2007 Europhysics Conference
on High Energy Physics
Manchester 19-25 July 2007

INFN
Istituto Nazionale di Fisica Nucleare

The design of the MICE time of flight

MICE Collaboration

M. Bonesini

INFN, Sezione di Milano Bicocca - Dipartimento di Fisica G. Occhialini

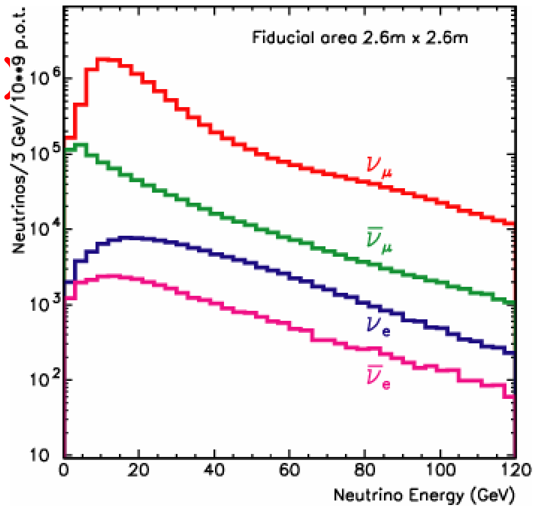
Milano Italy

Outline

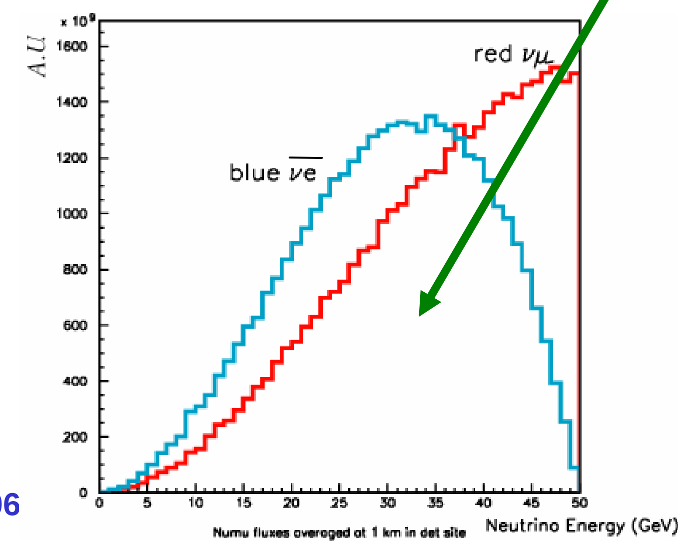
- Introduction
- Towards a Neutrino Factory
- The MICE cooling expt
- The design of MICE TOF
- Conventional and fine-mesh PMTs tests
- BTF testbeam results
- Conclusions

ν beams: conventional and nufact beams

WANF (conventional)



Nufact

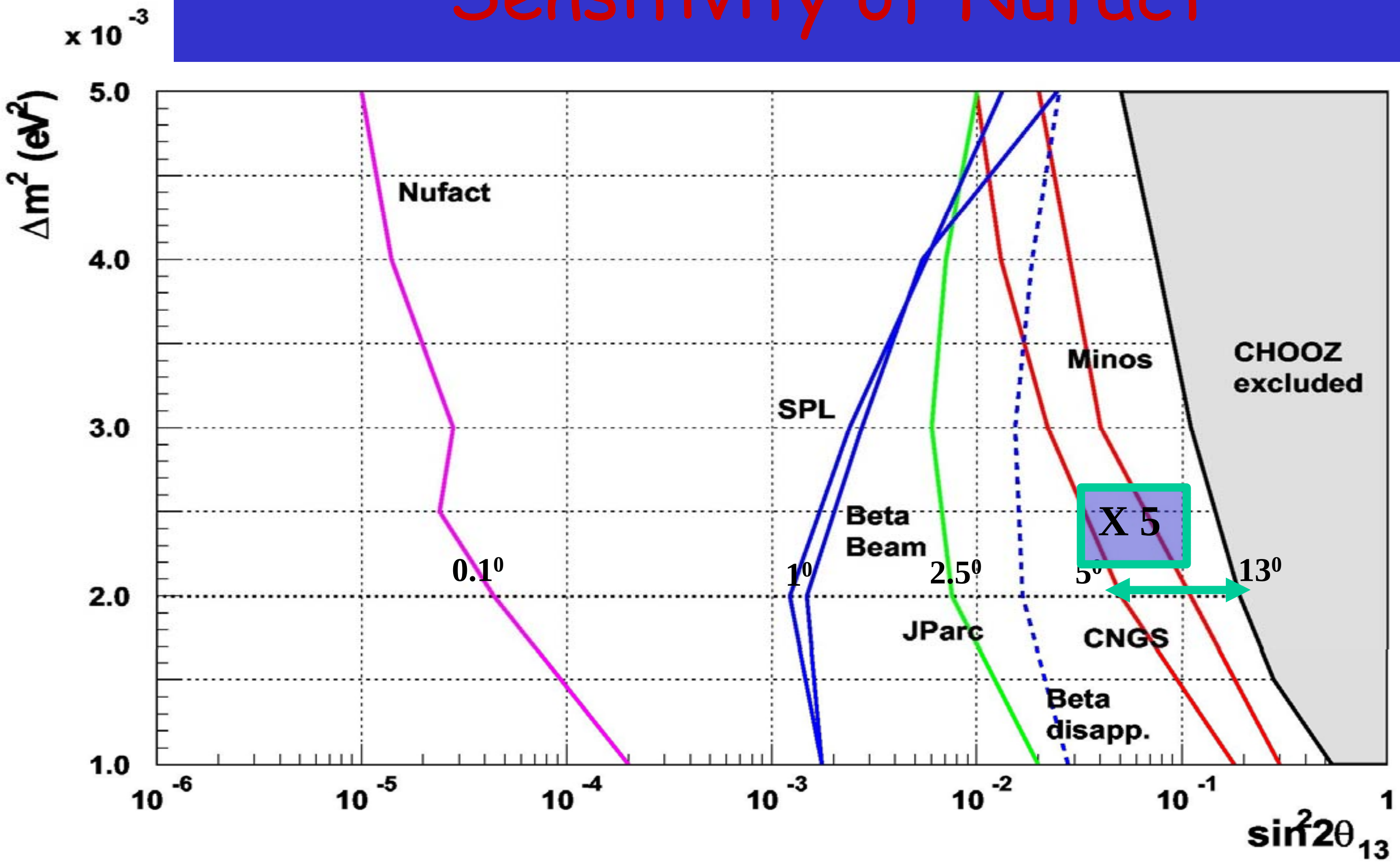


- Problem in conventional beams: a lot of minority components (beam understanding)
- Following muon collider studies, accelerated muons are ALSO an intense source of "high energy" ν

$$\mu^- \to e^- \nu_\mu \bar{\nu}_e \qquad \mu^+ \to e^+ \bar{\nu}_\mu \nu_e$$

- Crucial features
  - high intensity (x 100 conventional beams)
  - known beam composition (50% ν_μ 50% ν_e)
  - Possibility to have an intense ν_e beam
- Essential detector capabilities: detect μ and determine their sign

Sensitivity of Nufact



M. Mezzetto

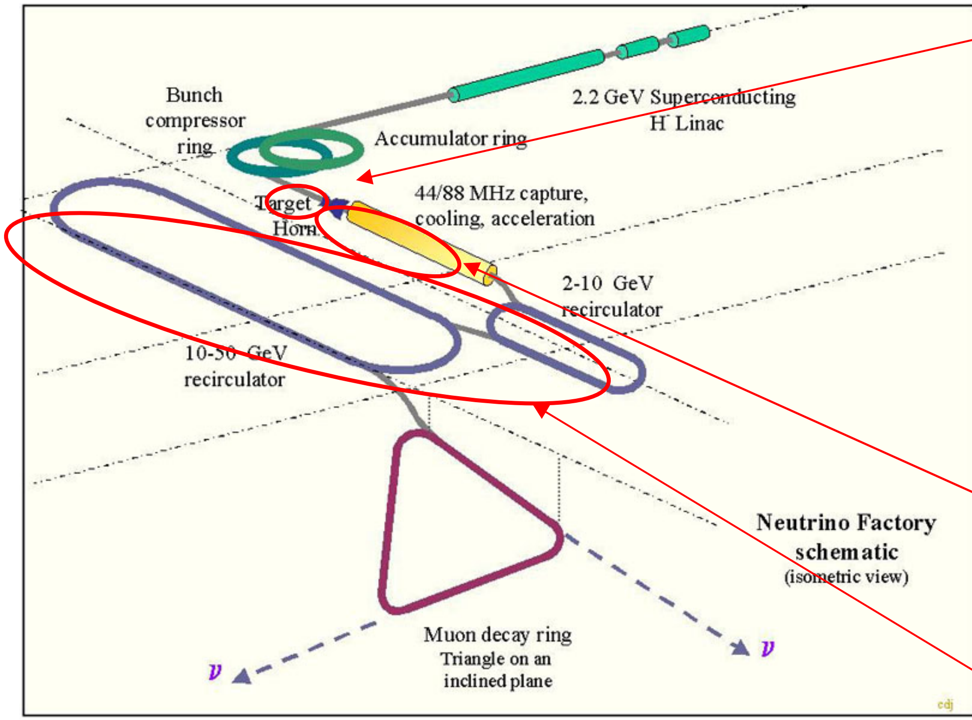
present limit from the CHOOZ experiment

0.75 MW JHF to super Kamiokande with an off-axis narrow-band beam,

Superbeam: 4 MW CERN-SPL to a 400 kt water Cerenkov@ Fréjus (J-PARC phase II similar)

Neutrino Factory with 40 kton large magnetic detector.

Towards a Neutrino Factory: the challenges



- **Target and collection (HARP/MERIT)**
  - **Maximize π^+ and π^- production**
  - **Sustain high power (MW driver)**
  - **Optimize pion capture**

  INTENSE PROTON SOURCE (MW); GOOD COLLECTION SCHEME
- **Muon cooling (MICE)**
  - **Reduce $\mu+/\mu-$ phase space to capture as many muons as possible in an accelerator**
- **Muon acceleration**
  - **Has to be fast, because muons are short-lived !**

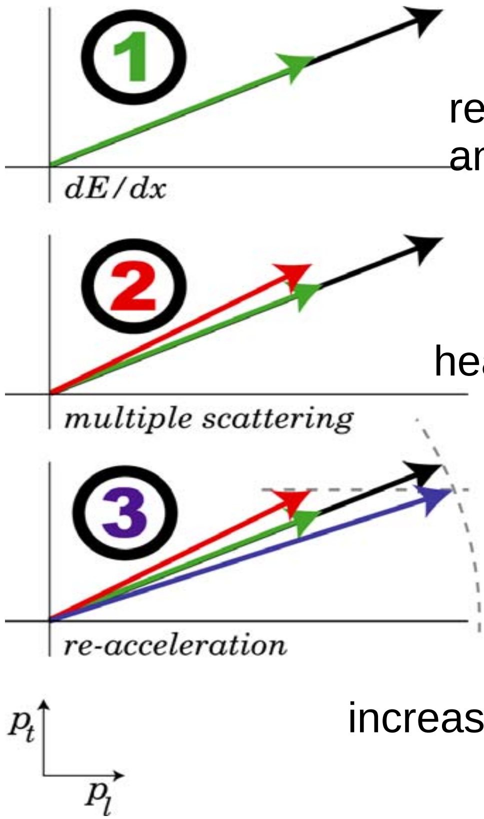
  (RLA, FFAG, …)

Muon ionization cooling

Stochastic cooling is too slow.

A novel method for μ+ <u>and</u> μ- is needed: **ionization cooling**

principle

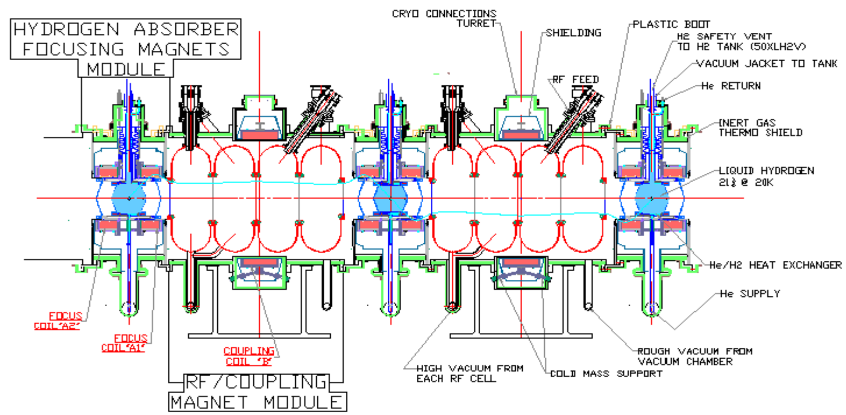


reduce p_t and p_l

heating

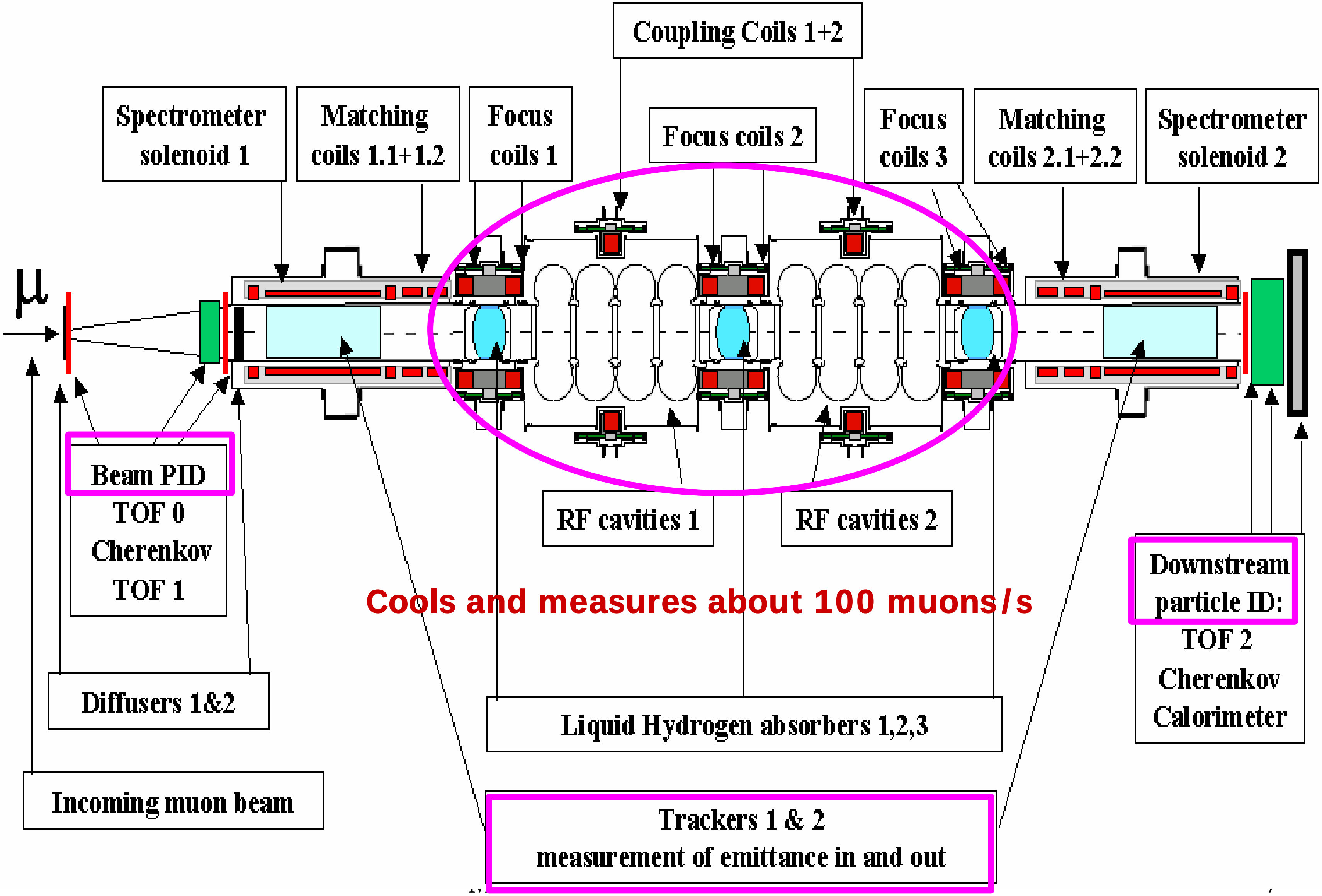
increase p_l

reality (simplified)



- Build a section of cooling channel long enough to provide measurable cooling (10%) and short enough to be affordable and flexible
- Wish to measure this change to 1%
- Requires measurement of emittance of beams into and out of cooling channel to 0.1% !
- Cannot be done with conventional beam monitoring device
- Instead perform a single particle experiment:
  - High precision measurement of each track (x,y,z,px,py,pz,t,E)
  - Build up a virtual bunch offline
  - Analyse effect of cooling channel on many different bunches
  - Study cooling channels parameters over a range of initial beam momenta and emittances

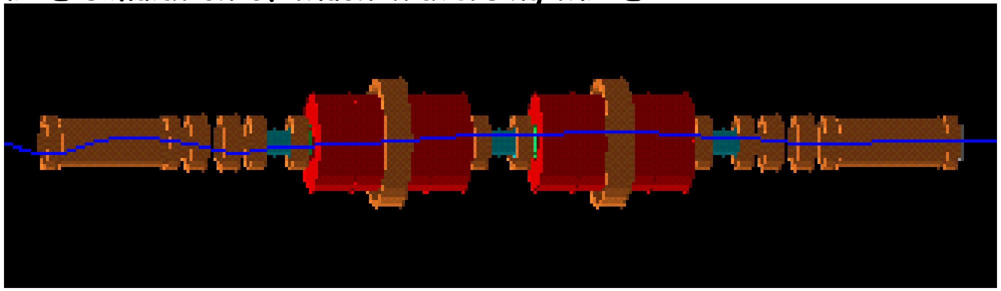
MICE setup: cooling + diagnostics



Cools and measures about 100 muons/s

Muon Emittance measurement

G4MICE simulation of Muon traversing MICE



Each spectrometer measures 6 parameters per particle
x y t $x' = dx/dz = P_x/P_z$ $y' = dy/dz = P_y/P_z$ $t' = dt/dz = E/P_z$

Determines, for an ensemble (sample) of N particles, the moments:
Averages $\langle x \rangle$ $\langle y \rangle$ etc…
Second moments: variance(x) $\sigma_x^2 = \langle x^2 - \langle x \rangle^2 \rangle$ etc…
covariance(x) $\sigma_{xy} = \langle x.y - \langle x \rangle \langle y \rangle \rangle$

Covariance matrix

$$M = \begin{pmatrix} \sigma_x^2 & \sigma_{xy} & \sigma_{xt} & \sigma_{xx'} & \sigma_{xy'} & \sigma_{xt'} \\ \dots & \sigma_y^2 & \dots & \dots & \dots & \sigma_{yt'} \\ \dots & \dots & \sigma_t^2 & \dots & \dots & \sigma_{tt'} \\ \dots & \dots & \dots & \sigma_{x'}^2 & \dots & \sigma_{x't'} \\ \dots & \dots & \dots & \dots & \sigma_{y'}^2 & \sigma_{y't'} \\ \dots & \dots & \dots & \dots & \dots & \sigma_{t'}^2 \end{pmatrix}$$

Getting at e.g. $\sigma_{x't'}$ is essentially impossible with multiparticle bunch measurements

Evaluate emittance with:

$$\varepsilon^{6D} = \sqrt{\det(M_{xytx'y't'})}$$

$$\varepsilon^{4D} = \sqrt{\det(M_{xyx'y'})} = \varepsilon_\perp^2$$

Compare ε^{in} with ε^{out}

TOF station requirements

- Exp trigger, upstream/downstream PID and measure of t vs RF
- Work in a harsh environment (high incoming particle rate, high fringe fields from solenoids, X rays from converted e^-)

with good timing performances ($\sigma_t \sim 50$ ps)

Tof resolution can be expressed as:

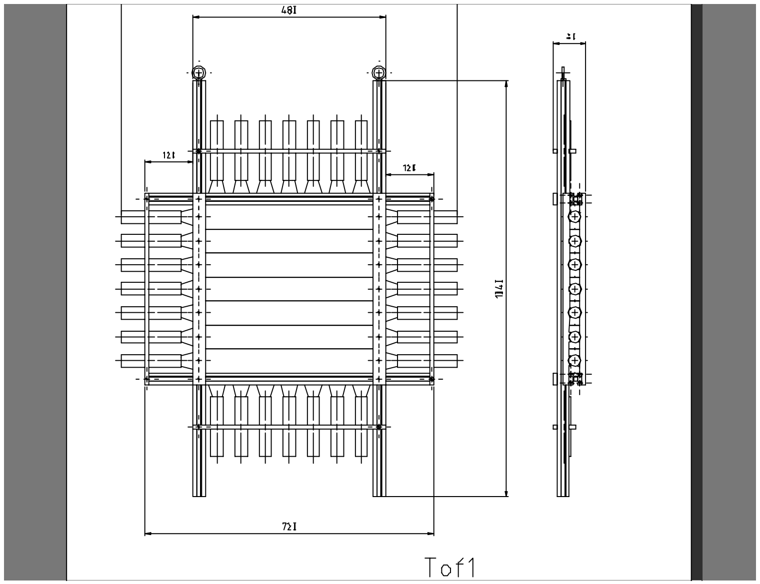
$$\sigma_t = \sqrt{\frac{\sigma^2_{scint} + \sigma^2_{PMT} + \sigma^2_{pl}}{N_{pe}} + \sigma^2_{elec}}$$

→ **Some points to look to have high resolution TOFs**

- σ_{pl} **dominated by geometrical dimensions $\sim\sqrt{(L/Npe)}$**
- $\sigma_{scint} \sim$ **50-60 ps (mainly connected with produced number of γ's fast and scintillator characteristics, such as risetime)**
- σ_{PMT} **PMT TTS (typically 150-300 ps)**

+ ENVIRONMENT

TOF design



- "conventional" X/Y scintillator structure with readout at both ends, to provide redundancy & intercalibration with inc. μ
- problem: choice of PMTs for high incident particle rate (1 MHz) and solenoid B fringe field

$B_{//}$ ~ 200-300 G, B_{perp} ~ 1K G

Studies with fast conv. PMTS or fine-mesh PMTs

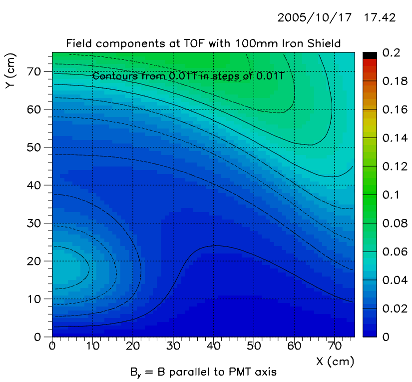


Figure 4: $B_{\parallel}$ at the position of TOF2 with the 100 mm iron shield.

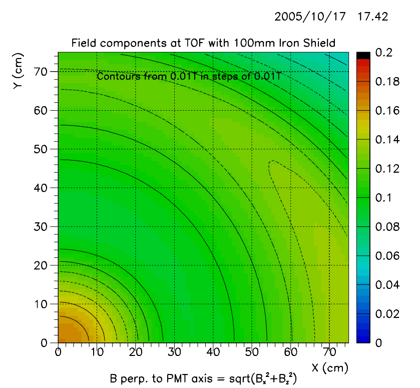
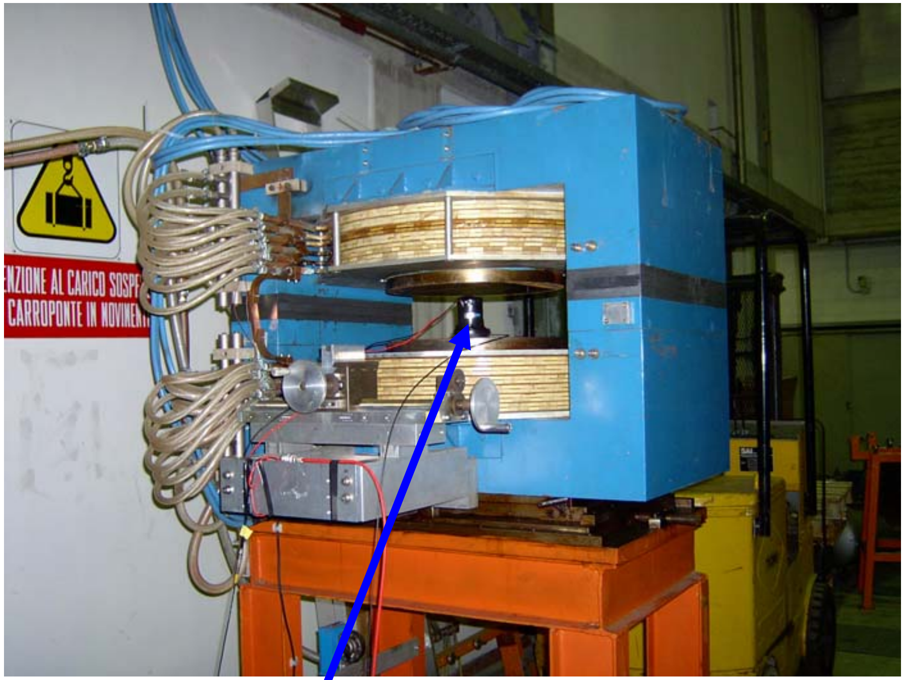


Figure 5: $B_{\perp}$ at the position of TOF2 with the 100 mm iron shield.

Exp. setup for PMT test: extensive studies



PMT under test

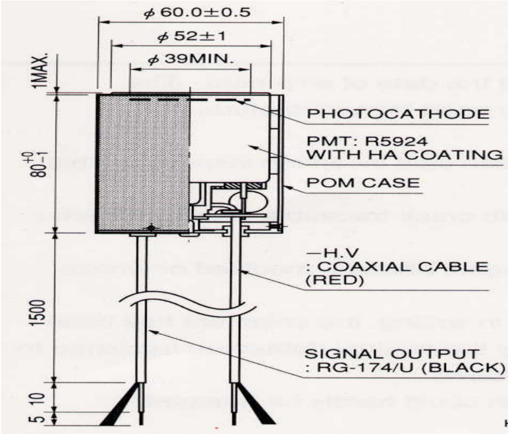
- Light source: Hamamatsu fast PLP-10 laser ($\lambda \approx 405$ nm, FWHM 60 ps, 250 mW peak power)
- Optical system: x,y,z flexure movement + lenses/ filters to inject light into a CERAM/OPTEC multimode fiber (spread 15 ps/m)
- Optical signal 1-2000 p.e., in most tests 200- 300 p.e. (compatible with a MIP crossing a typical scintillator)
- Light monitor with a laser powermeter

Gain, timing and rate measurements for 1”, 1.5”, 2” fine-mesh PMTs and conv R4998 PMTs

VME acquisition with TDC, QADC measurements (P.H. + timing)

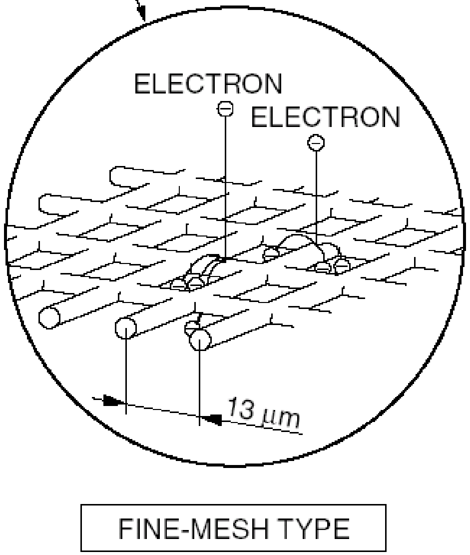
PMTs tests: Fine Mesh Photomultiplier Tubes

- **Secondary electrons accelerated parallel to the B-field.**
- **Gain with no field: 5 x 10 ^{5} - 10 ^{7}**
- **With B=1.0 Tesla: 2 x 10^{4} - 2.5 x 10 ^{5}**
- **Prompt risetime and good TTS**
- **Manufactured by Hamamatsu Photonics**

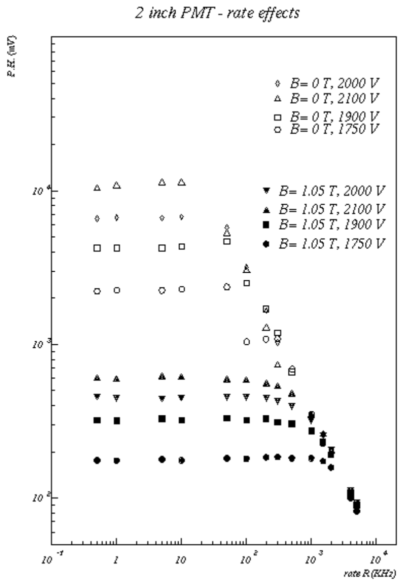


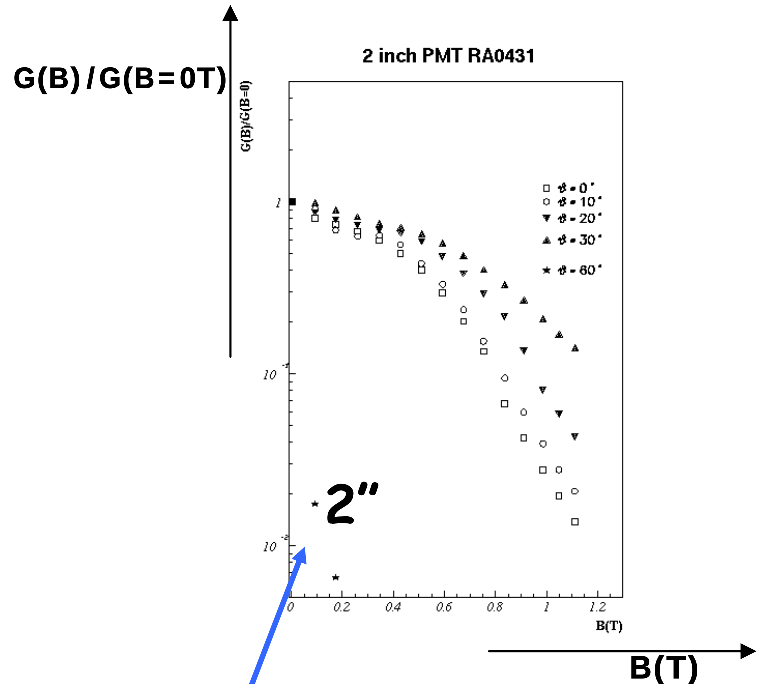
Measures at INFN LASA laboratory to study behaviour in B field (up to 1.2 T) as respect to gain, rate capability, timing

	R5505	R7761	R5924
Tube diameter	1”	1.5”	2 “
No. Of stages	15	19	19
Q.E.at peak	.23	.23	.22
Gain (B=0 T) typ	5.0 x 10 ^{5}	1.0 x 10 ^{7}	1.0 x 10 ^{7}
Gain (B=1 T) typ	1.8 x 10 ^{4}	1.5 x 10 ^{5}	2.0 x 10 ^{5}
Risetime (ns)	1.5	2.1	2.5
TTS (ns)	0.35	0.35	0.44



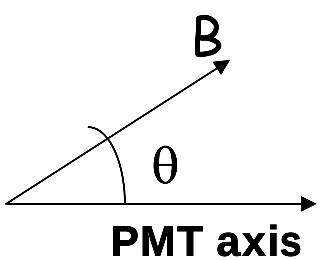
Rate effects (as a function of HV)
Gain in B field (various orientations)





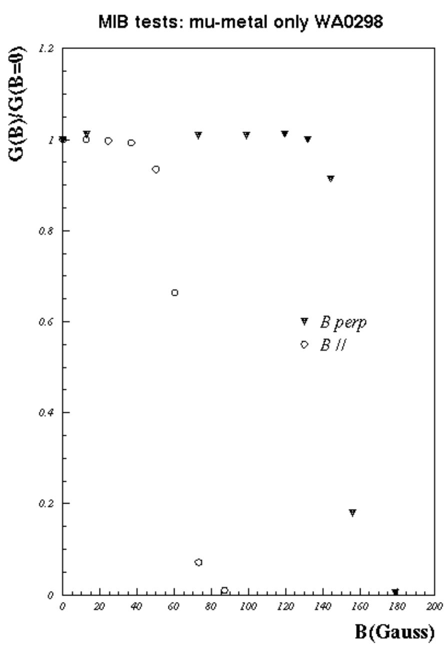
- **rate capability is limited by max anode mean current (tipically 0.1mA for a 2" R5924 PMT)**
- **With very high particle rates: try to reduce mean current**

θ > critical angle

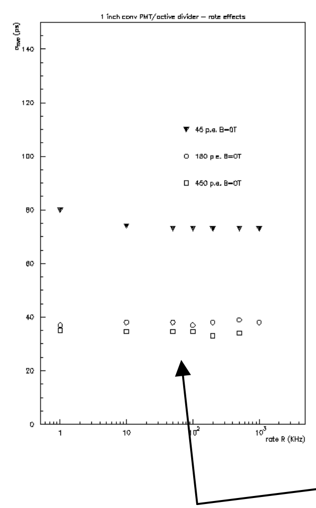


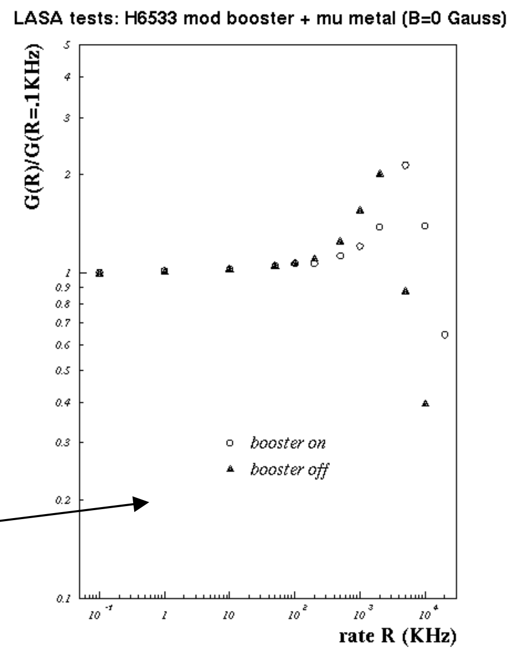
Use instead conventional PMTs: lower cost, better support from Hamamatsu

- Shielding issues: local or global shield (cage)
- Rate issue (active divider or booster)

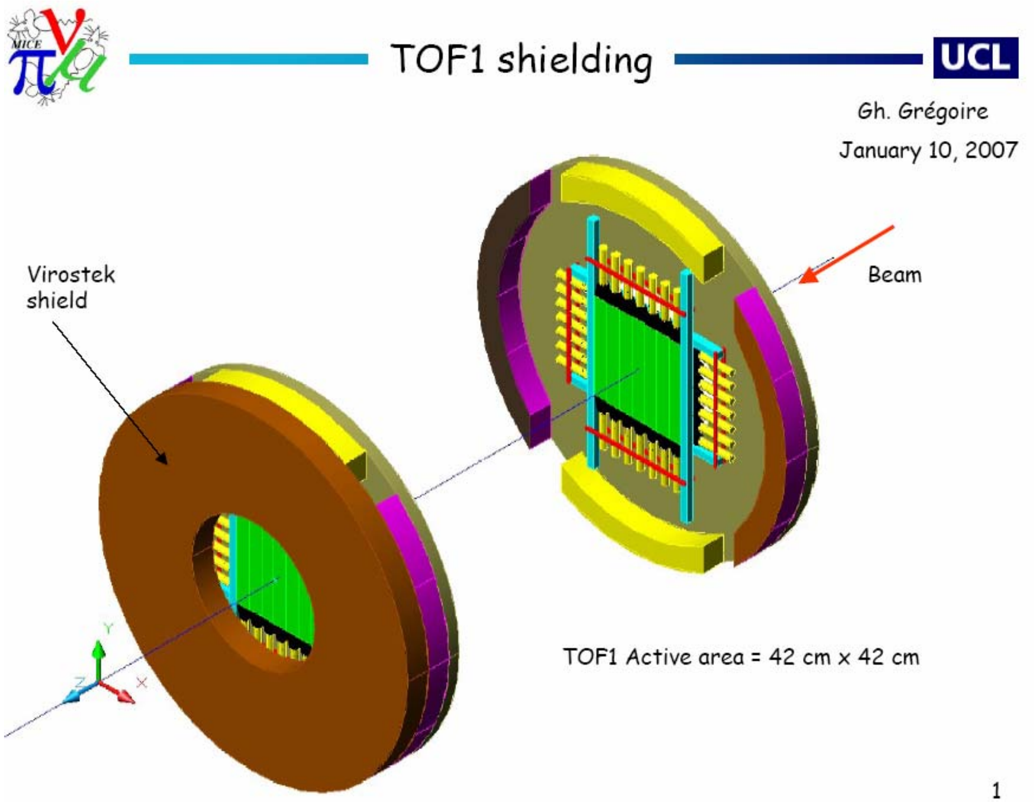


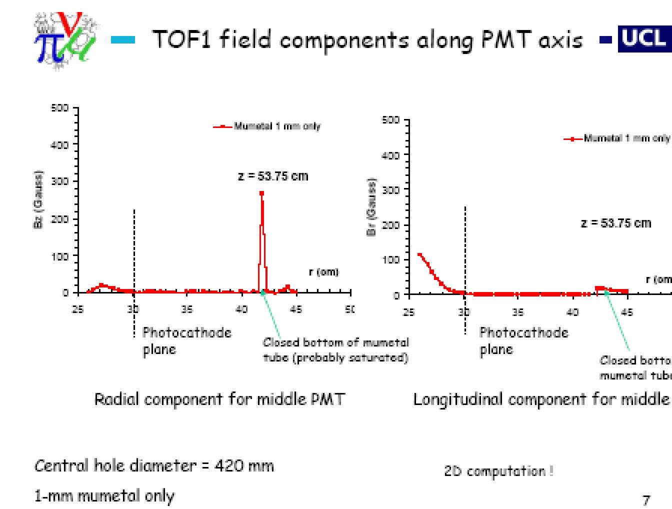
Shielding issue





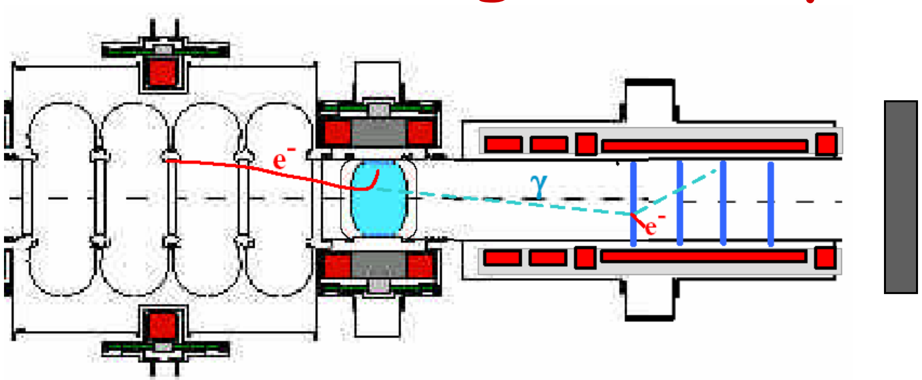
Rate issues

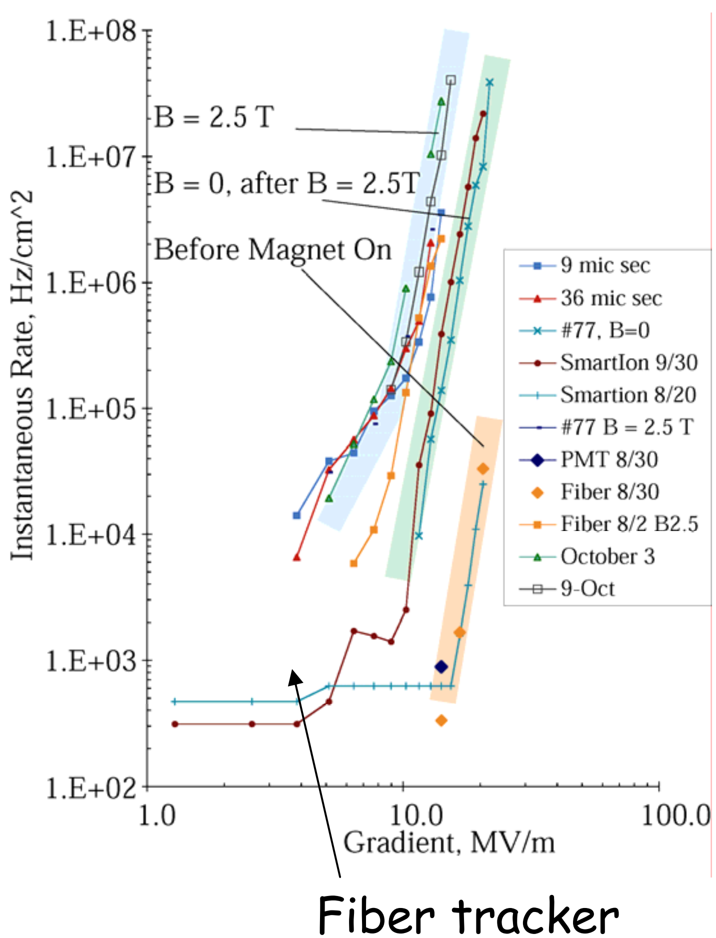




With an external cage B field is reduced to tolerable levels for conventional R4198 PMTs

RF background: yet another problem

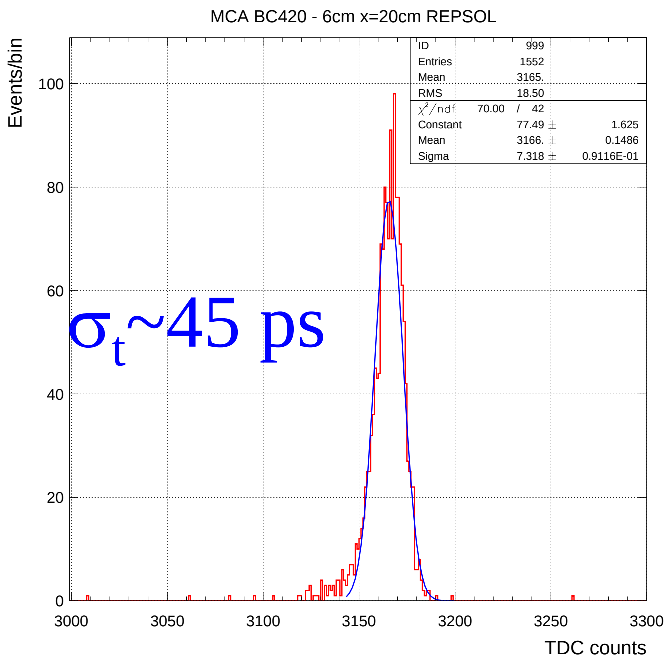




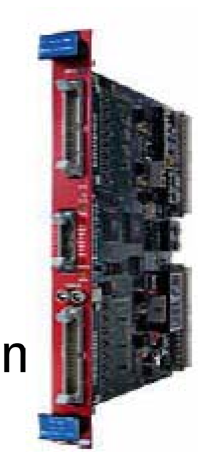
- **RF cavities produce electron due to field emission**
    - converted to x-rays in absorbers
    - causing backgrounds in trackers and TOF stations
    - in phase with muons we want (peak at RF crest)
- **Emission rate rises very steeply with electric field and magnetic field (1.5-2.5 t at MICE cavity location)**
- **test problem with MTA setup at FNAL**
- **rates: ~26KHz/cm^2 for 8 MV/m at B=0 at 4.5 m f rom RF cavity, with energy deposit ~ 400-600 KeV (for a MIP ~5 MeV)**

BTF testbeam

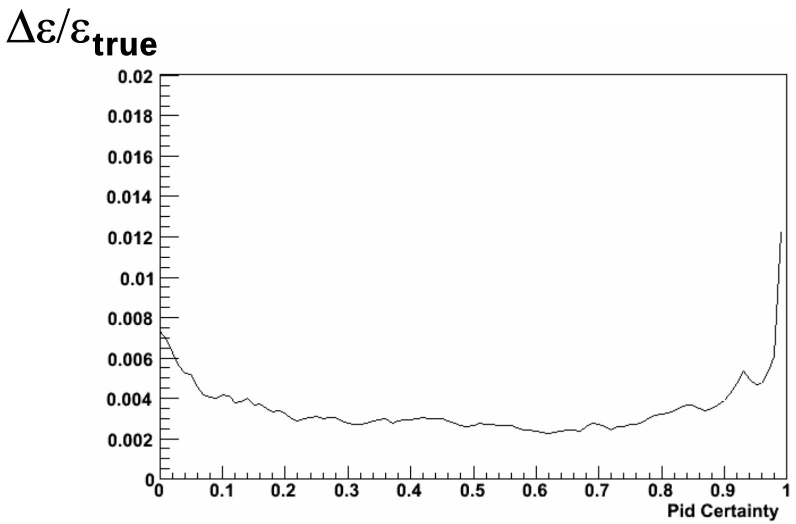
Energy range	25-750 MeV e^-/e^+
Max rep rate	50 Hz
Pulse duration	10 ns
Current/pulse	$1-10^{10}$ particles



- tests with e at BTF LNF
- different scintillator and PMTs used : best BC4040 or BC420 + R4998 PMTs
- fast MCA analysis
- Similar results with final electronics (new caen V1290 TDC and V1724 FADC +custon splitter/stretcher)



PID downstream: TOF2 inside MICE



Upstream:

- **TOF0/1 with 10m path, ~60 ps resol.**
- **Cherenkov**

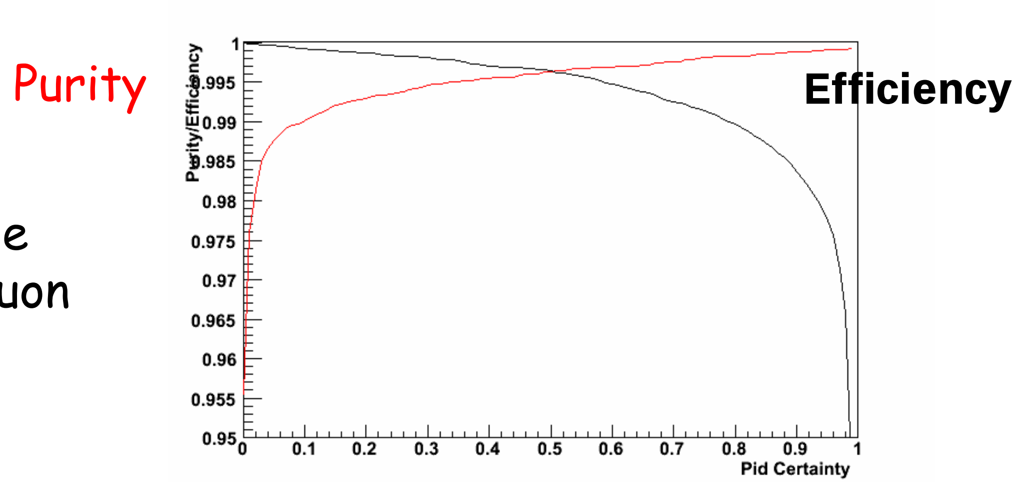
π/μ separation at better than 1% at 300 MeV/c

Downstream:

.5% of μ's decay in flight: need electron jection at 10^{-3} to avoid bias on emittance reduction measurement

- **TOF2 hodoscope**
- **Calorimeter for MIP vs E.M. Shower**

- *Underestimating* **downstream emittance by about 2-3 per mil**



"PID Certainty" *estimate* of the probability that a particle is a muon (0 definitely not a muon)

Conclusions

- “conventional” scintillator based TOF stations
- in an “unconventional” environment: high particle rate, B fringe fields, X-rays from converted e from RF
- needs a lot of tests for components
- soon to work in MICE experiment

- Acknowledgements: many thanks to the MICE TOF team and in particular to R. Bertoni, J.S. Graulich, Y. Kharadzhov, R. Sandstrom, G. Ghislain and J. Cobb