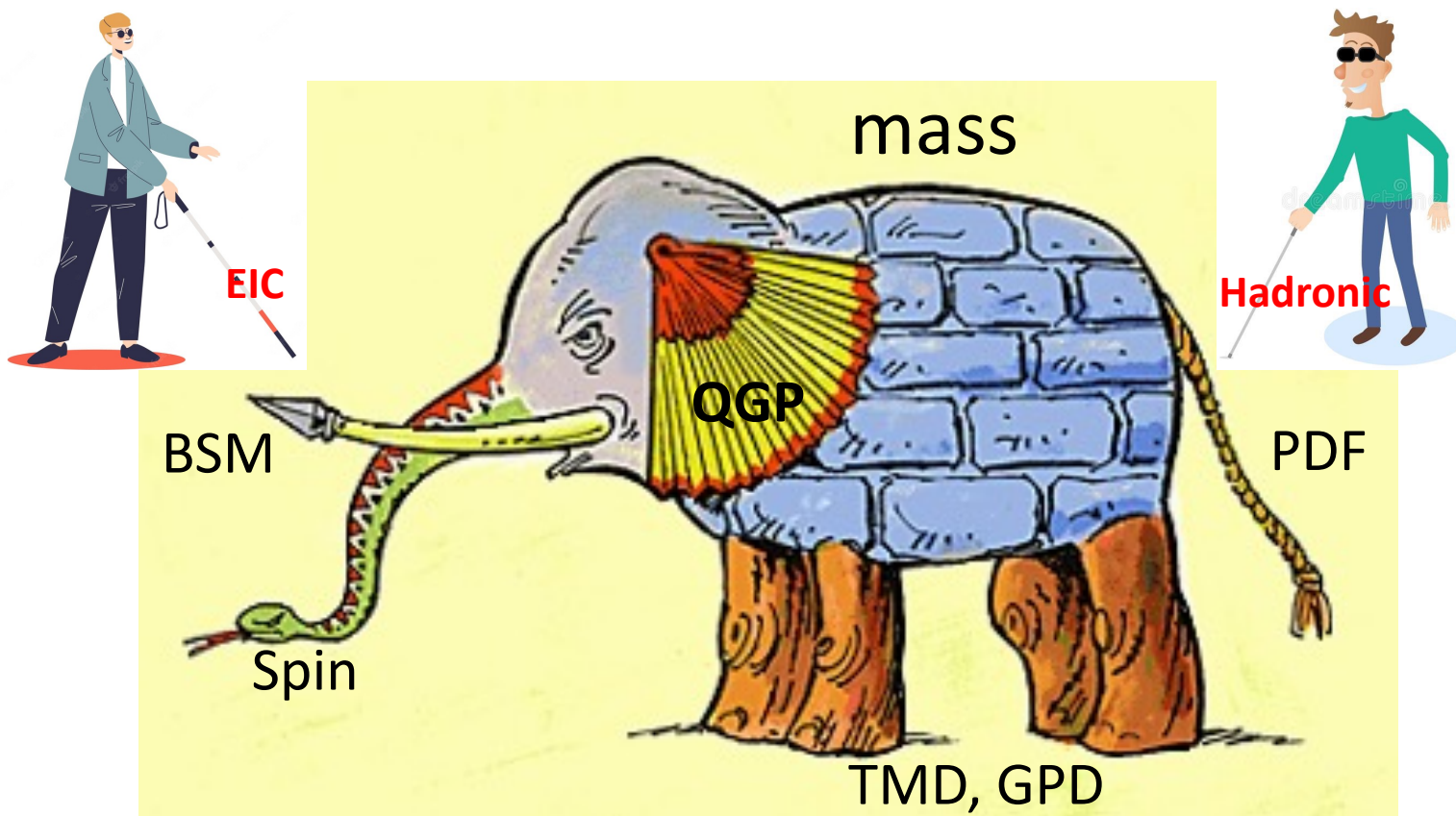


# On the Importance of Hadronic Interaction Physics Program at EIC Era

- study the emergent properties of Strong Interactions

Ming Liu, Los Alamos National Lab



## Two complementary tools to study strong interaction phenomena

- EM probe, EIC@BNL
- Hadronic probe @RHIC, FNAL, CERN
  - Proton beam, target
  - Charged pion and Kaon, @AMBER/CERN

## Selected key EIC physics

- EHM -> origin of hadron mass
  - Proton structure
  - Pion, Kaon structures
- TMD -> hadron structures
  - Test pQCD TMD factorization
  - Sign change in DY TSSA vs SIDIS
  - $Q^2$  evolution, QCD dynamics

# Opportunities in next 5~10 Years

## EHM and TMDs @CERN

- **Charged pi/K beams**
  - Direct access to hadron structures vs virtual ones with Sullivan process at EIC
  - Origin of hadron mass, p, pi, K
- **TMD physics and more**
  - Polarized target

## Quark/Gluon Spin, TMDs @RHIC, FNAL

- Polarized proton beam @RHIC
- Polarized p/n targets @FNAL

## Initial vs final states, DY vs DIS

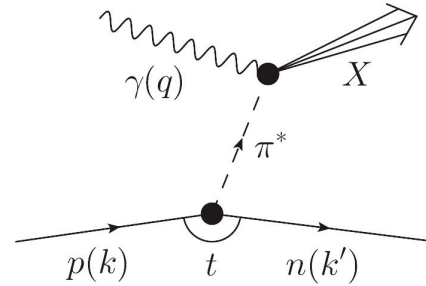
- Parton energy loss in Heavy Ion
- Saturation physics

## Complementary /Cross-check EIC physics interpretations

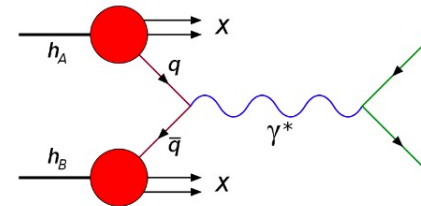
- Establish theoretical and experimental foundations

9/23/22

EIC:

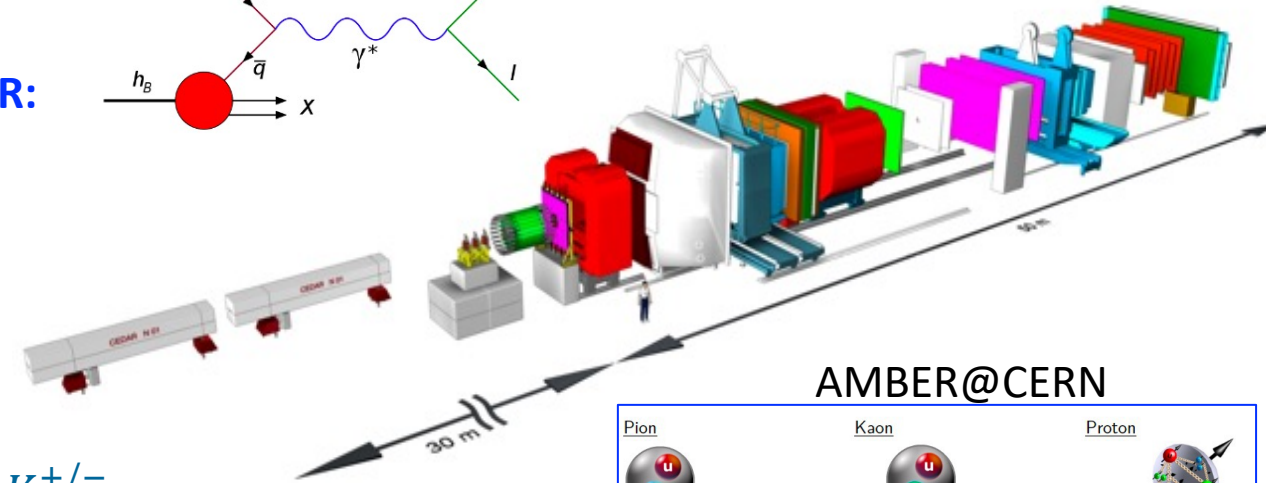
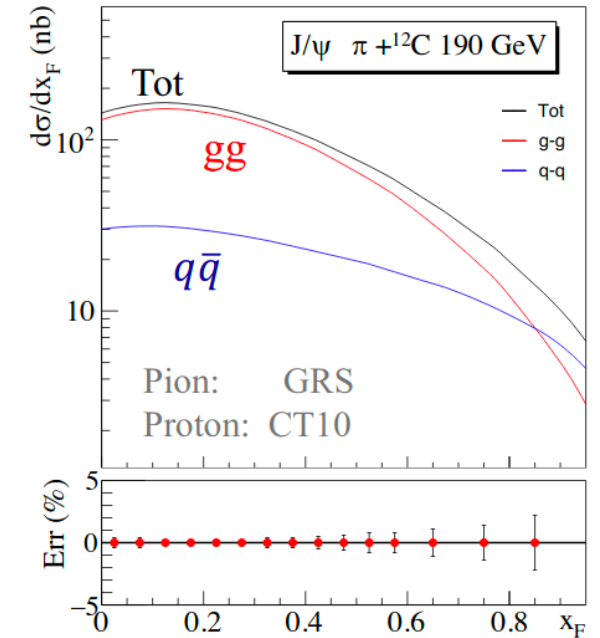


AMBER:



$\pi^{+/-}$  and  $K^{+/-}$  beam 190 GeV

Ming Liu @ QCD Town Hall



## AMBER@CERN

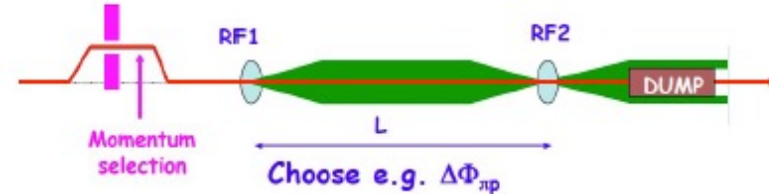
Pion	Kaon	Proton
<ul style="list-style-type: none"> <li>• <math>M_\pi \sim 140\text{MeV}</math></li> <li>• Spin 0</li> <li>• 2 light valence quarks</li> </ul>	<ul style="list-style-type: none"> <li>• <math>M_K \sim 490\text{MeV}</math></li> <li>• Spin 0</li> <li>• 1 light and 1 "heavy" valence quarks</li> </ul>	<ul style="list-style-type: none"> <li>• <math>M_p \sim 940\text{MeV}</math></li> <li>• Spin 1/2</li> <li>• 3 light valence quarks</li> </ul>

# backup

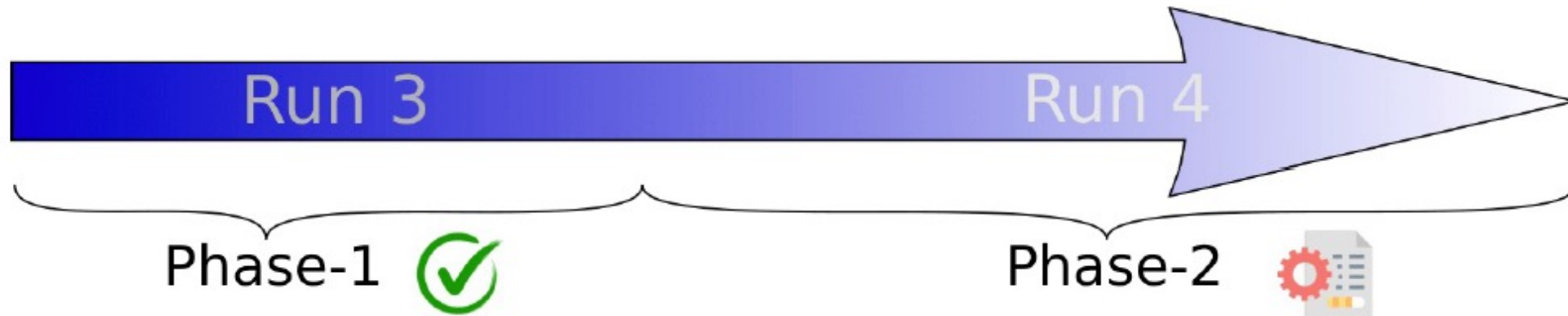
# AMBER Timeline

From Oleg Denisov

Conventional muon/hadron M2 beams



$$\Delta\Phi = 2\pi (L f / c) (\beta_1^{-1} - \beta_2^{-1}) \text{ with } \beta_1^{-1} - \beta_2^{-1} = (m_1^2 - m_2^2) / 2p^2$$



Proton Radius Measurement  
Antimatter production cross section  
**Pion structure (PDFs) via DY and charmonia**

**Kaon and pion structure (PDFs and PDAs)**  
High precision strange-meson spectrum  
**Kaon and pion charge radius**  
**Kaon induced Primakoff reaction**

Phase-1 Proposal approved by RB on 02/12/2020

Phase-2 Proposal submission in the beginning of 2022

# Complete RHIC Science – Hot and Cold QCD

- RHIC runs:  
2023 – 2025+

Physics data  
analysis continues  
beyond 2025...

## Inner workings of QGP

- Jets and HF interactions with QGP
- Cold Nuclear Matter, small systems
- Saturation physics

## Proton structure and QCD Dynamics

- Spin
- TMD

# EHM and Hadron Structures

## Pion



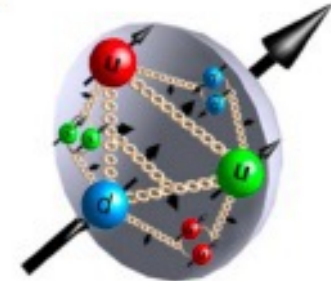
- $M_\pi \sim 140\text{MeV}$
- Spin 0
- 2 light valence quarks

## Kaon



- $M_K \sim 490\text{MeV}$
- Spin 0
- 1 light and 1 "heavy" valence quarks

## Proton



- $M_p \sim 940\text{MeV}$
- Spin 1/2
- 3 light valence quarks