TPC readout with Micromegas

Vincent Lepeltier
LAL, Orsay, France

outlook:

- Micromegas TPC for the ILC
  - Micromegas
  - how to improve the spatial resolution?
  - cosmic rays studies with the Saclay-Orsay-Berkeley TPC prototype
  - beam measurements at KEK with the MPI-Munich TPC
- resistive Micromegas read-out
  - principle
  - beam measurements at KEK with the Carleton-Ottawa TPC (+MPI one)
- pixel readout TPC
- bulk developments and Micromegas TPC for T2K
- conclusions
which constraints on the ILC TPC?

most of them come from ILC physics and machine:
- excellent separation between 2 tracks (<3mm in r-\(\Phi\)),
- momentum resolution 10x better than at LEP,
- very low ion backflow in the drift space,
- working gas (nearly) without H (n background)
- high magnetic field B (~4T) to remove background.

\(\rightarrow\) a Micromegas TPC has been proposed in 1999 by DAPNIA and LAL to fulfill these constraints.

advantages:
- no ExB effect: excellent for 2-track separation and for spatial resolution
- high gain
- very fast signal on the anode plane
- very low ion back-flow into drift space
- cheap, robust and easy to implement

previous successful studies on:
- ion feedback
- gain stability, diffusion and drift velocities
- aging
- behaviour in the magnetic field
- attachment (Ar-CF\(_4\))

using small Micromegas devices and various e sources (X-rays gun or source, B source, laser)

ILC-TPC readout with Micromegas

how to improve the spatial resolution of the TPC?

the ILC TPC:
L~2x250cm, Φ=300cm
pads everywhere, size ~ 6x2 mm²
N_{pads} ~ 1-2 x10^6
~200-250 pad rows
resolution per pad row ~100µm

point resolution for a pad:
\[ \sigma^2 \propto \sigma_0^2 + D_t^2 \times l_d / n_{eff} \]

\( \sigma_0 \)
constant term
\( l_d \)
drift distance
\( n_{eff} \)
effective number of electrons contributing to the signal ~20-30 for 1cm
\( D_t \)
transverse diffusion coefficient in the gas, decreased by the magnetic field

example: Ar-CF\textsubscript{4} mixture (no H!)

at B=0T, \( D_t \sim 350\mu m/\sqrt{cm} @ 200V/cm \)
\[ \Rightarrow \text{for } l_d=100cm, n_e \sim 25, \text{ resolution } \sigma = 800\mu m \]
at B=4T: \( D_t(B) = D_t(B=0)/\sqrt{(1+\omega^2\tau^2)} \) with \( \omega \tau \approx (v_d/E)xB\sim 20 \)
\[ \Rightarrow D_t \sim 20\mu m/\sqrt{cm} \text{ only, ie } 200\mu m \text{ for } 100cm \]
\[ \Rightarrow \text{resolution better by a factor } 20! \]
potential resolution \( \sigma = 40\mu m@100cm \) (64µm@250cm)!

BUT the pad width (2mm) is too large as compared to diffusio

\[ \mu = v_d/E \sim 5T^{-1} \]
\[ \Rightarrow \omega \tau \approx 20 \text{ at } 4T \]
TPC readout with Micromegas

calculation: $B = 0, 0.5, 1T, \phi = 0^\circ$ Ar-5% iso-$C_4H_{10}$

calculation by K. Fuji with:
- Magboltz diffusion values
- pad width $w = 2.3$ mm
- no noise, $N_{eff} = 27$

extrapolation to ILC case

$B = 4T$, Ar-3%CF$_4$
$D_t \sim 20 \mu m/\sqrt{cm}, \phi = 0^\circ$

solutions?

1. decrease by a huge factor the pad width $\leftarrow$
   → new very promising concept of digital TPC minipads ($\ll 1$ mm$^2$), with single electron detection.

2. diffuse electrons AFTER multiplication «impossible» for Micromegas, difficult for GEM

3. bond a resistive foil on the anode plane $\leftarrow$
   proposed by Madhu Dixit (Carleton, Ottawa) $\sim 2000$

data: Micromegas $B = 1T, \phi = 0^\circ$ Ar-5% iso-$C_4H_{10}$

$w/12 \sim 660 \mu m$

measurements with 4 GeV/c $\pi$

$\sigma^2_{\chi} = \sigma^2_{\chi 0} + D^2 / N_{eff} z$

$B = 0.5T$

$w = 2.30$ mm

$B = 1T$

$w = 1.27$ mm

$B = 0T$

see presentation by Makoto Kobayashi, LCWS06@Bangalore, March 06

Vincent Lepeltier LAL-Orsay SNIC symposium, Stanford, April 2006, 3-6th
results of a Micromegas TPC cosmic test
Saclay-Orsay-Berkeley

more explanations on poster # 153 by Mike Ronan

P. Colas5, I. Giomataris5, V. Lepeltier4, M. Ronan1, K. Sachs2, T. Zerguerras3
1) LBNL Berkeley, 2) Carleton Univ., 3) IPN Orsay, 4) LAL Orsay,
5) DAPNIA Saclay + many other people

TPC built in 2003
data taking mainly in april-may 04:
≈ 150 k cosmic tracks registered
B= 0.1, 0.3, 0.5, 0.7, 1, 1.5 & 2 Tesla
gas mixtures : Ar + CF4 / CH4 / iso-C4H10
3% 10% 5%

2T NMR supra magnet
at Saclay

Micromegas has been working during many weeks without any problem!

1024 pads in ten rows
2x10 mm² pads
1x10 mm² pads
2x10 mm² pads
Cu mesh CERN
50 μm pitch and gap
readout anode pad plane

(software from D. Karlen, adapted by M. Ronan)

time distribution@20MHz

online event display

Vincent Lepeltier LAL-Orsay SNIC symposium, Stanford, April 2006, 3-6th
results of a Micromegas TPC cosmic test
Saclay-Orsay-Berkeley

Drift velocity measurements

Select tracks near the far end. Look at the time at which they exit the chamber. Add offset 200+100 ns (trigger delay)
Divide by the length (47.9 cm)

Excellent agreement with Magboltz
(S. Biaggi, 2004)
within 2% accuracy!

<table>
<thead>
<tr>
<th>Gas mixture</th>
<th>E drift (V/cm)</th>
<th>V drift (cm/μs)</th>
<th>Magboltz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ar+5%iso</td>
<td>210</td>
<td>4.24±0.08</td>
<td>4.17</td>
</tr>
<tr>
<td>P10</td>
<td>66</td>
<td>4.43±0.07</td>
<td>4.46</td>
</tr>
<tr>
<td>P10</td>
<td>150</td>
<td>5.61±0.09</td>
<td>5.50</td>
</tr>
<tr>
<td>Ar+3%CF4</td>
<td>200</td>
<td>8.8±0.2</td>
<td>8.51</td>
</tr>
</tbody>
</table>

Transverse diffusion

Results

Preliminary

Drift velocities:
perfect agreement between measurements and Magboltz simulations

Diffusion:
quite in good agreement for the three gas mixtures
results of a Micromegas TPC cosmic test
Saclay-Orsay-Berkeley

- good agreement between MC and data for \textbf{Ar-CH}_4 and \textbf{Ar-isoC}_4\textbf{H}_{10}
- extrapolated value at zero drift very small ($\approx 50 \, \mu m$)
- large disagreement (factor 2!) for \textbf{Ar-CF}_4
  since the diffusion is well reproduced, \textbf{N}e is two times too small as expected:
  no attachment $\Rightarrow$ bad quenching?
  $\Rightarrow$ we are investigating this gas mixture
  $\Rightarrow$ add 1% \textbf{isoC}_4\textbf{H}_{10}?
First results of the Purdue-3M Micromegas Cornell TPC (Ian Shipsey, Dan Petersen et al.)

Resolution vs drift distance

1st measurement (April 5th!)

Ar-CO2 mixture
E=330V/cm (430V)
B=0T
Resolution at Z=0: ~150μm
beam measurements at KEK with a Micromegas TPC

June 05

Canada, France, Germany, Japan, Philippines collaboration
KEK, TUAT Tokyo Univ., Hiroshima Univ., Kogakuin Univ.
Kinki Univ., Saga Univ., Tsukuba Univ., Japan, MSU, Philippines,
Carleton Univ. of Ottawa, Univ. de Montréal, Canada, MPI, Germany,
DAPNIA-CEA, Saclay, IN2P3-LAL and IPN, Orsay, France

T. Araki, D. C. Arogancia, A. M. Bacala, A. Bellerive, K. Boudjemline,
M. Burke, P. Colas, M. Dixit, H. Fujishima, K. Fujii, A. Giganon,
I. Giomataris, H. C. Gooc, M. Habu,
T. Higashi, Y. Kato, M. Kobayashi, K. Kodomatsu, H. Kuroiwa,
V. Lepeltier, J. Miyamoto, J.-P. Martin, T. Matsuda,
S. Matsushita, K. Nakamura, E. Neuheimer,
O. Nitoh, J. Pouthas, R. L. Reserva, E. Rollin, Ph. Rosier,
K. Sachs, R. Settles, Y. Shin,
A. Sugiyama, T. Takahashi, Y. Tanaka, T. Watanabe,
A. Yamaguchi, T. Yamamoto,
H. Yamaoka, Th. Zerguerras

JACEE magnet
L = 1 m, \( \Phi = 85 \text{cm} \), B = 1.2 T

- Micromegas 10 x10 cm\(^2\)
- drift distance 26 cm
- 24 x 16 = 384 pads 2.3 x 6.3 mm\(^2\)/16 rows
- ALEPH preamps (500 ns shaping time)
- 11 MHz ALEPH Time Proj. Digitizers
- beam: 4 GeV/c, \( \pi \)
- gas mixture: Ar+5% Isobutane
- \( E = 220 \text{V/cm} \), B = 0, 0.5 & 1 Tesla
- gain = 10,000

see presentation by Rosario Reserva at LCWS06@Bangalore March 2006
beam measurements at KEK with a Micromegas TPC

June 05

Charge  Width  Measurement vs Z

Xtrack – Xcenter – pad – +2  0  –2  +4 mm

z=0

B = 0.5 Tesla

B = 0 Tesla

z=26

B = 0.5 Tesla

B = 1.0 Tesla

Data

Theory

Data

Theory

Data

Theory

Data

Theory

<table>
<thead>
<tr>
<th>B</th>
<th>C_D Magboltz µm/m cm</th>
<th>C_D meas.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0T</td>
<td>469</td>
<td>489</td>
</tr>
<tr>
<td>0.5T</td>
<td>285</td>
<td>287</td>
</tr>
<tr>
<td>1T</td>
<td>193</td>
<td>189</td>
</tr>
</tbody>
</table>

Vincent Lepeltier  LAL-Orsay  SNIC symposium, Stanford, April 2006, 3-6th
### beam measurements at KEK with a Micromegas TPC

**June 05**

<table>
<thead>
<tr>
<th>( B )</th>
<th>( \sigma_x(0) ) ( \mu m/\sqrt{cm} ) measured</th>
<th>( \sigma_x(0) ) fit</th>
</tr>
</thead>
<tbody>
<tr>
<td>0T</td>
<td>154 ( \pm ) 22.3</td>
<td>132 ( \pm ) 2</td>
</tr>
<tr>
<td>0.5T</td>
<td>199 ( \pm ) 15.2</td>
<td>127 ( \pm ) 2</td>
</tr>
<tr>
<td>1T</td>
<td>134 ( \pm ) 76.2</td>
<td>128 ( \pm ) 2</td>
</tr>
</tbody>
</table>

**Spatial Resolution** \( \sigma_x(z) \)

- **\( B = 0 \) Tesla**
  - \( \sigma_0 = (132 \pm 2) \mu m \)
  - \( C_0 = 469 \mu m/\sqrt{cm} \)
  - \( N_{e,p} = 28 \pm 0 \)

- **\( B = 0.5 \) Tesla**
  - \( \sigma_0 = (127 \pm 2) \mu m \)
  - \( C_0 = 285 \mu m/\sqrt{cm} \)
  - \( N_{e,p} = 28 \pm 0 \)

- **\( B = 1 \) Tesla**
  - \( \sigma_0 = (128 \pm 2) \mu m \)
  - \( C_0 = 193 \mu m/\sqrt{cm} \)
  - \( N_{e,p} = 28 \pm 0 \)

**Constant term** \( \sigma_0 \) in good agreement with analytical calculation:

\[
\sigma_0 = 2.3 \text{ mm} / \sqrt{(12 \times 28)} = 126 \mu m
\]

Simulation by Khalil Boudjemline (Carleton Univ)

---

Vincent Lepeltier LAL-Orsay SNIC symposium, Stanford, April 2006, 3-6th
the avalanche charge is spread by coating the anode plane with a highly resistive foil ($1\text{M}\Omega/\square$ Al-Si Cermet) 50µm + 50µm glue.

- 2-dimensional continuous RC network defined by material properties ($R$) & geometry ($C$).
- Point charge at $r = 0$ & $t = 0$ disperses with time.

The charge evolution in $r$ and $t$ is the “telegraph” equation, governed by the RC time constant parameter:

$$\frac{\partial \rho}{\partial t} = \frac{1}{RC} \left[ \frac{\partial^2 \rho}{\partial r^2} + \frac{1}{r} \frac{\partial \rho}{\partial r} \right]$$

$$\Rightarrow \rho(r, t) = \frac{RC}{2t} e^{-\frac{r^2}{4tRC}}$$


Vincent Lepeltier LAL-Orsay SNIC symposium, Stanford, April 2006, 3-6th
beam tests at KEK with a resistive anode
(october 05)

same people, same beam at KEK, same magnet, but...
- a 2\textsuperscript{nd} small TPC from Carleton in addition to MPI one
- both equipped with Micromegas + resistive foil
- TPCs in the beam, alternately inside the 1T-magnet

- Micromegas 10 \times 10 \text{ cm}^2
- Drift distance: 16 cm
- 126 pads 2\times 6 \text{ mm}^2/7 rows
- ALEPH preamps
- 25 MHz FADCs

people ...working ...discussing ...and ...drinking
beam tests at KEK with a resistive anode
(october 05)

CARLETON-TPC TRACK DISPLAY

MPP TPC event display

amplitude vs time distributions

charge spreading due to resistive foil is effective on at least 4 pads

Typical and expected PRF width vs z

\[ \text{Ar-5\%isoC_4H_{10} \& 1T} \]

\[ \text{Ar+3\%CF_4 \& 4T} \]

Carleton Ottawa TPC

Vincent Lepeltier LAL-Orsay SNIC symposium, Stanford, April 2006, 3-6th
transverse spatial resolution $C_d = 125 \, \mu\text{m}/\sqrt{\text{cm}}$ (Magboltz) for: Ar+5%\text{iC}_4\text{H}_{10}, E=70\, \text{V/cm}, B=1\, \text{T}

Carleton TPC with Micromegas+ resistive layer $2 \times 6 \, \text{mm}^2$ pads

conclusions

1. NO pad width limitation
2. extrapolation from present data to $B = 4\, \text{T}$ and $C_d = 25 \, \mu\text{m}/\sqrt{\text{cm}}$

$\sigma_t \approx 100 \, \mu\text{m} \, @2.5 \, \text{m drift and 2x6 mm pads}$

near future for the Carleton group

- next summer: 4T cosmic tests at DESY with various gas mixtures
- this year: develop a 25 MHz digitizer
- next year: study 2-track resolution with a beam (or a laser)
the digital TPC

idea: (see presentation by Paul Colas at LCWS06)

- reconstruct a track electron by electron (or cluster by cluster)
- the pixel size and gas choice should be a compromise between ionisation and diffusion (300 to 50 µm?, He based mixture?)
- the whole coverage of the ILC-TPC end plate surface
  ⇒ 10⁸ to 10⁹ channels! (instead of ~10⁶), but all digital (1/0)
  ☻ insensitive to gain fluctuations (1/0)
  ☻ optimal dE/dx resolution (for the ILC-TPC: ~5% → ~2%?)
  ☻ probably a better position resolution (for one e: diffusion\(\otimes\)pixel size)
- questions:
  costing: 1rst attempts show that it should be less expensive than a standard readout
  efficiency: should be large enough for single e detection (gain vs threshold)
- ILC: full coverage or replace a few pad-rings by digital anode chips (gas “club sandwich”)?

---

a CERN, Freiburg, MESA+/Twente, NIKHEF, Saclay collaboration


Vincent Lepeltier LAL-Orsay SNIC symposium, Stanford, April 2006, 3-6th
the digital TPC

Micromegas + Medipix (~55µm pitch) ⊗ no time measurement!

55Fe spectrum Ar-20%iso-C₄H₁₀

He+20% isobutane
Ortec preamplifier

Gain vs HV

50x50 µm²

Micromegas
256x256 channels

M. Hauschild

55Fe Kα

σₑ/ₑ = 6.5%

Ar escape

Vincent Lepeltier
LAL-Orsay
SNIC symposium, Stanford, April 2006, 3-6th
the digital TPC

- Medipix collaboration: 17 institutes, since 1999
- CMOS chip, 0.25\(\mu\) technology, 65000 pixels on 2cm\(^2\)
- Upgrade of Medipix2: MXR version, less sensitive to temperature, under development at Saclay
- Also new readout board/card: USB

- next step: from Medipix2 to Timepix (time measurement)
- more tests with smaller gaps (40 \(\mu\)m already successful)
- study of the gas gain fluctuations in progress

EUDET European Detector for the ILC (4 years EC action)
CERN-Freiburg-NIKHEF-Saclay-Bonn?-Bucarest? 2M€ (850 k€ allocated by EC)
program: TimePix design at CERN,
- develop post-processings for protection and mesh integration
- build a detector (deliverable in 2 years),
- watch the outcome of 130 nm and 90 nm technologies (CERN), etc
**other Micromegas developments: bulk**

I. Giomataris (Saclay), Rui de Oliveira (CERN), and many other people, DAPNIA O4-8O see poster #221 by Paul Colas

1) cleaning of PCB (strips, pixels,...)
2) photoresist lamination (50 to 150µm)
3) woven mesh deposition (inox 19µm, 500 lpi)
4) photoresist lamination (50 to 500 µm)
5) UV insolation through a mask
6) development (sodium carbonate)
7) solidification (UV and hoven)

**many advantages:**

- clean and well protected detector
- no frame needed,
- large areas available
- low cost and very fast realisation
- robustness, easy to implement
- can be cut easily!

---

Vincent Lepeltier  LAL-Orsay  SNIC symposium, Stanford, April 2006, 3-6th
other Micromegas developments

T2K cosmic tests in the HARP/TPC at CERN (november 05)

Ar + 2% isobutane + 3% CF₄
Micromegas gain ~5000
B=0.2T
1. **Micromegas** has been successfully working on a few TPCs for long period.

2. The measured **spatial resolution** are in good agreement with the expected values. All ingredients of the spatial resolution are quite well understood (pad width, number of effective electrons, etc.)

4. For the **pad width limitation**, very critical for the ILC-TPC, it has been demonstrated that it is necessary to **diffuse the electrons after the avalanche**...

5. **Resistive deposition on the anode** is a good solution to overcome this limitation, it works very well, more tests will be performed very soon.

4. **Pixellised readout**: lot of progress since two years, more expected in the future, very promising application to tracking.

5. **New developments**:

   It will be possible in the near future to produce large surfaces of **unexpensive**, robust, made “à la carte”, **easy to implement**, and potentially **very transparent** Micromegas detectors (“bulk”) including all processes in a short time.