The χ_c at the EIC: Experimental Aspects

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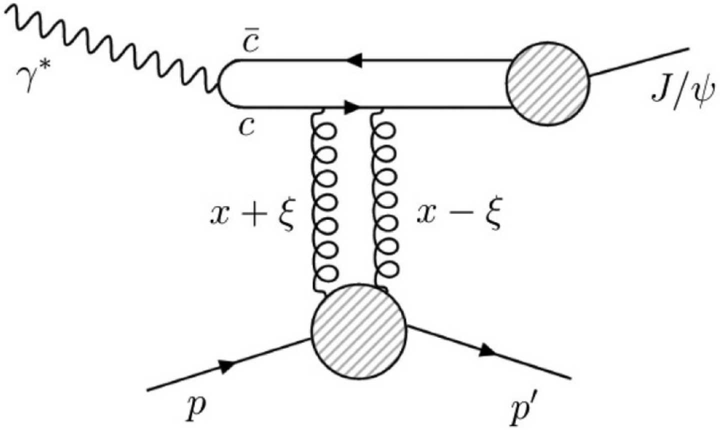
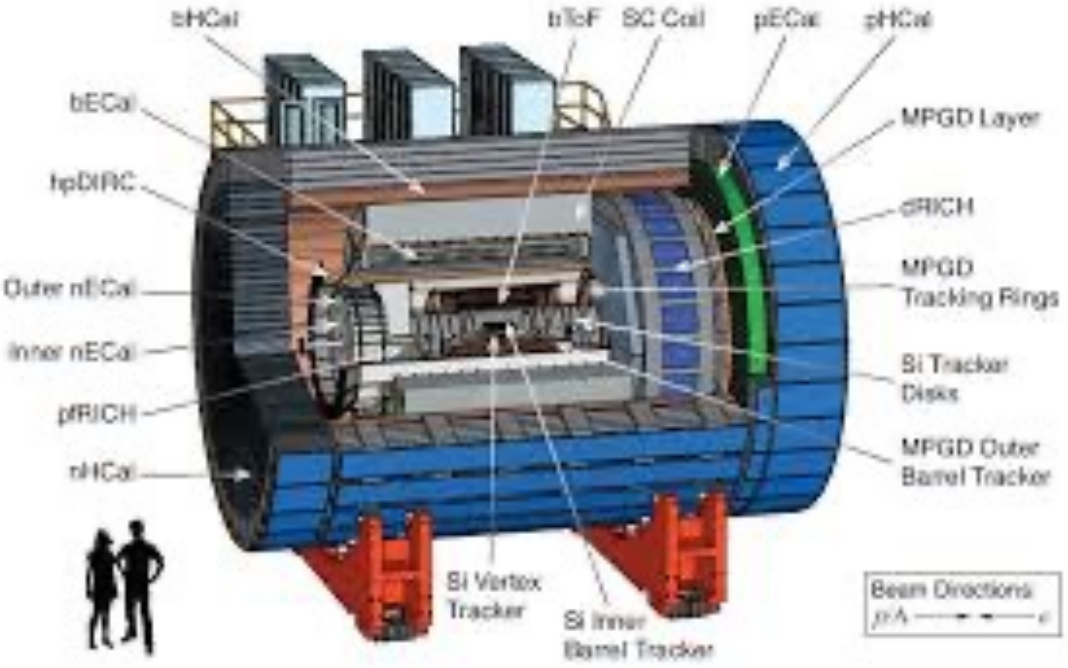


- χ_c decays
- Detecting the χ_c
- Important backgrounds



χ_c properties

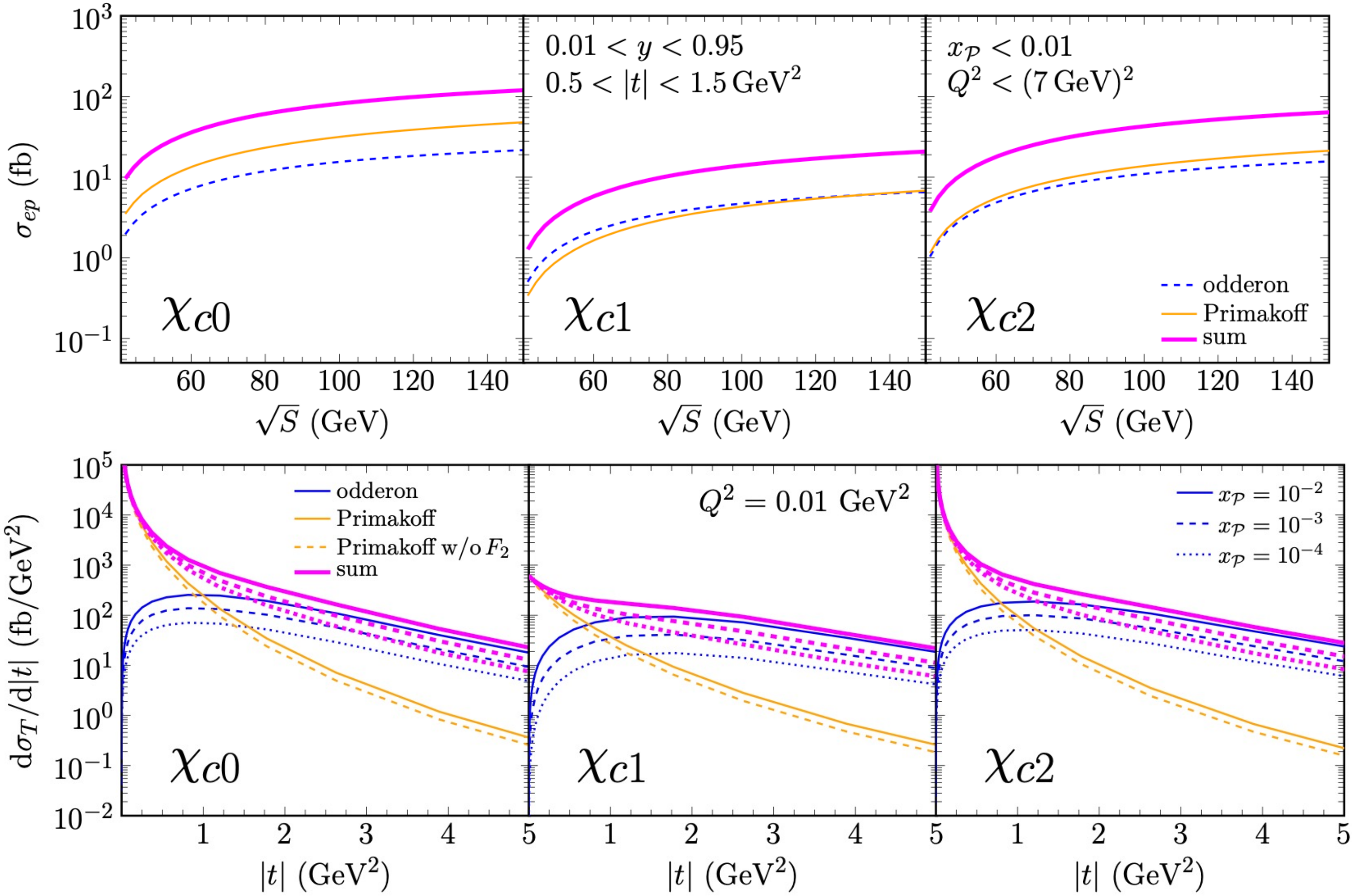
- 3 χ_c states

State	Mass	Width
χ_{c0}	3415 MeV	10.7 MeV
χ_{c1}	3511 MeV	0.84 MeV
χ_{c2}	3556 MeV	1.98 MeV

- Two classes of useful decays: hadronic final states or $\gamma J/\psi$
  - Br ($\chi_{c1} \to \gamma J/\psi$) = 34.3% (19.5% for χ_{c2} state, 1.4% for χ_{c0})
  - Specific hadronic final states have Br of at most a few percent.
    - Tedious to add up enough different hadronic states to achieve a reasonable efficiency.
- Mass separation ~ 50-100 MeV
  - Tough, but ~ within ePIC capabilities for all-charged final states
    - χ_{c0} - χ_{c1} has similar $\Delta M/M$ as $\Upsilon(2S)$ - $\Upsilon(3S)$
  - May be challenging for states containing neutrals

Production via γOdderon and γγ in ep

- Cross-section in femtobarn range – largest for χ_{c0}
- σ increases with √S, but faster increase for γγ process
- γγ process dominates up to ~~ |t| ~ 1 GeV^2



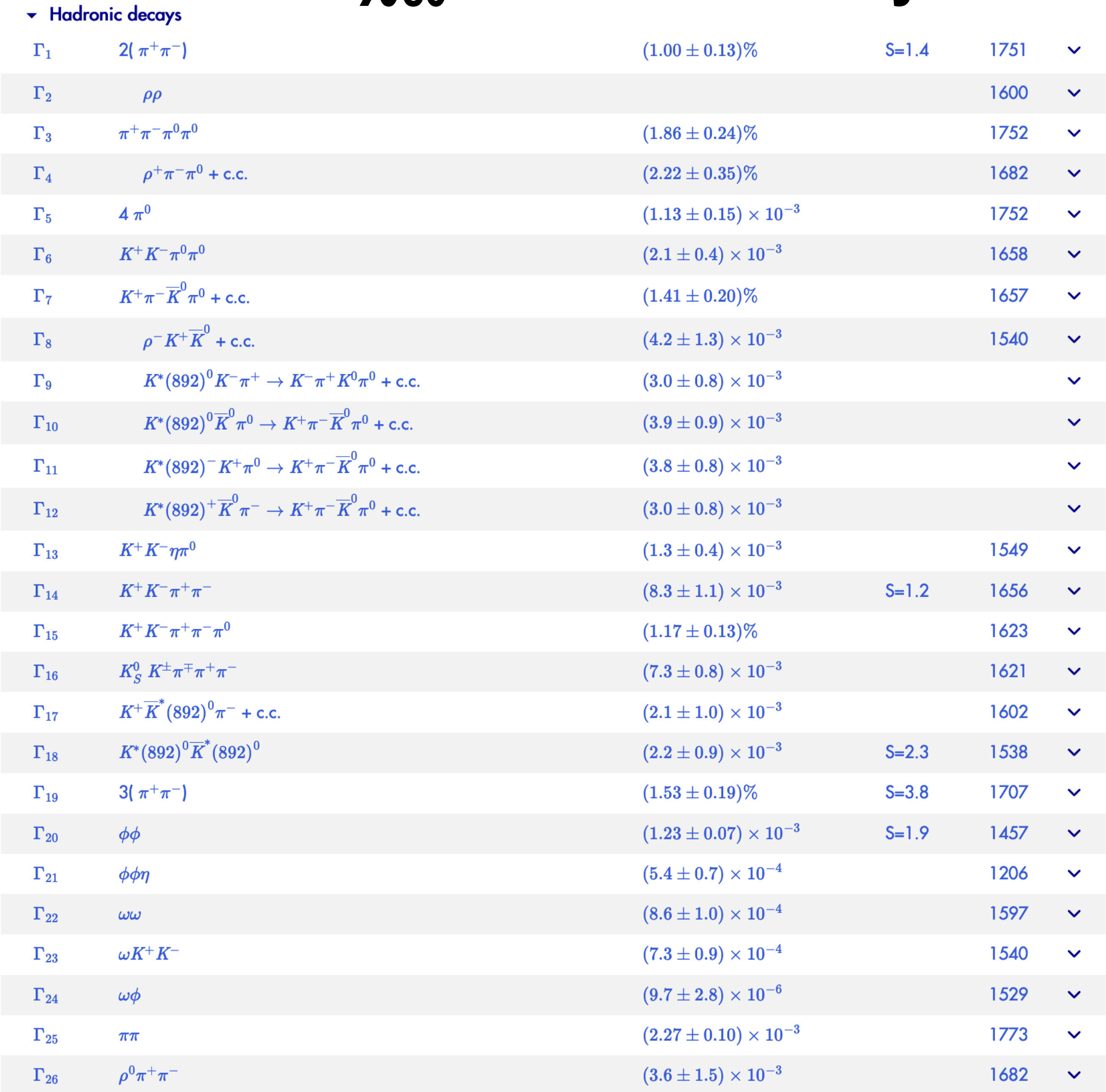
S. Benic *et al.*,
arXiv: 2402.19134

Assumes constructive γγ-γO interference

χ_{c0} detection

- χ_{c0} has the largest production rate, but Br(χ_{c0} -> $\gamma J/\psi$) ~ 1.4%
  - Most decays are 4+ prong final states
- If σ(total, with $\gamma\gamma$) = 50 fb, and Luminosity=100 fb^{-1} (after several years), this is 5,000 events total (mostly $\gamma\gamma$)
- Loss of efficiency due to limited acceptance in rapidity
  - May be different for $\gamma\gamma$ and γO
- If efficiency=70% and branching ratios are 2%, this is 70 events/channel, before acceptance.
- Isolation of a reasonably pure γO sample requires $|t|$>~~1 GeV^2
  - There are more sophisticated approaches involving fitting $d\sigma/dt$, but for a simple estimate, consider a hard cut
  - Lose ~ > 95% of the sample but still far from a pure γO sample
    - 3 events/decay channel? -> very tough

χ_{c0} hadronic decays



Hadronic decays

Γ_1	$2(\pi^+\pi^-)$	$(1.00 \pm 0.13)\%$	S=1.4	1751
Γ_2	$\rho\rho$			1600
Γ_3	$\pi^+\pi^-\pi^0\pi^0$	$(1.86 \pm 0.24)\%$		1752
Γ_4	$\rho^+\pi^-\pi^0$ + c.c.	$(2.22 \pm 0.35)\%$		1682
Γ_5	$4\pi^0$	$(1.13 \pm 0.15) \times 10^{-3}$		1752
Γ_6	$K^+K^-\pi^0\pi^0$	$(2.1 \pm 0.4) \times 10^{-3}$		1658
Γ_7	$K^+\pi^-\overline{K}^0\pi^0$ + c.c.	$(1.41 \pm 0.20)\%$		1657
Γ_8	$\rho^-K^+\overline{K}^0$ + c.c.	$(4.2 \pm 1.3) \times 10^{-3}$		1540
Γ_9	$K^*(892)^0K^-\pi^+ \to K^-\pi^+K^0\pi^0$ + c.c.	$(3.0 \pm 0.8) \times 10^{-3}$		
Γ_{10}	$K^*(892)^0\overline{K}^0\pi^0 \to K^+\pi^-\overline{K}^0\pi^0$ + c.c.	$(3.9 \pm 0.9) \times 10^{-3}$		
Γ_{11}	$K^*(892)^-K^+\pi^0 \to K^+\pi^-\overline{K}^0\pi^0$ + c.c.	$(3.8 \pm 0.8) \times 10^{-3}$		
Γ_{12}	$K^*(892)^+\overline{K}^0\pi^- \to K^+\pi^-\overline{K}^0\pi^0$ + c.c.	$(3.0 \pm 0.8) \times 10^{-3}$		
Γ_{13}	$K^+K^-\eta\pi^0$	$(1.3 \pm 0.4) \times 10^{-3}$		1549
Γ_{14}	$K^+K^-\pi^+\pi^-$	$(8.3 \pm 1.1) \times 10^{-3}$	S=1.2	1656
Γ_{15}	$K^+K^-\pi^+\pi^-\pi^0$	$(1.17 \pm 0.13)\%$		1623
Γ_{16}	$K^0_S K^\pm\pi^\mp\pi^+\pi^-$	$(7.3 \pm 0.8) \times 10^{-3}$		1621
Γ_{17}	$K^+\overline{K}^*(892)^0\pi^-$ + c.c.	$(2.1 \pm 1.0) \times 10^{-3}$		1602
Γ_{18}	$K^*(892)^0\overline{K}^*(892)^0$	$(2.2 \pm 0.9) \times 10^{-3}$	S=2.3	1538
Γ_{19}	$3(\pi^+\pi^-)$	$(1.53 \pm 0.19)\%$	S=3.8	1707
Γ_{20}	$\phi\phi$	$(1.23 \pm 0.07) \times 10^{-3}$	S=1.9	1457
Γ_{21}	$\phi\phi\eta$	$(5.4 \pm 0.7) \times 10^{-4}$		1206
Γ_{22}	$\omega\omega$	$(8.6 \pm 1.0) \times 10^{-4}$		1597
Γ_{23}	ωK^+K^-	$(7.3 \pm 0.9) \times 10^{-4}$		1540
Γ_{24}	$\omega\phi$	$(9.7 \pm 2.8) \times 10^{-6}$		1529
Γ_{25}	$\pi\pi$	$(2.27 \pm 0.10) \times 10^{-3}$		1773
Γ_{26}	$\rho^0\pi^+\pi^-$	$(3.6 \pm 1.5) \times 10^{-3}$		1682

From the Particle Data Book

Another background

- Vector meson dominance → large $\Psi(2S)$ production rate
  - $\sigma(ep\text{->}\ \Psi(2S)p)$ = 1.4 nb for 18 GeV e on 275 GeV p
  - 30,000 times larger than for χ_{c0}
- Br $(\Psi(2S)\text{->}\ \gamma\chi_{c0})$ = 9.8 ± 0.2%
  - 3,000 times larger than direct χ_{c0} production
  - In $\Psi(2S)$ rest frame photon energy = 260 MeV
    - Good energy for calorimetry, but solid angle < 100%
    - If ~95% coverage, then missed-photon background is 150 times larger than direct χ_{c0} production
    - Also, some photons may be Lorentz downshifted below threshold
- Missing energy/momentum cuts could eliminate some background
  - Missing photons with low p_T probably cannot be adequately rejected
- χ_c from $\Upsilon(2S)$ probably have similar p_T spectrum to χ_c from πO

Concept: SK, Phys. Rev. D **98**, 118501 (2018)
σ: SK and M. Lomnitz, Phys. Rev. C **99**, 015203 (2019)

$\Psi(2S)$ backgrounds to the $\chi_c 1$ and $\chi_c 2$

- Branching ratios $\Psi(2S)\text{->}\ \gamma\chi_{cn}$ all similar

State	Br (Y(2S)-> χ_{cn}
χ_{c0}	9.8 ± 0.2%
χ_{c1}	9.7 ± 0.3%
χ_{c2}	9.4 ± 0.2%

- Backgrounds are similar, so experimentally, χ_{c0} seems most attractive because of its larger direct production rate.

Detection of the χ_c1 and χ_c2

- Detection via $\chi_{c1,2}$ -> γJ/ψ may be relatively more attractive because of larger radiative branching ratios
  - Br (χ_{c1}-> γJ/ψ) = 34.3% & Br (χ_{c2}-> γJ/ψ) = 19.5%
    - Not a panacea, because Br (J/y-> ee, $\mu\mu$) are only 6% each.
- For same 50 fb cross-section and Luminosity=100 fb^{-1} the rate of γee and $\gamma\mu\mu$ final states is ~~100 each for $\gamma\gamma+\gamma$o
  - Radiative branching ratio for ξ_{c1} is larger, but predicted production cross section is larger for ξ_{c2}.
  - Background from Y(2S) feeddown is ~285,000/164,000 γee and $\gamma\mu\mu$ events each through the χ_{c1} and χ_{c2} respectively.
    - 95% calorimeter coverage would reduce this background to ~14,500 and 8200 events each respectively.
- At best, extremely challenging.

Conclusions

- The χ_c states are interesting to study as possible channels to detect the Odderon.
- However, the rates are low, and there are many possible final states
  - The χ_{c0} is most copiously produced, so may be the most attractive experimental target
- Backgrounds are large
  - $\gamma\gamma$–> dominates over γ + Odderon, except at large |t|
  - γP -> Ψ(2S)->$\gamma\chi_c$ dominates over direct χ_c production mechanisms
    - Vector meson dominance strikes again!