A study of baryon production in single and multiple hadronic collisions

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June 24-28, 2013, Glasgow

Introduction

- Data obtained with NA49 experiment
- Beam momentum 158 GeV/c

1. Hadron-proton interactions
   - ➜ p + p
   - n + p
   - $\pi^{\pm}$ + p
2. Hadron-nucleus interactions
   - d + p
   - ➜ p + C
   - p + Pb (with controlled centrality)
   - $\pi^{\pm}$ + Pb
3. Nucleus-nucleus interactions
   - Pb+Pb

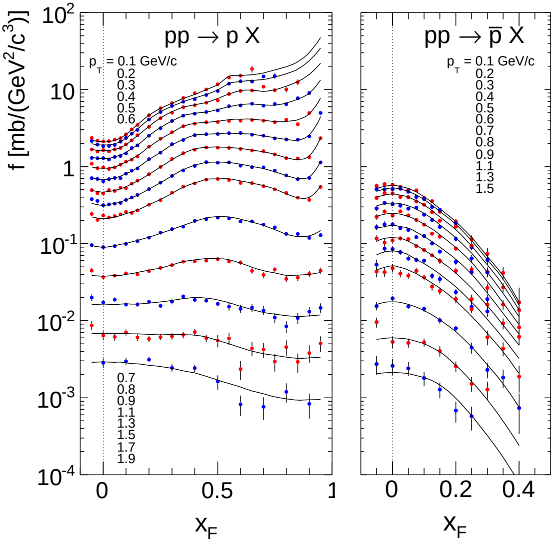
- Precision data in variety of reactions, syst. <3%
- Maximum phase space coverage
- Detailed comparison with existing measurements
- Model independent analysis and interpretation of the data

Outline

1. Single hadronic collisions – p+p collisions
   - Inclusive proton and antiproton distributions
   - Proton and neutron p_T integrated distributions
   - Net baryon distribution
   - Two component mechanism
   - Resonance decay – baryon number transfer
   - Charge-exchange and non-charge-exchange processes
2. Multiple hadronic collisions – p+C collisions with $\langle \nu \rangle = 1.6$
   - Inclusive proton and antiproton distributions
   - Proton and neutron p_T integrated distributions
   - Baryon number transfer
   - Three component mechanism
   - Prediction of the target component from p+p collisions
   - Extraction of the nuclear cascading

Single collisions

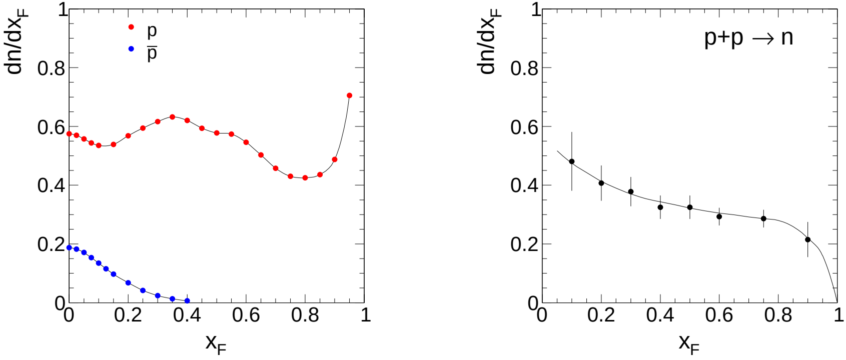
Protons and anti-protons in p+p collisions



- Used variables:
  - $x_F = 2p_L^*/\sqrt{s}$
  - transverse momentum – p_T
- $x_F = 0 \div 0.95$ and $p_T = 0 \div 1.9$ GeV/c for p
- $x_F = 0 \div 0.4$ and $p_T = 0 \div 1.5$ GeV/c for $\overline{\mathrm{p}}$

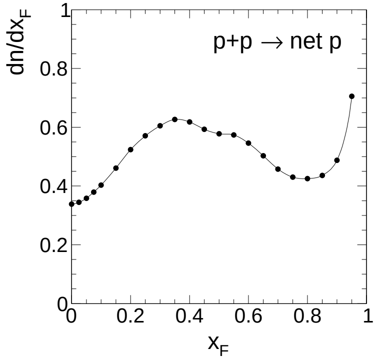
Protons and neutrons in p+p collisions: p_T integrated

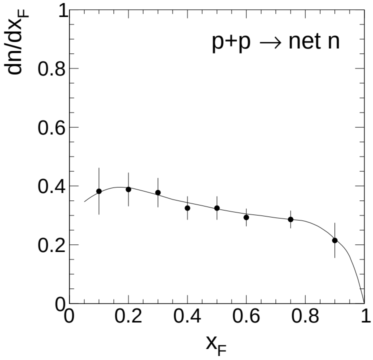
- Neutron coverage: $x_F = 0.1 \div 0.95$, p_T integrated



Net protons and net neutrons in p+p collisions

- Net baryons = baryons - pair produced baryons
- Pair produced baryons are extracted from measured antiprotons taking into account the isospin effect

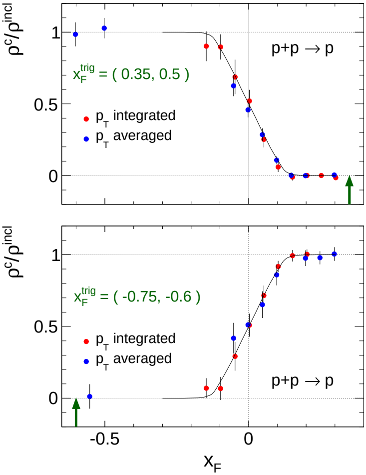




Two component mechanism in p+p interactions

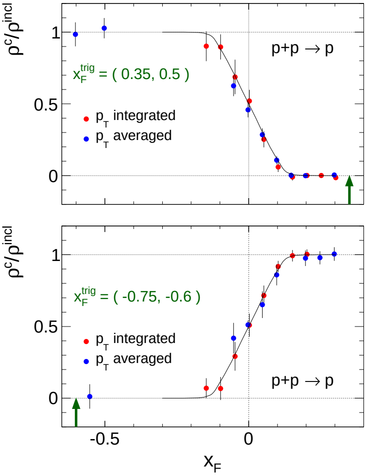
- Two components
  - Projectile fragmentation
  - Target fragmentation
- Overlap between projectile and target components

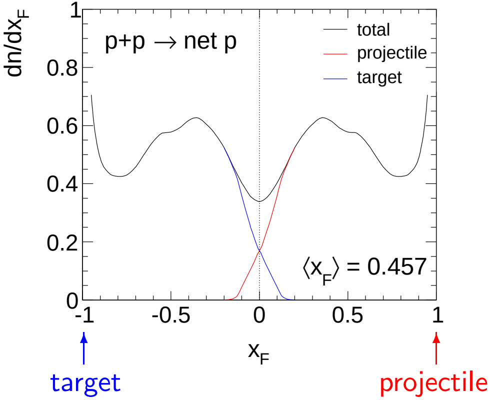
Net proton overlap function



- Study of net proton overlap function between target and projectile fragmentation by fixing the baryon number
- Proton is fixed at large $|x_F|$, excluding pair produced protons:
  - projectile hemisphere: $0.35 < x_F < 0.5$
  - target hemisphere: $-0.75 < x_F < -0.6$
- Overlap range is $|x_F| < 0.2$

Net proton overlap function

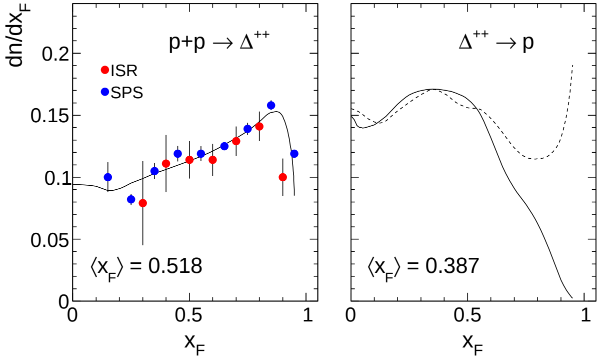




- Baryon number transfer from projectile (target) to central region
- Mean transfer of about 0.55 units of x_F

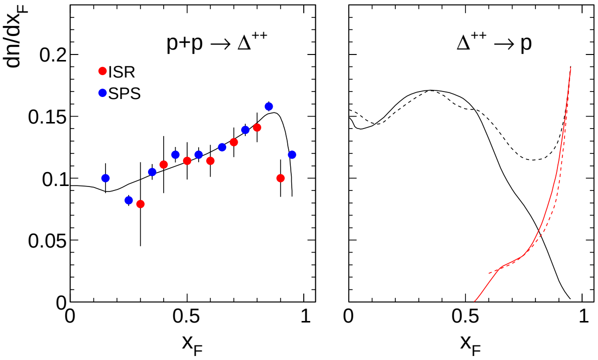
Proton produced from Δ decays

- Resonance decay is very efficient in baryon number transfer
- Most if not all of the final state baryon are produced from resonance decay
- Δ^{++} example – baryon number transfer is more than 0.1 in x_F



- For $|x_F| < 0.6$ the shape of the decay protons from Δ^{++} reproduces the inclusive proton distribution multiplied by factor of 0.27
- Δ^{+} and Δ^{0} increase proton production to about 40%

Proton produced from Δ decays



- The difference between decay and inclusive distribution is well described by $1/M_x^2$
- Single diffraction $M_x^2 \sim s(1 - x_F)$ (dashed red line)

Charge exchange vs non-charge exchange

- 40% of all non-diffractive protons come from Δ decay
- Absence of charge and flavour exchange at SPS energies
- No direct Δ production because there is no charge-exchange at SPS energy

Charge exchange

- Elastic charge exchange scattering

  $\mathbf{n} + \mathbf{p} \rightarrow \mathbf{p} + \mathbf{n}$

- Single dissociation

  $\mathbf{p} + \mathbf{p} \rightarrow \mathbf{n} + \boldsymbol{\Delta}^{++} \rightarrow \mathbf{n} + (\mathbf{p} + \pi^{+})$

- Double dissociation

  $\mathbf{p} + \mathbf{p} \rightarrow (\mathbf{p} + \pi^{-}) + (\mathbf{p} + \pi^{+})$

Non-charge exchange

- Elastic scattering

  $\mathbf{p} + \mathbf{p} \rightarrow \mathbf{p} + \mathbf{p}$

- Single dissociation

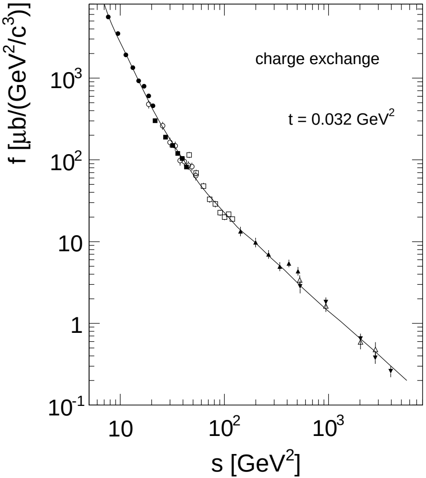
  $\mathbf{p} + \mathbf{p} \rightarrow \mathbf{p} + (\mathbf{p} + \pi^{+} + \pi^{-})$

- Double dissociation

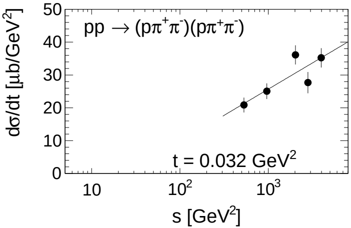
  $\mathbf{p} + \mathbf{p} \rightarrow (\mathbf{p} + \pi^{+} + \pi^{-}) + (\mathbf{p} + \pi^{+} + \pi^{-})$

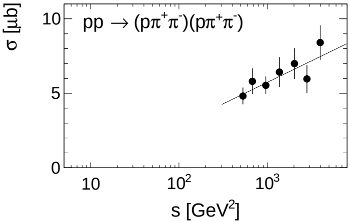
Charge exchange vs non-charge exchange II

Charge exchange



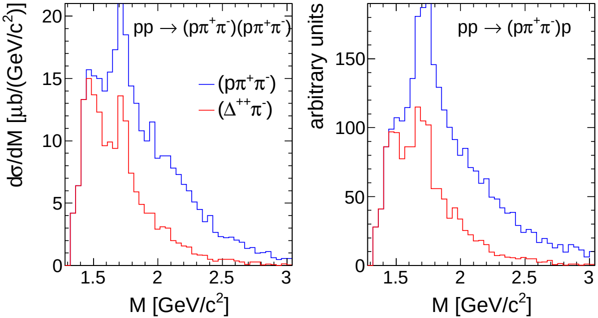
Non-charge exchange





Double and single dissociation from ISR

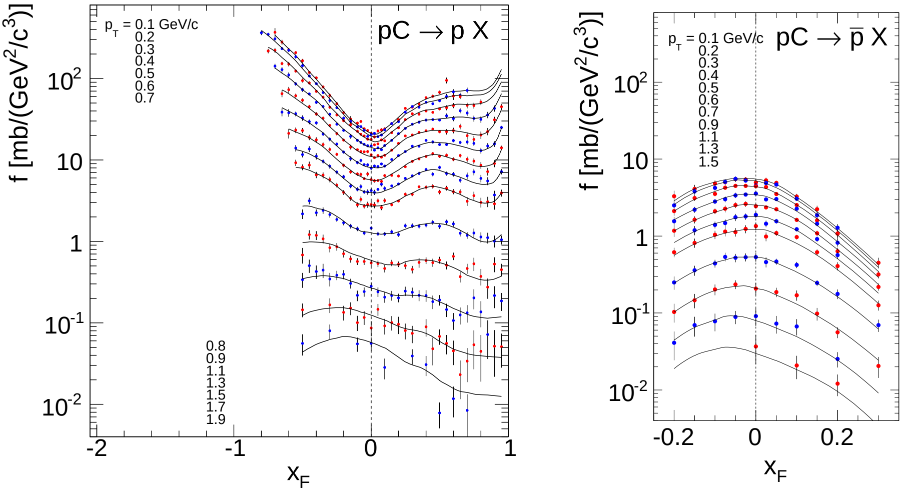
- Double and single dissociation from ISR at $\sqrt{s} = 53$ GeV
- $\Delta^{++}\pi^-$ channel is fully contained in $p\pi^+\pi^-$
- All Δ comes from N^* decay



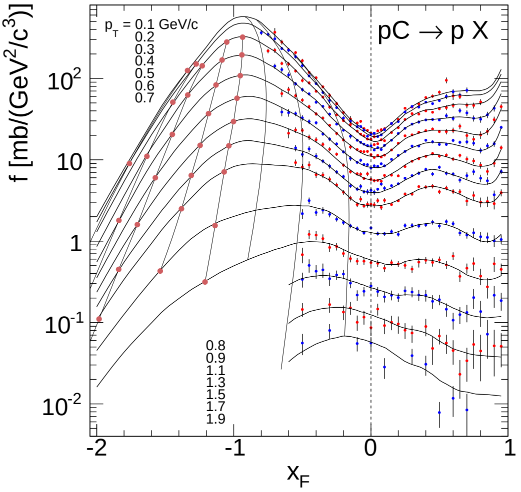
Multiple collisions

- Mean number of projectile interactions $\langle \nu \rangle$ inside the nucleus in p+A collisions
  - p+C – $\langle \nu \rangle = 1.6$
  - p+Pb – $\langle \nu \rangle = 3.7$

Protons and anti-protons in p+C collisions

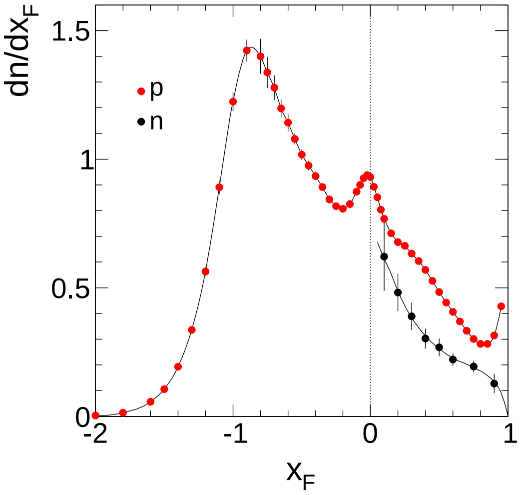


Protons and anti-protons in p+C collisions



- Data from Fermilab at 400 GeV/c beam momentum
- *s*-dependence is negligible
- Measurement from x_F =-2 to $x_F = 1$
- No indication of diffractive structure close to x_F = -1
- Maximum of the distributions is at x_F = -0.92

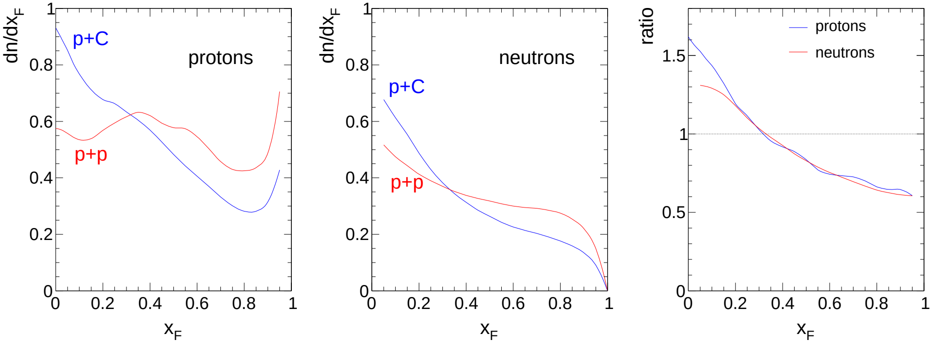
Protons and neutrons in p+C collisions: p_T integrated



- Proton distribution from x_F = -2 to x_F = +1
- Neutron distribution only in the forward hemisphere

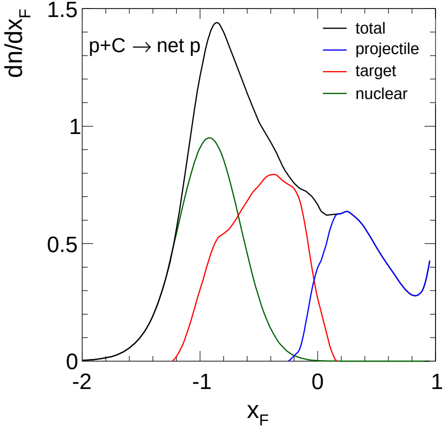
Baryon transfer ("stopping")

- Baryon transfer is equal for protons and neutrons



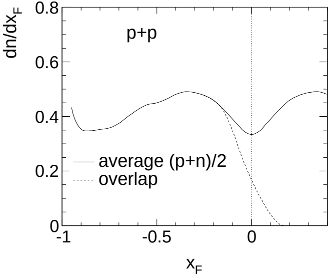
Three components in p+C interactions

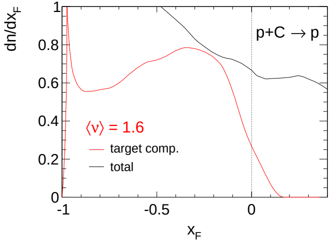
- Net protons
- The three components
  - Projectile fragmentation
  - Target fragmentation
  - Nuclear cascading



Target and projectile component of protons in p+C

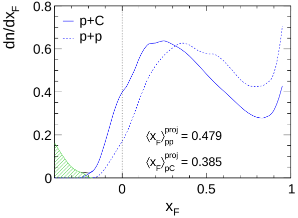
Target fragmentation





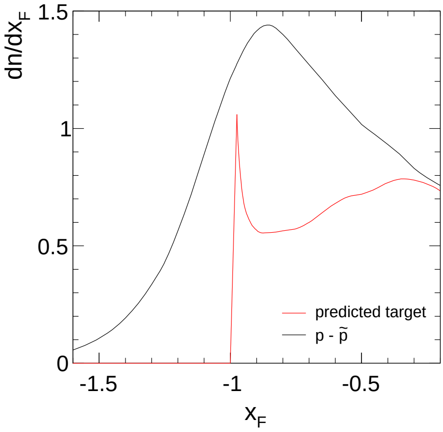
- Target component predicted from p+p collisions
- Isoscalar nucleus – average between protons and neutrons, multiplied by $\langle\nu\rangle = 1.6$

Projectile fragmentation



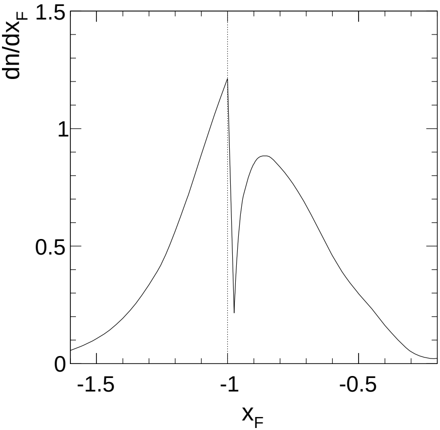
- Shift in $x_F \sim 0.1$
- Verifies baryon number conservation
- Below $x_F = -0.2$ onset of nuclear component

Nuclear component



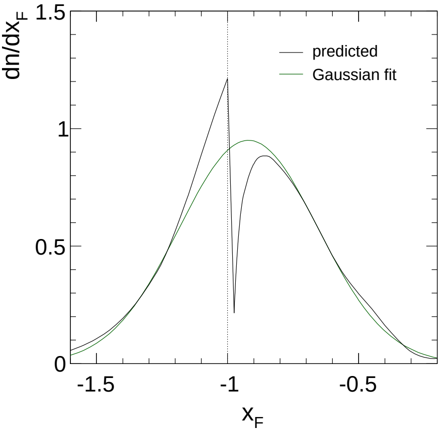
- Subtraction of the predicted target component from total

Nuclear component



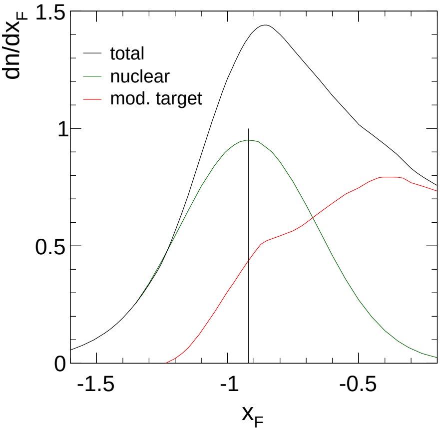
- Subtraction of the predicted target component from total
- No diffractive peak at target hemisphere due to the quasi-elastic scattering in the nucleus

Nuclear component



- Subtraction of the predicted target component from total
- No diffractive peak at target hemisphere due to the quasi-elastic scattering in the nucleus
- Nuclear component described by Gaussian with:
  - $\sigma \sim 0.26$ units of x_F
  - centered at $x_F \sim$ -0.92

Nuclear component



- Subtraction of the predicted target component from total
- No diffractive peak at target hemisphere due to the quasi-elastic scattering in the nucleus
- Nuclear component described by Gaussian with:
  - $\sigma \sim 0.26$ units of x_F
  - centered at $x_F \sim$ -0.92
- Modified target component reaches $x_F =$ -1.2

Conclusions

- Precise measurement, with wide acceptance coverage, of inclusive cross sections of baryons in single and multiple collisions is performed with the same detector at 158 GeV/c beam momentum
- Extraction in a model independent way the two (three) components of hadronization in single (multiple) collisions
- Most if not all the final state baryons come from resonance decay. The resonance decay is very effective way of transferring the baryon number towards the central region