AN ANALYSIS OF THE SEARCH FOR FRACTIONALLY CHARGED PARTICLES FROM GROUPS TO PARTICLE COLLIDERS

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Motivation

- No free particle with a charge smaller than the elementary charge, ***e***, has yet been observed.
- However, these theorised 'fractionally-charged particles' (FCPs) are **not forbidden** by the Standard Model.
- If discovered, FCPs could help discover the **true group structure** of the Standard Model
- This research aimed to examine searches for FCPs to identify promising areas for future experiment, as well as investigating the link between group theory and quantisation through the simpler analogy with spin.

Group Theory

- Quantisation conditions differ depending on underlying group structure
- Devised a proof for the global relationship between the spin group SU(2) and its 3-dim representation SO(3)
- SU(2) is the **double cover** of SO(3)
  - $SO(3) = \frac{SU(2)}{\mathbb{Z}_2}$
  - SU(2) allows ½-integer spin
  - SO(3) allows only integer spin
- Similarly, the SM gauge group has a number of candidates:

$$G_p = \frac{SU(3)_C \times SU(2)_L \times U(1)_Y}{\mathbb{Z}_p}, p \in \{1, 2, 3, 6\}$$

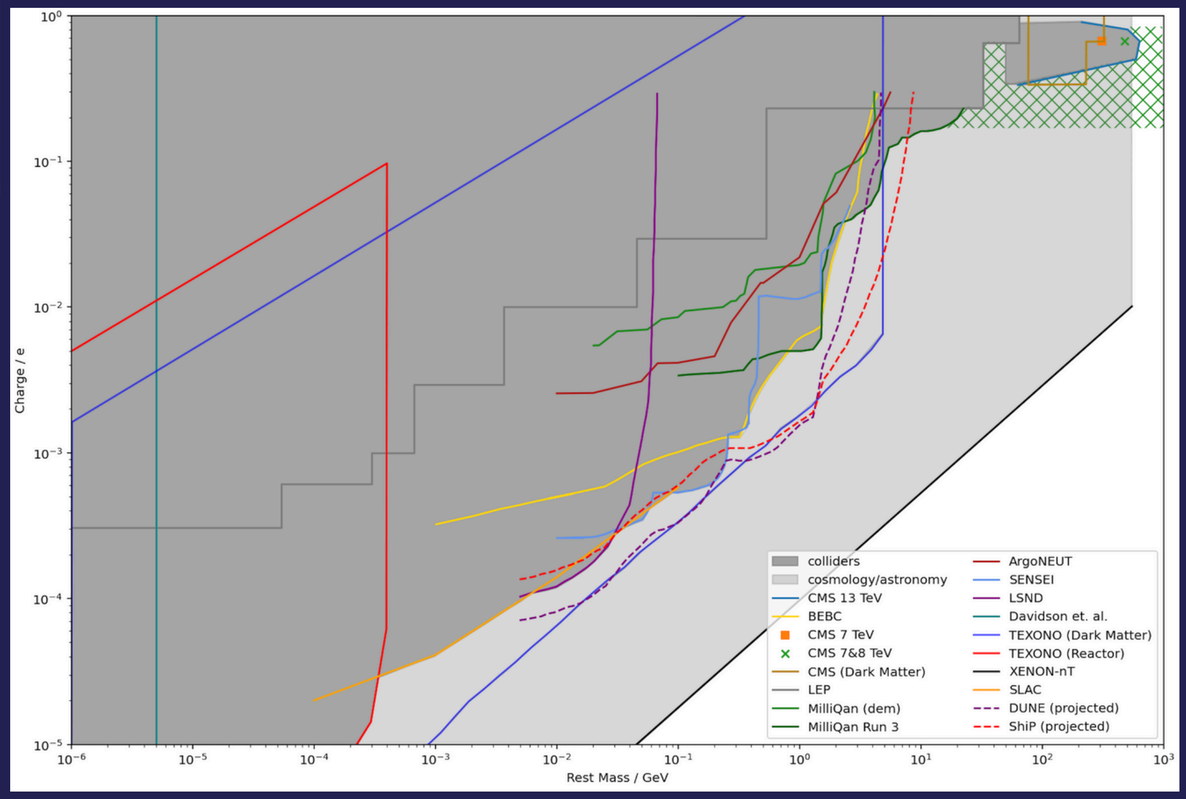
- Where different *p* allow different minimum charges - *p* = 1 permits ⅙*e*, and the others ⅓e, ½*e* and *e* respectively.
- The discovery of any FCP would narrow down the candidates, and the discovery of a particle of charge ⅙*e* would single out the true SM group.

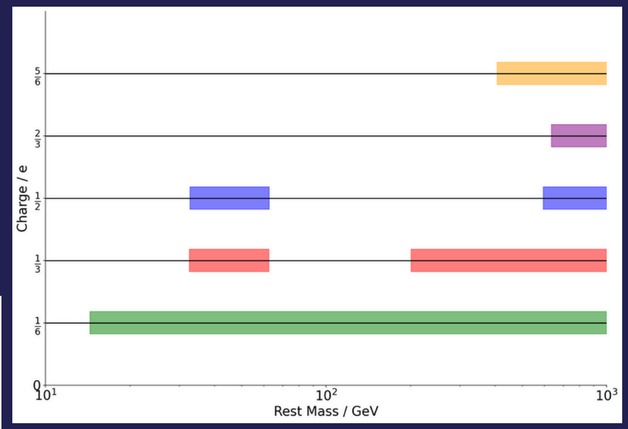
References

[1] R. Alonso *et al*, "Fractional-charge hadrons and leptons to tell the Standard Model group apart", 2024.

Methodology

- Exclusion limits were extracted from published direct detection and cosmological bounds (latter not included in results) using *plotdigitizer*
- Plotted using python's matplotlib library.
- Combined limits for charges relevant to SM group extracted and re-plotted
  - Q/*e* = 1/6, 1/3, 1/2, 2/3, 5/6





Q/e	Excluded m / GeV
$\frac{1}{6}$	< 14
$\frac{1}{3}$	$< 33, 50 - 600$
$\frac{1}{2}$	$< 33, 50 - 595$
$\frac{2}{3}$	< 640
$\frac{5}{6}$	< 405

Findings

- Strongest bounds for Q/*e* = 2/3, 5/6
- Weakest limits for Q/*e* = 1/6.
- 30 - 50 GeV window for 1/3*e*, 1/2*e*

Conclusions

- Weakest limits for 1/6e as the CMS search (high-energy) could only probe to 1/3*e*
- 30-50 GeV pocket *could* contain an undiscovered FCP, corresponding to $Z \to \chi\overline{\chi}$ or $H \to 2\chi\, 2\overline{\chi}$

I recommend the following future experimental directions:

- Use data from HL-LHC to probe 1/6*e* at high energies
- Carry out further CMS/collider searches at 30-50Gev
- Develop next-generation colliders (e.g. FCC) to extend FCP searches to higher energies (>TeV)