Implementation of lattice s(x) - sbar(x) in CT fits

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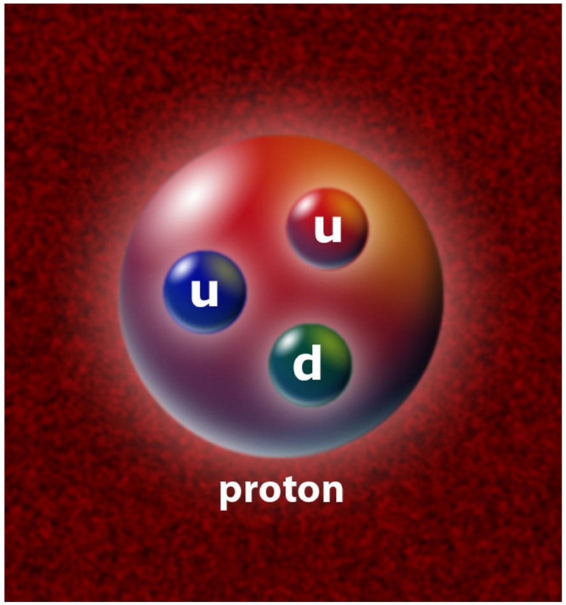
- The quark model predict the content of proton to be uud, which is realized as the valence ingredient of proton. This resulting as the number sum rule:

$$\int_0^1 [u(x) - \bar{u}(x)]dx = 2 \qquad \int_0^1 [d(x) - \bar{d}(x)]dx = 1$$

$$\int_0^1 dx\ [s(x) - \bar{s}(x)] = 0.$$

- The zero-number sum of strange lead to the different feature of s_v from u_v and d_v: half area of the s_v has to be negative.

- In CT18, we presume s=sbar.



- People used to parametrize the strange as s^+=(s+sbar) and s^-=(s-sbar) because the DGLAP equ. preserve the Int[s^-]=0.
- The zero-number sum of strange is controlled by one parameter in s^- :

For ex. CTEQ 6

$$
\begin{aligned}
s^+(x,Q_0) &= A_0\,x^{A_1}(1-x)^{A_2}P_+(x;A_3,A_4,\ldots)\\
s^-(x,Q_0) &= s^+(x,Q_0)\tanh[a\,x^b(1-x)^c P_-(x;x_0,d,e,\ldots)]
\end{aligned}
$$

$$P_-(x) = \left(1-\frac{x}{x_0}\right)\left(1+dx+ex^2+\cdots\right)$$

MMHT2014/MSHT20

$$s_-(x,Q_0^2) = A_{s_-}(1-x)^{\eta_{s-}}(1-x_0/x)x^{\delta_{s-}}$$

- We consider an alternative way on parametrizing the strangeness. Consider both s and sbar contain an overall factor A:

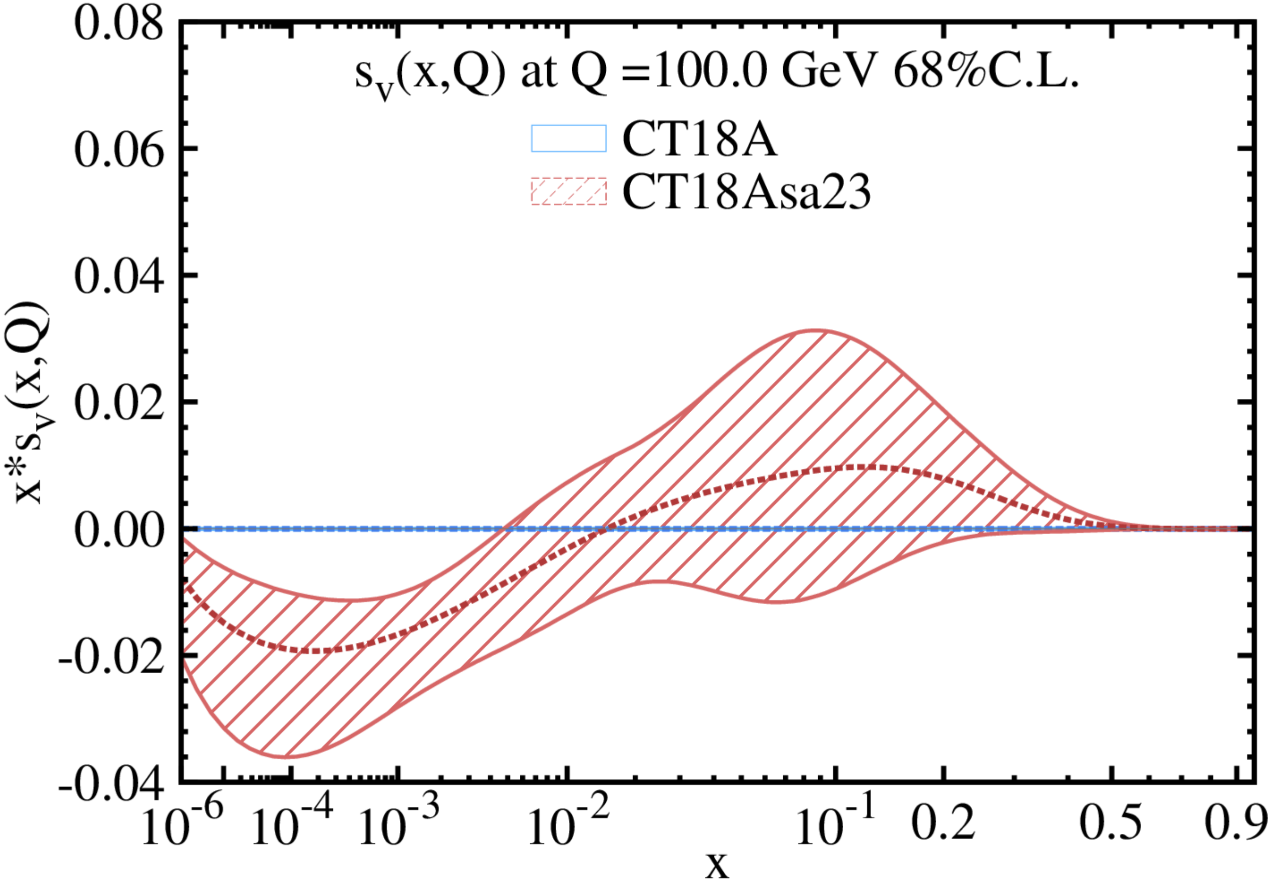
$$\int dx \left(A(s)g(s) - A(\bar{s})g(\bar{s})\right) = 0$$

- By given A(sb) first and,

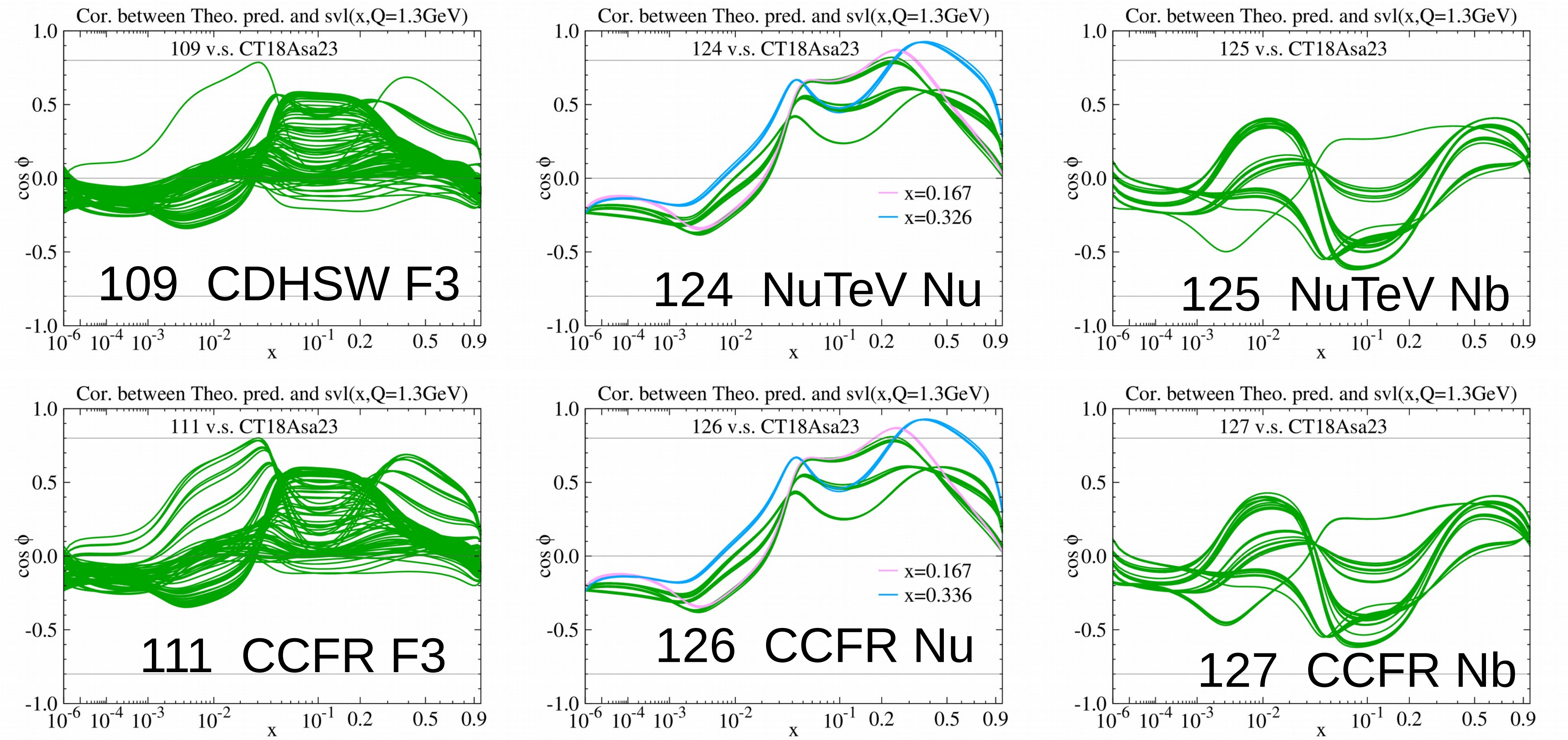
$$A(s) = \frac{\int dx\, A(\bar{s})g(\bar{s})}{\int dx\, g(s)}$$

The function of g(s) and g(sb) can be parametrized independently.

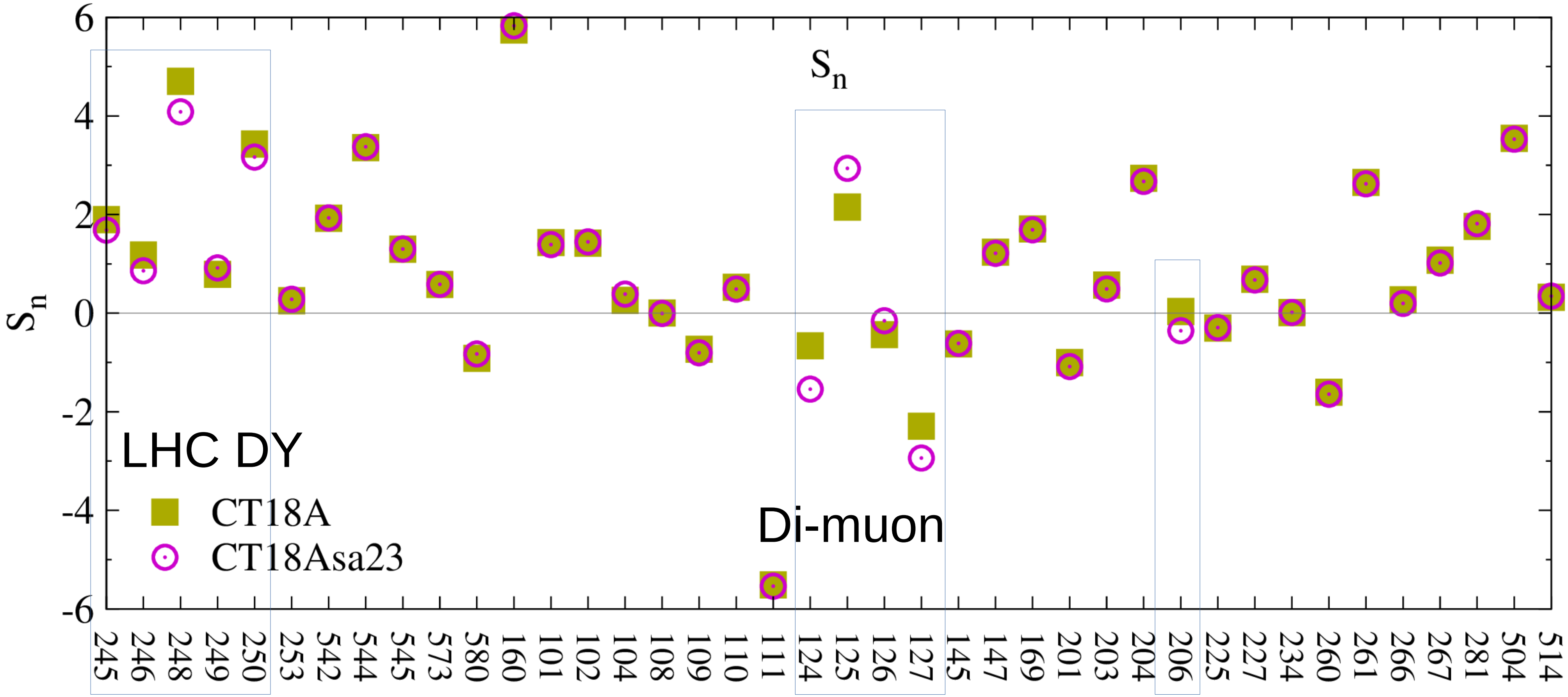
- Different from the root-finding method, there is no presumed requirement on the function of g(s) and g(sb). But it is relatively hard to control the number of crossing in s-sb.



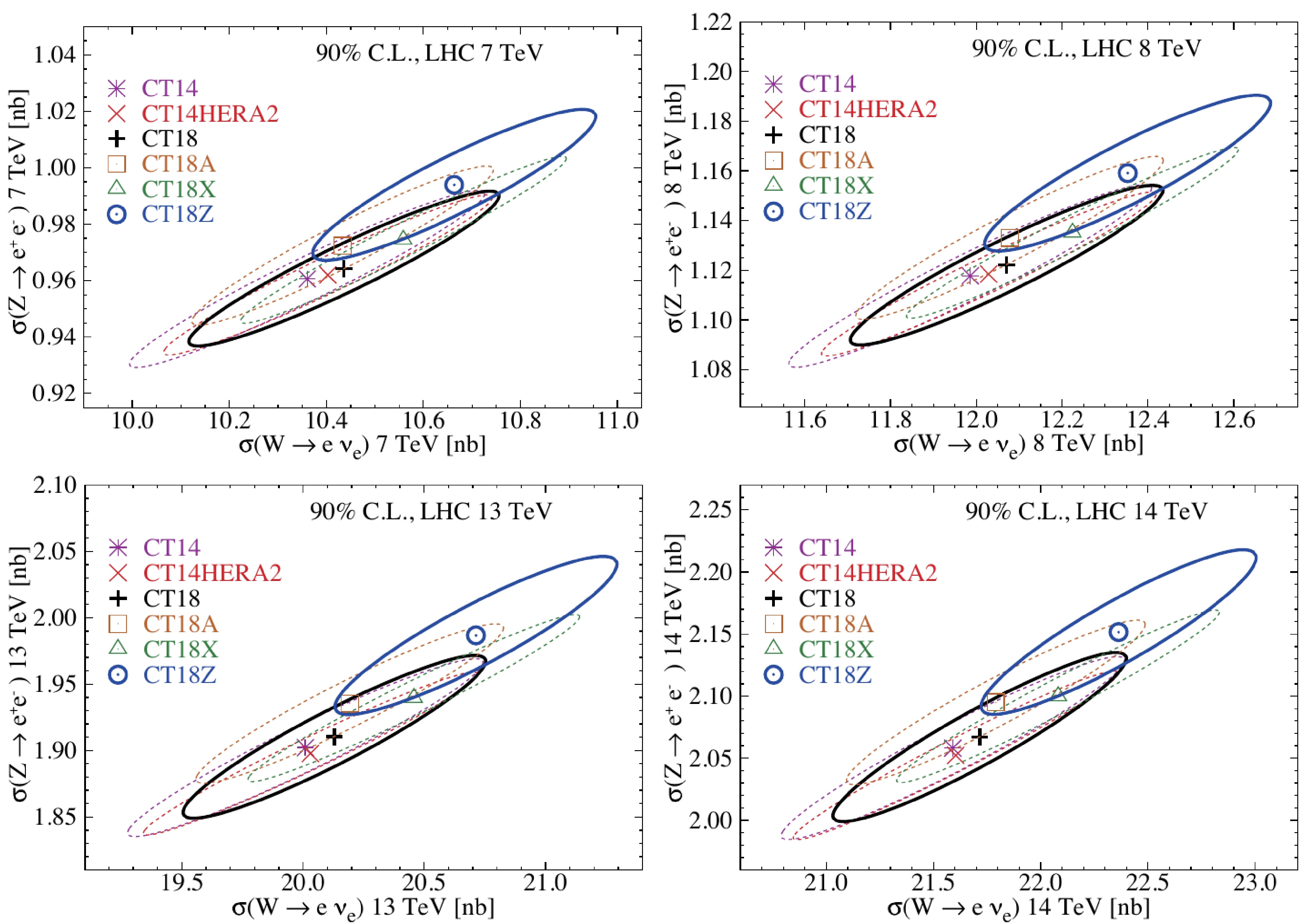
- Starting from CT18A, which contains the ATLAS 7 TeV ZW data(248), we select the strange asymmetry with one crossing from various trial parametrizations.



- Naively, we expect the F_3 data and di-muon data would sensitive to the s_v the most, and the correlation between s_v and data also agree with this expectation.



- The changing in Gaussian variable Sn shows, besides the di-muon data, it is the LHC Drell-Yan meausrements, i.e. 245, 246, 248, 250, sensitive to s_v; the F_3 data 109 and 111 are not precise enough to constraint s_v.



90% C.L., LHC 7 TeV
90% C.L., LHC 8 TeV
90% C.L., LHC 13 TeV
90% C.L., LHC 14 TeV
CT14
CT14HERA2
CT18
CT18A
CT18X
CT18Z
σ(W → e ν_e) 7 TeV [nb]
σ(Z → e⁺e⁻) 7 TeV [nb]
σ(W → e ν_e) 8 TeV [nb]
σ(Z → e⁺e⁻) 8 TeV [nb]
σ(W → e ν_e) 13 TeV [nb]
σ(Z → e⁺e⁻) 13 TeV [nb]
σ(W → e ν_e) 14 TeV [nb]
σ(Z → e⁺e⁻) 14 TeV [nb]

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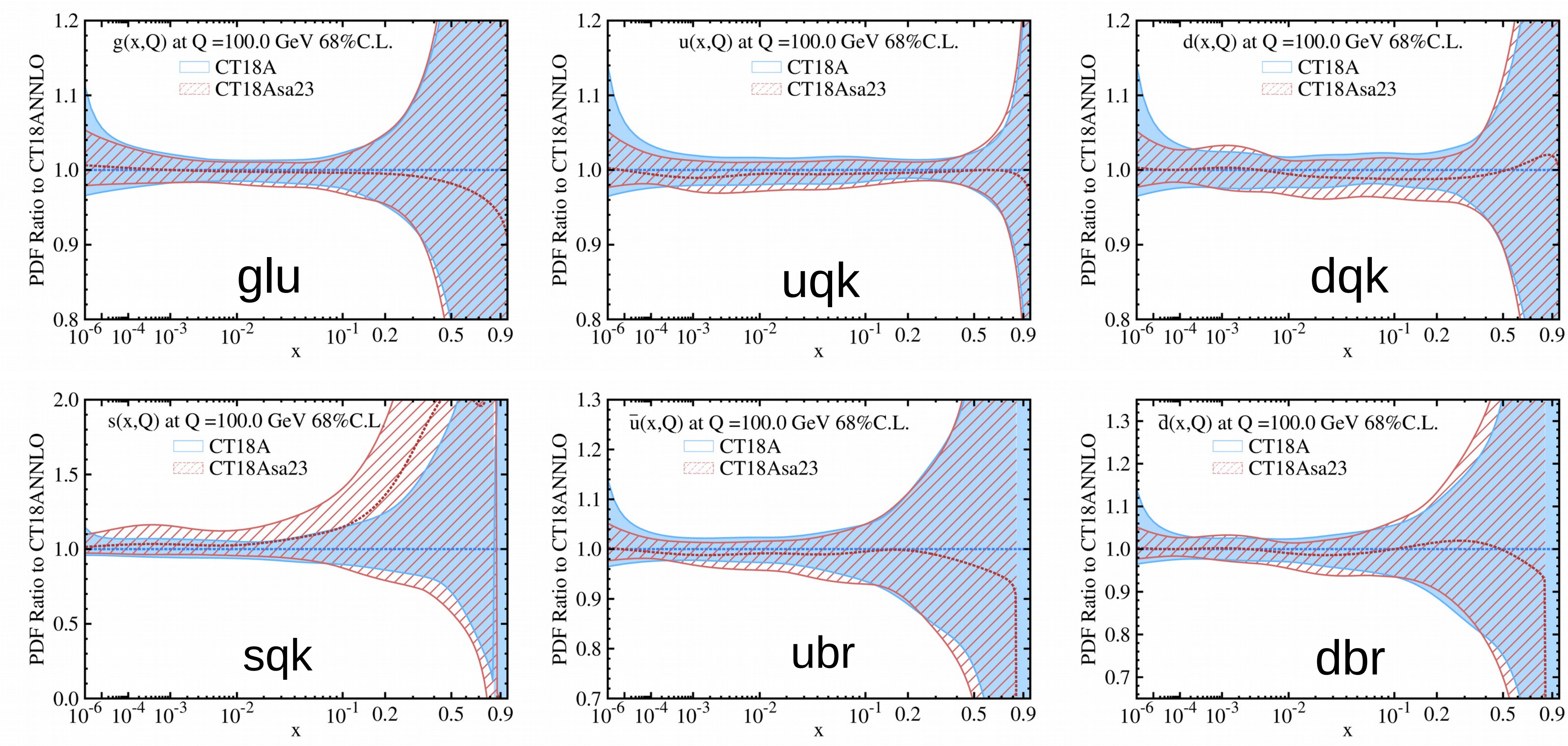
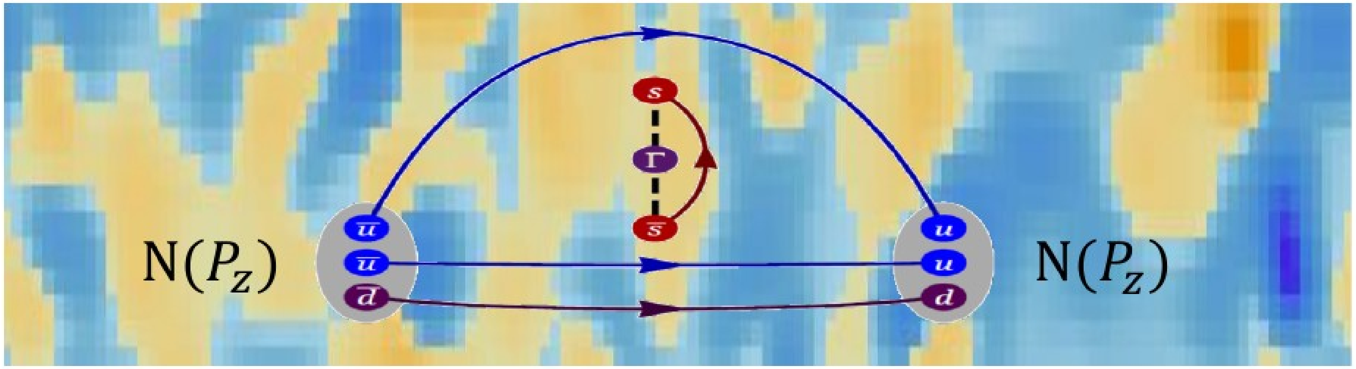


- The inclusion of non-zero s_v lead to the reduction of u and d quark, and enhancement of strange and its uncertainty.

First Lattice Strange PDF

§ On the lattice, one needs to calculate the following

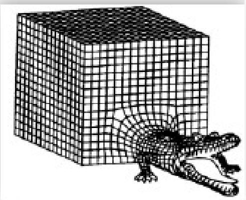


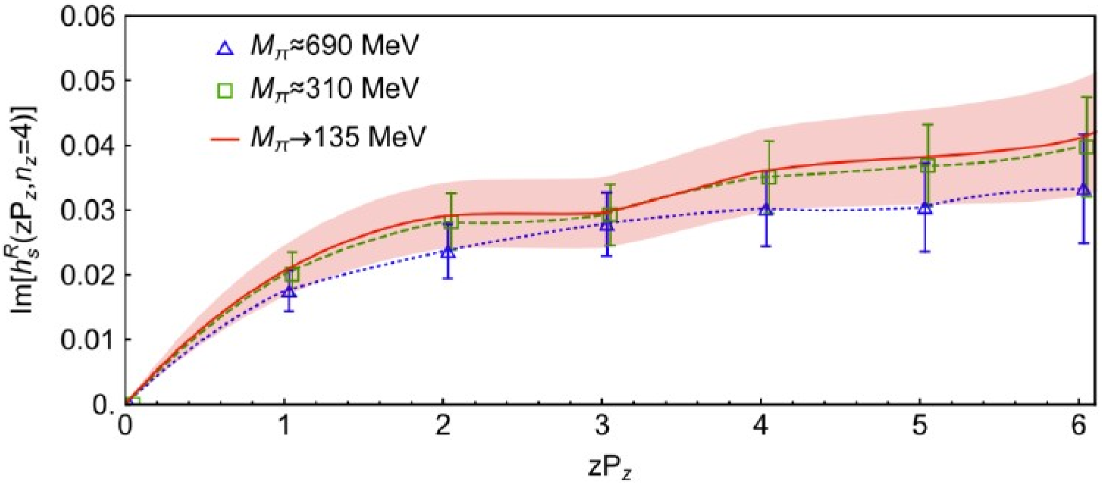
2005.12015, Zhang, Lin, Yoon

§ Results by MSULat/quasi-PDF method

- Clover on 2+1+1 HISQ 0.12-fm 310-MeV QCD vacuum
  - 7,184,000 strange loops
  - 344,832 nucleon correlators
- RI/MOM renormalization
- Extrapolated to

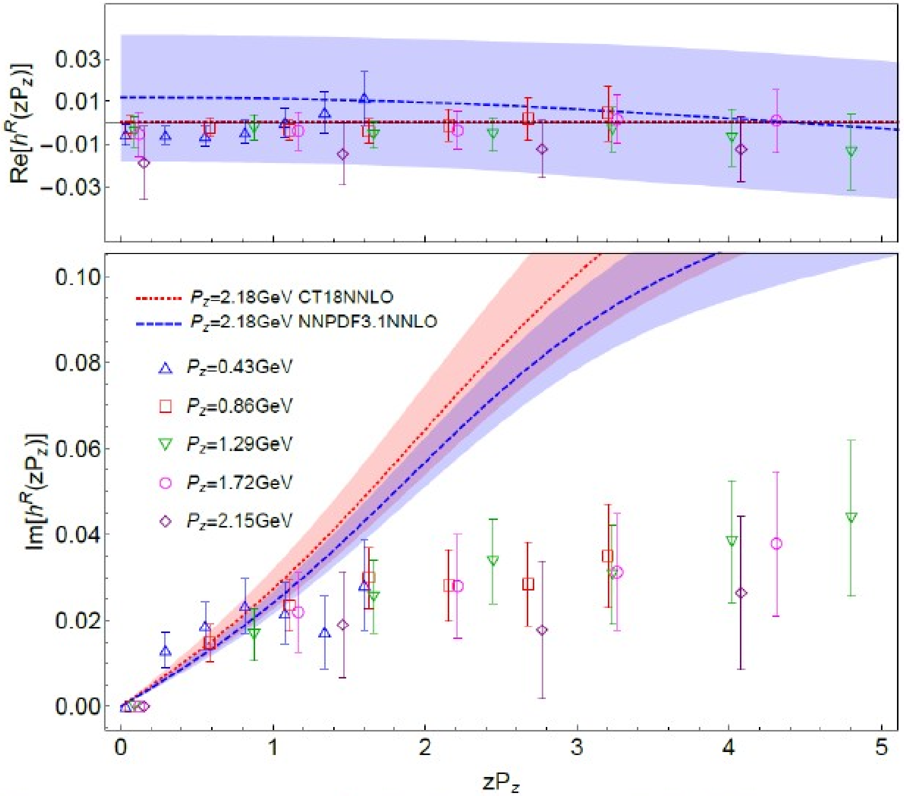
  $M_\pi \approx 140$ MeV





First Lattice Strange PDF

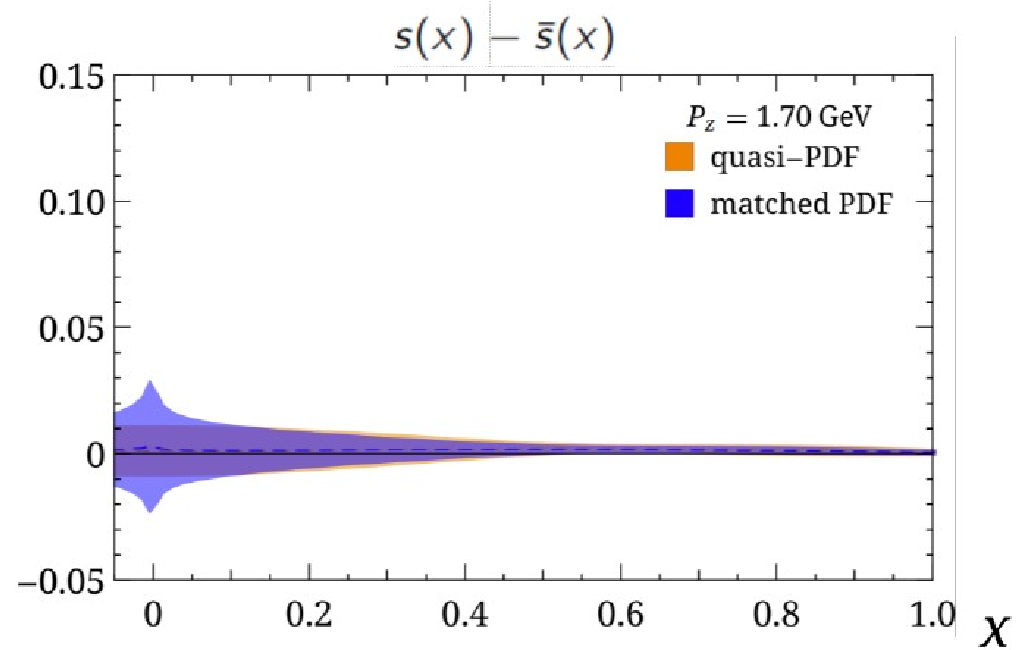
§ Lattice matrix elements



- Strange-antistrange symmetry

$$\mathrm{Re}[h(z)] \propto \int dx\, (s(x) - \bar{s}(x)) \cos(xzP_z)$$

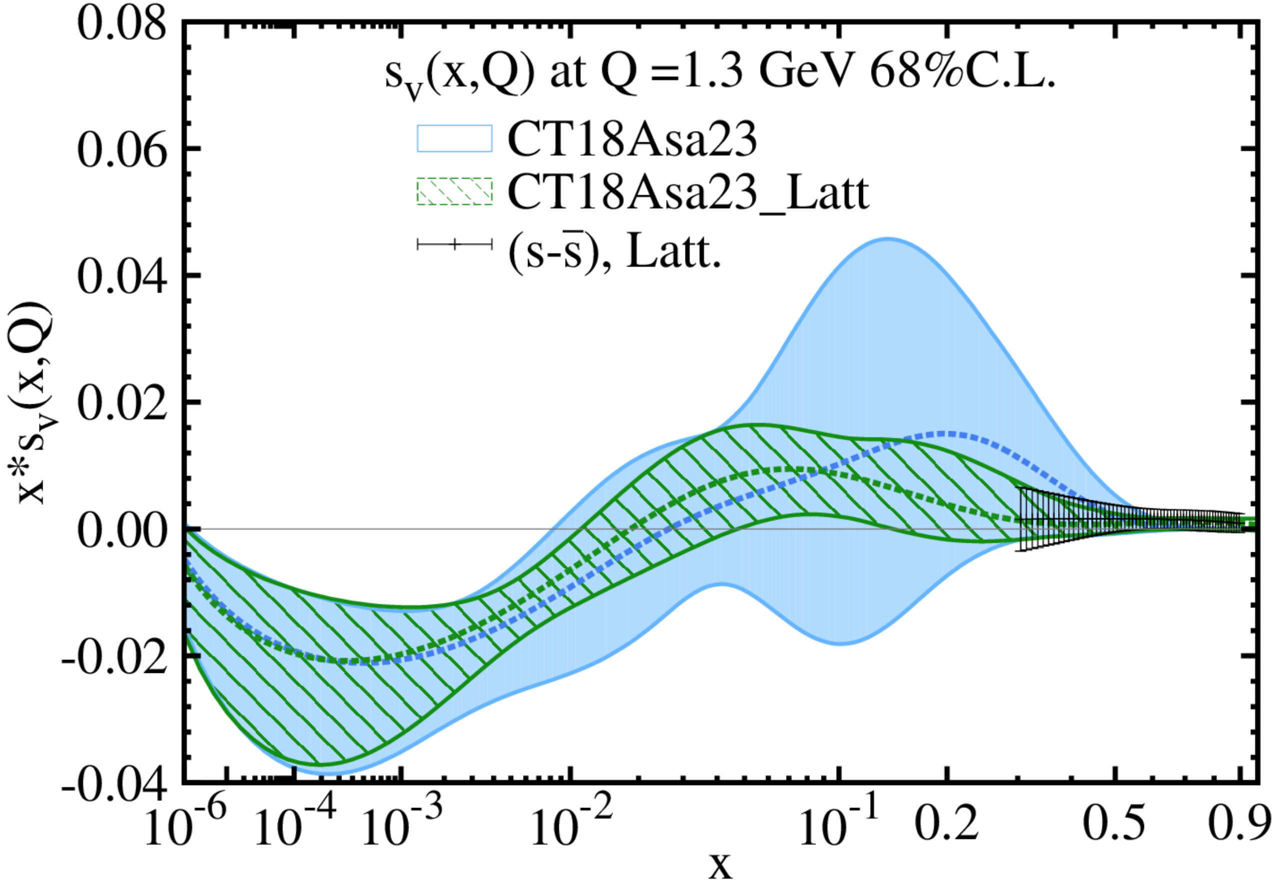
$$\mathrm{Im}[h(z)] \propto \int dx\, (s(x) + \bar{s}(x)) \sin(xzP_z)$$



§ From quasi-PDF to PDF

$$\tilde{f}_q(x, P_z) = \int_{-1}^{1} \frac{dy}{|y|} f_q(y) C_{q/q}(x, y, P_z, \mu)$$

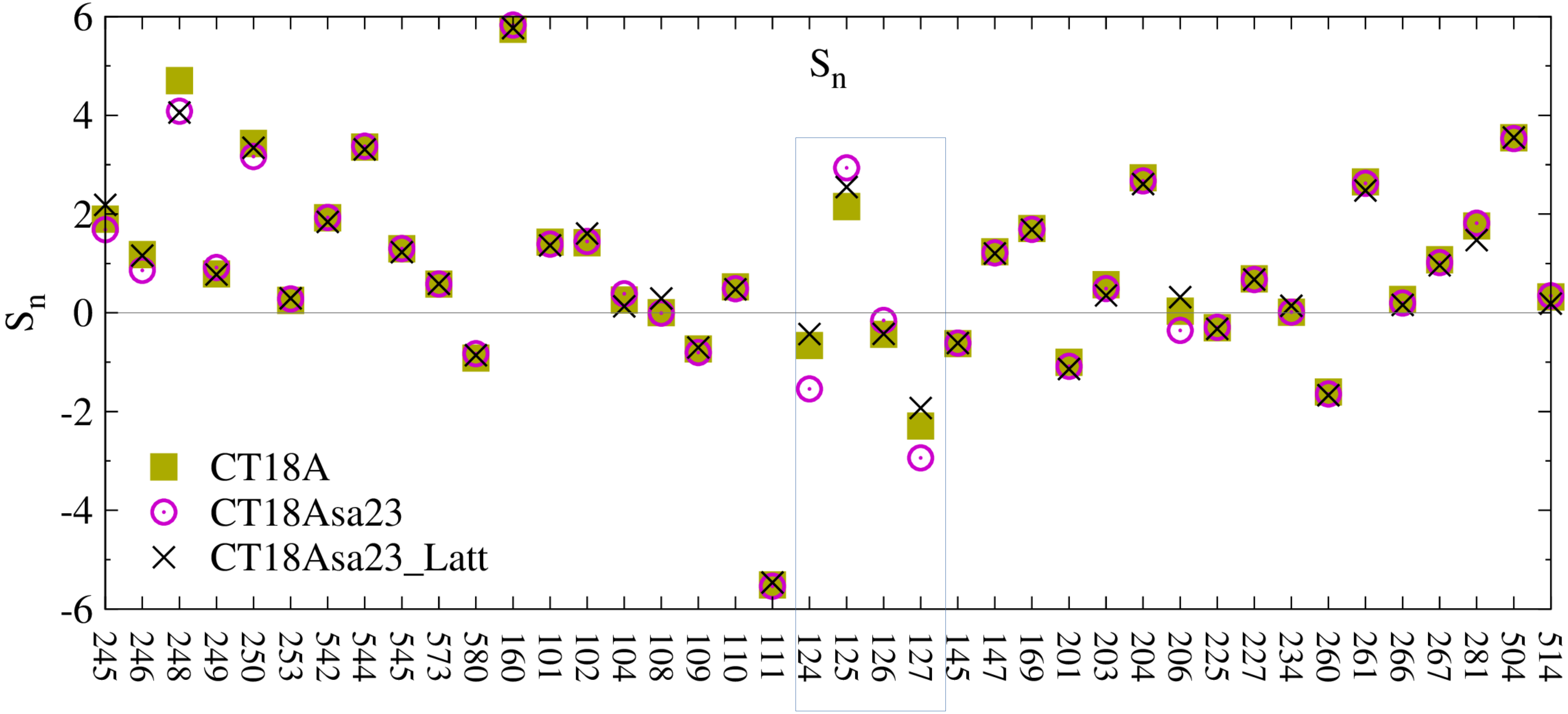
$$+O\left(\frac{\Lambda_{QCD}^2}{x^2 P_z^2}, \frac{\Lambda_{QCD}^2}{(1-x)^2 P_z^2}\right)$$



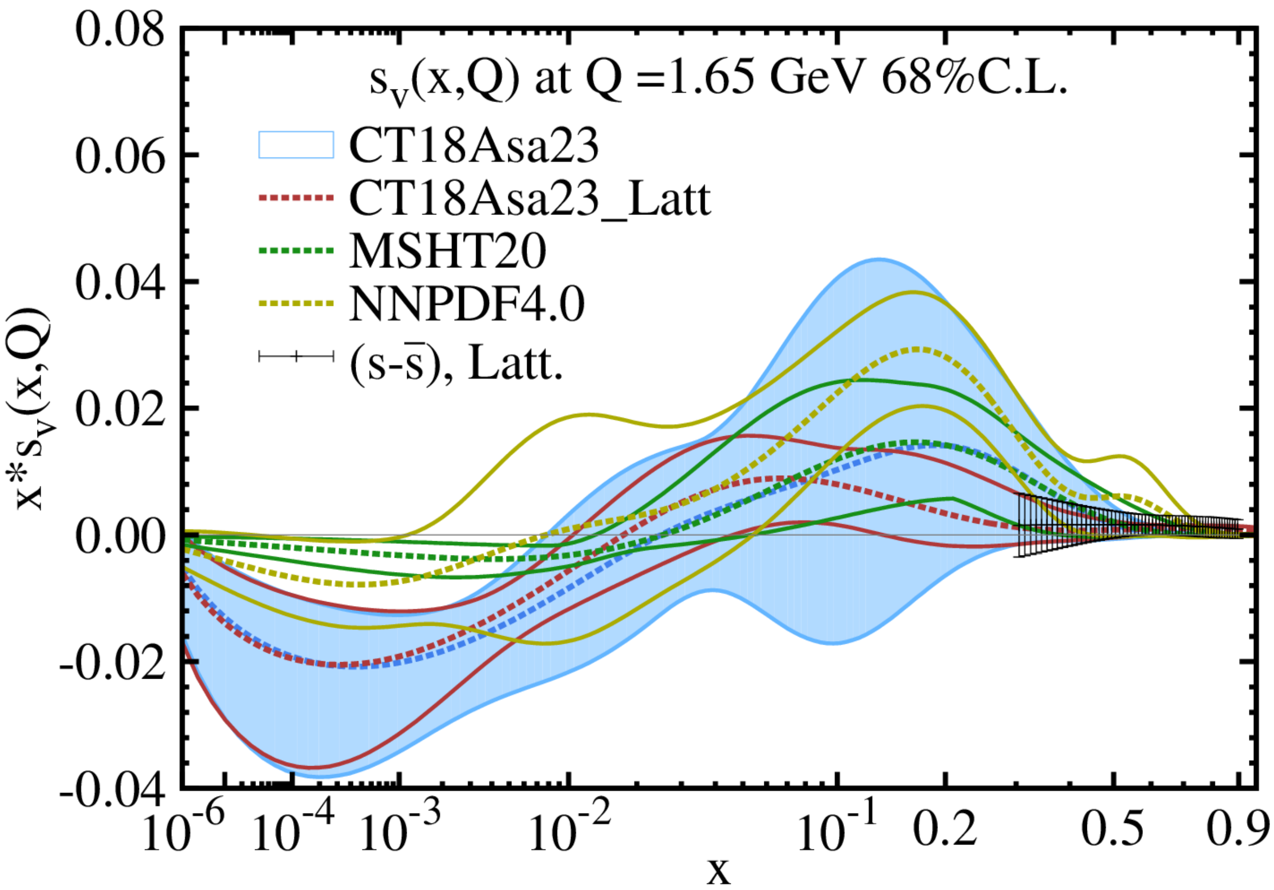
- The lattice calculation constraint the s_v for 0.3 < x < 0.9, which overlap with the x region of di-muon data, 0.015 < x < 0.336.

- The lattice constraint is treated as data:

$$\chi^2_{tot} = \chi^2 + w \sum_i \left(\frac{f(x_i, Q) - f_{Latt}(x_i, Q)}{\varepsilon_{Latt}} \right)^2$$



- The lattice calculation has little tension with the di-muon data.



- The central prediction of s_v in CT18Asa23(blue) is almost identical to that of MSHT20 for x > 0.01, but with much larger uncertainty.
- Inclusion of constraint from lattice would pull down the central prediction of s_v and reduce the uncertainty.

Summery

- Starting from CT18A, we consider non-zero $s_v(x,Q)$ by using more flexible method.
- Not just the di-muon data NuTeV and CCFR, the LHC precise Drell-Yan data also sensitive to the s_v, while the F_3 data CDHSW and CCFR are not precise enough to constraint s_v.
- By treating lattice calculation as data, the s_v receive strong constraint on both central prediction and uncertainty in large-x region.