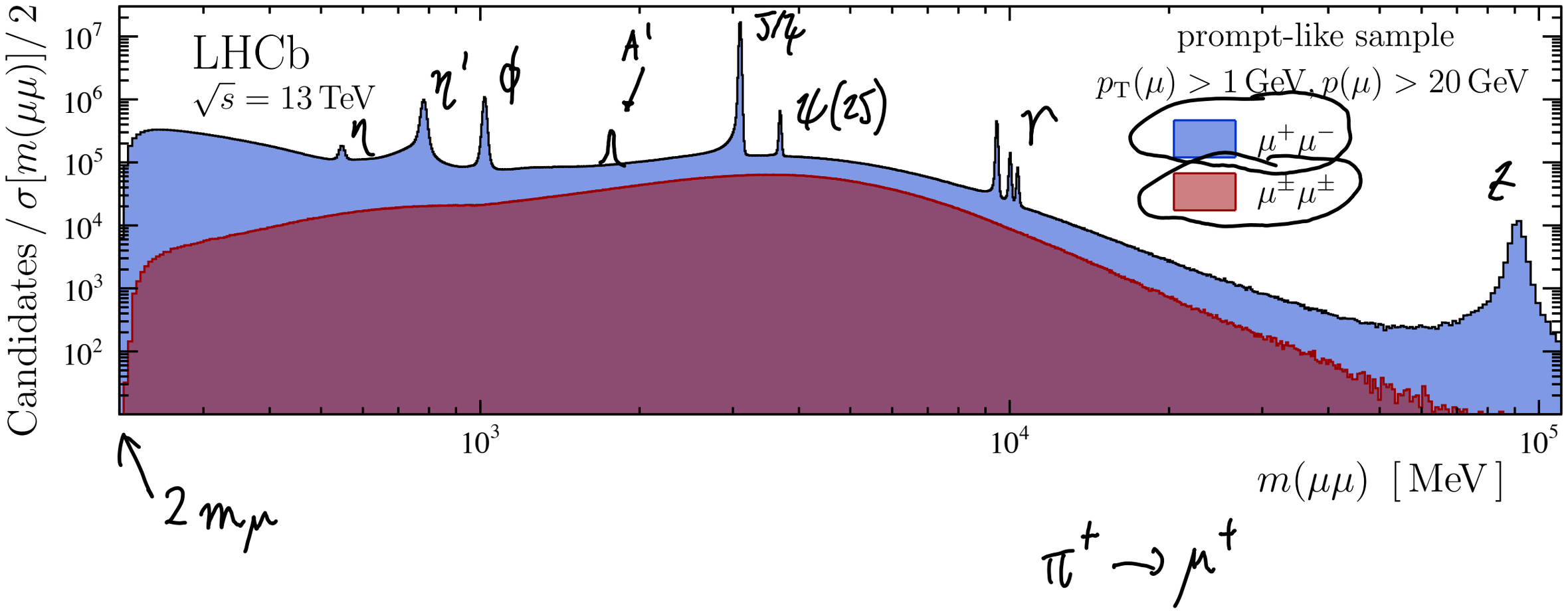


Prompt μμ trigger



Prompt μμ trigger

- Removed prescale thanks to real-time alignment and reduced event size (turbo stream)

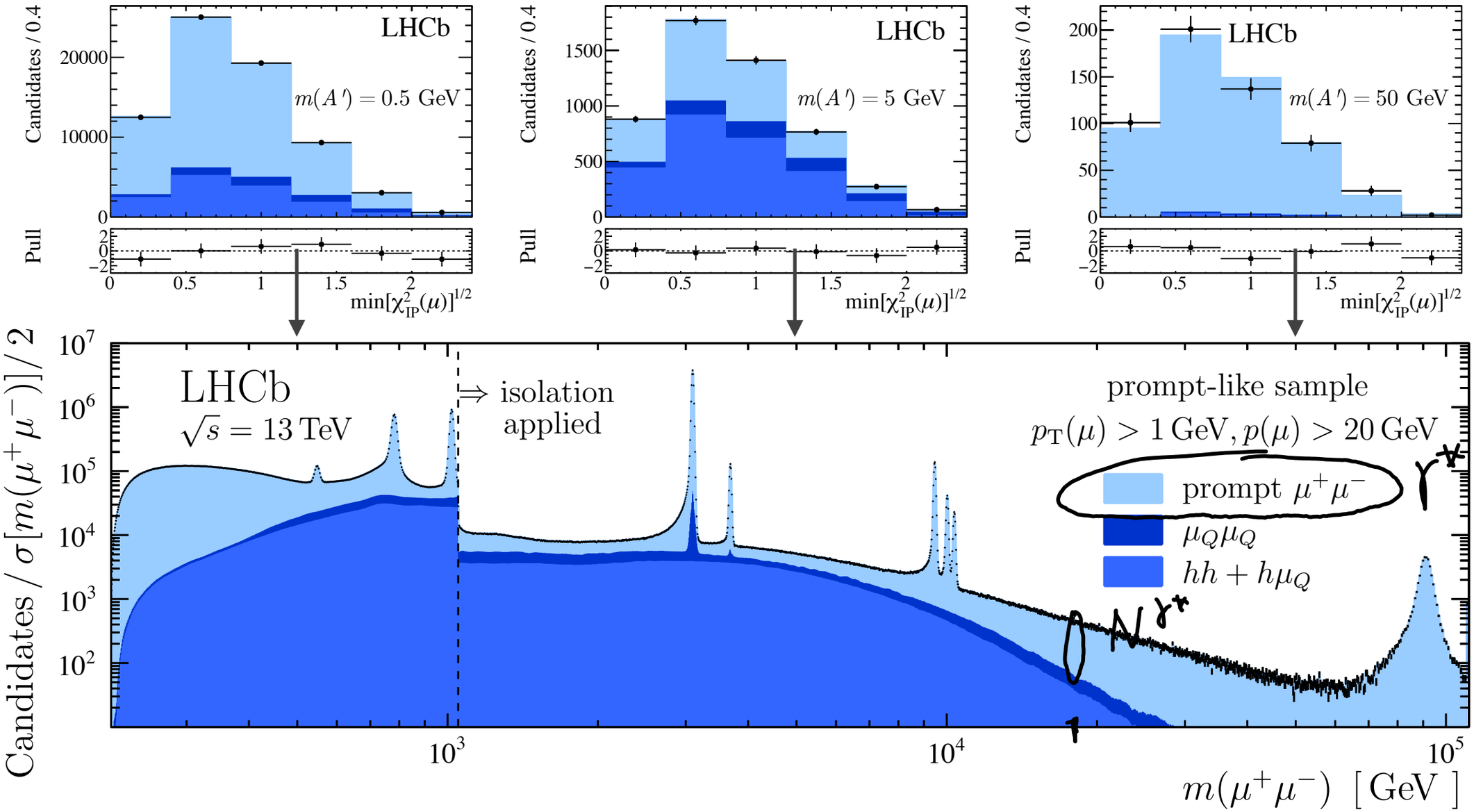


Measuring N^{γ^*}

- prompt $\mu^+\mu^-$ → the N^{γ^*} we want to measure
- $\mu_Q\mu_Q$ → muons from heavy flavour decays
- $hh + h\mu_Q$ → mis-identified pions as muons

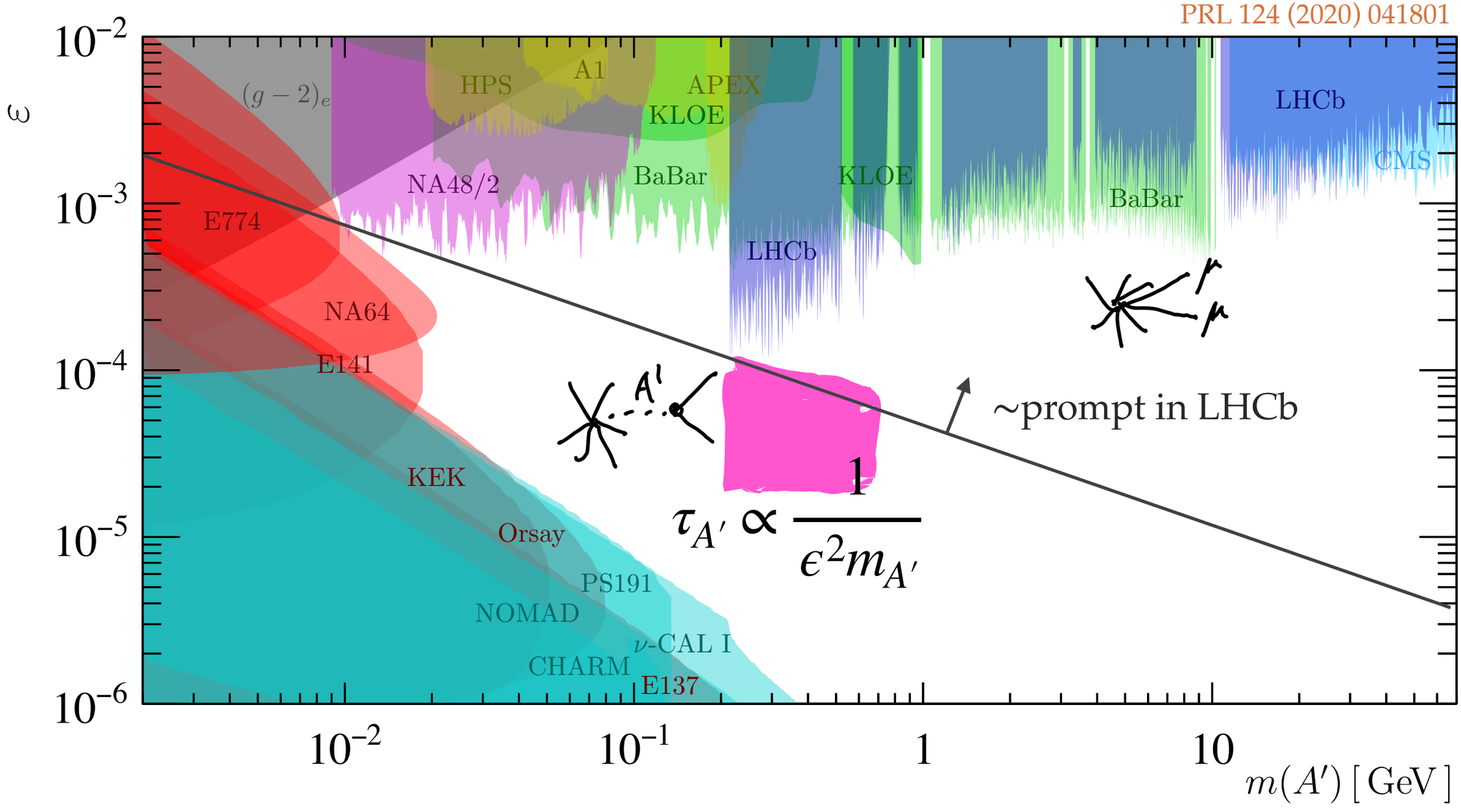
BHG

→ Using templates for $\min[\chi^2_{IP}]$ (small mass dep)

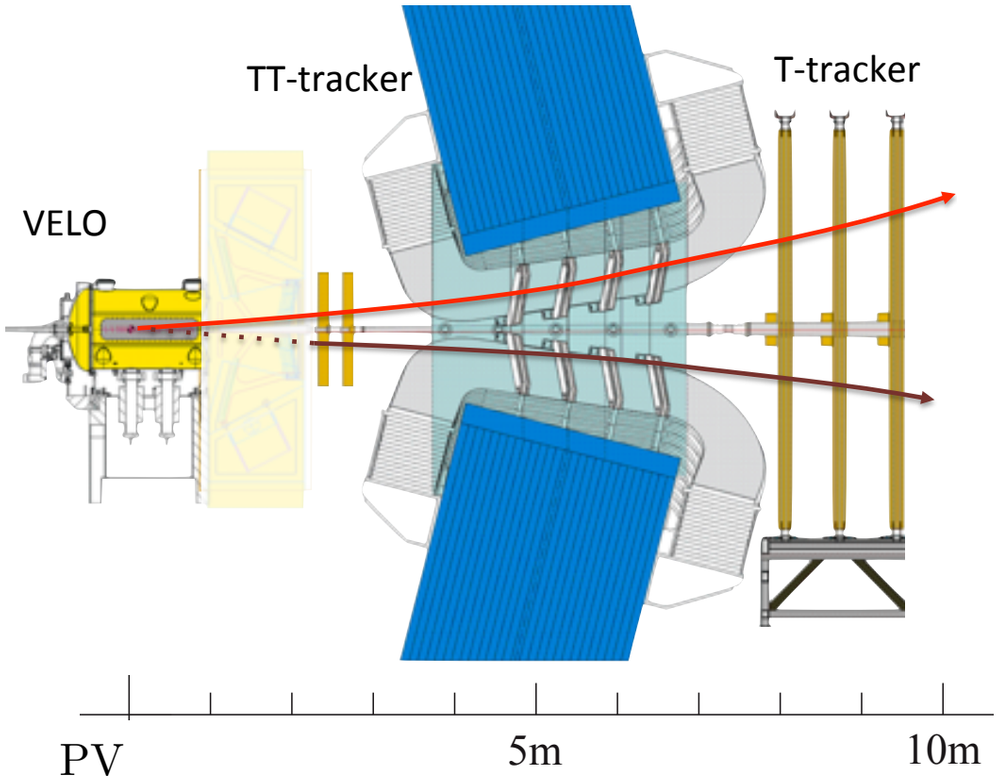


Visible A' limits

PRL 124 (2020) 041801

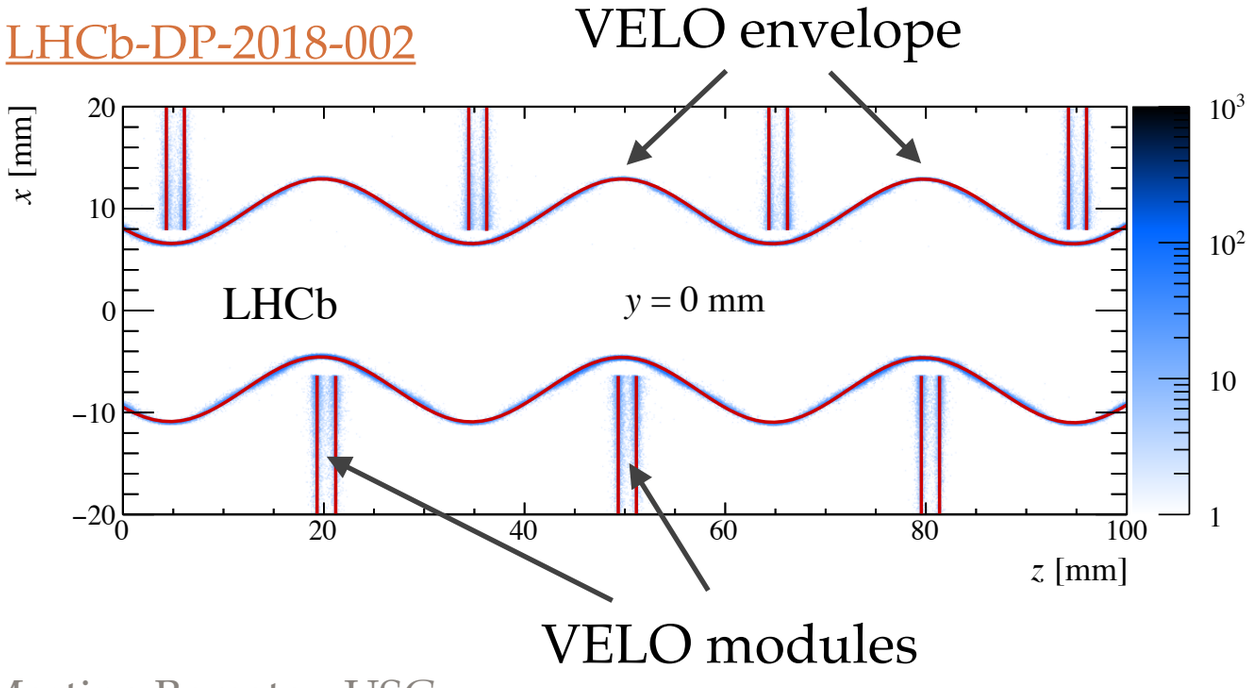


Displaced Vertices at LHCb



- Currently only **within VELO**
  - Displacement < 20 cm (but with boost)
- Could extend to **upstream tracker**
  - Displacement < 200 cm
  - Worse vertex and p resolution ($m(\pi\pi)$ resolution 2× larger)
  - Not yet available in trigger

LHCb-DP-2018-002



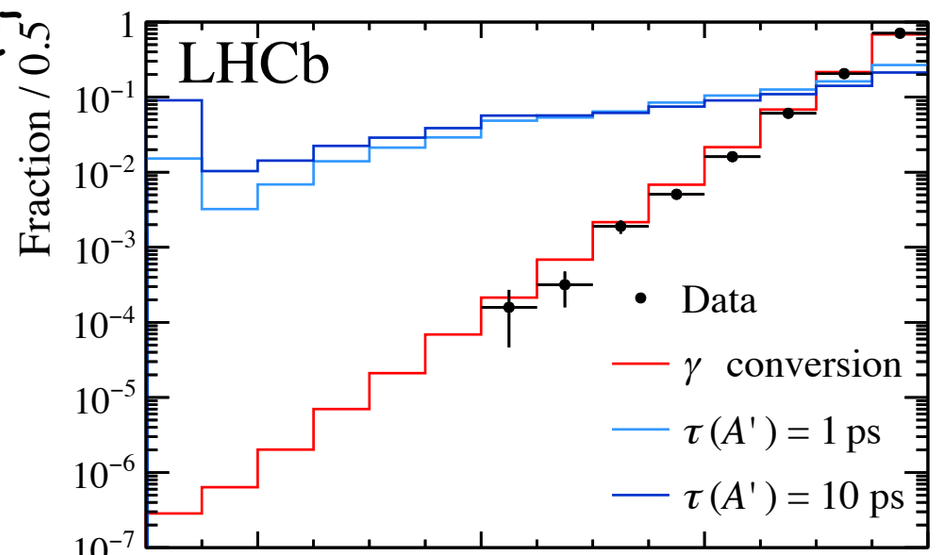
Backgrounds in VELO

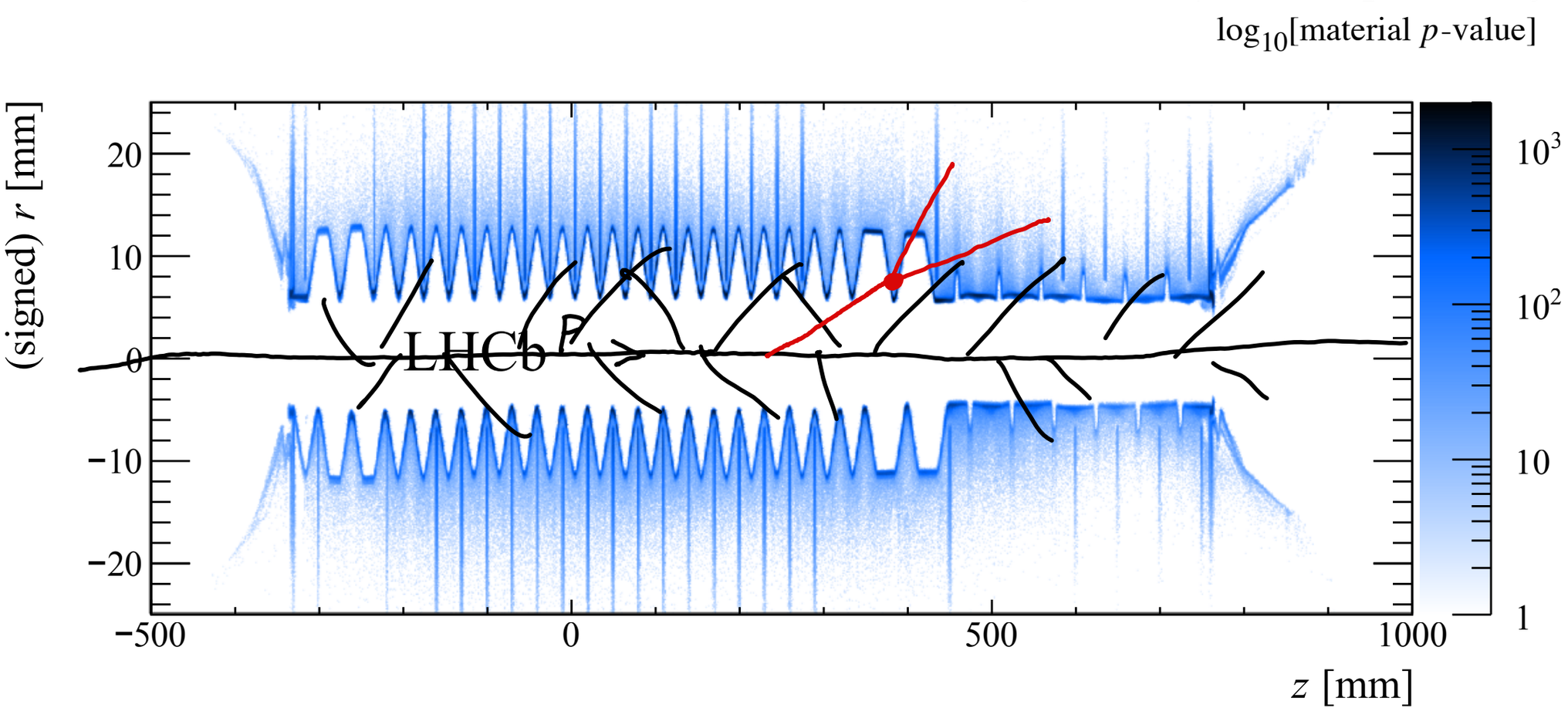
- Heavy Flavour displaced decays
  - $\tau(B)$~1.5 ps, $\beta\gamma$~10 ⇒ few mm
- Thin VELO envelope
  - **< 5 mm**: background mainly from heavy-flavour background
  - **> 5 mm**: background mainly from material interaction

VELO material map

LHCb-DP-2018-002

- VELO material map
  - based on material interactions from hadrons produced in beam-gas collisions
  - Assign probability of material interaction hypothesis to each $\mu\mu$

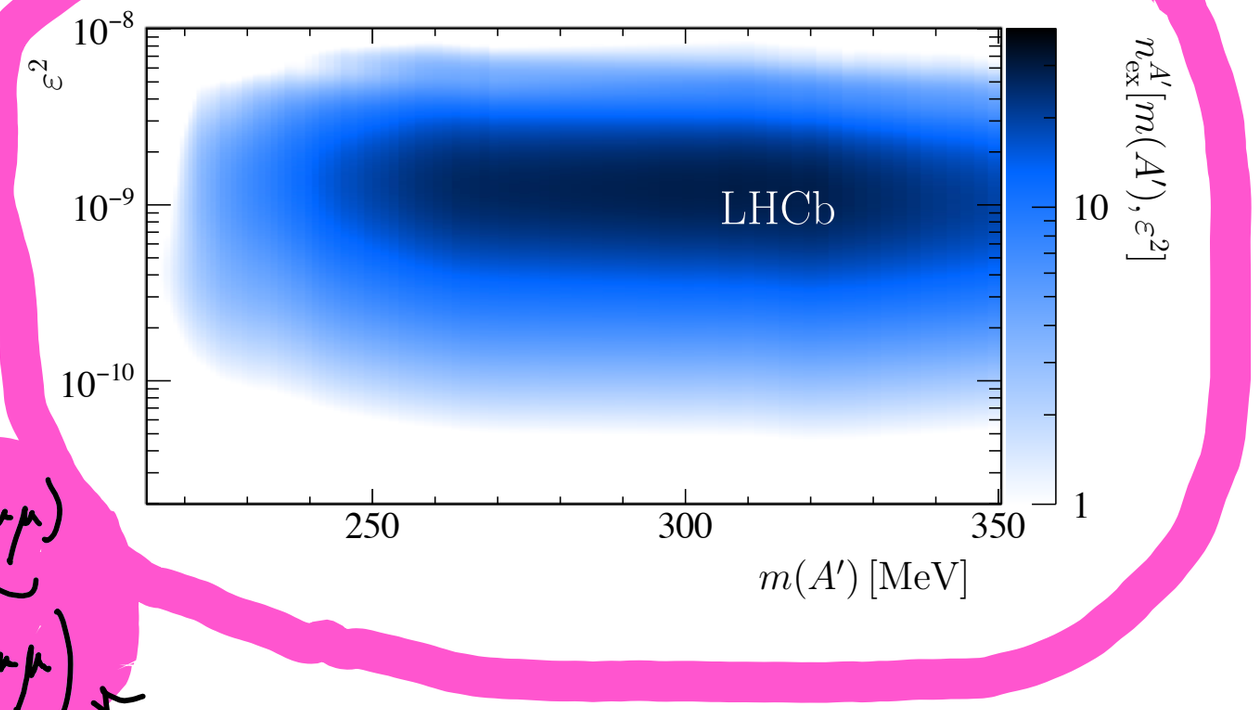




Displaced dark photon

$B \to \mu\mu$ 10^{-9}

- Much lower background
  - No long-lived SM particle decaying to $\mu\mu$
  - Main background from $\gamma \to \mu\mu$ conversions in the VELO vetoed

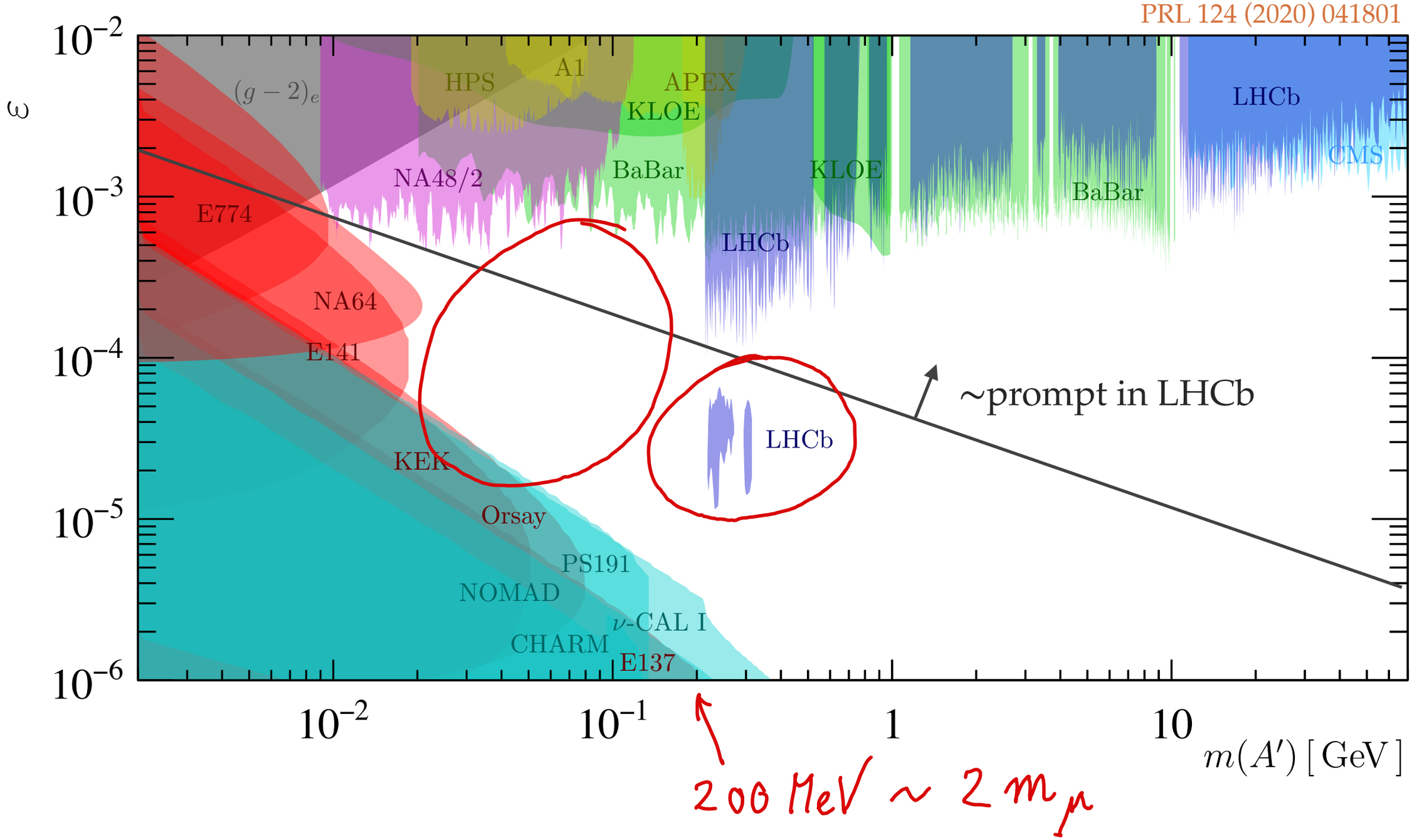


$$N^{A'}(m_{A'}, \varepsilon) = N^{\gamma^*}(m_{A'}) \cdot \varepsilon^2 \, \frac{\text{eff}(A' \to \mu\mu)}{\text{eff}(\gamma^* \to \mu\mu)}$$

SIMULATION

Visible A' limits

PRL 124 (2020) 041801



Dark Photons below $2m_\mu$

EXPERIM. TRICK

$pp \to D^{*0} \to D^0 \gamma$, $D^0 \to A' \to e^+ e^-$, $D^0 \to K^+ \pi^-$

$\text{Rate}\left(pp \to D^{*0} \to D^0 \gamma\right)^{LHCb} = 0.7\ MHz$

CONSTRAIN $m(D^{*0})$ $m(D^0)$ $\longrightarrow$ $m(e^+e^-)$ BETTER RESOLUTION

Dark Photons below $2m_\mu$