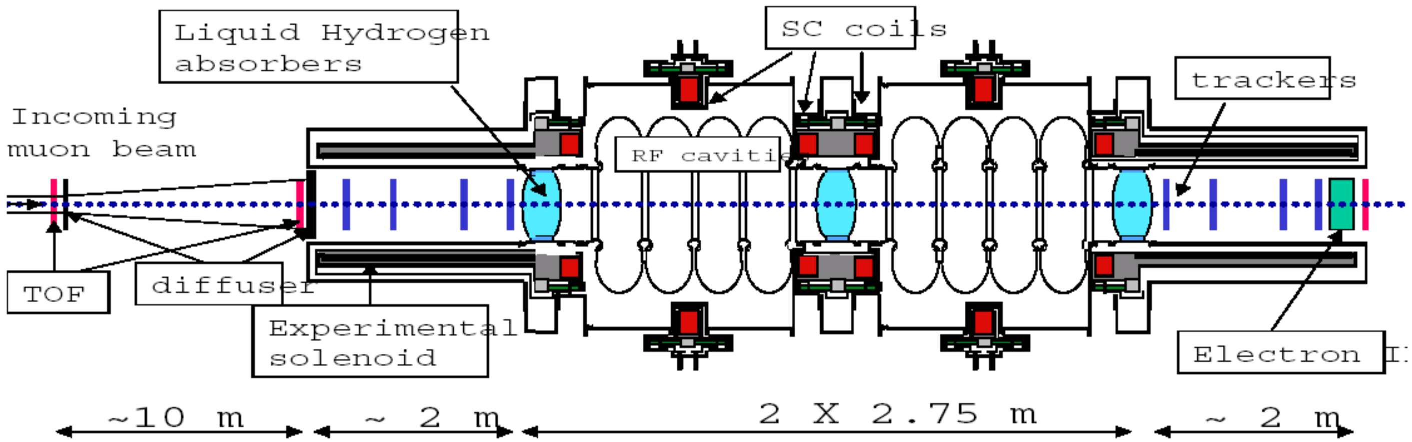
# MICE Spectrometer Design

## Requirements and Proposed Detector Implementations

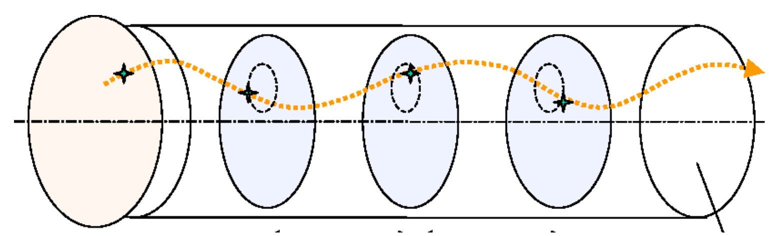
A. Bross

Fermilab

# Spectrometer Requirements




- **Experimental goal is**
  - Measure 6D emittance
    - $\varepsilon_n = \sqrt{D}$
    - $(x,y,t)$ and $(x',y',t') \Rightarrow (p_x/p_z, p_y/p_z, E/p_z)$
- **Single-particle experiment**
  - Measures $x_i, y_i$ position at $z_i$
    - Plus possibly $t$
  - Resolution requirement
    - rms $\leq$ 10% of beam parameter rms
  - At least 3 planes
  - $\approx$ 1 m long (2/3 turn @ 200 MeV/c and 3T
    - Beam with $\approx$ 30 MeV/c $p_\perp$



# Spectrometer Requirements

| | | | |
|---|---|---|---|
| Energy Loss & RF | 7 MeV | 14 MeV | 28 MeV |
| Expected Trans. Cooling | -6.1% | -11.5% | -20.0% |
| Measured Trans. Cooling | -6.1% | -11.5% | -20.0% |
| Bias | +0.0% | +0.0% | +0.0% |
| Stat. resolution | ±0.7% | ±0.8% | ±0.9% |
| Nb. of muons needed for 10 σ | 1,400 | 500 | 200 |

Transverse cooling for 7, 14, and 28 MeV cooling channels

- Rough transverse beam specs
  - $\sigma_{x,y}$ = 5 cm
  - $\sigma_{x',y'}$ = 100 mrad
- Using the PSI LOI analysis
  - SCIFI option
    - 4 planes
    - 150 micron resolution
- On the order of 1000 muons needed for 10σ
  - Assumes
    - π contamination < 10%
    - π rejection 99%
    - e identification
- Does not address problem of operating near RF cavities
  - Ionizing background (e,γ)
  - EM (rf) background

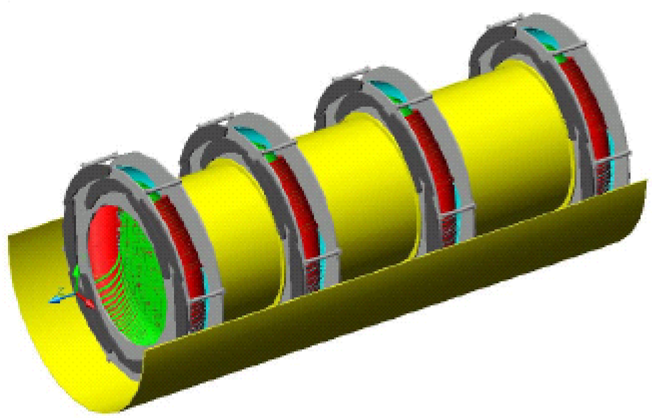
# Spectrometer Requirements

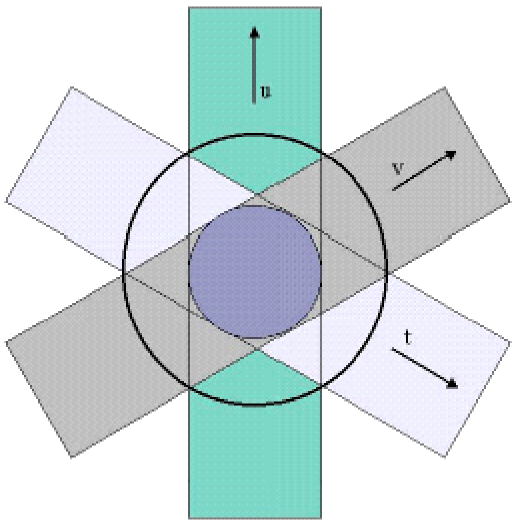
| Energy Loss & RF | 7 MeV | 14 MeV | 28 MeV |
|---|---|---|---|
| Expected 6D cooling | -8.6% | -14.5% | -17.0% |
| Measured 6D cooling | -7.6% | -13.0% | -16.2% |
| Bias | +1.0% | +1.5% | +0.8% |
| Stat. resolution with 1000 useful muons | ±1.3% | ±2.1% | ±3.0% |
| Nb. muons needed for 10 σ meast. | 3,000 | 2,600 | 3,400 |

- 6 D measurement
  - $\sigma_t \approx 2$ ns
  - $\sigma_E/E \approx 10\%$
- Approximately 3000 muons needed for $10\sigma$ measurement

# Detector Options

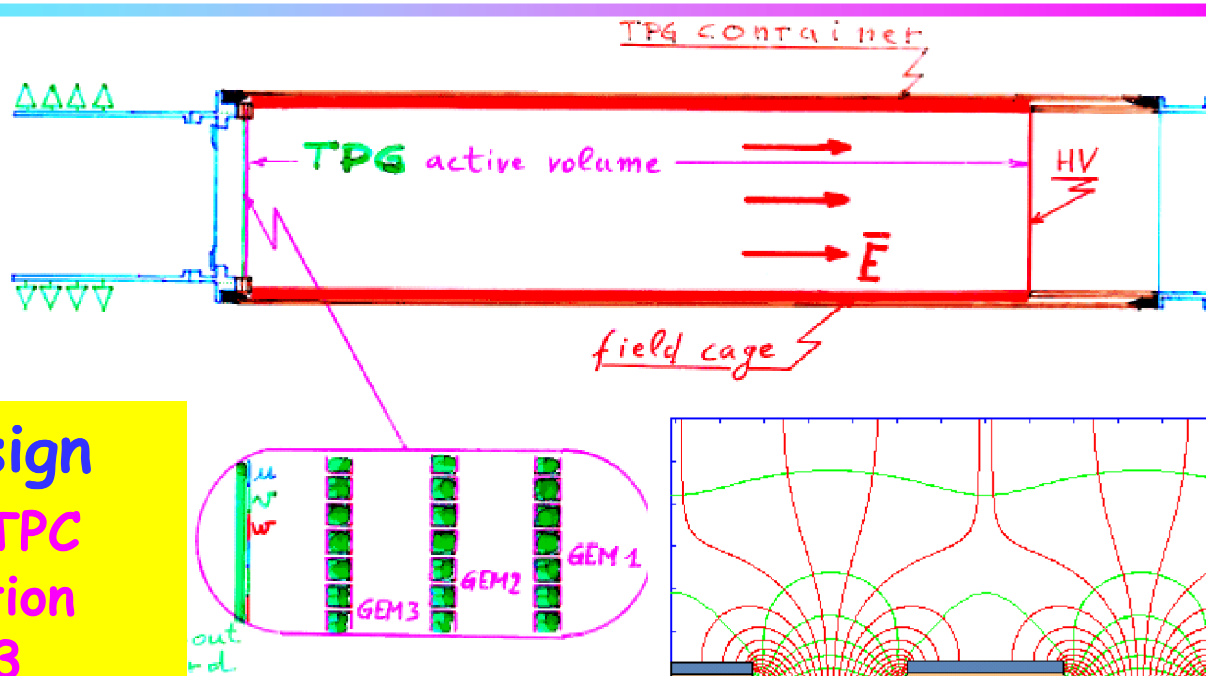
- The PSI Letter of Intent based the trackers on four planes of scintillating fiber





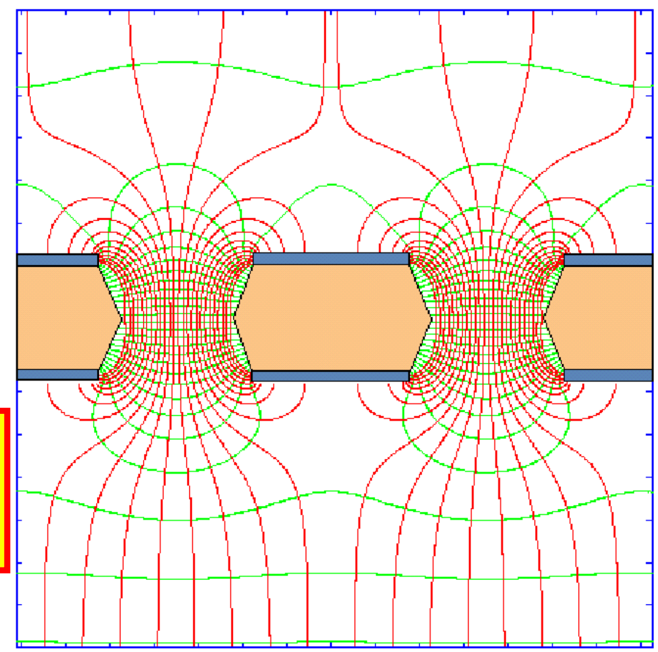

- However Ugo Gastaldi has proposed a GEM based Time Projection Chamber or TPG
  - Actually G-TPC, but then we would have to pay both Nygren and Sauli royalties

# TPG Concept for MICE




- **Basic TPG Design**
  - Ar-Methane TPC with gain section consisting of 3 GEMs (gaseous electron multiplier)
  - Readout plane - strip geometry

**5 μm Cu on 50 μm Kapton. 70 μm holes with 140 μm pitch**



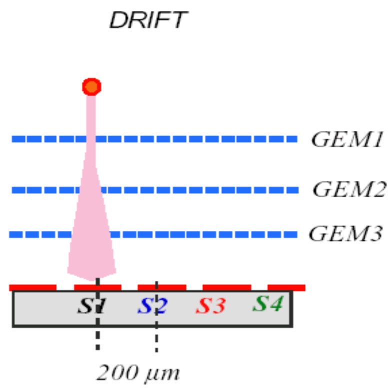
*F. Sauli, Nucl. Instrum. Methods A386(1997)531*

# Gaseous Electron Multiplier TPC

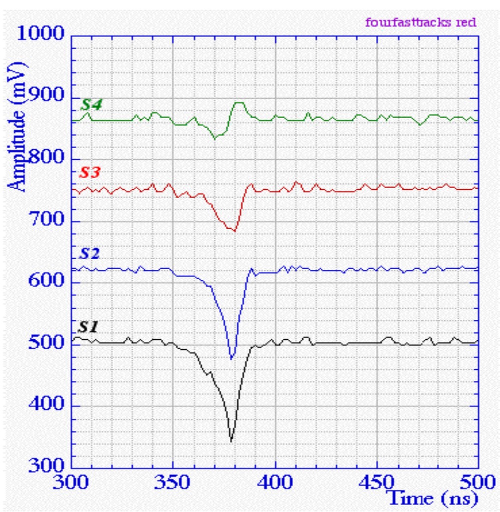


**GEM TPC**

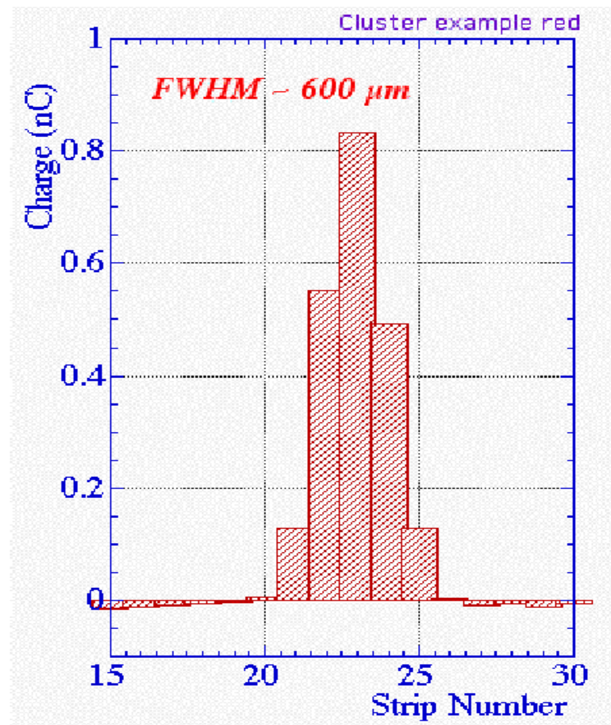
Improved multi-track resolution




*Fast signals (no ion tail)*
$\Delta T \sim 20$ *ns :*



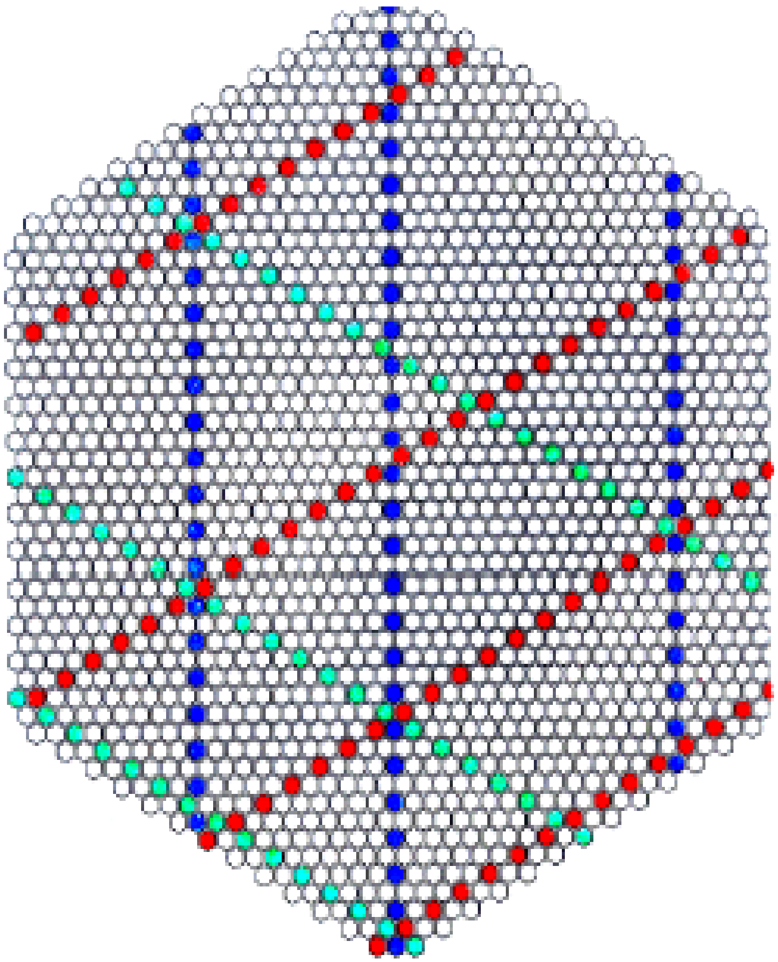

*Narrow pad response function ($\Delta s \sim 1$ mm):*




F Intrinsic multi-track resolution $\Delta V \sim 1$ mm$^3$
(Standard MWPC TPC ~ 1 cm$^3$)

# TPG Parameters

- Mechanical
  - Active diameter = 300 mm
  - Active length = 1500 mm
  - Material budget
    - ≤ 3% $X_0$ with Ar-Methane (less if He is used – 0.5%)
- Electrical/Readout
  - 3 GEM amplification
    - Gain upwards of $10^5$ (but would likely run with lower value)
    - Gated during RF pulse
      - [TPG readout between pulses]
      - 30 μs max drift time
        - RAL beam – 100 μs @ 50 Hz
  - u,v,*t* hexagonal pads
    - Readout with u,v,*t* strips
      - 500 μm pitch
  - ≤ 300 samples in z
    - 5 cm/μs drift with 10 MHz FADC



# Expected TPG Performance

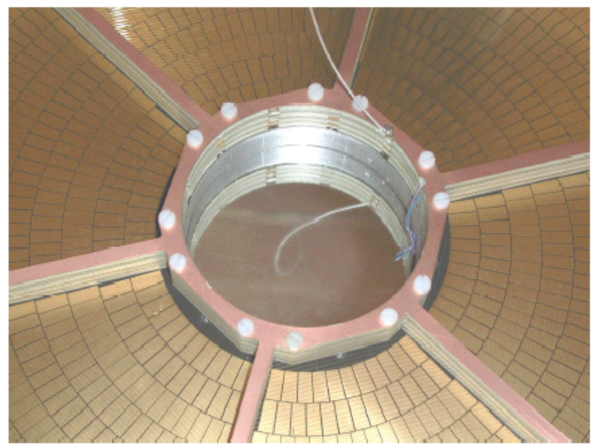
- Tracking
  - $\sigma_x = \sigma_y \cong 150\ \mu m$ + diffusion (gas, type & pressure dep.)
  - $\delta p_\perp \cong 0.5$ MeV/c
  - $\delta p_\perp / p_\perp \cong 0.5/R(mm)$ [0.5% for $p_\perp > 100$ MeV/c]
  - With u,v,*t* readout expect to be able to readout 400 muons during a single time window
    - 3-D tracking gives unmatched pattern recognition and background rejection capability
      - But the 30 μs drift time gives – large sensitivity to background from cavities.
        - X-ray conversions can produce charge in many TPG x-y-z cells.
      - RF could induce EM background to front-end electronics
        - Preamps remote from GEM planes makes this problem much worse
- Timing
  - The TPG requires a fine grained hodoscope in order to "tag" each muon so that its arrival time relative to the RF phase can be measured.
    - Possibly SCIFI layer + High resolution (50-100 ps) TOF

# TPG Electronics

- It has been proposed that the HARP electronics could be used for a MICE TPG

## HARP tpc

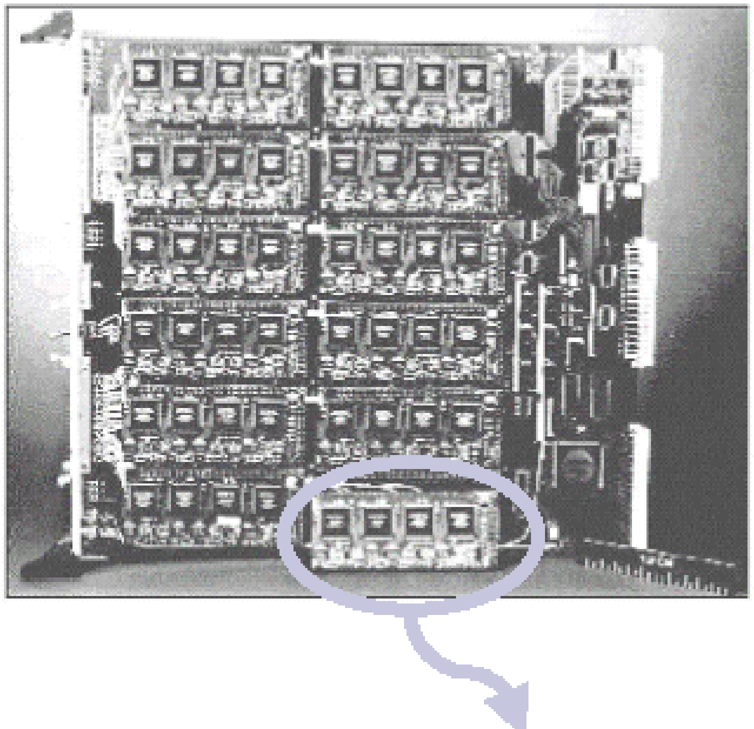
- 1.5m long, 0.8m diameter
- 0.7T solenoidal magnetic field
- 12Kv/m electric field makes the ionization drift to the readout plane with a speed of 5cm/$\mu$s → about 30$\mu$s total drift time
- about 4000 readout pads arranged in 20 concentric rows
- ionization level is sampled on each pad in 0.1$\mu$s time bins
- formidable amount of data → online zero-suppression + fast readout
- construction:
  - Aleph's TPC90 magnet
  - design inspired by existing detectors or designs (Aleph, NA49, Alice)
  - readout from Alice/NA45



20/03/2002 E.Radicioni 4

# HARP TPC Electronics

- Based on ALICE prototypes
- ALTRO (Alice Tpc ReadOut) chip
  - Sophisticated zero-suppression and time-over-threshold logic
  - 100 μs depth @10 MHz sampling
- Uses FEDC board version of ALTRO readout system
- 1 FEDC = 48 channels
  - 4 - 10 bit ADCs + ALTRO on daughter card (12/FEDC)
    - Fed by preamps on TPC pad plane
- 4000 channels available
  - 6 9U VME crates
  - MICE TPG $\Rightarrow$ 600X3X2 = 3600 ch
- Can handle expected data rates

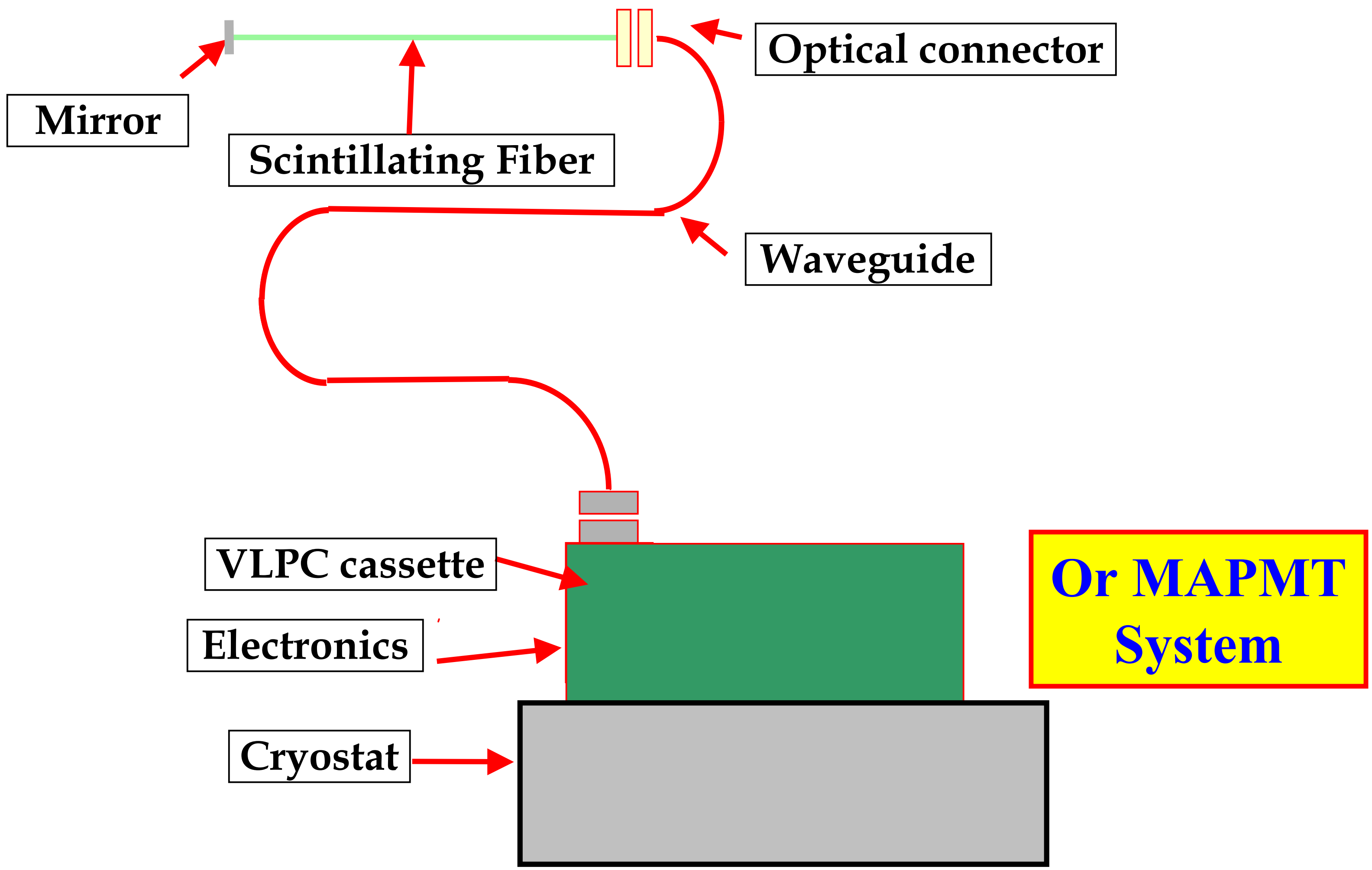


daughter card with 4 ALTRO chips + 4 ADCs

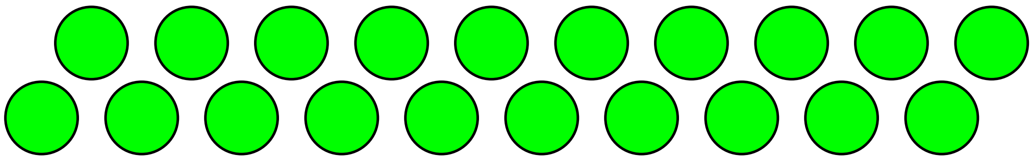
# Fiber Tracker Option for MICE

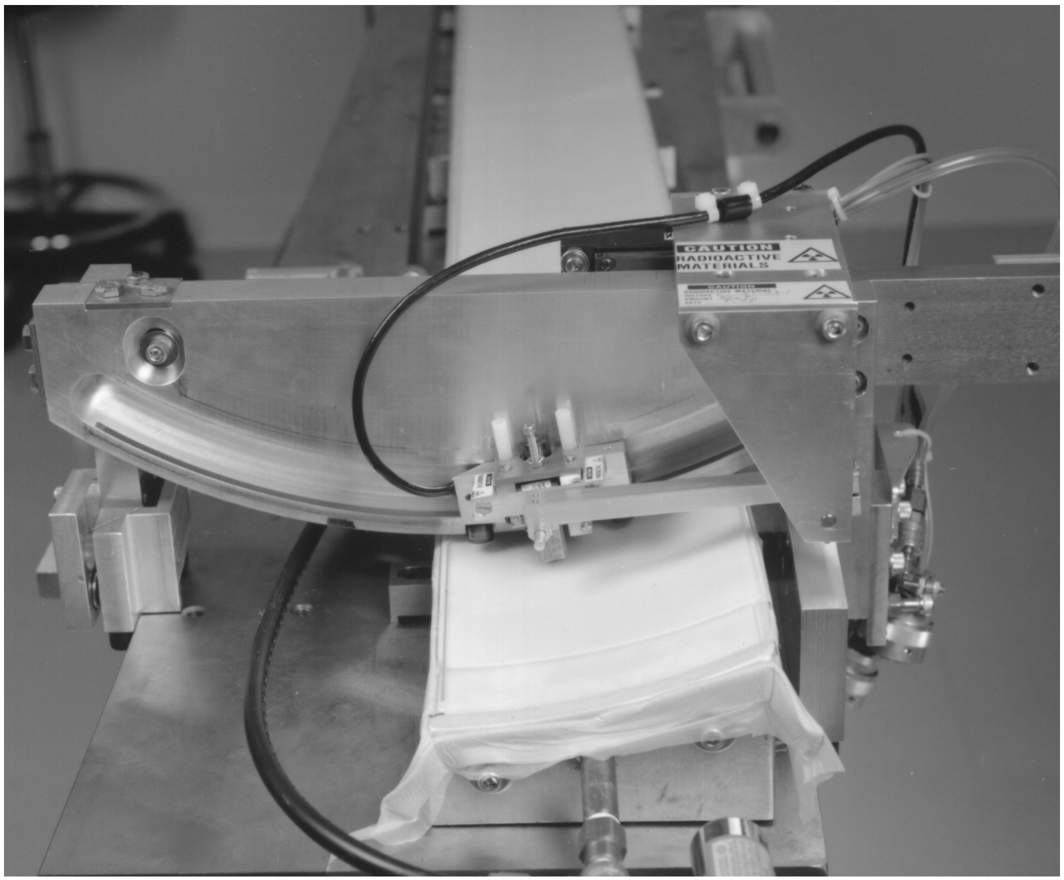
- In its simplest implementation, a FT for MICE could consist of 3 upstream and 3 downstream u-v-*t* tracking stations
- With 500 micron round fiber and a fiber doublet structure (detail later) – 30 cm active width
  - 600 fibers/layer X 2 layers/doublet X 3 measurements (u-v-*t*) X 3 (stations) X 2 (up/downstream) yields
    - 21,600 channels [Baseline 4-plane ⇒ 28k ch]
    - Expect ≈ 40 μm point-set resolution extrapolated from D0 results (90 μm) with 835 μm fiber
    - Material Budget
      - ≈ 0.4%$X_0$ per station = 1.2%
- However, IF BACKGROUNDS ARE LOW – 4:1 multiplexing possible with 1 mm pixel
- Tremendous Premium in lowering backgrounds

# Fiber Tracker Channel

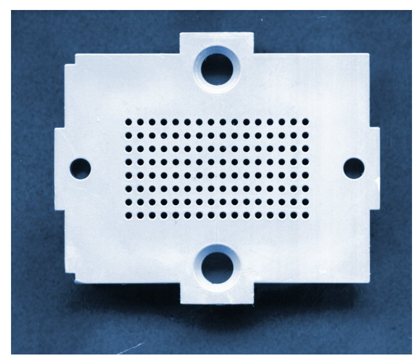


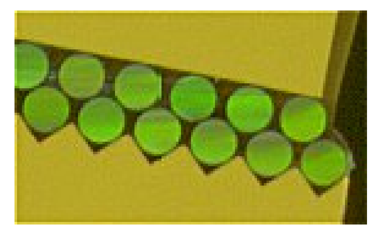
# Scintillating Fiber Ribbons






- Interlocking doublet
- 835 μm 3HF scintillating fiber
  - Fluorescence 525 nm (peak) to 610 nm
- Grooved substrate - machined Delrin
  - Pitch between 915 and 990 μm
    - Optimal P/d ≈ 1.2
- Substrate put into curved backbone
  - Fibers glued together with polyurethane adhesive
- Ribbons is then QC'ed using scanning X-ray source
- Technique is very fast
  - All MICE planes require ≈ 4 MM effort + Tooling



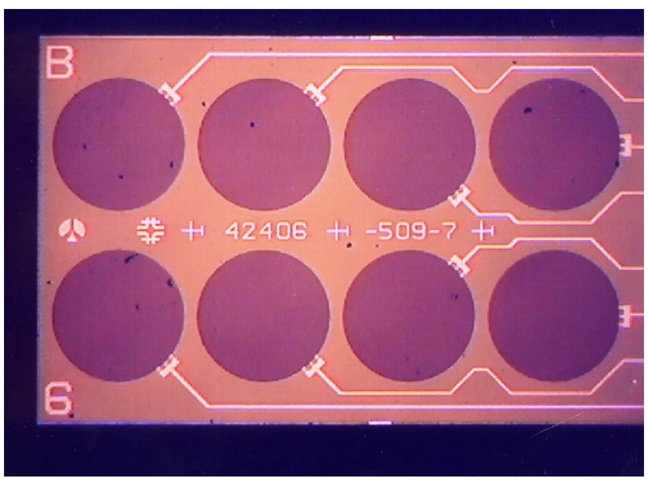


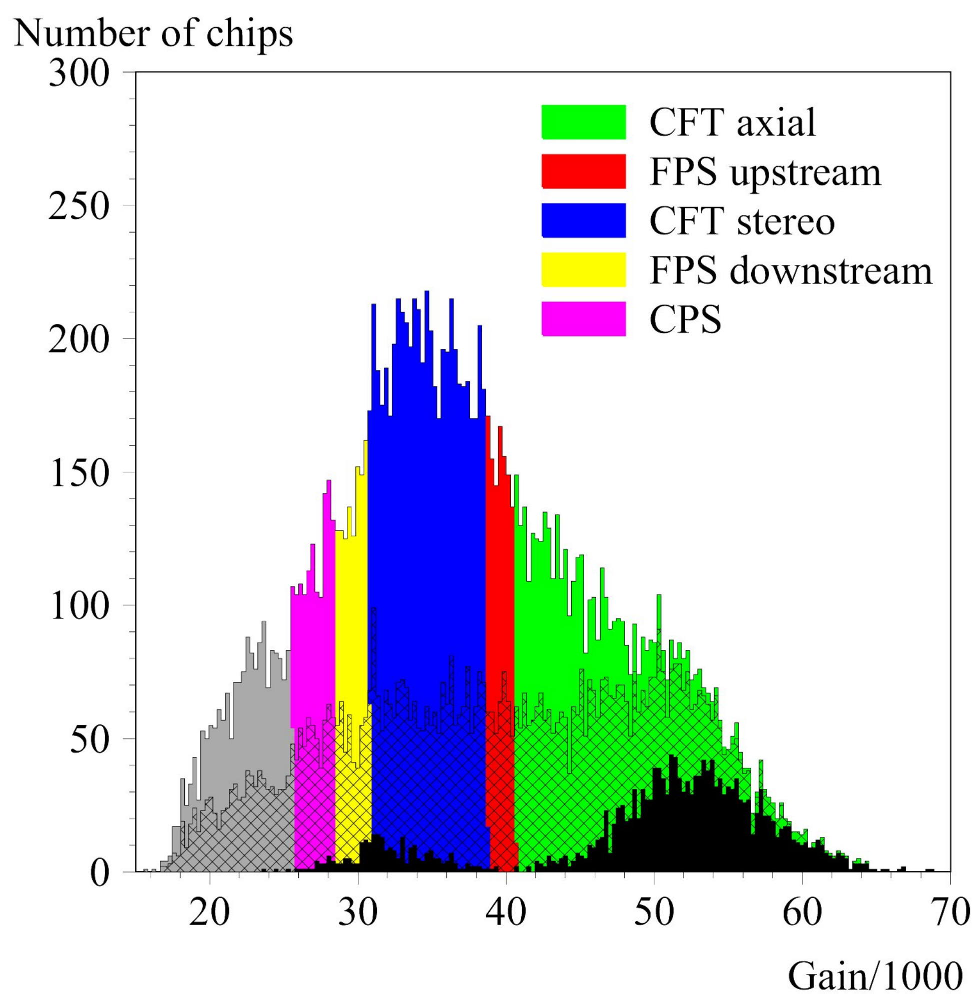
# Scintillating Fiber Ribbons

- For MICE
  - Consider "stretched-fiber" planes. No adhesive holding fibers together in active region – only at ends
  - Plan to prototype this summer
    - Split rectangular frame
    - Will Test
      - 500 micron fiber (0.4% $X_0$ per station)
      - 350 micron fiber (0.3% $X_0$ per station)
        - Pitch/diameter = 1.2
    - Simple tests with VLPC readout with waveguide lengths between 3 and 5 m

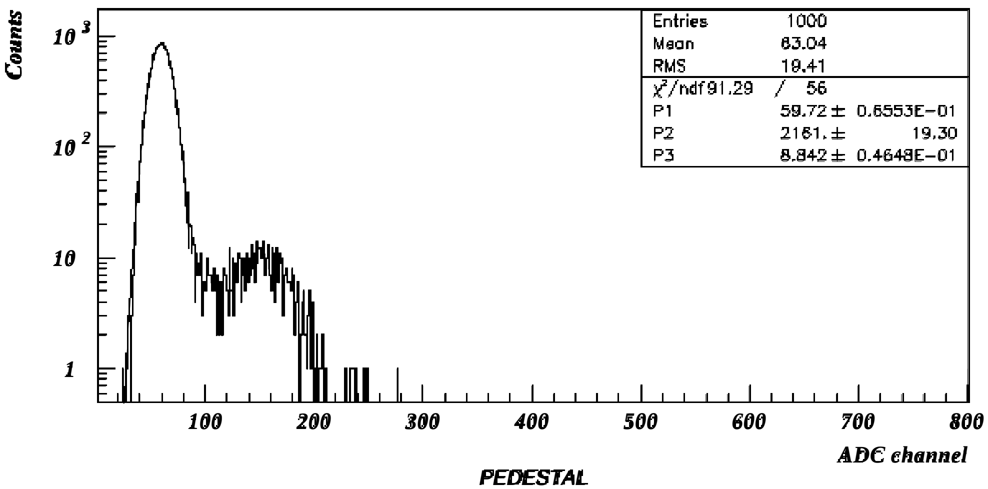
# VLPC Readout Option

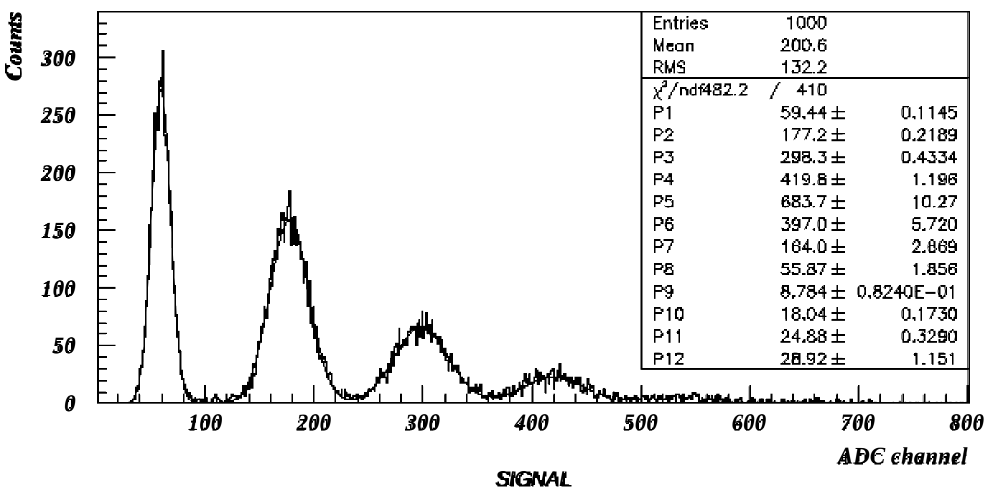
- VLPC (Visible Light Photon Counter)
  - Cryogenic APD operating @ 9K
- Characterization/test/sort Cassette Assignment
  - As shown



# VLPCs

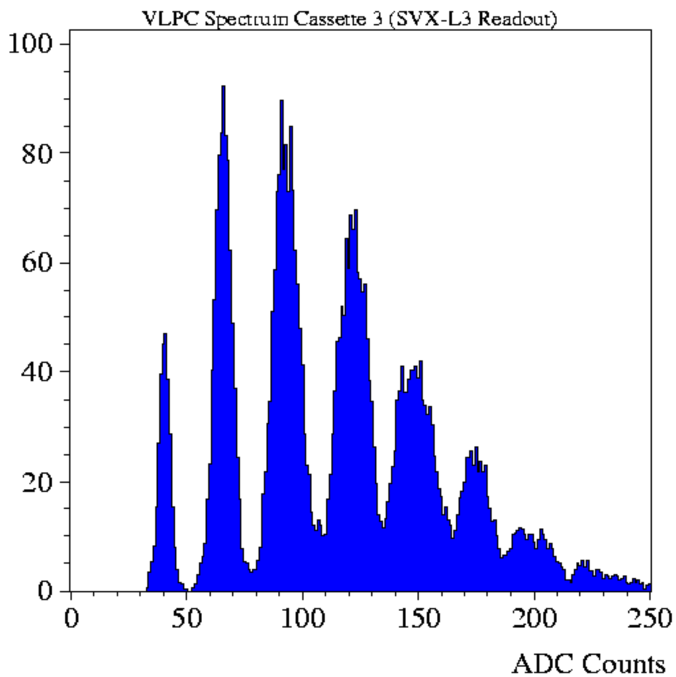


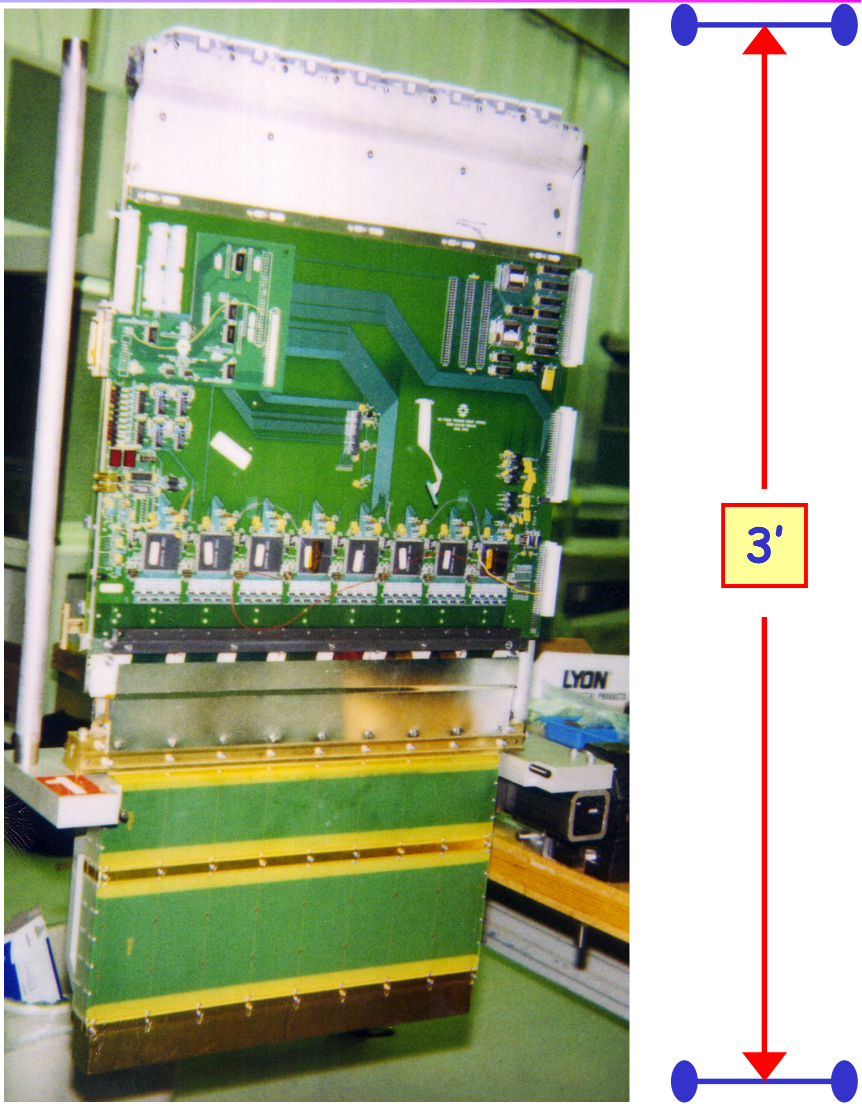




- VLPC → HISTE VI
  - High QE ≈ 80%
  - Low noise <5X10$^4$ Hz (@≈1.0 pe)
  - High Rate capability
    - >40 MHz
  - High production yield
    - ≈ 70%
      (vs. 27% projected)

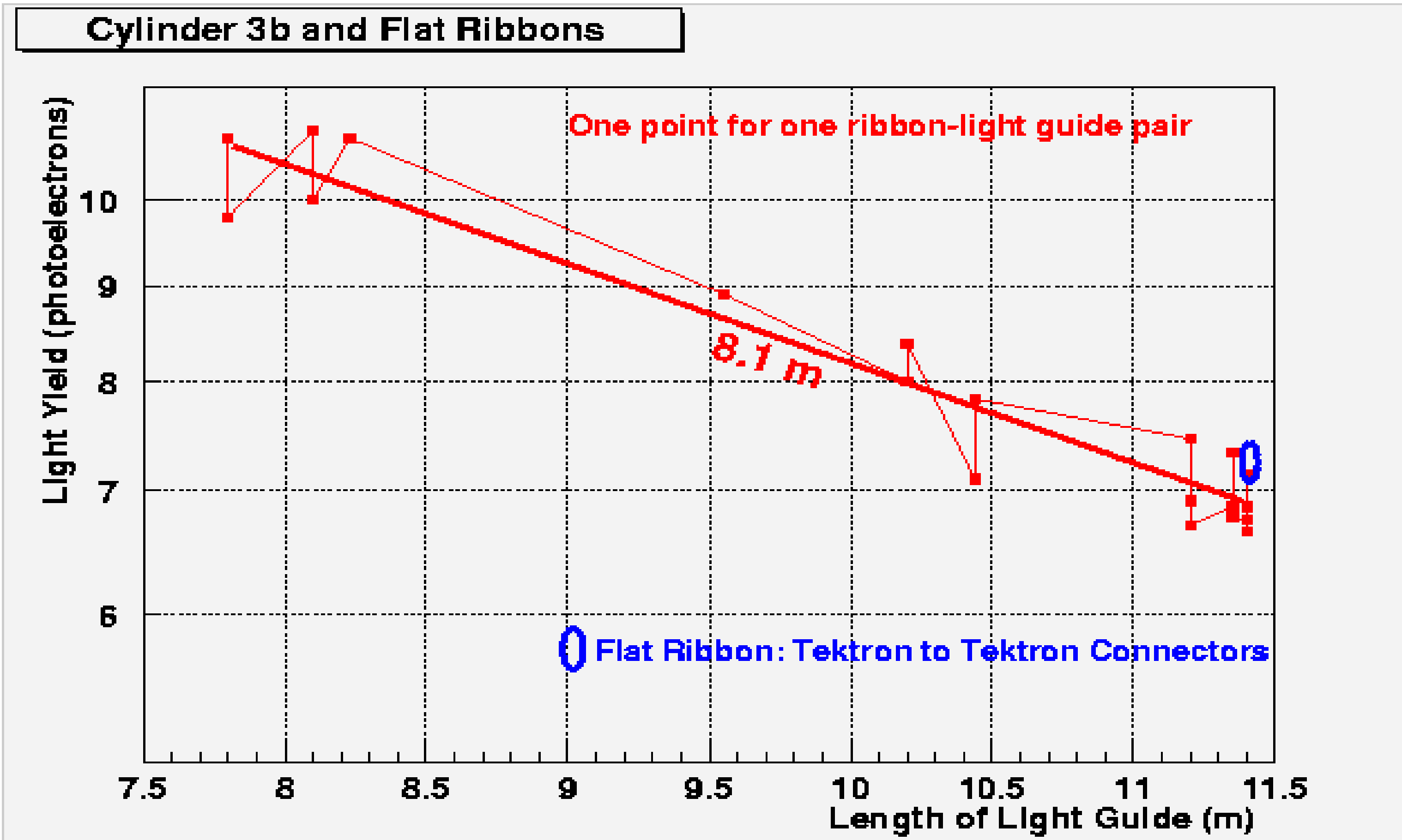
# 1024 Channel VLPC Cassettes

- Engineering Design
  - 8 – 128 channel modules
  - Cassette carries two 512 ch readout boards
    - Front-end amp/discriminator
    - Analog – SVX IIe



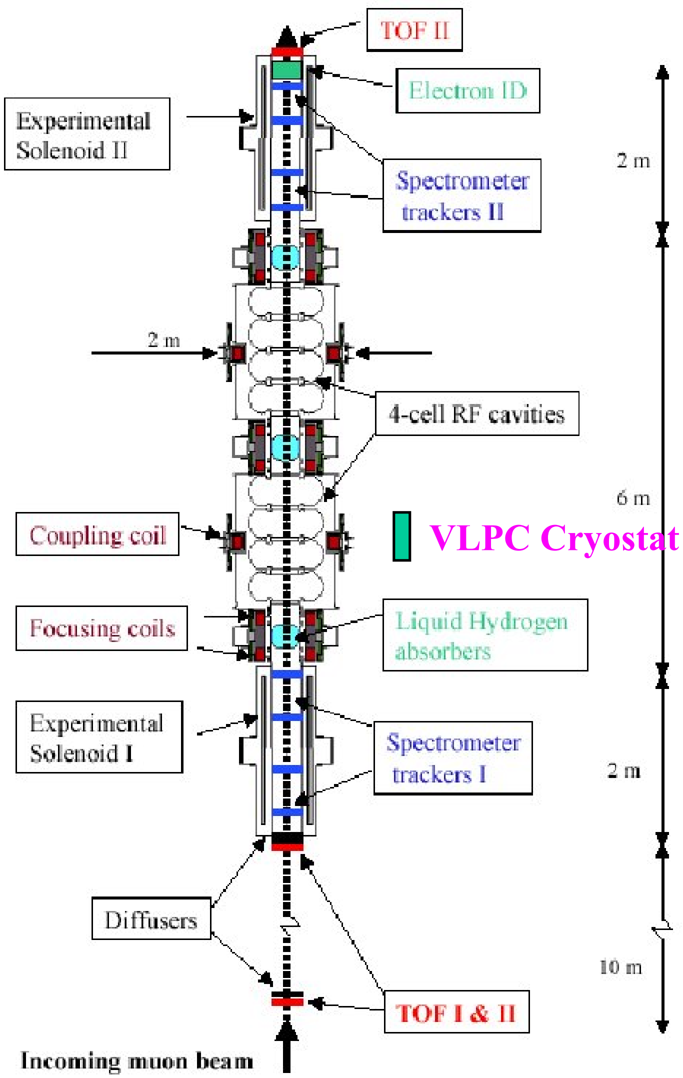
# Lab 3 CRT (Singlet) Light Yield




**Lab 3 CRT Light Yield Summary**

**Covers Waveguide lengths 7.7-11.4m**

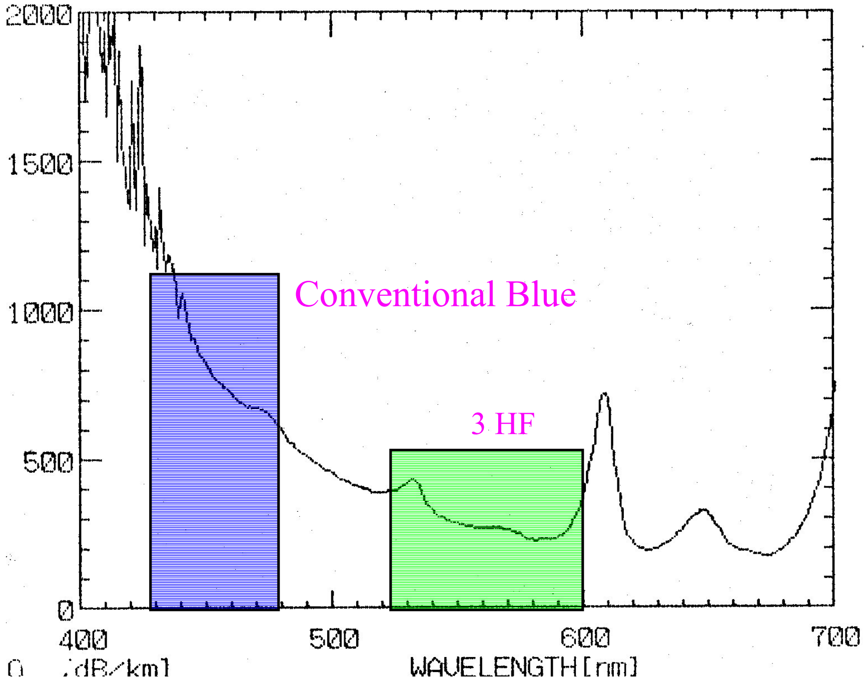
# MICE Fiber Tracker




- Could envision a single VLPC cryostat reading out both up and downstream spectrometers
  - If multiplexing was an option
    - D0 test cryostat can hold required number of channels
- Waveguide length about 5 m
  - Yield with VLPCs
  - $\Rightarrow [\exp(-5/8)]/[\exp(-11.4/8)] X7\ X.5/.84 \approx 9$ pe (per singlet layer)
- However
  - This assumes multiplexing
    - 0.5 mm scintillating fiber coupled to 0.835 mm waveguide fiber
      - Could use 1 mm fiber also and get small improvement

# MICE Fiber Tracker

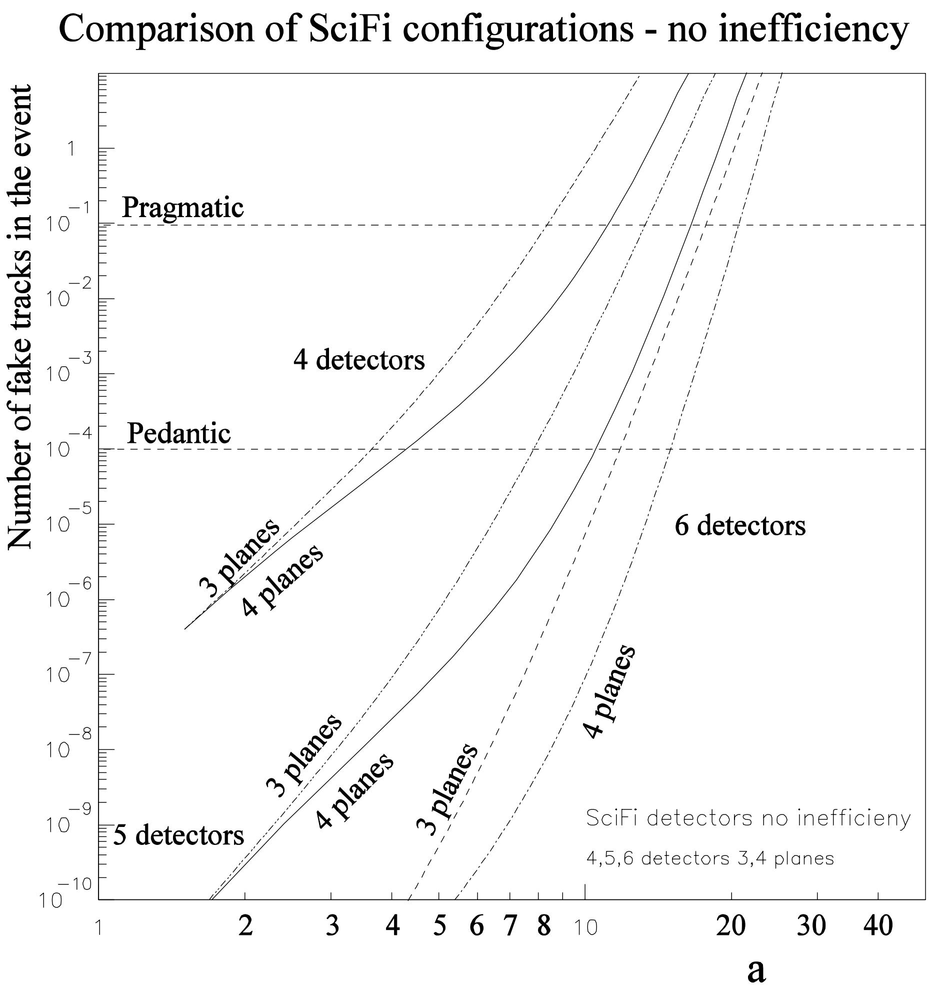
**Attenuation vs. wavelength of Kuraray clear fiber**




- Conventional FT using MAPMT
- With same length of readout fiber
  - If waveguides are used
    - $\Lambda_{430\ nm}$ = 1300 dB/km (1/e = 3.4m)
    - $\Lambda_{525\ nm}$ = 450 dB/km (1/e = 9.6m)
      - D0 measured 8.1m @ $\lambda_f^p$ = 525 nm
  - QE = 20%
  - Yield =
    - 9 X 20/80 X exp(-5/3.4)/exp(-5/8)
    - ≈ 1 pe
- Waveguide length would have to be limited to 2 to 3 meters

# MICE Fiber Tracker

Giles Barr's analysis




- Background rate absolutely critical to FT performance
- >10 hits/plane/read is "outer" limit
- However,
  - Fiber live-time small
    - 10 – 20 ns
  - u,v,t, planes **might** reject low-energy $\gamma$ conversions
    - Require "Doublet hits" – i.e., both layers in a view fire.

# Conclusions

- In the absence of backgrounds, the choice of tracker for the spectrometers would likely only be based on cost.
  - Both TPG and SCIFI can easily meet the experiment requirements in terms of tracking performance (resolution) and pattern recognition (in zero BG conditions) and do so within an acceptable material budget $\approx$ 3% $X_0$ (extrapolating from P. Janot's analysis).
- Radiation, ionizing + $\gamma$ from RF cavities still present a very difficult environment in which to operate, however
- Sensitive electronics (front-end preamps) may also have problems due to EM leakage from cavities
  - Detailed shielding question

# Conclusions

- The TPG option has un-matched pattern recognition and background rejection capabilities and electronics/readout come for "free"! Clear front-runner. However:
  - Still requires fine-grained hodoscope for "time-tagging" muons relative to RF
  - Operation near RF cavities?
    - "Live-time" 30 μs
      - For same material budget – number of bkg hits/"readout-plane" possible as much as 5X the case for fibers (Ar-Methane case). However, 300 planes vs. 4 (6?)
    - Preamp issue?

# Conclusions

- The fiber tracker option is more sensitive to backgrounds and readout costs are a problem. However,
  - Good timing resolution
  - Very small live-time, 10-20 ns
  - Insensitive to EM radiation (passive front-end)
  - Excellent spatial resolution
  - Possibly slightly less mass then the TPG option with (Ar-Methane)
- Critical near-term tasks
  - "Best-possible" measurement of ionization background
  - Demonstration of prototype operation near cavity to determine effect of EM fields on sensitive front-end electronics (TPG)