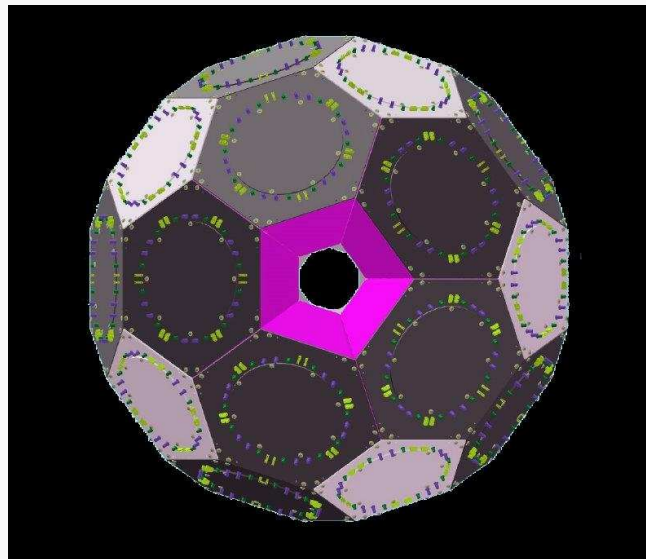


MuLan Experiment Progress Report

PSI Experiment R-99-07

Françoise Mulhauser, University of Illinois at Urbana-Champaign (USA)



**The MuLan Collaboration: BERKELEY – BOSTON – ILLINOIS – ITU – JAMES MADISON –
KENTUCKY – KVI – PSI**

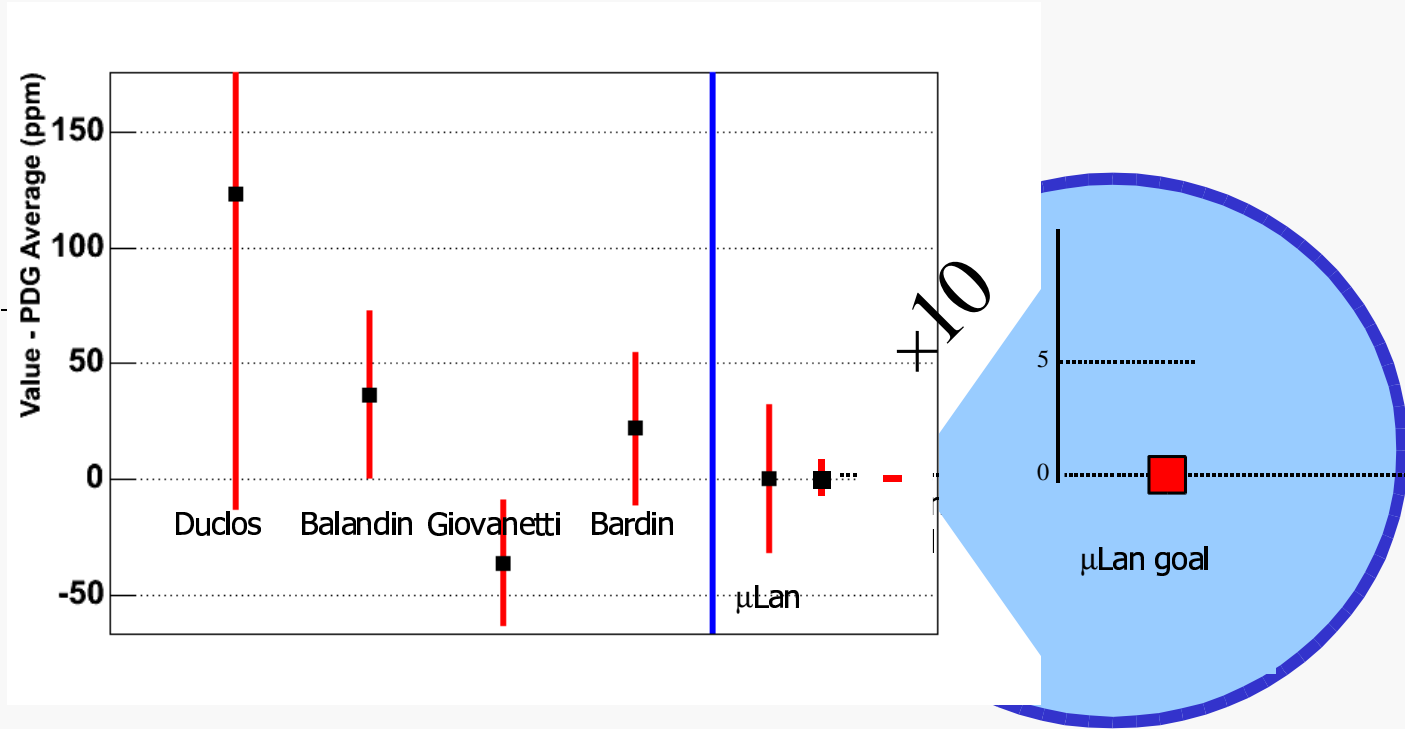
Successes

- ✓ Extinction factor > 1000 and rate of 7 MHz.
- ✓ Kicker worked flawlessly.
- ✓ EMC was readout by a custom FPGA.
- ✓ Ran with online monitoring system.
- ✓ All 340 WFD channels were used.
- ✓ More than 8×10^{10} positron decays were obtained in 2 weeks.

To do

- ✓ Finalize the WFD firmware
- ✓ Reach $> 1 \times 10^{12}$ positron decays

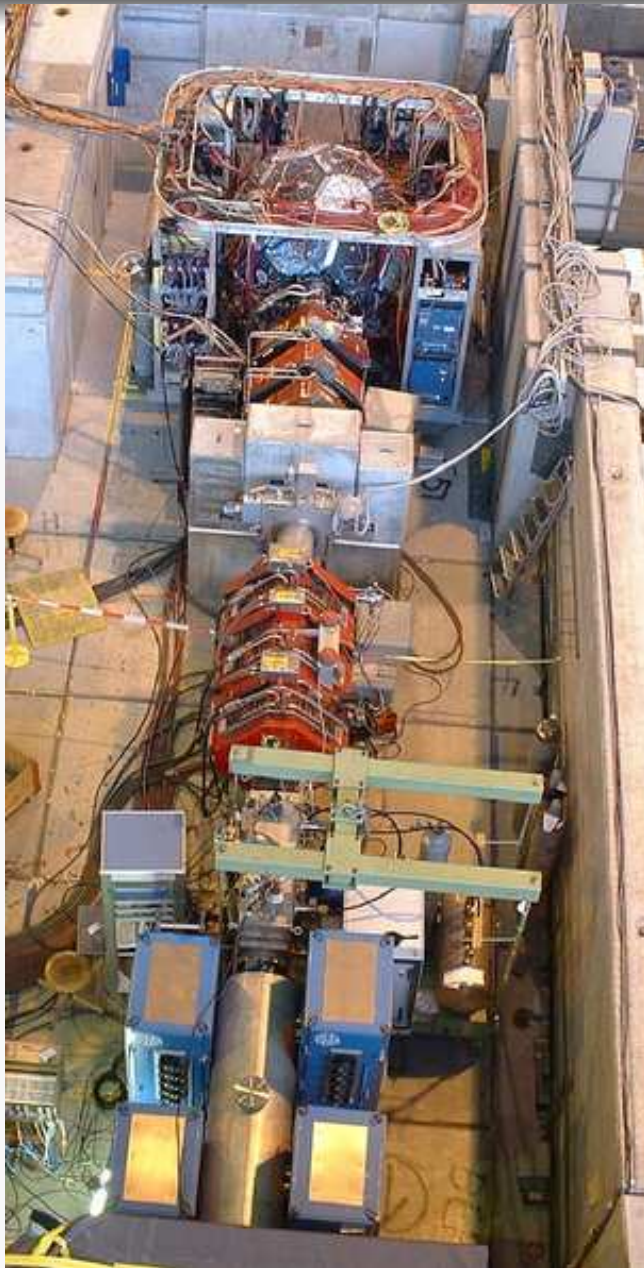
Experimental status



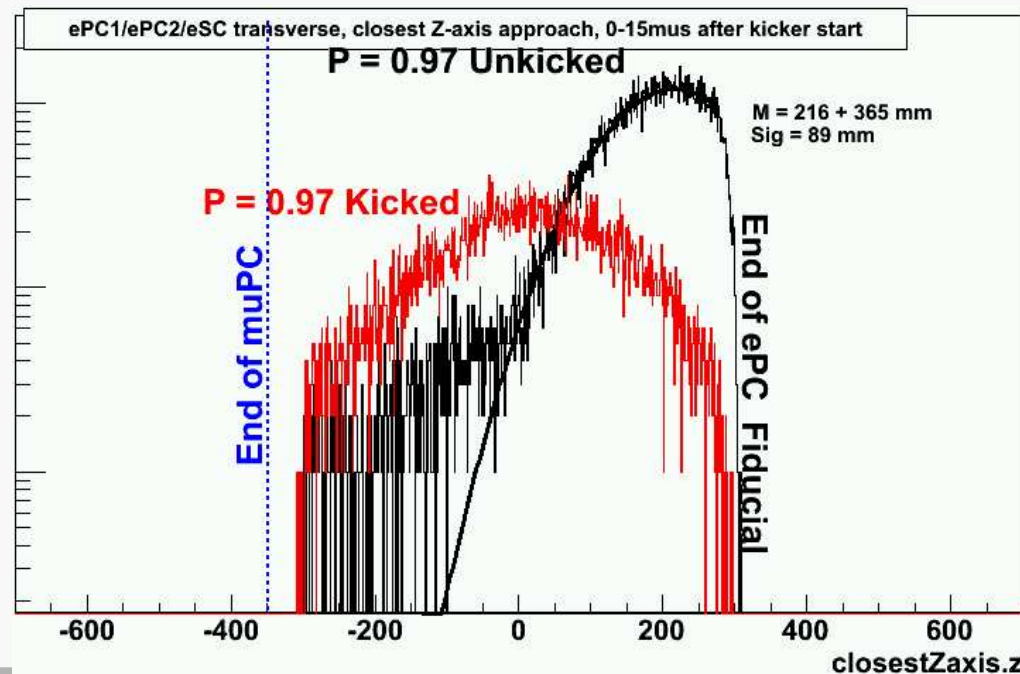
- ✓ Experiments mostly statistics limited
- ✓ PDG: $\tau_\mu = 2.19703 \pm 0.00004 \mu\text{s}$ (18 ppm)
- ✓ Our goal: 1 ppm uncertainty in τ_μ (0.5 ppm in G_F)

$$\frac{\delta G_F}{G_F} = 4 \frac{m_{\nu_\mu}^2}{m_\mu^2} - \frac{5}{2} \frac{\delta m_\mu}{m_\mu} - \frac{1}{2} \frac{\delta \tau_\mu}{\tau_\mu}$$

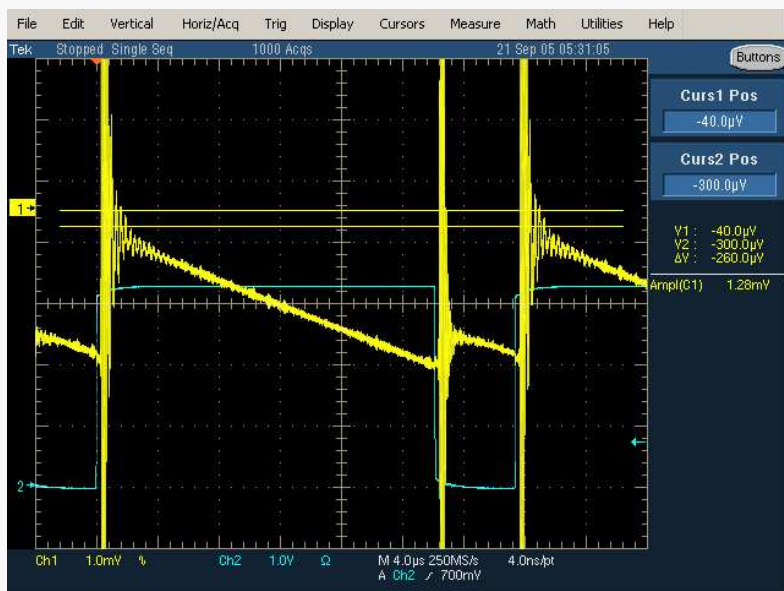
Beamline & June beam tests



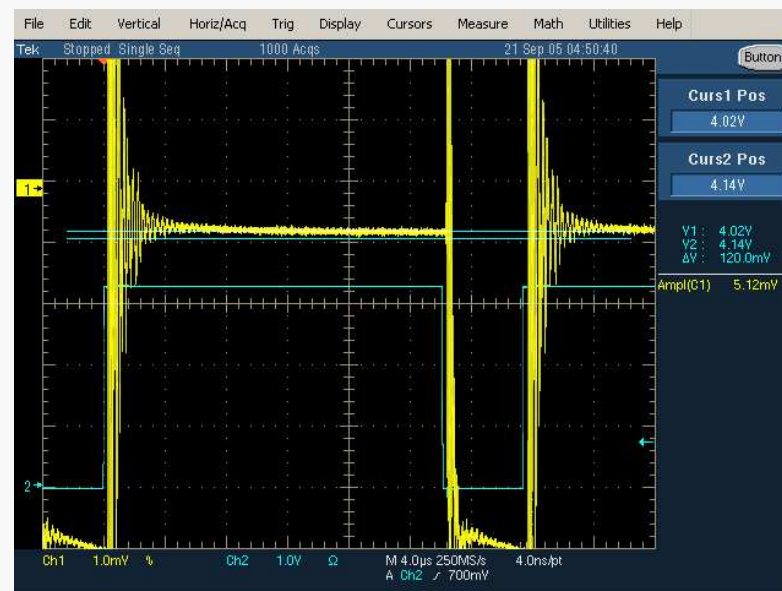
- ✓ Kicker first mode
- ✓ Reduce the kicker gap from 15 cm to 12 cm
- ✓ Muon flux up to 7 MHz with $EF > 1000$
- ✓ Low momentum tail, already seen in 2004, confirmed in 2005
- ✓ Few per 1000 muons will stop before the target



Kicker Status: ready and OK

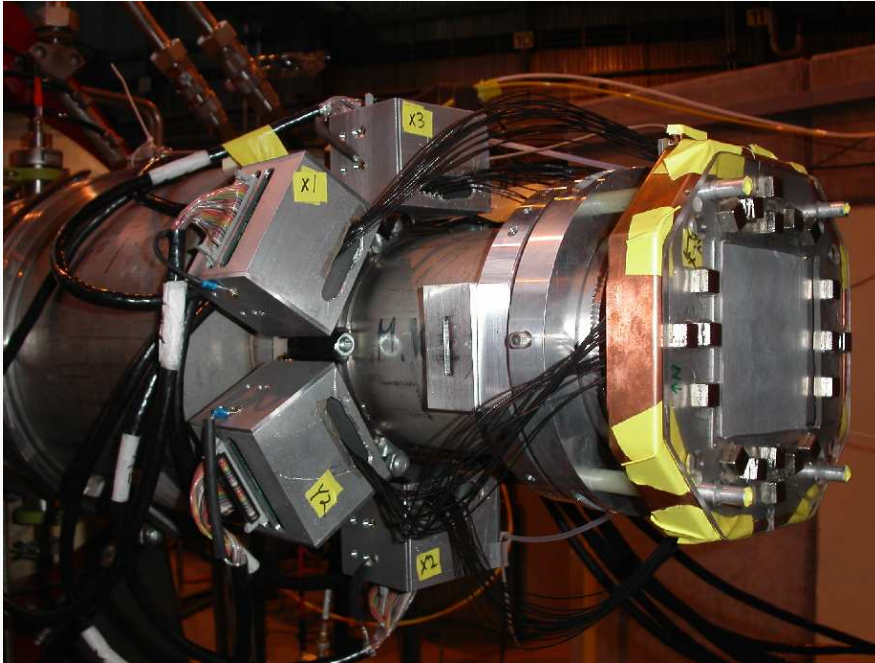


- ✓ Noise problems solved in 2004
- ✓ HV breakdown solved in 2005
- ✓ MOSFET cards failure solved in 2005
- ✓ Gap reduced from 15 to 12 cm

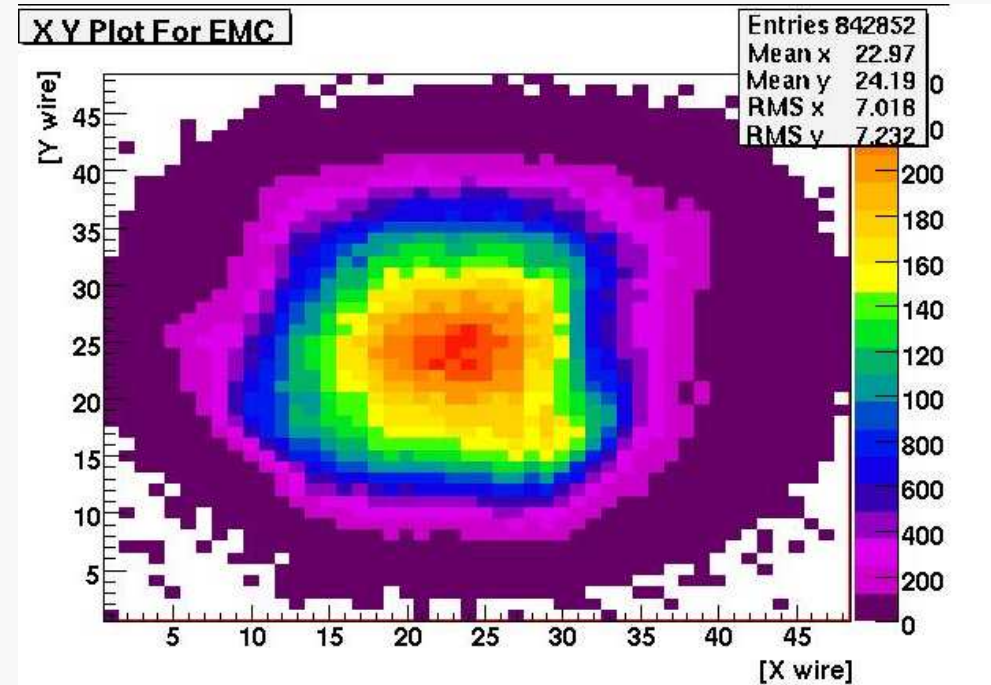


- ✓ Flatness 2.4×10^{-5} reached
- ✓ Kicker was **in action for 4 months** in 2005
- ✓ Over current system operational
- ✓ Two possible modes:
Fixed frequency or Muon on Demand

Entrance Muon Counter

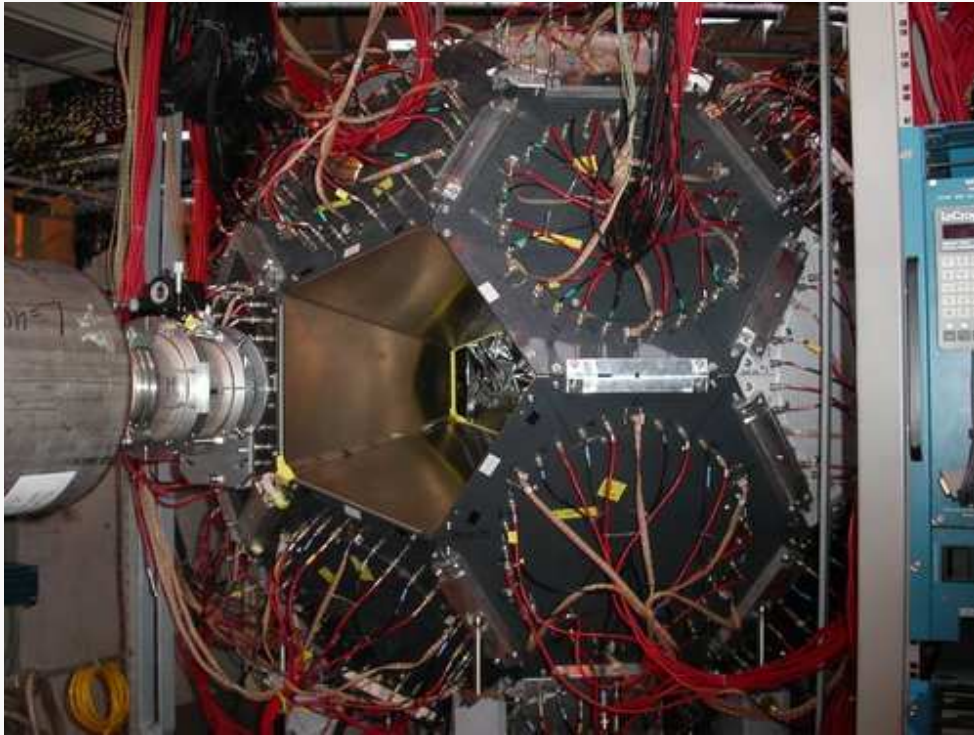


- ✓ 96 active wires on each plane
- ✓ 1 mm spacing
- ✓ reading every two wires
- ✓ resolution: 2 mm

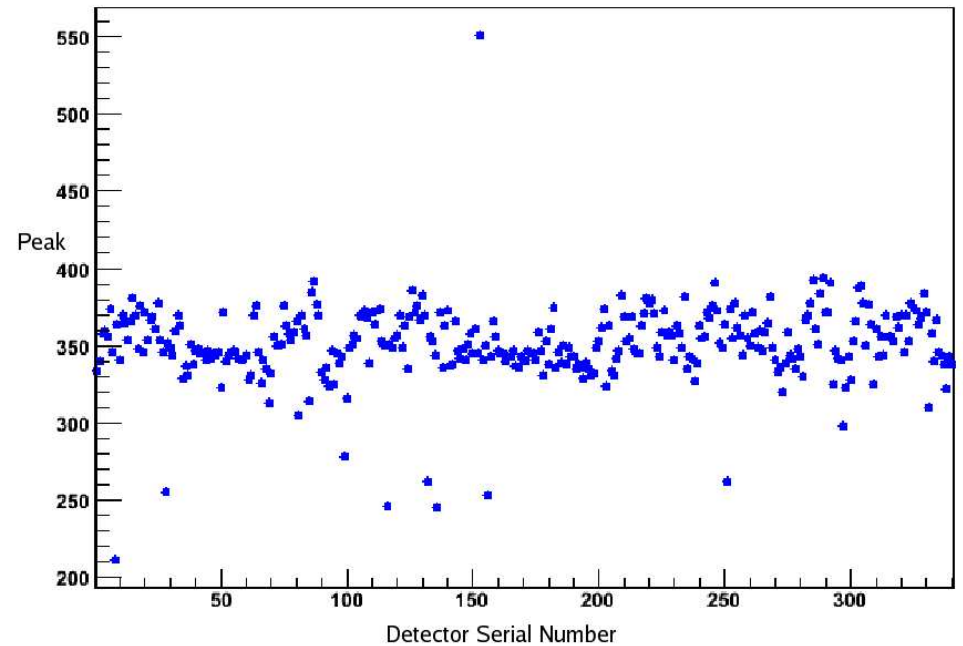


- ✓ Logic pulses between 40 and 100 ns long
- ✓ FPGA for time and position hits
- ✓ Accumulation: Prescaling
- ✓ Measurement: No-prescaling

Detector Ball

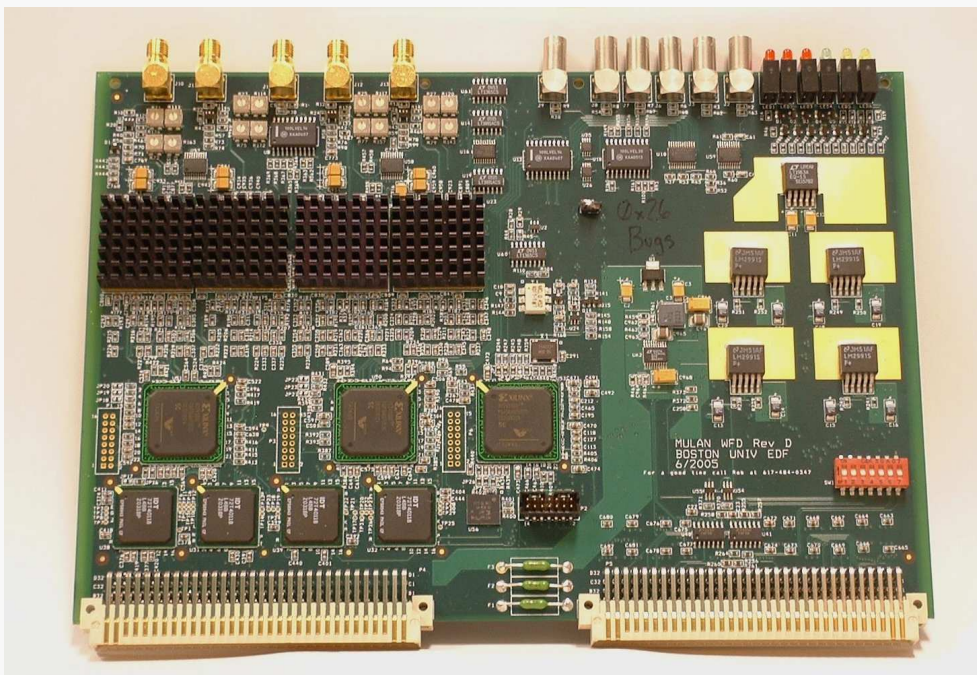


fit mpv vs. SN

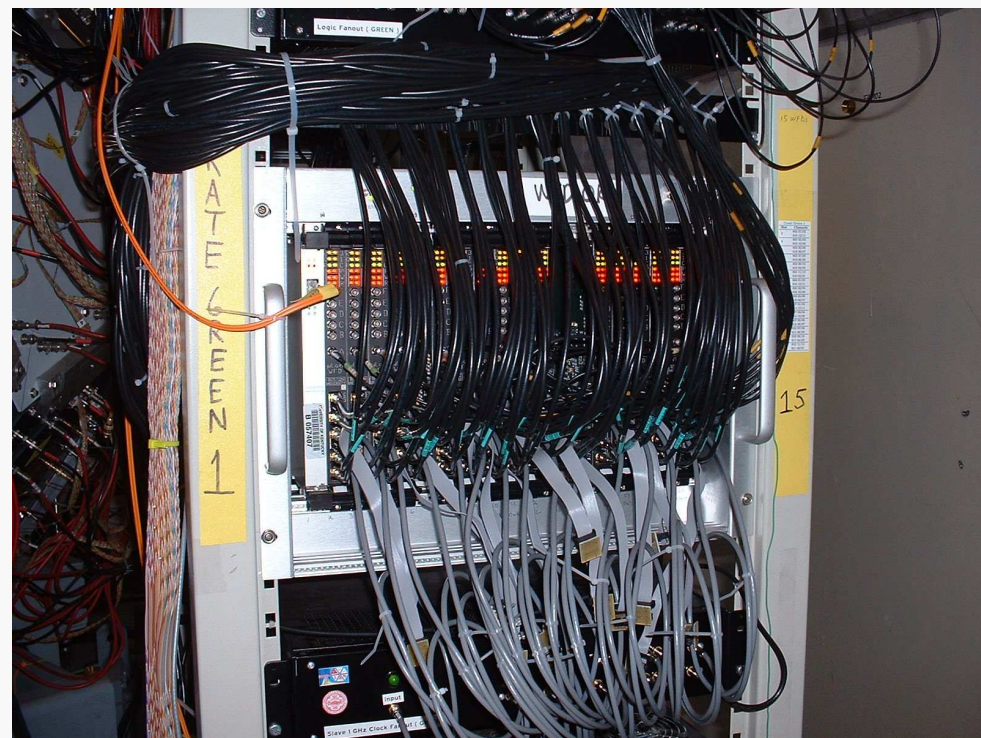


- ✓ Commissioned in 2003
- ✓ Operational since 2004
- ✓ 340 scintillators in 170 tile pairs
- ✓ Calibration, monitoring, and debugging of individual tiles is much easier since arrival of WFDs.
- ✓ The fitted peak for the minimum ionization energy deposited for all detectors, with all but ten at satisfactory values.

Waveform Digitizers



- ✓ four channels per board
- ✓ 500 MHz
- ✓ 64 bit wide data bus to VME
- ✓ inner and outer tiles as well as opposite tiles on each board

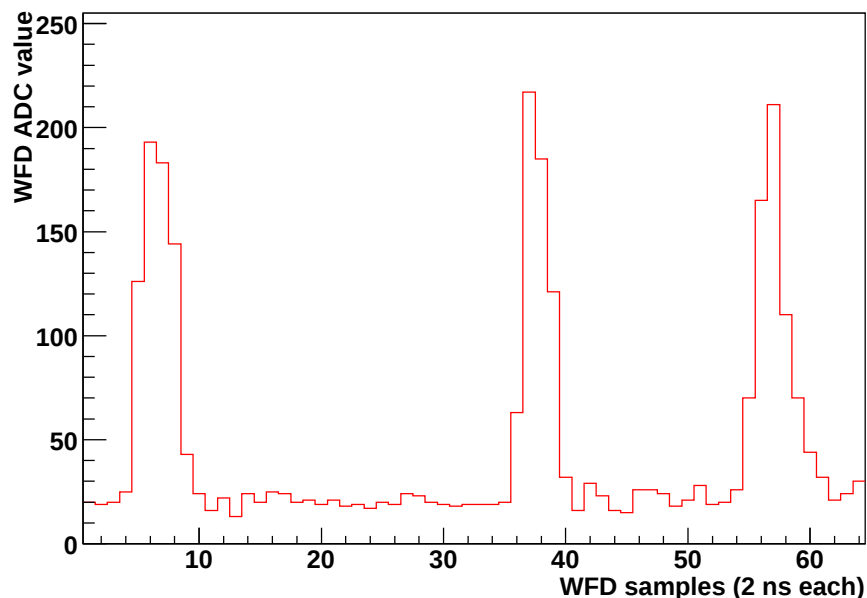


Three modes

- ✓ Oscilloscope: classical ADC
- ✓ Fill and Offset: internal timer with clock ticks: **MuLan**
- ✓ Large Time-word: same with 32 bit clock tick: **MuCap**

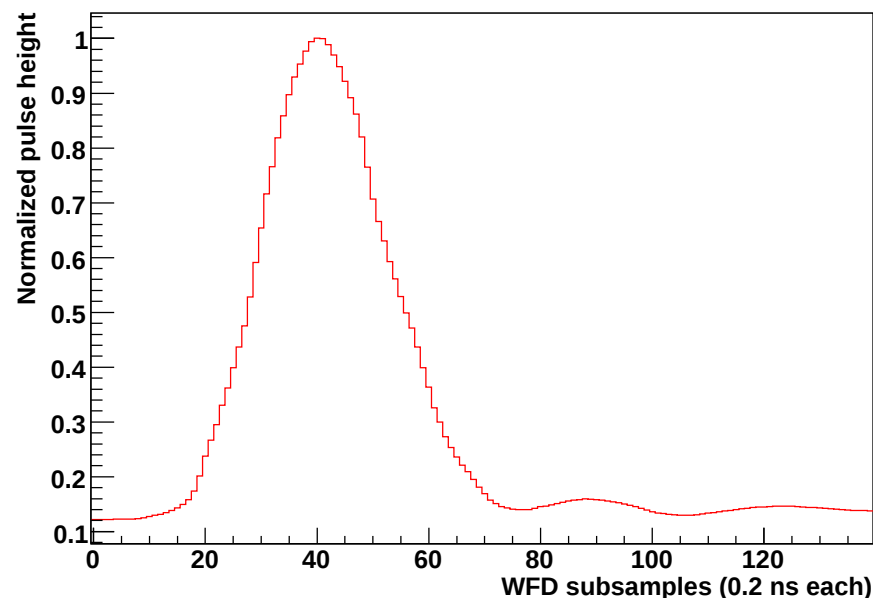
Waveform Digitizers Analysis

Waveform Digitizer trace



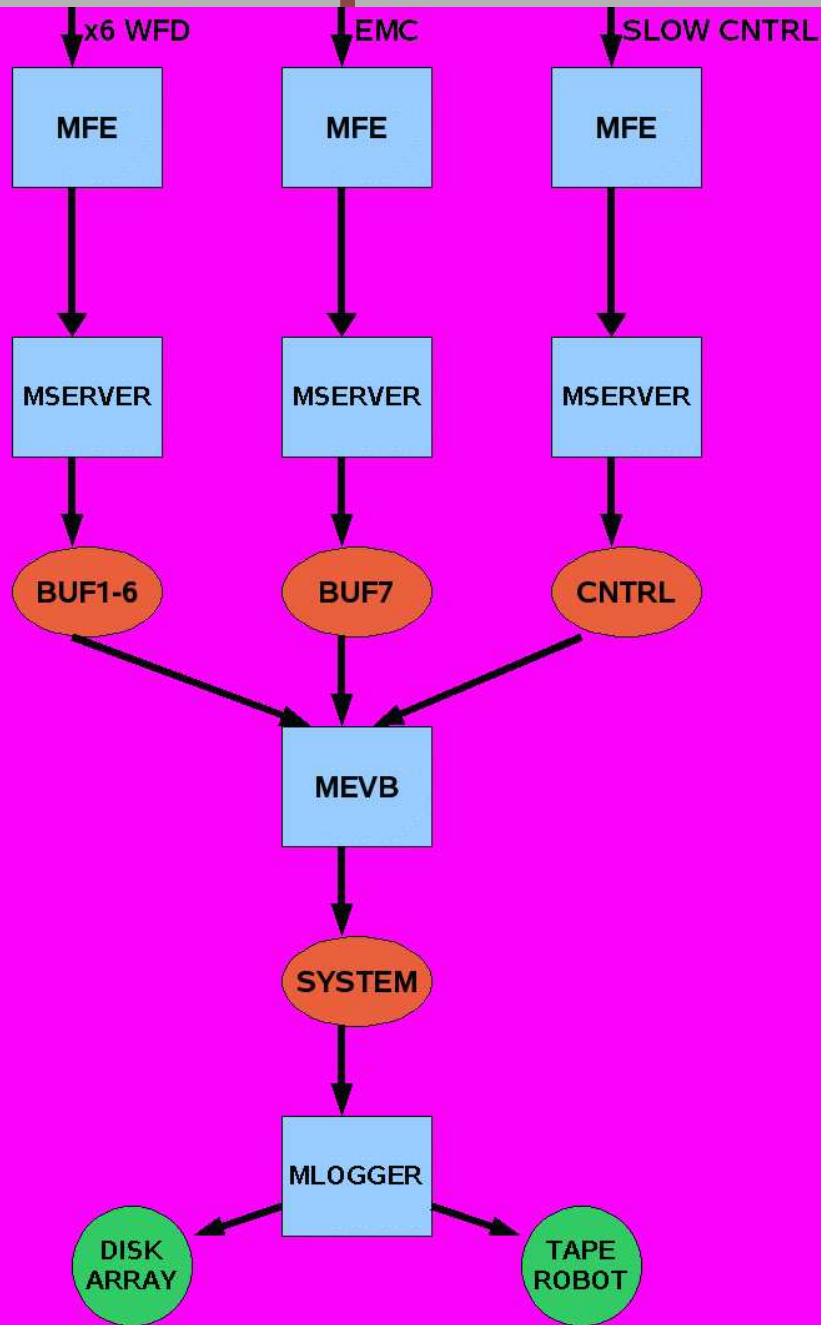
- ✓ Measure **time and energy** of each pulse
- ✓ Three pulses close together in one channel are easily distinguishable using waveform digitizers
 - ◇ Calibration made easy
 - ◇ Pileup visible
 - ◇ Baseline stability accessible

Average pulse for detector number 003



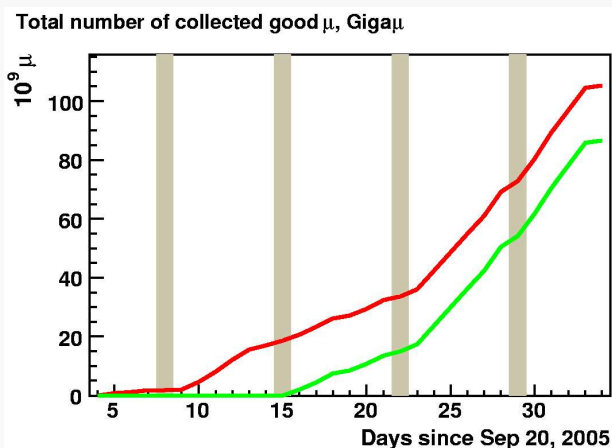
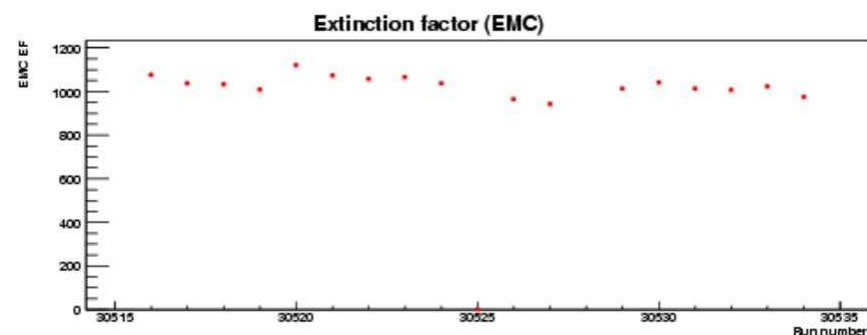
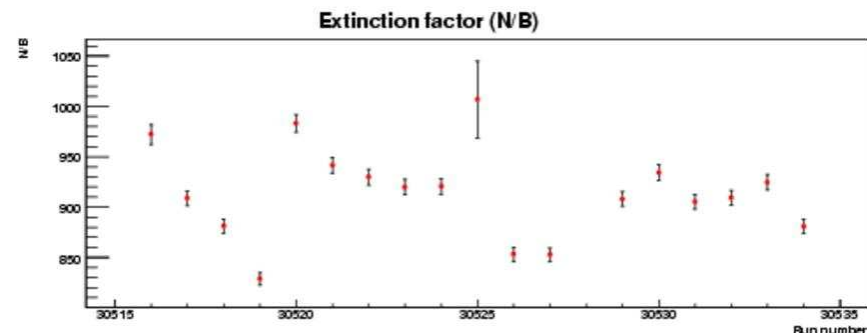
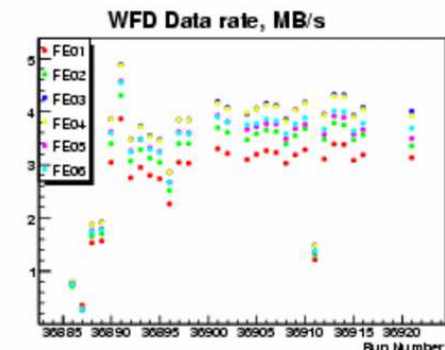
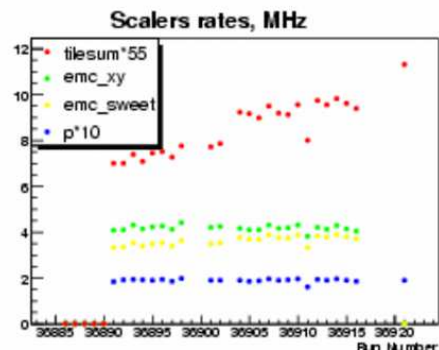
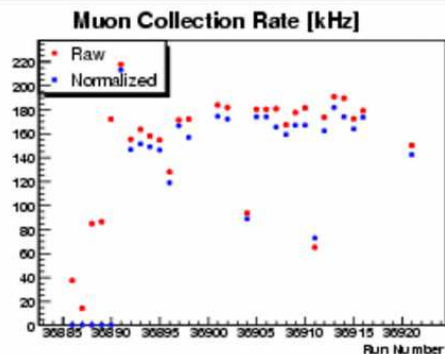
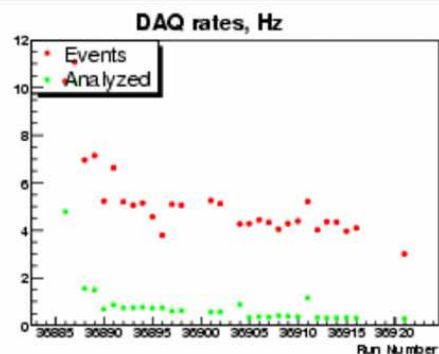
- ✓ The average pulse for one detector
- ✓ Determination of pulse height and times for the full data set
- ✓ Rejection when pulses are in disagreement with average one.

Data Acquisition



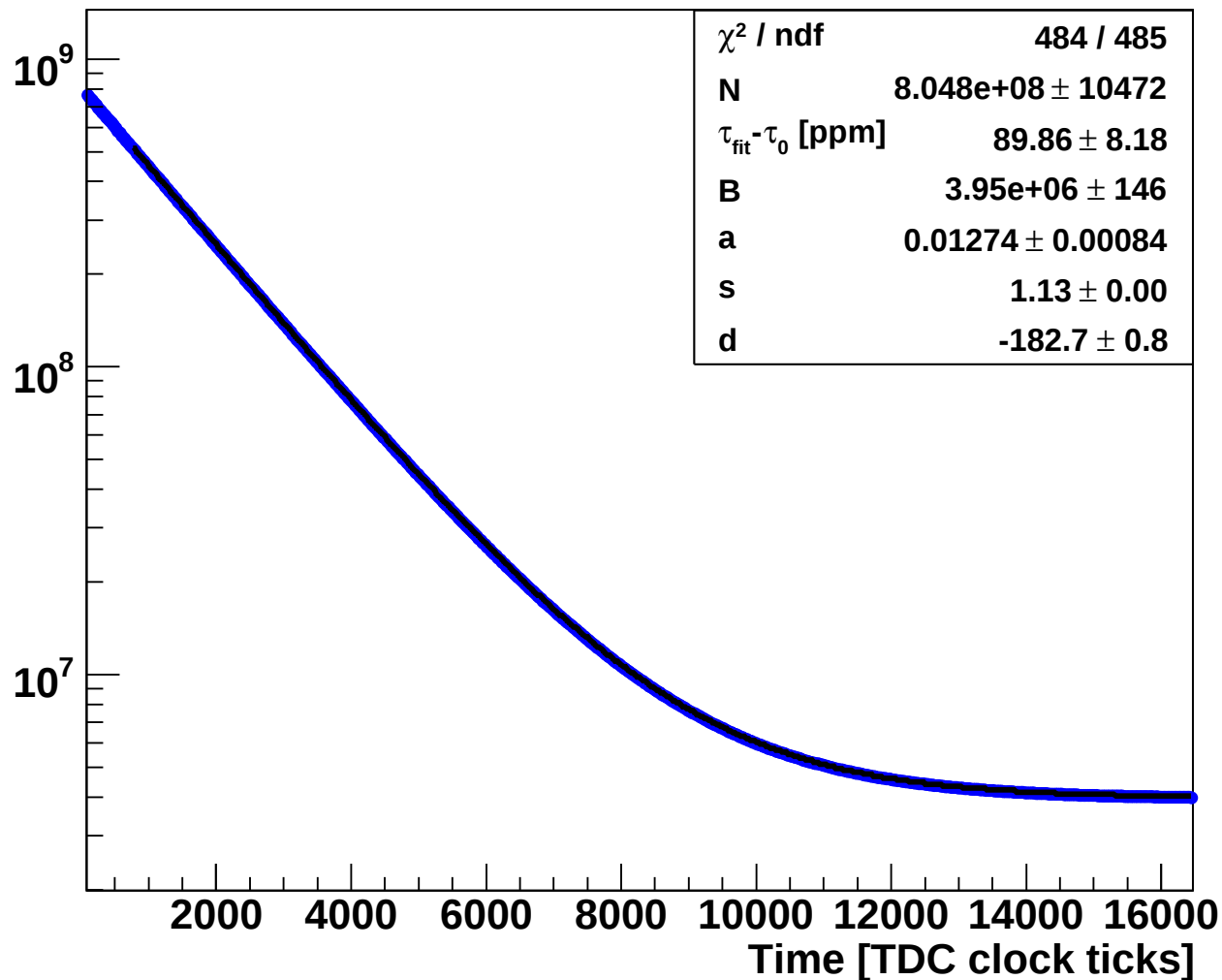
- ✓ Midas based
- ✓ Two new components: WFD & FPGA for EMC
- ✓ Front Ends and Back End toward Event Builder
- ✓ Very reliable
- ✓ Deadtime 50% in 2005, will reach 20% in 2006
- ✓ Run 2005: 16.5 TB. Expect 100 TB for the final data set

New Online Monitoring System



- ✓ We estimate at least 8×10^{10} good muon decay positrons were collected.
- ✓ Additional analyzer extracts the parameters for data quality. (Dead channels, extinction factor, data collection rate)

2004 Analysis

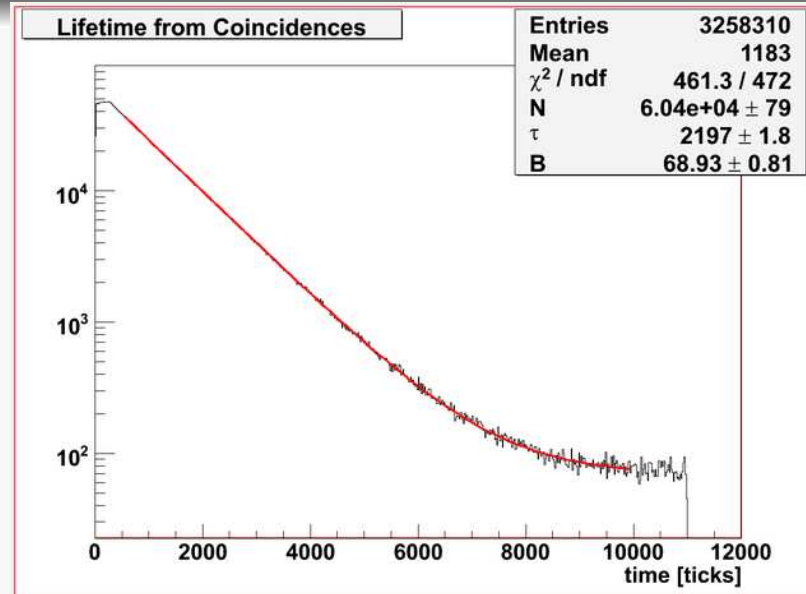


Full statistics lifetime histogram with fit. The fit parameter $\tau_{\text{fit}} - \tau_0$ shows the statistical precision of this data set to be 8.2 ppm.

2004 Analysis

	Done	Current Focus	To be done
Systematic Studies:			
Pileup and dead time effects	✓		
TDC timing shifts	✓		
Flatness of background		✓	
Polarization and corridor stops		✓	
Gain stability of PMTs (from 2005 data)			✓
Timing stability relative to event rate			✓
Consistency Checks:			
Tau vs. Fit start time	✓		
Tau vs. Target (AK3 and Sulfur)	✓		
Tau vs. Target magnet orientation	✓		
Tau vs. EMC magnet orientation	✓		
Tau vs. Extinction factor	✓		
Tau vs. Rate (limited range from 1 to 2 MHz)	✓		
Tau vs. Discriminator threshold	✓		
Tau vs. Detector		✓	
Tau vs. EMC events			✓

First glance at 2005 Analysis



	Done	To be done
Construct skeleton code	✓	
Develop new output data format	✓	
Reconstruct raw data into fills	✓	
Find average pulse shapes for each detector	✓	
Fit for pulse areas and times		✓
Set up large-scale analysis infrastructure		✓
Check for theta-phi effect present in 2004 data		✓
Check phototube gain vs time in fill		✓
Look for WFD hardware issues		✓

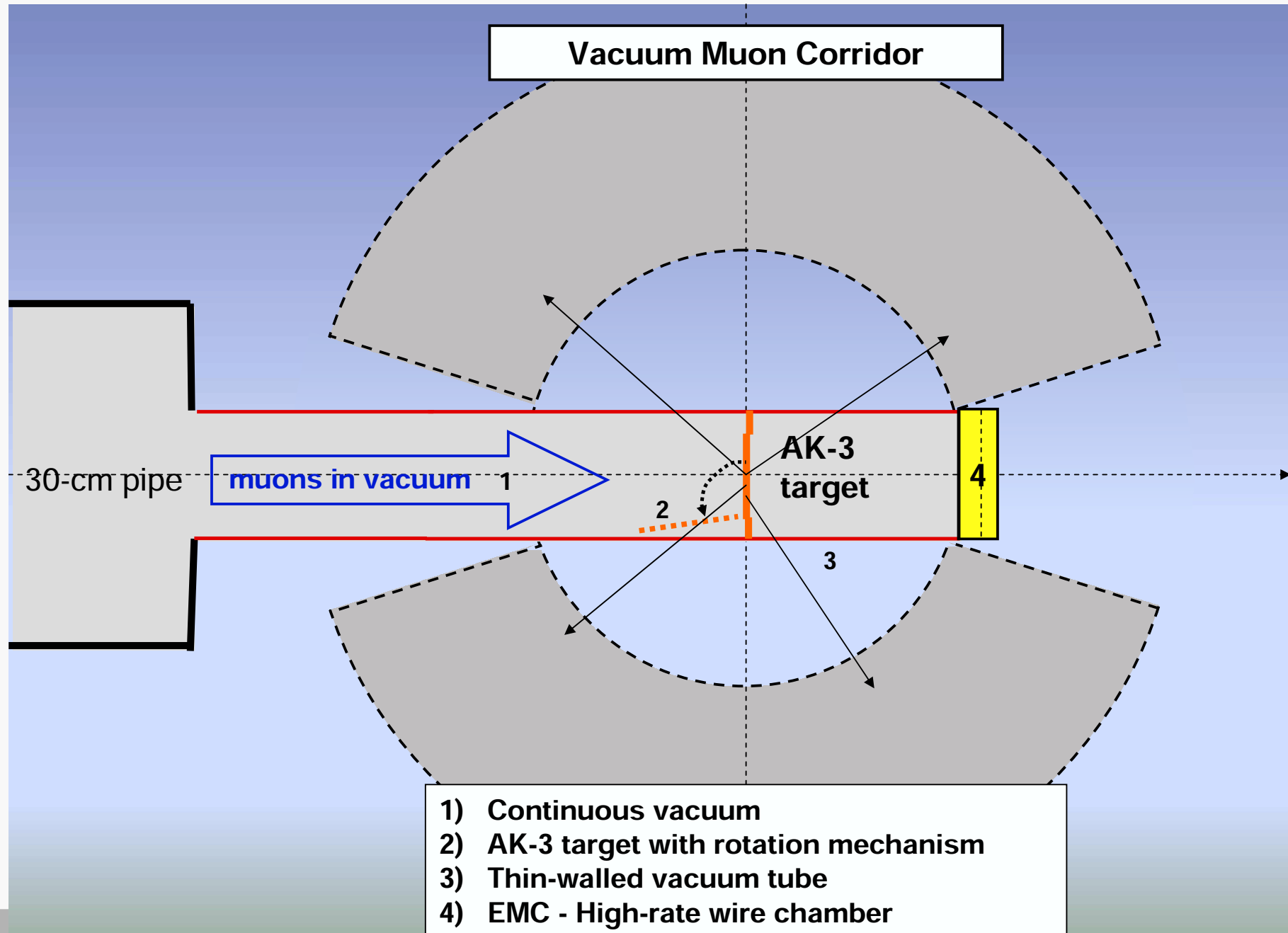
Actions Regarding Systematic Errors

Year	2004	2005	2006
Major Improvements	Kicker	Kicker HV /WFDs	Muon Corridor
Pileup	Discriminators 2 MHz $DT \geq 20$ ns	WFD 8Mhz $DT \leq 5$ ns	WFD 8Mhz $DT \leq 5$ ns
Gain and Ped. Shifts	Threshold Changes + 2005 Data	WFD data	WFD data
Background Flatness	Measured kicker stability $\sigma \sim 4$ ppm	Higher kicker voltage $\Rightarrow$ $\sigma \sim 0.5$ ppm	Same as 2005
Spin Precession+ Relaxation	MuCap Scans EMC/Target Polarity Intentional Early Stops	Same as 2005	Muon Corridor Upgrade
Statistical	~ 9 ppm	~ 5 ppm	1 – 2 ppm

Plans for 2006

- ✓ Finalize WFD **firmware** version
- ✓ Improve the DAQ
- ✓ Add new computers and storage
- ✓ Muon corridor

Muon Corridor Extension



Beam Request 2006 and Apparatus Change

User	Dates	Duration (weeks)
MuCap	April 5 - June 19	10.5
ALC	June 21 - July 24	4.5
MuLan	July 26 - October 9	10.5
ALC	October 11 - shutdown	9.5

- ✓ We request an Additional pumping station at the kicker side to allow the proper usage of all safety valves in the π E3 area