
# STAR Time Of Flight

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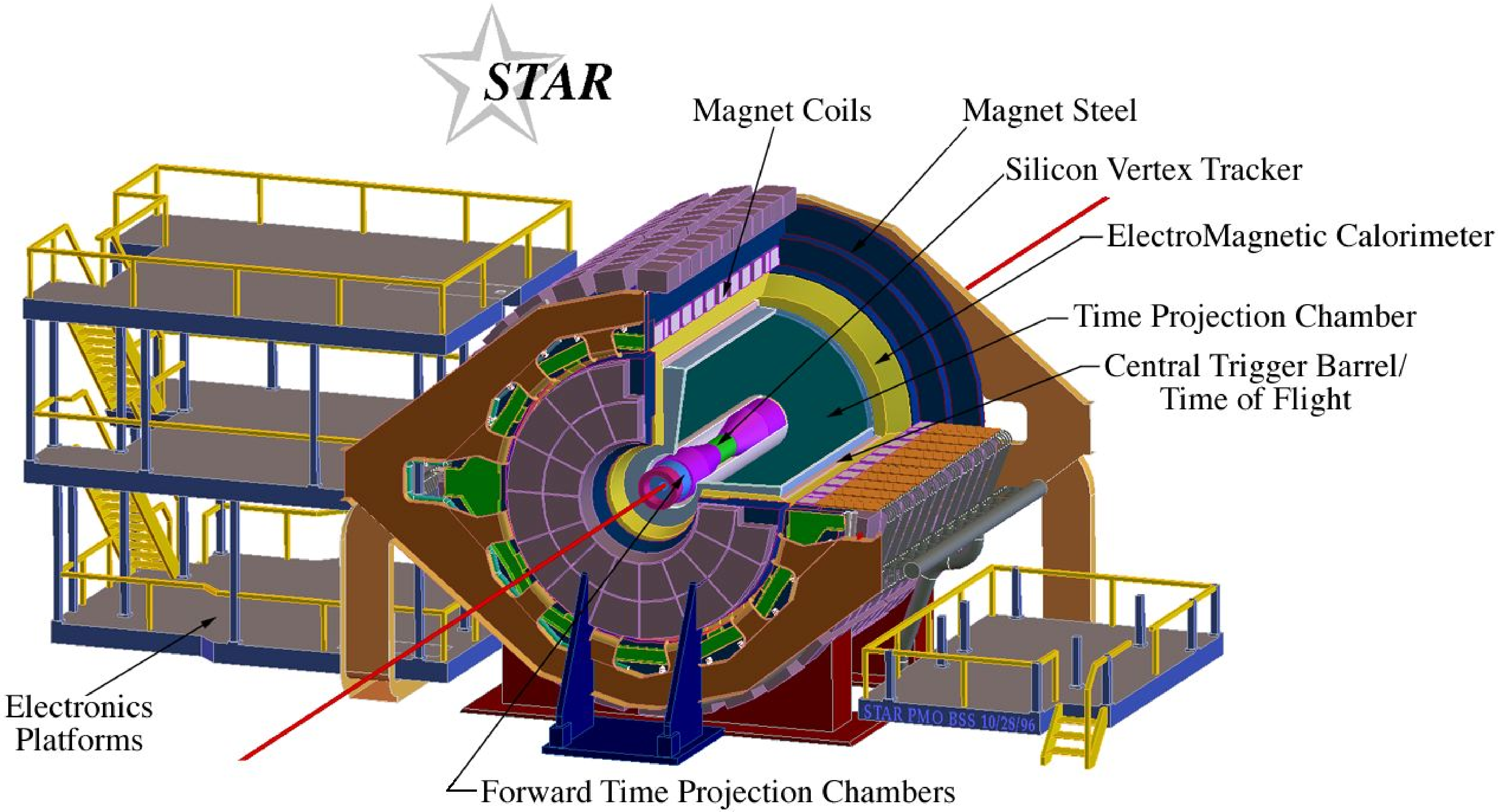
**OUTLINE:**

- Technique...
- A few physics benefits...
- Technology...
- STAR Prototypes...
- The large-area system...
- New start detector...
- Run-8 performance...
- Summary...




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

electrons "cut through" the low-momentum charged hadrons...

Roughly **half** of the charged hadrons in any given event thus cannot be directly identified...

(and this "PID-blindness" is in the harder halves of the spectra)

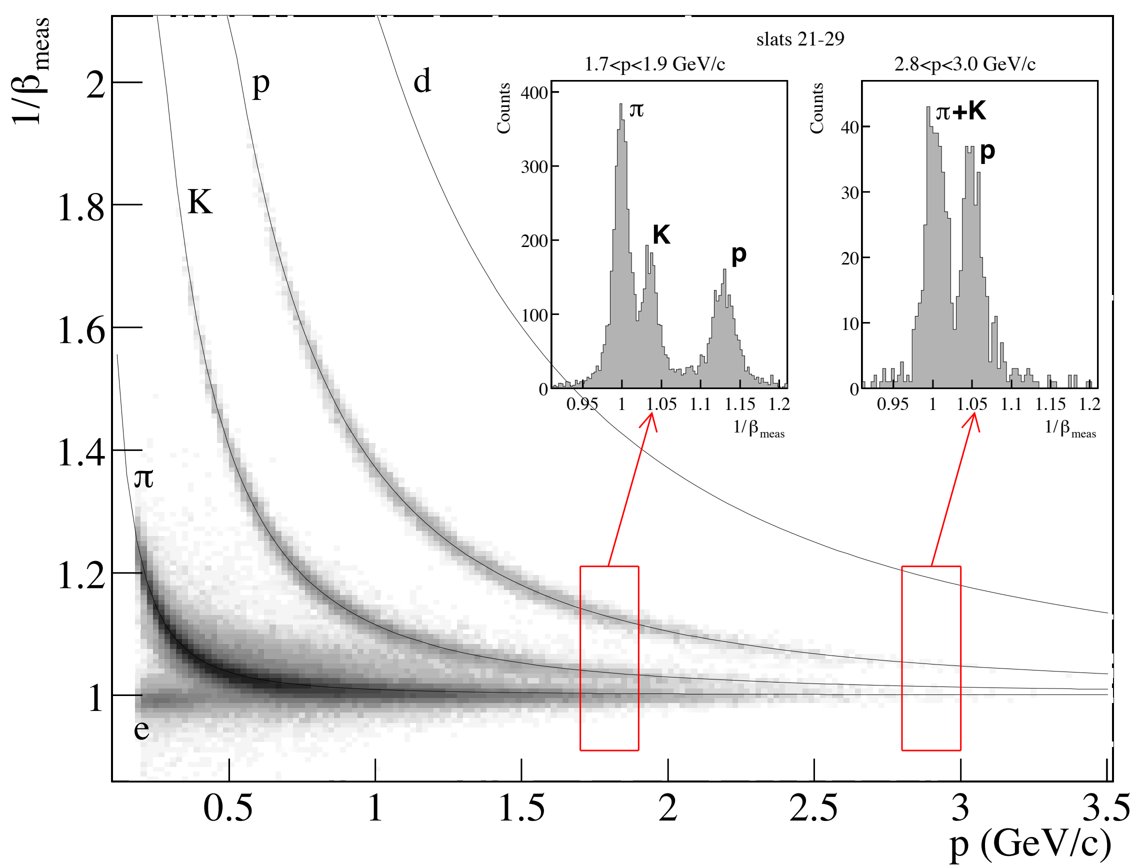
**STAR with a Time Of Flight (TOF) completely surrounding its TPC....**

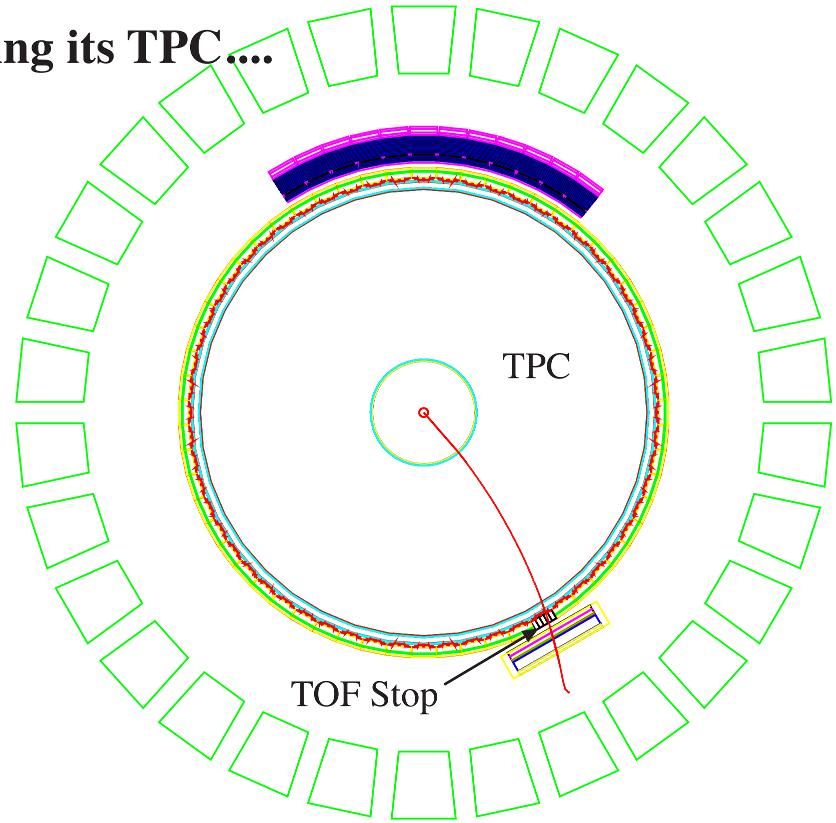
p from TPC tracking
s from TPC tracking, & STAR geometry

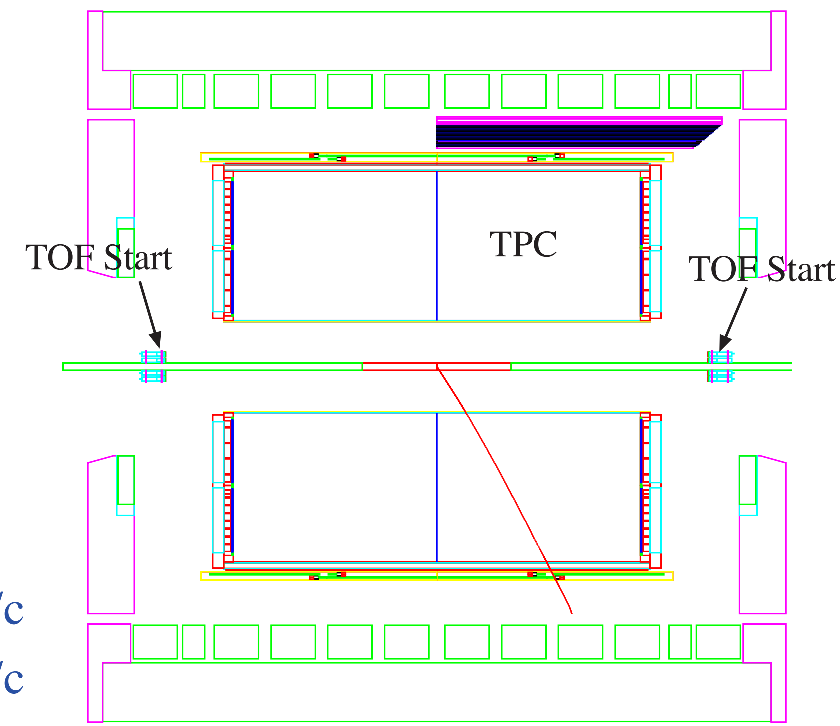
$\Delta t = t_{stop} - t_{start}$ from TOF

$s = \beta c \Delta t$ and $\gamma = 1/\sqrt{(1-\beta^2)}$

$\rightarrow m = p/\gamma\beta c$ $\rightarrow$ Particle Identification



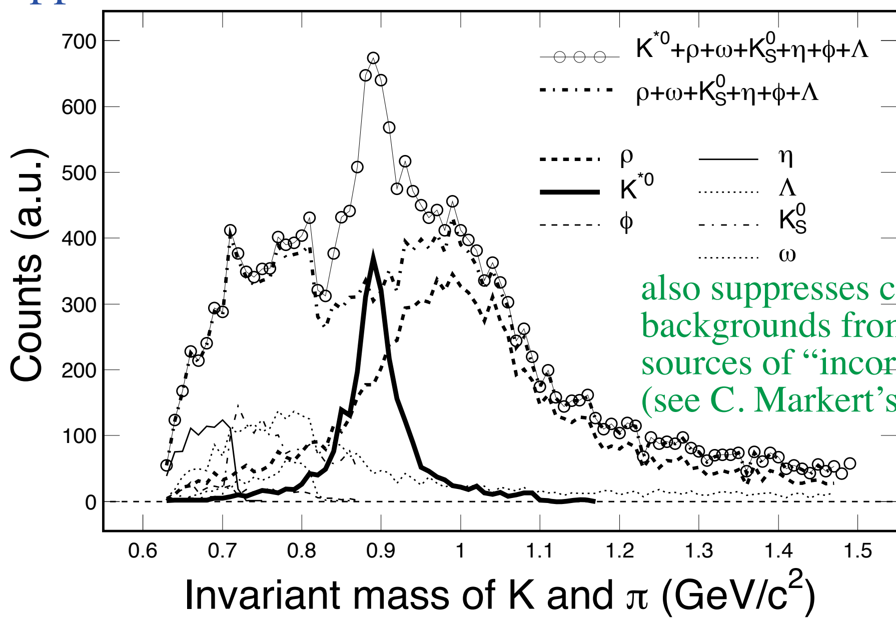




Then, with the TPC tracking & a $\Delta t$ = 100ps TOF system:

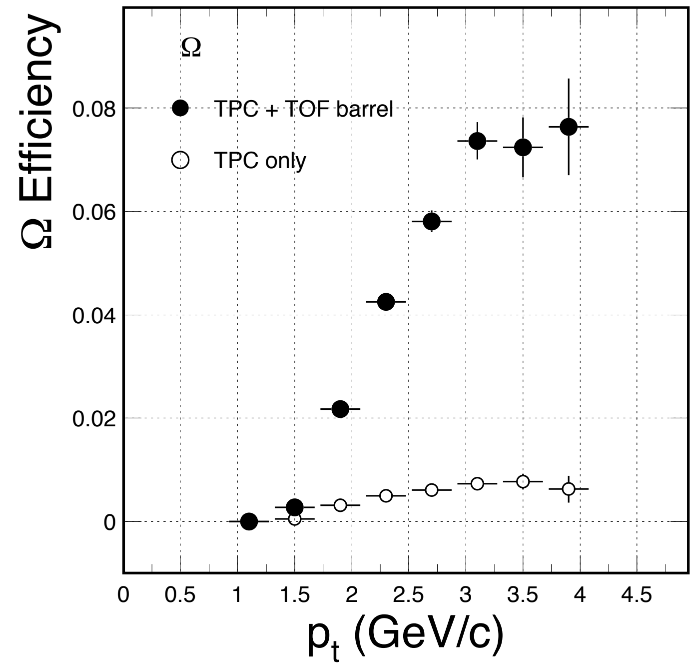
- π/K/p direct PID: ~0.3 GeV/c < p < 1.7-1.9 GeV/c
- (π+K)/p direct PID: ~0.3 GeV/c < p < 2.8-3.0 GeV/c

## Suppress Misidentification...




also suppresses combinatorial backgrounds from all other sources of "incorrect" particles... (see C. Markert's talk)

## Rare particles in single running periods



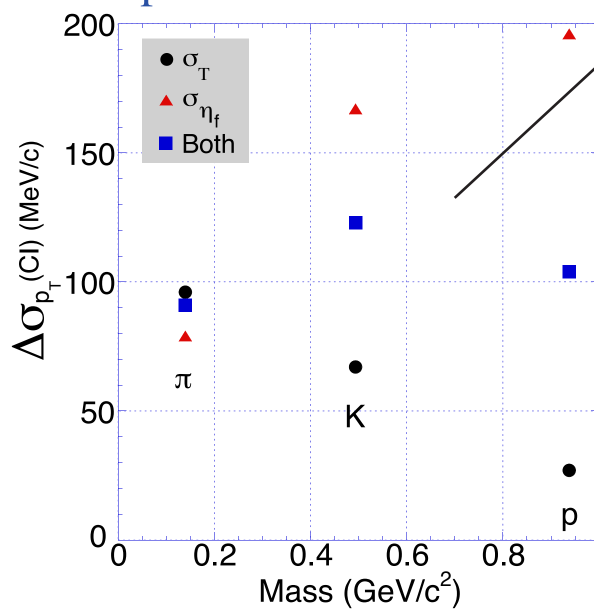

| Resonance | Parent PT(GeV/c) | TPC+TOF |
|---|---|---|
| K*0 | 0-1 | 2.0 |
| K*0 | 1-2 | 1.85 |
| K*0 | 2-3 | 1.74 |
| K*0 | 3-5 | 1.39 |
| φ(1020) | 0-2 | 5.0 |
| φ(1020) | 2-5 | 3.42 |
| Λ(1520) | 0-1.6 | 11.4 |

decrease sample sizes required to reach same level of S/B w/out TOF

**$D^0$ Sensitivity in $p_T$**

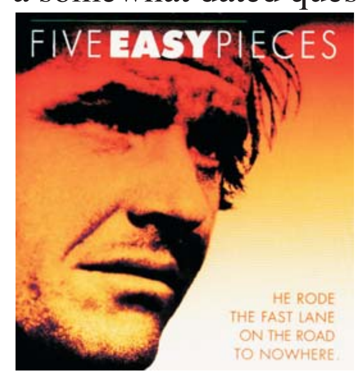
| | Without TOF | With TOF |
|---|---|---|
| All $p_T$ | 12M | 2.6M |
| $p_T$>2. | 59M | 23M |
| 2>$p_T$>4. | 85M | 42M |
| 4>$p_T$>6. | 115M | 115M |

## <pT> Correlations...




Is <Pt> variance excess from temperature fluctuations? particle species fluctuations?

...now a somewhat dated question

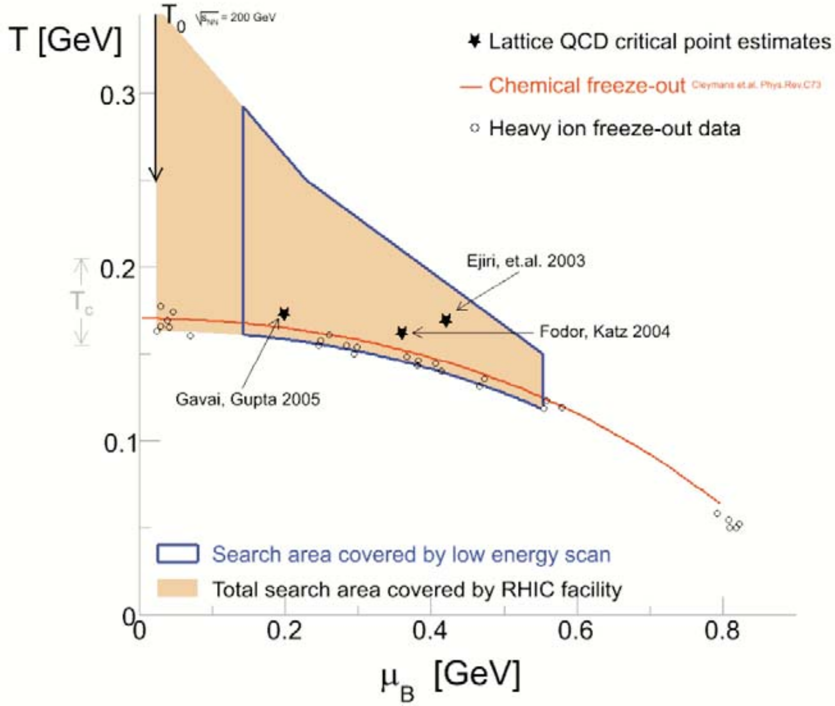


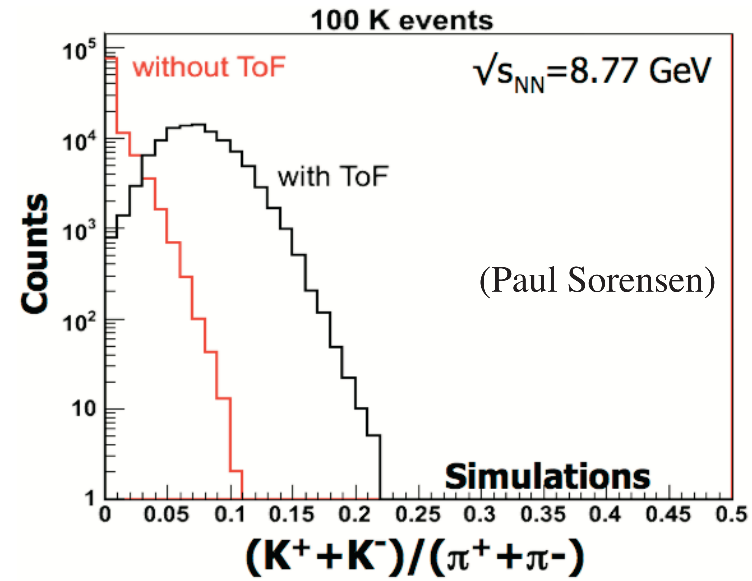

The "Ridge" w/ full PID...

Modification of local quantum number conservation due to presence of dense medium...

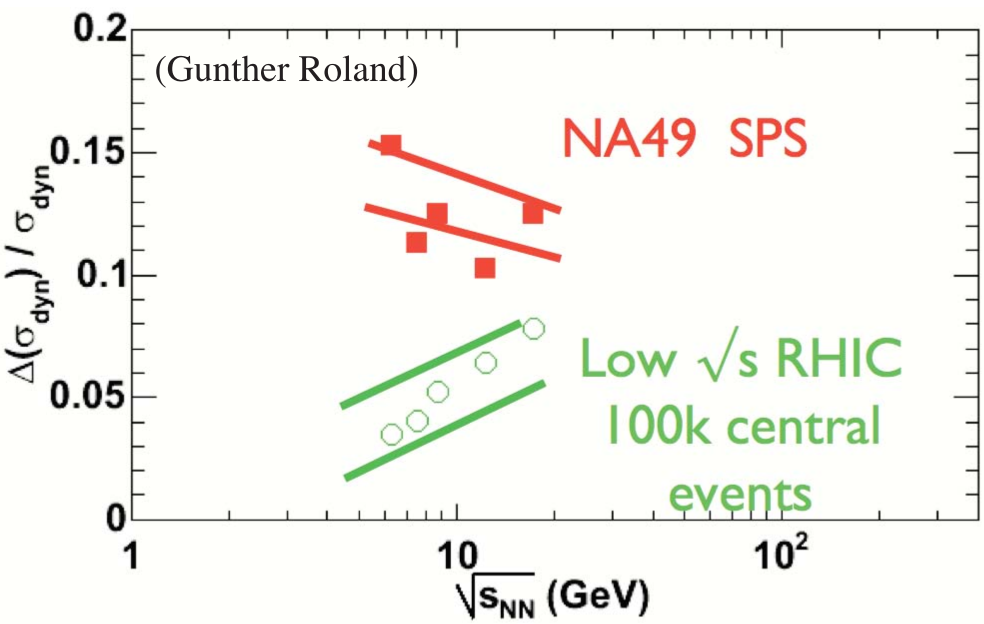
# Critical Point Search (Run-10)

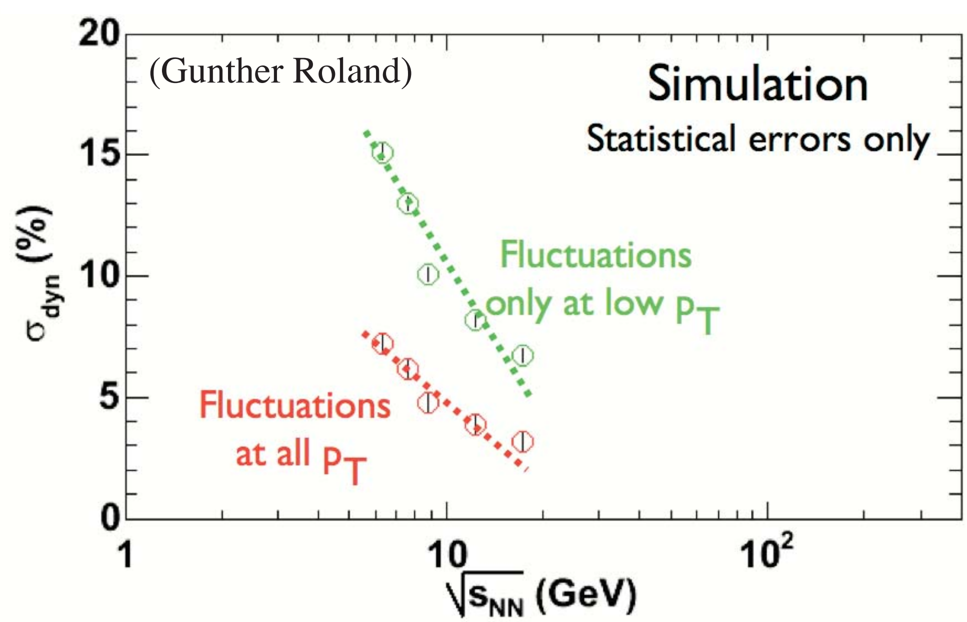
concentrating here in the **K+/π+ "Horn"** seen at AGS/SPS energies
also of interest: v1 & v2, v2 fluctuations, <pT> fluctuations




0.5% mis-identification suppresses width by 5%
"signal" is of order ~4%

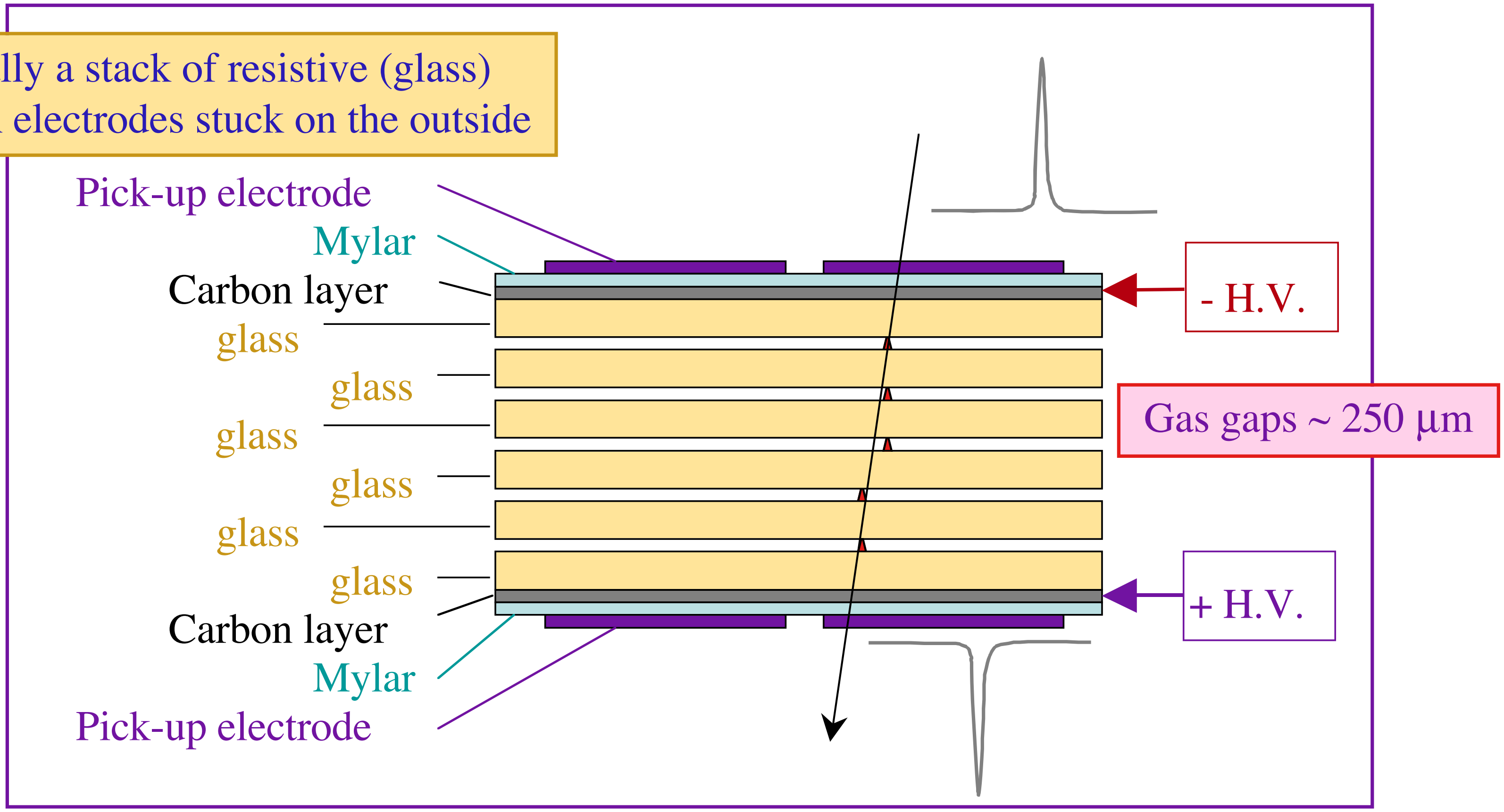



These assume the (2) benefits of a collider environment but also a nearly complete direct PID

# 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...

# Why does it work?

E. Cerron Zeballos, I. Crotty,
D. Hatzifotiadou, J. Lamas Valverde,
S. Neupane, M.C.S. Williams,
and A. Zhichichi, NIM A **374**, 132 (1996)

E. Cerron Zeballos, I. Crotty,
D. Hatzifotiadou, J. Lamas Valverde,
R.J. Veenhof, M.C.S. Williams,
and A. Zhichichi, NIM A **381**, 569 (1996)

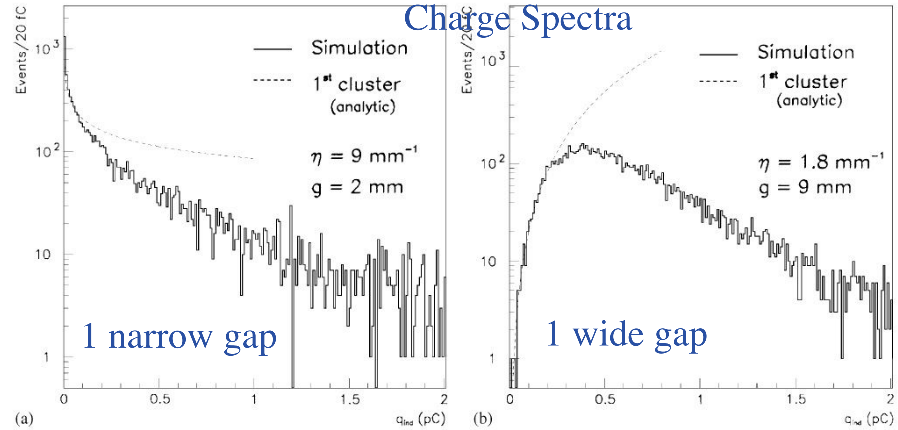



Fig. 1. Comparison between the simulated charge spectra for single (a) narrow ($g = 2$ mm) and (b) wide ($g = 9$ mm) gap RPCs.

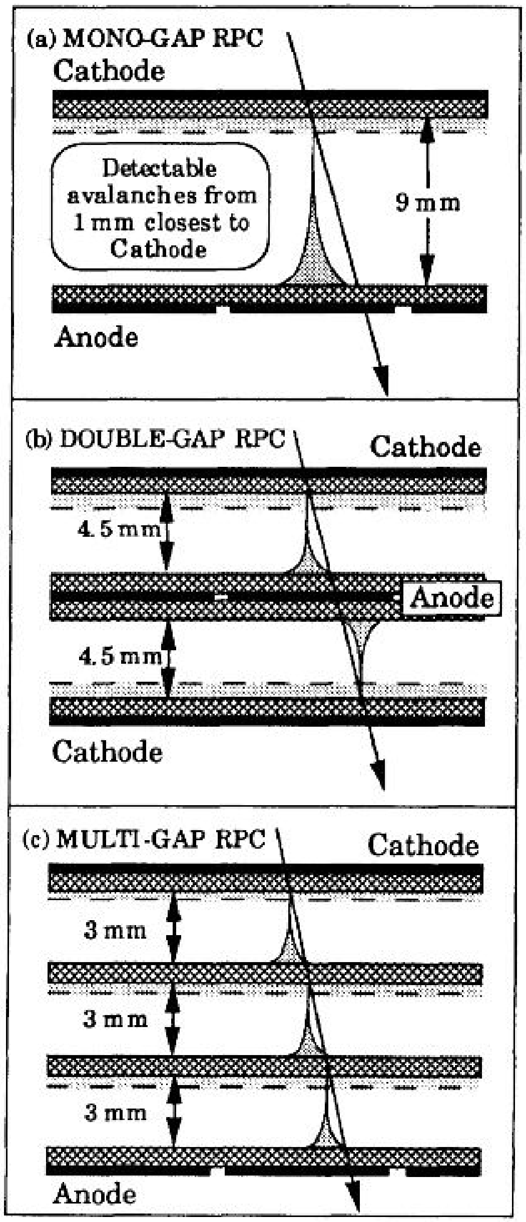



Figure 2. Schematic representation of a monogap RPC (top); a double gap RPC (middle) and a multigap RPC (bottom).

narrow single gaps don't work well in avalanche mode

wider single gaps?

enhanced streamer-free range of operating voltage, & bigger signals...

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...

Interplay between Townsend Coefficient
and room available for avalanches to grow
results in very weak dependence on gap width
(easy to build the detectors!)

M.C.S. Williams, NIM A **525**, 168 (2005)

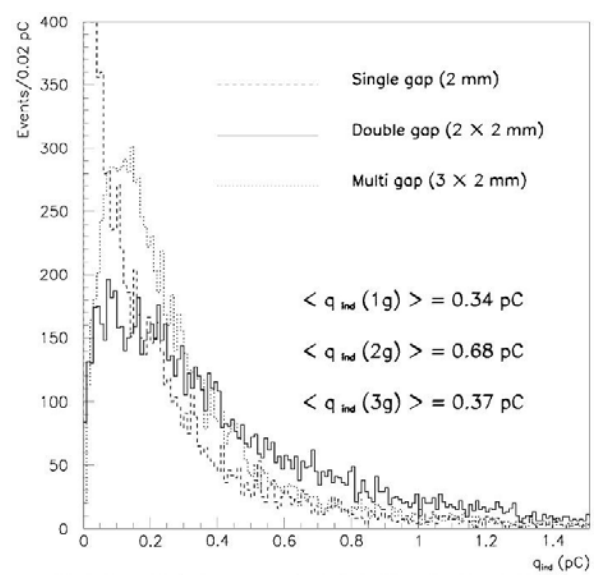



Fig. 3. Monte Carlo charge spectra for single- double- and multi-gap RPCs.

**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.

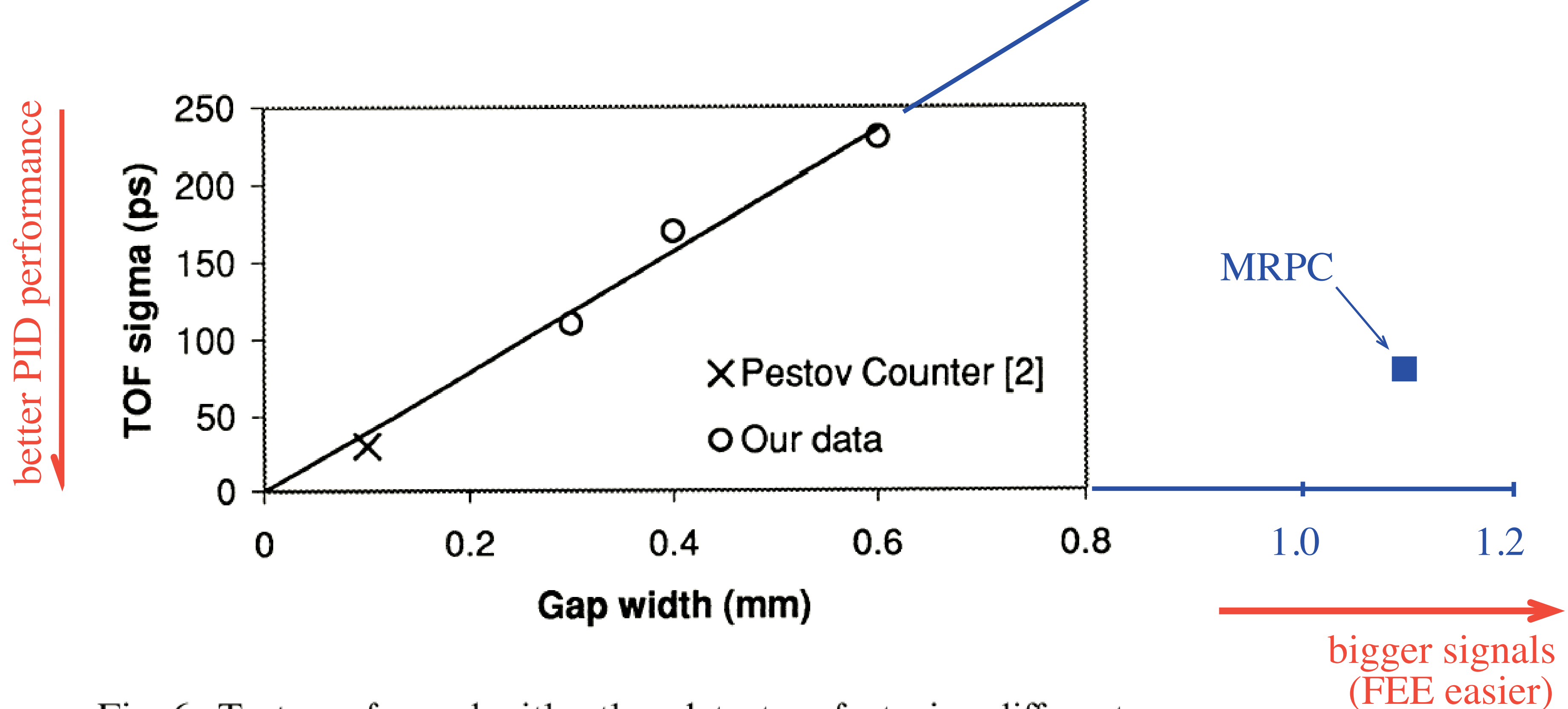



Fig. 6. Tests performed with other detectors featuring different widths of the gas gap suggest that the main contribution to the time jitter is associated to the amplification process in the gas. The timing resolution seems to depend almost linearly on the gap width, with a slope of approximately 40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

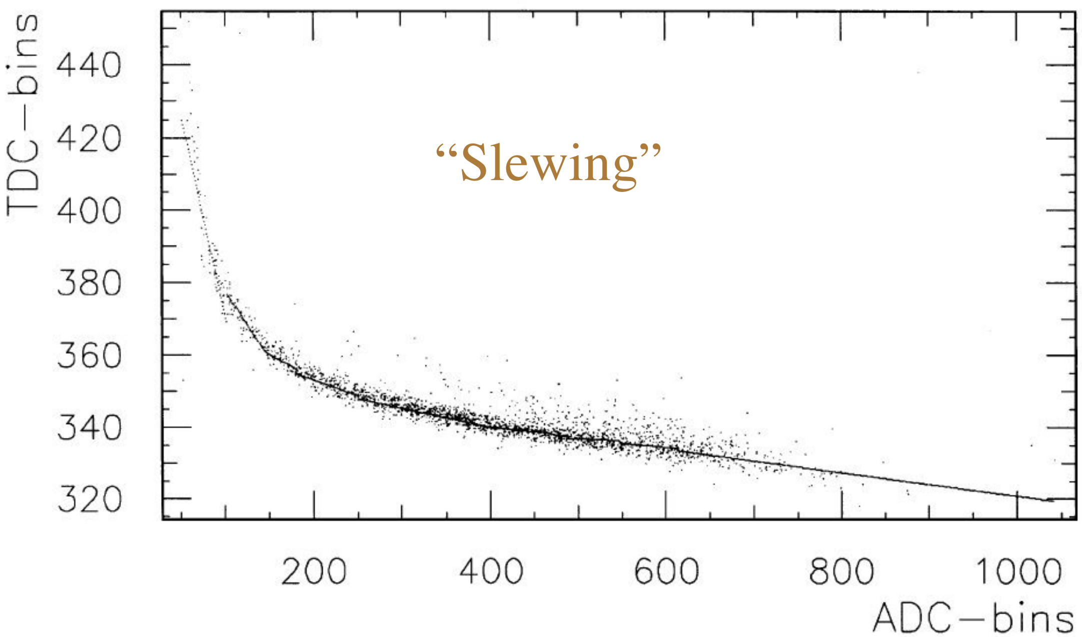



Fig. 4. Correlation of raw time difference between MRPC detector and reference counter and MRPC signal amplitude.

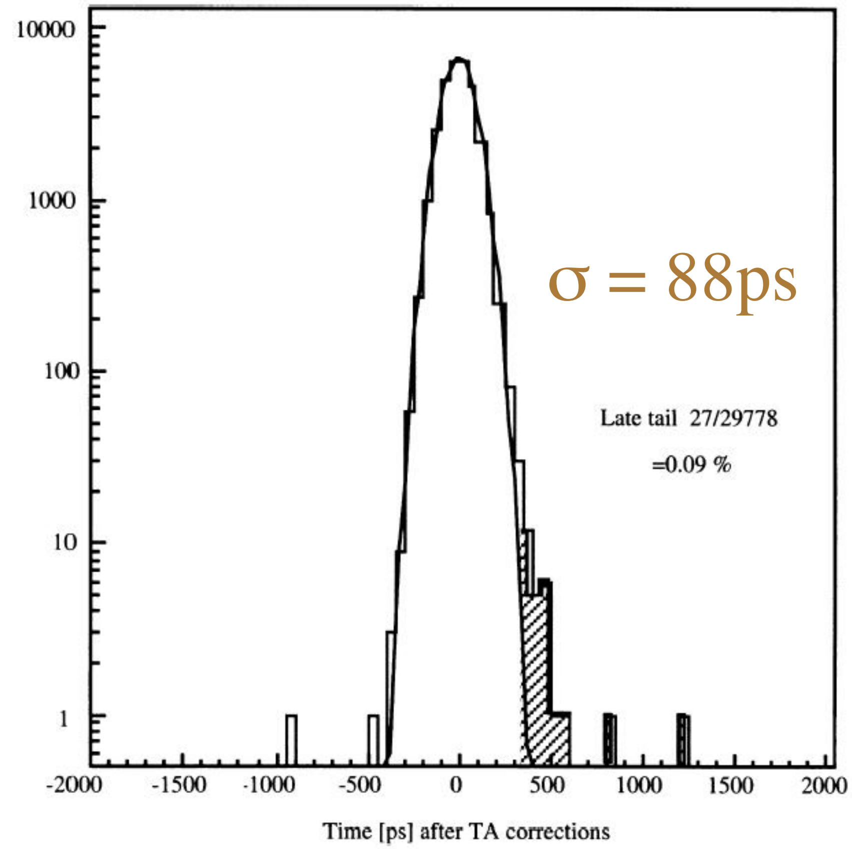
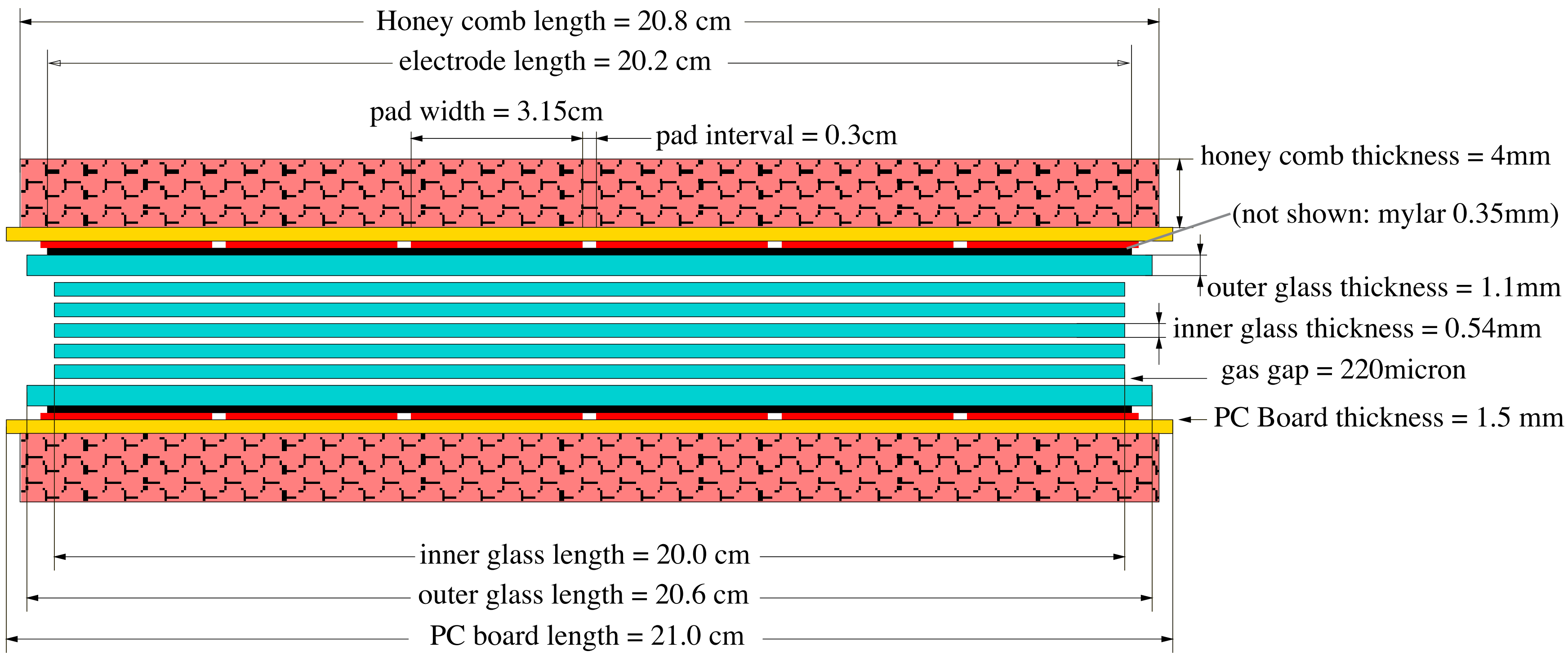
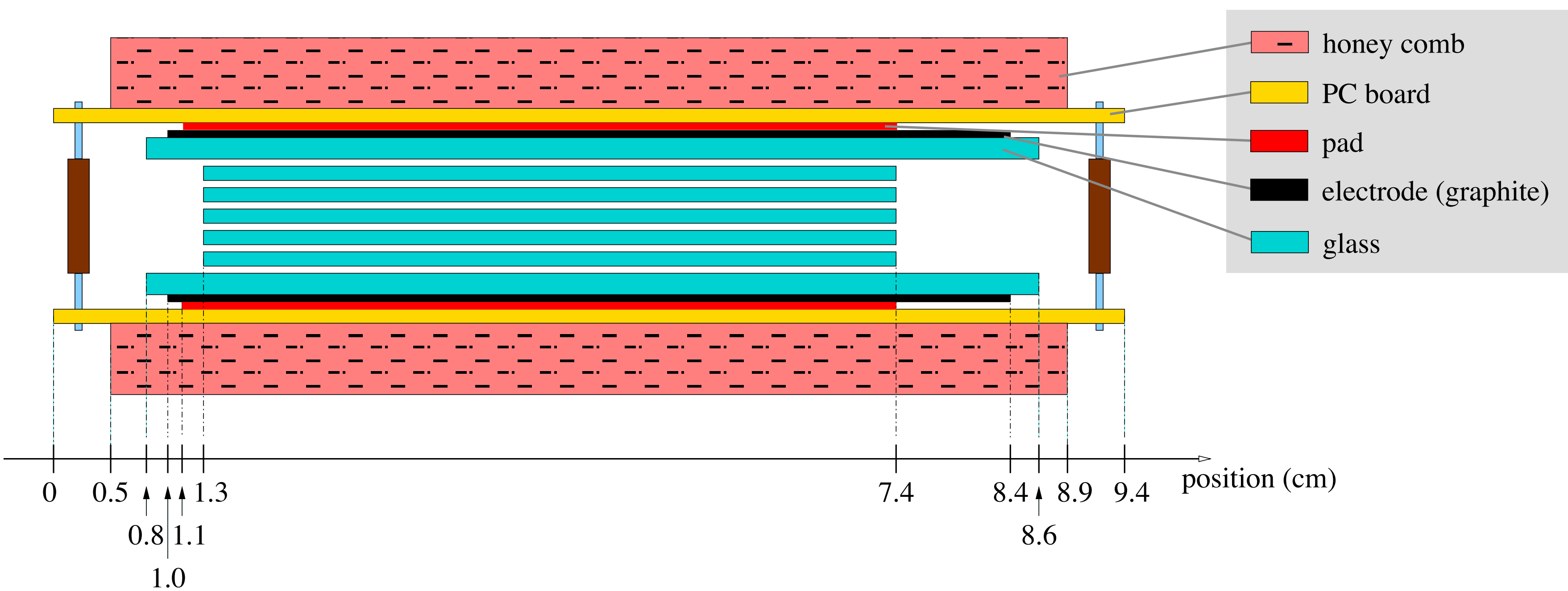



Fig. 5. Time distribution measured with an MRPC with five gaps of 220 μm operated at 12 kV (109 kV/cm). The width of the Gaussian fit is $\sigma = 88$ ps.

# STAR's Variant...

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

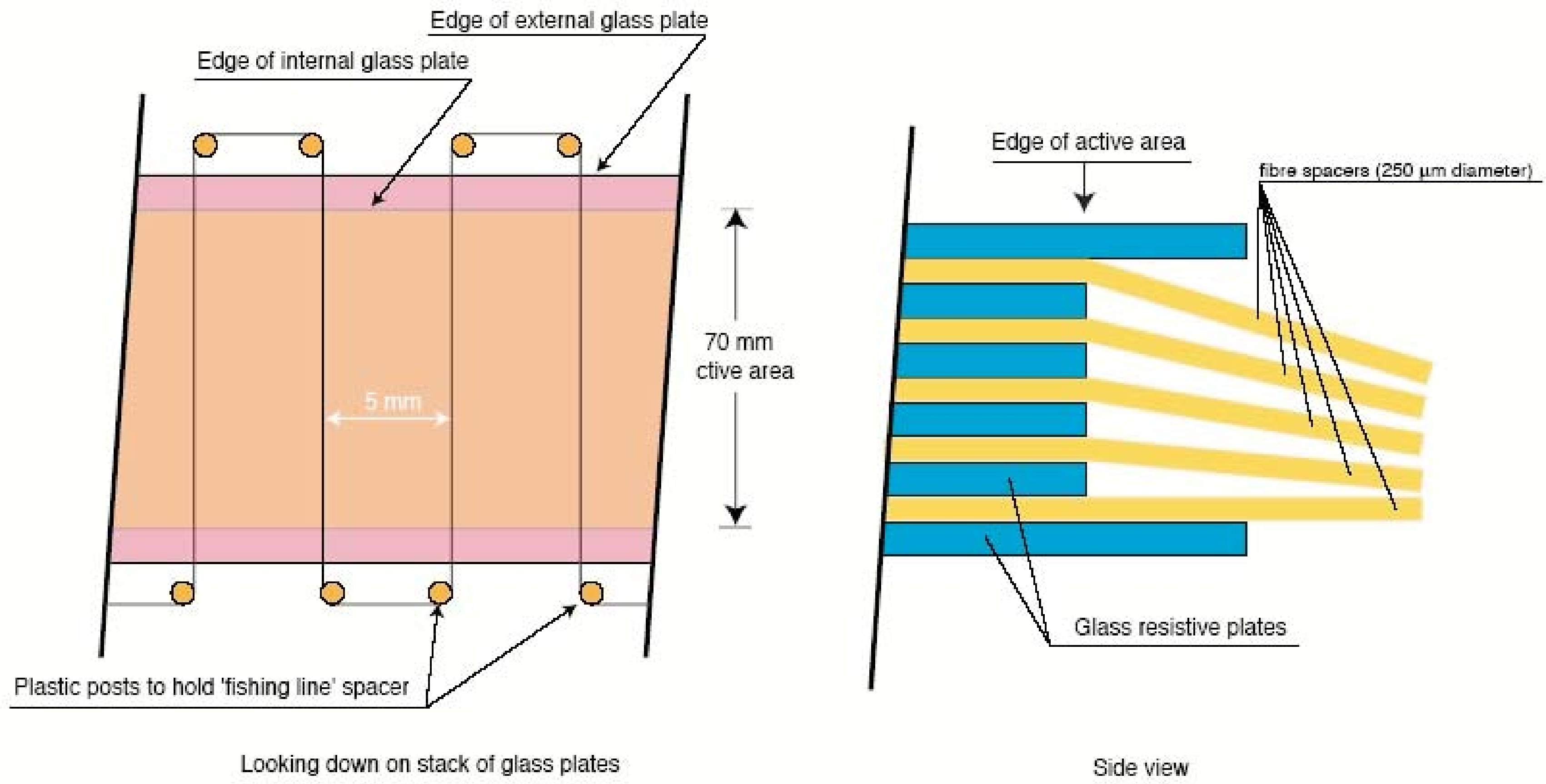


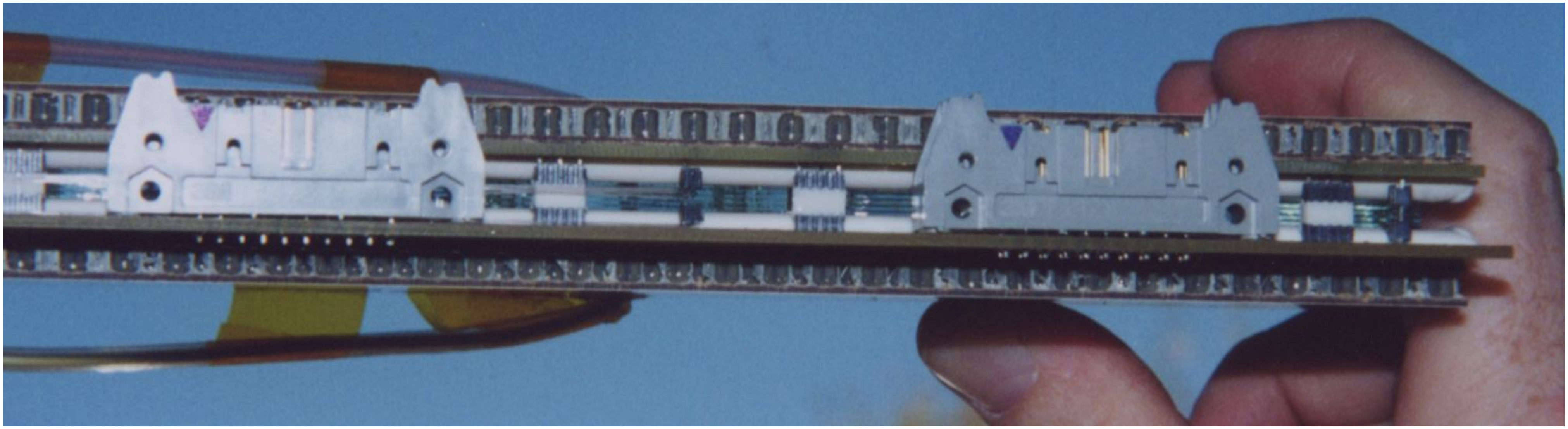



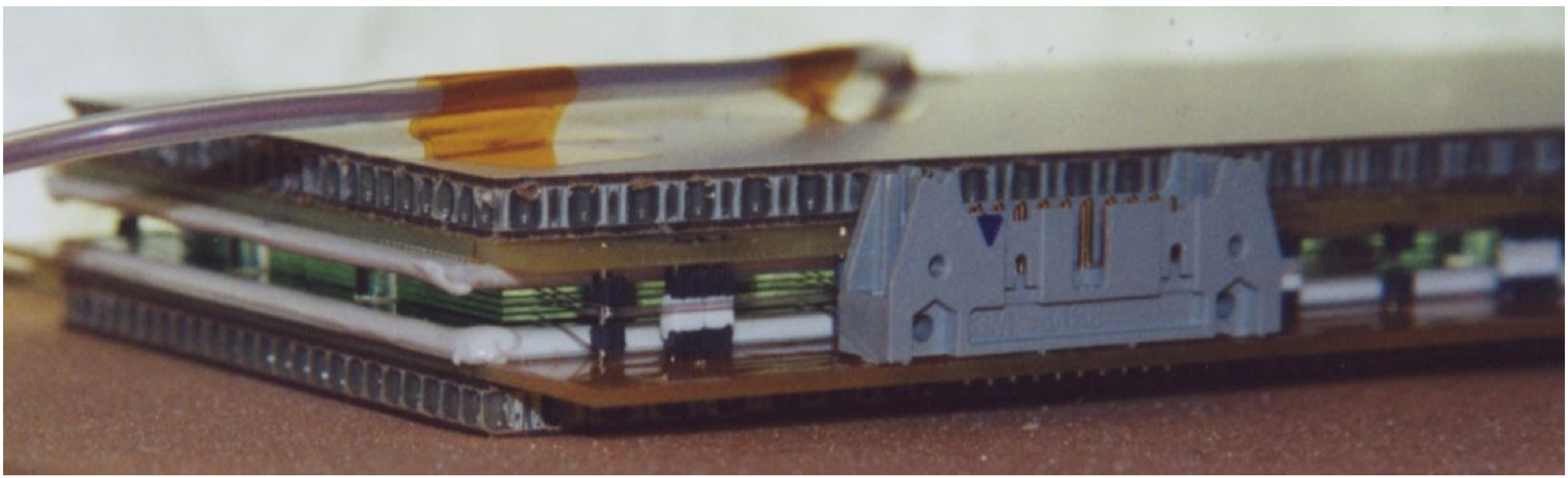
Spacing of inner glass plates is set by *monofilament fishing line*... (ALICE, HARP, & STAR)

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

Glass plates are just common float glass...





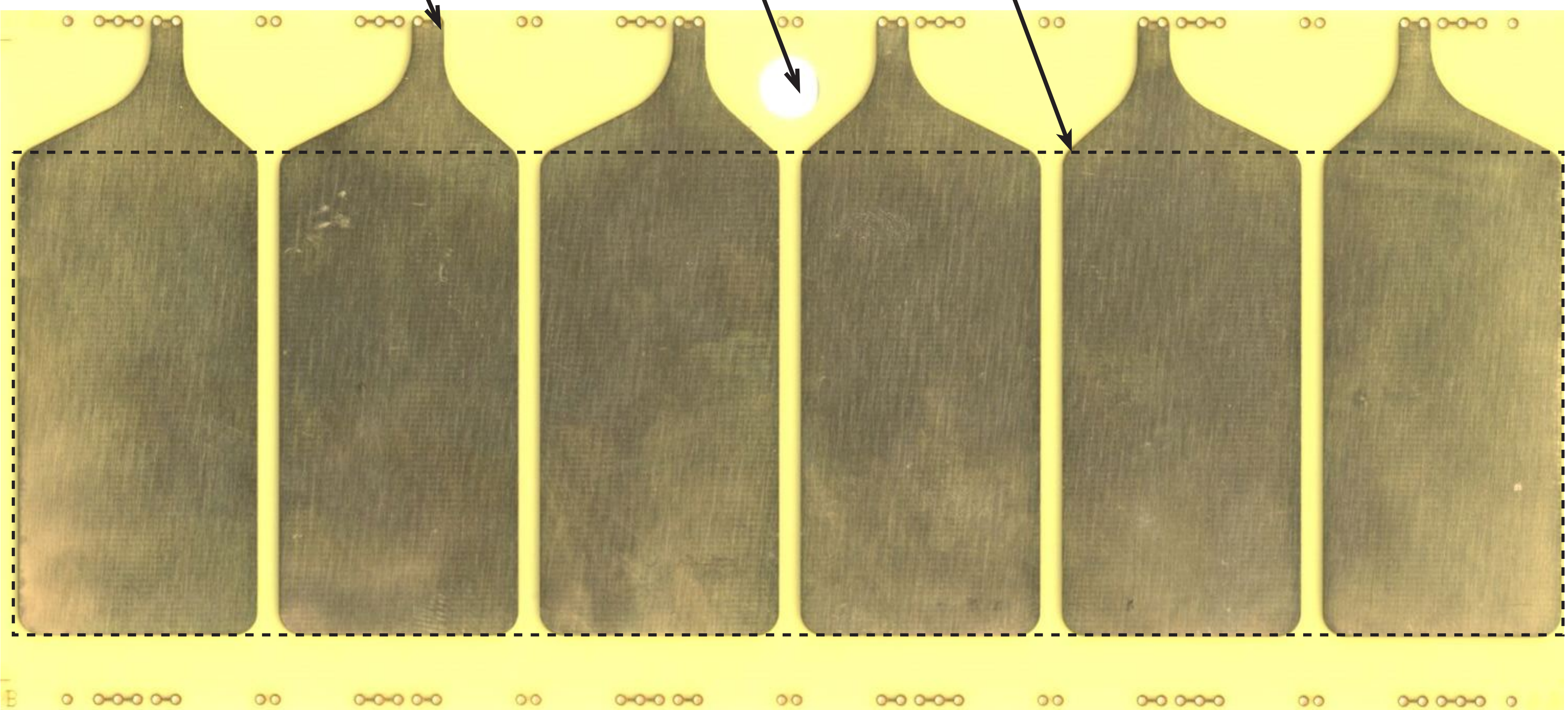


## Readout Pads

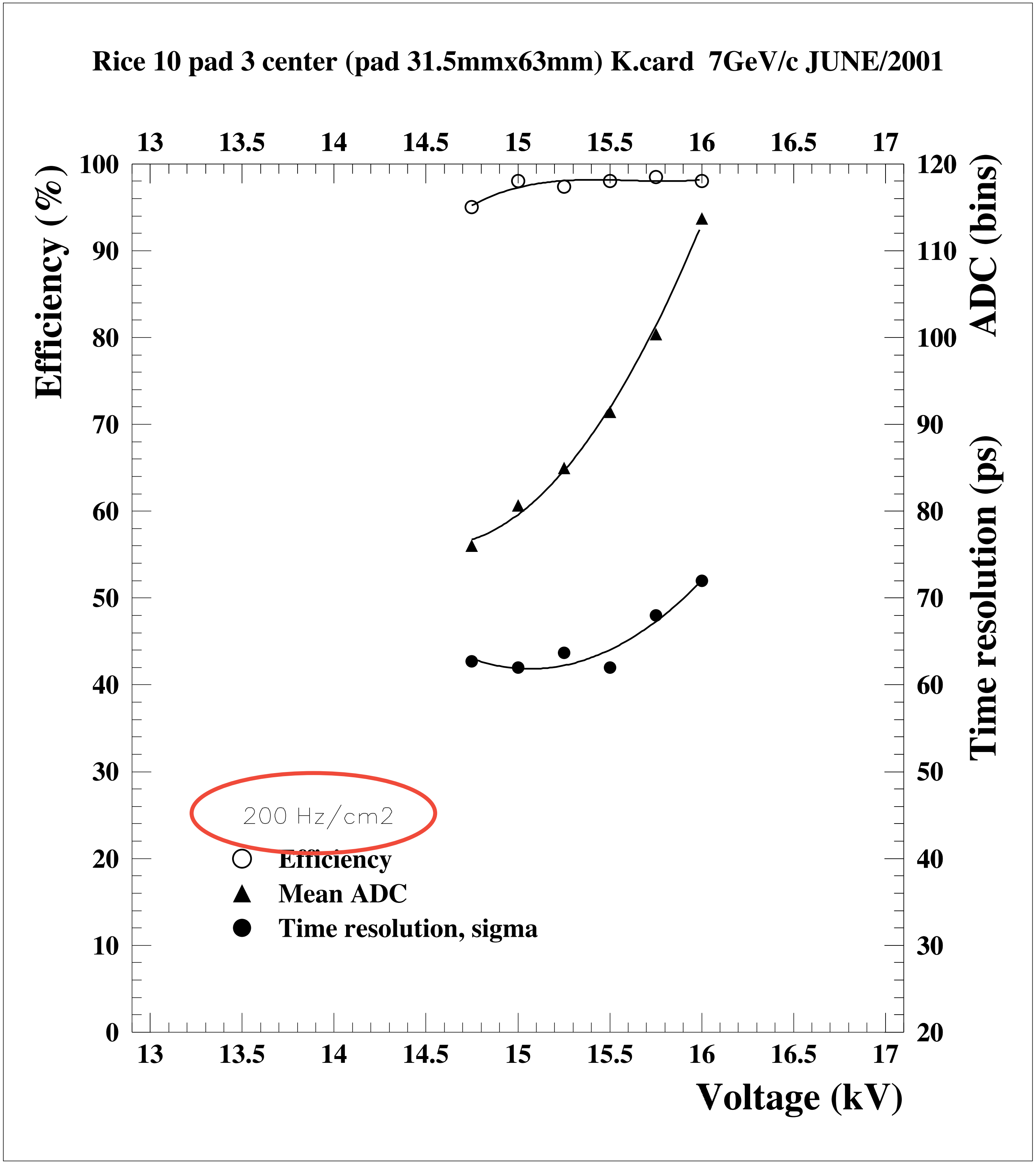
region of pads above thin glass indicated by dashed box

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 $2\pi$

with ~30 MRPCs

## STAR full-sized prototypes (2002-2005)

optimize the mechanical design, simplify fabrication, improve tolerances
develop and optimize the electronics

TOFr (Run-3)

Box built by hand
Gaskets + wrong sealant
Two layers of electronics
- long cables
- CAMAC DAQ

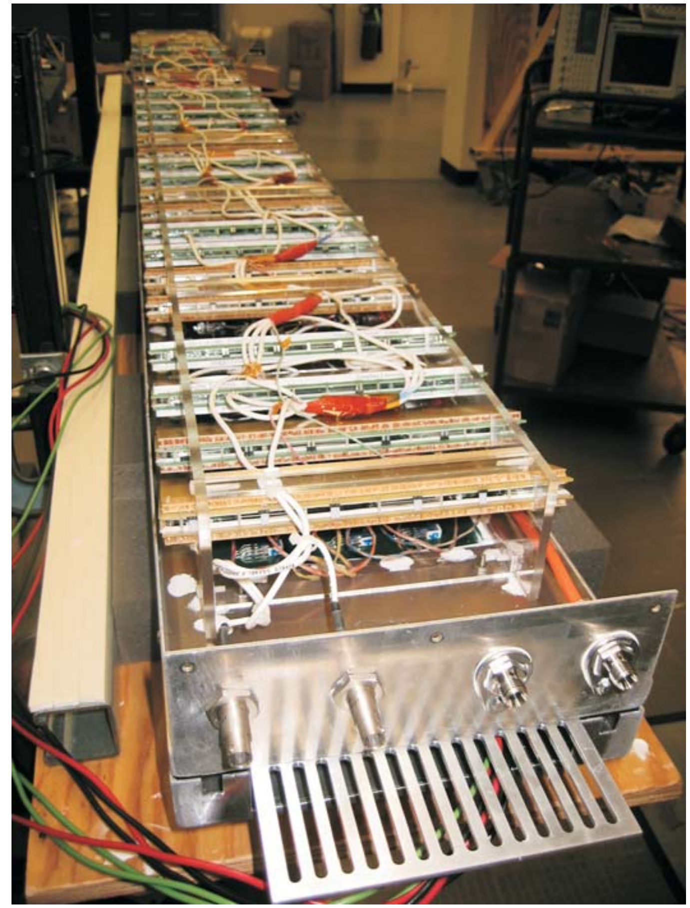
Imprecise MRPC positioning

TOFr' (Run-4)

"Shoebox" built out-of-house
Correct sealant
One layer of electronics
- long cables
- CAMAC DAQ

Imprecise MRPC positioning

TOFr5 (Run-5)

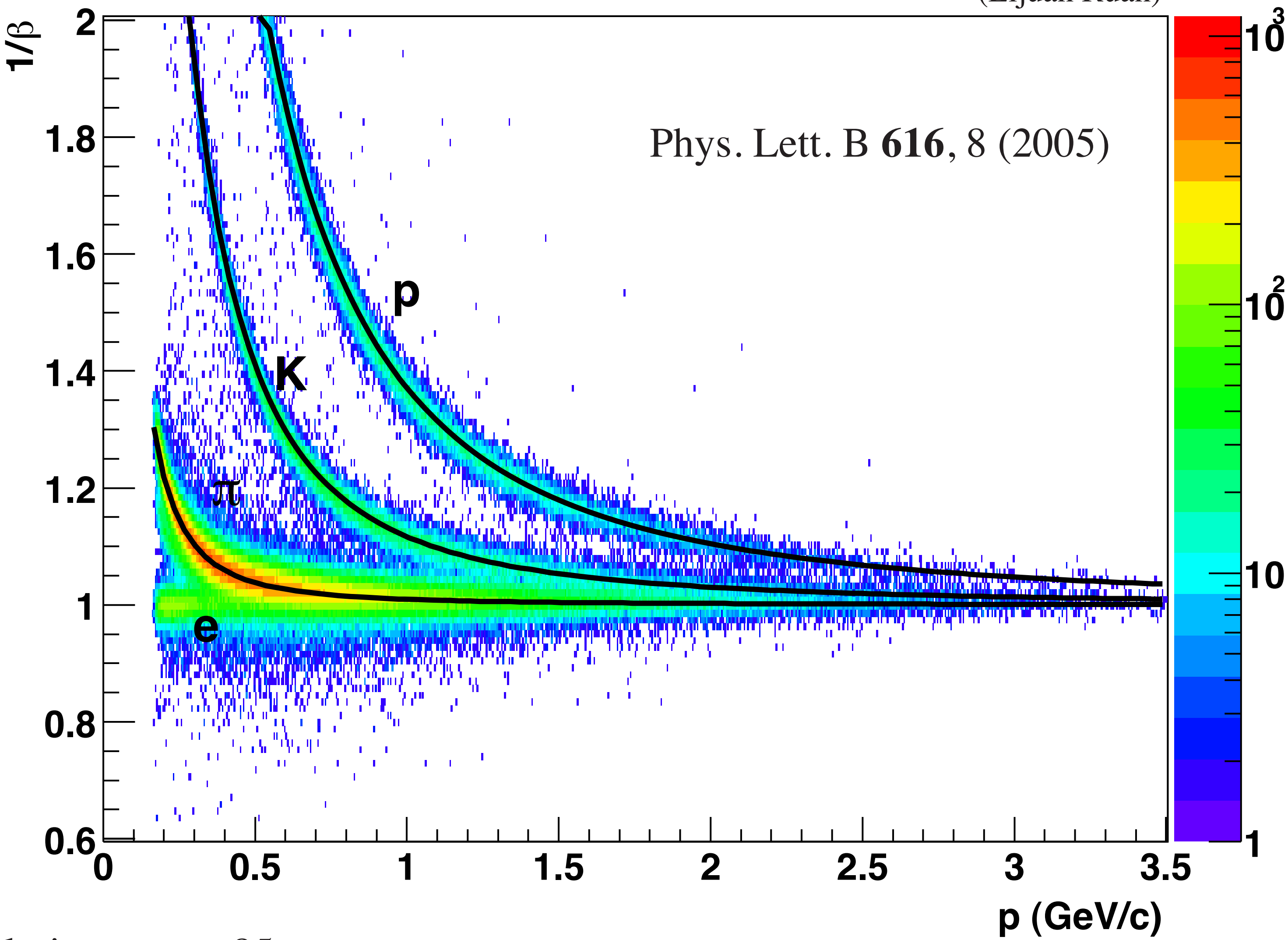


"Shoebox" built out-of-house
Correct sealant
Two layer of electronics
- local digitization (CERN HPTDC)

Precise MRPC positioning
"Integrated" water cooling

Each prototype completely new "from the ground up"
a few MRPCs used in all three prototypes to look for aging effects...

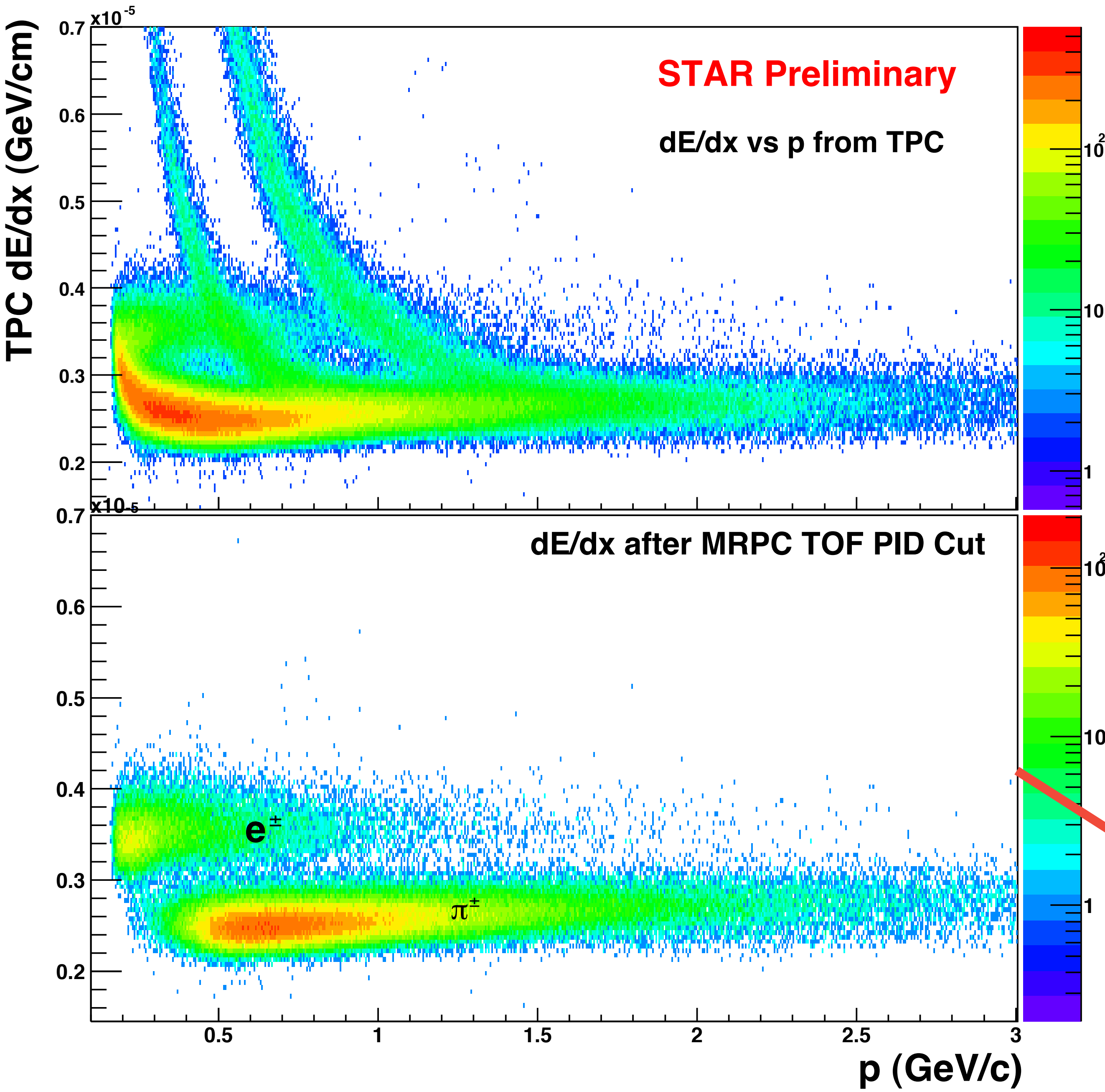
TOFr+pVPD in RHIC Run-3 (d+Au)



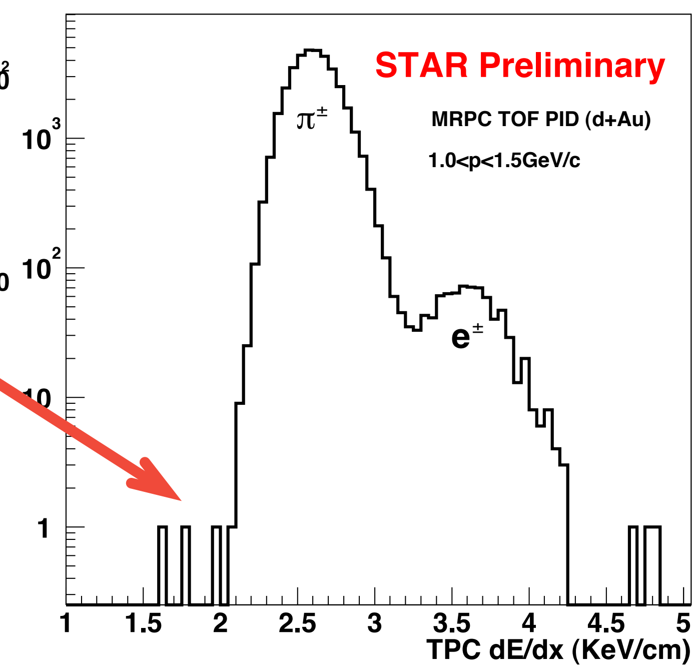

start resolution ~85ps
stop (MRPC) resn ~85ps
total ~120ps → π/K/p to ~1.6 GeV/c, and (π+K)/p to ~2.8 GeV/c

First physics result from an MRPC-based TOF System
on hadron Pt-distributions & the Cronin Effect in RHIC p+p & d+Au collisions

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




Phys. Rev. Lett. **94**, 062301 (2005)

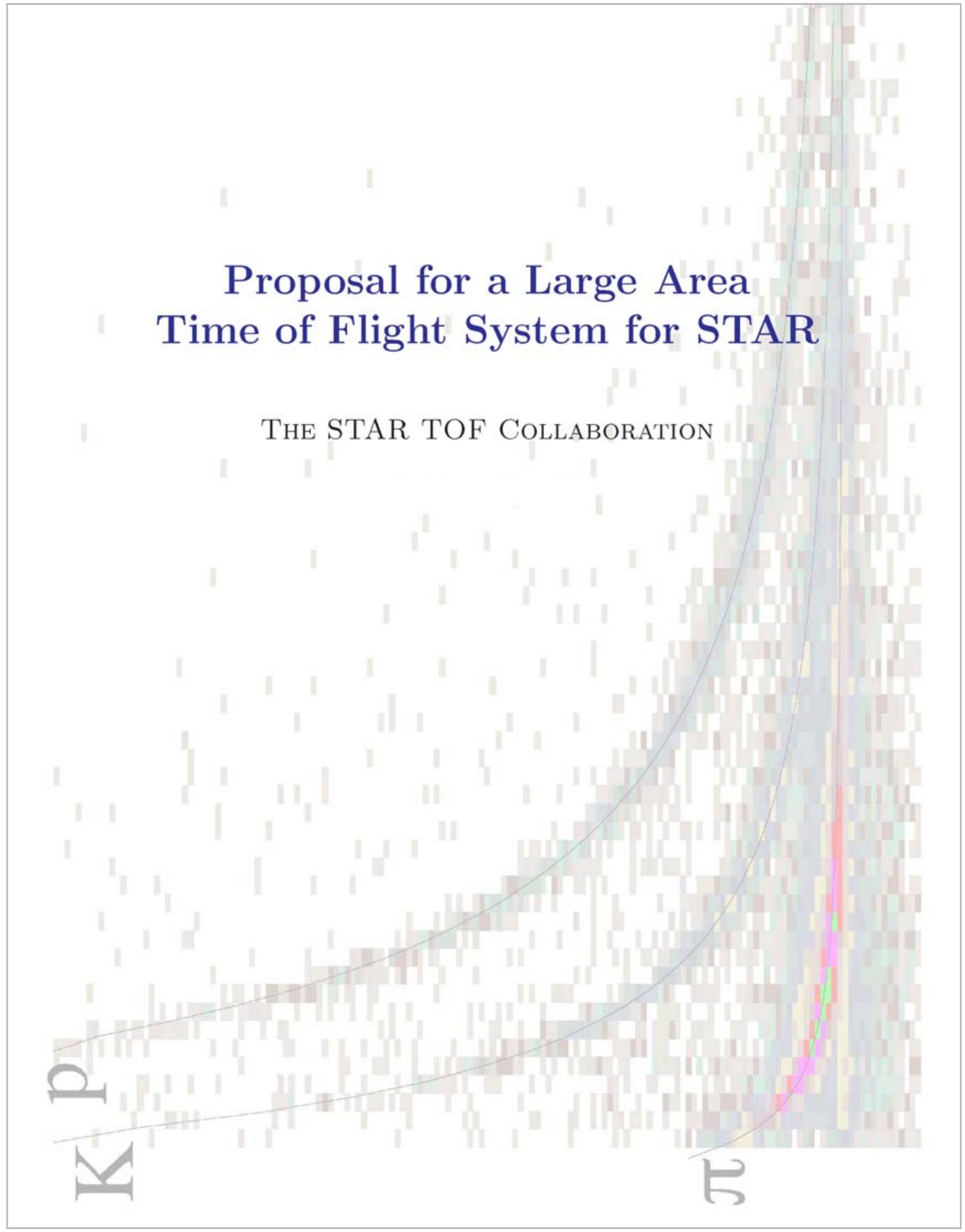


http://wjllope.rice.edu/~TOF/TOF/Documents/TOF_20040521.pdf

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 → 23,040 chs
- 3840+ MRPCs contributed by China
- Tray fabrication & testing in Texas
- Digitization on-board
- US Cost: 4.7 M$
  Chinese contribution: 2.3 M$ (US$ equiv.)

Construction now underway!


Proposal for a Large Area Time of Flight System for STAR

The STAR TOF Collaboration

## Status of the Tray Assembly......

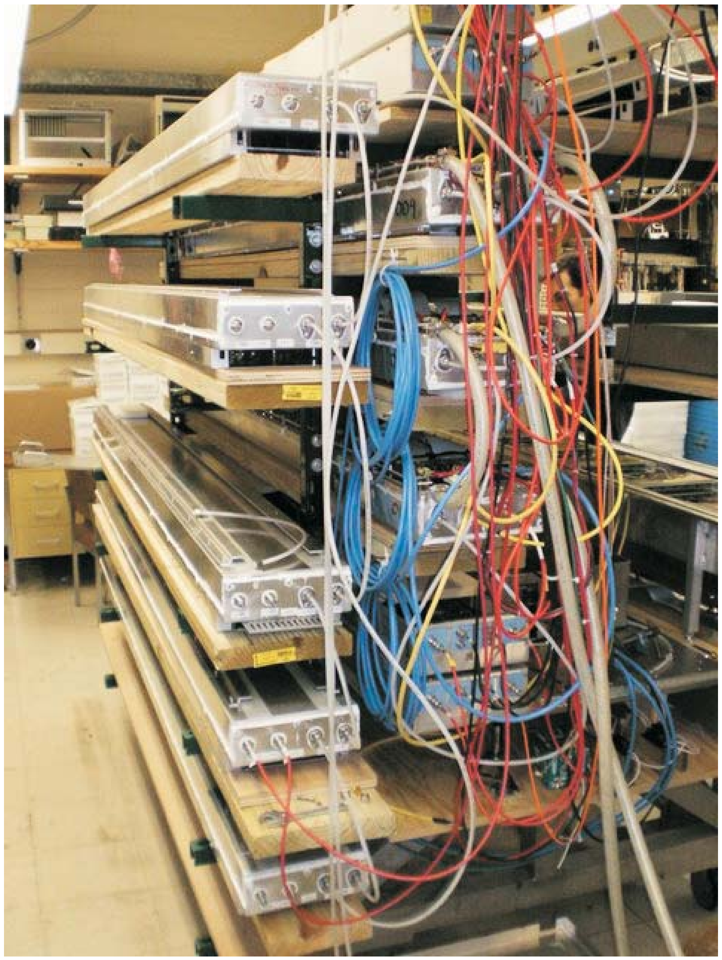
MRPCs from USTC and Tsinghua, China
Tray design and fabrication at Rice
TDIG and TCPU fab at Blue Sky, Houston

RICE

FEE fab and testing
TDIG calibration

MRPC testing
Tray assembly
Tray cosmics testing
THUB fabrication
Firmware

*Cosmics testing stand...*



*Leak testing and storage....*

38 trays fabricated and in various stages of test.... assembly rate is 2 trays/week...
deliver 24 trays to BNL in June, 36 more in September, and 25 more in November
...pushing for 90 trays (3/4 of total system) installed for Run-9...

Run-8 Installation

d+Au and p+p at full energy, plus a very short low-energy Au+Au engineering run

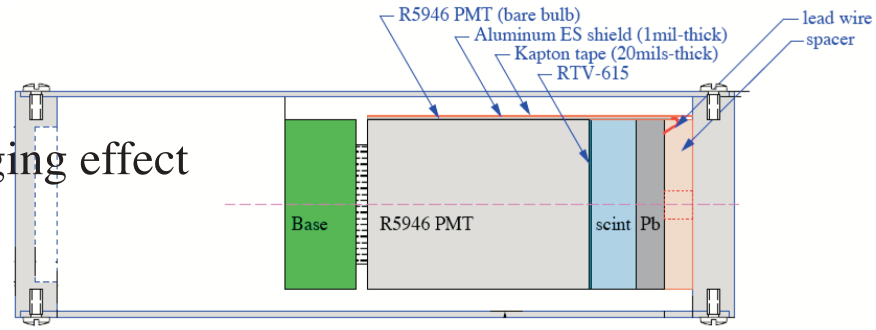
Upgraded Start-detector (upVPD)...

Five “final” trays installed on the East side of STAR... (same sector as DAQ-1000 prototype)

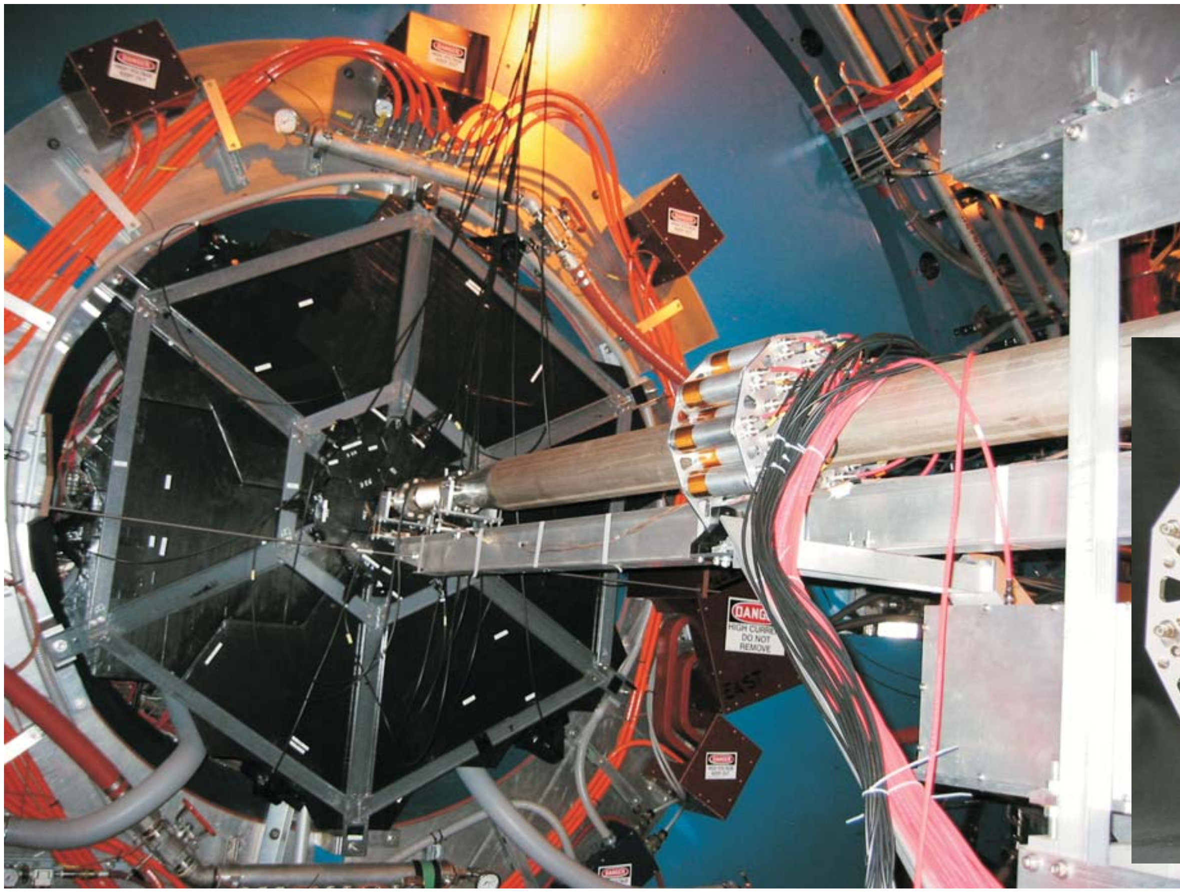
STAR Level-0 trigger on hits on the start- and stop-sides to improve statistics in the p+p phase

# Upgraded Start Detector

3 chs/side “pVPD” → 19 chs/side “upVPD”
improves efficiency per event, and resolution due to averaging effect




Pb + Scint + Mesh dynode PMTs
standard linear resistive bases

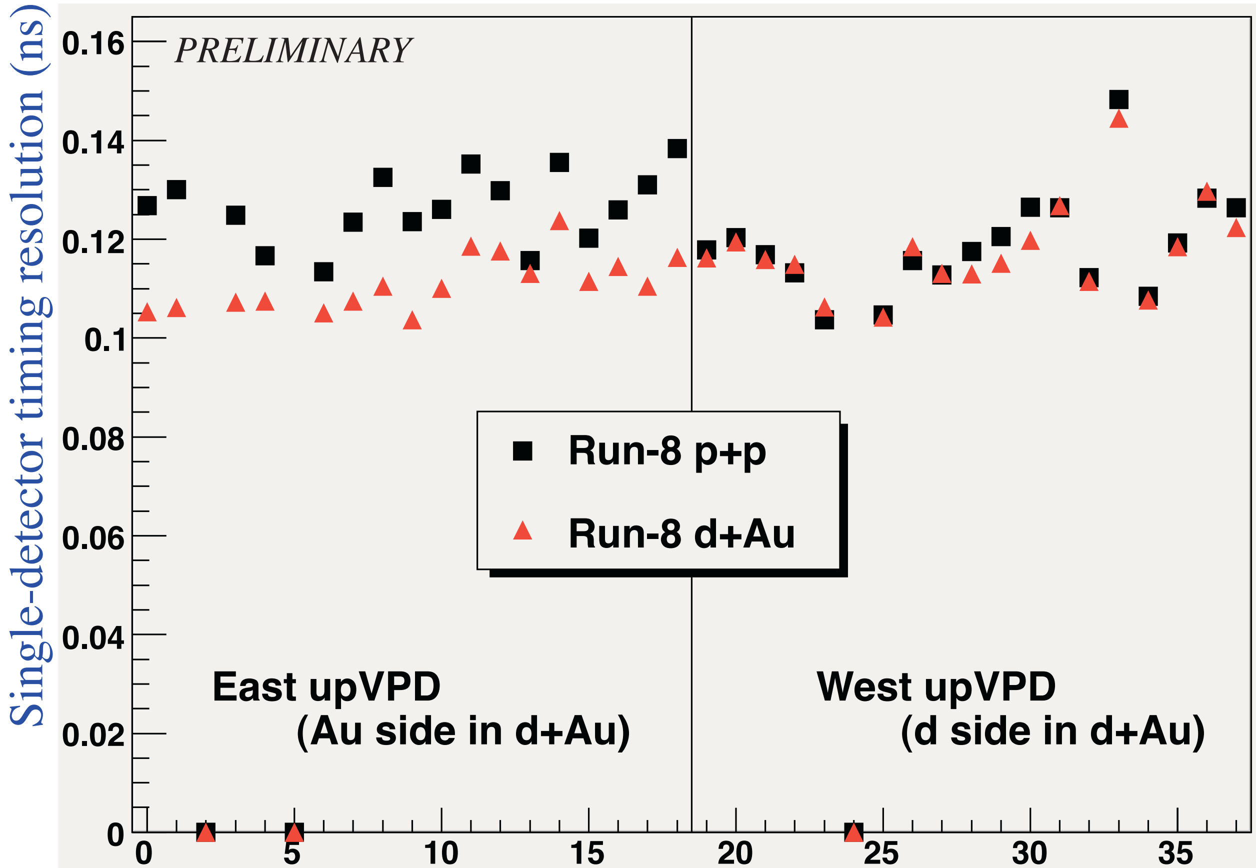


improves efficiency per event for a start-time in p+p from ~10% to ~35%...
improves start-time resolution in Au+Au by a factor of sqrt(6)...

provides inputs to STAR triggers to select primary vertex positions near the center of STAR
main input to STAR min. bias triggers in Run-7, 76M events collected with mb-vpd trigger

showed a ~60% efficiency per event in the Run-8 low-energy engineering run!!

## Start Detector Performance in Run-8 (d+Au and p+p)




Single-detector resolution $\sigma_o \sim 120$ps

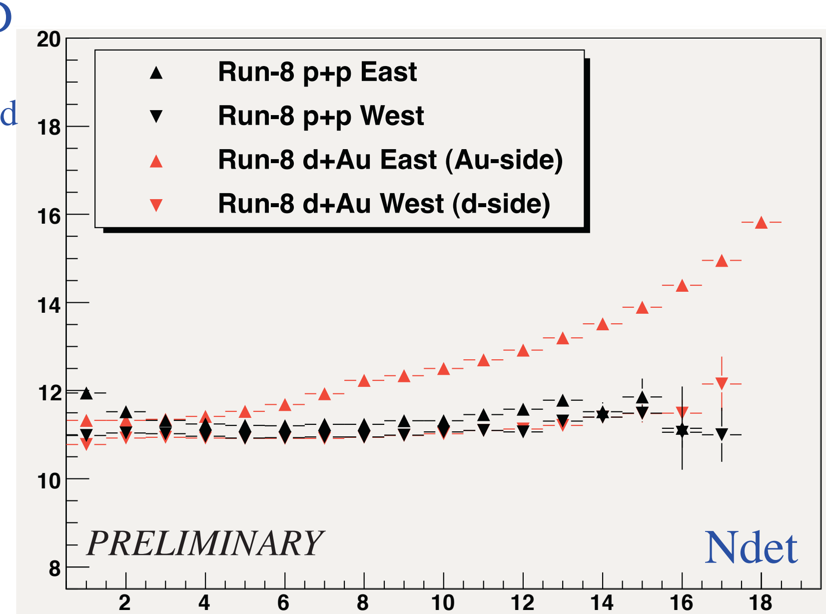
Mean multiplicity of lit PMTs
East ~ 10
West ~ 2

Start-time needed by TOF is
Tstart = (<Teast>+<Twest>)/2

Tside ~ $\sigma_o$ / sqrt(Ndet)

Start-time resolution can be improved at loss of efficiency

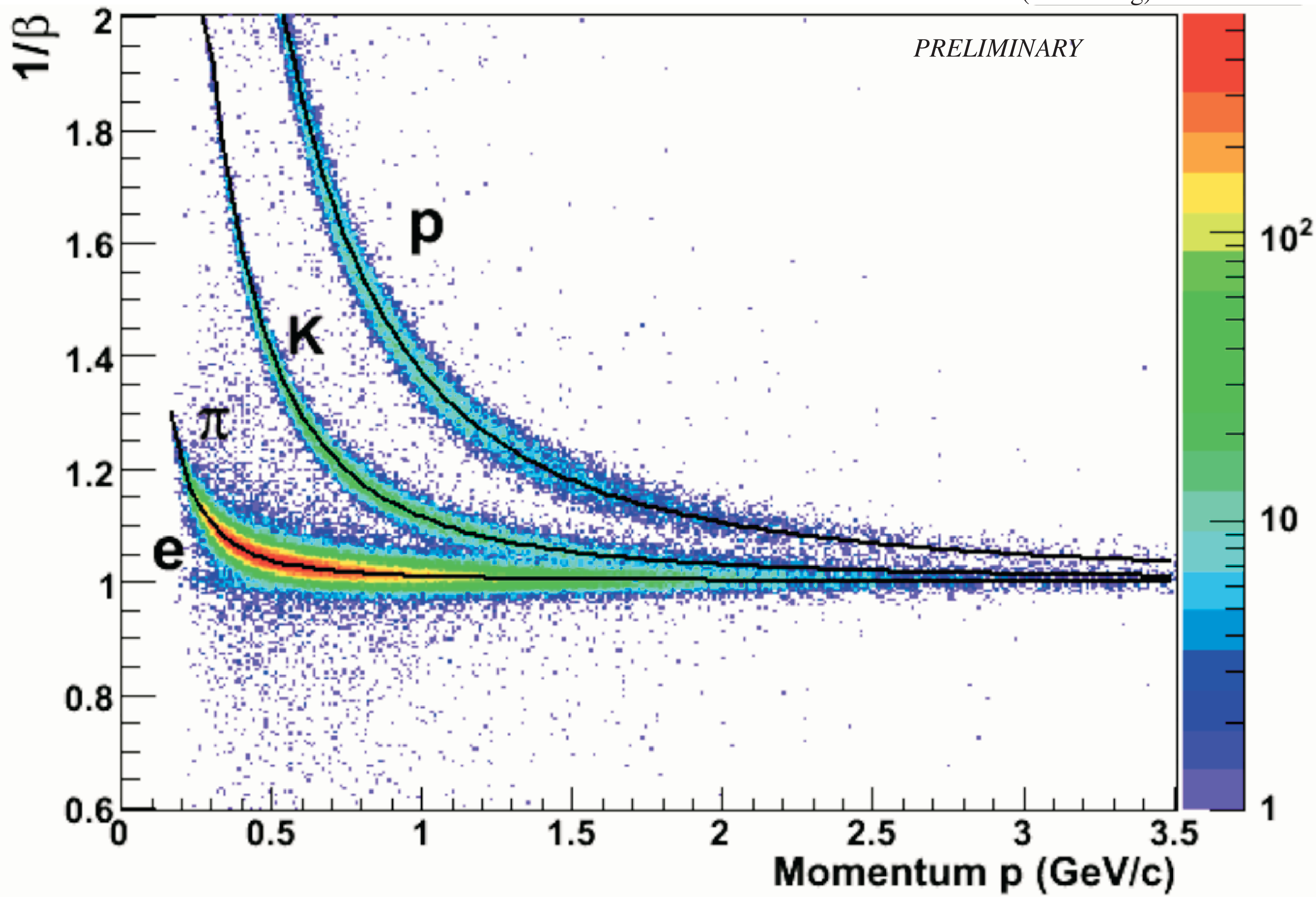
Total Time-Over-Threshold divided by Ndet




Au-side in d+Au sees onset of multi-particle timing....

Total System Performance in Run-8 p+p

(Zebo Tang)




Statistics Starved (Stop-side channels grouped together, 24 chs/group)
TPC uncalibrated

Yet indicates pure-stop resolution around 85-90ps (final trays “work”)....

## Summary

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

From INFN (Crispin Williams) to Rice & China (~1998-2001)

now we have: STAR TOF (MRPCs from China, mechanics from Rice, electronics from Rice, Blue Sky, and UT)

STAR MTD (MRPCs from China, mechanics and electronics from Rice)

PHENIX prototype and TOFw (electronics from Rice, consultant on MRPCs and mechanics)

STAR “ringTOF” for Run-10?

...MRPCs are becoming a popular technology!

very inexpensive, components readily available, manufacturing tolerances are “loose”...

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

performed to expectations...

pure stop resolution of ~80-95ps achieved in all of the different phases of Runs 3, 4, 5, & 8

Final design now DOE-funded and under construction....

Start-detector for TOF upgraded....

increased channel count → increased efficiency/event and improved Tstart and Zvtx resn...

Increases STAR’s charged hadron PID acceptance by factor ~2, at <5% of STAR’s total cost....

90 trays for Run-9.... (3/4 of the full system)

system complete for Run-10 (the low energy scan)....