Nucleon isovector scaling functions with 2+1 flavor Lattice QCD

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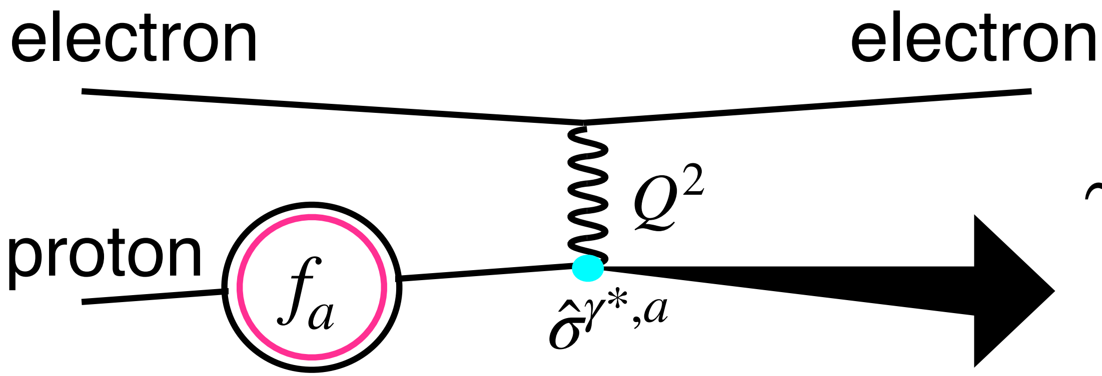
S. Sasaki, E. Shintani and T. Yamazaki
for PACS Collaboration

Nucleon structure



Factorize the cross section

$$\sim \sum_{\text{parton}\{a\}} \underline{f_a(x,\mu)} \otimes \underline{\hat{\sigma}^{\gamma^*,a}(x,\mu)}$$

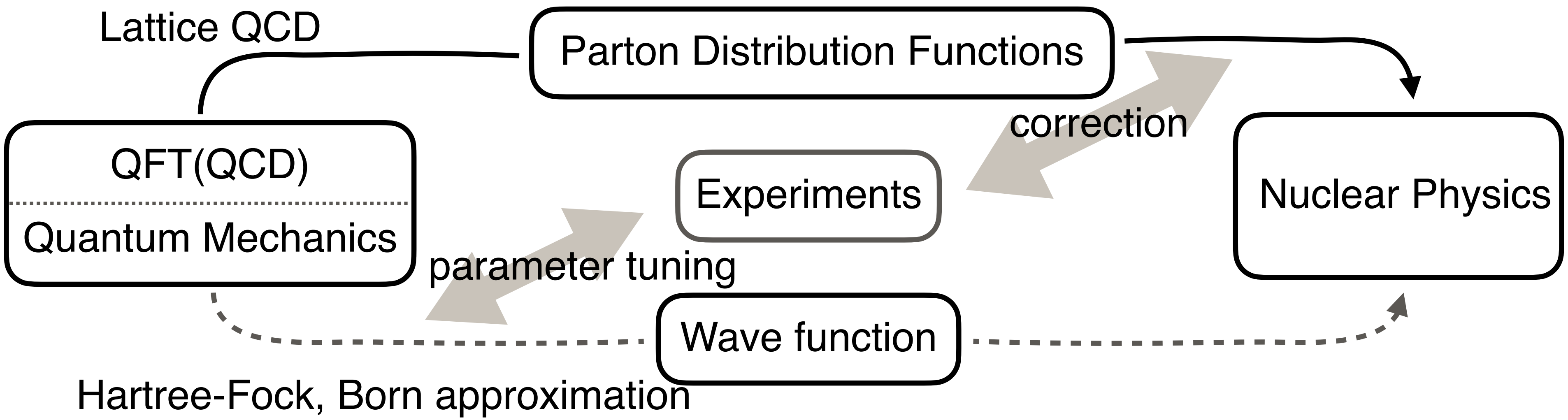
Non perturbative

in scale μ. (DIS process)

Parton Distribution Functions

Many applications of PDFs…

1. Access to small bjorken x region.
   Gluon saturation → Discovery of CGC = QGP's initial condition
2. Alternative approach to Nuclear physics.



Plans for research

Nucleon structure with LQCD toward the nuclear physics

M2	D1	D2	D3

(Benchmark calculations of PDFs)

Moments of scaling funcs. → **Parton distribution funcs.**

- **Excited state contamination**
- **Discretization error**
- **Non perturbative renormalization**
- **Renormalization respecting symmetry**

Application

- **Comparison with experiment**
- **Medium effect**

Non perturbative renormalization of PDFs

- **Operator mixing problem**
- **Relevance to Heavy quark effective theory on Lattice**
- **Comparison with traditional method**

Cleared :

On going :

I have already reported our works at

- R. Tsuji, Y. Aoki, K.-I. Ishikawa, Y. Kuramashi,S. Sasaki, E. Shintani and T. Yamazaki for PACS Collaboration, “Nucleon structure at physical point in 2+1 flavor Lattice QCD” Asia-Pacific Symposium for Lattice Field Theory (APLAT 2020), KEK, AUG 2020

and others.

Overseas training

There are 2 ways depending on the COVID-19 outbreak.

A. Long-stay (≥ 3 mos.)

→ Brookhaven National Laboratory (RIKEN-BNL)

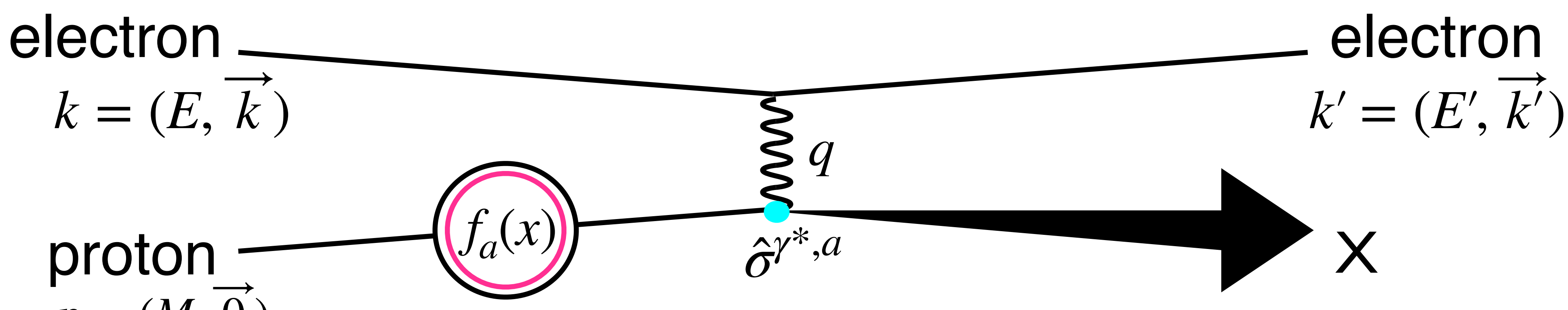
B. Conference and School (~ 1 mo. in 2021)

Conference	Time	Location	Online
Lattice 2021	26-31JUL	U.S.	✓
CIPANP 2021	1-6JUN	U.S.	※
PANIC 2021	30AUG-3SEP	Portugal	※
QNP 2021	20-24SEP	Germany	※
QCD-N 2021	4-8OCT	Spain	※
Baryons 2021	19-22OCT	Spain	※

※ There is no information yet.

BACKUPS

Deep inelastic scattering process



Parton Distribution function

◉Kinematics

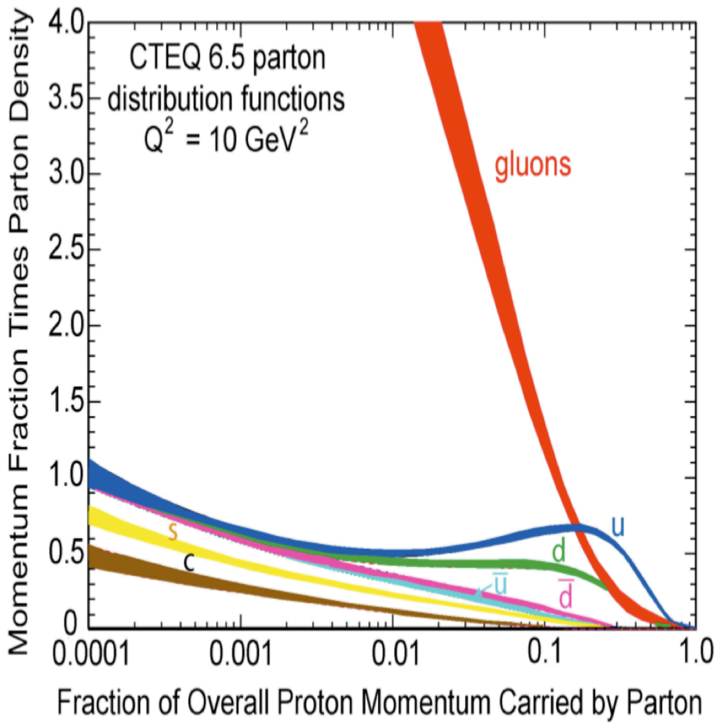
$$Q^2 = -q^2 = -(k-k')^2, \nu = \frac{p\cdot q}{M_N}, x = \frac{1}{\omega} = \frac{Q^2}{2M\nu}$$

x is regarded as fractional proton momentum carried by quark

◉Patron Distribution functions and Scaling functions

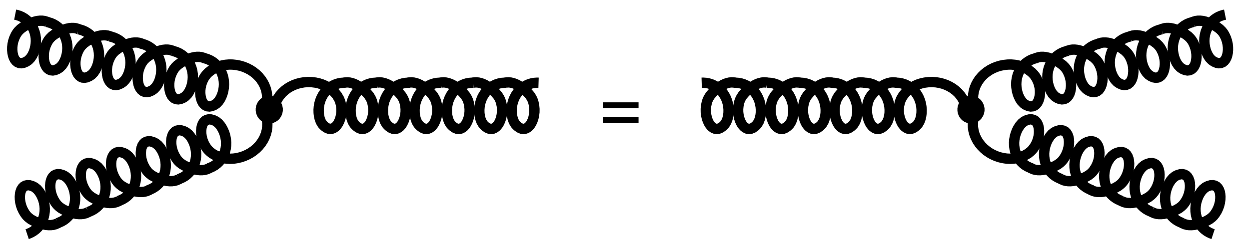
$$F_1(x) = \frac{1}{2}\sum_q e_q^2 f_q(x) \quad \& \quad g_1(x) = \frac{1}{2}\sum_q e_q^2 \left(f_{q+}(x) - f_{q-}(x)\right)$$

Gluon saturation at small Bjorken x



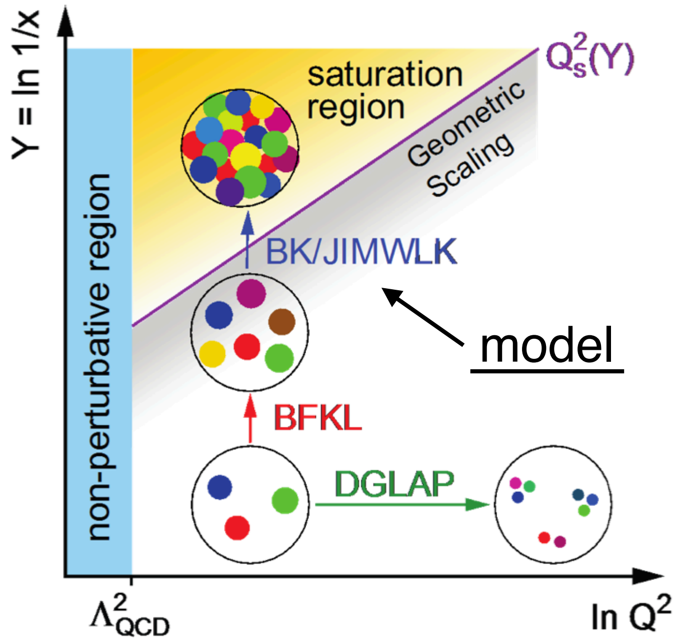
Gluon -> Massless particle

Recombination | Emission



Restrict divergence | Diverge at small x

-> SATURATION = CGC



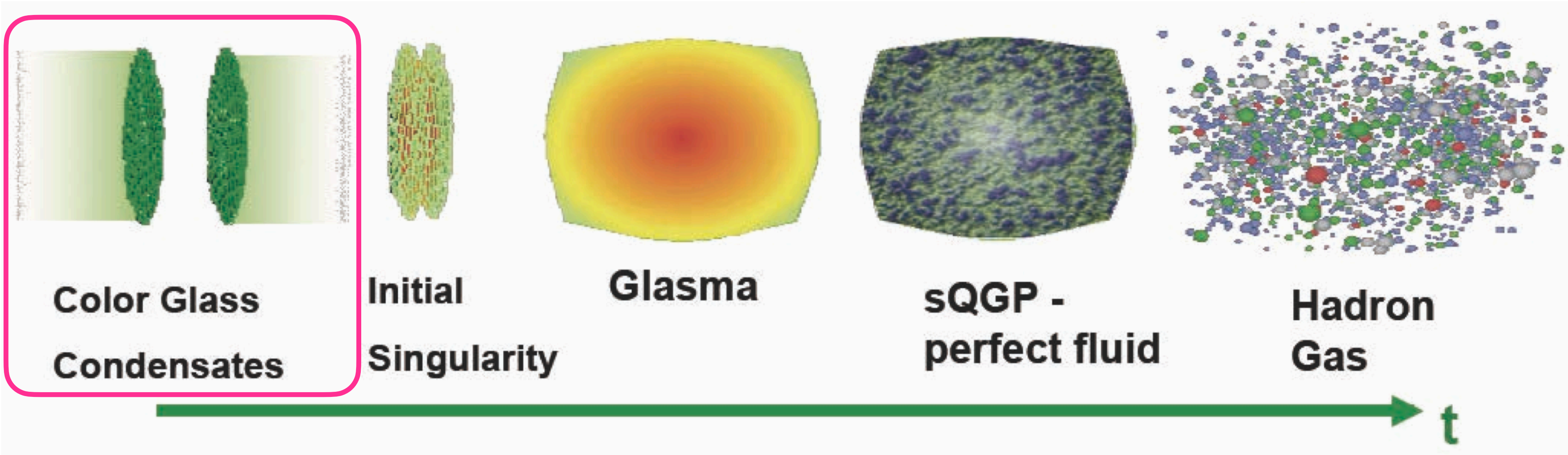
Problems

- Power of bjorken x? $\left(G(x) \sim x^{\alpha}\right)$
- Where dose the saturation occur?

Model-independent approach = LQCD

QGP's initial condition

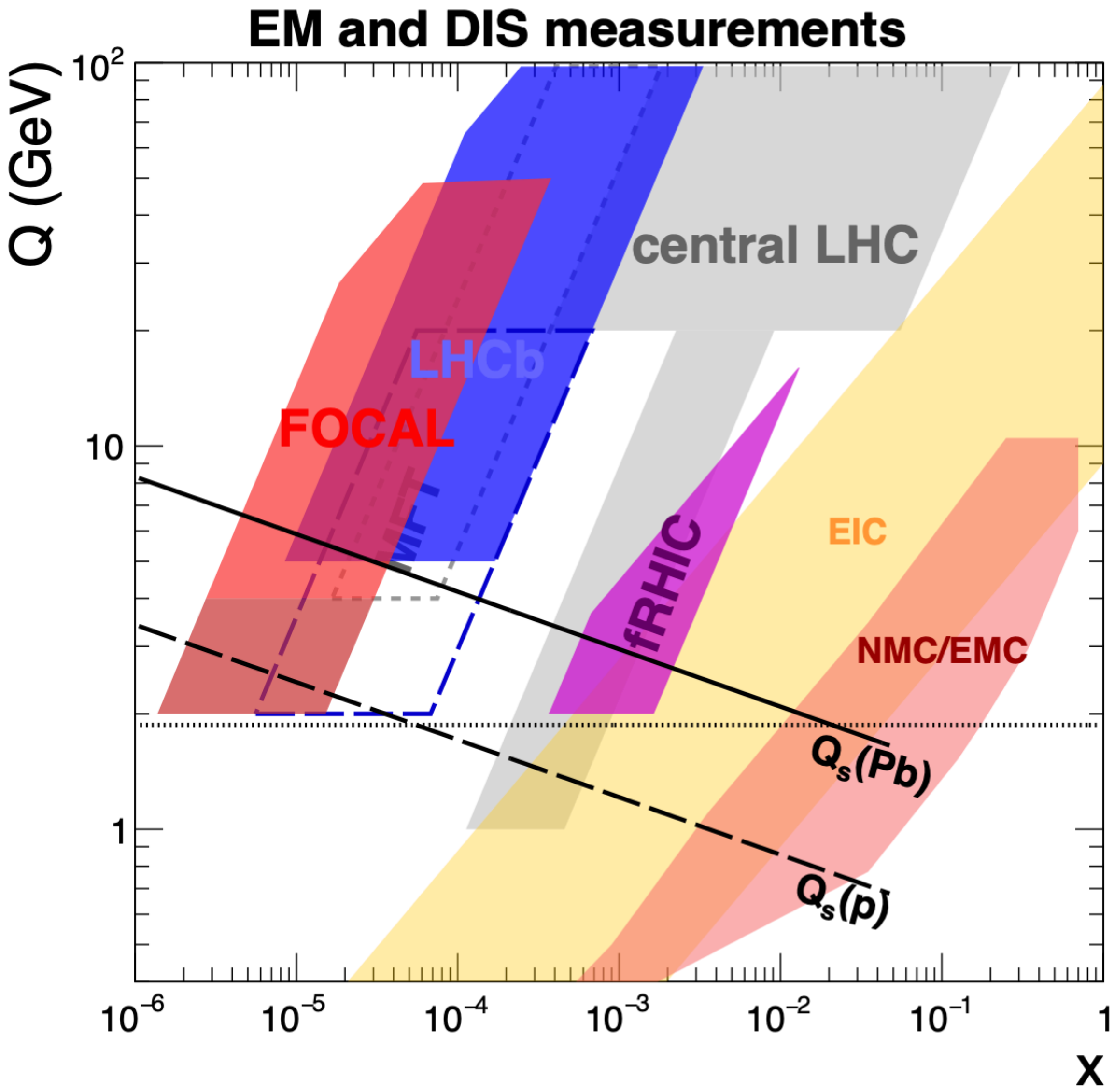
Experimental research of QGP = Relativistic heavy ion collisions



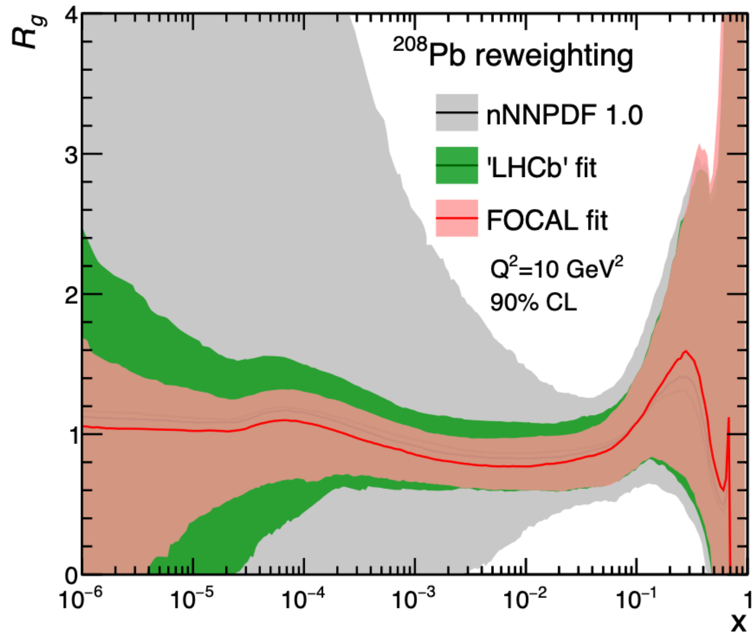
CGC is a candidate of QGP's initial condition.

However, there is NO evidence for CGC.
-> Experimental/Theoretical search is NEEDED.

Experiments for CGC & gluon PDF



e.g) FoCal ALICE @ LHC
-> RUN : 2027 ~

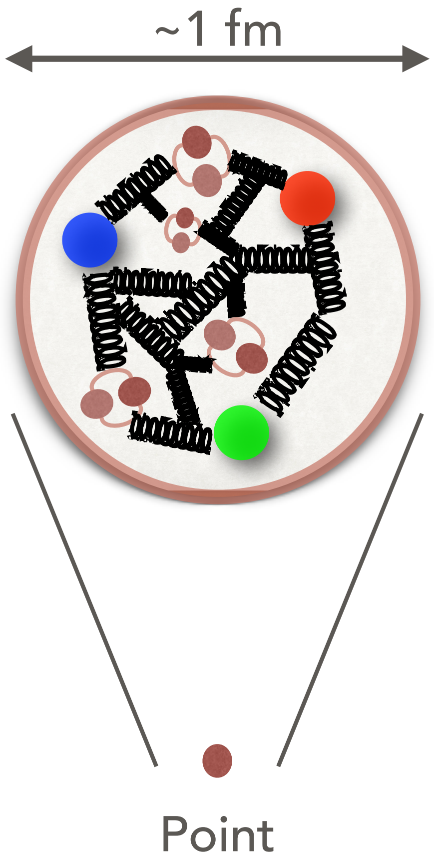


Determine gluon PDF
with less uncertainty.

Defects in historical approach

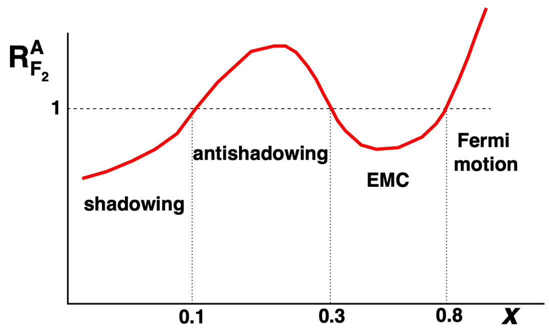
There is mainly 2 defects.

① Ignore the structure of nucleon



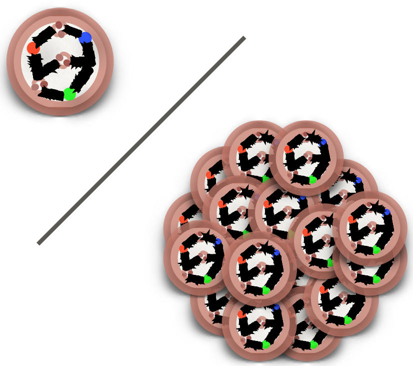
◉ Theory can't consider finite size effect

e.g.1) Nuclear shadowing effect



Collective effects?
Nucleon structure?

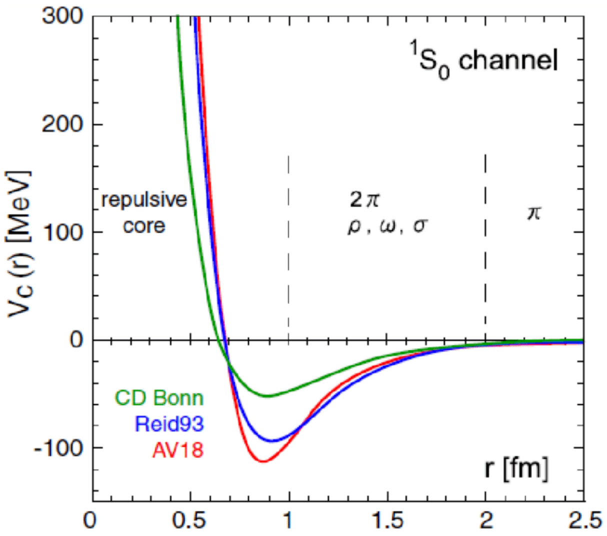
e.g.2) Mismatch



$\sim A^{-1/3} \ll 1$?

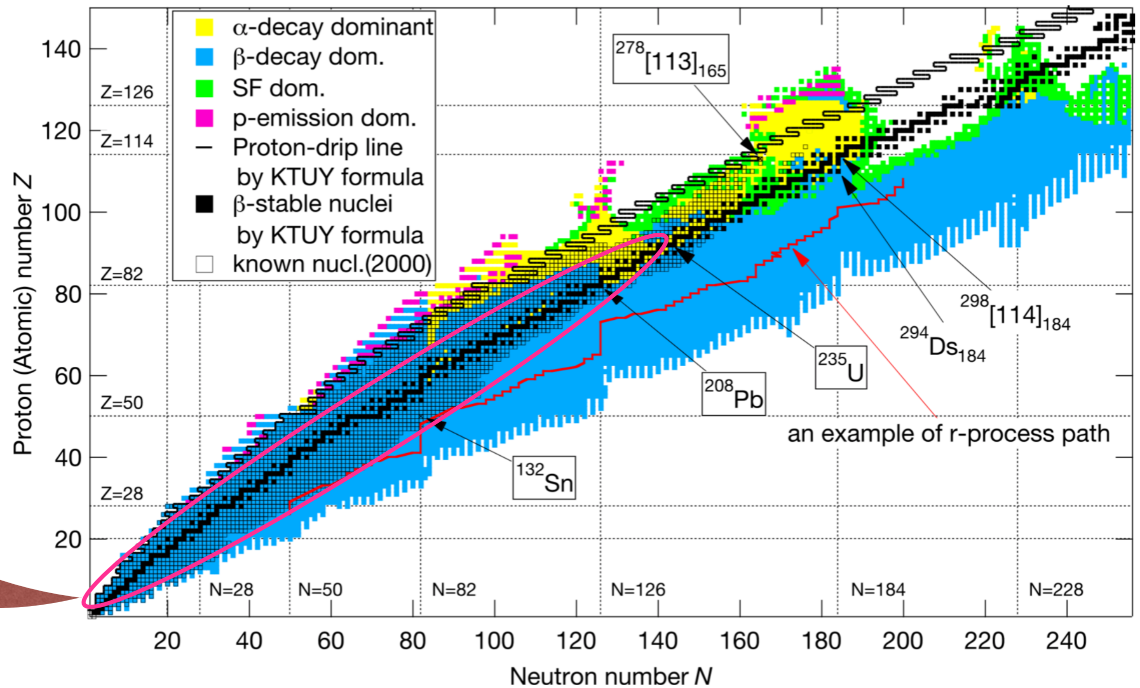
A : mass number

② Tune the parameters with experiments = STABLE nucleus



Are these potentials predictive in all nucleus?

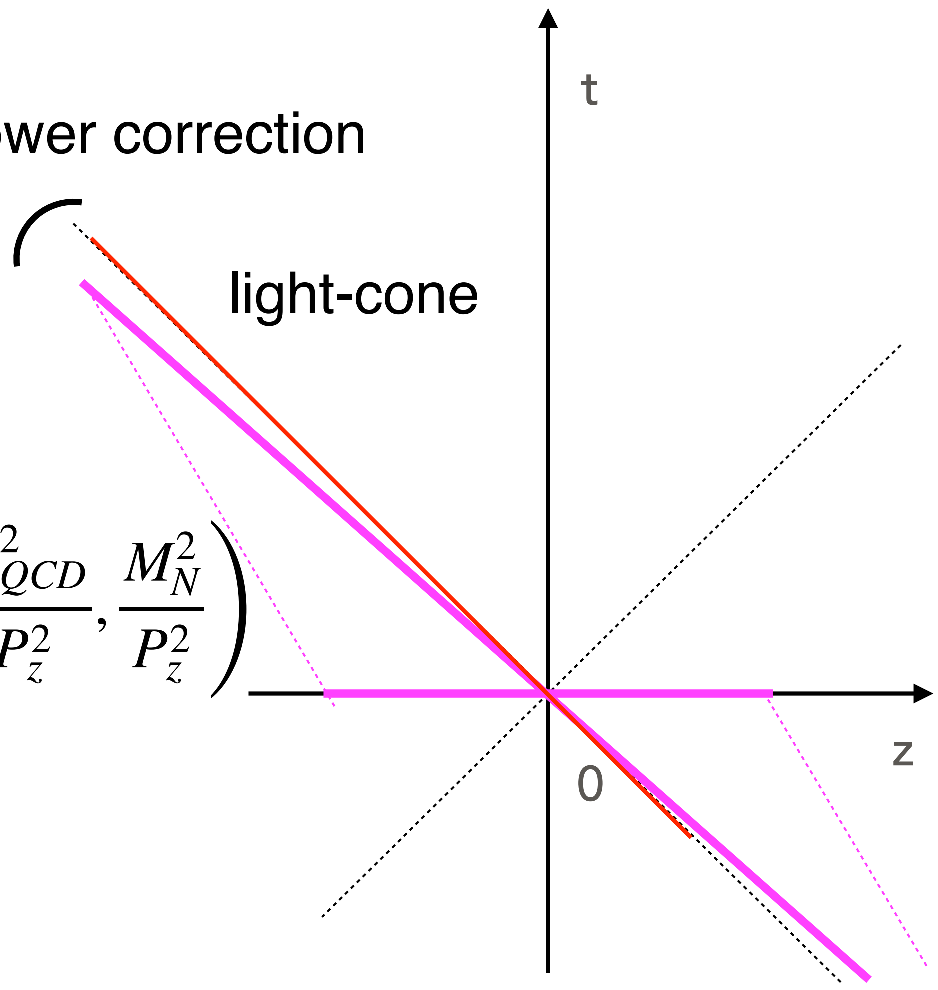
Obtain the realistic potential



PDFs on Lattice QCD -> quasi-PDFs

PDFs are defined as non-local correlation on light-cone
-> By definition, naively forbidden

However ,
we can access it
via Lorentz boost & Matching



e.g) Unpolarized Quark DF

$$\tilde{q}(x,\mu,P_z) = \int_0^1 \frac{dy}{y} Z\left(\frac{x}{y},\frac{\mu}{P_z}\right) q(y,\mu) + O\left(\frac{\Lambda_{QCD}^2}{P_z^2},\frac{M_N^2}{P_z^2}\right)$$

PDF

Calculable
(Lattice QCD)

-> quasi-PDF