Meson Structure Study via Drell-Yan and Charmonia Production at AMBER Phase-I/II

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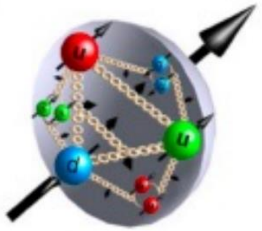
Importance of the meson structure measurement

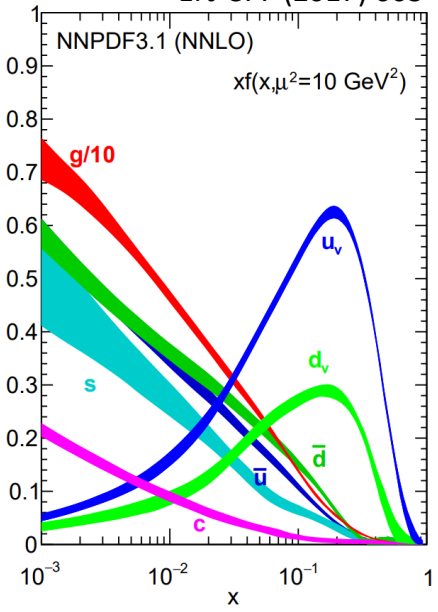
Proton



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

Abundant experimental data

EPJ C77 (2017) 663



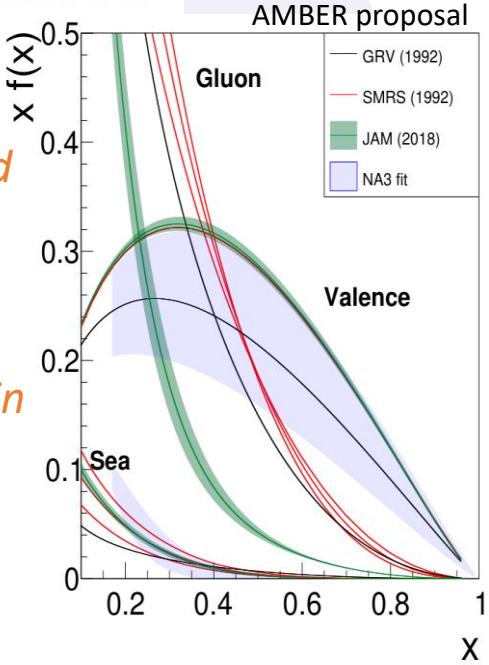
Pion

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

Limited old data

Sizable difference in global fits

AMBER proposal

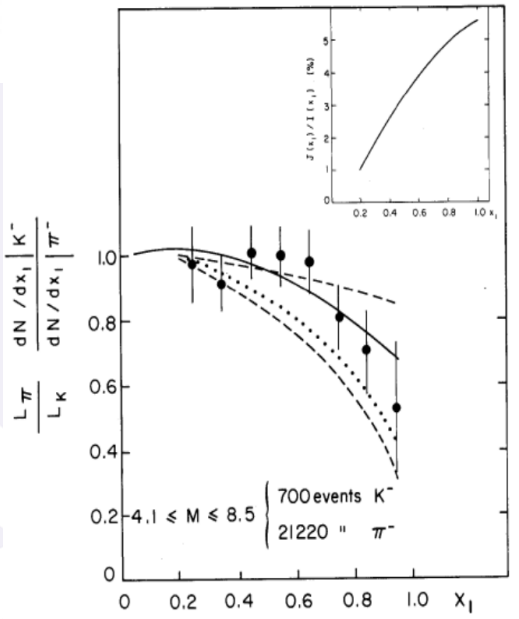


Kaon

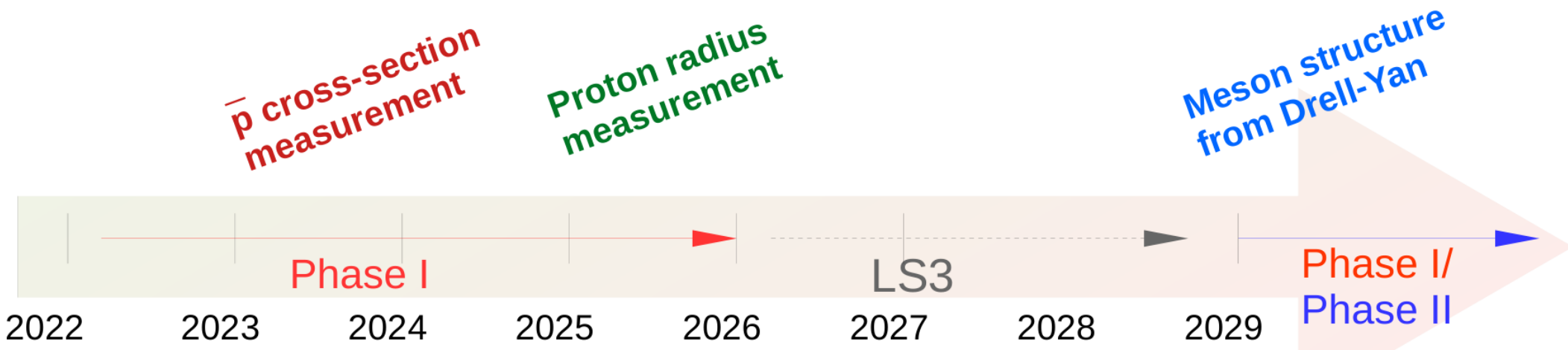
- $M_K \sim 490$MeV
- Spin 0
- 1 light and 1 "heavy" valence quarks

Only ~700 events from NA3

NA3: PLB 93 (1980) 354



Timeline of AMBER Drell-Yan program



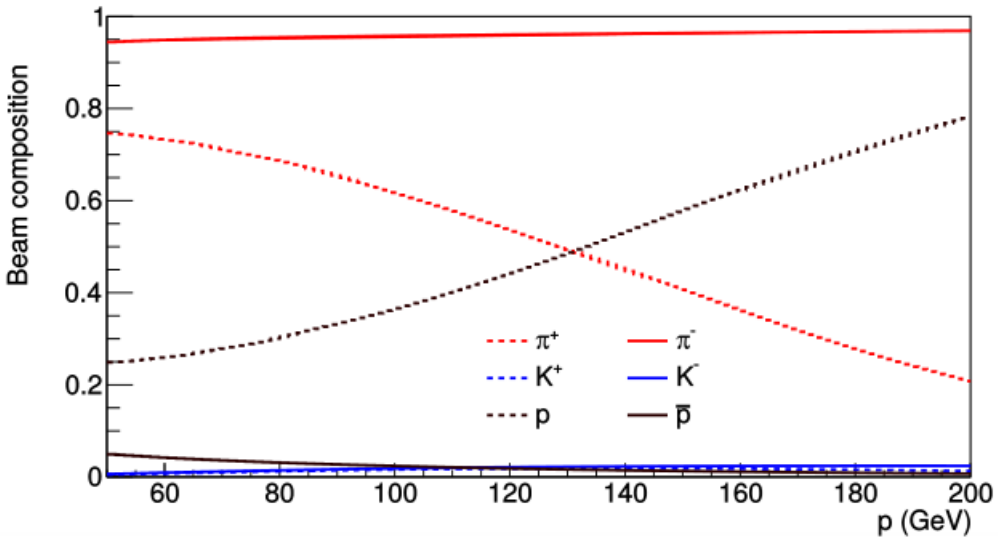
Approved Phase-I data taking plan:

- Short pilot run before LS3
- Two years of production scheduled after LS3, starting 2029
- Conventional 190 GeV hadron beam

Phase-II data taking plan under preparation

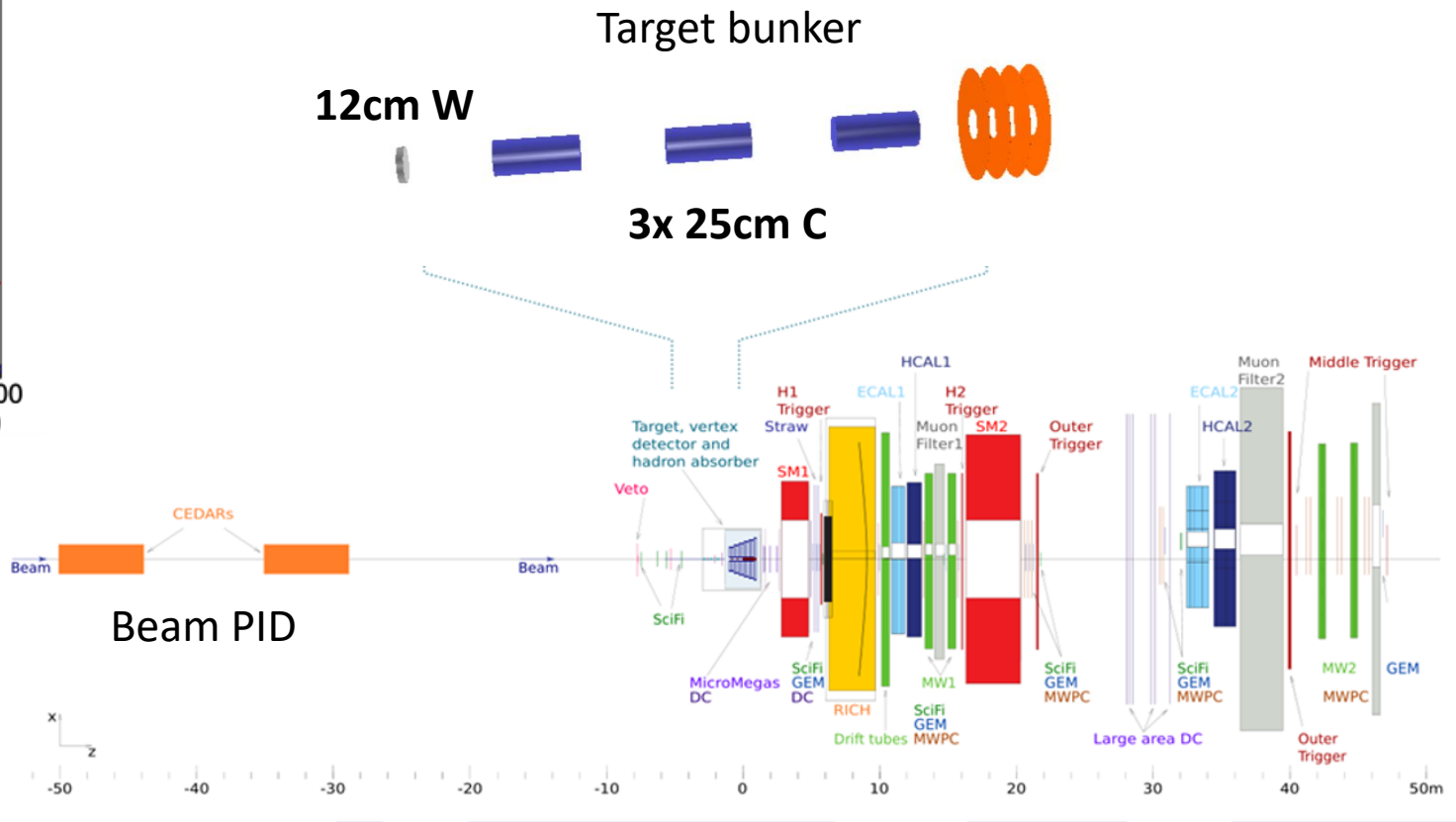
- High-purity kaon beam appeared to be challenging
- Continued DY data-taking with Phase-I beam configuration

Experimental setup for Phase-I Drell-Yan data-taking

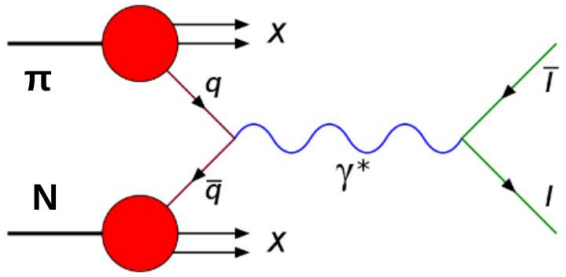


Conventional meson beam:

- Wide range of beam energy
- Beam intensity up to 7x10^7 p/s limited by the radiation protection
- Time sharing between h^+/h^- = 3:1
- Pions and protons dominate, but kaon accounts for ~2%

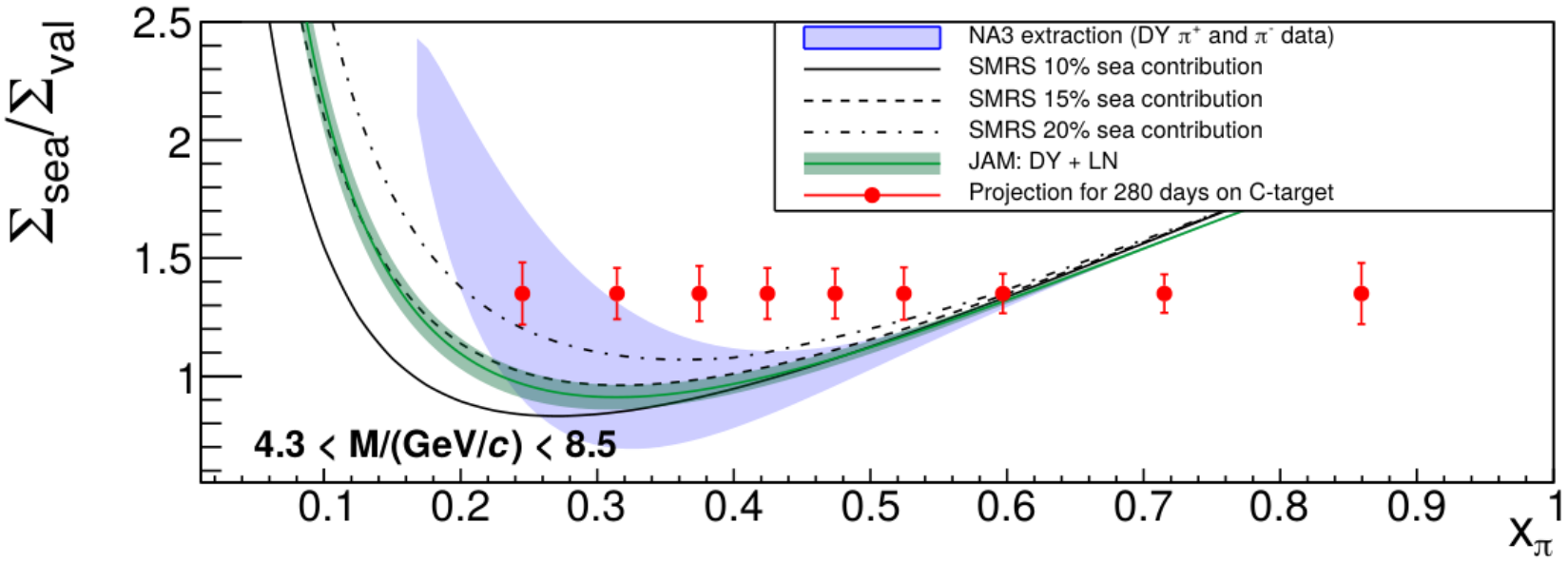


Accessing pion structure through Drell-Yan process



This exp	75 cm C	190	π^+	1.7×10^7	4.3 – 8.5 4.0 – 8.5	21700 31000
		190	π^-	6.8×10^7	4.3 – 8.5 4.0 – 8.5	67000 91100
	12 cm W	190	π^+	0.4×10^7	4.3 – 8.5 4.0 – 8.5	8300 11700
		190	π^-	1.6×10^7	4.3 – 8.5 4.0 – 8.5	24100 32100

Expected statistics after 280 days of running



$$\sum_{sea}^{\pi C} = 4\sigma^{\pi^+ C} - \sigma^{\pi^- C}$$

$$\sum_{val}^{\pi C} = -\sigma^{\pi^+ C} + \sigma^{\pi^- C}$$

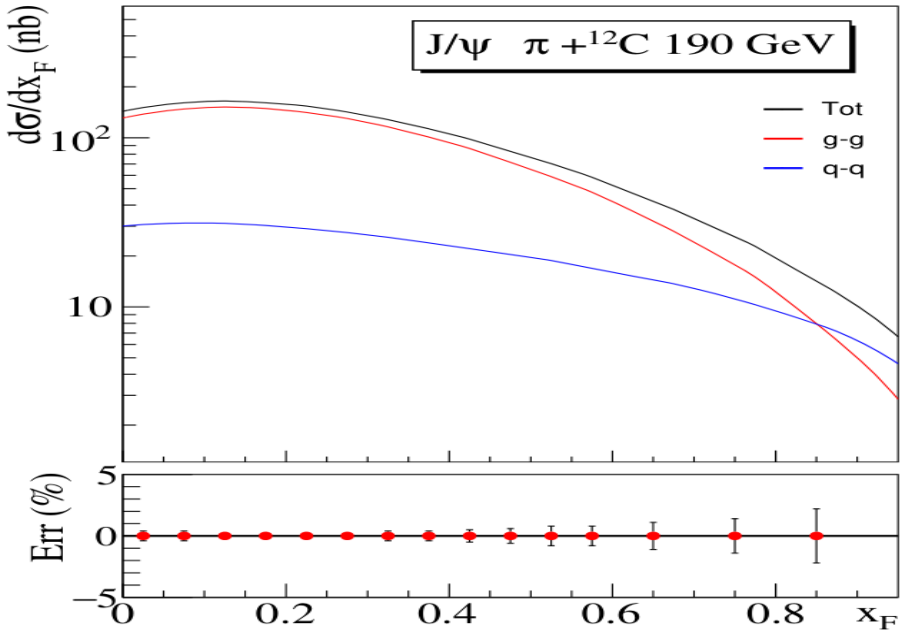
Parallel J/ψ production

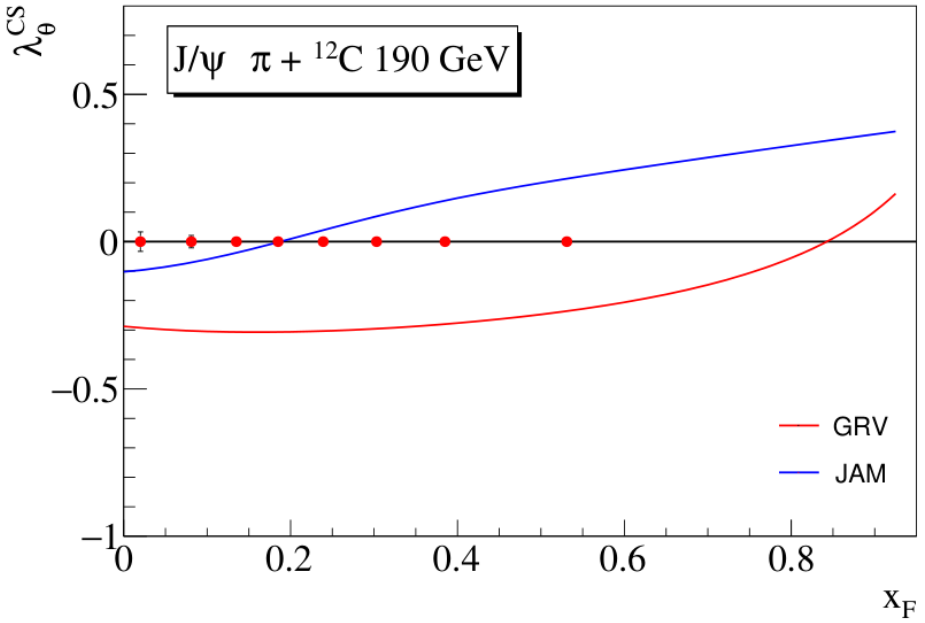
- Much larger cross section leads 20x more statistics accessing both gluon and quark content of the pion
  - ❑ Largest pion-induced J/ψ sample on a light isoscalar target, even with just the short pilot run in 2025

- The polarization of J/ψ, i.e. the λ parameter in the angular distribution $1 + \lambda\cos^2\theta$, provide an independent constraint on the relative contribution from the qqbar and gg process
  - ❑ For gg, λ = +1
  - ❑ For qqbar, λ = -1

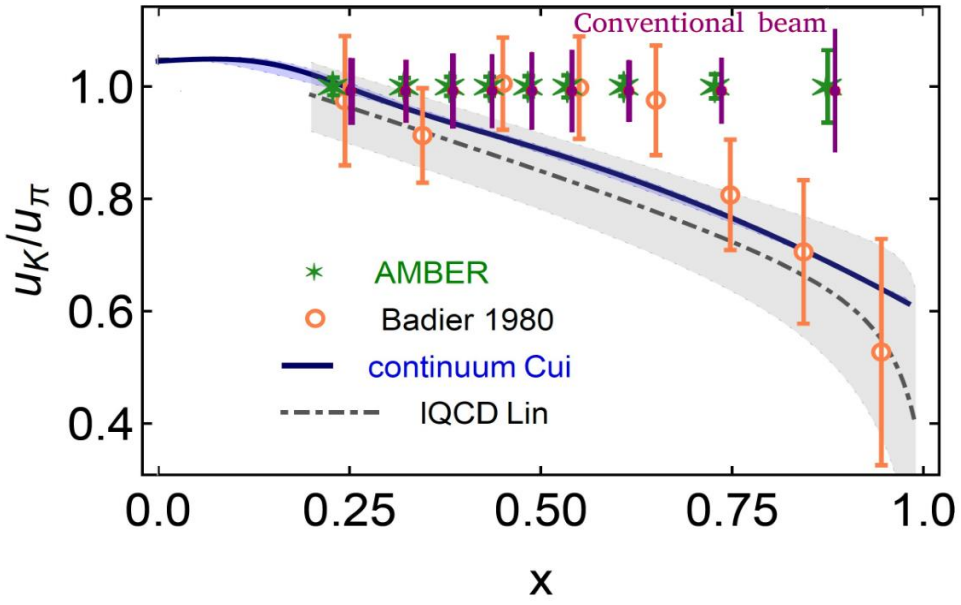
This exp	75 cm C	190	π^+	1200000
			π^-	1800000
			p	1500000
	12 cm W	190	π^+	500000
			π^-	700000
			p	700000

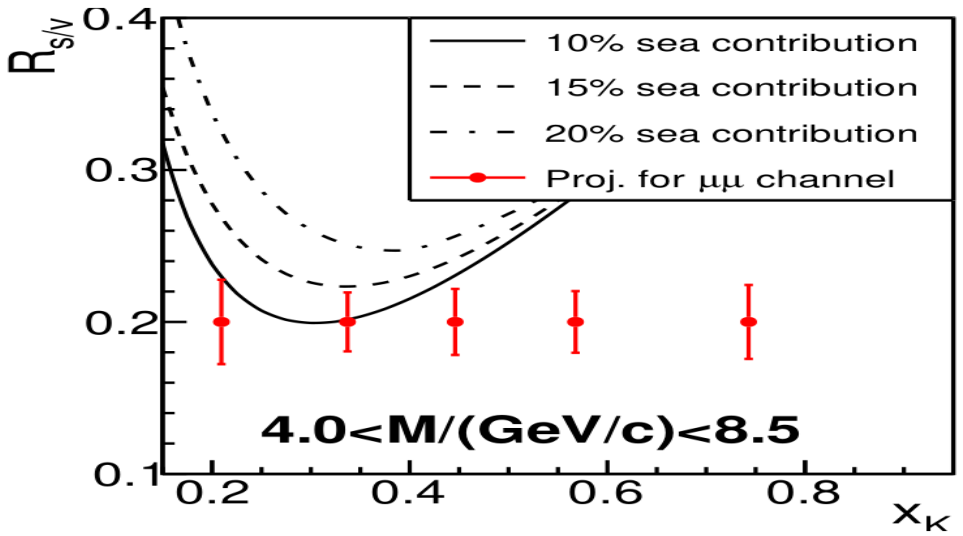
Expected statistics after 280 days of running





Kaon structure using conventional meson beam

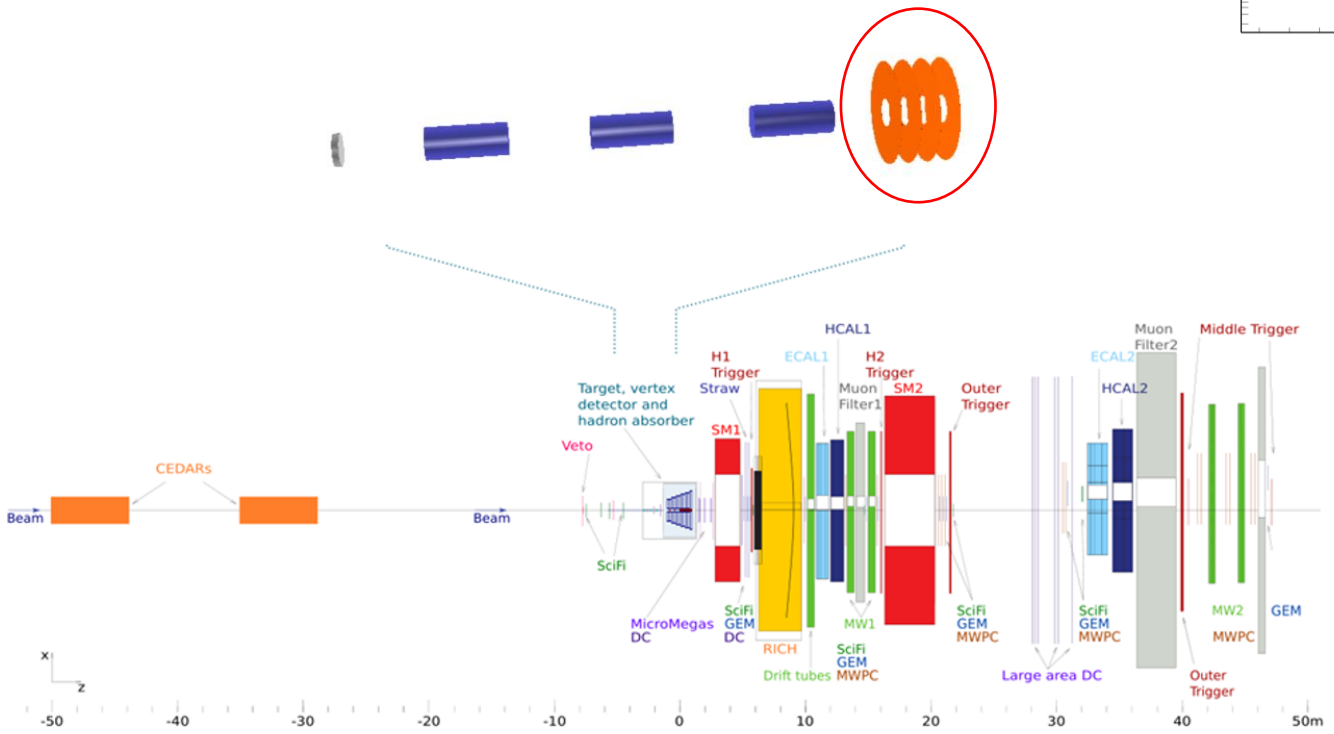


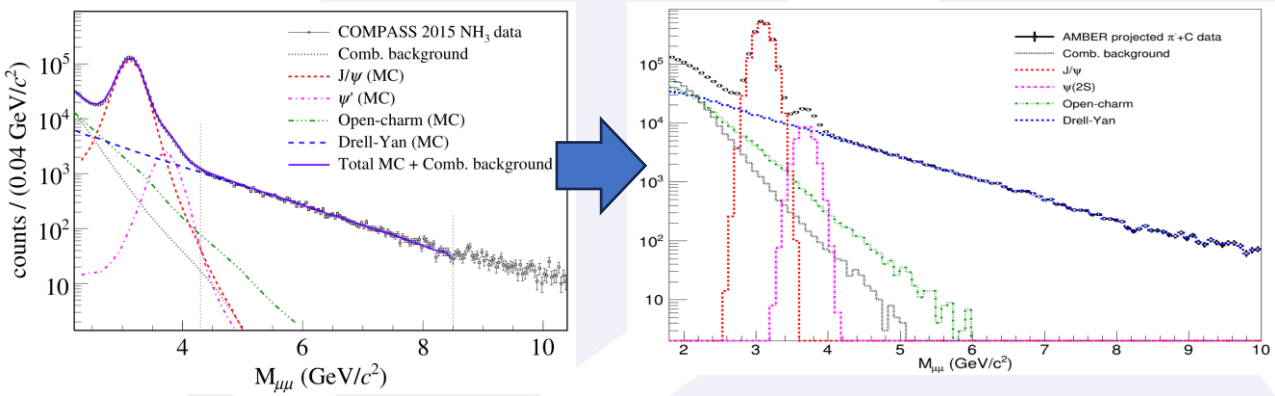


- Small kaon “contamination” (~2%) in the convention meson beam already gives us access to the kaon structure within the approved beam time in AMBER Phase-I
- DY cross section radio of K+C over π+C provides the measurement of the valance quark distribution in the kaon. Difference between K^+ and K^- probes the sea quark distribution.
- One year of data-taking with conventional beam yields data sample 3x larger than existing NA3 data
- We can also expect 3x larger kaon-induced Charmonia data sample, allowing us access to gluon content in the kaon

New silicon-strip vertex detector

- A new silicon strip vertex detector right after the last carbon target to improve the vertex and mass reconstruction
- Prototype detector planed for 2025 pilot run, and full detector planed for the long run after LS3





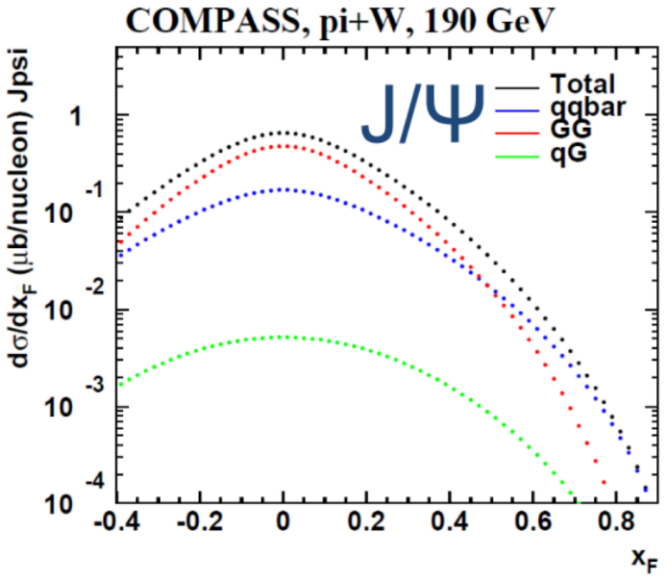
Preliminary simulation shows that the addition of vertex detector improves the mass resolution from ~200 MeV down to 100-150 MeV, the vertex resolution from ~12 cm down to <3 cm

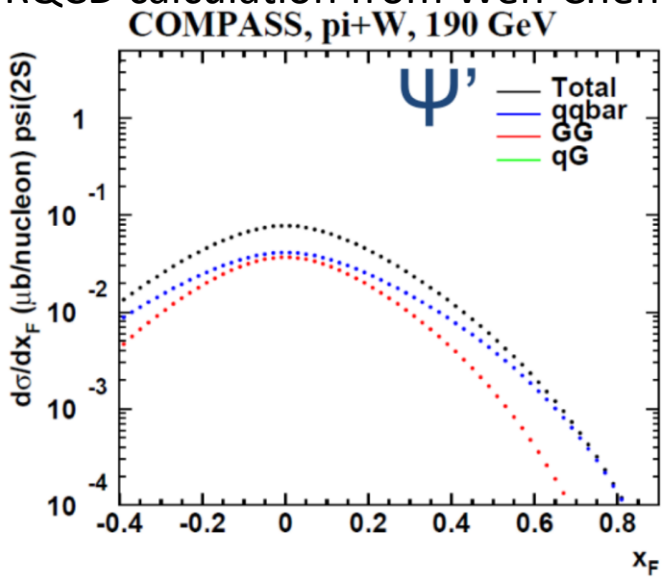
- Allows a lower mass cut for DY (4.3 GeV -> 4 GeV)
- Suppresses the combinatorial background through tighter vertex cut
- Might even allow us to access low-mass DY events
- Enables clean access to ψ'

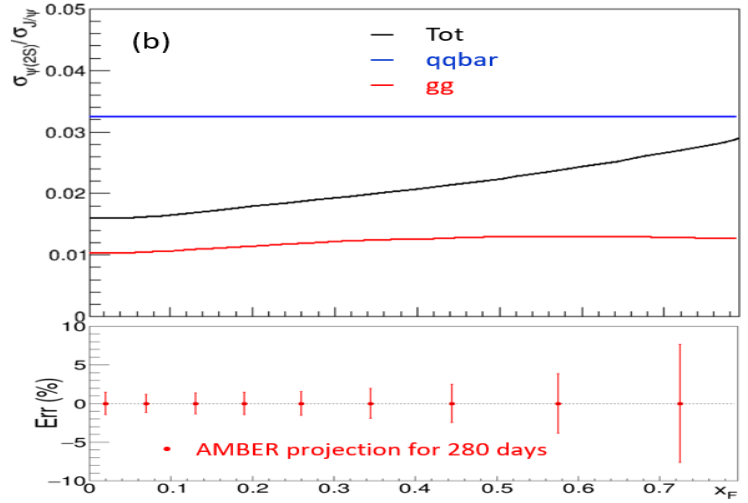
Additional probe through ψ' production

- Improved mass resolution from the vertex detector enables access to parallel ψ' production
  - ❑ Additional access to the gluon content in the meson
  - ❑ Free from the feed down from χ_{cJ} states
  - ❑ Insights into the charmonia production mechanism

NRQCD calculation from Wen-Chen







Other ongoing improvements (tomorrow's session)

- Improved radiation shielding – higher beam intensity

- Better beamline instrumentation – better beam PID
  - ❑ Optimization of the CEDARs performance
  - ❑ Reduction of beam divergence
  - ❑ Beamline tracking detectors to assist the CEDARs

We expect to see a factor of 2-3x improvement of the statistics with the same beam time

Summary and outlook

- AMBER's approved DY program at Phase-I will provided the largest pion-induced DY and charmonia data sample within this decade.
  - ❑ Simultaneous access to the valance, sea and gluon content inside the pion
  - ❑ Complementary to and constrains the EIC measurements in the next decade
- With conventional meson beam, kaon-induced data collected in parallel to the pion remains competitive (6x larger than NA3 data set after 2 years)
- Tremendous ongoing effort by CERN and AMBER collaboration to improve the beam intensity and spectrometer capabilities – expect 2-3x more statistics when we start the 2-yr production running in 2029.
- Meson structure program will continue to be a pivotal part of AMBER's phase-II data taking plan