
PDF4BSM
Parton Distributions in the Higgs Boson Era



# Characterising New Physics with Polarised Beams at High-Energy Hadron Colliders

Fuks, Proudon, J.R, Schienbein, arXiv:1403.2383

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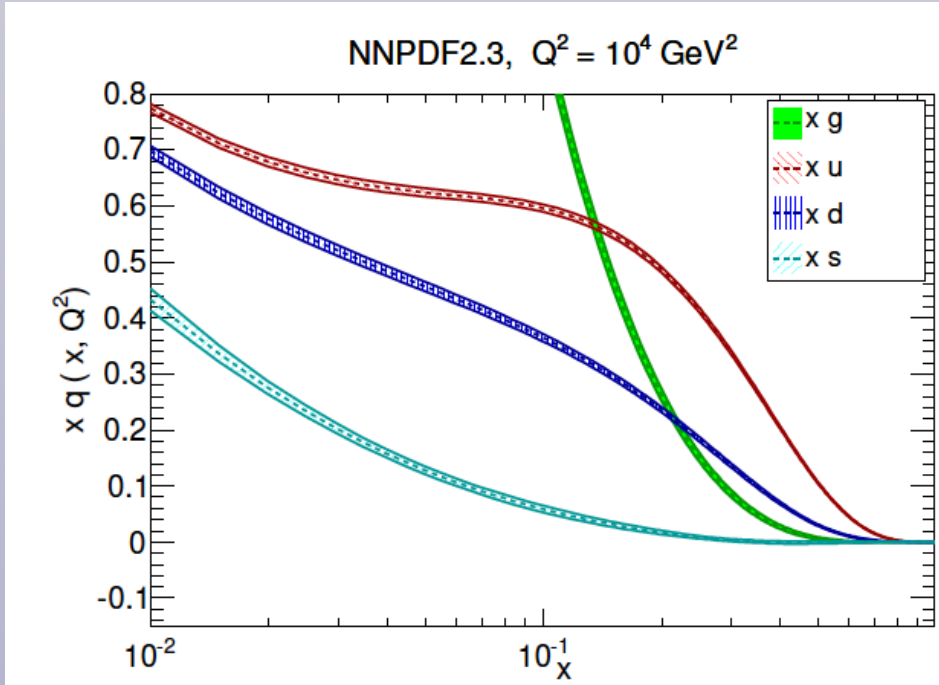
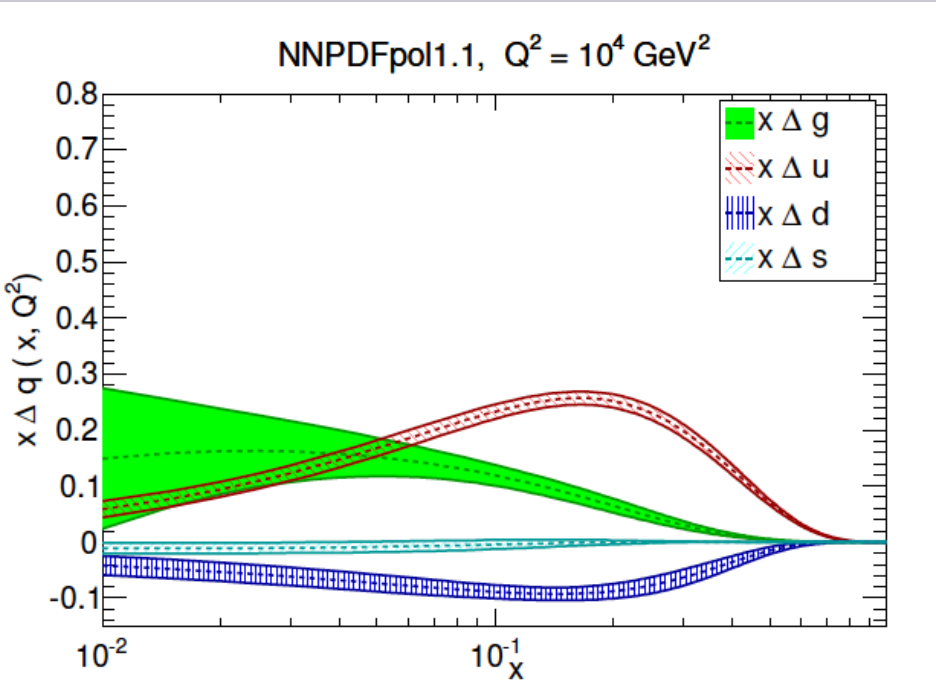
# Motivation

- The internal structure of the proton, quantified by the **Parton Distribution Functions,** looks very different if the protons are **unpolarised or polarised**
- In the case of BSM physics discovery at high masses, these differences provide an interesting probe to **characterise the structure of the BSM physics,** allowing for example to **disentangle its couplings to different quark flavours**

**Unpolarized PDFs**




**Polarized PDFs**




- Therefore, **production cross-sections for new heavy BSM physics** will look very different if the proton is unpolarised or polarised

# Polarised vs Unpolarised PDFs

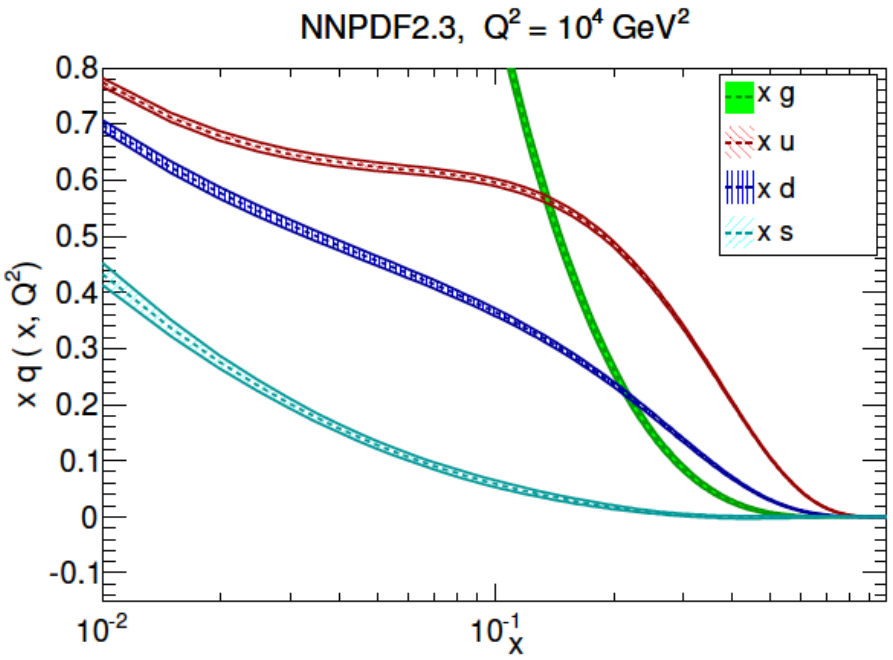
- Various factors contribute to the differences between polarised and unpolarised PDFs: different non-perturbative **sum rules**, **positivity constrain**s, different splitting functions and **small-*x* behaviour** …
- At large values of Bjorken-x, **polarised PDFs tend to saturate the positivity bound**, and thus their magnitude is comparable to the unpolarised PDFs but with different qualitative behaviours

$$q_i(x,Q^2) \equiv q_i^{\uparrow}(x,Q^2) + q_i^{\downarrow}(x,Q^2) \ ,$$

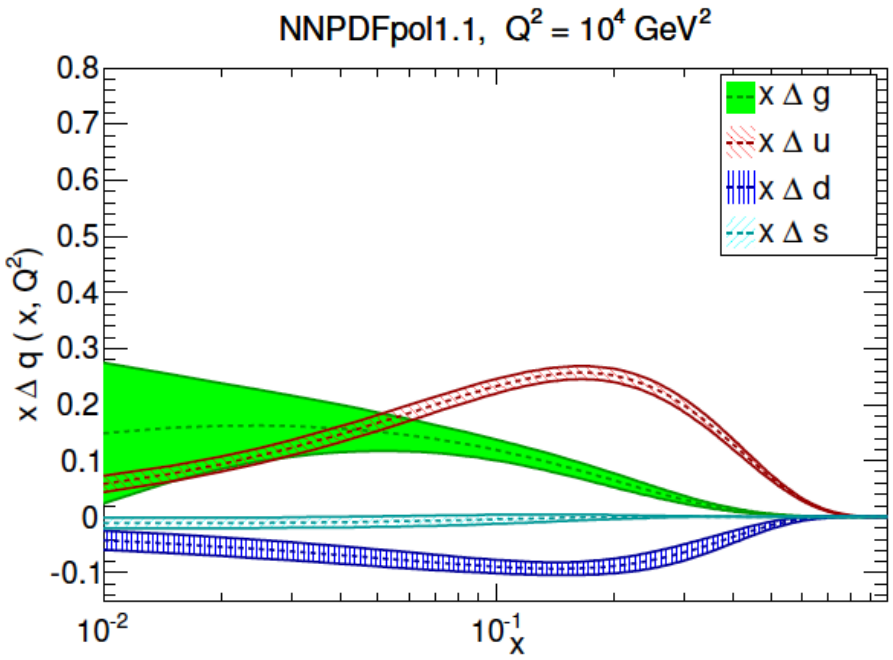
$$\Delta q_i(x,Q^2) \equiv q_i^{\uparrow}(x,Q^2) - q_i^{\downarrow}(x,Q^2) \ ,$$

$$|\Delta q_i(x,Q^2)| \leq q_i(x,Q^2) \ .$$

**Unpolarized PDFs**




**Polarized PDFs**



# PDF luminosities

A first estimate of the **behaviour of BSM cross-sections with polarised proton beams** can be provided by the **parton-parton luminosities**

**Unpol + Unpol**

$$\mathcal{L}_{ij} = \frac{1}{S}\int_\tau^1 \frac{dx}{x}\frac{1}{1+\delta_{ij}}\left[q_i\left(x,m_X\right)q_j\left(\frac{\tau}{x},m_X\right)+q_i\left(\frac{\tau}{x},m_X\right)q_j\left(x,m_X\right)\right]$$

**Unpol + Pol**

$$\mathcal{L}^L_{ij} = \frac{1}{S}\int_\tau^1 \frac{dx}{x}\frac{1}{1+\delta_{ij}}\left[q_i\left(x,m_X\right)\Delta q_j\left(\frac{\tau}{x},m_X\right)+q_i\left(\frac{\tau}{x},m_X\right)\Delta q_j\left(x,m_X\right)\right]$$

**Pol + Pol**

$$\mathcal{L}^{LL}_{ij} = \frac{1}{S}\int_\tau^1 \frac{dx}{x}\frac{1}{1+\delta_{ij}}\left[\Delta q_i\left(x,m_X\right)\Delta q_j\left(\frac{\tau}{x},m_X\right)+\Delta q_i\left(\frac{\tau}{x},m_X\right)\Delta q_j\left(x,m_X\right)\right]$$

The first case is the standard at the LHC. The second would correspond to a s**ingle proton beam polarised**, and the third scenario is when the **two proton beams are polarised**

# Single and Double Spin Asymmetries

- Experimentally, cross-sections involving polarised hadron beams are **normalised to their experimental counterparts**, since many uncertainties cancel without affecting the physical information of the measurement

$$\sigma_0 = \frac{1}{4}\left[\sigma^{\uparrow\uparrow} + \sigma^{\downarrow\downarrow} + \sigma^{\uparrow\downarrow} + \sigma^{\downarrow\uparrow}\right]$$
$$\sigma_L = \frac{1}{4}\left[\sigma^{\uparrow\uparrow} - \sigma^{\downarrow\downarrow} - \sigma^{\uparrow\downarrow} + \sigma^{\downarrow\uparrow}\right]$$
$$\sigma_{LL} = \frac{1}{4}\left[\sigma^{\uparrow\uparrow} + \sigma^{\downarrow\downarrow} - \sigma^{\uparrow\downarrow} - \sigma^{\downarrow\uparrow}\right]$$

$$A_L = \frac{\sigma_L}{\sigma_0}$$

Single-spin asymmetry

$$A_{LL} = \frac{\sigma_{LL}}{\sigma_0}$$

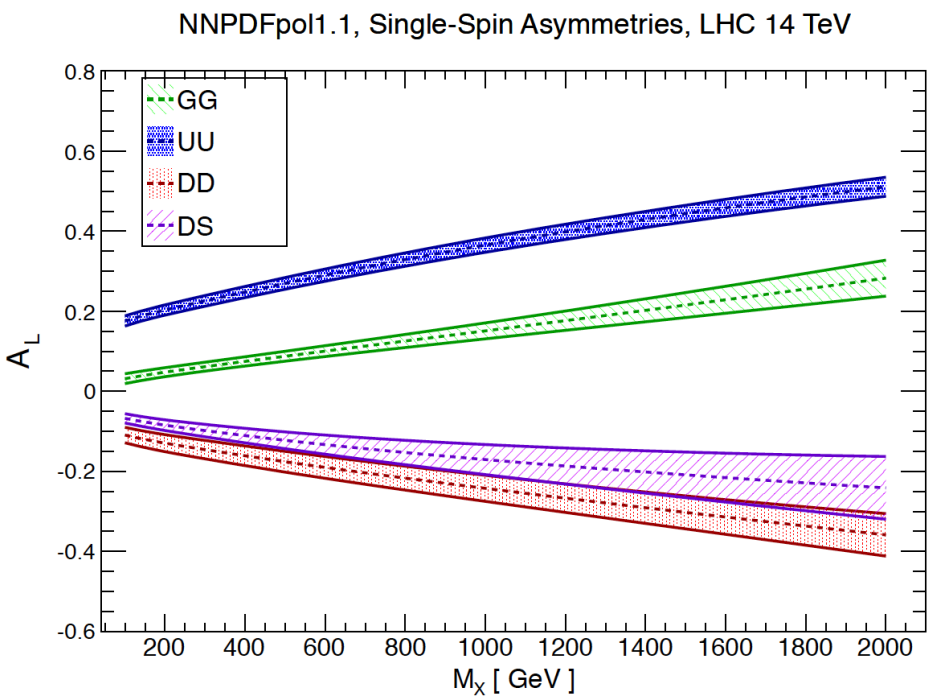
Double-spin asymmetry

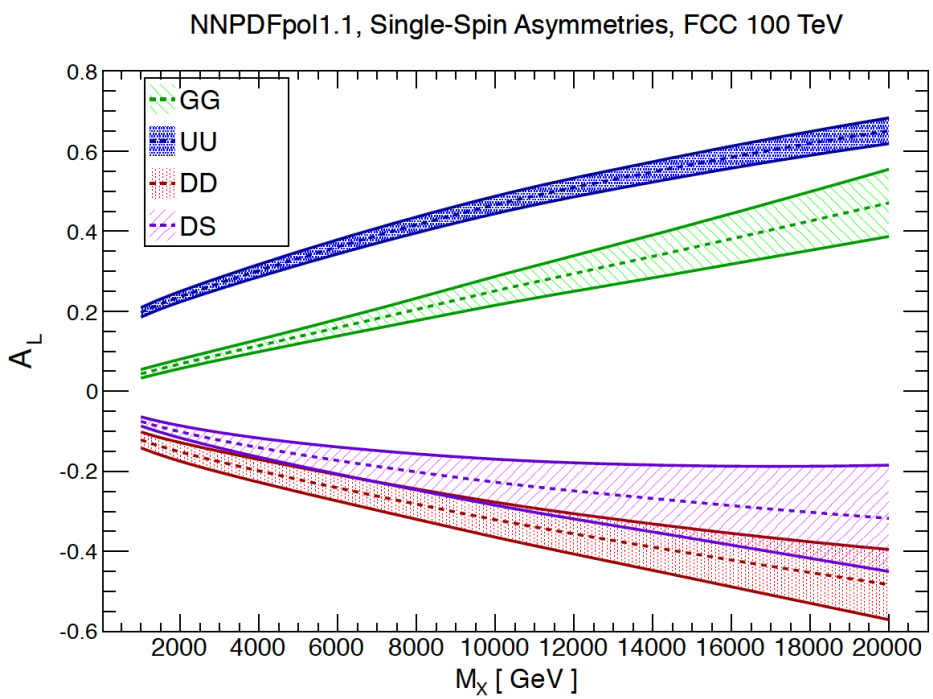
$$\sigma_0 = q_i \otimes q_j \otimes \hat{\sigma}_{0,ij} = \mathcal{L}_{ij} \otimes \left[\hat{s}\ \hat{\sigma}_{0,ij}\right],$$
$$\sigma_L = q_i \otimes \Delta q_j \otimes \hat{\sigma}_{L,ij} = \mathcal{L}^L_{ij} \otimes \left[\hat{s}\ \hat{\sigma}_{L,ij}\right],$$
$$\sigma_{LL} = \Delta q_i \otimes \Delta q_j \otimes \hat{\sigma}_{LL,ij} = \mathcal{L}^{LL}_{ij} \otimes \left[\hat{s}\ \hat{\sigma}_{LL,ij}\right].$$

Relation between polarised xsecs and PDF luminosities

- To maximise the number of events at high-mass, convenient to focus on the **single-spin asymmetries**
- Double-spin asymmetries are more useful to **constrain the polarised PDFs themselves**
- Polarised PDFs are currently affected by large uncertainties (reduced dataset) but this would be solved if **polarised protons were injected at the FCC** by means of a **dedicated program**, analogous to that being carried at the LHC for unpolarised PDFs

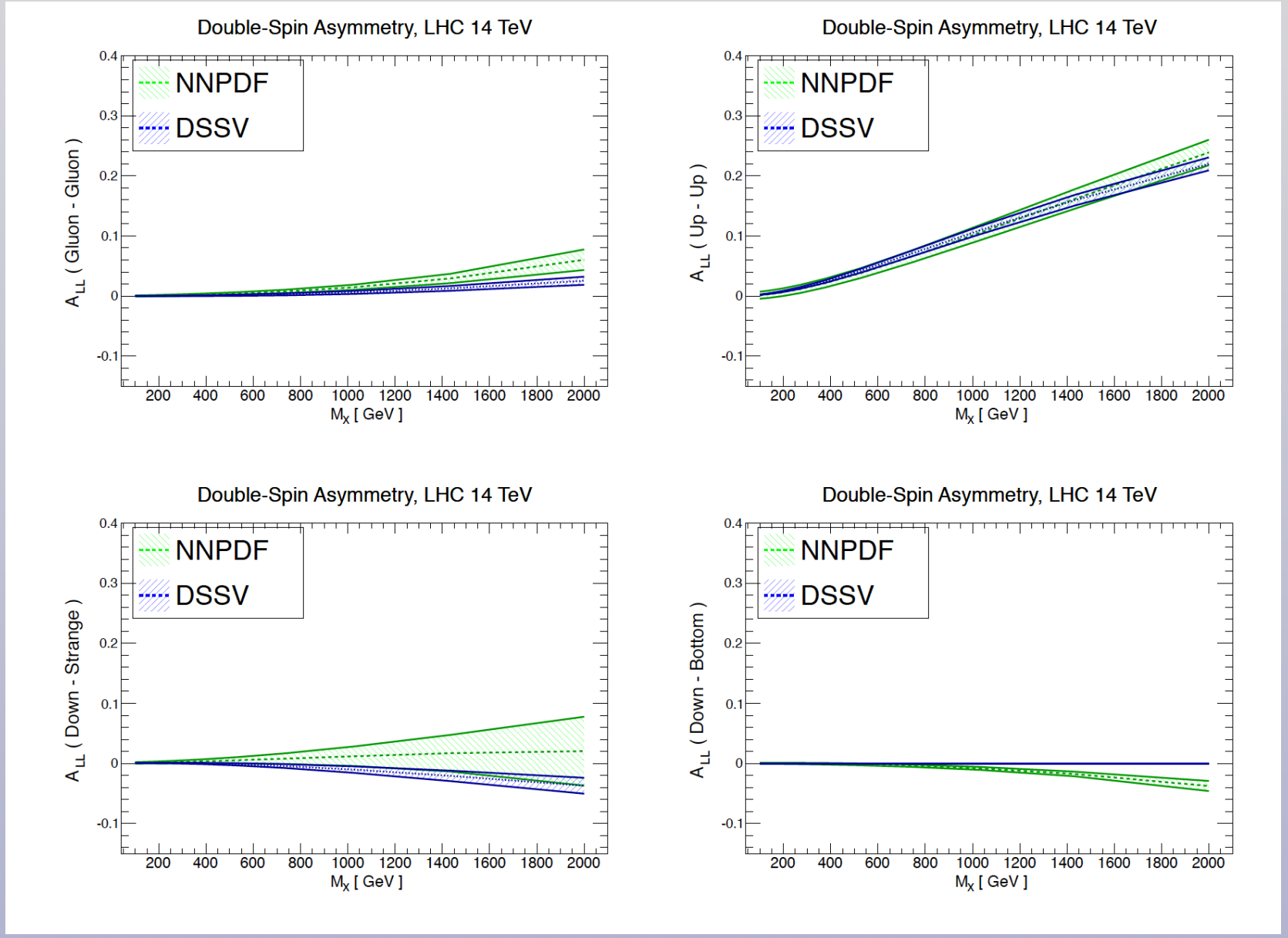
# Single Spin Asymmetries



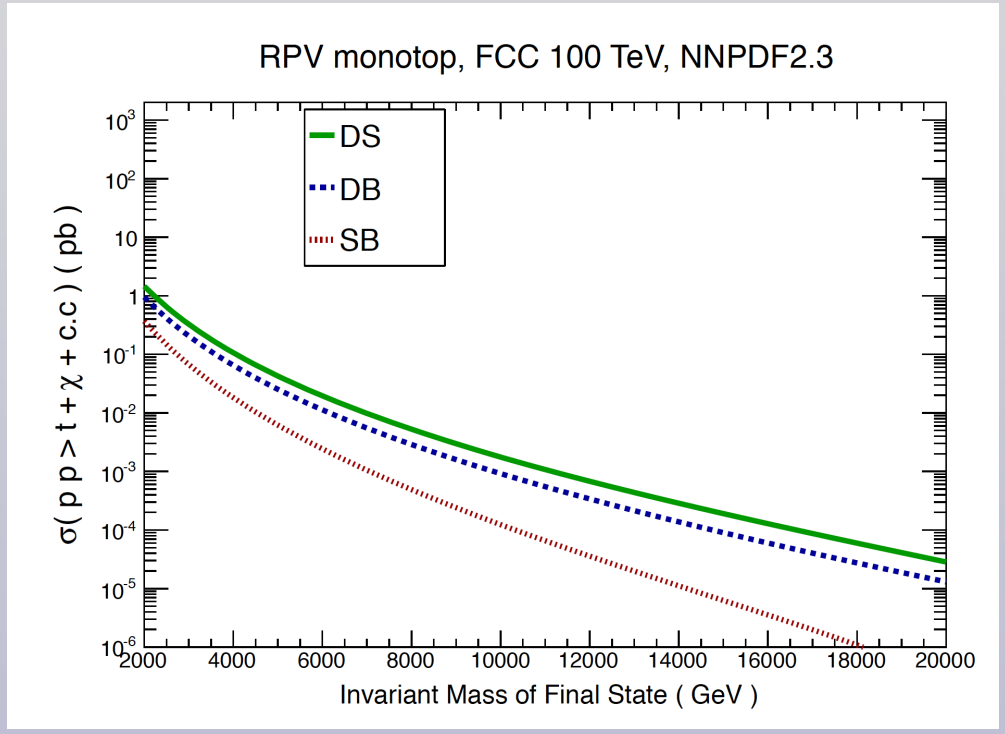

- The **asymmetries grow with the mass of the final state**, since for large-*x* polarised PDFs become comparable to unpolarised PDFs
- On the other hand, the **polarised cross-section will also decrease for large masses**
- Provided enough statistics, **BSM cross-sections will look very different if they are initiated by up quarks** (large positive asymmetry), **gluons** (moderate positive asymmetry) or **down quarks** (negative asymmetry)
- We can now illustrate the advantages of polarised protons in specific scenarios, but the idea itself is completely **model-independent**

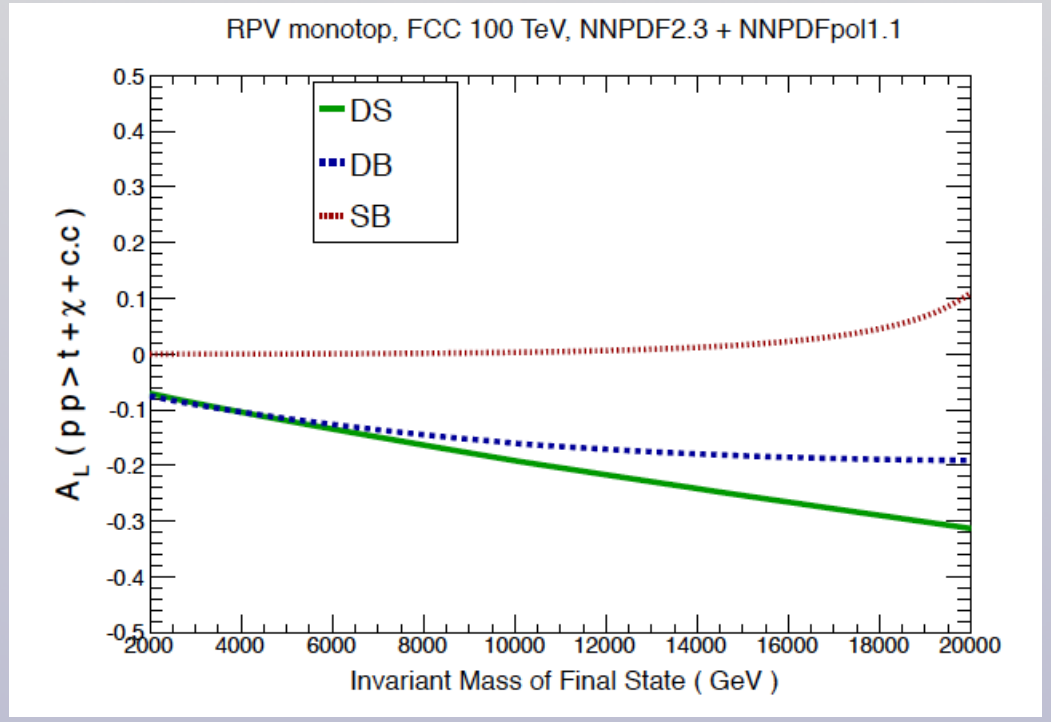
# Double Spin Asymmetries

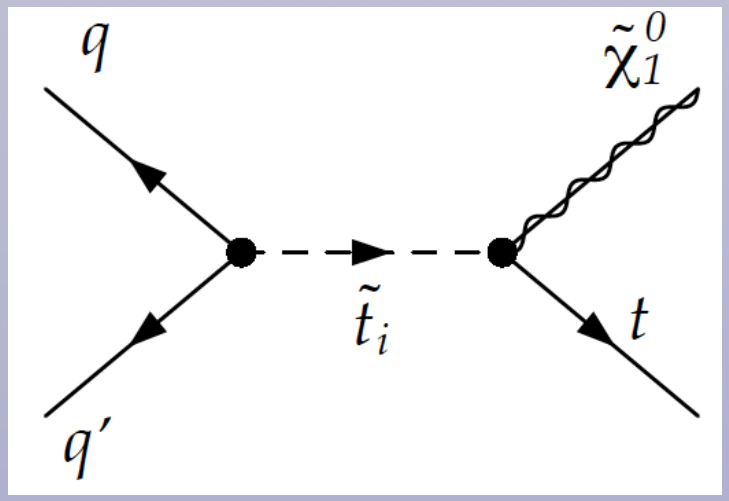



Reasonable agreement between the two leading polarised PDF sets, NNPDFpol and DSSV, although PDF uncertainties are still much larger than in the unpolarised case

# Monotop production in RPV MSSM



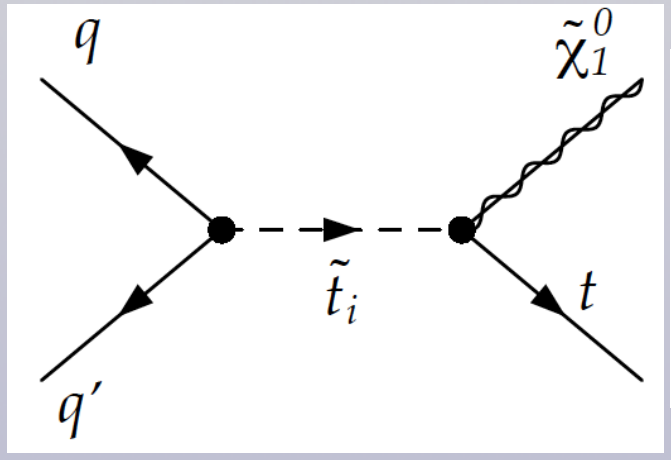




- At the **unpolarised** level, all partonic production channels show **same qualitative behaviour**
- At the **polarised** level, **asymmetries will vary between -30% and +10%** depending on the dominant coupling
- So provided a signal in unpolarised collisions, the polarised data would help in **understanding the nature of the BSM physics**

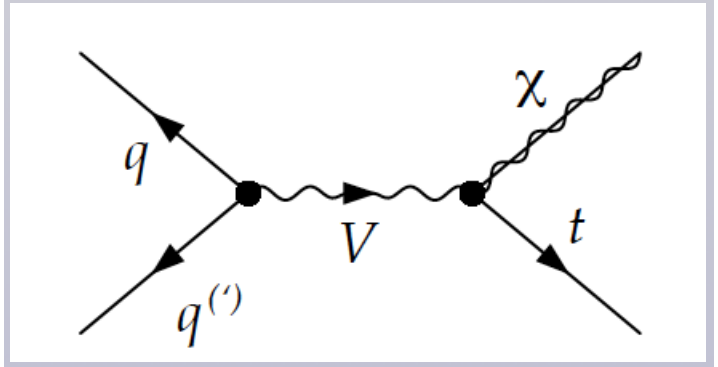
# Monotop production in other models

- The polarised data would not only help in pinning down the BSM couplings within a given model, it would also be crucial in **disentangling between different scenarios that lead to the same signature**
- As an illustration, consider three different scenarios for **monotop production at hadron colliders**

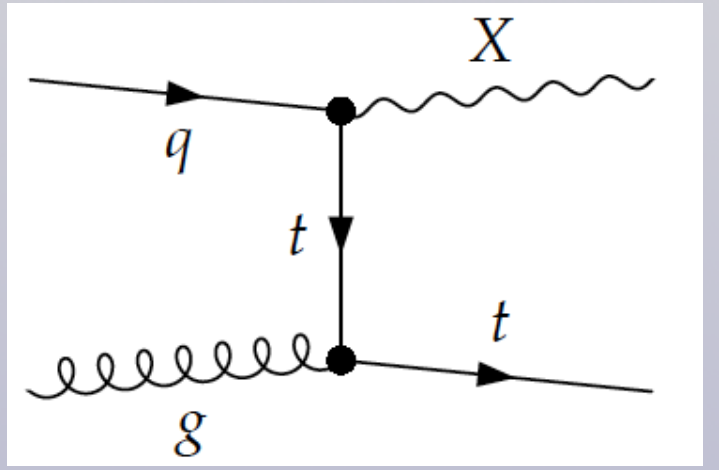
**RPV MSSM**



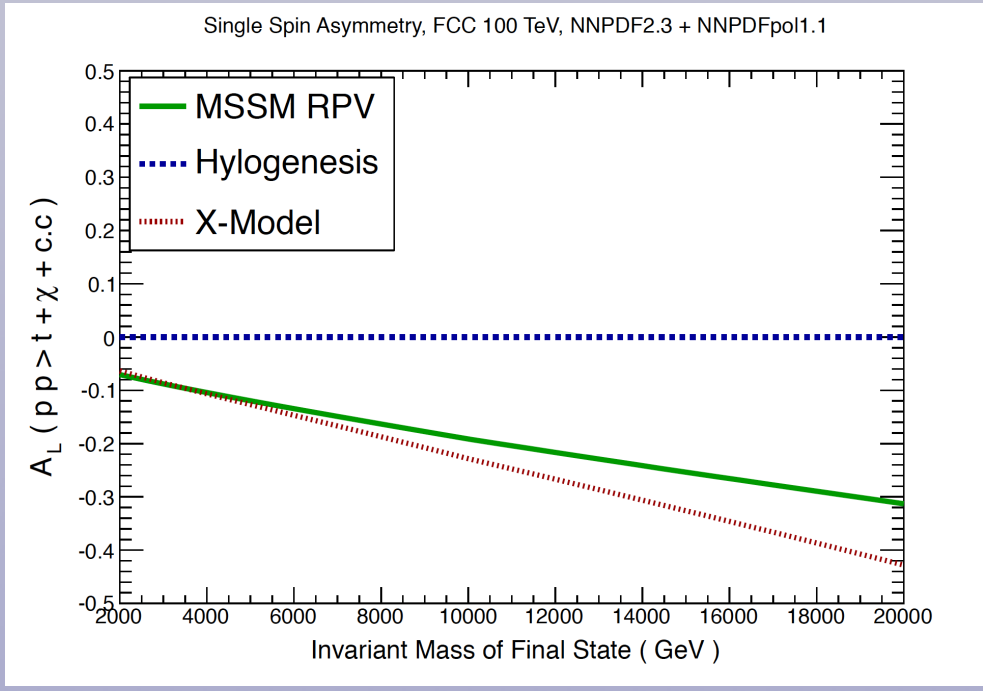

**Hylogenesis**




**Dark Matter X-Model**




- For illustration, set all couplings to one here
- The **predictions for single-spin asymmetries** are quite different in the different scenarios
- This is due to the different leading PDF luminosity in each scenario
- Note that the three scenarios lead to **similar signatures in unpolarised collisions**



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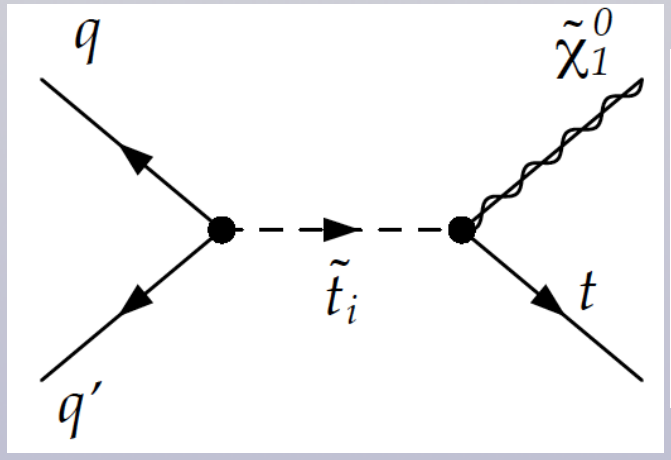


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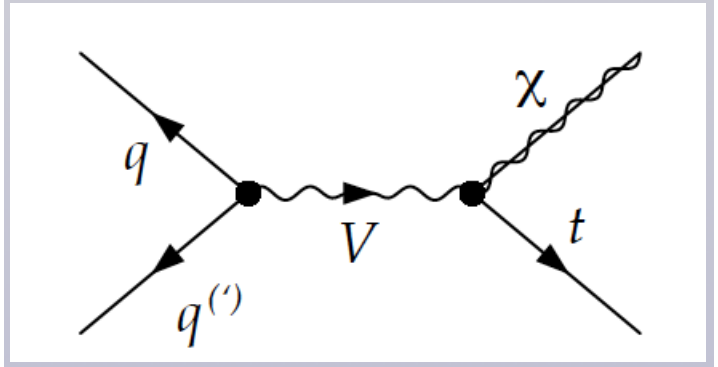


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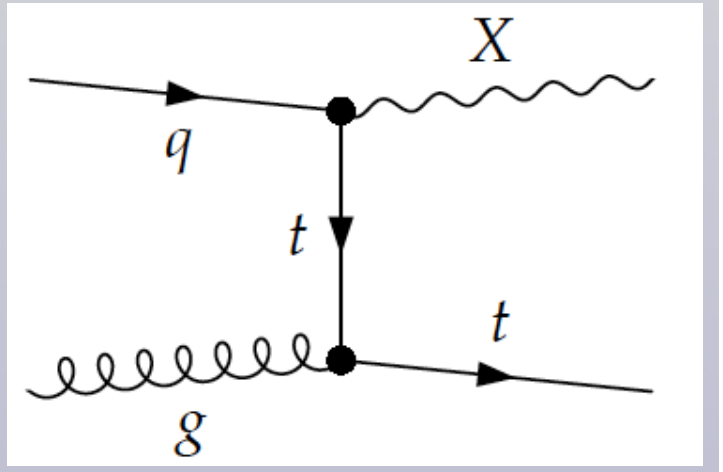
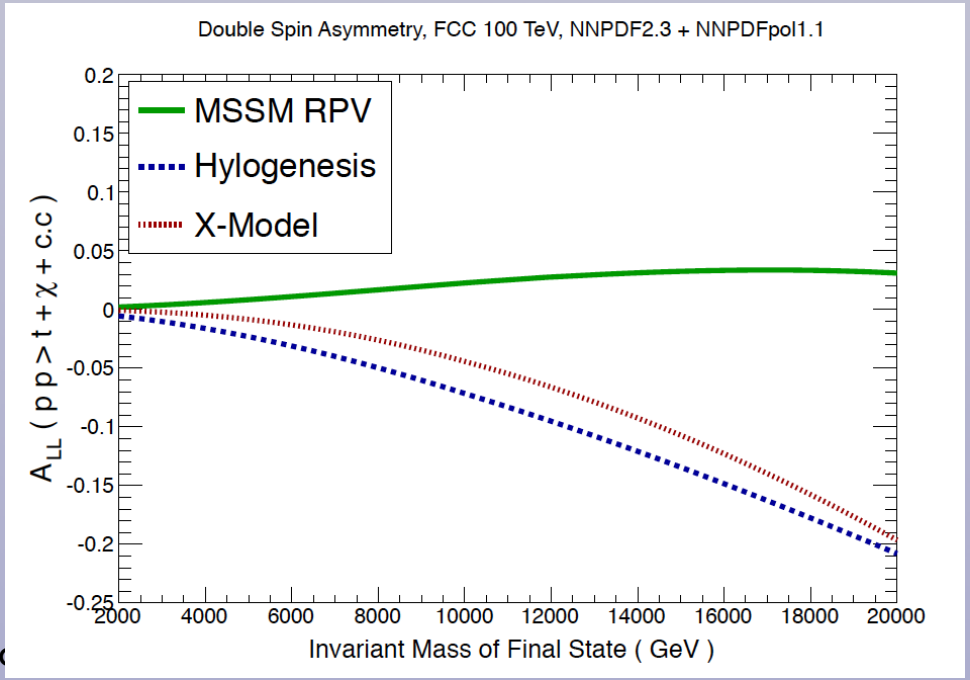



- Complementary information can be obtained from the **double spin asymmetries,** though statistics might be more a problem here



# Summary and outlook

- In the case of a discovery of **heavy new physics** at the LHC, the availability of polarised collisions would provide very useful information on the structure of the **BSM scenario**
- The main reason for this is the **different qualitative behaviour of polarised and unpolarised PDFs**, which allow to disentangle production mechanisms initiated by different parton luminosities
- More work is required to quantify the feasibility of this idea, in terms of **polarisation degree of the beams**, **integrated luminosity required for BSM studies** etc
- Incidentally, polarised protons at the FCC would be great to **pin down the spin structure of the proton with unparalleled precision** and address important issues like the gluon and quark polarisation at small-$x$