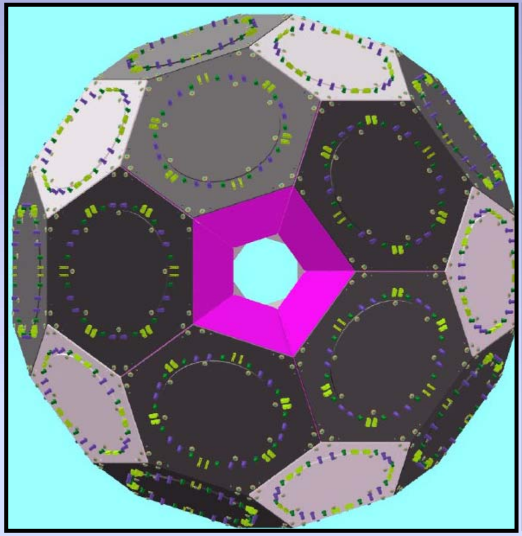
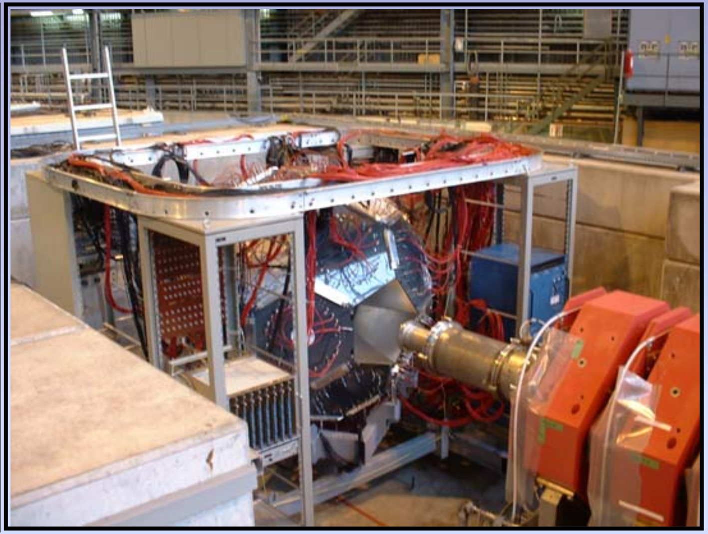
# Progress Report from the $\mu$*Lan* Experiment

**David Hertzog***
***University of Illinois at Urbana-Champaign***





**Fall 2003: Experiment installed in $\pi$E3 beamline**

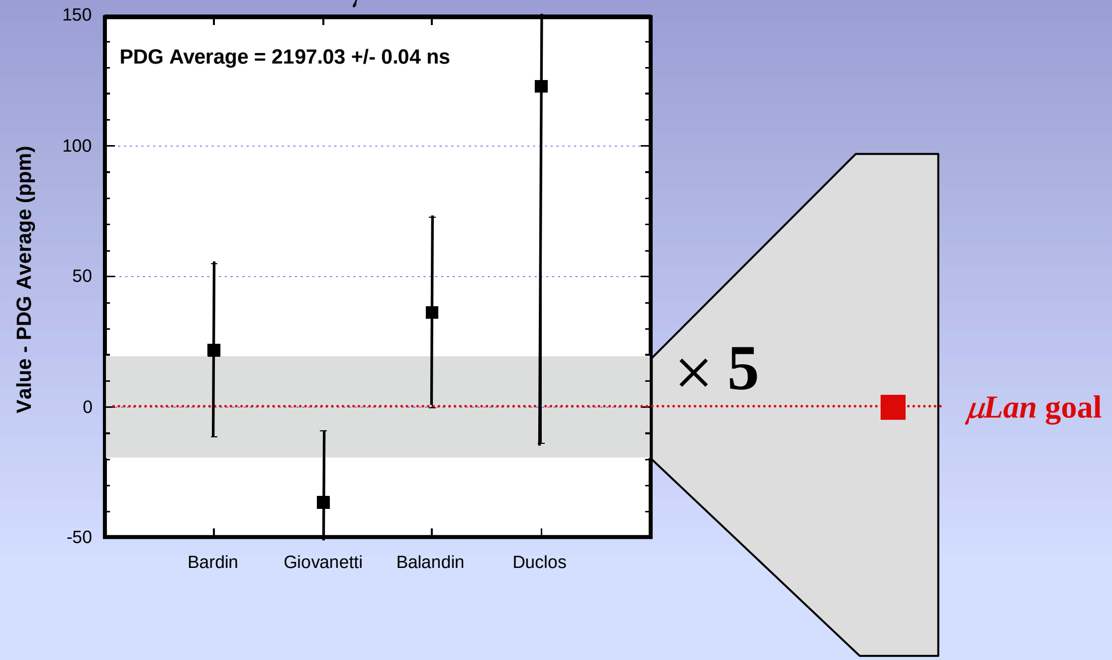
**PSI Experiment R-99-07.1** ***approved 7/99 U.S. NSF funding 7/00***

***** ***Representing the $\mu$Lan Collaboration*: Berkeley, Boston, Illinois, James Madison, Kentucky**

# Outline

- Physics goal:  unchanged since proposal
  - Factor 20 improvement in $G_F$
- Measurement concept: unchanged since proposal
  - Minor hardware “substitutions”
- Special developments
  - Beamline
  - Kicker
  - Detector
  - WFD
  - DAQ
  - Target region
- Analysis of fall 2003 lifetime data
- Issues related to schedule and beam-time request

# Present $\frac{\delta\tau_{\mu^+}}{\tau_{\mu^+}}$ is 18 ppm




$\tau_\mu \rightarrow G_F$ extraction no longer limited by theory

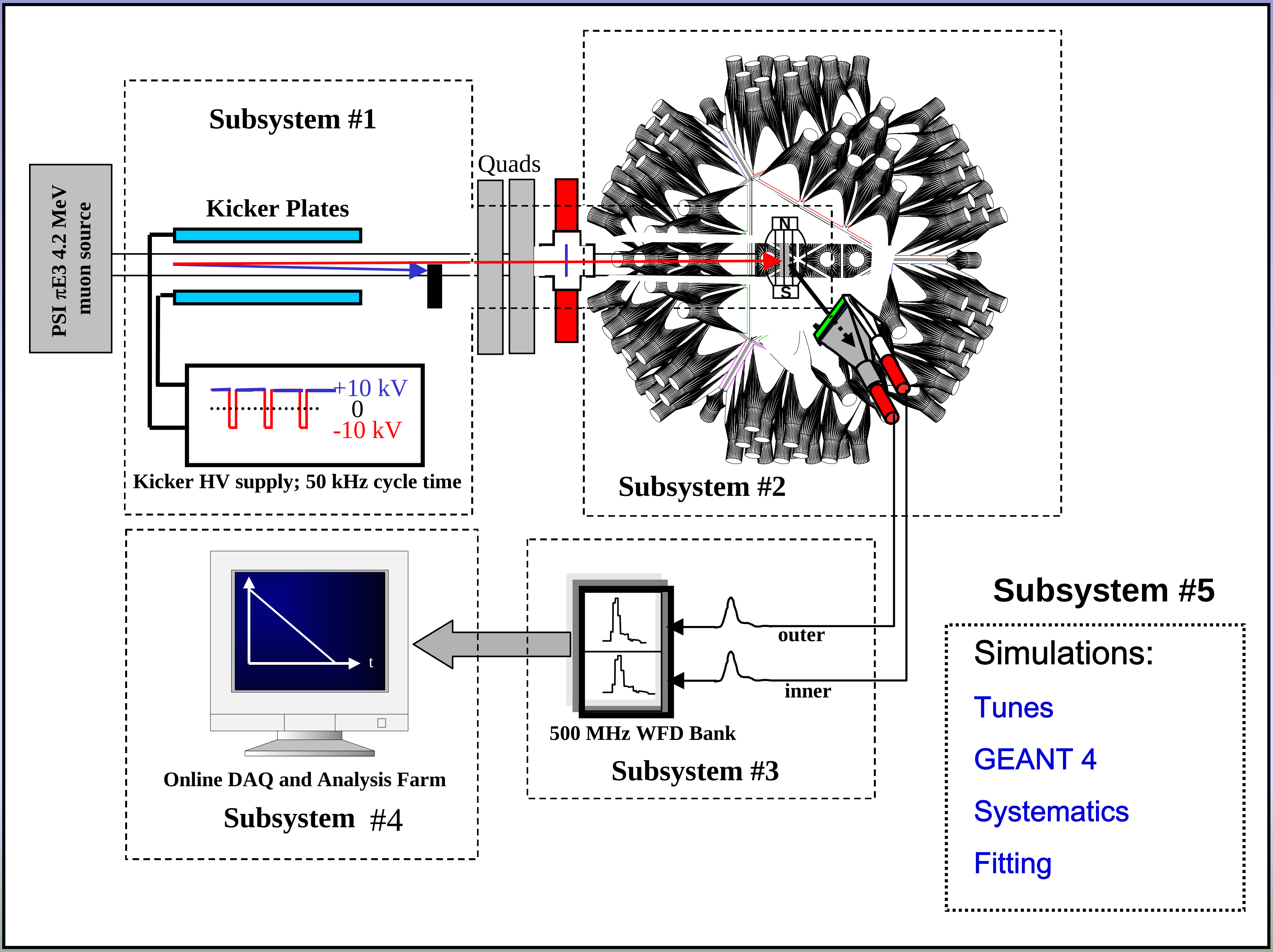
$$\frac{1}{\tau} = \frac{G_F^2 m_\mu^5}{192\pi^3}(1+\delta)$$

**QED radiative**

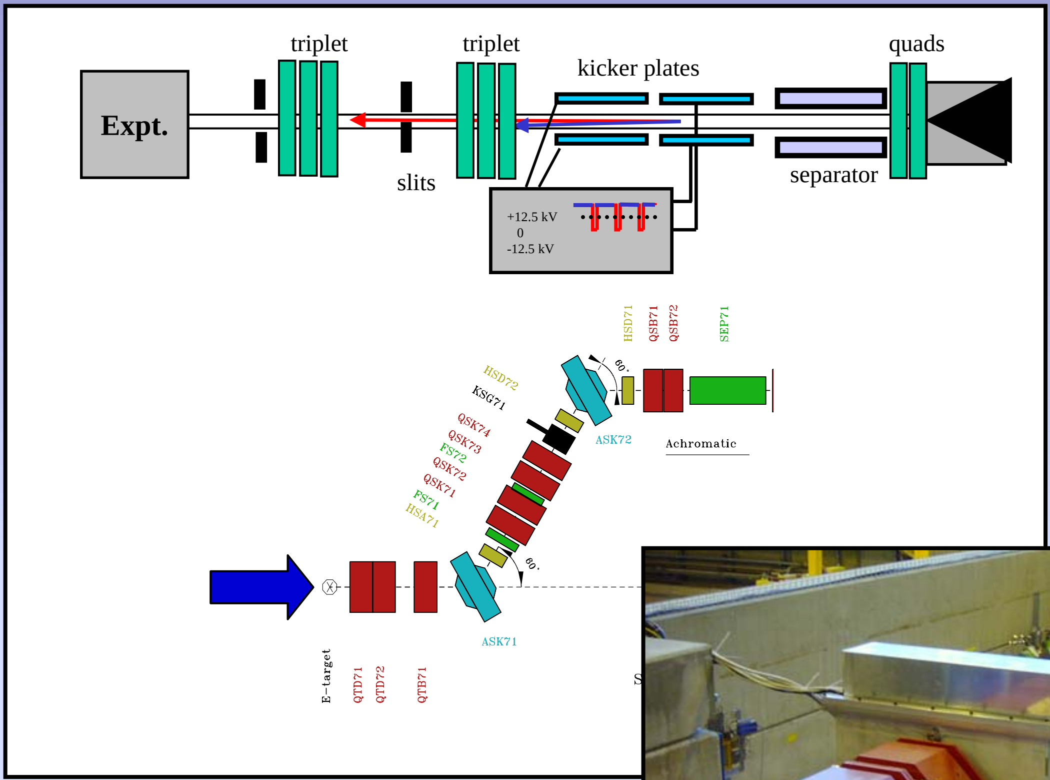
# Project Summary

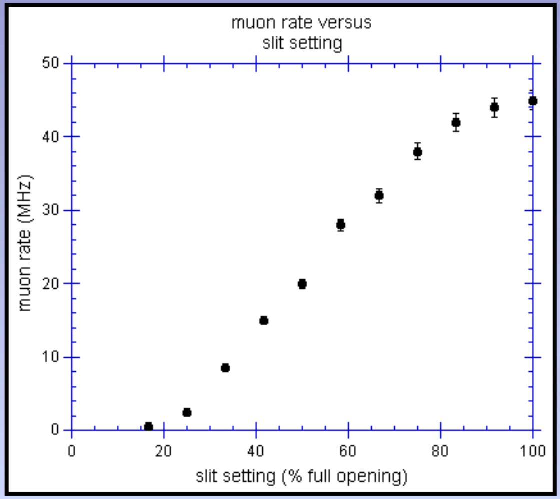
- Determine $\tau_{\mu^+}$ to 1 ppm to measure $G_F$
- Requires
  - > $10^{12}$ good events:
    - Affects DAQ, run time, storage, analysis considerations
- Tasks
  - Pulsed low-energy muon source:
    - Tune developed
    - Kicker built, but not yet "rf tight"
  - Symmetric, segmented timing detector:
    - Completed and working, fall 2003
  - Stopping (depolarizing) target
    - Sulfur works; AK-3 promising; magnet built
    - Final beam transport system and wire chamber, fall 2004
  - Custom Electronics:
    - WFD Prototype built, production behind schedule
    - Clocks, Flight Simulators, VME crates, ready
  - DAQ / Analyzer farm "online"
    - MiniMuLan developed
    - Final system with multi-Terabyte storage fall 2004
  - Systematic studies:
    - Pileup, gain, spin; errant and sneaky muons, rates

# Our “subsystems”



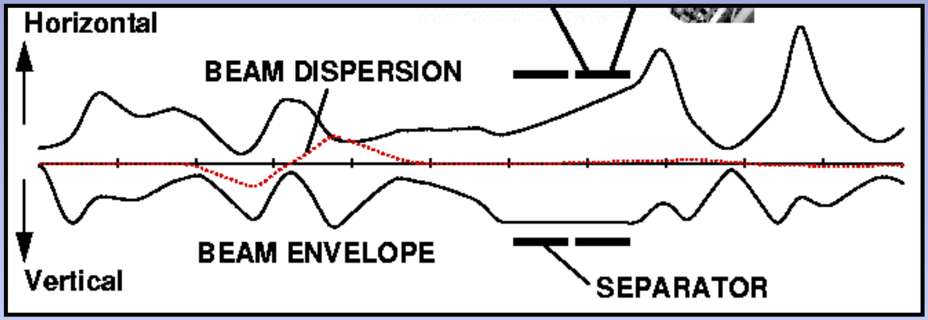
# Beamline for $\mu Lan$



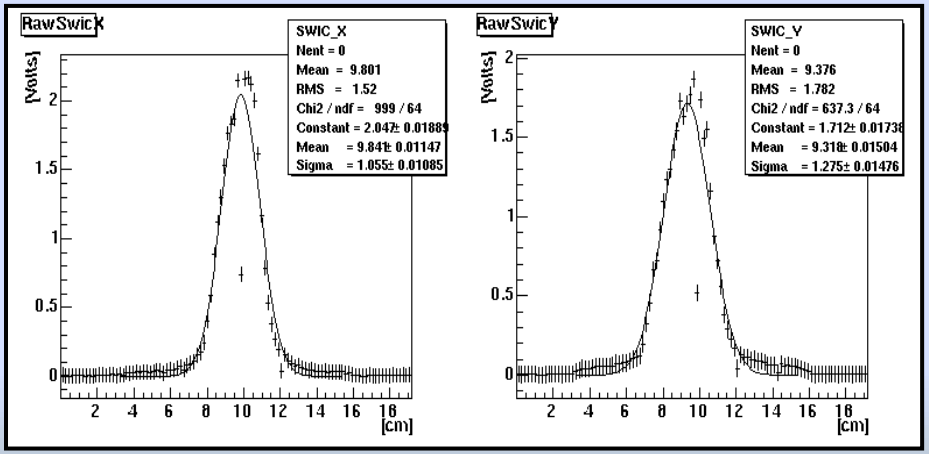




# Beam at experiment

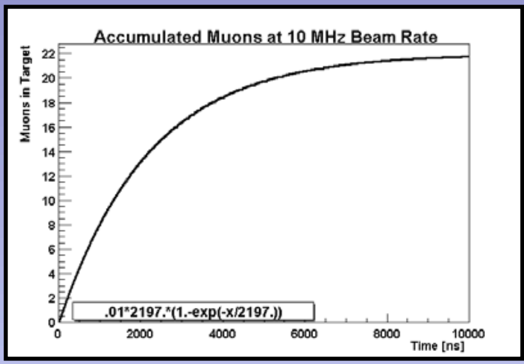
- Key is parallel beam through separator and kicker (about 2.5 m)

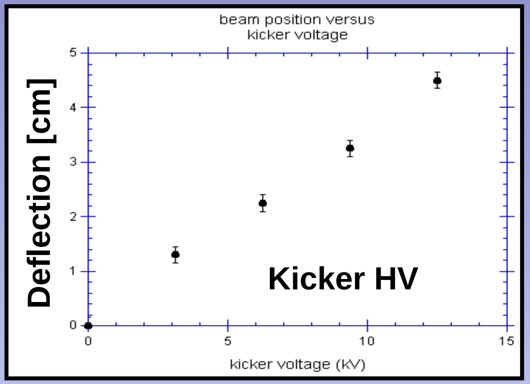


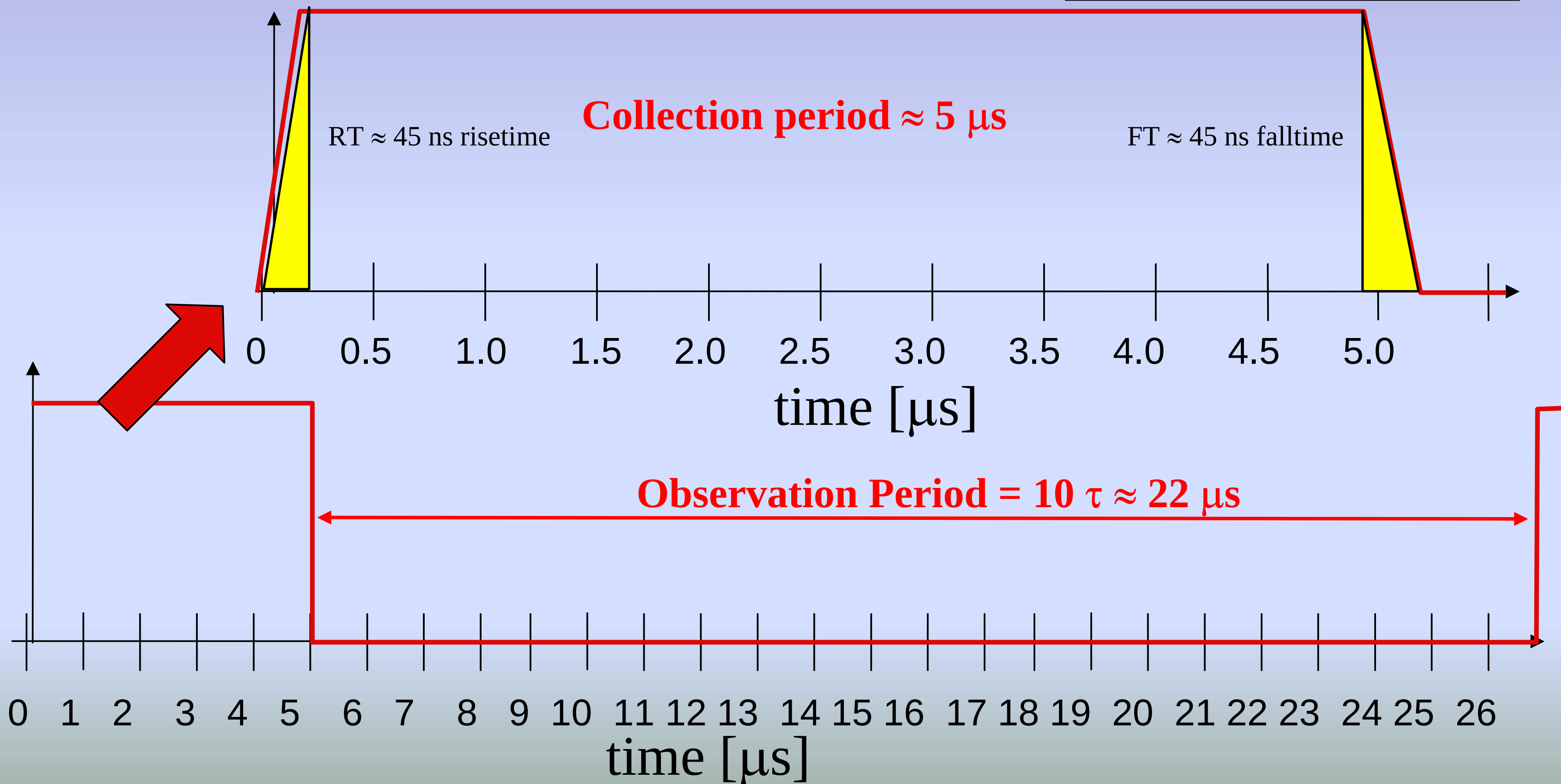

- Rate is > 12 MHz
- Spot at target, few cm$^2$
- Final transport to target dominated by scattering
  - Doubles spot size
  - Ideas to transport in vacuum



# Kicker Timeline



# Realization of Kicker

- **TRIUMF-built** kicker meets electrical specs of +25 kV swing on two sets of 0.75 m long plates

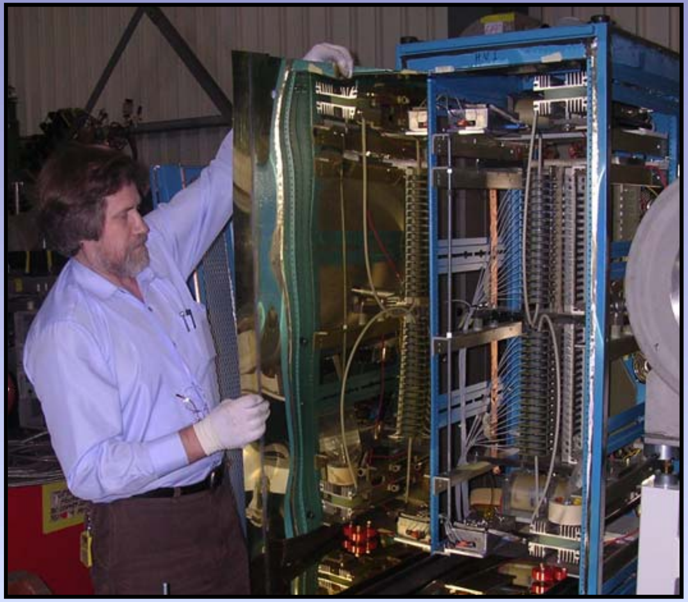
- **Mock-up** in summer 2002 shows this has excellent extinction

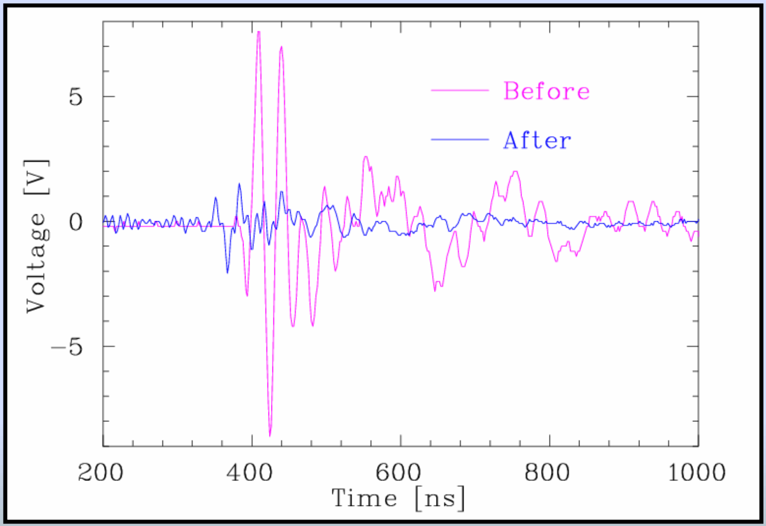
- **Static tests** in summer 2003 with real kicker give good extinction, > 300 integrated, before HV failure

- **Bad news:** radiates though air and ground at unacceptable levels for us and for our neighbors

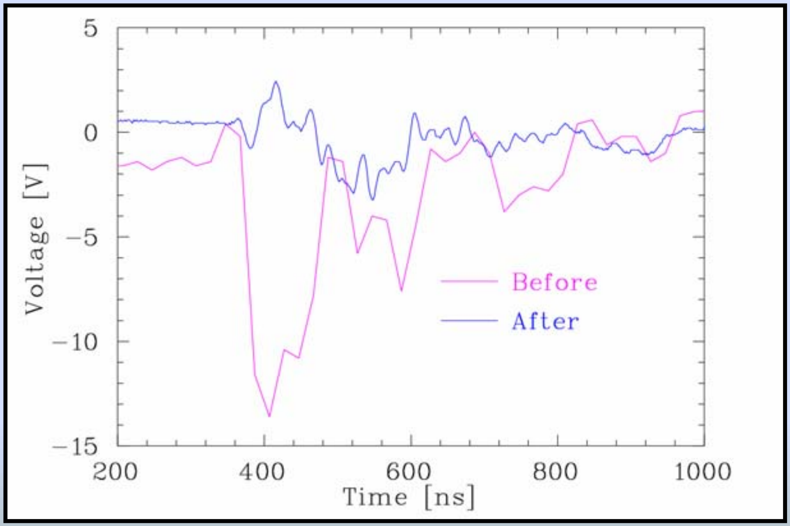
# We have made a series of (mostly successful) steps to reduce the noise

- Fixed – reroute internal grounds
- Blah blah
- Tested an internal Faraday cage:





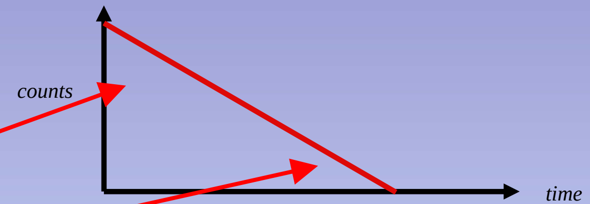

In the air: antenna measurement



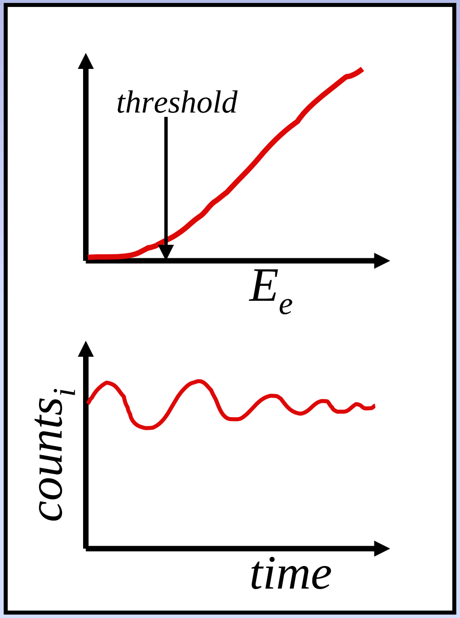

In the ground: loop measurement

# Systematic Error Reminders

- What can go wrong?



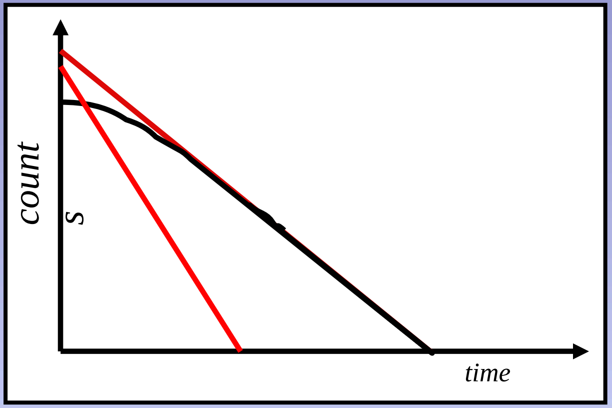

- "Early-to-late" changes
  - Instrumental shifts
    - Gain or threshold
    - Time response
  - Effective acceptance
    - Residual polarization
- Pileup
- NEW:  Kicker-related "noise"

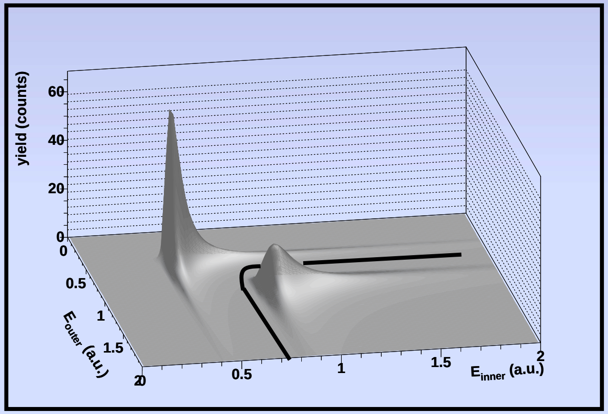


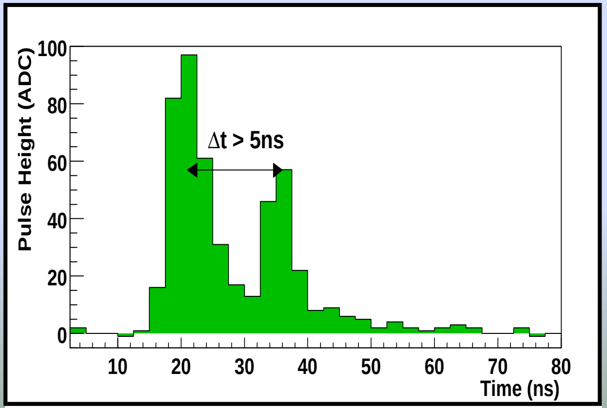
# Pileup ~ $e^{-2t/\tau}$

$$\frac{\Delta\tau}{\tau} \approx \frac{(N-1)\delta t}{2F_{dh}F_{seg}\tau}\frac{1}{(1+T/2\tau)} < 1\,ppm$$

- **Proposal:**
  - **Segment detector** $F_{seg}$ = 180
  - **Double-hit timing resolution** $\delta t$ = 4 ns
  - **Overlap rejection by energy** $F_{dh}$ = 25
- **NEW: Based on g-2 experience**
  - **Side-band subtraction routines can eliminate about 95% of pileup**
  - **Implies, considerable "safety" margin; this is no longer our concern**

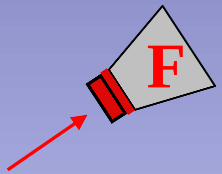


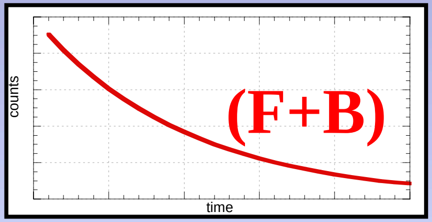



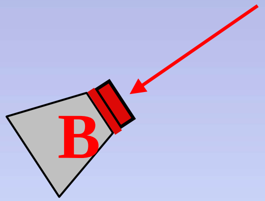
# Spin Precession Effects

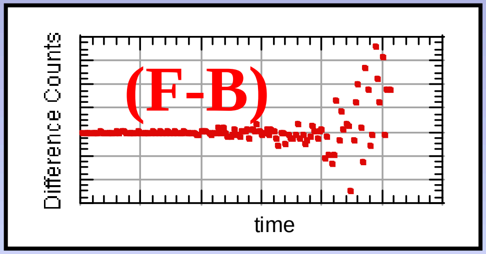
## change in effective efficiency versus time



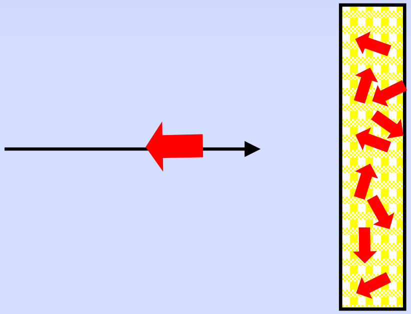

- **Detector asymmetry**
  - **Mimimized by point-like symmetry**



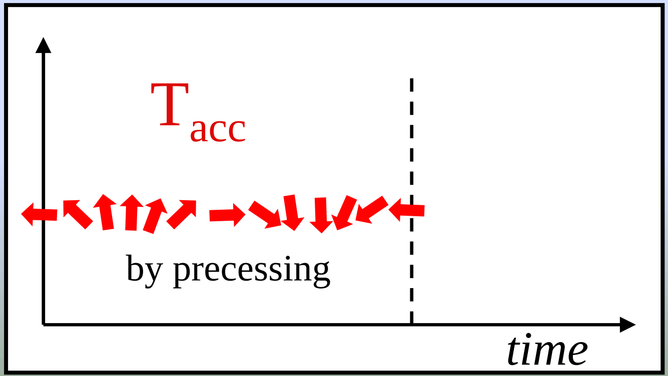




- **Residual polarization of ensemble**
  - **Sulfur target ≈ 8% (measured by us)**

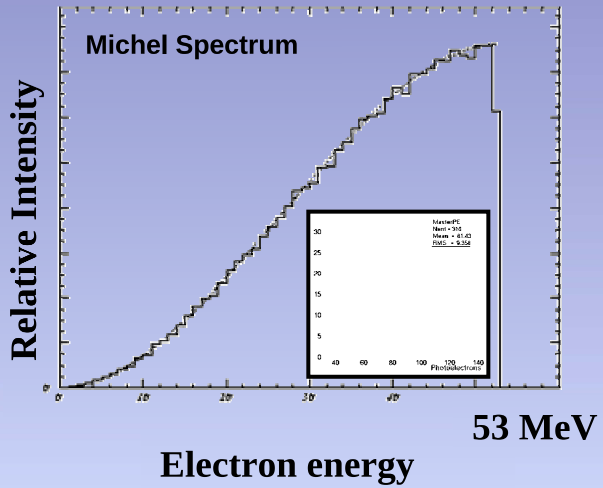


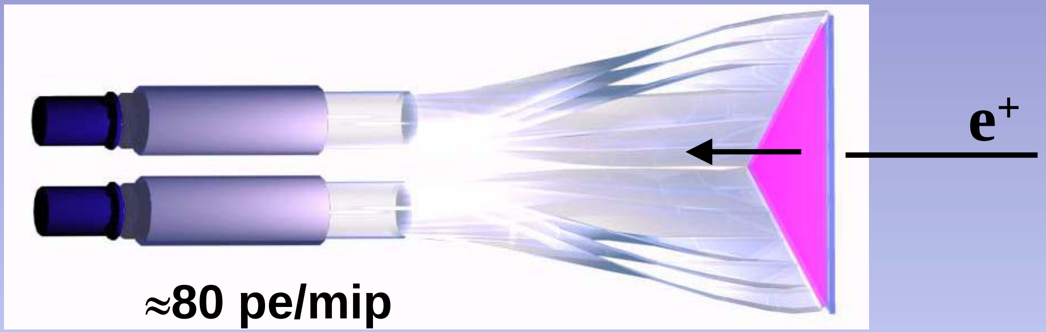
- **Dephasing**
  - **Rotate muons during accumulation**
  - **≈ 5% …**

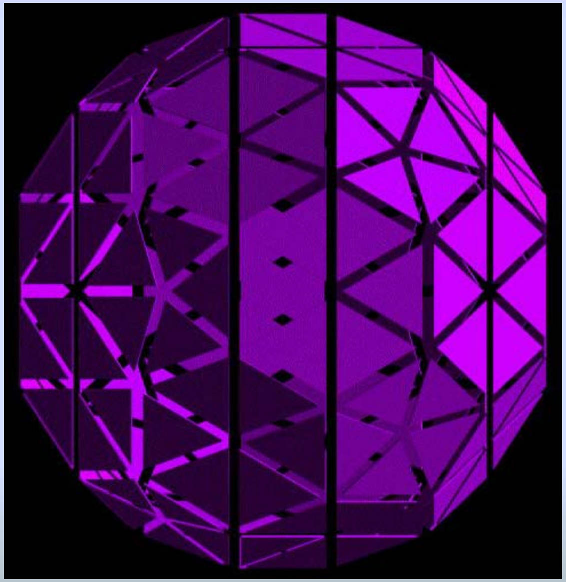


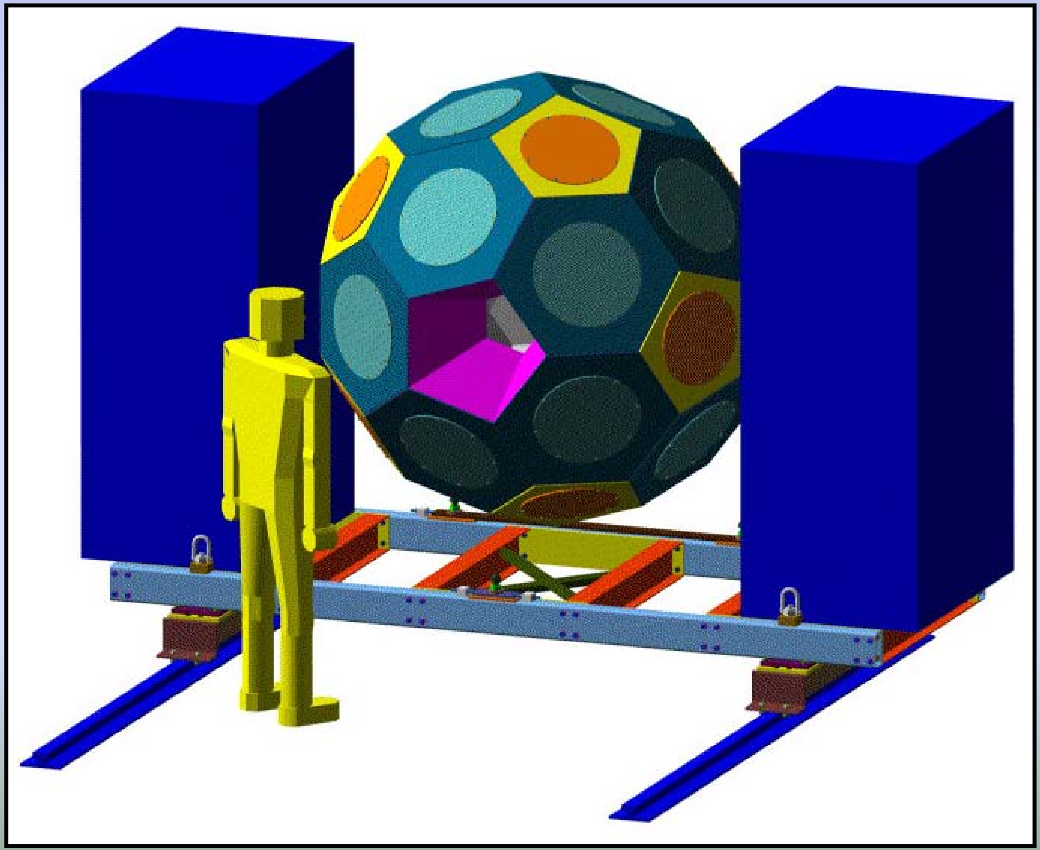

- **New: use of high-internal field target**

# Detectors and Support Updated Since Proposal

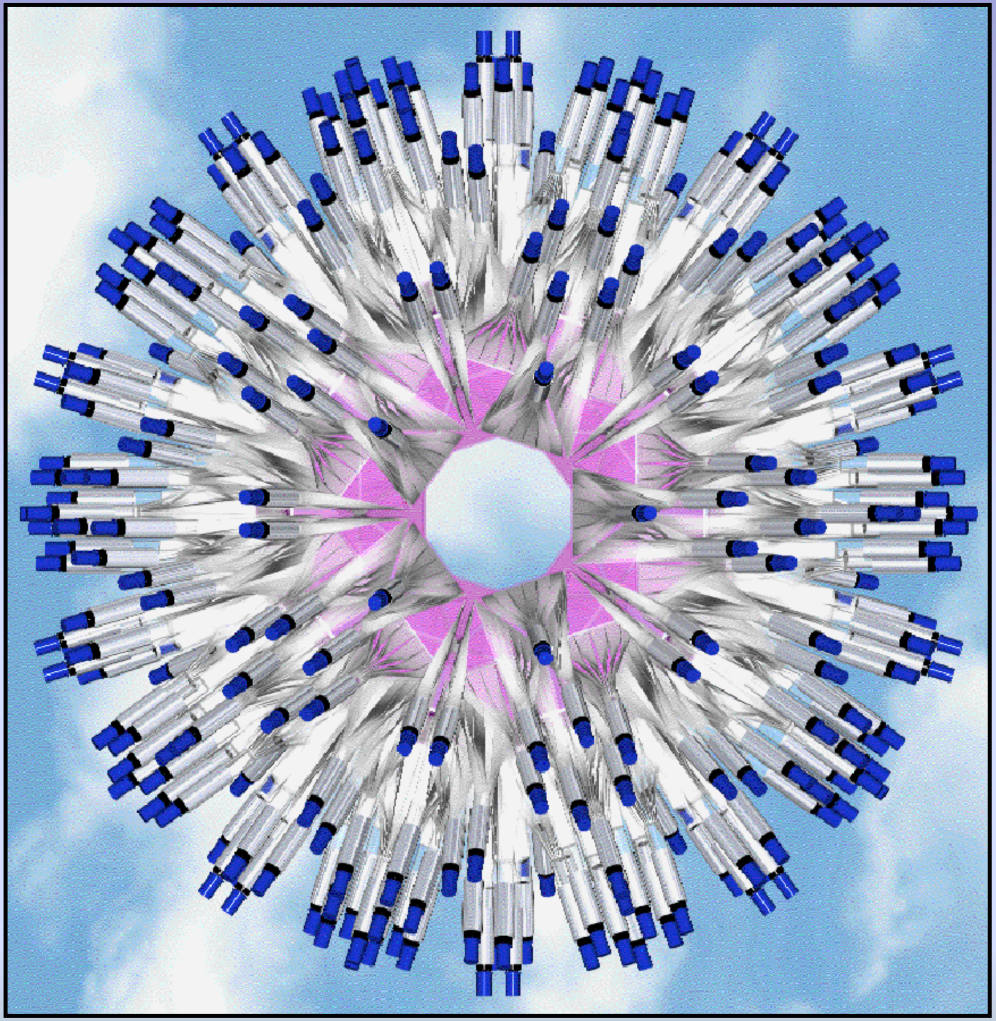


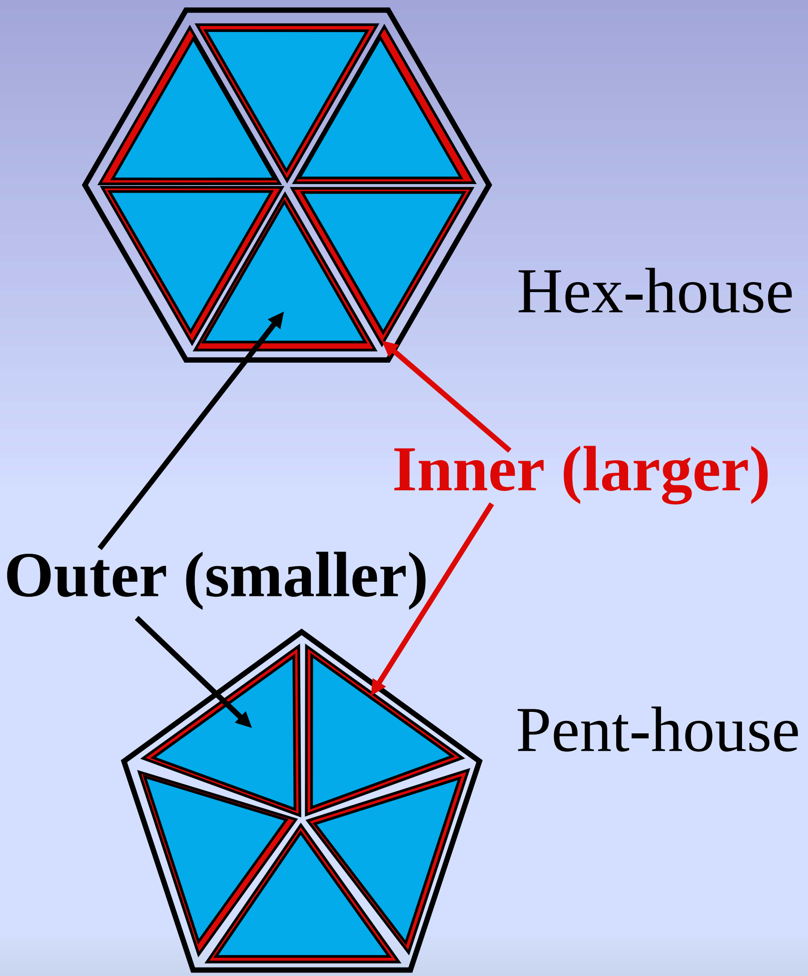





# 32-sided, soccer-ball geometry





# Data Acquisition coming along well

- **Computers, VME interface, and software framework of the DAQ are complete.**
  - Midas running under Linux
  - Data stored on Terabyte arrays
- **Fall 2003 run revealed several minor slow control problems and issues with the CAEN TDCs**
  - We are finding and trying to solve these in our offline analysis effort
- **To do:**
  - Software for LED calibration pulses
  - Experiment timing using Magic Box
  - WFD readout and online pulse finding
  - Wire chamber readout and beam monitoring
  - Online detector monitoring and fast-turnaround analysis

# Fall 2003 Run with *dc* Beam

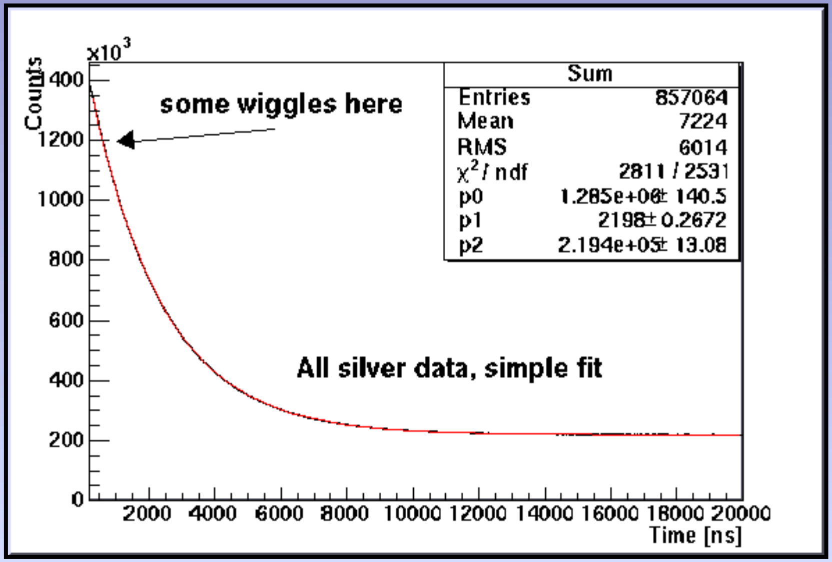
**Estimate of precision on lifetime for each target and rate in ppm.**

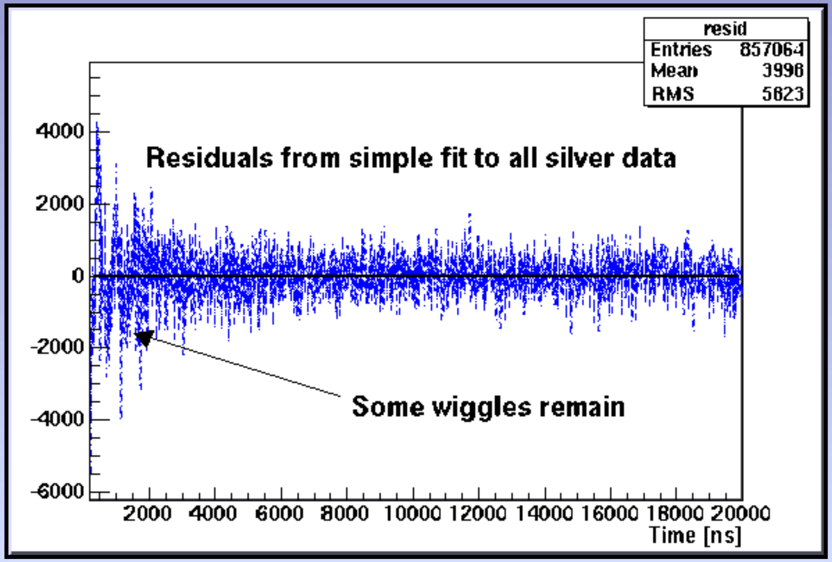
| | Silver | Sulfur | AK3 | Totals |
|---|---|---|---|---|
| Very Low Rate 30 - 40 kHz | - | - | 97 | 97 |
| Low Rate 45 - 60 kHz | 175 | - | 52 | 50 |
| Mid Rate 100 - 130 kHz | 112 | 66 | 55 | 40 |
| High Rate 300 - 450 kHz | 211 | 81 | 74 | 53 |
| Ultra High Rate > 500 kHz | - | 130 | 165 | 102 |
| Totals | 86 | 48 | 31 | **25** |

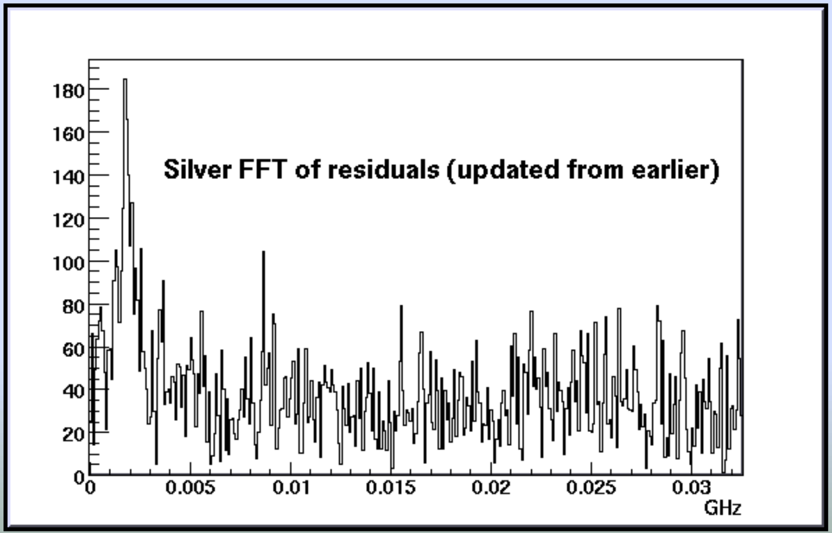
**30 ppm**

- Explore targets, rates
- Exploit full symmetry of detector for first time
- Confront "real" analysis issues (CAEN tdcs, disc, etc)
- "Blind" offset to clock; real time bin width is hidden for now

# Example of “Online” Analysis with Silver

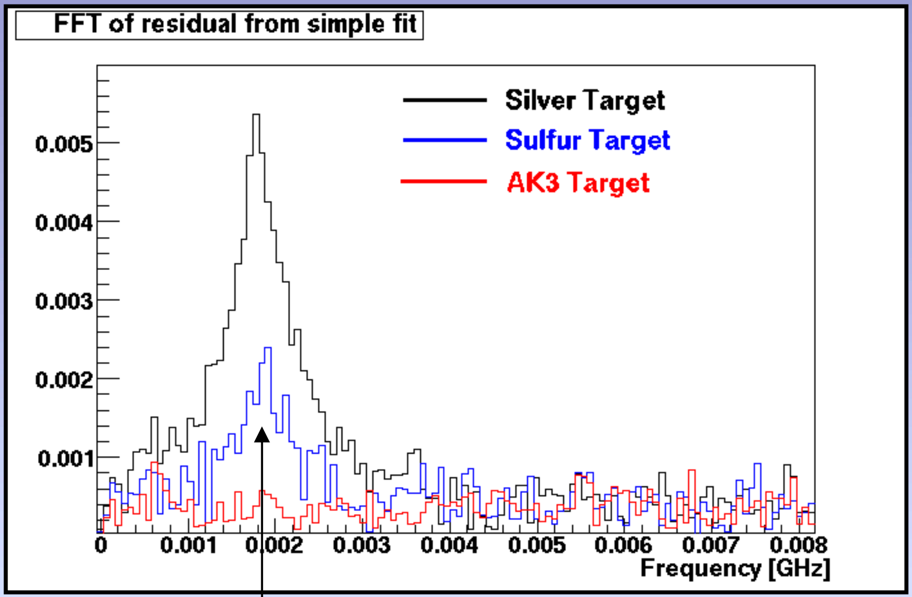


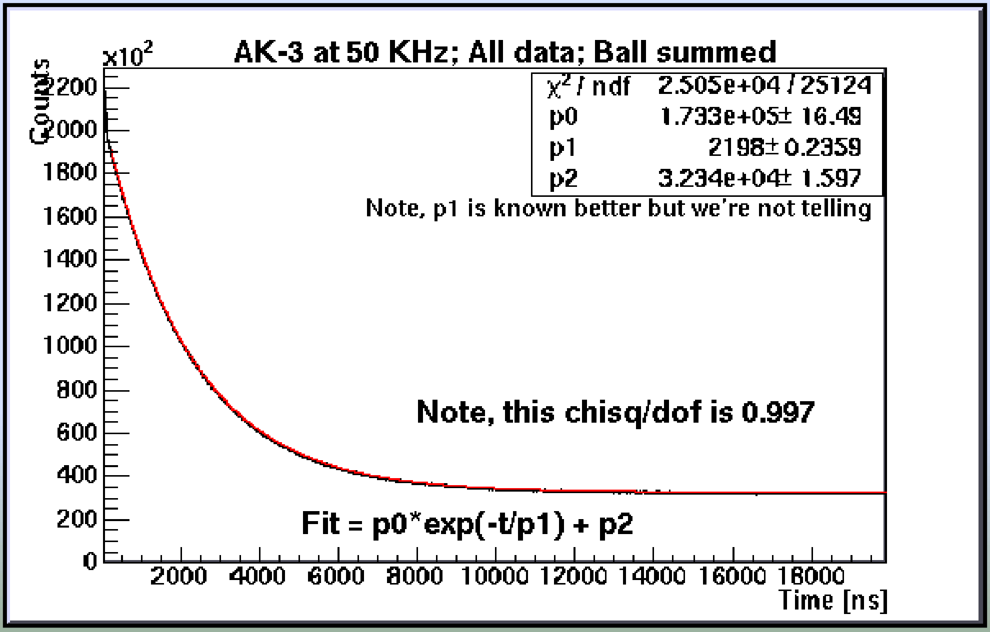
# Now, with new AK-3 target

(Arnokrome-3: 30% chromium, 10% cobalt, 60% iron)

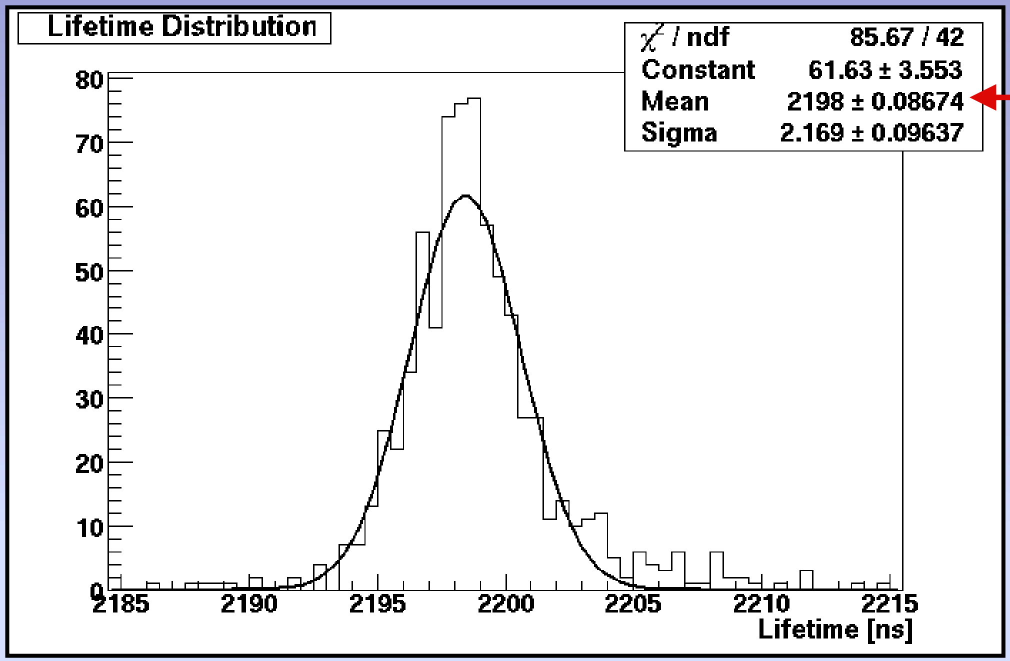



B ≈ 135 G

- Internal field ≈1 T
- No precession peak observed
- Fits well to simple $e^{-t/\tau}$



# Some recent offline 3-parameter fits to most of the data (all targets, rates, etc.)



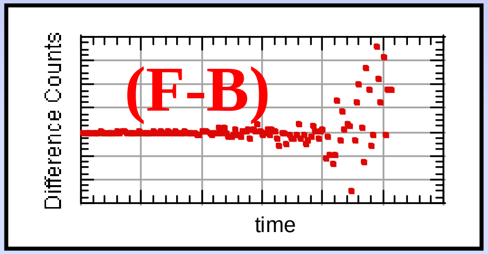

**Remember, this "clock" has a secret offset, unknown to us**

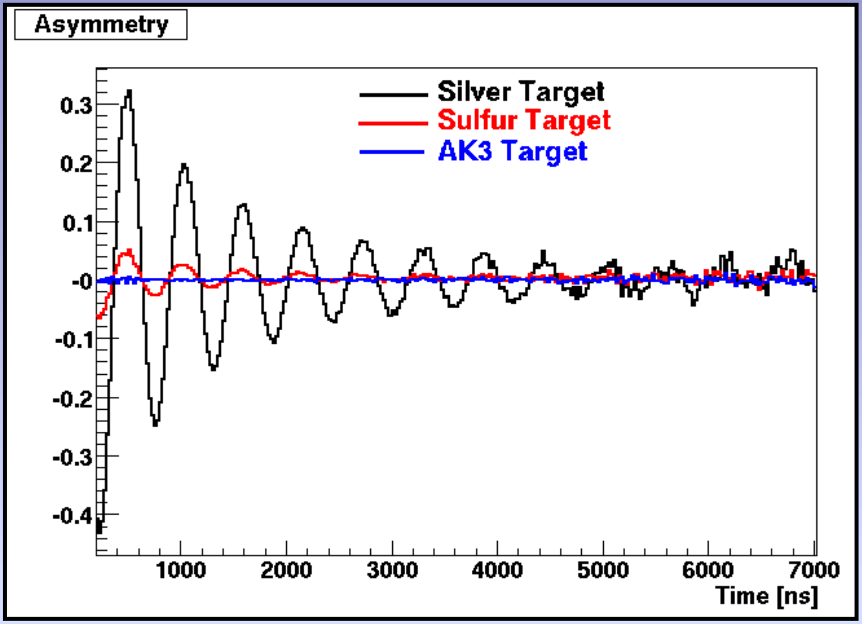
**Distribution of "$\tau$" from different runs**

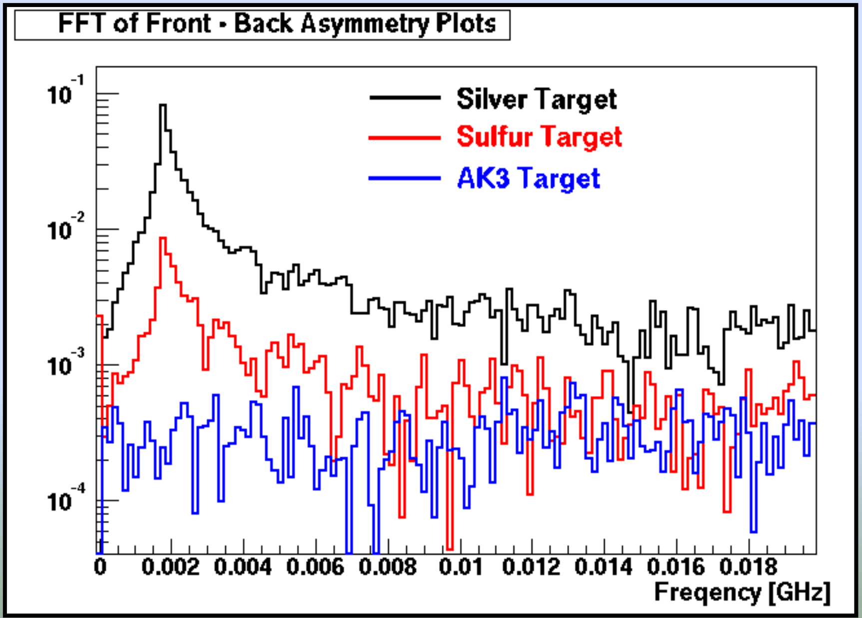
$$N(t) = N_0\, e^{-t/\tau} + B$$

# How effective is the F-B difference ?

**Recall**



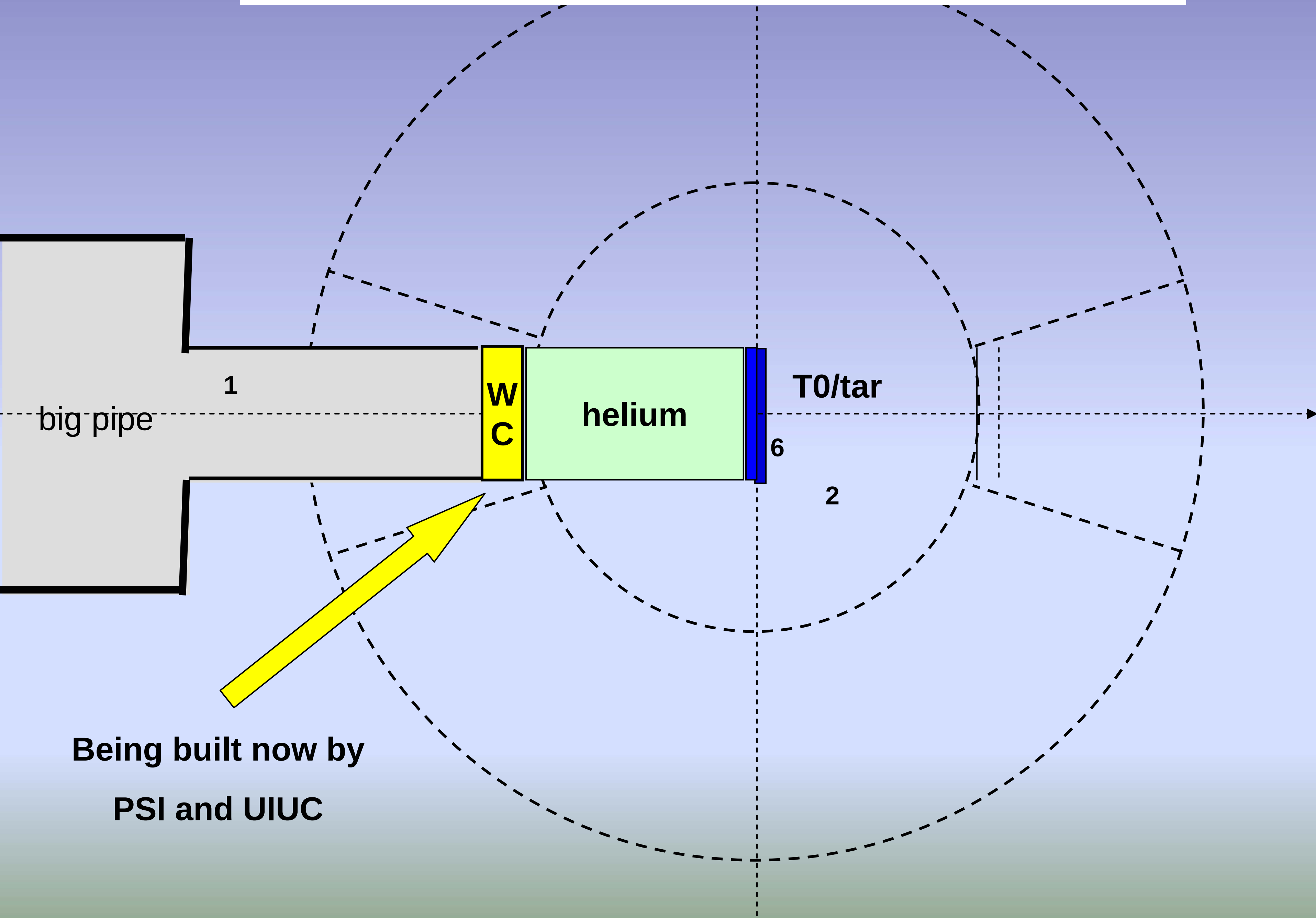
# Update on the Waveform Digitizers

- **Since the written progress report, Jan. 2004**
  - **Solved VHDL simulation problems**
  - **Solved VME transaction issues**
  - **Inter-FPGA simulation successful**
  - **FIFO-FPGA simulation successful**
- **Remaining prototype work issues:**
  - **Inter-FPGA hardware tests**
  - **FIFO-FPGA hardware tests**
- **Layout changes:**
  - **Spartan II → Virtex II change**
  - **Minor bug corrections**

**This drives our desire to run late in the year**

- **Tentative timeline:**
  - **Remaining prototype issues: 2-4 weeks**
  - **Final prototype: 7-9 weeks**
  - **Full production: 6-8 weeks**
  - **Production testing: 6-8 weeks**
  - **DAQ integration: 4-6 weeks**
  - **Shipping to PSI: 2-3 weeks**
  - **Total: 27-37 weeks (October 2004?)**
  - **In parallel: firmware and software development**

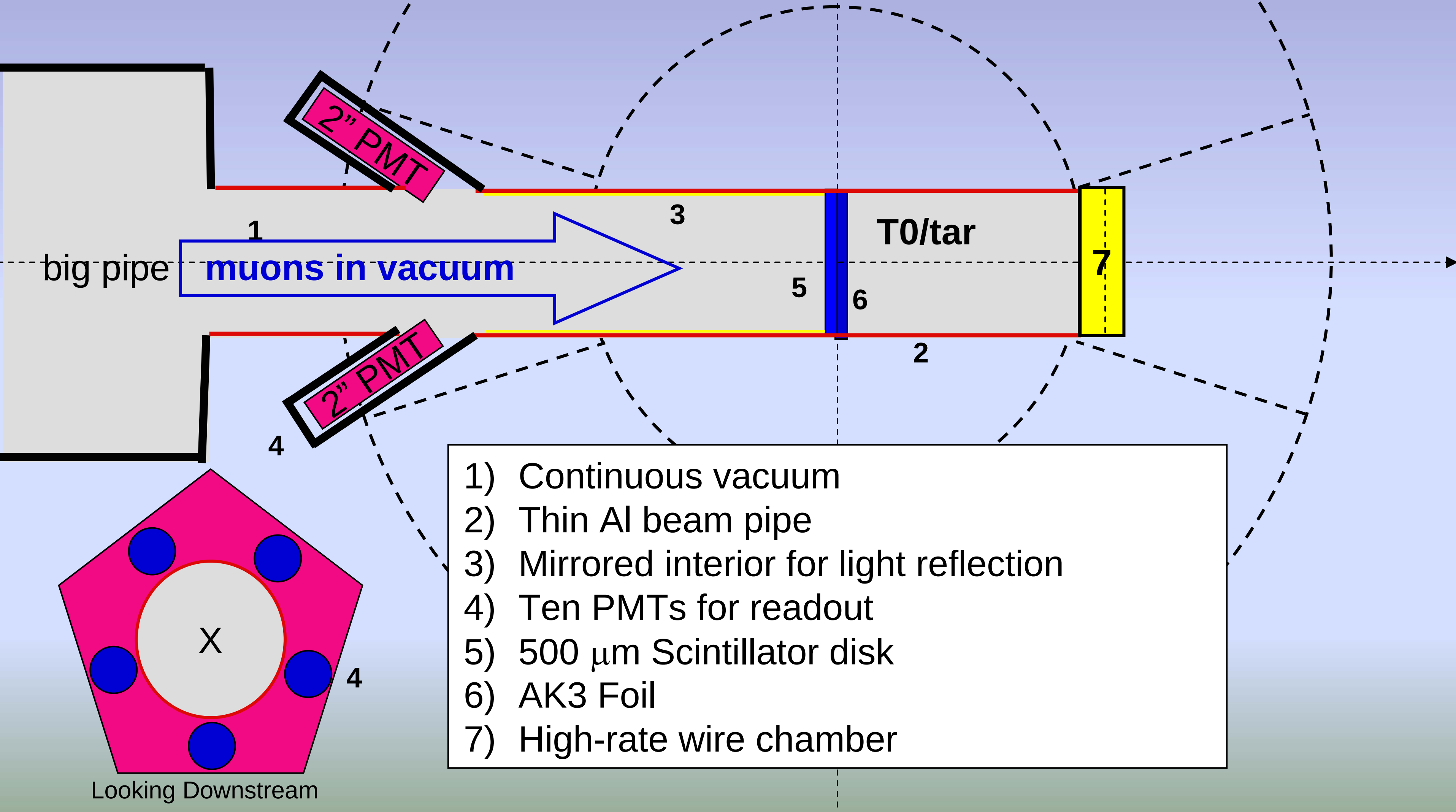
# Plans for New High-Rate Wire Chamber to Map Beam




**Being built now by**

**PSI and UIUC**

# Plans for New Active T0 with Vacuum Beam Transport




1) Continuous vacuum
2) Thin Al beam pipe
3) Mirrored interior for light reflection
4) Ten PMTs for readout
5) 500 μm Scintillator disk
6) AK3 Foil
7) High-rate wire chamber

# Beam Request 2004

(plans 2005)

- **Six weeks in the $\pi$E3 line**
  - Commission kicker / line with dc mode (extinction)
  - Commission kicker in pulsed mode
  - Calibrate detector, first use of waveform digitizers
  - Data taking for lifetime (2-3 weeks)

- **Scheduling**
  - As late as possible in year:
    - We are waiting on kicker repair
    - We have a fixed-length WFD production schedule
    - Last year, we were moved forward; the gap between the summer beam-tune run and the fall “detector” run was too short
- **Obviously …**
  - We have a significant overlap with mCap
  - We will work as hard as possible to be ready as soon as possible