This talk will partly cover

- dE/dX and related techniques
- Cherenkov Ring Imaging
- Some aspects of Transition Radiation
- Time of Flight measurement

Progress with Particle Identification

Olav Ullaland / CERN
At this point we notice that this equation is beautifully simplified if we assume that particle identification has 92 dimensions.
Pion-Kaon separation for different PID methods. The length of the detectors needed for $3\sigma$ separation.

Dolgoshein, NIM A 433 (1999)

The same as above, but for electron-pion separation.
Data from the DELPHI RICHes

\( p \) from \( \Lambda \)
\( K \) from \( \Phi \), \( D^* \)
\( \pi \) from \( K^0 \)

Data from J. Seguinot CERN-EP/89-92
**Experiments with CsI photon detectors in RICHes**

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Id. aim</th>
<th>Momentum range (GeV/c)</th>
<th># CsI PCs (total m²)</th>
<th>Status</th>
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<tbody>
<tr>
<td>NA44 TIC</td>
<td>$\pi^+/K^+$ (gas)</td>
<td>3-8</td>
<td>2 (~0.3)</td>
<td>Terminated</td>
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<tr>
<td>CERN</td>
<td></td>
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<tr>
<td>STAR RICH</td>
<td>$\pi^+/K^+$ ($p/\bar{p}$ (liquid)</td>
<td>1-3 2-5</td>
<td>4 (~1)</td>
<td>Terminated</td>
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<tr>
<td>BNL</td>
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<td></td>
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<tr>
<td>ALICE HMPID</td>
<td>$\pi^+/K^+$ ($p/\bar{p}$ (liquid)</td>
<td>1-3 2-5</td>
<td>42 (~10)</td>
<td>in preparation</td>
</tr>
<tr>
<td>CERN</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>HADES RICH</td>
<td>Hadron blind</td>
<td>&lt;1.5</td>
<td>18 (1.5)</td>
<td>Running</td>
</tr>
<tr>
<td>GSI</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>COMPASS RICH</td>
<td>$\pi^+/K^+$ ($p/\bar{p}$ (gas)</td>
<td>&lt;60</td>
<td>16 (~5.8)</td>
<td>Running</td>
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<tr>
<td>CERN</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HALL-A RICH</td>
<td>$\pi^+/K^+$ ($p/\bar{p}$ (liquid)</td>
<td>&lt;4</td>
<td>3 (~0.7)</td>
<td>Starting</td>
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<tr>
<td>JLab</td>
<td></td>
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</tbody>
</table>

Schyns, Novosibirsk 2002
The COMPASS RICH-1 detector

The Mirrors

The $C_4F_{10}$ Gas

The Photon Detector

Cooling plates
Readout boards
CsI photocathode boards
Anode wires
Distance frame
Cathode wires
Collection wires
Fused silica plates
Fused silica frame

+ transparency for 186 cm  – Rayleigh scattering

Wavelength [nm]

Transparency

The Rings
Di Mauro, Hamburg 2001
HAMAMATSU Multianode Photomultiplier Tubes

Typical Single Photoelectron PHD per Channel

Schematic view of a lens system. CERN LHCC 2000-037, LHCb TDR 3
Hybrid Photo Diodes HPD

An alternative technique to amplify an electron in a vacuum tube is by bombarding it onto a silicon diode.

(Some) commercially available HPDs

Photocathode:
Solar Blind
Bialkali
S20
Super S-25

Electrostatic focussing

Proximity focussing
DIRC is a 3-D device, measuring: \( x \), \( y \) and time of Cherenkov photons.

**Single photon resolution**

\[ \sigma(\Delta \Theta_{c\gamma}) = 9.6 \, \text{mrad} \]

Expectation: \( \sim 9.5 \, \text{mrad} \)
dominated by:
- 7 mrad from PMT/bar size,
- 5.4 mrad from chromatic term,
- 2-3 mrad from bar imperfections.

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Leith, Novosibirsk 2002
$D^* \rightarrow D^0 \pi^- K^- \pi^+$

Leith, Novosibirsk 2002
**Time Of Propagation counter**

- **Butterfly-shaped mirror (Focusing mirror)**
- **Photon detectors**
- **Particle**
- **Radiator-bar**
- **Forward**
- **I.P.**
- **e+**
- **e-**
- **R = 1 m**
- **L**

**Graphs and Data**

- **p = 3 GeV/c, L = 2 m, \( \Theta_{in} = 90^\circ \)** (normal incident angle)
- **\( \Delta \text{TOP} = 200 \text{ps} \)**
- **\( \sigma_{\text{TOP}} \)**
- **Chromaticity**
- **Aberration**
- **T.T.S**

**Y. Enari Novosibirsk 2002**
**Time Of Propagation counter**

$4\text{GeV/c} \pi @ L = 1 \text{ m}$

$\Theta_{\text{in}} = \Phi_{\text{in}} = 90^\circ$

**Beam test.**: $3 \text{ GeV/c} \pi^- \ L=0.3 \text{ m}$

$\tau_{\text{in}} = \Phi_{\text{in}} = 90^\circ$

- **ADC & TDC distributions**
  - Single photo-electron peak
  - TDC distribution ($x=11.3\text{mm}$)
    - 6 Gaussian fit.
    - $\sigma_{\text{common}} = 82, \text{ps}$

Y. Enari Novosibirsk 2002
A little about optics

The main uncertainties are
- Emission point error
- Chromatic aberration
- Detector pixel size
- Particle track error
- Opto-mechanical error(s)

And reflectivity

And, of course, for the optics
- Radiation length $\equiv 0$
- Interaction length $\equiv 0$

Spot size. $R=6.6$ m, $\varnothing=50$ cm, thickness 6 mm glass or 4.7% $X_0$

Beryllium-Glass mirror. $R=1.7$ m, $X_0=2\%$

IHEP Protvino, Just Optic, Ltd. St. Petersburg and Kompozit Korolev
Measured and calculated saturated Cherenkov angle and resolution for single photons in mrad.

<table>
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<tr>
<th>Producer</th>
<th>Novosibirsk</th>
<th>Matsushita</th>
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<tbody>
<tr>
<td>Thickness (cm)</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Clarity ($10^4 \mu m/cm$)</td>
<td>72.2</td>
<td>69.5</td>
</tr>
<tr>
<td>$n$ (at 600 nm)</td>
<td>1.0306</td>
<td>1.0298</td>
</tr>
</tbody>
</table>

$$T = T_{\lambda \to \infty} \cdot e^{-CL/\lambda^4}$$
Time Of Flight techniques

\[ \frac{dm}{m} = \frac{dp}{p} + \gamma^2 \left( \frac{dt}{t} + \frac{dL}{L} \right) \]

Something about Spark Chambers
Scintillator hodoscopes
and
Resistive Plate Chambers

on your marks!
Time-of-Flights detectors at the exit of the NA49 spectrometer. 
891 scintillator tiles connected to PM: XP2972
Each tile: 8-10 cm x 3.3 cm x 2.3 cm
TDC and ADC spectra read out.

Klempt, NIM A 433 (1999)
Mass distribution from TOF measurements for particle momenta below 1.2 GeV/c.
Custom-made Hamamatsu R7766
19 dynode (High gain)
Fine mesh (Increased tolerance to magnetic field)
Small size 1.5 x 2.5 inches
Operated with a positive HV up to 2500V.
Gain reduction factor at B=1.4 T in the range of ~500

216 Scintillator bars 279 cm x 4 cm x 4 cm) with phototubes attached to both ends (432).

Target performance:
- 100ps resolution over length bar using both PMTS
- Comparison between the time difference for east and west pmt with 100ps resolution Montecarlo (σ_{AE}=2σ_{TOF})
- From this “systematic-free” time difference resolution
- preliminary σ_{TOF}=125ps
- Working on the improvement

Vila, Novosibirsk 2002
**Pestov Spark Counters**

The standard gas mixture

- 0.6% C\textsubscript{4}H\textsubscript{6} 1,3-Butadiene
- 2.5% C\textsubscript{2}H\textsubscript{4} Ethylene
- 20.4% C\textsubscript{4}H\textsubscript{10} i-Butane
- 76.5% Ar

Time resolution (FWHM/2.35) as function of overvoltage applied to the counter. The graph compares experiments done at GSI and at BNIP. At BNIP gas mixtures with different fractions of butadiene were used. Tails extend beyond the gaussian distribution.

Parallel Plate Chambers

Ceramic Cells
Surface:
- $2 \times 2$ cm$^2$
- $5 \times 5$ cm$^2$
- $10 \times 10$ cm$^2$

Ceramic substrate
- $1.0 \pm 0.01$ mm

Chromium layer
- 0.5-1 µm

Flatness
- $<4$ µm

Grooves
- Ø 1 mm

Gas gap
- 1, 1.5, 2 mm ± 0.05 mm

Spark probability as function of gas gain.

Iglesias, PhD thesis 1997
Single cell 3 x 3 cm² active area

5 gas gaps of 220 micron
Anode electrode 3 x 3 cm²
Schott A14 (0.5 mm thick)
Cathode electrode 3 x 3 cm²
Schott A2 (0.5 mm thick)
Schott 8540 (2 mm thick)

5 cm

Standard unit detector for ALICE detector (ALICE TOF will be constructed with ~1,600 such strips)

Typical time spectra from readout pad of 1.2 m strip

Counts per 50 ps

0.65% earlier than 250 ps

0.06 % later than 500 ps

0.5% later than 250 ps

MAXIM 3760
Sigma 70 ps

Efficiency [%] vs. HV (kV)

Efficiency [%] vs. Resolution [ps]
RPC at HARP

- 0.6 mm glass \(-9\times10^{12}\) \(\Omega\text{cm}\)
- Three fishing lines with spacing of 35 mm between them.
- Four fishing line with 40 mm space between them were in chambers made of 130x200 cm\(^2\) plates.
- High voltage was applied to each of double-gap RPCs through electrodes made of high resistive (~1 M\(\Omega/\text{[]}\)) carbon film.
- Two 200 \(\mu\text{m}\) mylar sheets one at the top and one at the bottom provide with an isolation between high voltage electrodes and walls of boxes.
- \(\text{C}_2\text{H}_2\text{F}_4/\text{C}_4\text{H}_{10}/\text{SF}_6\) 90/5/5%

**Time resolution as function of particle rate**

**Efficiency as function of particle rate**

Ammosov, hep-ex/0204022, 2002
\[ p = m \beta \gamma \]

\[
\frac{dE}{dx} \propto \frac{1}{\beta^2} \ln(\beta^2 \gamma^2) \quad \text{Simultaneous measurement of } p \text{ and } \frac{dE}{dx} \text{ defines } m.
\]

<table>
<thead>
<tr>
<th>det.</th>
<th>n</th>
<th>x (cm)</th>
<th>P</th>
<th>exp.</th>
<th>meas.</th>
<th>exp.</th>
<th>meas.</th>
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<td>CLEO2</td>
<td>51</td>
<td>1.4</td>
<td>1 atm</td>
<td>6.4%</td>
<td>5.7%</td>
<td>(µ)</td>
<td></td>
</tr>
<tr>
<td>Belle</td>
<td>52</td>
<td>1.5</td>
<td>1 atm</td>
<td>6.6%</td>
<td>5.1%</td>
<td>(µ)</td>
<td></td>
</tr>
<tr>
<td>MKII/SLC</td>
<td>72</td>
<td>0.833</td>
<td>1 atm</td>
<td>6.9%</td>
<td>7.0%</td>
<td>(µ)</td>
<td></td>
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<tr>
<td>OPAL</td>
<td>159</td>
<td>0.5</td>
<td>4 atm</td>
<td>3.0%</td>
<td>3.1%</td>
<td>(µ)</td>
<td></td>
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<tr>
<td>TPC/PEP</td>
<td>180</td>
<td>0.5</td>
<td>8.5 atm</td>
<td>2.8%</td>
<td>2.5%</td>
<td>(µ)</td>
<td></td>
</tr>
<tr>
<td>Aleph</td>
<td>344</td>
<td>0.36</td>
<td>1 atm</td>
<td>4.6%</td>
<td>4.5%</td>
<td>(µ)</td>
<td></td>
</tr>
</tbody>
</table>

Yeah, just gloat about your tail. It is still a Vavilov to me!
The chamber is 4 m long with an inner diameter of 0.5 m and an outer diameter of 3.7 m. The sensitive volume is divided into 24 identical sectors, each containing a plane with 159 sense wires.
NA49
Particle identification by simultaneous dE/dX and TOF measurement in the momentum range 5 to 6 GeV/c for central Pb+Pb collision
Particle identification @ CDF

During CDF I particle ID based on dE/dx method using the central drift chamber

For CDF II a TOF complement dE/dx.
- $2\sigma$ K/$\pi$ separation $p<1.6$ GeV/c
- $2\sigma$ K/p separation $p<2.7$ GeV/c
- $2\sigma$ p/$\pi$ separation $p<3.2$ GeV/c
- $1.2\sigma$ K/p separation over all $p$

For $L=140$ cm $\sim R_{\text{tof}}$
Timing resolution $\sigma_t = 100$ ps
and combined
Transition Radiation Detectors

If $\omega \gg \omega_0$ = plasma frequency

$$\frac{d^2 S_0}{d\Theta d\omega} = \frac{2\alpha \hbar \Theta^3}{\pi \omega} \left[ \frac{1}{a_1} - \frac{1}{a_2} \right]^2$$

$$a_i = \frac{1}{\gamma^2} + \Theta^2 + \frac{\omega_i^2}{\omega^2}$$

Need more $\gamma$

Enough $\gamma$
The display of a simulated $B^0 \rightarrow J/\Psi K^0_s$ event in the ATLAS barrel Inner Detector, at low luminosity ($10^{33} \text{ cm}^{-2}\text{s}^{-1}$) is shown in Fig. 1a. The small box selects a part of a pion track from the $K^0_s$ decay and of an electron track from a $J/\Psi$ decay, shown in an enlarged frame in Fig. 1b.

Pion misidentification probability versus electron efficiency at 5 GeV for pseudo-tracks constructed from test beam data. The results are shown for the standard cluster counting technique and for the combined method using also the time-over-threshold information.
Conclusion

Particle Identification has proven to be a very fertile ground for novel ideas. In particular the progress in photon detection and in combined systems has evolved very rapidly.

Further information on PID and related techniques at this conference can be found in the following talks:

A. Tonazzo/Milano, The laser calibration system of the Harp tof
G. Prior/Geneve, The HARP Time Projection Chamber
J.-L. Faure/Saclay, Progress with photodectors
R. Pani/Roma, Flat Panel PMT: advances in position sensitive photodetection
P. Antonioli/Bologna, MRPC for the ALICE-tof system
M. Capeans/CERN, ATLAS straw tube TRD
G. Osteria/Napoli, The tof system of the Pamela experiment
R. Pegna/Siena, The HPD: new UV detector for IACT (Imaging Air Cerenkov Telescopes)
D. Casadei/Bologna, Design and test results of the AMS RICH detector
G. Passaleva/Firenze, New results from an extensive aging test on bakelite RPCs

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