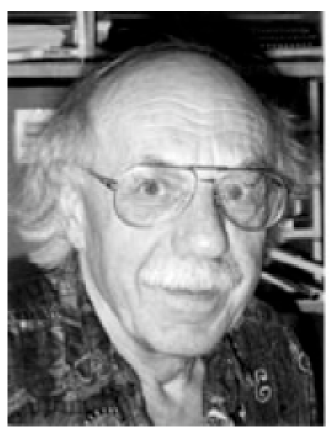
Polarization Experiments for a Rainy Day (or Decade)

Two Gedanken experiments teetering on the brink of feasibility …

- ***Testing pp parity violation at high energies via the helicity-dependence of a stored proton beam lifetime***
- ***Exploiting time-reversal invariance to study low-energy π^0-n scattering and isospin violation***

With thanks to Willy … ng me to the fun of thinking up “crazy”

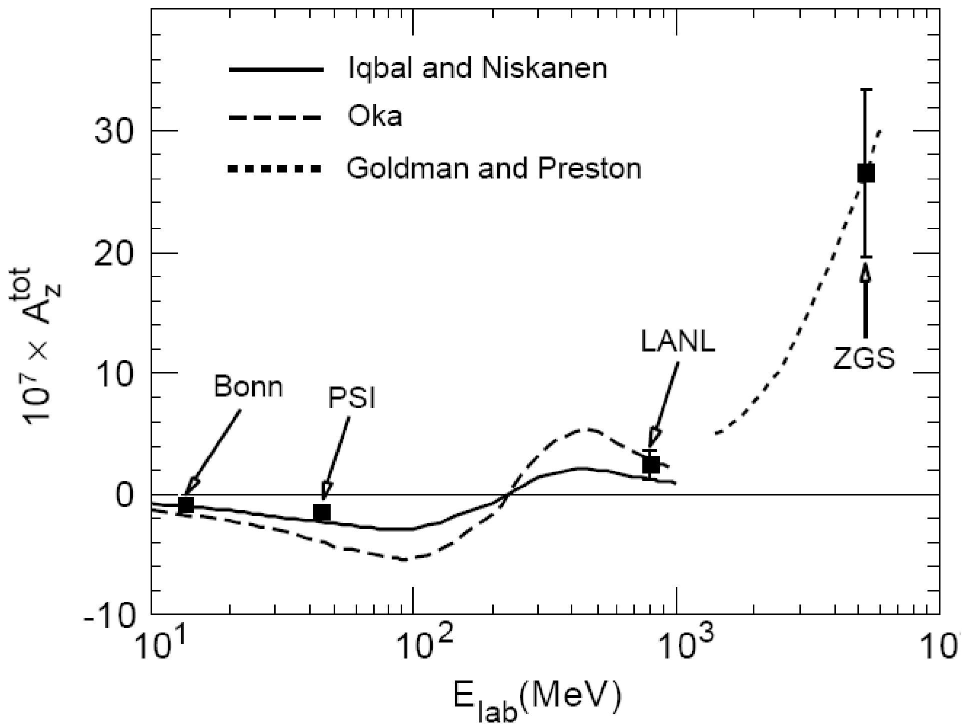


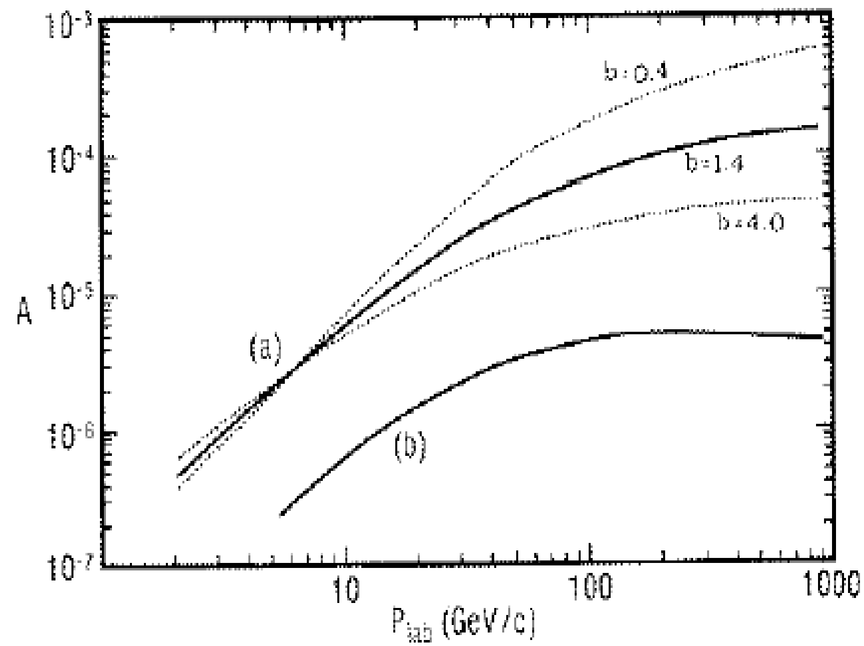
Happy Birthday, Willy!

S. Vigdor, WillyFest,
June 10, 2005

Is Parity Significantly Violated in High-Energy pp Scattering?

Measure, e.g., via dependence of total cross section on beam helicity



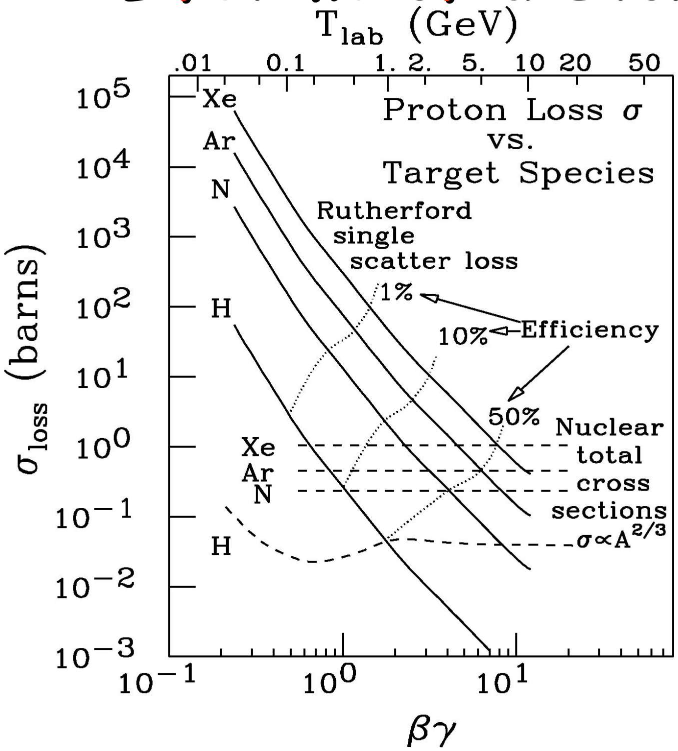


➢ *The ZGS anomaly: mistake or the start of something big?*

➢ *Goldman & Preston: weak interactions modify L-handed, but not R-handed, quark interactions (the two remain separated by QCD's chiral symmetry), leading to energy-dependent parity violation in pp.*

➢ *Normalizing to ZGS result, they predict effects ~ 10^{-4} at RHIC energies!*

The Concept: Measure the Helicity-Dependence of the Lifetime of a Stored Polarized High-Energy Beam



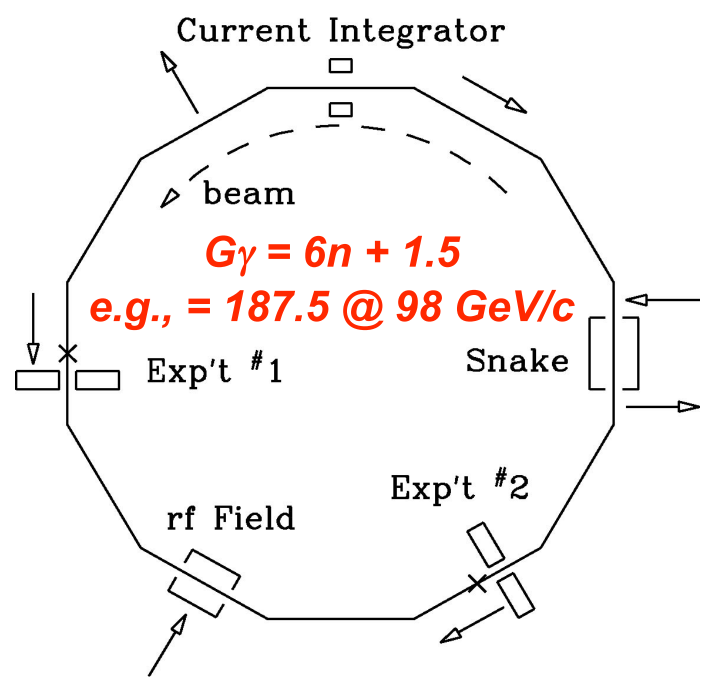
➢ At multi-GeV energy, stored beam lifetime can be dominated by nuclear interactions in a gaseous internal target of sufficient thickness

➢ E.g., target with ~10^{17} p/cm^2 should ⇒ τ ~ 3000 s at RHIC.

¬ Precise measurement of I(t) is then equivalent to folding traditional transmission measurement of σ_{tot} into a ring/spectrometer !

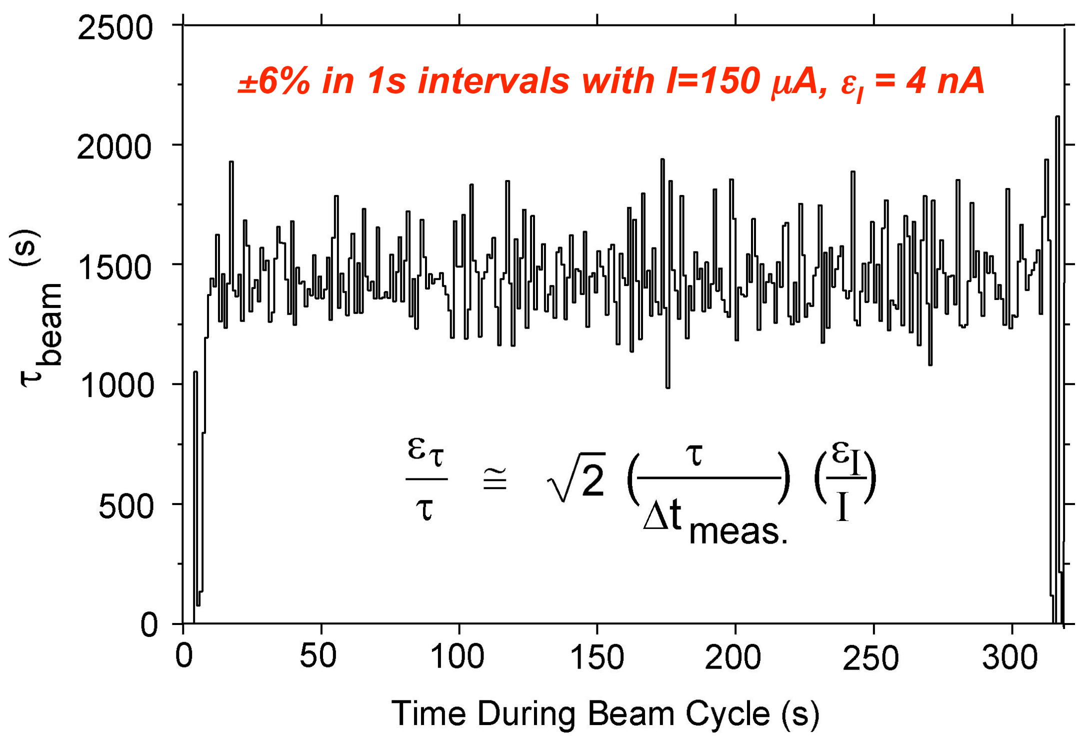
➢ Locate target opposite a single full Siberian Snake ⇒ only longitudinal spin component stable (transverse components flip on alternate passes, reducing syst. errors!)

¬ Inject beam with opposite spin direction for alternate bunches and/or flip stored beam spin periodically via rf techniques.



What Level of Uncertainty is Achievable?

- At IUCF Cooler, we improved resolution of beam current monitor over transformers magnetically coupled to beam by ~2 orders of magnitude, using rf-tuned electrostatic pickup AC-coupled to beam



- Comparable absolute resolution on beam current measurement at RHIC would dominate precision over counting statistics on lost particles for measurement times > 12 s, $\Rightarrow \varepsilon_\tau/\tau \sim 10^{-6}$ per fill

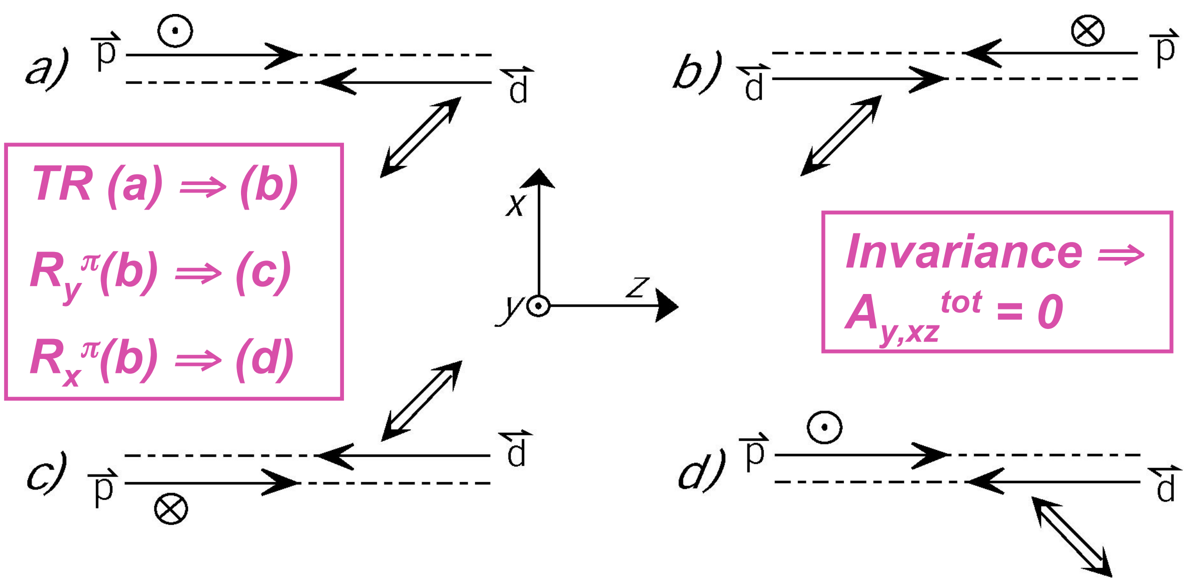
¬ Systematic uncertainties smaller than 10^{-6} seem achievable, but it's a whole new ballgame…

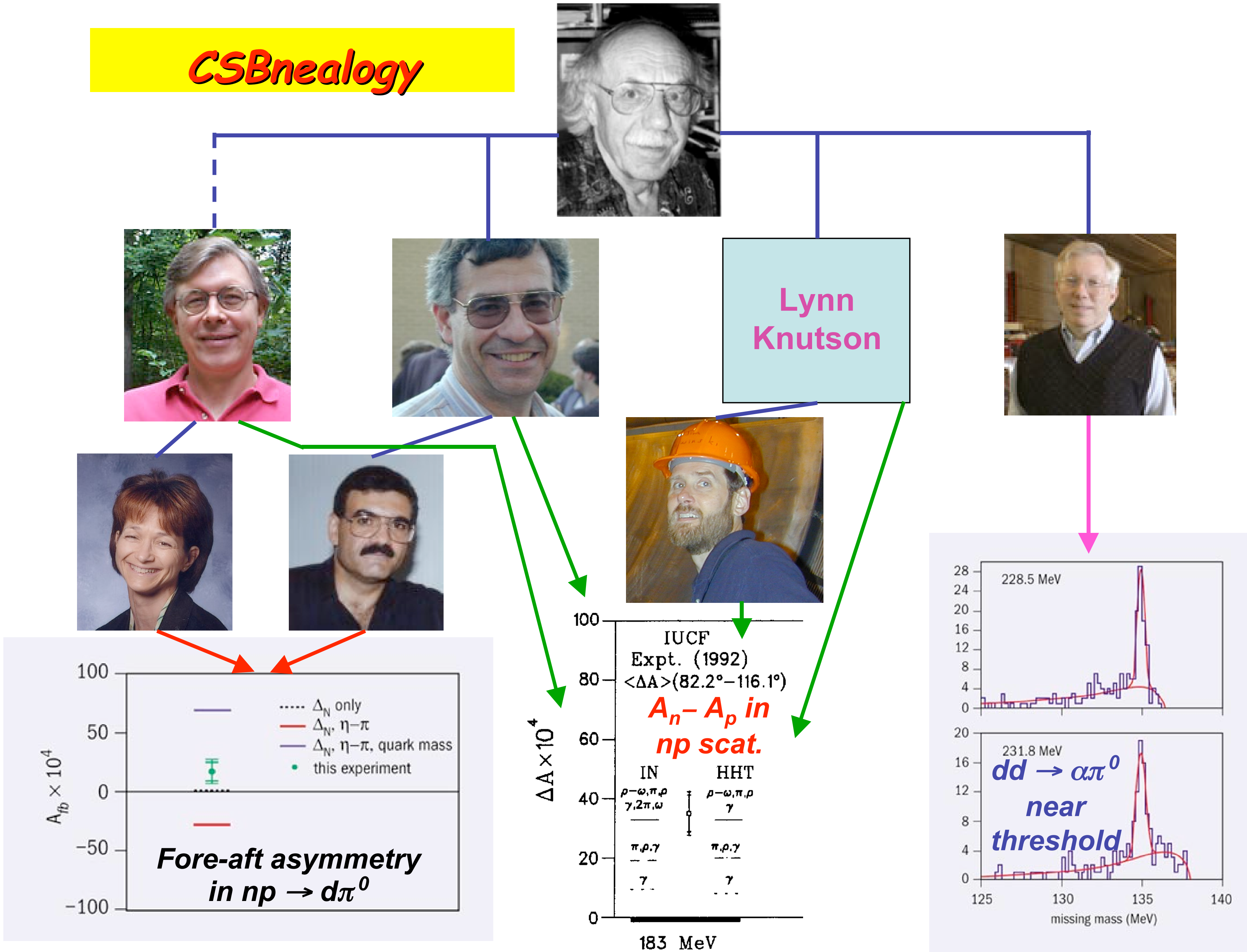
What Else Could One Measure by Same Technique?

Other interesting spin-dependent total cross section measurements require polarized target as well as beam. Then it may be harder to arrange for luminosities that dominate beam lifetime (over beam interactions with non-target material). If this can be achieved, one could measure:

- ***$\Delta\sigma_L$, $\Delta\sigma_T$ for pp scattering***

♣parity-even, time-reversal-odd forbidden spin-dependence in pd scattering





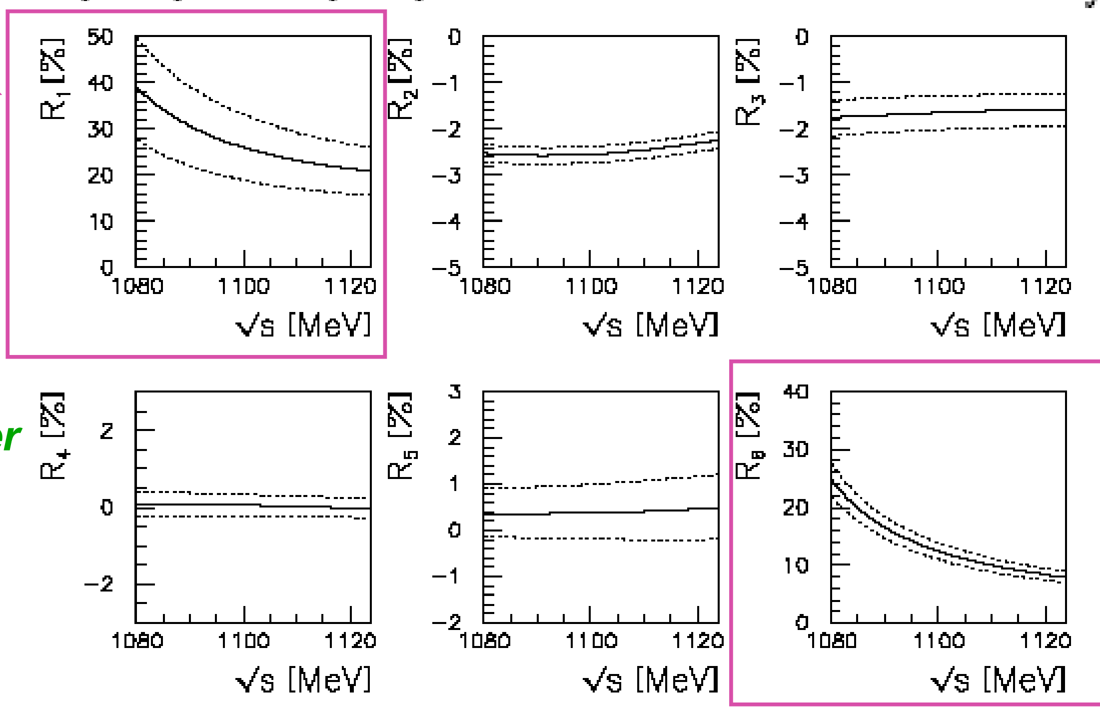
CSBnealogy
Lynn Knutson
100
50
0
−50
−100
$A_{fb} \times 10^4$
Δ_N only
Δ_N, η−π
Δ_N, η−π, quark mass
this experiment
Fore-aft asymmetry in $np \to d\pi^0$
100
80
60
40
20
0
$\Delta A \times 10^4$
IUCF
Expt. (1992)
<ΔA>(82.2°−116.1°)
$A_n - A_p$ in np scat.
IN
HHT
ρ−ω,π,ρ
γ,2π,ω
π,ρ,γ
γ
ρ−ω,π,ρ
γ
π,ρ,γ
γ
183 MeV
228.5 MeV
28
24
20
16
12
8
4
0
231.8 MeV
20
16
12
8
4
0
$dd \to \alpha\pi^0$
near threshold
125
130
135
140
missing mass (MeV)

Looking Through the Wrong End of the Telescope?

- Non-em sources of CSB arise from u-d quark mass difference
- Latest lattice QCD/chiral extrapolation results ⇒ $m_u \cong 1.7$ MeV, $m_d \cong 3.9$ MeV ⇒ $\varepsilon \equiv (m_d - m_u)/(m_d + m_u) \cong 0.4$ at the current quark level
- Denominator, but not numerator, greatly increased by dynamical chiral symmetry breaking (constituent quarks)
- Weinberg; van Kolck; Fettes & Meissner ⇒ can see effect at ~ε level by comparing low-energy π^0-n and π^0-p scattering. Thanks!

$$R_1 = 2\,\frac{f_{\pi^+p\to\pi^+p} + f_{\pi^-p\to\pi^-p} - 2\,f_{\pi^0p\to\pi^0p}}{f_{\pi^+p\to\pi^+p} + f_{\pi^-p\to\pi^-p} + 2\,f_{\pi^0p\to\pi^0p}}$$

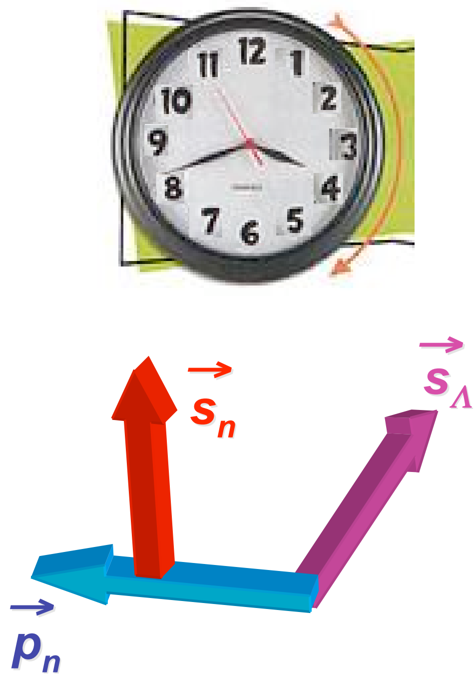
$$R_6 = 2\,\frac{f_{\pi^0p\to\pi^0p} - f_{\pi^0n\to\pi^0n}}{f_{\pi^0p\to\pi^0p} + f_{\pi^0n\to\pi^0n}}$$

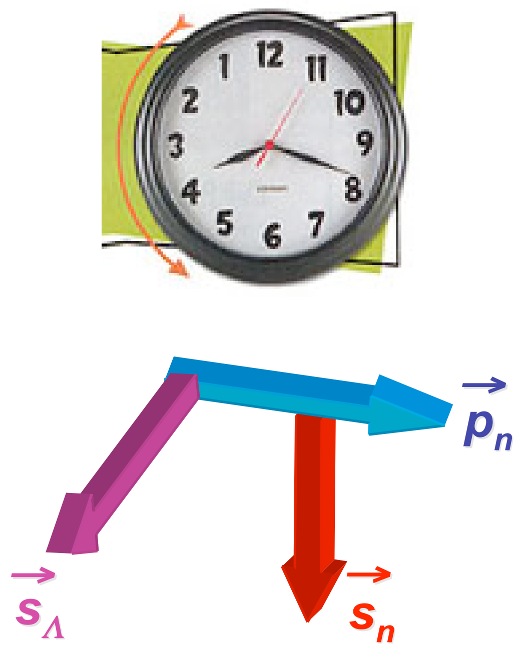


Fettes & Meissner (2000) calcs. of isospin-violating πN ratios

How to Measure π^0-n Scattering?

➢ *Must rely on final-state interactions (FSI) to study $\pi^0 N$ – how do we make sure FSI of interest dominates observables?*





$\vec{s}_n \bullet (\vec{s}_\Lambda \times \vec{p}_n) > 0$ $\quad$ $\vec{s}_n \bullet (\vec{s}_\Lambda \times \vec{p}_n) < 0$

Best existing (1972) measurement of P_y^p/P_z^Λ for $\pi^- p$ is -0.094 ± 0.060.

➢ *For $\pi^0 p$ use $\gamma\, p \to \pi^0 p$ below the opening of the threshold for the dominant $\pi^+ n$ channel.*

¬ *A "crazy" idea for $\pi^0 n$: look at time-reversal-odd triple-spin correlation in the weak decay of a polarized Λ:*

$$\vec{\Lambda} \to \pi^0 \vec{n}$$

e.g., for Λ spin in z-direction and neutron emission in x-direction in Λ rest frame, measure P_y^n.

¬ *Assuming time-reversal-invariance, effect arises purely from s- and p-wave πN strong FSI phase shifts @ 37.2 MeV:*

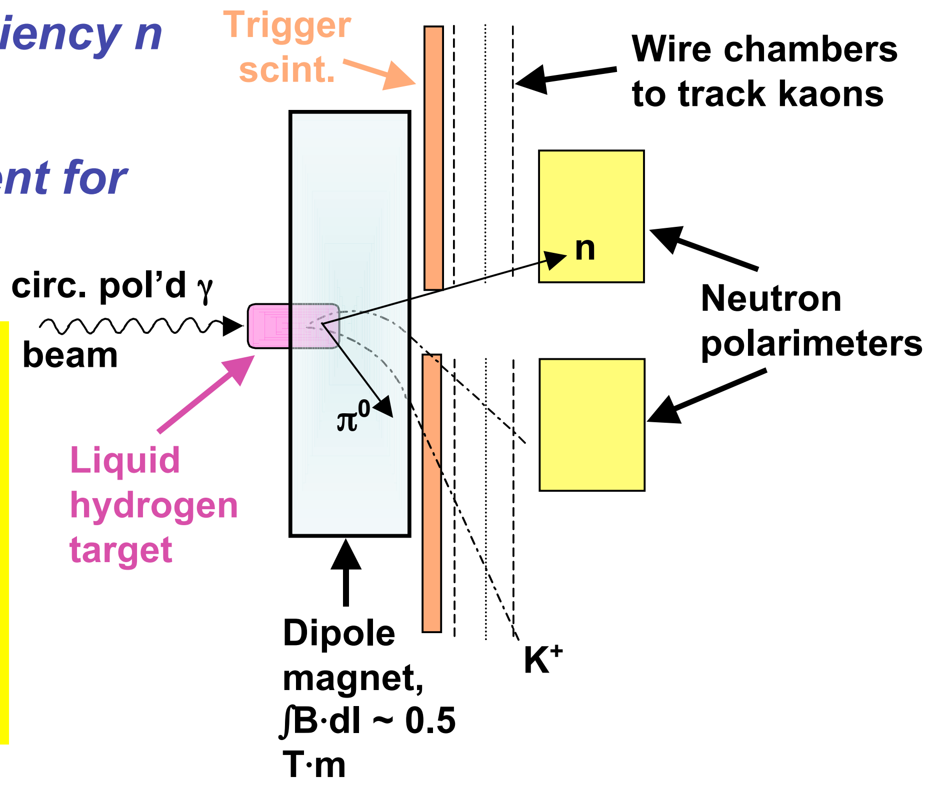
$$P_y^n/P_z^\Lambda = -\alpha \tan(\delta_s - \delta_p)$$

α = normal Λ decay asym. = 0.642

Tagging Λ's of Known Direction and Polarization:

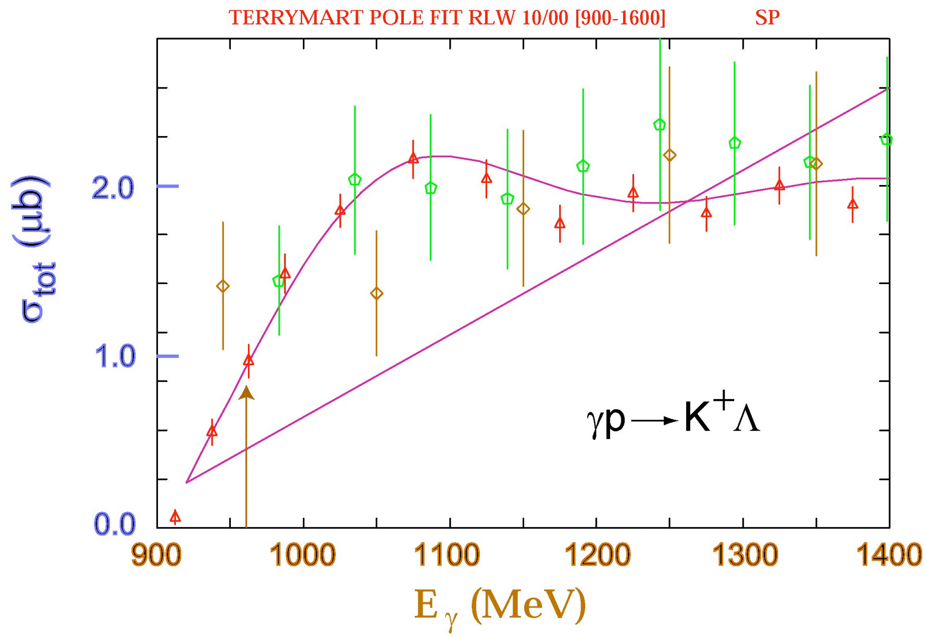
Wish List:

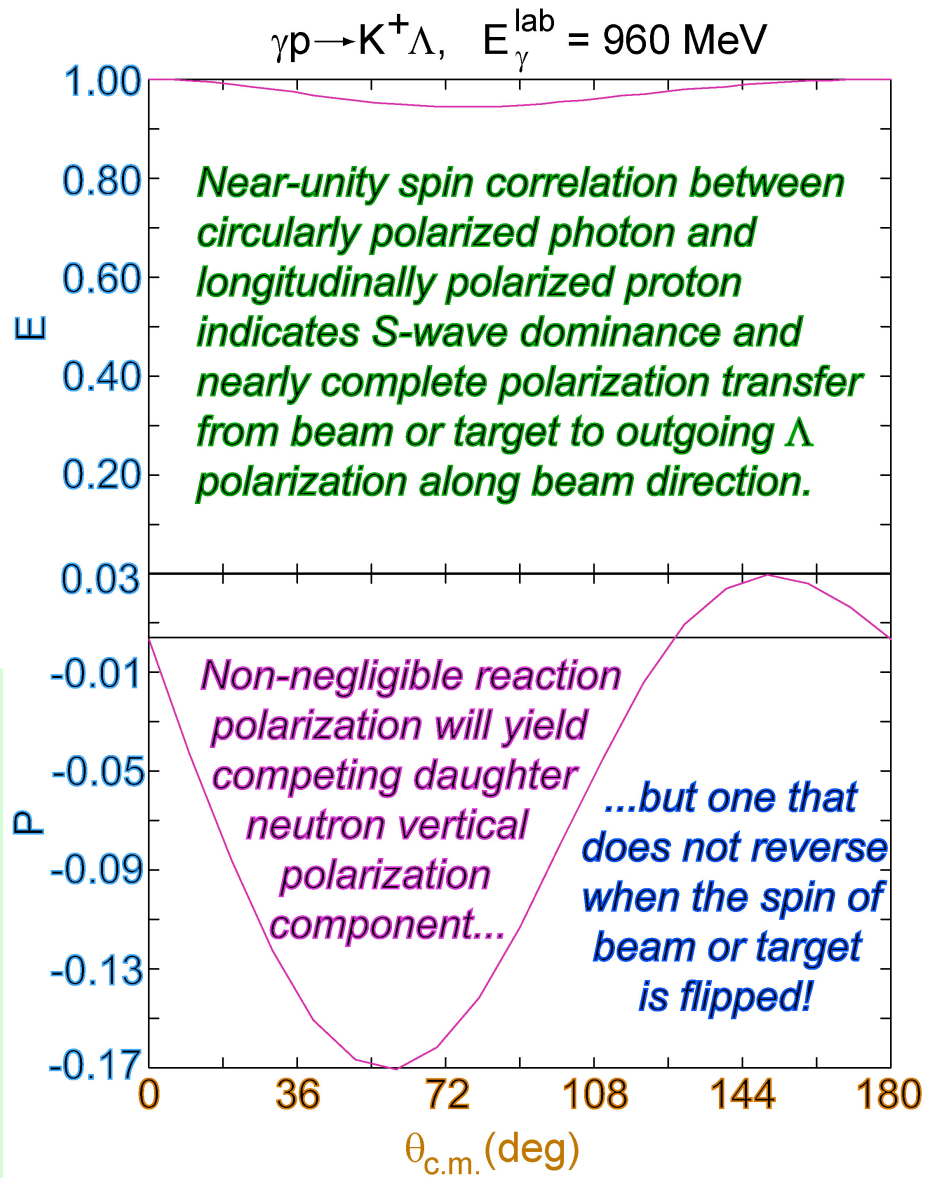
1) ***2-body reaction with charged tag for Λ, so don't need to reconstruct from neutral particle decay***
2) ***Large polarization transfer from beam or target to Λ for experimental control of polarization direction***
3) ***Hopefully known Λ polarization to avoid having to measure it from decay asym.***
4) ***Sizable production rate, high efficiency n polarimeters***
5) ***Capability to do same measurement for π^-p channel simultaneously***



Consider: ***$\gamma + p \rightarrow K^+ + \Lambda$ with real photon beam. At 0°, 180° ($m_{L,z} = 0$), z (beam)-projections of γ and p spins must be opposite. Pol'n transfer from beam or target to Λ is then 100%. True at other angles to extent that s-wave prod'n dominates.***

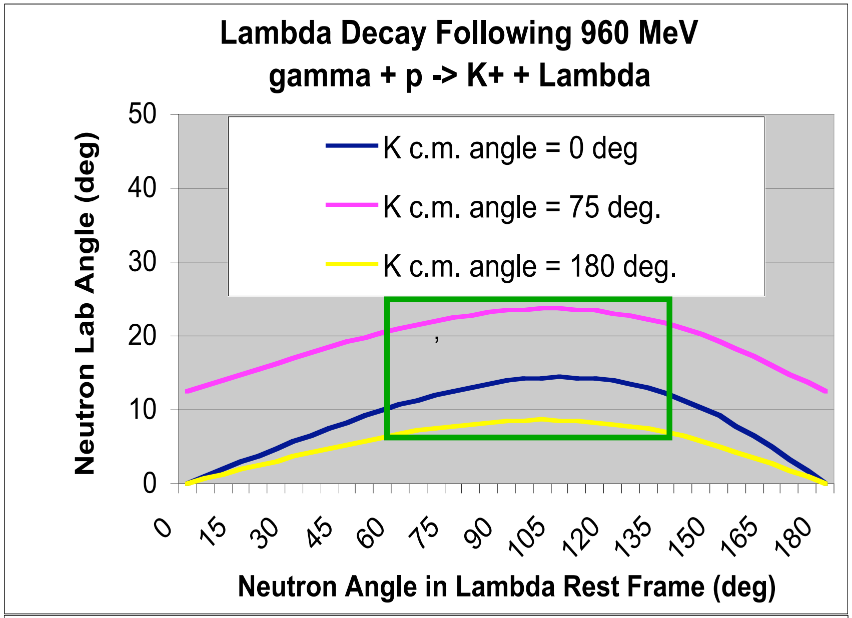
Exploiting the Nice Features of PhotoProduction Near the KΛ Threshold

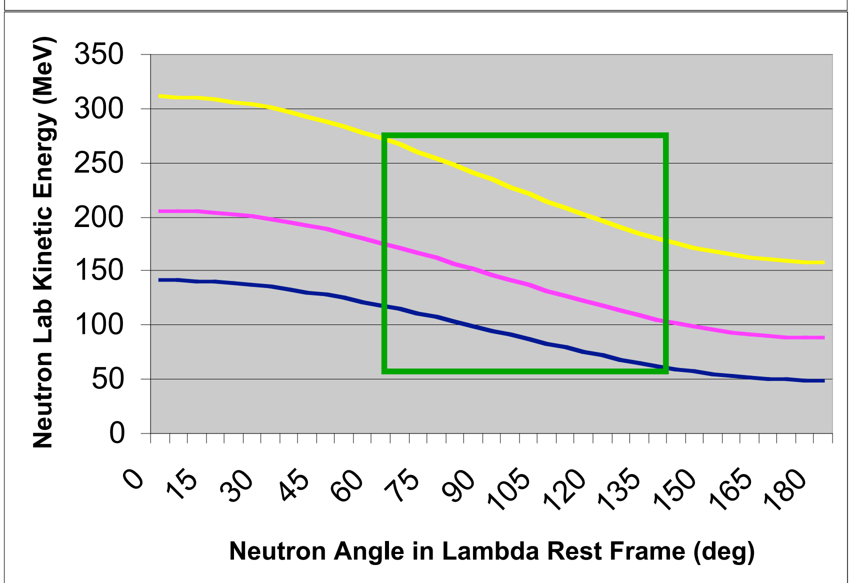




- ➢ ***Dominance of S_{11} N*(1650) resonance ⇒ rapid rise of σ above threshold + nearly complete transfer of polarization from $\vec{\gamma}$ beam or $\vec{p}$ target to $\vec{\Lambda}$***
- ¬ ***Near-threshold kinematics ⇒ relatively narrow Λ energy and angle ranges in the lab:*** ***E_γ^{lab}=960 MeV ⇒ T_Λ^{lab} from 106 to 270 MeV, $\theta_\Lambda^{lab} \leq 12.4°$, $\theta_K^{lab} \leq 28°$***

Kinematics Permits Efficient Coverage of Λ Decay Phase Space

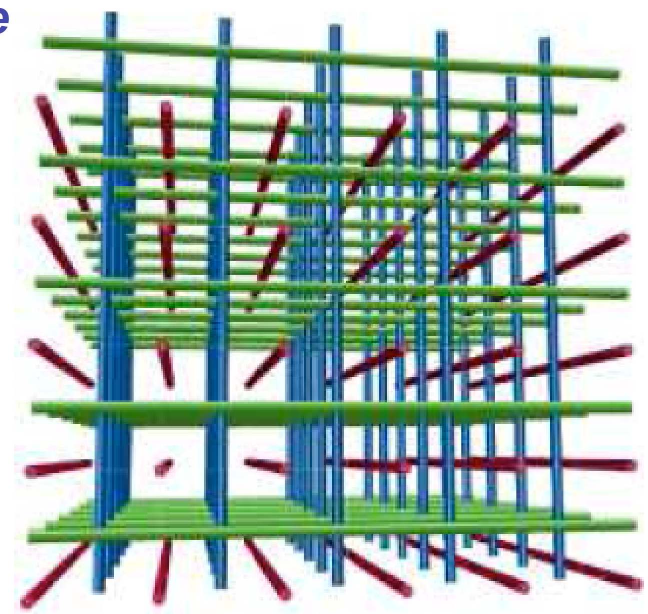




- ***A polarimeter covering ~15° in the lab would accept a large fraction of daughter neutrons from all produced Λ's***

¬ ***The neutron energy range (~100—250 MeV) is one for which we know how to make efficient polarimeters***

¬ ***Could "scibath" technology (3D fiber grid embedded in liquid scint.) proposed by Hans-Otto Meyer and Rex Tayloe for ν tracking be adapted to improve the state of the art in n polarimetry?***



Here's the Rub…

Need ~10^9 circularly polarized photons/s @ 1 GeV [TUNL HIγS phase n?] on ~10^{24} p/cm^2 target for ~10^3 Λ/s !

But that's not the rub – that just means it's for a rainy decade in the future…

Time reversal violation provides an inseparable background !

I've had less interesting backgrounds…

Λ weak decay subject to ΔI = _ rule ⇒ don't get 'free' isoscalar $[\sqrt{2/3}\, f^{I=3/2} + \sqrt{1/3}\, f^{I=1/2}]$ π^0-n scattering, but I = _ dominated scattering. Unfortunately, the large predicted CSB arises from chiral suppression of the isoscalar scattering amplitude sum in the denominator (i.e., from cancellation between I = 3/2 and I = _ amplitudes). If truly I = _ and isospin conserved (we know it's not), then π^-p and π^0n channels should give identical triple-spin coefficients. But unclear how large the violation might be.

That's the rub! Time for a beer!