Precision muon lifetime at PSI

MuLan Experiment

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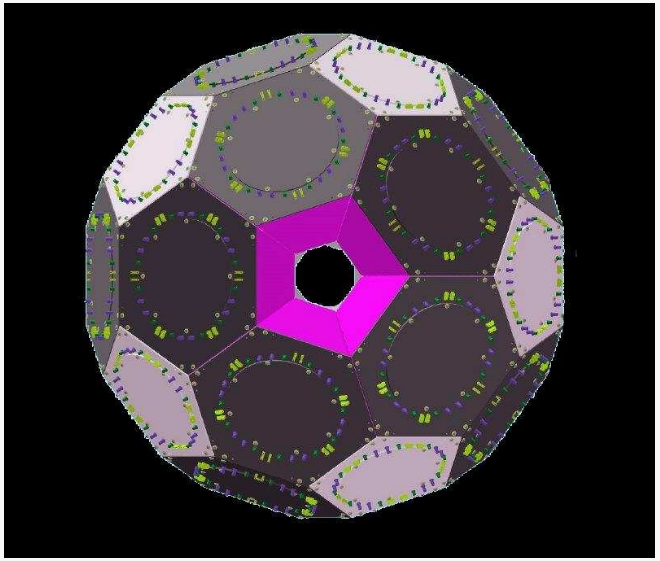

On behalf of the MuLan Collaboration

Outline

- √ **Motivation:** Theory and actual experimental situation
- √ **Experimental Principle:** How will we reach 1 ppm precision
- √ **Kicker:** Principle and results
- √ **Detectors:** Scintillators and Wire chamber
- √ **First Results:** Run December 2004
- √ **Future:** This year and the next ones

Scientific Questions

What are the fundamental electroweak parameters?

$$G_F, \alpha(Z), m_Z$$

Precision μ^+ lifetime

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Precision μ^+ lifetime

$$\mu^+ \rightarrow e^+ + \tilde{\nu}_e + \nu_\mu$$

Current World average

$$\begin{array}{lllll} \tau_{\mu^+} & = 2197.03 & \pm 0.04\,\text{ns} & (18\text{ppm}) \\ & & \Downarrow & \Downarrow \\ & & \pm 0.002\,\text{ns} & (1\text{ppm}) \end{array}$$

Muon Lifetime

The muon lifetime τ_μ is closely related to the Fermi coupling constant GF , which sets the basic strength of the weak interaction:

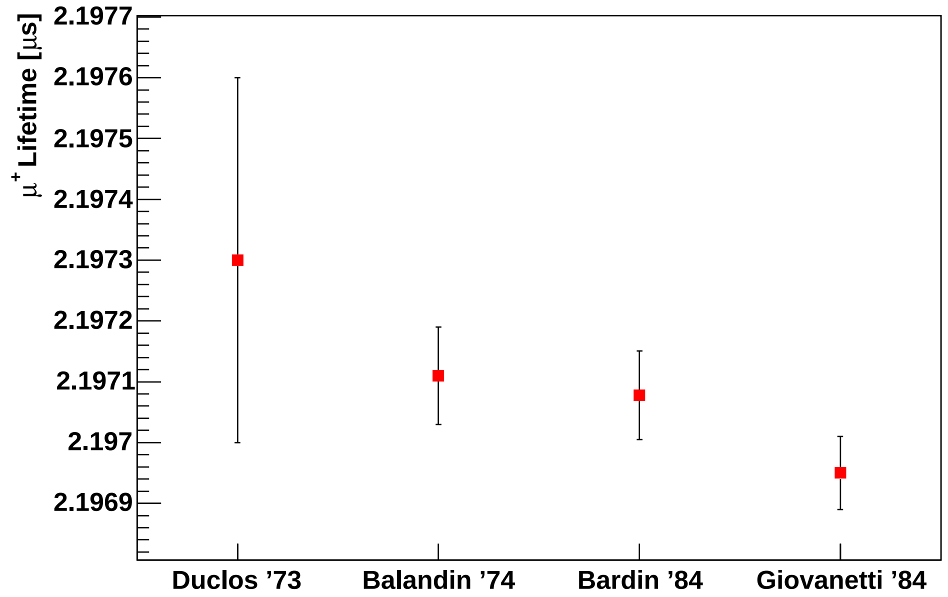
$$\frac{1}{\tau_\mu} = \frac{G_F^2 m_\mu^5}{192\pi^3}\left(1 + \delta q\right)$$

QED radiative corrections: Two-loop diagrams finished in 1999 by Stuart and van Ritbergen*; now known to < $\pm$ 0.3 ppm (previously $\pm$ 30 ppm)

Extraction of G_F is now limited by the muon lifetime a truly fundamental parameter of the standard model that should be measured as precisely as possible with today s technology.

*T. van Ritbergen and R.G. Stuart, Phys. Rev. Lett. 82, 488 (1999); and Phys. Rev. D 437, 201 (1998).

Experimental status



- √ Experiments mostly statistics limited
- √ PDG: $\tau_\mu = 2.19703 \pm 0.00004\ \mu$s (18 ppm)
- √ Our goal: 1 ppm uncertainty in τ_μ (0.5 ppm in G_F)

$$\frac{\delta G_F}{G_F} = 4\frac{m^2_{\nu_\mu}}{m^2_\mu}(< 25\,\text{ppb}) - \frac{5}{2}\frac{\delta m_\mu}{m_\mu}(75\,\text{ppb}) - \frac{1}{2}\frac{\delta \tau_\mu}{\tau_\mu}(9\,\text{ppm})$$

10^{12} Statistics: more than one muon at a time

- 1 ppm measurement $\rightarrow$ at least 10^{12} stopped muons.
- Each muon (or pion) enters target individually with pre– and post–quiet periods. Watch for decay positron and record its time.
- For 10^{12} muon, one need about 4×10^{7} s . . . several years !
- To be practical, we need to observe several muons at once:

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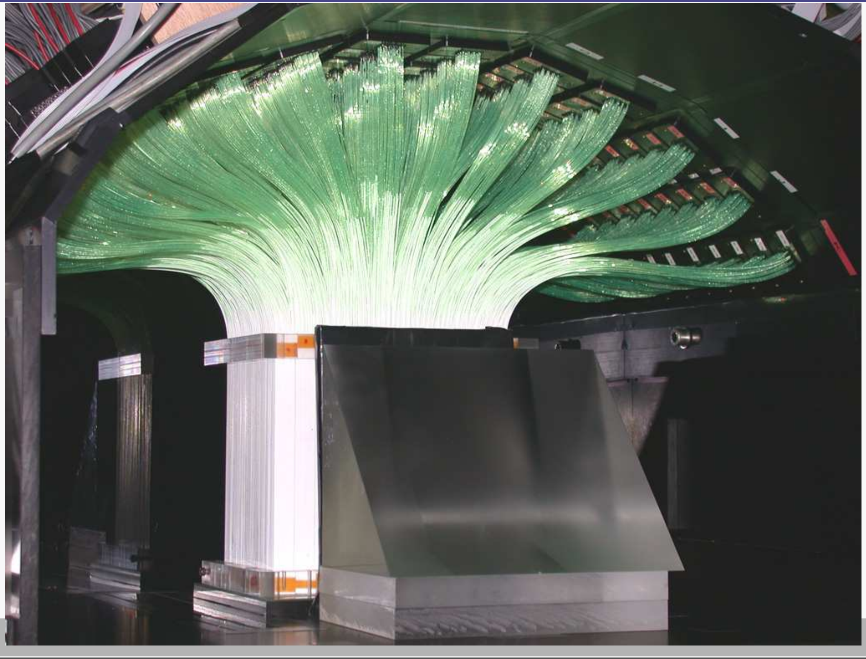
Spatial separation: FAST π **arrive continuously into highly segmented timer/tracker; several events can overlap**	
	

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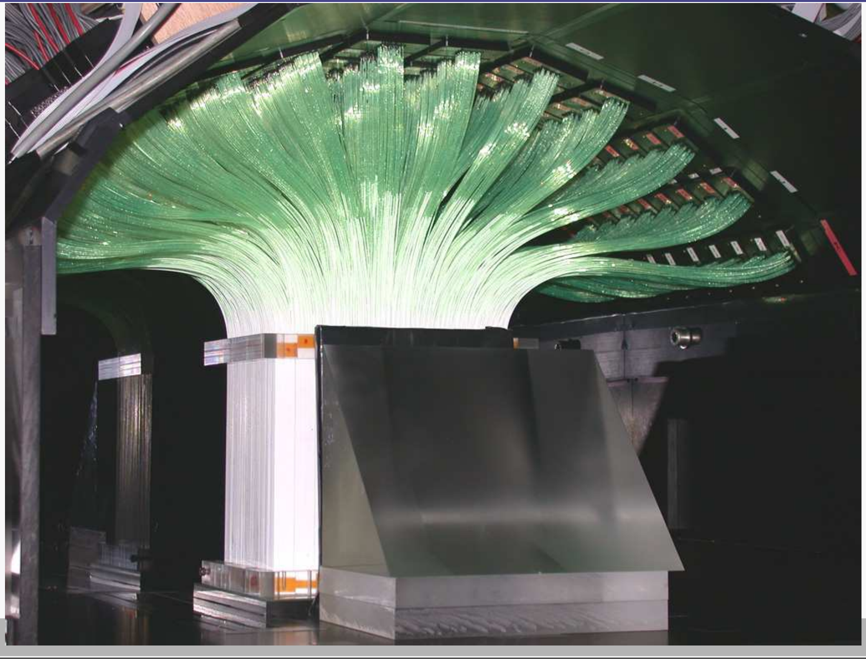
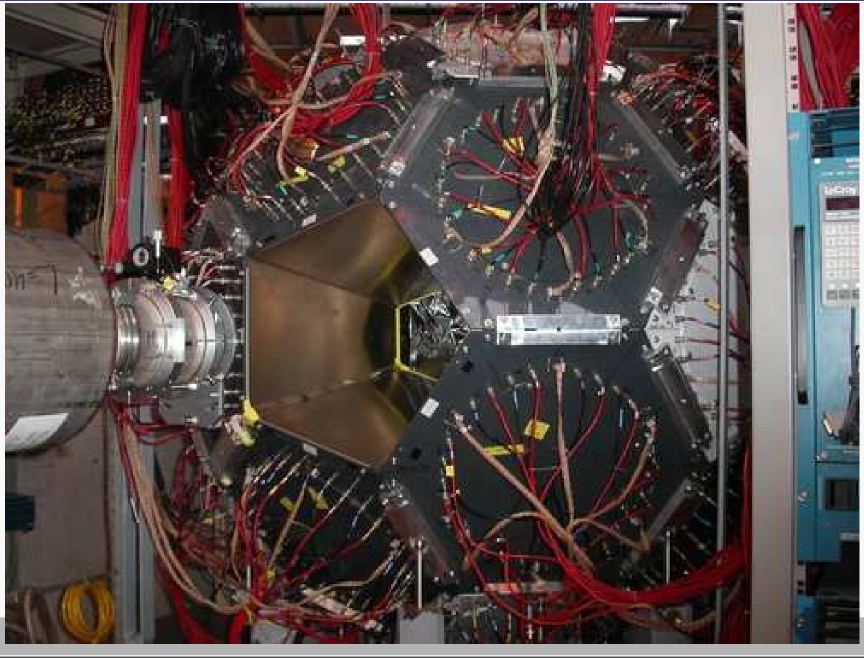
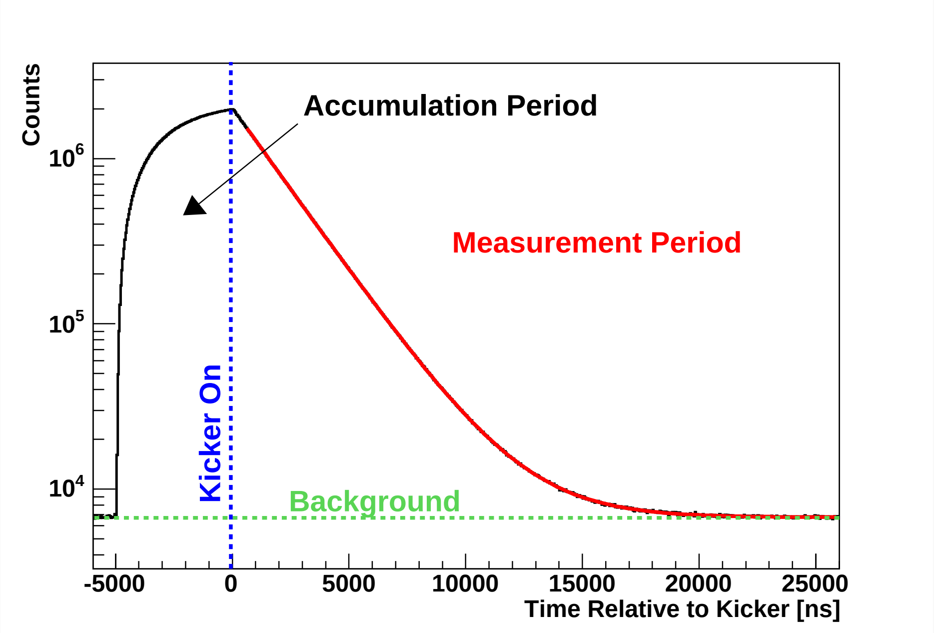
Spatial separation: FAST	Bunched muons: MuLan
π arrive continuously into highly segmented timer/tracker; several events can overlap	**Many muons arrive "at once" and decay into segmented detector**
	

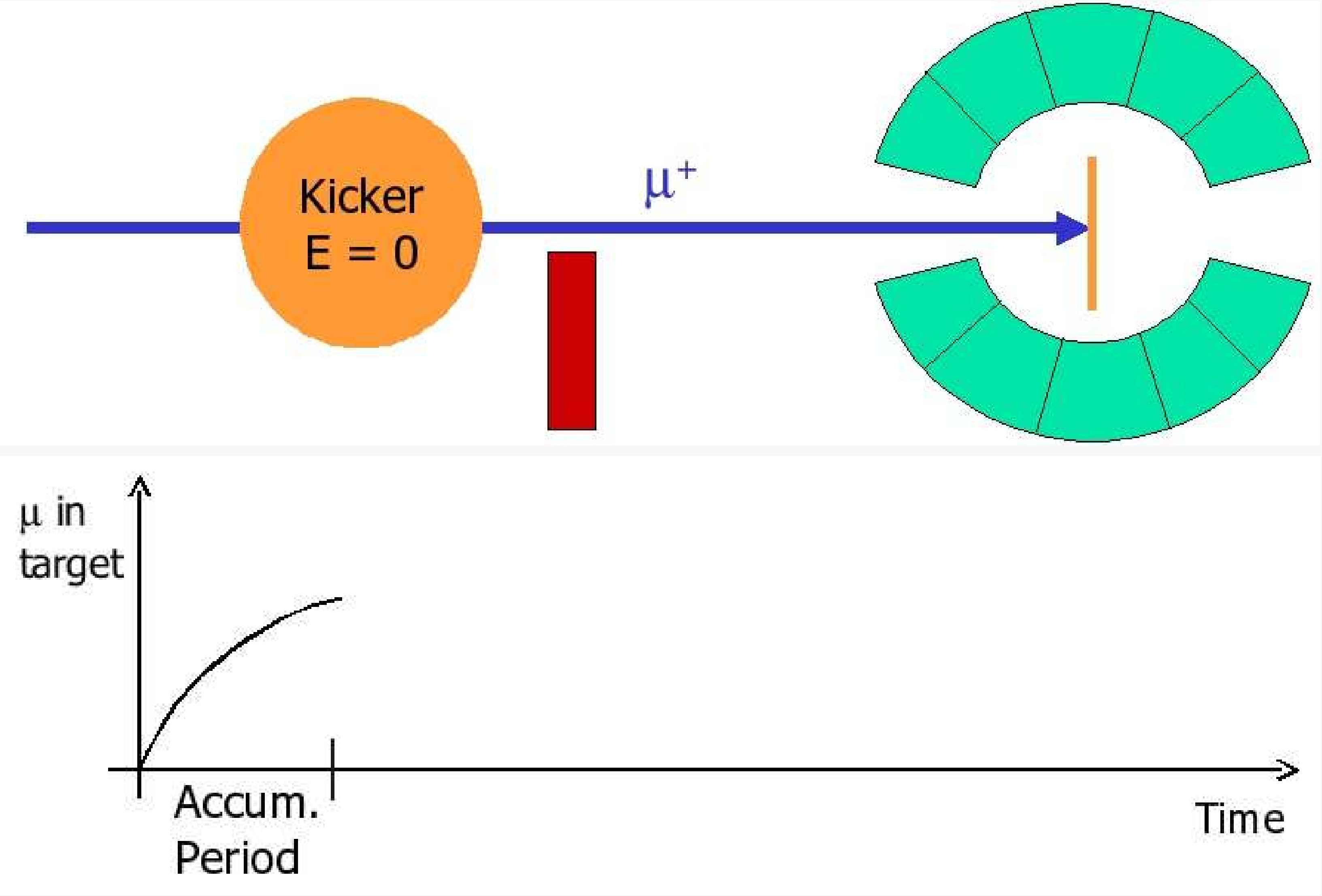
Muon Lifetime Techniques

- Burst of N muons arrives during accumulation period T_{acc}
  - Observe muon decays during measuring period of length T_{meas}
  - No other muons arrive during this time
  - Get another burst
- Ideally:
  - A small $N \Longrightarrow$ Reduces pileup
  - $T_{acc} + T_{meas} \sim 32\mu\text{s} \Longrightarrow$ Cycles fast



Pulsed Muon Beam

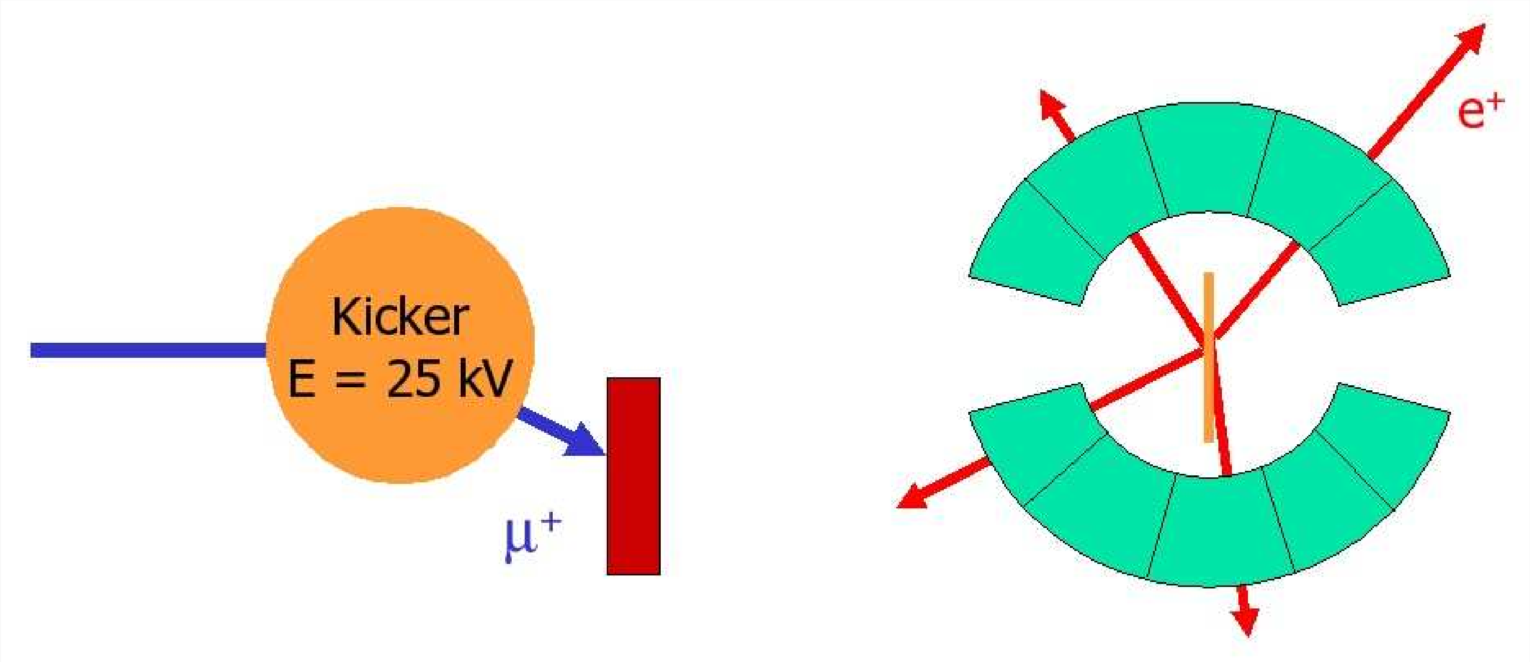
√ Collect handful of muons in a few μs Accumulation Period

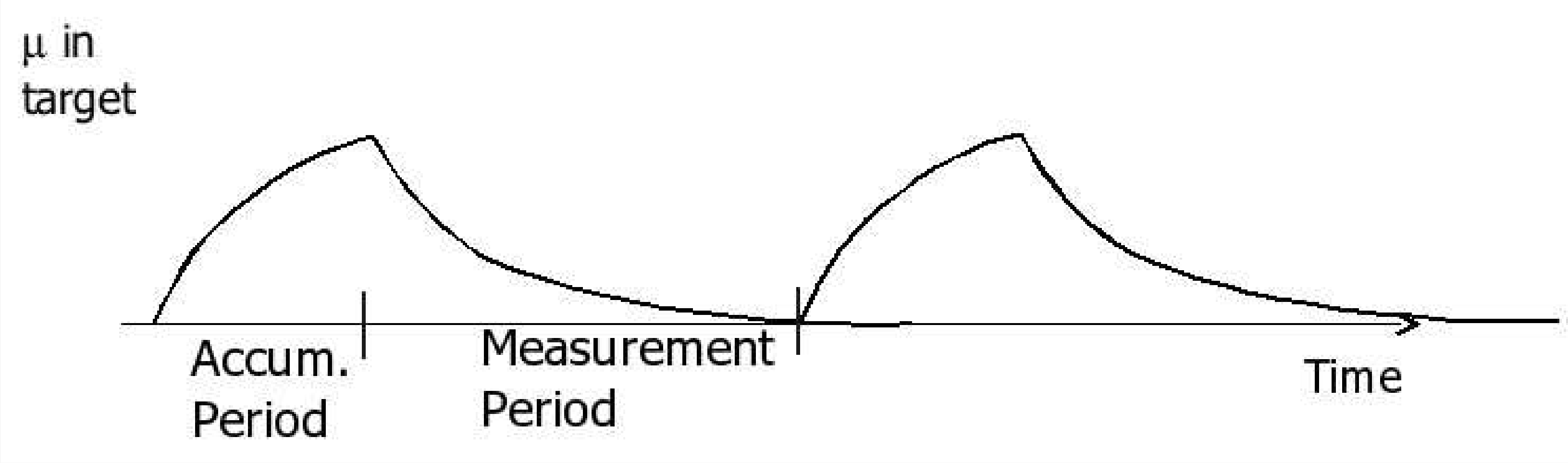


Pulsed Muon Beam

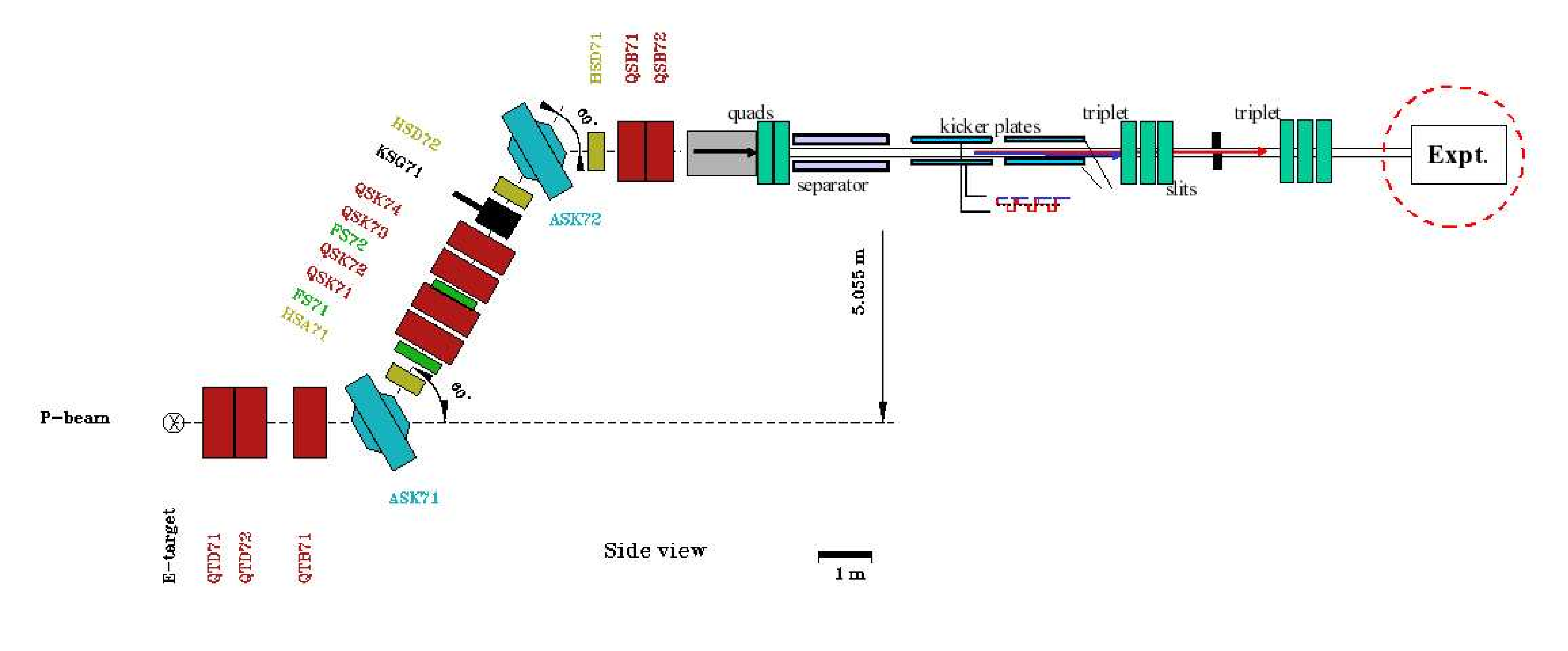
√ Turn off beam and watch them decay

Measurement Period



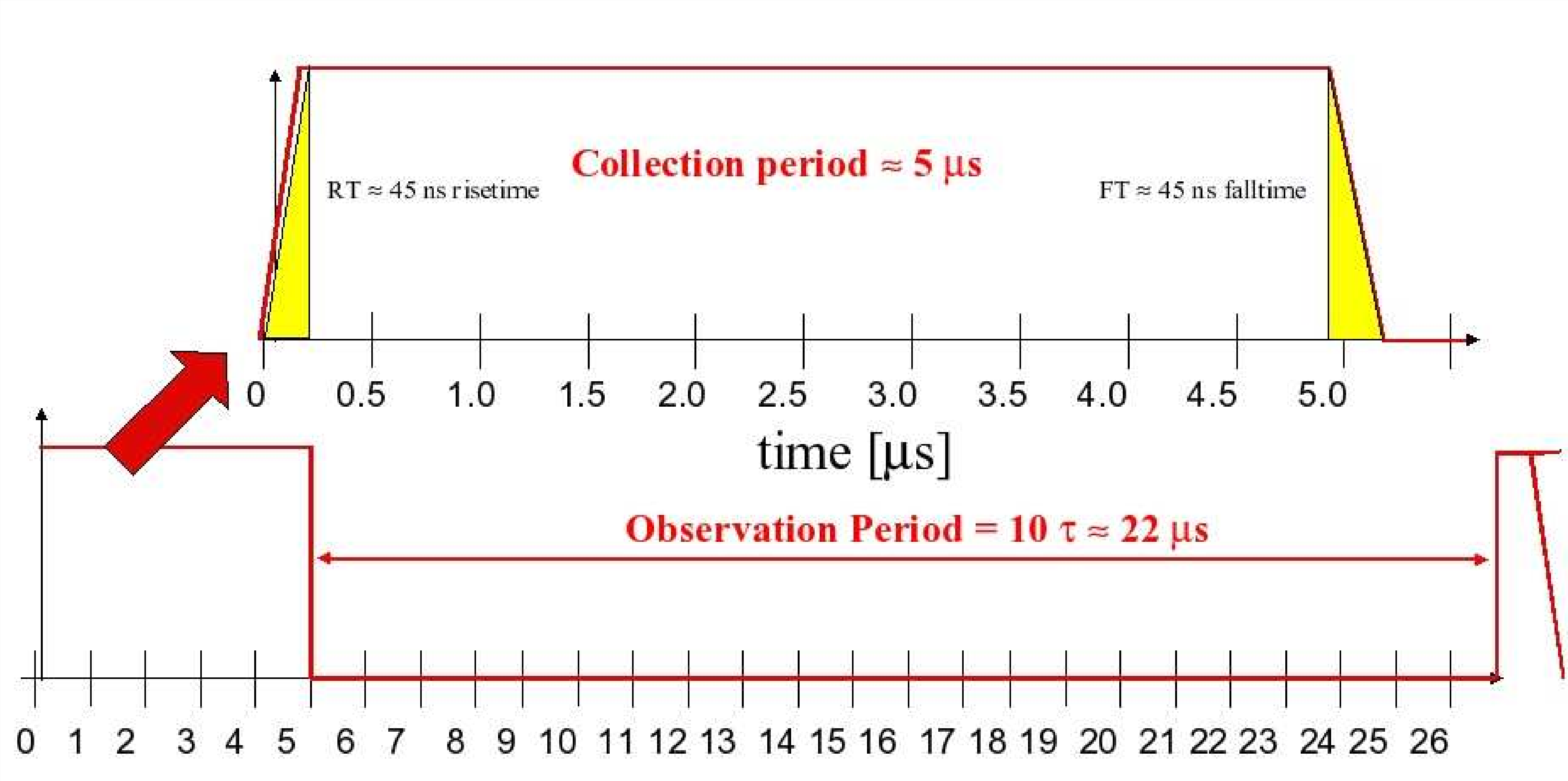


πE3: Adequate flux but high complexity



- A **Beam Rate** > 12 **MHz**; Spot at target, only few cm^2.
- Separator leaves about 5–10% positron background.
- Many elements to tune. Tricky to have a straight beam.
- Extinction fraction looks reasonable.
- The **Final transport through helium**.

Kicker Time-line

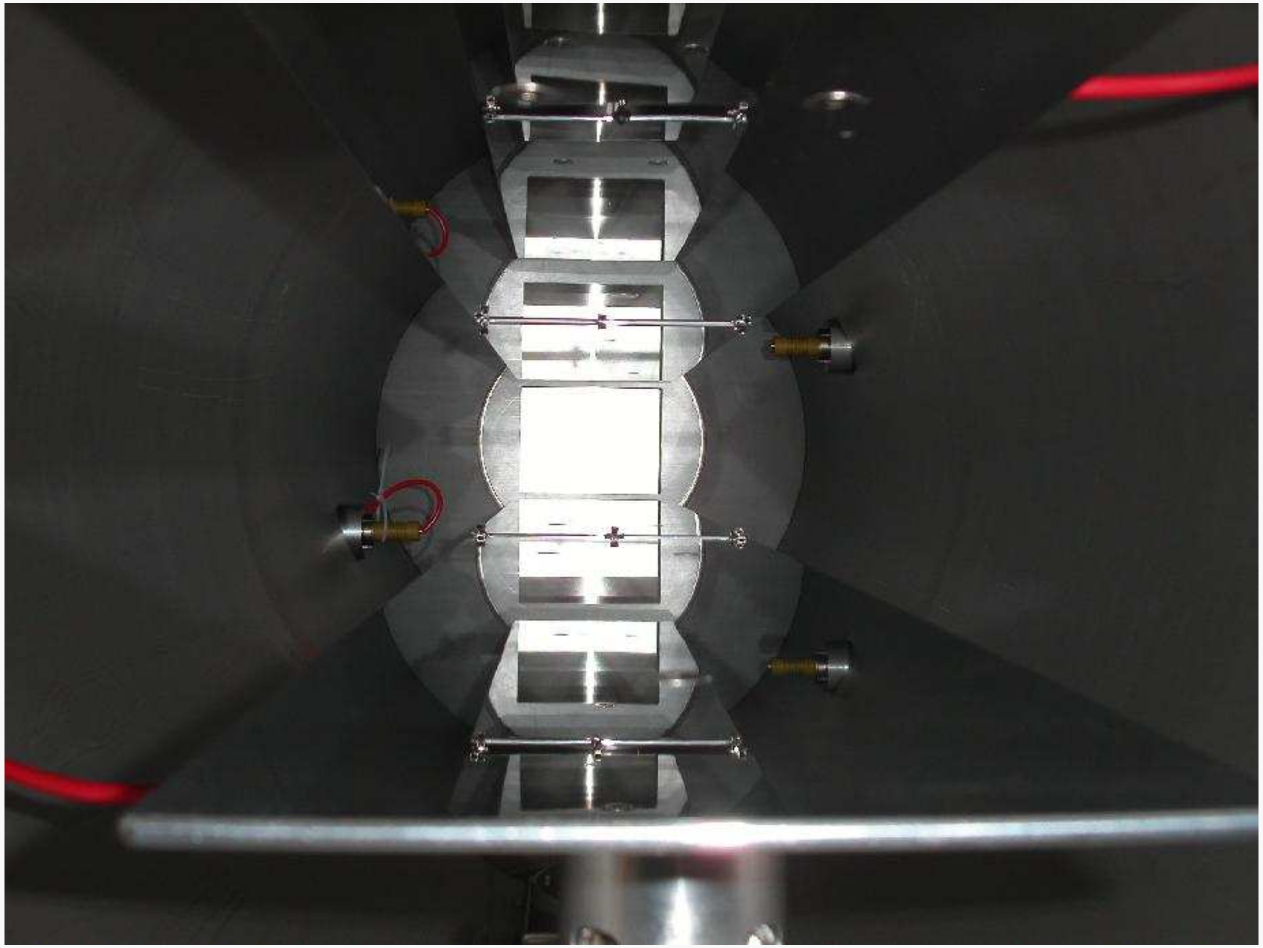


Fast Kicker

√ TRIUMF-built kicker

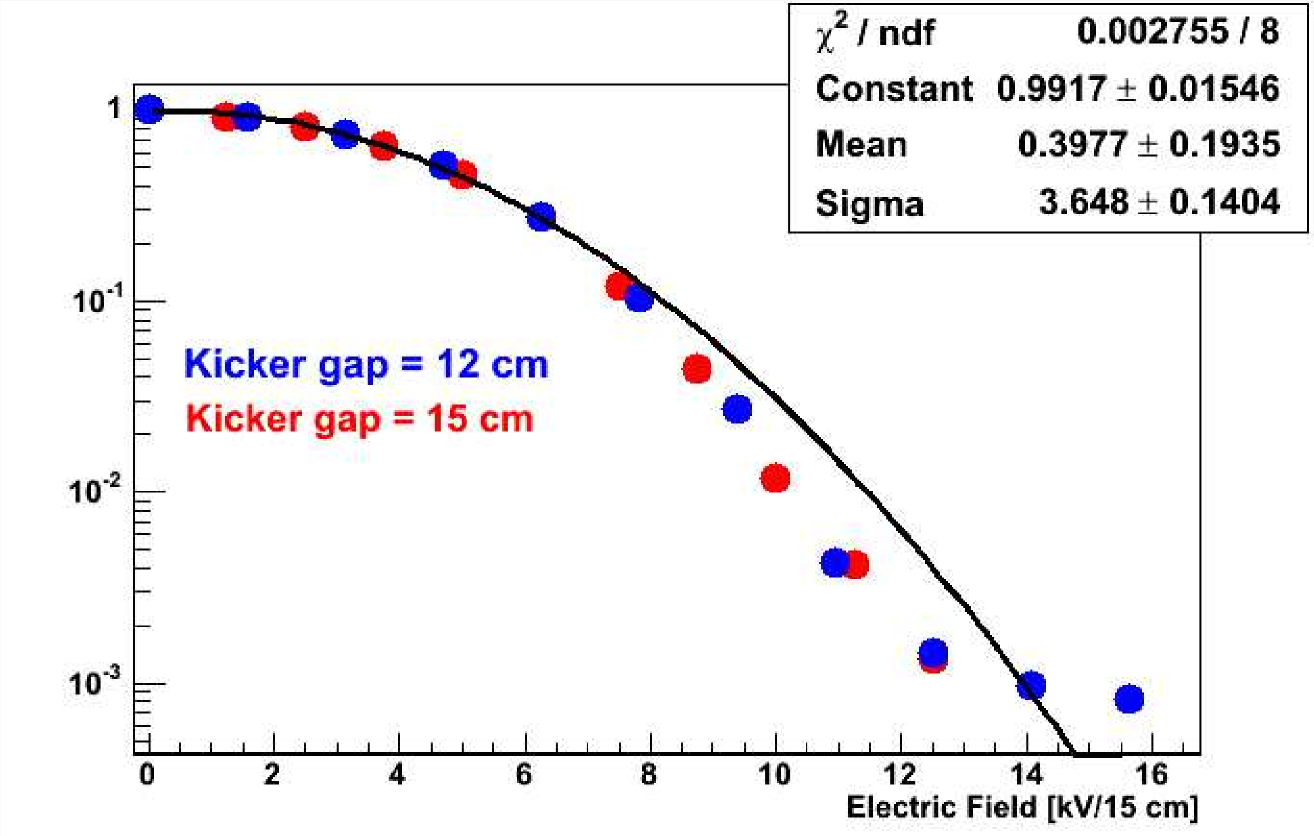
Fast Kicker

- TRIUMF-built kicker
  - $\sim$45 ns rise/fall time,
  - $\pm$ 25 kV swing,
  - two 75 cm plates



Fast Kicker

- √ TRIUMF-built kicker
  - ◇ ∼45 ns rise/fall time,
  - ◇ ± 25 kV swing,
  - ◇ two 75 cm plates
- √ Extinction factor
  - ◇ is quite subtle (seems momentum dependent)
  - ◇ ~ 300 during Run 2004
  - ◇ > 1000 in during Beam test in 2005.



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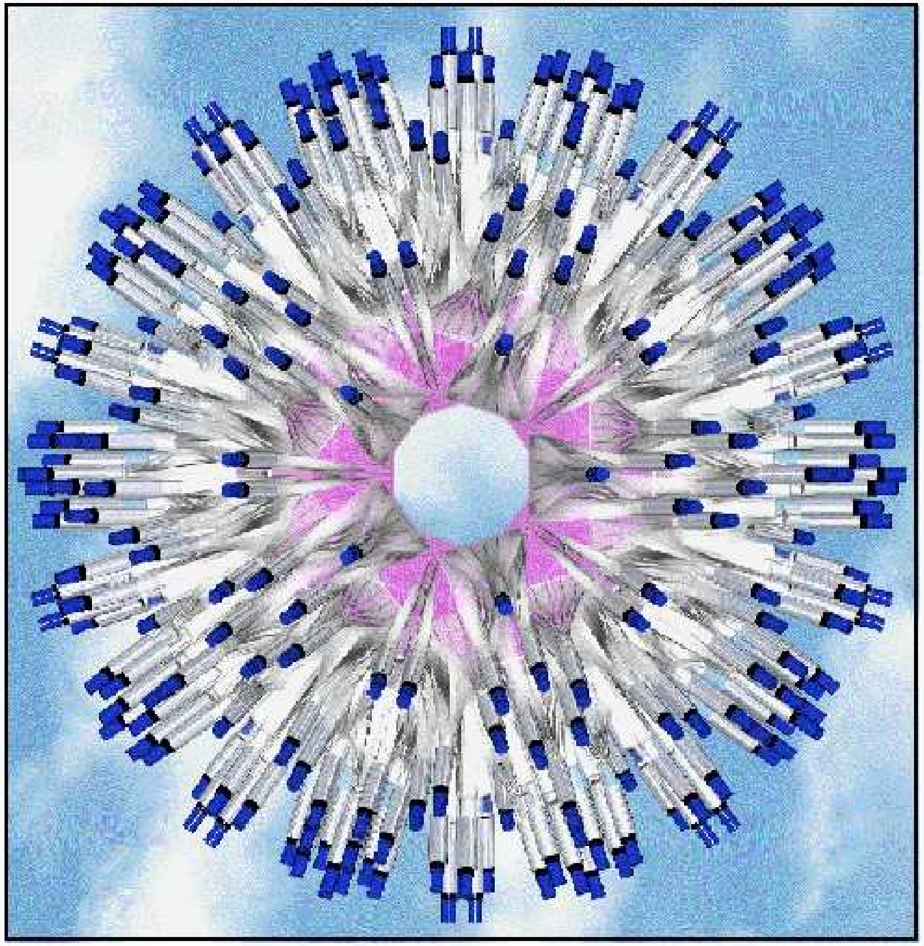
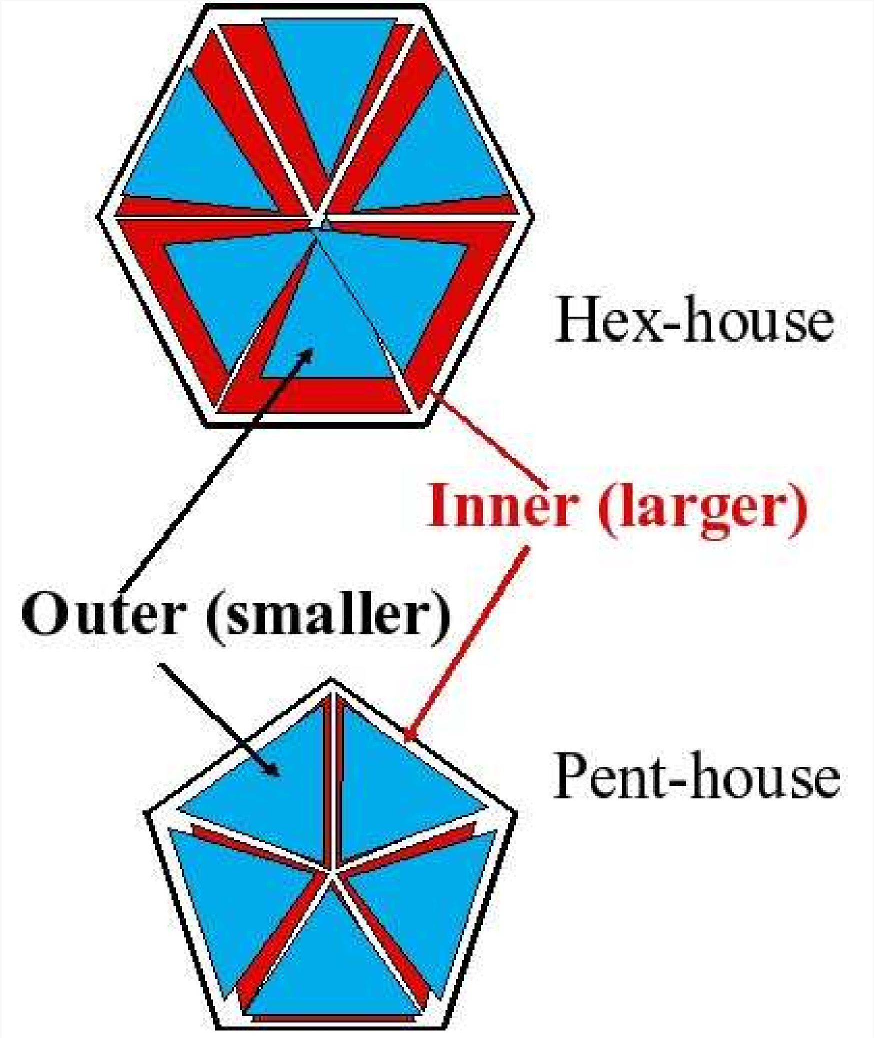
  - ◇ > 1000 in during Beam test in 2005.
- √ Some bad news too . . .
  - ◇ We killed many MOSFETS in 2004.
  - ◇ We ran with half of them, at lower voltage.

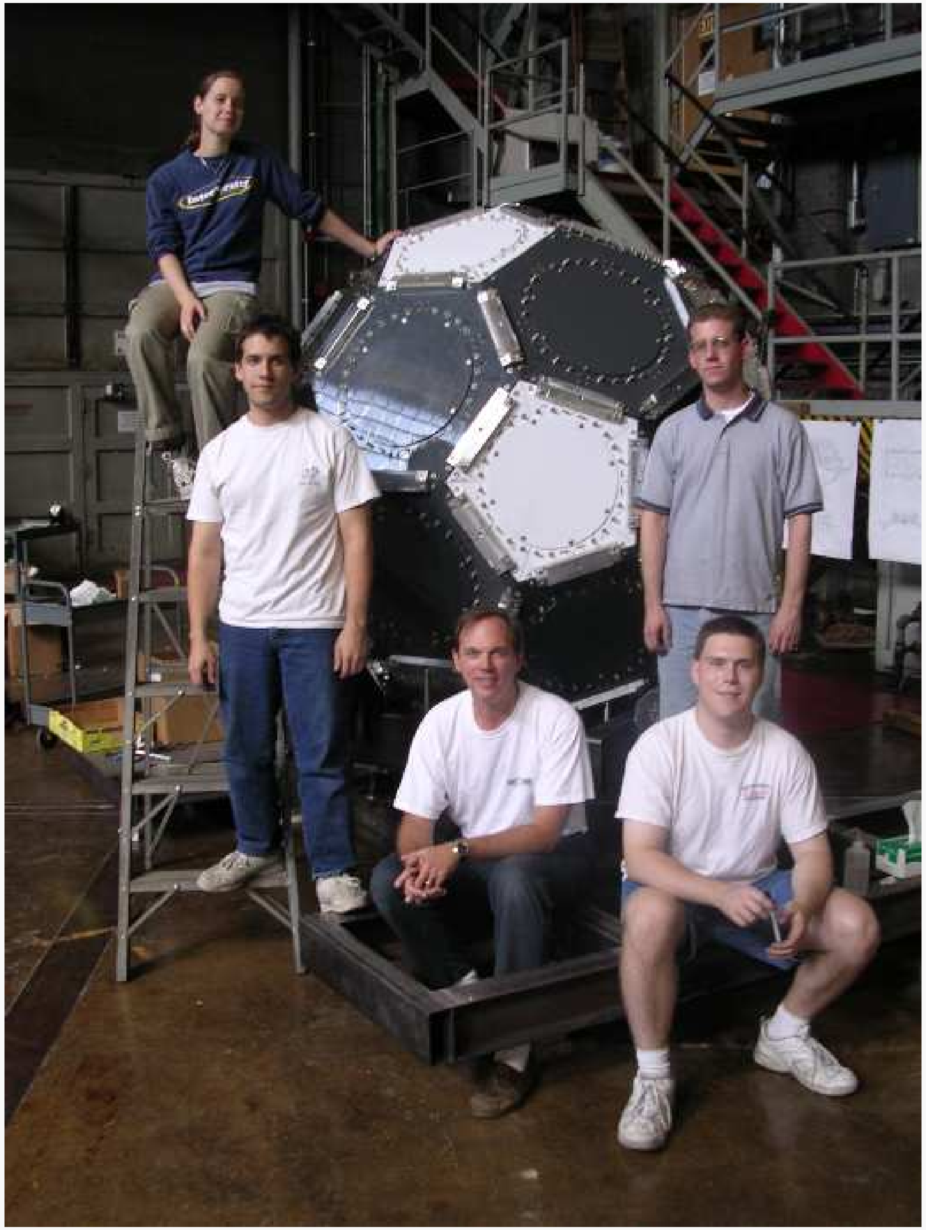
Scintillators: 32–sided, soccer–ball geometry

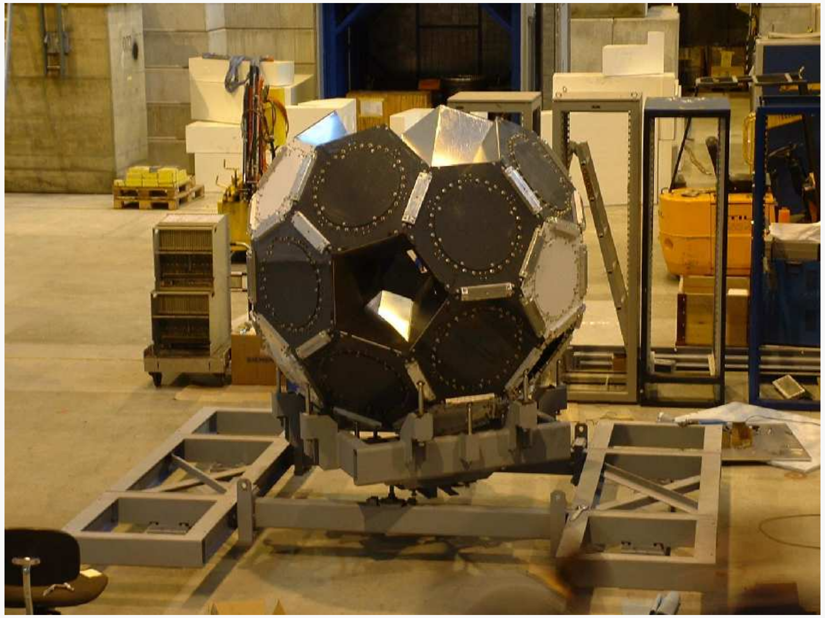




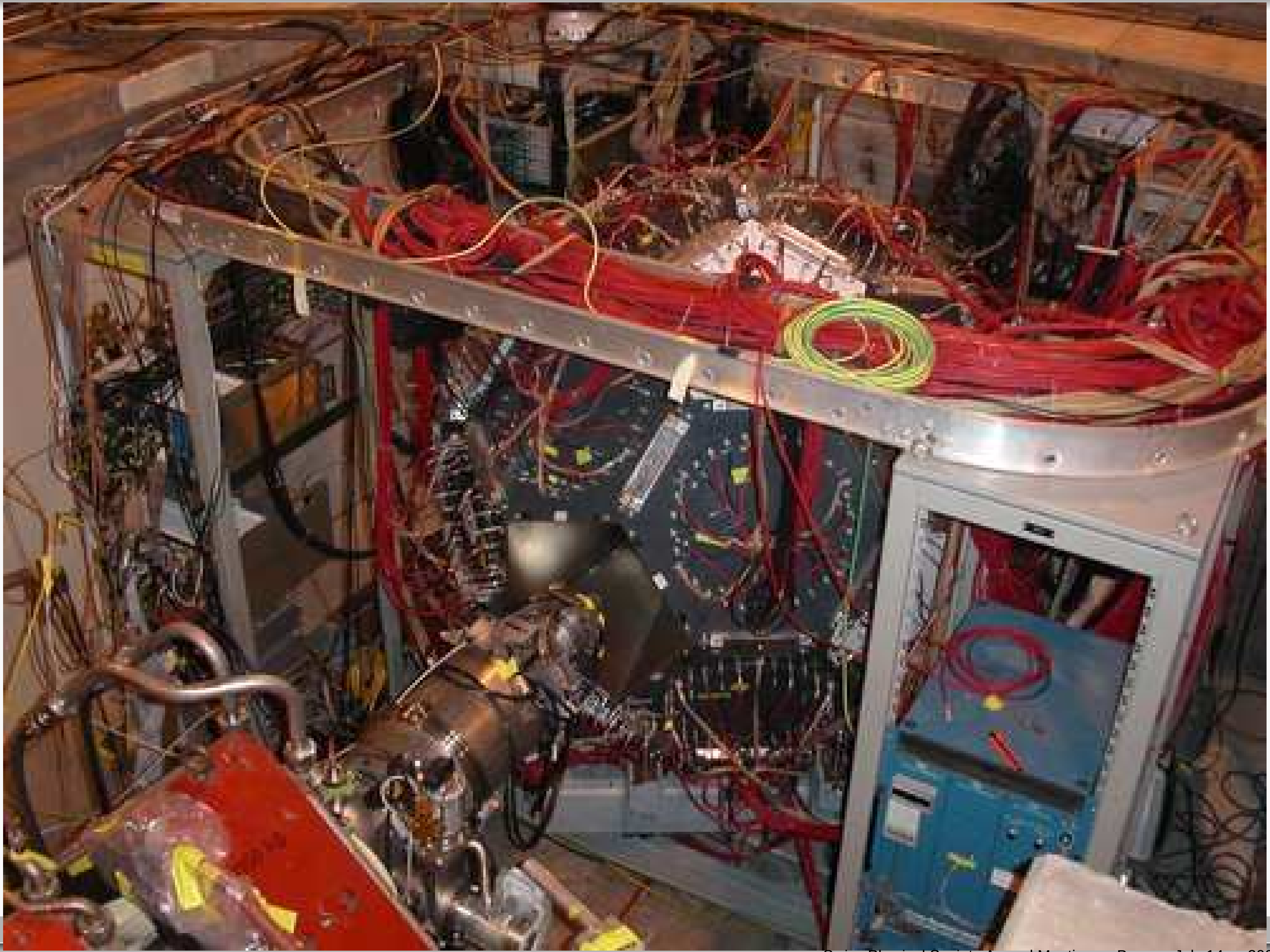
The complete detector has 30 active “houses”, with 170 tile pairs

The Crew



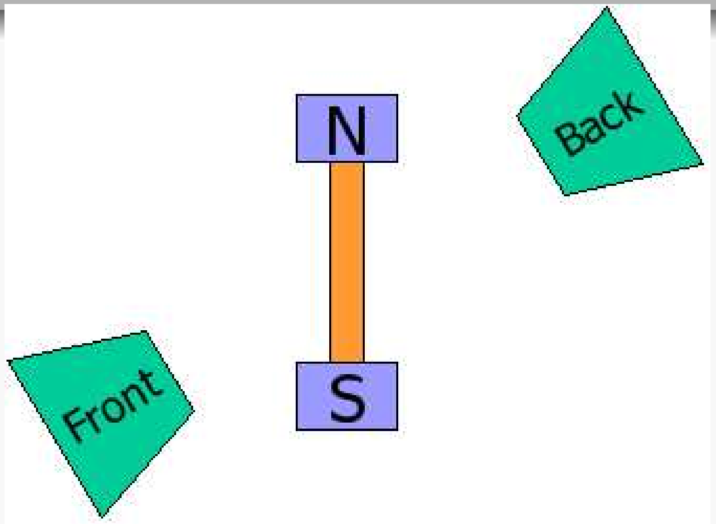


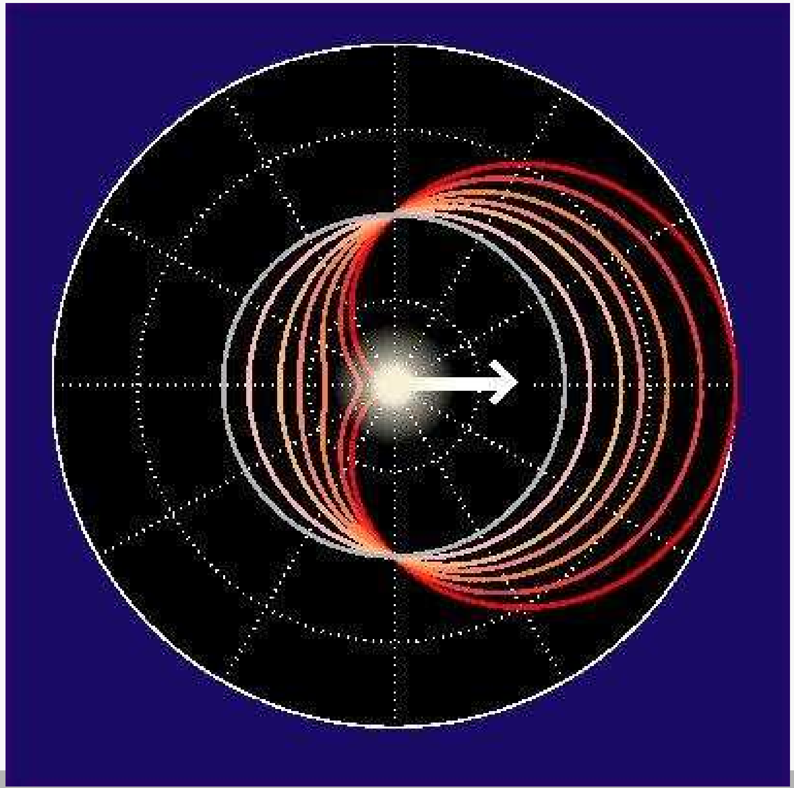
The Detector in Area



Impact of muon spin rotation (μSR)

- The muon beam is polarized $\Longrightarrow$ muon precesses in magnetic field
- Decay e^+s are preferentially emitted in the direction of the μ^+ spin.
- Residual polarization effects will produce direction-dependent distortions in the μ^+ lifetime histograms.
- Pointlike symmetric geometry
  - Fit $F + B$
  - Monitor $F - B$





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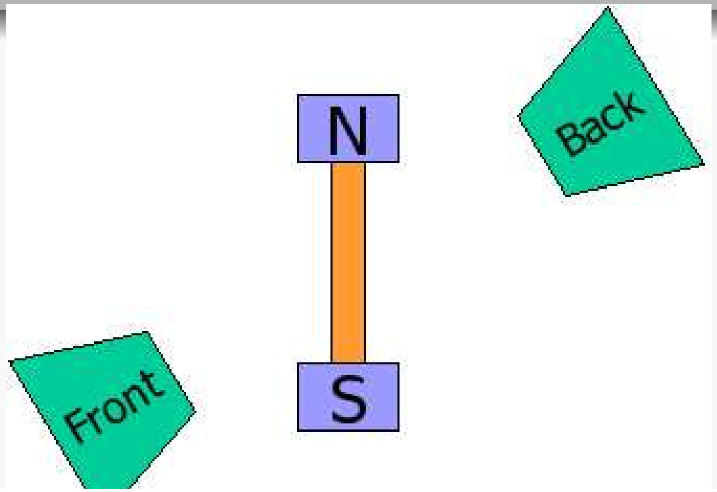
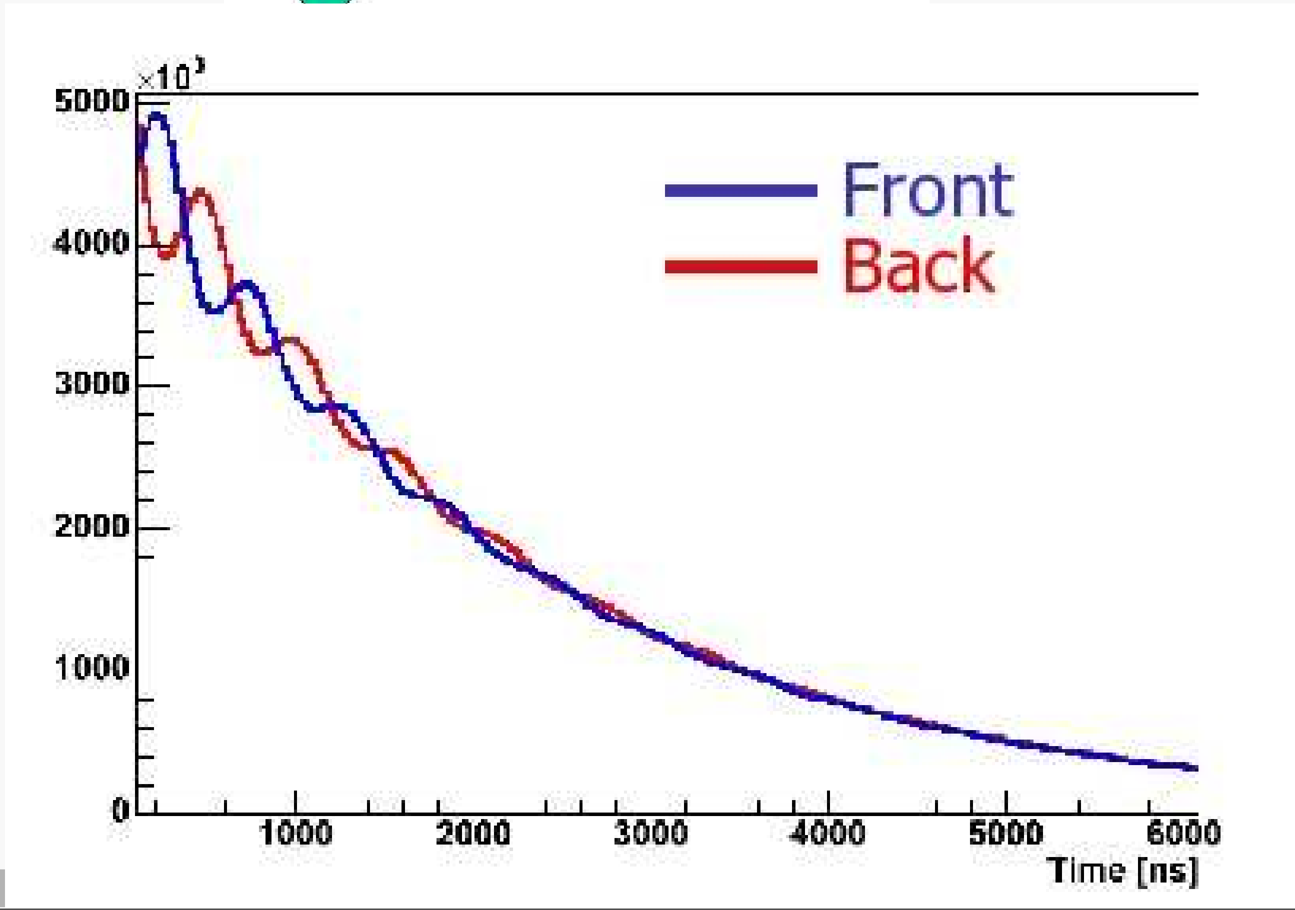
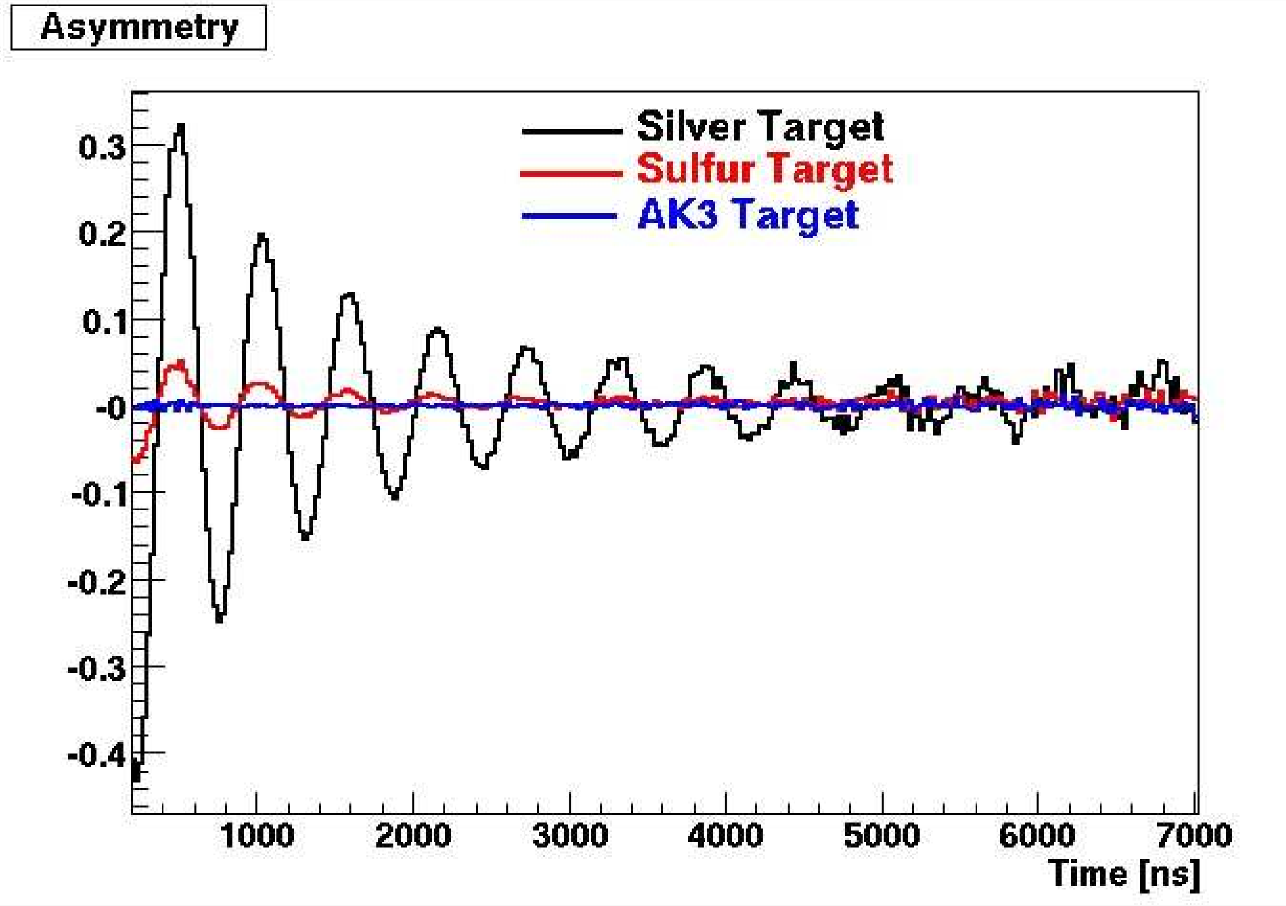




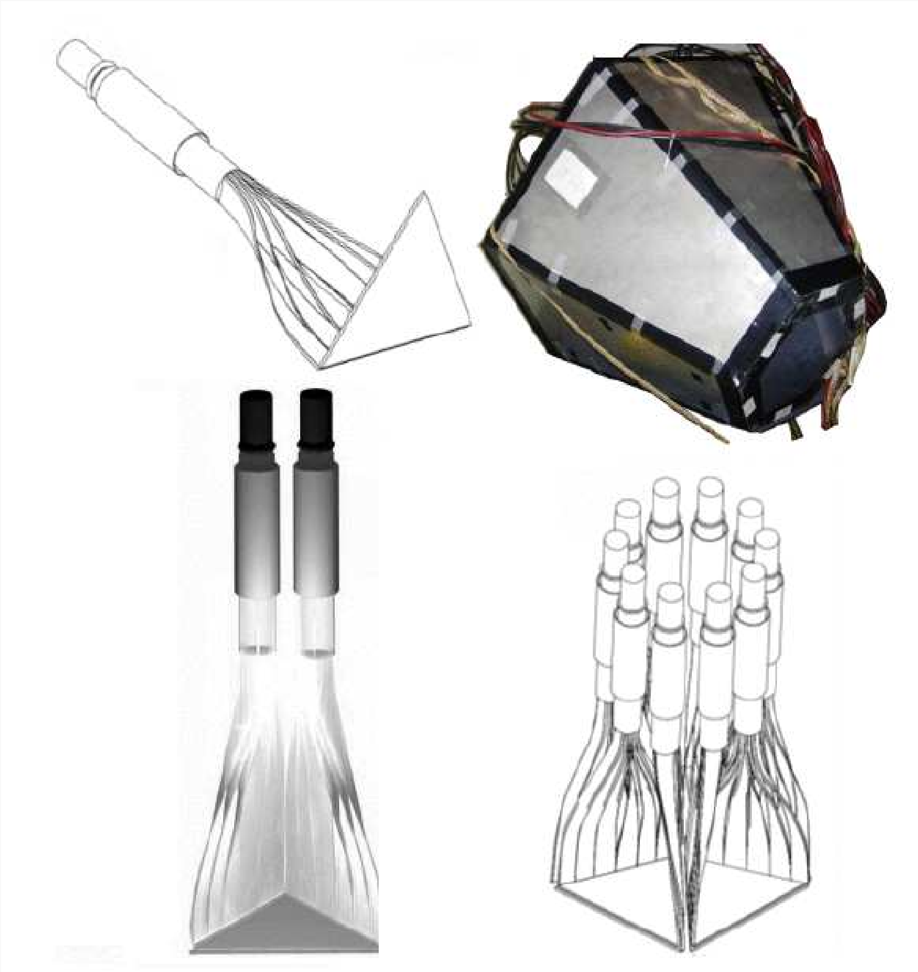
Impact of muon spin rotation (μSR)

- $\surd$ Silver
  preserves muon polarization (100%)
- $\surd$ Sulfur
  residual polarization (8%)
- $\surd$ Arnokrome-3 (AK3)
  - ◇ (30% chromium, 10% cobalt, 60% iron)
  - ◇ Internal Field $\approx$ 1 T
  - ◇ No observable precession frequency up to 320 MHz or $< B >= 2.4$ T

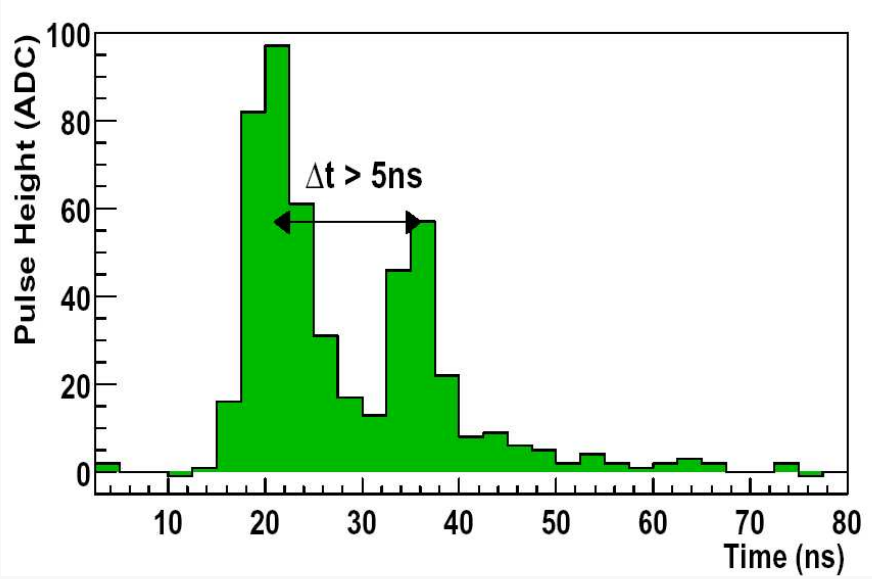


Double-Pulse Resolution - Hit Pileup

detector modularity:
170 tile pairs

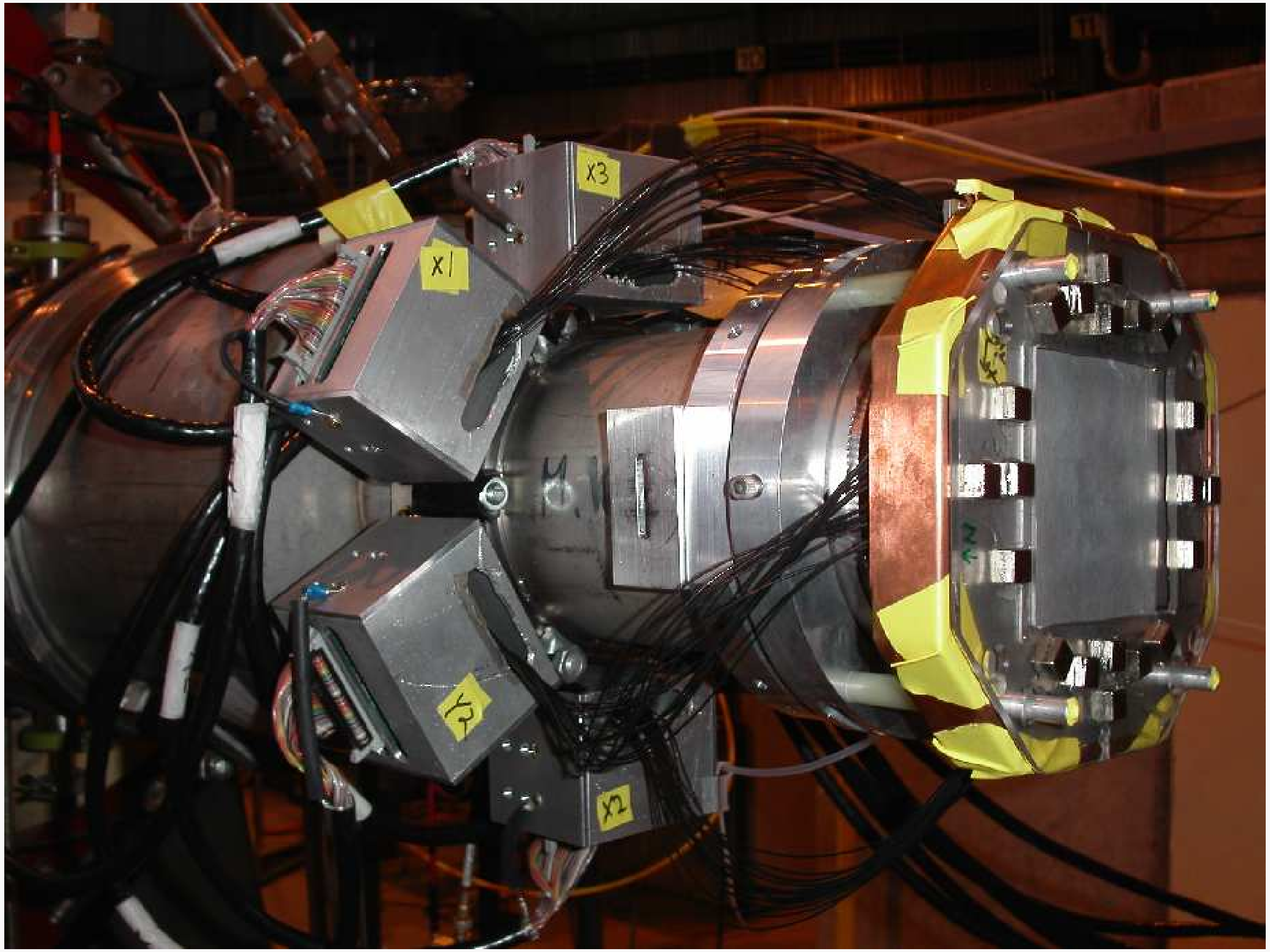


new electronics:
500 MHz wave form digitizers



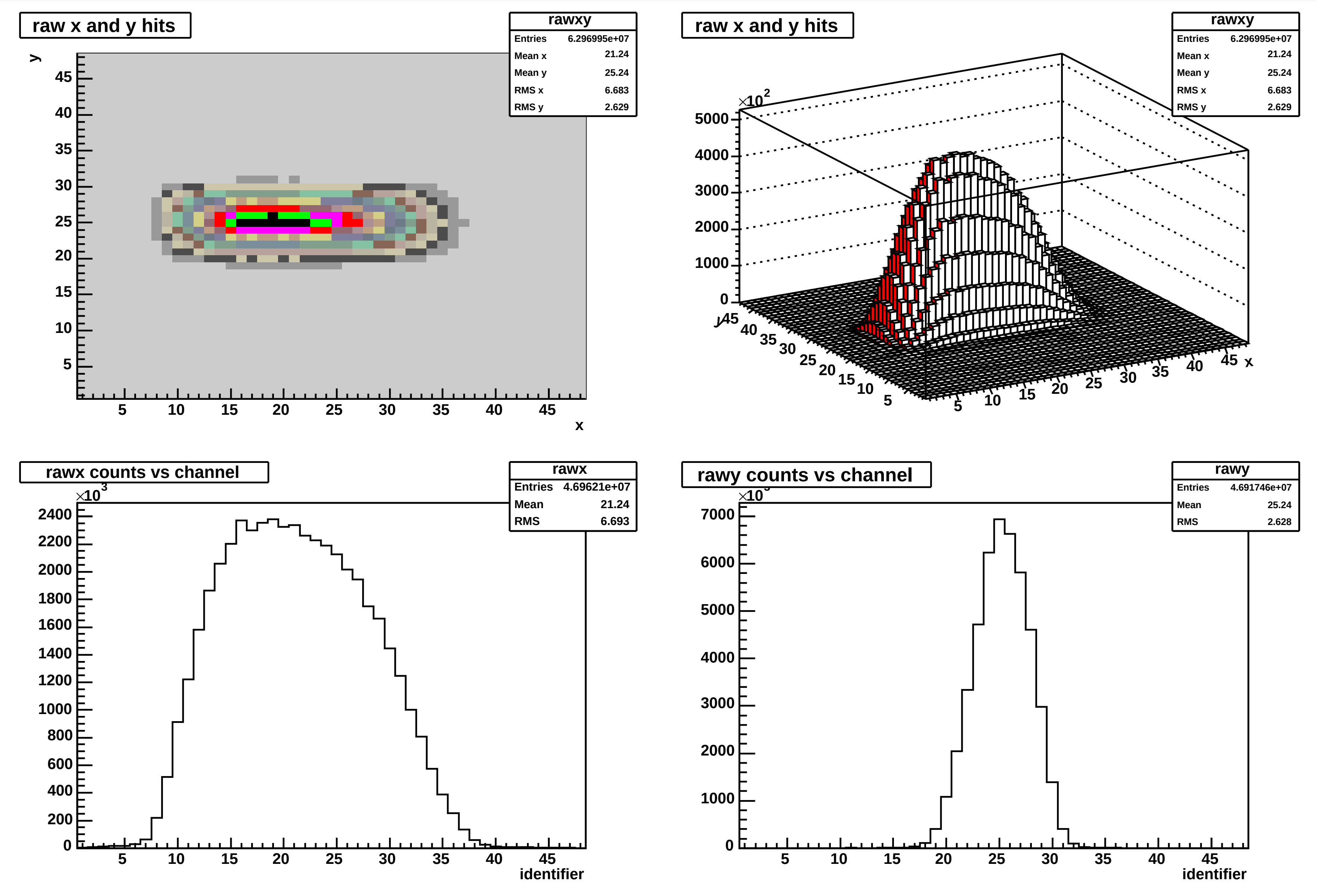
"Sneaky Muons"

During beam-off period sneaky muons lead to time dependent background



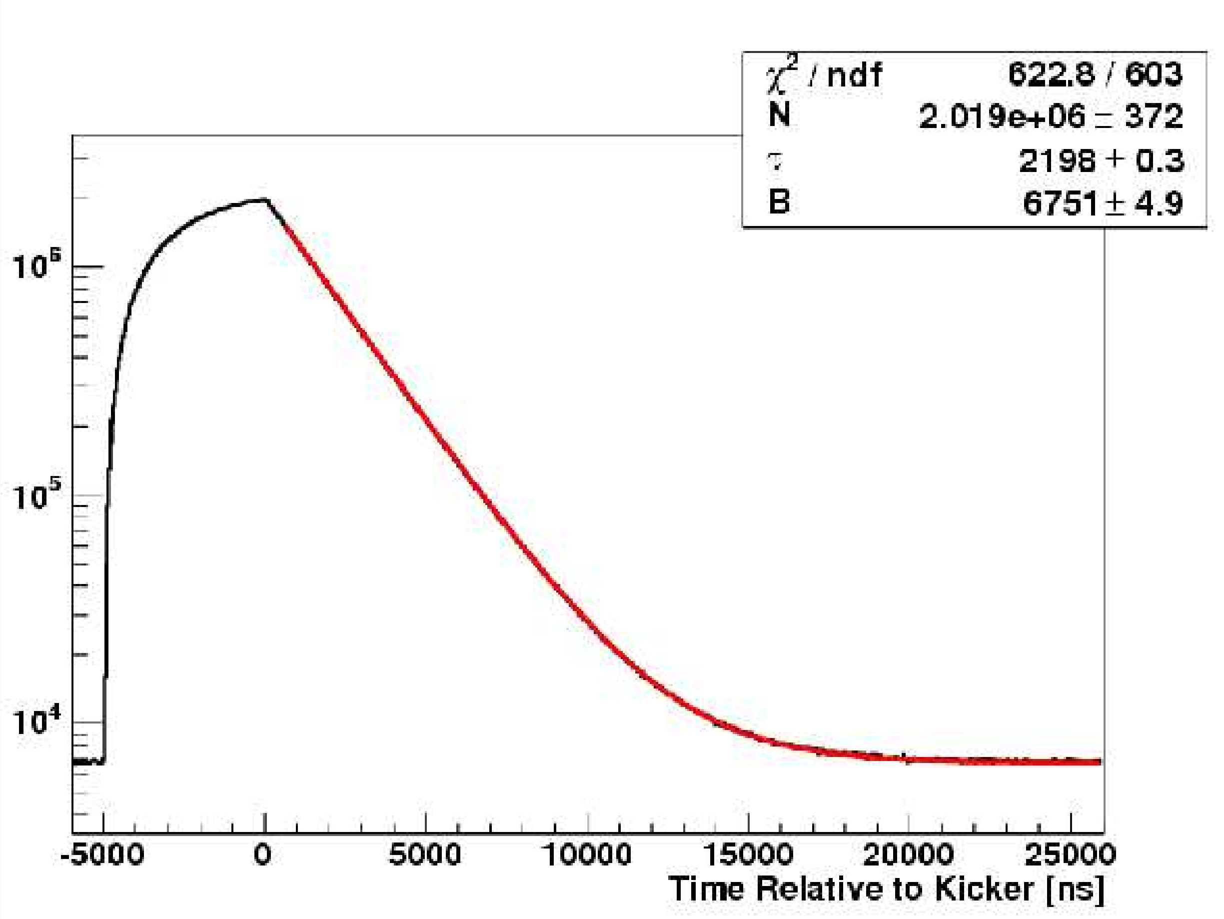
high rate (MHz), thin, fast (30 ns FWHM) wire chamber
Efficiency $>$95%, stable within 5%
Active Area 94×100 mm

Beam Profile



First physics fits

(the clock timescale is only approx in ns . . . and they don't know the offset)



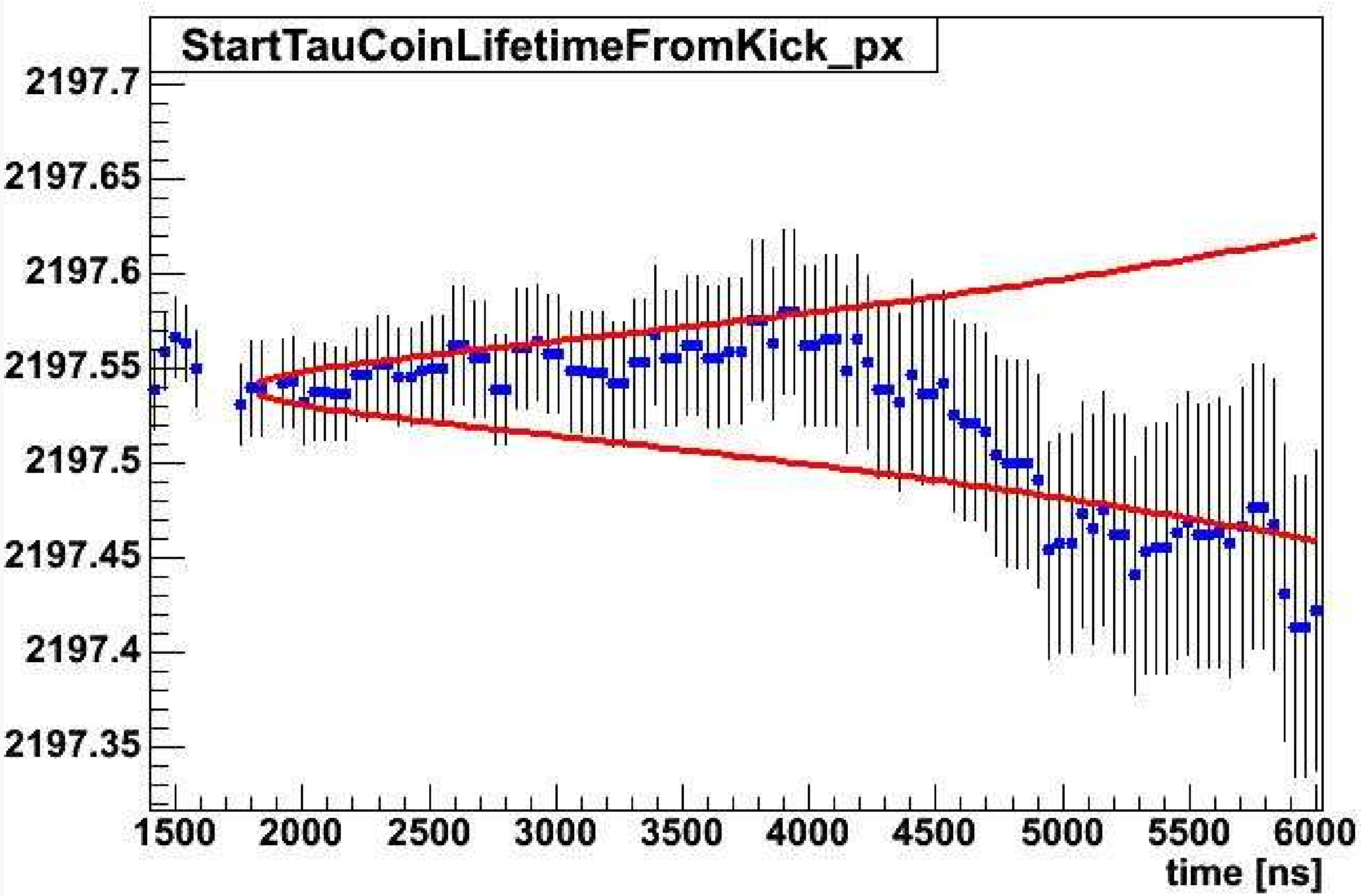
All kicked data summed up without too much screening

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

Better than 10 ppm and good, stable fits (so far)

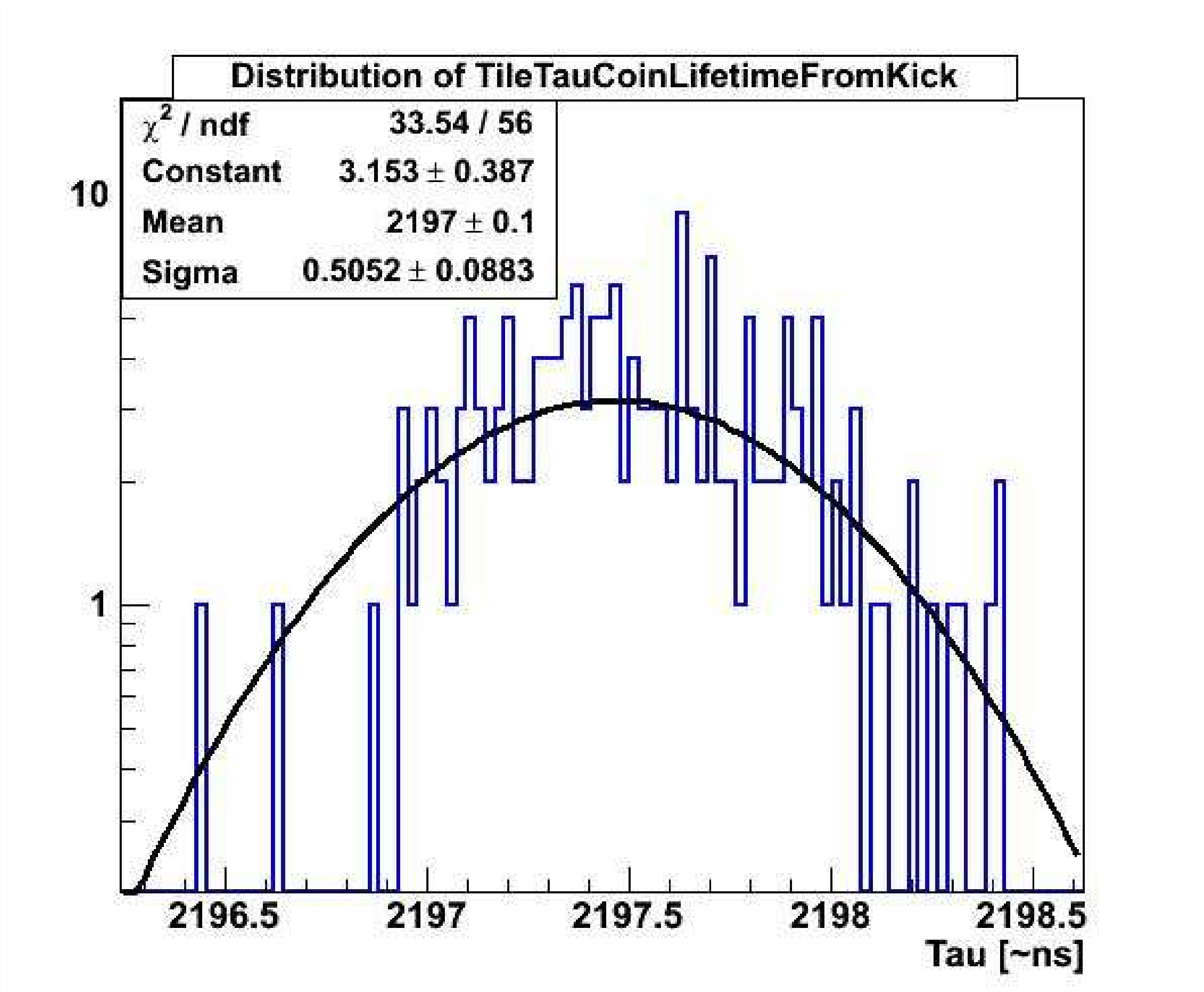
Fit Stability

Stability of fit parameters versus fit start time is a good barometer of fit quality



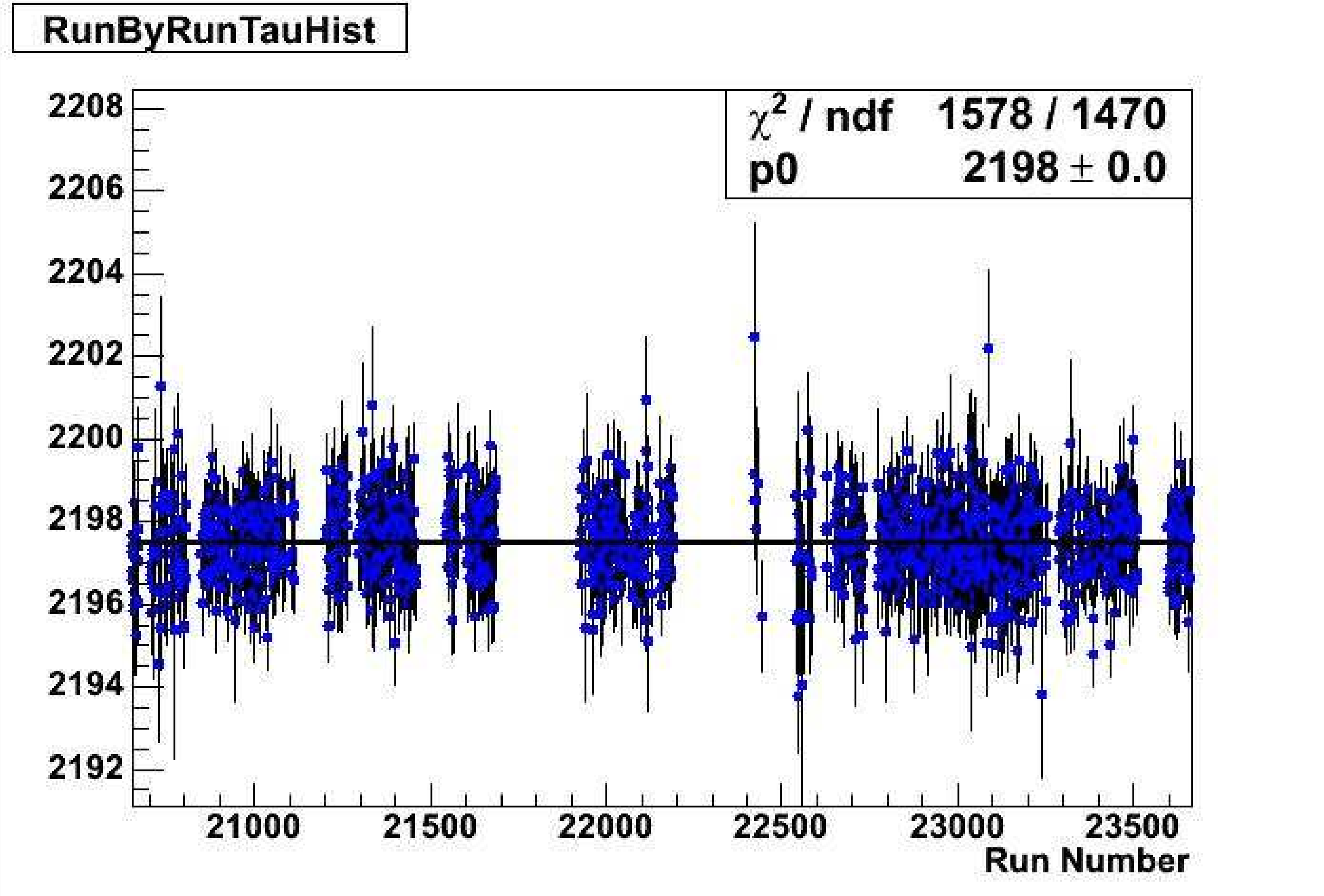
Fit Stability

Also important, behavior of different detectors . . .



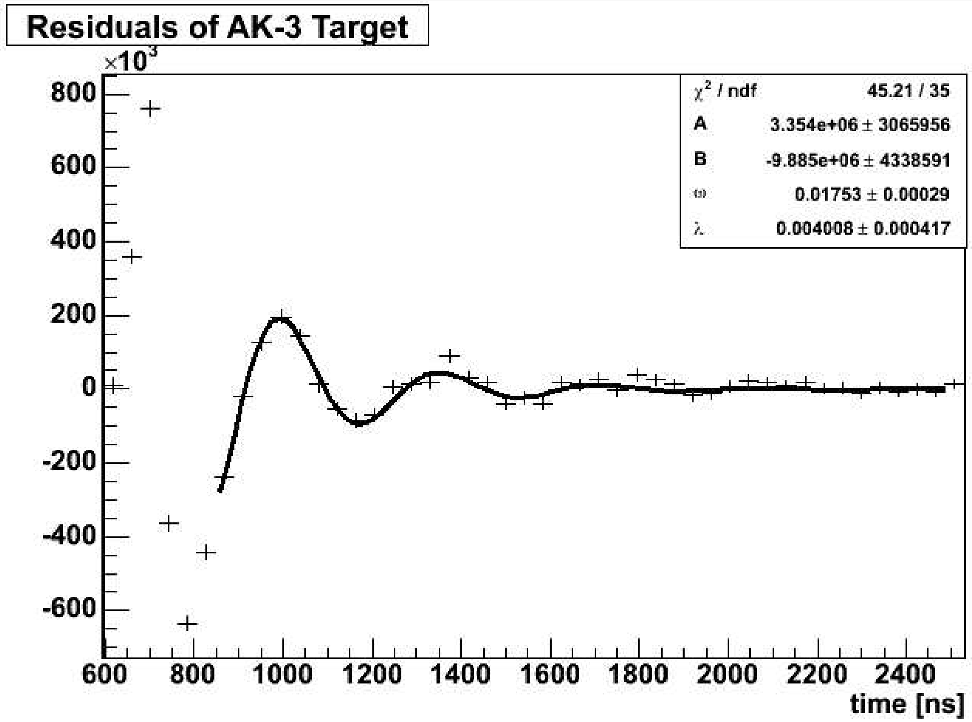
Fit Stability

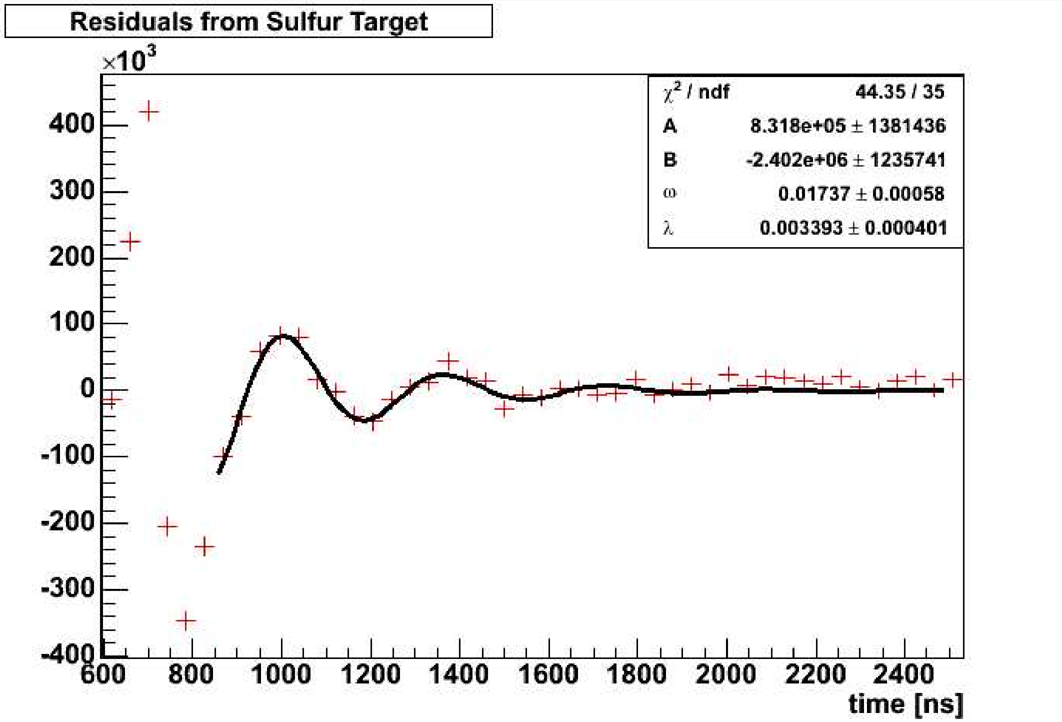
. . . and by run number, but . . .



Fit Stability

. . . These fits started about 1.8 μs after kicker off because of a nasty ripple in the data, probably from the kicker, but we are not sure yet . . . we will figure it out





Conclusion on data:
We are hoping for a 5–10 ppm result by the end of the summer

MuLan Future plans

- √ June 2005:
  - ◇ Beam Tuning:
    - $\longrightarrow$ Improve Rate
    - $\longrightarrow$ Improve Extinction Factor
  - ◇ Many combinations were studied. Improvement achieved.
- √ Fall 2005:
  - ◇ First Run with waveform digitizers
  - ◇ New Run with the improved kicker
- √ 2006:
  - ◇ Major production run with waveform digitizers
  - ◇ Full proposed $O(10^{12})$ statistics

MuLan Collaboration

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