Wide-angle exclusive photoproduction of π^0 mesons

Report on E12-14-005 (Amaryan, Dutta, Gao, Kunkel, Strakovsky, Širca)

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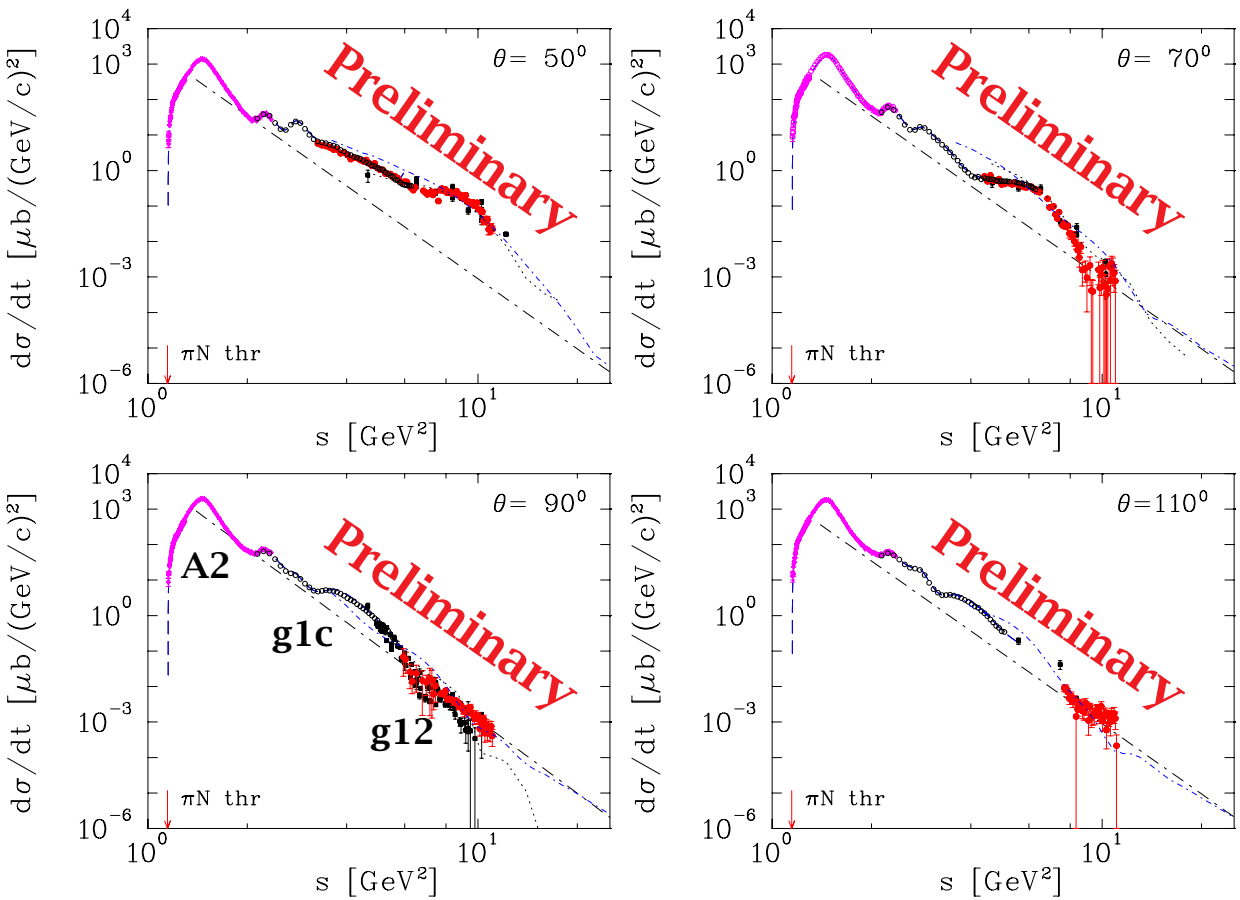
Motivation

- **Hard exclusive reactions** ideal for studying hadronic dynamics of underlying parton-level processes
  In particular: does exclusive π photo-production proceed through the interaction of the photon with a single quark?
- **Small number of elementary fields** in $\gamma p \to \gamma p$ and $\gamma p \to p\pi^0$ ideal to test **scaling relations**
- Accessing the regime $s \approx |t| \approx |u| \gg \Lambda^2$,
  i. e. high energies, high momentum transfers, large angles ($p_T > 1\,\mathrm{GeV}/c$) crucial to understand **short-range structure of nucleons**
- Testing ground of QCD at intermediate energies to explore the onset of **transition from npQCD to pQCD**

Existing data for $\gamma p \to p\pi^0$ $\mathbf{d\sigma/dt(s)}$

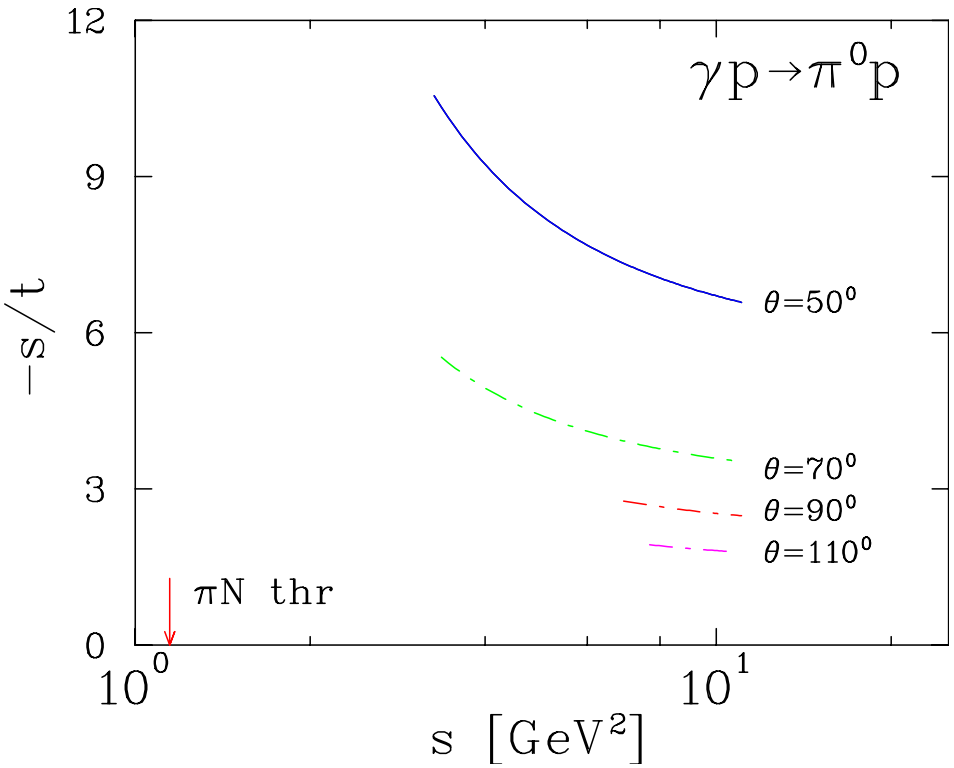
- $\theta^* = 50°, 70°, 90°, 110°$
- Latest g12 (CLAS) results from $\gamma p \to p\pi^0 \to p\gamma\gamma \to pe^+e^-\gamma$
- High s, large θ^*: consistent with s^{-7} scaling (s^{-n}, $n = 6.89 \pm 0.26$)

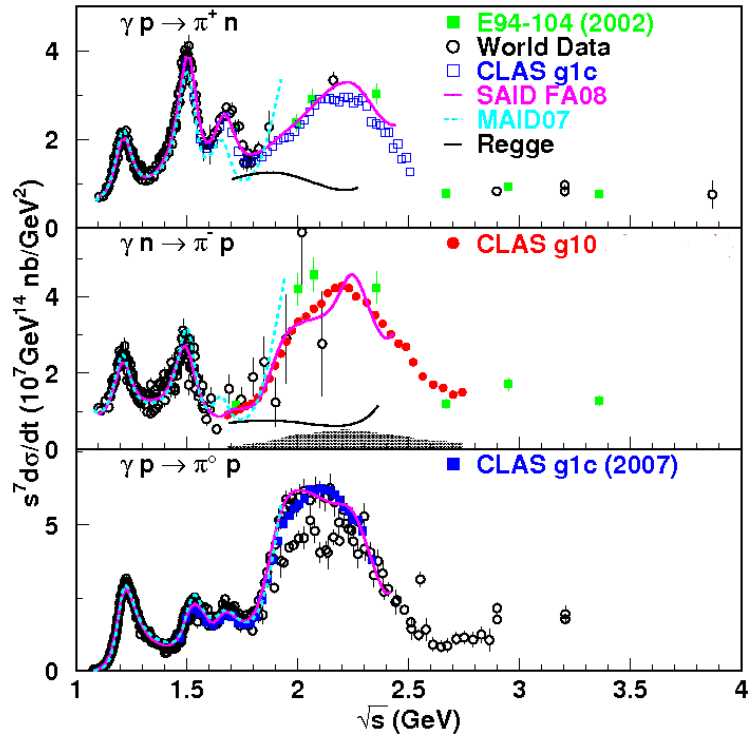


Figures courtesy of I. Strakovsky

Onset of scaling regime

- Data at lower θ^* tend to reach power-law behavior at higher s
- At small angles the values of $|t|$ are much smaller than s violating the $s \approx |t| \approx |u| \gg \Lambda^2$ requirement

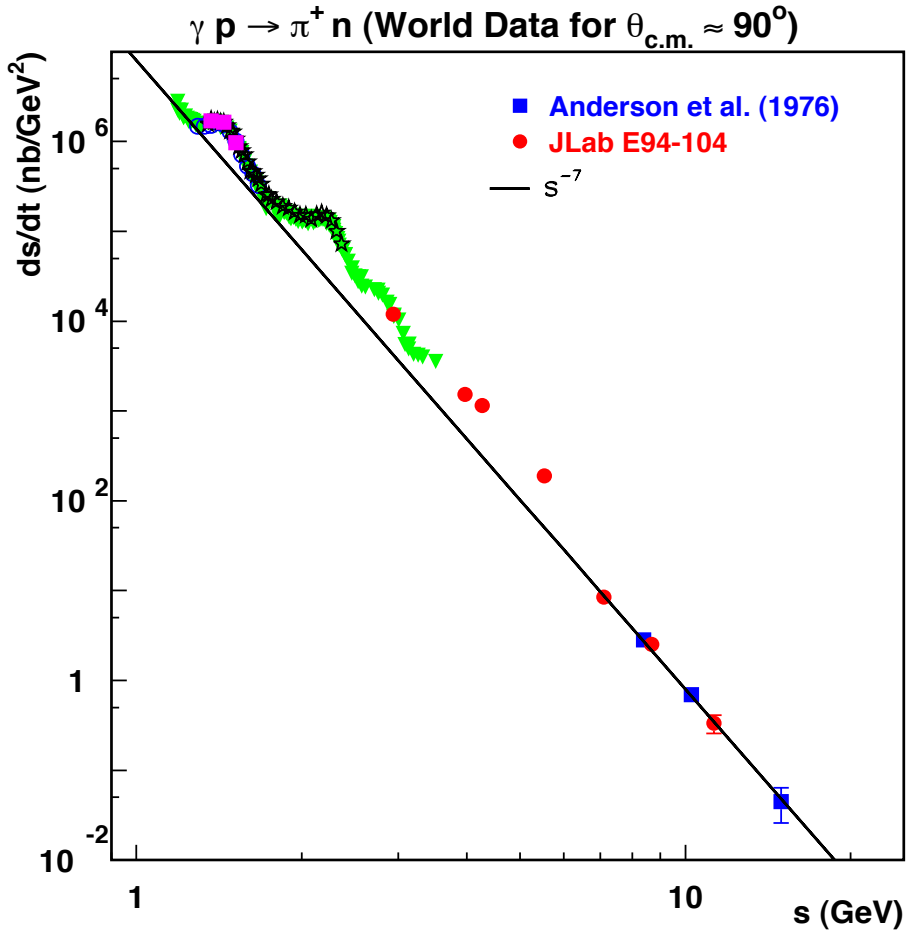




- Charged photo-production data at highest s also indicates scaling

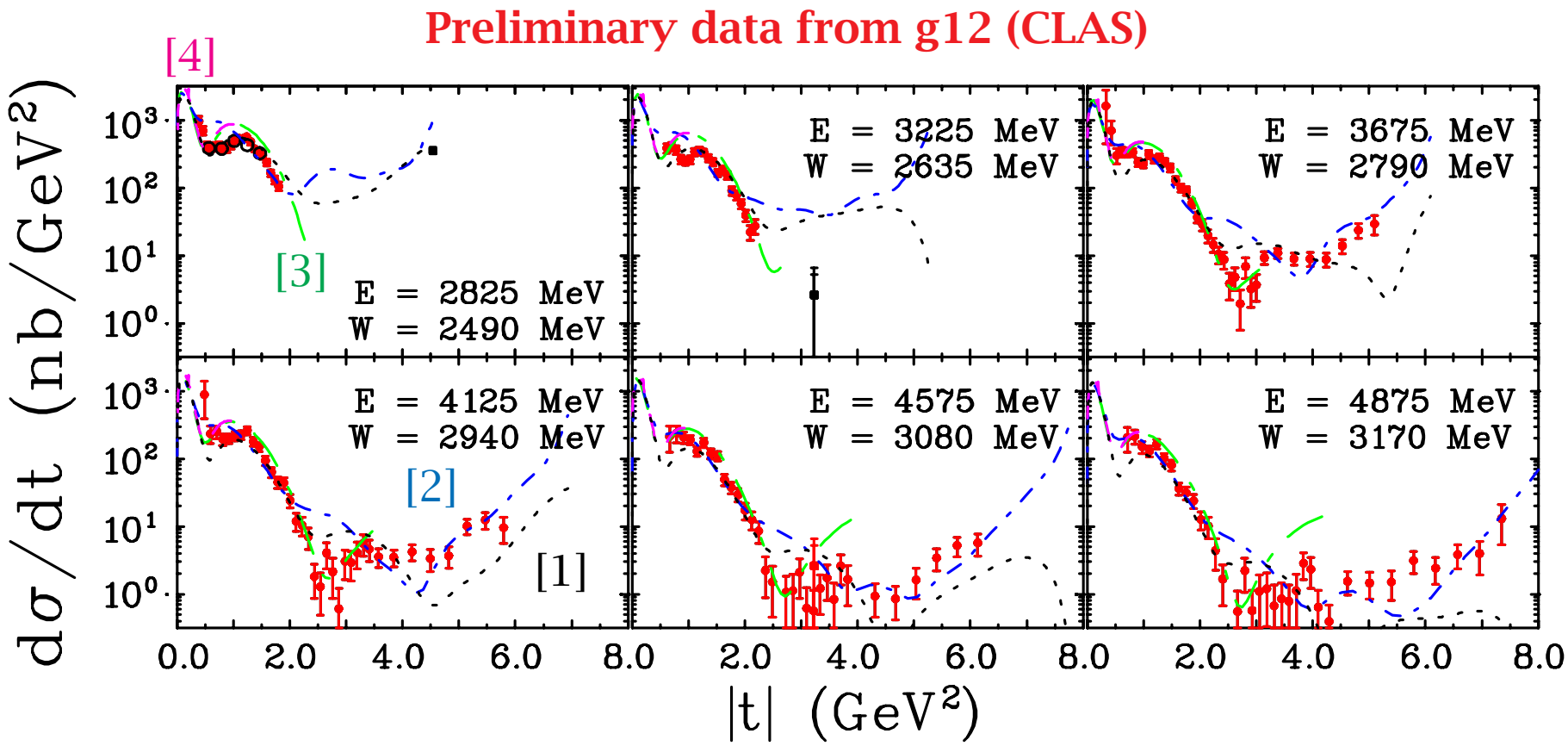
Onset of scaling in π^+ photo-production

Zhu++ PRL **91** (2003) 022003, PRC **71** (2005) 044603



- We wish to see someting like this with π^0 at high s

Existing data for $\gamma p \to p\pi^0$ $\quad$ $d\sigma/dt(t)$



- Qualitative description in terms of Regge models:

  [1] Goldstein, Owens, PRD **7** (1973) 865

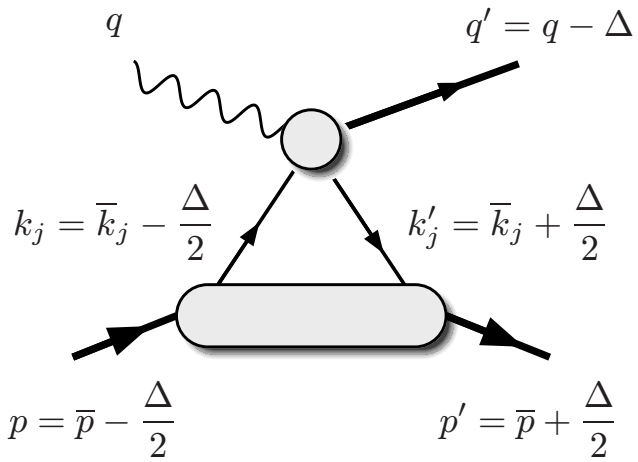
  [2] Laget, PRC **7** (2005) 022202 (R)

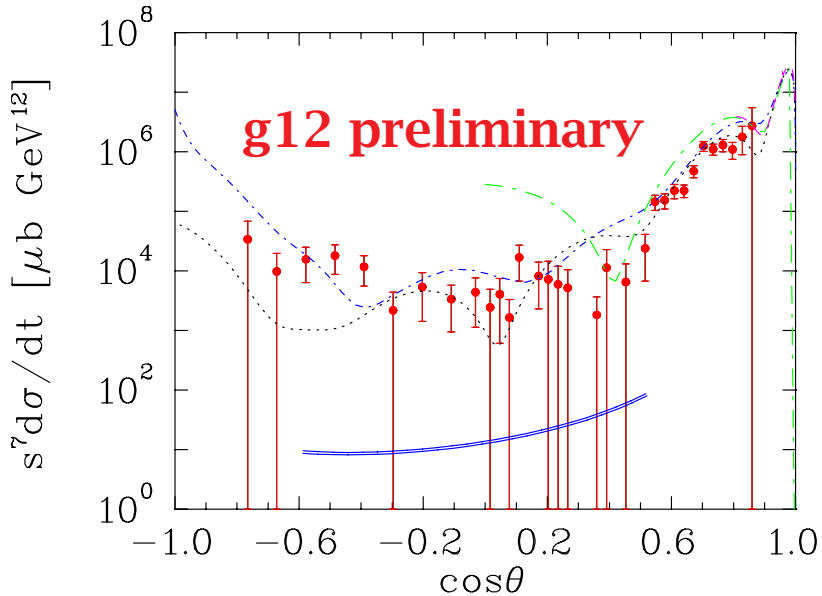
  [3] Mathieu, Fox, Szczepaniak, PRD **92** (2015) 074013

  [4] Donnachie, Kalashnikova, PRC **93** (2016) 025203

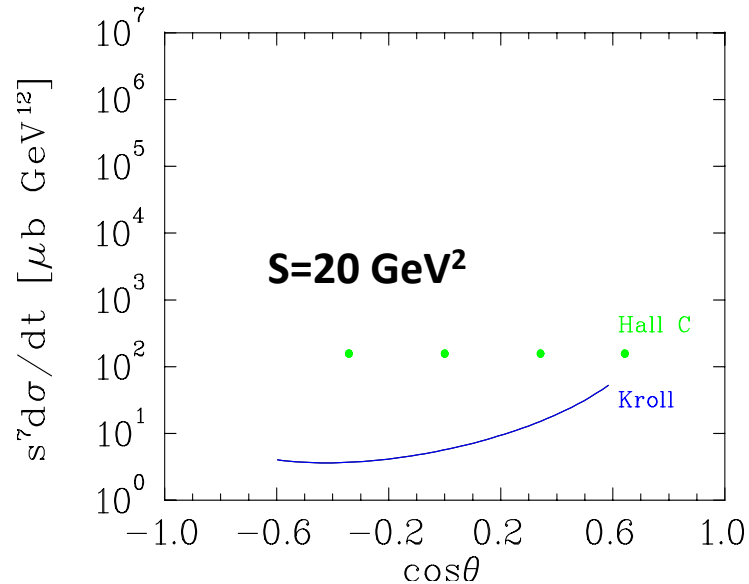
Figures courtesy of I. Strakovsky

The handbag mechanism, GPD- and Regge-based models





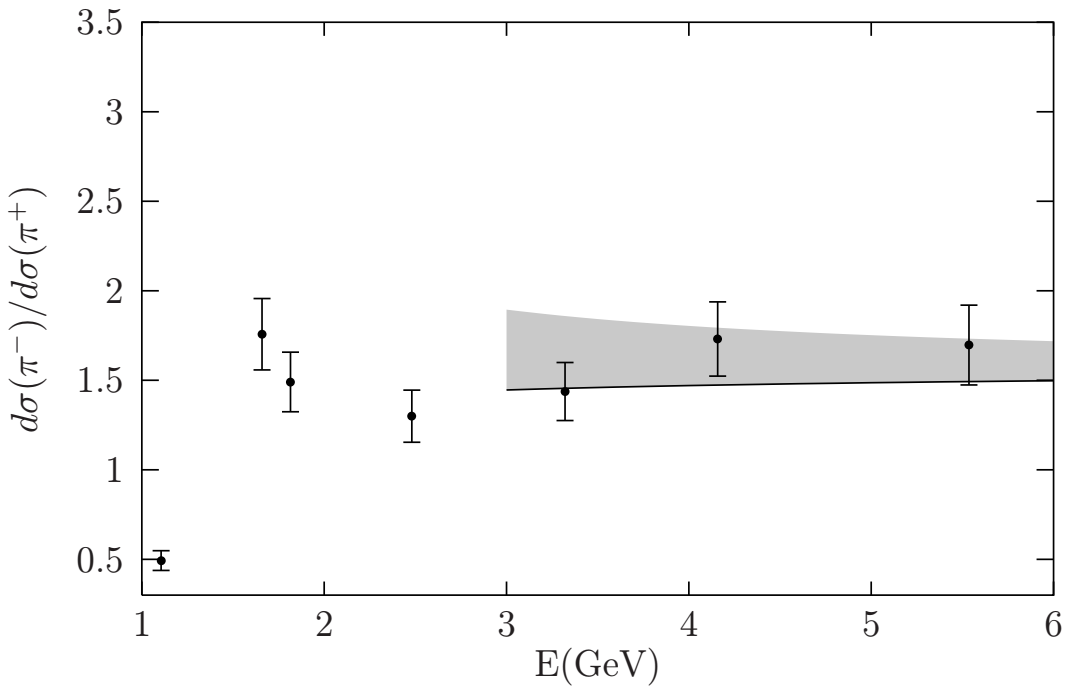
- Very nice description of data by Regge-type approaches
- Handbag predictions typically off by several orders of magnitude!
  - — Huang, Kroll, EPJC **17** (2000) 423
  - — Huang, Jacob, Kroll, EPJC **33** (2004) 91
  - — Diehl, Kroll, EPJC **73** (2013) 2397



Charged-pion XS ratios

- Search for signatures of handbag mechanism in photo-production of **charged** pions at large angles // Huang++ EPJC **33** (2004) 91

$$\frac{\mathrm{d}\sigma(\gamma n \to \pi^- p)}{\mathrm{d}\sigma(\gamma p \to \pi^+ n)} = \left(\frac{e_u s + e_d u}{e_u u + e_d s}\right)^2$$

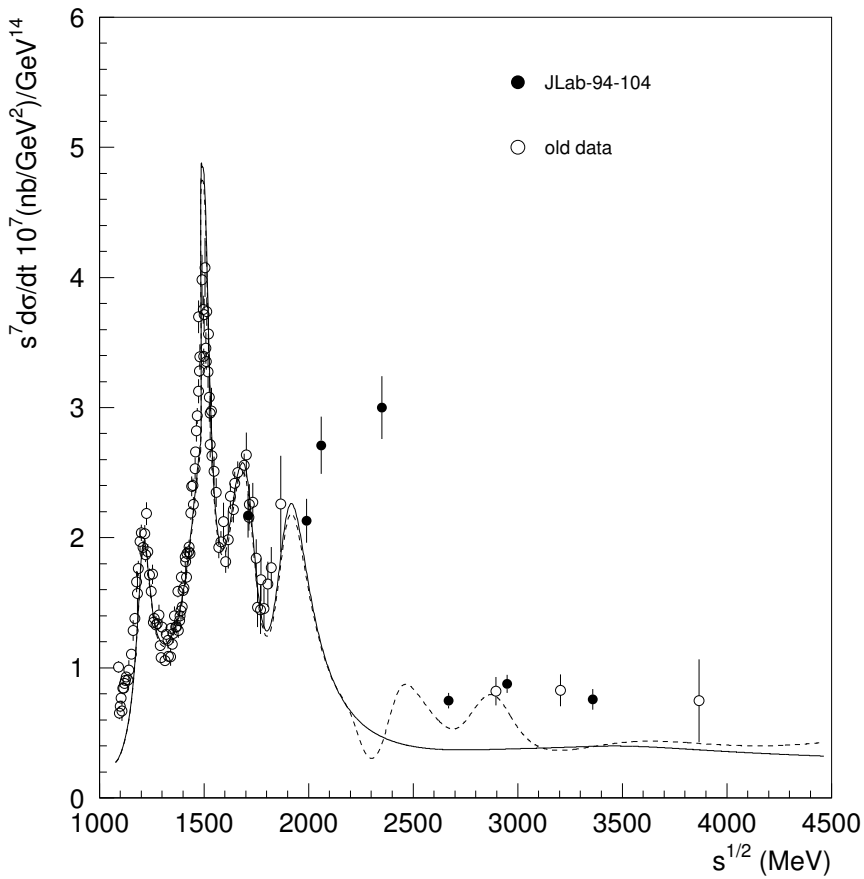


Data (Hall A):
PRL **91** (2003) 022003
PRC **71** (2005) 044603

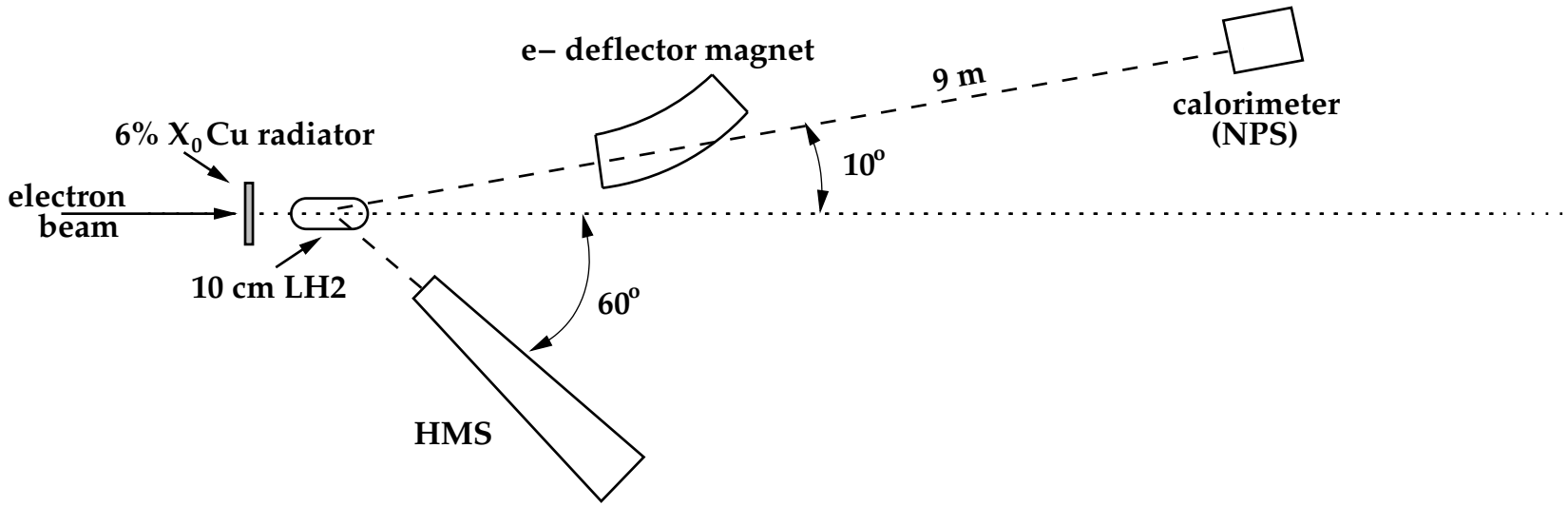
- Calculated XS do not match experiment, but ratio does (FFs cancel)
- Neither $\pi^\pm$ XS nor $\pi^0/\pi^\pm$ ratios agree with data (no FF cancellation)

Deviations from (expected) quark counting rules π^+

- Broken locality in quark-hadron duality // Zhao, Close PRL **91** (2003) 022004
- High s: destructive interferences between various intermediate states $\Longrightarrow$ smooth scaling behavior
- Low s: these cancellations broken locally $\Longrightarrow$ oscillations

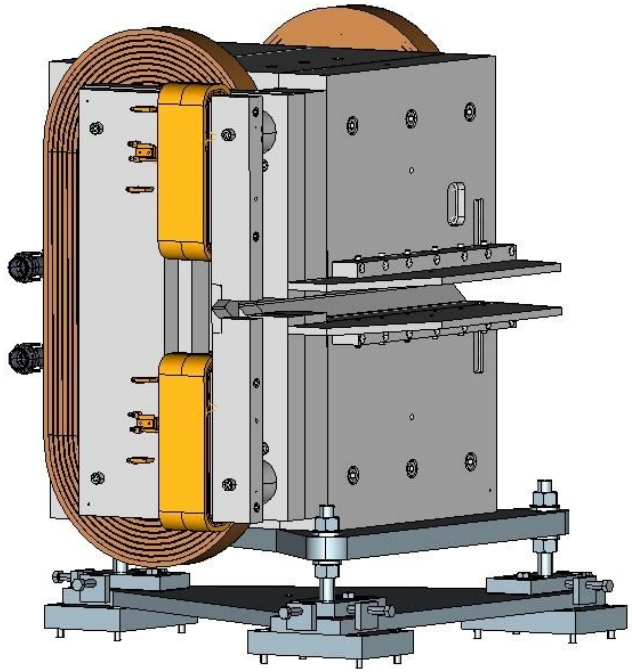


(Typical) experimental setup — 5B E12–14–005



- Need 3-pass, 4-pass and 5-pass unpolarized CW beam
- 6 % X_0 copper radiator
- Mixed e-γ beam on 10 cm LH2 target
- Deflector magnet, $\int \vec{B}\,\mathrm{d}\vec{l} \approx 0.6\,\mathrm{Tm}$
- EM calorimeter (NPS) for $\pi^0 \to 2\gamma$
- HMS for recoil protons
- Running in parallel with WACS (E12–14–003) — several kinematic overlaps

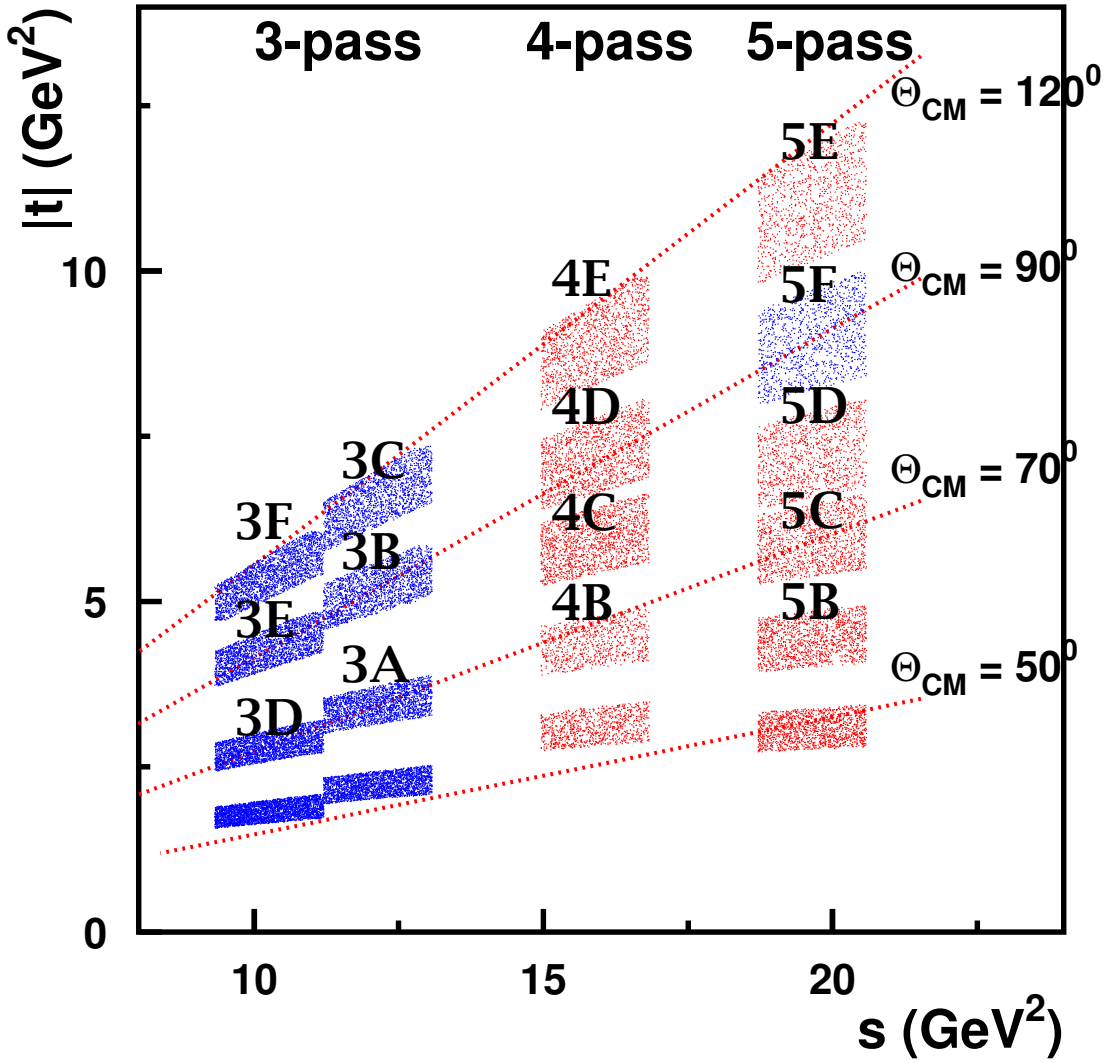
Deflector magnet and NPS



- Same key components as for WACS, both under construction
  ⟶ see dedicated talks
- Optimized deflection and detector resolution with respect to:
  — NPS drift distance
  — Deflector magnet location
  — Background rates

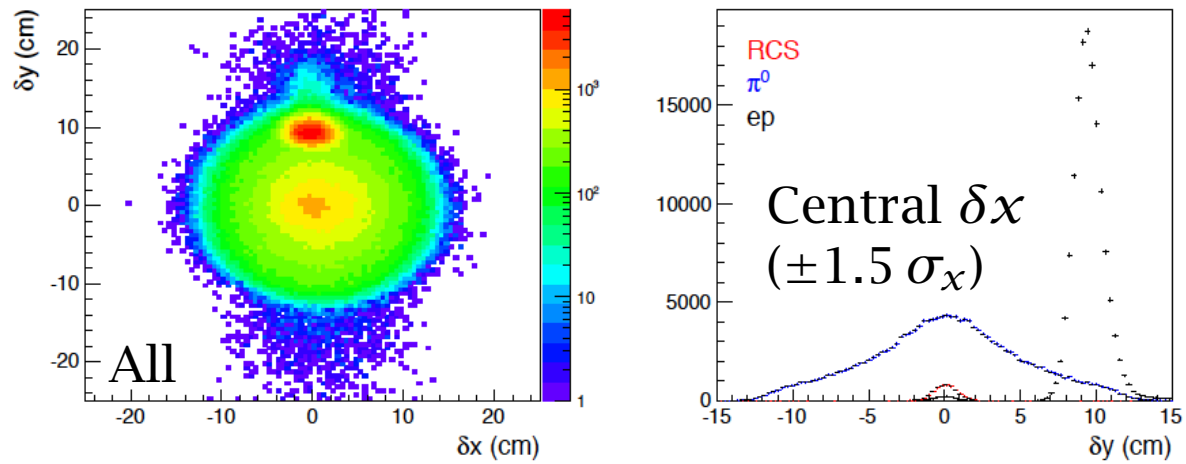
Kinematic coverage

approx. $9.5 < s < 21\,\mathrm{GeV}^2$, $60^\circ < \theta^* < 110^\circ$

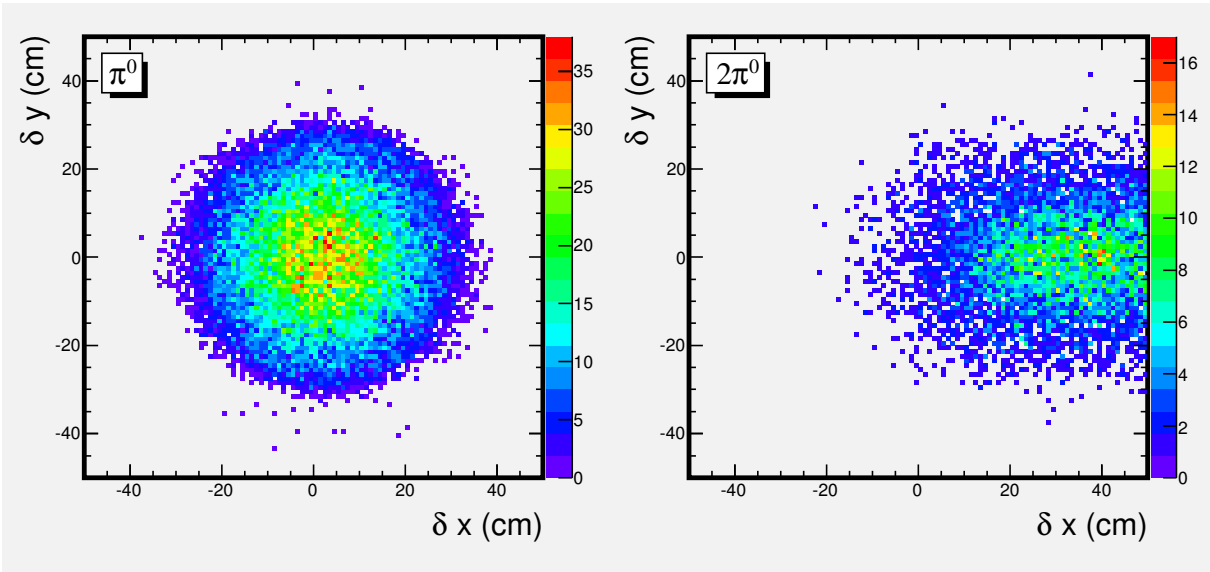


Event identification with single-γ detection

- Assume 2-body kinematics; use difference between measured and predicted NPS hit position (δx and δy) to identify reaction



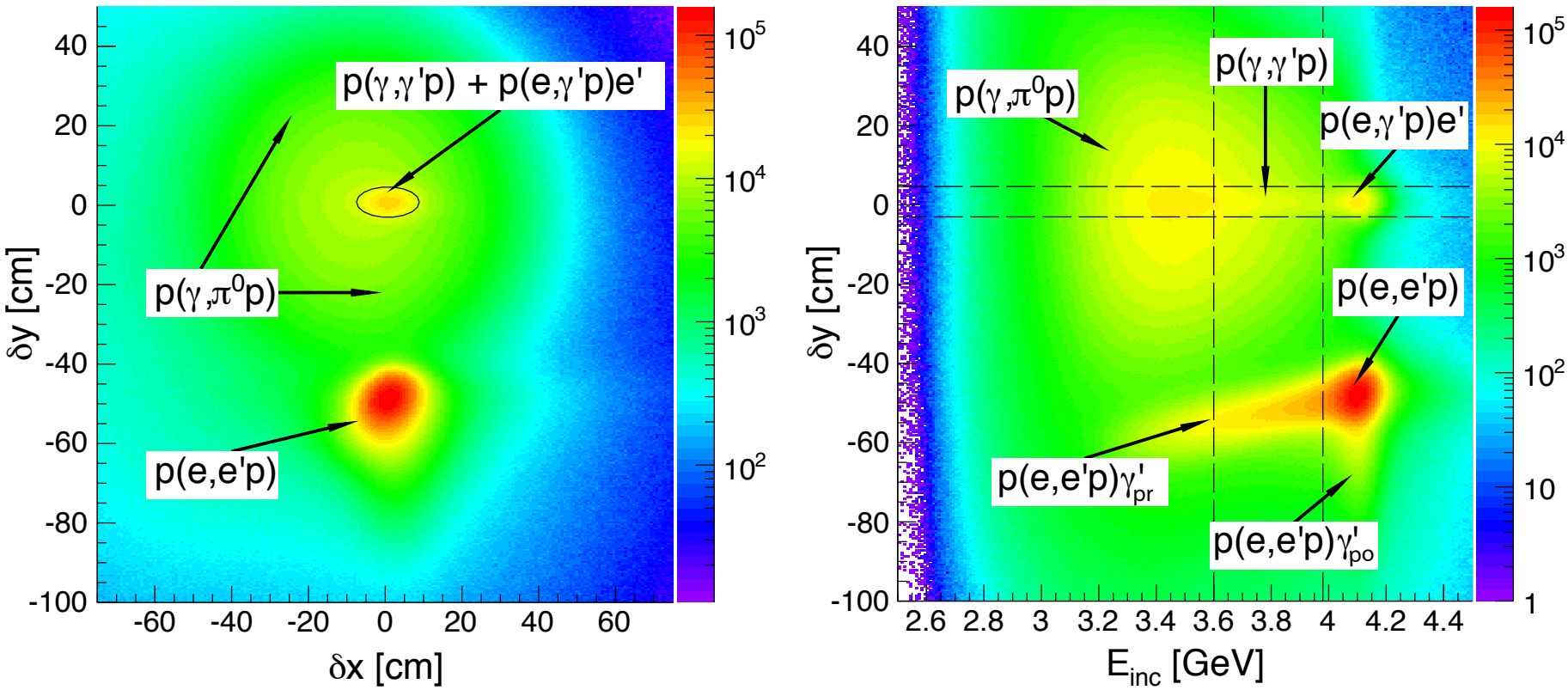
4D



3B

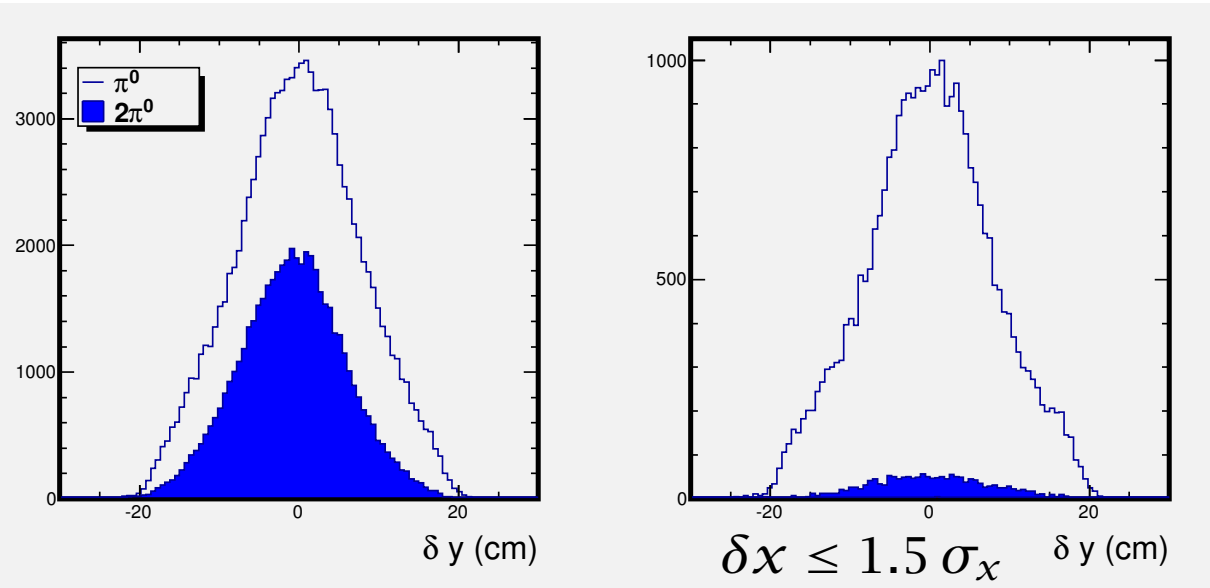
Event identification cont'd

- Lots of experience from WACS, old and new, polarized and unpolarized
- Most recent work from Hall C:

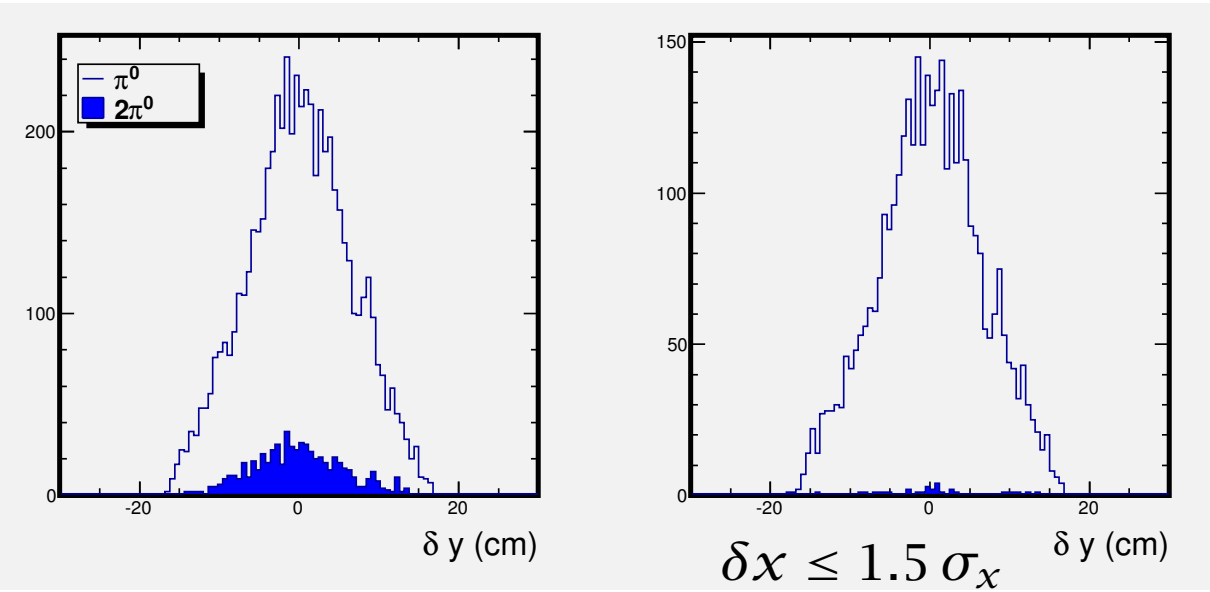


Fanelli++ PRL **115** (2015) 152001

Separation of $\pi/2\pi$ events

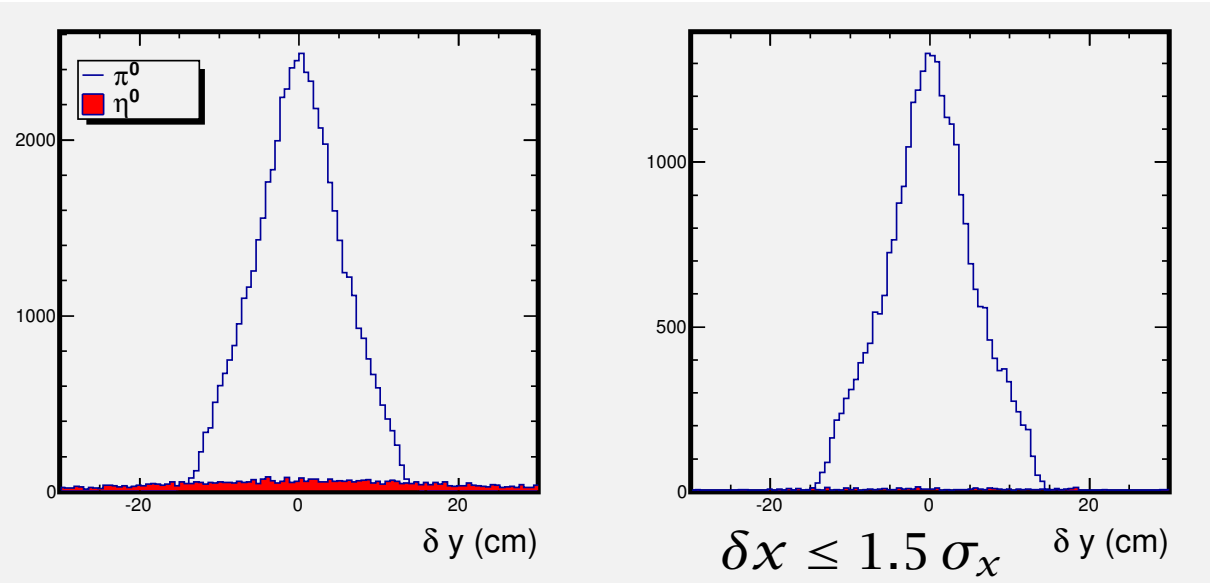


3F
(worst case)
≈ 5 % contamination



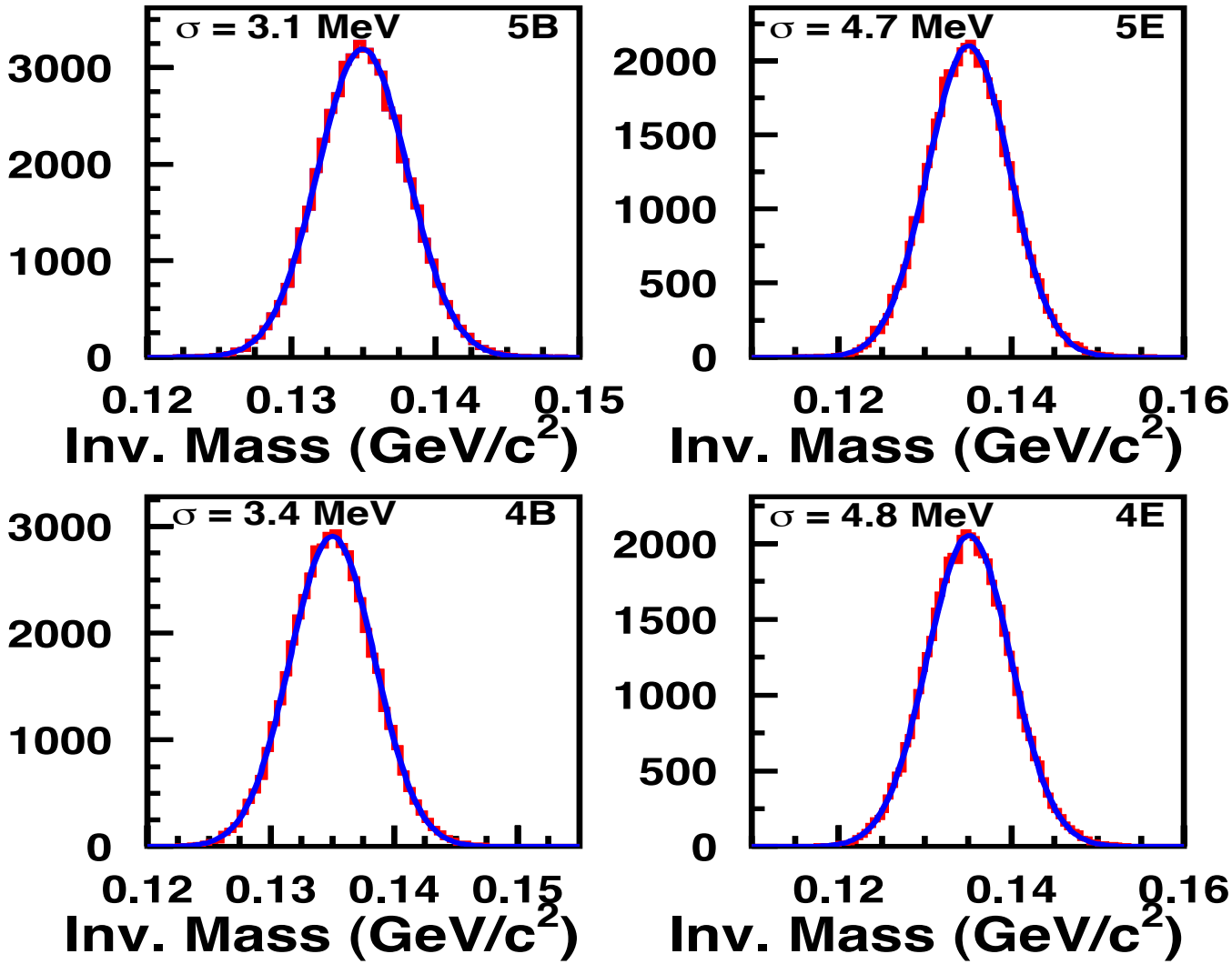
5B
(more typical)
≈ 1 % contamination

Separation of π/η events



5D
(worst case)
$< 1\,\%$ contamination

Event identification with 2γ detection

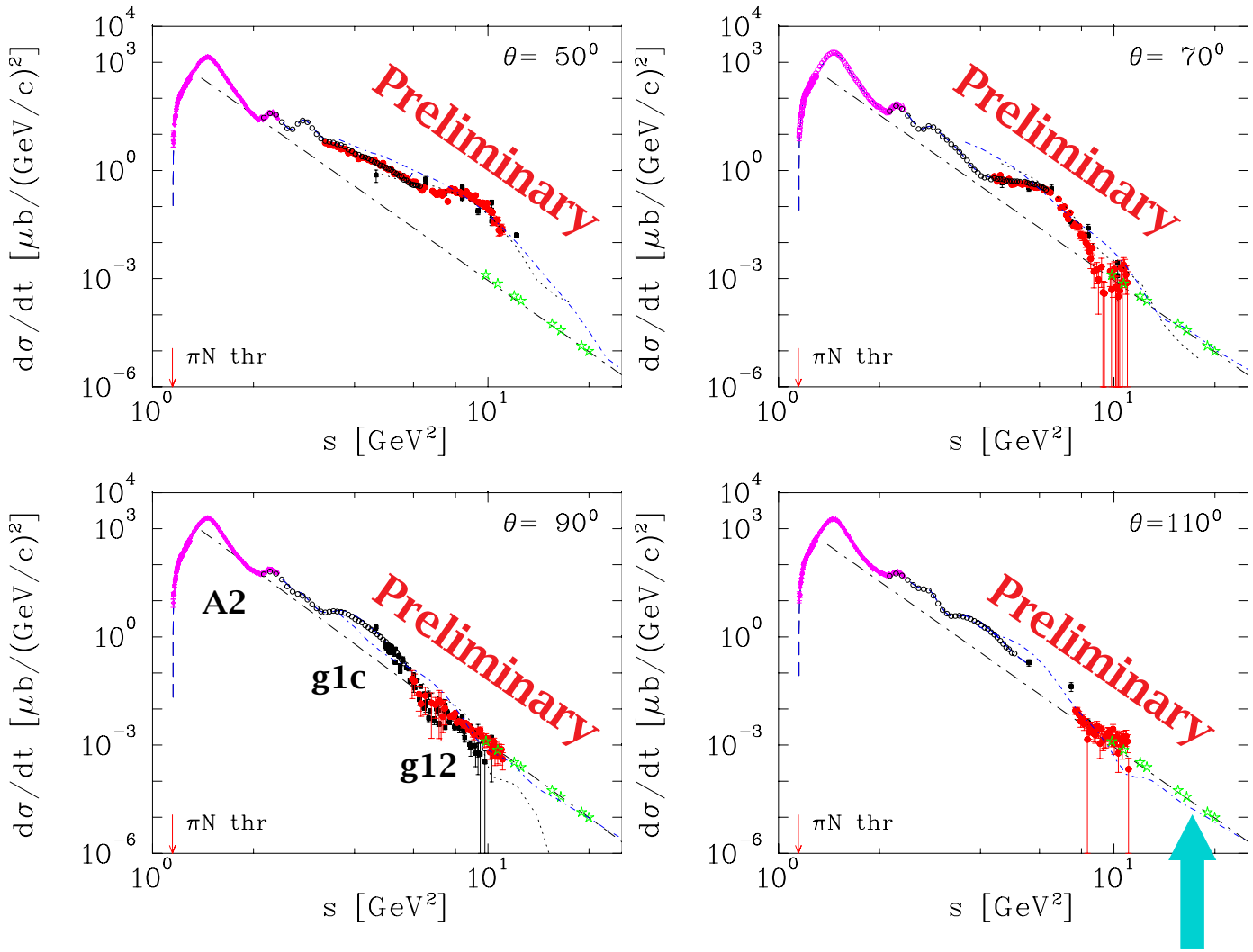


- Reduced acceptance (ranging from $\approx 50\,\%$ to $\approx 70\,\%$)

Kinematic coverage

Label	D_{NPS} (m)	E_γ (GeV)	s (GeV^2)	$\theta_{\pi^0}^{CM}$ (deg)	θ_{π^0} (lab) (deg)	P_{π^0} (GeV/c)	N_{π^0}	current (μA)	time (hrs)	2γ Acc. (%)
4B	7.0	8	15.89	68	17.9	5.663	8400	15	27	63.9
4C	5.0	8	15.89	81	22.5	4.851	20200	30	27	58.7
4D	3.5	8	15.89	91	26.9	4.161	37900	60	37	51.8
4E	3.0	8	15.89	105	34.0	3.255	68800	60	47	50.1
5B	9.0	10	19.65	60	13.8	7.647	56600	30	32	71.4
5C	7.0	10	19.65	70	16.9	6.848	14300	60	27	70.2
5D	6.0	10	19.65	79	19.7	6.158	26400	60	47	67.5
5E	3.25	10	19.65	103	29.9	4.135	78600	60	127	51.5
5F	5.0	10	19.65	90	23.9	5.227	3800	60	8	61.7
3A	5.0	6	12.14	70	21.2	4.170	8900	15	8	51.9
3B	3.5	6	12.14	90	30.1	3.218	16000	15	8	50.1
3C	3.0	6	12.14	105	38.5	2.5	26700	30	8	49.4
3D	5.0	5	10.26	70	23.1	3.497	8100	15	8	49.8
3E	3.5	5	10.26	90	32.5	2.716	22800	15	8	49.7
3F	3.0	5	10.26	105	41.6	2.125	20900	15	8	49.3

Projected E12–14–005 data

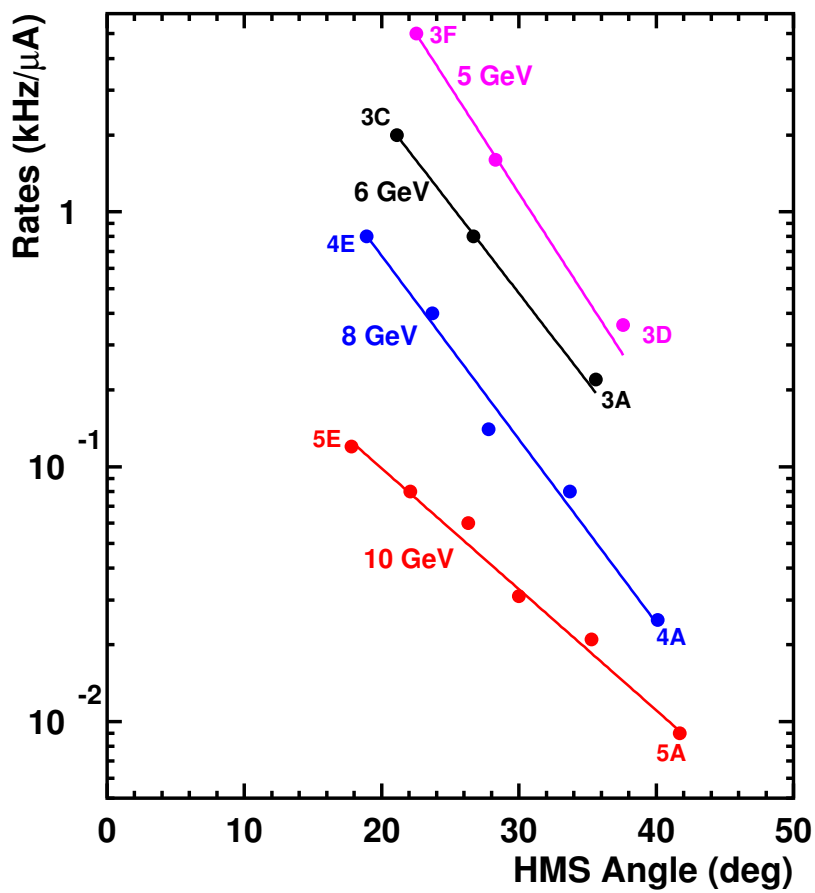


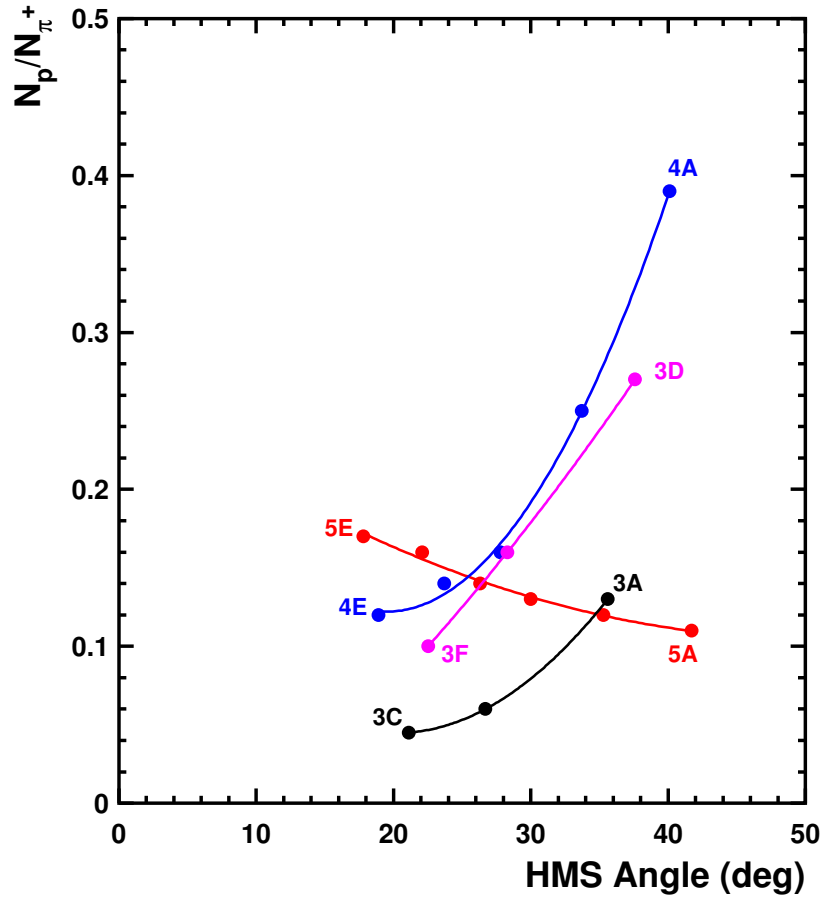
Future Hall C

Conclusions and outlook

- Study $\gamma p \to p\pi^0$ at high s and t, large CM angles
- Explore onset (?) of scaling
  Measurement of s-dependence of $\mathrm{d}\sigma/\mathrm{d}t$ at different θ^*
- Check validity of GPD/handbag-type approaches
  Does not work for $s \lesssim 10\,\mathrm{GeV}^2$, might work at higher energies
  Measurement of t-dependence of $\mathrm{d}\sigma/\mathrm{d}t$
- Earliest possible opportunity to run: 2021
- Will run (almost) concurrently with WACS
- How can HIPS help?

HMS rates and proton-to-π^+ ratios





NPS rates and radiation budget