Overview
of
MICE detectors

MICE Collaboration Meeting
Friday 8 Feb 2002, Illinois Institute of Technology

V. Palladino
for the task force on Detectors

Goal of detector system

Measure precisely enough

all parameters ... in and out

\[ X, Y, P_x, P_y, P_z, t \text{ in} \]
\[ X, Y, P_x, P_y, P_z, t \text{ out} \]

of each muon of a sample

large enough

..... to measure an order 1 % reduction

of muon emittance

\[ 1 - R = 1 - \frac{\varepsilon_{\text{final}}}{\varepsilon_{\text{in}}} = \text{few to 20 %} \]

beam \[ T_\mu \text{ typically 200 MeV (}P_\mu \text{ 280 MeV/c)} \]
spread \( \pm 10\% \)
50 mm* 200 mrad rms emittance in each proj.
Experimental Layout

$B_{\text{sol}} \sim 3-5 \text{ T}$

$4 \times X_0$

beam preparation

$.1 \times X_0$ incoming muon beam

4-cell RF cavities

Spectrometer trackers II

Experimental Solenoid II

TOF II

Coupling coil

Focusing coils

Experimental Solenoid I

Spectrometer trackers I

Diffusers

TOF I & II

$t_{\text{out}}$

$p_{\text{out}}, x_{\text{out}}$

$p_{\text{in}}, x_{\text{in}}$

$t_{\text{in}}$

$\mu$-id (TOF)

$2 \text{ m}$

$6 \text{ m}$

$2 \text{ m}$

$10 \text{ m}$

Figure V.1: Overview of the International Muon Ionization Cooling Experiment (top view)

300 mm diameter

up to $10^7 \mu$/sec
Emittance Measurement: Improvement (I)

- The previous (minimal) design leads to reconstruction ambiguities for particle which make – a full turn between the two plates (only two points to determine a circle).

- It also leads to reconstruction efficiencies and momentum resolutions dependent on the longitudinal momentum, which bias the emittance measurements.

Solution: Add one plate, make the plates not equidistant

\[ \chi^2_{\rho_T} = \sum_{i=1}^{4} \left[ \frac{(x_i - x_0 - R \cos \phi_i)^2}{\sigma_i} \right] + \left[ \frac{(y_i - y_0 - R \sin \phi_i)^2}{\sigma_i} \right]^2 \] and \[ \chi^2_{\rho_Z} = \sum_{i\neq j} \left( \frac{R \Delta \phi_{ij} - \frac{p_T}{p_Z} \Delta z_{ij}}{\sigma_{R \Delta \phi_{ij}}} \right)^2 \]

To find \( p_T \) and \( p_Z \), minimize:

25-27 Oct, 2001

Beam Emittance Reduction Measurements
Summary of Detector requirements

π rejection <1%

.1 % at PSI: <10% in beam * <1% after TOF

TOF to ~70 ps or less

π/μ separation to 1% or better
timing wrt RF (5°/360°/200 Mhz=70 ps)

tracking

precision to ~200 μm/point

σ(P_μ) ~ few Mev/c
σ(θ_μ) ~ few mrad
σ(X_μ) ~ order 100 μm

robust to bkgnd x-rays from RF cavity

major worry, potential killer !!!!!!!!!!!

e rejection to <1%

need e-identifier beyond kin cuts (20%)

DAQ

up to few thousand muons/sec
(1% because of in-out correlation)
Trigger, timing and \( \mu \)-ID by TOF

Two planes, \( \sim 10 \text{ m} \) apart, in front
\( t_\pi - t_\mu \sim 1400 \text{ ps (280 MeV/c)} \)

One plane at the back

3-fold (2-fold) coincidence

Baseline: fast conventional scintillators
(Milano, Napoli, Padova)

10 1 cm*10 cm*2 cm thick BC-420
8 2.5cm*40 cm*2.5 cm BC-404
8 2.5cm*40 cm*2.5 cm BC-404

1 R4998 Hamamatsu PMT/slab/end
(20 mm diameter, 0.7ps rise, 160 ps transit)

see next
about 75 KEuros (+HARP)

Alternative: ultra-fast Cherenkov radiators
(Fermilab)

see next
about 100 KS
PAMELA TOF SYSTEM

40x4x0.7 cm$^3$ BC408 slabs

Can be improved with:

- Thicker slabs (0.7 → 2.5 cm)
- Faster plastic (BC408 or BC420)
- Faster PMT (R5900 → R4998)
Published resolutions of TOF systems based on plastic scintillators of similar dimensions

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Dimensions (cm)</th>
<th>Plastic</th>
<th>PMT</th>
<th>Resolution (ps)</th>
</tr>
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<tbody>
<tr>
<td>BESS</td>
<td>$95 \times 10 \times 2$</td>
<td>BC-408</td>
<td>R6504s</td>
<td>50</td>
</tr>
<tr>
<td>ISOMAX</td>
<td>$10 \times 2 \times 1$</td>
<td>BC-420</td>
<td>R2083</td>
<td>47</td>
</tr>
<tr>
<td>NA49</td>
<td>$8 \times 3.4 \times 2.5$</td>
<td>BC-408</td>
<td>XP2972</td>
<td>59</td>
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<tr>
<td>NA49</td>
<td>$48 \times 2.4 \times 2.5$</td>
<td>BC-408</td>
<td>R3478</td>
<td>70</td>
</tr>
<tr>
<td>NA52</td>
<td>$10 \times 1 \times 1$</td>
<td>NE110</td>
<td>XP2020</td>
<td>90</td>
</tr>
</tbody>
</table>
Ultra-High Precision TOF Detector based on Cerenkov Radiators
(A.Bross, Fermilab)

MgF2 Cerenkov radiator **disk perpendicular to the beam.**

CsI photocathode deposited on the back side of the MgF2 radiator.

Micro-channel plate (MCP) or micro-sphere plate structure amplifies up to $10^7$.

Anode structure with a 50 Ohm output connector maintains pulse fidelity.

For a **2 mm thick** radiator, expect a signal of 30-40 pc.

Preliminary measurements with the first detector head (33 mm diameter)

- very good pulse response.
- single pe initiated pulses rise time 300 ps
- rise time jitter between 15 and 30 ps
- In the initial phases of this work we have used

plan to test a **superconducting TDC** (4 ps least count)

for ICE,

- use a mosaic of micro channel plates for coverage
- anode segmentation ie # of TDC’s will follow from backgrounds rate

(commercially available) general purpose MCPs drive costs, about $25 USD/cm$^2$

(75 K$ for 30 cm diameter)

adequate for a 30 ps timing resolution
Note on $\mu$-ID

TOF adequate if beam clean
if not (RAL $\pi/\mu \sim$ several 10%?)

...dedicated Cerenkov system (Mississipi)

+ redundancy desirable...

**PROGRESS on MC SIMULATION of PID**

L. Cremaldi, P. Rubinov, D. Summers
U. MISSISSIPPI 5-15-99

- **MUUCOOL GEANT PID Simulation**
  - 1/2 mm - entrance window
  - 1.00 cm - fc-72 Cv radiator
  - 1/2 mm - quartz window
  - 30 cm - He gap
  - 1/2 mm - glass mirror
  - 1/2 mm - exit window

- $P_{inc} = 180$ MeV $\pi, \mu, e$ (No decays)
- $n = 1.244$ $\Delta z=1$CM OF C6F14 (PC72)
- Features:
  - $-\alpha/\lambda^2$ spectrum
  - $-Q(\lambda)$ PMT quantum efficiency
  - chromatic dispersion
  - $-T(\lambda)$ quartz transmission
  - 1/2 PE noise
- $<N_{Pe}> = 0.5/cm \pi$
- $<N_{Pe}> = 18/cm \mu \varepsilon_{\mu} = .98 \rightarrow r_e \mid sid = 4 \times 10^{-3}$, $r_\mu \mid sid < 10^{-5}$
- $<N_{Pe}> = 45/cm e$

- NEAR FUTURE- DECAYS IN FLIGHT
  REFINEMENT OF CONSTANTS
Detector Solenoids

$L \geq 1 \text{ full turn}$ of helix, at typical muon momenta

(1 m for 200 MeV/ν at 3 T)

$L + 2D$ for uniformity .... 2 meters or so

NB uniformity non crucial

(1% ok, mostly CPU wise)

diameter $D$

single coil ....... take signals out

... bend radius $\sim$100 fiber radius

bore $D$ up to $\text{600 mm}$

J. M. Rey

split coils, feedtroughs ?

bore of somewhat smaller $D$

Stray fields ..... flux return, in fact !!!

Lab safety

Readout (PMT's ..... open ......
Tracking in the solenoids

>3 stations for x, θ, P

as thin as possible \( \theta_{MS}/\theta_{COOL} \leq 10\% \)
min X-ray conversion

0.4 % \( X_0 \sim 1.5 \) mm plastic Sci
(last plane!)

fast (well below 100 ns)

robust to RF X-rays (major scare !!!!!!)

two options in L0I

1D (SciFi)

**MUSCAT like SciFi's** (multiplex)
+MAPMT's \( \sim 700 \) K$
see E. Mc Kigney
(1 College, RAL, Thesio)

**D0** like SciFi's
+VLPC's \( \sim 1000 \) K$
see A. Bross (Fermilab)

2D (pixels) at least station closest to RF?

\( \leq 2 \) um, 300 \( \mu \)m thick
ALICE-like (P. Jarron) \( \sim 1400 \) K$
...not quite mature yet...
(Geneva, EPFL, Strasbourg)

recently TPG (TPC+GEM) being revisited
see U. Gastaldi
ALICE pixel ladder

ALICE silicon pixel ladder

Consists of 5 readout chips bumped on a silicon detector of 70.72 mm x 16.8 mm
detector thickness: 150 micron - thinned
chip thickness: 200 micron - thinned
Octagonal construction

based on ALICE pixel Stave: diameter 29 cm

To Daq

10/25/2001
Conclusions

- 3 solutions of Muon Cooling Project tracking system
  - ALICE pixel based
    - ready made solution no development
    - thick: not the best for minimum radiation length and X-ray rejection
    - 20% dead area
  - MCM-D ALICE based
    - 100% full coverage
    - uncertain technology development
    - thick: not the best for minimum radiation length and X-ray rejection
  - A-Si:H layer on VLSI wafer
    - the best possible X-ray rejection
    - offers the hardest detector
    - technology not mature
  - RF cavity test
    - Proposal to use MEDIPIX (already used for CLIC test)
      - Contact M. Campbell, B. Mikulec EP-MIC-FE
e- identification

needed

\( <P_\mu> > <P_e> \)

\( <\theta_\mu> < <\theta_e> \)

\( <\chi^2_\mu> < <\chi^2_e> \)

but \( \sim 20\% \) e survive

size

\( \sigma_\mu \sim \sigma_e \sim 60 \text{ mm at the end} \)

Cerenkov (\( \sim 1\% \))

viable ... low \( \beta_e \) ... low c/n ...
... but \( \beta_\mu \) stays below it
\( n-1 = 0.005 \) already ok (1-3 m)

(Greece, Trieste) Louvain

Pb-Sci em calo (<1%) 
also viable ... long. & transv. profiles
... deposit
(Rome)

30-50 K$ for either device
Identification strategy

- Particle properties as obtained by P. Janot fast simulation
  - Simulation features as described on Thursday 25th
  - ~10000 muons
  - ~4000 electrons

- Kinematical properties
  - Transverse position distribution $\sigma_x = \sigma_y \approx 6$ cm
  - Momentum and direction from the fast simulation (P. Janot)

- Electron and muon spectra
  - Due to the big mass difference, beta for muon and electrons is not overlapping
  - A threshold cherenkov detector seems appropriate
Electron identification

- Detector response
  - Quantum Efficiency QE=15%
  - Collection efficiency 80%
  - Poisson fluctuations

Scan of refractive indices
- \( n = 1 \Rightarrow 10^{-1} \)
- Corresponding to gaseous radiators
  - Nitrogen taken as a reference

Muons have an effective threshold of \( n = 1.06 \)
- Ckov effect negligible for most of the points

Electrons vary from a few photoelectrons (@ low \( n \)) up to about 1 thousand of ph.el. (@ \( n = 1.1 \))

Electron identification
- Detection of \( \geq 3 \) ph.el

Electrons mis-identification probability

\( n = 1.005 \)
\( \text{N}_2 @ 17 \text{ bar} \)

length 1 m
Some design ideas

- Just after the channel
- After the TOF
- One Phototube option
- Inside the channel?
- Before the TOF
**electromagnetic calo**

Fig. a: The Construction Technique of KLOE EmCal

- Density $\approx 5 \text{ g/cm}^3$
- Sampling fraction for mip $\approx 15\%$
- Radiation length $\approx 1.5 \text{ cm}$

- Scintillating fibres
- Lead

- Pb-SciFi (1mm) a la KLOE

- e/$\mu$ separation from range/profiles & deposit
- $48\text{cm} \times 48\text{cm}$ $16\text{ cm}$ thick (full containment)

- deposit linear with kin. energy
  - $1 \text{ mip} = \mu = 27 \text{ MeV}$ electron

- can tell e, if not too soft
  - up to $300 \text{ MeV}$ or so

- expect $<1\%$ e survival
DAQ, rates etc (at PSI)

50 MHz p from cyclotron \( < 5 \times 10^7 \) p/s

run at .1 \( \mu /p \)

RF-on duty cycle \( \sim 5 \times 10^{-3} \)

a) 100 \( \mu \)s live @ 50 Hz
b) 500 \( \mu \)s live @ 10 Hz

\( \sim 20\% \) \( \mu \) “in time” with RF
\( \sim 20\% \) \( \mu \) within channel

\( < 1000 \) “events”/sec

\( \sim 1\% \) on \( \epsilon_{\text{final}} \) in seconds

\( \sim .1\% \) \( \epsilon_{\text{in}} \) in minutes
DAQ... continued

most data from trackers

multiplexed MUSCAT option
0.5 Kbytes/event

⇒ present design
(6 VME crates, event-building
over switched Gbit-Etherne Network)
can take up to $10^5$ events/sec

.. quite a margin ...

TDC's, ADC's add little

but buffers limited, favour 100 µs live @ 50 Hz

100 KS for computer cluster
220 KS for readout hardware

... rent? ... re-use? ...

No road stoppers in sight
Conclusion

baseline detector scheme exists

with few alternatives and variants

X-ray answers eagerly expected

revisit .... while deciding

host beam
background condition
solenoid design
stray B fields

.................

not a driving cost ... 1200-1900 $ or £