CFNS Workshop: Pion and Kaon Structure Functions at the EIC

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Overview – Pion and Kaon Structure

- Protons, neutrons, pions and kaons are the main building blocks of nuclear matter

> If we really want to claim we understand hadron structure as relevant for the visible world, we HAVE to understand at least the pion, kaon, proton, neutron (and likely the Lambda) at the same level.

- Paradoxically, the lightest pseudoscalar mesons appear to be the key to the further understanding of the emergent mass and structure mechanisms.
  - These mesons, namely the pion and kaon, are the Nambu-Goldstone boson modes of QCD.

- Unravelling their partonic structure and the interplay between emergent and Higgs-boson mass mechanisms is a common goal of three interdependent approaches -- continuum QCD phenomenology, lattice-regularised QCD, and the global analysis of parton distributions -- linked to experimental measurements of hadron structure.

Center for Frontiers in Nuclear Science
Workshop series

Workshop on Pion and Kaon Structure Functions at the EIC

2-5 June 2020
Online
US/Eastern timezone

Remote Workshop 2-5 June, 2020

- Overview
- Call for Abstracts
- Timetable
- Contribution List
- Registration
- Participant List

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The Lagrangian masses of the quarks deliver only ≈ 1% of the proton mass, m_p; and it is the emergence of the bulk of m_p and the (very probably) related mechanism of confinement that are the key unresolved issues in hadron physics. In addressing these issues, the potential of the EIC is enormous. It promises to enable a quantitative understanding of the structure of hadrons, such as the nucleon, pion and kaon, in terms of quarks and gluons, thereby achieving key goals of modern physics. Recent synergistic advances in computation, experiment and theory reveal the prospects for a precise description of the one-dimensional structure of hadrons, exemplified by parton distribution functions (PDFs) and electromagnetic form factors, and of constructing three-dimensional images of hadrons, as expressed in Generalized Parton Distributions (GPDs) and Transverse-Momentum-Dependent Distributions (TMDs). Hence, today, there is an unprecedented opportunity to chart the in-hadron distributions of, *inter alia*, mass, charge, magnetization and angular momentum.

This workshop will canvass recent progress toward a coherent program of pion and kaon structure studies at the Electron-Ion Collider (EIC) that will d
interplay between experiment and theory. Here, rec
by new theoretical insights and rapid computationa
level phenomenology in the form of global structur
exascale computing are both expected to play a m

This workshop aims to capitalize on the success o
led to a White Paper, published in Eur.Phys.J.A 55 (
documentation, driving toward a significant new el
Handbook, and develop contributions as part of th

Starts Jun 2, 2020, 8:00 AM
Ends Jun 5, 2020, 7:00 PM
US/Eastern

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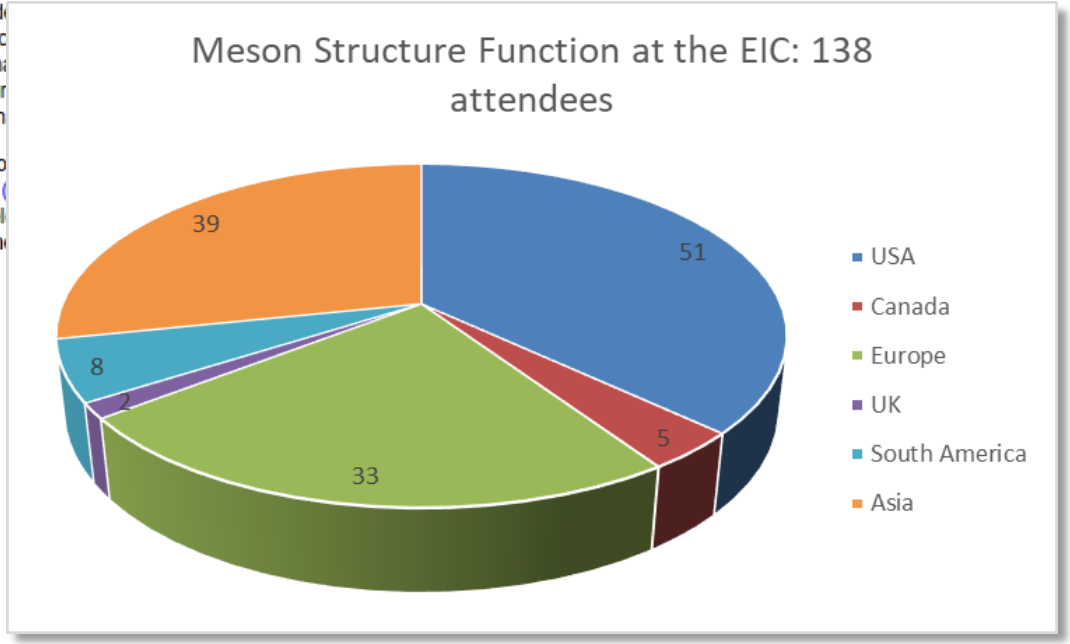
Large (remote) interest:

- 138 participants registered
- 25% early career researchers
- Attendance: ~100/day

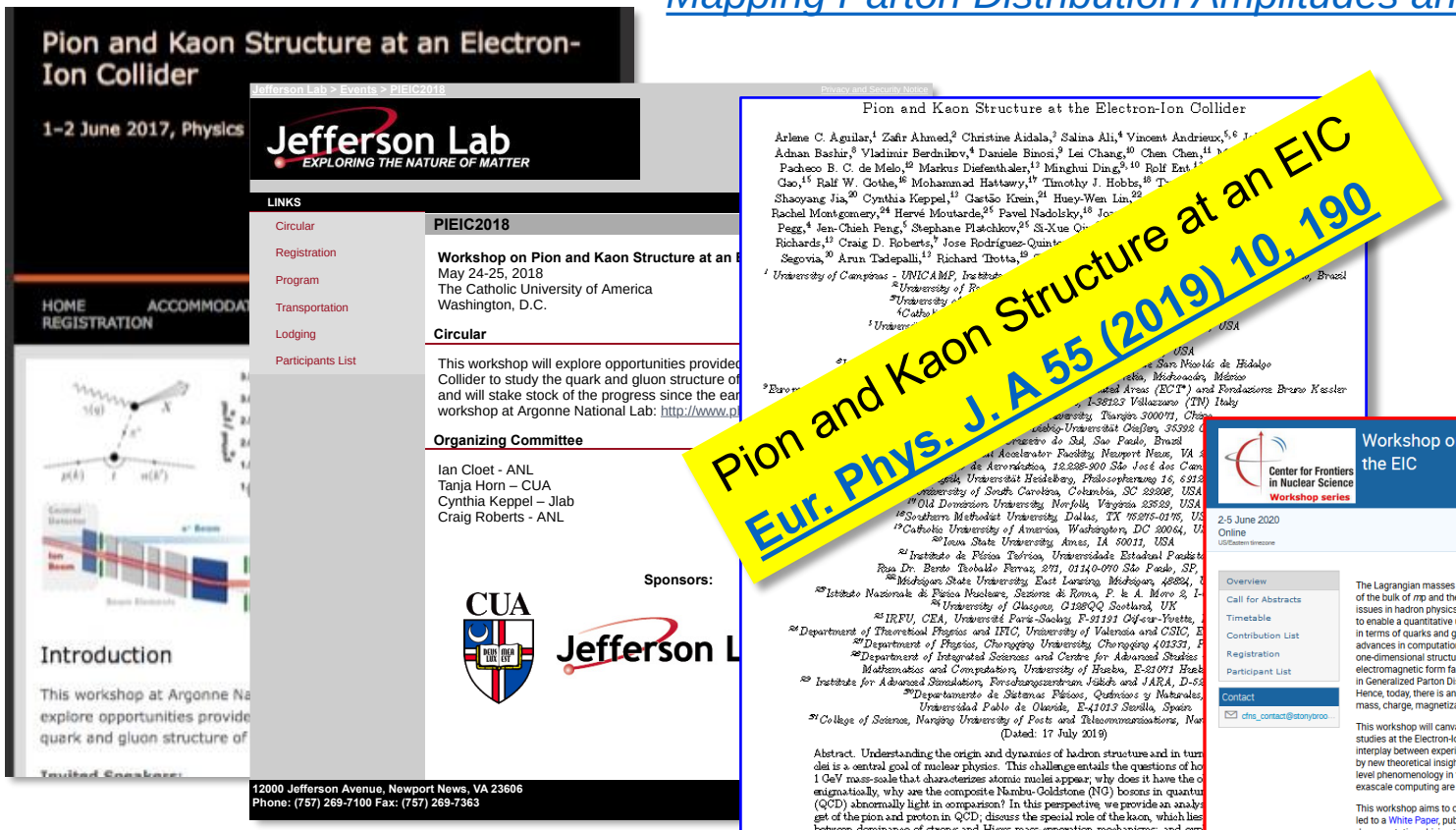


https://indico.bnl.gov/e/PIEIC2020

Pion and Kaon Structure at the EIC – History

- PIEIC Workshops hosted at ANL (2017) and CUA (2018)
- ECT* Workshops: Emergent Mass and its Consequences (2018)

  Mapping Parton Distribution Amplitudes and Functions, (2018).

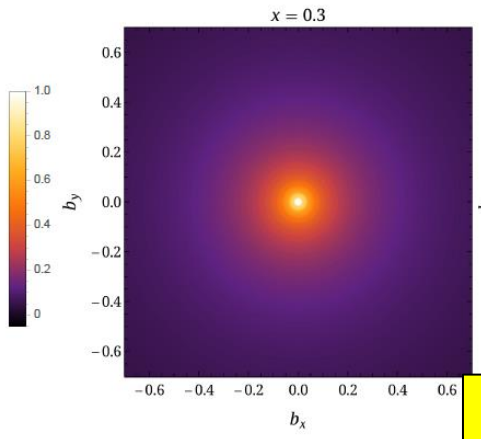
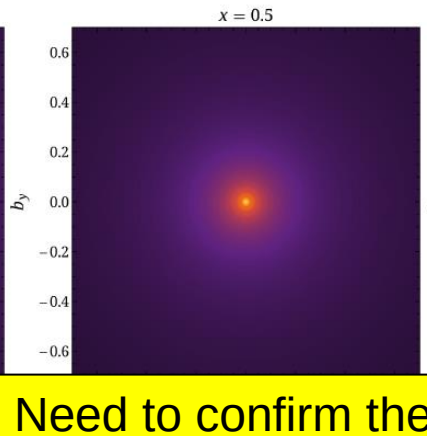
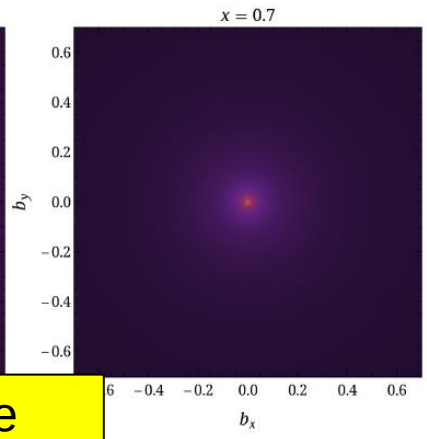
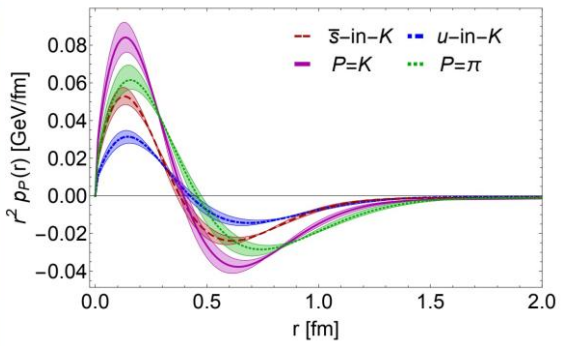


- AMBER/CERN Workshops (2019+)
- CFNS Workshop (2020)
- ECT* Workshops (2021): Mass in the Standard Model and Consequences of its Emergence

EIC – Meson Structure Questions

Science Question	Key Measurement[1]	Key Requirements[2]
What are the quark and gluon energy contributions to the pion mass?	Pion structure function data over a range of x and Q^2.	• Need to uniquely determine $e+p \to e'+X+n$ (low $-t$) • CM energy range ~10-100 GeV • Charged and neutral currents desirable
Is the pion full or empty of gluons as viewed at large Q^2?	Pion structure function data at large Q^2.	• CM energy ~100 GeV • Inclusive and open-charm detection
What are the quark and gluon energy contributions to the kaon mass?	Kaon structure function data over a range of x and Q^2.	• Need to uniquely determine $e+p \to e'+X+\Lambda/\Sigma^0$ (low $-t$) • CM energy range ~10-100 GeV
Are there more or less gluons in kaons than in pions as viewed at large Q^2?	Kaon structure function data at large Q^2.	• CM energy ~100 GeV • Inclusive and open-charm detection
Can we get quantitative guidance on the emergent pion mass mechanism?	Pion form factor data for Q^2 = 10-40 $(\mathrm{GeV/c})^2$.	• Need to uniquely determine exclusive process $e+p \to e'+\pi^+ +n$ (low $-t$) • $e+p$ and $e+D$ at similar energies • CM energy ~10-75 GeV
What is the size and range of interference between emergent-mass and the Higgs-mass mechanism?	Kaon form factor data for Q^2 = 10-20 $(\mathrm{GeV/c})^2$.	• Need to uniquely determine exclusive process $e+p \to e'+K+\Lambda$ (low $-t$) • L/T separation at CM energy ~10-20 GeV • Λ/Σ^0 ratios at CM energy ~10-50 GeV
What is the difference between the impacts of emergent- and Higgs-mass mechanisms on light-quark behavior?	Behavior of (valence) up quarks in pion and kaon at large x.	• CM energy ~20 GeV (lowest CM energy to access large-x region) • Higher CM energy for range in Q^2 desirable
What is the relationship between dynamically chiral symmetry breaking and confinement?	Transverse-momentum dependent Fragmentation Functions of quarks into pions and kaons.	• Collider kinematics desirable (as compared to fixed-target kinematics) • CM energy range ~20-140 GeV

EIC – Meson Structure Questions

Science Question	Key Measurement[1]	Key Requirements[2]
    Need to confirm the pressure distributions Pressure profiles of dressed-quarks in the pion and kaon		
More speculative observables		
What is the trace anomaly contribution to the pion mass?	Elastic J/Ψ production at low W off the pion.	• Need to uniqu $e + p \to e' + J/\Psi + \pi^+ + n$ (low $-t$) • High luminosity (10^{34+}cm^{-2} sec^{-1}) • CM energy ~70 GeV
Can we obtain tomographic snapshots of the pion in the transverse plane? What is the pressure distribution in a pion?	Measurement of DVCS off pion target as defined with Sullivan process.	• Need to uniquely determine exclusive process $e + p \to e' + \gamma + \pi^+ + n$ (low $-t$) • High luminosity (10^{34+}cm^{-2} sec^{-1}) • CM energy ~10-100 GeV
Are transverse momentum distributions universal in pions and protons?	Hadron multiplicities in SIDIS off a pion target as defined with Sullivan process.	• Need to uniquely determine SIDIS off pion $e + p \to e' + h + X + n$ (low $-t$) • High luminosity (10^{34}cm^{-2} sec^{-1}) • $e + p$ and $e + D$ at similar energies desirable • CM energy ~10-100 GeV

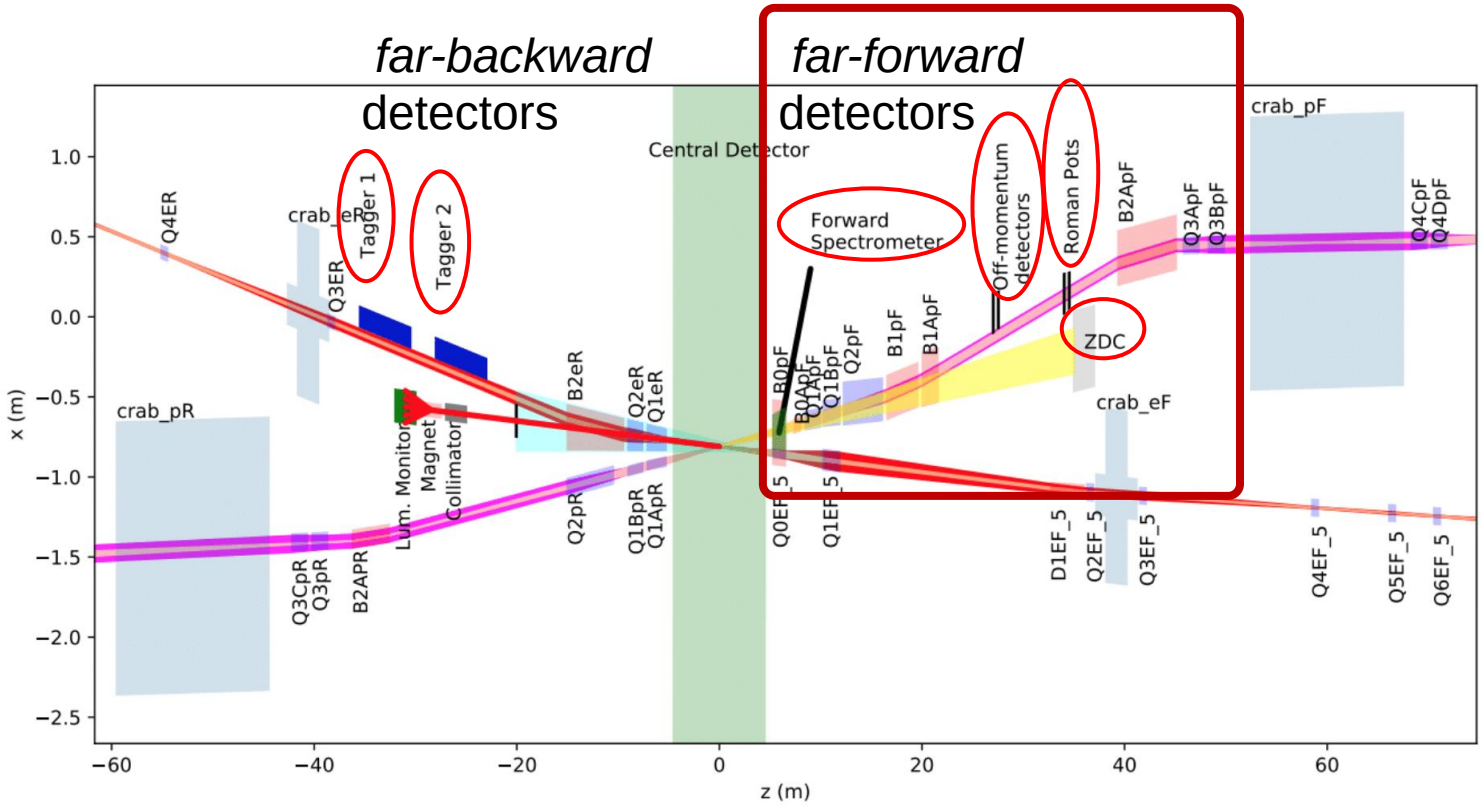
Impact on EIC Far-Forward Detector Design

Highly Integrated detector system: ~75m

1. Central detector: ~10m
2. Backward electron detection: ~35m
3. Forward hadron spectrometer: ~40m

Lesson learned from HERA – ensure low-Q^2 coverage

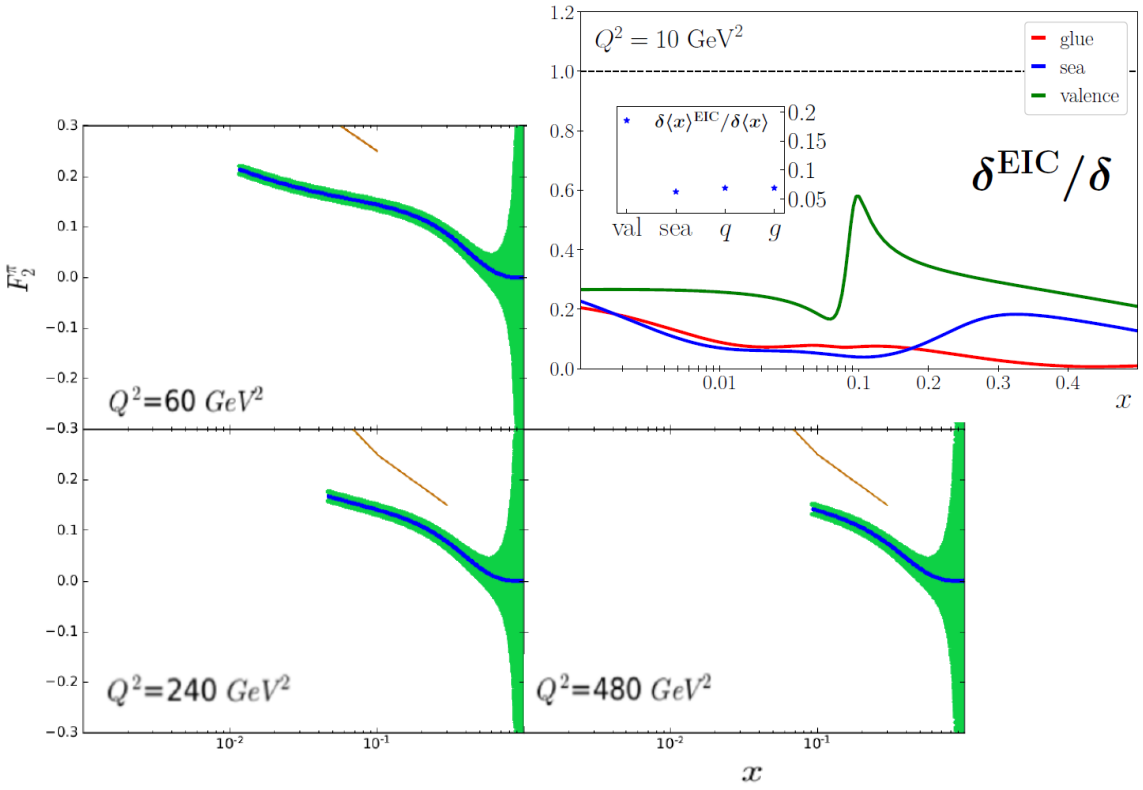
Various stage detector to capture forward-going protons and neutrons, and also decay products (Δ, Λ).

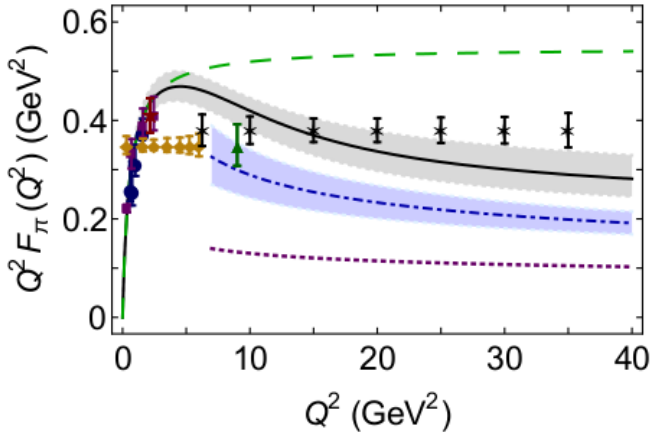


Role of EIC in Meson SF Studies

EIC promises to be the first facility on earth to see scaling violations in a hard exclusive process = pion form factor => locating at the crossover between soft and hard interactions

The unique role of EIC is its access to pion and kaon structure over a versatile large CM energy range, ~20-140 GeV. With its larger CM energy range, the EIC will have the final word on the contributions of gluons in pions and kaons as compared to protons, settle how many gluons persist as viewed with highest resolution, and vastly extend the x and Q^2 range of pion and kaon charts, and meson structure knowledge.





Big Picture Publications based on the WS

- “*Insights into the Emergence of Mass from Studies of Pion and Kaon Structure*.”, Invited review article for Progress in Particle and Nuclear Physics – submitted in January 2021

- “*Revealing the structure of light pseudoscalar mesons at the Electron-Ion Collider*” – submission planned to J. Phys. G

- EIC Yellow Report, Volume 2, Chapters 7 and 8; Volume 3, Chapter 11 – submission planned for early 2021

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Assistance provided by the CFNS

- Aided with promoting the meeting
- Effective support with web page, registration, etc.
- Technical assistance with "carrying" our broadcasts
- Easy to work with the CFNS people ... confident and competent
- All aspects of the teleworkshop proceeded without complication

Thank you!

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