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dE/dx from boosted long-lived particles

with G.F. Giudice and M. McCullough, 2205.04473

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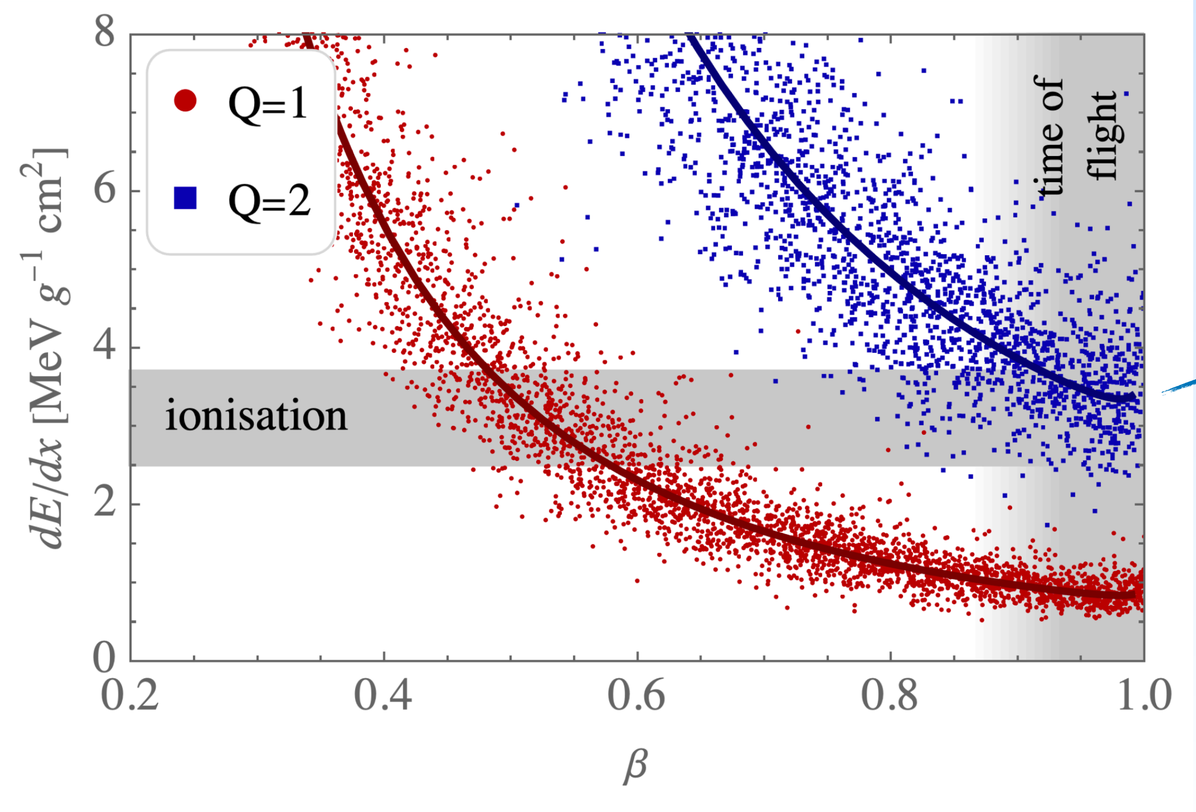
The ATLAS *dE/dx* excess

- ATLAS sees 7 events with $dE/dx \in [2.5, 3.7]\,\mathrm{MeV\,g^{-1}\,cm^2}$ in a region with 0.7 ± 0.4 background events, with $p_\mathrm{T} \in [0.8,1.5]\,\mathrm{TeV}$
- Charged SM particles have large *dE/dx* if “slow”, but $p_\mathrm{T} \gtrsim \mathrm{TeV}$ cuts them away
- ATLAS analyses in terms of “slow” BSM particles with $\beta \sim 0.5 - 0.6$
- The excess survives all checks apart from …
- … excess events have $\beta \gtrsim 0.9$ from time of flight

ATLAS excess from boosted Q=2 particles

Bethe-Bloch gives most-probable value:

$$-\left\langle \frac{dE}{dx} \right\rangle = 4\pi m_e n_e r_e^2 Q^2 \left(-1 + \frac{2}{\beta^2} \ln \frac{\beta\gamma}{I_e} \right)$$



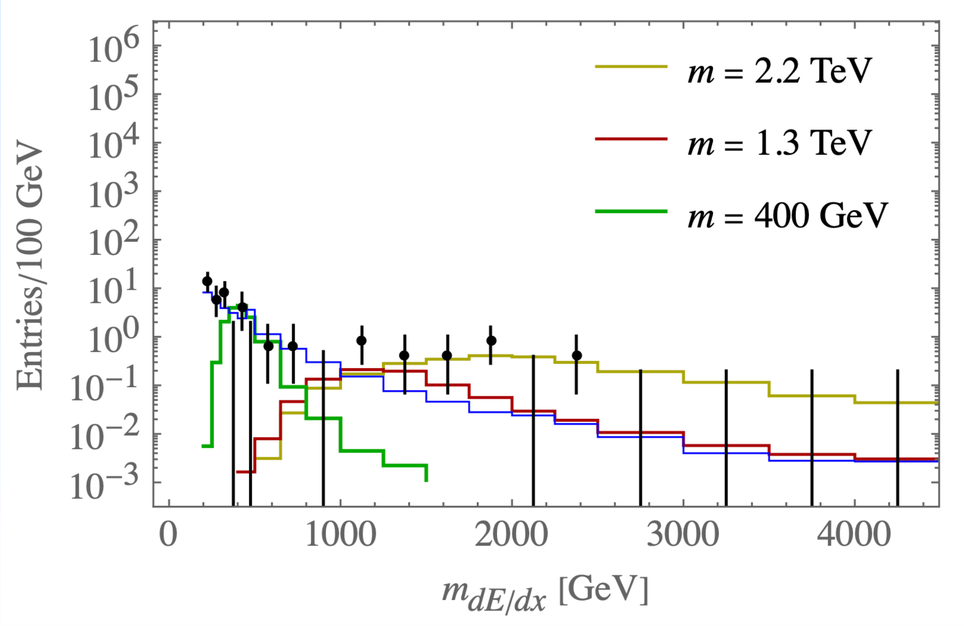
data suggest
$Q = 2$ and boosted

Interpreting *Q=1* as *Q=2*

ATLAS protocol in short

- For each event, ATLAS measures p and dE/dx
- Bethe-Bloch $f(\beta\gamma)$, invert it to find $m_{dE/dx}$
- For $Q = 1$, $m_{dE/dx} \simeq m$ up to Δp, $\Delta(dE/dx)$
- Build histograms in $m_{dE/dx}$

$$\left.\frac{dE}{dx}\right|_{\mathrm{MPV}}(p_{\mathrm{m}}/m_{dE/dx}) = \left.\frac{dE}{dx}\right|_{\mathrm{m}}$$



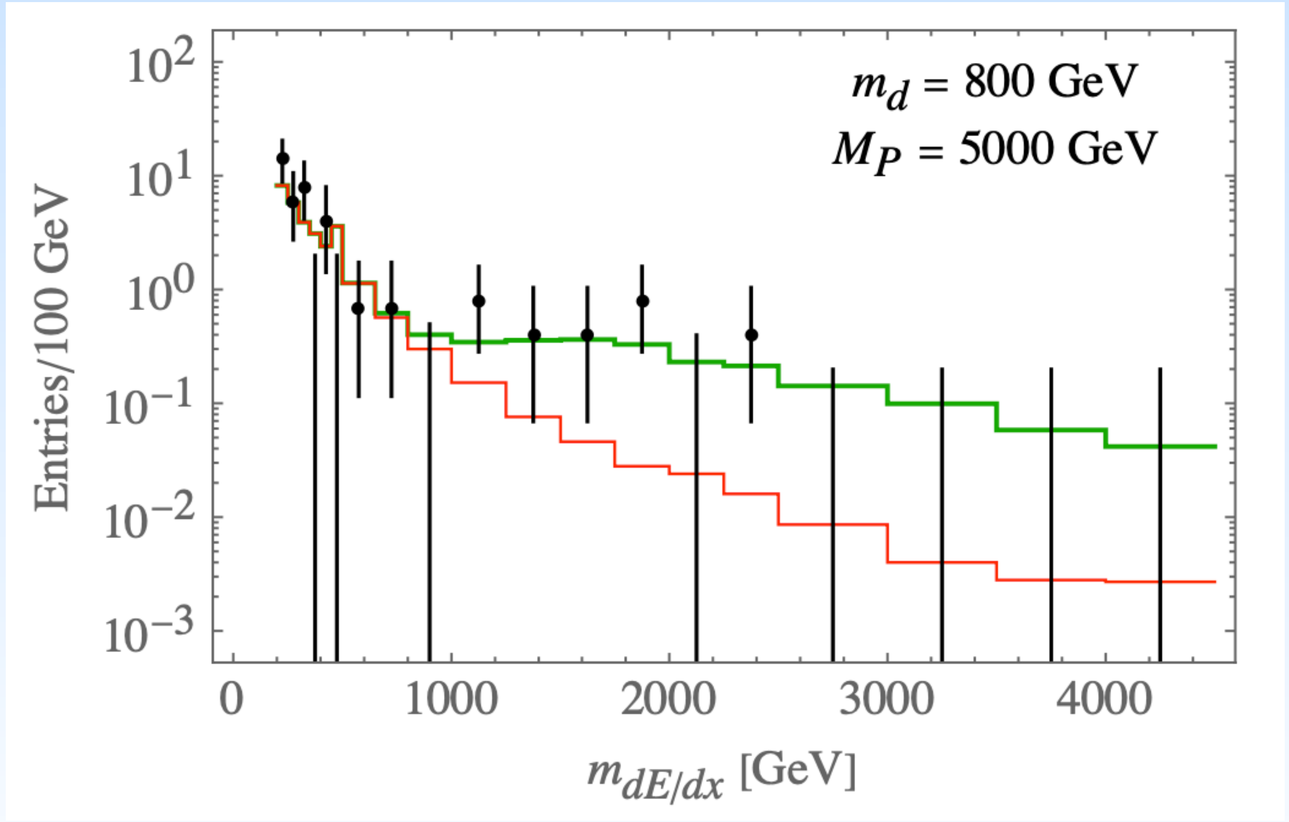
Interpreting *Q=1* as *Q=2*

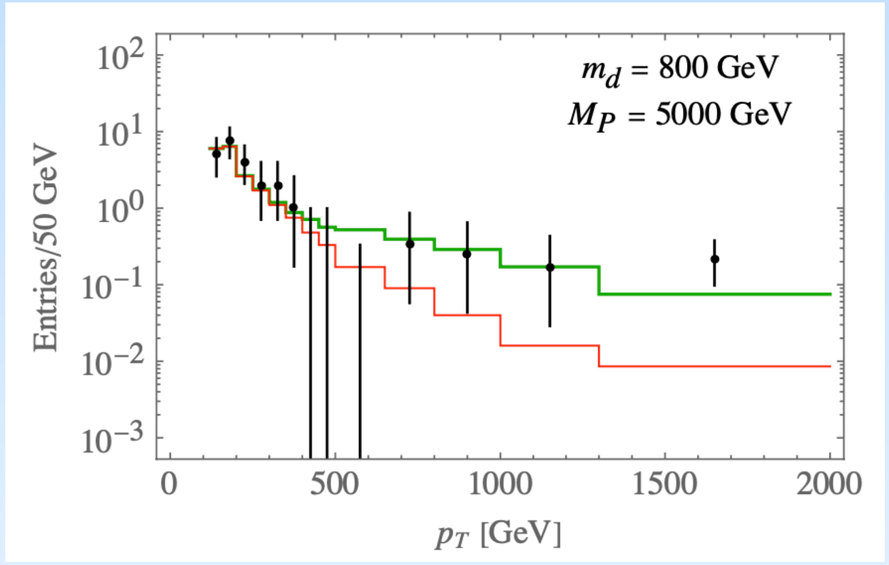
Our re-interpretation

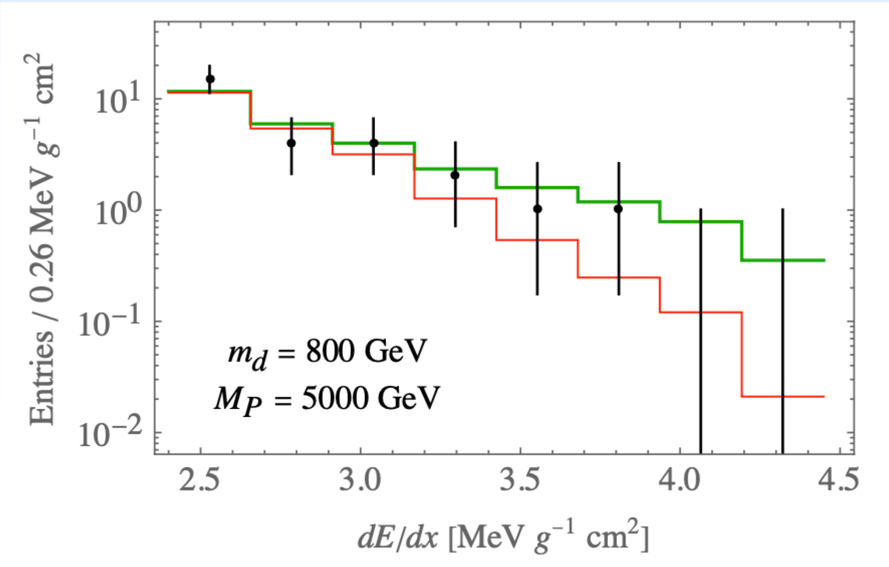
- We cannot re-interpret data as $Q = 2$, instead…
- We simulate how $Q = 2$ physics would be seen when applying ATLAS $Q = 1$ protocol and build signal models
- $$\left.\frac{dE}{dx}\right|_{\mathrm{MPV}}^{Q=2} \approx 2^2 \times \left.\frac{dE}{dx}\right|_{\mathrm{MPV}}^{Q=1}$$
- Now $m_{dE/dx} \neq m$, recall also $p_{\mathrm{rec}} = p_{\mathrm{true}}/2$
- Boosted production from decay of Parent into $Q = 2$ daughters: $pp \to P \to dd$

Results

recall cut $dE/dx > 2.4\,\mathrm{MeV\,g^{-1}cm^2}$

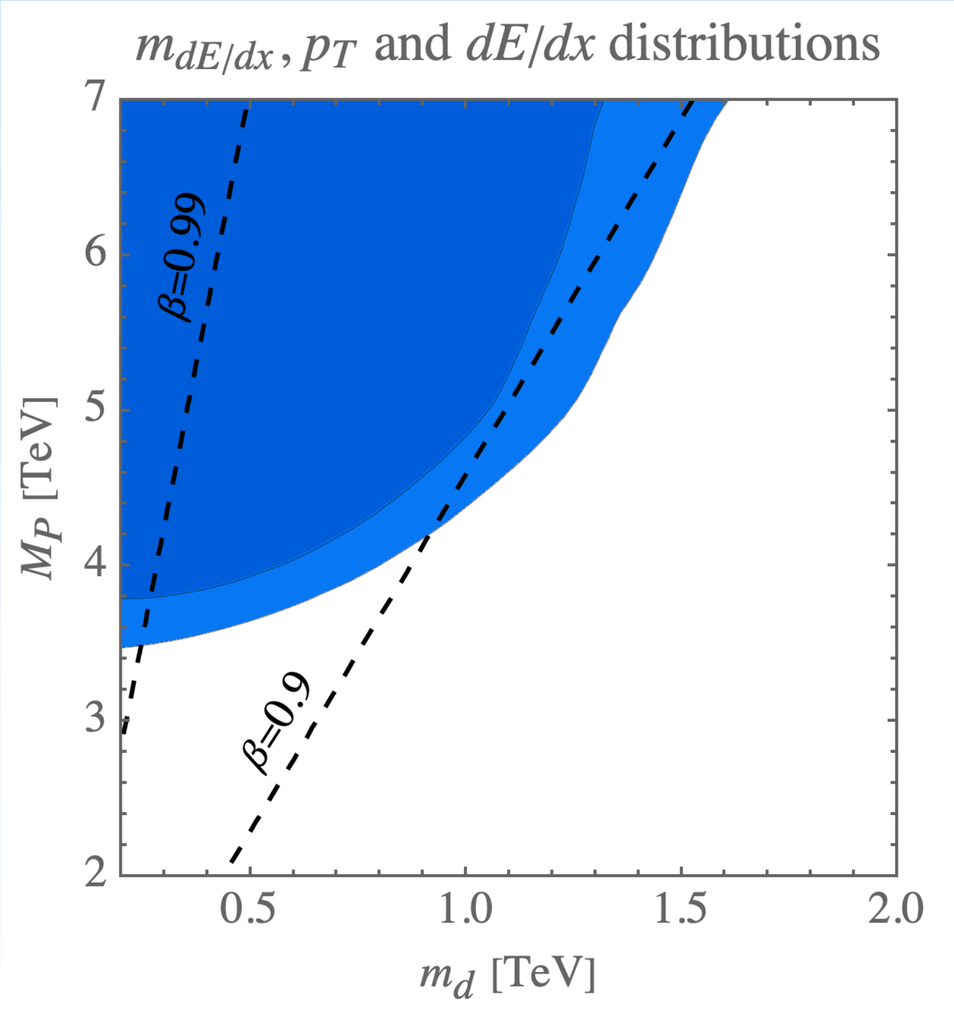






Parameter space

- Profile-likelihood fit
- Fit all three histograms, estimate confidence intervals by toy pseudo-experiments
- Only boosted $pp \rightarrow P \rightarrow dd$ production



Model-independent predictions

- Irreducible: EM unboosted production of $Q = 2$ daughters

  ⟶ events with even larger *dE/dx*

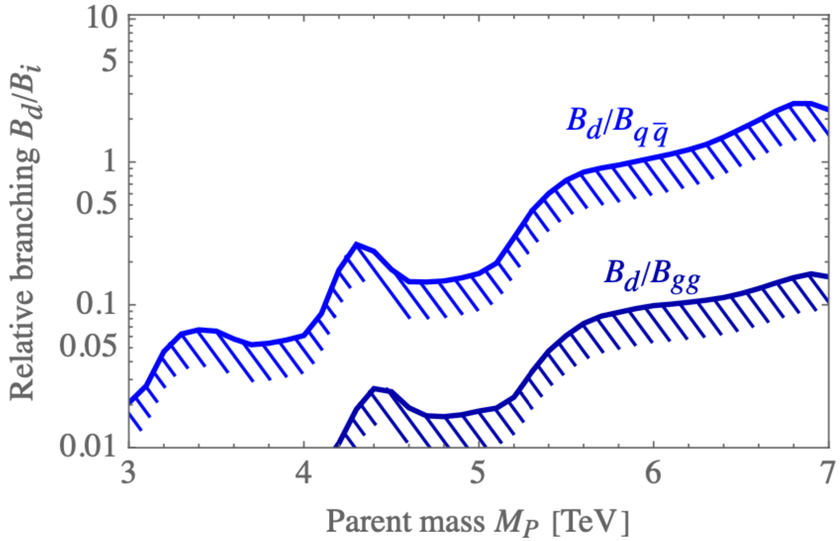
  last-week ATLAS new limits: $m_d \gtrsim 1\,\mathrm{TeV}$ (with 1.5σ excess) ⟶ $M_P \gtrsim 4.5\,\mathrm{TeV}$

- Almost irreducible: *P* resonance in dijets

  $pp \to P \implies P \to jj$

  signal determined by *dE/dx* excess,

  up to $\mathrm{BR}(P \to dd)/\mathrm{BR}(P \to jj)$



Microscopic models for the parent

- A scalar singlet coupled to gluons: $\frac{\alpha_s}{\Lambda_P} P G^2_{\mu\nu} + \kappa P d^c d$

  → it must be strongly coupled

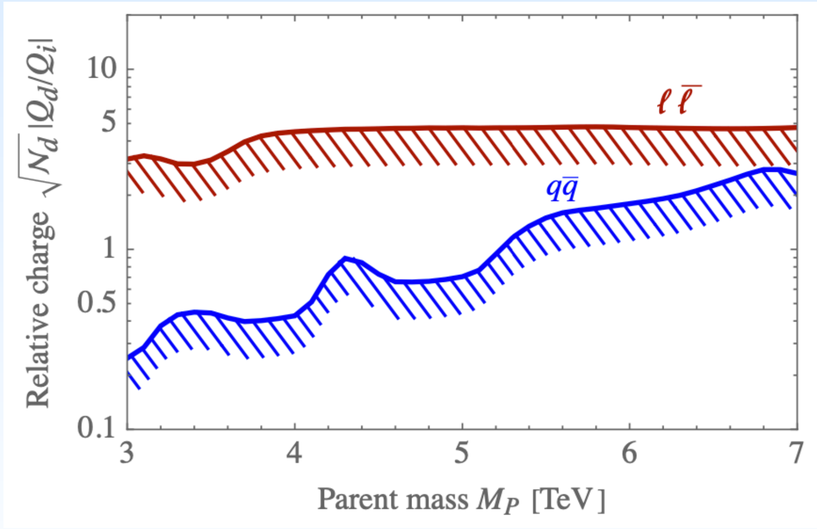
Resonance mass	Scalar resonance coupled to gluons	Vector resonance coupled to quarks
M_P [TeV]	$\Lambda_P/\sqrt{B_d}$ [TeV]	$g_{Z'}\,\lvert Q_q\rvert\sqrt{B_d}$
3	12	0.013
4	4.0	0.041
5	1.4	0.12
6	0.4	0.39

- A vector Z' coupled to quarks

  → it must be moderately leptophobic

- $\mathrm{SU(2)_L}$- or $\mathrm{SU(3)_C}$-charged parent

  → useful to model-build decay into two different daughters



Conclusions

- unknown physical background (unlikely)
- statistical fluctuation (very unlikely)
- experimental issues (no idea)
- new physics (wait for CMS and run 3: $\gtrsim 6\sigma$ if at best-fit cross-section)

Thanks