Other PID techniques

J. Va'vra, SLAC

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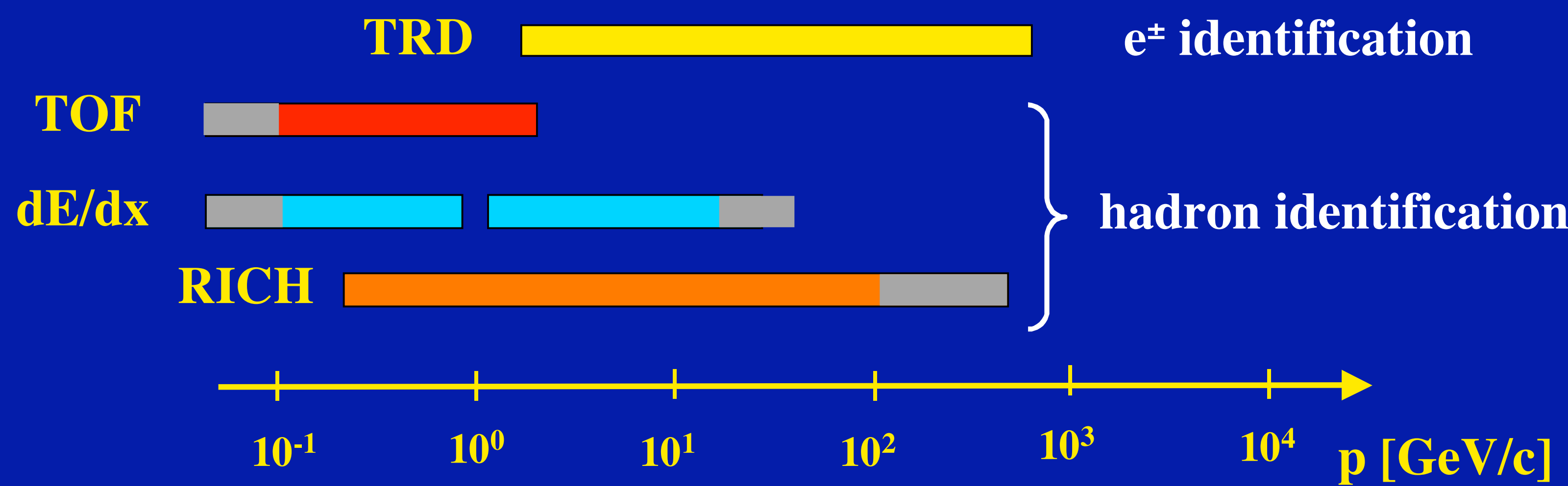
  - ATLAS TRT first results

- **dE/dx**
  - Cluster counting in central drift chamber for SuperB ?

- **TOF**
  - Detector candidates for TOF: MCP-PMTs, Multi-gap RPCs, G-APDs
  - ALICE, RHIC and CBM and their glass multi-gap RPCs
  - LHC ATLAS & CMS forward diffractive pp scattering R&D
  - SuperB R&D: Pixilated TOF, DIRC-like TOF

Comparison of various PID techniques



- TOF & dE/dx work mainly in low momentum region.
- TRD is useful for the electron identification at higher momenta.

Challenges of new experiments

SuperB & BelleII:

- L ~ 10^{36} cm^{-2} sec^{-1}

- Total neutron doses: ~10^{12} /cm^2
- Total Gamma doses : ~5×10^{11} /cm^2
- Total charged particle doses : ~5×10^{11} /cm^2
- Bhabha rate per entire detector: ~100 kHz

LHC ATLAS central region

- Total neutron doses: ~10^{14} /cm^2 (after 10 years)
- Total charged particle doses : ~10 MRads
- Total charged particle rate : ~10^5 /cm^2 sec
- Total photon rate : ~10^6 /cm^2 sec
- Total neutron rate : ~10^6 /cm^2 sec (~1 m from IP)

ALICE Pb + Pb collisions:

- Multiplicity of tracks: ~10,000/event
- Rate: ~50-100 Hz/cm^2

LHC pp diffractive scattering

- Total neutron doses per year: ~10^{12} /cm^2
- Total charged particle doses per year: ~5×10^{11} /cm^2
- Proton rate in the inner radiator: ~10-15 MHz/cm^2

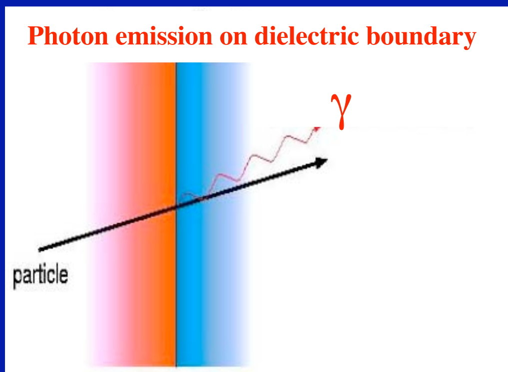
TRD

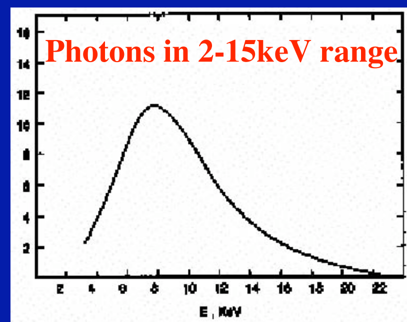
- ATLAS
- ALICE
- Overall comparison

TRD Principle

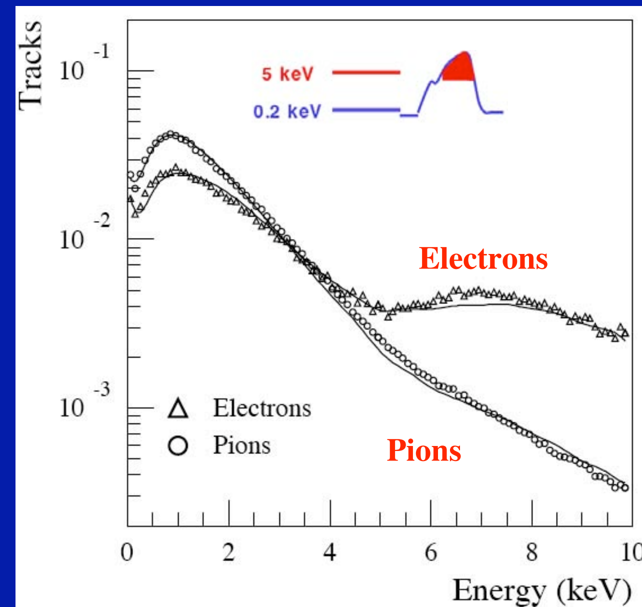
ATLAS Collaboration, ATLAS Inner Detector Technical Design Report, Volume 2, ATLAS TDR 5, CERN/LHCC/97-16 (30 April 1997).

Radiative power in TRD: $W \sim \gamma = E/m$
Number of emitted photons is small: $N_{ph} \sim \alpha \sim 1/137$
Emission at small angle: $\theta \sim 1/\gamma$

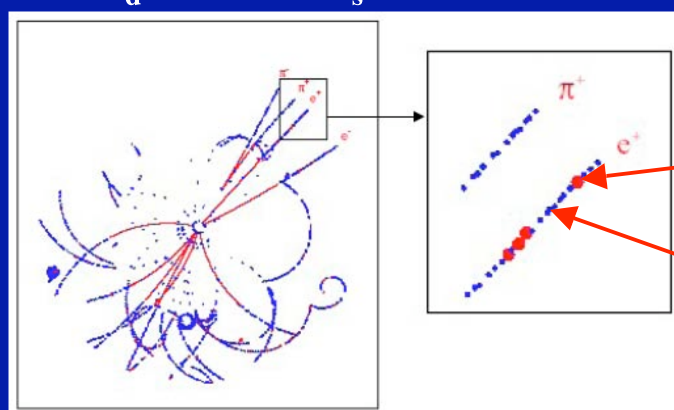




Test beam:



B_d^o -> $J/\Psi + K_s^o$

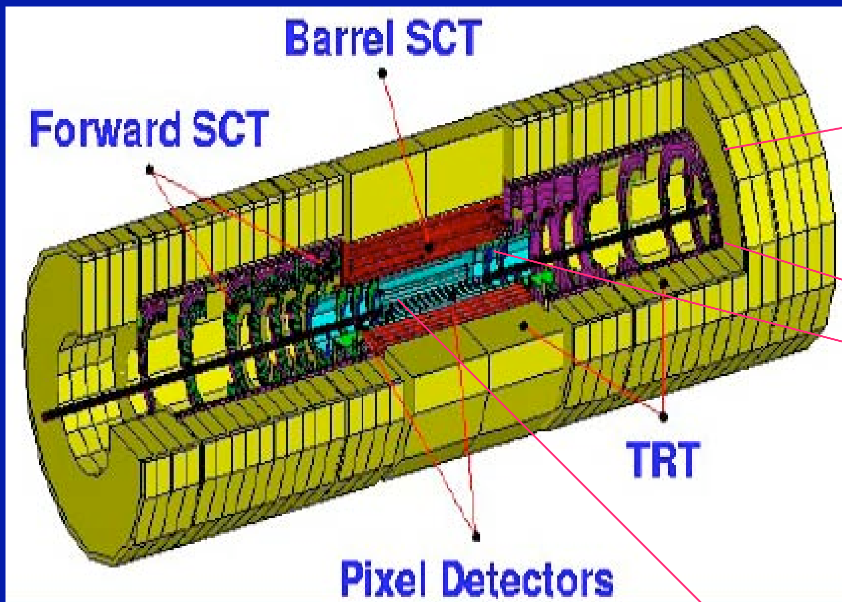


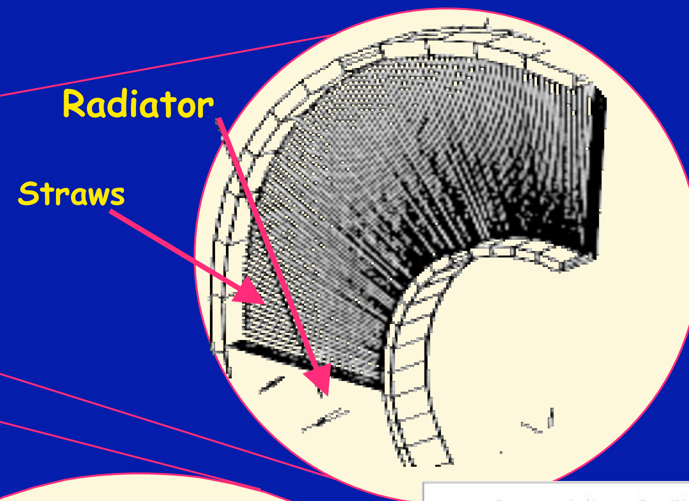
Transition radiation

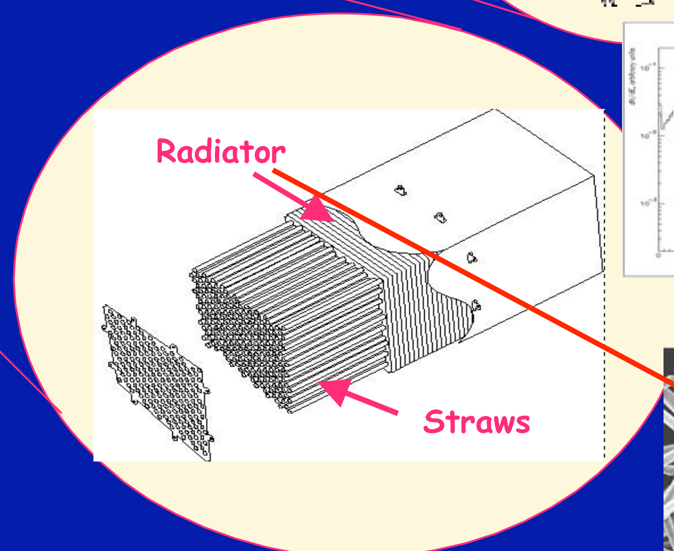
dE/dx

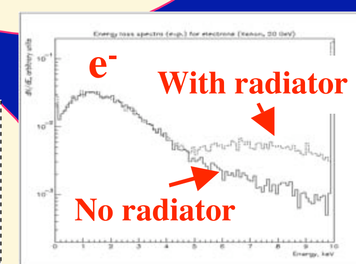
Example of ATLAS TRT in LHC

A. Romaniuk, TRD Workshop, Bari, 2001

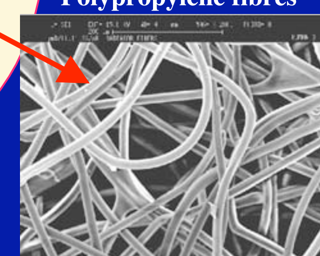








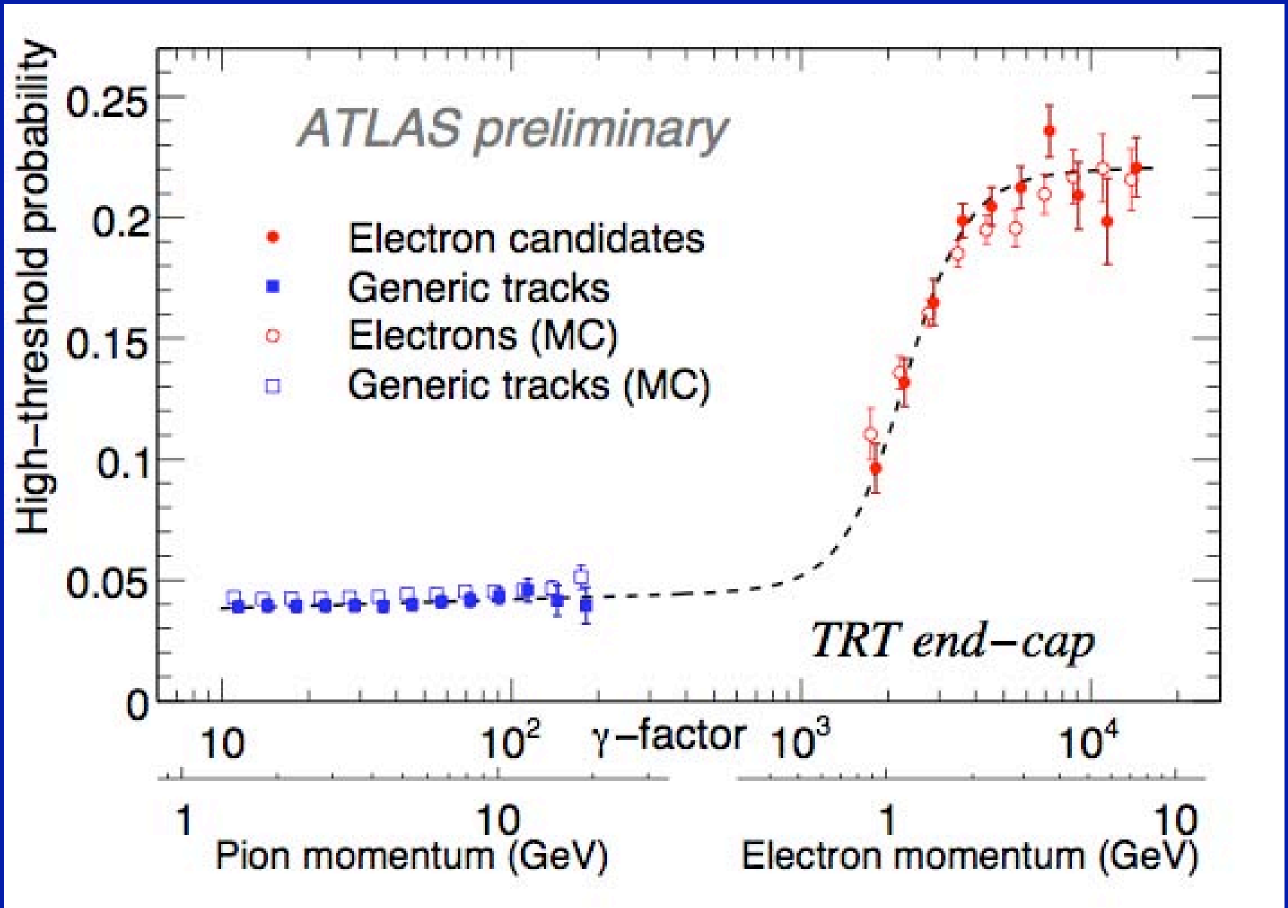
Polypropylene fibres



- ~ 425k active channels
- Gas: 70%Xe + 27%CO_2 + 3% O_2
- Gain ~$2x10^4$
- Position track resolution ~150 μm
- Counting rate per wire: ~20 MHz
- Charge collected over 10 years: >10 C/cm
- Current per wire: <10 μA
- Total dissipating power from min. ion. tracks: ~5 kW

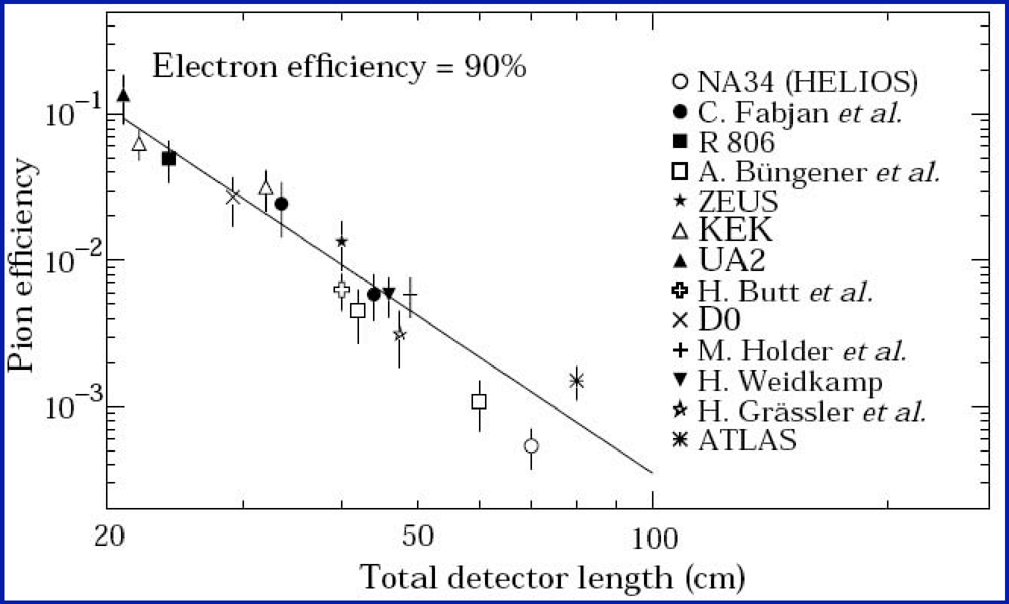
ATLAS TRT PID performance

LHC collisions:



- **Only high energy electron has a sufficiently high value of γ to produce the significant number of the TRD X-rays.**

Pion rejection in TRD detectors



Experiment	Gas	L (cm)	No of channels	$\pi_{rejection}$
HELLIOS (NA34)	Xe-C_4H_{10}	70	1744	2000
H1	Xe-He-C_2H_6	60	1728	10
NA31	Xe-He-CH_4	96	384	70
ZEUS	Xe-He-CH_4	40	2112	100
D0	Xe-CH_4	33	1536	50
NOMAD	Xe-CO_2	150	1584	1000
kTeV	Xe-CO_2	144	~10k	250
PHENIX	Xe-CH_4	4	43k	300
PAMELA	Xe-CO_2	28	964	50
AMS	Xe-CO_2	55	5248	1000
ATLAS	Xe-CF_4-CO_2	51-108	425k	100
ALICE	Xe-CO_2	52	1.2 M	200

- **An order of magnitude in rejection power against pions is gained each time the TRD detector length is increased by ~ 20 cm.**
- **A typical pion/electron rejection factor is ~ 100 for ~ 40 cm of detector length.**

dE/dx

- Cluster counting

Cluster counting

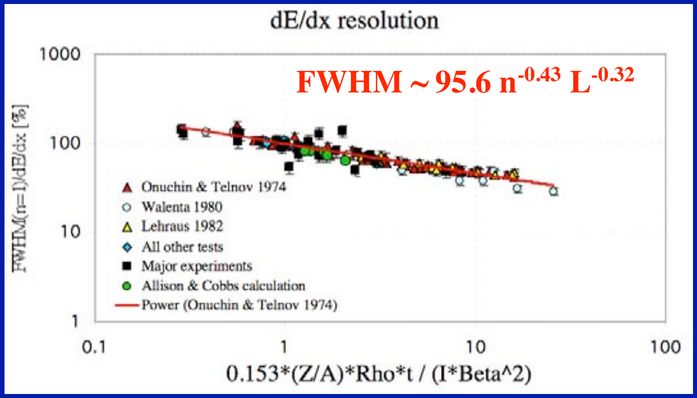
Original idea to use cluster counting for dE/dx PID by A.Walenta, IEEE NS-26, 73(1979),
others studies: Lapique, F. Piuz, A. Breskin's group, etc. - all doing it with a Time-Expansion-Chamber (TEC).

Can we do it in a SuperB drift chambers ? He-based gas plays a role of TEC.

He: 5.5 ± 0.9 clusters/cm & iC_4H_{10}: 70 ± 12 clusters/cm

Need to choose the right mix to prevent a pile-up.

Typical dE/dx resolution in typical drift chambers for 1cm in Ar gas at 1 bar:
FWHM/dE/dx$_{\text{most probable}}$ ~ 100%



G. Cataldi et al., NIM A 386 (1997) 458-469

What do we expect from cluster counting ?
$N_{primary}$ ~ **35**/2.6cm-long drift cell at 1 bar in **95%He+5%iC_4H_{10} gas**:

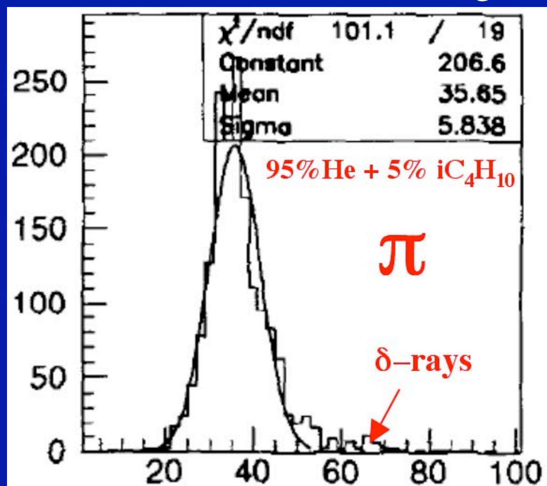
FWHM/ dE/dx$_{\text{most probable}}$ = 2.35 $\sqrt{N_{primary}}/N_{primary}$ ~40%

- **So far nobody has succeeded to do this in a large experiment. KLOE experiment did a lot of R&D on this. SuperB might to try it.**

KLOE drift chamber R&D

G. Cataldi, F. Grancagnolo, S. Spagnolo, Nucl. Instr.&Meth A 386 (1997) 458-469

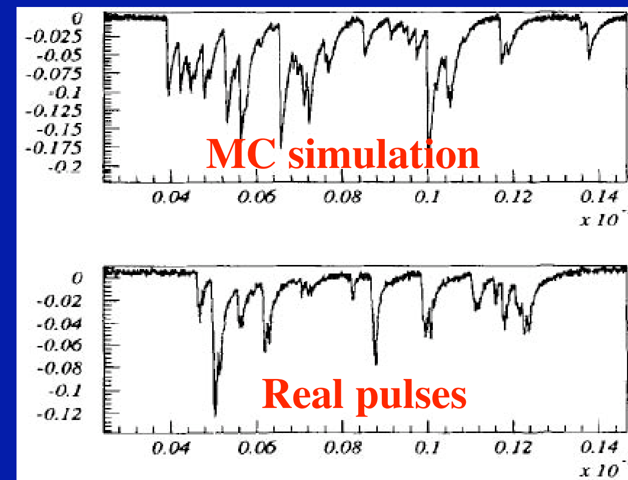
Measured cluster distribution in single 2.6cm drift cell:



$N_{clusters}$/cell

95%He + 5% iC_4H_{10}

Drift chamber pulses (measured & simulated):



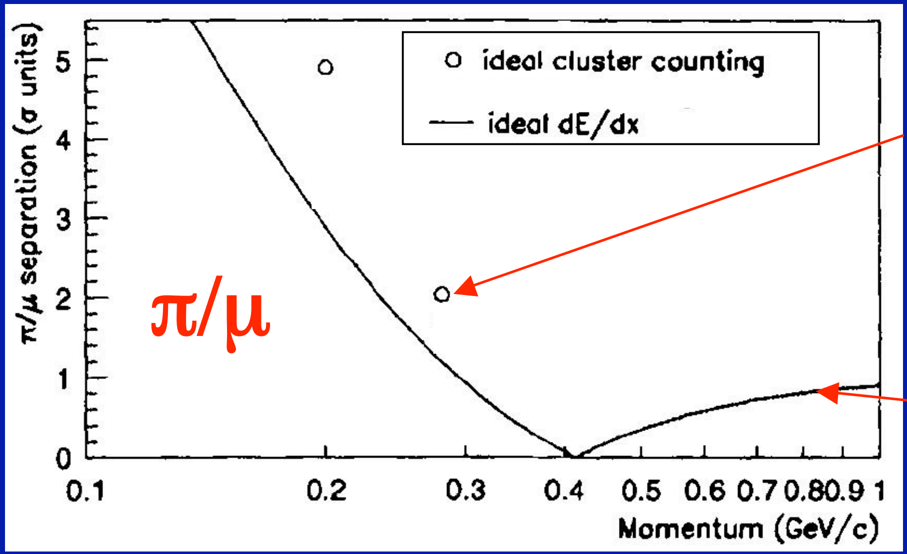
[sec]

- For a square drift cell with **2.6 cm** side, filled with **95%He + 5% iC_4H_{10} gas**, the test measured **~35 clusters/cell**. The distribution has a tail due to delta electrons, which can be handled by a truncated mean method.
- **Data analysed with:** 1.7 GHz bandwidth preamplifier, a **digital sampling oscilloscope,** 8 bits, 1 GHz, 2 GSa/s
- Number of randomly distributed clusters **N** along a track of length **L** fluctuates around mean of **$N_o = L\, N_{primary\ clusters}$** with a probability described by Poisson distribution: **$P(N) = e^{-N_o} (N_o)^N/(N_o!)$**. Its Gaussian limit is achieved as soon as the mean value approaches **$N_o \sim 20$**, which is of the order of **~1 cm** track length for most of the commonly used gas mixtures.

KLOE drift chamber R&D

G. Cataldi, F. Grancagnolo, S. Spagnolo, Nucl. Instr.&Meth A 386 (1997) 458-469

PID performance:



Ideal cluster counting:
- Get rid of δ-ray tail by using Gaussian portion only (open circles)

Ideal dE/dx:
- assume:
$\sigma(\%) = 40.7\ n^{-0.43}\ L^{-0.3}$

- **Their conclusion:**

  - one needs a preamplifier with **~ 500MHz BW**

  - sampling rate of **~1.25 GSa/sec**

  - Memory needs to be deep **~2-3 μsec !!!**

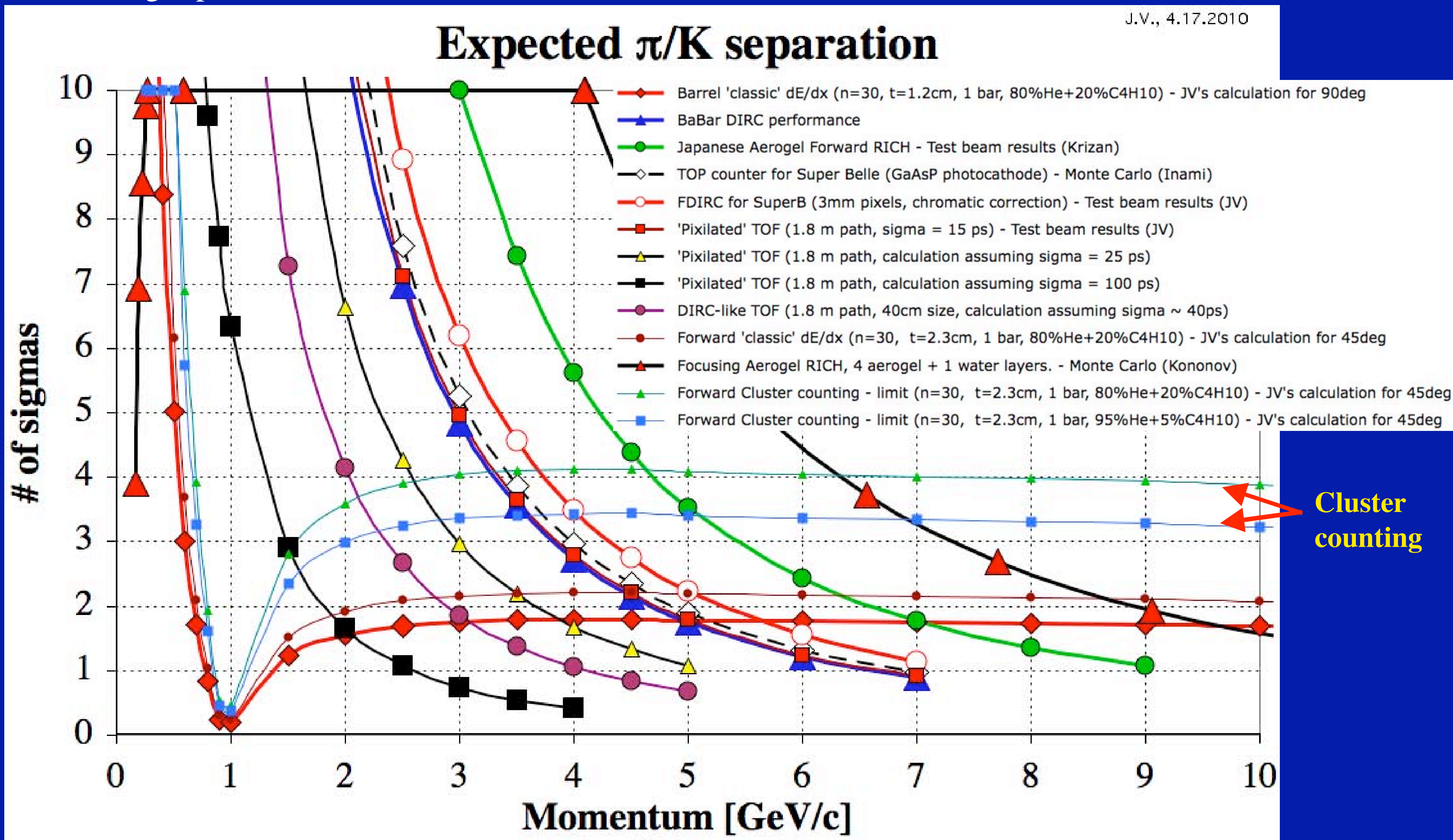
  - ADC dynamical range of **8 bits**

  (for a concrete example of square drift cell with **2.6 cm** side, filled with a gas having $N_{primary\ clusters}$ ~ **12/cm/m.i.p.**, and a **drift velocity ~ 1cm/μs &** $\sigma_{long.diffusion}$ **~ 170μm**)

Example: π/K separation in SuperB forward endcap

J. Va'vra, dE/dx part: A453(2000)262-272

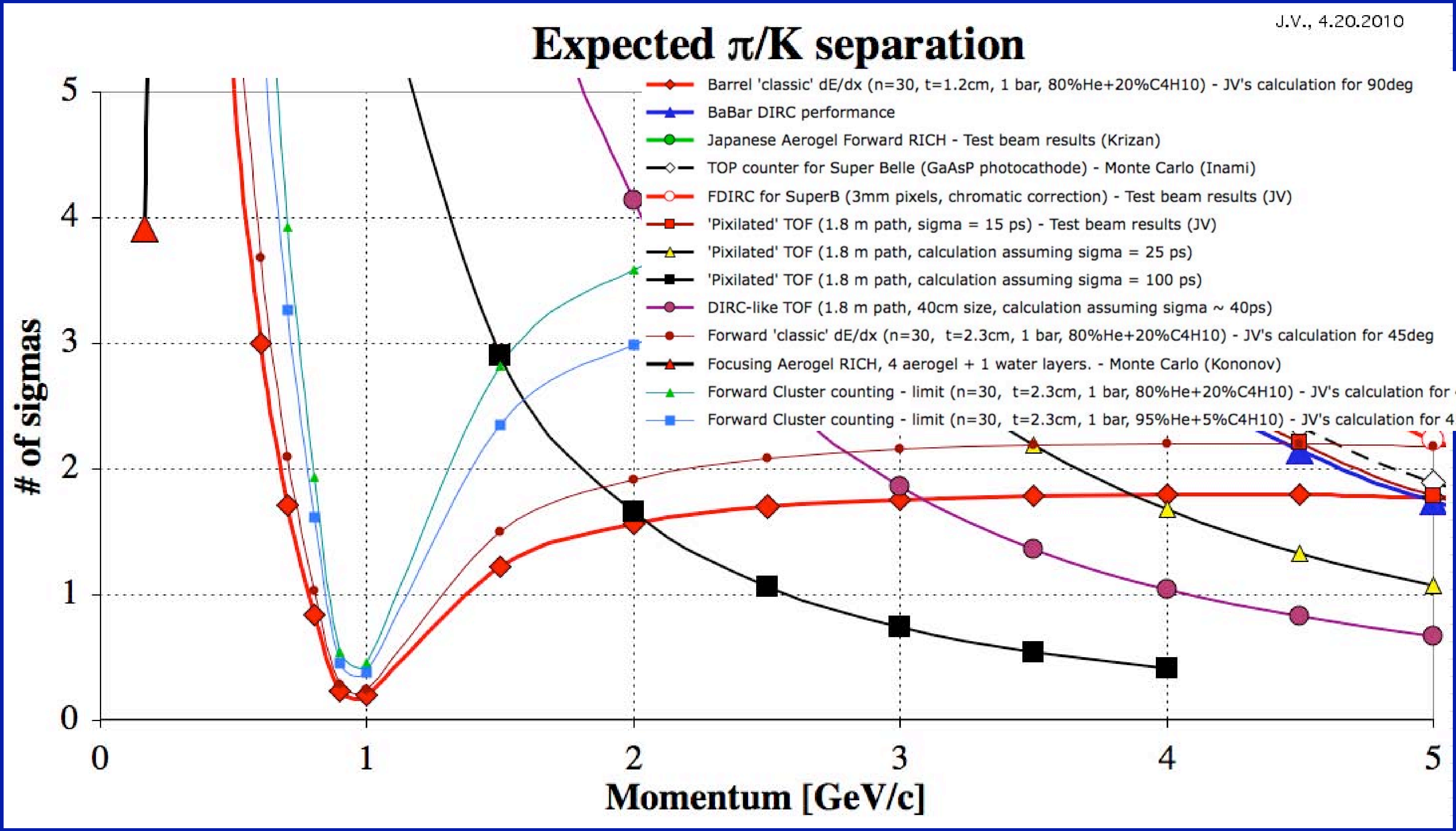
~1.8 m flight path:



Zoom into a region of ~1GeV/c

J. Va'vra

~1.8 m flight path:



TOF

- ALICE
- STAR
- CMB
- ATLAS & CMS
- Super B R&D

TOF PID technique

Principle is simple:

$$\Delta t = (L_{path}/c) * (1/\beta_1 - 1/\beta_2) = (L_{path}/c) * [\sqrt{(1+(m_1c/p)^2)} - \sqrt{(1+(m_2c/p)^2}] =$$

$$\sim (L_{path}c/2p^2) * (m_1^2 - m_2^2)$$

Therefore expected particle separation: $\boxed{N_\sigma = [(L_{path}c/2p^2) * (m_1^2 - m_2^2)] / \sigma_{Total}}$

Example of contributions to the timing resolution:

$$\sigma_{Total} \sim \sqrt{[\,(\sigma_{TTS}/\sqrt{N_{pe}})^2 + (\sigma_{Chromatic}/\sqrt{N_{pe}})^2 + \sigma^2_{Electronics} + \sigma^2_{Track} + \sigma^2_{T0}]}$$

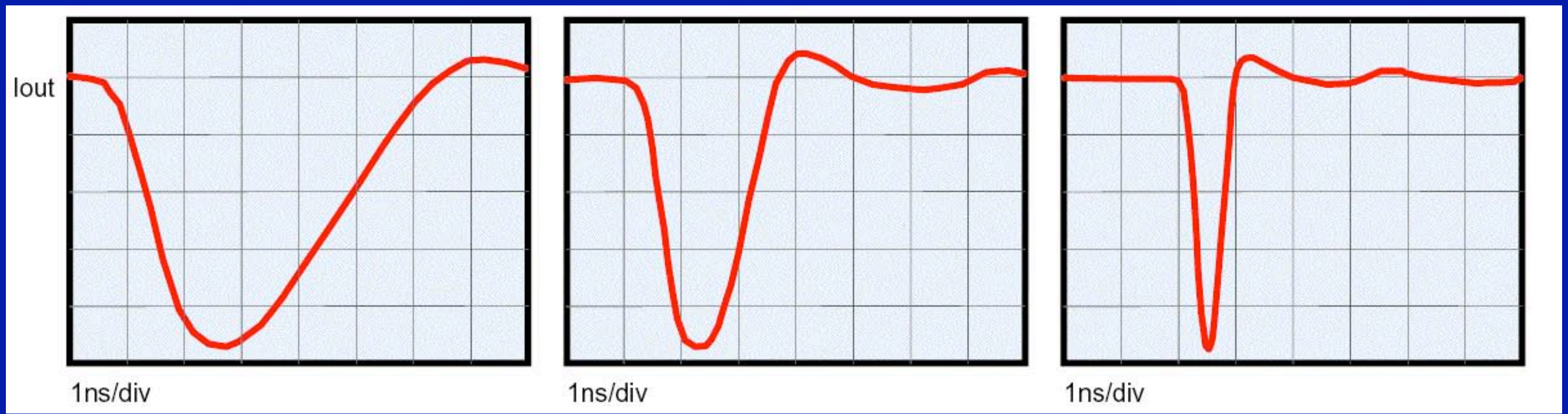
$\sigma_{Electronics}$ - electronics contribution
$\sigma_{Chromatic}$ - chromatic term = f (photon path length)
σ_{TTS} - transit time spread
σ_{Track} - timing error due to track length L_{path}
$\sigma_{T\,0}$ - start time (often dominated by the bunch length)
etc.

Detector candidates for TOF

- Multi-gap glass RPCs ≡ MRPC
- MCP-based PMTs
- G-APDs

Relative comparison of pulses

Standard PMT: **MaPMT:** **MCP-PMT or MRPC:**



PMT	Eff. gain	Pulse FWHM	$I_{\text{Single el. pulse}}$	$V_{\text{Single el. pulse}}(50\Omega)$
Standard PMT	$\sim 10^7$	~ 3.5 ns	~ 500 μA	~ 23 mV
MaPMT	$\sim 10^6$	~ 1.5 ns	~ 100 μA	~ 5 mV
MCP-PMT	$\sim 5 \times 10^5$	~ 400 ps	~ 200 μA	~10 mV
MRPC	$\sim 10^7$	~ 1000 ps	~ 2000 μA	~10 mV*

$I_{\text{single el. pule}}$ ~ Gain x electron/FWHM(pulse width), $V_{\text{single el. pule}}$ ~ $I_{\text{single el. pule}}$ x 50 Ω, *** typical signal observed**

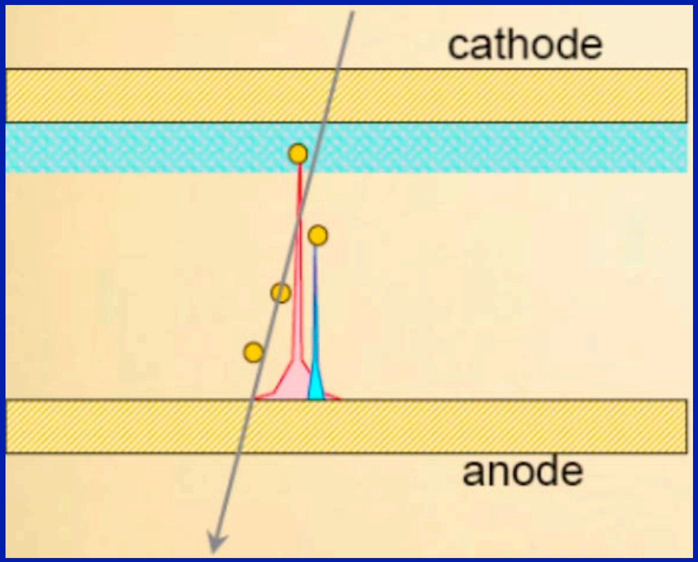
- **MCP-PMT, MaPMT and MRPC need a fast amplifier.**

MRPC

- ALICE experiment at LHC
- STAR experiment at RHIC
- CBM experiment at FAIR

Why many gaps in MRPC ?

C. Williams, talk in Orsay, 2009, and Katayoun, Ph.D. thesis, 2010



Townsend law: $N = N_o e^{\alpha x}$

<u>Idea of this detector:</u>

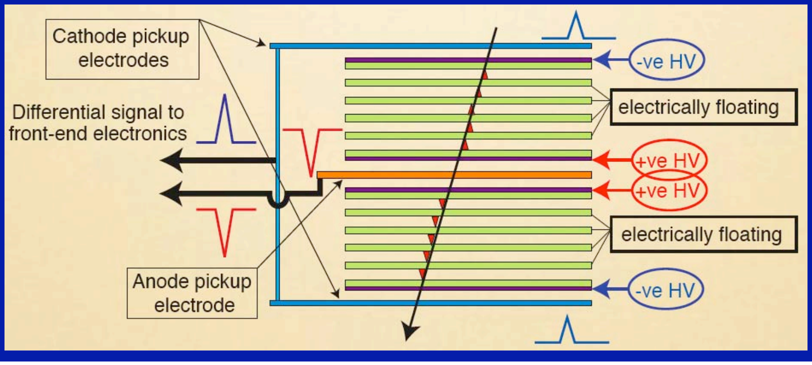
- **High gain operation, limited by a space charge.**
- **To prevent sparking make very tiny gaps to stop avalanche growth.**
- **Electron has to be produced very near cathode to get a large enough signal.**
- **To get a high overall efficiency one needs many gaps.**

ALICE MRPC

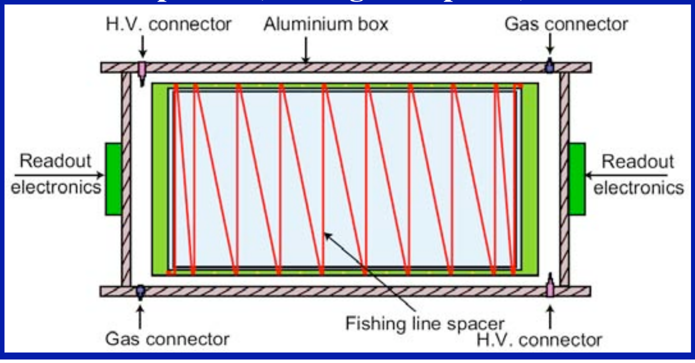
C. Williams, talk in Orsay, 2009 and private discussion at CERN, 2010.

Side view (10 gaps/MRPC):

Fully differential output to get a good S/N:



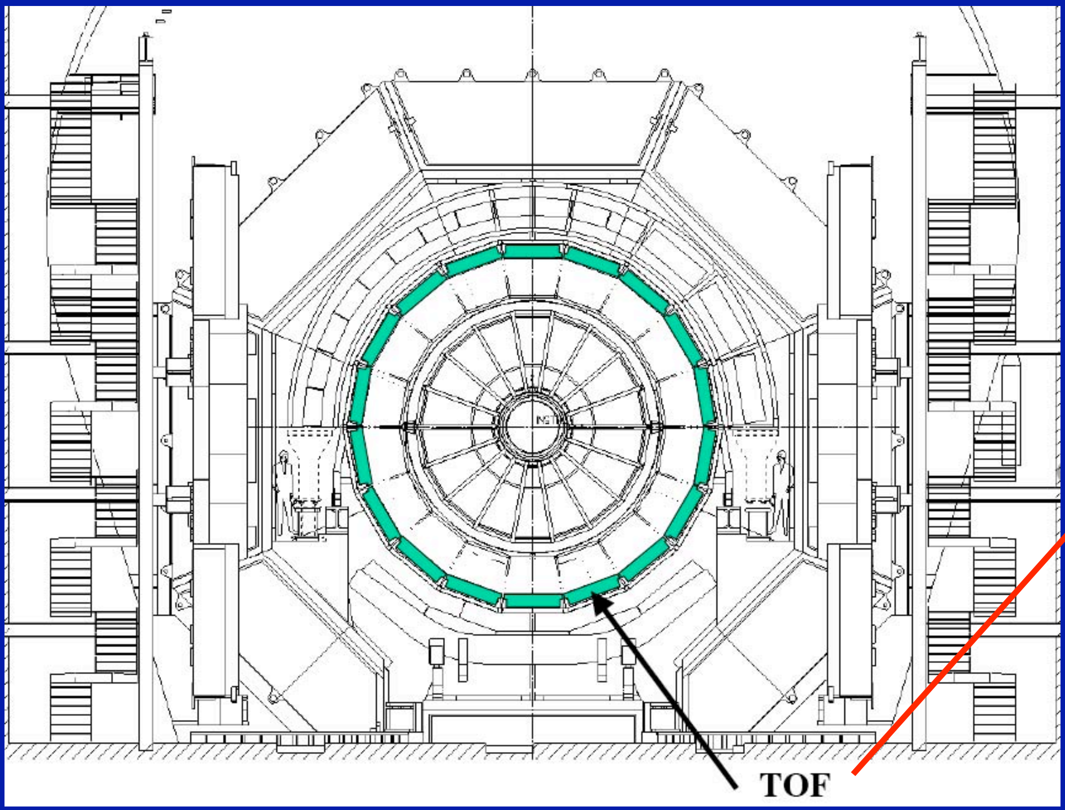
Top view (Fishing line spacer):



Parameter	Value
Total number of active gaps per MRPC & total in ALICE	10 / MRPC & 160,000 total in ALICE
Gap size (controlled by a fishing line)	250 µm
Glass size in one MRPC & total in ALICE	1200 x 72 mm^2 & 150 m^2 in ALICE
Pad geometry & number of pads/MRPC	25 x 36 mm^2 & 96 pads /MRPC
Gas	90% $C_2F_4H_2$ + 5% iC_4H_{10} + 5% CF_6
Signal rise time	~500 ps
Average total charge	~ 2pC / MRPC
Typical counting rate	~ 100 Hz/cm^2 (max rate: ~ 1kHz/cm^2)
Total mass per MRPC with 10 gaps	~ 6% of r.l. / particle passage
Magnetic field in ALICE	16 kG
Pulse height correction	Leading & trailing edge timing (TOT)

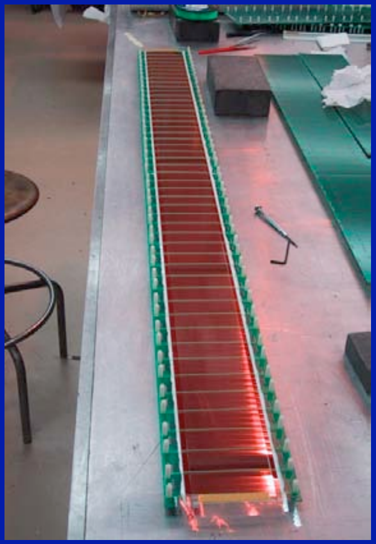
Note: Voltages applied only to outer electrodes, the rest is floating => easy to build

ALICE TOF



Boxes contain MRPC modules:

MRPC module:



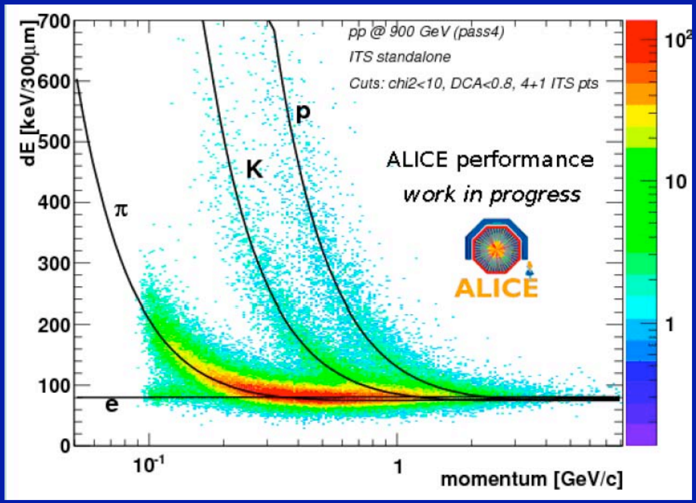
~ 160,000 electronics channels
~ 150 m^2 total area in ALICE

ALICE: power of combining dE/dx & TOF

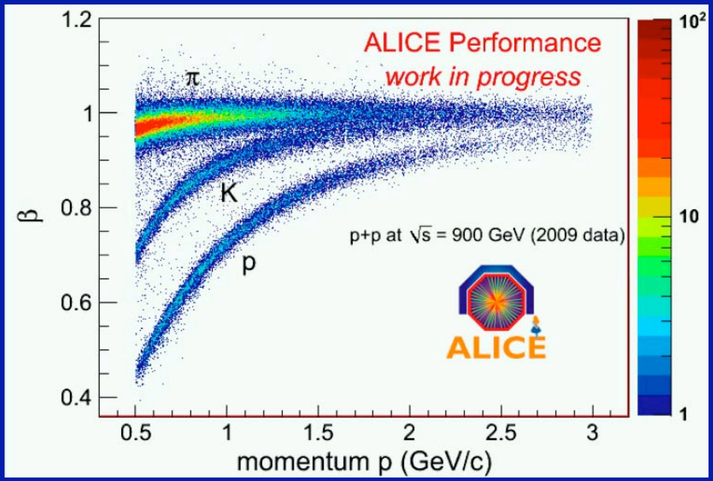
F.Noferini, Moriond, 2010

pp colisions at 900 GeV

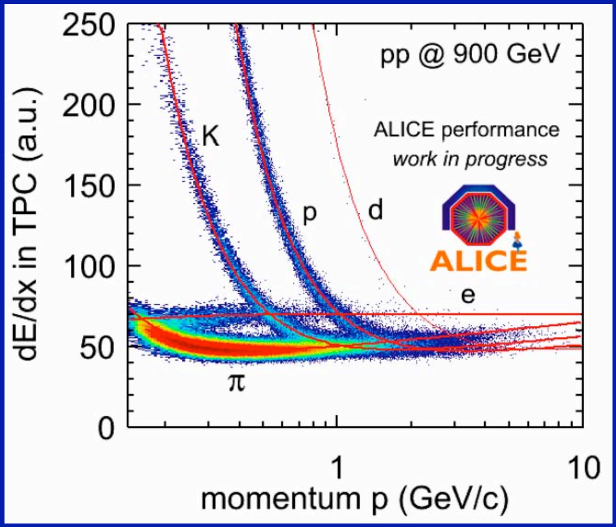
ITC
(6 layers of Si)



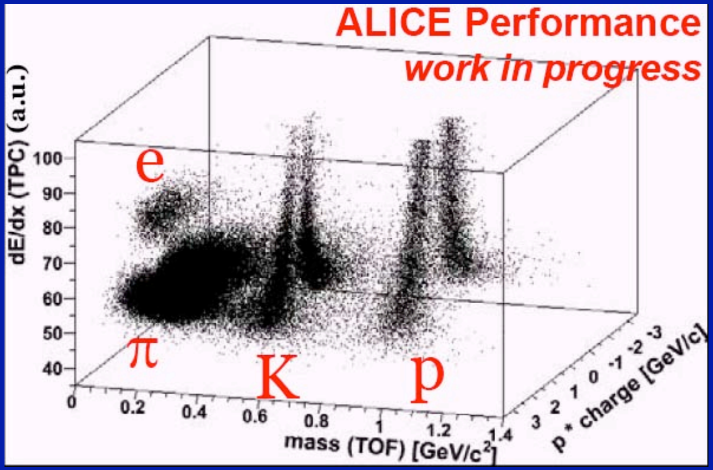
TOF



TPC



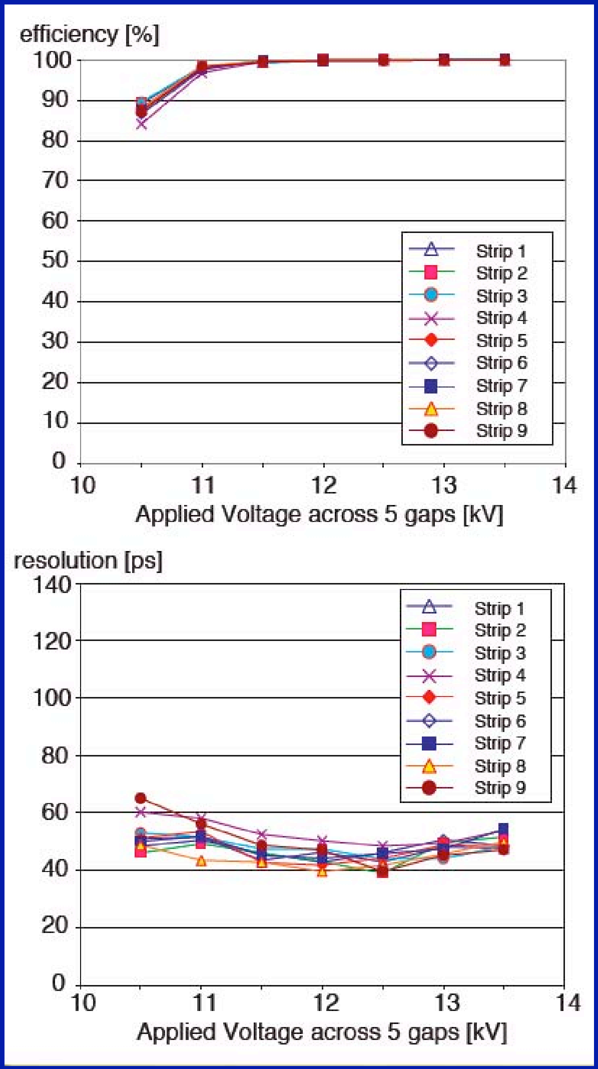
dE/dx & TOF



Present TOF resolution: ~130ps (very preliminary)
~150k channels to calibrate

ALICE: MRPC beam test results

C. Williams, talk in Orsay, 2009 and private discussion at CERN, 2010.



- **Obtained a resolution: 40-50 ps**
- **TOF_{MRPC1} - TOF_{MRPC2}:**

$$\sigma^2_{Total} \sim \sigma^2_{NINO\ ASIC\ +\ cables} + \sigma^2_{Beam\ spot} + \\ + \sigma^2_{MRPC} + \sigma^2_{TDC} \sim \\ \sim \sqrt{(21^2 + 14^2 + \underline{11}^2 + 30^2)} \sim 41\ ps$$

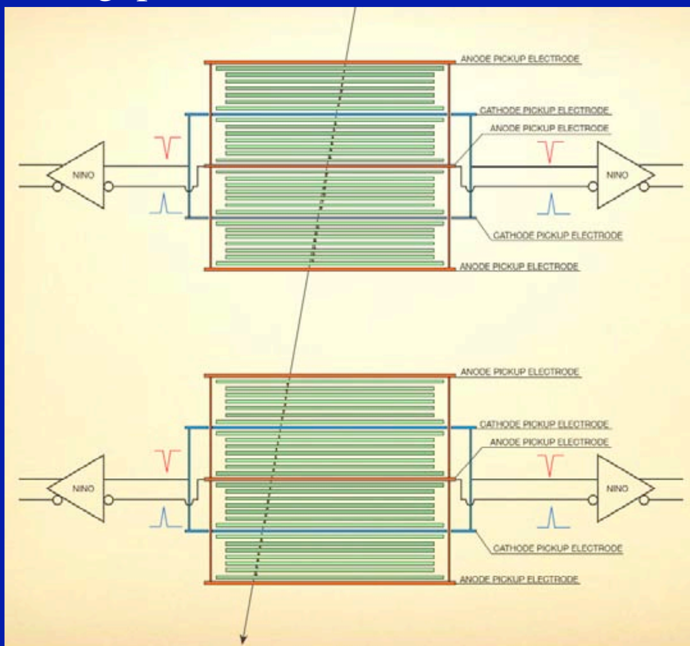
- **MRPC is contributing ~11ps !!!**

Note: in real application one has to add also σ_{Track} & σ_{to}

New R&D effort: 24 MRPC gaps

C. Williams, talk in Orsay, 2009 and private discussion at CERN, 2010.

24-gap MRPC:



- **24 active gaps/MRPC**
- **Gap size: 160 μm**
- **~ 14% of r.l.**
- **Pad readout**
- **Max. possible rate ≤ 1 kHz/cm²**

- **Aim for a resolution: ~10 ps**
- **What does one expect for d(TOF) ?:**
- $\sigma^2_{\text{NINO ASIC + cables}}$ **: $\cancel{21}$ ps --> 5 ps**
  (faster risetime & mount directly on the MRPC)
- $\sigma^2_{\text{1 cm beam spot}}$ **: 50 ps/√12 ~ $\cancel{14}$ ps --> 5 ps**
  (read out both sides of a pad)
- σ^2_{MRPC} **: $\cancel{11}$ ps --> 5 ps**
  (go from 10 ~250μm-gaps to 24 ~160μm-gaps)
- σ^2_{TDC} **: $\cancel{30}$ ps --> 5 ps**
  (replace TDC with 4-channel oscilloscope with **10 GSa/s**)

Expect:

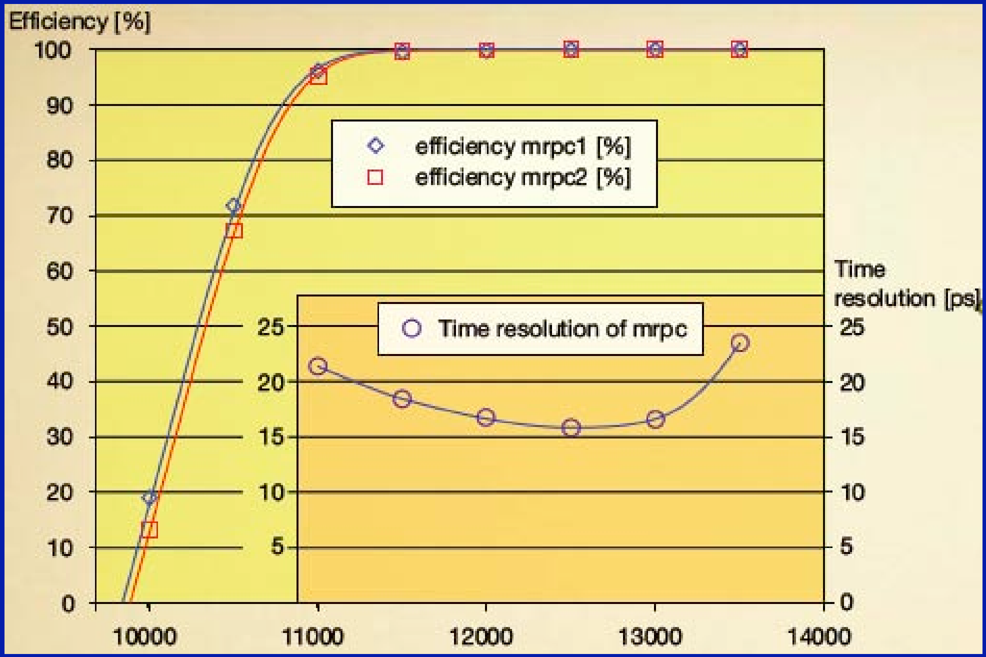
$$\sigma^2_{\text{Total}} \sim \sqrt{(5^2 + 5^2 + 5^2 + 5^2)} \sim 10 \text{ ps}$$

Note: in real application one has to add also σ_{Track} & σ_{to}

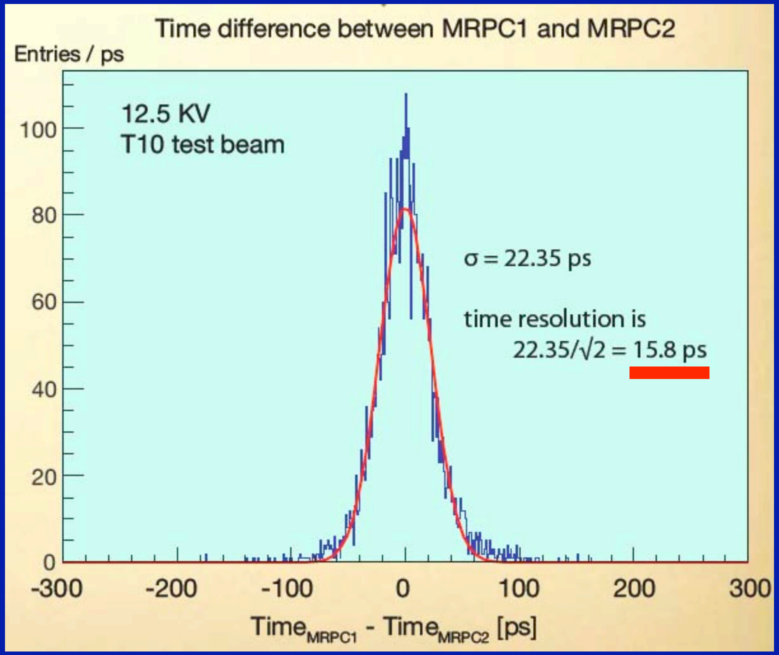
New R&D effort: 24 MRPC gaps

C. Williams, talk in Orsay, 2009, and private discussion at CERN, 2010.

Test beam results: Tuning of operating point

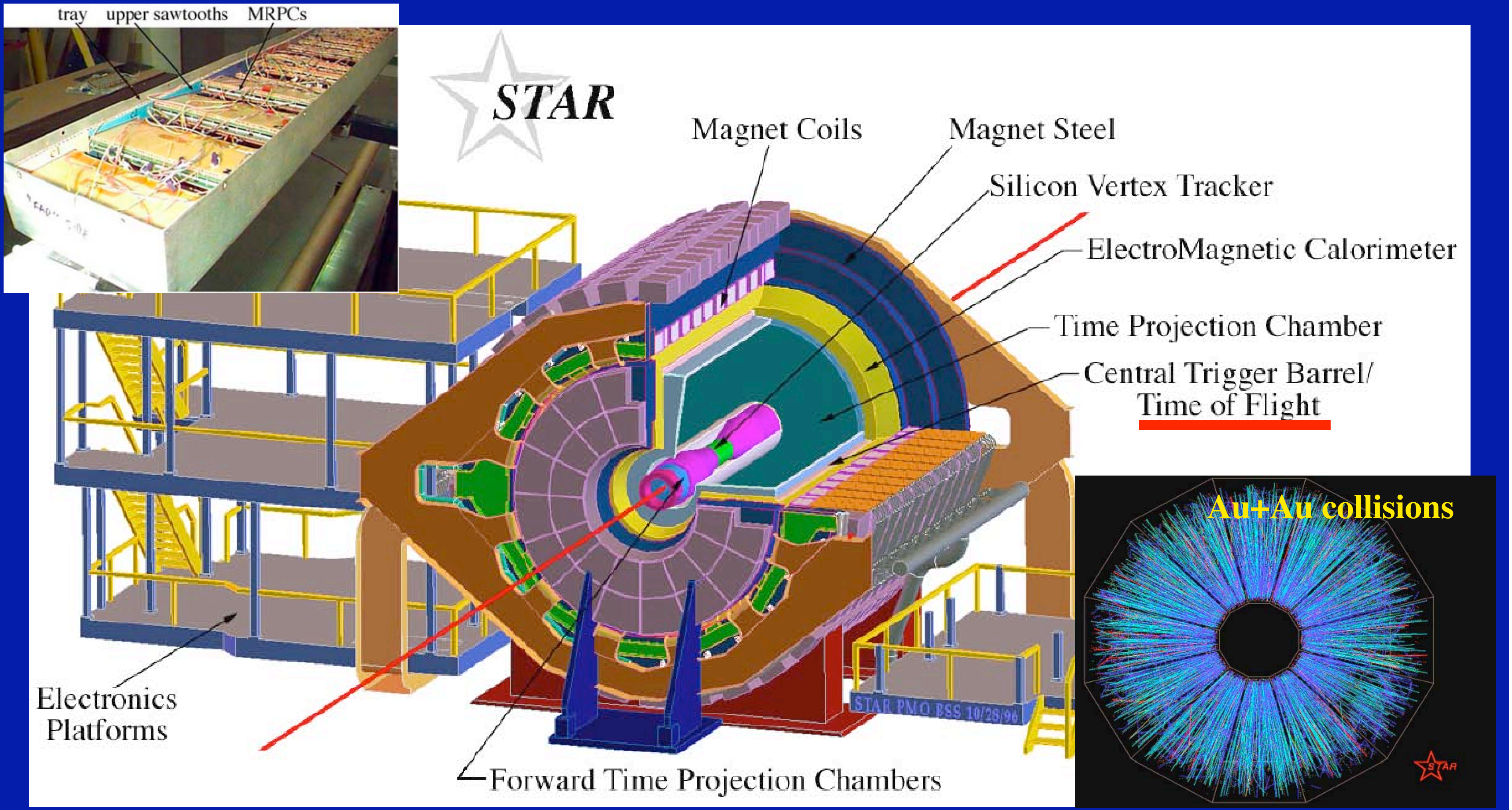


Test beam results: resolution/MRPC



- **MRPC contribution to the final resolution: <10ps !**
- **Present limiting factor: electronics**
- **Presently they use fast scopes for the electronics**

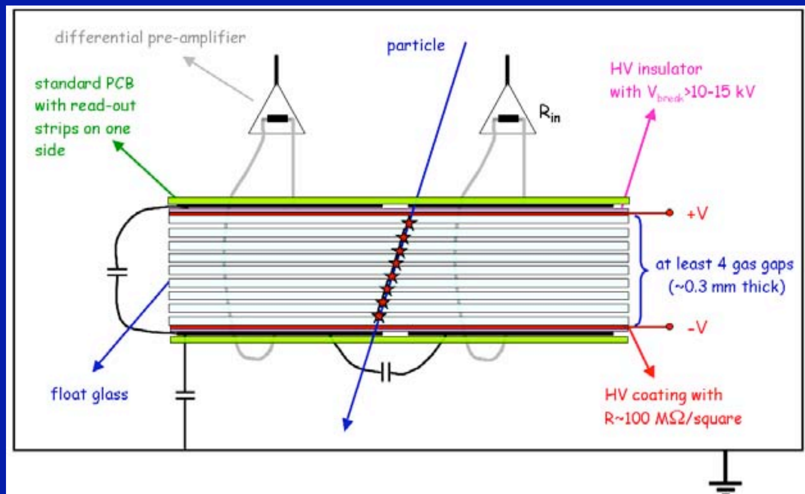
STAR experiment at RHIC



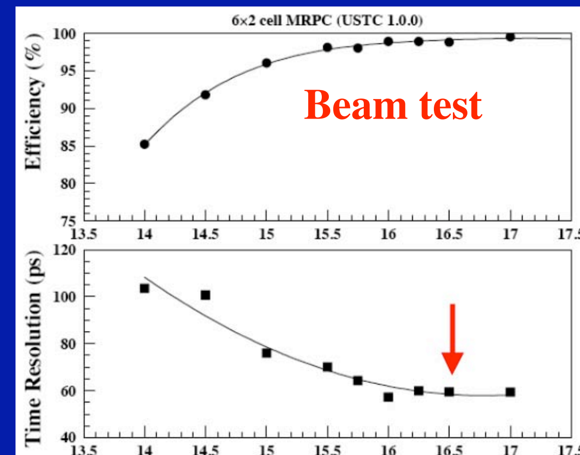
- The experiment is also using MRPC TOF detectors

STAR MRPC TOF performance

MRPC:



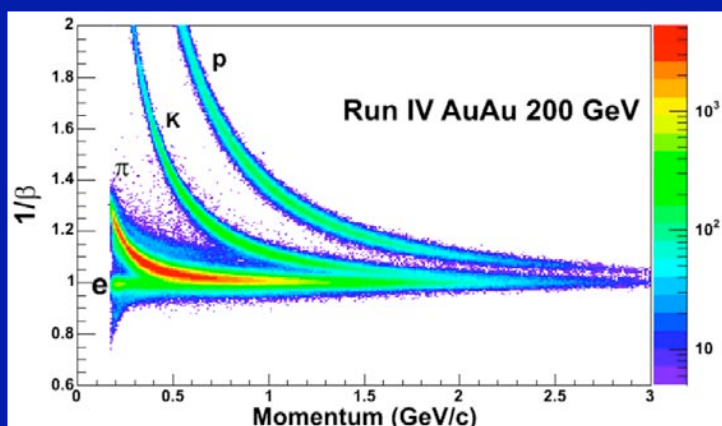
MRPC efficiency & TOF resolution:



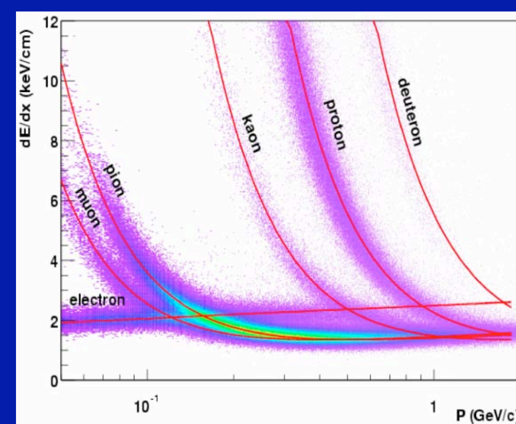
Voltage [kV]

PID in STAR:

TOF:

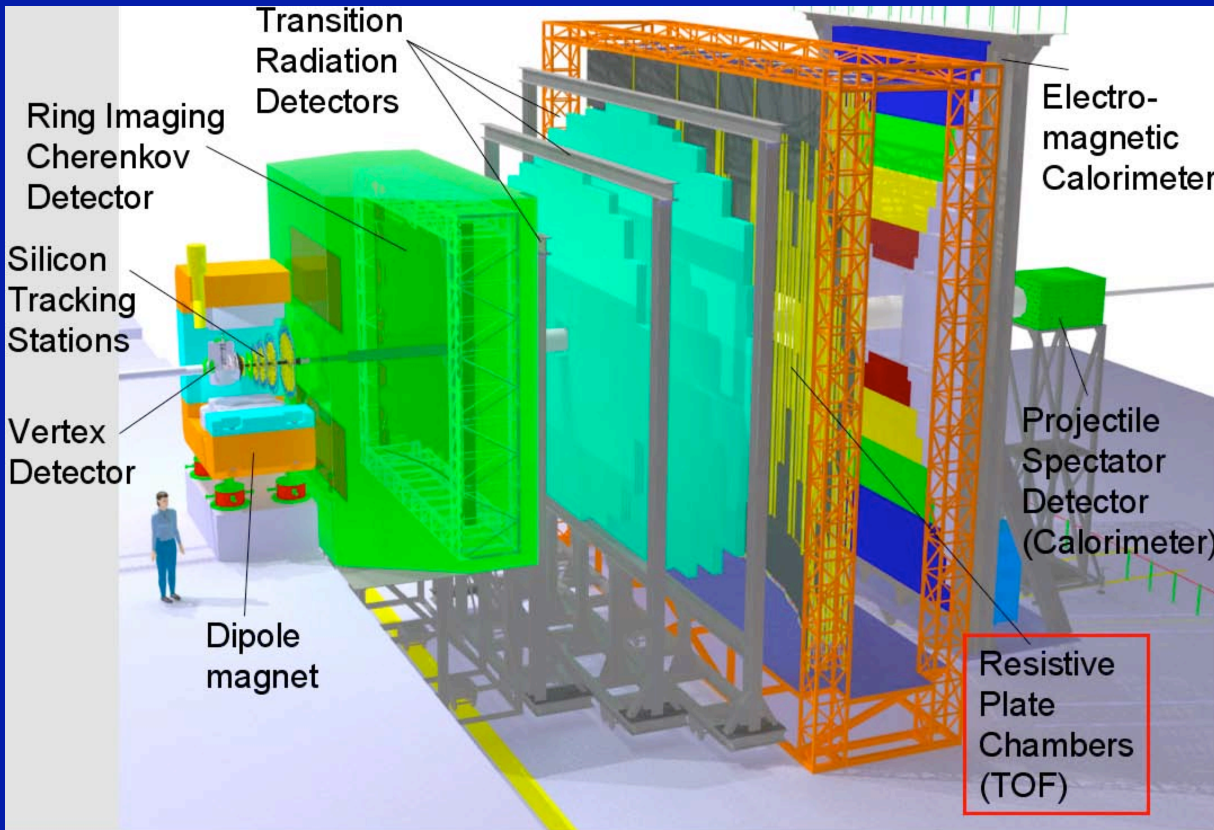


dE/dx in TPC:

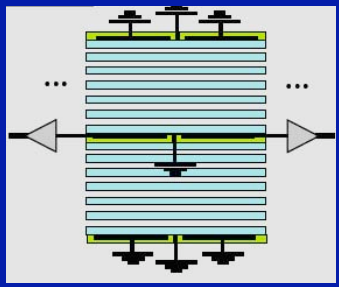


- **8-gap MRPC gives a timing resolution of ~60 ps.**

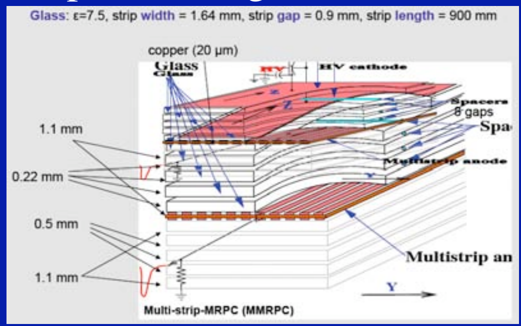
CBM experiment at FAIR



12-gap design:



Strip-line design:



- They are developing MRPCs with multiple strip line readout (called MMRPC), to reduce the channel count.

MCP-PMT

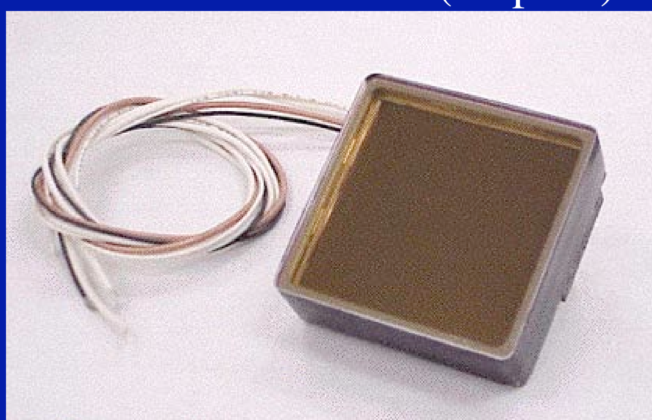
- ATLAS & CMS forward detectors at LHC
- TOP counter at Super Belle
- Forward TOF detector at SuperB ?

Examples of MCP-PMT tubes used for TOF

HPK-6 (single pad):

Photek 210 & 240 (single pad):

Photonis 10 & 25 (64 pads):



HPK SL-10 (4 pads):

MCP-PMTs used in TOF tests

Data from Hamamatsu[+], Burle/Photonis, Photek*,
and from K. Inami (Nagoya) [a], J. Va'vra (SLAC) [b] , A.Lehman [c], A.Brandt (Arlington) [δ], A.Rozhnin (Fermilab) [e]

MCP-PMT	# of anodes	# of MCPs	MCP size	Hole [μm]	QE [%]	Photocathode	TTS [ps]	Rise time [ps]
HPK 6	1	2	ϕ11mm	6	26	Multi-alkali	~11 [+]	< 150 [+]
HPK 10	1	2	ϕ25mm	10	26	Multi-alkali	< 35 [a]	< 200
HPK SL-10	4	2	22x22	10	24	Multi-alkali	< 30 [a]	< 200
BINP 8	1	2	ϕ18mm	8	18	Multi-alkali	< 27 [c]	< 200
Photonis 10	64	2	49x49	10	24	Bi-alkali	< 30 [b]	< 200
Photonis 25	64	2	49x49	25	24	Bi-alkali	< 50 [b]	< 250
Photek 110	1	1	ϕ10mm	3.2	30	Multi-alkali	?	~70 *
Photek 210	1	2	ϕ10mm	3.2	30	Multi-alkali	< 25 [d, e]	~81 *
Photek 210	1	2	ϕ10mm	6	30	Multi-alkali	?	~95 *
Photek 240	1	2	40mm	10	30	Multi-alkali	?	~180 *

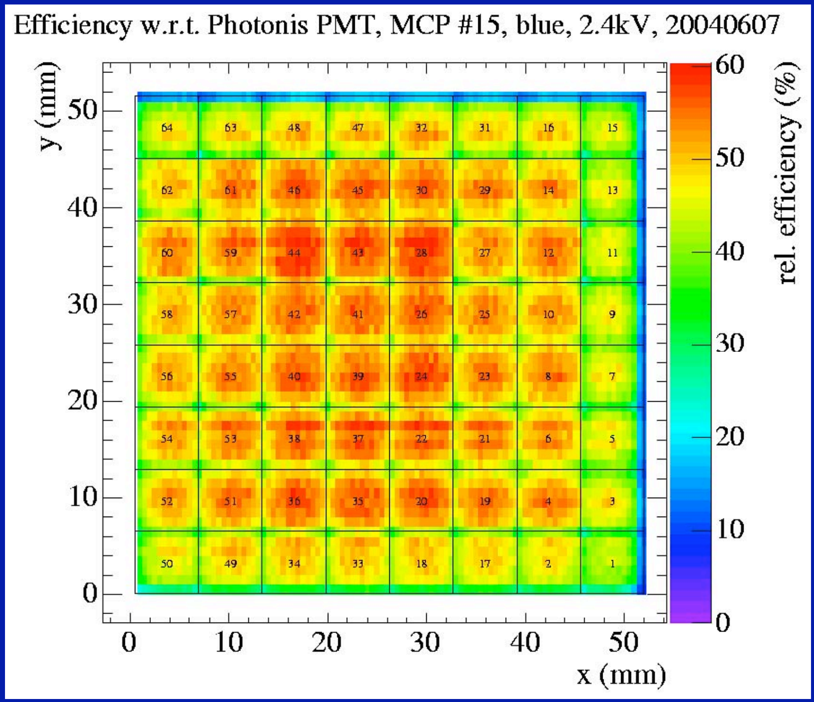
HPK6 is R3809U-50-11X, HPK10 is R3809U-50-25X, SL-10 is R10754-00-L4 in Hamamatsu catalog

To get the best out of these tubes one may have to develop a new fast electronics

MCP-PMT Relative efficiency to Photonis XP2262B

C. Field, T. Hadig, D.W.G.S. Leith, G. Mazaheri, B. Ratcliff, J. Schwiening, J. Uher, and J. Va'vra, Nucl.Instr. & Meth., A553(2005)96-106

Planacon with 25μm holes:



- **Relative photon detection efficiency (PDE) to 2" dia. Photonis XP2262/B is only 50-60%. To claculate this efficiency all hits were used, including the tail hits => the "in-time hit" efficiency is smaller by 20-30% !!**
- **I do not have a similar plot for 10μm hole MCP unfortunatelly.**

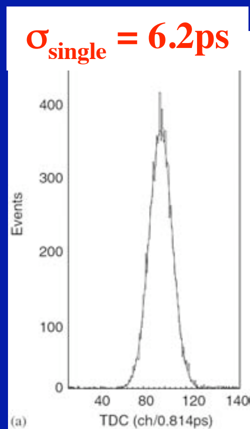
Two detectors directly in the beam

$\sigma_{single} = \sigma_{measure}/\sqrt{2}$

Two **HPK6** (6 µm holes, vary radiator length)
(K. Inami et al, NIM A560(2006)303-308)

10 + 3mm

High gain of ~10^6 & Npe ~ 80:

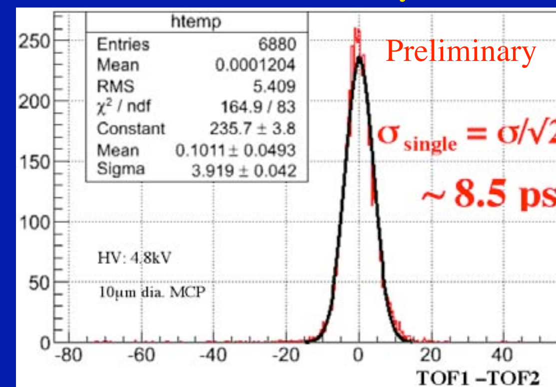


HPK6

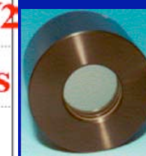
Two **Photek 240** (10 µm holes, window is radiator,)
(M. Albrow, A .Rozhnin, E. Ramberg, to be published)

9.6 mm window only

High gain of ~10^6 & Npe ~ ?:



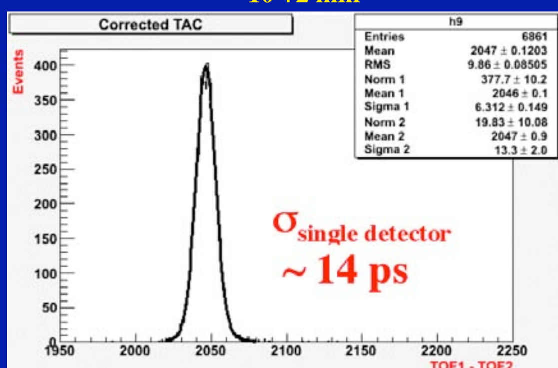
Photek 240



Two **Planacons** (10 µm holes, 10mm long radiator)
(J. Va'vra, A.Rozhnin, et al, Fermilab test, NIM A606(2009)404-410)

10 +2 mm

Low gain of 2x10^4 & Npe ~ 35:



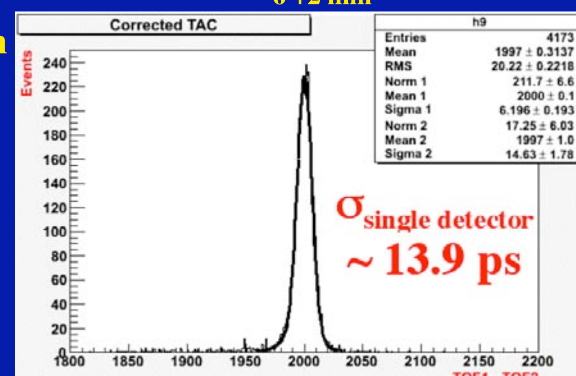
Planacon 10

(Low gain to limit the single pe background at SuperB)

Two **Planacons** (25 µm holes, 6mm long radiator)
(A.Rozhnin, E.Ramberg, J.Va'vra et al., Fermilab test, unpublished)

6 +2 mm

High gain of ~10^6 & Npe ~ ?:



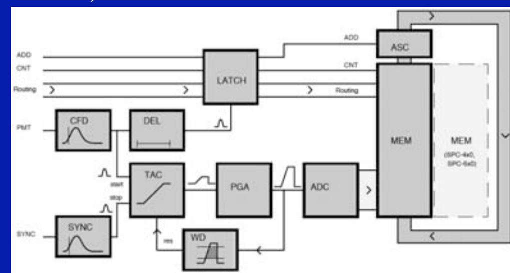
Planacon 25

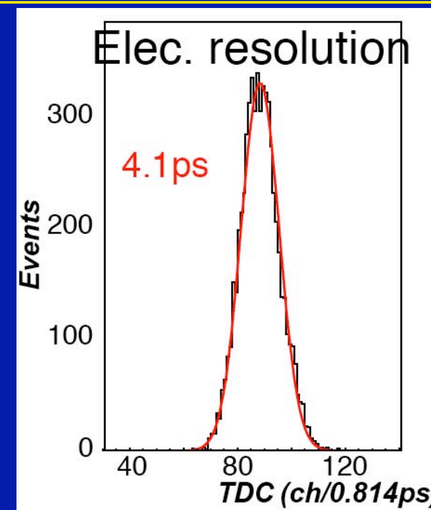
(This tube had much larger number of photoelectrons)

What electronics resolution do we need ?

1) **Nagoya test: Electronics resolution of Becker&Hickl SPC-134 CFD/TAC/ADC**

(K. Inami et al, NIM A560(2006)303-308)

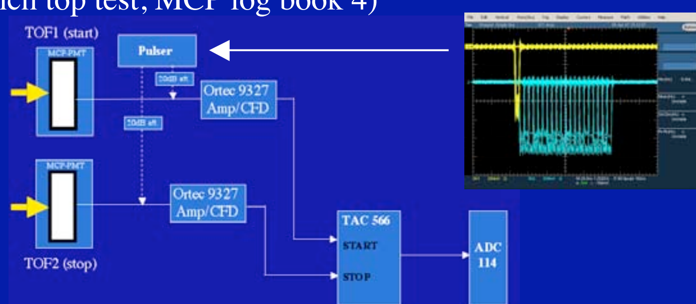


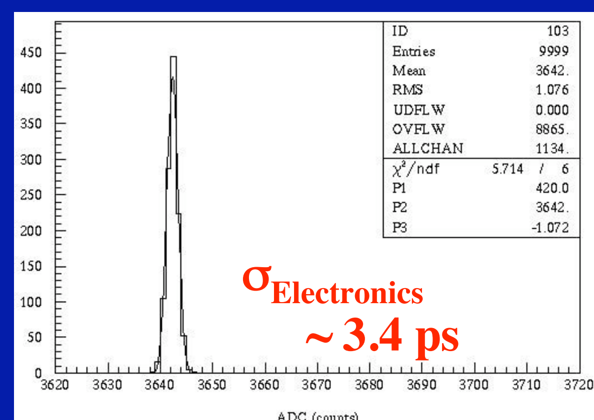


- Time scale calibration: **813 fs / count**
- Time resolution achieved: $\sigma_{Electronics} \sim 4.1$ ps

2) **Fermilab tests: Electronics resolution of Ortec 9327CFD / 566TAC / 114ADC:**

(J. Va'vra, bench top test, MCP log book 4)





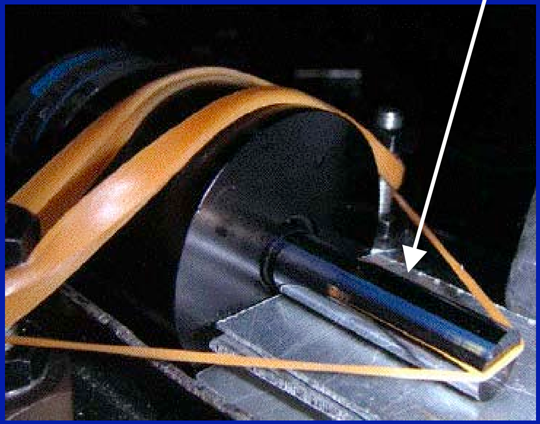
- Time scale calibration: **3.19 ps / count**
- Time resolution achieved: $\sigma_{Electronics} \sim 3.4$ ps

Note: Fermilab people actually got 2ps resolution with this electronics

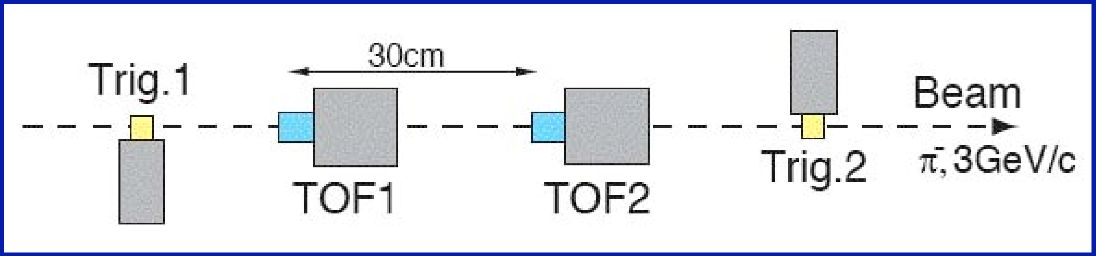
The Nagoya test in the beam

K. Inami, H. Kishimoto, Y. Enari, M. Nagamine, and T. Ohshima, " A 5 ps TOF-counter with MCP-PMT", Nucl. Instr. & Meth., A560(2006)303-308.

Vary the length



Beam test setup: two identical TOF detectors

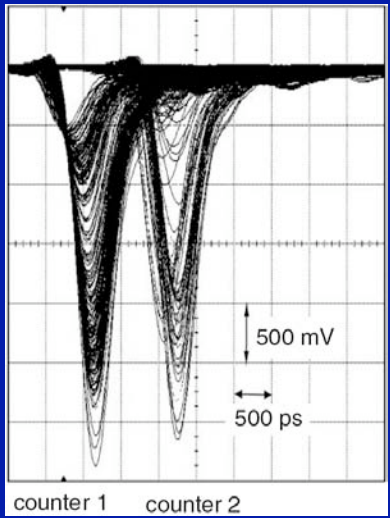


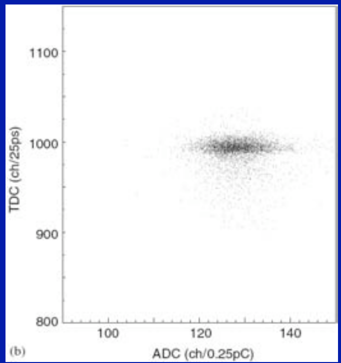
- **<u>Quartz radiator:</u> 10 mm dia. rod, coated with Al on its round sides, and Length: 40, 30, 20, 10 mm and no radiator (just a 3 mm quartz window).**
- **Npe ~ 20 for L = 3 mm, and Npe ~ 40-50 for L = 10 + 3 mm.**
- **The best resolution result was obtained for L = 10 + 3 mm.**

Does one need ADC correction ?

1) High gain (G~2x10^6):

(K. Inami et al., NIM, A560(2006)303-308)

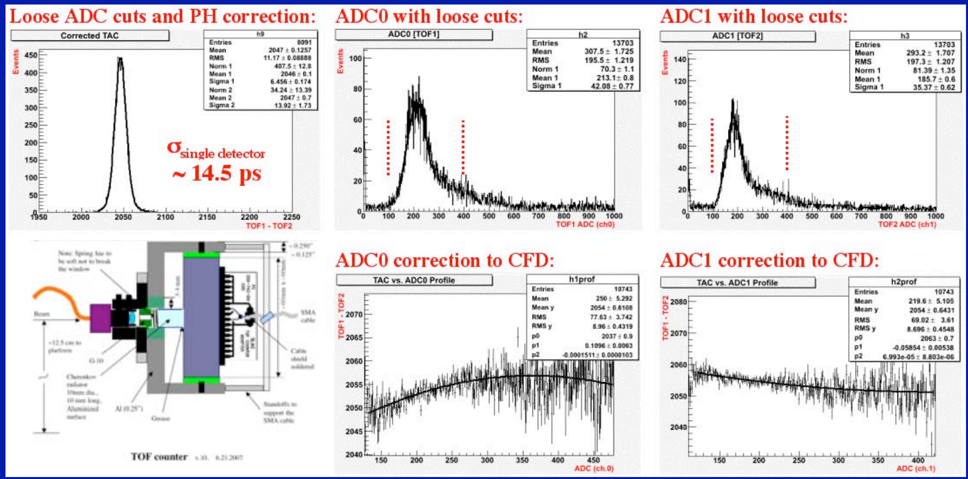




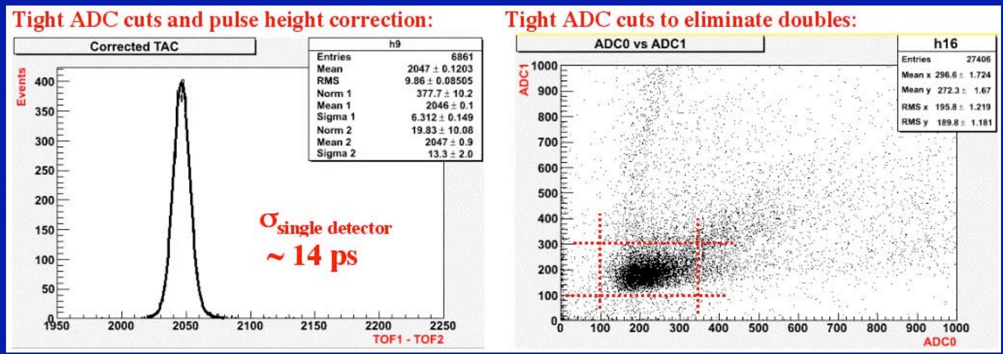
No ADC correction necessary

2) Low gain (G~2x10^4, N$_{total}$ ~6x10^5 el.)**:**

(J. Va'vra et al., NIM A606(2009)404-410)



Need CFD & ADC correction to get good result



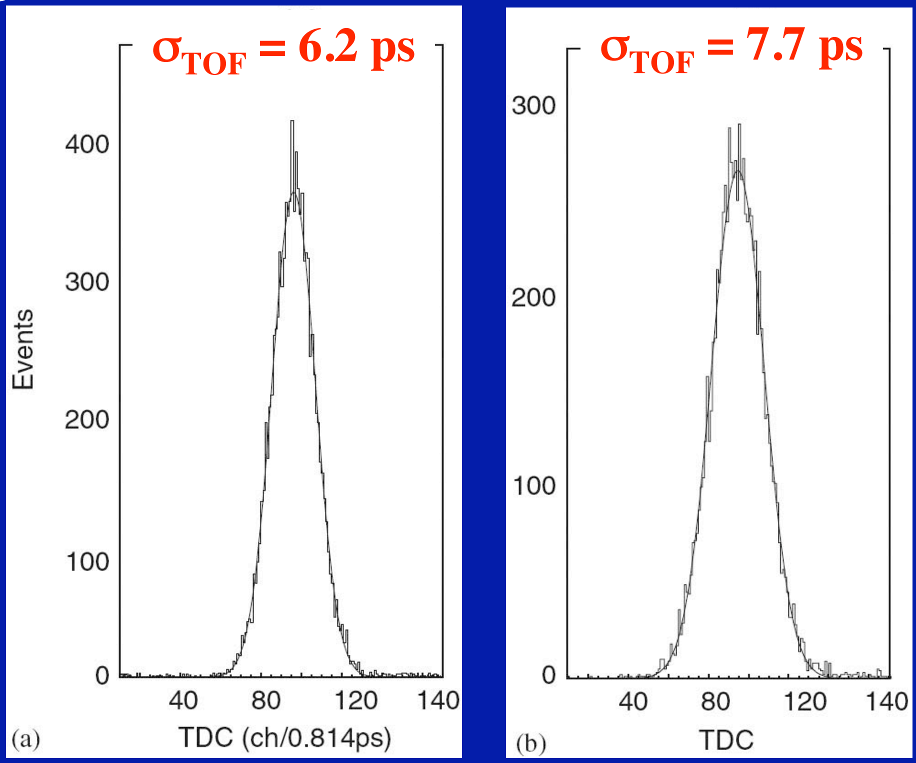
Not sensitive to single pe background
However, one needs a thicker radiator

Nagoya test: the best beam results so far

K. Inami, H. Kishimoto, Y. Enari, M. Nagamine, and T. Ohshima, " A 5 ps TOF-counter with MCP-PMT", Nucl. Instr. & Meth., A560(2006)303-308.

Quartz radiator length: **10 + 3 mm** **3 mm**

Single detector resolution:



$\sigma_{TOF} = \sigma_{measure}/\sqrt{2}$

- **Two identical HPK MCP-PMT R3809U-59-11 with 6 µm holes.**
- **MCP-PMT operated at a very high gain of ~2×10^6.**
- **No amplifier to avoid saturation effects in CFD timing**

Nagoya test: can a simple calculation explain data ?

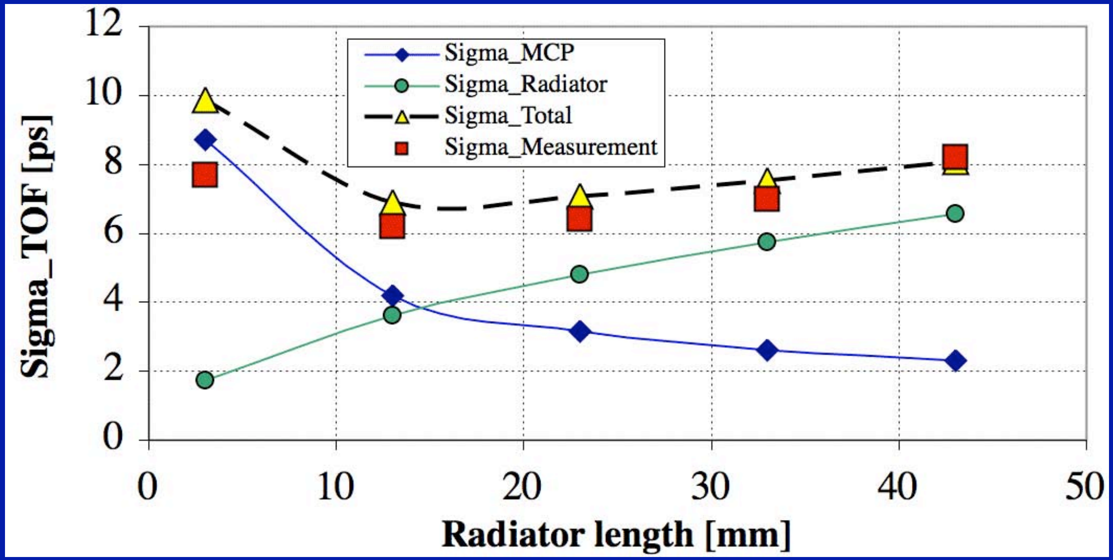
My version of a simple model

$$\sigma_{TOF} \sim \sqrt{[\sigma^2_{MCP\text{-}PMT} + \sigma^2_{Radiator} + \sigma^2_{Pad\ broadenibng} + \sigma^2_{Electronics}]} =$$

$$= \sqrt{[(\sigma_{TTS}/\sqrt{N_{pe}})^2 + (((L*1000\mu m/\cos\theta_C)/(300\mu m/ps)/n_{group})/\sqrt{(12Npe)})^2 + ((5*1000\mu m/300\mu m/ps)/\sqrt{(12Npe)})^2 + (4.1\ ps)^2]}$$

For L = 13 mm: $\sigma_{TOF} \sim \sqrt{[4.18^2 + 3.6^2 + 0.63^2 + 4.1^2]} \sim 6.9$ ps

Assume: $\sigma_{TTS} \sim 32$ ps & Npe = 40-50 pe/10 mm

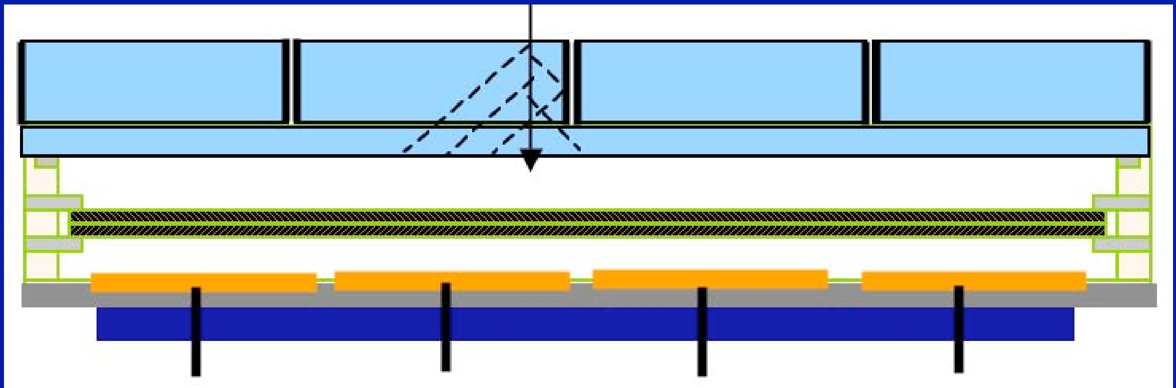


- **A simple model actually does work quite well.**

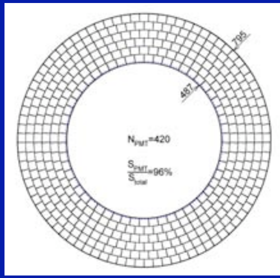
Too soon to think about a pixilated TOF ?

J. Va'vra, "Forward PID", SuperB workshop, Orsay, Feb. 2009

SuperB-related based on the Planacon MCP-PMT:



Forward TOF:

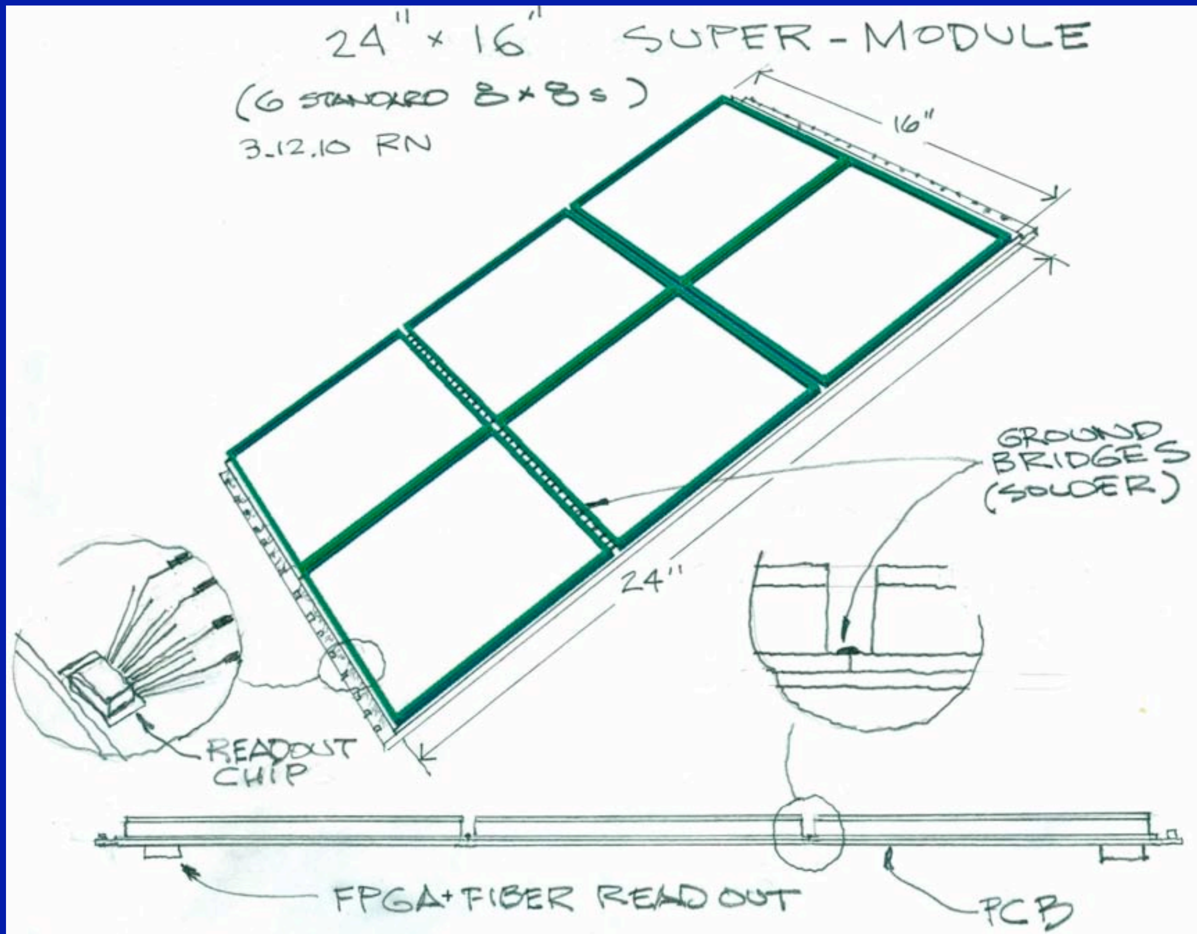


Would need ~550

- **Low enough gain (2-3 x 10^4) to be insensitive to single photoelectron background, i.e., detect only <u>charged tracks</u>.**
- **Radiator thick enough to produce N_{total} ~ 6-8 x 10^5 electrons/track to get a sufficient S/N ratio for good timing. Radiator is made of Fused silica cubes with polished sides.**
- **Combine 4 pads into one to reduce a number of pixels.**
- **This detector, unfortunatelly, may not happen at SuperB as these MCP-PMTs are too expensive at present.**

New MCP-PMT Development

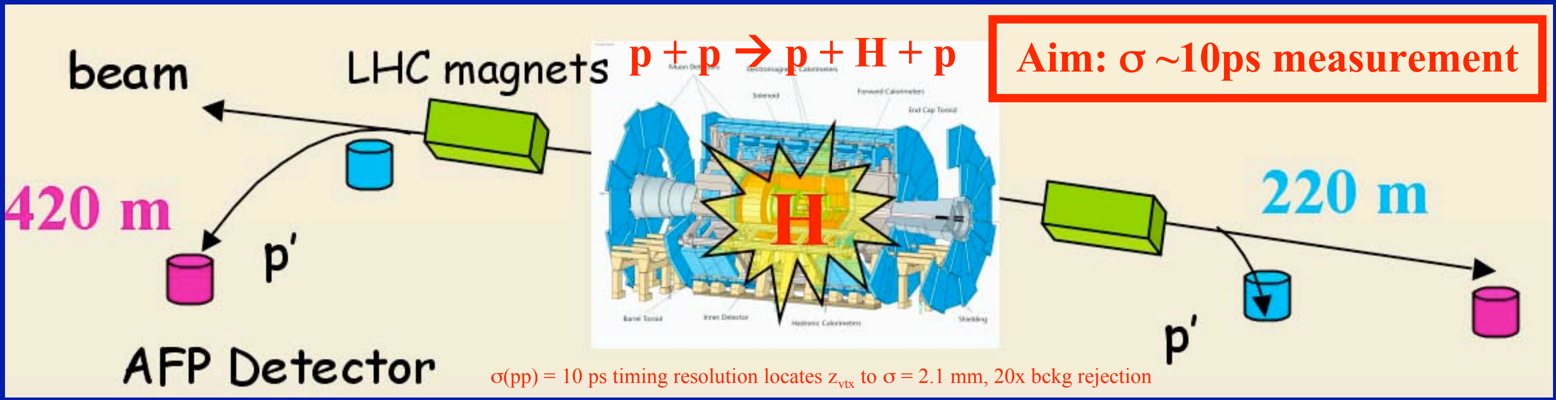
H. Frisch et al., R&D effort of University of Chicago, Argonne Natl. lab, Berkely Space Scienec lab, Fermilab Natl. lab, etc.



- **See talk of Ossy Siegmund for more details on this new R&D.**

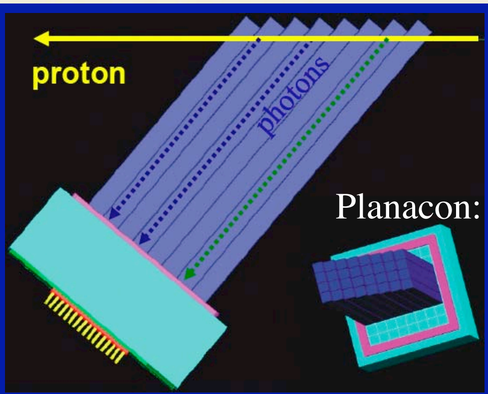
ATLAS & CMS: pp-diffraction scattering

Andrew Brandt, Krzysztof Piotrzkowski, Mike Albrow, Erik Ramberg, Anatoly Roznhin, and others

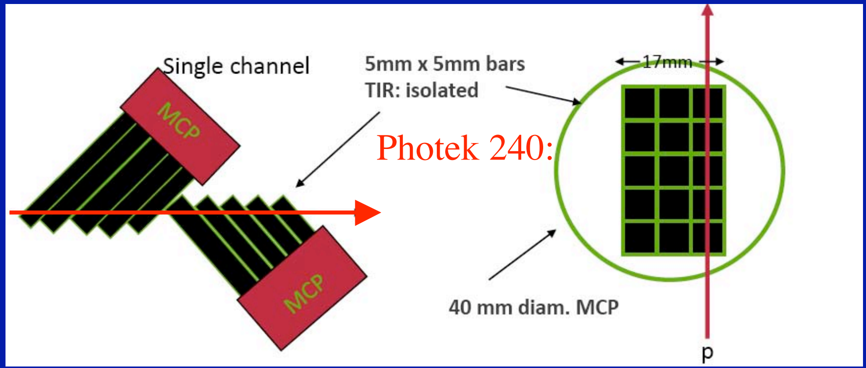


1)

Quartic:

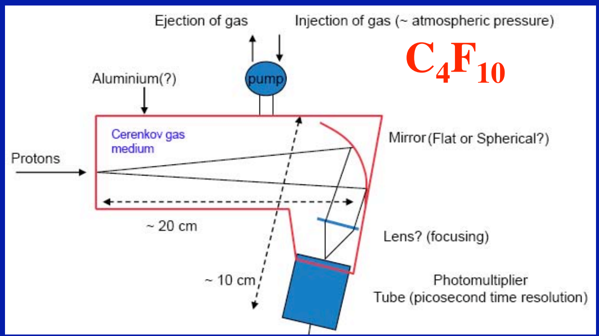


Qbar:



2)

Gastof:

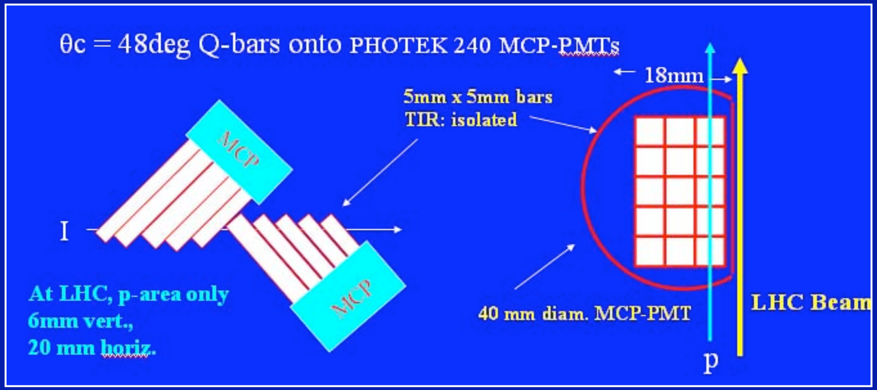


- **QUARTIC/Qbar** – multiple quartz bar detector (**single bar resolution 30-40 ps, resulting in total of ~10ps**).
- **GASTOF** – a gas Cerenkov detector (**single σ ~ 10 ps measurement**)
  (C_4F_{10}-based Cherenkov detector with very fast light (<1ps), limited by the detector presently !!).
- **Very challenging environment at LHC:**
  (a) High event rate, (b) Running MCP close to max anode current,
  (c) Large annual collected charge (~10C/cm^2)

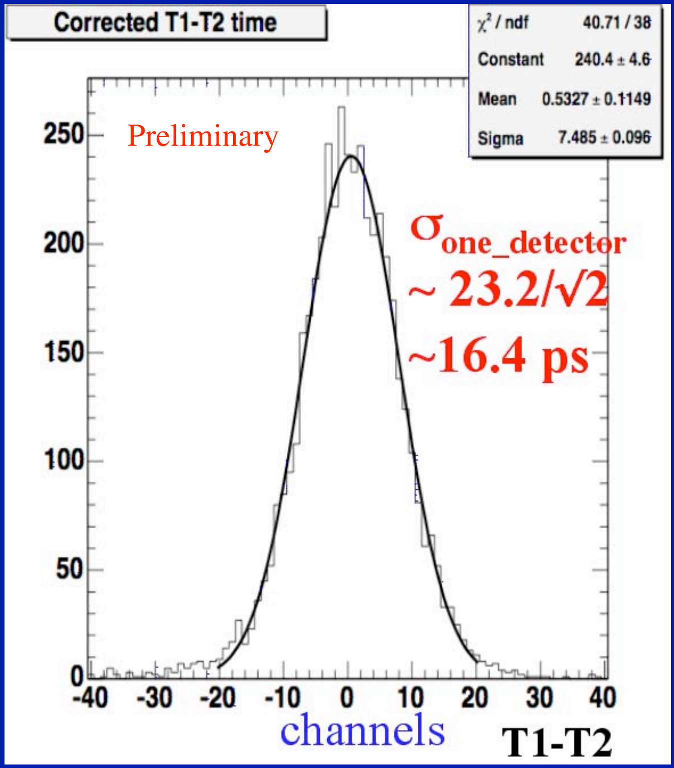
CMS R&D: Q-bar

Mike Albrow et al., Fermilab, April 2010

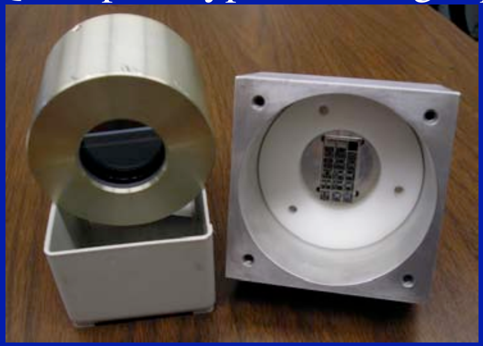
Electronics: Ortec 9327 CFD, 566 TAC, 114 ADC:

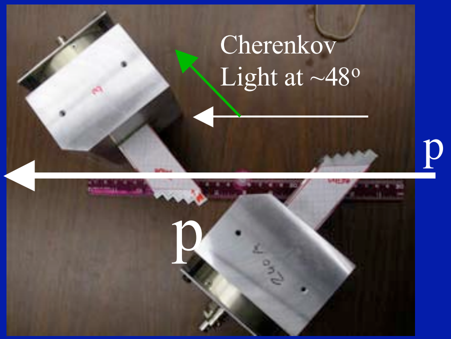


Fermilab 120 GeV protons:



Q-bar prototype with single-pixel Photek PMT 240:





- **In the final application at LHC, they will use two Qbar detectors, and therefore the final resolution is $\sigma_{final} \sim \sigma_{One\_detector} / \sqrt{2} \sim 16.4 / \sqrt{2} \sim$ <u>11.2 ps</u>. In fact, I am told by Mike Albrow, that they plan to add more detectors in line to reduce the error further.**
- **<u>This is the 1-st real success of the entire ps-timing effort.</u>**
- **The next challenge: aging and rate issues.**

TOP-like/DIRC-like
TOF detectors
for SuperB and Belle II factories

Note: all these devices are really DIRC in various form

- Small TOP counter
- TOF counter effort in SuperB
- Forward Disc DIRC at Panda

TOP counter: measuring x & TOP only

B. Ratcliff, ICFA Inst. Bulletin, http://www.slac.stanford.edu/pubs/icfa/spring01/paper2/paper2a.html, 2001

For $\theta_{dip} = 90^o$:

$TOP = L_{path} / v_g = L_{path}\, n_g / c = L_{bar}\, n_g / (k_z\, c)$

$\tan \alpha_x = k_x / k_z$

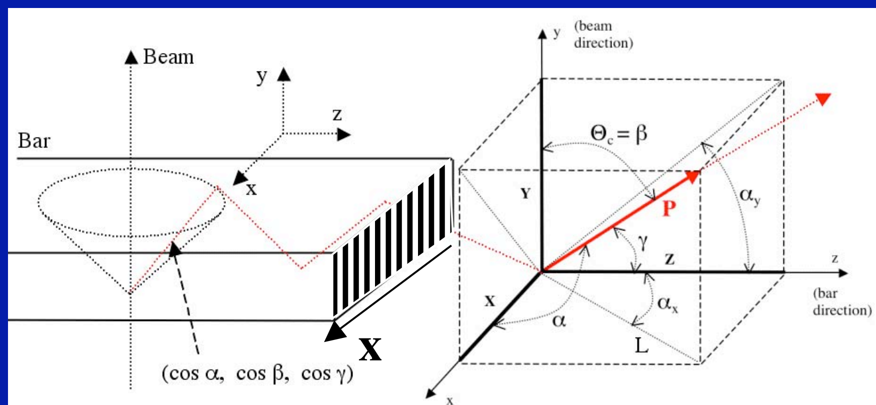
$$\boxed{\sin \theta_c = k_z * \sqrt{(\tan^2 \alpha_x + 1)}}$$

$k_x = \sin \phi_c \sin \theta_c$

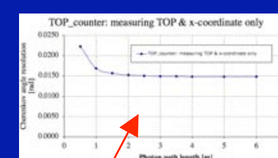
$k_y = \cos \theta_c$

$k_z = \cos \phi_c \sin \theta_c$

Imaging with x & TOP:



$$\boxed{\sigma^2_{\theta c} \sim \tan^2 \theta_c \left[(\sigma(n_g)/n_g)^2 + (\sigma(TOP)/TOP)^2 + \sigma^2(\alpha_x) \tan^2 \alpha_x\right]}$$

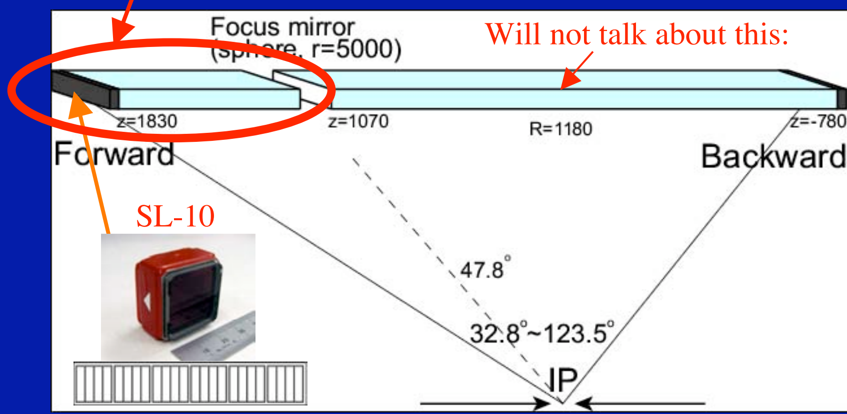


- **When measuring of TOP & α_x is good enough to measure θ_c well ?**
- Putting numbers into the above equation: $L_{path} = 2$ m, $\sigma_{TTS} \sim 40$ ps, $\sigma(n_g)/n_g \sim 0.013$ for Bialkali photocathode, $\sigma(TOP)/TOP \sim 0.0039$, and $\sigma(\alpha_x) \sim 0.005$, one obtains $\sigma_{\theta c} \sim 15$ mrads (constant for Lpath > 1.5 meters).
- **<u>This is not good enough.</u> Therefore, one has to use: (a) use red-sensitive photocathodes, such as GaAsP, to reduce the chromatic error, (b) a UV filter to cut off low wavelengths, (c) add a mirror segmentation, which is a "cheap way" to do y-pixillization (measurement of α_y), (d) add dispersion limiting optics (Panda), etc.**
- **If θ_c is measured poorly, such detector is basically a TOF counter.**

TOP counter for forward region

K.Inami, ps-workshop, 2008, Lyon, France

Will talk about this TOP-counter only:

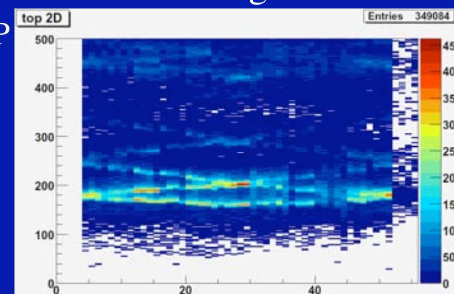


Size : 91.5cm x 40cm x 2cm

The small TOP counter is more a TOF counter rather than a RICH counter measuring θ_c

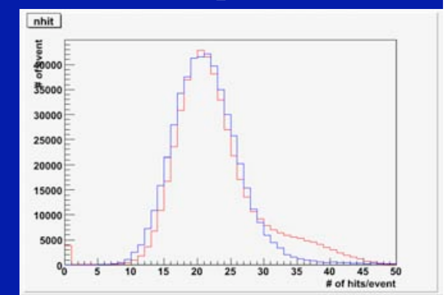
Observed images:

TOP



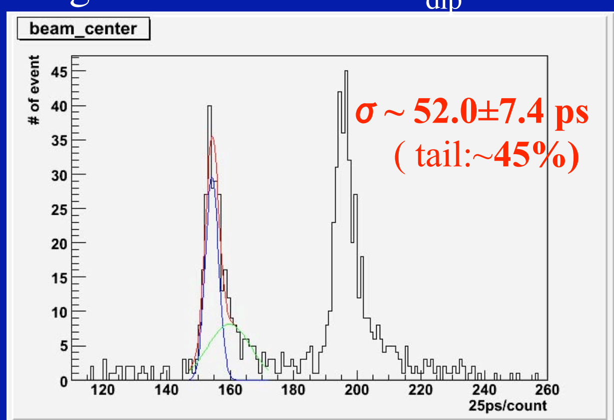
x

Detect 20 pe's/track:



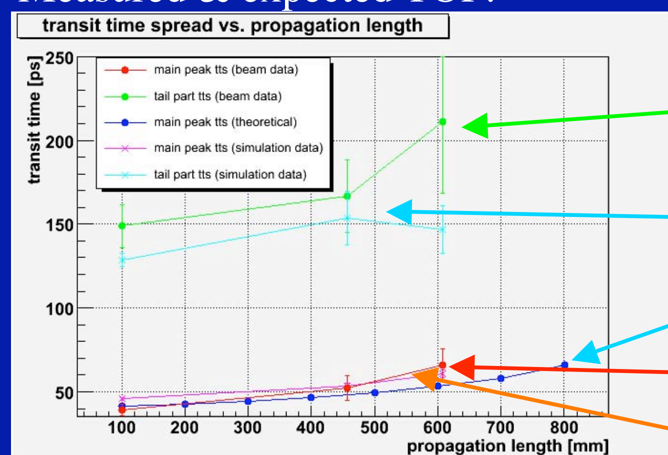
Npe

Signal distribution at θ_{dip} = 90°:



TOP

Measured & expected TOP:



Tail part - beam data (green)

Tail part - simulation (light blue)

Peak - theoretical exp. (blue)

Peak - beam data (red)

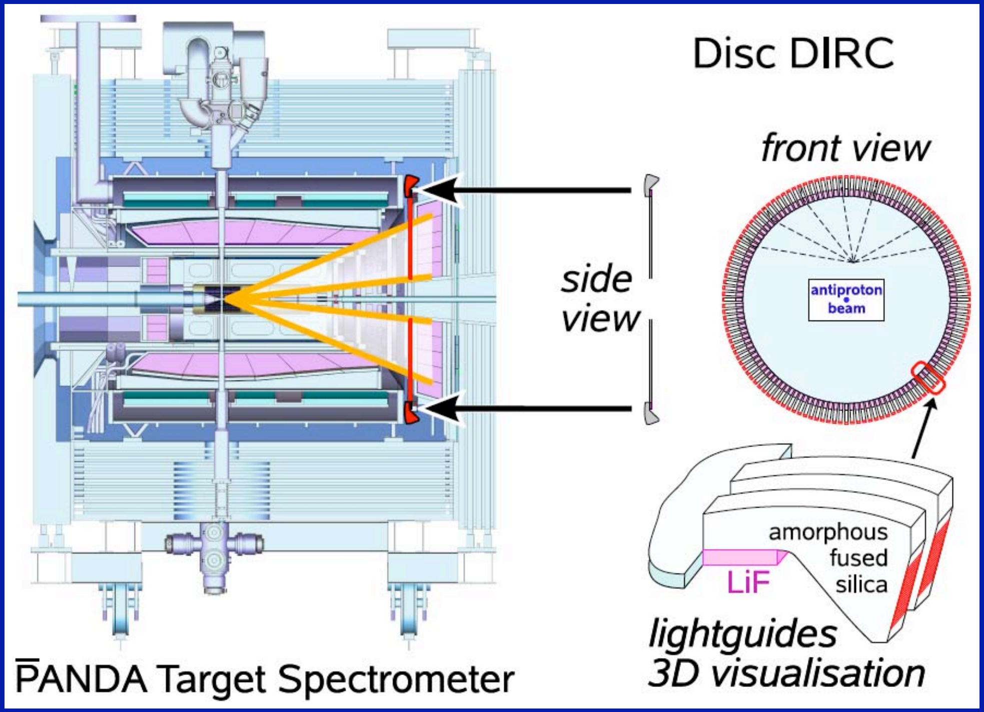
Peak - simulation data (pink)

Form "$TOP_{measured}$ - $TOP_{expected}$" to do subsequent PID analysis

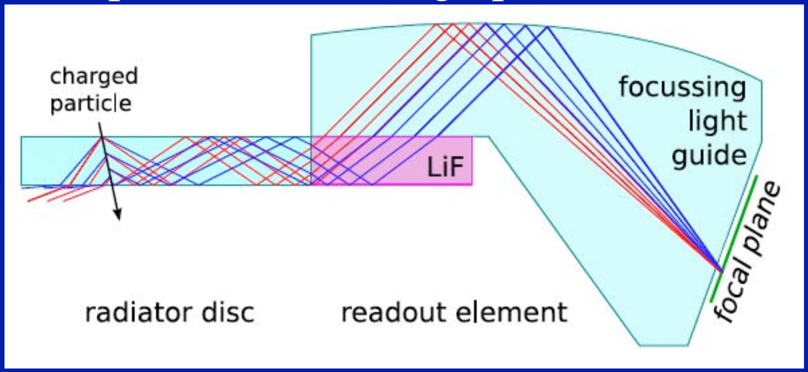
Panda Disc DIRC

K. Fohl, I. Brodski, M. Duren, A. Hayrapetyan, P. Koch, B. Krock, O. Merle, M. Sporleder and M. Zuhlsdorf, JINST, 2009

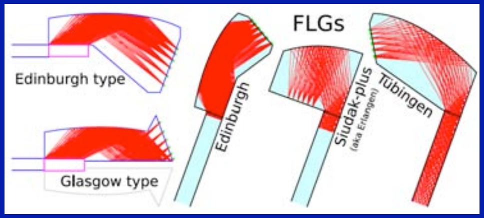
Panda experiment and Forward DIRC:



Dispersion correcting optical element



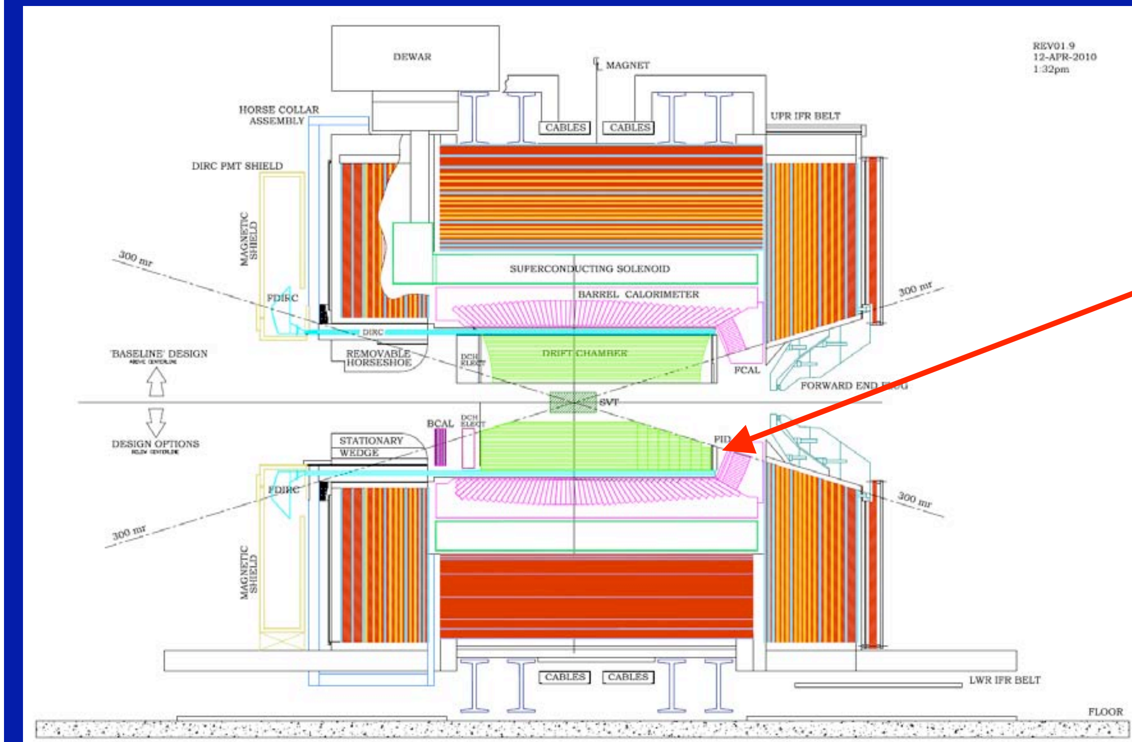
Other optical element designs:



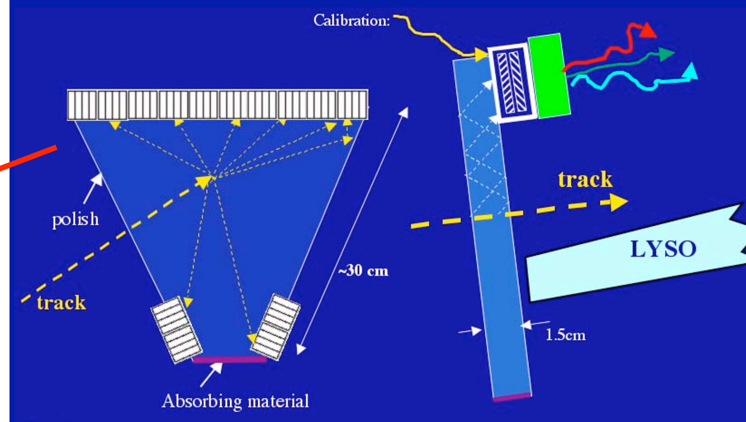
- **The first DIRC-like detector to correct the chromatic error by an optical element.**

SuperB DIRC-like TOF

L. Burmistrov, N. Arnaud, O. Bezshyyko, H. Dolinskaya, A.Perez, A. Stocchi, and J.Va'vra



Sectors:



- **Forward PID represents ~5% of solid angle. Therefore it is appropriate that the cost scales similarly. Mass in front of LYSO calorimeter has to be < 15% X_o.**
- **Tuning of the variables with MC is under way.**
- **Goal: σ ~ 40-50ps/track**

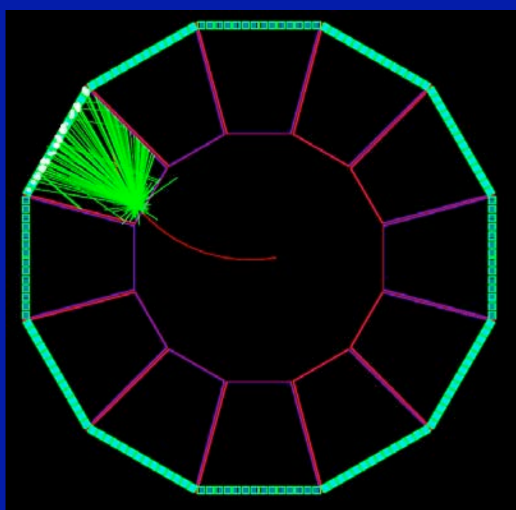
SuperB DIRC-like TOF

L. Burmistrov, N. Arnaud, O. Bezshyyko, H. Dolinskaya, A.Perez, A. Stocchi, and J.Va'vra

$$\sigma_{Total} \sim \sqrt{\left[\sigma^2_{Electronics} + \left(\sigma_{Chromatic} / \sqrt{(\varepsilon_{Geometrical\_loss} * N_{pe})}\right)^2 + \left(\sigma_{TTS} / \sqrt{\varepsilon * N_{pe}}\right)^2 + \sigma^2_{Track} + \sigma^2_{detector\ coupling\ to\ bar} + \sigma^2_{to}\right]}$$

$\sigma_{Electronics}$ - electronics contribution ~ 5-10 ps (waveform sampling digitizer WaveCatcher)
$\sigma_{Chromatic}$ - chromatic term = f (photon path length) ~ 10-25 **(Geant 4)**
σ_{TTS} - transit time spread ~ 35-40 ps
σ_{Track} - timing error due to track length L_{path} (poor tracking in the forward direction) ~ 5-20 ps **(Fast Sim)**
$\sigma_{detector\ coupling\ to\ bar}$ - timing error due to detector coupling to the bar ~ 1-20 ps **(Fast Sim)**
$\sigma_{t\,o}$ - start time dominated by the SuperB crossing bunch length ~ 15-20 ps

MC simulation:

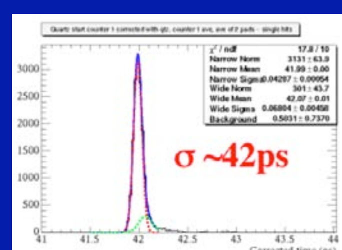


MC results:

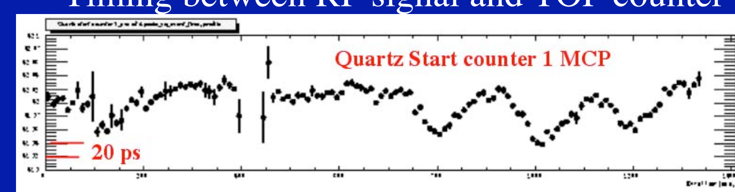
- **The total time resolution will be between <u>30-40 ps</u>**
- **<u>Npe > 5</u> photoelectrons at present, aiming for 10.**

We had a "DIRC-like" TOF counter in the test beam:

- Obtained routinely σ ~40-45 ps
- But watch out for the systematic errors:



Timing between RF signal and TOF counter



Time [min]

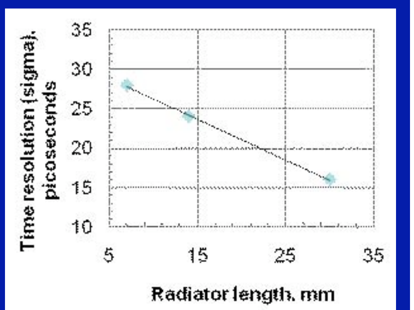
Geiger mode APD
(G-APD)

- **Other names:** SiPM, SiPMT, MGPD, MRS-APD, PSiPs, SPM, MPPC, …

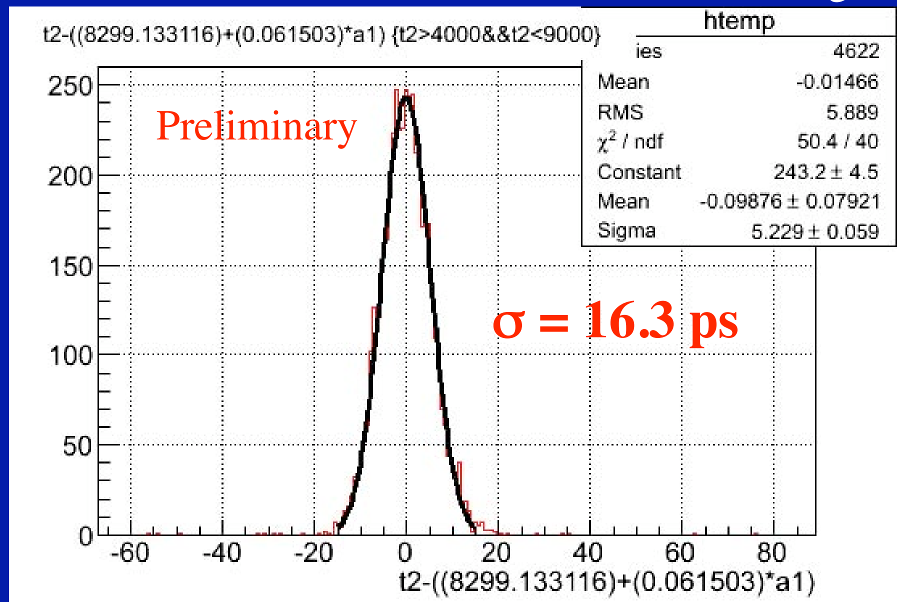
Beam tests with G-APD in Fermilab

A. Rozhnin et al., Fermilab

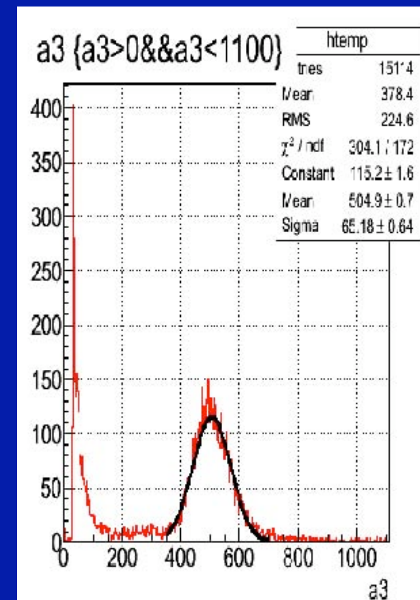
Single 3x3mm^2 G-APD with 3cm-long quartz radiator:



Fused Silica radiator: 3x3mm^2, 3cm long



Npe ~ 60 pe's



- **Timing start: G-APD (Hamamatsu MPPC, radiator is fused silica, 3x3 mm^2 and 30 mm long, all surfaces polished)**

  Timing stop: Photek 240 (radiator is the MCP window, 9.6 mm thick).
- **The MPPC time resolution is <15 ps assuming the Photek 240 time resolution is 7.7 ps. Small pulse height cuts and slewing correction applied.**
- **120 GeV protons used for the test. Normal incidence.**
- **Attention has to be paid to ΔT & ΔV stability: 11.5ps/0.5^{o}C & 6.2ps/10mV !!**

Summary

- **TRD technique clearly works very well as demonstrated at ATLAS**.
- **The "Cluster counting" technique might be tried in a real experiment such as SuperB. It is, however, electronics and data handling challenge**.
- **TOF technique progressed a lot due to new developments in (a) MRPCs, (b) MCP-PMTs and (c) G-APDs.** It will progress significantly further in the next few years thanks to new experience at LHC (ALICE, forward pp-scattering at ATLAS and CMS), Super Belle (TOP counter) and SuperB (new FDIRC, and possibly forward TOF).
- However, the large scale application of MCP-PMTs and G-APD arrays will depend on their cost. One reason why the MRPCdetectors have developed so quickly is that they are cheap and easy to make.
- Therefore the new R&D on new ways of making MCP-PMTs, which is going on at the U. of Chicago, Argonne Natl. lab, and Berkeley Space Scienec lab, is a very important step.