Toward

A rough estimation of the charmed baryon production in perturbative QCD

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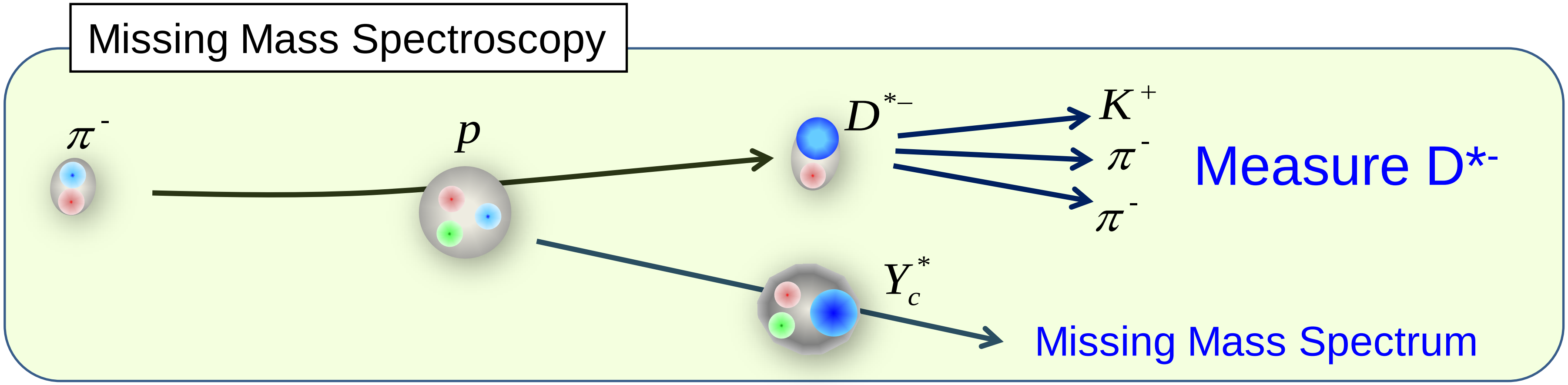
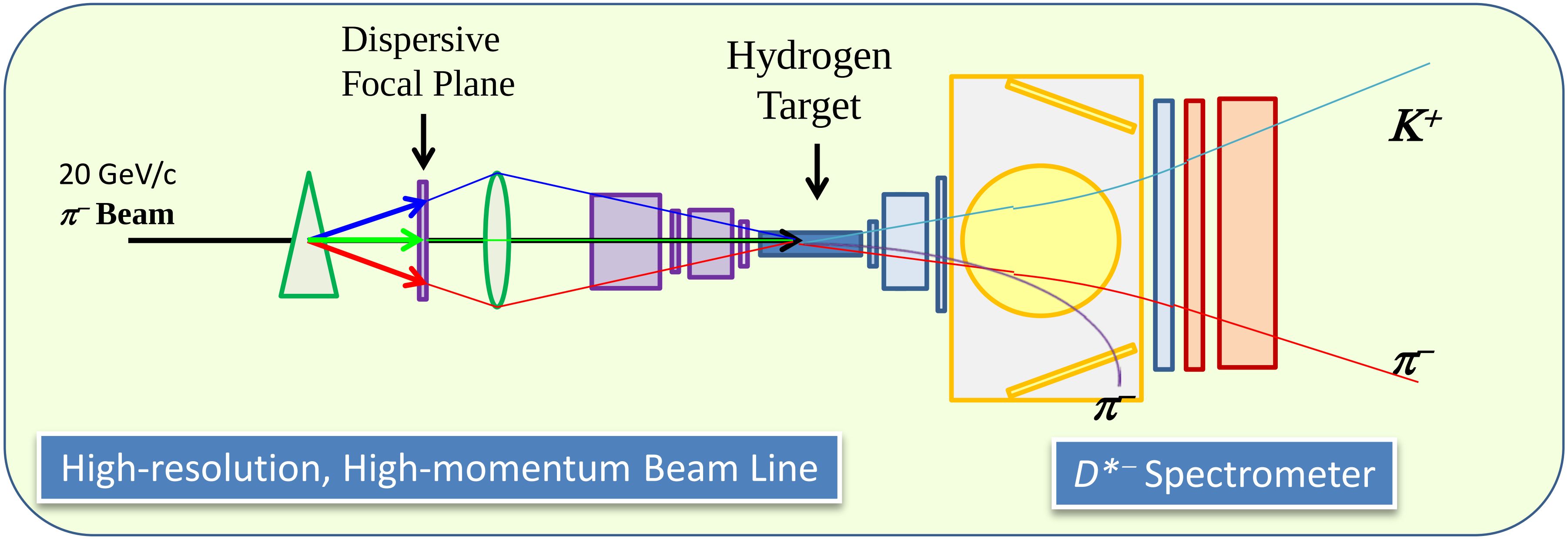
Sep.10, 2013
Discussion at KEK Tokai

Noumi-san

Charmed Baryon Spectroscopy





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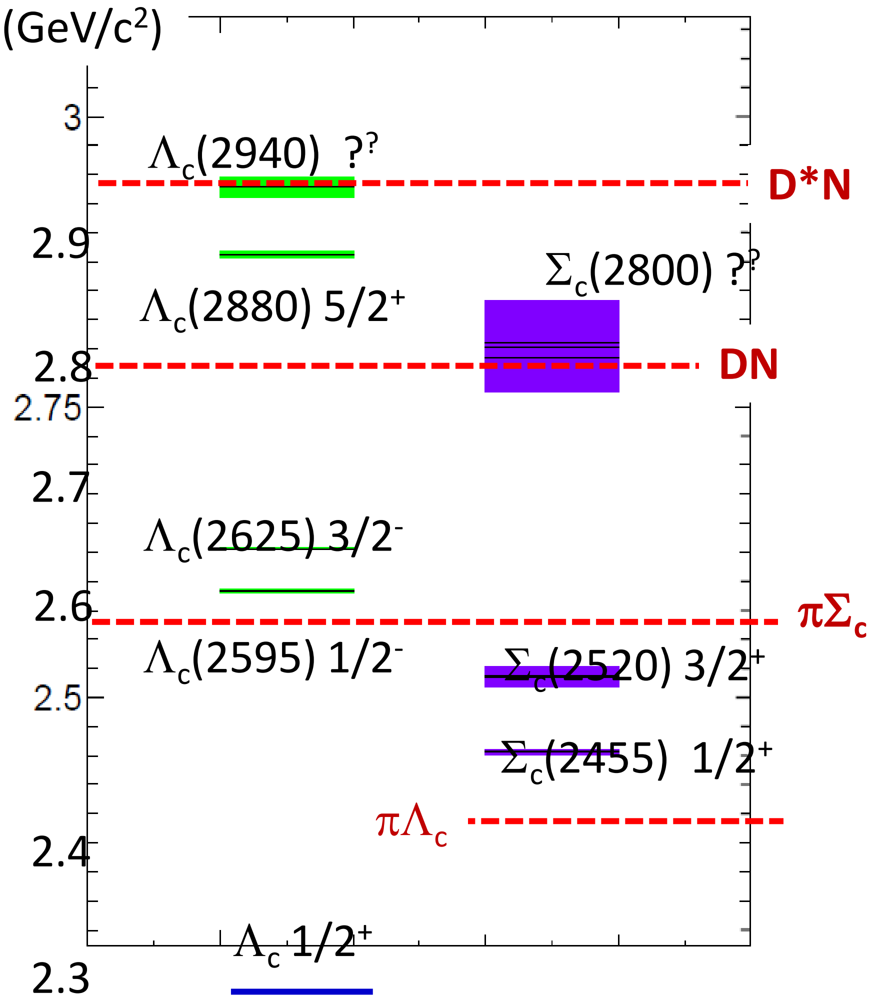
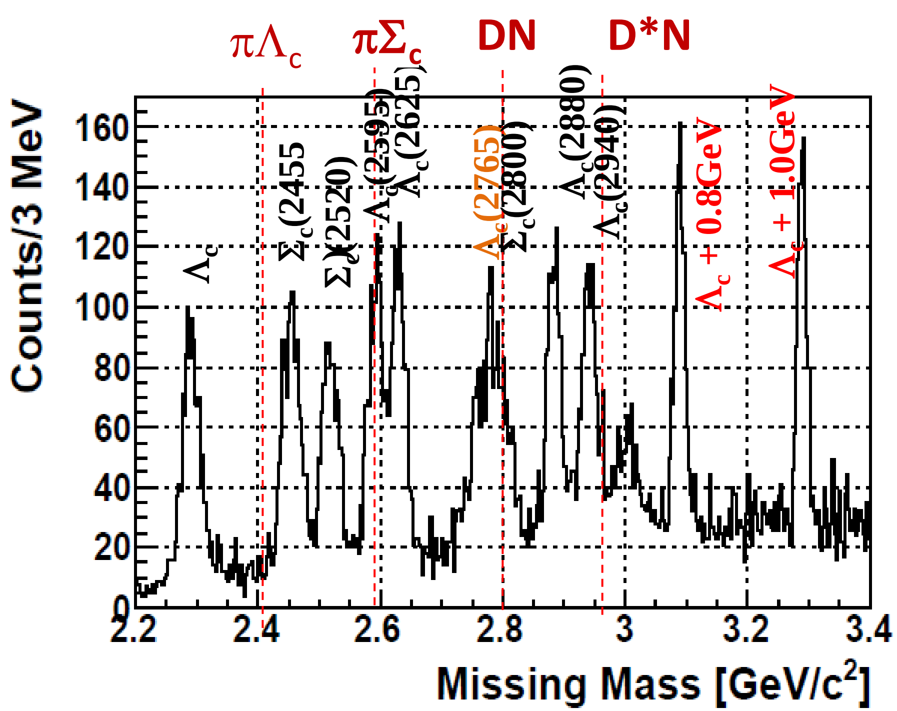
Expected Spectrum in the (π, D^{*-}) reaction



Signal: 1 nb/Yc* :~1000 events
Sensitivity: ~0.1 nb (3σ, Γ~0.1 GeV)



How much is $\sigma(\pi^- p \rightarrow D^{*-} Y_c^*)$?

- No observation
  - the upper limit: 7 nb (68% CL)
- We want to know:
  - A plausible estimation of the cross section
    - Coupling Constant/ Form Factor
  - possible ambiguity of the estimation: Lower Limit
    - Validity of $SU_F(4)$, analogy of the strangeness production, …
  - How it changes in excited state
- What we can learn from the measurement
  - If it is much beyond that we expected…

PQCD for exclusive processes

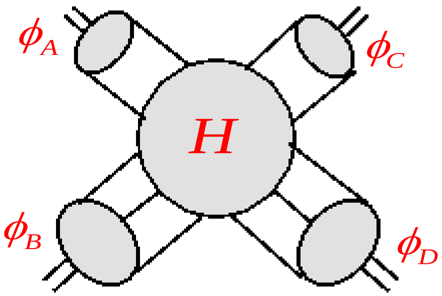
Lepage, Brodsky, PRD22(1989)2157

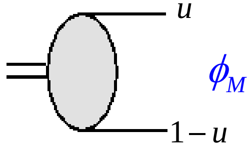
- Perturbative QCD O.K., if $s, |t|, |u| \gg \Lambda_{QCD}^2$.

parton scattering amplitude

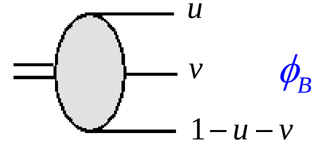
$$M(A+B \to C+D)\,|_{s,t,u \gg \Lambda_{QCD}^2} = \phi_A \times \phi_B \times \mathrm{H}(\alpha_s(\mathrm{s})) \times \phi_C \times \phi_D$$

light-cone distribution amplitude



meson 

$\phi_M(u)$

baryon 

$\phi_B(u,v)$

- How much energy (s,t,u) is needed to justify the use of PQCD ?

Ans. it depends not only on energies but also on the behavior of distribution amplitude , etc. .

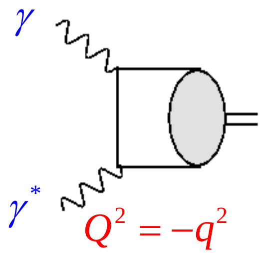
Typical momentum integral: $\int_0^1 \frac{du}{u} \phi_M(u) \times \alpha_s(uQ^2)$ $\qquad Q^2 \sim s, |t|, |u|$

Even if Q^2 is large, uQ^2 is not necessary large (depends on the shape of ϕ_M .)

- Some hints on PQCD applicability to exclusive processes

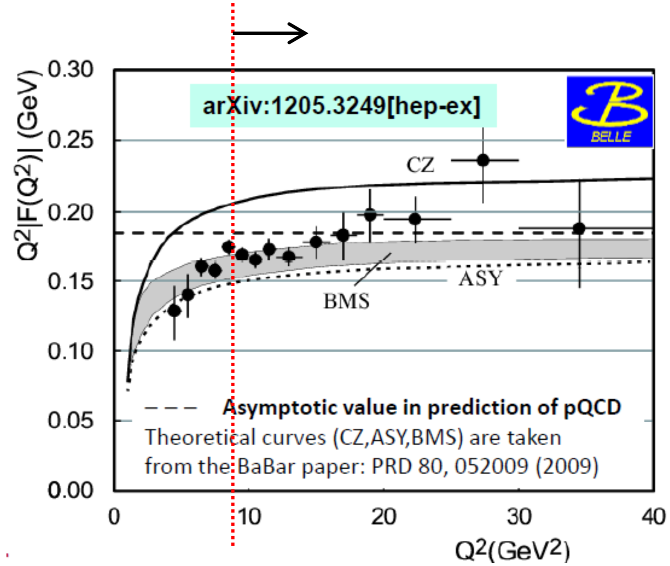
(1) Pion transition form factor

From Belle experiment



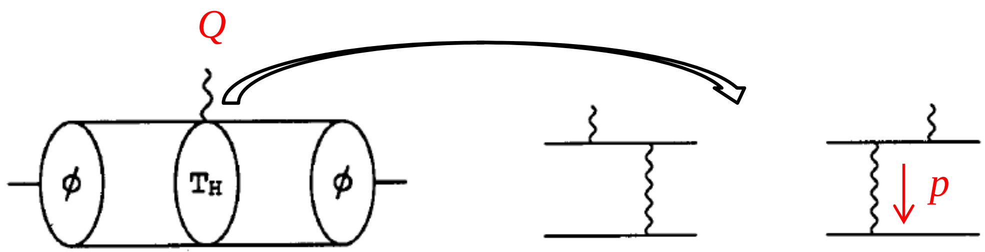
$$F(Q^2) = \frac{\sqrt{2} f_\pi}{3} \int T_H(x, Q^2, \mu) \phi_\pi(x, \mu) dx$$

PQCD O.K. for $Q \geq 3\text{GeV}$?



(2) Pion EM form factor

Theoretical study



If $\alpha_s(p^2)$ small in the dominant p^2 region, PQCD is O.K.

With quite an elaborated framework, i.e., “k_t factorization” & “Sudakov resummation”, the contribution from the perturbative region is dominant when

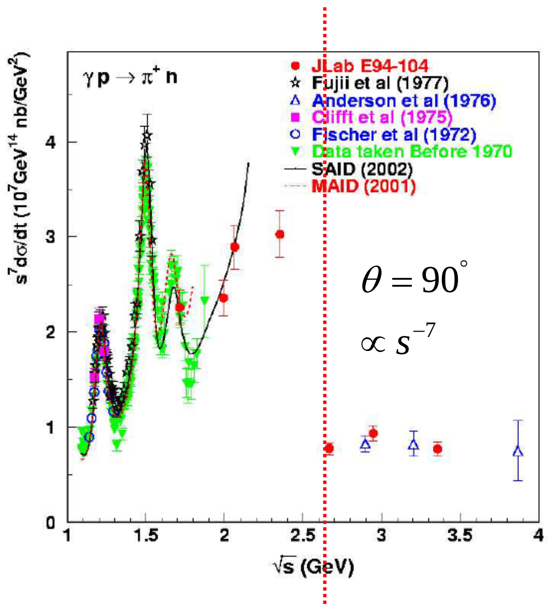
$$Q \geq 20\Lambda_{QCD} \approx 2-3\text{GeV}$$

Li & Sterman (1992)

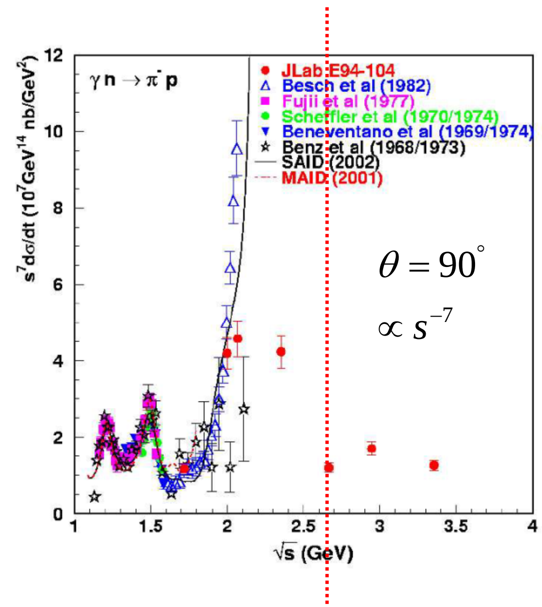
Exclusive photoproduction at Jefferson Lab.

$$\frac{d\sigma}{dt} = f(\theta_{cm}) \frac{1}{s^{n-2}}$$

$\gamma + p \rightarrow \pi^{+} + n$



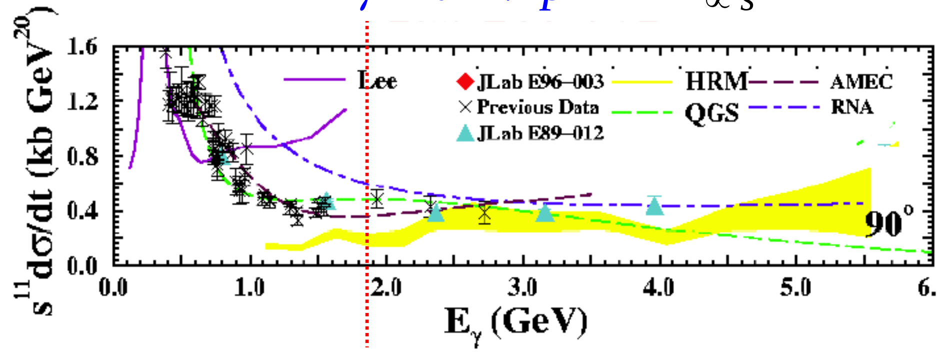
$\gamma + n \rightarrow \pi^{-} + p$



Onset of counting rule

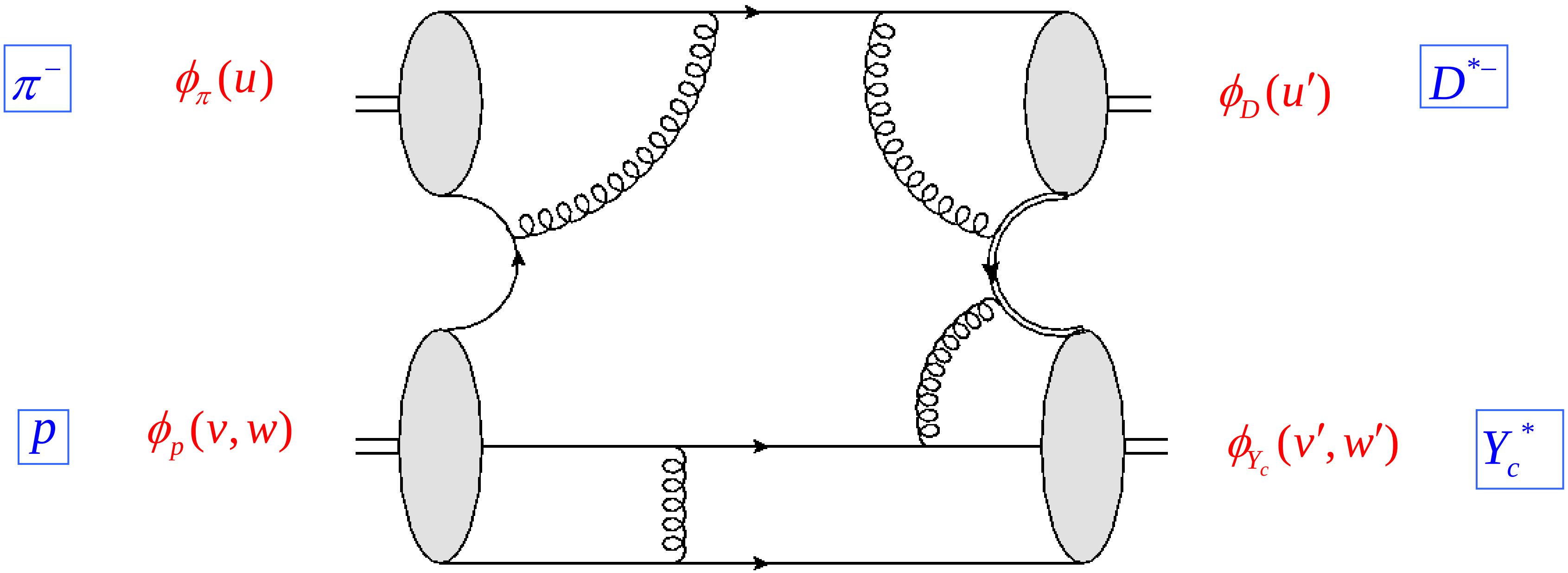
$Q \geq 2 - 3\text{GeV}$

$\gamma + d \rightarrow p + n \quad \propto s^{-11}$



- $\pi^- + p \rightarrow D^{*-} + Y_c^{\,*}$ at J-PARC

$$E_\pi = 20\text{GeV}$$



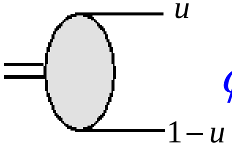
$$\sigma(\pi^- + p \rightarrow D^{*-} + \Lambda_c)$$

$$= \phi_\pi(u) \times \phi_P(v_1, v_2) \times H(u, u', v_i, v_i{}', \alpha_s(\mu)) \times \phi_D(u') \times \phi_\Lambda(v_1{}', v_2{}')$$

$$\sigma(\pi^- + p \to D^{*-} + \Lambda_c)$$

$$= \phi_\pi(u) \times \phi_P(v_1, v_2) \times H(u, u', v_i, v_i', \alpha_s(\mu)) \times \phi_D(u') \times \phi_\Lambda(v_1', v_2')$$

$\phi_\pi(u)$ Pion's light-cone distribution amplitude (LCDA)

pion 

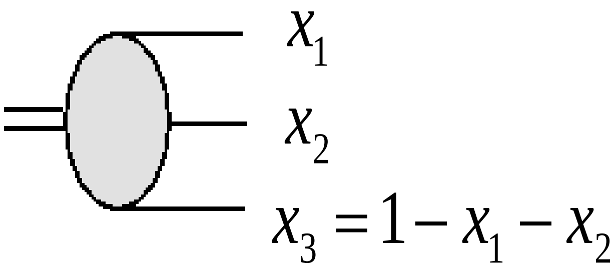
$\phi_\pi(u)$

$$\langle 0 \,|\, \bar{d}(0)_\alpha \, u(z)_\beta \,|\, \pi^+(p) \rangle = \frac{i f_\pi}{4} \int_0^1 du \, e^{-iup^+z^-} \left(\gamma_5 \not{p}\right)_{\beta\alpha} \phi_\pi(u, \mu)$$

$$\varphi^{(t=2)}(x; \mu_0^2) = \varphi^{as}(x) \left[1 + a_2(\mu_0^2)\, C_2^{3/2}(2x-1) + a_4(\mu_0^2)\, C_4^{3/2}(2x-1) + \ldots\right]$$

$$\phi_\pi^{as}(u) = 6u(1-u)$$

$\phi_p(x_1, x_2)$ Proton LCDA



$$\langle 0 | \varepsilon^{ijk} u_\alpha^i(z_1) u_\beta^i(z_2) u_\gamma^k(z_3) | N(p) \rangle$$
$$= \frac{f_N}{4} \{ (\not{p}C)_{\alpha\beta} (\gamma_5 N(p))_\gamma V(z_1 p)$$
$$+ (\not{p}\gamma_5 C)_{\alpha\beta} N(p)_\gamma A(z_i p)$$
$$-(\sigma_{\mu\nu} p^\nu C)_{\alpha\beta} (\gamma_\mu \gamma_5 N(p))_\gamma T(z_i p) \}$$

$$V(zp) = \int_0^1 dx_1 dx_2 dx_3 \delta(1 - x_1 - x_2 - x_3) e^{-i \sum x_i zp} \phi^V(x_i)$$

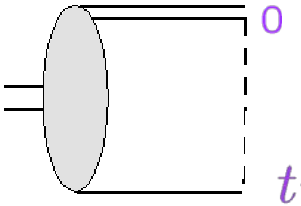
$$\phi^V(x_i, \mu) = 120 x_1 x_2 x_3 [\phi_3^0(\mu) + \phi_3^+(\mu)(1 - 3x_3)],$$
$$\phi^A(x_i, \mu) = 120 x_1 x_2 x_3 (x_2 - x_1) \phi_3^-(\mu),$$
$$\phi^T(x_i, \mu) = 120 x_1 x_2 x_3 [\phi_3^0(\mu) - \tfrac{1}{2}(\phi_3^+ - \phi_3^-)(\mu)(1 - 3x_3)].$$

$$\phi_3^0 = f_N, \qquad \phi_3^- = \frac{21}{2} f_N A_1^u, \quad \phi_3^+ = \frac{7}{2} f_N (1 - 3V_1^d),$$

$$|f_N| = (5.0 \pm 0.5) \times 10^{-3}\ \text{GeV}^2, \qquad A_1^u = 0.38 \pm 0.15,$$

Heavy meson DA in HQET

B-meson LCDA in HQET



$k^+ = \omega v^+$

Grozin, Neubert (97)
HK,Kodaira,Tanaka,Qiao (01)

$$\tilde{\phi}_+^B(t,\mu) = \frac{1}{iF(\mu)}\langle 0|\bar{q}(tn)[tn,0]\gamma_+\gamma_5 h_v(0)|\bar{B}(v)\rangle = \int_0^\infty d\omega e^{-i\omega t}\phi_+^B(\omega,\mu)$$

Light-like vector : $n^\mu = (n^+, n^-, \mathbf{n}_\perp) = (0, 1, \mathbf{0}_\perp), \ \ n\cdot v = 1$

Wilson line : $[tn, 0] = \mathcal{P}\exp\left(ig\int_0^t d\lambda n_\mu A^\mu(\lambda n)\right)$

Decay constant : $iF(\mu) = \langle 0|\bar{q}(0)\gamma_+\gamma_5 h_v(0)|\bar{B}(v)\rangle$

Scale : μ renomalization scale of operators

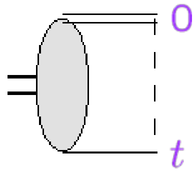
HQET field : $b(x) = e^{-im_b v\cdot x}\left[h_v(x) + \mathcal{O}\left(\frac{1}{m_b}\right)\right], \quad \not{v} h_v(x) = h_v(x)$

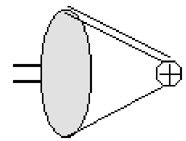
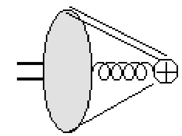
v^μ velocity of B meson

Heavy quark limit $m_b \to \infty \ \ \Rightarrow \ \ 0 \le \omega \le \infty$

OPE for B meson LCDA

OPE with 1-loop coeff. functions up to dim.5 operators HK,Tanaka (09)

$\tilde{\phi}_+^B(t,\mu)$ = 

$\sim \sum_i C_i(t,\mu)$ =  $+ \sum_j C_j(t,\mu)$ = 

$$
\begin{aligned}
\tilde{\phi}_+^B(t,\mu) = {} & 1 - \frac{\alpha_s(\mu)}{4\pi} C_F \left(2L^2 + 2L + \frac{5}{12}\pi^2 \right) && \bar{q}\Gamma h_v \quad \text{dim.3} \\
& - it \frac{4\bar{\Lambda}}{3} \left[1 - \frac{\alpha_s(\mu)}{4\pi} C_F \left(2L^2 + 4L - \frac{9}{4} + \frac{5}{12}\pi^2 \right) \right] && \bar{q} D \Gamma h_v, \quad \text{dim.4} \\
& - t^2 \bar{\Lambda}^2 \left[1 - \frac{\alpha_s(\mu)}{4\pi} C_F \left(2L^2 + \frac{16}{3} L - \frac{35}{9} + \frac{5}{12}\pi^2 \right) \right] && \bar{q} D D \Gamma h_v, \bar{q} G \Gamma h_v \quad \text{dim.5} \\
& - t^2 \frac{\lambda_E^2(\mu)}{3} \left[1 - \frac{\alpha_s(\mu)}{4\pi} \left\{ C_F \left(2L^2 + 2L - \frac{2}{3} + \frac{5}{12}\pi^2 \right) + C_G \left(\frac{3}{4} L - \frac{1}{2} \right) \right\} \right] \\
& - t^2 \frac{\lambda_H^2(\mu)}{6} \left[1 - \frac{\alpha_s(\mu)}{4\pi} \left\{ C_F \left(2L^2 + \frac{2}{3} + \frac{5}{12}\pi^2 \right) + C_G \left(\frac{1}{2} L - \frac{1}{2} \right) \right\} \right]
\end{aligned}
$$

$$L \equiv \log(it\mu e^{\gamma_E})$$

- Valid in the small t region. $t \leq 1/\mu, \ \mu \sim 1\text{GeV}$
- 3 HQET parameters

$$\bar{\Lambda} = m_B - m_b$$

$$\langle 0 | \bar{q} \alpha \cdot \mathbf{gE} \gamma_5 h_v | \bar{B}(v) \rangle = F(\mu) \lambda_E^2(\mu)$$

$$\langle 0 | \bar{q} \sigma \cdot \mathbf{gH} \gamma_5 h_v | \bar{B}(v) \rangle = i F(\mu) \lambda_H^2(\mu)$$

OPE + NP ansatz

$L \equiv \log(it\mu e^{\gamma_E}) \to t = -i\tau$

HK,Tanaka, PLB673(2009)201

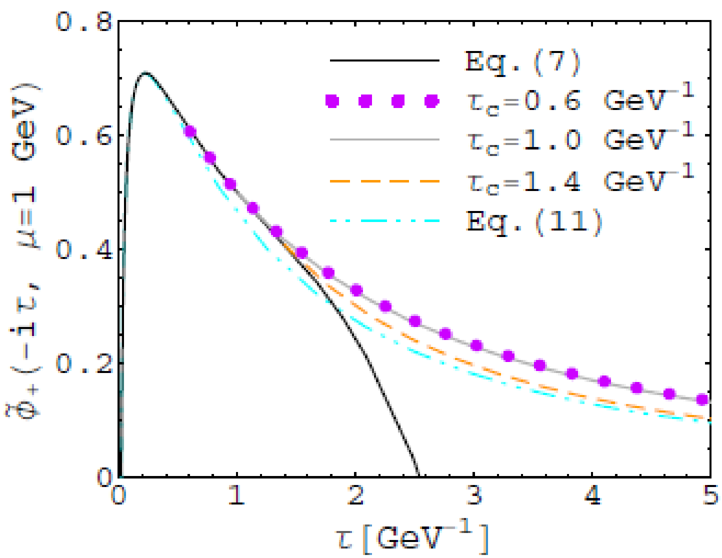
$$\tilde{\phi}_+^B(-i\tau,\mu) = \tilde{\phi}_+^{B,OPE}(-i\tau,\mu)\theta(\tau_c-\tau) + \tilde{\phi}_+^{B,NP}(-i\tau,\mu)\theta(\tau-\tau_c)$$

$$\tilde{\phi}_+^{B,NP}(-i\tau,\mu) = \int_0^\infty d\omega e^{-\omega\tau} \boxed{N\frac{\omega}{\omega_0^2}e^{-\omega/\omega_0}} = \frac{N}{(\tau\omega_0+1)^2}$$

Consistent with QCD sum rule

$\tilde{\phi}_+^B,\ \tilde{\phi}_+^{B\prime}$ continuous at $\tau = \tau_c \ \to \ (N,\omega_0)$

cf. Lee, Neubert ('07)
OPE up to dim.4, mom. space



- Inputs

Short distance mass in the "shape function scheme"

$$\bar{\Lambda}_{SF}(1.5\ \text{GeV}, 1.5\text{GeV}) = 0.65 \pm 0.06\ \text{GeV}$$

Neubert (05)

$$\lambda_E^2(1\ \text{GeV}) = 0.11 \pm 0.06\ \text{GeV}^2$$
$$\lambda_H^2(1\ \text{GeV}) = 0.18 \pm 0.07\ \text{GeV}^2$$

Grozin,Neubert (97)

- τ_c dependence is small.

$\phi_{D^*}(\omega)$ vector meson

pol. vector

$$\langle 0 | \bar{h}_v(0)\Gamma q(tn) | D^*(p,\varepsilon) \rangle$$
$$= \frac{f_D M_D}{2} \mathrm{Tr}\left[\left\{ \tilde{\phi}_+(t) + \frac{1}{2}(\tilde{\phi}_-(t) - \tilde{\phi}_+(t))\not{n} \right\} \frac{1+\not{v}}{2} \not{\varepsilon}\, \Gamma \right]$$

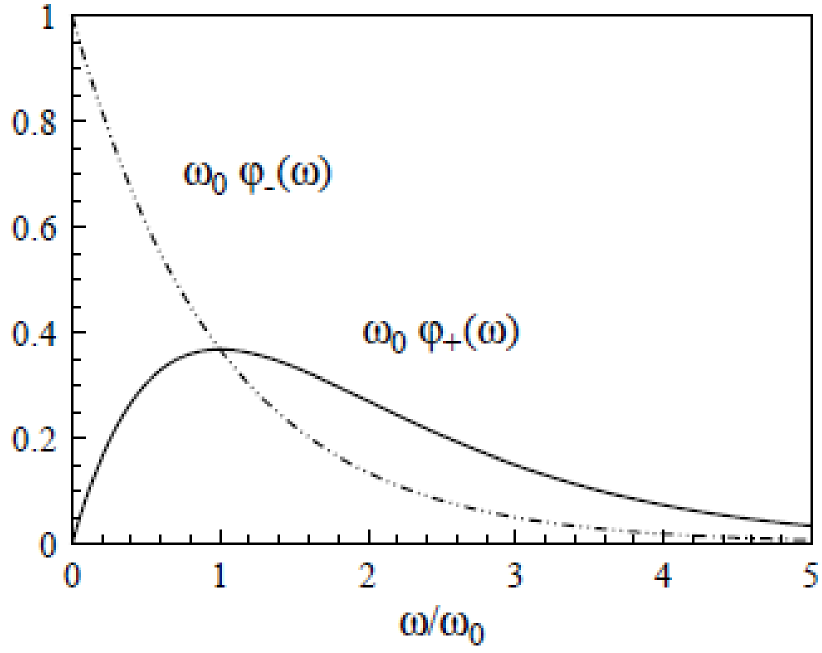
leading DA $\phi_{D^*}(\omega)$

HQ spin symmetry $\rightarrow$ $\left\{ \phi_{D^*,B^*}(\omega), \phi_{D,B}(\omega) \right\}$

All commonly given by $\phi_+(\omega)$

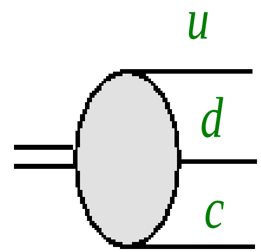
$\phi_{\pm}(\omega)$ A simple parametrization by Grozin & Neubert (1996).

Light-cone sum rule $$\phi_{+}(\omega) = \frac{\omega}{\omega_0^2} e^{-\omega/\omega_0}, \;\; \phi_{-}(\omega) = \frac{1}{\omega_0} e^{-\omega/\omega_0}$$



$$\omega_0 = \frac{2}{3}\bar{\Lambda} \approx 0.3\mathrm{GeV}$$

$\phi_\Lambda(\omega_1, \omega_2)$



$k_1^+ = \omega_1 v^+ = \omega\, u\, v^+$

$k_2^+ = \omega_2 v^+ = \omega\, \bar{u}\, v^+$

$$\langle 0 | \varepsilon^{ijk} h_v^i(0)_\alpha u^i(t_1 n)_\beta d^k(t_2 n)_\gamma | \Lambda_c(p) \rangle$$

$$= \frac{f_\Lambda M_\Lambda}{2} \left[\frac{1+\not{v}}{2} \gamma_5 C \right]_{\beta\gamma} [\Lambda_c(v)]_\alpha \;\; \phi_\Lambda(t_1, t_2)$$

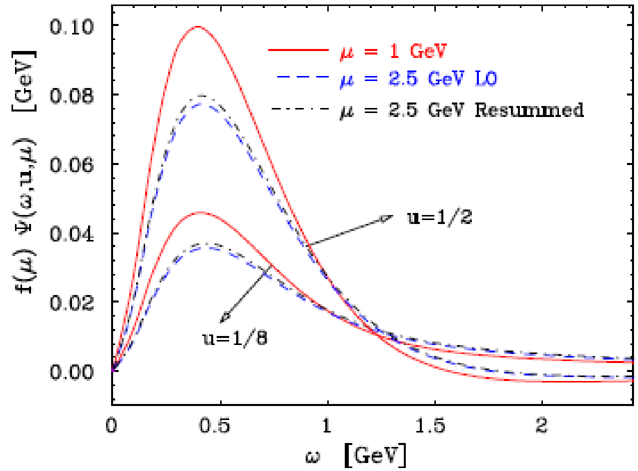
$$\phi_\Lambda(t_1,t_2) = \int_0^\infty d\omega_1 \int_0^\infty d\omega_2 e^{-it_1\omega_1 - it_2\omega_2} \phi_\Lambda(\omega_1, \omega_2)$$

$$= \int_0^\infty \omega d\omega \int_0^1 du e^{-i\omega(t_1 u + t_2 \bar{u})} \phi_\Lambda(\omega, u)$$

Evolution eq. + LC sum rule:

$$\psi^{\rm QCD}(\omega, u) = \omega^2 u(1-u)\left[\frac{1}{\epsilon_0^4} e^{-(\omega/\epsilon_0)} + a_2 C_2^{3/2}(2u-1) \times \frac{1}{\epsilon_1^4} e^{-(\omega/\epsilon_1)}\right] \qquad (22)$$

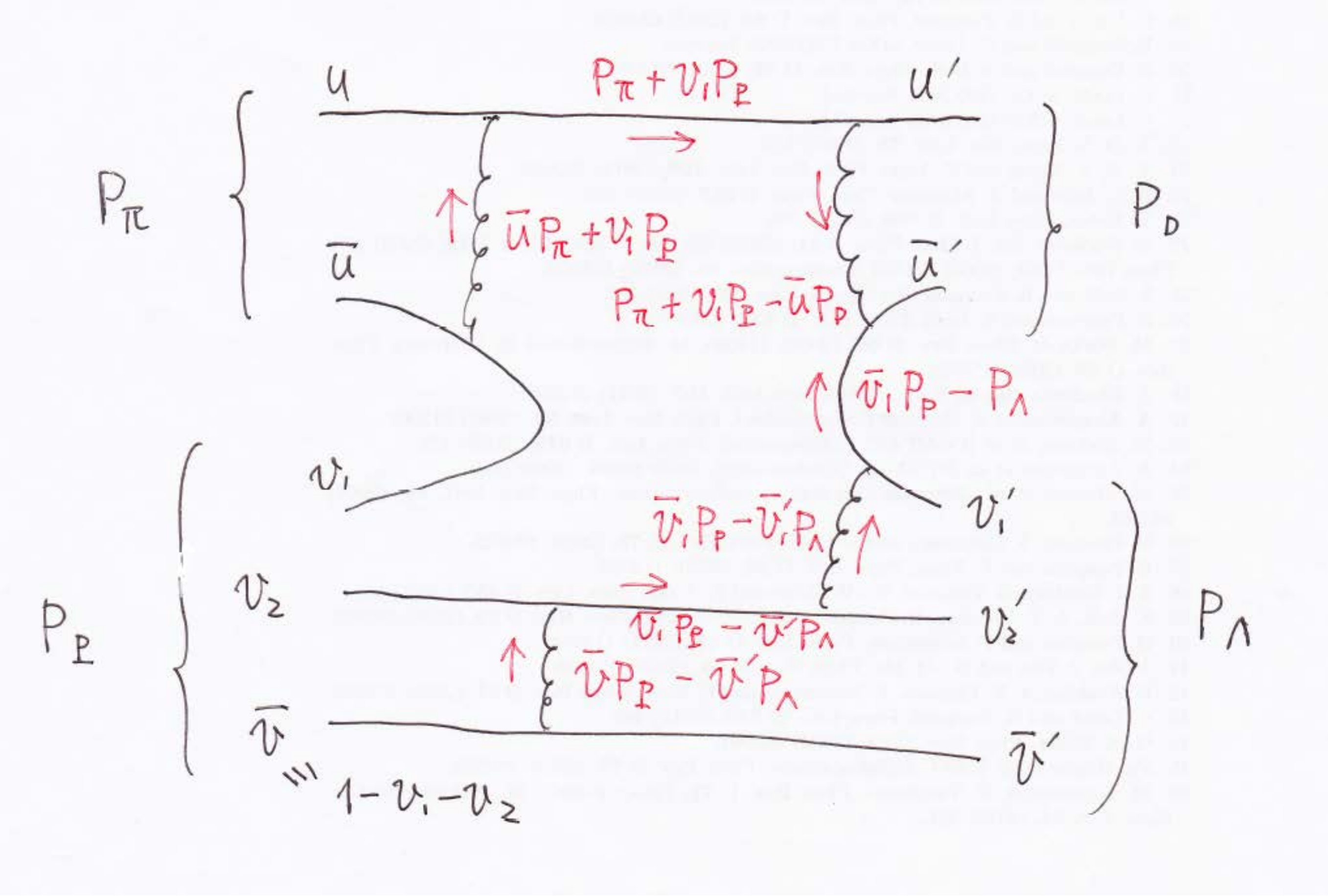
with $\epsilon_0 = 200^{+130}_{-60}$ MeV, $\epsilon_1 = 650^{+650}_{-300}$ MeV, and $a_2 = 0.333^{+0.250}_{-0.333}$. In the above representation, ω is the total



Ball, Braun, Gardi (2008)

Hard Part

$$H(u,u',v_i,v_i',\alpha_s(\mu))$$



Comments

- Large number of diagrams.
  $\leftrightarrow$ Connected diagrams with 4 gluon lines connecting 5 fermion lines

- Uncertainty of LCDAs

- Scale uncertainty

- Final State Interaction