The STAR Resistive Plate Chambers

W.J. Llope
Rice University

PHENIX Muon Physics and Forward Upgrades Workshop
Santa Fe, NM
June 23, 2004

OUTLINE:

- Multi-gap RPCs...
  high-resn, easy to build, cheap
- The MRPCs for STAR...
- The STAR TOFr Prototypes
- ALICE MRPCs...
- HARP MRPCs...
- GSI MRPCs...
- PHENIX TOF MRPCs...
- Summary

Multi-gap

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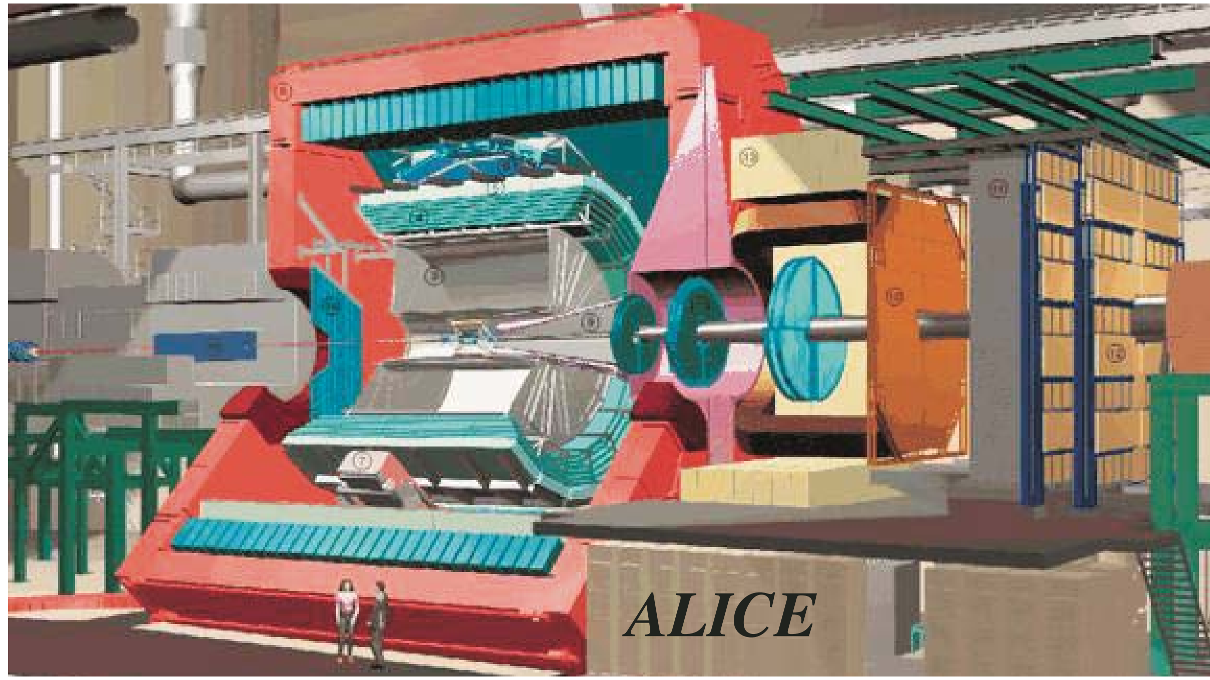
- PHENIX TOF MRPCs...
- Summary

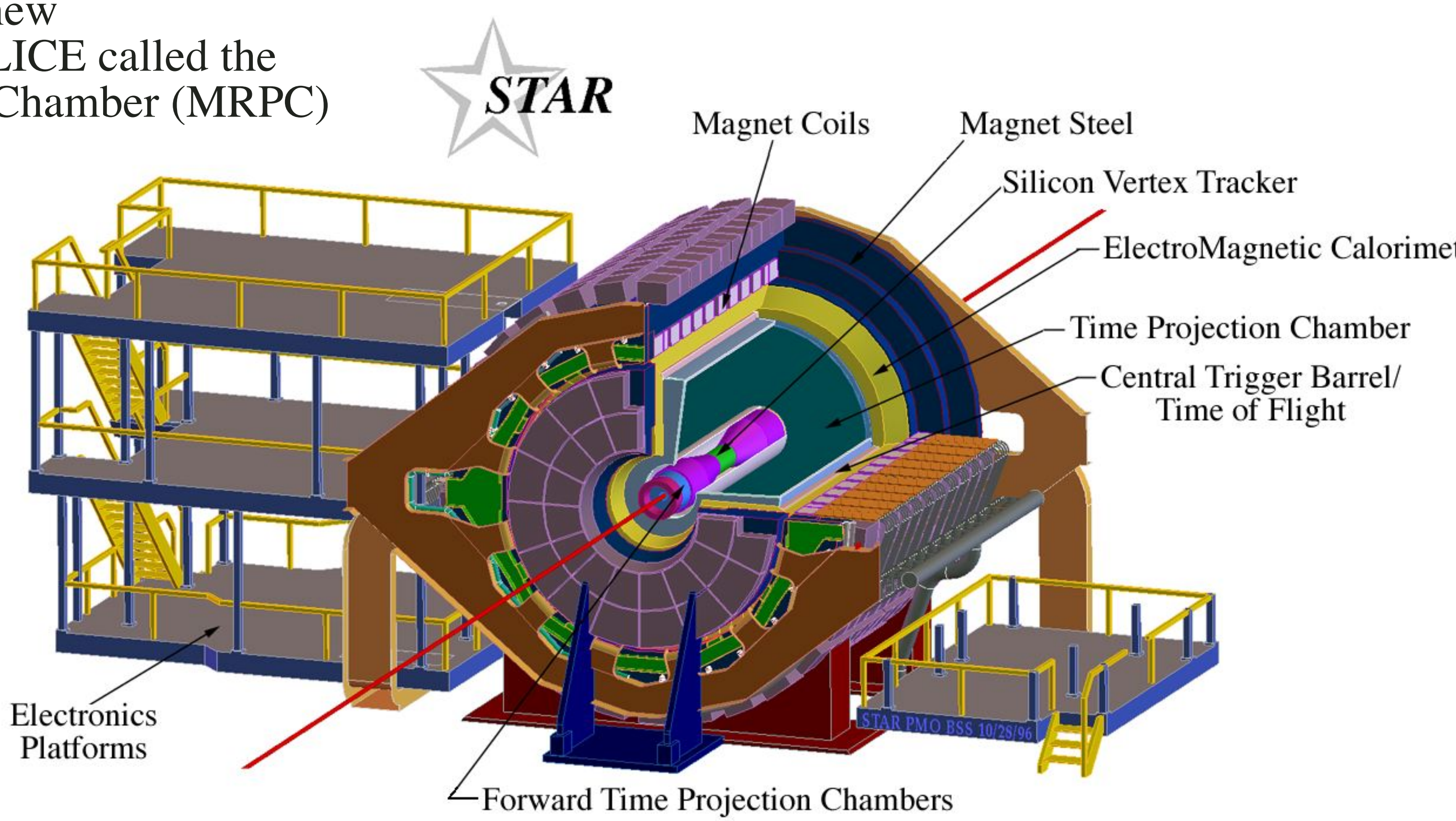
Two large and very similar collider experiments needing large-area TOF coverage....

area's too large to even consider using PMTs and plastic.



1998 to present:
LAA detector development project (A. Zhichichi *et al*.) and M.C.S. Williams *et al*. develop a new technology for TOF for ALICE called the Multi-gap Resistive Plate Chamber (MRPC)

1999-2001:
Rice group develops version for STAR...



TOFp/pVPD in Run-II

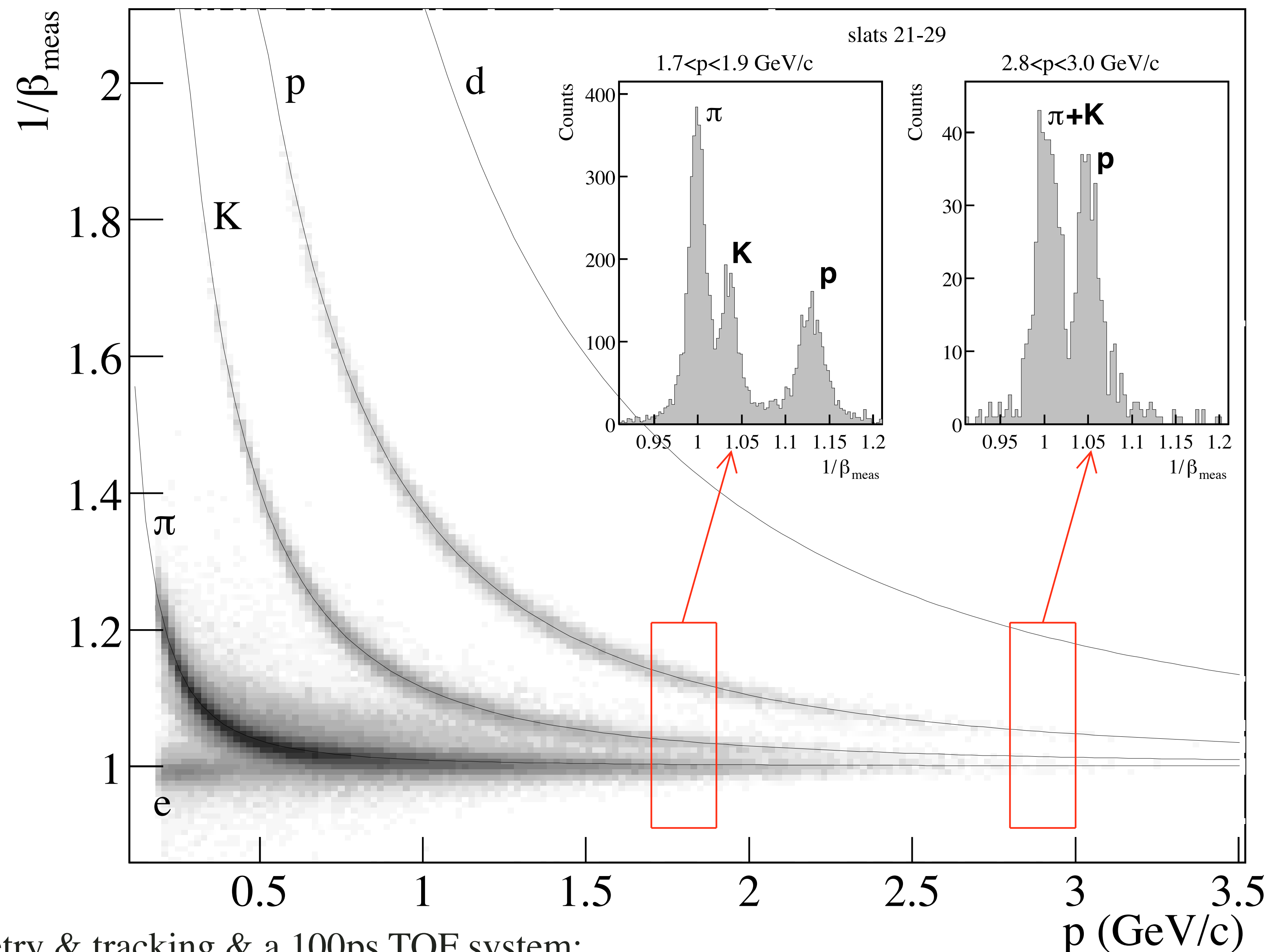
WJL *et al.*, NIM A **522**, 252 (2004).

slat&PMT system
long cables
digitize in CAMAC

Start resn (pVPD):
~24ps
>99% efficiency

Total resn:
~87ps (all slats)
~79ps (best 25)

(for central Au+Au)



With STAR's geometry & tracking & a 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
- w/ TPC dE/dx, also clean electron PID at "low" momenta...

But:
50 m^2 of this, w/ granularity s.t. occupancy is <15%, is **>20 M$**

Resistive Plate Chambers

(in avalanche mode)

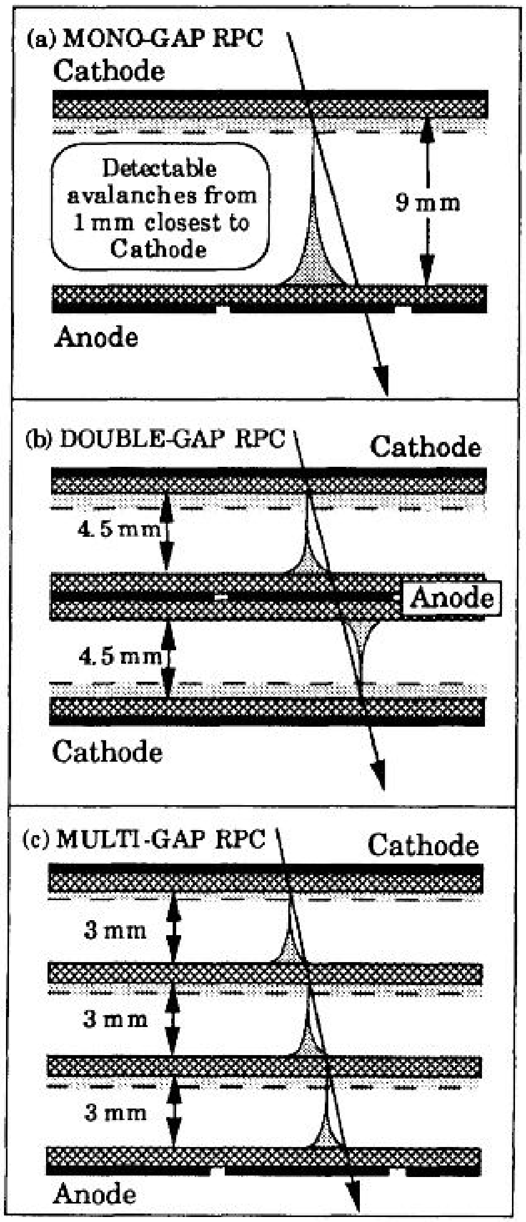


Figure 2. Schematic representation of a monogap RPC (top); a double gap RPC (middle) and a multigap RPC (bottom).

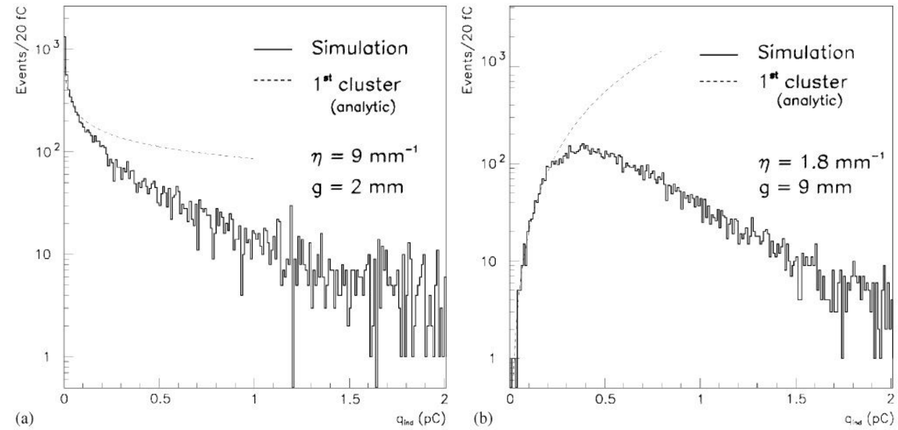


Fig. 1. Comparison between the simulated charge spectra for single (a) narrow ($g = 2$ mm) and (b) wide ($g = 9$ mm) gap RPCs.

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
→ 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...

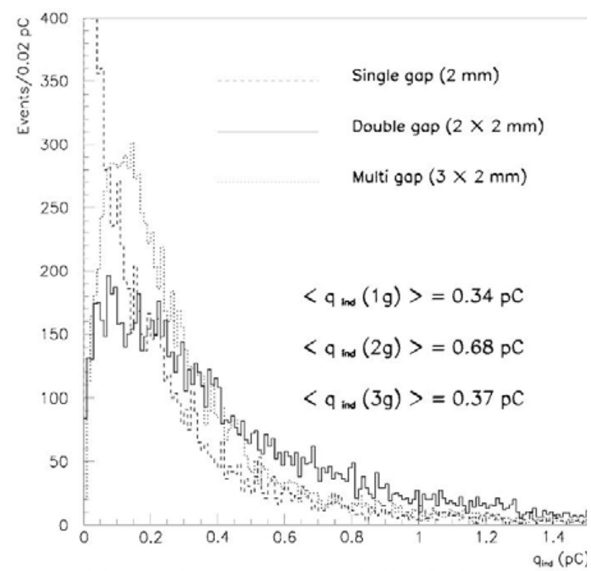
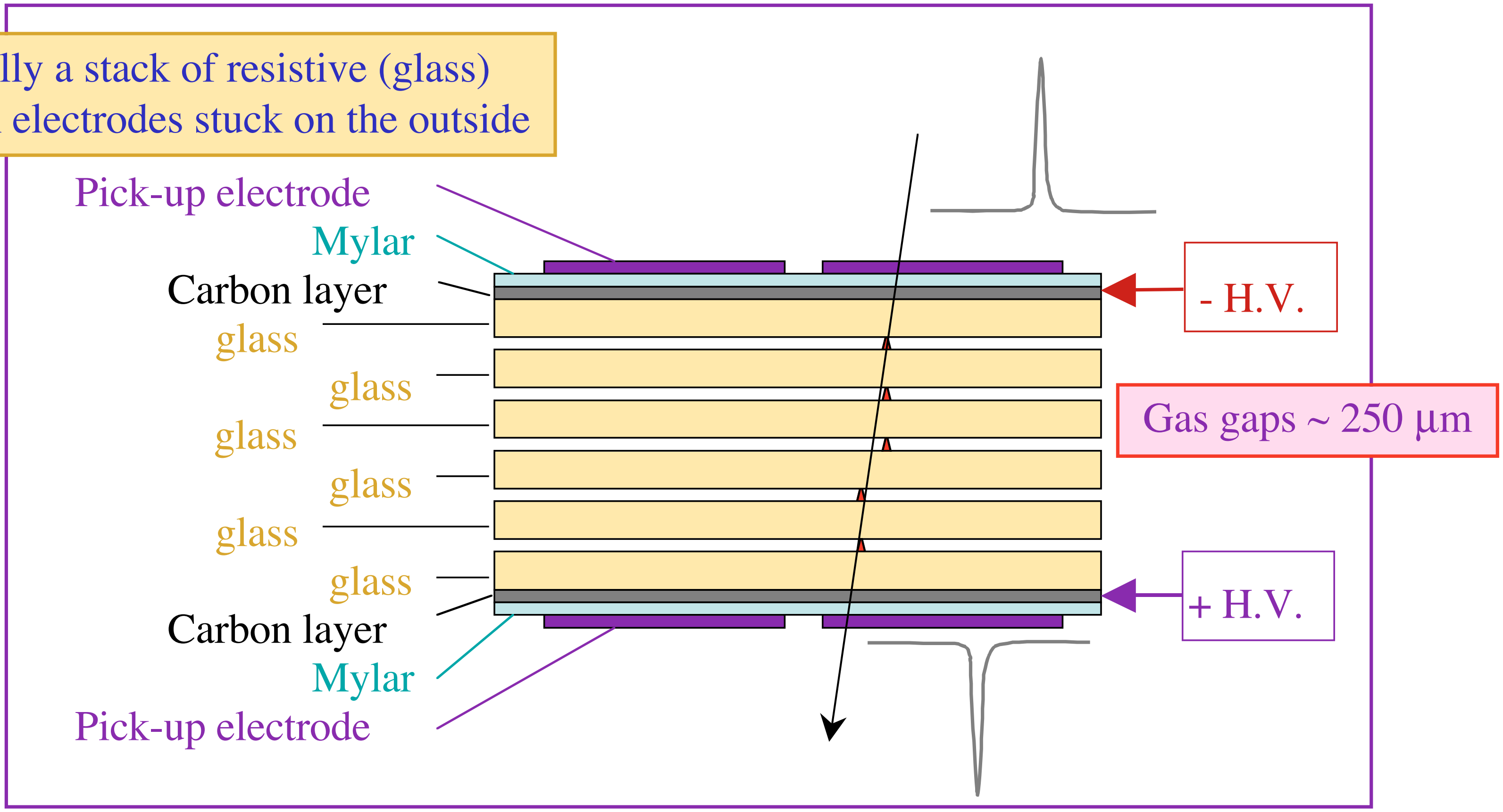


Fig. 3. Monte Carlo charge spectra for single- double- and multi-gap RPCs.

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.

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.

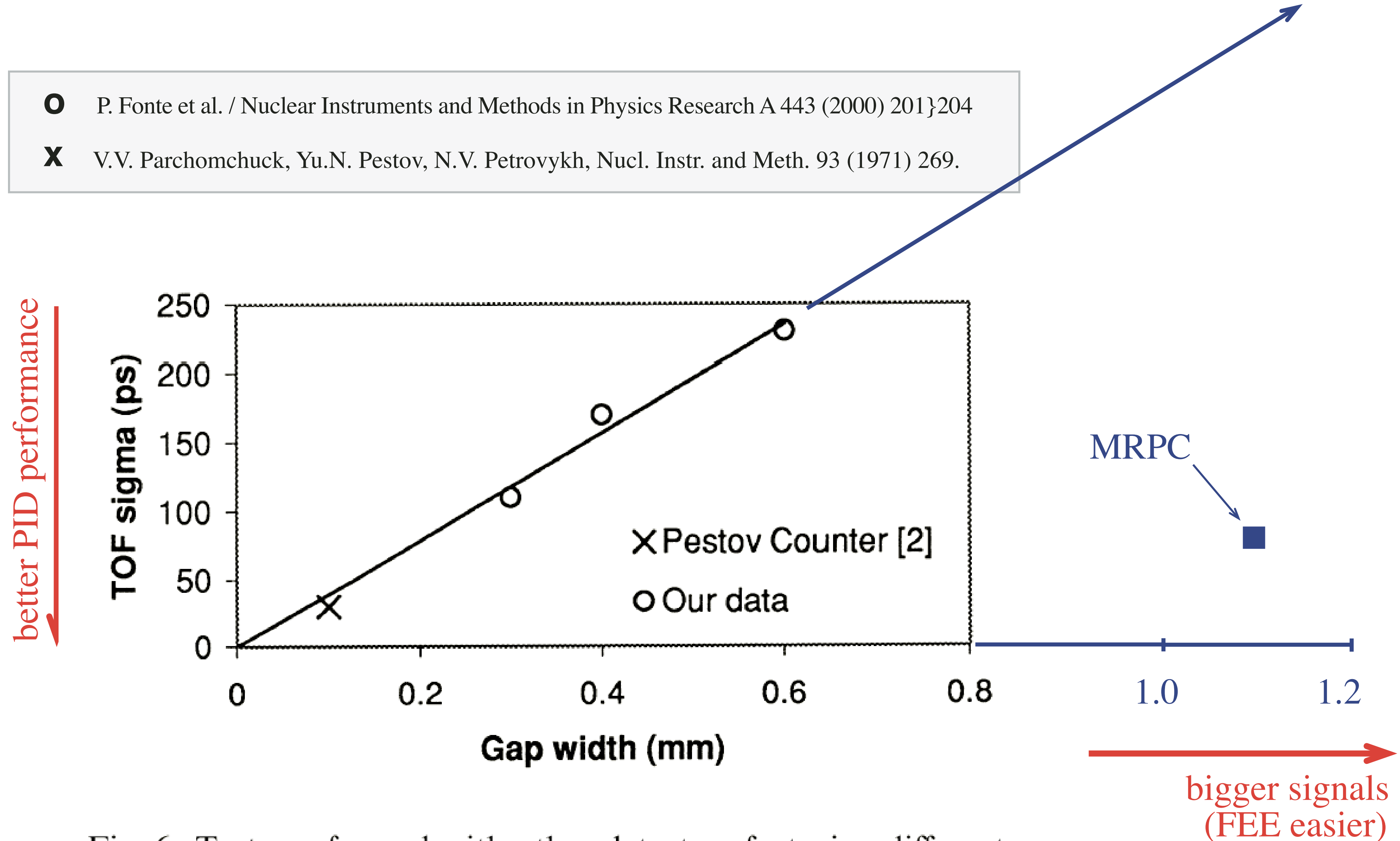


Fig. 6. Tests performed with other detectors featuring different widths of the gas gap suggest that the main contribution to the time jitter is associated to the amplification process in the gas. The timing resolution seems to depend almost linearly on the gap width, with a slope of approximately 40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

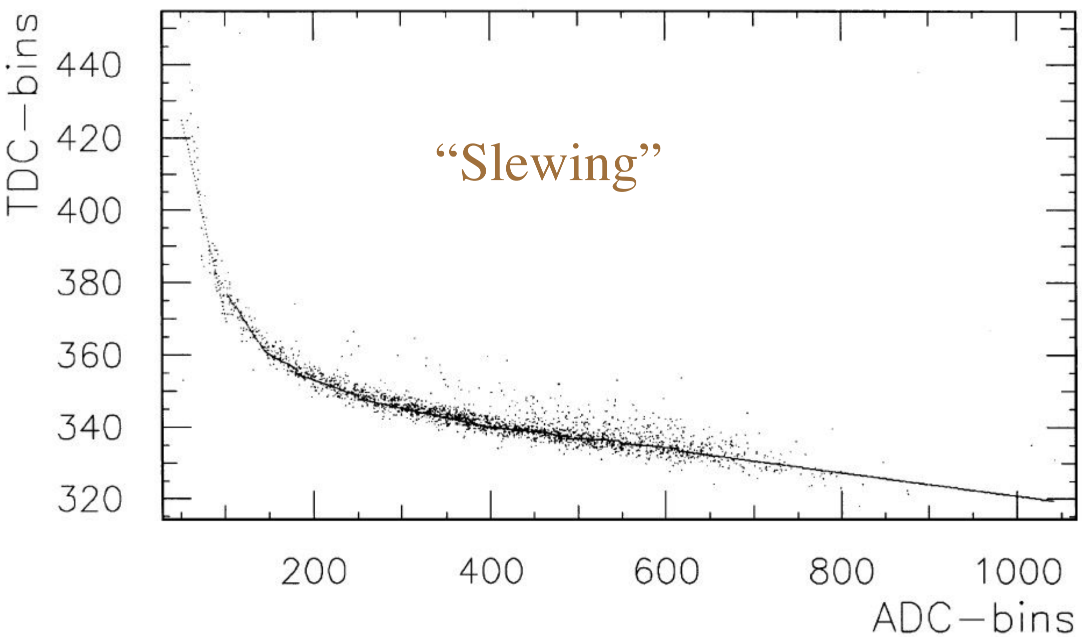


Fig. 4. Correlation of raw time difference between MRPC detector and reference counter and MRPC signal amplitude.

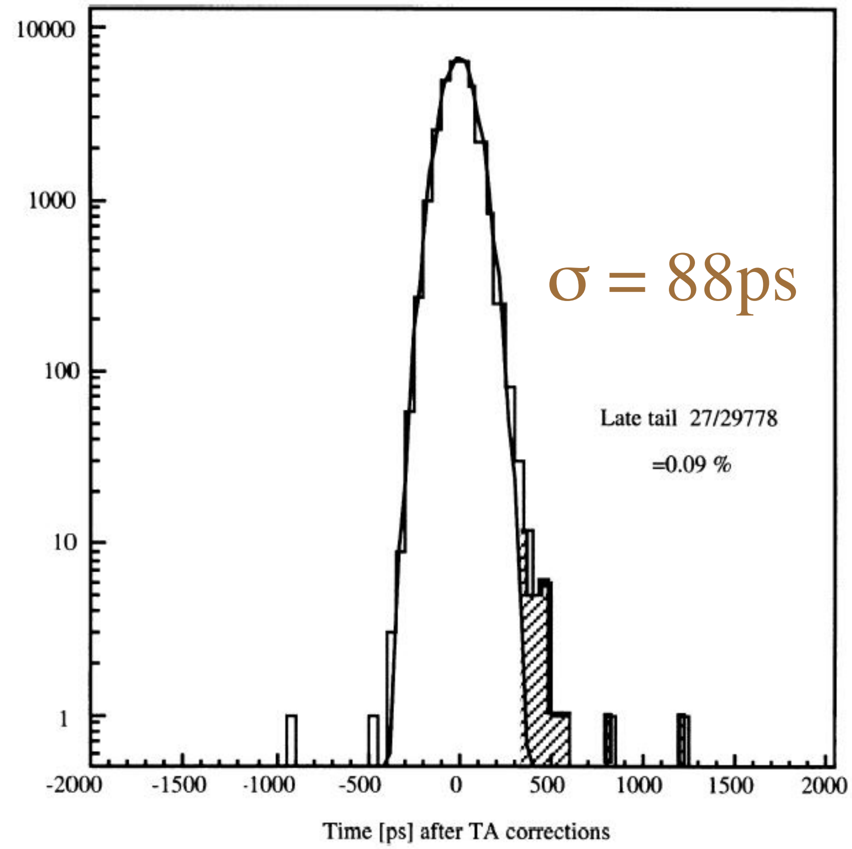
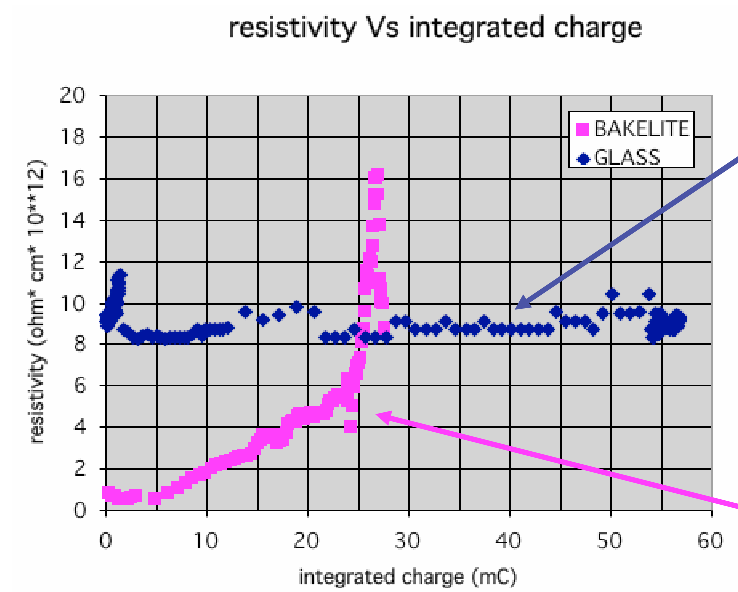


Fig. 5. Time distribution measured with an MRPC with five gaps of 220 μm operated at 12 kV (109 kV/cm). The width of the Gaussian fit is $\sigma = 88$ ps.

MRPCs are chambers w/ resistive plates but are ***not*** "RPC's".....

1.Float Glass vs. Bakelite +linseed oil

2. Avalanche Mode vs. Streamer Mode

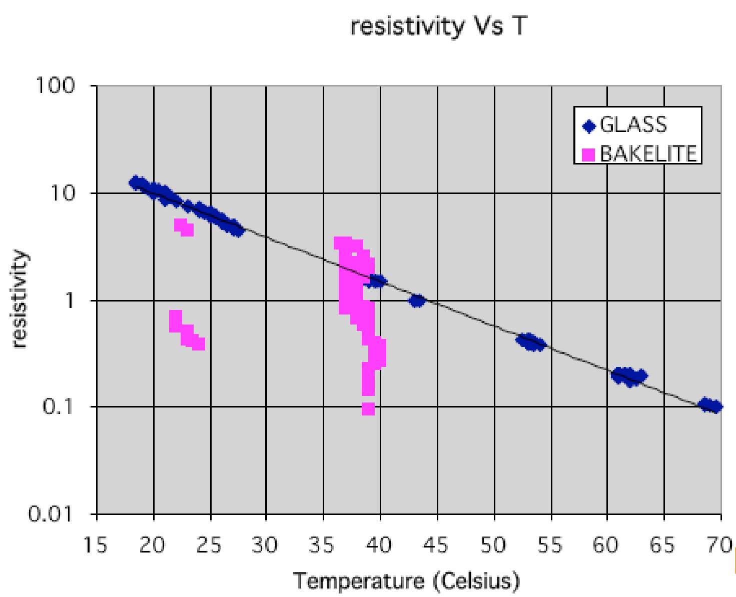


Float Glass:

Has a stable resistivity (hopping conductivity)
$\rho = 10^{12}$-10^{13} Ωcm at normal temperature

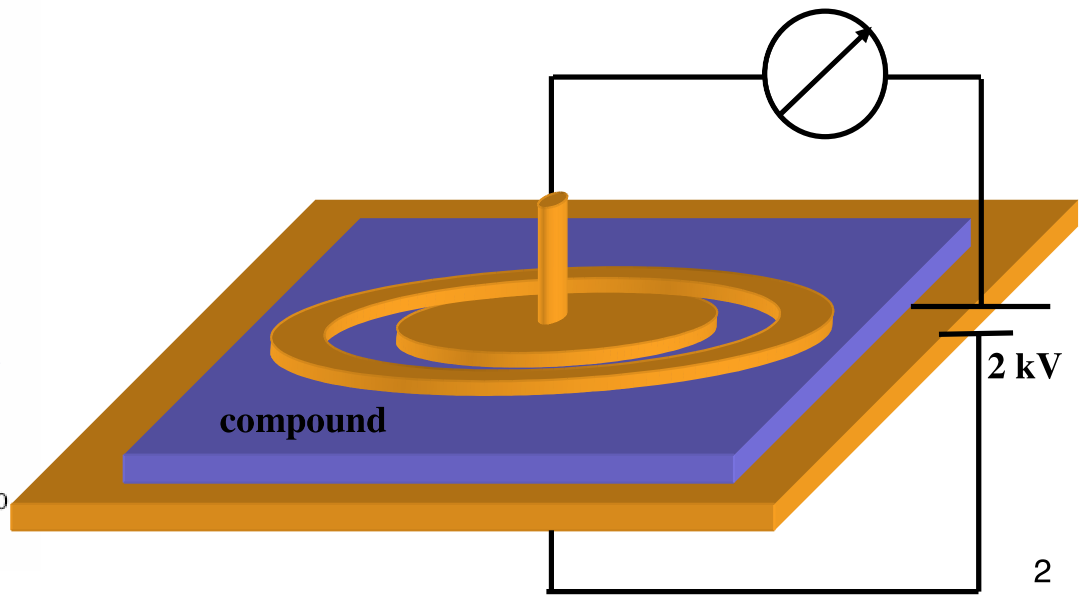
Resistivity depends only on temperature

$$\rho = \rho_{20} 10^{(T-20)/25}$$



Bakelite:

$\rho = 10^{10}$-10^{12} Ωcm at normal temperature
resistivity increases with the integrated charge (ionic conductivity)
Need a surface treatement with linseed oil



C.Gustavino, 20-22 october 2003, Clermont-Ferrand more on (M)RPC Aging..

ALICE TOF prototype tested at GIF over 200 days
7×10^9 events/cm^2 at 50 Hz/cm^2 → 54 years Alice running at 30days/year

Chemical analysis (Chromatography) of the outgoing gas from both MRPCs (CH1, CH2) by CERN EST/SM-CP :
measured concentration of Fluorine under the limit of detection (0.02 **ppm**), I.e. no trace of HF in the samples

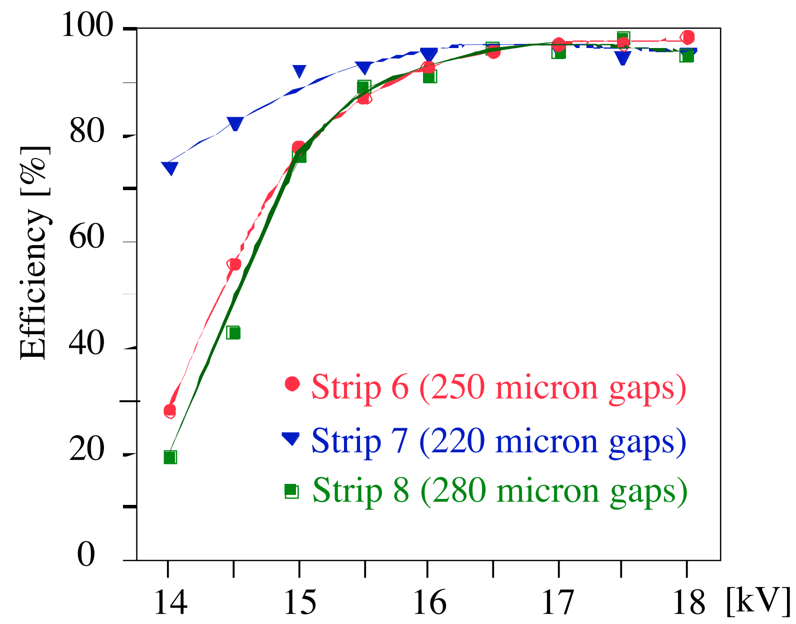
- Active detector volume is 2% of the total volume of the gas box;
- Diffusion for the gas exchange between strip and the surrounding gas.

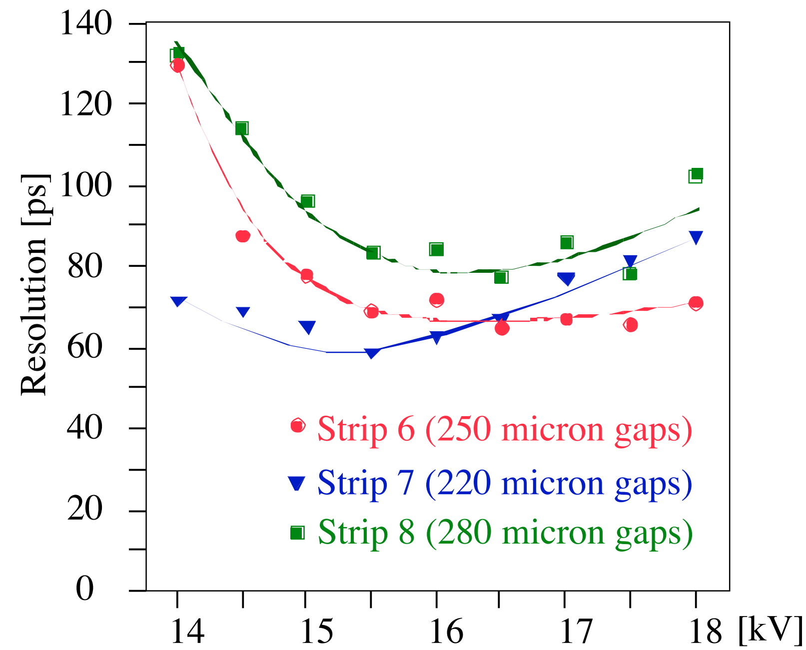
- No sign of degradation;
- No increase of dark current;
- No degradation in efficiency;
- No degradation in time resolution;

MRPCs are (relatively) easy to build!

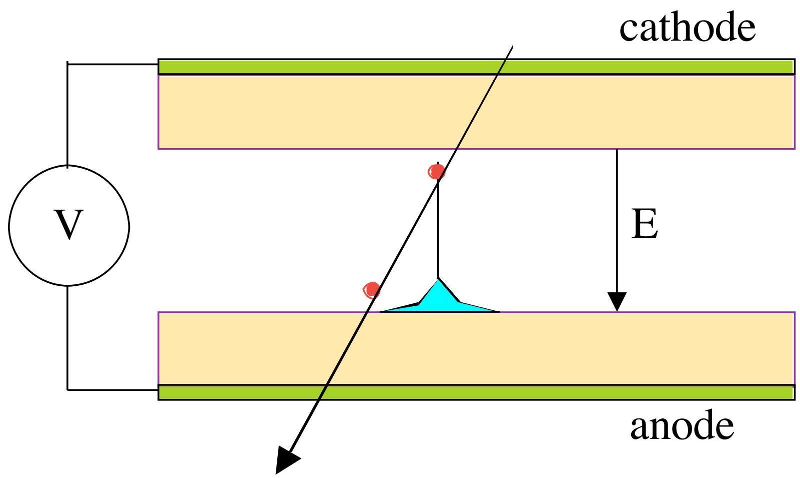
Big change in gap size $\longrightarrow$ small change in operating voltage. Large 'plateau' region where efficiency high, time resolution excellent and gap can vary by ± 30 μm

Thus device with this excellent time resolution can be built with very 'relaxed' mechanical tolerances



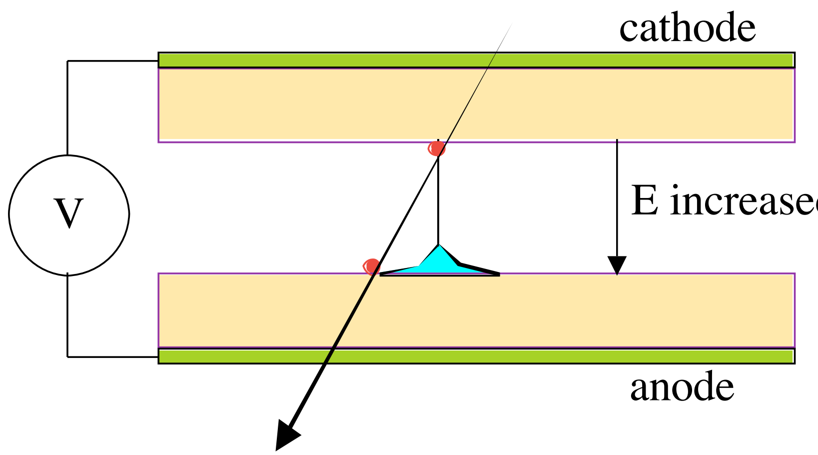


MRPCs apparently aren't very sensitive to tolerances on the gas gaps....



Charged particle passes through gas gap and creates clusters of electrons and positive ions electrons avalanche towards anode →fast signal on external electrodes - etc

Now consider smaller gap



E increased (same V - smaller gap)

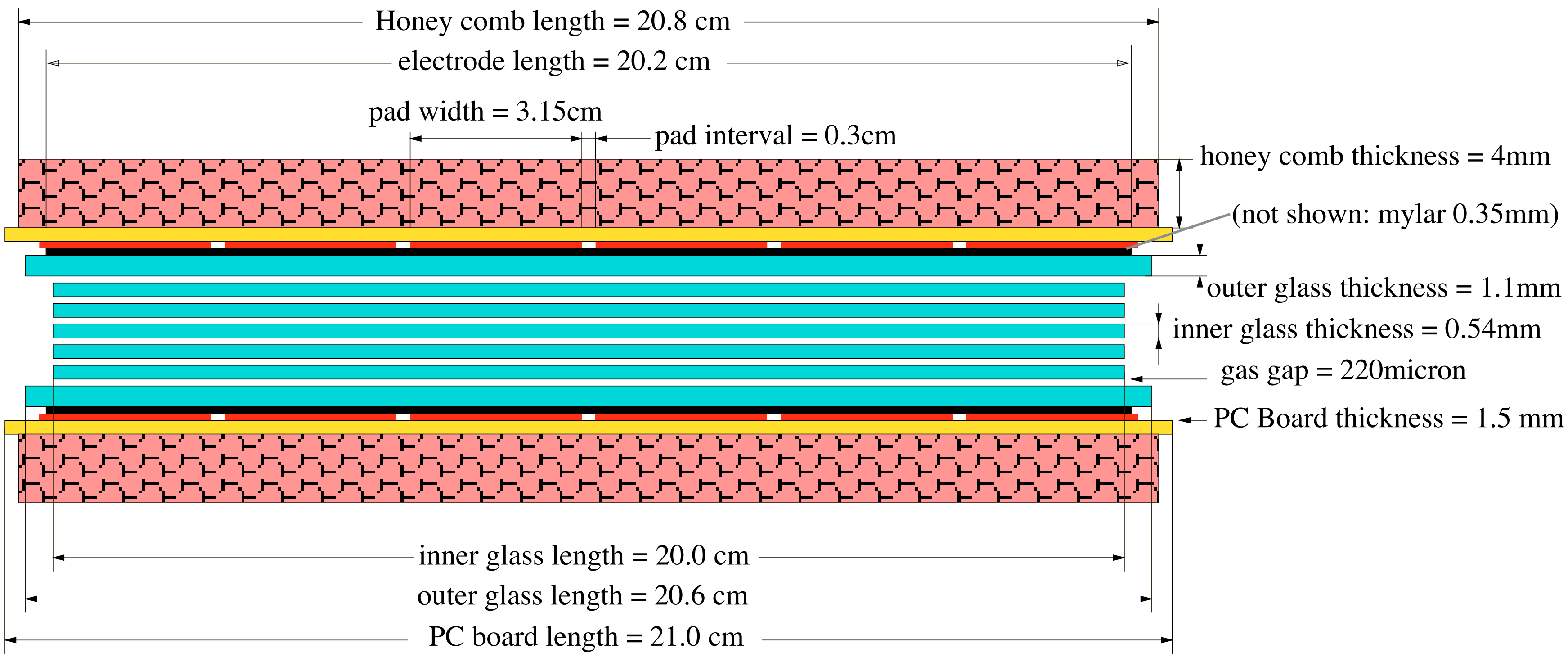
Thus Townsend coefficient higher - bigger avalanche (i.e. higher gain)

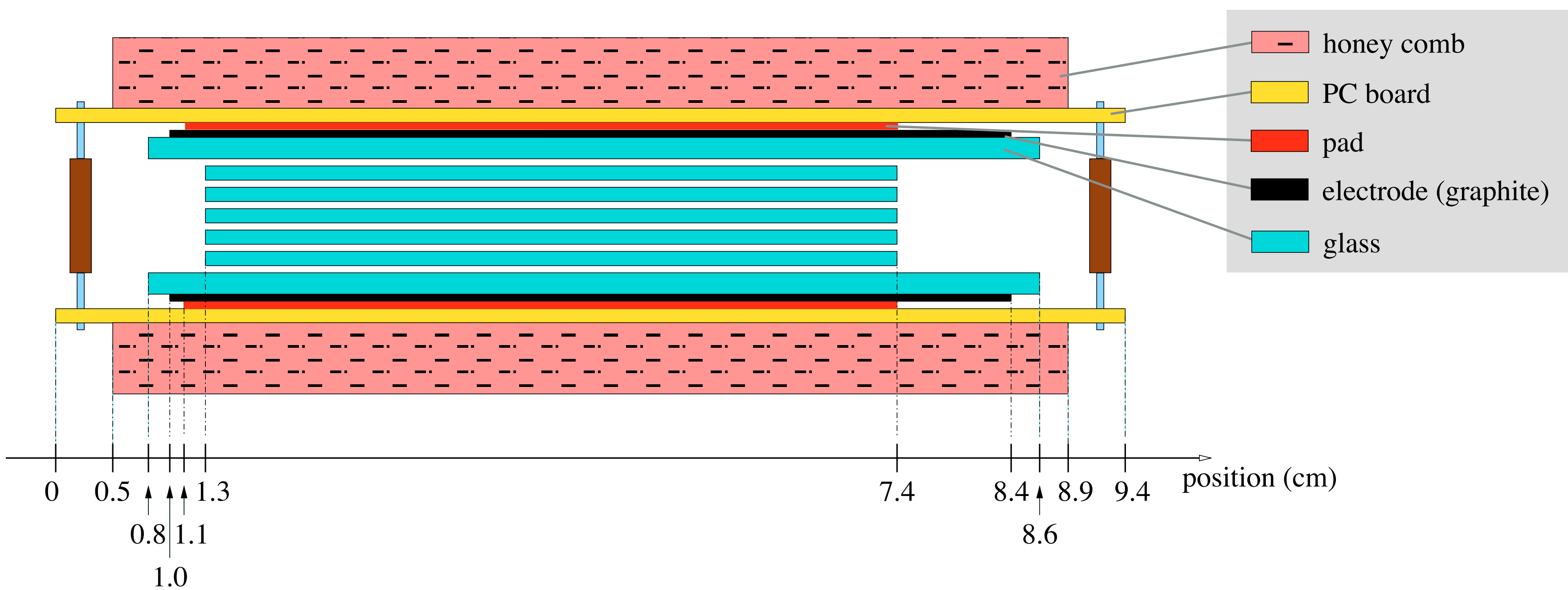
however gap smaller therefore less distance for avalanche to grow (i.e. lower gain)

Apparently we are working in region where both effects cancel (by 'magic' it is rather an exact cancellation)

STAR's Variant...

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

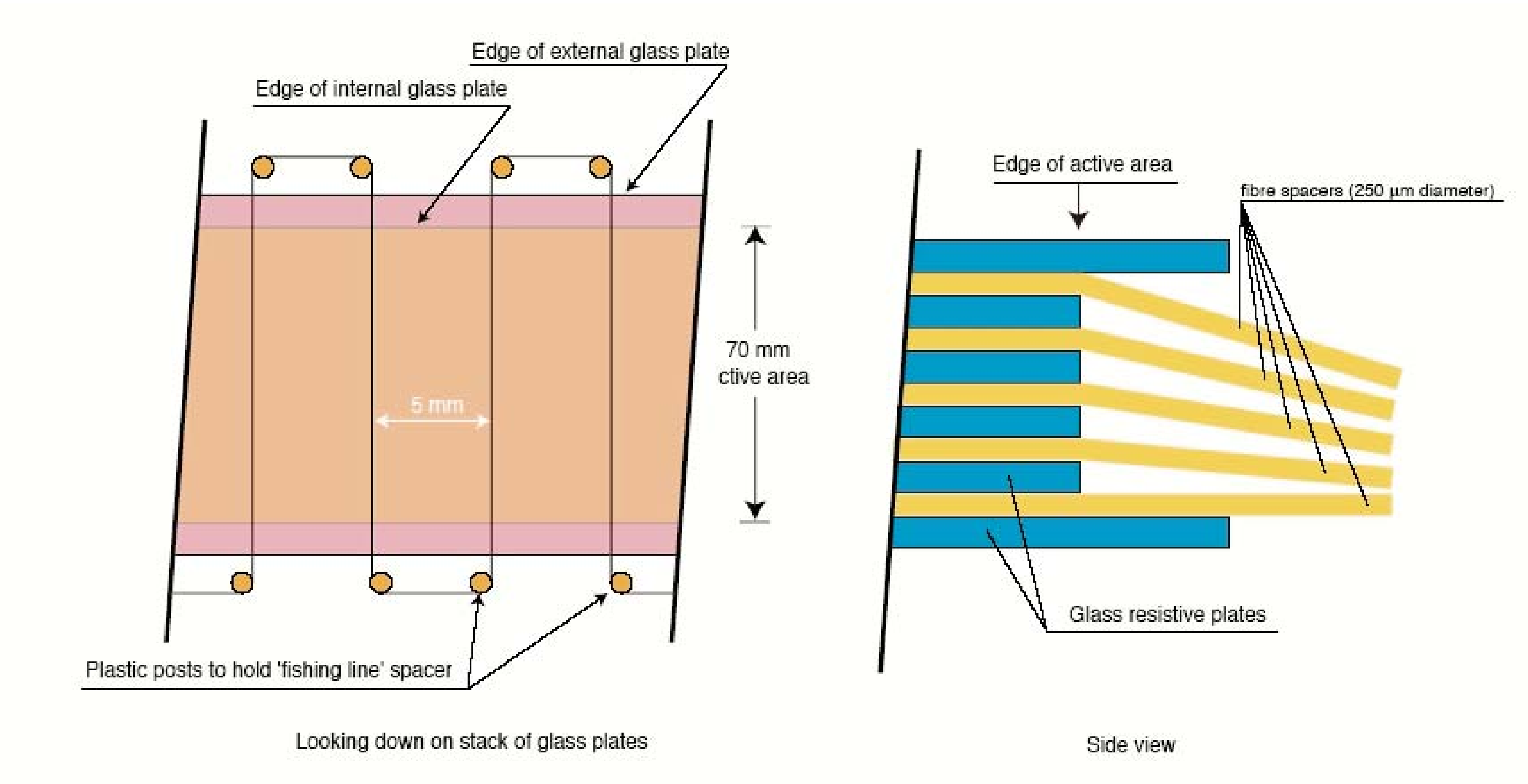


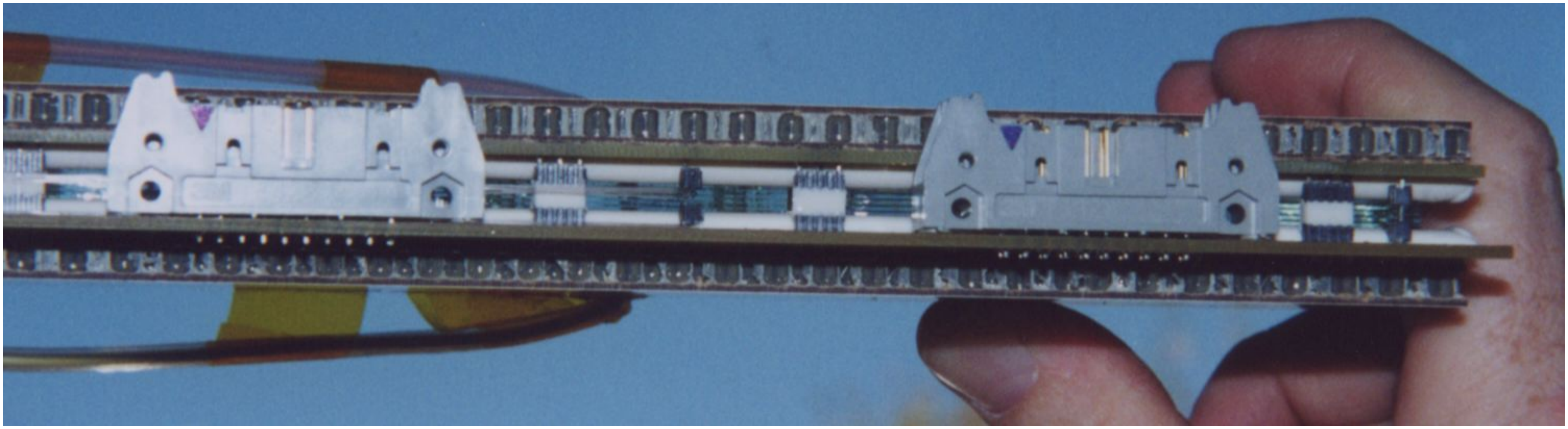


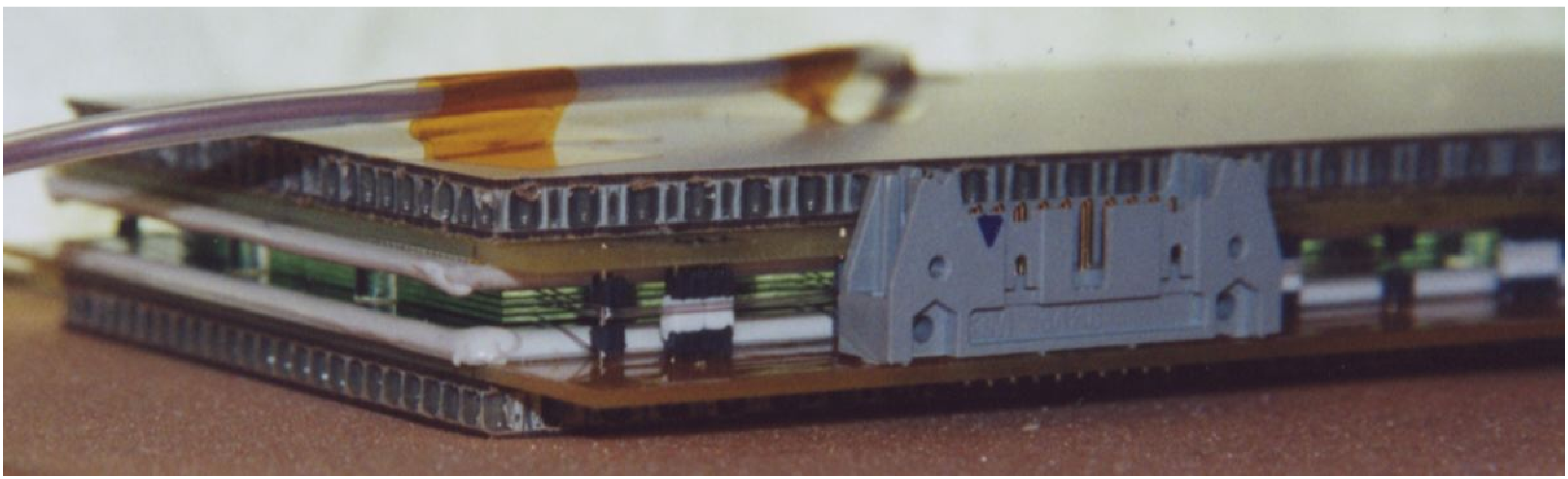
Spacing of inner glass plates is set by *monofilament fishing line*... (ALICE, HARP, & STAR)

- 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...





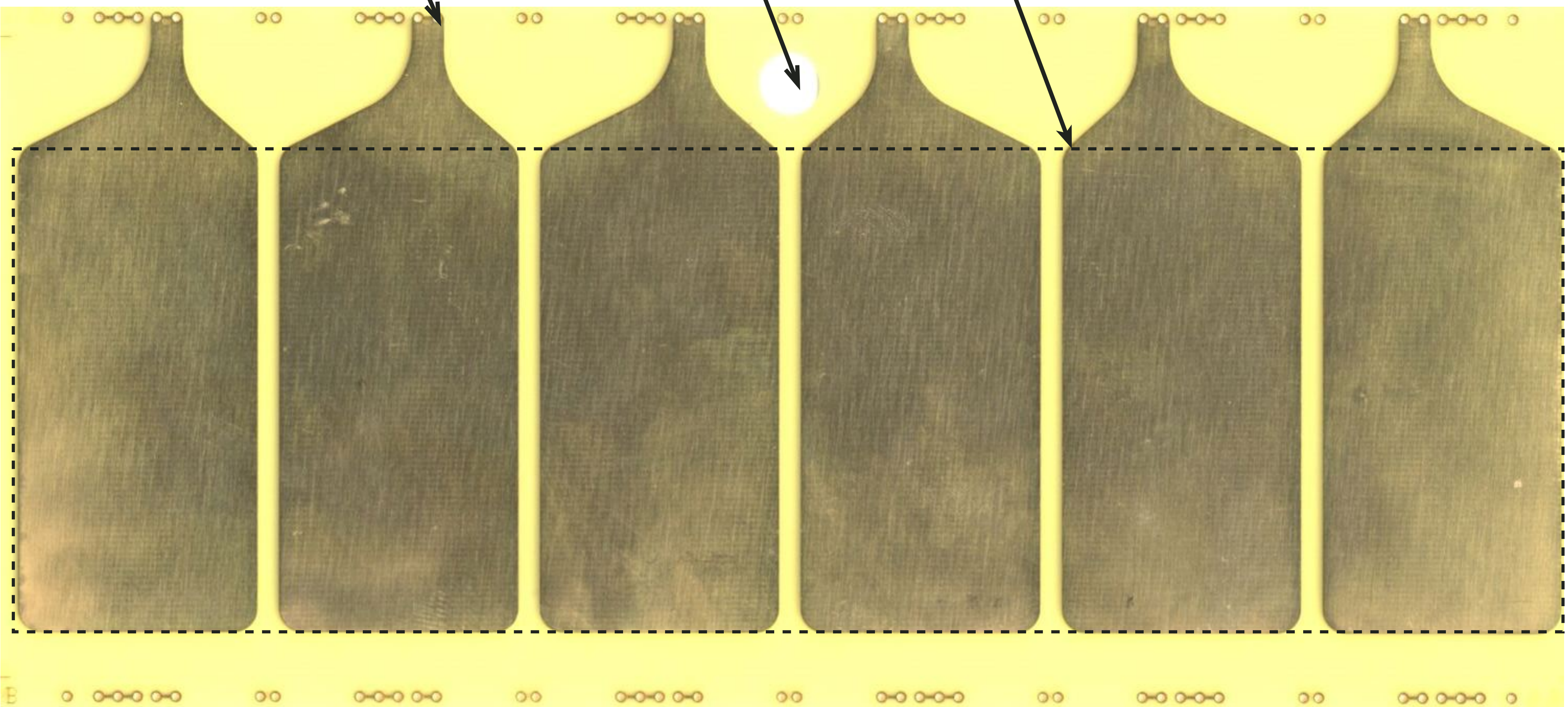


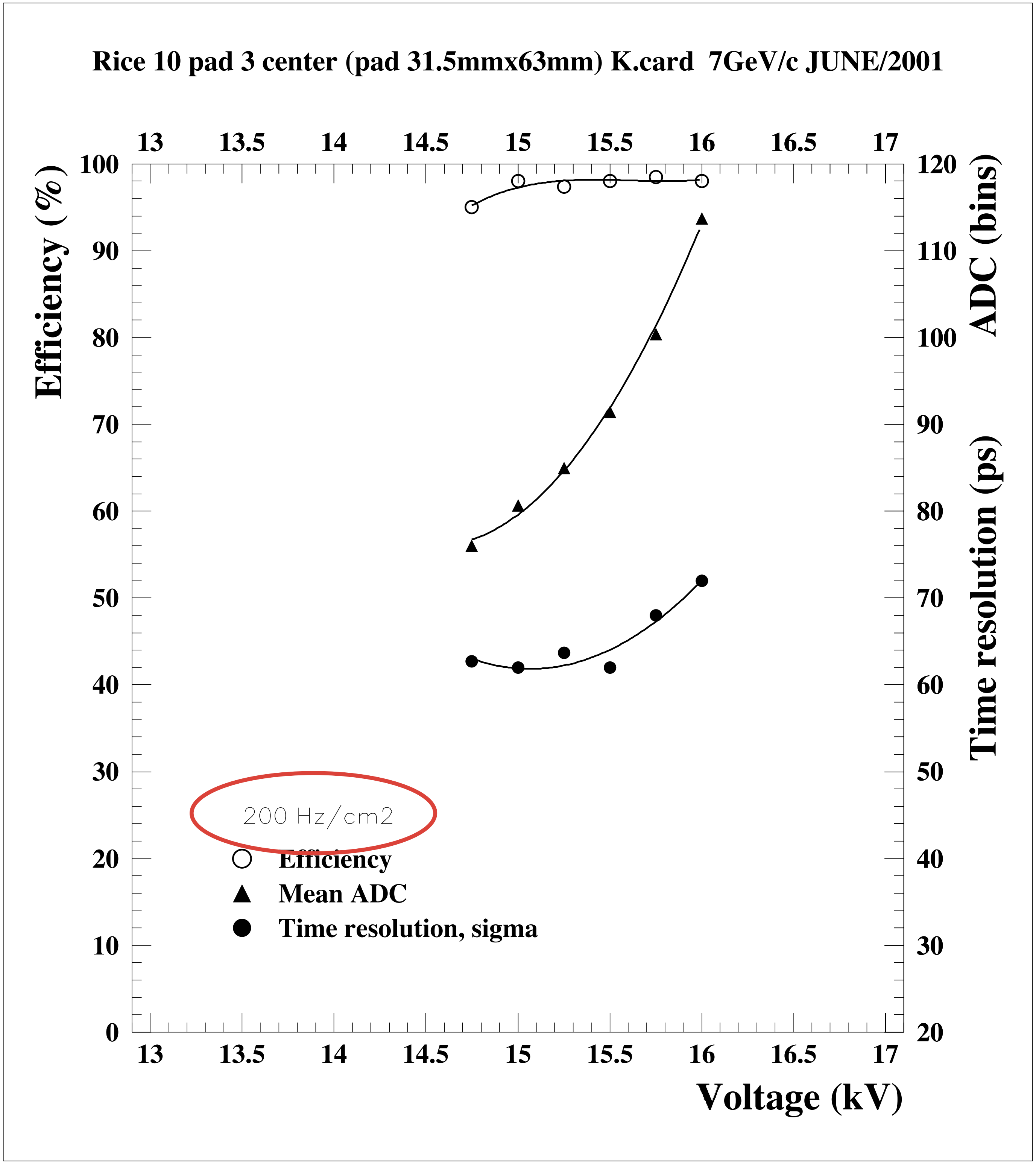
Readout Pads

region of pads above thin glass indicated by dashed box

hole to pass HV through to graphite layer

pins for signal output





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

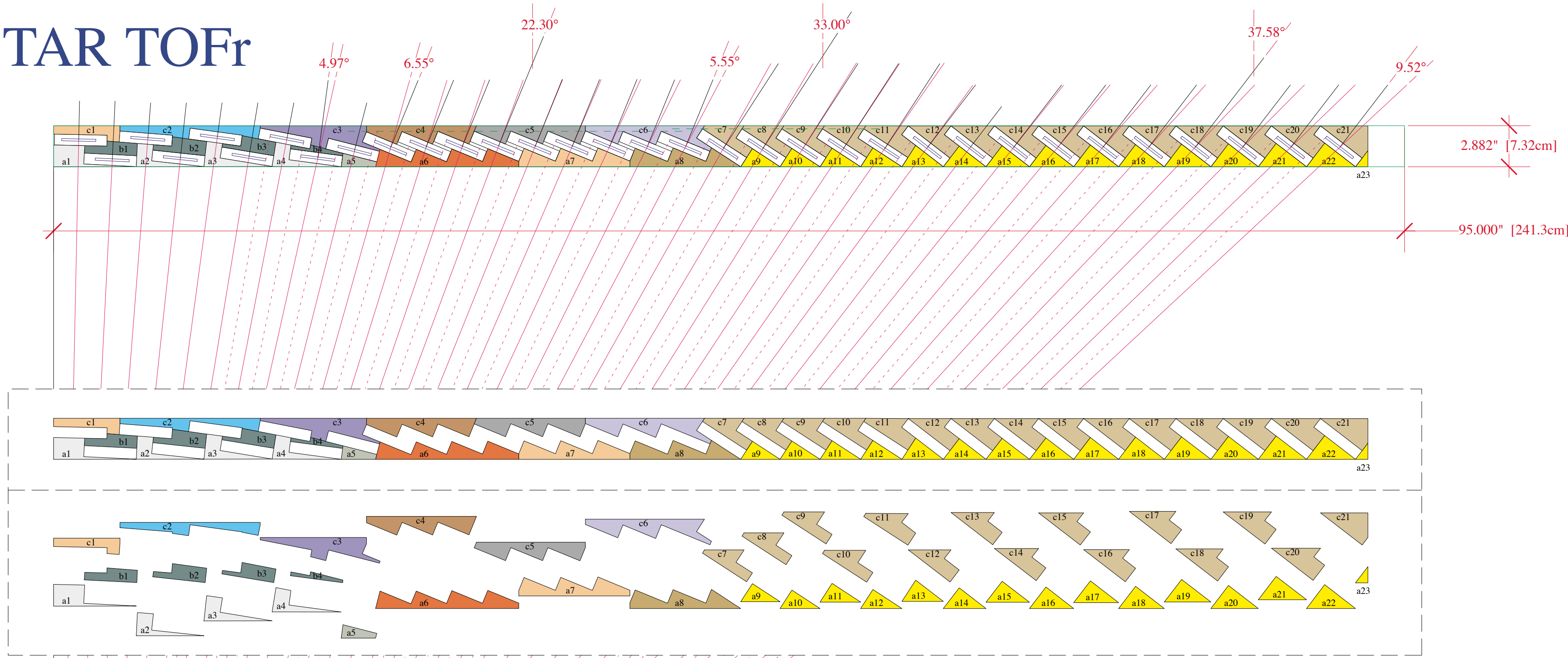
focus then shifted to a full-sized prototype system for STAR:

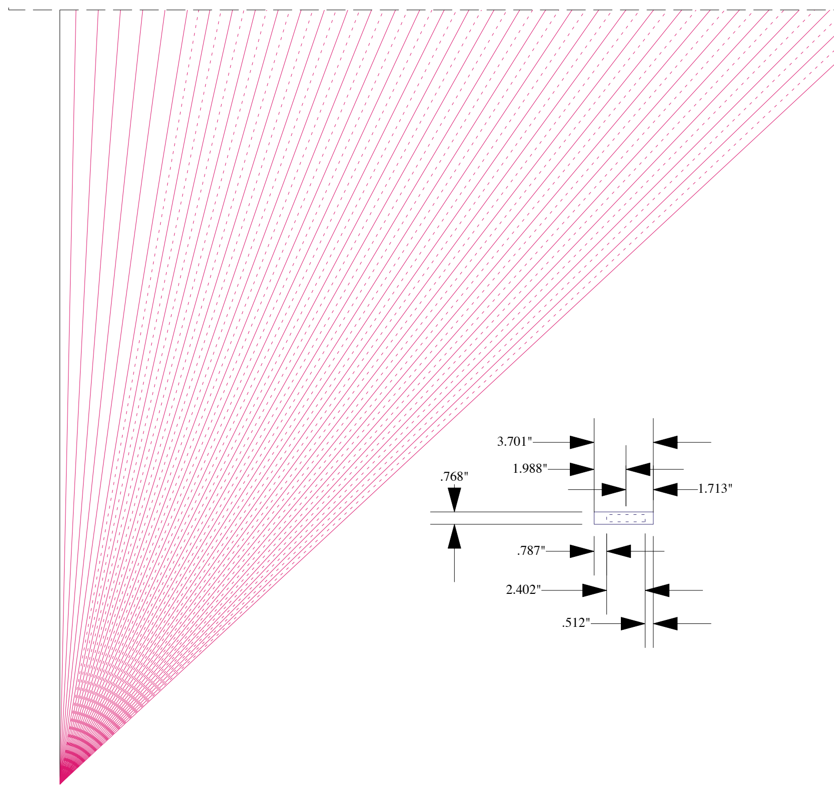
"TOFr"

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-III, Fall 2002

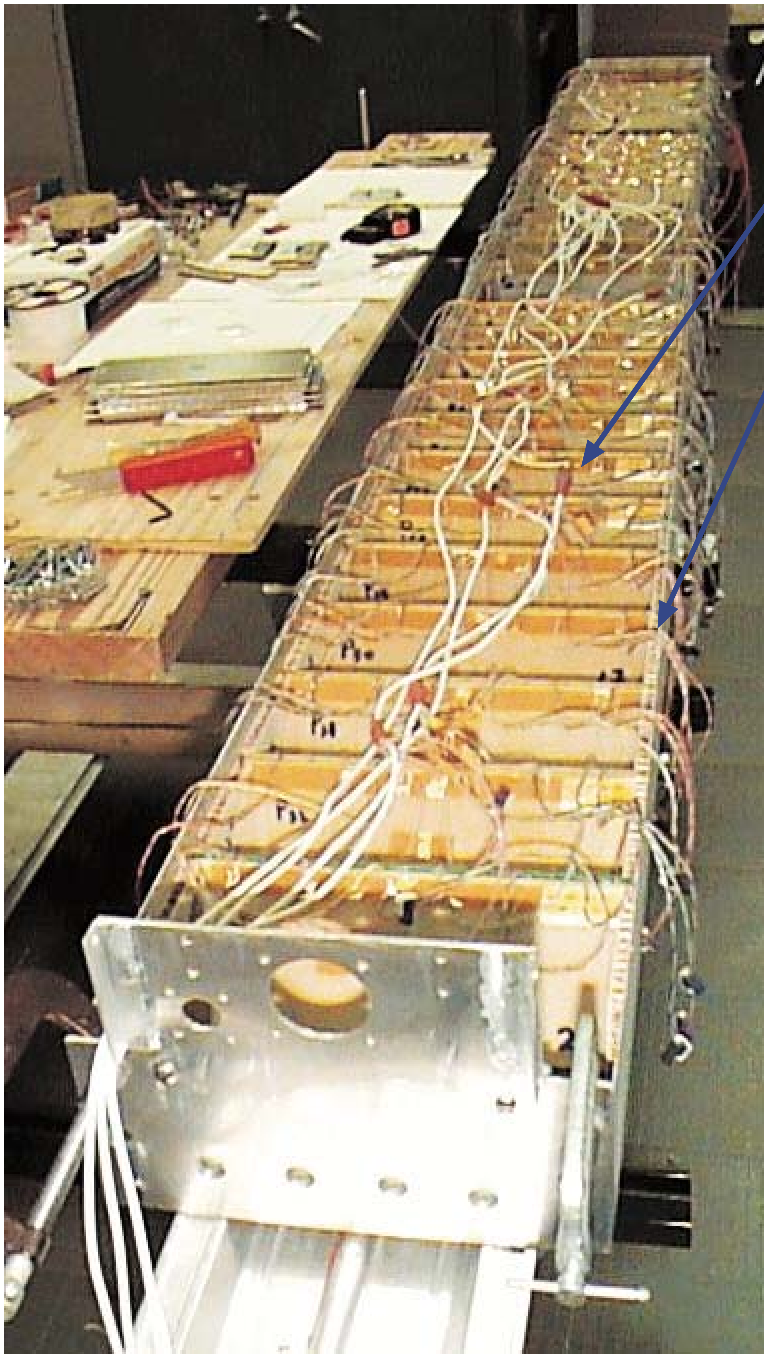
  → Realistic test of viability of this technology in an actual collider experiment......

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

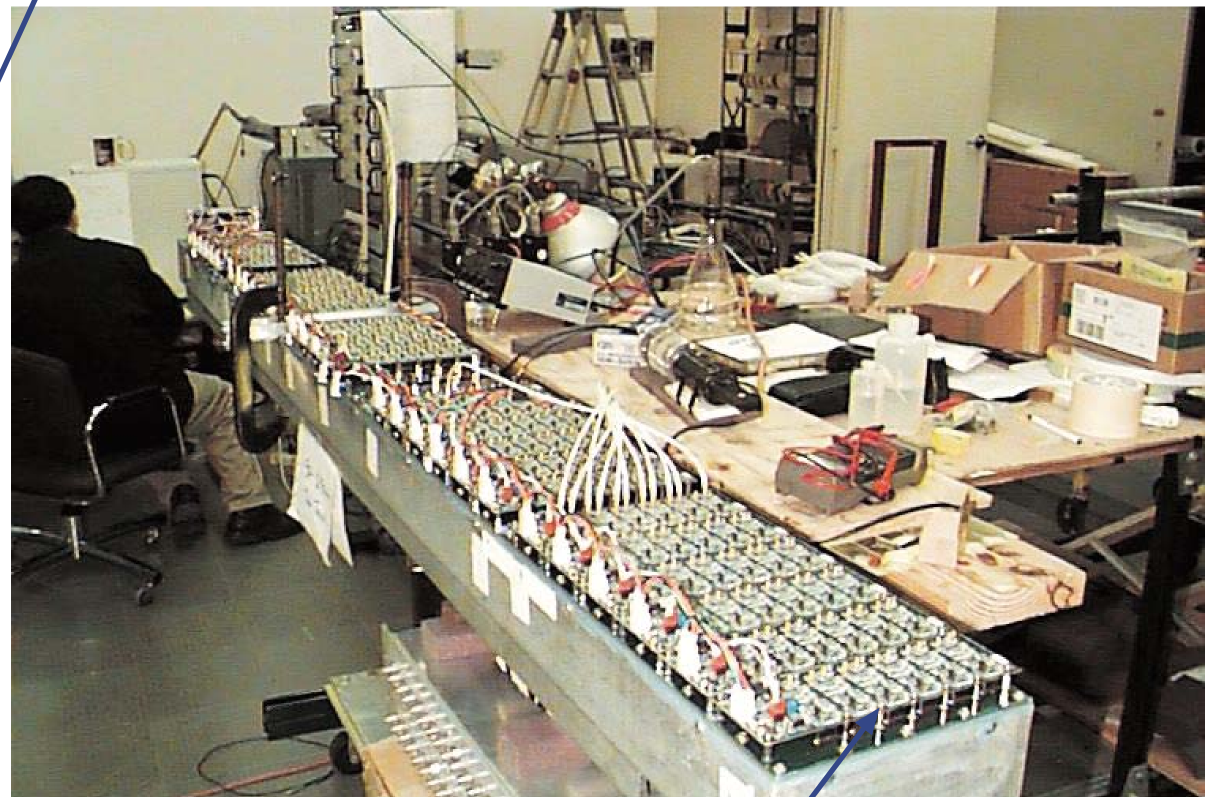
TOFr
(Run-3)

MRPCs

Tray (gas box)

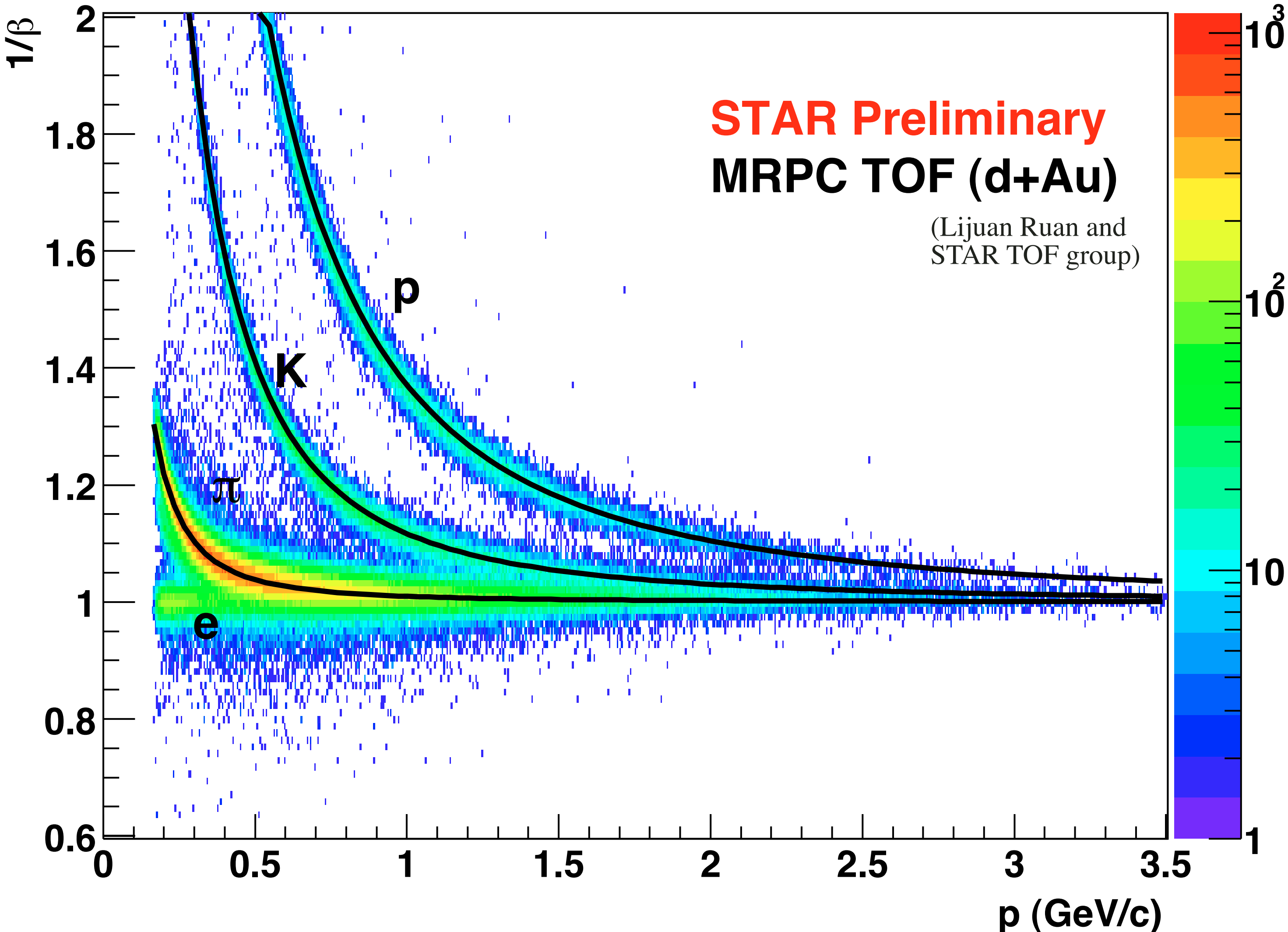


Testing at Rice



TOFr FEE & F/T plates
(will come back to these)

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



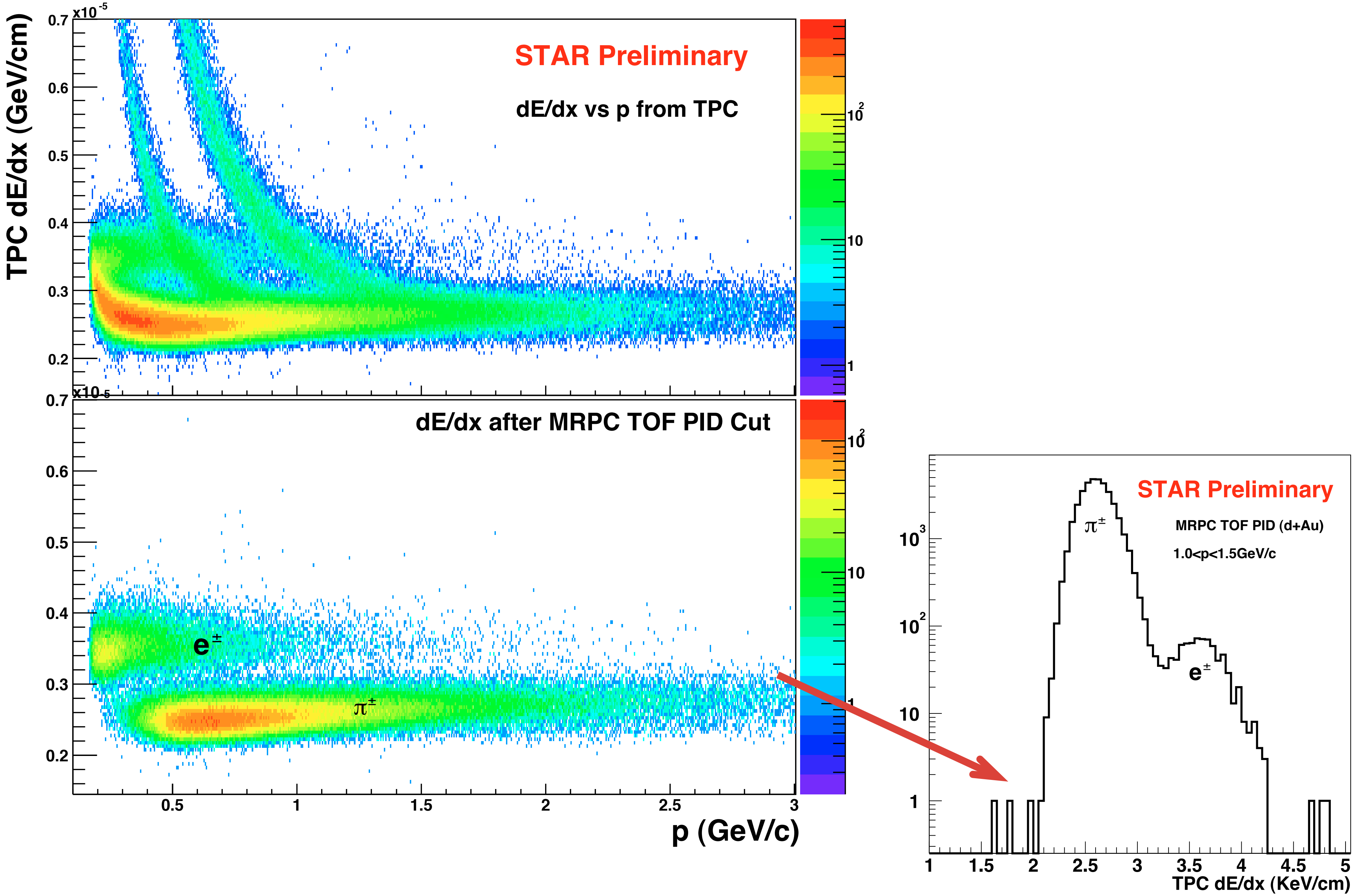
start resolution	~85ps
stop (MRPC) resn	~85ps
total	~120ps

→ 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/030912, submitted to PRL)

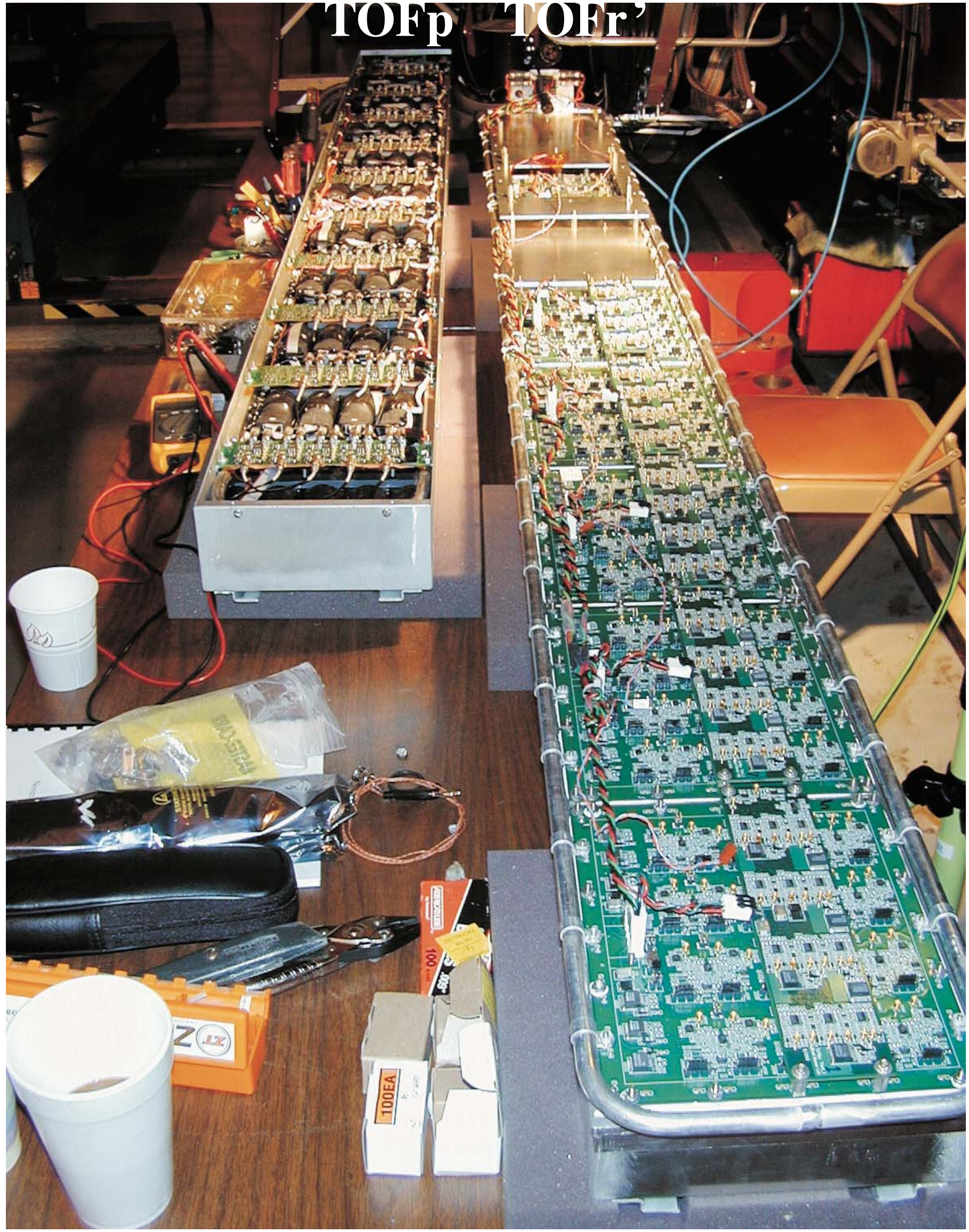
TOF in STAR also allows effective *electron PID*...

most powerful in (low) momentum regions where STAR EMC-based e-PID is difficult....



The second-generation prototype
for RHIC Run-IV:

STAR TOFr'



similar module arrangement...

new "showbox" tray design...
vastly simpler fabrication
better gas hermiticity

FEE layer now closes the box...

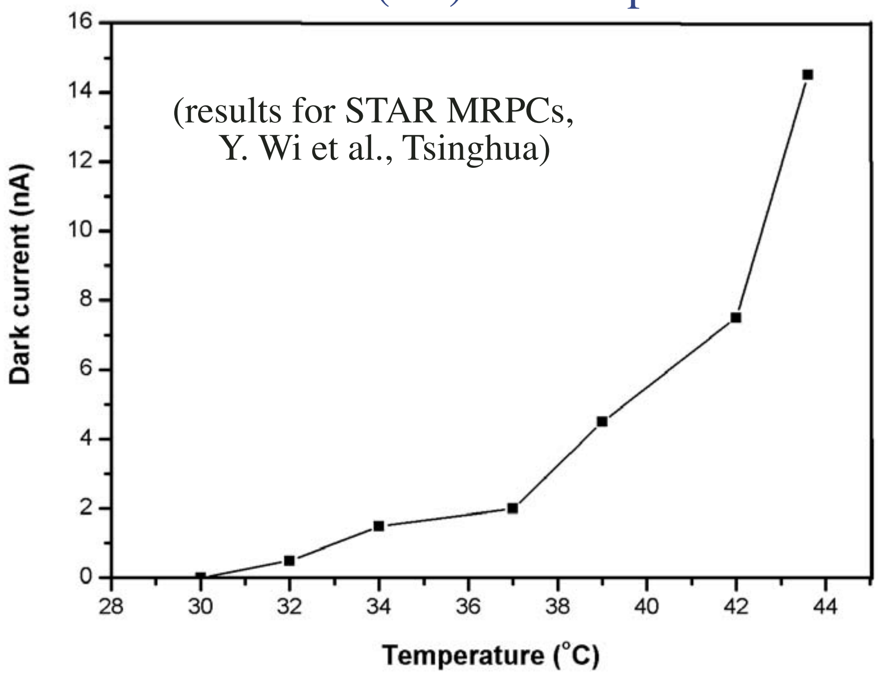
same camac digitization
over long cables into TOFp DAQ

test implementation of "Jalepeno"
based on CERN HPTDC chip
separate path to STAR DAQ

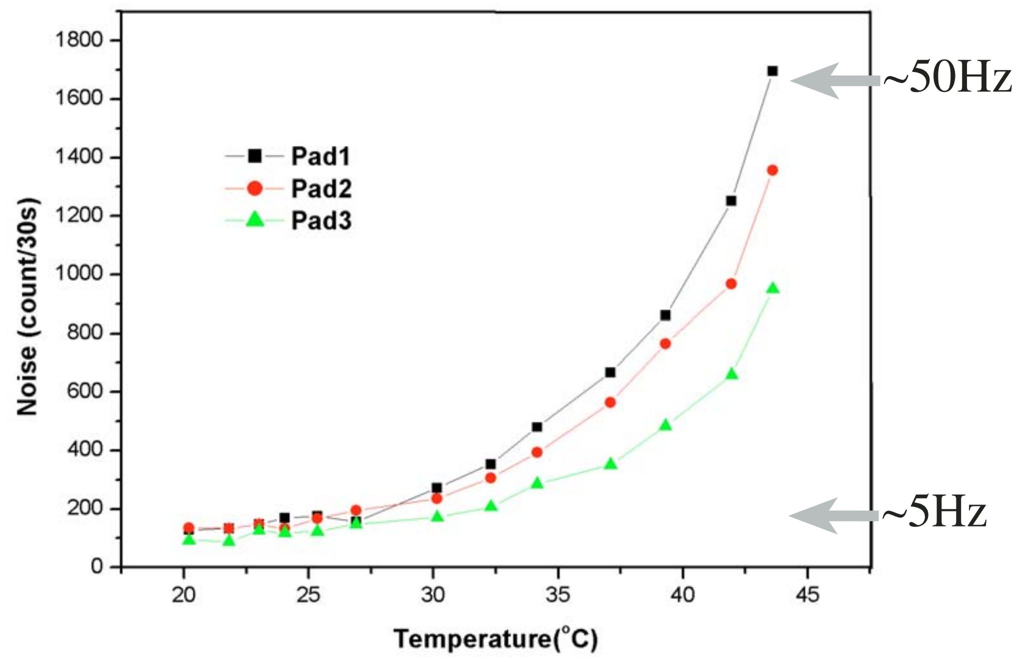
TOF' (Run-4) runs hotter than TOFr (Run-3)...

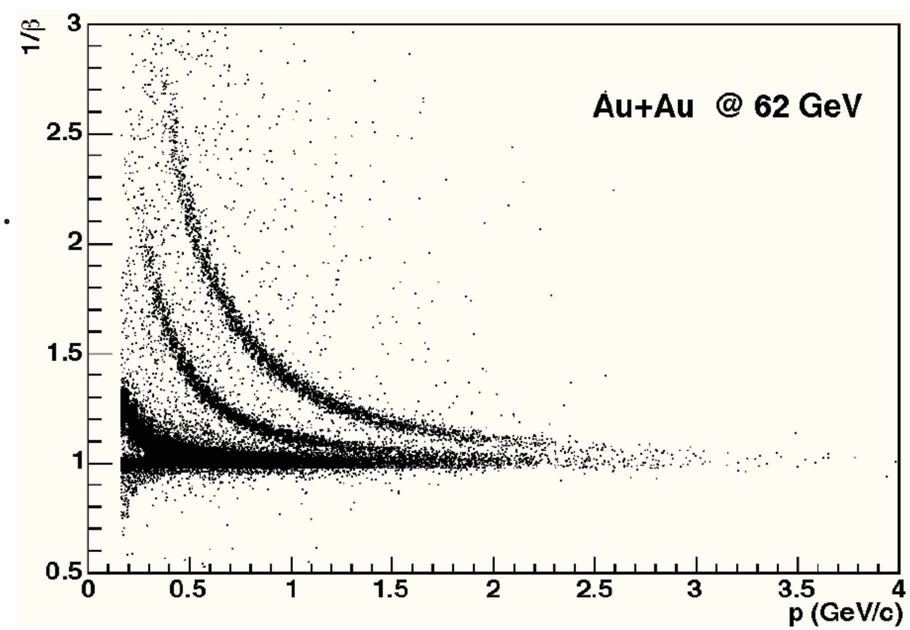
large number of components on FEE layer that also seals the gas box ***heats the box interior***

Dark Current (nA) vs. Temperature



Noise Rate (counts/30s) vs Temperature



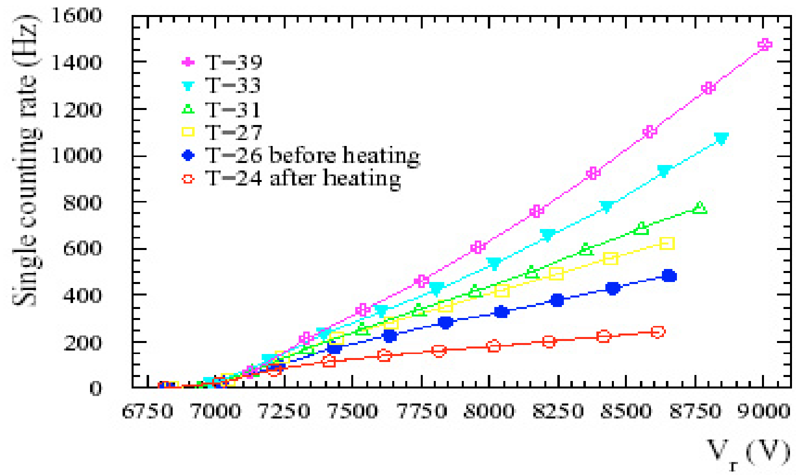


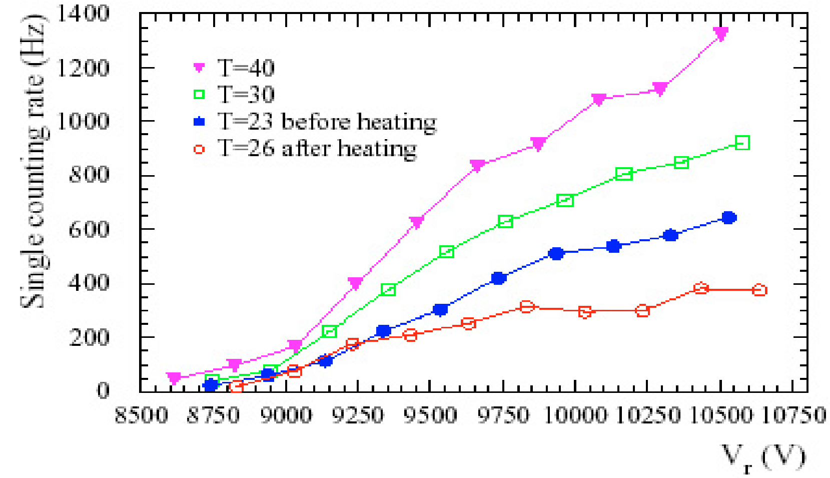
preliminary analyses from Run-4 indicate
that timing performance not significantly degraded...

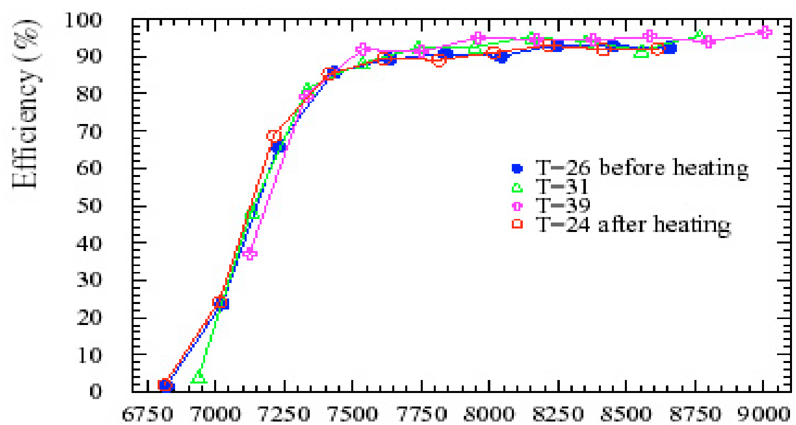
heat improves the rate capabilities
but overall this is unattractive (for us)

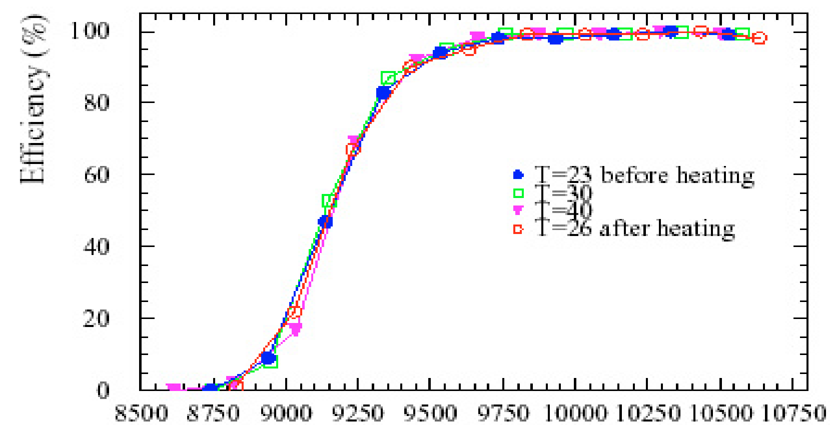
Run-5 Design addresses this
now under construction

Aging: temperature tests









Streamer mode

Argon/TFE/C_4H_{10}/SF_6= 48/47/4/1

Avalanche mode

TFE/C_4H_{10}/SF_6= 95/4/1

$$V=V_0*T/T_{ref}*P_{ref}/P$$

Differently from Bakelite, Glass RPC do not suffer high temperatures

STAR has officially adopted (our variant) of 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)

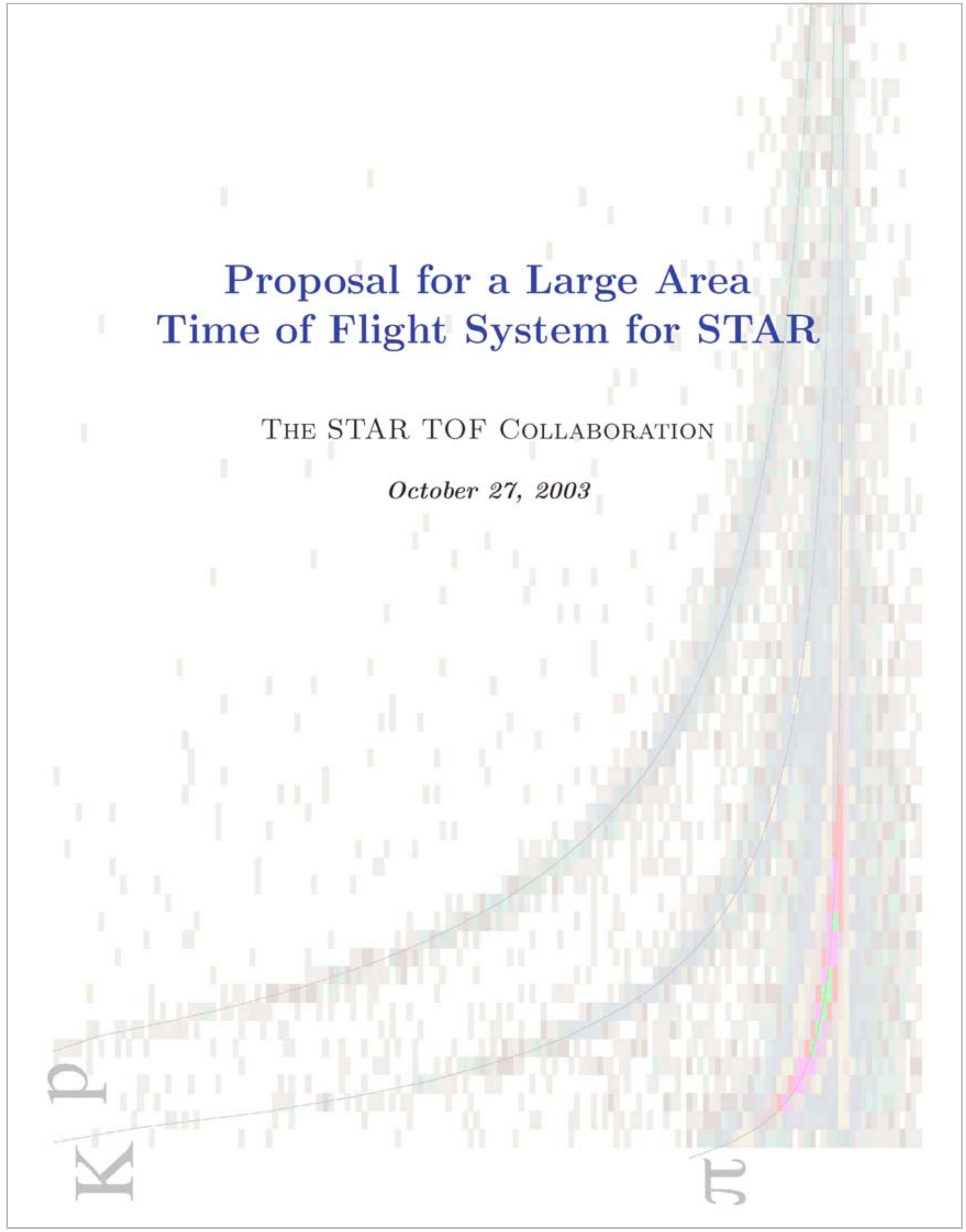
- US Cost: 4.7 M$
  Chinese contribution: 2.3 M$ (US$ equiv.)

Proposal now under review @ DOE....

Proposing construction during FY05→FY07
...project complete 2/15/07.

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

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

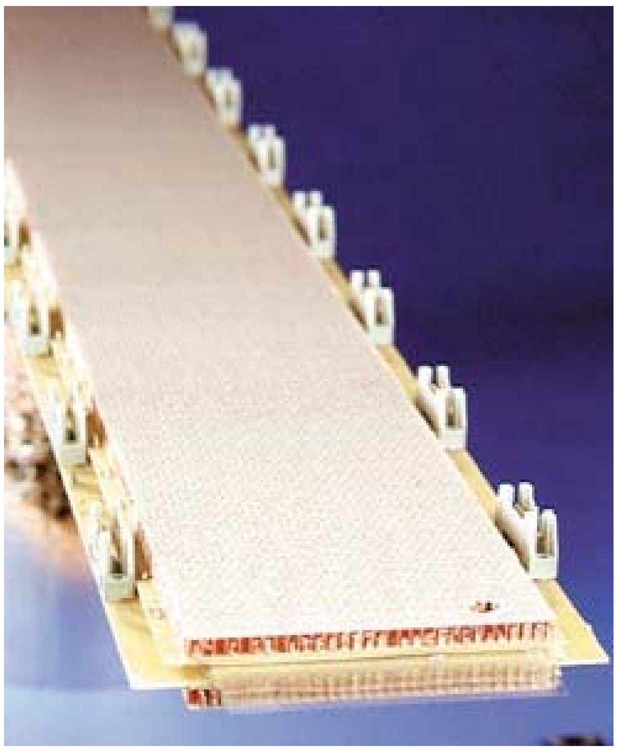

Proposal for a Large Area Time of Flight System for STAR

The STAR TOF Collaboration

October 27, 2003

Bookshelf

MRPC



The ALICE experiment at the LHC will use multigap resistive plate chambers (MRPCs) like this in its time-of-flight (TOF) system. The MRPC is a stack of resistive plates that define a number of independent gas gaps (10 in the case of the ALICE TOF), allowing full detection efficiency and excellent time resolution (< 50 ps). This device was developed by Crispin Williams et al. within the framework of the LAA project detector R&D initiated by Antonino Zichichi.

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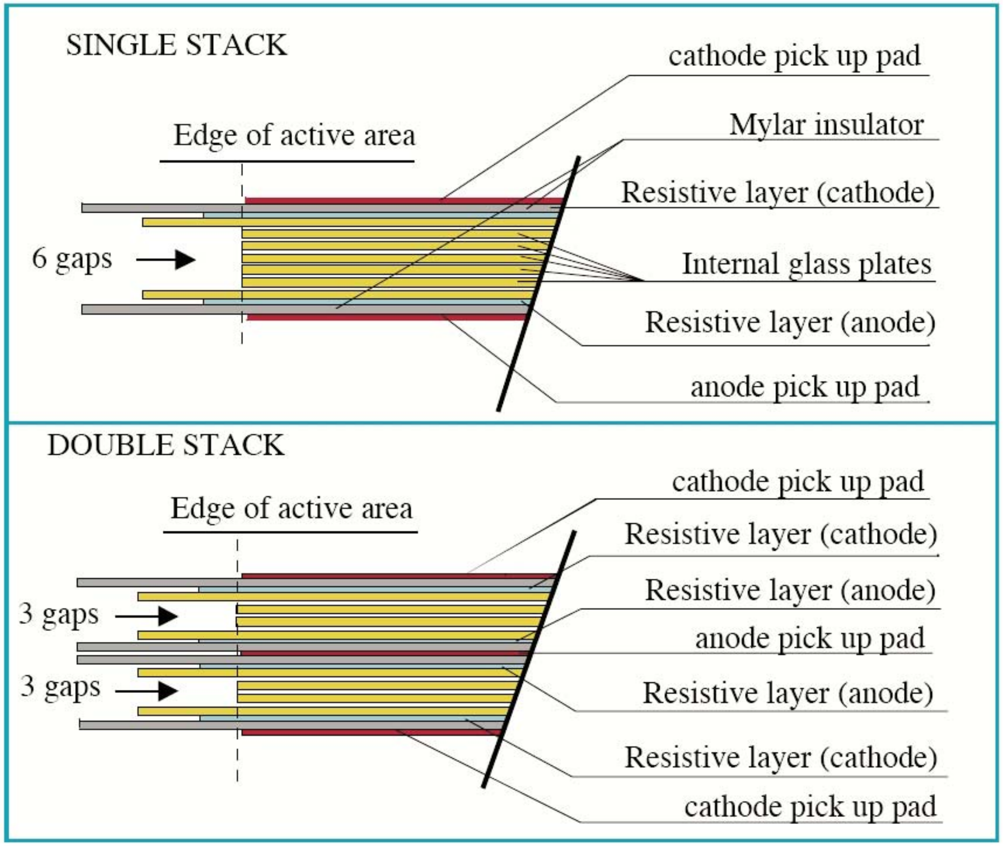
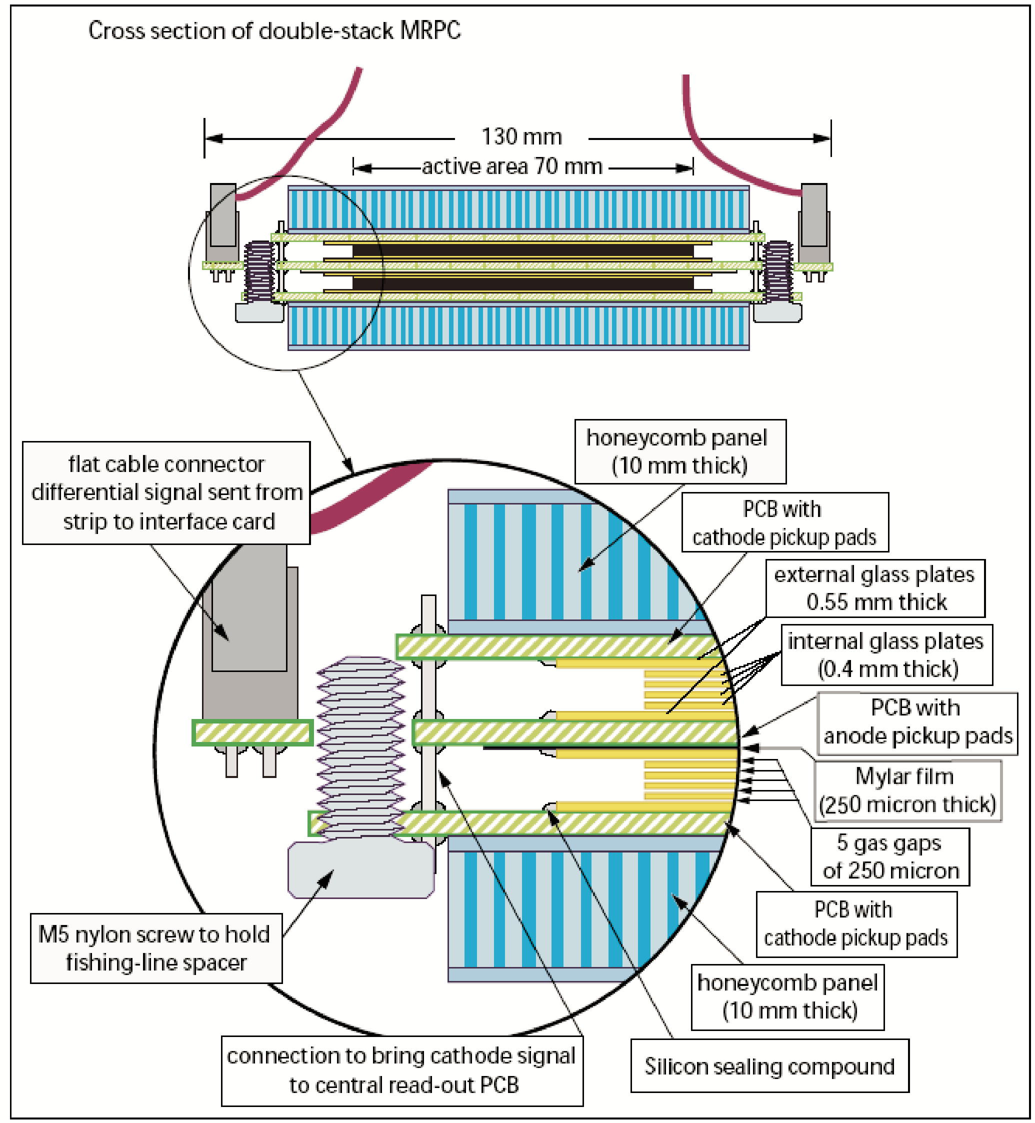
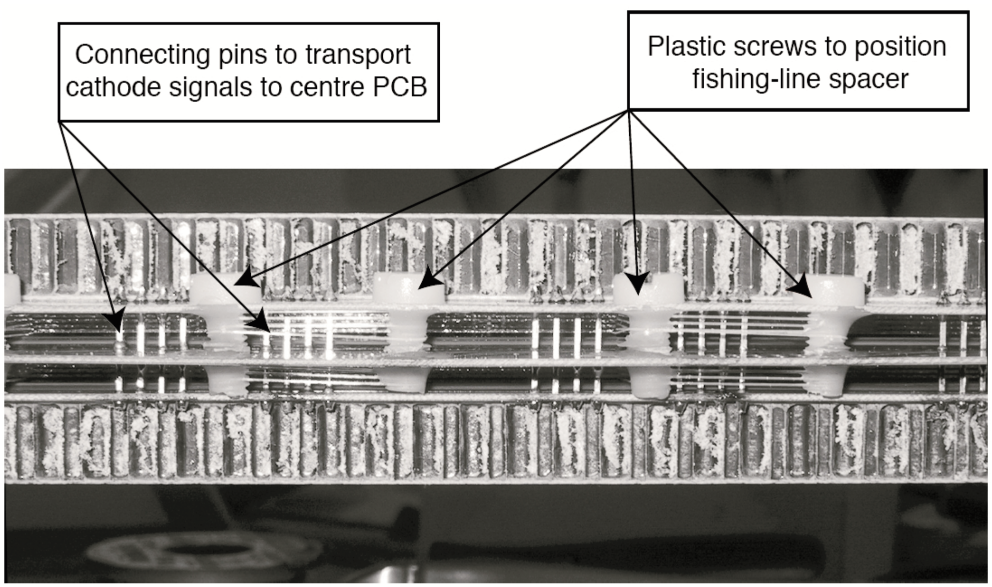
ALICE MRPCs

single and double stacks...

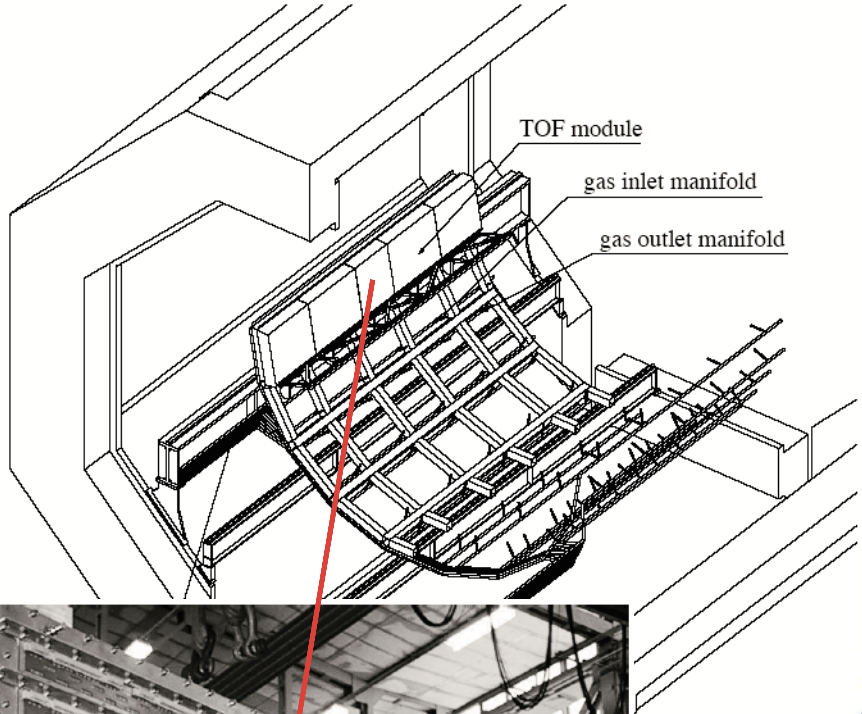
long and narrow...

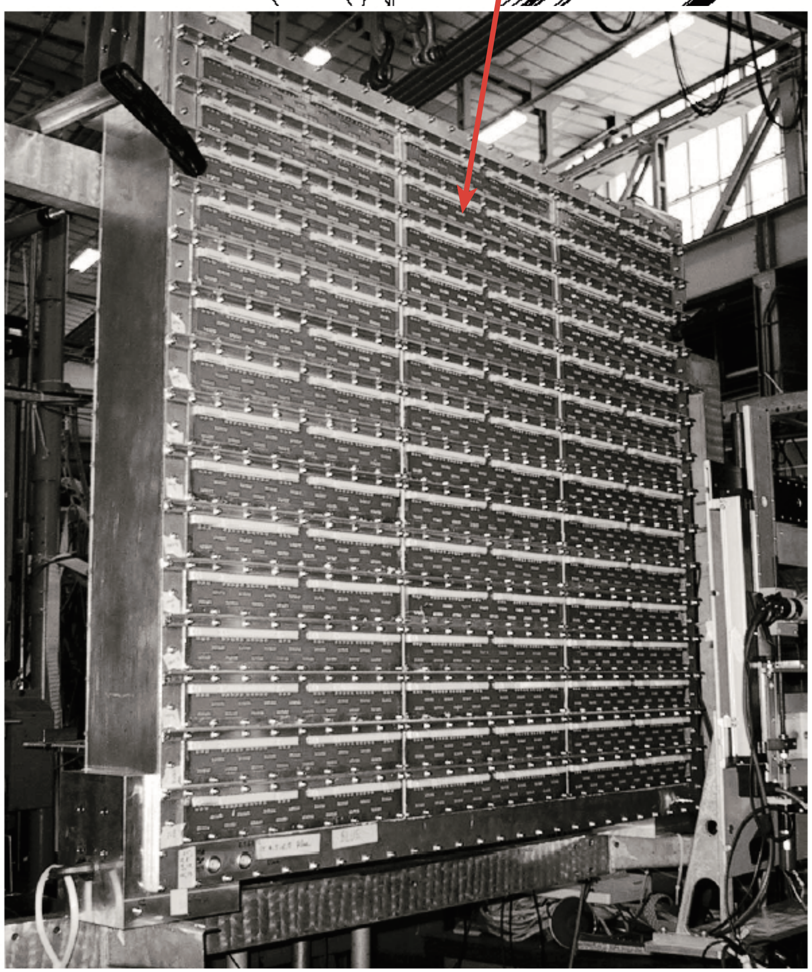






ALICE





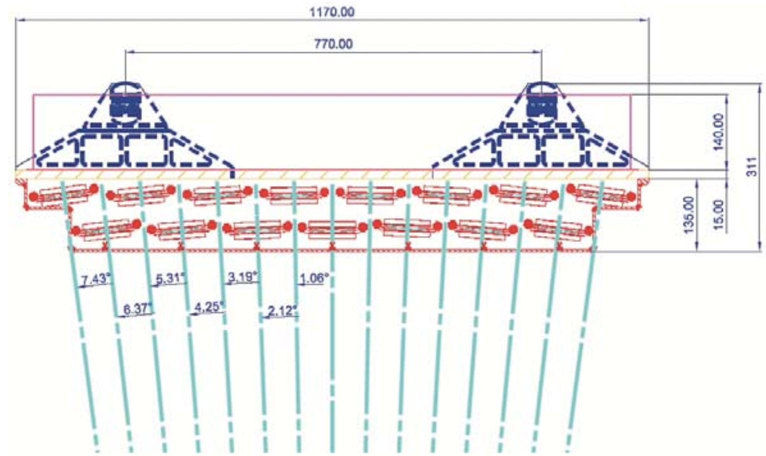


Figure 3.4: Central TOF module showing the positions and tilt angles of the MRPC strips.

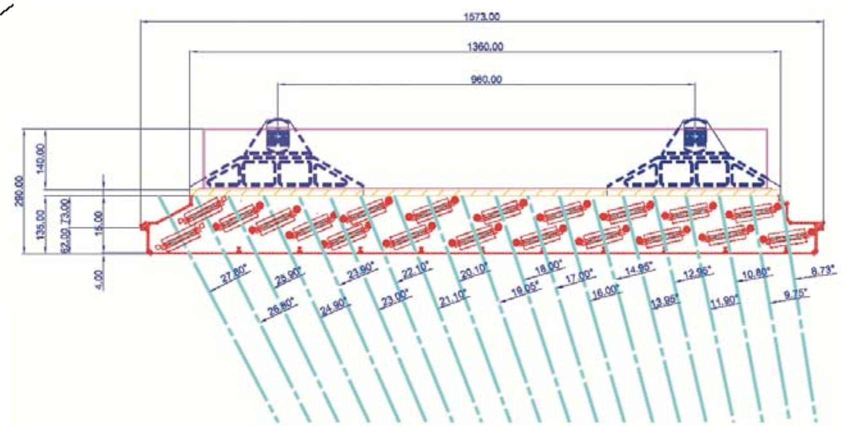


Figure 3.5: Intermediate TOF module showing the positions and tilt angles of the MRPC strips.

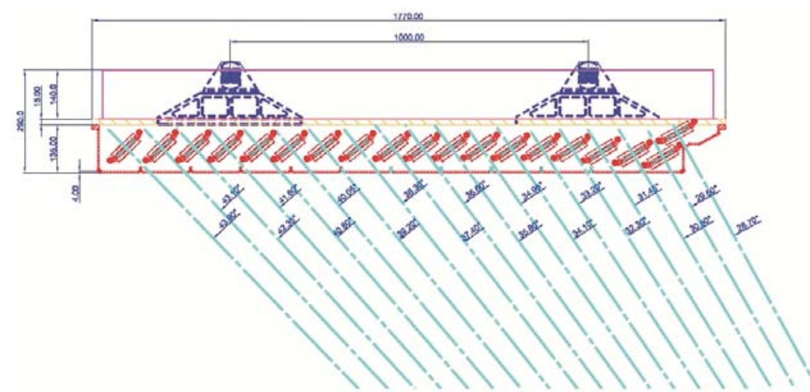
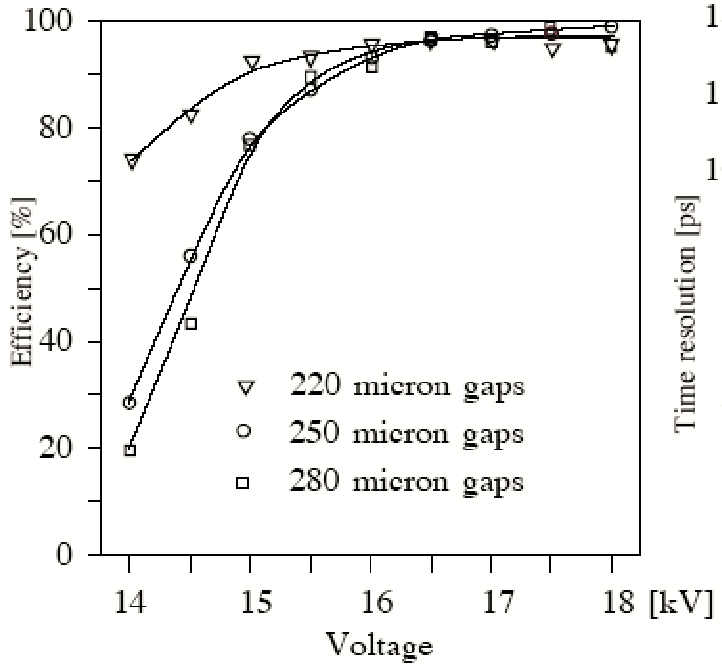
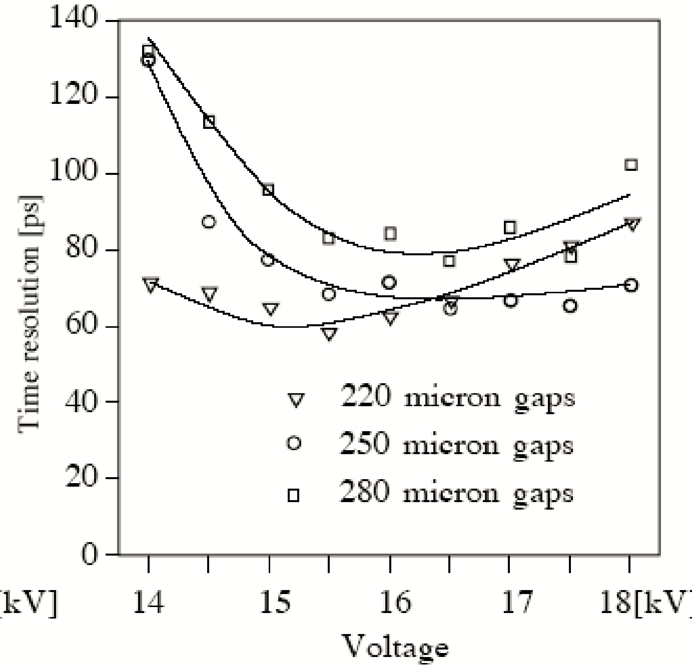
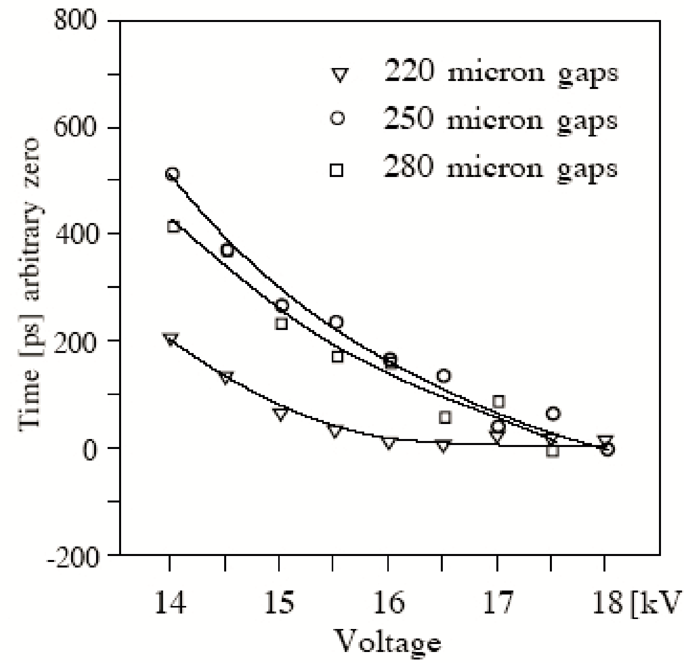


Figure 3.6: External TOF module showing the positions and tilt angles of the MRPC strips.

ALICE performance
(from proposal addendum, 2002)







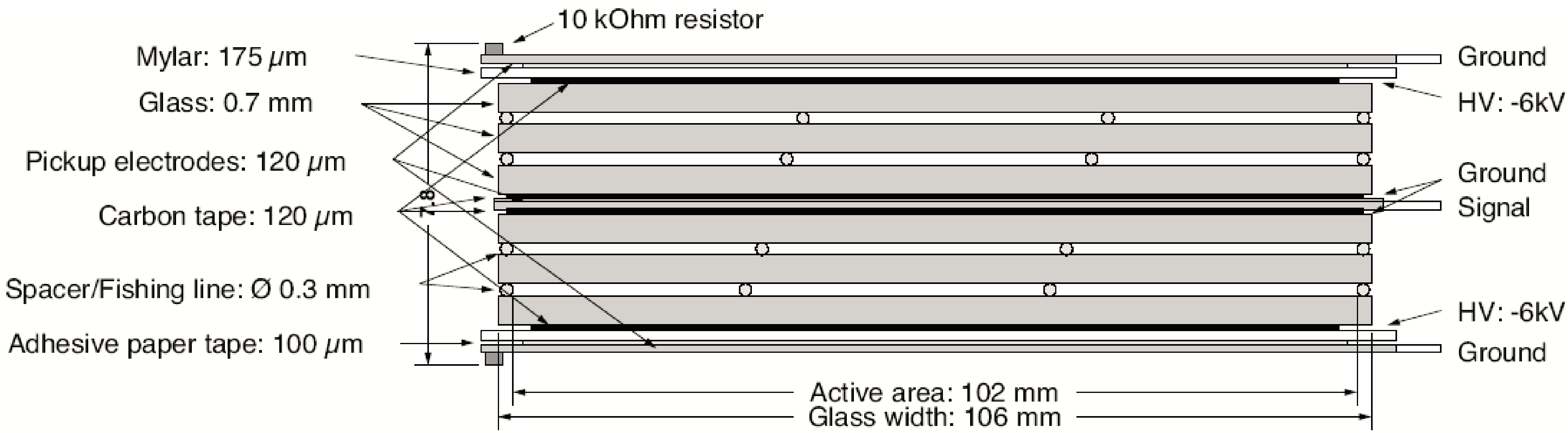
efficiency near and above 95% for HV in range 16 – 18 kV.

time resolution in this range is 60-80ps for 220 μm gaps

time walk reasonable...

HARP TOF

- two implementations
  - barrel around target TPC to reject out of time tracks...
  - forward wall for PID...
- looking for ~200ps or better...



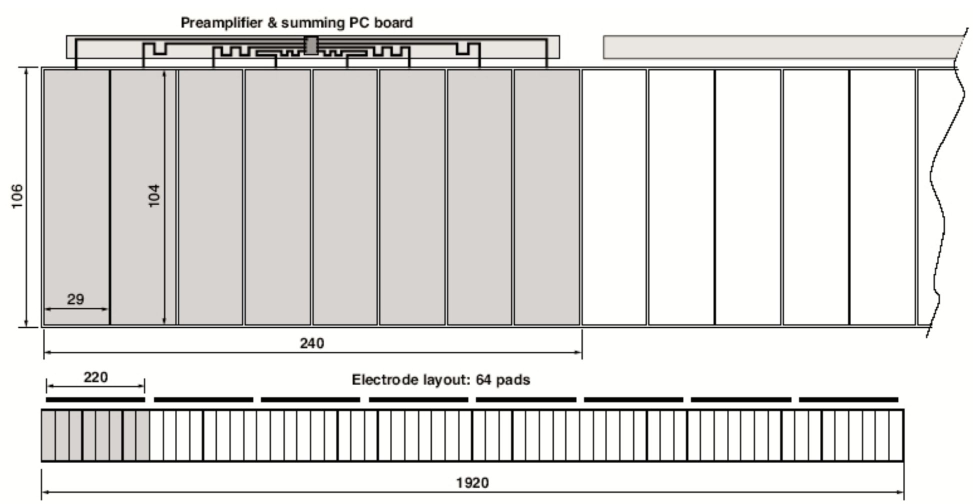
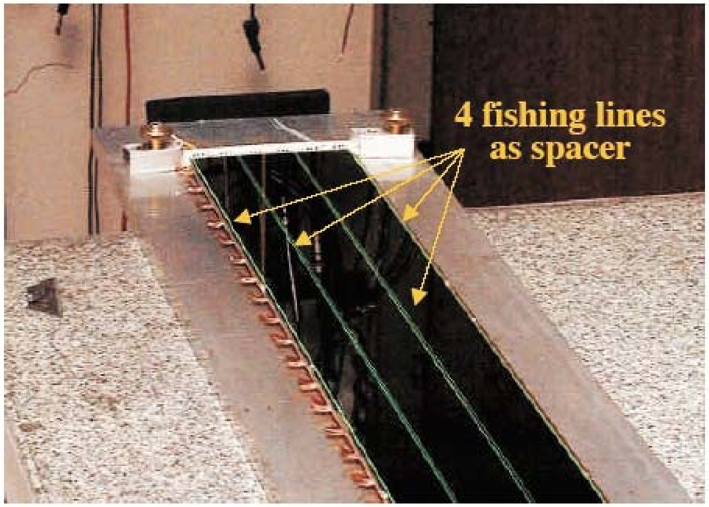
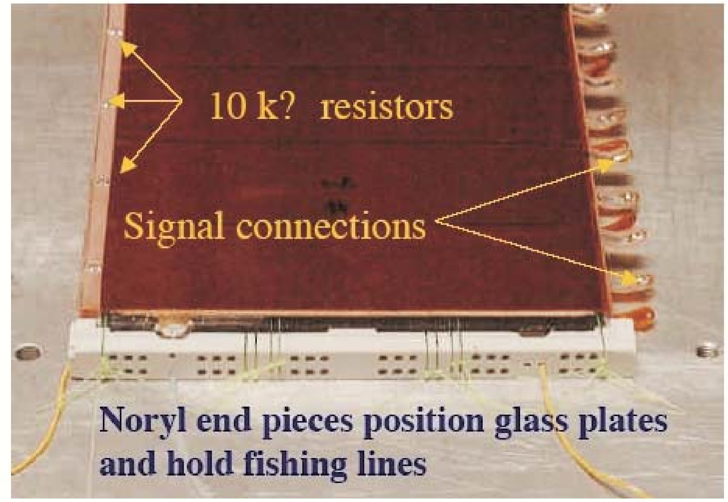


Fig. 4. Layout of the readout electrodes; eight pads are connected to the same preamplifier

HARP TOF

- Prep. of plates: long
- Stacking easy: = 1 hr



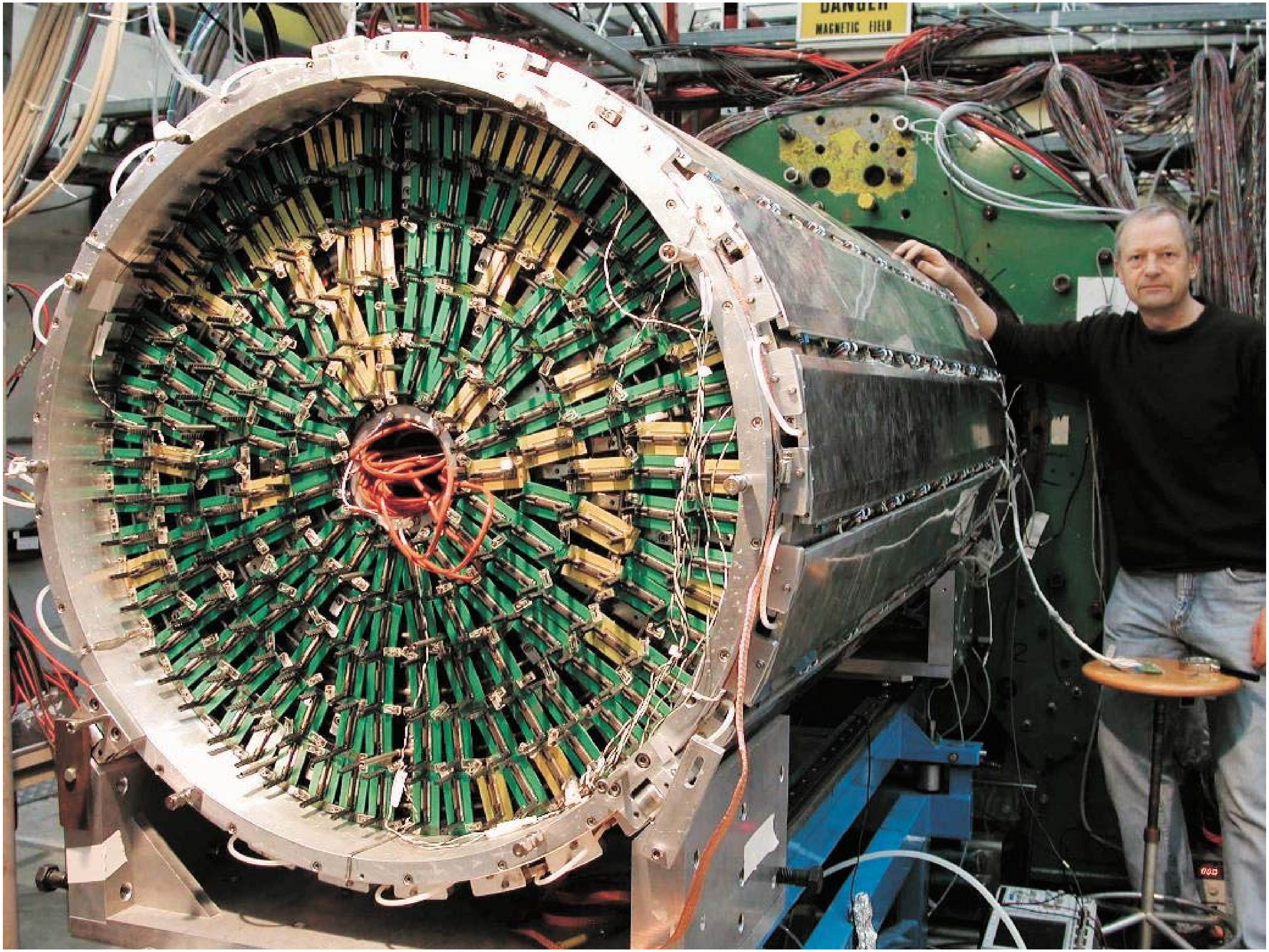


- HV test in air before integration in housing
- Stack -> box + test: 2 hrs

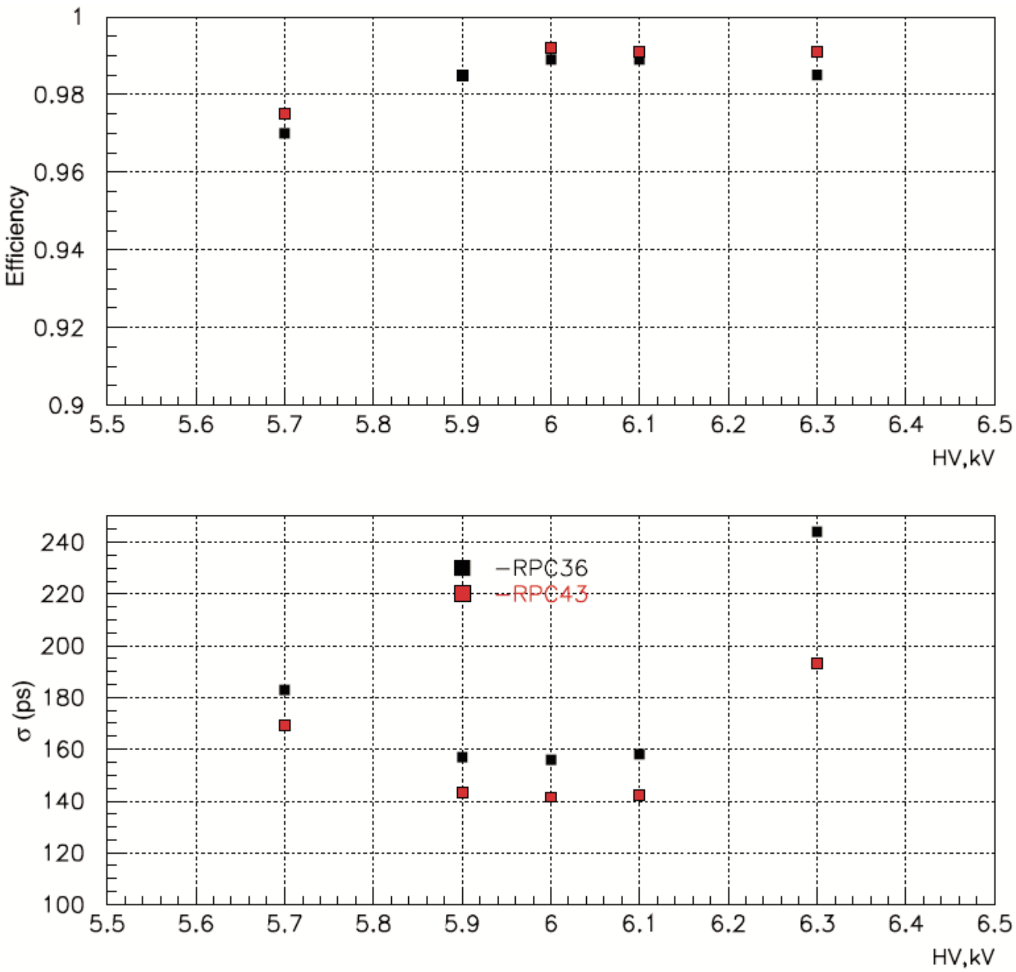
- Glass stack placed in aluminium housing with removable cover (O-ring)
- Box: 2m x 10mm x 150mm
- 64 signal feedthroughs along edge on one side
- 8 plug-in preamplifier cards
- HV supply on one end
- Gas in/out on two ends

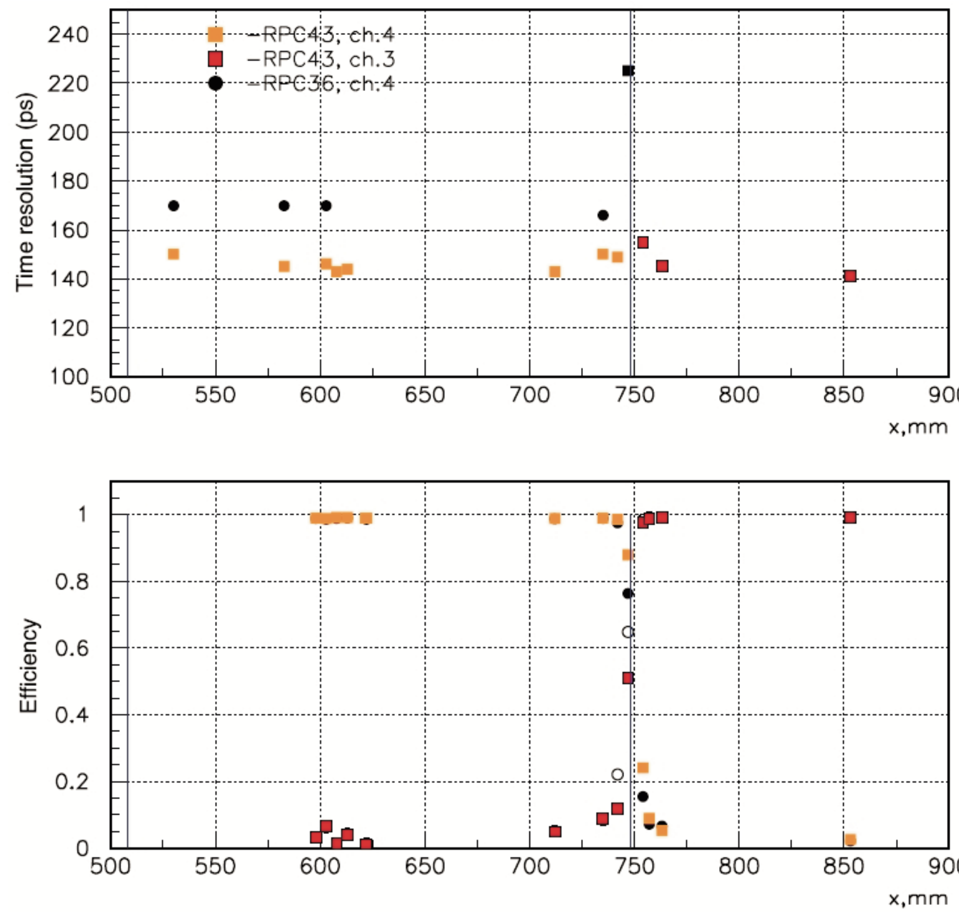
HARP TOF

showing here the barrel TOF (@target)
also have forward wall w/ same MRPCs



HARP TOF





>98% efficiency at HV plateau...

~140-160ps resolution....

uniform response across pads...

GSI prototypes

M. Petrovici et al., NIM A **487**, 337 (2002)
M. Petrovici et al., NIM A **508**, 75 (2003)

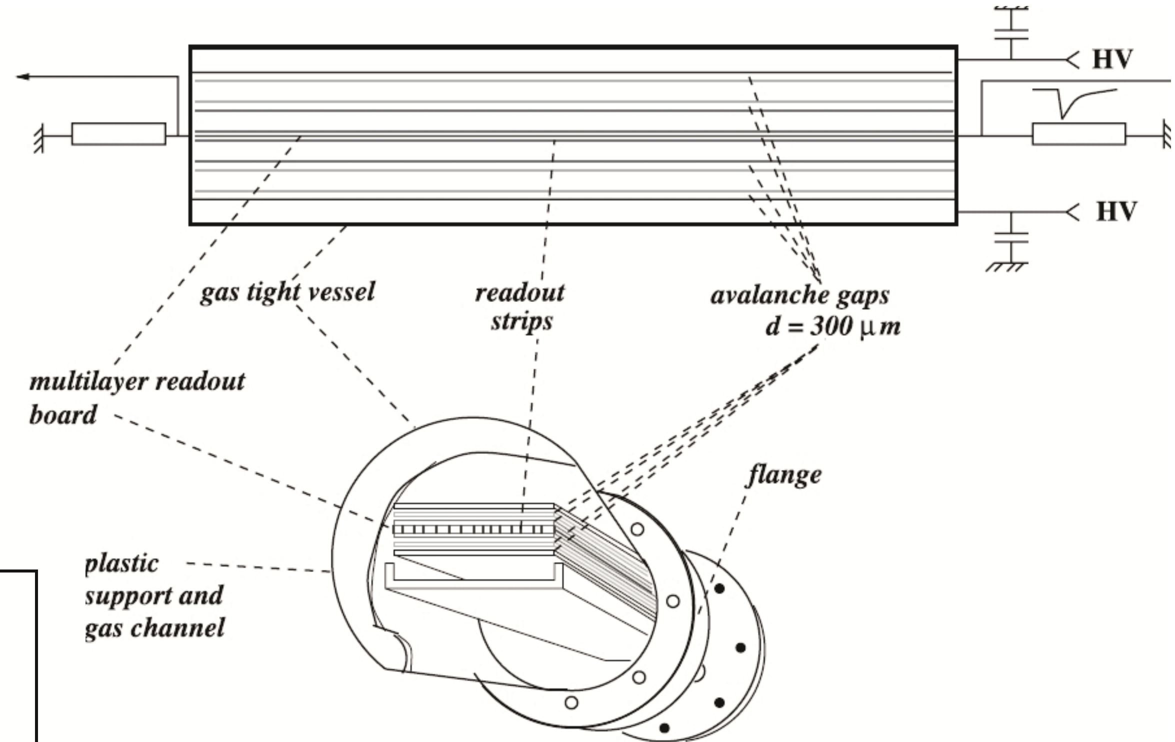


Fig. 1. Schematic construction of the used counters.

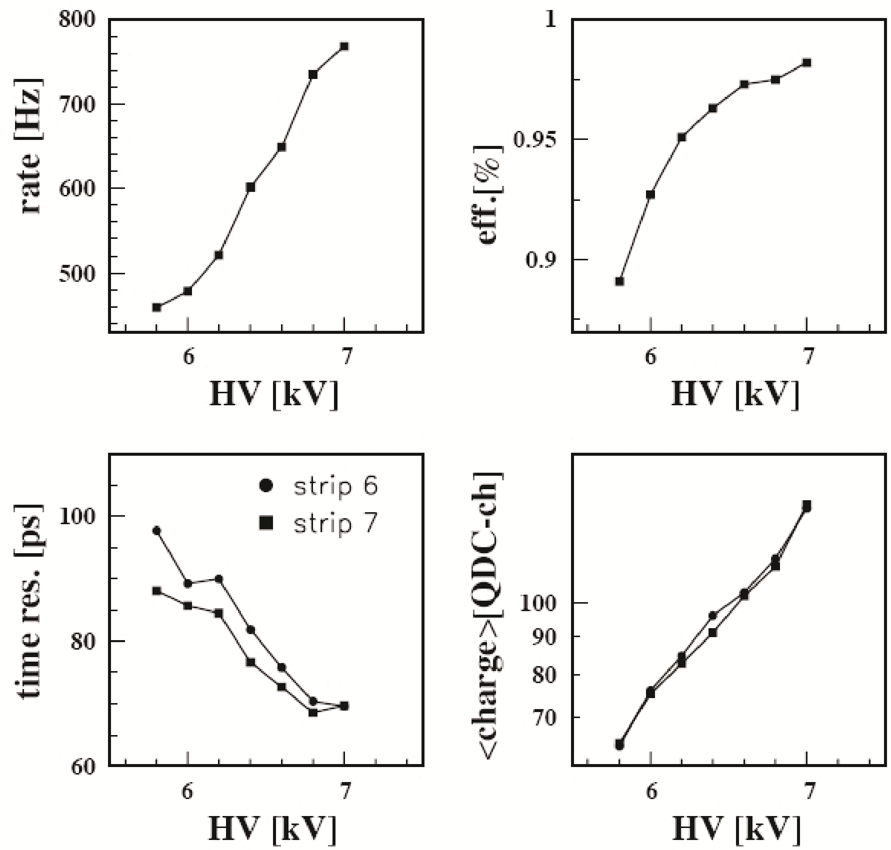
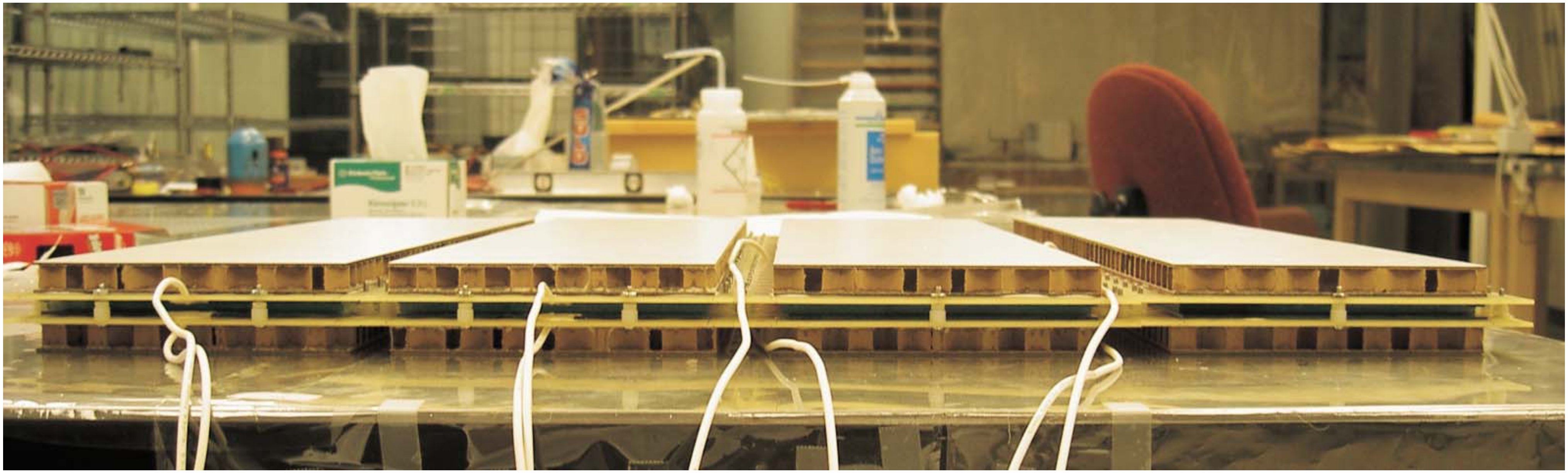
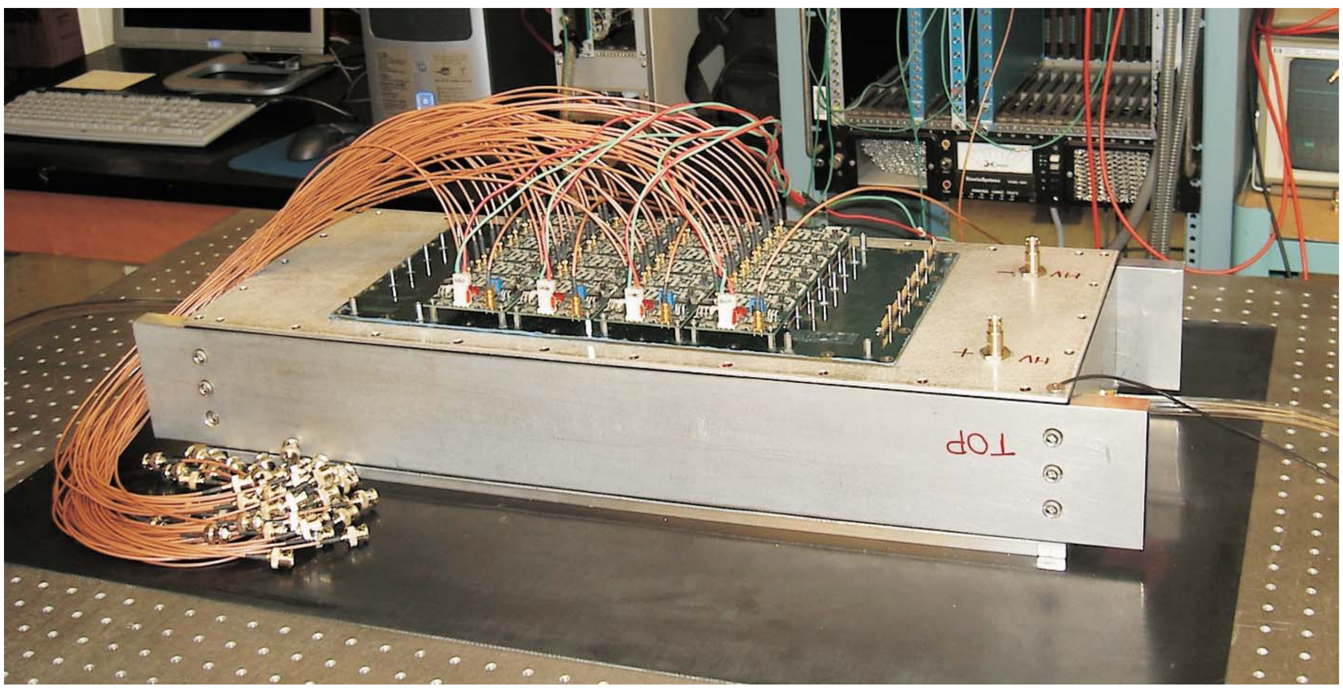


Fig. 1. The dark rate, efficiency, time resolution and average charge as a function of high voltage for Prototype I RPC.

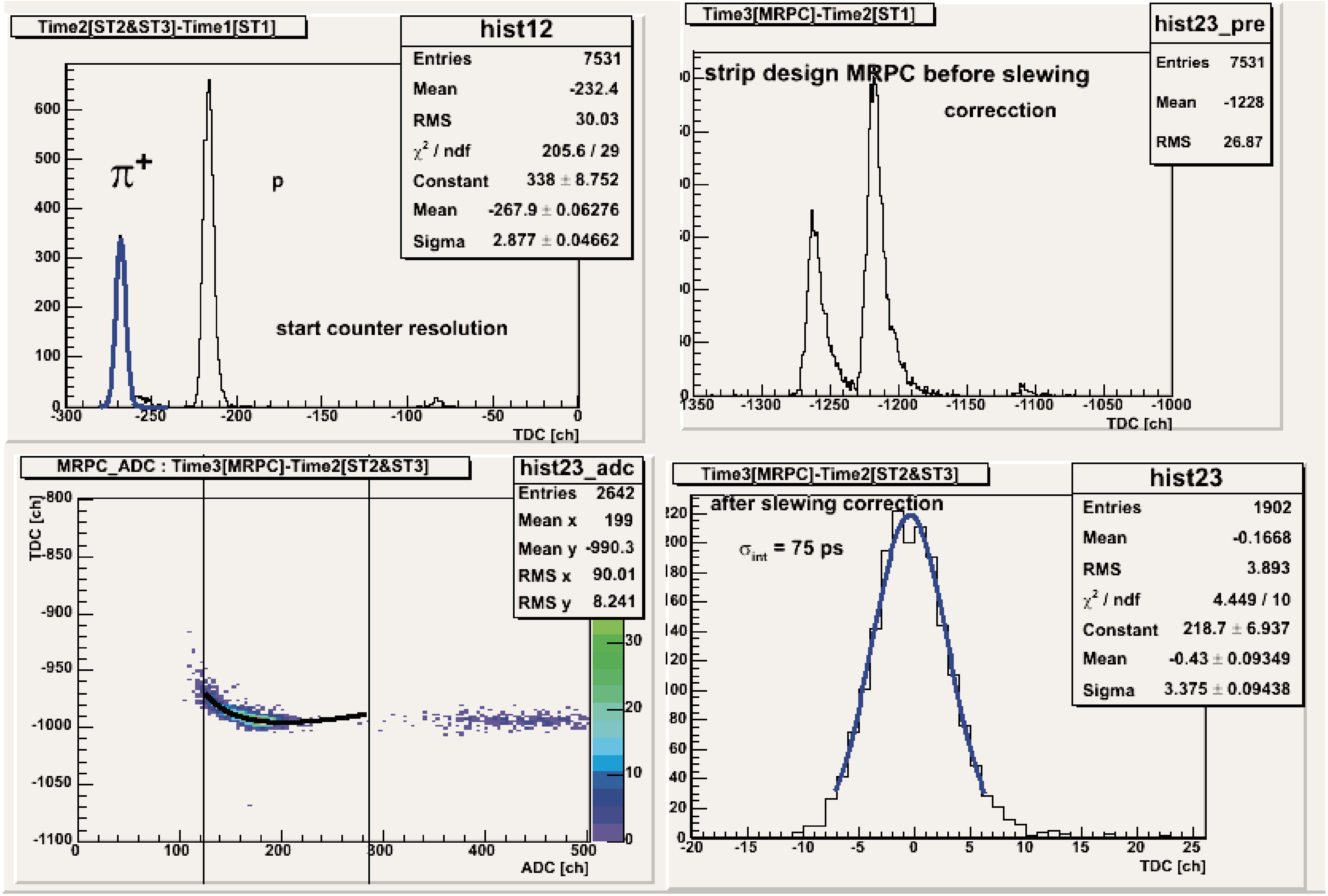
PHENIX TOF - First prototypes   (J. Velkovska, T. Chujo, *et al.*)





FEE from TOFr (Run-3)
Digitization in CAMAC

Tested at KEK....



- Strip and pad versions tested....
- 75ps resolution achieved...

Summary

TOF remains a viable technique for Particle Identification (or triggering) in modern experiments...

The conventional technology of Scintillator+PMTs is extremely well-understood...

The new MRPC technology is becoming well-understood, and is a lot cheaper...

Adopted for, or already used in, ALICE, STAR, & HARP.....

Prototyping efforts underway at GSI, Nashville, ...

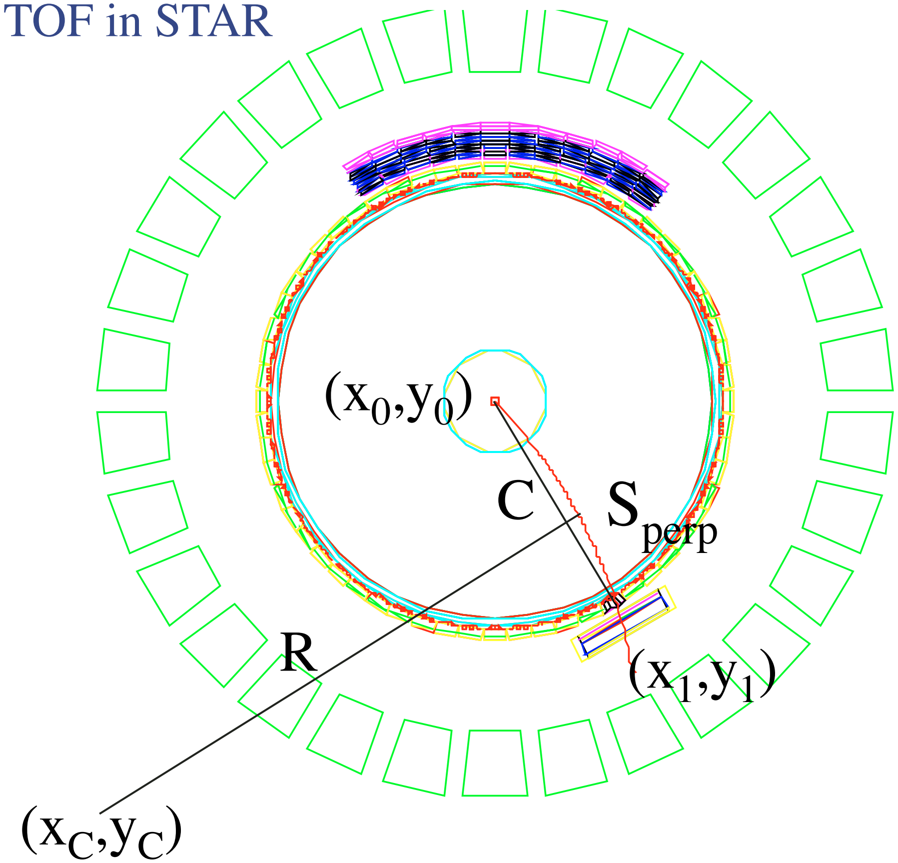
MRPC detectors

- are not “RPC’s”...
- are dirt cheap (parts <30$/module), and relatively easy to construct...
- can outperform the conventional technology...
- slew, and have finite signal propagation times inside the pads, just like single-ended scintillator...
  - all the usual calibration techniques and software apply...
- are sensitive to the local temperature
  - higher temperatures → higher current draw and noise rates, better rate capability...
    - degradation to timing performance not severe
  - detectors not damaged by high temperatures...
- exhibit aging effects that are very small...
  - lengthy GIF-testing of ALICE MRPCs showed no significant effects...
  - more experience is still needed though... (TOFr5 and TOFr’ contain many modules used in TOFr)

Bottom Line: MRPCs worth considering wherever granular, low-cost, ~100ps timing is needed....

(how can i help?)

TOF in STAR



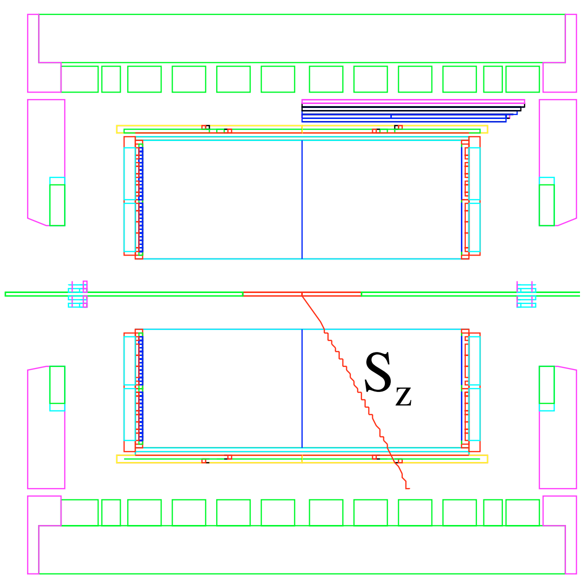
$$s = \sqrt{(s_{perp}^2 + s_z^2)} \text{ with}$$

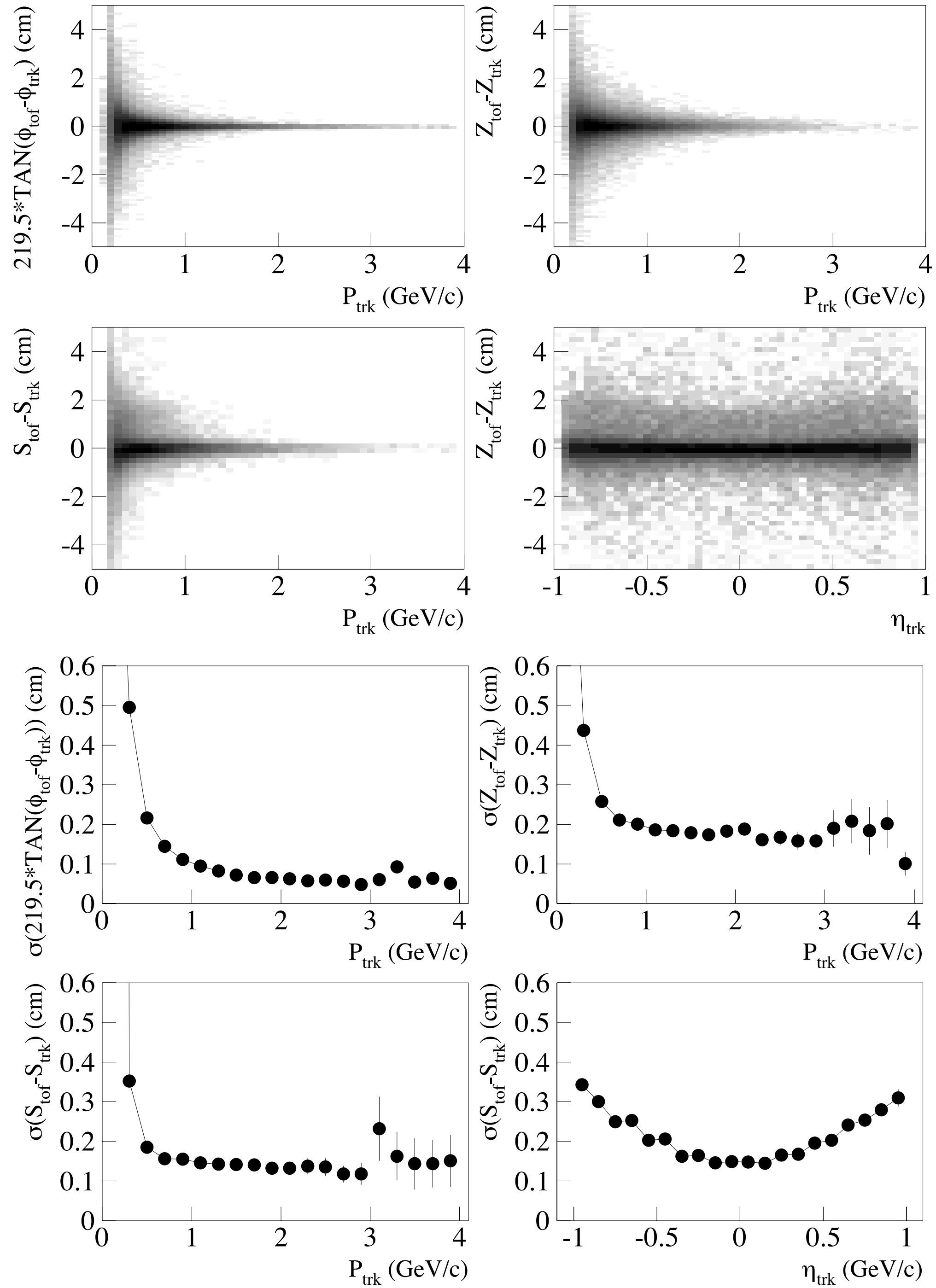
$s_{perp} = 2R \sin^{-1}(C/2R)$

$s_z = z_1 - z_0$

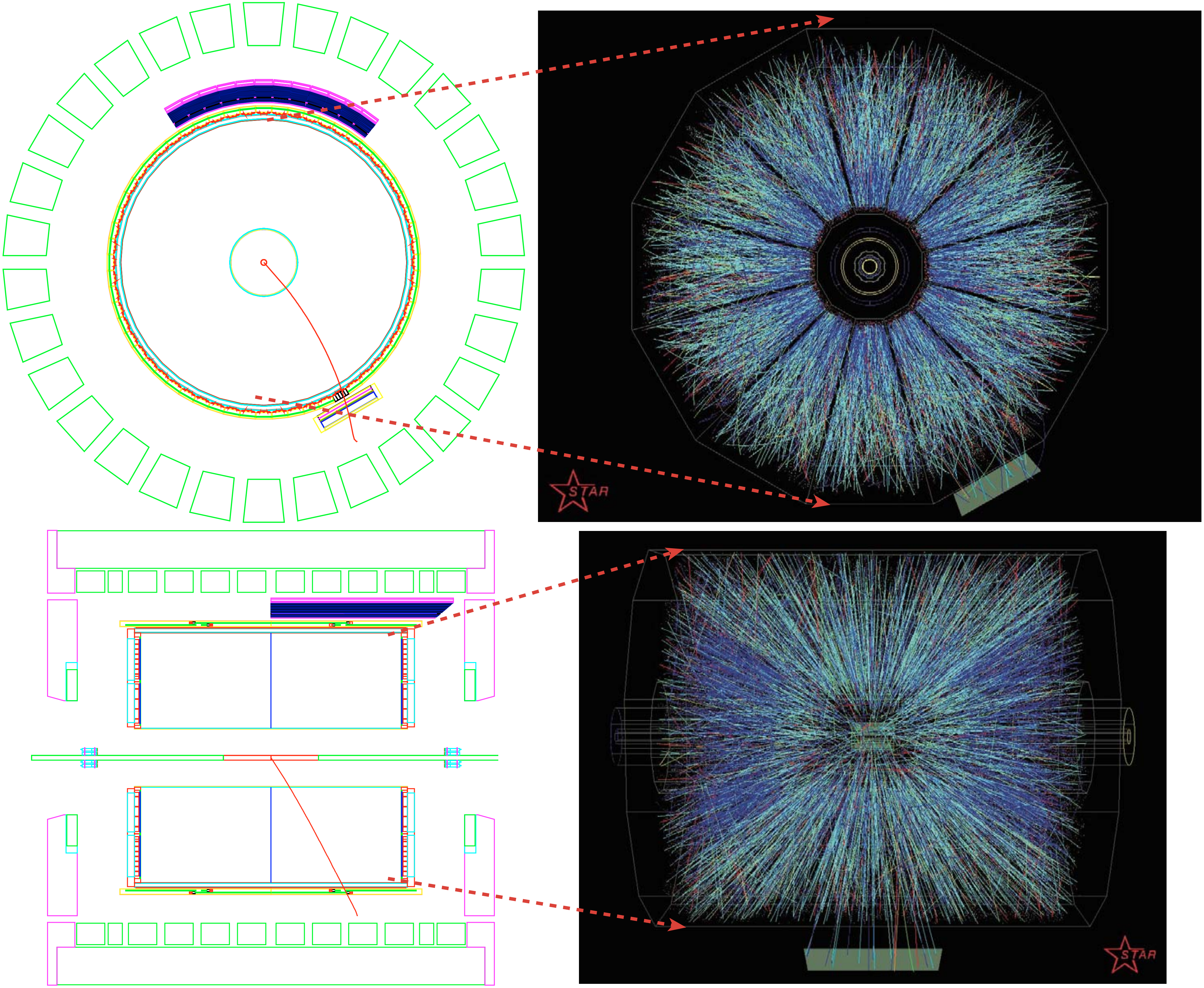
R is the helix radius

$C=\sqrt{((x_1 - x_0)^2 + (y_1 - y_0)^2)}$

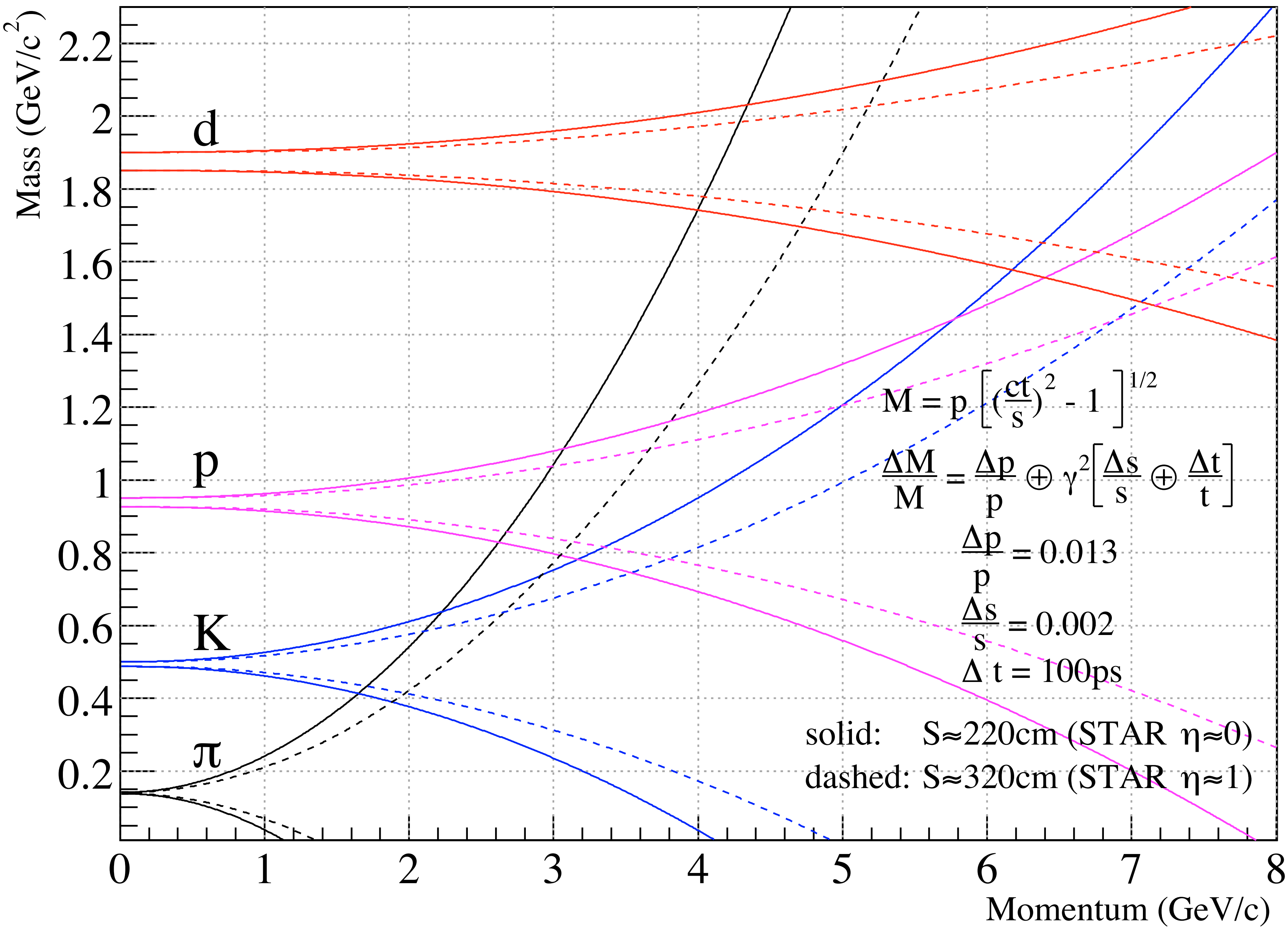




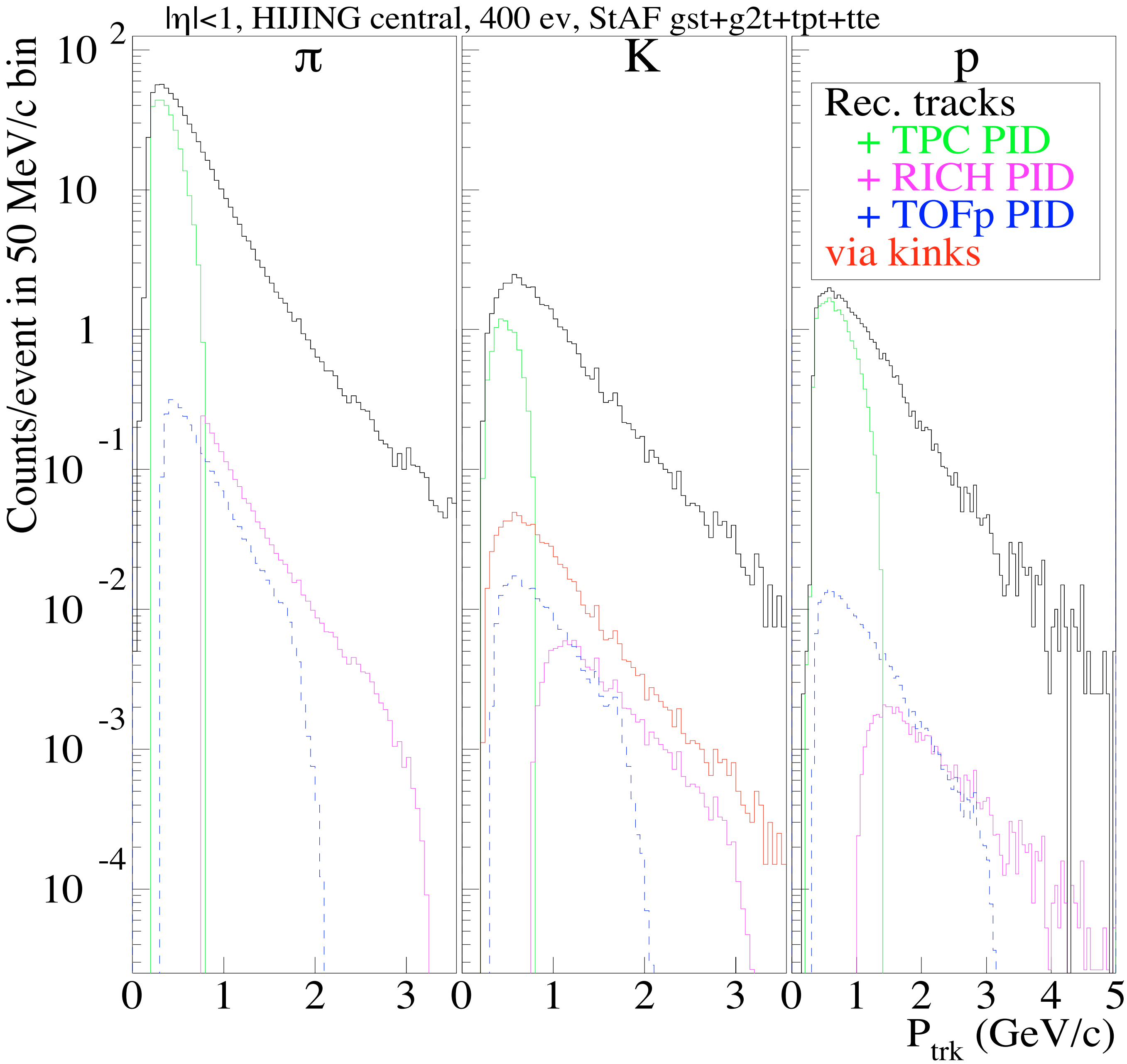
...the STAR TPC an extremely powerful tracker for a TOF system...


STAR
STAR

PID reach for TOF in STAR   (here assuming a 100ps TOF system)



in STAR: TOF resolution by far the dominant contribution to total mass resolution...
better total timing resolution of course gives PID to higher momenta...



Examples from STAR (for full energy Au+Au collisions)

TPC dE/dx directly identifies ~60% of tracks it can reconstruct

w/ a ~100ps TOF system in STAR's geometry,

→ ~97% of reconstructed tracks can be directly identified

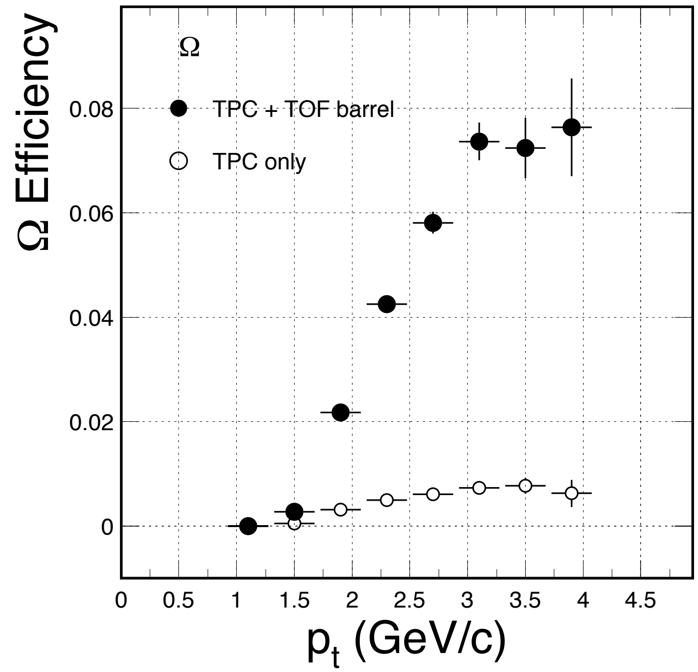
charged hadron PID at even higher momenta:

→ Cerenkov detectors (Aerogel, RICH, ...)

A small-area TOF system is not enough though...

Numerous interesting/relevant topics requiring a large-area system:

- Elliptic Flow for hadrons with no light valence quarks
- Fluctuations/Correlations studies with PID
- Away-side jet fragmentation yields and spectra
- Yields and spectra of high-mass resonances
- Unlike particle correlations
- Charmed hadron flow and yield ratios
- Exotic particle searches (pentaquark, H, ...)
- Heavy quark jets; D,B-meson spectra at high pT
- Lepton, di-Lepton spectra, Vector meson e+e- decays
- e+e- production in ultra-peripheral collisions



TOF PID significantly reduces backgrounds

→ higher-significance results in same-sized data set...

→ reduction of data set required to get same S/B...

and reduces systematic errors from correlated backgrounds due to misidentified particles

BUT

Cost of a ~50m² TOF system for STAR based on the conventional technology is >20M$

Simply can't afford large area TOF systems based on scintillator.

“Conventional TOF” example 2:
STAR Time-Of-Flight Patch (TOFp/pVPD)

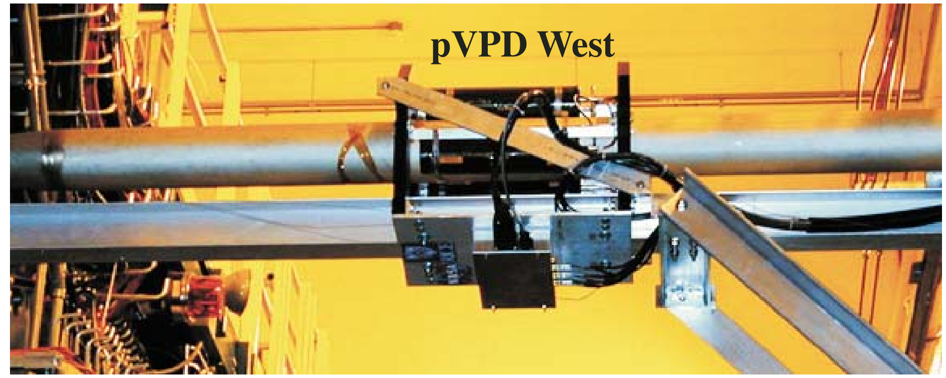
Start detector: pVPD, Stop Detector: TOFp tray

Conventional technology: scint+(mesh)PMT
On-board custom FEE
Camac digitization after long cables

41 total stop channels, $\Delta\eta\sim1$, $\Delta\phi\sim6$ degrees

good data from Runs 2 and 3, ready for Run-4...

(also see W.J. Llope et al, nucl-ex/0308022, NIM A in press)



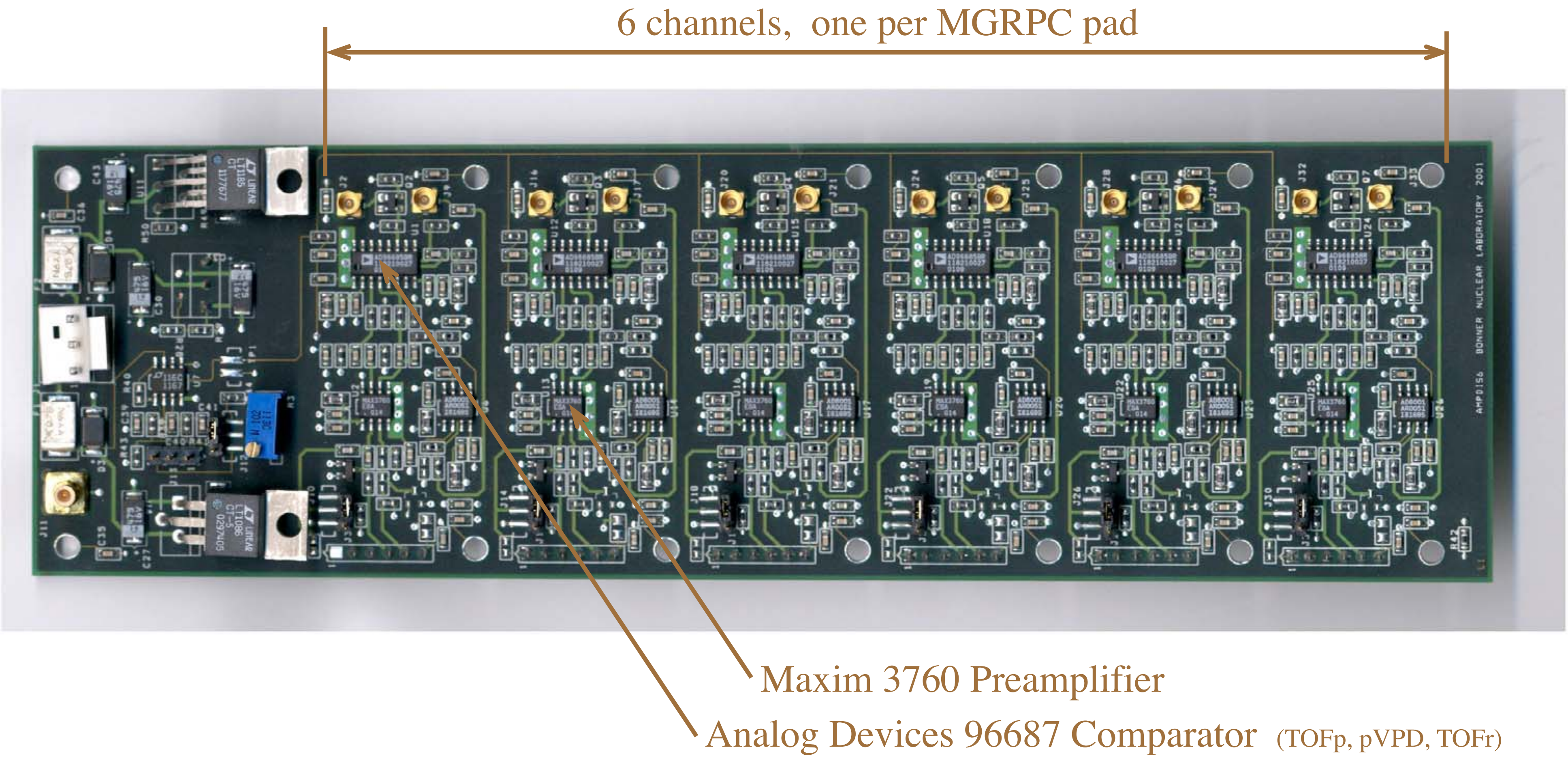
TOFr’s Front-End Electronics

typical MIP hit in a STAR MRPC equivalent to **~25 fC**   (not a typo)

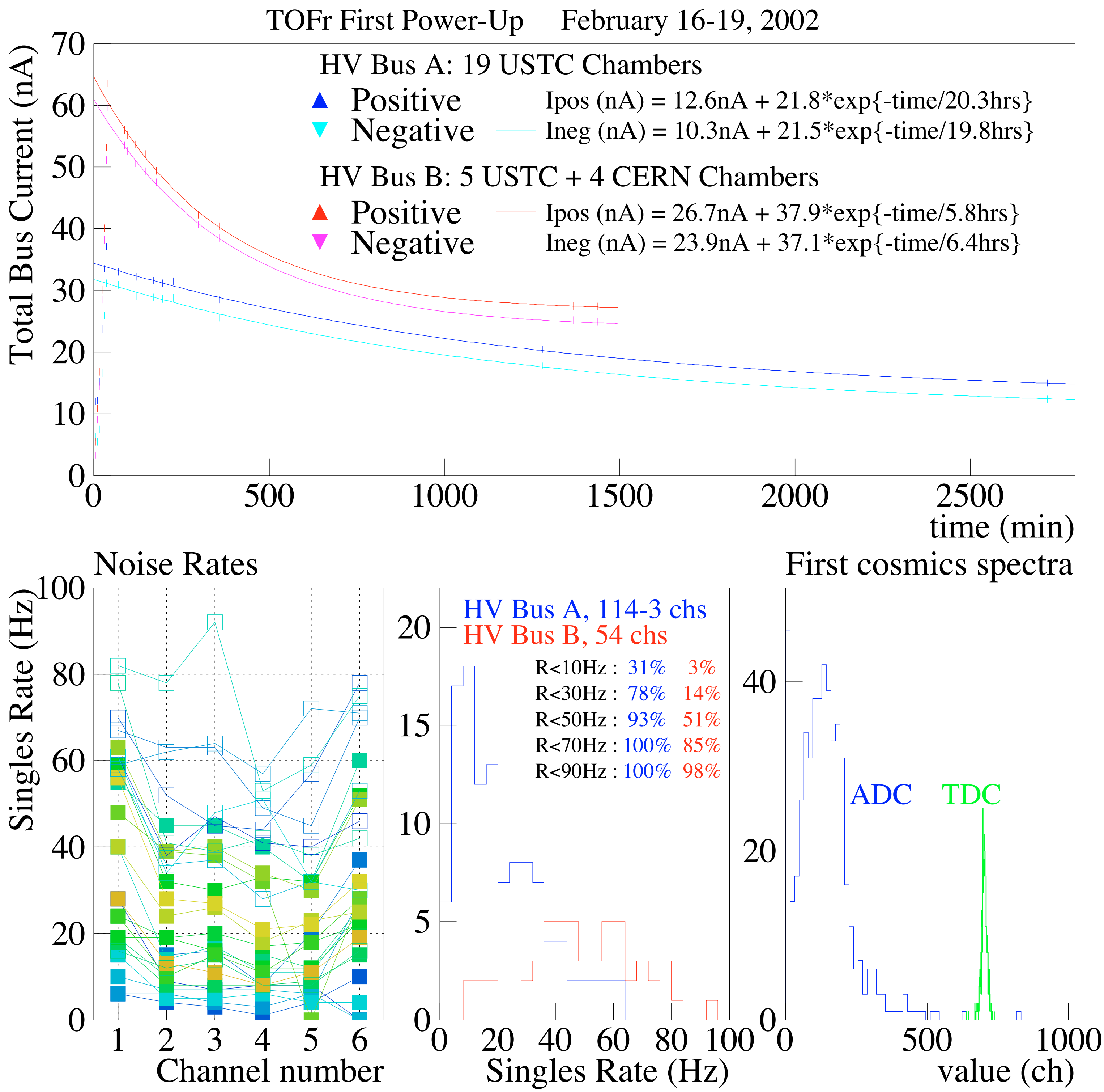
need to amplify first

rise time of [detector+FEE] practically limited only by bandwidth of this preamp
major breakthrough came w/ adoption of MAXIM 3760

then discriminate using standard components



Initial Testing of TOFr just after construction...



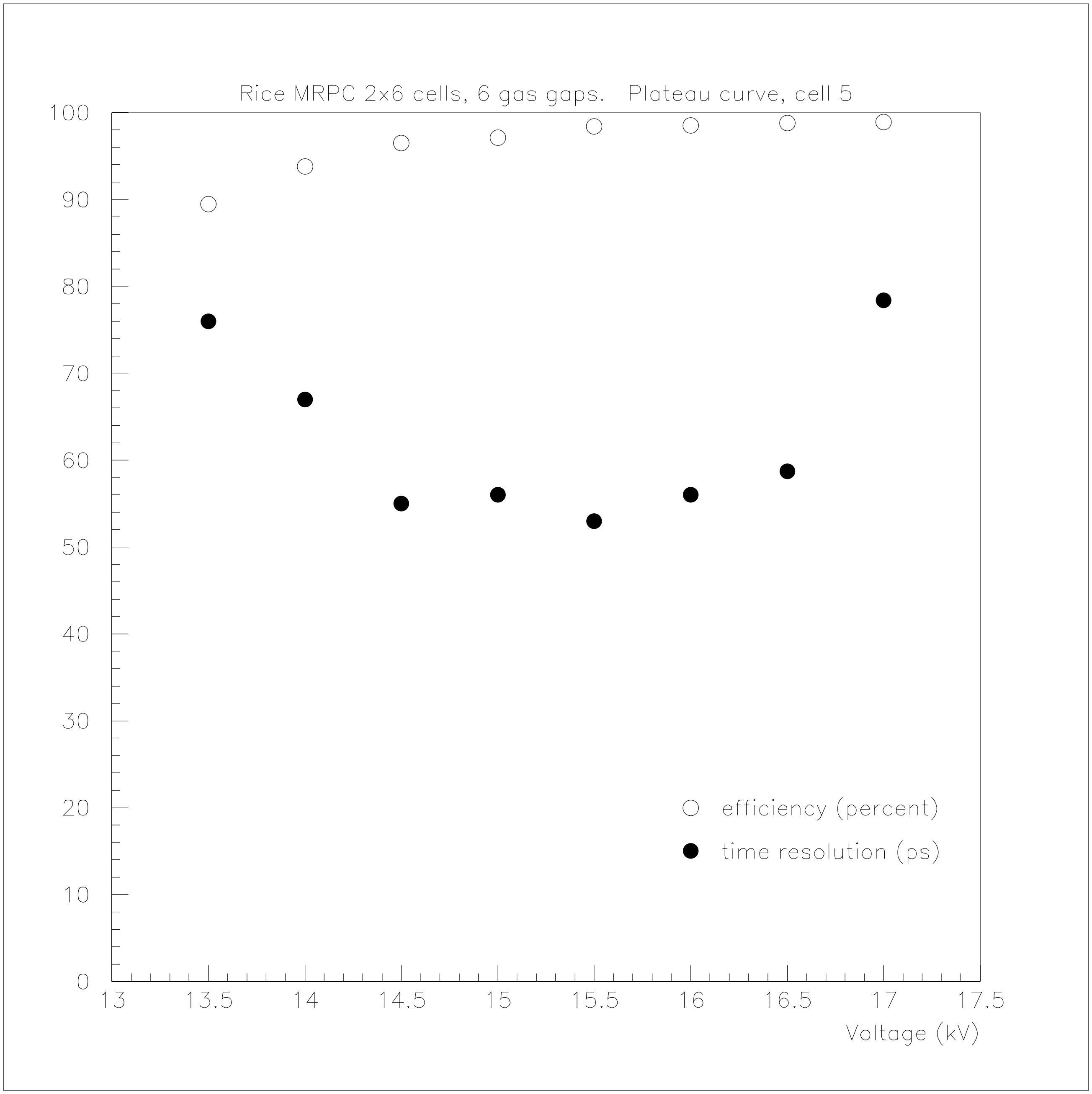
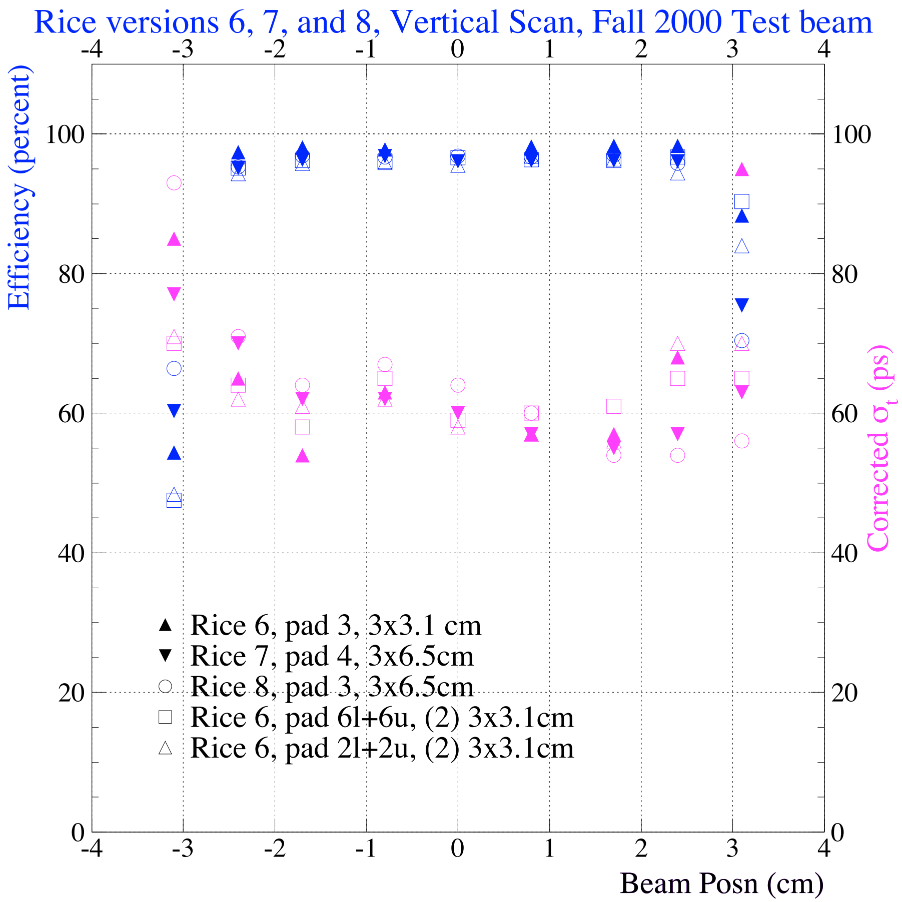
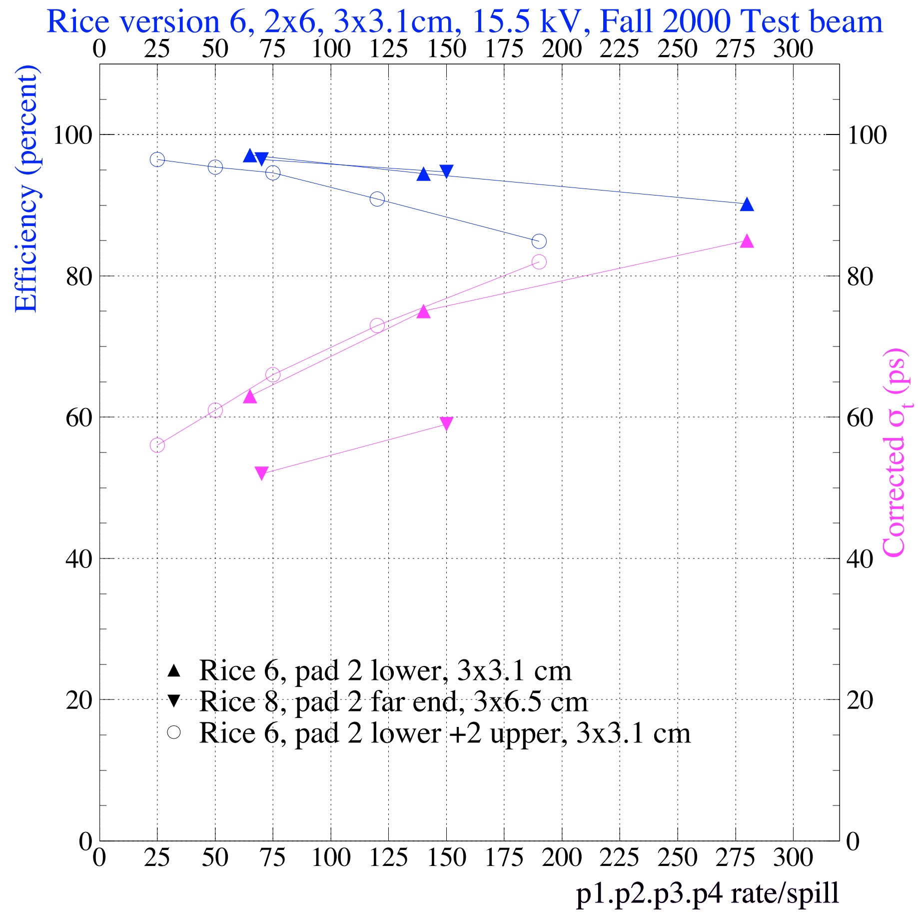


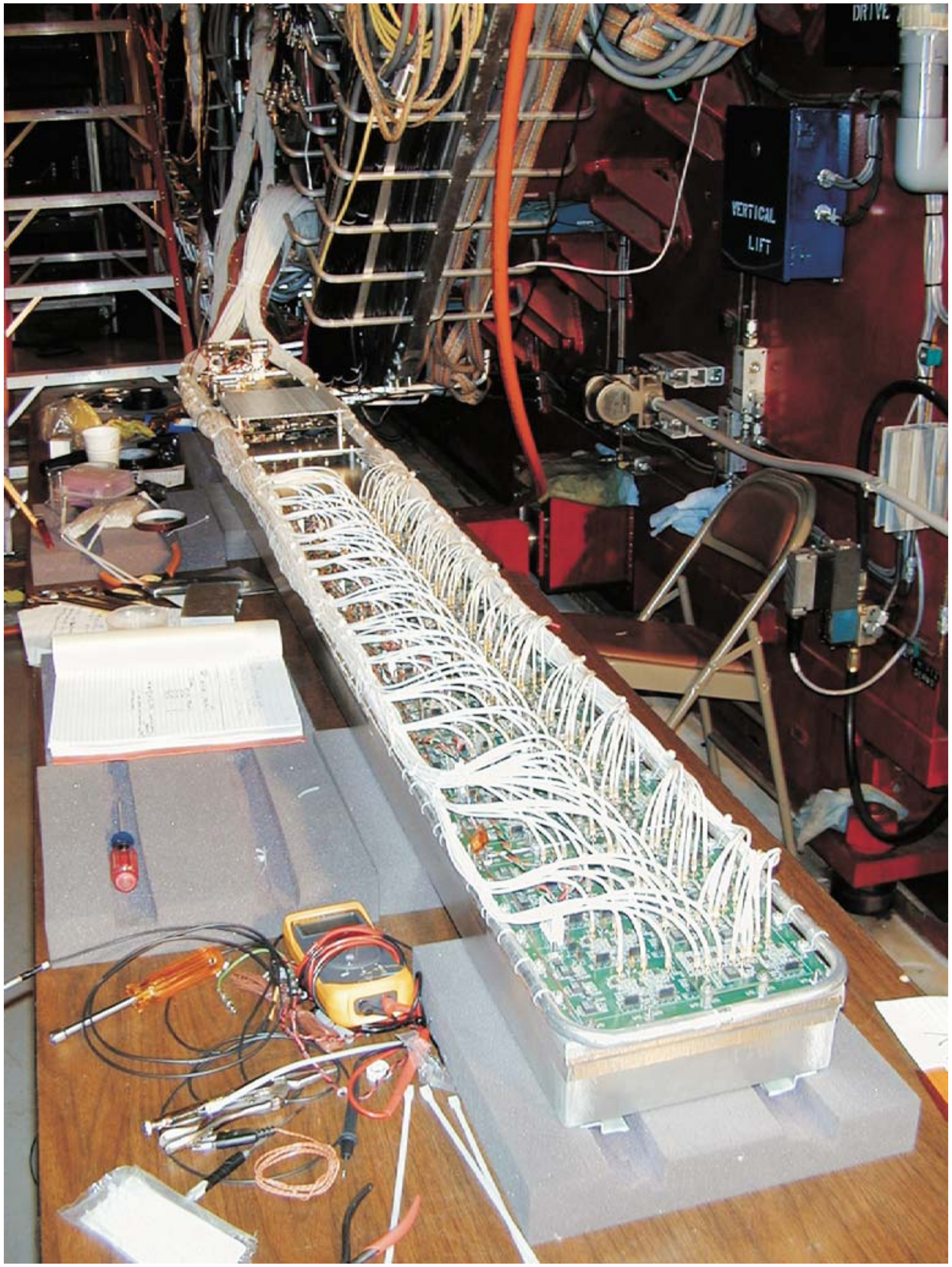
Fig. 2. The efficiency and corrected time resolution (σ) versus voltage for the prototype with 2x6 pads and pad area of 3x3 cm^2.

Position Dependence w.r.t. Pads



Rate Dependence




DRIVE
VERTICAL
LIFT