Particle Physics Seminar — DESY/Zeuthen

24 January 2001

Electron-Proton Scattering at $\sqrt{s} = 1 \text{ TeV}$

Report from the THERA Study Group

J. A. Crittenden
DESY/ZEUS
(on leave from Phys. Inst. Bonn)

THERA Chronology

☞ M. Tigner, B. Wiik and F. Willeke
IEEE Proceedings 1990

☞ R. Brinkmann, Tr. J. of Phys. 22 (1998) 661
(Ankara workshop)

☞ A. Wagner, *Future of HERA and TESLA*
(DIS'99, Zeuthen)

TESLA tunnel tangential to HERA "... with the clear intention to have the future option to collide electron beams from TESLA with proton beams in HERA."

"It would be good to include in the TDR a chapter on the physics potential of electron-proton collisions with TESLA on HERA."

☞ DIS Workshops

$\longrightarrow$ 1998: A. De Roeck

$\longrightarrow$ 1999: Y. Sirois

$\longrightarrow$ 2000: M. Klein

☞ U. Katz, *Physics with THERA*
ECFA/DESY Linear Collider Workshop, May/2000

☞ The THERA Study Group

$\longrightarrow$ Convenors established in late 1999

$\longrightarrow$ Meetings/Workshops:
February, April, October, December

$\longrightarrow$ Contribution to TDR now being edited

October Meeting Agenda

Programme of the THERA meeting

DESY, Hamburg, 18./19. October 2000

Wednesday 18.10.	**17.00-19.30 (big room below canteene)**
M. Klein	status and work towards the TDR (pdf-file)
A. Wagner	remarks and welcome
A. Vogt	QCD beyond NLO (ps-file)
W. van Neerven	Precison tests of perturbative QCD at THERA (pdf-file)
evening (20.00): joint dinner	
E. Levin	After Dinner Talk (pdf-file)
Thursday 19.10.	**morning: parallel sessions**
	Heavy Flavours and Gamma (Sem. 5)
	Low x (Sem. 1)
	Detector and Machine (Sem. 3a)
Thursday 19.10.	**14.00.-20.00 (big room below canteen)**
	progress reports from the working groups
E. Levin	Low x
H. Jung	QCD and Simulation (pdf-file)
M. Kuze	High Q^2 (pdf-file)
E. Perez	High Q^2
M. Krawczyk	Structure of Photon (pdf-file)
J. Crittenden	Diffractive Vector-Meson Photoproduction at High Momentum Transfer (ps-file)
L. Gladilin	Progress from Heavy Flavours and Gamma Groups (pdf-file)
E. Rondio	Polarization (pdf-file)
U. Katz	Machine and Detector (pdf-file)

Doris Eckstein
Last modified: Mon Nov 27 19:18:03 MET 2000

The THERA Convenors

	Working Groups	Convenors
•	**Low *x* and Diffraction**	P Newman (U Birmingham) E Levin (Tel Aviv) A Levy (Tel Aviv)
•	**Tests of QCD and MC Simulation**	L Lönnblad (U Lund) H Spiesberger (U Mainz) H Jung (U Lund)
•	**Heavy Flavours**	K Daum (Wuppertal) L Gladilin (U Hamburg,Moscow)
•	**Photon Structure**	J Butterworth (UC London) S Söldner-Rembold (CERN/U Freiburg) M Krawczyk (Warsawa)
•	**High Q^2 and BSM**	E Perez (Saclay) K Long (IC London) M Kuze (KEK)
•	**Detector and Machine**	J Crittenden (U Bonn) U Katz (U Bonn) M Klein (DESY Z) D Pitzl (DESY HH) S Schlenstedt (DESY Z) U Schneekloth (DESY)
•	***eA* Scattering**	M Strikman (Penn State)
•	**Real *Gamma p***	S Sultansoy (Ankara)
•	**Polarization**	E Rondio (Warsawa) A Deshpande (Yale U)

Mail to: Max Klein (max.klein@ifh.de) Stefan Schlenstedt (stefan.schlenstedt@ifh.de)

In consultation with: R. Brinkmann, W. Bialowons, P. Wesolowski, F. Willeke

Participants from 43 institutes

Ankara University
CEN-Saclay
CERN
Charles University
DESY/Hamburg
DESY/Zeuthen
East China Normal University
Forschungszentrum Jülich
Gazi University (Ankara)
Harish-Chandra Research Institute
Imperial College London
Institute of Experimental Physics (Košice)
Institute of Mathematics (Novosibirsk)
ITEP (Moscow)
KEK
LAL-Orsay
Lebedev Physical Institute
Lund University
Max-Planck-Institut
McGill University
Michigan State University
Moscow State University
Paul Scherrer Institute
Pennsylvania State University
RIKEN-BNL Research Center
RWTH Aachen
Tel Aviv University
University of Oxford
Univ. Autonoma Madrid
University of Birmingham
University of Bologna
University of Bonn
University of Colorado
University of Dortmund
University of Freiburg
University of Hamburg
University of Leiden
University of Liverpool
University of Mainz
University of Warsaw
University of Wuppertal
University of Zürich
Weizmann Institute
Yale University

Participants

S. Atag, O. Cakir, A.K. Ciftci, O. Yavas, E. Perez, A. De Roeck,
T. Laštovička, W. Bialowons, R. Brinkmann, H. Jung,
R. Klanner, H. Kowalski, D. Pitzl,, U. Schneekloth,
P. Wesolowski, F. Willeke, J. Blümlein, D. Eckstein, M. Klein,
P. Kostka, T. Naumann, S. Schlenstedt, J. Ruan, W. Zhu,
N. Nikolaev, W. Schäfer, H. Koru, M. Yilmaz, S. Sultansoy,
V. Ravindran, K. Long, T. Kurča, I. Ginzburg, A. Zhokin,
V. Zoller, M. Kuze, K. Nagano, C. Pascaud, S.P. Baranov,
N. Gogitidze, L. Lönnblad, B. Pötter, M. Wing, W.K. Tung,
B. Levchenko, N.P. Zhotov, J. Gassner, M. Strikman,
L. Frankfurt, E. Gotsman, K. Tuchin, P. Landshoff, G. Rädel,
I. Redondo, P. Newman, M. Corradi, J.A. Crittenden, U. Katz,
U. Stösslein J.G. Conteras, M. Glück, E. Reya,
S. Soeldner-Rembold, J. Bartels, K. Golec-Biernat, M. Klasen,
W. van Neerven, A. Vogt , M. McDermott, H. Spiesberger,
P. Jankowski, M. Krawczyk, E. Rondio, A. Zarnecki,
A. Zembrzuski, K. Daum, R. Wallny, L. Gladilin, E. Levin,
A. Levy, U. Maor, A. Deshpande

All volunteers

Ernest Rutherford (1871 – 1937)

„All science is either physics or stamp-collecting“

(Nobel Prize for Chemistry 1908)

The Discovery of the Very Small

„It seems certain that these large deviations of the α particle are produced by a single atomic encounter."

„A simple calculation shows that the atom must be a seat of an intense electric field in order to produce such a large deflexion at a single encounter."

– E. Rutherford (1911)

„It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you."

– Notes from one of Rutherford's last lectures

Niels Bohr (1913)

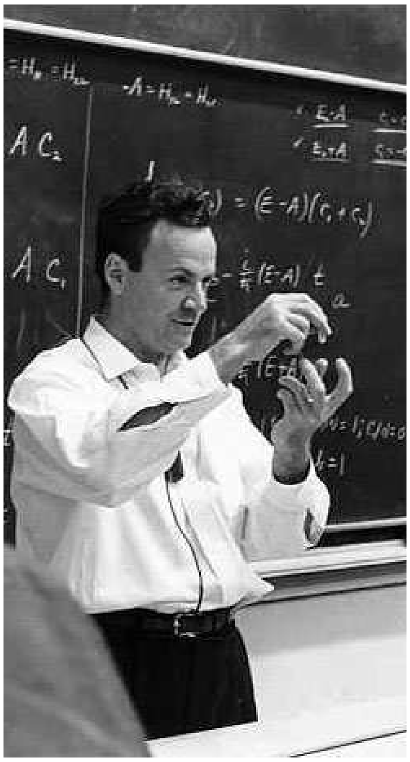
The atom is empty!

The Bohr Radius

$$a_0 = \frac{\hbar^2}{e^2\, m_e} \simeq 50.000 \text{ fm}$$

Richard Feynman (1918–1988)

Nobel Prize for Physics 1965

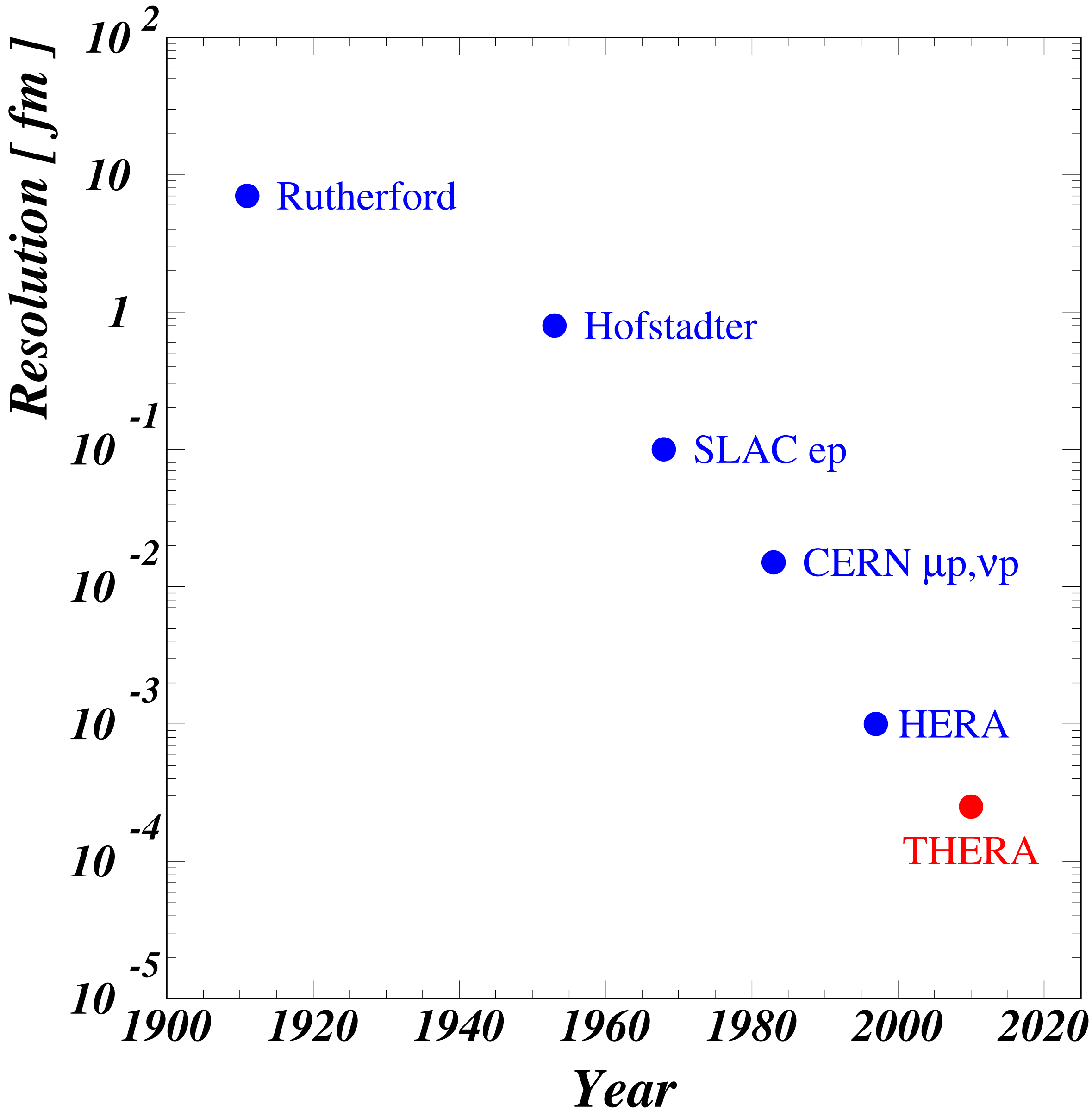


" ... And that was the problem that Rutherford wanted solved, and when he had the correct solution, he then checked it against experiment. And he found that the ones that were supposed to be deflected through large angles were not there. ... So those which come very close to the nucleus do not seem to come out the way they ought to, and the reason is that the nucleus has a size ... I've got the story backwards. I got mixed up. Excuse me. I start again. "

– *from* Feynman's Lost Lecture, *Goodstein (1996)*

100 Years of Scattering Experiments

	HERA	THERA
E_e	27.5 GeV	250 GeV
E_p	920 GeV	920 GeV
E_{cm}	318 GeV	960 GeV



The next redefinition of "elementary"

Assessment of HERA Results (I)

What have we learned?

☞ $F_2(x, Q^2)$: Steep dependence on x in DIS region

✔ High density of sea quarks

✔ Raging controversy over saturation

☞ $F_2(x, Q^2)$: Steep dependence on Q^2 at low x

✔ High density of gluons

✔ Precision measurement of α_s made possible

✔ Reached theoretical level of precision

☞ Gold mine of Strong Interaction Dynamics

✔ Soft diffraction

Pomeron intercept depends on energy, process, Δp
Physics of $\alpha'_{\mathbb{P}}$
Unitarity

✔ Hard diffraction

Factorization theorem, diffractive PDF's
New scaling laws
Discovery potential high

✔ Transition regions in Q^2, W, t, M

Best hope for unified understanding of very old problems

✔ Exclusive processes in QCD

Scaling, energy dependence, helicity selection rules

Assessment of HERA Results (II)

☞ Heavy flavor $\rightarrow$ test of QCD at NLO

- ✔ Precision charm
- ✔ Treacherous beauty

☞ No structure to partons down to scale of 10^{-18} m

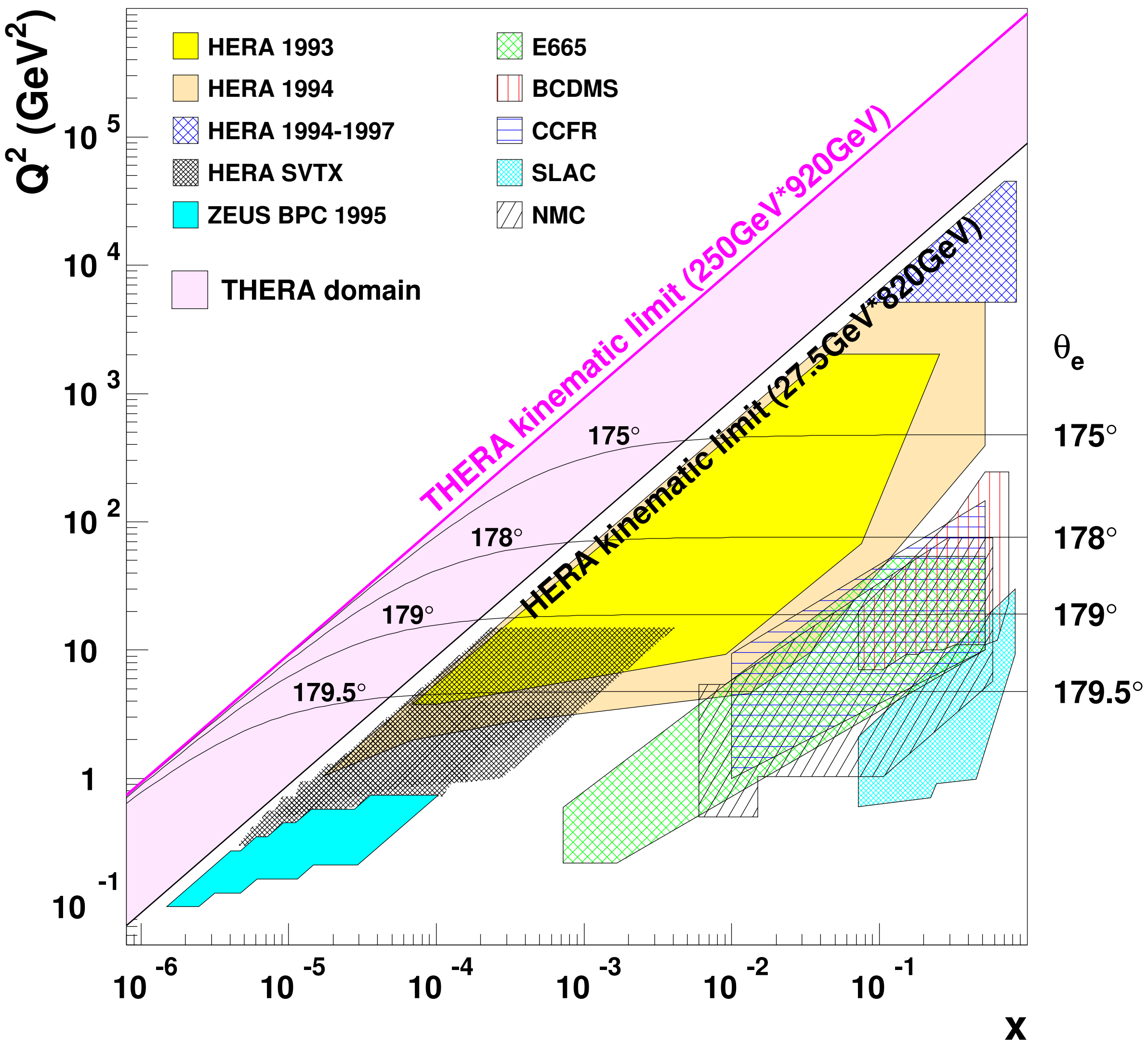
- ✔ No leptoquarks, no contact interactions, no nuthin

☞ No deviation from SM in spacelike region

- ✔ Mechanism of electroweak unification verified to HERA accuracy

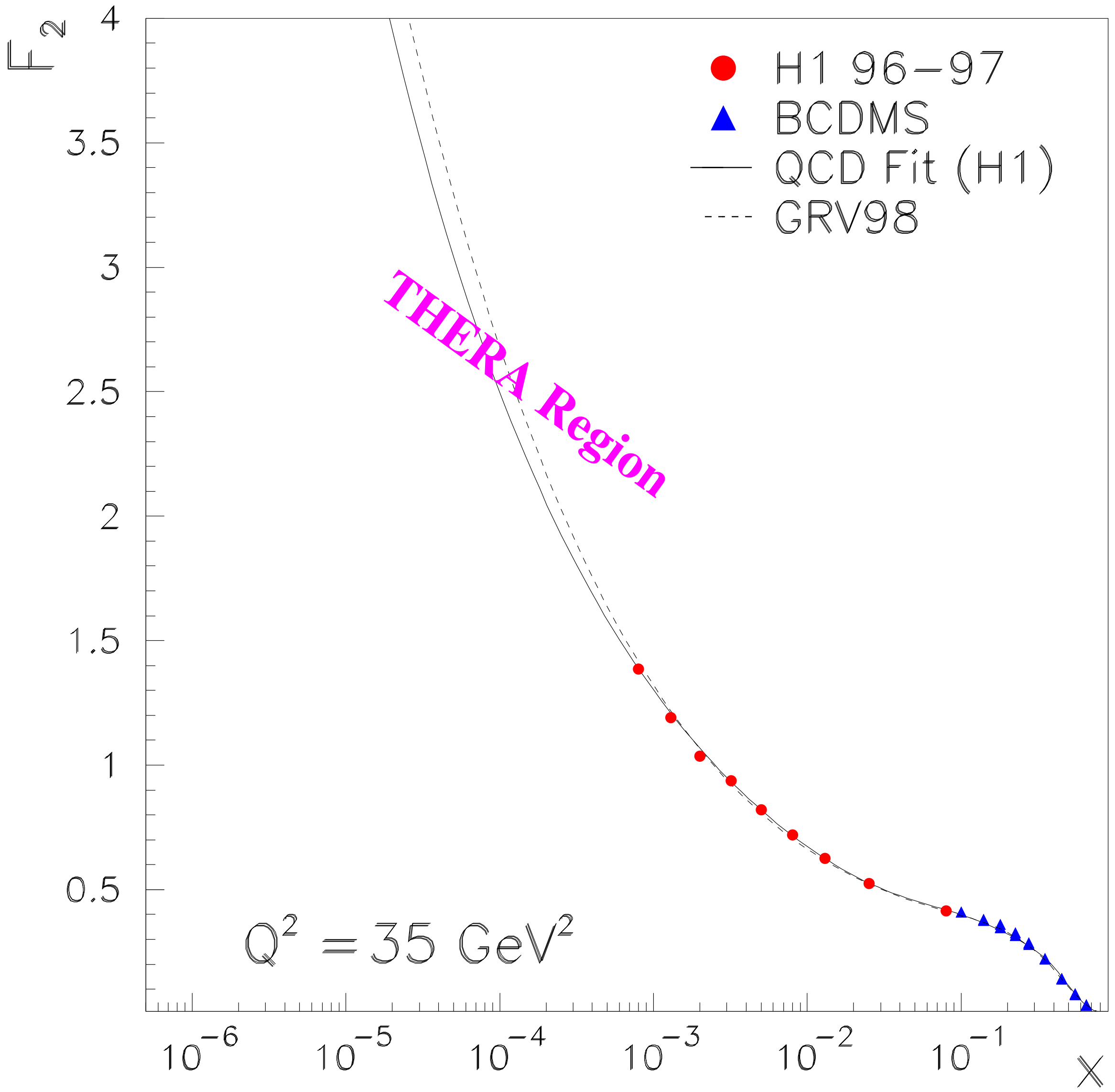
THERA makes sense

The THERA Kinematic Plane



- ☞ Extend x range down to 5×10^{-6} for $Q^2 \simeq 1$ GeV^2
- ☞ Cover factor 10 in pQCD regime at $x \simeq 10^{-4}$
- ☞ Extend one order of magnitude in Q^2 into region of electroweak unification

PDF (I): Low x



Scaling violations yield high sensitivity to

$$\boxed{\alpha_S}$$

Prel. estimate of $\Delta\alpha_S \simeq 0.0005$ indicates 3-loop calculations necessary

PDF (II): Saturation

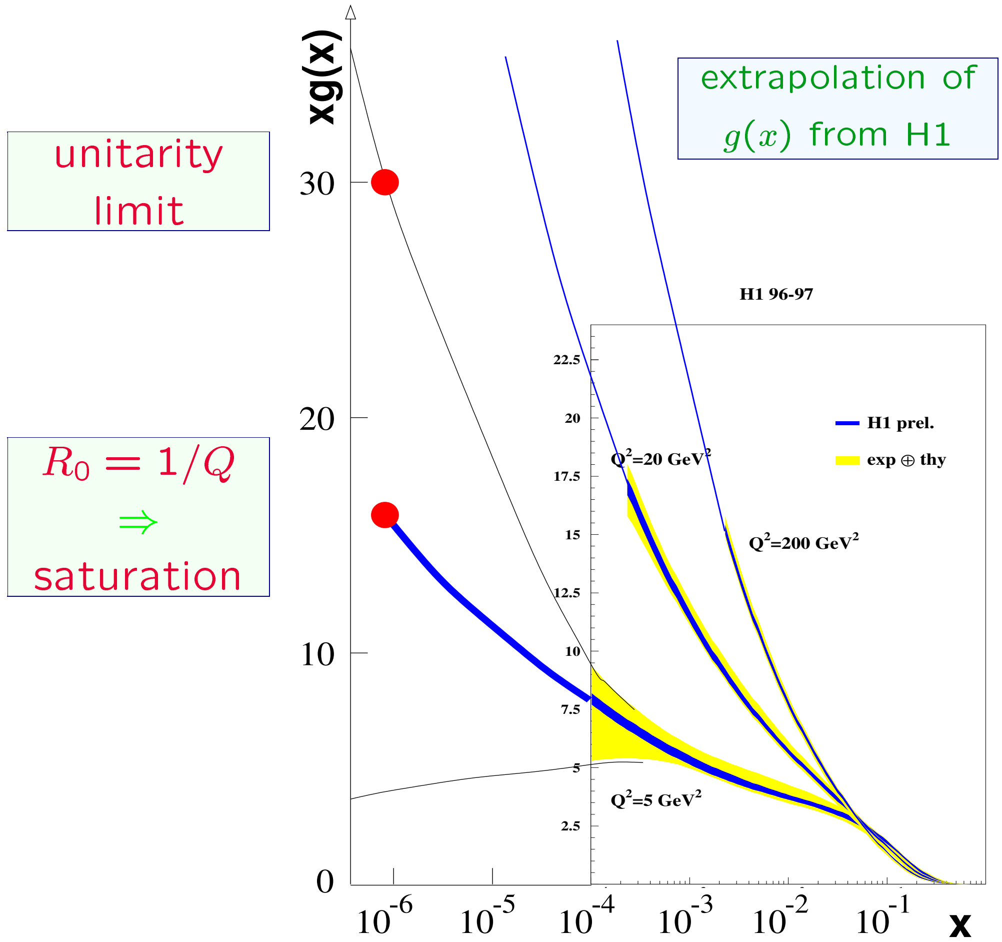
The gluon density at low x

At low x: $(\partial F_2/\partial \ln Q^2) \sim \alpha_s x g(x)$

need sufficient Q^2 range to disentangle:

- pQCD evolution
- higher-twist effects
- saturation
- non-pQCD effects
- ...

need THERA to reach sufficiently large Q^2 at $x \sim 10^{-4}$



U. Katz ECFA/DESY LC Workshop, Padova, 05.05.00 16

PDF (III): Higgs

Z. Kunzst, S. Moretti, W.J. Stirling, hep-ph/9611397

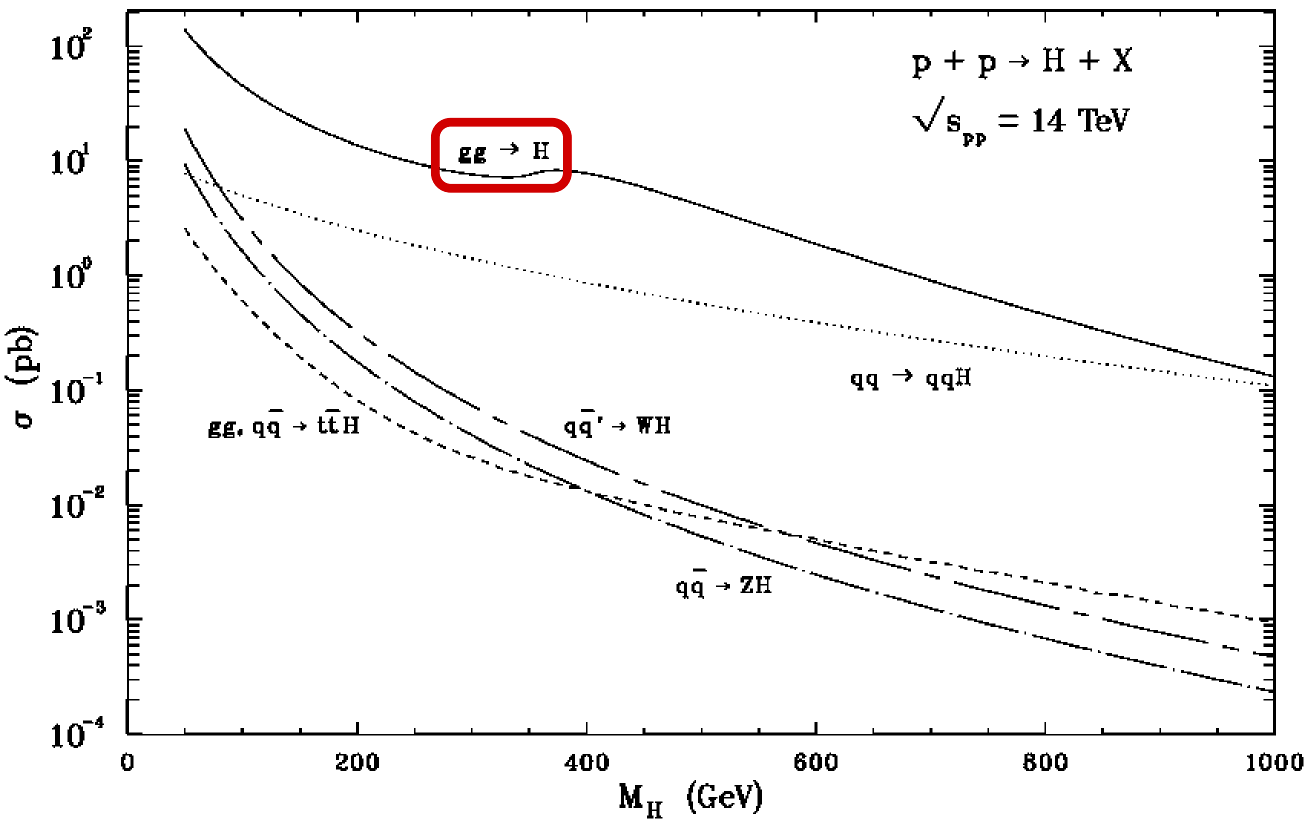


Fig. 5b

⇒ Gluon fusion dominates Higgs production at LHC

PDF (IV): UHE Neutrinos

M. Glück, S. Kretzer, E. Reya, astro-ph/9809273

See also Gandhi, Quigg, Reno, Sarcevic

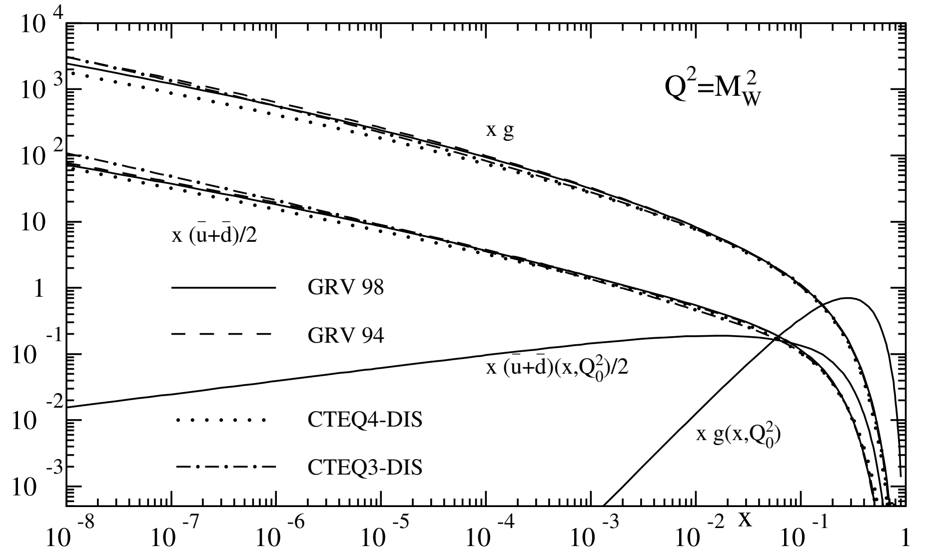


Fig. 1

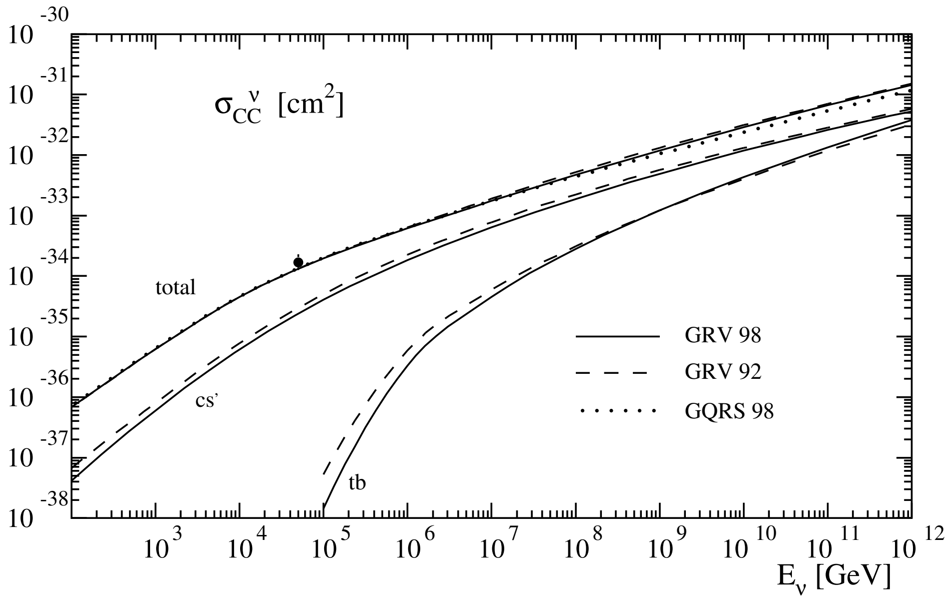


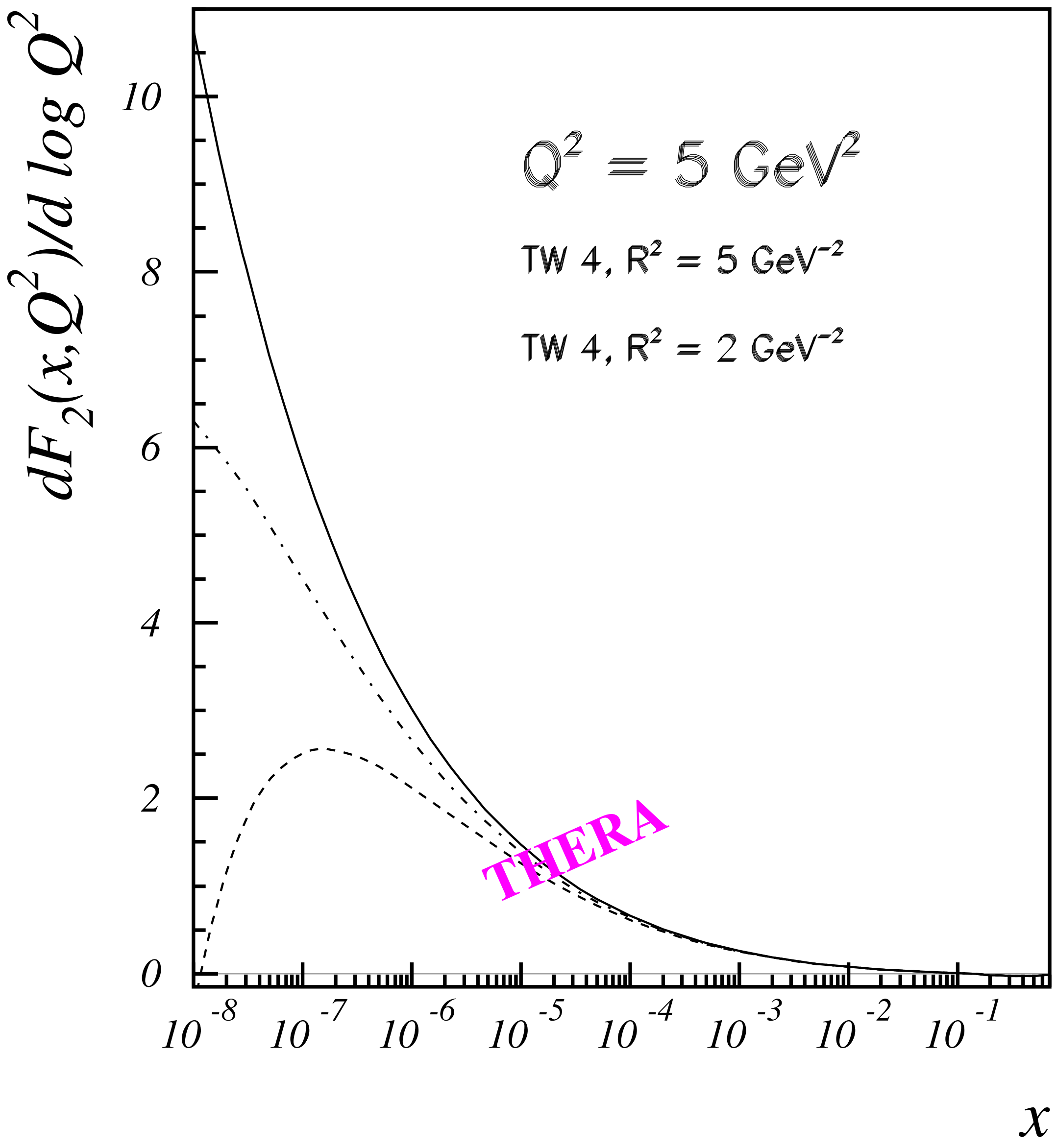
Fig. 2

Low-x PDFs needed for earth tomography
with "ultra-high-energy" neutrinos from AGNs, GRBs

AMANDA, NESTOR, Antares

PDF (V): Twist 4

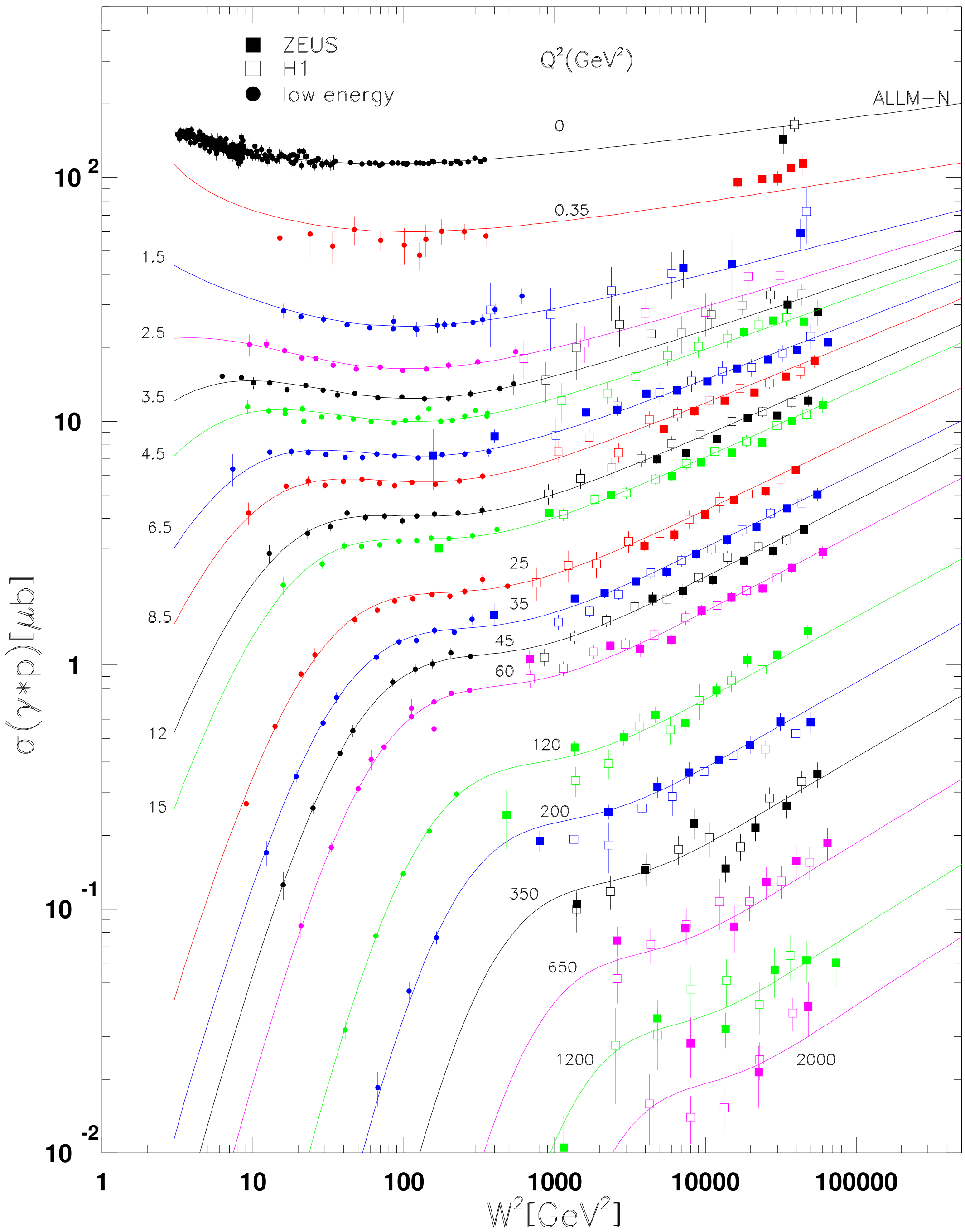
J. Blümlein, V. Ravindran, J. Ruan, W. Zhu, THERA TDR



$\Rightarrow$Twist-4 contribution predicted to slow rise of F_2

Alternative Viewpoint: Total Photon-Proton Cross Sections

$$\sigma^{tot}_{\gamma^* p} \approx \frac{4\pi^2\alpha}{Q^2(1-x)} F_2(x, Q^2)$$



$\Rightarrow$ Steeply rising cross sections at high energy

Diffraction (I): Inclusive Kinematics

Low-x/Diffraction Working Group: THERA TDR

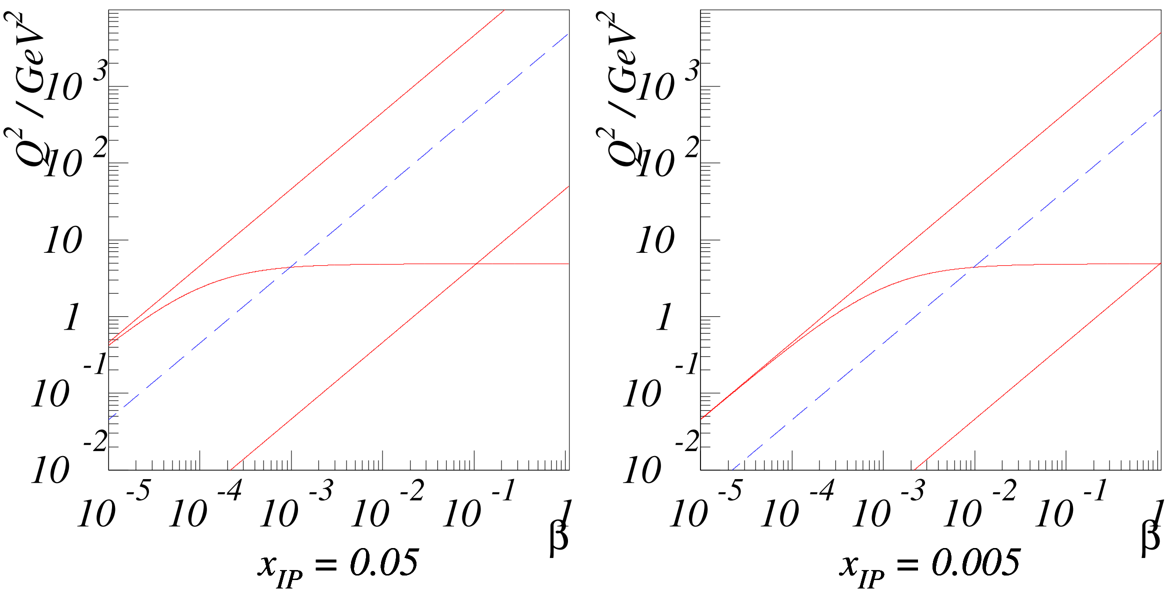


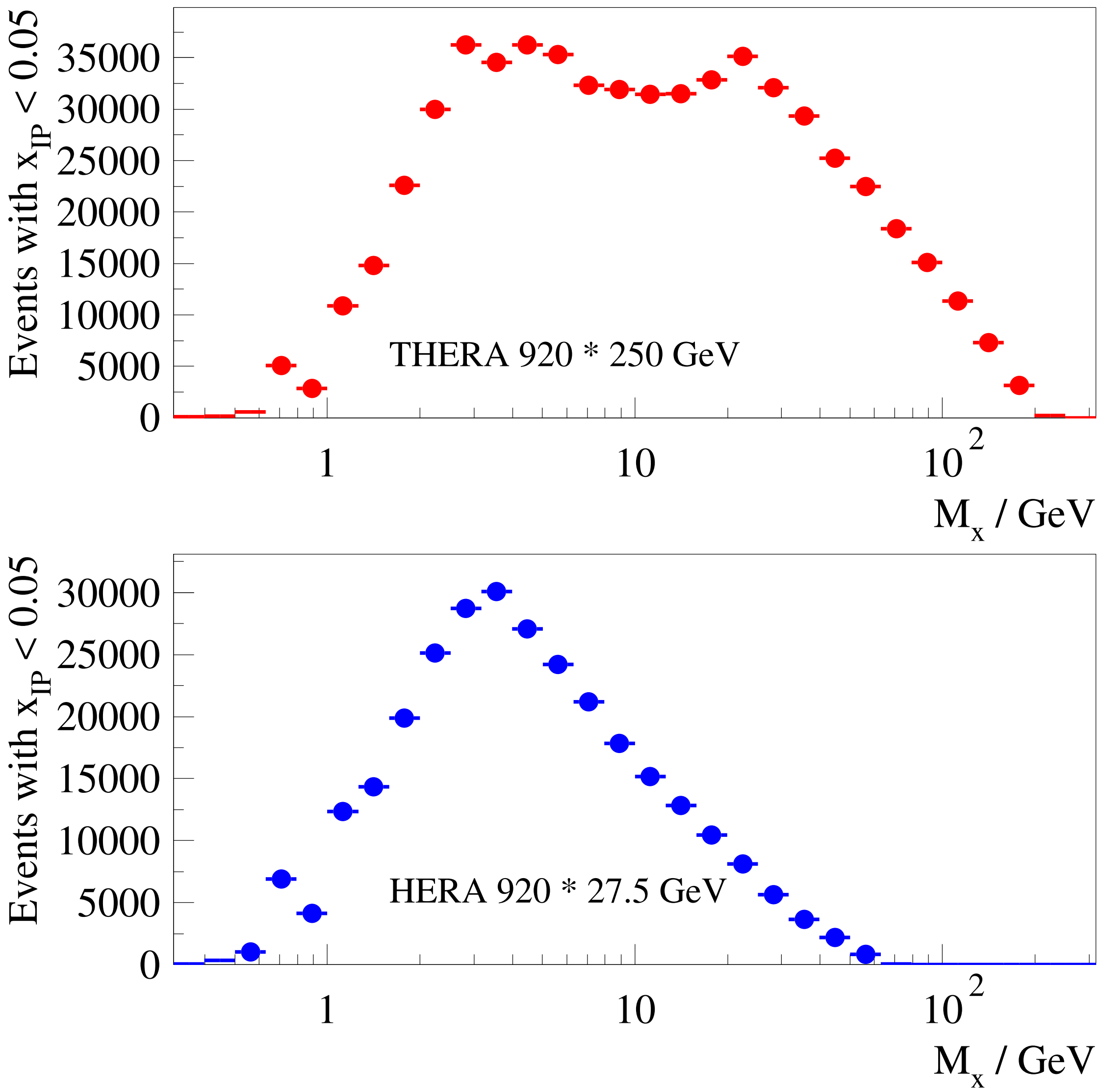
Figure 1: The kinematic plane in β and Q^2 for diffractive DIS at two different values of $x_{I\!P}$. The red solid lines show the limits imposed by the cuts $0.001 < y < 1$ and $\theta'_e < 179.5$ for THERA with electrons of 250 GeV colliding with protons at 820 GeV. The dashed blue lines show the limit imposed by the restriction $y < 1$ at HERA.

- Gains in x, Q^2 similar to F_2
- Gain one unit in rapidity
- Big gain in M_X range
- Appropriately-designed detectors!

Diffraction (II): Inclusive M_X Range

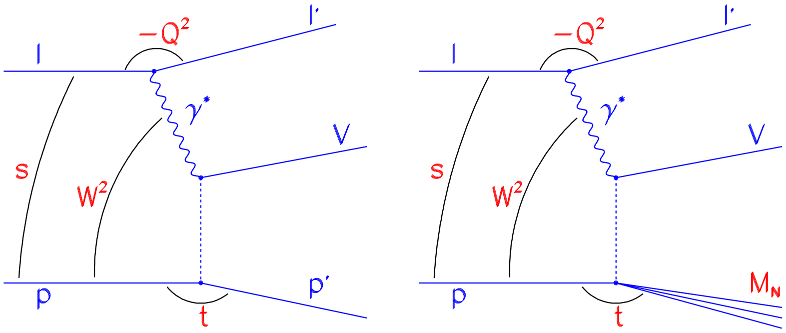
Low-x Working Group: THERA TDR

RAPGAP MC MODEL (Extrapolated H1 QCD fit)

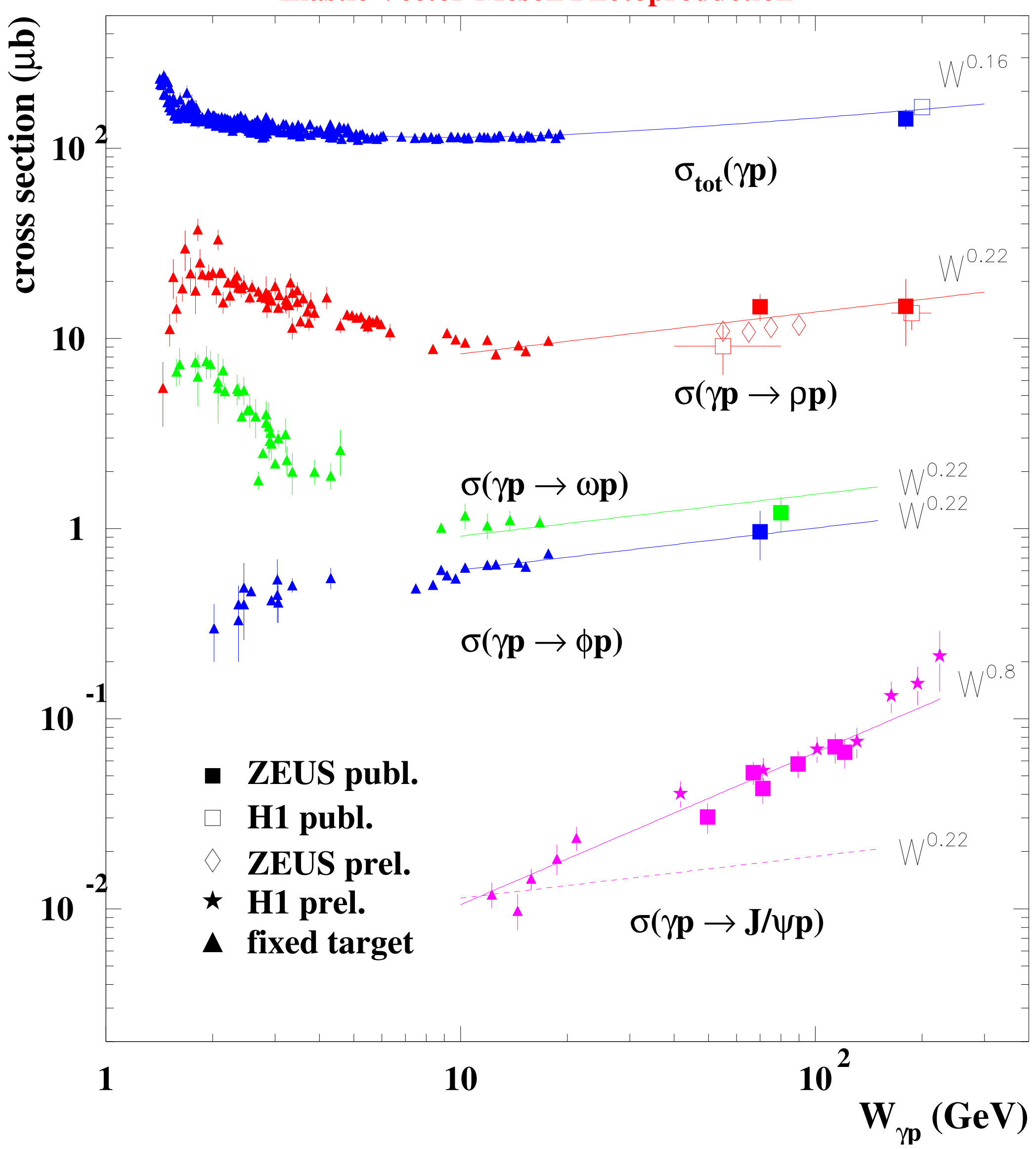


Diffraction (III): Vector Mesons

Elastic   Proton Dissociative



Elastic Vector-Meson Photoproduction



Purpose-built photon-tagging systems

Scan in energy and momentum transfer

THERA Region

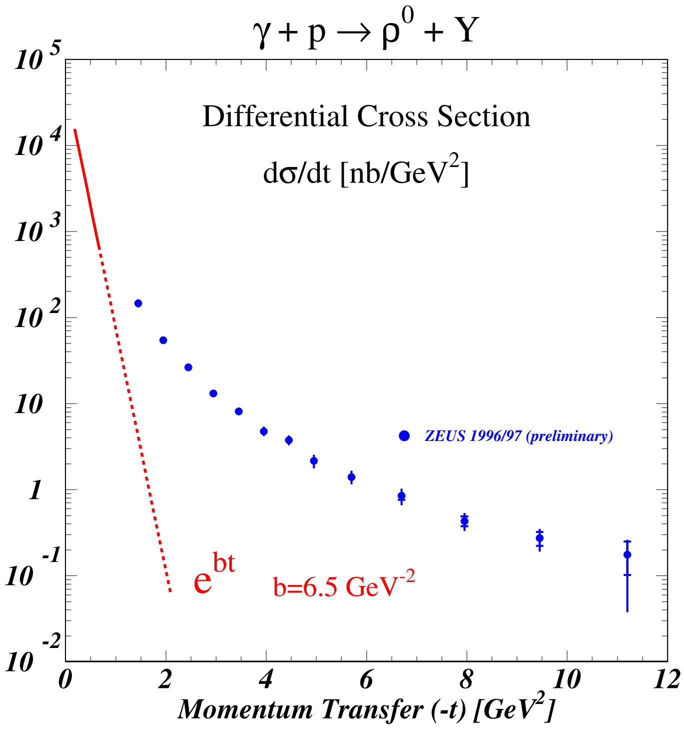
$\Rightarrow$ Steeply rising J/ψ cross section at high energy

$\Rightarrow$ QCD prediction for Υ much steeper

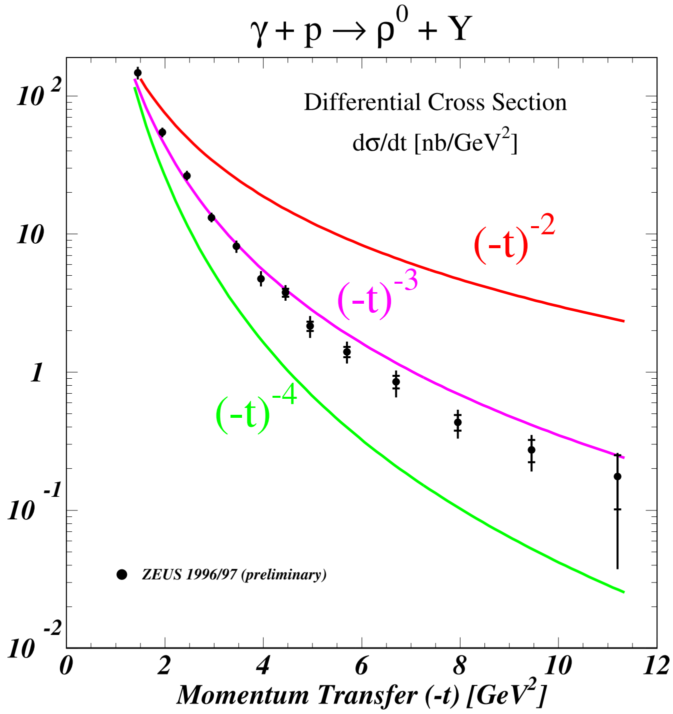
Diffraction (IV): VM at High $|t|$

Semi-exclusive Vector-Meson Photoproduction

at High Momentum Transfer



Recent breakthrough to
power-law behavior reached



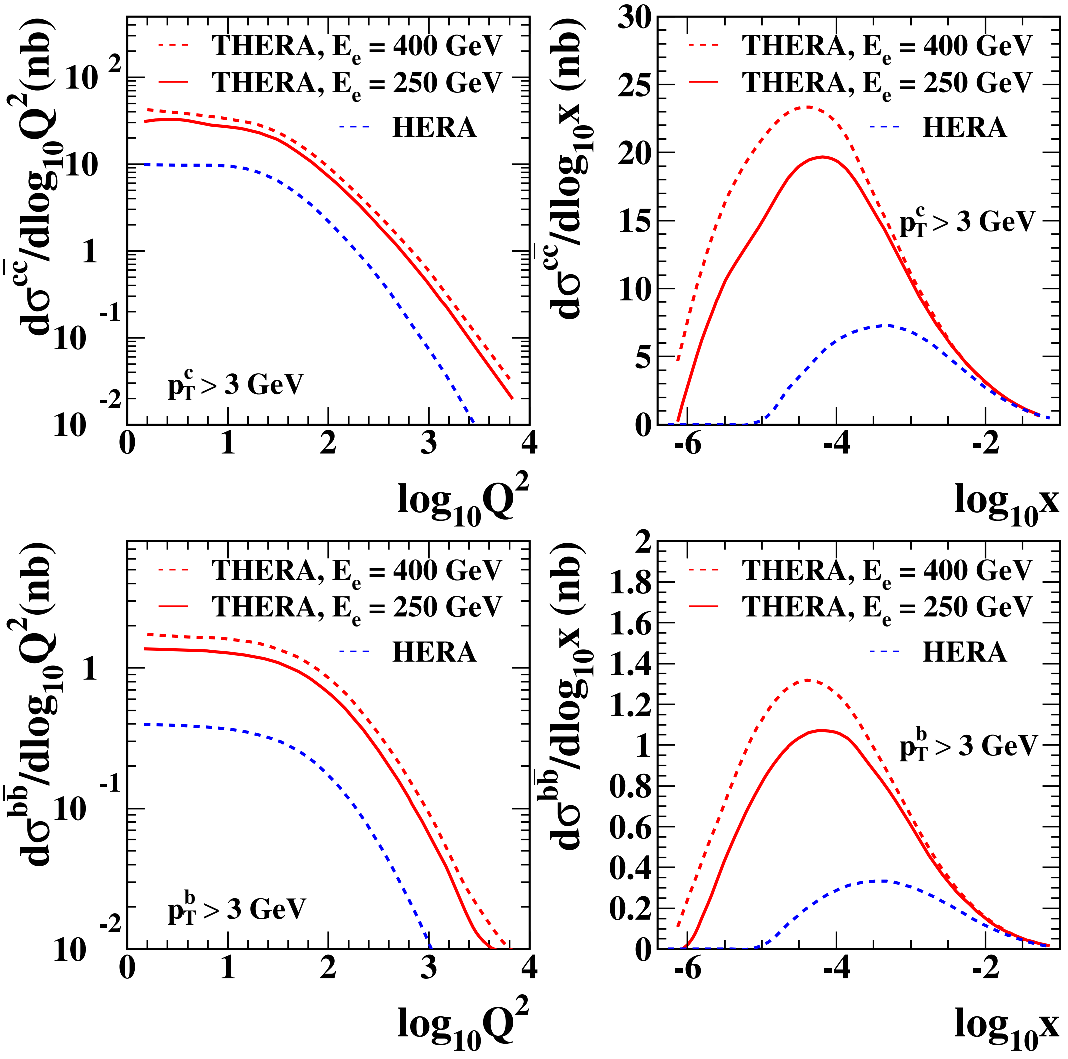
Spectrum is
harder than expected
for transverse production

Heavy Flavor (I): Manifesto

"Electroproduction of heavy flavours is the best testing ground of QCD.
This phenomenon is due to the light cone dominance for $F_{k,c}$, $F_{k,b}$."

W. van Neerven, Dec/2000, THERA Workshop

Electroproduction



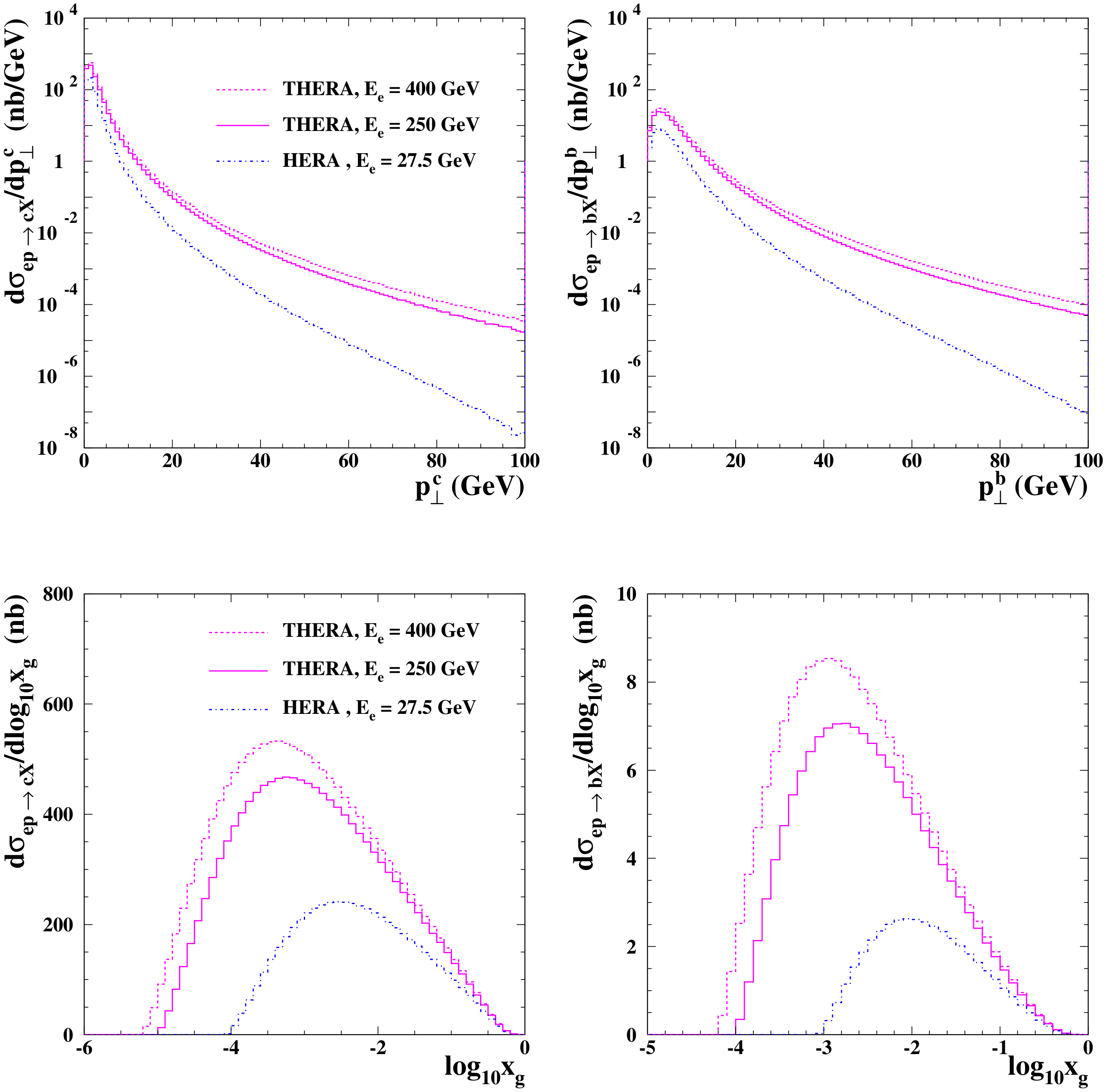
Charm

Beauty

Heavy Flavor (II): Photoproduction

Heavy Flavor Working Group: THERA TDR

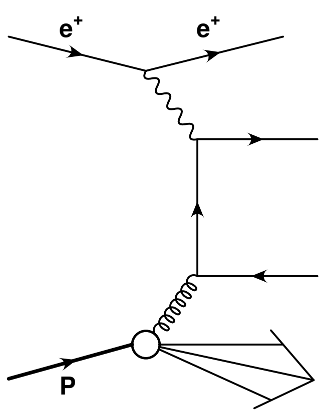
Charm *Beauty*

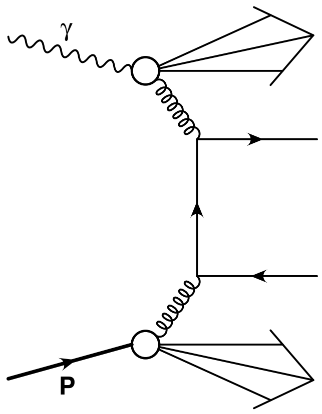


$\Rightarrow$ HUGE gains at high P_T and at low x

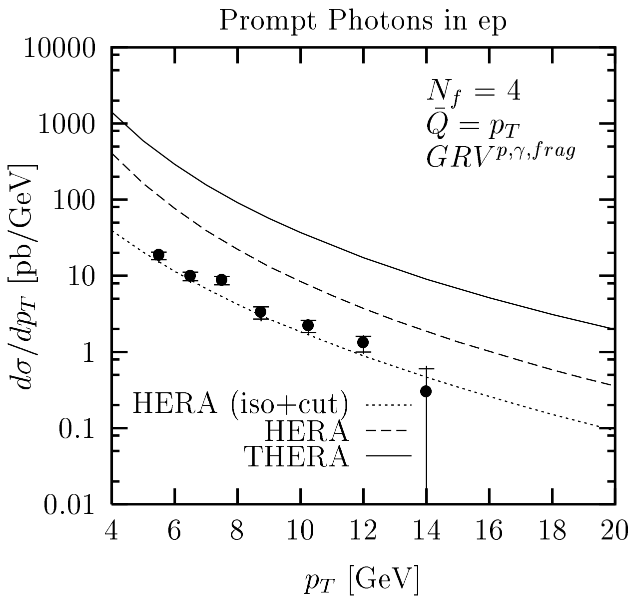
Partonic Structure of the Photon

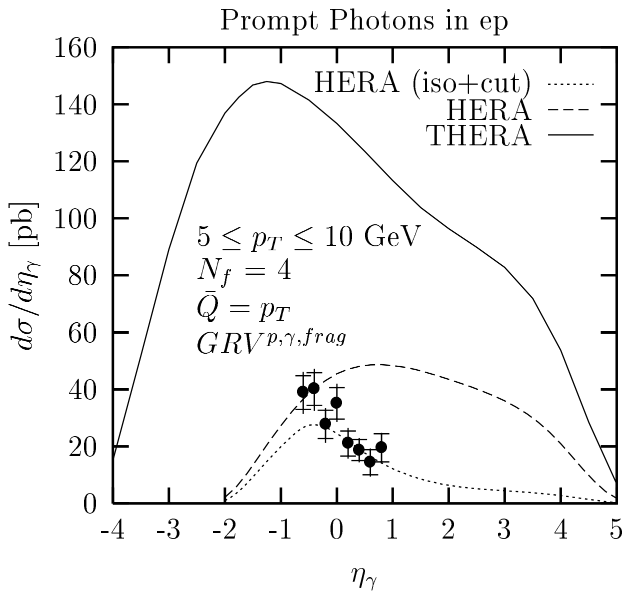
Direct





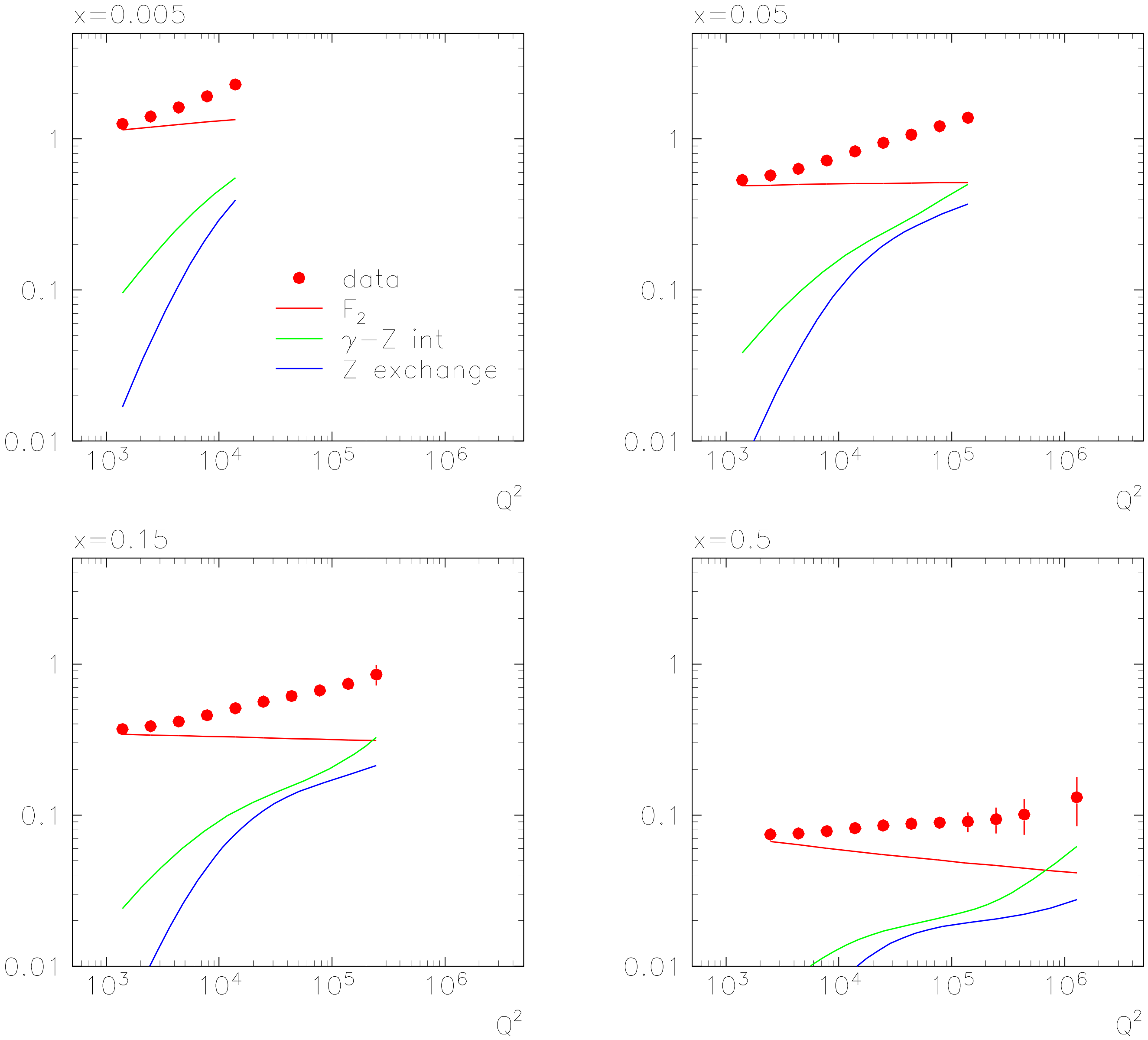
Resolved





$\Longrightarrow$ Striking gains as for heavy flavor

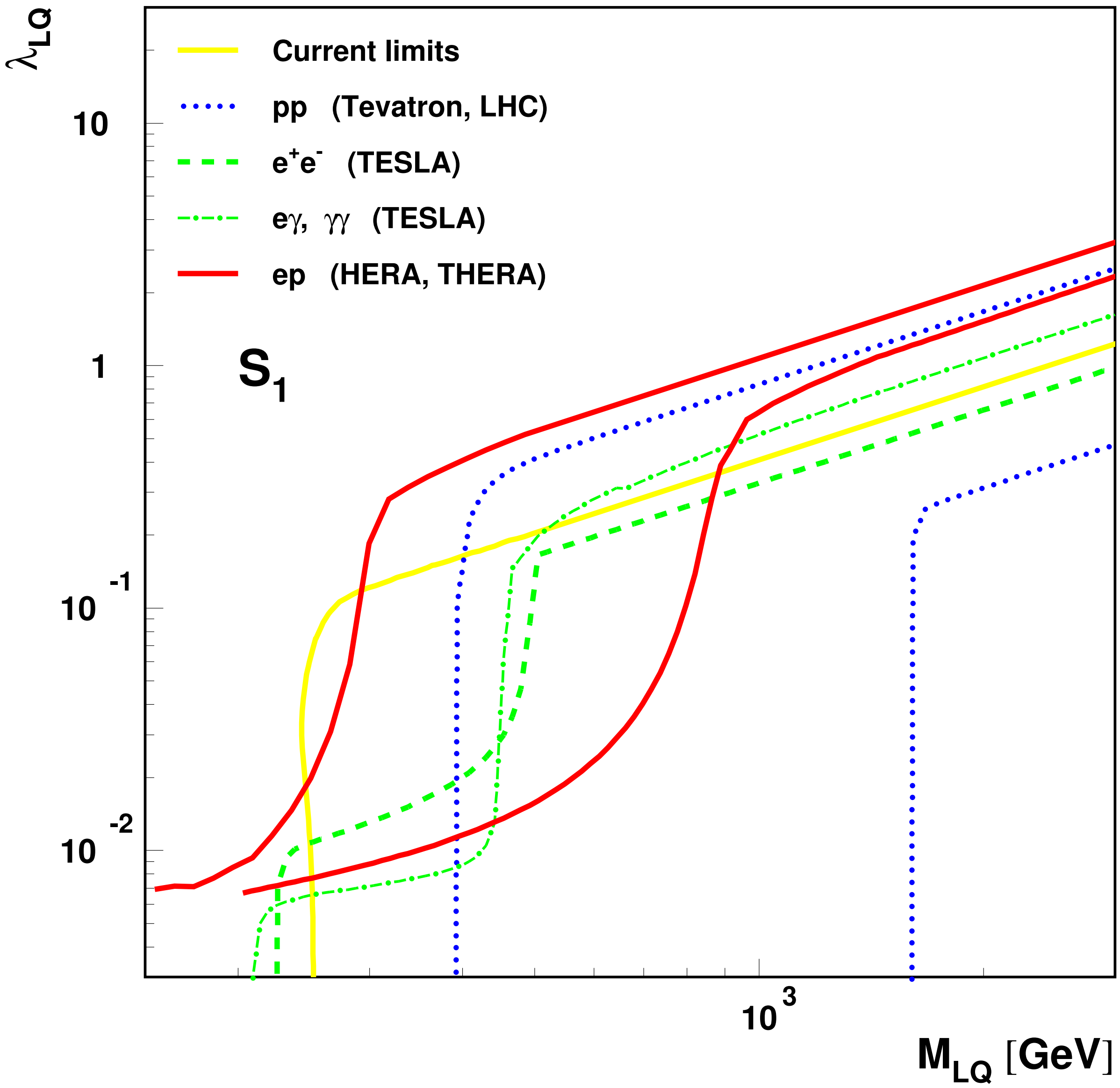
Electroweak Unification



$\Rightarrow$ New level of sensitivity to SM predictions
(CC, polarization, R.H.C.)

Leptoquarks

Exotics Group: THERA TDR



Spectroscopy ($e^{\pm}_{L,R}$)

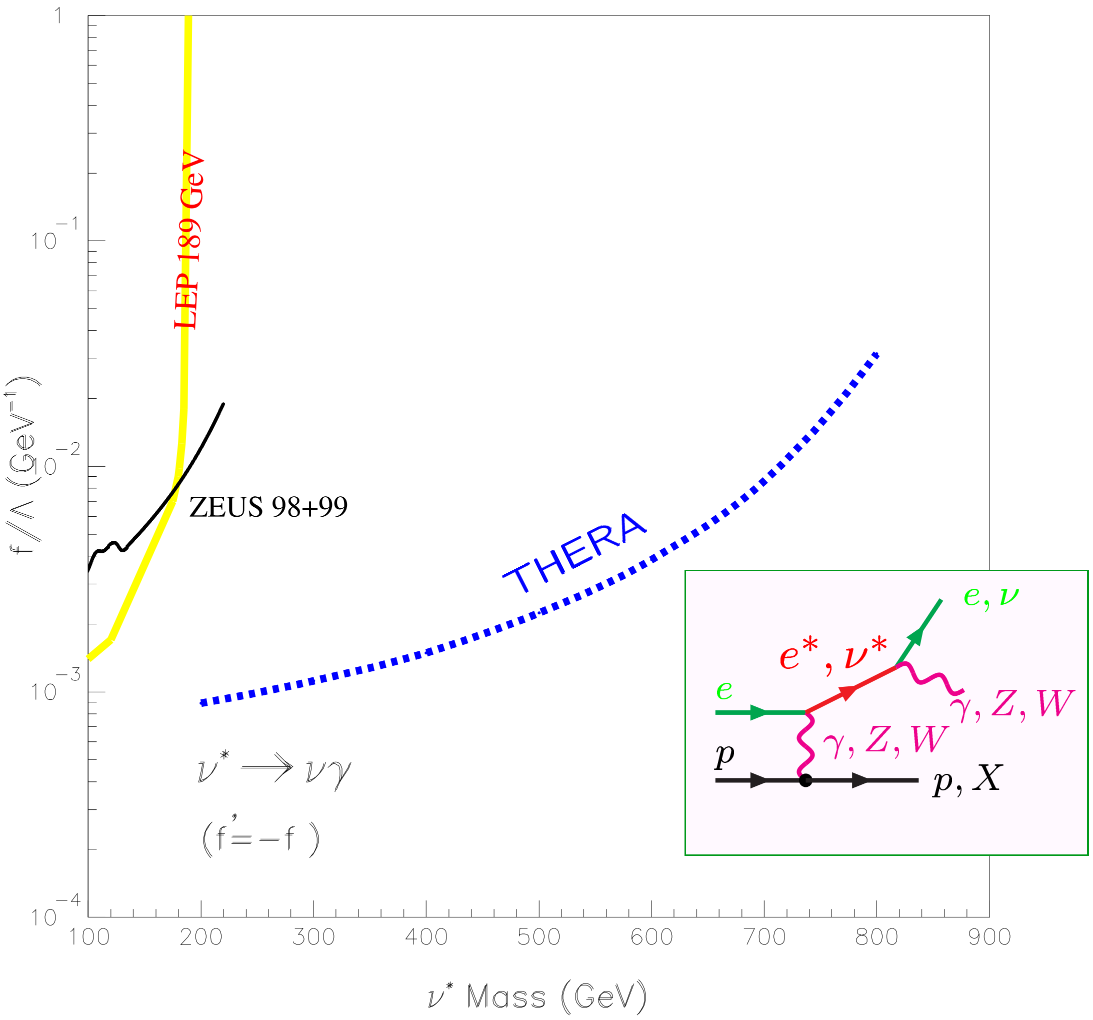
only possible if LQ within HERA range

Excited fermions

If fermions are composite ...

- e^*, ν^* and q^* can be directly produced at THERA
- competition:
  $e^+e^- \to ff^*$ at TESLA,
  $q\bar{q} \to f^*\overline{f^*}$ (Drell-Yan) at LHC
- But: cross section at LHC is suppressed
  by factor $\mathcal{O}(\alpha/\alpha_s)$ w.r.t. LQ channel

THERA 250GeV e x 920 GeV p, 30 pb -1



. Katz ECFA/DESY LC Workshop, Padova, 05.05.00 23

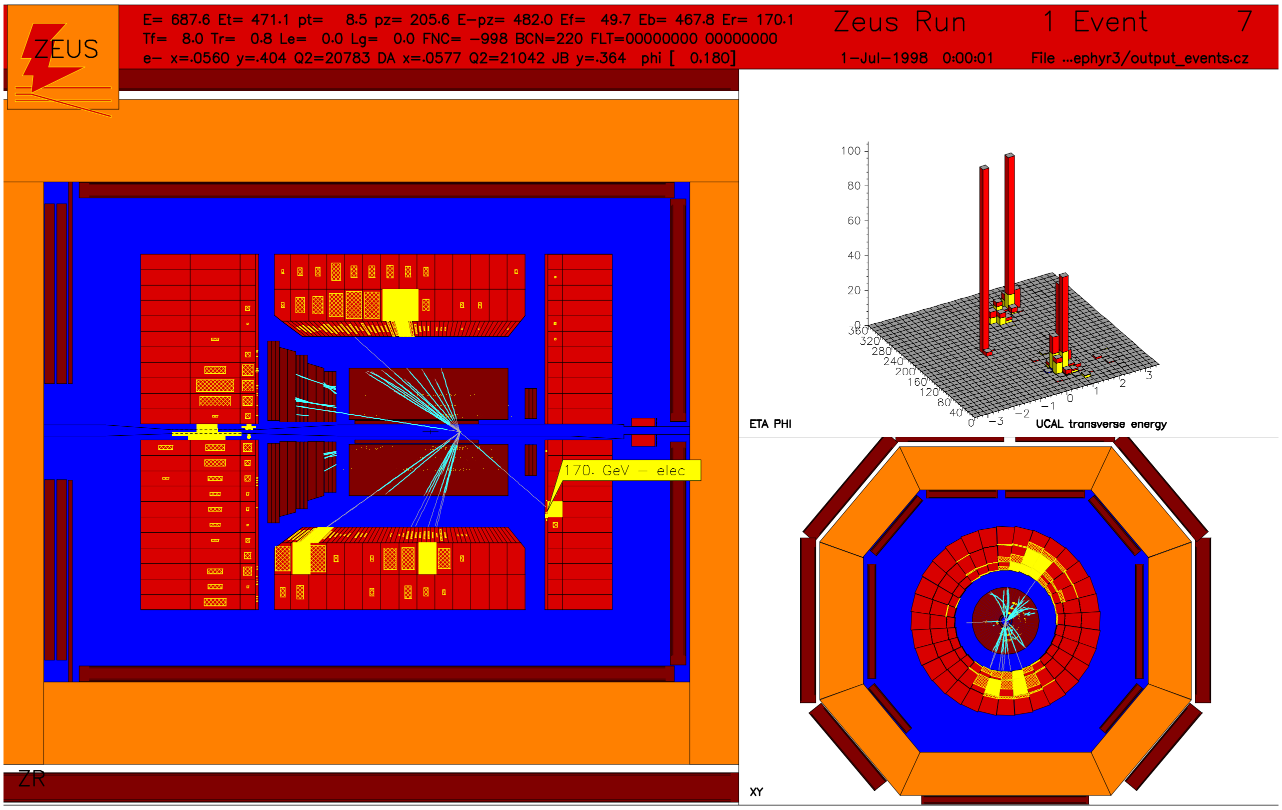
Simulated ν^* Event at THERA

$$ep \to \nu^* + jet + X \to e + 3jet + X$$

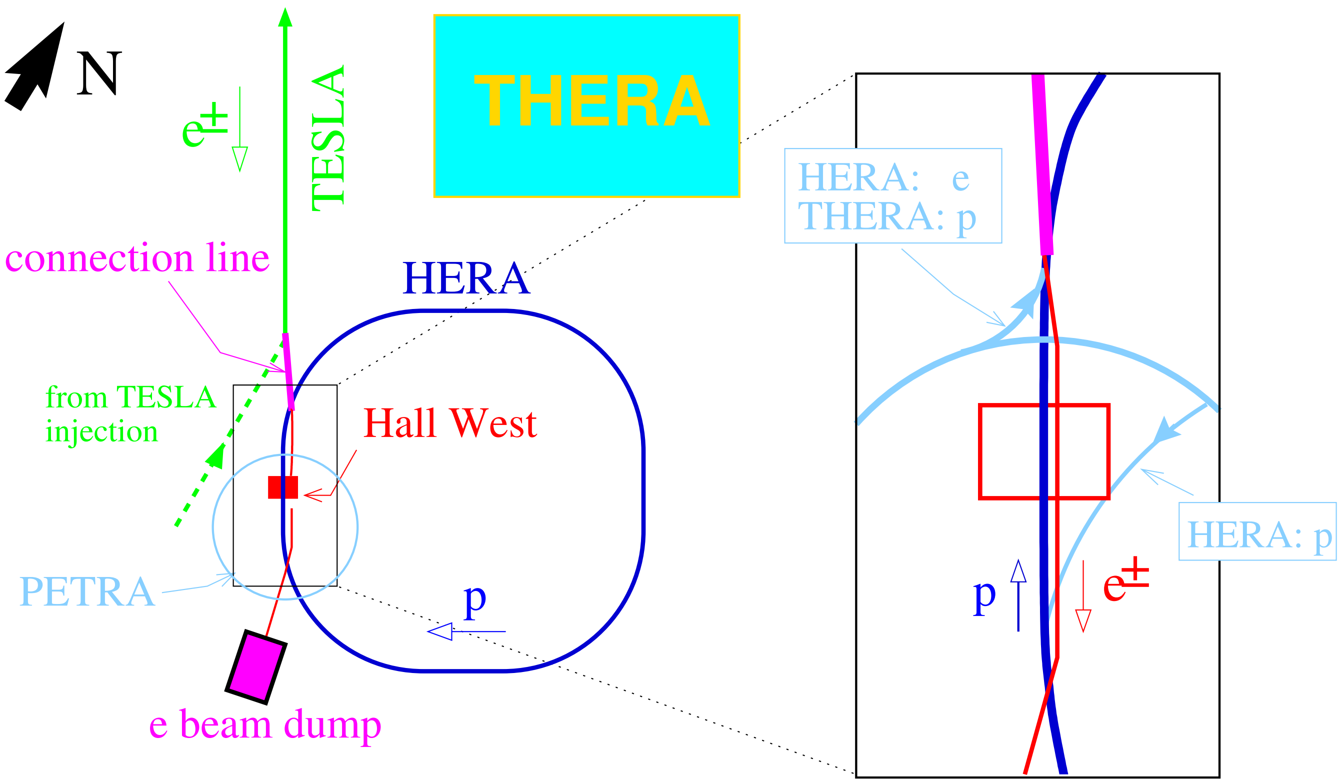
$$\nu^* \to eW \to eq\bar{q}$$

Simulated in the ZEUS detector for
250 GeV $\times$ 920 GeV

($M_{\nu^*} = 400$ GeV)



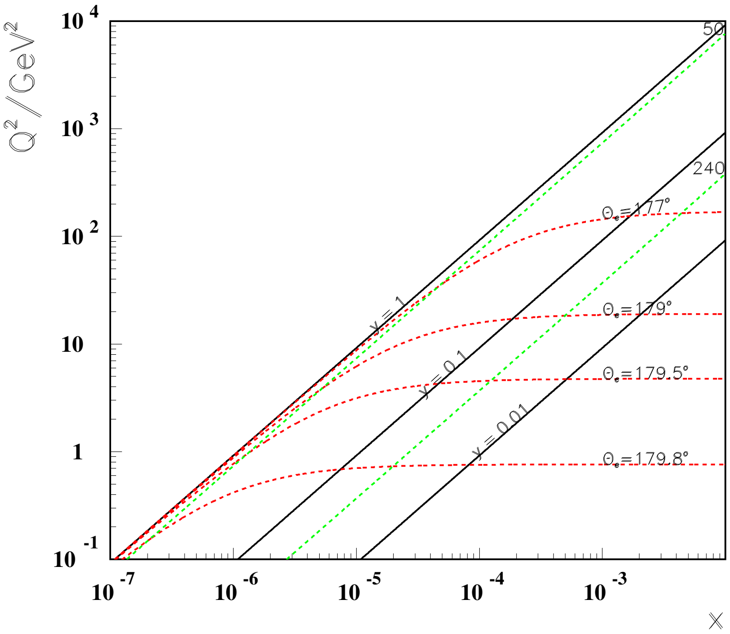
Accelerator Layout



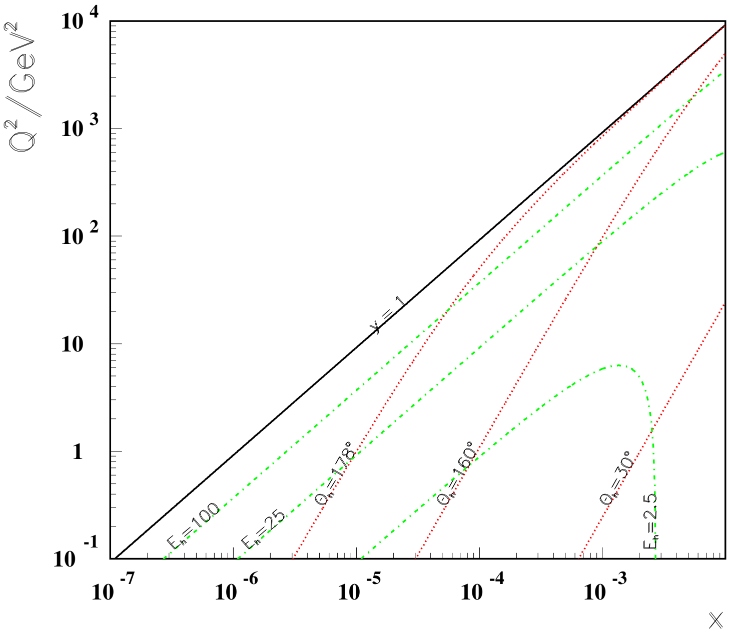
- ☞ Electron beam Energy: limited to 400 GeV (800 GeVfor two arms)
- ☞ Luminosity: Latest estimate 40 pb^{-1} per year
  Proton-cooling R&D$\rightarrow$ $\times 2.5$
- ☞ Polarization: No transfer problem
- ☞ Need to reverse proton beam
- ☞ Need electron dump

Kinematical Considerations

(250 GeV × 920 GeV)

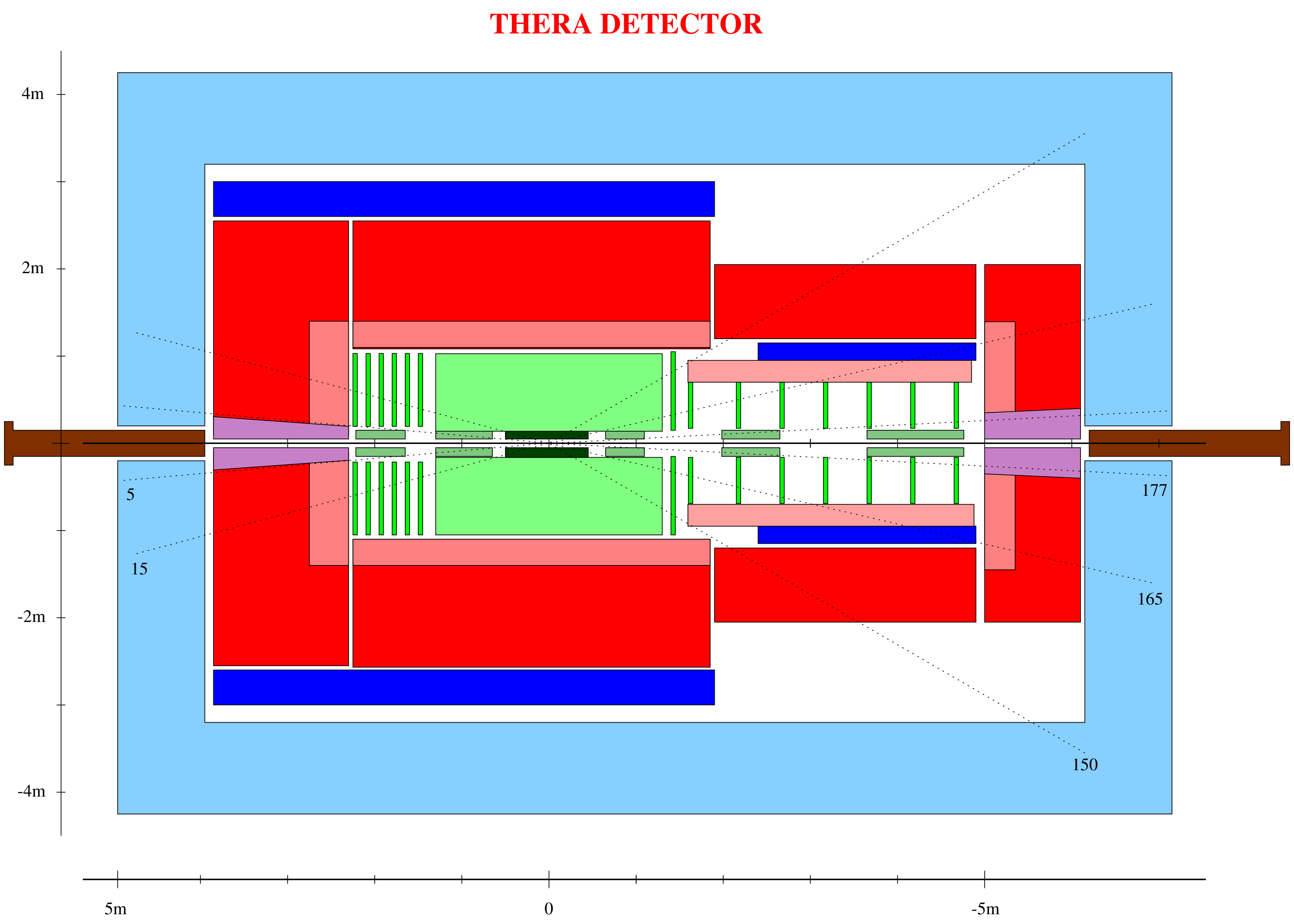


Electrons in very narrow backward cone

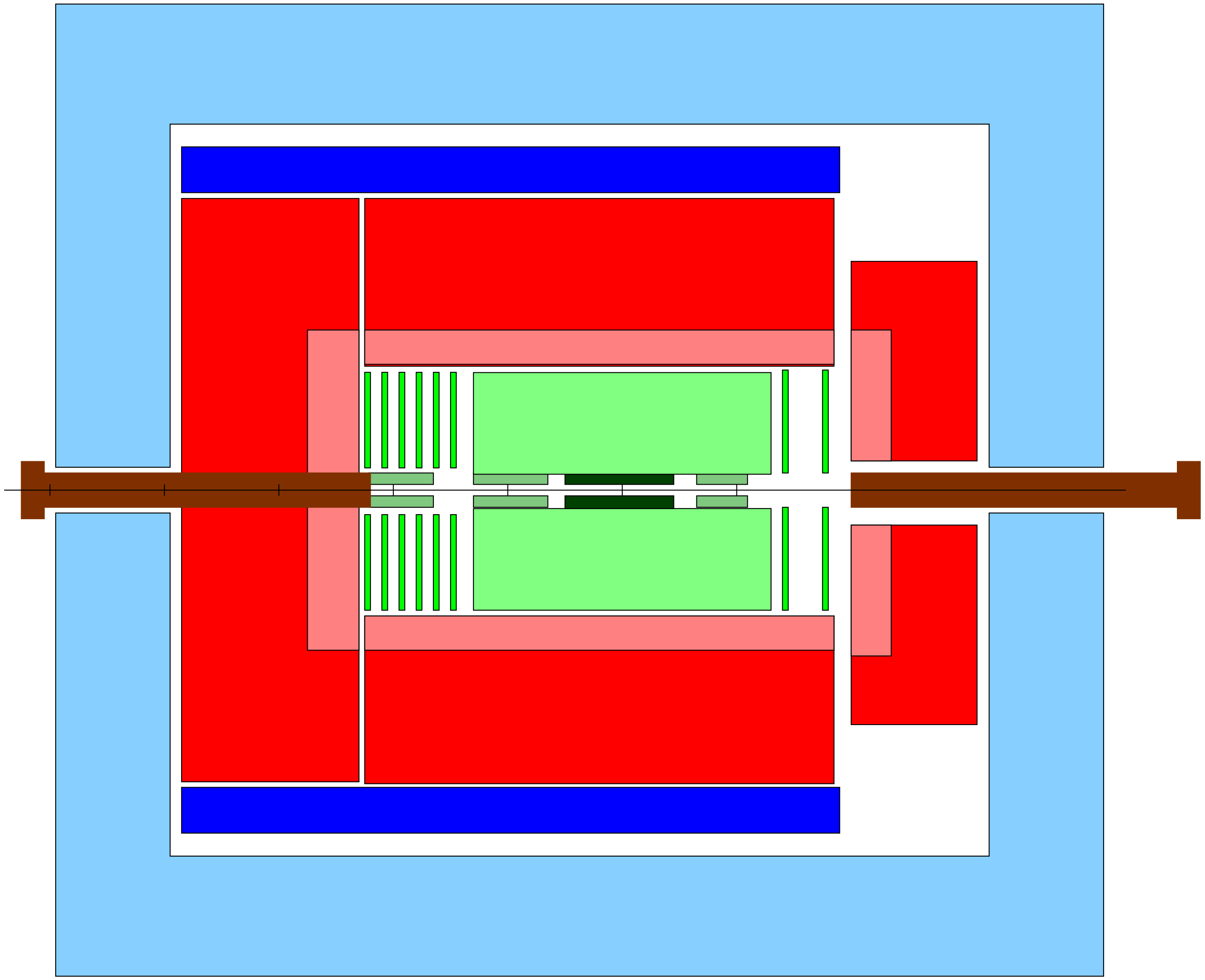


Broad spectrum of hadrons also backward

General Detector Design Considerations



The THERA Detector: High Luminosity Configuration



Conclusions

THERA is technology-driven

Experience from HERA

Community present

Golden Opportunity