Charged particle multiplicity in proton-proton collisions with ALICE

- Introduction on the motivations for a pp physics programme with ALICE
- A short review on the detectors used to reconstruct charged particle multiplicity and to measure tracks. Typical features in pp running.
- The tracklet algorithm for the multiplicity reconstruction with the Silicon Pixel Detector.

A complete understanding of the physics of collisions between protons at LHC, will require the study of all processes, included those with big cross sections (ranging around 100 mb(σ_{tot}), 60 mb(σ_{inel.}) and 12 mb(σ_{diff.})), which represent the majority of the events. They are generally characterized by the production of particles with low P_T.

At the start up of LHC, when the luminosity will be still rather low for ATLAS and CMS (10^{33} cm^{-2} s^{-1}), ATLAS, CMS, LHCb and ALICE will study minimum bias events in the new energy domain at 14 TeV. Therefore a proton-proton programme has to be considered integral part of the ALICE experiment to establish a reference for the measurements with heavy ion collisions (strangeness enhancement, J/ψ and Υ suppression, jet-quenching), and to estimate the background to signals at high P_T (Higgs, SUSY, etc.).
A reasonable programme of Minimum Bias physics with the ALICE central detector requires $10^9$ MB events to be taken. In a typical year of running ($10^7$ seconds) the detector can collect up to $5 \times 10^9$ events (readout time limited to 500 Hz). Therefore even a loose interaction trigger and a very low luminosity of $10^{28} \text{ cm}^{-2} \text{s}^{-1}$ would be sufficient.

If the luminosity increases, there is a progressive deterioration of the detector performances, due to the pile-up in the 100 µs of drift time of the TPC. Events start to overlap in the TPC for $L > 2 \times 10^{29} \text{ cm}^{-2} \text{s}^{-1}$. However piled-up with virtual vertices shifted along the drift direction. At $L = 3 \times 10^{30} \text{ cm}^{-2} \text{s}^{-1}$ events start to pile-up also in the Silicon Drift Detectors. At this L about 20 events are superimposed in the TPC. However, the total number of tracks in the TPC is an order of magnitude smaller than in Pb-Pb, and therefore easily manageable.

This luminosity can be used as a benchmark because at this level the tracking can be considered safe.
Complementarity of different experiments at LHC

- ATLAS & CMS optimized for high $P_T$ and high luminosities
- LHCb optimized for the B physics (only in the “forward” kinematic region).
- TOTEM is dedicated to the measurement of the total and elastic cross sections, and of diffractive processes (absolute calibration of the luminosity).
- ALICE is optimized for the study of Heavy Ion collisions, therefore it is ideal for low $P_T$ and high multiplicities (but good also for rather high $P_T$ in some cases).

(Charged particles except muons)
The ALICE detector
Time Projection Chamber
largest ever: 88 m³,
570 k channels

for tracking
and PID via
dE/dx

- 0.9 < η < 0.9

Central Electrode Prototype
25 µm aluminized Mylar on Al frame

~ 3 m diameter

Field Cage
Inner Vessel

drift gas
90% Ne - 10%CO₂
The Inner Tracking System

- 6 Layers, three technologies (keep occupancy ~constant ~2% for max mult)
  - Silicon Pixels (0.2 m², 9.8 Mchannels)
  - Silicon Drift (1.3 m², 133 kchannels)
  - Double-sided Strip Strip (4.9 m², 2.6 Mchannels)
ALICE: a soft particle tracker

- ALICE is sensitive down to very low $P_T$

<table>
<thead>
<tr>
<th></th>
<th>Magnetic field (T)</th>
<th>$P_T$ cutoff (GeV/c)</th>
<th>Material thickness: $X/X_0$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALICE</td>
<td>0.2-0.5</td>
<td>0.1-0.25</td>
<td>7</td>
</tr>
<tr>
<td>ATLAS</td>
<td>2.0</td>
<td>0.5</td>
<td>30</td>
</tr>
<tr>
<td>CMS</td>
<td>4.0</td>
<td>0.75</td>
<td>20</td>
</tr>
<tr>
<td>LHCb</td>
<td>4Tm</td>
<td>0.1*</td>
<td>3.2</td>
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</tbody>
</table>

- Moreover ALICE has remarkable capabilities of particle identification
• $\pi$, $K$, $p$ identified in large acceptance ($2\pi \times 1.8$ units $\eta$) via a combination of $dE/dx$ in Si and TPC and TOF from $\sim 100$ MeV to $2 (p/K) - 3.5 (K/p)$ GeV/c
• Electrons identified from 100 MeV/c to 100 GeV/c (with varying efficiency) combining Si+TPC+TOF with a dedicated TRD
• In small acceptance HMPID extends PID to $\sim 5$ GeV
• Photons measured with high resolution in PHOS, counting in PMD
In ALICE the Minimum Bias trigger is provided by a coincidence between the V0 counters, scintillator layers that cover the pseudorapidity interval $-5 < \eta < -3.2$ and $1.6 < \eta < 4.8$. That corresponds to a visible inelastic cross section of $\sim 60$ mb.

The charged particle multiplicity is measured over 8.8 rapidity units, whereas the momentum is measured in the TPC and in the Inner Tracking System (ITS) over 1.8 rapidity units with optimal resolution, and up to 3 units in total.
• Detector composed by 5 rings of Silicon Strips devoted to provide (offline) the charged particle multiplicity in the range $-3.4<\eta<-1.7$ and $1.7<\eta<5.1$
• While occupancies for Pb+Pb collisions are typically in the range 1-5, occupancies for p+p collisions will be less than 0.01 per strip and per collisions. Thus analysis of multiplicities can be done cleanly
Tracking in the central barrel

- \( \frac{dN}{d\eta} \bigg|_{\text{max}} = 8000 \) (in Pb-Pb) 
- Tracking in the central barrel is a great challenge!

Requirements (TPC+ITS):
- Good efficiency (> 90%) for \( p_T > 0.2 \) GeV/c @ 0.4 Tesla magnetic field
- Momentum resolution \( \frac{dp}{p} \) ~ 1\% - 2\% at low momenta and few % at 5 GeV/s
- Good vertexing capabilities: V0, charm
- Particle identification \( \frac{dE}{dx}, \text{kinks} \)
Tracking solutions

- Tracking finding and fitting: Kalman filtering
- Track seeding: outer TPC (lower track density)
- Tracks prolonged to ITS
- In ITS: Kalman + vertex constraint ($\sigma_z=100 \, \mu m$)
- From ITS: back propagation to TRD and TOF

Needs

Primary vertex position measurement

Remark: The size of the luminous region (vertex spread) for LHC pp beams is $\sigma = 5.4 \, \text{cm}$ (in the approximation of Gaussian shaped bunches)
$Z_v$ is estimated starting from a correlation between the first 2 ITS layers (PIXEL) in a narrow azimuthal ($\Delta\phi$) window (here high multiplicity HELPS!)

The coordinates in the bending plane are measured in a similar way.

More precise results can be obtained by using the reconstructed tracks $\rightarrow$ necessary for secondary vertices in p-p collisions.
**Vertex determination /2**

\[ \sigma_z = \frac{A}{\sqrt{dN_{ch}/d\eta}} \]

\[ Z_{\text{true}} = 5 \, \text{cm} \]

\[ \text{Chi}^2 / \text{ndf} = 0.1894 / 2 \]

\[ A = 292.1 \pm 9.25 \]

\[ B = 1.806 \pm 0.1583 \]

\[ \sigma_z \cong 5 \div 10 \, \mu \text{m} \]

\[ \text{p-p} \rightarrow \sigma_z \cong 150 - 200 \, \mu \text{m} \text{ (better when using tracks)} \]

No dependence on B
Example of a p-p event in ALICE (PYTHIA + AliROOT)
Main problems respect to Pb-Pb: **lower hit density**

statistical fluctuations become very large;

the **vertex position is not always reconstructed** (also, in some cases the reconstruction is poor). **That affects sizeably the method that uses “tracklets”** for the reconstruction of the multiplicity, based on the alignment of hits on the two pixel layers with the **guessed** vertex position.
Two methods are compared:
- counting of clusters on one layer
- counting of tracklets

\[ |\eta| < 0.5 \]

Analyzed a sample of 7900 MC events (gen. with PYTHIA 6.150, CTEQ4L as pdf)
Multiplicity reconstruction: efficiency

T. Virgili

$|\eta| < 0.5$

After rejection of events with vertex not reconstructed

All events

Clusters Layer 1

Clusters Layer 2

Tracklets
Multiplicity reconstruction: relative error

\[ |\eta| < 1.4 \]
Multiplicity distributions: \(|\eta| < 1.4\)

Generated (line) and reconstructed (symbols) multiplicity distributions (using tracklet method)

Only events with reconstructed vertex position are considered.

T. Virgili
dN/d\(\eta\) reconstruction (with pixel detector)

Clusters Layer 1
Clusters Layer 2
Tracklets

Cut on event multiplicity to exclude events without reconstructed vertex position

T. Virgili
Conclusions on Multip. Rec. with pixels

- Good reconstruction of both charged multiplicity and dN/d\(\eta\), for both p-p and Pb-Pb interactions;

- A detailed investigation of the physical and methodological effects on the reconstruction has been performed;

- Errors determination shows a good resolution at both low and high multiplicity.
Another issue: the correlation \( \langle p_T \rangle \) vs multiplicity

- One interesting issue is the study of charged tracks \( \langle P_T \rangle \) as a function of multiplicity. The increase of \( \langle P_T \rangle \) discovered by UA1, also observed by E735 for exclusive states is still not well understood. Correlations, attributed to the onset of gluon radiation and the formation of minijet, seem to depend on the type of particle. While DPMJET fits the pion data, it does not fit the kaon data well and completely misses for antiprotons.

- These studies can be an interesting subject for ALICE, with its powerful PID system.

- Since the bulk of the produced particles has a \( p_T \) less than 0.5 GeV/c the low-\( p_T \) cutoff of ALICE is an important asset for the measurement of \( \langle p_T \rangle \).
Most of the events in a Min.Bias sample are produced by soft collisions of the beam projectiles, featuring lower multiplicity in the hadronic final state (and showing KNO-scaling of multiplicity distributions and of the correlation $<p_T>$ vs multiplicity (CDF analysis by Rimondi et al.).

As energy increases, a larger fraction of p-p collisions is due to hard interactions, where the scattered energetic partons undergo a fragmentation process that produces clusters of hadrons called jets (or mini-jets, for lower energy scale of the hard process).

The “underlying event” consists of hard initial & final-state radiation plus the “beam-beam remnants” and possible multiple parton interactions.

Underlying Event is all the rest of the event other than the hard scatter.
The standard jet definition used in p-p experiments rely on a calorimetric criterion.

The challenge for ALICE, where no extensive hadronic calorimetry is available (at least so far), is to define and construct jets out of tracking measurements.

Recent progress in this respect has been reported by CDF at Tevatron. They have extensively studied the properties of jets in proton-antiproton collisions measuring only the charged particle in the jets.

In Min.Bias data they observed jets with total charged particle momenta of ~2 GeV/c (with two charged particles on average), while for jets up to 50 GeV/c ~10 charged particles were observed.

QCD Monte Carlo models (PYTHIA 6.2 and HERWIG) describe quite well jet observables such as the multiplicity distributions of charged particles within the leading jet, the radial distribution of charged particles and their transverse momentum.

The models fail to describe correctly the next few jets at a lower $p_T$.

None of the QCD models describes correctly all the properties of the UE.
Look at the charged particle density in the "transverse" region!

Look at charged particle correlations in the azimuthal angle $\Delta\phi$ relative to the leading charged particle jet.

Define $|\Delta\phi| < 60^\circ$ as "Toward", $60^\circ < |\Delta\phi| < 120^\circ$ as "Transverse", and $|\Delta\phi| > 120^\circ$ as "Away".

All three regions have the same size in $\eta$-$\phi$ space, $\Delta\eta \times \Delta\phi = 2\times120^\circ = 4\pi$.
Average “transverse” charge particle density (|η|<1, \(P_T>0.5\) GeV) versus \(P_T\) (leading charged jet)

Min-Bias Mean Charge density = 0.24

The Underlying Event has an higher multiplicity than an average MB event. Normalized multiplicity in the Transverse region is twice that of the ordinary MB events.
The Underlying Event has a harder $p_T$ spectrum than an average MB event. The harder is the hard scattering, the more energy enters into the Underlying Event outside the hard scattering.
Comparison of models for minimum bias and the underlying event

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Recent studies on PYTHIA tuning performed within CDF (R.Field et al, Analysis of UE event) and within ATLAS (A.Moraes et al), as reported at the last MC4LHC workshop (July 2003). These two groups have performed some cross-checks: finally on Dec.1 2003 there was an ATLAS SM Working group meeting, where A.Moraes (Sheffield Univ.) presented his final results on the tuning of PYTHIA 6.214 (actually the best on the market, to reproduce collider data from ISR to Tevatron energies). He made comparisons also with PHOJET 1.12.

- PYTHIA 6.214-tuned and PHOJET 1.12 generate LHC predictions with \(\sim 30\%\) difference for Min.Bias events, and a factor \(\sim 2\) for UE distributions.

- When extrapolating from Tevatron to LHC energy PYTHIA 6.214 predicts an increase of a factor \(\sim 2\) in the UE activity, whereas PHOJET 1.12 suggests that the ratio UE/Min.Bias will remain the same.
Jet Rates in Central ALICE ($|\eta|<0.9$)

ALICE will reconstruct charged particles with sufficient accuracy to allow similar measurements up to charged particle momenta $\sim 100$ GeV/c.

Benchmark luminosity for pp runs:

$$L = 10^{30} \text{cm}^{-2}\text{s}^{-1}$$

Reasonable rate up to $E_T \sim 200$ GeV
Charged particle jets via leading particle in TPC

1) Find the leading particle
2) If leading particle has a $p_{t\text{max}} \geq 4 \text{ GeV/c}$ use it as a seed for jet.
3) Particles with $p_t > 2 \text{ GeV}$ are associated to the jet if $\Delta R = \sqrt{(\Delta \phi^2 + \Delta \eta^2)} < 0.7$
4) Calculate sum of momentum vectors.
5) Mark all used particles.
6) Repeat until no more seeds are found.
Summary and prospects

- Crucial importance of the pp programme for the ALICE project: first ALICE papers will come out from the measurements on pp collisions at the LHC start-up !!!
- Promising studies of Physics Performances in the reconstruction of multiplicity and $dN/d\eta$ with ITS pixels already performed
- In progress a massive production of full MC events (Data Challenge 2004) to complete the study of ALICE performances on several aspects of its physics programme
- **Exciting physics in front of us (less than 3 years before Day 1!!!)**