Magnetic monopole production in photon fusion process

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Kolymvari, Greece

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Introduction:

- Monopole production processes at collider experiments:

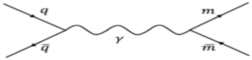


Figure: Drell-Yan (DY) production process

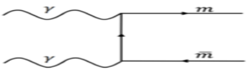
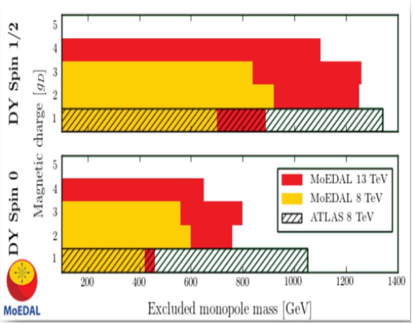


Figure: Photon fusion ($\gamma\gamma$) process



mass limits (GeV)		$1g_D$	$2g_D$	$3g_D$	$4g_D$
MoEDAL 13 TeV	spin-1/2	890	1250	1260	1100
	spin-0	460	760	800	650
MoEDAL 8 TeV	spin-1/2	700	920	840	-
	spin-0	420	600	560	-
ATLAS 8 TeV	spin-1/2	1340	-	-	-
	spin-0	1050	-	-	-

Things to remember:

- Mass limits depend on the models considered.
- Considered DY process in the colliders (in ATLAS, CDF and MoEDAL) to date.
- Only tree-level diagrams considered due to the non-perturbative nature of the large monopole-photon coupling

The reason:

- Dougall and Wick (S.D. Eur. Phys. J. A (2009) **39**: 213) showed that the $\gamma\gamma$/DY cross section ratio of monopole production is $\sim$ 4700 times $\gamma\gamma$/DY cross section ratio of lepton production.
- Drees et.al. (Phys. Rev. D **50**, 2335 (1994)) showed that the $\gamma\gamma$/DY cross-section ratio of lepton productions is nearly 10^{-2} for pp collisions at $\sqrt{s} = 14$ TeV.
- Hence a factor of $\sim$ 47 dominance of $\gamma\gamma$ over DY for monopole production (when monopole velocity $\beta = \frac{v}{c} \approx 1$)

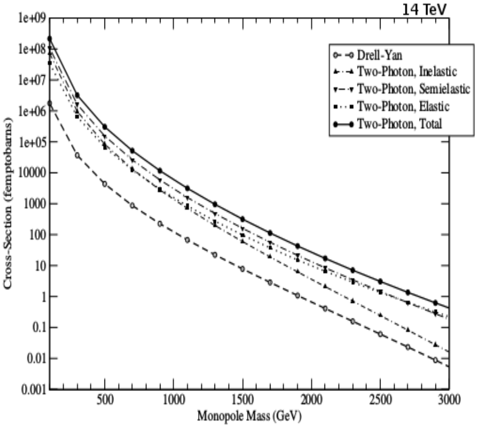


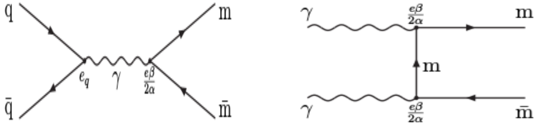
Figure: Cross-section vs mass plot for photon fusion and DY process (Spin 1/2). (S.D. Eur. Phys. J. A (2009) **39**: 213)

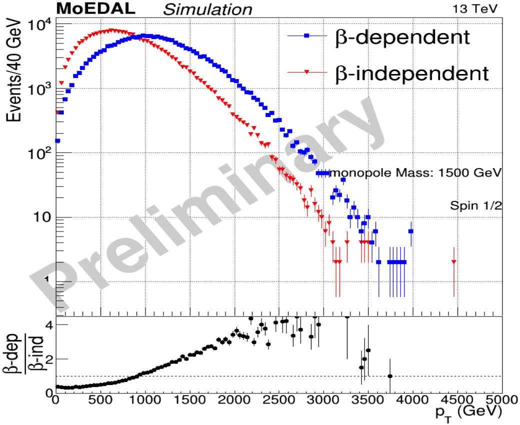
β-dependent coupling:

- What if the coupling of monopole-photon does depend on β?
- Need to consider β-dependent coupling models and see what the experimental result is.
- Good to test the model dependence of MoEDAL results.

Changes expected:

- $\beta(\leq 1)$ term in the coupling, hence cross section should be lower than before.
- Monopoles with higher velocity are produced at higher rate, makes a right shift to the transverse momentum distribution.





Implementation in the MadGraph :

- **Two** possible ways to introduce monopole in MadGraph models:

1. FeynRules

- Take the Lagrangian and then FeynRules gives an UFO model $\rightarrow$ import it in MadGraph .
- FeynRules calculates higher order diagrams, good for perturbative processes.
- **Problem:** The coupling is too high ($g \approx 68.5e$) for monopoles, cannot use perturbative processes.
- Hence need to rely only on the tree level process.

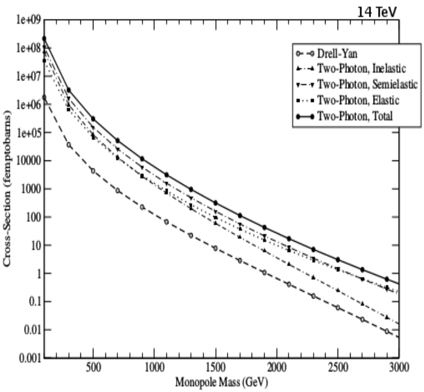
2. User mode

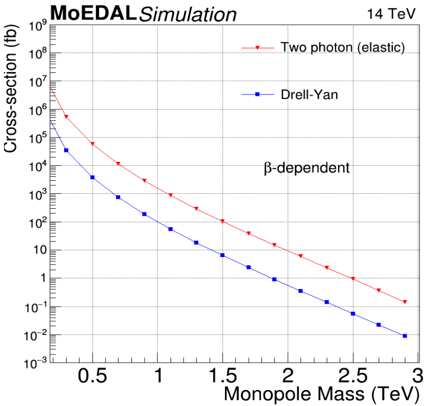
- Define a user model in MadGraph .
- New particles m and $\bar{m}$ with spin 1/2 (spin 0 and 1 are also considered).
- Use factorization and renormalization scales carefully to include β-dependent coupling.

MadGraph process:

- Collisions at $\sqrt{s} = 13$ TeV (Validation is done with $\sqrt{s} = 14$ TeV).
- Use the photons from proton option to generate photon fusion process (elastic), otherwise use the proton option to generate the DY process.
- Generate root files from the LHE files to analyze further.

Validation of β-dependent photon fusion process:





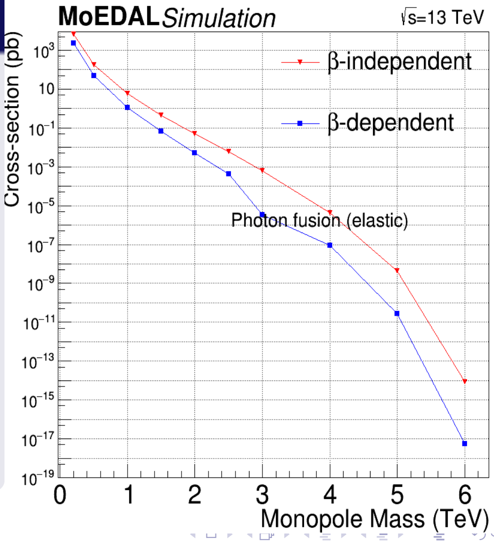
Comparison

- Compare the cross-section presented in Dougall and Wick paper with the calculations done by our MadGraph model.
- Matches within one order of magnitude, which accounts for different selected PDFs.

Comparison with the β-independent photon fusion process:

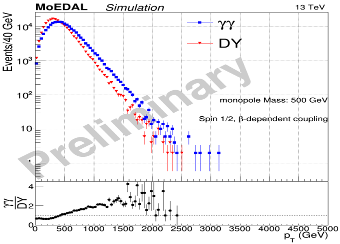
Comparing β-independent and β-dependent cross sections:

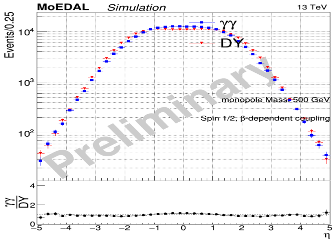
- Compared two scenarios from photon fusion model:
  1. Cross-section with β-independent coupling.
  2. Cross-section with β-dependent coupling.
- If everything works as wanted in MADGRAPH , then:
  - Cross-section in case 2 will be only a few magnitudes away from that of case 1.
  - As monopole masses increase, they become slower: cross-section should be even lower than case 1.
- The figure in the right shows that the expected behavior is seen.

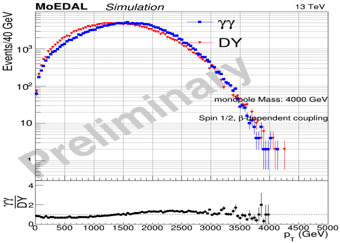


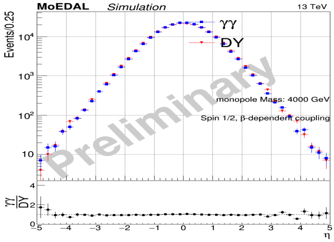
Comparison of kinematic variable distributions between $\gamma\gamma$ and DY processes (Spin 1/2)

- Distributions of kinematic variables like transverse momentum (p_T) and η, for both $\gamma\gamma$ and DY processes.









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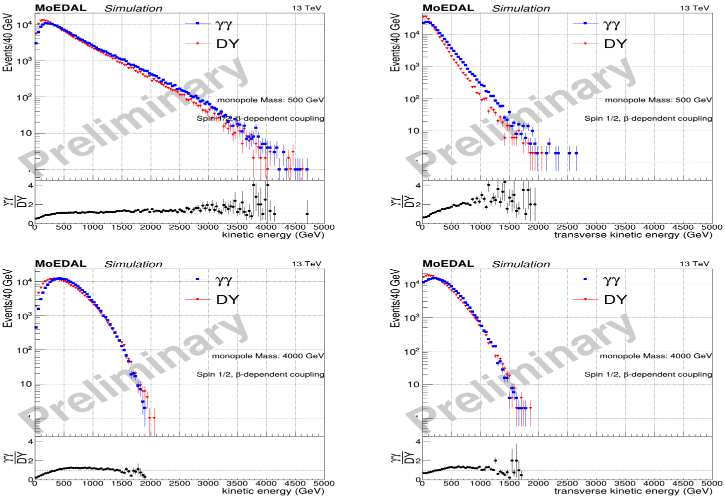
Comparison of kinematic variable distributions between $\gamma\gamma$ and DY processes (Spin 1/2):

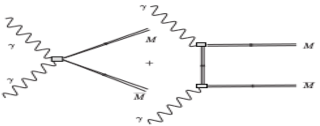
- If total energy is E and mass of the particle is M, then total kinetic energy, $E_{kin} = \text{E} - \text{M}$
- transverse kinetic energy, $E_{kinT} = \sqrt{p_T^2 + M^2} - M$.



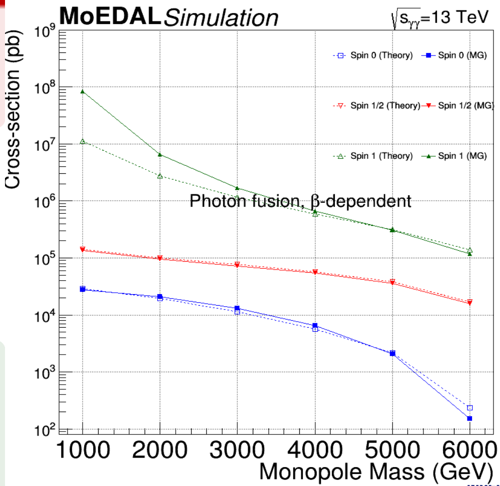
Working with spin 0 and spin 1 monopoles: Comparison of cross-sections with theory and MadGraph (MG)

What if monopoles are bosons (unlike electron)?

- Need to interpret the data keeping this in mind.
- Need to simulate the scenarios when monopole spin is integer.

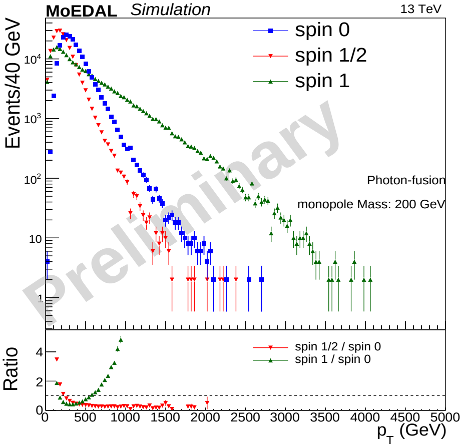


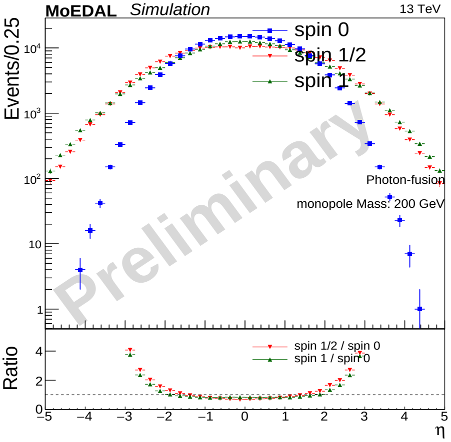
- Theoretical calculations of cross-sections of monopole production in photon fusion for spin 0, 1/2 and 1 were done by Rusakovich et al (Mod. Phys. Lett. A 21 (2006) 2873).



Comparison of kinematic distributions among spin 0, spin 1/2 and spin 1 models: monopole mass 200 GeV

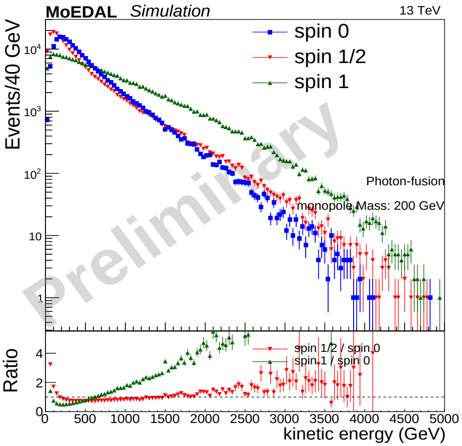
- Distributions of kinematic variables like transverse momentum (p_T) and η.

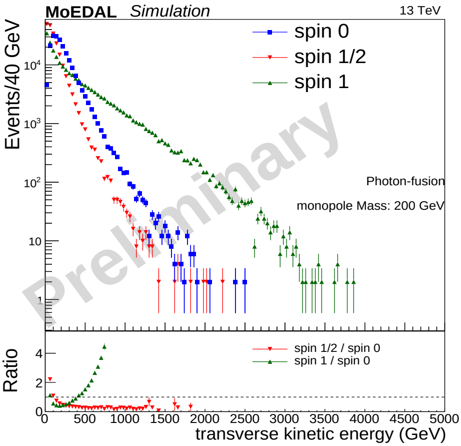




Comparison of kinematic distributions among spin 0, spin 1/2 and spin 1 models: monopole mass 200 GeV

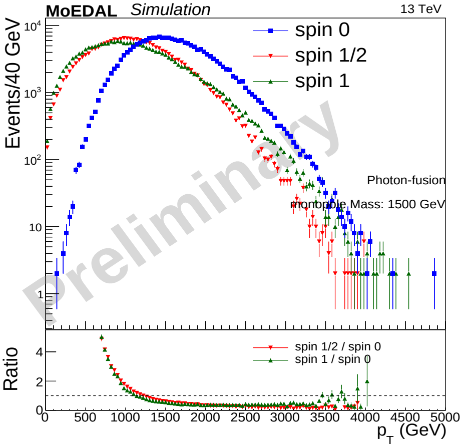
- Distributions of kinematic variables like total kinetic energy and transverse kinetic energy.

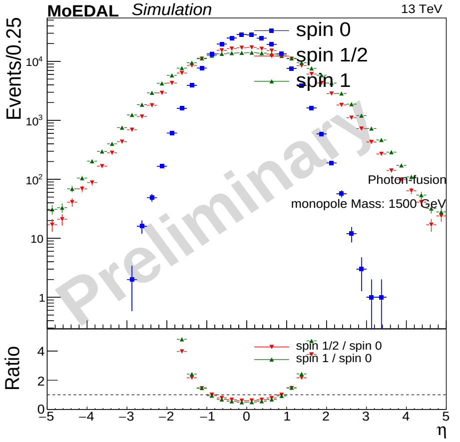




Comparison of kinematic distributions among spin 0, spin 1/2 and spin 1 models: monopole mass 1500 GeV

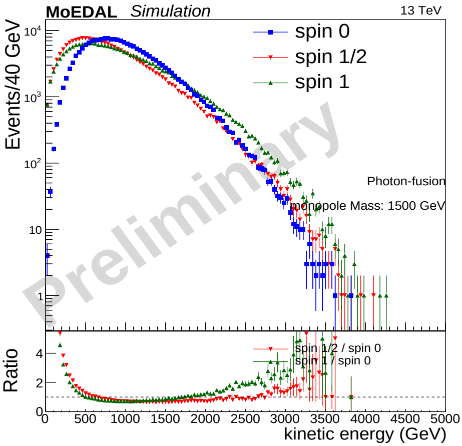
- Distributions of kinematic variables like transverse momentum (p_T) and η.

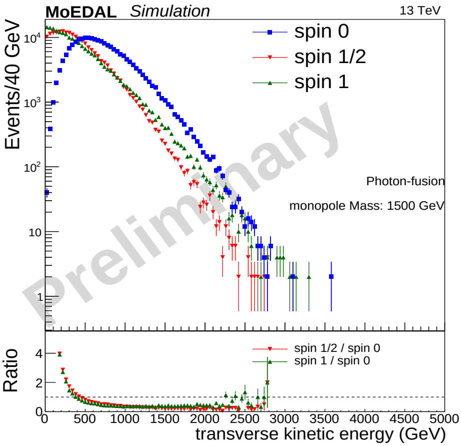




Comparison of kinematic distributions among spin 0, spin 1/2 and spin 1 models: monopole mass 1500 GeV

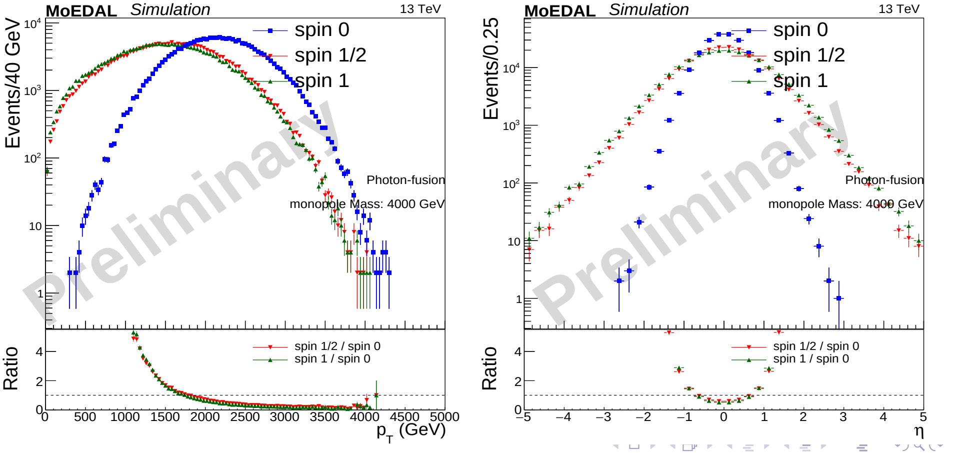
- Distributions of kinematic variables like total kinetic energy and transverse kinetic energy.





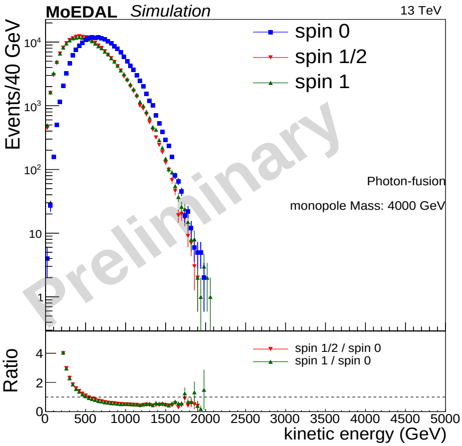
Comparison of kinematic distributions among spin 0, spin 1/2 and spin 1 models: monopole mass 4000 GeV

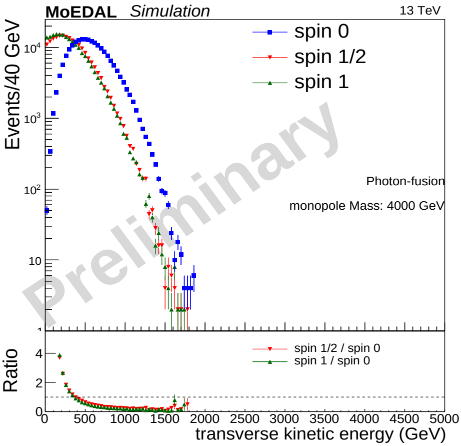
- Distributions of kinematic variables like transverse momentum (p_T) and η.



Comparison of kinematic distributions among spin 0, spin 1/2 and spin 1 models: monopole mass 4000 GeV

- Distributions of kinematic variables like total kinetic energy and transverse kinetic energy.





Summary and Outlook:

- Successful in using MadGraph to generate LHE files for of photon-monopole coupling.
- Generated events when monopole spin is 0, 1/2 and 1.
- Comparison of kinematic distributions were done.
- Need to use the LHE files to simulate the detector effect.

Next steps:

- Still some discrepancies in spin 1 case. Need to find out why.
- Need to confirm if MadGraph is considering all the graphs in calculating the cross-section of spin 0 and spin 1 cases.
- Statistically interpret the data.

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Thank you

- Back Up

Rusakovich's calculations:

$$\sigma_{\gamma\gamma}^{s=0}(\hat{s}) = \frac{4\pi\alpha_g^2}{\hat{s}}\beta\left[2-\beta^2-\frac{1-\beta^4}{2\beta}\ln\left(\frac{1+\beta}{1-\beta}\right)\right] \quad (1)$$

$$\sigma_{\gamma\gamma}^{s=1/2}(\hat{s}) = \frac{4\pi\alpha_g^2}{\hat{s}}\beta\left[-2+\beta^2+\frac{3-\beta^4}{2\beta}\ln\left(\frac{1+\beta}{1-\beta}\right)\right] \quad (2)$$

$$\sigma_{\gamma\gamma}^{s=1}(\hat{s}) = \frac{\pi\alpha_g^2}{\hat{s}}\beta\left[2\frac{22-9\beta^2+3\beta^4}{1-\beta^2}-3\frac{1-\beta^4}{\beta}\ln\left(\frac{1+\beta}{1-\beta}\right)\right] \quad (3)$$

where

$$\alpha_g = g^2\beta^2,\ \beta = \sqrt{1-4M^2/\hat{s}},\ \hat{s} = z_1 z_2 s \quad (4)$$

.

1. $g = \sqrt{137/4} = 5.85$
2. $\alpha_g = 34.25$
3. form factor $= 1.0$
4. $z_1 = z_2 = 1$
5. $\sqrt{s} = 13$ TeV
6. 1 pb $= 2.5819 \times 10^{-9}$ GeV^{-2}
7. $\hat{s} = 13 \times 13$ TeV^2

Conditions for MadGraph

- Spin 0, Spin 1/2 and Spin 1, Kinematic distributions.
- Photon fusion, elastic.
- β-dependent coupling
- total kinetic energy, E_{kin} = total energy, E − mass, M
- transverse kinetic energy, $E_{kint} = \sqrt{p_T^2 + M^2} - M$.
- longitudinal kinetic energy, $E_{kinl} = E_{kin} - E_{kint}$

Argument against β-dependent coupling:

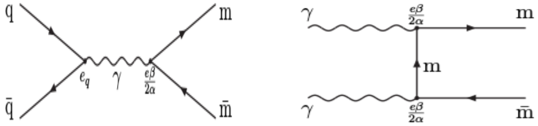
ATLAS 'shrugged':

- ATLAS has moved from β-dependent coupling (7 TeV, arXiv:1207.6411) to β-independent coupling (8 TeV, arXiv:1509.08059) following an argument by Roman Koniuk (York).

- Milton (arXiv:hep-ex/0602040) derived the electron-monopole scattering cross-section for small scattering angle : $\frac{d\sigma}{d\Omega} = \frac{1}{(2\mu v_0)^2}\left[\left(\frac{eg}{c}\right)^2\right]\frac{1}{(\theta/2)^4}$ where g is the magnetic charge of the monopole.
- Rutherford scattering formula: $\frac{d\sigma}{d\Omega} = \frac{1}{(2\mu v_0)^2}\left[\left(\frac{e_1 e_2}{v_0}\right)^2\right]\frac{1}{(\theta/2)^4}$ can be obtained from Milton's calculation if $\frac{e_2}{v_0} \rightarrow \frac{g}{c}$ or $e_2 \rightarrow \frac{g v_0}{c} = g\beta$.
- This leads to $\alpha = \frac{e^2}{\hbar c} \rightarrow \alpha_m = \frac{(g\beta)^2}{\hbar c}$.
- The Lorentz Force law: $\vec{F} = e\vec{E} + e\beta\vec{c}\times\vec{B}$; even though the interaction with the magnetic field depends on β, the QED coupling depends only on e: $\alpha = \frac{e^2}{\hbar c}$.
- Force on the monopole: $\vec{F} = g\vec{B} - g\beta\vec{c}\times\vec{E}$.
- This does not necessarily imply that the photon-monopole coupling should be β-dependent.

Symmetry argument between electricity and magnetism:

- There is no velocity dependent coupling for photon-electron, will there be any for photon-monopole?



- The ratio of couplings in photon fusion and DY process in the monopole production is given by: $r_m = \frac{e_q^4(\frac{e\beta}{2\alpha})^4}{e_q^2(\frac{e\beta}{2\alpha})^2}$ (S.D. Eur. Phys. J. A (2009) **39**: 213).
- The ratio of couplings in photon fusion and DY process in the lepton production is given by: $r_l = \frac{e_q^4 e^4}{e_q^2 e^2} = \bar{\eta}^2\alpha^2$. Here $\bar{\eta}$ is the average fractional quark charge contributing to the cross-section.
- Change in the $\gamma\gamma$/DY cross-section ratio expected for monopole versus lepton production is given by: $R = \frac{r_m}{r_l} = \frac{\beta^2/4}{\alpha^2} \sim 4700$ when $\beta \sim 1$.
- Dress et al found that $r_l \sim 0.01$, hence $r_m \sim 47$ when $\beta \sim 1$.

- Milton derived the electron-monopole scattering cross-section for small scattering angle: $\frac{d\sigma}{d\Omega} = \frac{1}{(2\mu v_0)^2}\left[\left(\frac{e_1 g_2 - e_2 g_1}{c}\right)^2 + \left(\frac{e_1 e_2 - g_2 g_1}{v_0}\right)^2\right]\frac{1}{(\theta/2)^4}$, where e_i and g_i are the electric and magnetic charge for dyon i.
- For electron and monopole $e_1 = e$, $g_1 = 0$, $e_2 = 0$, $g_2 = 1$.
- Hence $\frac{d\sigma}{d\Omega} = \frac{1}{(2\mu v_0)^2}\left[\left(\frac{eg}{c}\right)^2\right]\frac{1}{(\theta/2)^4}$
- Rutherford scattering formula: $\frac{d\sigma}{d\Omega} = \frac{1}{(2\mu v_0)^2}\left[\left(\frac{e_1 e_2}{v_0}\right)^2\right]\frac{1}{(\theta/2)^4}$ can be obtained from Milton's calculation if $\frac{e_2}{v_0} \to \frac{g}{c}$ or $e_2 \to \frac{g v_0}{c}$.
- This leads to $\alpha = \frac{e^2}{\hbar c} \to \alpha_m = \frac{(g\beta)^2}{\hbar c}$

Details of the argument against β-dependent coupling:

- The Bethe-Bloch formula of energy loss: $-\frac{dE}{dx} = K\frac{Z}{A}\frac{z^2}{\beta^2}\left[\ln\frac{2m_ec^2\beta^2\gamma^2}{I} - \beta^2 - \delta/2\right]$.
- If we replace z by $g\beta$, then (Ahlen, Phys.Rev. D14 (1976) 2935-2940): $-\frac{dE}{dx} = K\frac{Z}{A}g^2\left[\ln\frac{2m_ec^2\beta^2\gamma^2}{I} + \frac{k(|g|)}{2} - \frac{1}{2} - \delta/2 - B(|n|)\right]$.
- The β factor appears in the electron-monopole scattering formula because of the Lorentz force interaction of monopoles with the electric field.
- It also appears in the formula of $-\frac{dE}{dx}$, but it is not justified for the photon-monopole coupling.

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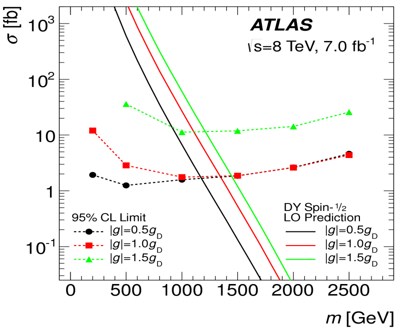
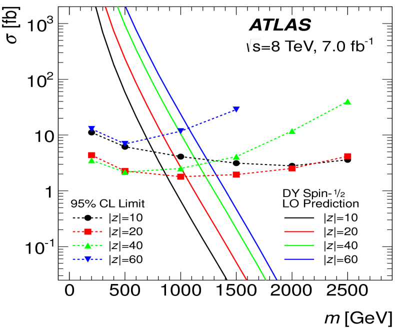
DY process (β-independent coupling): Results from ATLAS

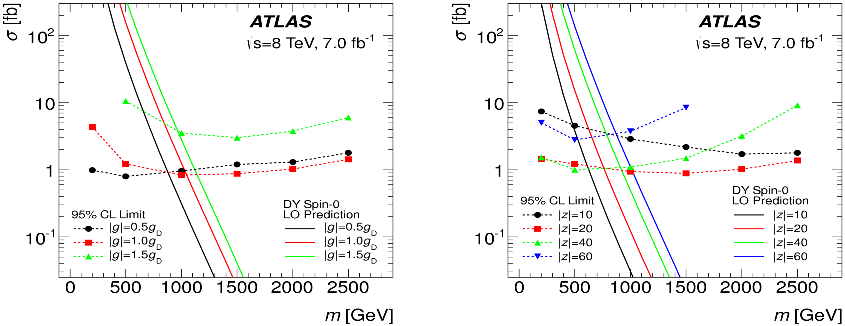
- ATLAS searched for monopoles with DY production.
- The latest public result is from 8 TeV analysis (**arxiv:1509.08059**).
- Spin-1/2 monopole:





Drell-Yan Lower Mass Limit (GeV)							
	$\|g\| = 0.5\ g_D$	$\|g\| = 1.0 g_D$	$\|g\|=1.5 g_D$	$\|z\| = 10$	$\|z\| = 20$	$\|z\| = 40$	$\|z\| = 60$
spin-1/2	1180	1340	1210	780	1050	1160	1070

- Spin 0 monopole:



Drell-Yan Lower Mass Limit (GeV)							
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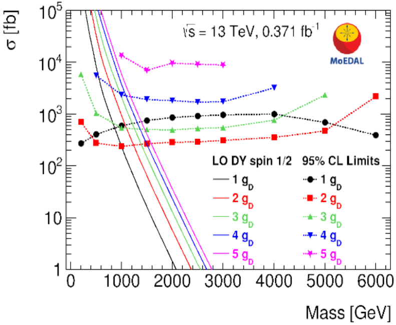
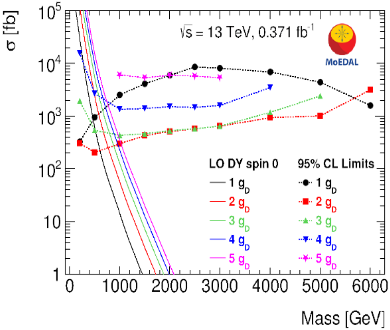
spin-0	890	1050	970	490	780	920	880

DY process (β-independent coupling): Results from MoEDAL

- The latest result from MoEDAL uses 0.371 fb^{-1} (13 TeV) of data (arXiv:1611.06817).
- Again, the DY production with no velocity dependent coupling was considered.
- Monopole velocity $\beta \leq 10^{-3}$.





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