

# *Historical Review of High Energy Polarized Proton Experiments in USA*

*memory of Aki Yokosawa and Alan Krisch*

*Kenichi IMAI*

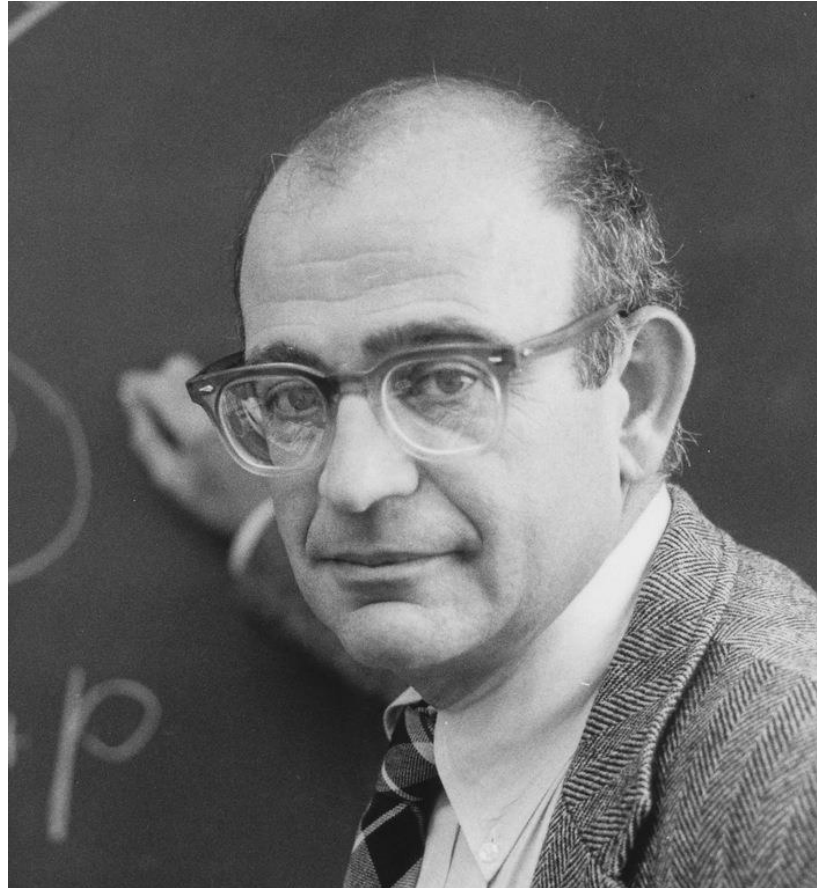
*JAEA & Kyoto*

# Aki Yokosawa



*Passed away on 2009.5.25 age 81*

# Alan Krisch



*Passed away on 2020.12/5 age 81*

## *Early days of spin physics in USA (60 & 70's)*

- “high energy” spin physics started with **polarized proton targets**. (and then polarized proton beams)

**A. Yokosawa ,    A. Krisch**

Polarization ( rotation) measurements were necessary to determine scattering amplitude, **spin and parity of baryon resonances**, in  $\pi N$  and  $KN$  scatterings.

Polarization is also used to understand reaction mechanism (Regge theory) of  $\pi N, KN, NN$  scattering.

# *Polarized proton beam*

- *Both polarized proton beam and target were used to determine phase shifts of  $pp(n)$  scattering and understand nuclear force (complete experiments  $\sigma, p, R, A_{nn}, A_{LL}, A_{SS}, \dots$ )*
- *Many experiments with Pol. Beam and target were done and analyzed in USA .*
- *Surprise (resonance like structure) from Pol.  $pp$  scattering at GeV/c region (ZGS) – “dibaryon”*

*A.Yokosawa*

# $\Delta\sigma_{L,T}$ in $pp$ scattering at $\sim GeV/c$

$\Delta\sigma_T$   
(mb)

$\Delta\sigma_L$   
(mb)

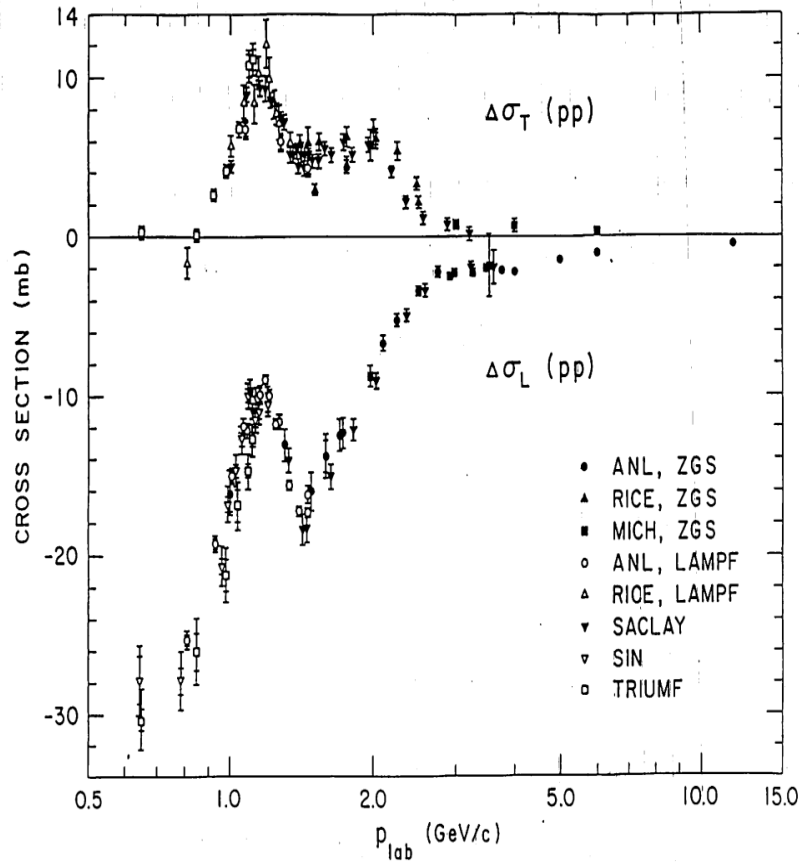
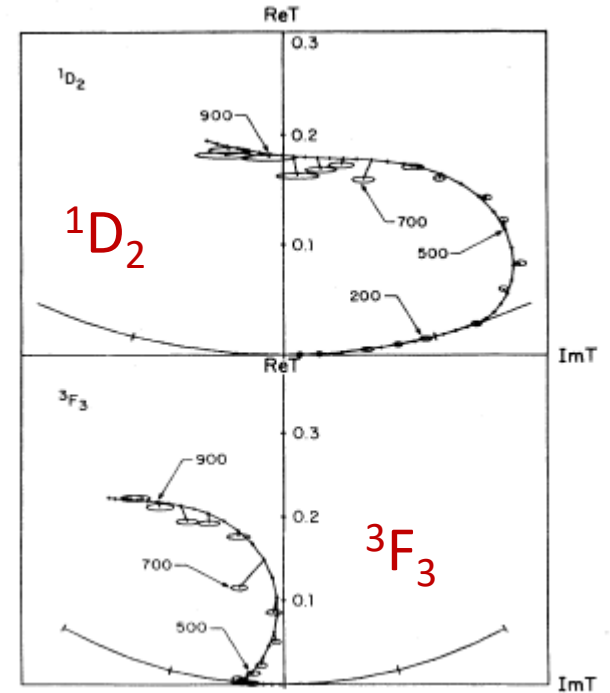


Figure 6



Resonance-like motion of  
phase shifts

# *Outcome of “dibaryon”*

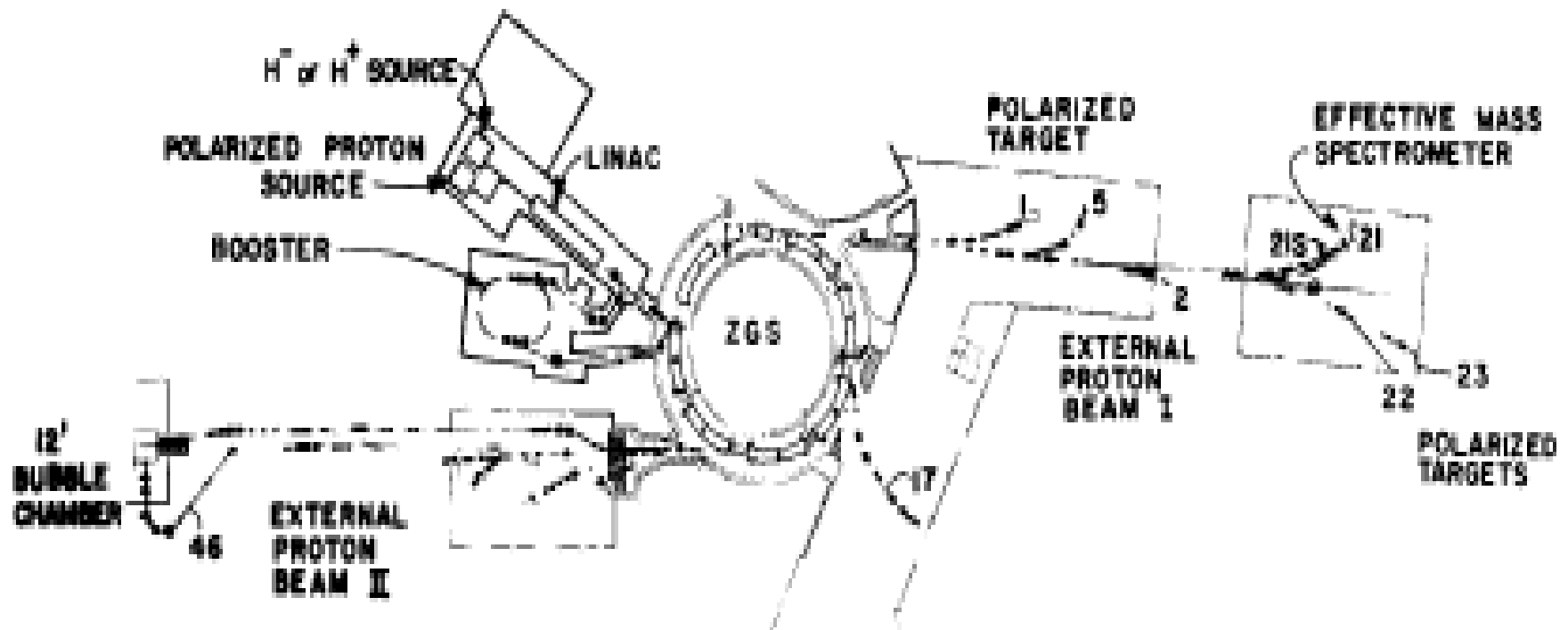
- Many measurements on various spin states were made (~complete measurements of NN)
  - > determination of nuclear force, SAID
- Exotic hadron physics
  - tetra-quark (B-factory),
  - penta-quark (LHC),
  - dibaryon

# *ZGS (Argonne)*

- 12 GeV weak focusing synchrotron

Polarized proton up to 12 GeV

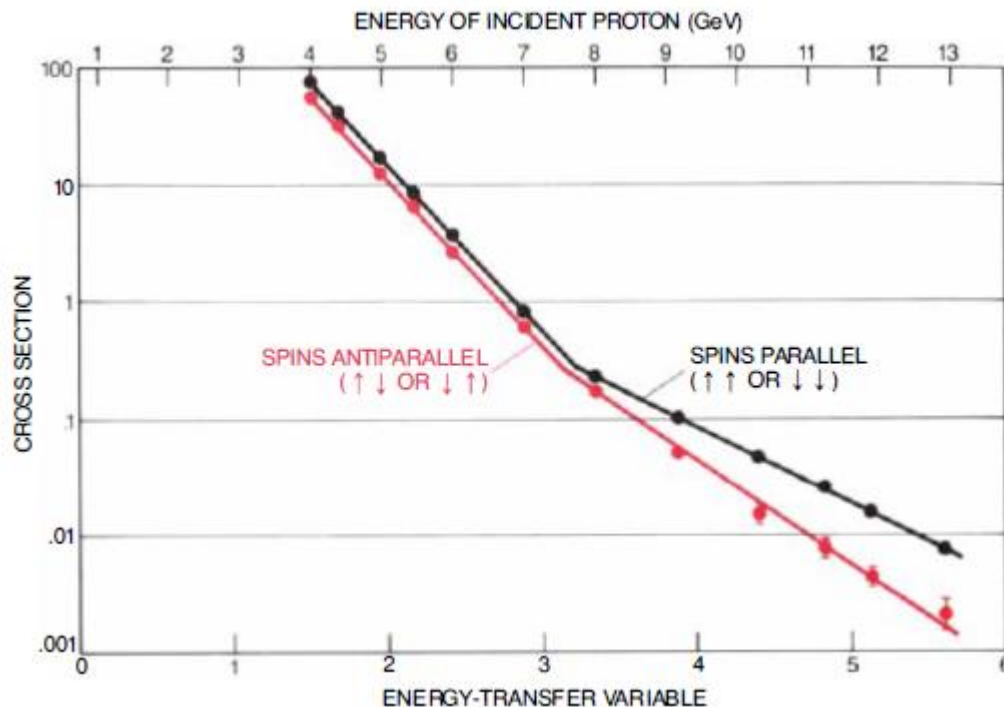
mainly spin physics before shut down





# Spin effects at high energy

- “Spin effects go to zero at high energy”  
(Regge theory) **But!**
- Ann in pp elastic scattering



A.Krisch  
Scientific American 1987

# Motive to higher energy pol. proton

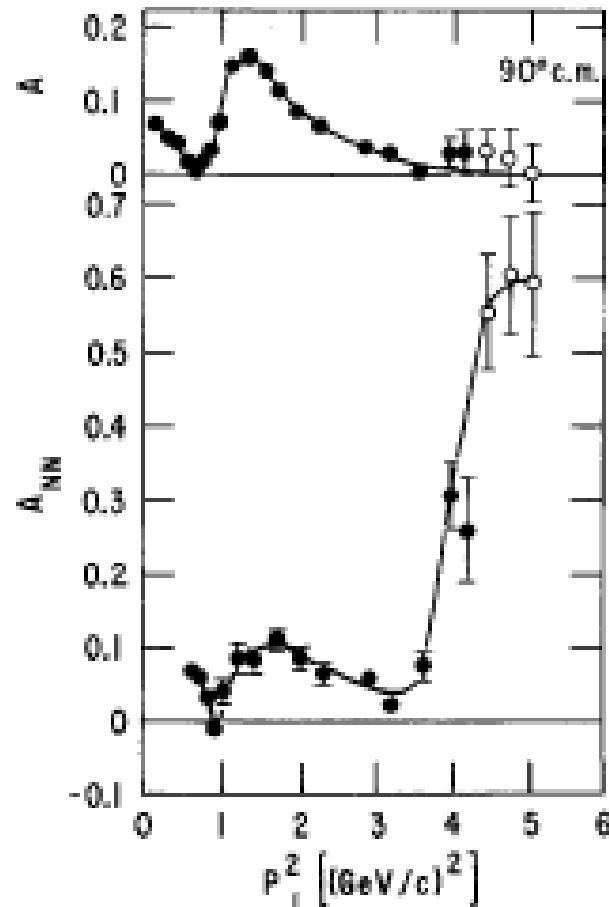


Fig. 37.  $A_{NN} = C_{NN}$  at 12 GeV/c.

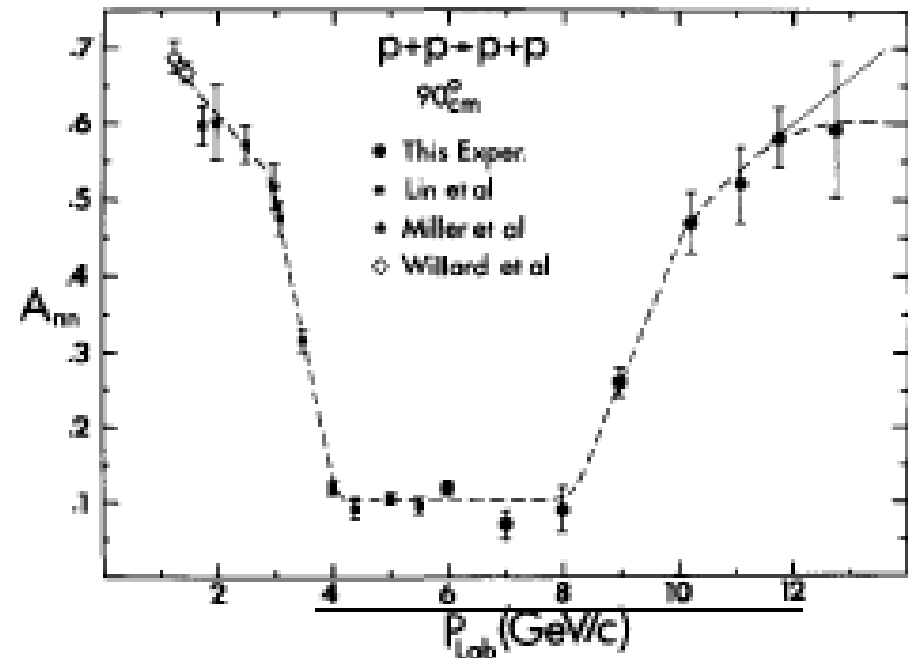


Fig. 38.  $C_{NN}$  at  $\theta_{\text{c.m.}} = 90^\circ$  as a function of  $p_{\text{lab}}$ . See E.A. Crosbie et al., UM HE 80-2 preprint (March 5, 1980).

# To higher energy of pol. proton

- Secondary pol. proton (anti-proton) beams from  $\Lambda$  (anti- $\Lambda$ ) decay at Fermilab. 200GeV/c

E581 & E704 (A.Yokosawa)

- Acceleration of polarized protons at higher energy accelerators

AGS, Tevatron, SSC, HERA, -> RHIC

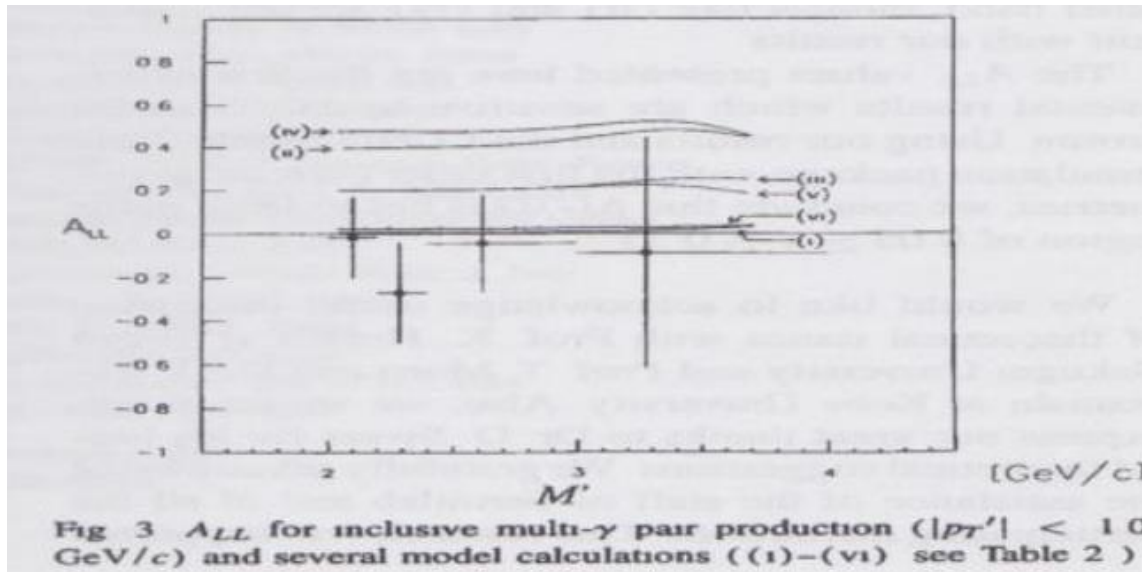
How to overcome depolarization during acceleration?

-> Siberian snake

Demonstration at IUCF cooler ring (A. Krisch)

# 200 GeV Polarized proton and anti-proton beam at Fermilab (E704 A.Yokosawa) 80' 90'

- QCD and spin physics
- First attempt to measure gluon spin  
 $J/\psi$  production,  $\pi^0$ ,



P.L.B 336(1994)269

low intensity (luminosity) -> spin collider

# Discovery of large $A_N$

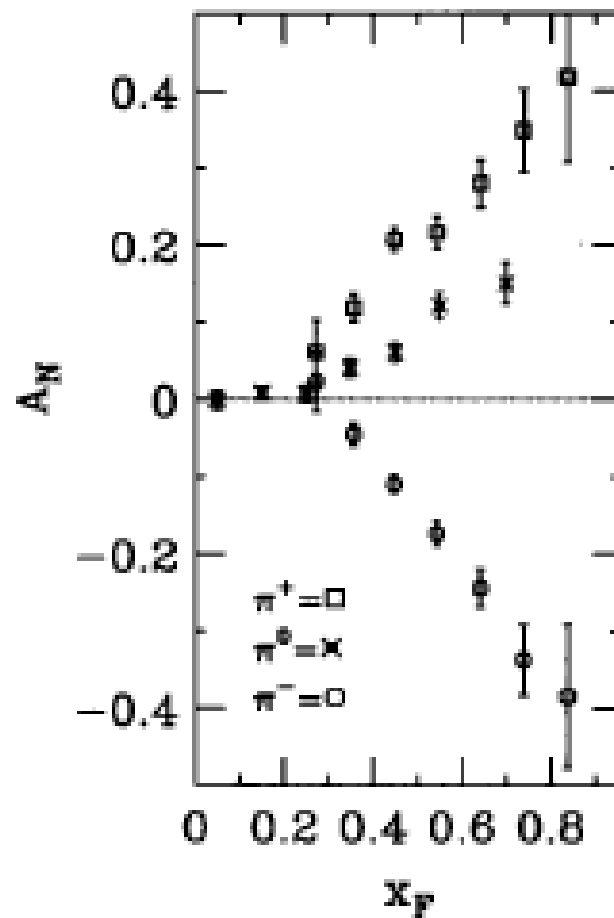
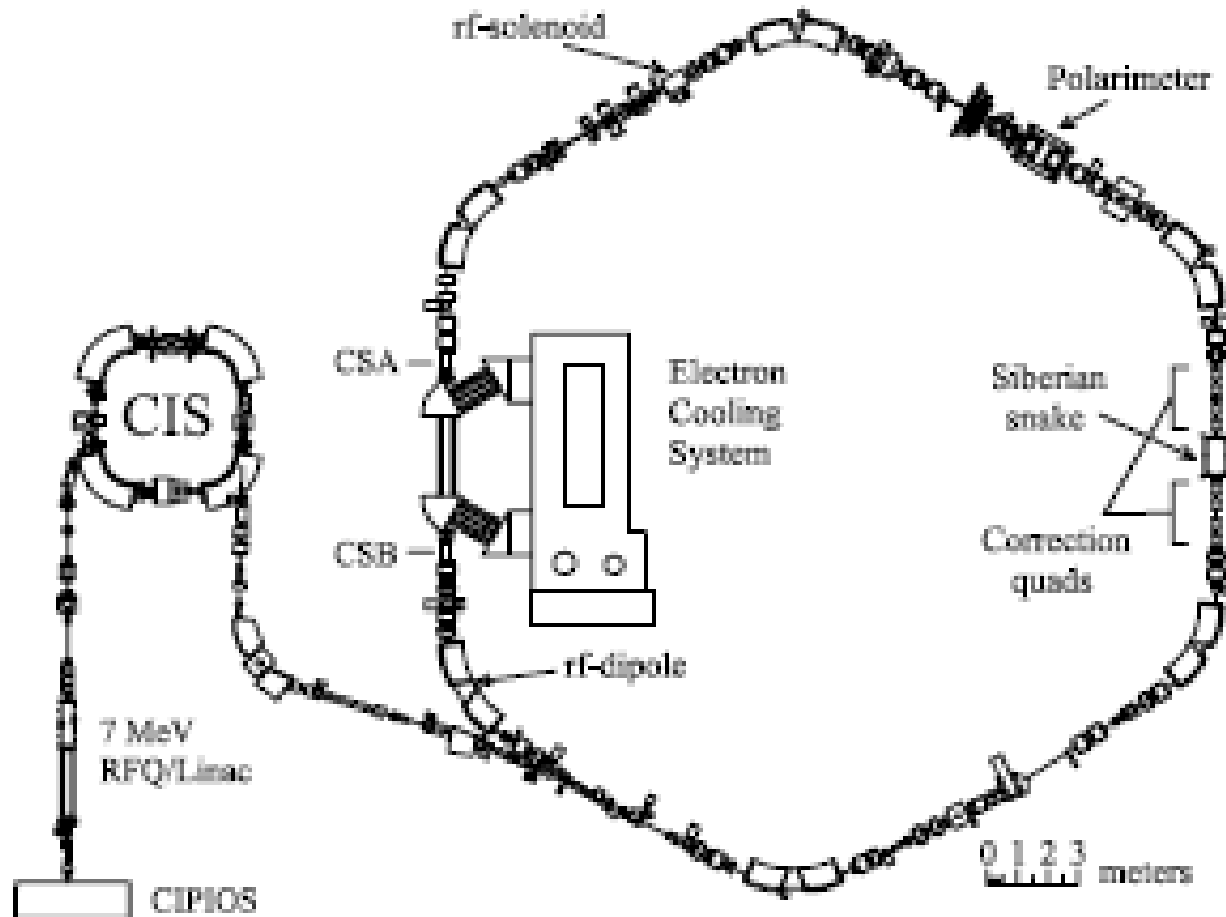


Fig. 4.  $A_N$  versus  $x_F$  for  $\pi^+$ ,  $\pi^-$  and  $\pi^0$  data.

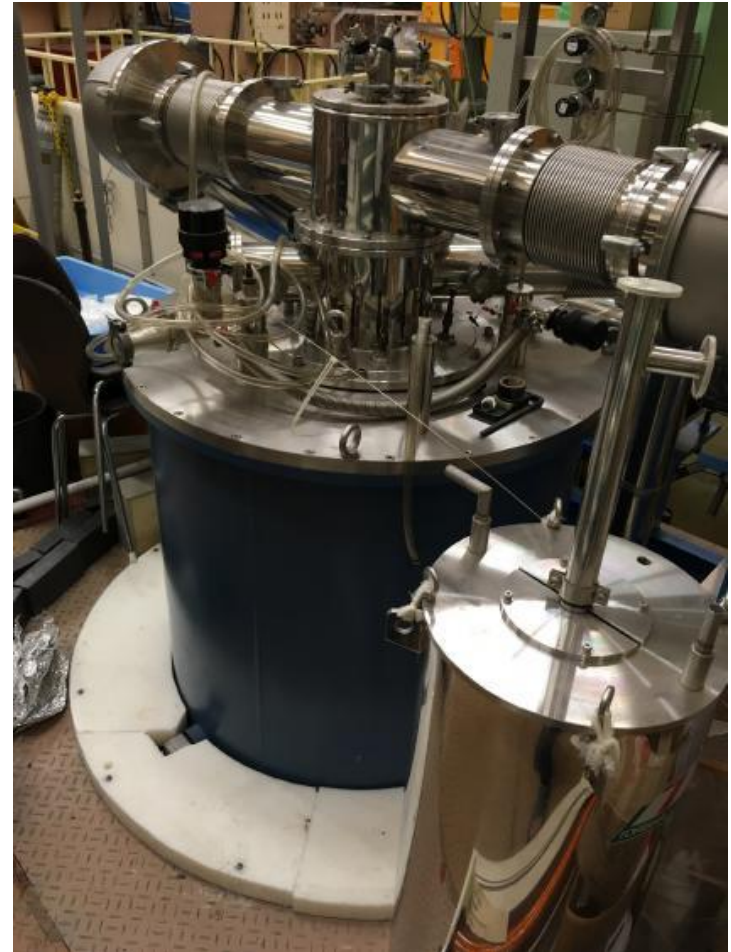
# IUCF cooler ring



- “Prof. Krisch was one of the founders of the spin culture not only in the sense of fundamental physics but in the accelerator physics as well. He was a great enthusiast of polarized beam experiments and a strong proponent, supporter and contributor to the **development of polarized beam acceleration and manipulation techniques**. Just to mention some of his work in this area, he attained the highest energy of a polarized proton beam without Siberian snakes, **demonstrated for the first time functioning of a Siberian snake**, was the first one to achieve high spin-flipping efficiency of polarized proton and deuteron beams. His scientific heritage includes a large array of researches from graduate students and postdoctoral fellows to senior scientists who continue studies in the polarized beam physics. I am lucky enough to be one of them. Prof. Krisch had always been a true experimenter. He only believed what he could measure and understand the physics of. He taught that to his students and this advice served them well. In modern times, as computer modeling plays an increasingly wider role, his advice always reminds one to look at the results critically, interpret the physics behind them, and compare them with experimental data. Prof. Krisch left a priceless scientific legacy to the entire polarized beam physics community.
- **/ V. Morozov, ORNL/.**
- 
- “Alan Krisch was a great man and good friend to many of his colleagues. He was a man of principles, and consistent ethics in his scientific life as well as in his collegial and human communications. His mind, while solidly independent, was always open for the recognition of the critical achievements of others.”
- **/ Y. Derbenev, Jefferson Lab/.**

Krisch 's polarized target system was moved to Japan, and is now used for T-violation measurement by polarized neutron and polarized La scattering.

(photo: from H.Shimizu)



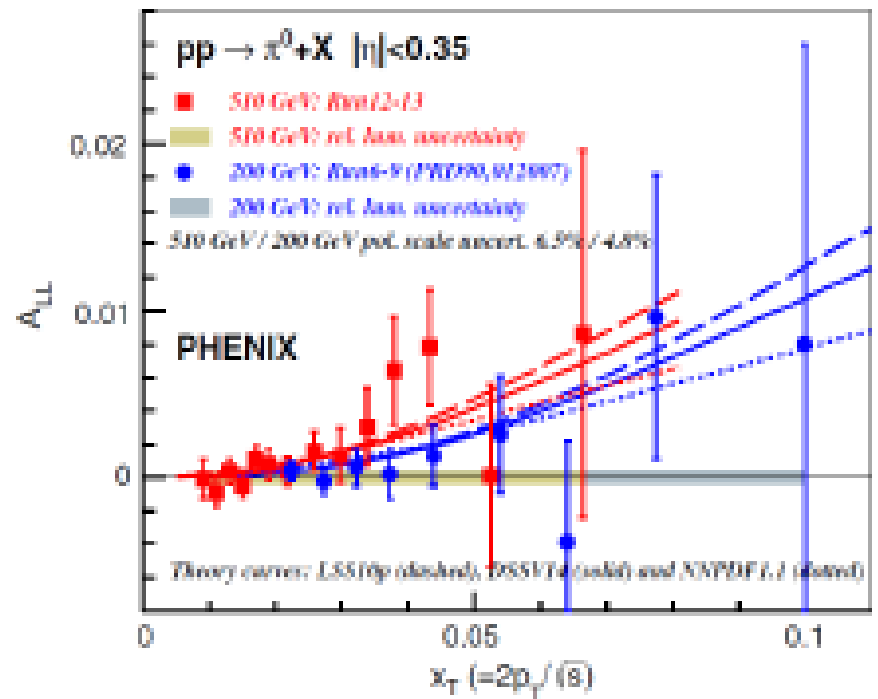
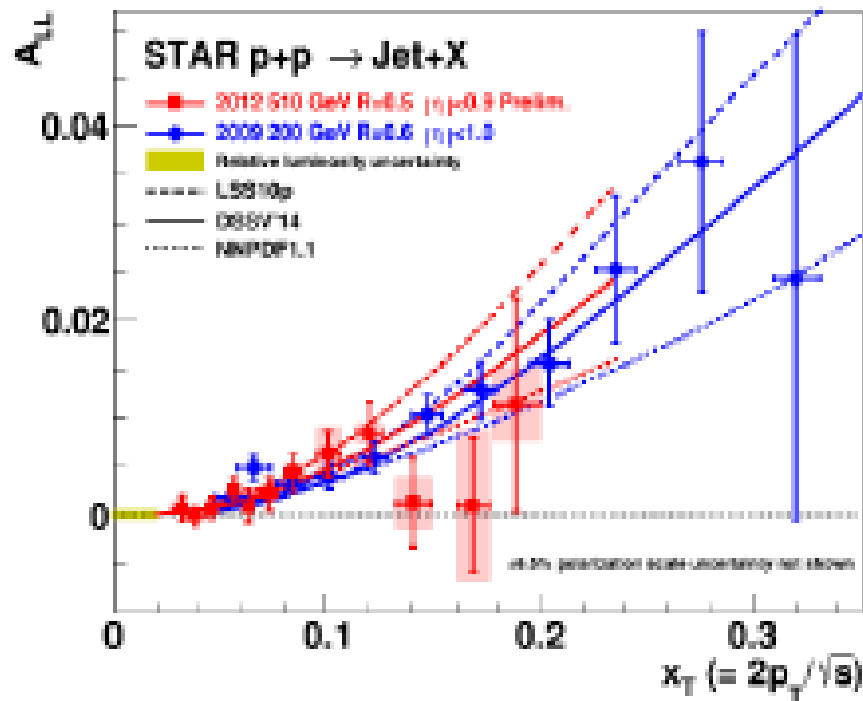


# RHIC SPIN

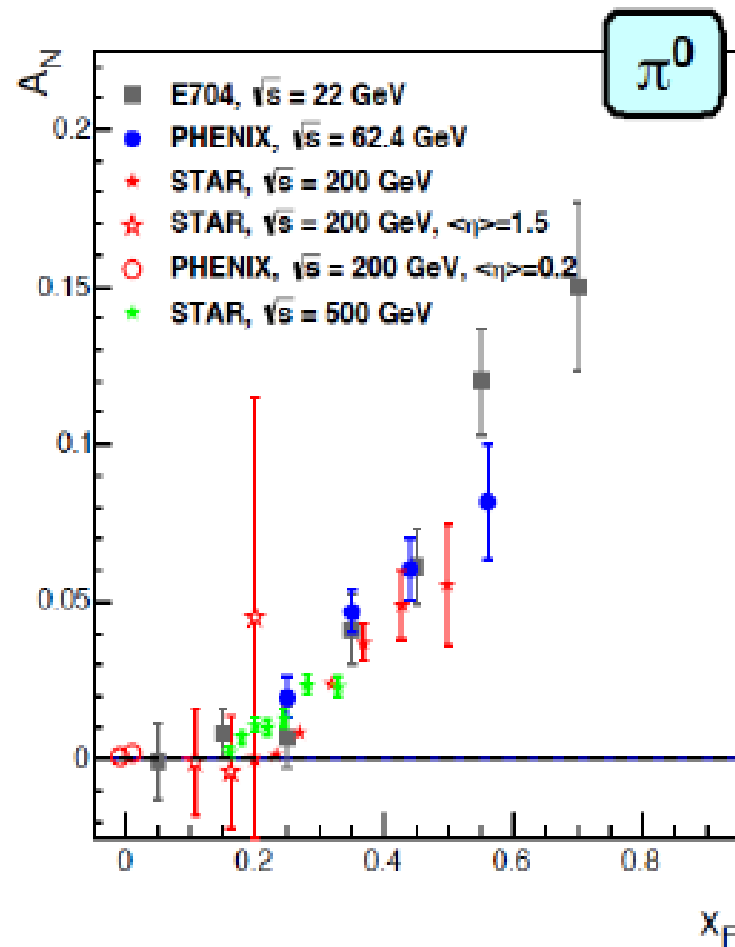
*Realized by*

- *As an extension of physics motivation of Fermilab E704 (A. Yokosawa)*
- *Accelerator technology development for polarized proton (snake) (A. Krisch)*
- *US-Japan collaboration through Riken (RBRC)  
(M. Ishihara)*

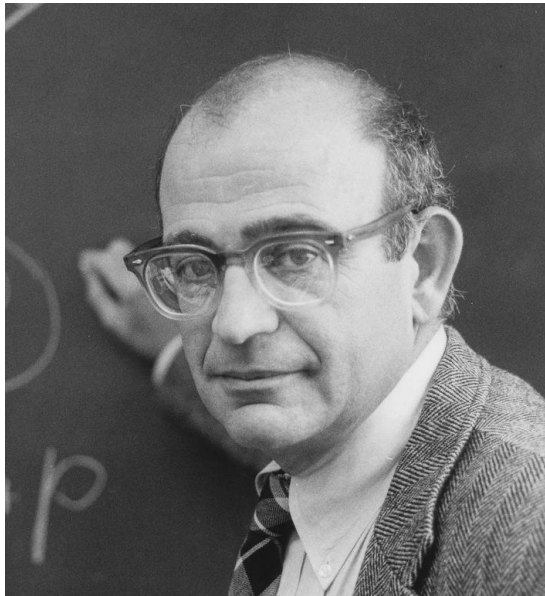
# Gluon spin at RHIC



# Transverse asymmetry



We like to thank their contributions to  
spin physics

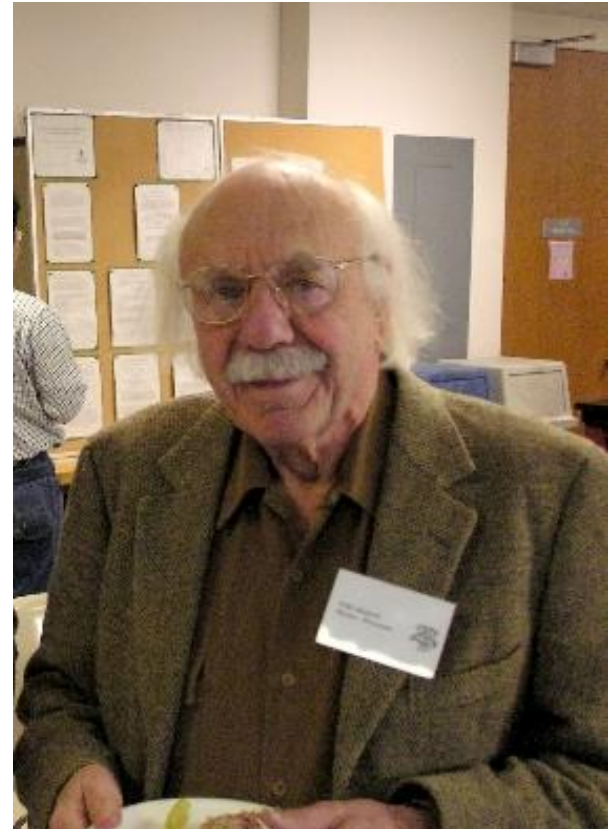


# Hal Spinka



*Passed away on 2020. 12/27 age 75*

# Willy Haeberli



*Passed away on 2021 10/5 age 96*