Recent Progress on MGRPCs for Large-Area Time-Of-Flight for STAR

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RHIC DetectorWorkshop
BNL
Nov. 13-14, 2001

A Brief History of Time (of Flight for STAR)

1991	STAR is formed by a merger of two RHIC proposals
1992	RICE leading STAR TOF efforts
1993	In-beam test results for scintillator TOF published A. Ahmad *et al*., Nucl. Inst. and Methods **A330**, 416 (1993)
1994	RICE proposes large-area scintillator TOF for STAR
1995	NSAC Review of Additional Experimental Equipment C.K. Gelbke, chair

"A small-area TOF array ... will be sufficient to measure inclusive particle ratios and correlate them to other observables measured event-by-event in STAR. Such a smaller array would already significantly enhance the physics capabilities of this experiment. ... STAR should aim at a coverage which is sufficient for event-by-event Kaon (and possibly proton) identification, which in other observables is the prominent feature and strength of STAR. If fiscal constraints are such that this cannot be realized, a small area TOF array would still be very valuable, and further R&D should be encouraged to search for a viable solution for large area coverage."

1996	Successful Final Design Review of large-area scint. TOF (~15M$)
1996	RICE/MELZ/ELECTRON begin development of low cost Russian PMTs
	Prototype Russian PMTs released, testing begins at RICE
1997	Russian PMT tests published A. Ahmad *et al*., Nucl. Inst. and Methods **A400**, 149 (1997)
1998	RICE/BNL/Burle CRADA to develop Russian PMTs for STAR
1999	CRADA Approved.
1998	Llope proposes single-tray of scint. TOF, called **"TOFp"** (0.12M$)
2000	Successful Final Design Review of TOFp. Construction at RICE.
2001	Installed, collecting data in present RHIC running.
1998	RICE participating in CMS RPC R&D, and later, MGRPC R&D
1999	First successful test beams of our MGRPC detectors
2000	LOI for large-area TOF Proposal, optimization of MGRPC design
2001	Proposal for single-tray of MGRPC TOF, called **"TOFr"** (~0.2M$)
	Successsful Review. Construction underway.
2002	Test beam studies of TOFr, Then Installation in STAR.
	Proposal for large-area MGRPC TOF, called **"TOFR"** (~5M$)
2004	TOFR Installed.

Small-Area TOF:

existing STAR TOFp → singles spectra of π, K, p, d, t, ... $0<\eta<1$ and $\Delta\phi \sim 1/60$ of π

Large-Area TOF:

- singles spectra w/ direct PID at vastly higher rate, azimuthal observables, ...

- form E-by-E observables based on direct PID, and use these to classify potentially interesting events for more detailed analyses
  → E-by-E is practically STAR's reason for being....

  No. Kaons or protons E-by-E
  K/π, K+/K-, and p/pbar ratios E-by-E
  K or p <Mt> E-by-E *et al*........

- High efficiency PID on both daughters from interesting particle decays
  → substantially suppressed backgrounds → cleaner spectra...
  → greater efficiency over wider range of Pt spectrum → more precise integrals...

  $\Lambda \rightarrow p\ \pi$ $\quad$ $Ks \rightarrow \pi^+\ \pi^-$ $\quad$ $\phi \rightarrow K^+\ K^-$ $\quad$ $\Lambda(1520) \rightarrow p\ K$ $\quad$ $K^* \rightarrow K\ \pi$

STAR Long Range Planning Committee (Summer 2000), R. Bellwied *et al.*

(paraphrased) "...after completion of calorimetry, large-area TOF is considered highest priority near-term upgrade to STAR."

Resistive Plate Chambers

(in avalanche mode)

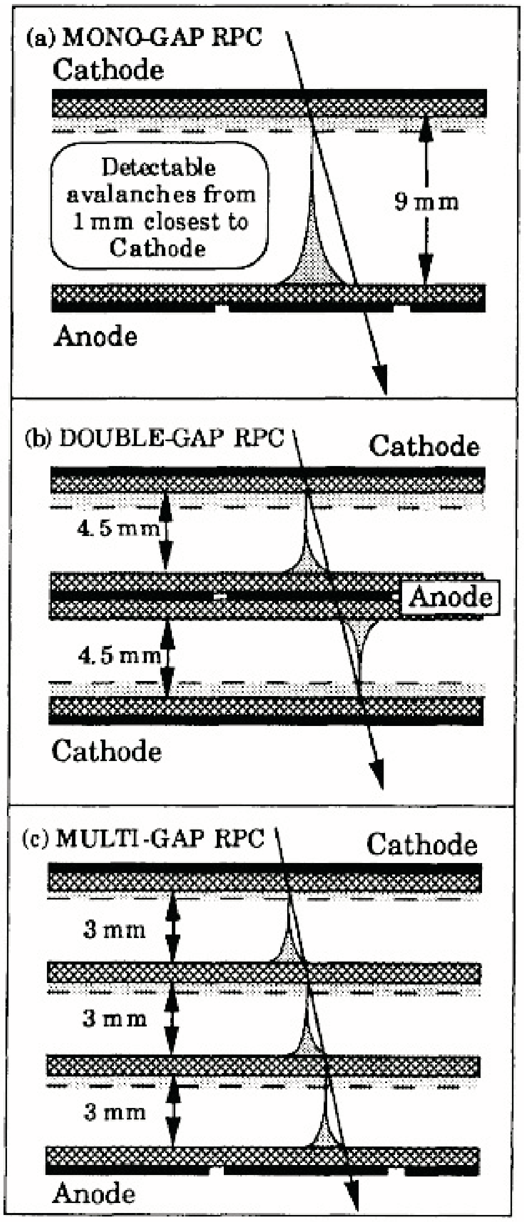


Figure 2. Schematic representation of a monogap RPC (top); a double gap RPC (middle) and a multigap RPC (bottom).

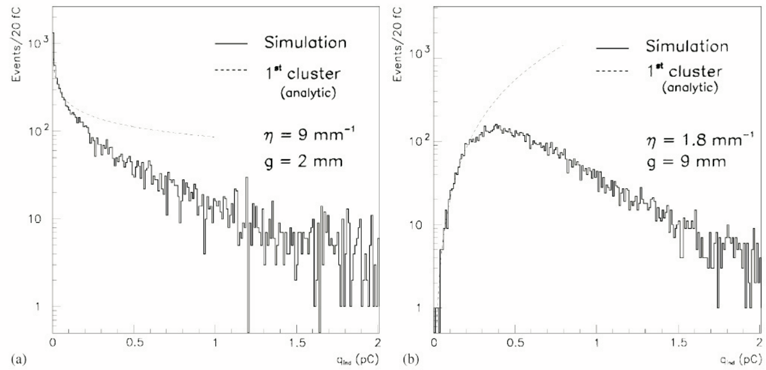


Fig. 1. Comparison between the simulated charge spectra for single (a) narrow ($g = 2$ mm) and (b) wide ($g = 9$ mm) gap RPCs.

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!
  $\longrightarrow$ timing jitter from location of ionization in RPC
- avalanches from single primary clusters tend to merge
  $\longrightarrow$ fluctuations in avalanche development dominate

many narrow gaps!

- characteristic distance for primary ionization decreased
  $\longrightarrow$ decreased timing jitter from primary ionization step
- N-independent avalanches, hence an averaging
  $\longrightarrow$ decreased timing jitter from avalanche fluctuations

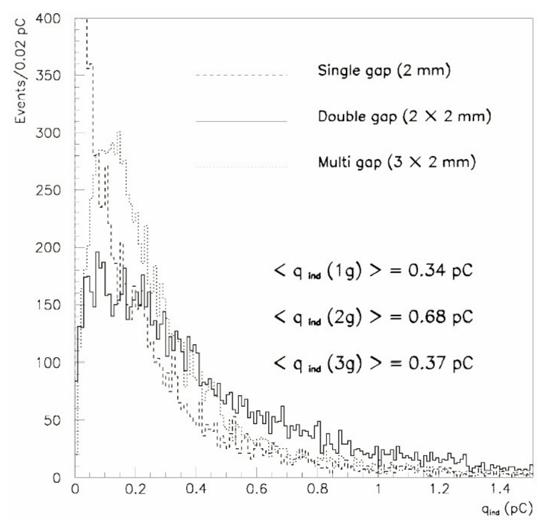


Fig. 3. Monte Carlo charge spectra for single- double- and multi-gap RPCs.

With many small gaps,

- the resistive plates are transparent to the fast signals generated by the avalanches in each gas gap. The induced signal is the *sum over all gaps*.
- the internal resistive plates are electrically floating, so the stable state is *equal gain in all gaps*.

...perhaps the MultiGap Resistive Plate Chamber (MGRPC)?

(also referred to as Micro-Gap RPC)

Cheaper per detector channel than Hamamatsu mesh dynode PMTs

But do they work for fast timing?!?!?

i.e. can they provide timing stops w/ <100ps resolution
at high efficiency,
at up to the maximum expected particle rates/channel,
with cell sizes small enough to handle highest occupancies
but large enough to afford,
with sufficiently low detector noise rates,
with sufficiently low detector and FEE dead-time,
and be stable, or correctably so, over short and long terms

Answering these questions, and hence deciding if MGRPCs are appropriate for TOF in several experiments, has been the focus of very recent R&D.

Italy and CERN (C. Williams et al. & INFN-Bologna), towards ALICE TOF and since mid-1997 by a Bonner Lab group, potentially for STAR.

Jose “Pepe” Lamas-Valverde (full-time at CERN)
Geary Eppley (leading our R&D efforts)
Ted Nussbaum, Nick Adams (electronics engineers)
Jay Roberts, Ed Platner, Billy Bonner, Bill Llope

Important differences between ALICE and STAR environments!

particle rates:	<300 Hz/cm2 vs. <10 Hz/cm2
beam rep rate:	25ns vs. ~100ns
due date:	in some years vs. *now*

On the other hand, many functional requirements are similar.

So, Bonner Lab and ALICE groups have been collaborating very closely over the years...

Not such a crazy idea.

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

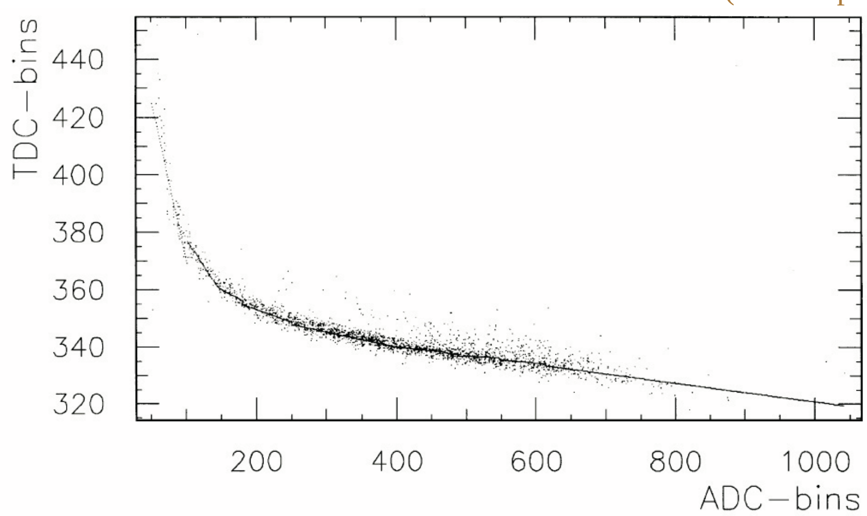


Fig. 4. Correlation of raw time difference between MRPC detector and reference counter and MRPC signal amplitude.

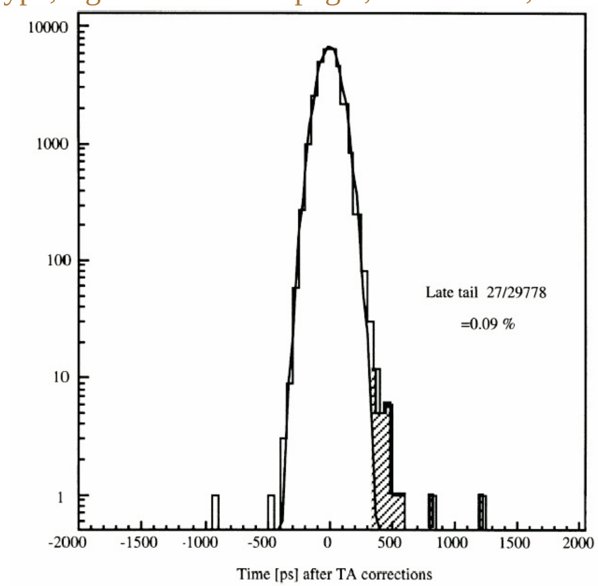


Fig. 5. Time distribution measured with an MRPC with five gaps of 220 μm operated at 12 kV (109 kV/cm). The width of the Gaussian fit is $\sigma = 88$ ps.

For Additional Details.... (articles in blue are "must reads"!)

"The development of the multigap resistive plate chamber", M.C.S. Williams, Nucl. Phys. B (Proc. Suppl.) **61B**, 250 (1998).
"Microstreamers and the micro-gap Resistive Plate Chamber", E. Cerron-Zeballos *et al.* (inc. Lamas-Valverde, Platner, & Roberts), NIM A **411**, 51 (1998)
"Effect of adding SF6 to the gas mixture in a multigap resisitve plate chamber", E. Cerron-Zeballos *et al.* (inc. Lamas-Valverde, Platner, & Roberts), NIM A **419**, 475 (1998)
"A very large multigap resisitive plate chamber", E. Cerron-Zeballos *et al.* (inc. Lamas-Valverde, Platner, & Roberts), NIM A **434**, 362 (1999)
"Recent Progress on RPCs for the ALICE TOF system", M. Spegel for the ALICE Collaboration, NIM A **453**, 308 (2000)
"A new high-resolution TOF technology", P. Fonte *et al.*, NIM A **443**, 201 (2000)
"A Multigap Resistive Plate Chamber prototype for the Time-Of-Flight of STAR at RHIC", J. Lamas-Valverde *et al.*, Vienna Conference on Instrumentation, 2001 (submitted)

"Optical observation of discharge in resistive plate chamber", I. Kitayama *et al.*, NIM A **424**, 474 (1999)
"Test beam results on resistive plate chamber prototype at gamma irradiation facility in CERN", C.H. Chung *et al.*, NIM A **432**, 14 (1999)
"Study of avalanche mode operation of resistive plate chambers with different gas gap structures", V.V. Ammosov *et al.*, NIM A **441**, 348 (2000)

...and on the theory side...

"Resistive Plate Chambers in avalanche mode: a comparison between model predictions and experimental results", M. Abbrescia *et al.*, NIM A **409**, 1 (1998)
"A simple theory of rsignals induced by a point charge moving in a resistive plate chamber", Th. Heubrandtner *et al.*, NIM A **419**, 721 (1998)
"The simulation of resistive plate chambers in avalanche mode: charge spectra and efficiency", M. Abbrescia *et al.*, NIM A **431**, 413 (1999)

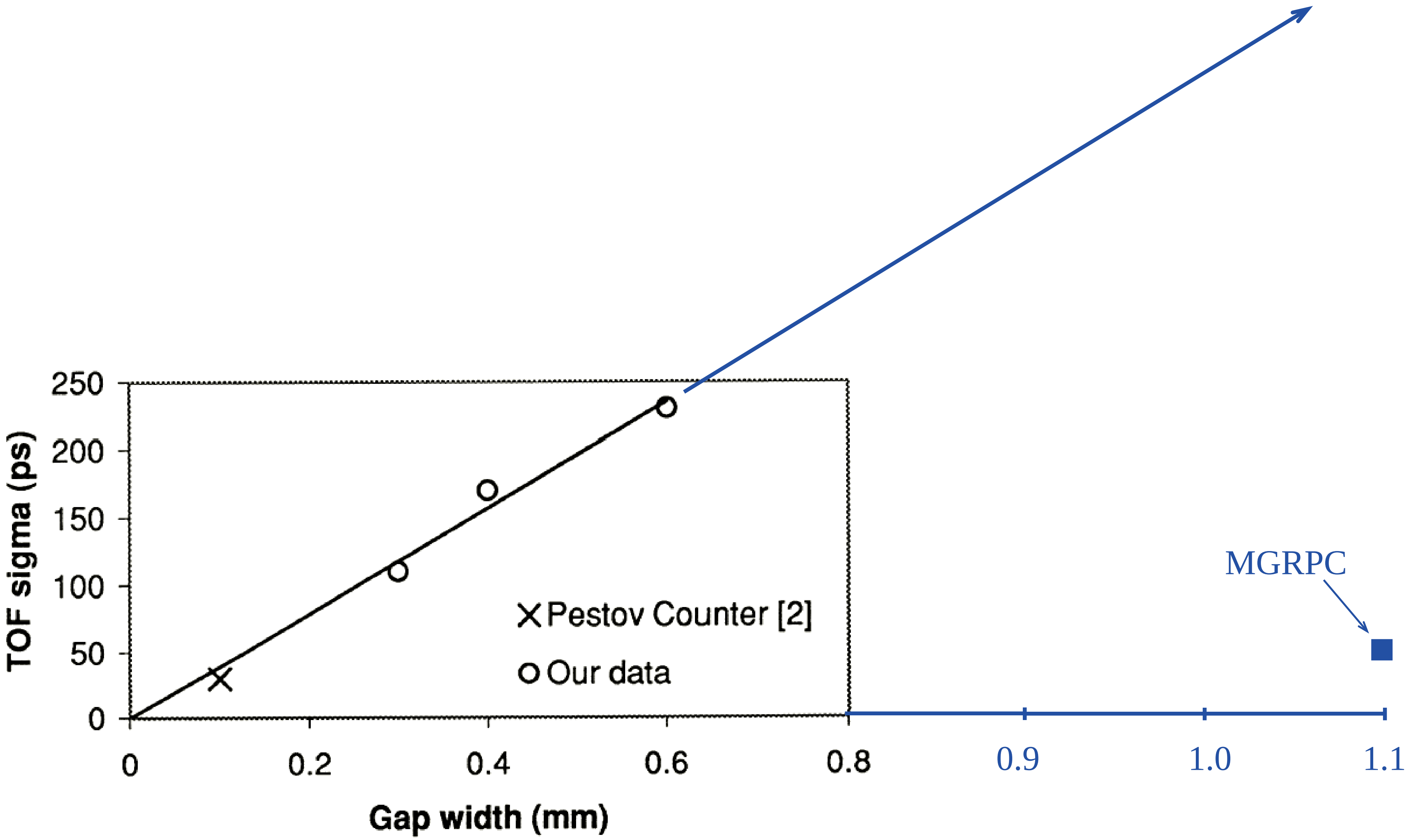


Fig. 6. Tests performed with other detectors featuring different widths of the gas gap suggest that the main contribution to the time jitter is associated to the amplification process in the gas. The timing resolution seems to depend almost linearly on the gap width, with a slope of approximately 40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

History of MGRPC R&D at Rice

Lamas-Valverde, Eppley, Nussbaum, Roberts, Adams, Platner, Bonner, Llope

Summer 1997 Rice begins thinking about this for STAR

initiate close collaboration with Alice groups, still going strong
initial prototyping of detectors and specific electronics

.....

Apr.-Jul. 2000 CERN T10 beam tests of Rice version 4 & 5 MGRPCs
several single channel versions built
four 2x8ch detectors built, 3x3cm pads

sandblasted or acid washed outer glass
different thickness outer glass, different thickness inner glass
→ these variants resulted in factor 2-3 worse timing resolution

various internal support schemes

proved different choice of preamplifier would work better
russian preamp changed to Maxim 3760

typical performance: 95-97% efficient, stop resolution ~80 ps
some channel by channel variations

construction techniques not suitable for mass production

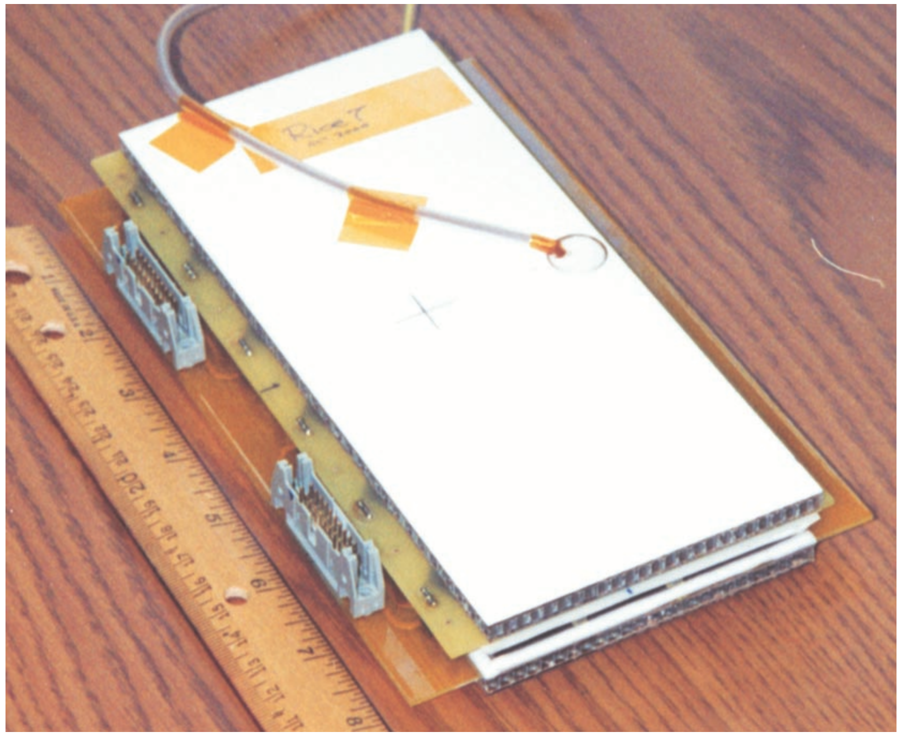
Oct.-Nov. 2000 CERN T10 beam tests of Rice versions 6, 7, & 8
all 6 gap chambers with same glass, pads differ

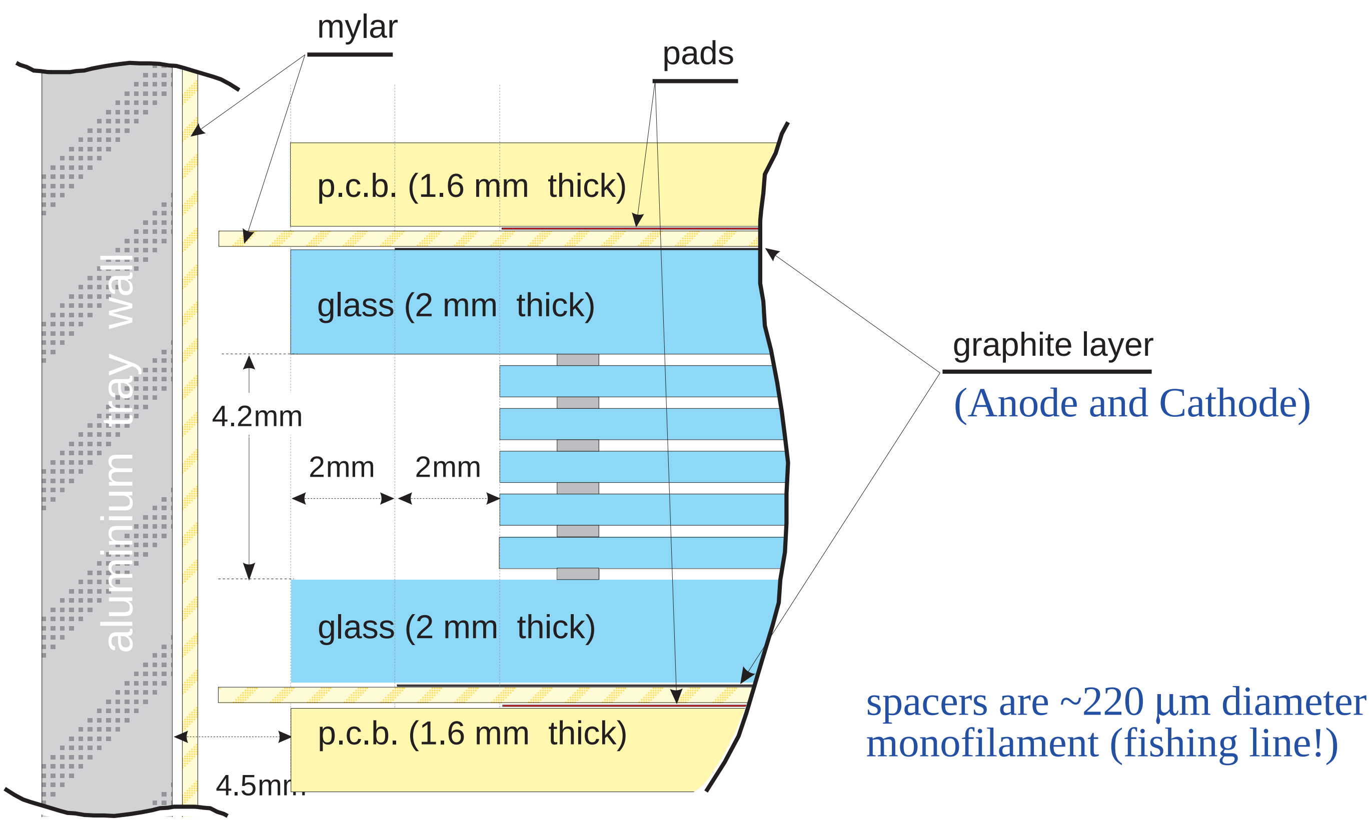
Rice 6: 2 x 6 array of 3 x 3.1 cm pads, 3mm space between pads.
Rice 7: 1 x 6 array of 3 x 6.5 cm pads read out from one end.
Rice 8: 1 x 6 array of 3 x 6.5 cm pads read out from both ends.

numerous studies of performance with larger pad sizes, different shapes
results on following slides...

first RPC-related Rice-China direct collaboration....
significant shift-taking, first chinese chamber...

Rice Version 7 MGRPC





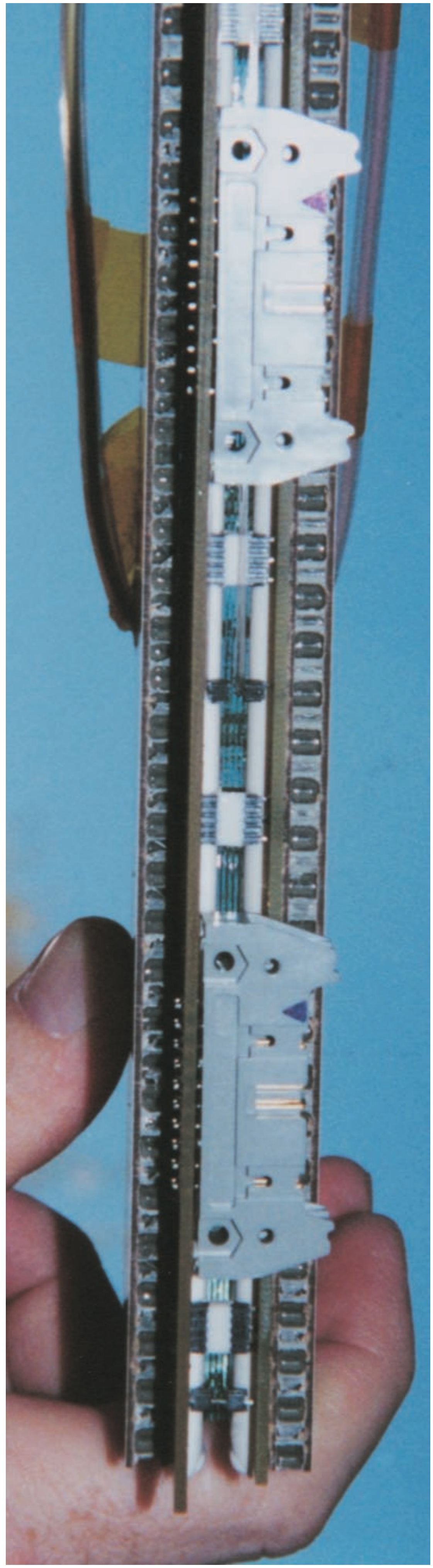
Tray inner dimensions: 213mmx2413mmx85mm

outer glass: 84mm x 204mm (10mm extra width for HV / gnd. connect. included)

graphite layer: 70mm x 200mm

inner glass: 65mm x 195mm

pad size: 31mm x 30mm, distance between pads = 3mm



Rice version 6.x

12 “square” 3×3.1cm pads,
read out separately or w/
adjacent pads into same preamp

60 sq.m / 9.3 sq.cm = 71,000 chs

Rice version 7.x

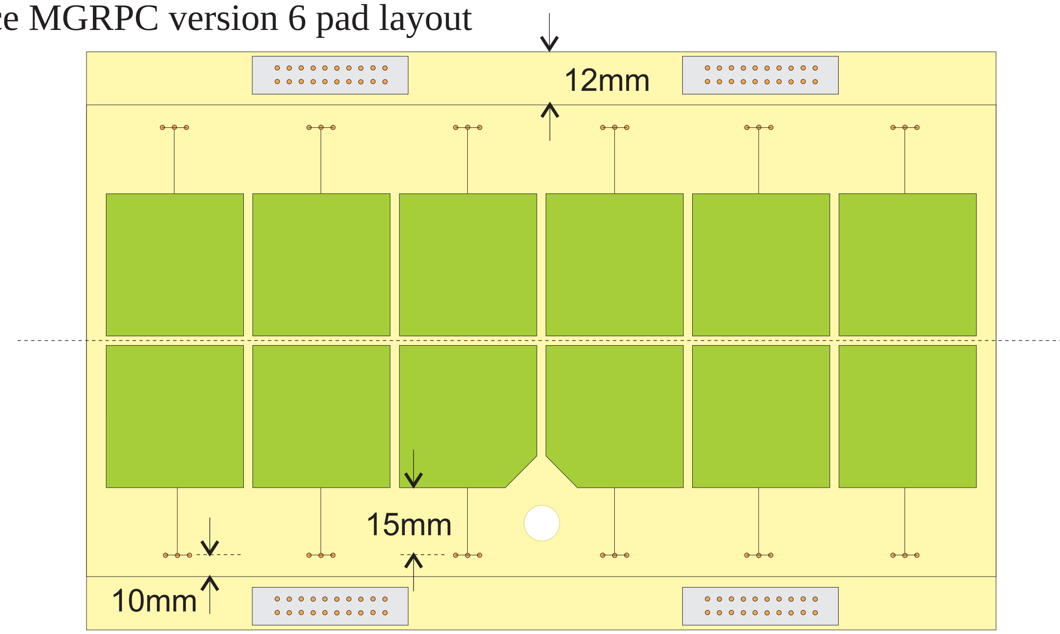
6 rectangular 3×6.5cm pads
read out on one side

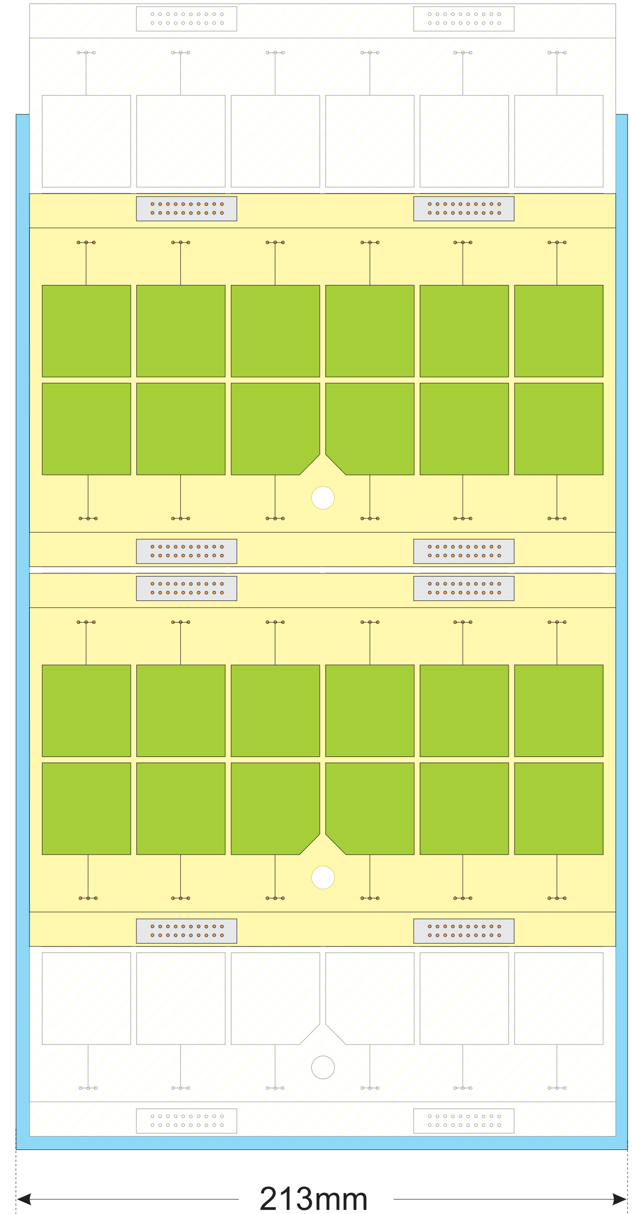
Rice version 8.x

6 rectangular 3×6.5cm pads
read out on both sides

60 sq.m / 19.5 sq.cm = 34,000 chs
or
216ch/tray * 120 trays = 26,000 chs

Rice MGRPC version 6 pad layout





Internal dimensions of the aluminium trays
213mm x 2413mm x85mm

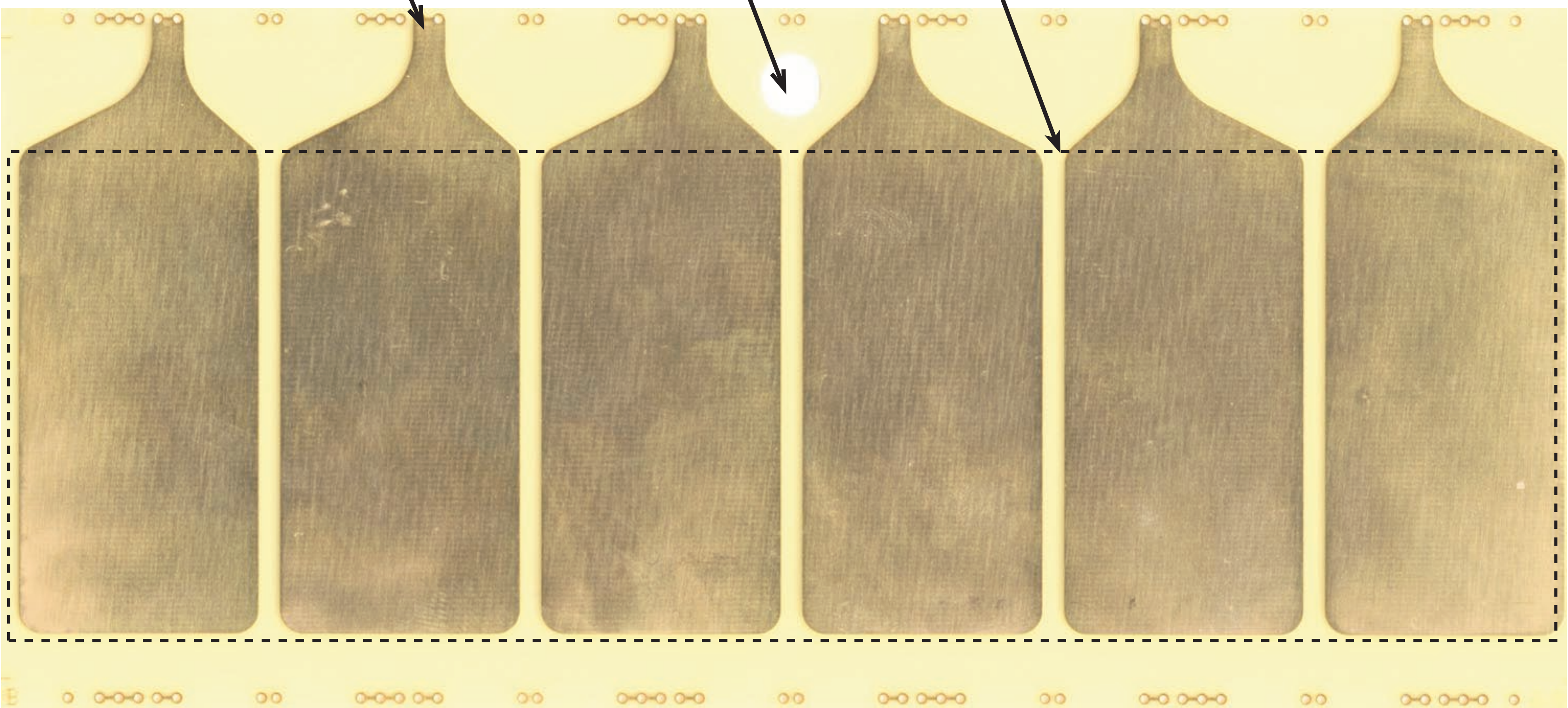
(Dwgs by Jose Lamas-Valverde)

Readout Pads for TOFr and TOFR

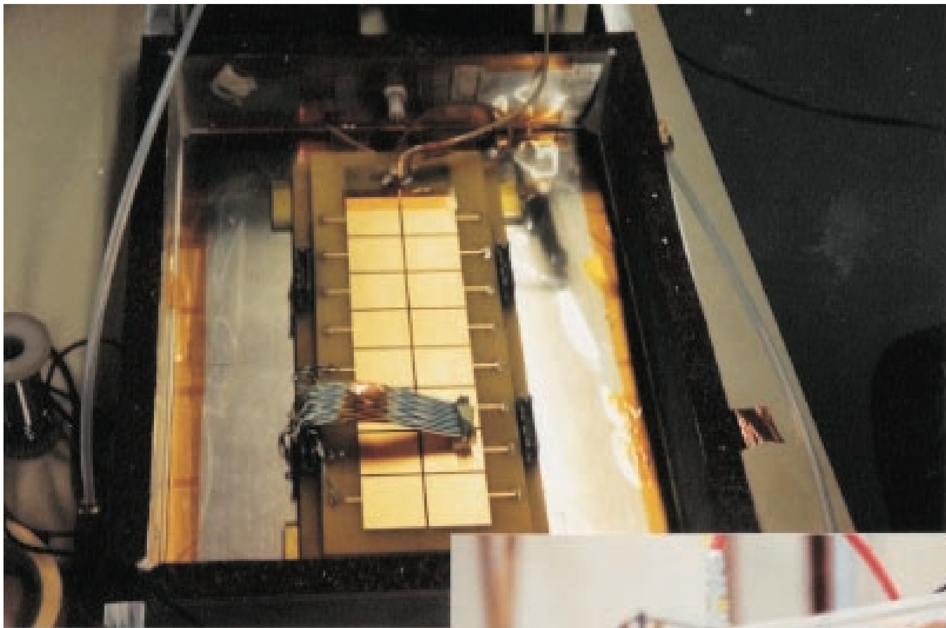
region of pads above thin glass indicated by dashed box

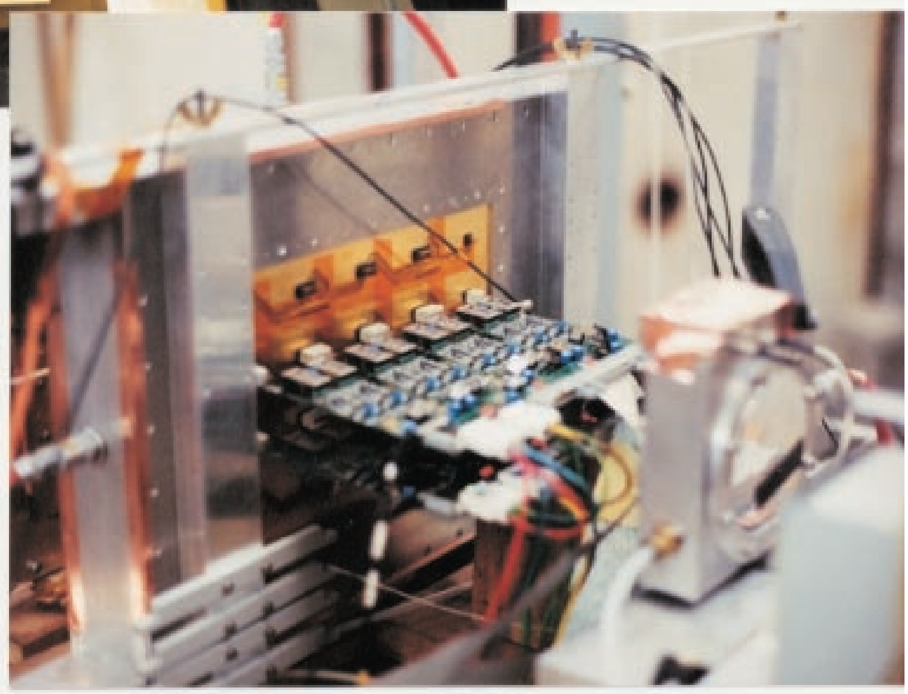
hole to pass HV through to graphite layer

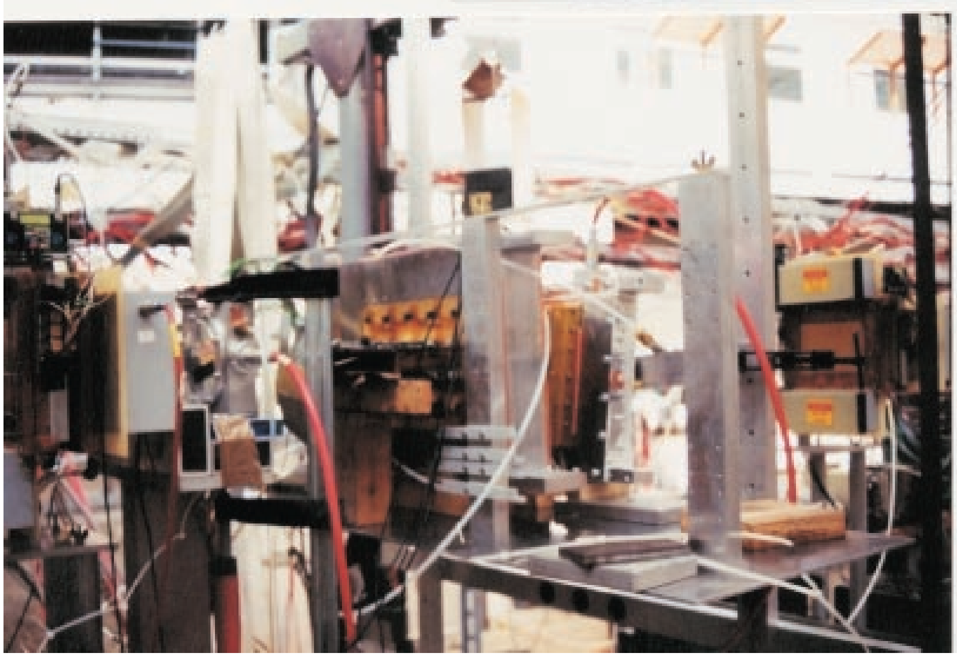
pins for signal output



Photos from May-July, 2000 CERN Test Beam Run





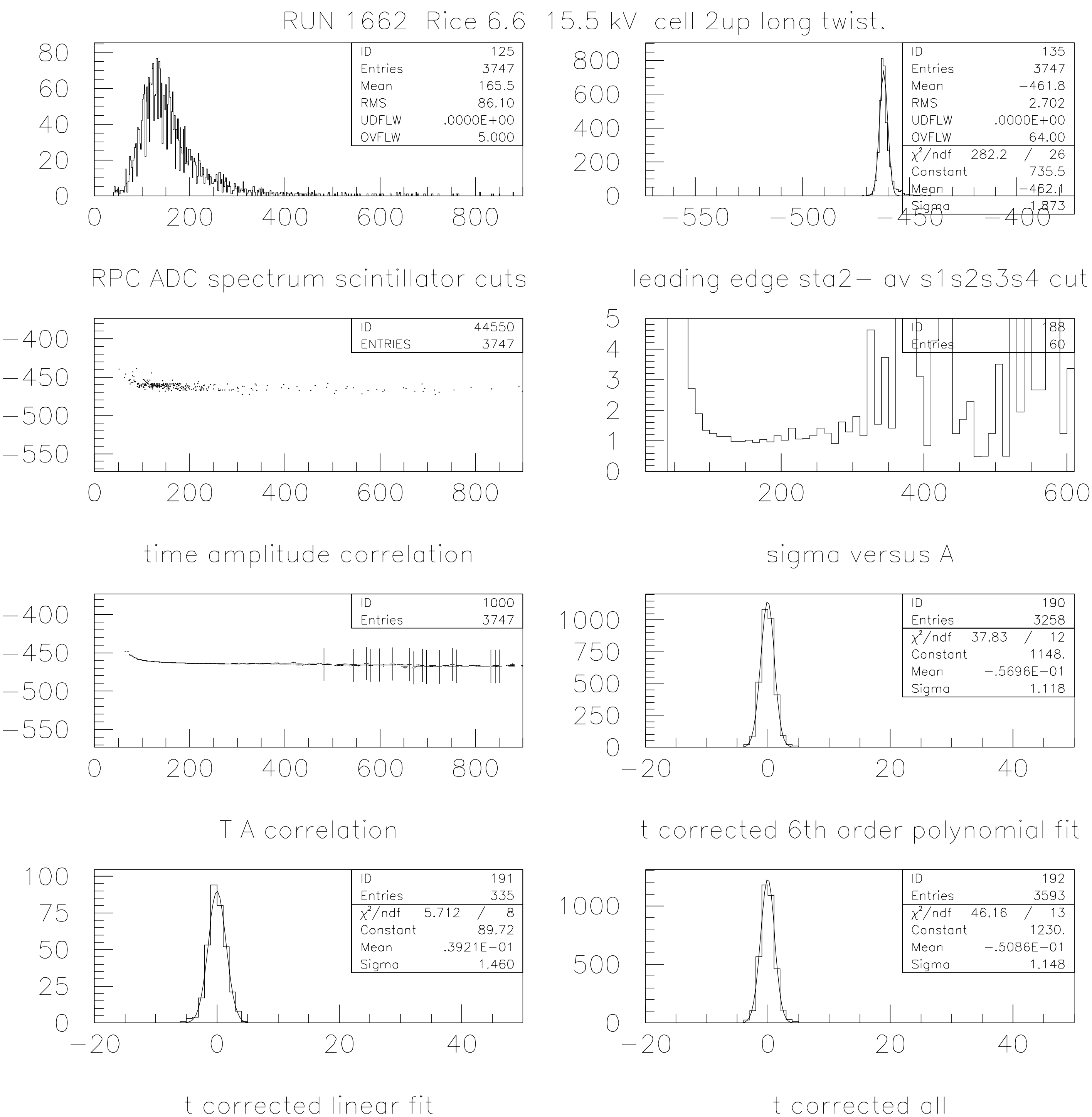


Fall 2000 Test Beam

an example set of detector performance histograms from one run...

the usual cuts and corrections apply for this technology too:
good beams selection, slewing correction, start resolution correction....

(Plot from Jose Lamas-Valverde)



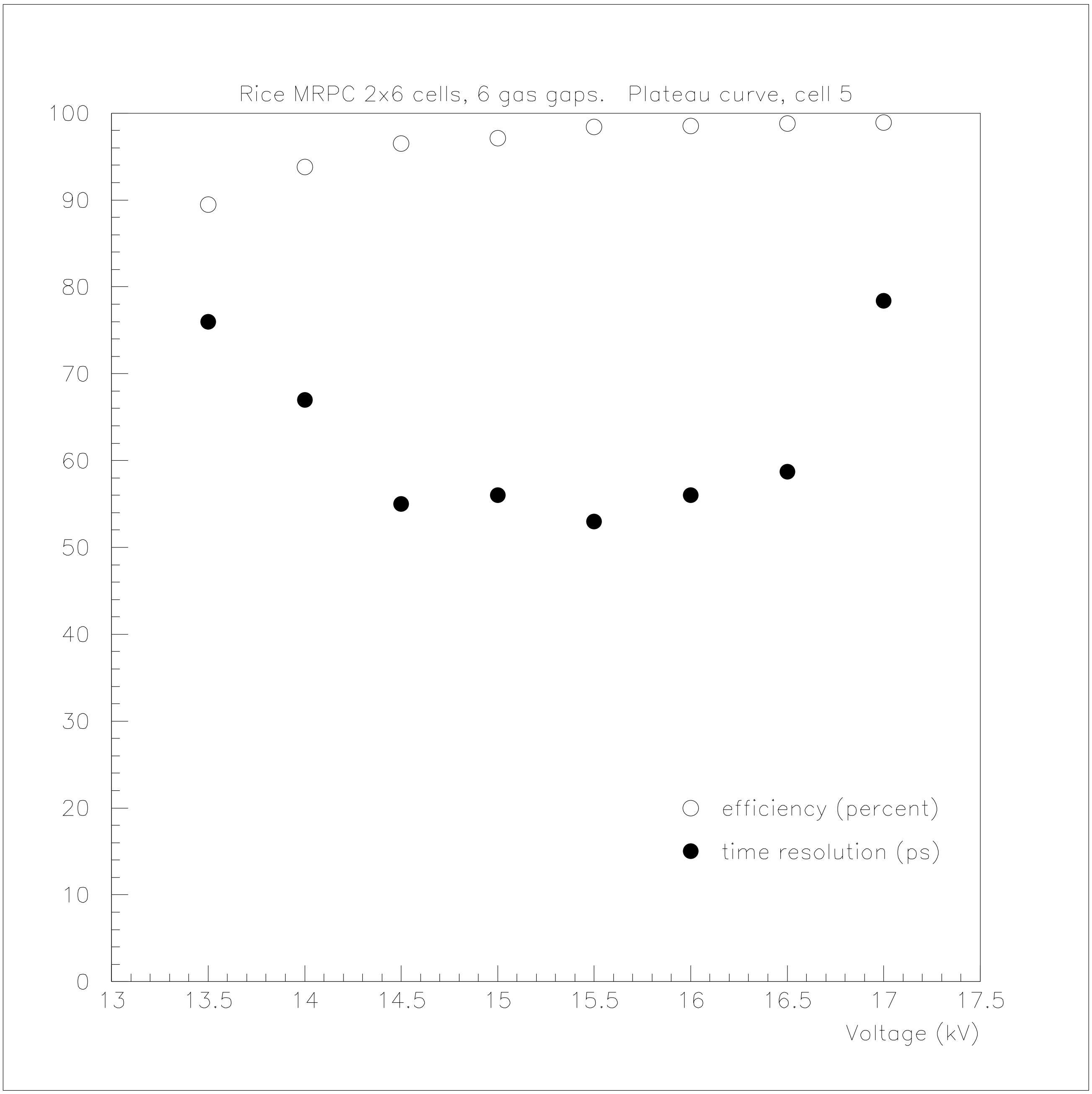


Fig. 2. The efficiency and corrected time resolution (σ) versus voltage for the prototype with 2x6 pads and pad area of 3x3 cm^2.

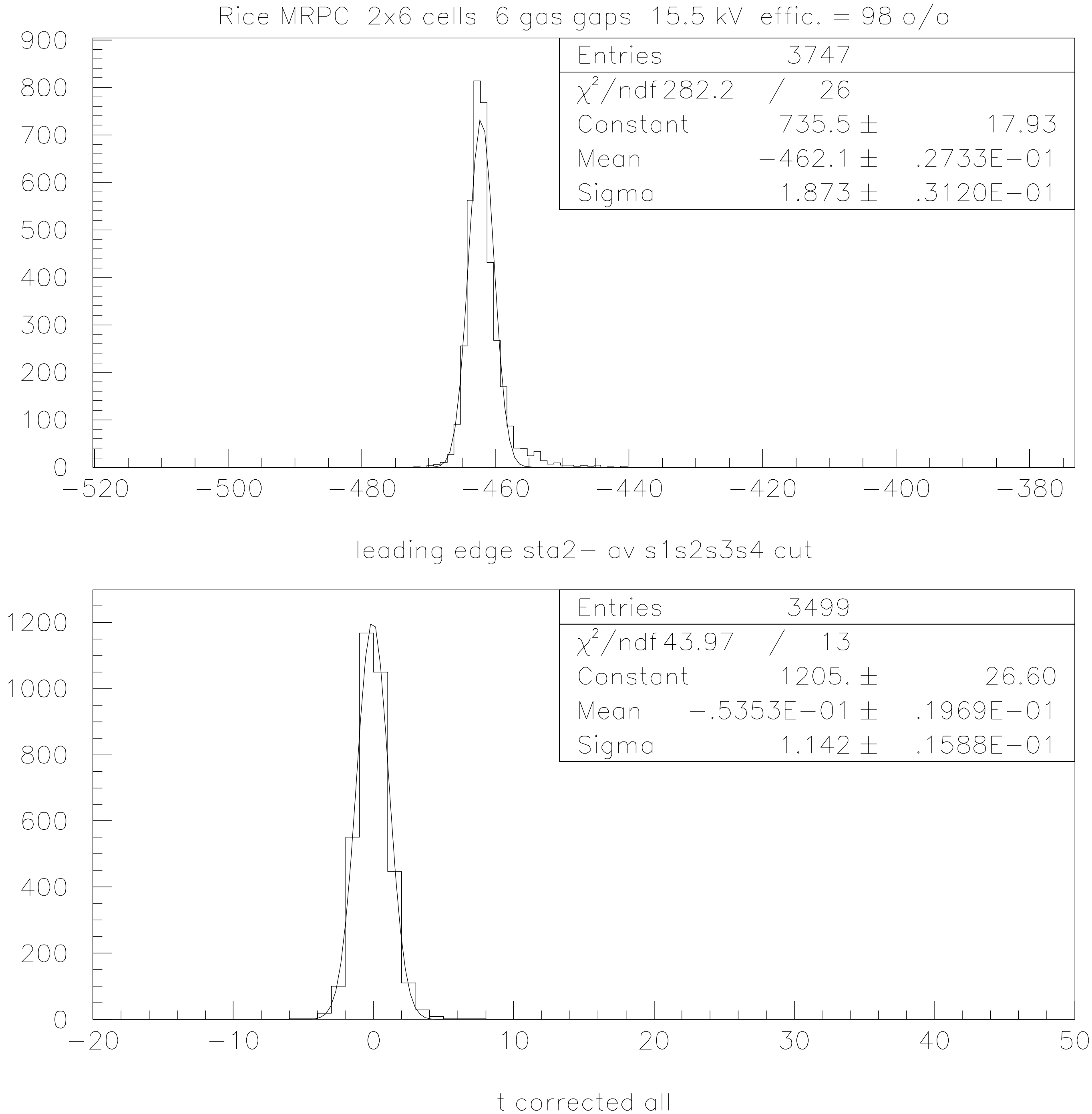
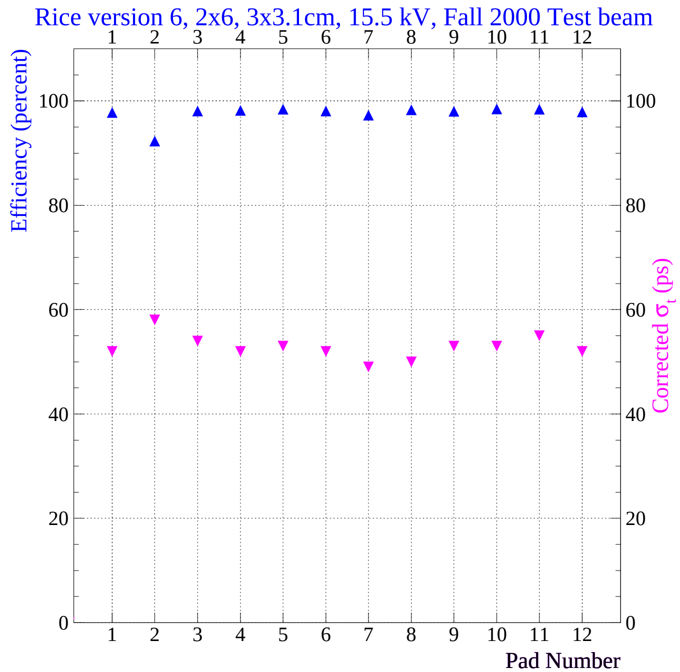
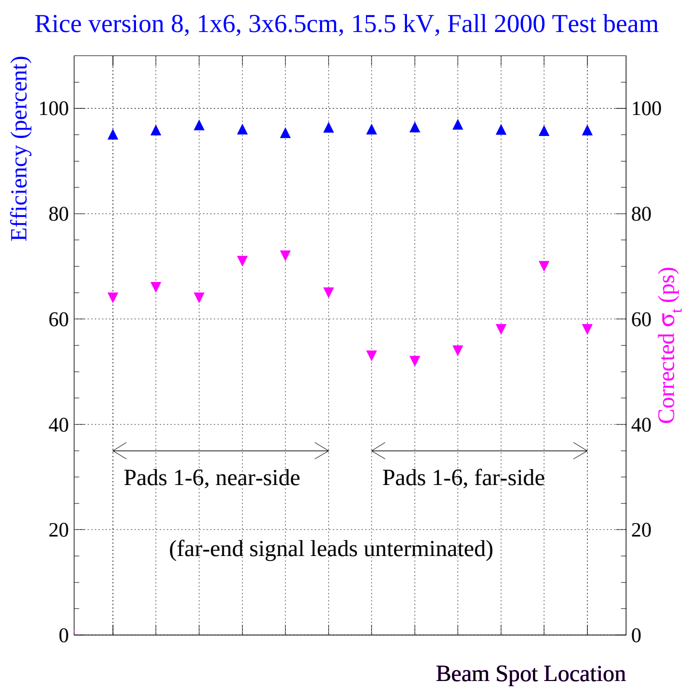
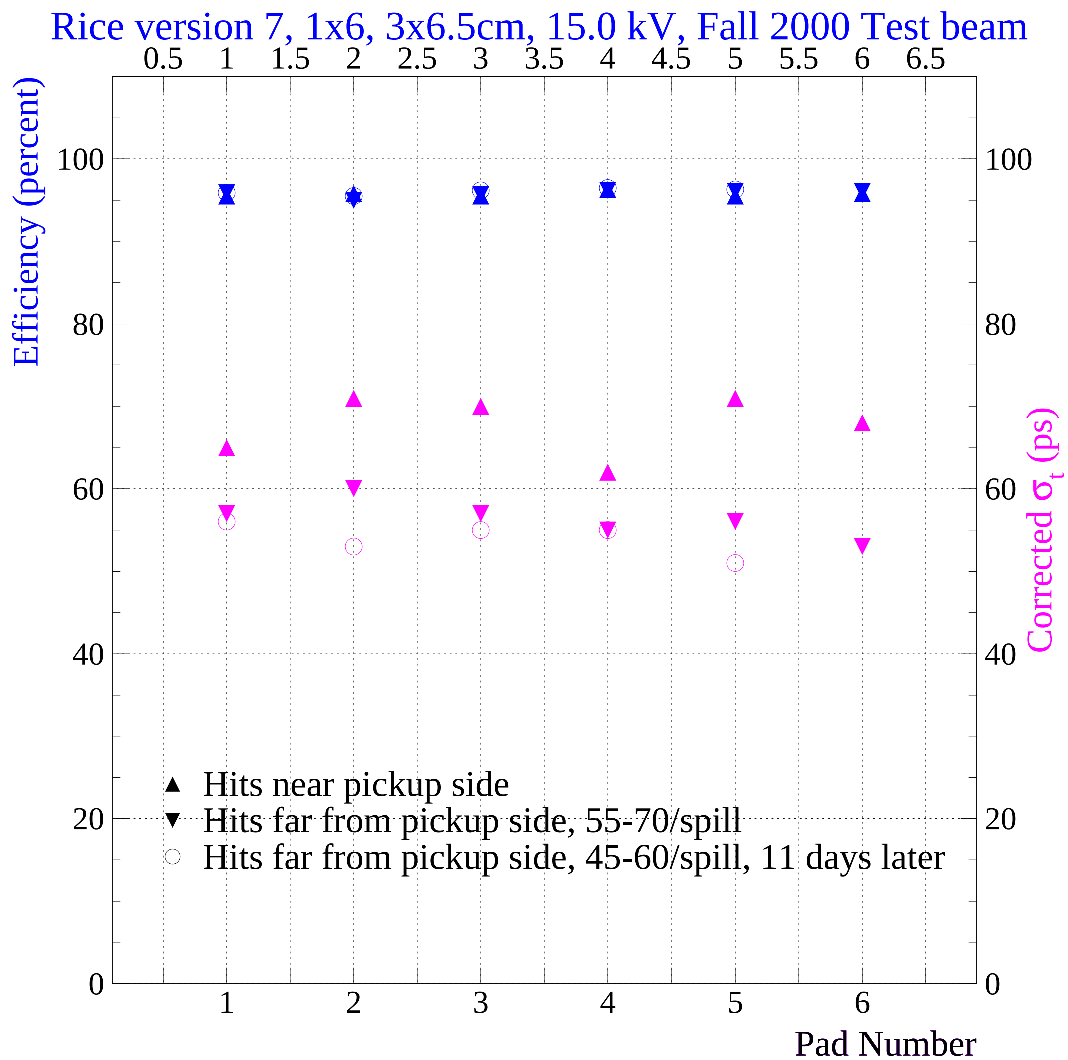


Fig. 1. The histogram on the top shows the raw time, and the histogram on the bottom shows the Time-to-Amplitude corrected time. The distributions are fitted with Gaussians, and the variance, σ, is reported in the boxes in each frame in units of TDC bins, which are 50 ps wide. Comparing the two frames, one observes the overall timing resolution improves from 94 ps to 57 ps following the offline correction for slewing [3] and, by subtracting the mean jitter introduced by scintillators counters, we obtain 90 ps and 50 ps respectively.

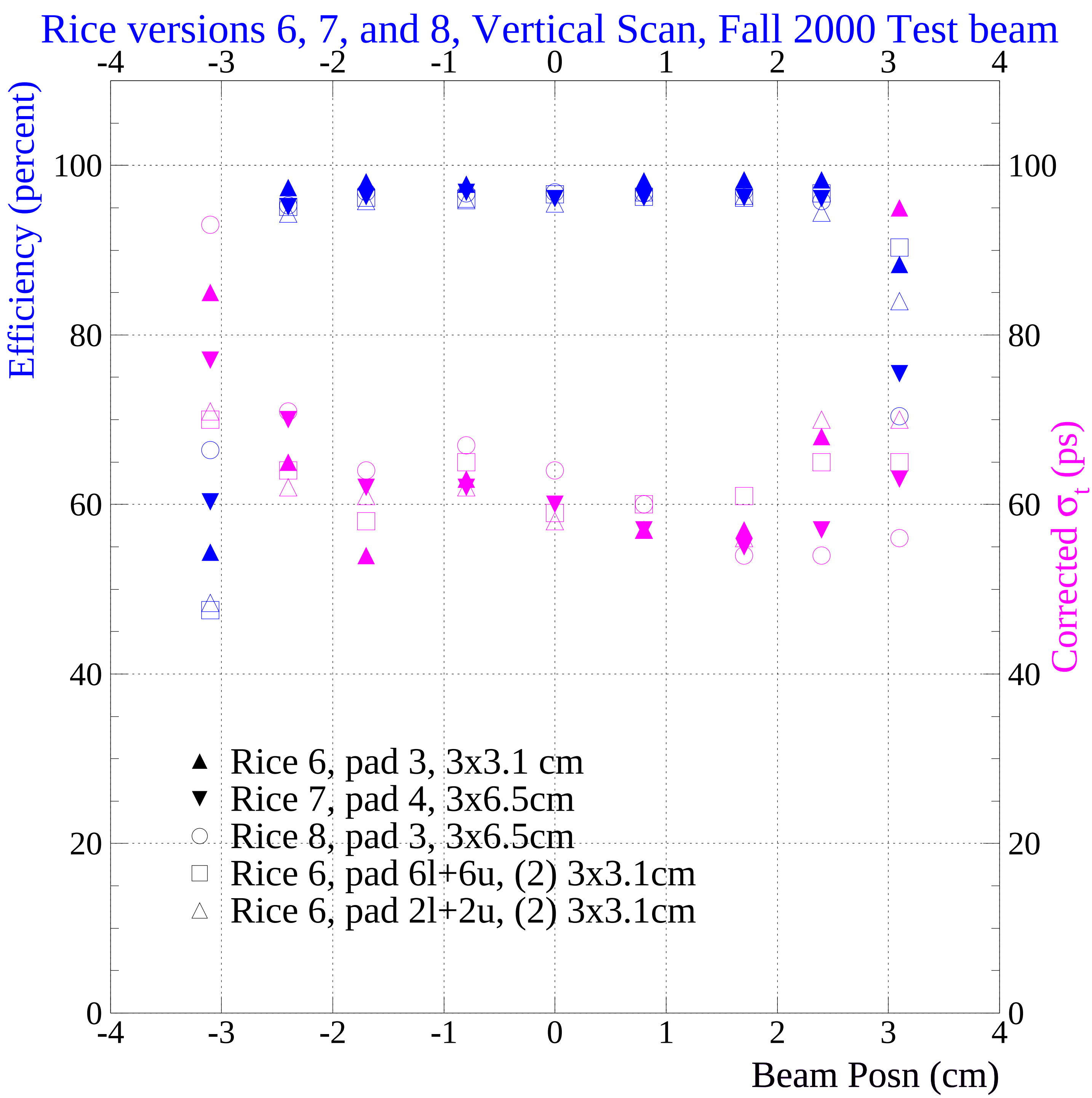
Channel-by-Channel Variations



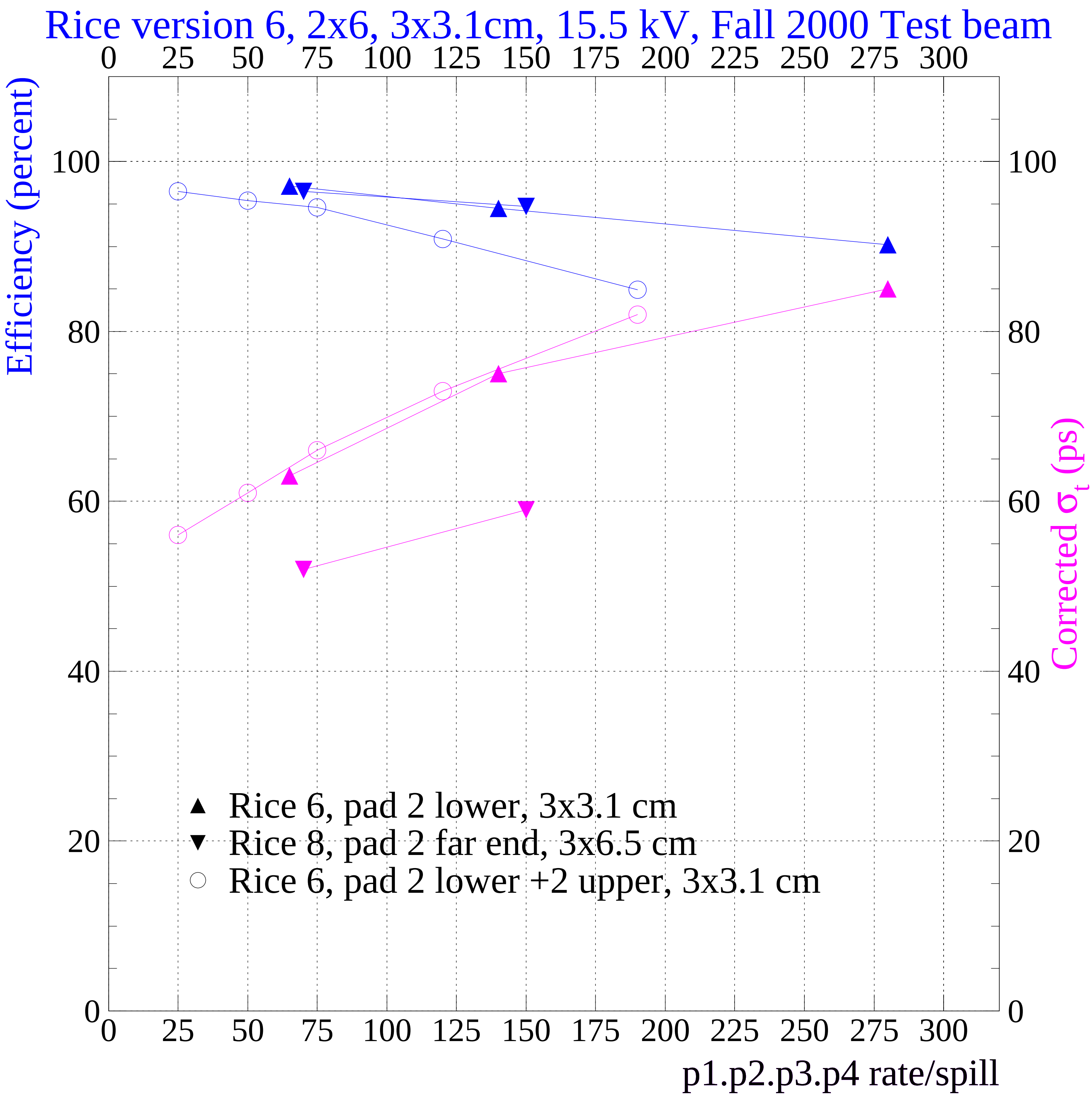


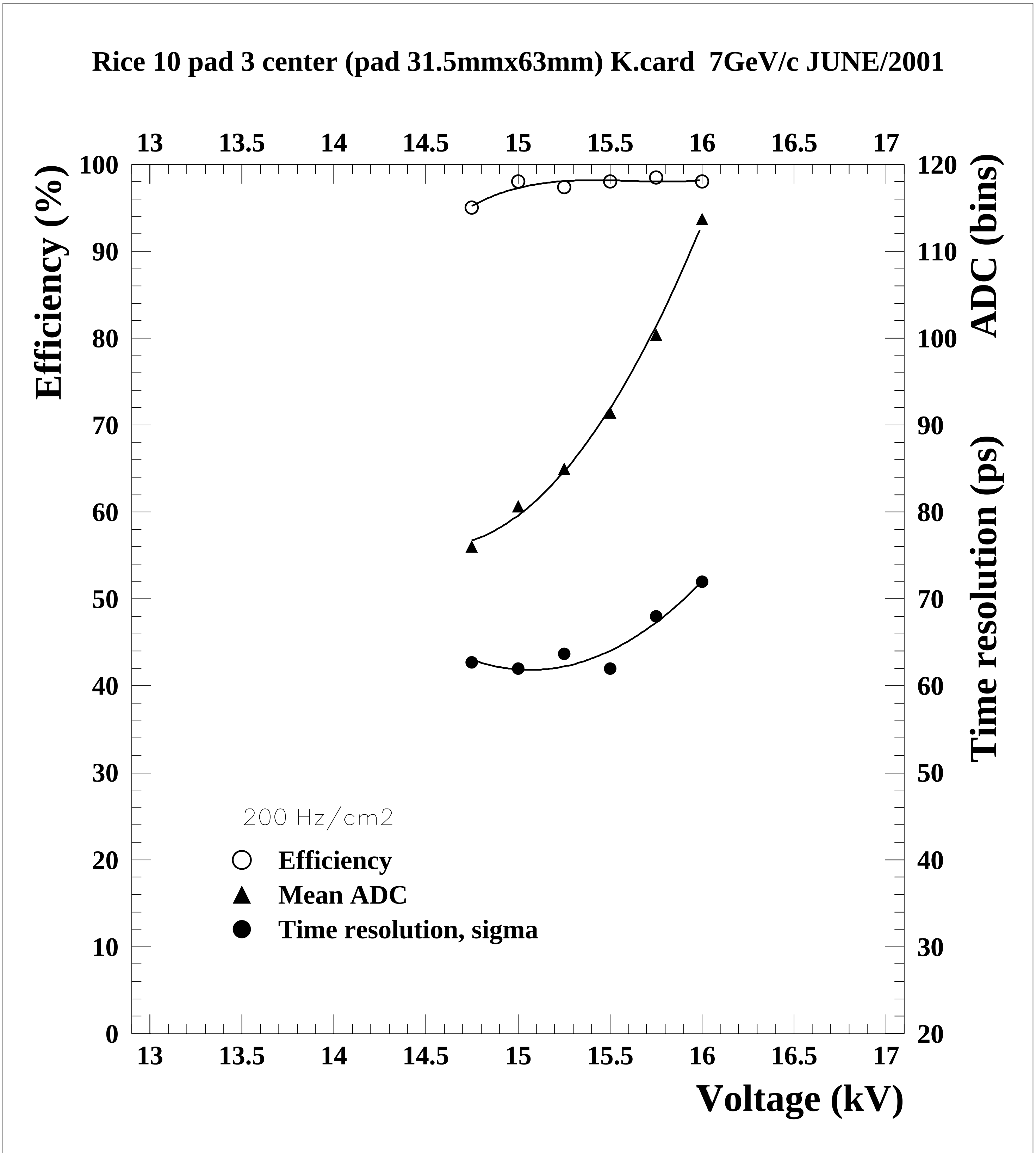


Position Dependence w.r.t. Pads



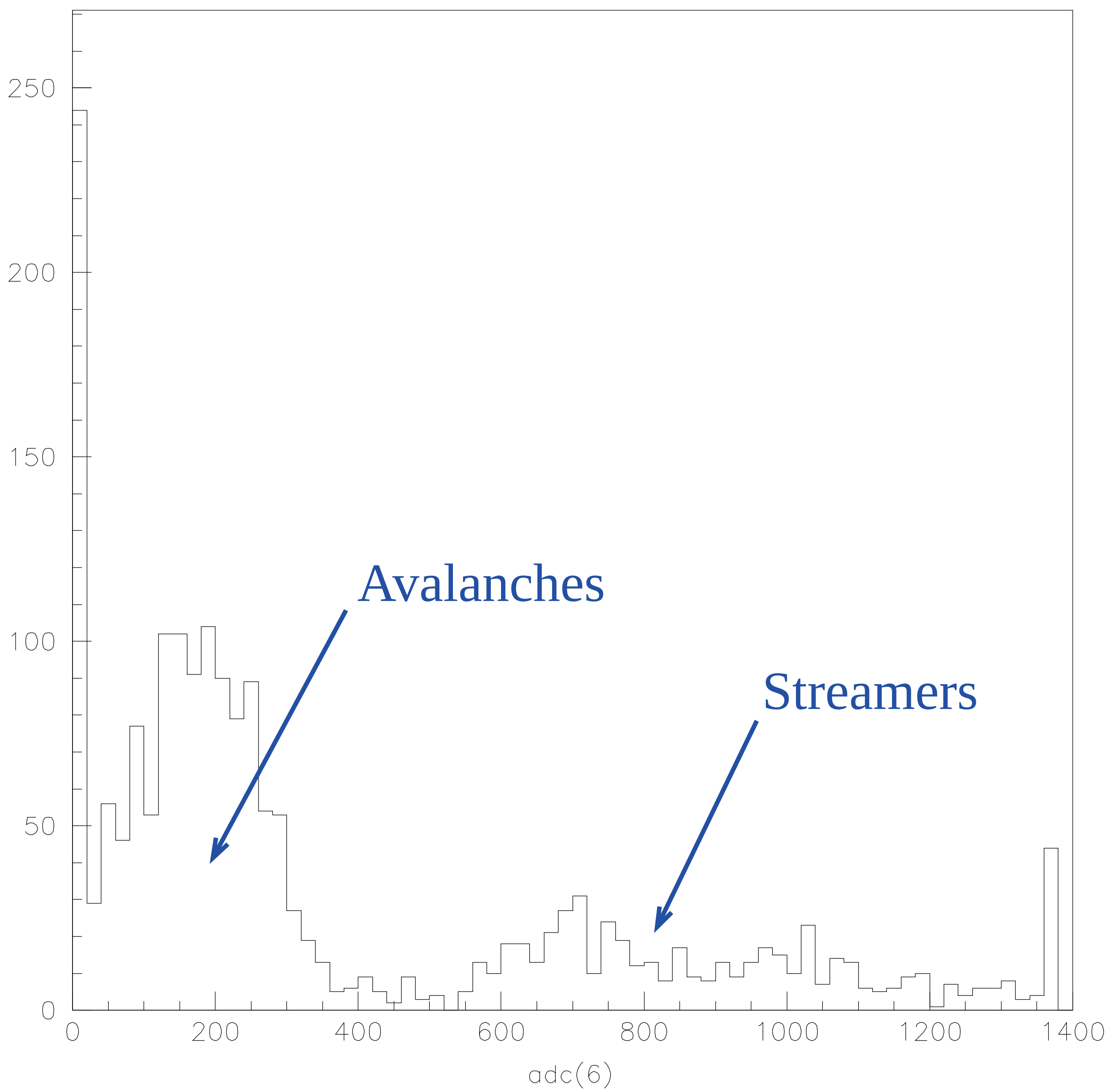
Rate Dependence




Rice 10 pad 3 center (pad 31.5mmx63mm) K.card 7GeV/c JUNE/2001
Efficiency (%)
ADC (bins)
Time resolution (ps)
Voltage (kV)
13
13.5
14
14.5
15
15.5
16
16.5
17
0
10
20
30
40
50
60
70
80
90
100
20
30
40
50
60
70
80
90
100
110
120
200 Hz/cm2
Efficiency
Mean ADC
Time resolution, sigma

Testing

- beams are best by far...
- cosmics useful for pulse area studies...
  - chamber-to-chamber comparisons...
  - chamber HV settings...
  - FEE ADC gain....
  - spotting gas problems...



TOFr FEE

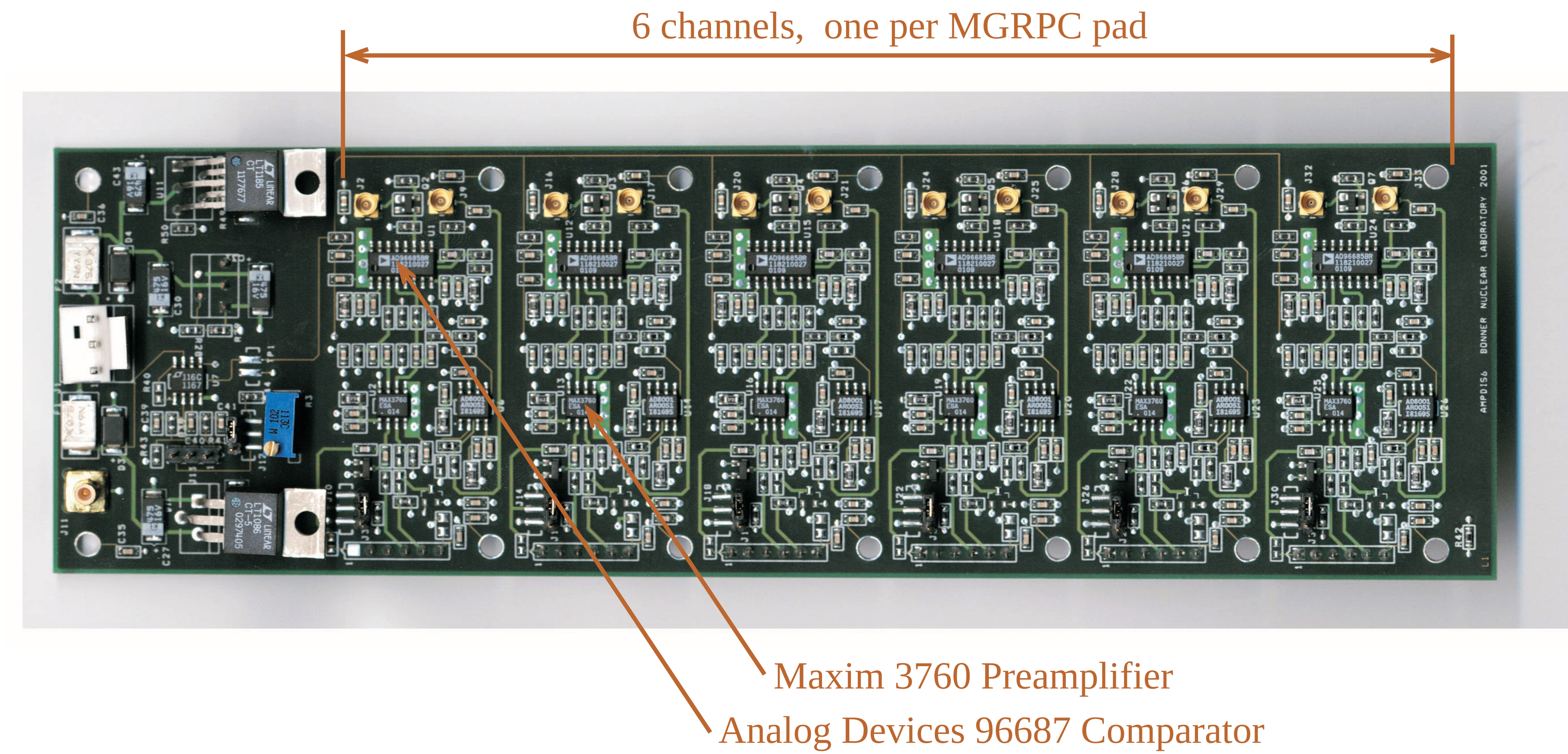
typical MIP hit in a MGRPC equivalent to ~25 fC   (not a typo)

need to amplify first

  rise time of detector practically limited only by bandwidth of this preamp

  major breakthrough for ALICE and STAR FEE development came w/ adoption of MAXIM 3760

then discriminate using standard components

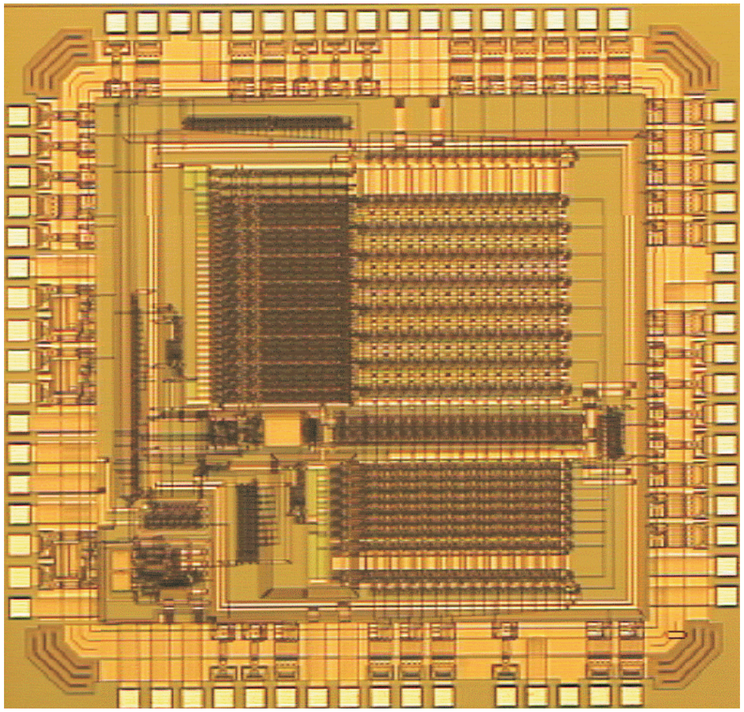


Digitization...

ADC

"easier"
existing example at Rice, 8 bits (M. Wright and H. Themann)

evaluation board for AD9058 (8 bit, 40 MSPS) in hand → would work for us...
when available, will evaluate 10 bit, 80 MSPS version from MAXIM



TDC

"harder"
presently investigating candidates....

- CERN group.... http://mota.home.cern.ch/mota/
  http://pcvlsi5.cern.ch:80/MicDig/hrtdc.htm
  http://pcvlsi5.cern.ch:80/MicDig/hptdc.htm
- Finnish group... IEEE Journal of Solid-State Circuits, **35**, 1507 (October 2000)
- German company.... http://www.acam.de/Content/gp1_e.HTM

standing request for prototypes from CERN R&D....
contacting Finnish group also...

Summary/Outlook:

The detectors are dirt cheap and appear to outperform the conventional technology...

The basic long-range plan....

Single tray of MGRPC for STAR, "TOFr," now under construction → *realistic* proof of principle...
Long cables & digitization by existing STAR TOFp System...

Proposal for large-area system, "TOFR," in Spring 2002...

Installation of TOFR in the 2004 shutdown...

Recent Major Successes

- Fishing line is a *great* choice for the 220 μm spacer...
- Maxim 3760 preamp...
- Collaboration of US and CN institutions developed. CN groups making solid progress....
- Detector module design (Rice v.11) is now final... <60ps stop-resolution is typical...
  Chamber construction for TOFr now underway at CERN and CN...
- 40 FEE boards for TOFr constructed and look very good on the bench....

Hurdles Still Ahead of Us

- Solving the problems uncovered during the TOFr project...
- ADC & TDC Digitization for the large-area system must be "on-board"...
  TDC chip w/ required specs does not exist, although CERN efforts look promising...
  We have standing request for these when they become available...
- Marriage of preamp+comparator w/ the digitization on one board...
  Facing the age-old nightmare of analog and digital electronics on the same board...
  ~6 EE-year engineering effort...
- Locating funding for these electronics R&D... (~500+ k$?) spinoff applications exist...
- Locating funding for the large-area system itself.... (~5M$? = 4M DOE + 1M CN-contributed)