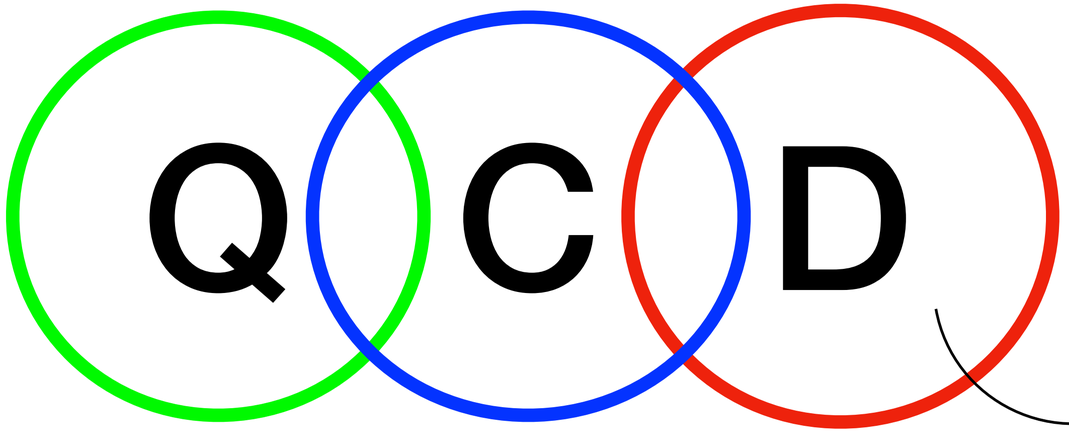
On the way to transversity: A PhD triathlon

PhD candidate:
Luca Polano

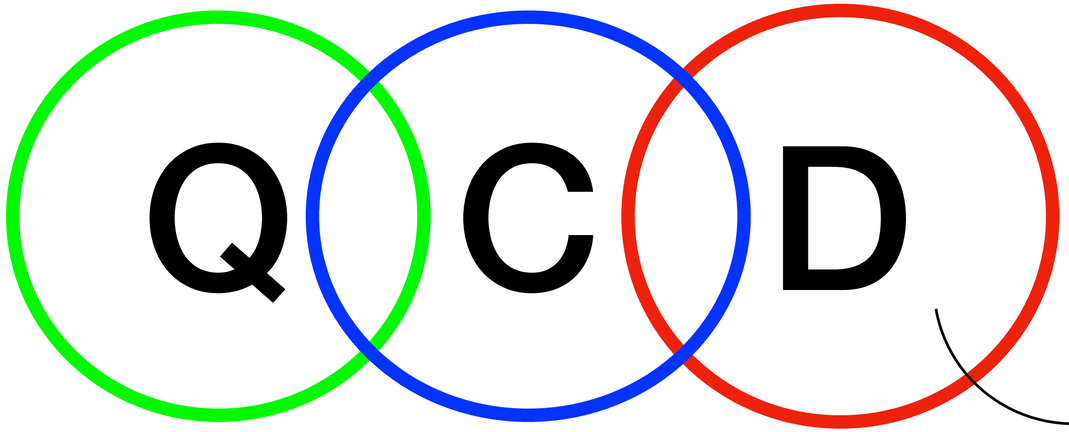
Supervisor:
Marco Radici
Alessandro Bacchetta

End of year seminars 2025



Quarks &

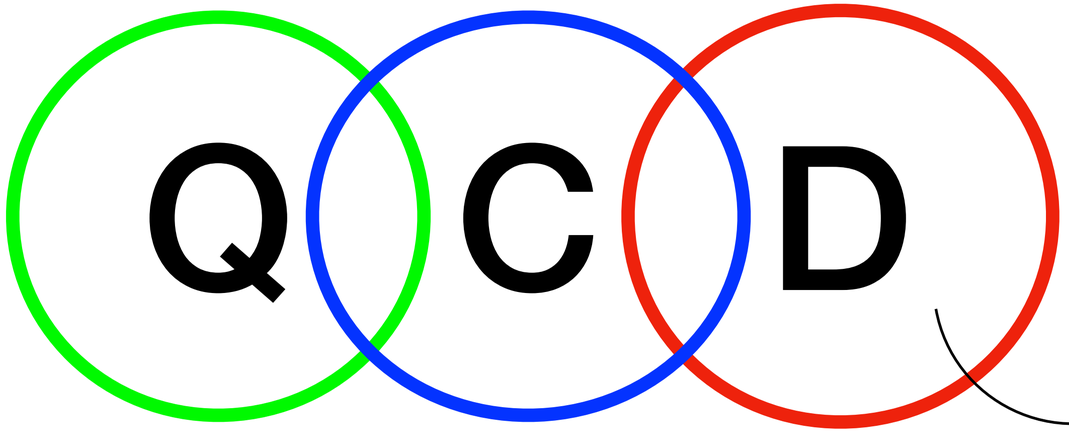
gluons



Quarks &

gluons

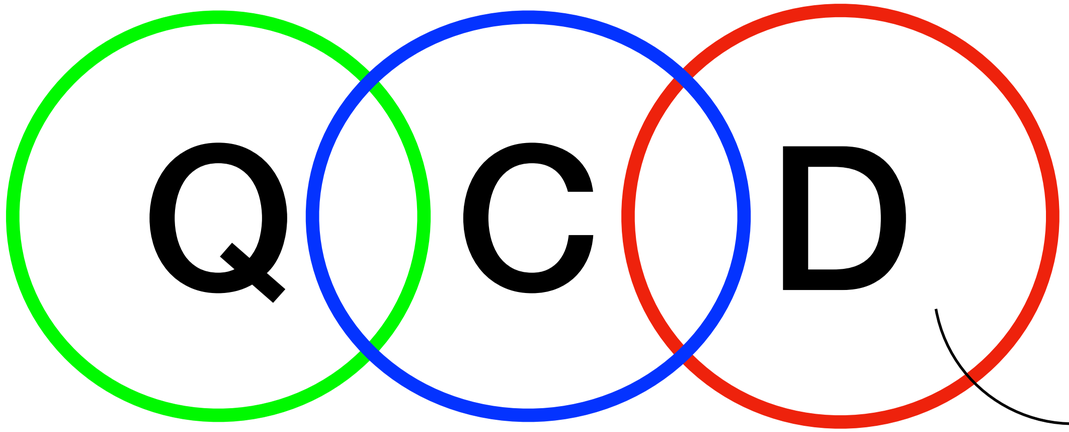
Depends on the energy scale



Quarks &

gluons

High energies

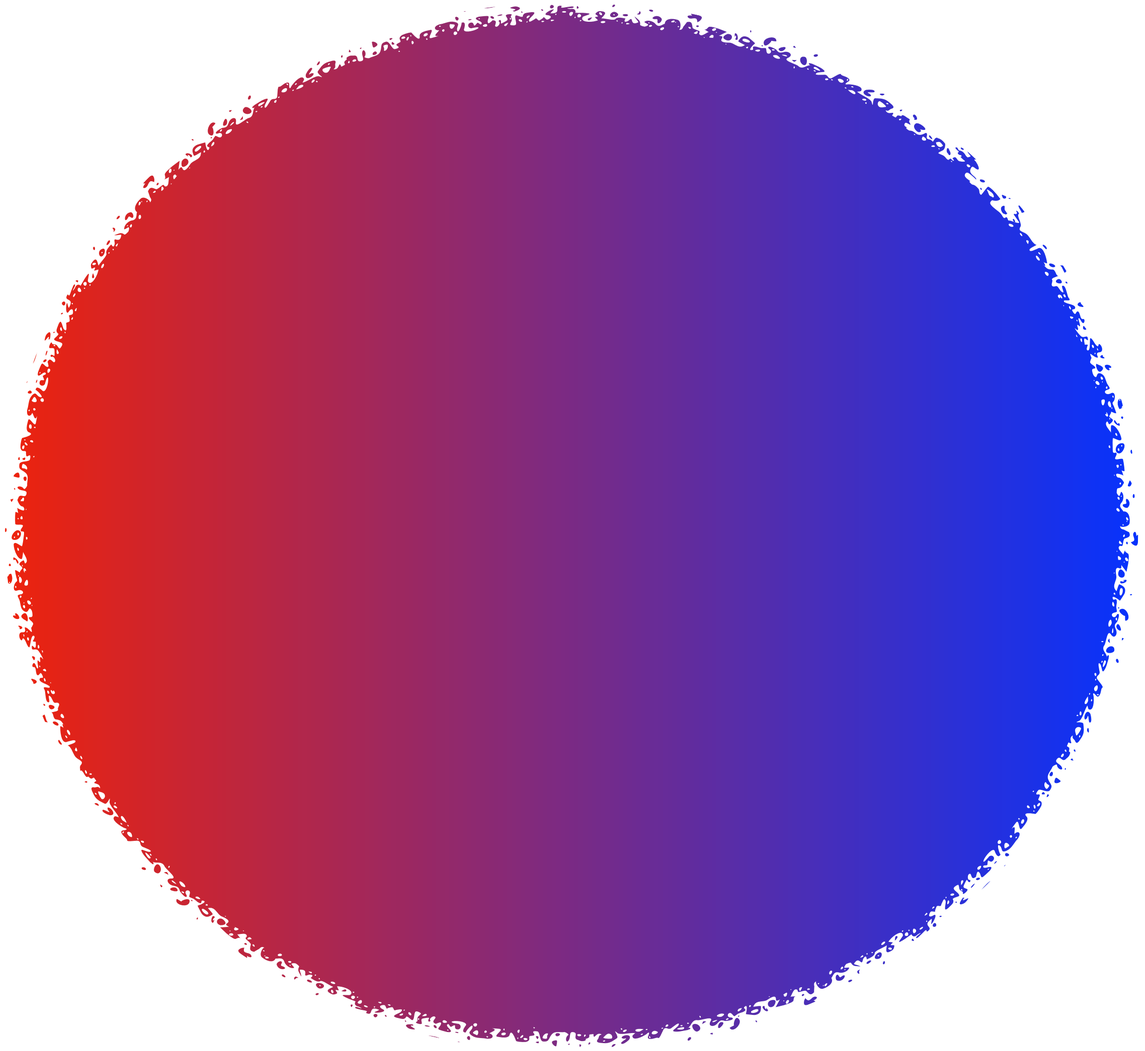


Quarks & gluons

High energies

Low, $\Lambda_{QCD} \sim 200$ MeV

At $\sim \Lambda_{QCD} \sim 200$ MeV



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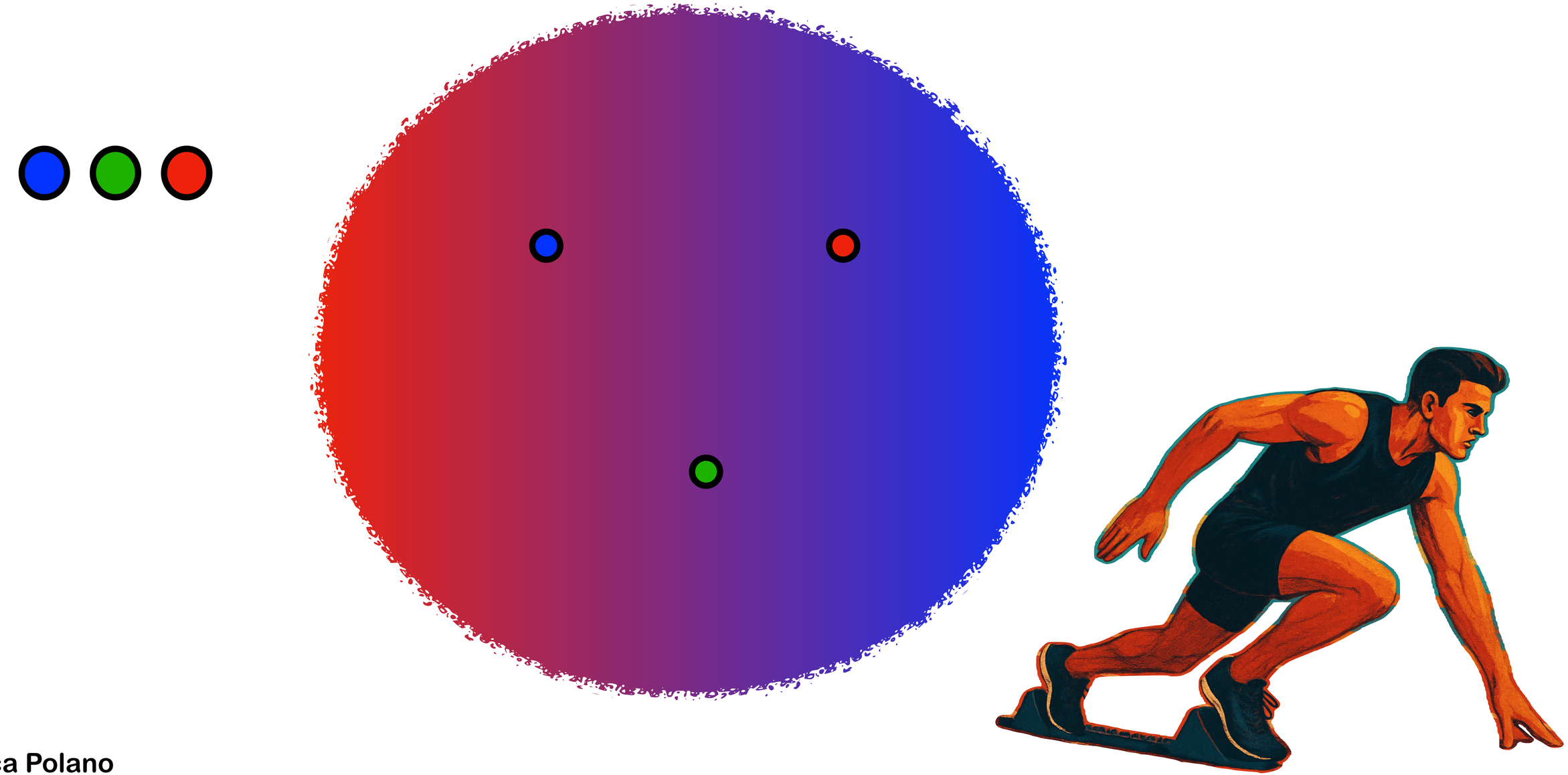

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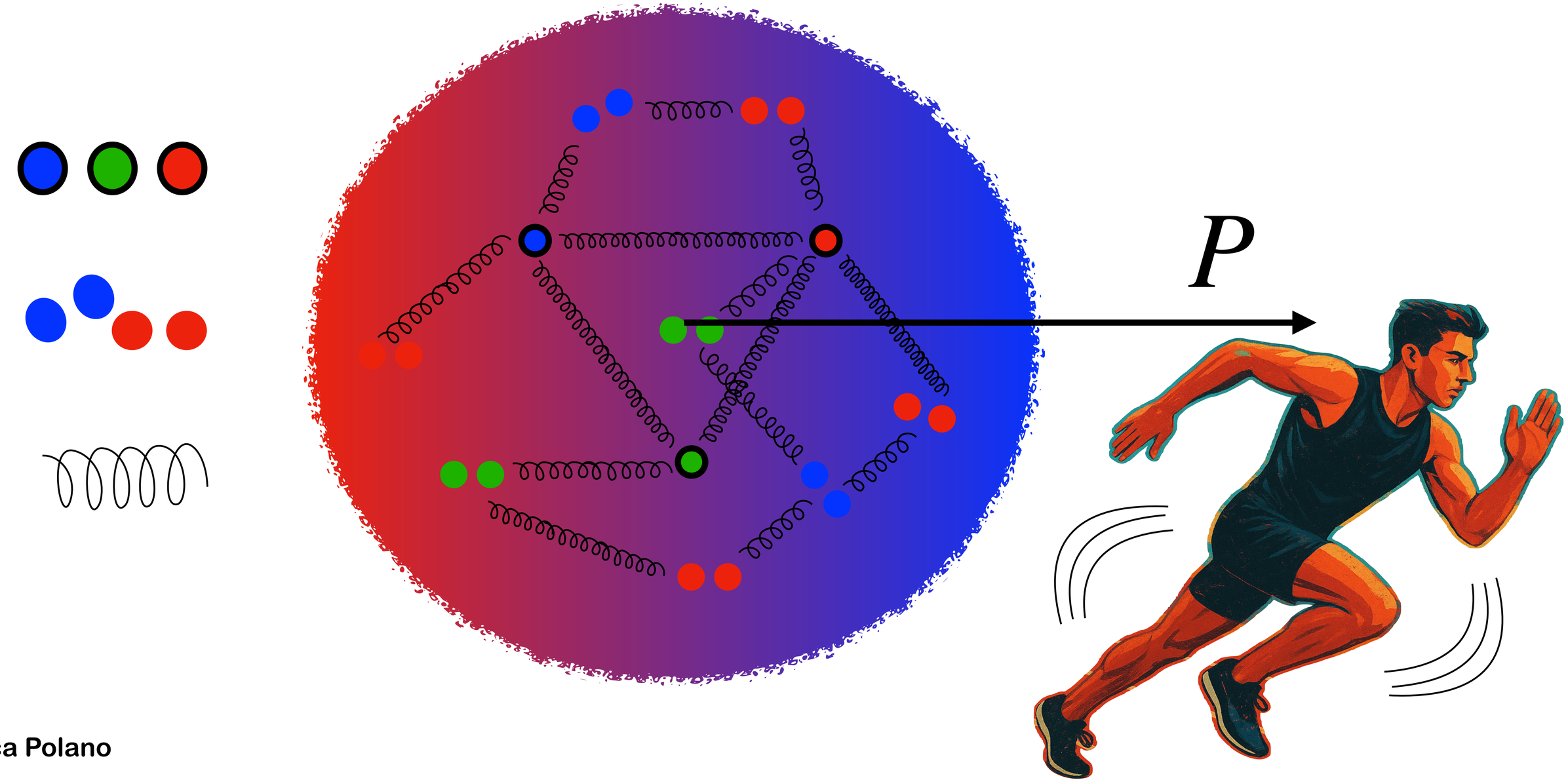

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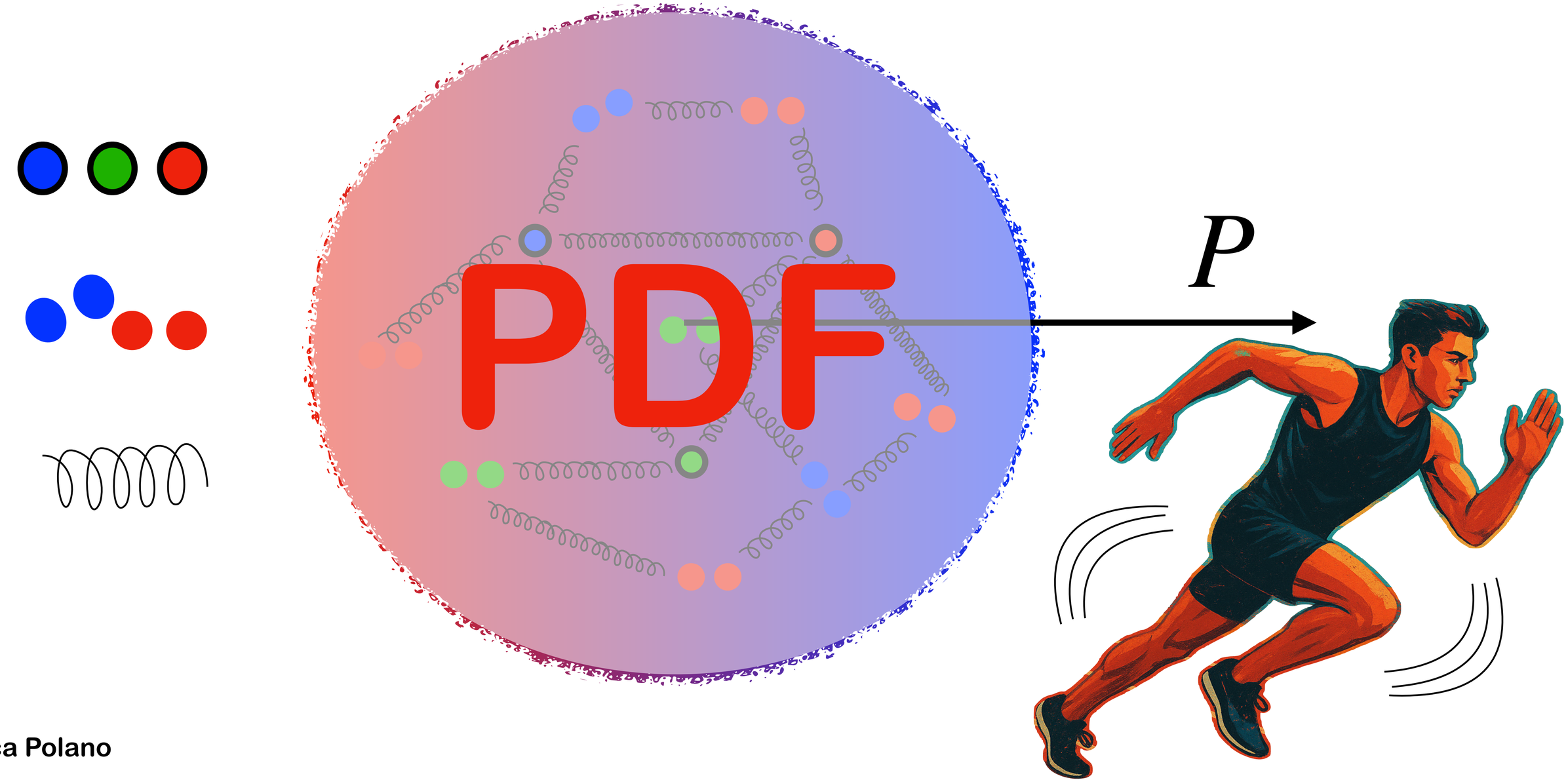
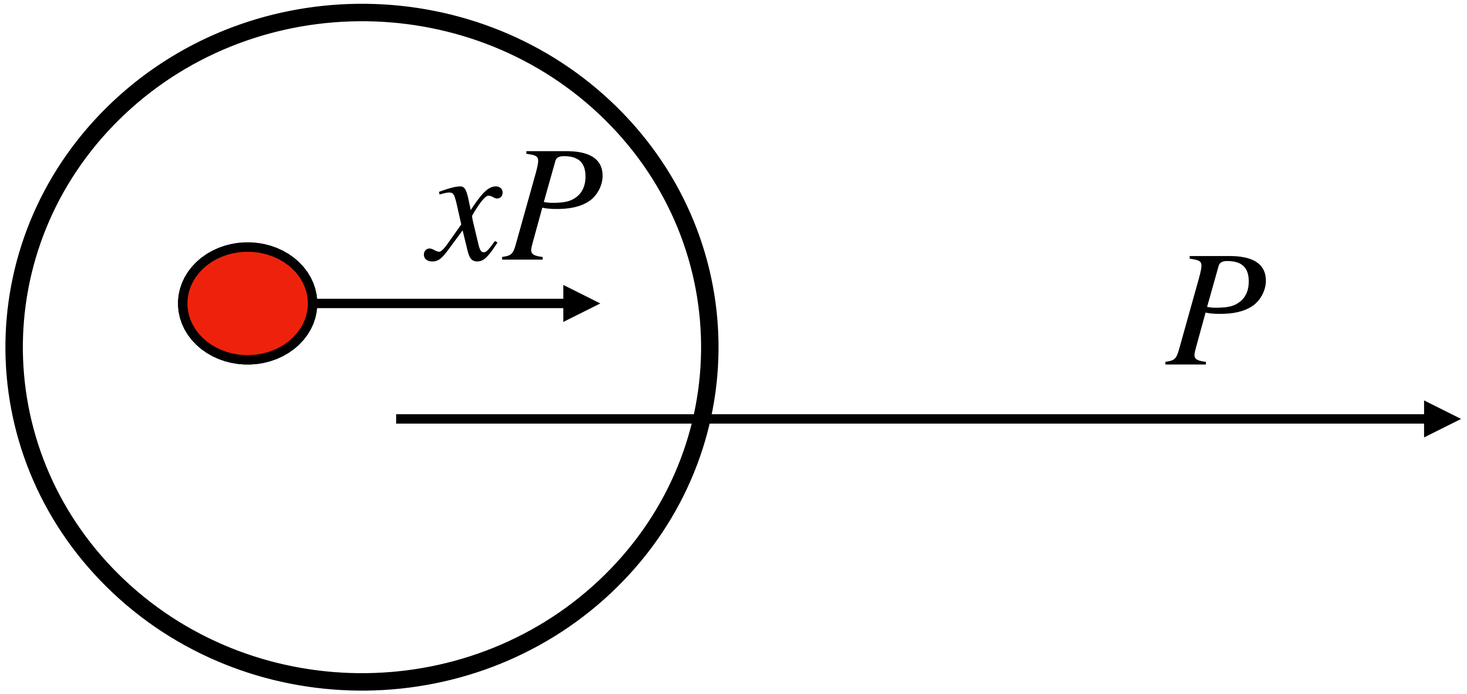


At $\sim \Lambda_{QCD} \sim 200$ MeV

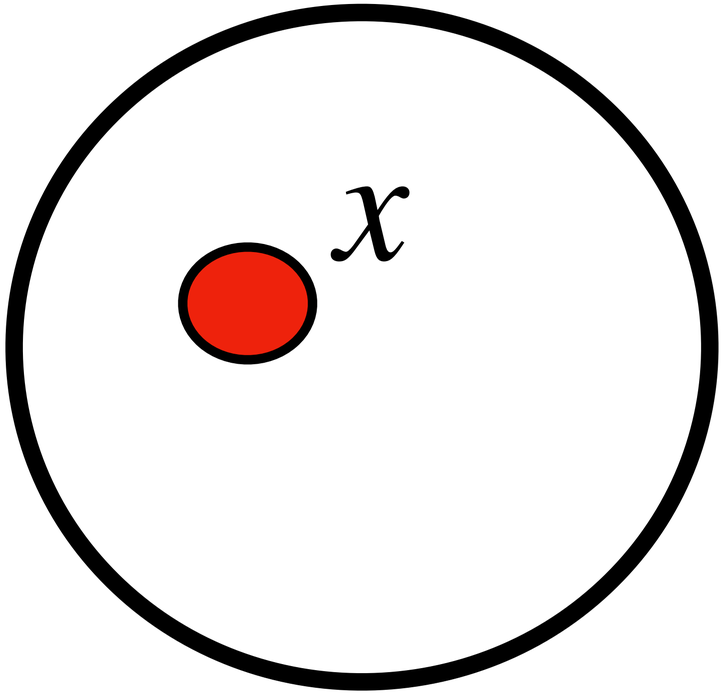
PDF



At $\sim \Lambda_{QCD} \sim 200$ MeV

PDF

f_1



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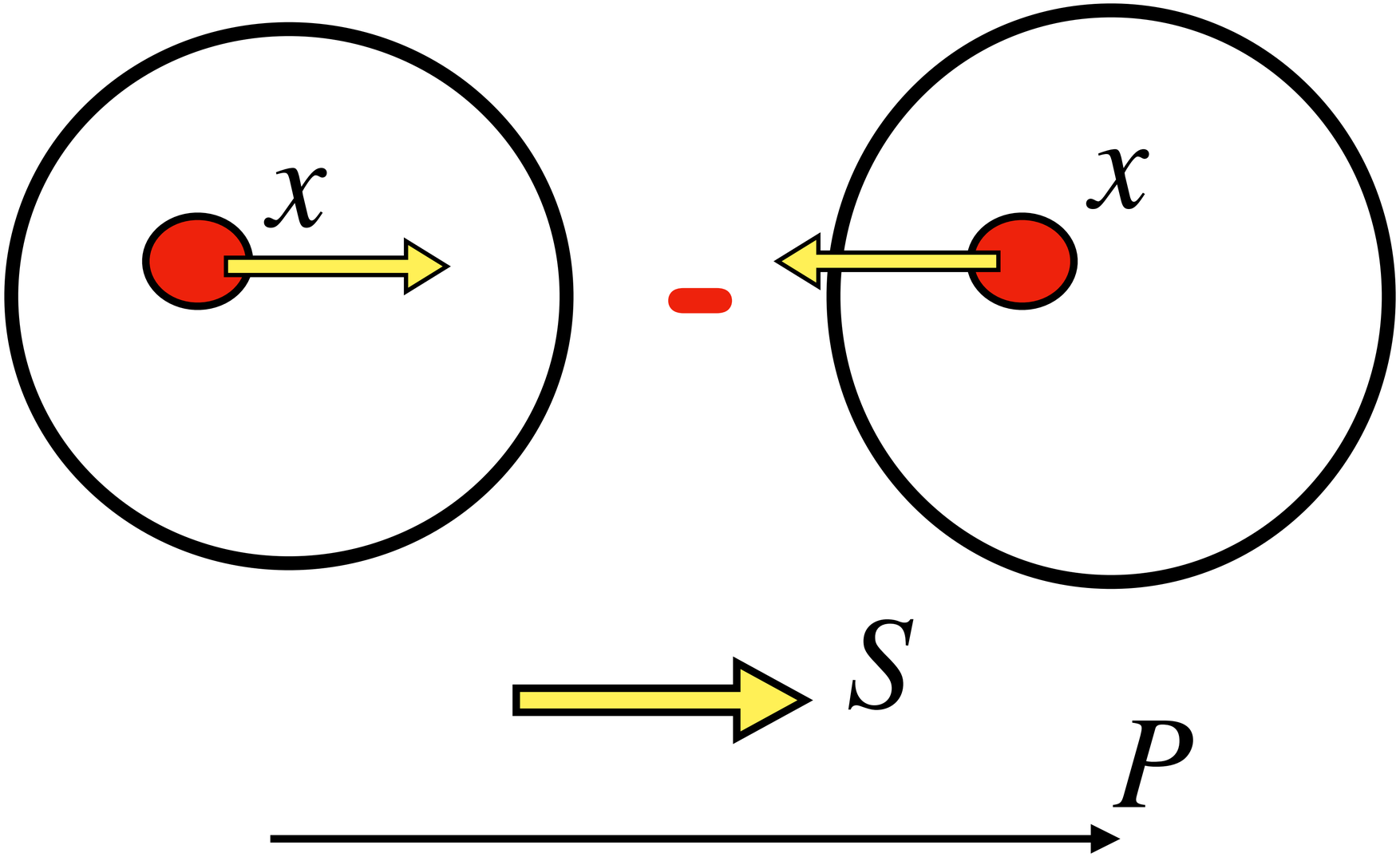
PDF

g_1



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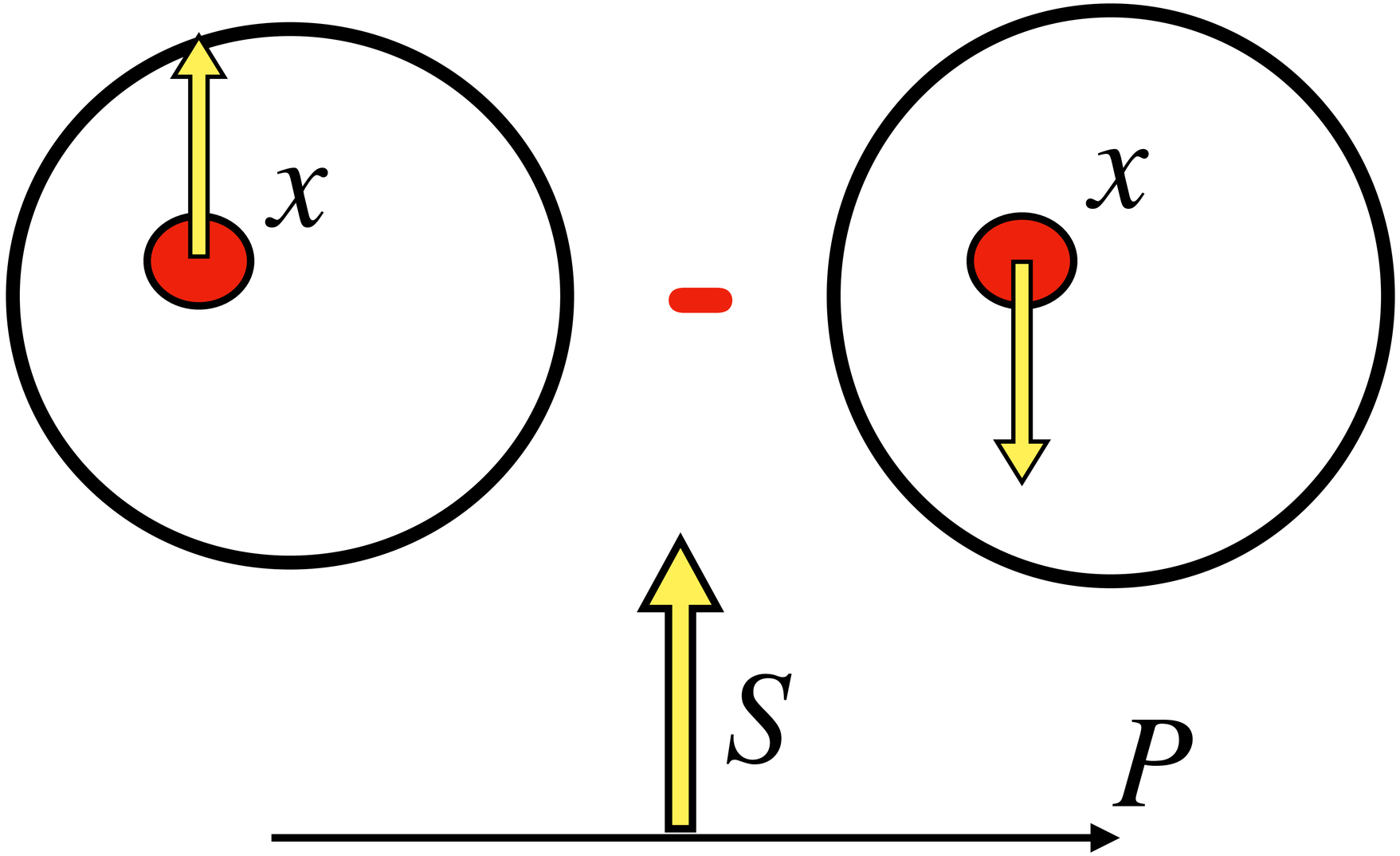
PDF

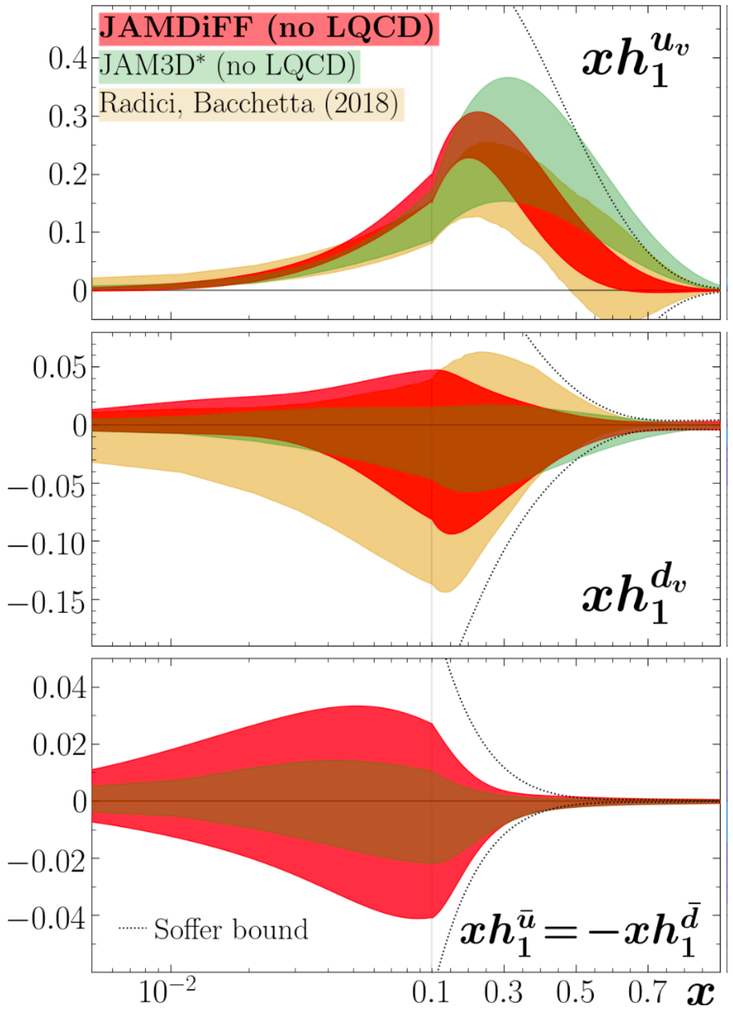
h_1



Why caring about transversity?

- Have a better knowledge of the proton structure

N.Sato et al, Phys. Rev. D 109, (2024) 034024



Why caring about transversity?

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- Can be used to investigate physics beyond the Standard Model

Chiral-odd structures do not appear in the SM Tree level Lagrangian

<u>Neutrino β-decay</u>

$$g_T = \delta u - \delta d$$

$$\delta q = \int_0^1 dx\, h_1^q(x)$$

<u>constraints on CP violation</u>

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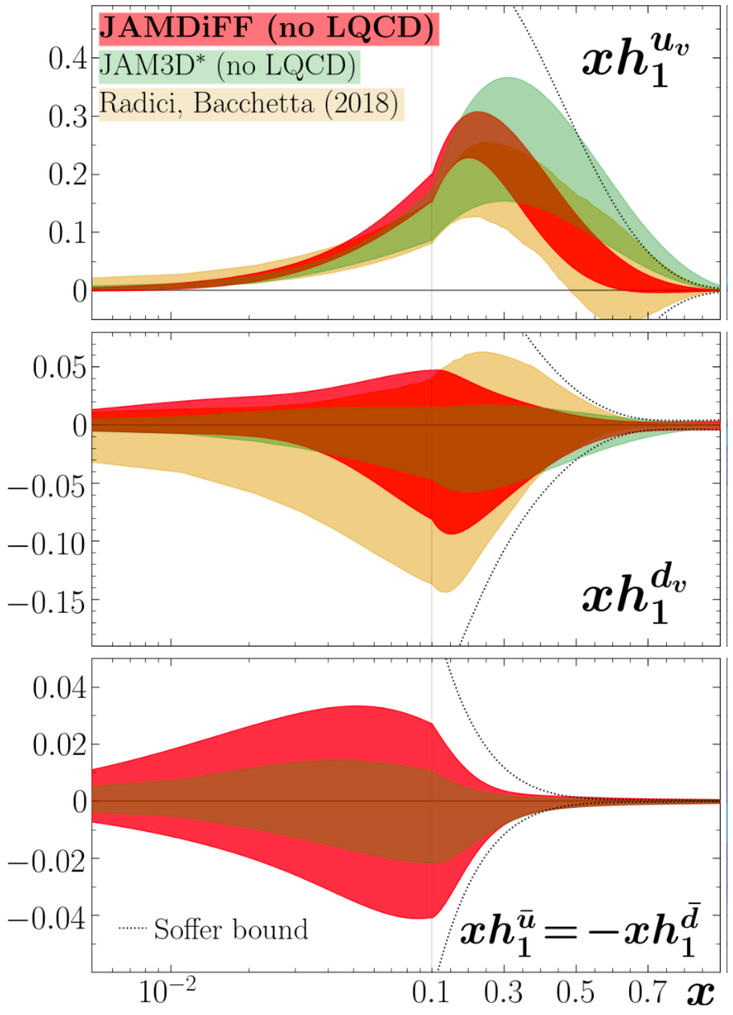

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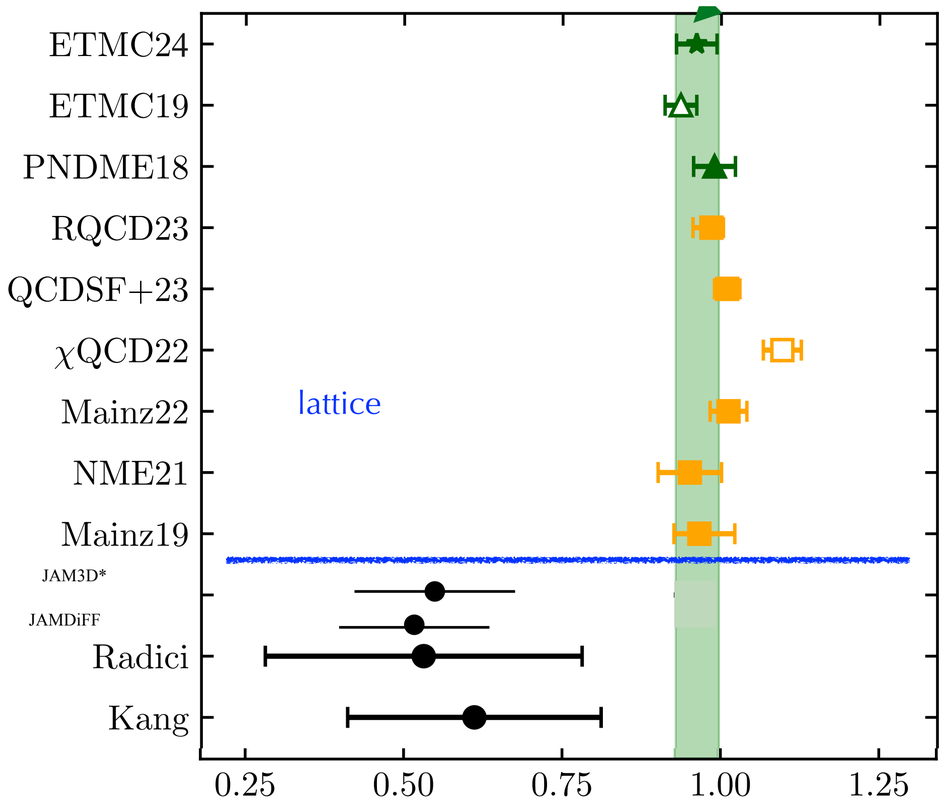
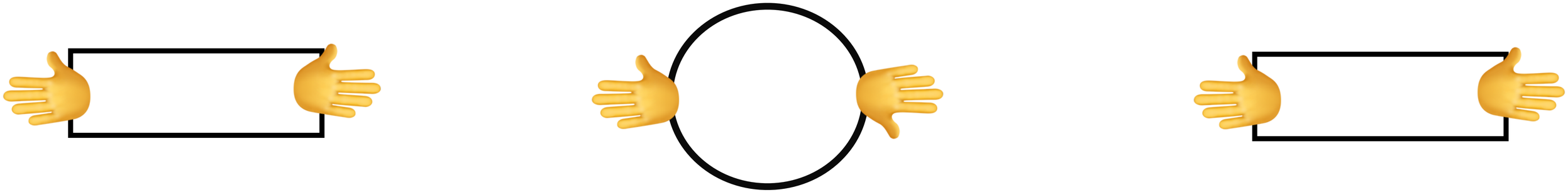
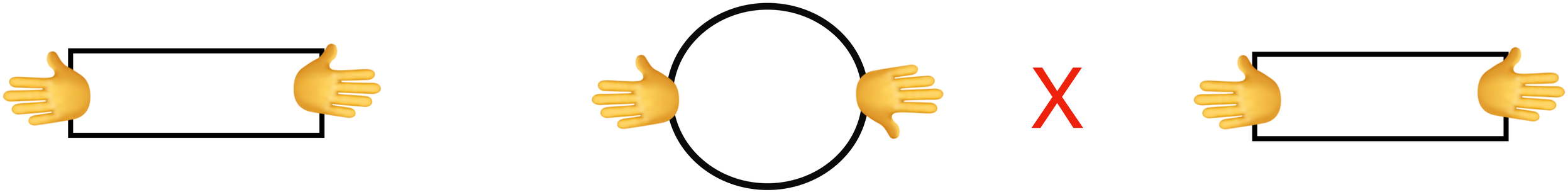
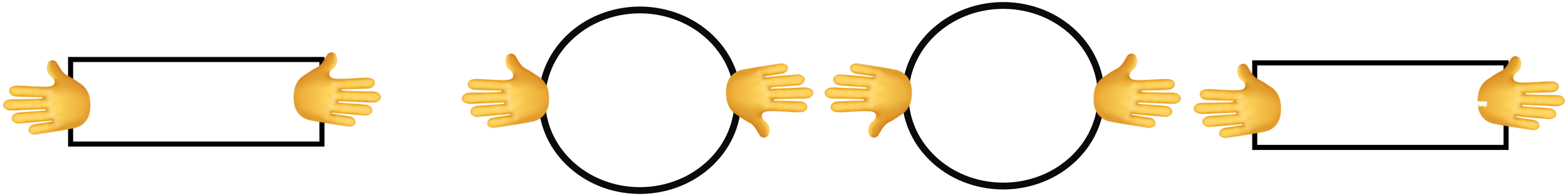
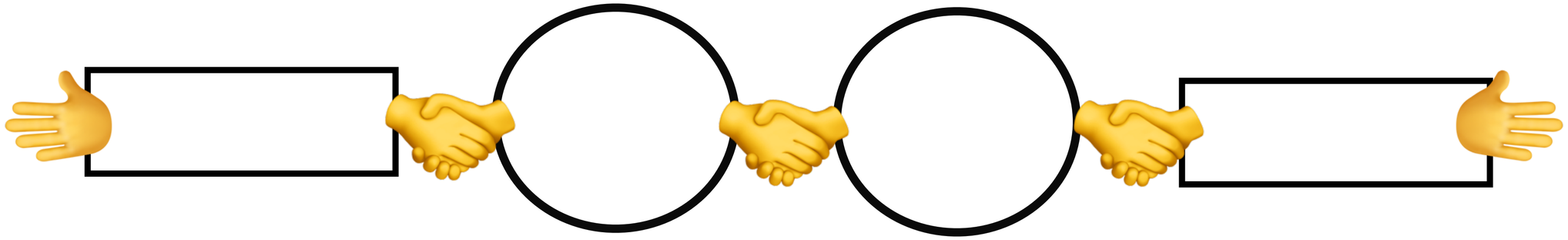
adapted from C. Alexandrou, QCD Evolution 24

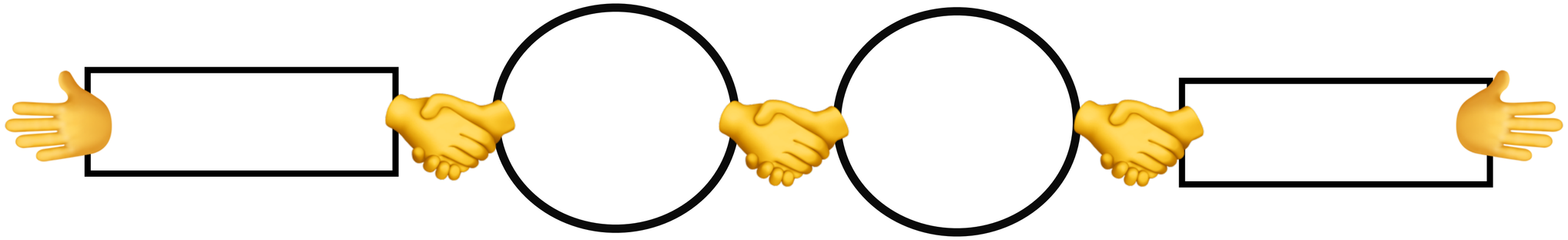


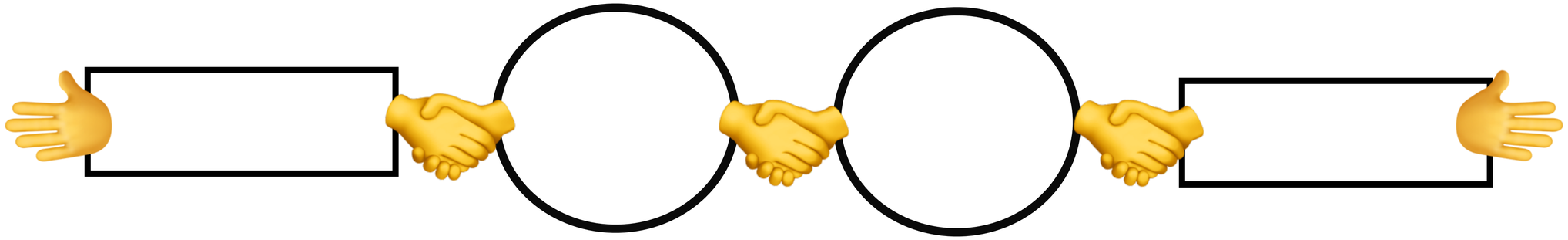




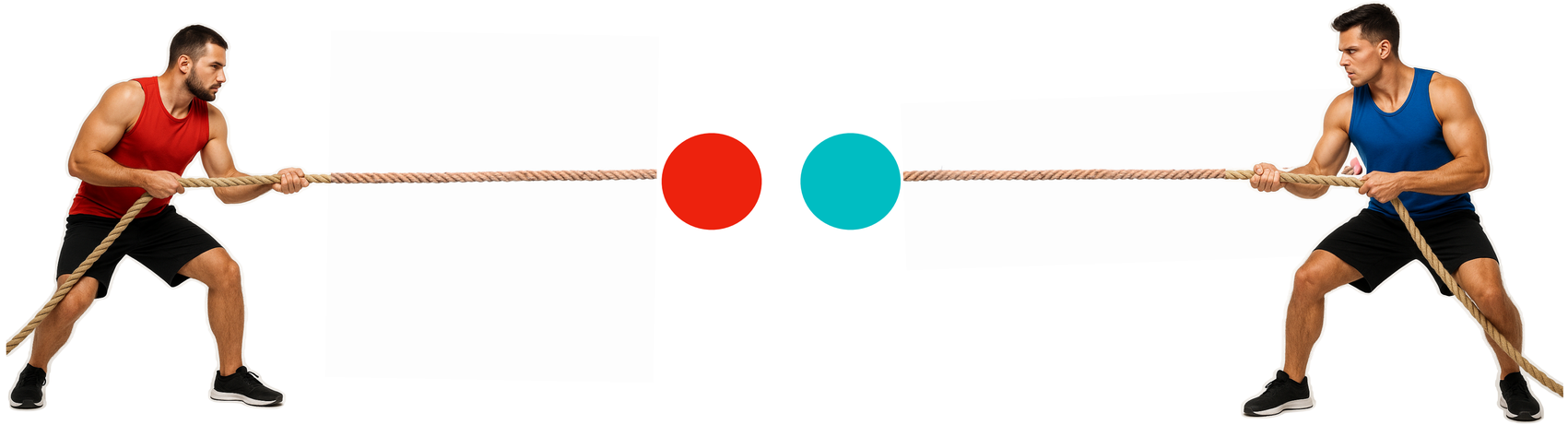




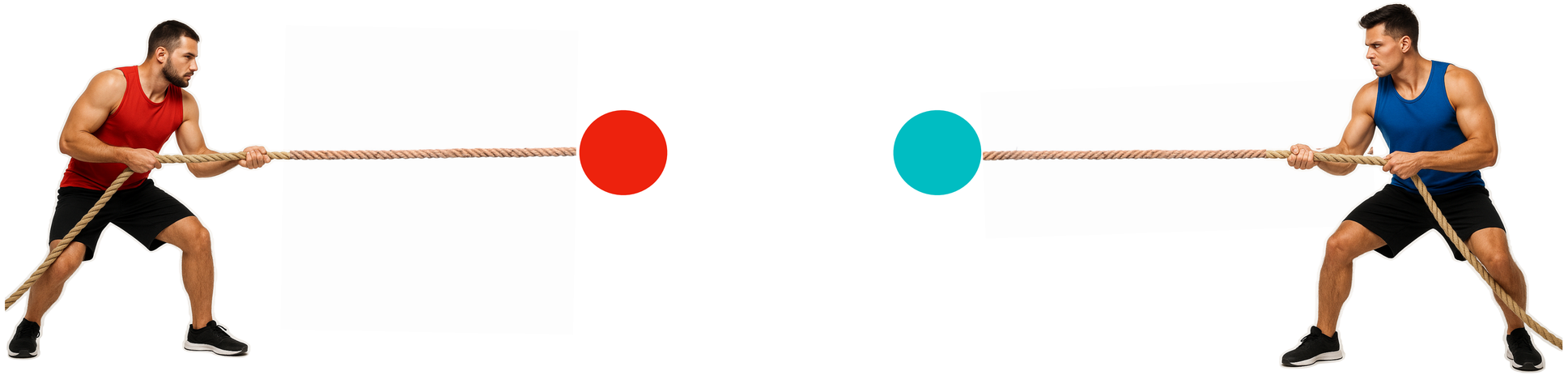




Fragmentation Functions



Fragmentation Functions



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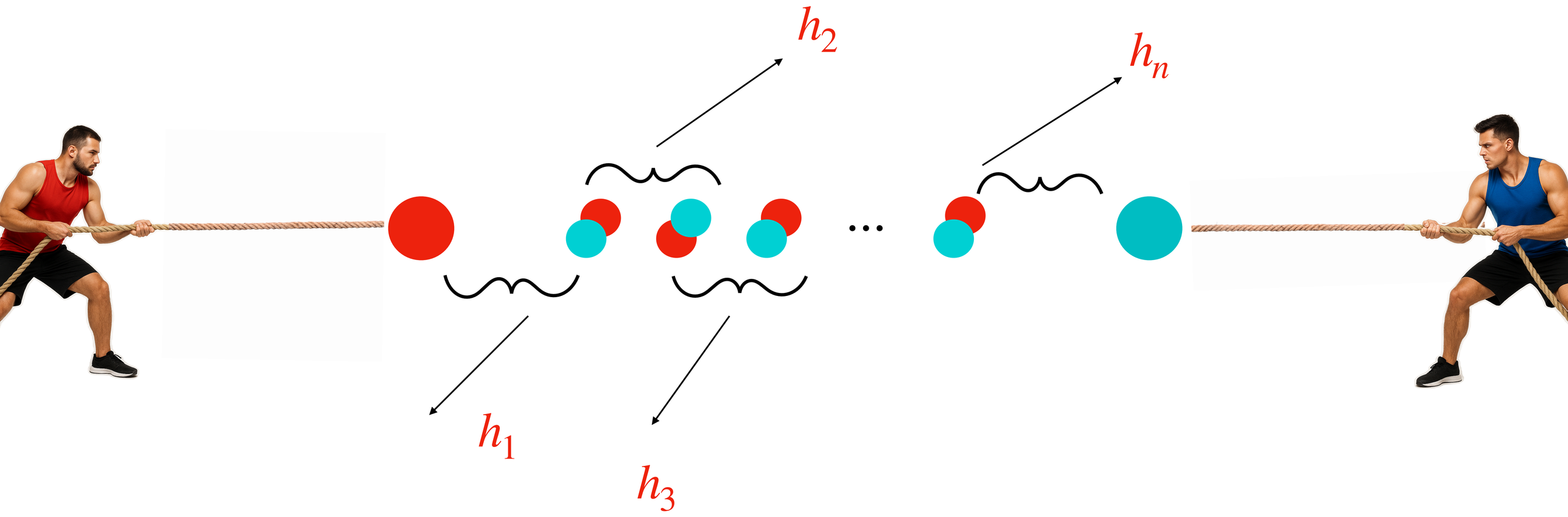
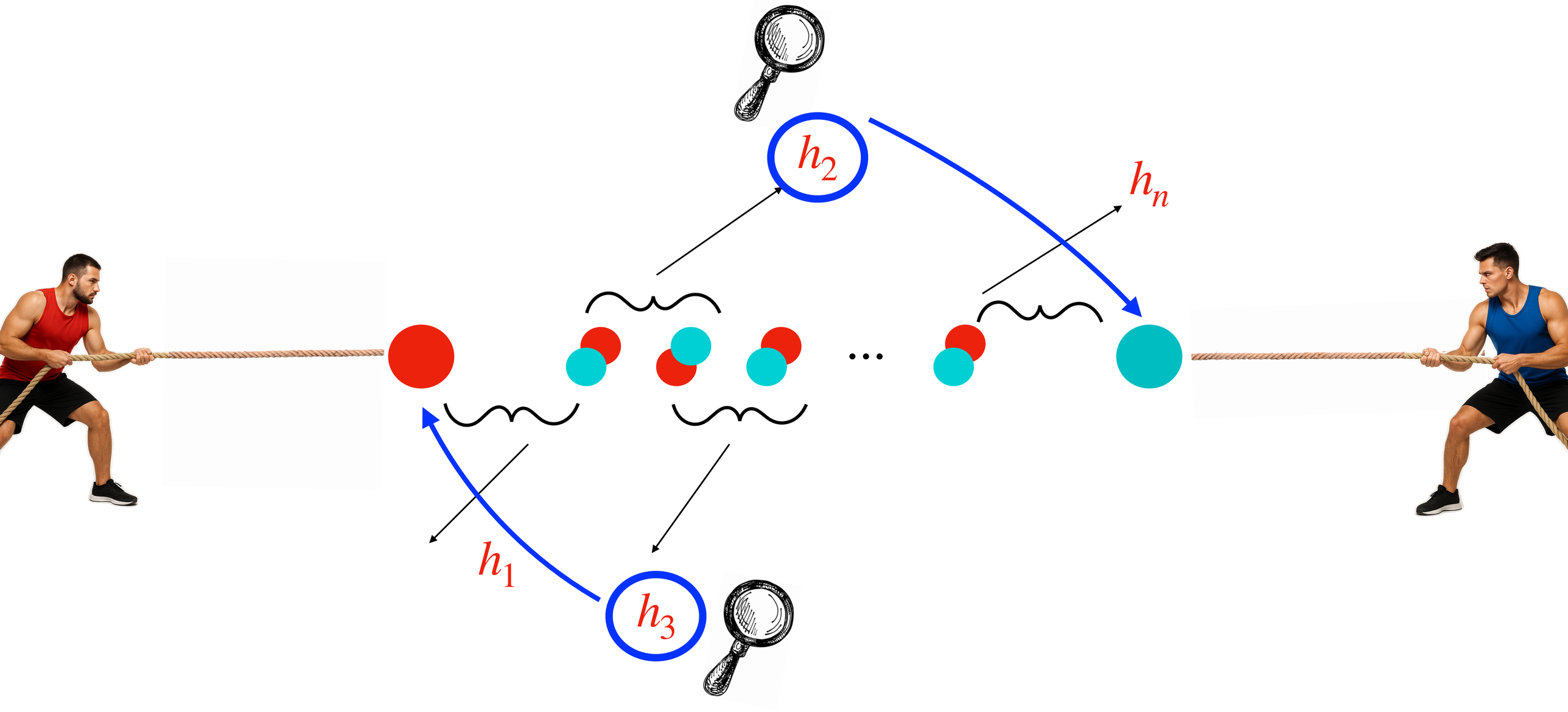

h_2
h_n
h_1
h_3


h_2
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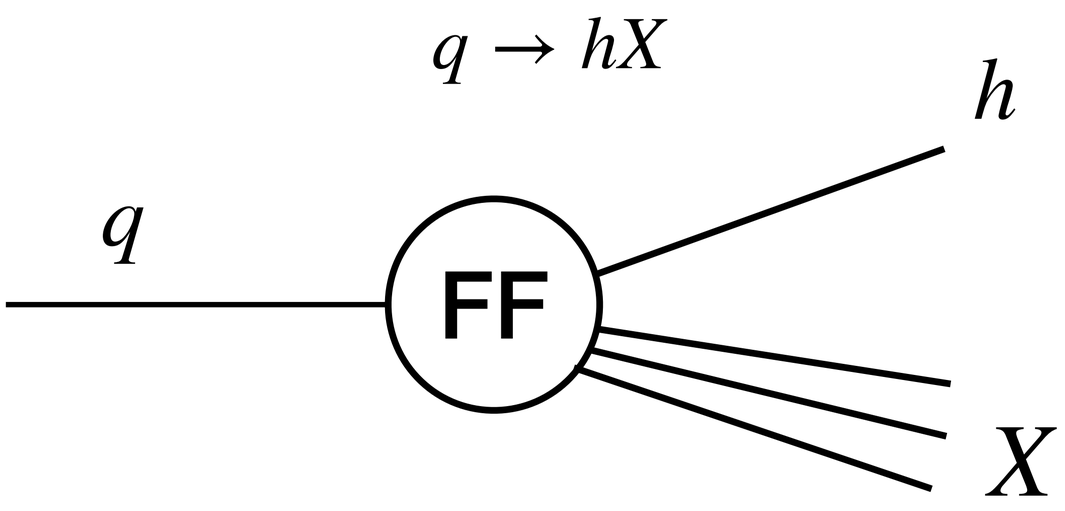
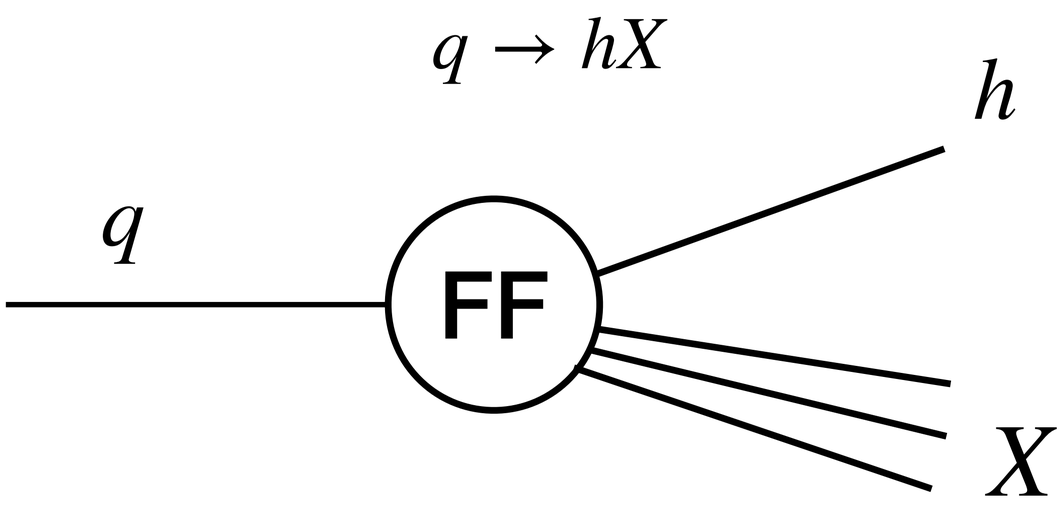
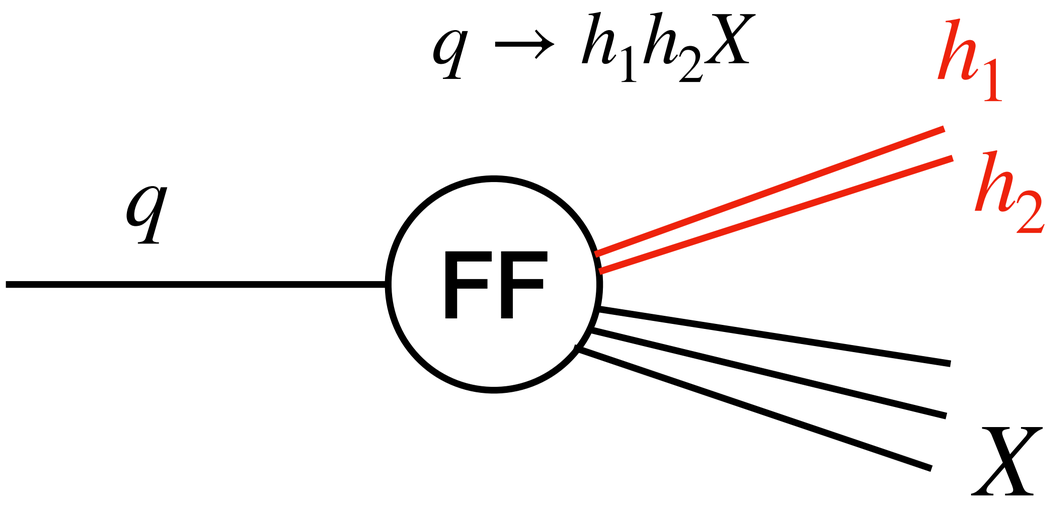
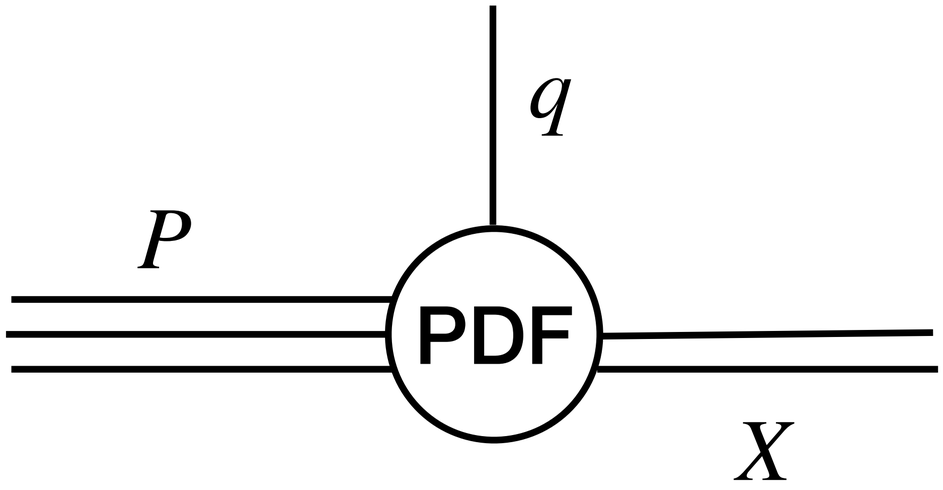
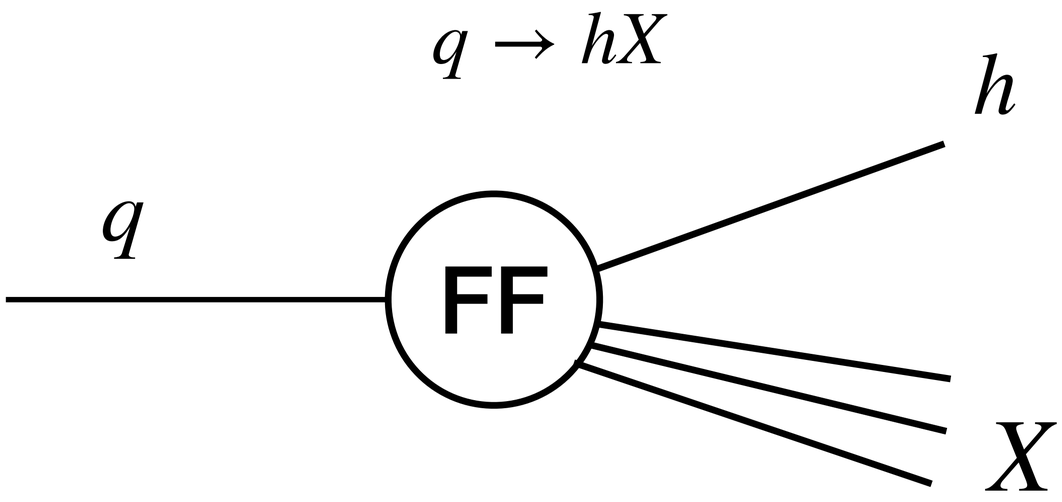
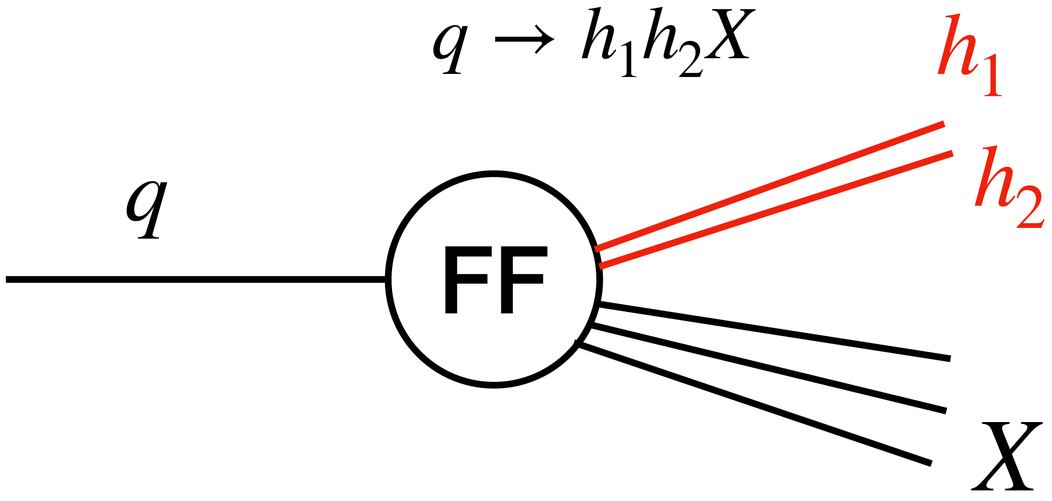

$q \to hX$
h
q
FF
X

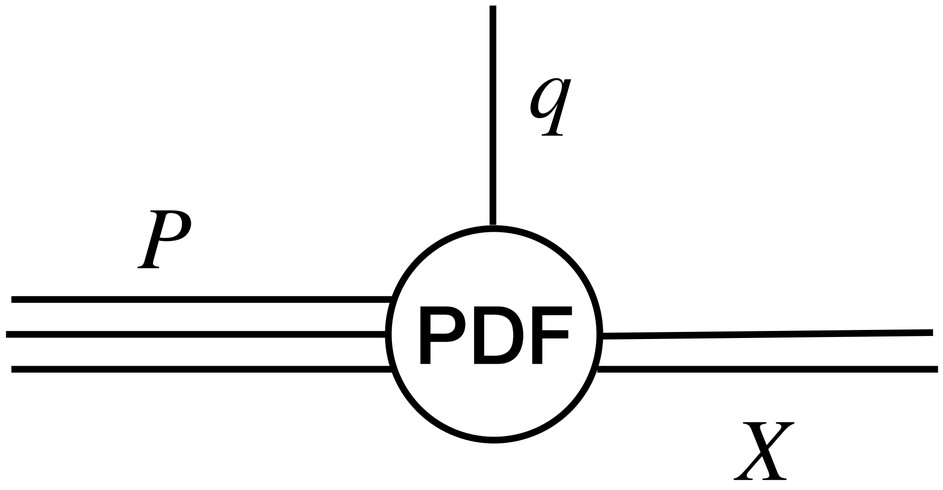

$q \to hX$
h
q
FF
X

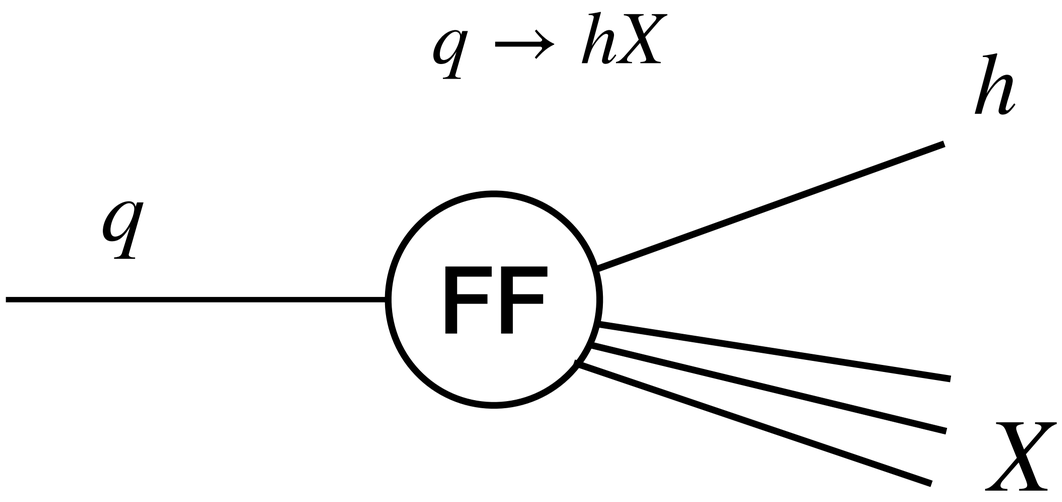

$q \to h_1 h_2 X$
h_1
h_2
q
FF
X

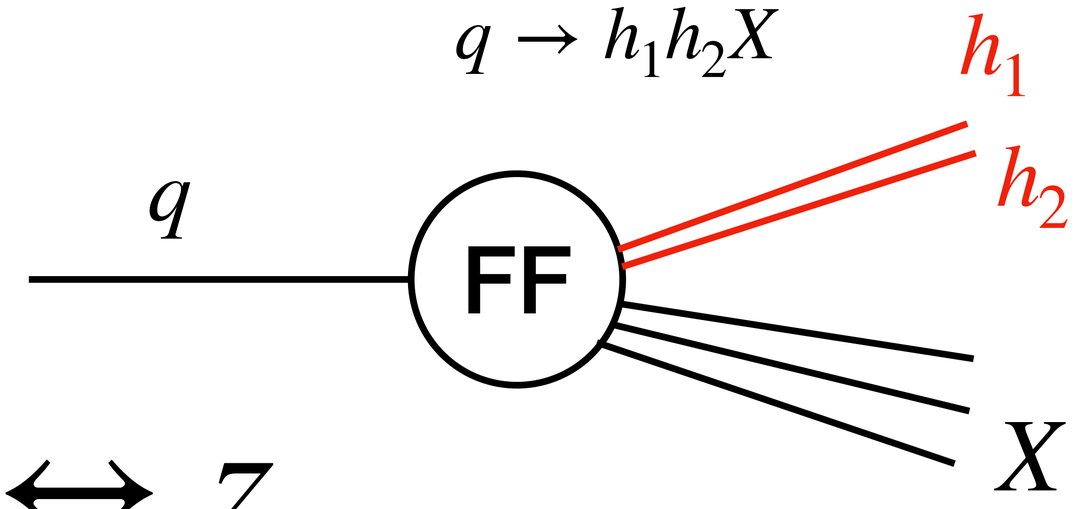

q
P
PDF
X


$q \to hX$
h
q
FF
X


$q \to h_1 h_2 X$
h_1
h_2
q
FF
X



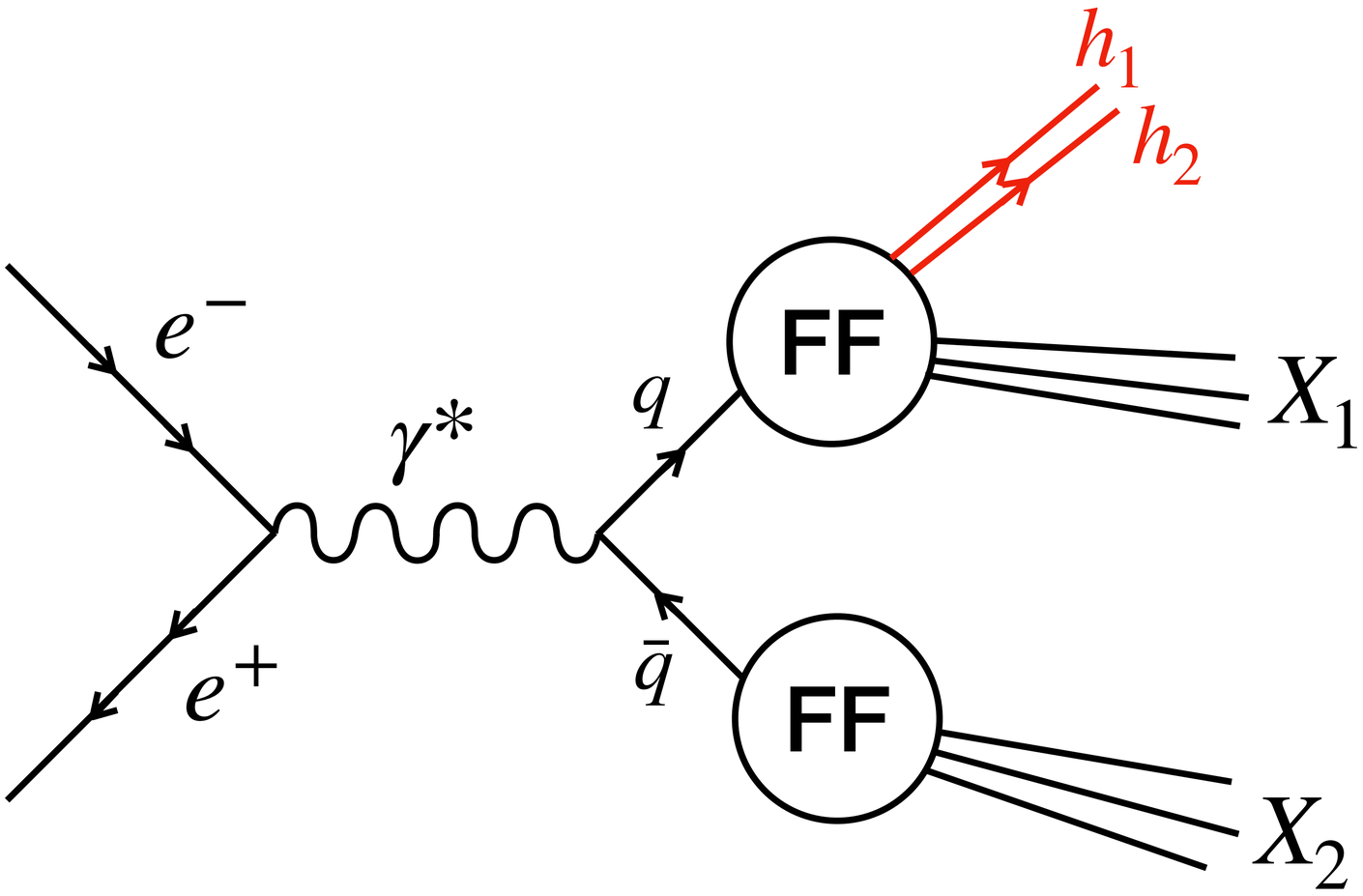




$$x_B \leftrightarrow z$$

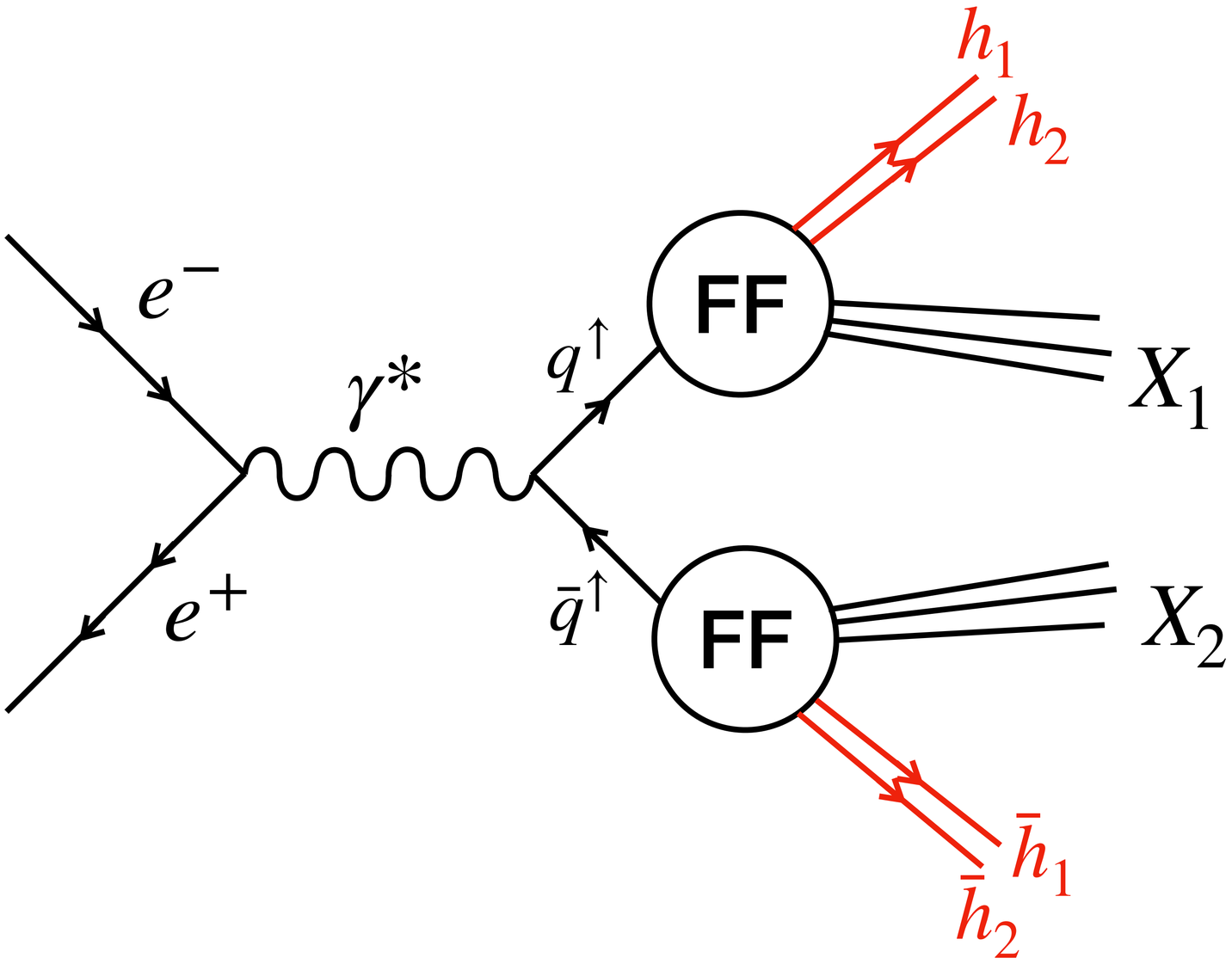
D_1

Electron-positron annihilation



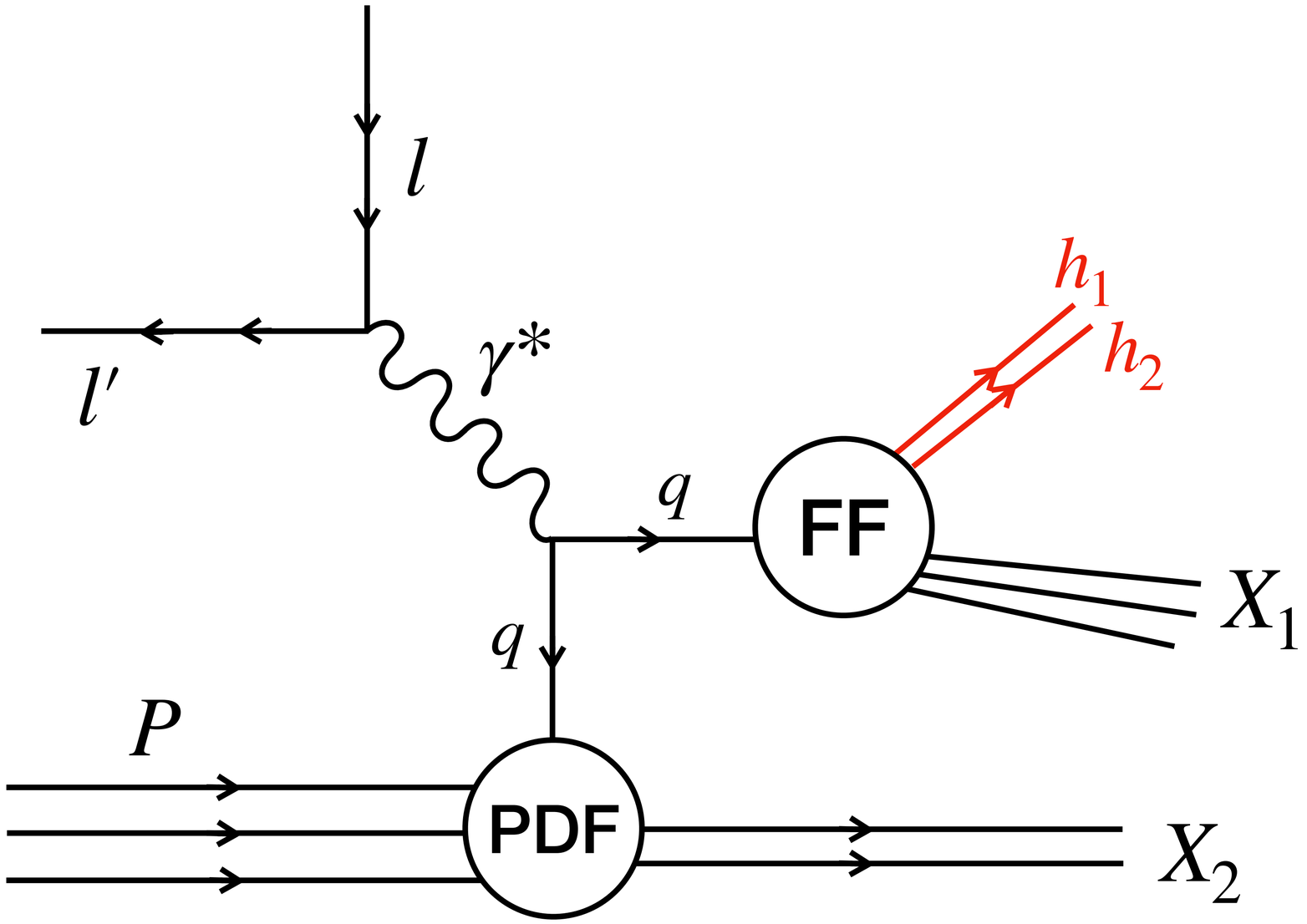
Electron-positron annihilation

$H_1^{\sphericalangle}$



Semi-inclusive Deep Inelastic Scattering

h_1



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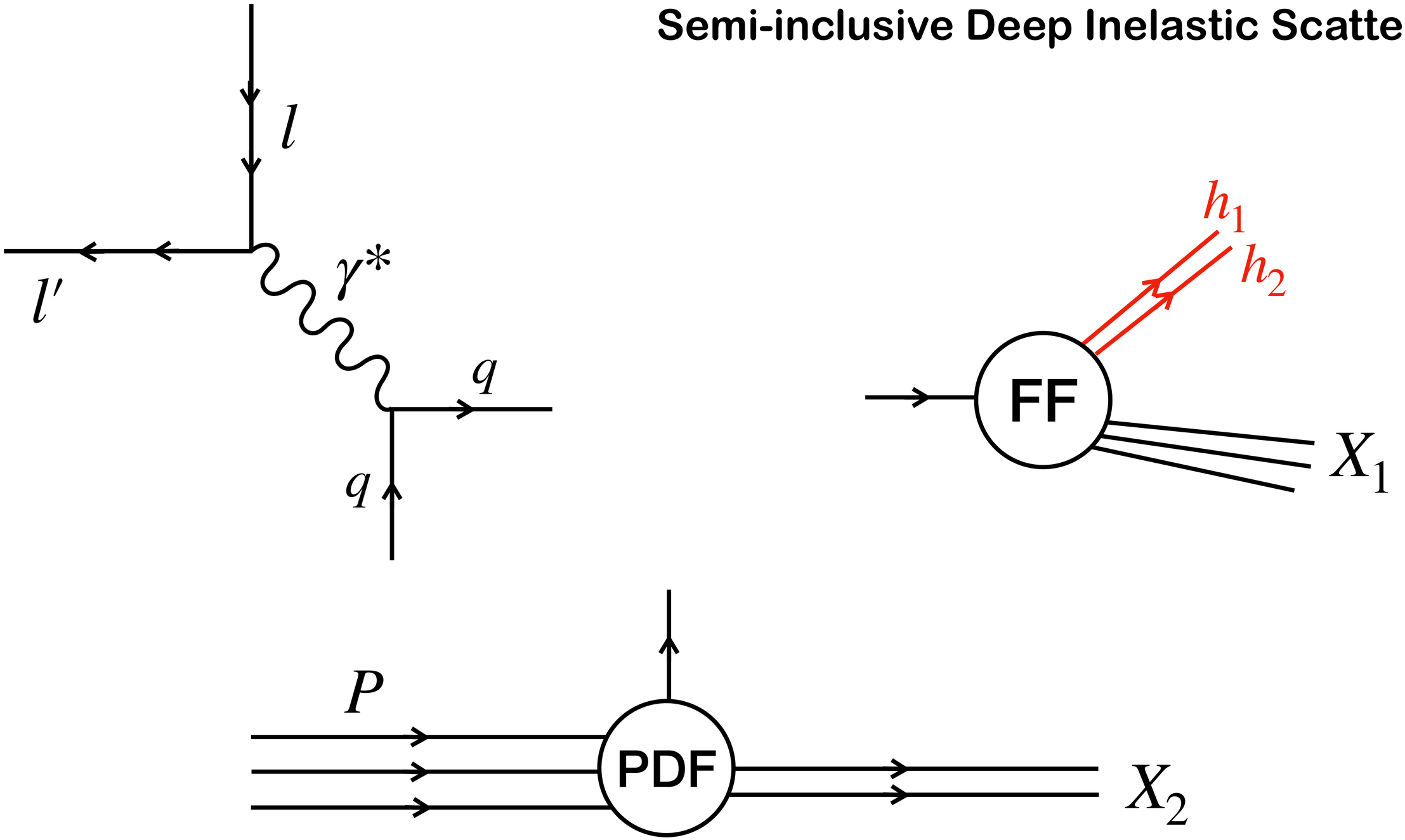

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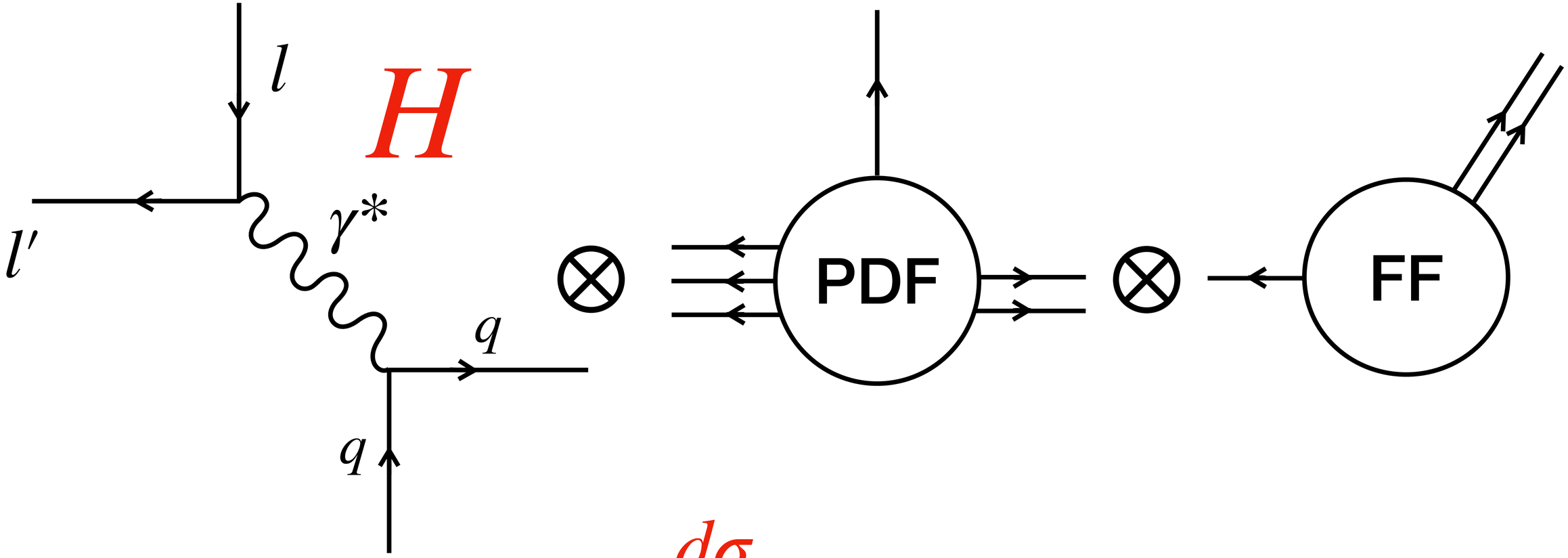
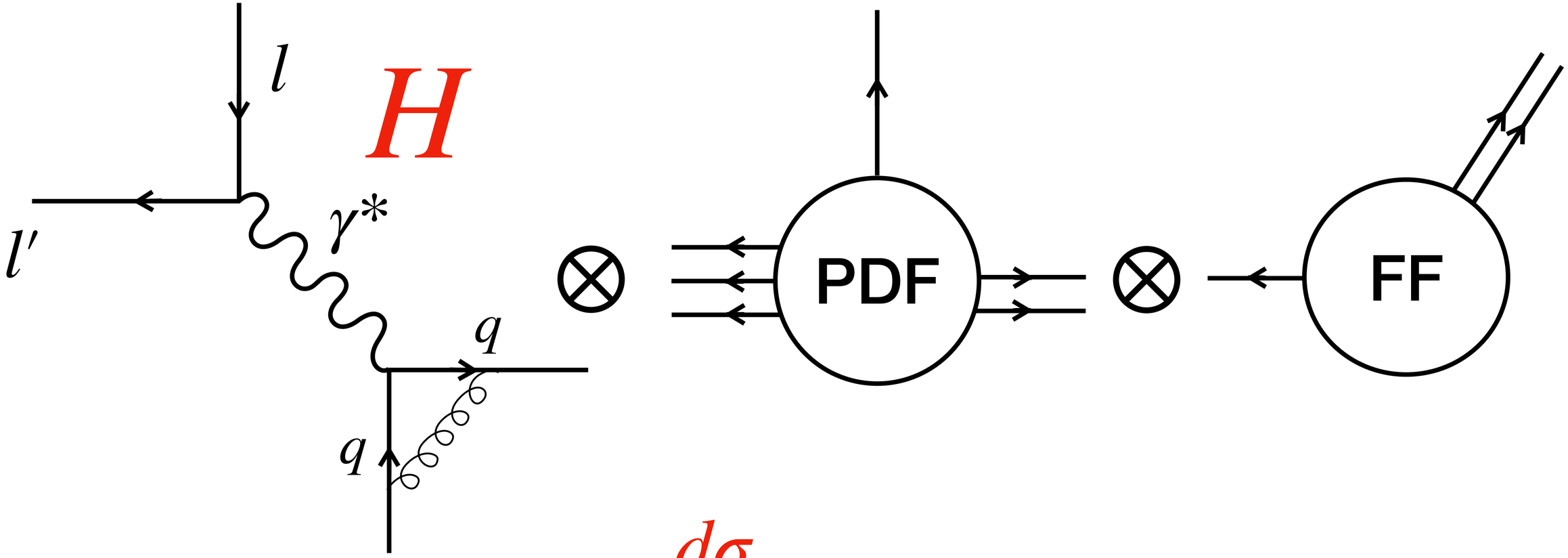


$$\frac{d\sigma}{dx dQ^2 \ldots} = H \otimes PDF \otimes FF$$



Ex.: NLO

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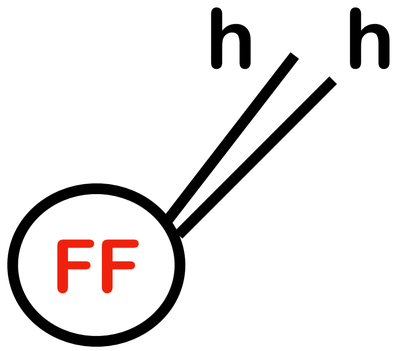
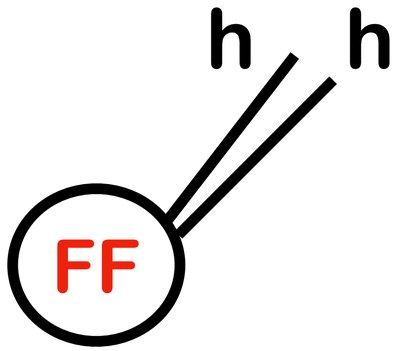
2 measured hadrons + X



$$A_{UT}^{hh} \sim \frac{\sum_q e_q^2 \cdot h_1^q(x_B) \cdot H_1^{\sphericalangle,q}(z, M_h)}{\sum_q e_q^2 \cdot f_1^q(x_B) \cdot D_1^q(z, M_h)}$$

2 measured hadrons + X



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How to acces them?

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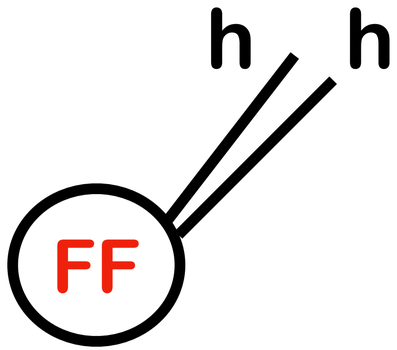

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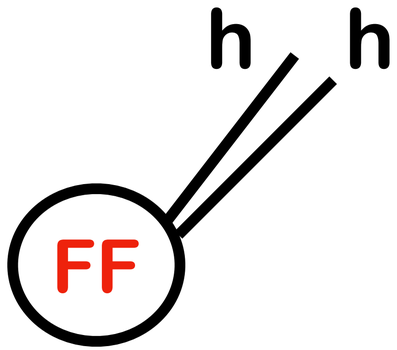

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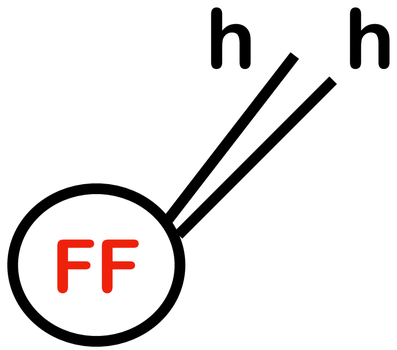

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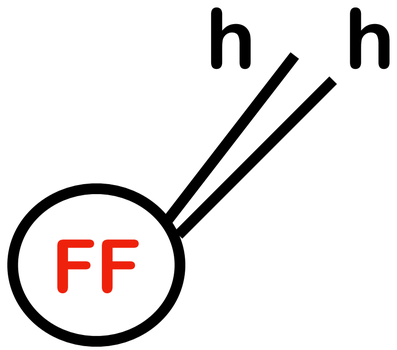

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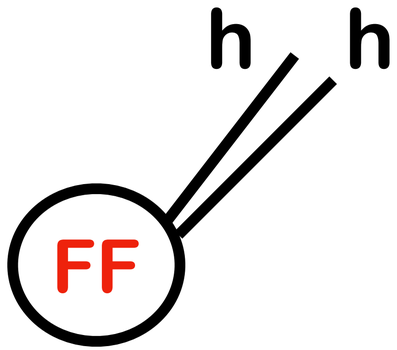

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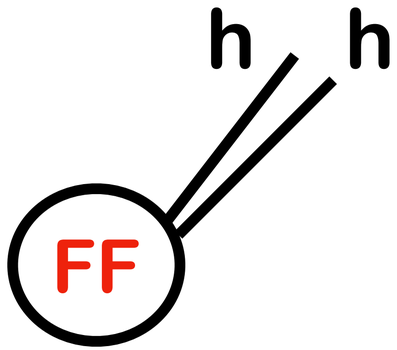

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GOALS of the D_1 extraction

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- **2017 BELLE data of** $e^+e^- \to \pi^+\pi^- X$ **at** $\sqrt{S} = 10.58$ **GeV**

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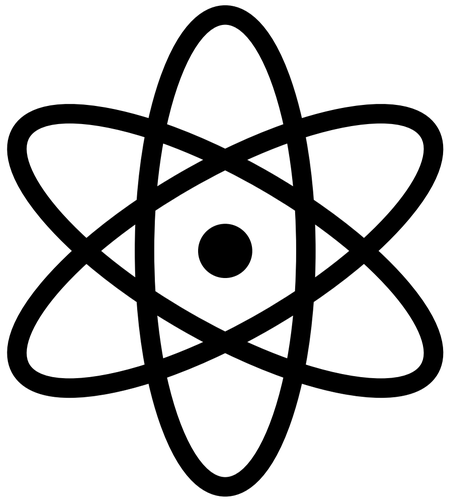
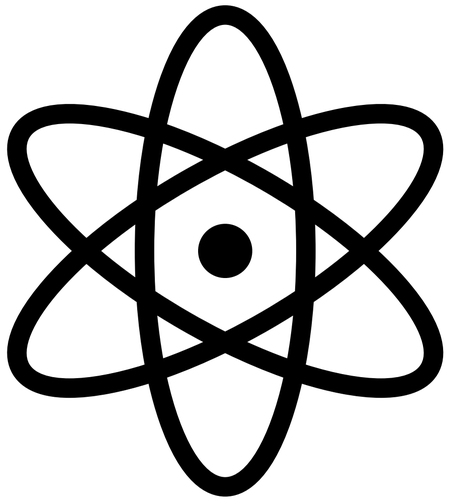
- 2017 BELLE data of $e^+e^- \to \pi^+\pi^- X$ at $\sqrt{S} = 10.58$ GeV
- Use of Monte-Carlo simulation for flavor separation only
- Extend the analysis up to NNLO
- Explore a Neural Network parameterisation

PHYSICS INFORMED



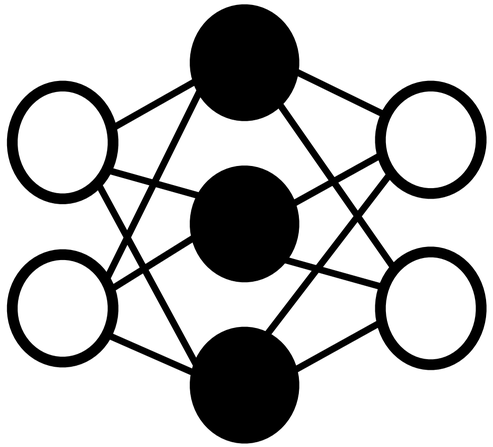
71 par

PHYSICS INFORMED



71 par

NEURAL NETWORK



NN architecture

[2,25,5] ⇝ 205 par

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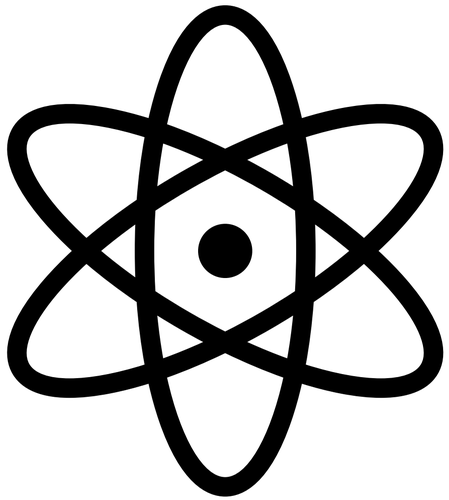

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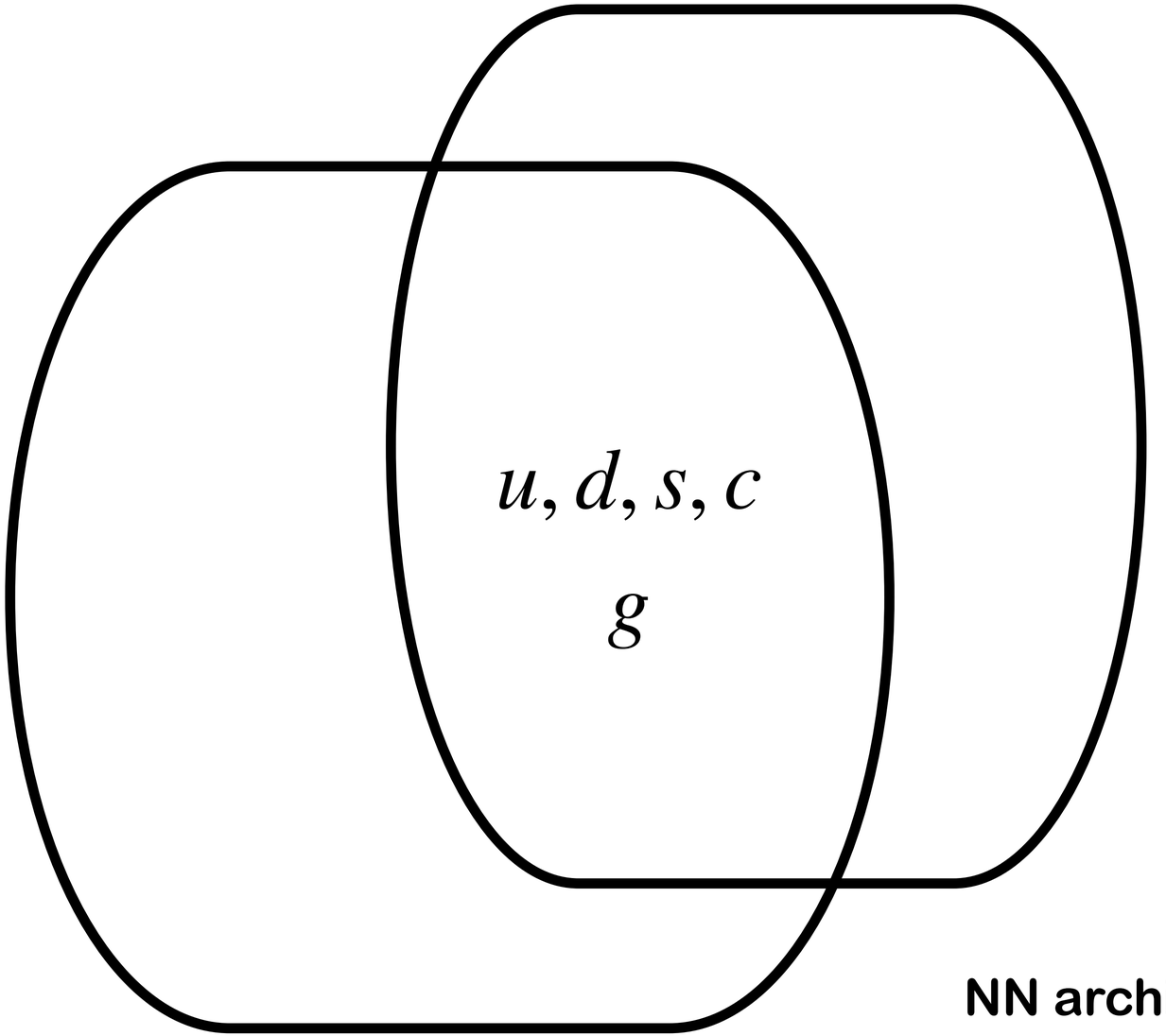
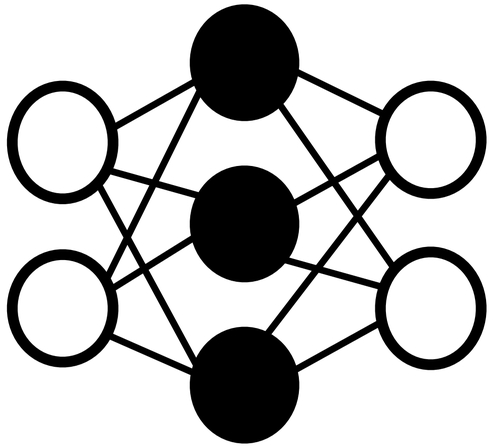


NEURAL NETWORK



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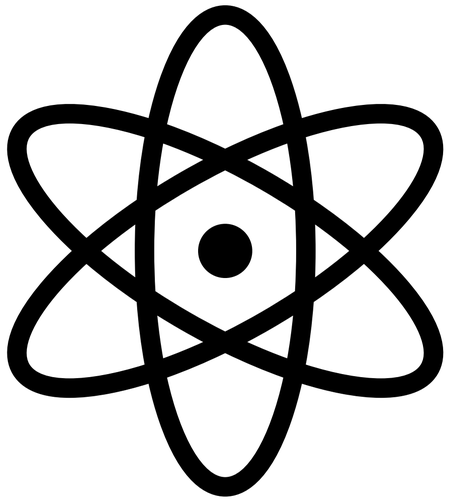

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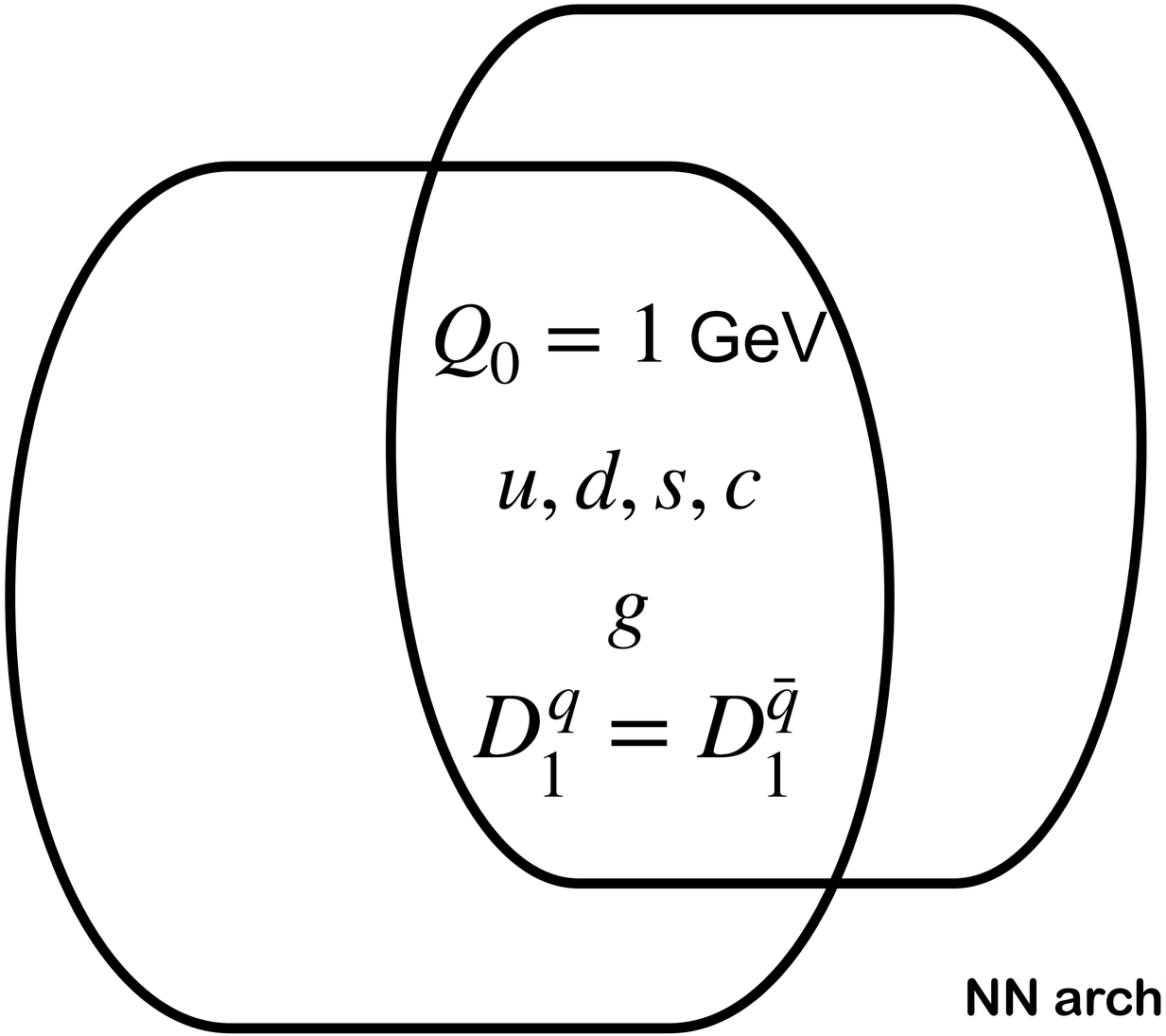

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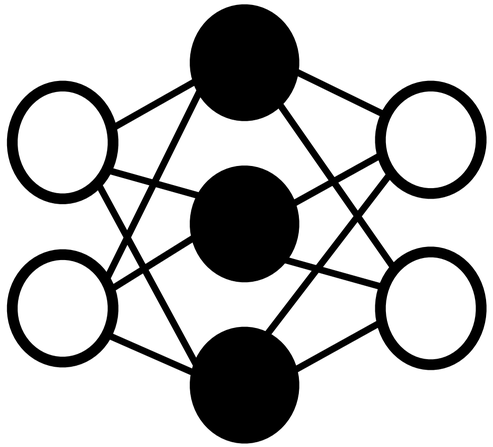

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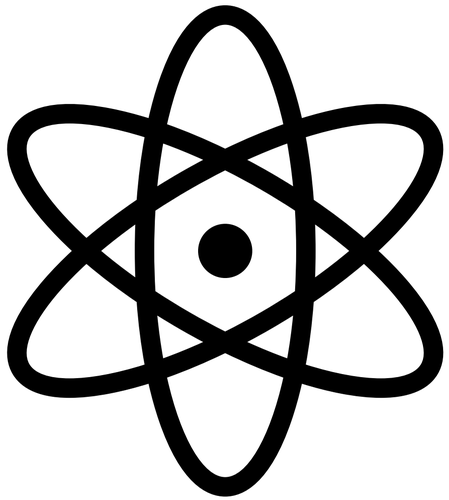


71 par

$D_1^u = D_1^d$

ansatz

D_1^g

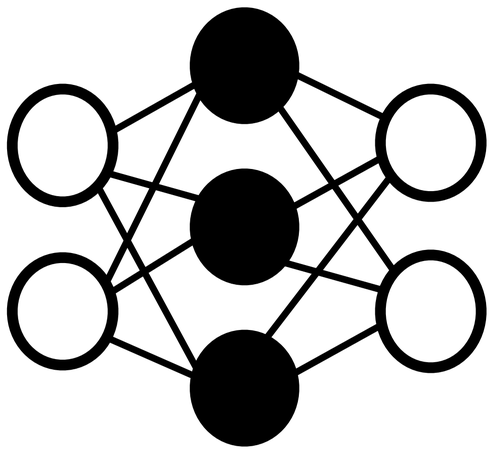
$Q_0 = 1$ GeV

u, d, s, c

g

$D_1^q = D_1^{\bar{q}}$

NEURAL NETWORK



NN architecture

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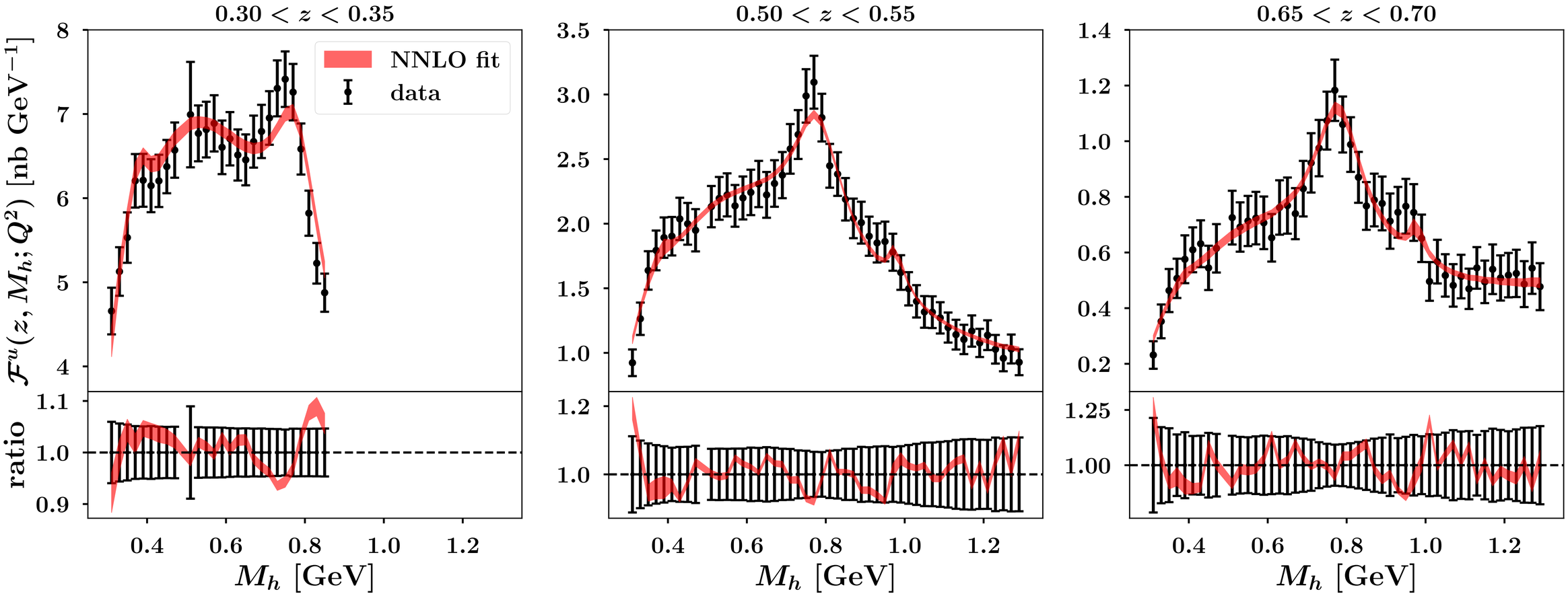
Predictions: Physics informed



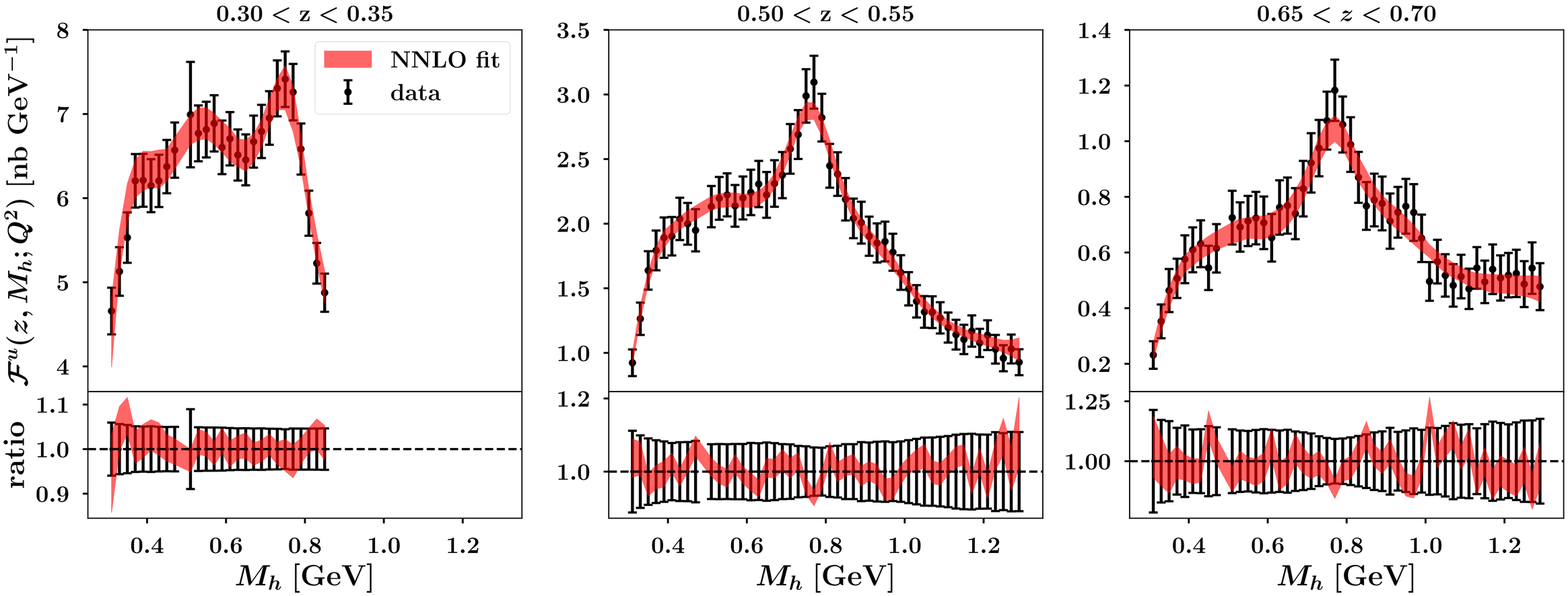
NNLO

100 replicas

$\chi^2_u = 0.380$ $\chi^2_s = 0.876$ $\chi^2_{tot} = 0.687$

$\chi^2_d = 0.613$ $\chi^2_c = 0.879$

Predictions: Neural Network



NNLO

100 replicas

$\chi^2_u = 0.209$ $\chi^2_s = 0.793$ $\chi^2_{tot} = 0.535$

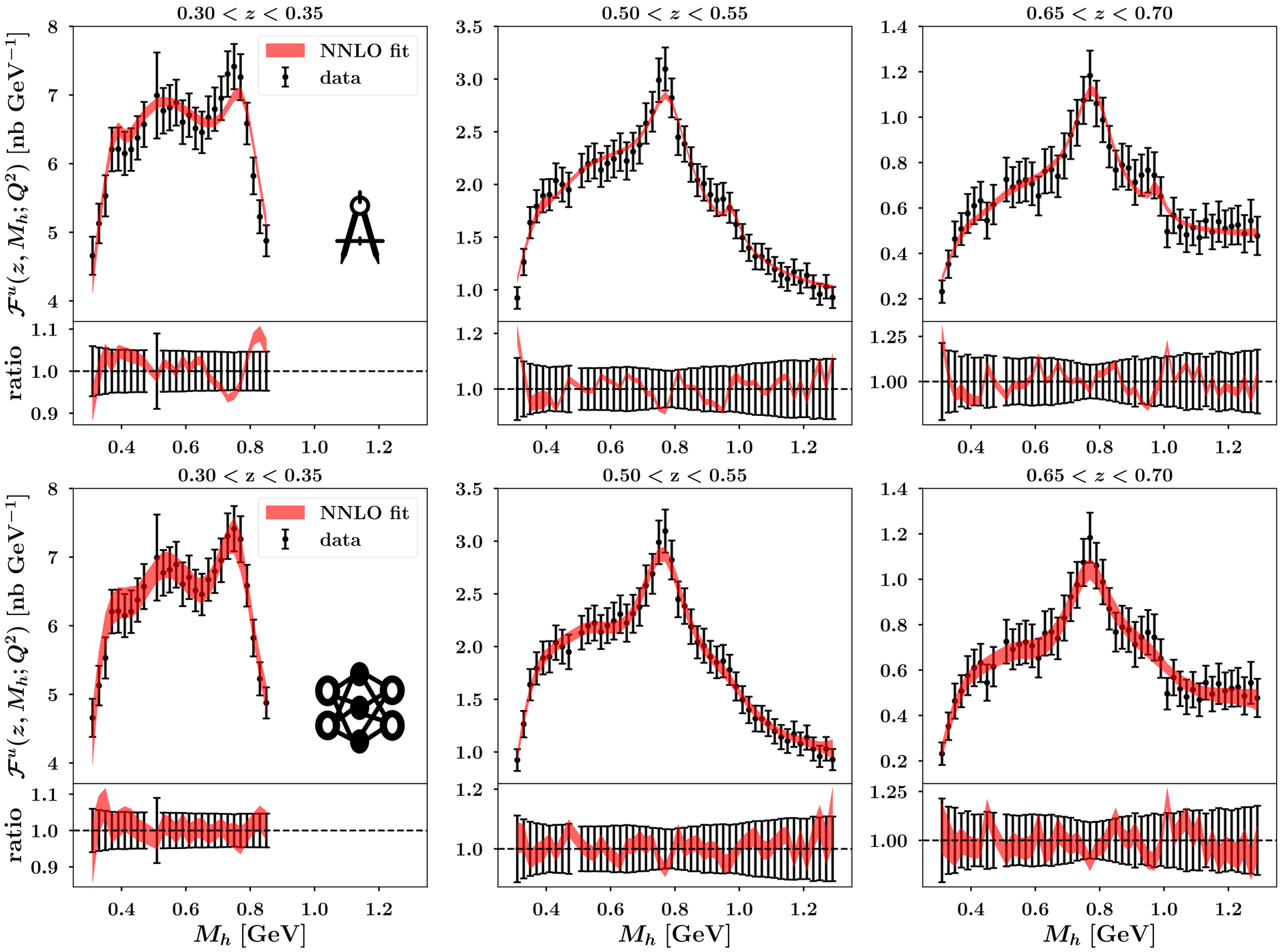
$\chi^2_d = 0.530$ $\chi^2_c = 0.606$

Comparison

vs

NN seems to describe data better

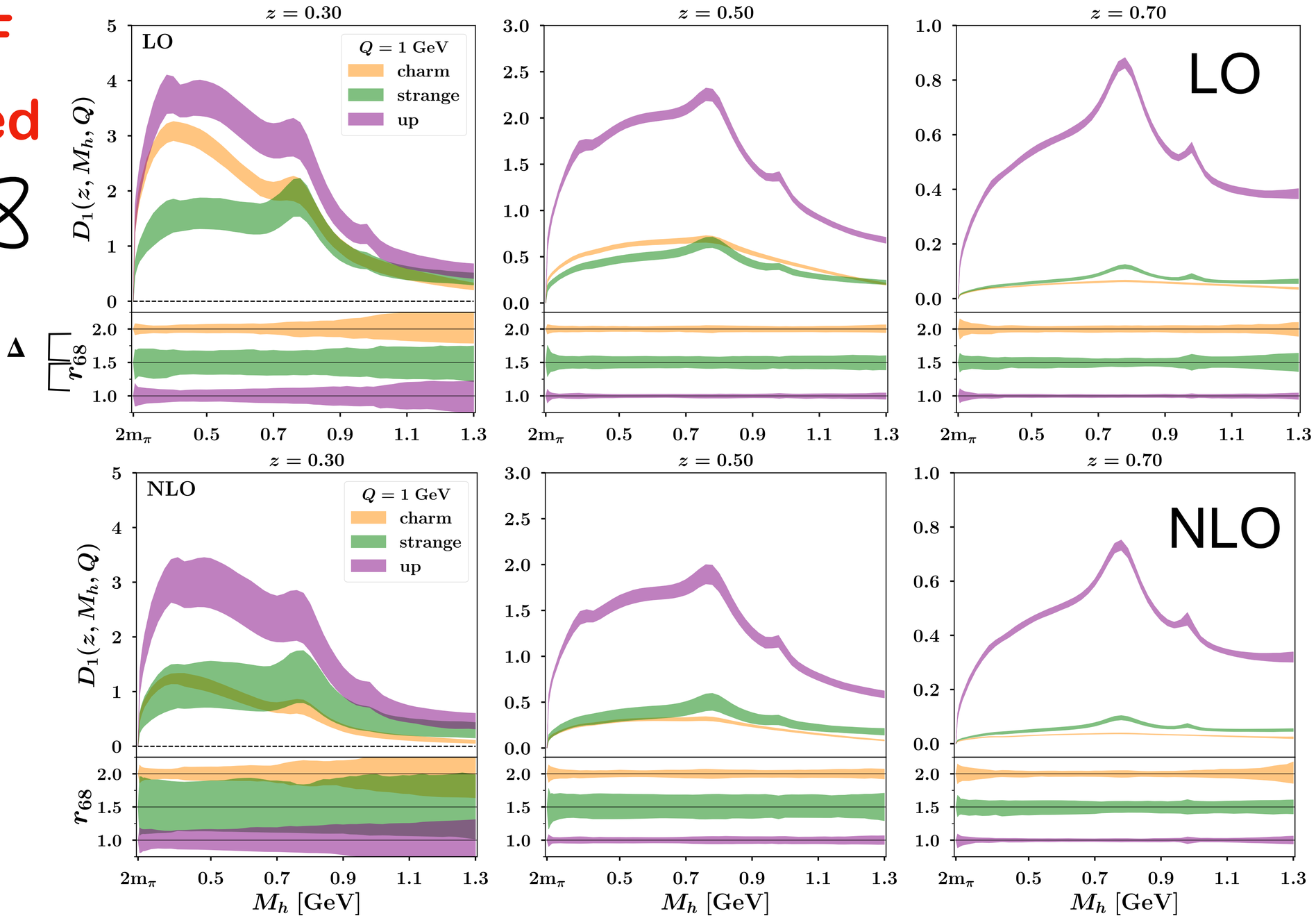
NN has less sensitivity on resonances



DI-HADRON FF
Physics informed

u=d

ratio offset Δ = 0.5



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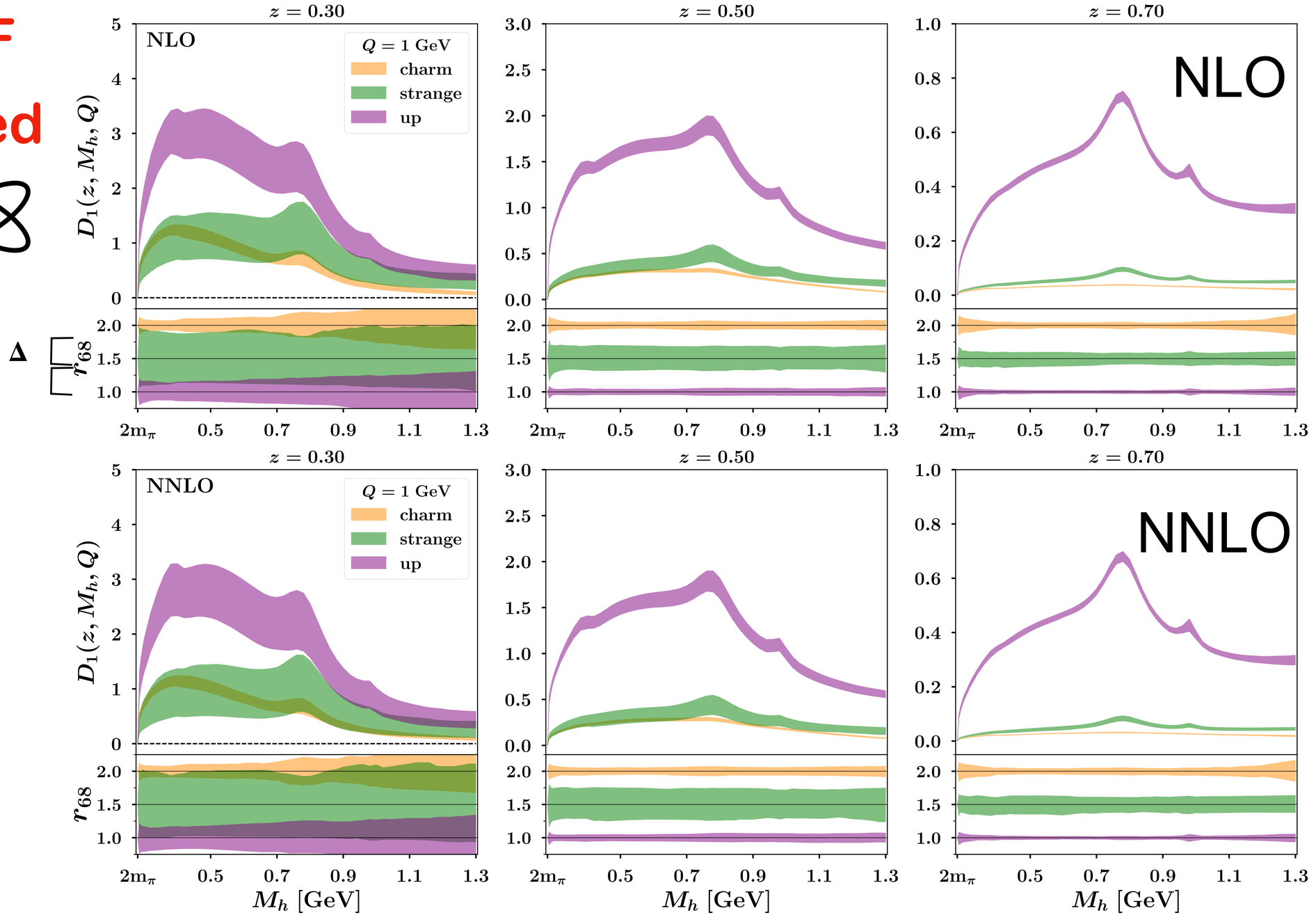
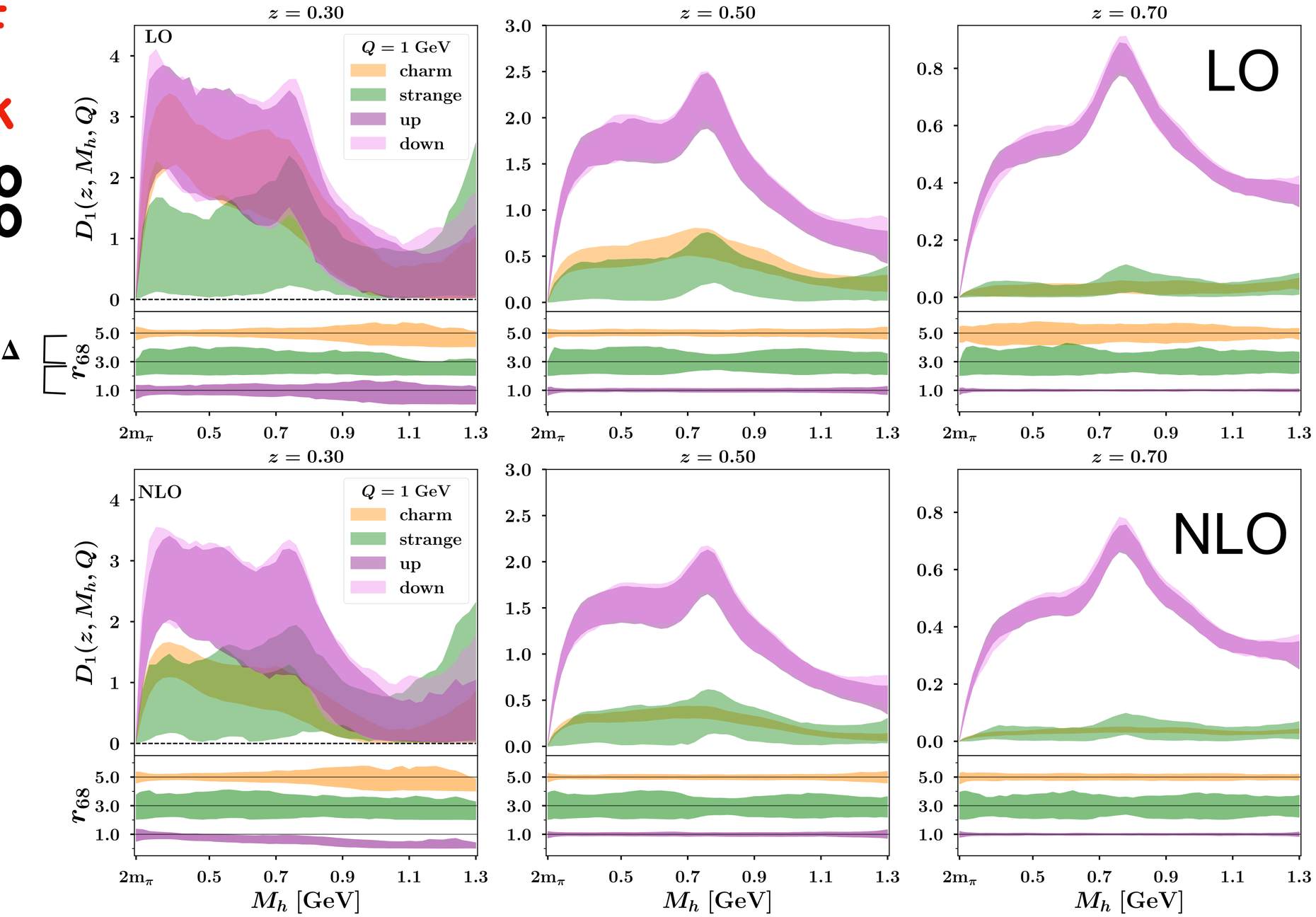


DI-HADRON FF
Neural Network

$\mathbf{u \neq d}$

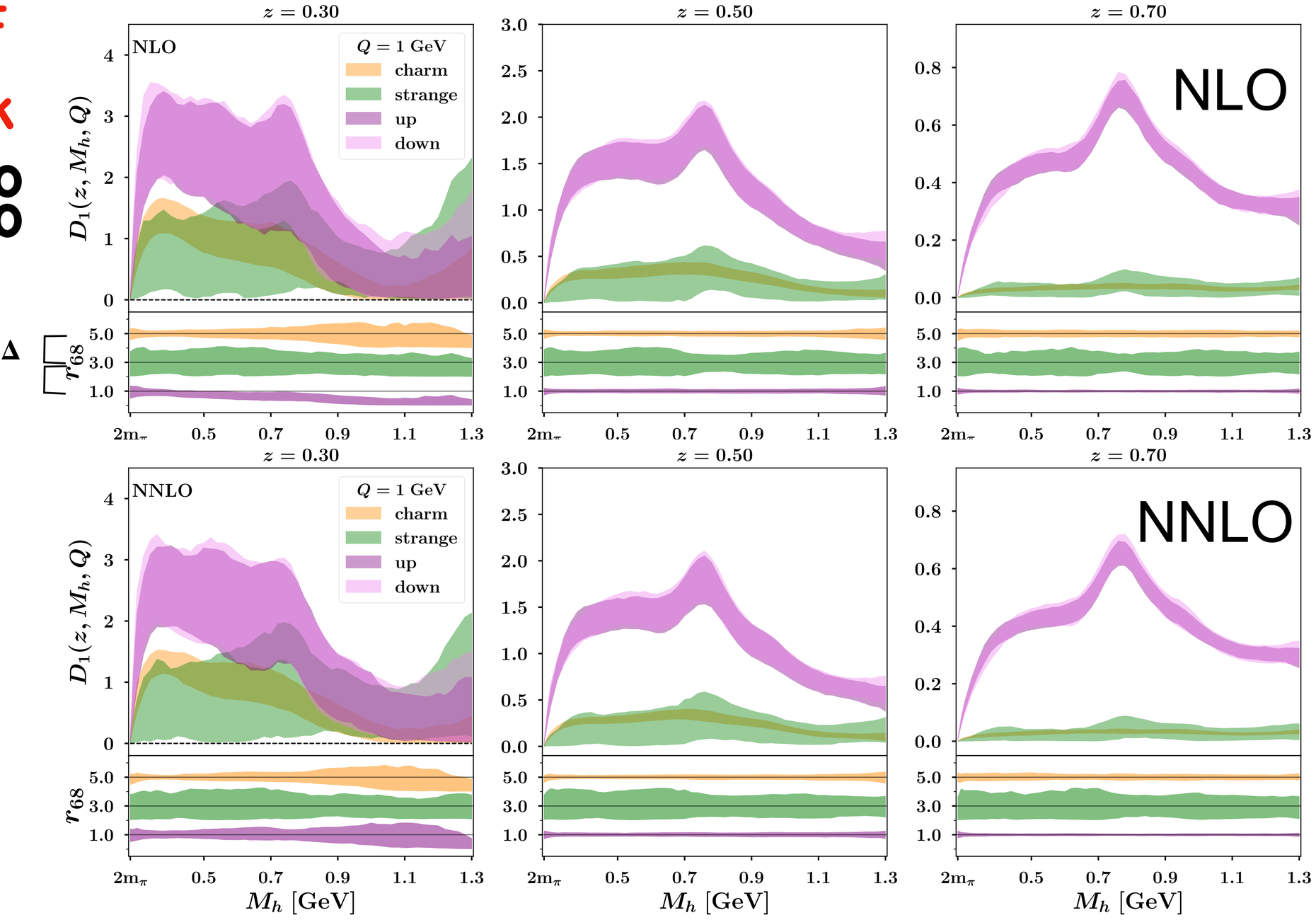
ratio offset Δ = 2.5



DI-HADRON FF
Neural Network

$\mathbf{u \neq d}$

ratio offset Δ = 2.5



Comparison at NNLO:

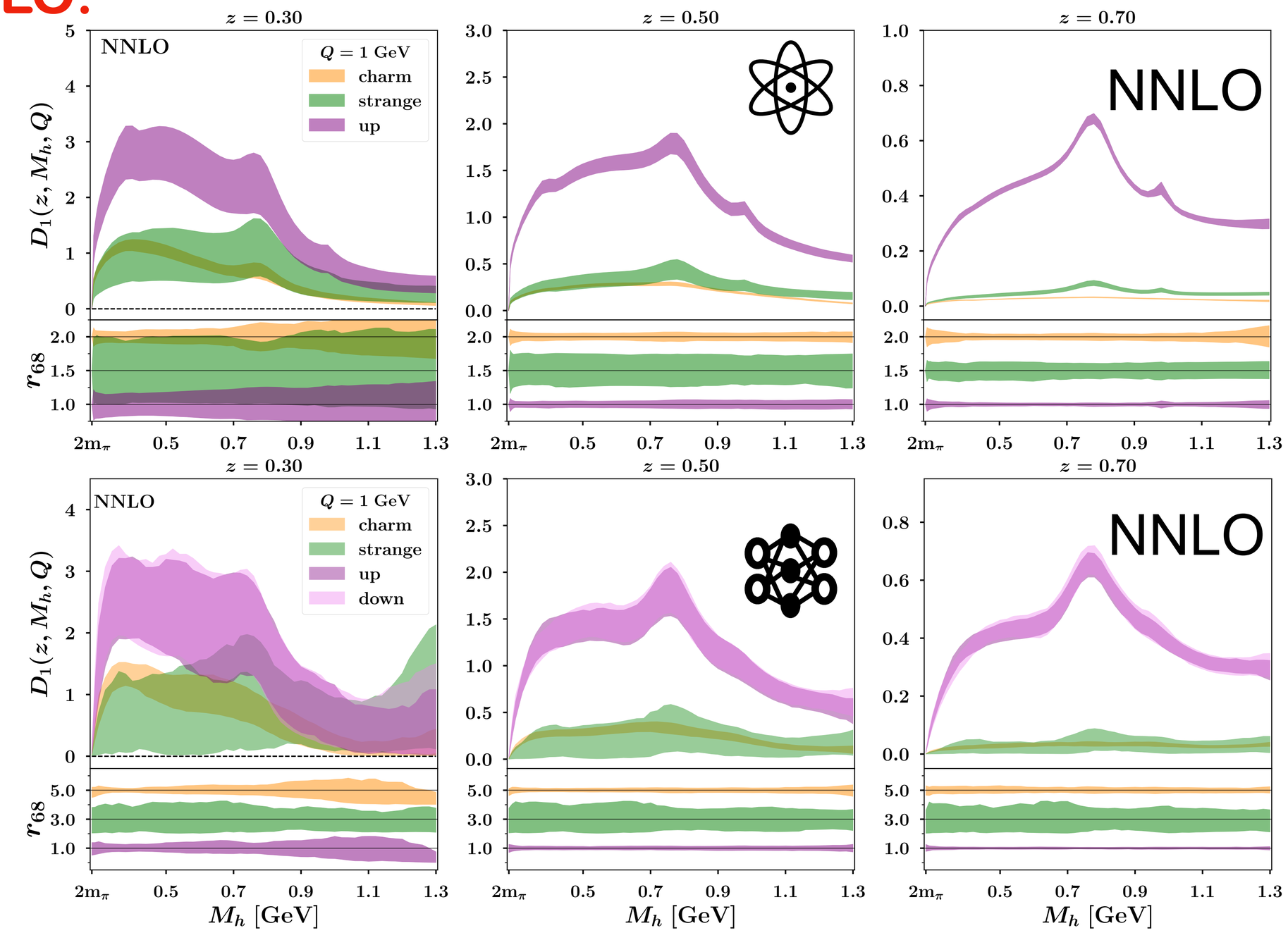
vs

Similar features and compatible results

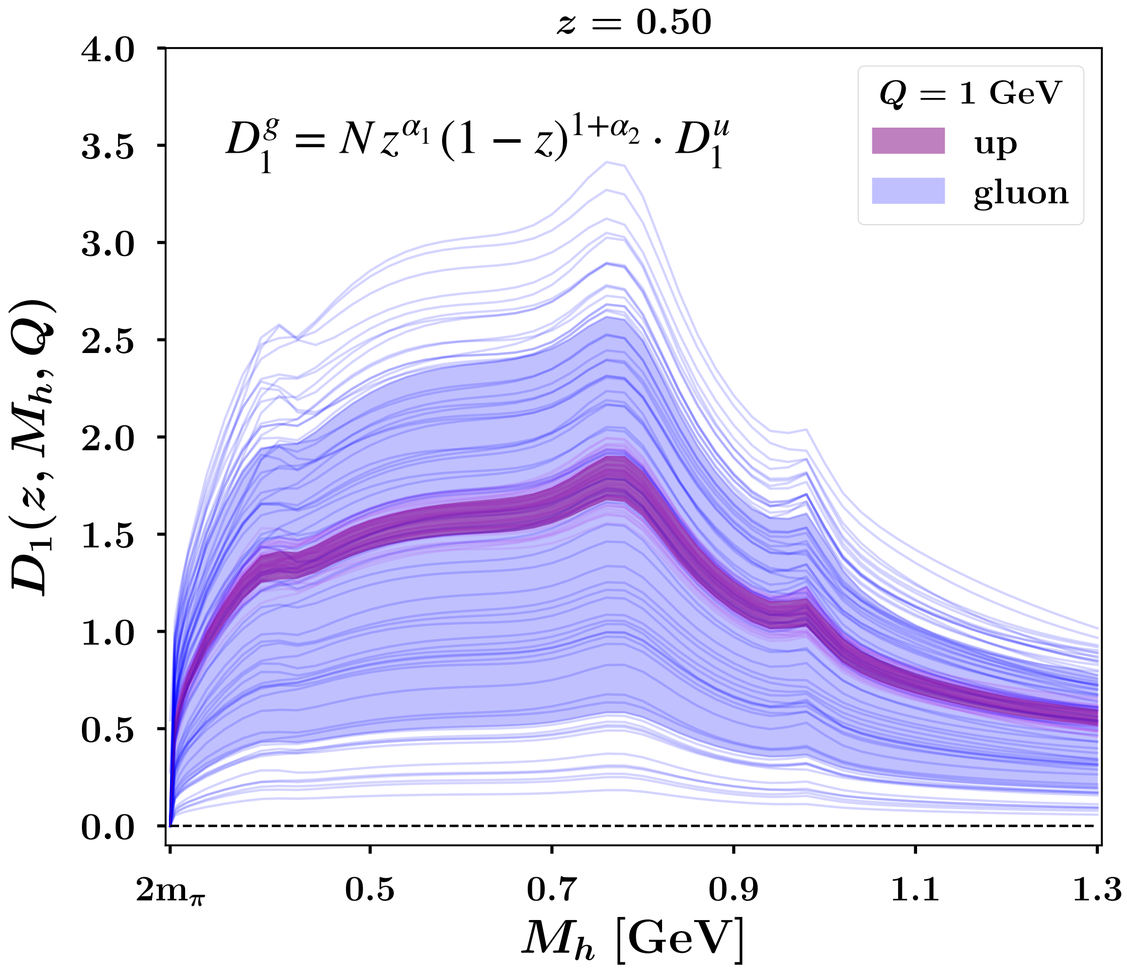
NN has wider uncertainty bands

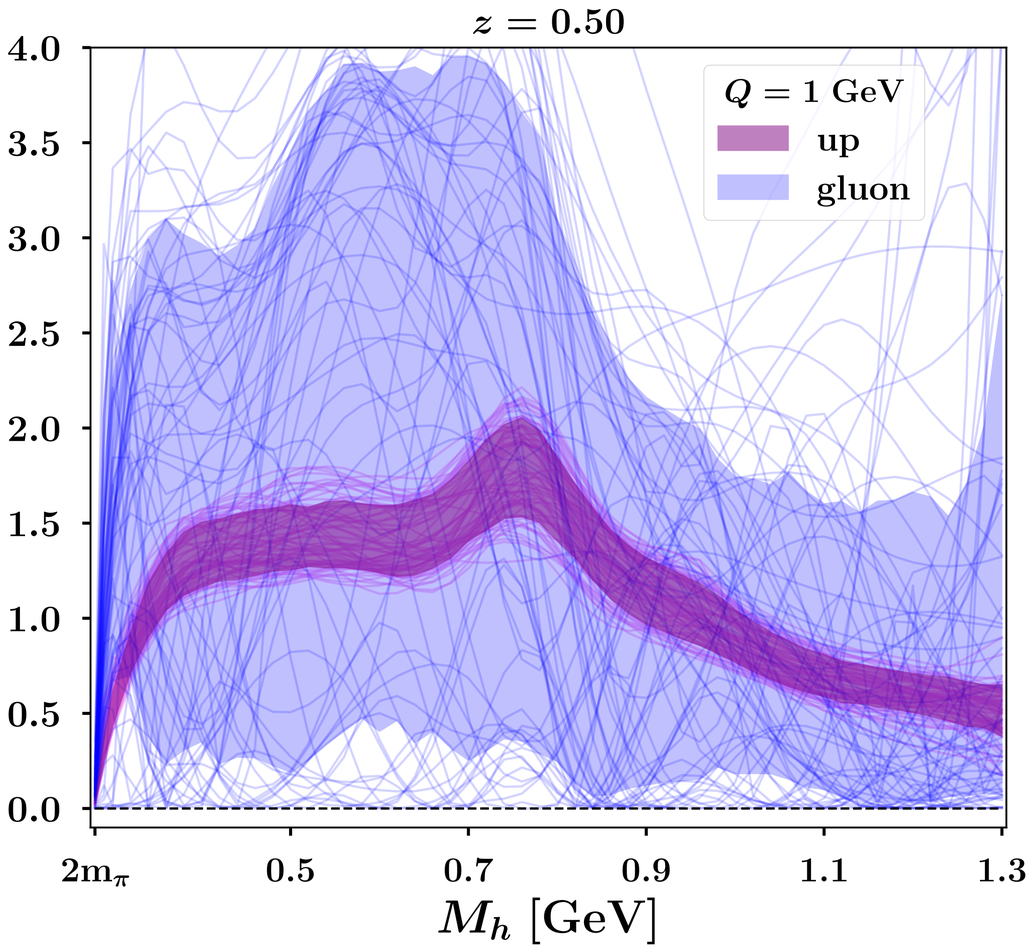
Resonances are better captured by the P.I. fit

Gluon?



Gluon and up bands at NNLO





CONCLUSIONS AND OUTLOOKS

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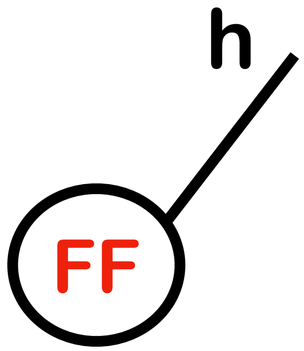
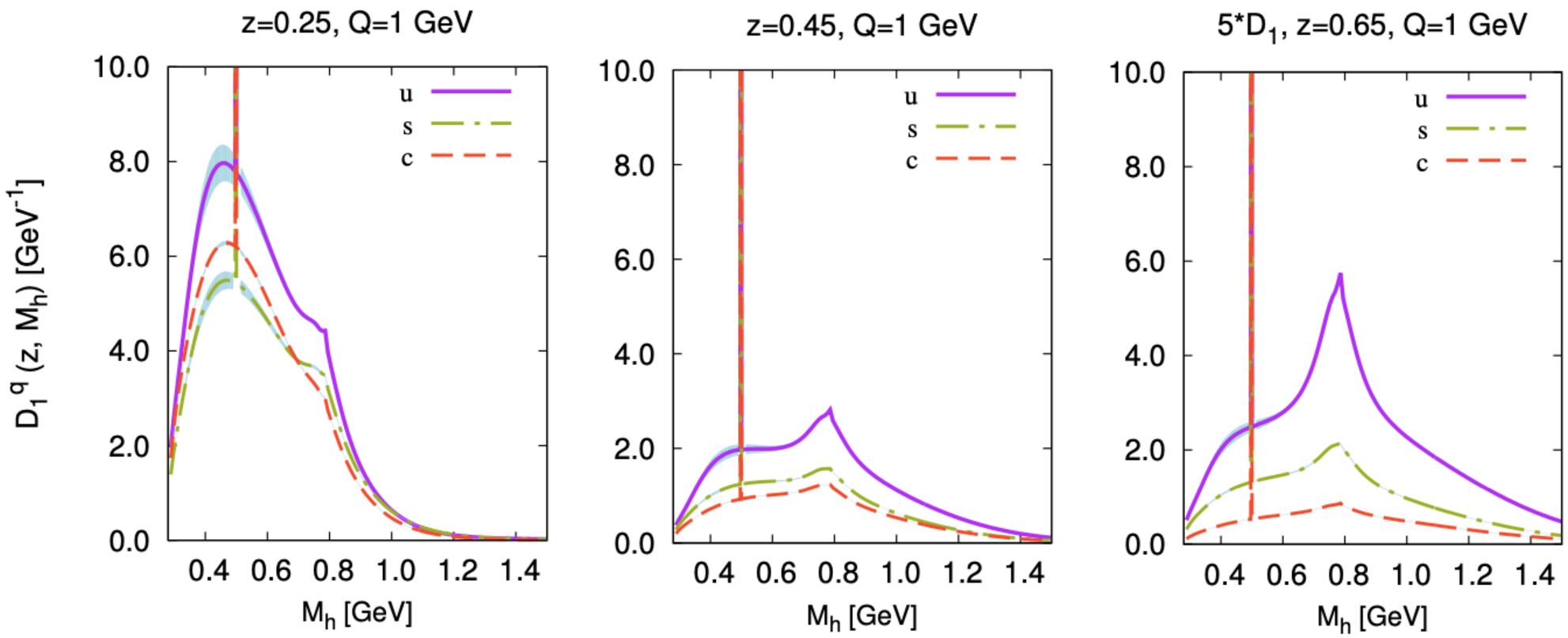
1 measured hadron+ X



$$A_{UT}^{h} \sim \frac{\sum_q e_q^2 \cdot h_1^q(x_B, k_T) \otimes H_1^{\perp,q}(z, p_\perp)}{\sum_q e_q^2 f_1^q(x_B, k_T) \otimes D_1^q(z, p_\perp)}$$

2012 extraction by Pavia group



A.Bacchetta, M.Radici, A.Bianconi, A.Courtoy, Phys. Rev. D 85, (2012) 114023

Fit of MonteCarlo simulation

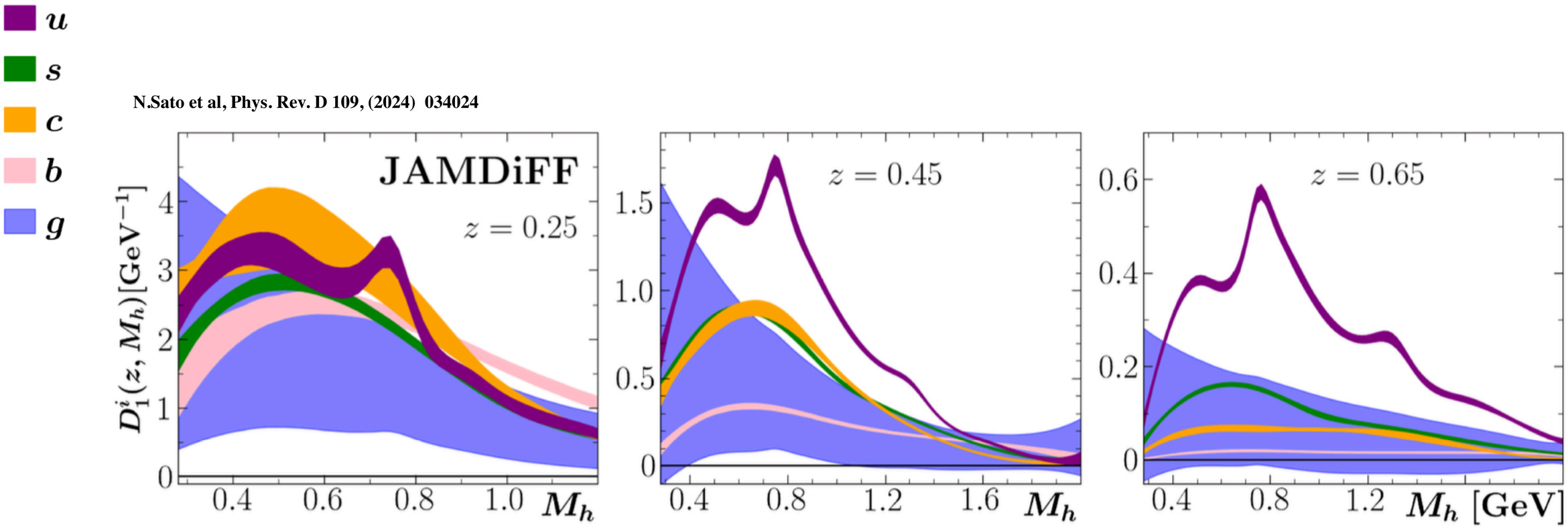
79 free parameters

LO

2017 BELLE data of $e^+e^- \to \pi^+\pi^- X$ at $\sqrt{S} = 10.58$ GeV

Latest extraction:

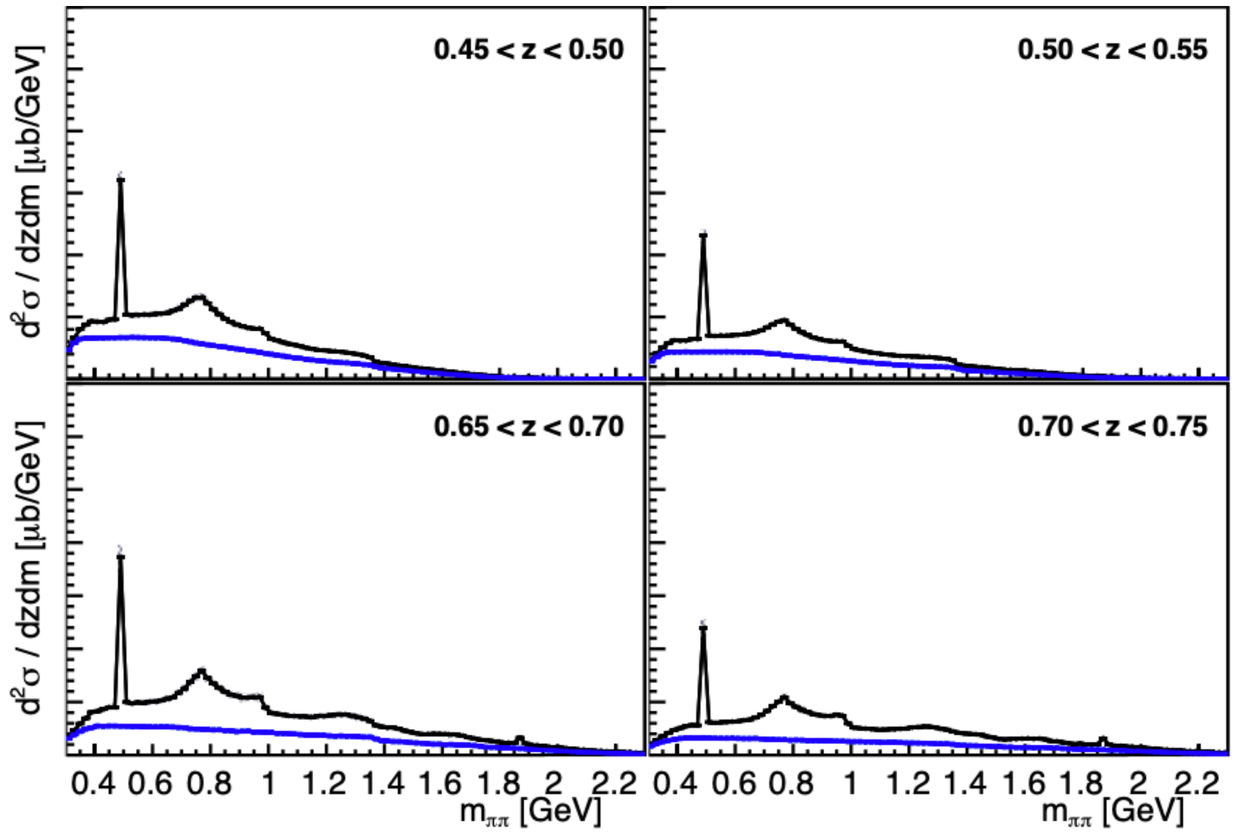
+ MonteCarlo simulation **LO**



Flavour analysis

Physical review D 96 (2017)
R.Siedl et al

$$\frac{d\sigma}{dz dM_h dQ^2} = \frac{4\pi\alpha^2}{Q^2} \sum_q e_q^2 D_1^q(z, Mh, Q) =$$



Flavour analysis

$$\frac{d\sigma}{dz dM_h dQ^2} = \frac{4\pi\alpha^2}{Q^2} \sum_q e_q^2 D_1^q(z, Mh, Q) = \frac{4\pi\alpha^2}{Q^2} \mathbf{D(z, Mh, Q)}$$

Need of extra information → **Monte Carlo**

$$\mathbf{R_u^{MC}} = \frac{\mathbf{D_{MC}^u(z, M_h, Q)}}{\mathbf{D_{MC}(z, M_h, Q)}}$$

→ **Build 4 pseudo-dataset**

$$\boxed{\mathcal{F}^u(z, M_h; Q^2) = \frac{4\pi\alpha^2}{Q^2} \mathbf{D(z, M_h, Q)} \times \frac{\mathbf{D_{MC}^u(z, M_h, Q)}}{\mathbf{D_{MC}(z, M_h, Q)}}}$$

$$\mathcal{F}^q$$

$$q = u, d, s, c$$

DI-HADRON FF
Physics informed

u=d

gluon assumptions

$$D_1^g(z, M_h; Q^2) = N z^{\alpha_1} (1-z)^{1+\alpha_2} \cdot D_1^u(z, M_h; Q^2)$$

N random unif. in (0,2)

α_1, α_2 random unif. in (0,1)