A laser diode calibration system for fast TOF systems

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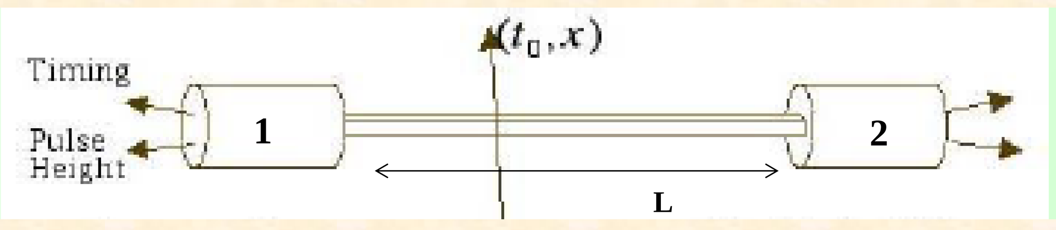
Introduction: double-sided TOF systems



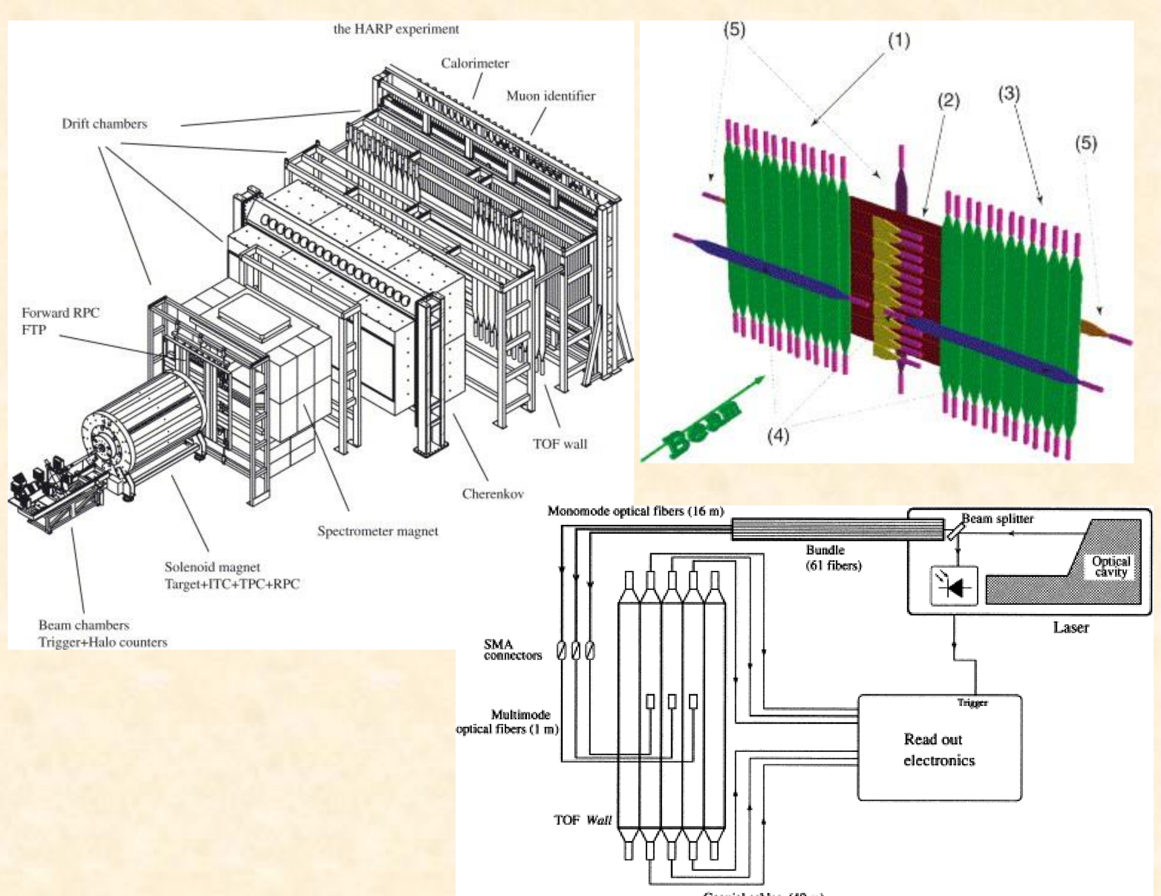
$$\Delta t_{i,j} = t_0 + \frac{L/2 \pm x}{v_{eff}} - t_s + \delta_{i,j}, j = 1,2$$

$$\Delta t_{+,i} = \frac{\Delta t_{i,1} + \Delta t_{i,2}}{2} = t_0 + \frac{L}{2 \cdot v_{eff}} - t_s$$

*High precision time-of-flight (TOF) detectors need fast and accurate calibration systems to keep under control drifts of single channels **delays** δ_i due to*

- *change in cable delays (termic excursions) ➡ problems with long cables*
  - *Typically: RG58 cables have a single channel time variation of 95 ppm/^{0}C; RG213 cables of 30 ppm/ ^{0}C*
- *Change in PMTs transit time*
- *Change in electronics delay*
  - *A test on a CAEN V775 TDC measured a typical absolute drift of 1300 ppm/ ^{0}C in the TDC slope and a relative drift (channel to channel) of 88 ppm/ ^{0}C*
- *…*

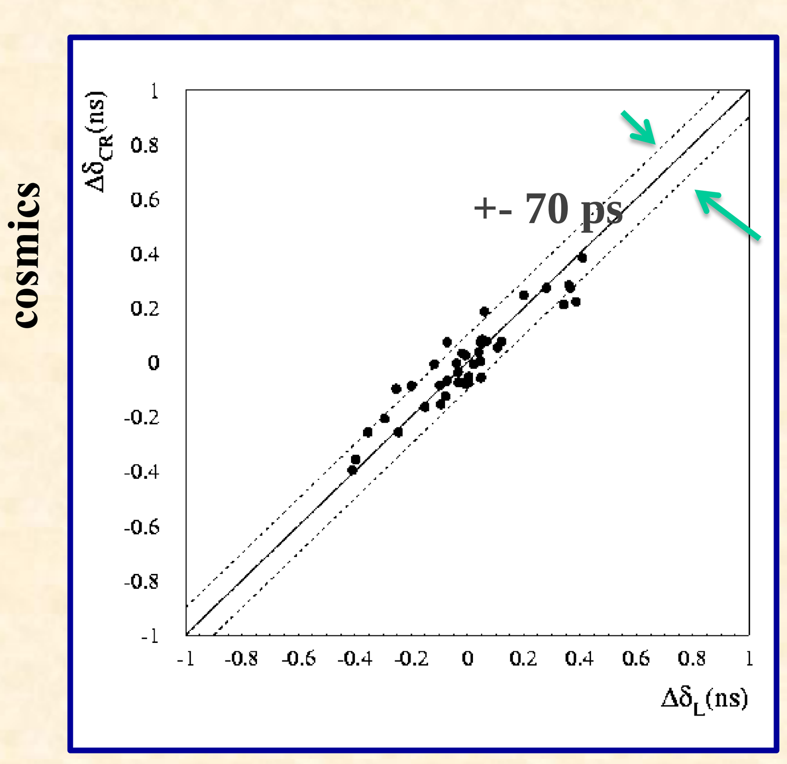
An example : the HARP TOF calibration System



Large area TOF system (7 m x 2.5 m) based on BC408 scintillator bars + XP2020 PMT readout (at both sides). 200 ps time resolution (σ_t) on arrival time
Calibration system based on :

- *Q-switch+ mode locking Nd/Yag Quanta Laser at 532 nm with 3 mJ pulses of 60 ps FWHM*
- *Distribution of pulses to 39 channels (scintillator bars) with a bundle of IR monomode Corning SMF-28 fibers (8 μm core)*
- *calibration resolution ~70 ps*

Shifts of calibration constants from 2001 to 2002 data taking



Next steps: calibration of more performant systems

*For use in **more performant systems** (e.g. MICE TOF with σ_t ~50 ps), improvements were sought for:*

- *Laser system: use a laser diode (low cost and better reliability), but peak power ~1-2 W/pulse instead of 10^7-10^8 W/pulse*
  - *This implies a tight control on power budget to distribute laser pulse to many channels (~50)*
- *Distribute laser pulses to single channels (scintillation counters) via optical switches/fused fiber splitters (1x4,1x8) .*
- *Use MM fibers instead of SM to reduce injection problems*
- *All is available in the TeleCom range (IR) but not in the visible range (~400 nm) ➡ needs tests to qualify components*

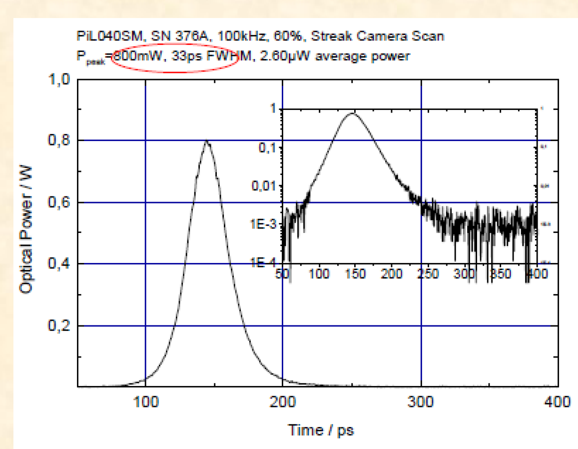
Components characterization

***Strategy**:*

- *try to characterize components for use at 400 nm, taking into account mainly timing properties (FWHM)*
- *Try to use low cost components, e.g. laser diodes ($) instead of Q-switched lasers ($$)*

A) Laser source

Advanced Laser System Pilas 405



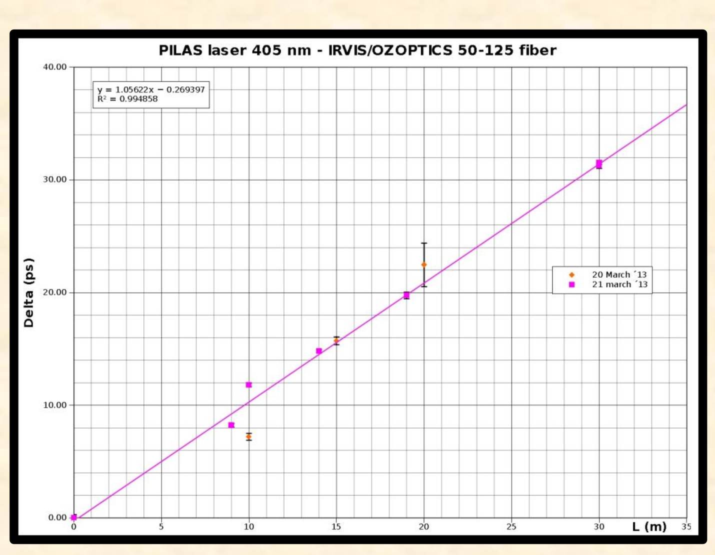
Streak camera measurement

Handy laser diodes (A.L.S, PicoQuant, Hamamatsu, …)

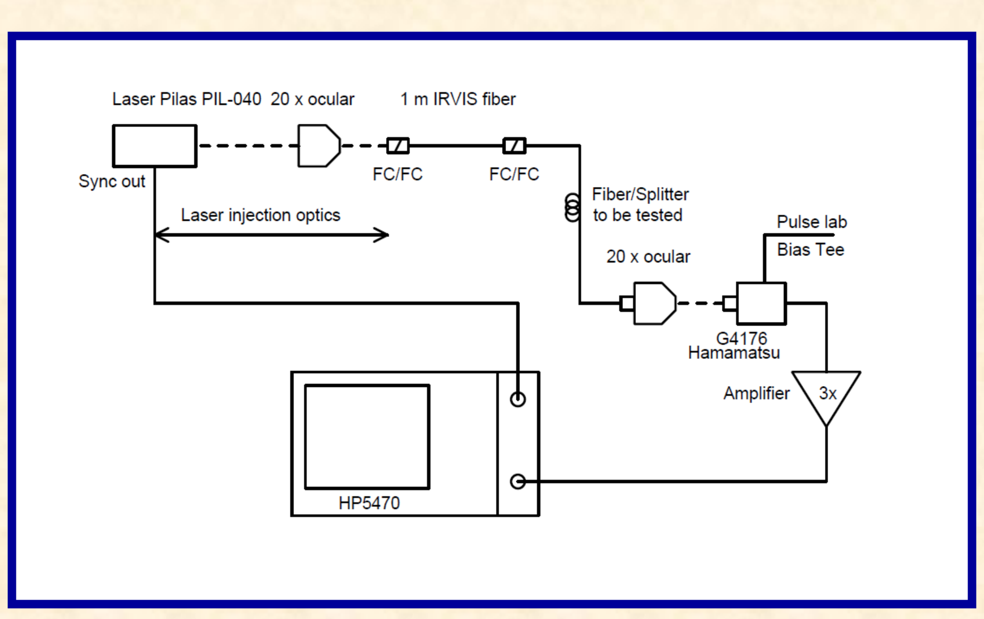
- Pros: easy setup, robust, low cost ($)
- Cons: low peak power (< 1 W) ➡ **power budget** in the calibration system is a **must** (eg instead of using 1xN splitters, with N=16, 32, … , use optical switch+ 1x4 only splitters; use MM fibers instead of SM fibers to reduce injection problems, losses …)

B) Fiber characterization: MM vs SM

- **To reduce** injection problems, use MM instead of SM fibers.
- **Needs to study** timing and attenuation properties of MM fibers



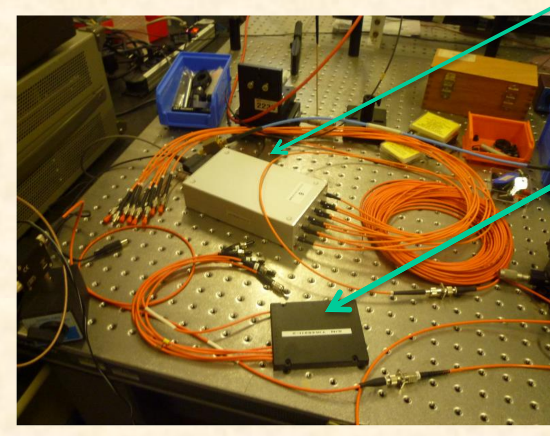
Typical timing spread increase (σ_t) vs fiber length L (m) for a MM fiber (IRVIS 50/125 OZ/OPTICS) : 1 ps/m. Similar results for other MM fibers with 50/62.5 μm core.



__Test system:__ the laser pulse is detected by an Hamamatsu G4176 photodetector (t_R,t_F ~40 ps) and measured by a 20 GHz HP 54750 sampling scope (timing studies) or by an OPHIR powermeter (attenuation studies) .

- *The same system used to characterize optical switches, fused fiber splitters*

C) Tests of optical switches/fused fiber splitters

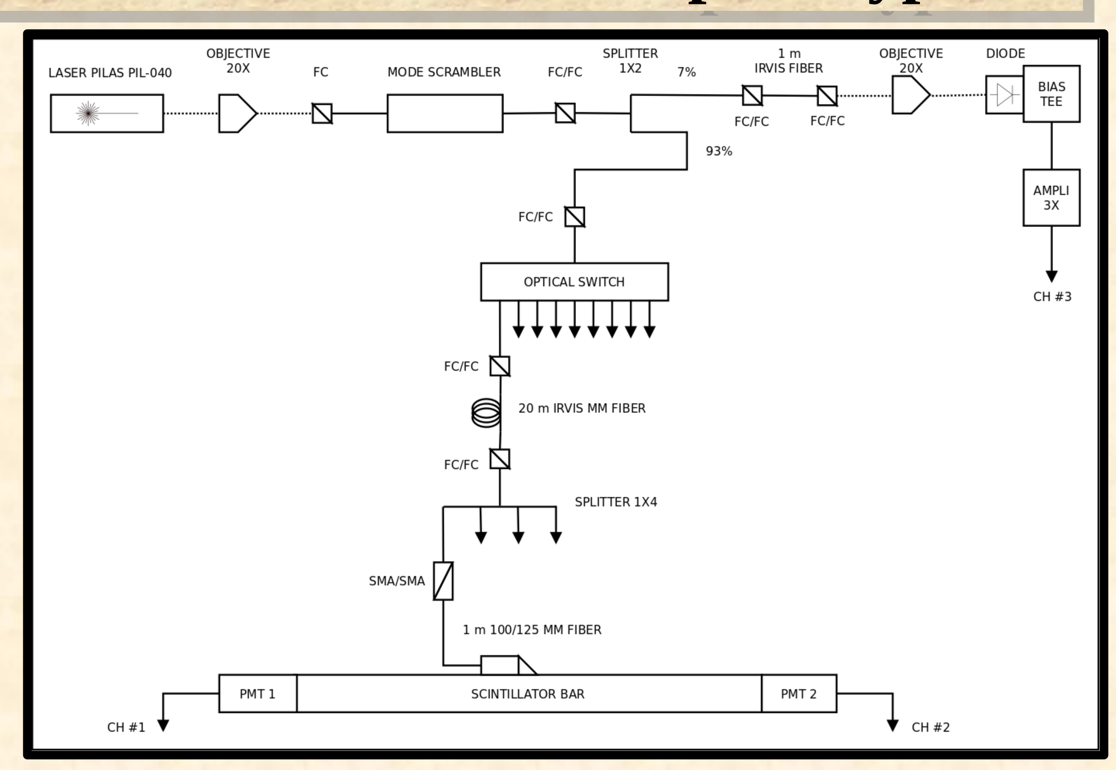


- **Optical switch**: to send input signal to 1 of N output lines. MM fiber type to work at 400 nm. Insertion loss ~1.5 dB, cross –talk ~70 dB
- **Optical splitters 1xN** : divide input signal to N output lines.
  - Fused 1xN splitters are cheaper ($), but usually available for Telecom (850/1300 nm) not visible light (400 nm)
  - Splitting ratio may be odd at ~400 nm -> needs mode scrambler
  - What happens to input signal ? Attenuation, time spread -> needs careful measurements

Results:

- Laser pulse FWHM after an optical switch (PiezoJena F-109-05) is increased at most of ~ 3%
- Laser pulse FWHM after a fused optical splitter 1x4 is increased of less than 4-8% [depends on output branch]

Results with a full size prototype



- START from Hamamatsu G4176 detector with ALPHALAS BBA-10 3X 4 GHz amplifier or Thorlabs DET02A (t_R~50 ps, t_F~150 ps) with CAEN 1423 wideband amplifier (ch # 3)
- STOP from discriminated PMT(1,2) signal (ch # 1,2)
- Measure with CAEN V1290 TDC (25 ps resolution) $\Delta TDC_{1,2}$ with direct injection into scintillation counter (after 1m IRVIS fiber) or with the full calibration system inserted (splitters+switch+ 20 m patch cables+ …)
- **Results:**
  - Calibration system delivers in each channel a signal up to 2-3 MIP
  - Compatible timings in the two cases, estimated via $\Delta TDC_{1,2}$ resolution (within 10 %)
  - Splitting ratio (after 1x4 fiber splitters): equal within 10-15 % (using an Arden Photonics mode scrambler at the laser injection)

Conclusions

A calibration/monitoring system based on laser diode+optical switch+ fused fiber splitters for TOF systems with N~50-100 channels and detector resolution ~50-60 ps is feasible.

References:

- *M. Baldo Ceolin et al., Nucl. Instr. Meth. A532(2004)548*
- *M. Bonesini et al., IEEE Trans. Nucl. Science 50 (2003) 1053*
- *R. Bertoni et al.* NIM A 615 (2010) 14

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