The Large-Area Time Of Flight System for STAR

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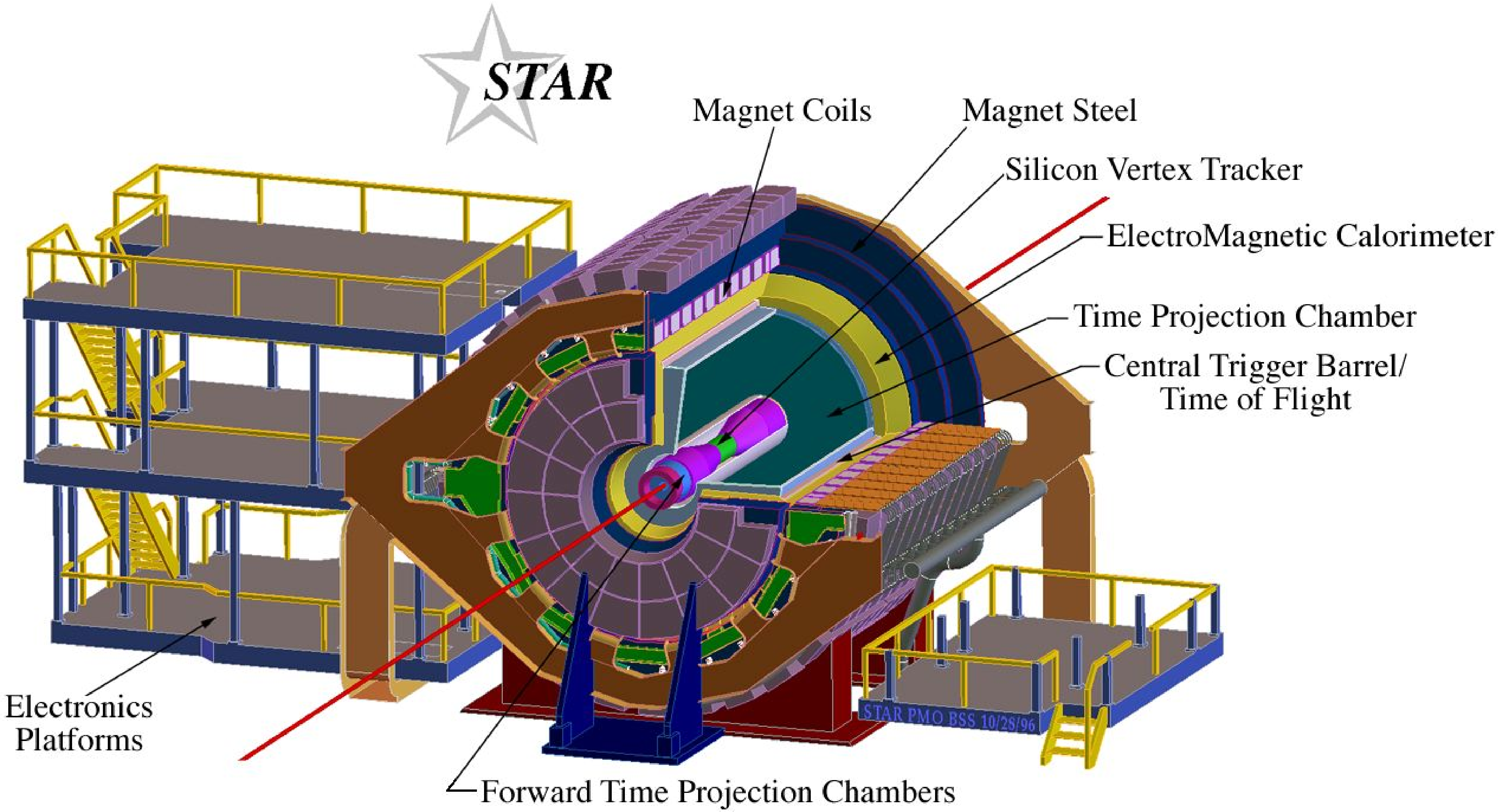
OUTLINE:

- **The STAR Experiment at RHIC**
  needs Time-Of-Flight for Particle Identification
- **Multi-gap Resistive Plate Chambers**
  high-resn, cheap, easy to build
- **The STAR-variant MRPCs and**
  prototype systems operated in STAR...

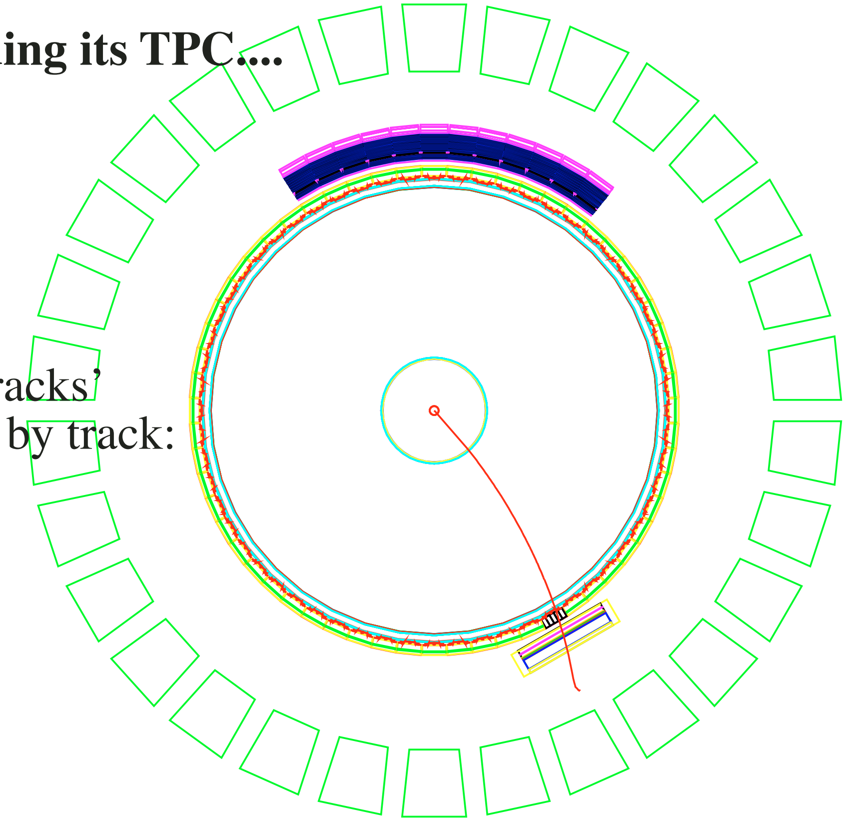
  TOFr (Run-3), TOFr' (Run-4), TOFr5 (Run-5)
- **Proposed full-sized system (~TOFr5×120)**



STAR baseline: charged hadron PID using TPC dE/dx:
can identify pions and Kaons up to ~0.7 GeV/c, and protons up to ~1.0 GeV/c

~30% of the charged hadrons in any given event thus cannot be directly identified...

STAR needs Time Of Flight (TOF) completely surrounding its TPC....



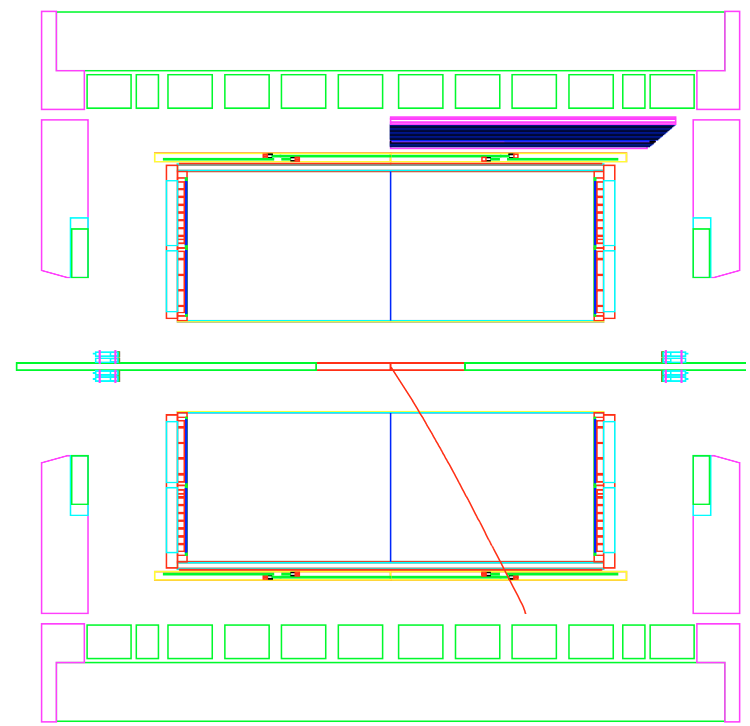
TPC provides
- momenta of tracks to $\Delta p/p \sim 1\text{-}2\%$
- track total path lengths to a few millimeters over 2.1-2.9m flight path...

surrounding the TPC with a detector that can measure the tracks' time of flight (TOF) allows the following calculation, track by track:

- p from TPC tracking
- s from TPC tracking, & STAR geometry
- $\Delta t = t_{stop} - t_{start}$ from TOF
- $s = \beta c \Delta t$ and $\gamma = 1/\sqrt{(1-\beta^2)}$
- $\rightarrow m = p/\gamma\beta c$ $\rightarrow$ Particle Identification!

Since the Mass resolution of a TOF system is:

$$\Delta M/M = \Delta p/p \oplus \gamma^2 [\Delta s/s \oplus \Delta t/t]$$



Then, with the TPC tracking & a Δt = 100ps TOF system:

- π/K/p direct PID: ~0.3 GeV/c < p < 1.7-1.9 GeV/c
- (π+K)/p direct PID: ~0.3 GeV/c < p < 2.8-3.0 GeV/c

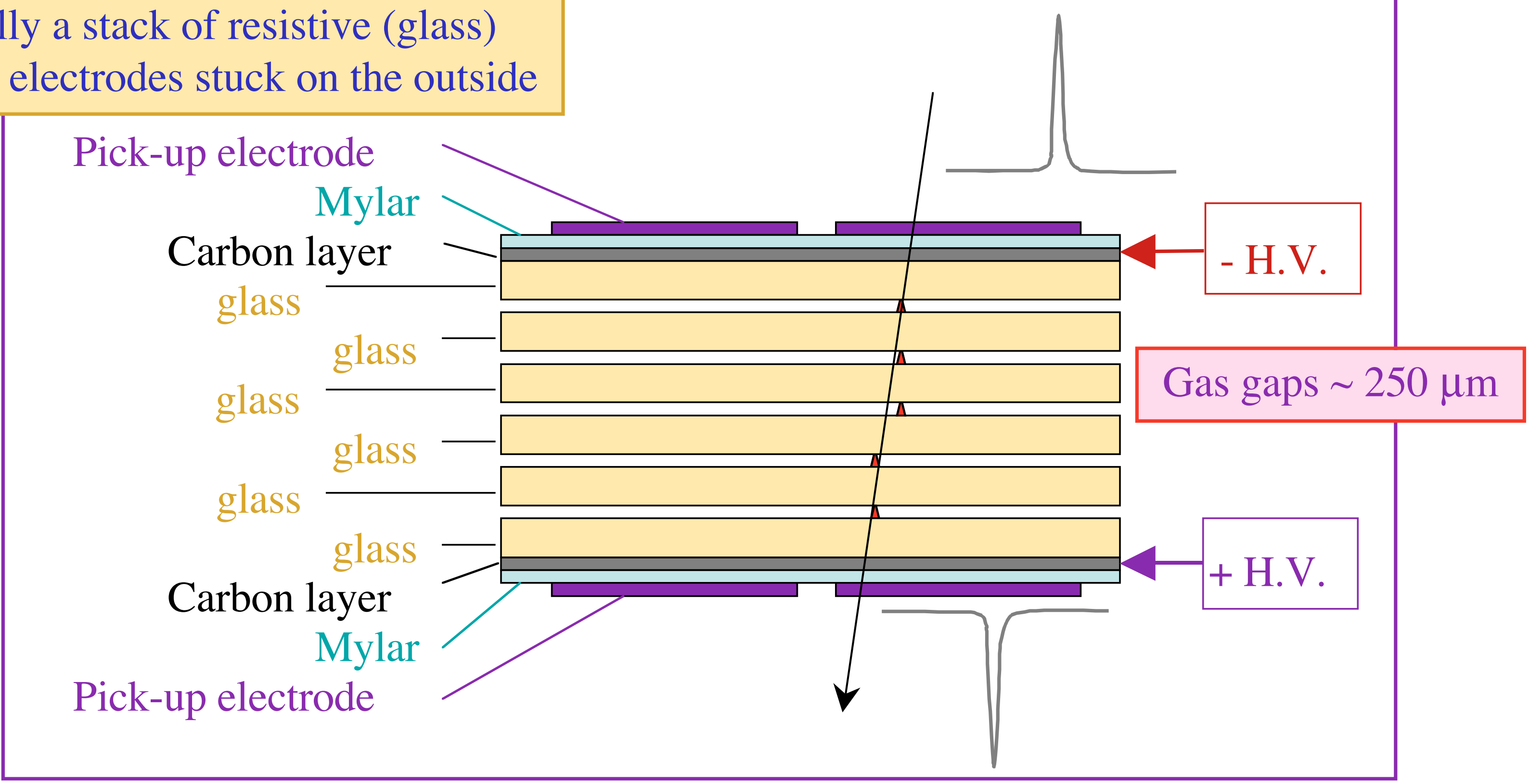
i.e. just what STAR needs....

but 50 m^2 of scintillator+PMTs would run > 30M$

need a technology with the same timing resolution and efficiency but much much cheaper!

The MULTIGAP Resistive Plate Chamber

Essentially a stack of resistive (glass) plates with electrodes stuck on the outside



Note 1: internal glass plates electrically floating - take and keep correct voltage by electrostatics and flow of electrons and ions produced in gas avalanches

Note 2: resistive plates transparent to fast signals - induced signals on external electrodes is sum of signals from all gaps (also, equal gain in all gaps...)

- HV differential: ~10-15 kV
- Gas in gaps is typically 90-95% Freon R-134a, rest being isobutane and/or SF6
- signals are small: R/O requires careful amplification and careful RFI shielding...

Resistive Plate Chambers

(in avalanche mode)

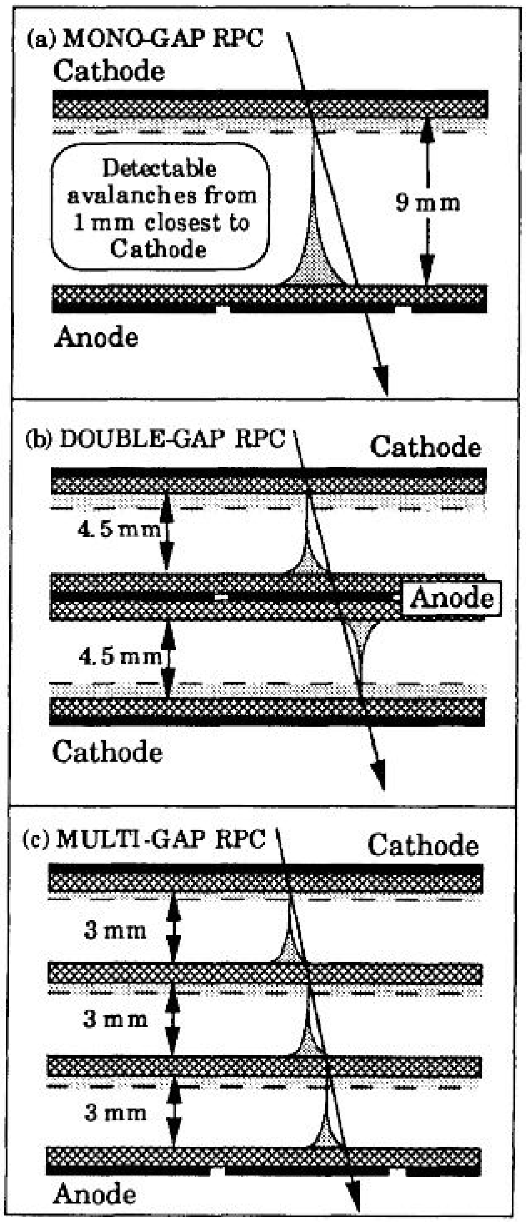


Figure 2. Schematic representation of a monogap RPC (top); a double gap RPC (middle) and a multigap RPC (bottom).

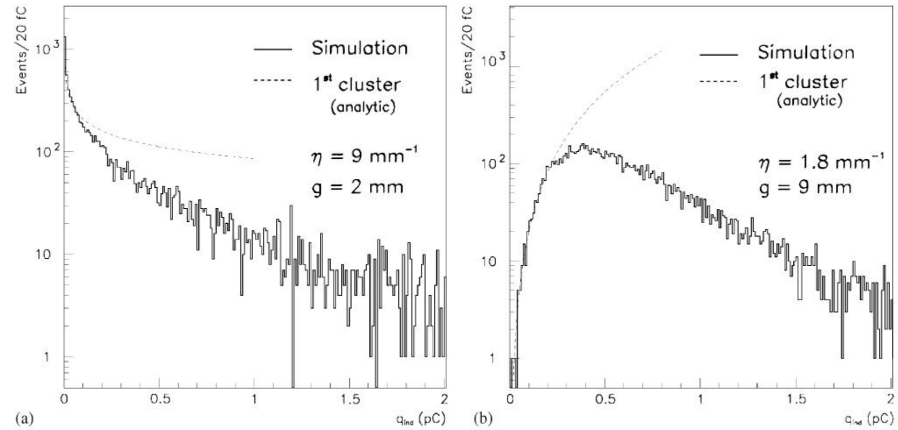


Fig. 1. Comparison between the simulated charge spectra for single (a) narrow ($g = 2$ mm) and (b) wide ($g = 9$ mm) gap RPCs.

narrow single gaps don't work well in avalanche mode

wider single gaps?

enhanced streamer-free range of operating voltage

but **time resolution suffers**...

- primary ionziation is a stochastic process
  → timing jitter from location of ionization in RPC
- avalanches from single primary clusters tend to merge & interact with each other
  → fluctuations in avalanche development dominate

many narrow gaps!

- characteristic distance for primary ionization decreased
  → **decreased jitter from primary ionization step**
- N-independent avalanches, hence an averaging
  → **decreased jitter from avalanche fluctuations**

optimizes the timing performance, yet leads to signals that are "large enough" to work with...

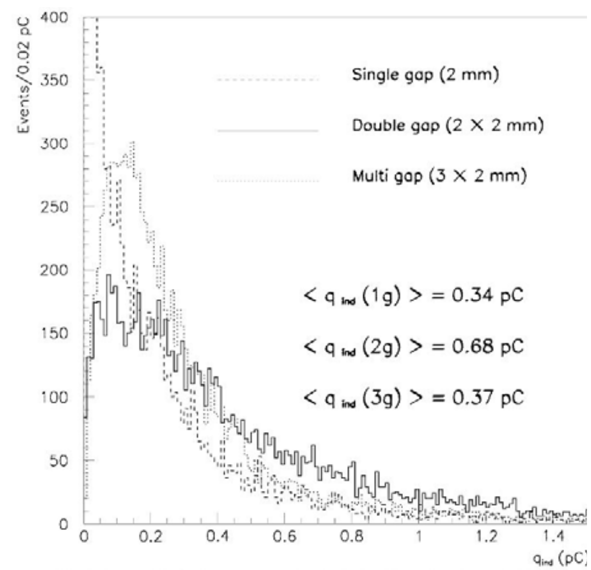


Fig. 3. Monte Carlo charge spectra for single- double- and multi-gap RPCs.

O P. Fonte et al. / Nuclear Instruments and Methods in Physics Research A 443 (2000) 201}204

X V.V. Parchomchuck, Yu.N. Pestov, N.V. Petrovykh, Nucl. Instr. and Meth. 93 (1971) 269.

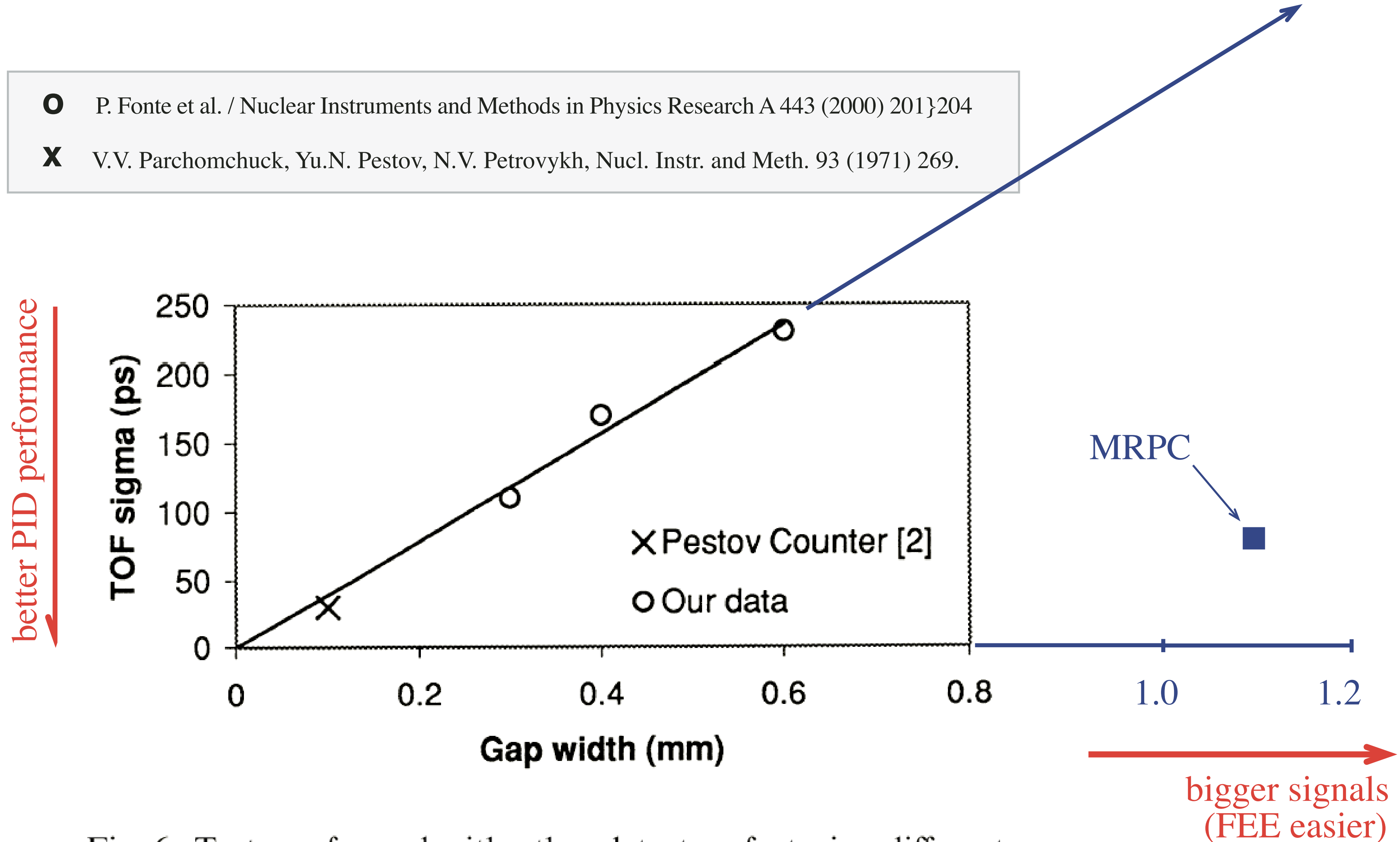


Fig. 6. Tests performed with other detectors featuring different widths of the gas gap suggest that the main contribution to the time jitter is associated to the amplification process in the gas. The timing resolution seems to depend almost linearly on the gap width, with a slope of approximately 40 ps/0.1 mm.

...acts just like the conventional technology...

...all the usual calibration techniques apply...

(ALICE prototype, figures from M. Spegel, NIM A 453, 308 (2000).

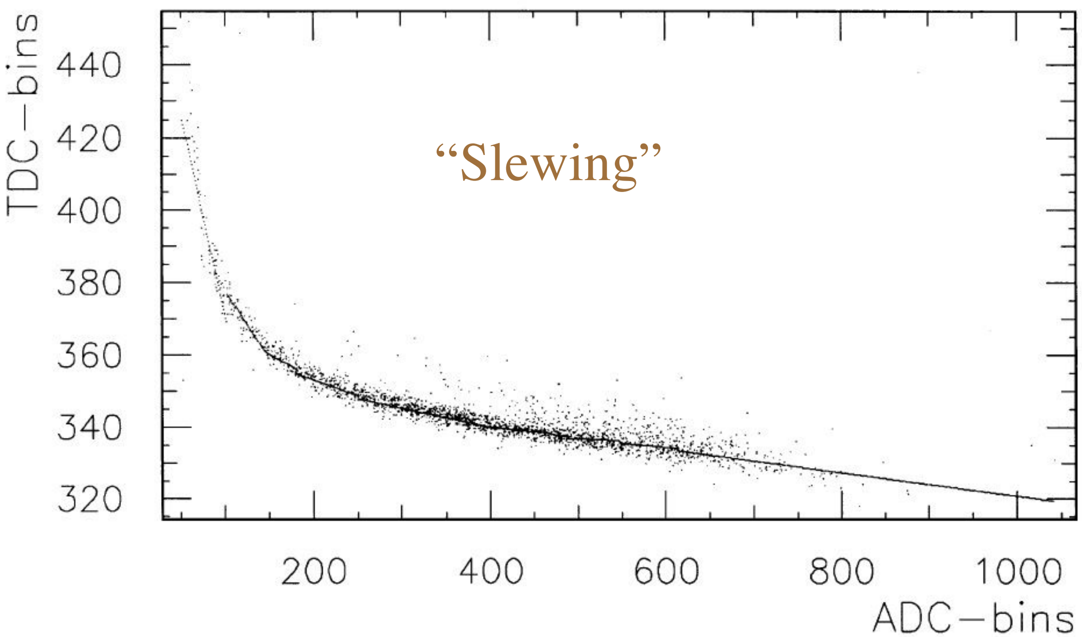


Fig. 4. Correlation of raw time difference between MRPC detector and reference counter and MRPC signal amplitude.

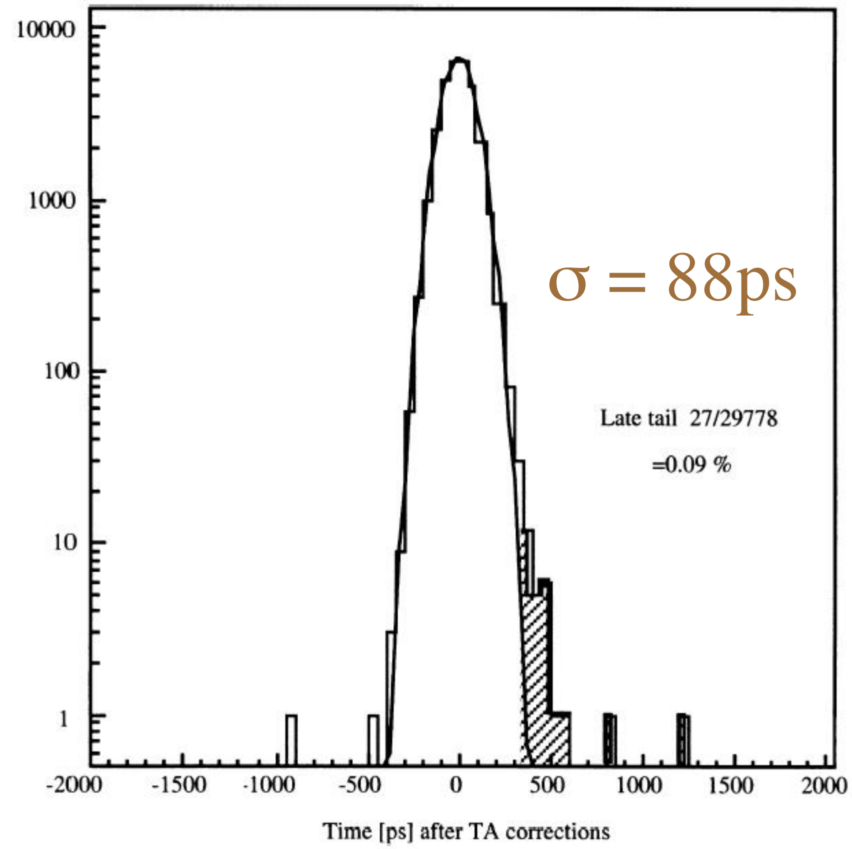
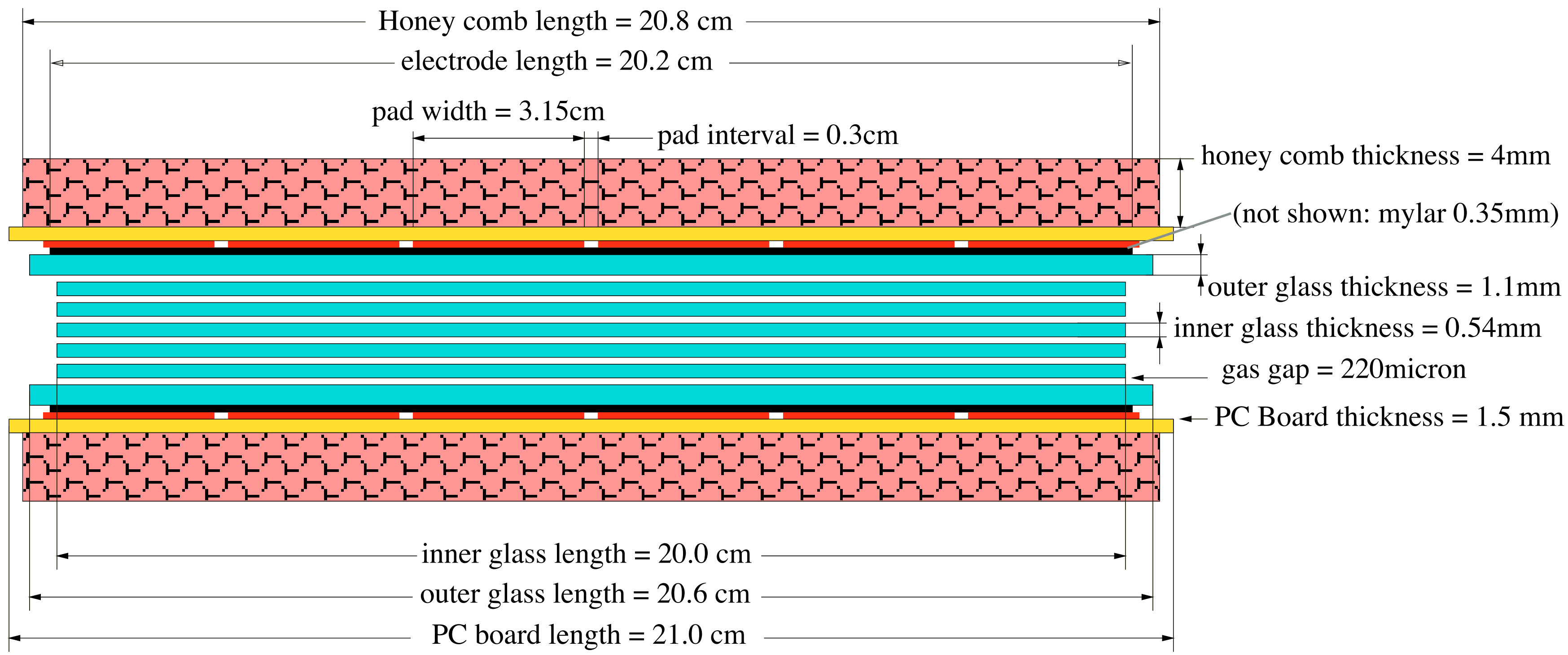
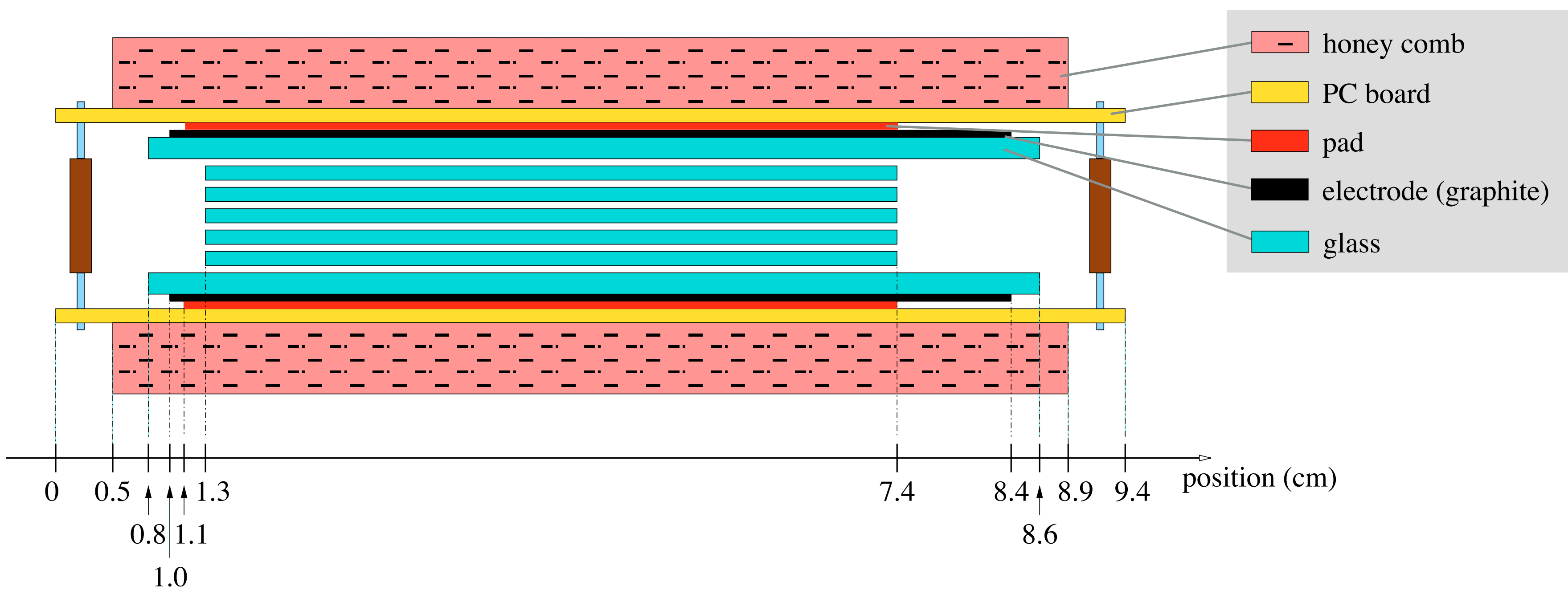


Fig. 5. Time distribution measured with an MRPC with five gaps of 220 μm operated at 12 kV (109 kV/cm). The width of the Gaussian fit is $\sigma = 88$ ps.

STAR's Variant...

all components are more-or-less "off the shelf"

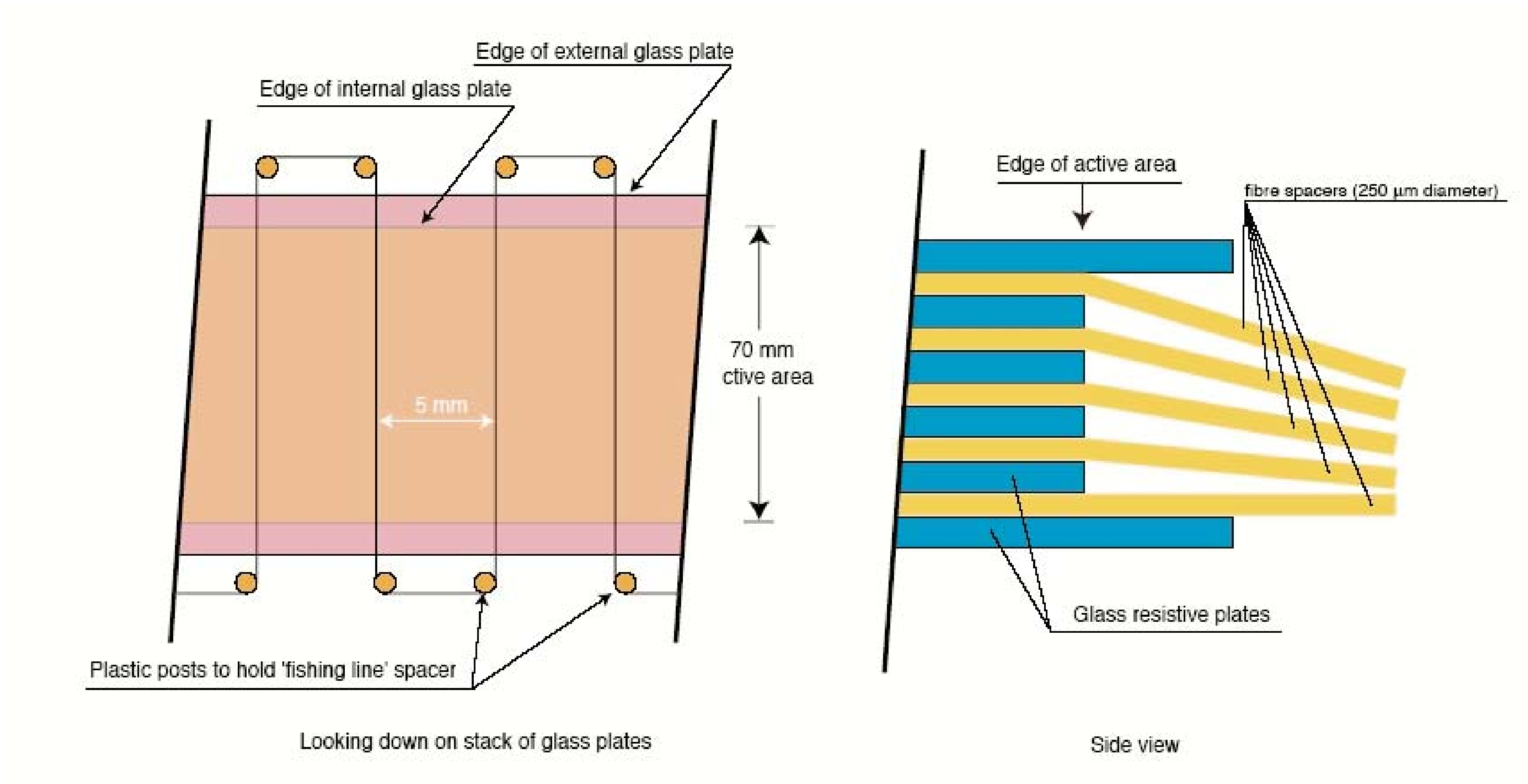


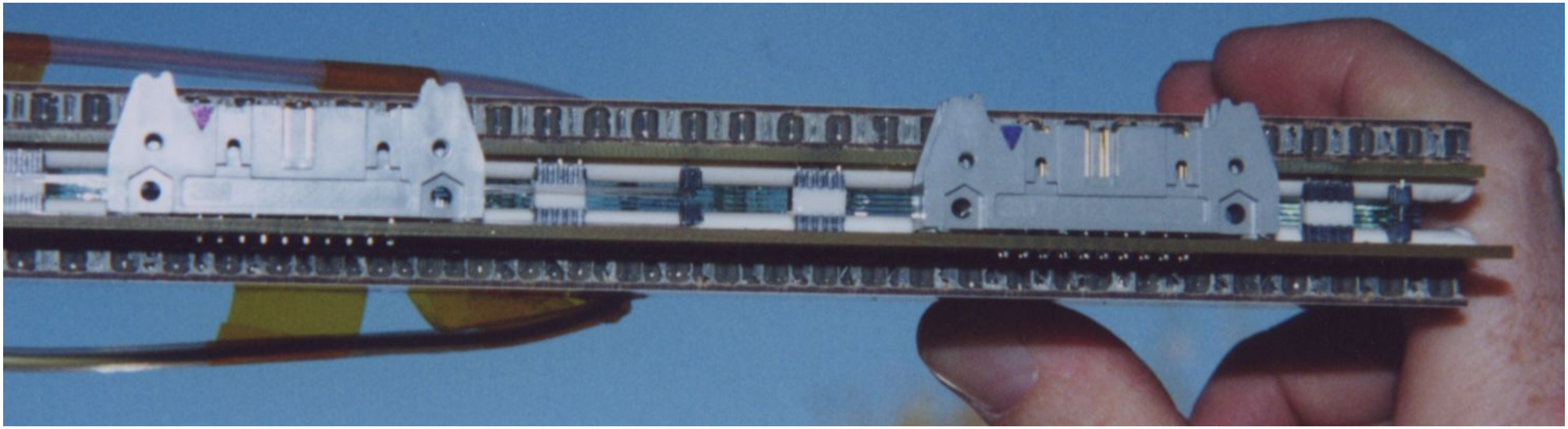


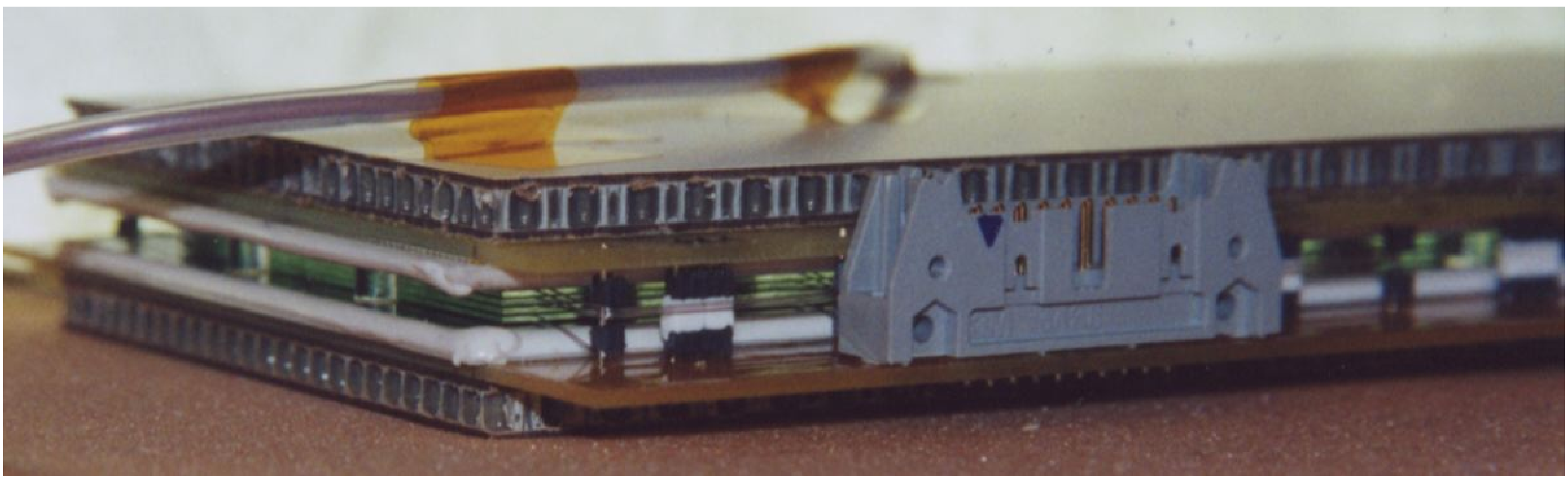
Spacing of inner glass plates is set by *monofilament fishing line*... (ALICE, HARP, & STAR)

- available in a variety of diameters in ~20μm steps around 200μm...
- gap size very uniform: ±10 μm...
- very difficult to compress...

Glass plates are just common float glass...





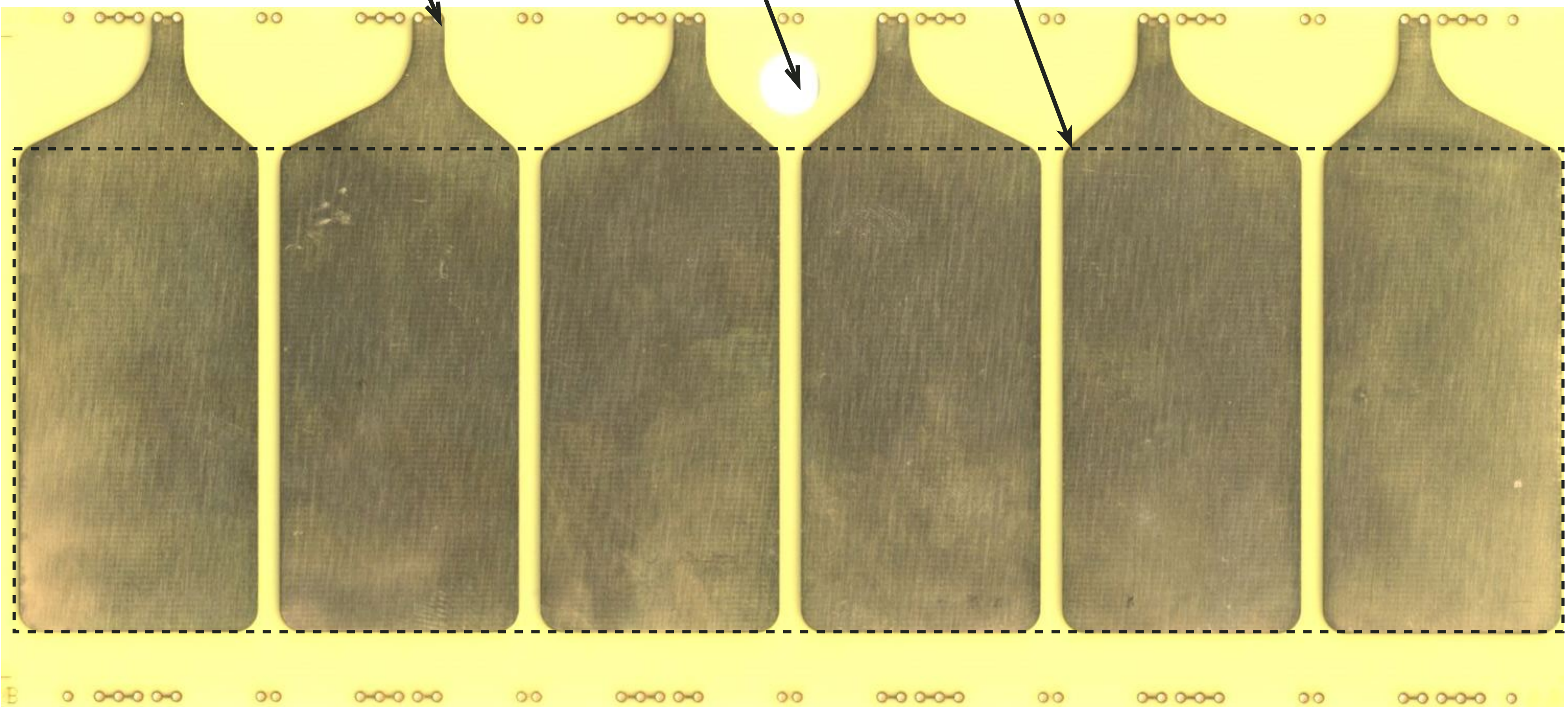


Readout Pads

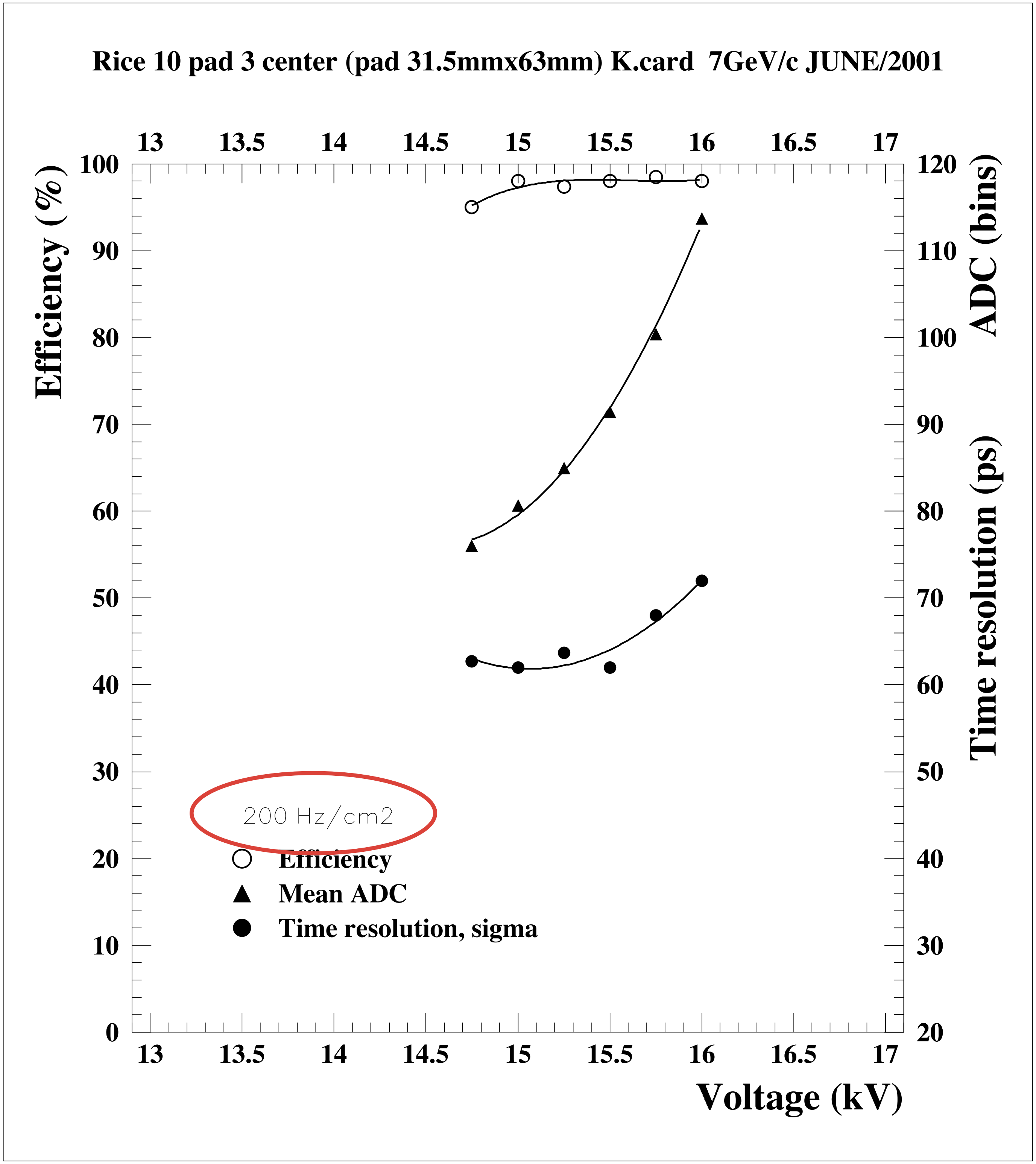
region of pads above thin glass indicated by dashed box

hole to pass HV through to graphite layer

pins for signal output



active area of each pad is 3.1cm (along phi) by 6.5 cm (along eta)



June 2001:
"final" cern test results...

focus then shifted to a full-sized prototype system for STAR:

"TOFr"

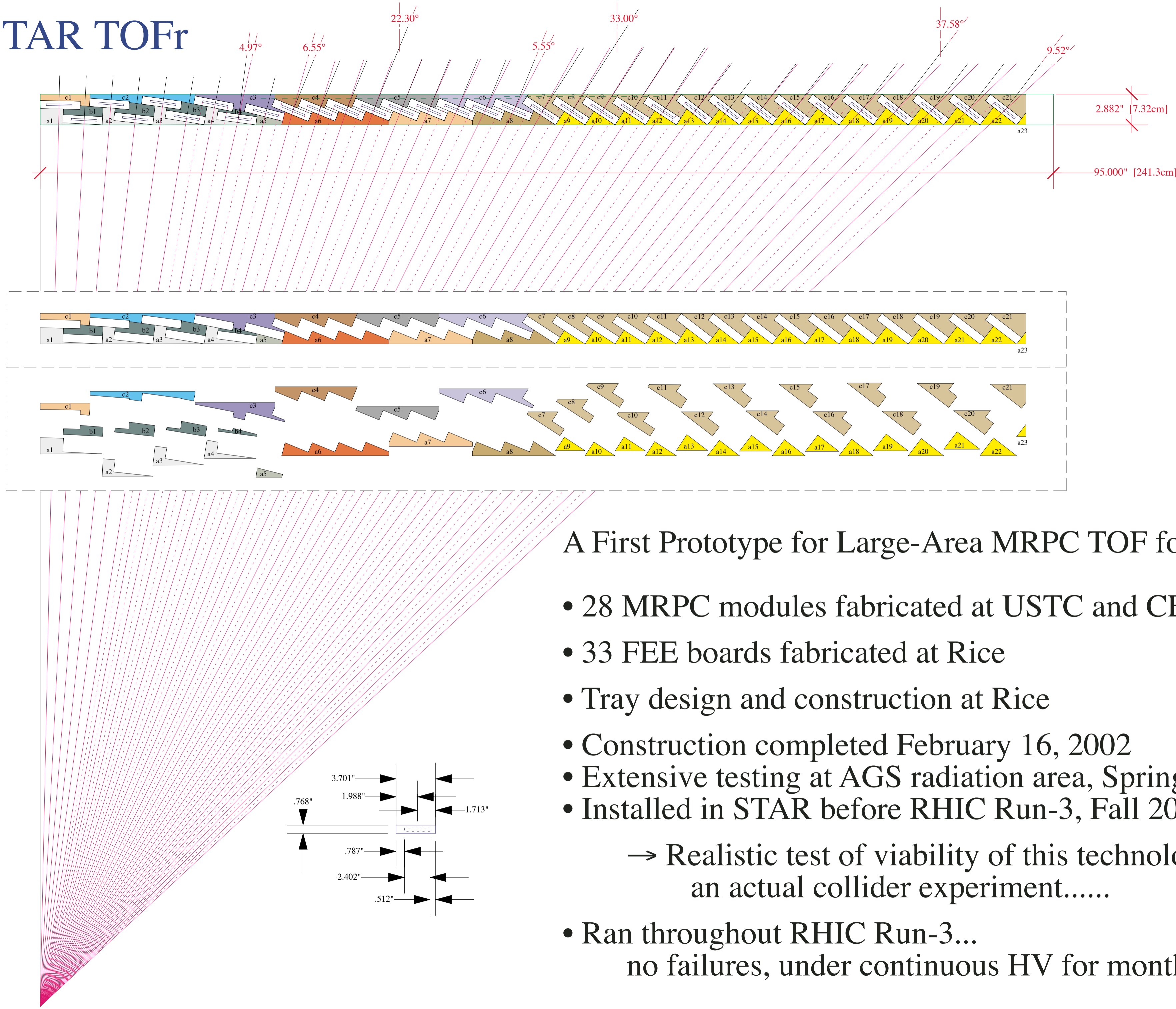
a "tray"

$-1<\eta<0$

$\Delta\phi \sim 1/60^{th}$ of 2π

with ~30 MRPCs

STAR TOFr



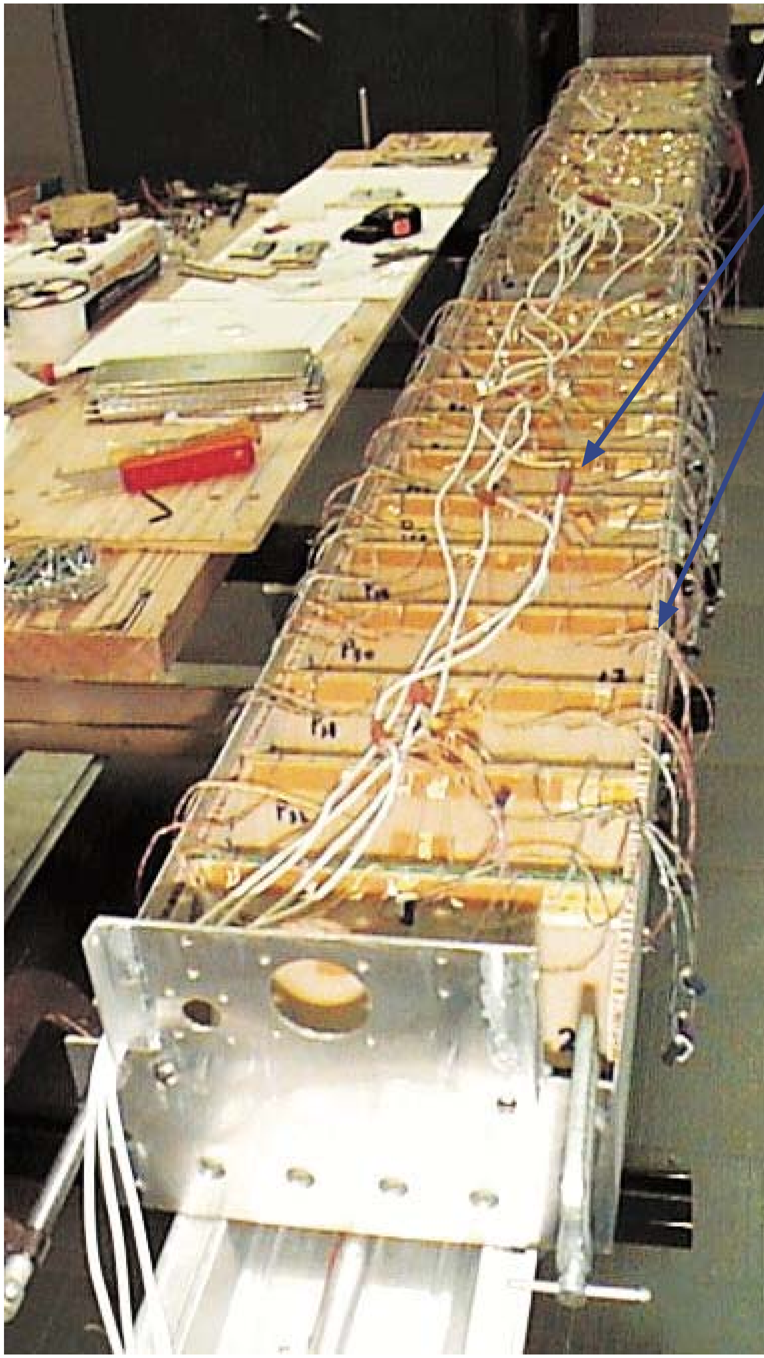
A First Prototype for Large-Area MRPC TOF for STAR

- 28 MRPC modules fabricated at USTC and CERN
- 33 FEE boards fabricated at Rice
- Tray design and construction at Rice
- Construction completed February 16, 2002
- Extensive testing at AGS radiation area, Spring 2002
- Installed in STAR before RHIC Run-3, Fall 2002

→ Realistic test of viability of this technology in an actual collider experiment......

- Ran throughout RHIC Run-3...
  no failures, under continuous HV for months...

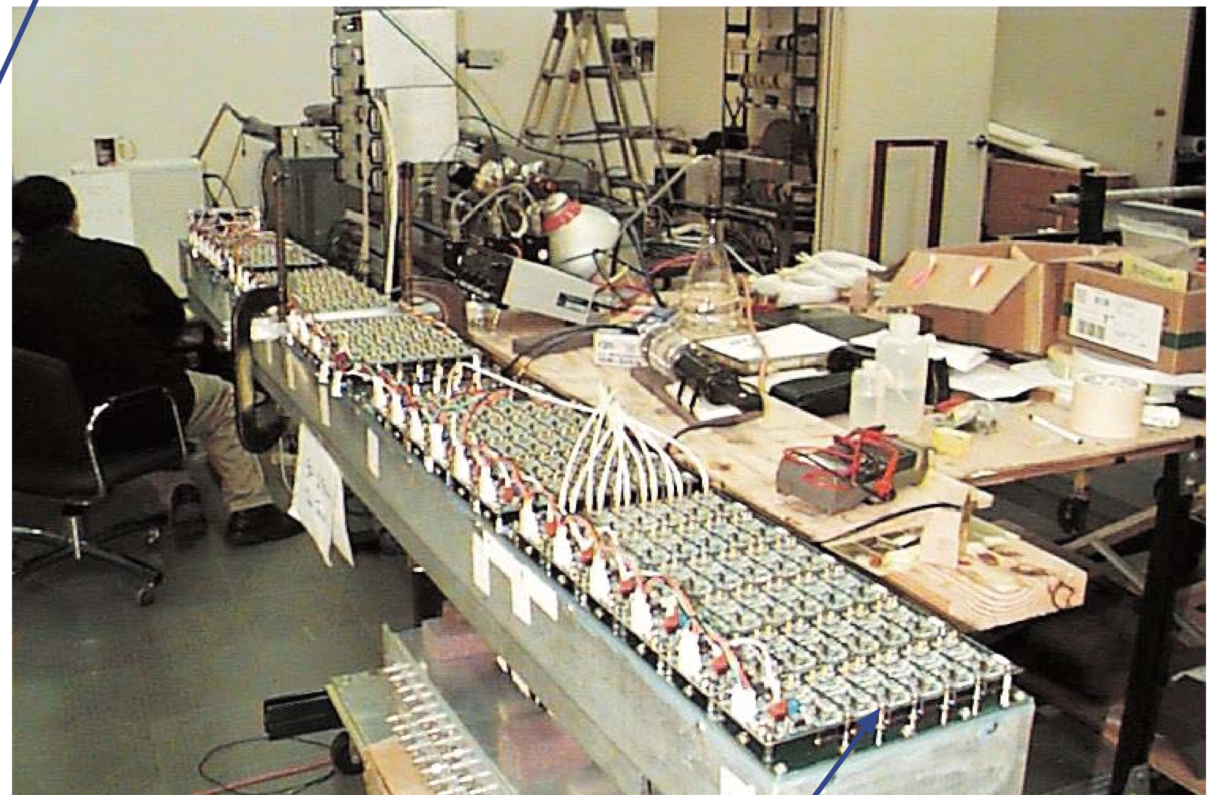
TOFr
(for RHIC Run-3)



MRPCs

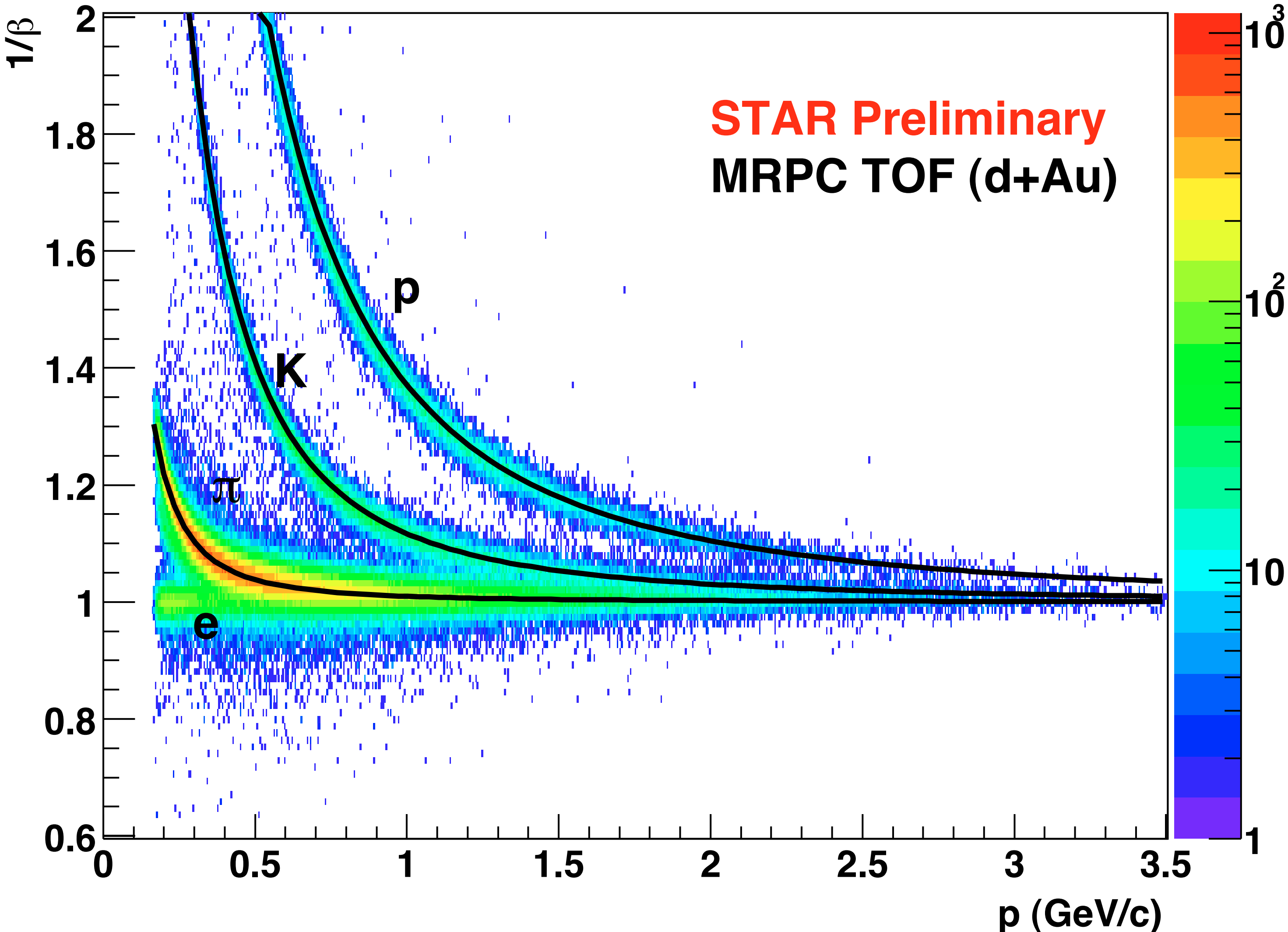
Tray (gas box)

Testing at Rice



TOFr FEE & F/T plates

TOFr+pVPD in RHIC Run-3 (d+Au)

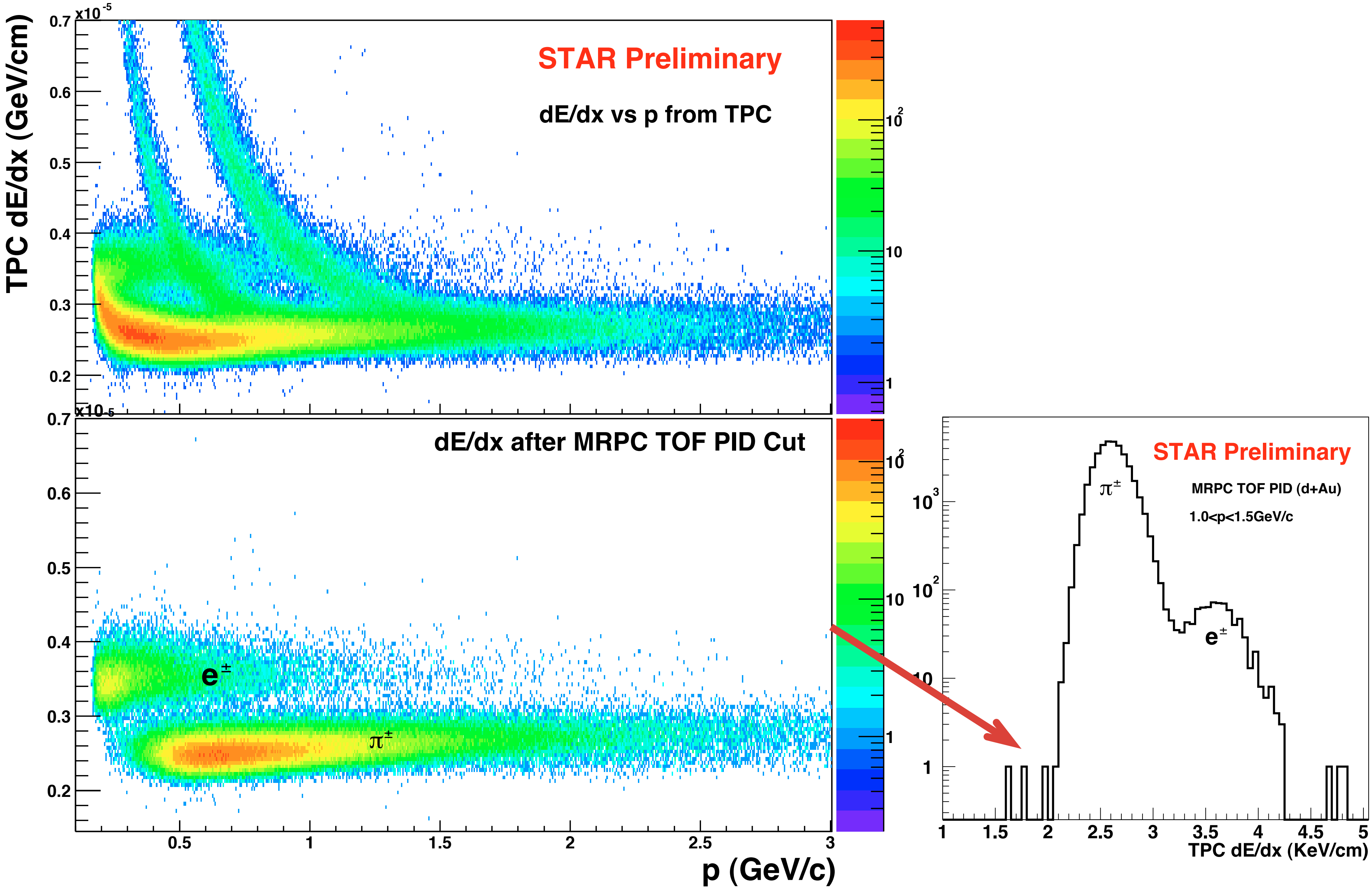


start resolution	~85ps
stop (MRPC) resn	~85ps
total	~120ps

→ π/K/p to ~1.6 GeV/c, and (π+K)/p to ~2.8 GeV/c

First physics result from an MRPC-based TOF System
on hadron Pt-distributions & the Cronin Effect in RHIC d+Au collisions
(J. Adams *et al*., STAR Collaboration, nucl-ex/0309012, submitted to PRL)

TOF in combination with TPC dE/dx also allows effective *electron PID*...
complementary to calorimetric measurements from BEMC/BSMD....



The second-generation prototype
for RHIC Run-4:

STAR TOFr'

similar module arrangement...

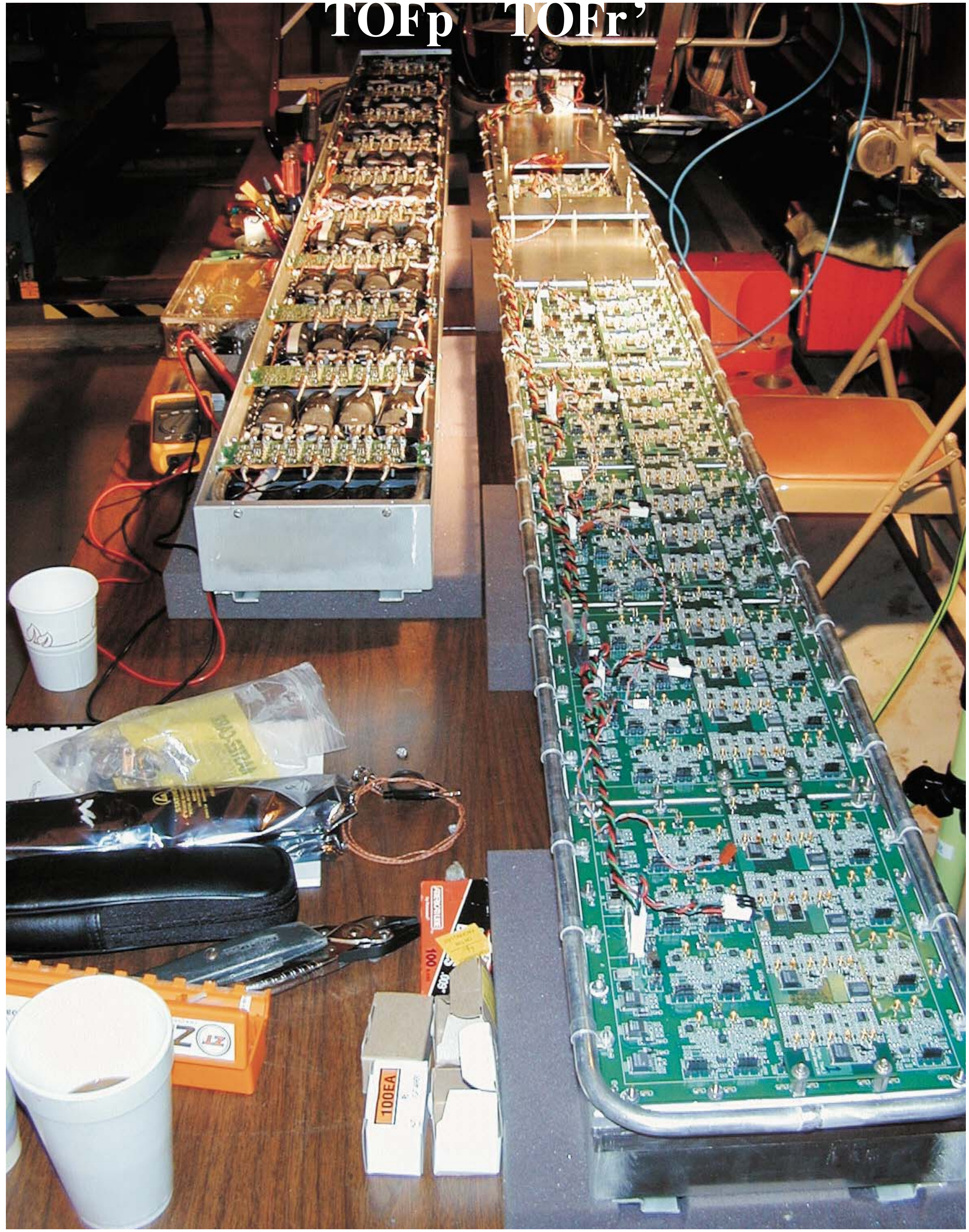
new "showbox" tray design...
- simpler fabrication process
- simpler to seal perfectly

FEE layer now closes the box...

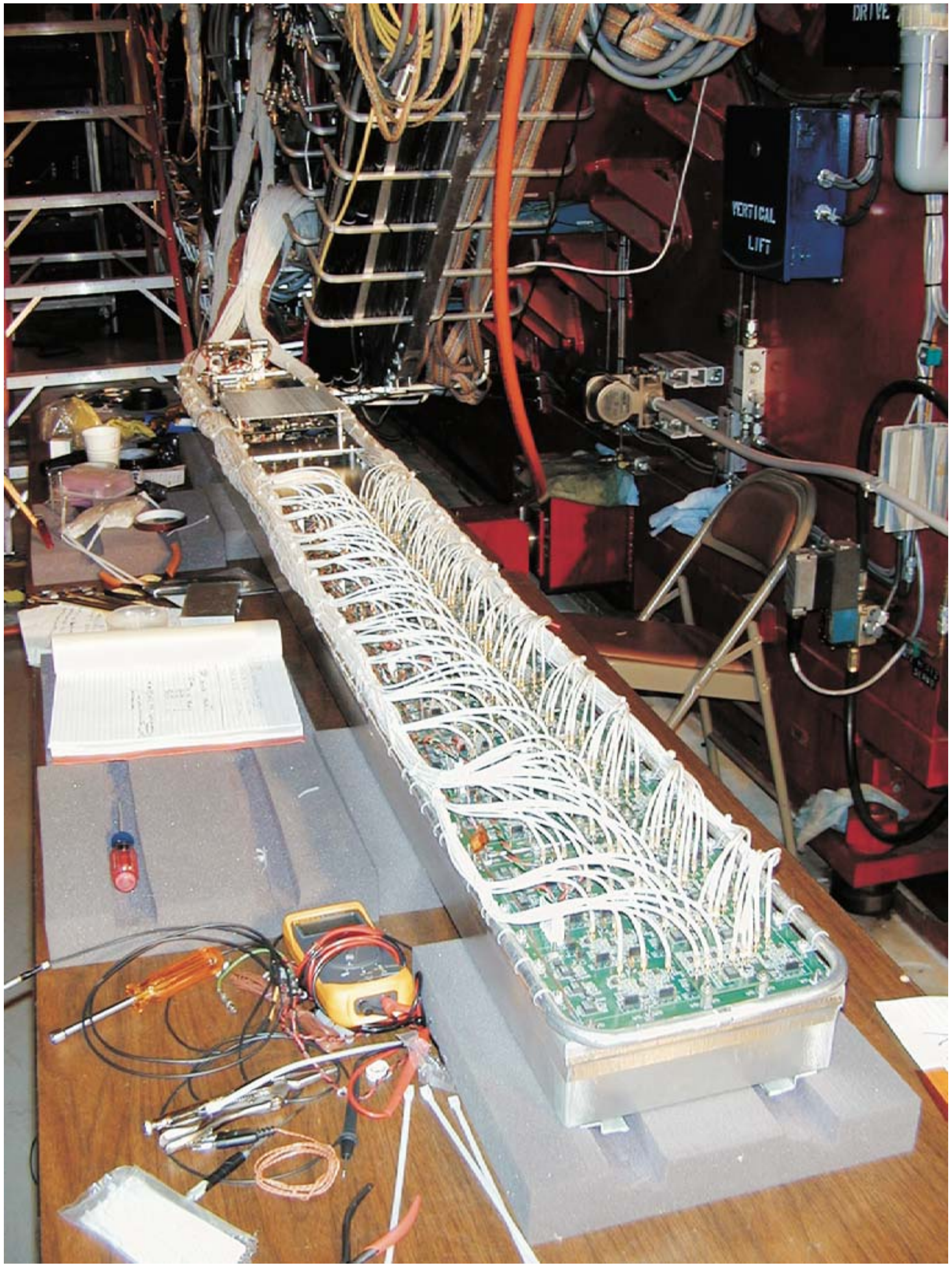
same camac digitization
over long cables into TOFp DAQ

stop-timing resolution consistent
with that w/ TOFr in Run-3
(performed to expectations for PID)

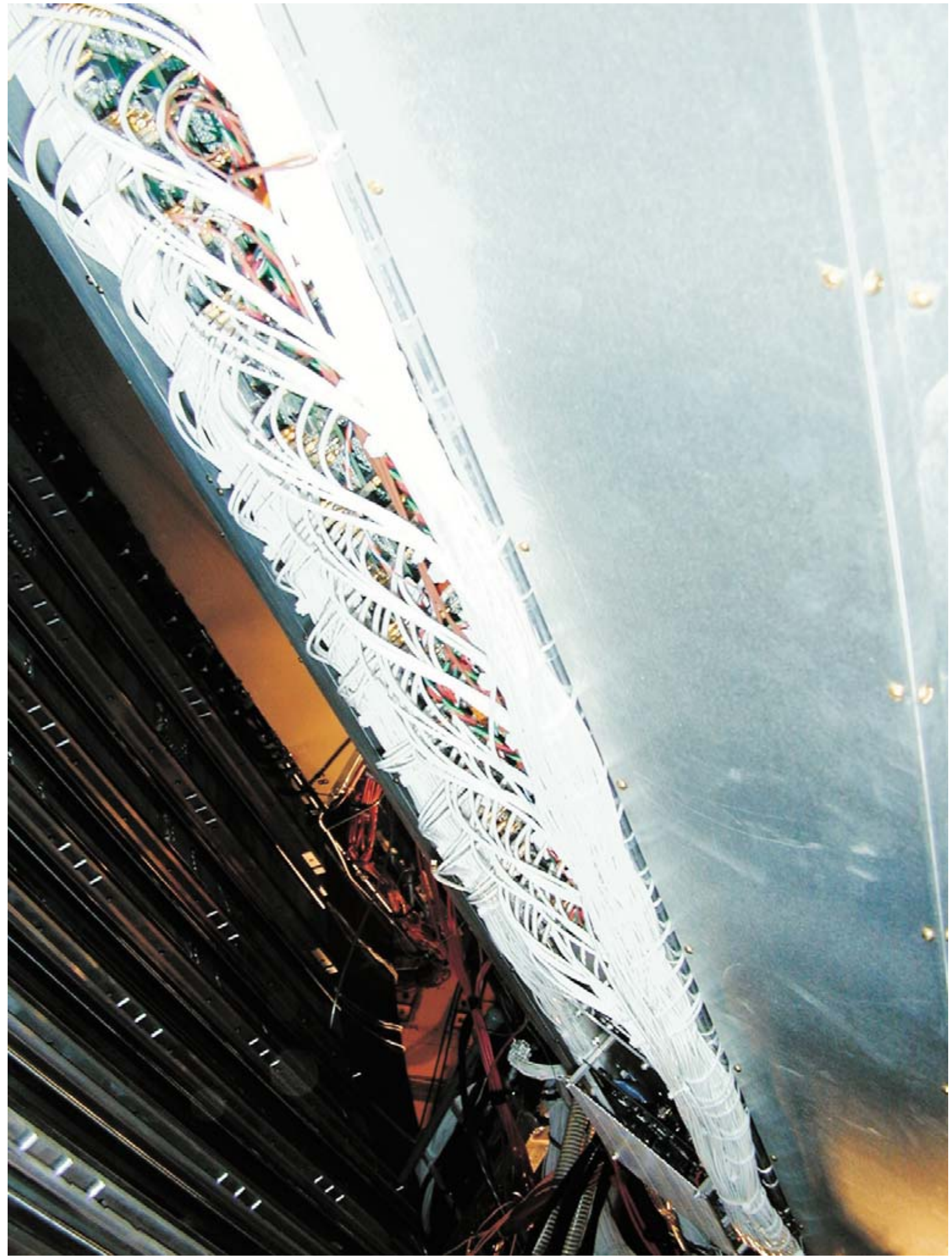
TOFr' problem areas:
- FEE heated the gas box...
- Too many cables to CAMAC...
- Too big...



TOFr’ with on-board cabling.....



TOFr’ installed for RHIC Run-4

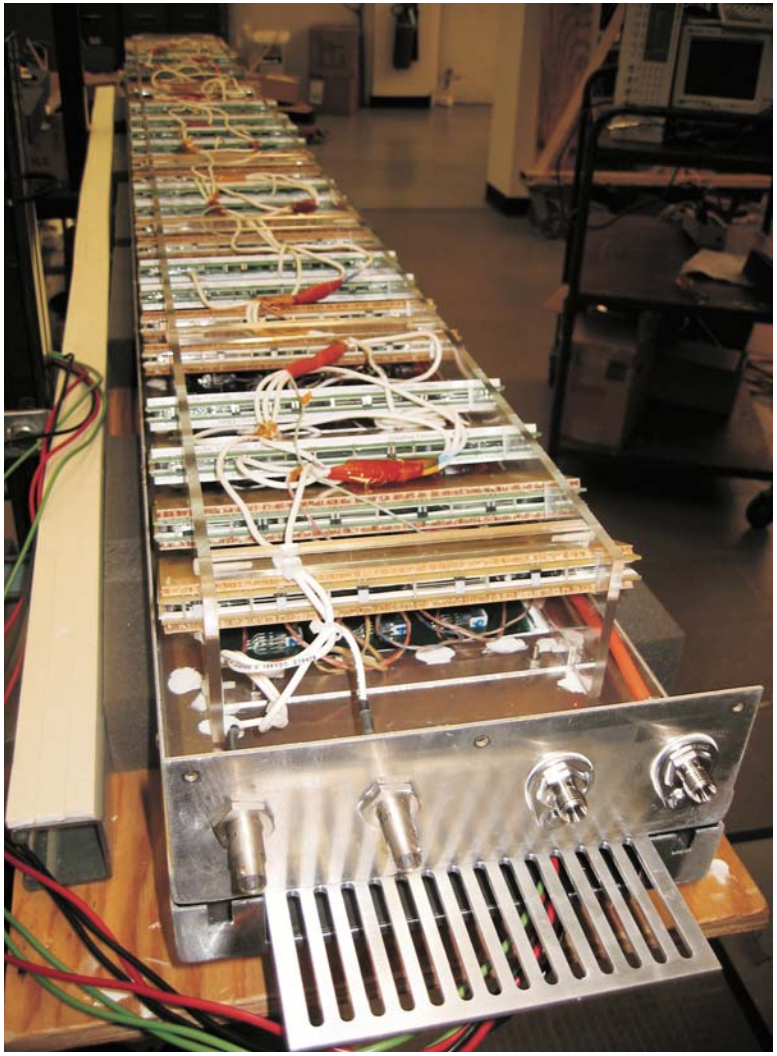


TOFr5 for RHIC Run-5

further improvements to mechanical design
full complement of MRPCs (32/tray)

first attempt at on-board digitization based on the HPTDC chip developed at CERN
digital data shipped off each detector tray via optical fiber.
major sea-change with respect to previous runs - we have lots to do in the next few weeks!

inside the box: 32 MRPCs...



tray closed up and ready for operation....

STAR has officially adopted
MRPCs for its large-area system...

- cover entire cylindrical surface of TPC
  $\Delta\phi=2\pi$, $-1<\eta<1$
- ~50 m^2 total area
  120 trays
  32 MRPCs/tray
  6 channels/MRPC $\rightarrow$ 23,040 chs
- 3840+ MRPCs contributed by China
- Tray fabrication & testing in Texas
- Digitization on-board
  (major R&D now is on electronics)

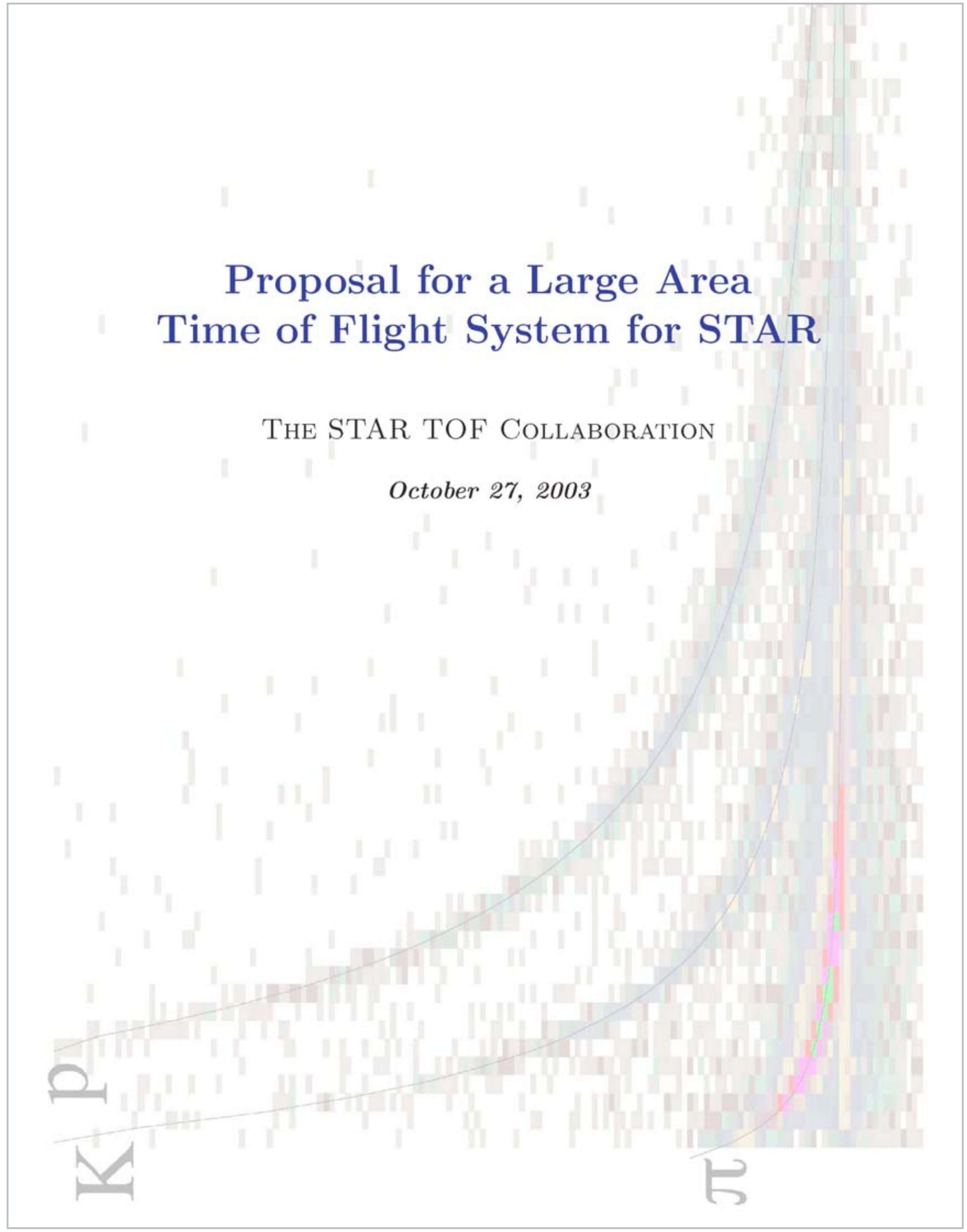
- US Cost: 4.7 M$
  Chinese contribution: 2.3 M$ (US$ equiv.)

Proposal now under review @ DOE....

hopefully, construction during FY05→FY08
...installed & ready before Run-9

increasingly larger patches each RHIC run
until the full system there...

http://wjllope.rice.edu/~TOF/TOF/Documents/TOF_20040521.pdf



Summary

The era of Scintillator+PMTs TOF systems is ***over***... The conventional technology is now obsolete.

The new MRPC technology is:

a *lot cheaper*,
easy to construct repeatably using simple off-the-shelf items,
apparently *stable* over long-terms, and

yet it matches or exceeds the timing performance & efficiency of conventional systems...

Used successfully in **HARP** experiment at CERN PS, and in STAR
Large-area systems under development for **ALICE** and **STAR**
R&D efforts at **GSI**, in **PHENIX** (×2)

STAR-specific prototypes tested under "battle conditions" throughout several RHIC runs...

Run-3 (**TOFr**), Run-4 (**TOFr'**), and in the upcoming Run-5 (**TOFr5**)...
Proven capable of good timing and producing new physics results...

TOFr5 has first implementation of on-board digitization... Major sea-change, but important for:

proposed STAR TOF System - **120 TOFr5-like trays** plus an **upgraded start detector**

to surround the STAR TPC, ~50m^2, 23,040 channels.
approved by STAR & BNL and now under review at DOE.
Optimistic for construction start in late 2005 and completion in advance of Run-9 (2008-2009).
Increasing patches installed in STAR during RHIC runs 6 to 8.

Increases STAR's charged hadron PID acceptance by ~30%, at <5% of STAR's total cost....