# SPIN@J-PARC PROPOSAL UPDATE

2008 October 16

# Analyzing Power $A_n$ and $A_{nn}$ in 30-50 GeV Very-High-$P_{\perp}^2$ Proton-Proton Elastic Scattering


| | |
|---|---|
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** SPOKESPERSON, # RETIRED*

## UNPOLARIZED BEAM and TARGET

$$\langle d\sigma/dt\rangle \propto \left(N_{\uparrow\uparrow}+N_{\uparrow\downarrow}+N_{\downarrow\uparrow}+N_{\downarrow\downarrow}\right)$$

## EITHER BEAM or TARGET POLARIZED (ONE-SPIN)

$$A_{nB}=\frac{A_{meas}}{P_B}=\frac{\left(N_{\uparrow\uparrow}+N_{\uparrow\downarrow}-N_{\downarrow\uparrow}-N_{\downarrow\downarrow}\right)}{P_B\left(N_{\uparrow\uparrow}+N_{\uparrow\downarrow}+N_{\downarrow\uparrow}+N_{\downarrow\downarrow}\right)}$$

$$A_{nT}=\frac{A_{meas}}{P_T}=\frac{\left(N_{\uparrow\uparrow}-N_{\uparrow\downarrow}+N_{\downarrow\uparrow}-N_{\downarrow\downarrow}\right)}{P_T\left(N_{\uparrow\uparrow}+N_{\uparrow\downarrow}+N_{\downarrow\uparrow}+N_{\downarrow\downarrow}\right)}$$

## BOTH BEAM and TARGET POLARIZED (TWO-SPIN)

$$A_{nn}=\frac{A_{meas}}{P_BP_T}=\frac{\left(N_{\uparrow\uparrow}-N_{\uparrow\downarrow}-N_{\downarrow\uparrow}+N_{\downarrow\downarrow}\right)}{P_BP_T\left(N_{\uparrow\uparrow}+N_{\uparrow\downarrow}+N_{\downarrow\uparrow}+N_{\downarrow\downarrow}\right)}$$

$A_{meas}$ = measured asymmetry

$P_T$ and $P_B$ = target and beam polarizations

$N_{BT}$ = normalized elastic event rate for (B,T) polarization directions

***PAC Question 1: Does Polarized Beam help the $A_n$ measurement?***

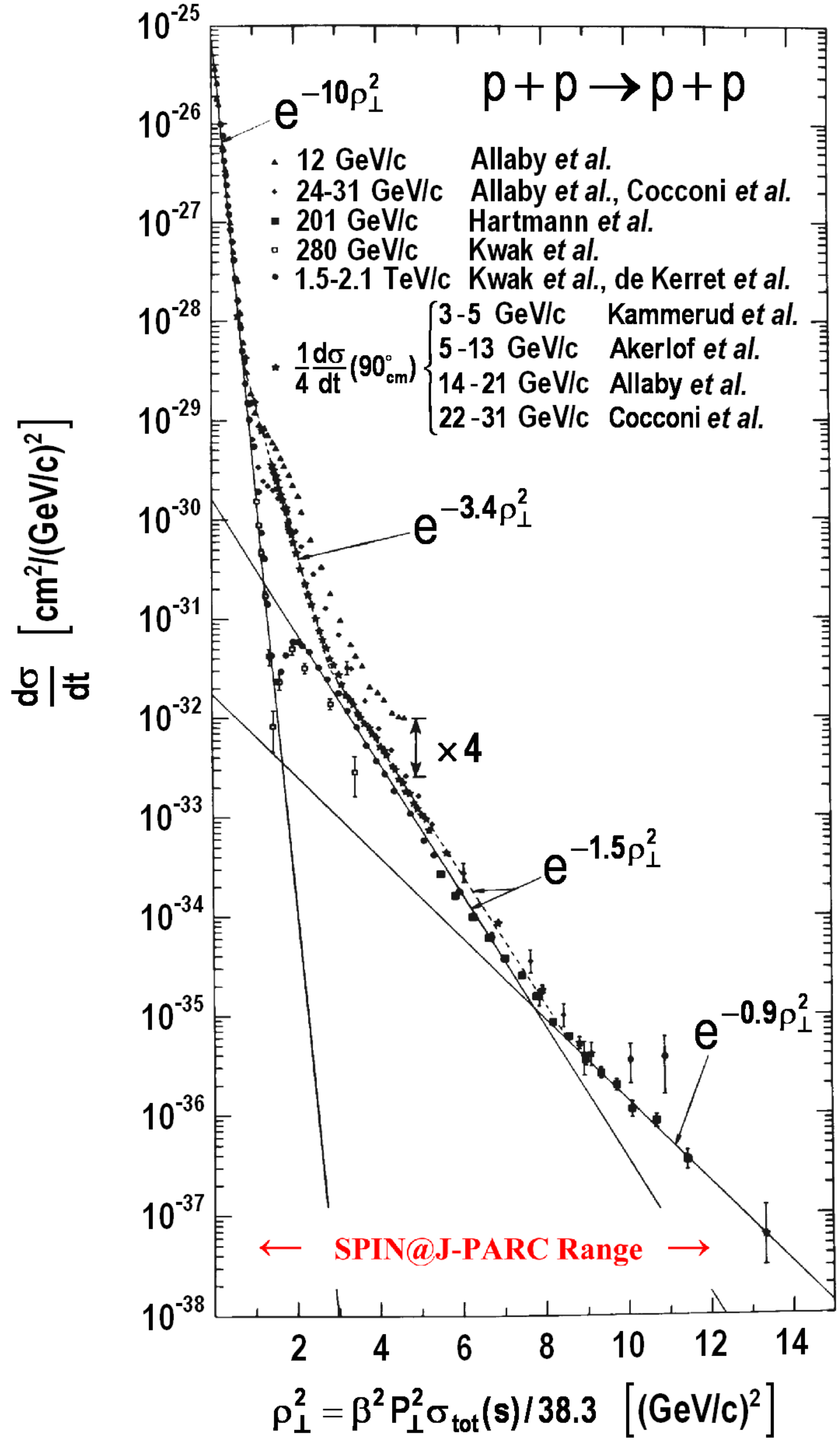
**Answer: Yes. One simultaneously measures $A_{nT}$ and $A_{nB}$ which MUST be equal.**

- Reduces Run-time by almost 50%
- Calibrates beam polarization

# PROTON-PROTON ELASTIC CROSS-SECTION

**UNPOLARIZED dσ/dt for all**
**$p + p \rightarrow p + p$ data above 3 GeV**
**PLOTTED vs. SCALED $P_\perp^2$ VARIABLE**

**NOTE 4 DIFFERENT SLOPES**
**FIRST EVIDENCE for STRUCTURE inside PROTON (Akerlof *et al.* 1966)**



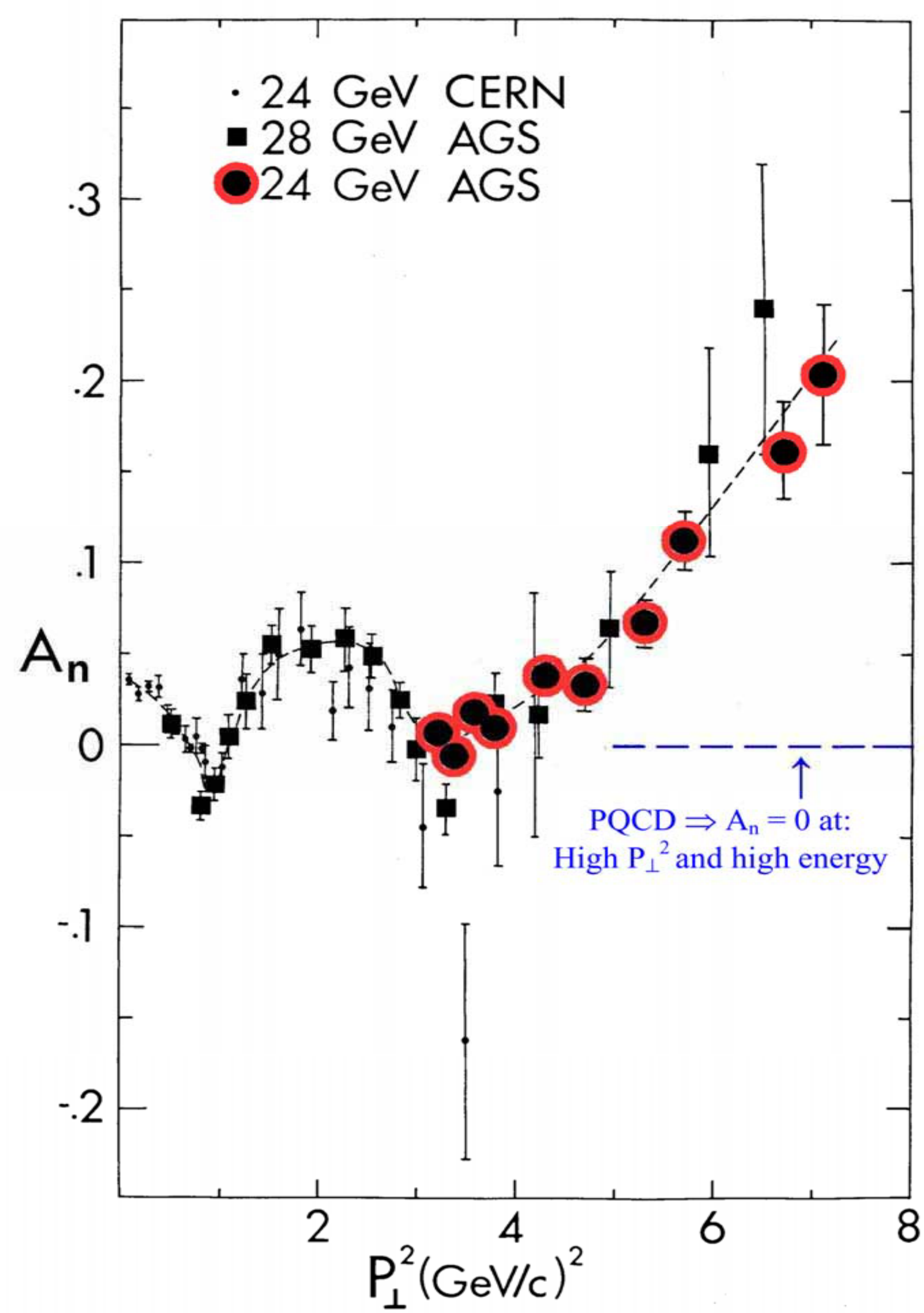
# PROTON-PROTON ELASTIC $A_n$

**PERTURBATIVE QCD $\Rightarrow$**
**$A_n = 0$ at HIGH $P_\perp^2$ and HIGH ENERGY**

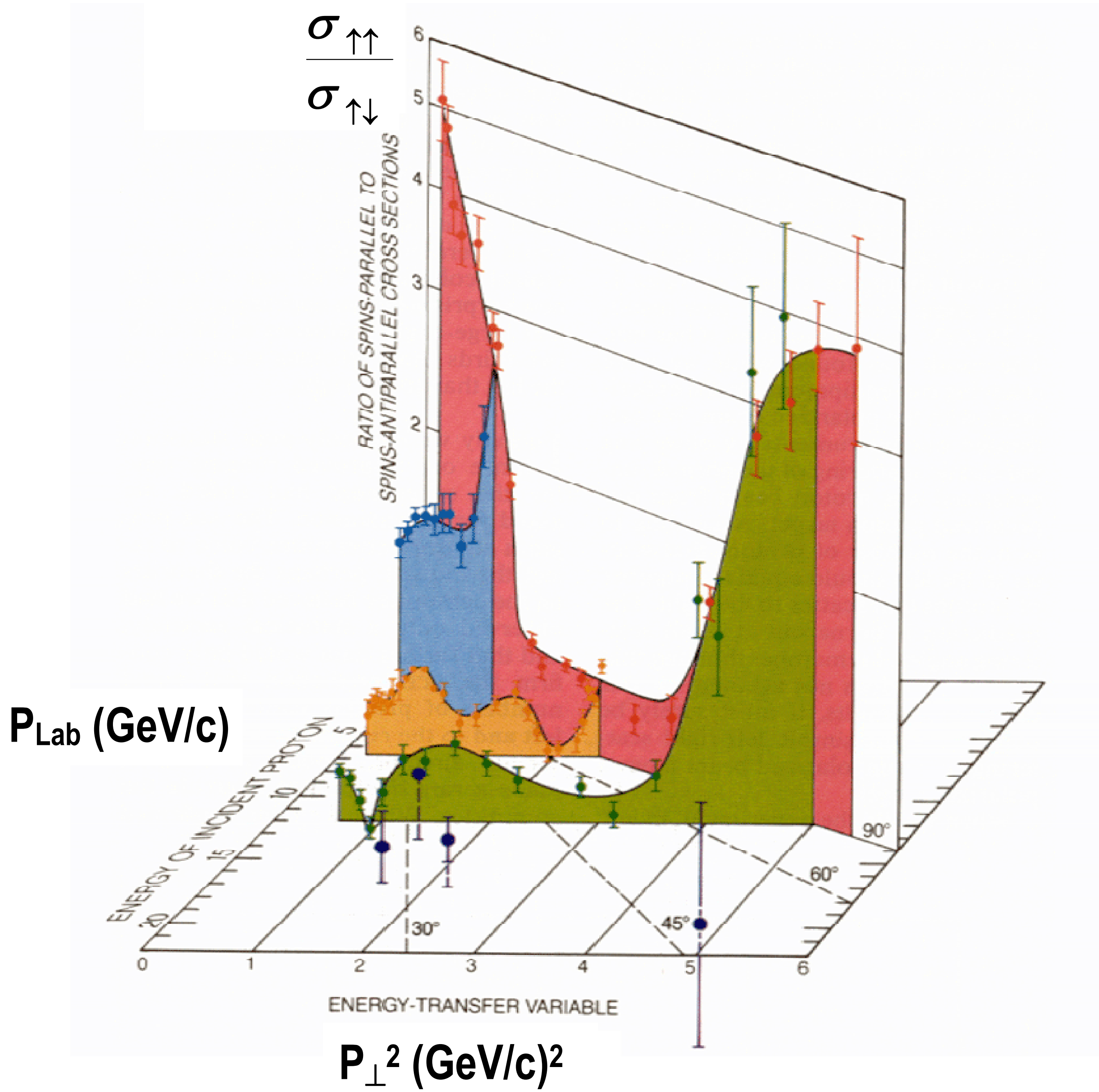
**$A_n \neq 0 \Rightarrow$**
**PROBLEM with PQCD?**

**NO MODEL can EXPLAIN ALL**
**HIGH-$P_\perp^2$ SPIN EFFECTS ($A_n$ & $A_{nn}$)**

**GOAL at J-PARC**
**MEASURE $A_n$ & $d\sigma/dt$ (& $A_{nn}$)**
**up to $P_\perp^2 = 12$ (GeV/c)$^2$**



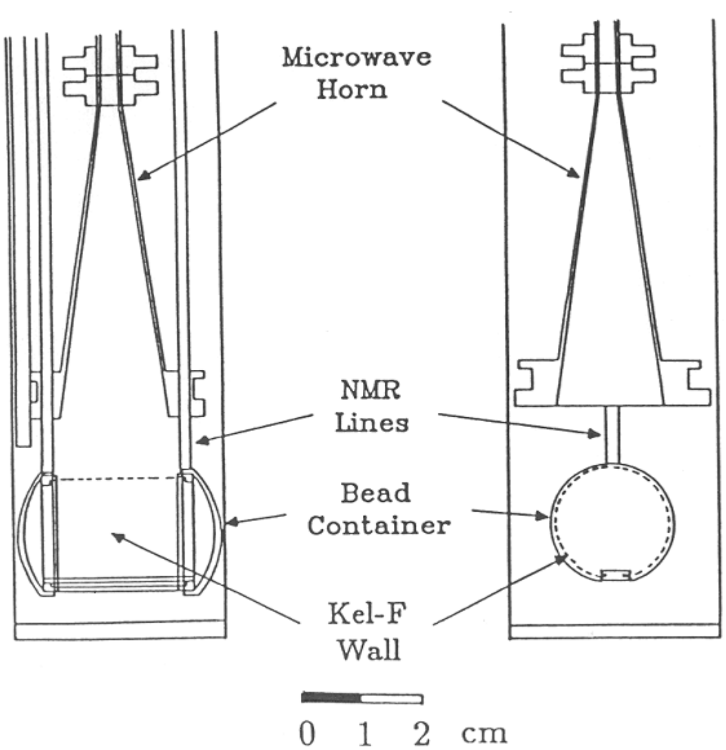
# Ratio Spin-Parallel: Spin-Antiparallel Proton-Proton Elastic Cross-Sections

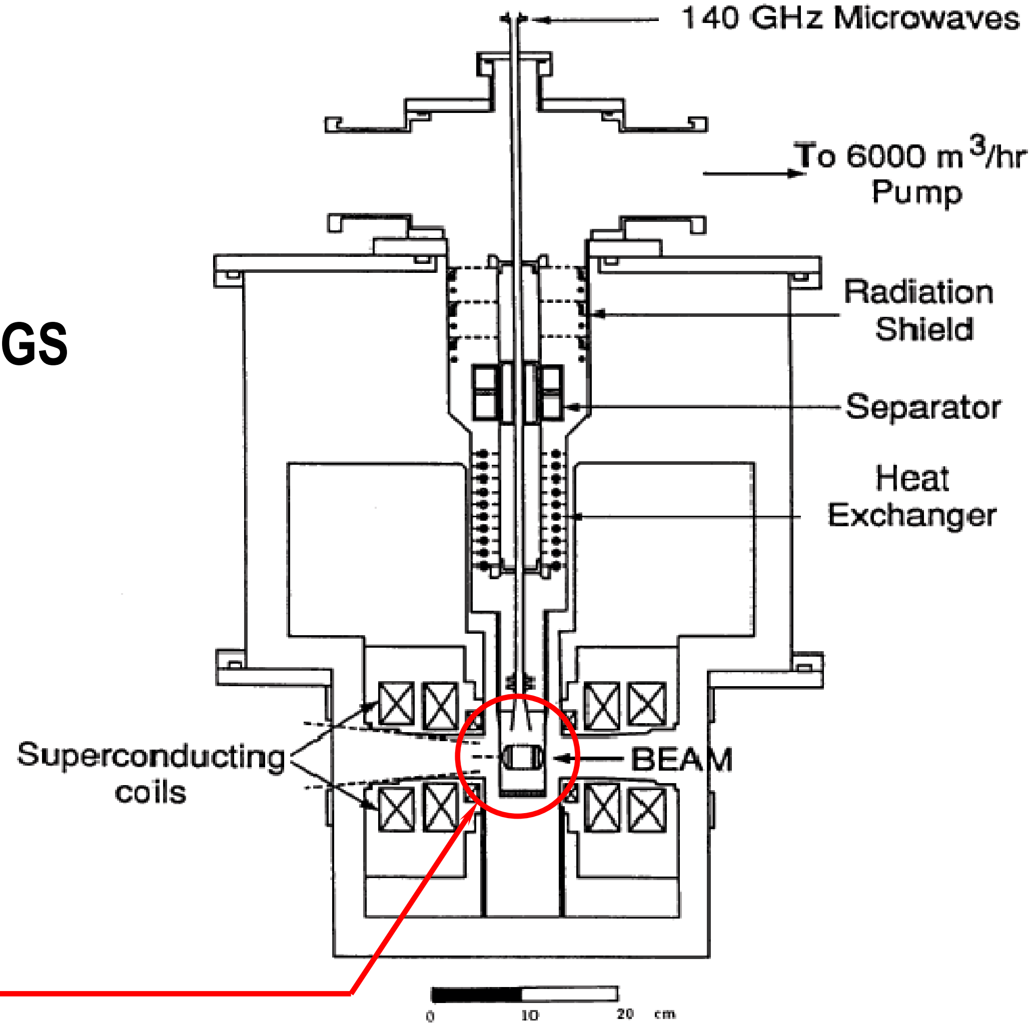


# MICHIGAN SOLID POLARIZED PROTON TARGET

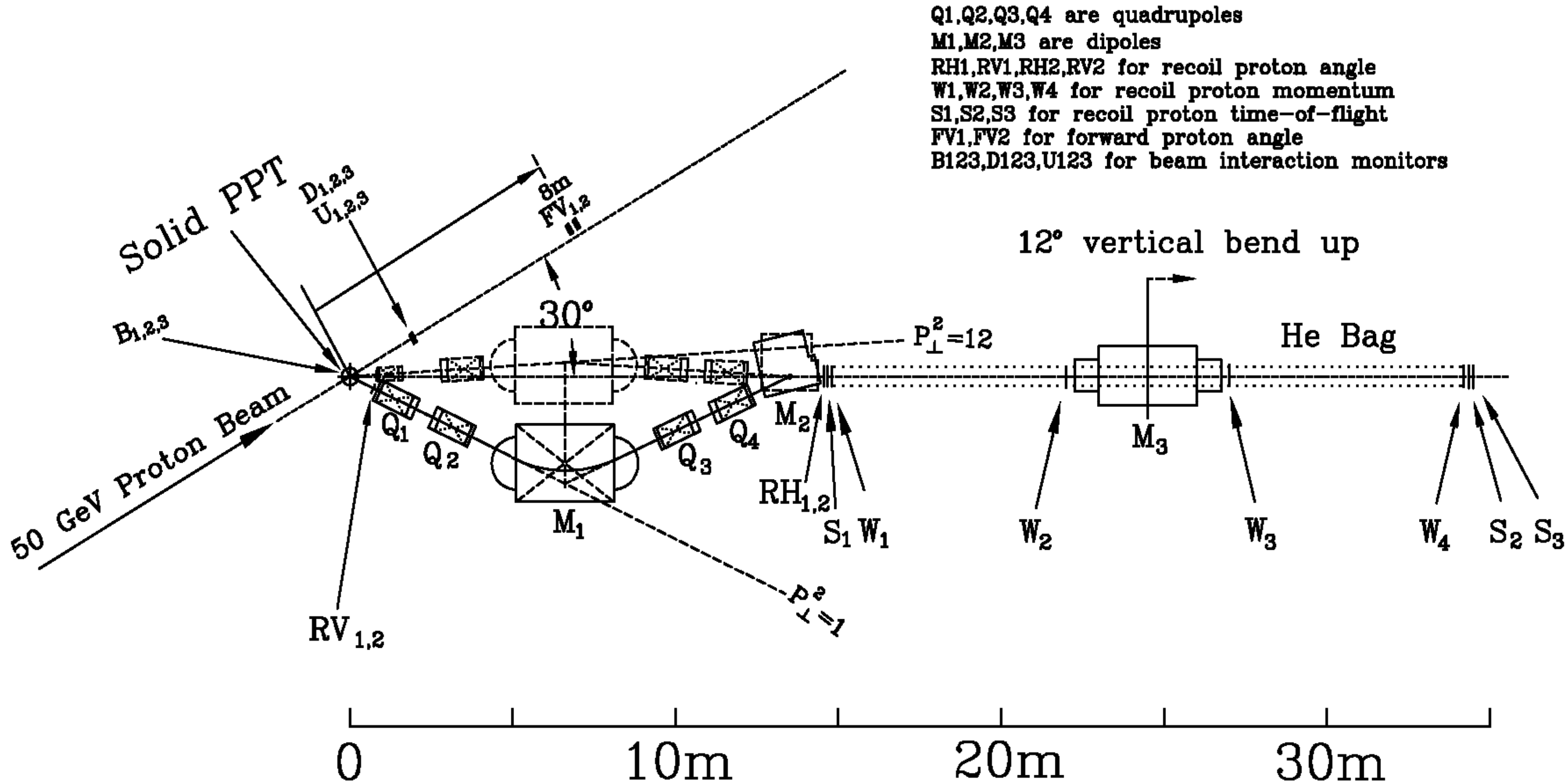
## NOW at KEK

- Highly uniform 5 T field
- 0.9 W of cooling power at 1 K
- Target cavity filled with $NH_3$
- 96% proton polarization in $NH_3$
- 85% average over 3-month at AGS



# PROPOSED SPIN@J-PARC SPECTROMETER




## MAGNET PARAMETERS

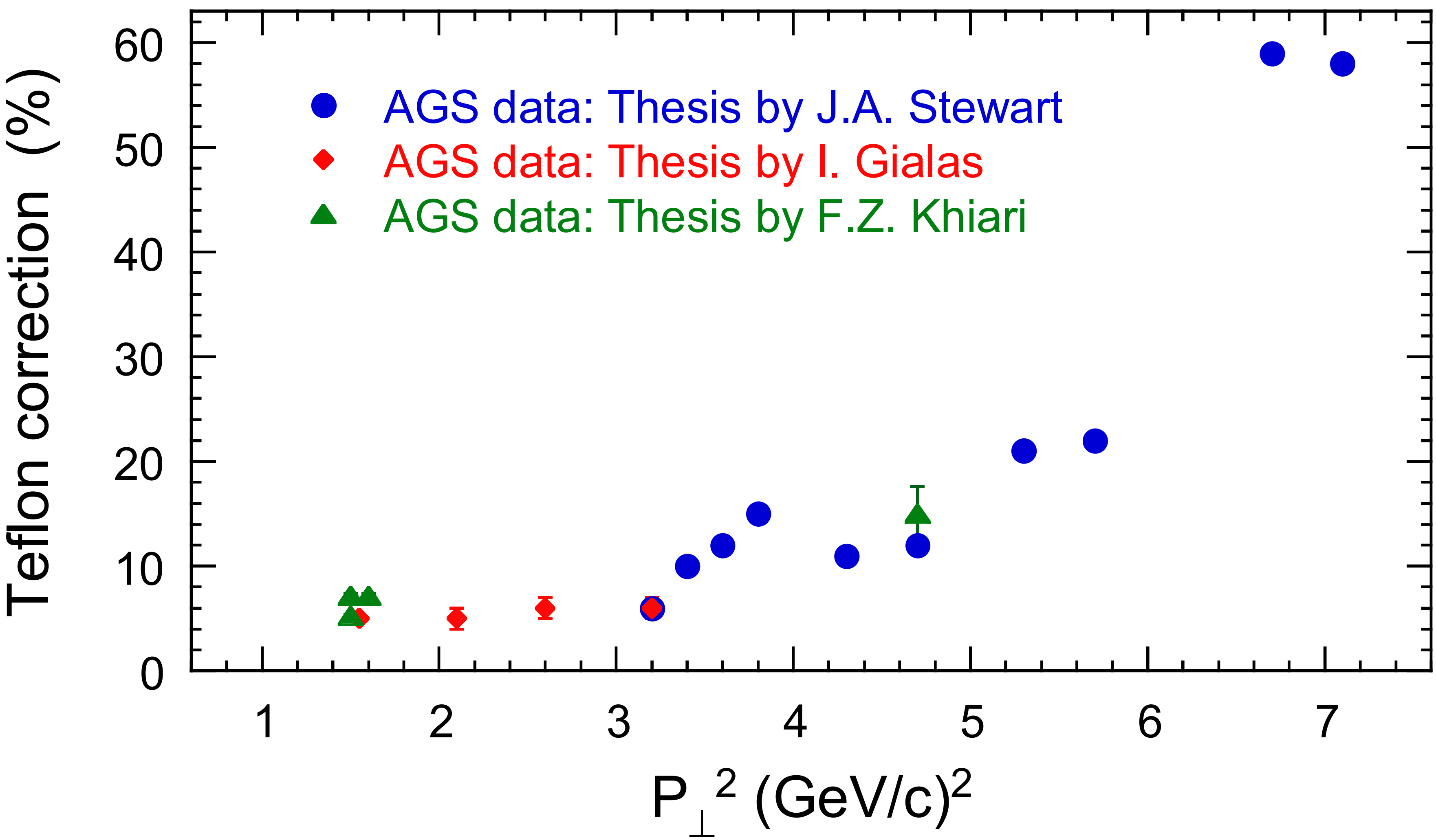
| MAGNET | LENGTH (m) | DIAMETER OR GAP (cm) | $B'_{MAX}$ (T/m) | $B_{MAX}$ (T) |
|---|---|---|---|---|
| $Q_1,Q_2,Q_3,Q_4$ | 1.00 | 20 | 14.8 | |
| $Q_1^{SUPER}$ | 0.60 | 10x16 | 60.8 | |
| $M_1,M_3$ | 3.00 | 20 | | 1.8 |
| $M_2$ | 1.50 | 20 | | 1.8 |

# SPIN@U-70 SPECTROMETER

## *PAC QUESTION 2: What is the Background at Large $P_\perp$ ?*

## Will MEASURE Inelastic & Quasi-elastic Background in p-p elastic scattering

- as in AGS $A_n$ and $A_{nn}$ Experiments at 24 and 28 GeV/c 1983-1990
- runs with Hydrogen-free Teflon beads replacing H-proton-polarized $NH_3$ beads
- simultaneously measures Quasi-elastic and inelastic backgrounds



# Combine Experimental Data from U-70 and AGS

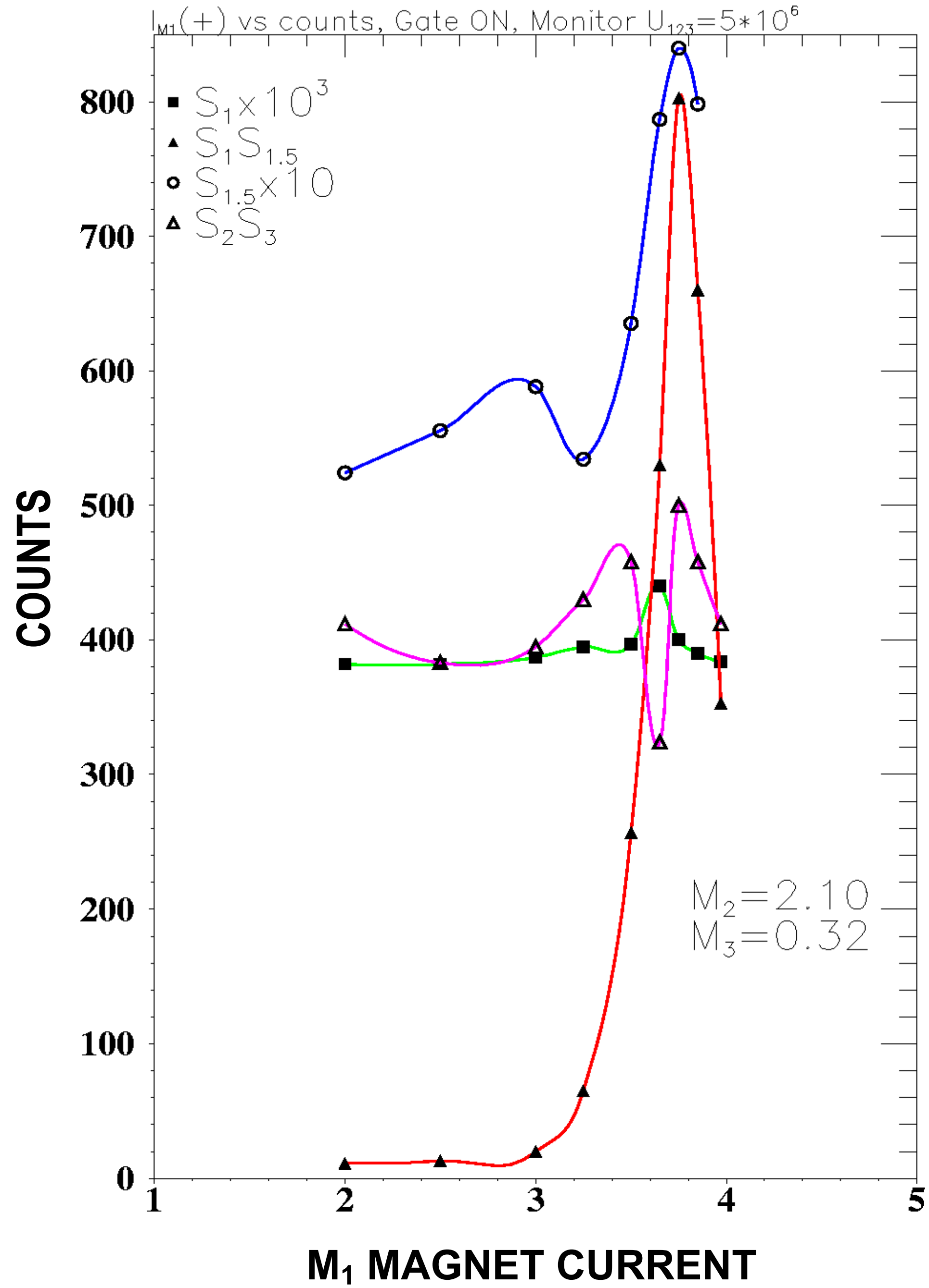
## SPIN@U70 TEST RUN
## at $P_\perp^2 \sim 1.5\ (GeV/c)^2$

Only 1st Half of Recoil Spectrometer
No Forward Hodoscope
SIGNAL : BACKGROUND ~ 80 : 1

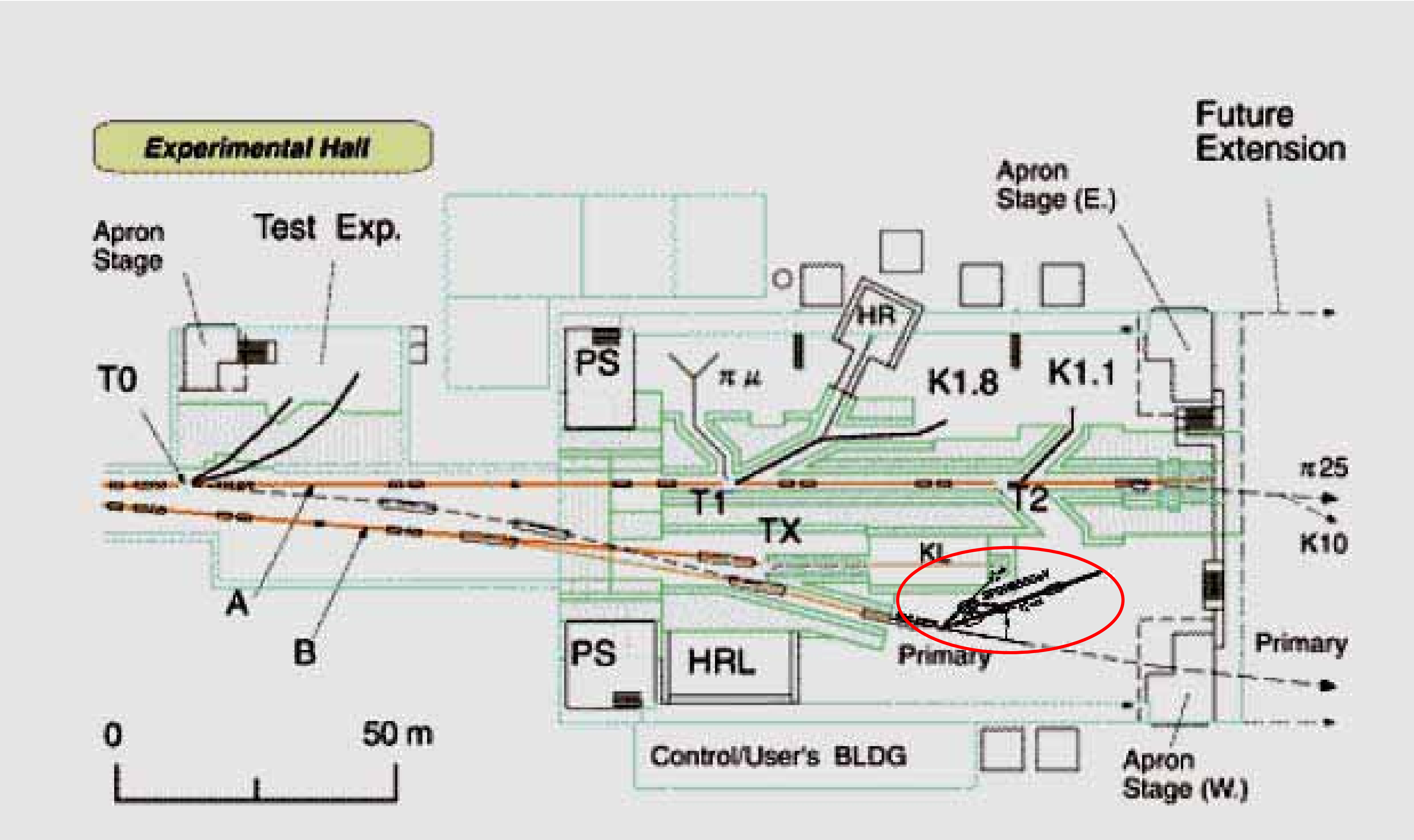
With Full Recoil Spectrometer and
Forward Hodoscope
SIGNAL : BACKGROUND
Should be Far Better than 80 : 1
Perhaps 400 : 1

Scale measured AGS $P_\perp^2$ dependence
using U-70 data

| | $P_\perp^2\ (GeV/c)^2$ | Teflon correction |
|---|---|---|
| AGS | 1.5<br>7 | 5%<br>60% |
| U-70 | 1.5 | 1.2% |
| J-PARC | (80:1) 1.5<br>7 | 1.2%<br>15% |
| J-PARC | (400:1) 1.5<br>7<br>12 | 0.24%<br>3%<br>? |



# POSSIBLE SPIN@J-PARC PLACEMENT




Or upstream in existing Hadron Hall (See Summary)

# PROTON-PROTON ELASTIC CROSS-SECTIONS

**PPT THICKNESS:**

$T = N_o \cdot \rho \cdot 3.2\ \text{cm} \cong 2\ 10^{23}$ protons $\text{cm}^{-2}$

**BEAM INTENSITY:**

$I_B = 10^{11}$ protons / s

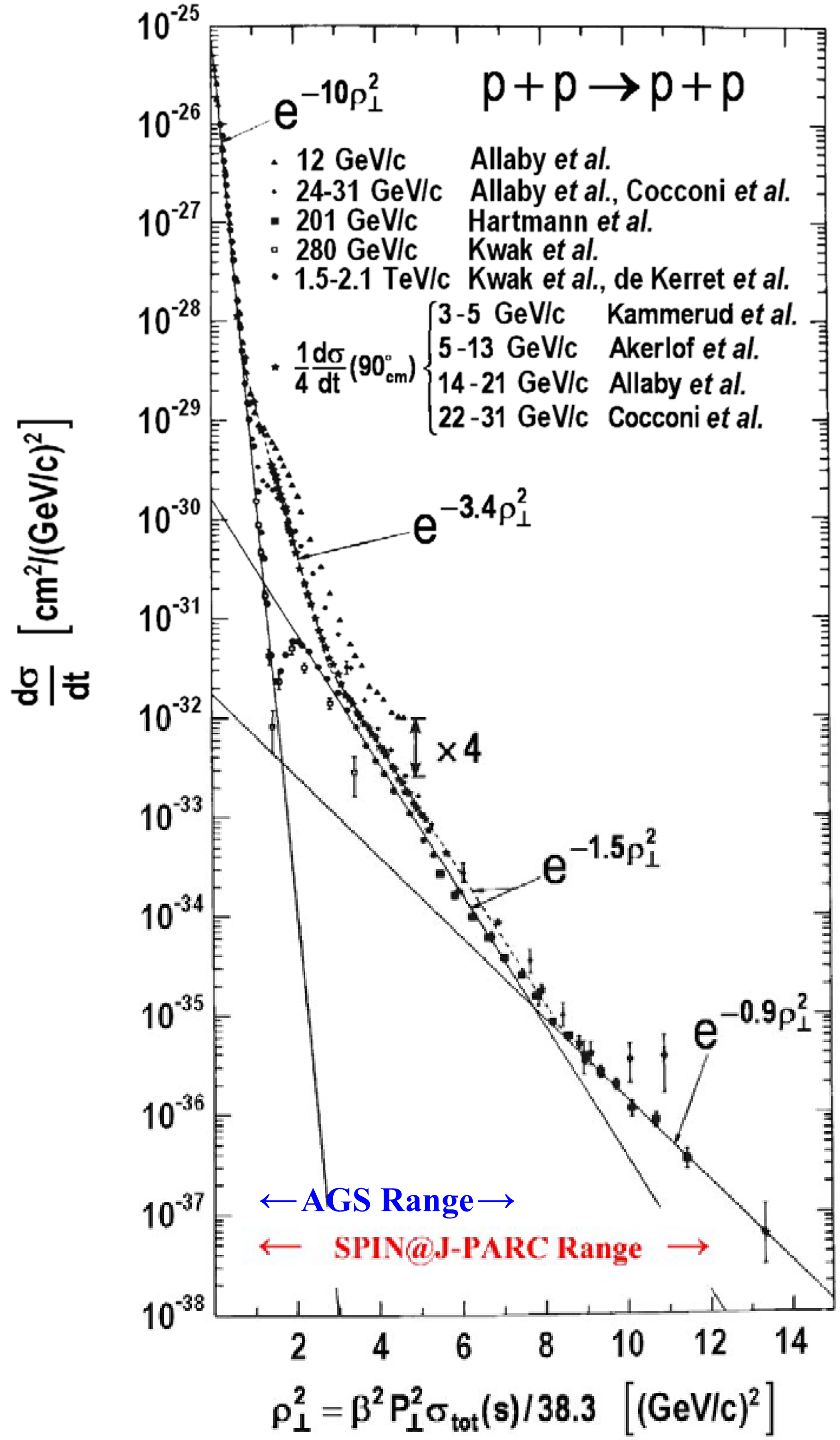
**TIME-AVERAGED LUMINOSITY:**

$L = I_B \cdot T \cong 2\ 10^{34}\ \text{s}^{-1}\ \text{cm}^{-2} \Rightarrow$

**SPIN@J-PARC Events/hour**

$$= L\ d\sigma/dt \left( \frac{\Delta t \cdot \Delta\phi \cdot \varepsilon}{2\pi} \right) 3600\ ^{s}/_{hr}$$

$$= 6 \cdot (d\sigma/dt\ [nb]) \cdot (\Delta t\ [(GeV/c)^2] \cdot \Delta\phi\ [mr])$$



# EVENT RATES and ERRORS in $A_n$

| $P_\perp^2$ (GeV/c)$^2$ | $\Delta t$ (GeV/c)$^2$ | $\Delta\phi$ mr | $d\sigma/dt$ nb/(GeV/c)$^2$ | EVENTS per hour | HOURS | EVENTS | $\Delta A_n = [.85\sqrt{N}]^{-1}$ (%) | |
|---|---|---|---|---|---|---|---|---|
| 1.0 | 0.06 | 159 | 4000 | 230000 | 100 | $2.3\cdot10^7$ | 0.03 | |
| 2.0 | 0.09 | 177 | 90 | 8600 | 100 | $8.6\cdot10^5$ | 0.1 | |
| 3.0 | 0.25 | 194 | 19 | 5500 | 100 | $5.5\cdot10^5$ | 0.2 | |
| 4.0 | 0.35 | 210 | 4.0 | 1800 | 100 | $1.8\cdot10^5$ | 0.3 | |
| 5.0 | 0.45 | 225 | 0.9 | 550 | 100 | $5.5\cdot10^4$ | 0.5 | |
| 6.0 | 0.56 | 240 | 0.22 | 180 | 200 | $3.6\cdot10^4$ | 0.6 | |
| 7.0 | 0.67 | 254 | 0.055 | 56 | 200 | $1.1\cdot10^4$ | 1.1 | Super $Q_1$ |
| 8.0 | 0.79 | 268 | 0.016 | 20 | 300 | $6.0\cdot10^3$ | 1.5 | " |
| 9.0 | 0.92 | 282 | 0.0047 | 7.3 | 400 | $2.9\cdot10^3$ | 2.2 | " |
| 10.0 | 1.06 | 296 | 0.0017 | 3.2 | 600 | $1.9\cdot10^3$ | 2.7 | " |
| 12.0 | 1.25 | 324 | 0.0003 | 0.73 | 800 | $4.4\cdot10^2$ | 4.9 | " |

**TOTAL HOURS: 3000 + 500 (TUNE-UP)** with $10^{11}$ protons/sec

**ERRORS with POLARIZED BEAM ($P_B$) and POLARIZED TARGET ($P_T$)**

$\Delta A_{nB} = (P_B\sqrt{N})^{-1}$ ; $\Delta A_{nT} = (P_T\sqrt{N})^{-1}$ ; $\Delta A_{nn} = (P_B P_T \sqrt{N})^{-1}$ ; $\Delta d\sigma/dt = (\sqrt{N})^{-1}$

***PAC Question 1: Does Polarized Beam help the $A_n$ measurement?***

**Answer: Yes. One simultaneously measures $A_{nT}$ and $A_{nB}$ which MUST be equal.**

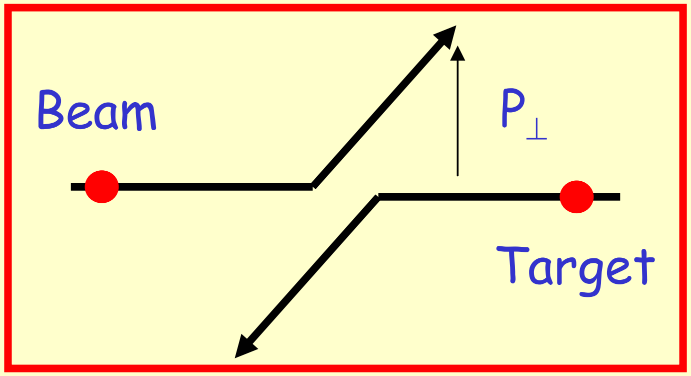
$$A_n = \tfrac{1}{2}[A_{nB} + A_{nT}] \qquad \Delta A_n = \tfrac{1}{2}[(\Delta A_{nB})^2 + (\Delta A_{nT})^2]^{1/2}$$

- **Reduces Run-time by almost 50% $\Rightarrow$ 1750 + 500 hours**
- **Calibrates Beam Polarization**

**NOTES by SPIN@J-PARC shown in this Blue Type**

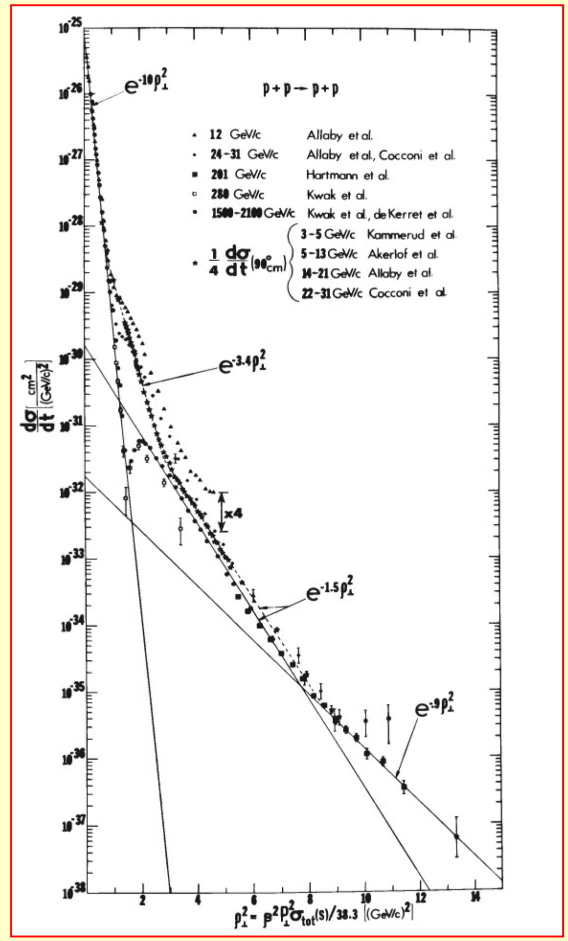
**Answers by: Profs. Lenisa (pp 14-16), Glashow (16), Brodsky (pp 16-19), Goulianos (20), Sivers (21) & Salam (22)**

# Hard polarized scattering




Unpolarized p-p elastic cross section

$d\sigma/dt$




scaled $p^2_\perp$

Dividing $d\sigma/dt$ at 90° c.m by 4 made all p-p elastic data fit on a single curve …

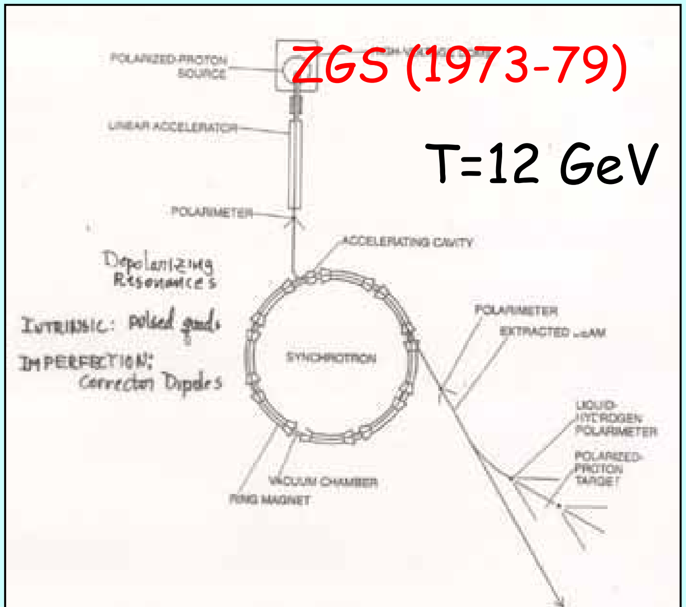
**P. LENISA Ferrara University**

**Medium Energy antiproton-proton Experimenter**

NOTE by SPIN@J-PARC: Prof. Lenisa wants Ultra-cold Jet (not PPT) for FAIR

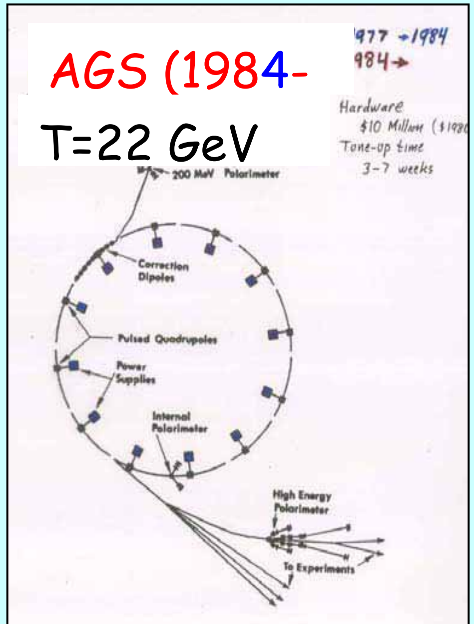
# Experimental

- Development of polarized proton beams

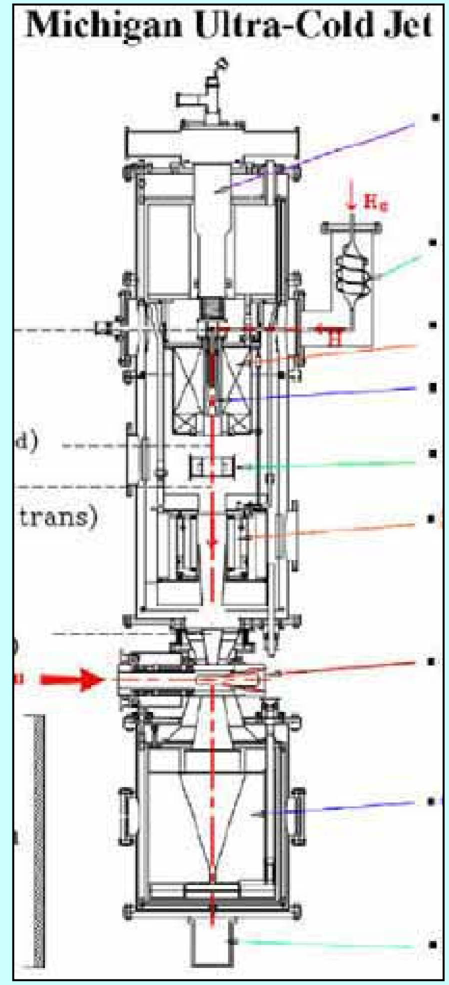



- 19 dep. resonances

$P_B$>70%

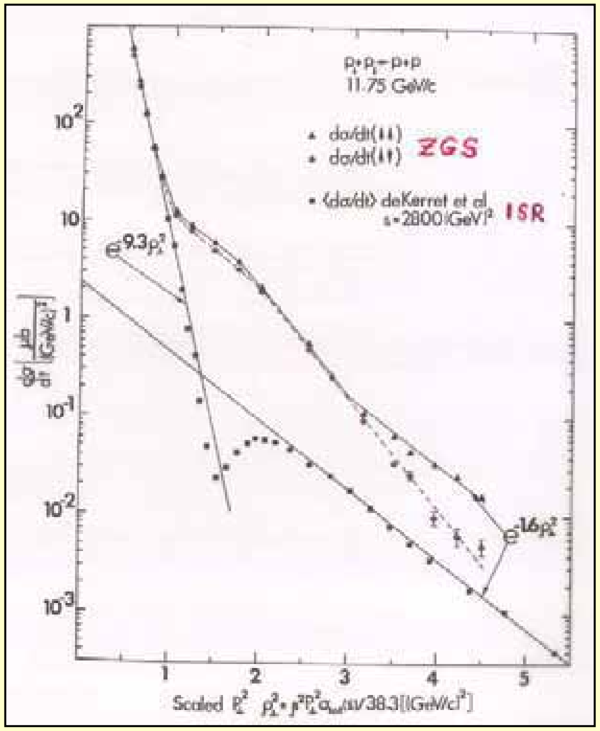



- 45 dep. resonances

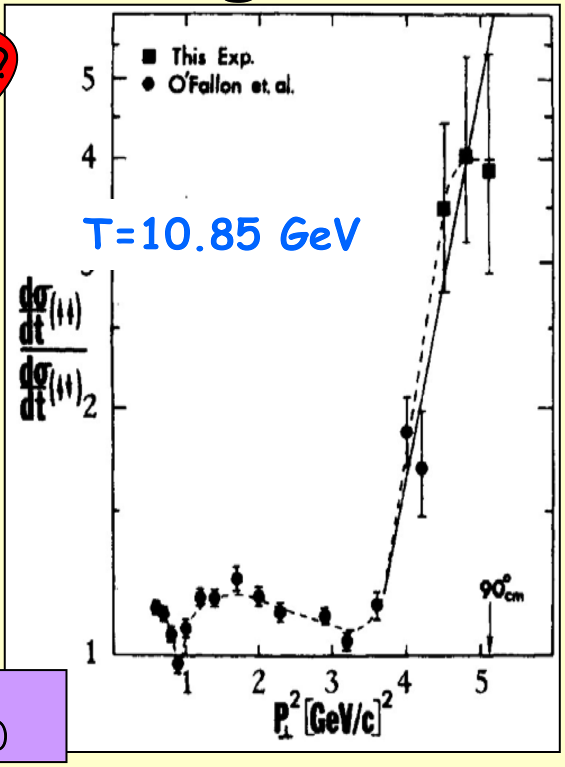



- Polarized target

# Hard p-p polarized scattering




Spin Crisis "ante litteram"?




"The graeatest asymmetries in hadron physics ever seen by a human being" (Brodsky)

D.G. Crabb et al., PRL 41, 1257 (1978)

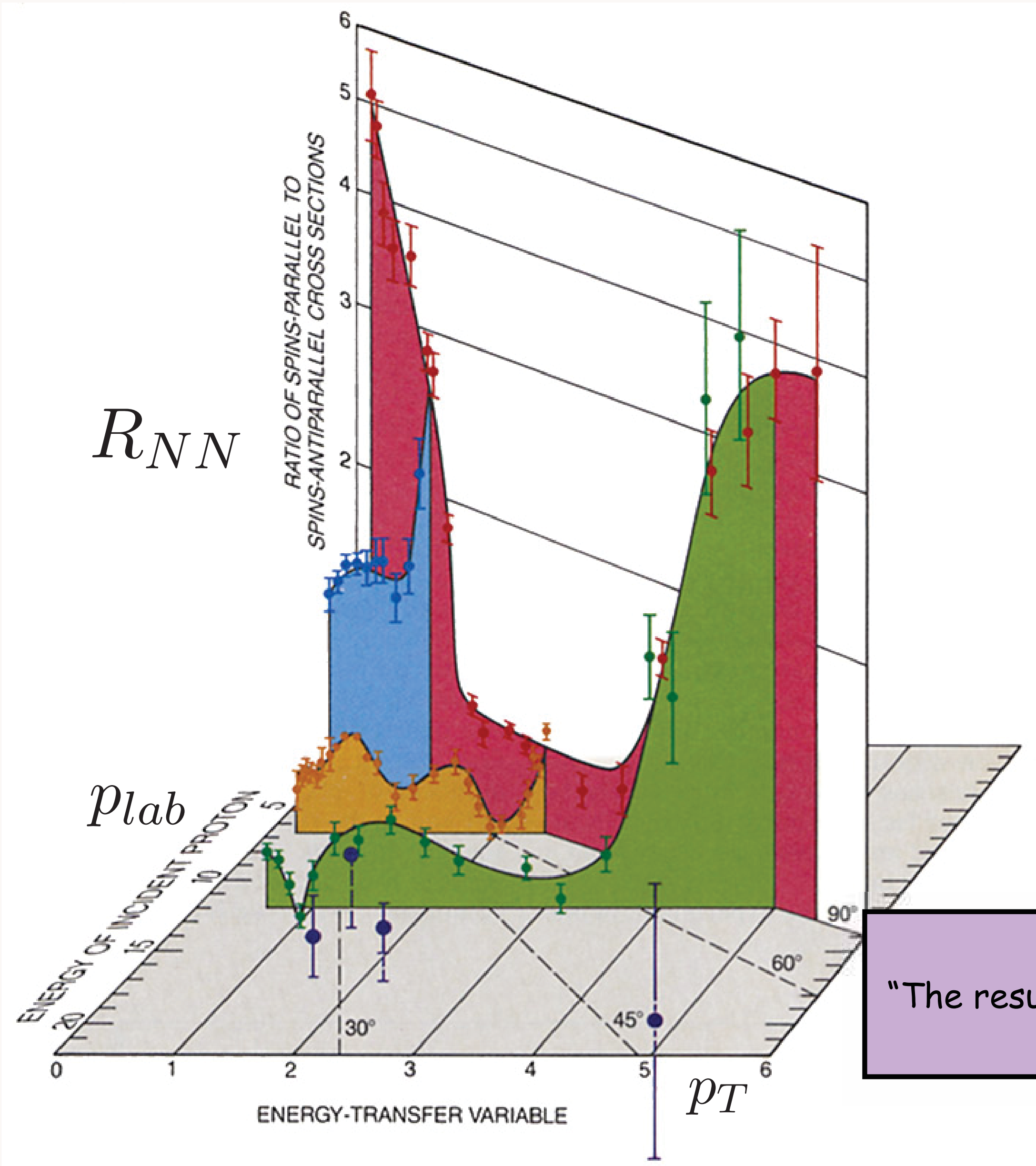
"The results challenge the prevailing theory that describes the proton's structure and forces" (Krish, 1987)

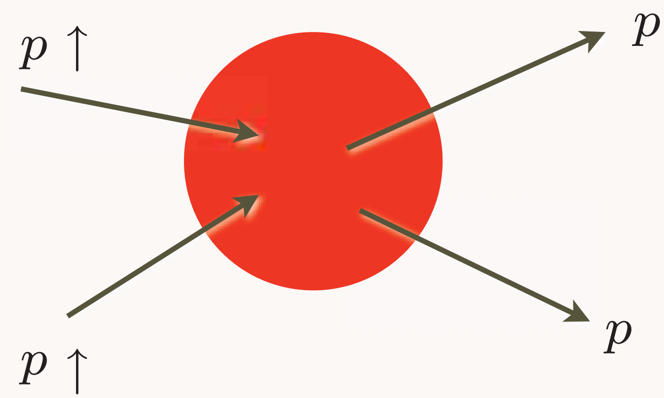
"One of the unsolved mysteries of hadron physics"(Brodsky, 2005)

"… the thorn in the side of QCD" (Glashow)

It would be very interesting to performe this measurements with polarized antiprotons.

# Spin Correlations in Elastic $p-p$ Scattering




polarization normal to scattering plane

Ratio reaches 4:1 !

A. Krisch, Sci. Am. 257 (1987)
"The results challenge the prevailing theory that describes the proton's structure and forces"

# "Exclusive Transversity"

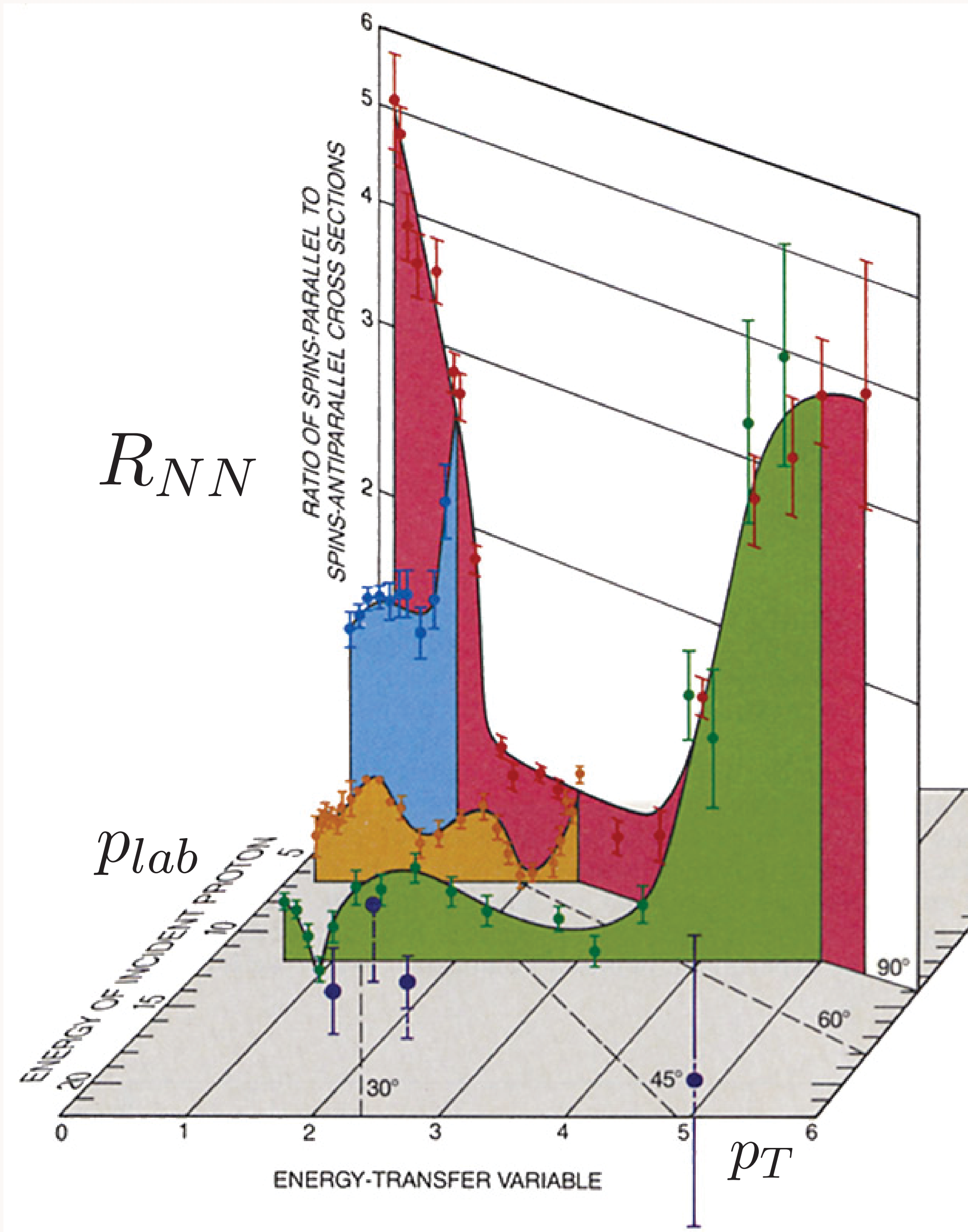
> A. Krisch, Sci. Am. 257 (1987)
> "The results challenge the prevailing theory that describes the proton's structure and forces"

Spin-dependence at large-$P_T$ ($90^\circ_{cm}$):

**Hard scattering takes place only with spins ↑↑**

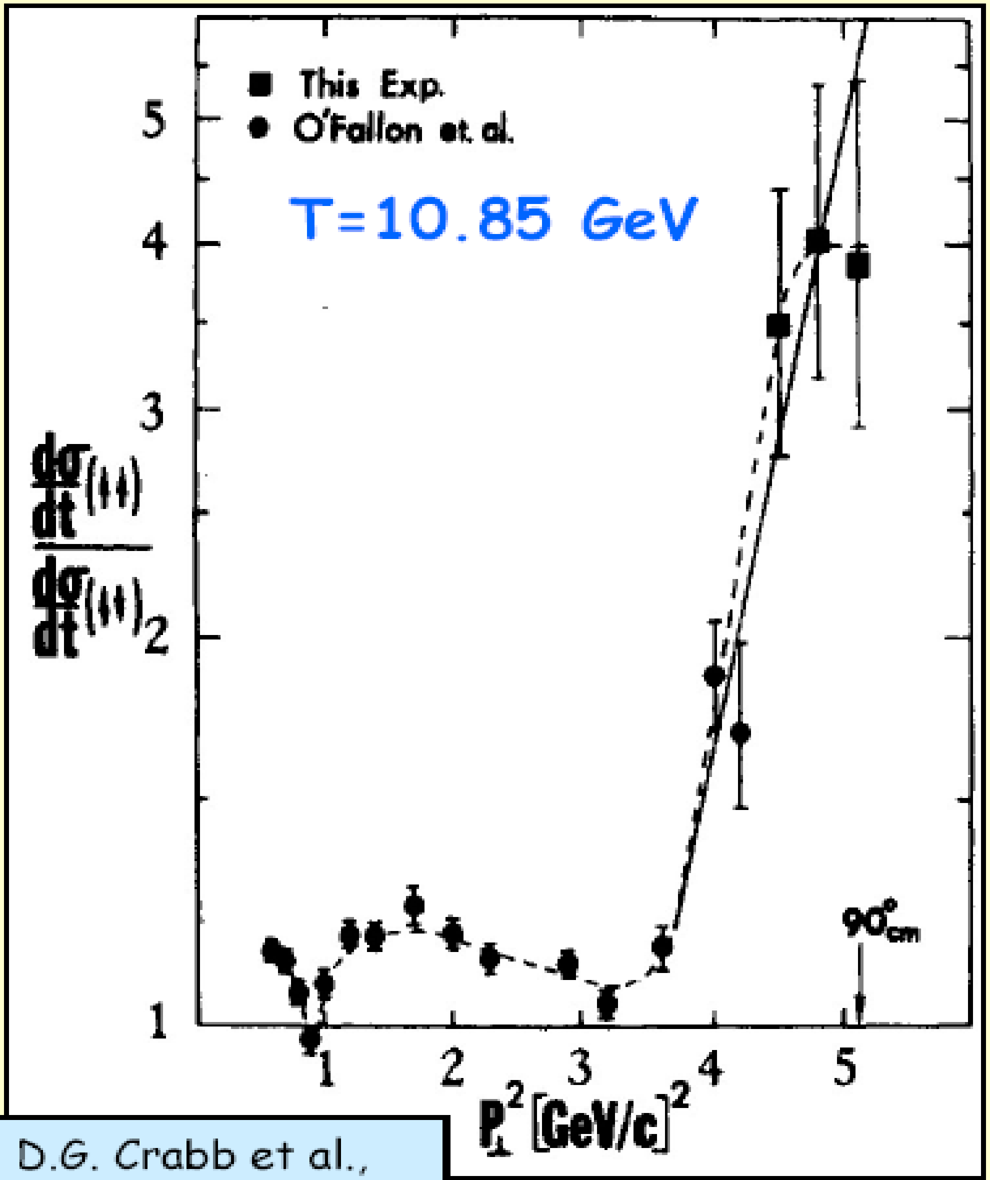
*Coincidence?: Quenching of Color Transparency*

*Coincidence?: Charm and Strangeness Thresholds*



from Brodsky's Peking Talk

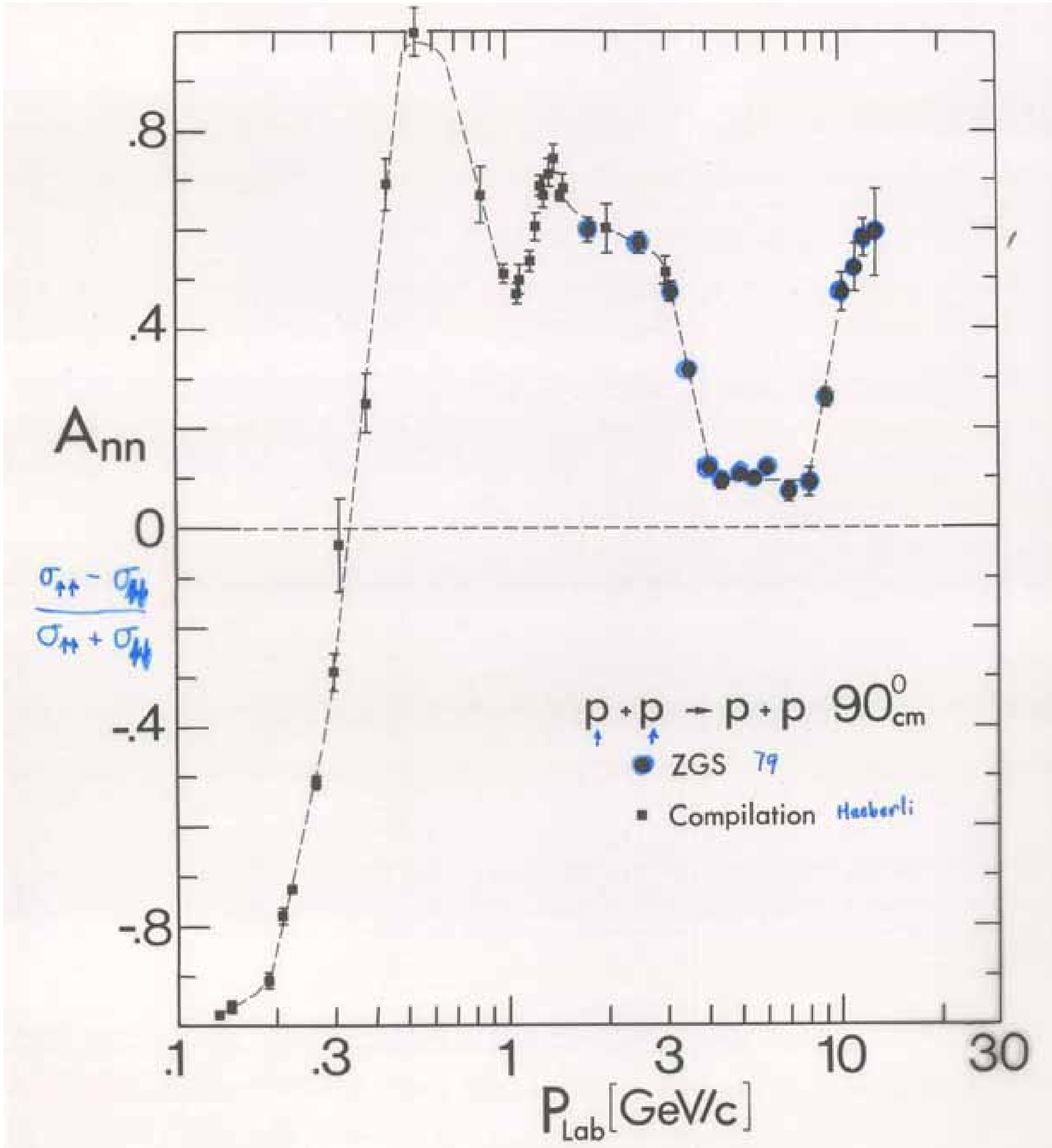
# Unexpected spin effects in pp elastic scattering




D.G. Crabb et al., PRL 41, 1257 (1978)

larger t region can be explored in $p\bar{p}$

# Compilation: Proton-Proton Elastic $A_{nn}$ at $90^{o}_{cm}$ (10 MeV to 12 GeV)



# A. SALAM
# Particle physics today

*Annales de l' I.H.P., section A,* tome 49, n° 3 (1988), p. 369-385
<http://www.numdam .org/item?id=AIH PA_1988_49_3_369_0>

●●●

**11. THREE TYPES OF IDEAS**

We shall divide our remarks into three topics:

**A)** Ideas which have been tested or will soon be tested with accelerators which are in existence or presently being constructed;

**B)** Theoretical ideas whose time has not yet come (so far as the availability of accelerators to test them goes), but hopefully the situation may change before the year 2000 AD; and

**C)** Passive, non-accelerator experiments which have tested-but not conclusively so far - some of the theories of the 1970's. To give a brief summary, consider each of these three topics in turn.

●●●

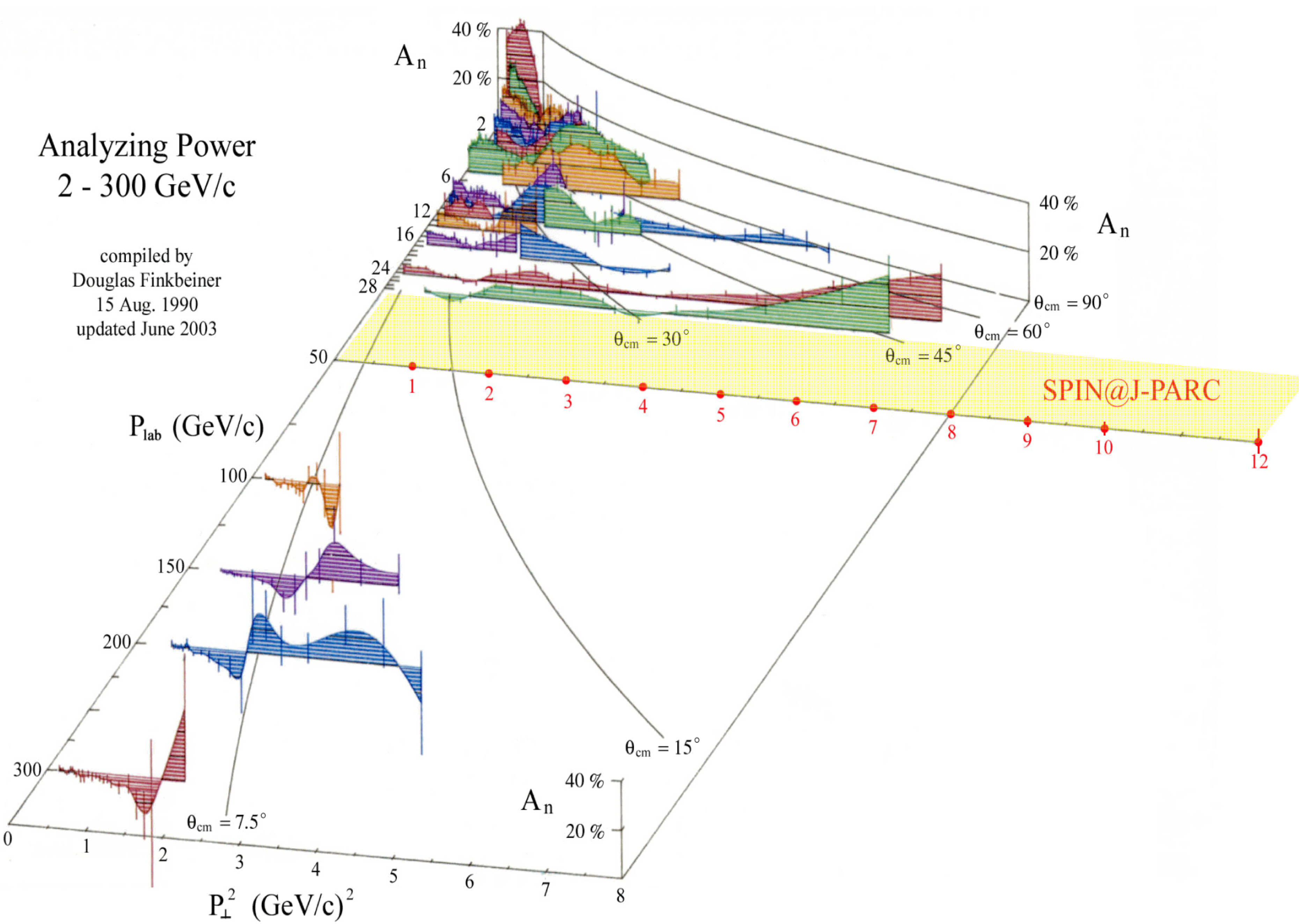
**B)** Theoretical ideas whose time has not yet come (from supersymmetry to the Theory of everything); basically because accelerators to test them are not yet commissioned. These ideas include:

●●●

**vi.)** Superstrings. (The axial colour gluons interfering with vector gluons may give the simplest explanation of the spin dependence of scattering of polarised protons as well as of the left-right asymmetry observed by Krisch and collaborators in pp scattering up to 30 GeV.)

*Annules de I'Institut Henri Poincure'* - **Physique theorique** **PARTICLE PHYSICS TODAY** **37 1**

# $A_n$ for PROTON-PROTON ELASTIC SCATTERING at J-PARC



# *ADDITIONAL PAC QUESTIONS*

***Quest. 1: What is the beam luminosity and spectrometer performance at J-PARC relative to the AGS/ZGS experiments?***

**Answer:**

- **Luminosity similar to AGS; ~20 times > ZGS**
- **Spectrometer's acceptance angle ~20X > AGS/ZGS**
- **Background much less: far better θ and P resolution in recoil spectrometer. ~5X better at U-70; probably at least 25X better at J-PARC.** **(see pp 7 & 8)**

***Quest. 2: Why does division by 4 at 90° put all p-p dσ/dt data on a universal curve?***

**Answer:** **For IDENTICAL particles, the measured dσ/dt includes $d\sigma/dt_{F\text{-left}} + d\sigma/dt_{B\text{-right}}$.**
**Adding $d\sigma/dt_F + d\sigma/dt_B \Rightarrow 2$; Adding amplitudes $\Rightarrow 4$ for some $A_n$ & $A_{nn}$.**
**See: ADK PRL 19, 1149 (1967); R. Serber (1968); V.K. Weisskopf & H.A. Bethe (1978)**

***Quest. 3: a.) What are origins of distinct changes in unpolarized dσ/dt slope at different $P_\perp^2$?***
***b.) Are the $P_\perp^2$ dependences of dσ/dt, $A_n$ & $A_{nn}$ related?***

**Answer:** **a.) The change at $P_\perp^2 = 3\ (GeV/c)^2$ may be the start of constituent scattering.**
**b.) dσ/dt, $A_n$ & $A_{nn}$ all change near $P_\perp^2$ of 1 and 3 $(GeV/c)^2$; thus, probably yes.**

***Quest. 4: What $A_n$ and $A_{nn}$ behavior is expected at $P_\perp^2 = 7.5\ (GeV/c)^2$ where dσ/dt may change slope?***

**Answer:** **This region is totally unexplored. The question may be answered by the SPIN@J-PARC experiment; it could also confirm the slope change in dσ/dt.**

***Quest. 5: Why are the $A_n$ [& $A_{nn}$] asymmetries still unsolved mysteries after so many years?***

**Answer:** **One does not know why they are unsolved. But SPIN@J-PARC data might answer these mysteries about the fundamental nature of strong interactions and of spin. These mysteries can not be answered by any existing theory.**

# SUMMARY

Elastic ZGS $A_{nn}$ & AGS $A_n$ experiments & inclusive π production Fermilab & new RHIC experiments disagree with all QCD-based calculations during the past 30 years.
Both $A_{nn}$ and $A_n$ do not go to zero at high energy or high $P_\perp^2$ as predicted.

**BASIC LAW OF SCIENCE:**

**If theory disagrees with reproducible experimental data: theory must be modified.**

Exploring elastic dσ/dt, $A_{nn}$ & $A_n$ at high $P_\perp^2$ could allow J-PARC to provide experimental guidance for required modification of Strong Interactions theory.

These elastic dσ/dt, $A_{nn}$ & $A_n$ experiments could revitalize elastic spin physics, just as recent RHIC inclusive π production $A_n$ experiments revitalized similar Fermilab experiments (E704 Yokosawa et al.).

Elastic dσ/dt is important since it is the only exclusive process large enough to be measured at TeV energy;
it is dominated by diffraction caused by millions of different inelastic processes.
Many people have forgotten these geometrical ideas.
See: R. Serber, PRL 10, 357 (1963); ADK, PRL 11, 217 (1963); PR 135, B1456 (1964).

30 GeV $A_n$ & dσ/dt experiment to $P_\perp^2$ = 9 $(GeV/c)^2$ could start J-PARC high energy hadron spin physics at small cost. [No 50 GeV; No polarized beam; PPT at KEK; in existing Hall]

High intensity 15-25 GeV π beamline & PPT could also allow π-p elastic $A_n$ experiments.