Time of Flight (ToF) Measurements

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Outline

- ToF basic's
- Detector concepts
- Readout concepts
- Why RPCs for ToF ?
- Working principle
- How are timing RPCs operated
- Future ToF ideas
- Concluding remarks

Units I will use

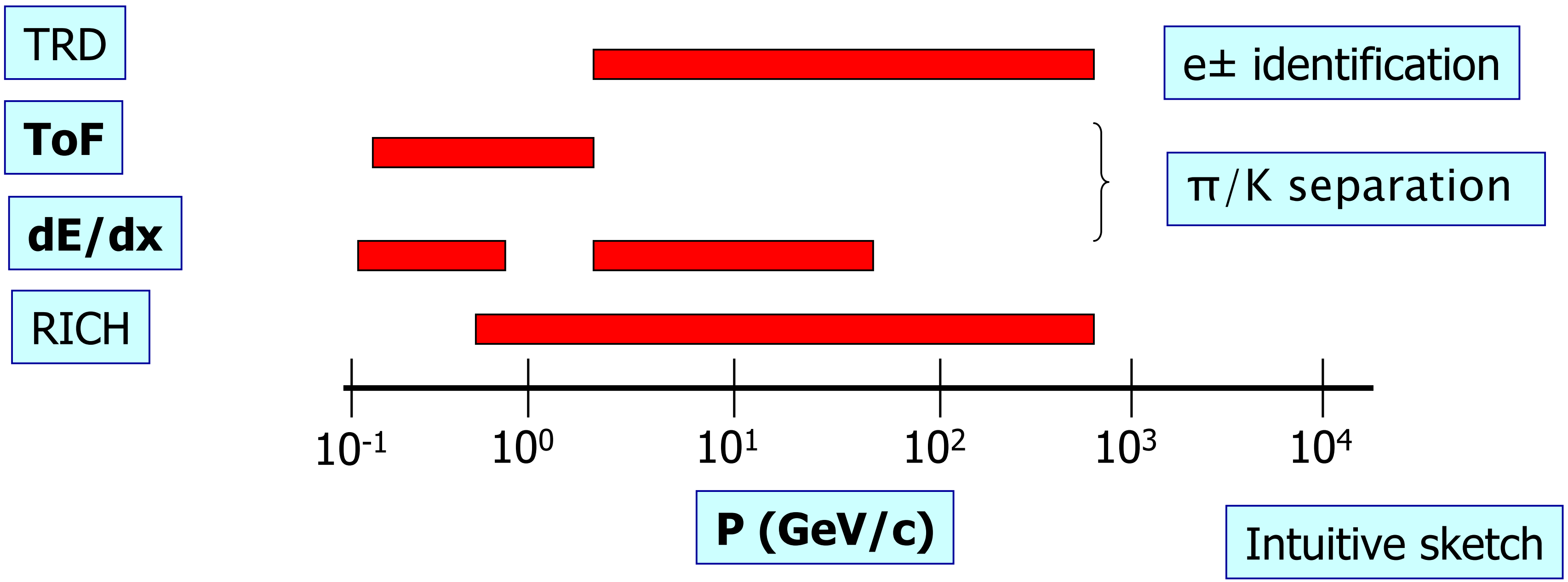
- **Energy - *electron-volt***
  - 1 electron-volt = kinetic energy of an electron when moving through potential difference of 1 Volt;
    - 1 eV = 1.6 × 10^{-19} Joules = 2.1 × 10^{-6} W•s
    - 1 kW•hr = 3.6 × 10^{6} Joules = 2.25 × 10^{25} eV
- **Mass - *eV/c²***
    - 1 eV/c^2 = 1.78 × 10^{-36} kg
    - electron mass = 0.000511 GeV/c^2
    - proton mass = 0.938 GeV/c^2
    - my mass (85 kg) ≈ 4.8 × 10^{37} eV/c^2
- **Momentum - *eV/c*:**
    - 1 eV/c = 5.3 × 10^{-28} kg m/s
    - momentum of a soccer ball at 128 km/h ≈ 5.29 kgm/s ≈ 9.9 × 10^{27} eV/c

Particles through matter

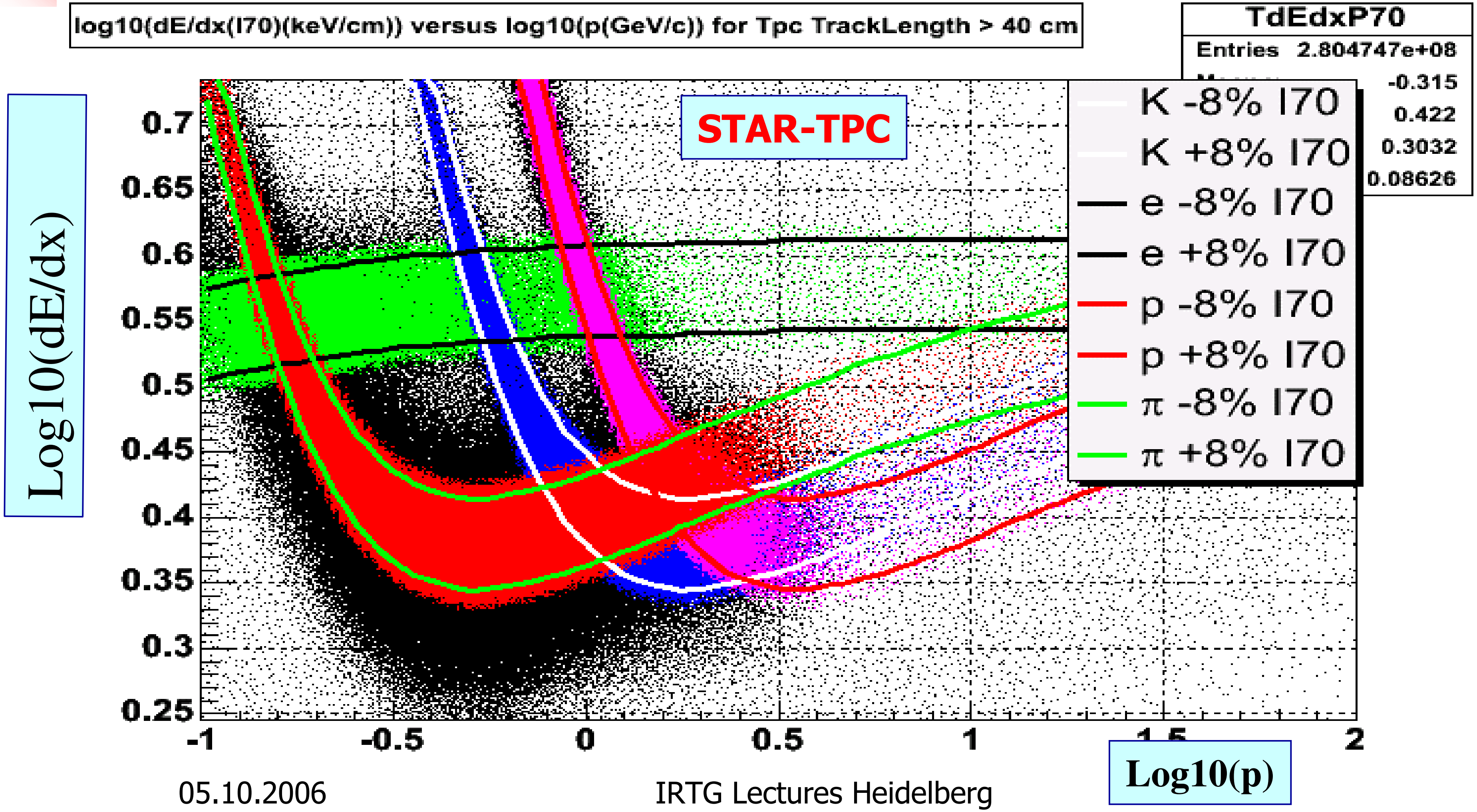
- When passing through matter,
  - particles interact with the electrons and/or nuclei of the medium;
  - this interaction can be *weak*, ***electromagnetic*** or *strong interaction*, depending on the kind of particle; its effects can be used to detect the particles;
- Possible interactions and effects in passage of particles through matter:
  - **excitation** of atoms or molecules (e.m. int.):
    - charged particles can excite an atom or molecule (i.e. lift electron to higher energy state);
    - subsequent de-excitation leads to emission of photons;
  - **ionization** (e.m. int.)
    - electrons liberated from atom or molecule, can be collected, and charge is detected
  - **Cherenkov radiation** (e.m. int.):
    - if particle's speed is higher than speed of light in the medium, e.m. radiation is emitted -- "Cherenkov light" or Cherenkov radiation, which can be detected;
    - amount of light and angle of emission depend on particle velocity;
  - **transition radiation** (e.m. int.):
    - when a charged particle crosses the boundary between two media with different speeds of light (different "refractive index"), e.m. radiation is emitted -- "transition radiation"
    - amount of radiation grows with (energy/mass);
  - **bremsstrahlung** (= braking radiation) (e.m. int.):
    - when charged particle's velocity changes, e.m. radiation is emitted;
    - due to interaction with nuclei, particles deflected and slowed down emit bremsstrahlung;
    - effect stronger, the bigger (energy/mass) ⇒ electrons with high energy most strongly affected;
  - **pair production** (e.m. int.):
    - by interaction with e.m. field of nucleus, photons can convert into electron-positron pairs
  - **electromagnetic shower** (e.m. int.):
    - high energy electrons and photons can cause "*electromagnetic shower*" by successive bremsstrahlung and pair production
  - **hadron production** (strong int.):
    - strongly interacting particles can produce new particles by strong interaction, which in turn can produce particles,... "*hadronic shower*"

Why do we need ToF

ToF can improve the particle id of a detector setup.
Especially:
ToF bridges, rather cheap the gap in between the dE/dx measurement

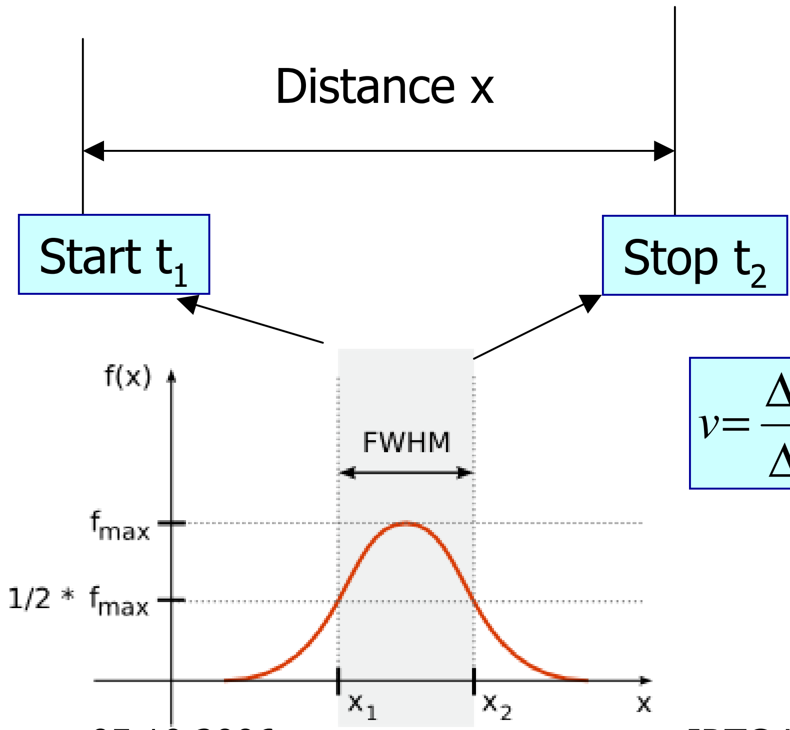


Why do we need ToF



Detector resolution needed

Measurement idea :
Simple, measure time difference between start and stop for a given distance x.

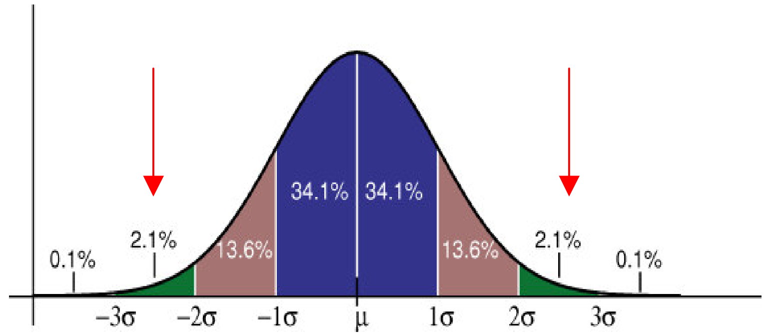


$$v = \frac{\Delta x}{\Delta t}$$

Resolution :
Gauss distribution
FWHM:
Sigma: σ =FWHM/2.35
Integral:

$\pm 1\sigma$ = 68 %
$\pm 2\sigma$ = 95 %
$\pm 3\sigma$ = 99 %

For a clean separation we need 2-3σ difference.



Typical setups for ToF detectors

Fix target accelerators

SIS (FOPI,HADES)
AGS (E895)
SPS (NA49)

Advantage:
Long flight pass (5-10m)

Disadvantage:
High granularity

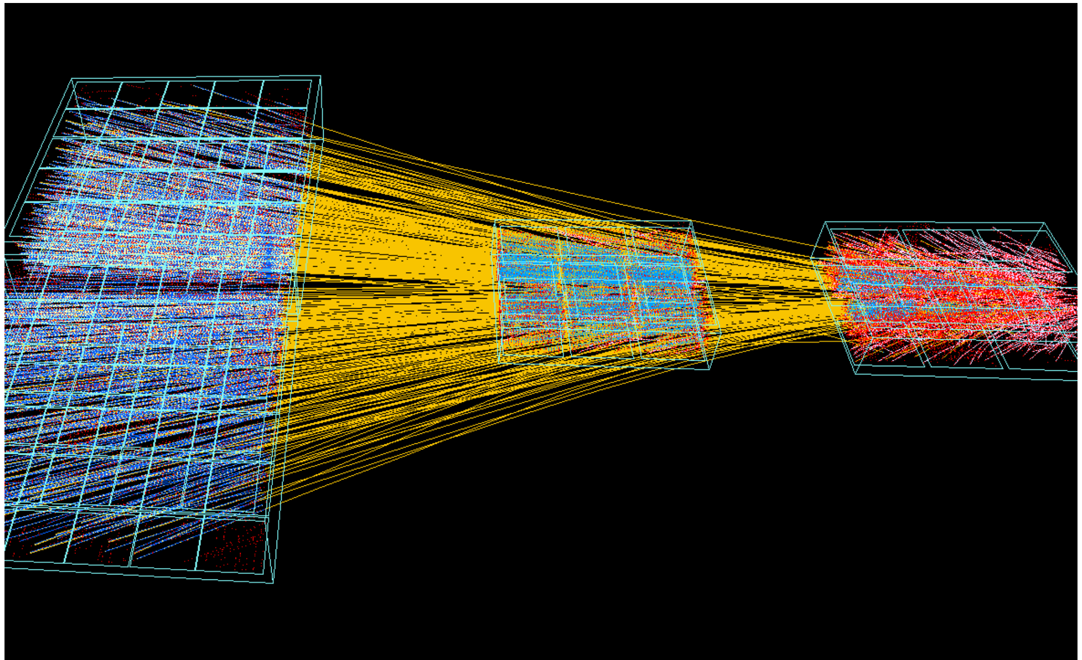
Colliders

LEP (ALEPH)
RHIC (STAR)
LHC (ALICE)

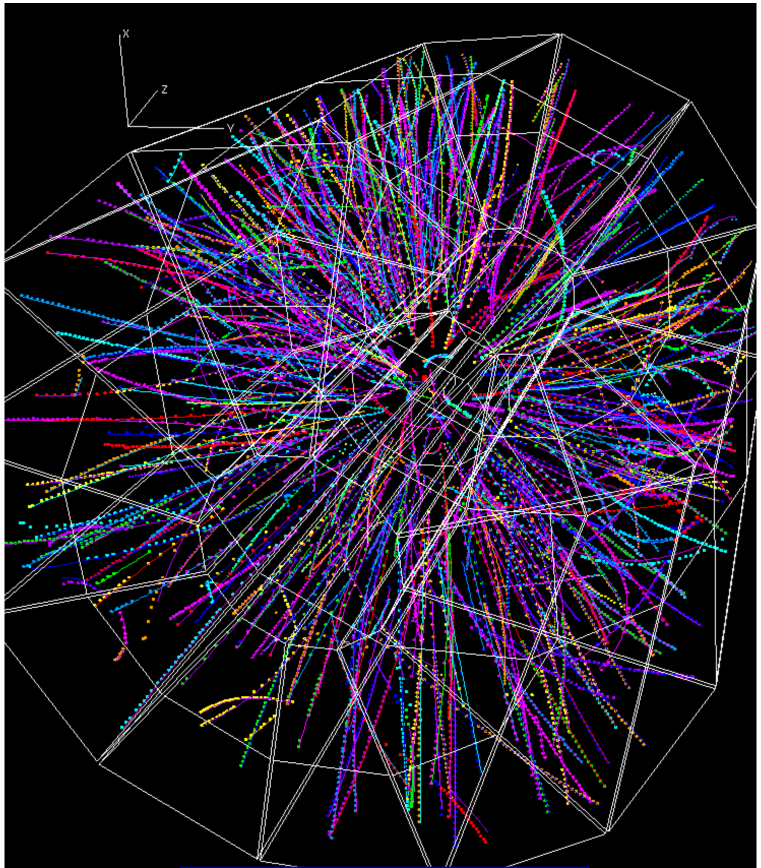
Advantage:
Lower rate
CM system

Disadvantage:
Shorter flight pass (2-3m)

Typical setups for ToF detectors



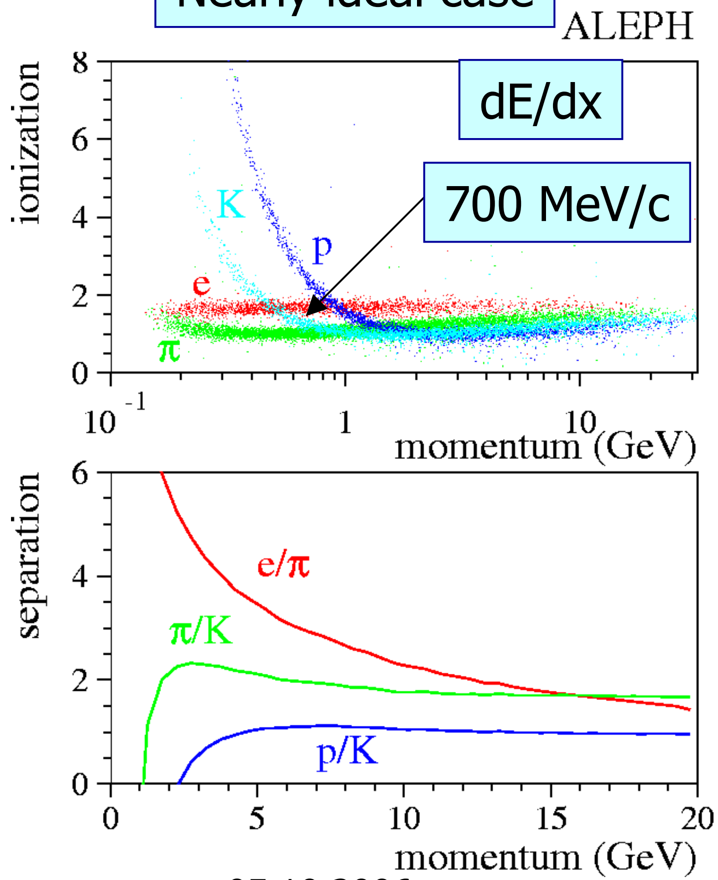
17.2 AGeV NA49 (158 AGeV)



19.9 AGeV STAR

Particle id @ LEP e^-+e^+

Nearly ideal case



Particle id with ALEPH TPC
R.Settles MPI-Munich
W.Blum MPI-Munich
G.Rolandi CERN

Good dE/dx resolution requires
- long track length
- large number of samples/track
- good calibration, no noise, ...

ALEPH TPC resolution
- up to 334 wire samples/track
- truncated (60%) mean of samples
- 5% (330 samples)

ToF kinematic's

How to calculate the ToF difference between 2 particles of mass m_1 & m_2

$$\gamma = \frac{1}{\sqrt{1-\beta^2}}$$

$$\beta = \sqrt{1-\frac{1}{\gamma^2}}$$

$$\beta\gamma = \sqrt{\gamma^2 - 1}$$

$$p = \gamma\beta m_0$$

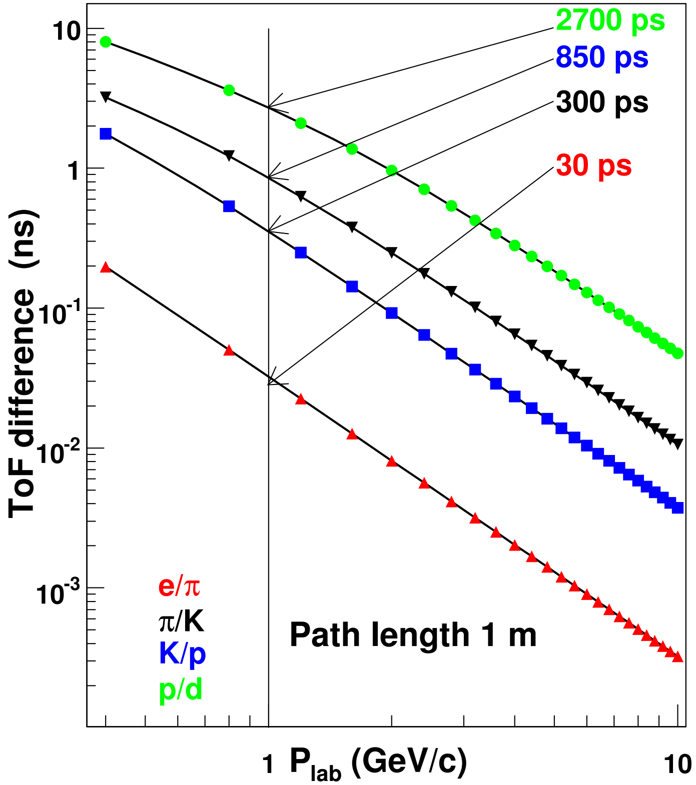
$$E^2 = p^2c^2 + m^2c^4$$

$$t = \frac{l}{\beta c}$$

$$m = p\sqrt{\frac{c^2t^2}{l^2} - 1}$$

$$\frac{dm}{m} = \frac{dp}{p} + \gamma^2\left(\frac{dt}{t} + \frac{dl}{l}\right)$$

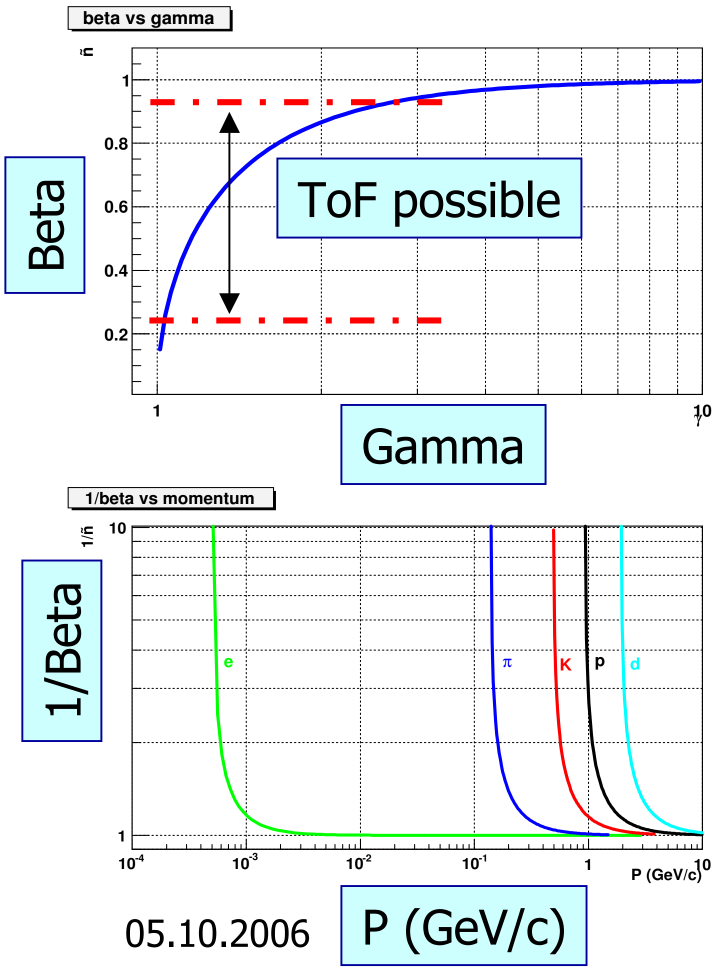
$$\Delta t = \frac{l}{c}\left(\frac{1}{\beta_1} - \frac{1}{\beta_2}\right) = \frac{l}{c}\left(\sqrt{1+m_1^2c^2/p^2} - \sqrt{1+m_2^2c^2/p^2}\right) \approx \frac{lc}{2p^2}\left(m_1^2 - m_2^2\right)$$



At 1GeV/c we would need:

$\sigma_t(e/\pi) < 10$ ps
$\sigma_t(\pi/K) < 100$ ps
$\sigma_t(K/p) < 275$ ps
$\sigma_t(p/d) < 900$ ps

ToF basic numbers

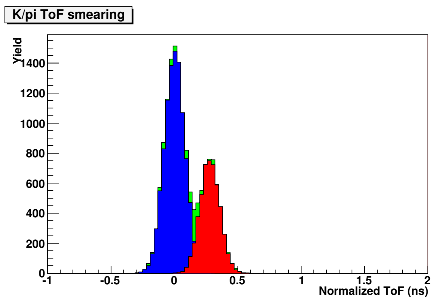


There is an optimal range for ToF measurement !

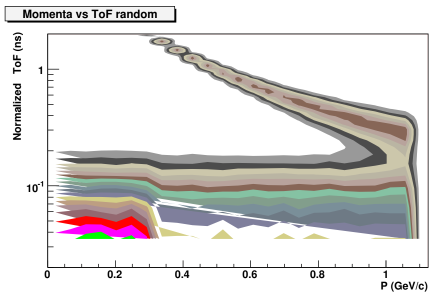
Nowadays we can limit this range for the π,K,p separation below P < 2-4 GeV/c depending on the detector resolution and flight path.

Example: Separation of π/K for 1m flight path

80 ps

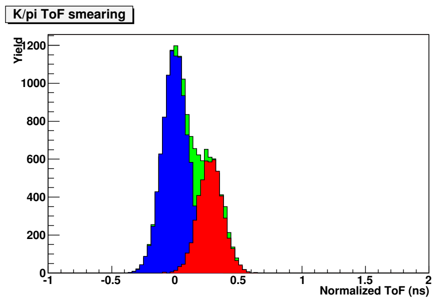


Δt (ns)

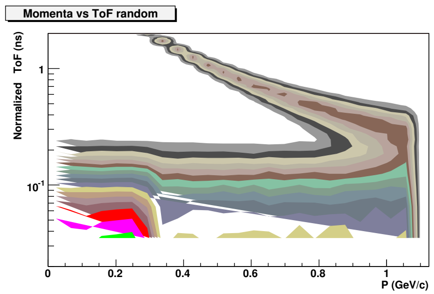


P (GeV/c)

100 ps

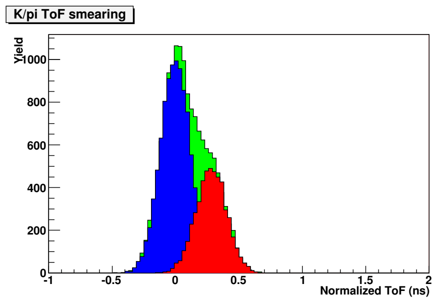


Δt (ns)

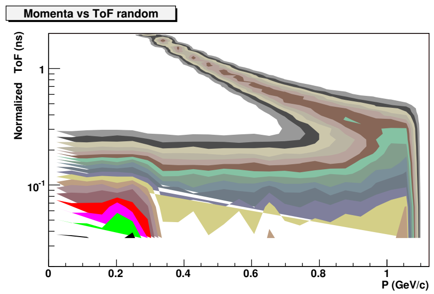


P (GeV/c)

120 ps

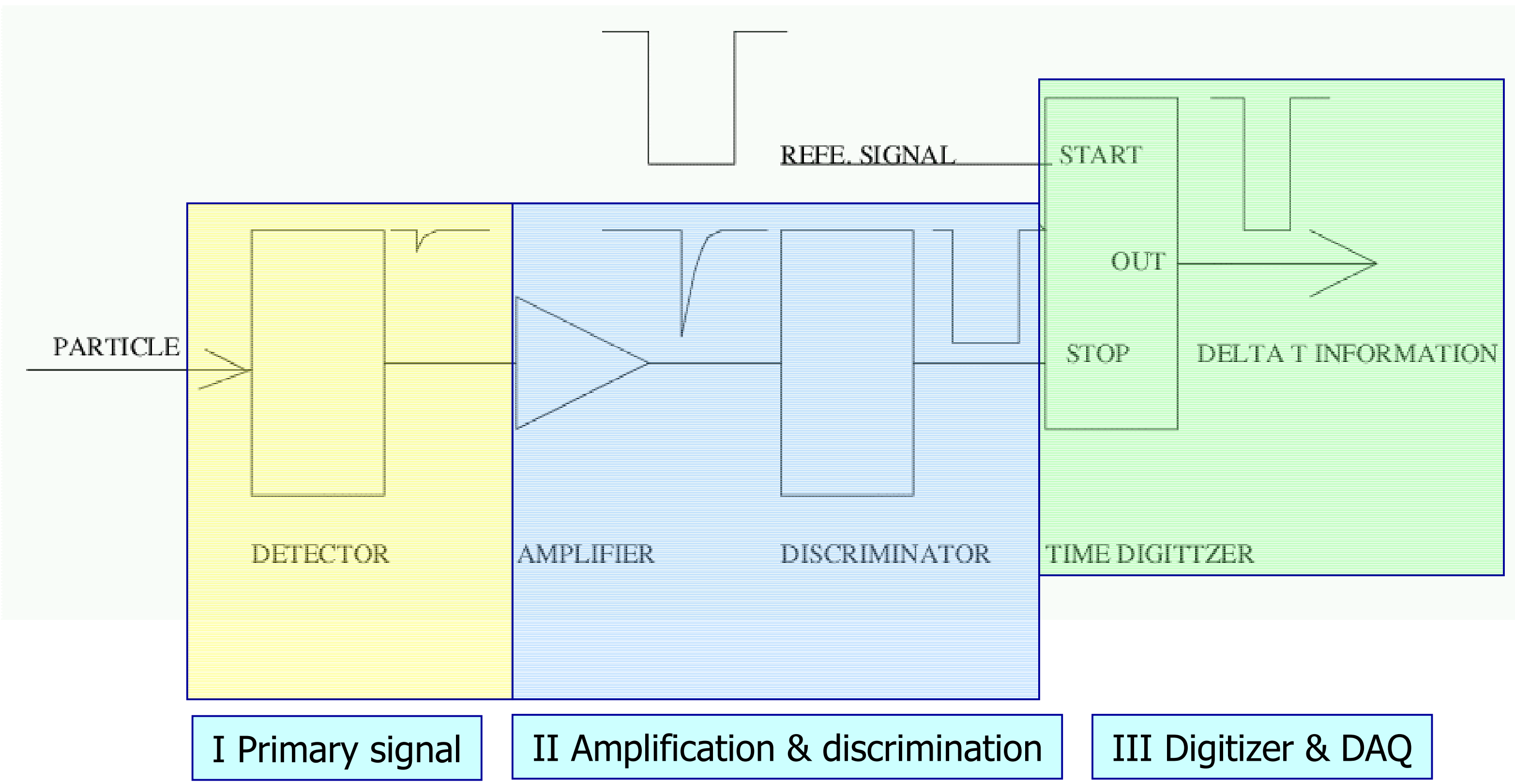


Δt (ns)



P (GeV/c)

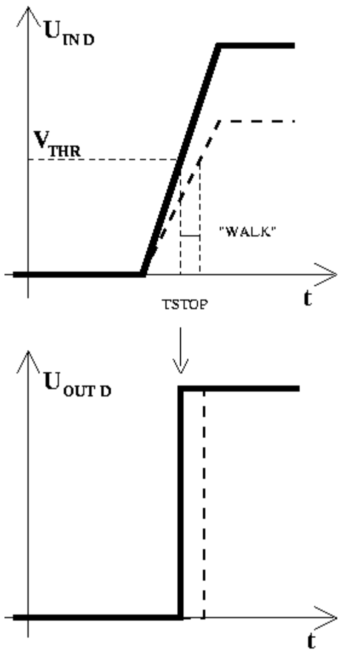
Principle sketch of signal creation and forming



Signal properties

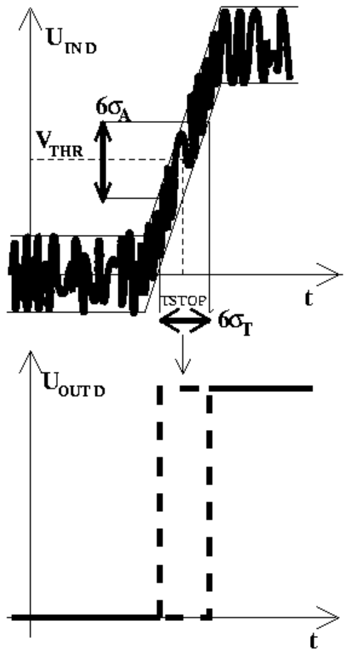
M.Ciobanu

Walk:
Possible to correct for



CLEAN SIGNAL APPLIED TO DISCRIMINATOR

Jitter:
Impossible to correct for



NOISY SIGNAL APPLIED TO DISCRIMINATOR

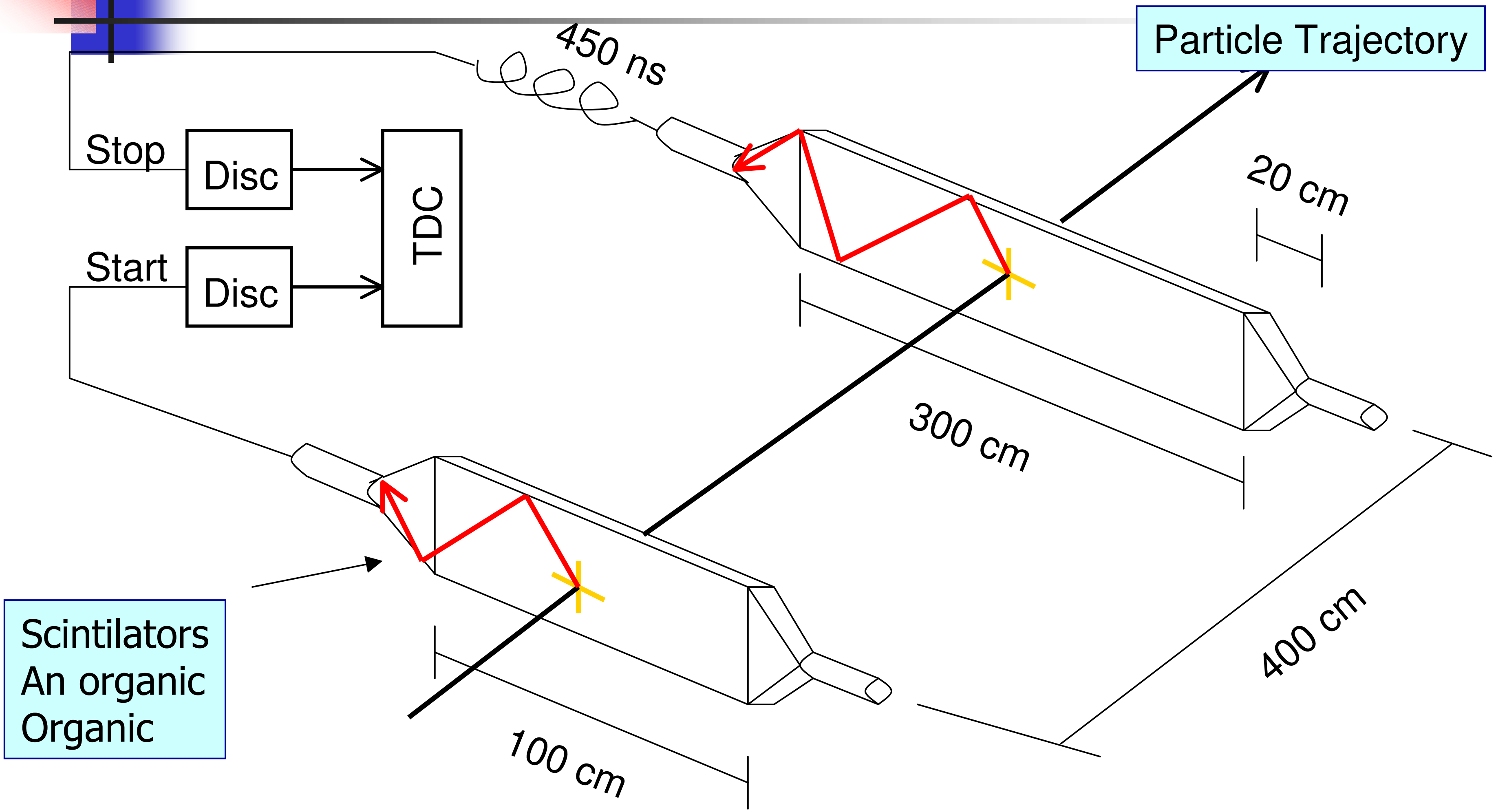
$$\sigma_t = \frac{\sigma_n}{\left.\frac{dV}{dt}\right|_{V_{THR}}}$$

Ideal

$$\sigma_t = \frac{\sigma_n}{\left.\frac{dV}{dt}\right|_{V_{THR}}} + \delta t$$

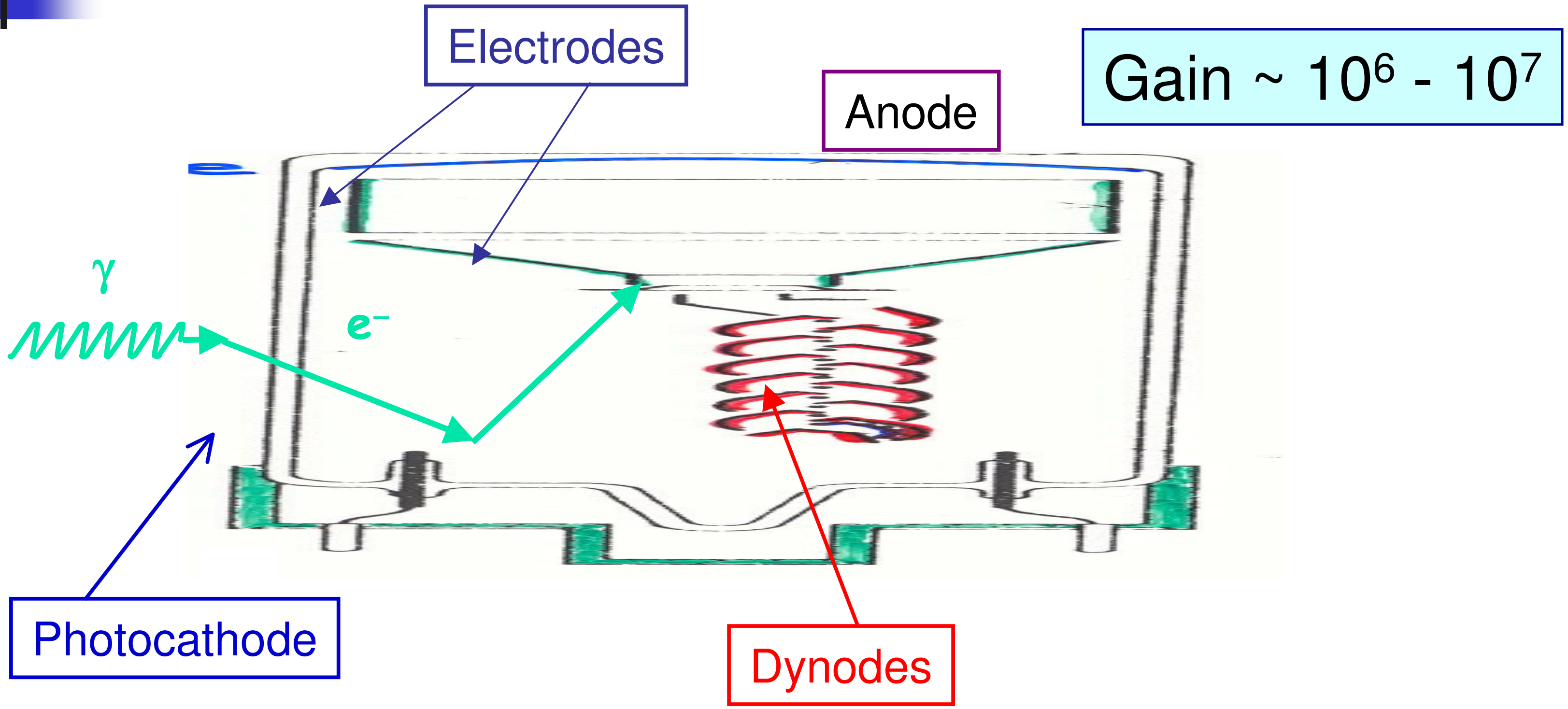
Real

Measurement principle



ToF Detectors I

photomultipliers (pmt) + scintillators (standard solution)



Scintillators in use for ToF

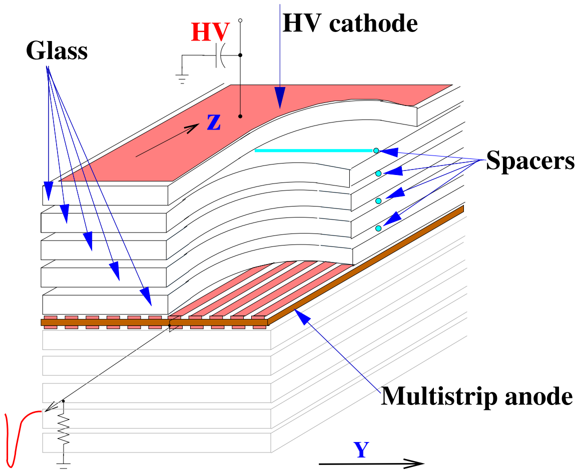
- **Organic**
  - Liquid
    - Economical
    - Hard to handle
  - **Solid**
    - Fast decay time
    - Long attenuation length
    - Emission spectra

- **Inorganic**
  - NaI, CsI
    - Excellent γ resolution
    - Slow decay time
  - BGO
    - High density, compact

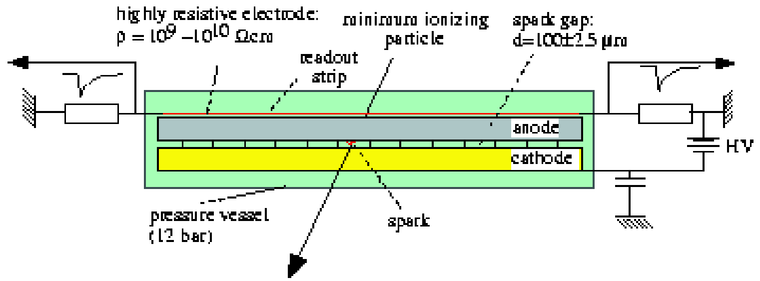
Typical plastic scintillators use anthracene plus wavelength shifter and can reach σ_t < 60 ps.

ToF Detectors II
gas based detectors

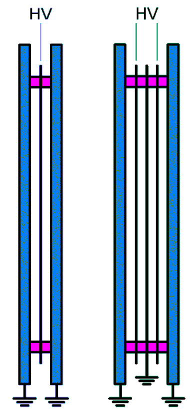
Gas based ToF detectors	
Pestof (PToF)	spark mode
Parallel Plate Chambers (PPACs)	avalanche mode
Resistive Plate Chambers (RPCs)	



RPC 50-100 ps



PTOF 50-100 ps



PPAC 250 ps

Resistive Plate Chamber history

σ_t~5 ns

Trigger RPC developed in 1981
by R.Santonico and R. Cardarelli
Development of Resistive Plate Counters
Nucl. Inst. and Methods 187 (1981) 377-380

σ_t~3-4 ns

Multi Gap RPCs started
by E.C. Zeballos et al
A new type of Resistive Pate Chambers :
The Multigap RPC
Nucl. Inst. and Methods A 374 (1996) 132

σ_t~50 ps

Timing RPC started
By P.Fonte A.Smirnitski, M.C.S. Williams
A new high-resolution TOF technology
Nucl. Inst. and Methods A 443 (2000) 201-204

Why RPCs for ToF

Common ToF-systems used plastic scintillators and
PMPs with σ_t<60 ps.

Advantage:
$Z^2 \sim dE/dx$
Simple detector system .
Reliable system.

Disadvantage:
Price
Granularity

For large scale or high granularity experiments price is an issue.

Examples :

FOPI TOF:
Size ~5 m^2
Channels ~5000
σ_t<100 ps
σ_φ<0.5 cm

ALICE TOF:
Size ~160 m^2
Channels ~160 000
σ_t<100 ps

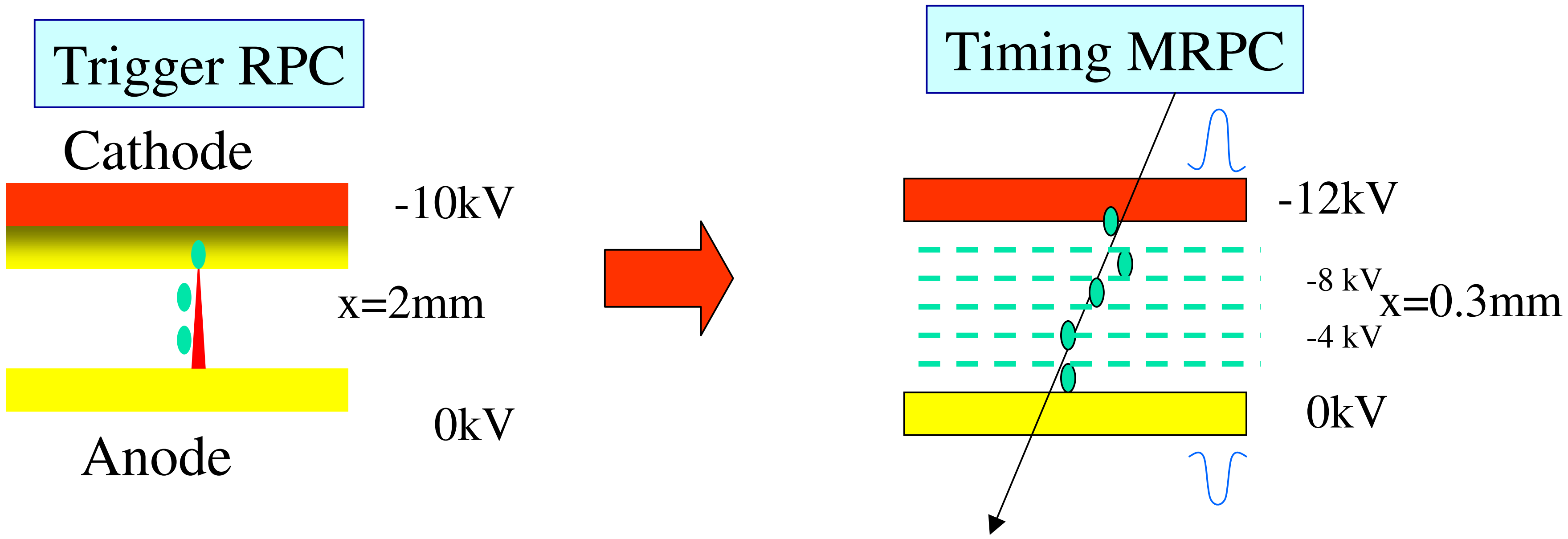
HADES:
Size ~ 3 m^2
Channels ~1000
σ_t<100 ps
δf<600 Hz/cm^2

Solutions :
Gaseous detector systems like:

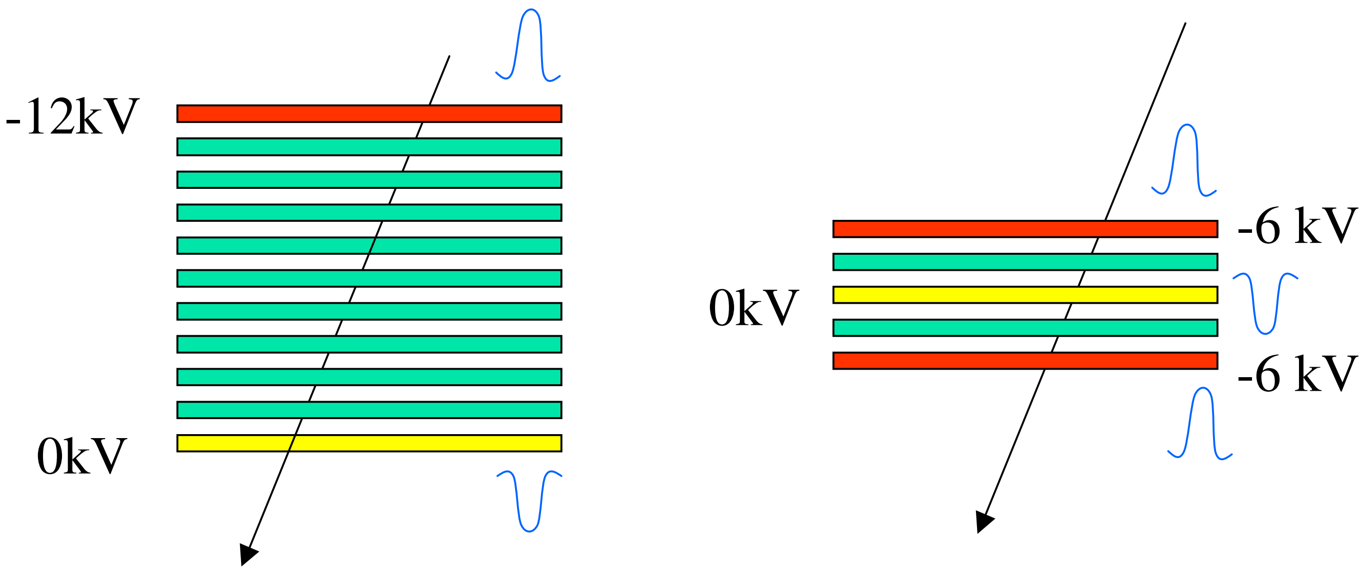
PPAC σ_t<250 ps
Pestov σ_t<50 ps

RPC (T) σ_t<2 ns
MRPC (t) σ_t<100 ps

How do RPCs work ?



How do RPCs work ?



Single stack configuration

Double stack configuration (often used)

How to build a timing RPC ?

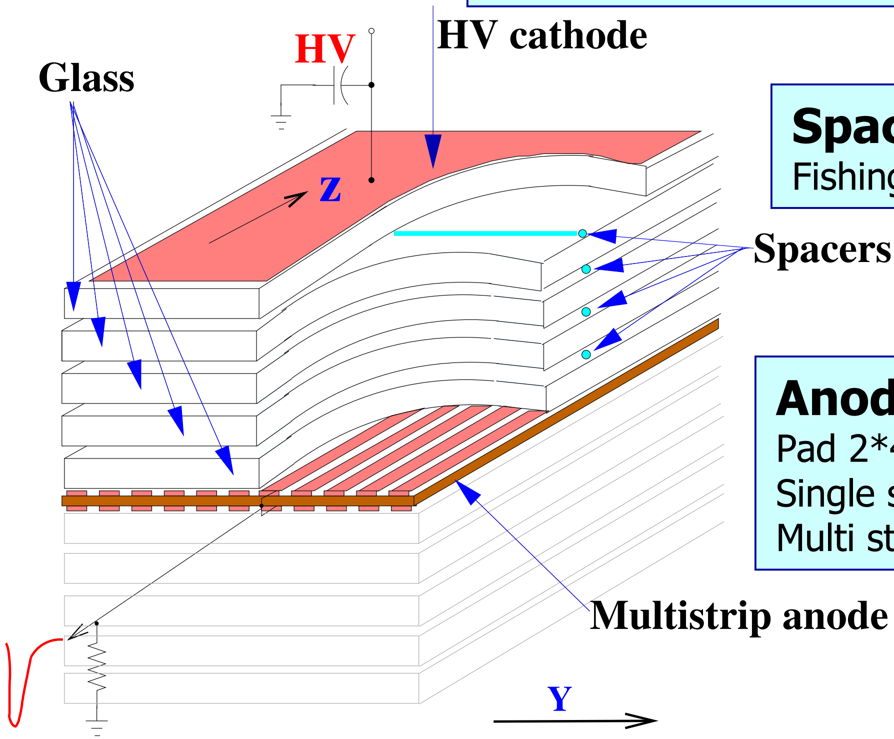
Glass:
Typical window glass (float glass)
Thickness 0.2-2.0 mm
Surface resistance 10^{12} Ωcm

HV cathode:
Glass plate with an carbon film
Aluminum plate
Glass plate with a copper tape

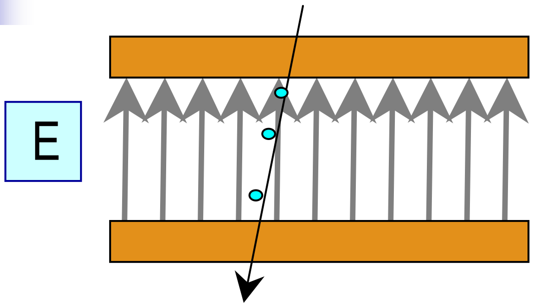
Spacers:
Fishing line 0.1-0.3 mm

Anode:
Pad 2*4 cm
Single strip 2 cm
Multi strip 16 1.96/0.6 mm

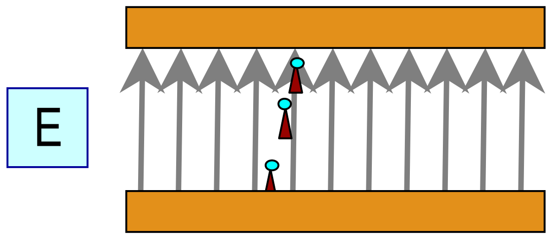
Readout:
Single ended 50 Ω
Differential 100 Ω



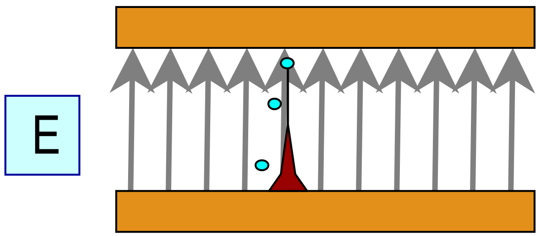
Avalanches in high E-fields



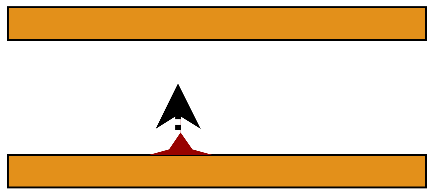
Through-going charged particle creates cluster of electrons and positive ions



Electrons avalanche in high electric field
$N=N_oe^{ax}$

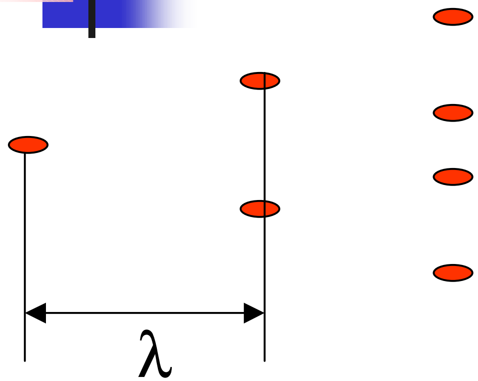


In avalanche mode - only avalanches that start close to cathode grow big enough to induce signal in external electrodes



Cloud of positive ions (n.b. same number as electrons in avalanche) drift slowly to cathode (large distance therefore large signal)

The avalanche



$N(x)=N_0 \bullet e^{\alpha x}$

α = Townsend coefficient

η = Attachment coefficient

α-η = Effective townsend coefficient

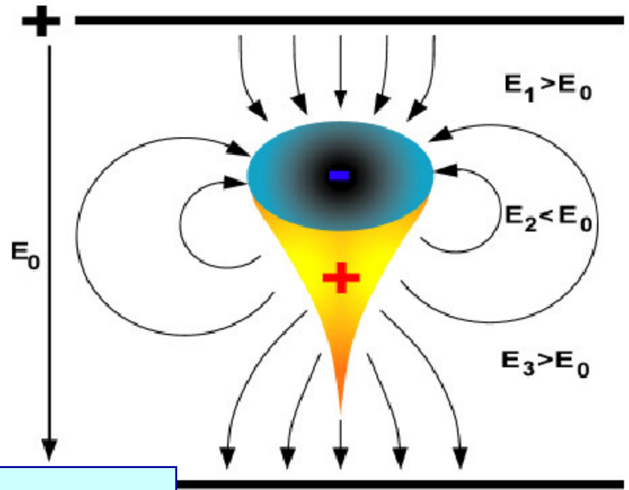
x = Distance

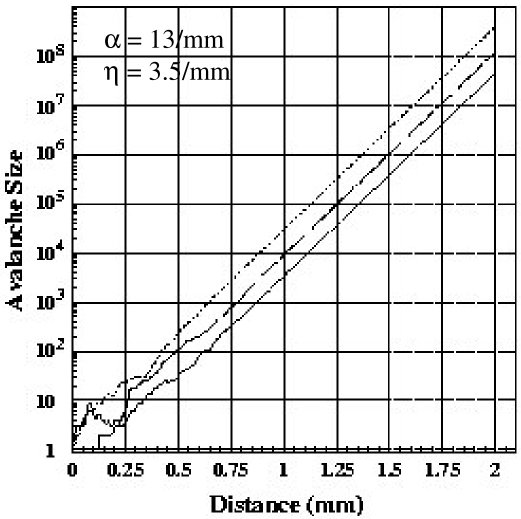
$\lambda=1/\alpha$

$\alpha=\sigma_{ionisation}N_A/V_{mol}$

T-RPC α~10/mm

MRPC α~100/mm



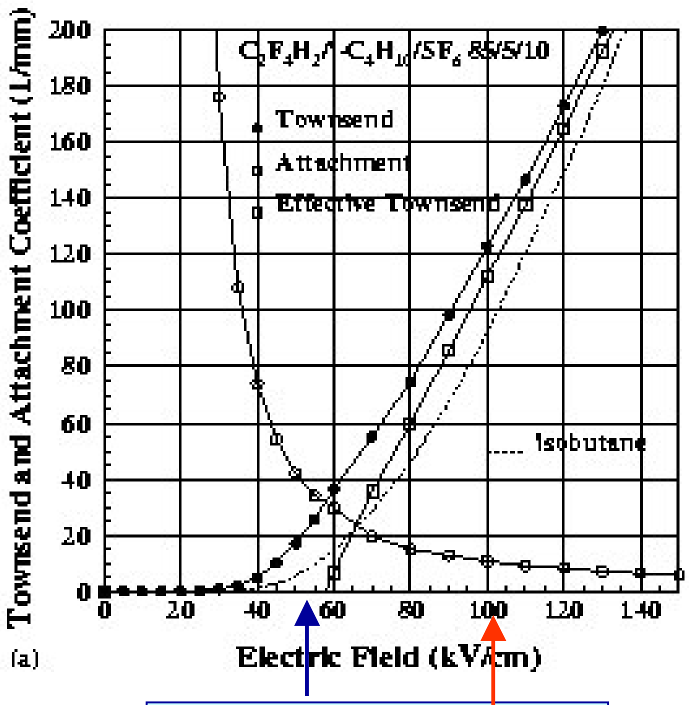


T-RPC $C_2F_4H_2$/isobutene/SF_6 97/2.5/0.5

MRPC $C_2F_4H_2$/isobutene/SF_6 85/5/10

W.Legler Die Statistik der Elektronenlawine In elektronegativen Gasen bei hohen Feldstärken Und grosser Gasverstärkung, Z. Naturforschg.16a (1961) 253-261

RPC timing & gas theory



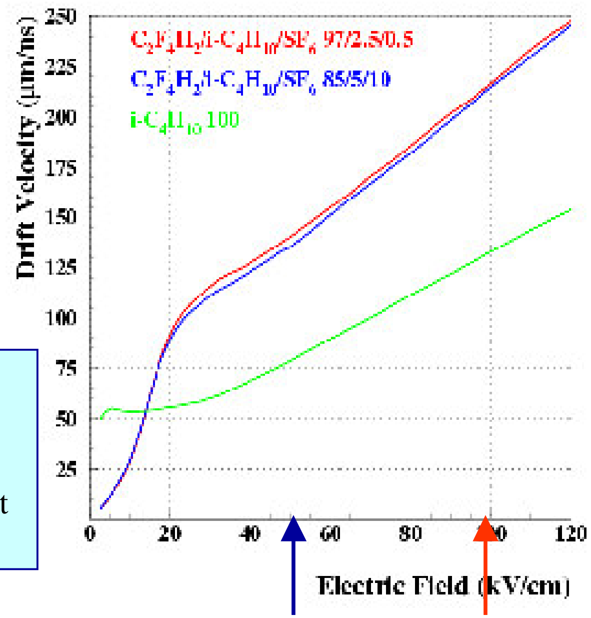
$\sigma_t = 1.28255/(\alpha-\eta)v$

α= Townsend coefficient

η=Attachment coefficient

$\alpha-\eta$ = Effective townsend coefficient

v= Drift velocity



T-RPC E~50 kV/cm

MRPC E~100kV/cm

T-RPC σ_t ~ 1ns

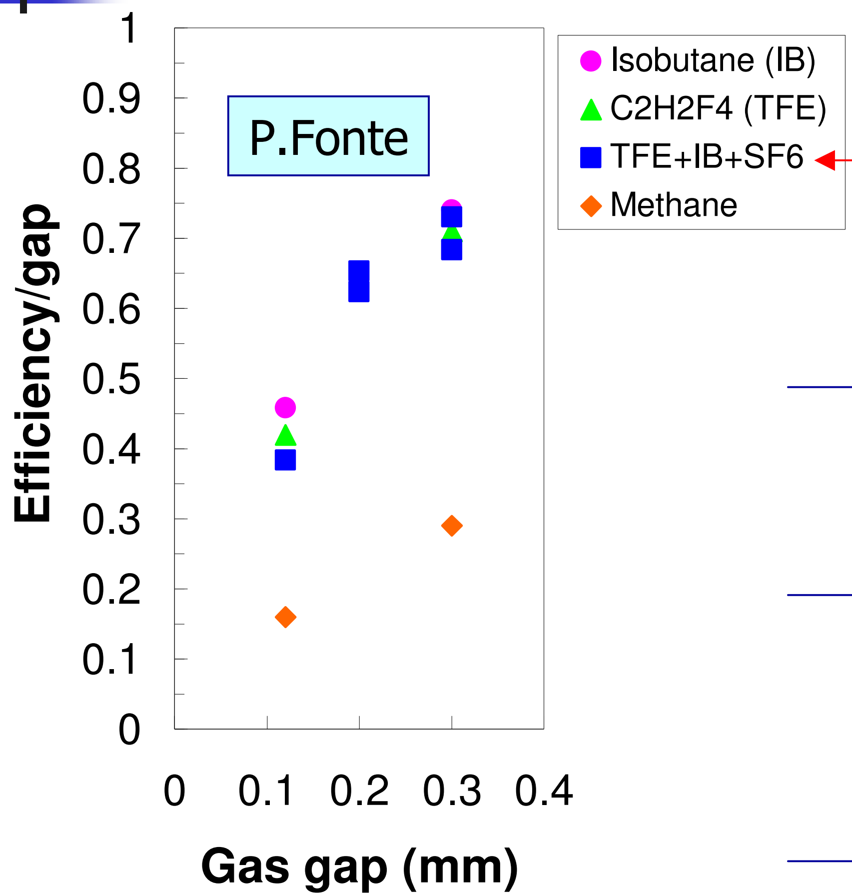
MRPC σ_t ~ 58ps

T-RPC v~130 µm/ns

MRPC v~220 µm/ns

W.Riegler et al: Detector physics and simulation of resistive plate chambers. **NIMA 500 (2003) 144-162**

Efficiency and gap size

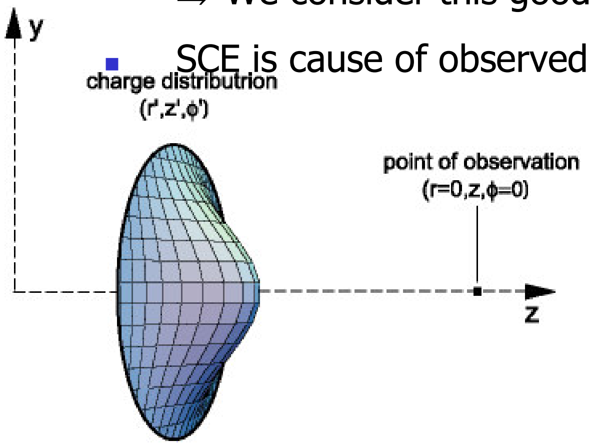


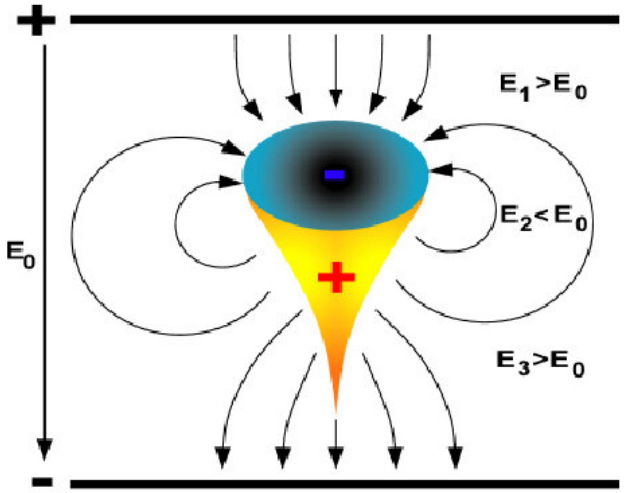
$$\varepsilon_{total} = 1 - (1 - \varepsilon_{Gap})^{n_{Gap}}$$

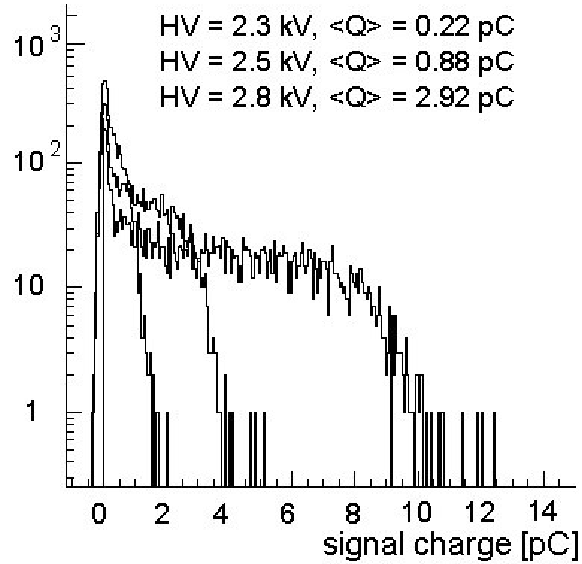
n_{Gaps}	gap(mm)	ε_{Gap}	ε_{total}
2	0.3	0.7	0.91
4	0.3	0.7	0.99
2	0.2	0.65	0.88
4	0.2	0.65	0.98
6	0.2	0.65	0.99
4	0.1	0.4	0.84
6	0.1	0.4	0.87
8	0.1	0.4	0.98
10	0.1	0.4	0.99

The charge problem within timing RPCs

- Mean values deviate by a factor 2.
- Reminder: This has to be compared with a factor 10^7 difference without inclusion of SCE in simulation!
  $\Rightarrow$ We consider this good agreement!
- SCE is cause of observed 'small' charges and of shapes of charge spectra





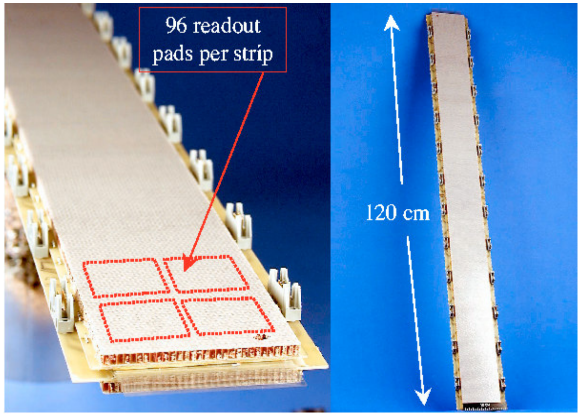
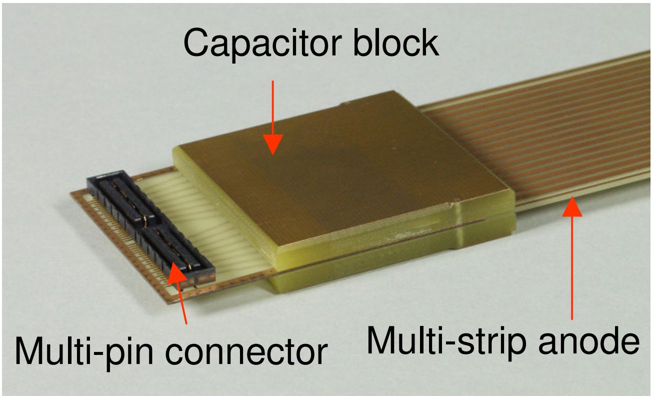
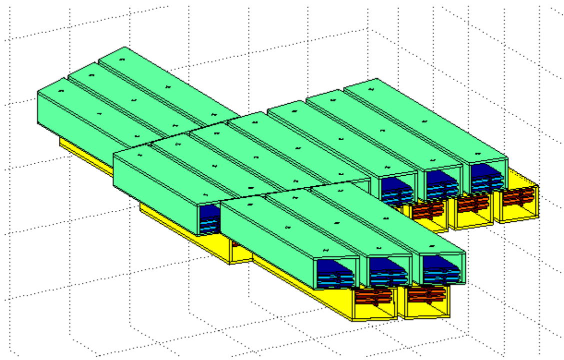


a) Simulation

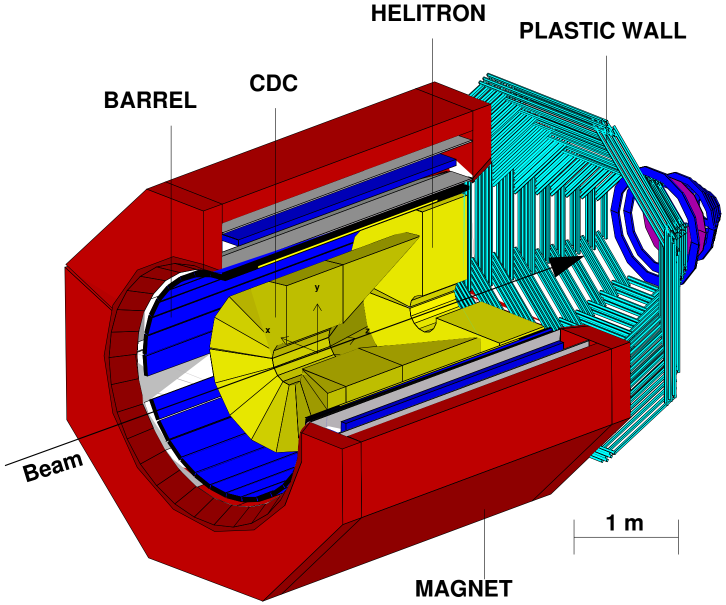
C.Lippmann (PhD)
W.Riegler

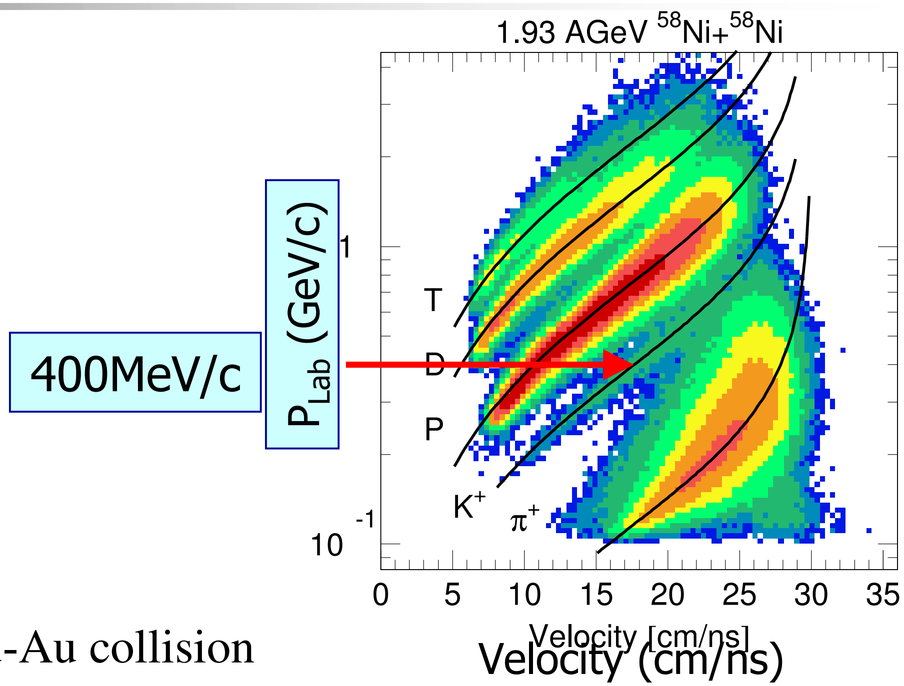
The Hardware

Timing RPC branches

ALICE Pad-Anode MRPC	FOPI Strip-Anode MMRPC	HADES Single-Strip
		
σ_t<50 ps	σ_t<60 ps	σ_t<60 ps

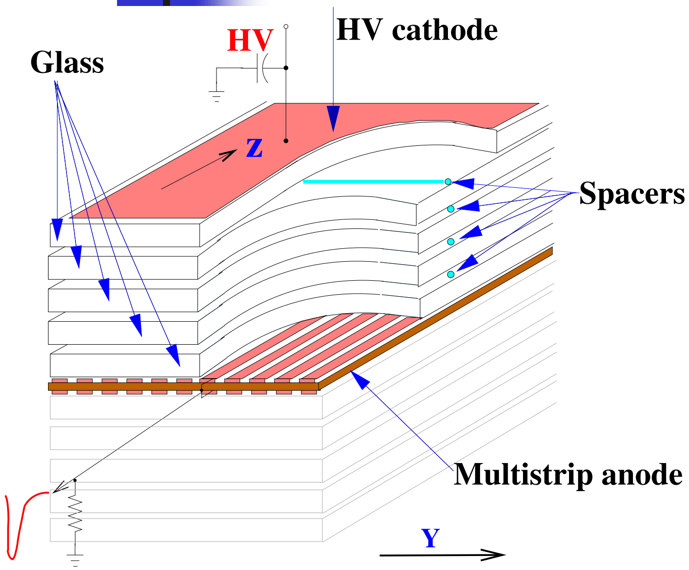
FOPIs MRPC based ToF system





Central Au-Au collision
at 1.45 AGeV has ~60-
particles in the acceptance
of the proposed MMRPC barrel
This needs a granularity of
700 cells (2500 strips)

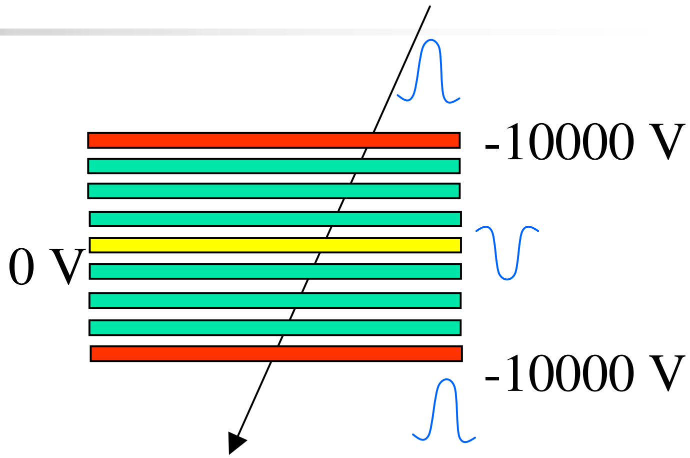
Multistrip-MRPC (single ended strips)



Multi-strip anode:

$x_{pos} = (t_1 - t_2)/2 \bullet v_s$

$t_m = (t_1 + t_2)/2$



Timing:

$\sigma_t = 1.28255/(\alpha - \eta)v$

$\alpha - \eta$ = Effective Townsend coefficient

v = Drift velocity

Global MMRPC parameters:

Gas : $C_2F_4H_2$/isobutene/SF_6 85/5/10

E-Field ~ 100 kV/cm

Spacing ~ 220-270 µm

Glass ~ 0.25-1.1 mm

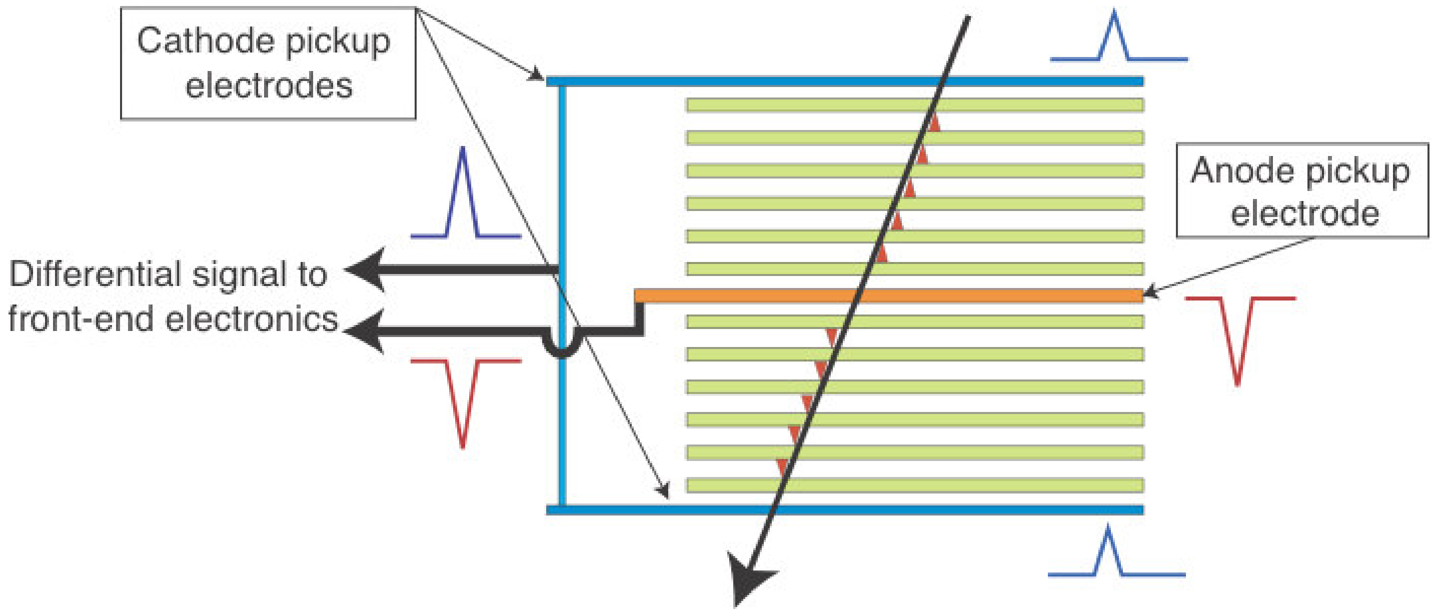
$\alpha - \eta$ ~ 100/mm

v ~ 220 µm/ns

σ_t ~ 58 ps

ALICE MRPCs (differential pad)

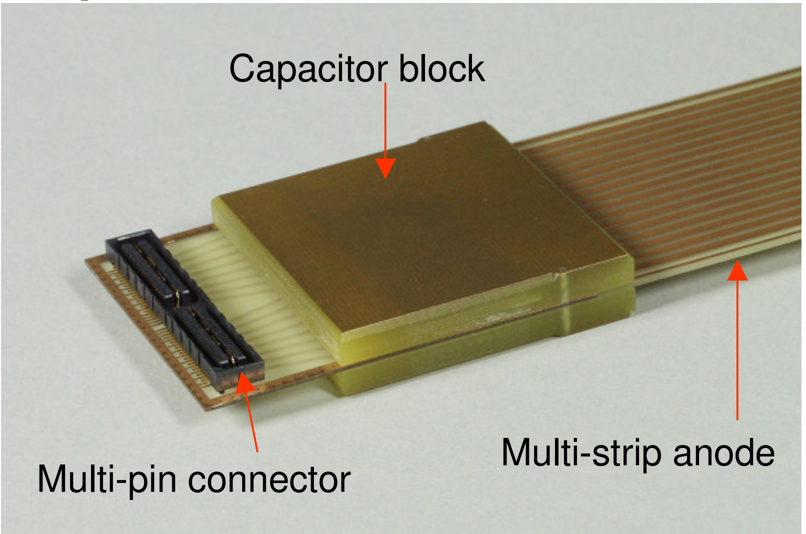
ALICE-TOF has 10 gas gaps, each of 250 micron width
Built in the form of strips, each with an active area of 120 x 7 cm^2, readout by 96 pads (each 2.5 x 3.5 cm^2)



Timing depends on individual gap
Efficiency depends on total gas gap (10x250 μm)

M.C.S.Williams INFN Bologna

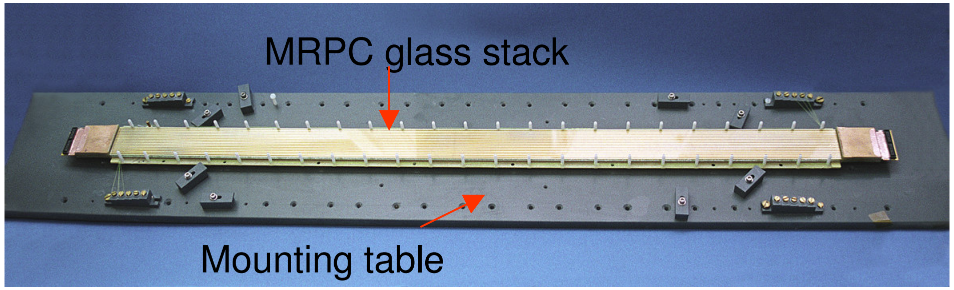
MMRPCs parts

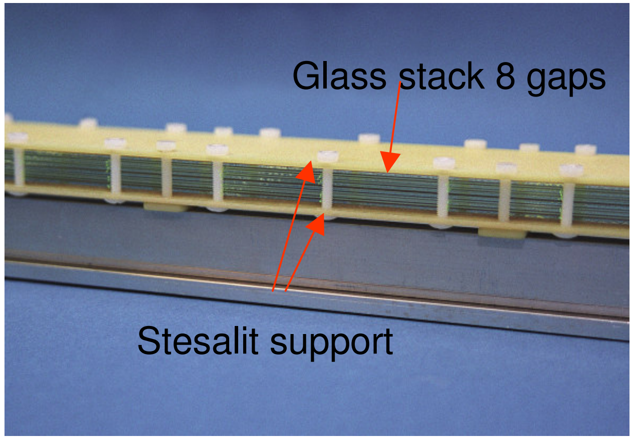


FOPIs MMRPC parameters:

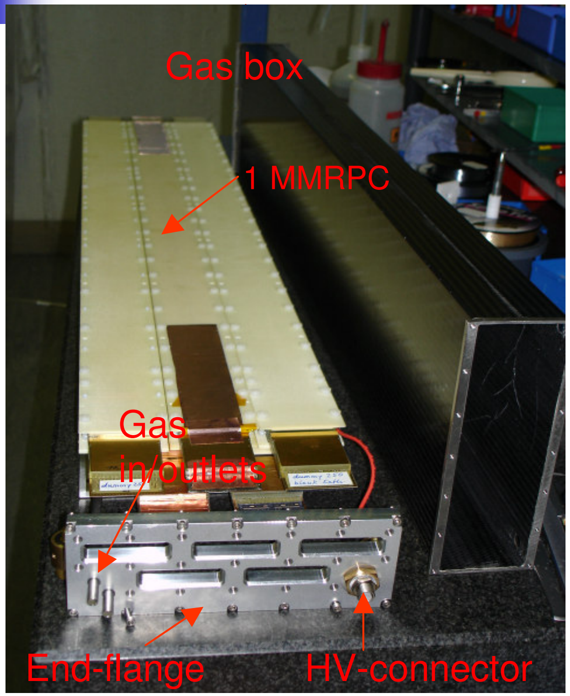
90 x 4.6 cm²	**active area**
1.1 & 0.5 mm	**10 glass plates**
8 x 220 µm	**gaps** (fishing rope)
16	**strips**
1.94/0.6 mm	**strip/gap**
~10 kV	**applied voltage**

Gas:
$C_2F_4H_2$/isobutene/SF6 85/5/10





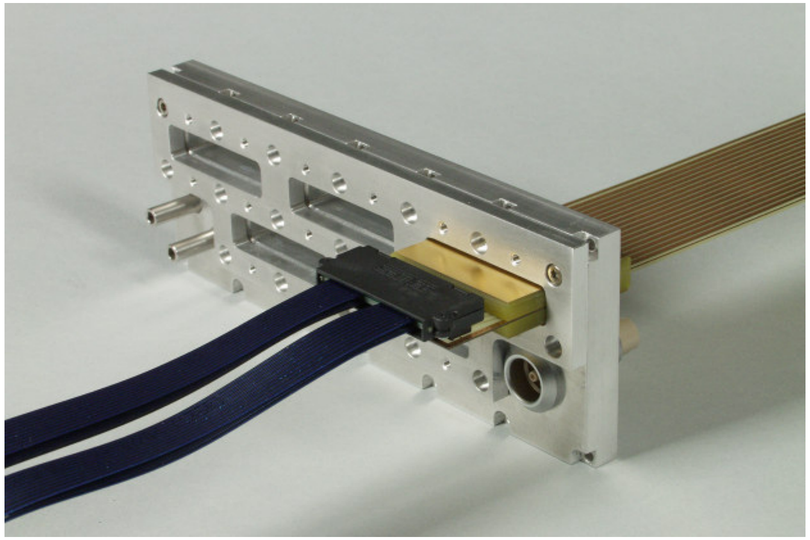
Compact module



5 MMRPCs in a Super Module (SM)
30 SMs within FOPI

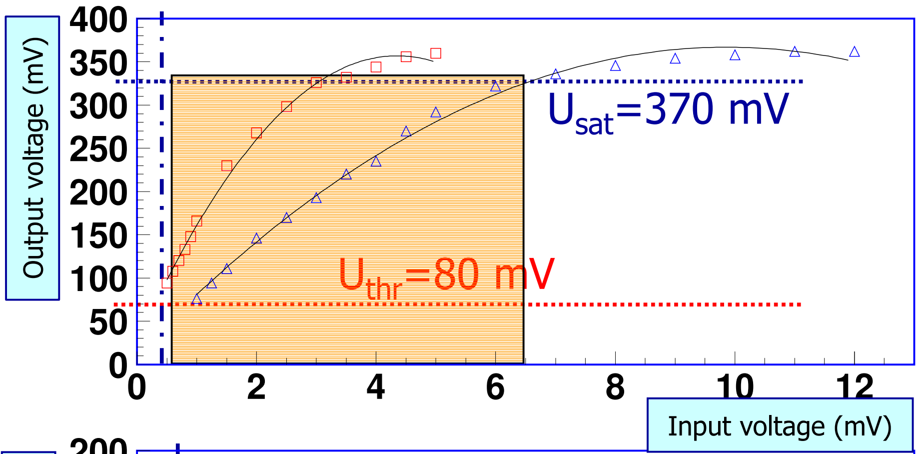
K.D.Hildenbrand
M.Kis
X.Zhang
Y.J.Kim

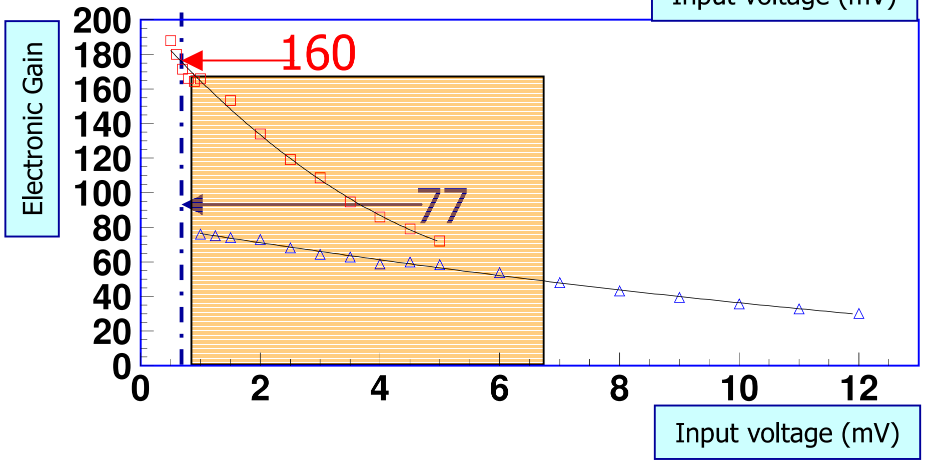
Interface between MMRPC & Electronics
SAMTEC 50 Ω multi-coaxial cable
0.8 mm pitch. In total 80 connections
(16 used).

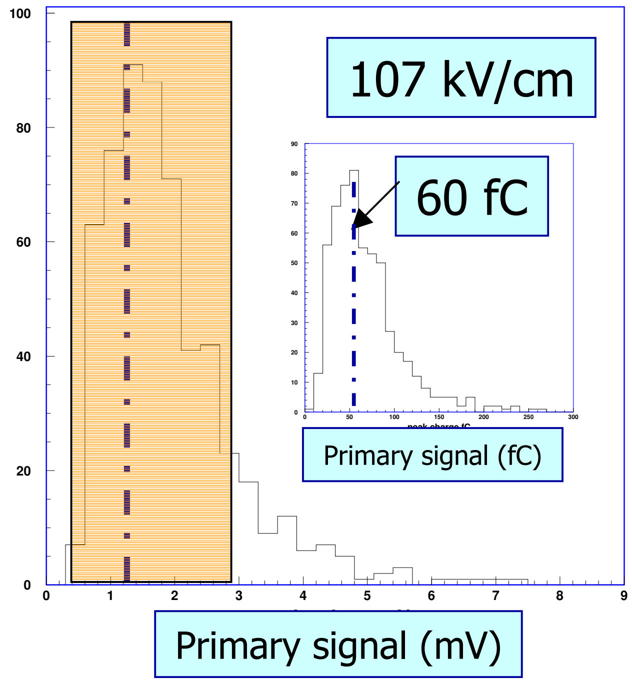


The Electronics

FEE-gain & RPC-charge





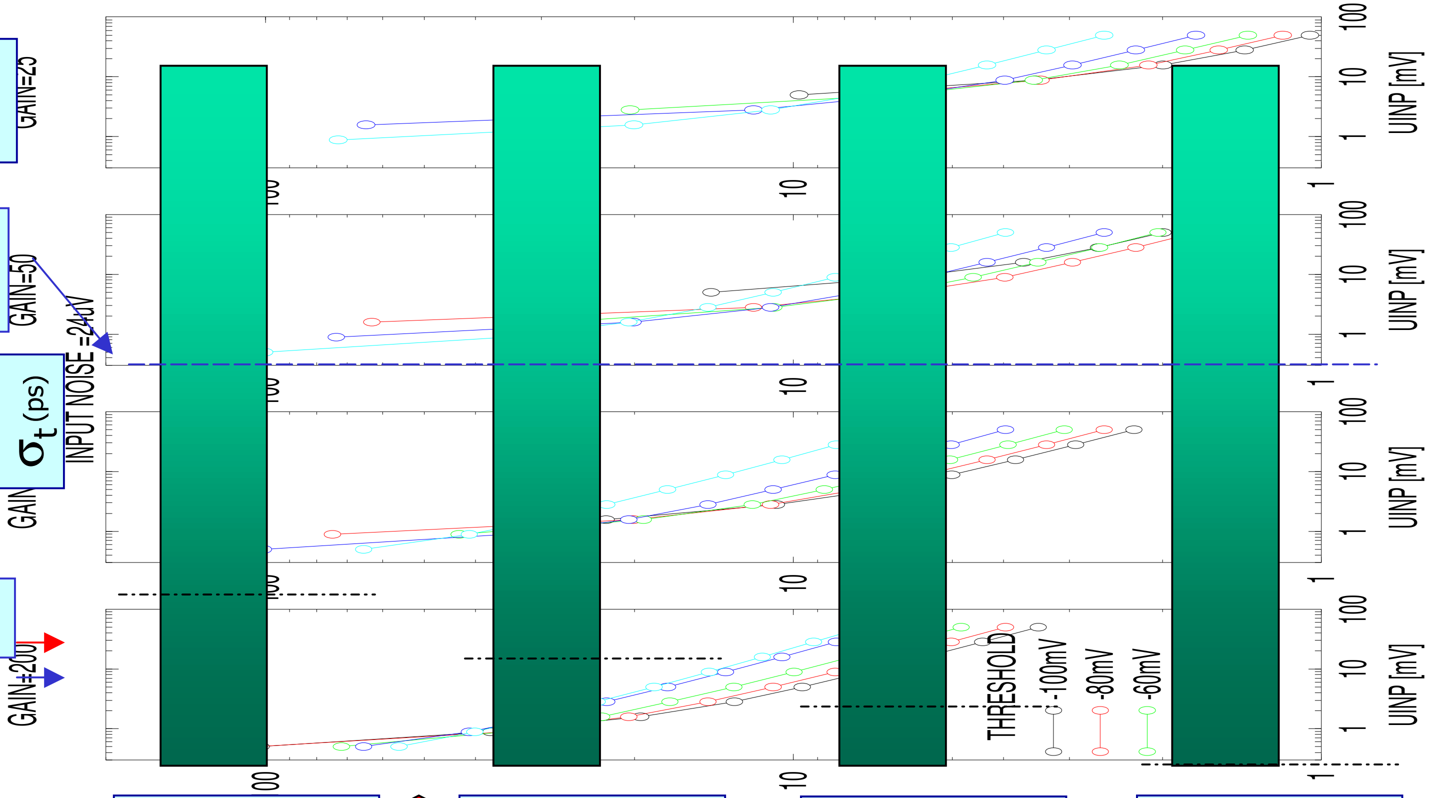


Strong non-linear dependence of FEE-gain with a saturation at 370 mV.
The charge for a signal is 40-100 fC which is in our case between 1-7 mV

FEE-simulations

GSI+HD+I3HP
M.Ciobanu

Upper limit for FEE electronic resolution



Input voltage (mV)   Input voltage (mV)   Input voltage (mV)   Input voltage (mV)

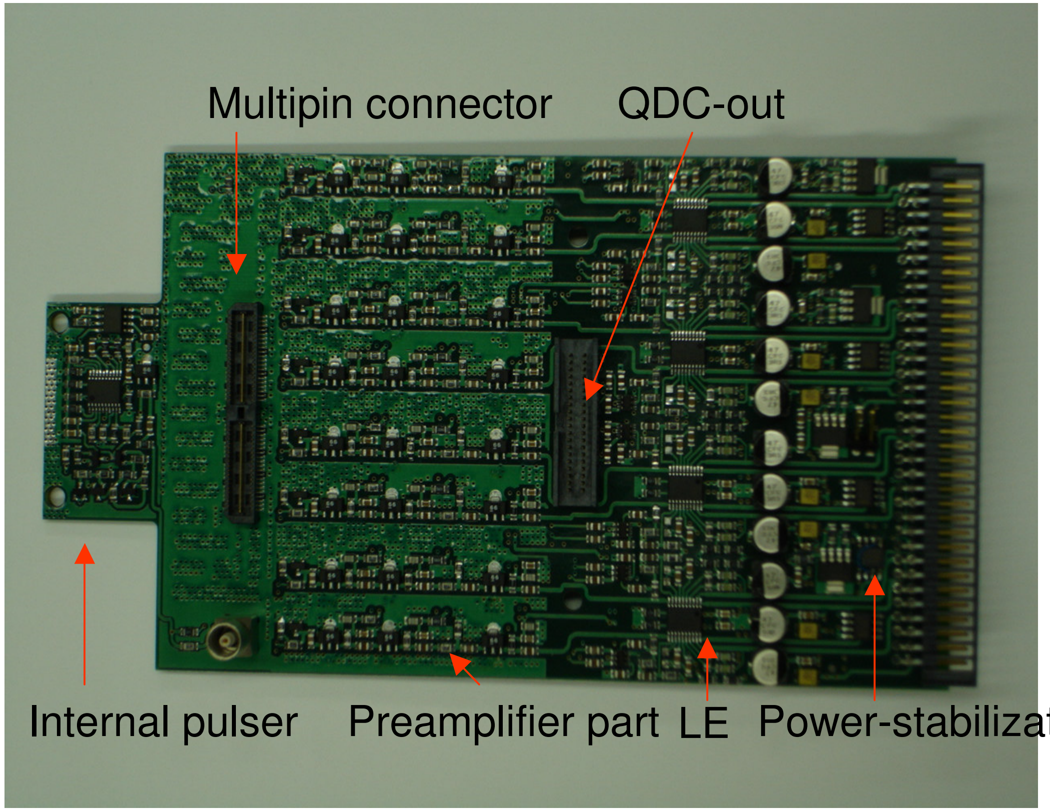
FOPI-threshold

FOPI-combined "noise level" U_n ~50-60 mV

Electronic gain for MRPCs in avalanche mode is between 130-180

FOPIs Front-End-Electronic-card

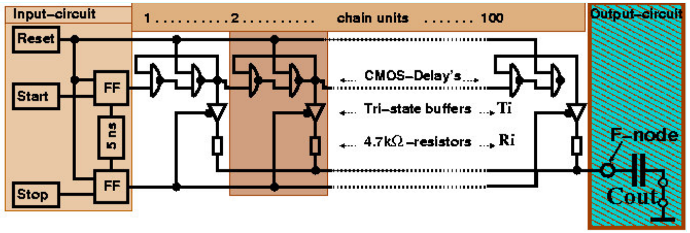
GSI+HD+I3HP
M.Ciobanu



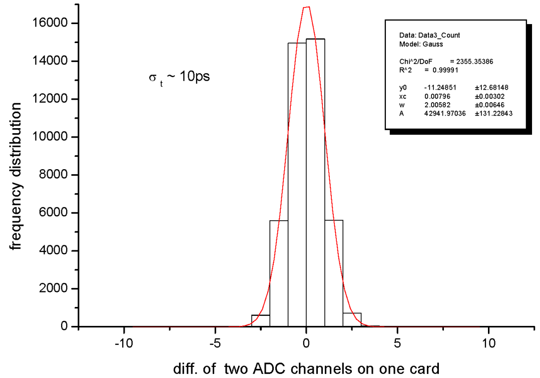
FEE4:
9.5 • 14.5 cm^2
6 layer PCB
16 ch. T/Q
Gain 160
T/Q ~ 2
0.55 W/ch
σ_E<18 ps

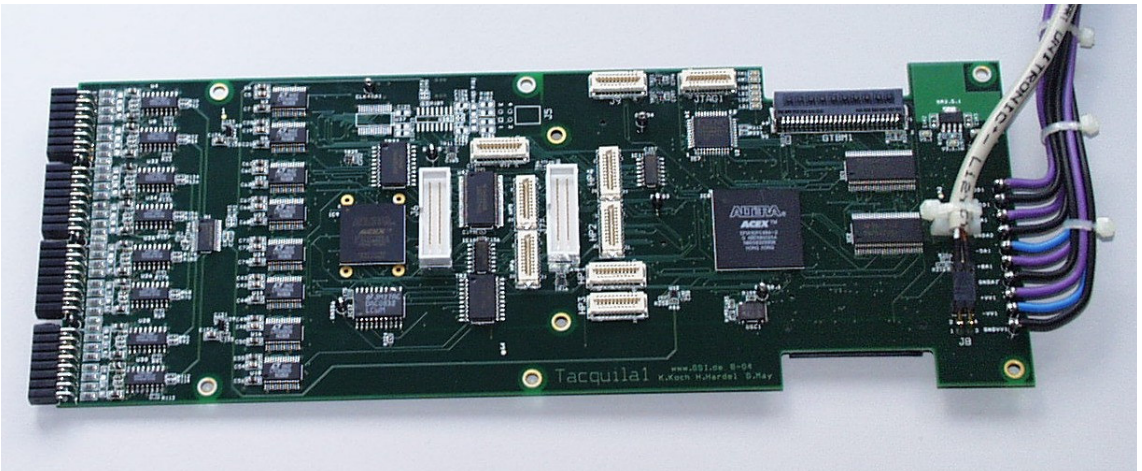
FOPIs digitizer (TACQUILA)

GSI-ELEX
R.Schulze.R.Hardel
K.Koch,E.Badura



TAC ASIC
1 ch.
σ_t <10 ps

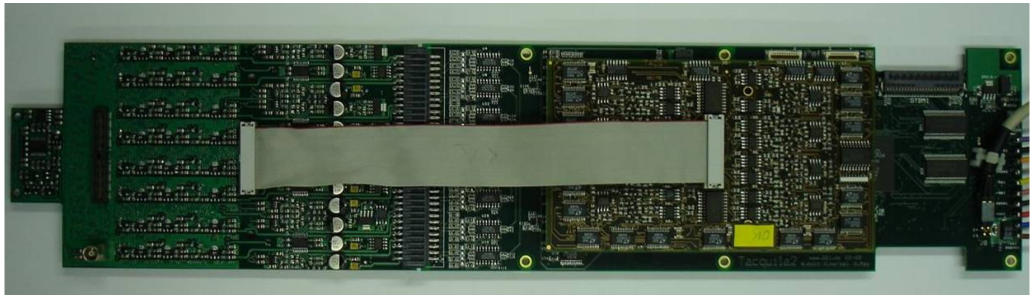


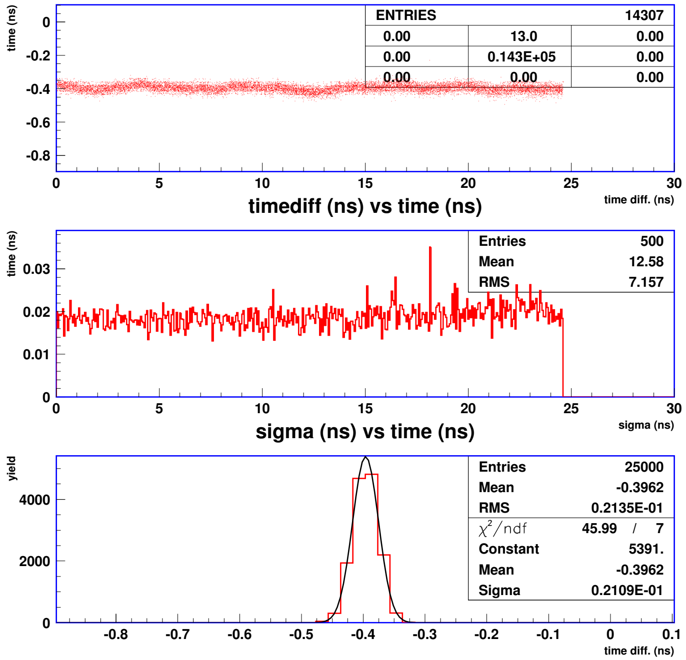


TACQUILA:
Size: 9.5 • 25 cm^2
#T ch.: 16 TACs
#A ch.: 16 ADCs
0.5 W/ch
On board Z.S..
Daisy chain 30 TQ
1 ➔GTB-SAM4

Full readout system

Free running common stop system at 40 MHz.
Individual TAC resets 0.2-2.0 µs.





FEE + TAC/QDC-Digitizer

16 ch.

G ~ 50-250 TAC ~10 ps/ch

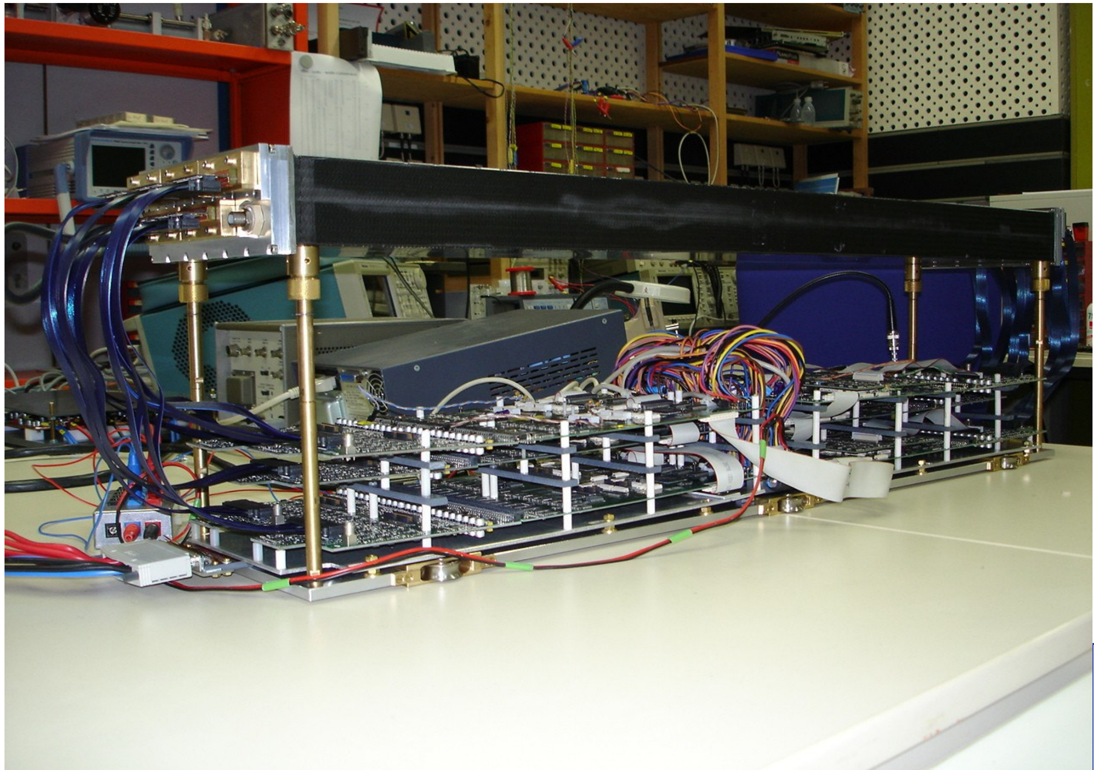
δf ~ 1.5 GHz Zero-suppression

P_F ~ 0.56 W/ch P_T ~ 0.5 W/ch

Full system electronic resolution
σ_E < 25 ps

Full readout system

Free running common stop system at 40 MHz.
Individual TAC resets 0.2-2.0 µs.



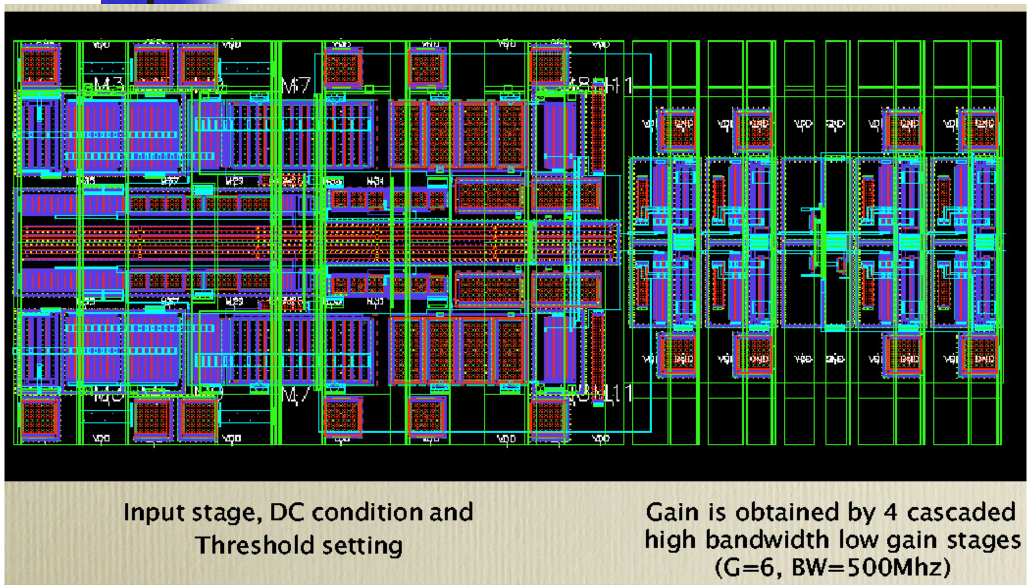
Electronic resolution

FEE ~ 18 ps
TAC ~ 10 ps
δt ~ 15 ps

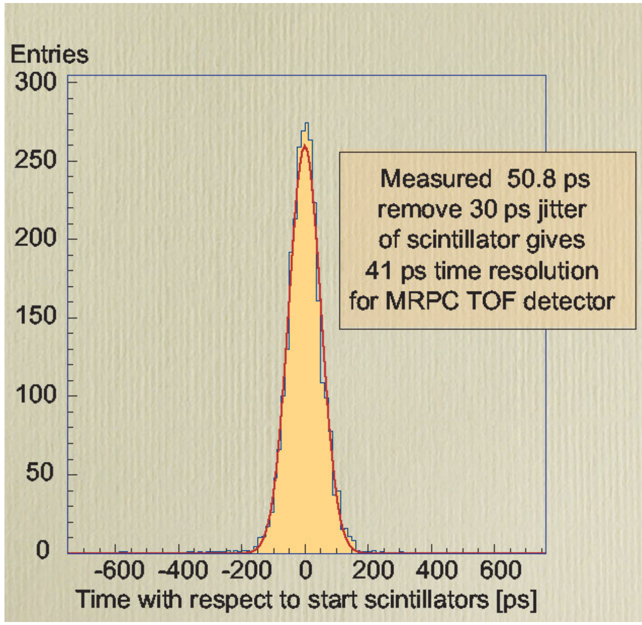
TAC	**< 2 ps**
+ FEE	**< 3 ps**
+ Card	**➔ 10 ps**
+ Clock	**➔ 10 ps**
Σ➔ δt	**~ 15 ps**

Full system electronic resolution
$\sigma_E < 25$ ps

ALICE-FEE (NINO)



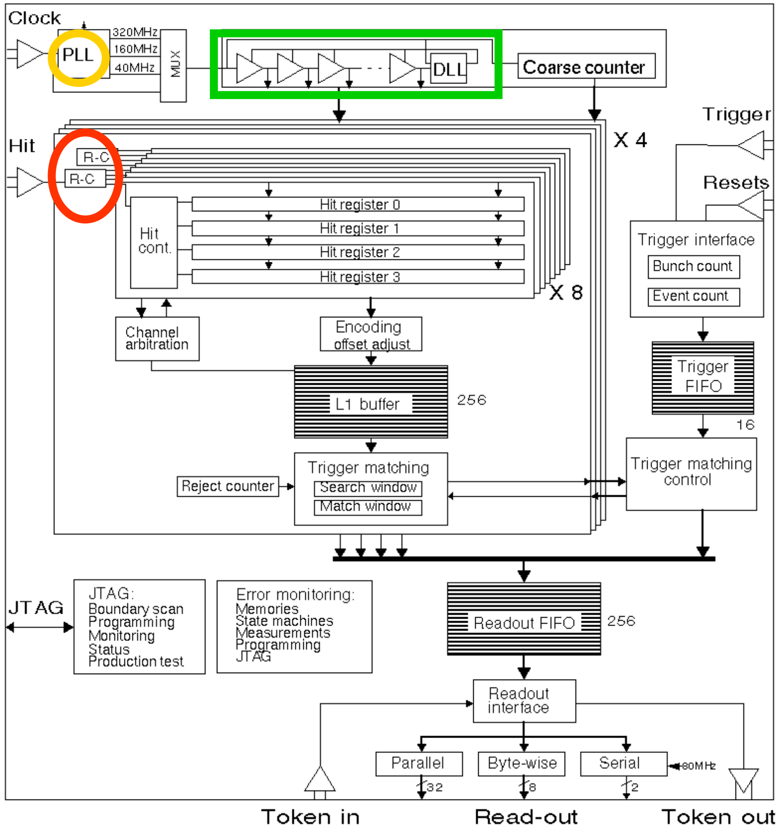
P.Jarron
F.Krummenacher
M.C.S. Williams



- Using 0.25 µm CMOS IBM technology
- Full differential 8 ch design with ToT
- Low power 40 mW/ch
- Resolution below σ_t<20 ps

ALICE-digitizer (TDC)

F.Anghiolfi



HPTDC is fed by a **40 MHz clock** giving us a basic 25 ns period (coarse count).

A **PLL (Phase Locked Loop)** device inside the chip does clock multiplication by a factor 8 (3 bits) to 320 MHz (3.125 ns period) .

A **DLL (Delay Locked Loop)** done by 32 cells fed by the PLL clock acts a 5 bits hit register for each PLL clock (98 ps width LSB = 3.125 ns/32).

4 **R-C delay lines** divides each DLL bin in 4 parts (R-C interpolation)

ALICE electronics summary

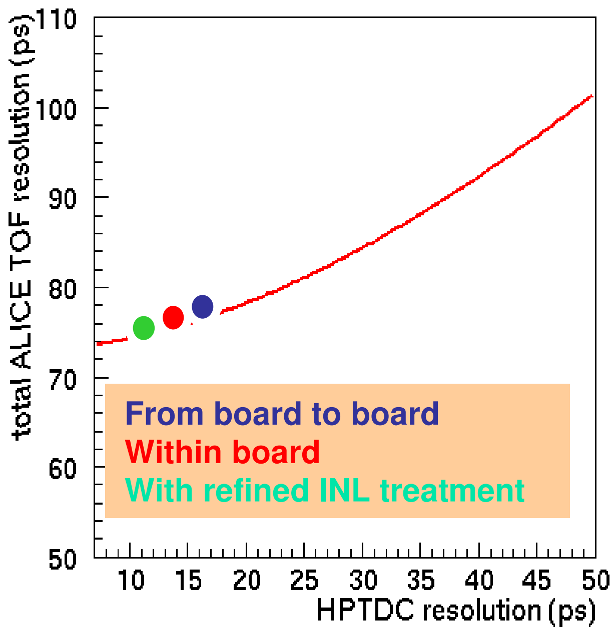
$$\sigma^2 = \sigma^2_{FEE} + \sigma^2_{T0} + 2\sigma^2_{TDC} + \sigma^2_{clock} + \sigma^2_{clockTRM}$$

Reference values (TDR addendum):

FEE	20 ps
T_0	*50 ps*
TDC	25 ps
CLOCK	15 ps
CLTRM	10 ps

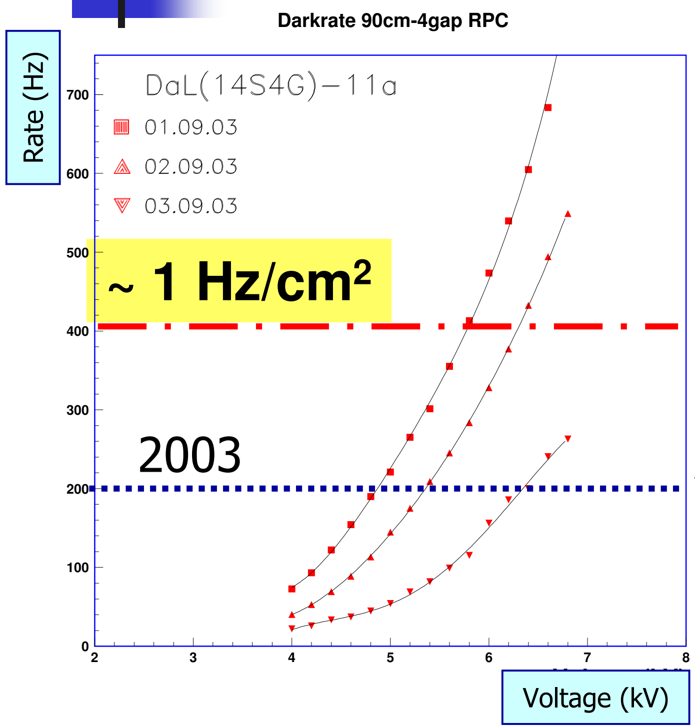
Total:	62 ps
	36 ps

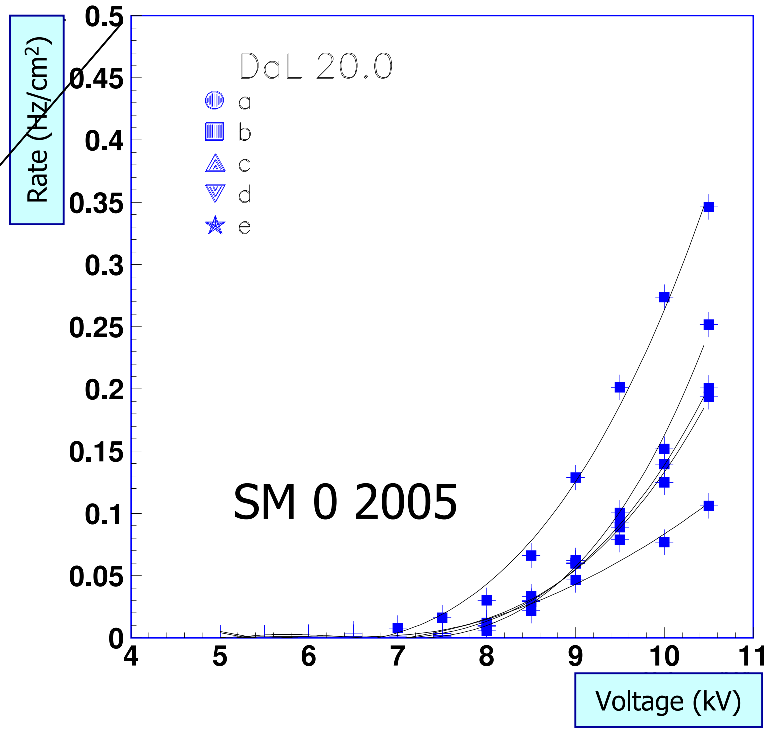
M.C.S. Williams
F.Anghiolfi



Detector performance

Darkrate of MMRPCs

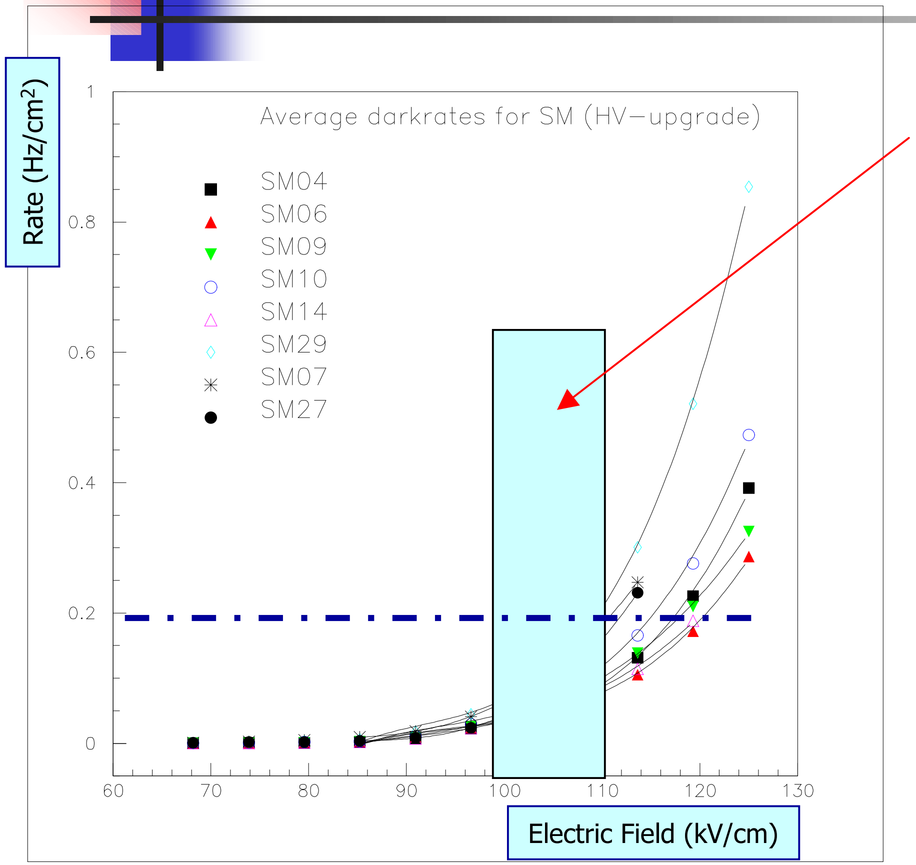




3 days under high voltage to get optimal conditions.

SM 0 shows in Dec. 2005 darkrates well below 0.5 Hz/cm^2 for all counters

Darkrate vs E-field

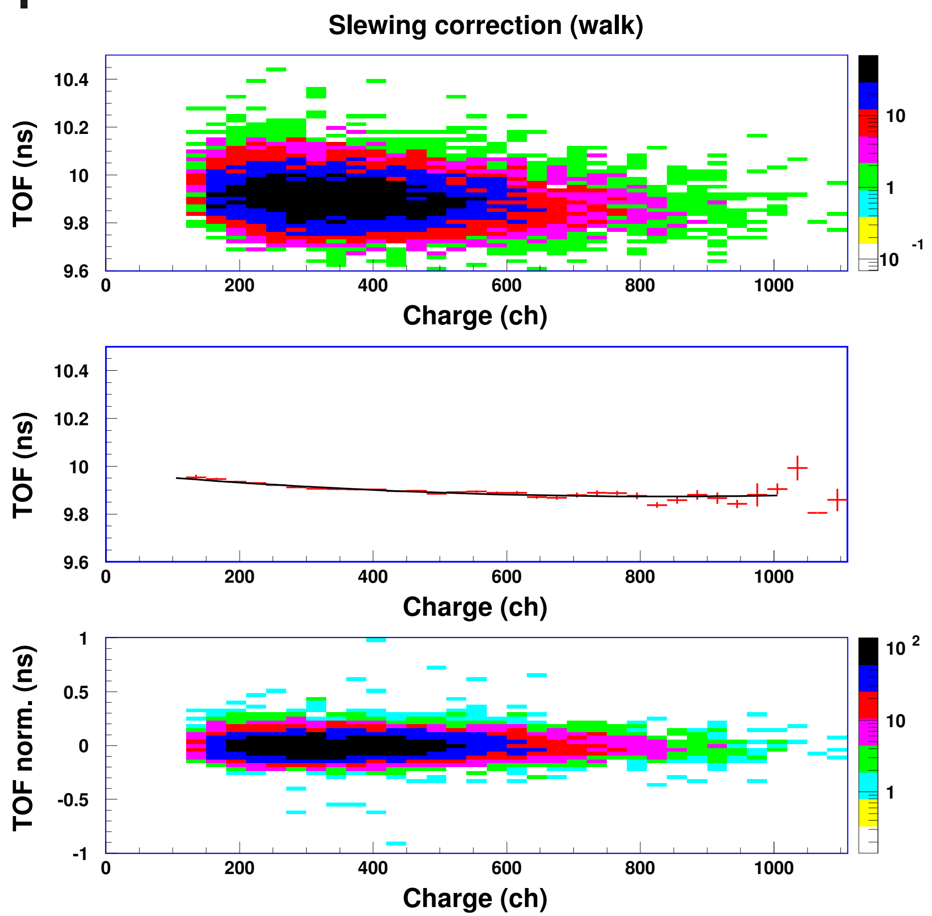


E-field = App. Voltage / Gap size
Exp:
4x0.22 mm = 0.088 cm
8.8 kV ➔ 100 kV/cm

Trigger option:
Normal < 0.2 Hz/cm² ➔ 80 Hz/counter
Typically FEE5+TAQ ➔ 40 Hz/counter

Needs ➔ Multiplicity or Mor for 1 SM

Slewing correction

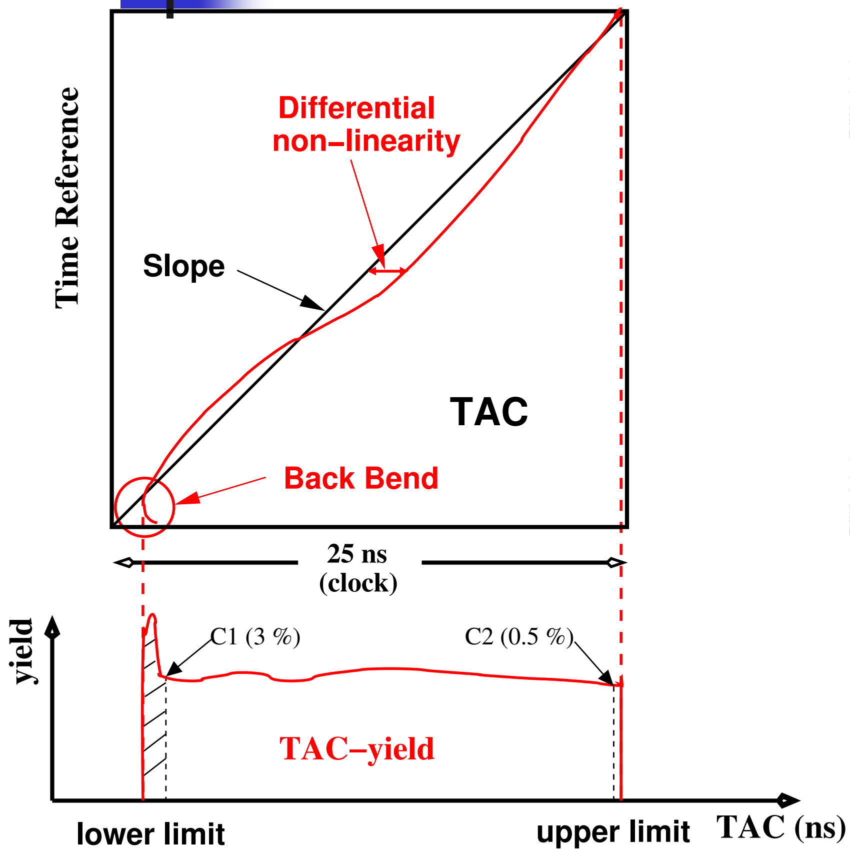


Uncorrected TOF spectra for all strips.

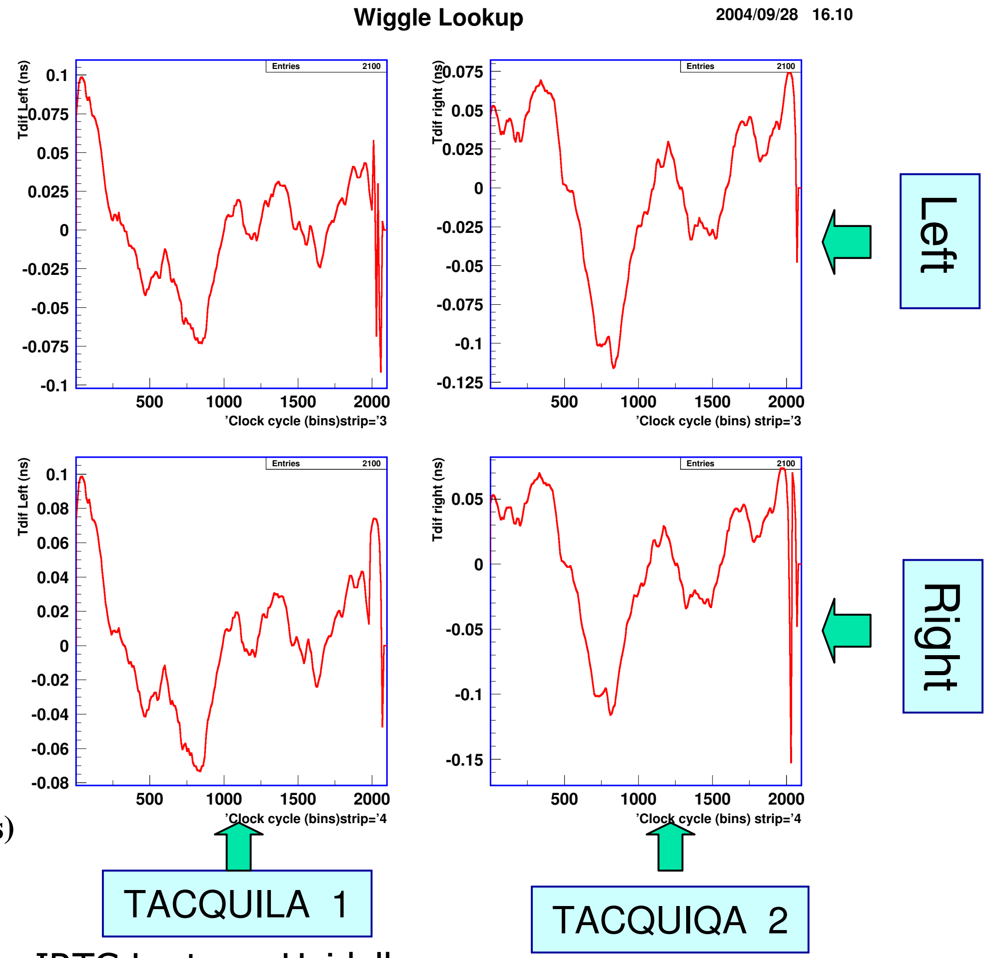
Determined walk correction
T_{walk} < 100 ps

Corrected and normalized TOF

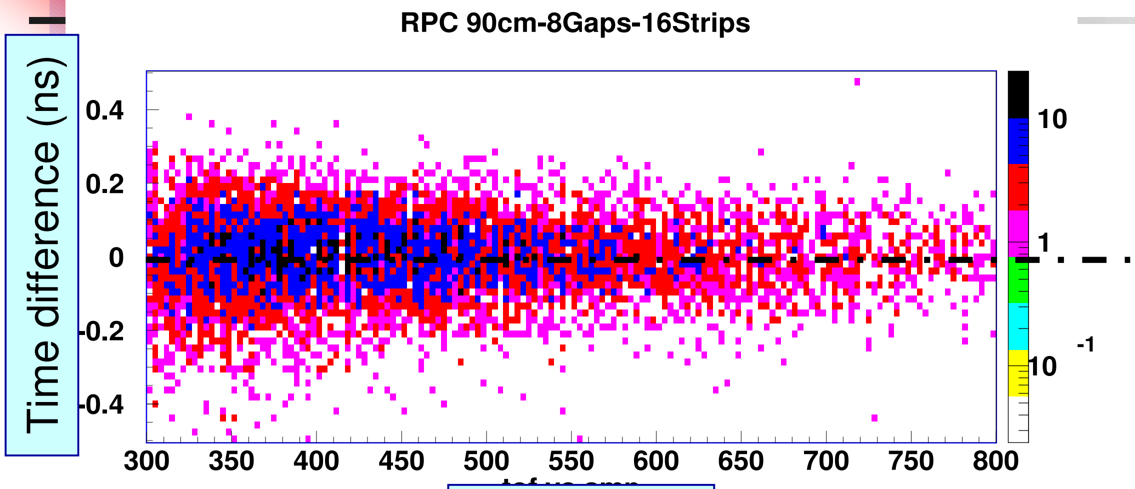
Integral non-linearity's



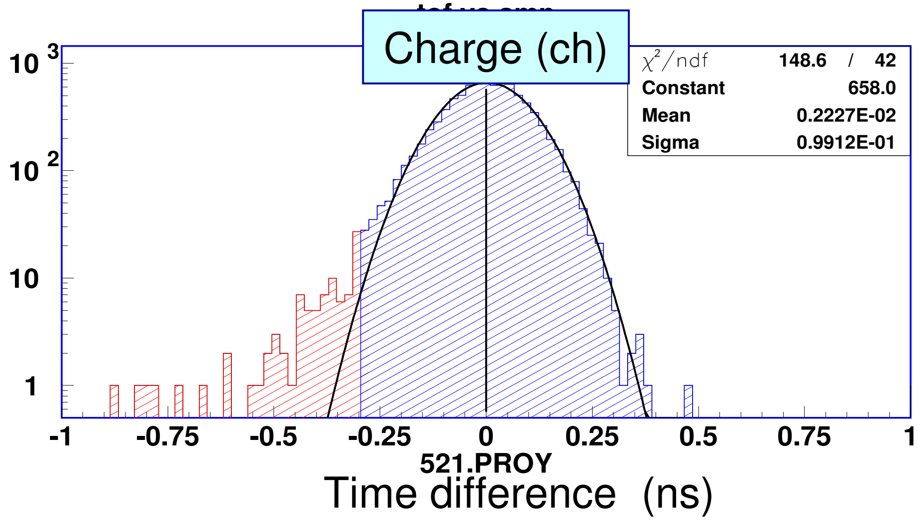
Principle of calibration



Walk, wiggle and tail



After combined corrections for MMRPC B at 108 kV/cm (9.5 kV).



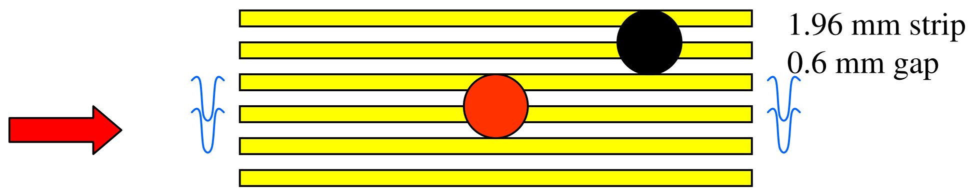
Final resolution plot below 90 ps with a tail < 1%.
Rest tail is from non-perfect wiggle and walk corrections **not** from the detector itself.
When the counter is in **avalanche** mode.

What is the operating point of a Multistrip MRPC ?

Timing → σ_t < 100 ps

Efficiency → ε > 98%

Double hit capability:



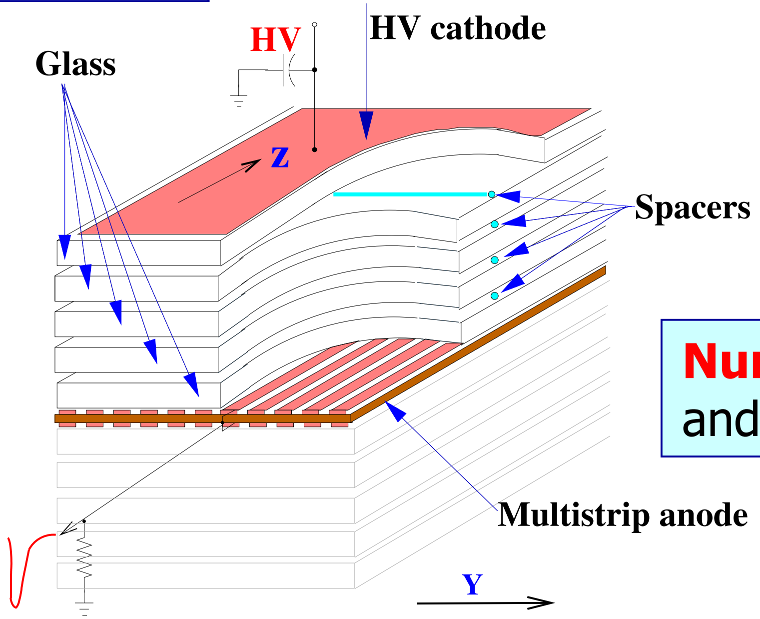
Small cluster (avalanche) size on the anode

Low reflection probability → Optimal adoption to 50 Ω

Small crosstalk (strips, cables) → Below 5 %

What to optimize for what ?

Glass plate thickness and **gap thickness** for **rate**.

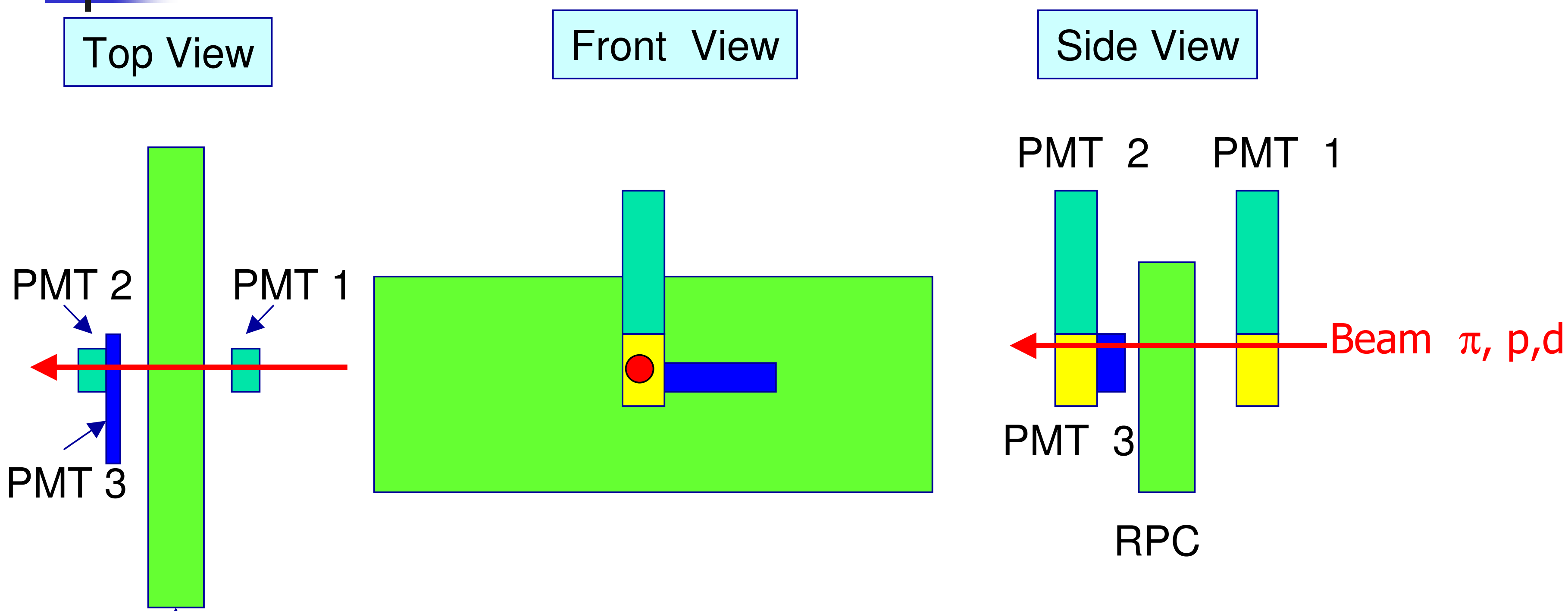


Gap size for **timing** and **cluster size**.

Number of gaps for **efficiency** and **charge distribution**.

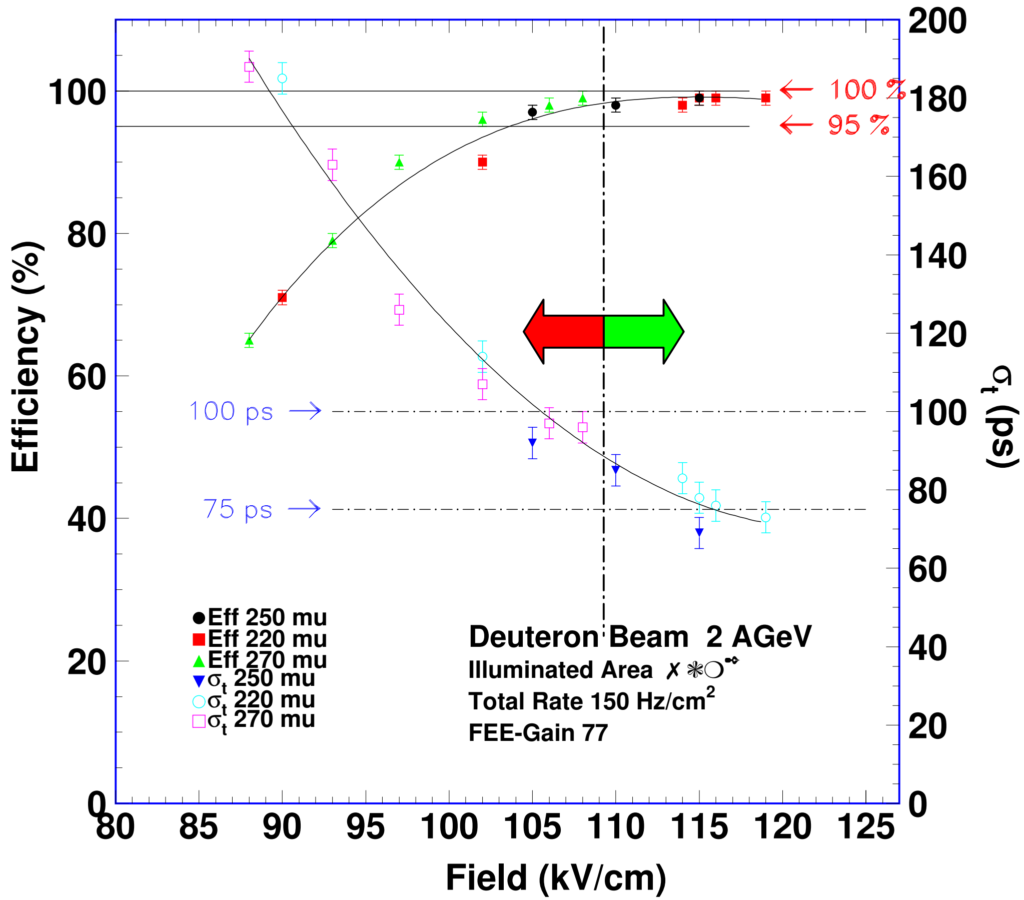
Electronic gain in relation to threshold and **detector gain** for optimizing the **timing**.

Test setup I (direct beam)



Trigger → PMT1 & PMT2
Efficiency → PMT1 & PMT2 & PMT3

Gap size universality for timing and efficiency

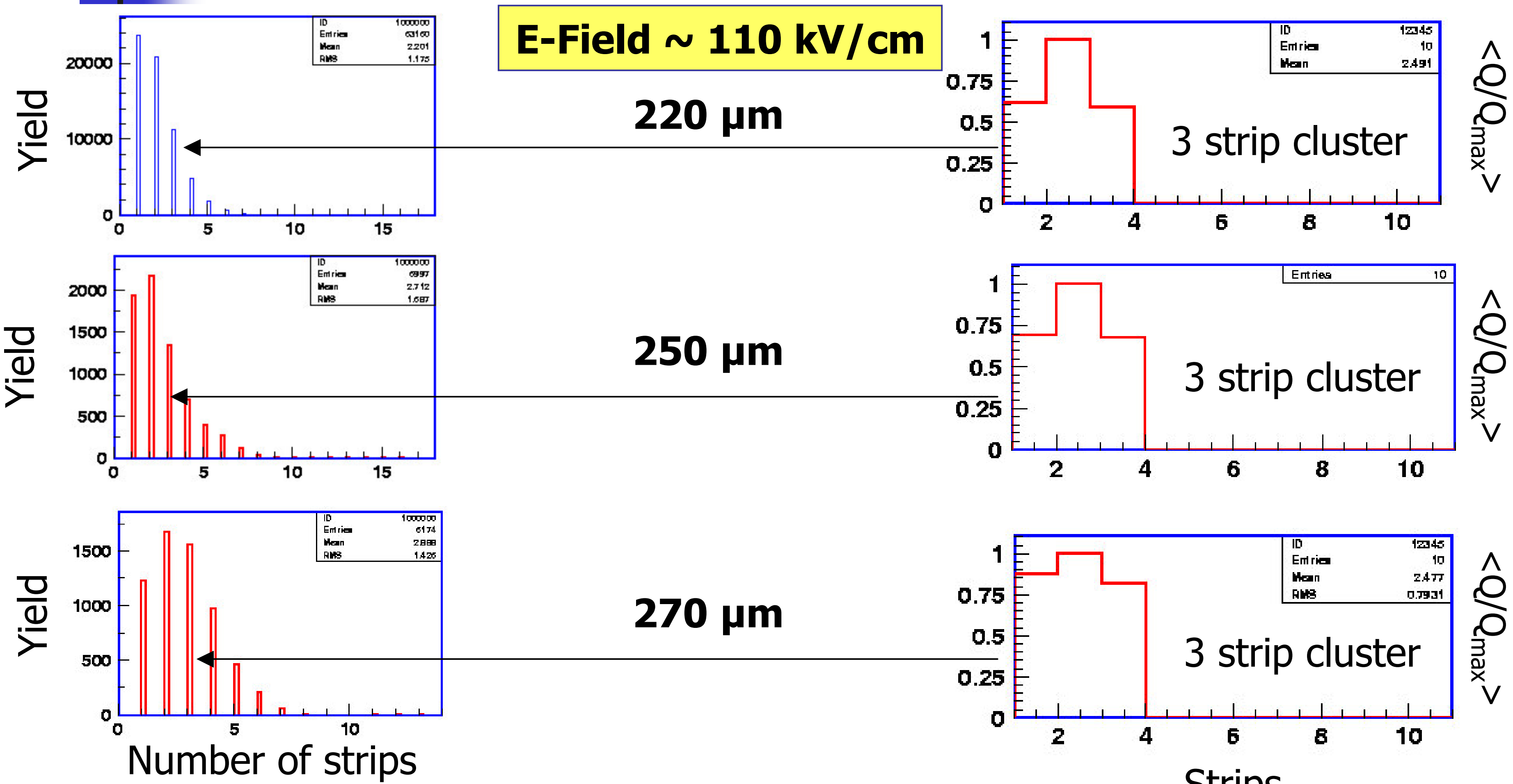


Comparison of timing and efficiency for **220**,**250** and **270 µm** gaps (8).

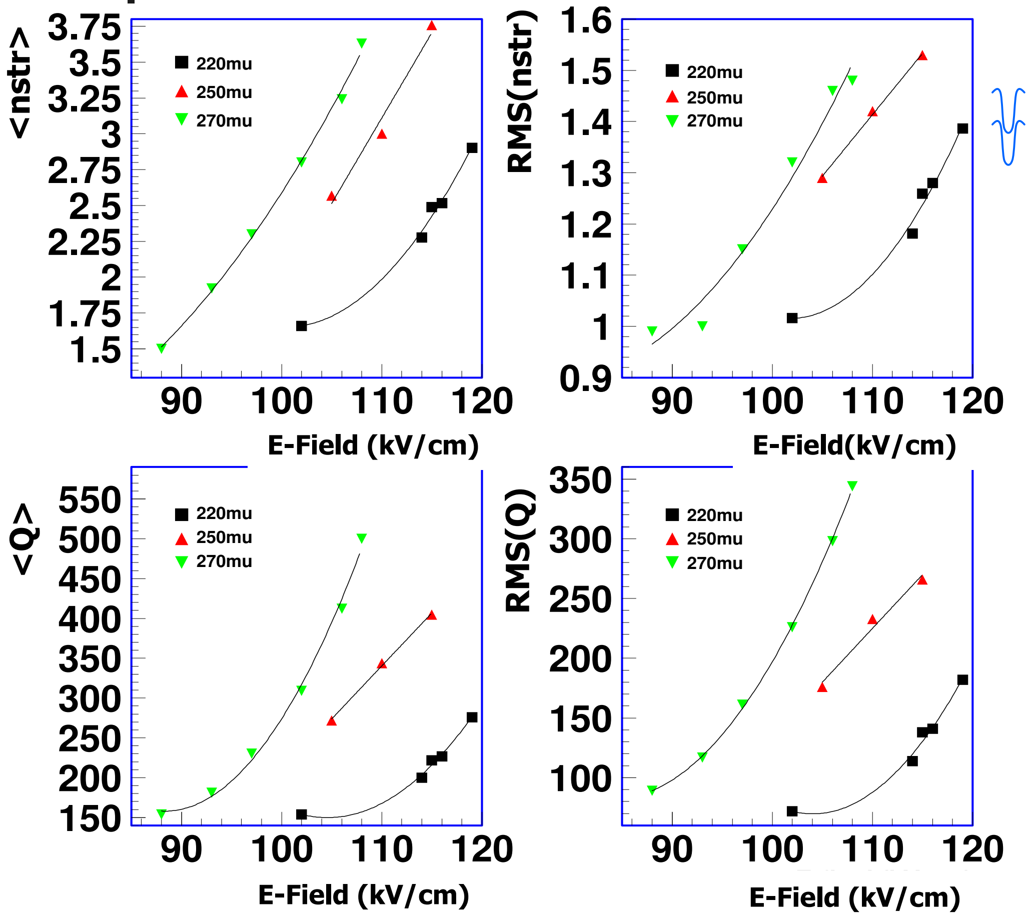
Results:
Fully efficient > 107 kV/cm (98 %)
Best timing > 112 kV/cm (75 ps)

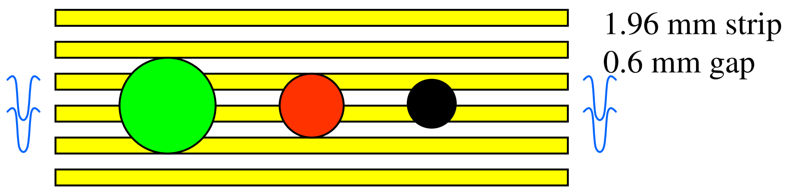
Timing and efficiency depend in the avalanche regime only on the E-field. Both are directly correlated to the field.

What is a cluster ?



Gap size dependence on cluster size and charge

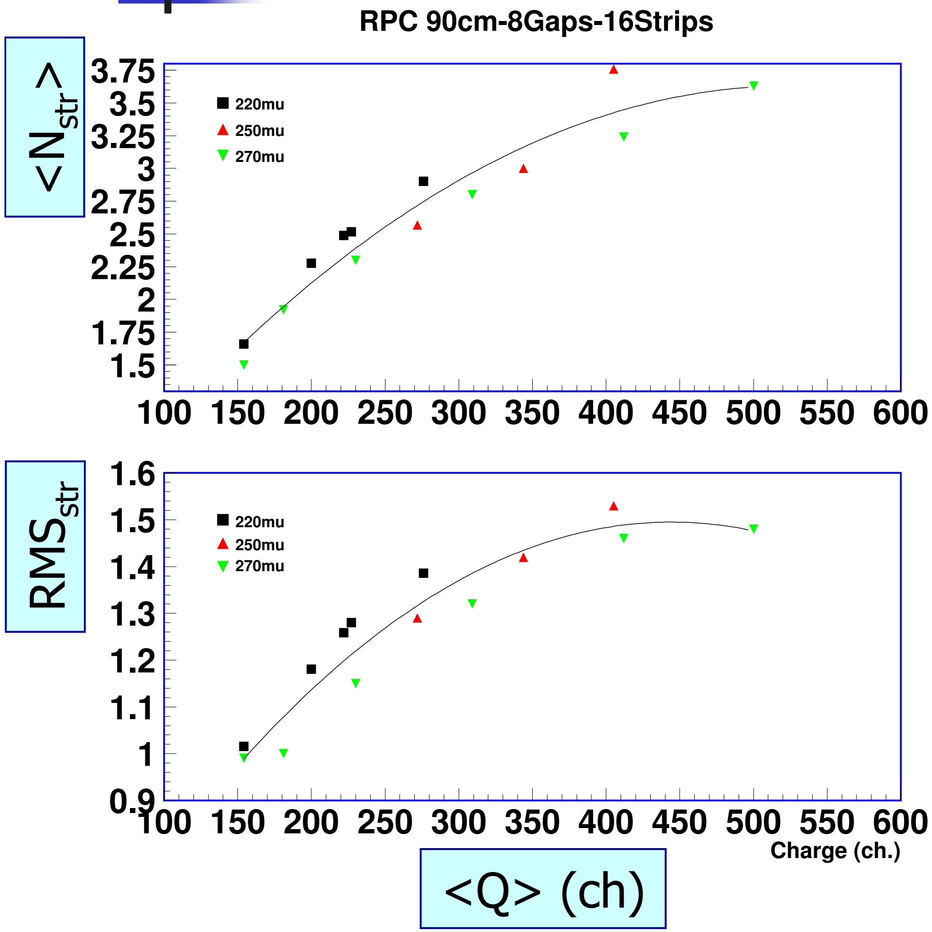




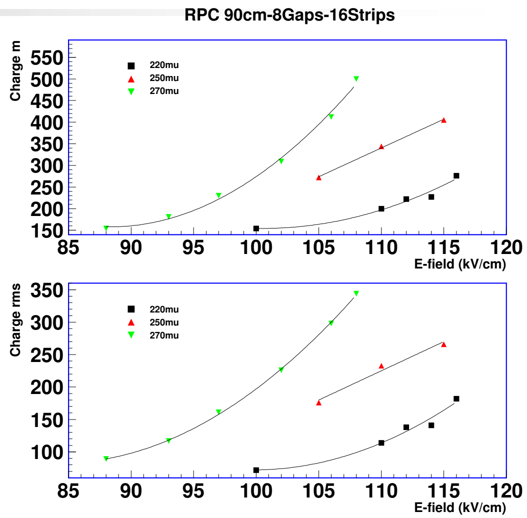
Comparison of cluster size and charge distribution for 220,250 and 270 µm gaps (8).

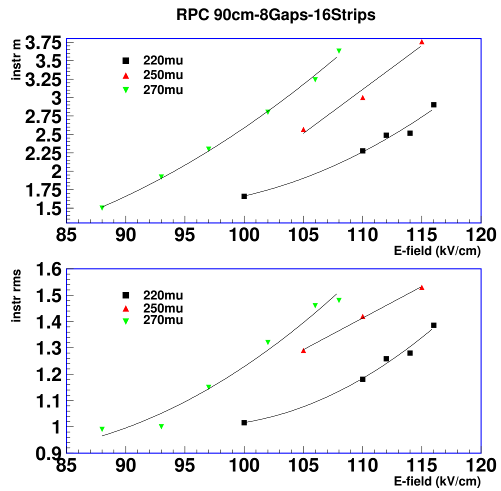
Results:
Cluster size and charge distribution strongly depend on the gap size. Both are only correlated to the E-field for a given gap size.

Cluster size universality

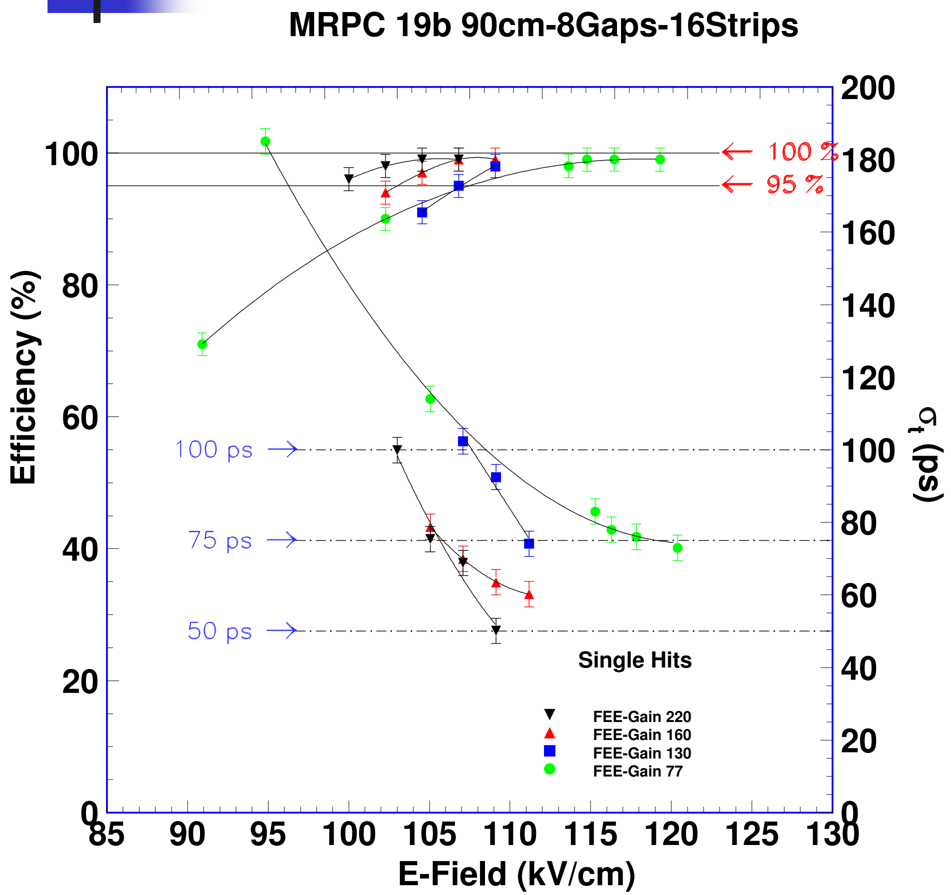


Cluster size is universal too, for the charge dependence





FEE-gain dependence on timing & efficiency



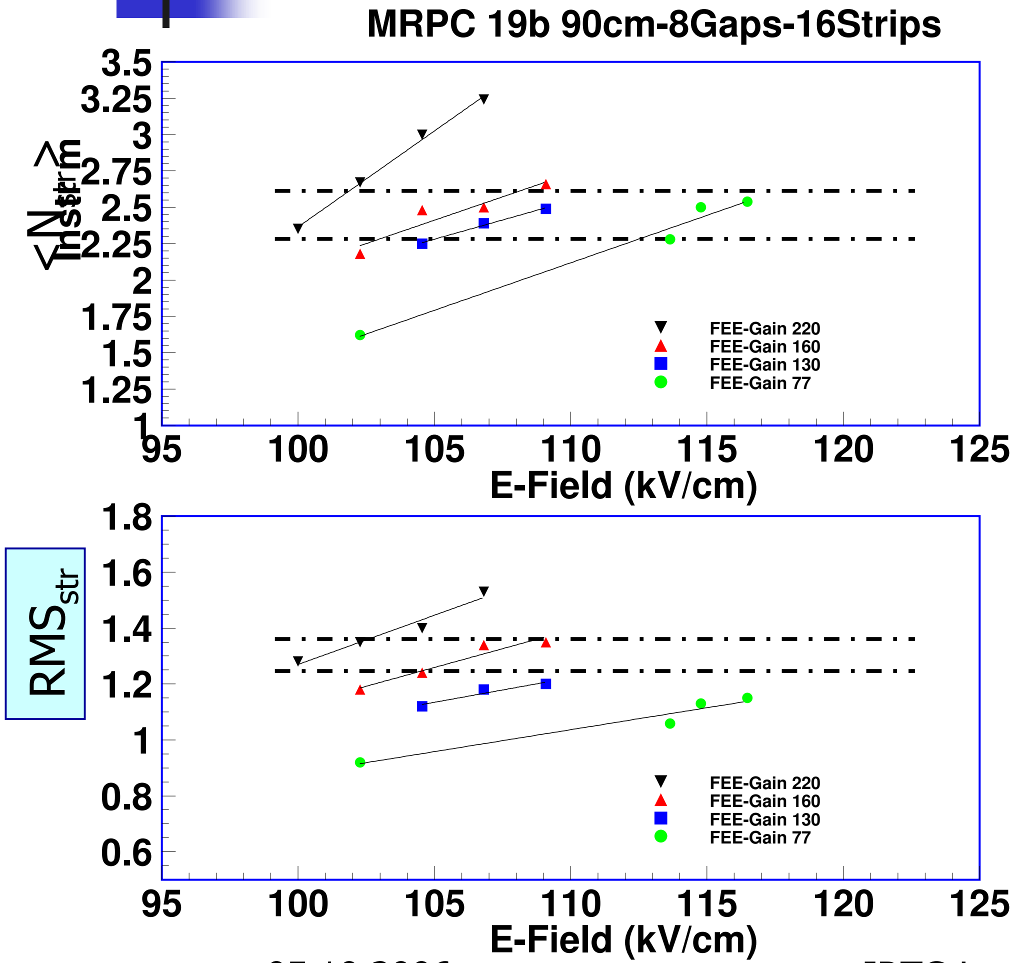
The timing and efficiency dependence from the E-field shift towards lower fields for higher electronic gain.

We reach at lower E-fields the same or better timing performance.

Optimal range: 150 -170

Why not 200 ???

FEE-gain dependence on cluster size

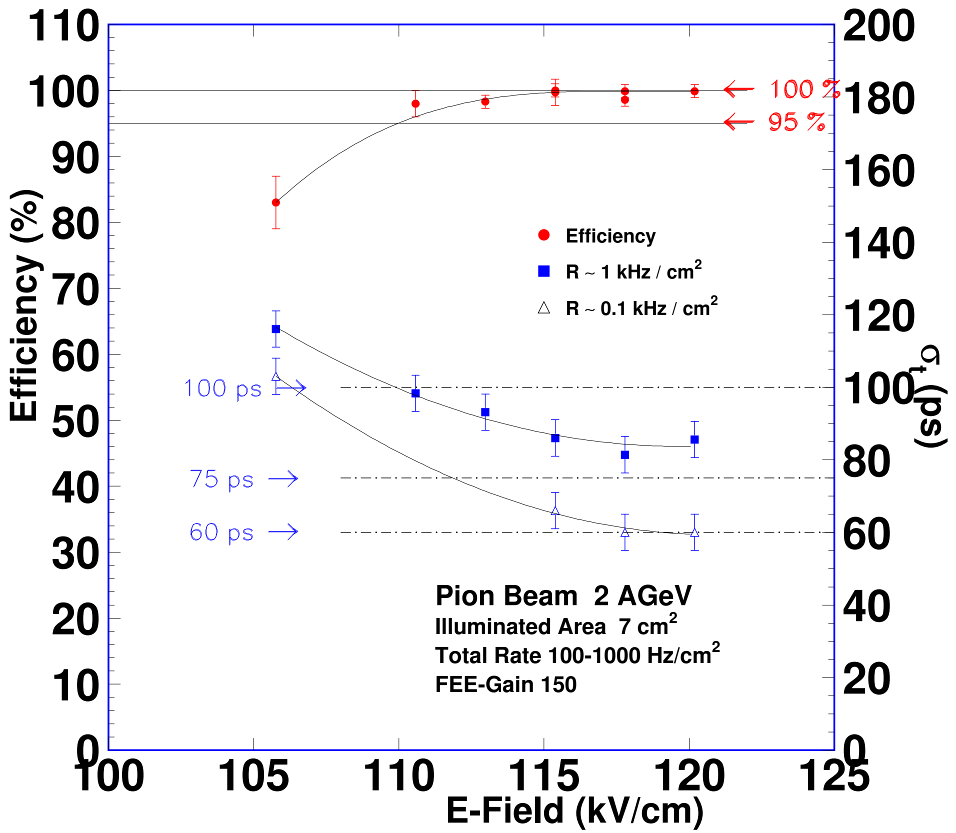


The cluster size shows as well a strong effect on the FEE-gain.

For the same cluster width (small) we get at lower E-fields better timing and efficiency.

That's why we will not use gain 200 !!

Rate dependence on timing & efficiency



MMRPC resolution

Single hits

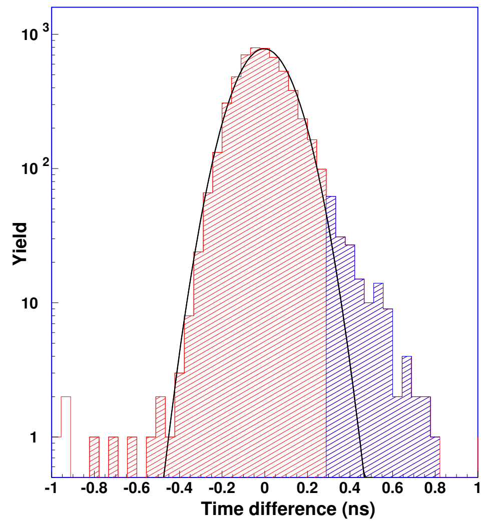
Gap 220 µm (8)

σ_t < 60 ps 0.1 kHz/cm²

σ_t < 85 ps 1.0 kHz/cm²

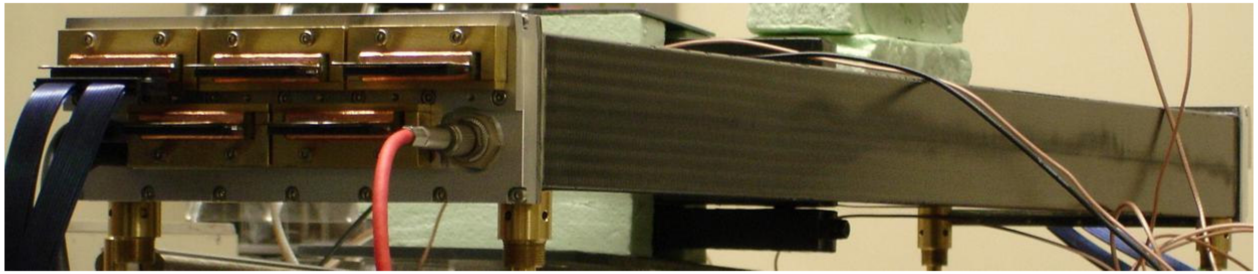
ε > 98 %

Tail < 3 %

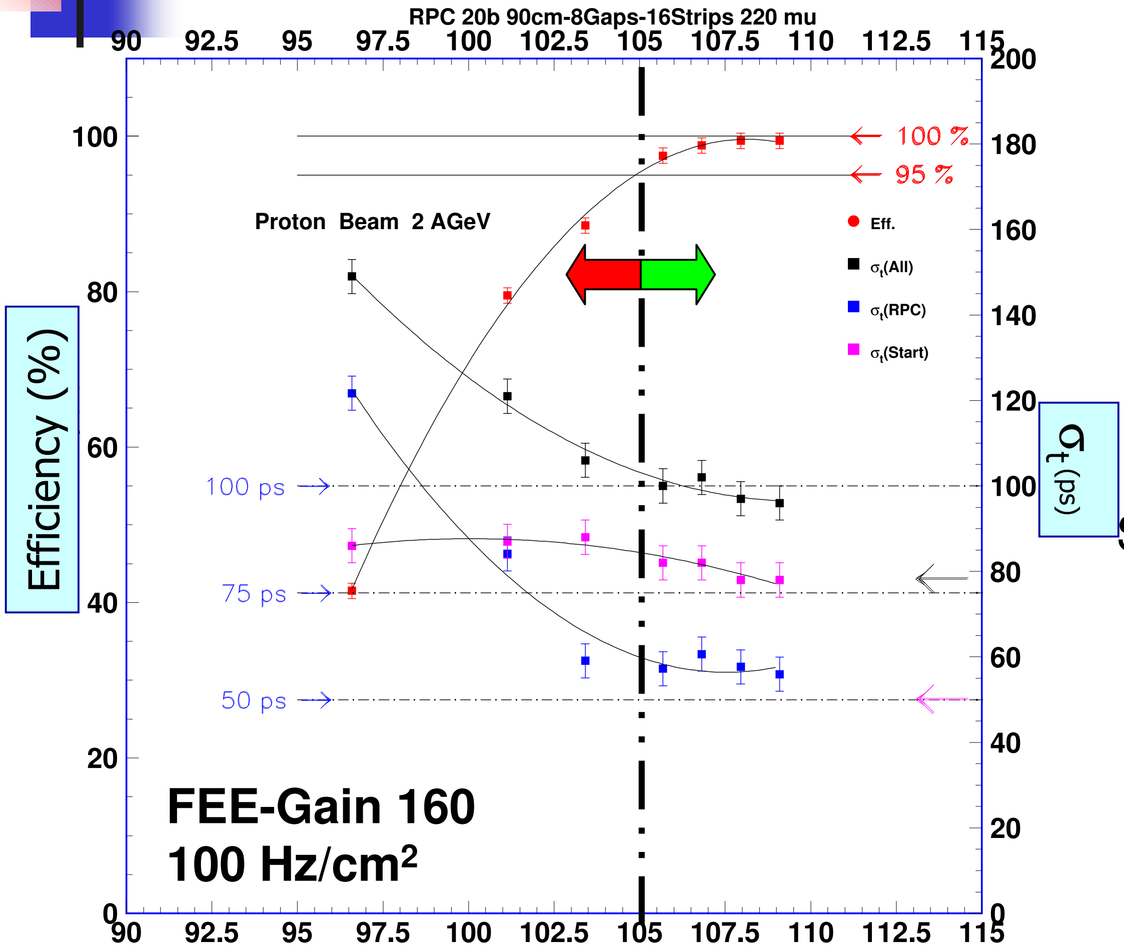


Using this R&D information

1. Gap size set to 8x220 μm for good timing and small cluster size
2. Electronic gain set to 160 at a discriminator threshold of 75 mV
3. Glass plates in a staggered configuration 0.5 mm and 1mm
4. Optimal timing at full efficiency around 105 kV/cm



MMRPC (B) vs start (plastic)



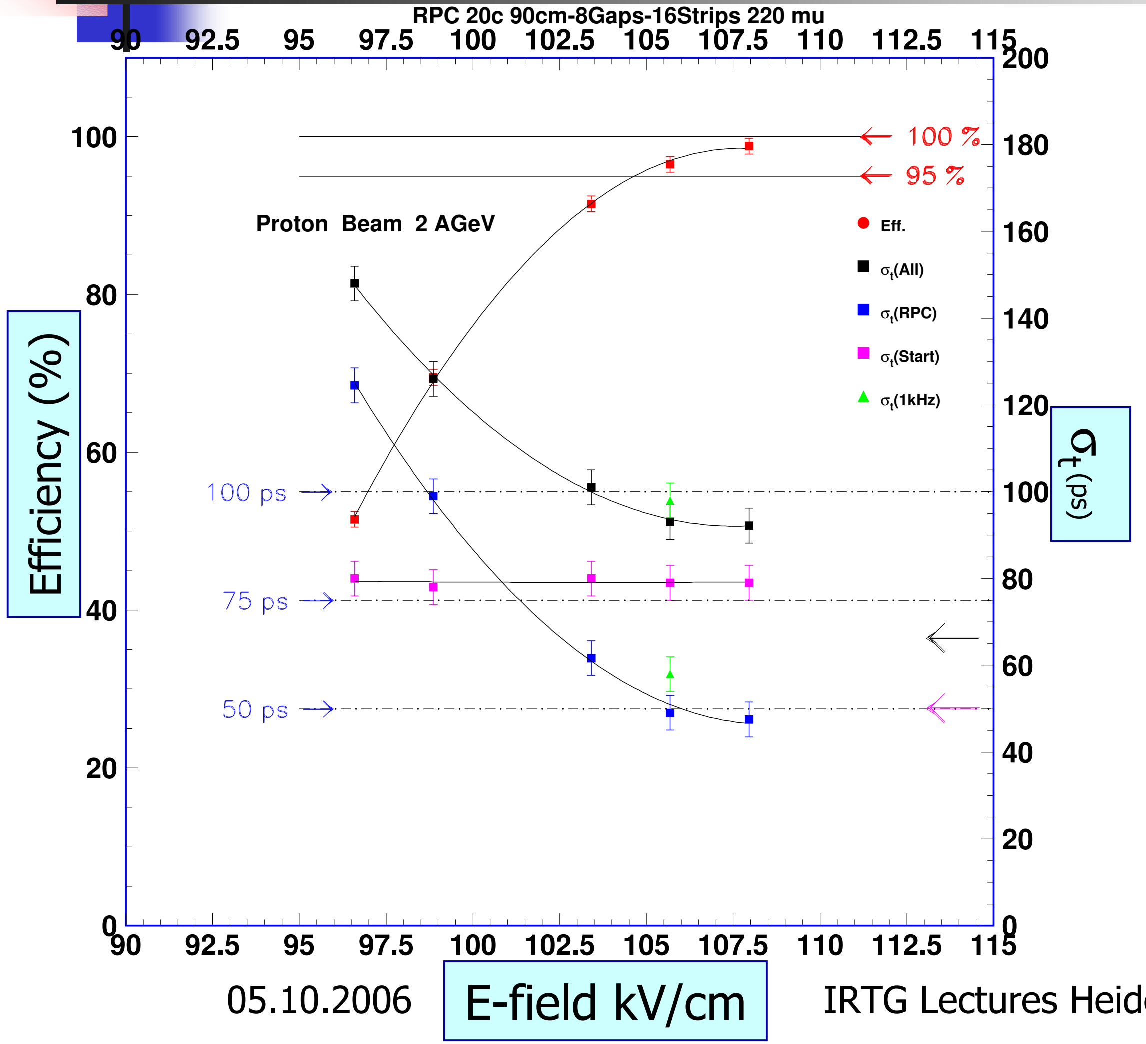
We need a start counter with 50 ps or even better.

Single hit 78 ps

Start 50 ps

RPC_b + Start	$\sigma_t < 96$ ps
Start	$\sigma_{ts} < 78$ ps
RPC	$\sigma_{RPC} < 56$ ps

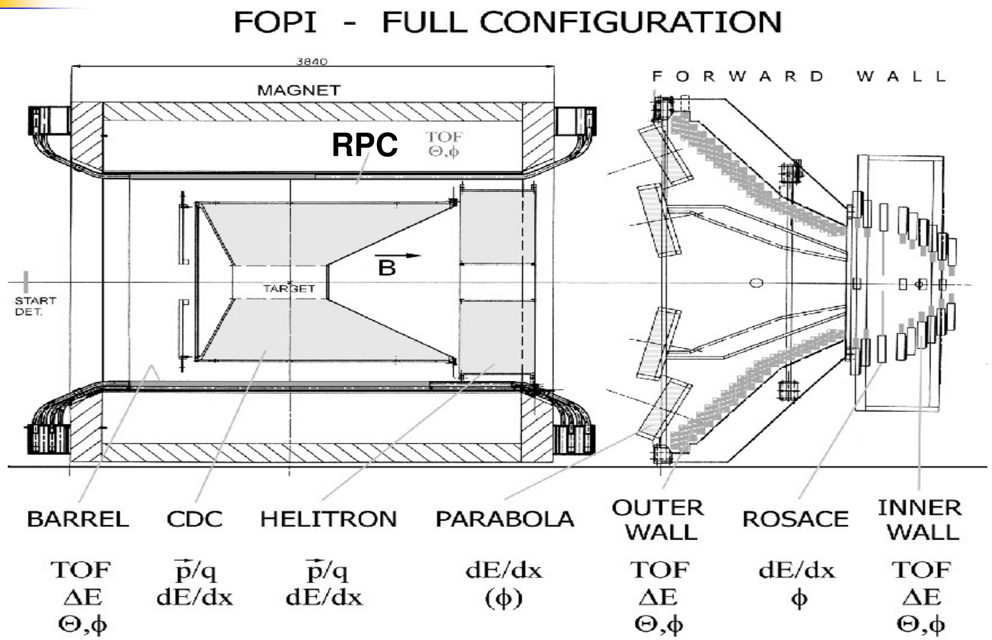
MMRPC (C) vs start (plastic)



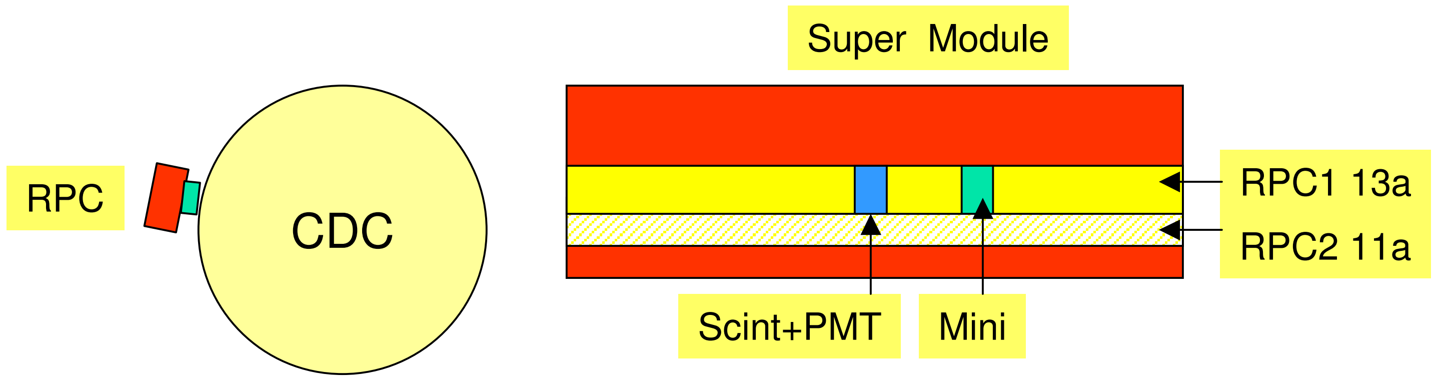
Stable scan with a stable start. The start is very important. saturation above 105 kV/cm

At higher rates ~ **1kHz** we see a decrease of the timing 10-15 ps.

Experimental setup III

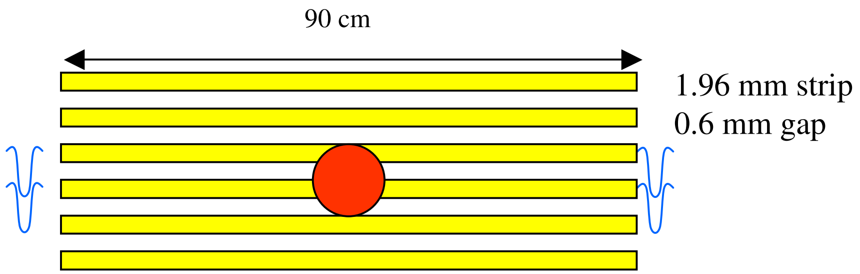


U+Au 900 AMeV
2 MMRPCs + Mini



Hit classification

Single Hit Clean

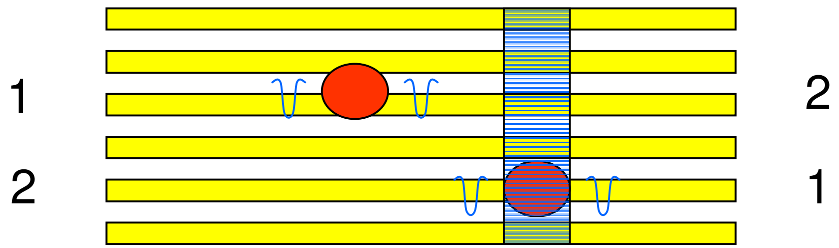


Double Hit Clean

Both signals arrive first → 101
Both signals arrive second → 202

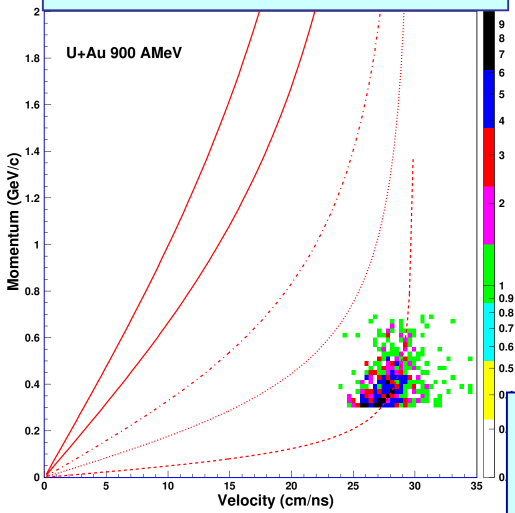
Mixed

One signal arrives second → 102
One signal arrives second → 201



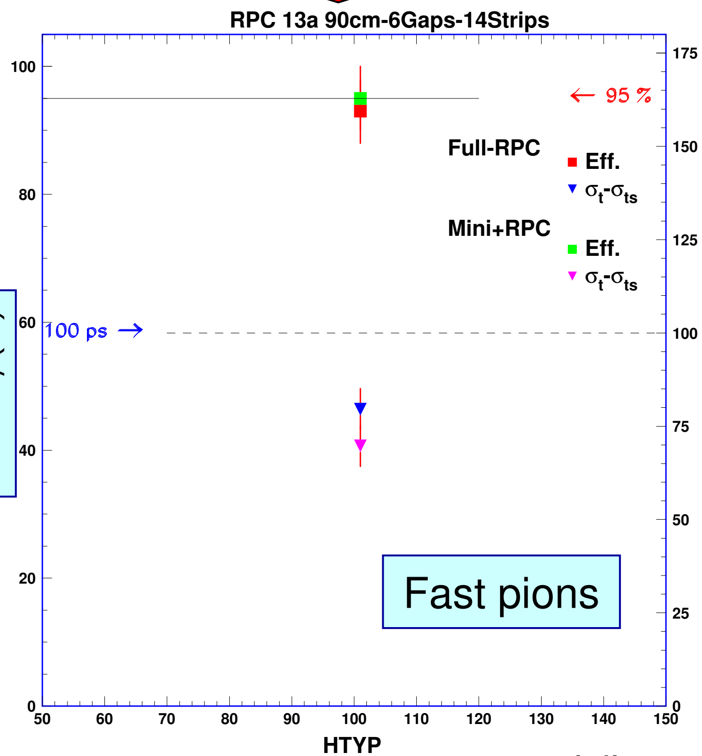
Timing & efficiency

Matched CDC-MRPC hits

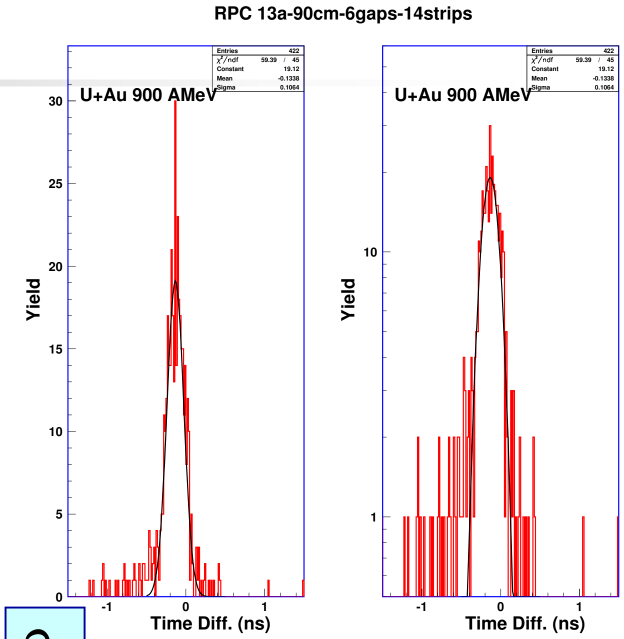


P-v plot for fast pions
Small momentum dependence.

σ_t< 75 ps
ε > 95 %



Fast pions

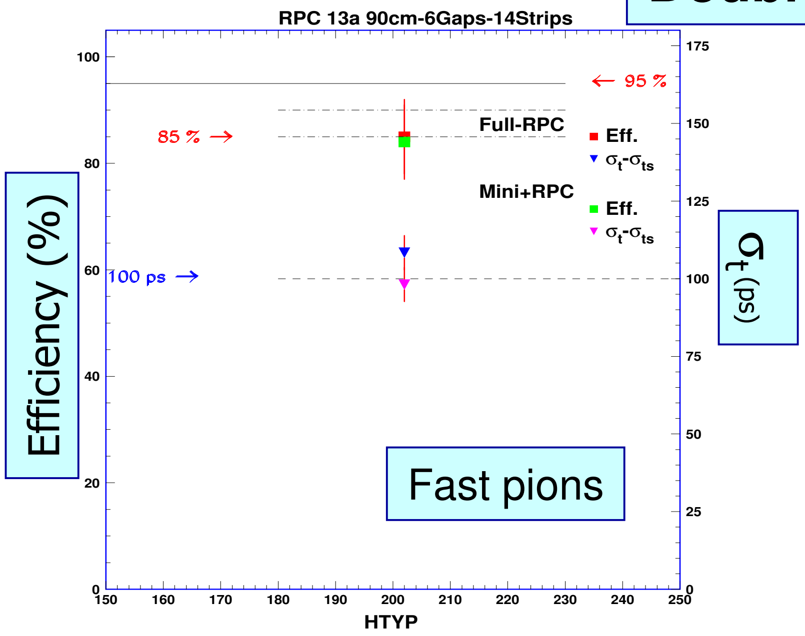


σ_t < 75 ps
Tail < 3 %

Single Hit Case

Timing & efficiency

Double Hit Case

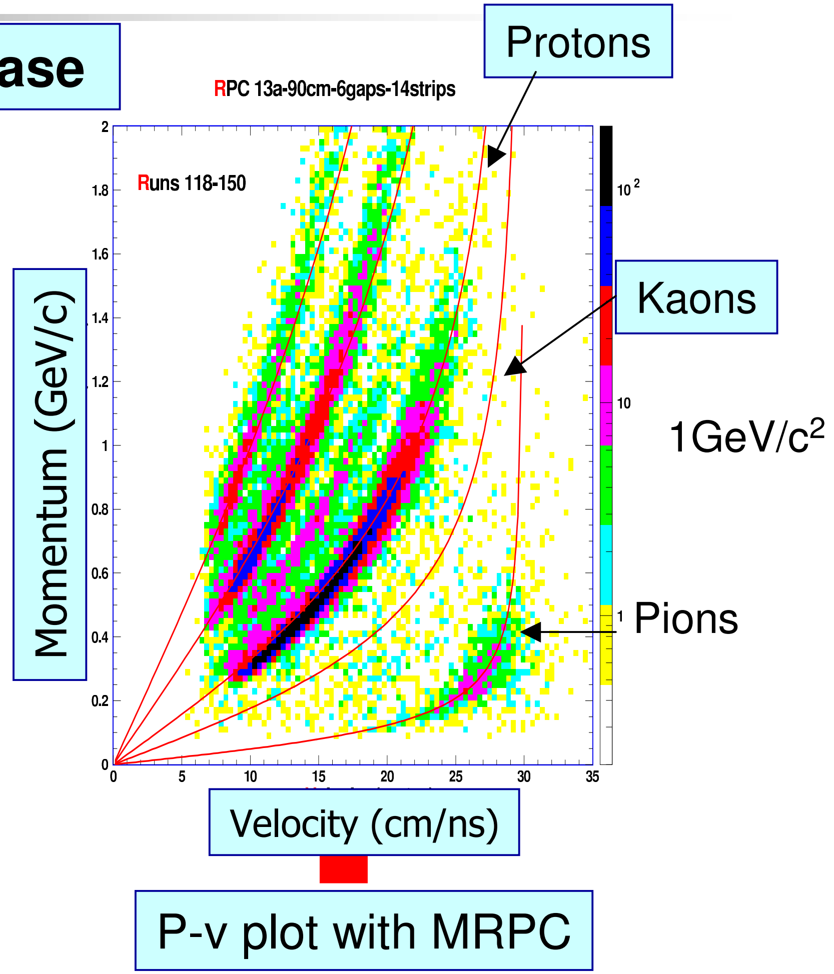


MRPC resolution

Double hits

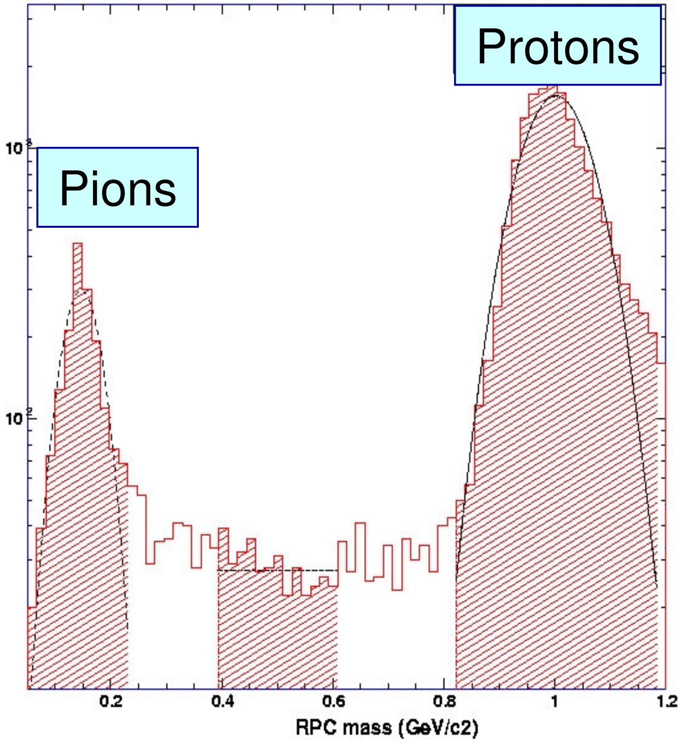
σ_t < 100 ps

ε > 85 %



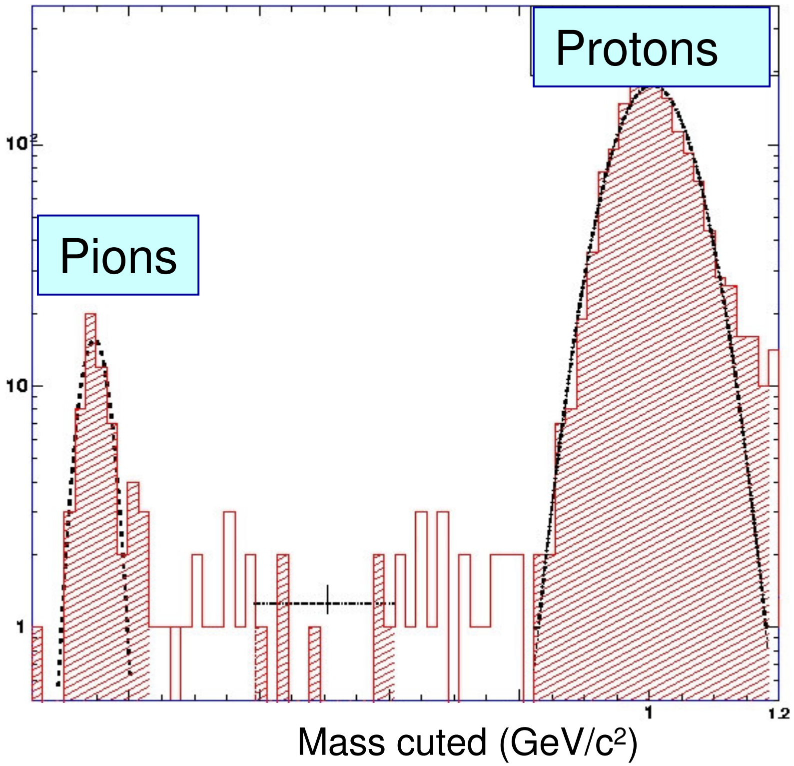
Background

E.Cordier



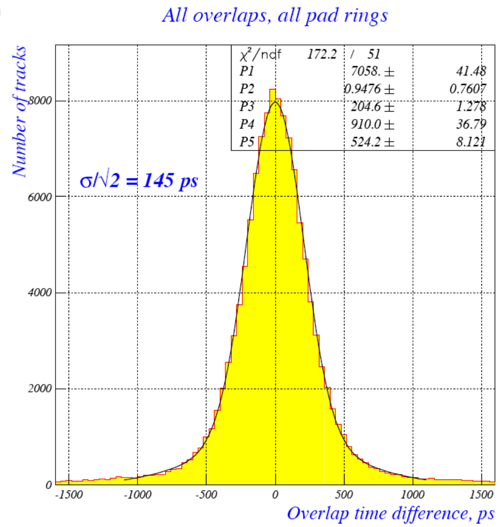
Background 2.5%

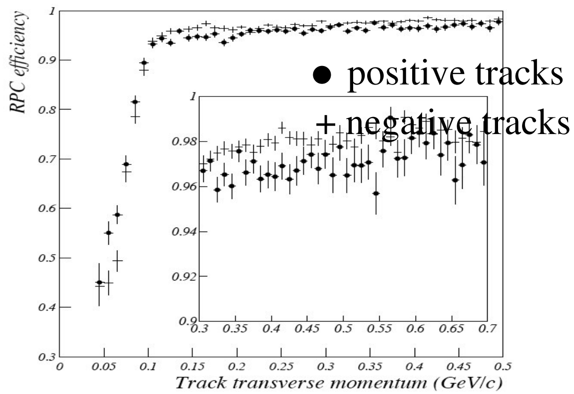
Strong cuts on CDC tracks quality
Background 0.5%



Existing setups

Harp layout (CERN)



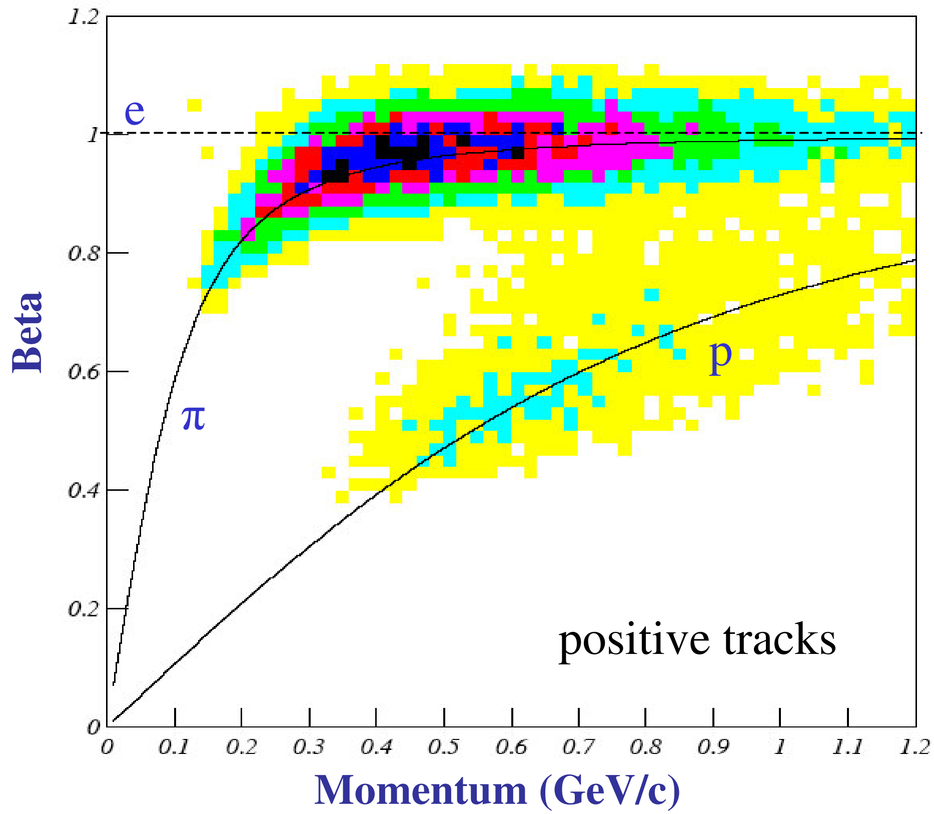


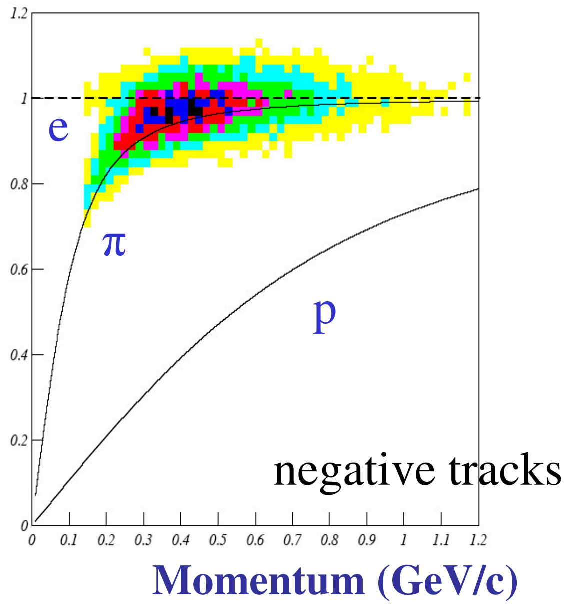
Barrel: 30 RPCs in 2 layers

- **Length: 2 m**
- **Width: 150 mm**
- **Thickness: 10 mm**

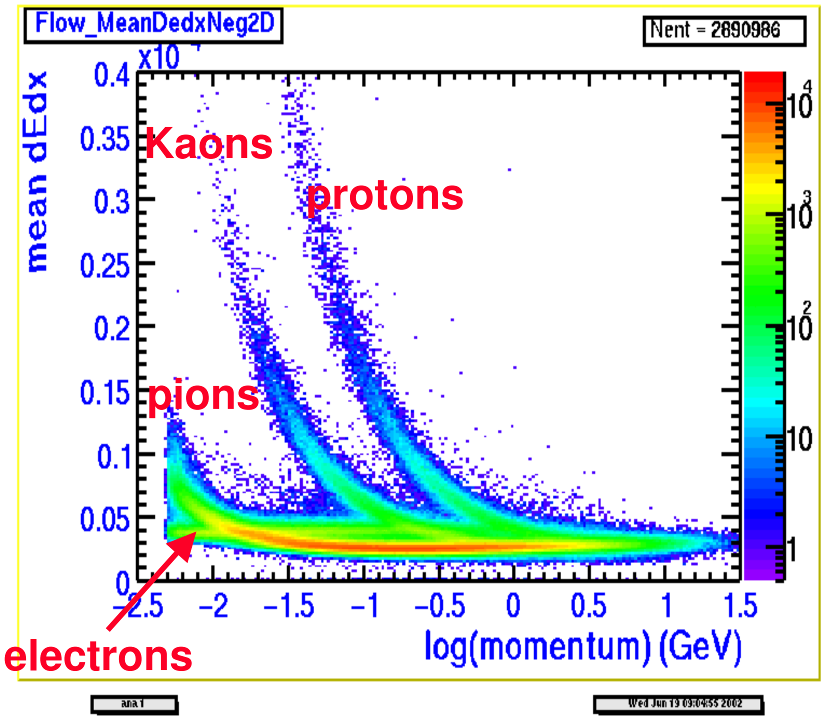
Harp Results

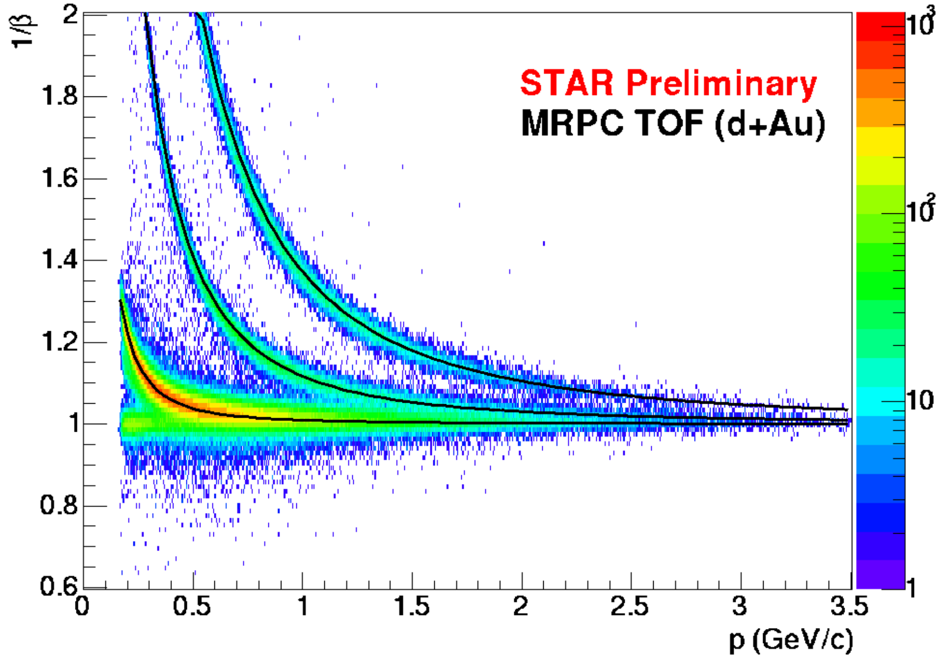
+8.9 GeV/c 0.05 λ Be target – pad ring 5 (average σ_t)





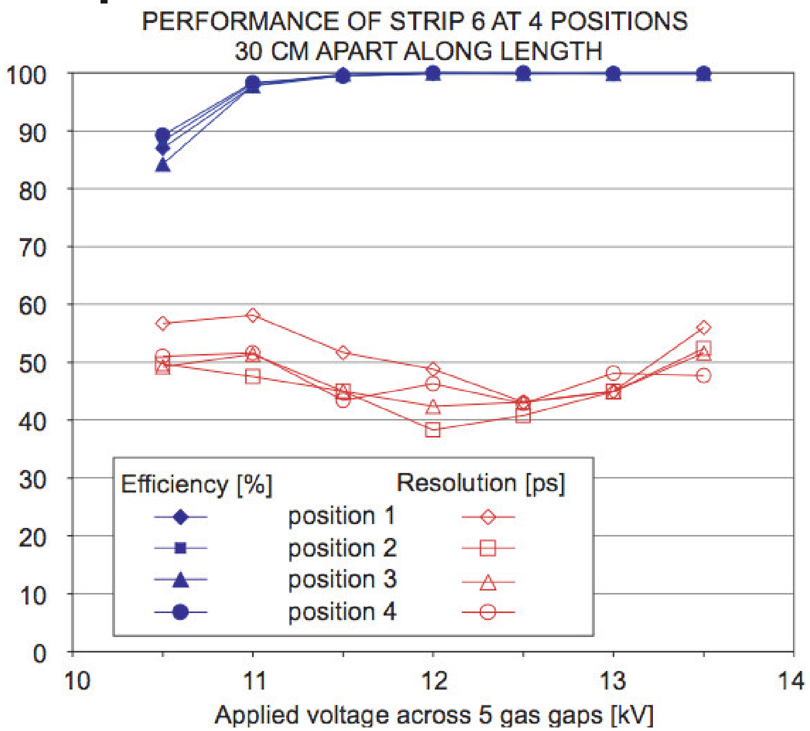
Particle id @ RHIC d+Au

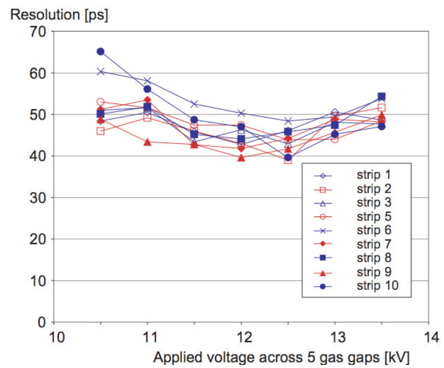


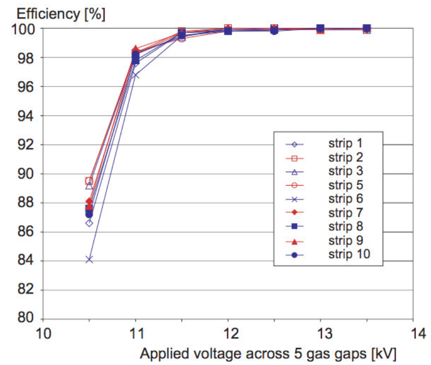


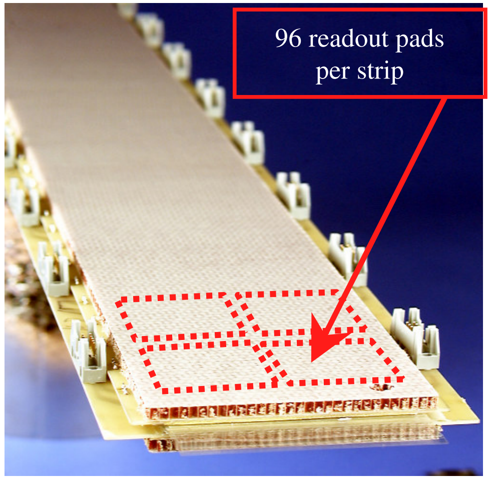
Particle id with STAR
T.Hallman BNL
H.Wiemann LBNL
F.Guerts RICE

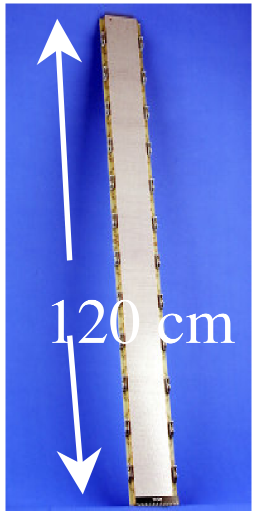
ALICE MRPC performance





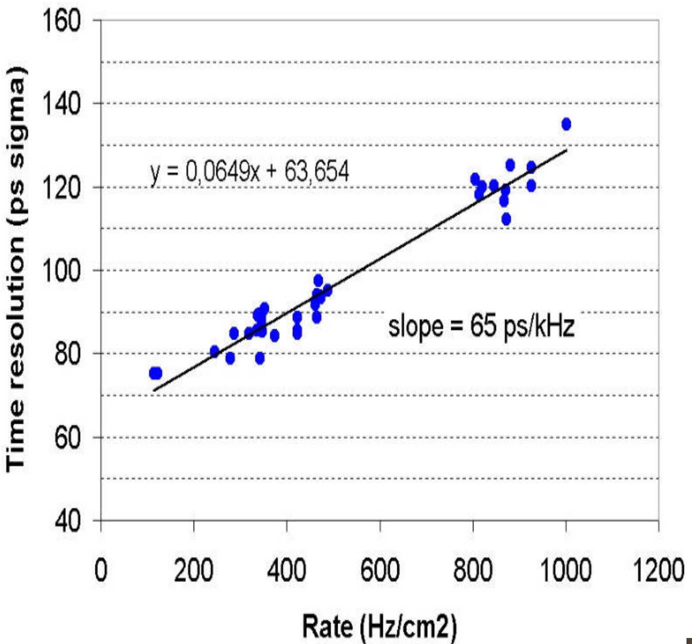


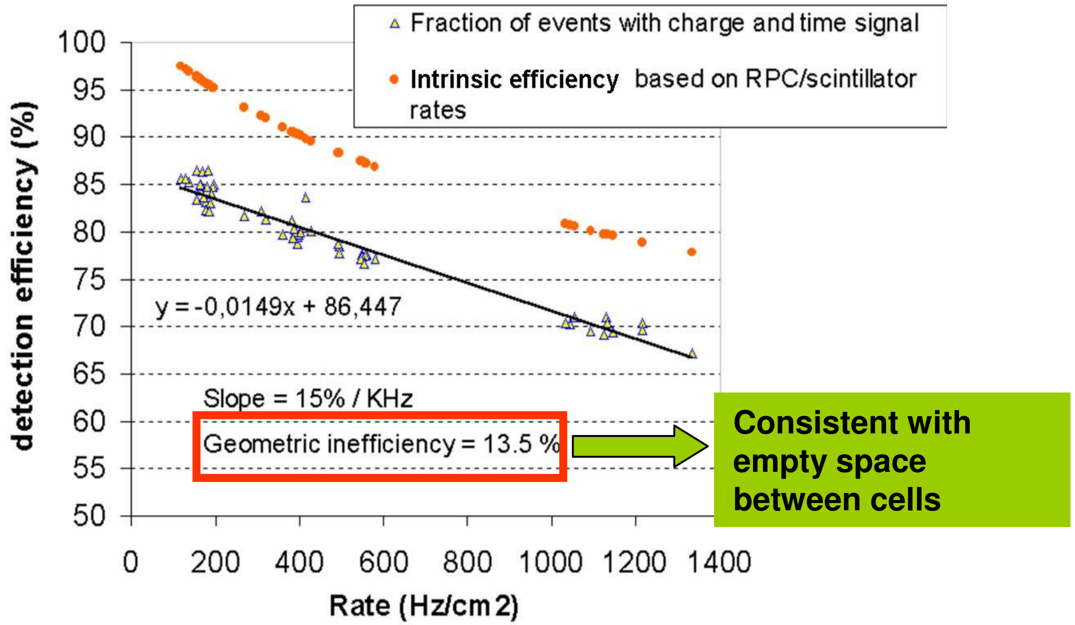


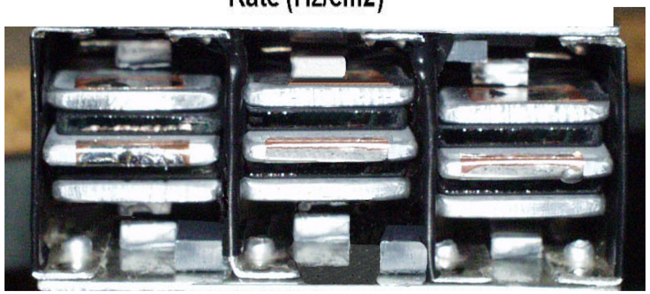


C.Williams
D.Hatzifotiadou RPC 2003

HADES RPC performance





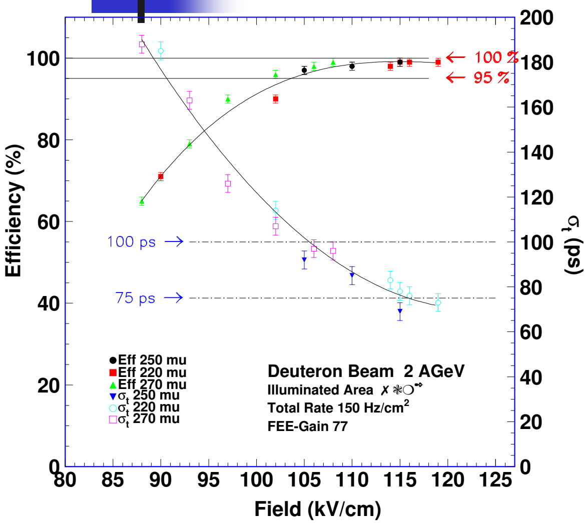


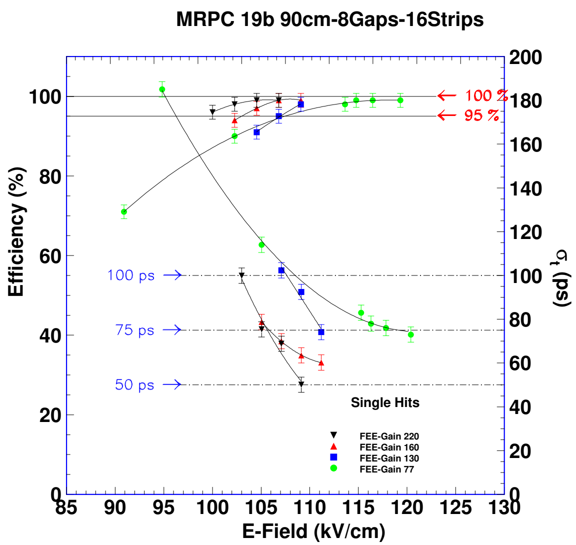
Gas admixture: 98.5% $C_2H_2F_4$ + 1% SF_6 + 0.5 iso-C_4H_{10}

D.Gonzalez RPC 2003

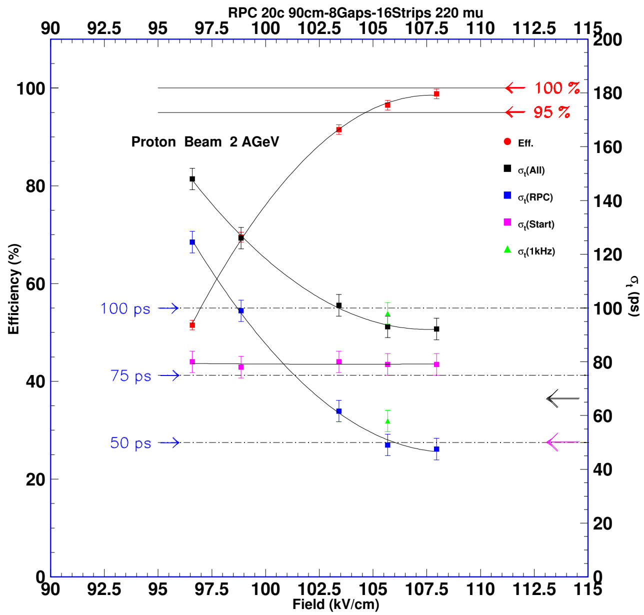
Summary, Conclusion & Outlook

Conclusions on gap size, FEE-gain and rate





Universal behavior of timing and efficiency, only dependent on E-field.



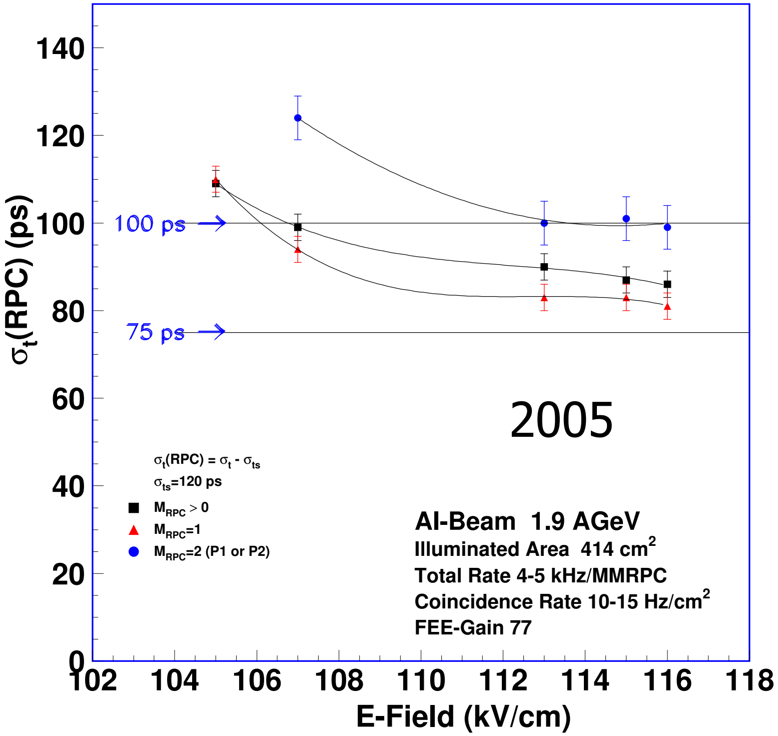
MMRPC resolution

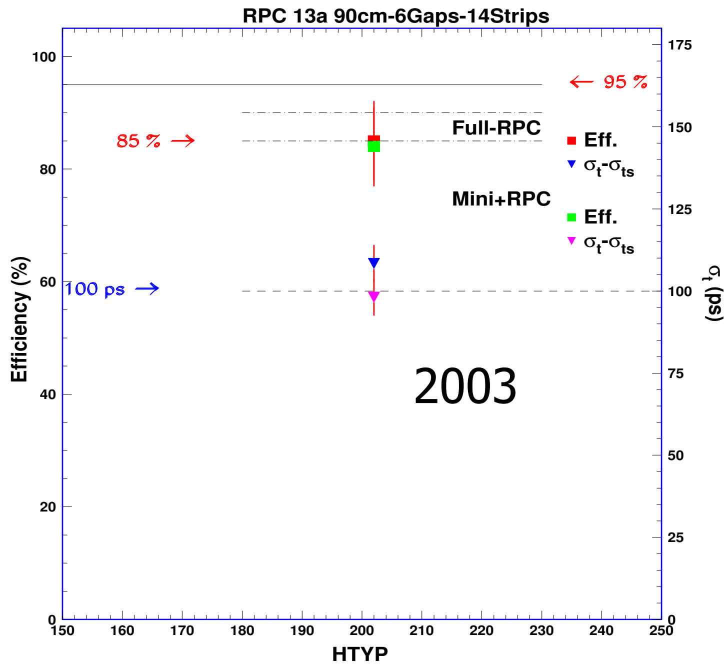
Single hits

- **σ_t < 50 ps FEE (200)**
- **σ_t < 60 ps FEE (150)**
- **σ_t < 75 ps FEE (77)**
- **ε > 99 %**

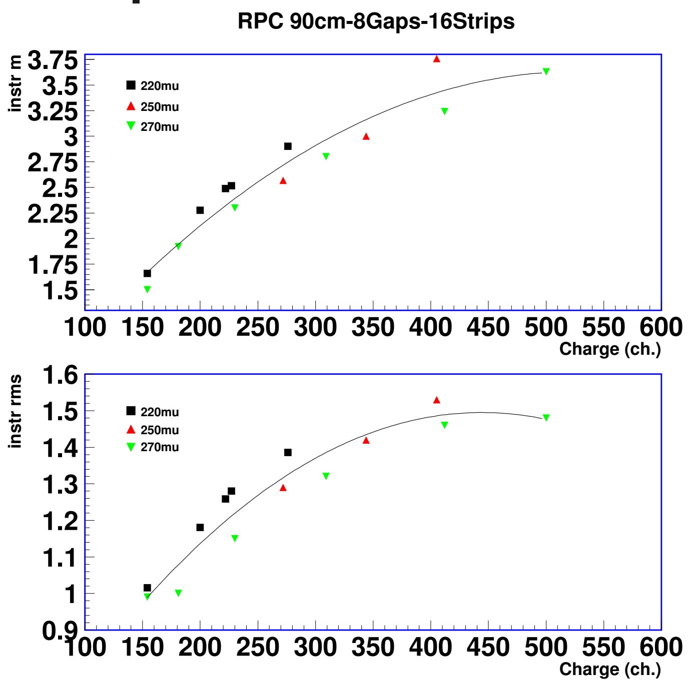
Conclusions on double hits

MMRPC resolution
Double hits
σ_t < 100 ps
ε > 85 %

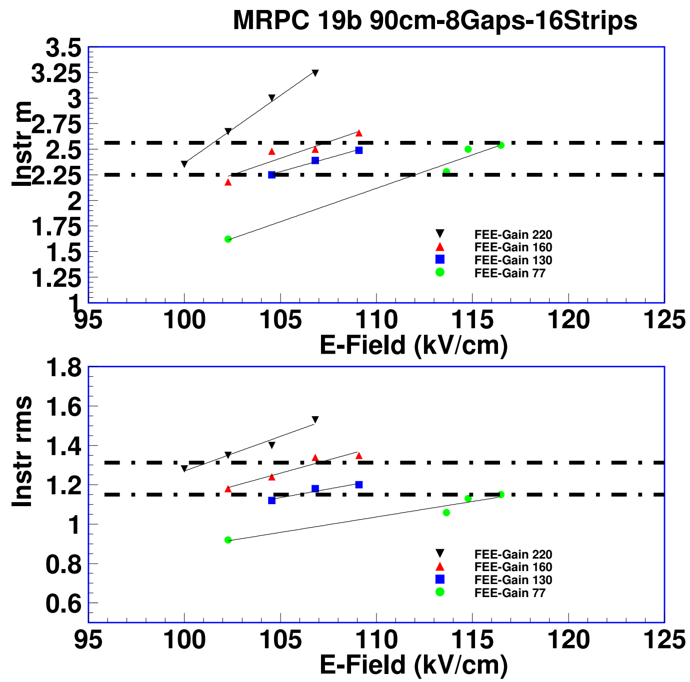




Conclusions on cluster size



Cluster size depends only on cluster charge. We need 220 μm and medium FEE-gain 160.

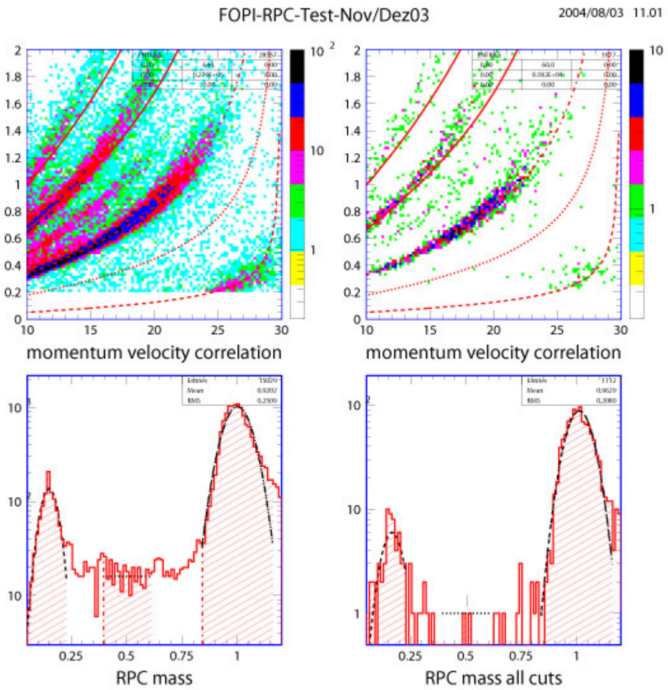


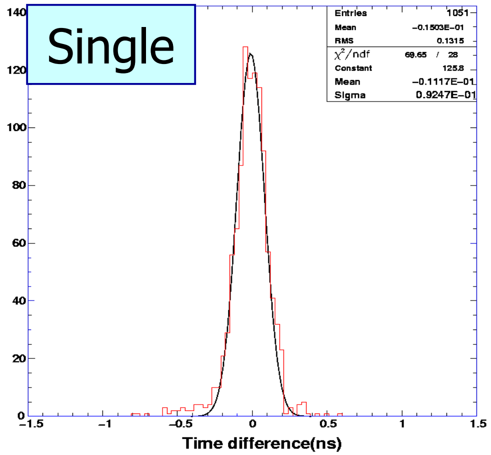
Detector gain f(E,d)

versus

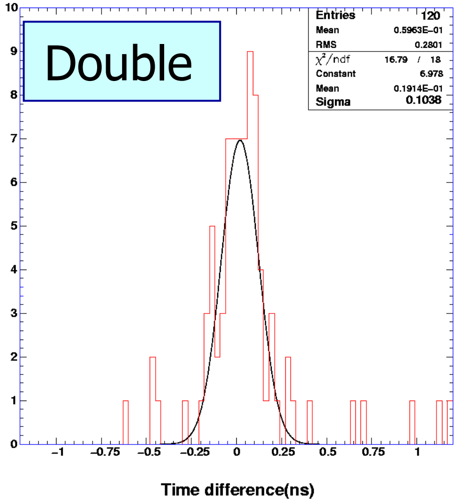
Electronic gain

Background & Timing



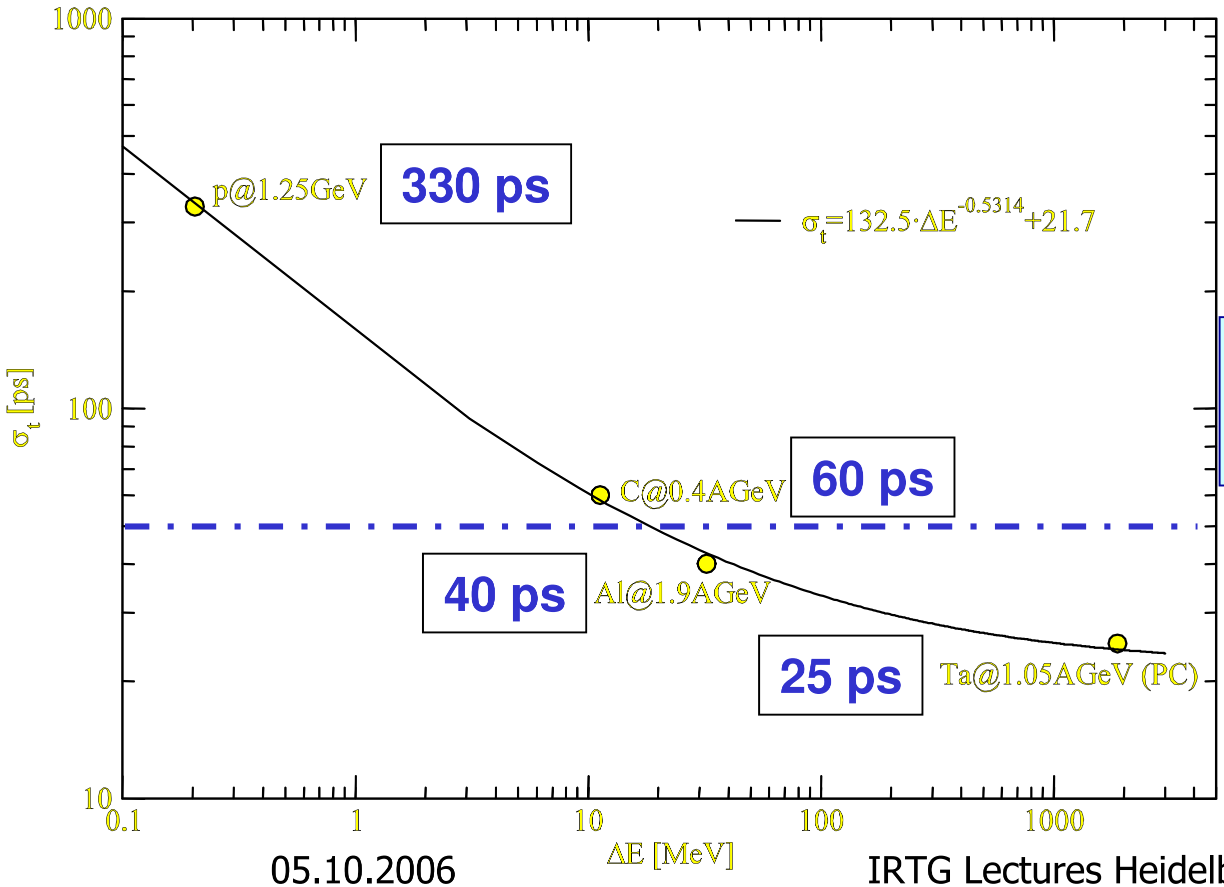


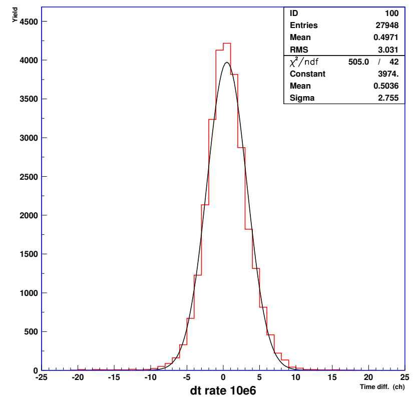
E.Cordier



Conclusion on start timing

Timing measurements with CVD diamonds at FOPI



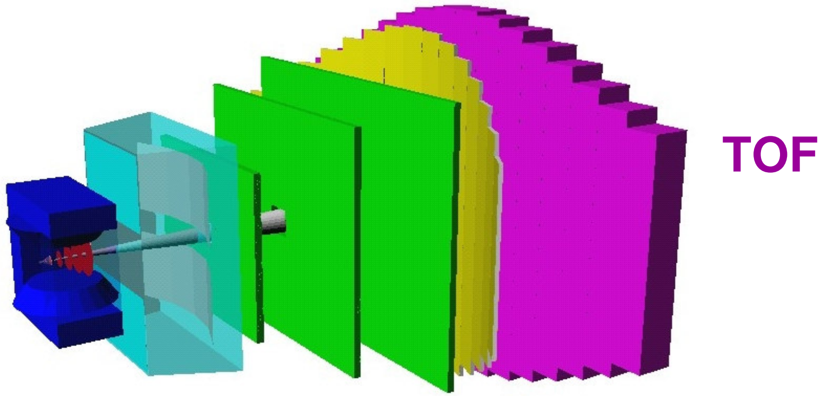


A possible candidate for the start is a single crystal diamond detector which has $\boldsymbol{\sigma_{ts} < 50}$ **ps** for a C beam at 1 MHz.

$\sigma_{total} = \sqrt{45^2 + 35^2 + \sigma_{ts}^2}$ ps

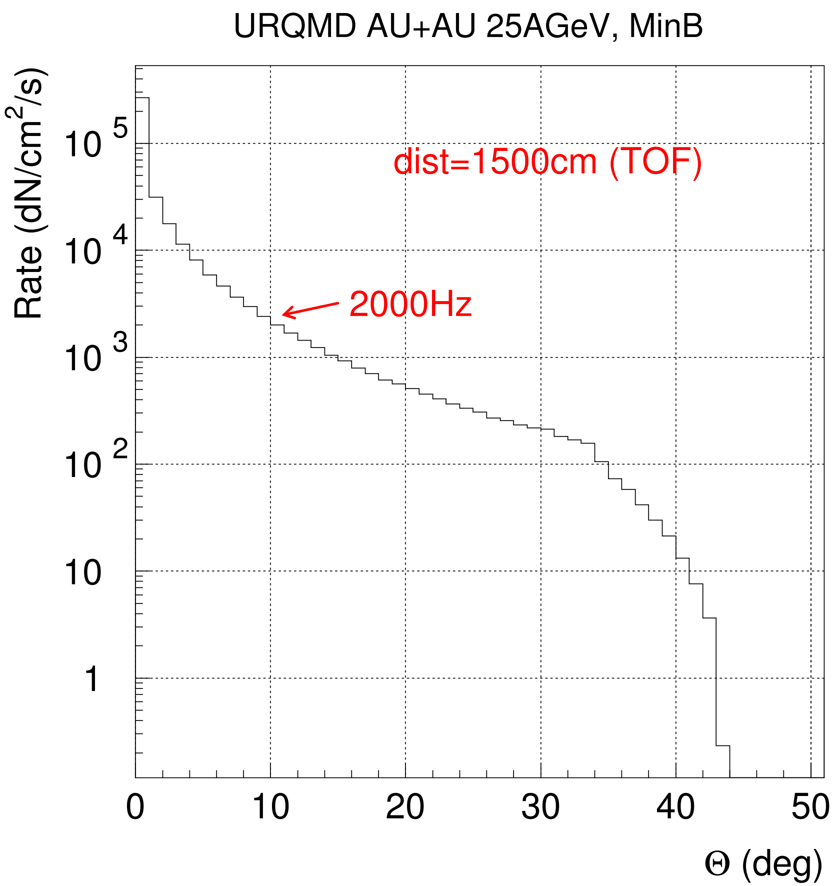
$\sigma_{total} = 75$ ps $\quad \sigma_{ts} = 50$ ps

Future applications
MRPCs for CBM



- Interaction rate **10^7Hz** (10% central collisions)
  ~1000 tracks /event
- TOF wall at 10m from target from 3º to 27º (same coverage STS):
  - **Rate from 1kHz/cm^2 (27º) to 20kHz/cm^2 (3º)**
  - Hit density from **6.10^{-2}/dm^2** to **1/dm^2** , more than **60000 cells** to have occupancy below 5%
  - **Total area >100m^2**: cannot use traditional scintillator with photomultiplier

Granularity for CBM



Concepts:
Different detectors types in low and the high rate environment.

Low rate <2 kHz
- Pad anode
- Multi strip anode
- Single strip anode

High rate > 2 kHz
- Pad anode
- Single cells

Problem:
Different counters may need different electronics.

Papers on timing RPCs

Doctoral Thesis, C. Lippmann, May 2003 (CERN, University of Frankfurt)
NIMA 500 (2003) 144-162, W. Riegler, C. Lippmann, R. Veenhof
NIMA 491 (2002) 258-271, W. Riegler
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Proceedings of IEEE NSS/MIC (2002), C. Lippmann, W. Riegler
NIMA 489 (2002) 439-443, CERN-OPEN-2001-074, T. Heubrandtner, B. Schnizer, C. Lippmann, W. Riegler

G. Carboni et al. NIM A 498(2003)135 [2 mm RPC]
G. Aielli et al. NIM A 508(2001)6, RPC 2001 [2 mm RPC]
P. Colrain et al. NIM A 456(2000)62
A. Mangiarotti et al. NIM A 533(2004)16 RPC 2003

D.Gozalez Diaz et al. Nucl. Phy. B (Proc.Suppl.) 158 (2006) 111-117
V.Ammosov et al. Nucl. Phy. B (Proc.Suppl.) 158 (2006) 56-59
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H. Alvarez-Pol et al. NIM A 535 (2004)277
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M.Petrovici et al. NIM A 508 (2000) 75-78