QCD & Electroweak @ LHeC: Wishlist for studies

- ✔ SM Higgs and top production physics potential
- ✔ Expected electroweak parameters precision (need to know polarisation)
- ✔ **PDF** precisions:
  - ✔ Inclusive DIS: further refined & alternative estimates (from other PDF fitter groups)
  - ✔ Direct proton gluon density determinations from jets (high x), charm (low x)
  - ✔ Clarification of transition from massive to massless regime for charm and beauty
- ✔ alpha_s from jets (exploiting NNLO calculations)
- ✔ QCD dynamics and PDFs from final states: jets, heavy flavours, prompt photons, DVCS, vector mesons, diffraction
- ✔ Look for QCD expected, special or novel features: *BFKL – forward jets at low x, intrinsic charm, instantons*
- ✔ **For all studies: matched to expected (refined) detector acceptance, energy, momentum & vertexing resolutions ... and accelerator energy & lumi prospects**

Physics @ the LHeC

Summary report of Elektroweak and precision QCD group

Olaf Behnke, Paolo Gambino, Thomas Gehrmann

LHeC workshop, Divonne, 2. Sep 2008

Electroweak & QCD Wishlist for LheC

WW-> Higgs

Precise electroweak couplings aq,vq

alpha_s @ ~1% precision

u/d for x --> 1

g(x) for x>0.1

intrinsic c,b,t x>0.1?

Effective b-density at x=0.01

XF3 valence quarks down to small x

Direct s(x)

Precise Fl and g(x) at low x

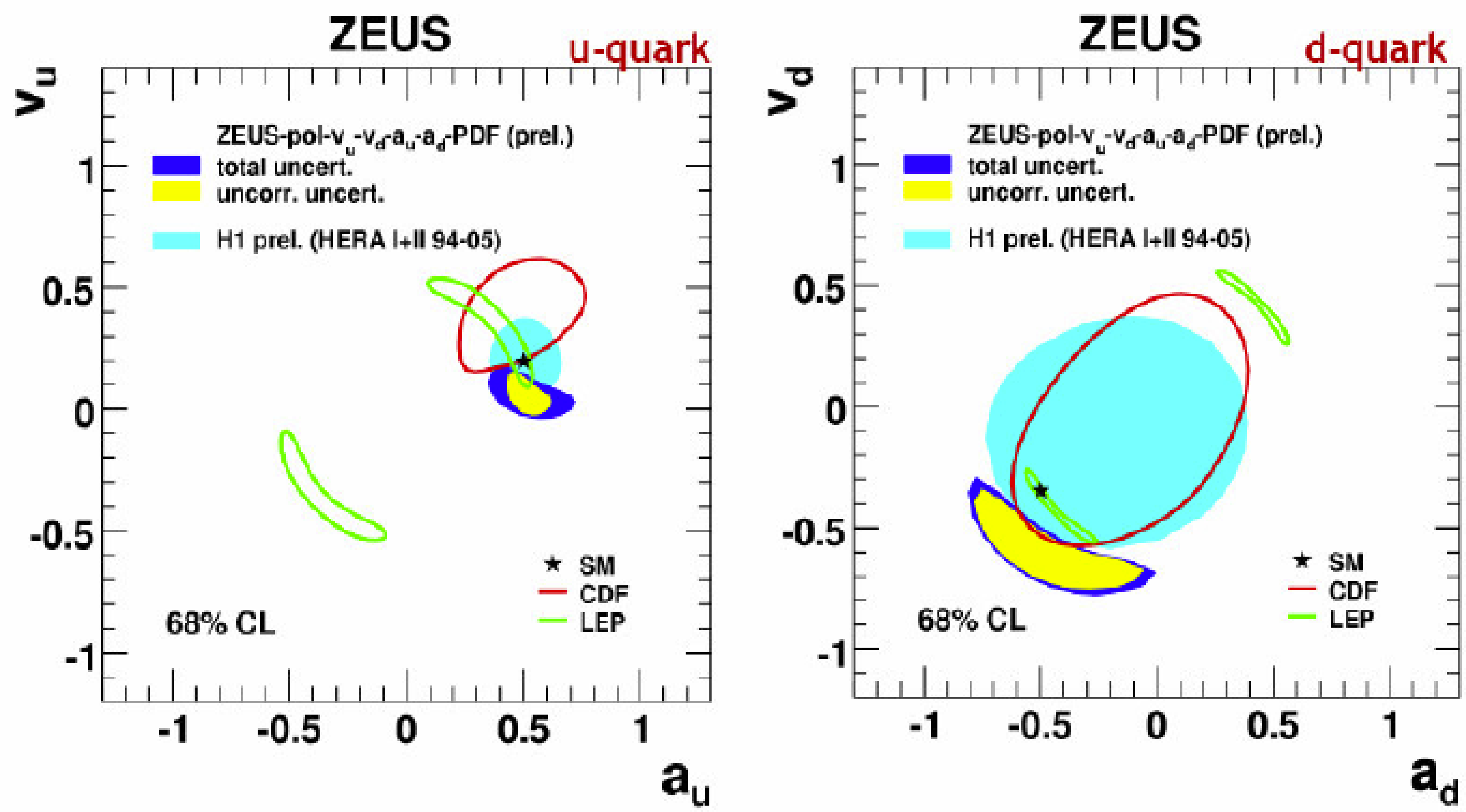
+much much many more...

NC couplings to light quarks

Degrassi

unpol: $\sigma(e^+) - \sigma(e^-) \quad \rightarrow \quad a_e\, k_Z\, xF_3^{\gamma Z} \propto e_q a_q$

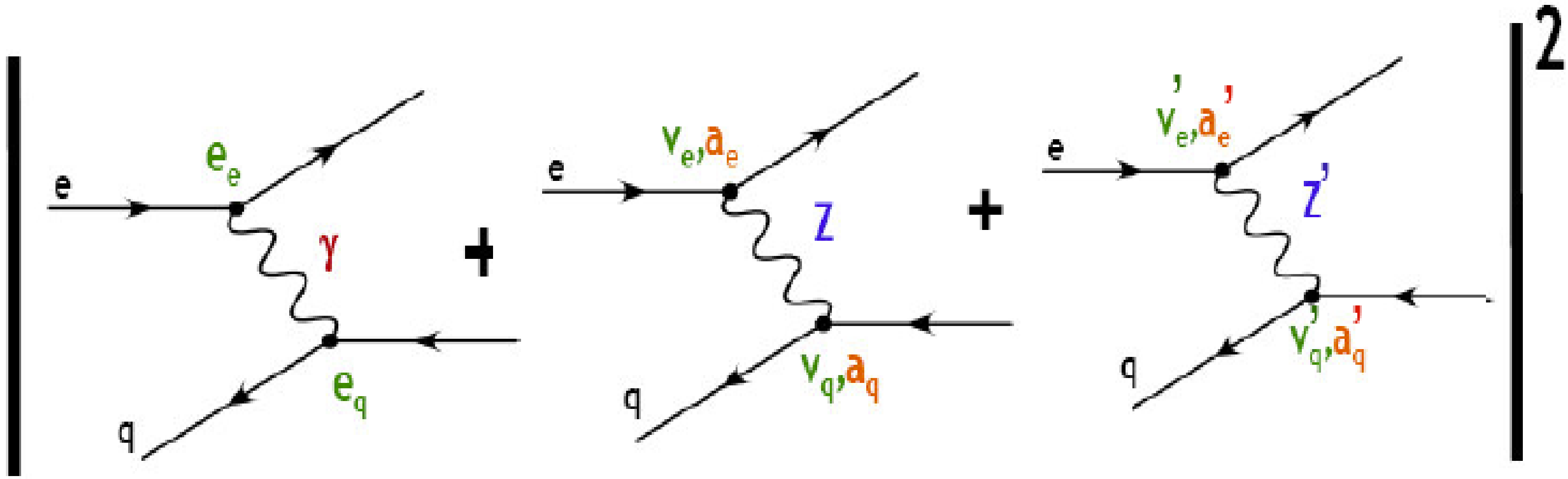
pol: $\sigma(P_R) - \sigma(P_L) \quad \rightarrow \quad a_e\, k_Z\, F_2^{\gamma Z} \propto e_q v_q$



Improvements: $v_q \rightarrow$ polarization
$a_q \rightarrow$ luminosity

Z' physics@ LHeC

Degrassi

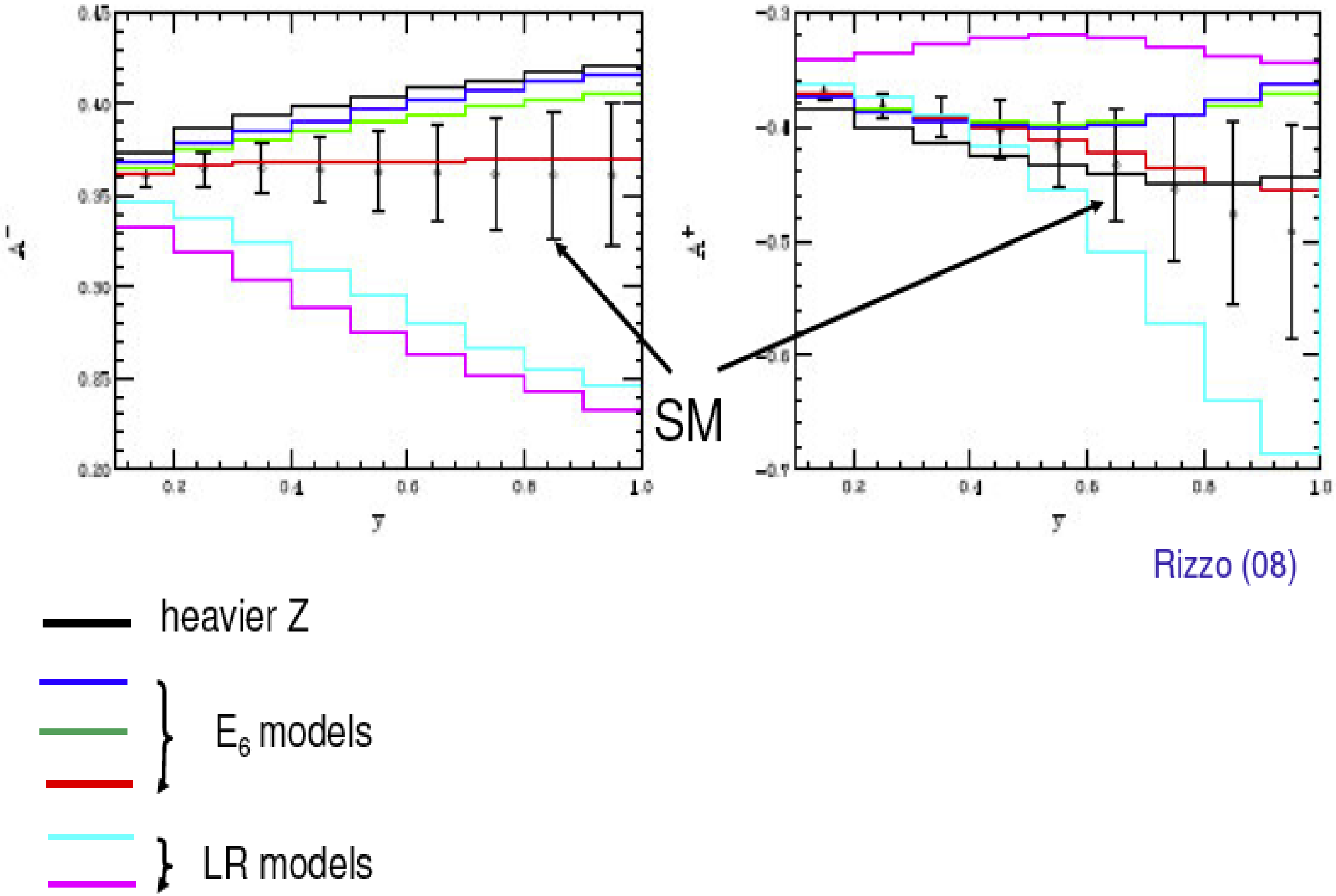


Z' effects can show up in NC asymmetries from the interference with SM contributions

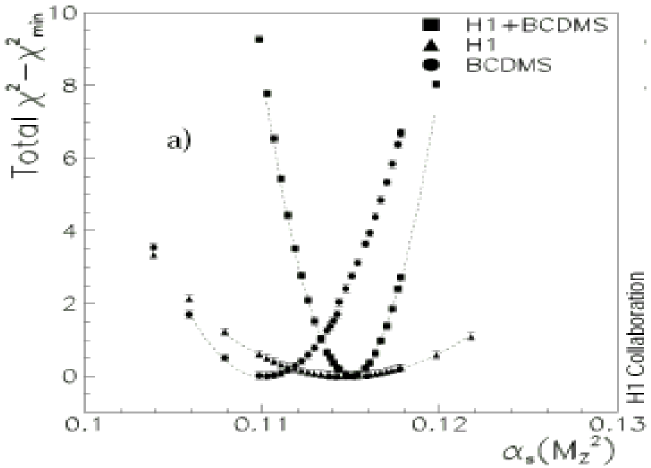
$$A^{\pm} = \frac{2}{P_R - P_L} \frac{\sigma^{\pm}(P_R) - \sigma^{\pm}(P_L)}{\sigma^{\pm}(P_R) + \sigma^{\pm}(P_L)} \approx k_Z \frac{F_2^{\gamma Z}}{F_2^{\gamma}} + k_{Z'} \frac{F_2^{\gamma Z'}}{F_2^{\gamma}} \propto k_Z v_q + k_{Z'} v'_q$$

$$\sqrt{s} = 1.5\ \mathrm{TeV},\ M_{Z'} = 1.2\ \mathrm{TeV},\ x \geq 0.25,\ y \geq 0.$$

Degrassi



Ultraprecise alpha_s from inclusive DIS @ LHeC



Kluge

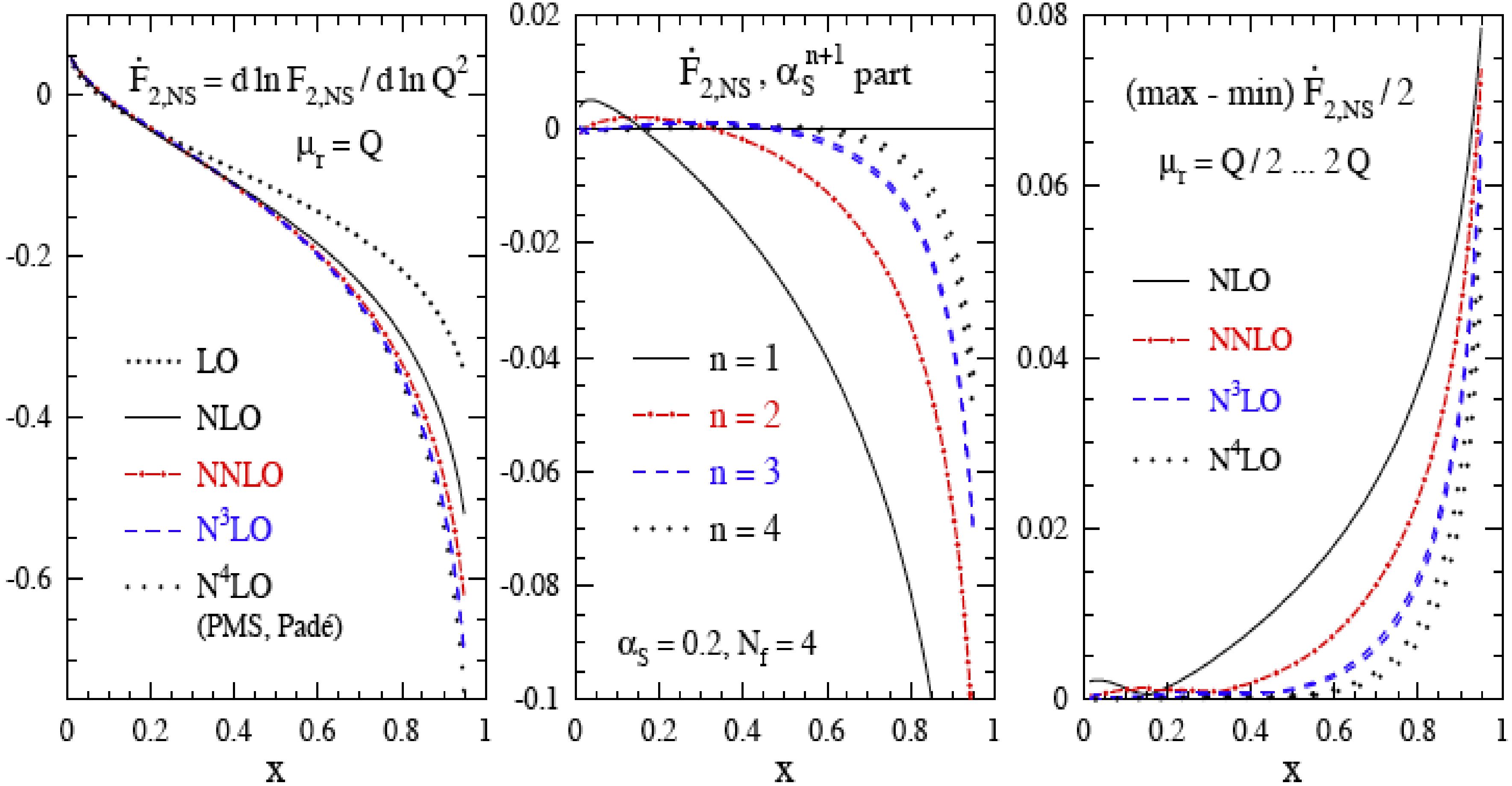
LheC Expectations:

DATA	exp. error on α_s
NC e^+ only	0.48%
NC	0.41%
NC & CC	**0.23% :=$^{(1)}$**
(1) $\gamma_h > 5°$	0.36% :=$^{(2)}$
(1) +BCDMS	0.22%
(2) +BCDMS	0.22%
(1) stat. *= 2	0.35%

Scaling violations of non-singlet part of F_2

Vogt

Large-x ($\gtrsim 10^{-2}$) convergence of P series: effect. N^{3}LO scaling violations



Gold plated alpha_s: ~1% scale uncertainty

Ultraprecise alpha_s from inclusive DIS @ LHeC

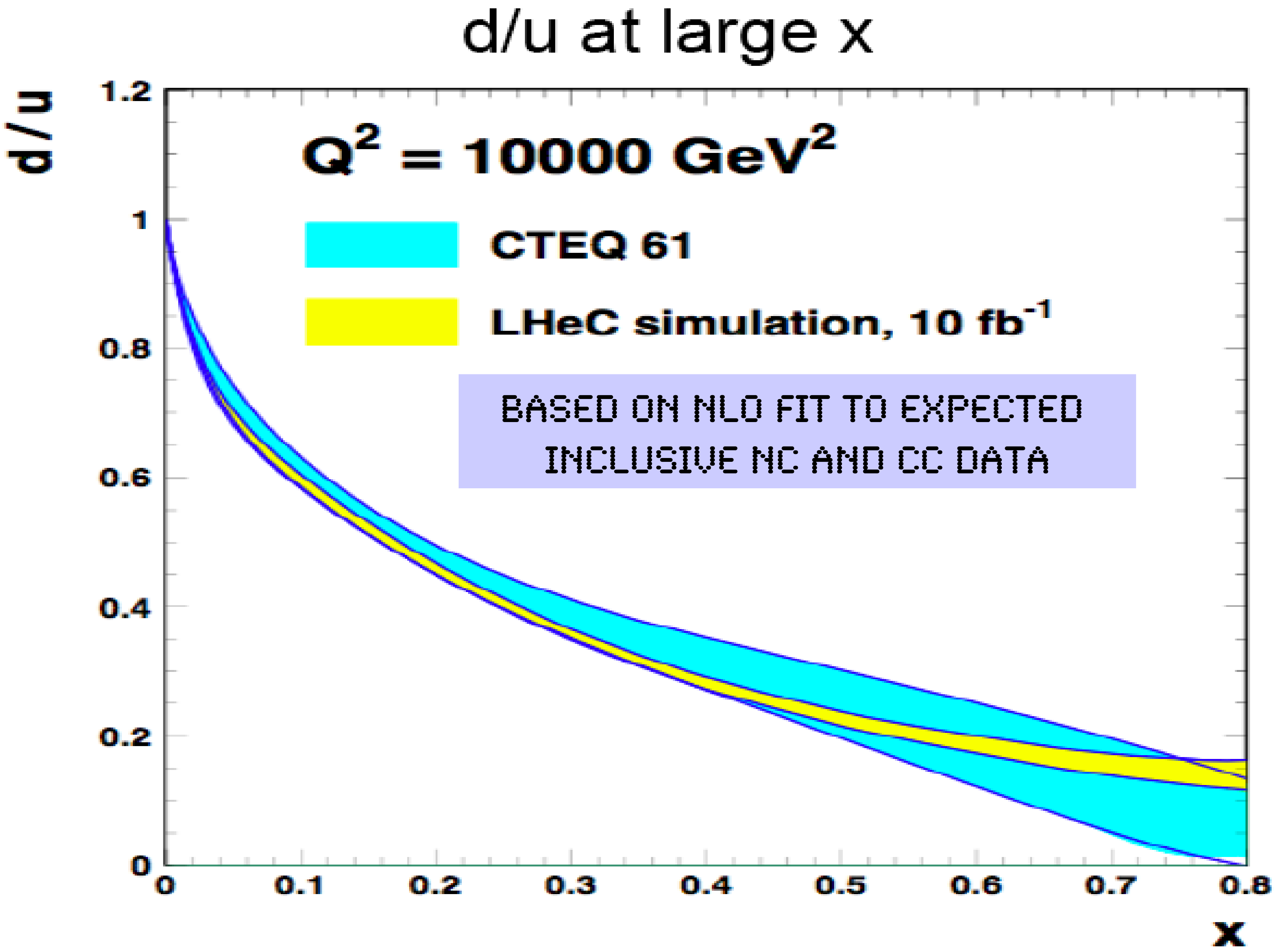
Theory model uncertainties: need to **beat them down**

analysis uncertainty	$+\delta\ \alpha_s$	$-\delta\ \alpha_s$
$Q^2_{min} = 2$ GeV^2		0.00002
$Q^2_{min} = 5$ GeV^2	0.00016	
parameterisations	0.00011	
$Q^2_0 = 2.5$ GeV^2	0.00023	
$Q^2_0 = 6$ GeV^2		0.00018
$y_e < 0.35$	0.00013	
$x < 0.6$	0.00033	
$y_\mu > 0.4$	0.00025	
$x > 5 \cdot 10^{-4}$	0.00051	
uncertainty of $\overline{u} - \overline{d}$	0.00005	0.00005
strange quark contribution $\epsilon = 0$	0.00010	
$m_c + 0.1$ GeV	0.00047	
$m_c - 0.1$ GeV		0.00044
$m_b + 0.2$ GeV	0.00007	
$m_b - 0.2$ GeV		0.00007
total uncertainty	0.00088	0.00048

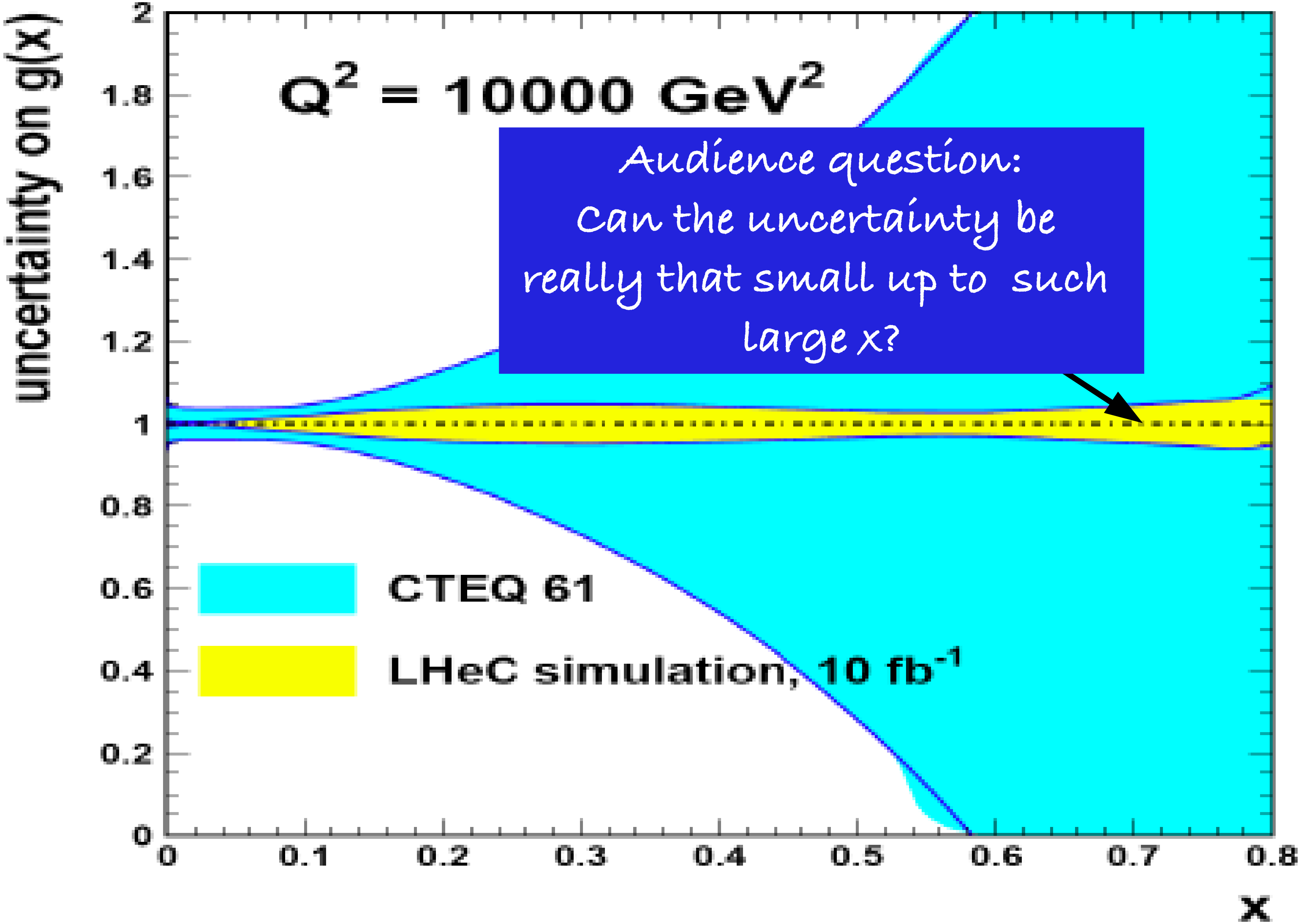
Kluge

Amongst others also to please Frank Wilczek

Klein, Perez



g(x) for x>0.1



Klein, Perez

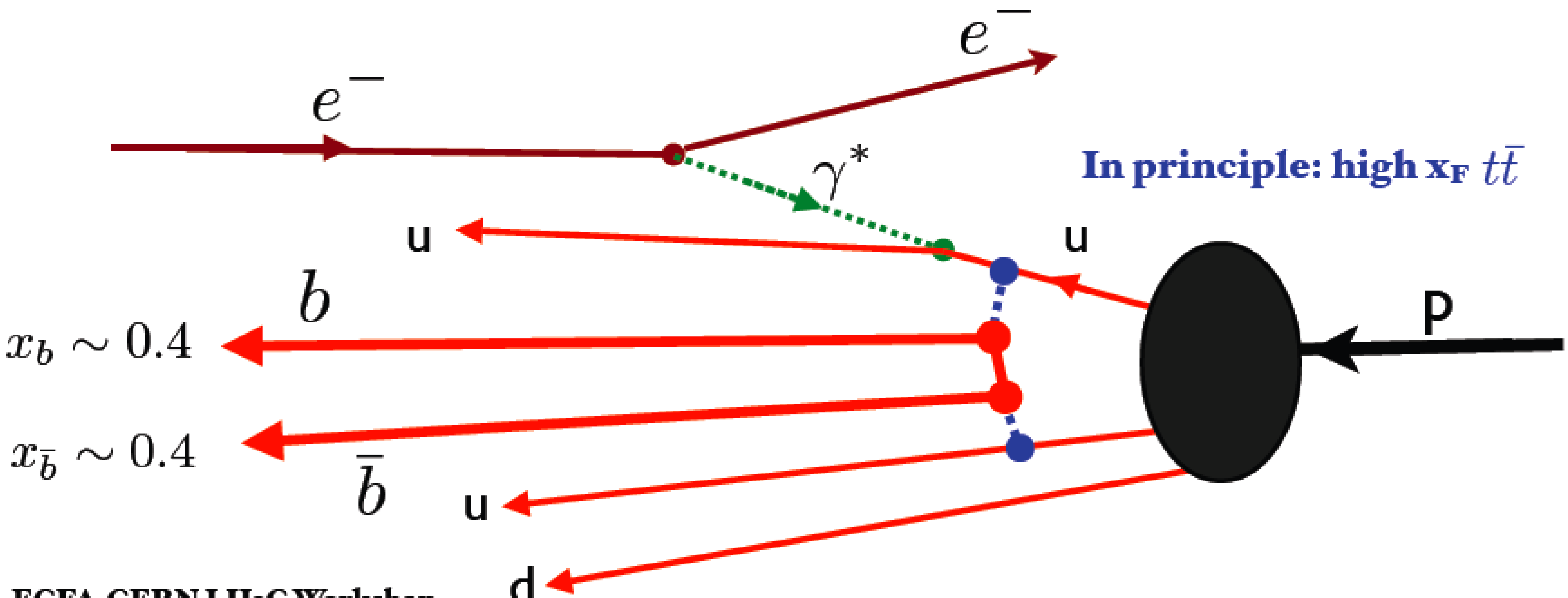
Excitation of Intrinsic Heavy Quarks in Proton

Amplitude maximal at small invariant mass, equal rapidity

$$x_i \sim \frac{m_{\perp i}}{\sum_j^n m_{\perp j}}$$

Produce forward, high x_F
$\Upsilon(b\bar{b}), \Lambda_b(bud), B^+(\bar{b}u), B^0(\bar{b}d)$

Need Forward Small Angle Detection

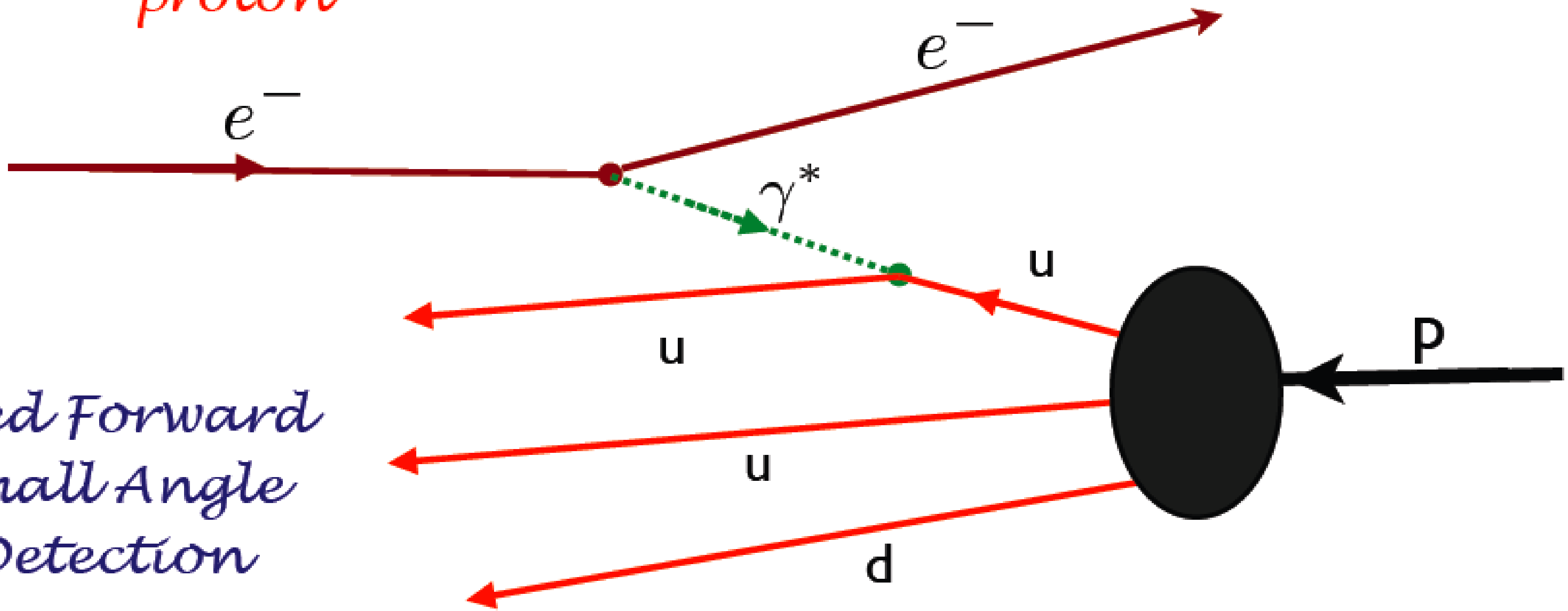


Electromagnetic Tri-Jet Excitation of Proton

$$ep \longrightarrow e \text{ jet jet jet}$$

Measure light-front wavefunction of proton

$$\frac{\partial}{\partial k_\perp} \Psi^p_{n=3}(x_i, \vec{k}_{\perp i}, \lambda_i)$$

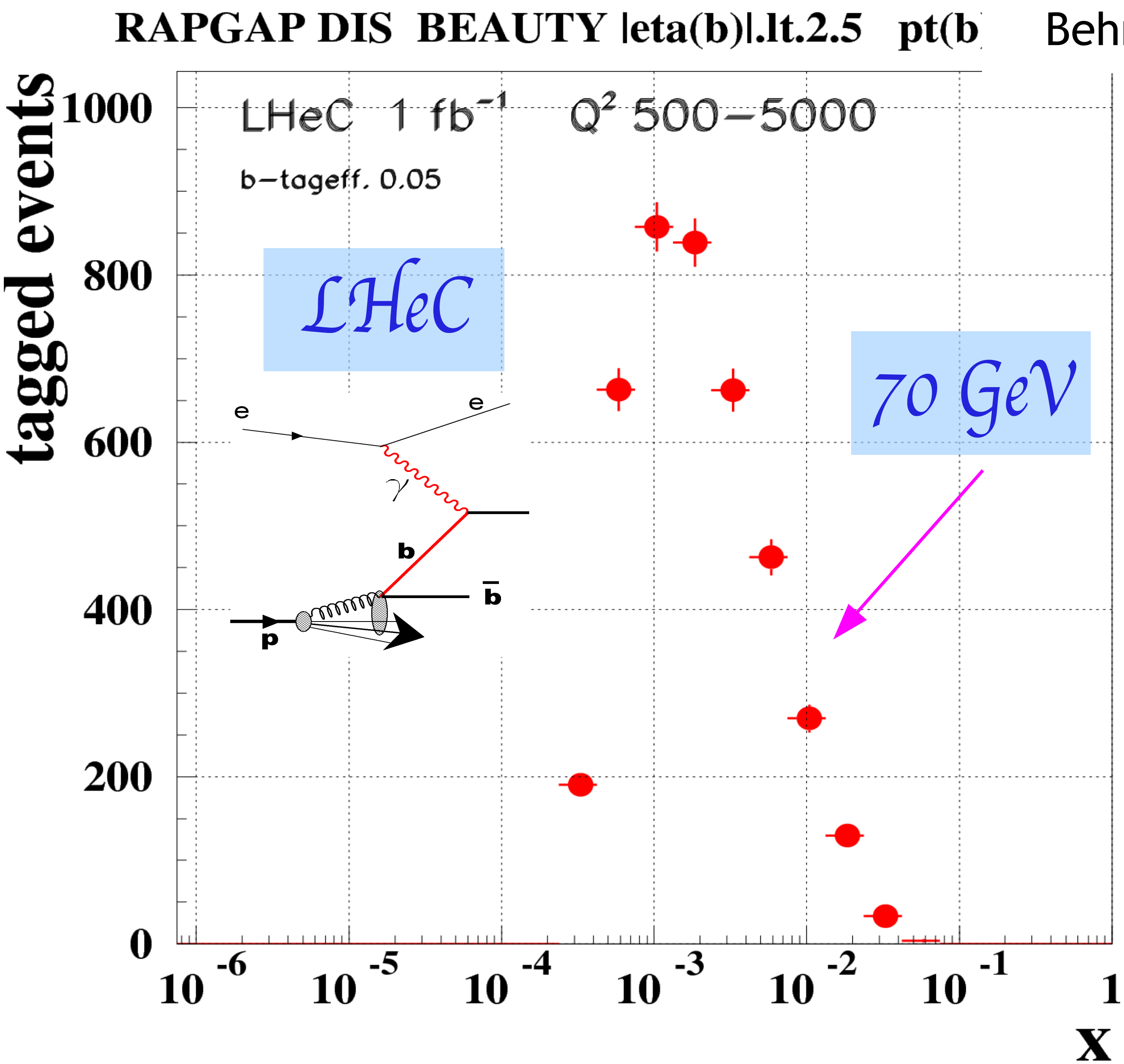


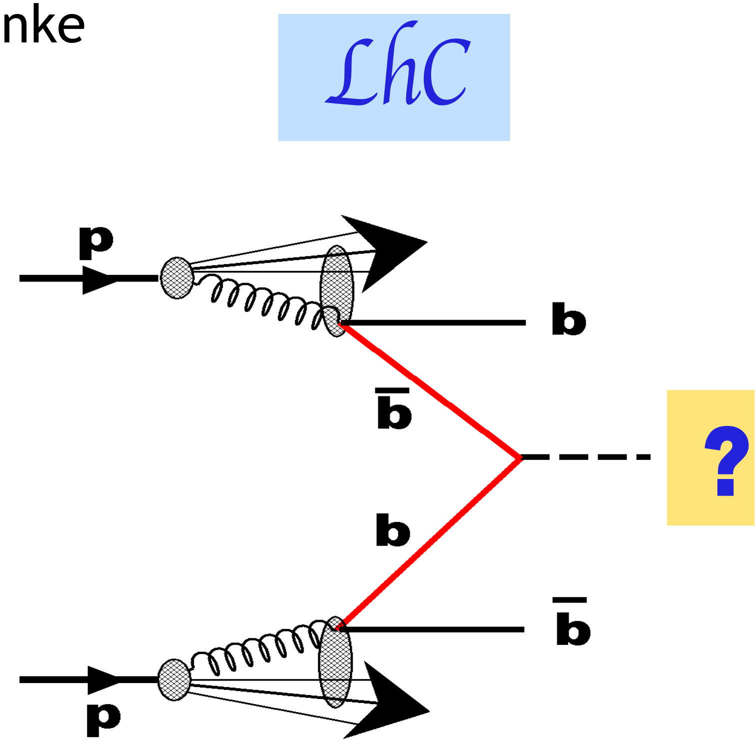
Need Forward Small Angle Detection

Detector expert notes from the physics session

✔ Many noble physics wishes
for x-> 1, dare say this will provide
quite exciting challenges
for (very) forward instrumentation
at the LheC
(acceptance, fine granularity,
energy flow, heavy flavour tagging)

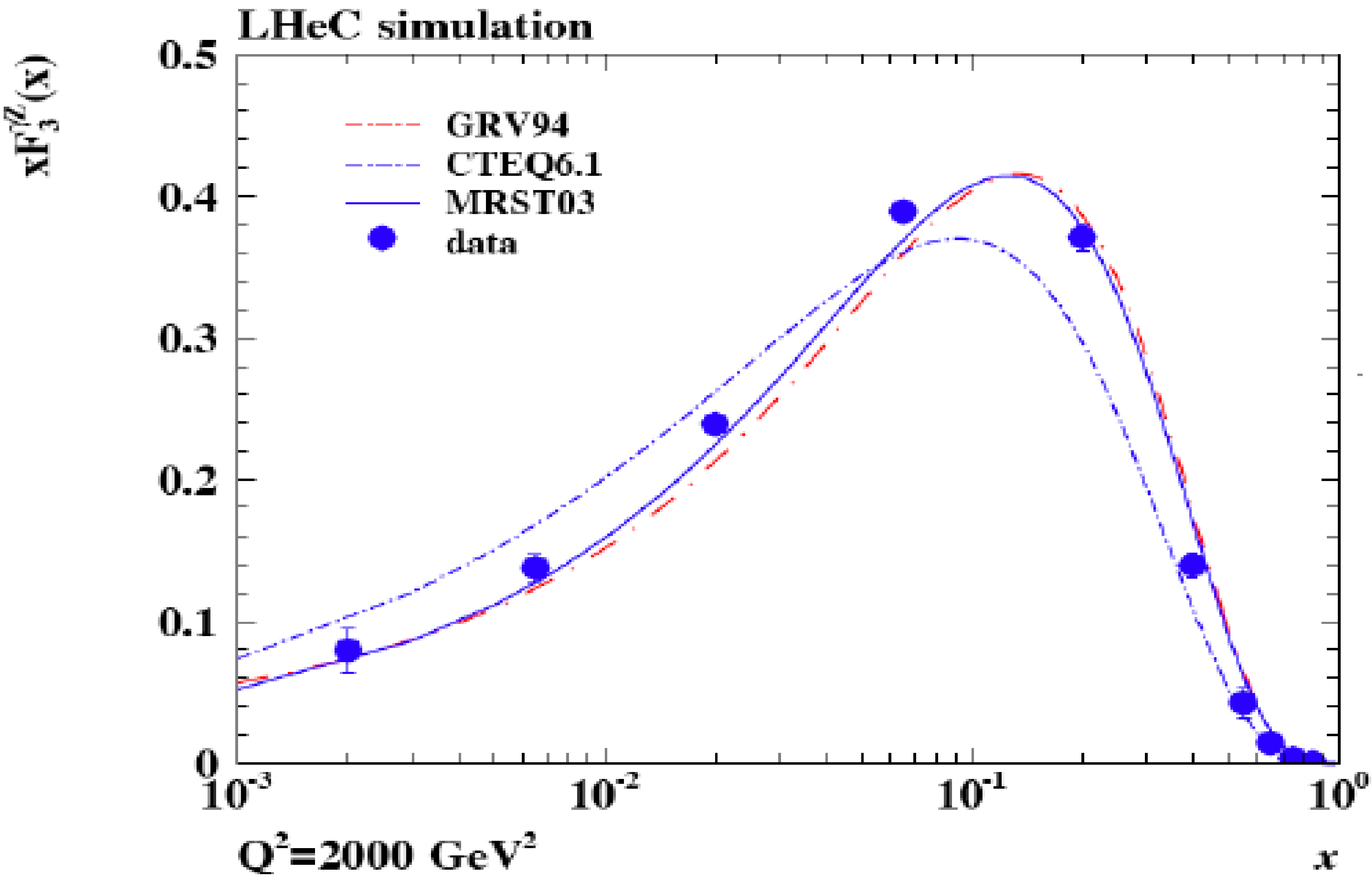
Effective b-parton density in the proton @ x=0.01





Note: exact b(x,Q2) (probably) not needed for disovery at LHC (wouldl come too late anyway) but for (precision) understanding

Precise valence quarks down to x=0.001



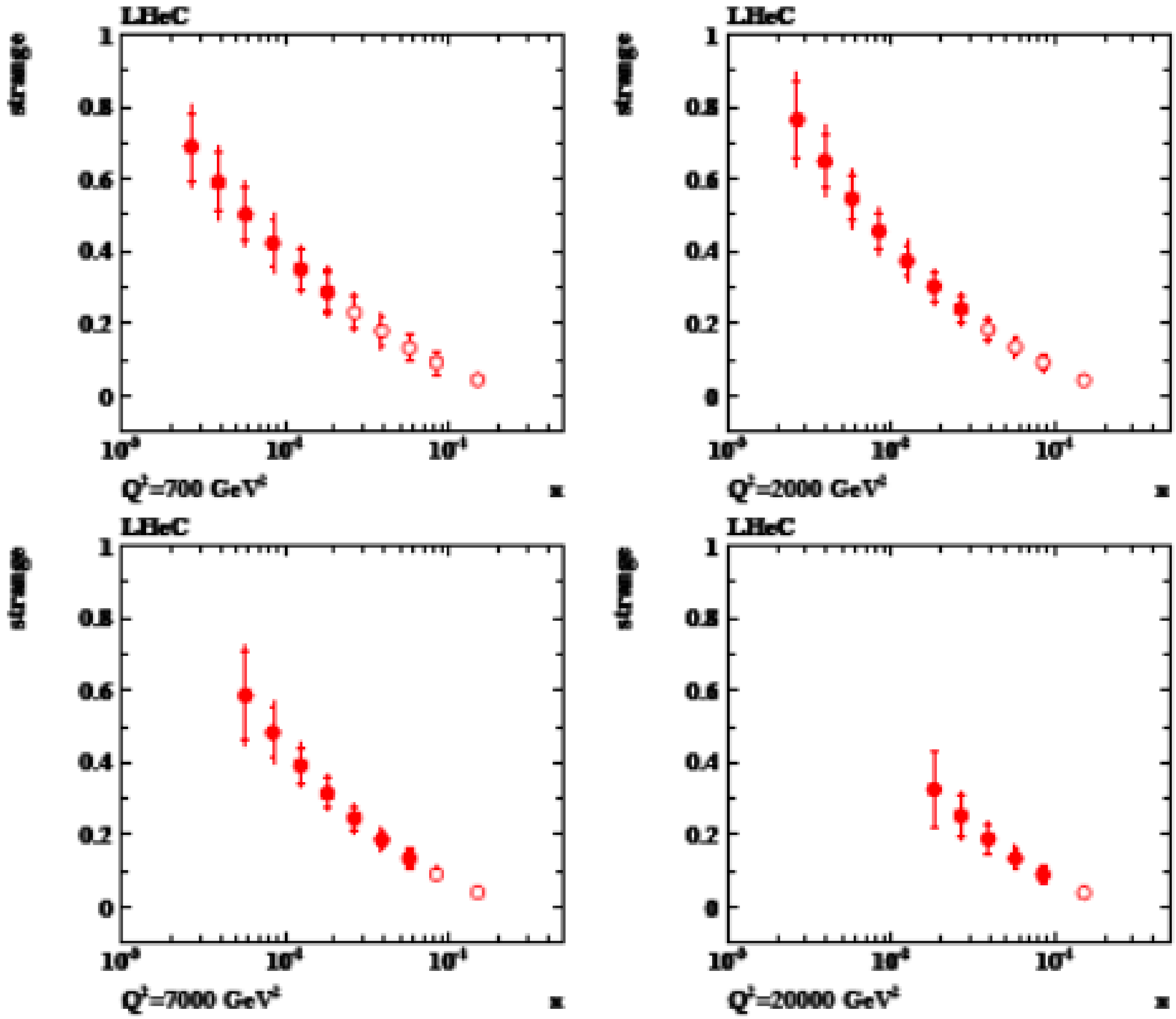
Klein, Perez

$$xF_3^{\gamma Z} = 2x[e_u a_u(u_v + \Delta_u) + e_d a_d(d_v + \Delta_d)]$$

Strange quark distribution

Klein, Mehta

Note: s(x) could be also determined at LHC in sg -> cW



$W^+ s \to c$

$1 fb^{-1}$

$\varepsilon_c = 0.1$

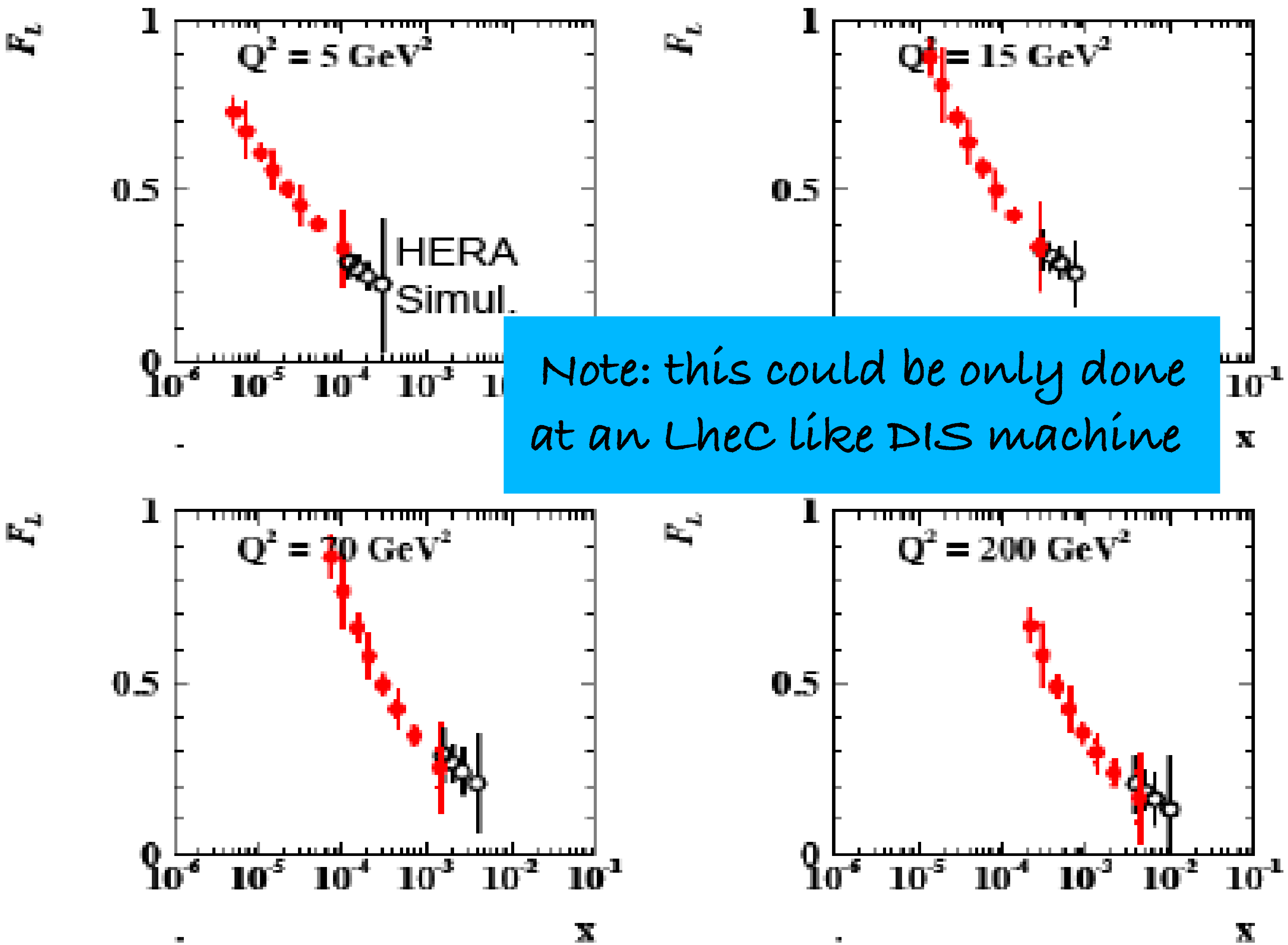
$\varepsilon_q = 0.01$

$\delta_{syst} = 0.1$

$\circ - \vartheta_h \geq 1^o$

$\bullet - \vartheta_h \geq 10^o$

Towards lower/lowest x: Precise Fl



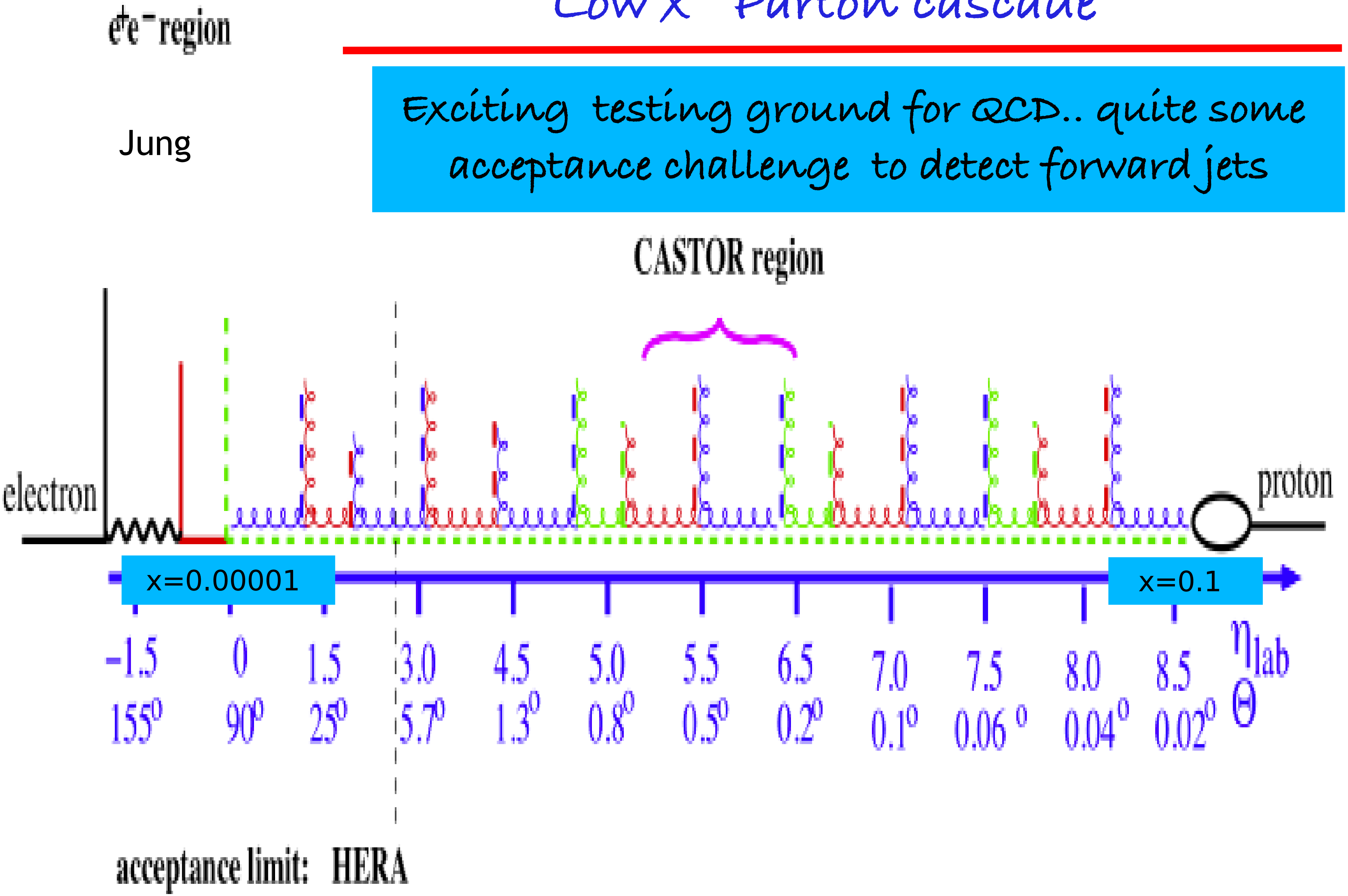
Klein

Note: this could be only done at an LheC like DIS machine

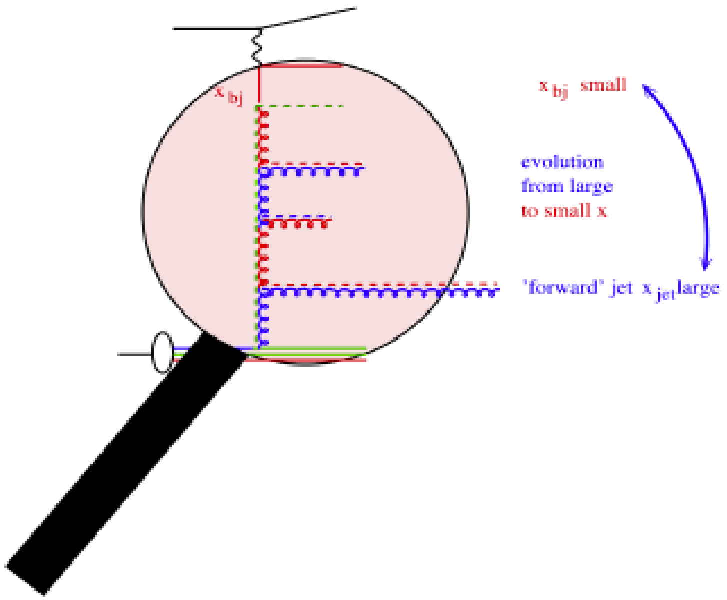
Low x Parton cascade

Jung

Exciting testing ground for QCD.. quite some acceptance challenge to detect forward jets



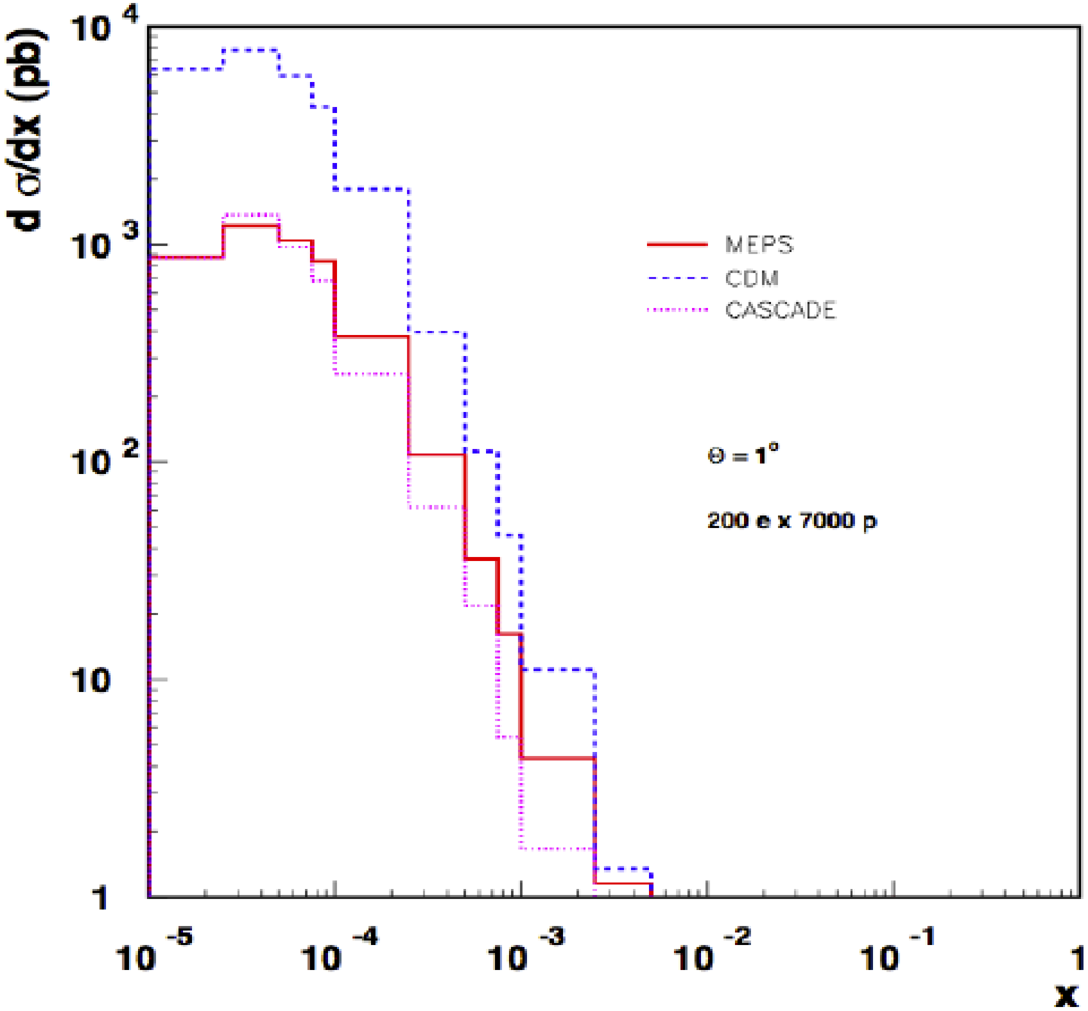
Forward jets at LHeC



- DIS and forward jet:

$x_{jet} > 0.03$

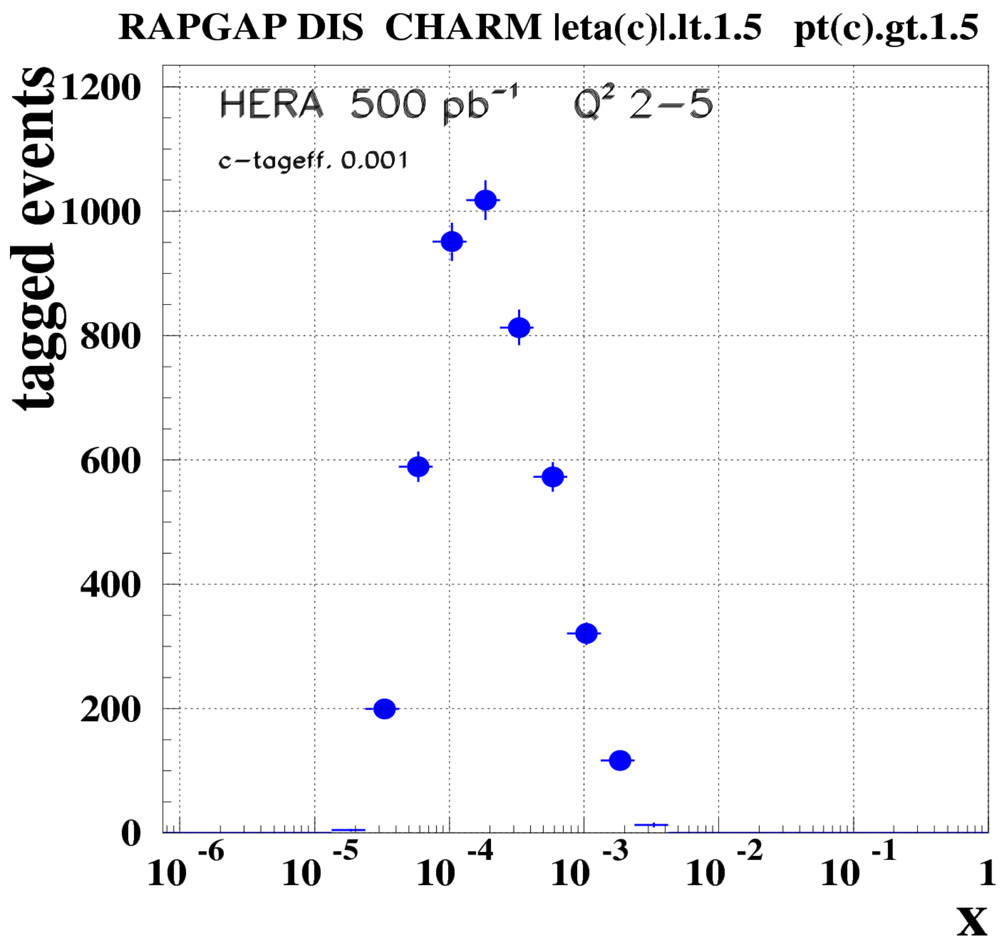
$0.5 < \frac{p_{t\ jet}^2}{Q^2} < 2$

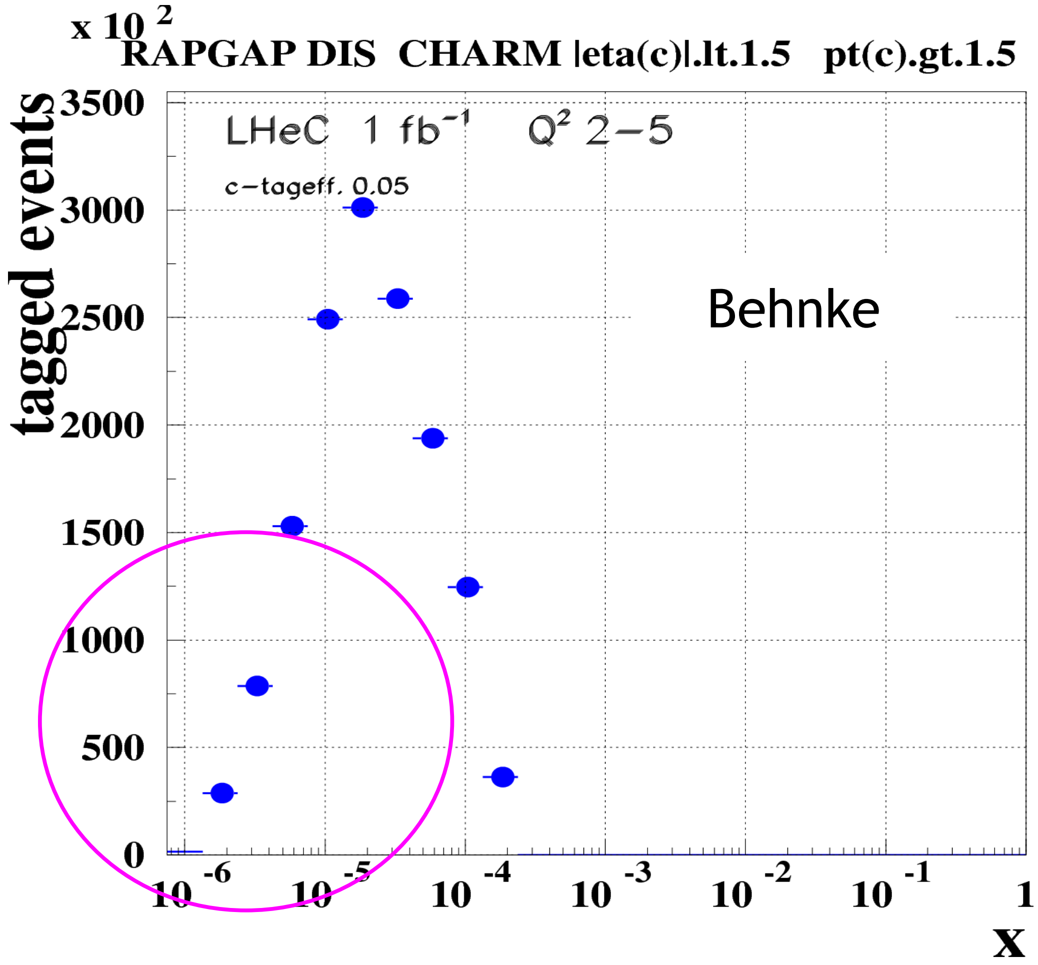


Results: Charm Q^2: [2-5 GeV^2]; pt_c>1.5, |h_c|<1.5

HERA with typical effective c-tageff~ 0.001 (D*)

LHeC assume improved c-tageff~0.05 (lifetime+mass)





➔ Would probably add very valuable information on low x gluon density

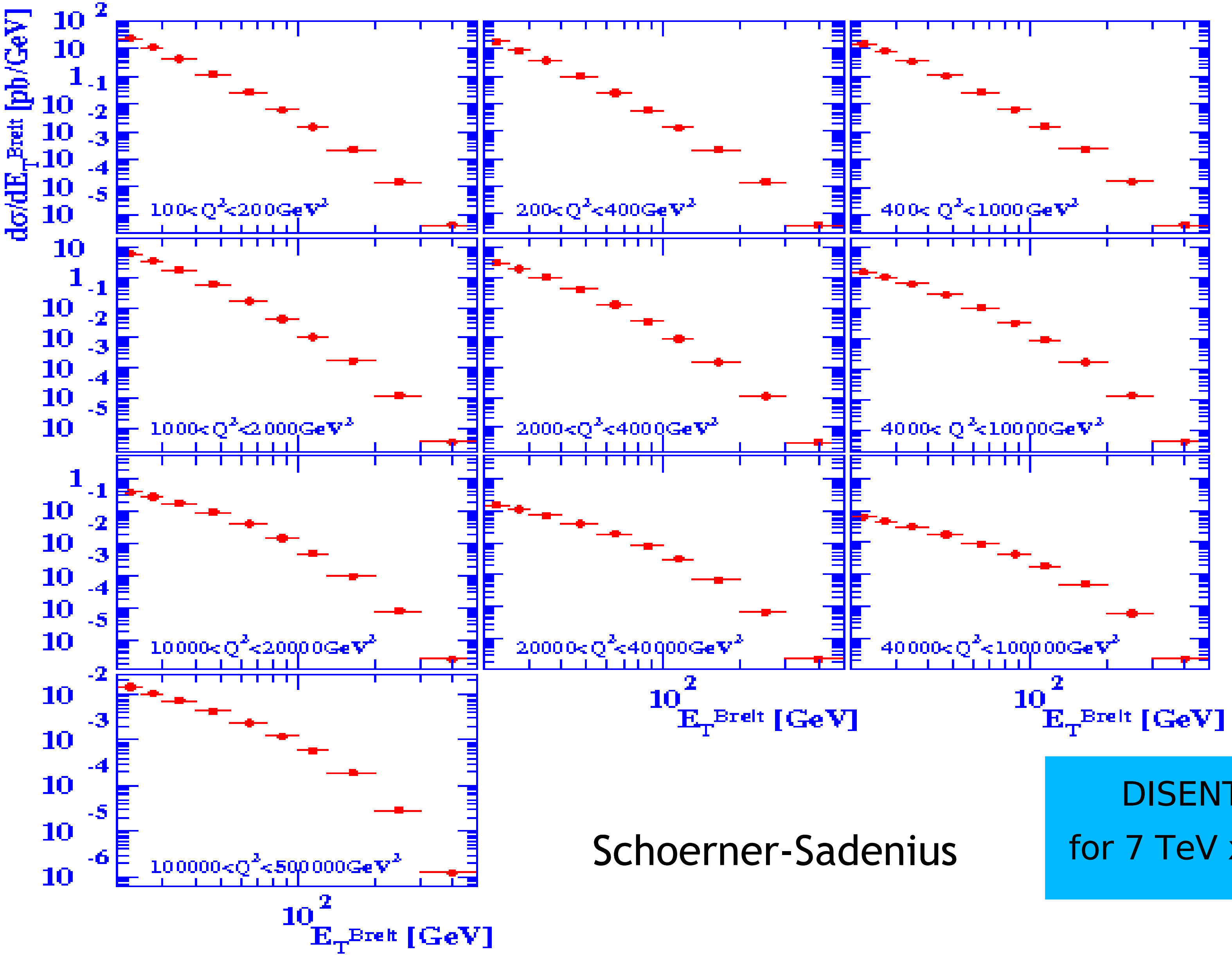
Conclusions

- ✔ Electroweak physics: High lumi and high degree of polarisation are quite essential to make an impact with the LHeC.
- ✔ QCD: Many interests & hopes for filling essential gaps of our proton knowledge, e.g. gluon density at large x, strange sea, effective b density, etc...
- ✔ Physics at largest x require excellent detector/acceptance/granularity in the forward region, also true for large part of final state physics at low x
- ✔ Studies presented here were often just a first start up, and should be continued – target goal DIS 2009 or earlier

Some further studies/ideas presented at this workshop

- ✔ Thomas Schoerner Sadenius: Jets cross sections in high Q2 DIS – 10-100 times larger at LheC than at HERA and reaching up to a few 100 GeV in pt (see next slide)
- ✔ Juan Rojo: Neural net pdf fits --> will be interesting to see how the uncertainties could change including the LheC kinematic region (especially lower x)
- ✔ Emmanuelle Perez: New physics in s-channel contact interaction qqbar --> ll (=Drell Yan) at LHC could be difficult to identify at the LHC .. but possible to identify in inclusive (t-channel) eq -> eq DIS at the LHeC.
- ✔ Many further intriguing ideas by Stan Brodsky (see next but one slide) :-)

INCLUSIVE JETS: DOUBLE-DIFFERENTIAL



Schoerner-Sadenius

DISENT predictions

for 7 TeV x 70 GeV LHeC

Novel Aspects of QCD in ep scattering

- Clash of DGLAP and BFKL with unitarity: saturation phenomena; off-shell effects at high x
- Heavy quark distributions do not derive exclusively from DGLAP or gluon splitting -- component intrinsic to hadron wavefunction:
  Intrinsic c(x,Q), b(x,Q), t(x,Q):
- Hidden-Color of Nuclear Wavefunction
- Antishadowing is quark specific!
- Polarized u(x) and d(x) at large x; duality
- Virtual Compton scattering : DVCS, DVMS, GPDs; J=0 fixed pole reflects elementary source of electromagnetic current
- Initial-and Final-State Interactions: leading twist SSA, DDIS
- Direct Higher-Twist Processes; Color Transparency

Introduction

Bartels

What is fundamental about QCD at high energies:

- structure of the proton at high energies reveals the nature of strong forces aspects of confinement
- at high energies standard model (QCD) must merge into any theory beyond the standard model. Some structure has already been made visible: integrability in evolution equations.

Regge limit contains information not accessible in the short distance (collinear) limit: unitarity; interface between short and long distance behavior. Starting point: BFKL

Experience has shown that deep inelastic ep-scattering is a very good place: perturbative starting point, variation of photon virtuality Q^2 allows to interpolate between short and long distance regimes.

For discussion with the detector group

- Precision silicon tracking for c- and b-lifetime tag:
  - 30<theta<150: highest quality desirable as always, e.g. For F2cc & F2bb at medium Q2
  - 10<theta<30: highest quality e.g. For b from ww -> H -> bb or b from top decays or new very heavy resonances
  - Theta<10: for many final state physics c or b would add 'real flavour'/information, e.g. Separating quark from gluon jets etc. how far can/need we go down in theta?