Di-hadron study using CLAS12 Spectometer

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Open questions in the nucleon structure

The simple model considering only 3 valence quarks moving longitudinally is not enough to explain the experimental observations.

- Only a small part(<2%) of the mass is due to the bare mass of the quarks, most of it is build up from dynamical processes.

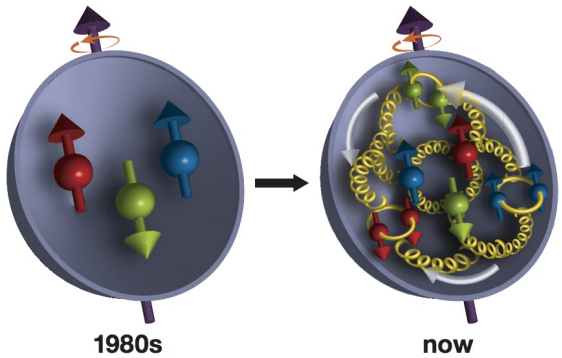
- Spin of the proton is not explained only in terms of quarks spin (spin crisis), contribution from sea quarks and orbital angular momentum is crucial.

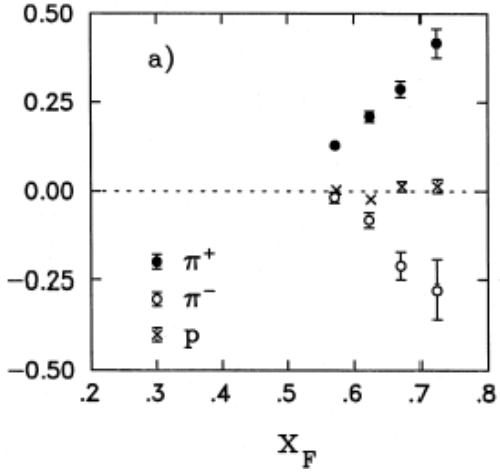
$$\frac{1}{2}\left(\Delta\Sigma_v+\Delta\Sigma_s\right)+\Delta G+L_g=\frac{1}{2}$$

- Large asymmetry observed at BNL-AGN, FermiLab ~70's

$$A_N=\frac{d\sigma^{\uparrow}-d\sigma^{\downarrow}}{d\sigma^{\uparrow}+d\sigma^{\downarrow}}$$

$$\cancel{A_N \propto \frac{m_q}{E}\alpha_s}$$





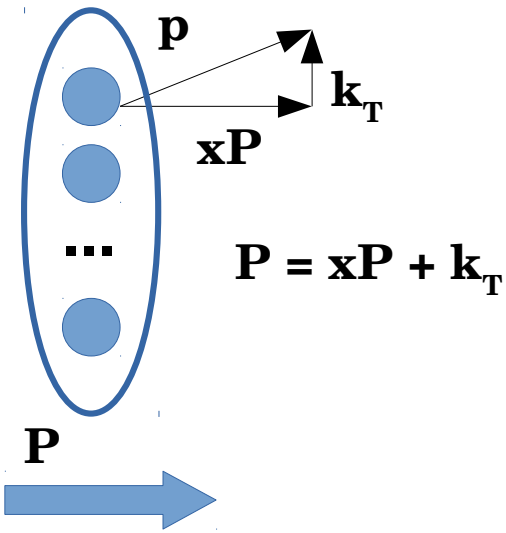
How to study the nucleons

Perturbative QCD calculations are not possible in the region ~ 1-10GeV

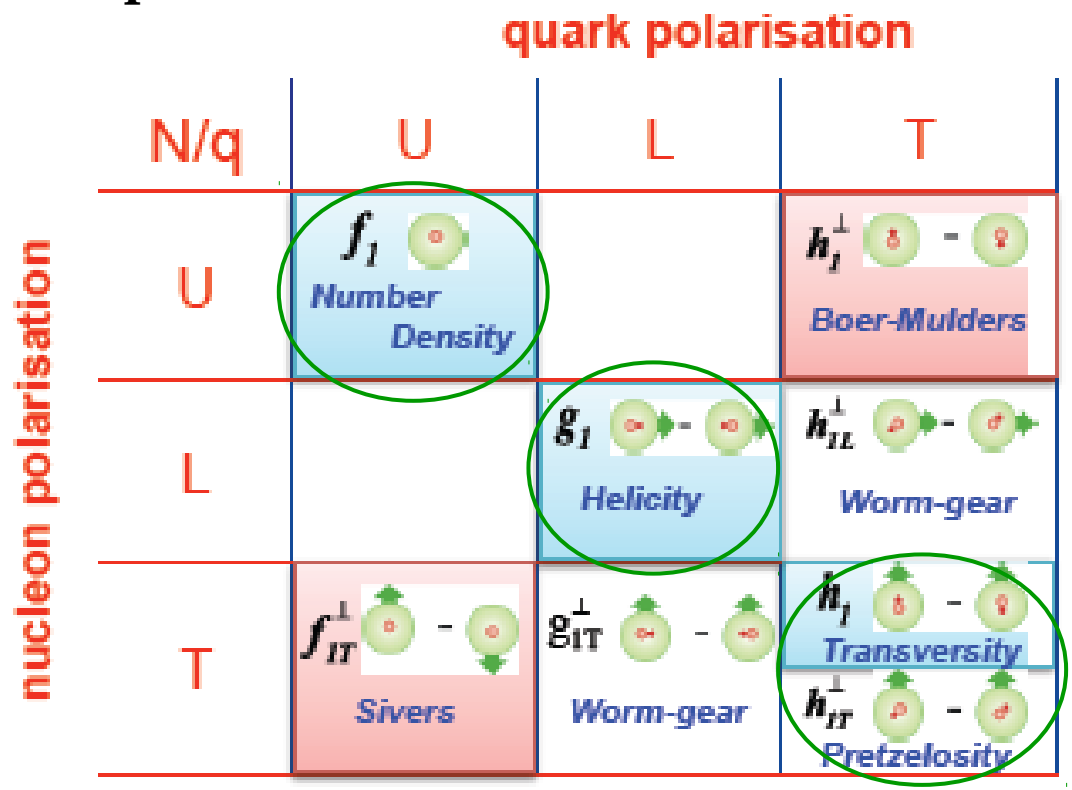
To model the quarks inside the nucleons we use mathematical objects called parton distribution functions.

Transverse momentum dependent (TMD) DF

Taking into account the transverse motion of partons, we can include the orbital angular momentum



Complex dependency. To do evolution is possible including non-perturbative calculations. Comparison between different experiments.



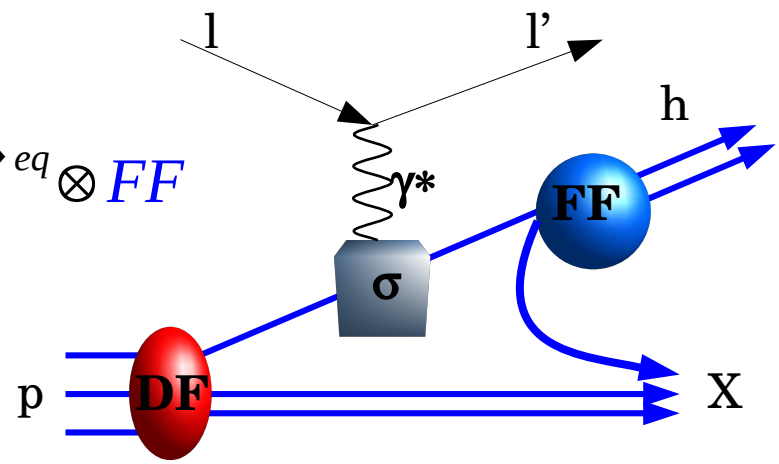
3D picture of partons inside the nucleons.
Mostly unknown.

How can we measure TMDs?

Only diagonal survive integration over transverse momentum

Semi inclusive deep inelastic scattering (SIDIS)

$$\sigma^{ep\to ehX} = \sum_q DF \otimes \sigma^{eq\to eq} \otimes FF$$



TMDs can be measured only if we tag the quark in the final state.

$$\frac{d\sigma}{d\phi} \propto F_{UU} + \cos(2\phi) F_{UU}^{\cos(2\phi)} + \frac{1}{Q}\cos(\phi) F_{UU}^{\cos(\phi)} + \lambda \frac{1}{Q}\sin(\phi) F_{LU}^{\sin(\phi)} + \cdots$$

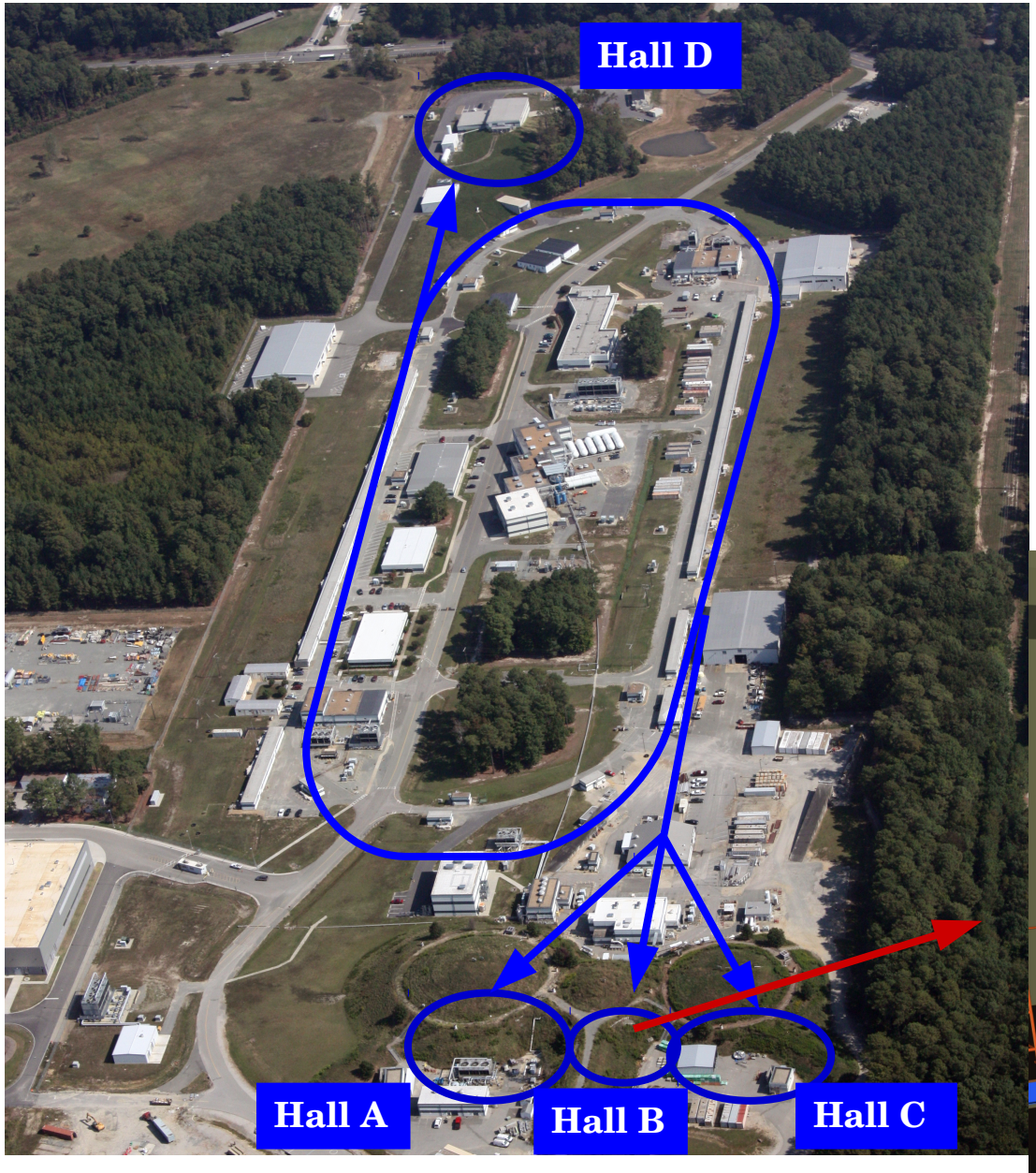
The structure functions contains convoluted TMD DF and TMD FF over transverse momentum and summed over quark flavors. They are universal.

- From σ_{tot} → unpol. SF
- From asymmetries → pol. SF ($A_{LU} \sim F_{LU}/F_{UU}$, ...)

The unpol. SF are needed for the extraction of pol. SF

JLab physics program is mainly devoted to SIDIS experiments

JLab



Forward Detectors:

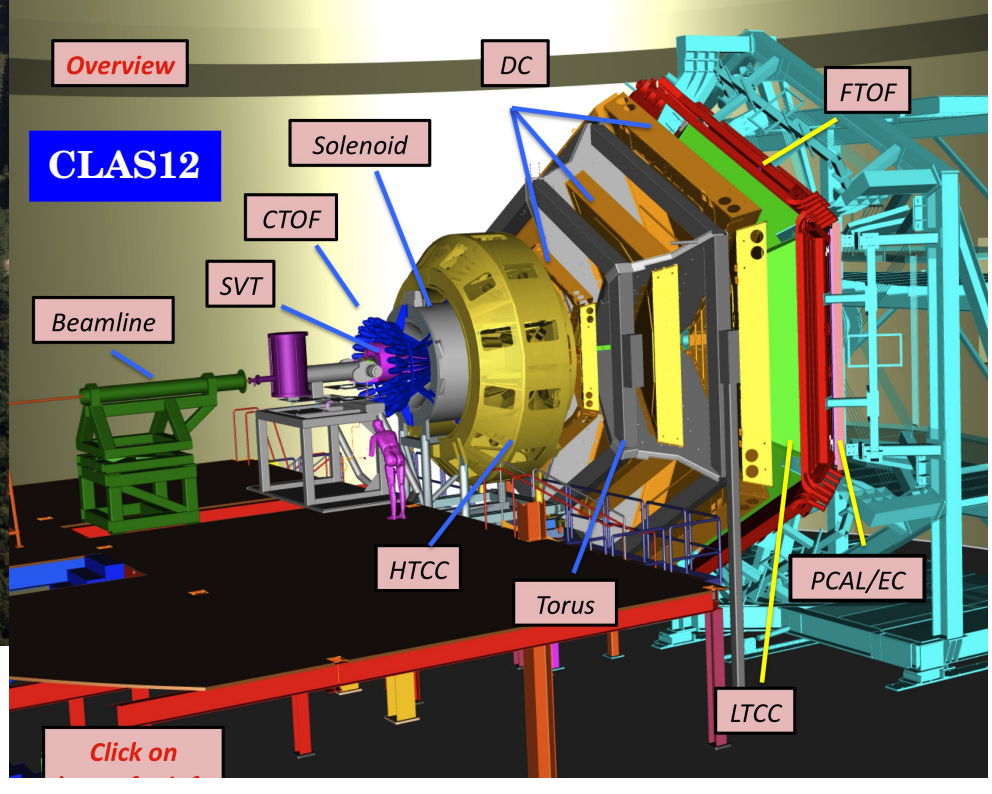
- *TORUS magnet*
- *HT Cherenkov Counter*
- *Drift chamber system*
- *LT Cherenkov Counter*
- *Forward ToF System*
- *Preshower calorimeter*
- *E.M. calorimeter (EC)*
- *RICH detector*
- *Forward Tagger*

Central Detectors:

- *SOLENOID magnet*
- *Barrel Silicon Tracker*
- *Central Time-of-Flight*
- *Micromegas*
- *Neutron detector*

Targets:

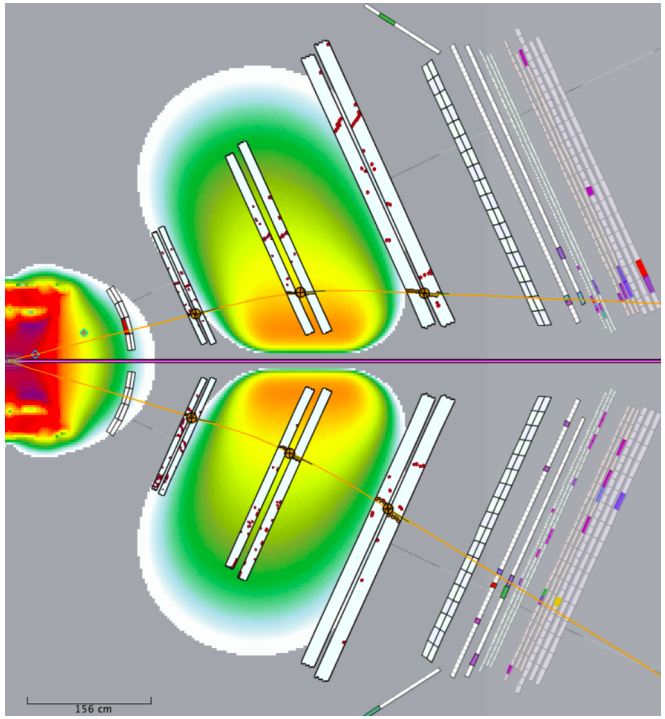
- **Unpolarized: LH, LD_2**
- **Long. Pol.: NH_3, ND_3**
- **Trans. Pol.: HD-Ice**



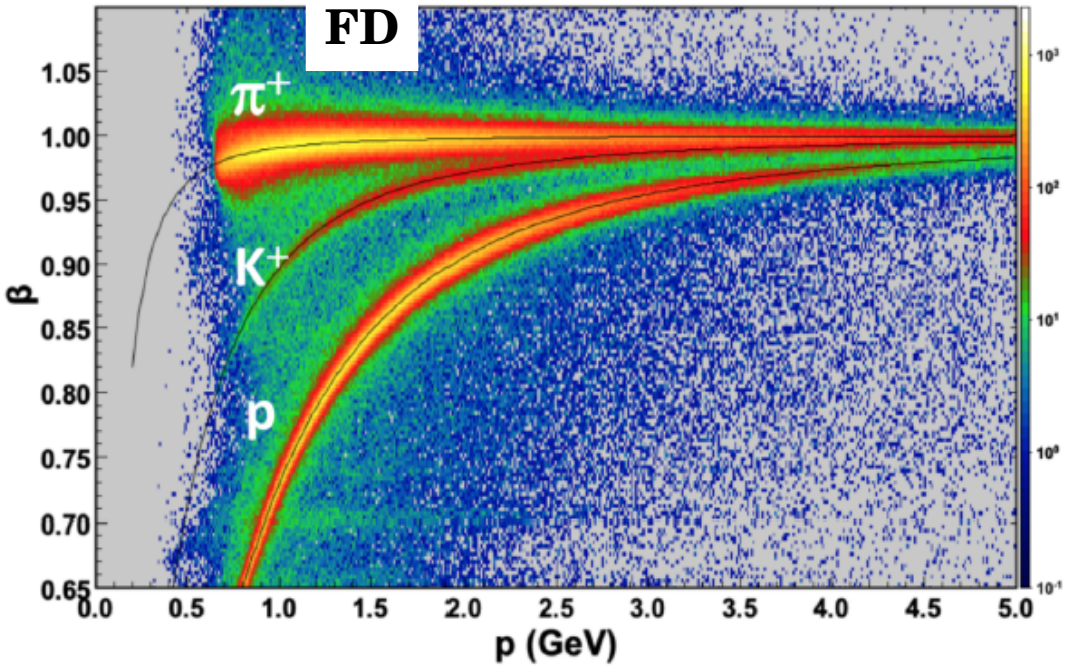
CLAS12 Capabilities

The Clas colaboration, NIMA vol. 959, pp 163419, 2020

Event based trigger



The Clas colaboration, NIMA vol. 959, pp 163419, 2020



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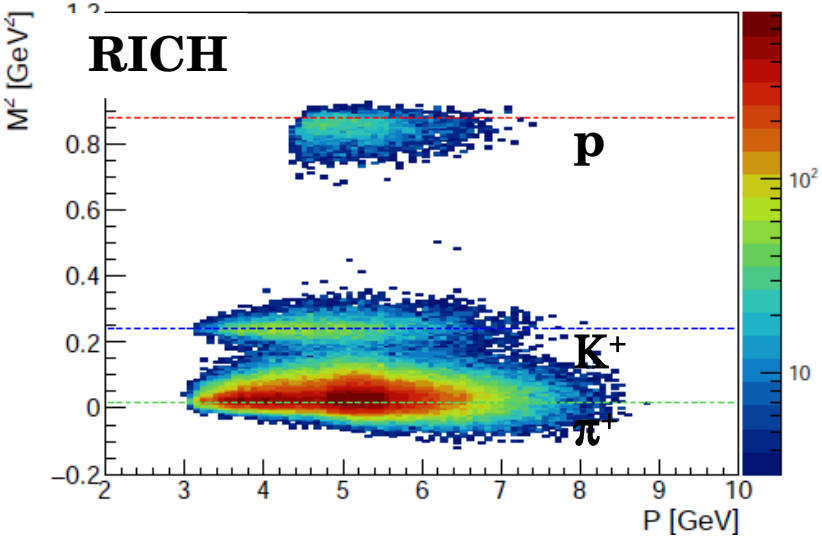
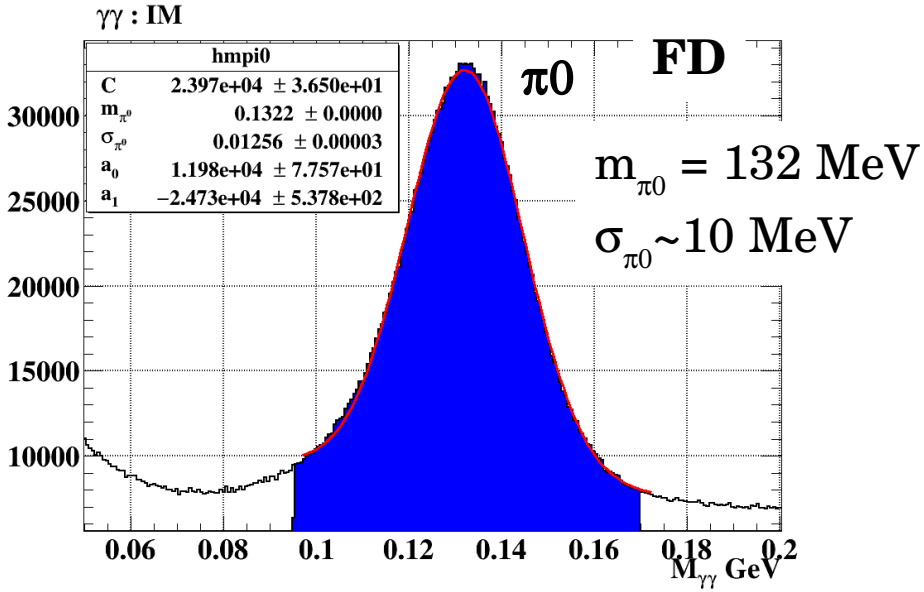




CLAS12 SIDIS program

Currently ongoing analysis on:

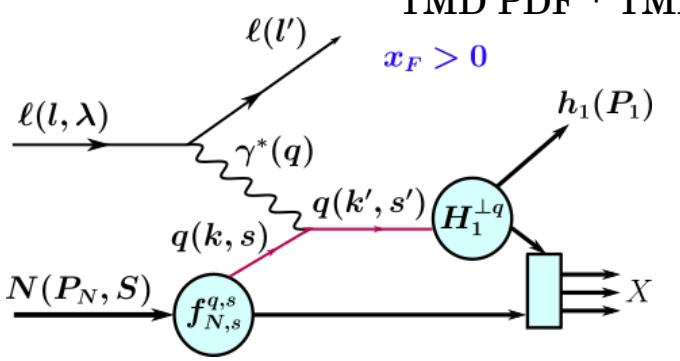
- Single hadron BSA and multiplicities on: π^+, π^-, π^0, K^+, K^-
- Di-hadron BSA and Multiplicities on: $\pi^+\pi^-$, $\pi^+\pi^0$, $\pi^-\pi^0$, K^+K^-, πK, …

On different targets: unpol. LH and LD_2

Preliminary analyses on BSA for single hadron π^+ and di-hadron $\pi^+\pi^-$ has been shown

Single hadron

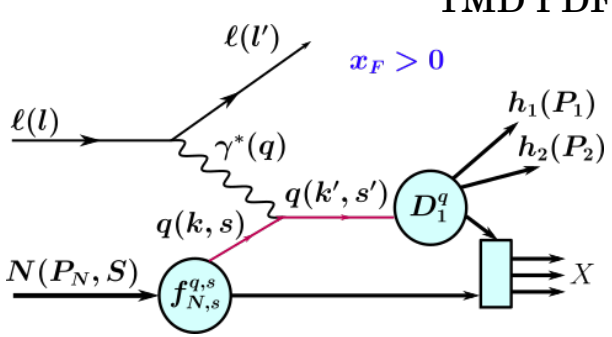
TMD PDF * TMD FF



Integration over transverse momentum require model assumptions

Di-hadron

TMD PDF x TMD FF

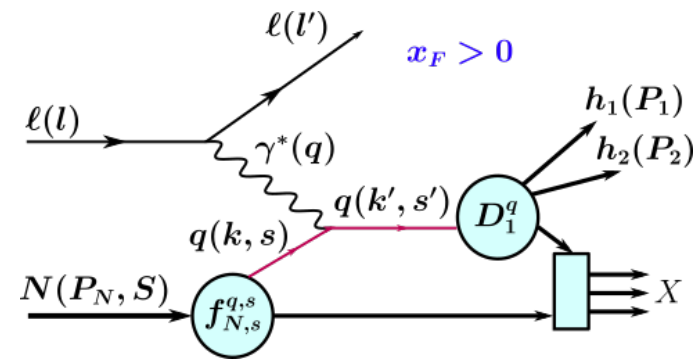


Integration on transverse momentum results in products

Multiplicity measurement

The cross section of the Di-hadron lepto production can be studied through the measurement of the Multiplicities:

$$\mathcal{M}(z, Q2, x, M_{hh}) = \frac{d\sigma^{dh}/dx_B dQ^2 dz\, dM_{hh}}{d\sigma_e^{DIS}/dx_B dQ^2}$$



From the experimental point of view

$$\mathcal{M}(z, Q2, x, M_{dh}, p_T) = \frac{N^{dh}(z, Q2, x_B, M_{dh}, p_T)/(\Delta x_B \Delta Q^2 \Delta z \Delta M_{dh} \Delta p_T)}{N_e^{DIS}(Q2, x)/(\Delta x_B \Delta Q^2)}$$

In TMD frame work we have:

$$\mathcal{M}(z, Q2, x, M_{dh}, p_T) \propto \frac{\sum_q e_q^2 x_B f_1^q(x_B) \boxed{D_1^q(z, M_{dh}, \cos(\theta), p_T)}}{\sum_q e_q^2 x_B f_1^q(x_B)}$$

K_f : is a kinematic factor

f_1 : are the well known collinear PDF

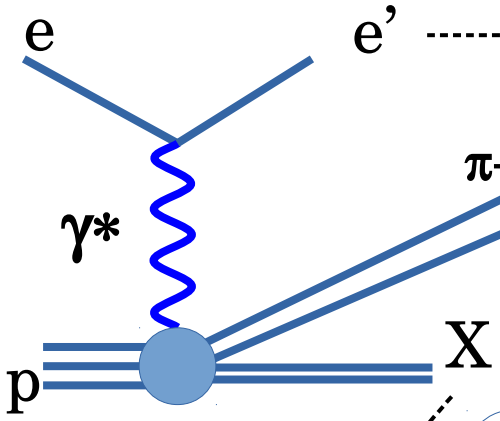
From the Multiplicity we can extract D_1 using proton and Deuteron targets:

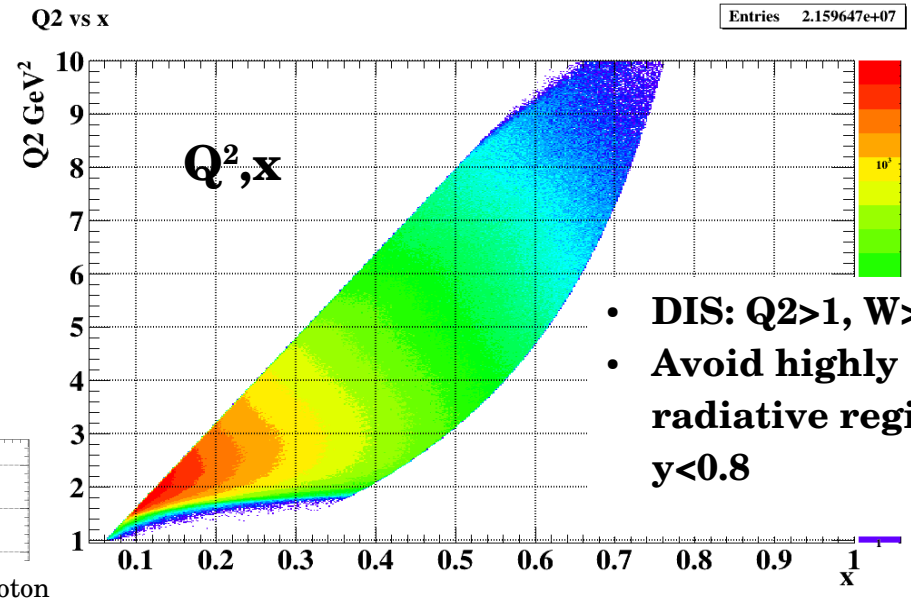
$$D_1^u = 3\frac{\mathcal{M}^{(p)}\left(\frac{4}{9}f_1^u + \frac{1}{9}f_1^d\right) - \frac{1}{9}\mathcal{M}^{(d)}\left(f_1^u + f_1^d\right)}{K_f f_1^u}$$

$$D_1^d = 3\frac{\frac{4}{9}\mathcal{M}^{(d)}\left(f_1^u + f_1^d\right) - \mathcal{M}^{(p)}\left(\frac{4}{9}f_1^u + \frac{1}{9}f_1^d\right)}{K_f f_1^d}$$

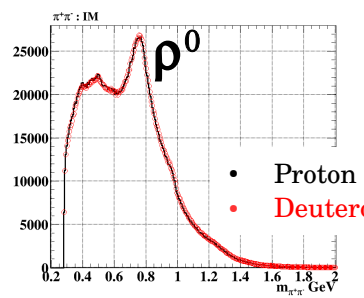
Kinematics

- Events: **eN→ eπ+π-X**
- We apply kinematics cuts to ensure current fragmentation region, such as x_F>0 and minimum z

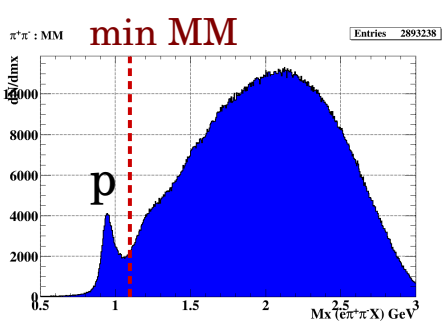


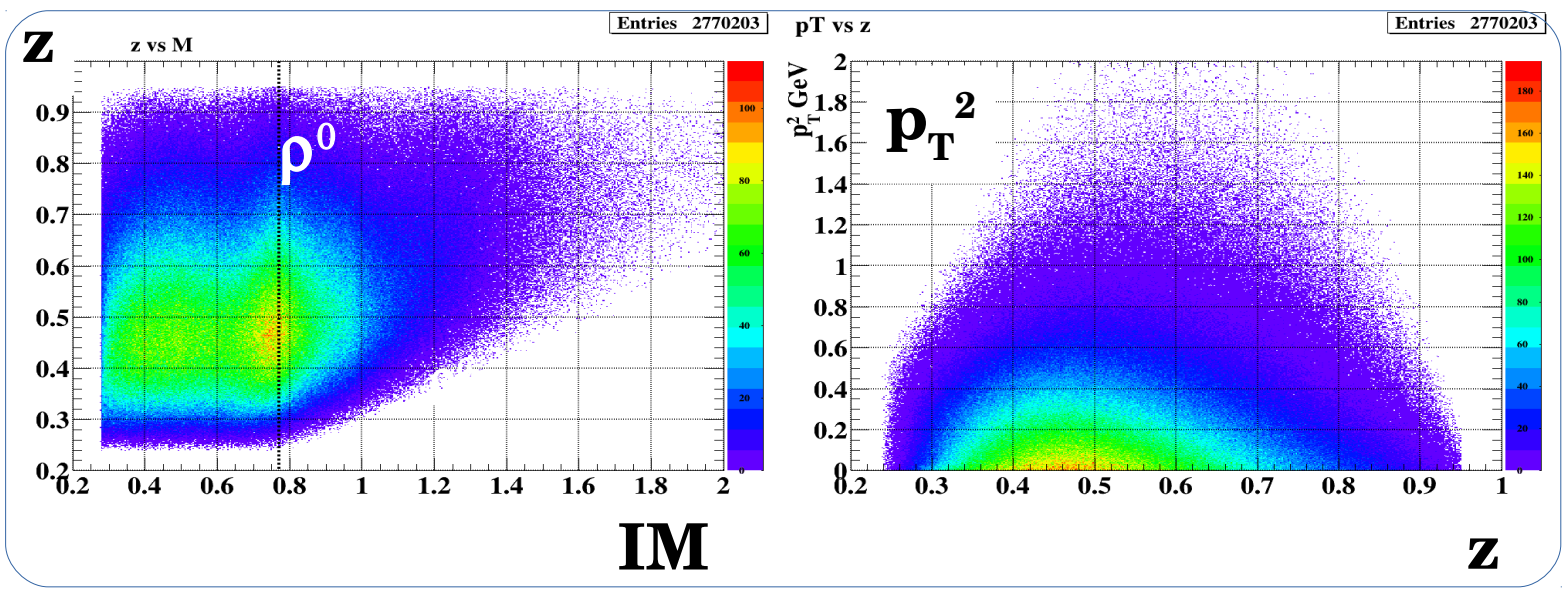


- **DIS: Q2>1, W>2**
- **Avoid highly radiative region: y<0.8**



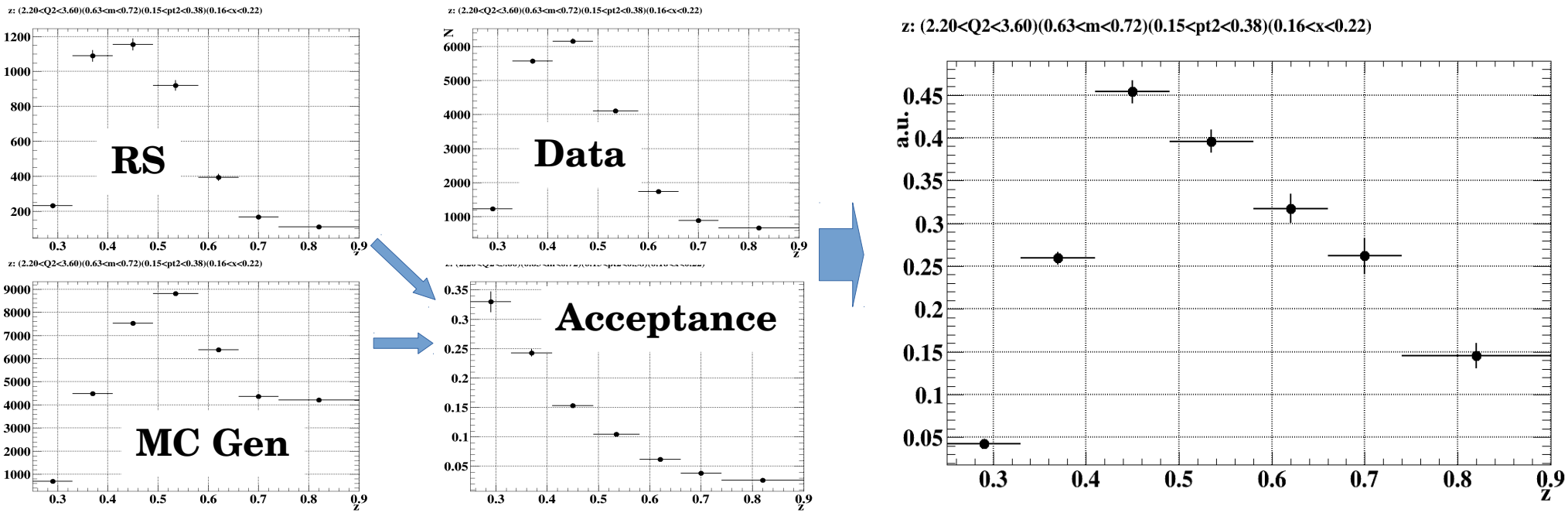
- Proton
- Deuteron





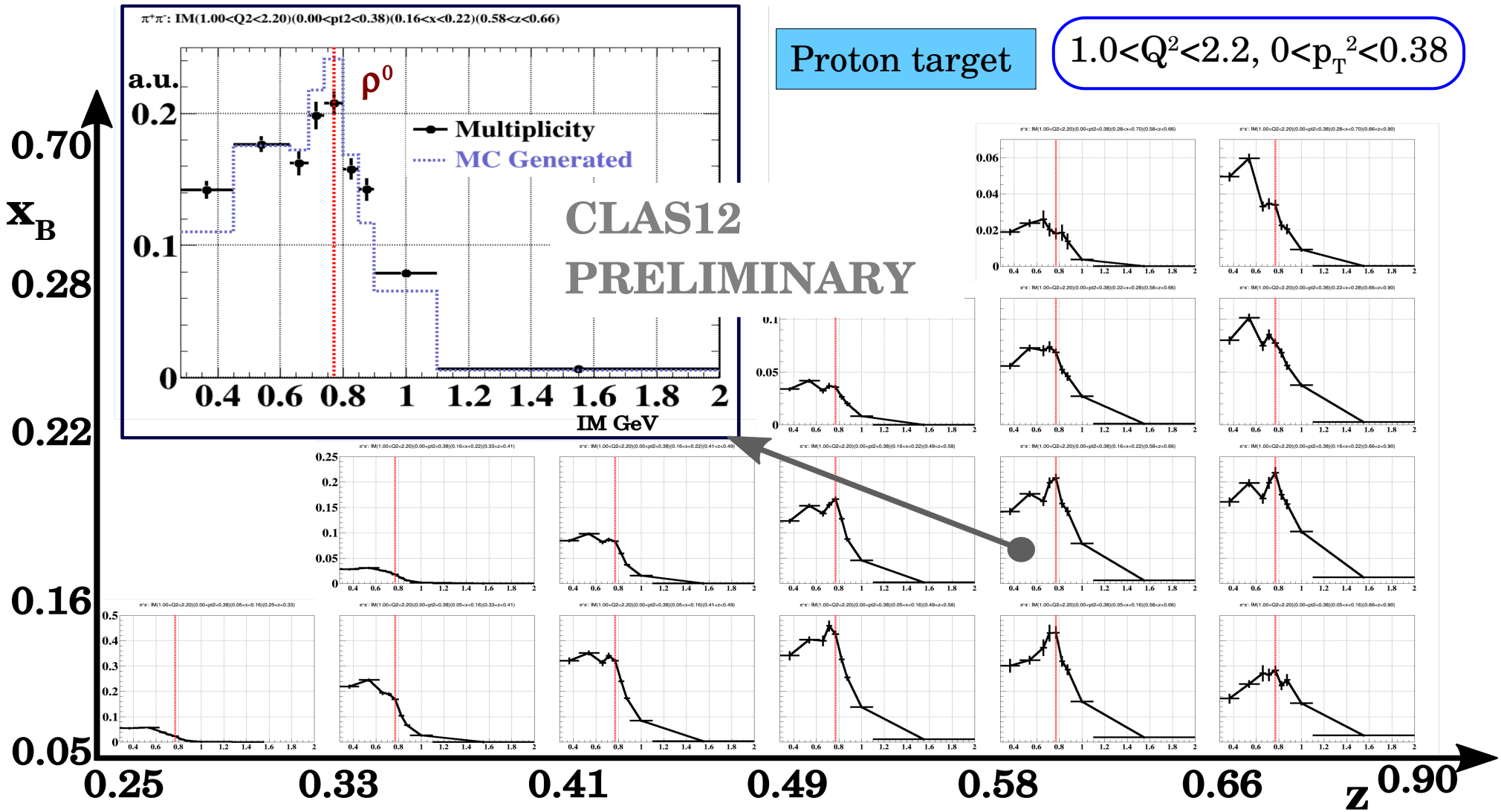
Multiplicity extraction

The number of hadron pairs is registered for data, MC Gen. and RS (reconstructed simulation), in each (Q^2,x,z,m,p_T^2) bin



$$\mathcal{M}(z, Q2, x, M_{dh}, p_T) = \frac{\frac{N^{dh}_{data}}{A^{e\pi^+\pi^- X}} / (\Delta x_B \Delta Q^2 \Delta z \Delta M_{dh} \Delta p_T)}{\frac{N^{DIS}_{e}}{A^{eX}}(Q2, x) / (\Delta x_B \Delta Q^2)}$$

Multiplicity, 5D



CLAS12 can measure the dihadron ($\pi^+\pi^-$) multiplicity in a wide kinematic range.

Conclusions

- CLAS12 have collected unprecedented statistic in the SIDIS region, allowing multi dimensional SIDIS analyses of various kinds.
- Generated Monte Carlo yields used to make the acceptance corrections are consistent with the experimental data.
- The presented results on multiplicity show the wide kinematic coverage in the di-hadron SIDIS spectrum.
- The multiplicity on proton an deuteron targets will allow the extraction of the di-hadron flavored D_1.

End,
Thanks