Probing the new physics with jet charge

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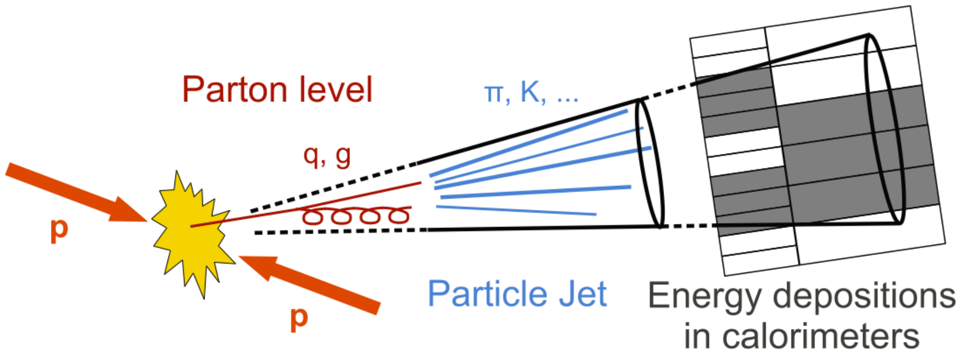
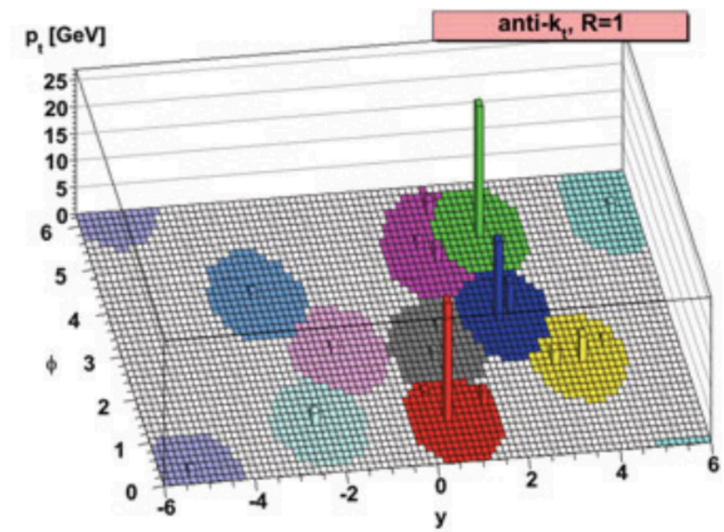
Hai Tao Li, Bin Yan and C.-P. Yuan, PLB833(2022)137300, 2211.xxxxx

Jet charge definition





Transverse-momentum-weighting scheme:

$$Q_J = \frac{1}{(p_T^j)^\kappa} \sum_{i \in jet} Q_i (p_T^i)^\kappa, \;\; \kappa > 0$$

K: To regulate the sensitivity of the soft gluon radiation

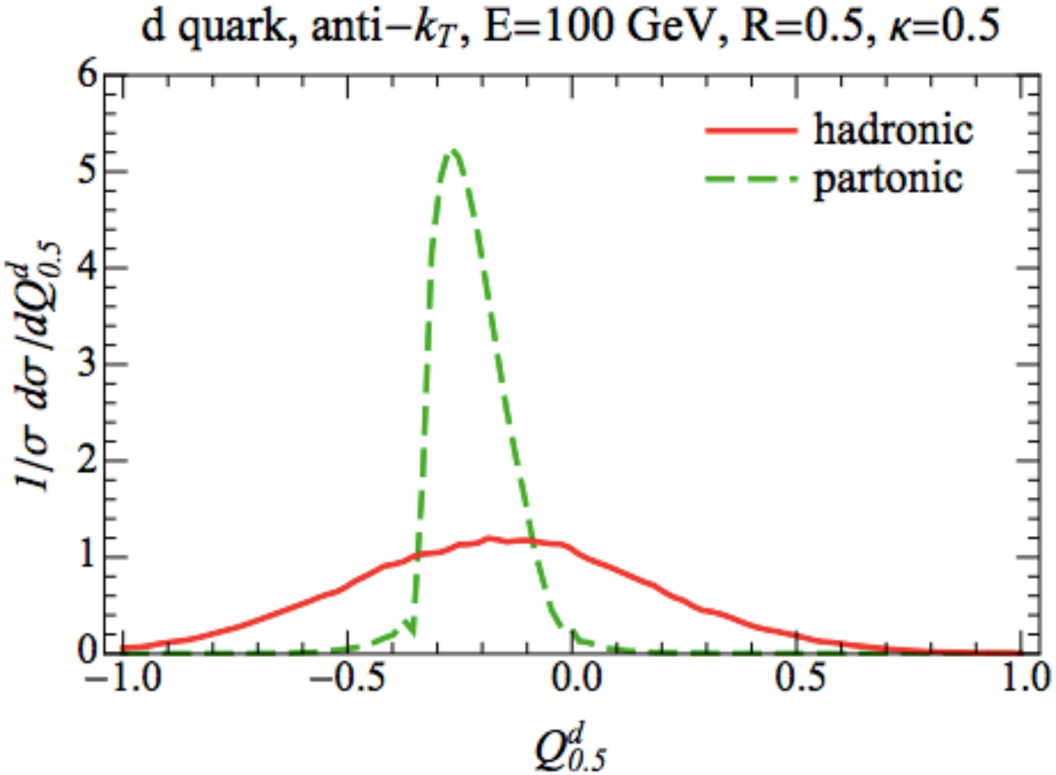
R.D. Field and R.P. Feynman, NPB136,1(1978)

Jet charge definition

Jet charge is not an Infrared-safe quantity

$$Q_J = \frac{1}{(p_T^j)^\kappa} \sum_{i \in jet} Q_i (p_T^i)^\kappa, \ \kappa > 0$$

The collinear radiation



W.J.Waalewijn, PRD86(2012)094030

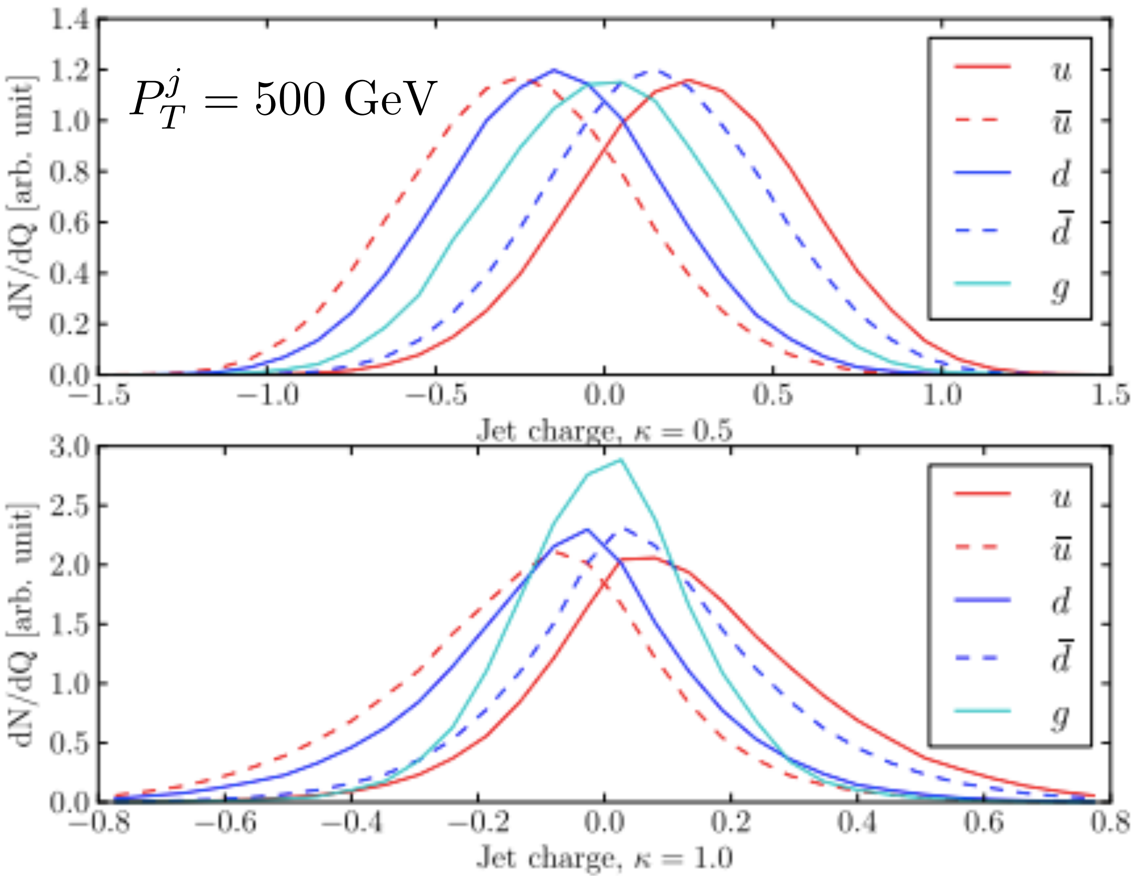
$$Q_q \neq (1-z)^k Q_q$$

The jet charge can be defined only at the hadron level

It depends on the knowledge of the Fragmentation functions

Jet charge definition

$$Q_J = \frac{1}{(p_T^j)^\kappa} \sum_{i \in jet} Q_i (p_T^i)^\kappa, \ \ \kappa > 0$$



D. Krohn, M. D. Schwartz, T. Lin, W.J. Waalewijn, PRL 110(2013)21,212001

Parton shower and hadronization can not wash out the primordial quark charge information

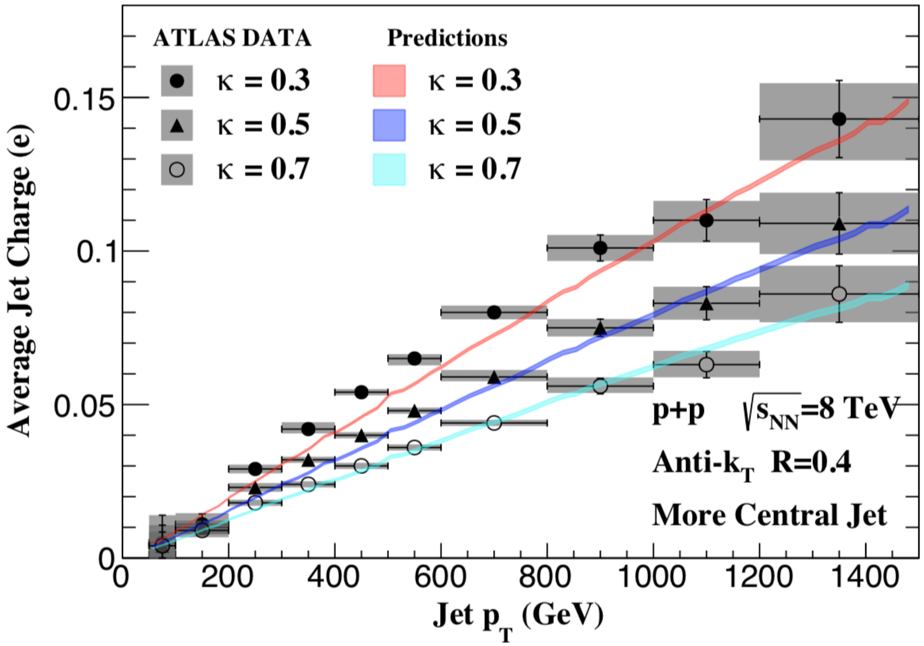
The average of Jet charge

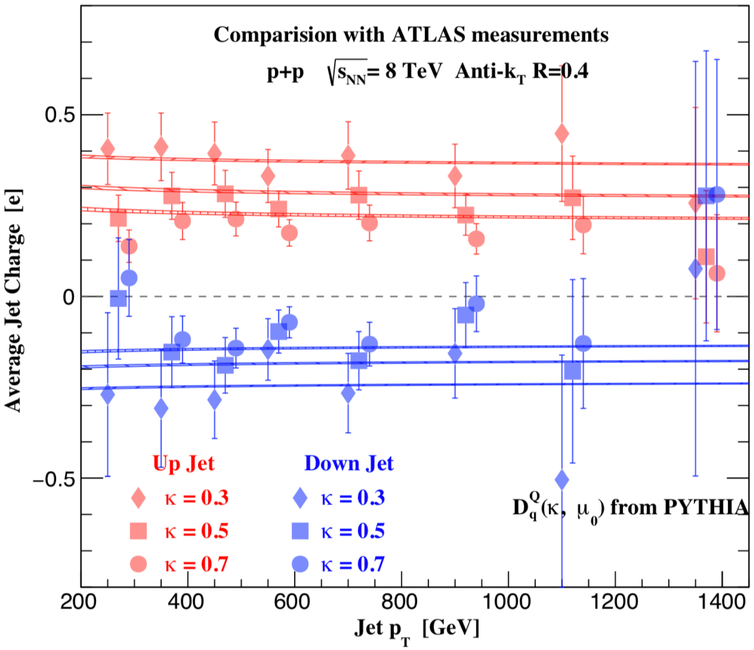
$$\langle Q_k^q \rangle = \frac{1}{\sigma_{q-jet}} \int d\sigma_{q-jet} Q_\kappa(\sigma_{q-jet})$$

D. Krohn, M. D. Schwartz, T. Lin, W.J. Waalewijn, PRL 110(2013)21,212001

W.J.Waalewijn, PRD86(2012)094030

H. T. Li and I. Vitev, PRD 101(2020)076020

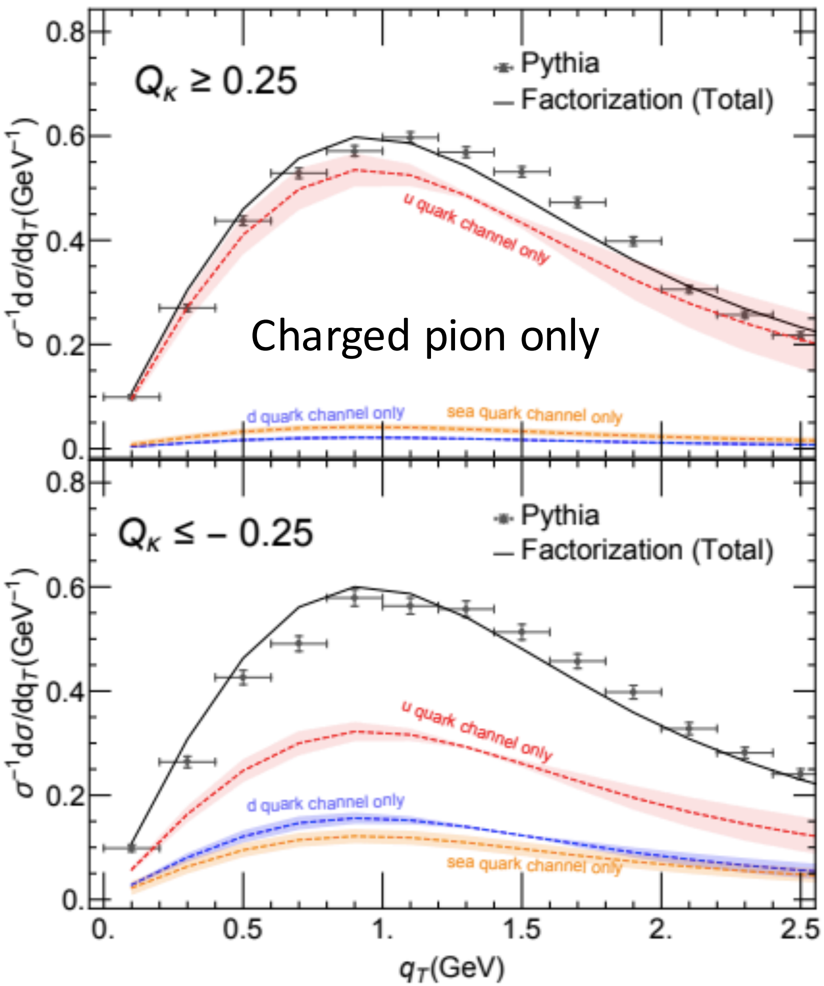


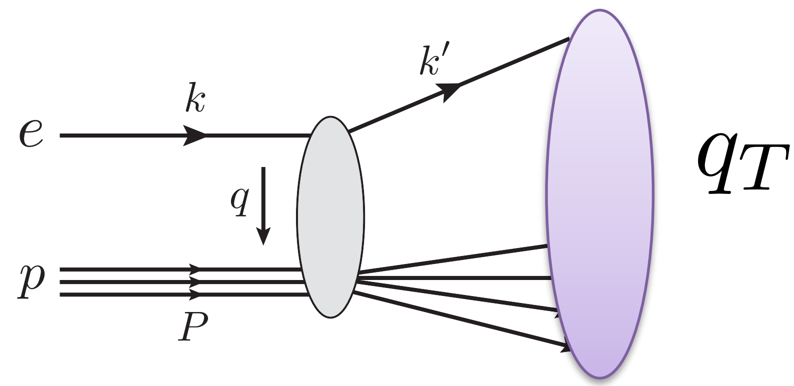


Perfect agreement between theory and data

Jet charge: A Flavor Prism

Z. B. Kang, X.H.Liu, S. Mantry, D. Y. Shao, PRL125(2020)242003





The jet charge can be used as a flavor tagging at the EIC

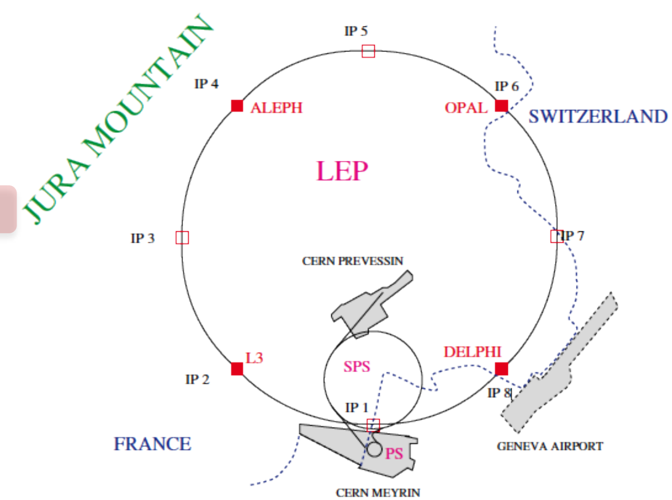
Probing the Zbb coupling with jet charge

Electroweak Precision measurement

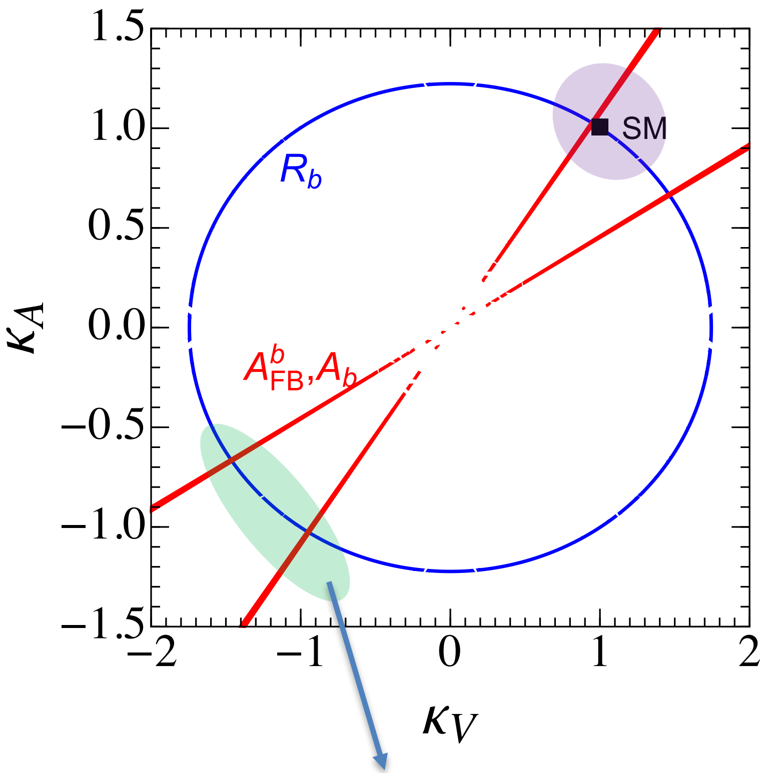
	Measurement with Total Error	Systematic Error	Standard Model High-Q^2 Fit	Pull
$\Delta\alpha_{had}^{(5)}(m_Z^2)$ [59]	0.02758 ± 0.00035	0.00034	0.02767 ± 0.00035	0.3
m_Z [GeV]	91.1875 ± 0.0021	$^{(a)}0.0017$	91.1874 ± 0.0021	0.1
Γ_Z [GeV]	2.4952 ± 0.0023	$^{(a)}0.0012$	2.4965 ± 0.0015	0.6
σ_{had}^0 [nb]	41.540 ± 0.037	$^{(a)}0.028$	41.481 ± 0.014	1.6
R_ℓ^0	20.767 ± 0.025	$^{(a)}0.007$	20.739 ± 0.018	1.1
$A_{FB}^{0,\ell}$	0.0171 ± 0.0010	$^{(a)}0.0003$	0.01642 ± 0.00024	0.8
+ correlation matrix Table 2.13				
$\mathcal{A}_\ell$ (P_τ)	0.1465 ± 0.0033	0.0015	0.1480 ± 0.0011	0.5
$\mathcal{A}_\ell$ (SLD)	0.1513 ± 0.0021	0.0011	0.1480 ± 0.0011	1.6
R_b^0	0.21629 ± 0.00066	0.00050	0.21562 ± 0.00013	1.0
R_c^0	0.1721 ± 0.0030	0.0019	0.1723 ± 0.0001	0.1
$A_{FB}^{0,b}$	0.0992 ± 0.0016	0.0007	0.1037 ± 0.0008	2.8
$A_{FB}^{0,c}$	0.0707 ± 0.0035	0.0017	0.0742 ± 0.0006	1.0
$\mathcal{A}_b$	0.923 ± 0.020	0.013	0.9346 ± 0.0001	0.6
$\mathcal{A}_c$	0.670 ± 0.027	0.015	0.6683 ± 0.0005	0.1
+ correlation matrix Table 5.11				
$\sin^2\theta_{eff}^{lept}$ (Q_{FB}^{had})	0.2324 ± 0.0012	0.0010	0.23140 ± 0.00014	0.8
m_t [GeV] (Run-I [212])	178.0 ± 4.3	3.3	178.5 ± 3.9	0.1
m_W [GeV]	80.425 ± 0.034		80.389 ± 0.019	1.1
Γ_W [GeV]	2.133 ± 0.069		2.093 ± 0.002	0.6
+ correlation given in Section 8.3.2				

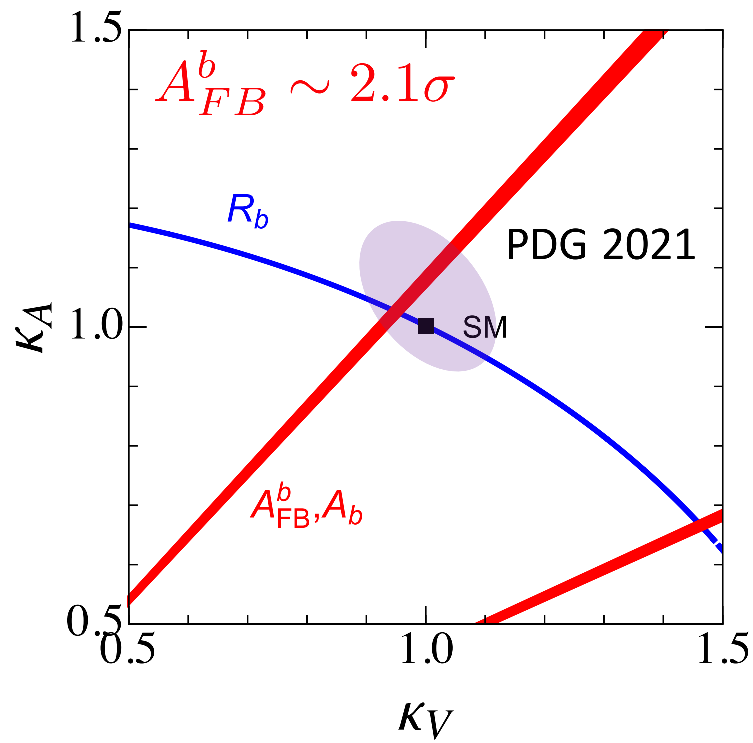
Phys.Rept. 427 (2006) 257-454

LEP： 1989-2000



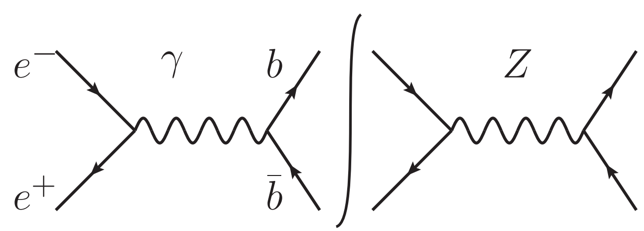
Status of Zbb couplings





Excluded by off-Z pole data

$$\mathcal{L} = \bar{b}\gamma_\mu(\kappa_V g_V - \kappa_A g_A \gamma_5) b Z_\mu$$



- *Large deviation* of the Zbb coupling
- The degeneracy of the Zbb coupling

Status of Zbb couplings

A. How to break the degeneracy of the Zbb coupling?

New experiments: CEPC (e+e- collider), etc.

B. How to explain the LEP data?

New Physics?

Many new physics models

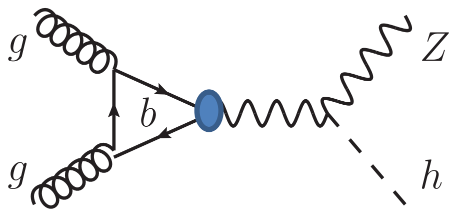
e.g. Custodial symmetry + heavy B' quark

K. Agashe, R. Contino, L. Rold, A. pomarol, 2006'

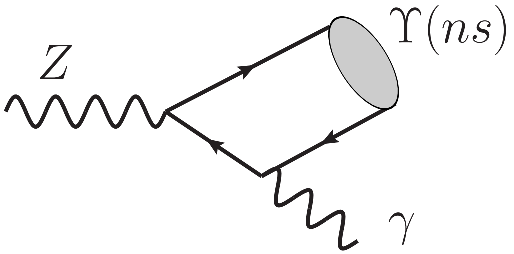
Statistical Fluctuation or Systematic error?

New experiments: e.g. CEPC

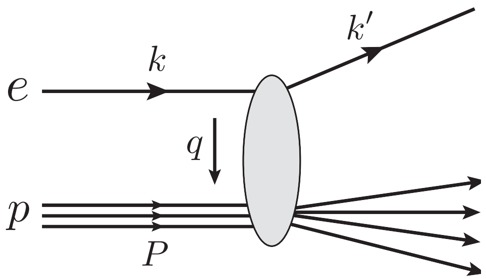
Zbb couplings@ LHC and EIC



Bin Yan, C.-P. Yuan, PRL127(2021)5,051801



Hongxin Dong, Peng Sun, Bin Yan and C.-P. Yuan, PLB829(2022)137076

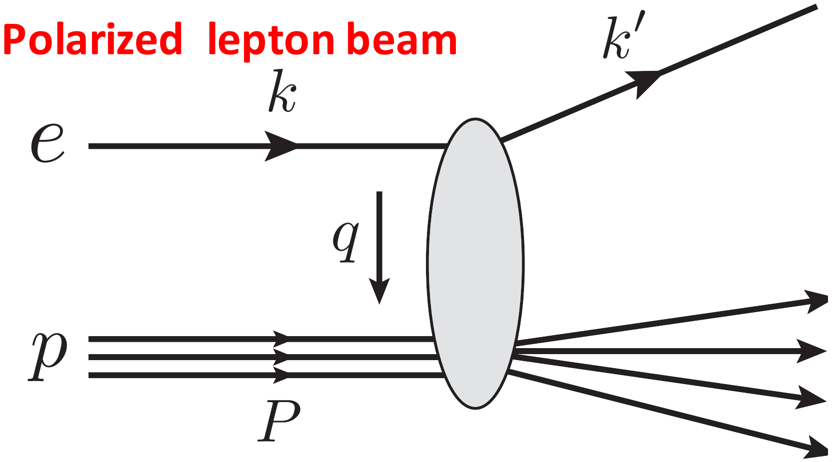


Bin Yan, Zhite Yu and C.-P. Yuan, PLB822(2021)136697
Hai Tao Li, Bin Yan and C.-P. Yuan, PLB833(2022)137300

Zbb couplings@EIC

Bin Yan, Zhite Yu and C.-P. Yuan, PLB822(2021)136697

Polarized lepton beam



Single-Spin Asymmetry (SSA):

$$A_e^b = \frac{\sigma_{b,+}^{\rm tot} - \sigma_{b,-}^{\rm tot}}{\sigma_{b,+}^{\rm tot} + \sigma_{b,-}^{\rm tot}}$$

$+/-$: right/left-handed lepton

1. Photon-only diagrams will cancel in SSA
2. Leading contribution: γ-Z interference
3. Only sensitive to the vector component of the Zbb coupling

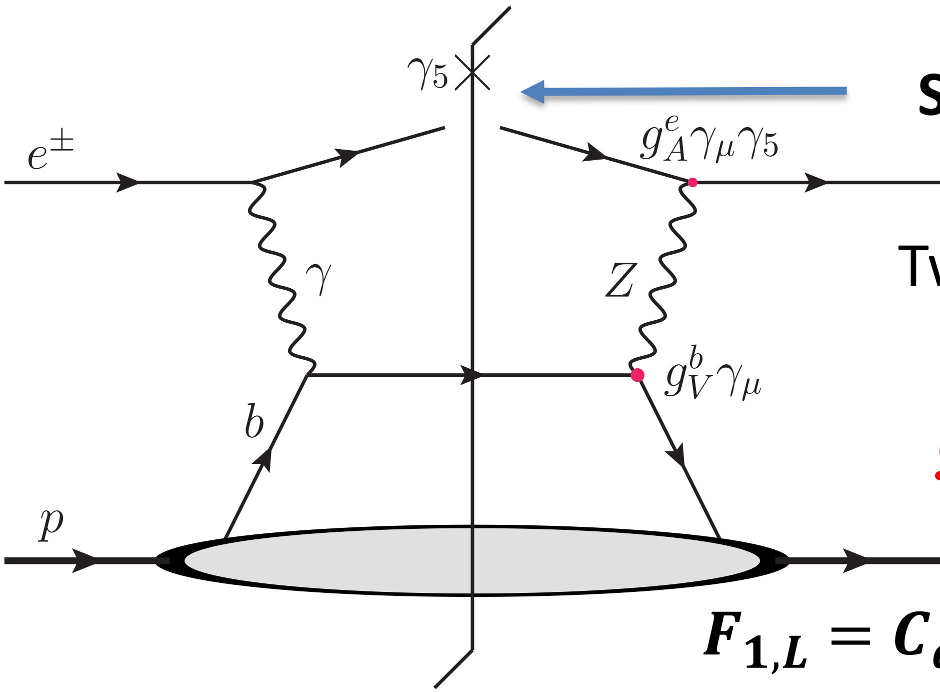
DIS cross section

Polarized cross section

$$F_{1,L,3} \equiv F_{1,L,3}(\lambda_e)$$

$$\frac{d\sigma^{\pm}_{\lambda_e}}{\sigma_0 dx dy} = F_1\left((1-y)^2+1\right) + F_L\frac{1-y}{x} \mp F_3\lambda_e\left(y-\frac{y^2}{2}\right)$$

$\lambda_e = \pm 1$: lepton helicity



SSA: $\sigma_{b,+} - \sigma_{b,-}$

Two possible combination:

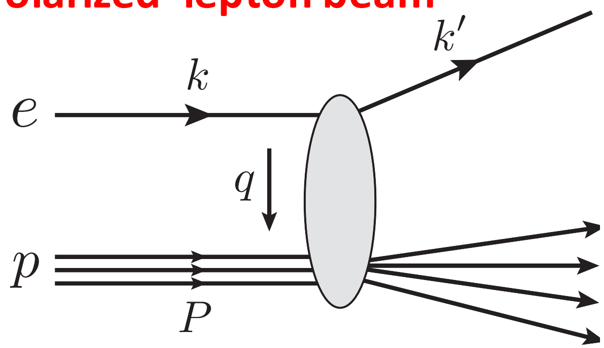
$g^e_A g^b_V$  $g^e_V g^b_A$

$$\boldsymbol{F_{1,L} = C_q \otimes (q+\bar{q})} \quad \boldsymbol{F_3 = C_q \otimes (q-\bar{q})}$$

$$\mathcal{L}_{\text{eff}} = \frac{g_W}{2c_W}\bar{f}\gamma_\mu(g^f_V - g^f_A\gamma_5)fZ_\mu$$

Zbb couplings @EIC

Polarized lepton beam



Single-Spin Asymmetry:

$$A_e^b = \frac{\sigma_{b,+}^{\text{tot}} - \sigma_{b,-}^{\text{tot}}}{\sigma_{b,+}^{\text{tot}} + \sigma_{b,-}^{\text{tot}}}$$

vector component of the Zbb coupling

Is it possible to probe the axial-vector component at the EIC?

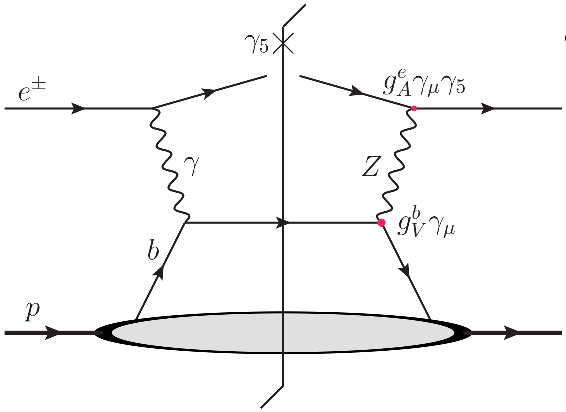
Average jet charge weighted Single-Spin Asymmetry (WSSA):

$$A_e^{bQ} = \frac{\sigma_{b,+}^{Q} - \sigma_{b,-}^{Q}}{\sigma_{b,+}^{Q} + \sigma_{b,-}^{Q}}$$

$$\sigma_{b,\pm}^{Q} = \int dp_T^j \frac{d\sigma_{b,\pm}^{\text{tot}}}{dp_T^j} \langle Q_J \rangle_b (p_T^j)$$

$$\langle Q_J \rangle_b (p_T^j) = \sum_{q=u,d,c,s,b} \left[f_J^q(p_T^j, \epsilon_q^b) - f_J^{\bar{q}}(p_T^j, \epsilon_q^b) \right] \langle Q_J^q \rangle_b (p_T^j)$$

Jet Charge Weighted SSA



SSA: $\boldsymbol{\sigma_{b,+} - \sigma_{b,-}}$

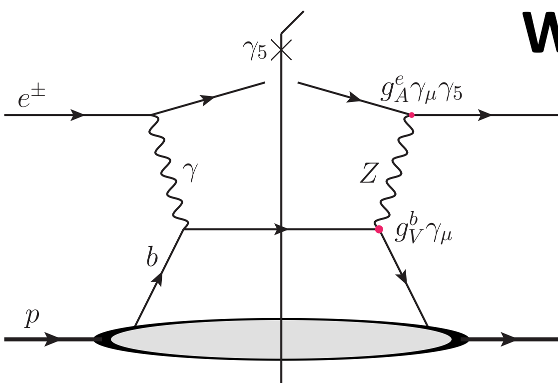
$g_A^e g_V^b$

$$\boldsymbol{F_{1,L} = C_q \otimes (q + \bar{q})}$$

$g_V^e g_A^b$

$$\boldsymbol{F_3 = C_q \otimes (q - \bar{q})}$$

Key point: $\langle Q_J^q \rangle = -\langle Q_J^{\bar{q}} \rangle$



WSSA: $\sigma_{b,+}^{Q} - \sigma_{b,-}^{Q}$

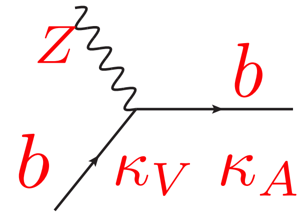
$g_A^e g_V^b$

$$F_{1,L} = C_q \otimes (q - \bar{q}) \langle Q_J^q \rangle$$

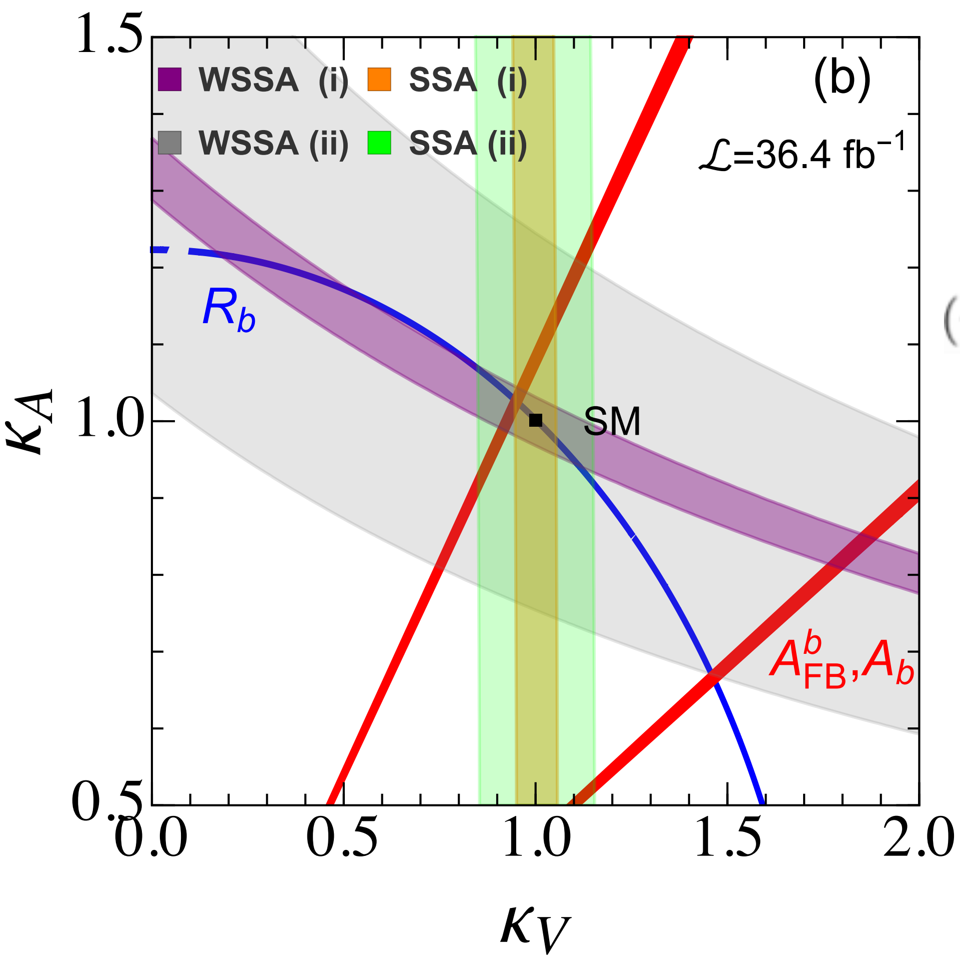
$g_V^e g_A^b$

$$F_3 = C_q \otimes (q + \bar{q}) \langle Q_J^q \rangle$$

$$\mathcal{L}_{\text{eff}} = \frac{g_W}{2c_W} \bar{f} \gamma_\mu (g_V^f - g_A^f \gamma_5) f Z_\mu$$



Zbb couplings @EIC



$$\mathcal{L} = \bar{b}\gamma_\mu(\kappa_V g_V - \kappa_A g_A \gamma_5) b Z_\mu$$

$$(i)\ \epsilon_q^b = 0.001, \quad \epsilon_c^b = 0.03, \quad \epsilon_b = 0.7;$$

$$(ii)\ \epsilon_q^b = 0.01, \quad \epsilon_c^b = 0.2, \quad \epsilon_b = 0.5.$$

WSSA	SSA
$(i): \mathcal{L} > 0.6\ \text{fb}^{-1};$	$(i): \mathcal{L} > 0.5\ \text{fb}^{-1};$
$(ii): \mathcal{L} > 36.4\ \text{fb}^{-1}.$	$(ii): \mathcal{L} > 4.0\ \text{fb}^{-1}.$

Summary

A. The jet charge is a useful observable for both the QCD and new physics searches;

B. We propose to use jet charge weighted single-spin asymmetry to probe the Zbb anomalous couplings;

Searching for the new physics with jet charge is just beginning!

Other possibilities:
Quark-gluon discrimination
Higgs production mechanism discrimination
……

Thank you!