Absolute calibration of magnetic spectrometers by TOF

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Outline

- **Magnetic Spectrometer**
- **Hyperfragment decay pion spectroscopy at electron accelerators**
- **Magnetic spectrometer: absolute calibration by TOF**
- **Magnetic spectrometer: absolute calibration by (e,π) TOF difference**
- **A new picosecond timing technique with RF PMT based Cherenkov detector**
- **Results of MC simulations**
- **Summary**

Magnetic Spectrometer

- **Magnetic spectrometer is a basic equipment for momentum analizing in high energy nuclear and particle physics**

- **High resolution magnetic spectrometers can provide** $\Delta p/p < 10^{-4}$

- **High resolution: fine structure; new phenomena**

- **Absolute calibration of magnetic spectrometers typically is about** 10^{-3}

- **High precision: check of theory**

Hyperon Nucleon Interactions

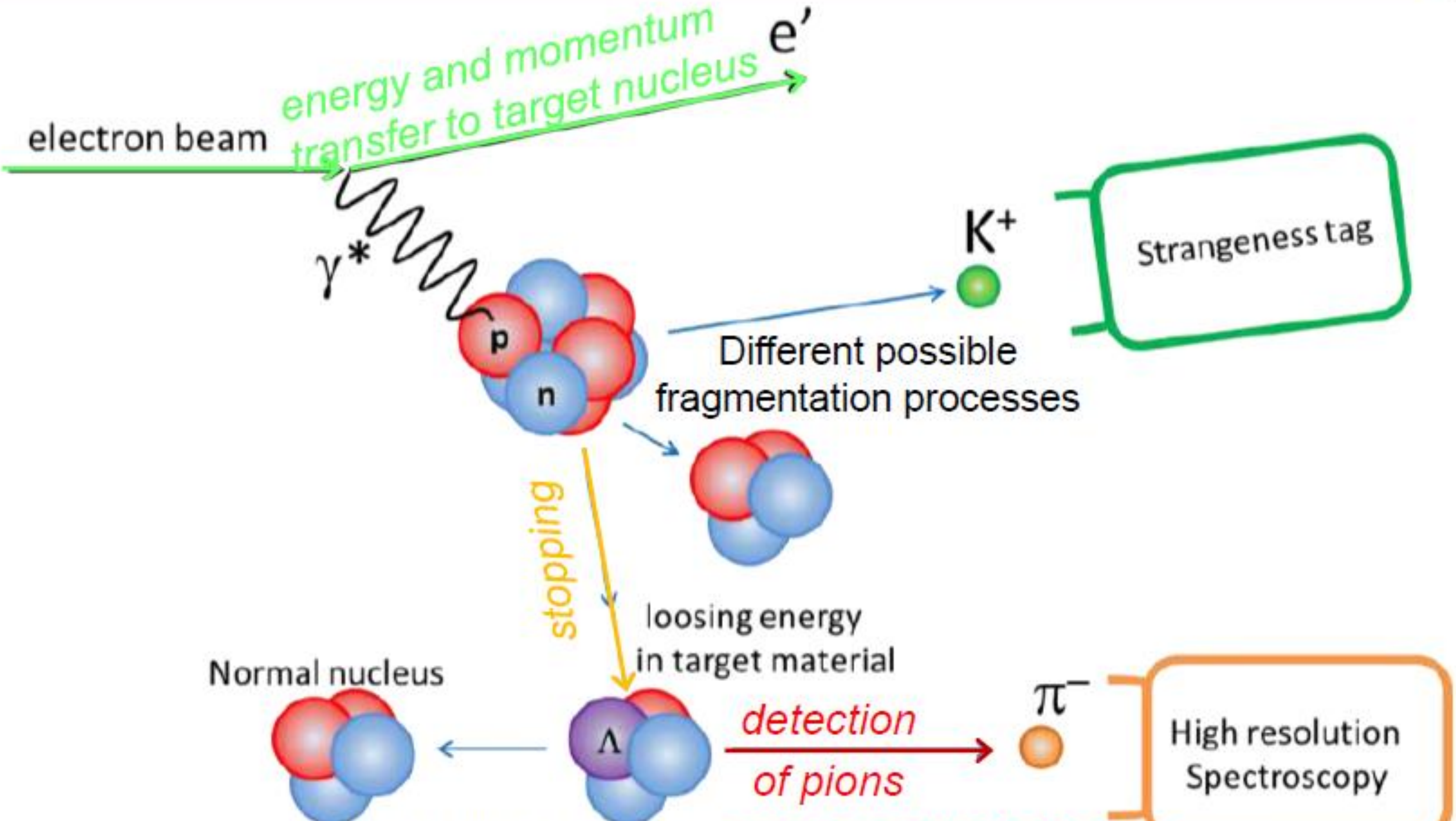
YN	$B_\Lambda(^3{}_\Lambda H)$	$B_\Lambda(^4{}_\Lambda H)$	$B_\Lambda(^4{}_\Lambda H^*)$	$B_\Lambda(^4{}_\Lambda He)$	$B_\Lambda(^4{}_\Lambda He^*)$	$B_\Lambda(^5{}_\Lambda He)$
SC97d(S)	0.01	1.67	1.2	1.62	1.17	3.17
SC97e(S)	0.10	2.06	0.92	2.02	0.90	2.75
SC97f(S)	0.18	2.16	0.63	2.11	0.62	2.10
SC89(S)	0.37	2.55	Unbound	2.47	Unbound	0.35
Experiment	0.13 ± 0.05	2.04 ± 0.04	1.00 ± 0.04	2.39 ± 0.03	1.24 ± 0.04	3.12± 0.02

Accurate values of binding energies B_Λ of light hypernuclei is extremely important and needed for parameterization of the two body effective potential!!!

$$V_{\Lambda N}(r) = V_c(r) + V_s(r)(S_\Lambda * S_N) + V_\Lambda(r)(l_{\Lambda N} * S_\Lambda) + V_N(r)(l_{\Lambda N} * S_N) + V_T(r) S_{12}$$

High precision γ-spectroscopy has been successful for the spin dependent terms but unable to measure binding energies

Hyperfragment decay-pion spectroscopy with electron beams



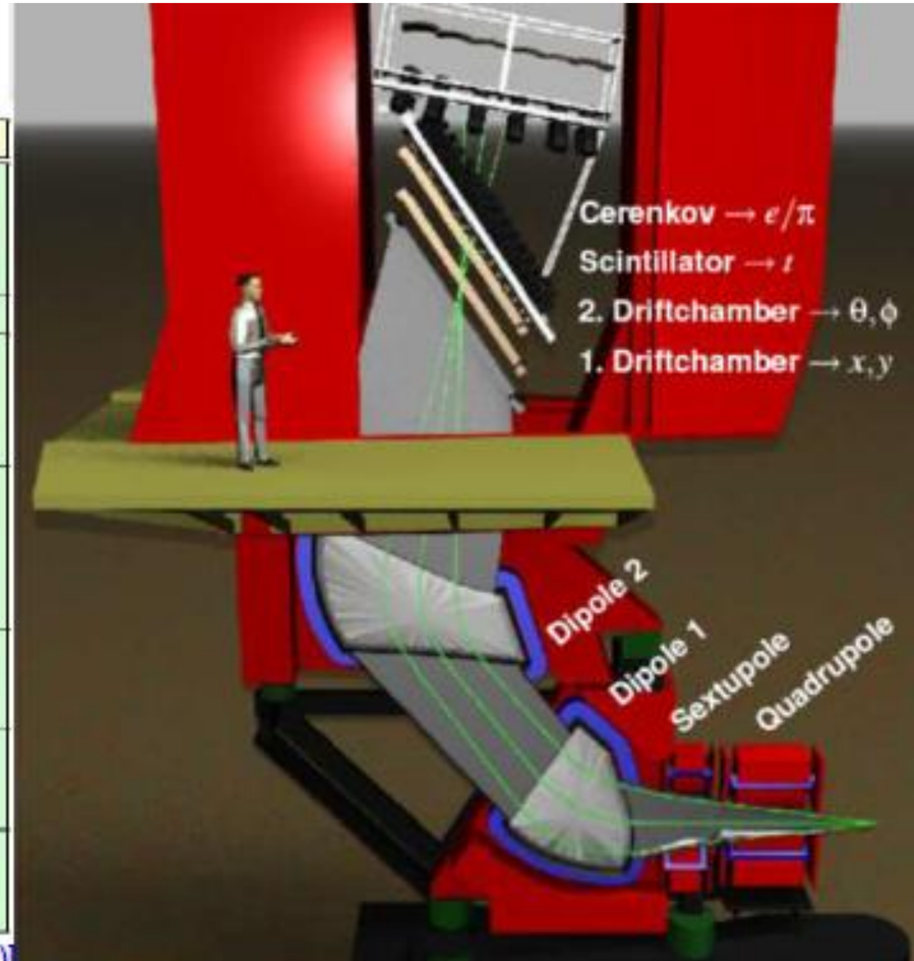
two-body decay at rest ⇒ mono-energetic pions

$$M_{\mathrm{HYP}} = \sqrt{M_{\mathrm{ncl}}^2 + p_{\pi^-}^2} + \sqrt{M_{\pi^-}^2 + p_{\pi^-}^2}$$

Magnetic Spectrometers at MAMI, Mainz

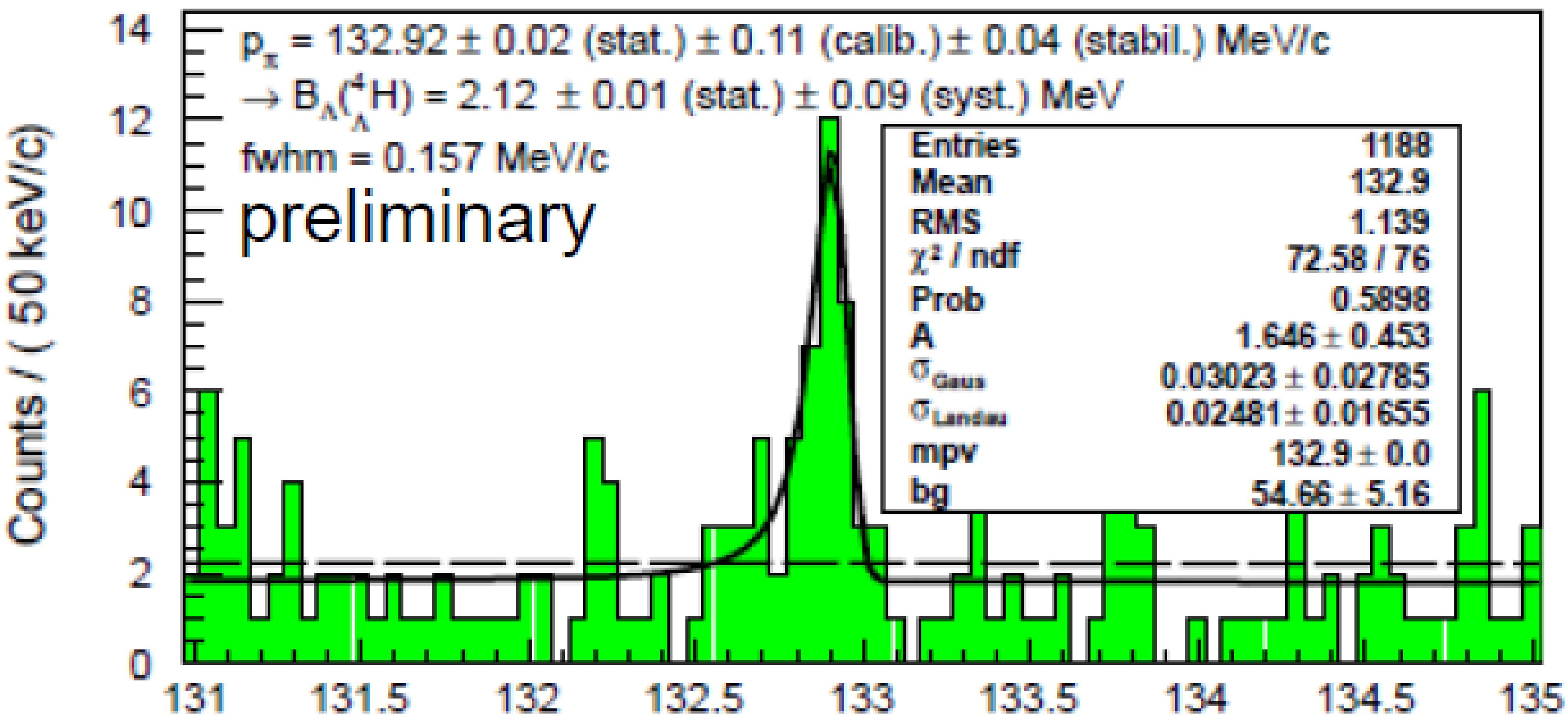
Basics of Magnetic Spectrometer:* $B\rho = p/q$, *q-is known, ρ-is determined by traektory measurement with error 0.0001, B-is known with typical precision 0.001

Spectrometer		A	B	C
Configuration		QSDD	D	QSDD
Focussing properties				
dispersive plane		pt → pt	pt → pt	pt → pt
nondispersive plane		‖ → pt	pt → pt	‖ → pt
Maximum momentum	[MeV/c]	735	870	551
Solid angle	[msr]	28	5.6	28
Angular range				
minimum angle		18°	7°	18°
maximum angle		160°	62°	160°
Momentum acceptance	[%]	20	15	25
Angular acceptance				
dispersive plane	[mrad]	±70	±70	±70
nondispersive plane	[mrad]	±100	±20	±100
long-target acceptance	[mm]	50	50	50
Angle of focal plane		45°	47°	45°
Length of focal plane	[m]	1.80	1.80	1.60
Length of trajectory	[m]	10.75	12.03	8.53
Dispersion (central)	[cm/%]	5.77	8.22	4.52
Magnigfication (central)		0.53	0.85	0.51
Dispersion / Magnification	[cm/%]	10.83	9.64	8.81
Momentum resolution		10^{-4}	10^{-4}	10^{-4}
angular resolution at target	[mrad]	≤ 3	≤ 3	≤ 3
position resolution at target	[mm]	3 – 5	1	3 – 5



[K.I. Blomqvist et al., Nucl. Inst. Meth. A 403 (1998)]

Binding energy extraction



Absolute calibration is realized by electron elastic scattering refering to beam energy

Depicted from P. Achenbach 2015, PRL

MS Absolute Calibration by TOF

From TOF concept for particles with identical flight length - L and p we have

$$t_\pi = L/(\beta_\pi c) = (L/c)\sqrt{1 + m_\pi^2 c^2 / p^2}$$

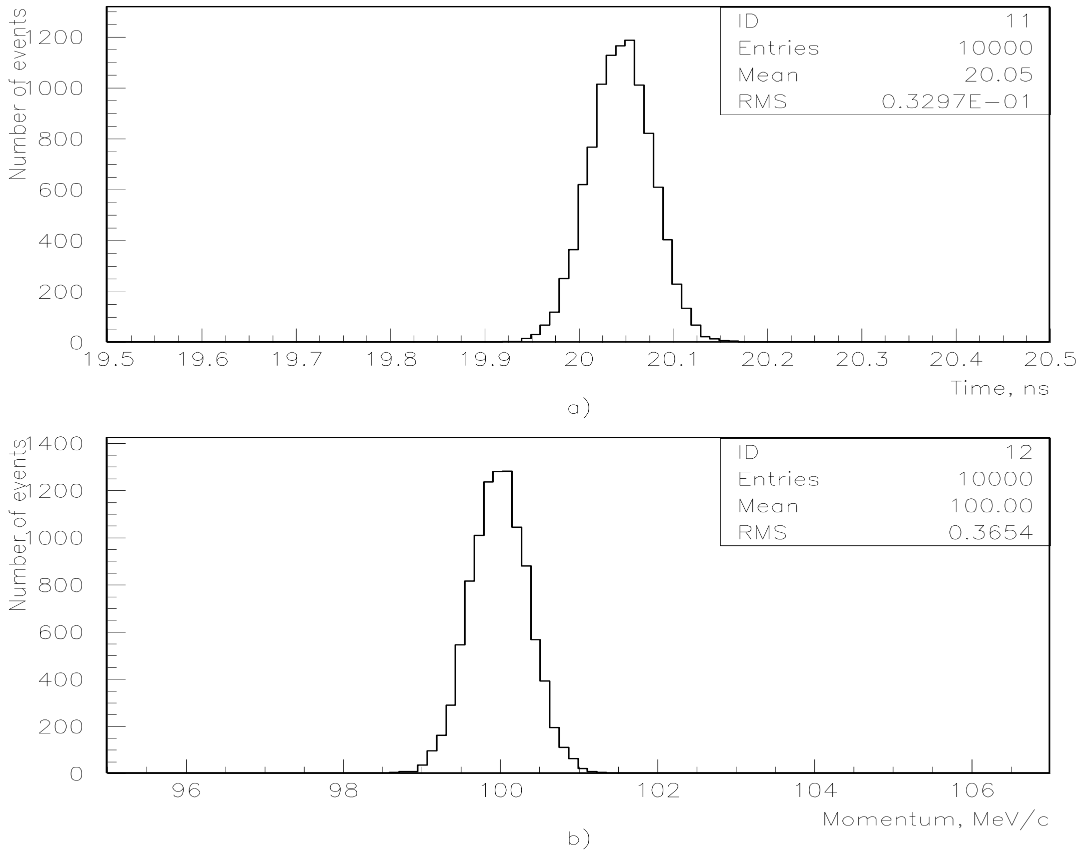
$$t_e = L/(\beta_e c) = (L/c)\sqrt{1 + m_e^2 c^2 / p^2}$$

From these two equations

$$L/c = \sqrt{\frac{t_e^2 m_\pi^2 - t_\pi^2 m_e^2}{m_\pi^2 - m_e^2}}$$

$$p_\pi = (L/c)\frac{m_\pi c}{\sqrt{t_\pi^2 - (L/c)^2}}$$

HπS Calibration: MC simulation



Pion momentum can be determined by TOF measurement of prompt pions and electrons with in accuracy < 10keV/c in the momentum range

Pion momentum range $\leq$ 140 MeV/c

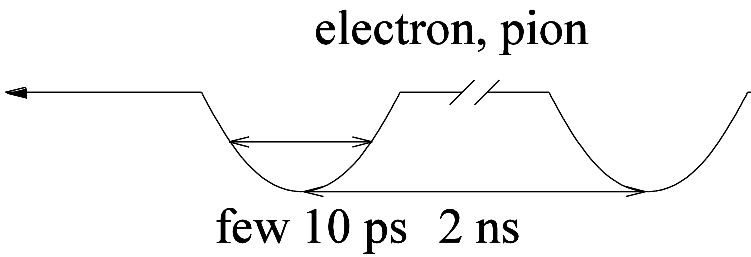
Incident parameters: p_π = 100 MeV/c, σ_p= 200 keV, L = 3.5 m, σ_t = 20 ps.

(a) Measured (simulated) 100 MeV/c pion TOF distribution

(b) Pion momentum distribution (reconstructed from measured electron and pion TOFs)

Decay Pion Spectrometer: Absolute Calibration by TOF Difference

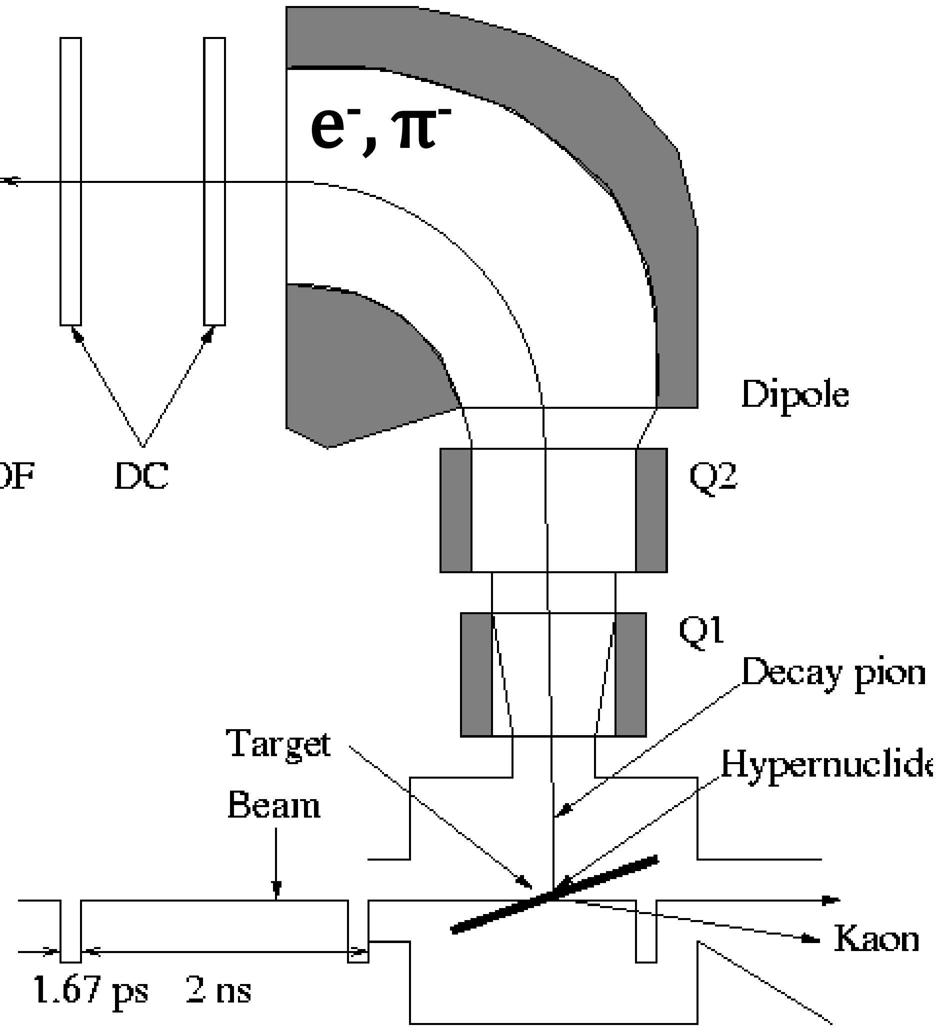
Time structuer of promtly produced particles



Instead of $t_{\pi}^{i} \quad t_{e}^{j}$

Use $t_{\pi}^{i} - t_{e}^{j}$

Time structuer of the incident beam



Schematic of the experimental setup

MS Calibration by TOF Difference: Theory

$$\left(\frac{L}{c}\right)^2 = \frac{t_e^2 m_\pi^2 - (t_e + \Delta T_{\pi e})^2 m_e^2}{m_\pi^2 - m_e^2} \qquad t_\pi = t_e + \Delta T_{\pi e}$$

$$t_e^2 - \frac{2 t_e \Delta T_{\pi e} m_e^2}{m_\pi^2 - m_e^2} - \frac{\Delta T_{\pi e}^2 m_e^2}{m_\pi^2 - m_e^2} - \left(\frac{L}{c}\right)^2 = 0$$

$$t_e = 0.5\left(\frac{2\Delta T_{\pi e} m_e^2}{m_\pi^2 - m_e^2}\right) + \sqrt{D}$$

$$D = 4\Delta T_{\pi e}^2 \left(\frac{m_e^2}{m_\pi^2 - m_e^2}\right)^2 + 4\left(\Delta T_{\pi e}^2 \frac{m_e^2}{m_\pi^2 - m_e^2} + (L/c)^2\right)$$

MS Calibration by TOF Difference

Practical Implementation

L is known with error 0.5 mm

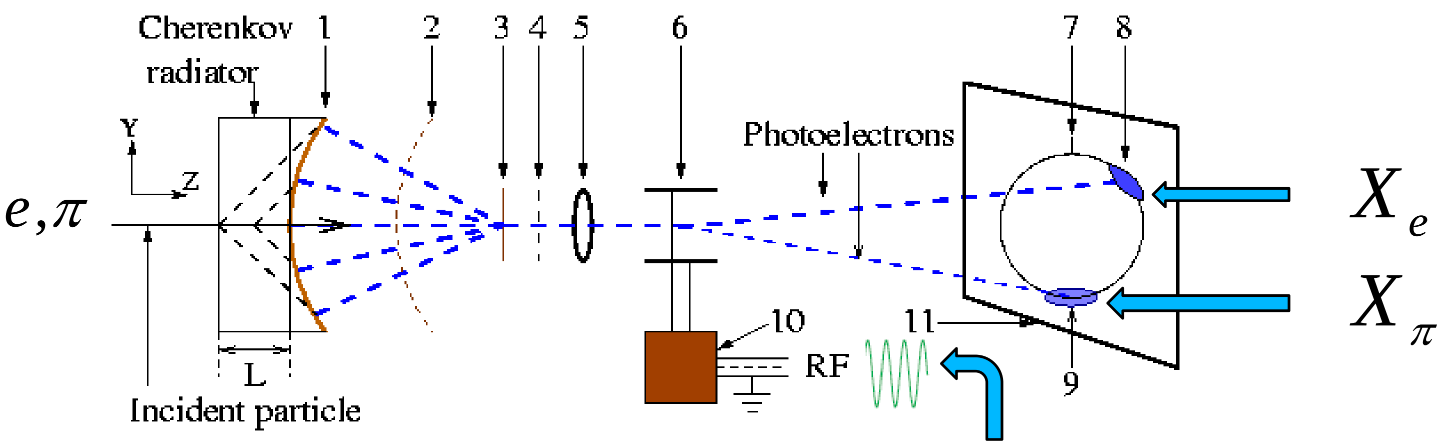
p_π or P_e are known with error 1:1000

T_0 Period of the RF Voltage -is known with high precision

$$t_\pi^i = N_\pi T_0 + X_\pi^i T_0$$

$$t_e^j = N_e T_0 + X_e^j T_0$$

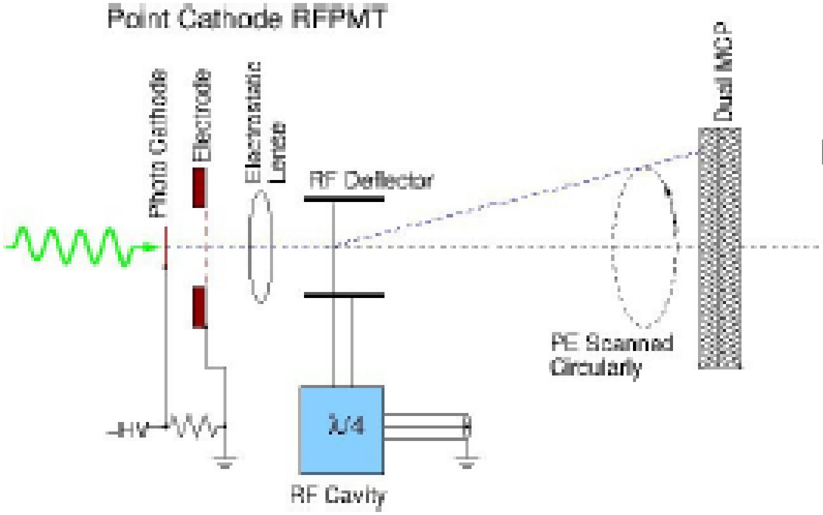
N_π and N_e Can be determined by using L and P

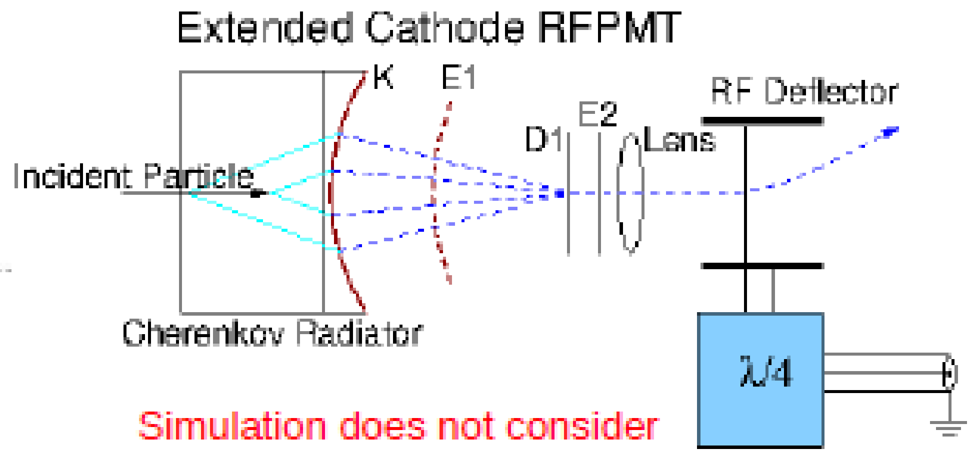


Synchron with incident electron bunches

The schematic layout of the Cherenkov TOF detector with RF phototube

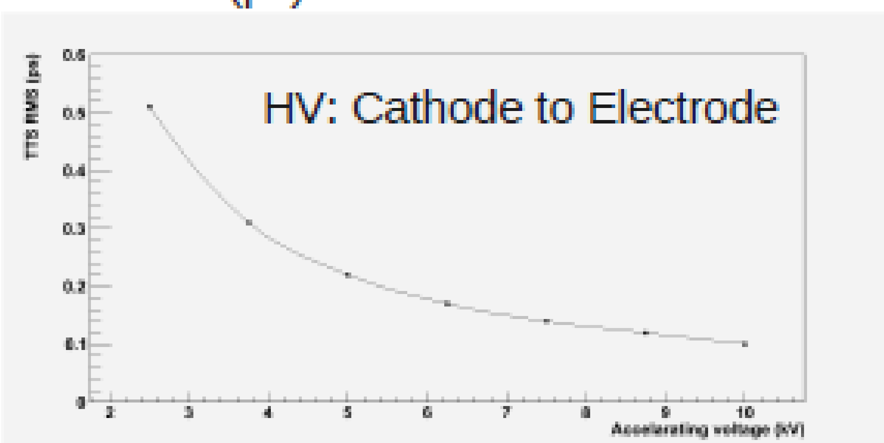
Simulation of Transit Time Spread
(Simion-8: charged particle trajectories in EM fields)



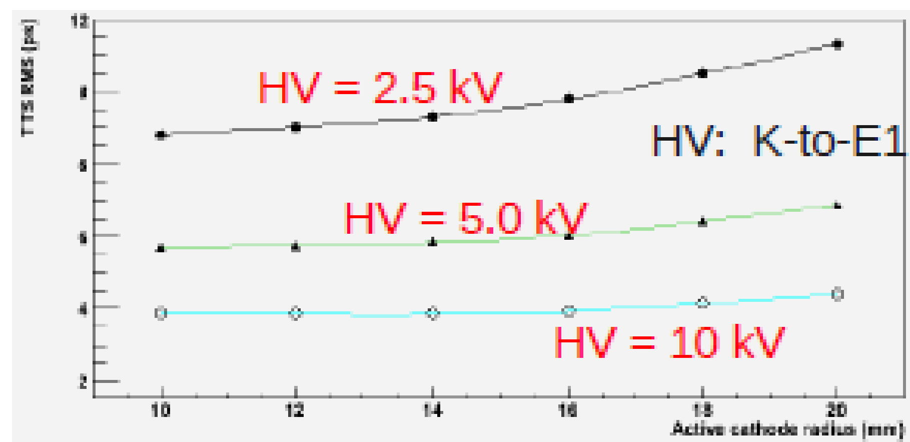


Simulation does not consider
time dispersion of Cherenokov photons

TTS (ps) to MCP electron detector



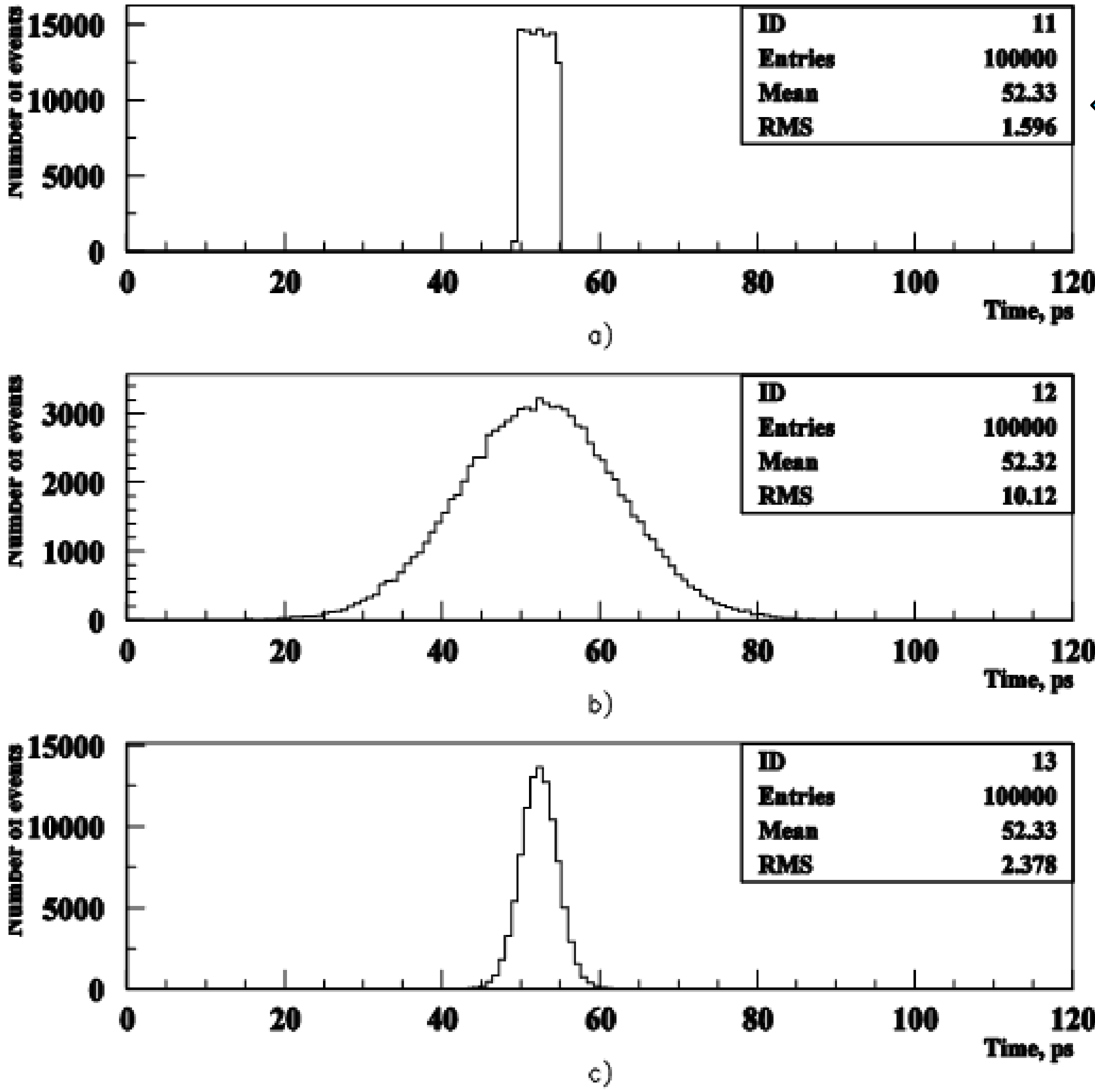
TTS (ps) to cross-over at D1



MC Simulation of the Cherenkov TOF Detector

- Radiator of finite thickness
- The transit time spread of Cherenkov photons due to different trajectories
- The chromatic effect of Cherenkov photons ($n = 1.82 \pm 0.008$)
- The timing accuracy of RF phototube ($\sigma = 10$ ps)
- The number of detected photoelectrons -100 cm^{-1}

Time distribution of Cherenkov detector: p = 133 MeV/c pions in 2mm PbF2

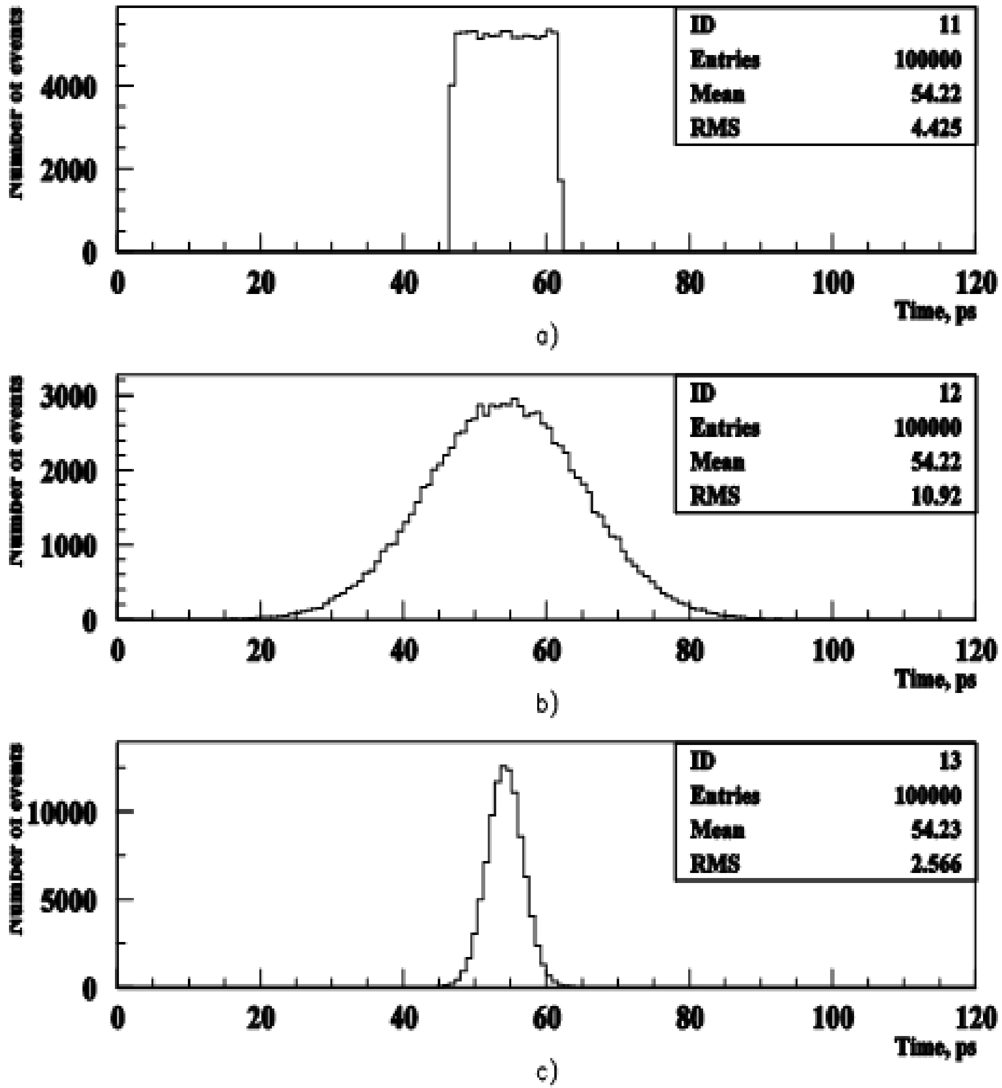


Single Cherenkov photons

Single Photo-Electrons

Mean of 20 Photo-Electrons

Time distribution of Cherenkov detector: p = 133 MeV/c electrons in 2mm PbF2

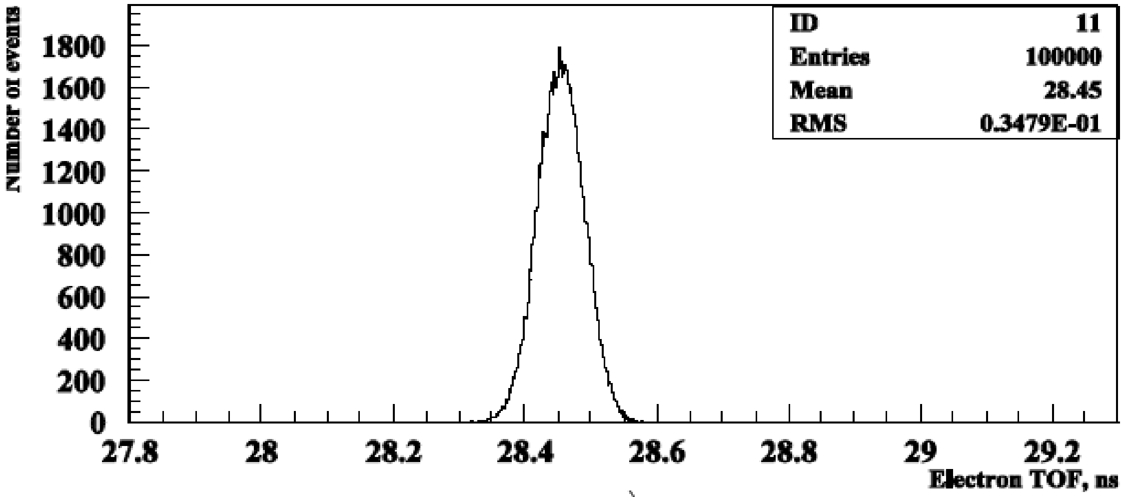


Single Cherenkov photons

Single Photo-Electrons

Mean of 20 Photo-Electrons

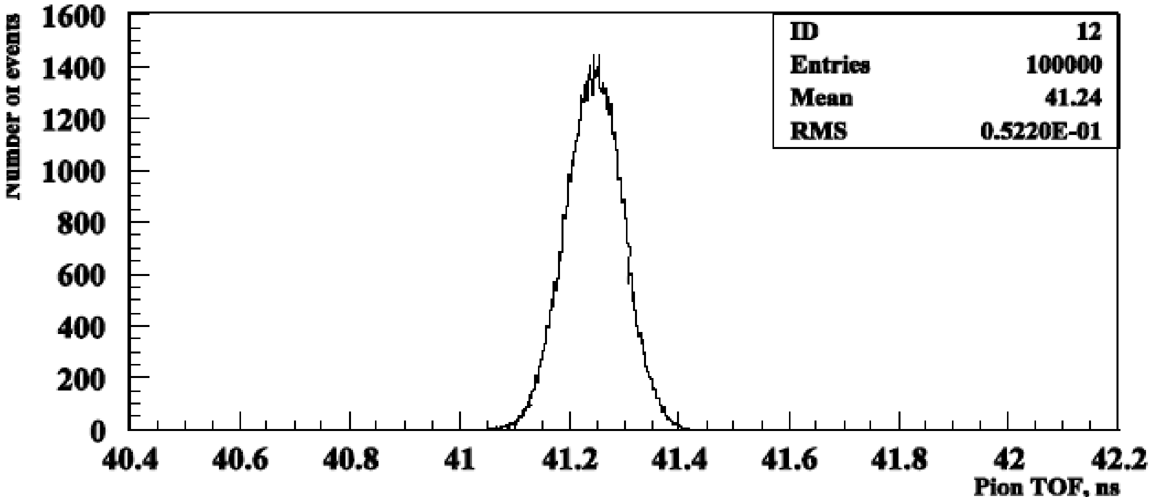
MC: TOF distribution of electrons and pions in a MAMI Spekt B



a)

TOF of electrons

$t_e^{av} = 28453.2$ ps



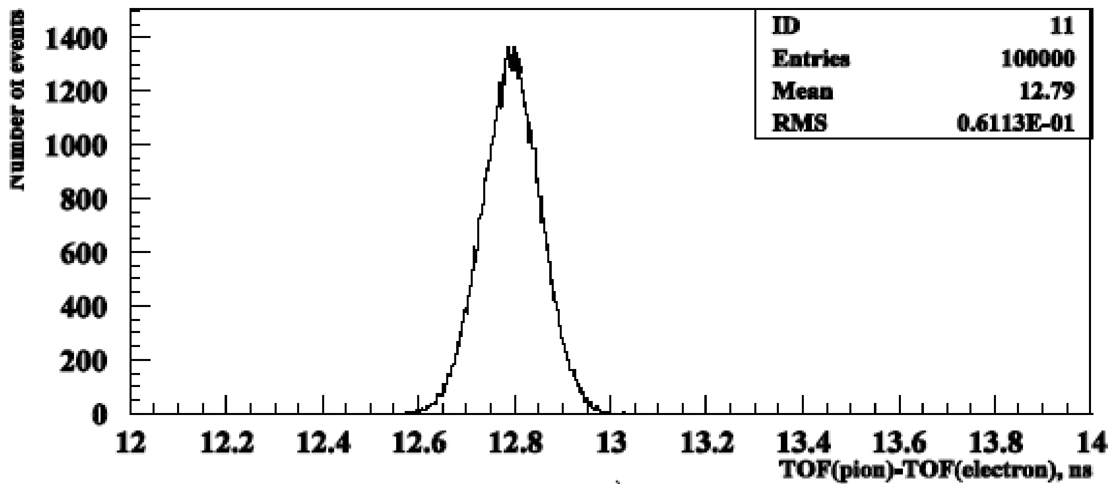
b)

TOF of pions

$t_\pi^{av} = 41244.8$ ps

Spekt B: L = 853 cm , $\sigma_L = 1.0$ cm ; P = 133 MeV/c, $\sigma_p = 100$ keV/c.

MC: TOF difference and momentum distributions

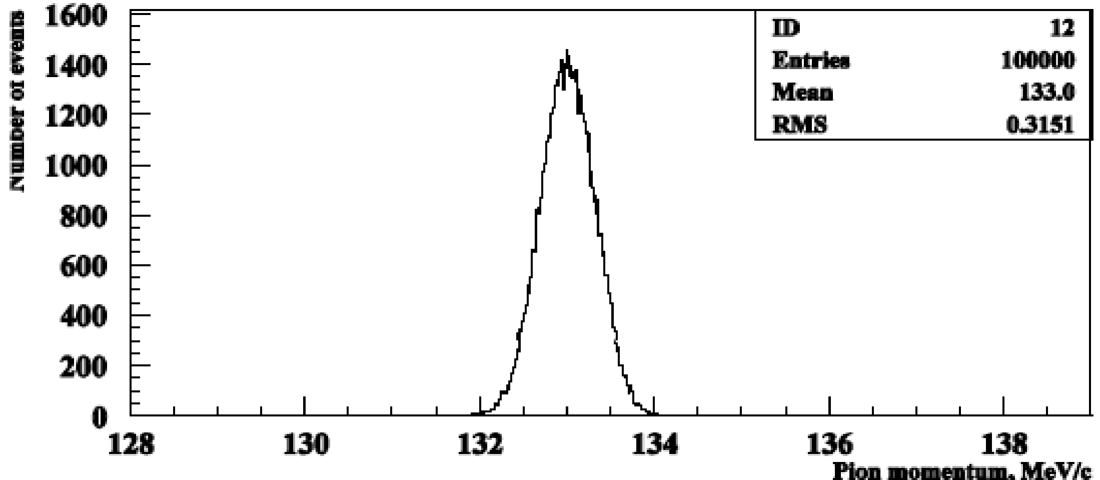


a)

TOF difference

$t_{\pi} - t_{e} = 12792.4$ ps

Magnetic Spectrometer absolute calibration with an accuracy less than 1:10000 is achievable!!!



b)

Momentum determined by TOF difference

Spekt B: L = 853 cm , $\sigma_L = 1.0$ cm ; P = 133 MeV/c, $\sigma_p = 100$ keV/c, $\sigma_t = 10$ ps

Cherenkov radiation dedection by circular scan streak camera opereting in a Synchroscan mode

Phil. Trans. R. Soc. Lond. A **298**, 287–293 (1980)
Printed in Great Britain

The Synchroscan picosecond streak camera system

By A. E. Huston and K. Helbrough
Hadland Photonics Ltd, Bovingdon, Herts. HP3 0EL, U.K.

Time stability ~1ps/hrs

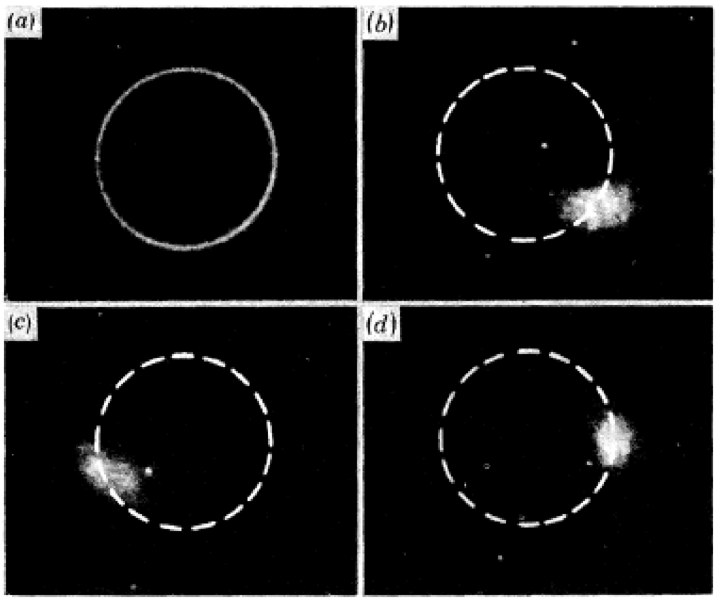


Figure 4. Records taken with circular scan Synchroscan. (*a*) Test record showing circular deflexion at 201.25 MHz, with continuous illumination. (*b*–*d*) Recorded Čerenkov light showing variation of timing obtained by altering the experimental conditions.

Average time is 10 s,
each record is a result of
summation of 2×10^9 events

Summary

- Absolute calibration of magnetic spectrometers by TOF difference of pair of particles at RF driven accelerators is possible

- RF PMT based Cherenkov detector is a proper technique for such an application

- MC simulatuions demonstrated that the Magnetic Spectrometer absolute calibration with an accuracy ≤ 1:10000 is achievable

- Any pair of particles with different mass, such as (e,π); (e,K); (e,p) and etc, can be used. The momentum of one of particles

  $P \leq mc$

  where m is a mass of the particle, c velocitiy of light.

Thank you for your attention