Photon-to-pion transition FF and endpoint behavior of pion DA

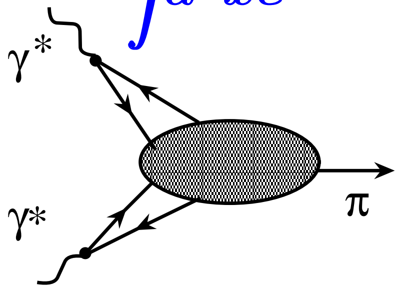
Alexander Pimikov[1]
in collaboration with S. Mikhailov[1], N. Stefanis[2]

Bogoliubov Lab. Theor. Phys., JINR (Dubna, Russia)[1]
ITP-II, Ruhr-Universität (Bochum, Germany)[2]

Outline:

- Introduction to “factorization” and its components
  - Transition $\gamma\gamma^* \to \pi^0$ form factor (FF)
  - Pion distribution amplitudes (DA) $\varphi_\pi(x)$
  - Data on the pion to photon transition form factor (FF)
- QCD sum rules (SR) approach
  - Nonlocal scalar quark condensate
  - QCD SR for pion DA
  - QCD SR for slope of pion DA at the origin: derivative $\varphi'_\pi(0)$ and “integral derivatives”.
- Comparison of our results with other models
- Conclusions

"Factorization" $\gamma^*(q_1)\gamma^*(q_2) \to \pi^0(P)$ in pQCD



$$\int d^4x e^{-iq_1\cdot z}\langle\pi^0(P)|T\{j_\mu(z)j_\nu(0)\}|0\rangle = i\epsilon_{\mu\nu\alpha\beta}q_1^\alpha q_2^\beta\cdot F^{\gamma^*\gamma^*\pi}(Q^2,q^2)\,,$$

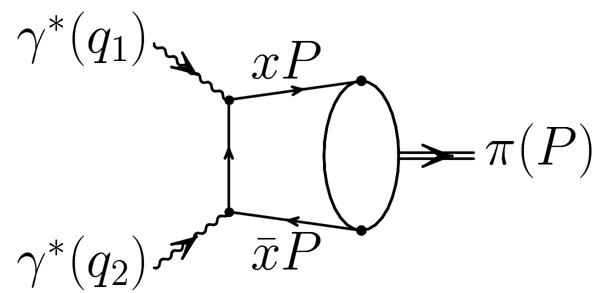
where $-q_1^2 = Q^2 > 0,\ \ -q_2^2 = q^2 \geq 0$

Collinear factorization at $Q^2, q^2 \gg$ (hadron scale $\sim m_\rho^2$)

$$F^{\gamma^*\gamma^*\pi}(Q^2,q^2) = T(Q^2,q^2,\mu_F^2;x)\otimes\varphi_\pi(x;\mu_F^2) + O(\frac{1}{Q^4})\,,$$

where μ_F^2 – boundary between large scale and hadronic one.

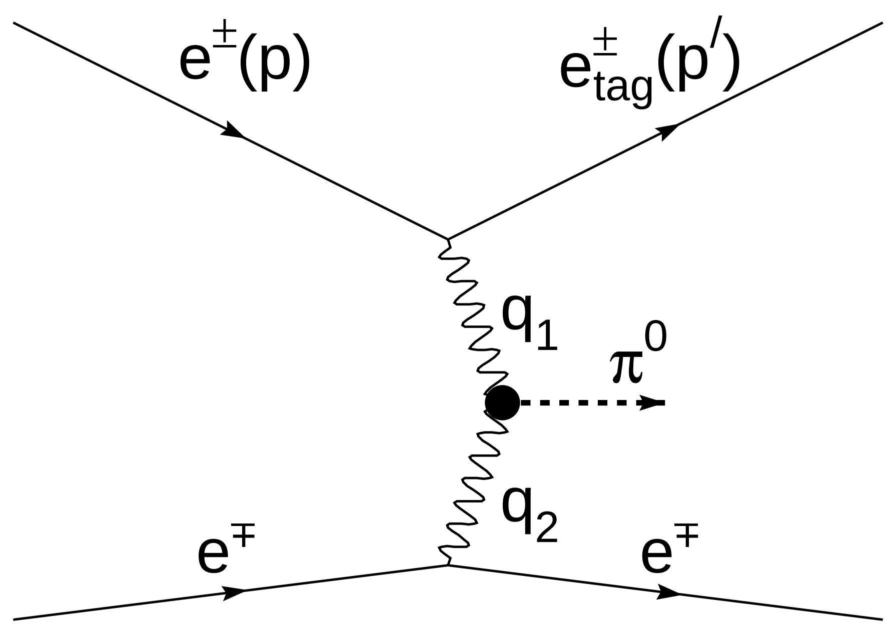
$$F^{\gamma^*\gamma^*\pi}(Q^2,q^2) = \frac{\sqrt{2}}{3}f_\pi\int_0^1 dx\frac{1}{Q^2x+q^2\bar{x}}\,\varphi_\pi(x)$$



$$Q^2F^{\gamma^*\gamma\pi}(Q^2,q^2\to 0) = \frac{\sqrt{2}}{3}f_\pi\int_0^1\frac{dx}{x}\varphi_\pi(x) \equiv \frac{\sqrt{2}}{3}f_\pi\langle x^{-1}\rangle_\pi$$

Feynman diagram for $e^+e^- \to e^+e^-\pi^0$

One of the most accurate data on exclusive reactions is data on transition FF $F^{\gamma^*\gamma^*\pi^0}(q_1^2, q_2^2)$ provided by series of experiments $e^+e^- \to e^+e^-\pi^0$ with $q_2^2 \approx 0$.



CELLO (1991) $0.7 - 2.2$ GeV^2 ,

CLEO (1998) $1.6 - 8.0$ GeV^2 ,

BaBar (2009) $4 - 40$ GeV^2 .

Pion distribution amplitude $\varphi_\pi(x,\mu^2)$

- The pion DA parameterizes this matrix element:

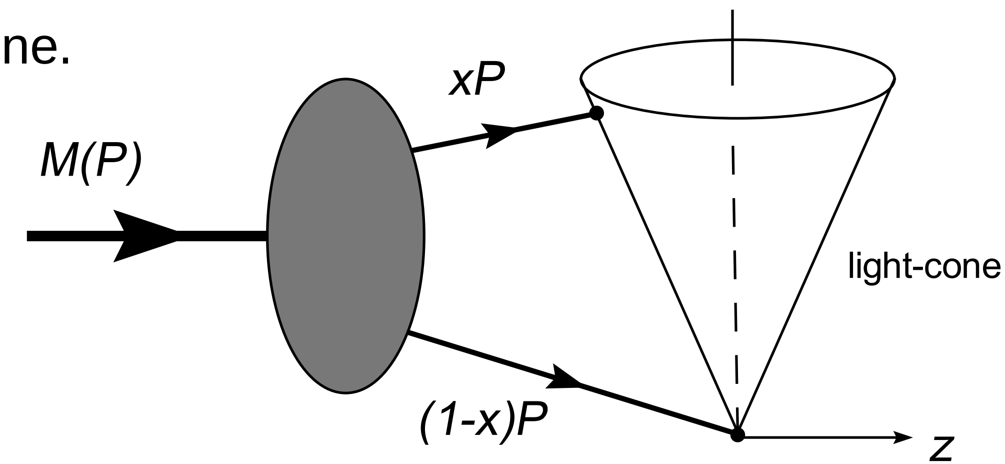
$$\langle 0|\,\bar{d}(z)\gamma_\nu\gamma_5[z,0]u(0)\,|\,\pi(P)\rangle\Big|_{z^2=0} = if_\pi P_\nu \int_0^1 dx\, e^{ix(zP)}\varphi_\pi(x,\mu^2)\,.$$

where the path-ordered exponential

$$[z,0] = \mathcal{P}\,exp\left[ig\int_0^z t^a A_\mu^a(y)dy^\mu\right],$$

i.e., the light-like gauge link, ensures the gauge invariance.

- Pion DA describes the transition of a physical pion into two valence quarks, separated at light cone.



Pion distribution amplitude $\varphi_\pi(x,\mu^2)$

- The pion DA parameterizes this matrix element:

$$\langle 0|\,\bar{d}(z)\gamma_\nu\gamma_5[z,0]u(0)\,|\,\pi(P)\rangle\Big|_{z^2=0} = if_\pi P_\nu \int_0^1 dx\; e^{ix(zP)}\varphi_\pi(x,\mu^2)\,.$$

Distribution amplitudes are **nonperturbative** quantities to be derived from

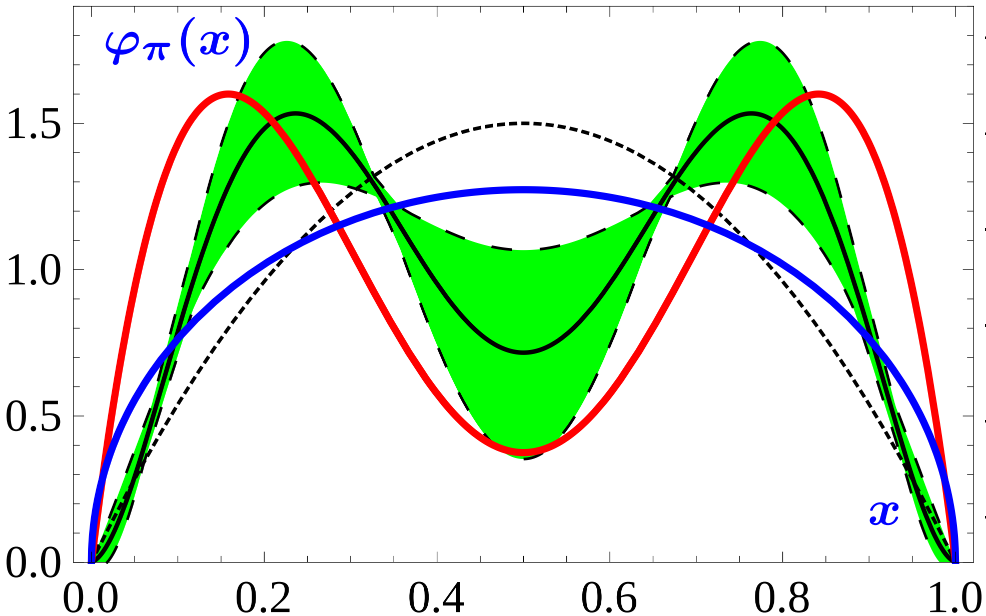
- QCD SR **[CZ 1984]**,
  NLC QCD SR **[M&Radyushkin 1988-91,B&Mikhailov&S 1998,2001–04]**
- instanton-vacuum approaches, e.g.
  [Dorokhov *et al.* 2000; Polyakov *et al.* 1998, 2009]
- Lattice QCD, **[Braun *et al.* 2006; Donnellan *et al.* 2007]**
- from experimental data **[Schmedding&Yakovlev 2000, BMS 2003–2006]**

DA evolves with μ_F^2 according to **ERBL equation in pQCD**.

Pion distribution amplitude $\varphi_\pi(x,\mu^2)$

- The pion DA parameterizes this matrix element:

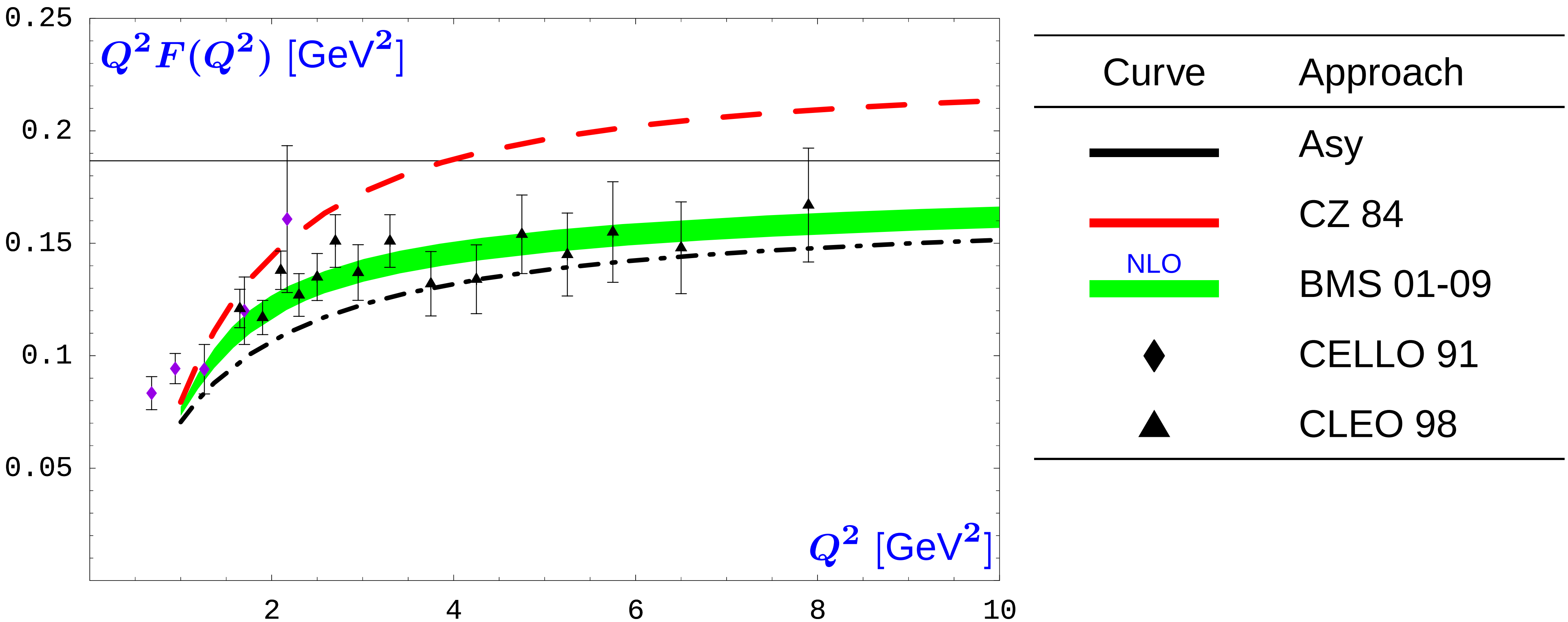
$$\langle 0|\,\bar{d}(z)\gamma_\nu\gamma_5[z,0]u(0)\,|\,\pi(P)\rangle\Big|_{z^2=0} = i f_\pi P_\nu \int_0^1 dx\; e^{ix(zP)}\varphi_\pi(x,\mu^2)\,.$$



Curve	Approach
dashed black	Asymptotic
green band with black line	BMS from NLC QCD SR
red	CZ from QCD SR
blue	AdS/QCD result

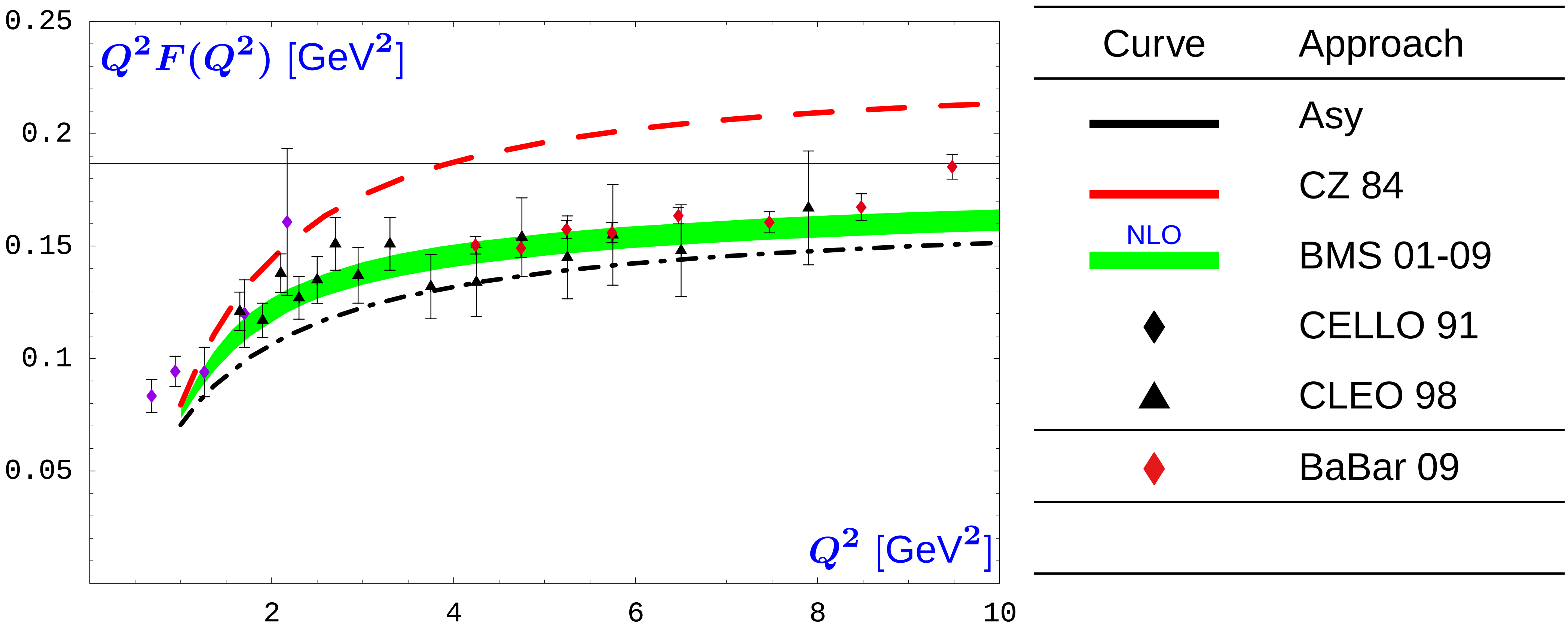
There are numbers of models for pion DA on a market. We could qualitatively collect them in two groups by their behavior at the end-point region $x = 0$: **end-point suppressed** and **end-point enhanced** pion DAs.

CELLO and CLEO data on the transition FF



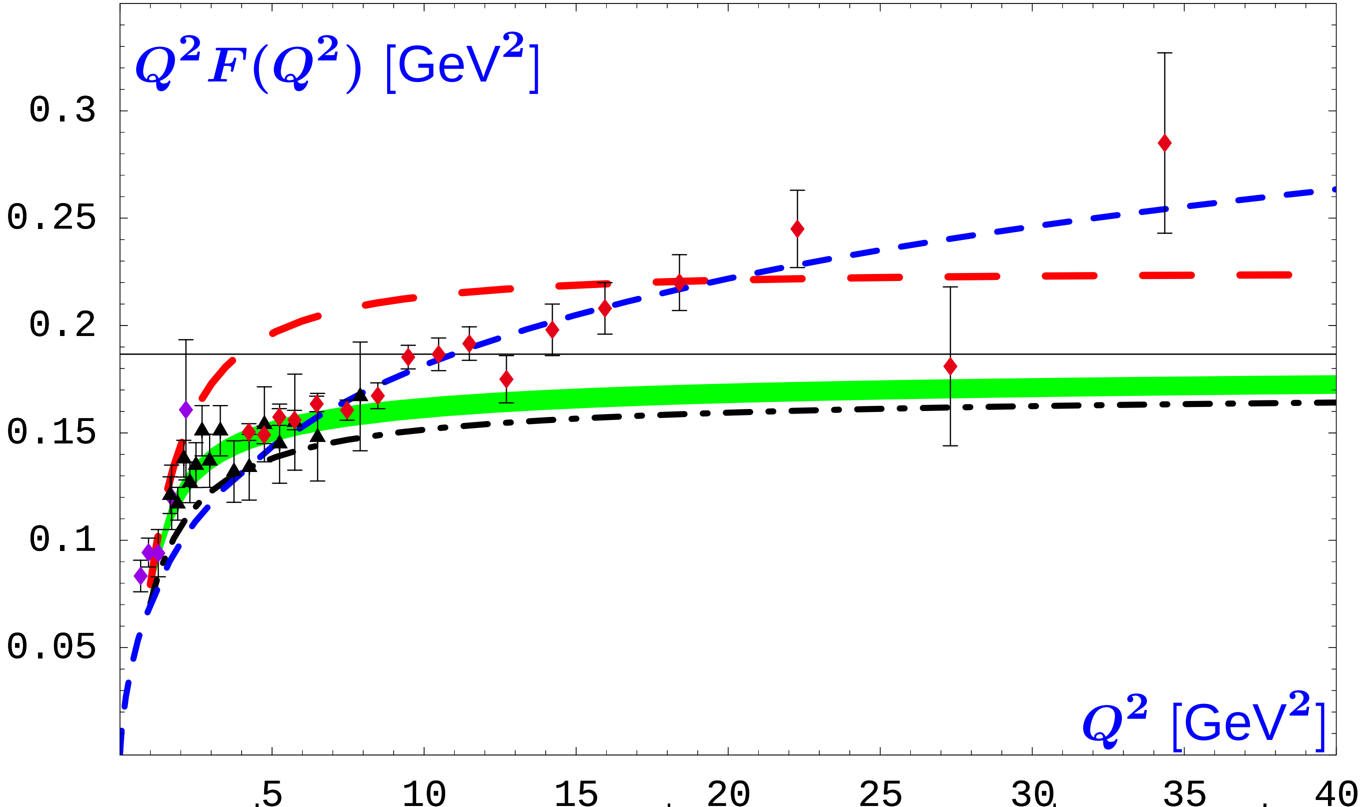
CLEO and CELLO data favor **endpoint-suppressed** π DA; BMS "bunch" within 1σ level. Endpoint suppression controlled by vacuum-quark nonlocality: $\lambda_q^2 = 0.4$ GeV^2.

BaBar data on the $\gamma\gamma* \to \pi$ transition FF



- For momentum transfer up to **9** GeV^2, new BaBar data agree well with the previous CLEO data and prefer the DA with endpoints strongly suppressed. (NLO in LCSR)

BaBar data on the $\gamma\gamma^* \to \pi$ transition FF



Curve	Approach
(black line)	Asy
(red line)	CZ 84
NLO (green band)	BMS 01-09
♦	CELLO 91
▲	CLEO 98
(red ♦)	BaBar 09
(blue line)	Radyushkin 09

$\bar{\chi}^2$	CLEO&CELLO	CLEO&BaBar	BaBar	BaBar($Q^2 > 10$ GeV^2)
Asy	**3.9**	**11.5**	**19.2**	**19.8**
BMS	**0.56**	**4.4**	**7.8**	**11.9**
CZ	**5.2**	**20.9**	**36.0**	**6.0**

Table from **[M.&Stefanis Nucl.Phys.B821, 291-326, 2009]**

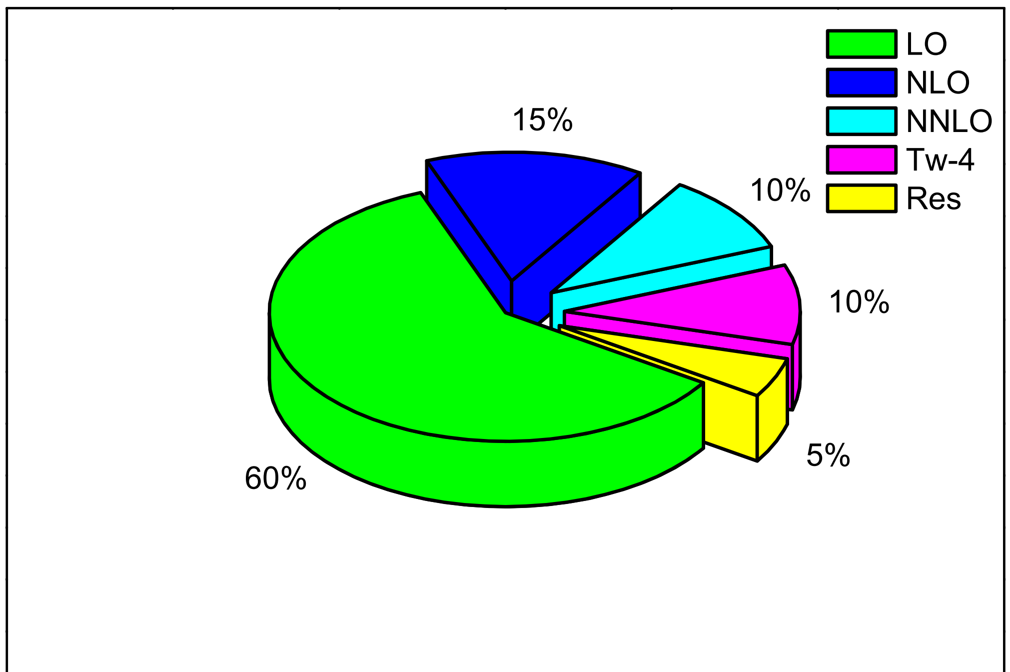
BaBar data—the facts

- 9 **BaBar data points** **conform** with the QCD paradigm and approach the pQCD boundary $\sqrt{2}f_\pi$ (horizontal dashed line) of $Q^2F(Q^2)$ from below
- 8 **BaBar data points** **deviate** from the “orthodox” scaling behavior of $Q^2F(Q^2)$; they lie above the pQCD boundary and move with Q^2 farther away from it up to the highest measured point at 40 GeV^2
- Moreover, they contradict the collinear factorization formula in QCD per se.
- They contradict the “counting rules” – the most reliable method up to now.
- As a corollary, **CZ DA does not conform with the BaBar data:** In the CLEO region it is off by 4σ; above 10 GeV^2 it starts to scale—**no growth** [Opposite statements by **BaBar, PRD80(2009)052002 and Druzhinin in arXiv:0909.3148 [hep-ex]** are **unfounded**.]

QCD correction to transition FF

Mikhailov&Stefanis Mod.Phys.Lett.A24:2858-2867, 2009.

- **Higher radiative corrections up to NNLO**$_\beta$ provide to $Q^2F(Q^2)$ **suppression**
- **Twist-4** contribution to $Q^2F(Q^2)$ also provides **suppression**
- Hadronic content of real photon, parameterized via a Breit-Wigner resonance , gives **some enhancement at low** Q^2

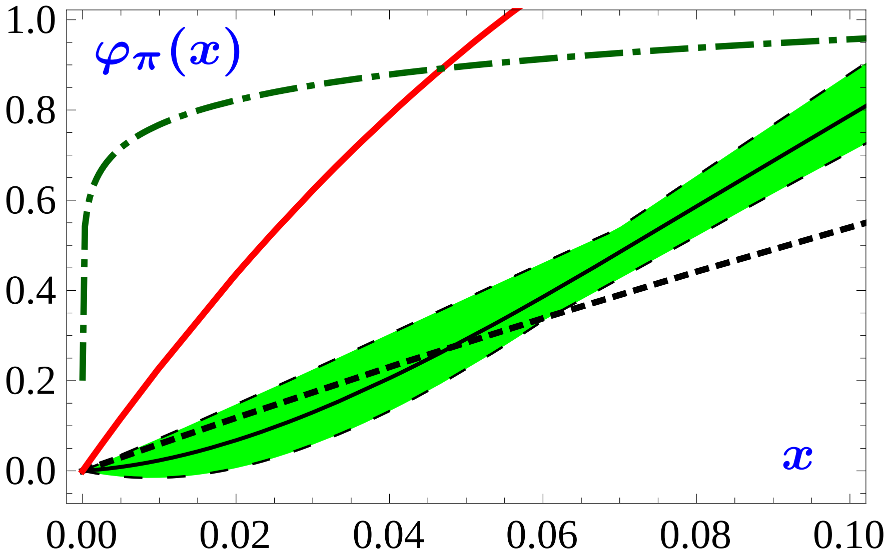


Stefanis, 2008, Nucl.Phys.Proc.Suppl.199

Contextual explanations of the “BaBar effect”

- **Dorokhov**, arXiv:1003.4693 **Quark-loop (triangle) diagram**:
  $Q^2 F^{\gamma^*\gamma\pi^0}(Q^2) \sim \ln\left(Q^2/M_q^2\right)$ with typical values of $M_q^2 = 0.2 - 0.3$ GeV^2
- **Radyushkin**, PRD80 (2009) 094009: **Flattop pion DA** – no radiative corrections, no evolution
- **Polyakov**, JETP Lett. 90 (2009) 228: π **DA close to unity** with $\phi'_\pi(0)/6 \gg 1$ at $\mu = 0.6 \div 0.8$ GeV—convex DA obtained from χ quark model. **Evolution included**
- **Li, Mishima**, PRD80 (2009) 074024: k_T-dependent hard kernel convoluted with flat π DA and resumming terms $\sim \alpha_s \ln^2 x$ at low-Q^2—Sudakov resummation
- **Klopot, Oganesian, Teryaev**, arXiv:1009.1120: Uses **Axial anomaly** SR to show importance of higher-state contributions to transition FF
- **Kuraev et al.**, arXiv:0912.3668: **Sudakov suppression of quark-photon vertex** in triangle $\pi\gamma\gamma^*$ diagram
- **Kochelev, Vento**, PRD81 (2010) 034009: **Includes gluonic components** to $F^{\gamma^*\gamma\pi^0}$ stemming from nonperturbative QCD vacuum in the instanton liquid model
- **Broniowski, Ruiz-Arriola**, arXiv:0910.0869, – **S**pectral **Q**uark **M**odel, arXiv:1008.2317 – Regge approach.
- **Chernyak**, arXiv:0912.0623: **Explains BaBar data by denying Q^2 growth**
- **Lih**, arXiv:0912.2147: **L**ight- **F**ront **Q**uark **M**odel
- **Noguera, Vento**, arXiv:1001.3075: **Match low-Q^2 description with high-Q^2 QCD-based calculation** involving $\varphi_\pi(x) = 1$ and evolving from Q_0 to Q; twist-3 effects also included

Motivations and aims



Model	$\int_0^1 \frac{\varphi_\pi(x)}{x}dx$	$\varphi'_\pi(0)$
Asy	3	6
BMS	3.15	$\lesssim 6$
CZ	4.5	26
$\sim x^{0.1}$ Rad.	$\gg 3$	$\gg 6$

- High-Q^2 BaBar data call for **endpoints enhanced** π-DAs.
  But, CLEO and low-Q^2 BaBar data prefer **endpoint-suppressed** π-DAs.
- Observable pion FF is mainly defined by unobservable pion DA slope at the origin through inverse moment in collinear factorization.
- BMS bunch is based on NLC QCD SR and has large errors in endpoint region.
- Our purpose is the analysis of pion DA endpoint behavior using NLC QCD SR **Mikhailov, et.al. PRD82 (2010) 054020**

QCD SR Approach

Determination of spectral parameters from requirement of agreement between two representations for correlator:

- 1. way — Dispersion relation: decay constants f_h and masses m_h,

$$\Pi_{\text{had}}\left(Q^2\right) = \int_0^\infty \frac{\rho_{\text{had}}(s)\ ds}{s+Q^2} + \text{subtractions}\,.$$

  - model spectral density: $\rho_{\text{had}}(s) = f_h^2\,\delta\left(s-m_h^2\right) + \rho_{\text{pert}}(s)\,\theta\left(s-s_0\right)\,.$

- 2. way — Operator product expansion:

$$\Pi_{\text{OPE}}\left(Q^2\right) = \Pi_{\text{pert}}\left(Q^2\right) + \sum_n C_n \frac{\langle 0| :O_n: |0\rangle}{Q^{2n}}\,.$$

  - Condensates $\langle 0| :O_n: |0\rangle \equiv \langle O_n\rangle = ?$ (next slides).

QCD SR reads:

$$\Pi_{\text{had}}\left(Q^2, m_h, f_h\right) = \Pi_{\text{OPE}}\left(Q^2\right)\,.$$

Introducing condensates in QCD calculations

$$\langle 0|T\left(\bar{q}_B(0)q_A(x)\right)|0\rangle = \boxed{\langle 0| :\bar{q}_B(0)q_A(x): |0\rangle} - i\hat{S}_{AB}(x)$$

QCD PT

$$\langle \bar{q}q \rangle \overset{\text{def}}{=} 0$$

QCD SR

$$\langle \bar{q}_A(0)q_A(x)\rangle = \langle \bar{q}q\rangle$$

CONST $\neq 0$

[SVZ'79]

Condensate

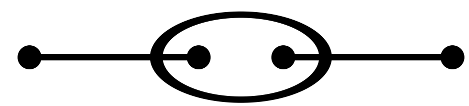
Decay constants,

masses of hadrons

NLC QCD SR

$$\langle \bar{q}(0)q(x)\rangle =$$

$$F_S(x^2) + \hat{x}F_V(x^2)$$



M&R '86

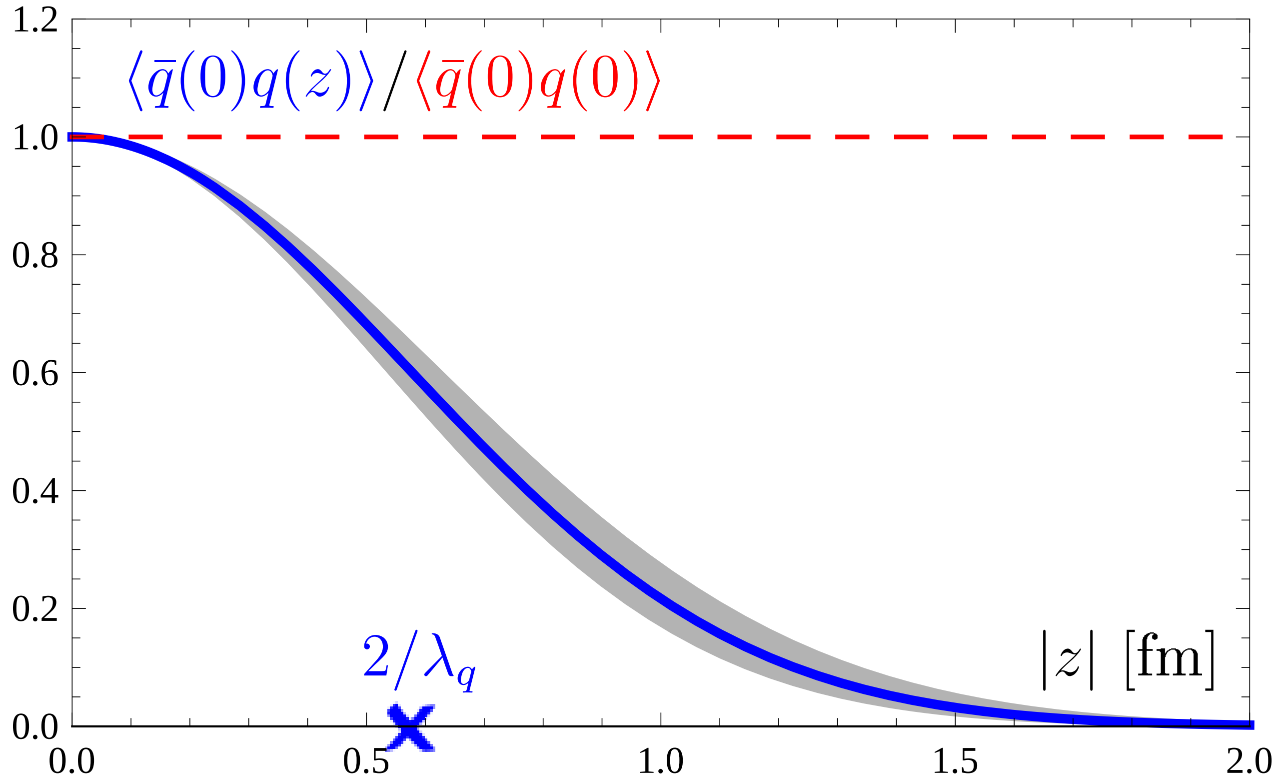
Nonlocal condensate

Distribution Amplitudes,

Form Factors

$$\langle \bar{q}_B(0)\, q_A(x)\rangle = \frac{\delta_{AB}}{4}\left[\langle \bar{q}q\rangle + \frac{x^2}{4}\frac{\langle \bar{q}D^2q\rangle}{2} + \ldots\right] + i\frac{\widehat{x}_{AB}}{4}\frac{x^2}{4}\left[\frac{2\alpha_s\pi\langle \bar{q}q\rangle^2}{81} + \ldots\right].$$

Lattice data of Pisa group



The fit **[BM-PRD65(2002)]** of lattice data **[Di Giacomo et al., PRD59(1999)]** with Gaussian model of condensate $\langle\bar{q}(0)q(z)\rangle \sim$ **exp** $\left(\lambda_q^2 z^2/8\right)$ vs. **local limit**.

- Nonlocality of quark condensates is $\lambda_q^2 = 0.42(8)$ GeV^2 from fit.
- Even at $|z| \simeq 0.5$ fm nonlocality is quite important!

Coordinate dependence of condensates

Parameterization for scalar condensate was suggested in works by Bakulev, Mikhailov following previous work by Radyushkin:

$$\langle :\bar{q}_A(0)q_A(z):\rangle \;=\; \langle\bar{q}q\rangle\int_0^\infty \boxed{f_S(\alpha)}\, e^{\alpha z^2/4}\,d\alpha\,,\ \text{where } z^2 < 0.$$

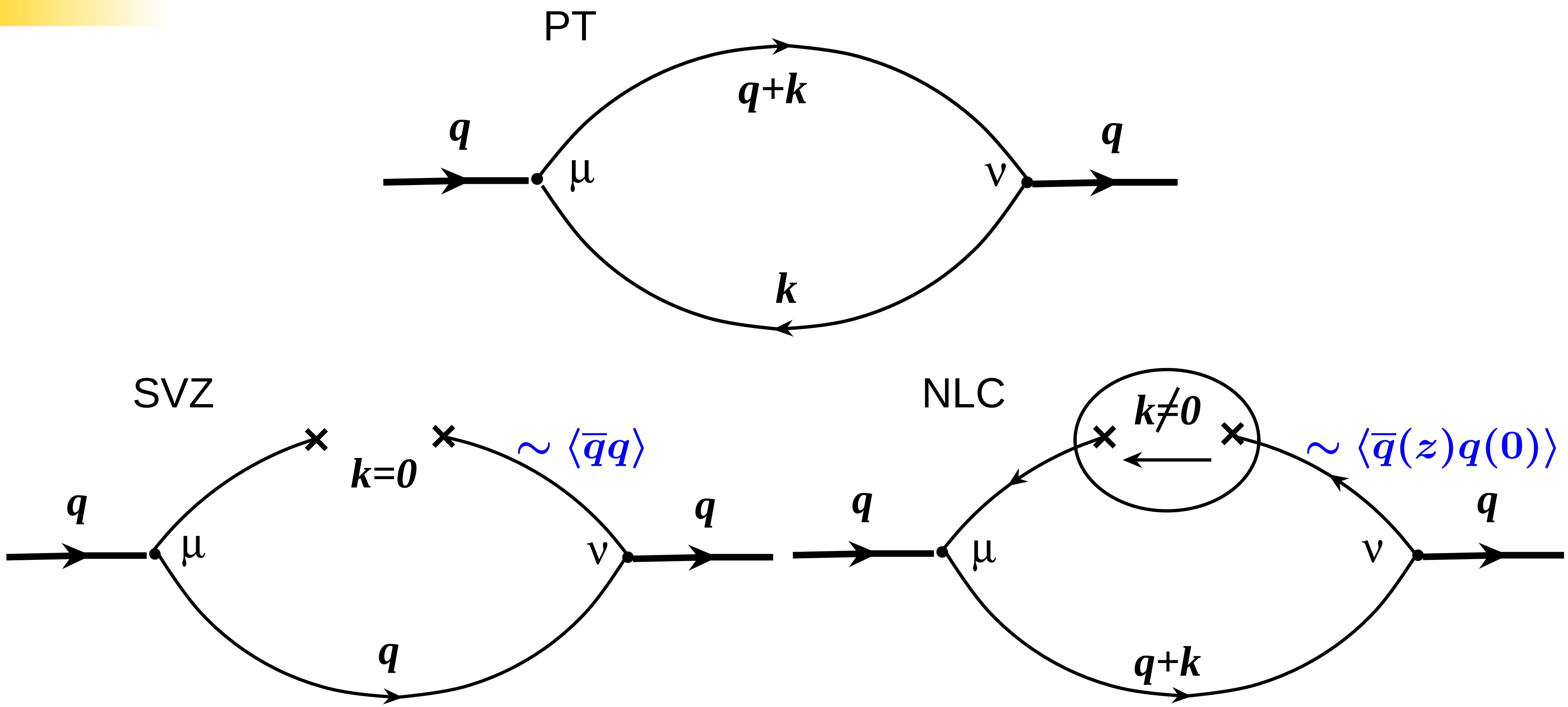
- First anzatz which takes into account a single parameter — width of quark distribution in vacuum:

$$f_S(\alpha) = \delta\left(\alpha - \frac{\lambda_q^2}{2}\right),\quad \lambda_q^2 = \frac{\langle\bar{q}D^2q\rangle}{\langle\bar{q}q\rangle}$$

- Such representation corresponds to **Gaussian** form $\sim$ **exp** $\left(\lambda_q^2 z^2/8\right)$ of NLC in coordinate representation.

- **Smooth model** $f_S(\alpha)$ $\sim$ **exp** $\left(-\Lambda^2/\alpha - \sigma^2\alpha\right)$ has two correlation lengths and physically motivated exponential decay $\langle\bar{q}(0)q(z)\rangle\Big|_{z^2\to\infty}$ $\sim$ **exp** $\left(-\Lambda z\right)$ in coordinate representation.

Diagrams for $\langle T\left(J_\nu(z)J_\mu(0)\right)\rangle$



- Quarks run through vacuum with nonzero momentum $k \neq 0$:

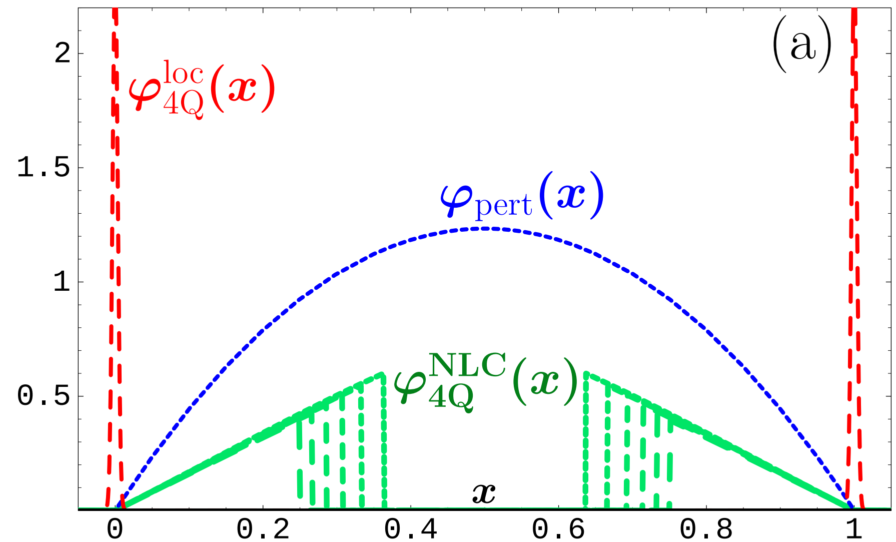
$$2\langle k^2\rangle = \frac{\langle \bar{q}D^2q\rangle}{\langle \bar{q}q\rangle} = \lambda_q^2 = 0.40(5)\,\text{GeV}^2$$

QCD SR for pion DA

QCD SR technique for correlator of two axial current leads to SR for π-DA $\varphi_\pi(x)$:

$$f_\pi^2\,\varphi_\pi(x) + f_{A_1}^2\,\varphi_{A_1}(x)\,e^{-m_{A_1}^2/M^2} = \int_0^{s_0} \rho_{\text{pert}}\,(s,x)\,e^{-s/M^2} ds + \Phi_{\text{npert}}(x, M^2)\,,$$

where $\Phi_{\text{npert}} = \Phi_{\text{4Q}} + \Phi_{\text{T}} + \Phi_{\text{V}} + \Phi_{\text{G}}$,
M^2 – Borel parameter,
ρ_{pert} – pert. spec. density.
The largest nonperturbative term:
$\Phi_{\text{4Q}} \sim x\theta(\Delta - x) \xrightarrow{\text{loc. lim}} \Phi_{\text{4Q}}^{\text{loc}} \sim \delta(x)$,
is defined by scalar quark condensate,
where $\Delta = \lambda_q^2/M^2 \in [0.01, 0.3]$.

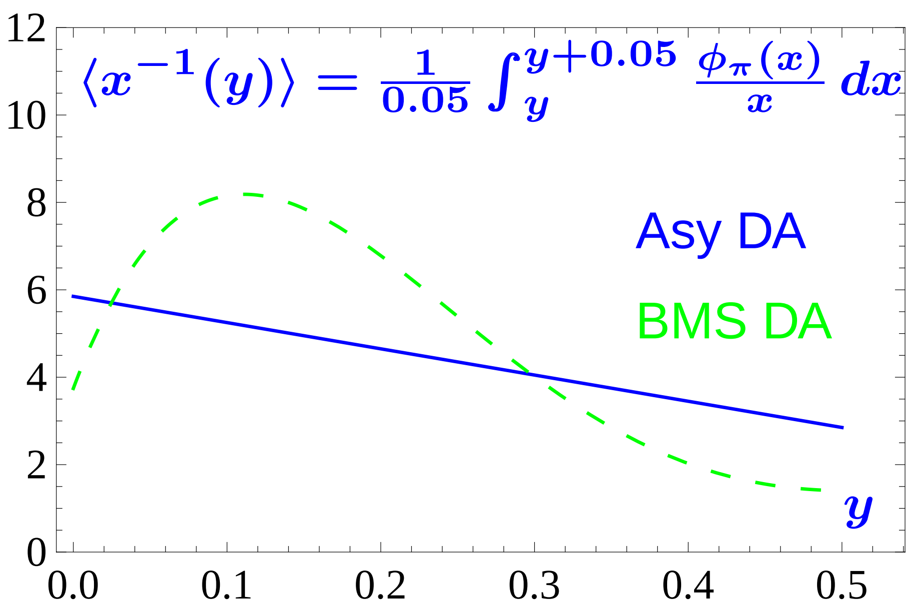


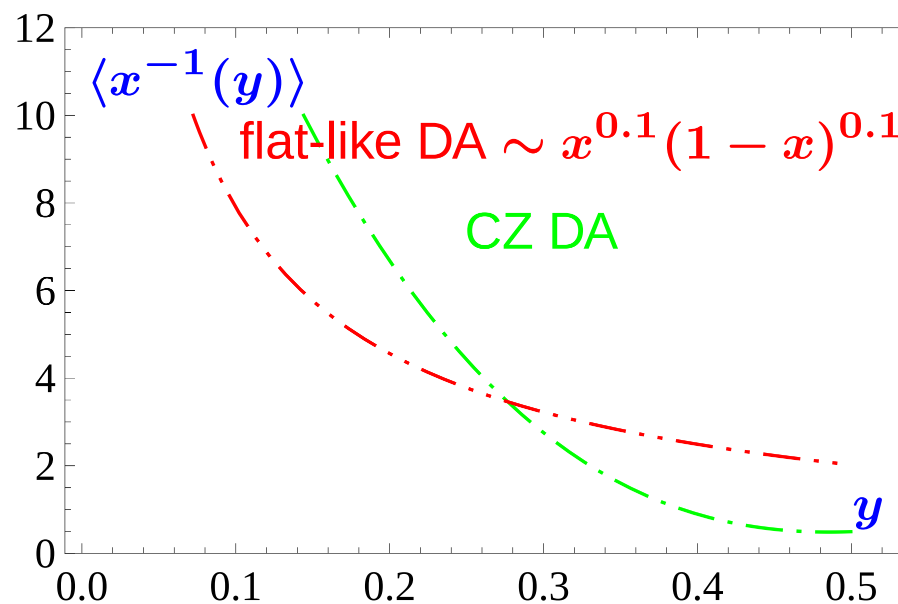
- Since nonperturbative contribution has **singularities** ($x\delta'(\Delta - x)$, $\delta(\Delta - x)$), we should study **integral characteristics** of π-DA in order to take into account all condensates.
- Exception is end-point region where only 4-quark condensate Φ_{4Q} contributes without any singularities.

Integral characteristics of pion DA

Moments: $\langle \xi^{2N} \rangle \equiv \int_0^1 dx\, \varphi_\pi(x)(2x-1)^{2N}\,, \quad \langle x^{-1} \rangle \equiv \int_0^1 dx\, \varphi_\pi(x) x^{-1}\,.$

SVZ	$\langle \xi^0 \rangle$	LO	local cond.	f_π
CZ	$\langle \xi^{2N} \rangle$ $N = 0, 1$	LO	local cond.	$f_\pi,\, a_2$
BMS	$\langle \xi^{2N} \rangle$, $N = 0, 1, \ldots, 5$	NLO	nonlocal cond.	$f_\pi,\, a_2,\, a_4$ $\langle x^{-1} \rangle$





Integral characteristics of pion DA

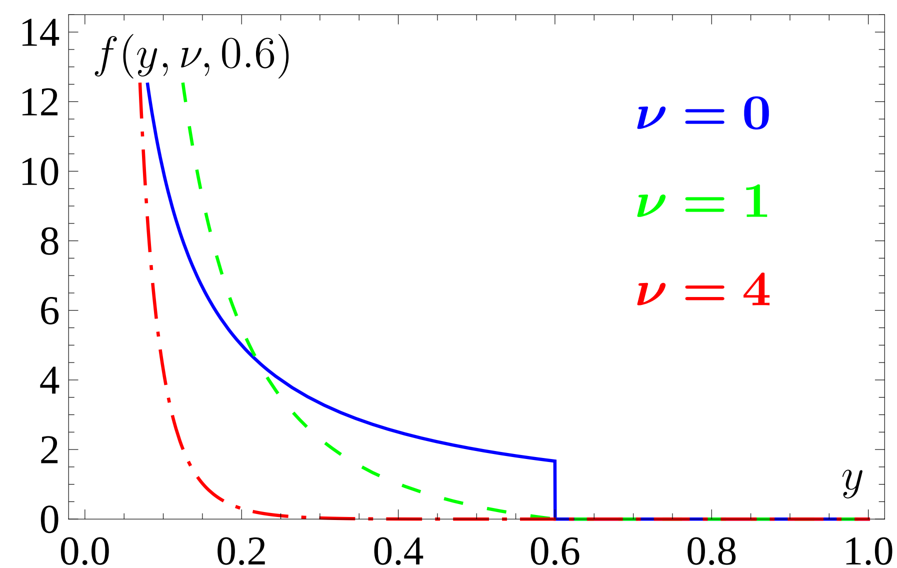
Moments: $\langle\xi^{2N}\rangle \equiv \int_0^1 dx\,\varphi_\pi(x)(2x-1)^{2N}\,,\quad \langle x^{-1}\rangle \equiv \int_0^1 dx\,\varphi_\pi(x)x^{-1}\,.$

SVZ	$\langle\xi^0\rangle$	LO	local cond.	f_π
CZ	$\langle\xi^{2N}\rangle\ N=0,1$	LO	local cond.	$f_\pi,\,a_2$
BMS	$\langle\xi^{2N}\rangle$, $N=0,1,\ldots,5$	NLO	nonlocal cond.	$f_\pi,\,a_2,\,a_4\ \langle x^{-1}\rangle$
Here	$[D^{(\nu)}\varphi_\pi](x)$	NLO	nonlocal cond.	$\varphi'_\pi(0)$

The definition of **"integral derivative"**:

$$[D^{(\nu+2)}\varphi](x) = \frac{1}{x}\int_0^1 dy\,\varphi(y)\,f(y,\nu,x)\,,$$

where $f(y,\nu,x) = \frac{\theta(x-y)}{\Gamma(\nu+1)\,y}\left(\ln\frac{x}{y}\right)^\nu$.



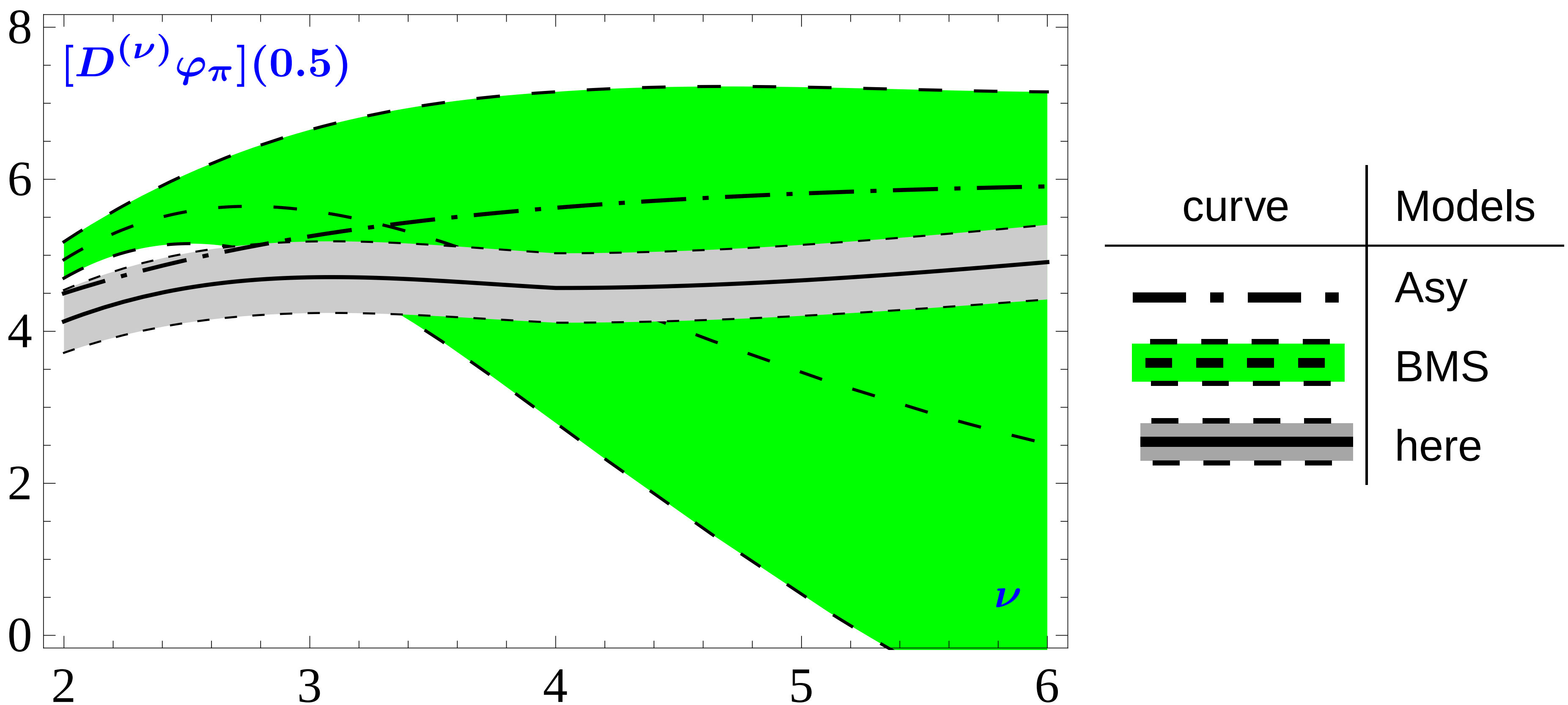
“Integral” derivatives $[D^{(\nu)}\varphi_\pi](x)$ of pion DA

$$[D^{(\nu+2)}\varphi](x) = \frac{1}{x}\int_0^x dy\,\varphi(y) f(y,\nu,x)\,, \text{where} \quad f(y,\nu,x) = \frac{\theta(x-y)}{\Gamma(\nu+1)\,y}\left(\ln\frac{x}{y}\right)^\nu .$$

It provides “average” derivatives in interval $[0,x]$.

- Properties of “integral derivative”:
  - $[D^{(0)}\varphi](x) = \varphi'(x)\,,\ [D^{(1)}\varphi](x) = \frac{\varphi(x)}{x}\,,$
  - $[D^{(2)}\varphi](x) = \frac{1}{x}\int_0^x \frac{\varphi(y)}{y} dy [D^{(2)}\varphi](1) \ \xrightarrow{x\to 1}\ \langle x^{-1}\rangle\,,$
  - $[D^{(\nu+1)}\varphi](x) = \frac{1}{x}\int_0^x dy\,[D^{(\nu)}\varphi](y)\,,$
  - $[D^{(\nu+2)}\varphi](x) = \varphi'(0) + \varphi''(0)\frac{x}{2!2^{\nu+1}} + \ldots\,.$
- Each higher derivative $D^{(\nu+1)}$ is stronger averaged compare to previous one $D^{(\nu)}$.
- Defined operator $D^{(\nu)}$ reproduces at small x and/or large ν derivative of $\varphi(x)$ at origin $x=0$.

QCD SR result vs BMS and Asy DA



- Image of operator $D^{(\nu)}$ for $\nu \geq 5$ is numerically close to differentiation $\varphi'_\pi(0)$. SR for pion DA slope $\varphi'_\pi(0)$ will be presented shortly.
- SR result for $[D^{(2\leq\nu<5)}\varphi_\pi](x)$ leads to slope of π-DA: $\varphi'_\pi(0) = 5.5 \pm 1.5$.

QCD SR for $\varphi'_\pi(0)$ in Gaussian model

By differentiating QCD SR for pion DA at $x=0$. We arrive at SR for $\varphi'_\pi(0)$

$$f_\pi^2\,\varphi'_\pi(0) = \frac{3}{2\pi^2}M^2\left(1-\mathrm{e}^{-s_0/M^2}\right) - f_{A_1}^2\,\varphi'_{A_1}(0)\,\mathrm{e}^{-m_{A_1}^2/M^2} + \frac{144\pi\alpha_S}{81}\langle\bar{q}q\rangle^2\Phi'\,,$$

where only 4-quark condensate contribution survives.

- Nonperturbative term mainly defined by scalar-quark condensate at large and moderate distances

$$\Phi' = \int_0^\infty d\alpha\,\frac{f_S(\alpha)}{\alpha^2} = \langle\bar{q}q\rangle^{-1}\int_0^\infty z^2\langle\bar{q}(0)q(z)\rangle dz^2\,.$$

- Simplest assumption for scalar condensate model $f_S(\alpha)=\delta(\alpha-\lambda_q^2/2)$ leads to Gaussian behavior $\sim \exp\left(\lambda_q^2 x^2/8\right)$ of coordinate dependence and to simple expression for nonperturbative contribution to SR:

$$\Phi' \longrightarrow \Phi'_{\text{Gauss}} = 4/\lambda_q^4\,.$$

- Then QCD SR result is $\varphi'_\pi(0)=5.3(5)$, where nonlocality parameter $\lambda_q^2 = 0.4\,\text{GeV}^2$ was used.

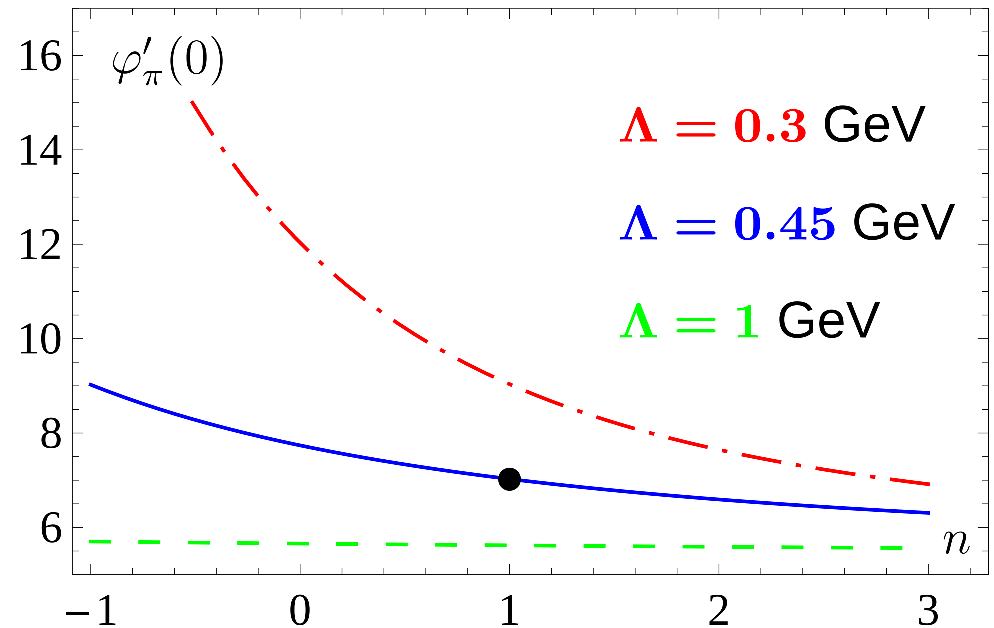
QCD SR for $\varphi'_\pi(0)$ with smooth NLC

- There is an indication from heavy-quark effective theory **[Radyushkin 91]** that in reality quark-virtuality distribution f_S should be parameterized in a different way as to ensure that scalar condensate **decreases exponentially** at large distances. $\langle\bar{q}(0)q(z)\rangle \sim |z|^{-(2n+1)/2}e^{-\Lambda|z|}$.

- This could be realized by model:

$$f_S(\alpha;\Lambda,n,\sigma) \sim \alpha^{n-1}e^{-\Lambda^2/\alpha-\alpha\,\sigma^2} .$$

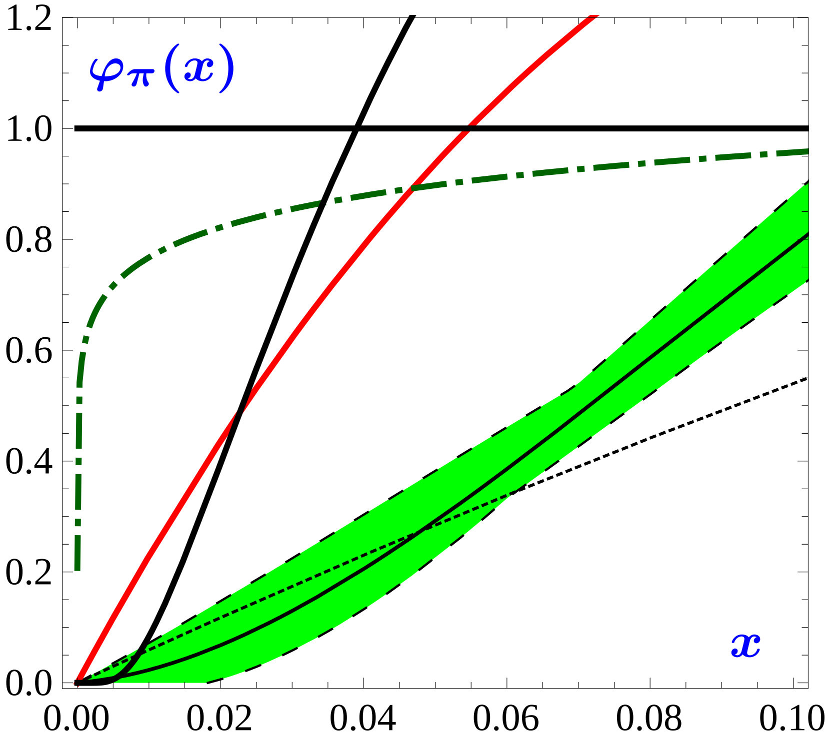
- Analysis of SR for the heavy-light meson, obtained in heavy quark effective theory, leads to values $\Lambda = 0.45$ GeV and $n = 1$. For these parameters we get $\varphi'_\pi(0) = 7.0(7)$ (black point in Fig.).



- Slower decay at large distances, causes an increase of the pion DA slope $\varphi'_\pi(0)$;

Comparison of results with pion DA models

Approach	$[D^{(3)}\varphi_\pi](0.5)$	$\varphi'_\pi(0)$
Integral LO QCD SR	4.7 ± 0.5	5.5 ± 1.5
Differential LO QCD SR, Gaussian decay of NLC	—	5.3 ± 0.5
Differential LO QCD SR, exponential decay of NLC	—	7.0 ± 0.7



Curve	Model	$[D^{(3)}\varphi_\pi](0.5)$	$\varphi'_\pi(0)$
	BMS DA	5.7 ± 1.0	1.7 ± 5.3
	Asy DA	5.25	6
	CZ DA	15.1	26.2
	$\sim x^{0.1}$	227	$\gg 6$
	[WH10]	14	0

Conclusion

- CELLO, CLEO, and BaBar data up to $\mathbf{9}$ GeV$^{\mathbf{2}}$ prefer endpoint suppressed π-DA and are **well-described by BMS "bunch" of pion DAs**.
- Provided the BaBar data effect is correct, in order to get an increase of the form factor with Q^2, **direct form of collinear factorization has to be abandoned** in favor of a flat pion DA.
- LO QCD sum rules with natural choices of NLC lead to behavior at the origin **close to asymptotic DA** and contradicting **flat-type pion DAs**.
- Slop of pion DA at the origin is limited by "speed" of quark condensate decay at large distances. Slower decay at large distances, causes an increase of the pion DA slope $\varphi'_\pi(0)$.
- Main **challenge**: Which QCD mechanism(s) provide(s) enhancement at intermediate momenta and suppression asymptotically? If such mechanism does not exist and the BaBar data are correct, then QCD is in danger.
- Great **opportunity** for other Collaborations, e.g., Belle, to solidify/disprove the BaBar effect.