Study of $pp$ interactions at high multiplicity at U-70

E. Kokouлина. On behalf of SVD Collaboration (IHEP-SINP MSU-JINR)

17.09.2013 ISMD13
High Multiplicity Region (HMR)

Thermalization project (U-70, IHEP) is aimed at studying of $pp$ interactions

\[ p + p \rightarrow 2N + n\pi \]

50 GeV proton beam, multiplicity

\[ n_{ch} \gg \langle n_{ch}(s) \rangle \approx 5, \]

the kinematical limit:

\[ n_{thresh} \approx \left( \sqrt{s} - 2m_p \right) / m_\pi, \quad n_{thresh} \sim 57 \]

SVD-2 setup registers $\pi^\pm$ & $\gamma$’s

Pions are copiously formed at U-70

17.09.2013 ISMD13
At HMR MC event generators are mistaken, models predict diverse topological cross section values

Search for collective phenomena in pp interactions at HMR: Bose-Einstein Condensation (BEC) in system of charged & neutral pions: $N_{\text{tot}} = N_{\text{ch}} + N_0$
SVD-2 setup

1 – Beam Stations
2 – Hydrogen Target
3 – Vertex Detector
4 – High Multipl Trigger
5 – Drift Tube Tracker
6 – Magnet & Proportion Chambers (MS)
7 – Cherenkov Counter
8 – ECal
9 – SPEC (soft photon ECal)

17.09.2013 ISMD13
SVD-2 setup

Trigger level, \( l : n \geq l \) (\( l=2, 4, 6, 8, 10, 12 \))

Scintillator hodoscope – suppression of low multiplicity events

17.09.2013 ISMD13
Selection, reconstruction & corrections

Software is based on Kalman Filter technique. It takes into account heterogeneous magnetic field, multiple scattering, energy losses. 

~1 mln events have been selected, VD data, run 2008 (l=8), H₂

MC simulation (GEANT3.14). 

Corrections: acceptance and efficiency of PVD work, algorithm of track reconstruction efficiency.

Redistributed equation system gives:
Correction of previous data and addition of new points, \( n=18, 20, 22, 24. \)

\[ \sigma = 31.50 \pm 1.14 \text{ mb} \]

\[ <n_{ch}> = 5.45 \pm 0.24 \]

\[ D = 7.21 \pm 2.80 \]

\[ f_2 = 1.75 \]
Gluon Dominance Model (GDM)

GDM describes well multiplicity distributions (MD) in $e^+e^-$ annihilation as two stage model based on QCD quark-gluon cascade (PT QCD) and hadronization:

$$e^+ + e^- \rightarrow \gamma(Z^0) \rightarrow q\bar{q} \rightarrow (q\bar{q}g) \rightarrow h_1 + h_2 + \ldots + h_n$$

1. **I stage**
   - qg-cascade: a) g -> gg; b) q->qg; c) g->qqbar

2. **II stage**
   - hadronization
   - BD

Convolution of two stages

$$P_n = \sum_{m=0}^{n} P_m^G \cdot C_{(2+\alpha m)N}^{n-2} p^{n-2} (1-p)^{(2+\alpha m)N-(n-2)}.$$

$$P_m^G = \frac{k_p (k_p + 1) \ldots (k_p + m - 1)}{m!} \left(\frac{m}{m + k_p}\right)^m \left(\frac{k_p}{m + k_p}\right)^{k_p}.$$
GDM, $e^+e^-$ annihilation

Hadronization in vacuum (fragmentation mechanism) is confirmed:

$$1 \text{ parton} \rightarrow 1 \text{ hadron}$$

(LoPAD)

$$\bar{n}_g^h \approx 1$$

$$\frac{\text{Baryon}}{\text{Meson}} \ll 1$$

Average number of hadrons nascent from single gluon source at its passage through hadronization stage

$$\bar{n}_g^h$$

B Muller, nucl-th/0404015

17.09.2013 ISMD13
GDM: \( pp \) & \( p\bar{p} \) interactions

**GDM:** quarks of initial protons stay in leading particles (U70 - ISR). Multiparticle production is realized by active gluons. Two schemes (with/without gluon branching): g-cascade \( \times \) hadronization (BD)

Recombination mechanism of hadronization is confirmed in \( pp \), \( p\bar{p} \), AA interactions.

**Growth** \( \bar{n}^h \) in \( pp \):

1.5 (50 GeV/c, U-70) ->
3.3 (62.2 GeV, ISR)

hadronization occurs in quark-gluon medium

B Muller, nucl-th/0404015

\[
\frac{Baryon}{Meson} \approx 1, RHIC
\]

17.09.2013 ISMD13
Gluon fission (gf) in pp, \( p\bar{p} \), \( e^+e^- \)

E. Kuraev, S. Bakmaev, E. K.
Nucl. Phys B851 (2011)

In double-logarithmic approximation the emission of two g-jets explains the angle broadening of distributions at high energies (interference). At U-70 it can be realized.
COMPARISON: GDM and other models

- NBD
- GDM wo gf
- IHEP

GDM w gf

\[ \sigma_n (pp) - \sigma_n (pp) = \sigma_n^{\text{ann}} (pp) \]

\[ \langle N_0 \rangle \]

69 GeV/c

14.75 GeV/c

ISR 62.2 GeV

17.09.2013 ISMD13
**The Charged Exchange (CE)**

First indications were observed in $\pi^+p$ and $pp$ in experiments on proportional chambers and CR:

**CE:** $p + p \rightarrow n + \pi^+ + p + N (\pi^+ \pi^-)$

\[
\sigma_2 = \sigma_{2,el} + \sigma_{2,inel}, \quad \sigma_{2,inel} = \sigma_{2,-exch} + \sigma_{2,+esch}, \quad k_2 = \frac{\sigma_{2,+esch}}{\sigma_{2,inel}} \cdot 100\%
\]

**GDM:**

\[
\sigma_{2,el} = e^{-\bar{m}}, \quad \sigma_{2,-exch} = \sum_{m=0}^{Mg} e^{-\bar{m}} \frac{\bar{m}^m}{m!} C_{mN}^{n-2} \left(1 - \frac{\bar{n}^h}{N}\right)^{mN}.
\]

1) Data description of $\sigma_n$, $2 \leq n \leq 24$, $\sigma_{2,inel} = p_2 \cdot \sigma_{2,-exch}$

2) Fitting data by GDM $\rightarrow p_2 \rightarrow k_2 = p_2 / (p_2 - 1) \times 100$

3) $k_2 \approx 50\pm5\%$ is comparable with data [Murzin, Sarycheva]

*17.09.2013 ISMD13*
V. Begun and M. Gorenstein (PL, 2007; PR, 2008) have predicted possibility of the Bose-Einstein Condensation (BEC) formation in pp interactions at U-70 at high total multiplicity, $n_{\text{tot}} = n_{\text{ch}} + n_0$, based on ideal pion gas model.

The phase diagram of pion gas with $\mu_Q = 0$. The dashed line corresponds to $\rho_\pi(T, \mu_\pi = 0)$ and the solid line to BEC. The dotted lines show the states with fixed energy densities, $\varepsilon = 6$, 20, 60 MeV/fm$^3$. $N_\pi$ numbers correspond to $\mu_\pi = 0$ and $\mu_\pi = m_\pi$ at these densities for total pion energy, $E = 9.7$ GeV.
Search for Collective phenomena

Scaled variance, $\omega^0 = D/<N_0>$, $D$ is variance for $\pi^0$-mesons, $N_{\text{tot}} = N_\pi$ — fixed. MC, Poisson give $\omega = 1$.

B-G predictions — $\omega^0$ for the number fluctuations of $\pi^0$ & $\pi^\pm$ increases dramatically and abruptly if the pion system approaches the BEC line at TL $T_C$.

$T_C(\pi) >> T_C(A)$

$\frac{T_C(\pi)}{T_C(A)} \approx \frac{m_A}{m} \left( \frac{r_A}{r_\pi} \right)^2 \approx \frac{m_A}{m} 10^{10}$

The case of the finite size system, relativistic pion gas: 1) $T \rightarrow T_C$ ($T < T_C$), $\omega^0 \sim \sqrt{V}$; 2) $T = T_C$, $\omega^0 \sim \sqrt{V}$.

17.09.2013 ISMD13
Experimental Results

Scaled variable, \( n_0 = \frac{N_0}{N_{\text{tot}}} \) (\( 0 \leq n_0 \leq 1 \))

\[ r_0 = P(N_0, N_{\text{tot}}) \]

Multiplicity distributions of \( \pi^0 \)'s at fixed \( N_{\text{tot}} \)

\[ D = \sigma^2 \]

SVD Collaboration, EPJ, 2012; ICHEP 2012.

17.09.2013 ISMD13
Experimental Results

SVD Collaboration EPJ, 2012

17.09.2013 ISMD13
Experiment: $\sigma_\gamma$ for soft direct photons are considerably above than expected from hadronic bremsstrahlung

Lichard & Van Hove (1990) – model cold QGP describes data well

S. Barshay  PL B227(1989) – excess of soft photon yield can be stipulated of BEC formation

17.09.2013 ISMD13
ECal of Soft Photons (SPEC)

- BGO crystal
- PMP butt ends assembly
- HV power source plateau
- Cooling system of thermo-stabilization of whole assembly
- Matching amplifier between ADC & preamplifier (IHEP)

17.09.2013 ISMD13
ECal of Soft Photons

Protecting system

Polyethylene neutron-background protection (abatement of neutron background)

17.09.2013 ISMD13
Low formula of SP spectra

\[
\frac{d\sigma}{dp} = \frac{C}{E}
\]

\[
\sigma_{SP} = \int_{10}^{30(MeV)} \frac{d\sigma}{dp} dp \approx 4mb
\]

Response of SPEC on $^{137}$Cs line (661.6keV) features:
- Radiation length $\approx 16$
- Solid angle 10 sr
- Dynamic range $0.5 - 10^3$ MeV
- Noise level < 80 keV
- Thermo stability $18\pm1$ °C
- Amplifiers & HV bias build in
- Guard system 12 counters
- Power consumption 13 Wt

17.09.2013 ISMD13
CONCLUSIONS & OUTLOOK

1. HMR is unique and hopeful region
2. Study of total HM is fruitful
3. Collective phenomena exist in HMR
4. Active role of gluons is confirmed at HMR by GDM
5. Study of Soft Photon yield at U-70 & Nuclotron versus multiplicity

17.09.2013 ISMD13