Identified particle spectra in single diffractive dissociation process in pp at $\sqrt{s} = 200$ GeV measured with the STAR detector

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Motivation

- **Single Diffractive Dissociation:**
  \[ a + b \rightarrow a + X \]
  where \( a \) and \( b \) denote hadrons, whereas \( X \) is a multi-particle state of the same quantum numbers as particle \( b \).

- **Regge Theory** → colorless exchange mediated by the Pomeron.

- **Experiments:**
  - \( pp(p\bar{p}) \) ISR, SPS, TEVATRON, LHC, RHIC
  - \( ep \) HERA
  - \( pA \) LHC, RHIC

- Study of particle spectra in diffractive dissociation and compare it with non-diffractive dissociation.

- Measurement of baryon number transfer from forward to mid rapidity in SDD.

- Compare measurement with PYTHIA8 expectation.
Antiparticle-to-particle ratios in non-diffractive dissociation

- Antiparticle/particle ($\pi^-/\pi^+, K/K^+, \bar{p}/p$) ratios as a function of the charged particle multiplicity in $pp$, $d+Au$ at 200 GeV and $Au+Au$ collisions at 62.4 GeV, 130 GeV, and 200 GeV measured at STAR[1].
- The $\pi^-/\pi^+$ ratio $\sim 1$ for all measured collision systems and collision energies.
- The $K/K^+$ ratios close to 1 in $pp$, $d+Au$ and $Au+Au$ collisions at 200 GeV.
- The $\bar{p}/p$ ratio in peripheral $Au+Au$ at 200 GeV similar to that in $pp$ and $d+Au$ collisions at the same energy and varies between 0.75 – 0.9.
- A sizeable baryon-antibaryon asymmetry in photon-proton interaction observed by the H1 Collaboration[2] for $p/\bar{p}$ with small momentum: $A = 2 \cdot \left( \frac{N_p - N_{\bar{p}}}{N_p + N_{\bar{p}}} \right) = (8.0 \pm 1.0 \pm 2.5)\% \rightarrow$ net baryon number transported through phase space.
- Study particle/antiparticle ratios as a function of $p_T$ in SDD process in $pp$ collision at $\sqrt{s} = 200$ GeV.
polarized proton-proton (transversely and longitudinally)
center-of-mass energy up to $\sqrt{s} = 510$ GeV for pp and $\sqrt{s_{NN}} = 200$ GeV for AA
Measuring SDD at STAR

- Need detectors to tag forward protons and detector with good acceptance and particle ID to measure diffractive system
- 4 Roman Pot stations: $3 \cdot 10^{-3} < -t < 3 \cdot 10^{-2}$ GeV$^2$, $0 < \phi < 2\pi$
- TPC tracking and particle identification (dE/dx): $-1 < \eta < 1$
- BBCs and ZDCs used for triggering and luminosity determination.
- TPC track matched with TOF hit - primary tracks and proton come from the same bunch crossing;
Selection of SDD events and kinematic range of the measurement

- Select events using trigger conditions:
  - one reconstructed proton in the Roman Pot (RP) station on west or east;
  - signal in BBC or ZDC on opposite side;
  - no signal in BBC and ZDC on the proton side;

- Diffractive system $X$ registered in TPC:
  - $|\eta| < 1.0$;
  - $p_T > 0.15$ GeV/c;
  - primary TPC tracks $\geq 2$ and one of them matched with TOF hit;
  - $|z\text{-vertex}| < 100$ cm;
  - Particle spectra analysis - $|\eta| < 0.5$;

- Acceptance limits kinematic range to:
  - diffractive system $X$:
    - $15 < M_X < 110$ GeV
  - proton kinematics:
    - $4 \cdot 10^{-3} < -t < 3 \cdot 10^{-2}$ GeV$^2$
    - $0.002 < \xi = \frac{\Delta p}{p} < 0.25$
Background rejection by additional position cuts;
- Compare data with PYTHIA8 (Single Diffraction, Double Diffraction, Central Diffraction and Minimum Bias)
- PYTHIA8 normalized to the luminosity in data;
- Selected sample dominated by SD process.
Compare data with MC: TPC primary tracks

PYTHIA8 normalized to data - compare shape of the distributions;
PYTHIA8 weighted with z-vertex;
PYTHIA8 describes data well but small discrepancies in pseudorapidity
Particle identification

- Measure mass and momentum dependent energy loss \((dE/dx)\);
- Convert \(dE/dx\) into momentum independent Gaussian variable \(z_i\) \((i = \pi, K, p)\) [1];
- \(z_i = \ln \left( \frac{dE/dx}{(dE/dx)_i^{BB}} \right)\)
- \((dE/dx)_i^{BB}\) - the Bethe-Bloch inspired parameterization of \(dE/dx\) for the given particle type;
- \((dE/dx)_i^{BB} = A_i^{BB} \left( 1 + \frac{m_i^2}{p^2} \right)\)
- \(A_i^{BB}\) factor determined from data;
- The expected value of \(z_i\) for the particle in study around 0.
Extraction of raw particle yields

\[ \chi^2 / \text{ndf} = 95.02 / 27 \]

**\( 0.35 < p_T < 0.40 \text{ GeV/c}, \text{statistical errors only} \)**

- **\( C_\pi = 0.909 \pm 0.007 \)**
- **\( \mu_\pi = -0.002058 \pm 0.000585 \)**
- **\( \sigma_\pi = 0.07503 \pm 0.00046 \)**
- **\( C_\mu = 0.000869 \pm 0.000724 \)**
- **\( \mu_\mu = 0.3677 \pm 0.0063 \)**
- **\( \sigma_\mu = 0.07 \pm 0.01 \)**
- **\( C_e = 0.03307 \pm 0.00128 \)**
- **\( \mu_e = 0.7315 \pm 0.0037 \)**
- **\( \sigma_e = 0.08804 \pm 0.00279 \)**

**\( 0.35 < p_T < 0.40 \text{ GeV/c}, \text{statistical errors only} \)**

- **\( C_\pi = 0.8967 \pm 0.0125 \)**
- **\( \mu_\pi = -0.7394 \pm 0.0010 \)**
- **\( \sigma_\pi = 0.09649 \pm 0.00084 \)**
- **\( C_\mu = 0.02558 \pm 0.01086 \)**
- **\( \mu_\mu = -0.4881 \pm 0.0782 \)**
- **\( \sigma_\mu = 0.1679 \pm 0.0376 \)**
- **\( C_e = 0.000873 \pm 0.00047 \)**
- **\( \mu_e = 0.0782 \pm 0.4881 \)**
- **\( \sigma_e = 0.0010 \pm 0.0037 \)**

**\( 0.3 < p_T < 0.4 \text{ GeV/c}, \text{statistical errors only} \)**

- **\( C_p = 0.03446 \pm 0.00087 \)**
- **\( \mu_p = -0.009548 \pm 0.001774 \)**
- **\( \sigma_p = 0.06854 \pm 0.00140 \)**

- Plot \( z_i \) distributions for a given particle in a given \( p_T \) range;
- The \( z_i \) distributions/peaks simultaneously fitted by multiple Gaussians to extract the raw particle yields;
- Contribution of electrons and deuterons.
Particle identification: pion and kaon

- \( \pi^+ / \pi^- \) and \( K^+ / K^- \) ratios consistent with STAR non-diffractive measurements.
- PYTHIA8 particle production model describes data well.
Proton background subtraction

- Proton sample contains background protons knocked out from the beam pipe and the detector materials by interactions of produced hadrons in these materials - nearly flat DCA tail in the proton distribution (DCA - the closest distance from the collision vertex to a track helix).

- Antiprotons do not have knock-out background - the flat DCA tail absent from their DCA distribution.

- Based on MC simulation studies made for the other analysis, i.e. [1], it was found that the description of the background protons:

\[ p_{bkgd}(DCA) \propto [1 - \exp(-DCA/d_0)] \]

Assuming that the shape of the background-subtracted proton DCA distribution is identical to that for the antiproton DCA distribution, the proton data can be fit by:

\[ p(DCA) = \bar{p}(DCA)/r_{\bar{p}/p} + A \cdot p_{bkgd}(DCA) \]

where the parameters \(d_0, r_{\bar{p}/p}\) and \(A\) are free parameters.

- Above assumption is not strictly valid because the weak decay contributions to the proton and antiproton samples are in principle different. However, the difference in DCA distributions between \(p\) and \(\bar{p}\) arising from weak decay contamination is small.
Proton background subtraction

\[ \frac{dN}{d(DCA)} \]

\[ \chi^2/\text{ndf} = 12.69 / 7 \]
\[ r_{pp} = 0.632 \pm 0.065 \]
\[ A = 195.6 \pm 7.0 \]
\[ d_o = 0.1976 \pm 0.1070 \]

\[ \langle p/p \rangle < 0.5 \text{ GeV/c} \]

\[ 0.4 < p_T < 0.5 \text{ GeV/c}, \text{ PYTHIA8} \]
\[ \chi^2/\text{ndf} = 14.31 / 7 \]
\[ r_{pp} = 0.756 \pm 0.050 \]
\[ A = 26.3 \pm 5.3 \]
\[ d_o = 0.8033 \pm 0.5940 \]

\[ \bar{p}/p \] ratio below 1 for data and PYTHIA8;
- Discrepancy between data and PYTHIA8;
- \( \bar{p}/p \) ratio about 0.8 and consistent with STAR nondiffractive measurements;
- Baryon number transport may be higher than expected by PYTHIA8 model but larger data sample needed.
New RP setup (STAR Phase II configuration) to be able to take data without special conditions to acquire large data samples.

\[ 0.03 \leq -t \leq 0.3 \text{ GeV}^2 \]

35 mln SDD events collected $\rightarrow$ analysis in progress.

We are looking forward to more data in pp run 2017 at $\sqrt{s} = 510$ GeV.
Summary

- Measurement of particle production in SDD at $\sqrt{s} = 200$ GeV has been shown;
- Preliminary results on $\pi^+ / \pi^-$ and $K^+ / K^-$ ratios are well reproduced by the PYTHIA 8 particle production model and agree with STAR previous non-diffractive measurements.
- Preliminary results on $\bar{p}/p$ ratio equals to $\sim 0.8$ and is consistent with STAR non-diffractive measurements.
- Preliminary results on $\bar{p}/p$ ratio may indicate that baryon number transport is higher than expected by PYTHIA 8 model but larger data sample is needed.
- Comparisons with different simulators, e.g. HIJING, are also planned to understand the dynamics of baryon number transport.
- We had a very successful data taking in just finished 2015 run in pp collisions.
- We are looking forward to more data in pp run 2017 at $\sqrt{s} = 510$ GeV.
The String Models[3]:
- two protons create "excitations" in form of two strings, which consist of one quark on the one side and a diquark on the other side:
  1. Longitudinal excitation - string consists only of one proton valence quarks;
  2. Color exchange - string created by joining a quark of one proton and a diquark from the other proton;
- hadronization - break the string and form a pair of $q - \bar{q}$;

Quark-Gluon Strings Model QGSM[4]:
- based on nonperturbative notions, combining QCD with Regge theory and using parton structure of hadrons;
- the baryon number cannot be transported over large rapidity space.

The Multisource thermal model[5] - particles divided into sources described by Erlang distribution. The source is considered as a thermodynamic system of quantum ideal gas.


