Reliable collider Mass Bounds for Highly Ionising Particles via Resummation

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in collaboration with J.Alexander, N. Mavromatos and V. A. Mitsou

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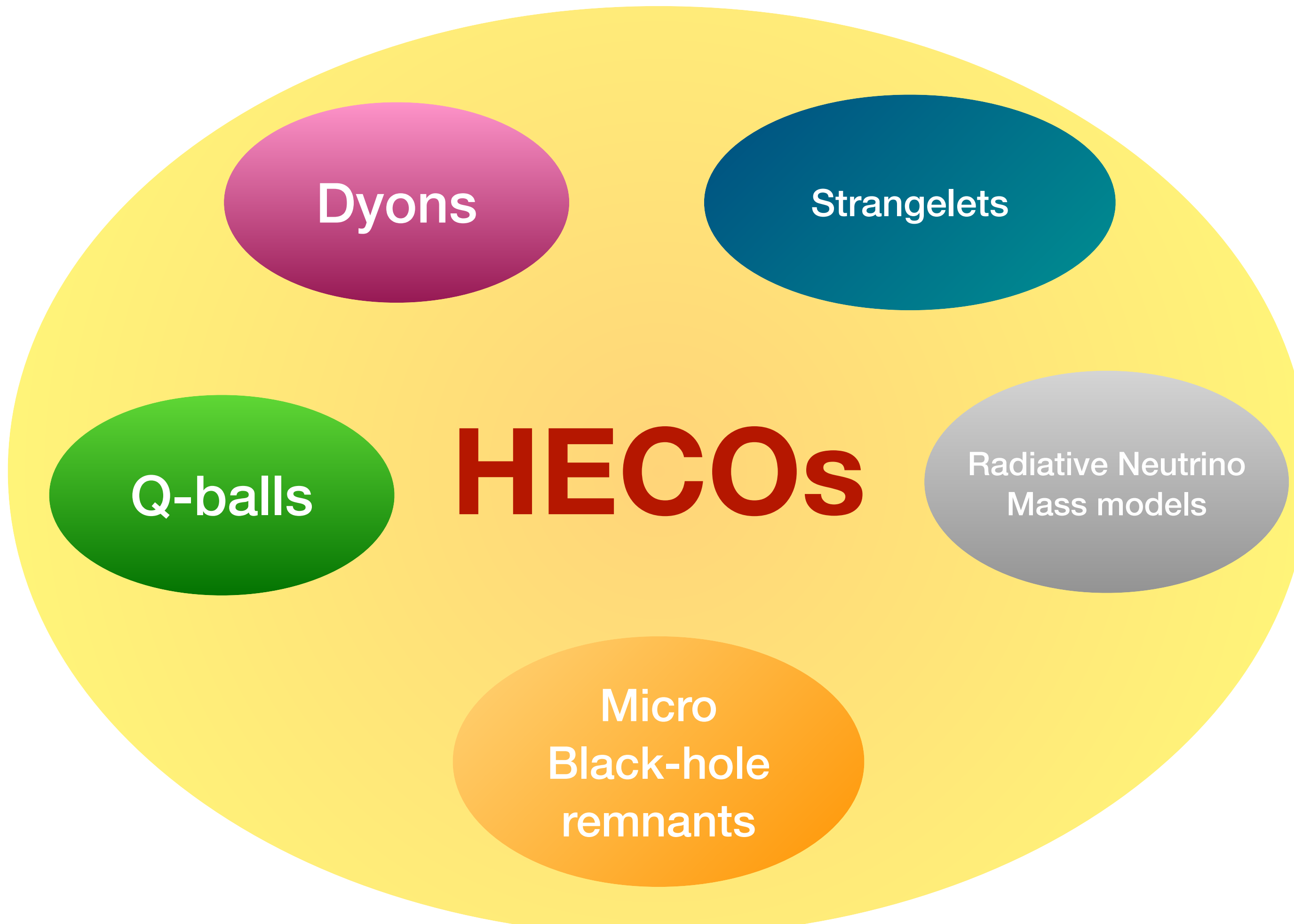
Phys. Rev. D 111, 076010

Eur.Phys.J.C 86 , 942

13/11/2026

High Electric Charge Objects

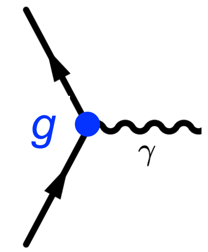
Predicted by various theories Beyond the Standard Model



- **Q=** $ne, \ n \in \mathbb{Z}$
- High Ionisation
- Mass and Spin are *free parameters*
- Same production mechanisms at colliders as monopoles

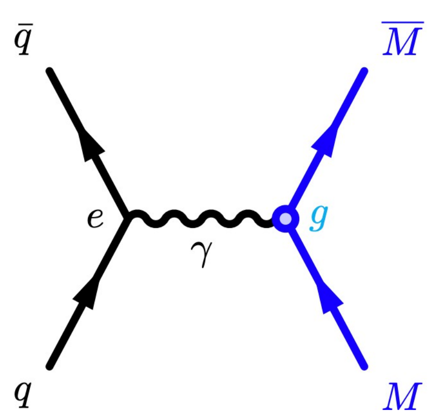
Magnetic Monopoles

One would expect that monopoles could be produced by similar electromagnetic processes that produce pairs of electrically charged particles.

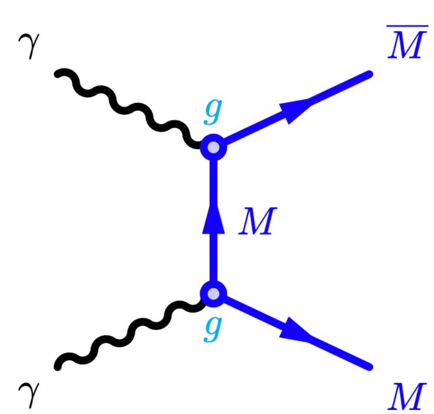
Monopole-photon coupling g is analogous to the electron-photon one 

Production mechanisms at **colliders**

Direct

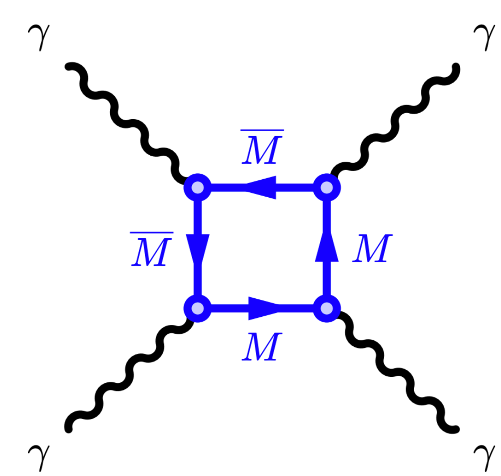


Drell-Yan like

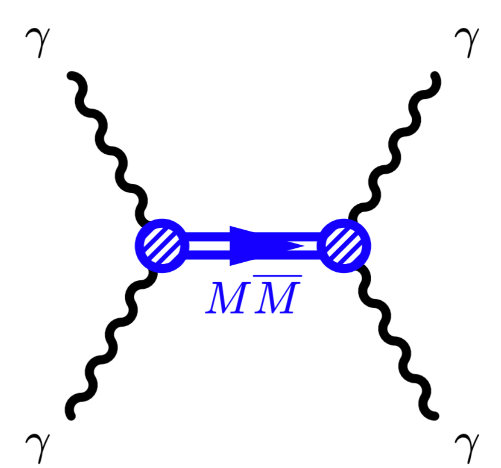


Photon Fusion

Indirect



Monopole box diagram



Monopolium production

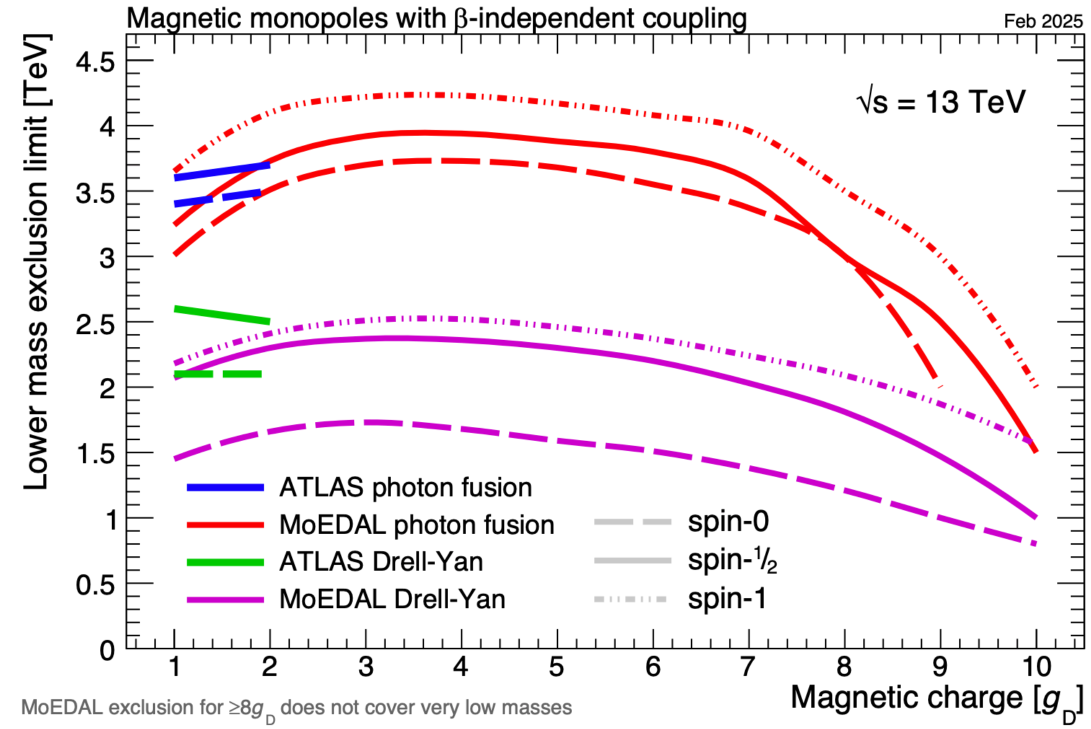
N.Mavromatos & V.Mitsou,
Int.J.Mod.Phys.A 35 (2020) 2030012

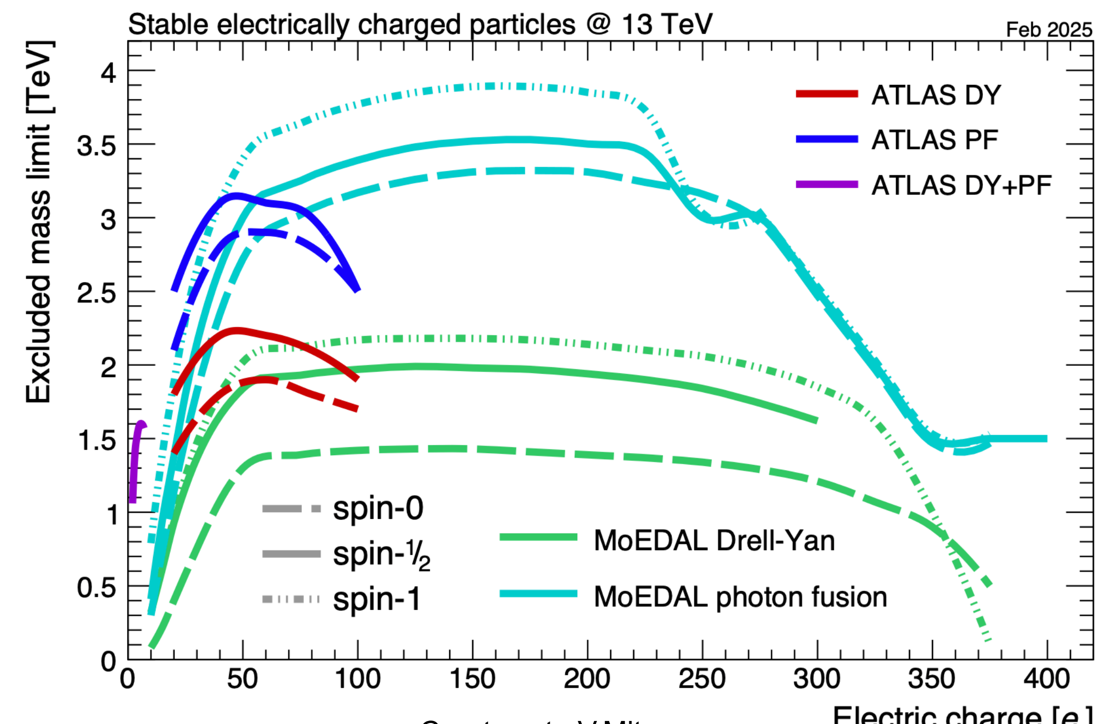
Highly Ionising Particles

Recent searches at the LHC

ATLAS

MoEDAL





Courtesy to V.Mitsou

Highly Ionising Particles

Recent searches at the LHC

⚠ **At tree level**

ATLAS

MoEDAL

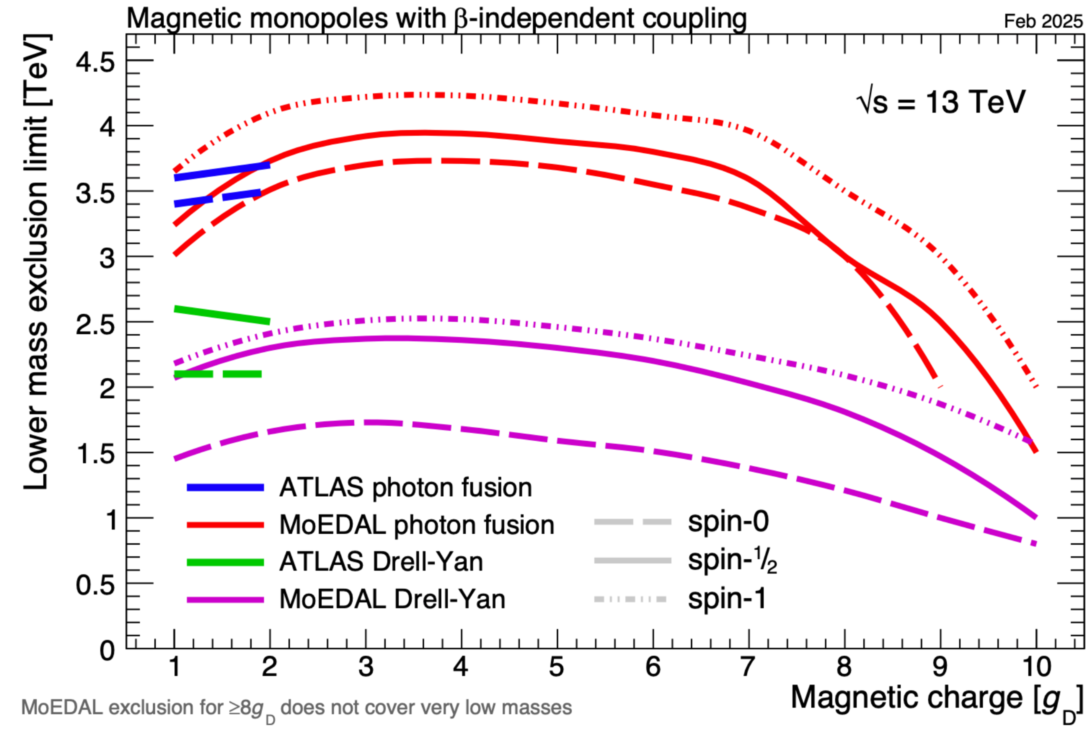
⚠ Large coupling *g*

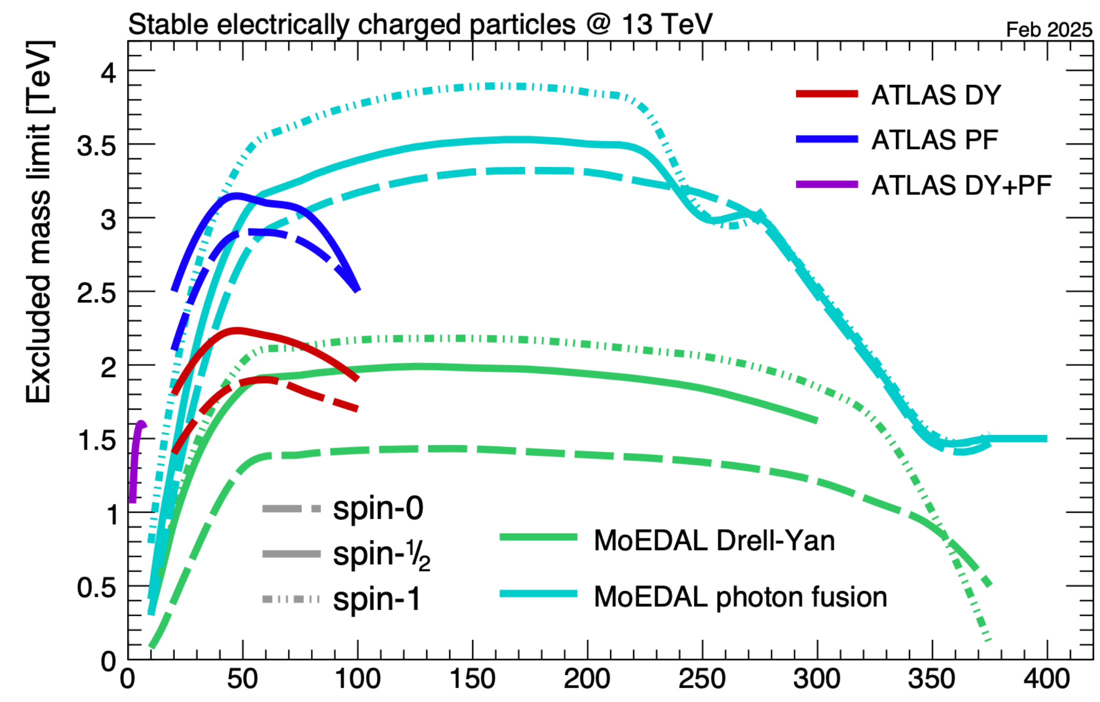
↓

Perturbation theory breaks down

↓

Resummation needed!





Courtesy to V.Mitsou

Electromagnetic Interactions - QED-like Lagrangian

Photon

$$\mathcal{L}_{\text{bare}} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + \overline{\psi} \left(i\not{\partial} + g\not{A} - m \right) \psi$$

HECO fermion

HECO charge
g= ne

Bare mass

RESUMMATION for SPIN-1/2 HECOs

Electromagnetic Interactions - QED-like Lagrangian

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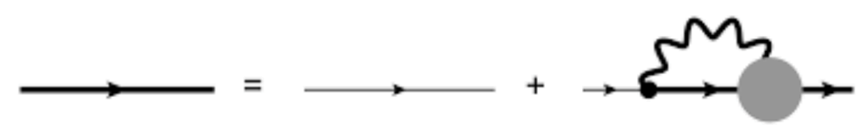
$n \geq 11$

Fermion dressed propagator

$$\boxed{G = i\frac{Z p\!\!\!/ + M}{Z^2 p^2 - M^2}}$$

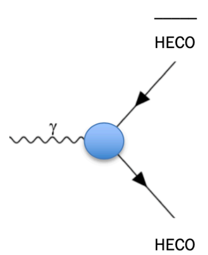


Photon dressed propagator

$$\boxed{\Delta_{\mu\nu} = \frac{-i}{(1+\omega)q^2}\left(\eta_{\mu\nu} + \frac{1+\omega-\lambda}{\lambda}\frac{q_\mu q_\nu}{q^2}\right)}$$

HECO-γ dressed vertex

$$\boxed{\Gamma_\mu = g Z \gamma_\mu}$$



Z, ω, M quantum corrections

RESUMMATION for SPIN-1/2 HECOs

Electromagnetic Interactions - QED-like Lagrangian

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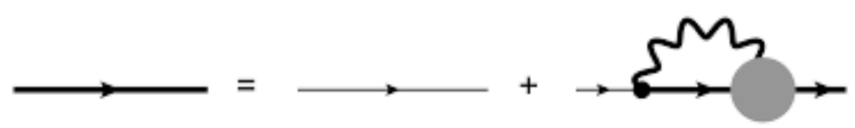

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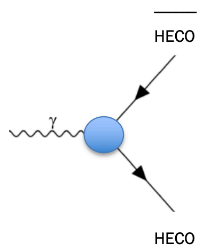

Z, ω, M quantum corrections

- The aim is to solve Dyson-Schwinger (DS) equations for HECO and γ self-energies without assuming $g^2 \ll 1$

$$\begin{aligned}
\mathcal{Z} &= 1 + \frac{g^2}{8\pi^2\lambda}\frac{1}{\epsilon}\left(\frac{\mathcal{Z}k}{M}\right)^{\epsilon} + \text{finite},\\
\omega &= \frac{g^2}{6\pi^2\,\mathcal{Z}}\frac{1}{\epsilon}\left(\frac{\mathcal{Z}\,k}{M}\right)^{\epsilon} + \text{finite},\\
1 - \frac{m}{M} &= \frac{g^2}{8\pi^2\lambda\,\mathcal{Z}}\frac{1+3\lambda+\omega}{1+\omega}\frac{1}{\epsilon}\left(\frac{\mathcal{Z}\,k}{M}\right)^{\epsilon} + \text{finite},
\end{aligned}$$

RESUMMATION for SPIN-1/2 HECOs

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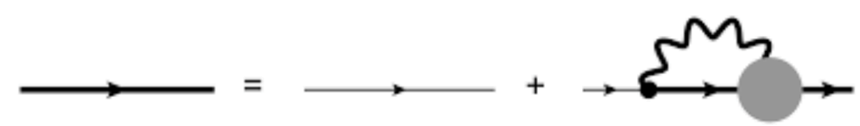

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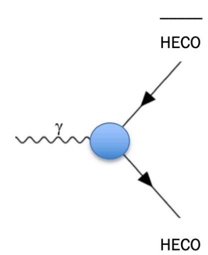

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1-\frac{m}{M} &= \frac{g^2}{8\pi^2\lambda\,\mathcal{Z}}\frac{1+3\lambda+\omega}{1+\omega}\frac{1}{\epsilon}\left(\frac{\mathcal{Z}\,k}{M}\right)^{\epsilon} + \text{finite},
\end{aligned}$$

Derivate wrt k and integrate back

$(Z,\omega,M) = (1,0,m)$ when $k = m$

Usual one-loop results for $g^2 << 1$

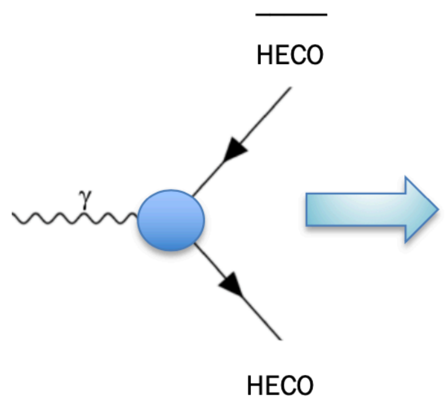
$$\begin{aligned}
Z &= 1 + \frac{g^2}{8\pi^2\lambda}\ln\left(\frac{Zk}{M}\right)\\
Z\omega &= \frac{g^2}{6\pi^2}\ln\left(\frac{Zk}{M}\right)\\
Z\left(1-\frac{m}{M}\right) &= \frac{g^2}{8\pi^2\lambda}\frac{1+3\lambda+\omega}{1+\omega}\ln\left(\frac{Zk}{M}\right)
\end{aligned}$$

UV Fixed-point solution

$$\lim_{k\to\infty}(Z,\omega,\tilde{M}) = (Z^\star,\omega^\star,\tilde{M}^\star)$$

such that $\displaystyle\lim_{k\to\infty}\frac{kZ}{M} = \text{finite}$

RESUMMATION for SPIN-1/2 HECOs



Lagrangian based on the running effective parameters

$$\boxed{\mathcal{L}_{eff} = \frac{1}{2}A_\mu\Big((1+\omega)\eta^{\mu\nu}\Box - \omega\partial^\mu\partial^\nu\Big)A_\nu \;\; +\overline{\psi}\Big(Zi\partial\!\!\!/ + ZgA\!\!\!/ - M\Big)\psi}$$

$A_\mu \to A_\mu/\sqrt{1+\omega}$ and $\psi \to \psi/\sqrt{Z}$ rescaling

$$\boxed{\mathcal{L}_{eff} \to \frac{1}{2}A_\mu\left(\eta^{\mu\nu}\Box - \frac{\omega}{1+\omega}\partial^\mu\partial^\nu\right)A_\nu + \overline{\psi}\left(i\partial\!\!\!/ + \frac{g}{\sqrt{1+\omega}}A\!\!\!/ - \frac{M}{Z}\right)\psi}$$

Shifted covariant gauge parameter $\lambda_{eff} = \dfrac{1}{1+\omega}$

Running coupling: $\alpha(k) = \dfrac{g^2/(4\pi)}{1+\omega(k)}$ with g= n e, $\omega(k) > 0$

Effective HECO Mass: $\mathcal{M}(k) = \dfrac{M(k)}{Z(k)} = k\exp\left(-\dfrac{2\pi}{\alpha(k)}(Z(k)-1)\right)$

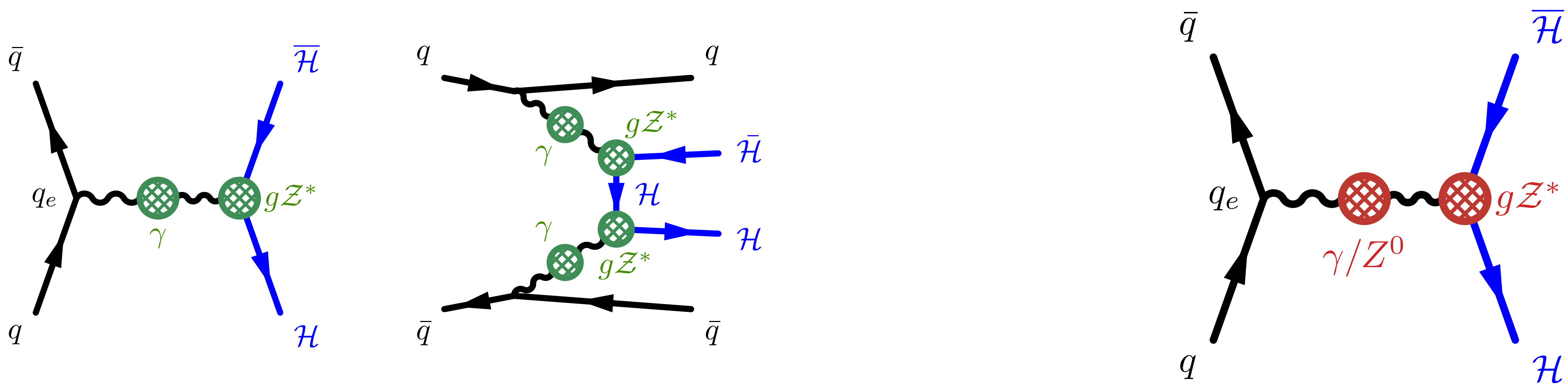
Non-trivial UV fixed point

- $Z^\star = 1.447,$
- $\omega^\star = \dfrac{4}{3}(1 - \dfrac{1}{Z^\star})$
- $M^\star = \lim_{k\to\Lambda} M(k) \equiv M(\Lambda) = \Lambda\exp\big(-\dfrac{2\pi}{\alpha^\star}(Z^\star - 1)\big), \quad \Lambda \gg m$

RESUMMATION for SPIN-1/2 HECOs

SPIN 1/2

Feynman Rules



γ-only exchange

Running mass: $\mathcal{M}(\Lambda) = \Lambda \exp\left(-\frac{2\pi}{\alpha^\star}(Z^\star - 1)\right)$

HECO-fermion propagator: $G^{\text{eff}} = i\frac{\not{p}+\mathcal{M}(\Lambda)}{p^2-\mathcal{M}(\Lambda)^2}$

Photon propagator: $\Delta^{\text{eff}}_{\mu\nu} = \frac{-i}{q^2}\left(\eta_{\mu\nu} + \omega^\star \frac{q_\mu q_\nu}{q^2}\right)$

Photon-HECO vertex: $\Gamma^{\text{eff}}_\mu = g\, Z^\star \gamma_\mu$

with $\hat{\alpha}^\star$ is the rescaled electric coupling $\hat{\alpha}^\star = \frac{g^2/4\pi}{1+\hat{\omega}^\star}$, $Z^\star = 1.477$

the wavefunction renormalization and $\omega^\star = \frac{4}{3}\left(1 - \frac{1}{Z^\star}\right) \simeq 0.431$

Z^0 inclusion

SU(2) singlet

Same procedure as for photon with the replacement:

$g^2 \to \hat{g}^2 \equiv g^2 + 3g'^2/4$ where g' is the Z_0-HECO coupling

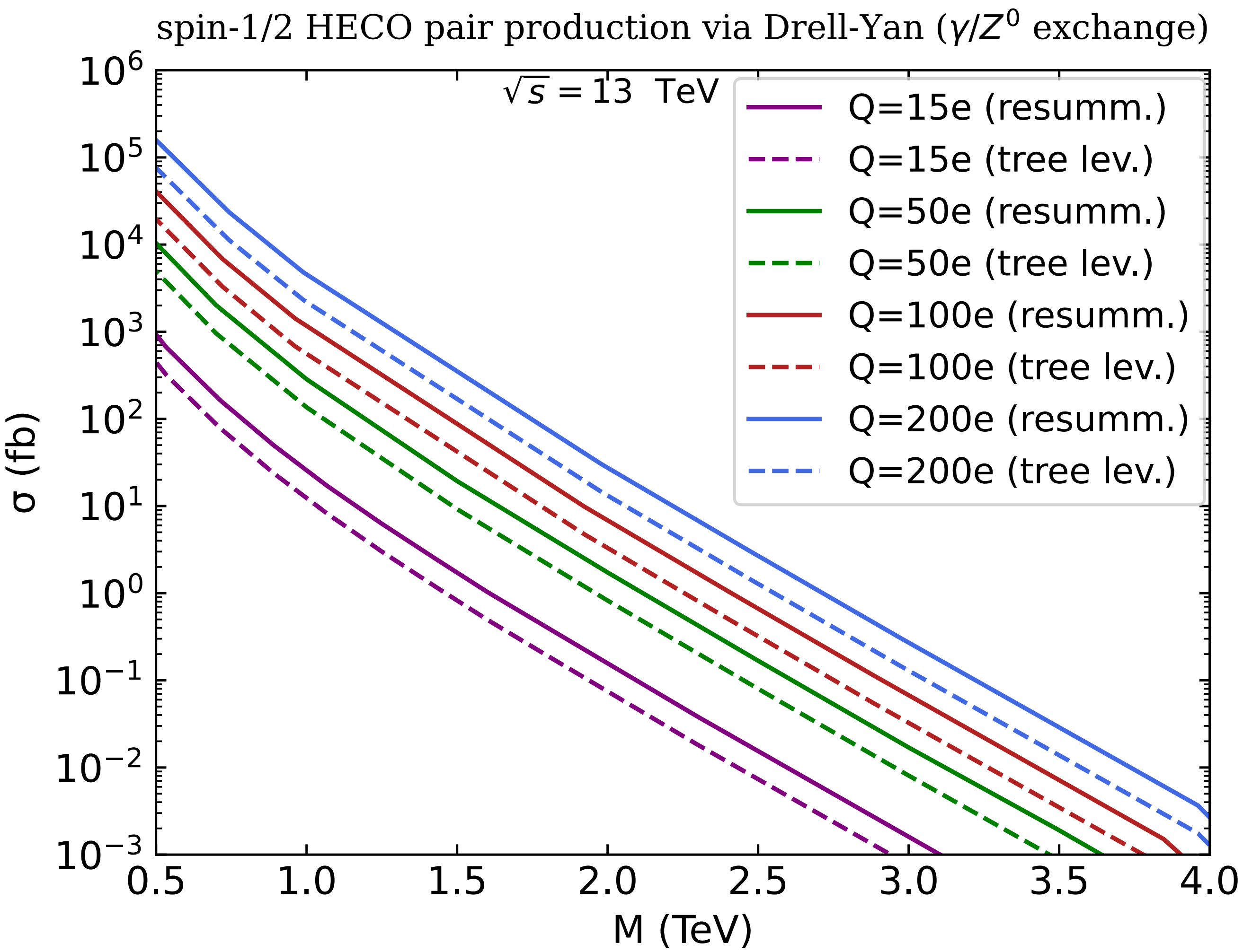
$\hat{\mathcal{M}}(\Lambda) = \Lambda \exp\left(-\frac{2\pi}{\hat{\alpha}^\star}(\hat{Z}^\star - 1)\right)$

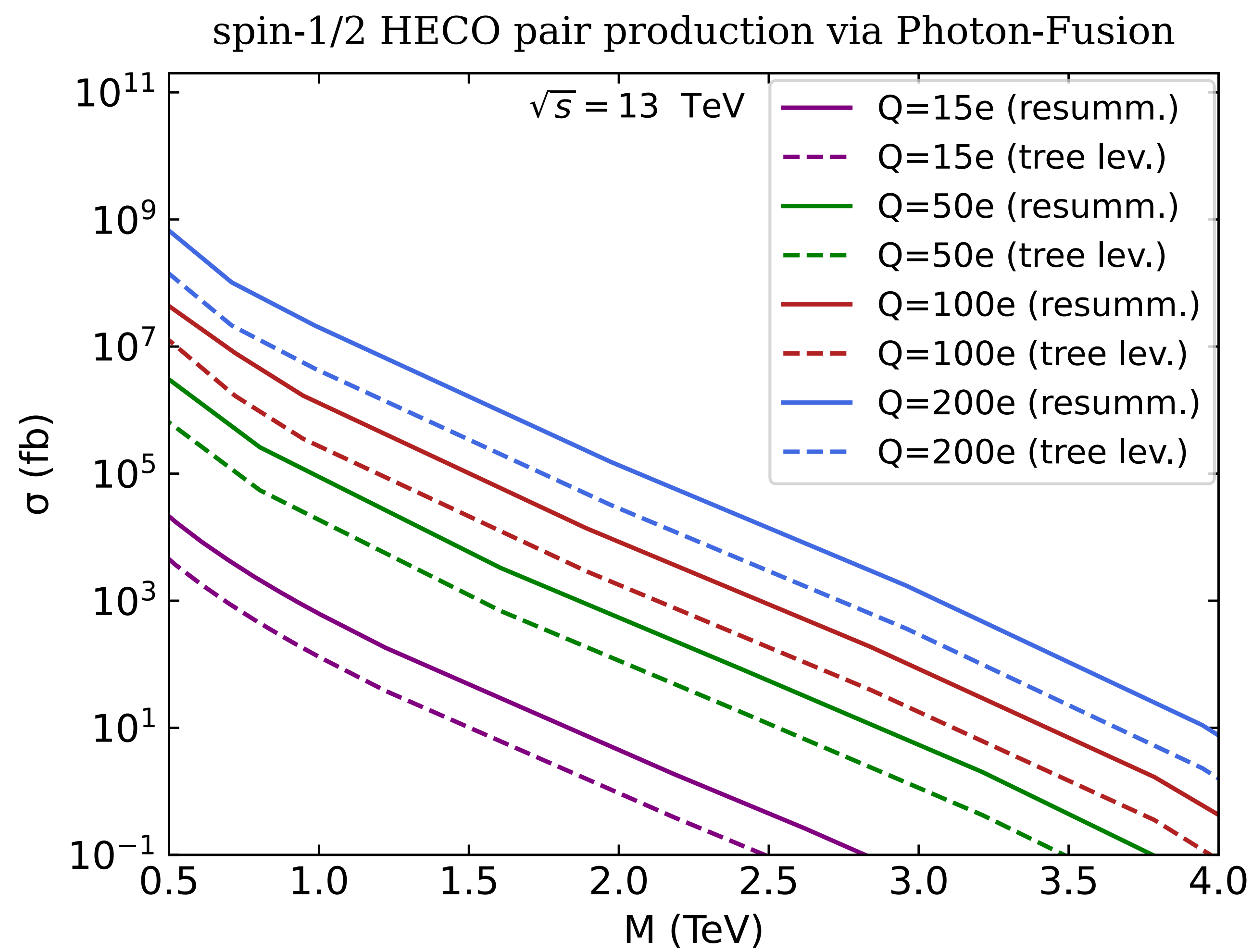
$\hat{Z}^\star = \hat{Z}_+ = \frac{2}{9}(3+\eta)\left(1 + \sqrt{1 - \frac{9\eta}{(3+\eta)^2}}\right)$

$\hat{\omega}^\star = \frac{4}{3}\eta\left(1 - \frac{1}{\hat{Z}^\star}\right)$ with $\eta \equiv g^2/\hat{g}^2 < 1$.

IMPACT ON PRODUCTION CROSS SECTIONS

SPIN-1/2





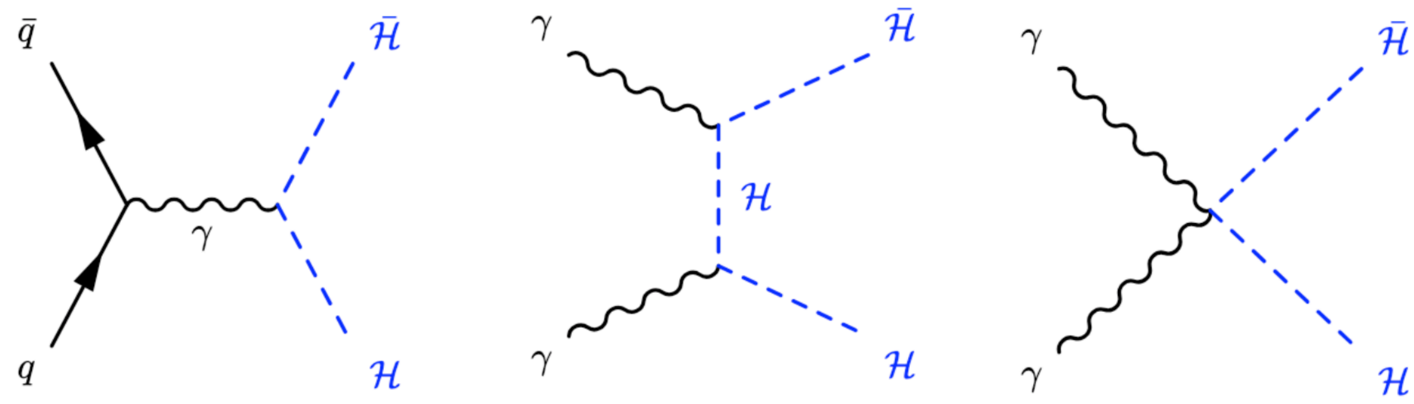
After resummation…

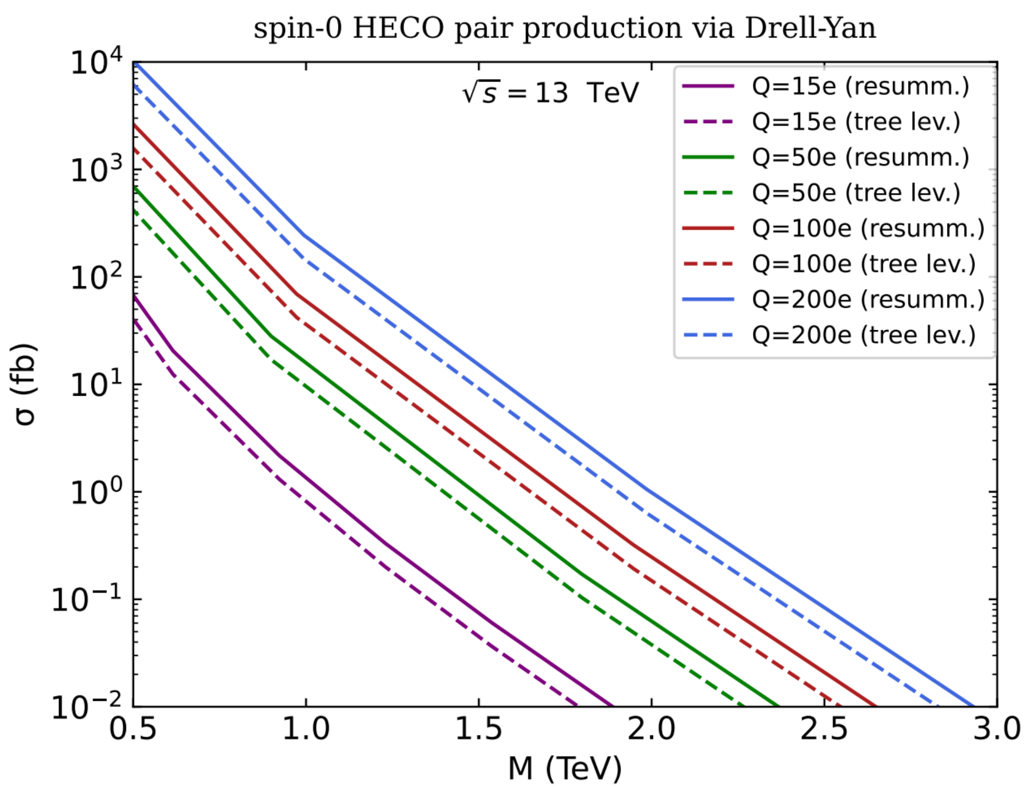
- the production via Drell-Yan cross section increases by a factor of ~ 2.1
- the production via Photon-Fusion cross section increases by a factor of ~ 4.75

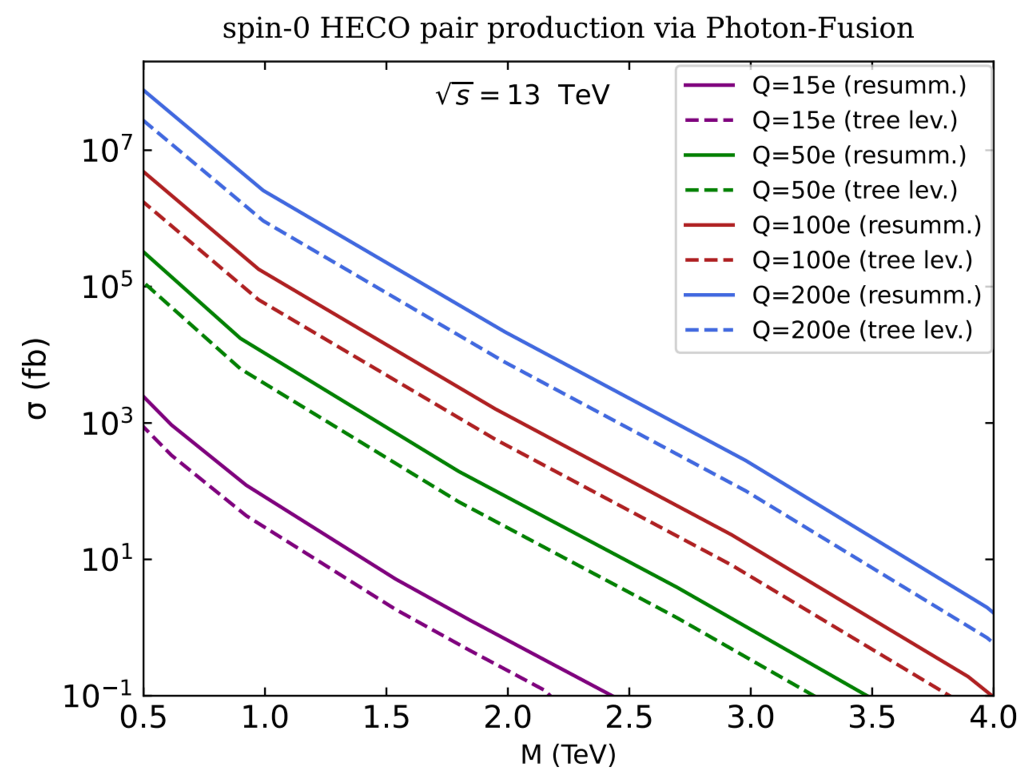
IMPACT ON PRODUCTION CROSS SECTIONS

SPIN-0

Similar results for spin-0 HECOs







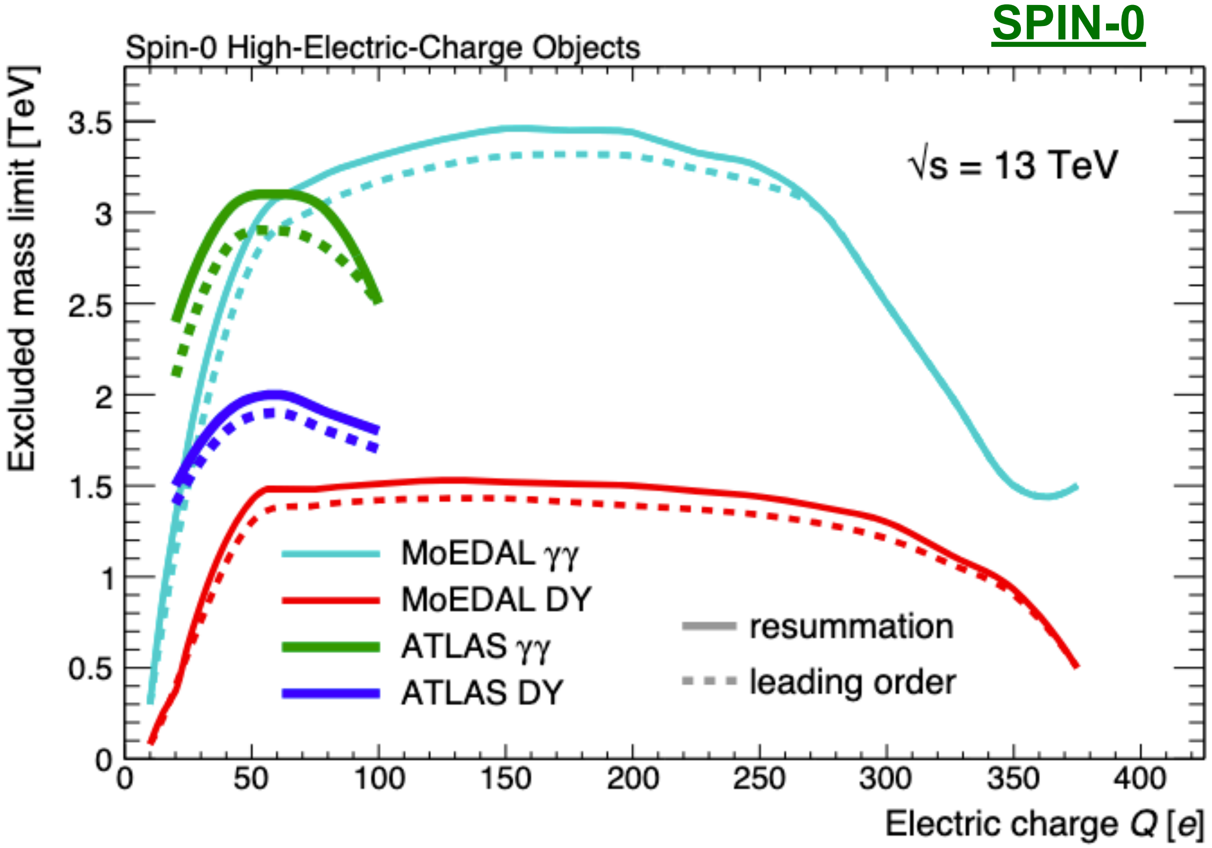
After resummation...

- the production via Drell-Yan cross section increases by a factor of ~ 1.66
- the production via Photon-Fusion cross section increases by a factor of ~ 2.76

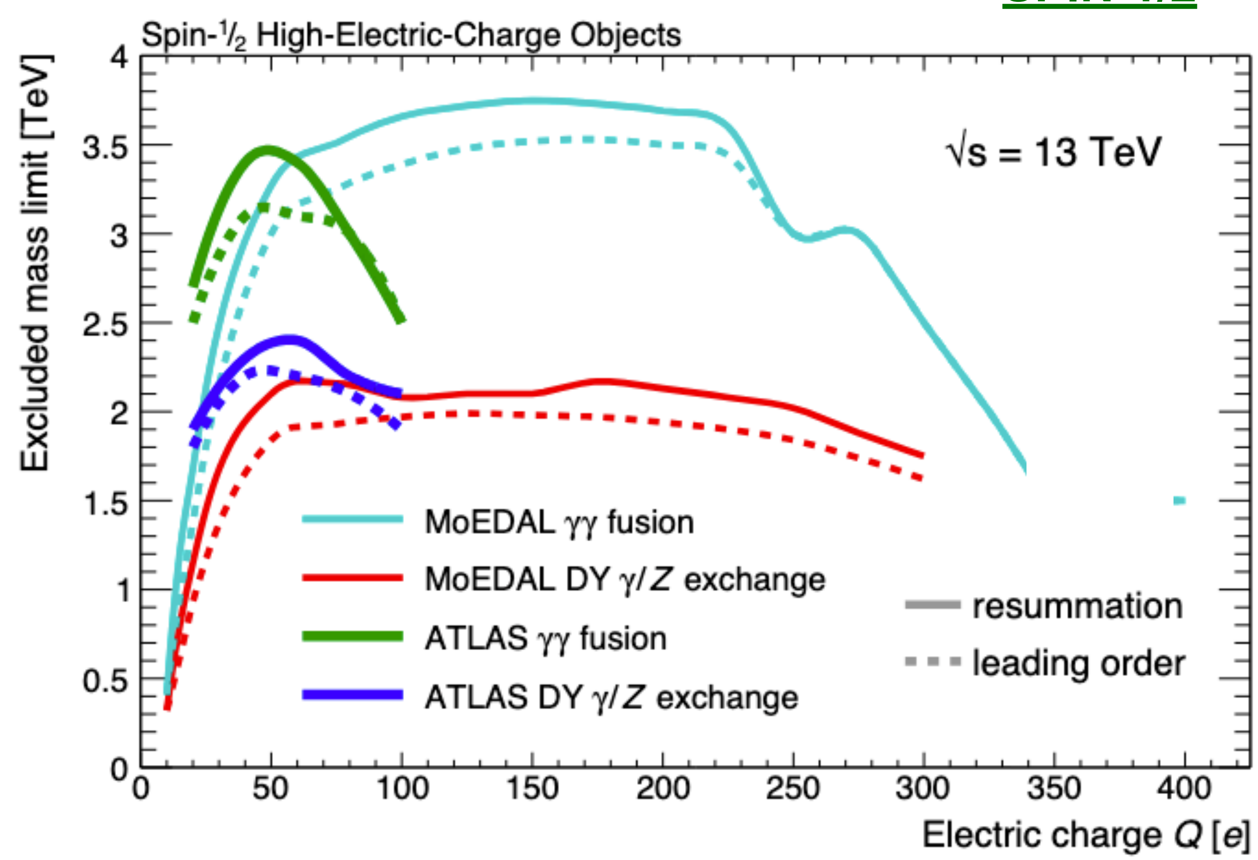
RE-EVALUATED MASS LIMITS

New mass limits from ATLAS and MoEDAL searches at the LHC

SPIN-0



SPIN-1/2



The increase in the mass limits spans a wide range of values up to 20%!!

The increase in the mass limits spans a wide range of values up to ~30%!!

UNIVERSAL FEYNRULES OUTPUT

UFO models including resummation effects created:

i) Spin-1/2

ii) Spin-0

Tested on Madgraph!

☑ Calculation of the analytical cross section (Wolfram Mathematica)

☑ Comparison results from Madgraph with those obtained from Mathematica

Available on the FeynRules model database >Simple extensions of the SM

General 2HDM	The most general 2HDM, including all flavor violation and mixing terms.	C. Duhr, M. Herquet	**Available**
Heavy Scalar Effective Model	A model with one heavy scalar with effective couplings to the vector bosons.	Y. Wu, Y. Xu, X. Chen	**Available**
Heavy Neutrino	The SM with three heavy Majorana neutrinos that couple to SM fields through mixing with active neutrinos.	R. Ruiz	**Available**
Heavy Neutral Leptons	The SM with heavy neutrinos interacting with mesons.	P. Coloma, E. Fernández-Martínez, M. González-López, J. Hernández-García	**Available**
Hidden Abelian Higgs Model	A Z' model where the Z' interacts with the SM through mixings, leading to very small non-SM like Z' couplings.	D. Curtin	**Available**
HECO	High Electric Charge Objects (HECOs) pair production by including resummation effects	E. Musumeci	**Available**
Hill Model	A model with an unusual extension of the SM Higgs sector.	P. de Aquino, C. Duhr	**Available**
Inert Doublet Model	A model with an additional complex scalar SU(2)L doublet and an unbroken Z2 symmetry under which all SM particles are even while the extra doublet is odd.	A. Goudelis, B. Herrmann, O. Stal	**Available**
Flavor-violating KK gluon	A Kaluza-Klein Gluon Model with FCNC Decay to a Single Top Quark	E. Drueke, R. Schwienhorst, N. Vignaroli, J. Nutter, D. Walker, J.-H. Yu, R. S. Chivukula, E. Simmons	**Available**
Simplified Freeze-in models	LHC-friendly minimal freeze-in models with a charged parent	A. Goudelis	**Available**
Leptoquarks + dark matter	Minimal model including dark matter and leptoquarks	B. Fuks	**Available**
Minimal Zp models	The minimal Z' extension of the SM.	L. Basso	**Available**
Minimal Dilaton Model	Minimal Dilaton Model	J. Cao, X. Hao, Z. Heng, L. Shang, Y. Zhang	**Available**

Two new input parameters:

i) Multiplicity of the electric charge n ($Q = n\,e$)

ii) Cut-off Λ

RESUMMATION FOR SPIN-1/2 MONOPOLES

$\mathrm{U}(1)_{em} \otimes \mathrm{U}(1)'$

Bare Lagrangian

electron mass

electron

MM bare mass

$$L = -\frac{1}{4} F_A^{\mu\nu} F^A_{\mu\nu} - \frac{1}{4} F_B^{\mu\nu}\, F^B_{\mu\nu} + \overline{\psi}(i\gamma^\mu D^A_\mu - m)\psi + \overline{\chi}(i\gamma^\mu D^{A+B}_\mu - M)\chi$$

MM fermion

$$F_A^{\mu\nu} = \partial^\mu A^\nu - \partial^\nu A^\mu$$

$$F_B^{\mu\nu} = \partial^\mu B^\nu - \partial^\nu B^\mu$$

$$D^A_\mu = \partial_\mu - i\, q_e A_\mu$$

$$D^{A+B}_\mu = \partial_\mu - ie_A A_\mu - ie_B B_\mu$$

J.Alexandre and N. E. Mavromatos, *Phys. Rev. D 100, 096005*

$$\boxed{e\,,\, e_A \ll e_B\,, \quad \text{with} \quad |e| \ll 1,\ |e_A| \ll 1}$$

RESUMMATION FOR SPIN-1/2 MONOPOLES

$\mathrm{U}(1)_{em} \otimes \mathrm{U}(1)'$

Bare Lagrangian

electron mass

electron

MM bare mass

$$L = -\frac{1}{4} F_A^{\mu\nu} F_{\mu\nu}^A - \frac{1}{4} F_B^{\mu\nu} F_{\mu\nu}^B + \overline{\psi}(i\gamma^\mu D_\mu^A - m)\psi + \overline{\chi}(i\gamma^\mu D_\mu^{A+B} - M)\chi$$

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$$D_\mu^A = \partial_\mu - i\, q_e A_\mu$$

$$D_\mu^{A+B} = \partial_\mu - ie_A A_\mu - ie_B B_\mu$$

J.Alexandre and N. E. Mavromatos, *Phys. Rev. D 100, 096005*

$e\,, e_A \ll e_B\,, \quad \text{with} \quad |e| \ll 1, \; |e_A| \ll 1$

Fermion dressed propagators

$$G_\psi \simeq i\frac{\not{p} + m}{p^2 - m^2}$$

$$G_\chi = i\frac{Z\not{p} + \tilde{M}}{Z^2 p^2 - \tilde{M}^2}$$

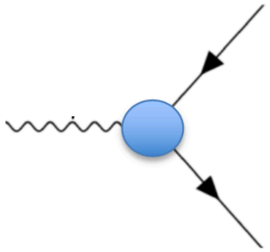
Dressed gauge propagators

$$\Delta_{\mu\nu}^A \simeq D_{\mu\nu} = \frac{-i}{q^2}\left(\eta_{\mu\nu} + \frac{1-\lambda}{\lambda}\frac{q_\mu q_\nu}{q^2}\right)$$

$$\Delta_{\mu\nu}^B = \frac{-i}{(1+\omega)q^2}\left(\eta_{\mu\nu} + \frac{1+\omega-\lambda}{\lambda}\frac{q_\mu q_\nu}{q^2}\right)$$

Dressed vertices

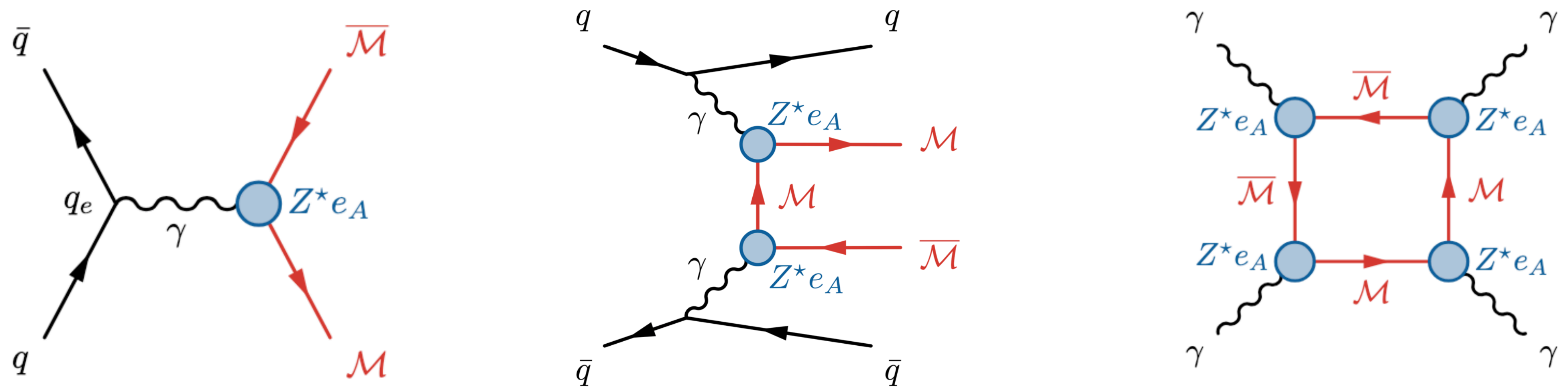
$$\Gamma_\mu^{B\chi} = e_B Z \gamma_\mu \quad \text{and} \quad \Gamma_\mu^{A\chi} = e_A Z \gamma_\mu$$



$Z, \omega, \tilde{M}$ quantum corrections

RESUMMATION FOR SPIN-1/2 MONOPOLES

$$\mathcal{L}^{\mathrm{DY/PF\ eff}}_{\chi,\psi,A} = \frac{1}{2} A_\mu\, \eta^{\mu\nu} \Box\, A_\nu + \overline{\psi}\Big(i\partial\!\!\!/ + q_e\, A\!\!\!/ - m\Big)\psi + \overline{\chi}\Big(i\partial\!\!\!/ + Z^\star e_A\, A\!\!\!/ - M^\star\Big)\chi$$



Definition of magnetic charge

$$\boxed{g_m = g^\star_{\mathrm{eff}} \equiv \lim_{k\to\Lambda} g_{\mathrm{eff}}(k/\varepsilon) = Z^\star\, e_A = \frac{7}{9\,\varepsilon} e_A = \frac{n}{\alpha}\, e}$$ satisfying *Dirac Quantisation Condition* $eg = \dfrac{n}{2}$

The DQC self-consistently identifies the renormalised MM–photon coupling $Z^\star e_A$ with the physical magnetic charge g_m

RESUMMATION FOR SPIN-1/2 MONOPOLES

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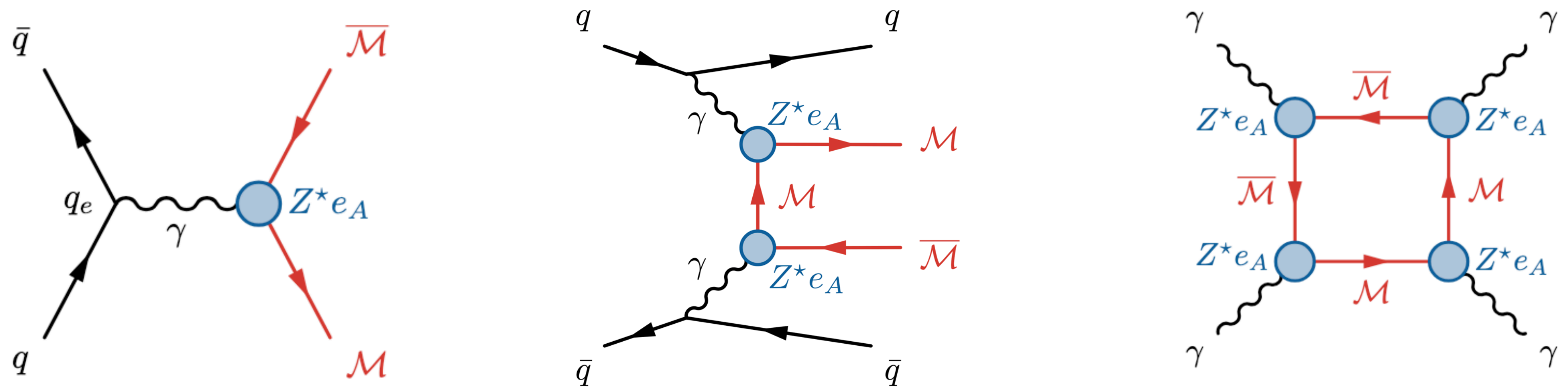

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The DQC self-consistently identifies the renormalised MM–photon coupling $Z^* e_A$ with the physical magnetic charge g_m

UV fixed point found:

$$Z^\star \simeq \frac{7}{9\,\varepsilon} \gg 1 \quad \varepsilon = \frac{7}{18n}\frac{e_A}{g_D}$$

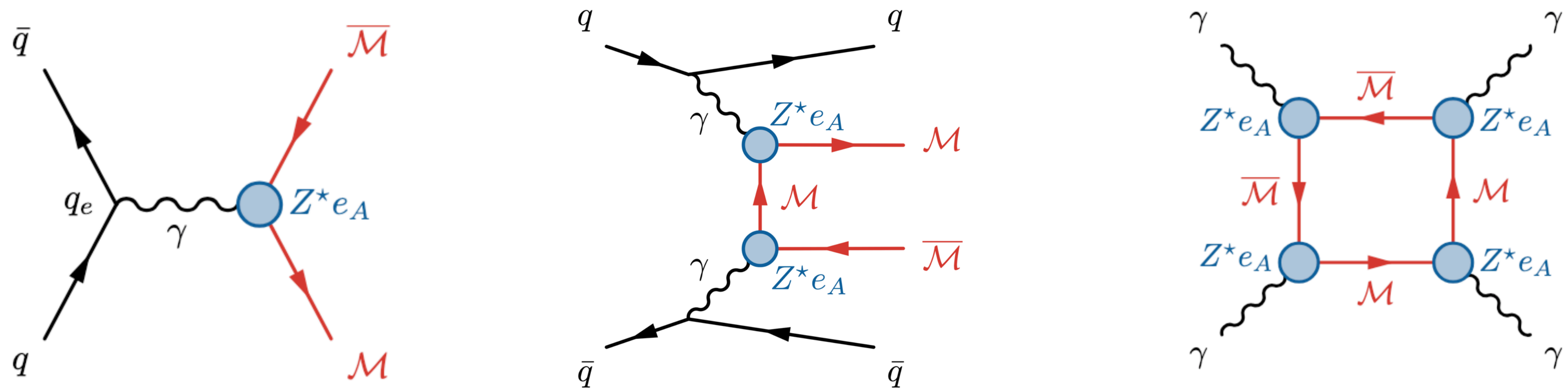
$$\omega^\star = \omega_0 \simeq \frac{4}{3}\,,$$

$$M^\star \simeq \frac{1}{2}\Lambda\,\exp\left(-\frac{56\pi^2}{9\,\varepsilon\,e_B^2}\right)\,.$$

$$g_m = \frac{n'}{2\alpha}\,e = n'\,g_{\rm D}$$

RESUMMATION FOR SPIN-1/2 MONOPOLES

$$\mathcal{L}^{\mathrm{DY/PF\ eff}}_{\chi,\psi,A} = \frac{1}{2} A_\mu \, \eta^{\mu\nu} \Box \, A_\nu + \overline{\psi}\Big(i\partial\!\!\!/ + q_e \, A\!\!\!/ - m\Big)\psi + \overline{\chi}\Big(i\partial\!\!\!/ + Z^\star e_A \, A\!\!\!/ - M^\star\Big)\chi$$



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$$g_m = \frac{n'}{2\alpha}\, e = n'\, g_D$$

$$Z^\star \, e_A = \frac{7}{9\,\varepsilon} e_A = \frac{n'}{2\alpha}\, e\,, \quad n' \in \mathbb{Z}\,,$$

$$e_A \ll \frac{9\, n'}{7}\, g_D \simeq 88.07\, n'\, e\,,$$

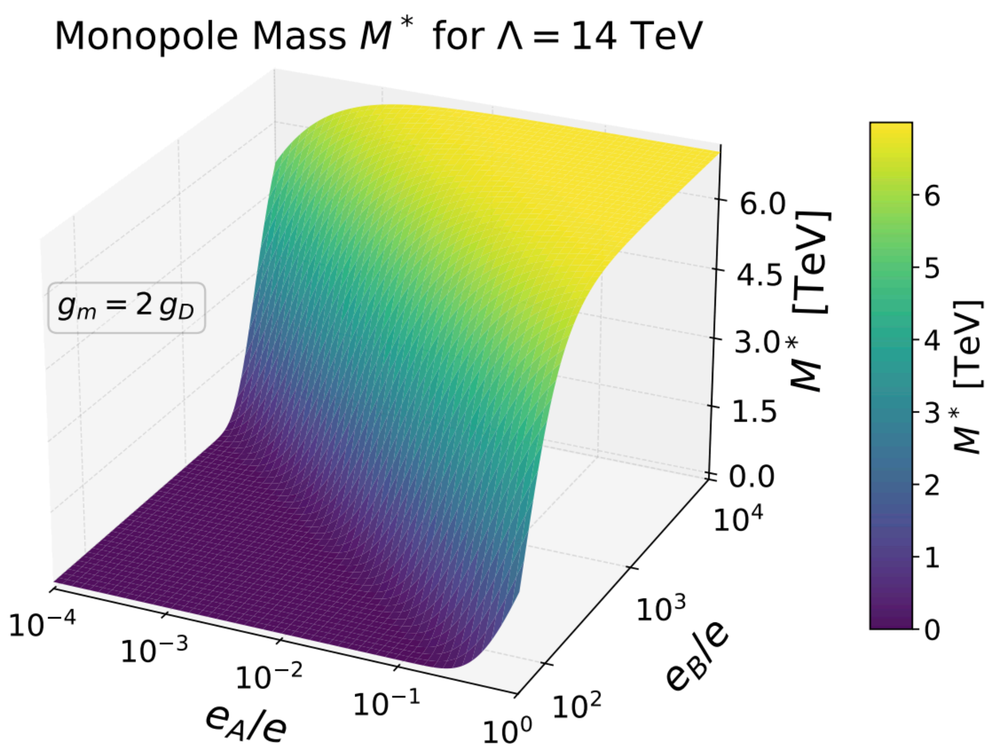
$$\boxed{M^\star = \frac{\Lambda}{2}\, \exp\left(-\frac{8\pi^2}{\frac{e_A}{g_m}\, e_B^2}\right) = \frac{\Lambda}{2}\, \exp\left(-\frac{8\pi^2}{\frac{e_A}{n'\, g_D}\, e_B^2}\right) = \frac{\Lambda}{2}\, \exp\left(-\frac{n'\,\pi}{\left(\frac{e_A}{e}\right)\left(\frac{e_B}{e}\right)^2 \alpha^2}\right)}$$

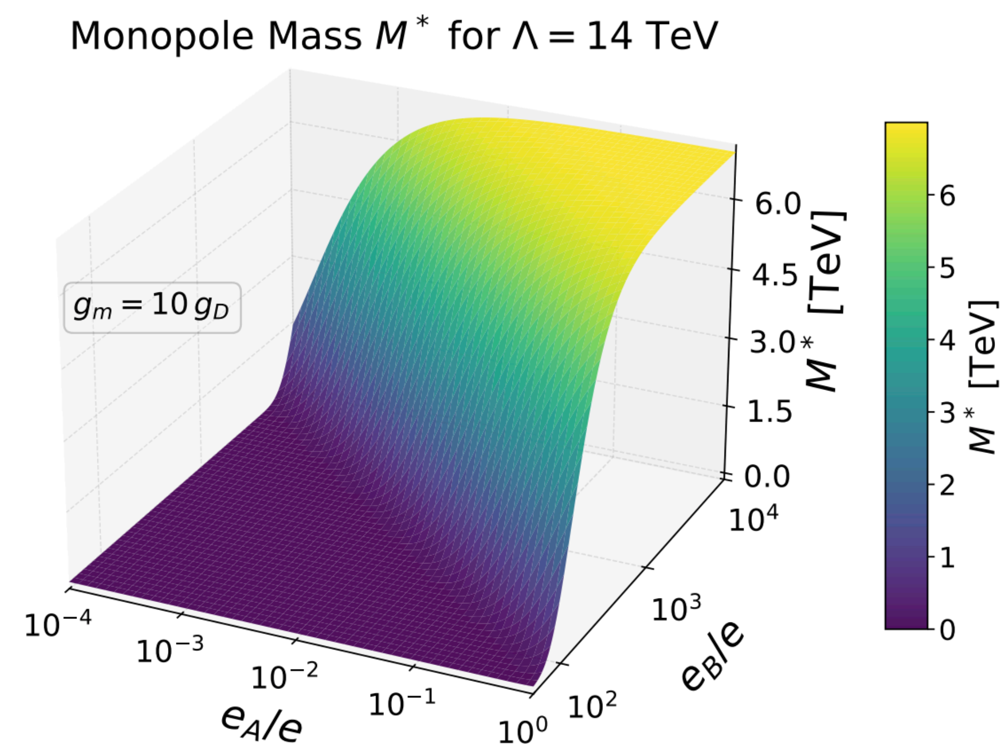
$$e\,, |e_A| \ll |e_B|\,, \quad \text{with} \quad 0 < e \ll 1,\ |e_A| \ll 1$$

The resummation leaves the Drell-Yan and photon-fusion production cross sections **identical to their tree-level values.**
Monopole mass bounds are formally justified for the first time.

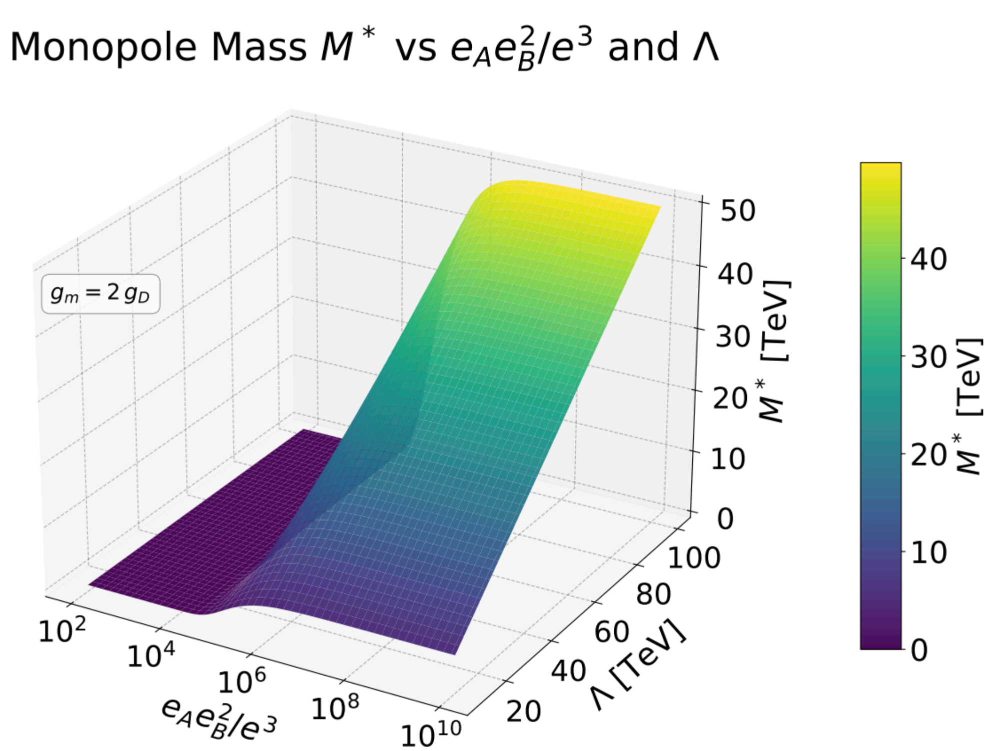
RESUMMATION FOR SPIN-1/2 MONOPOLES

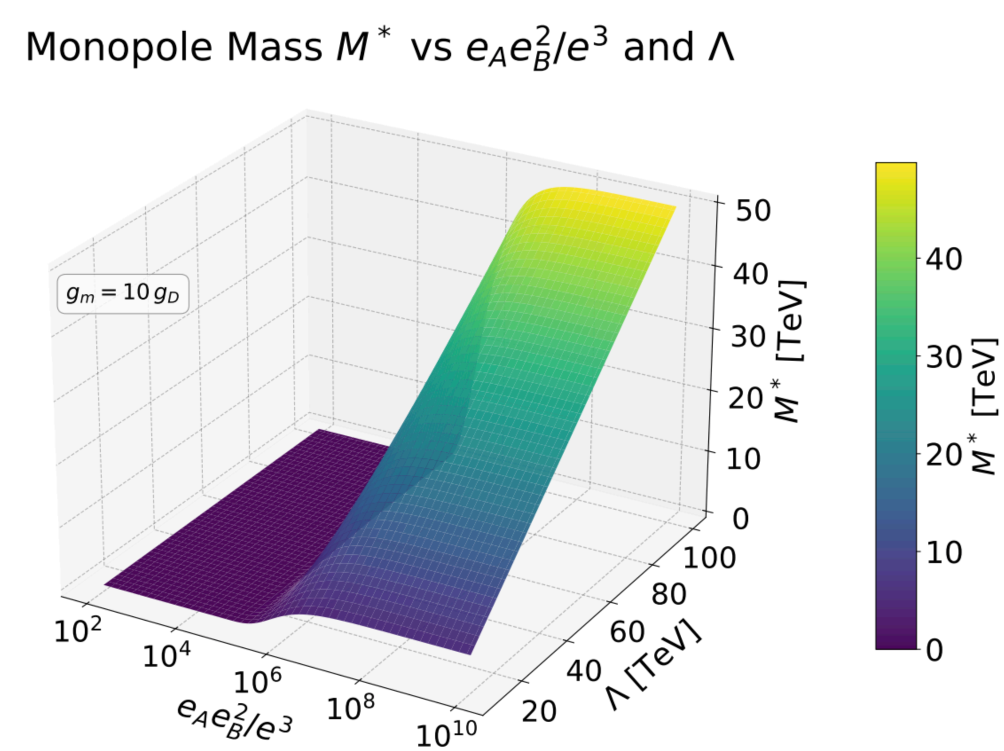
Mass versus e_A and e_B





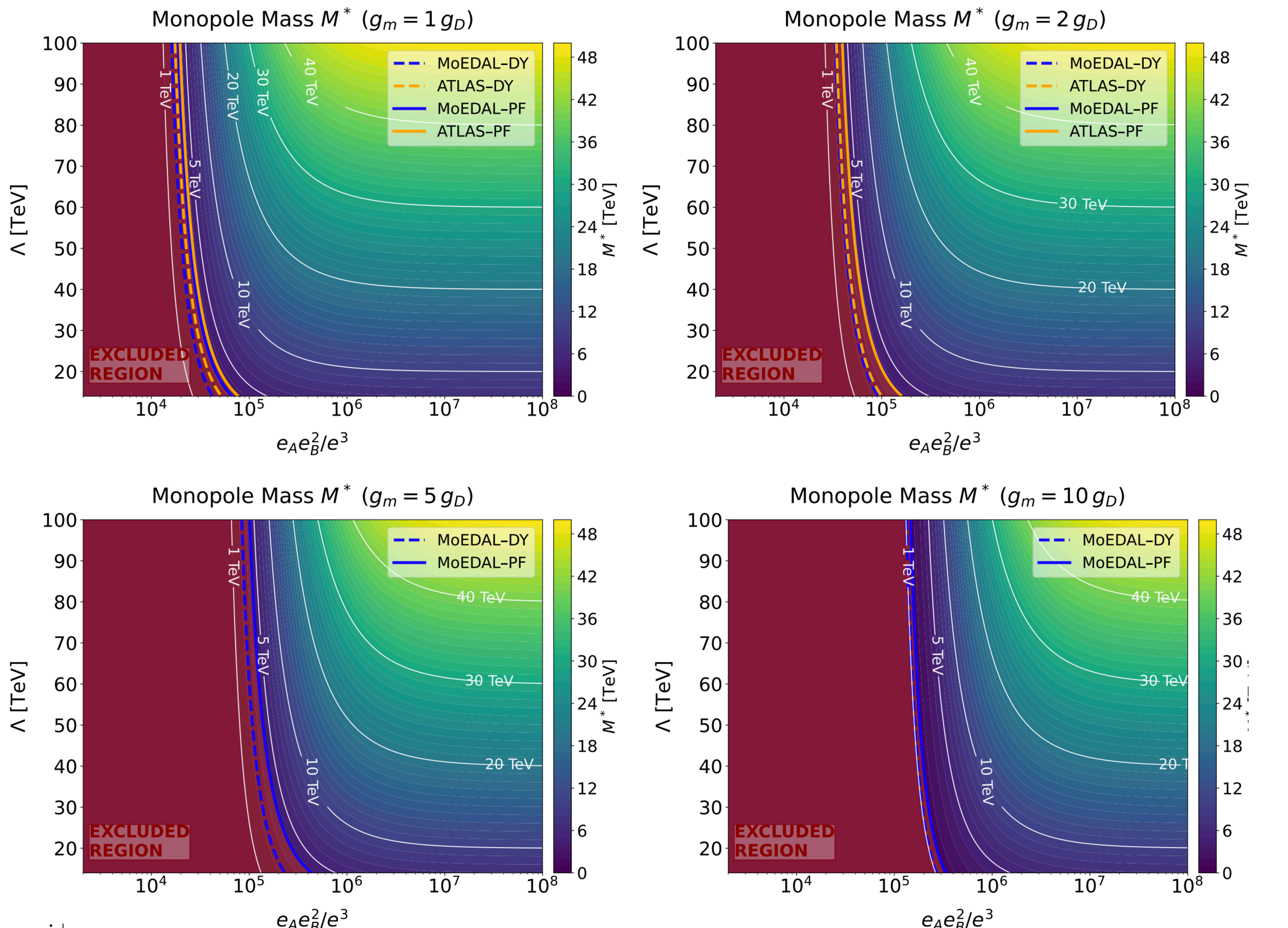
Mass versus Λ and $e_A e_B$





RESUMMATION FOR SPIN-1/2 MONOPOLES

Constraints on parameters from experimental mass limits (ATLAS & MoEDAL, $\sqrt{s}$ = 13 TeV)



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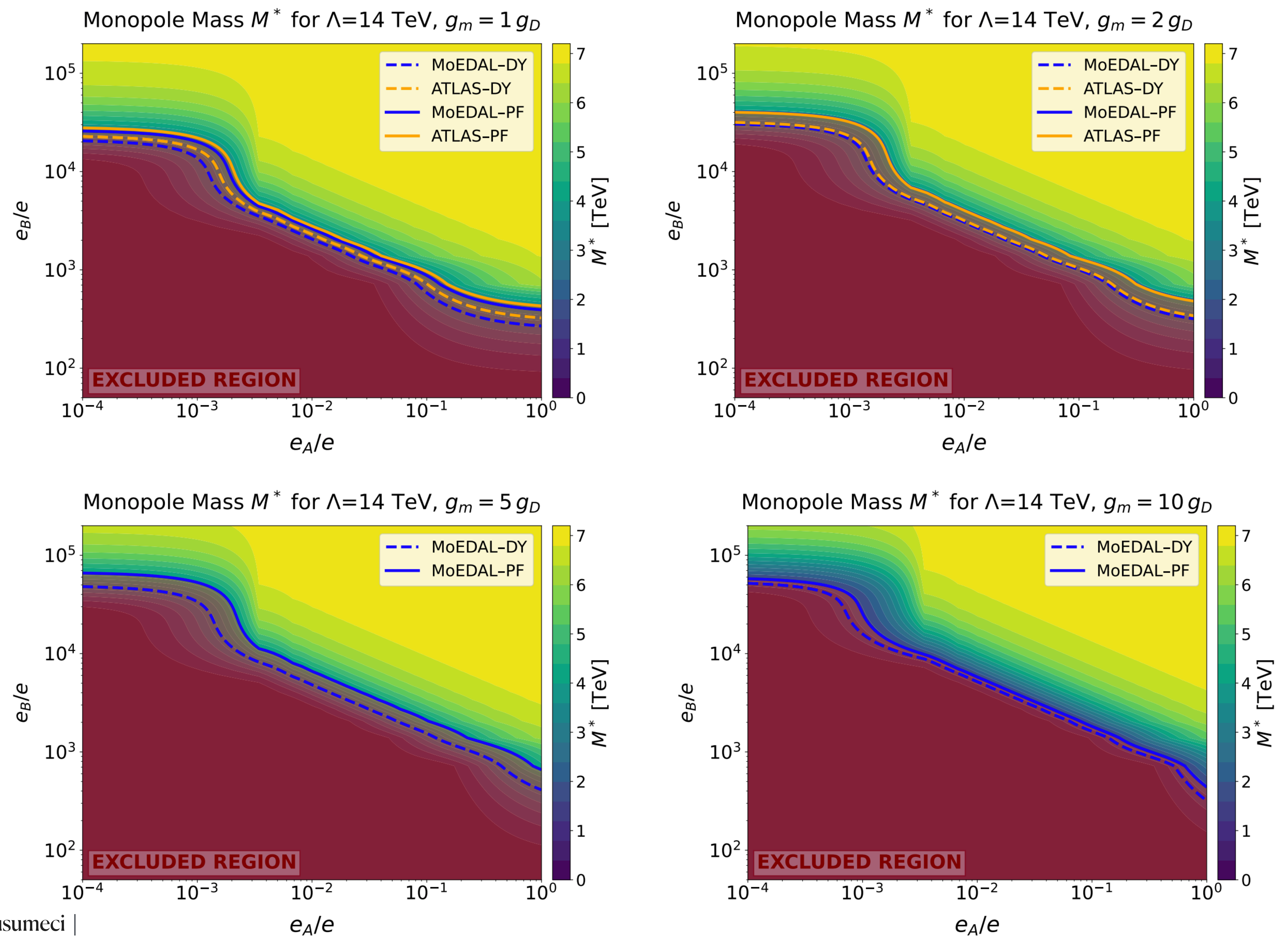
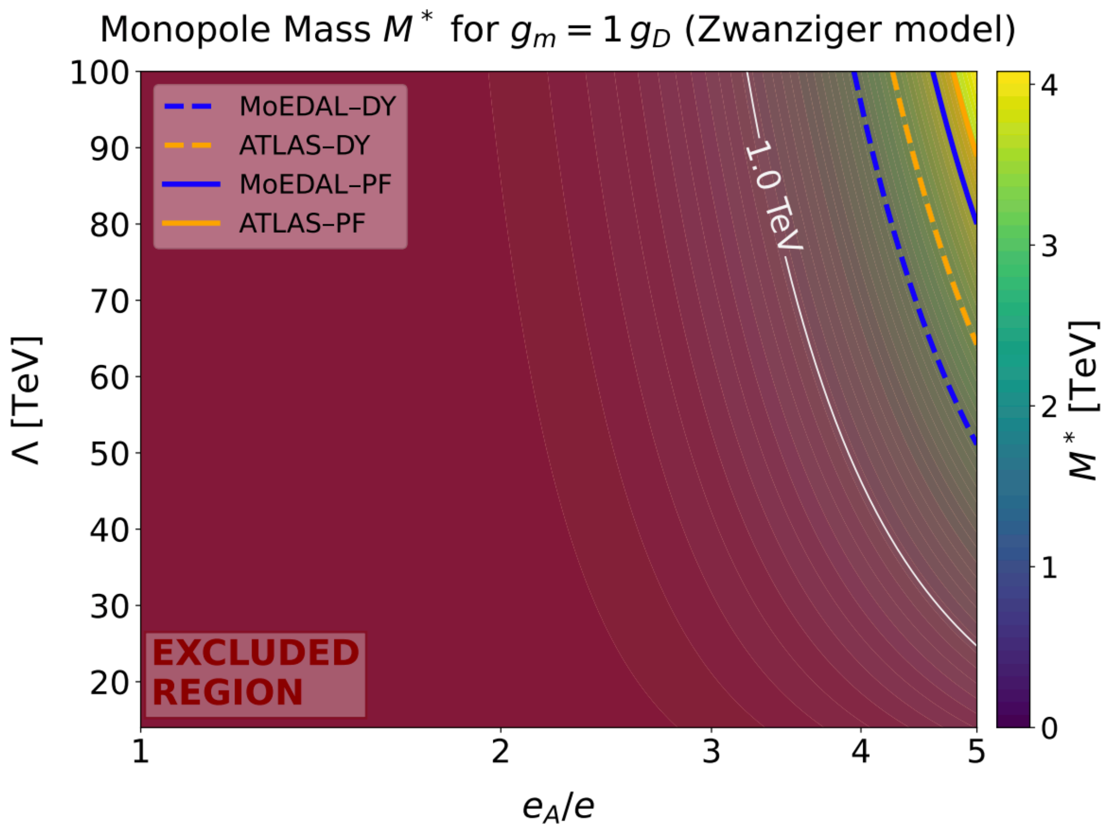
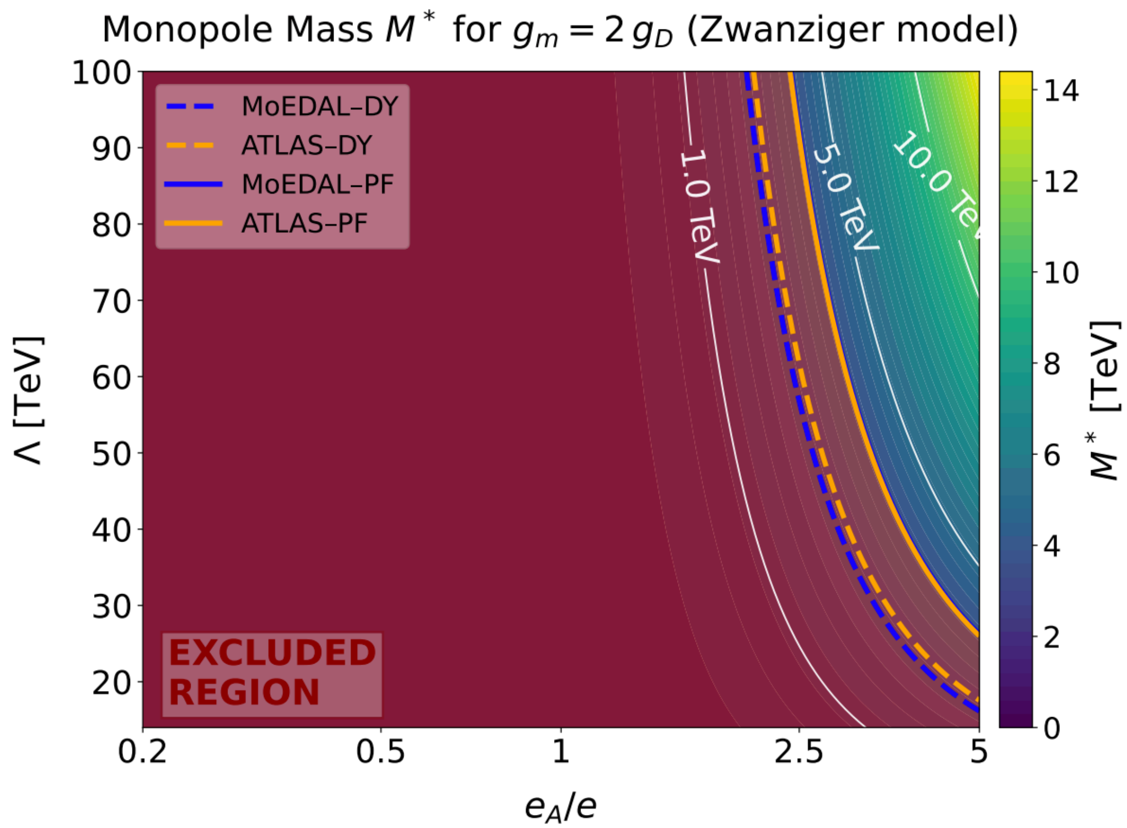
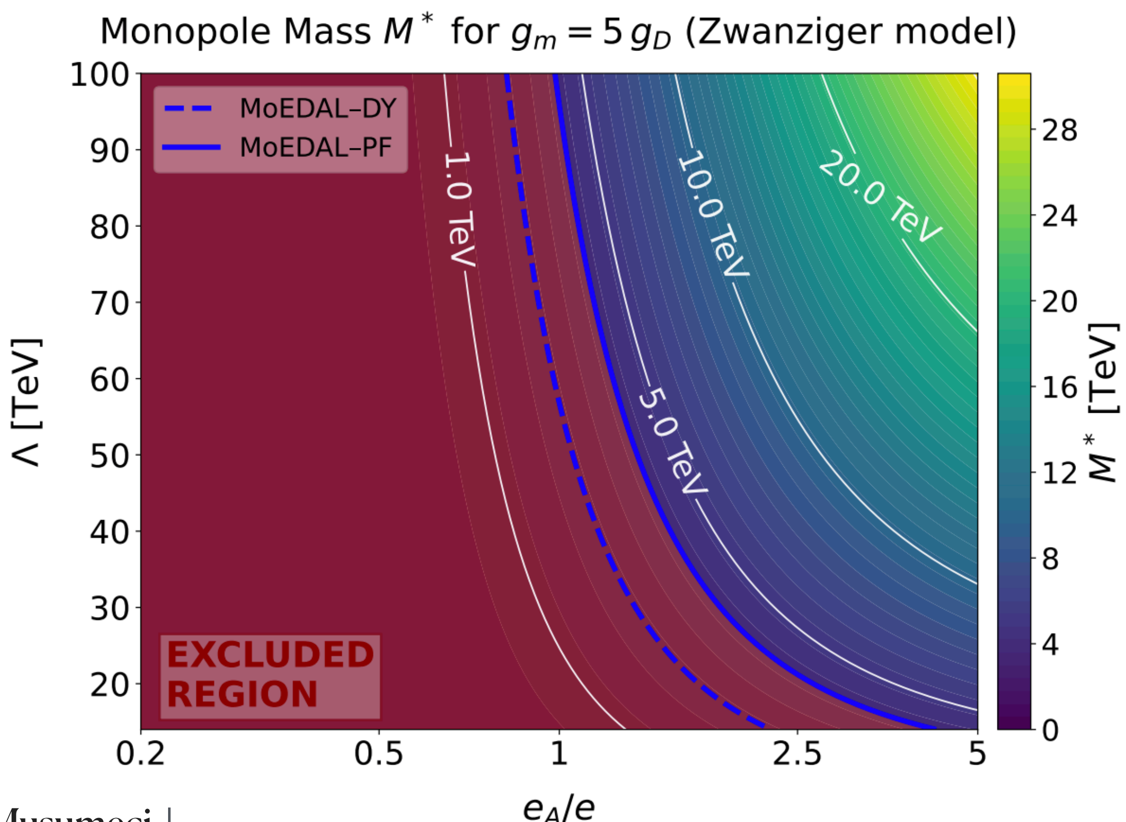


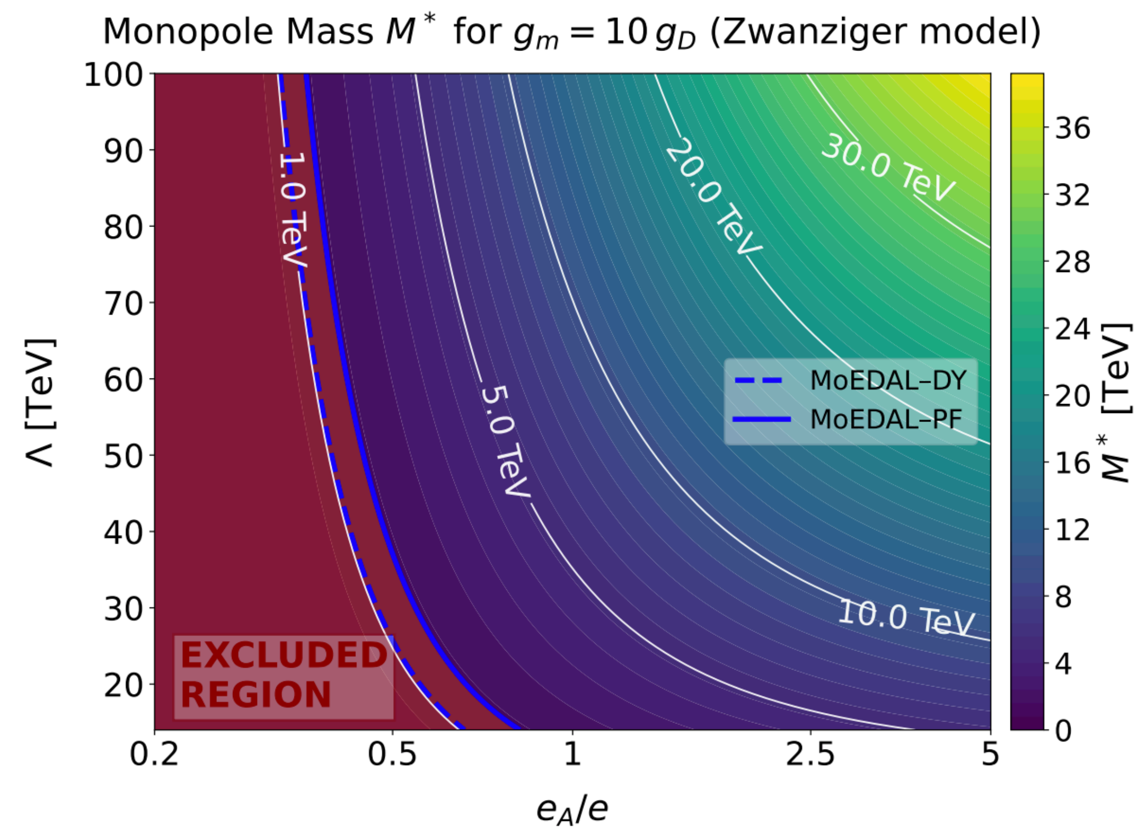
RESUMMATION FOR MAGNETIC MONOPOLES

Zwanziger model









COMPOSITE MONOPOLES

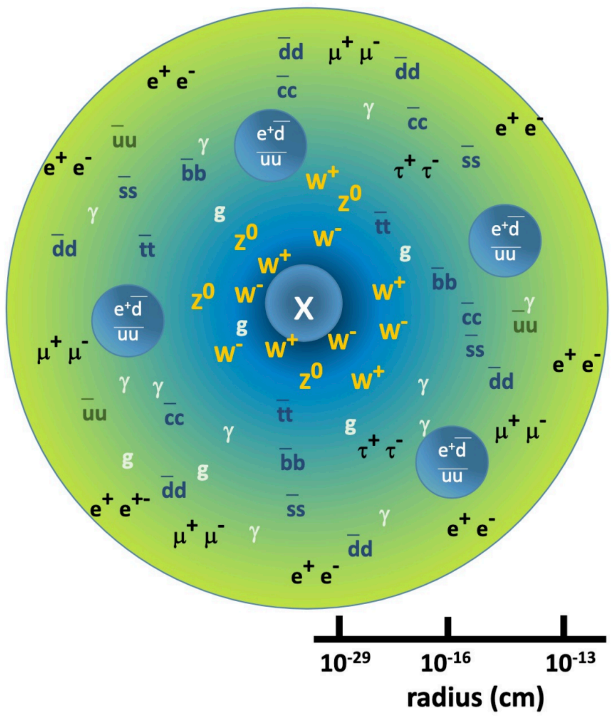
- **The resummed EFT is built for elementary, Dirac-type (structureless) MMs — no suppression there**

- **Composite (solitonic) MMs are a different story**

  - an electroweak MM is a coherent state of ~ $2/\alpha$ quanta of $W^{\pm}$ and $h^{\pm}$

  - amplitude suppressed by $\sim e^{-2/\alpha}$ $\Rightarrow$ σ suppressed by $\sim e^{-4/\alpha} \sim 10^{-250}$

  - no such suppression in the Schwinger mechanism — so far the only reliable composite-MM bound

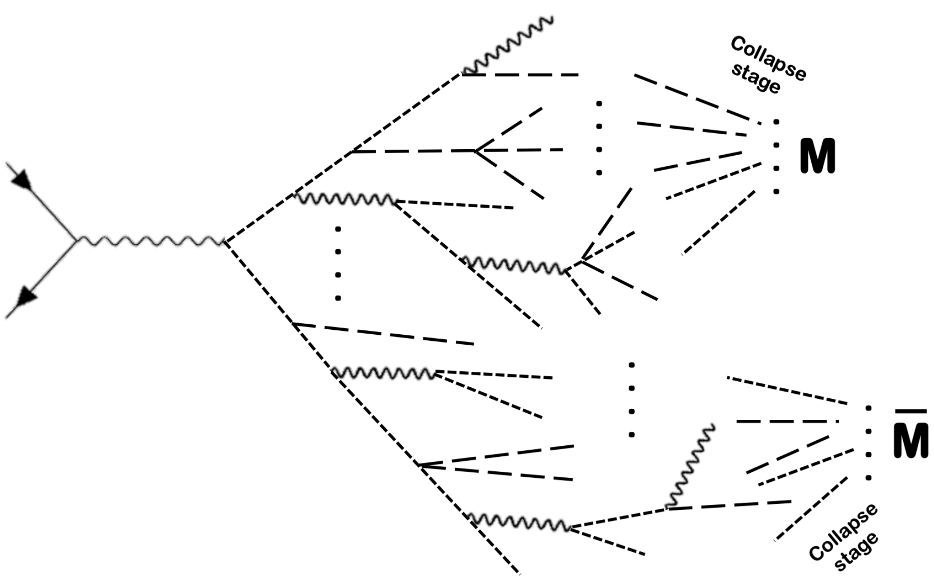


Patrizii & Spurio, Ann.Rev.Nucl.Part.Sci. 65 (2015) 279

- **Resummation provides enhancement factors,** via huge values of wave-function renormalisation at UV fixed point, which can cancel large “entropic” suppression

  - the huge $Z^{\star}$ may shrink the MM core down to its Compton wavelength ~ $1/M^{*}$, turning it into a quantum excitation

- **Still a conjecture — the link to microscopic solitonic models is open and model-dependent**



CONCLUSIONS

Dyson–Schwinger-like resummation gives a non-trivial UV fixed point where cross sections for strongly coupled HIPs can be computed reliably

- **HECOs — spin-1/2 and spin-0**
  - resummation ⇔ QED-like Lagrangian with a shifted gauge parameter, running charge and running mass
  - DY and PF cross sections are ENHANCED ⇒ mass limits increase by up to ~ 20–30%
  - UFO models (spin-1/2 and spin-0) public on the FeynRules database

- **Magnetic monopoles — spin-1/2**
  - U(1)em ⊗ U(1)′ EFT with a strongly coupled dark photon; UV fixed point with $Z^* \gg 1$
  - the DQC gives $g_m = Z^* e_A \Rightarrow$ cross sections and mass limits UNCHANGED
  - the LHC bounds instead constrain the EFT parameters Λ, e_A, e_B

Thanks for your attention! :)

Back-up slides

RESUMMATION for SPIN-0 HECOs

Electromagnetic Interactions - Scalar QED

Photon | HECO scalar | Self-interaction

$$\mathcal{L}_{\text{bare}} = \frac{1}{2}A^\mu \left[\eta_{\mu\nu}\Box - (1-\lambda)\partial_\mu\partial_\nu\right] A^\nu + D_\mu\phi(D^\mu\phi)^* - m^2\phi\phi^* - \frac{h}{4}(\phi\phi^*)^2$$

$D_\mu = \partial_\mu + igA_\mu$ | Bare mass

$n \geq 11$

Scalar dressed propagator

$$G(p) = \frac{i}{\mathcal{Z}^2 p^2 - M^2}$$

Photon dressed propagator

$$D_{\mu\nu}(q) = \frac{-i}{(1+\omega)q^2}\left(\eta_{\mu\nu} + \frac{1+\omega-\lambda}{\lambda}\frac{q_\mu q_\nu}{q^2}\right)$$

Dressed vertices

3-point	$ig\mathcal{Z}(p^1_\mu \pm p^2_\mu)$,
4-point	$2ig^2\mathcal{Z}^2\eta_{\mu\nu}$.

Dressed Lagrangian

$$\mathcal{L}_{\text{eff}} = \frac{1}{2}A^\mu \left[\eta_{\mu\nu}\Box - (1-\lambda)\partial_\mu\partial_\nu\right] A^\nu + \frac{\omega}{2}A^\mu\left[\eta_{\mu\nu}\Box - \partial_\mu\partial_\nu\right]A^\nu + \mathcal{Z}^2 D_\mu\phi(D^\mu\phi)^* - M^2\phi\phi^* - \frac{H}{4}(\phi\phi^*)^2$$

Rescaling $A_\mu \to A_\mu/\sqrt{1+\omega}$

$\phi \to \phi/Z$

$$\tilde{\mathcal{L}}_{\text{eff}} = \frac{1}{2}A^\mu\left[\eta_{\mu\nu}\Box - \frac{1-\lambda+\omega}{1+\omega}\partial_\mu\partial_\nu\right]A^\nu + (\partial_\mu\phi + i\tilde{g}A_\mu\phi)(\partial^\mu\phi^* - i\tilde{g}A^\mu\phi^*) - \tilde{M}^2\phi\phi^* - \frac{\tilde{H}}{4}(\phi\phi^*)^2$$

Effective parameters

$$\tilde{g} \equiv \frac{g}{\sqrt{1+\omega}} \ , \quad \tilde{H} \equiv \frac{H}{\mathcal{Z}^4} \ , \quad \tilde{M}^2 \equiv \frac{M^2}{\mathcal{Z}^2} \ .$$

RESUMMATION for SPIN-0 HECOs

Fixed point and dressed HECO mass

Looking for a fixed-point (ω^*, Z^*, H^*) solution of

$$\boxed{\begin{aligned} 1-\frac{m^2}{M^2} &= \frac{g^2}{8\pi^2\mathcal{Z}^2}\left(\frac{1}{\lambda}+\frac{H}{g^2\mathcal{Z}^2}\right)\ln\left(\frac{k\mathcal{Z}}{M}\right) , \\ \mathcal{Z}^2 &= 1+\frac{g^2}{8\pi^2}\frac{3\lambda-1-\omega}{\lambda(1+\omega)}\ln\left(\frac{k\mathcal{Z}}{M}\right) , \\ \omega &= \frac{g^2}{24\pi^2\mathcal{Z}^2}\ln\left(\frac{k\mathcal{Z}}{M}\right) , \\ H &= h+\frac{3}{8\pi^2}\left(-\frac{H^2}{\mathcal{Z}^4}+\frac{g^4}{\lambda^2}(2\mathcal{Z}^2-1)+\frac{Hg^2}{\mathcal{Z}^2\lambda}\right)\ln\left(\frac{k\mathcal{Z}}{M}\right) \end{aligned}}$$

$$\xrightarrow[g^2 \ll h]{M\to\infty}$$

$$\boxed{\omega^\star \simeq \frac{4g^2}{3h} \quad , \quad (\mathcal{Z}^\star)^2 \simeq 1+\frac{4g^2}{h}(3-1/\lambda) \quad , \quad H^\star \simeq \frac{h}{4}}$$

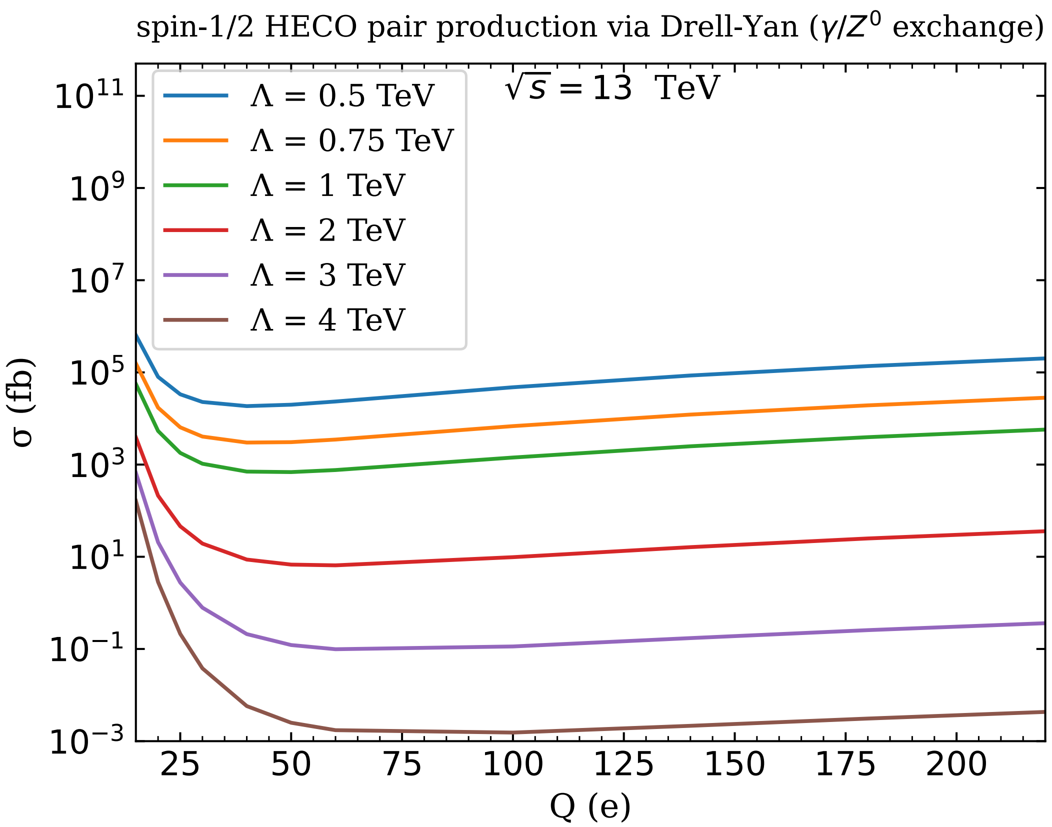
in the limit k → ∞, with fixed k/M such that the logarithms remain finite.

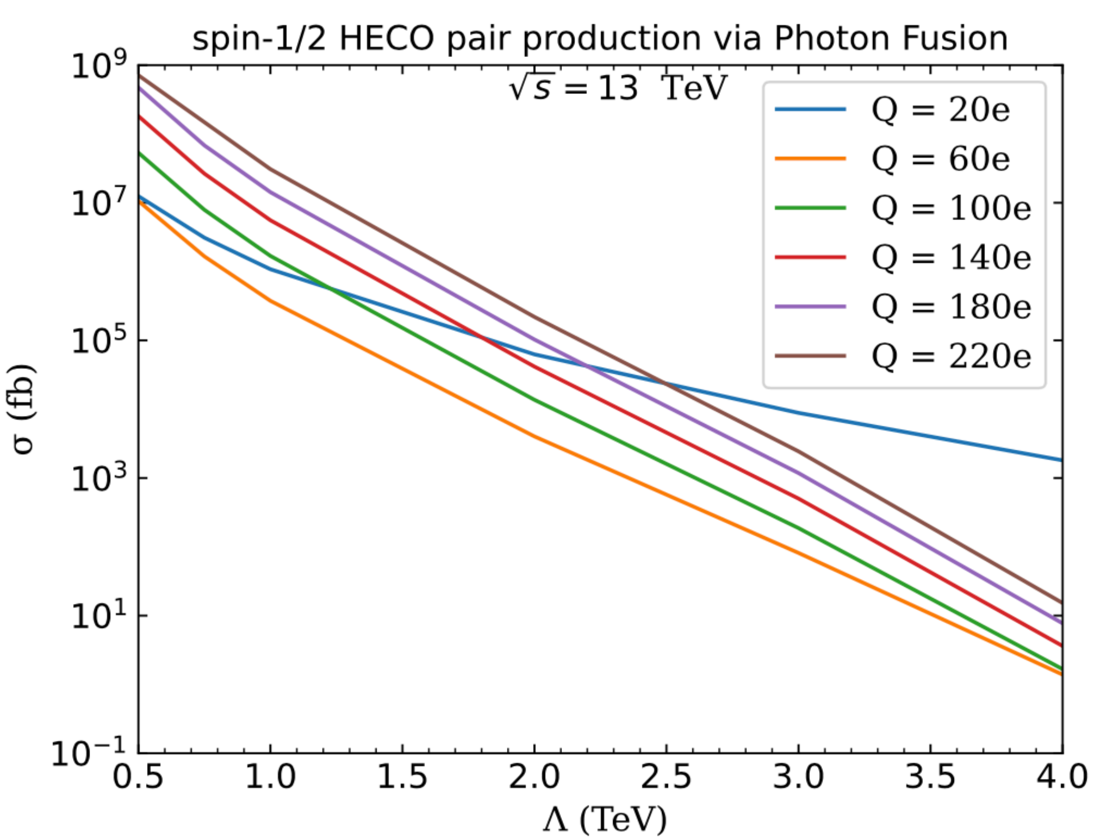
Feynman Rules @ UV fixed-point $\lambda = 1$

- **Scalar-γ vertex:** $-i\tilde{g}Z^\star \simeq -ig\sqrt{1+\frac{8g^2}{h}}$, $\left(\frac{g^2}{h} \lesssim 0.0825\right)$
- **Self-interaction vertex:** $-i\frac{H^\star}{Z^{\star 4}} \simeq -i\frac{h}{4}\left(1+\frac{8g^2}{h}\right)^{-2}$
- **Running mass:** $\tilde{M} \simeq \Lambda \exp\left(-\frac{32\pi^2}{h}\right) \lesssim \Lambda \exp\left(-\frac{2.64\,\pi^2}{n^2\,e^2}\right)$
- **Gauge Boson propagator:** $\frac{i}{p^2-i\epsilon}\left(-\eta_{\mu\nu}+\frac{4g^2}{3h}\frac{p_\mu p_\nu}{p^2}\right)$, $\epsilon \to 0^+$
- **Charged scalar propagator:** $\frac{i}{p^2-\tilde{M}^2+i\epsilon}$, $\epsilon \to 0^+$

IMPACT ON PRODUCTION CROSS SECTIONS

SPIN-1/2





SPIN-0