

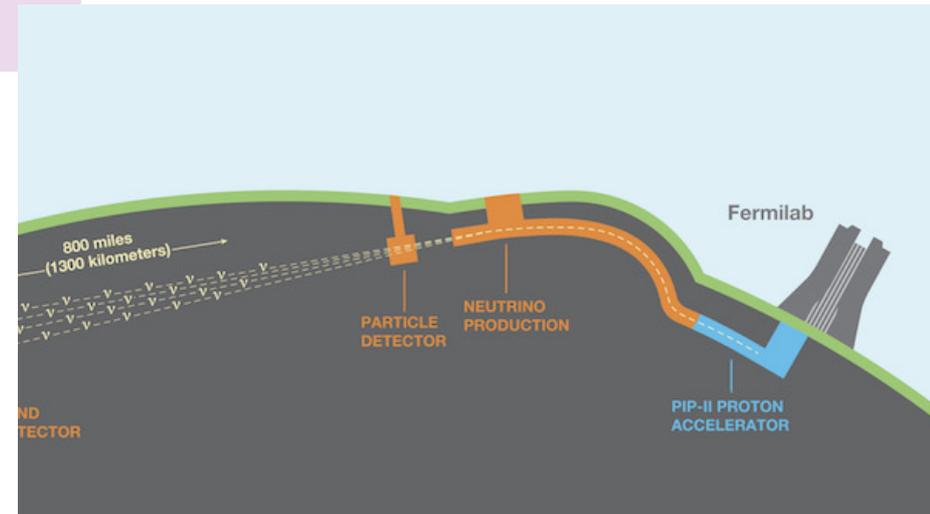
New directions in theory and computation

for GENIE and associated neutrino calculations

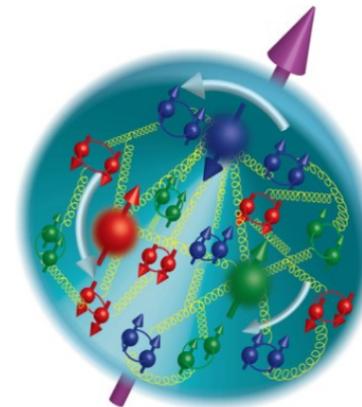
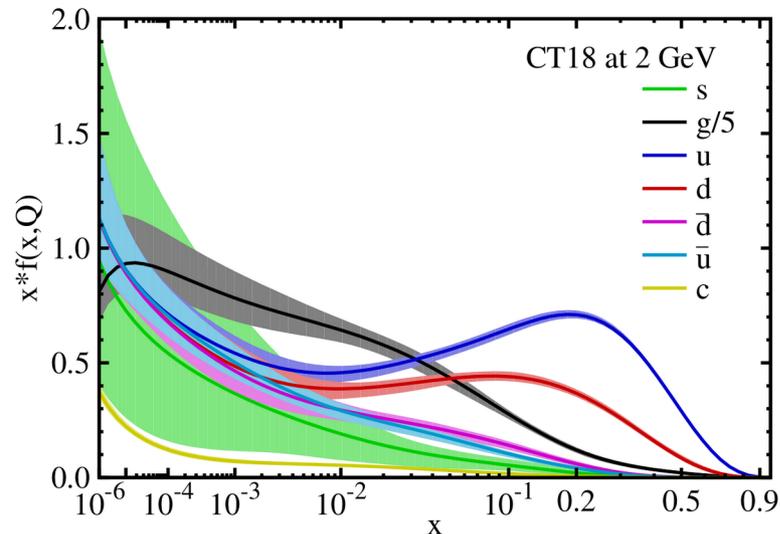
brief
introductory
comments

Tim Hobbs – Fermilab, IIT

23rd Sept 2021



CT18: PRD103 (2021) 1, 014013



quick background survey; possible *selected* topics of common interest

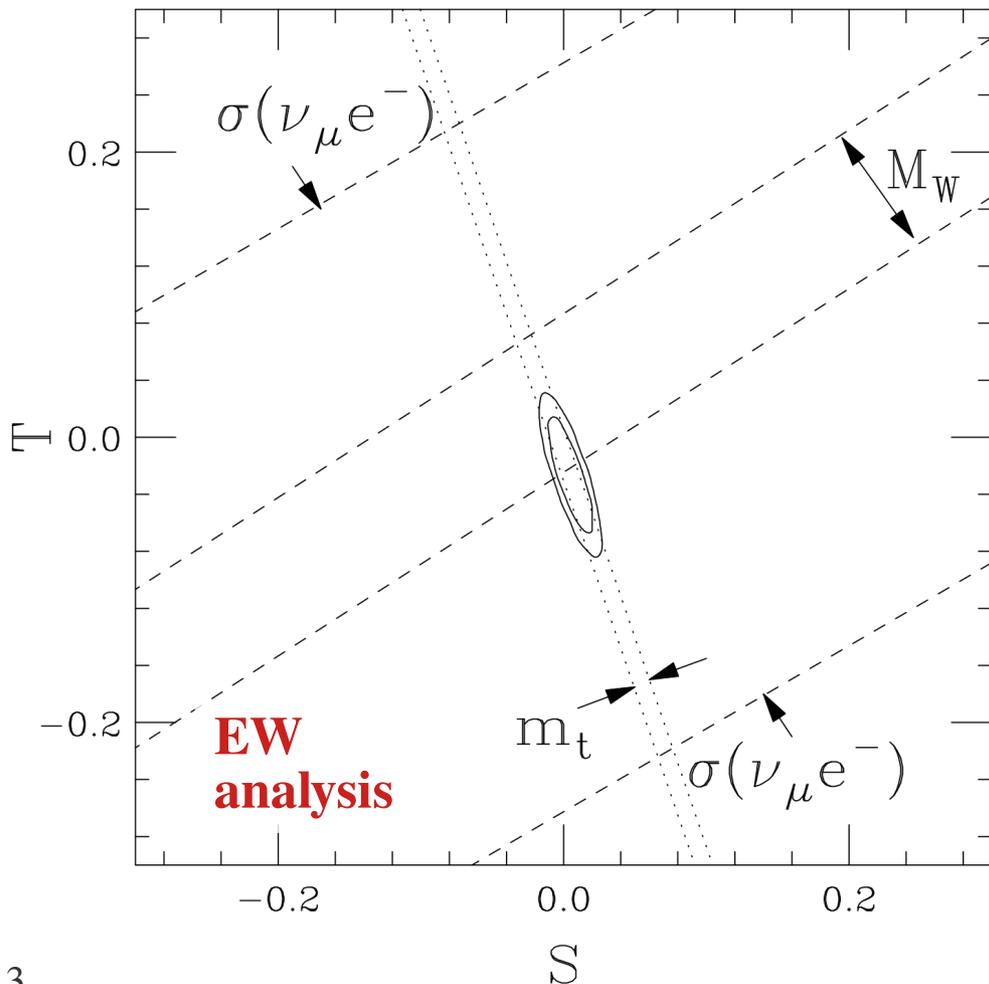
- scientific history and focuses [I]
 - EW pheno.; DIS/PDFs; nuclear effects; hadronic structure

- related opportunities for GENIE; associated ν calculations [II]
 - disentangling model uncertainties; parametric dependence
 - enhancing GENIE physics ingredients (DIS/SIS region)
 - understanding charged-lepton scattering ($e4\nu$)

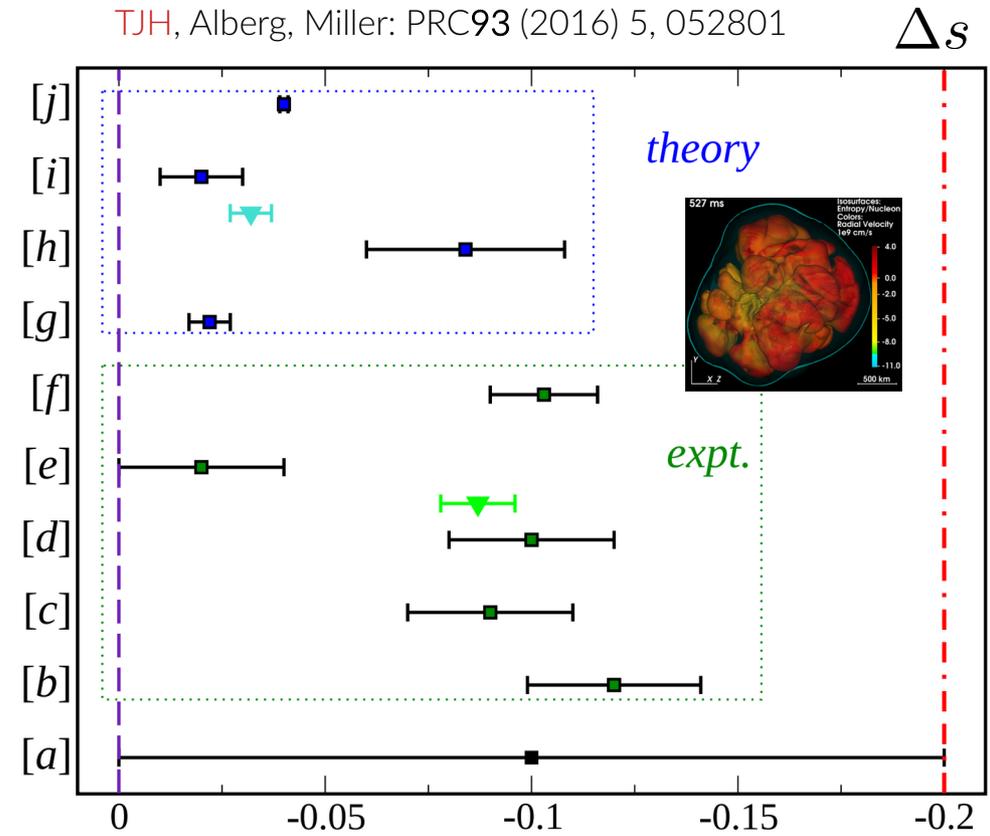
topical physics background: electroweak theory, pheno.

- role of neutrino data in constraining EW sector input parameters
- calculations of single-nucleon inputs for astrophysical neutrino mechanisms

TJH and Rosner: PRD82 (2010) 013001



TJH, Alberg, Miller: PRC93 (2016) 5, 052801



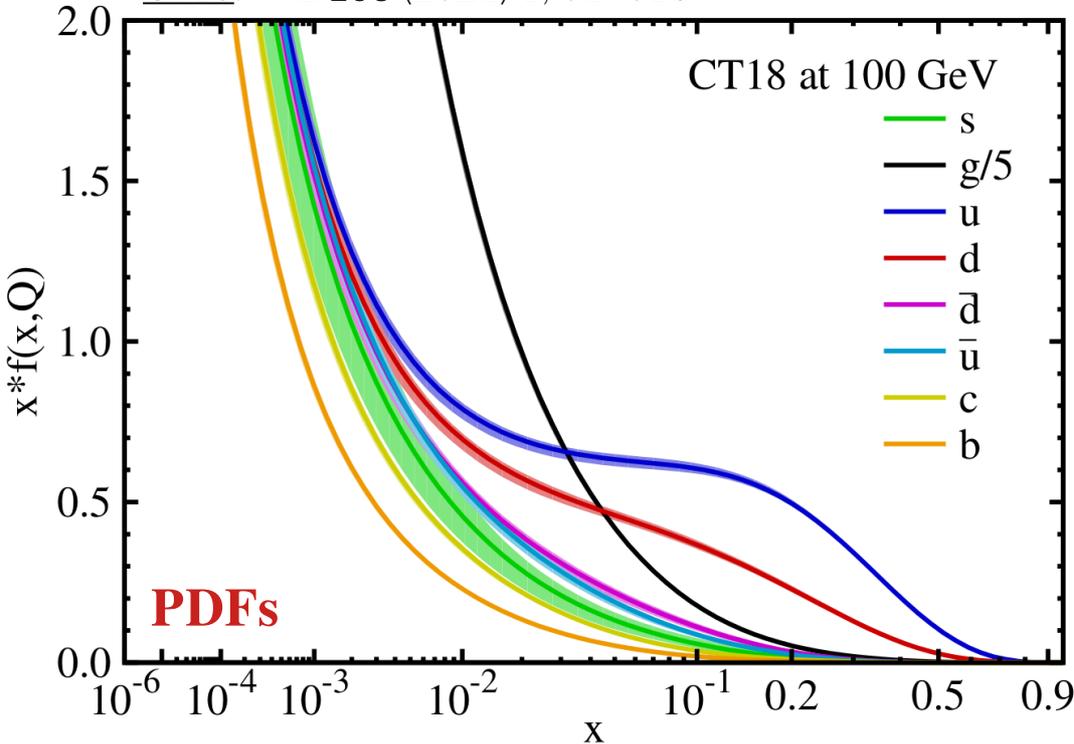
$$\sigma_i(\epsilon) = \frac{2G_F^2 \epsilon^2}{3\pi} (c_{Vi}^2 + 5c_{Ai}^2)$$

$$c_{Ai} = \frac{1}{2} \left(\pm G_A(0) - G_A^{s\bar{s}}(0) \right) = \frac{\pm g_A - \Delta s}{2}$$

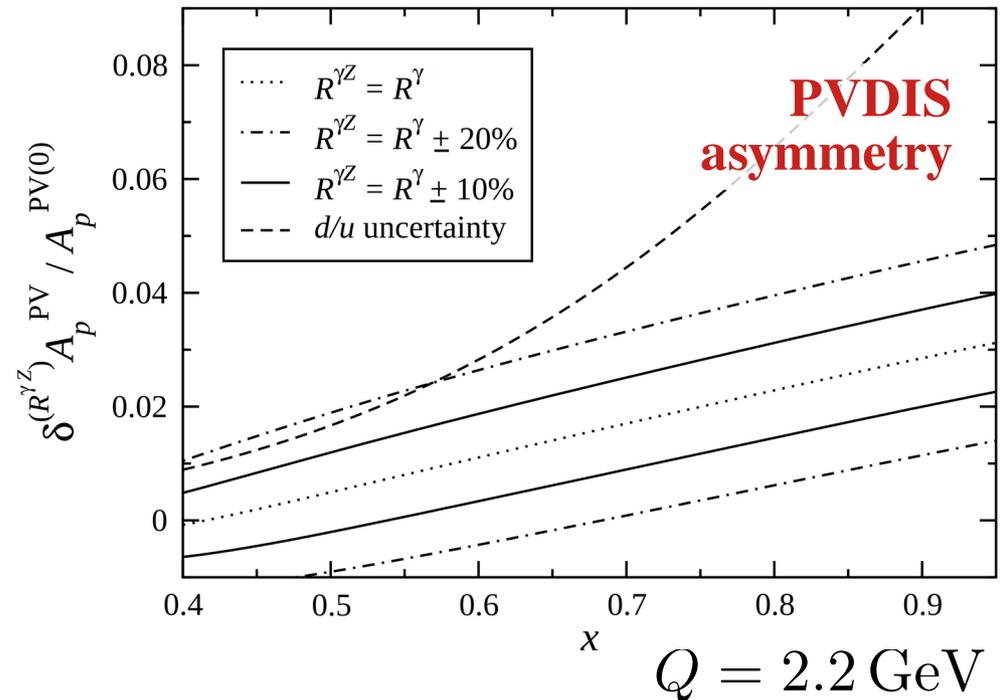
topical physics background: DIS, PDFs; SIS

- phenomenological determinations of PDFs from large sets of hadronic data
 - LHC, HERA, fixed-target (including neutrino-initiated)
 - NNLO theory accuracy in α_s ; NLO EW corrections
- studies of finite- Q^2 effects relevant at JLab; few-GeV transition region to SIS

CT18: PRD103 (2021) 1, 014013



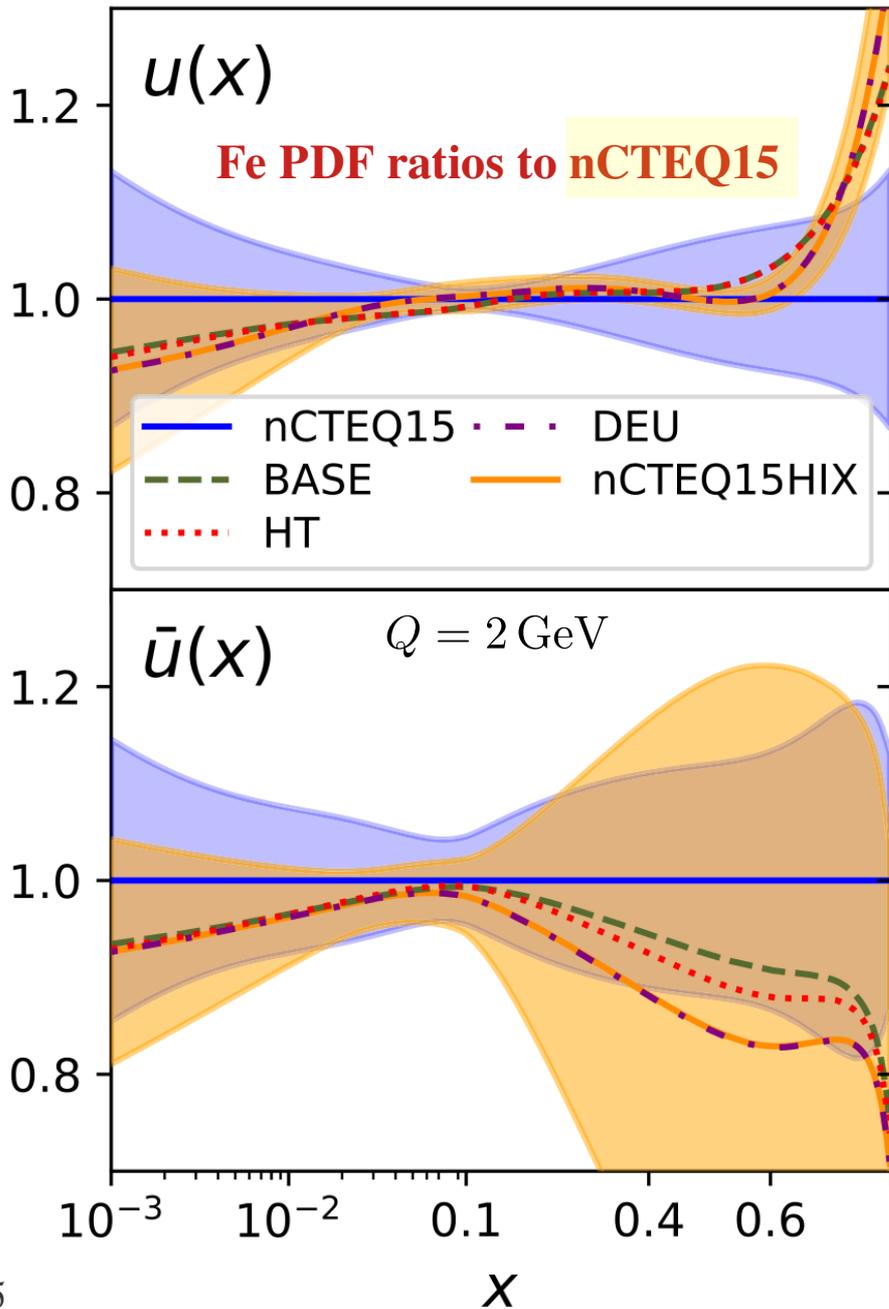
TJH and Melnitchouk: PRD77 (2008) 114023



topical physics background: nuclear medium; effects

C++ analysis code

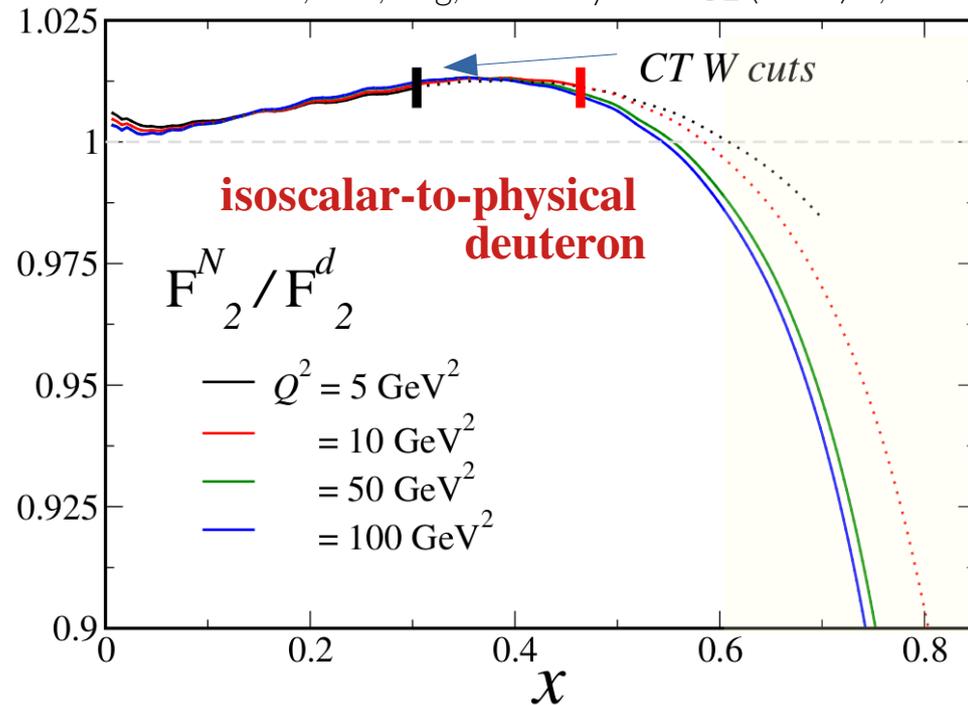
Segarra et al.: PRD103 (2021) 11, 114015



- complementary work learning A dependence of nuclear PDFs; e.g., **Fe**
- theoretical modeling, computation for few-body nuclear corrections

→ entangle with other few-GeV effects

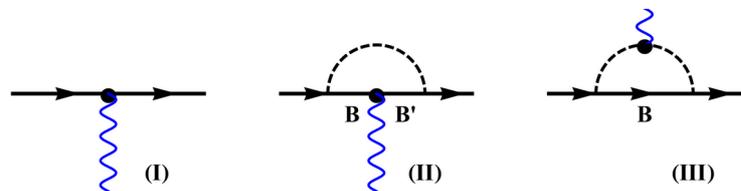
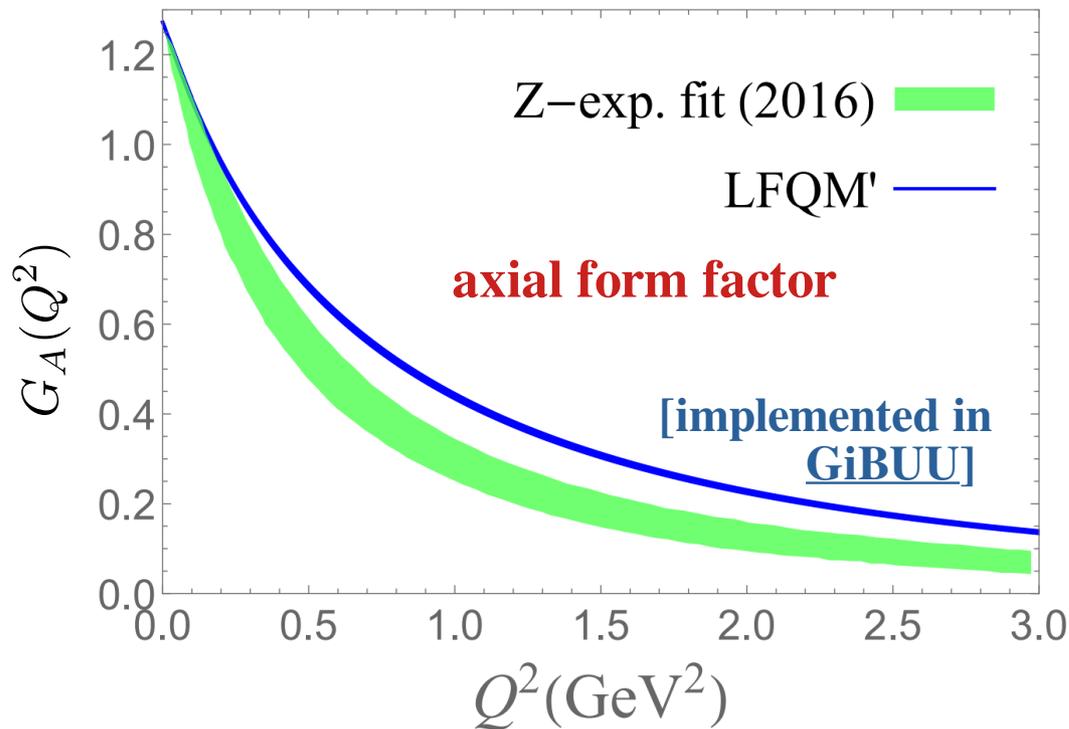
Accardi, TJH, Jing, Nadolsky: EPJC81 (2021) 7, 603



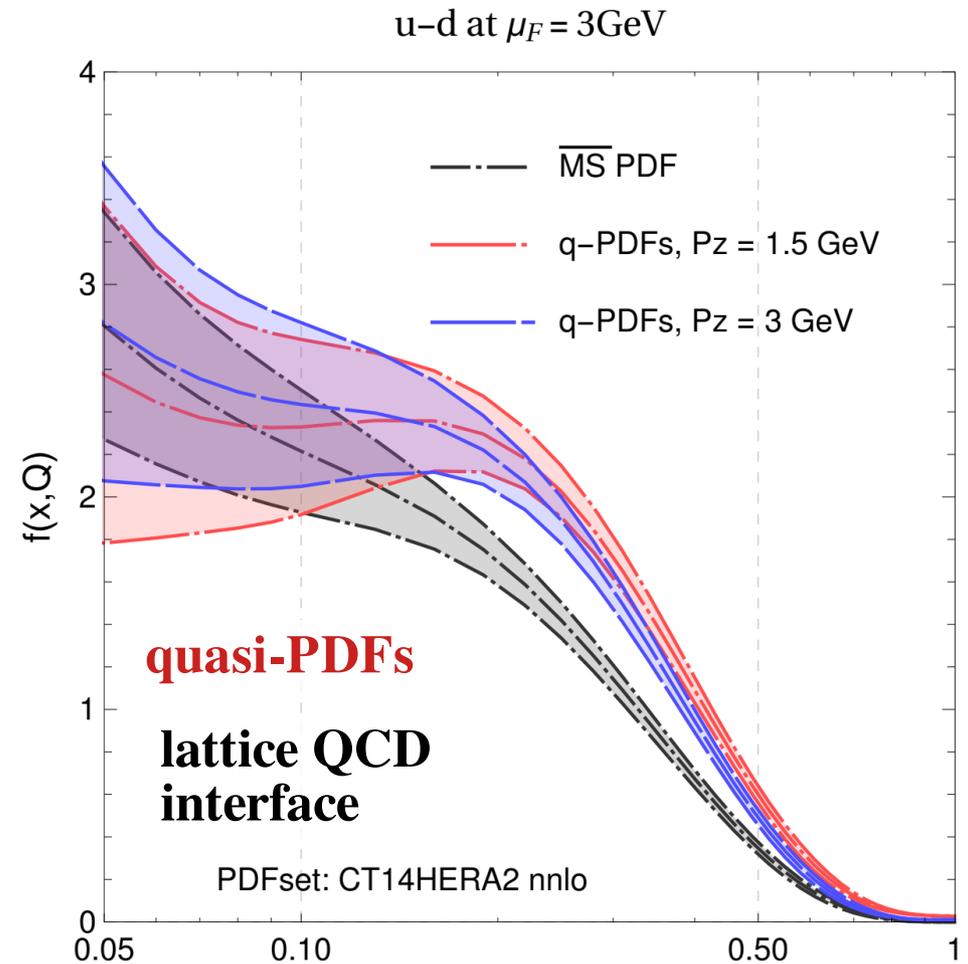
topical physics background: hadron structure; nonpert. QCD

- various efforts computing nonperturbative QCD aspects of hadron structure
 - provides single-nucleon observables for νA ; e.g., $G_A(Q^2)$
- synergies with lattice QCD output

Zhang, TJH, Miller: PRD102 (2020) 7, 074026

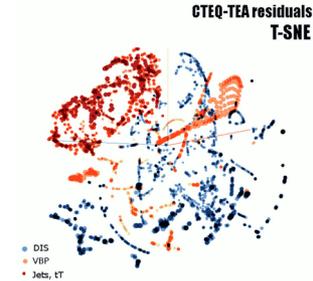


TJH, Wang, Nadolsky, Olness: PRD100 (2019) 9, 094040



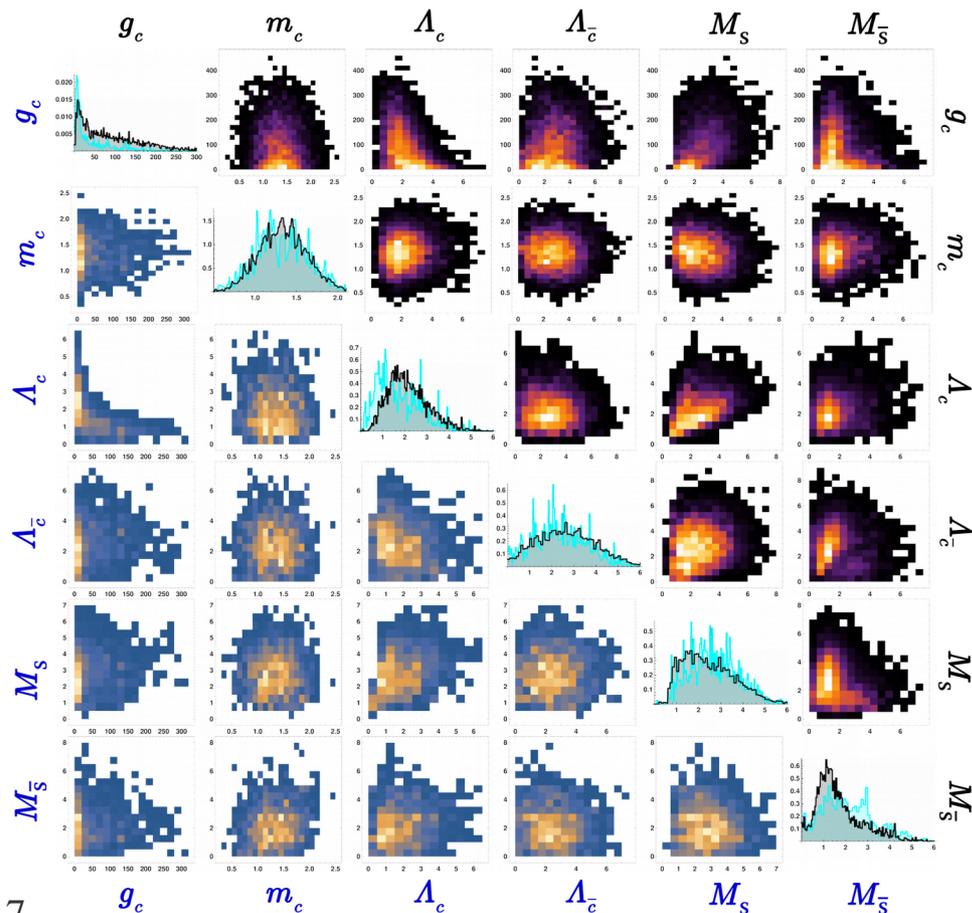
GENIE opportunities: uncertainties

- GENIE tunes are complex interplay of parameter selections
 - valuable to explore further to understand generator uncertainties
- various tools, fast methods available



TJH, Alberg, Miller: PRD97 (2017) 7, 074023

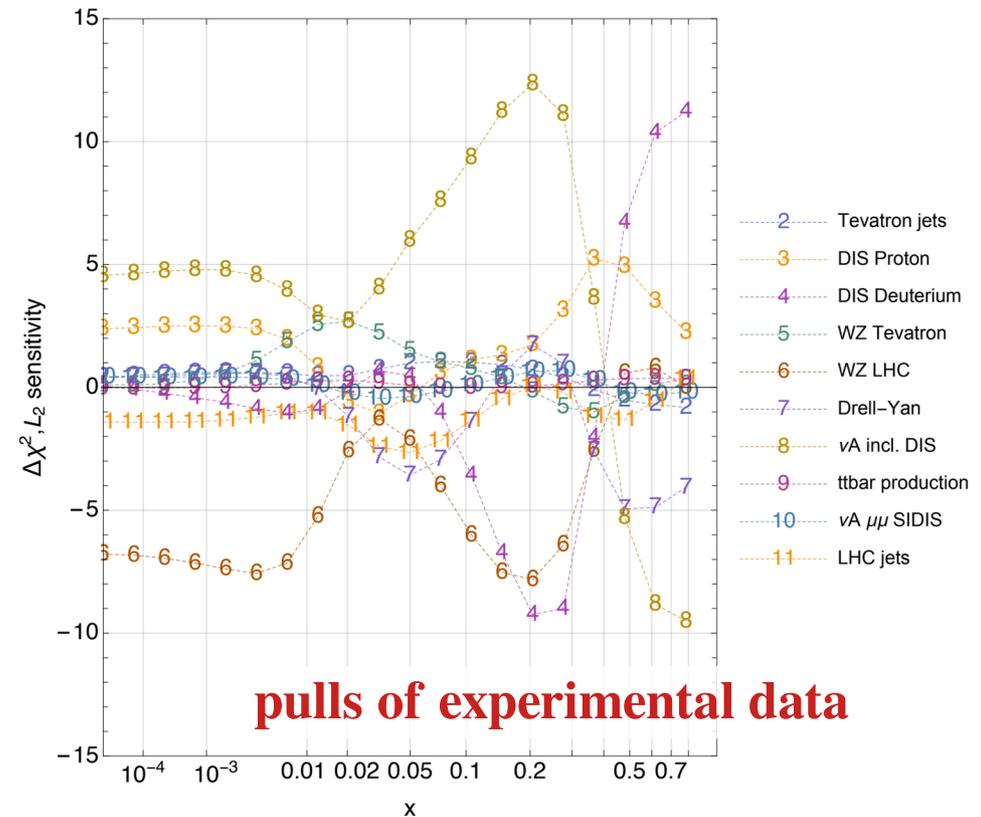
MCMC



Wang, TJH, et al.: PRD98 (2018) 9, 094030

Accardi, TJH, Jing, Nadolsky: EPJC81 (2021) 7, 603

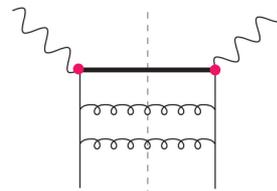
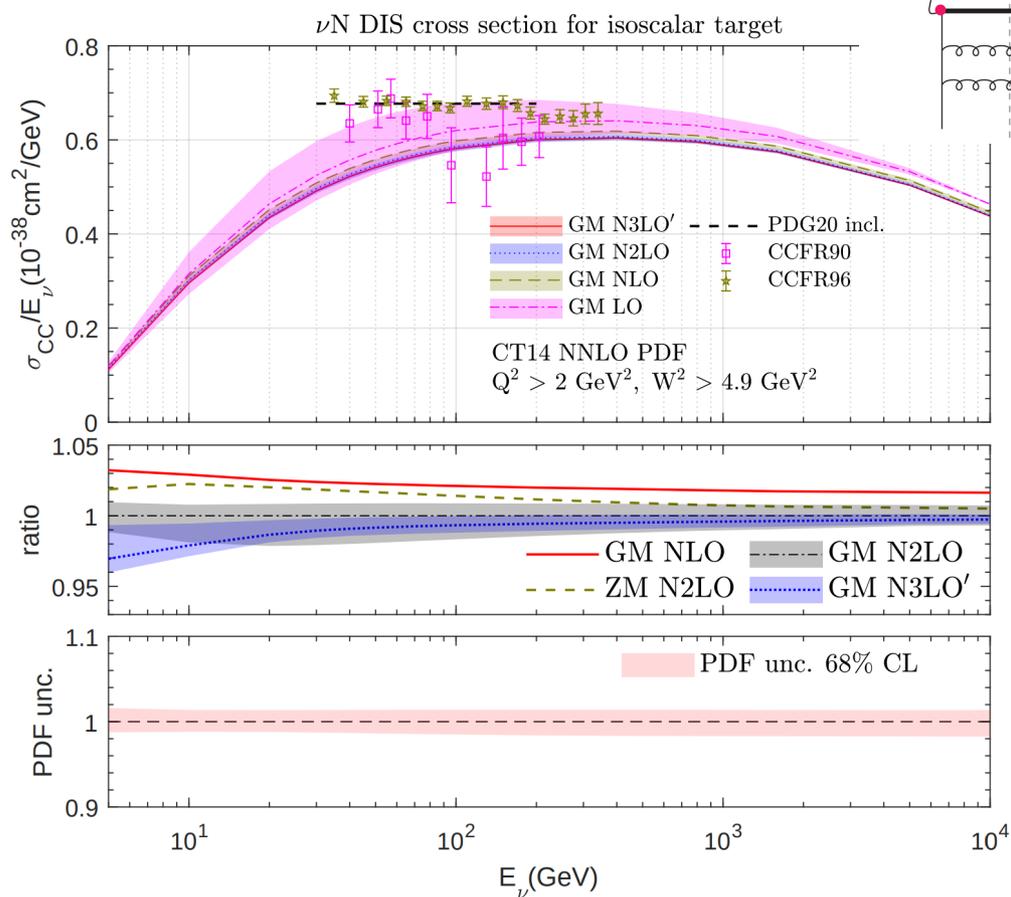
CT fixed d.c., $d(x,Q)/u(x,Q)(x, 2 \text{ GeV})$



GENIE opportunities: physics enhancements, i

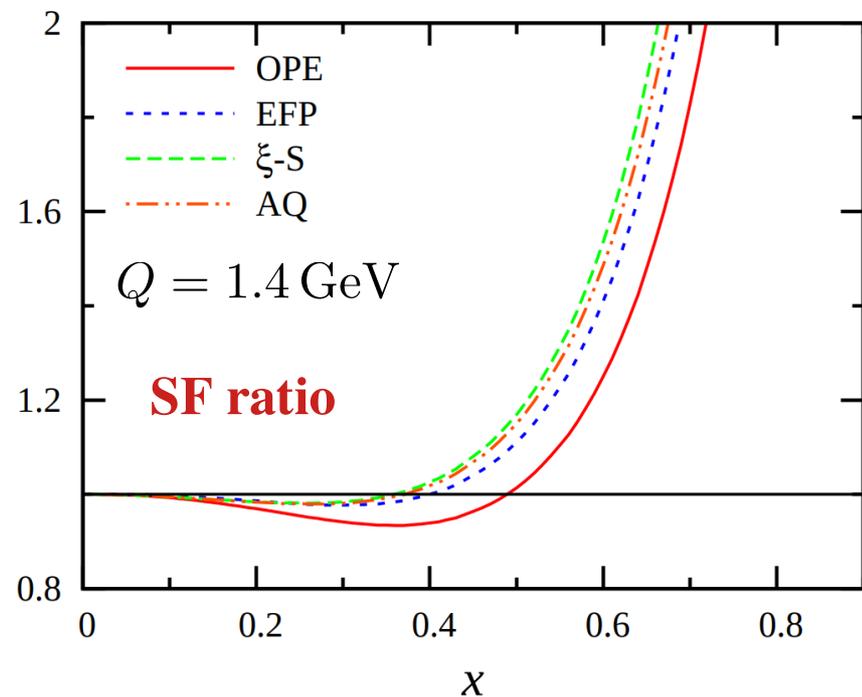
- *e.g.*, recent Snowmass LOIs note updates to DIS/SIS physics ingredients
 ...going beyond, *e.g.*, leading-order (LO) Bodek-Yang...
- these include both **higher perturbative accuracy** and **few-GeV corrections**

Gao, TJH Nadolsky, Sun, Yuan: 2107.00460



Brady, Accardi, TJH, Melnitchouk: PRD84 (2011) 9, 074008

$$F_3^{W^+} / F_3^{W^+}(0)$$



8 NNLO corrections, **DIS red. X-sect.**

TMCs, CC structure functions

GENIE opportunities: physics enhancements, ii

- hadronization: GENIE currently switches AGKY → Lund (Pythia)

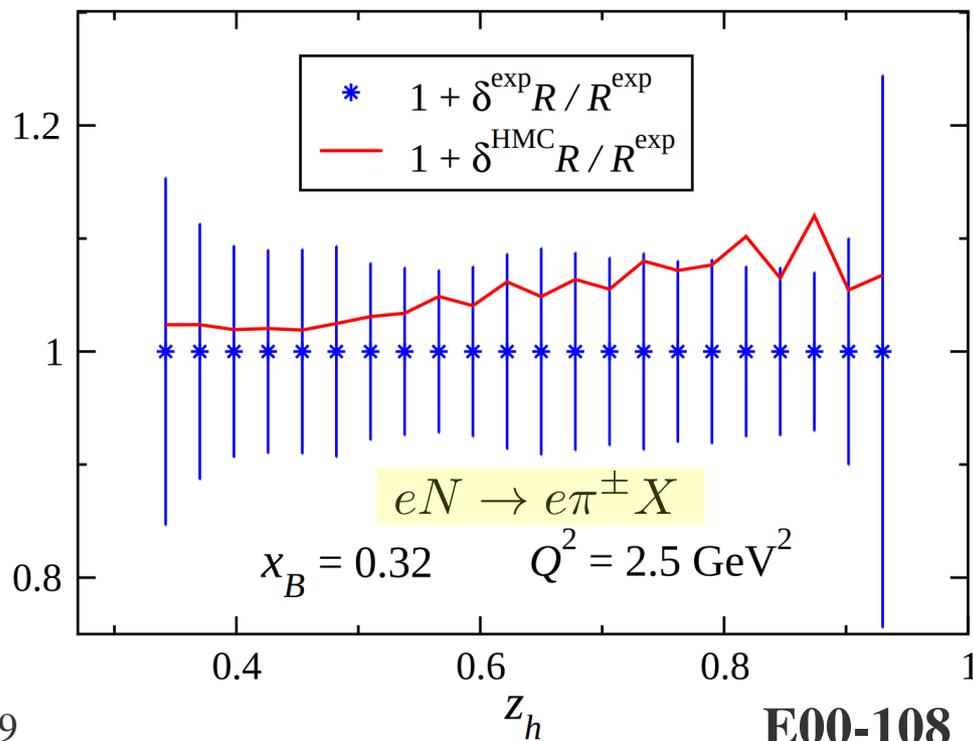
→ at finite Q^2 , \exists important mass, power-suppressed effects

- also: *are there* formal differences between weak, EM nuclear scattering?

→ opportunities for models

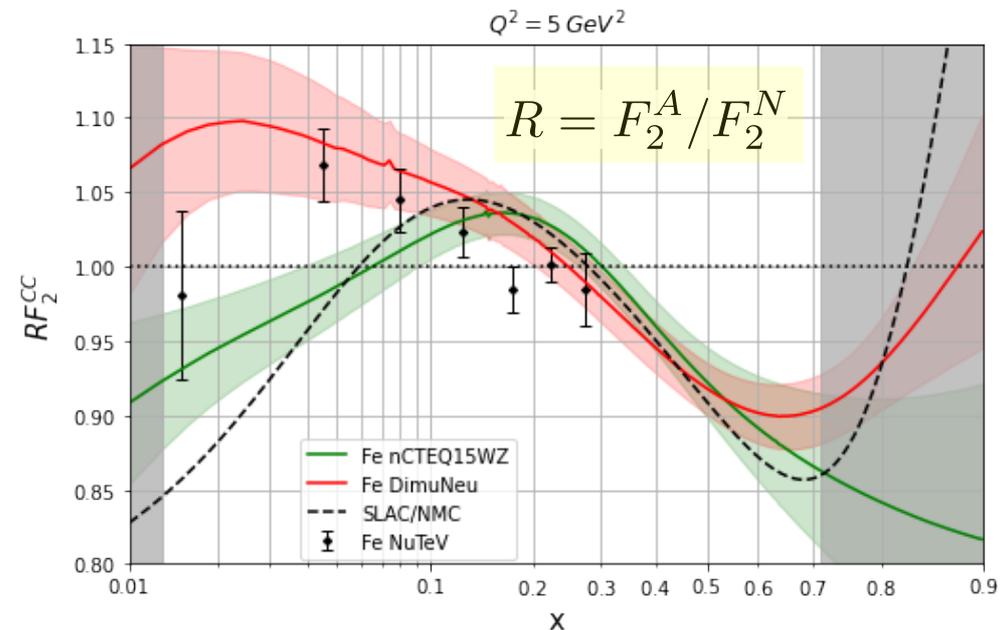
$$\frac{d\sigma}{dx_B dQ^2 dz_h} \sim \sum_q e_q^2 f_q(\xi_h, Q^2) D_q^h(\zeta_h, Q^2)$$

Accardi, TJH, Melnitchouk: JHEP11 (2009) 084



ongoing nCTEQ investigation(s)...

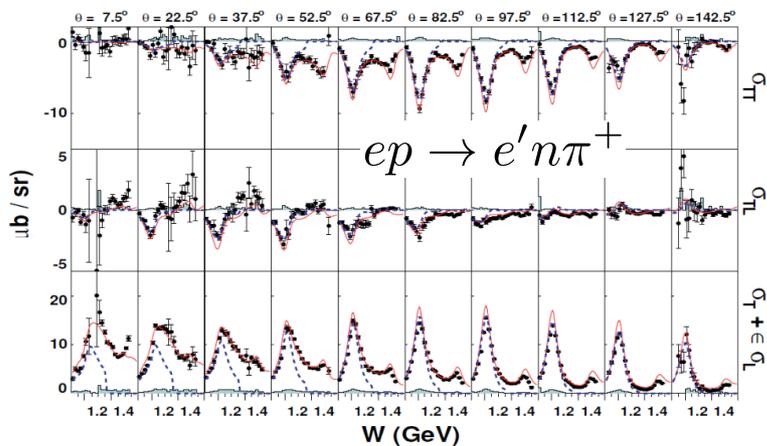
Muzakka, Duwentäster, TJH, et al.: 2107.13235



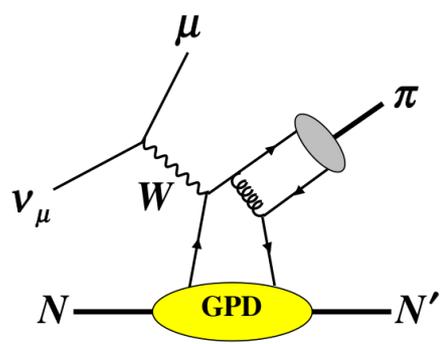
nuclear correction: SF ratio

GENIE opportunities: charged-lepton scattering

- for this reason, useful to further develop GENIE for charged-lepton
 - abundant constraining data; understand possible differences w.r.t. νA
 - extend from DIS/SIS to lower energies in resonance, elastic regions
- already information from JLab12 (CLAS12); synergies with future expts
 - e.g., GPD, form factor measurements at EIC

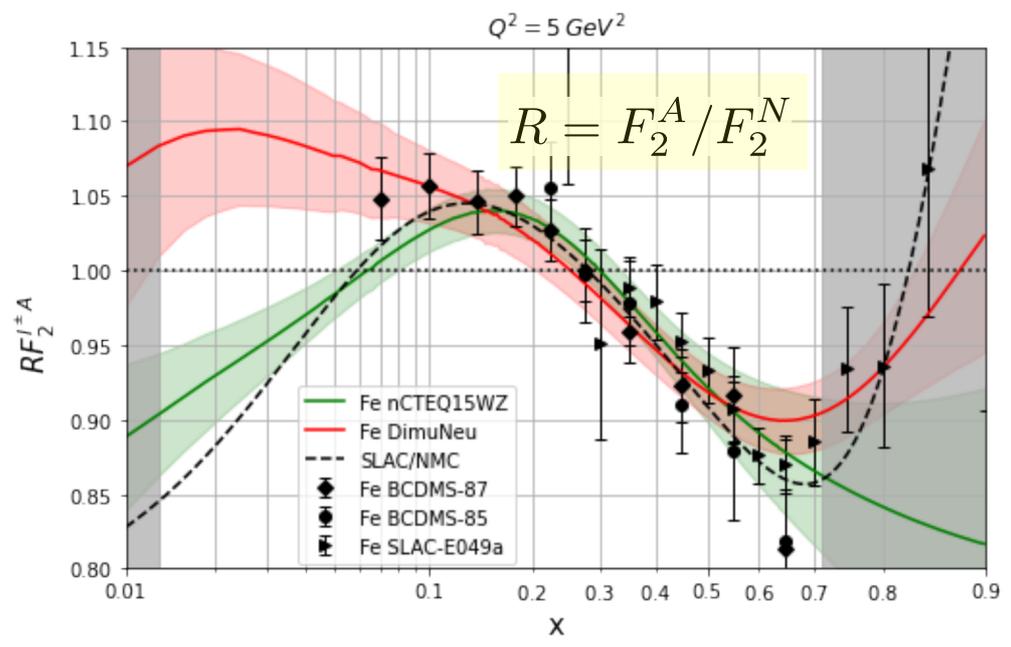


Egiyan, et al. PRC73, 025204 (2006)



EIC Yellow Report: 2103.05419

Muzakka, Duwentäster, TJH, et al.: 2107.13235



nuclear correction: SF ratio

conclusions: many opportunities for GENIE

- past work at the nuclear-HEP interface
 - particular focus on nonperturbative QCD; electroweak processes
 - pheno. focus on **DIS, SIS; nuclear** processes

.....
- exciting opportunities to further extend GENIE
 - **understand** uncertainties and parametric dependences, correlations
 - envision campaign to **enhance theory, physics ingredients**
 - application to **charged-lepton** is valuable; will yield insights
 - improvements accompanied by technical code development

.....
- openings for collaboration; **programmatic course emerging**