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"Instrumentation as enabler of Science"

Laboratory tests for Diode-laser based calibration systems for fast TOF detectors

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presented by **M. Bonesini**

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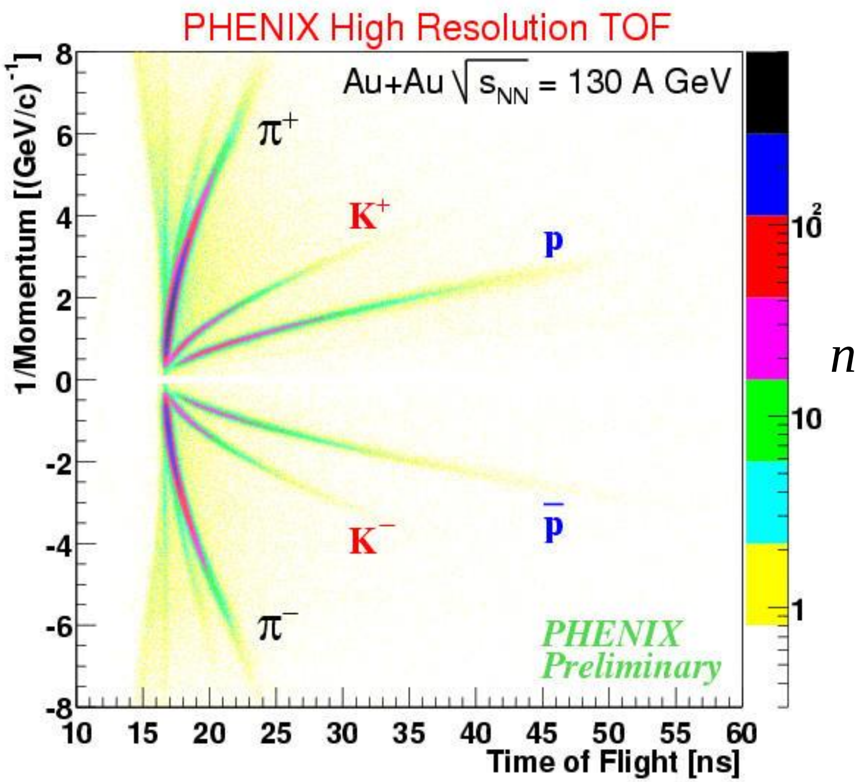
Outline

- Introduction: calibration of scintillator based TOF detectors
- Calibration with a laser light source
- An example: the large HARP TOFW
- Problems for the calibration of more performant systems (eg the MICE TOF system)
- Available laser diode sources
- Test of components: MM fibers, fused fiber splitters, optical switches
- Test of a prototype system in lab
- Conclusions

Particle ID with TOF



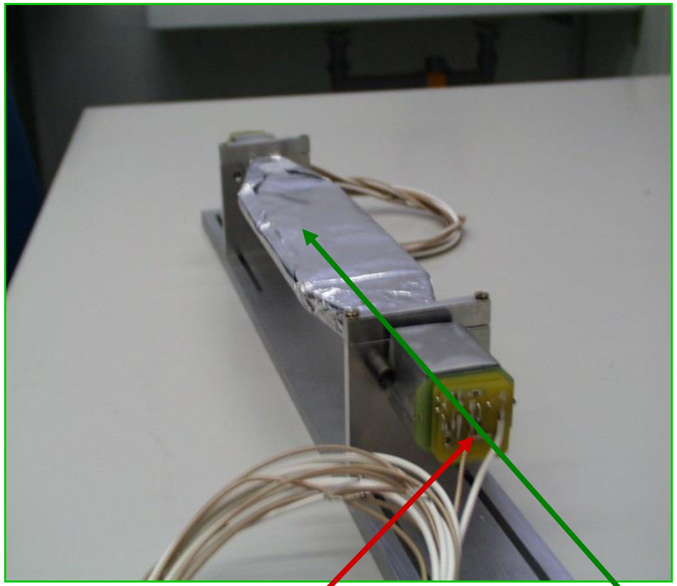
- TOF based on measure of t over a fixed length L

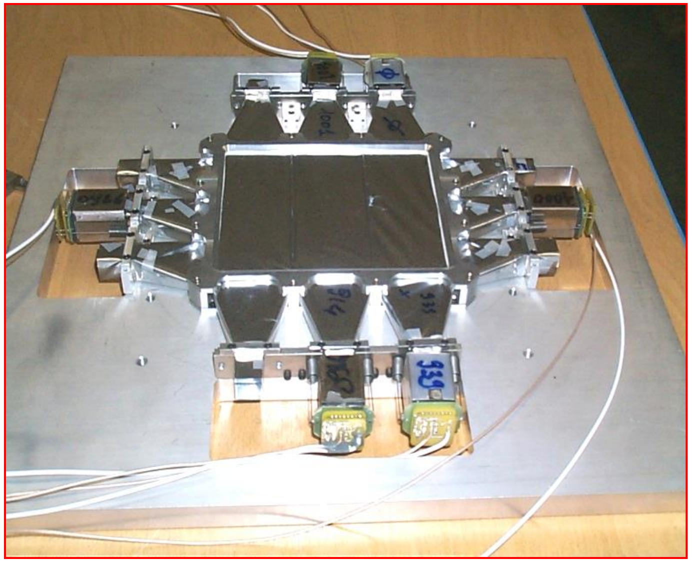
$$m = p\sqrt{\frac{c^2t^2}{L^2} - 1}$$

- Mass resolution dominated by σ_t (not measure of L, p)
- Separation power in standard deviation

$$n_{\sigma_t,1-2} = \frac{L(m_1^2 - m_2^2)}{2p^2c\sigma_t}$$

Scintillator based counters for TOF detectors



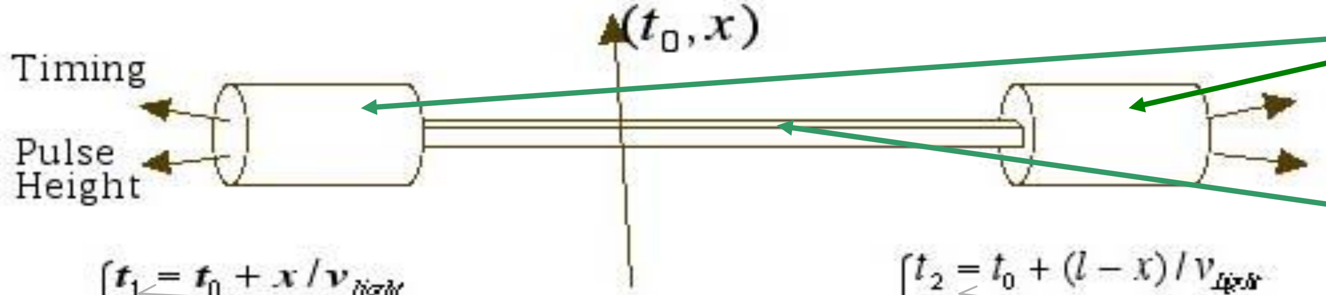


PMT

Scintillator bar (diamond finish)

Based on scintillator counters: simple to made, sensitive to B, read at both ends by PMTs, good resolutions -> 50-100 ps (depends mainly on L,N_{pe})

Basics of double-sided scintillator counters



Pmt

Scintillator + lightguide

$$\begin{cases} t_1 = t_0 + x / v_{light} \\ a_1 = a_0 \exp(-\frac{x}{\lambda}) \end{cases}$$

$$\begin{cases} t_2 = t_0 + (l - x) / v_{light} \\ a_2 = a_0 \exp(-\frac{l-x}{\lambda}) \end{cases}$$

But t_i are affected by exp delays δ_i due to excursion of cable delays (T), electronics … must be measured -> **calibration/monitoring (cosmics/laser syst)**

$$\therefore \begin{cases} t_0 = \dfrac{t_1 + t_2}{2} - l / v_{light} \\ x_0 = \dfrac{t_1 - t_2}{2} - v_{light} \end{cases}$$

$$\delta t_0 = \sqrt{\left(\frac{\delta t_1}{2}\right)^2 + \left(\frac{\delta t_2}{2}\right)^2} \cong \frac{\delta t_1}{\sqrt{2}}$$

$$\delta x = v_{light} \cdot \sqrt{\left(\frac{\delta t_1}{2}\right)^2 + \left(\frac{\delta t_2}{2}\right)^2} \cong v_{light} \cdot \frac{\delta t_1}{\sqrt{2}}$$

Precise TOF and Hit position

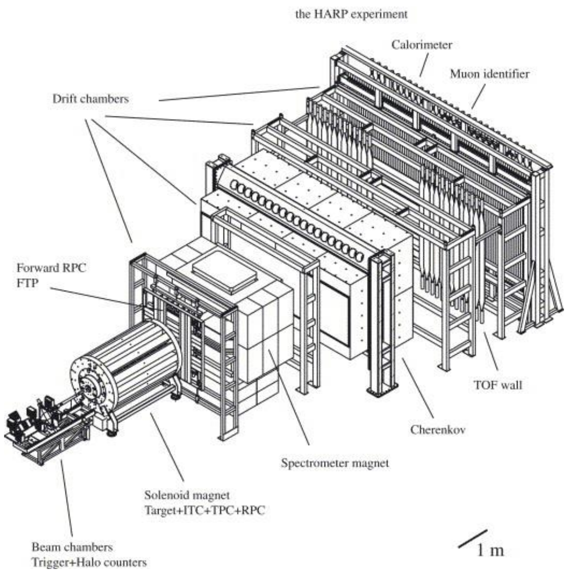
TOF may be measured using 2 planes at distance L (t_{01},t_{02}), each with a resolution

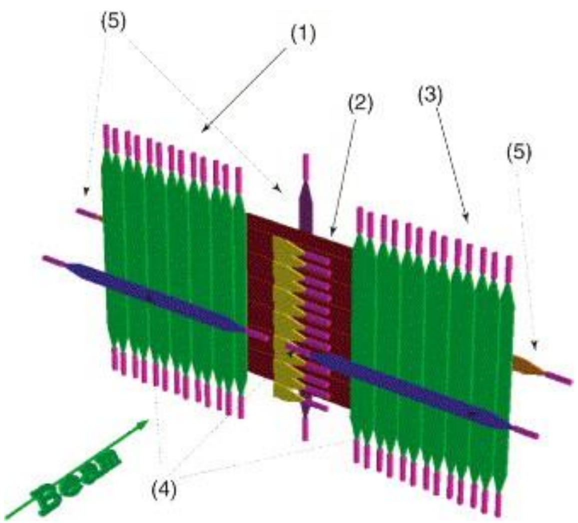
$$\sigma_t = \sqrt{\frac{\sigma^2{}_{scint} + \sigma^2{}_{PMT} + \sigma^2{}_{pl}}{N_{pe}} + \sigma^2{}_{elec}}$$

TOF measurement resolution can be expressed as:

$$\sigma_{TOF}{}^2 = \sigma_{t1}{}^2 + \sigma_{t2}{}^2 + \sigma_{cal}{}^2$$

Example: the large Harp TOF wall at CERN PS





➔Separation p-π up to 5 GeV/c, K-π up to 3 GeV/c ⇒ required time resolution 250ps

➔3 modules of 13 fast scintillator (Bicron BC-408) slabs:

- central, horizontal slabs (1.80x0.21x0.025)m^3
- lateral, vertical slabs (2.50x0.21x0.025)m^3
- cosmic trigger bars

➔slab → PMT
→TDC (time)
& ADC (charge) for
time-walk correction

➔2 PMs (XP2020) per slab
to measure time and position

⇒ t=(tdc0+tdc1)/2+cost
x=(tdc0-tdc1)/2+cost

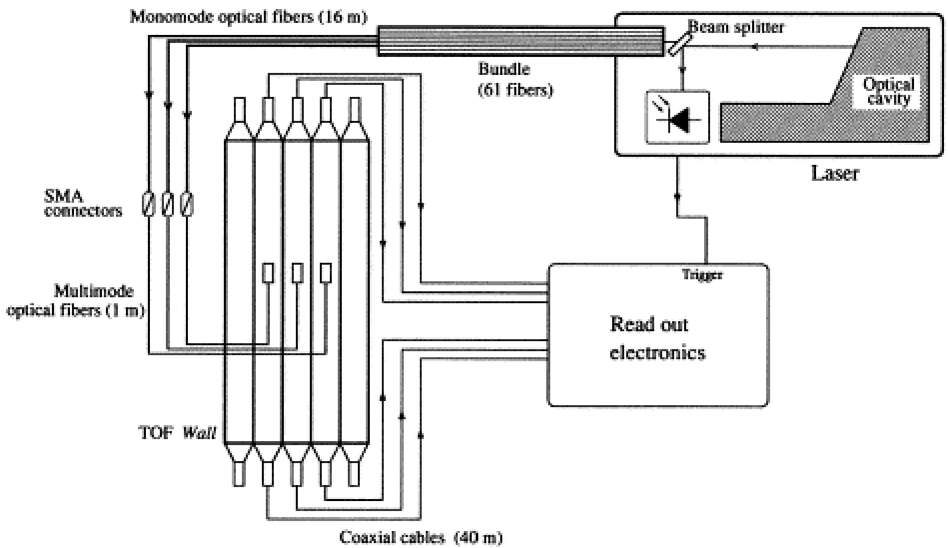
Calibration of the HARP TOF Wall

Intrinsic time resolution of scintillators =150 ps measured with laser system and in lab tests with cosmics

Accurate equalization of time response of the different slabs is achieved with two methods

- Cosmic muons:
  - Average values of equalization constants
  - Calibration runs every 2-3 months, about one week
- Laser:
  - Continuous monitoring of evolution of equalization constants
  - Calibration runs twice a day, few minutes during interspill time

The HARP TOFW calibration system



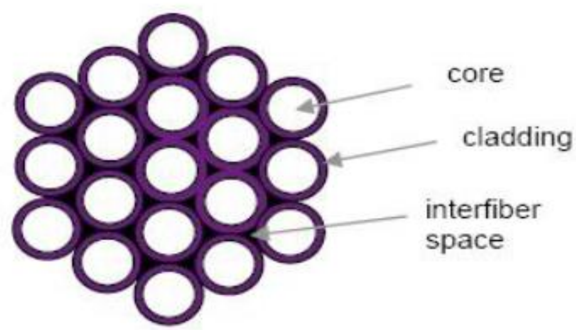
Powerful Nd-YAG laser with passive Q-switch (dye), active/passive mode locking and 10 Hz repetition rate

Pulse: width 60 ps energy 6 mJ

IR emission converted to a second harmonic (λ=532 nm) by a KD*P SHG crystal

Laser light delivered to single channels via a fiber bundle (IR SM)

Fiber type	Dt/L (ps/m)	L (m)
FOS SMR-R (single mode)	3.5	12 m
Ceram Optec UV 100/110 (MM)	14.9	6 m
Corning SMF-28 (IR SM)	3.6	15 m



Optical beam splitter:

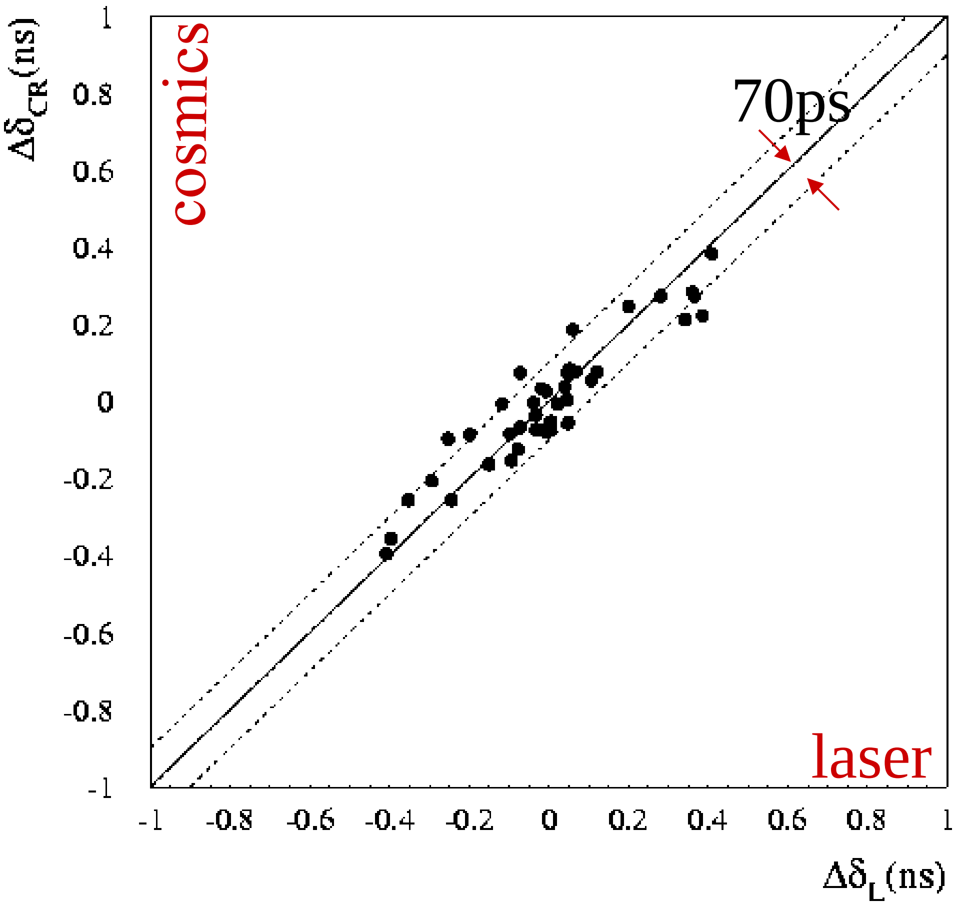
$\rightarrow$To ultra-fast (30 ps rise/fall) InGaAs Hamamatsu G4176 MSM photodiode => START

$\rightarrow$To detector slabs through custom-made optical fibre system => STOP

Comparison of laser with cosmics calibration data

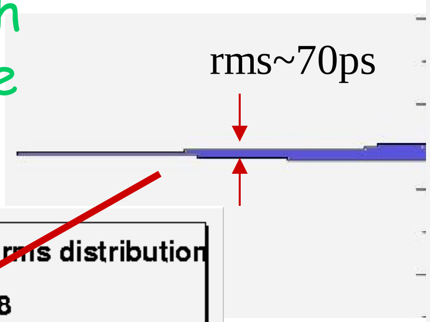
- The two calibration methods provide similar accuracy on the equalization constants δ
- The shifts of equalization constants ($\Delta\delta$) measured with the two methods are well correlated (within 100ps)

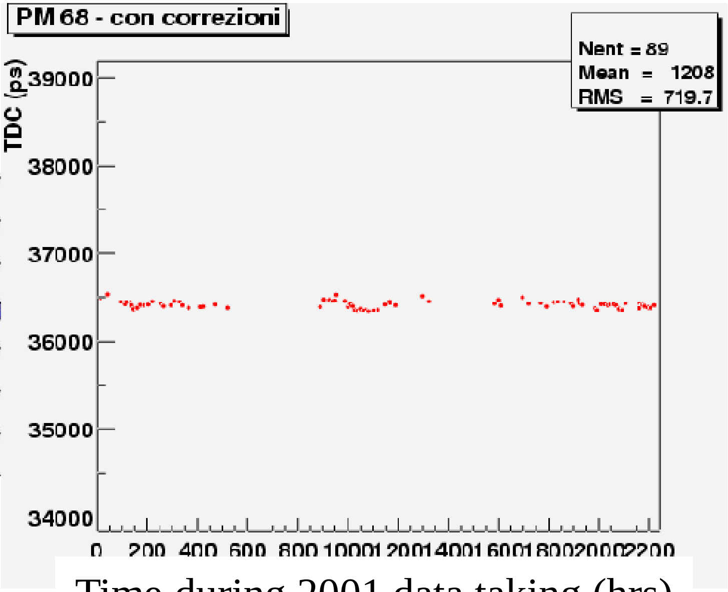
Shifts of calibration constants from Nov 2001 to May 2002 data taking



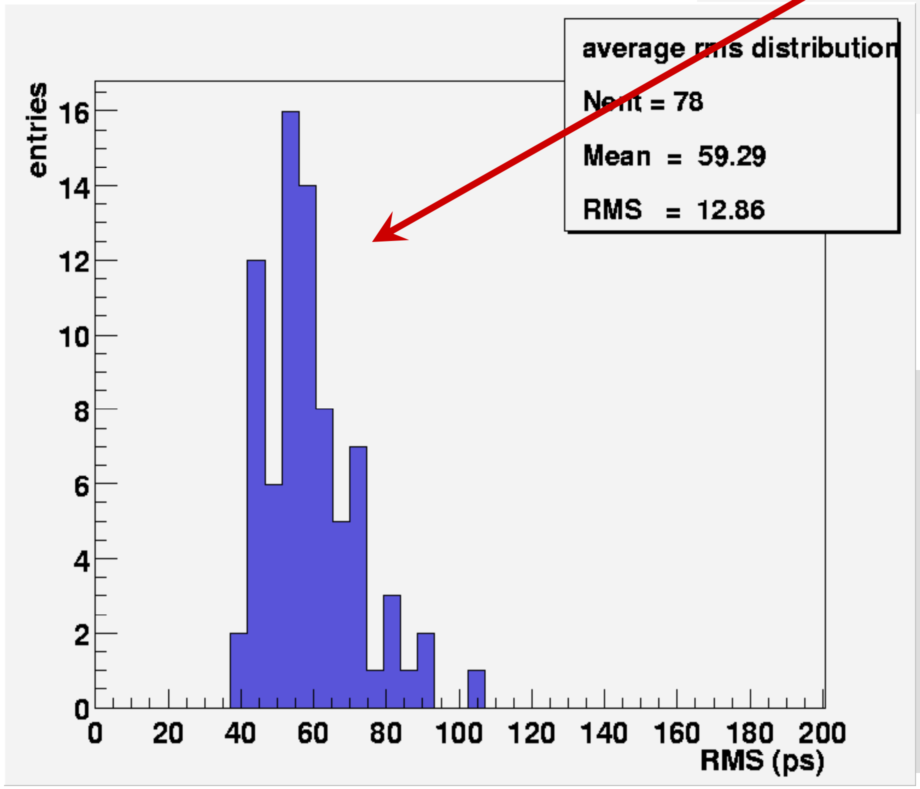
Time stability of the TOF

The TDC value in a single channel as measured with the laser has been stable in time





Time during 2001 data taking (hrs)



No evidence for time shifts in excess of ~70 ps

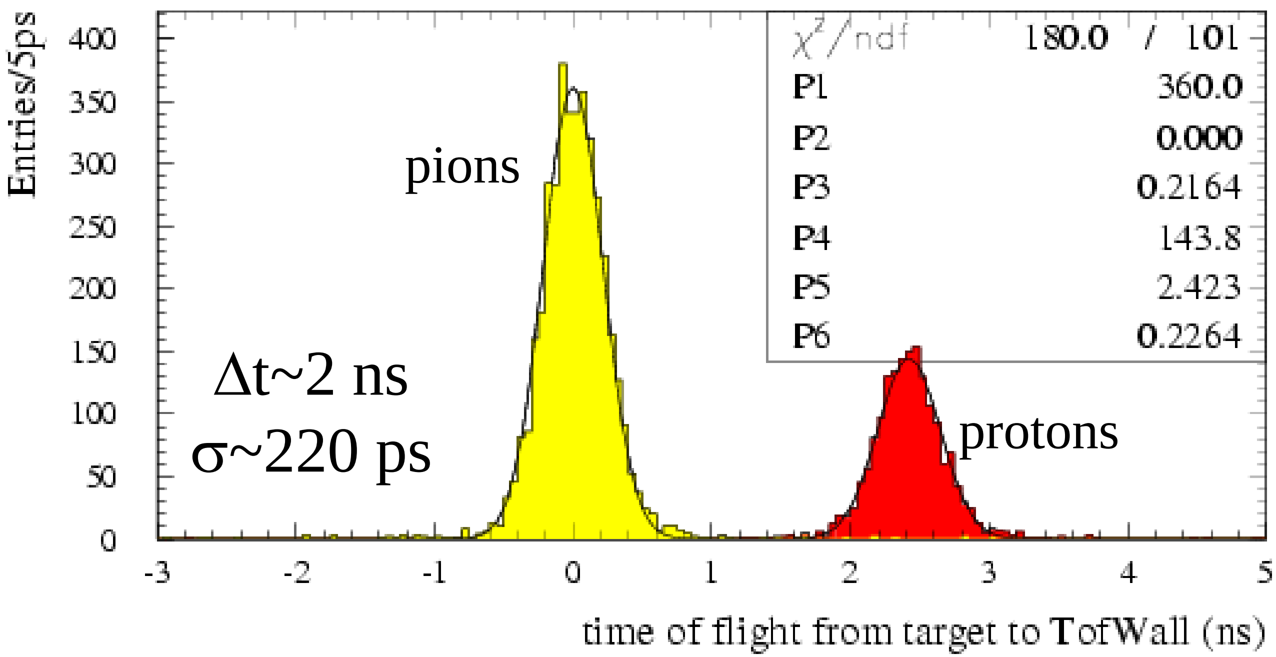
detect and correct variations of We can calibration constants larger than 100 ps

Time resolution of the HARP TOF

150 ps intrinsic resolution ⊗ <100 ps accuracy on time monitor

⇒ <200 ps resolution on particle arrival time

Discrimination π-p at 3 GeV/c

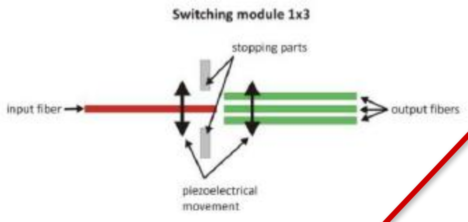


Next steps: towards calibration of more performant systems

- Calibration of systems with time resolution < 50 ps impose severe requirements on the monitoring/calibration system
- In addition the use of laser-diodes (cheaper, simpler to operate,…) impose a tight power-budget as respect to more conventional Nd-Yag duplicated laser (Q-switched) + fiber bundles : a factor 10^6-10^7 reduction in laser pulse energy to be managed !!
- Extensive tests on components: type of fiber (MM vs SM), splitters, optical switches, … to assess timing behaviour and attenuation in the visible range, are needed. Components are qualified for TELECOM use (IR) !!
- **Question**: is it feasible a calibration system made of a cheap laser-diode + some kind of fiber injection system into ~100 channels to be calibrated ?

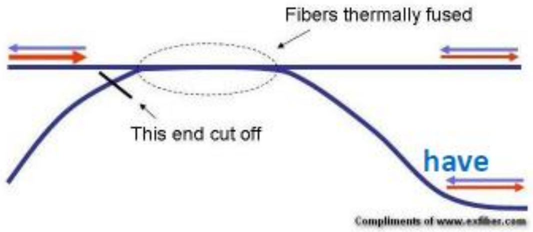
Components to be used

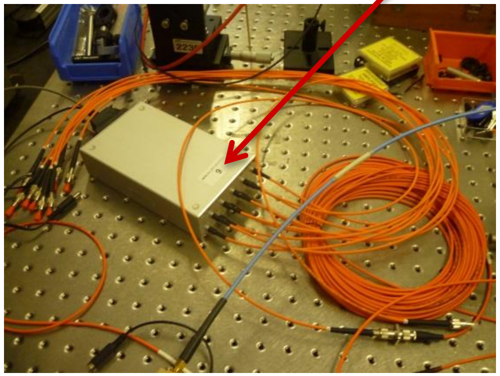
- A diode laser source
- Fiber patches to convey laser pulses to the channels to be calibrated
- Optical switches to send the laser pulse to 1 of N channels (active device, eg piezoelectric actuactors)
- Fused fiber splitter to split input laser pulse to N output channels (typically 1 -> 4, 1-> 8) (passive device)
- Needs to optimize all as respect to time spread + attenuation at λ ~400 nm



Optical switches advantages

- No λ dependance
- Low insertion loss
- Possibility to use MM fibers

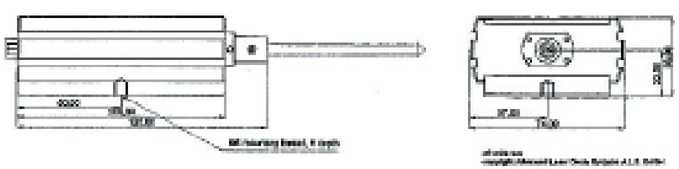




Fused fiber splitter: technology well-known for Telecom (> 1200 nm) not so common for visible light and MM fibers

Choice of laser source

A

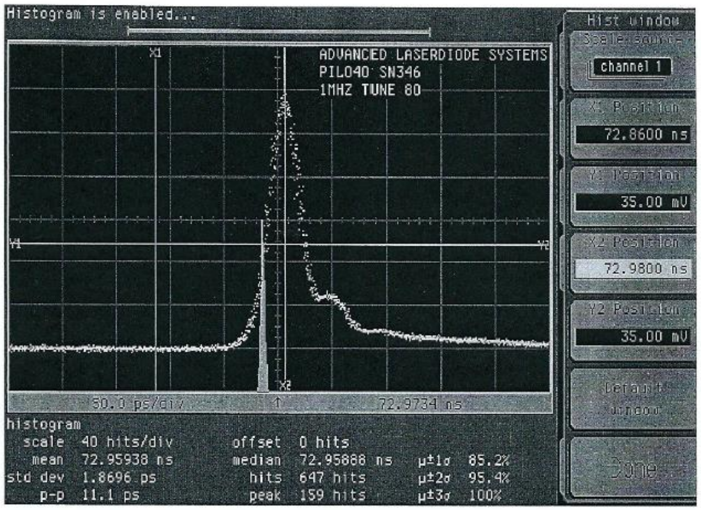


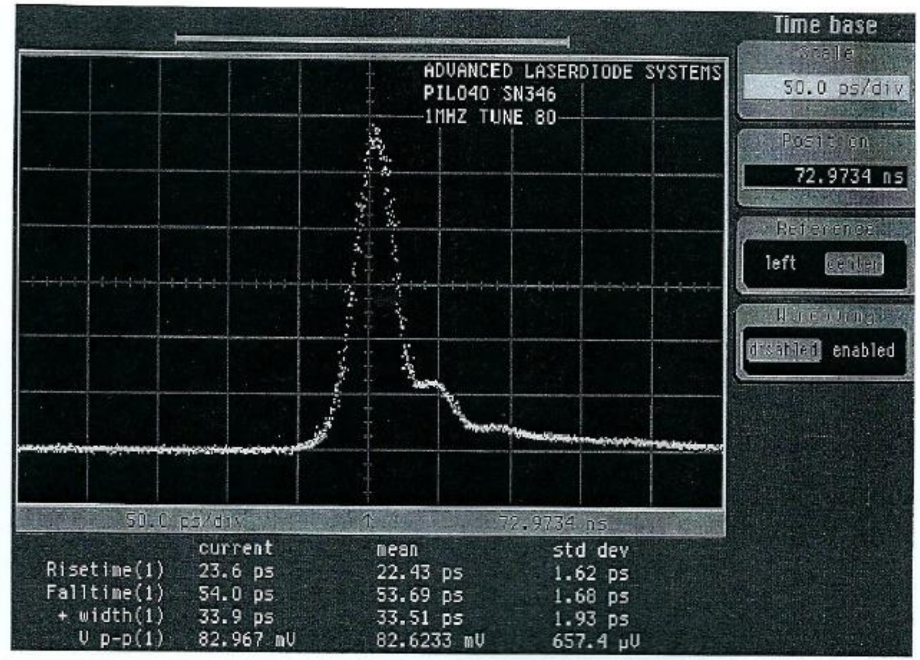
B

- Typical diode-laser source: Pilas 405 from ALS Gmbh (other options from Picoquant, Hamamatsu, …)
- Peak power < 1 W
- FWHM ~30-50 ps
- Repetition rate up to 1 MHz
- Optical head with:
  Collimating otics (free space beam) (A)
  Internal fiber coupling [best] (B)

Option (B) is best for maximal power delivery to the calibration system

Measured time characteristics of used ALS Pilas 405 Laser

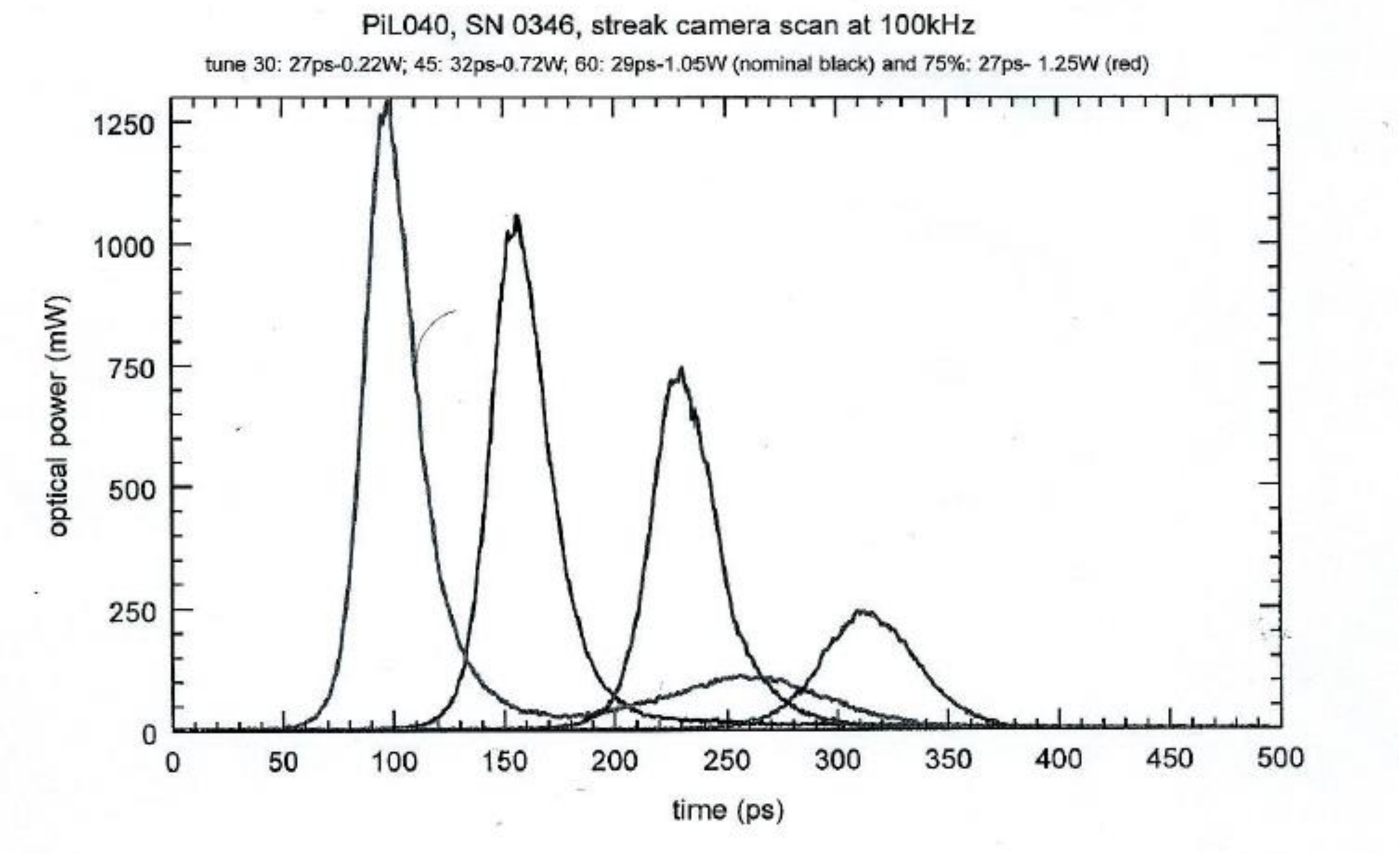




Measurements done with a HP 54750A sampling scope with a 50 GHz head + a 20 GHz MSM A.L.S. ultrafast detector. Light is injected into the detector via a 9 μm SM fiber input

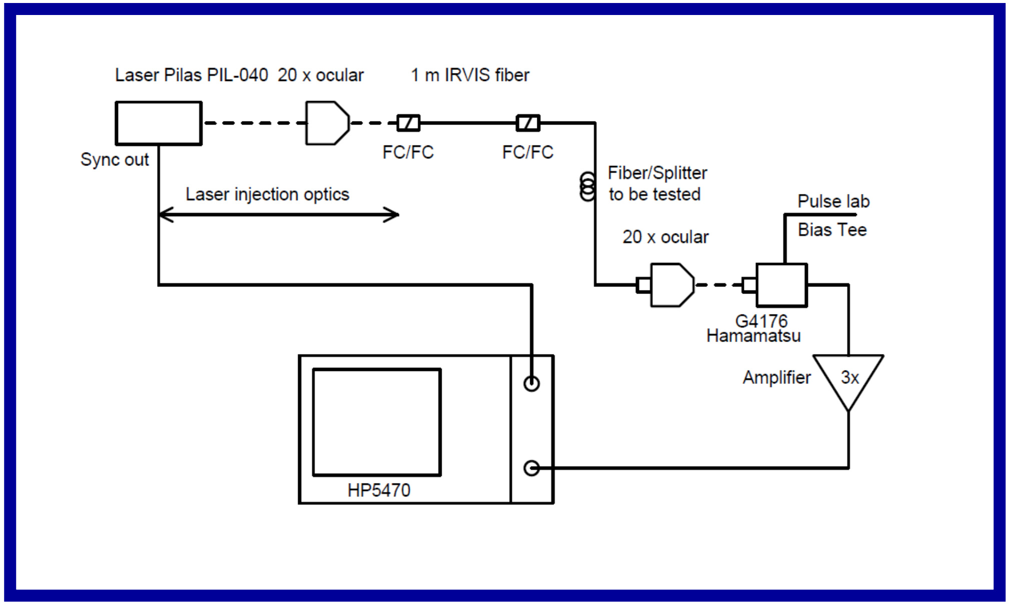
Rising edge is well defined, fall less

Additional measurement with a streak camera



Fiber characterization: MM vs SM

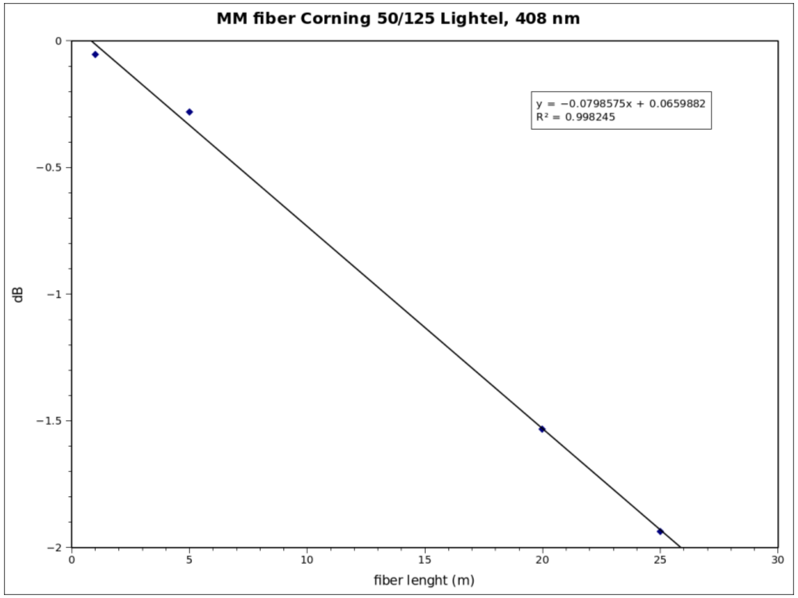
- To reduce injection problems (tight power budget with a laser diode) try to use MM instead of SM fibers
- Study timing (dispersion) and attenuation properties of MM fibers

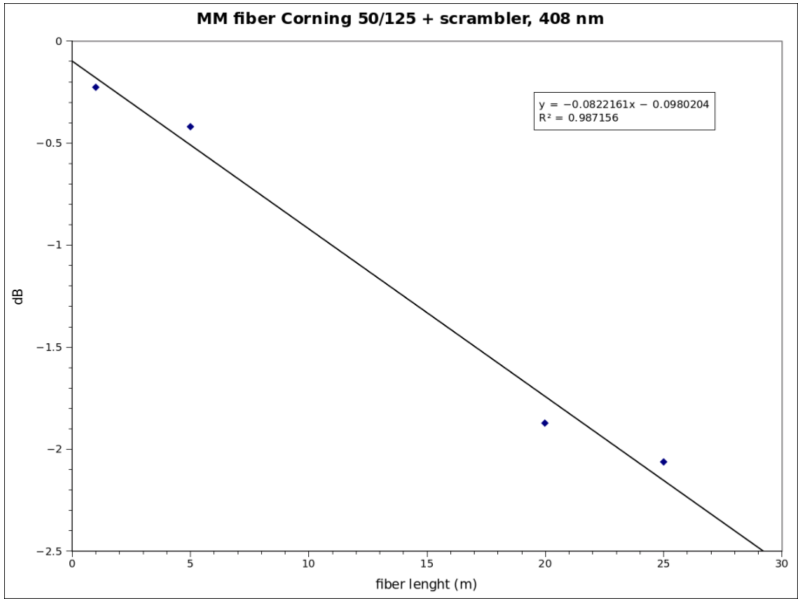


Used setup: in part of these studies a MM mode scrambler from Arden photonics (in place of the 1m IR/VIS fiber was used)

- Attenuation studies with an OPHIR NOVA powermeter
- Dispersion studies with an HP 54750A sampling scope with a 20 GHz head after an Hamamatsu G4176 photodetector powered by a 10 GHz bias tee (Model 5550B from Picosecond Pulse Lab)

Results on attenuation (I)





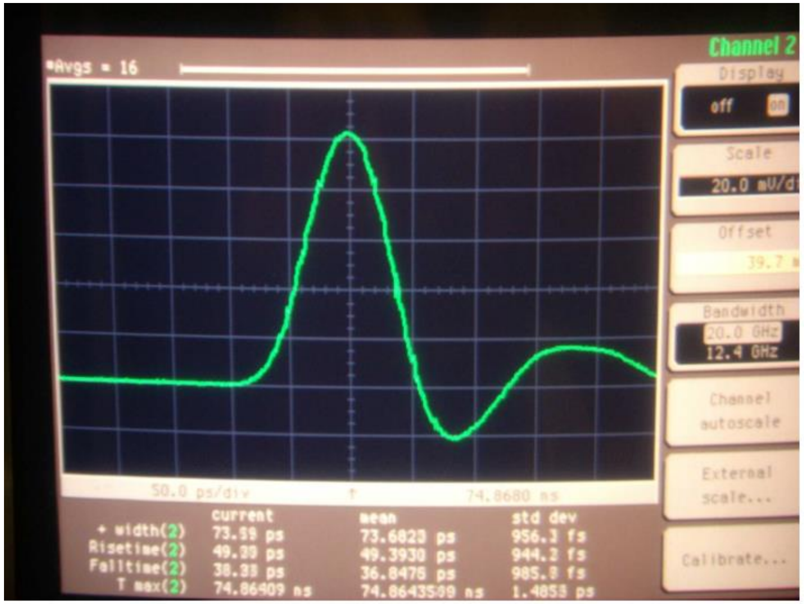
Fit of attenuation for Corning 50/125 using fiber patches of different length measured without (left) and with an Arden Photonics MODCON mode scrambler (right)

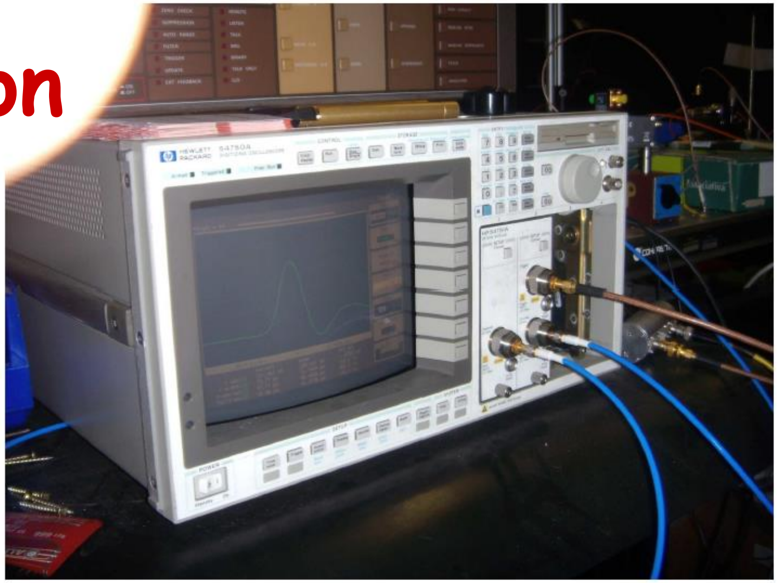
Results on attenuation (II)

MM fiber	type	Attenuation (dB/m) no scrambler	Attenuation (dB/m) with mode scrambler
Thorlabs AFS 50/125 Y (step index: 400-2400 nm)	50 μm core	0.169 +- 0.007	0.193+- 0.011
Thorlabs AFS 105/125Y (step index: 400-2400 nm)	100μm core	0.0796+- 0.0026	0.0808+- 0.0046
Corning 50/125 (graded index)	50 μm core	0.0794+- 0.0029	0.0894+-0.0051
OZ/OPTICS IRVIS 50/125 (graded index: 400-1800 nm)	50 μm core	0.0696+-0.0026	0.0569+-0.0063
OZ/OPTICS UVVIS 50/125 (step index: 200-900 nm)	50 μm core	0.118+-0.009	0.114+0.007
Thorlabs SFS 50/125 Y (step index: 250-1200 nm)	50 μm core	0.0657+-0.0052	0.0744+-0.0097

Choice for test system is OZ/OPTICS IRVIS 50/125

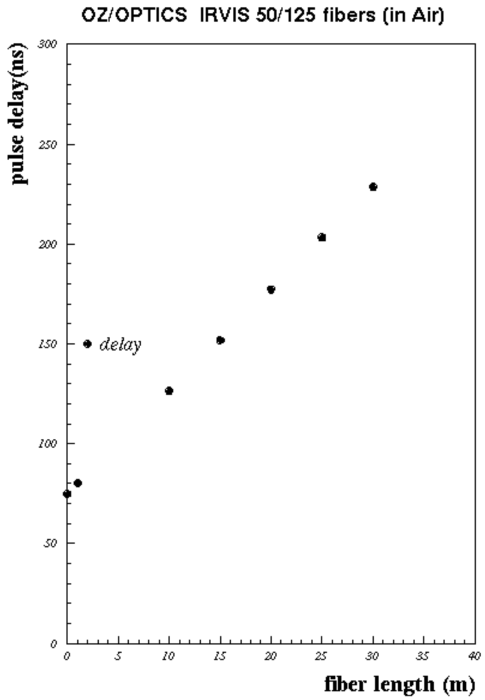
Results on dispersion

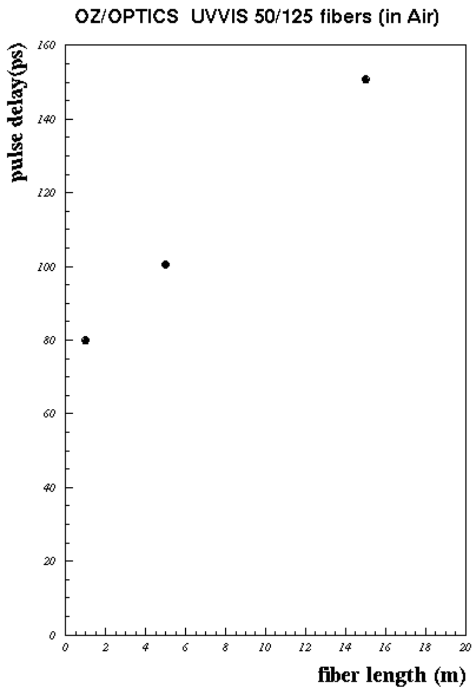




Measured with a ``vintage" HP54750 scope + a 20 GHz sampling head

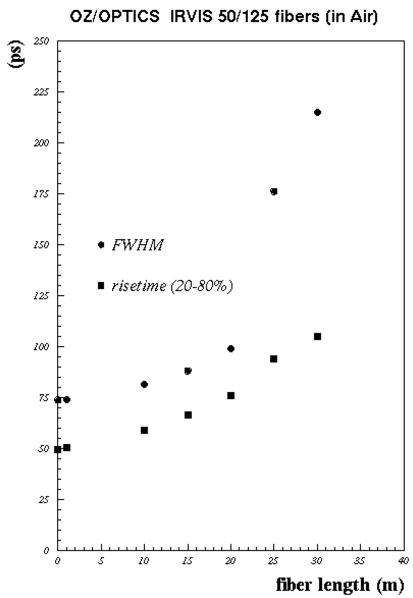
Results on fiber dispersion (I): pulse delay

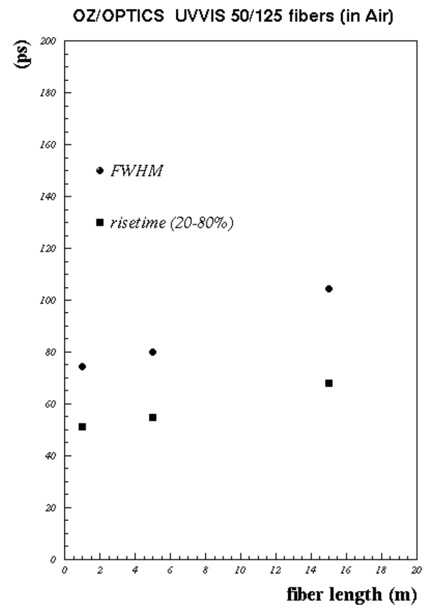


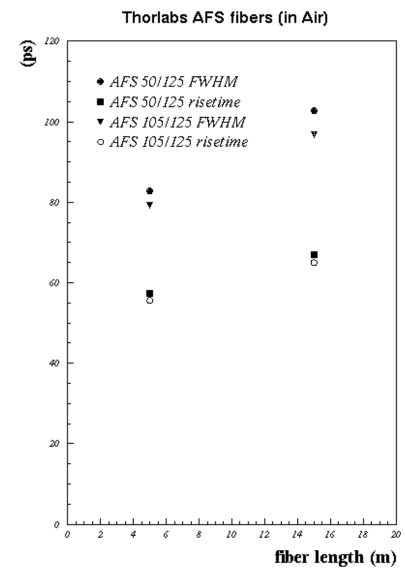


OZ OPTICS IRVIS 50/125 OZ OPTICS UVVIS 50/125
(measurement with an Arden Photonics mode scrambler before the fiber patch to be tested)

Results on fiber dispersion (II): pulse degradation







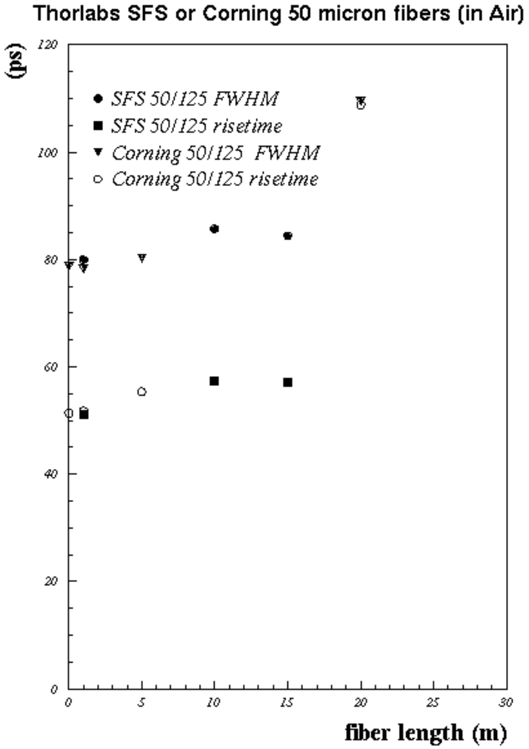
OZ OPTICS IRVIS 50/125

OZ OPTICS UVVIS 50/125

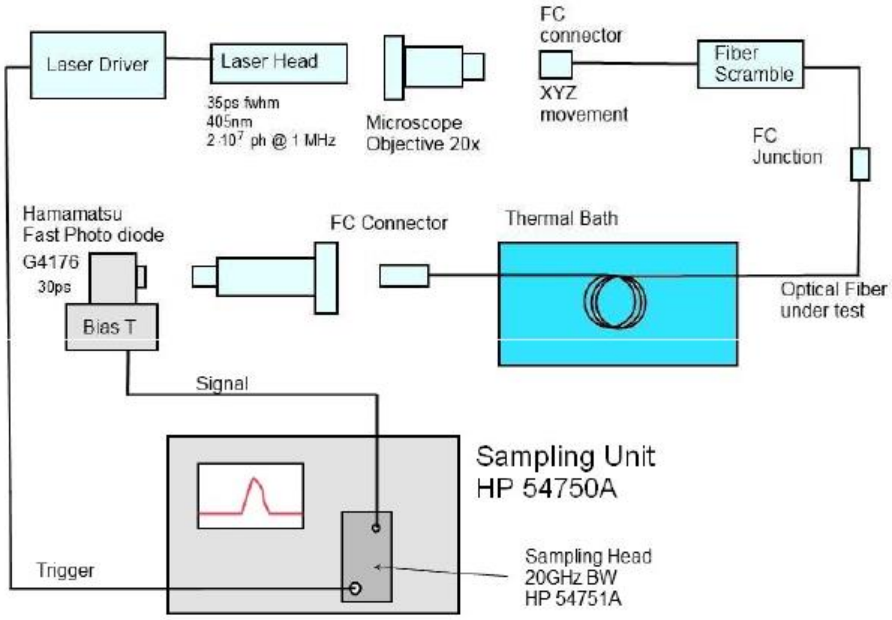
Thorlabs AFS 50/125 or 105/125

Results of fiber dispersion (III): pulse degradation

Measurement done without a mode scrambler



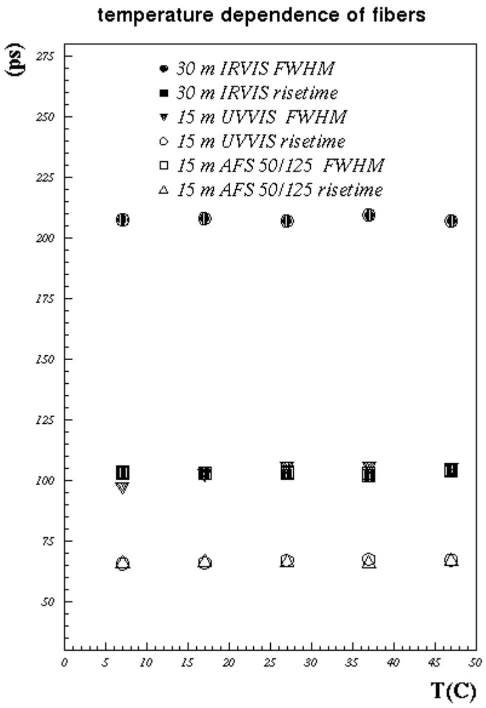
A detour on temperature effects on fibers

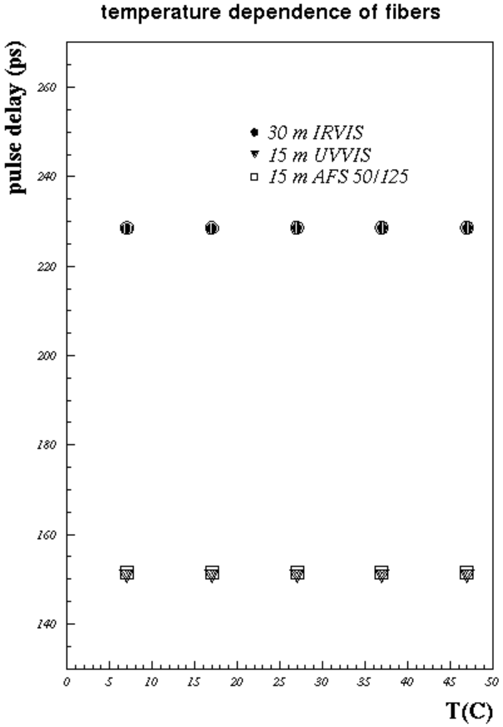


Test system includes a precision LAUDA thermal machine (precision of 0.1C) where part of the fiber may be kept at fixed temperature

Fiber under test: 15 m patches Thorlabs AFS 50/125Y or 105/125Y (14 m in thermal bath, 1m in air) ; 30 m patch OZ/OPTICS IRVIS 50/125 (28 m in thermal bath, 2m in air)

Temperature dependence results





Temperature effects are negligible

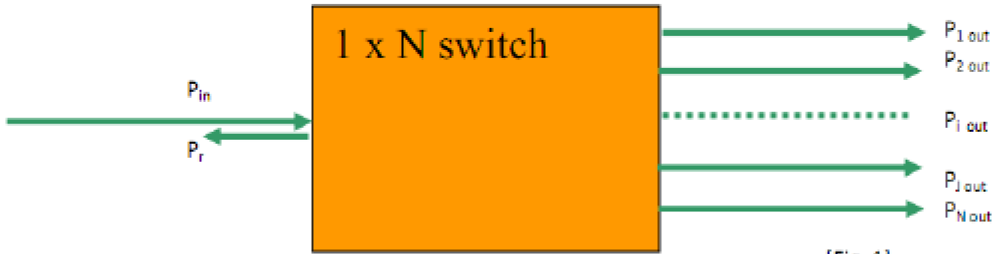
Conclusions on 50 μm core fibers test

	OZ Optics Irvis 50/125	OZ OPTICS UVVIS 50/125	Thorlabs AFS 50/125	Thorlabs SFS 50/125 (*)	Corning 50/125(*)
Delay (fs/m ^{0}C)	106	40.6	52.2	___	___
Delay (ns/m)	5.11	5.05	5.11	___	6.4
Attenuation (dB/m)	0.06	0.12	0.08	0.07	0.08
Pulse risetime dispersion (ps/m)	1.12	1.22	1.21	0.70	0.90
Pulse width dispersion (ps/m)	0.99	2.21	2.71	0.63	1.63

(*) measure without mode scrambler

Tests of optical switches

There are several key parameters for fiber optic switches that are relevant for all the applications mentioned above.



[Fig. 1]

Insertion loss [dB] :	$L_i = 10 * \log (P_{in} / P_{i\,out})$
Crosstalk [dB] :	$C_j = 10 * \log (P_{j\,out} / P_{i\,out})$; for signal switched to output channel Pi
Back reflection [dB] :	$R = 10 * \log (P_r / P_{in})$
Switching time – τ :	time difference of the 10% - 90% output power transition in the switched channel.

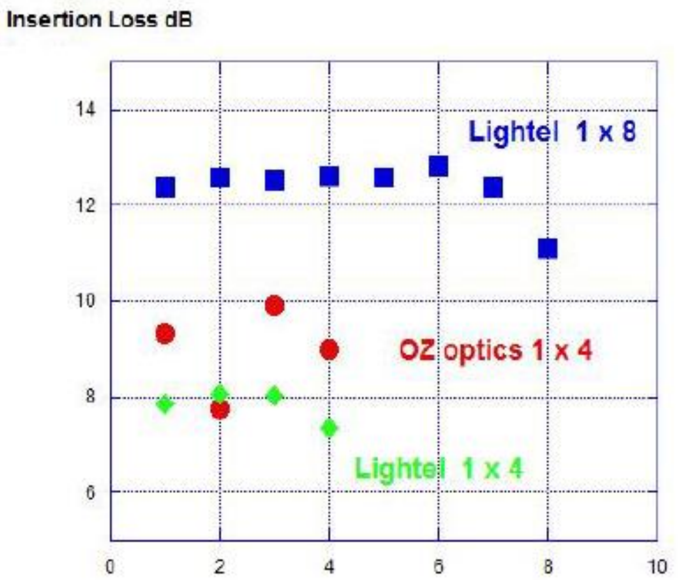
- Used PiezoJena 1-9 optical switch: model F-109-05 with SFS 50/125 fibers
- Standard test setup used for fiber patch characterization (both time dispersion & attenuation measurements)
- Manufacture's specs (at λ ~850 nm !!): insertion loss 1.5 dB, cross talk ~70 dB

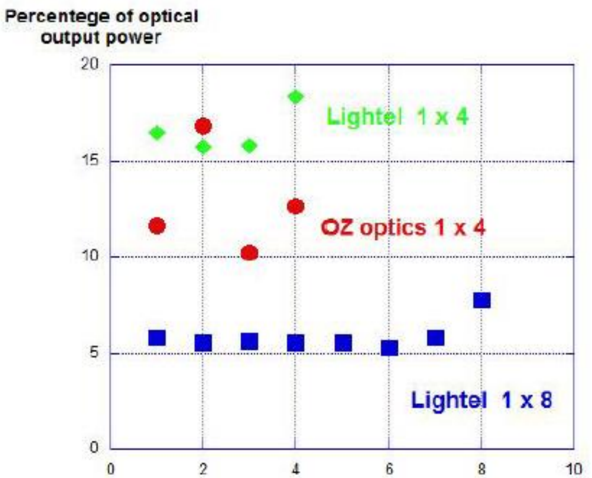
Results on optical switch

Average increase of signal FWHM	From 80.47+-0.61 ps (no switch) to 83.14+- 0.46 ps (switch inserted)
Output signal variation from channel to channel	< 1%
Cross-talk	~2%
Insertion loss	~40 %

All measurements at 408 nm

Study of fused optical splitters





Available splitters:

- Even ratio 1x4 OZ/OPTICS
- Even ratio 1x4 Lightel
- Even ratio 1x8 Lightel

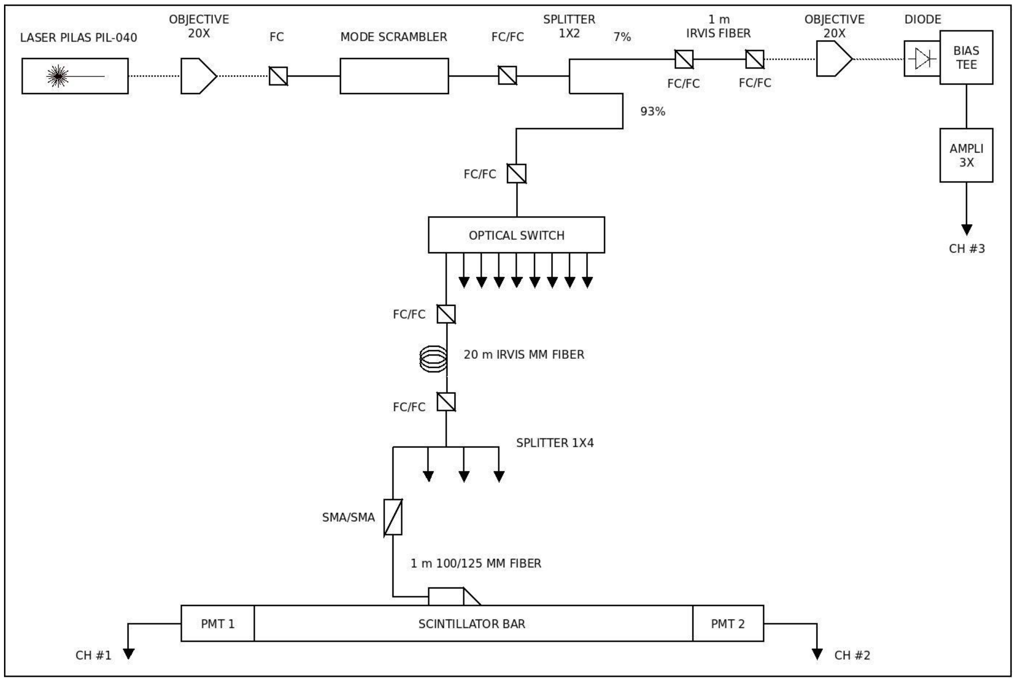
Results on fused fiber splitters :

	Spread in output splitting (as rms/average %)	<ΔFWHM> (ps)
OZ/OPTICS 1x4 (# 1)	9.5	2.36+-0.72
OZ/OPTICS 1X4 (#2)	6.2	1.44+-1.68
OZ/OPTICS 1x4 (#3)	15.2	2.34+-1.08
Lightel 1x4 (#1)	3.2	2.08+-0.86
Lightel 1x4 (#2)	6.7	2.10+-1.18
Lightel 1x4 (#3)	8.5	2.03+-0.97
Lightel 1x8 (#1)	11.5	2.14+-0.59

Increase in FWHM of pulse in/out: gives an idea of additional time spread introduced by a splitter

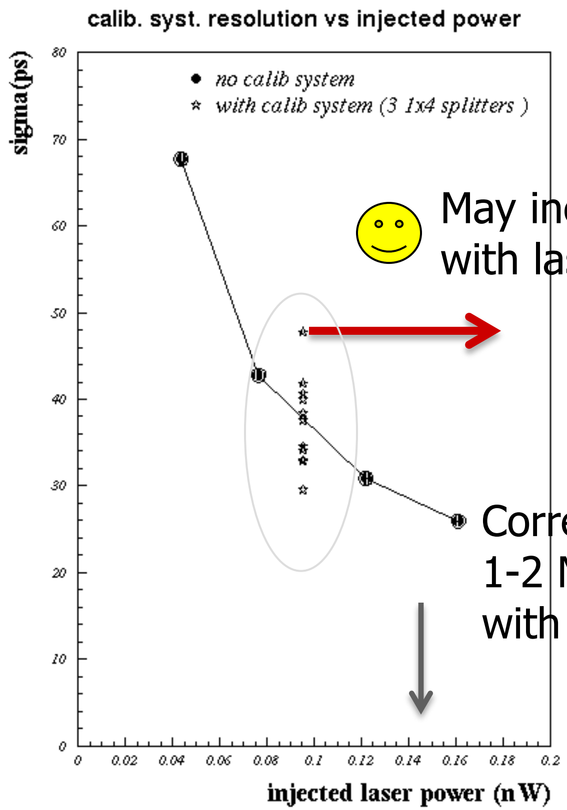
Gives an idea of splitter uniformity

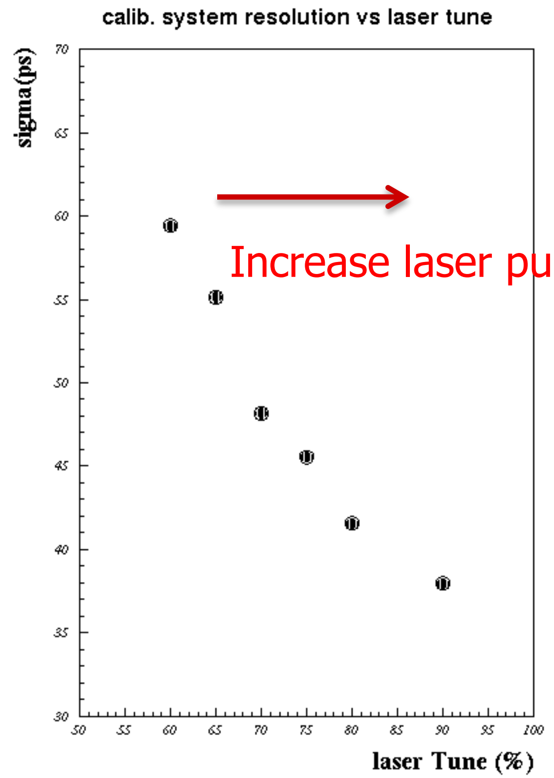
A laboratory full size prototype (up to 36 channels)



- Start from fast G4176 MSM photodiode; STOP from scintillation counter PMTs
- Time measurement with an ORTEC 567 TAC/SCA + CAEN N957 MCA : resolution ~12.4 ps/count; full scale 8096 counts
- Measure ΔTDC with and without calibration system, to see if any difference appears

Preliminary results





May increase with laser tune

Increase laser pumping

Corresponds to a 1-2 MIP signal with cosmics

Computed as ΔTDC (ch1-ch2)/2

Conclusions

- a diode-laser + optical switch+ fused MM fiber splitters may be feasible for scint. based TOF system up to N channels
- with present laser diodes (1W peak power) N ~ 100 channels seems feasible
- Preliminary studies show that the additional time spread introduced by the calibration system is < 30-40 ps

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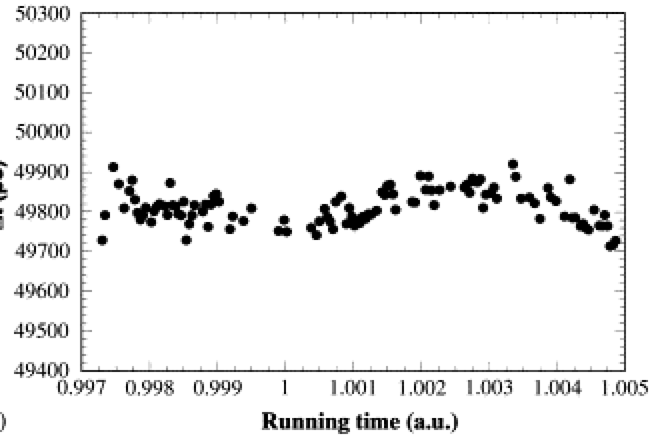
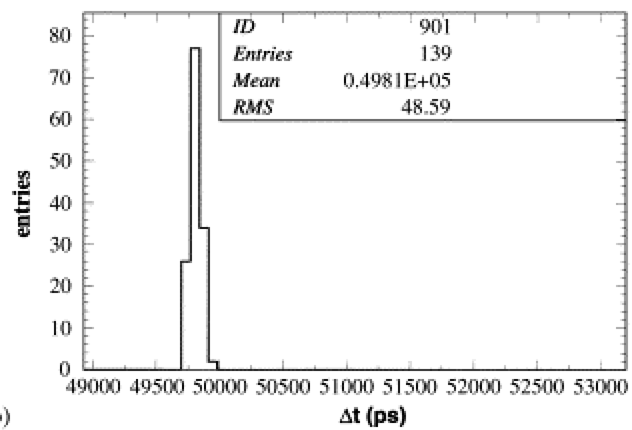
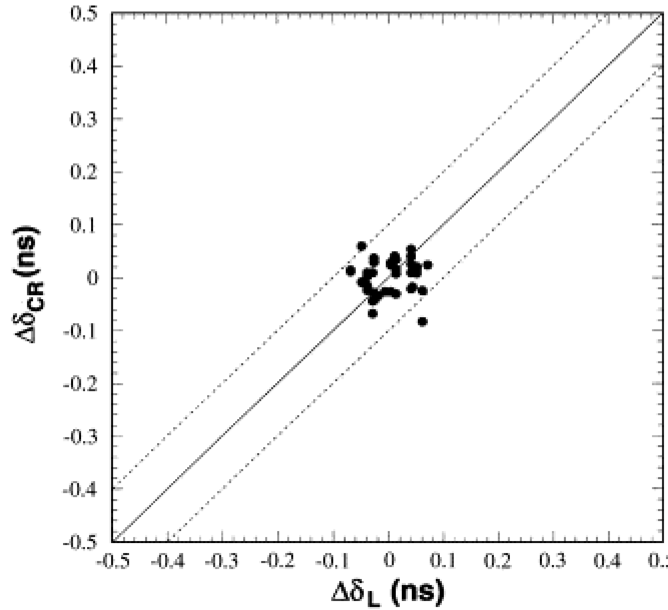
Backup Material

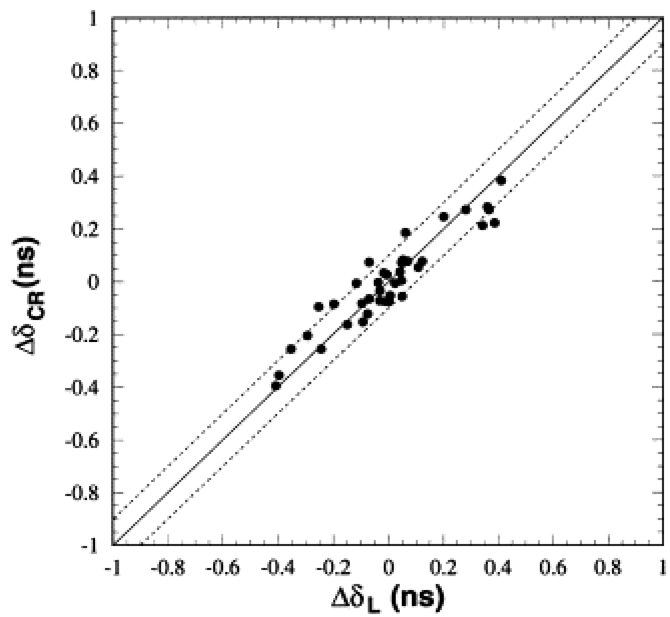

Δt (ps)
Running time (a.u.)

(a)


ID 901
Entries 139
Mean 0.4981E+05
RMS 48.59
entries
Δt (ps)

(b)

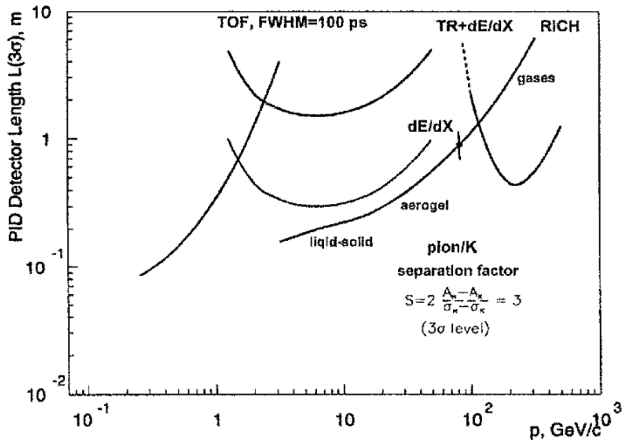

Δδ_CR (ns)
Δδ_L (ns)


Δδ_CR (ns)
Δδ_L (ns)

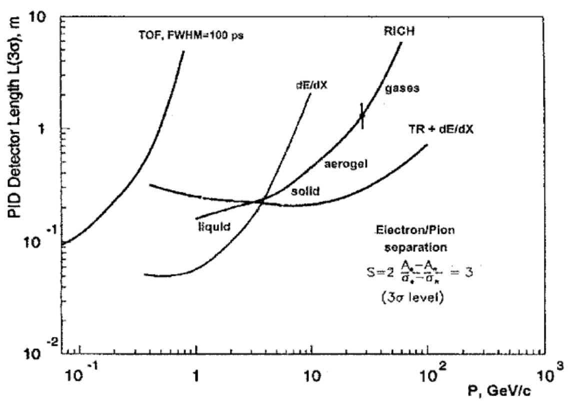
PID methods

- Particle identification (PID) is crucial in most experiments (from π/K identification in B physics to e/π separation at 10^{-2} level for p< 1GeV)
- At low momenta TOF methods are used (p≤ 3-4 GeV/c)

Pion-Kaon separation for different PID methods. The length of the detectors needed for 3σ separation.



The same as above, but for electron-pion separation.



Dolgoshein, NIM A 433 (1999)