Inclusive particle production in proton-proton collisions

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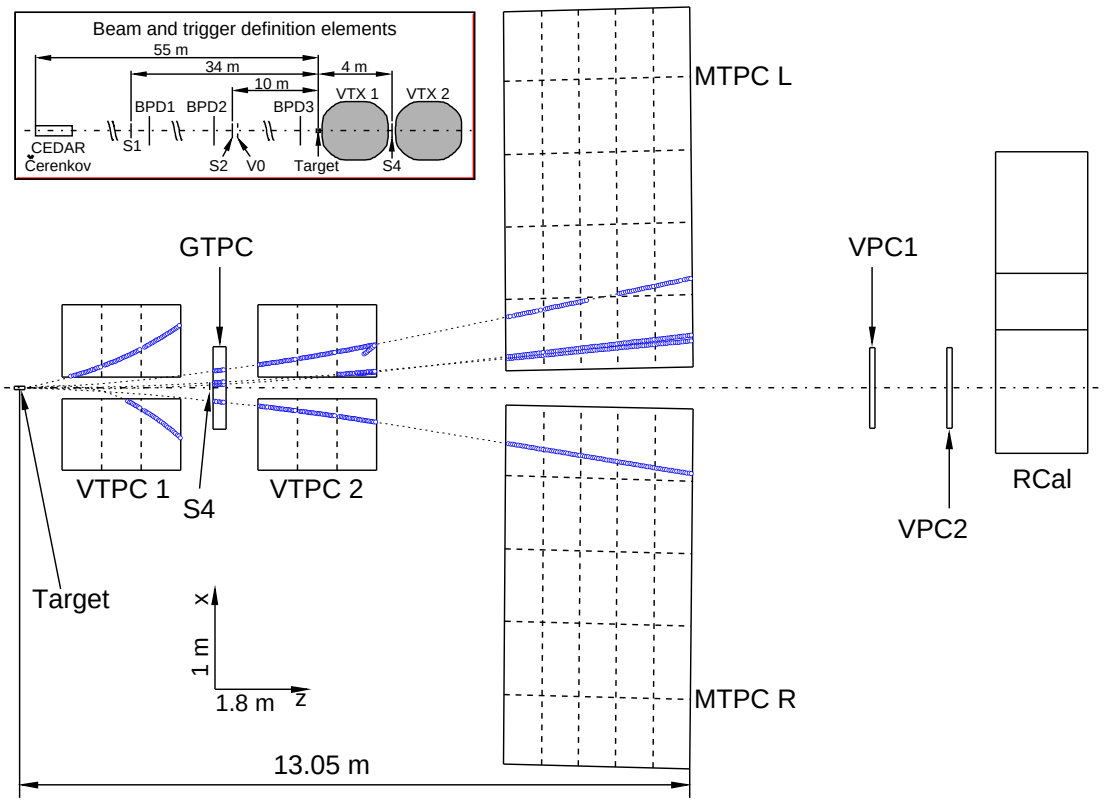
Introduction

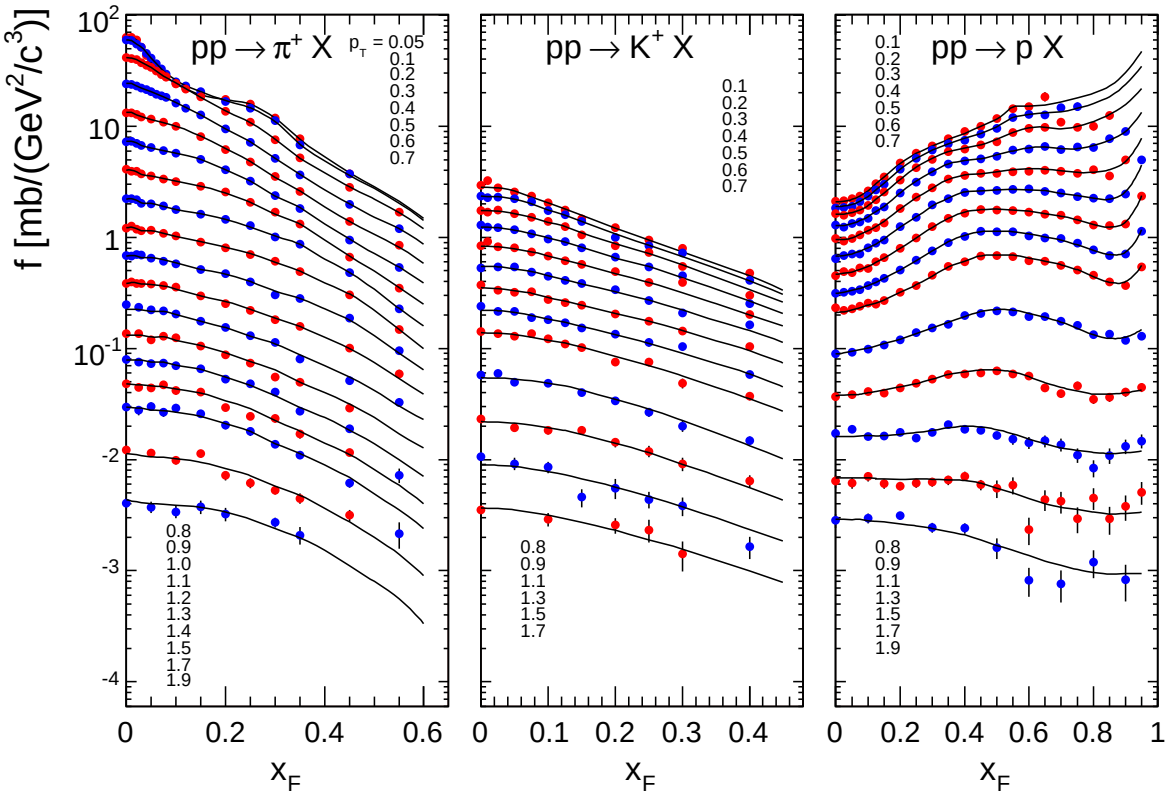
- NA49 data
- Total particle production
- Baryon production
- Kaon production

NA49 experiment



- two superconducting magnets
- four large Time Projecion chambers
- systematic uncertainties on few % level
- hadron-hadron collisions: p+p, d(n)+p, $\pi^{\pm}$+p
- hadron-nucleus collisions: p+C, p+Pb, $\pi^{\pm}$+Pb
- nucleus-nucleus collisions: C+C, Si+Si, Pb+Pb

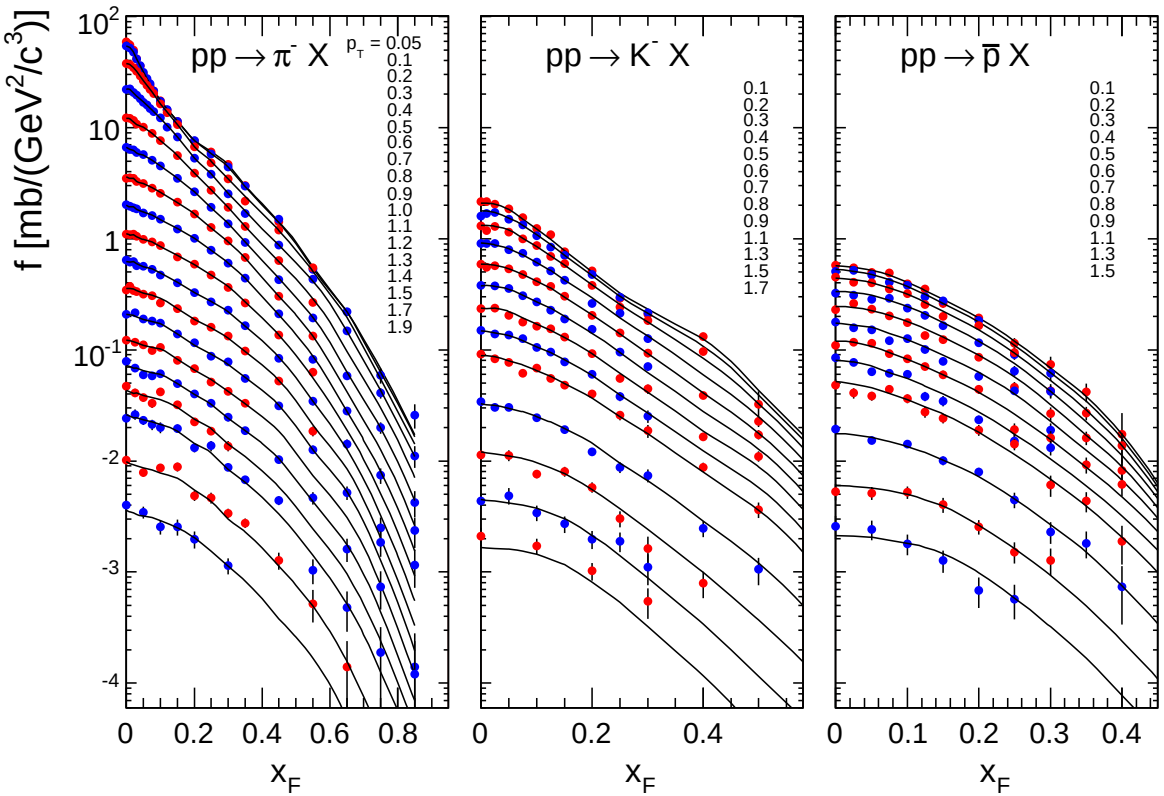
Double differential cross section of π^+,K^+,p in p+p collisions at 158 GeV/c beam momentum



- $p + p \rightarrow \pi^+ + X$
- $p + p \rightarrow K^+ + X$
- $p + p \rightarrow p + X$
- Wide x_F and p_T ranges:
  - $x_F = 0 \div 0.55$ and $p_T = 0 \div 1.9$ GeV/c for π^+
  - $x_F = 0 \div 0.4$ and $p_T = 0 \div 1.7$ GeV/c for K^+
  - $x_F = 0 \div 0.95$ and $p_T = 0 \div 1.9$ GeV/c for p

$$x_F = \frac{p_L}{\sqrt{s}/2}$$

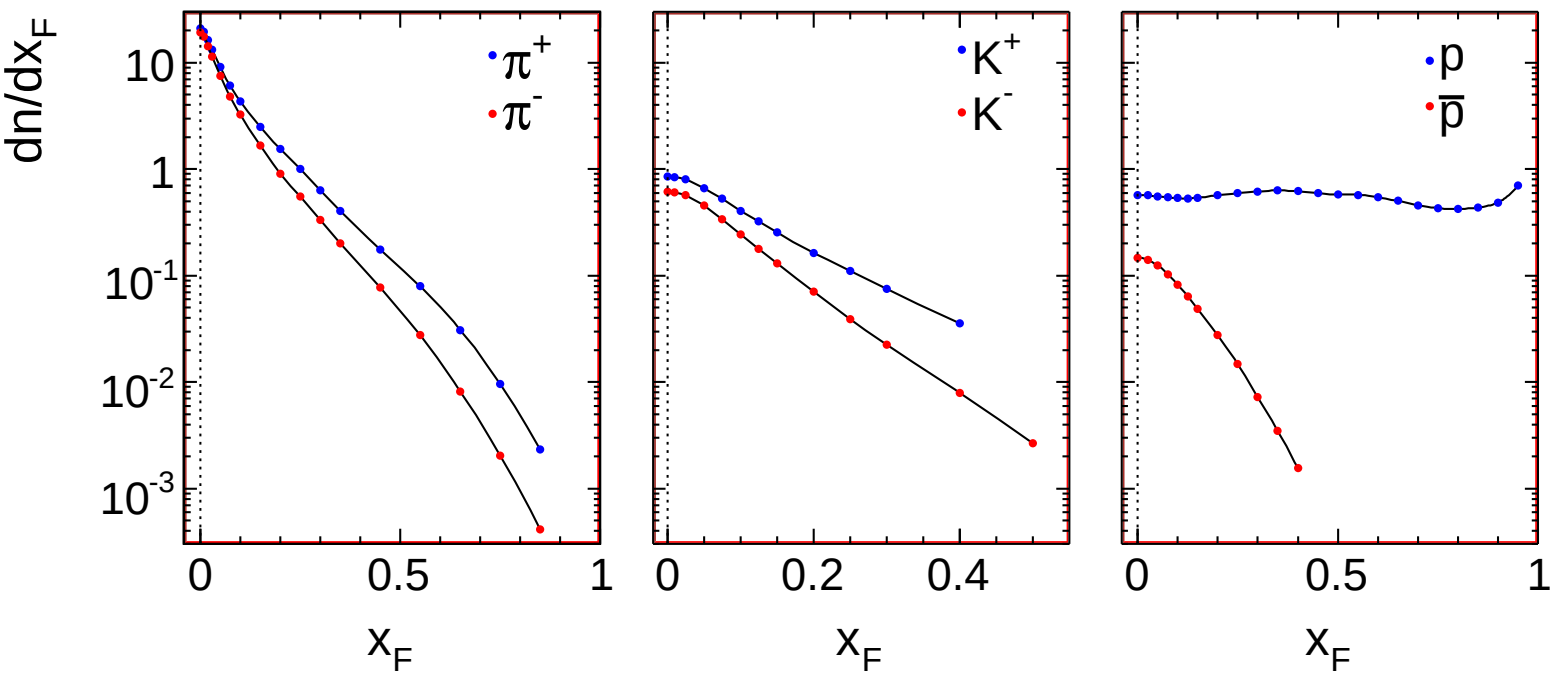
Double differential cross section of π^-,K^-,$\overline{p}$ in p+p collisions at 158 GeV/c beam momentum



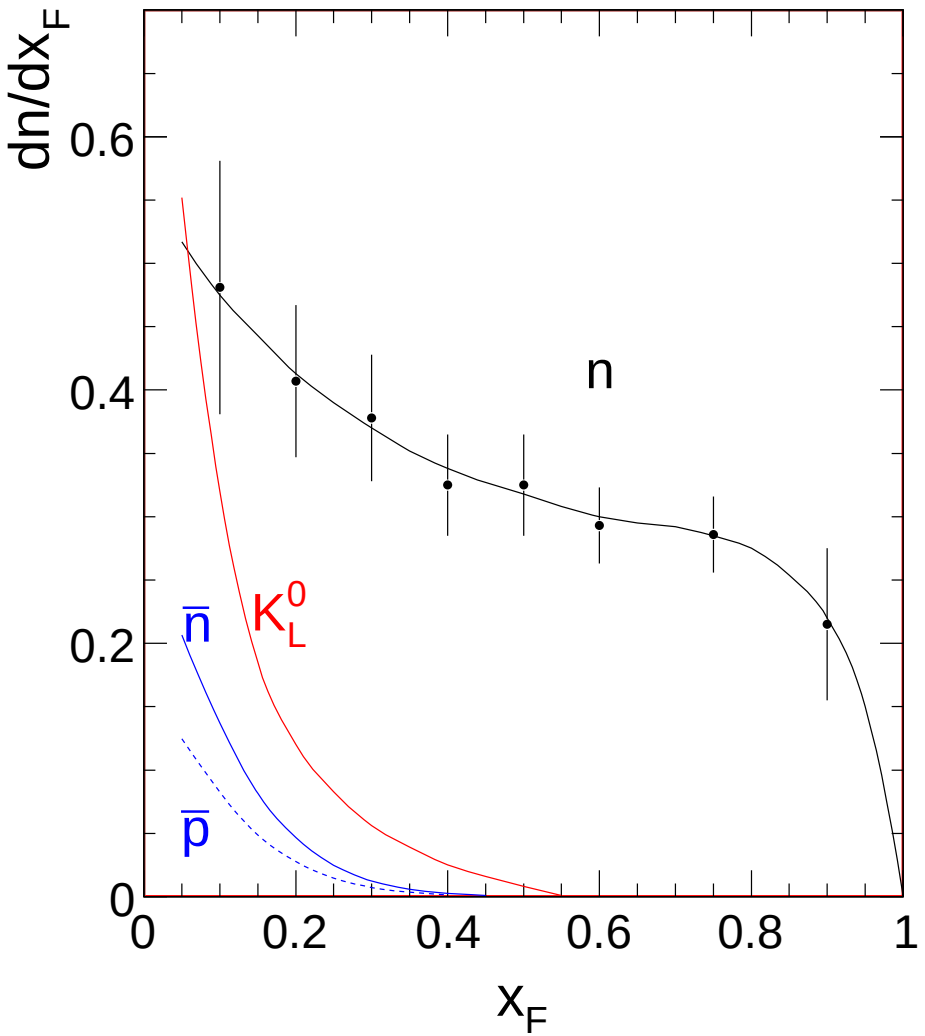
- $p + p \rightarrow \pi^- + X$
- $p + p \rightarrow K^- + X$
- $p + p \rightarrow \overline{p} + X$
- Wide x_F and p_T ranges:
  - $x_F = 0 \div 0.85$ and $p_T = 0 \div 1.9$ GeV/c for π^-
  - $x_F = 0 \div 0.5$ and $p_T = 0 \div 1.7$ GeV/c for K^-
  - $x_F = 0 \div 0.4$ and $p_T = 0 \div 1.5$ GeV/c for $\overline{p}$

p_T-integrated distributions

$$dn/dx_F = \pi/\sigma_{\text{inel}} \cdot \sqrt{s}/2 \cdot \int f/E \cdot dp_T^2$$



p_T-integrated neutron distributions



- feed-down correction
- K^0_L:

$$K^0_L = \frac{K^+ + K^-}{2}$$

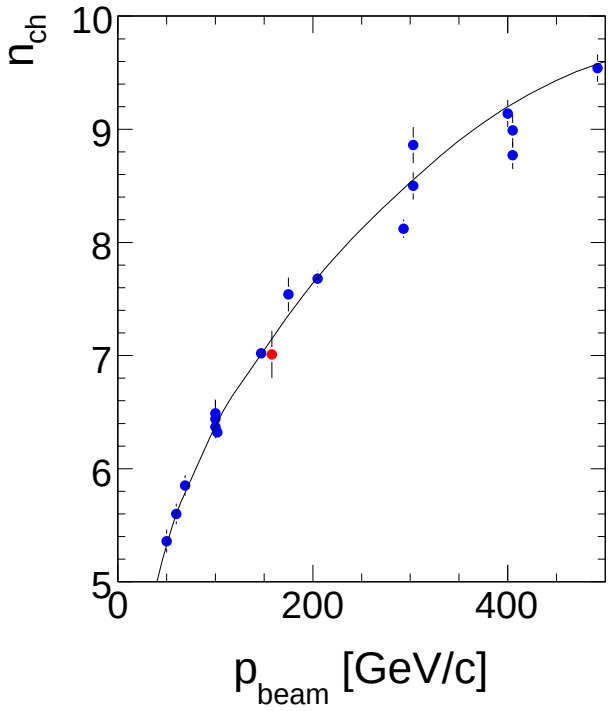
- $\overline{n}$:

I_3	-1	0	1
baryon pairs	$\overline{p}n$	$\overline{p}p$ $\overline{n}n$	$\overline{n}p$
relative yield	0.5	1 1	1.5

$$\overline{n}/\overline{p} = 1.66$$

Total charge multiplicities

	positives	negatives	total
$\langle n_\pi \rangle$	3.018	2.360	5.378
$\langle n_\mathrm{K} \rangle$	0.227	0.130	0.357
$\langle n_\mathrm{p} \rangle$	1.162	0.039	1.201
$\langle n_\Sigma \rangle$	0.054	0.016	0.070
$\langle n \rangle$	4.461	2.545	7.006

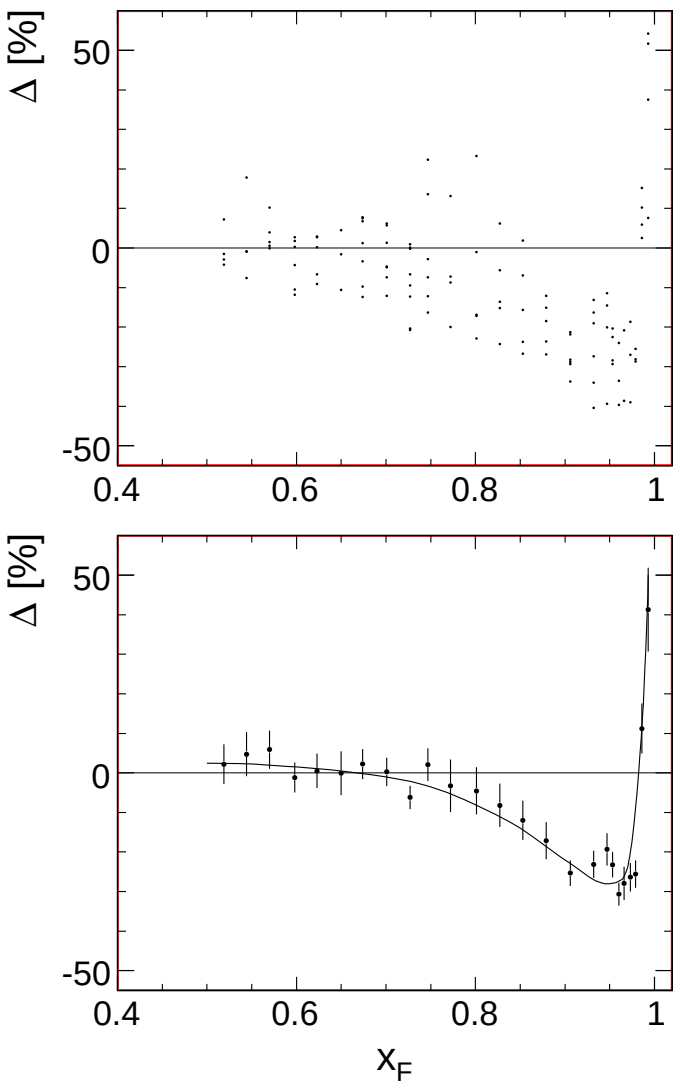


- Total charge multiplicity – 7.006 expected 7.15
- Charge conservation – 1.916 expected 2

Baryon production

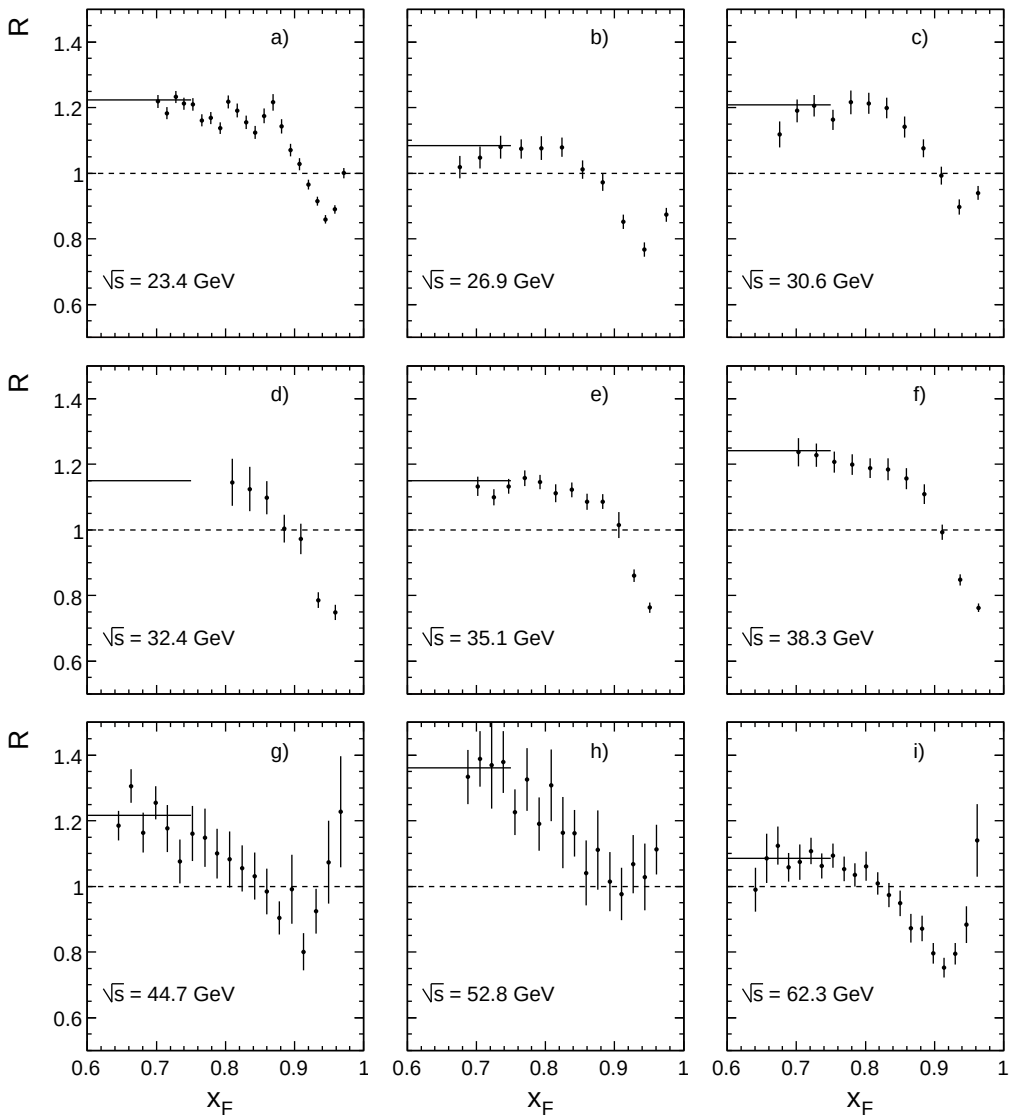
- Comparison to ISR proton x_F and p_T distributions
- Comparison to neutron data from Fermilab and ISR
- Comparison to results on protons and neutrons in e+p collisions from HERA

ISR proton production at $x_F > 0.6$



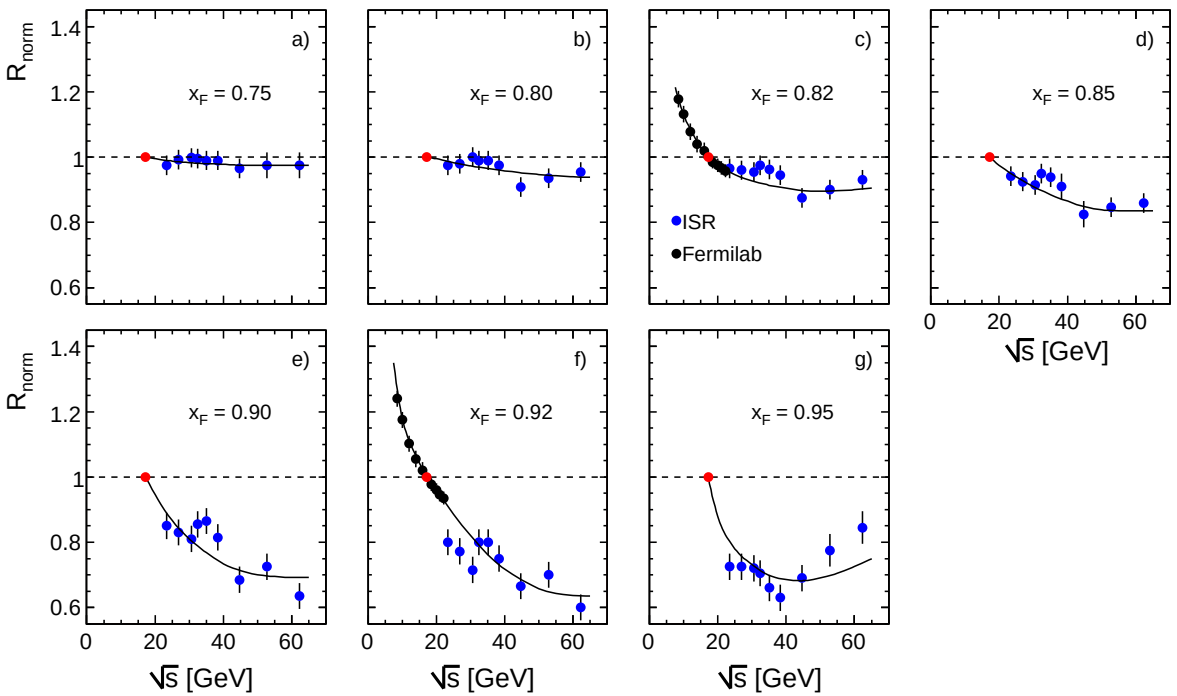
- $\sqrt{s} = 31$ GeV
- Difference between ISR and NA49 data Δ as a function of x_F
- Mean over p_T
- Depletion above $x_F = 0.7$
- Offset below $x_F = 0.7$ is about 2.5% – scaling

ISR proton production at $x_F > 0.6$



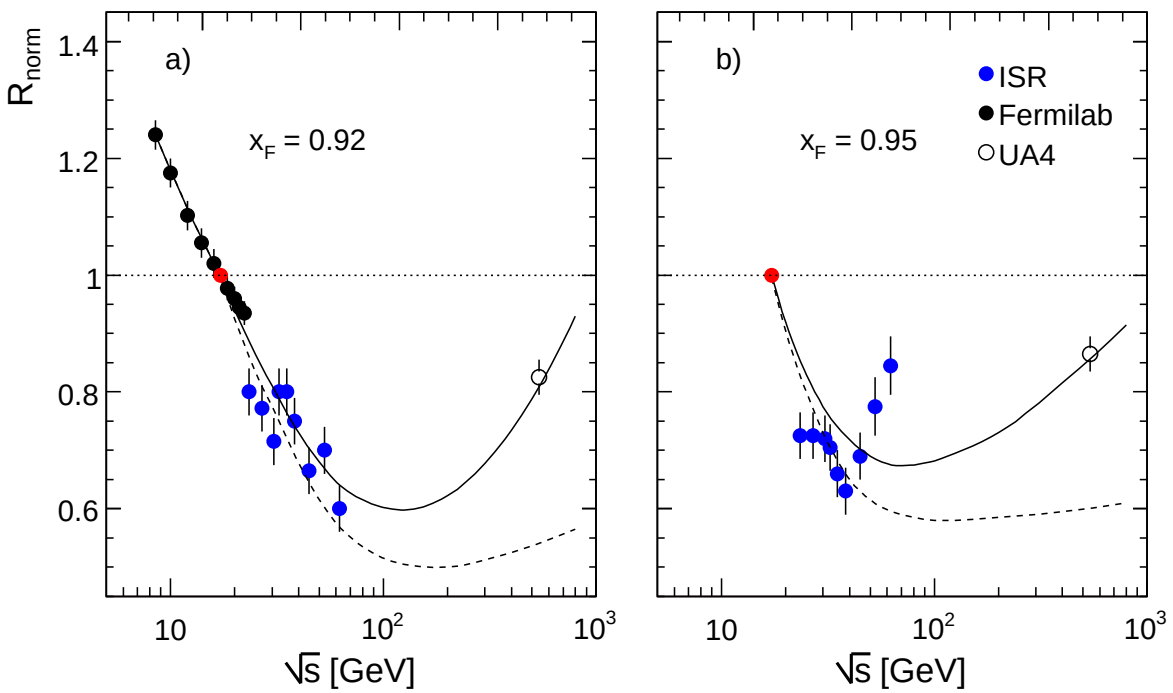
- $\sqrt{s} = 23 \div 63$ GeV
- Ratio $R = f_{ISR}/f_{NA49}$ as a function of x_F
- Mean over p_T
- Depletion above $x_F = 0.7$
- Relative shape consistency at different ISR energies, but sizeable normalization factors $F(x_F)$ indicated as full lines needed, $\langle F(x_F) \rangle \sim 16\%$

ISR proton production at $x_F > 0.6$



- Normalized ratio $R_{\mathrm{norm}} = R(x_F)/F(x_F)$ as a function of $\sqrt{s}$
- Smooth decrease as a function of x_F
- Depletion increases to about 40% at $x_F \sim 0.95$
- Included also low $\sqrt{s}$ data from Fermilab

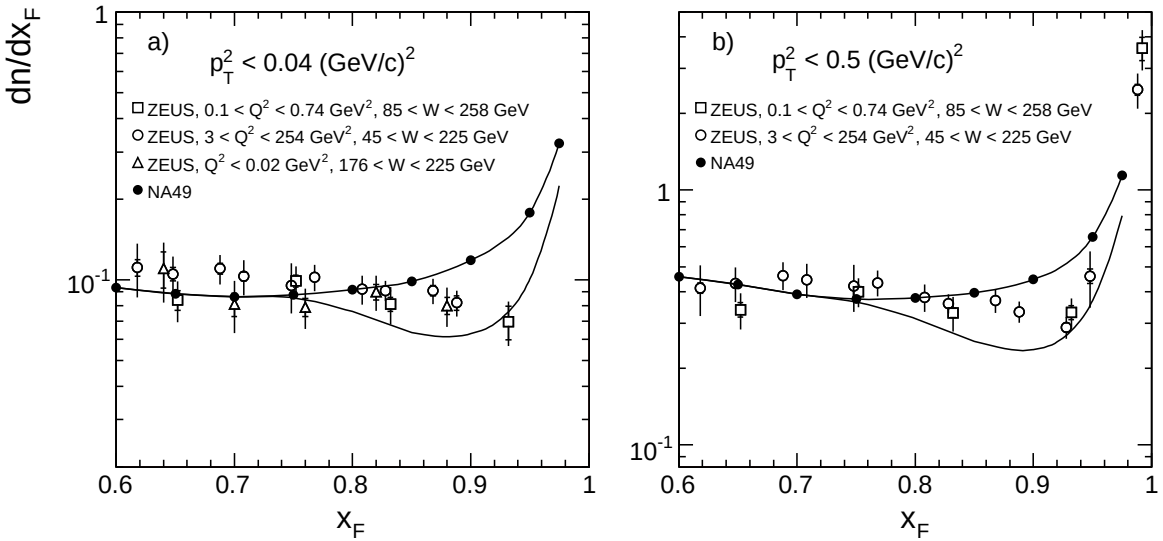
ISR proton production at $x_F > 0.6$



- Full lines – invariant cross section ratio
- Dashed lines – density ratio

- $x_F = 0.92$ and 0.95
- Normalized ratio $R_{\mathrm{norm}} = R(x_F)/F(x_F)$ as a function of $\sqrt{s}$
- UA4 from S$\bar{\mathrm{p}}$pS
- Density per inelastic event
- Baryon Number conservation

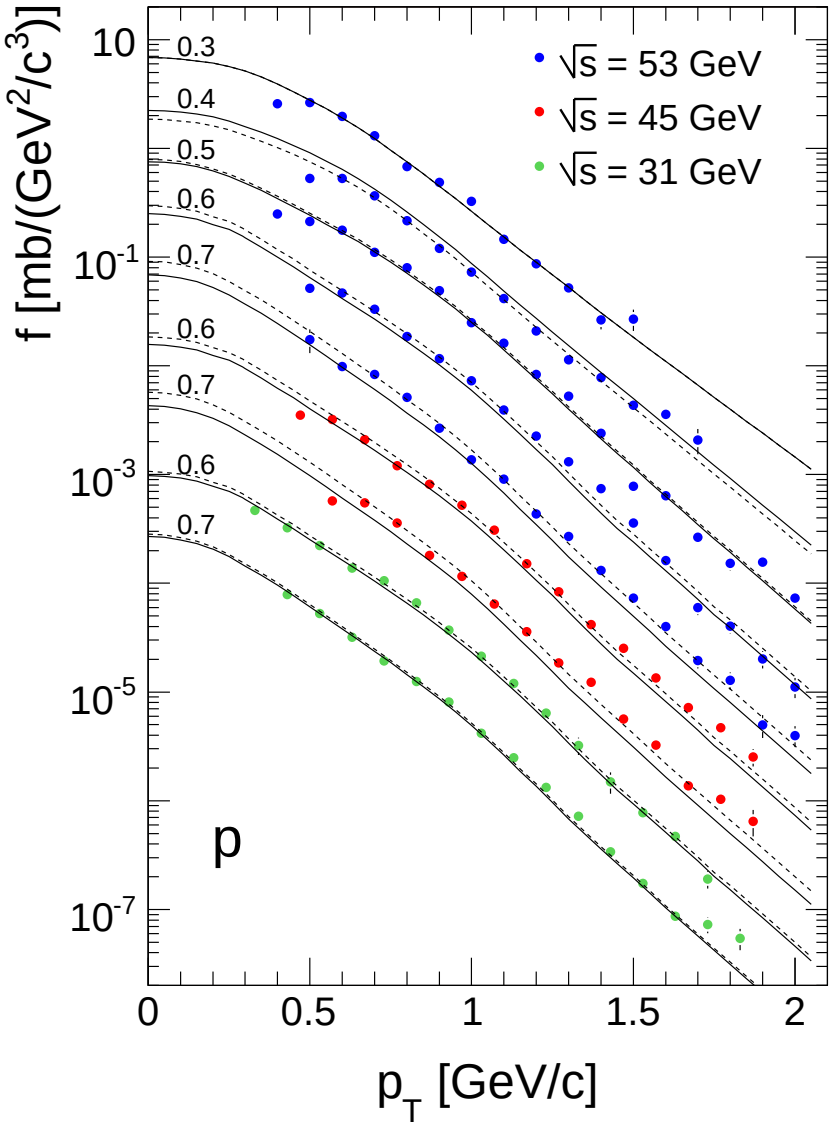
Proton production in e+p from HERA



- Upper line – NA49 data
- Lower line – Depletion from ISR included

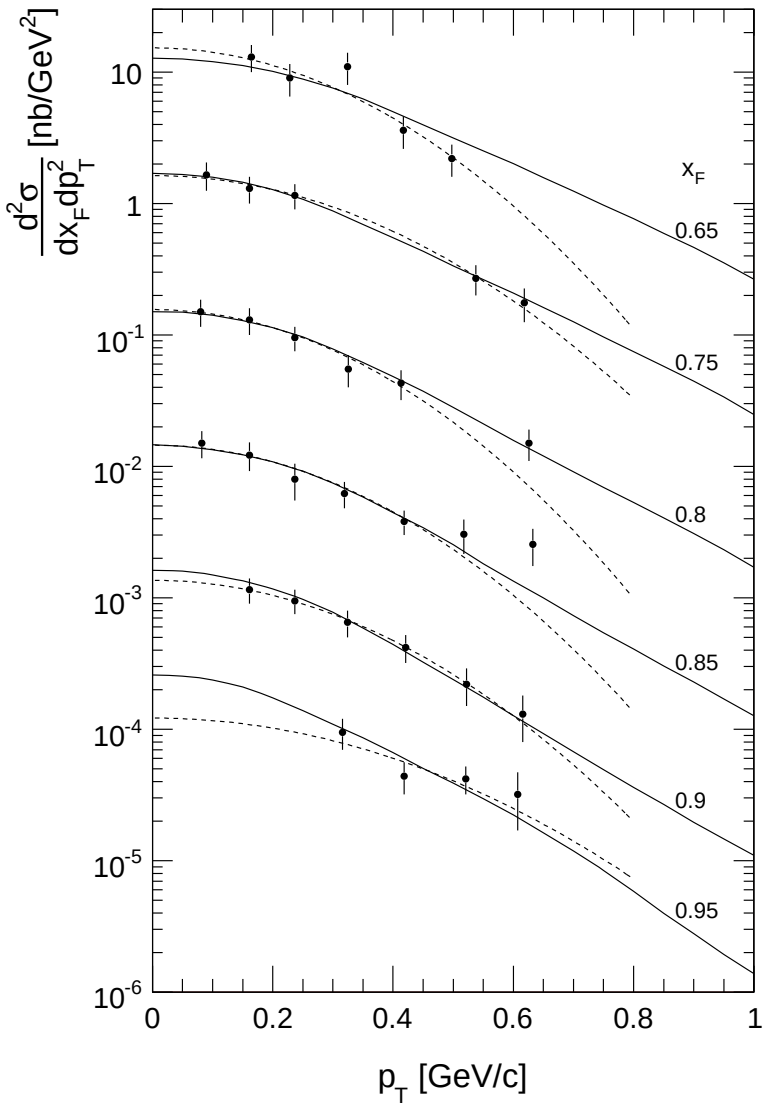
- $x_F = 0.6 \div 1.0$
- $\sqrt{s} \sim 130$ GeV
- p_T integrated with two ranges of integration $p_T^2 < 0.04$ and $p_T^2 < 0.5$ (GeV/c)^2
- Decrease of proton density above $x_F \sim 0.7$
- Good agreement between proton density in p+p and e+p

ISR proton p_T distributions



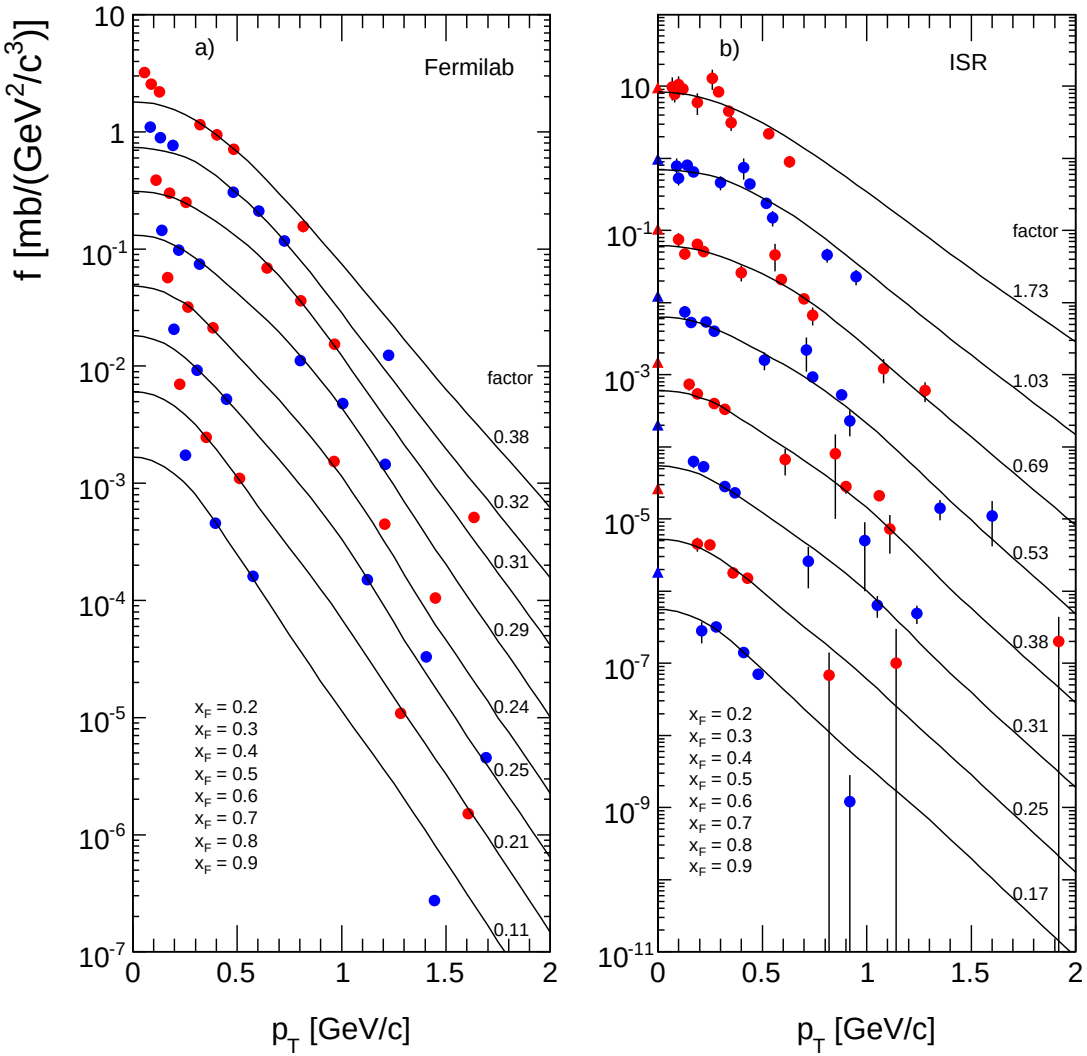
- $x_F = 0.3 \div 0.7$
- $\sqrt{s} = 31, 45, 53$ GeV
- Similar shape of the p_T distributions
- Offset between NA49 ans ISR data – normalization factors $F(x_F)$
- Mean offset is about 10%. Increase with $\sqrt{s}$
- Full lines – NA49 results
- Dash lines – NA49 results multiplied with a proper normalization factor

ZEUS proton p_T distributions



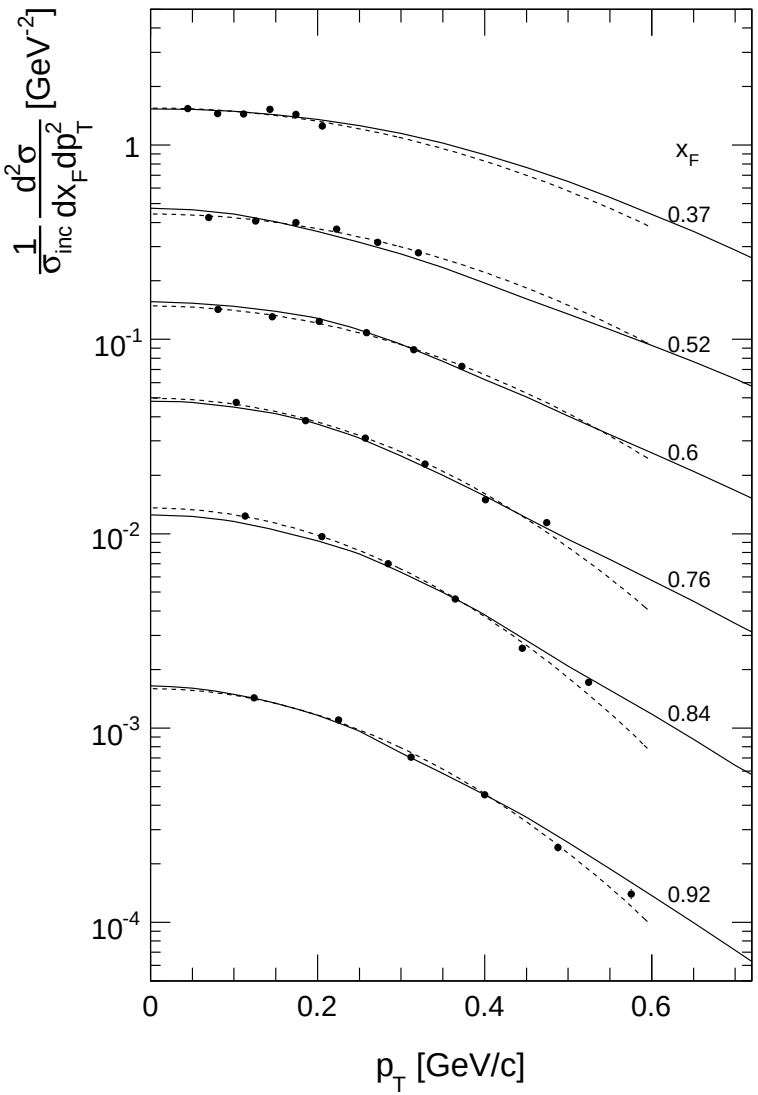
- $x_F = 0.6 \div 1.0$
- $\sqrt{s} \sim 130$ GeV
- Similar shape of the p_T distributions
- Full lines – NA49 p_T distributions
- Dash lines – ZEUS exponential fits in momentum transfer

Neutron p_T distributions from ISR and Fermilab



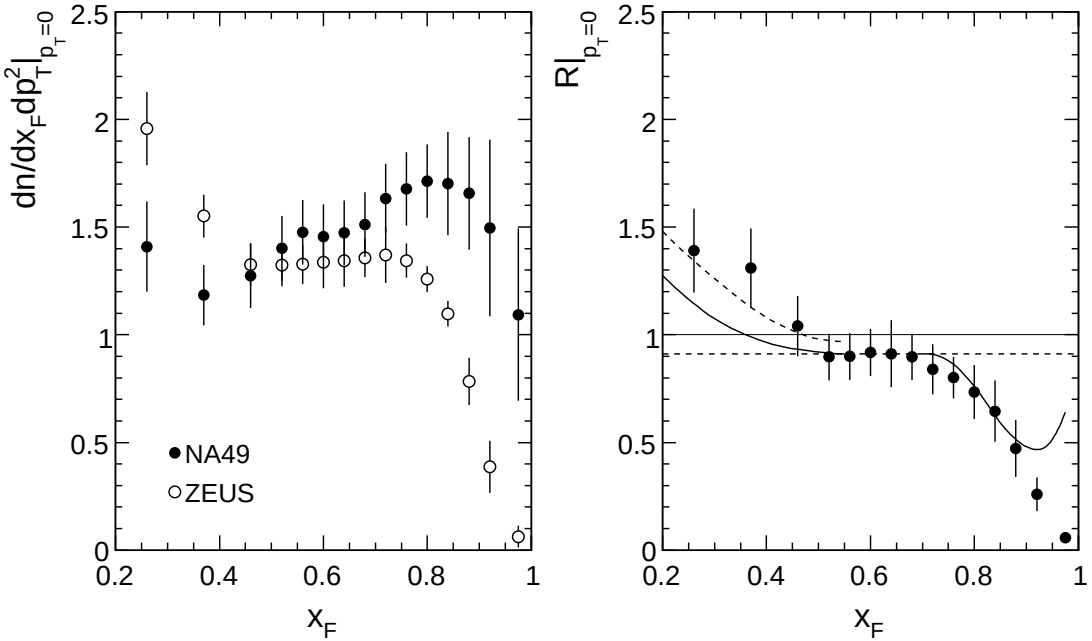
- $x_F = 0.2 \div 0.9$
- Full lines – NA49 proton p_T distributions
- Similar shape of the p_T distributions between protons and neutrons
- Big normalization factors – $0.1 \div 1.7$
- Problems at $p_T = 0$ GeV/c

ZEUS neutron p_T distributions



- $x_F = 0.26 \div 0.97$
- Similar shape of the p_T distributions between protons and neutrons
- Full lines – NA49 p_T distributions
- Dash lines – ZEUS exponential fits in momentum transfer

ZEUS neutron $p_T = 0$ GeV/c



- Extracting neutrons at $p_T = 0$ GeV using proton p_T distributions
- At $x_F = 0.45 \div 0.7$ yields are equal within 7–8%
- Enhancement of Zeus data at x_F below 0.5 – K^0_L contamination and feed-down

- Decrease at x_F above 0.7 is connected to depletion observed for protons, but there is no diffractive peak for neutrons

Kaon production

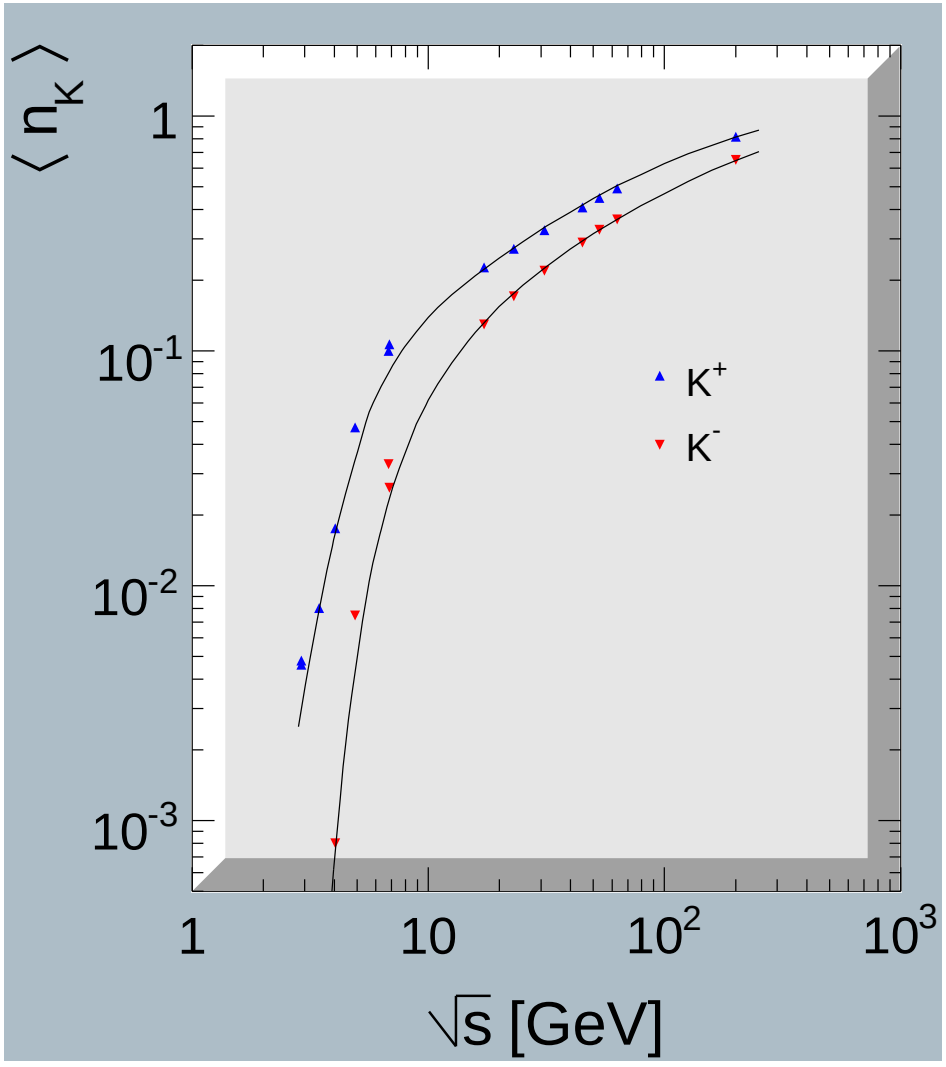
- Establish an $\sqrt{s}$ dependence from 3 to 540 GeV.
- Relation of charged kaon to K^0_S production

Charged kaons

- New attempt of establishing $\sqrt{s}$ dependence of total multiplicitites of charged kaons
- Available data
  1. Cosmotron/PPA – at 3.2 to 3.9 GeV/s beam momentum
  2. PS/AGS – at 12 to 24 GeV/s beam momentum
  3. NA49 – $\sqrt{s} = 17.2$ GeV
  4. ISR – $\sqrt{s} = 23 \div 63$ GeV
  5. Cern p+$\overline{\text{p}}$ and Fermilab colliders $\sqrt{s} = 200 \div 1800$ GeV

Charged kaons total multiplicities

ref.	$\sqrt{s}$ [GeV]	$\langle n_{K^+} \rangle$	$\langle n_{K^-} \rangle$
1	2.9	0.00462	
1	2.9	0.00481	
-	3.45	0.00802	
-	4.04	0.01760	0.00080
2	4.9	0.0473	0.00747
2	6.8	0.0999	0.0330
2	6.84	0.107	0.0262
3	17.2	0.227	0.130
4	23.0	0.273	0.171
4	31.0	0.327	0.220
4	45.0	0.409	0.290
4	52.0	0.448	0.328
4	63.0	0.493	0.363
4	200.0	0.819	0.651

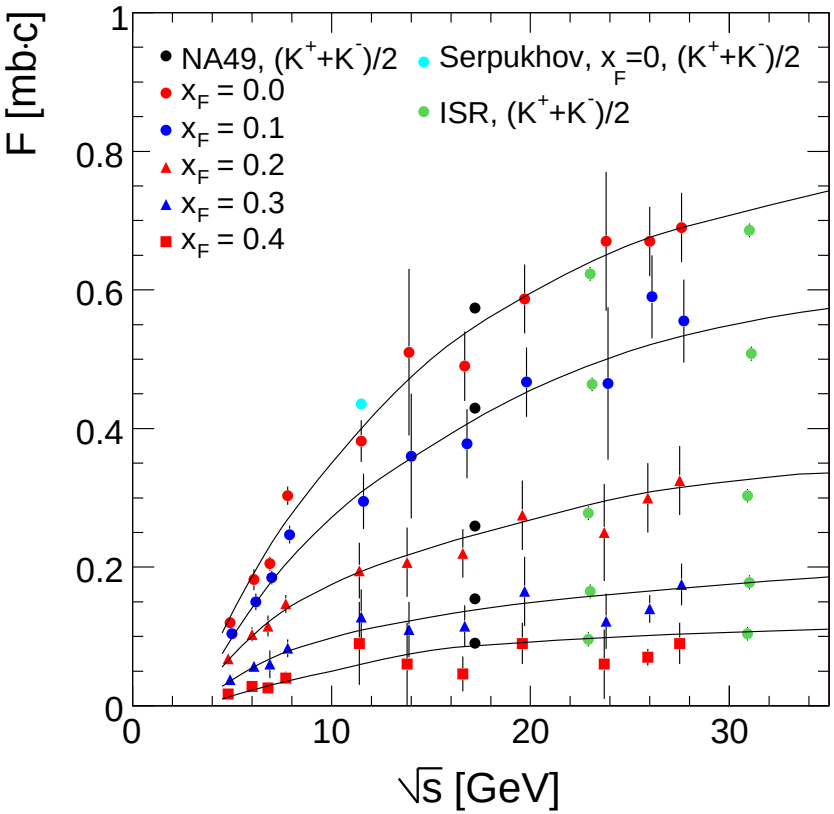


K^0_S data

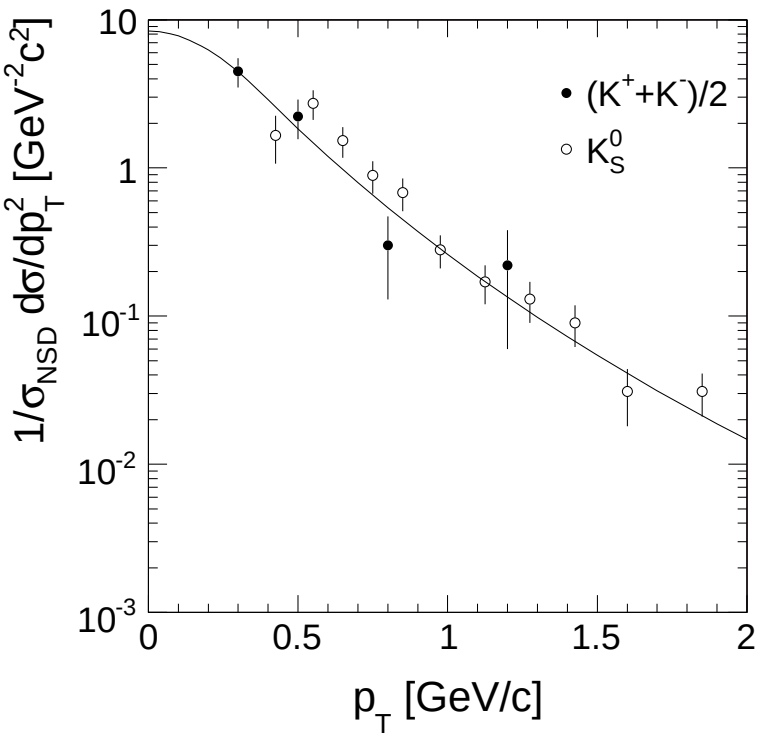
$\sqrt{s}$ [GeV]	$\langle n_{K^+} \rangle$	$\langle n_{K^-} \rangle$	$\langle n_{K^0_S} \rangle$
2.9	0.00462		0.00082
2.9	0.00481		
3.45	0.00802		0.00294
3.59			0.00670
4.04	0.01760	0.00080	0.00719
4.9			0.0190
4.9	0.0473	0.00747	0.0198
6.1			0.0420
6.8			0.0410
6.8	0.0999	0.0330	0.0493
6.84	0.107	0.0262	(0.0666)
7.8			0.0636
11.5			0.109
13.8			0.121
13.9			0.146
16.7			0.158
17.2	0.227	0.130	(0.179)
19.7			0.181
23.0	0.273	0.171	(0.222)
23.8			0.224
23.8			0.212
25.7			0.262
27.4			0.200
27.6			0.232
31.0	0.327	0.220	(0.274)
45.0	0.409	0.290	(0.350)
52.0	0.448	0.328	(0.388)
63.0	0.493	0.363	(0.428)
200.0	0.819	0.651	(0.735)
200.0			0.700
546.0			1.000

- More dense is $\sqrt{s}$ than for charged kaons
- Bubble chamber measurements – $\sqrt{s} = 3 \div 27.6$ GeV
- S$\bar{\text{p}}$pS – $\sqrt{s} = 200$ and 546 GeV
- $$K^0_L = \frac{K^+ + K^-}{2}$$

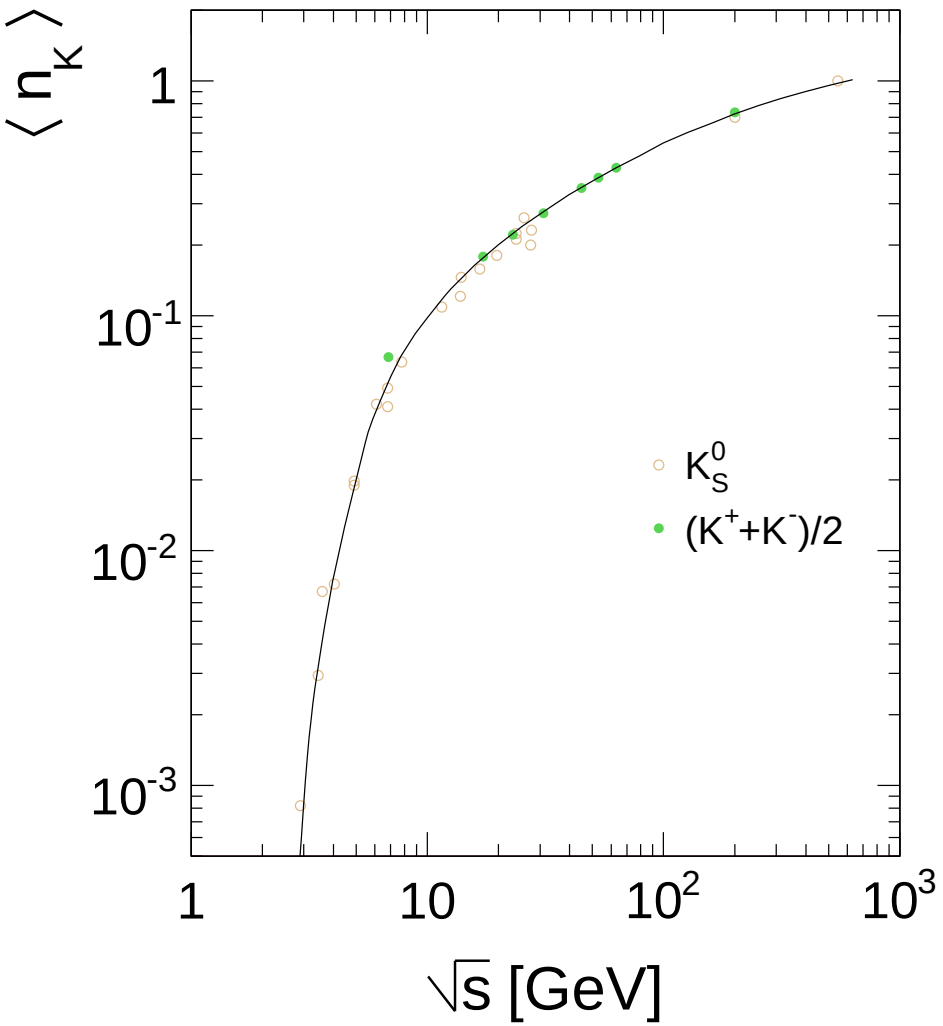
K^0_S vs $(K^+ + K^-)/2$



UA5 at $\sqrt{s} = 540$ GeV

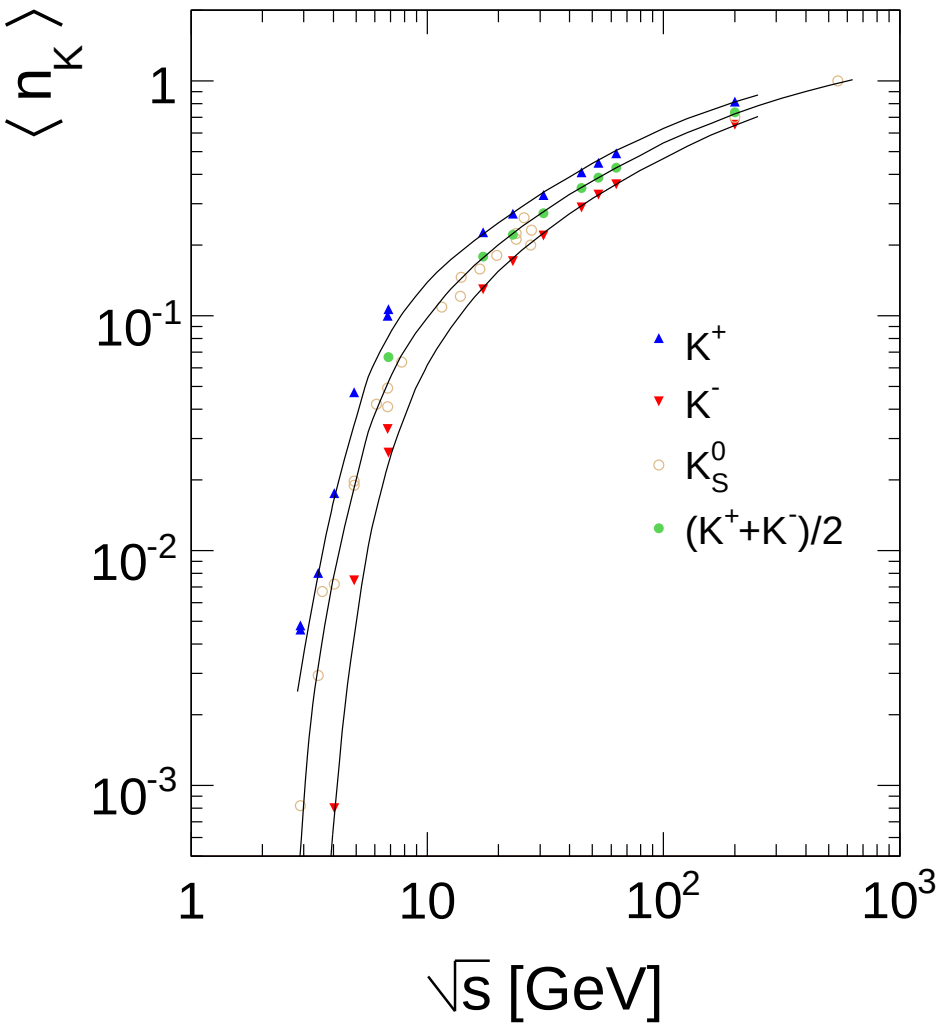


Total kaon multiplicities as a function of $\sqrt{s}$



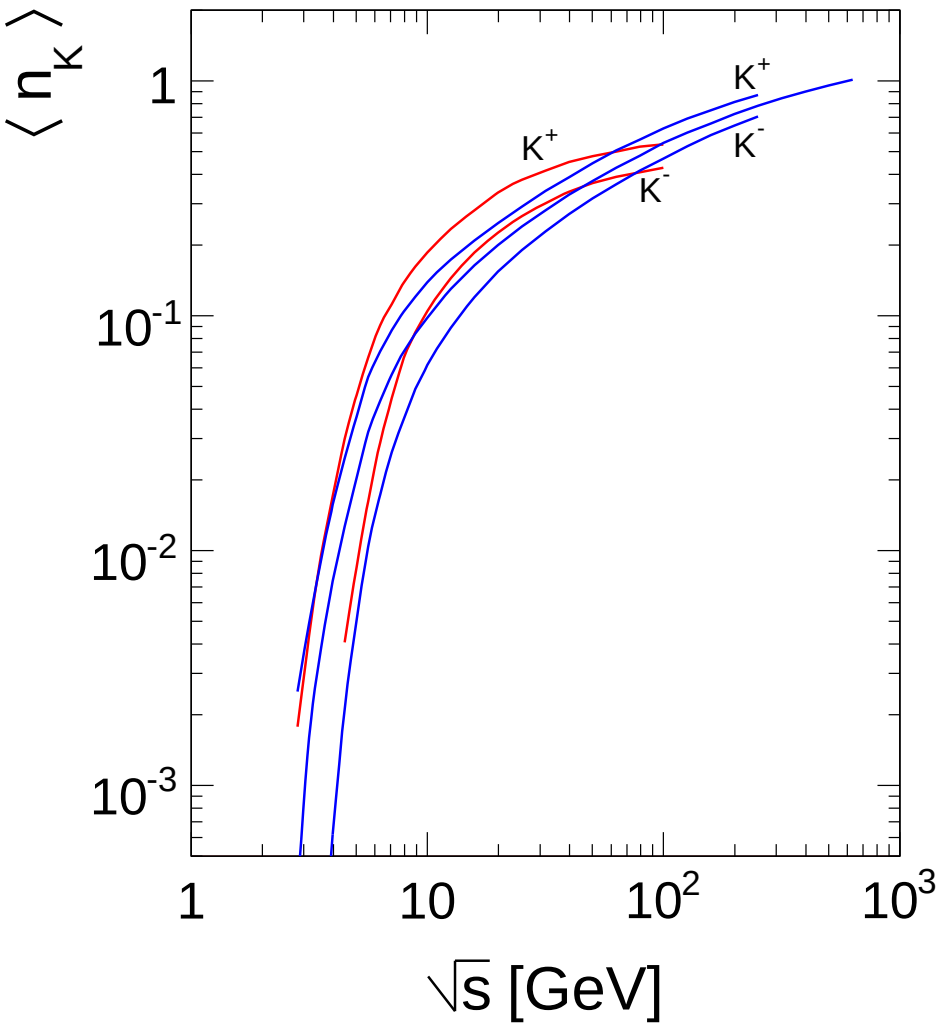
- K^0_S and ($K^+ + K^-$)/2 equals

Total kaon multiplicities as a function of $\sqrt{s}$



- K^0_S and ($K^+ + K^-$)/2 equals
- Consistent description of the kaons

Total kaon multiplicities as a function of $\sqrt{s}$



- K^0_S and ($K^+ + K^-$)/2 equals
- Consistent description of the kaons
- Comparison to old estimation shows that this new determination of s-dependence supersedes earlier parametrizations
- K^- is bigger than K^0_S in old data

Conclusions

- ☞ New data on inclusive production of pions, kaons, protons, anti-proton and neutrons in p+p colisions at $\sqrt{s} = 17.2$ GeV are presented
- ☞ Total multiplicities of charged particles and charge conservation are checked. Both of them are fulfilled within the systemathic uncertainties of order of 2%.
- ☞ The s-dependence of protons through the ISR energy range and up to HERA and p+$\overline{\mathrm{p}}$ collider energies has been investigated.Specific yield suppression at $x_F > 0.7$ with increasing cms energy has been quantified.
- ☞ A global independence of p_T distributions on baryon type (p,n) and on $\sqrt{s}$ has been observed. This is also confirmaed for electroproduction data from HERA.
- ☞ A new evaluation of s-dependence of kaons up to collider energies has been established.
- ☞ The relation $\mathrm{K}^0_S = 0.5(\mathrm{K}^+ + \mathrm{K}^-)$ has been found valid within the experimental precision.