B. Foster
Oxford

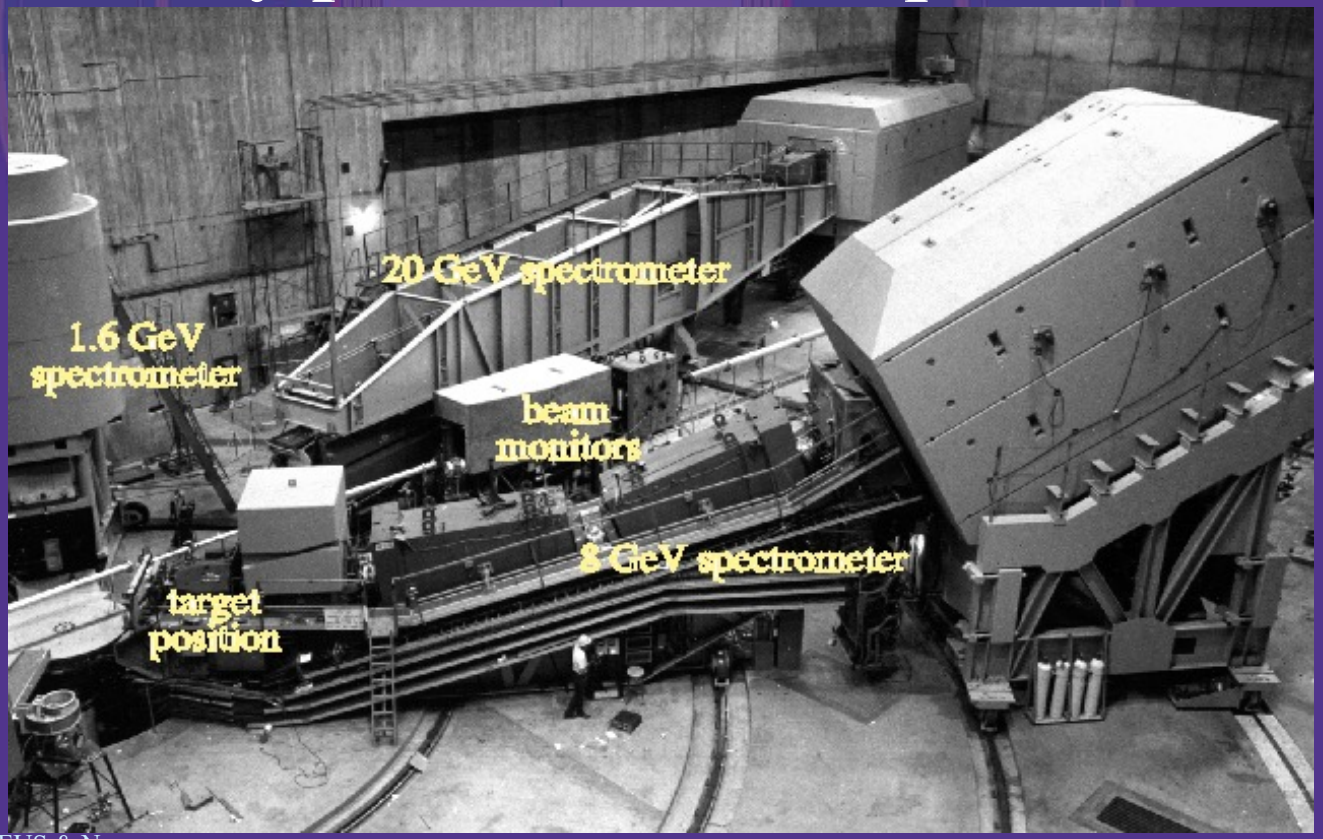
ZEUS & Nev

HARNEWFEST
28.9.22

- The early days - HERA & ZEUS
- The ZEUS detector
- The CTD & its electronics
- Installation
- A case study - the leptoquark
- Physics Highlights & final words

Prehistory

- **The SLAC-MIT experiment and the discovery of partons at SLAC in the 60s made it plain that lepton-proton scattering was a very powerful technique.**



The early meetings

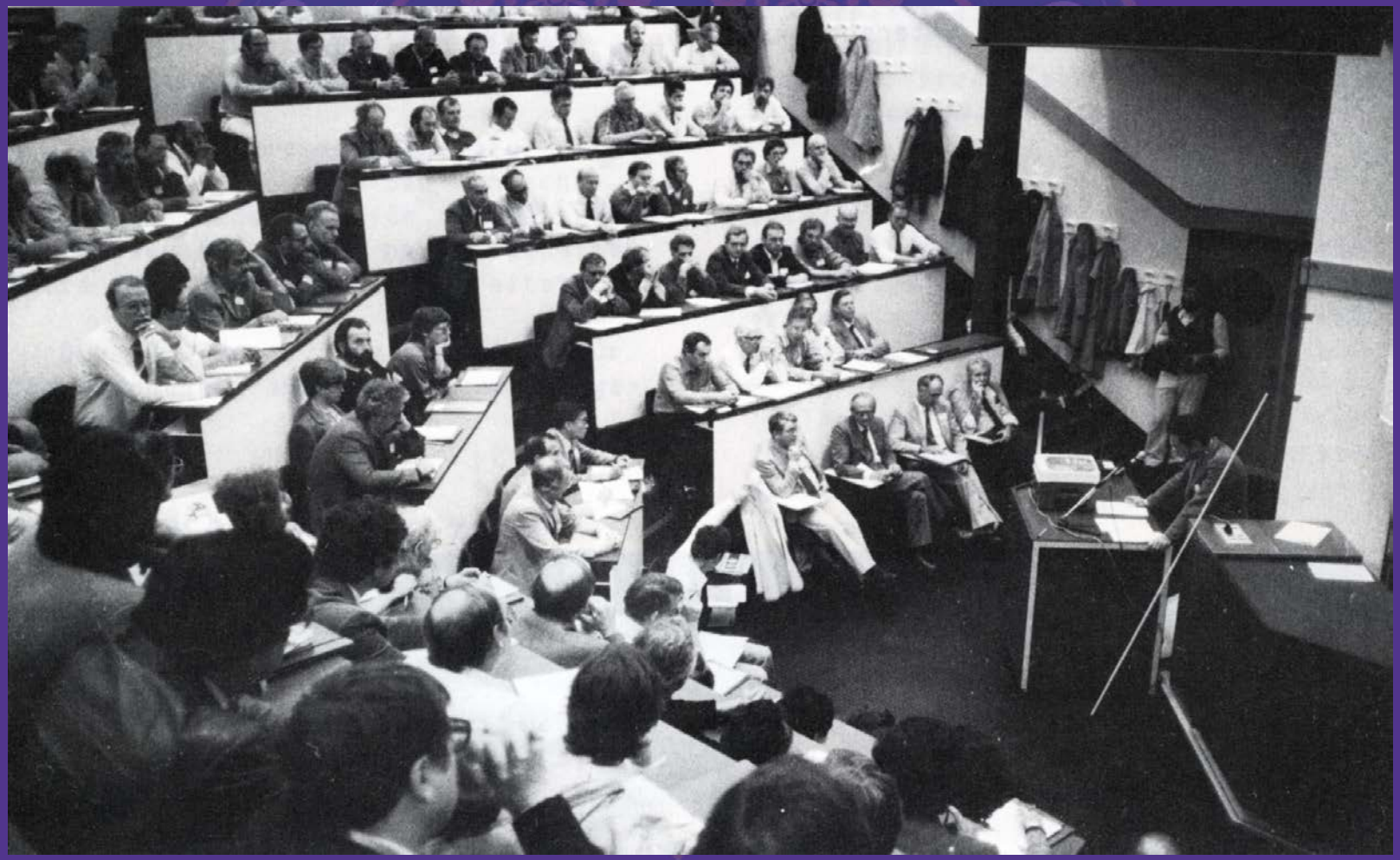
- HERA concept – 27.5 GeV e^+/e^-, 920 GeV p – in late 70's/early 80's - DESY meeting in '79; Amsterdam & Genoa meetings in '83, '84.

The early meetings

- Amsterdam in ‘83.

The early meetings

- Genoa ‘84.

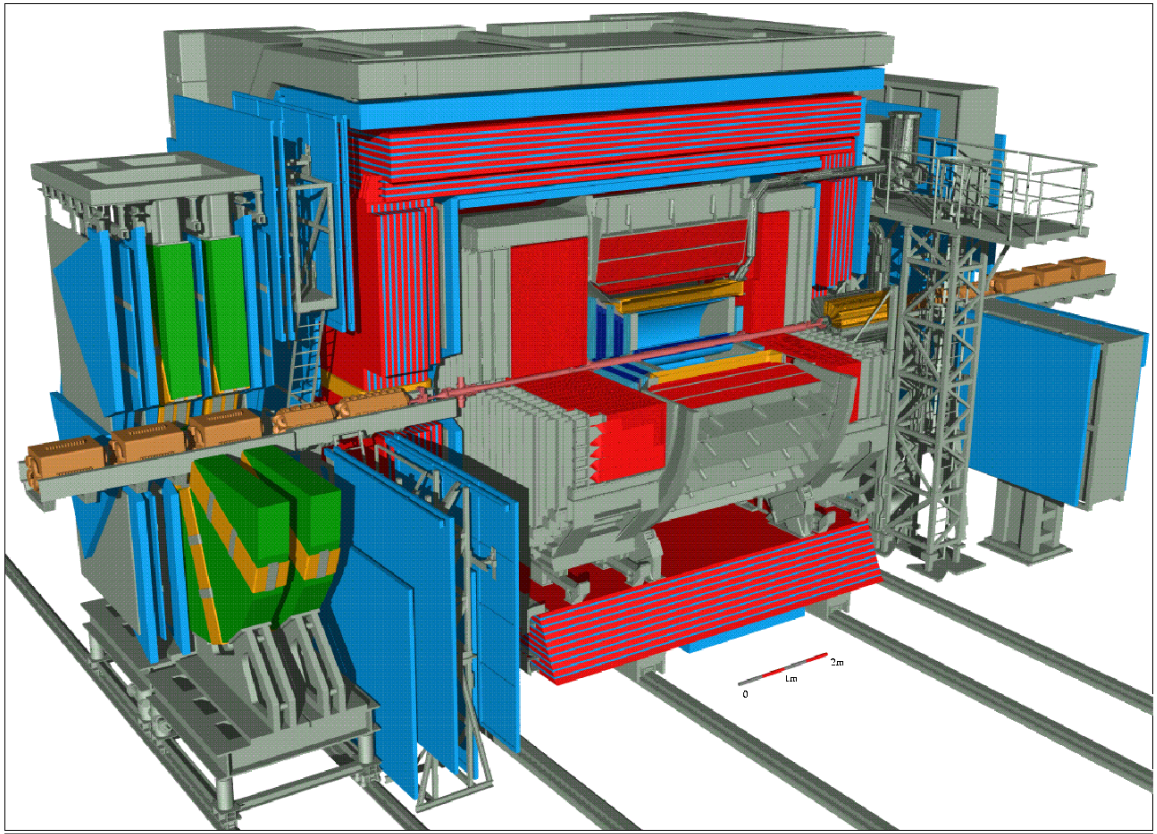


ZEUS begins

- ZEUS formed and put in an LoI in 1985 & a TP in 1986. In the meantime, HERA had been approved in 1984:

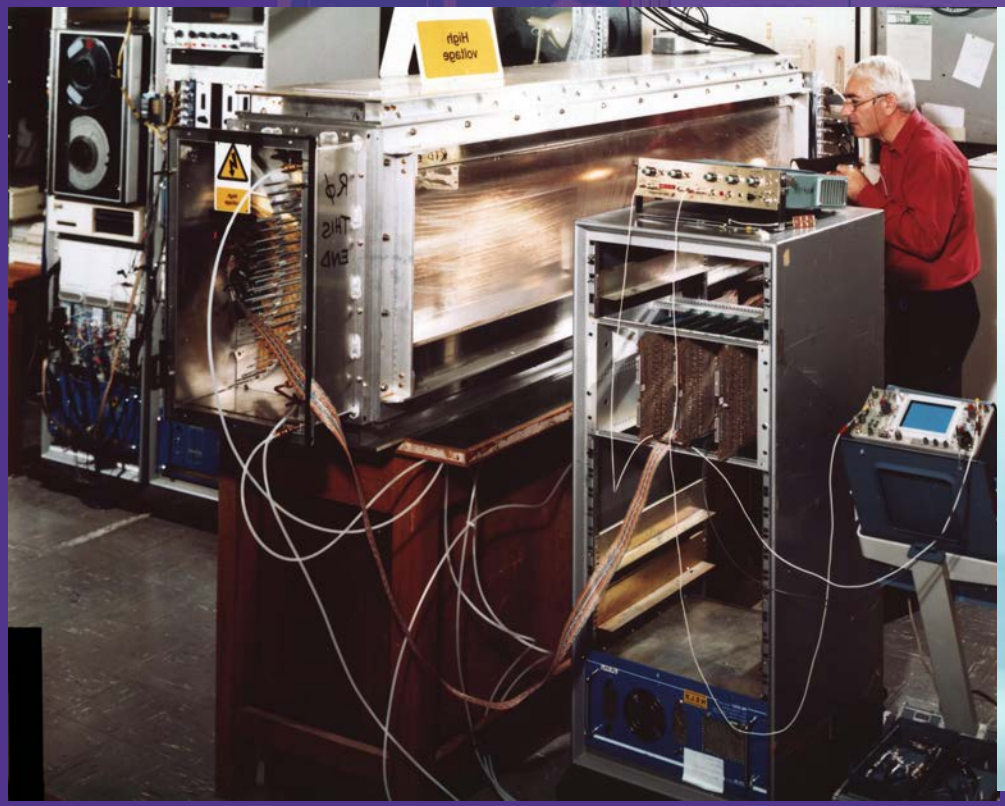
The ZEUS detector

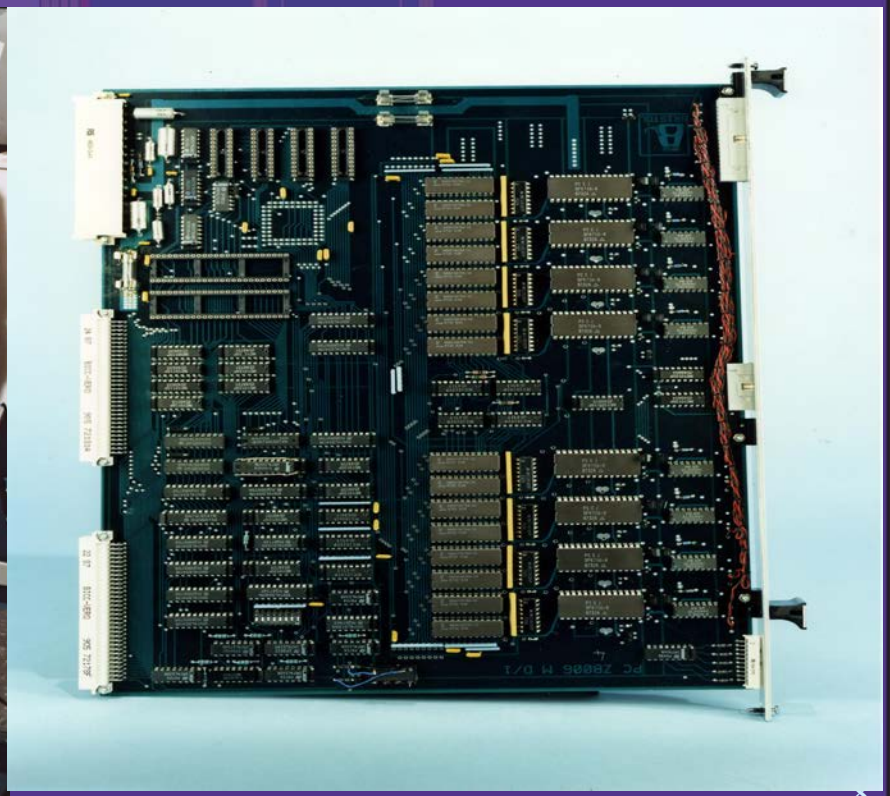
- ZEUS grew out of a core of TASSO - the chief actors shared a view of physics.
- The design drivers were: best possible energy res. => Uranium; compact, high-performance, multi-function tracking.



ZEUS Central Tracking Detector

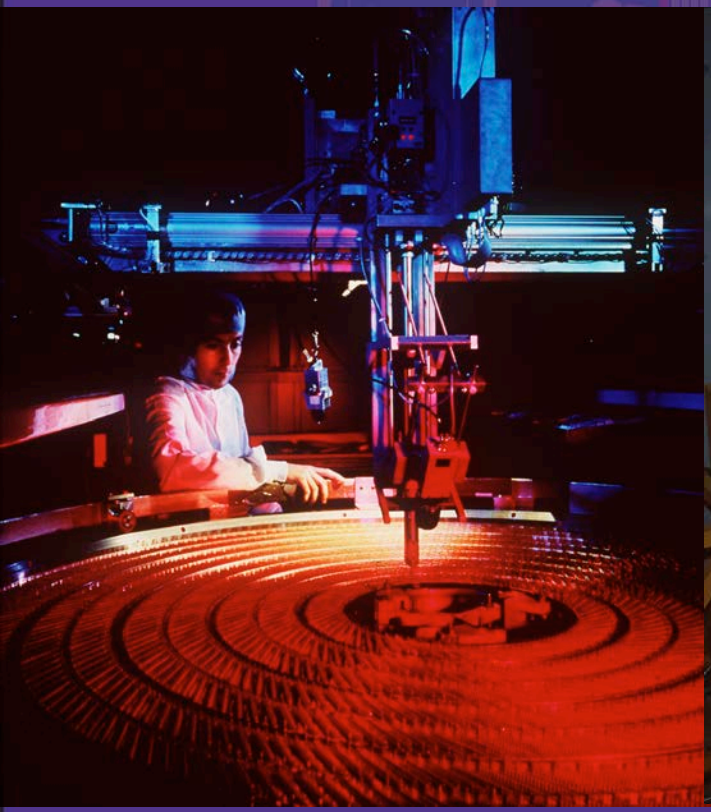
- The TASSO DC had been a great success - but moderate resolution, single function. ZEUS CTD was to have small cells cf TASSO, but to sing, dance, etc. Detailed design strongly influenced by CDF TCT.

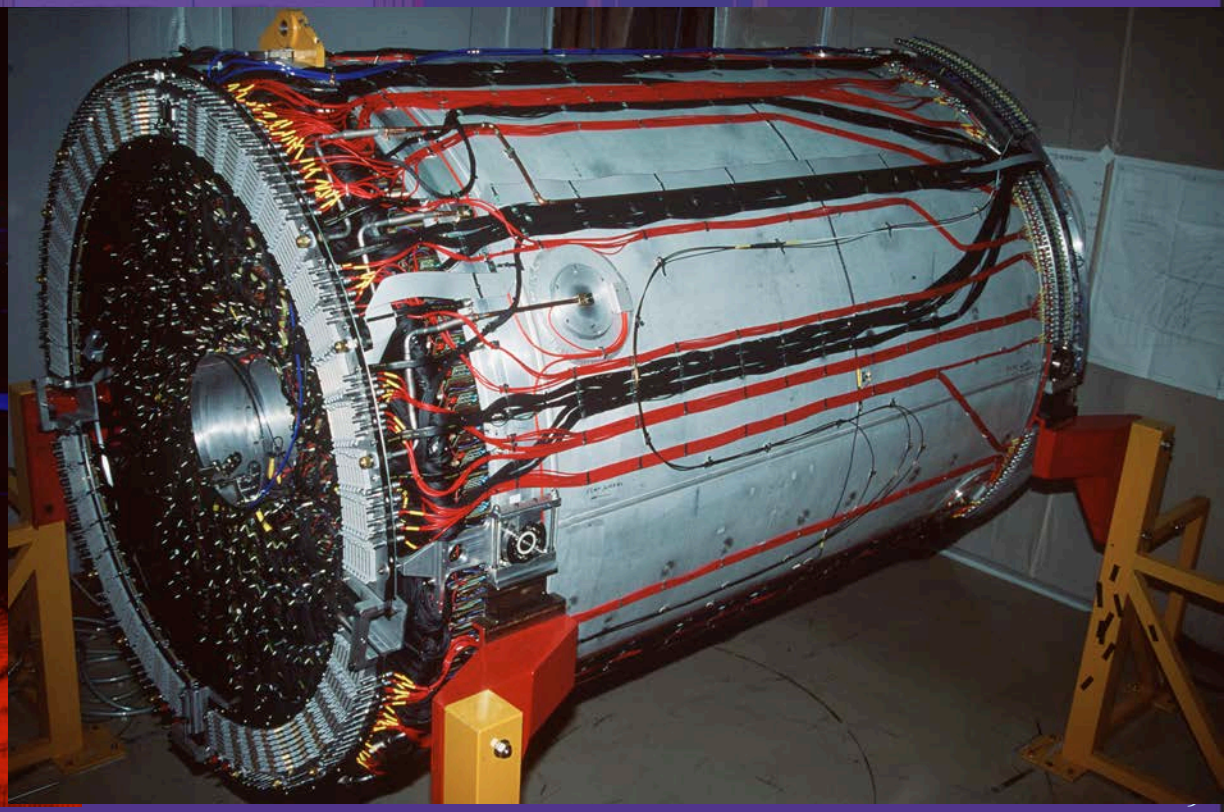




ZEUS CTD

- The TASSO DC had been a great success - but moderate resolution, single function. ZEUS CTD was to have small cells cf TASSO, but to sing, dance, etc. Detailed design strongly influenced by CDF CTC.

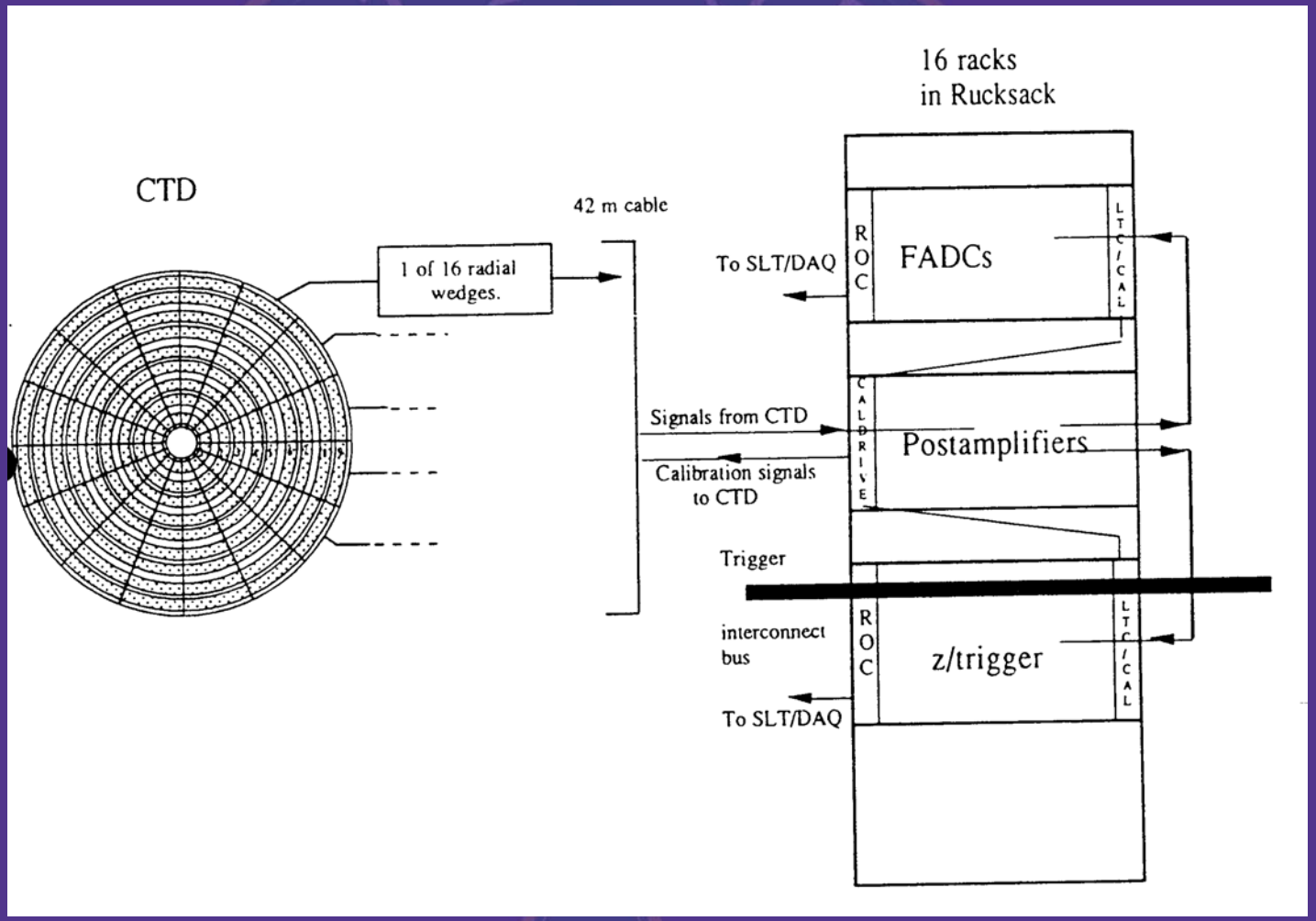




Nev appears

- Testing z-by-timing

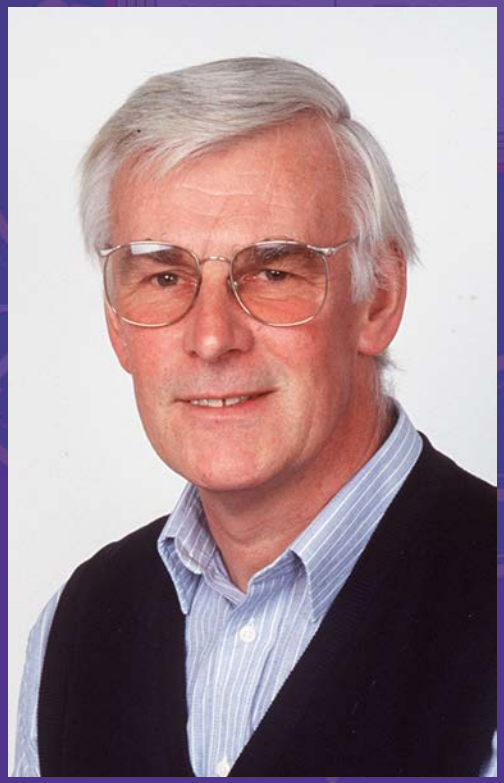
CTD Electronics



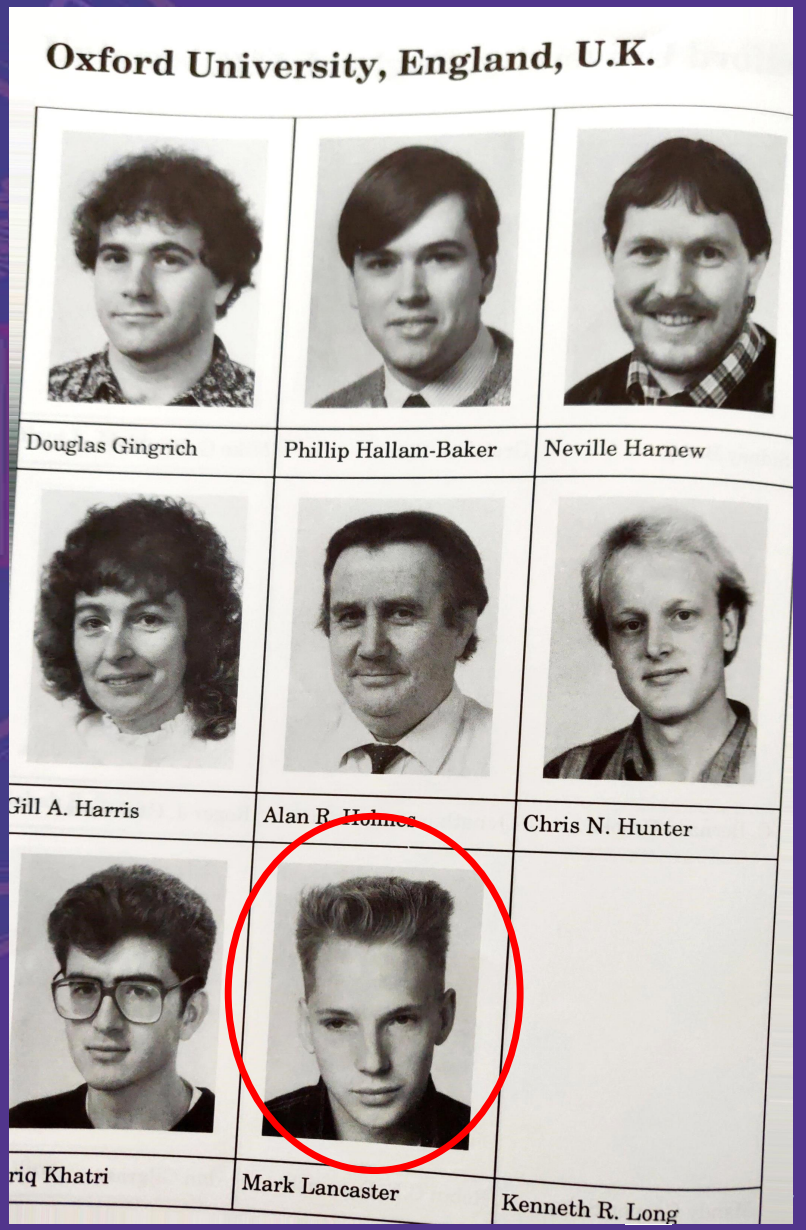
- State-of-art – first pipelined FADCs & Trigger - precursor of LHC electronics.

CTD Electronics

- It was so state-of-art that we even predicted "The Simpsons".

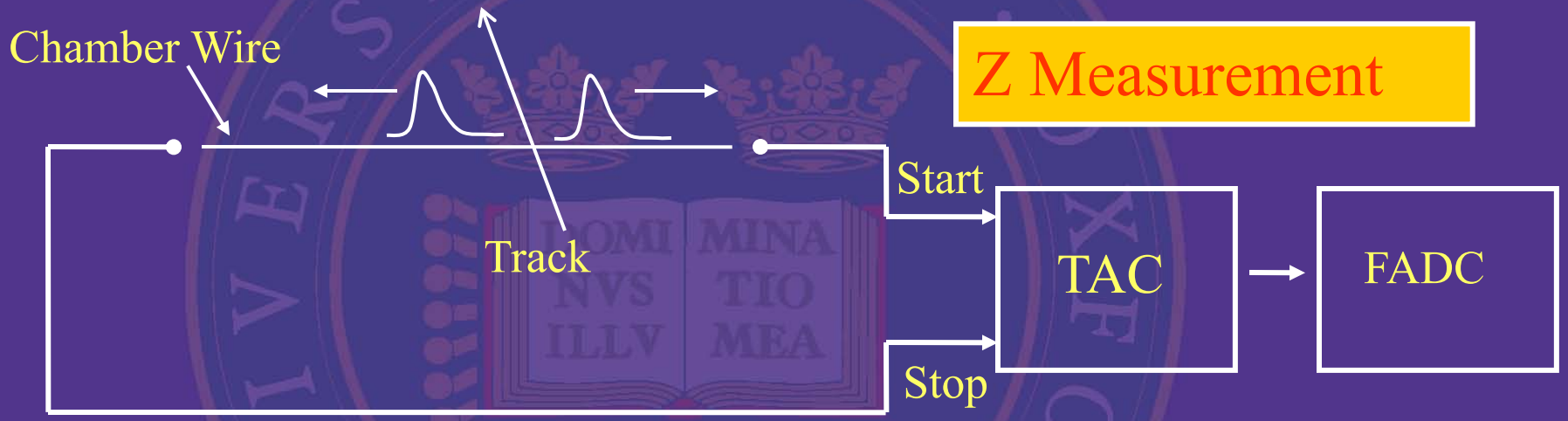


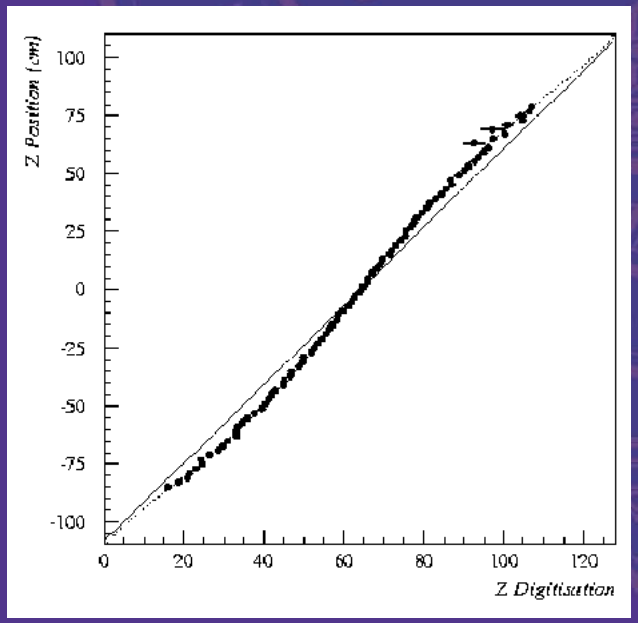
- One of the heroes of the story.



Z-by-timing

- *z*-by-timing readout

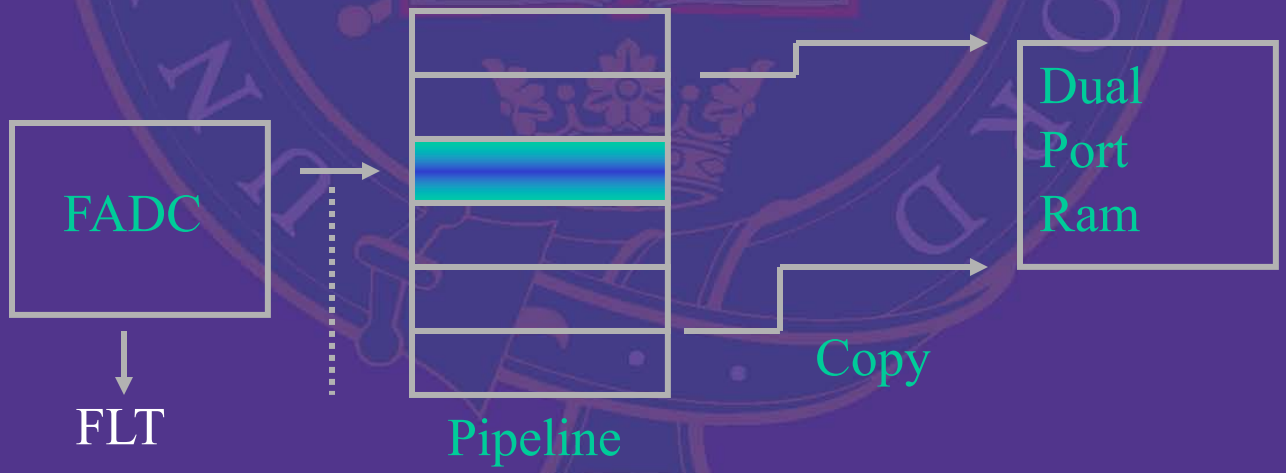




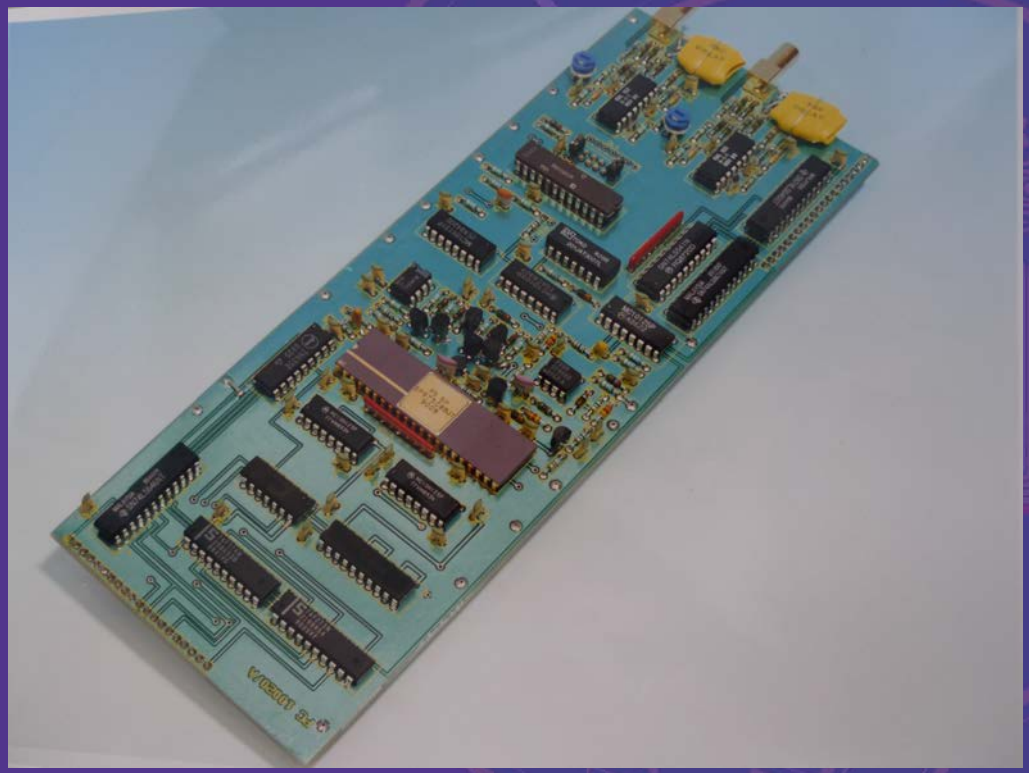
Wires terminated with LC - C from capacitance of feed-throughs + L = 1μH - to match characteristic impedance - but remaining mismatch = > S-Shape correction made online for FLT by PROMS on Z-by-T boards as well as offline

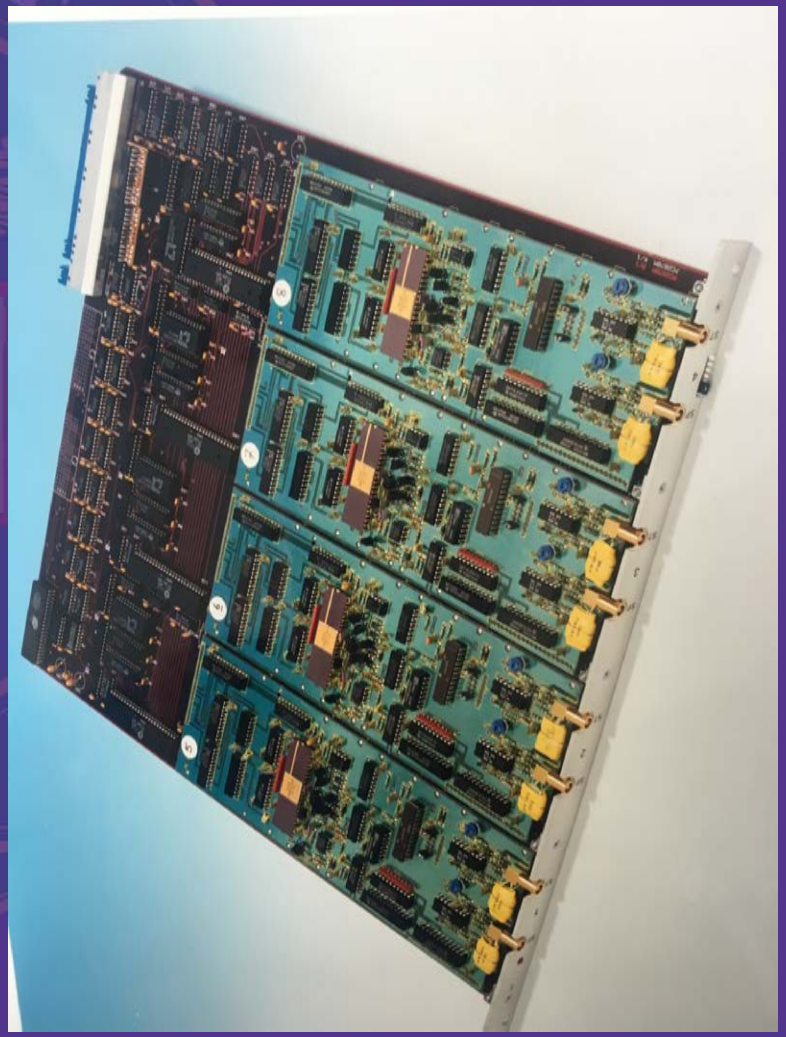
CTD operation

- *z*-by-timing readout
  - Digitised *z* positions stored in pipeline every 48ns
  - Position in pipeline gives crude drift time measurement
  - Data latched out to FLT every 48ns
  - Data copied to dual-port memory on GFLT accept



Z Electronics





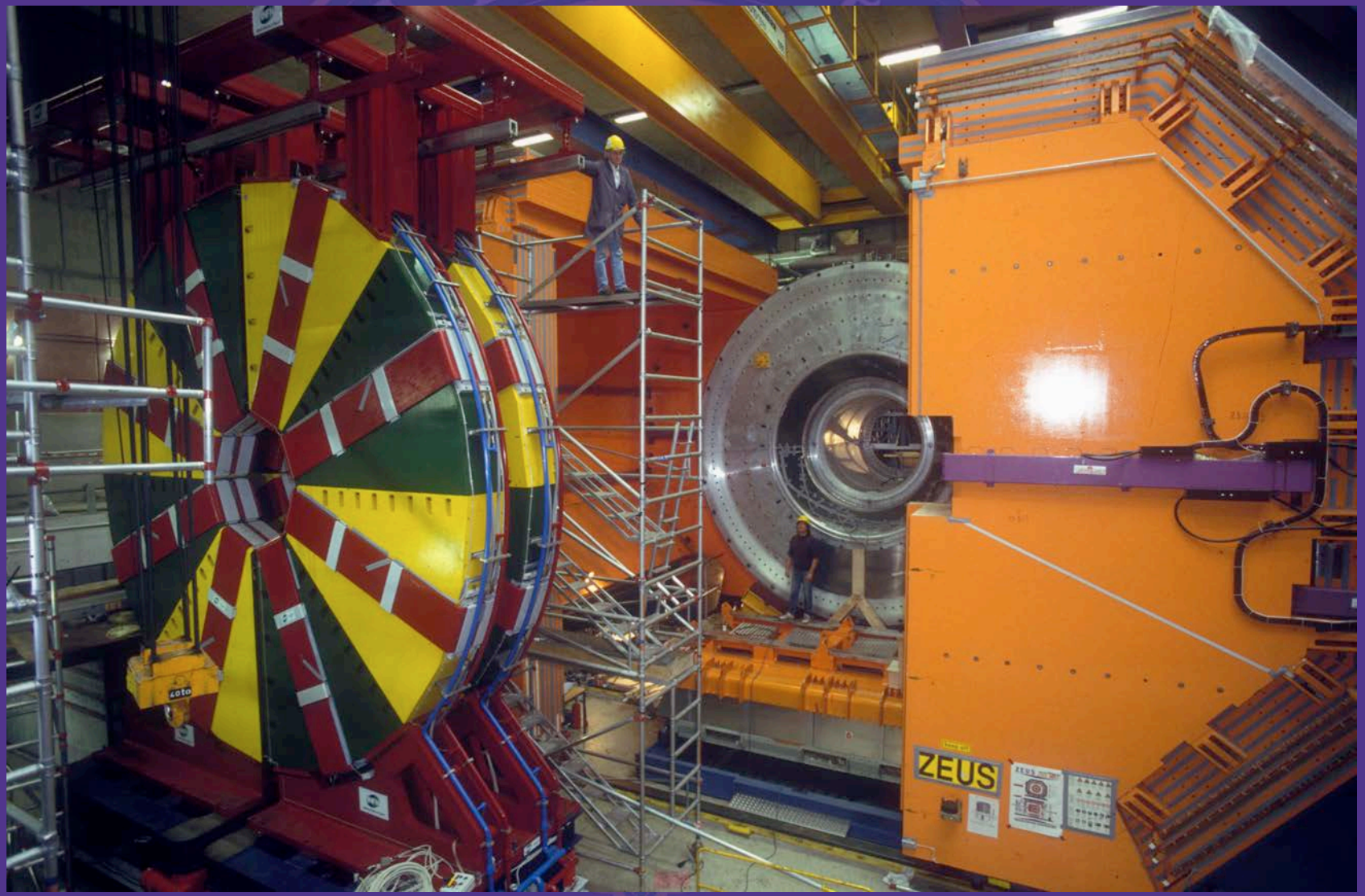
- Nev (& Tariq) got this all up and running & it worked perfectly!

ZEUS collaboration

- The ZEUS Collaboration around approval in 1986.

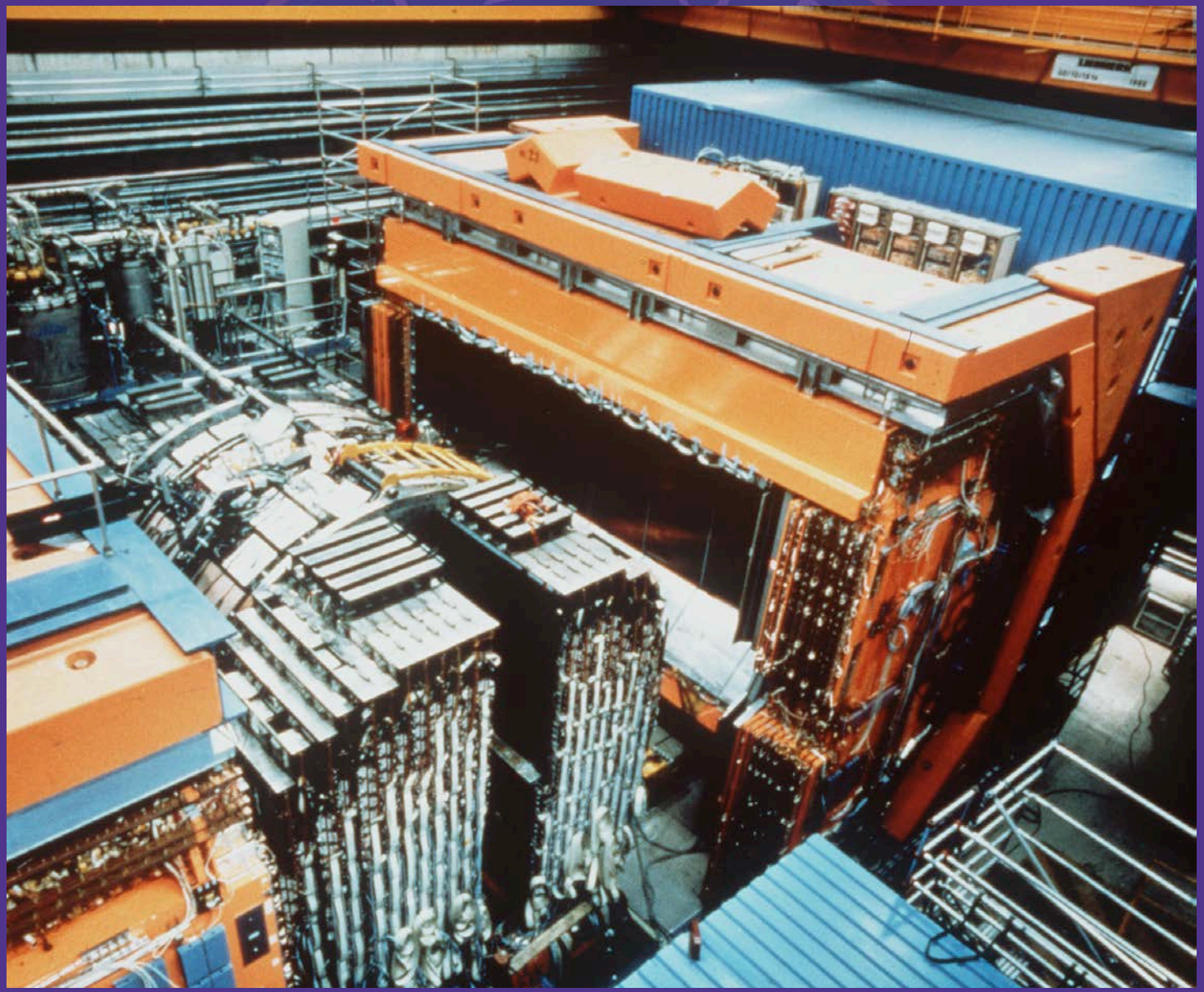
ZEUS installation

ZEUS installation

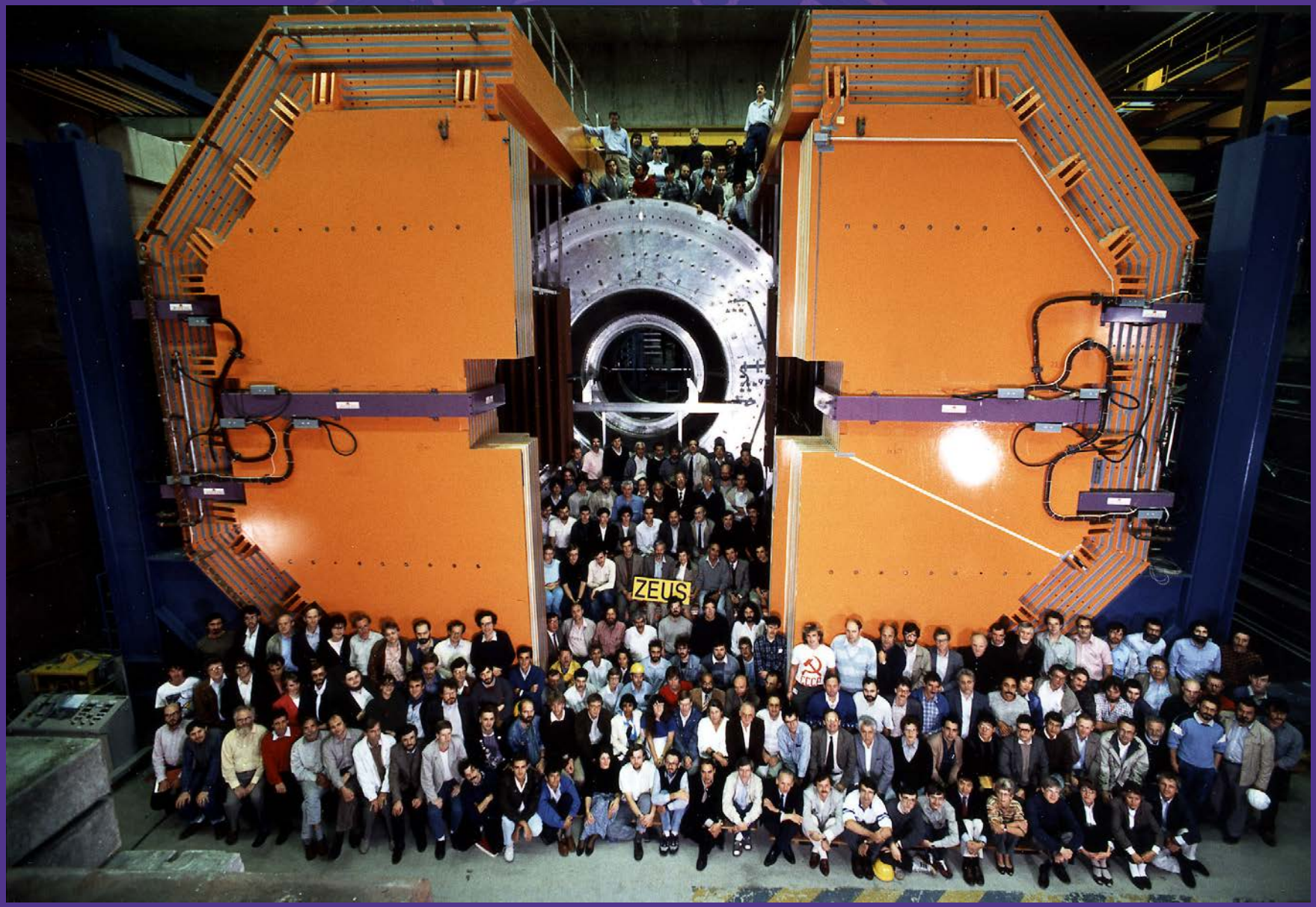


ZEUS installation

ZEUS installation

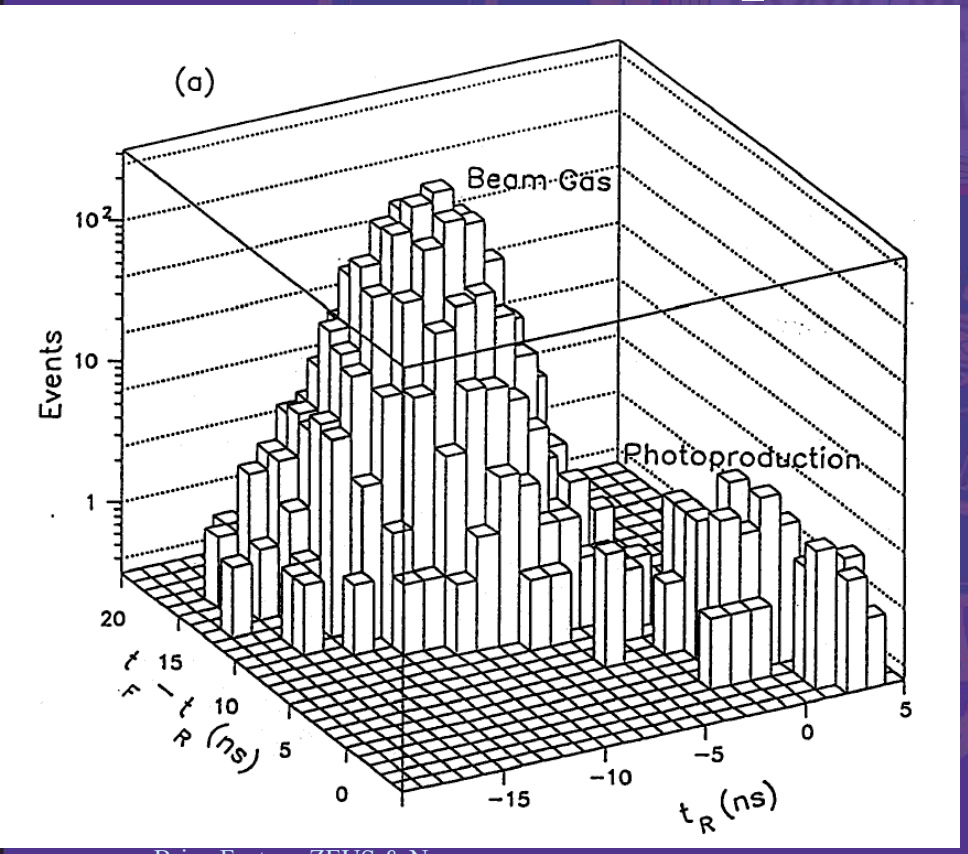


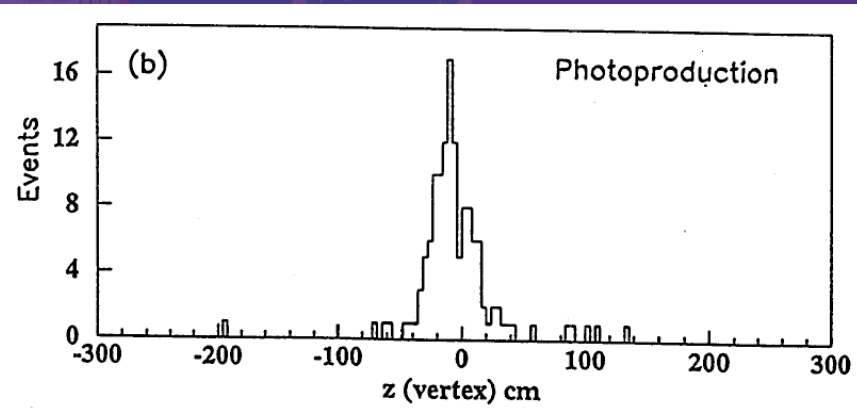
ZEUS installation

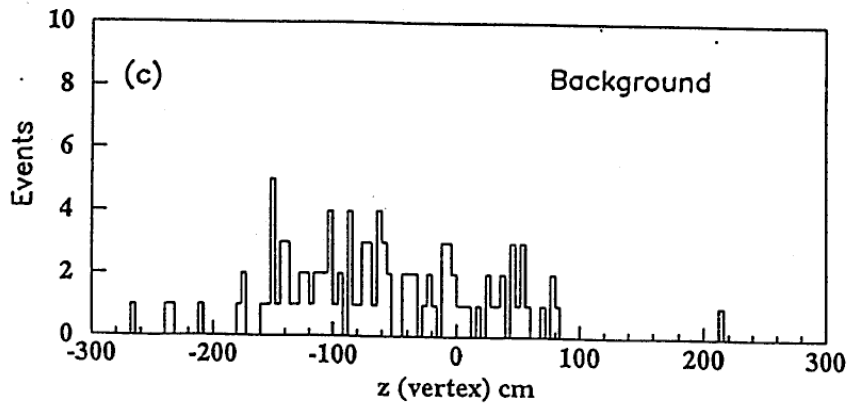


First beam

- The first lumi was seen in ZEUS at 17:40 on 31/5/92 - 1st 5 DIS events seen that day. First paper on the total cross section followed in September.



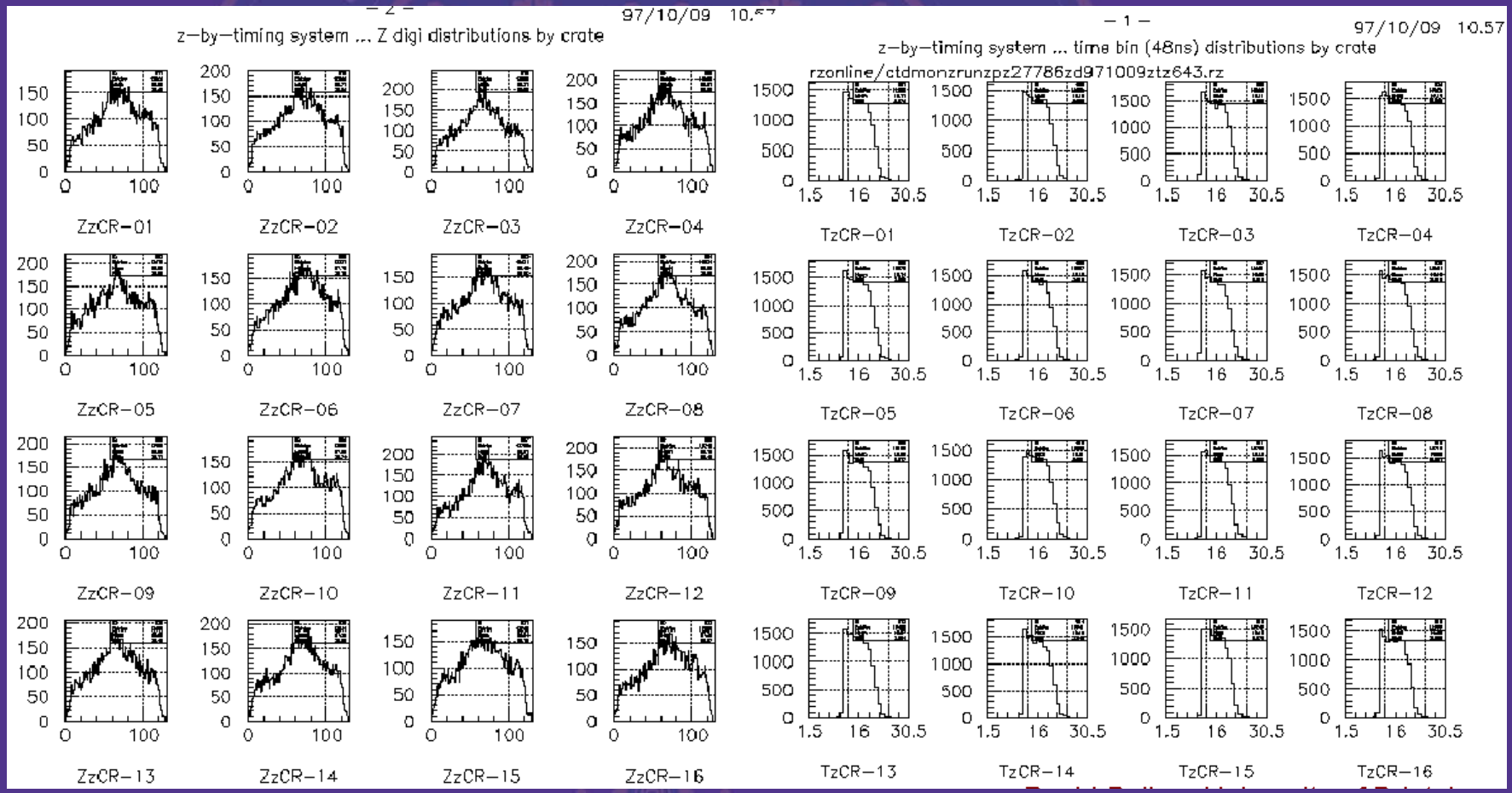




ZEUS Control Room

CTD operation

- Typical DQM plots for *z*-by-timing system:



The LQ - a case study

- **Nev's contribution to ZEUS physics:**

Physics Letters B 306 (1993) 173–186
North-Holland

PHYSICS LETTERS B

Search for leptoquarks with the ZEUS detector

ZEUS Collaboration

M. Derrick, D. Krakauer, S. Magill, B. Musgrave, J. Repond, S. Repond, R. Stanek, R.L. Talaga, J. Thron

Argonne National Laboratory, Argonne, IL, USA

F. Arzarello, R. Ayad [1], G. Bari, M. Basile, L. Bellagamba, D. Boscherini, A. Bruni, G. Bruni, P. Bruni, G. Cara Romeo, G. Castellini [2], M. Chiarini, L. Cifarelli, F. Cindolo, F. Ciralli, A. Contin, S. D'Auria, C. Del Papa, F. Frasconi, P. Giusti, G. Iacobucci, G. Laurenti, G. Levi, Q. Lin, B. Lisowski, G. Maccarrone, A. Margotti, T. Massam, R. Nania, C. Nemoz, F. Palmonari, G. Sartorelli, R. Timellini, Y. Zamora Garcia [1], A. Zichichi

University and INFN Bologna, Bologna, Italy

A. Bargende, J. Crittenden, H. Dabbous [3], K. Desch, B. Diekmann, T. Doeker, M. Geerts, G. Geitz, B. Gutjahr, H. Hartmann, D. Haun, K. Heinloth, E. Hilger, H.-P. Jakob, S. Kramarczyk, M. Kückes, A. Mass, S. Mengel, J. Mollen, D. Monaldi, H. Müsch, E. Paul, R. Schattevoy, J.-L. Schneider, R. Wedemeyer

Physikalisches Institut der Universität Bonn, Bonn, FRG

A. Cassidy, D.G. Cussans, N. Dyce, H.F. Fawcett, B. Foster, R. Gilmore, G.P. Heath, M. Lancaster, T.J. Llewellyn, J. Malos, C.J.S. Morgado, R.J. Tapper, S.S. Wilson

Bristol University, Bristol, UK

R.R. Rau

Brookhaven National Laboratory, Upton, L.I., NY, USA

M. Arneodo, T. Barillari, M. Schioppa, G. Susinno

Calabria University, Physics Department and INFN, Cosenza, Italy

A. Bernstein, A. Caldwell, I. Gialas, J.A. Parsons, S. Ritz, F. Sciulli [4], P.B. Straub, L. Wai, S. Yang

Columbia University, Nevis Labs., Irvington on Hudson, NY, USA

J. Chwastowski [5], A. Dwurażny, A. Eskreys, Z. Jakubowski [6], B. Nizioł, K. Piotrzkowski, M. Zachara, L. Zawiejski

Institute of Nuclear Physics, Cracow, Poland

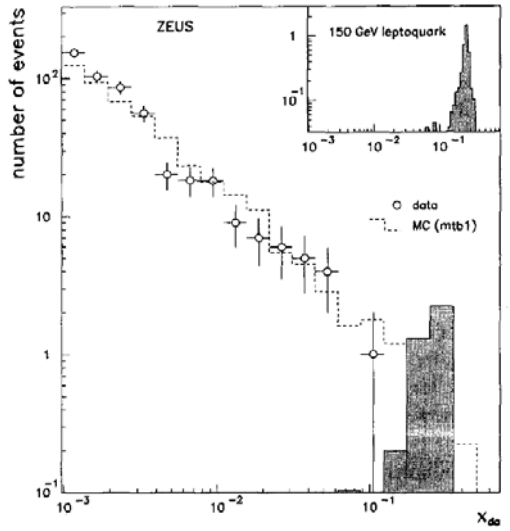
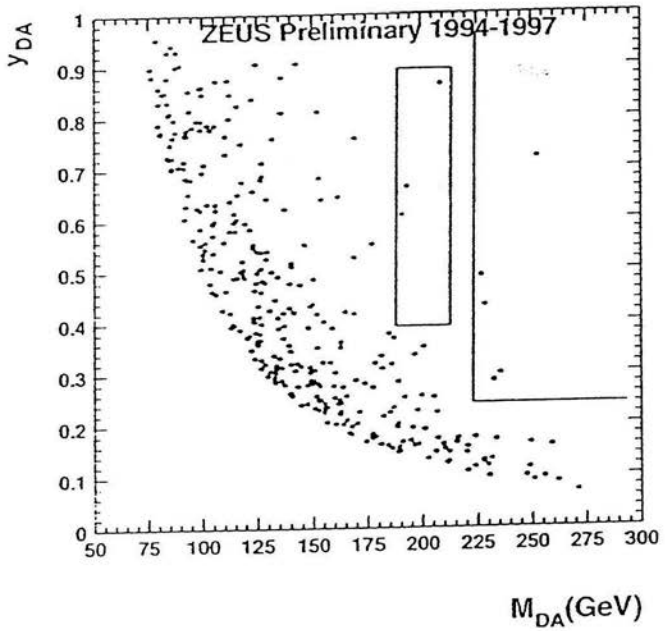


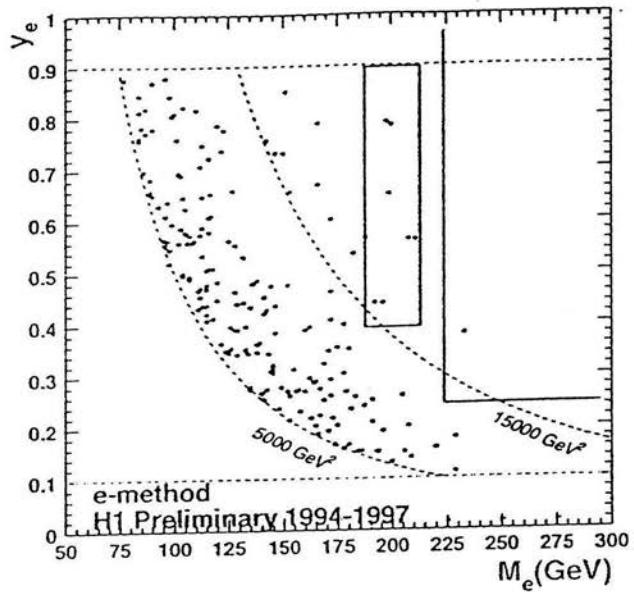
Fig. 1. Distribution in x_{DA} of the 465 events with $x_{DA} > 0.001$ in the final NC search sample (1659 candidates). The data (circles) are shown with statistical error bars. The Monte Carlo prediction, normalized to the data luminosity, is shown as the open dashed histogram. The shaded histogram at $x_{DA} \approx 0.25$ corresponds to the expected signal from a leptoquark of mass $M_{LQ} = 150$ GeV with electroweak coupling. The same distribution on an expanded scale is shown in the inset at the upper right of the figure.

- **LQs saw the one occasion where H1 & ZEUS agreed - well, sort of.**

Rich history of HERA LQ

- 1996-97: both collaborations became excited about an excess of events at high-x, high-Q^2.





- Were the excesses real? Were they compatible? What should we say? H1 & ZEUS press release caused theoretician orgasm – 100s of papers.

Rich history of ZEUS LQ

- But hope springs eternal!

PHYSICAL REVIEW D 99, 092006 (2019)

Limits on contact interactions and leptoquarks at HERA

H. Abramowicz,[26,q] I. Abt,[21] L. Adamczyk,[7] M. Adamus,[33] R. Aggarwal,[3,b] S. Antonelli,[1] V. Aushev,[18] O. Behnke,[9] U. Behrens,[9] A. Bertolin,[23] I. Bloch,[10] I. Brock,[2] N. H. Brook,[31,r] R. Brugnera,[24] A. Bruni,[1] P. J. Bussey,[11] A. Caldwell,[21] M. Capua,[4] C. D. Catterall,[35] J. Chwastowski,[6] J. Ciborowski,[32,t] R. Ciesielski,[9,e] A. M. Cooper-Sarkar,[22] M. Corradi,[1,a] R. K. Dementiev,[20] R. C. E. Devenish,[22] S. Dusini,[23] J. Ferrando,[9] B. Foster,[13,j] E. Gallo,[13,k] A. Garfagnini,[24] A. Geiser,[9] A. Gizhko,[9] L. K. Gladilin,[20] Yu. A. Golubkov,[20] G. Grzelak,[32] C. Gwenlan,[22] O. Hlushchenko,[18,o] D. Hochman,[34] Z. A. Ibrahim,[5] Y. Iga,[25] N. Z. Jomhari,[9] I. Kadenko,[18] S. Kananov,[26] U. Karshon,[34] P. Kaur,[3,c] D. Kisielewska,[7] R. Klanner,[13] U. Klein,[9,f] I. A. Korzhavina,[20] A. Kotański,[8] N. Kovalchuk,[13] H. Kowalski,[9] B. Krupa,[6] O. Kuprash,[9,g] M. Kuze,[28] B. B. Levchenko,[20] A. Levy,[26] V. Libov,[9] M. Lisovyi,[9,h] B. Löhr,[9] E. Lohrmann,[13] A. Longhin,[24] O. Yu. Lukina,[20] I. Makarenko,[9] J. Malka,[9] S. Mascioccchi,[12,l] F. Mohamad Idris,[5,d] N. Mohammad Nasir,[5] V. Myronenko,[9] K. Nagano,[15] J. D. Nam,[27] M. Nicassio,[14] J. Onderwaater,[14,m] Yu. Onishchuk,[18] E. Paul,[2] I. Pidhurskyi,[18] N. S. Pokrovskiy,[16] A. Polini,[1] M. Przybycień,[7] A. Quintero,[27] M. Ruspa,[30] D. H. Saxon,[11] M. Schioppa,[4] U. Schneekloth,[9] T. Schörner-Sadenius,[9] I. Selyuzhenkov,[12] M. Shchedrolosiev,[18] L. M. Shcheglova,[20,p] Yu. Shyrma,[17] I. O. Skillicorn,[11] W. Słomiński,[8] A. Solano,[29] L. Stanco,[23] N. Stefaniuk,[9] A. Stern,[26] P. Stopa,[6] B. Surrow,[27] J. Sztuk-Dambietz,[13,j] E. Tassi,[4] K. Tokushuku,[15] J. Tomaszewska,[32,u] T. Tsurugai,[19] M. Turcato,[13,i] O. Turkot,[9] T. Tymieniecka,[33] A. Verbytskyi,[21] W. A. T. Wan Abdullah,[5] K. Wichmann,[9] M. Wing,[31,s] S. Yamada,[15] Y. Yamazaki,[15,n] A. F. Żarnecki,[32] L. Zawiejski,[6] O. Zenaiev,[9] and B. O. Zhautykov[16]

(ZEUS Collaboration)

[1]*INFN Bologna, Bologna, Italy*
[2]*Physikalisches Institut der Universität Bonn, Bonn, Germany*
[3]*Panjab University, Department of Physics, Chandigarh, India*
[4]*Calabria University, Physics Department and INFN, Cosenza, Italy*
[5]*National Centre for Particle Physics, Universiti Malaya, 50603 Kuala Lumpur, Malaysia*
[6]*The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland*
[7]*AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow, Poland*
[8]*Department of Physics, Jagellonian University, Krakow, Poland*
[9]*Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany*
[10]*Deutsches Elektronen-Synchrotron DESY, Zeuthen, Germany*
[11]*School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom*
[12]*GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany*
[13]*Hamburg University, Institute of Experimental Physics, Hamburg, Germany*
[14]*Physikalisches Institut of the University of Heidelberg, Heidelberg, Germany*
[15]*Institute of Particle and Nuclear Studies, KEK, Tsukuba, Japan*
[16]*Institute of Physics and Technology of Ministry of Education and Science of Kazakhstan, Almaty, Kazakhstan*
[17]*Institute for Nuclear Research, National Academy of Sciences, Kyiv, Ukraine*
[18]*Department of Nuclear Physics, National Taras Shevchenko University of Kyiv, Kyiv, Ukraine*
[19]*Meiji Gakuin University, Faculty of General Education, Yokohama, Japan*
[20]*Lomonosov Moscow State University, Skobeltsyn Institute of Nuclear Physics, Moscow, Russia*
[21]*Max-Planck-Institut für Physik, München, Germany*
[22]*Department of Physics, University of Oxford, Oxford, United Kingdom*
[23]*INFN Padova, Padova, Italy*

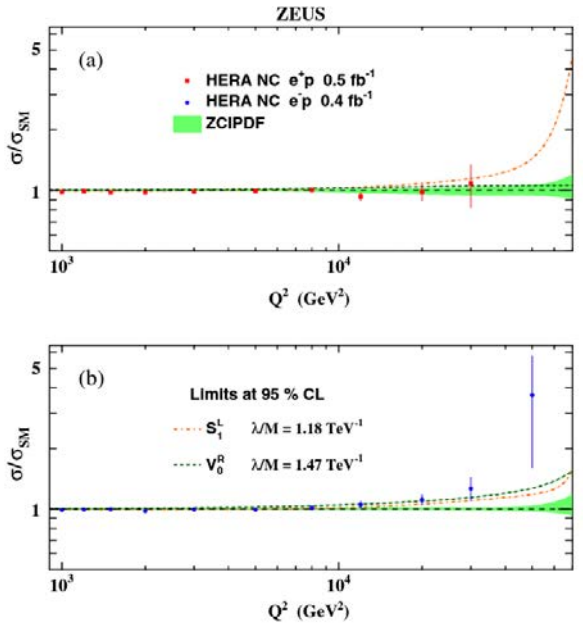
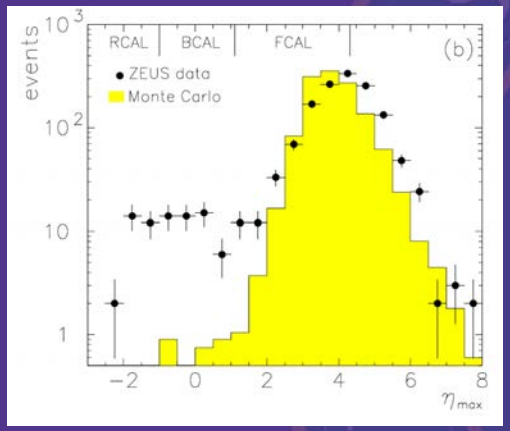


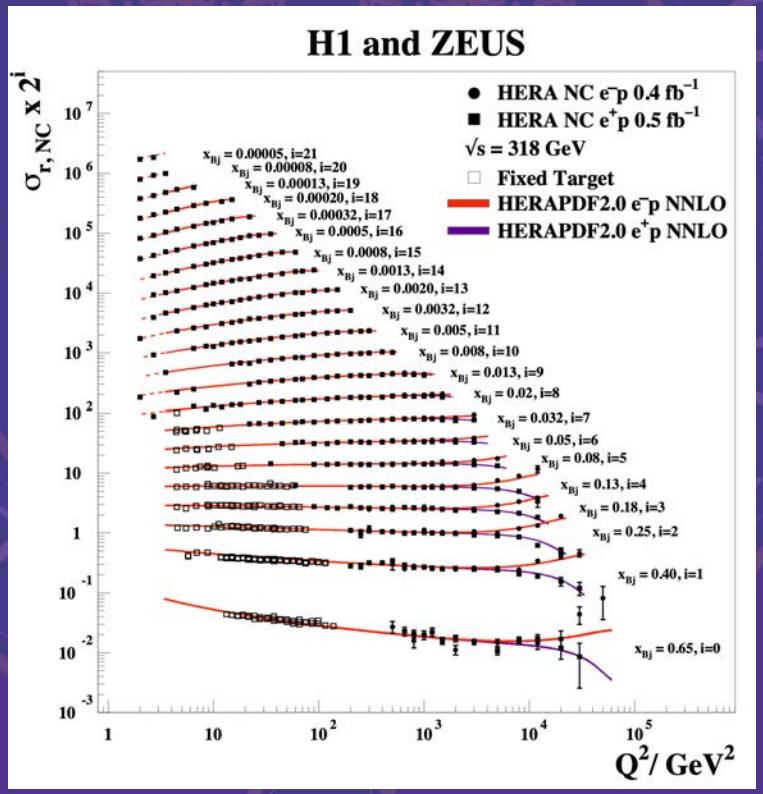
FIG. 6. HERA (a) e^+p and (b) e^-p NC DIS data, relative to the SM expectations based on the ZCIPDF fit to the HERA inclusive data, compared to expectations from the S_1^L and V_0^R leptoquark models with the ratios of the LQ Yukawa couplings to the LQ mass, λ/M, corresponding to the 95% C.L. limits. The same two models are shown on both plots. The bands represent the total uncertainty on the ZCIPDF fit predictions.

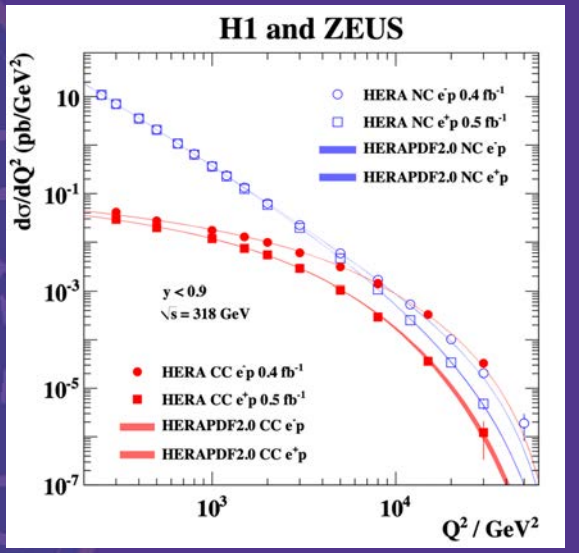
- More papers in the pipeline – although not on LQ.

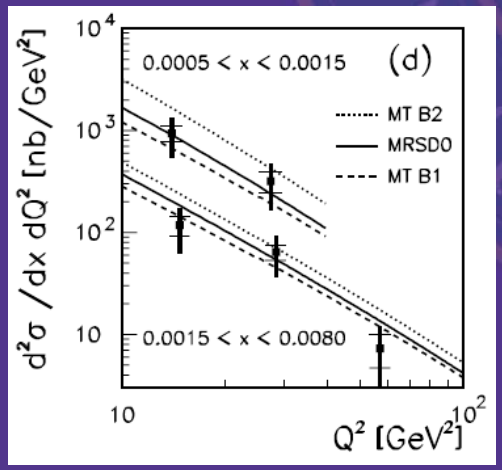
Physics highlights

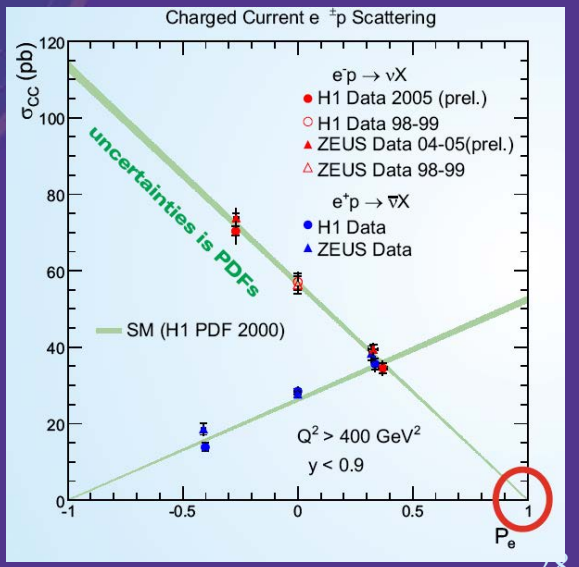
- So no LQs – but plenty else!





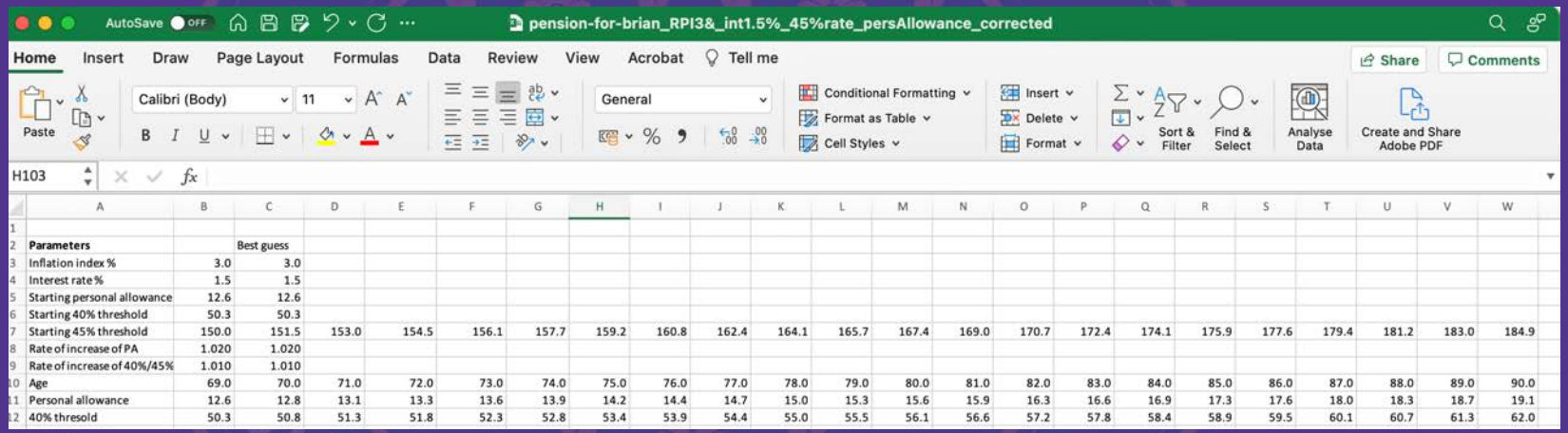






A new collaboration

- **Understanding USS – the final frontier**



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1																							
2	**Parameters**		Best guess																				
3	Inflation index %	3.0	3.0																				
4	Interest rate %	1.5	1.5																				
5	Starting personal allowance	12.6	12.6																				
6	Starting 40% threshold	50.3	50.3																				
7	Starting 45% threshold	150.0	151.5	153.0	154.5	156.1	157.7	159.2	160.8	162.4	164.1	165.7	167.4	169.0	170.7	172.4	174.1	175.9	177.6	179.4	181.2	183.0	184.9
8	Rate of increase of PA	1.020	1.020																				
9	Rate of increase of 40%/45%	1.010	1.010																				
10	Age	69.0	70.0	71.0	72.0	73.0	74.0	75.0	76.0	77.0	78.0	79.0	80.0	81.0	82.0	83.0	84.0	85.0	86.0	87.0	88.0	89.0	90.0
11	Personal allowance	12.6	12.8	13.1	13.3	13.6	13.9	14.2	14.4	14.7	15.0	15.3	15.6	15.9	16.3	16.6	16.9	17.3	17.6	18.0	18.3	18.7	19.1
12	40% thresold	50.3	50.8	51.3	51.8	52.3	52.8	53.4	53.9	54.4	55.0	55.5	56.1	56.6	57.2	57.8	58.4	58.9	59.5	60.1	60.7	61.3	62.0

- **The UK Tax Code**

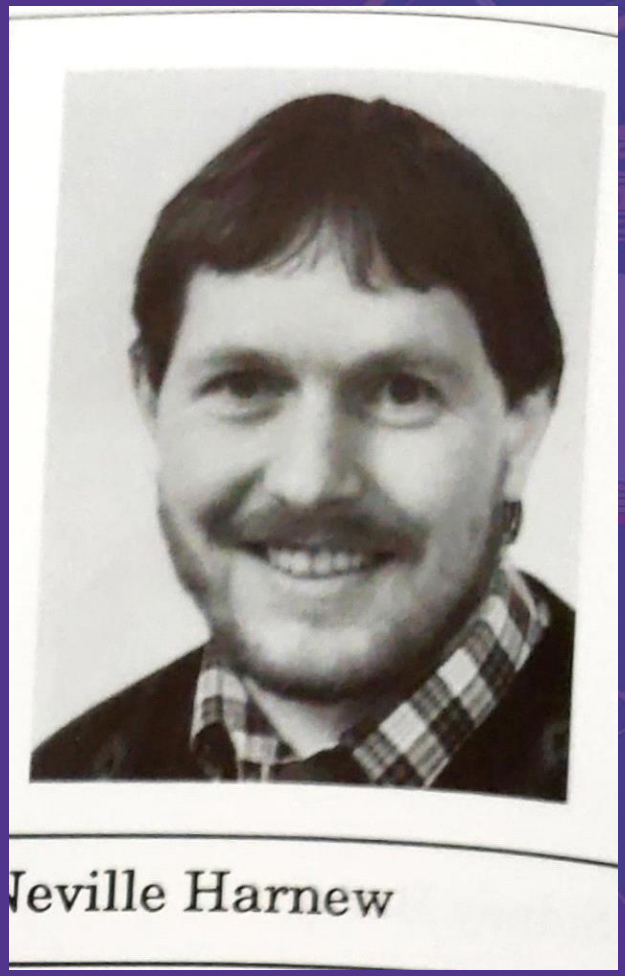
=IF(C27>C7,(C7-C12)*0.4+C12*0.2+(C27-C7+C24-B24)*0.45,IF(C27>100,(C27-C12+C24-B24)*

IF((C27-100)/2<C11,(C27-100)/2,C11))*0.2,(C27-C12+C24-B24)*0.4+(C12-C11)*0.2))

Which Kami-Kwasi

has now simplified to

Summary



- **Nev – it's been a blast!**