Guido Altarelli Award 2024

The Guido Altarelli Award honors the memory
of the late Guido Altarelli, one of the founding fathers of QCD,
an outstanding communicator of particle physics,
and a mentor and strong supporter of Junior Scientists.

Guido Altarelli Award 2024

Thank you to our sponsors

25 YEARS OF EPJ.org
your physics journal

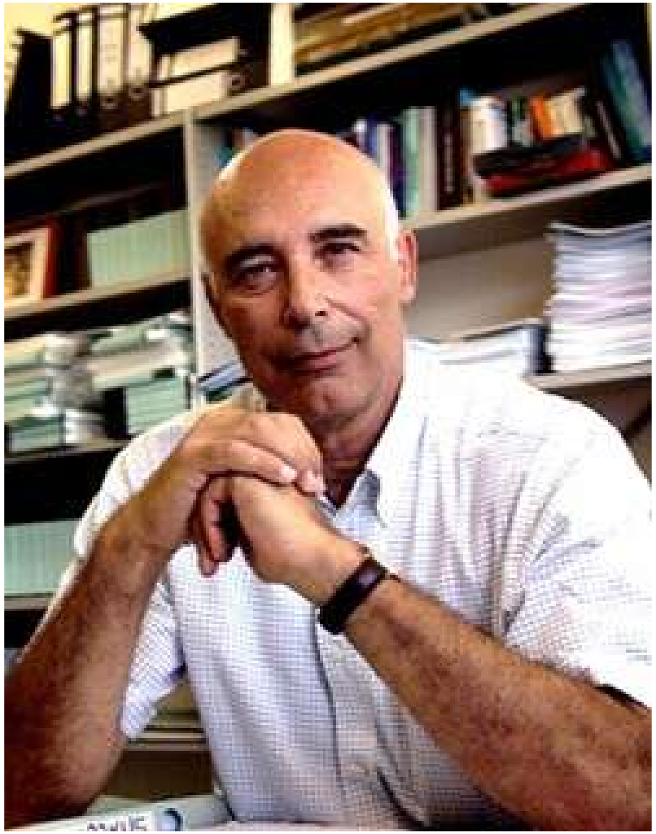
World Scientific
Connecting Great Minds

CENTRO RICERCHE ENRICO FERMI

Some History

First IAC

Guido Altarelli
John Dainton
Joel Feltesse
Aharon Levy
Lev Lipatov
James Stirling
Gunter Wolf



Some History … *first hand*

Professor Stefano Forte

University of Milan

… a close collaborator of Guido Altarelli

Spokesperson: NNPDF Collaboration

Editor & Co-Author:

“From My Vast Repertoire...: Guido Altarelli's Legacy”

Research interests include
theory of strong interactions, perturbative QCD,
properties of the Higgs boson, resummation,
development of computational techniques, &
use of AI methods for the determination of PDFs

Award History

Previous prize winners

Guido Altarelli Award Winners:

Year	Theory Award	Experimental Award	DIS Workshop Location
2023	Yong Zhao	Adinda de Wit	DIS2023 East Lansing, MI, (USA)
2022	Bernhard Mistlberger	Adi Ashkenazi	DIS2022 Santiago de Compostela (Spain)
2021	Eleni Vryonidou	Benjamin Nachman	DIS2021 online
2020	Pier Francesco Monni	Philip Ilten	DIS2020
2019	Jonathan Gaunt	Josh Bendavid	DIS2019 Torino (Italy)
2018	Jun Gao	Or Hen	DIS2018 Kobe (Japan)
2017	Maria Ubiali	Paolo Gunnellini	DIS2017 Birmingham (UK)
2016	Fabrizio Caola	Jan Kretzschmar	DIS2016 Hamburg (Germany)

See the webpage at:

https://www.desy.de/~gallo/AltarelliAward/

Guido Altarelli Award 2024

Thank you to our sponsors:

Centro Fermi **World Scientific** **Springer EPJ**

Thanks to all of you who nominated candidates.
This year we had impressive applications and difficult deliberations.

The selection committee in 2024: Rolf Ent (JLAB),
Elisabetta Gallo (deputy-chair, DESY and University of Hamburg),
Aharon Levy (Tel Aviv, co-chair of DIS), Fred Olness (chair, SMU),
Andrea Gabrielli (CREF), Juan Terron (UAM),
Yuji Yamazaki (Kobe), Maria Ubiali (Cambridge)

Holly Szumila-Vance

2020-Present: Staff Scientist I,
Halls A/C, Jefferson Lab

2019-2020: Postdoctoral Fellow,
MIT/GWU

2017-2019: Postdoctoral Fellow,
Hall C, Jefferson Lab

2017: Old Dominion University

Jefferson Lab Graduate Fellowship

Guido Altarelli Award 2024

awarded to

Holly Szumila-Vance

for her outstanding contributions

to investigations of color transparency

and other nuclear manifestations of QCD

Prof. Andrea Gabrielli **(CREF Scientific Director)**	**Dr. Christian Caron** **(Springer Executive Editor)**	**Prof. K.K. Puha** **(Chairman, WS Publishing)**	**Profs. Aharon Levy** **& Paul R. Newman** **(Chairs IAC of DIS2024)**

XXXI International Workshop on Deep-Inelastic Scattering and Related Subjects, 8-12 April 2024, Grenoble, France

Javier Mazzitelli

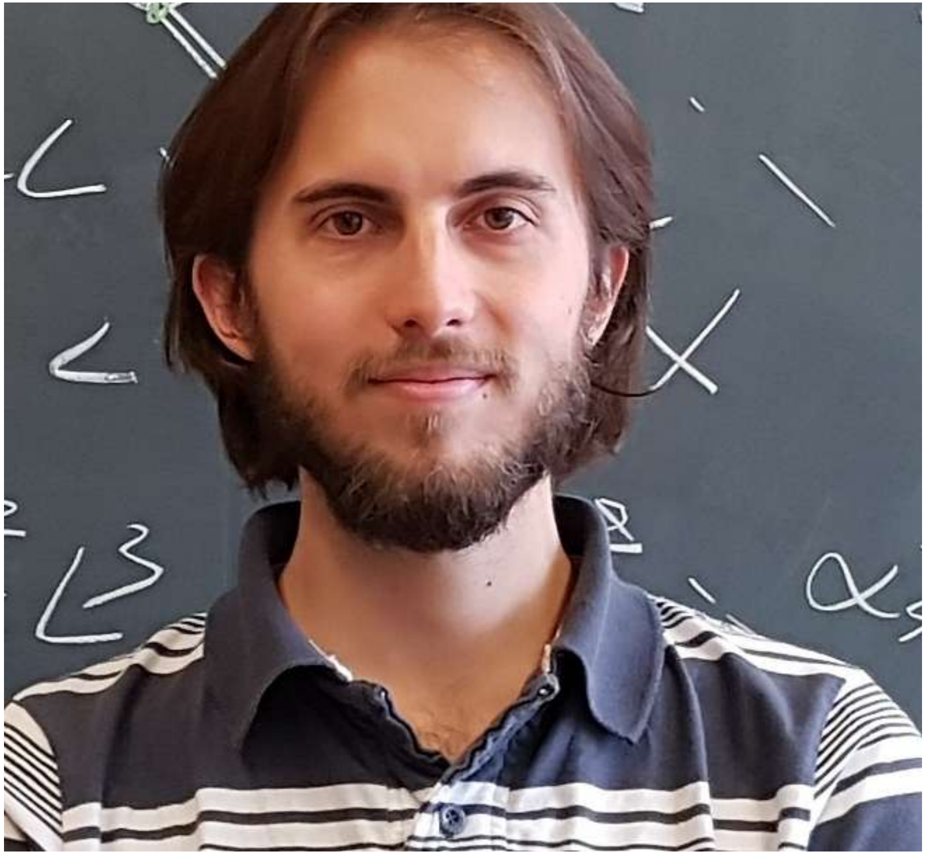
2016: PhD at University of Buenos Aires
- "QCD Effects in Higgs Physics"
- Giambiagi award for best Doctoral Thesis in Theoretical Physics in Argentina

2016-2019: Postdoc University of Zurich

2019-2022: Postdoc Max Planck Institute

2022-Present: Postdoc Paul Scherrer Institute

2018-Present: co-convener of the LHC Higgs Working Group 4 *(former double-Higgs subgroup)*



Guido Altarelli Award 2024

awarded to

Javier Mazzitelli

for his outstanding contributions
to precision calculations in Higgs boson
and top quark production at the LHC

Prof. Andrea Gabrielli (CREF Scientific Director)	Dr. Christian Caron (Springer Executive Editor)	Prof. K.K. Puha (Chairman, WS Publishing)	Profs. Aharon Levy & Paul R. Newman (Chairs IAC of DIS2024)

XXXI International Workshop on Deep-Inelastic Scattering and Related Subjects, 8-12 April 2024, Grenoble, France

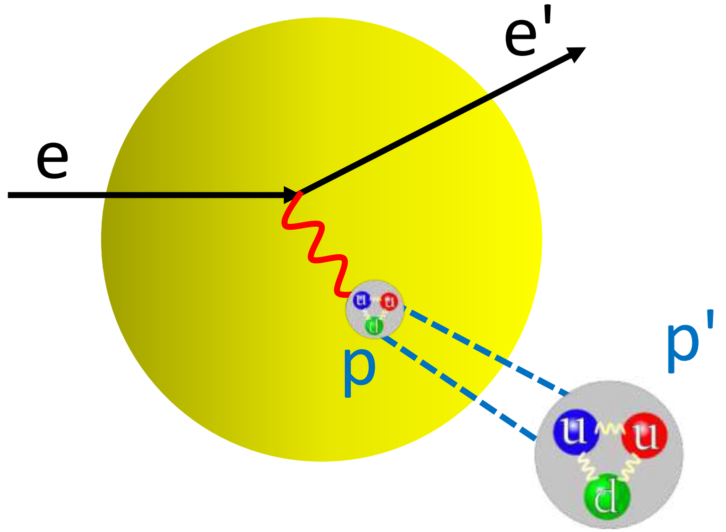
Chasing the QCD signatures in nuclei

Holly Szumila-Vance
Jefferson Lab
DIS 2024

Jefferson Lab

Color transparency is a fundamental prediction of pQCD

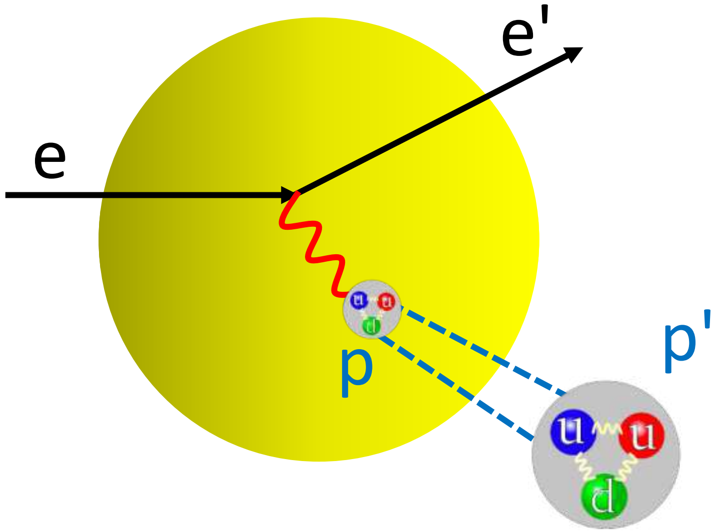
Introduced by
Mueller and Brodsky, 1982



Vanishing of final state interactions of hadrons with nuclear medium in exclusive processes at high momentum transfer

Color transparency is a fundamental prediction of pQCD

Quantum mechanics:
Shorter wavelength photons are absorbed on smaller-size hadrons (*squeezing*, transferred momentum)



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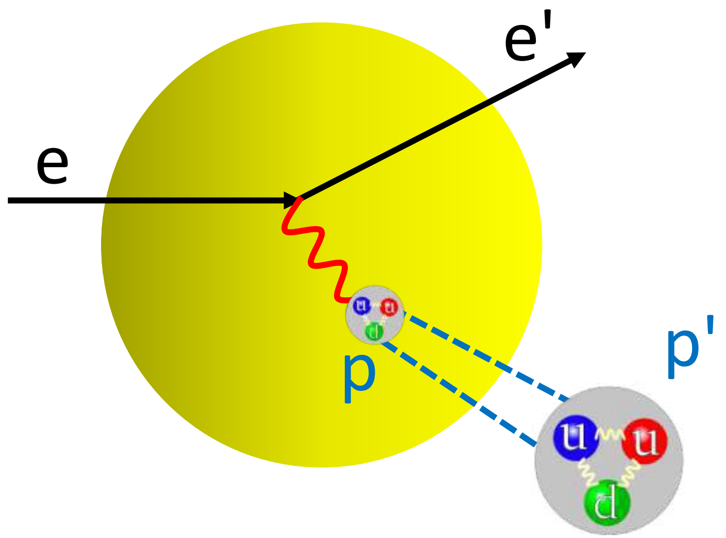
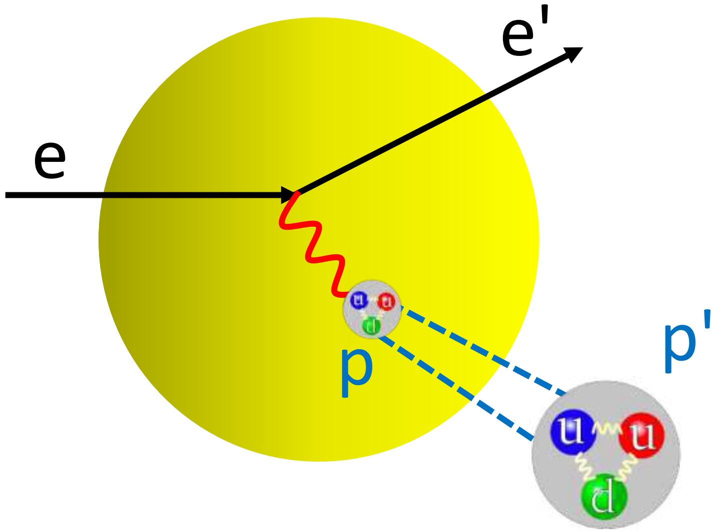


Relativity:
Maintains this small size as it propagates out of the nucleus (*freezing*, transferred energy)

$$\gamma t_l = \frac{E}{m} t_l$$

Color transparency is a fundamental prediction of pQCD

Quantum mechanics:
Shorter wavelength photons are absorbed on smaller-size hadrons (*squeezing*, transferred momentum)

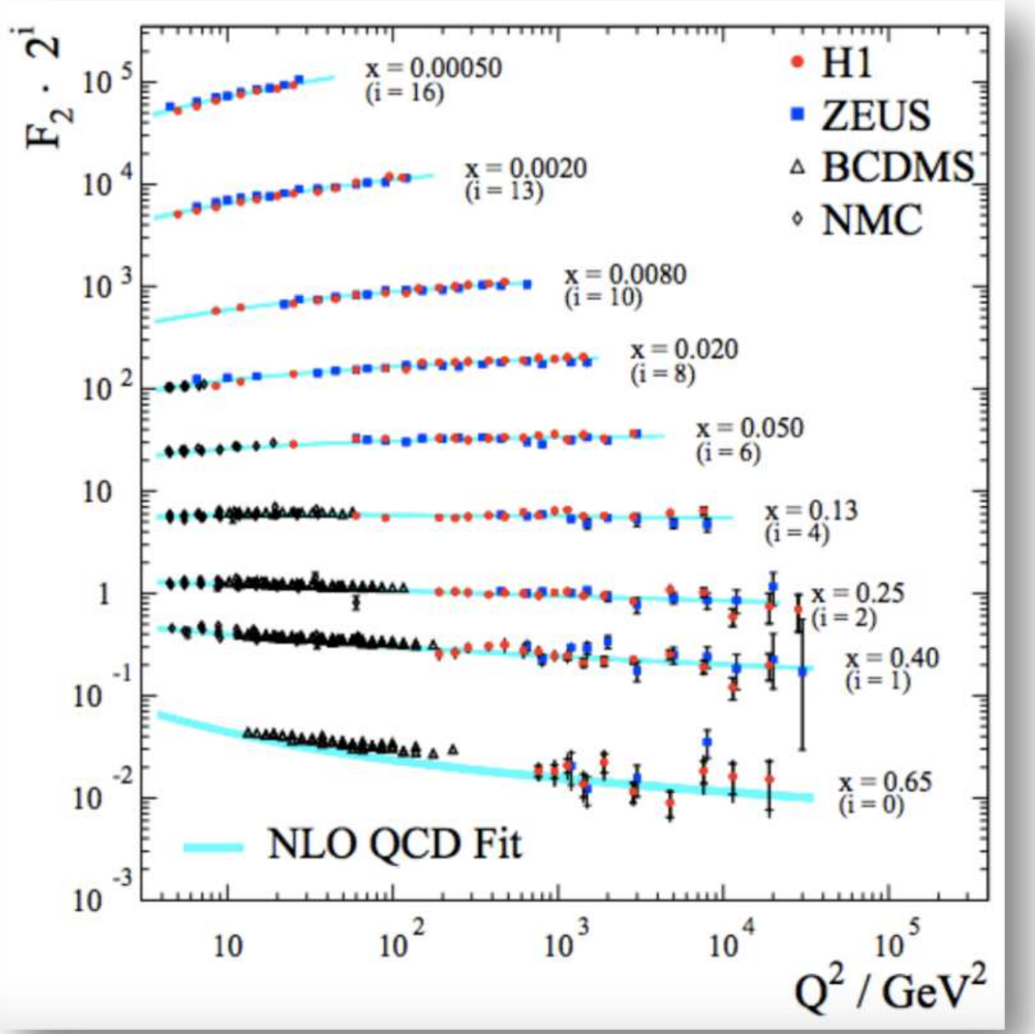


Relativity:
Maintains this small size as it propagates out of the nucleus (*freezing*, transferred energy)

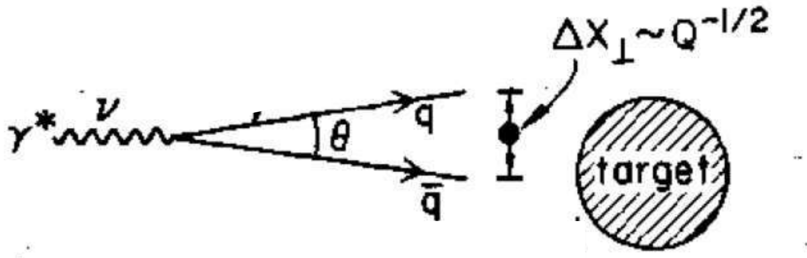
Strong force:
Experience reduced attenuation in the nucleus, color screened

$$\sigma_{PLC} \approx \sigma_{hN} \frac{b^2}{R_h^2}$$

First indirect evidence of CT:
Bjorken scaling at small x



Small x ($\leq 10^{-2}$) → long longitudinal distances
Virtual photon fluctuates into a $q\bar{q}$ pair



Scaling shows no evidence of this interaction

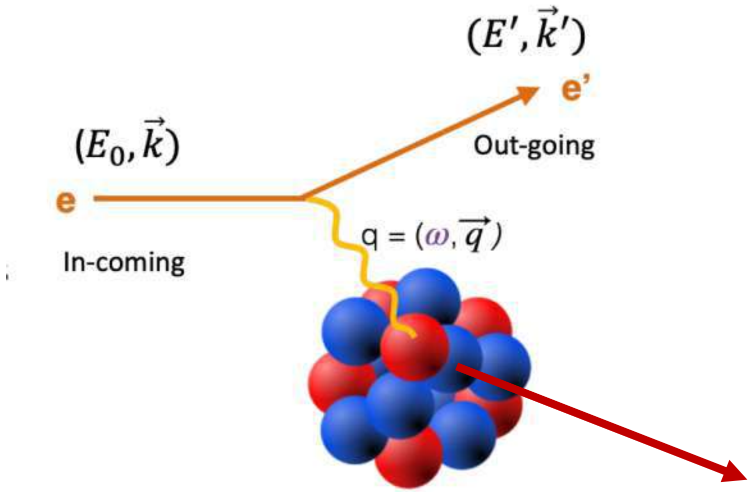
Bjorken, SLAC-PUB-1756
Frankfurt and Strikman, Phys Rep 160, 235 (1988)

So how do we observe small-sized configurations directly?

So how do we observe small-sized configurations directly?

We start by measuring the **Nuclear Transparency**:

Probability knocked out proton in scattering to be deflected or absorbed.



So how do we observe small-sized configurations directly?

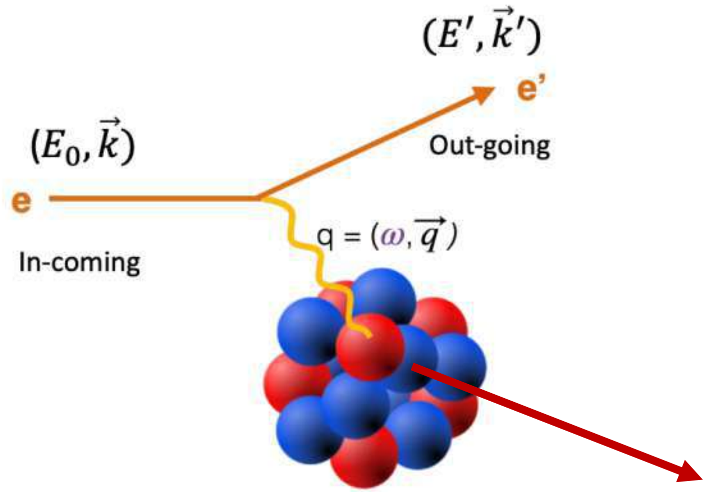
We start by measuring the **Nuclear Transparency**:

Probability knocked out proton in scattering to be deflected or absorbed.

$$T_A = \frac{\sigma_A}{A\ \sigma_N}$$

(nuclear cross section)

(free nucleon cross section)

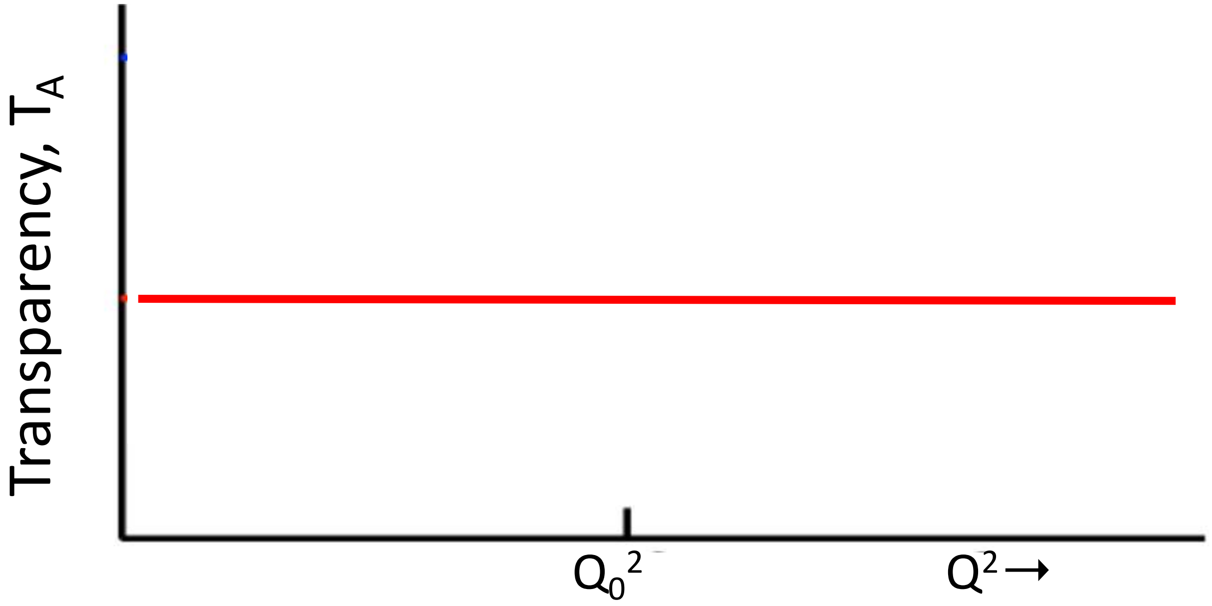


$$\sigma_A = \sigma_N\ A^{\alpha}$$

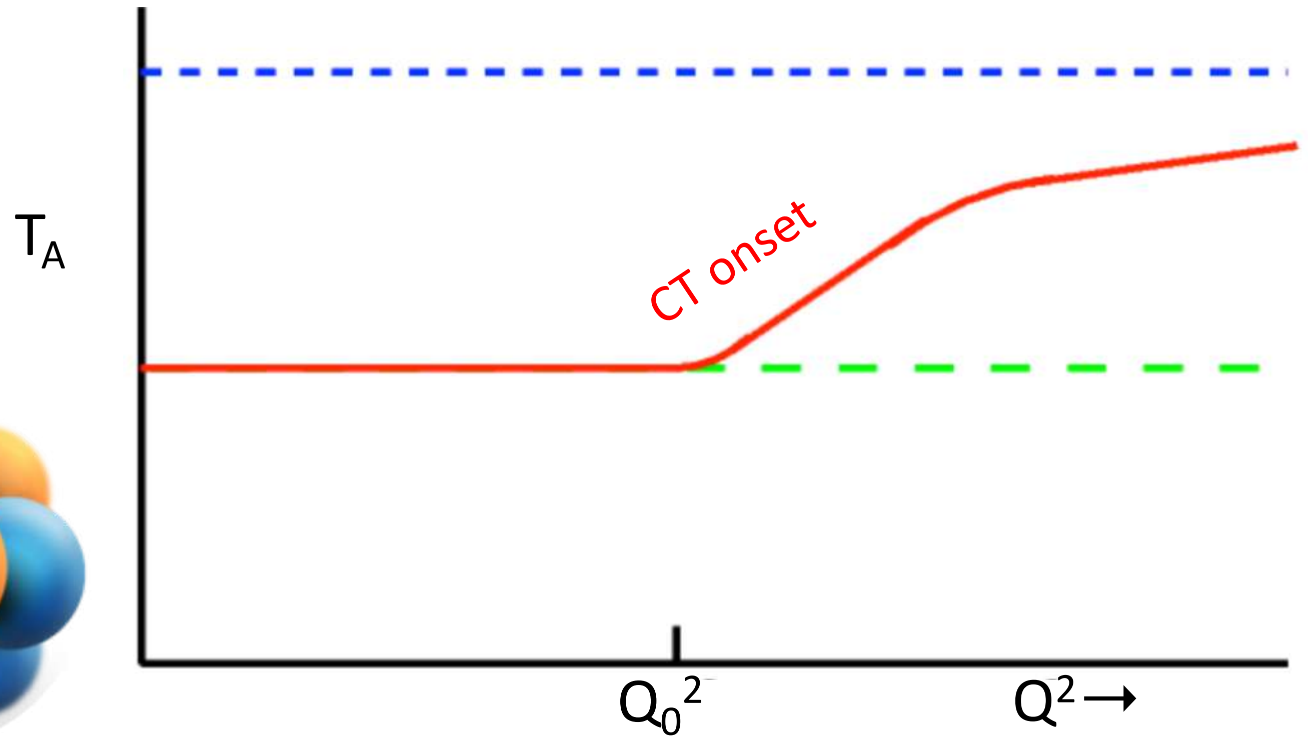
Transparency in the strongly interacting hadronic picture

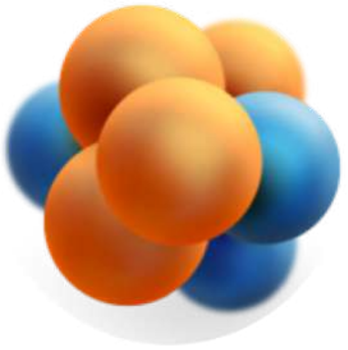
$$T_A = \frac{\sigma_A}{A\,\sigma_N}$$

- scattering cross section
- Glauber multiple scattering (interaction between scattered proton and residual nucleons)
- NN Correlations and Final State Interaction (FSI) effects



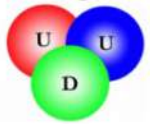
Onset of CT indicates the transition to quark-gluon degrees of freedom!





CT onset experiments

Baryon



A(p,2p): BNL
A(e,e'p): SLAC, JLab

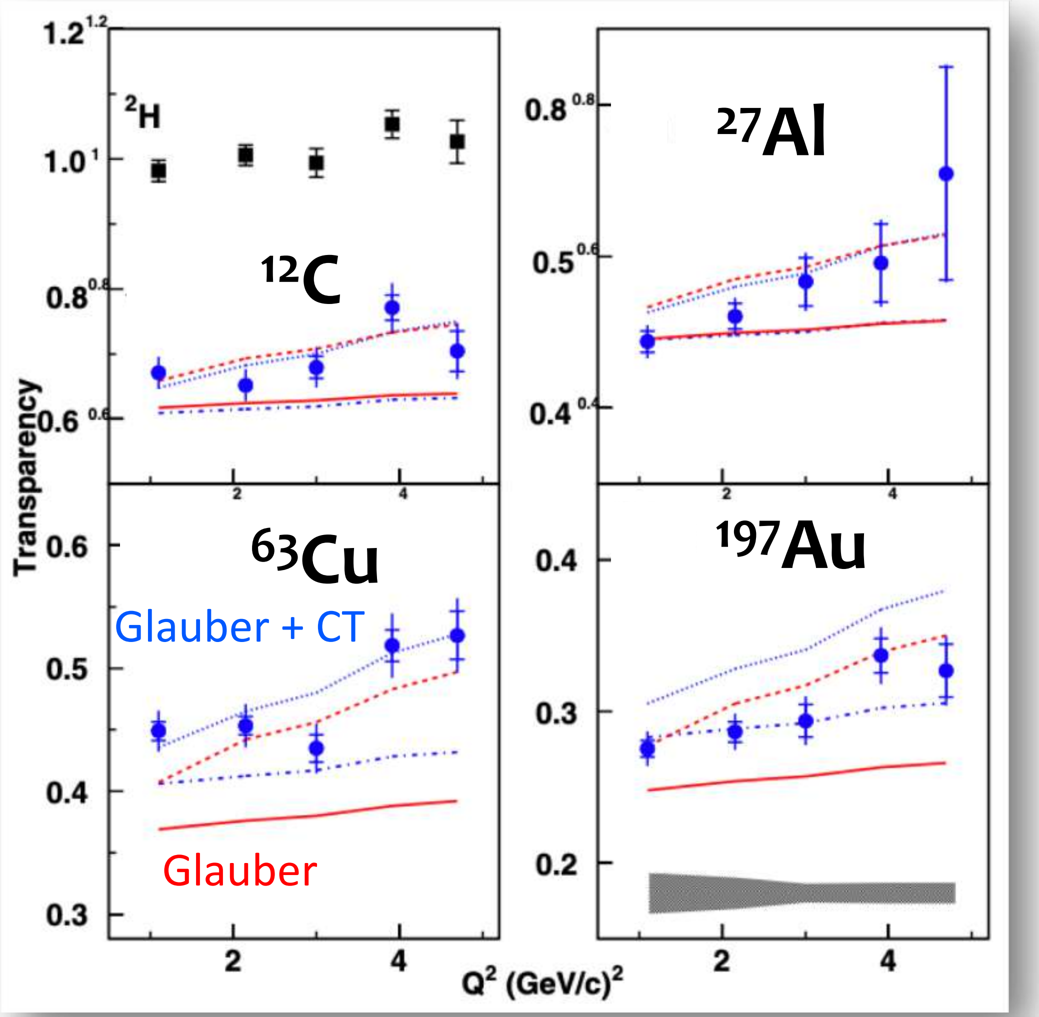
Meson

A(π,di-jet): FNAL
A(γ, π^- p): JLab
A(e, e'π^+): JLab
A(e, e'ρ^0): DESY & JLab

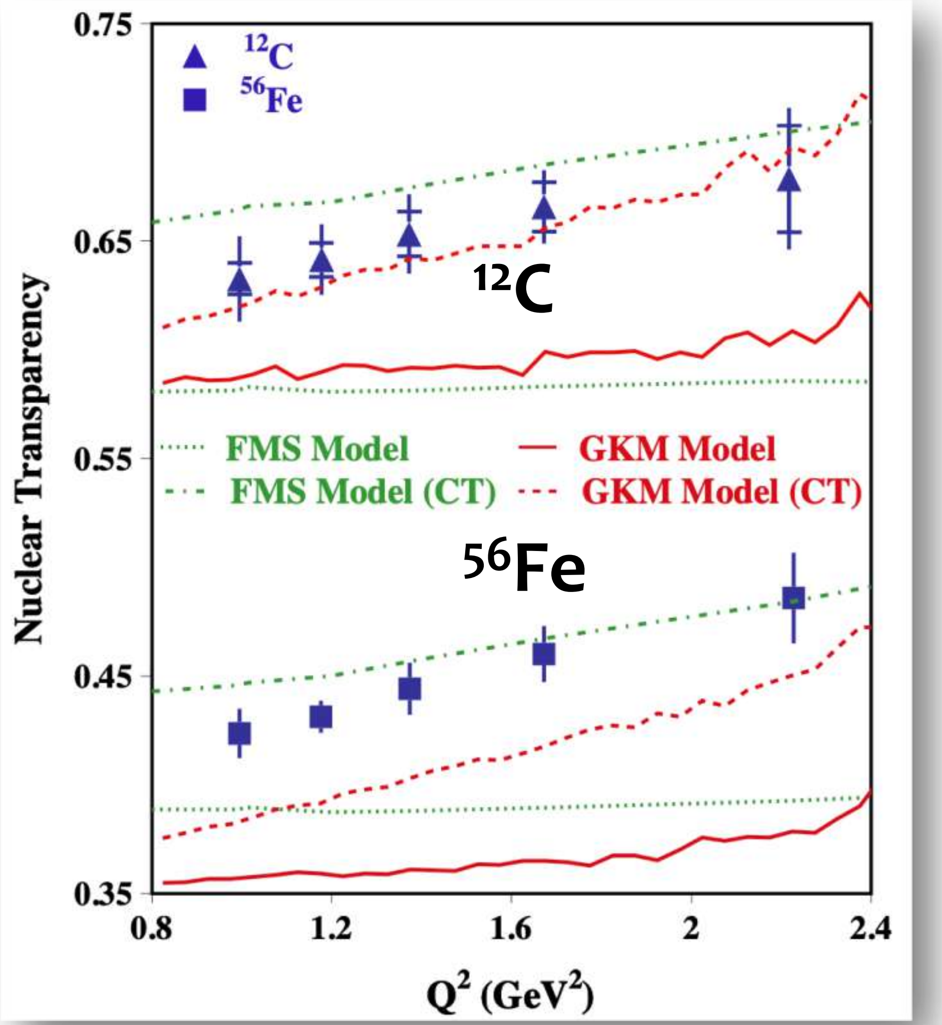
Jefferson Lab is uniquely suited to measure the onset regime.

CT onset for mesons observed at a few GeV²

A(e,e'π^+)



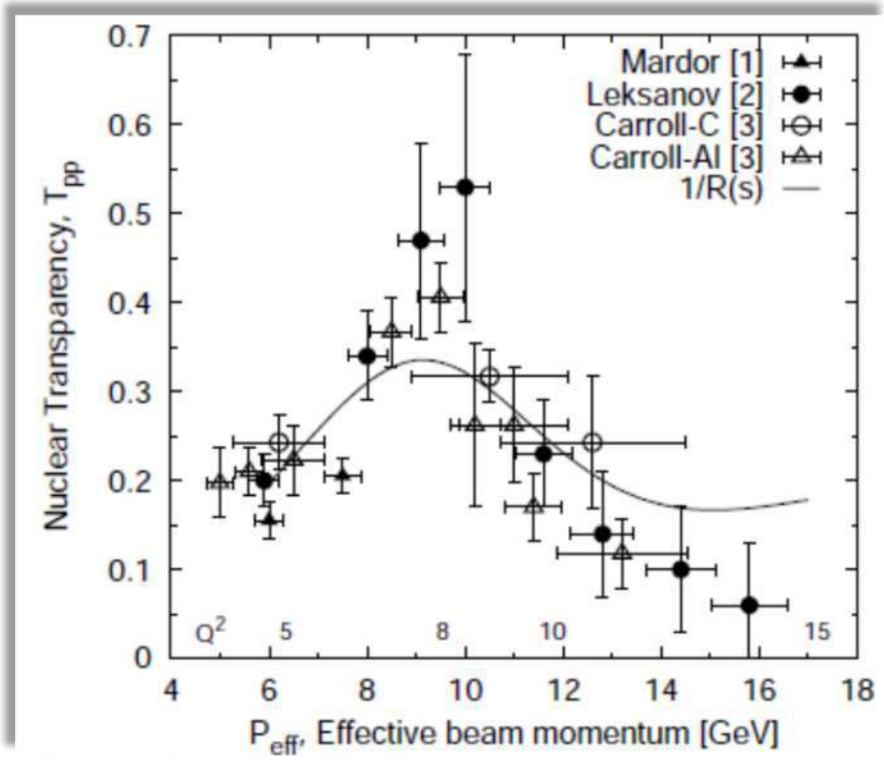
A(e,e'ρ^0)



B. Clasie et al, PRL99:242502 (2007)
X. Qian et al, PRC81:055209 (2010)

L. El Fassi et al, PLB 712,326 (2012)
L. El Fassi, Physics 4, no. 3 (2022)

First attempt to measure the onset in protons



A. Leksanov et al. PRL 87 (2001)
J. L. S. Aclander et al., PRC 70 (2004)

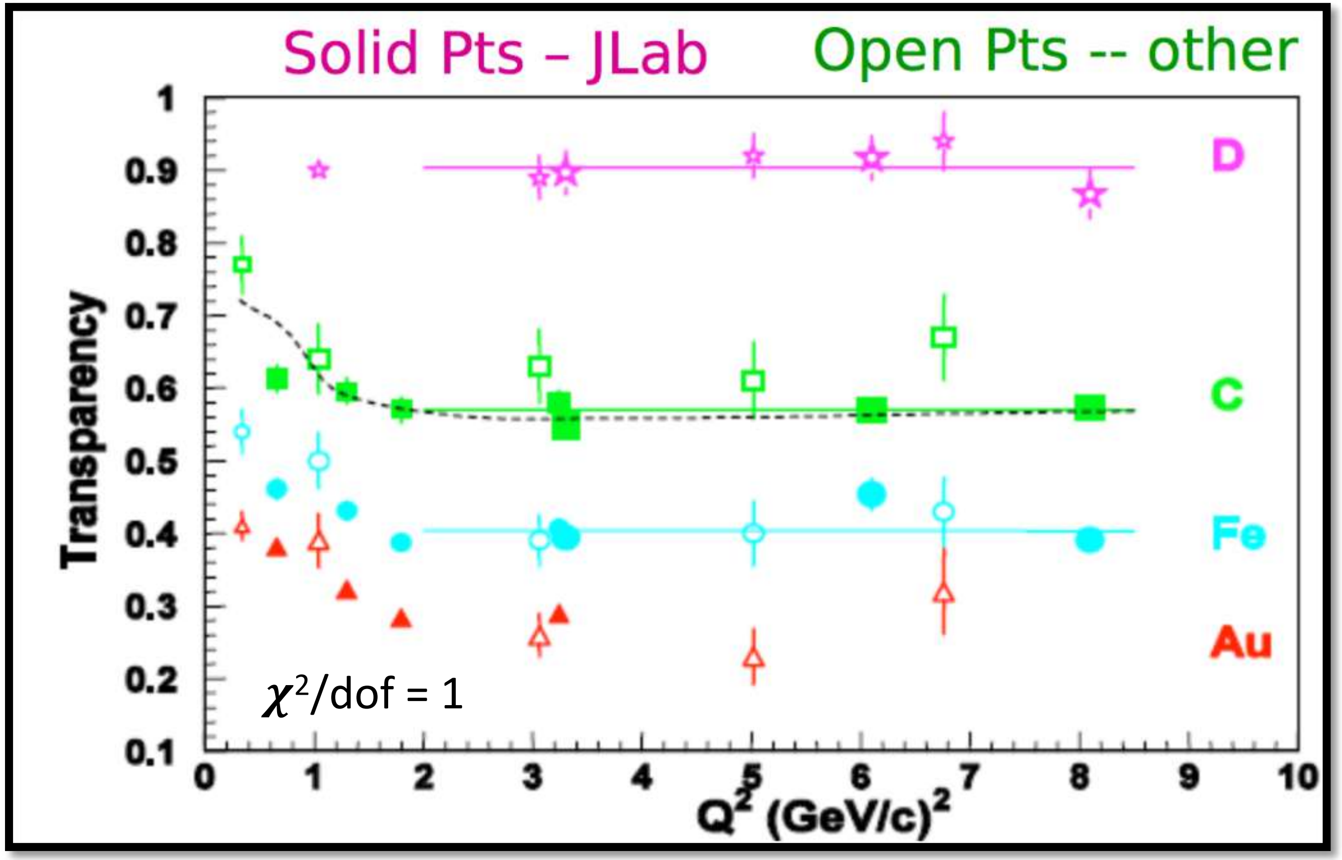
Transparency in A(p,2p) experiment at Brookhaven:

- observed enhancement in transparency
- inconsistent with CT only
- could be explained by including nuclear filtering[1] or charm resonance[2]

[1](Jain, Pire, Ralston)
[2](Brodsky, de Teramond)

No CT onset in protons in A(e,e'p)

No evidence for CT in A(e,e'p) up to $Q^2<8\ GeV^2$



N. C. R. Makins et al. PRL 72, 1986 (1994)
G. Garino et al. PRC 45, 780 (1992)
D. Abbott et al. PRL 80, 5072 (1998)
K. Garrow et al. PRC 66, 044613 (2002)

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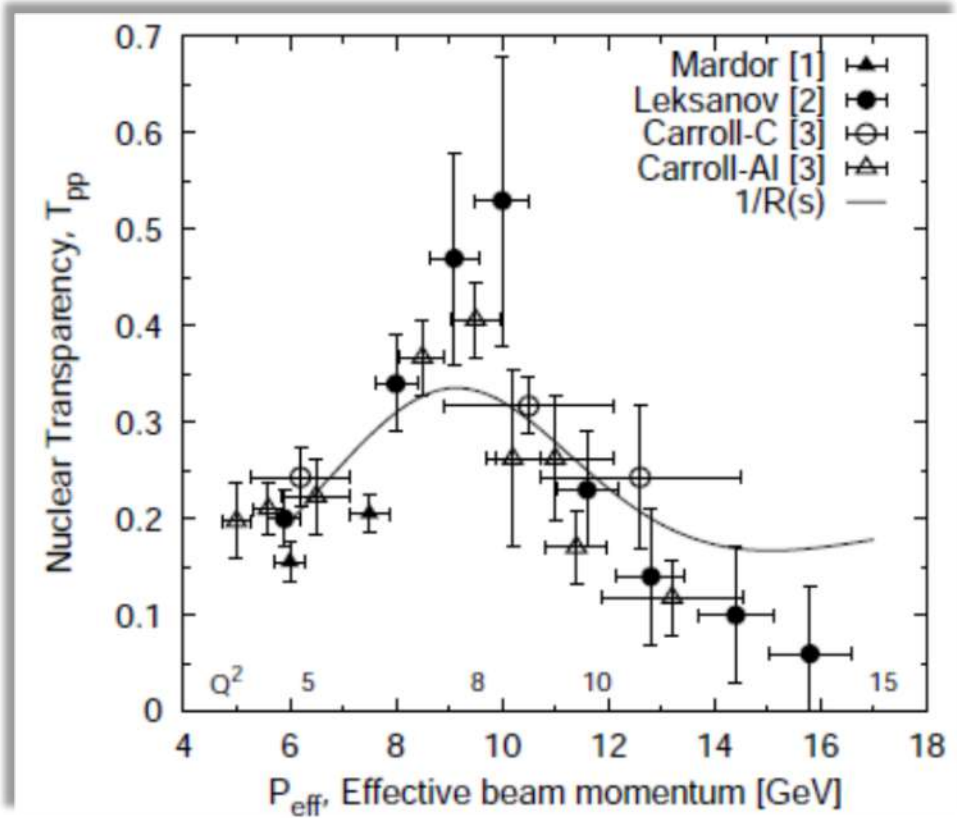

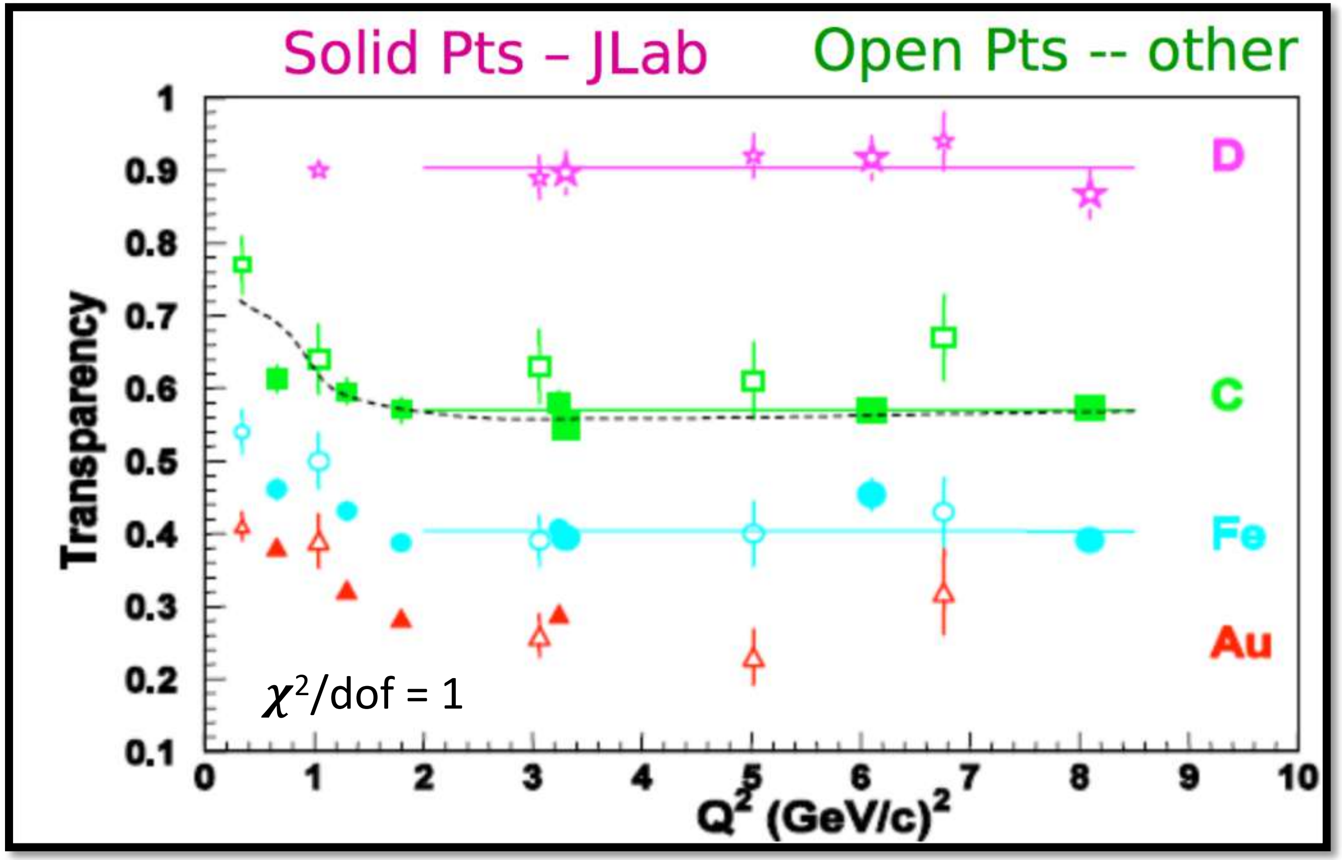

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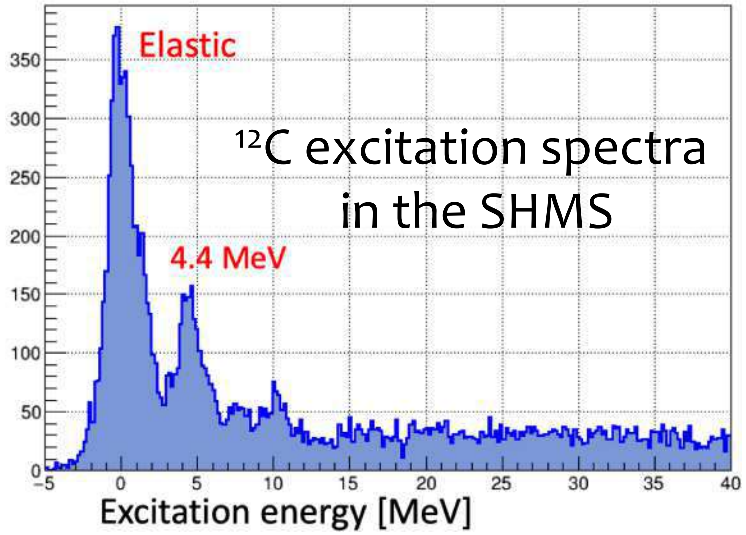
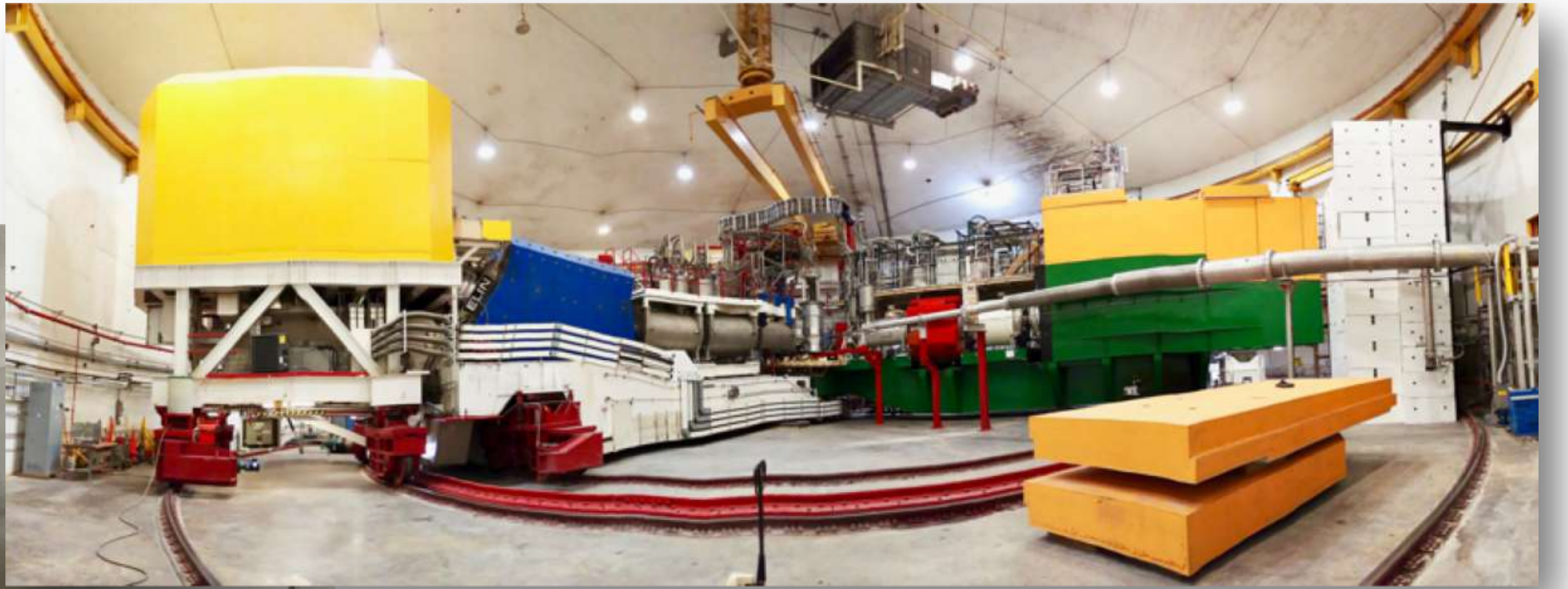
D. Abbott et al. PRL 80, 5072 (1998)
K. Garrow et al. PRC 66, 044613 (2002)

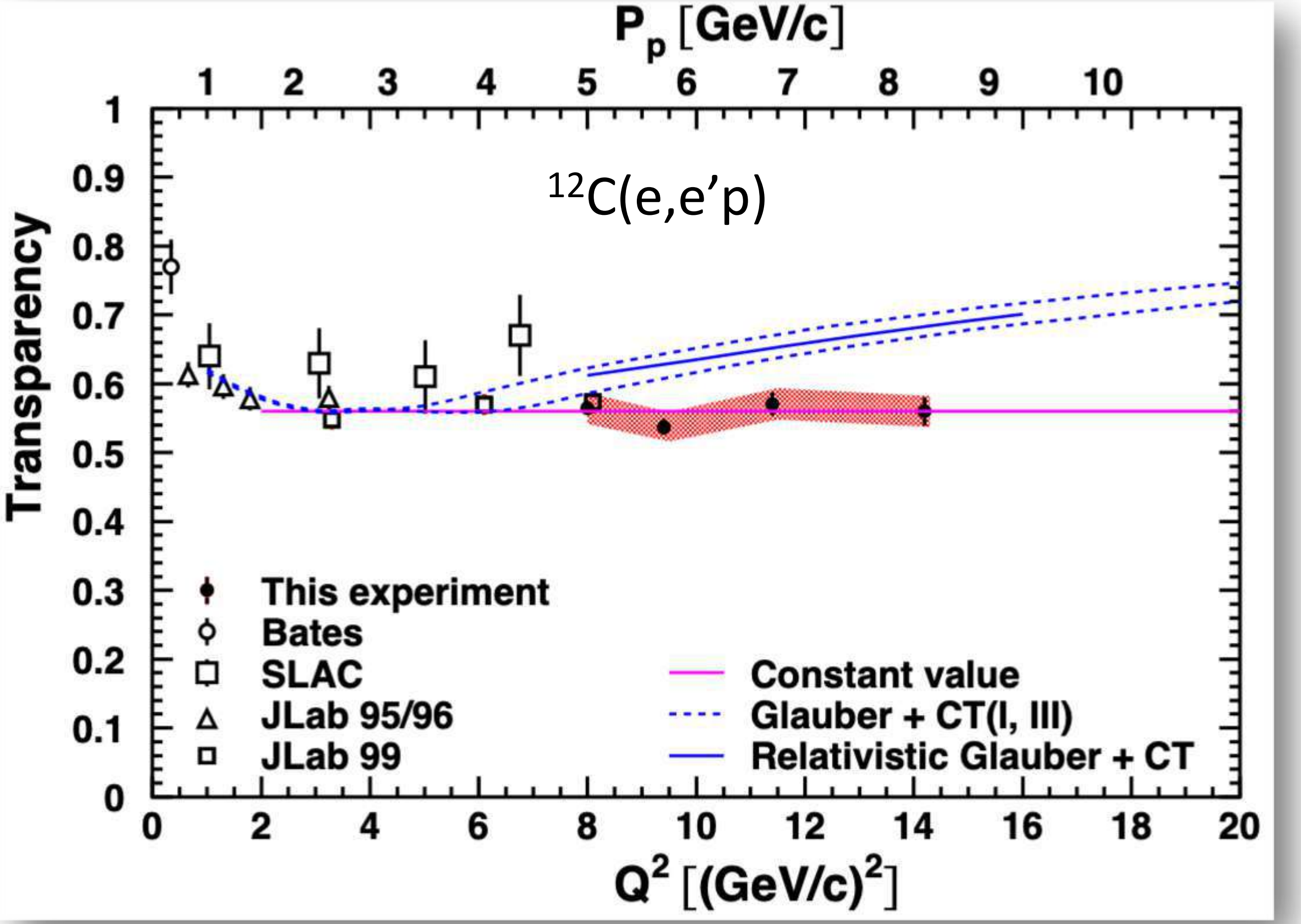
Commissioned the new SHMS spectrometer for the 12 GeV era





The new SHMS ran for the first time in the proton CT experiment in Hall C (enabling higher proton momenta)

Even with increased proton momenta, no observation for the onset of CT



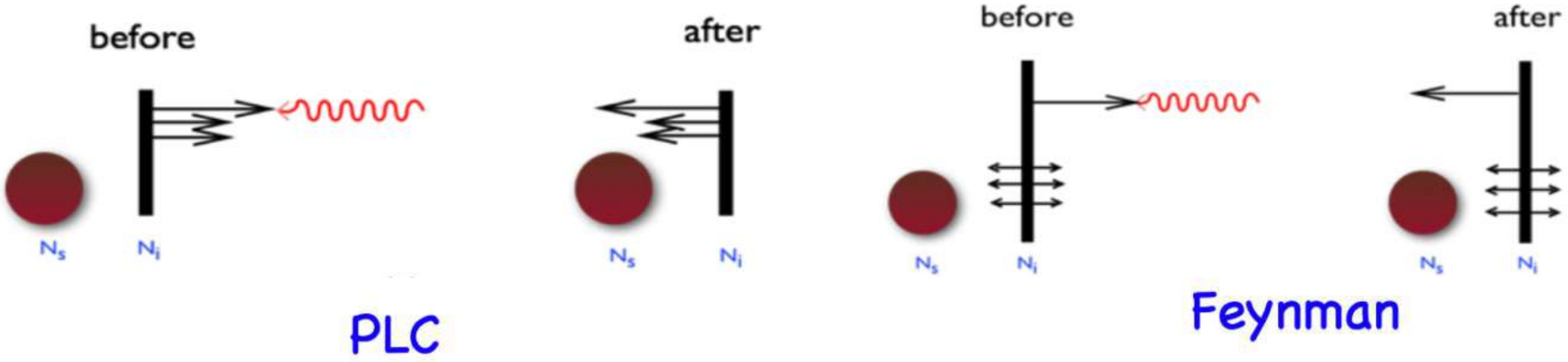
D. Bhetuwal et al, PRL126:082301 (2021)

Probably no PLC was formed...

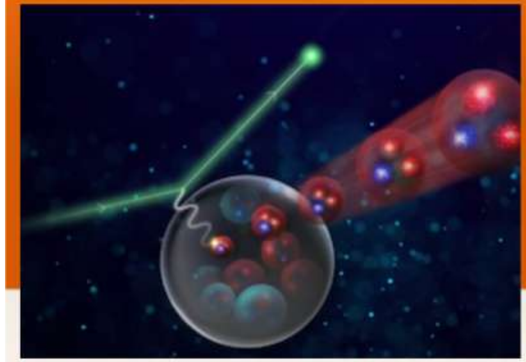
G. Miller, *Physics 2022*

O. Caplow-Munro and G. Miller, PRC 104 (2021)

Squeezing didn't work (Feynman Mechanism)



Susceptible to expansion effects



The Future of Color Transparency and Hadronization Studies at Jefferson Lab and Beyond

(Organizer)

https://indico.jlab.org/event/437

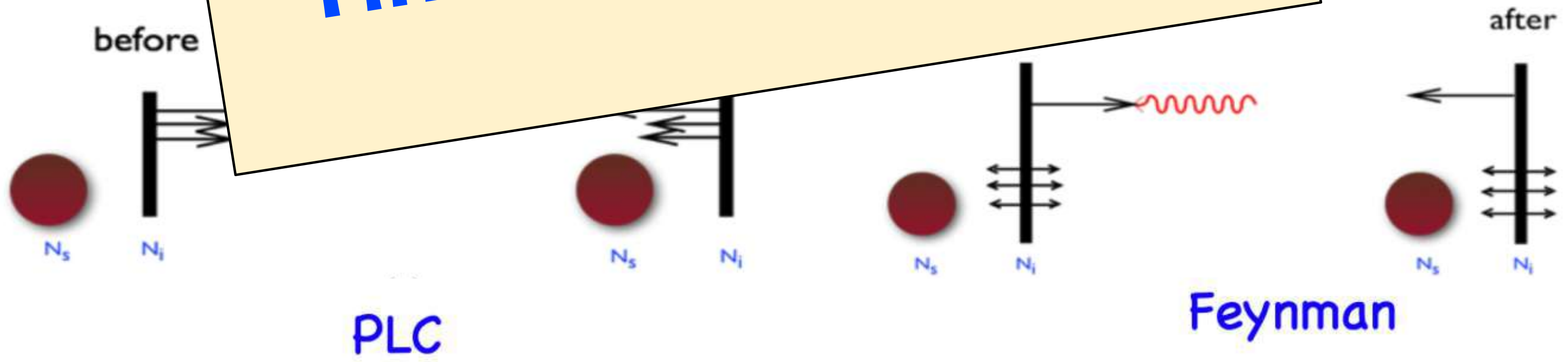
7-8 June 2021
Online
US/Eastern timezone

Probably … ned...

Time for new ideas!

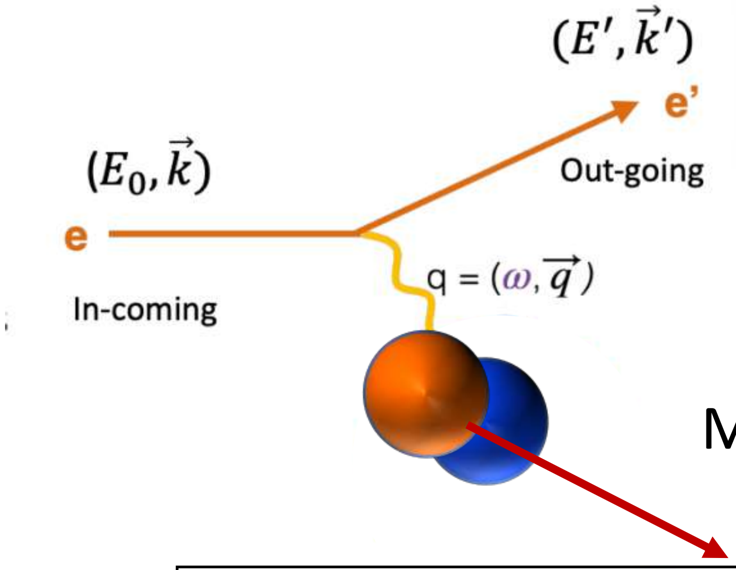
Squeezing didn't wor

G. Miller, Physics 2022
Munro and G. Miller, PRC 104 (2021)



Susceptible to expansion effects

Changing the strategy: kinematics and target!

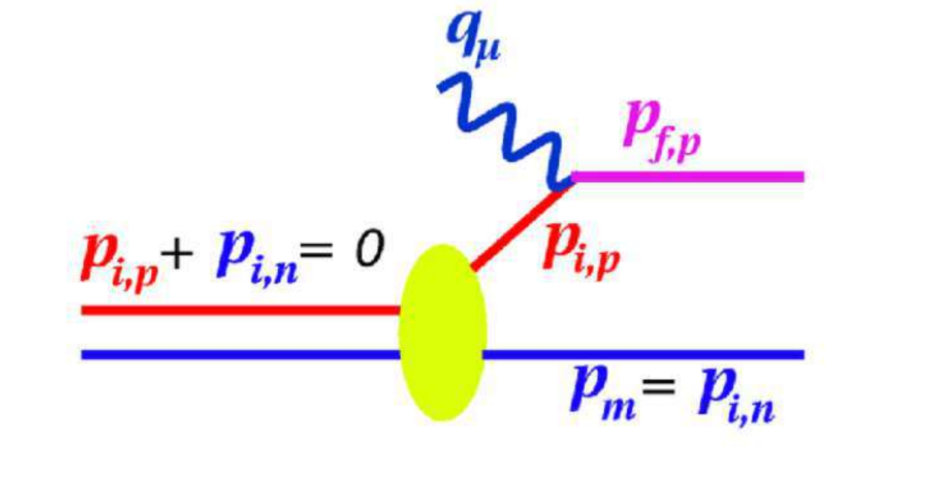


Proposal to PAC 51:
Color Transparency in Maximal Rescattering Kinematics

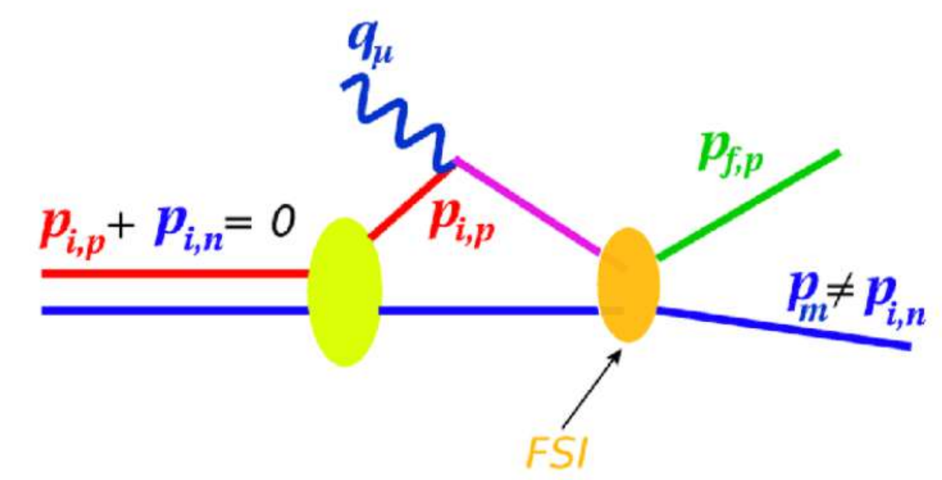
Szumila-Vance et al (spokesperson), JLab Experiment E12-23-010

Deuterium is well-described through the Generalized Eikonal Approximation (GEA)

Measure the knocked out proton & reconstruct the neutron



Plane Wave Impulse Approximation (PWIA)



Final State Interactions (FSI)

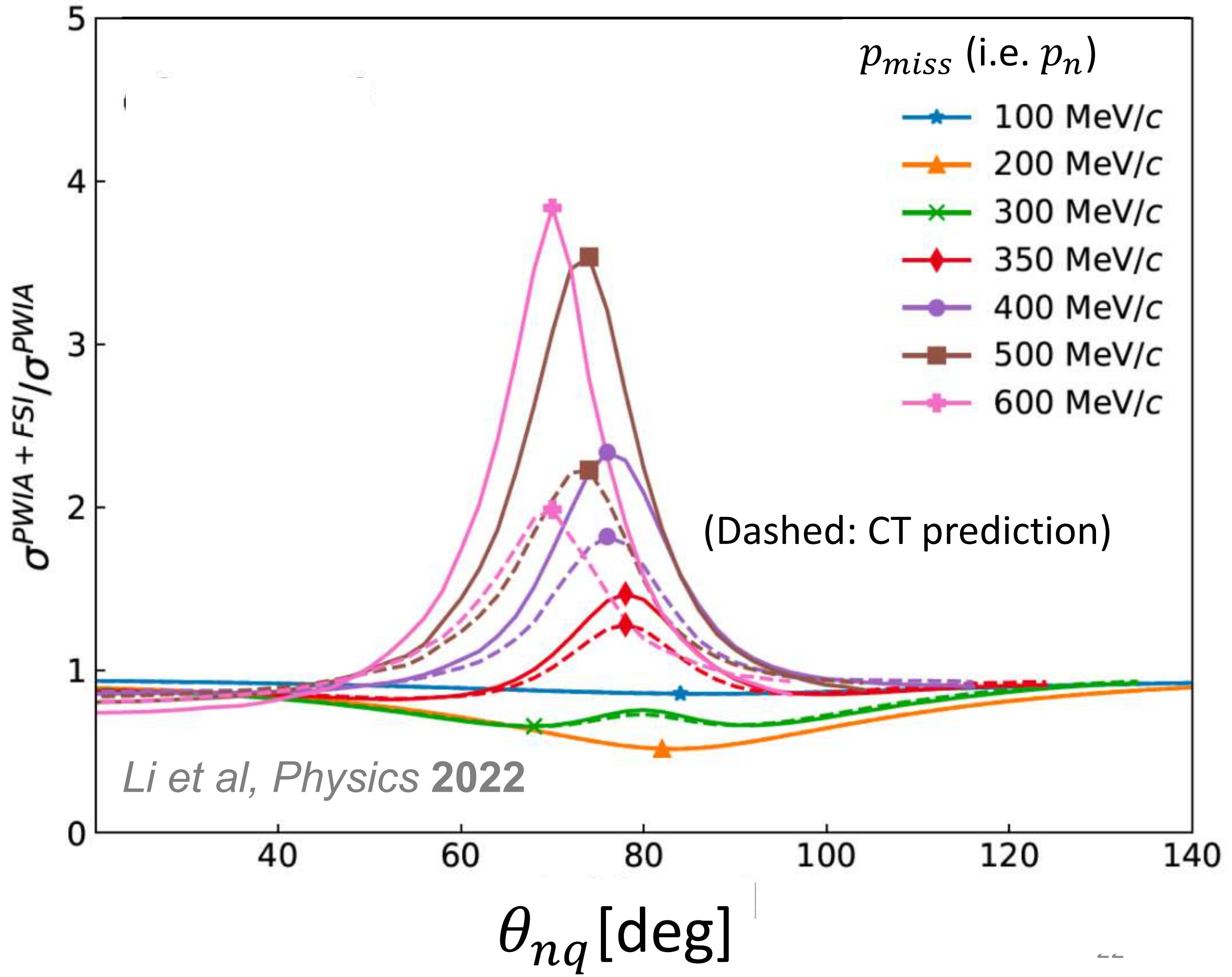
Looking in the region of high FSIs for CT

Specific choice of kinematics → large FSIs from double scattering

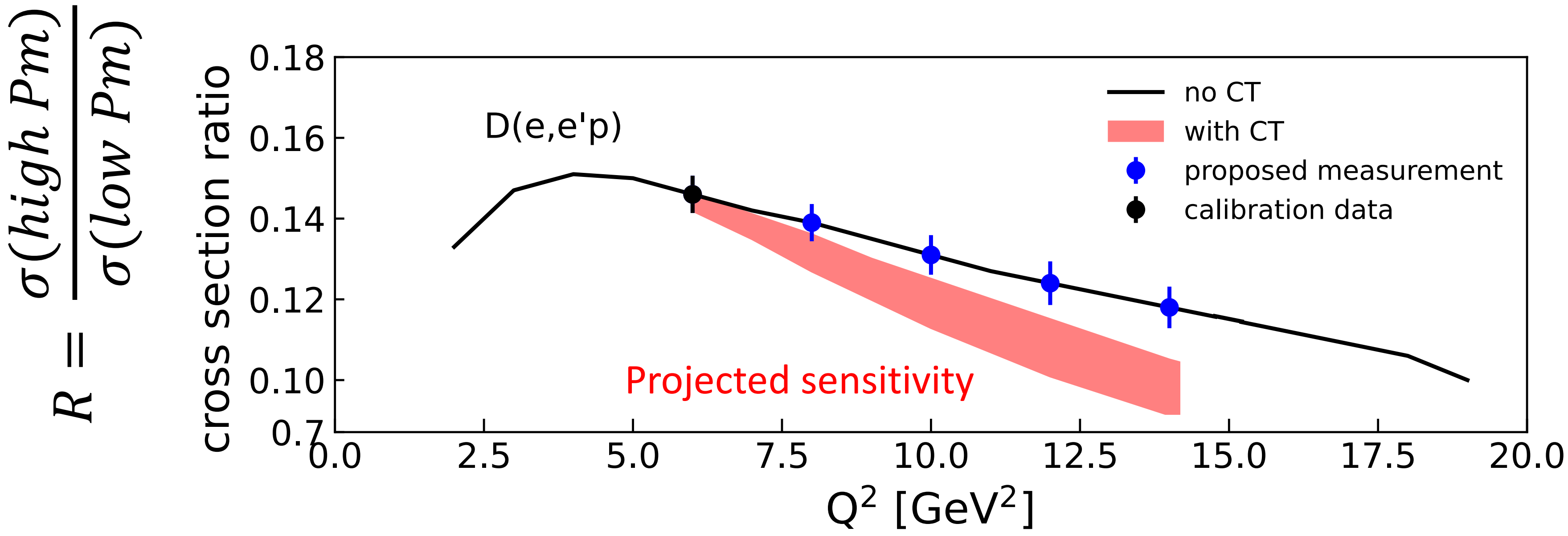
Measure the ratio of of counts in high/low FSIs:

$$\downarrow R = \frac{\sigma(p_r = 400\ MeV) \downarrow}{\sigma(p_r = 200\ MeV) \uparrow}$$

CT: reduction of FSI → reduction of R



Enhanced sensitivity for detecting CT



Sensitive to shorter PLC lifetime

The larger spectator momentum →
smaller distances between the production and rescattering vertices

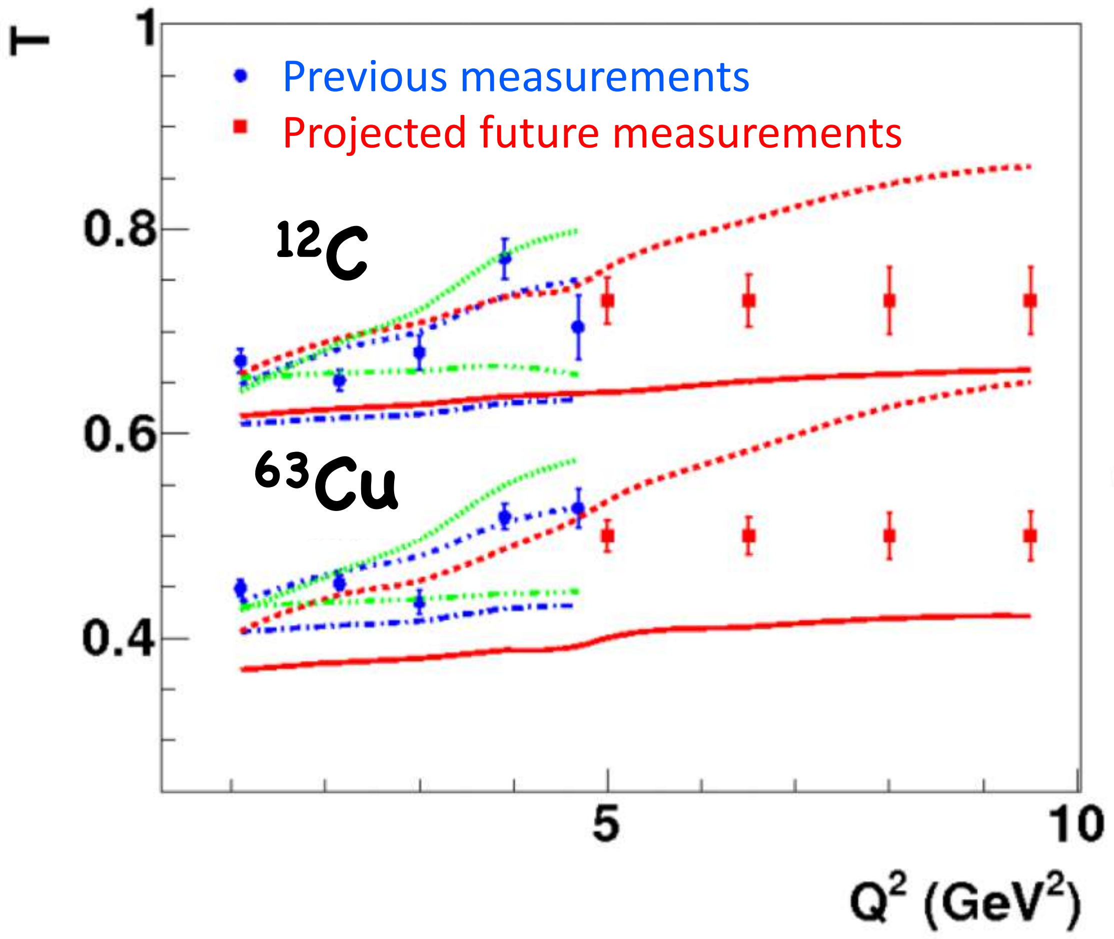
∴ **Disentangle the expansion from the observation of the PLC!**

This measurement could help estimate the energies needed in heavy ion collisions to produce a weakly interacting quark-gluon plasma

Extend and confirm onset of CT for pions (running next year!)

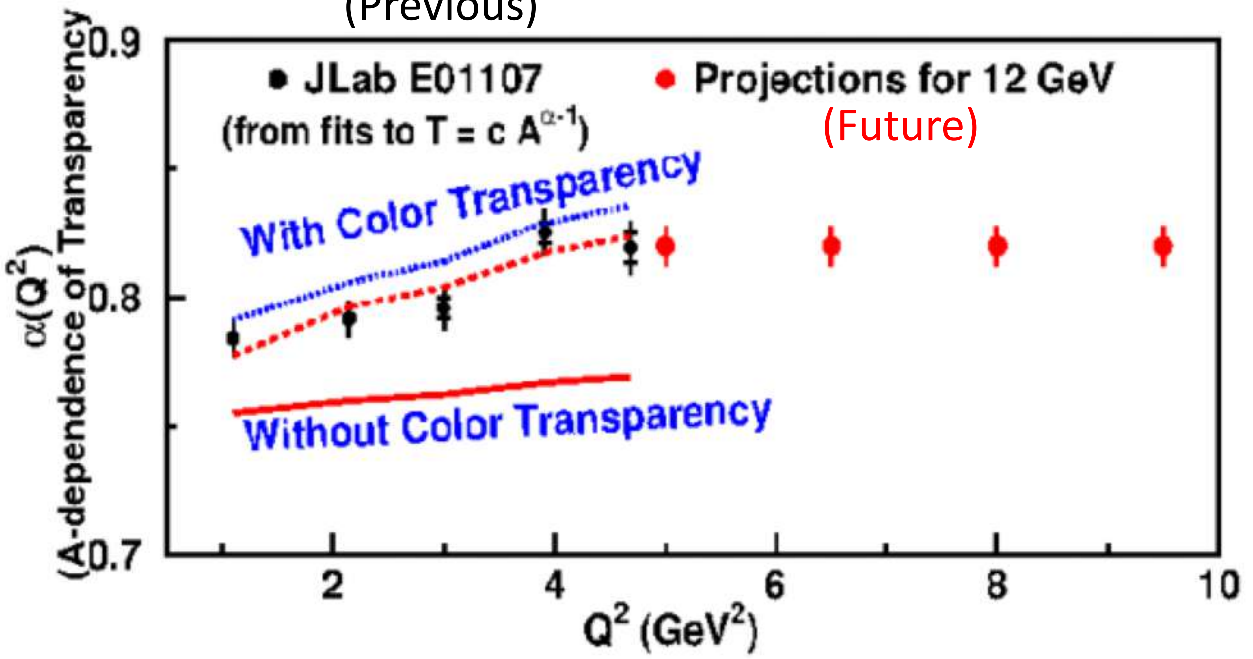
Szumila-Vance et al (co-spokesperson), JLab Experiment E12-06-107

Extend the T and nuclear dependence!

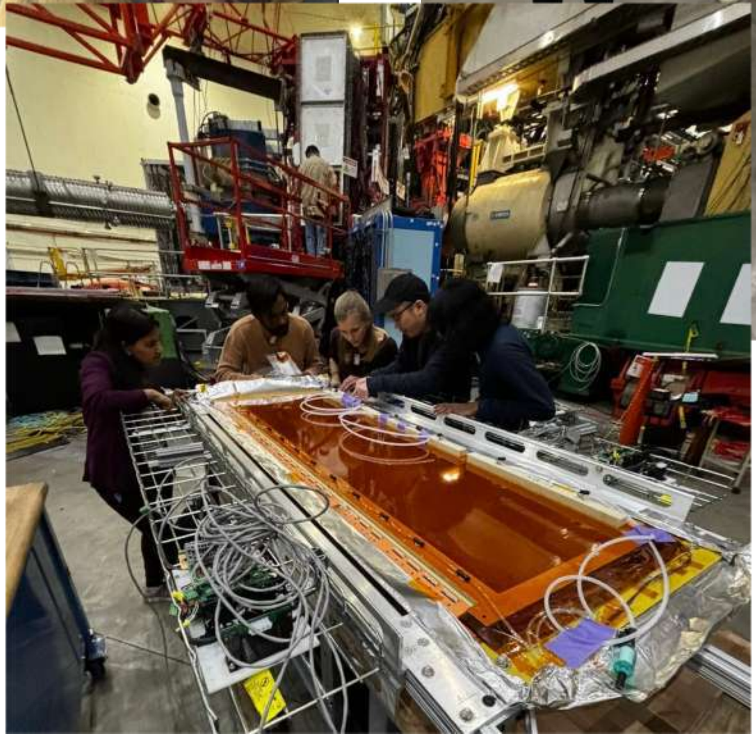


$\alpha(Q^2)$

(Previous)



While we wait, we build!



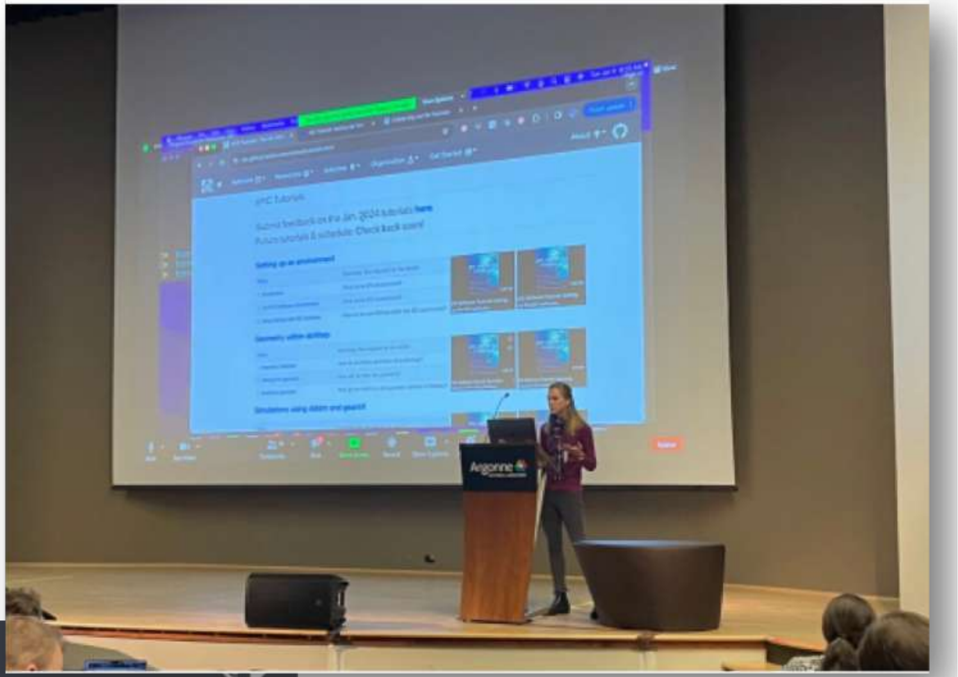
The SBS form factor experiments measure the proton and neutron form factors to the highest Q^2 in Hall A

Our GEM tracking detectors have measured the highest rates x area!

Looking toward the future!

Co-convener for the User Learning Software Working Group for ePIC

Supporting growing international User community to develop software for the next era of physics experiments



Software Resources Activities Organization Policies Get Started

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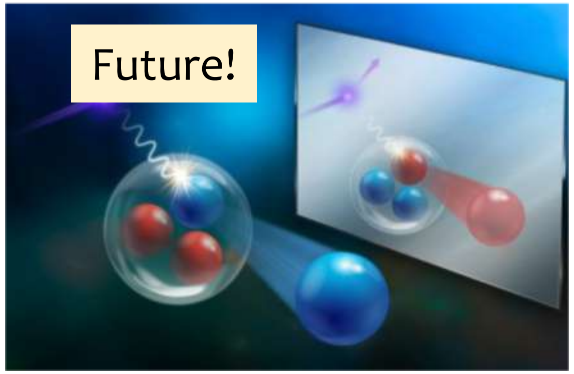
Subscribe here: https://lists.bnl.gov/mailman/listinfo/eic-projdet-compsw-l

Join us for the next software training workshop!
https://indico.cern.ch/event/1343984/

CT is only one way to look for a **direct** transition from quarks to nuclei

We explore the evidence for QCD in nuclei from other observations:

- Test the limits in our descriptions of A=3 nuclei
- Nucleon pairing amongst shells in nuclei
- Exploring the origins of the EMC Effect
- Testing our assumptions with photoproduction



Szumila-Vance et al (spokesperson),
JLab Experiment E12-20-005

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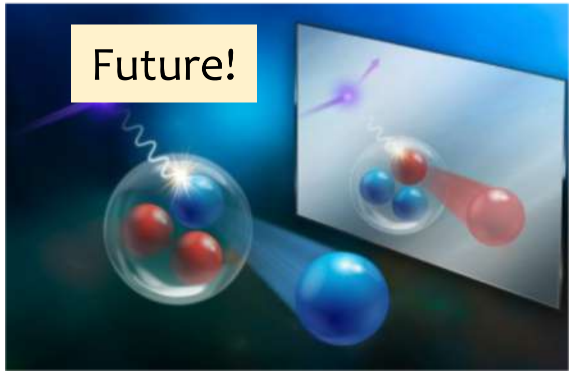
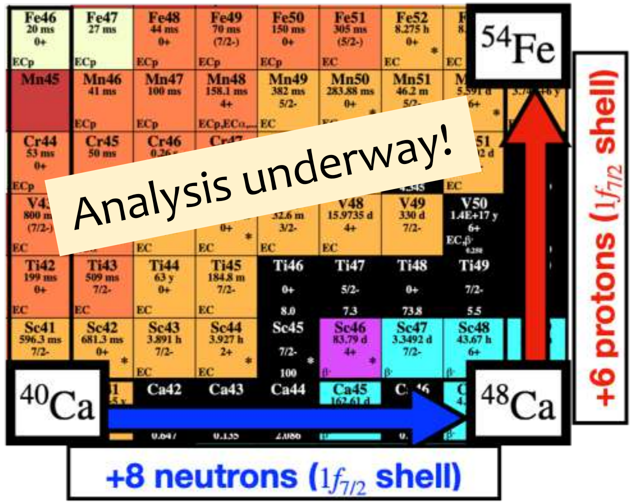


Szumila-Vance et al (spokesperson),
JLab Experiment E12-20-005



Szumila-Vance et al (spokesperson),
JLab Experiment E12-18-003

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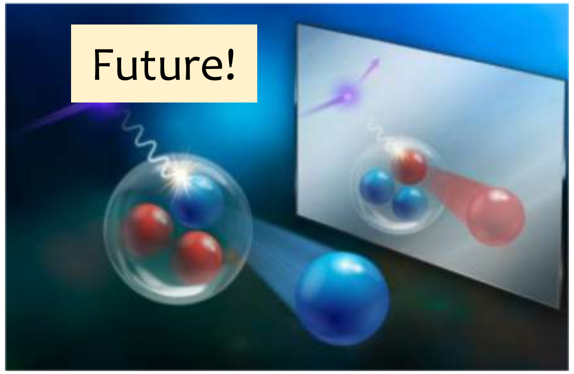
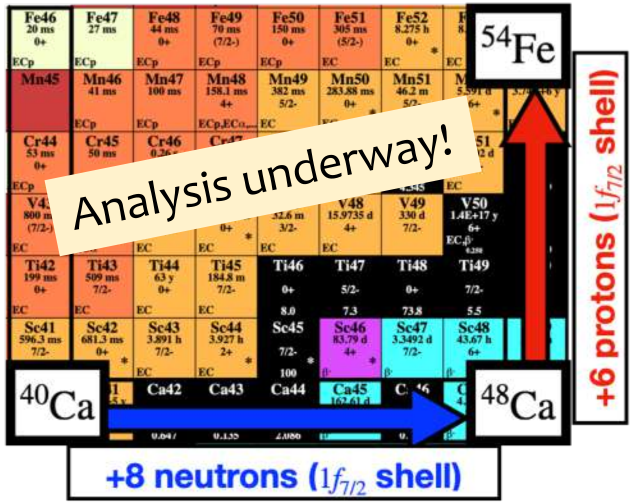
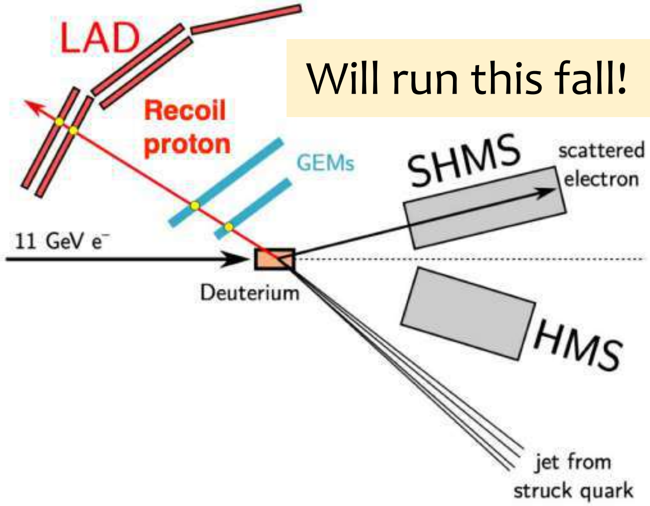


Szumila-Vance et al (spokesperson),
JLab Experiment E12-20-005



Szumila-Vance et al (spokesperson),
JLab Experiment E12-18-003



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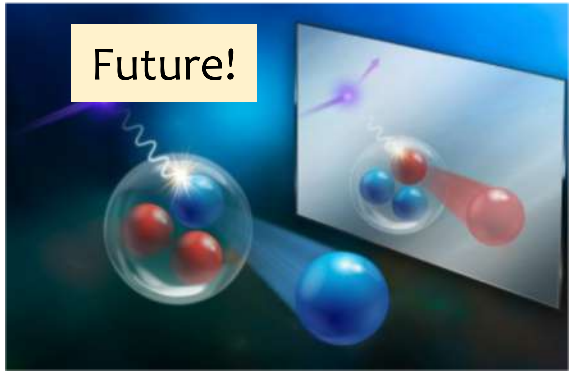
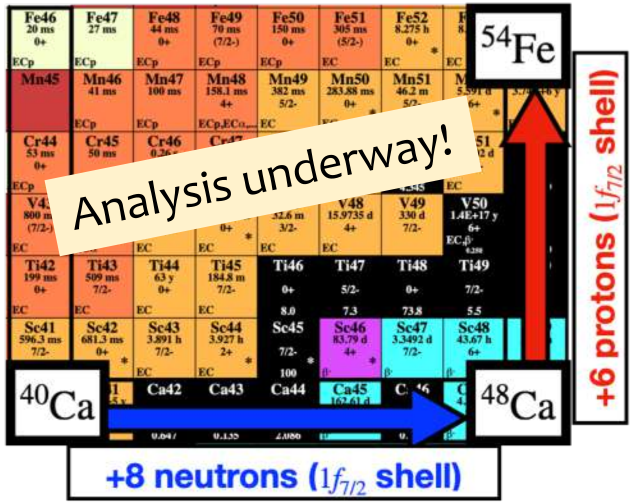
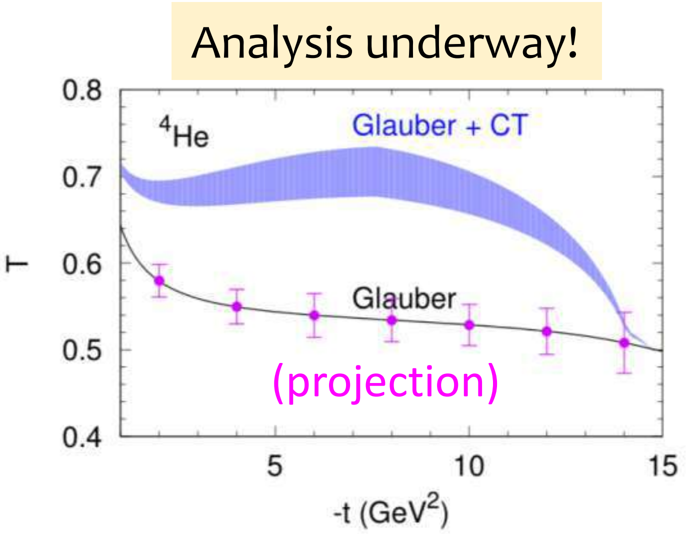


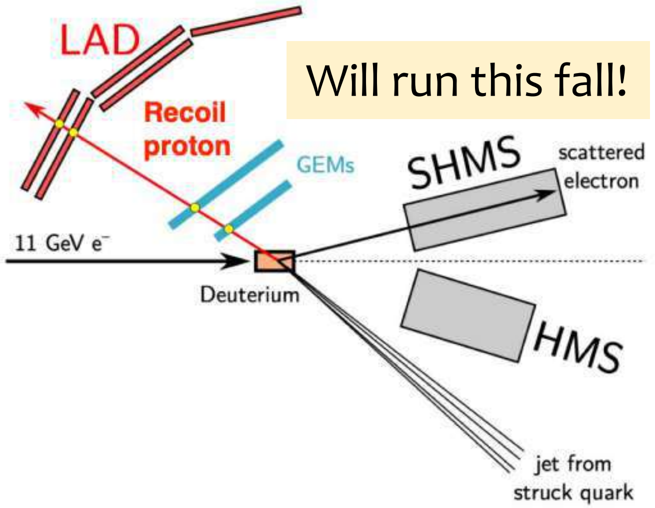
Szumila-Vance et al (spokesperson), JLab Experiment E12-20-005



Szumila-Vance et al (spokesperson), JLab Experiment E12-18-003



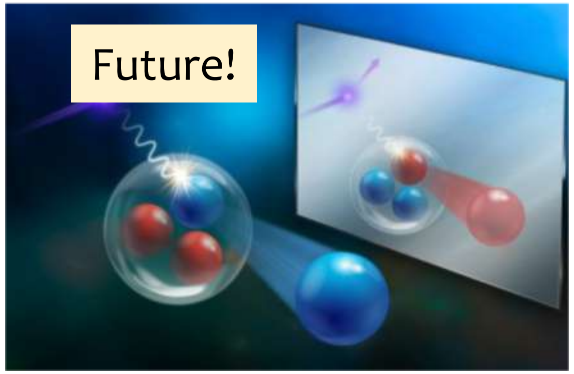
Szumila-Vance et al (spokesperson), JLab Experiment E12-17-007



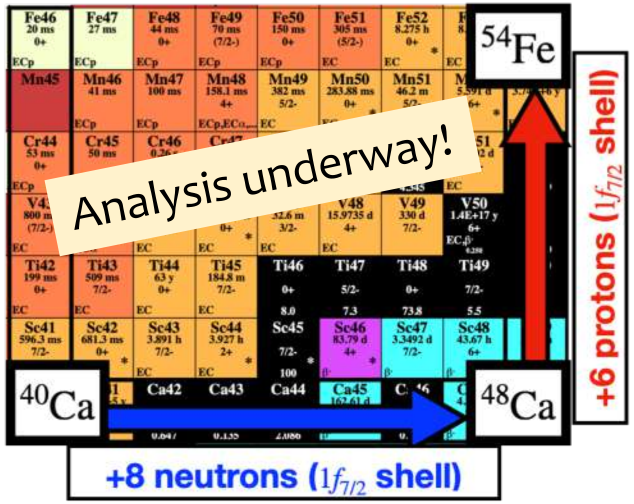
(Just to name a few!)

We explore the evidence for QCD in nuclei from other observations:

- Test the limits in our descriptions of A=3 nuclei
- Nucleon pairing amongst shells in nuclei
- Exploring the origins of the EMC Effect
- Testing our assumptions with photoproduction

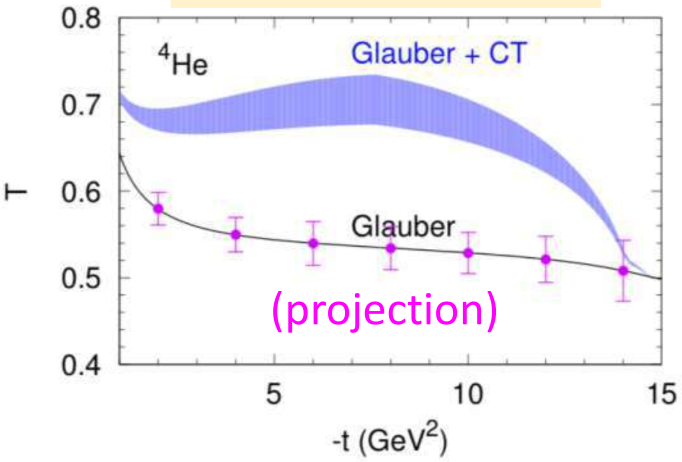


Szumila-Vance et al (spokesperson), JLab Experiment E12-20-005

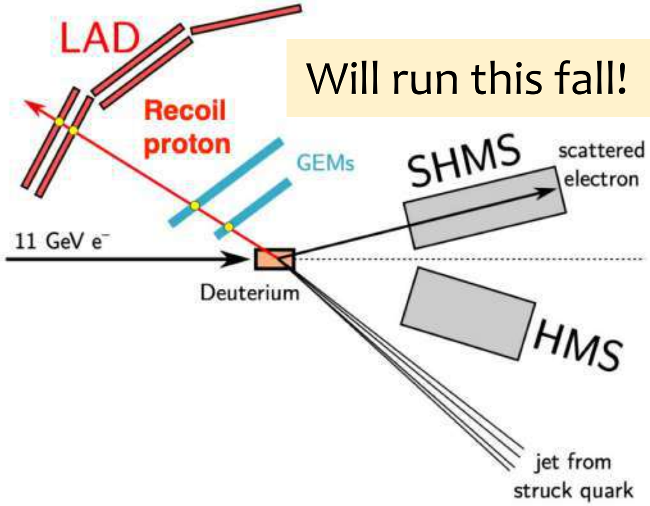


Szumila-Vance et al (spokesperson), JLab Experiment E12-18-003

Analysis underway!



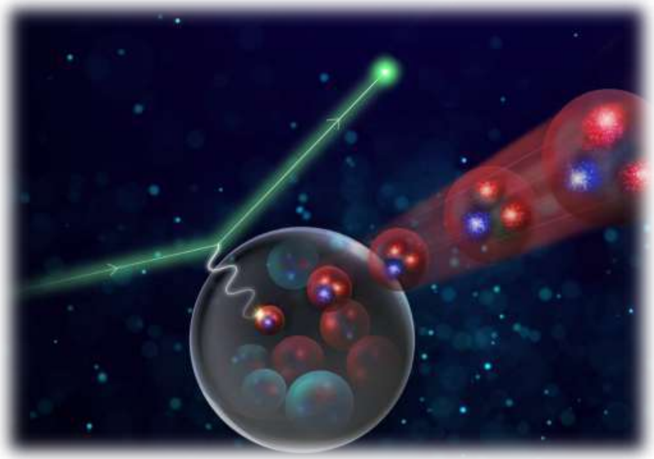
Szumila-Vance et al (spokesperson), JLab Experiment E12-17-007

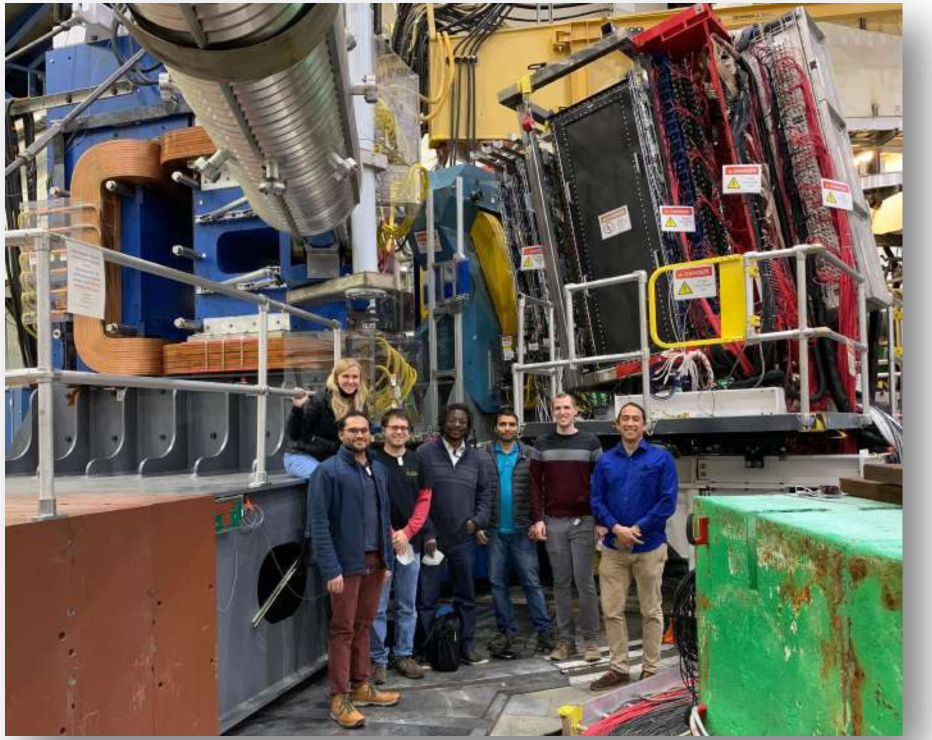


Thank you!

Thank you to my mentors!

And to the truly wonderful students, postdocs, and collaborators who make it possible to push to new boundaries of physics!





Precision Calculations in Higgs Boson and Top Quark Production

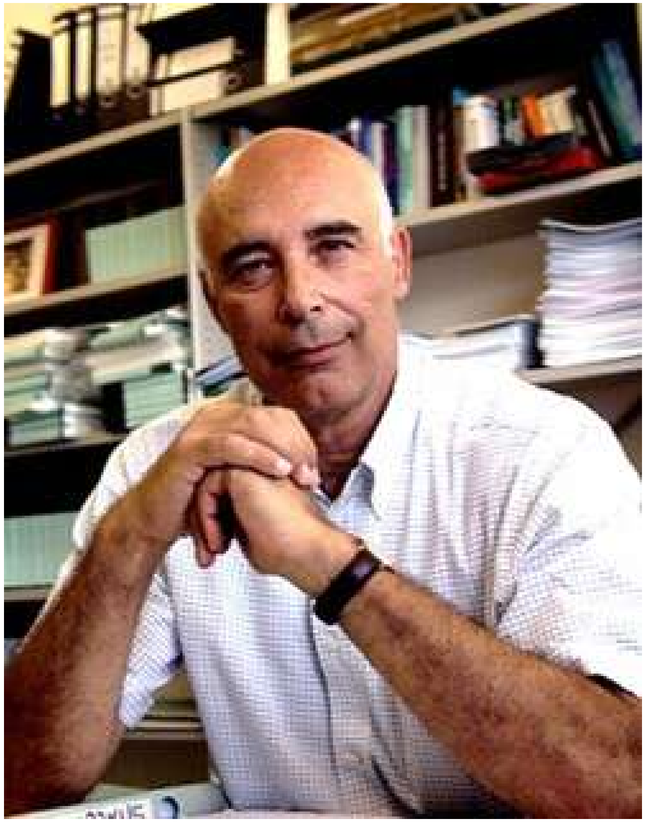
Javier Mazzitelli

PAUL SCHERRER INSTITUT

31st International Workshop on Deep-Inelastic Scattering and Related Subjects, April 8th 2024

- I am deeply honored to be the recipient of the Altarelli Award
- Huge thanks to the selection committee and to the sponsors!

This wouldn’t be possible without my **amazing collaborators**, big thanks to **all** of them!



Giudo Altarelli (1941 – 2015)

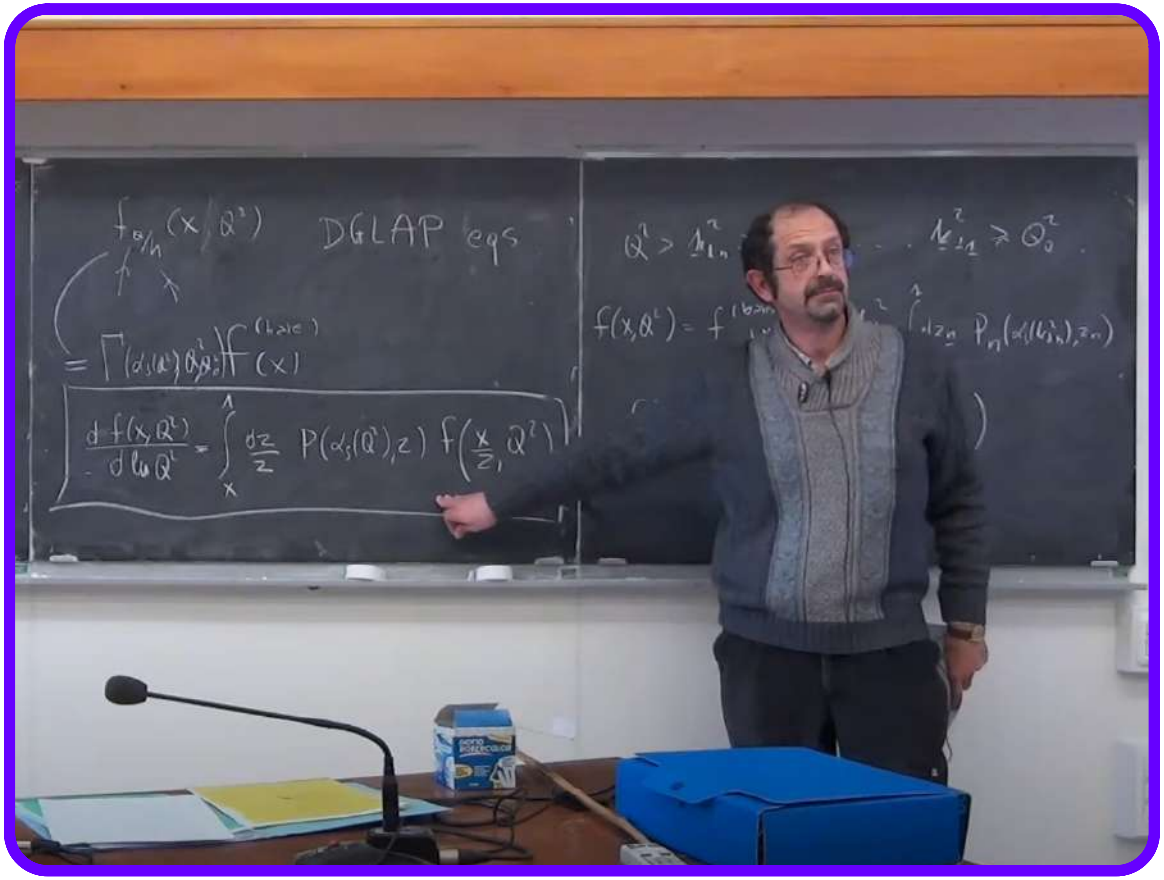
He was a true giant of particle physics and of CERN. His contributions to physics span all subjects, from strong to electroweak interactions, from neutrinos to theories beyond the Standard Model, and from the study of precision measurements to the analysis of apparent anomalies

CERN Bulletin

He made pioneering contributions to QCD, notably developing the DGLAP equations, a cornerstone in understanding the behaviour of quarks and gluons within protons and neutrons

His contributions have laid the groundwork for precision calculations in QCD, enabling us to make accurate predictions that can be tested against experimental data

Stefano Catani (1958 – 2024)

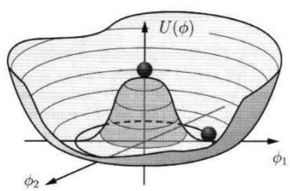


Another *true giant* of particle physics, and a wonderful person who will be deeply missed

- Precision calculations are crucial in the quest for new physics
- Advanced theoretical predictions can be the determining factor between discovering a signal and missing it among the uncertainties

- I'll focus on (in my opinion) two of the most interesting particles being studied at the LHC

Higgs boson

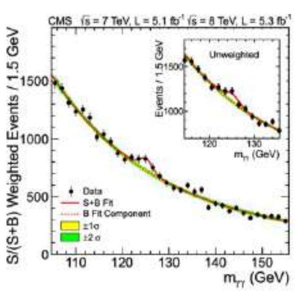


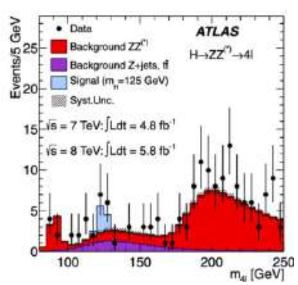
Responsible for EWSB

Last discovered particle

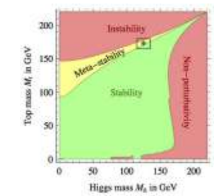
↓

Least explored sector of the SM



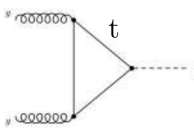


Top quark



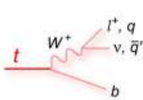
Strongest interaction with the Higgs field → Vacuum stability

→ Higgs observables



Heaviest particle in the SM

→ Decay before hadronization

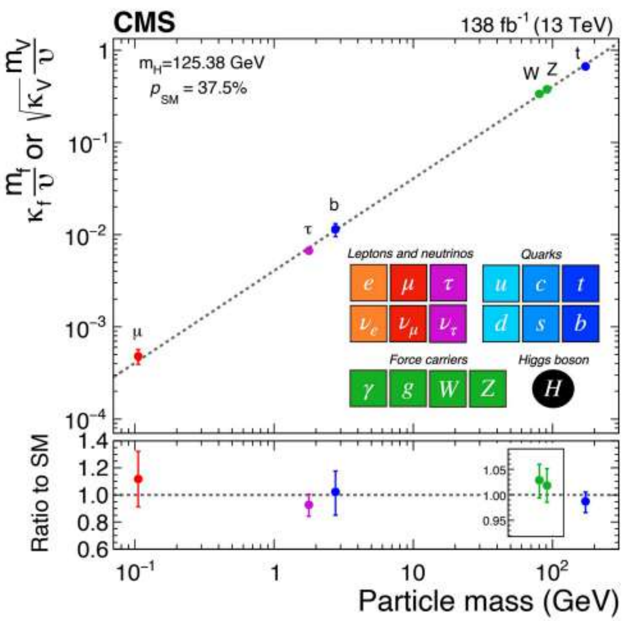


→ Gate and background to NP

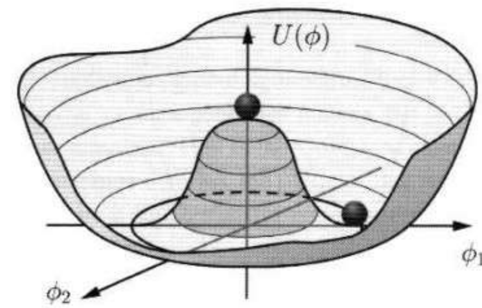
Precision calculations in Higgs boson and top quark production are of the utmost importance!

Higgs pair production

- Several Higgs couplings have been measured, and found to be consistent with SM

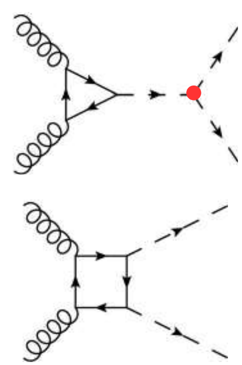


Not there yet for the Higgs self coupling, which is determined by the Higgs potential

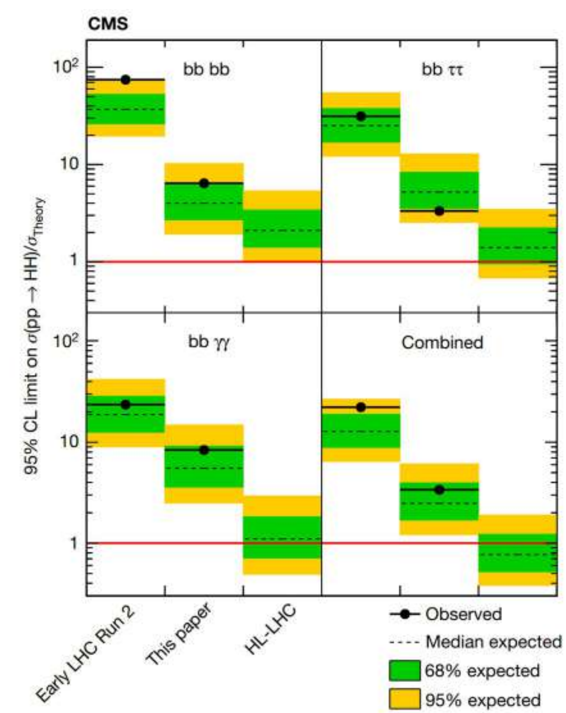


- Trilinear coupling can be directly accessed via di-Higgs production

- Main production mode: loop-induced top-quark mediated gluon fusion

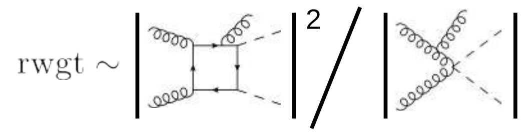


- Impressive experimental efforts constrained the HH cross section below ~3 x σ_{SM}, and future prospects indicate a measurement is possible at the HL-LHC

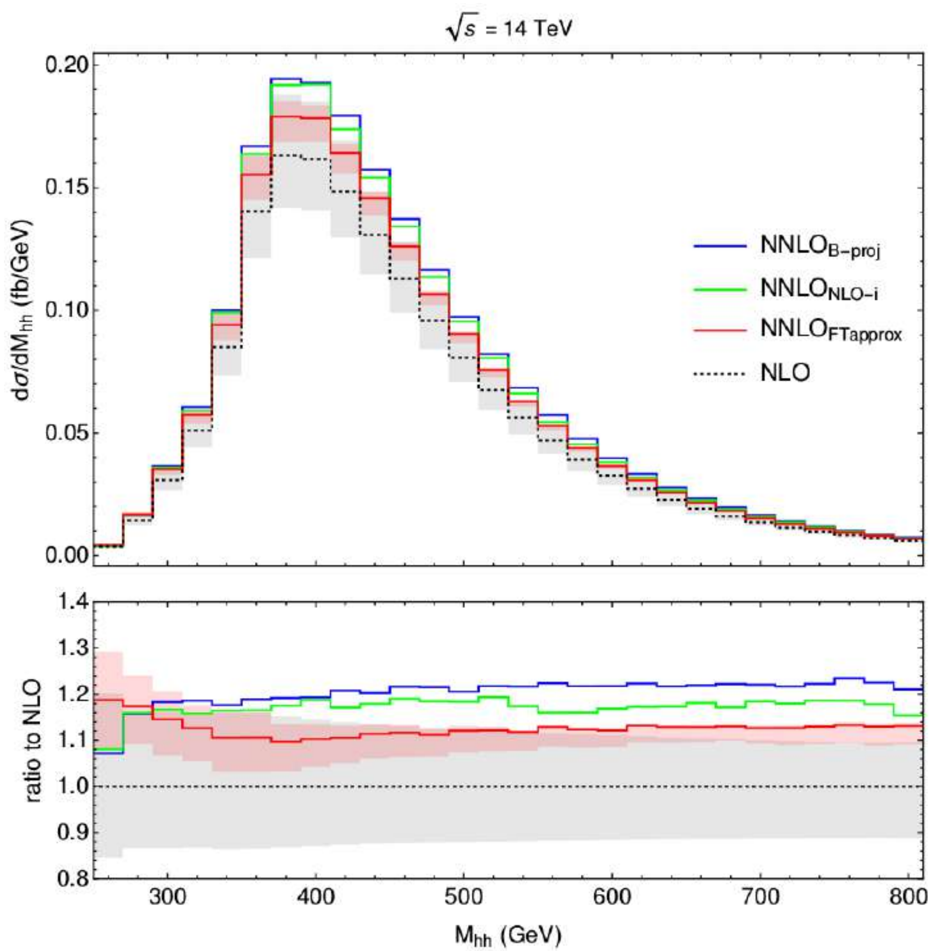


Higgs pair production

- Full NNLO corrections are still not known (loop-induced multi-scale process)
- We computed the NNLO corrections in the heavy-top limit
- We improved via a reweighting technique that allowed us to incorporate partial finite top-mass effects



- We combined it with the full NLO and performed threshold resummation to achieve the ultimate precision [note: more recently, N³LO in HTL also became available, Chen et al., 1909.06808]



[Grazzini, JM et al., 1803.02463]

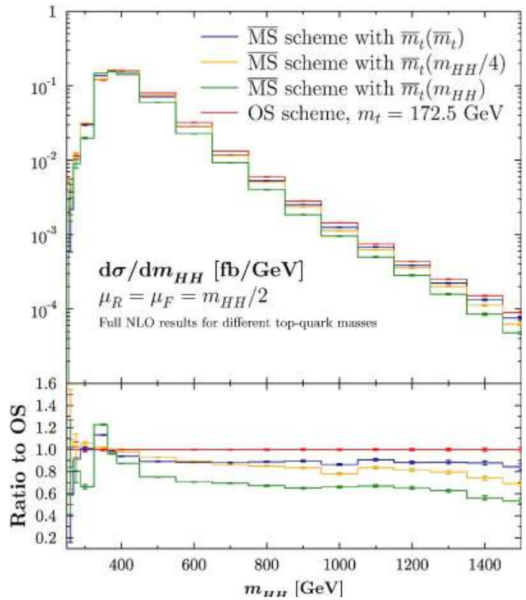
$\sqrt{s}$	13 TeV	14 TeV	27 TeV	100 TeV
NLO [fb]	$27.78^{+13.8\%}_{-12.8\%}$	$32.88^{+13.5\%}_{-12.5\%}$	$127.7^{+11.5\%}_{-10.4\%}$	$1147^{+10.7\%}_{-9.9\%}$
$\mathrm{NLO_{FTapprox}}$ [fb]	$28.91^{+15.0\%}_{-13.4\%}$	$34.25^{+14.7\%}_{-13.2\%}$	$134.1^{+12.7\%}_{-11.1\%}$	$1220^{+11.9\%}_{-10.6\%}$
$\mathrm{NNLO_{NLO-i}}$ [fb]	$32.69^{+5.3\%}_{-7.7\%}$	$38.66^{+5.3\%}_{-7.7\%}$	$149.3^{+4.8\%}_{-6.7\%}$	$1337^{+4.1\%}_{-5.4\%}$
$\mathrm{NNLO_{B-proj}}$ [fb]	$33.42^{+1.5\%}_{-4.8\%}$	$39.58^{+1.4\%}_{-4.7\%}$	$154.2^{+0.7\%}_{-3.8\%}$	$1406^{+0.5\%}_{-2.8\%}$
$\mathrm{NNLO_{FTapprox}}$ [fb]	$31.05^{+2.2\%}_{-5.0\%}$	$36.69^{+2.1\%}_{-4.9\%}$	$139.9^{+1.3\%}_{-3.9\%}$	$1224^{+0.9\%}_{-3.2\%}$
M_t unc. $\mathrm{NNLO_{FTapprox}}$	±2.6%	±2.7%	±3.4%	±4.6%
$\mathrm{NNLO_{FTapprox}/NLO}$	1.118	1.116	1.096	1.067

- NNLO corrections around of O(10%)
- Strong reduction of scale variation

Good control of perturbative uncertainties

The Higgs and the Top

- There are still sizeable uncertainties due to the choice of the renormalization scheme (on-shell vs $\overline{\text{MS}}$) and scale of the top-quark!



[Baglio et al.; 2003.03227]

$$\sigma_{\text{NLO}}(gg \to HH) = 32.81^{+4\%}_{-18\%}\,\text{fb}$$

$$\sigma(gg \to H^*)\Big|_{Q=125\text{ GeV}} = 42.17^{+0.4\%}_{-0.5\%}\,\text{pb}$$

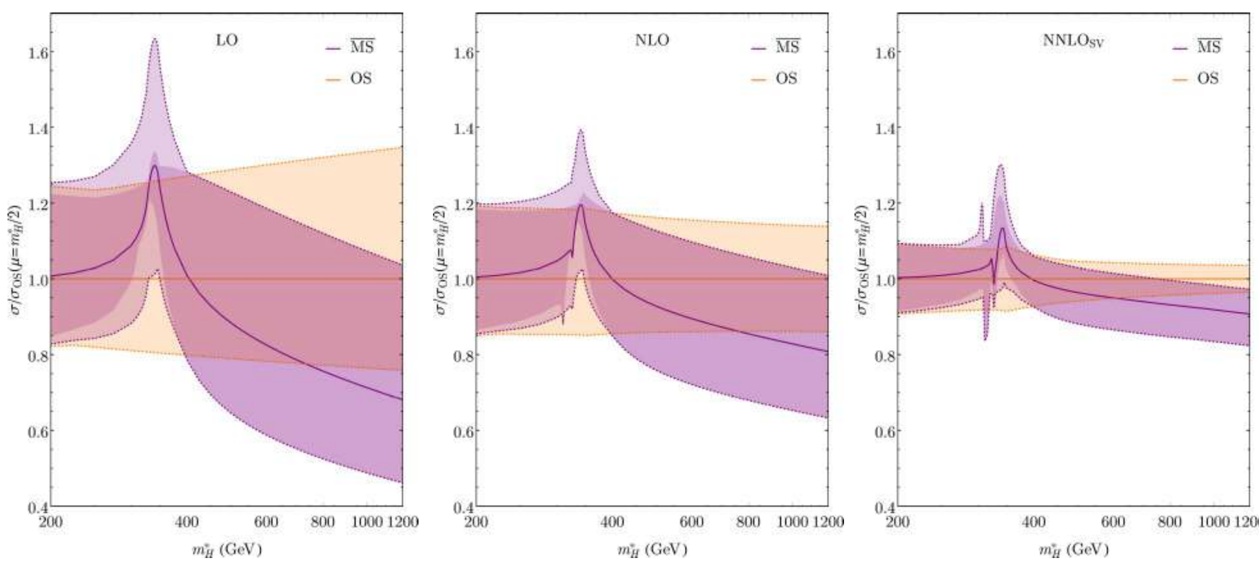
$$\sigma(gg \to H^*)\Big|_{Q=300\text{ GeV}} = 9.85^{+7.5\%}_{-0.3\%}\,\text{pb}$$

$$\sigma(gg \to H^*)\Big|_{Q=600\text{ GeV}} = 1.97^{+0.0\%}_{-15.9\%}\,\text{pb}$$

$$\sigma(gg \to H^*)\Big|_{Q=1200\text{ GeV}} = 0.0402^{+0.0\%}_{-26.0\%}\,\text{pb}$$

Similar effect found in off-shell Higgs production

- While they have only been studied at NLO for HH, we showed for H* production that NNLO corrections (with full top-mass dependence) allow to reduce them:

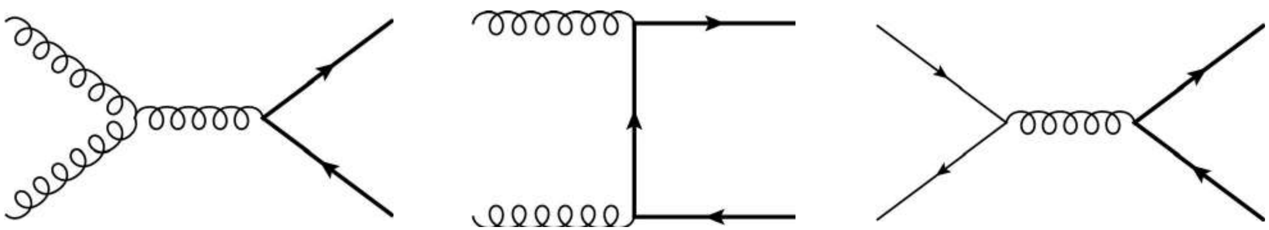


[JM, 2206.14667]

Difference between $\overline{\text{MS}}$ and OS predictions significantly reduced at NNLO

The Top Quark at the LHC

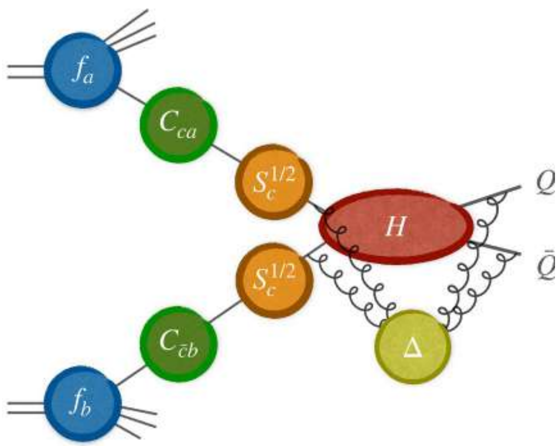
- Top quarks are ubiquitous at the LHC, main production mode: $t\bar{t}$ production



- Approx. 3 times larger than single-top production
- About **15** $t\bar{t}$ pairs produced **per second** at the LHC!

- We have extended the q_T-subtraction method to deal with the production of heavy quarks

[Catani, JM et al., 2301.11786]



$$d\sigma^{(\mathrm{sing})} \sim d\sigma^{(0)}_{c\bar{c}} \times \exp\left(-S_c\right) \times \left[H C_1 C_2\right]_{c\bar{c};a_1 a_2} \times f_{a_1} f_{a_2}$$

$$d\sigma^{(\mathrm{sing})} \sim d\sigma^{(0)}_{c\bar{c}} \times \exp\left(-S_c\right) \times \left[\mathrm{Tr}(\mathbf{H}\boldsymbol{\Delta}) C_1 C_2\right]_{c\bar{c};a_1 a_2} \times f_{a_1} f_{a_2}$$

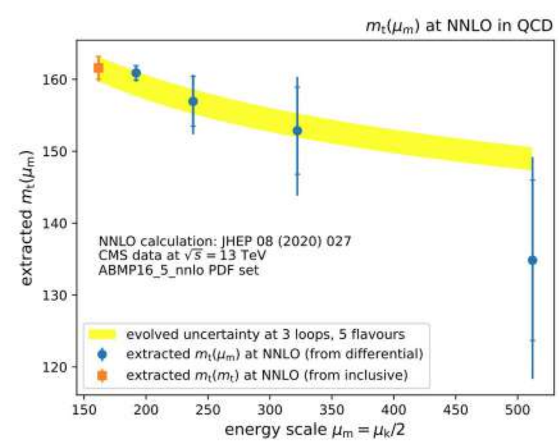
Effects coming from soft emissions from the FS contained in operator **Δ**

- We performed an independent NNLO calculation for $t\bar{t}$ and released the first public code to get NNLO distributions

[Catani, JM et al., 1901.04005, 1906.06535]

- We also obtained for the first time NNLO distributions using the $\overline{\mathrm{MS}}$ top mass, and extracted the running using CMS data

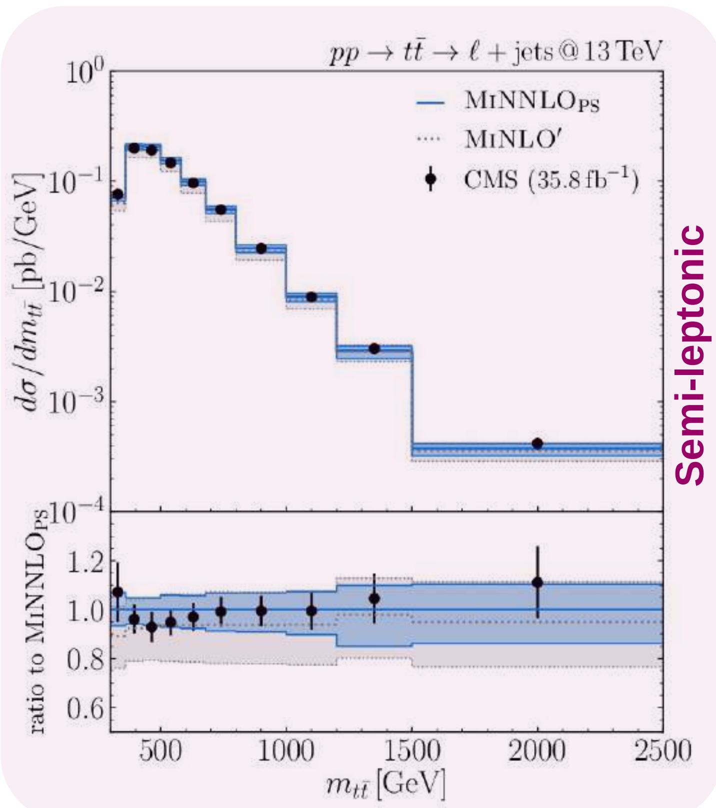
[Catani, JM et al., 2005.00557], [Defranchis, JM et al., 2208.11399]

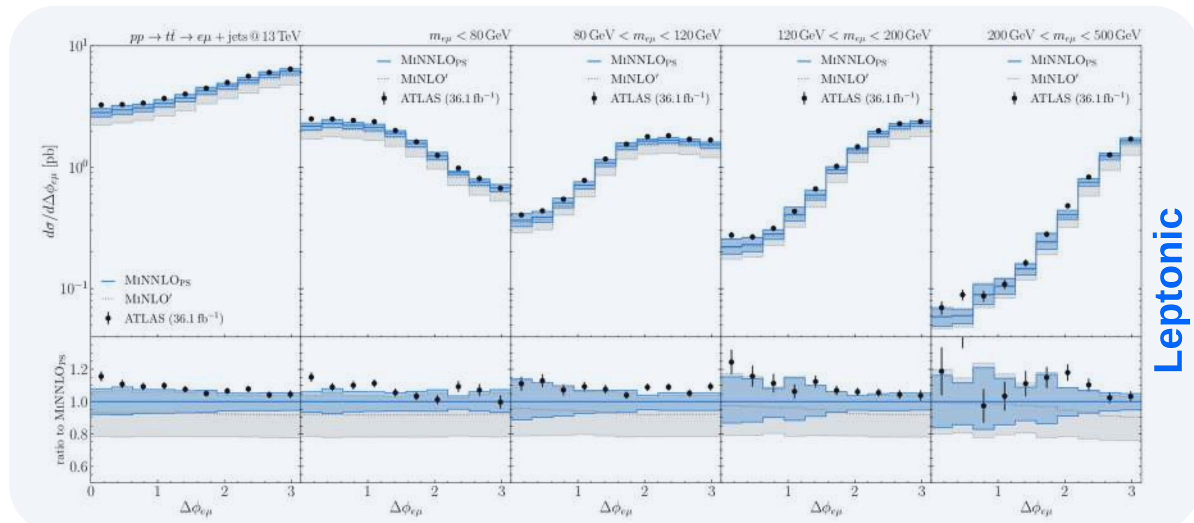


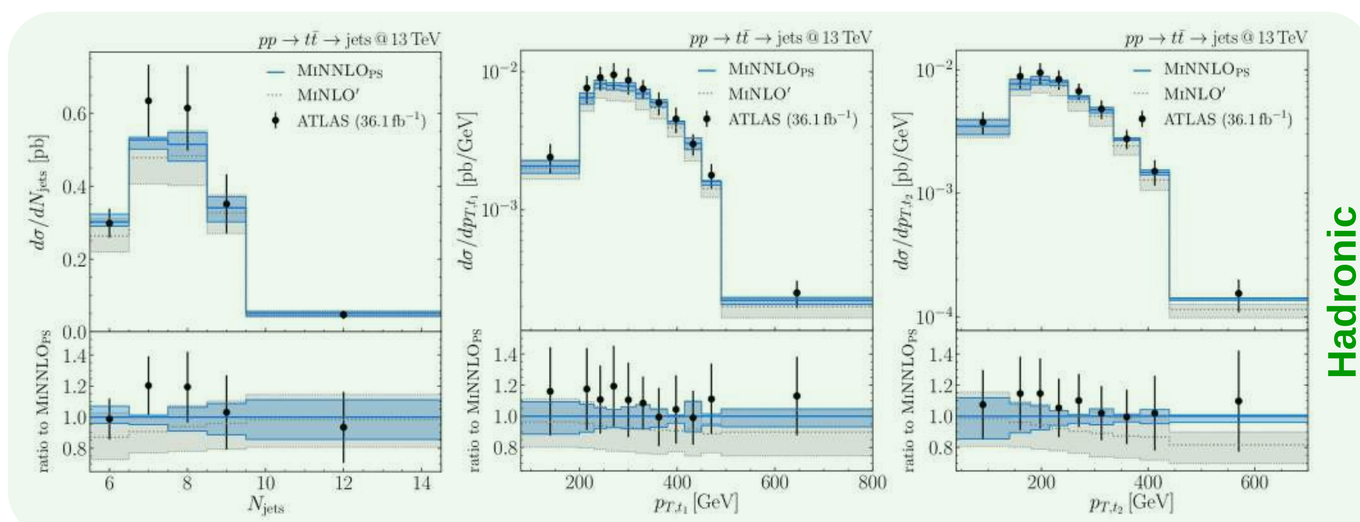
Top-pair production at NNLO+PS

- Our developments were also crucial in the context of NNLO+PS generators

  - We extended the MiNNLO$_{PS}$ method to deal with heavy-quark production [JM et al., 2012.14267, 2112.12135]
  - First and only case of NNLO+PS beyond colour-singlet hadroproduction

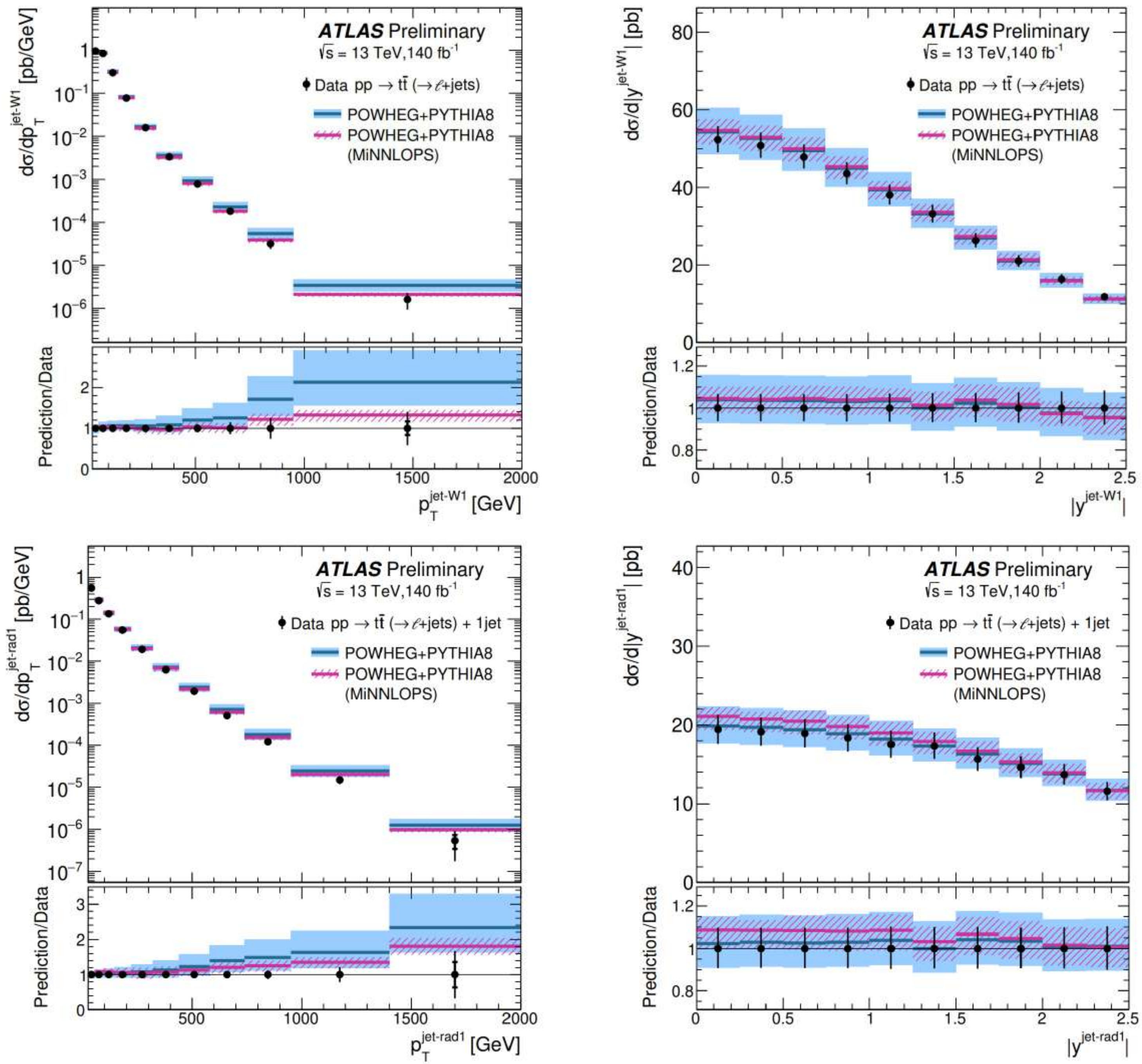






Top-pair production at NNLO+PS

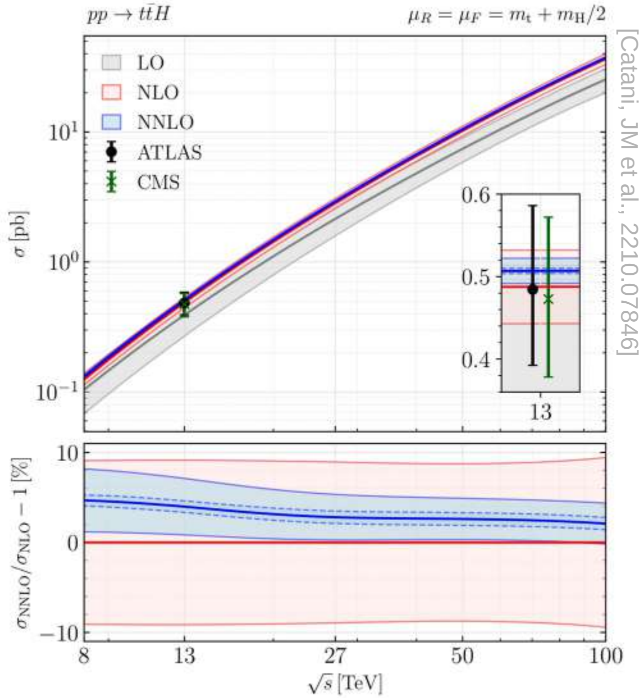
- NNLO+PS generator available in POWHEG, and already used by LHC collaborations

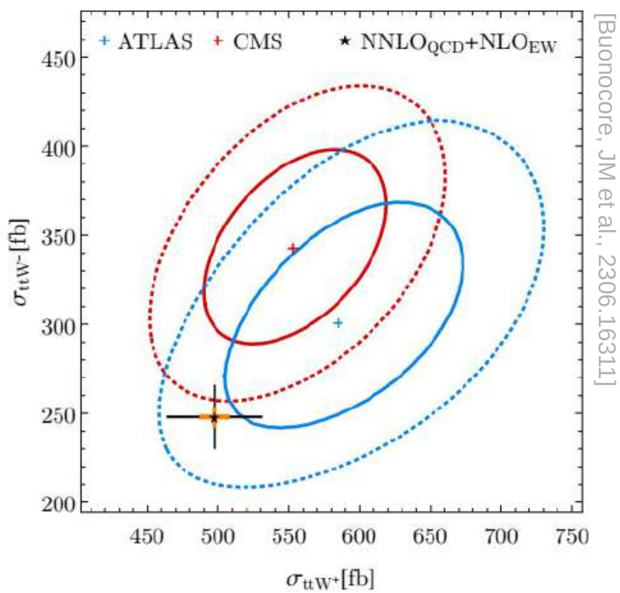


[ATLAS-CONF-2023-068]

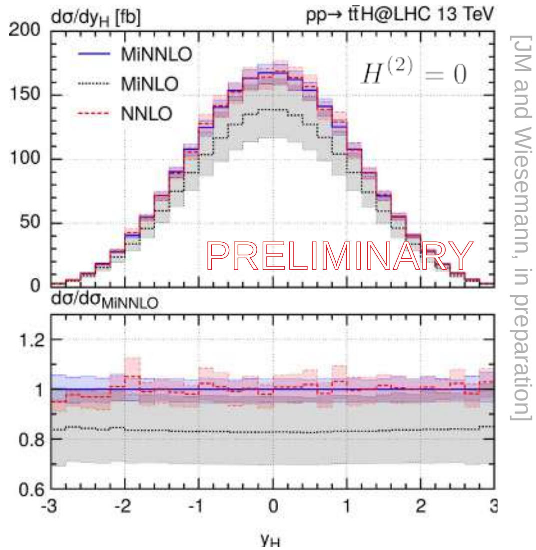
Heavy-quark + colour singlet at NNLO

- We further extended our subtraction method to deal with HQ+colourless FS
- By finding suitable approximations to the missing two-loop corrections, we obtained NNLO predictions for $t\bar{t}H$ and $t\bar{t}W$ production at the LHC





- NNLO brings $t\bar{t}H$ scale variations at the level of HL-LHC experimental uncertainties
- NNLO corrections allow for more meaningful studies of the tension in the $t\bar{t}W$ measurements
- The development of NNLO+PS generators for processes of this type ($Q\bar{Q}F$) is underway



Summary and Outlook

- Advanced theoretical predictions are crucial to fully exploit the physics potential of the LHC

- QCD corrections to HH production are in general in good shape

  Still sizeable uncertainties connected to scheme and scale ambiguity

- Top-pair production available at NNLO, also matched to parton showers

  Next: NNLO+PS with improved treatment of decays and eventually inclusion of non-resonant

- Formalism to obtain NNLO and NNLO+PS for $Q\bar{Q}F$ understood

  Current bottleneck: process-dependent 2-loop amplitudes

- Event generators still behind fixed-order progress (e.g. F+jet@NNLO, F@N^{3}LO)

- I only highlighted here my contributions to Higgs and top-quark processes

See an overview of theory developments on Higgs and top physics for a full picture!

Many other signatures are relevant and needed to high accuracy!

Attaining the level of accuracy demanded by the HL-LHC is undeniably a collective effort, and we need to keep pushing!

Thanks!

Guido Altarelli Award 2024

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