Bounds and Prospects for Stable Multiply Charged Particles at the LHC

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Based on arxiv:1812.03182.

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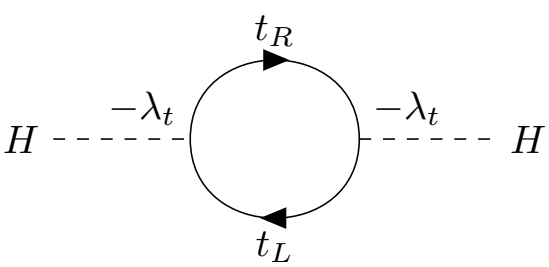
Overview

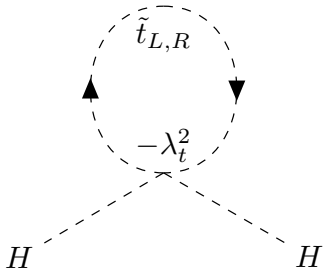
- Motivation
- Open Channel
- Closed Channel
- Combined Bounds

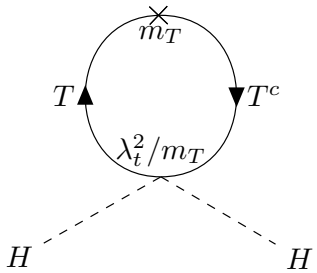
Colorful twisted top partners

Long-lived color-triplet top partners with arbitrary charges (arxiv:1704.03393):

- Naturalness motivated solution to the Hierarchy problem.
- Can be a scalar or a fermion.
- Stable due to approximate $U(1)_{partner}$ symmetry or approximate Z_2 symmetry.
- Charges other than $Q = 2/3 + n$ or $Q = -(1/3 + n)$, where n is a positive integer, cannot decay to SM particles altogether.







Partnerium

- If the top partner decay is suppressed - partnerium could form.
- Partnerium - partner and anti-partner bound state similar to positronium.
- Partnerium is bound both by QCD and EM potential.
- The bound state is free to annihilate to SM particles.

$$V(r) = -\frac{C\alpha_s + Q^2\alpha}{r}$$

Stable multiply charged particles

Goal: Obtain bounds on masses of stable multiply charged particles and project to future scenarios.

- “Open” signatures - pair produced top partners.
- “Closed” signatures - partnerium bound state resonance.
- Interplay of the two channels.

Model-independent study, including both colored and lepton-like particles.

Open channel - available searches

- No searches for stable multiply charged colored particles.

Other heavy stable particle searches:

- R-hadron searches - 7, 8 and 13 TeV, optimized for unit-charged R-hadrons, uses mass estimate as discriminator (arxiv:1609.08382).

- Multiply charged lepton-like particle searches - 7, 8 TeV, selections are mass and charge independent, no QCD effects, no photon-fusion (arxiv:1305.0491).

Recast is needed to obtain bounds on multiply charged particles.

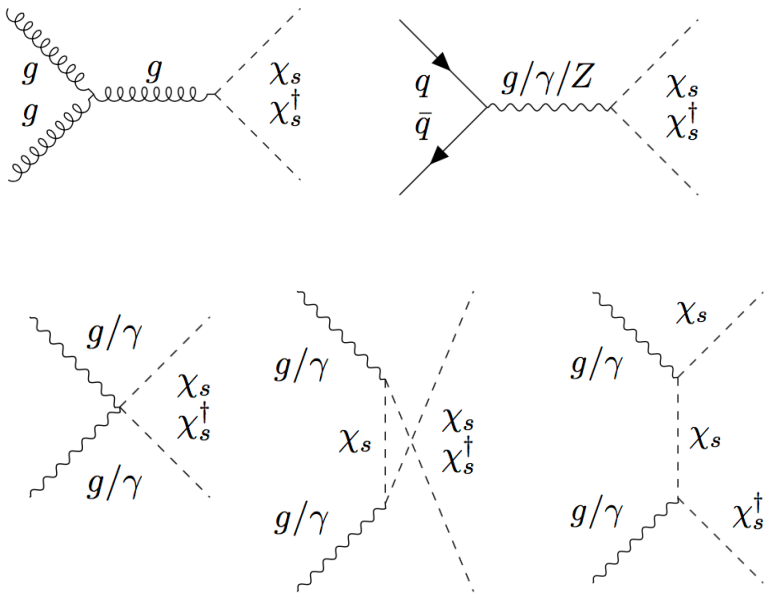
Open channel - recast procedure

- The search is a counting experiment which imposes an upper limit on the effective cross section (cross section x efficiency).
- Cross section: LUXqed PDF set, MadGraph5 and Pythia8.
- Efficiency:
  - p_T cut: $p_T^{truth} \geq Q \times (45\ \text{GeV})$.

Reduced efficiency for small m and large Q.

  - timing requirement - reach muon system in 25 (50) ns & ionisation energy loss.

Reduced efficiency for large m and large Q.



$$r = \frac{p_T}{0.3 \cdot B \cdot Q}$$

Closed channel - available analyses

- The bound state is unstable, hence can be detected as a resonance.
- The di-photon channel is the most sensitive because of the larger charges of constituents and small background.

Previous analyses:

- Partnerium resonances - only $Q < 10/3$ and does not include EM effects (arxiv:1704.03393, arxiv:1610.06582).
- Leptonium resonances - considers only color-singlets (arxiv: 1710.11396).

Not sufficient to set bounds on multiply charged particles.

Closed channel - recast procedure

- Using the CMS 13 TeV di-photon search at 35.9 fb^{-1} (CMS-PAS-EXO-17-017).
- Efficiency depends only on resonance width.
- Need the production cross section accounting for EM effects.

$$\Gamma_{B\to\gamma\gamma} = \frac{24\pi\alpha^2 Q^4}{M^2}|\Psi(0)|^2 \quad (\times 2 \text{ for fermions}, \times 1/3 \text{ for color-singlets}), \qquad |\Psi(0)|^2 = \frac{(C\alpha_s + Q^2\alpha)^3 M^3}{8\pi n},$$

$$\Gamma_{B\to gg} = \frac{16}{3}\frac{\pi\alpha_s^2}{M^2}|\Psi(0)|^2 \quad (\times 2 \text{ for fermions}),$$

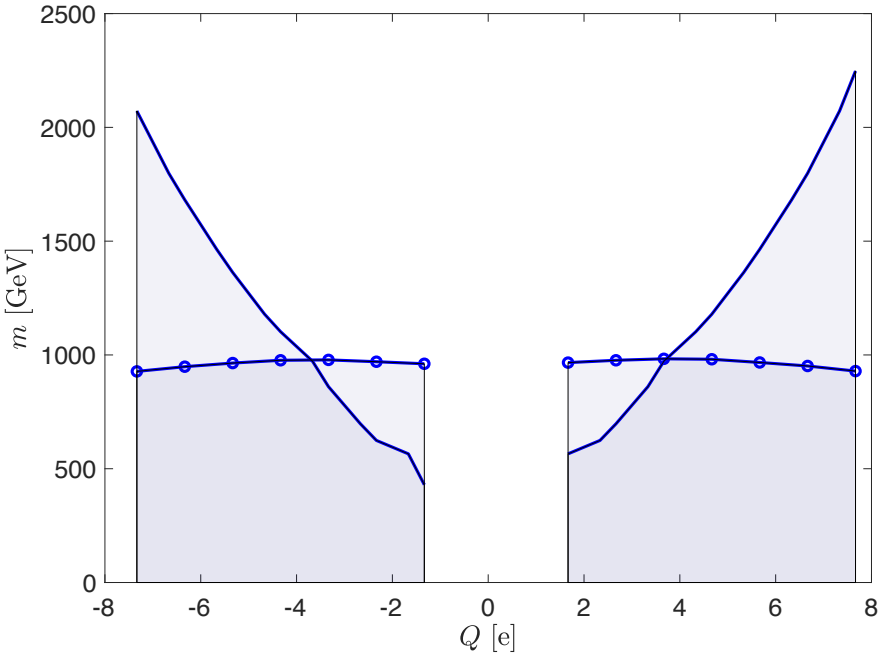
$$\sigma_{pp\to B\to\gamma\gamma} = 8\pi\int_0^1 \left[\frac{1}{64}\mathscr{L}_{gg}(\tau)\Gamma_{B\to gg} + \mathscr{L}_{\gamma\gamma}(\tau)\Gamma_{B\to\gamma\gamma}\right] \frac{\Gamma_{B\to\gamma\gamma}}{(\hat{s}-4m^2)^2 + \hat{s}(\Gamma_{B\to\gamma\gamma}(1+2\tan^2\theta_W+\tan^4\theta_W)+\Gamma_{B\to gg})^2}\frac{d\tau}{\tau}.$$

- Use LUXqed PDF set (arXiv:1607.04266).

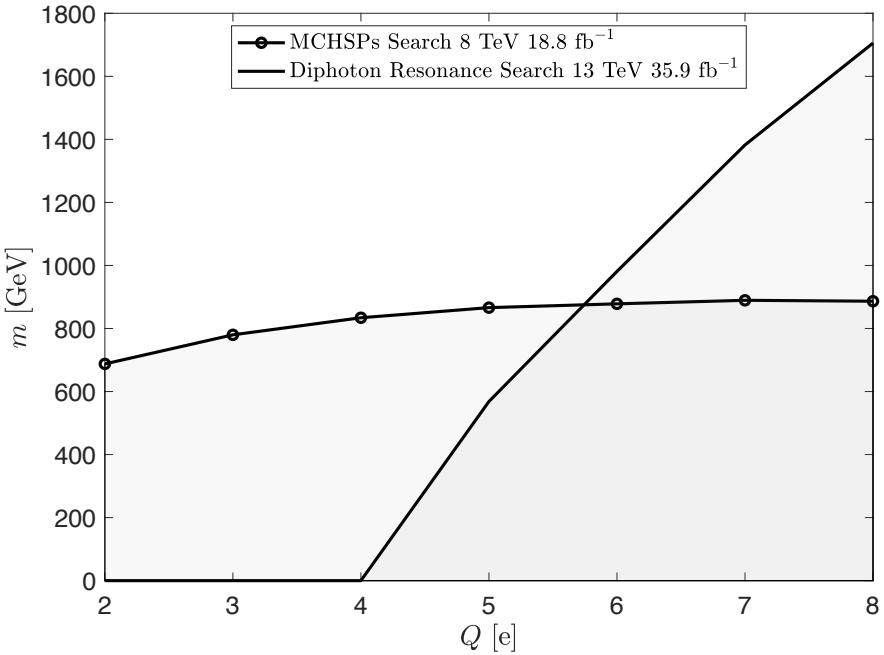
Recast bounds

- Open channel bounds are stronger for Q < 4 (6 for lepton-like).
- Closed channel bounds are stronger for Q > 4 (6 for lepton-like).

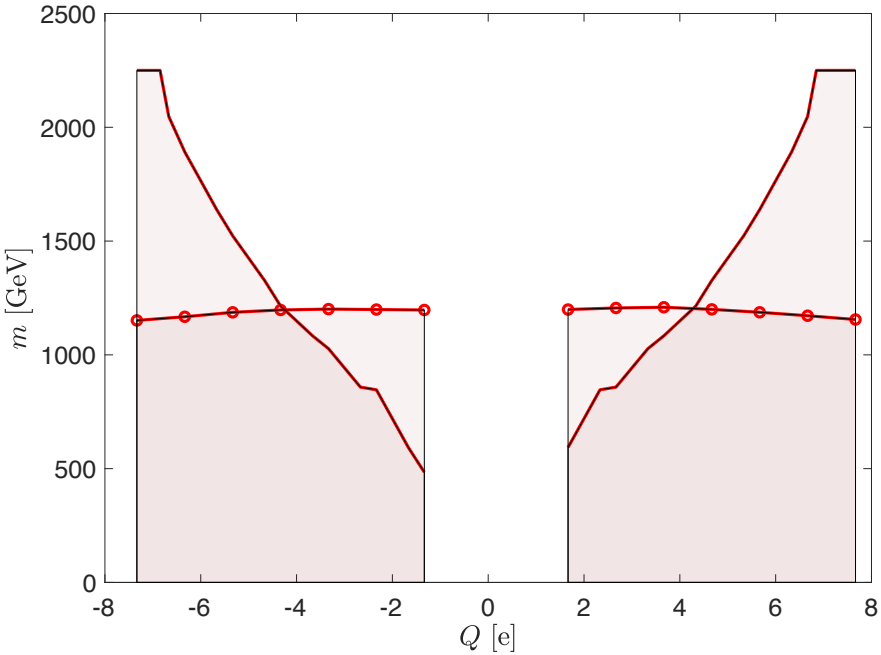
Colored scalars



Lepton-like particles

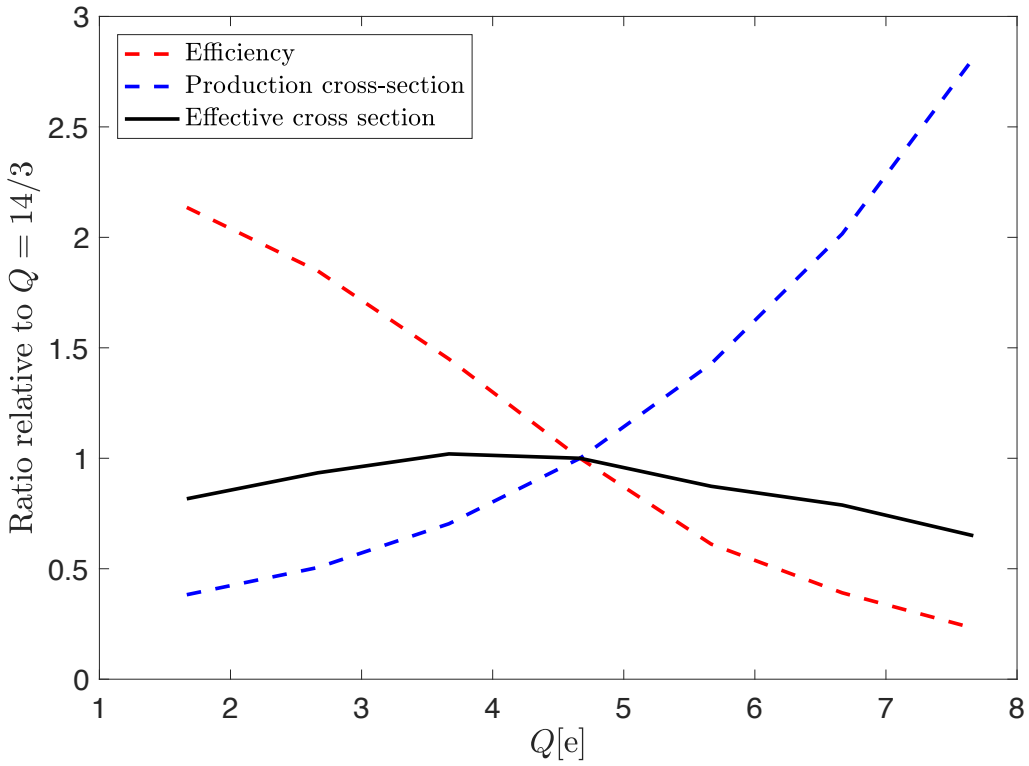


Colored fermions



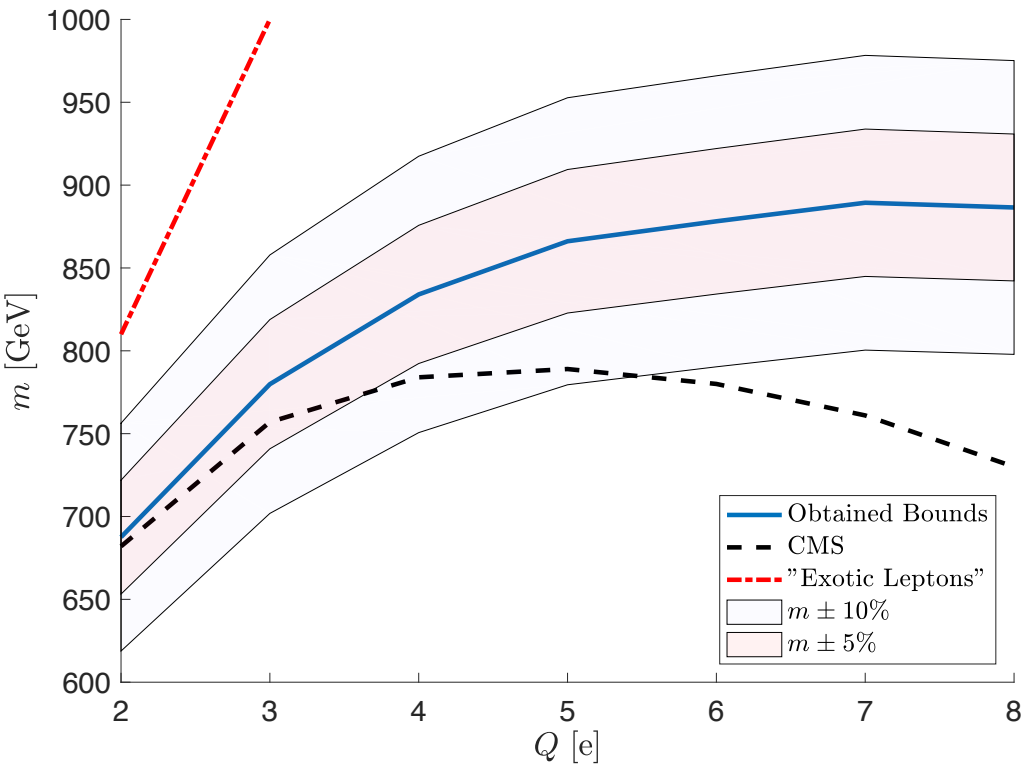
Flat bounds

- Open channel bounds are nearly charge independent for both scalars and fermions.
- Efficiency is worse with increasing charge due to p_T/Q for small m and timing for large m.
- Cross section increases with charge due to Drell-Yan, gγ and γγ fusion.
- Example for m = 1 TeV.



PDF choice - leptons

- Compare our result with the bound in arxiv:1710.11396.
- NNPDF2.3QED set central value overestimates the photon PDF.
- NNPDF2.3QED set uncertainties were not taken into account.
- Use LUXqed set.

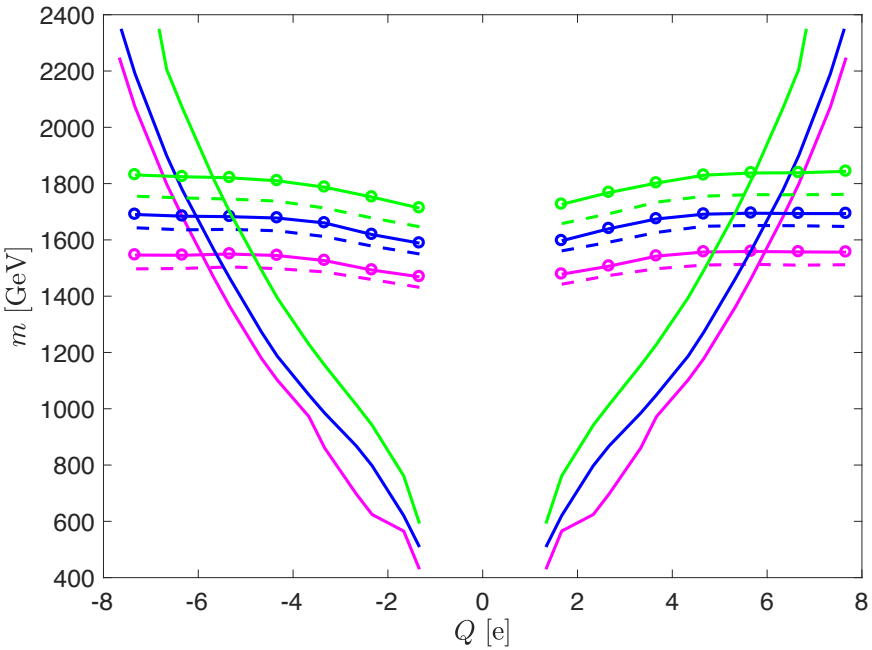


Future bounds - exclusion

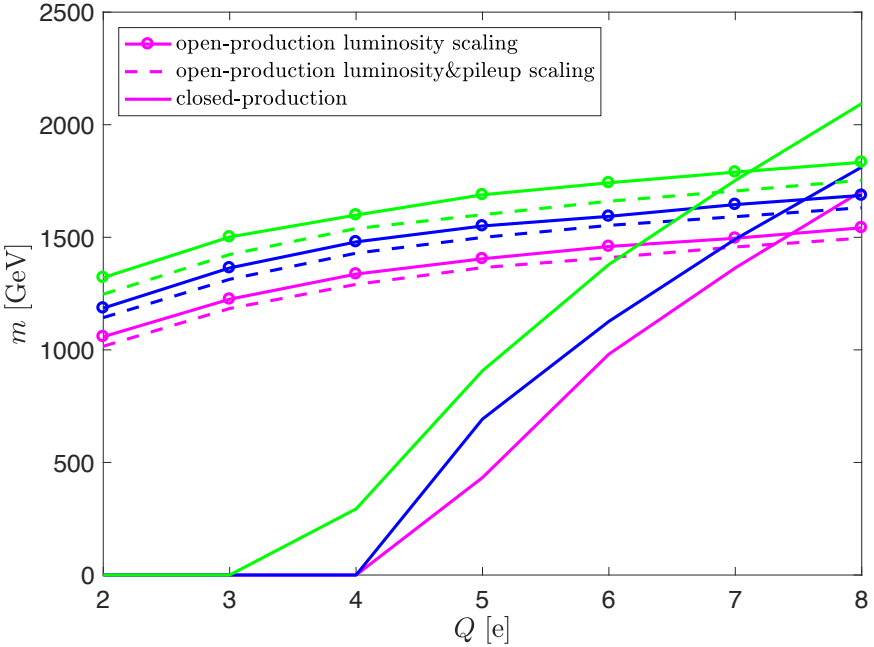
13 TeV projected mass bounds at

- L = 35.9 fb^{-1} (magenta),
- L = 100 fb^{-1} (blue),
- L = 300 fb^{-1} (green).

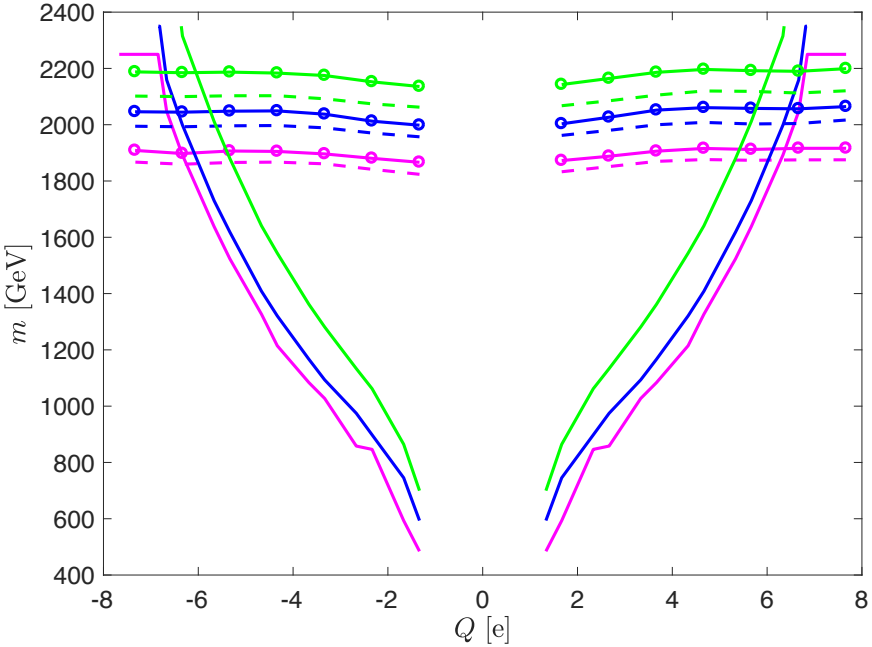
Colored scalars



Lepton-like particles

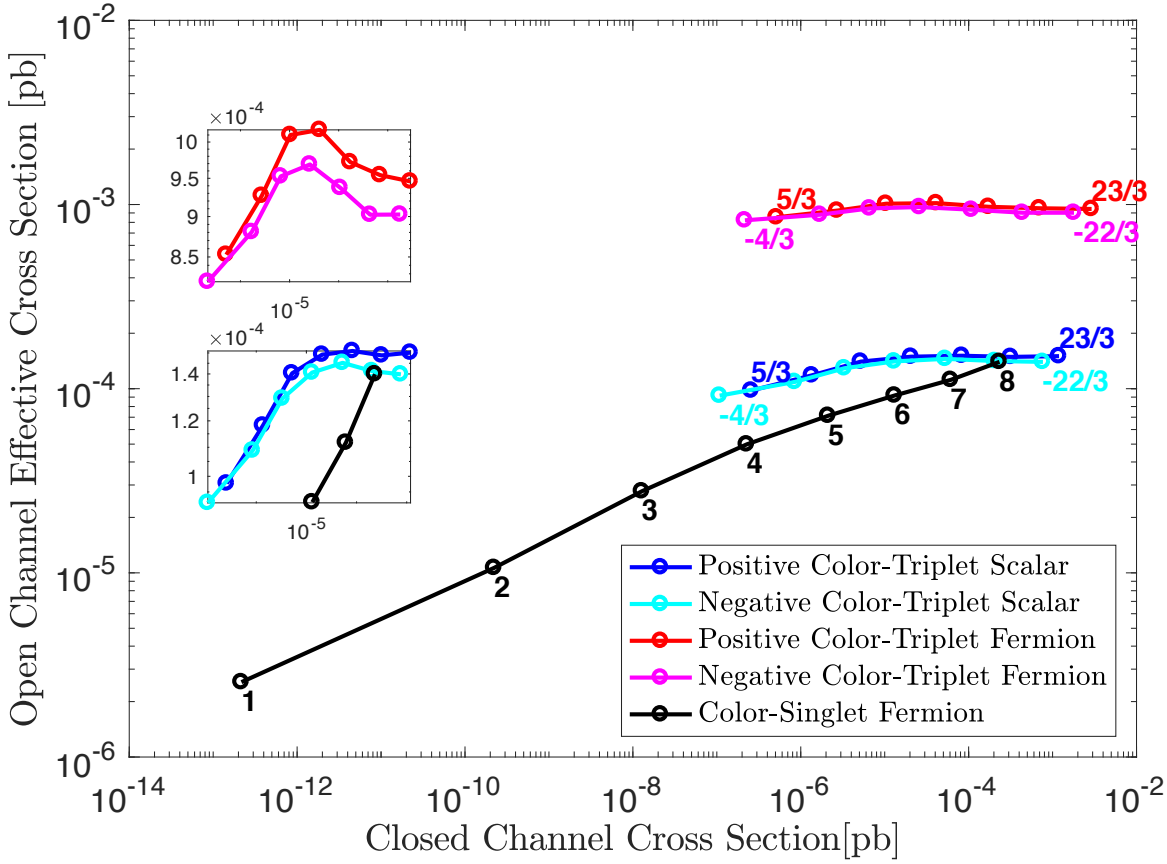


Colored fermions



Future bounds - discovery

- Mass from di-photon resonance peak.
- Spin, charge and color from the mass and effective cross sections of the two channels.
- Example for m = 1.5 TeV.



Conclusions and Outlook

- Obtained new and future bounds on the mass of stable colored multiply charged particles and updated the bounds for lepton-like particles.
- PDF choice and photo-production are important.
- Open searches - charge independent, dominant for small charges.
- Closed searches - charge dependent, dominant for large charges.
- By combining both searches can obtain mass, spin, charge and color of the particles.
- Future work: HL-LHC upgrade - new timing and improved *dE/dx* detectors.