Polarized Antiproton EXperiments

http://www.fz-juelich.de/ikp/pax

Future of Form Factor Physics with Polarized Antiprotons

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PAX Collaboration

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~180 scientists

35 Institutions (15 EU, 20 Non-EU)

QCD Physics at FAIR (CDR): unpolarized Antiprotons in HESR

PAX → Polarized Antiprotons

Central PAX Physics Case:

Transversity distribution of the nucleon in Drell-Yan:

→ FAIR as successor of DIS physics

- last leading-twist missing piece of the QCD description of the partonic structure of the nucleon
- **observation of $h_1^q(x,Q^2)$ of the proton for valence quarks** (A_{TT} in Drell-Yan >0.2)
  - **transversely polarized proton beam or target (✓)**
  - **transversely polarized antiproton beam (×)**

The PAX proposal

Jan. 04	LOI submitted
15.06.04	QCD PAC meeting at GSI
18-19.08.04	Workshop on polarized antiprotons at GSI
15.09.04	F. Rathmann et al., *A Method to polarize stored antiprotons to a high degree* (PRL 94, 014801 (2005))
15.01.05	Technical Report submitted
14-16.03.05	QCD-PAC meeting at GSI **Polarized $\bar{p}$ should enter FAIR core program**
31.8-2.9.05	Workshop on Spin Filtering in Storage Rings at Heimbach

Evaluation by QCD-PAC (March 2005)

… the PAC would like to stress again the uniqueness of the program with polarized anti-protons and polarized protons that could become available at GSI.

…the PAC considers it is essential for the FAIR project to commit to polarized antiproton capability at this time and include polarized transport and acceleration capability in the HESR, space for installation of the APR and CSR and associated hardware, and the APR in the core project

We request the PAX collaboration to:

1) Commit to the construction and testing of the APR
2) Explore all options to increase the luminosity to the value of 10^{31} $cm^{-2}s^{-1}$
3) Prepare a more detailed physics proposal and detector design for each of the proposed stages. These stages may include:
    a) 3.5 GeV/c polarized antiprotons on a polarized proton target
    b) 15 GeV/c polarized antiprotons with the PANDA detector (for single spin asymmetries)
    c) 15 GeV/c polarized antiprotons on a polarized proton target in a dedicated detector
    d) Collisions of 15 GeV/c antiprotons with 3.5 GeV/c polarized protons.

Recommendations of the STI Working Group on FAIR (Preliminary, August 2005)

PAX

Part of the basic research program as defined by the CDR	–
Part of the core experimental facility of FAIR	no

The STI requests R&D work to be continued on the proposed asymmetric collider experiment with both polarized anti-protons and protons,

- to demonstrate that the required luminosity for decisive measurements can be reached.
- to demonstrate that a high degree of anti-proton polarisation can be reached.
- to advance the studies of the APR and the CSR.

The experiment is invited to contribute to the TDR. The STI believes that PAX should become part of the FAIR core research program based on its strong scientific merit once the open problems are convincingly solved.

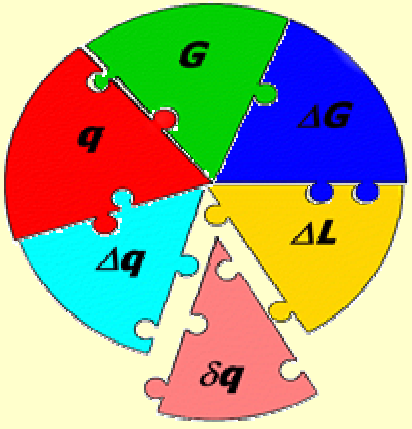
Outline

WHY?	Physics Case
HOW?	Polarized Antiprotons
WHAT?	Staging
	Detector and Signal Estimate
WHEN?	Timeline

Physic Topics

- Transversity
- Electromagnetic Form Factors
- Hard Scattering Effects
- SSA in DY, origin of Sivers function
- Soft Scattering
  - Low-t Physics
  - Total Cross Section
  - $\bar{p}p$ interaction

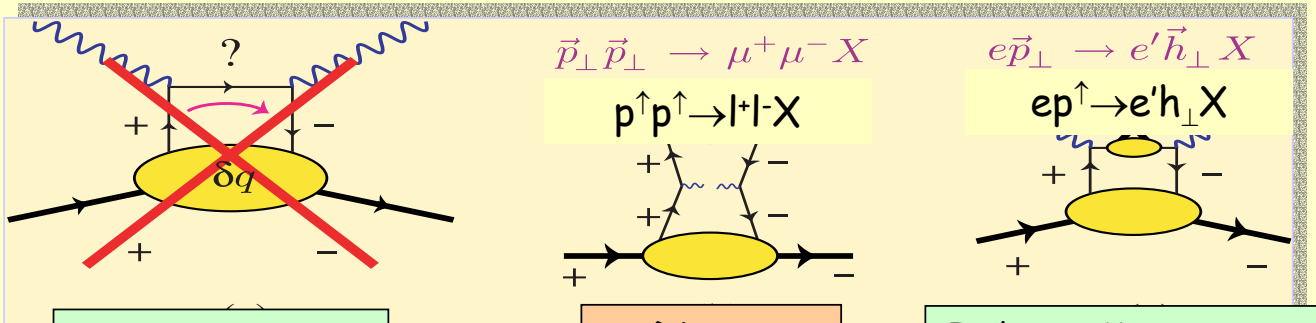
Transversity



Properties:

- Probes relativistic nature of quarks
- No gluon analog for spin-1/2 nucleon
- Different Q^2 evolution than Δq
- Sensitive to valence quark polarization

Chiral-odd: requires another chiral-odd partner

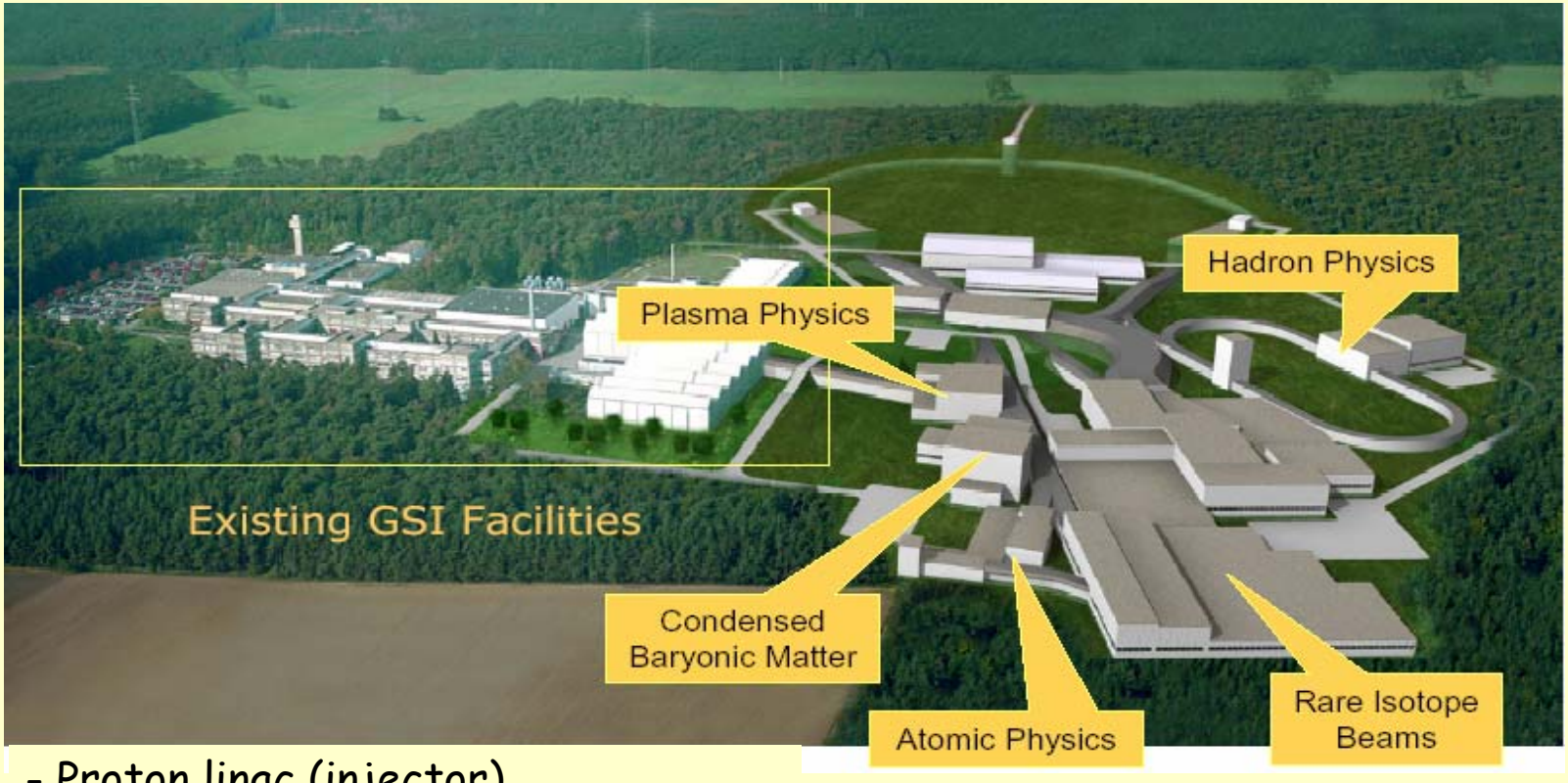


Impossible in DIS

Direct Measurement

Indirect Measurement: Convolution of with unknown fragment. fct.

Facilty for Antiproton and Ion Research (GSI, Darmstadt, Germany)



- Proton linac (injector)
- 2 synchrotons (30 GeV p)
- A number of storage rings

→ Parallel beams operation

PAX Accelerator Setup

Antiproton Polarizer Ring (APR)

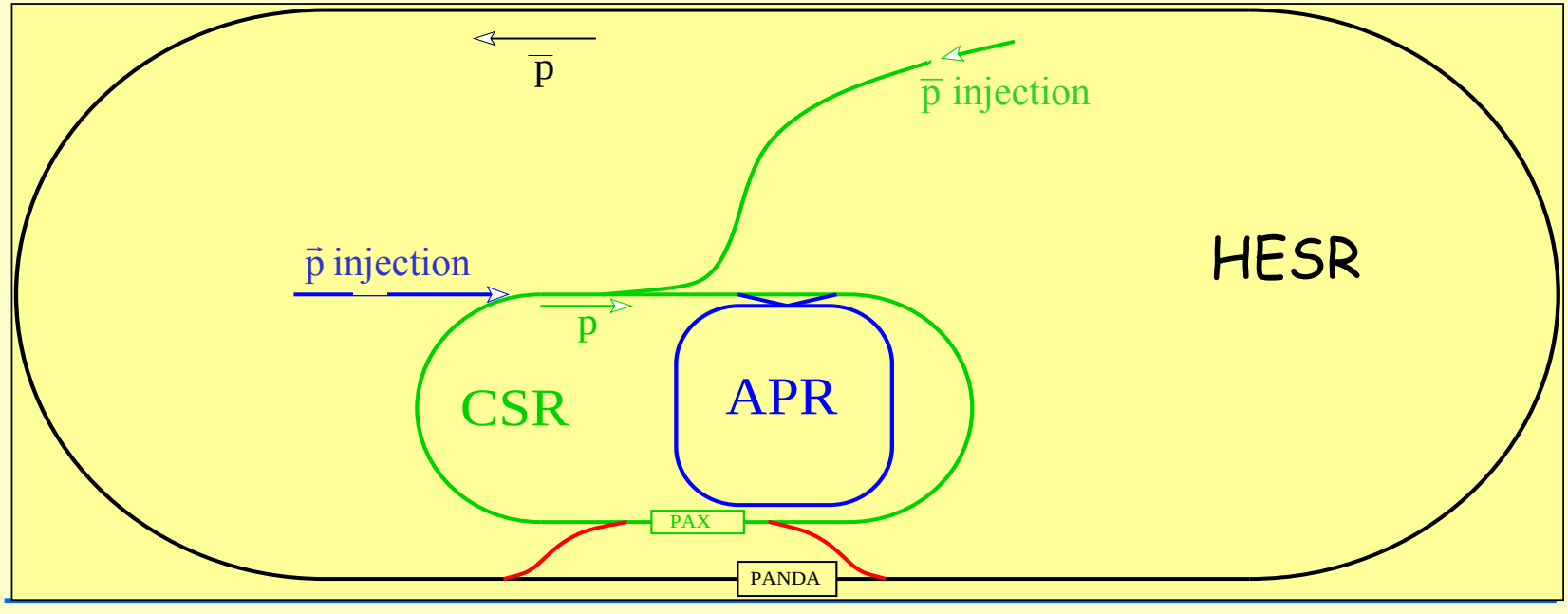
+

Cooler Storage Ring (CSR, COSY-like): 3.5 GeV/c

+

HESR: 15 GeV/c

→ **Asymmetric Double-Polarized Antiproton-Proton Collider**

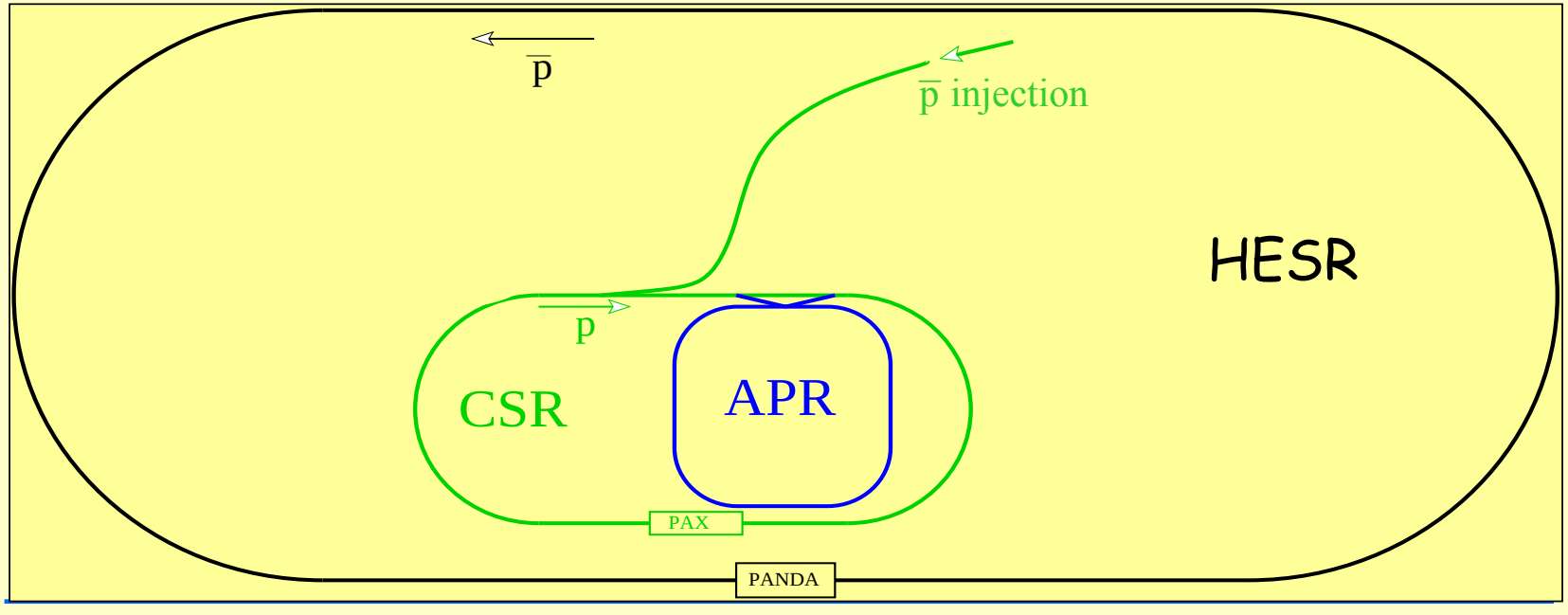


Phase I: PAX at CSR

Physics: Electromagnetic Form Factors
$\bar{p}p$ elastic scattering

Experiment: polarized/unpolarized $\bar{p}$ on polarized target

Independent of HESR experiments

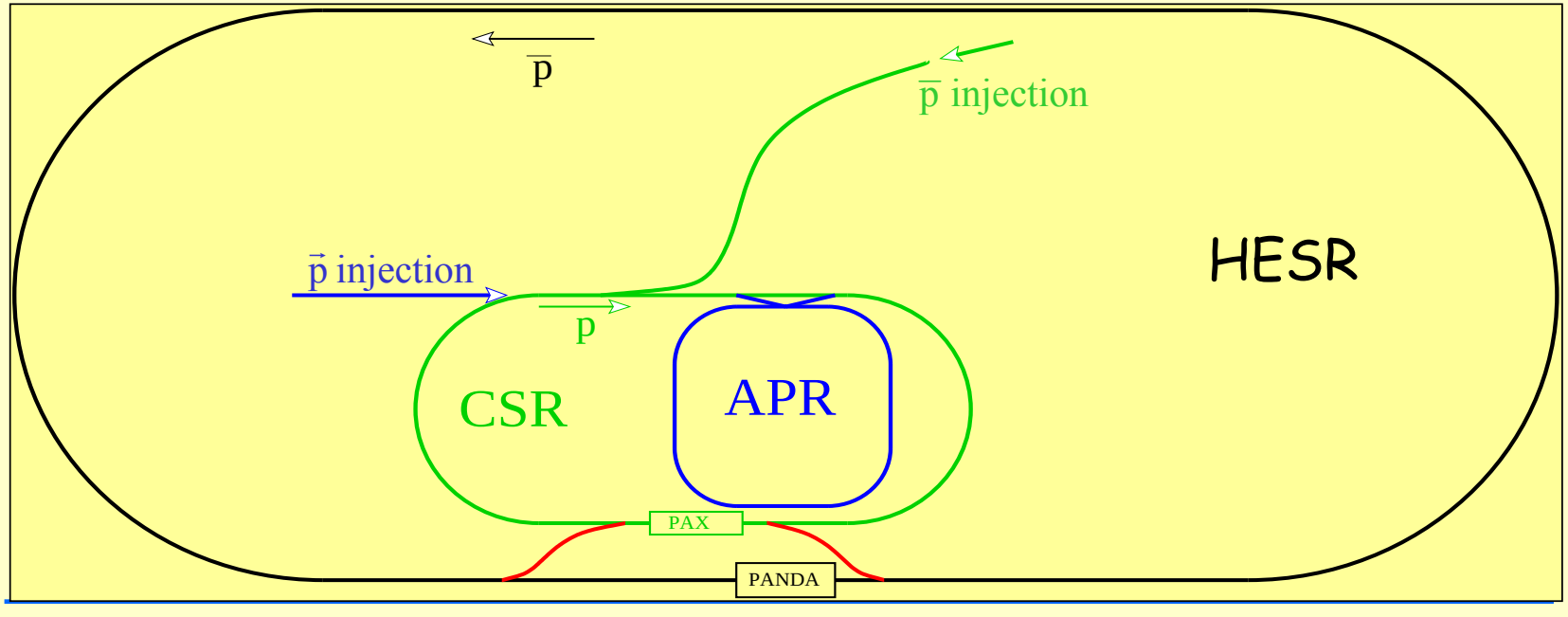


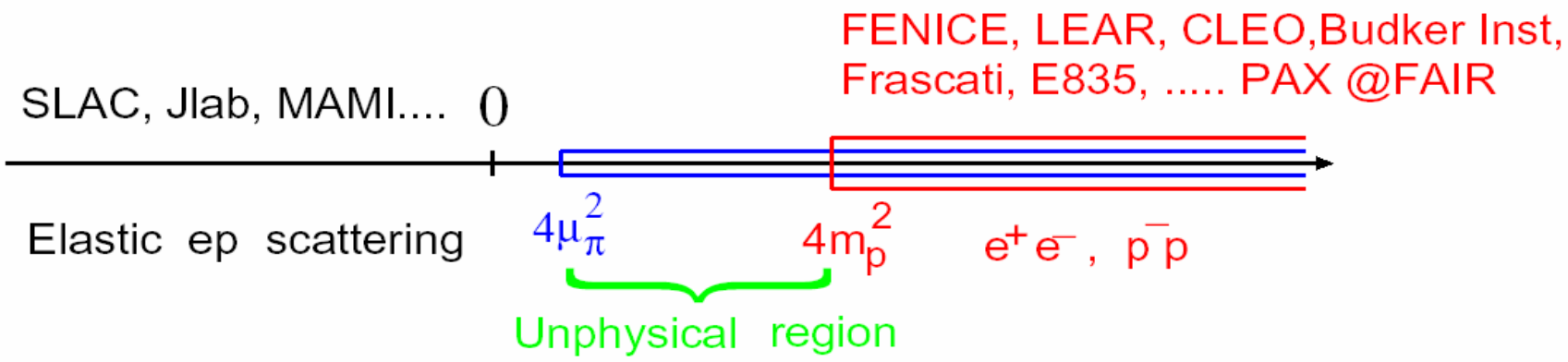
Phase II: PAX at CSR

Physics: Transversity

EXPERIMENT: Asymmetric Collider:
Polarized Antiprotons in HESR (15 GeV/c)
Polarized Protons in CSR (3.5 GeV/c)

Second IP with minor interference with PANDA

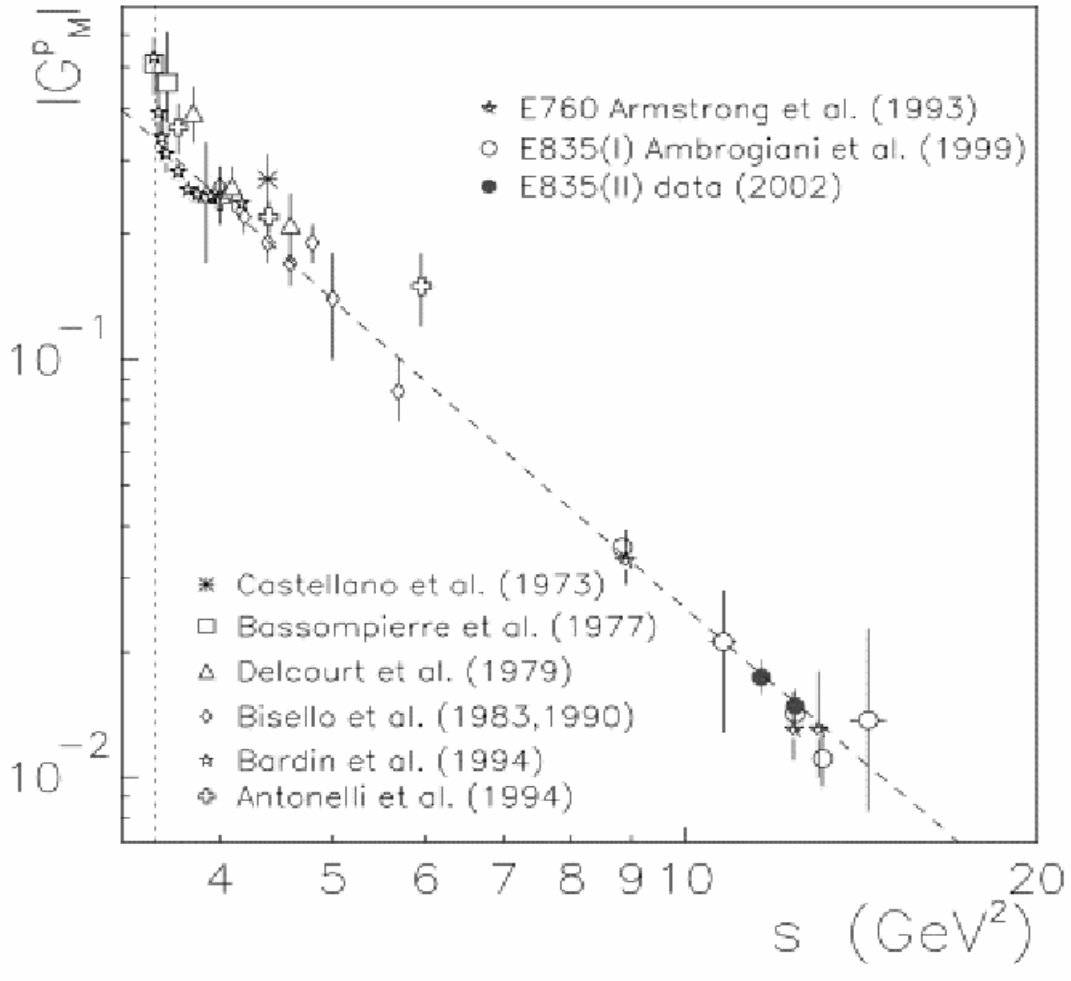




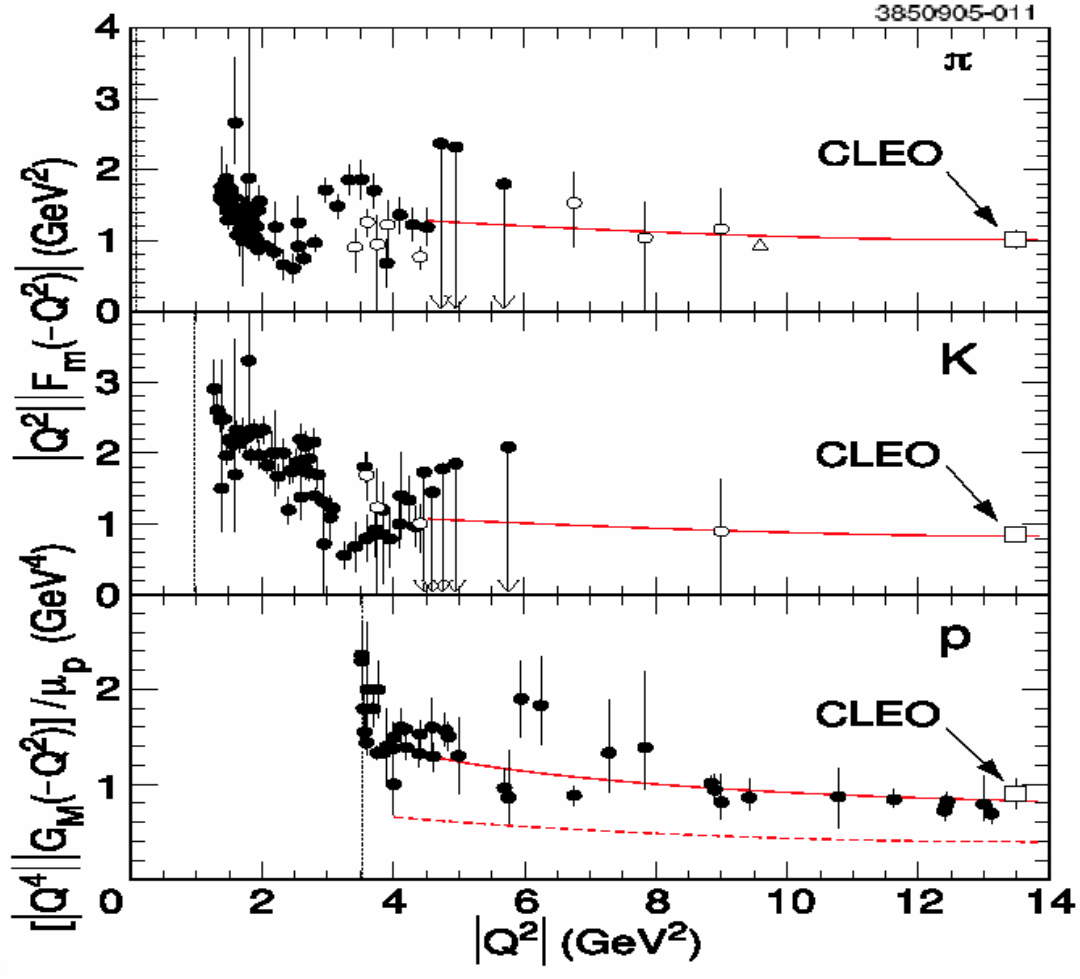
Phragmen-Lindeloeff: identical space- and timelike asymptotics.
Convergence as a signal of the onset of pQCD asymptopia?

Dispersion theory viewpoint:

Unphysical region:
(i) a province of all the prominent vector meson resonances
(ii) principal strength of the dispersion integral for FF's
(iii) dipole FF => non-trivial oscillations of the dicontinuity over unphysical cut
(v) strong phase variations of FF's
(iv) non-trivial energy dependence of S- and D-wave phases above the p-pbar threshold => strong energy dependence of spin observables: discriminationg power of PAX



E835 compilation assumung $|G_M| = |G_E|$ versus $s = q^2$.



E835 + CLEO compilation assuming $|G_M| = |G_E|$ versus $s = q^2$. A factor of two discrepancy between spacelike (dashed curve) and timelike (solid curve) proton FF's.

- Timelike region at PAX: (after Dubnickova, Dubnicka, Rekalo 1996)

$$\tau = \frac{s}{4m_p^2}$$

- The S, D-wave decomposition & phase motion:

$$G_M = G_S - G_D, \quad \frac{1}{\sqrt{\tau}} G_E = G_S + 2G_D$$

- The Rosenbluth separation in the timelike region:

$$d\sigma \propto |G_M^2|(1 + \cos^2\theta) + |G_E^2| \sin^2\theta$$

- The relative phase of $G_M \& G_E$: SSA (analyzing power) for transverse polarization

$$\mathcal{A}_y = \frac{\sin 2\theta \, \mathrm{Im} G_E^* G_M}{[(1 + \cos^2\theta)|G_M|^2 + \sin^2\theta |G_E|^2/\tau]\sqrt{\tau}}$$

- Resolving the phase ambiguity: longitudinal-transverse DSA

$$\mathcal{A}_{xz} = \frac{\sin 2\theta \, \mathrm{Re} G_E^* G_M}{[(1 + \cos^2\theta)|G_M|^2 + \sin^2\theta |G_E|^2/\tau]},$$

- DSA cross-check of the Rosenbluth separation

$$\mathcal{A}_{yy} = \frac{\sin^2\theta \, (|G_M|^2 - |G_E|^2/\tau)/\mathrm{Im}}{[(1 + \cos^2\theta)|\mathrm{G_M}|^2 + \sin^2\theta |\mathrm{G_E}|^2/\tau]}$$

Principle of Spin Filter Method

$$\sigma_{tot} = \sigma_0 + \sigma_{\perp} \cdot \vec{P} \cdot \vec{Q} + \sigma_{||} \cdot (\vec{P} \cdot \vec{k})(\vec{Q} \cdot \vec{k})$$

P beam polarization
Q target polarization
k || beam direction

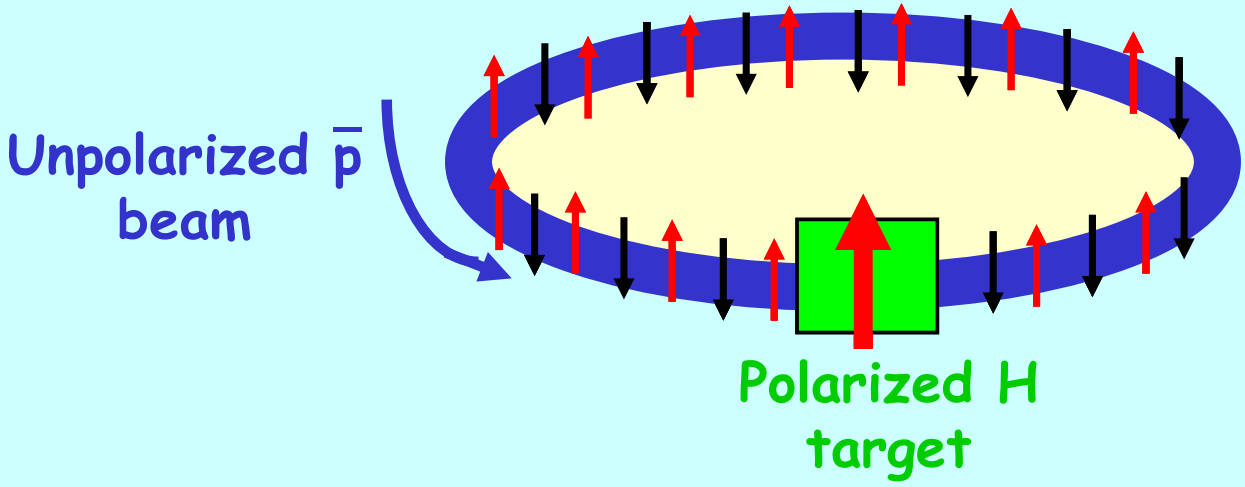
For initially equally populated spin states: ↑ ($m=+\frac{1}{2}$) and ↓ ($m=-\frac{1}{2}$)

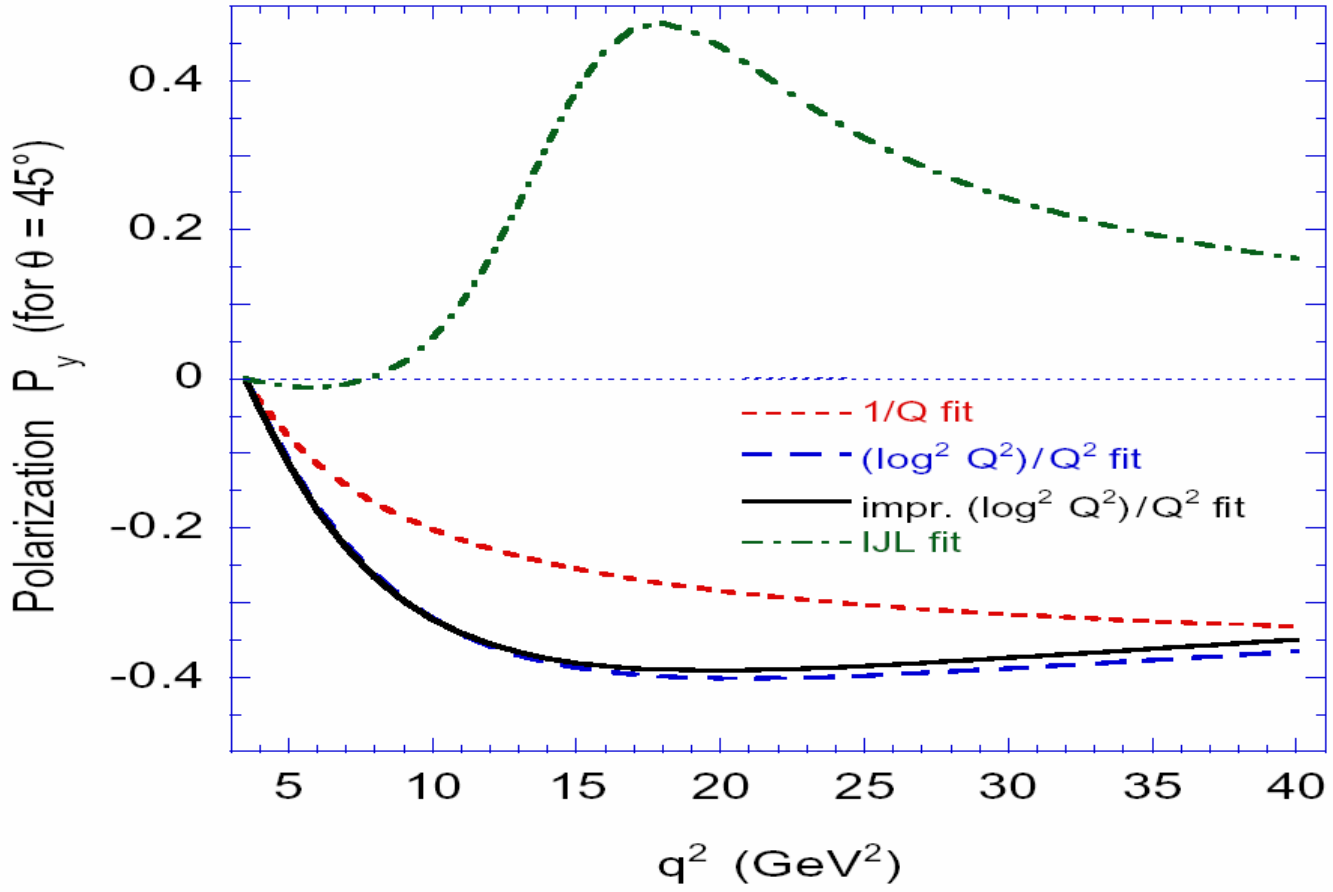
transverse case:

$$\sigma_{tot\pm} = \sigma_0 \pm \sigma_{\perp} \cdot Q$$

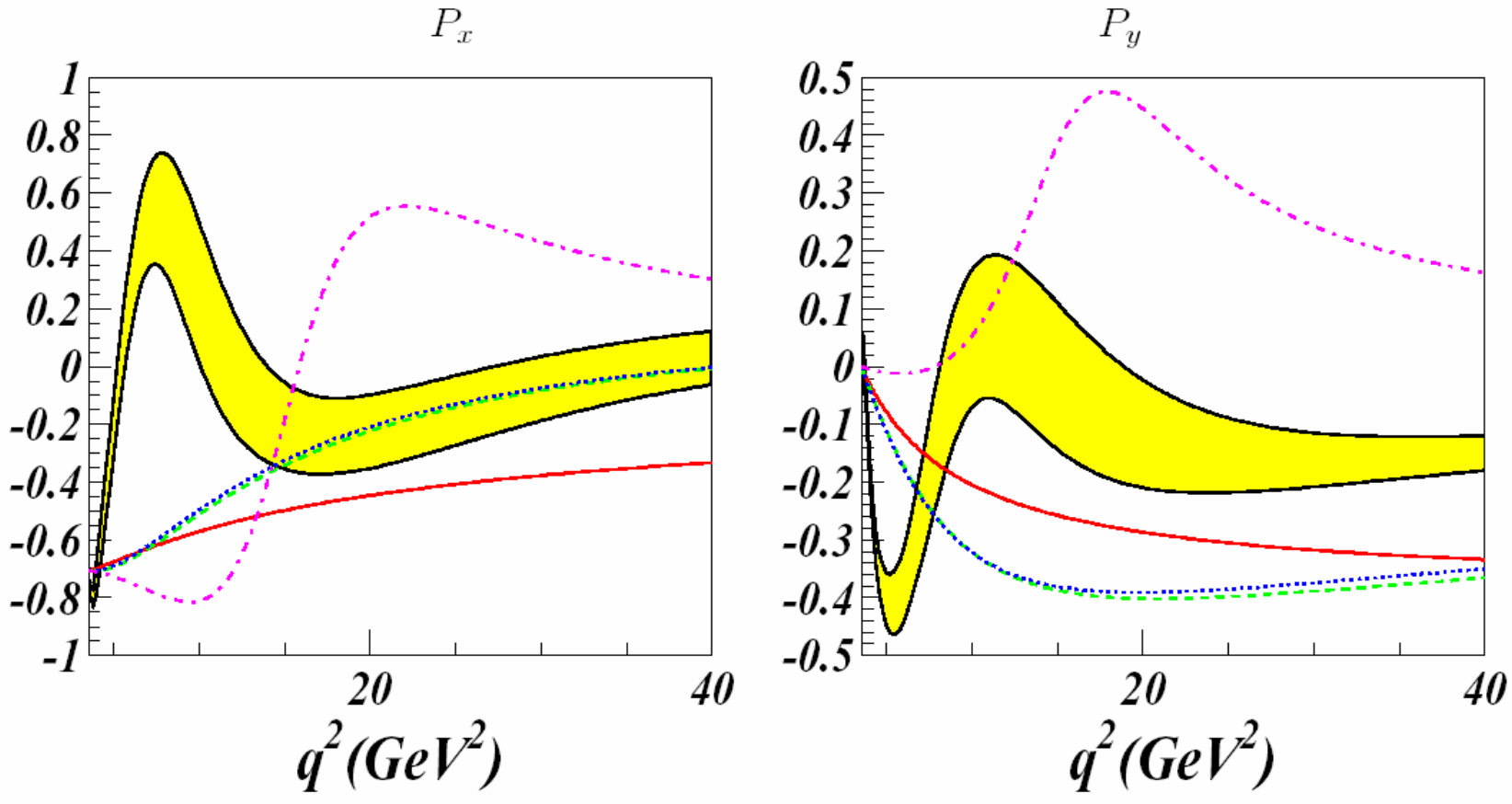
longitudinal case:

$$\sigma_{tot\pm} = \sigma_0 \pm (\sigma_{\perp} + \sigma_{||}) \cdot Q$$

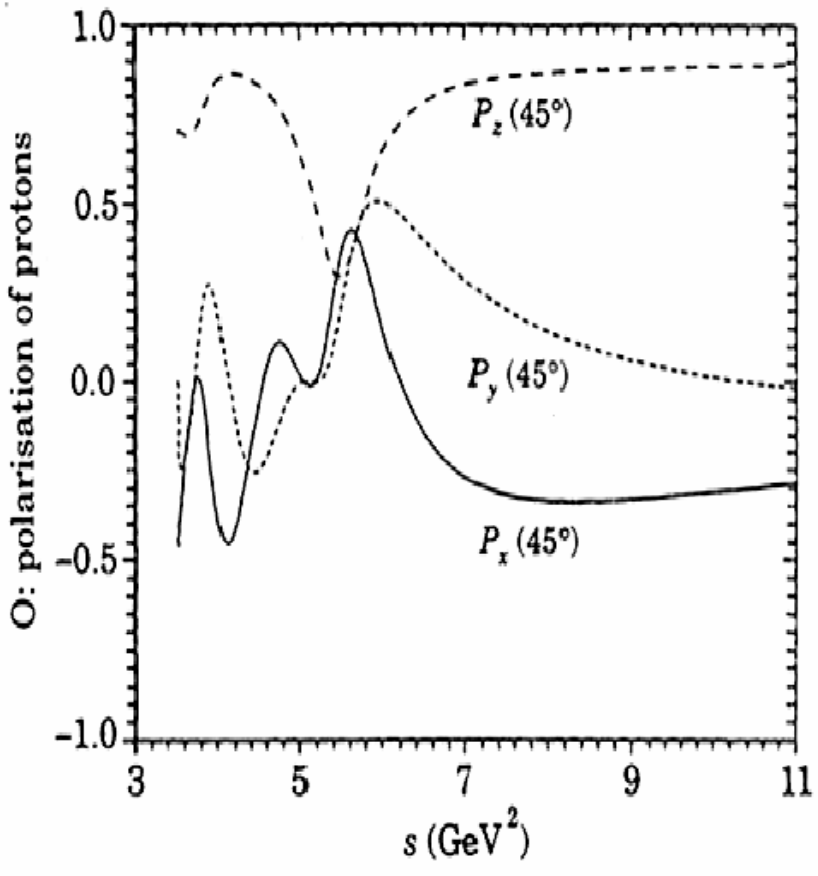


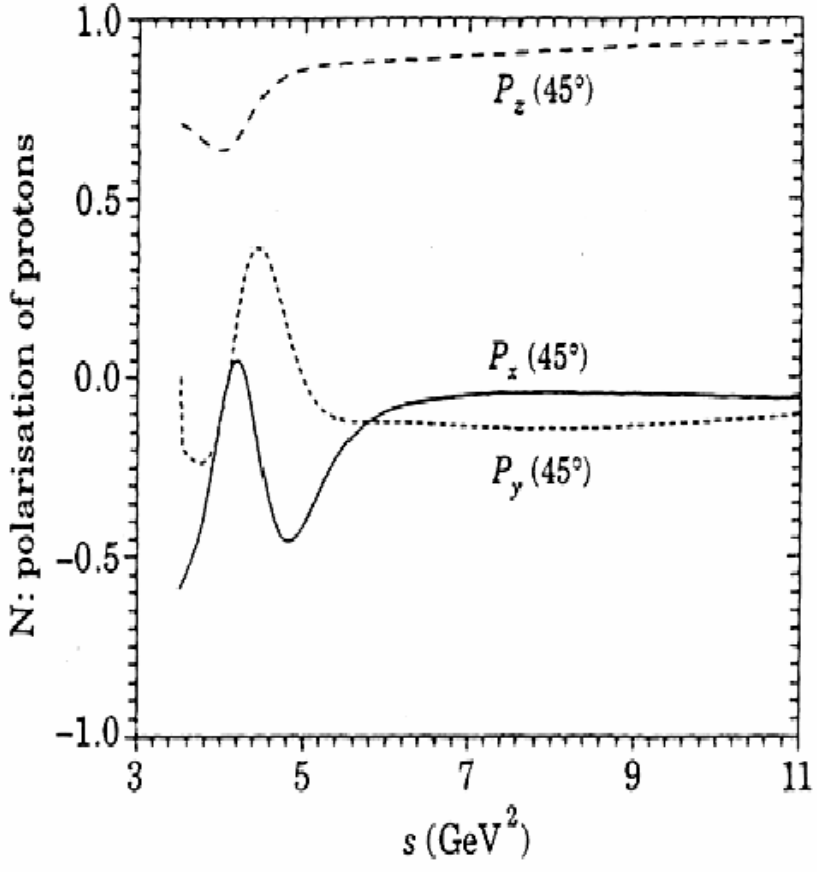


$\mathcal{A}_y = \mathcal{P}_y$ for $\theta = 45^\circ$ in the time–like region from analytic parameterizations: $F_2/F_1 \propto 1/Q$ fit (Brodsky et al.); $(\log^2 Q^2)/Q^2$ fit (Belitsky et al.); an improved $(\log^2 Q^2)/Q^2$ fit (Brodsky et al.); IJL fit from Iachello et al.



Yellow band: dispersion relation analysis by Baldini et al. vs. analytic parameterizations by Brodsky et al., Belitsky et al., Brodsky et al. and Iachello et al. The scattering angle $\theta = 45^o$, electron polarization $P_e = 1$.





$\mathcal{A}_y = \mathcal{P}_y$ for $\theta = 45^\circ$ in the time–like region for two versions (O (old) & N (new)) of the analytic and unitary vector-meson dominance (VDM) models (Dubnicka et al.)

Estimated signal for EMFF (Phase I)

$$L = N_{\bar{p}} \times f \times d_t \qquad N_{events} = L \times \sigma^{e+e-} \times \varepsilon \times \Delta t$$

$$\Delta O_{DS} = \frac{1}{QP}\frac{1}{\sqrt{N}}$$

$$\Delta O_{SS} = \frac{1}{Q}\frac{1}{\sqrt{N_{SS}}}$$

N_{pbar} = 1x10^{11}
f=$L_{CSR}/\beta c$
d_t=1x10^{14}cm^{-2}
Q=0.8 (p pol)
P=0.3 (pbar pol)
ε=0.5

Running days to get ΔO = 0.05

Beam (MeV/c)	<s> (GeV^2)	σ^{e+e-} (nbarn)*	L (cm^{-2}s^{-1})	Days DS	Days SS
549	3.76	7.3	7.8x10^{30}	2.9	0.3
900	4.18	3.7	1.1x10^{31}	4.7	0.5
3600	8.75	0.044	1.5x10^{31}	132	13

PS170 and E835

PAX could run down to 200 MeV/c with double polarization

Timeline

Phase 0: 2005-2012

APR design and construction.

Physics: buildup measurements @ COSY and CERN

Phase I: 2013-2017

APR+CSR @ GSI

Physics: EMFF, p-pbar elastic with fixed target.

Phase II: 2018 - …

HESR+CSR asymmetric collider

Physics: h_1

Conclusions

⋆ Excellent opportunities for the proton electromagnetic form factor physics in Phase-I of PAX@FAIR

⋆ Single- and Double-Spin Asymmetries will be accessible

⋆ Joint analysis of space- and timelike form factors crucial for understanding the onset of pQCD

⋆ Very strong sensitivity of Single Spin Asymmetry in $p\uparrow\bar{p}\longrightarrow e^+e^-$ to models for FF's

⋆ Double Spin Asymmetries alllow a full determination of the phase of G_E/G_M

⋆ DSA: a useful check of the Rosenbluth separation of $G_E|^2$ and $G_M|^2$

⋆ Alternative to PAX: polarimetry of protons from $e^+e^-\longrightarrow p\bar{p}$ (potential studies of electron-to-proton longitudinal spin transfer?).

Georg Christoph Lichtenberg (1742-1799)

"Man muß etwas Neues machen, um etwas Neues zu sehen."

"You have to make something new,
if you want to see something new"