H1+ZEUS Plenary Meeting

31 January 2018
DESY, Germany

Search for contact interactions

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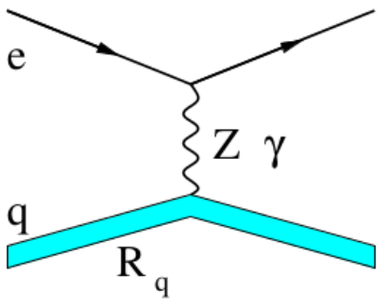
- Beyond-the-Standard-Model analysis combined with PDFs fit
- Simplified procedure for QCD+BSM fits

How big is a quark ?

One of the possible parameterisations of the deviations from the Standard Model - spatial distribution or substructure of electrons and/or quarks.

In a semi-classical form-factor approach cross sections are expected to **decrease** at high-Q^2:



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

There $\mathbf{R^2_e}$ and $\mathbf{R^2_q}$ are the mean-square radii of the electron and quark, respectively.

Same dependence expected for **NC** and **CC** e^+p and e^-p.

Electrons were assumed to be point-like, $\mathbf{R^2_e = 0}$, and both, positive and negative values of R^2_q were considered.

Reason for the simultaneous fit procedure

➢ BSM signal in the data could affect the PDF fit and result in **biased PDFs**.

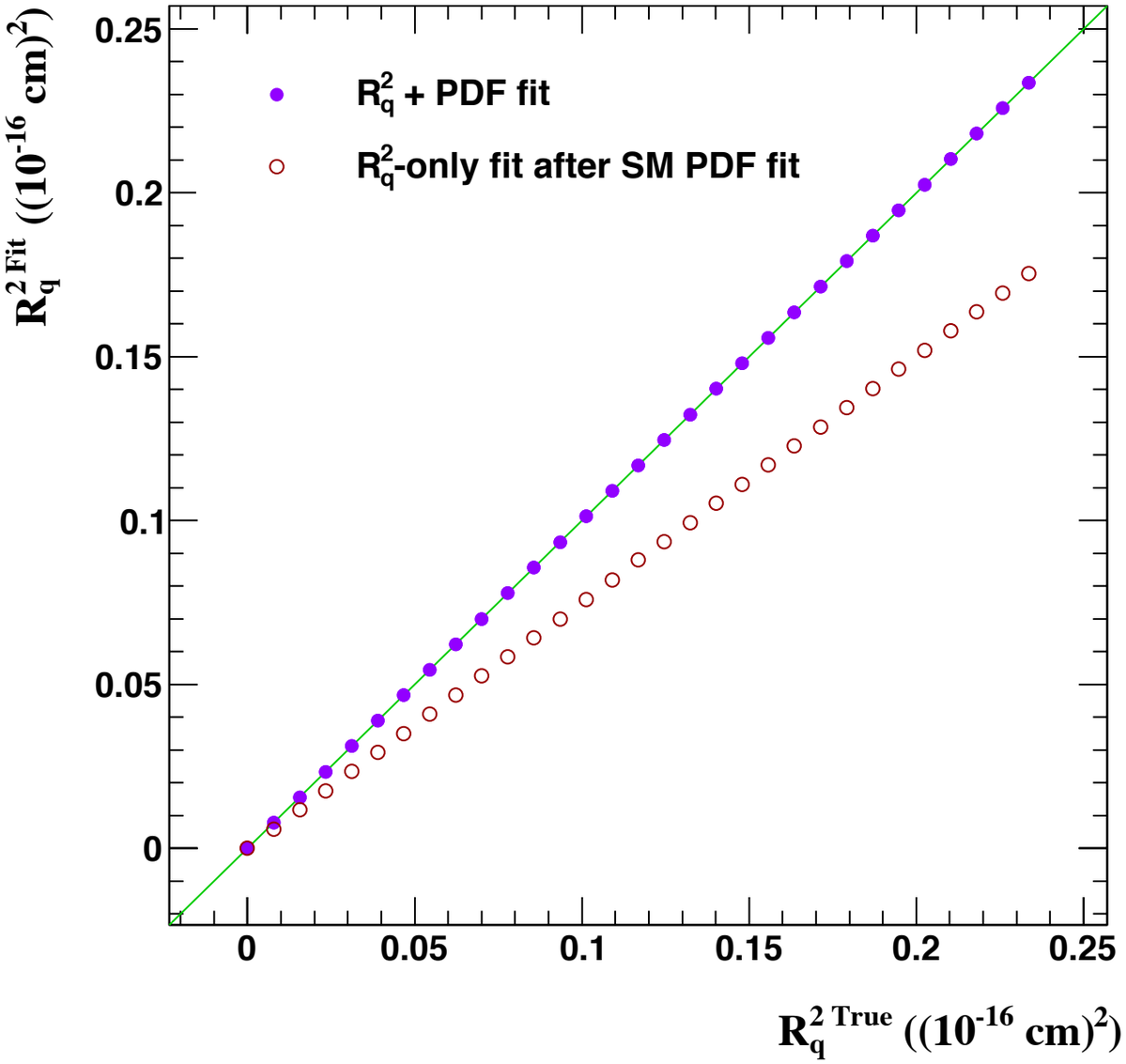
➢ Use of the **biased PDFs** in the BSM analysis would result in **overestimated limits**.

➢ This cannot be avoided for the analysis of HERA data by using another available PDF set, since all high-precision PDF fits include the DIS data from HERA (MMHT2014, NNPDF 3.0, etc.).

➢ The proper procedure for a BSM analysis of the HERA data - global **QCD analysis which includes a possible contribution from BSM** processes.

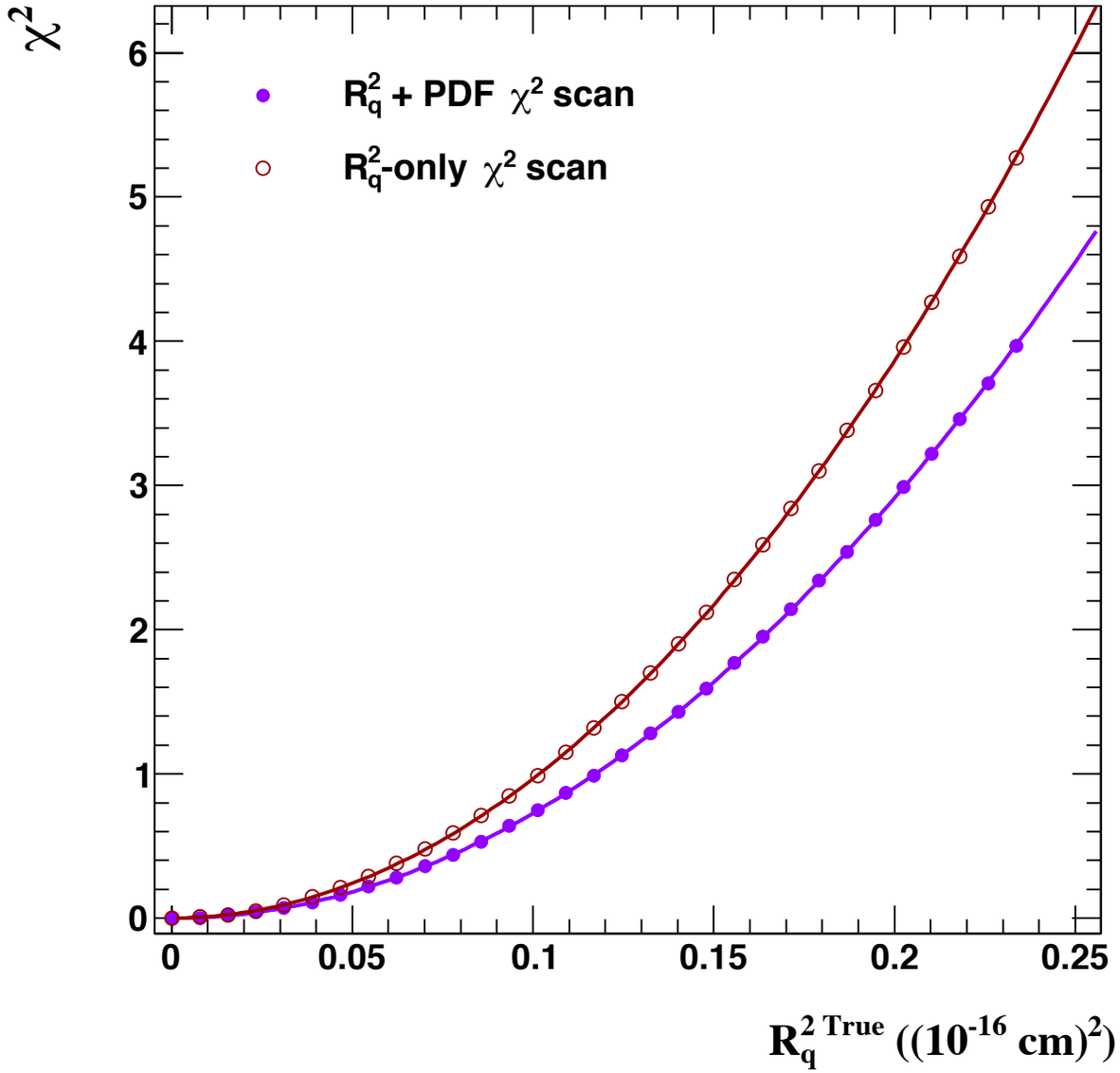
Necessity of the simultaneous fit procedure

Pseudodata generated for values of $R^2_q = R^2_q{}^{True}$



R^2_q+**PDF** procedure provides unbiased results of $R^2_q{}^{Fit}$

Pseudodata generated for value of $R^2_q = 0$



R^2_q**-only** procedure results in too strong limits

Limits setting method

Limits are derived in a frequentist approach using the technique of Monte Carlo replicas. Two procedures were used:

R_q-only Monte Carlo replicas generated for $R^2{}_q^{True}$ using **ZCIPDFs** and $R^2{}_q^{Fit}$ parameter fitted with PDFs **fixed to ZCIPDFs**.

PDF+R_q Monte Carlo replicas generated for $R^2{}_q^{True}$ using **ZCIPDFs** and $R^2{}_q^{Fit}$ parameter fitted **simultaneously** with PDFs.

The **PDF+R_q** frequentist method is the main analysis method.

Monte Carlo replicas

Monte Carlo replicas of the cross-section measurements are calculated with:

Cross-section prediction from the ZCIPDF modified with $R^2{}_q^{True}$

Measured cross-section value

Correlated systematic uncertainties

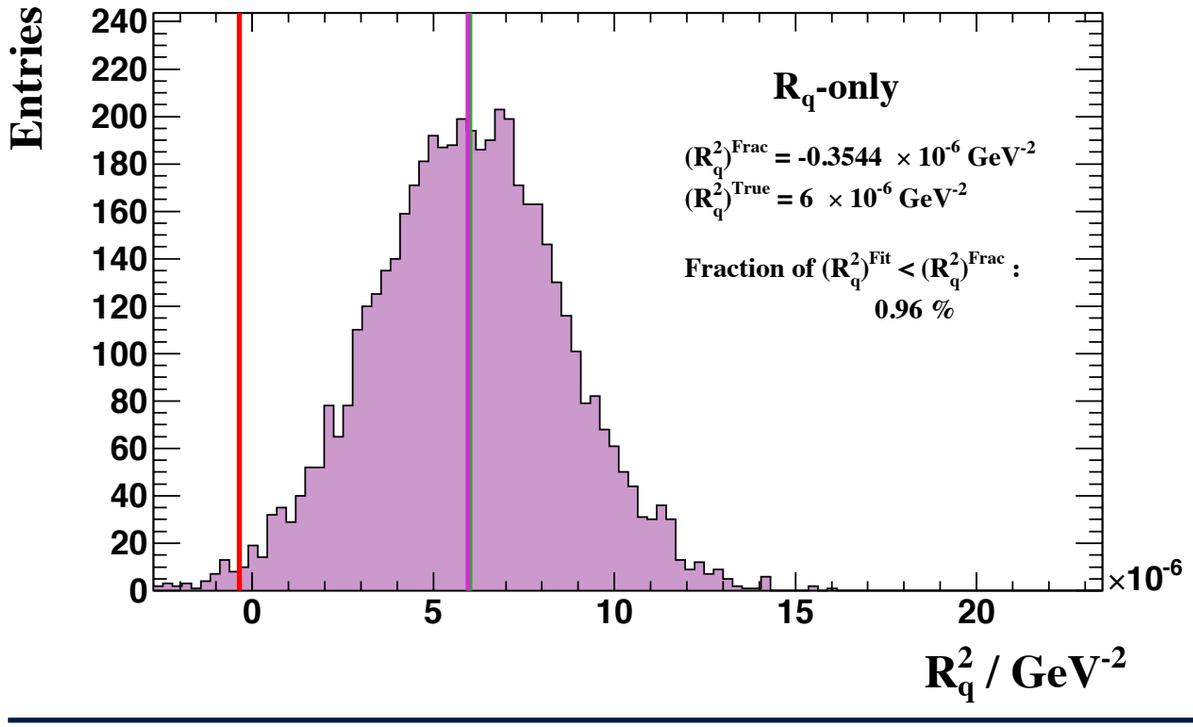
$$\mu^i = \left[m_0^i + \sqrt{\delta_{i,stat}^2 + \delta_{i,uncor}^2} \cdot \mu_0^i \cdot r_i \right] \cdot \left(1 + \sum_j \gamma_j^i \cdot r_j \right)$$

Relative statistical and uncorrelated systematic uncertainties

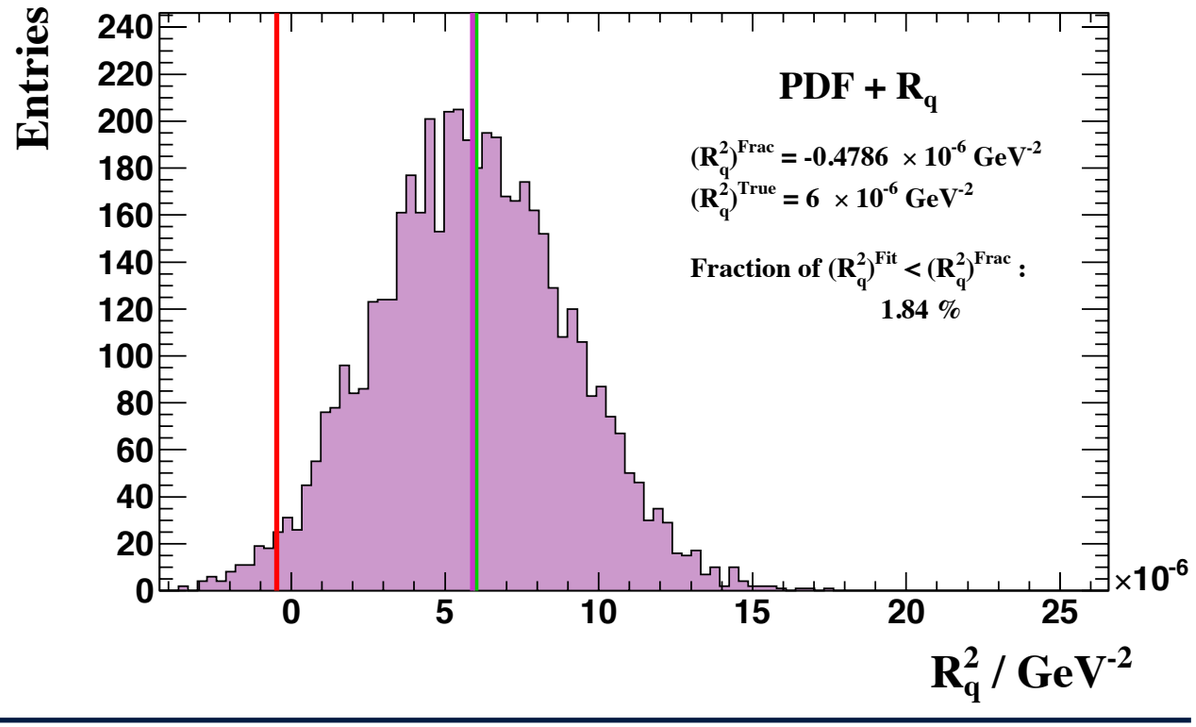
Random numbers from a normal distribution

Fitted MC replicas for $\mathbf{R_q^{True} = 0.48 \cdot 10^{-16}\ cm}$:

R_q-only

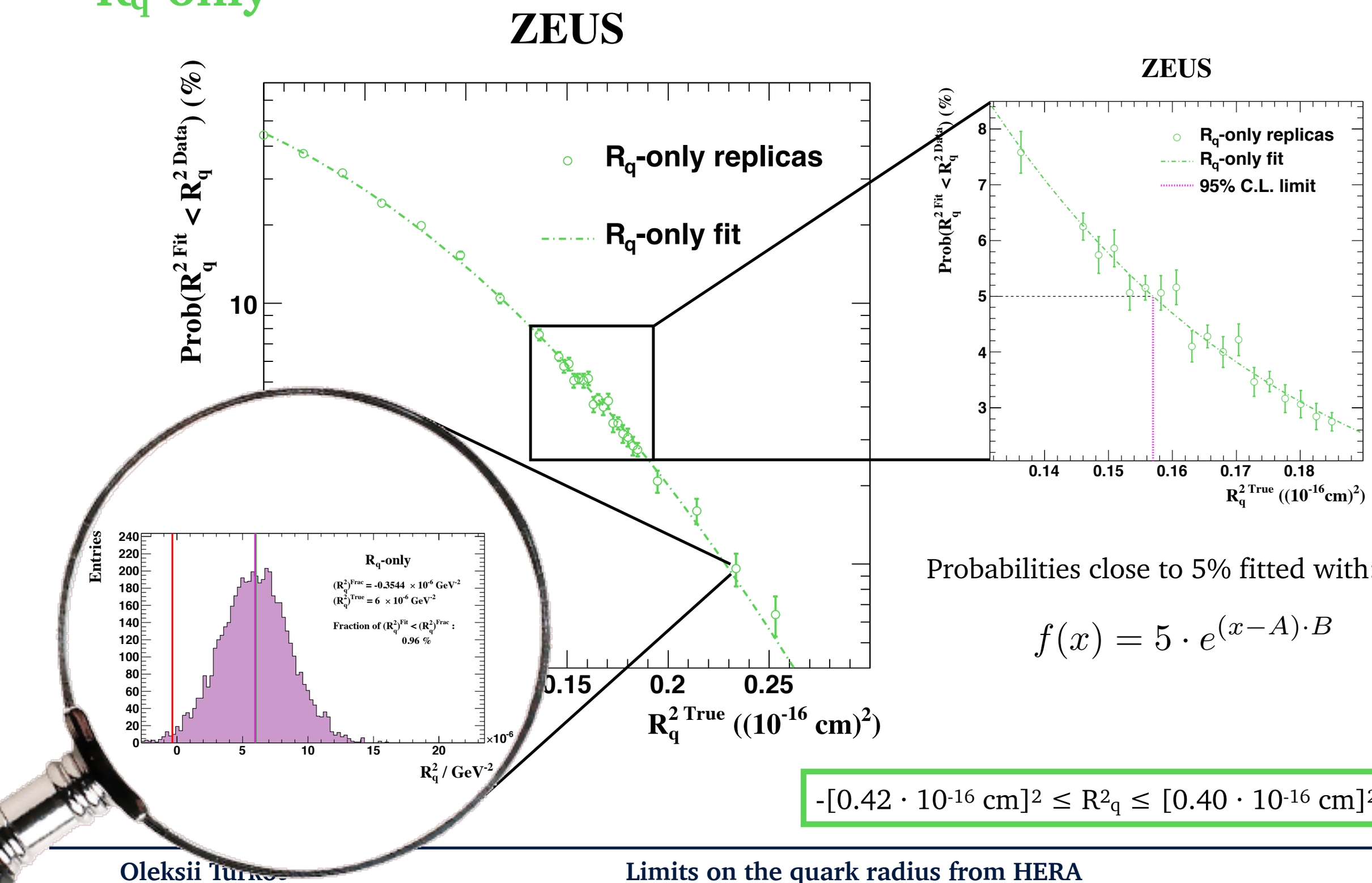


PDF + R_q



R_q limits with the MC replicas

R_q-only



Probabilities close to 5% fitted with:

$$f(x) = 5 \cdot e^{(x-A)\cdot B}$$

$$-[0.42 \cdot 10^{-16}\ \text{cm}]^2 \leq R^2_q \leq [0.40 \cdot 10^{-16}\ \text{cm}]^2$$

R_q limits with the MC replicas

PDF + R_q

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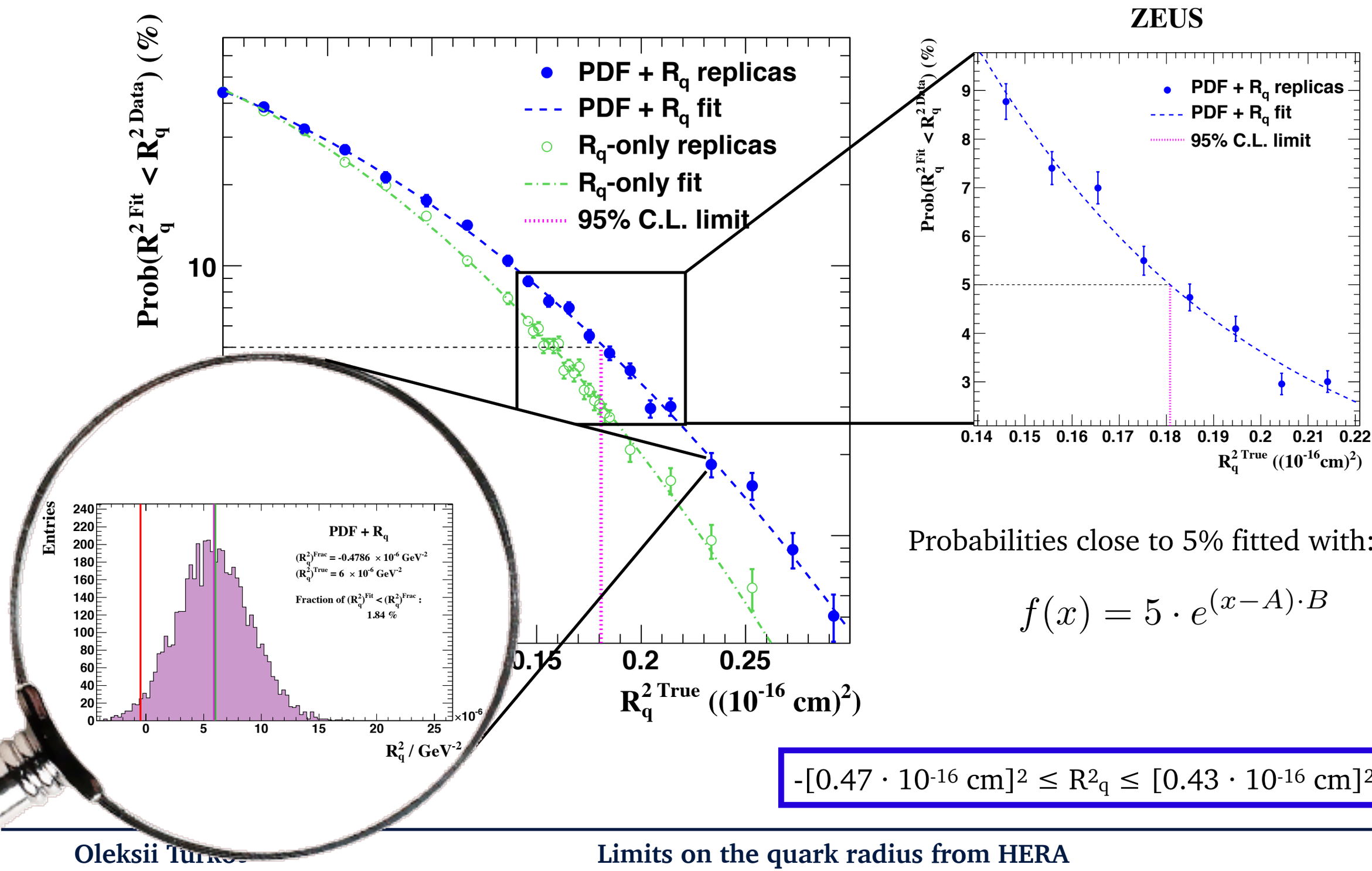


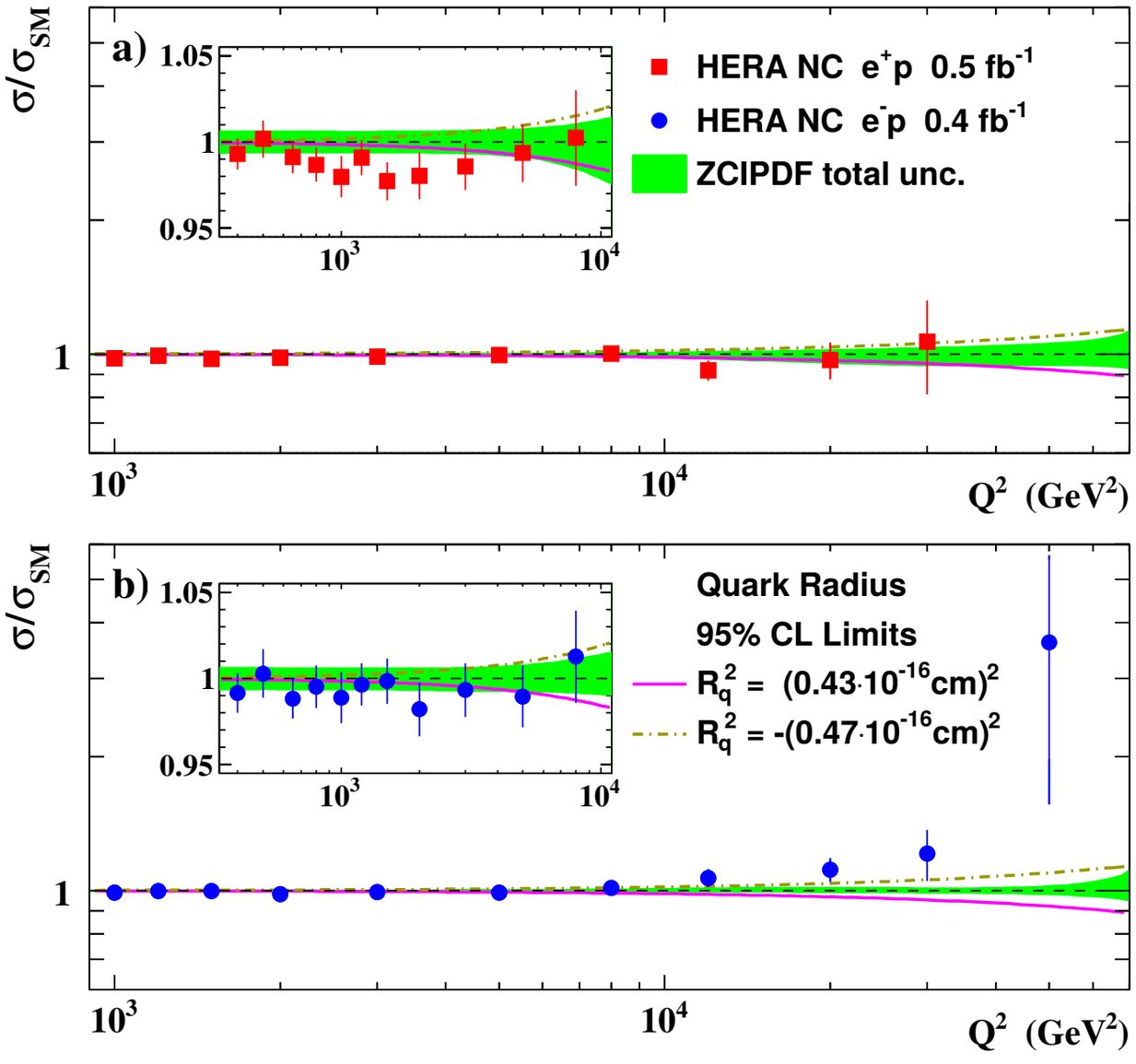
Probabilities close to 5% fitted with:

$$f(x) = 5 \cdot e^{(x-A)\cdot B}$$

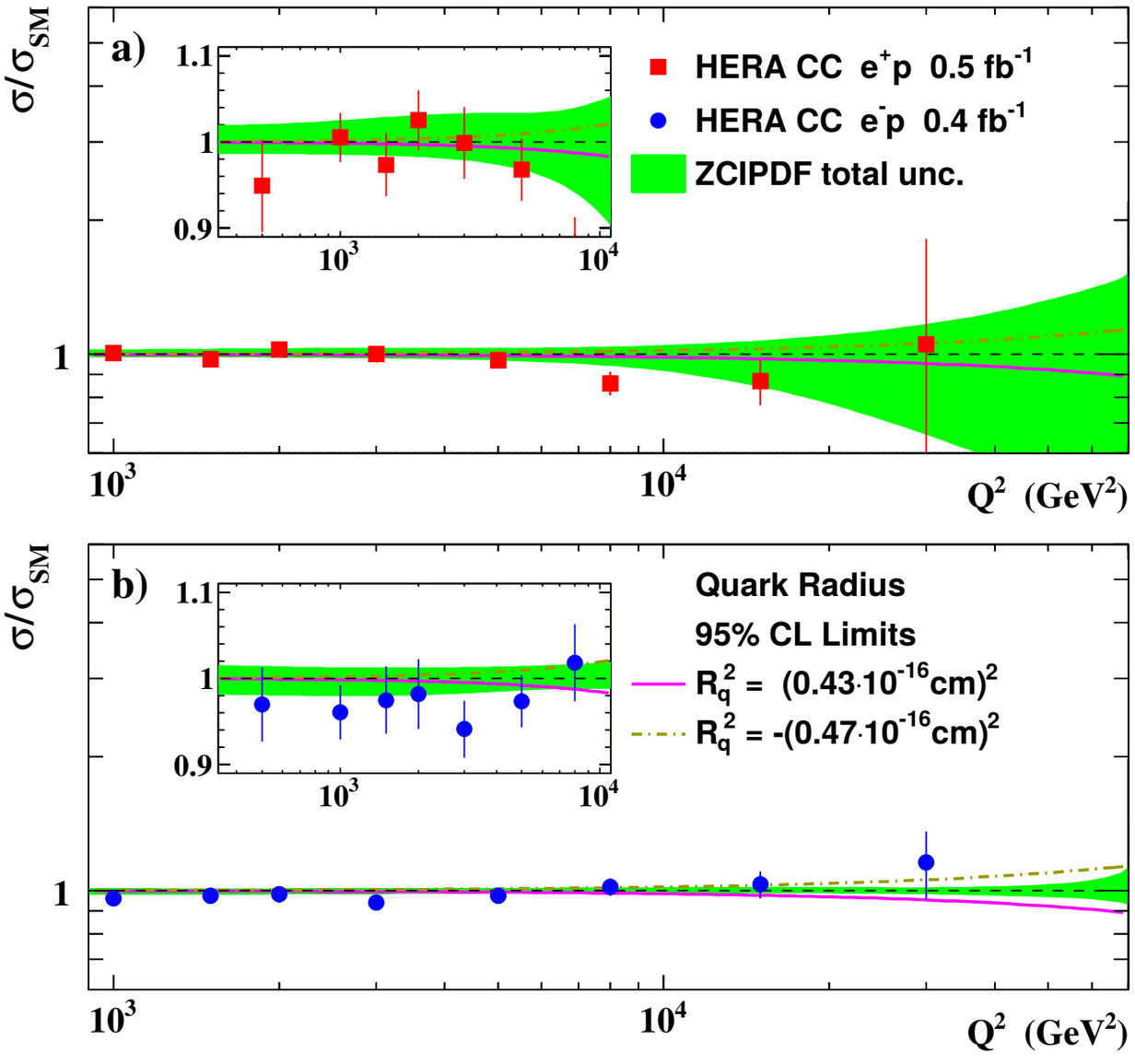
$$-[0.47 \cdot 10^{-16}\ \text{cm}]^2 \leq R^2_q \leq [0.43 \cdot 10^{-16}\ \text{cm}]^2$$

Comparison to Data

Neutral Current:



Charged Current:



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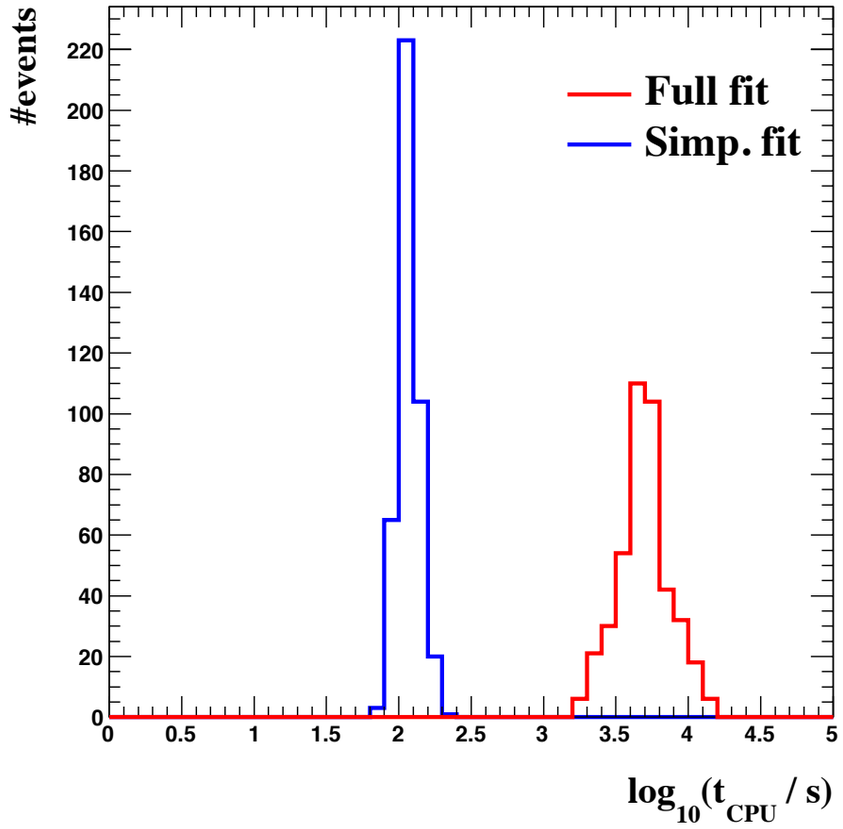
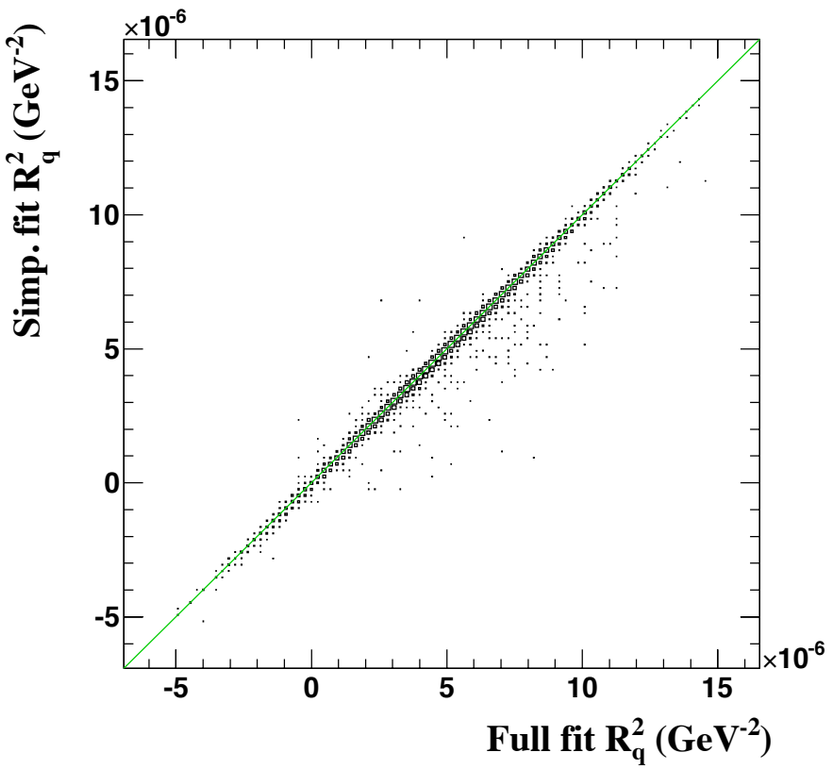
Simplified fit procedure

On average every CI+PDF fit takes **~1.5 hours** of the cpu time.
For the final R_q analysis about 215 000 replicas were fitted, taking **~36.8** years of the cpu time.
To proceed with other BSM models a simplified fit procedure based on the approximation of the cross-section predictions with a Taylor expansion have been developed and implemented, reducing the average fit duration to **~2 minutes** of the cpu time.

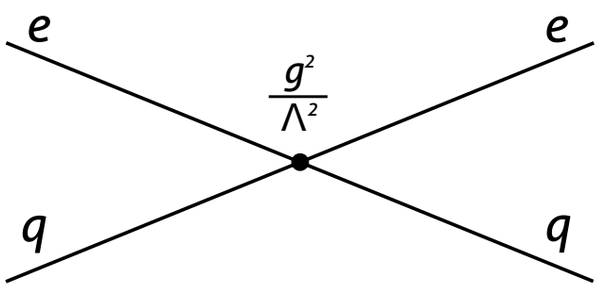
For $R_q = 0.43 \cdot 10^{-16}$ cm:





Contact interactions

Four-fermion eeqq contact interactions provide a convenient method to search for possible effects due to the virtual exchange of new particles with mass much higher than the centre-of-mass energy.



$$\mathcal{L}_{\mathrm{CI}} = \sum_{\substack{k,j=L,R \\ q=u,d,s,c,b}} \eta^{eq}_{kj} (\bar{e}_k \gamma^\mu e_k)(\bar{q}_j \gamma_\mu q_j)$$

$$\eta^{eq}_{kj} = \epsilon^{eq}_{kj} \frac{g^2}{\Lambda^2}$$

$$\epsilon^{eq}_{kj} = \pm 1; 0$$

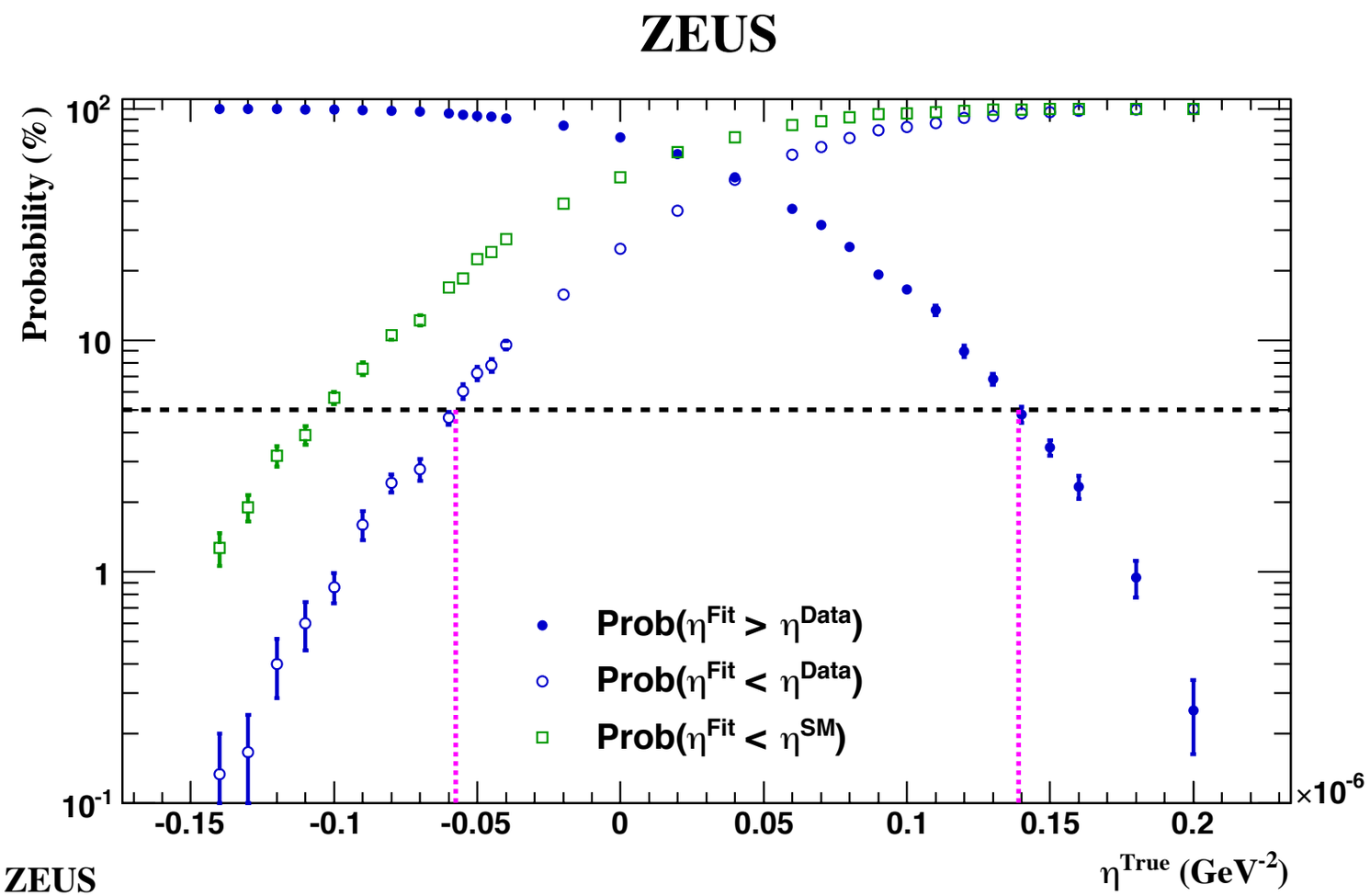
Models considered for ZEUS preliminary:

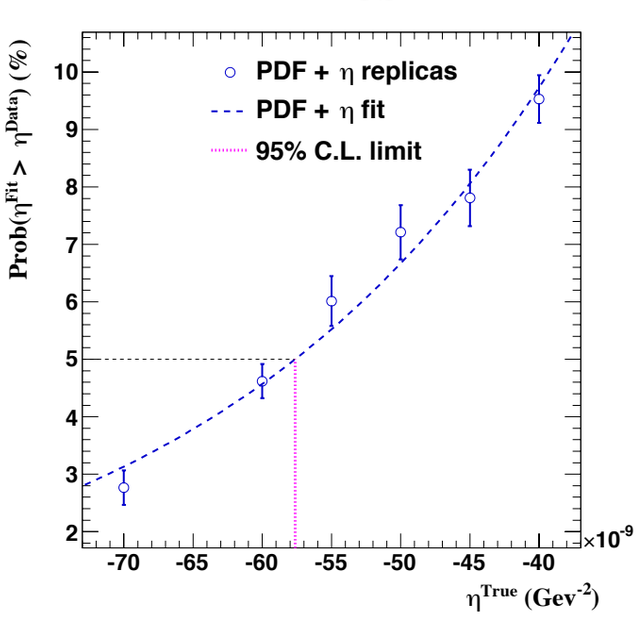
Model	η^{eq}_{LL}	η^{eq}_{LR}	η^{eq}_{RL}	η^{eq}_{RR}
LL	$+\eta$			
RR				$+\eta$
VV	$+\eta$	$+\eta$	$+\eta$	$+\eta$
AA	$+\eta$	$-\eta$	$-\eta$	$+\eta$
VA	$+\eta$	$-\eta$	$+\eta$	$-\eta$
X1	$+\eta$	$-\eta$		
X2	$+\eta$		$+\eta$	
X4		$+\eta$	$+\eta$	

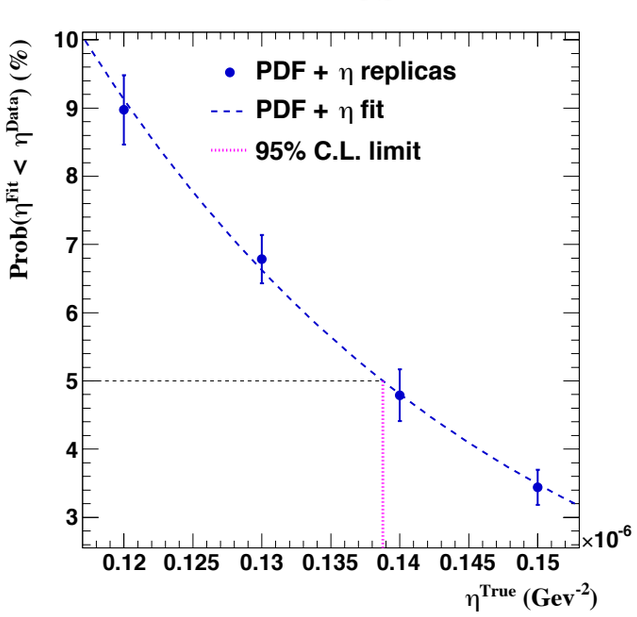
Contact interactions

Following the approach from the R_q analysis:

VV model
(highest sensitivity)







Evaluated 95% C.L. limits:

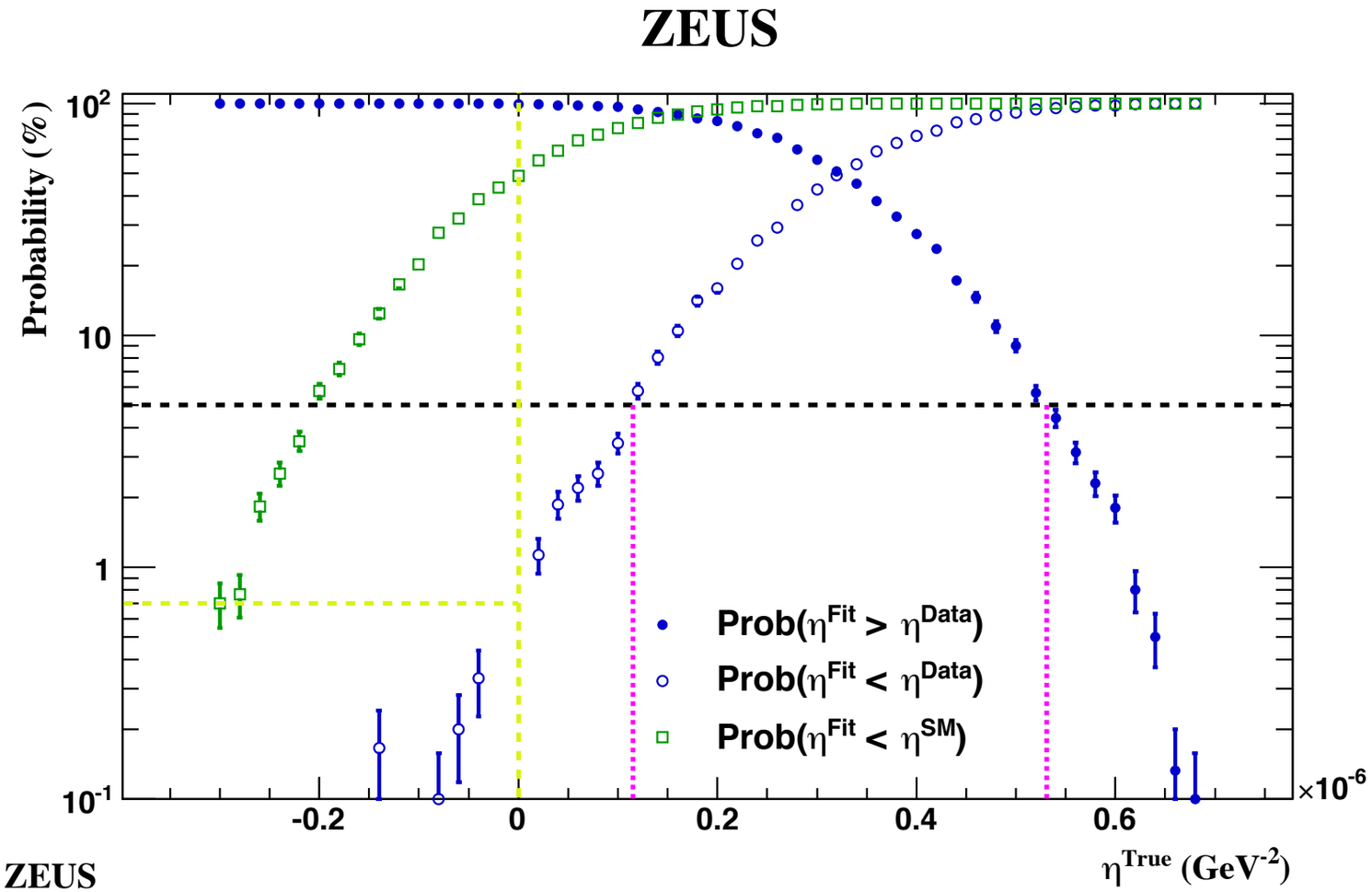
$-5.8 \cdot 10^{-8}$ GeV^{-2} < η < $13.9 \cdot 10^{-8}$ GeV^{-2}

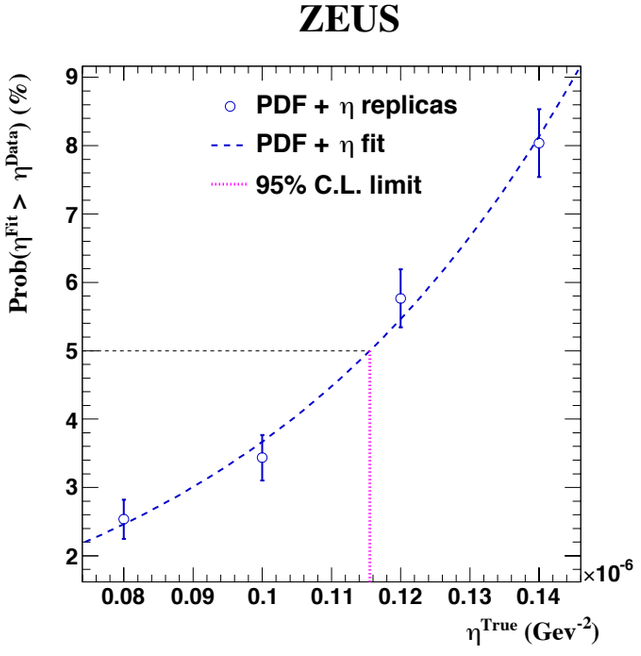
$\Lambda^- > 14.7$ TeV $\Lambda^+ > 9.5$ TeV

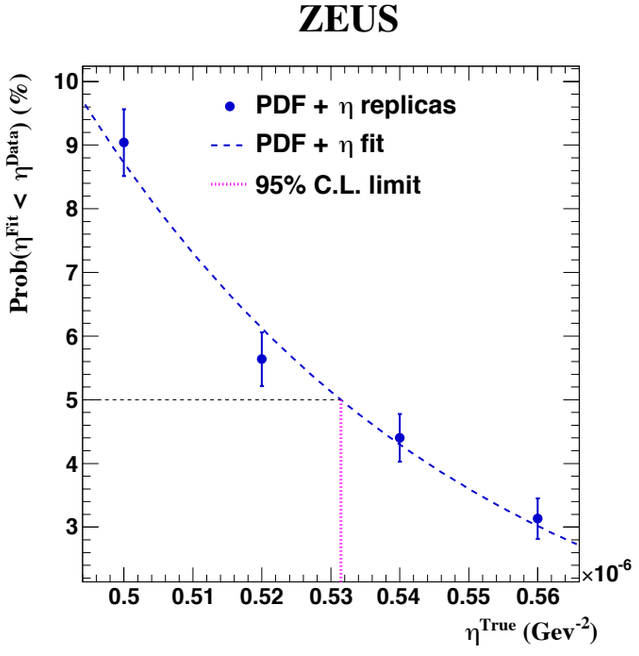
Contact interactions

Following the approach from the R_q analysis:

AA model
(deviation from SM 2.5σ)





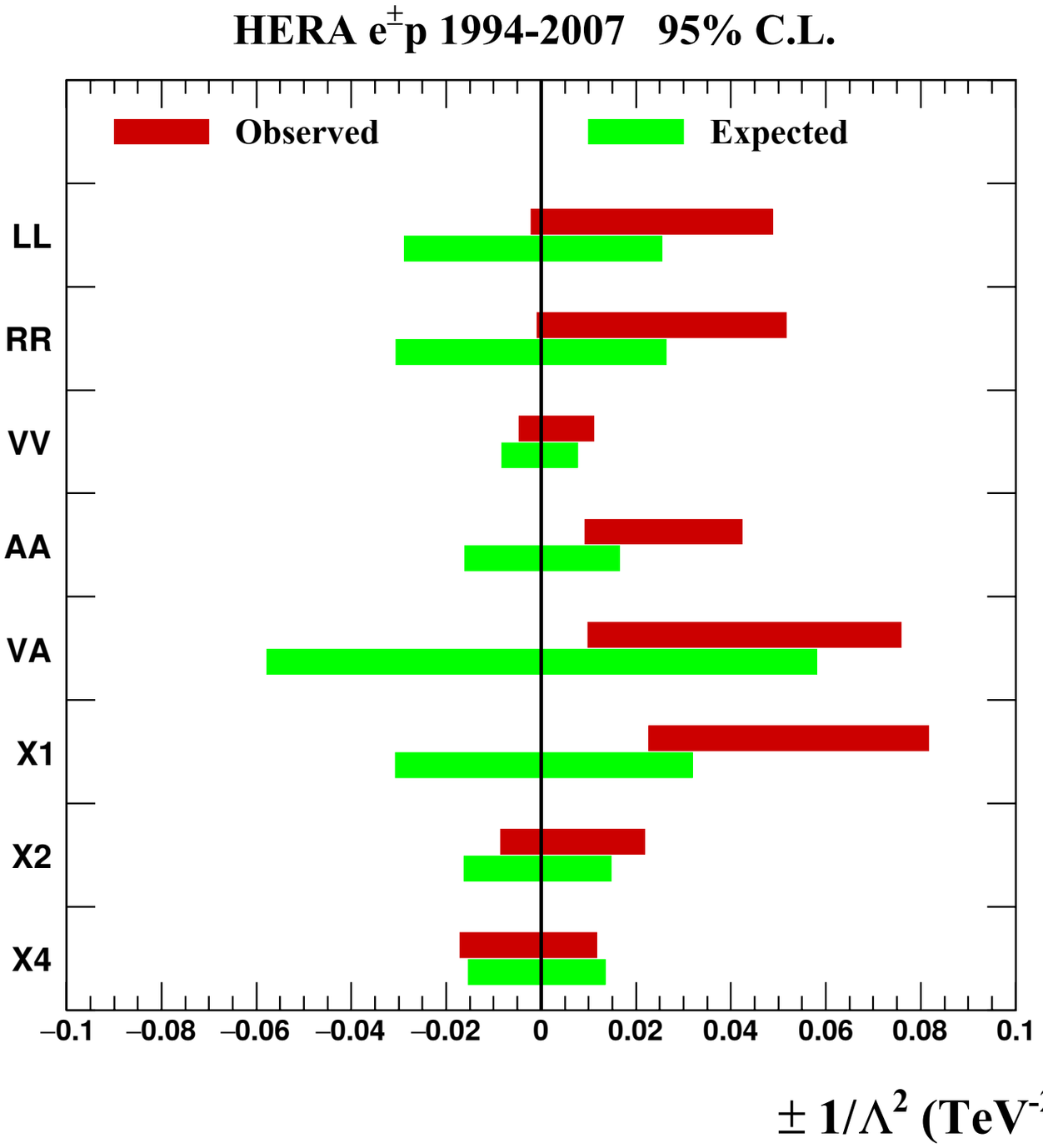


Evaluated 95% C.L. limits:

$11.6 \cdot 10^{-8}$ GeV^{-2} < η < $53.1 \cdot 10^{-8}$ GeV^{-2}

$\Lambda^+ < 10.4$ TeV $\Lambda^+ > 4.8$ TeV

Evaluated CI limits



95% C.L. limits (TeV)					
	Measured		Expected		pSM [%]
	Λ⁻	Λ⁺	Λ⁻	Λ⁺	
LL	22.0	4.5	5.9	6.2	6.5
RR	32.9	4.4	5.7	6.1	5.6
VV	14.7	9.5	11.0	11.4	24.8
AA	-	4.8 - 10.4	7.9	7.8	0.7
VA	-	3.6 - 10.1	4.1	4.1	2.1
X1	-	3.5 - 6.6	5.7	5.6	0.3
X2	10.8	6.8	7.8	8.2	23.1
X4	7.6	9.2	8.0	8.6	60.3

Analysis team

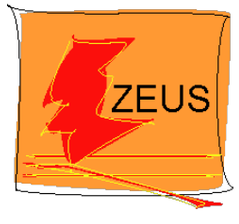
At the moment there are 5 ZEUS people working on the analysis - 3 from the quark-radius and preliminary contact interactions analyses:

Aleksander Filip Żarnecki

Katarzyna Wichmann

Oleksii Turkot

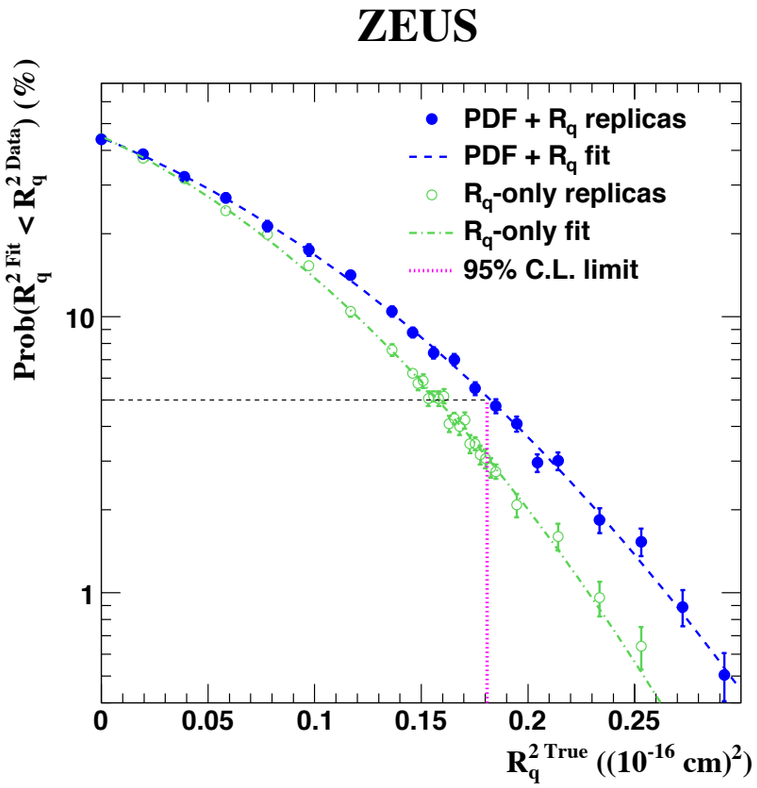
And 2 new active bachelor students:



Ivan Pidhurskyi

Mykyta Shchedrolosiev

Summary



➤ Combined HERA inclusive DIS cross-section measurements allow BSM searches up to TeV scales.

➤ The simultaneous analysis of PDFs and quark form factor yield the 95% C.L. limits of the effective quark radius of

$$-[0.47 \cdot 10^{-16}\ \text{cm}]^2 \leq R^2_q \leq [0.43 \cdot 10^{-16}\ \text{cm}]^2$$

➤ The simultaneous analysis is necessary since the limits that would be obtained otherwise are too strong by about 10%.

➤ Some of the contact interactions models provide improved description of the data.

➤ At the moment there are 5 ZEUS people working on the analysis.