Quark Confinement and the Hadron Spectrum XI

# Transverse Momentum Dependence of Spectra of Cumulative Particles Produced from Droplets of Dense Nuclear Matter

Vladimir Vechernin
*Saint-Petersburg State University*
v-vechernin@ya.ru

17-12 September 2014 St. Petersburg

# Cumulative Particle Production

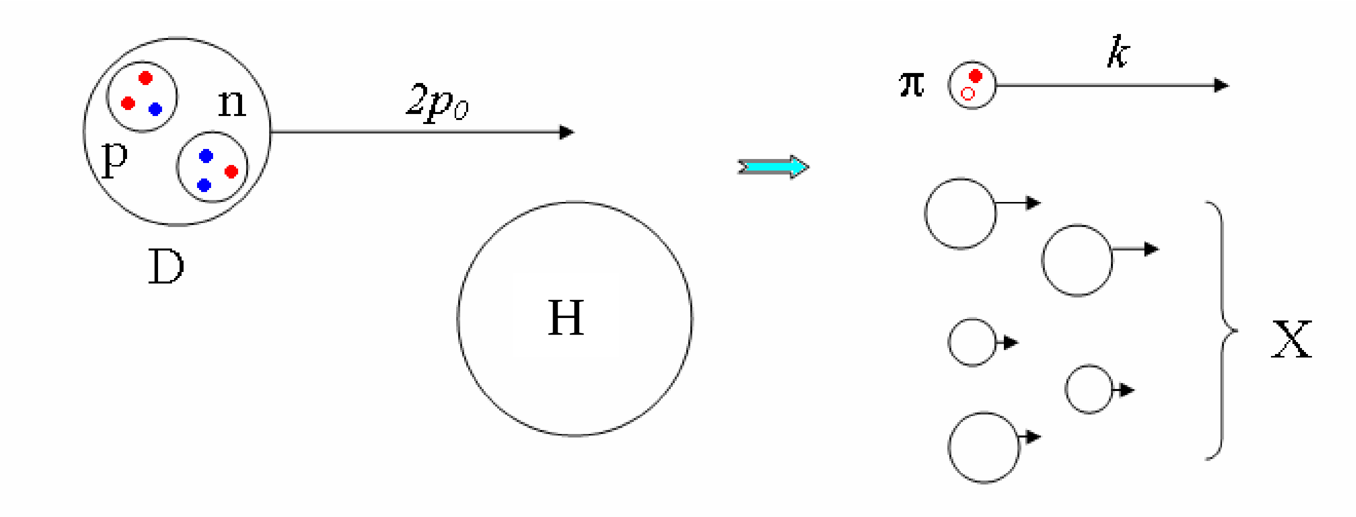
Production of particles from nuclei in a region, kinematically forbidden for reactions with free nucleons.

## Cumulative Pion Production

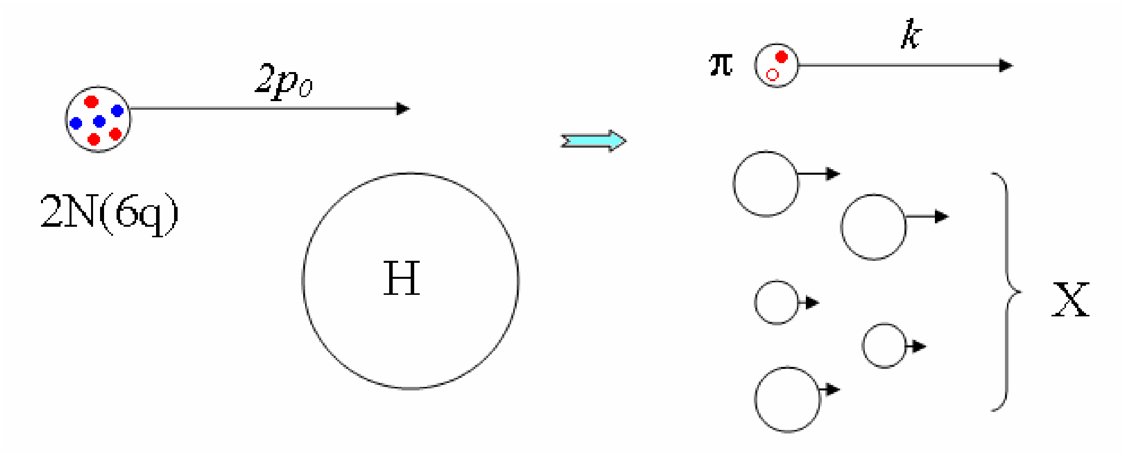
Fragmentation of deuterons, D, on some target, H.
*Baldin A.M. et al., Yad.Fiz.**18** (1973) 79* Nuclotron@Dubna ($p_0$=5 GeV/c)

$$D + H \Rightarrow \pi + X$$

$p_0 \gg m_N$ : $p_0 < k < 2p_0$ - cumulative pions



Flucton - droplet of dense cold nuclear matter (2N fluctuation – 6 quark state)
*Blokhintsev D.I., JETP **33** (1957) 1295*




Theoretical description near threshold: $k \to 2p_0$ , $x = k/p_0 \to 2$

$1 < x < 2$ - the cumulative region ( $1 < x < f$ - *for the fN flucton* )

*Brodsky S.J., Chertok B.T. Phys.Rev. **D14** (1976) 3003; Phys.Rev.Lett. **37** (1976) 269*
*Schmidt I.A., Blankenbecler R. Phys.Rev. **D15** (1977) 3321*

Quark counting rules: $\sim \Delta^{2n-3}$
***n*** – the number of constituents, ***n*** = *6*
$\Delta$ – the deviation from the threshold, $\Delta = 2 - x$ , $\Delta \ll 1$

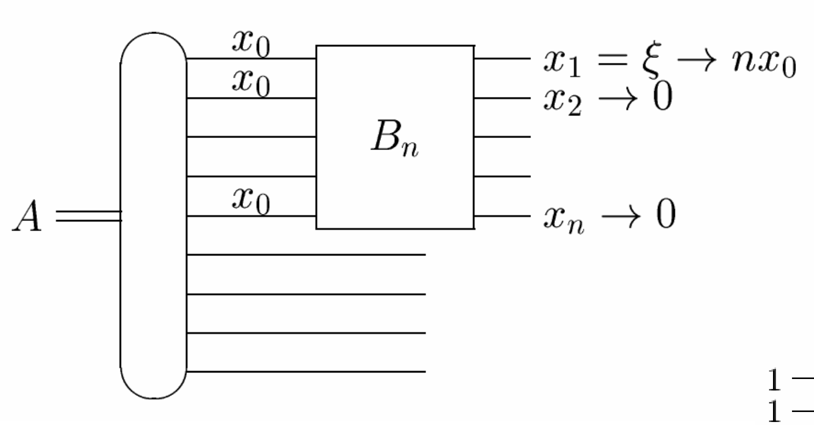
Description of the hadron asymptotics at x->1 by the intrinsic diagrams in QCD in light-cone gauge

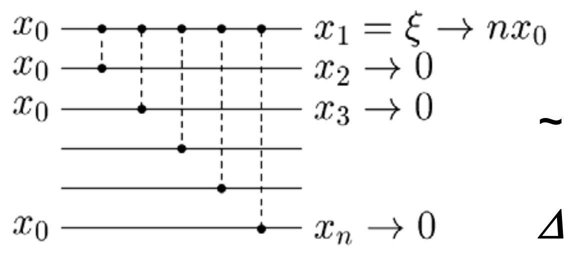
*Brodsky S.J., Hoyer P., Mueller A., Tang W.-K., Nucl.Phys.* ***B369*** *(1992) 519*

Description of the flucton asymptotic at *x->f,*

*f* - the number of nucleons in flucton, *n* - the number of quarks in flucton, $x_0 = f / n$.

*M.A. Braun, V.V. Vechernin, Nucl.Phys.* ***B427*** *(1994) 614.*

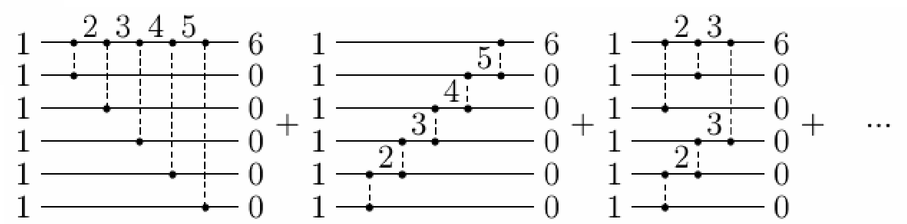


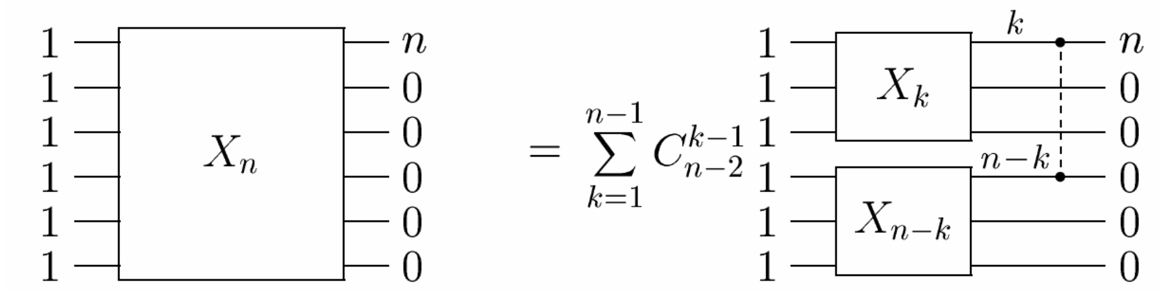




$\sim \Delta^{2n-3}$

$\Delta = n x_0 - \xi = f - \xi$

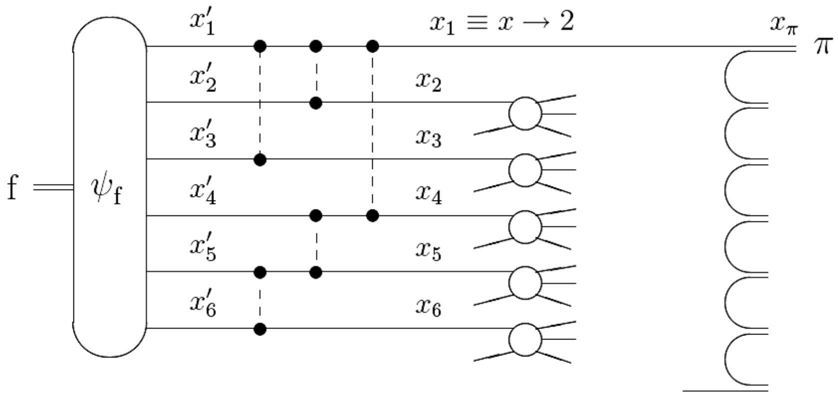
*p=n-1:* $\Delta^{2n-3} = \Delta^{2p-1}$





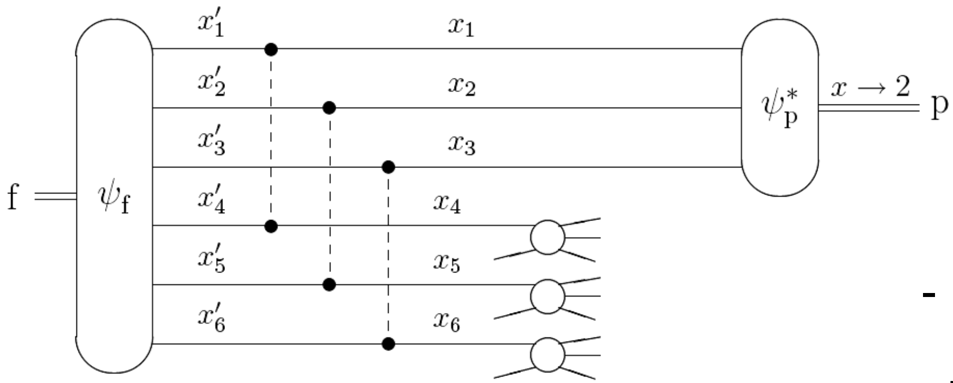

- the recurrence relation

# Coherent Quark Coalescence and Production of Cumulative Protons




- the cumulative pion production

$k_T$ – dependence:
*M.A. Braun, V.V. Vechernin,*
*Phys.Atom.Nucl.* ***63****, 1831 (2000)*




$p_1=p_2=p_3=1$

- the cumulative proton production

coherent quark coalescence mechanism:
*M.A. Braun, V.V. Vechernin,*
*Nucl.Phys.* ***B92****, 156 (2001);*
*Theor.Math.Phys* ***139****, 766 (2004)*

$W_j$ **:** *j=1,2,3.*

$n=n_1+n_2+n_3$

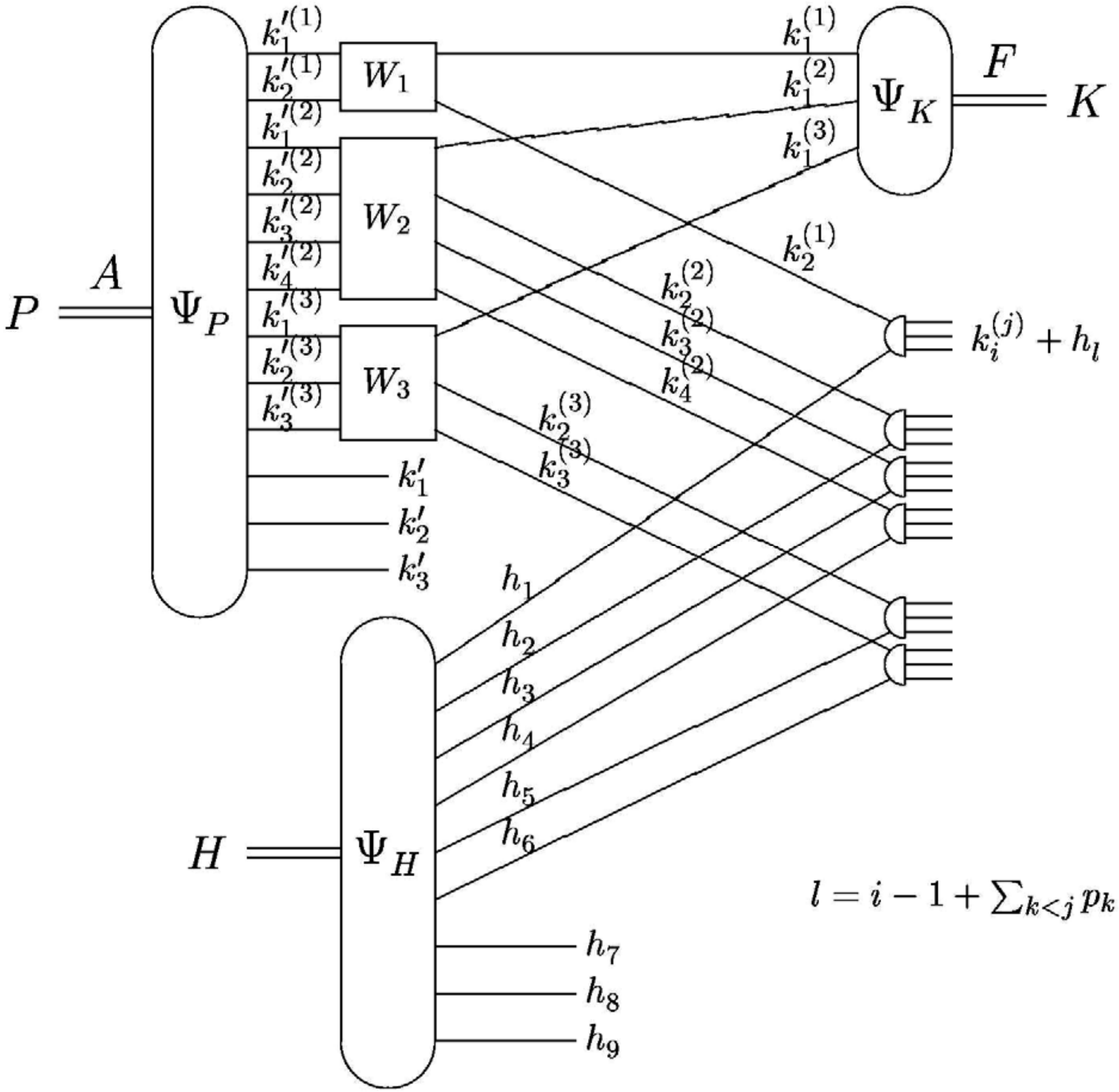
$p_1=n_1-1$

$p_2=n_2-1$

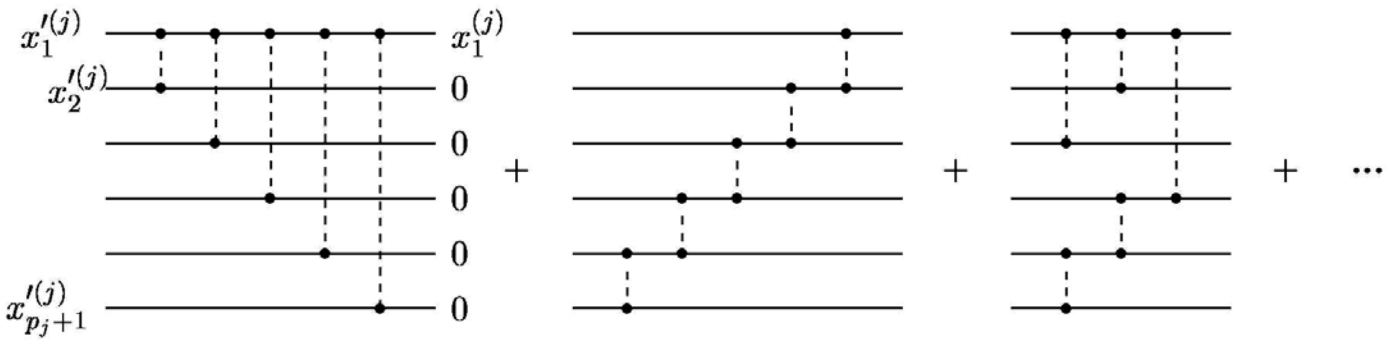
$p_3=n_3-1$

$p=p_1+p_2+p_3=1+3+2=6$

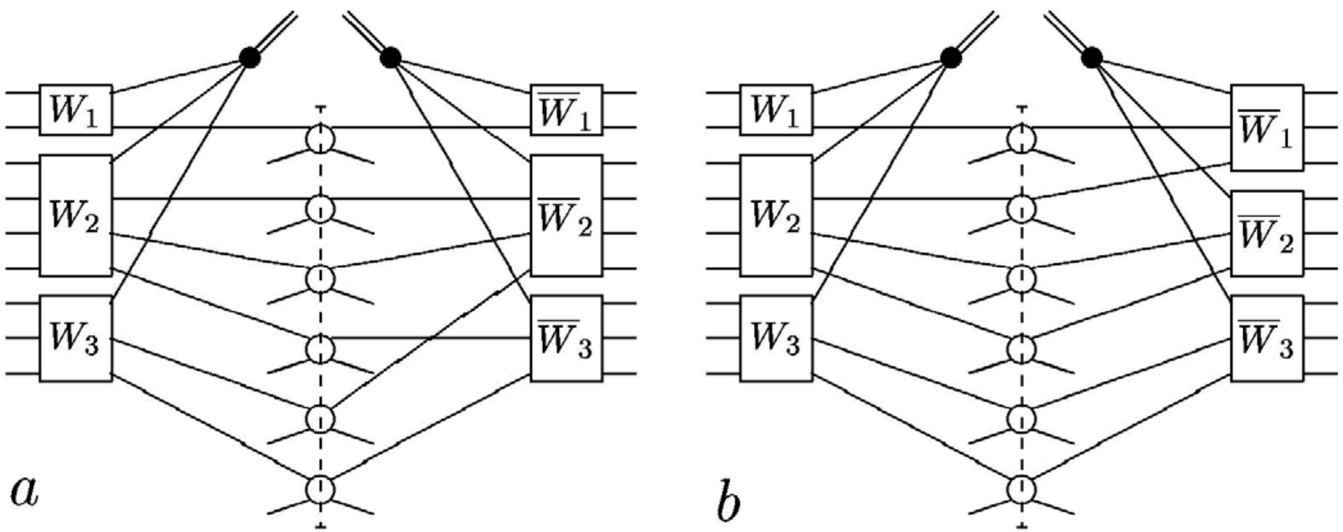
$n=p+3=9$



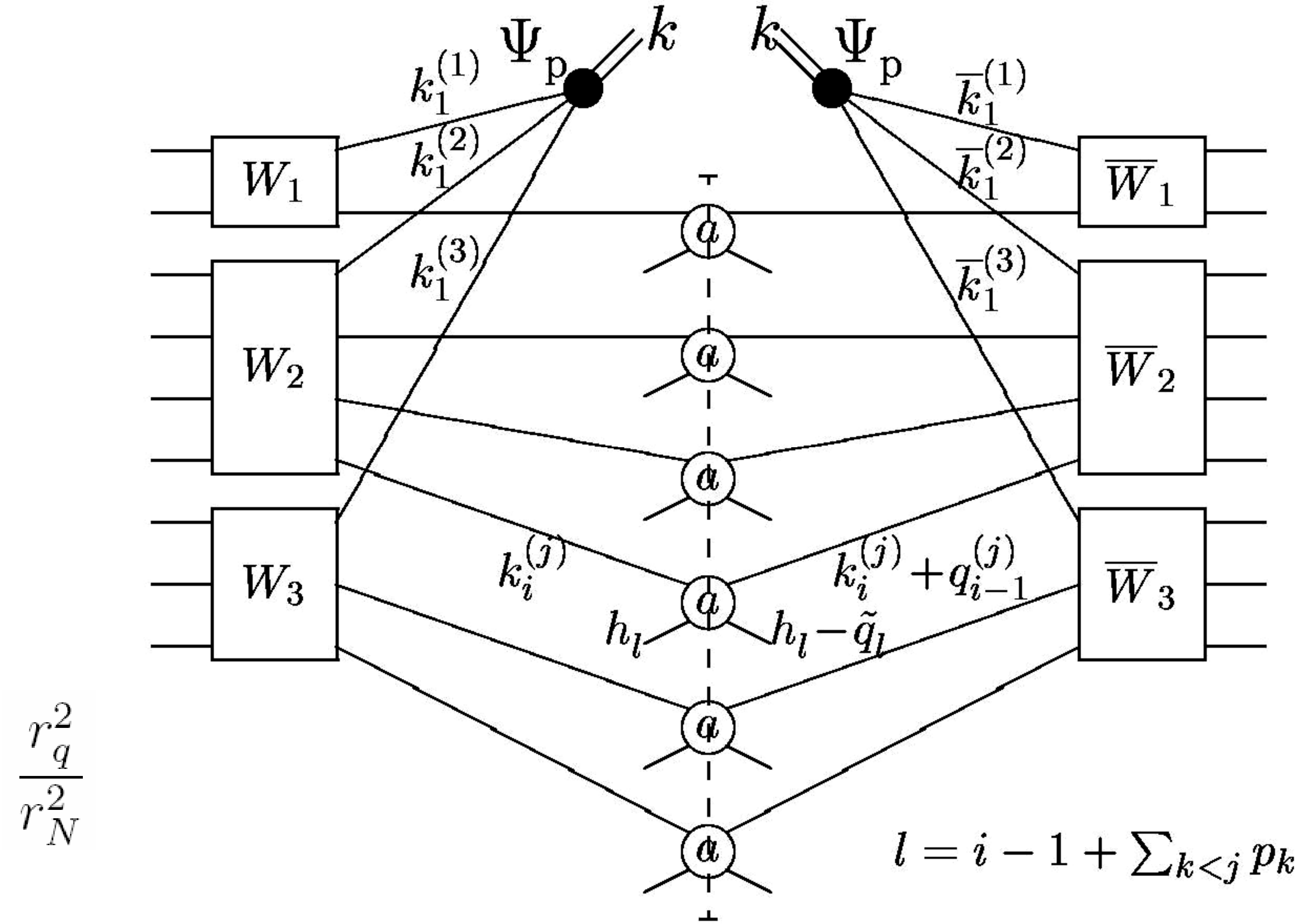
Contributions to the blobs $W_j$:




$$\sim \Delta^{2p_j-1}$$




The examples of two types of non-diagonal contributions to the cross section of cumulative proton production:
*a* – all $p_j = \overline{p}_j$, *b* – some $p_j \neq \overline{p}_j$




The diagonal contribution to the cross section of cumulative proton production.

Note the presence of the interference effects also in this case!

$$\sigma_{pion}(x, k_\perp; p) = C(p)\ (x_{frag} - x)^{2p-1}\ f_p\left(\frac{k_\perp}{m}\right)$$

$$x < x_{frag}(p) = 1/3 + p/3$$

*p=n-1*

*M.A. Braun, V.V. Vechernin, Phys.Atom.Nucl. **63**, 1831 (2000)*

$$\sigma_{prot}(x, k_\perp; p_1, p_2, p_3) = C(p_1, p_2, p_3)\ (x_{coal} - x)^{2p-1}\ f_{p_1}\left(\frac{k_\perp}{3m}\right)\ f_{p_2}\left(\frac{k_\perp}{3m}\right)\ f_{p_3}\left(\frac{k_\perp}{3m}\right)$$

$$x < x_{coal}(p) = 1 + p/3\ , \qquad p = p_1 + p_2 + p_3$$

*p=n-3*

*M.A. Braun, V.V. Vechernin, Theor.Math.Phys. **139**, 766 (2004)*

$$f_p(t) = 2\pi \int_0^\infty dz\, z J_0(tz)[zK_1(z)]^p$$

$J_0(z)$ - the Bessel function, $K_1(z)$ - the modified Bessel function.

$$(2\pi)^{-2} \int f_p(|\mathbf{b}|)\ d^2\mathbf{b} = (2\pi)^{-1} \int_0^\infty f_p(t)\ t\, dt = 1$$

Note that for *p=1* it can be simplified to $f_1(t) = 4\pi/(t^2+1)^2$

$$\varphi_{pion}(k_\perp, p) \equiv \sigma_{pion}(x, k_\perp; p)/\sigma_{pion}(x, 0; p) = f_p\left(\frac{k_\perp}{m}\right) / f_p(0)$$

---

$$\varphi_{prot}(k_\perp, p) \equiv \sigma_{prot}(x, k_\perp; p)/\sigma_{prot}(x, 0; p)$$

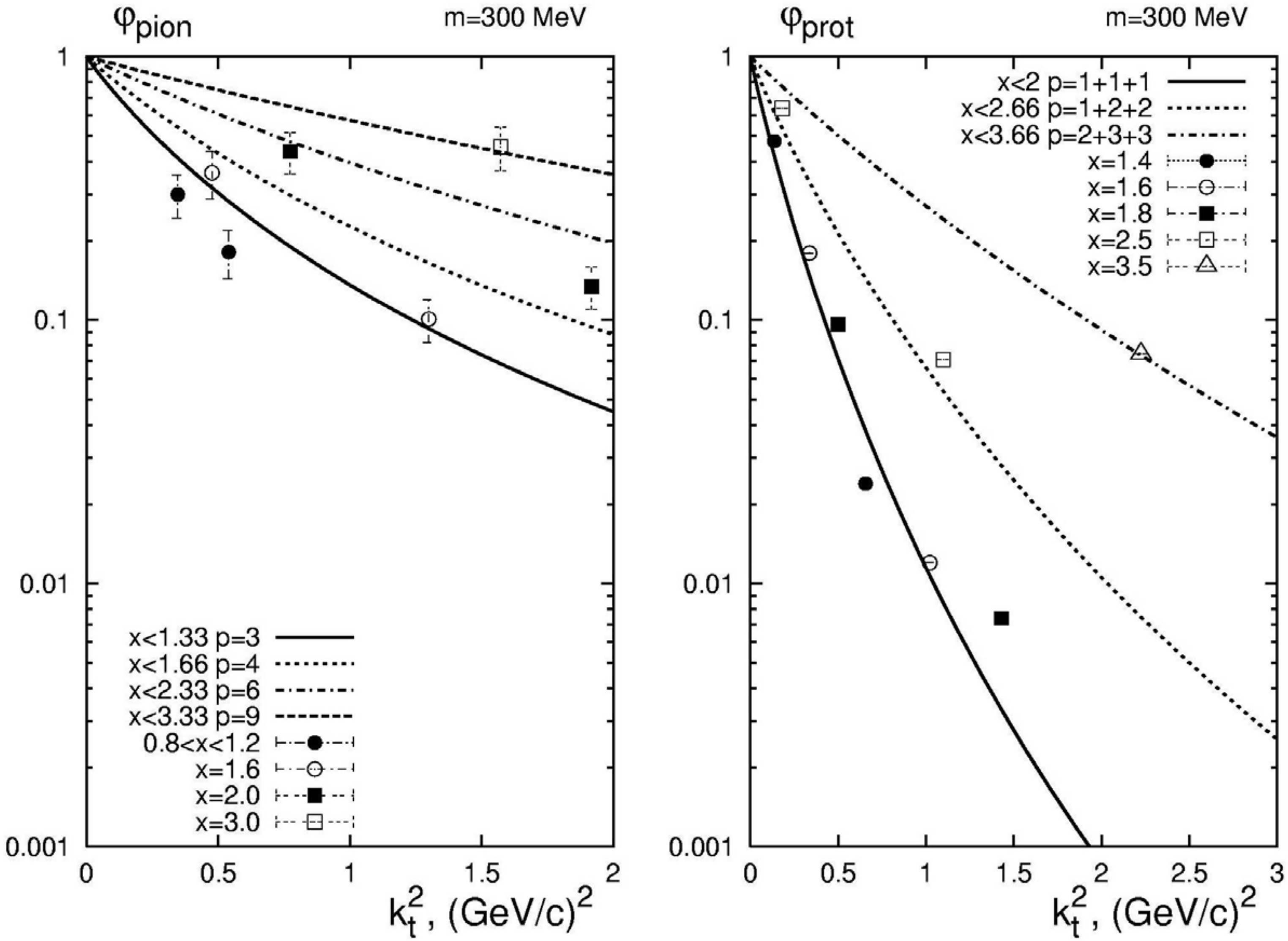
$$\varphi_{prot}(k_\perp, p) = \frac{\sum_{p_1,p_2,p_3} \ \delta_{p \ p_1+p_2+p_3} \ C(p_1, p_2, p_3) \ f_{p_1}\left(\frac{k_\perp}{3m}\right) \ f_{p_2}\left(\frac{k_\perp}{3m}\right) \ f_{p_3}\left(\frac{k_\perp}{3m}\right)}{\sum_{p_1,p_2,p_3} \ \delta_{p \ p_1+p_2+p_3} \ C(p_1, p_2, p_3) \ f_{p_1}(0) \ f_{p_2}(0) \ f_{p_3}(0)}$$

$$\varphi_{prot}(k_\perp, p_1, p_3, p_3) \equiv \frac{\sigma_{prot}(x, k_\perp; p_1, p_2, p_3)}{\sigma_{prot}(x, 0; p_1, p_2, p_3)} = \frac{f_{p_1}\left(\frac{k_\perp}{3m}\right)}{f_{p_1}(0)} \frac{f_{p_2}\left(\frac{k_\perp}{3m}\right)}{f_{p_2}(0)} \frac{f_{p_3}\left(\frac{k_\perp}{3m}\right)}{f_{p_3}(0)}$$

---

No free parameters (!) only *m* – the constituent quark mass: *m = 300 MeV.*

---





S.V. Boyarinov et al., Sov.J.Nucl.Phys. **46**, 871 (1987)
S.V. Boyarinov et al., Physics of Atomic Nuclei **57**, 1379 (1994)
S.V. Boyarinov et al., Sov.J.Nucl.Phys. **55**, 917 (1992)