Results from the NA50 experiment on J/ψ suppression and charged particle pseudorapidity distributions in Pb-Pb collisions

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The NA50 Collaboration

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Outline of the presentation

- **Introduction**
  - Goals and tools of the year 2000 Pb-Pb run
  - Determination of normal nuclear absorption from new p-A data
  - The standard analysis method: $\frac{\sigma(J/\psi)}{\sigma(\text{Drell-Yan})}$
  - Published NA50 results on J/ψ suppression

- **Results on J/ψ suppression from the year 2000 Pb-Pb run**
  - PRELIMINARY $\frac{\sigma(J/\psi)}{\sigma(\text{DY})}[2.9-4.5 \text{ GeV/c}^2]$ vs. transverse energy $E_T$
  - PRELIMINARY $\frac{\sigma(J/\psi)}{\sigma(\text{DY})}[2.9-4.5 \text{ GeV/c}^2]$ vs. forward energy $E_{ZDC}$
  - PRELIMINARY $\frac{\sigma(J/\psi)}{\sigma(\text{DY})}[4.2-7.0 \text{ GeV/c}^2]$ vs. transverse energy $E_T$
  - Comparison with published results

- **Results on $dN_{ch}/d\eta$ distributions**
  - Measurements at two different Pb beam energies: 40 GeV/c and 158 GeV/c
  - Analysis in bins of centrality
  - Study of scaling behaviour versus $N_{part}$ and versus energy

- **Summary**
NA50: the experimental setup

**Pb beam**
- 1999: 40 GeV/nucleon

**p beam**
- 450 GeV/nucleon

**Muon spectrometer (2.7<\eta<3.9)**
- Magnet+MWPC+hodoscopes

**Triggers**
- **DIMUON**: 2 muon tracks
- **MIN.BIAS**: Non-zero energy deposit in the ZDC

**Centrality detectors**
- E.M. Calorimeter (1.1<\eta<2.3)
- Zero Degree Calorimeter (\eta>6.3)
- Multiplicity Detector (1.9<\eta<4.2)
**NA50: the Multiplicity Detector and the target region**

**Silicon microstrip detector** measuring the number and the angular distribution of charged particles produced in the collision.

- Two planes (MD1, MD2)
- 36 azim.sectors ($\Delta\Phi=10^\circ$)
- 192 radial strips ($\Delta\eta=0.02$)
  > 6912 strips in each plane
NA50 published results on J/ψ suppression

- **Two different analysis methods:**
  - **Standard analysis:** 1) Drell-Yan used as a reference  2) fit of dimuon invariant mass spectra
  - **Minimum bias analysis:** Min.Bias events used as a reference

- **Results:**
  - **Threshold effect** at $E_T \lesssim 40$ GeV
  - **No saturation** observed for most central collisions

- **Limitations:**
  - Analysis of **peripheral Pb-Pb collisions** possibly limited by **Pb-air contamination** (are they really compatible with collisions observed in lighter systems?)
  - Comparison with **ordinary nuclear absorption** also limited by the **low statistics of NA38** p-A and S-U data
Goals and tools of the 2000 run

- **GOALS:**
  - Investigate *peripheral interactions* in improved experimental conditions
  - Check behaviour of the anomalous $J/\Psi$ suppression against “normal” *nuclear absorption*, as determined by more accurate (high statistics) $p$-$A$ data, collected by NA50 with the same set-up

- **TOOLS:**
  - Target region put under vacuum, up to the pre-absorber
  - Improved beam cleaning cuts
  - New vertex reconstruction method based on the Multiplicity Detector
Rejection of pile-up and upstream interactions

- **Beam cleaning cuts:**
  - Rejected parasitic interactions of incident ion in Beam Hodoscope (33 m upstream from the target)
  - Rejected double interactions by means of temporal analysis of signal in E.M. calorimeter

- **Residual pile-up and upstream interactions:**
  - Rejection based on a diagonal band cut in the $E_T - E_{ZDC}$ correlation plot
Primary vertex reconstruction with the Multiplicity Detector

- In the past, primary interaction vertex reconstruction was based on a system of quartz blades, located downstream of each sub-target. The efficiency of this method was low for peripheral collisions.

- A new method has been developed, based on the data recorded by the MD.
  
  - Hits from MD1 and MD2 are combined, under different hypotheses on vertex position.
  
  - Tracklets are counted to calculate the likelihood of different vertex positions, measured by a statistical estimator.

- The “largest” estimator determines the best estimate for vertex position (if above a given threshold).

- The method works for $E_T > 3$ GeV.

  **It has full efficiency for $E_T > 15$ GeV**
Effect of the target cuts (1)

After the vertex reconstruction:
- Selected candidate “in-target” events
- Event by event, a “global cut” rejects the muon tracks not pointing to the estimated primary vertex position

The effect of the above defined cuts are visible in the following plots 🔴

For each selected dimuon, $Z_{\text{vertex}}$ is the Z of the closest approach between the two muons. **Background tracks** (produced far from the target, in the absorber, and visible also in dedicated “empty target” runs) are **strongly suppressed by this cuts**.
Here the effect of the same cuts is visible in the plot of dimuon invariant-mass spectrum.

In the low $E_T$ region, the contamination of out-of-target tracks (as the ones produced in dedicated empty target runs), for dimuons with $M < M_{J/\psi}$, is completely removed by these cuts.

For $E_T > 20$ GeV, this kind of contamination is already low.
The “standard” $J/\psi$ DY analysis

$$\frac{dN^{+\mu}}{dM} = n_{DY}^{DY} \frac{dN}{dM} + n_{J/\psi}^{J/\psi} \frac{dN}{dM} + n_{\psi'}^{\psi'} \frac{dN}{dM} + n_{D\bar{D}}^{D\bar{D}} \frac{dN}{dM} + R_{BCK}^{BCK} \frac{dN}{dM}$$

Fit to $\mu^+\mu^-$ mass spectra with four contributions ($J/\psi$, $\psi'$, Drell-Yan and Open Charm) + combinatorial background determined by fit of $\mu^+\mu^+$ and $\mu^-\mu^-$ mass spectra.

$n^i$ are free parameters in the fit

Extracted $J/\psi$ and Drell-Yan yields, and their ratio.

- Efficiencies cancel out in the ratio
- Absolute normalization (straightforward comparison to normal absorption) **but (price to pay)**
- Low statistics for high-mass Drell-Yan
The Drell-Yan reference

The Drell-Yan yield is proportional to the number of nucleon-nucleon collisions from p-p to Pb-Pb

It is a good normalization for the \( \frac{\sigma_{J/\psi}}{\sigma_{DY}} \) yield

The centrality dependence of the cross section ratio \( \frac{\sigma_{J/\psi}}{\sigma_{DY}} \) (2.9-4.5) in Pb-Pb must be compared with precise measurement of the same ratio in lighter systems (p-A)
The “normal” absorption of J/ψ

Fit to p-A and S-U data with an absorption model “à la Glauber” are compatible simultaneous fit with a common absorption cross section is allowed

From new NA50 p-A data + previous data: \( \sigma_{abs} = 4.4 \pm 0.5 \text{ mb} \)
Both analyses confirm the $J/\psi$ suppression pattern:
- Peripheral interaction agree with normal absorption
- There is a “threshold” followed by a steady decrease (no saturation) for the most central Pb-Pb collisions
The analysis is affected by a systematic uncertainty coming from the set of p.d.f. used for calculation of DY cross section in the mass range 2.9-4.5 GeV/c²

In order to estimate this effect, the analysis of the 2000 data vs $E_T$ has been done also with the set MRS43.

The same pattern vs. $E_T$ is observed, as in the analysis with GRV LO, but slightly different absolute values of the cross-section ratio.
The 2000 results: $J/\psi / DY(4.2 - 7.0)$

- $\sigma_{DY}(2.9-4.5)$ depends on the extrapolation of $dN_{DY}/dM$ from a mass region where Drell-Yan is directly measured (without background)
  - Different p.d.f. lead to different results
- If directly measured $DY(4.2-7.0)$ used as a reference $\bigstar$ unique result!!
Centrality intervals defined in terms of fraction of inelastic cross section, as determined from bands in $dN/d\eta_T$ or $dN/d\eta_{ZDC}$ (Min. Bias) distributions.

- Distributions fitted with Gaussians, to extract:
  - $dN_{ch}/d\eta$ at the peak
  - Gaussian width
Scaling of $dN/d\eta \bigg|_{\text{max}}$ and $\sigma_{\text{Gauss}}$ vs centrality at 158 GeV/c

$dN/d\eta$ at the peak scales linearly both with $E_T$ and $E_{\text{ZDC}}$

Gaussian width decreases with centrality (stopping power effect)

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\( dN/d\eta \) distributions vs centrality at 40 GeV/c

\( N_{\text{ch}} \) density $\times$ 2 times smaller than at 158 GeV/c

Width smaller than at 158 GeV/c
Charged particle scaling vs $N_{\text{part}}$

Fit with a power-law:
\[
\frac{dN}{d\eta}_{\text{max}} \propto N_{\text{part}}^\alpha
\]

(with $N_{\text{part}}$ estimated in the framework of the Glauber model)

Results of the fits:
\[
\alpha = 1.00 \pm 0.01 \text{ (stat)} \pm 0.04 \text{ (syst)} \quad (158 \text{ GeV/c})
\]
\[
\alpha = 1.02 \pm 0.02 \text{ (stat)} \pm 0.06 \text{ (syst)} \quad (40 \text{ GeV/c})
\]

Within errors, same $N_{\text{part}}$ dependence observed at 158 and 40 GeV/c.

Nearly linear scaling with $N_{\text{part}}$ (as in WNM) indicates dominance of soft processes in particle production at the SPS energies.
**Charged particle scaling vs energy**

Pseudorapidity density of $N_{ch}$ at midrapidity, per participant pair, as a function of c.m.s. energy

Two points from NA50 at:
- $\sqrt{s} = 8.77$ GeV (40 GeV/nucleon)
- $\sqrt{s} = 17.2$ GeV (158 GeV/nucleon)

**Results:**
- The charged particle yield at 40 GeV/nucleon is compatible with the fit to data of inelastic $pp$ interactions.
- The yield at 158 GeV/nucleon is more than 50% higher than any fit to $pp$ data.
- A steep increase is observed that cannot be described by a simple energy scaling.
Summary

Preliminary results from the most recent NA50 data:
- confirm the $J/\psi$ suppression pattern: a threshold effect followed by a steady decrease for the most central Pb-Pb collisions;
- confirm the departure from a normal nuclear absorption (newly determined from p-A and S-U data);
- indicate that the most peripheral Pb-Pb interactions ($b>8.5$ fm) indeed follow the normal nuclear absorption pattern.

Dedicated measurements of $dN/d\eta$ distributions versus centrality showed that:
- at the SPS energies, charged particles scale linearly with $N_{\text{part}}$, in agreement with the Wounded Nucleon Model;
- the steep increase of charged particle production at midrapidity between 40 and 158 GeV/nucleon can not be described by the simple energy scaling observed in nucleon-nucleon collisions.