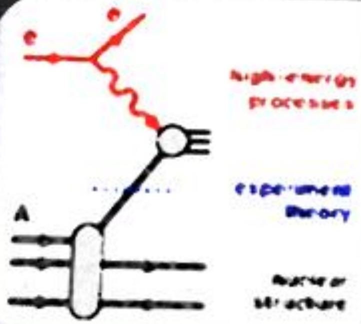

Summer School "Light-ion physics in the EIC era
From nuclear structure to high-energy processes"

Nuclear GPDs in IA

Matteo Rinaldi

Nuclear GPD expressions

We remind the master formulas of nuclear GPDs in IA:

$$H_q^3(x,\xi,\Delta^2) = \sum_{N=n,p} \sum_{S} \sum_{s} \int dE \int d\vec{p}\, P^N_{SS,ss}(\vec{p},\vec{p}\,',E)\, \frac{\xi'}{\xi}\, H_q^N(x',\xi',\Delta^2)$$

$$\left[H_q^3(x,\xi,\Delta^2) + E_q^3(x,\xi,\Delta^2)\right] = \sum_{N=n,p} \int dE \int d\vec{p}\, \frac{\xi'}{\xi} \left[H_q^N(x',\xi',\Delta^2) + E_q^N(x',\xi',\Delta^2)\right]$$

$$\times \left[P^N_{+-,+-}(\vec{p}\,',\vec{p},E) - P^N_{+-,-+}(\vec{p},\vec{p}\,',E)\right]$$

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$$H_q^3(x,\xi,\Delta^2)=\sum_{N=n,p}\sum_{S}\sum_{s}\oint dE\int d\vec{p}\,\rho^N_{SS,ss}(\vec{p},\vec{p}',E)\,\frac{\xi'}{\xi}\,H_q^N(x',\xi',\Delta^2)$$

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Free Nucleon GPDs

Nuclear GPDs

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Nuclear Spectral Function

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Nuclear Spectral Function

$$P^N_{SS',ss'}(\vec{p},\vec{p}\,',E) = \frac{1}{(2\pi)^6}\,\frac{M\sqrt{ME}}{2}\int d l_t \,\overline{\sum_{S_t}} \times$$

$$\times \langle \vec{P}'S'|\vec{p}\,'s',\vec{t}\,S_t\rangle_N \langle \vec{p}\,s,\vec{t}\,S_t|\vec{P}S\rangle$$

Nuclear GPD and Form Factors

We study this combination of GPDs to test 1st moment:

$$\tilde{G}_q^A(x,\xi,\Delta^2) \equiv H_q^A(x,\xi,\Delta^2) + E_q^A(x,\xi,\Delta^2)$$

Its integral:

$$\sum_q \int dx\, \tilde{G}_q^3(x,0,\Delta^2) = G_M^3(\Delta^2)$$

This is the magnetic form factor! This must be compared with Its calculation in IA!!

Nuclear GPD and Form Factors

This is the magnetic form factor! This must be compared with Its calculation in IA:

$$G_M^3(\Delta) = \frac{2M}{\mu}\frac{1}{\Delta}\langle \Psi + | J_x(\Delta) | \Psi - \rangle$$

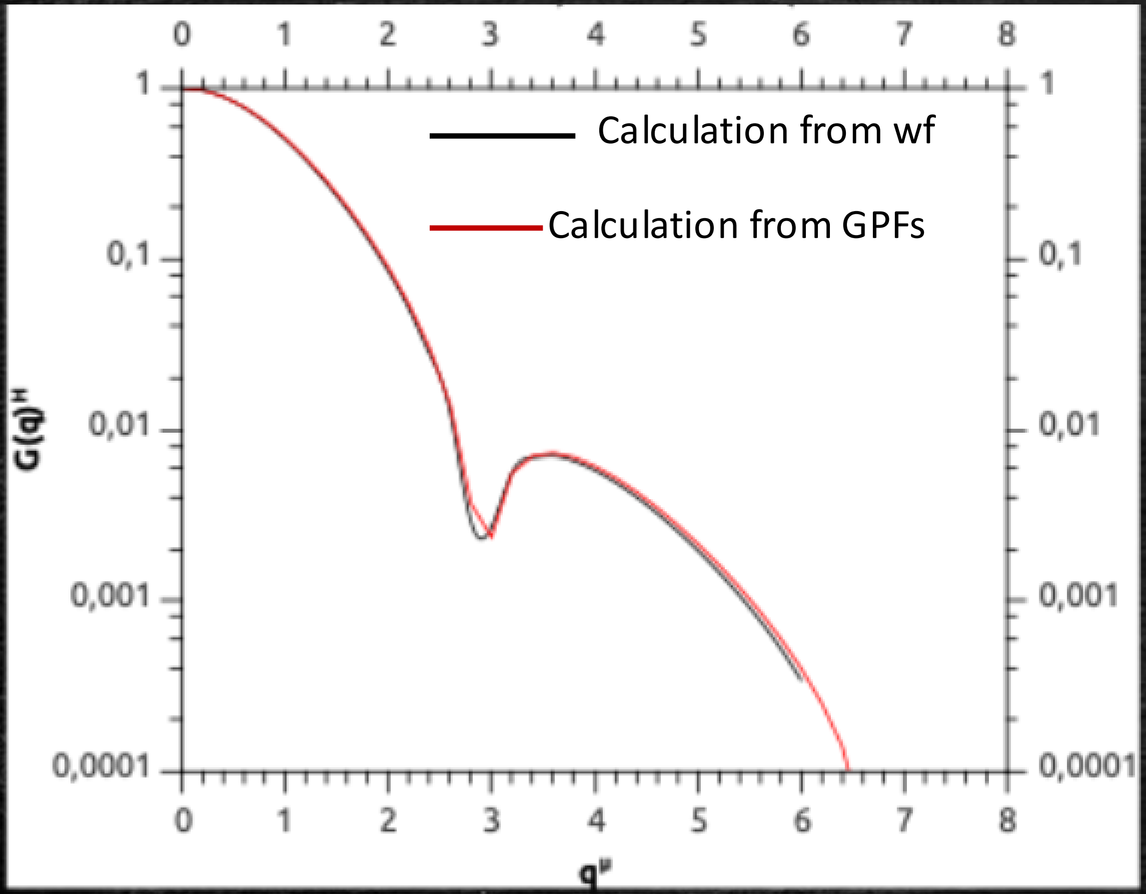
with $\vec{\Delta} = (0, 0, \Delta)$

$$J_x(\Delta) = \sum_i G_M^i(\Delta)\left(-\Delta\sigma_y^i\right) e^{i\vec{\Delta}\cdot\vec{r}_i}\frac{1}{i4M}$$

Nuclear current in IA

FF of the i nucleon

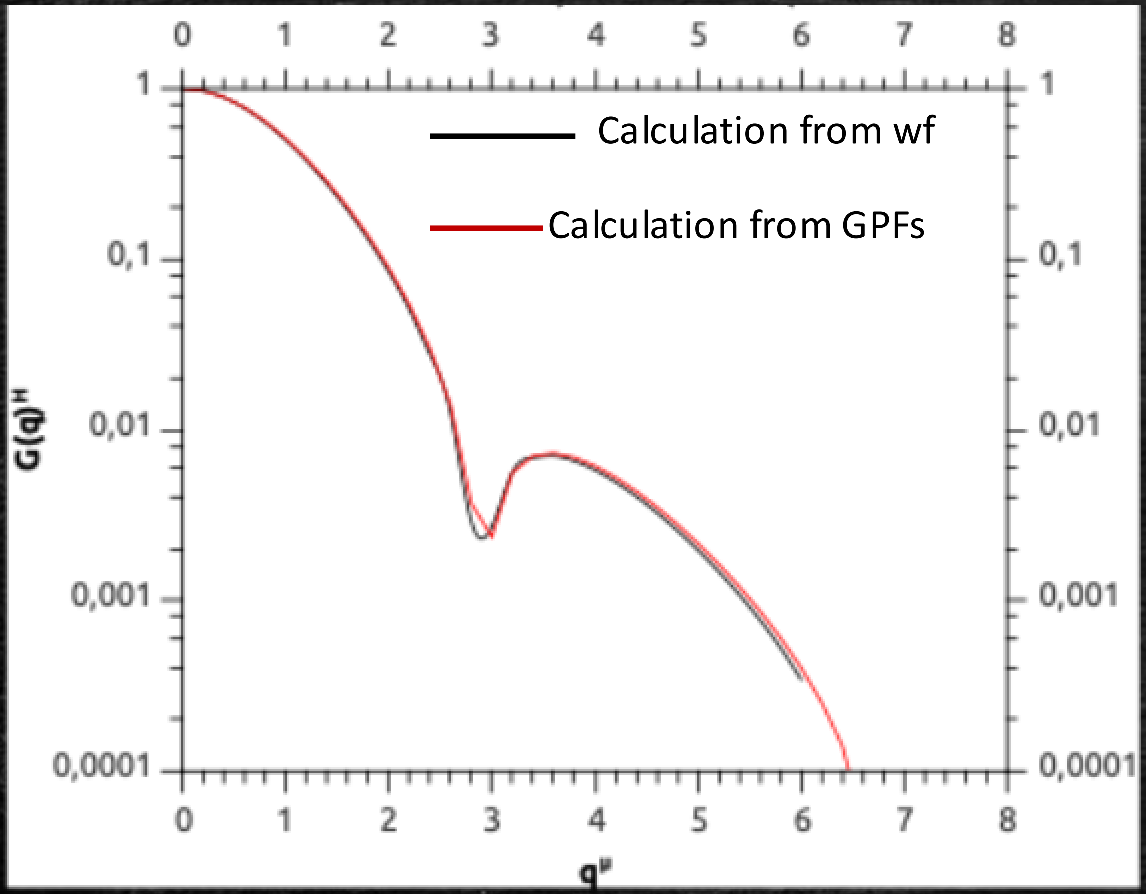
Nuclear GPD and Form Factors



1) The sum rule is verified

2) We have some violation of polynomiality (NR limit)

Nuclear GPD and Form Factors



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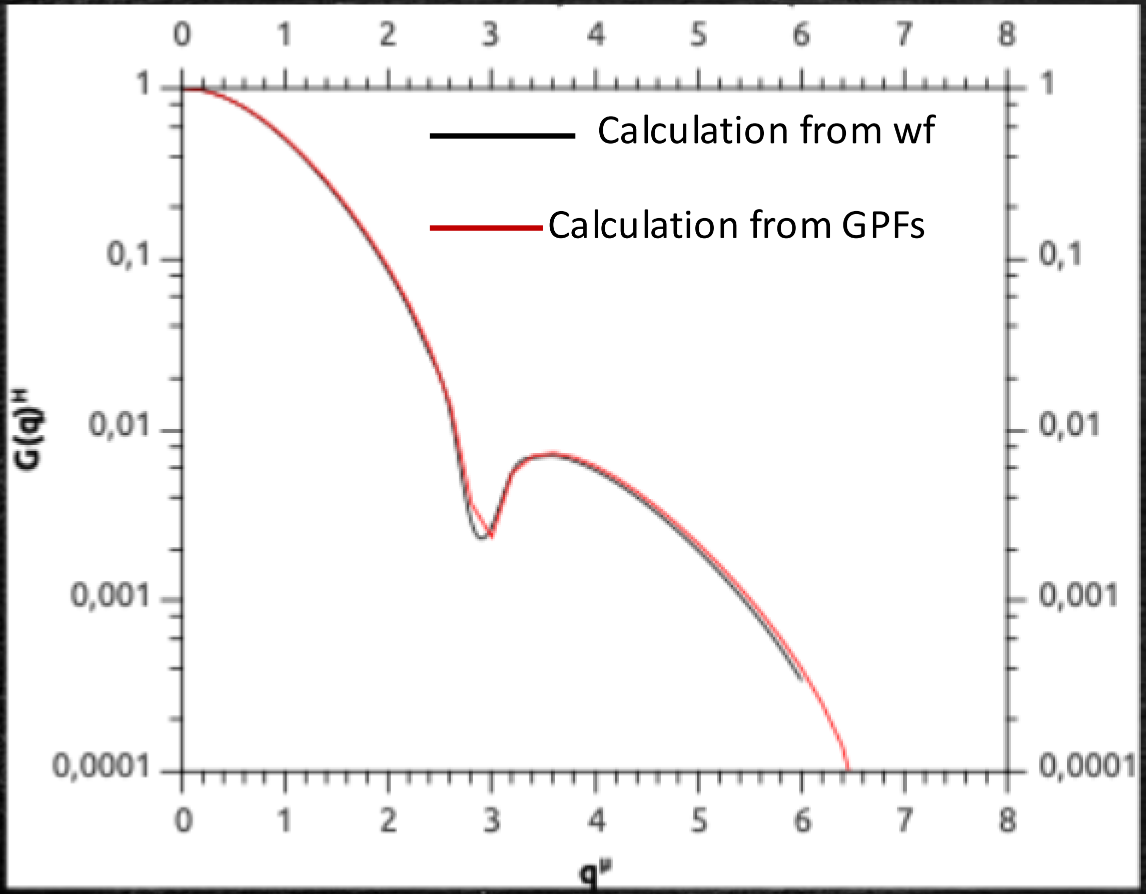

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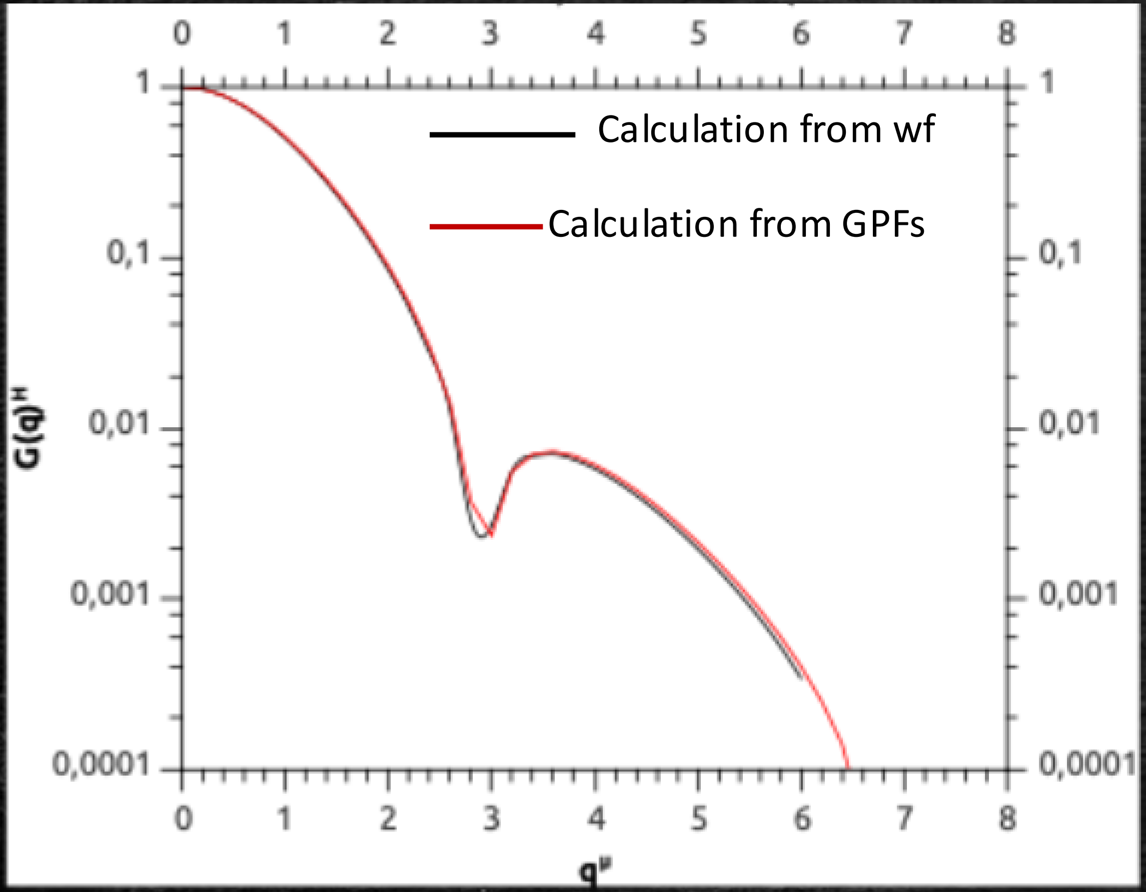
Nuclear GPD and Form Factors



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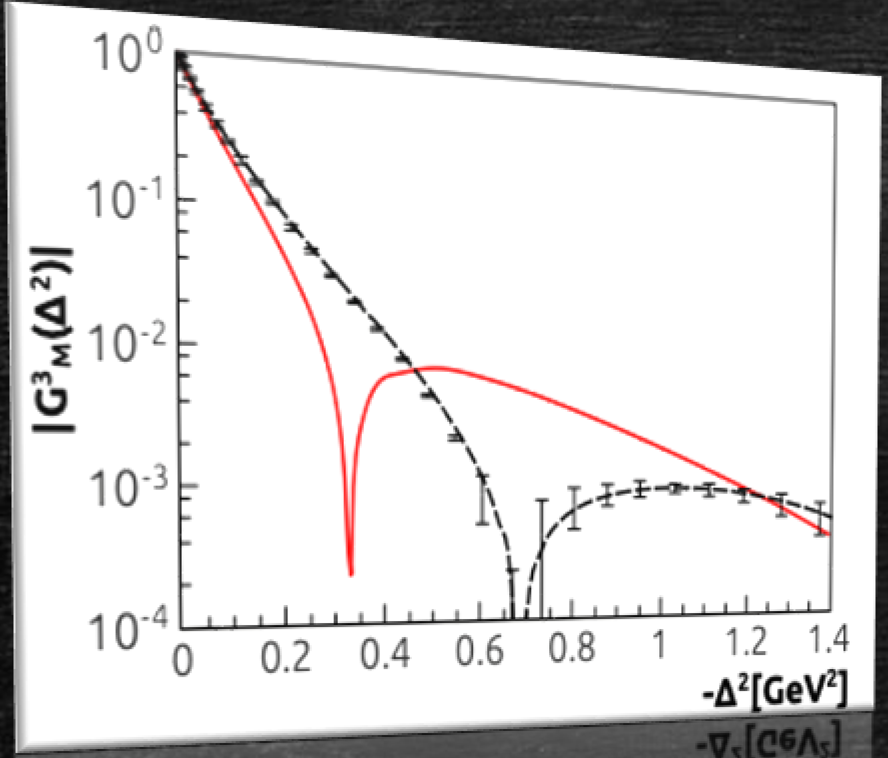
We can use the comparison with data to quantify the validity range of IA

Nuclear GPD and Form Factors



1) The sum rule is verified

2) We have some violation of polynomiality (NR limit)

We can use the comparison with data to quantify the validity range of IA

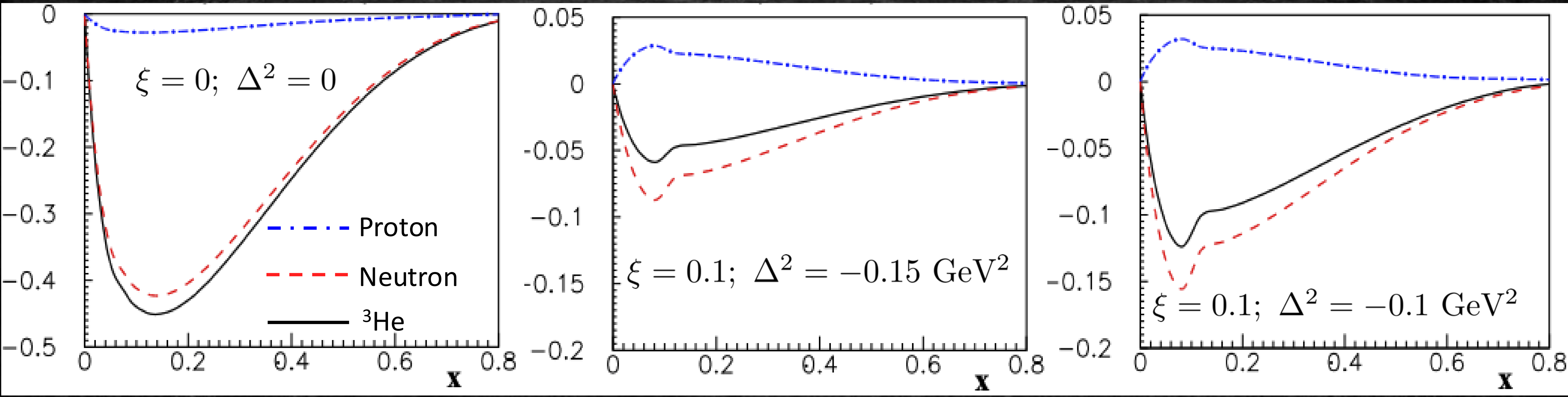
1) IA valid for $-\Delta^2 \leq 0.2\ GeV^2$

2) Data for the coherent channel:

$-\Delta^2 \lesssim 0.15\ GeV^2$

^{3}He GPDs

We plot $x\tilde{G}_M^A(x,\xi,\Delta^2) = \sum_q \tilde{G}_M^A(x,\xi,\Delta^2)$



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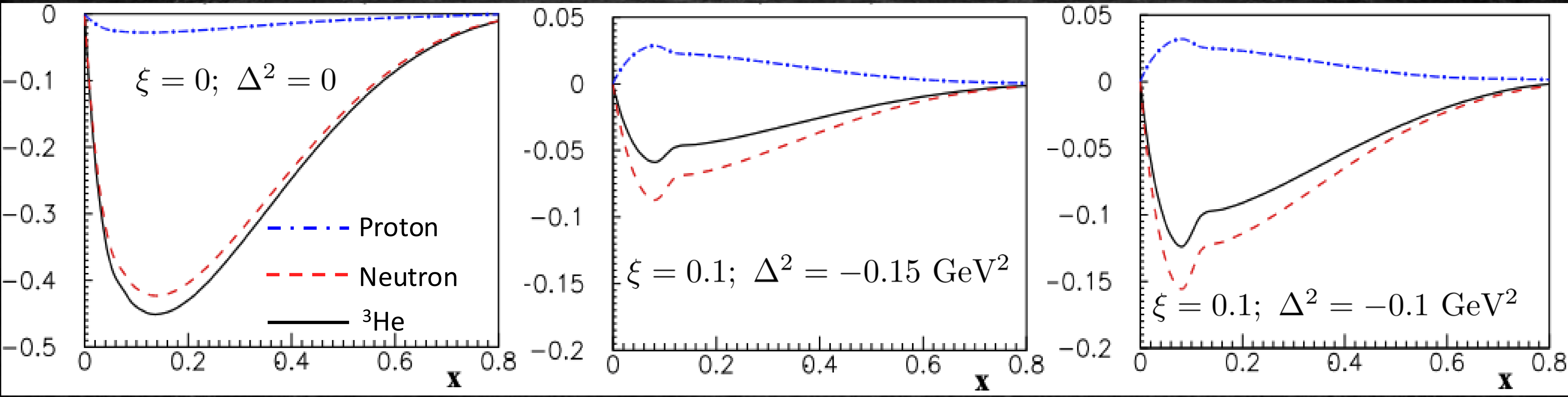
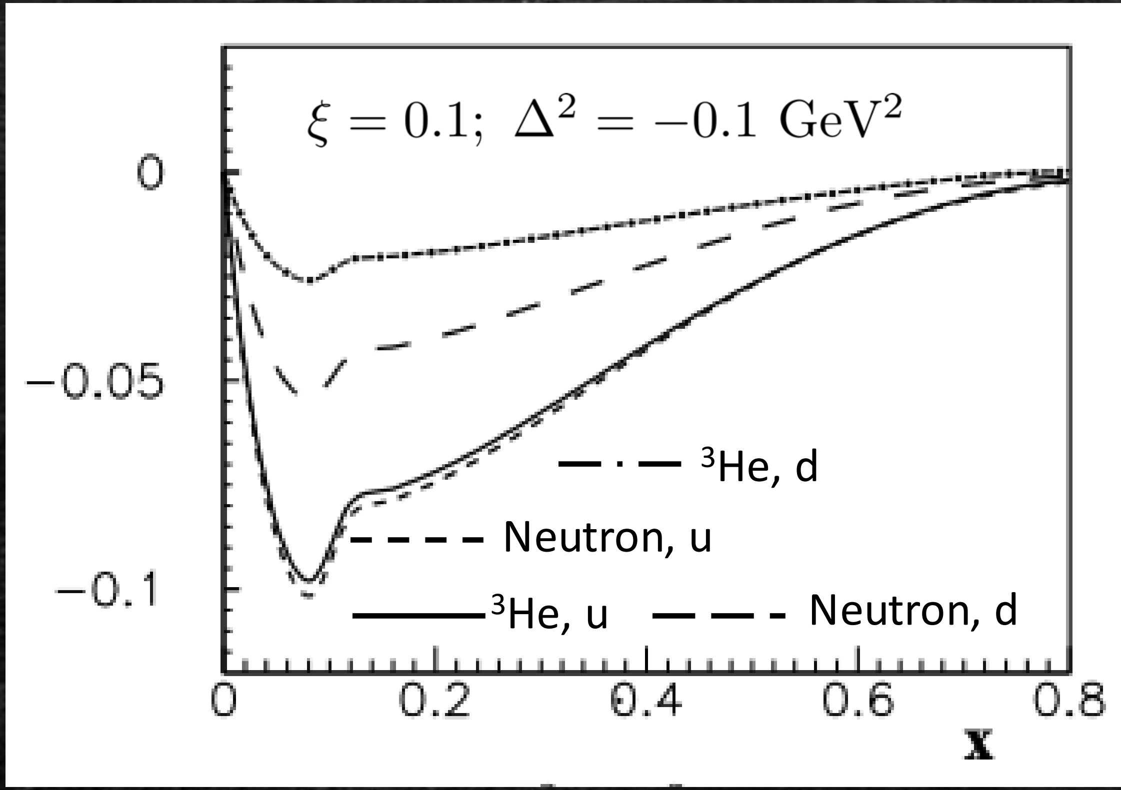


We can notice:

1) As expected from the ^{3}He spin structure the neutron contribution is the dominant!
2) Away from the forward limit nuclear effects increase and the proton contribution is not negligible. However:

^{3}He GPDs

1) We plot $x\tilde{G}_M^{A,q}(x,\xi,\Delta^2)$



In case of "u" quark, the neutron is still the dominant contribution and it is comparable with ^{3}He!!

Therefore, for this quark, If we extract the ^{3}He we are De facto getting the neutron Contribution!!

We can notice:

1) As expected from the ^{3}He spin structure the neutron contribution is the dominant!
2) Away from the forward limit nuclear effects increase and the proton contribution is not negligible.

Neutron extraction

2) In any case one should remember that we are extracting at least the NEUTRON CONTIBUTION:

$$\tilde{G}_q^{3,n}(x,\xi,\Delta^2) = \int dE \int d\vec{p}\, \frac{\xi'}{\xi} \left[P^n_{+-,+-}(\vec{p},\vec{p}\,',E) - P^n_{+-,-+}(\vec{p},\vec{p}\,',E) \right] \tilde{G}_q^{n}(x',\xi',\Delta^2)$$

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We have a convolution of a nuclear part

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We have a convolution of a nuclear part and a nucleonic part

Can we extract information on the neutron????

Neutron extraction

Yes but we need to simplify our formula! To this aim we rewrite:

$$\tilde{G}_q^A(x,\xi,\Delta^2) = \sum_{N=n,p} \int_{x\frac{M_A}{M_N}}^{\frac{M_A}{M_N}} \frac{dz}{z}\, g_N^A(z,\xi,\Delta^2)\, \tilde{G}_q^N\left(\frac{x}{z},\frac{\xi}{z},\Delta^2\right)$$

In terms of the off-forward Light Cone Momentum Distribution (LCMD):

$$g_N^A(z,\xi,\Delta^2) = \sum\!\!\!\!\!\!\int dE \int d\vec{p}\, \underbrace{\tilde{P}^N(\vec{p},\vec{p}\,',\Delta^2)}_{\text{THE PREV. COMBINATION}}\, \delta\left(z + \xi\frac{M_A}{M_N} - \frac{M_A}{M_N}\frac{\bar{p}^+}{\bar{P}^+}\right)$$

Neutron extraction

Since g^A is like $\delta(z-1)$, if there are no nuclear effects:

$$\tilde{G}_q^3(x,\xi,\Delta^2) = \sum_{N=n,p} \tilde{G}_q^N(x,\xi,\Delta^2) \int_{x\frac{M_3}{M_N}}^{M_3/M_N} dz\, g_N^3(z,\xi,\Delta^2) + \mathcal{O}(z-1)$$

$$\sim \sum_{N=n,p} \tilde{G}_q^N(x,\xi,\Delta^2) \underbrace{\int_0^{M_A/M_N} dz\, g_N^3(z,\xi,\Delta^2)}_{\text{Point-like FFs}} + \mathcal{O}(z-1)$$

Neutron extraction

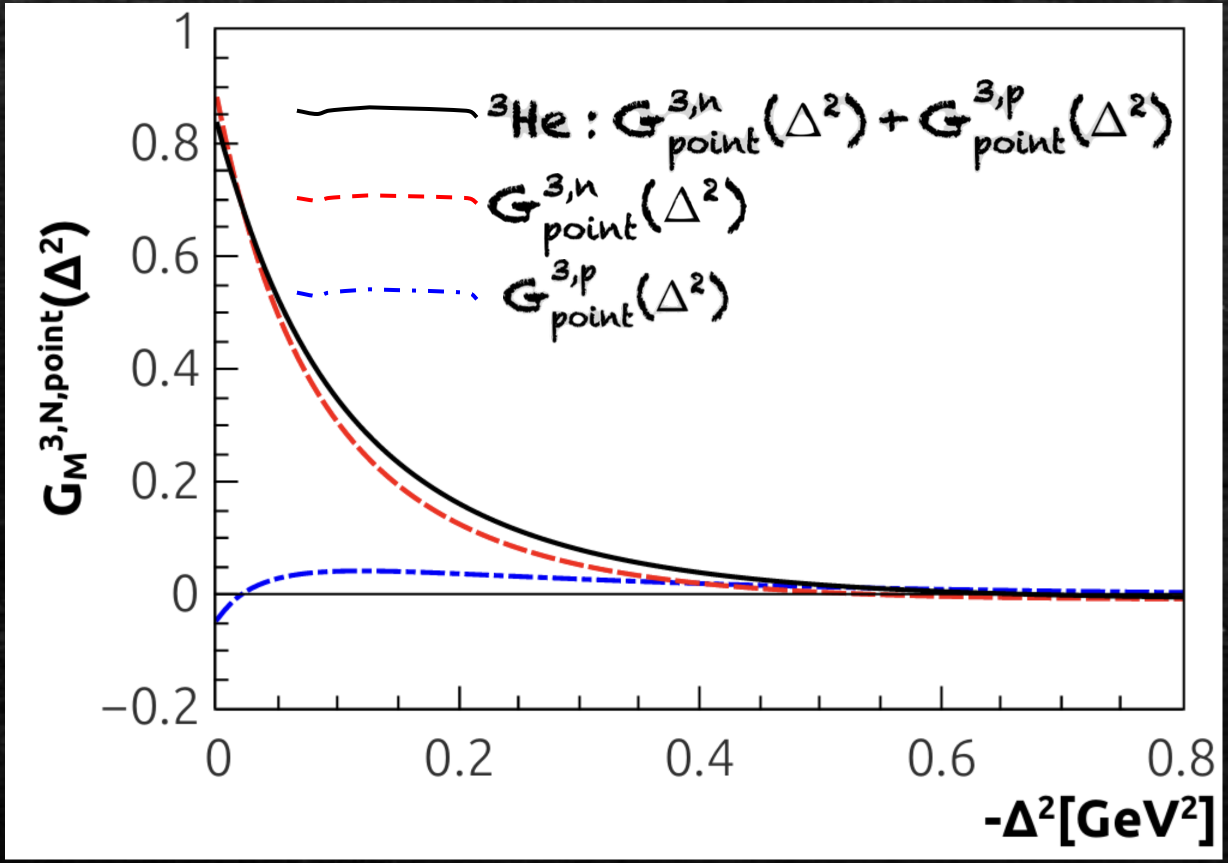
$$\tilde{G}_q^{3}(x,\xi,\Delta^2) = G^{3,p}_{\text{point}}(\Delta^2)\,\tilde{G}_q^{p}(x,\xi,\Delta^2) + G^{3,n}_{\text{point}}(\Delta^2)\,\tilde{G}_q^{n}(x,\xi,\Delta^2)$$

where:

$G^{3,p}_{\text{point}}(\Delta^2) + G^{3,n}_{\text{point}}(\Delta^2) =$ ^{3}He FF. if nucleons are point like!

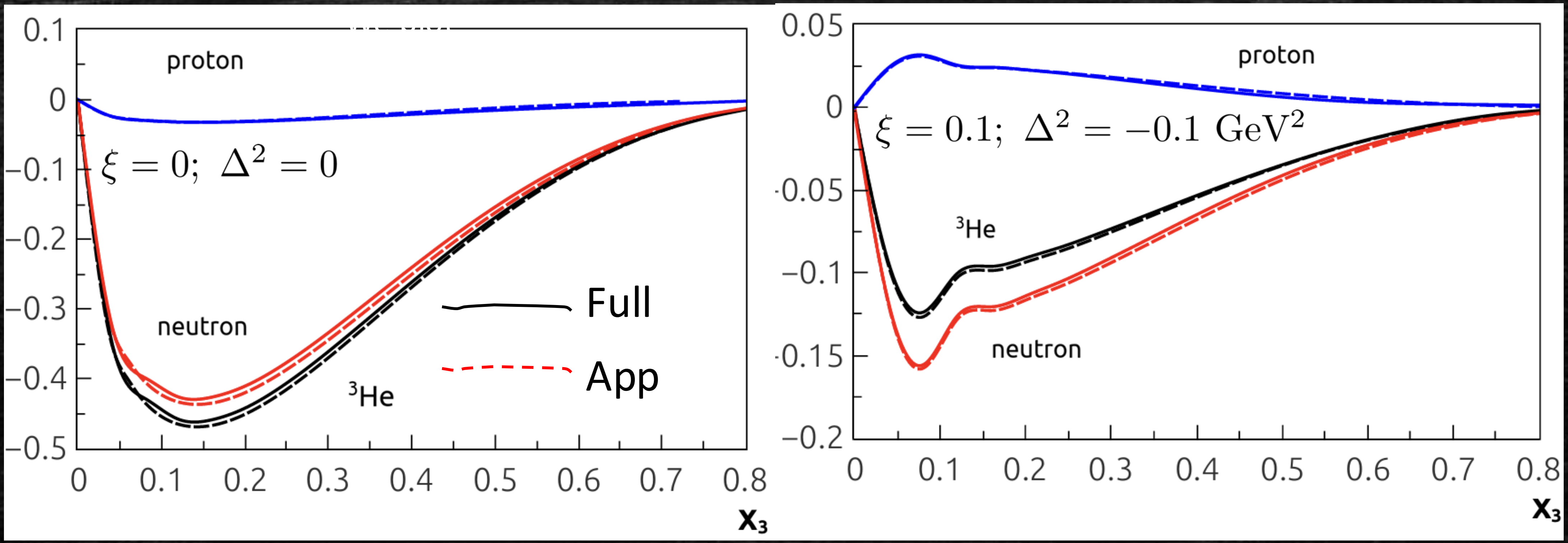
Neutron extraction

$$\tilde{G}_q^{3}(x,\xi,\Delta^2) = G^{3,p}_{\text{point}}(\Delta^2)\,\tilde{G}_q^{p}(x,\xi,\Delta^2) + G^{3,n}_{\text{point}}(\Delta^2)\,\tilde{G}_q^{n}(x,\xi,\Delta^2)$$



Neutron extraction

$$\tilde{G}_q^{3}(x,\xi,\Delta^2) = G^{3,p}_{Point}(\Delta^2)\,\tilde{G}_q^{p}(x,\xi,\Delta^2) + G^{3,n}_{Point}(\Delta^2)\,\tilde{G}_q^{n}(x,\xi,\Delta^2)$$



Neutron extraction

We can invert the simplified relation to extract the neutron GPD!

$$\tilde{G}_q^{n,ext}(x,\xi,\Delta^2) = \frac{1}{\underbrace{G^{3,n}_{\text{Point}}(\Delta^2)}_{^3\text{He w.f.}}} \left\{ \underbrace{\tilde{G}_q^{3}(x,\xi,\Delta^2)}_{\text{Future data}} - \underbrace{\tilde{G}_q^{p}(x,\xi,\Delta^2)}_{\text{Data}} \underbrace{G^{3,p}_{\text{Point}}(\Delta^2)}_{^3\text{He w.f.}} \right\}$$