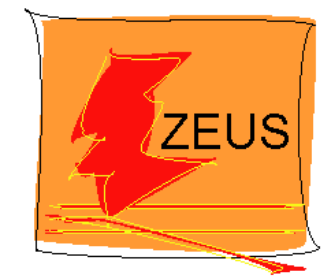


ZEUS Collaboration Meeting

September 9, 2015

Estimation of Negative Limits on the Effective Charge Radius of Quark

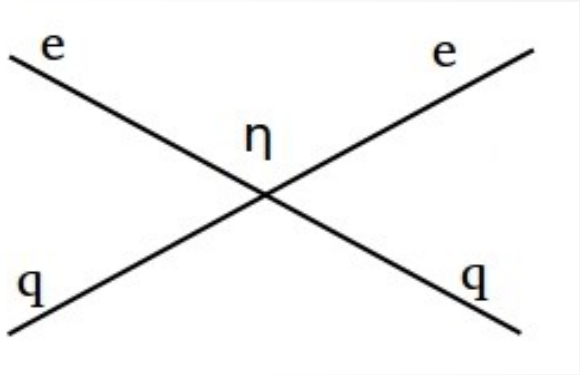
D. Sukhonos, O. Turkot, K. Wichmann

Outline

- Quark radius model
- Probability method of setting limits
- χ^2 scan
- Model and parametrization variations
- Results
- Conclusions

Briefly about Contact Interactions

- Contact Interactions (CI) – an effective theory that describes low-energy effects of the BSM contributions



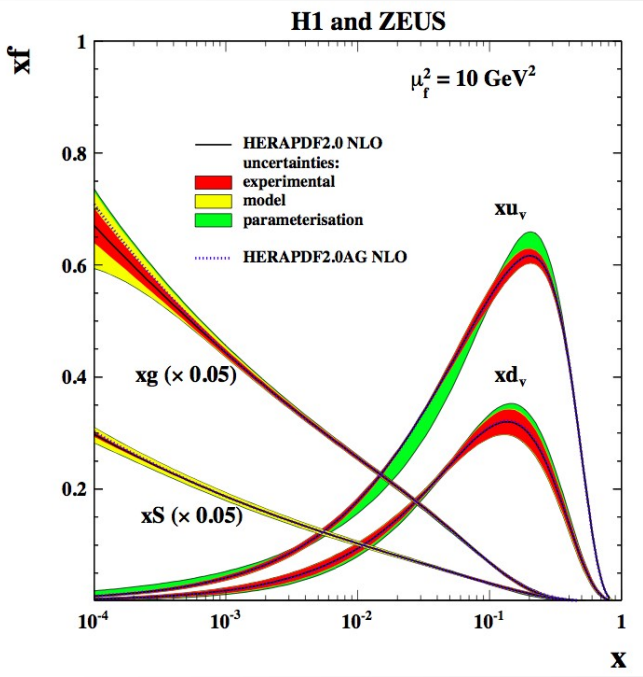
- To include CI into SM Lagrangian one should add additional terms:

$$L_{CI} = \sum_{\substack{i,j=L,R \\ q=u,d,s,c,b}} \eta_{ij}^{eq} \left(\bar{e}_i \gamma^\mu e_i\right)\left(\bar{q}_j \gamma_\mu q_j\right)$$

HERAFitter package (https://www.herafitter.org)

Input:

- Experimental data from HERA, Tevatron, LHC
- Different processes NC, CC, DIS, jets, diffraction, heavy quarks, Drell-Yan, W production



Together with theoretical tools:

- FastNLO, Applgrid
- DGLAP (QCDNUM)
- MSTW, CTEQ

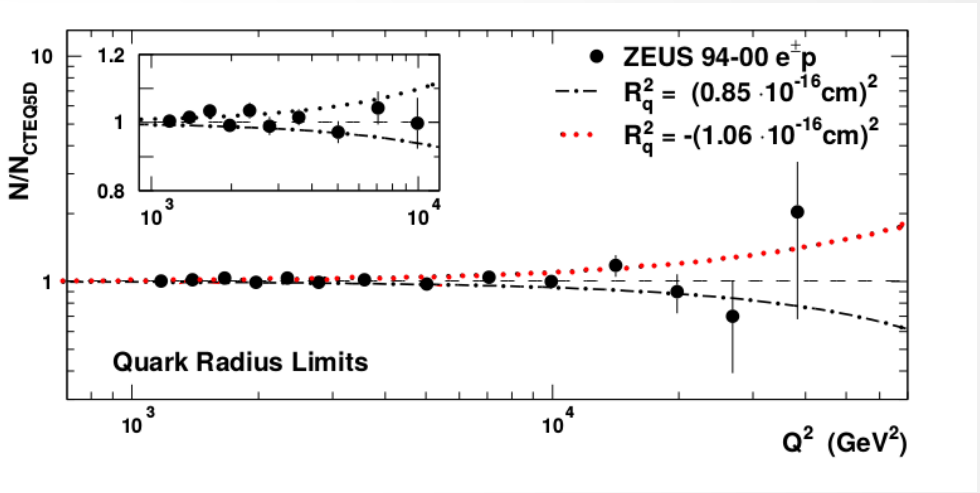
Output:

- Set of PDFs
- Constants: α_s, M_c, M_b, f_s ...
- Theory predictions
- Comparison of schemes

Quark Form Factor

Quark substructure can be detected by measuring the spatial distribution of the quark charge. If $Q^2 \ll 1/R_q^2$, the SM predictions for the cross sections are modified, approximately, to:

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma_{SM}}{dQ^2}\left(1 - \frac{R_q^2}{6}Q^2\right)$$



Combined 1994-2000 data compared with 95% C.L. exclusion limits for the effective mean-square radius of the electroweak charge of the quark (arXiv:hep-ex/0401009)

Probability Method

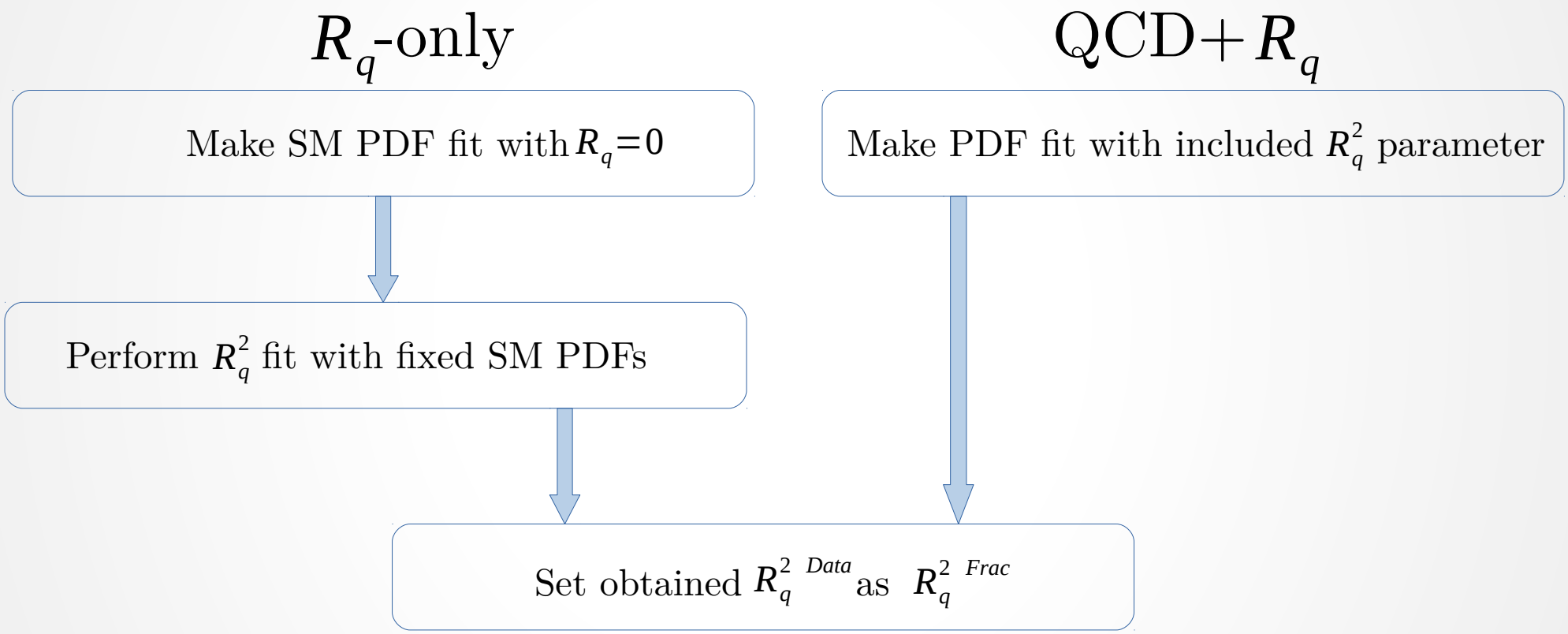
"R_q-only":

- Choose different values of $R_q^{2\ True}$ and generate Monte Carlo replicas, then make fits with fixed SM PDFs.

"QCD+R_q":

- Choose different values of $R_q^{2\ True}$ and generate Monte Carlo replicas, make fits of PDFs and R_q^2 parameter at one time for Monte Carlo replicas

Central Fitting Procedure



Results of the Fits

- R_q -only:

$$R_q^{2\ Data} = \left(-0.385 \pm 2.68\right) \times 10^{-6} GeV^{-2}$$

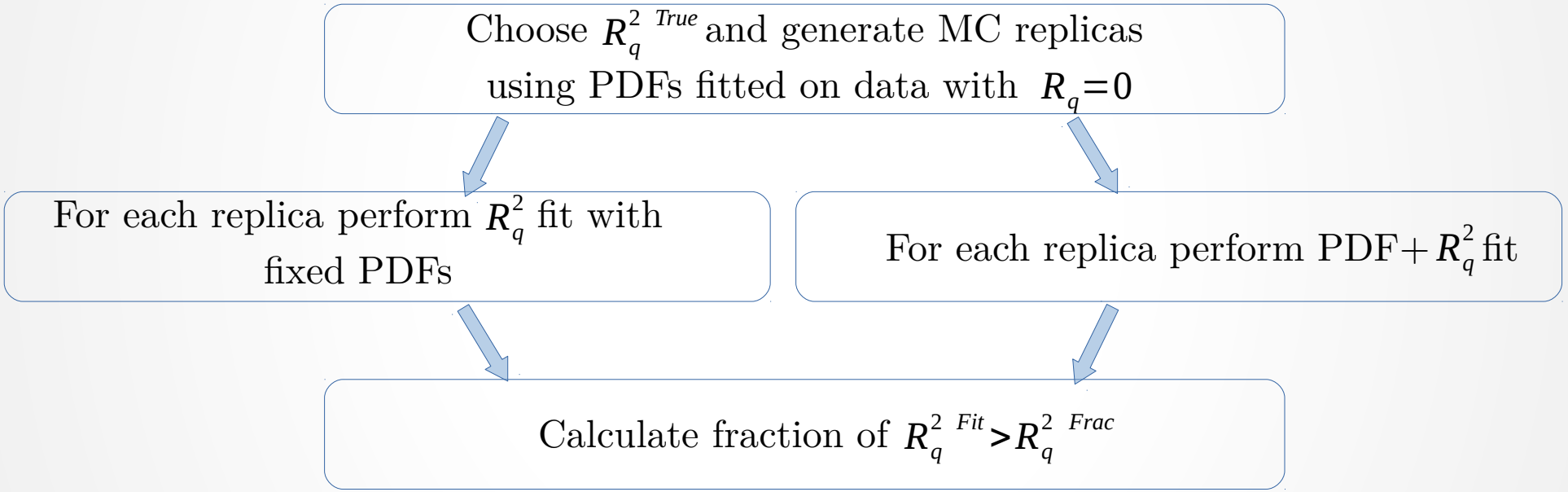
- QCD+R_q:

$$R_q^{2\ Data} = \left(-0.511 \pm 3.06\right) \times 10^{-6} GeV^{-2}$$

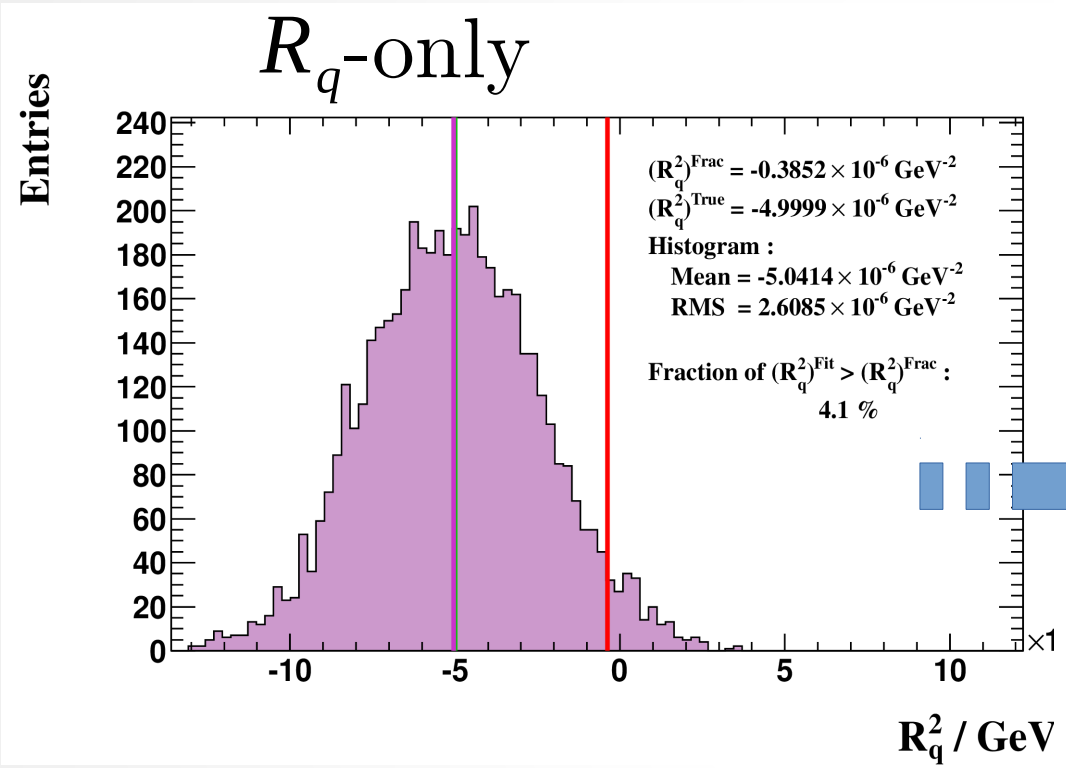
Preparing Monte Carlo Replicas

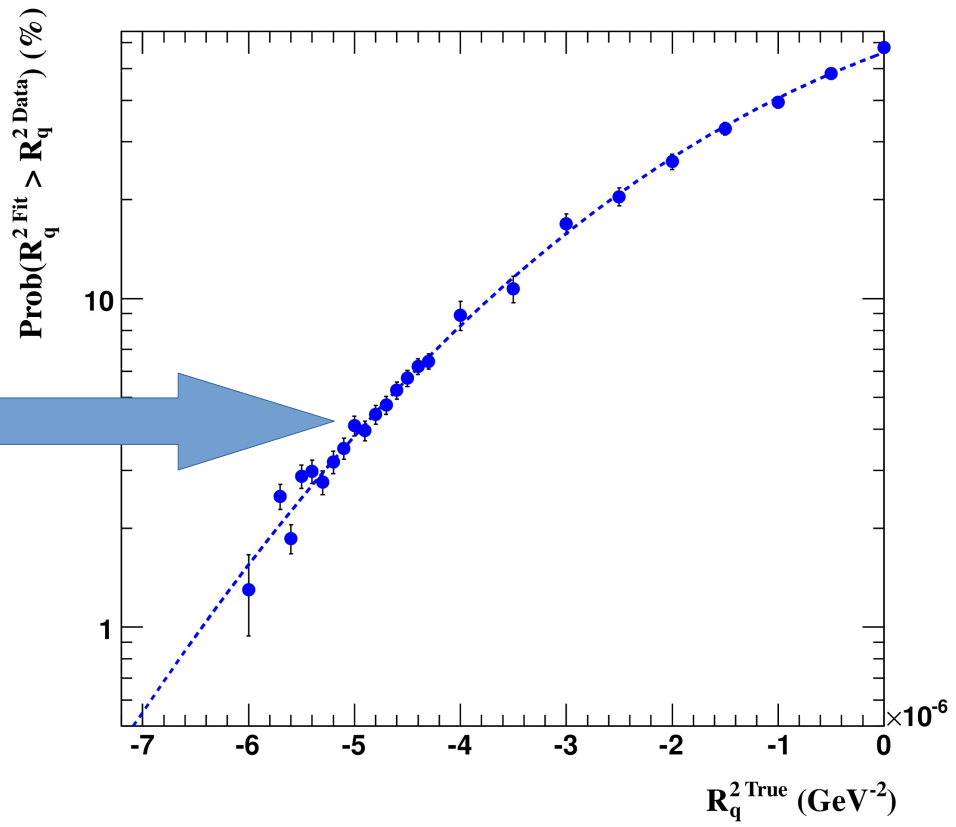
R_q-only

QCD+R_q



Estimating of the negative limit



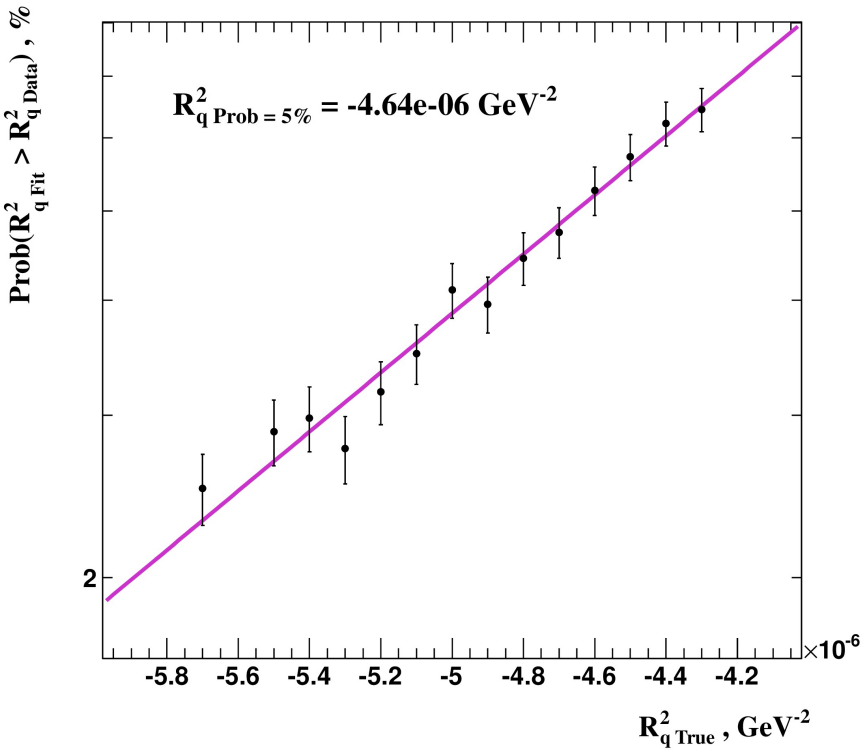


Monte Carlo replicas of cross sections are calculated as:

$$\mu^i = [M^i + \delta^i_{tot.uncor.} \cdot R^i_{tot.uncor.} \cdot D^i] \cdot \left(1 + \sum_j \gamma^j \cdot R^j_{sys.sh.}\right)$$

Final Limit

R_q-only



- Distribution is fitted with function:

$$f(x)=5\cdot\exp\left((x-A)\cdot B\right)$$

- Limit for central variation:

$$R_q^{2\ Limit}=\left(-4.653\pm0.027\right)\times10^{-6}\ \ GeV^{-2}$$

Model and Parametrization Variations

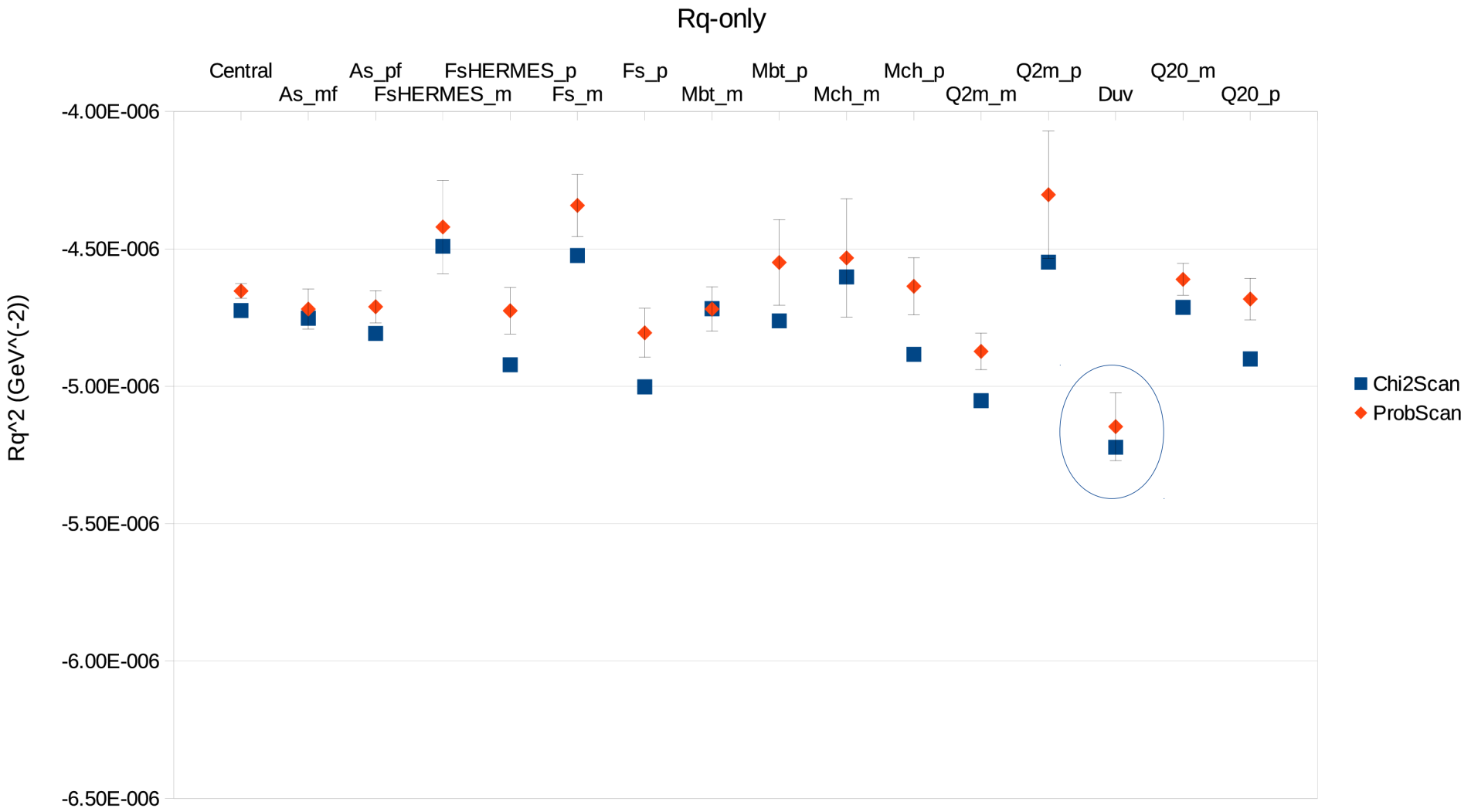
Model Variations

Variation	Standard Value	Lower Limit	Upper Limit
$Q^2_{min}\ [GeV^2]$	3.5	2.5	5.0
$M_c\ [GeV]$	1.47	1.41	1.53
$M_b\ [GeV]$	4.50	4.25	4.75
f_s	0.4	0.3	0.5
$f_{s\ HERMES}$	-	0.3	0.5
α_s	0.1180	0.1220	0.1146

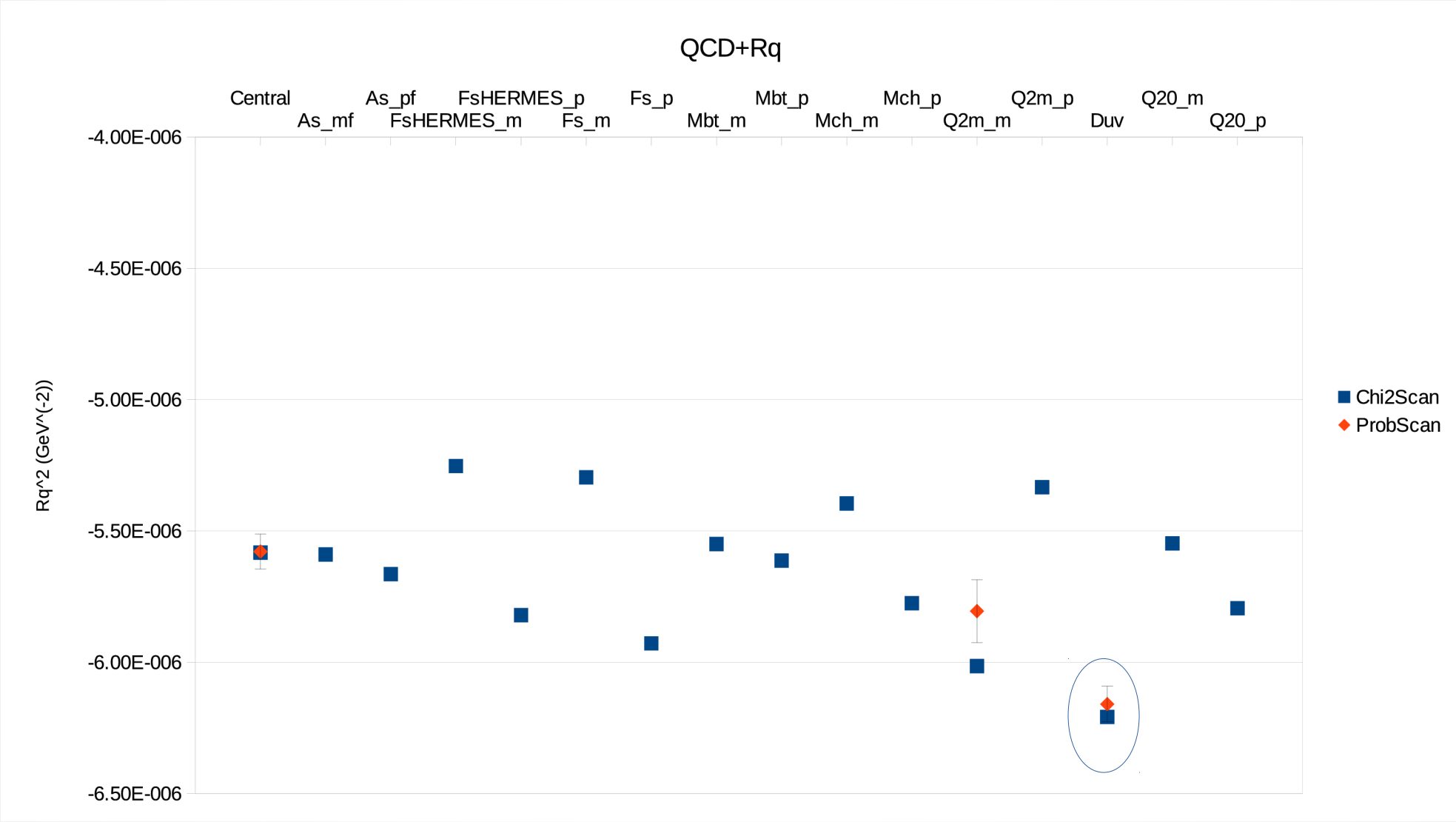
Parametrization Variations

Variation	Standard Value	Lower Limit	Upper Limit
$Q^2_0\ [GeV^2]$	1.9	1.6	2.2 $(M_c = 1.53\,GeV)$
D_{u_v}	-	-	+

Results of the Model and Parametrization Variations



Results of the Model and Parametrization Variations



Results of the Probability Scan

- For central variant:

R_q-only $\quad R_q^{2\ Limit} = -\left((0.426 \pm 0.033)\cdot 10^{-16}\ cm\right)^2$

QCD+R_q $\quad R_q^{2\ Limit} = -\left((0.466 \pm 0.051)\cdot 10^{-16}\ cm\right)^2$

- For variant with additional D_{u_v} parameter:

R_q-only $\quad R_q^{2\ Limit} = -\left((0.447 \pm 0.069)\cdot 10^{-16}\ cm\right)^2$

QCD+R_q $\quad R_q^{2\ Limit} = -\left((0.489 \pm 0.051)\cdot 10^{-16}\ cm\right)^2$

χ^2 Scan

- R_q-only

  R_q^2 fixed to $R_q^{2\ True}$ and PDFs fixed to SM PDFs.

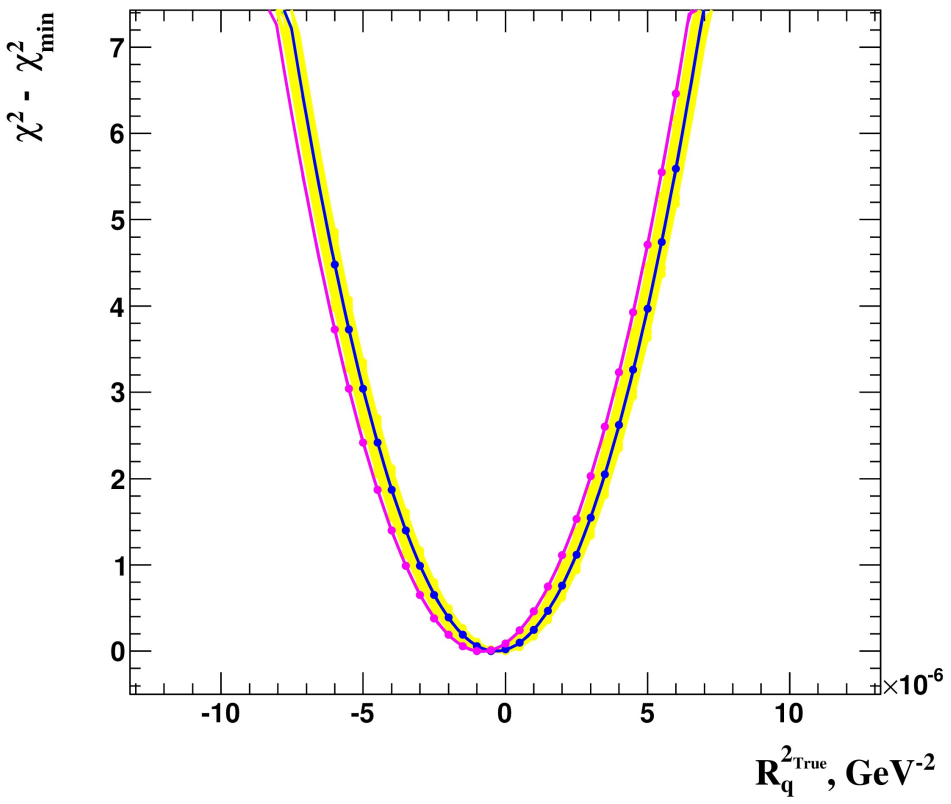
  χ^2 estimated for one iteration fit on Data.

- QCD+R_q

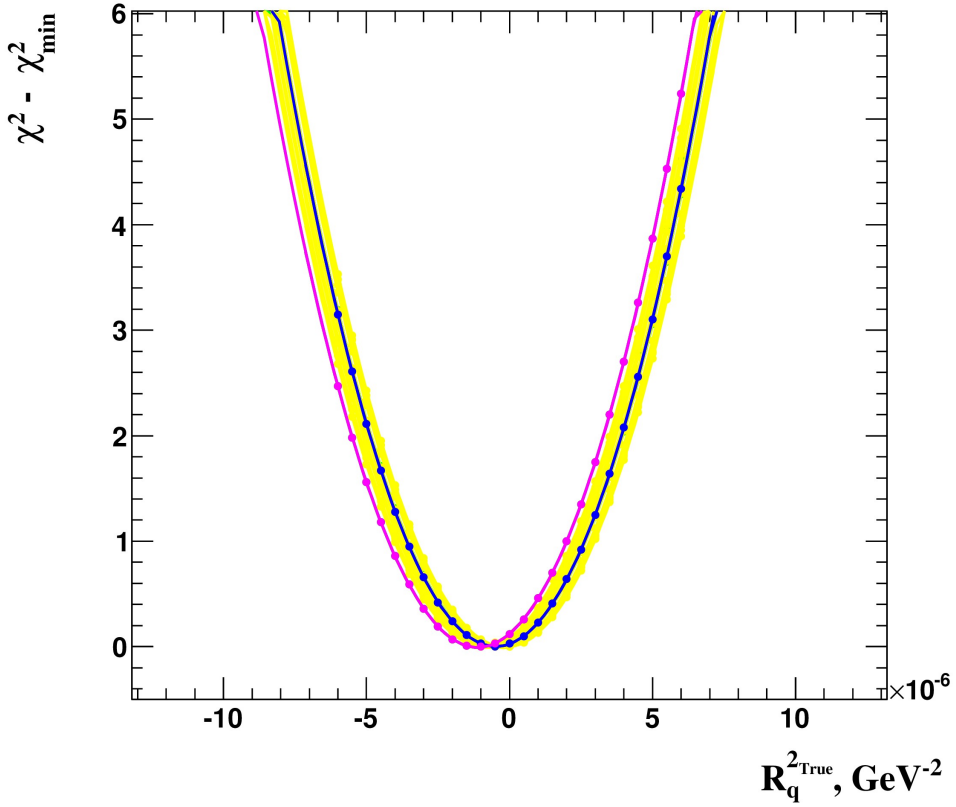
  R_q^2 fixed to $R_q^{2\ True}$ and PDFs are fitted, final χ^2 estimated.

χ^2 Scan Results

R_q-only



QCD+R_q



Blue – central fit. **Yellow** – model variations. **Green** – parametrization variations. **Magenta** – D_{u_v} variation.

Probability Scan vs χ^2 Scan

- Probability Scan:

R_q-only $\quad R_q^{2\ Limit} = -\left((0.447 \pm 0.069)\cdot 10^{-16}\ \ cm\right)^2$

QCD+R_q $\quad R_q^{2\ Limit} = -\left((0.489 \pm 0.051)\cdot 10^{-16}\ \ cm\right)^2$

- χ^2 Scan:

R_q-only $\quad R_q^{2\ Limit} = -\left(0.451\cdot 10^{-16}\ \ cm\right)^2$

QCD+R_q $\quad R_q^{2\ Limit} = -\left(0.491\cdot 10^{-16}\ \ cm\right)^2$

Conclusions

- Evaluated 95% C.L. lower limit:

$$R_q^2 > -\left(0.489 \cdot 10^{-16} \ \ cm\right)^2$$

- Probability method is fully consistent with χ^2 method