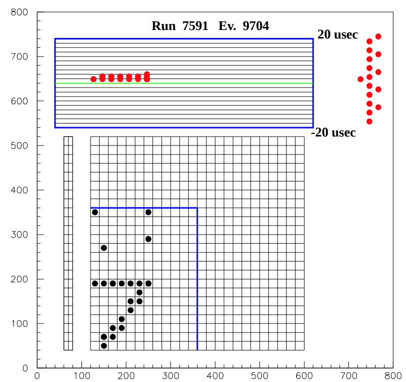
FAST:

towards a 1ppm muon lifetime (and G_F) measurement

Luca Malgeri on behalf of the FAST-UniGe group

University of Geneva

July 12, 2002 - Rencontres de Bossey



Outline:

- Motivations
- Conceptual design
- Proof of feasibility
- University of Geneva involvement:
  - detector
  - calibration system
  - data acquisition
  - simulation
- What is there / what is missing
- Timing
- Conclusions

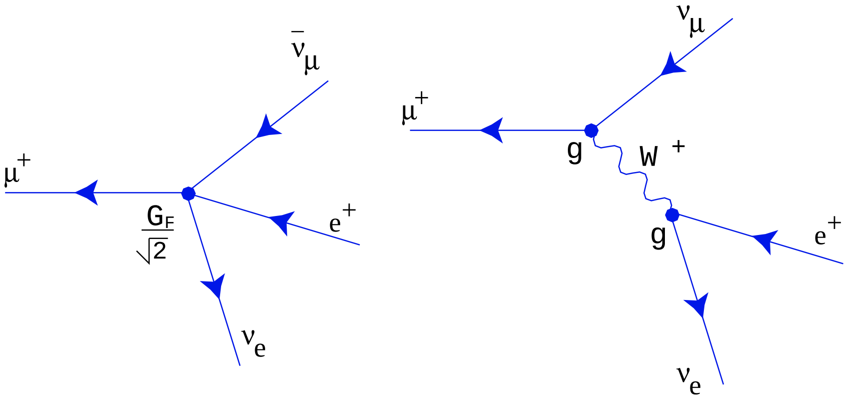
Motivations

G_F is one of the fundamental parameter of the Standard Model.

It is used as one of the three parameters needed to describe the bosonic sector of the Standard Model:

$$
\begin{array}{rcll}
\alpha(\mu^2 = 0) & = & 1/(137.035990 \pm 0.000006) & \rightarrow (0.045\ ppm) \\
M_Z & = & 91.1867 \pm 0.0021 \text{ GeV} & \rightarrow (23\ ppm) \\
G_F & = & 1.16639 \pm 0.00001 \times 10^{-5} \text{ GeV}^{-2} & \rightarrow (9\ ppm)
\end{array}
$$

It can be derived from the muon lifetime:



$$\tau_\mu^{-1} = \frac{G_F^2 M_\mu^5}{192\pi^3}(1 + \Delta q)$$

Δq include the higher order QED and QCD corrections

Motivations

Where the uncertainty on G_F comes from?

$$\frac{\delta G_F}{G_F} = -\frac{5}{2}\frac{\delta m_\mu}{m_\mu} - \frac{1}{2}\frac{\delta \tau_\mu}{\tau_\mu} + \text{th.} \left(+4\frac{m_\nu^2}{m_\mu^2} \right)$$

$$\frac{5}{2}\frac{\delta m_\mu}{m_\mu} = 0.38 \text{ ppm}$$ *PDG2000*

theory $= 0.50$ ppm *Ritbergen and Stuart PLB 437 (1998) 201*

$$4\frac{m_\nu^2}{m_\mu^2} = 10 \text{ ppm}$$ *PDG2000*

(if you assume neutrinos to be massive)

$$\frac{\delta \tau_\mu}{\tau_\mu} = 18 \text{ ppm}$$ *PDG2000*

Dominant contributions from:
Balandin et al. *(1974)*
Bardin et al. *(1984)*
Giovanetti et al. *(1984)*

Conceptual design

Goal: a 1ppm muon lifetime measurement

Requirements:

Large data sample of 10^{12} events over at least 9 τ_μ periods

$\Downarrow$

$10^{12} \times 9\tau_\mu = 1.5$ years of data taking at 50 % efficiency if only one event per cycle is accepted: parallelization needed!

$\Downarrow$

Tracking capabilities in order to disentangle overlapping events

$\Downarrow$

In order to stay in a reasonable data taking period ($\sim$2 months), a high data rate is needed: 1 MHz.

Key point: control time dependent systematics below 1 ppm

Conceptual design: systematics (past experiments)

Saclay experiment (Bardin *et al.*):
A scintillator telescope surrounding a sulphur target in a pulsed pion beam.

The polarized μ component of the beam introduced time dependent inefficiencies due to the limited coverage of the detector (μ-Spin-Rotation effect)

$\longrightarrow$ need the ability to recognize a $\pi \rightarrow \mu$ transition: use of a double threshold discriminator

TRIUMF experiment (Giovanetti *et al.*):
A water Čerenkov system coupled to two PM in a DC muon beam.

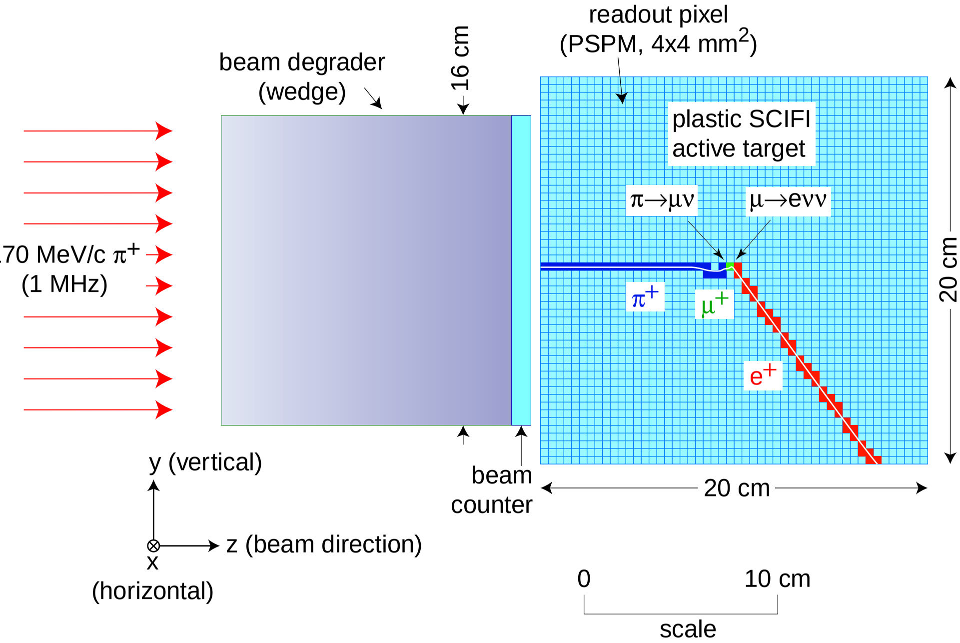
The low granularity of the detector produced time dependent effects due to the pile-up

$\longrightarrow$ need high granularity and tracking capabilities

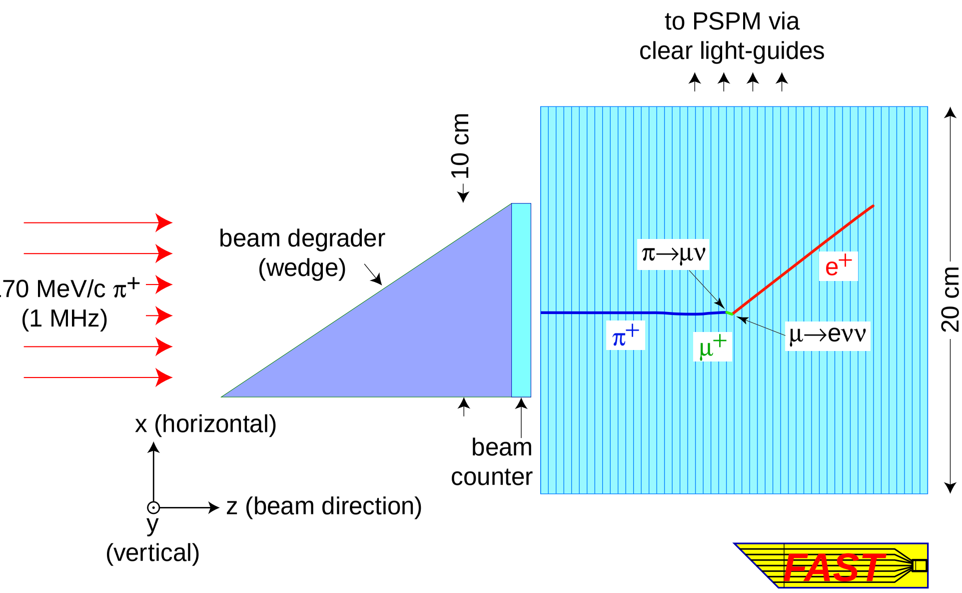
Conceptual design:

A scintillating pixel detector, on a DC pion beam, able to handle up to 30 $\pi \rightarrow \mu \rightarrow$ e decay chains in a 30 μs window:

a) yz view (elevation)



b) xz view (plan)



Conceptual design: characteristics

Beam:

- ✔ πM1 at PSI: DC current
- ✔ Momentum: 170 MeV/c ($\pm$ 3 %)
- ✔ Size: 10×16 cm^2
- ✔ Intensity: 10^6 s^{-1}
- ✔ Purity: 90 %

Target:

- ✔ 4*4*160 mm^3 scintillator baguettes forming the readout pixels
- ✔ 2 waveshifters fibers per baguette
- ✔ 25 p.e./pixel for minimum ionizing particle
- ✔ 40×40 pixel sensitive area

Readout system:

- ✔ 100 position sensitive PM with 4×4 photocatode pixels
- ✔ rise time < 2 ns
- ✔ 1.6 K deadtime-less TDC channels

Proof of feasibility: fit and summary

Including all systematic effects the final fit function looks like:

$$N(t) = \frac{N_0}{\tau_\mu}\delta t \left[P_0 + \exp\left(-\frac{t}{\tau_\mu}\right) + P_1 \exp\left(-\frac{2t}{\tau_\mu}\right) + P_2 \exp\left(+\frac{t}{\tau_\mu}\right)\right] \otimes \mu\mathrm{SR}$$

P_0 = flat accidental
P_1 = track overlap and pile-up
P_2 = late pions
μSR = μ-Spin-Rotation

Systematics summary tables

Source	Syst. error (ppm) Before	After corr.
Muon spin rotation	1.7	0.2
Time dep. efficien.	0.9	0.3
Track overlap	1.1	0.2
Physics effects	-	0.001
Total systematics		0.41

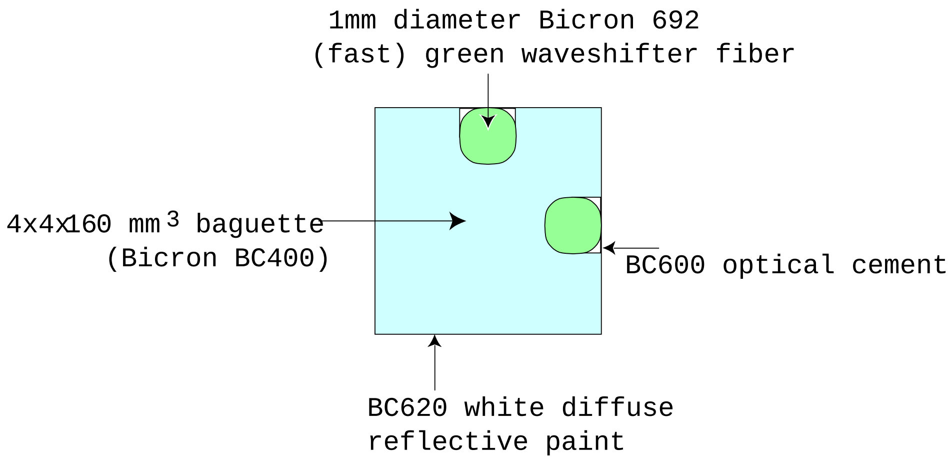
Source	Error (ppm)
Statist. + acc.	1.2
Systematics	0.4
Error on τ_μ	1.3
Radiative corr.	0.2
Error on G_F	0.66

Involvement of UniGe

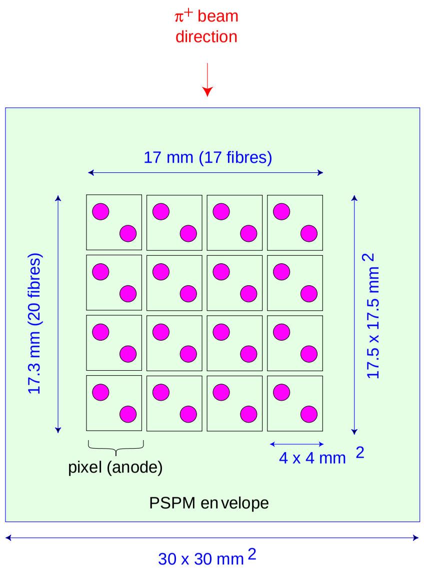
C. Casella (full time), *E. Delmeire*, *L. Malgeri*,
Prof. M. Pohl - spokesman

Detector and readout system:

The light from each scintillator baguette is transported by two clear fibers:



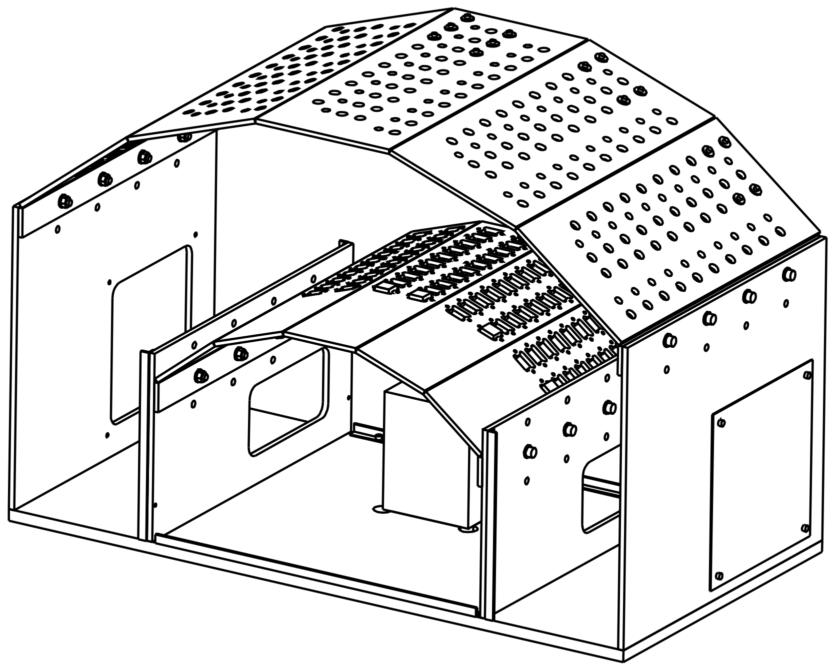
The signal is read by 100 Hamamatsu Position Sensitive PM's providing $4 \times 4 = 16$ anodes (channels), 4×4 mm^2 each:



Involvement of UniGe

The external cage hosting the detector, the PSPM's and the amplifier boards is designed at PSI, produced by Industry and will be assembled by UniGE:

Perspektive M1:10



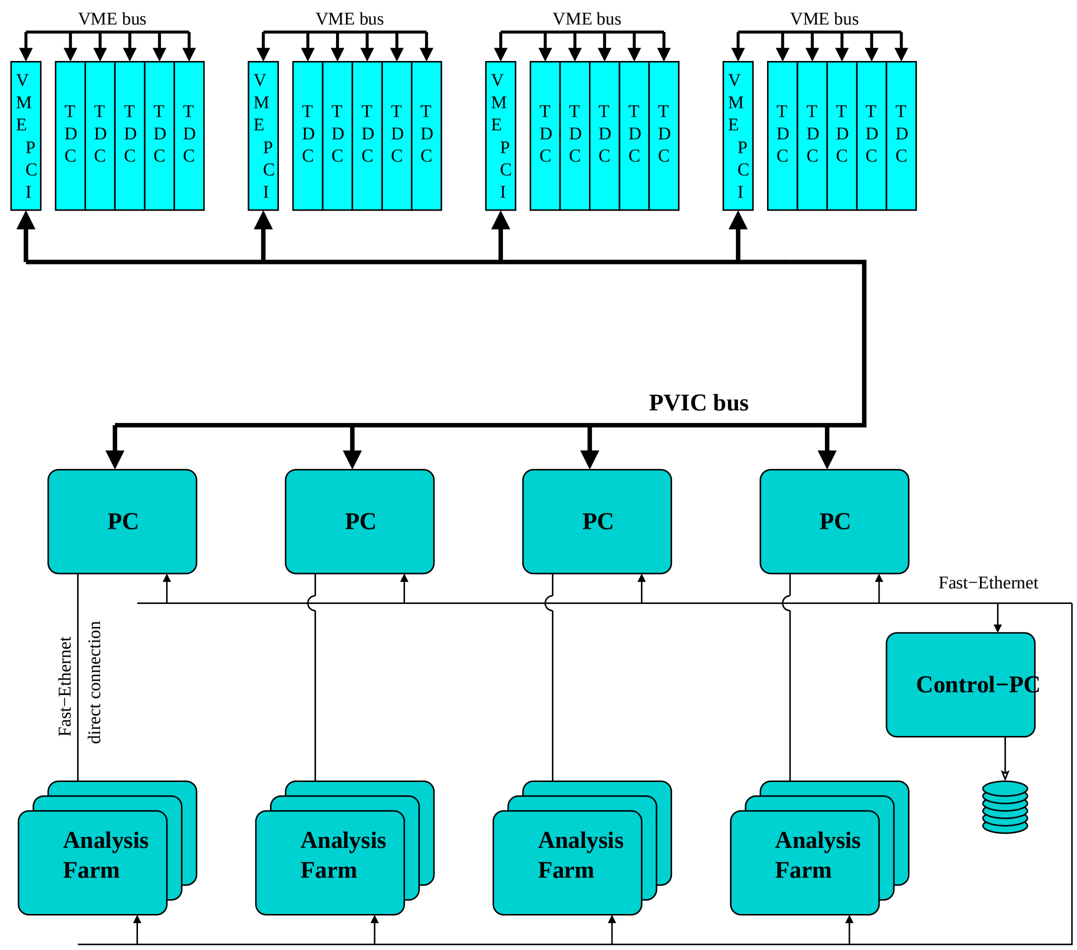
The calibration system, integrated into the external cage, allows to flash single channels. The flasher is driven by a VME programmable unit

Involvement of UniGe

The DAQ system: from TDC to PC's

A commercially available CPU-less solution has been adopted for the VME system:

- PVIC= PCI to VME Intercrate Connection: a desktop PC is used as a remote CPU for accessing VME addresses
- High PCI data rate → 80 MBytes/s
- High VME data rate (tested in lab.) → 18MBytes/s/crate
- 4 VME crates + 4 controller PC's are sufficient



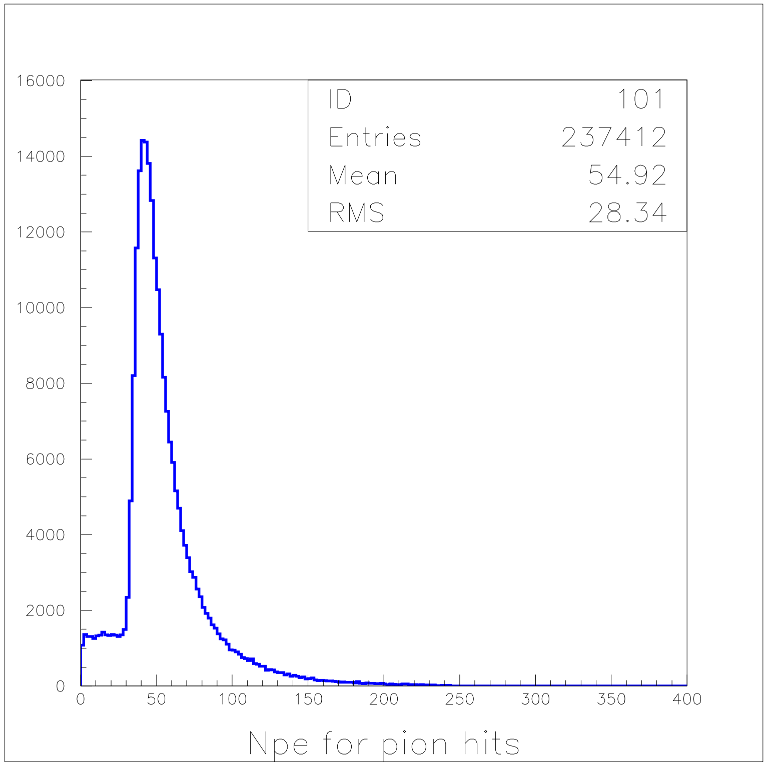
Involvement of UniGe

Simulation:

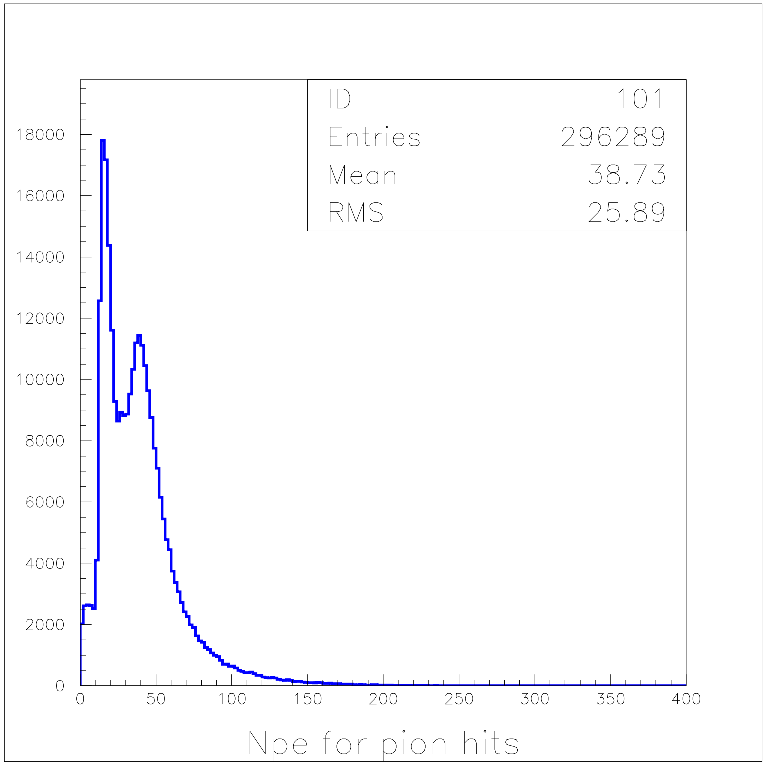
a full GEANT simulation has been adapted to the new geometry and design (scintillating fibers → baguettes).

The fibers topology is optimized to reduce dead space and detection inefficiencies:

Scintillating fibers (old)



Scintillator baguettes (new)

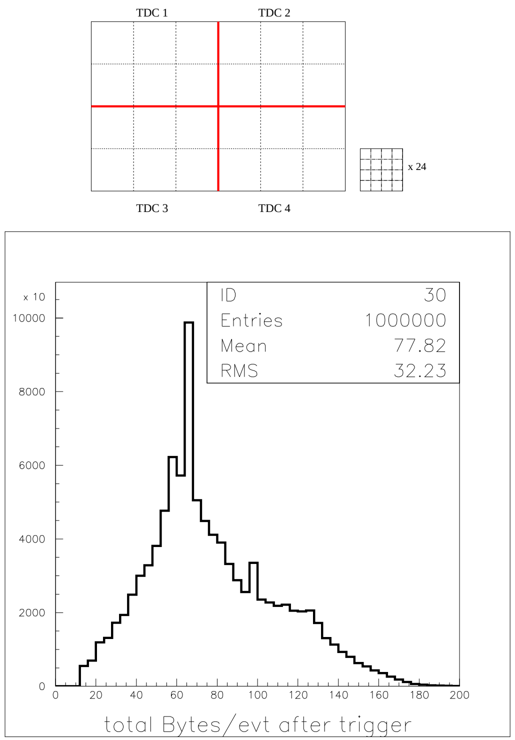


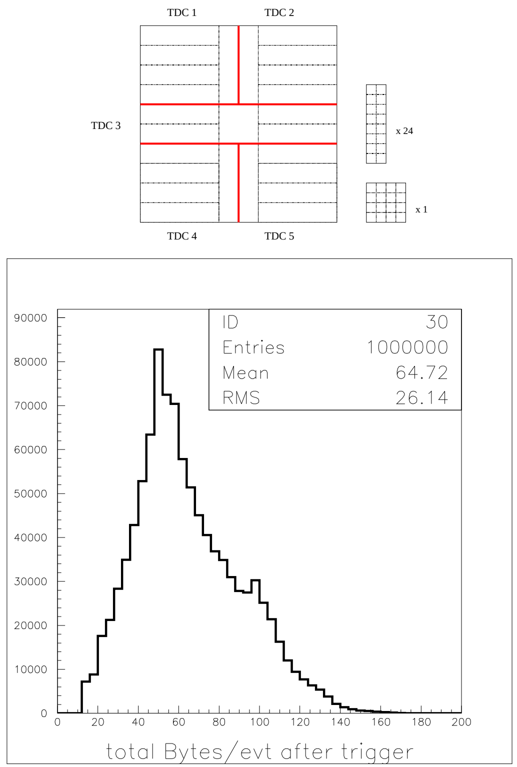
Involvement of UniGe

Simulation:

Also the readout structure has been optimized, according to simulations, to reduce the data rate.

The reduction is obtained reading out only the "interested TDC" and keeping high the TDC specific occupancy:





What is there/ What is left

Item	Responsibility	Availability
Baguette/clear fibers detector	UniGe	10/2002
Position sensitive phototubes	UniGe + NIKHEF	✔
Calibration system	UniGe	10/2002
Support Structure	UniGe + PSI	10/2002
Beam and related electronics	PSI	✔
Double Threshold discr.	PSI	10/2002
Amplifier boards	PSI	10/2002
TDC + VME electronics	CERN	✔
Data acquisition (boards + PC)	CERN	✔
Software	CERN + UniGe	before data taking
Trigger	Freiburg/Rome ?	✗

A preliminary trigger design was developed by an INFN-Bologna group who had to step down. Looking for alternative solutions.

Trigger requirements: give the pion stopping coordinate in ~ 100 ns.

Timing

First milestone met at the end of year 1998: test-beam at PSI

- Check feasibility studies
- 1/10 of the detector with several configurations
- Low intensity
- Check fibers, PSPM and TDC's behaviors

After then:

	Date	Activity
✔	2000 (1^{st})	Experiment approved at PSI
✔	2001 (1^{st})	Prototype tests, re-design of DAQ
	2002 (3^{rd})	System integration tests at PSI
	2003 (2^{nd})	Installation and Check-out
	2003 ($3^{rd}/4^{th}$)	Data taking

Conclusions

- FAST aims to measure with 10 times better accuracy than the present world average the Fermi coupling constant G_F
- Major challenges:
  - stability and data rate: from a 0.008 m^3 detector, a LHC detector equivalent throughput has to be handled $\rightarrow$ a test bench for new generation experiments
  - very subtle systematic effects have to be sorted out
- Feasibility established in simulation and test beams
- *Despite the low resources, UniGe plays a leading role in all aspects.*