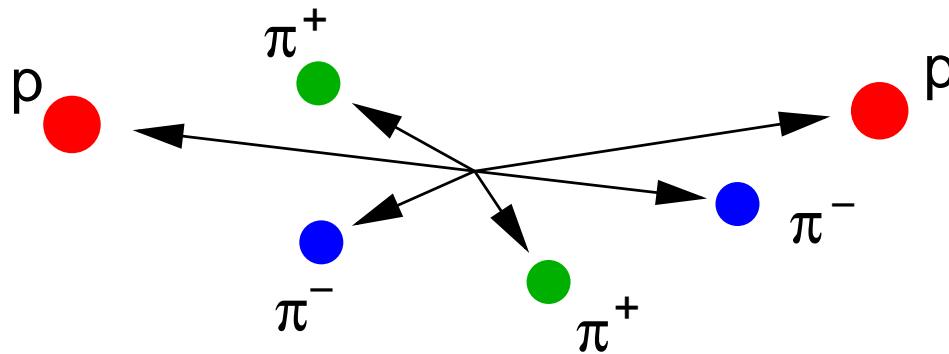
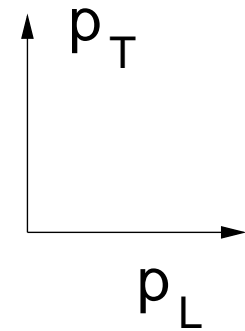
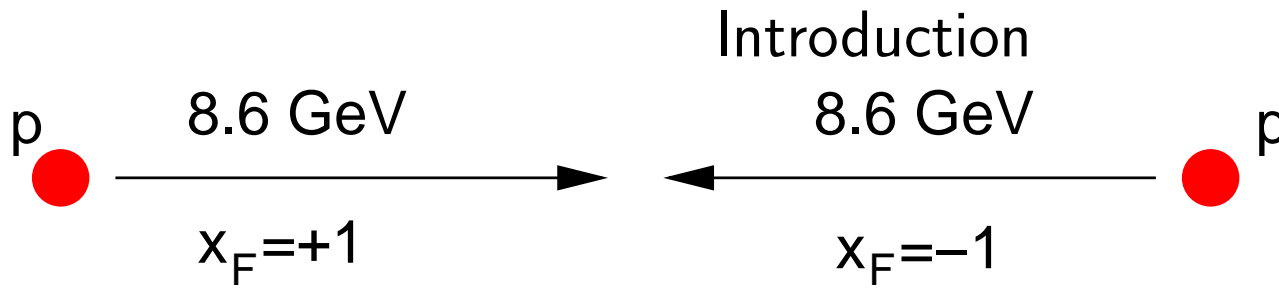


Quark Matter 2005, Budapest

$p+p$  and  $p+A$  physics at SPS  
– and their relation to  $A+A$

Dezső Varga (*CERN, Geneva, Switzerland*)  
for the NA49 Collaboration

- Why both  $p+p$  and  $p+A$  is needed as a reference for  $A+A$ ?
- How to understand baryon and pion production in  $p+p$  and  $p+A$ ?
- How to relate  $p+p$  and  $p+A$  to  $A+A$ ?

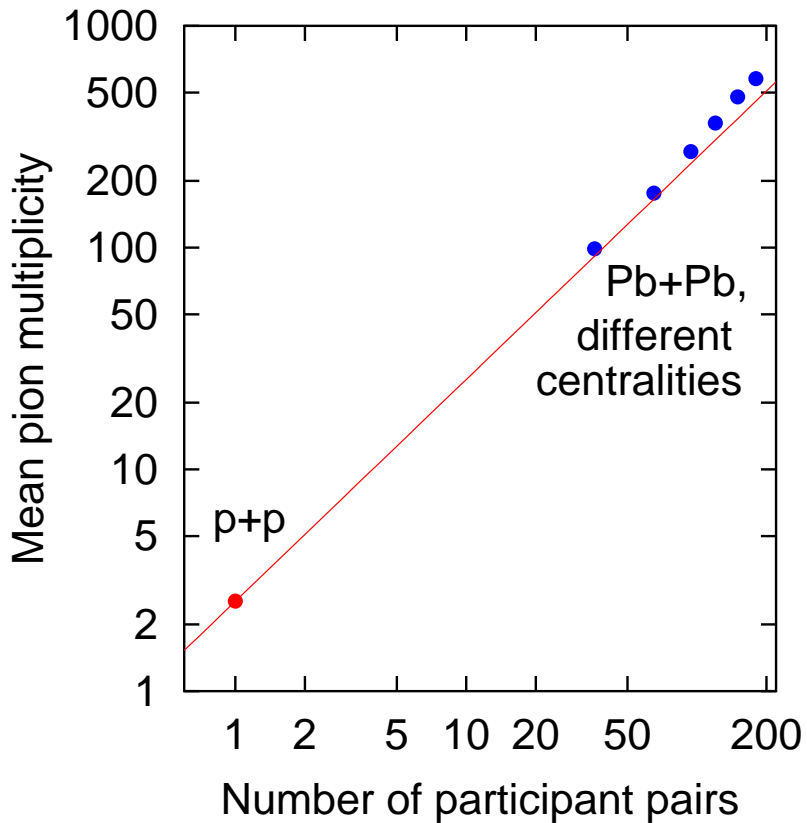


$$x_F = \frac{p_L}{p_{\max}}$$

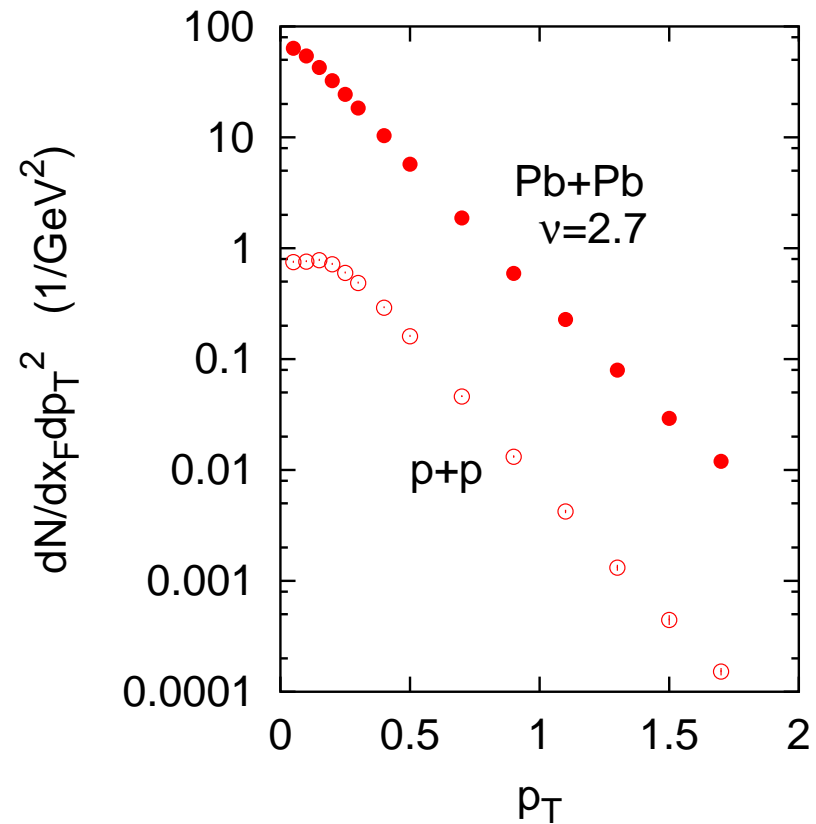
- Exponential damping in  $p_T$ , 95% of particles below 1 GeV
- Soft hadronic sector: no QCD calculations available
- This talk: no models, but conclude on phenomenological pictures based on experimental information

# Question 1. Why p+A is needed as reference?

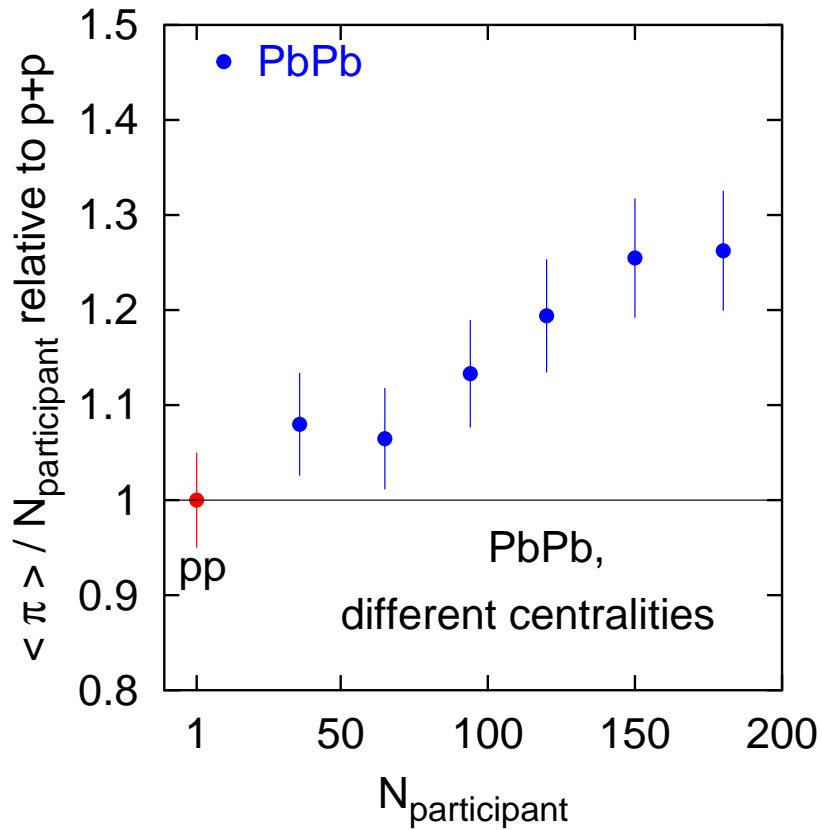
- Pion multiplicity



- Pion production (per event)

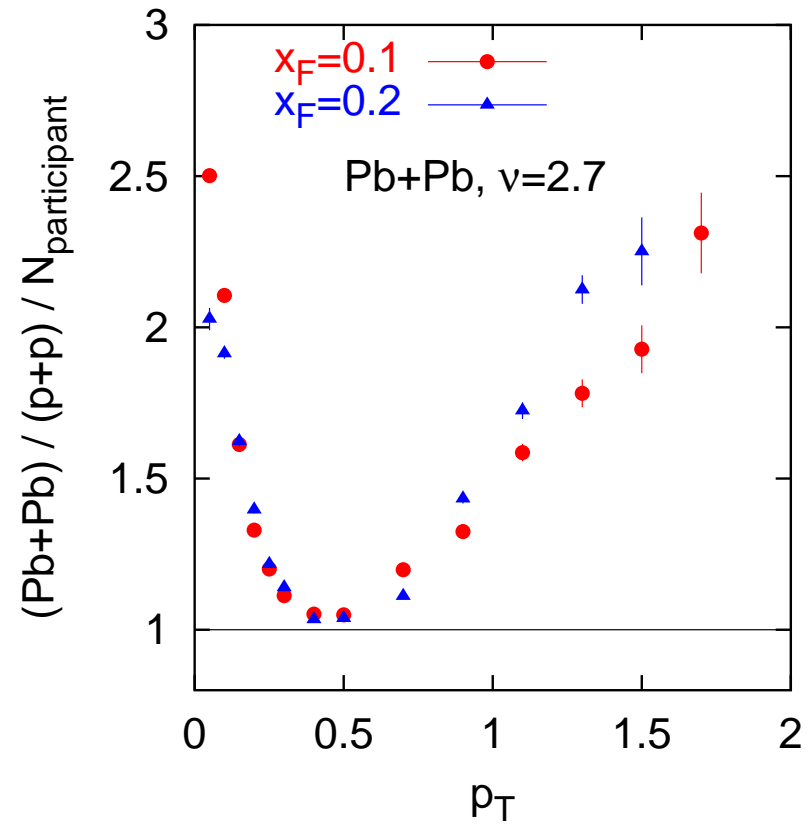


- Increased production in A+A !?



- New phenomena: difference not present in p+A
- Multiple collision effects controlled by p+A

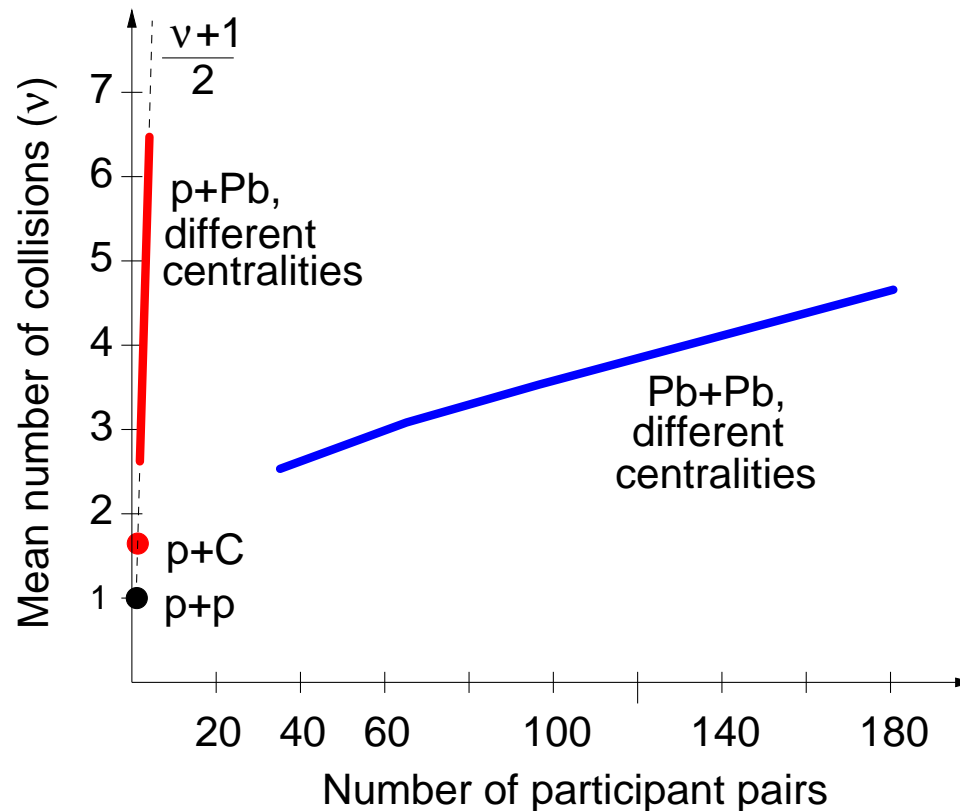
- Increase of high  $p_T$  yield !?



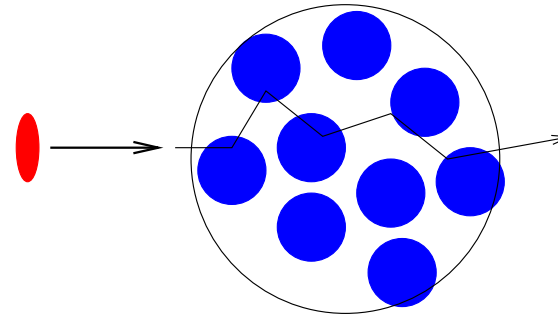
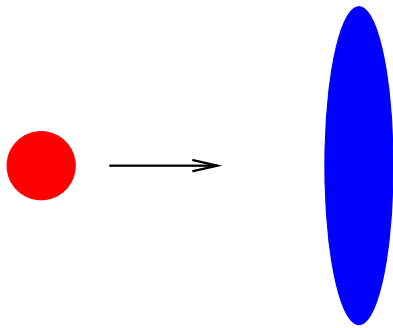
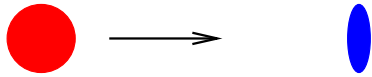
## Question 2. How to relate p+p and p+A to A+A?

Geometrical quantities characterising to the collision:

- Number of interacting nucleon pairs (participants,  $N_{participant}$ )  
(to first order, particle production in A+A proportional to  $N_{participant}$ )
- Number of collisions ( $\nu$ )



### Question 3. What is special about $p+A$ ?



Probes the projectile traversing nuclear matter  
⇒ probes the system after the first collision

Probes the target, “multiple collisions” by the same projectile

This talk concentrates on:

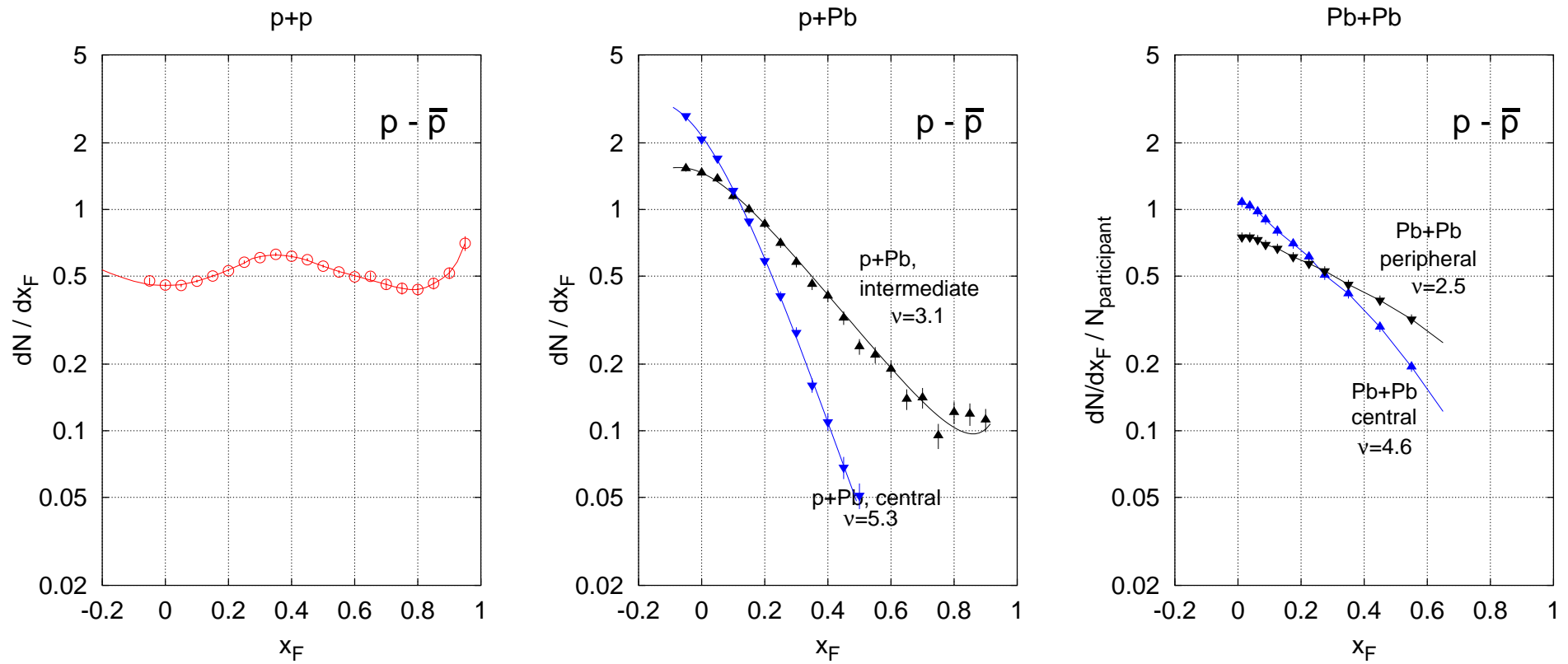
## Baryons:

- How does the Baryon number (BN) of the initial state translate to the final state?  
⇒ BN conservation imposes constraints
- Evolution from  $p+p$  to  $p+A$  and  $A+A$

## Pions:

- Relation to baryons
- Where do they originate from
- Evolution from  $p+p$  to  $p+A$  and  $A+A$

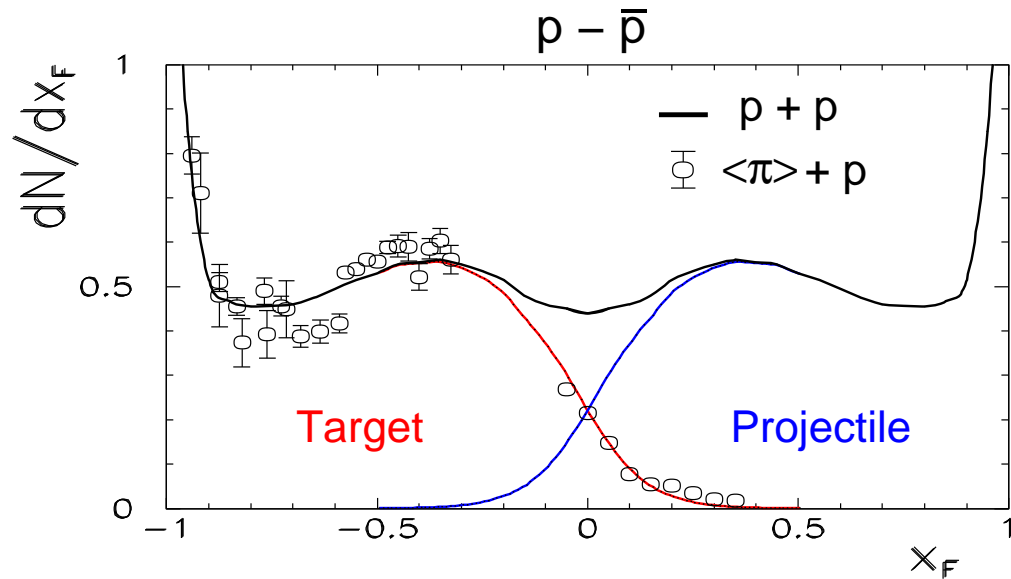
# Baryons: stopping in nuclear reactions



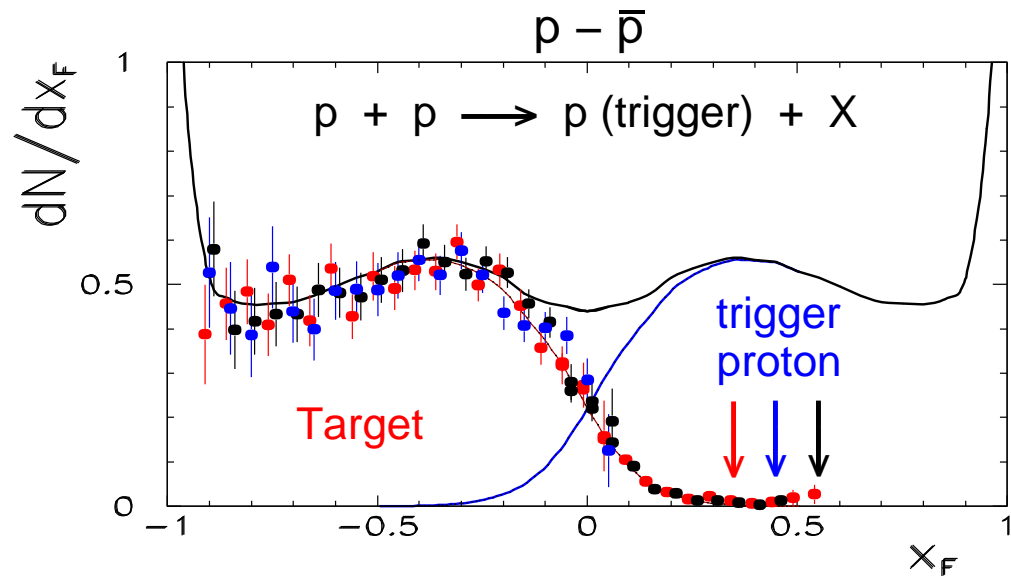
→ experimental possibility: non-baryonic beam



# Baryon density in h+h interactions



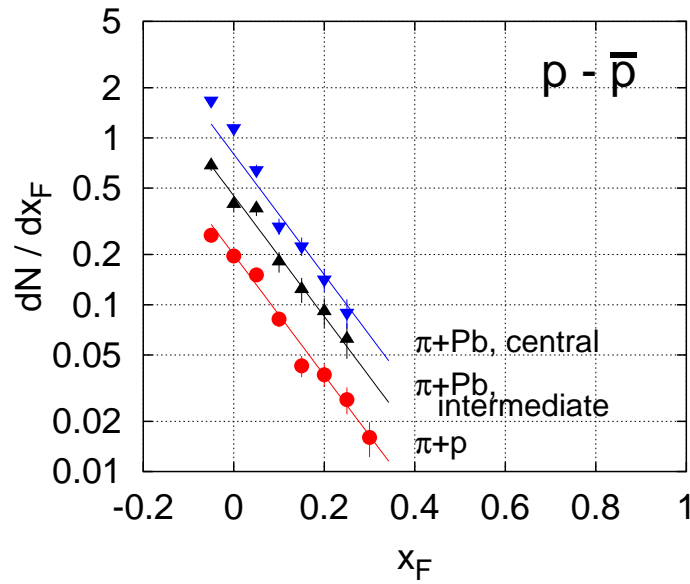
NA49 preliminary



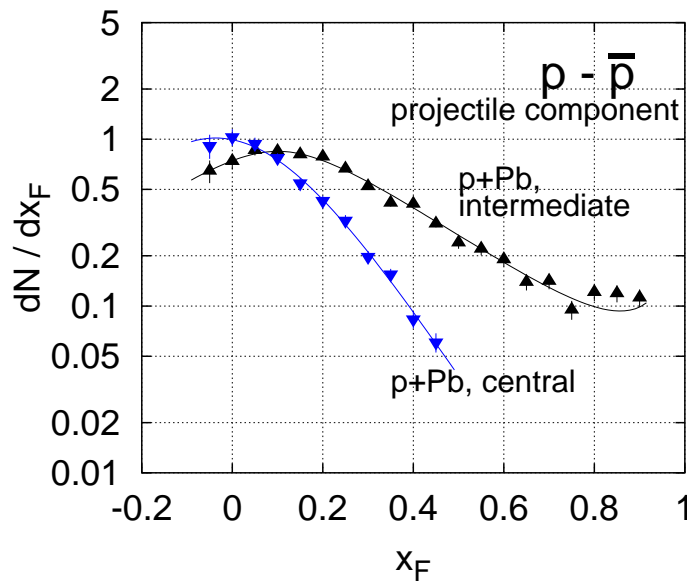
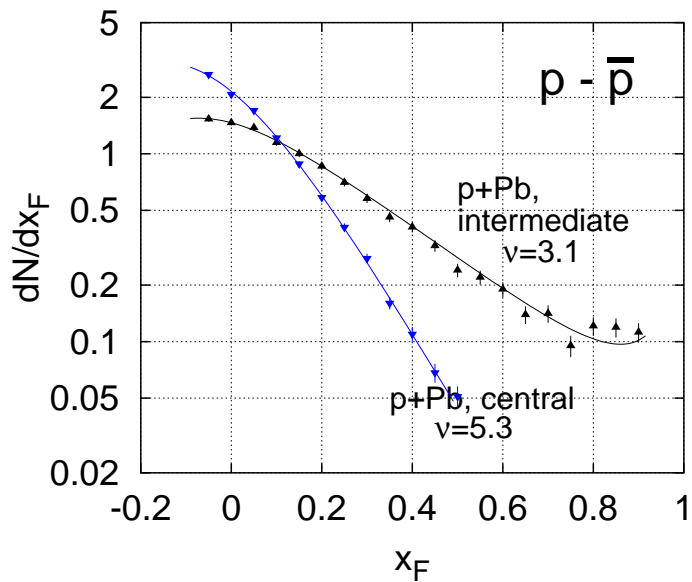
NA49 preliminary

- Baryon number free projectile: **pion beam**
- Fixing baryon number in the forward hemisphere
- Two component picture: target and projectile contribution

# Components of baryon number transfer in $h+A$ collisions

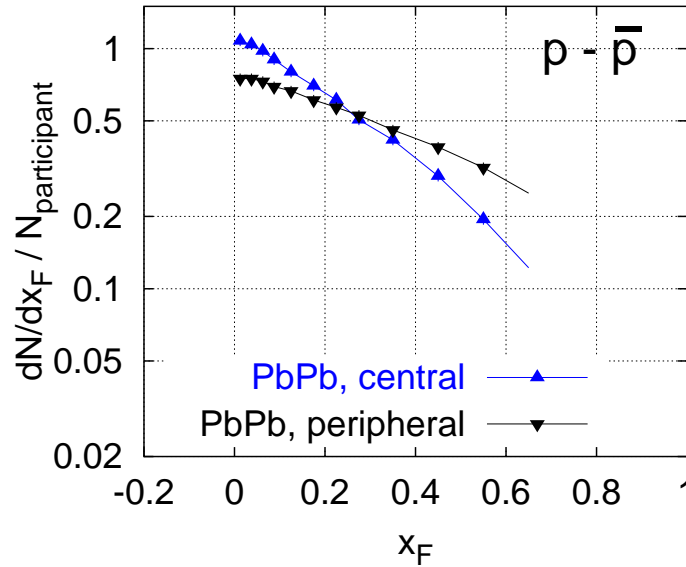
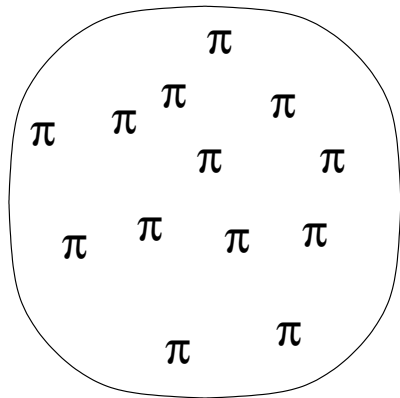
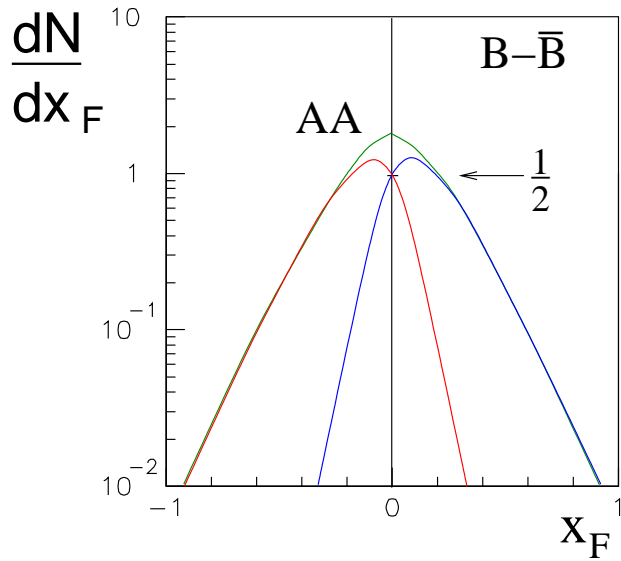


- $\pi+A$ : measurement of target component: **pileup**

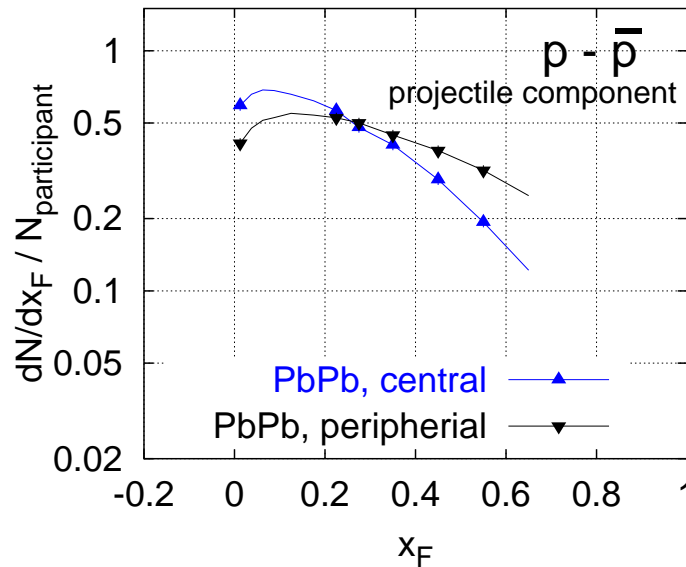


- $p+A$ : modified projectile component

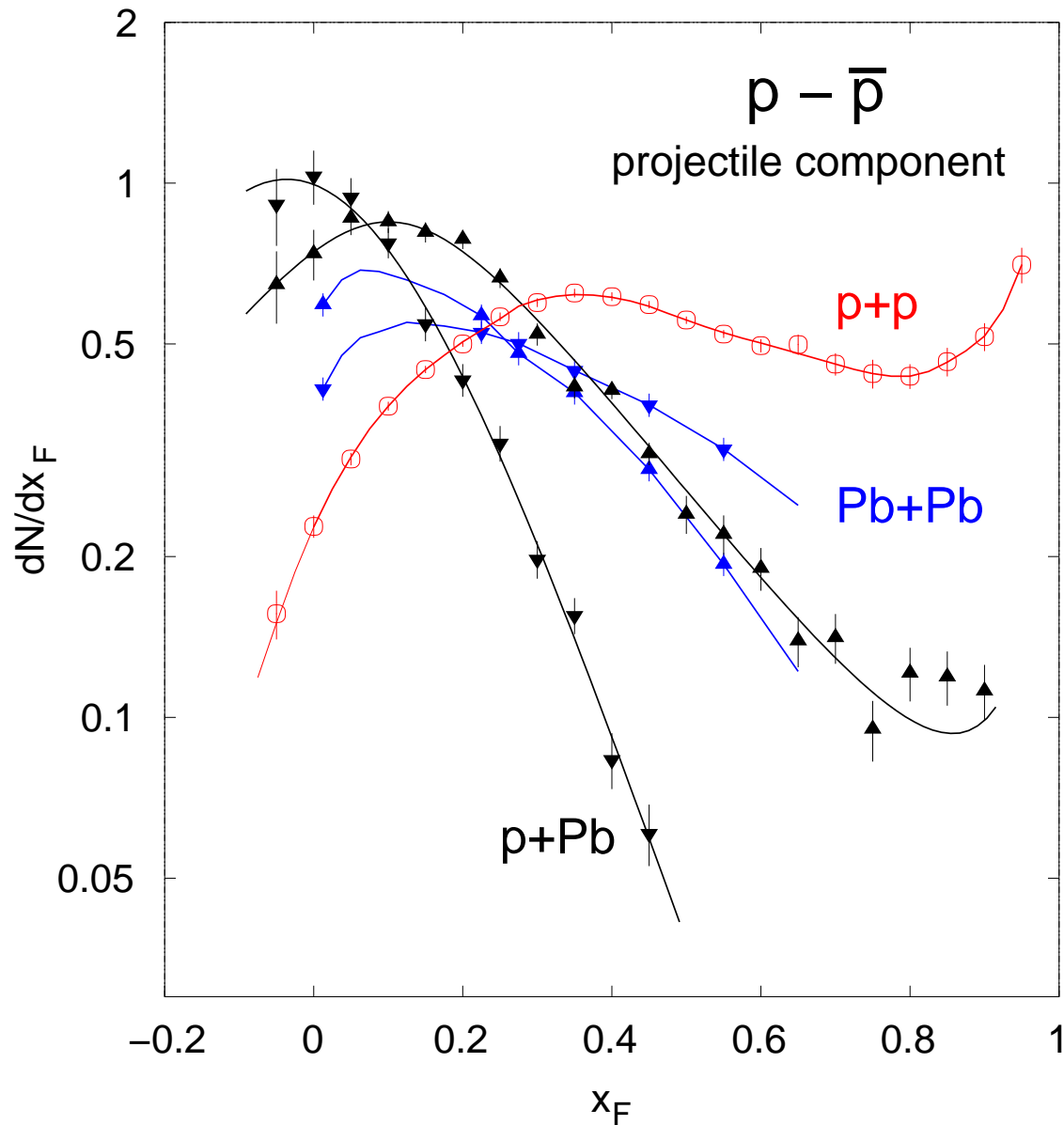
# Components of baryon number transfer in A+A collisions



- A+A: modified target and projectile component.

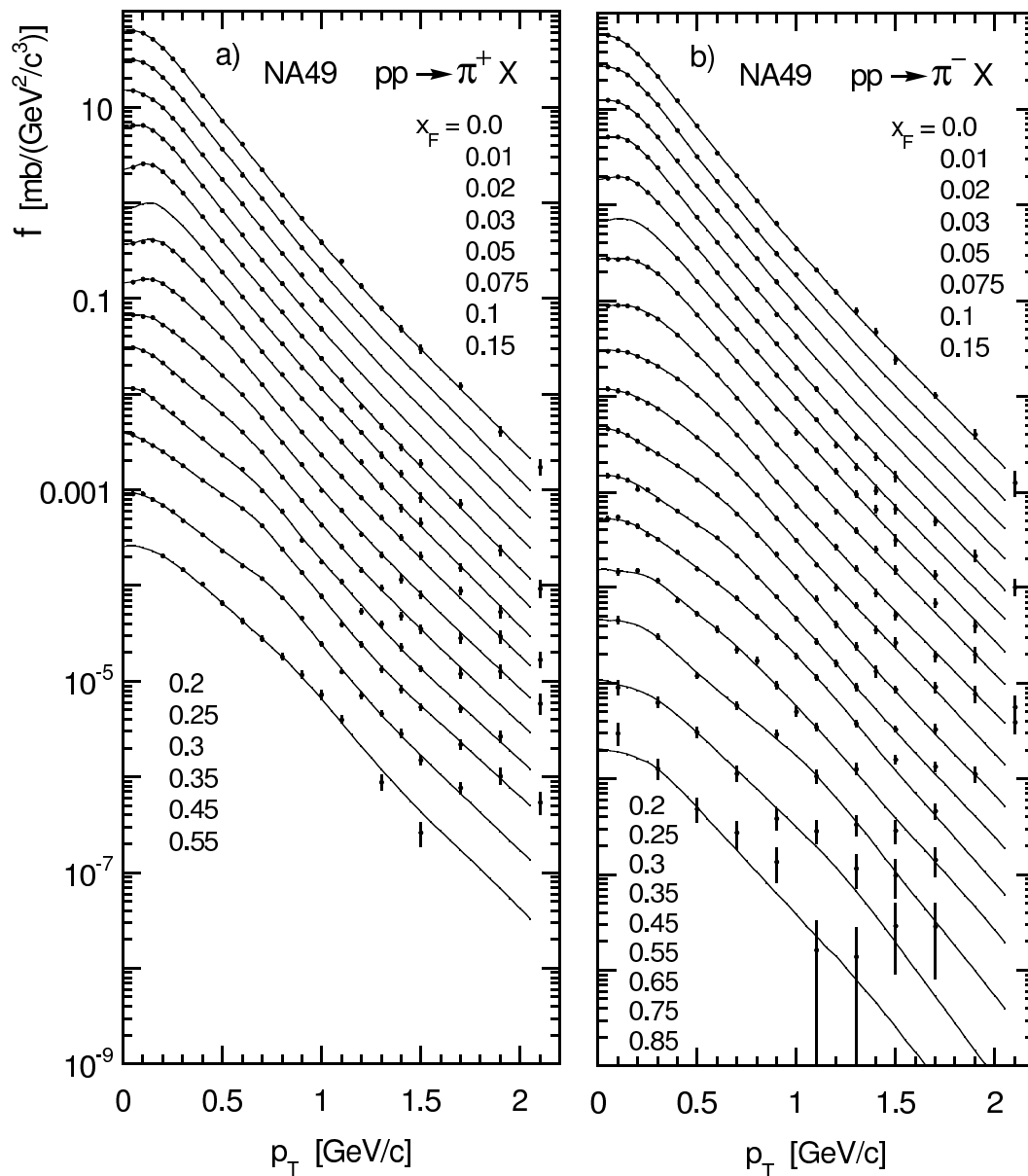


- Projectile component from symmetry argument (components are equal at  $x_F = 0$ )



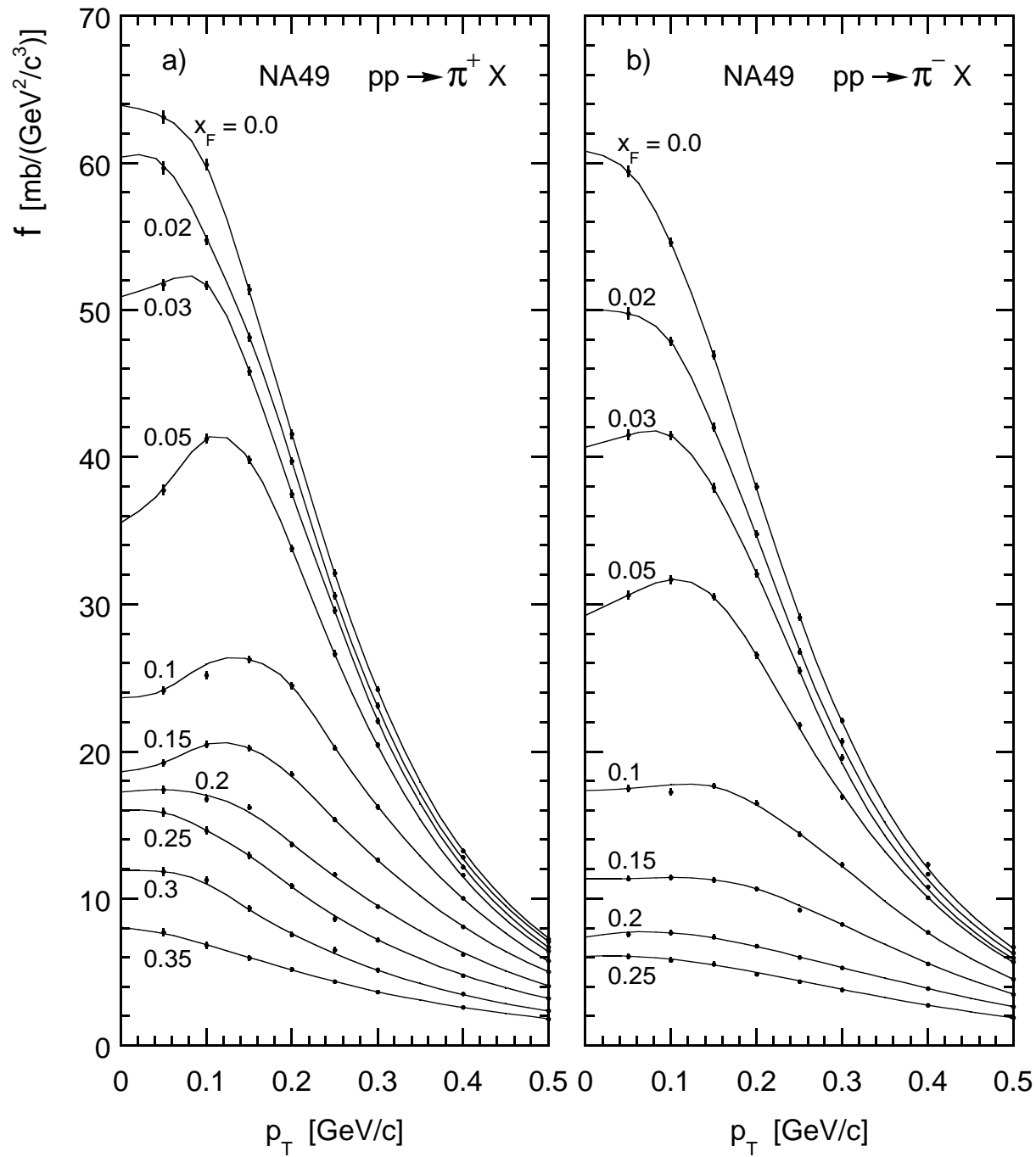
- Common, smooth evolution of baryon number transfer
- Question 2: How to relate pA to AA:  
 $\Rightarrow$  extract projectile component

# Pion production: $p+p$ interactions at 158 GeV beam from NA49



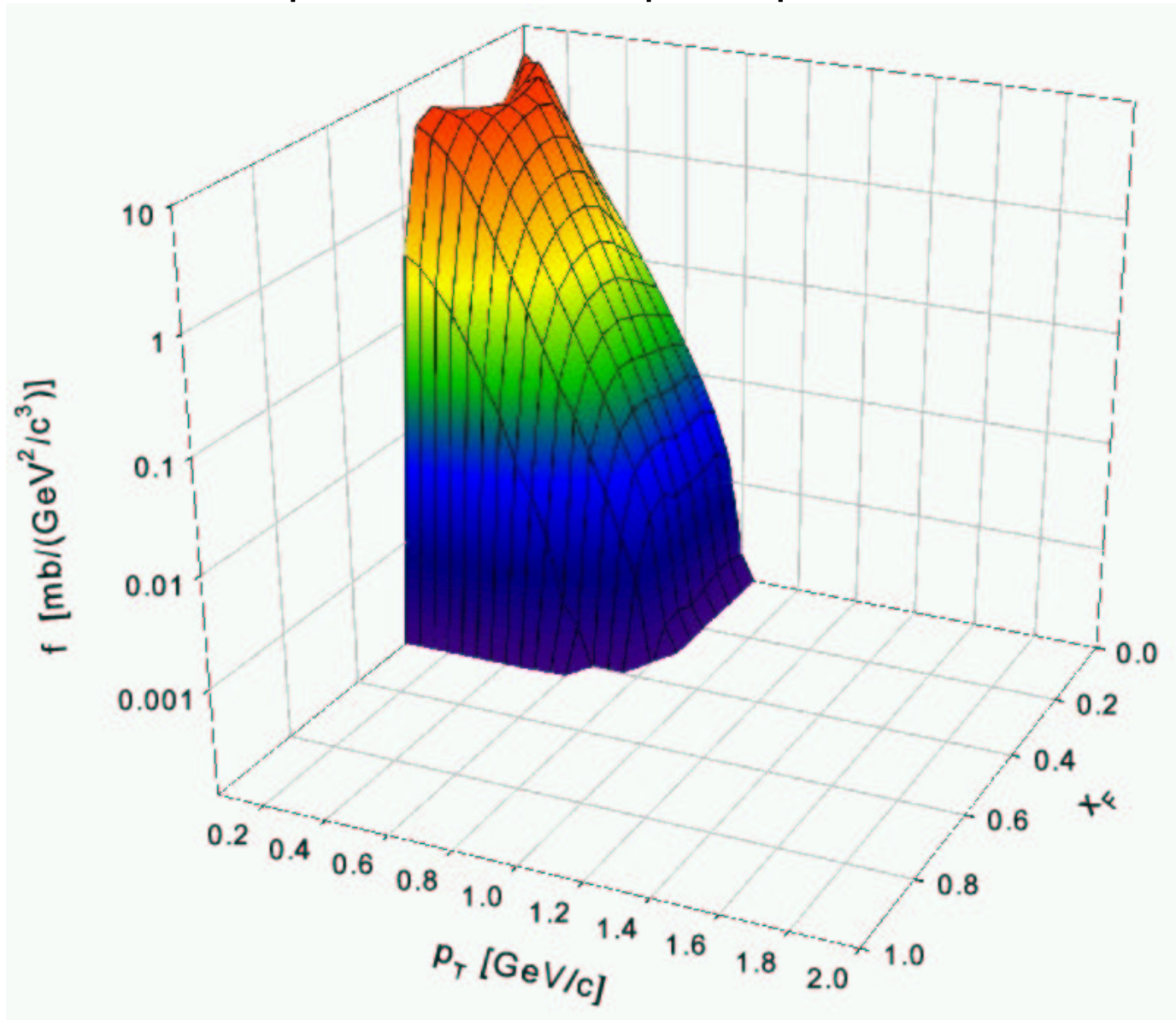
Question 4:  
Where do these pions originate from?

Question 5:  
Is there a “2-component” picture for pions?

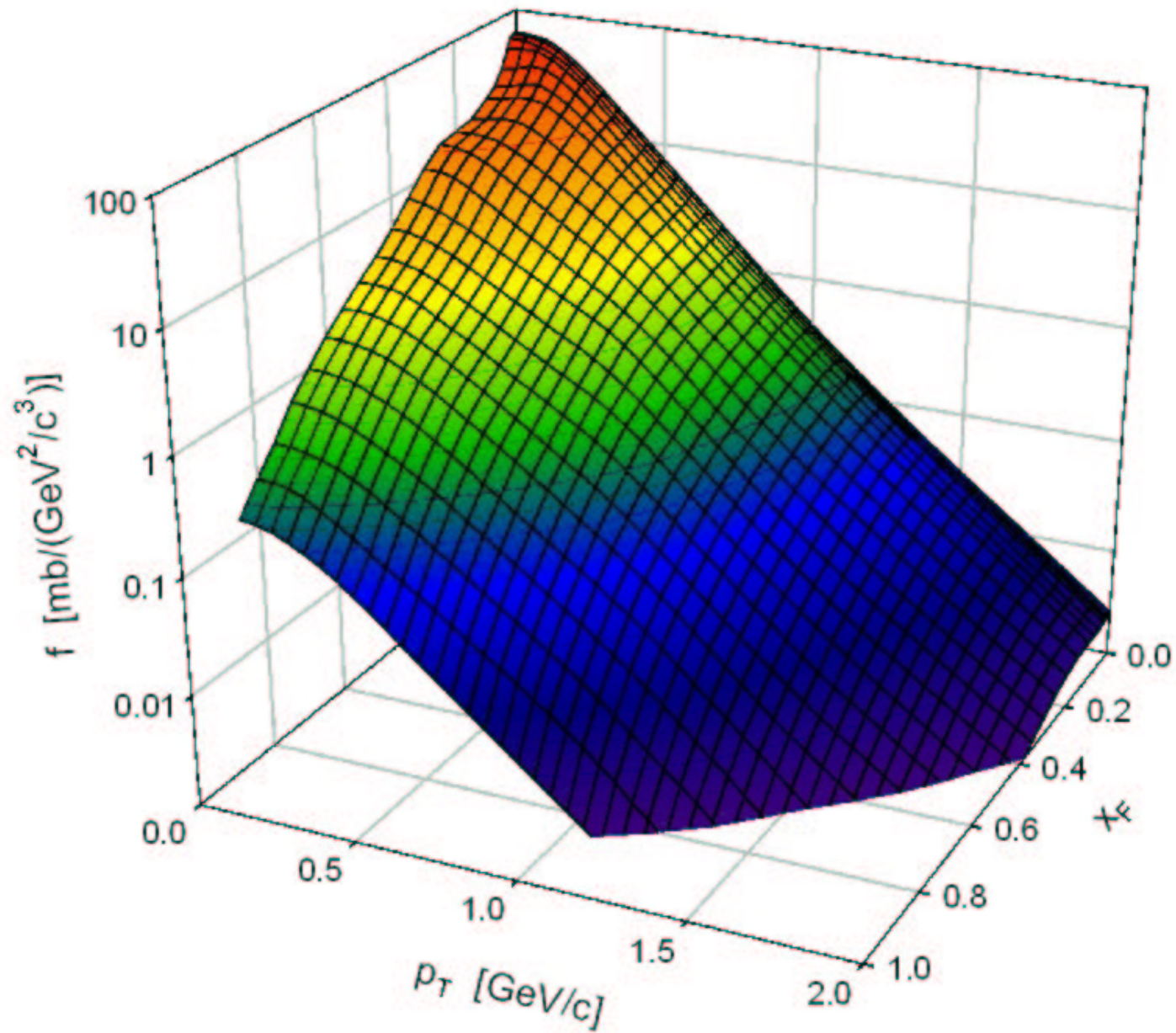


... surprising structures at low  $p_T$ ?

Effect of low-q resonances on pion spectra:  $\Delta^{++} \rightarrow \pi^+$

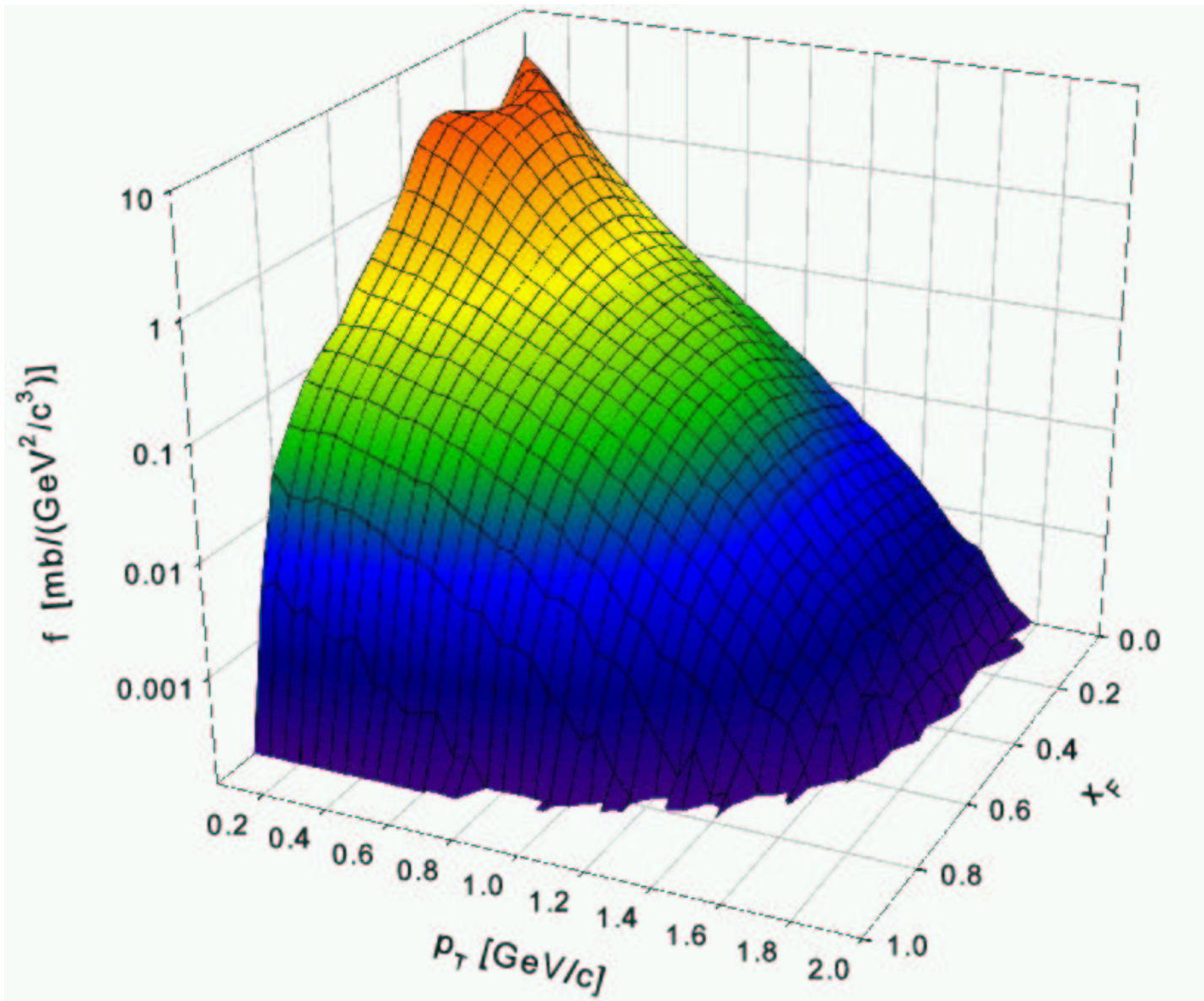


$\pi^+$  in p+p collisions from NA49



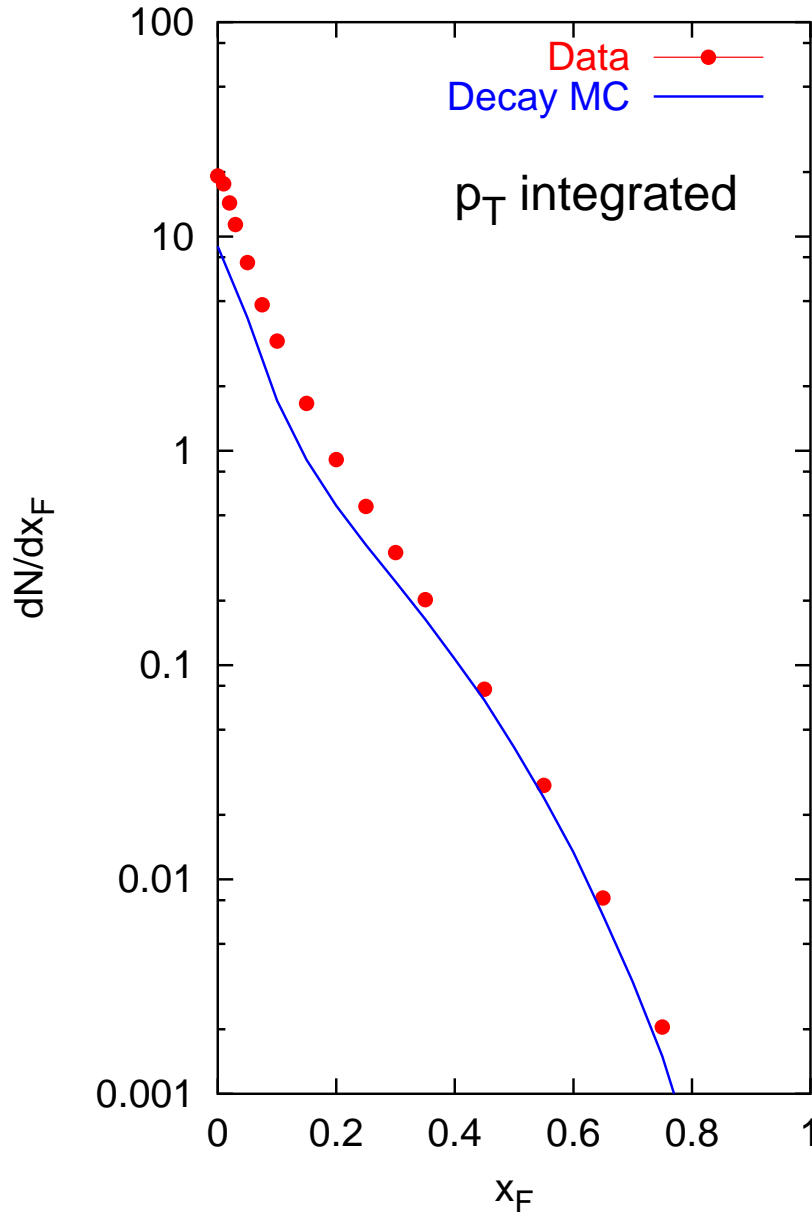


... Breit-Wigner shape of  $\Delta^{++}$  resonance opened up



(Question 4. What is the source of pions in p+p?)

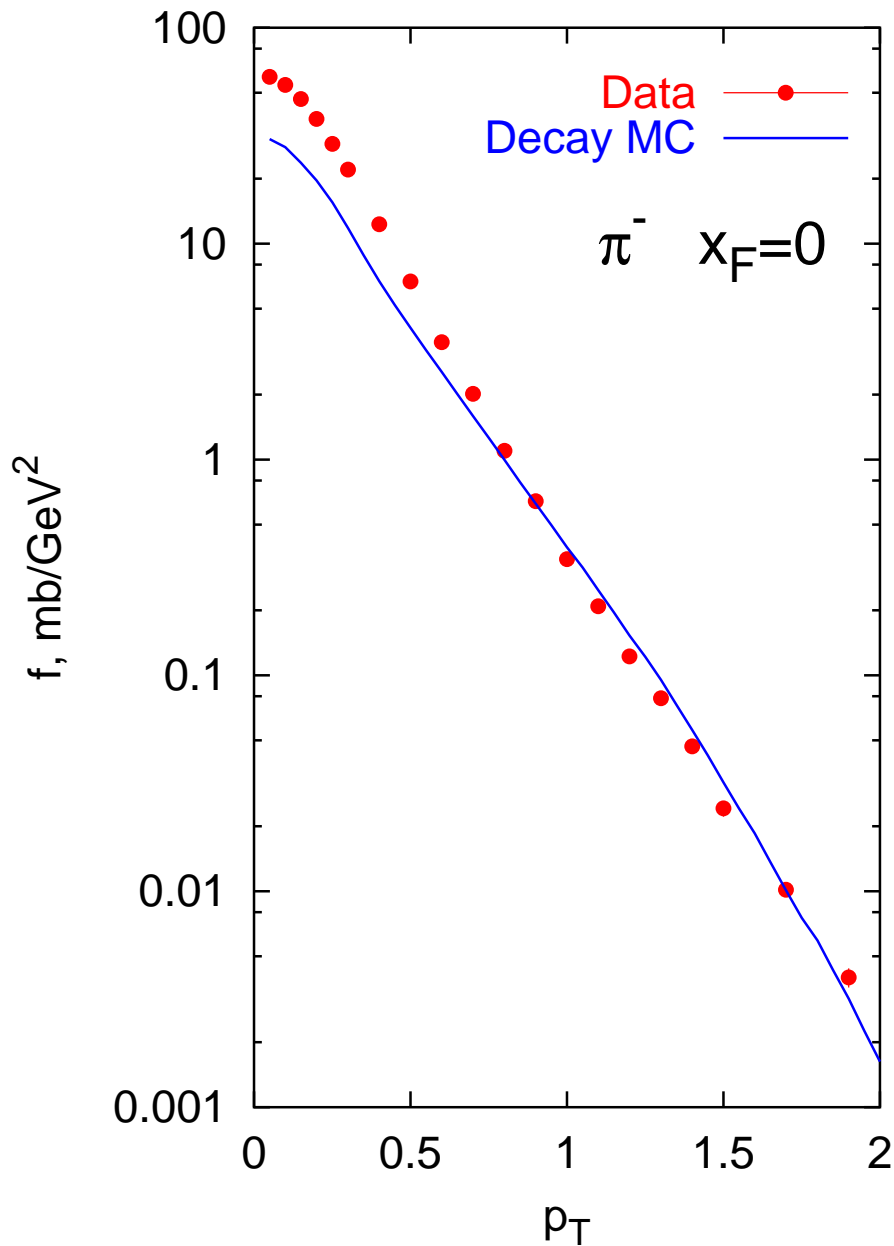
## Resonance contribution to negative pions



- Sum up measured resonances:

$\eta^0$	$\Delta^0$
$\omega^0$	$\Delta^-$
$\rho^0$	$N^*(1440)$
$\rho^-$	$N^*(1520)$
$f_2^0$	$N^*(1680)$
$\rho_3^0$	
$\rho_3^-$	
$f_4^0$	

- Take only  $2\text{-}\pi$  decays, to avoid double counting ( $3\pi$  for  $\eta$  and  $\omega$ )  
 $\Rightarrow$  Cascading not included, so lower limit is given
- Large (20-30%) systematic error to be considered

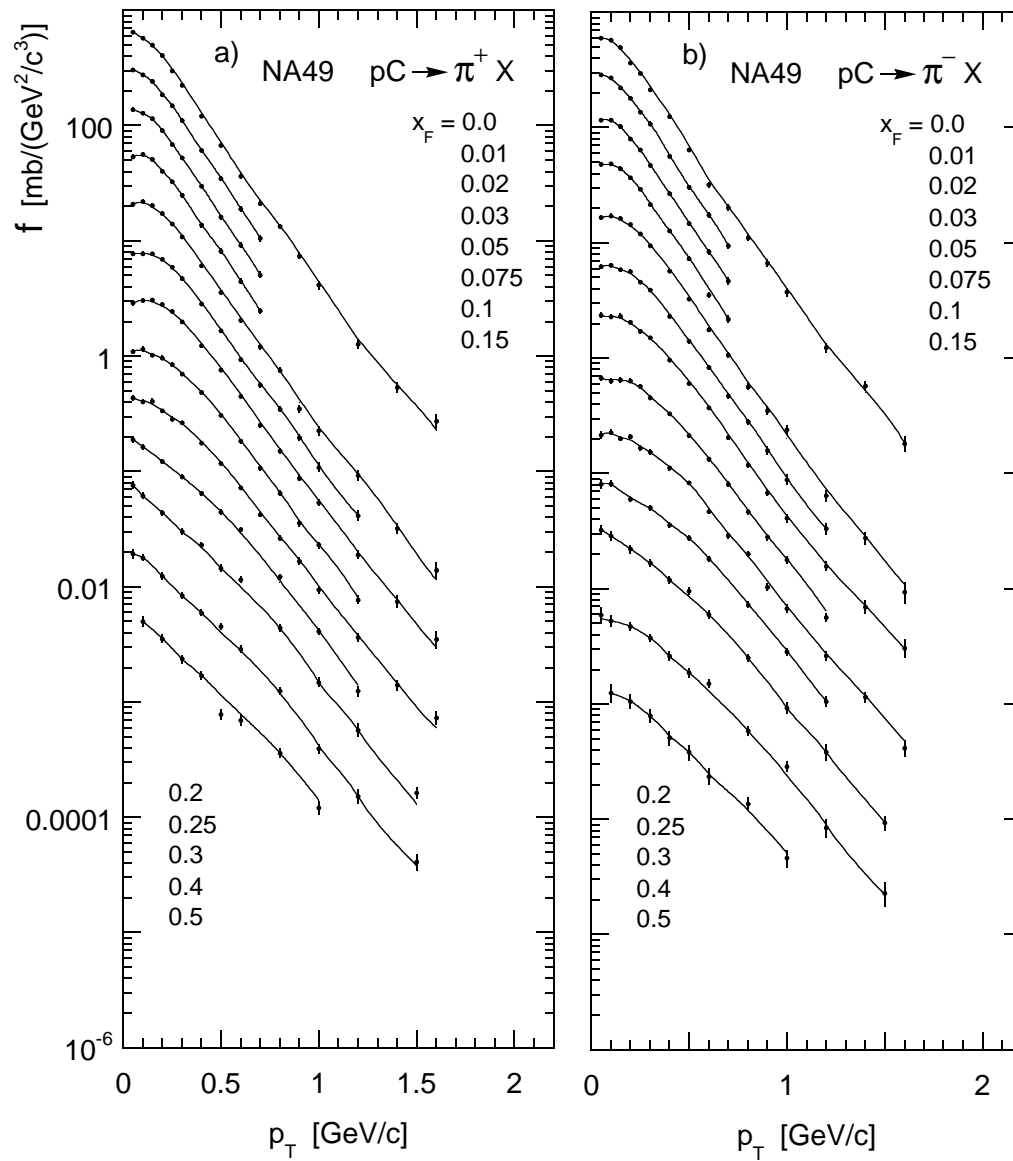


- Underestimated low- $p_T$  yield: room for cascading (e.g.  $N^* \rightarrow \Delta\pi$ )
- Conclusion: no “direct” pion production even at high  $p_T$  and high  $x_F$ ; main source is resonance decay!

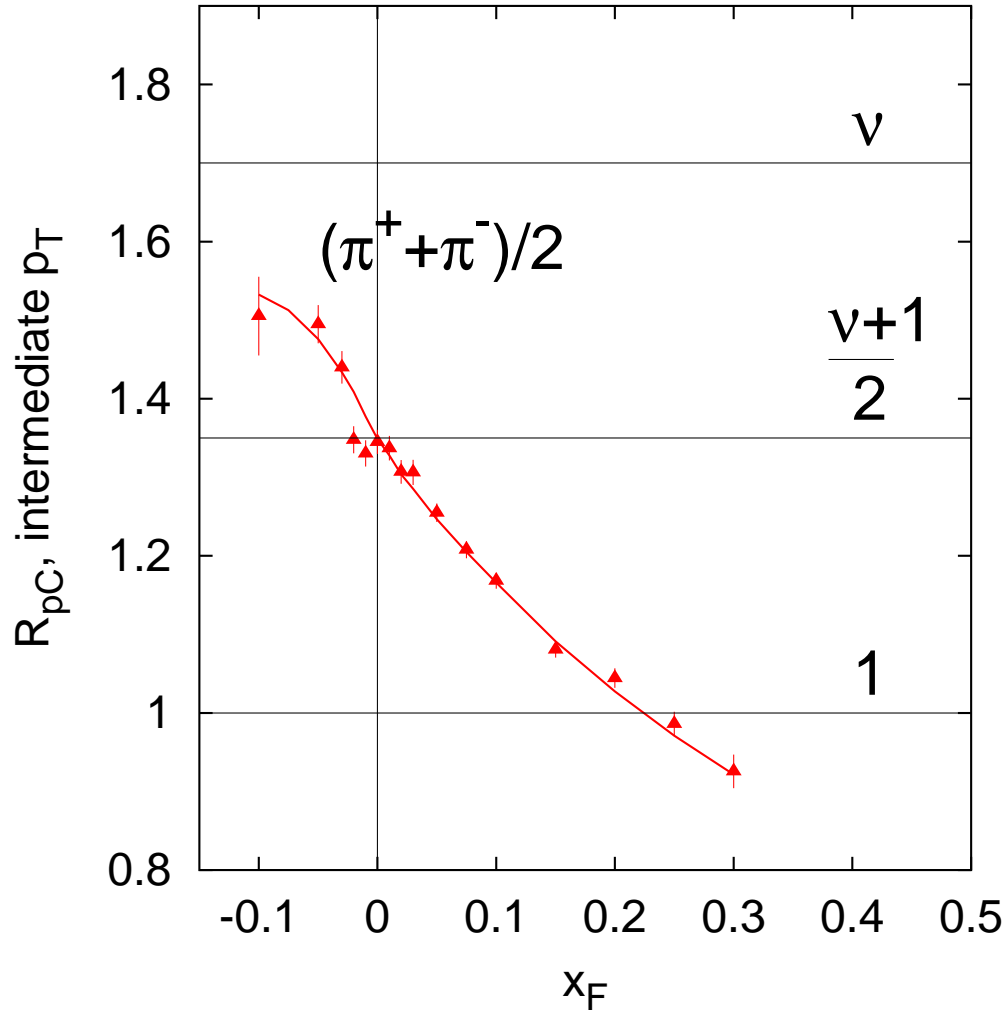
⇒ Where does hard scattering set in?

⇒ Large  $x$ : not just reflecting partonic structure!

# Pion production in p+C interactions at 158 GeV beam



# Question 5: Is there a two-component picture for pions?

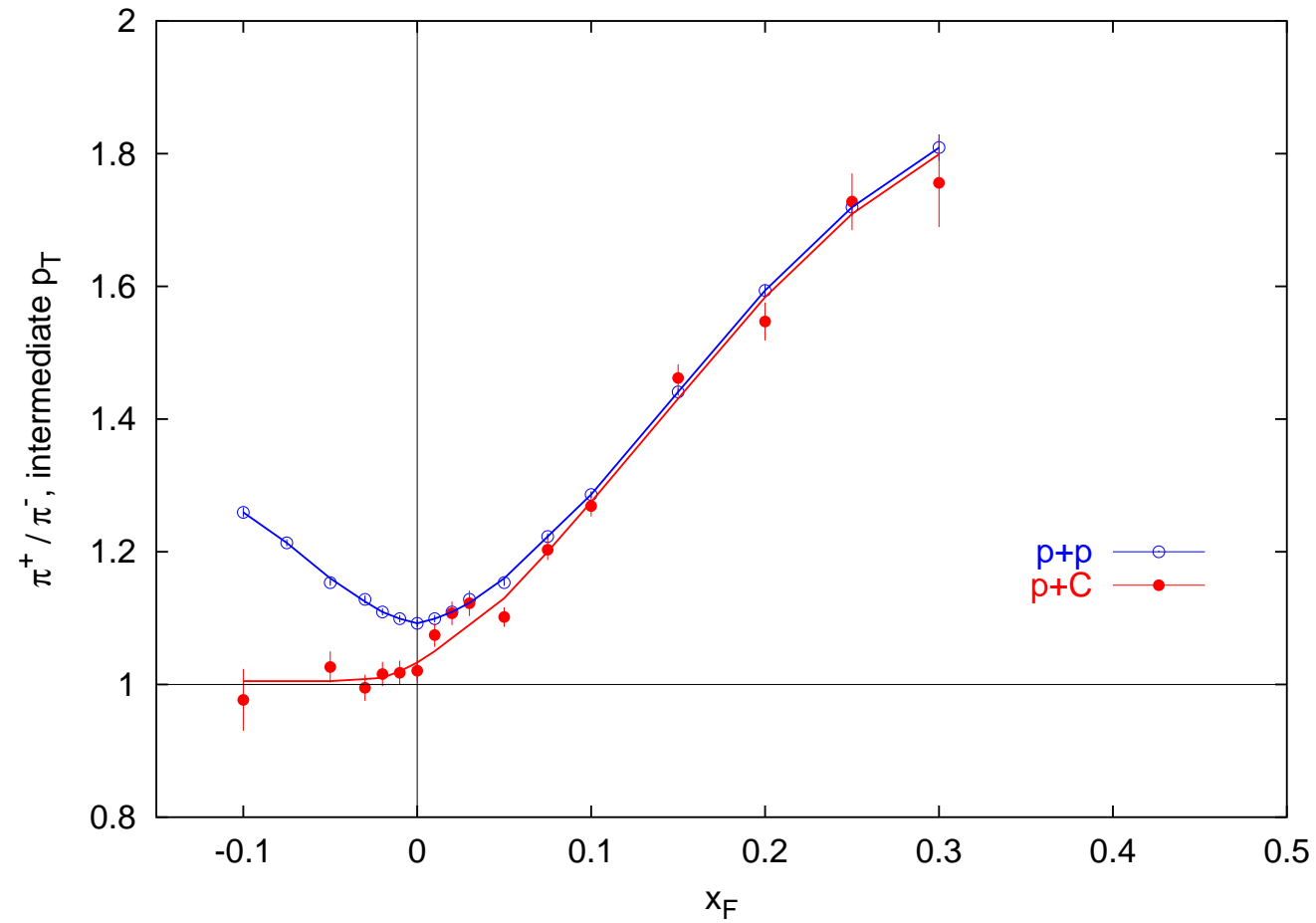


- Intermediate  $p_T$  region:  
0.3 – 0.6 GeV

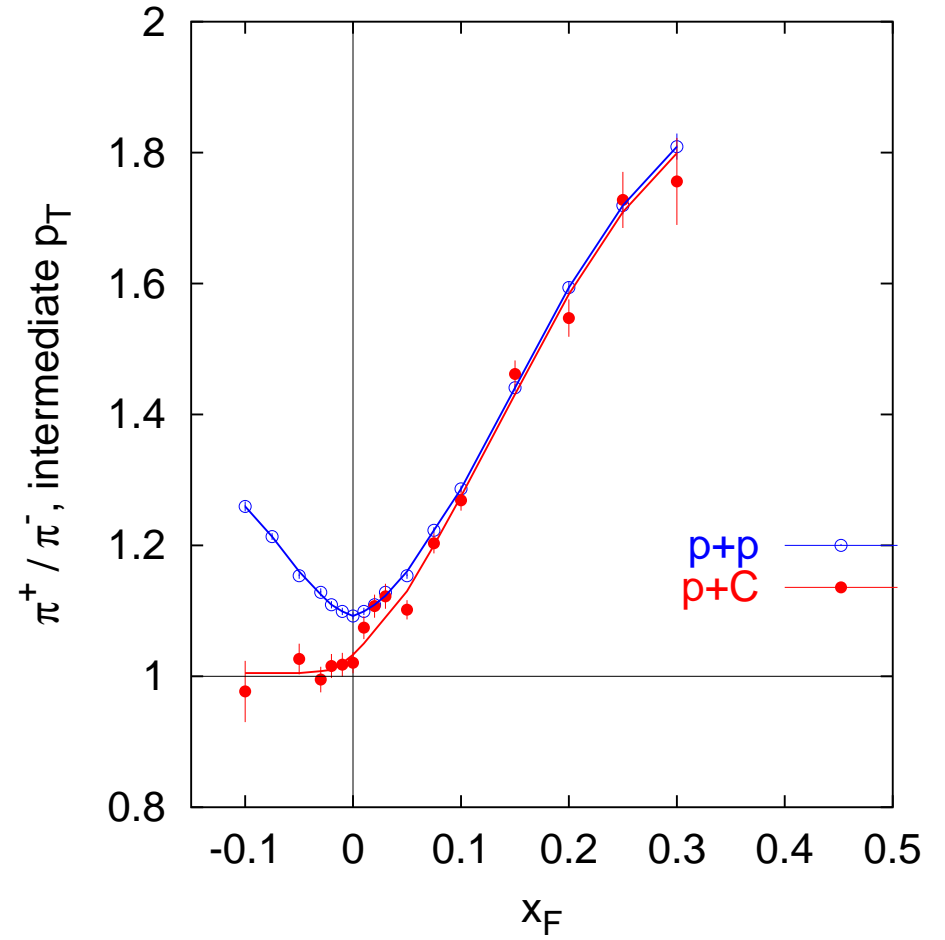
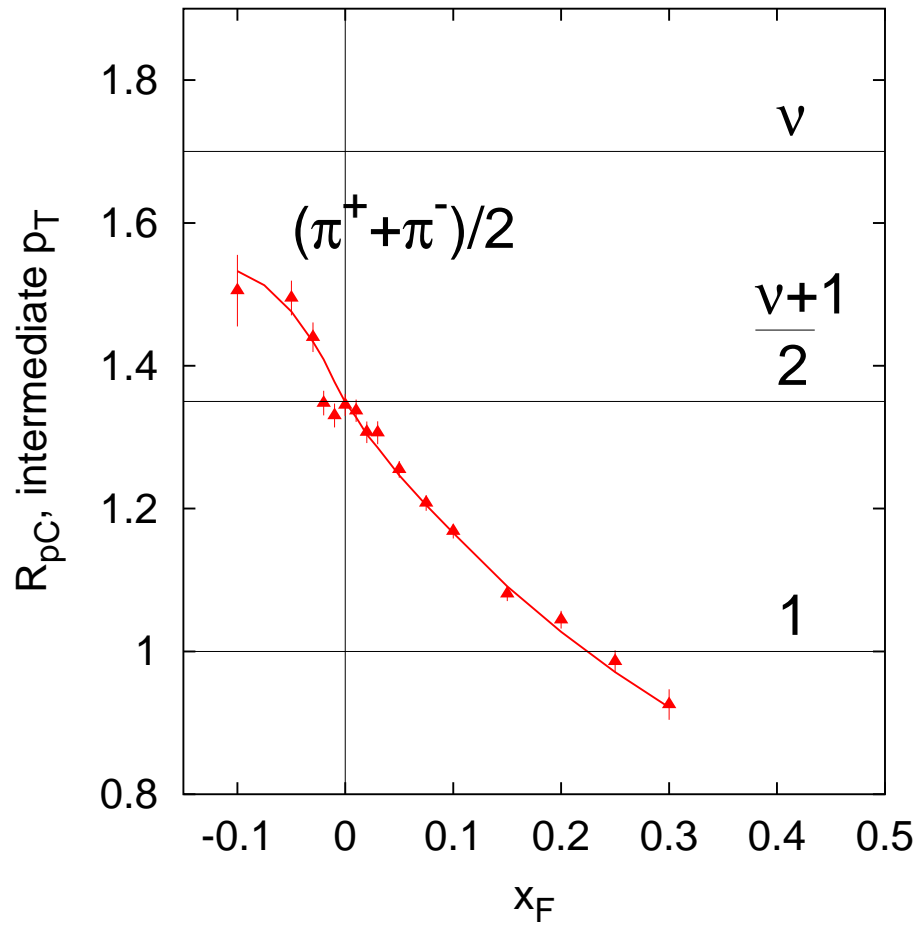
- $R_{pC} = \frac{(dN/dx_F)_{p+C}}{(dN/dx_F)_{p+p}}$

Take advantage of isospin effect:

$\pi^+ / \pi^-$  ratio in p+p and p+C

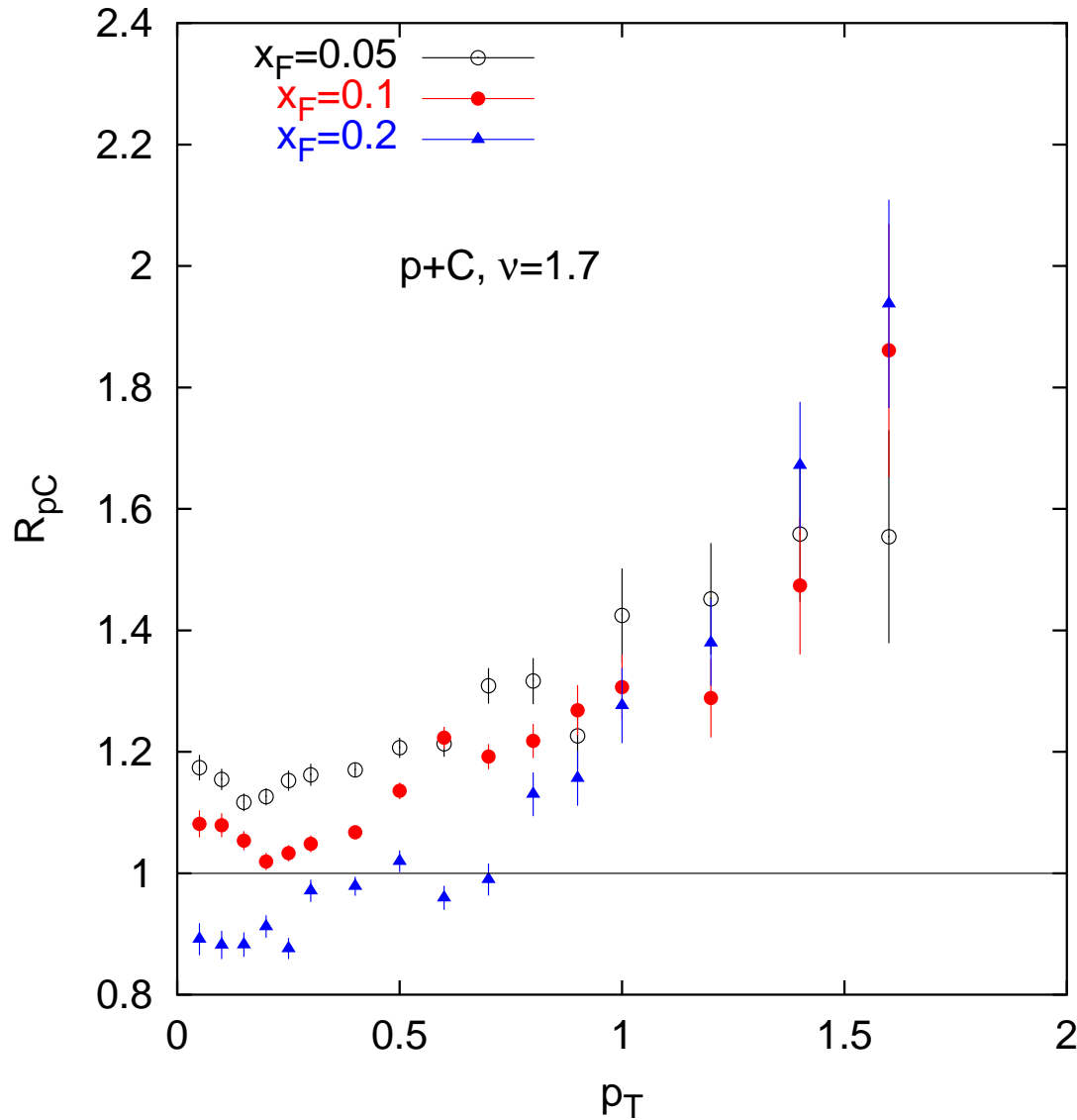


- backwards: close to 1 in p+C, following from isospin



- Target component does not reach far: at  $x_F = 0.1$ , it's fully projectile dominated

Transverse direction: increase with  $p_T$



Conclusion:

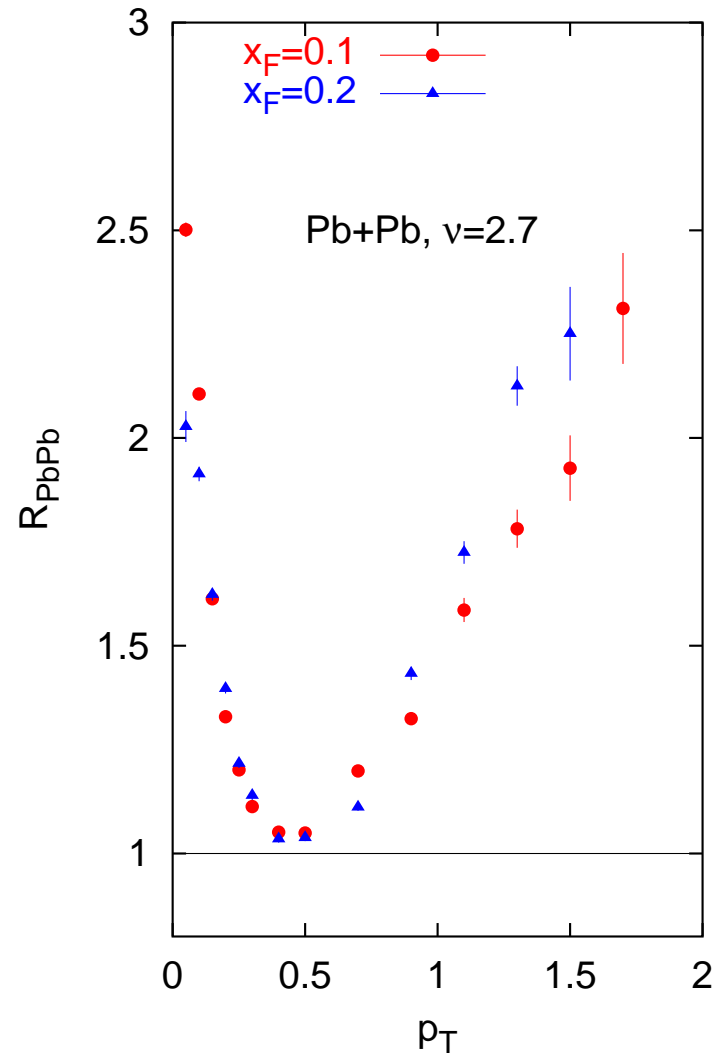
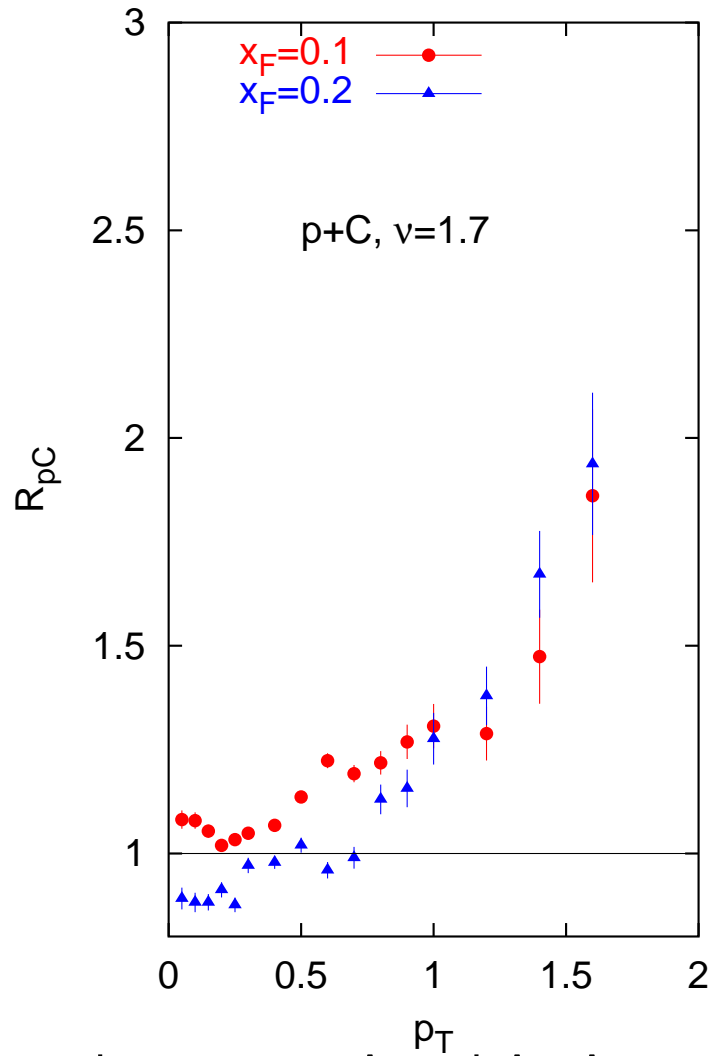
pion production in p+A can be understood as

- modified projectile component
- target component, as in p+p piled up  $\nu$  times



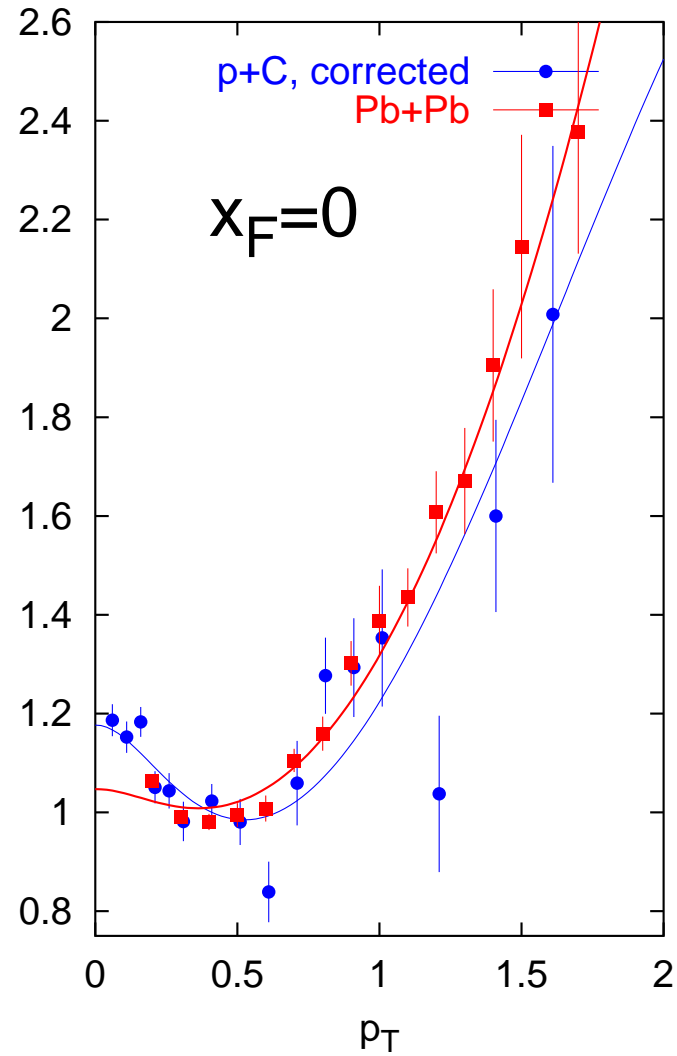
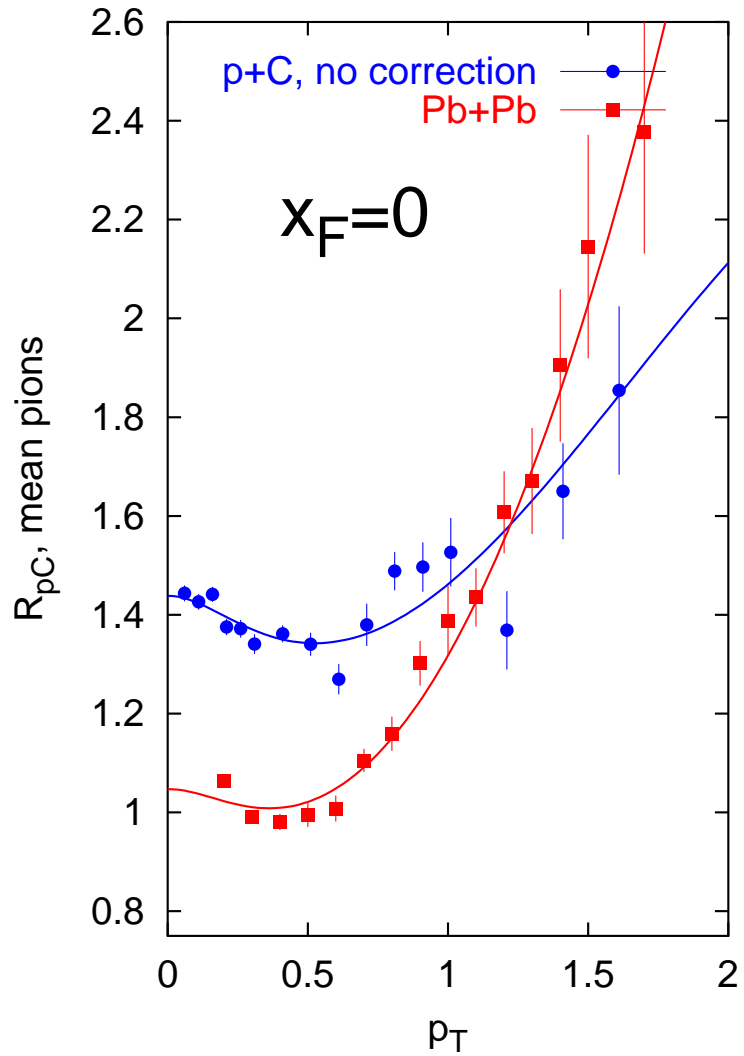
Question 2. How to compare p+p and p+A to A+A?

- projectile component: direct comparison



→ similarity between p+A and A+A interactions

-  $x_F = 0$  (midrapidity): target + projectile overlap

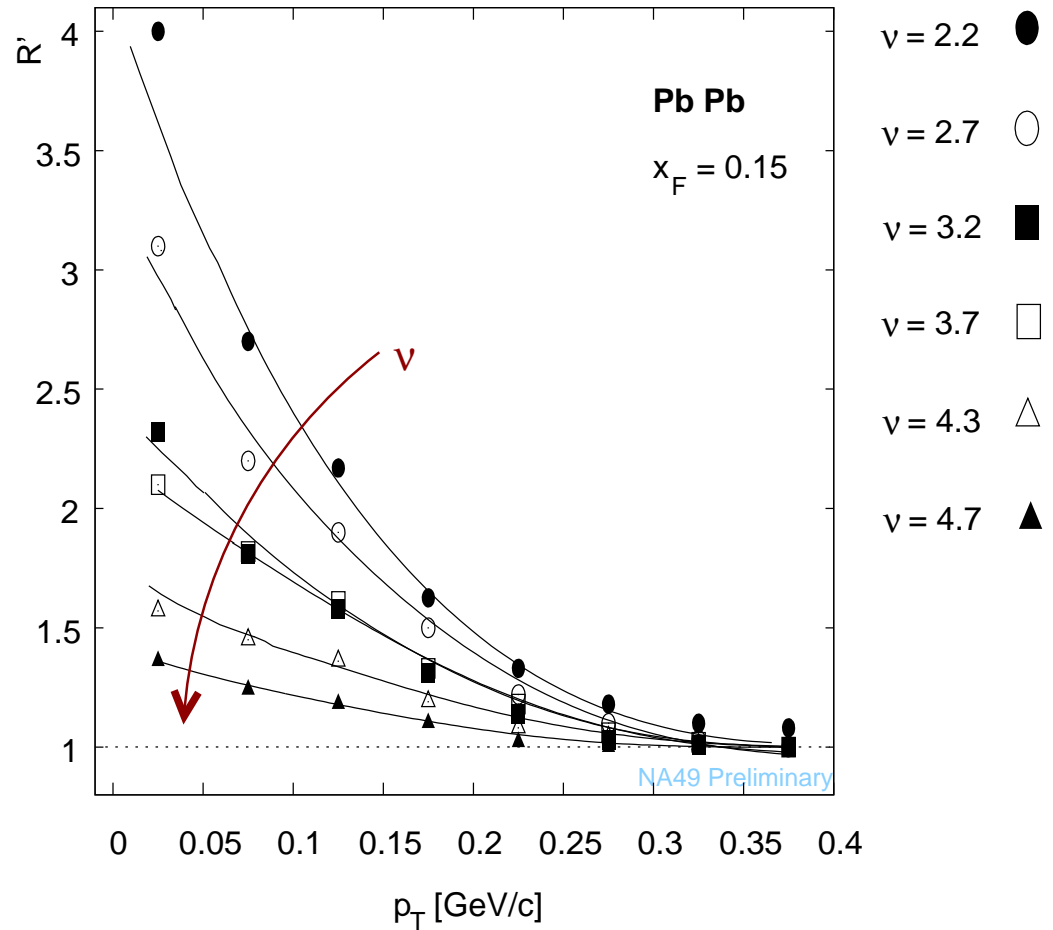
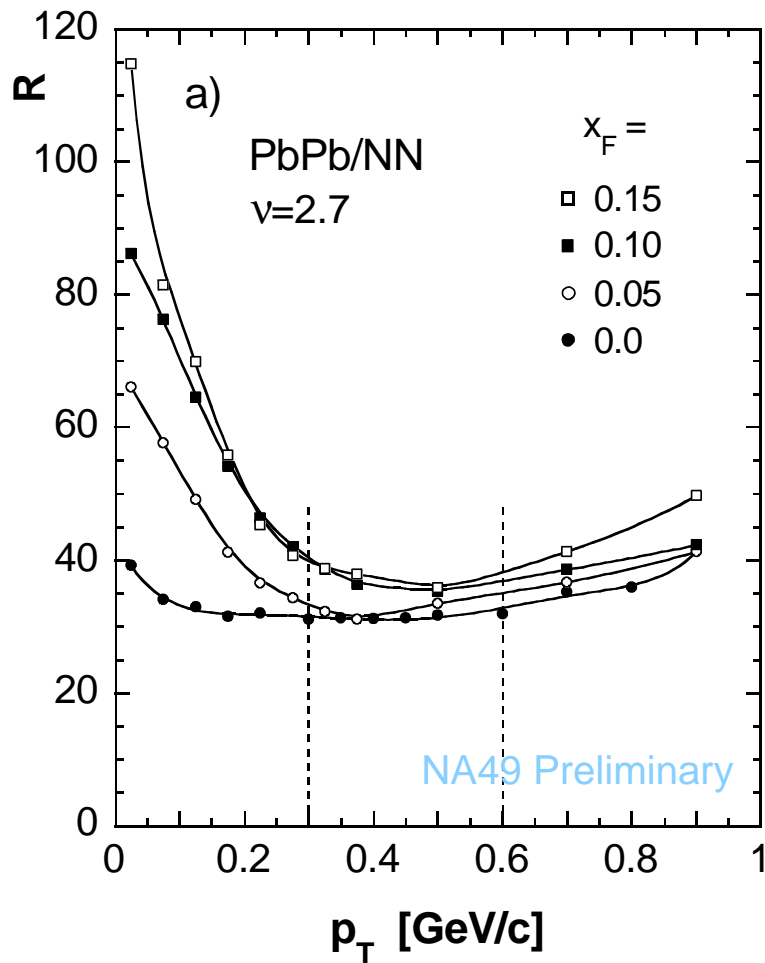


At  $x_F = 0$   
(by symmetry  
of p+p):

$$R_{corr} = 2R - \nu$$

## Question 7. Where are the evident final state effects?

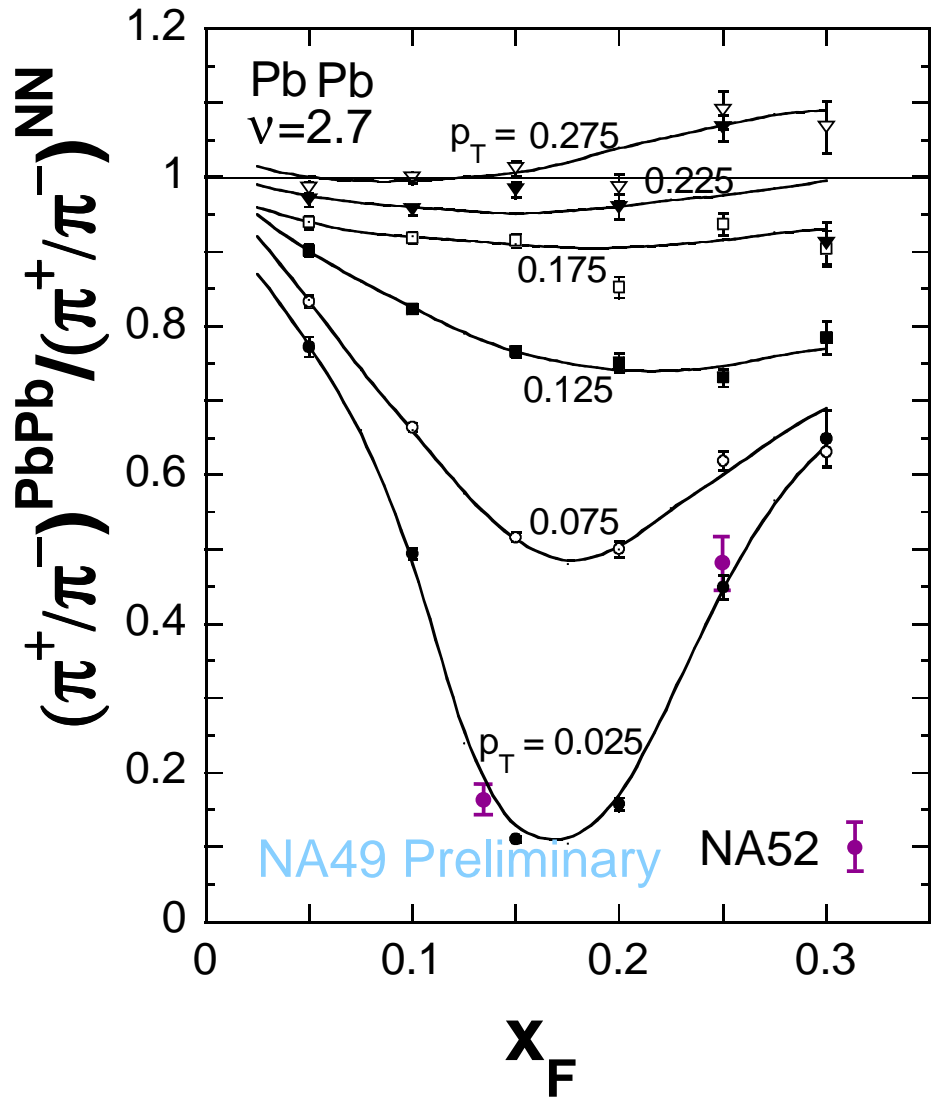
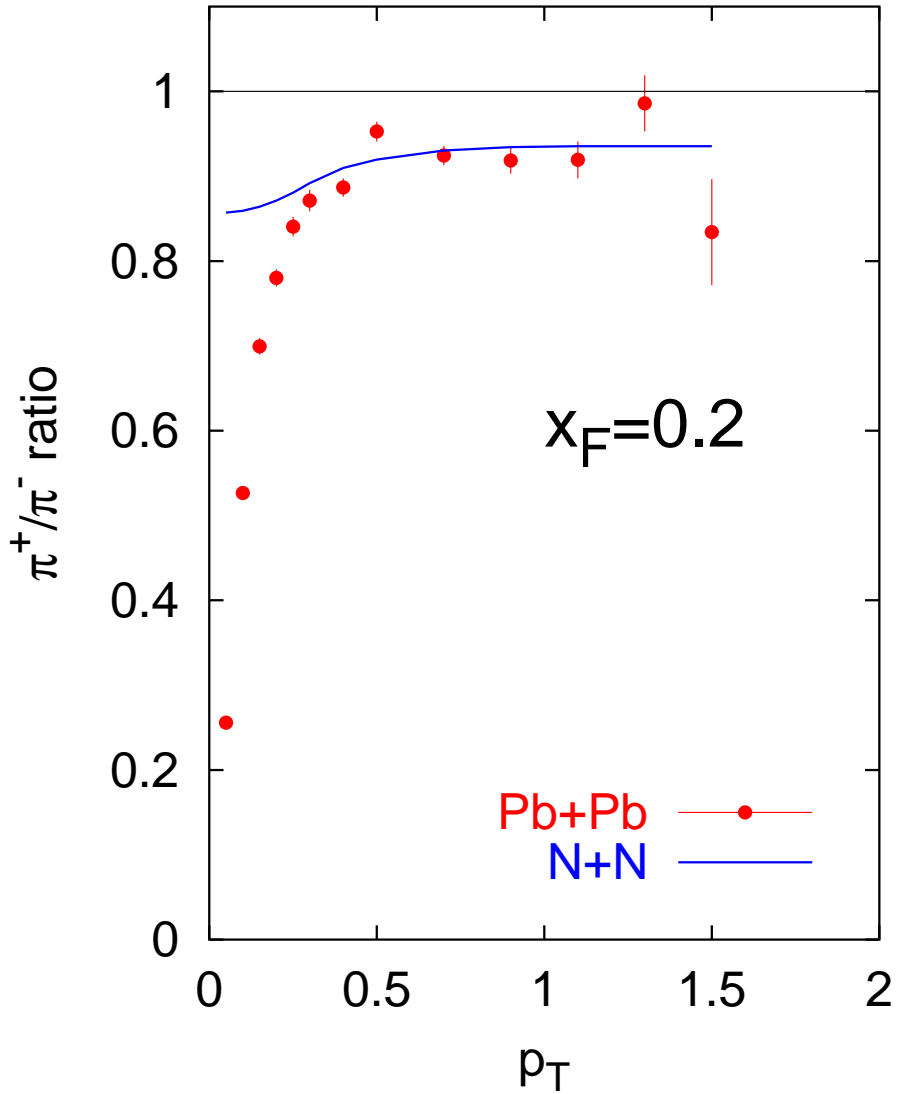
- Low- $p_T$  enhancement



$$x_F = 0.15 = m_\pi / m_{proton} ; \quad \beta_{pion} = \beta_{spectator}$$

Enhancement vanishes at higher centrality: spectator system (spectator excitation)

• Coulomb effect in  $\pi^+/\pi^-$  ratio



# Conclusions

Both for baryons and pions:

- 2 component picture, target and projectile
- Multiple collision effect: modified projectile component (stopping, high  $p_T$  increase)

How to relate p+p and p+A to A+A?

- Extract projectile component, multiple collision effects determined by p+A
- $x_F = 0$ : Normalisation problem due to the overlap of target and projectile

Comparison of p+p and p+A to A+A:

- Baryon stopping: present in p+A, multiple collision effect
- Increase of pion yield at higher  $p_T$ : already present in p+A
- Example of real collective (final state) effect: Coulomb and spectator excitation