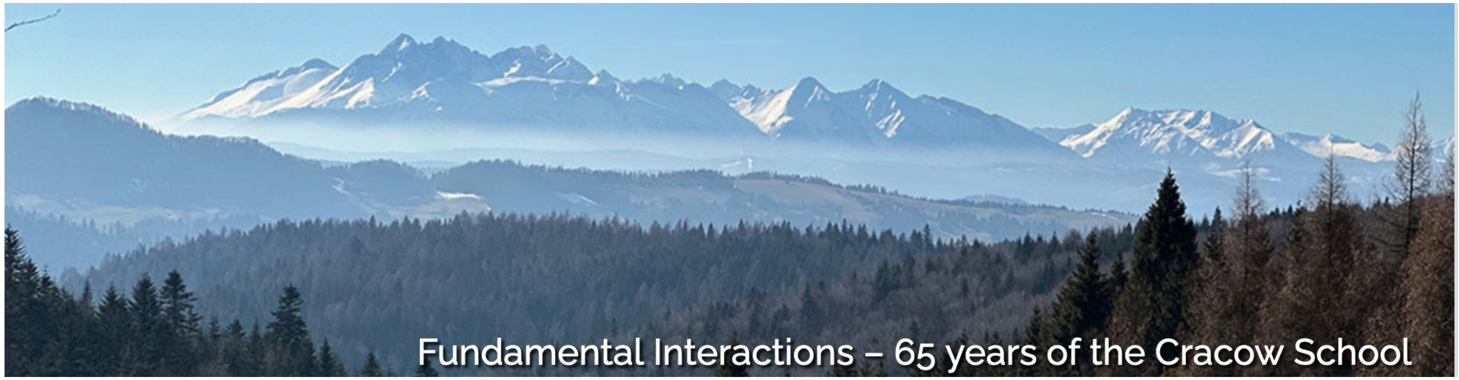
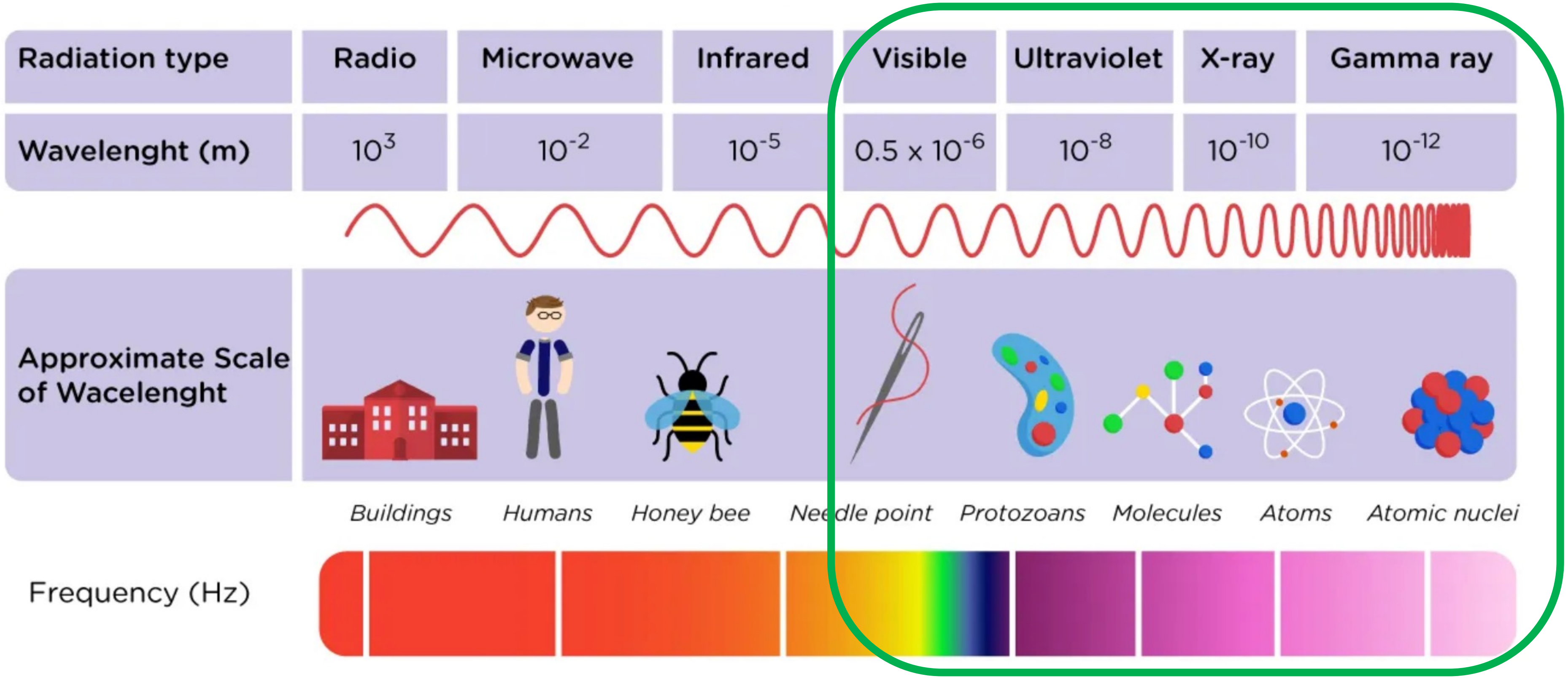
Photons as research tools
— the past and the future



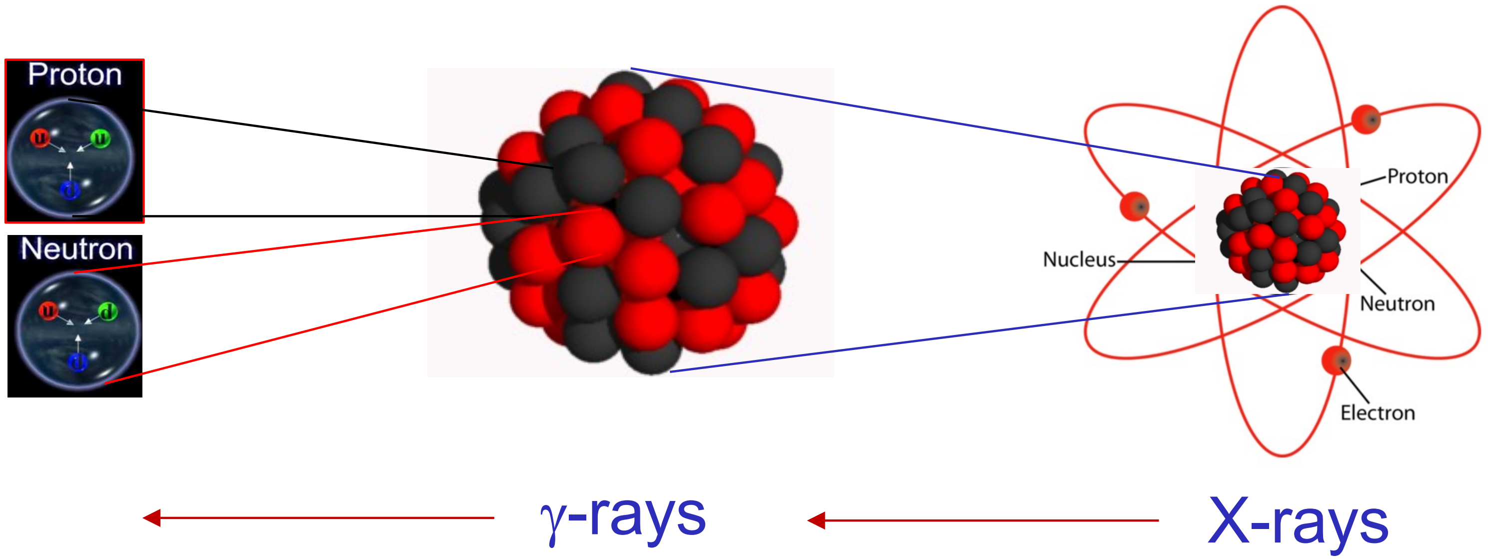
Zakopane School, *June 2025*

Mieczyslaw Witold Krasny
LPNHE, CNRS, University Paris Sorbonne and CERN, BE-ABP

Introduction

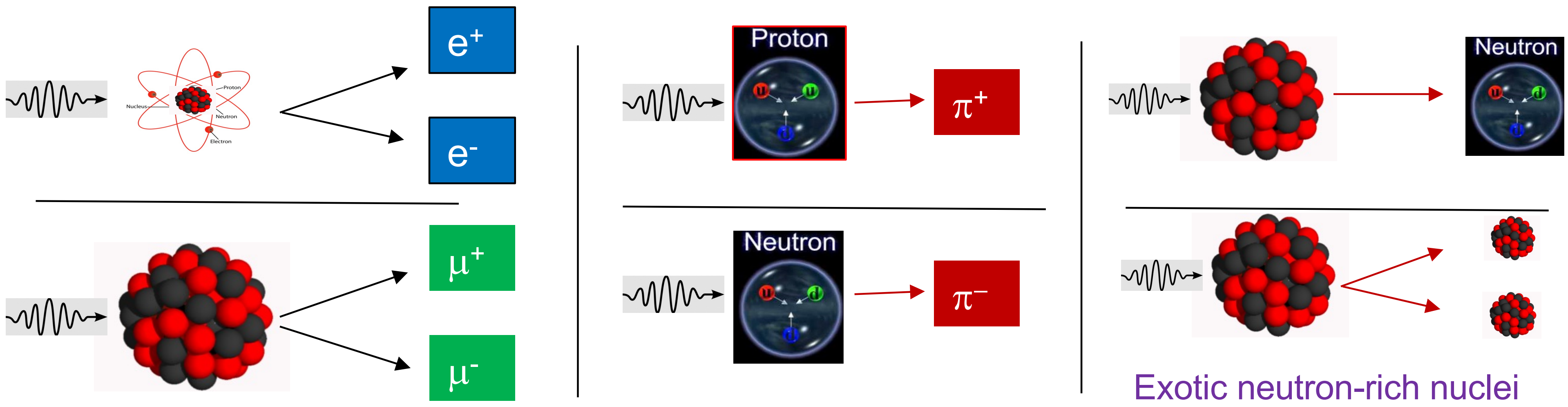

Radiation type
Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma ray
Wavelenght (m)
10^3
10^{-2}
10^{-5}
0.5×10^{-6}
10^{-8}
10^{-10}
10^{-12}
Approximate Scale of Wacelenght
Buildings
Humans
Honey bee
Needle point
Protozoans
Molecules
Atoms
Atomic nuclei
Frequency (Hz)

Photons – high precision tools to study the structure of molecules, atoms, nuclei and nucleons



Photons of energy in the range of sub-eV to hundreds of MeV
(wavelengths comparable to the size of objects)

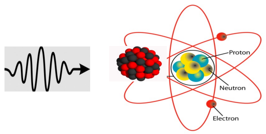
Photon – a tool to produce elementary particles of matter and antimatter (with identical characteristics) and exotic composite objects



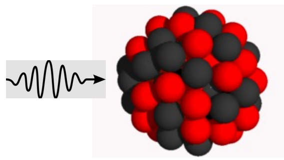
Require photons of the energy langer than ~1 MeV (γ-rays)

Photon – a tool to produce DARK MATTER (DM) particles

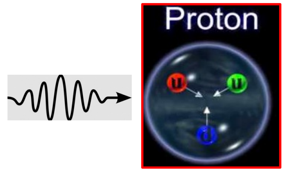
Search phase



DM



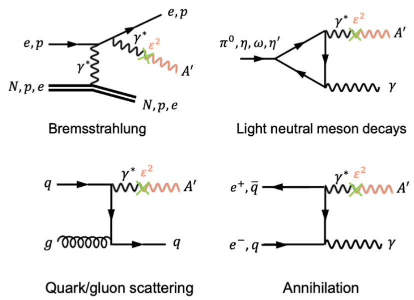
DM

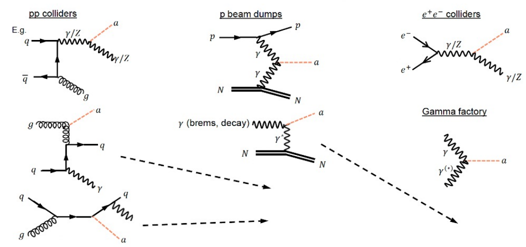


DM

"Production" phase

DM examples



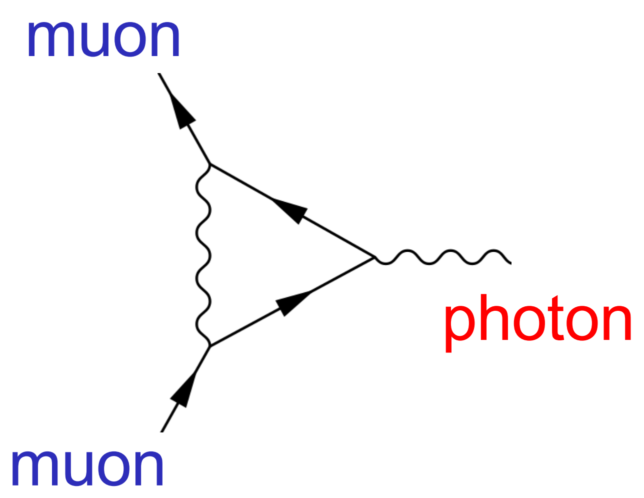


Dark Photon

Axion-like particle

Photons as research tools:

Extraordinary precision of Quantum Electrodynamics



g – measured magnetic moment of the muon

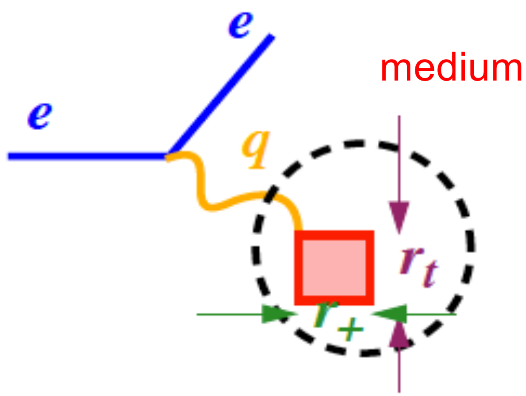
Dirac equation: g =2

$$a = \frac{g-2}{2}$$

$$\begin{aligned} a_\mu^{\mathrm{SM}} &= a_\mu^{\mathrm{QED}} + a_\mu^{\mathrm{EW}} + a_\mu^{\mathrm{hadron}} \\ &= 0.001\,165\,918\,04(51) \end{aligned}$$

$$a_\mu = 0.001\,165\,920\,61(41)$$

Photon probe of hadronic media (sub-femto-meter distances)



Light cone variables

$$q^{+} = (q^0 + q^3) \surd 2$$

$$q^{-} = (q^0 - q^3)/\surd 2$$

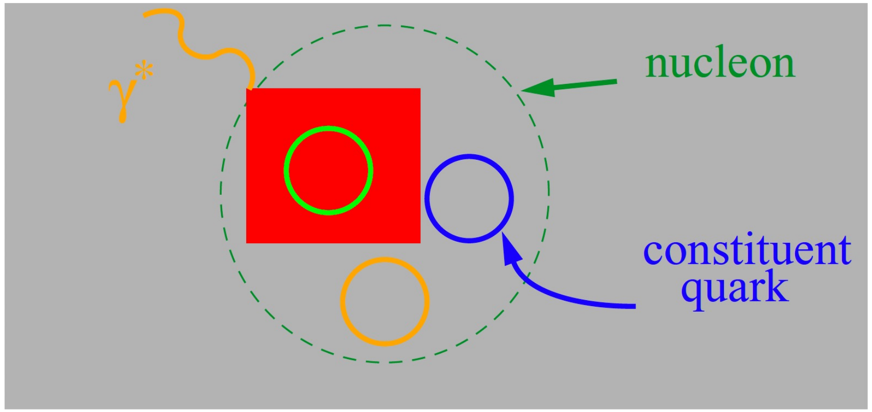
$$x = Q^2 / 2mq^0$$

$$y = q^0 / E_e$$

- *transverse distances:* $r_t \sim 1/Q \surd(1 - y)$
- *longitudinal distances:* $r_+ \sim \surd 2 \;/\; mxy$

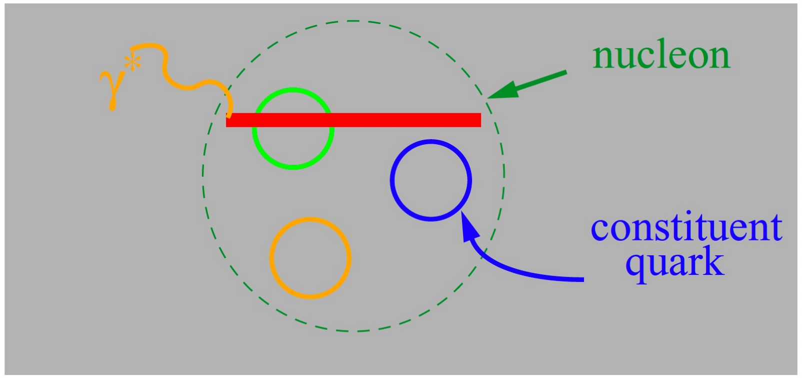
... probed on the light-cone ($r_+ = ct$) with the dispersion $r_- \sim 1/\surd 2\ q^0$

TJNAF: $Q^2 = 0.25\ GeV^2,\ x = 0.9,\ y = 0.5$



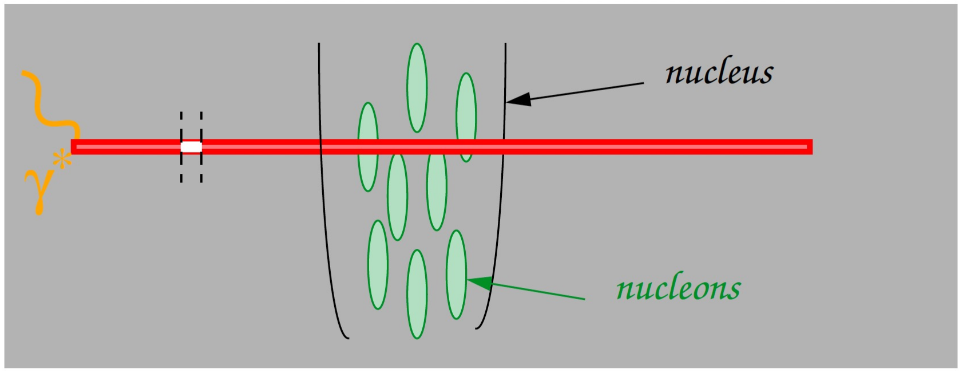
EIC

$Q^2 = 100\ GeV^2,\ x = 0.5,\ y = 0.5$



EIC

$Q^2 = 1\ GeV^2,\ x = 0.001,\ y = 0.5$



The past:

CERN/SLAC/DESY/GSI/BNL

(personal recollections)

The 80-ties: my SLAC recollections

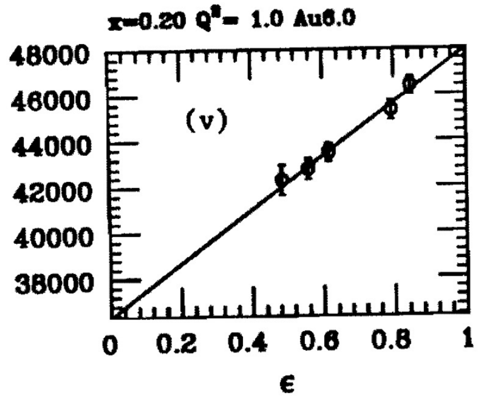
1. *Longitudinally and transversely polarised virtual photons*
2. *Filtering leading from higher twist processes (SLAC E140)*
3. *Photons, dark photons and axions (SLAC E141)*

$$\frac{d^2\sigma}{d\Omega dE'} = \Gamma\left[\sigma_T(x,Q^2) + \epsilon\sigma_L(x,Q^2)\right]$$

$$\Gamma = \frac{\alpha K E'}{4\pi^2 Q^2 E_0}\left(\frac{2}{1-\epsilon}\right) \quad K = \frac{2M\nu - Q^2}{2M}$$

$$\epsilon = \left[1 + 2\left(1 + \frac{Q^2}{4M^2x^2}\right)\tan^2\frac{\theta}{2}\right]^{-1}$$

$$\Sigma(x,Q^2,\epsilon) = \sigma_T(x,Q^2) + \epsilon\,\sigma_L(x,Q^2)$$



PHYSICAL REVIEW D
PARTICLES AND FIELDS

THIRD SERIES, VOLUME 49, NUMBER 11 — 1 JUNE 1994

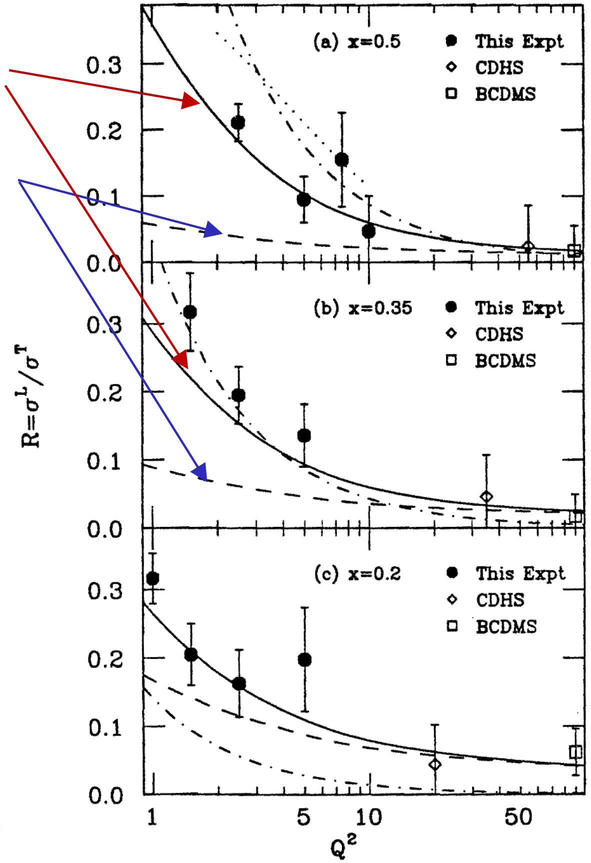
ARTICLES

Measurement of kinematic and nuclear dependence of $R = \sigma_L/\sigma_T$ in deep inelastic electron scattering

S. Dasu, P. de Barbaro, A. Bodek, H. Harada, M. W. Krasny, K. Lang, and E. M. Riordan
University of Rochester, Rochester, New York 14627

perturbative QCD + Higher Twists

perturbative QCD

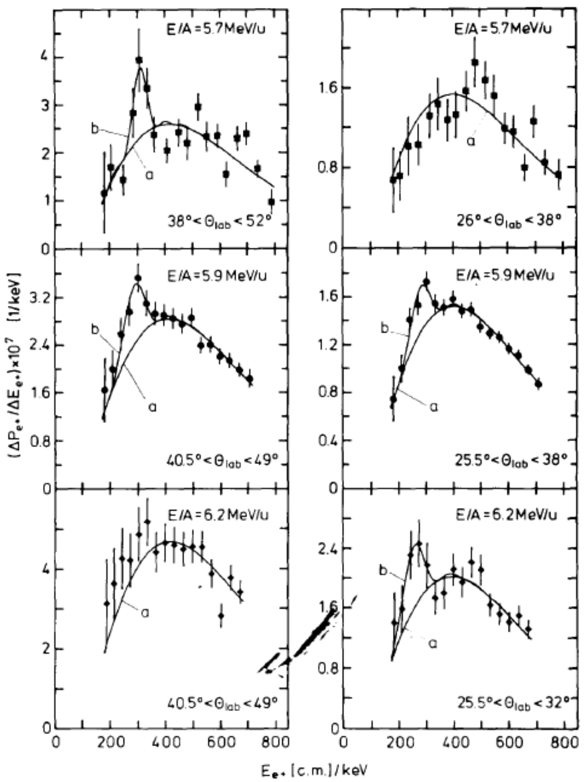


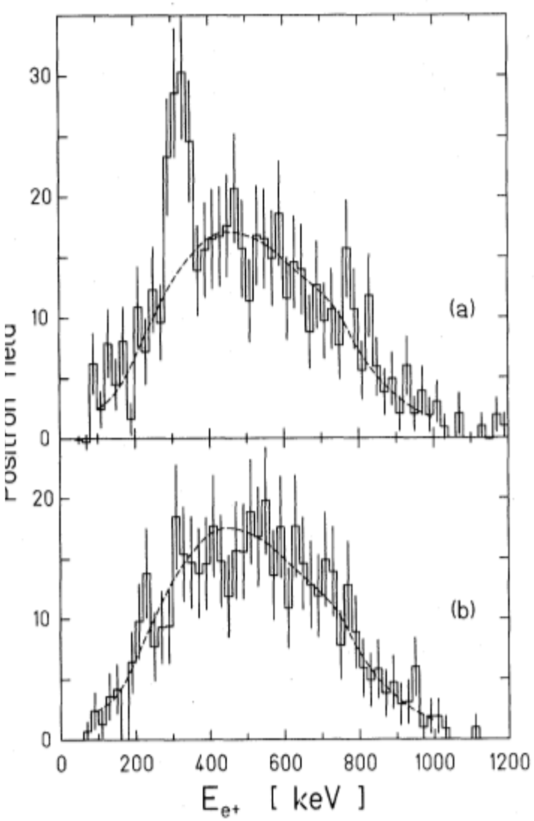
Importance of HT contribution !

1986 - GSI peaks -heavy ion collisions

sparking of the vacuum:

For Z> 173 electron binding energy exceeds $2m_ec^2$



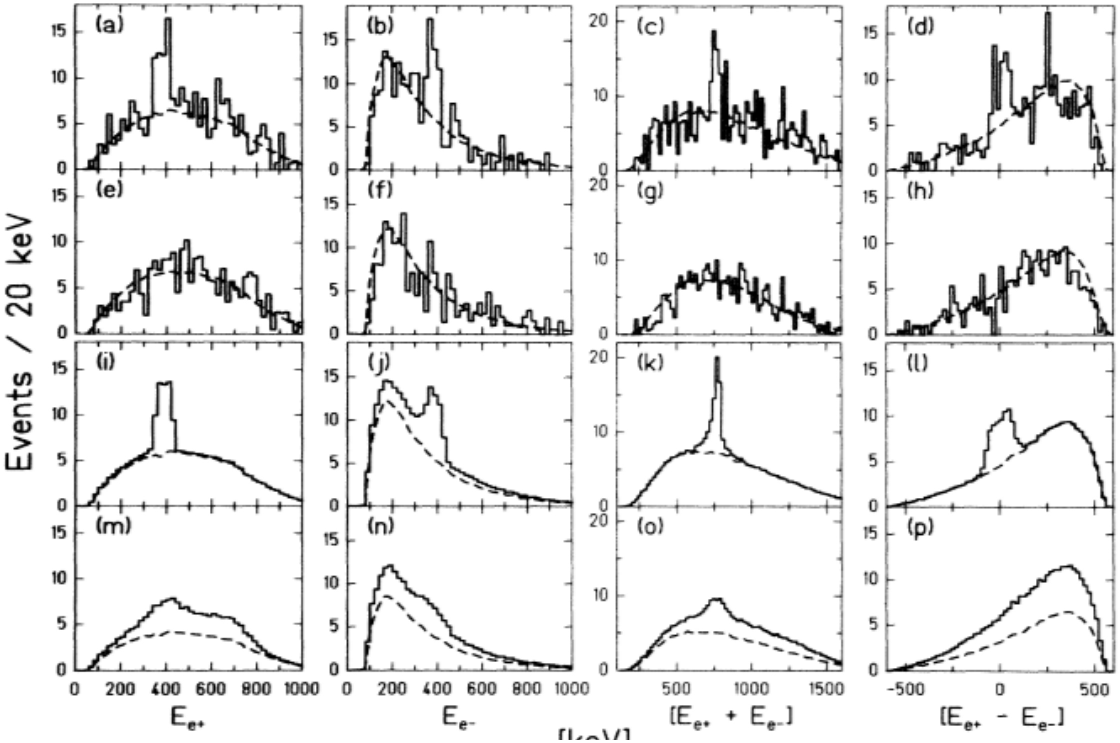


Found peaks in the positron and electron spectra …

Surprisingly, independent of the charge of colliding ions ~Z^{20} dependence !!!

U-U, U-Th, U-Cm, Th-Th, Cm-Cm

…and their interpretation as discovery of a 1.8 MeV scalar (pseudoscalar) particle



exp.data

simulated decays of a 1. 8 MeV scalar or pseudoscalar particle

The E141 experiment at SLAC

SLAC-E-141 Experiment UPDATE

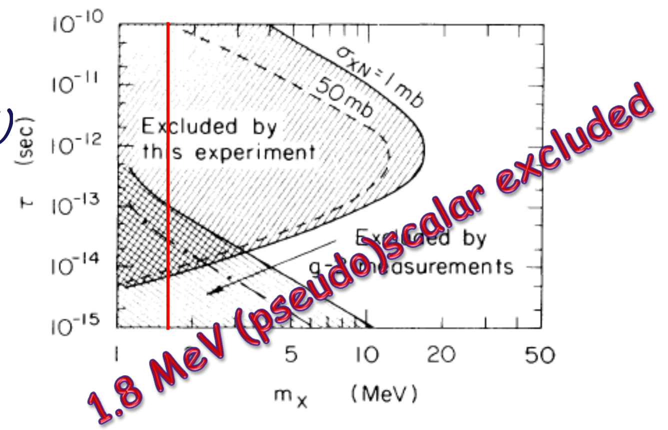
SEARCH FOR SHORT-LIVED NEUTRAL BOSONS FROM A BEAM DUMP

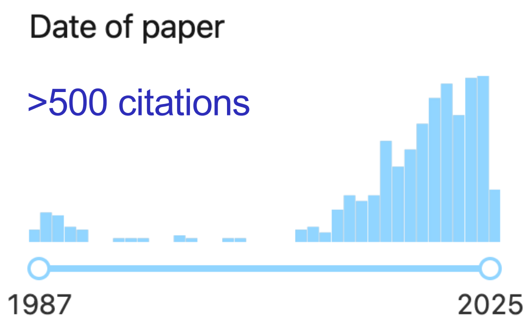
(Proposed: 1986, Approved: 2 May 1986, Began: June 1986, Completed: June 1986)

Final results presented at the Rochester Conference in Berkeley. July, 1986

*E141 proposal by M.W. Krasny,
K. Lang, A.Para, M. Riordan,
with a big help from J. Bjorken (Bj)*

*Wit Busza and
J. Dorfan referees*

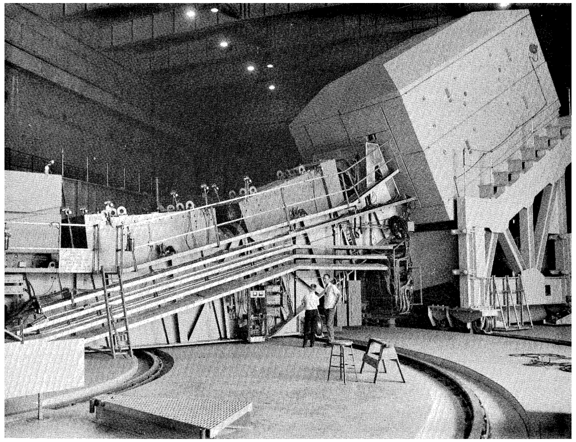




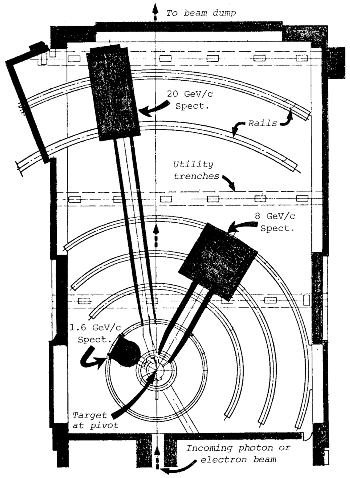
.. A revival of the interest in searches of anthropological dark matter ~10 new experiments

Use of the existing SLAC infrastructure, electronics, beam monitoring system…

Electron beam

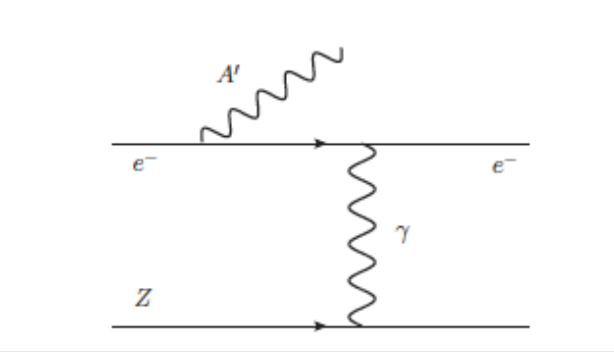


e+/e- detector



0- angle swing

SIMPLE CONCEPT:



…BUT:

- S/B ~ 10 $^{-15}$
- NO MONTE-CARLO SIMULATIONS
- ALLOWED BUDGET < 150 000 $
- EXP PROPOSED BY A THREE SHORT TERM "Polish" POST-DOCS … AND A BOOK-WRITER

Model dependent searches

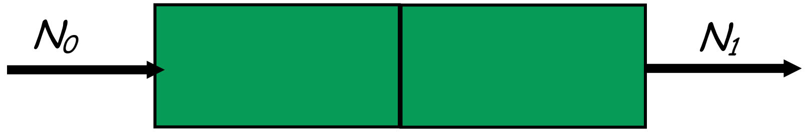
Canonical procedure:

Measure N_{e+e-}, at angle 0° (low mass), calculate (Monte Carlo) N_{back},
If N_{e+e-} > N_{back} discovery, otherwise rejection limits…

Need to generate 10^{19} cascades … Monte-Carlo methods useless
Approximate calculation methods fail in reaching the requisite precision

…specially designed precision measurement method obligatory

E141 concept of model independent searches



$N_A \sim exp\{-l/c\tau\gamma)$

$N_B \sim exp\{-d/X_0)$

Run 1: *dump thickness $d=d_1$, length $l=l_1$, $\gamma_{beam} = \gamma_0$, $B_{spectr} = B$*

if $(N_2<N_1)$-discovery

Run 2: *dump thickness $d=d_1$, length $l=l_2$ +, $\gamma_{beam} = \gamma_0$, $B_{spectr} = B$*

measure $N_3/(N_1-N_2)$
A' absorption cross-section

Run 3: *dump thickness $d=d_2$, length $l=l_2$ +, $\gamma_{beam} = \gamma_0$, $B_{spectr} = B$*

Repeat Run 1-3: for B ---> -B and $\gamma_{beam} = 2\gamma_0$
to verify the hypothesis of a decay of a neutral particle

The 90-ties: preparatory steps for the low-x measurements at HERA

1. *Detector upgrade(s) – HERA detectors have not been optimized to addressed the low-x physics!*

2. *Adequate measurement techniques (creation of the Brussels, Paris, Saclay (BPS) group)*

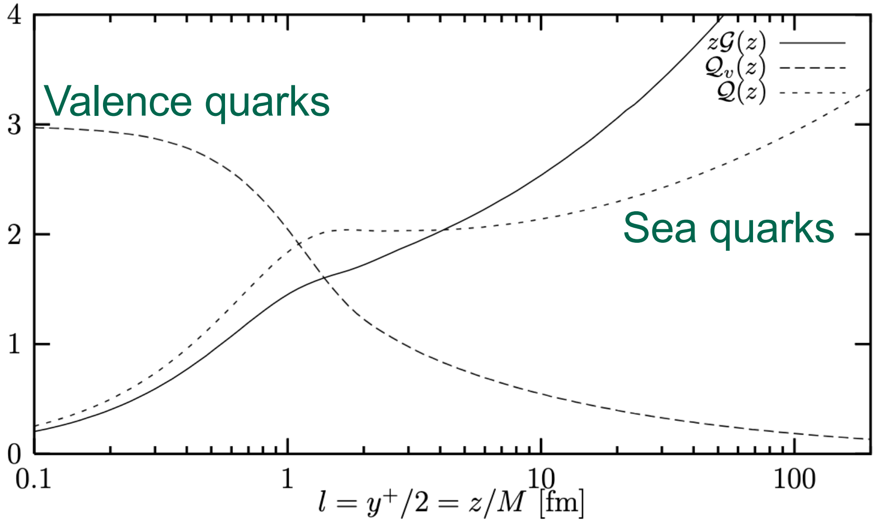
3. *Experimental control of radiative corrections (creation of the DESY radiative correction group – together with H. Spiesberger)*

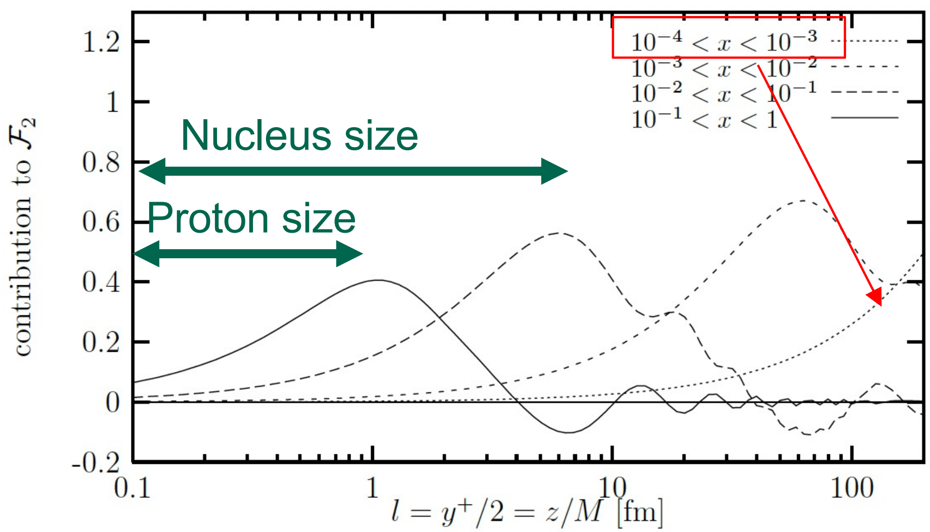
4. *Creation of a a new, low-x specific, QCD analysis tools*

5. *Generic analysis of of the Large-E_T processes at HERA – A task force*

Why low-x? -- Partonic distributions in the light-cone, space-time coordinates

B. L. Ioffe, Phys. Lett. B **90**, 123 (1969)



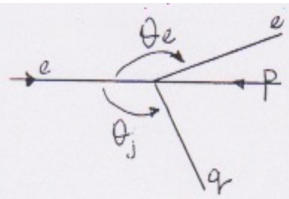


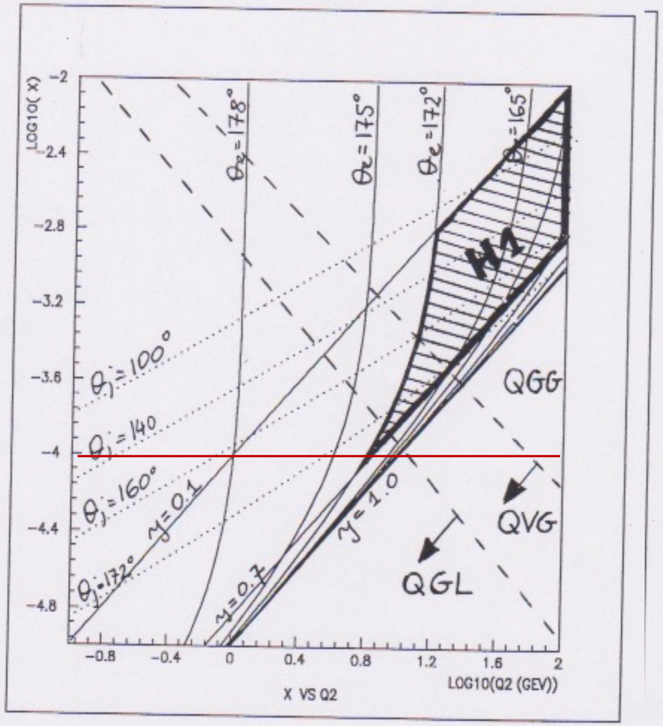
Memorandum to the Hermes collaboration:

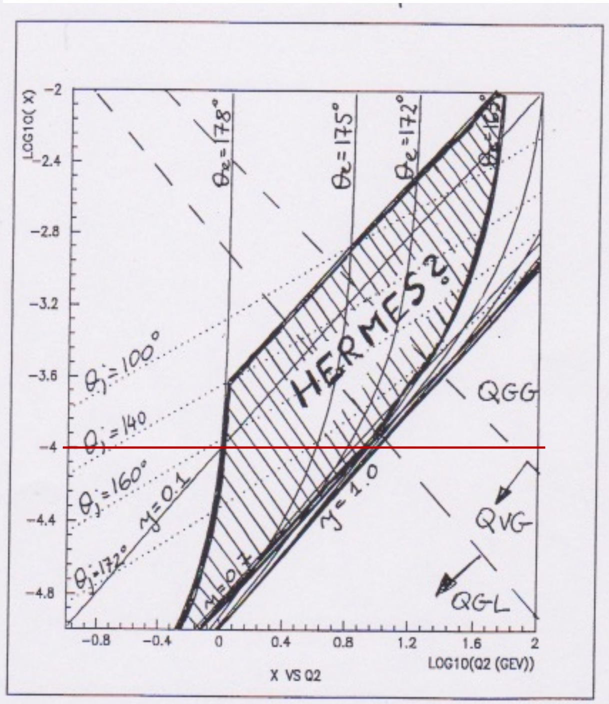
HERMES, a precision experiment to study low x physics at HERA?

M.W. Krasny
DAPNIA - SPP, Centre d'Etudes de Saclay
F-91191 Gif-sur-Yvette Cedex (France).

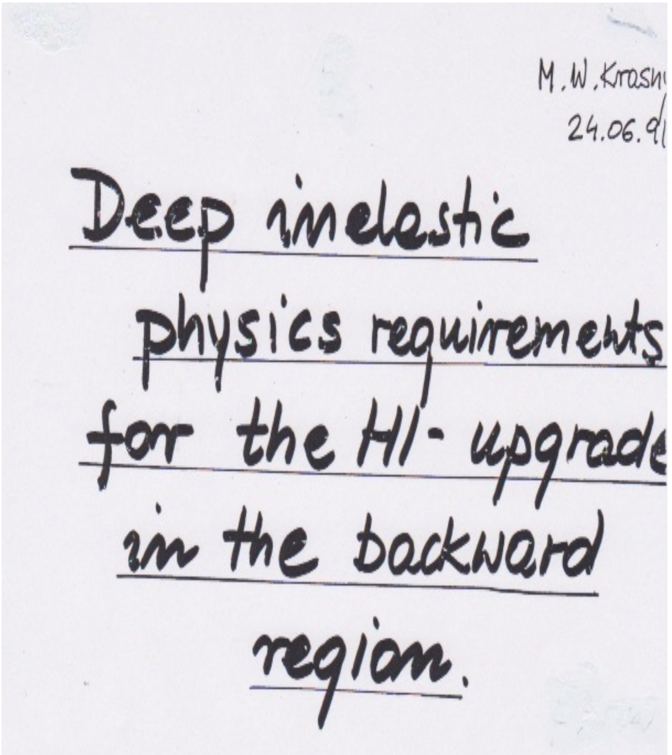
Abstract: In the course of the 1991 HERA workshop it became evident that the low x physics is one of the most exciting subjects to study at HERA. Study of high density parton system in the kinematical domain controled by the perturbative QCD may give us a new insight into the nature of strong interactions. The two existing Hera experiments H1 and ZEUS will soon provide a first glimpse into the low x domain. It has to be stressed however that both of them have been optimized for the high x (high Q^2) rather then for the low x physics. Therefore, if an onset of a new phenomena is observed, a dedicated low x experiment has to follow. In general, such an experiment has to resemble an open geometry fixed target experiment rather then a collider experiment in order to optimize the measurement of low x events, where electrons are scattered from "almost" stationary partons. A cost effective solution, in my opinion, would be to modify the existing proposal of the HERMES group such that their experiment would work both in the fixed target mode (spin physics) and in the colider mode (low x physics). In this note a physics potential of such a solution is discussed.



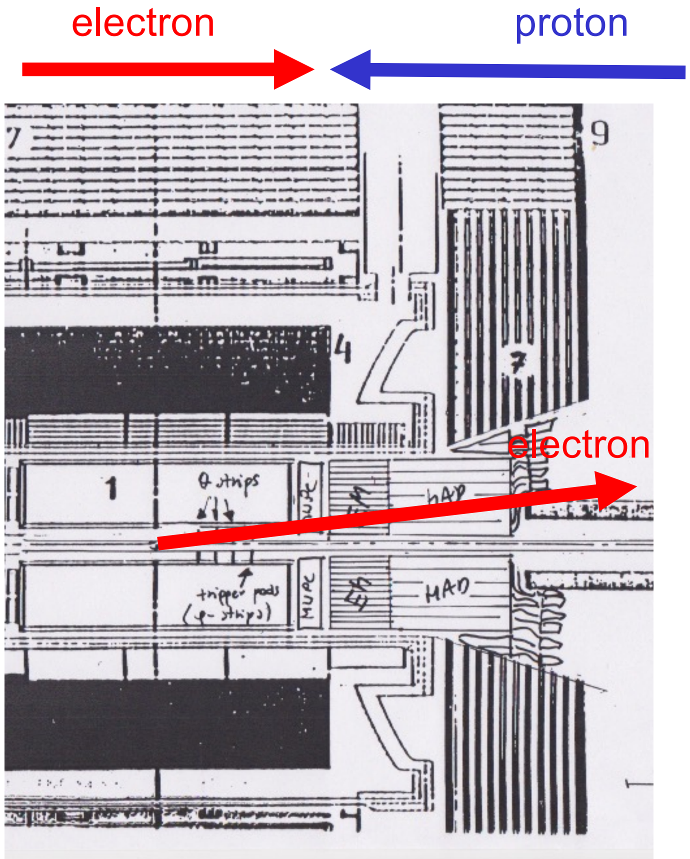




1991 – the H1 detector upgrade proposal:
precision measurements in the low-x region


M.W. Krasny
24.06.91

Deep inelastic physics requirements for the H1-upgrade in the backward region.



Low-x→ low angle scattering

Low-x region specific problem – large radiative corrections

COMMISSARIAT A L'ENERGIE ATOMIQUE
Direction des Sciences de la Matière
Centre d'Etudes Nucléaires de Saclay
91191 Gif-sur-Yvette Cedex

DPhPE 91-21
December 1991

Experimental Control of Radiative Corrections at HERA

M.W. Krasny

Rapporteur Talk at the HERA Physics Workshop at DESY, Hamburg, October 29-30, 1991

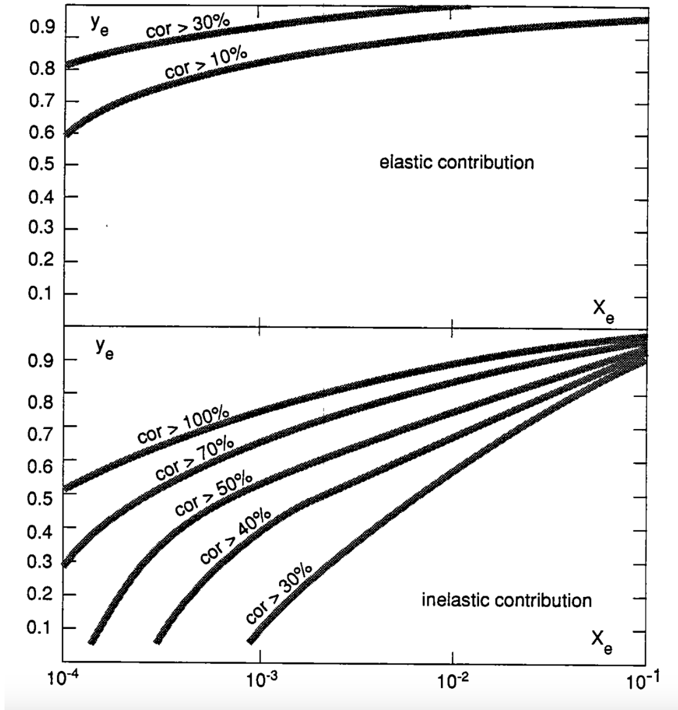


Fig 2. Contours of the constant leptonic radiative corrections. Elastic and inelastic contributions are shown separately.

HERA low-x - measurement techniques in presence of a large EM radiative corrections

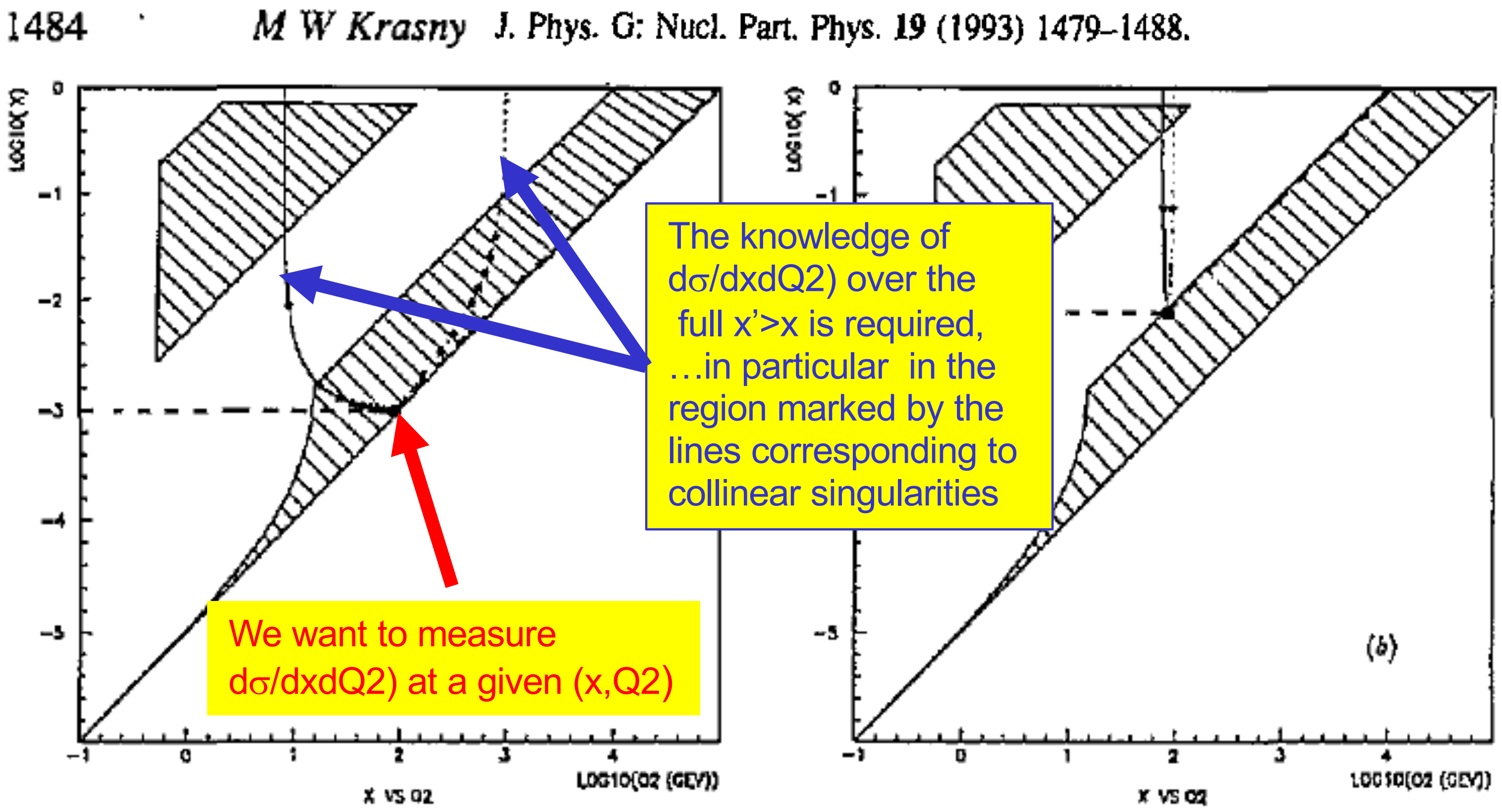


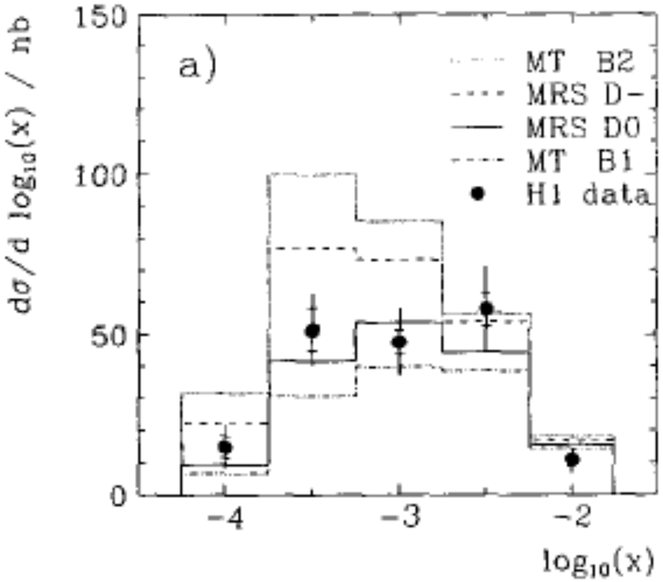
Figure 4. The topology of the (x, Q^2) domains contributing to the radiative differential cross section. See text for further explanations.

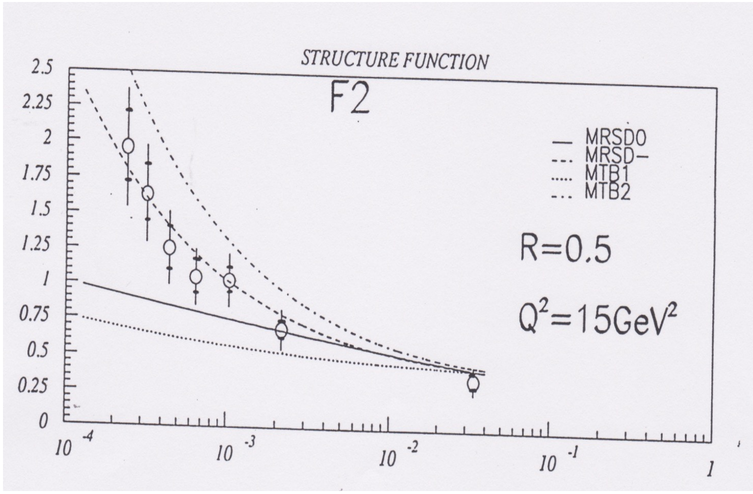
The basic experimental question which had to be answered in 1992:

(conditioning the subsequent phenomenological development of the small-x physics)

how fast partonic densities rise in the small-x region?

1992 - Two independent …and competing data analyses





Analysis by the group led by M. Klein and A.De Roeck, (and published in Phys.Lett. B299, January 1993) indicated "almost flat" (MRS D0 -type) partonic densities for x → 0

Analysis by the BPS group, (presented for the first time at DESY in December 1992) suggested a strong (MRS D- like) rise of partonic densities for for x → 0 (full collected data)

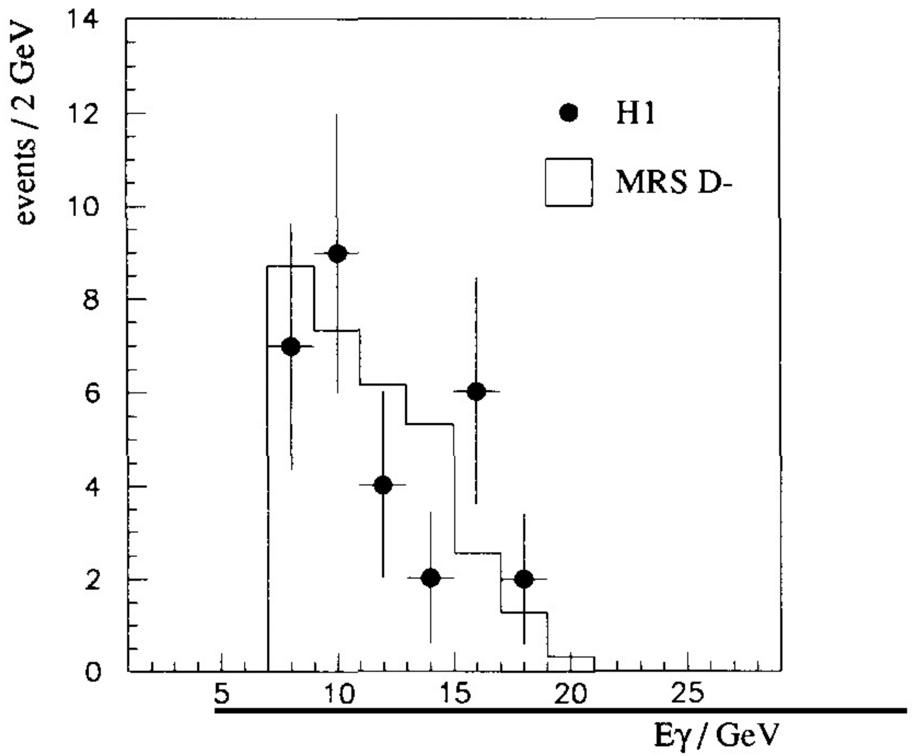
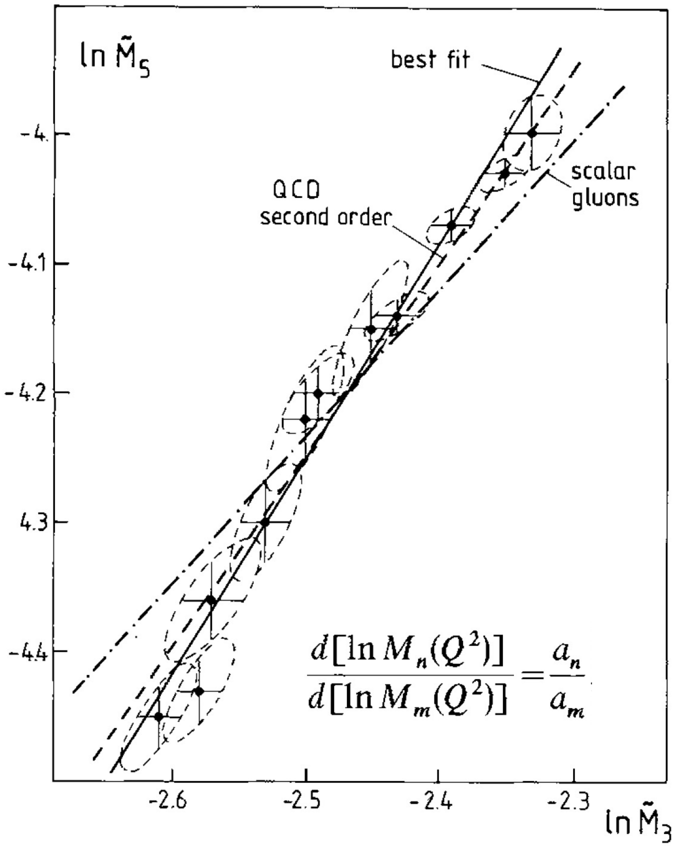


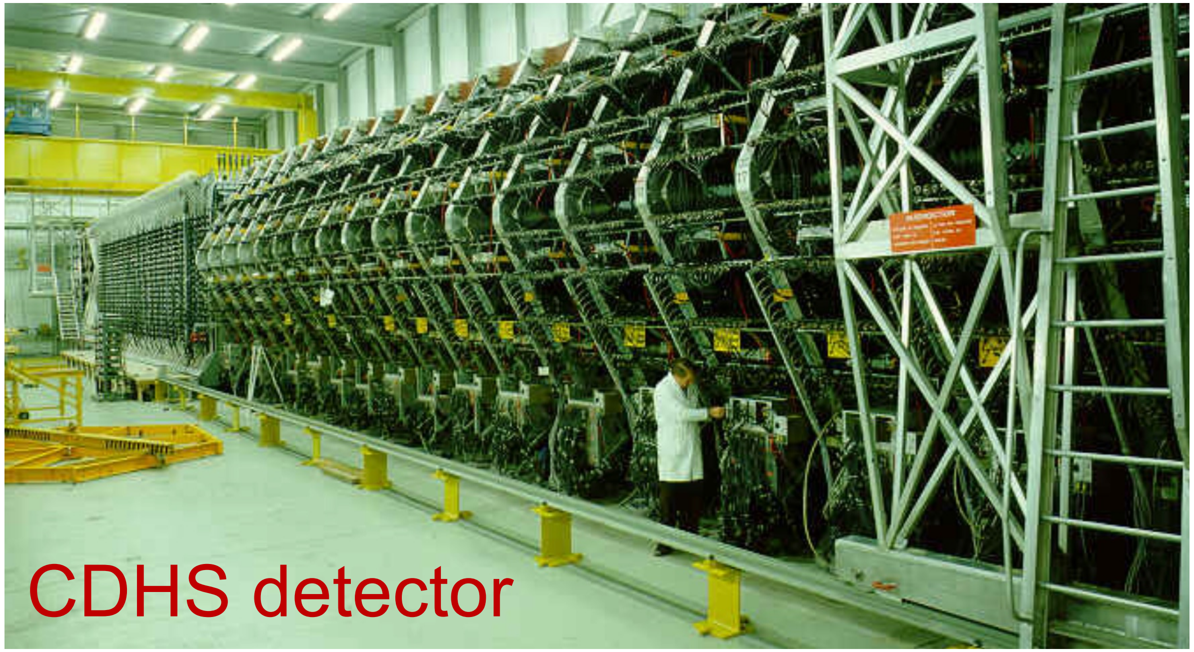
Fig. 3. Distribution of the photon energy E_γ for deep inelastic events with collinear bremsstrahlung as measured in the photon-tagging calorimeter (full points) compared to the Monte Carlo prediction, normalized to the integrated luminosity of the data sample.

$$\frac{d \ln M_n(Q^2)}{d(\ln Q^2)} = -\frac{\alpha_s}{2\pi} \int_0^1 x^{n-1} P_{qq}(z)\, dz = \frac{\alpha_s}{2\pi} a_n,$$

where

$$M_n(Q^2) = \int_0^1 dx\, x^{n-2}\, x F_3(x, Q^2)$$





The first–ever QCD analysis of the double-differential neutrino and antineutrino cross sections

arrival of CRAY machines to CERN in the 80-ties -**PDFs**

A MEASUREMENT OF DIFFERENTIAL CROSS-SECTIONS AND NUCLEON STRUCTURE FUNCTIONS IN CHARGED-CURRENT NEUTRINO INTERACTIONS ON IRON

P. Berge[1], H. Burkhardt, F. Dydak, R. Hagelberg, M.W. Krasny, H.J. Meyer, P. Palazzi, F. Ranjard, J. Rothberg[2], J. Steinberger, H. Taureg, H. Wahl, R.W. Williams[2] and J. Wotschack

CERN, Geneva, Switzerland

… a natural question followed immediately…

Can HERA provide an evidence for the partonic saturation (recombination) effects in the Q^2-evolution of partonic densities (independently of the assumed form of partonic distributions at fixed Q_0^2 scale)?

What measurements, detector and machine upgrades are necessary to achieve the requisite precision?

ELSEVIER

13 October 1994

PHYSICS LETTERS B

Physics Letters B 337 (1994) 367–372

Recombination effects in the structure function evolution at low x. Can they be observed at HERA?

K. Golec-Biernat [a], M.W. Krasny [b], S. Riess [c]

[a] *Dept. of Theoretical Physics, Institute of Nuclear Physics, ul Radzikowskiego 152, 31-342 Kraków, Poland*
[b] *L.P.N.H.E, IN2P3-CNRS, Universities Paris VI et VII, 4, pl. Jussieu, T33 RdC, 75252 Paris Cedex 05, France and High Energy Physics Lab., Institute of Nuclear Physics, PL-30055 Kraków, Poland*
[c] *II. Institut for Experimental Physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany*

A.H. Mueller and J. Qiu, Nucl. Phys. B 268 (1986) 427.

$$Q^2 \frac{\partial [xg(x,Q^2)]}{\partial Q^2} = P_{gg} \otimes g + P_{gq} \otimes q_s - \frac{81\alpha_s^2(Q^2)}{16\, R^2 Q^2} \theta(x_0 - x) \int_x^{x_0} \frac{dz}{z} \{zg(z,Q^2)\}^2 \quad (1)$$

$$Q^2 \frac{\partial [xq_s(x,Q^2)]}{\partial Q^2} = P_{qg} \otimes g + P_{qq} \otimes q_s - \frac{27\alpha_s^2(Q^2)}{160\, R^2 Q^2} \theta(x_0 - x) \{xg(x,Q^2)\}^2 + \frac{\alpha_s(Q^2)}{\pi Q^2} \theta(x_0 - x) \int_x^{x_0} dz \{\frac{x}{z} \gamma(\frac{x}{z}) G_H(z,Q^2)\}, \quad (2)$$

where $q_s(x,Q^2)$ and $g(x,Q^2)$ denote the sea quark and gluon distributions, respectively, and G_H satisfies

$$Q^2 \frac{\partial [xG_H(x,Q^2)]}{\partial Q^2} = -\frac{81\alpha_s^2(Q^2)}{16\, R^2} \theta(x_0 - x) \int_x^{x_0} \frac{dz}{z} \{zg(z,Q^2)\}^2. \quad (3)$$

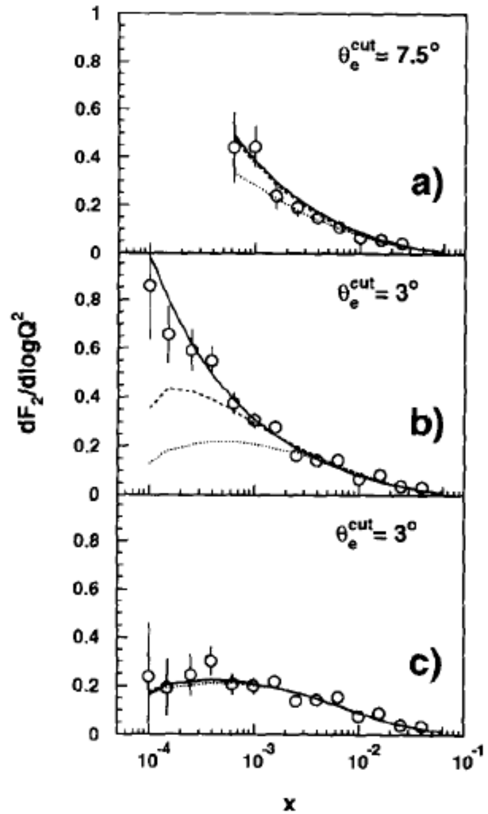


Fig. 2. The F_2 logarithmic slopes $\partial F_2/\partial \log(Q^2)$ as a function of x. The open points represent the values calculated for the R_∞ data set in the domain of $\theta_e > 7.5°$ (a) and $\theta_e > 3°$ (b), and the values calculated for the R_3 data set in the domain of $\theta_e > 3°$ (c). The solid, dashed and dotted lines are derived from the results of the $R = \infty$, 5, 3 GeV^2 fits, respectively.

HERA experiments will be unable to establish the existence of the saturation effects unless specific actions are taker!

… and its impact …

1. *Quantitative arguments for extending the measurement of the scattered electron down to lower angles (feedback on the H1 detector upgrade)*

2. *Importance of independent constraints on the gluon distribution coming from a precision measurement of $F_L(x,Q2)$ (feedback on the SPACAL front-end electronic design and on the HERA machine operation modes)*

3. *Importance of an extension of the HERA research programme: storage and collisions of heavy and light ion beams with electrons (gain the $A^{1/3}$ factor in the transverse-plane density of partons)*

The role of nuclear beams for the Future HERA programme

1. Study of the large density partonic systems. Search for nonlinear QCD phenomena.

2. Unique means of verifying how universal is the concept of Pomeron. Answer to the question:
   "Does Pomeron have an unique structure independent of the process in which it is created?"

3. Filtering out soft from hard processes (which "interplay" in the ep scattering). Establishing a list of ep processes where perturbative QCD must survive quantitative checks

4. Nucleus – the best invented so far femtovertex detector to study the space-time structure of strong interactions.

5. eA scattering ⇒ luminous $\gamma\gamma$ scattering

M.W.K, summary talk at the 1996 HERA workshop

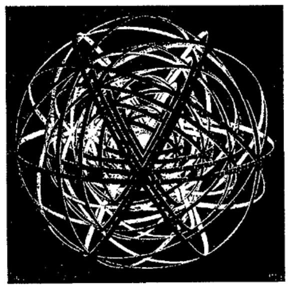
LPNHE 96-11

Laboratoire de Physique Nucléaire et de Hautes Energies

CNRS - IN2P3 - Universités Paris VI et VII

Nuclear beams in HERA

M. Arneodo, A. Bialas, M.W. Krasny, T. Sloan and M. Strikman



4, Place Jussieu - Tour 33 - Rez-de-Chaussée
75252 Paris Cedex 05

Tél: 33(1) 44 27 63 13 - FAX: 33(1)44 27 46 38

Hamburg, 11.07.1996.

Memorandum

To: B. Wiik, A. Wagner, DESY

From: M.W. Krasny, LPNHE - Paris

…selected two points of the memorandum to DESY directors:

- to build an "A-tunable" ion injector system and collide at HERA electrons with nuclei. The ePb collisions would have the world record center-of-mass energy (if realized before RHIC becomes operational) and, apart from several merits which I tried to explain in my summary talk of the HERA workshop, would provide the largest effective luminosity for photon-photon interactions in the intermediate W range. It is worth noticing that several physicists became interested in the nuclear option for HERA after introducing to the program of the Paris HERA workshop, back in 1995, a parallel session on nuclei and that this physics received some attention during the DESY workshop this year.
- to design a dedicated experiment for HERA for the "low Q^2" ($Q^2 \leq 100\ GeV^2$) domain optimized both for the ep and eA interactions. Let me note, as an example, that neither the upgraded H1 experiment nor the ZEUS experiment will be able to measure structure functions, in particular σ_L/σ_T, with the precision comparable to that of SLAC experiments of 70-ties, despite the energies and angles of the scattered electrons are, in this Q^2 range, similar. Such a detector would have to measure the energies and angles of particles produced over the large domain of η, covering in particular the proton (nucleus) fragmentation region, which still remains a "terra incognita". It should use large β rather than small β optics because the physics advocated here requires modest luminosities and high detection quality of particles emitted at small angles. I failed, back in 1991, to persuade the spokesman of the HERMES experiment that the first component of such an experiment could be the HERMES electron spectrometer used in the colliding beam mode.

DEUTSCHES ELEKTRONEN-SYNCHROTRON DESY

NOTKESTR. 85 - 22607 HAMBURG, TEL. 040/89 98-24 07 - TX 2 15 124 desy d - TTX 40 31 73=DESY - FAX 040/89 94 43 04

Der Vorsitzende des Direktoriums

Dr. M.W. Krasny
Universites Paris 6 +7
LPNHE
4, Place Jussieu, Tour 33
F-75252 Paris Cedex 05

August 19, 1996

Dear Dr. Krasny,

Thank you very much for your contribution to the HERA workshop and for your remarks to the HERA programme.

I agree with you that HERA will make a solid contribution to strong interaction physics and that colliding electrons with nuclei may open up new vistas and should be explored further. Indeed we want to do this in collaboratoin with GSI and I hope that you will be able to participate and contribute to this work. In order to carry out a prgramme in this direction there must be a well reasoned physics programme, a strong support including funds from the community, and GSI must be interested in a collaboration.

I'm not so sure that I agree with your comments concerning the luminosity frontier - at least I would feel somewhat uneasy if we neglected this frontier.

With my best wishes

Björn H. Wiik

Björn H. Wiik

A support for the initiative coming from USA:

Professor Bjorn Wiik, Director
DESY
Notkestrasse 85
D-22607 Hamburg
Germany

Dear Bjorn:

We write to you concerning the future physics program at HERA. The two-volume report "Future Physics at HERA" has given a remarkably thorough presentation of the possibilities that lie ahead. In surveying that report we have been struck by the fact that one particular proposal, having nuclear beams in HERA, builds on the most impressive results of the present HERA program and extends the range and scope of these experiments in a very significant way...

...We urge you to give the most careful consideration to the electron-ion option, and do hope that it may become a reality.

With our best regards,

James Bjorken
SLAC

Stanley Brodsky
SLAC

Alfred Mueller
Columbia Univ.

Larry McLerran
Theoretical

Towards a dedicated QCD-research program for DESY (1994-1999)

- *Proposal of the HERA upgrade (nuclear beams, accelerator and detector upgrades discussions at the Paris DIS workshop in 1995 and the HERA 1996 workshop)*

- *1995 -- Creation of the study group (~60 physicists participated in studies of nuclear beams option for HERA)*

- *An initiative of a joint European (DESY, GSI, NUPECC) QCD research program and its specialized electron-ion collider facility at DESY (Seeheim meeting 1997)*

The context of the 1997 Seeheim meeting

- *Parallel to the HERA operation, the European nuclear physics community (NuPECC) had been searching for the next nuclear facility capable study the physics of strongly interacting matter with electron probes*
- *GSI had been developing the ENC project*
- *NuPECC (in particular FRANCE) had been developing the ELFE concept of a high luminosity fixed target electron accelerator for a CEBAF-like programme*
- *DESY had just proven -- contrary to initial expectations -- its capacity to address strong interaction physics with its HERA programme*
- ***The main question was if (and how) the three projects could be combined into a joint European project, having as an ultimate goal to become a world facility to address the strong interaction physics, both in terms of nucleon and of quark and gluon degrees of freedom** (… and linking them).*

Joint DESY/GSI/NuPECC workshop

March 3/4 1997

Lufthansa - Zentrum, Seeheim near Darmstadt (Germany)

Monday, March 3:

9:00 - 9:15	Welcome	V. Metag
chair: W. Weise		
9:15 - 10:00	Electron - Nucleon/Nucleus scattering in the 21. Century	A. Mueller
10:00 - 10:15	Discussion	
10:15 - 10:45	Nuclear Physics with HERMES	K. Rith
10:45 - 11:00	Discussion	
11:00 - 11:30	Coffee	
chair: G. Middelkoop		
11:30 - 12:00	The physics program of COMPASS	F. Bradamante
12:00 - 12:15	Discussion	
12:15 - 13:00	Electron-Nucleus Collisions at HERA (theory)	M. Strikman
13:00 - 14:00	Lunch	
14:00 - 14:45	Electron-Nucleus Collisions at HERA (experiment)	W. Krasny
14:45 - 15:00	Discussion: Electron-Nucleus collisions at HERA	
chair: B. Schoch		
15:00 - 15:45	Physics with an e-N/A facility at GSI (theory)	A. Schäfer
15:45 - 16:30	Physics with a e-N/A facility at GSI (experiment)	D. v.Harrach
16:30 - 16:45	Discussion: Electron-Nucleon/Nucleus Collsions at GSI	
16:45 - 17:15	Coffee	
chair: B. Frois		
17:15 - 18:00	Physics with ELFE@DESY (theory)	P. Hoyer
18:00 - 18:45	Physics with ELFE@DESY (experiment)	J.M. Laget
18:45 - 19:00	Discussion: Electron-Nucleus Collisions at ELFE	

F. Willeke

Lead-Electron Luminosity

Beam Parameters (based on present Lattice)

	Ions Pb^{82+}_{208}	Electrons
Momentum	$P_i = 6.724\cdot10^4 \cdot GeV\cdot c^{-1}$	$P_e = 27.5\cdot GeV\cdot c^{-1}$
Energy	$E_i = 6.724\cdot10^4 \cdot GeV$	$E_e = 27.5\cdot GeV$
Energy per Nucleon	$E_n = 323.271\cdot GeV$	
Emittance	$\varepsilon_N = 4\cdot mrad\cdot mm$	$\varepsilon_e = 25\cdot nm$
	$\varepsilon_i = 11.61\cdot nm$	$\kappa = 0.10$
β-Function	$\beta_{xi} = 2.5\cdot m$	$\beta_{xe} = 1.2\cdot m$
	$\beta_{yi} = 0.15\cdot m$	$\beta_{ye} = 0.28\cdot m$
Beam Size	$\sigma_{xi} = 170.366\cdot \mu m$	$\sigma_{xe} = 173.205\cdot \mu m$
	$\sigma_{yi} = 41.731\cdot \mu m$	$\sigma_{ye} = 41.833\cdot \mu m$
Number of part/bunch	$N_i = 5\cdot10^7$	$N_e = 3.7\cdot10^{10}$
N. of Coll. Bunches	$N_c = 174$	
Beam Current	$I_i = 5.385\cdot mA$	$I_e = 55.16\cdot mA$
Beam-Beam Tuneshift	$\Delta\nu_{xi} = 7.868\cdot10^{-4}$	$\Delta\nu_{xe} = 0.001$
	$\Delta\nu_{yi} = 1.987\cdot10^{-4}$	$\Delta\nu_{ye} = 0.0011$
Effective Beam Size	$\sigma_x = 242.949\cdot \mu m$	
	$\sigma_y = 59.089\cdot \mu m$	
Luminosity	$L = \frac{N_i\cdot I_e}{2\cdot\pi\cdot e\cdot\sigma_x\cdot\sigma_y}$	$L = 1.911\cdot10^{28}\cdot sec^{-1}\cdot cm^{-2}$
	$L_{ep} = 8.015\cdot10^{31}\cdot cm^{-2}\cdot sec^{-1}$	$L\cdot A = 3.975\cdot10^{30}\cdot sec^{-1}\cdot cm^{-2}$
	$L\cdot L_{ep}^{-1}\cdot A = 0.05$	

$$\mathcal{L} \sim 2\cdot10^{28}\, cm^{-2} s^{-1}$$

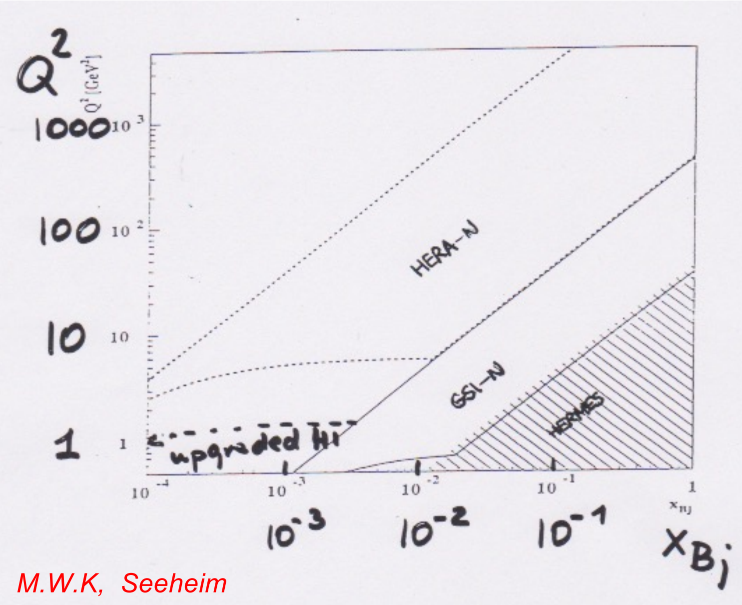
New upgraded HERA Lattice!

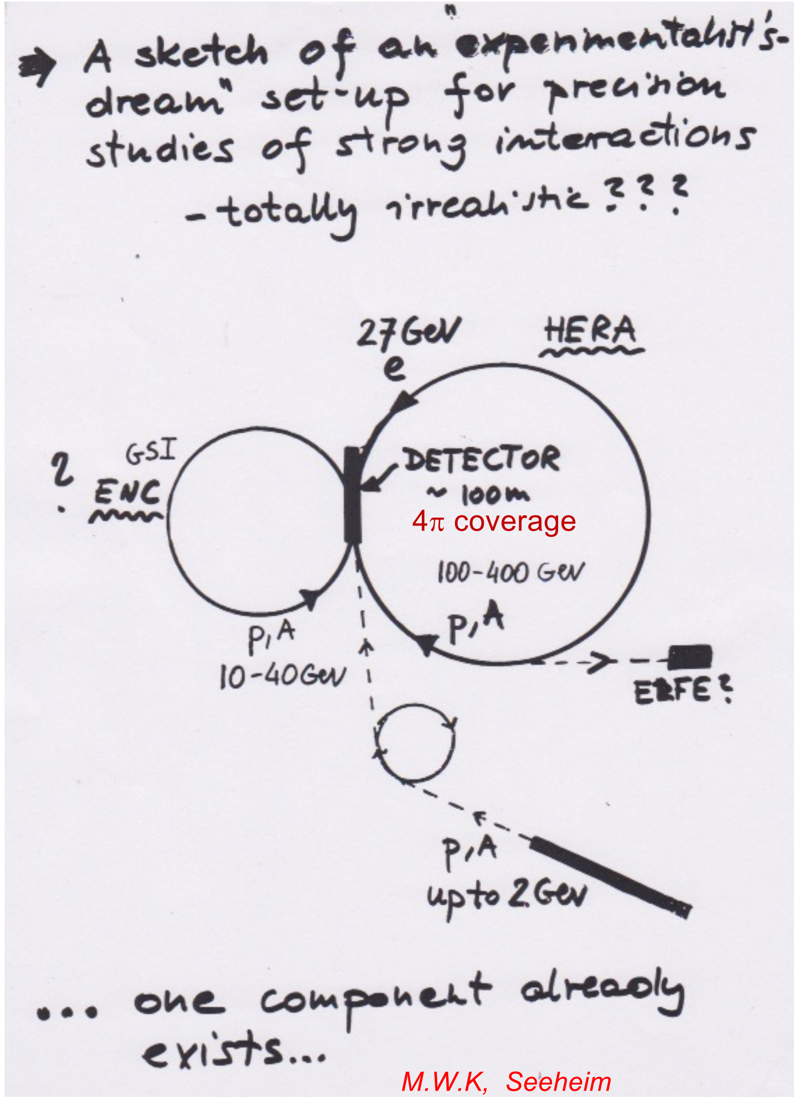
Three main problems to reach a requisite luminosity at HERA
(existing already for protons but significantly more severe for ions) :

- *The emittance blow up in the chain of HERA injectors*
- *Intra-beam scattering*
- *Slow ramping time*

GSI interested in construction of the pre-injector chain for DESY
(the estimated cost 25 MDM -- e.g. a ~2% of the cost the high luminosity CERN-LHC upgrade)

How to merge the presented three proposals into a single QCD-research facility ?





My main intransigent points (1997):

- *The QCD programme must include a development of high intensity sources of both isoscalar ions (including deuterium) and the highest Z ions, and their low emittance pre-injector(s)*

- *One of its detectors for must have a full 4π acceptance (allowing to detect all the fragments of the nucleus)*

- *The "HERA leg" of this programme requires a factor of O(100) increase of the collider luminosity :*
  - *-- statistics: F_2^c, F_2^b, F_L, EW, multidimensional studies*
  - *-- systematics: drastic reduction of syst. errors (e.g. x and Q2 scans at fixed theta as a function of (E_n E_e)*

- *RHIC was expected to start in 2000 and the LHC in 2006 –> the DESY QCD program -- capable to provide a vital input for the interpretation of the RHIC and the LHC data -- must start before (or soon after) the start of the RHIC and LHC operation*

Two important hurdles at DESY:

- *difficult to reconcile between TESLA proposal – and the QCD facility at DESY → B.Wiik's (wait and see) strategy*

- *The lepto-quark and supersymmetry "ghosts" invaded HERA –> strong political push (scientific populism) by the H1 and ZEUS spokesman's, physics coordinators and, finally, by the H1 and ZEUS collaboration members for the so-called "high-lumi", small $\beta*$ magnet-insert, HERA programme (despite the unquestionable experimental evidence, provided by the "Generic Analysis Group" that the claimed BSM signals were fake, and despite a clear assessment that the high-lumi programme will hardly improve already published HERA results)*

1999 – the end of a dream of the European QCD-facility at DESY

- *B. Wiik's unfortunate accident --*
  TESLA project loses its momentum and is finally abandoned

- *An unsuccessful trial of the nuclear option for HERA revival (1999 HERA workshop)*

- *GSI turns towards a local FAIR PROJECT (low energy, nucleon degrees of freedom), European ELFE groups join the CEBAF program*

- *The electron-ion concept moves to US (thanks to a strong commitment to this project of Peter Paul – the new BNL director)*

- *the HEP experimental, collider-based programme at DESY is stopped couple of years later*

The US reincarnation (end extension) of the project

- *The first presentation of the BNL option of the eA collider at the MORIOND 1999 conference*

- *the project, baptised eRHIC, gets its momentum in the US following the BNL (1999)), Yale (2000), and Snowmass (2001) workshops*

- *The first White Paper in 2002 …but NSAC decides to finance FRIB*

- *……*

- *Over the next 20 years the e-A collider design had been greatly refined*

- *The project gets the name EIC -- two labs wanted to host it: TJNF and BNL*

- *The EIC project approved with BNL as its construction site*

Perspectives of electron-nucleus scattering at RHIC

Preliminary studies (Peggs, Trbojevic 1999) show that it is possible to collide heavy ions with positrons at RHIC. Two scenarios are to be considered:

- positrons circulating in one of the two existing rings
- electrons circulating in a purpose built room temperature ring in the RHIC tunnel

providing luminosities for e.g. eAu collisions of :

- $L \approx 1.0 \times 10^{27} cm^{-2} s^{-1}$ at the positron energy of 10 GeV and the nuclus energy of 100A GeV - for the first scenario
- $L = 3.7 \times 10^{29} cm^{-2} s^{-1}$ - for the second scenario

The limit of the luminosity in the fist scenario is determined by the maximal heat load of 1 Watt/m of dipole bend, due to the synchrotron radiation

A path to EIC

(couple of personal recollections, USA phase)

The Second eRHIC Workshop
Yale University
April, 2000

Table of Contents:

Date: Tue, 12 Dec 2000 14:08:04 -0500
From: "Paul, Peter" <ppaul@bnl.gov> **BNL director**
To: 'Witek Krasny' <krasny@lpnhp5.in2p3.fr>
Subject: RE: 12/9

[The following text is in the "iso-8859-1" character set.]
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[characters may be displayed incorrectly.]

Dear Witek: I would be happy to come over after the end of January, when we have the last town meeting, or even better, after the final "reconciliation meeting" which takes place at the end of March. After that meeting, the priorities are set for the next decade.
At the Hadron Physics Town meeting, the working group voted in a recommendation that eRHIC should be the next construction program and that vigorous development program should be started immediately with the goal of a realistic proposal before five years. Considering that we have to work out the electron cooling and detector details, 3 years is about as fast as we can move toward a full-scale proposal. But it looks like an electron ion Collider will happen. There was a lot of excitement about it at the Town Meeting.
Thanks for your continuing help.
Peter Paul

Two Snowmass-2001 plenary summary talks: extensive discussion of lepton-ion colliders' merits

Physics with lepton-ion colliders

towards a dedicated facility for a generic research in QCD

Mieczyslaw Witold Krasny
LPNHE- Paris

(krasny@lpnhep.in2p3.fr)

1 of 60

03/07/2001

Snowmass workshop on the future of high energy physics

Detector Issues of Lepton-Hadron Colliders

Snowmass workshop on the future of high energy physics

Mieczyslaw Witold Krasny
LPNHE - Paris

(krasny@lpnhep.in2p3.fr)

1 of 43

06/07/2001

Snowmass workshop on the future of high energy physics

1995 – 2002 >30 plenary talks at the major HEP and Nuclear Physics conferences advocating the electron-ion collider research programme, first at DESY and then at BNL…

Luminosity versus detector hermeticity

(simple machine/detector interface)

eAu Luminosity ($cm^{-2}s^{-1}$)

free space for a detector (m)

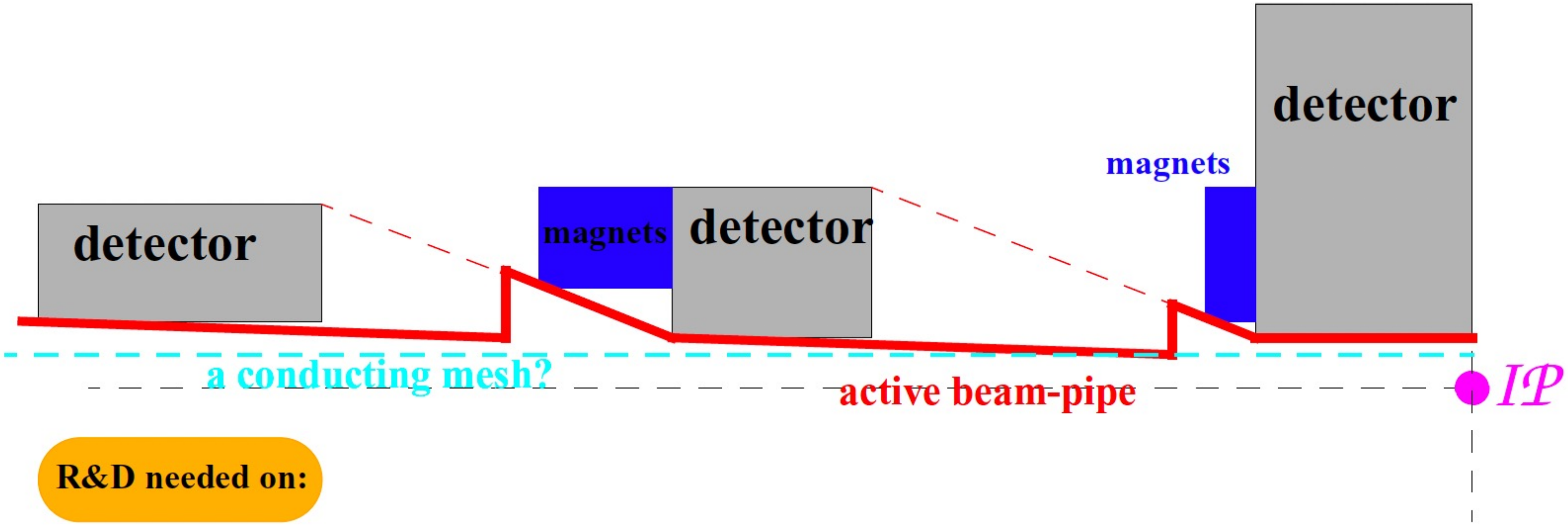
(beam-beam limit) (eRHIC scale)

eAu Luminosity ($cm^{-2}s^{-1}$)		Free space (m)
10^{31} — eRHIC 360 bunches		
	manipulating partons and rigidity of hadronic matter, exclusive and semi-exclusive studies, rare fluctuations of nuclear density, x>1-physics	1
10^{30}	multidimensional studies of hard processes tagged by various femto-detector response, charm physics luminous photon-photon scattering	
10^{29}	quark, gluon, colour dipole propagation in variable thickness nuclear matter - semi-inclusive studies, femto-detector R&D	10
HERA ePb estimate Willeke Seeheim '97		
10^{28}	gluon distribution, diffractive phenomena, vector meson coherent production, tagged structure functions, etc.	
10^{27}	inclusive double differential cross sections, quark distributions in nucleus, nucleus disintegration processes	

F. Willeke thumb rule: $\mathcal{L}=\mathcal{L}_o(d_o/d)^2$

Luminosity versus detector hermeticity, Trade-off?

(advanced machine/detector interface)



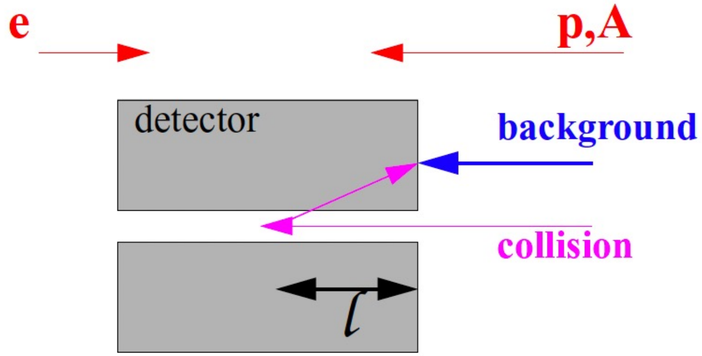
R&D needed on:

- **Large aperture final focus lens system with multi-function magnets (e.g. B. Parker dedicated design)**

  (constraints of permissible momentum spread, tolerable interaction region chromaticity are of lesser importance for lepton- hadron collider than for e.g. electron-positron colliders, note obvious advantages of low emittance electron beam (linac), ion beam (cooling) and their "small" momenta)

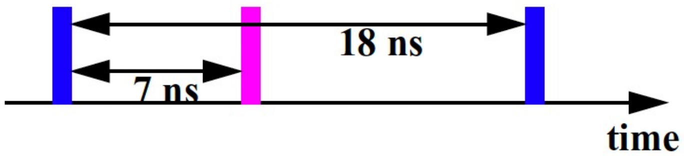
- **Dedicated "near-beam-pipe" detectors**
- **Dedicated beam pipe design "active beam pipe"**

Bunch collision frequency (bunch spacing)



$$\Delta t = 2l/c$$

→ **for l=1m and 720 eRHIC bunches:**

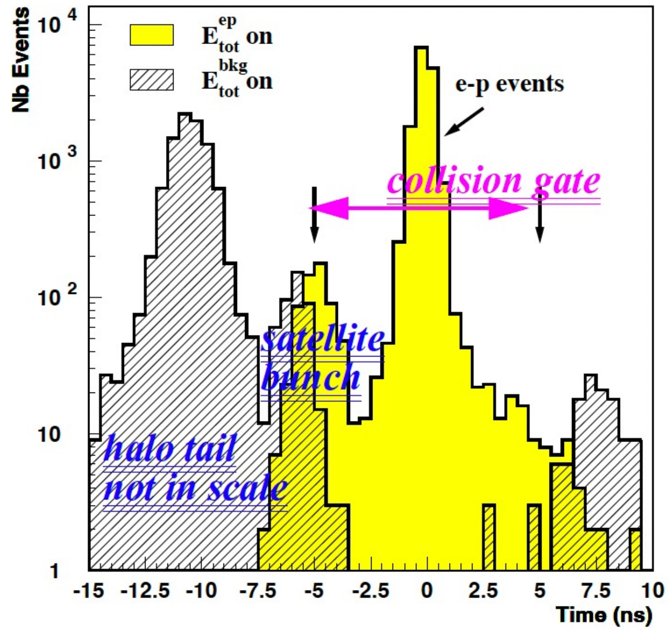


→ **in reality:**

beam halo
satellite bunches
bunch length

HERA (H1):

96 ns bunch spacing, SPACAL at l=1.5 m, CFD: 1ns resolution for MIP

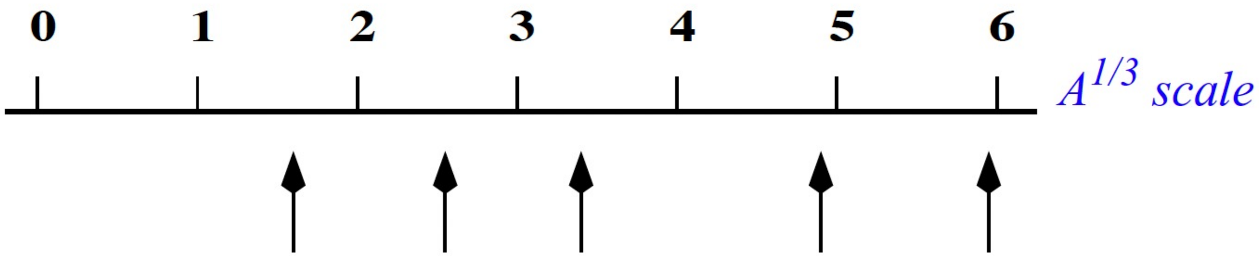


Note: lower scattered electron energy at eRHIC

Isoscalar ions: momentum spread and ion bunch length

→ *two complementary running strategies*

- *eAu runs - emphasis on maximizing the medium effects*
- *isoscalar target for high precision relative measurements*

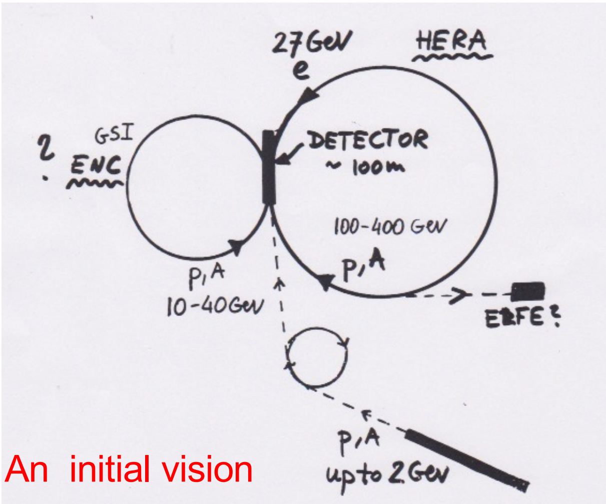


	He	O	Ca	Au
(M/Z-2)/2	.0013	-.0003	-.0009	→ (relative magnetic rigidity < 0.0022)

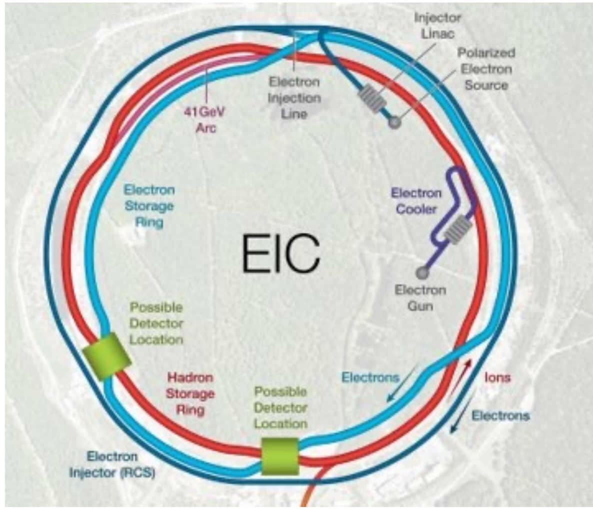
(if momentum spread of stored ions of 0.0025 can be tolerated a drastic reduction of measurement errors can be achieved by simultaneous storing of e.g. He, O and Ca ions)

NOTE: *Increasing ion bunch length should not diminish luminosity for 0-angle bunch crossing and could be useful for better control of systematic measurement errors*

Approval		Operation
1995 →	2023 →	2035?



An initial vision



The (more recent) past:

Photons as the support tools for the precision LHC EW experimental programme

The “2010-ties”: preparatory steps for the EW precision programme at the LHC

1. *The SPS ”precision support experiment” proposal*
2. *High-precision luminosity measurement at LHC*
3. *Photons and the Higgs coupling to tau-leptons*

LoI – SPS experiment and isoscalar beam collisions at the LHC

Eur. Phys. J. C (2009) 63: 33–56
DOI 10.1140/epjc/s10052-009-1084-1
THE EUROPEAN PHYSICAL JOURNAL C
Regular Article - Theoretical Physics

Measurement of $M_{W^+} - M_{W^-}$ at LHC

F. Fayette[1], M.W. Krasny[1,a], W. Płaczek[1,2], A. Siódmok[1,2]
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[2]Marian Smoluchowski Institute of Physics, Jagiellonian University, ul. Reymonta 4, 30-059 Cracow, Poland

Eur. Phys. J. C (2010) 69: 379–397
DOI 10.1140/epjc/s10052-010-1417-0
THE EUROPEAN PHYSICAL JOURNAL C
Regular Article - Experimental Physics

$\Delta M_W \leq 10$ MeV/c^2 at the LHC: a forlorn hope?*

M.W. Krasny[1,a], F. Dydak[2], F. Fayette[1], W. Płaczek[3], A. Siódmok[1,3]
[1]LPNHE, Universités Paris VI et VII and CNRS–IN2P3, Paris, France
[2]CERN, Geneva, Switzerland
[3]Institute of Physics, Jagiellonian University, Cracow, Poland

Eur. Phys. J. C 51, 607–617 (2007)
DOI 10.1140/epjc/s10052-007-0321-8
THE EUROPEAN PHYSICAL JOURNAL C
Regular Article – Theoretical Physics

Z boson as "the standard candle" for high-precision W boson physics at LHC[a]

M.W. Krasny[1,b], F. Fayette[1], W. Płaczek[1,2], A. Siódmok[2,3]
[1] LPNHE, Pierre and Marie Curie Universités Paris VI et Paris VII, Tour 33, RdC, 4, pl. Jussieu, 75005 Paris, France
[2] Marian Smoluchowski Institute of Physics, Jagiellonian University, ul. Reymonta 4, 30-059 Cracow, Poland
[3] CERN, Theory Division, 1211 Geneva 23, Switzerland

ep and ed collisions with COMPAS

CERN-LHCC-2009-014 / LHCC-I-017
17/09/2009

The measurement of the W mass at the LHC: shortcuts revisited

F. Dydak[1], M.W. Krasny[2*], and R. Voss[3]
[1] CERN, Geneva, Switzerland; *Friedrich.Dydak@cern.ch*
[2] LPNHE, Universités Paris VI et VII; *Mieczyslaw.Krasny@cern.ch*
[3] CERN, Geneva, Switzerland; *Rudiger.Voss@cern.ch*

Abstract

The claim that the W mass will be measured at the LHC with a precision of $\mathcal{O}(10)$ MeV is critically reviewed. It is argued that in order to achieve such precision, a considerably better knowledge of the u_v, d_v, s, c, and b structure functions of the proton than available today is needed. This will permit to assess with adequate precision the production characteristics of the W and Z bosons in the proton-proton collisions at the LHC, and their effect on the p_T spectra of charged leptons from W and Z decays. An experimental programme is suggested that will deliver the missing information. The core of this programme is a dedicated muon scattering experiment at the CERN SPS, with simultaneous measurements on hydrogen and deuterium targets.

* Contactperson

Cold isoscalar ions at the LHC

ELSEVIER
Progress in Particle and Nuclear Physics
Volume 114, September 2020, 103792
Review

High-luminosity Large Hadron Collider with laser-cooled isoscalar ion beams ☆

M.W. Krasny [a b], A. Petrenko [c b], W. Płaczek [d]

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Abstract

The existing CERN accelerator infrastructure is world unique and its research capacity should be fully exploited. In the coming decade its principal *modus operandi* will be focused on producing intense proton beams, accelerating and colliding them at the Large Hadron Collider (LHC) with the highest achievable luminosity. This activity should, in our view, be complemented by new initiatives and their feasibility studies targeted on re-using the existing CERN accelerator complex in novel ways that were not conceived when the machines were designed. They should provide attractive, ready-to-implement research options for the forthcoming *paradigm-shift* phase of the CERN research. This paper presents one of the case studies of the *Gamma Factory* initiative (Krasny, 2015) – a proposal of a new operation scheme of ion beams in the CERN accelerator complex. Its goal is to extend the scope and precision of the LHC-based research by complementing the proton–proton collision programme with the *high-luminosity* nucleus–nucleus one. Its numerous physics highlights include studies of the exclusive Higgs-boson production in photon–photon collisions and precision measurements of the electroweak (EW) parameters. There are two principal ways to increase the LHC luminosity which do not require an upgrade of the CERN injectors: (1) modification of the beam-collision optics and (2) reduction of the transverse emittance of the colliding beams. The former scheme is employed by the ongoing high-luminosity (HL-LHC) project. The latter one, applicable only to ion beams, is proposed in this paper. It is based on laser cooling of bunches of partially stripped ions at the SPS flat-top energy. For isoscalar calcium beams, which fulfil the present beam-operation constrains and which are particularly attractive for the EW physics, the transverse beam emittance can be reduced by a factor of 5 within the 8seconds long cooling phase. The predicted nucleon–nucleon luminosity of $L_{NN} = 4.2 \times 10^{34}$ s^{-1}cm^{-2} for collisions of the cooled calcium beams at the LHC top energy is comparable to the levelled luminosity for the HL-LHC proton–proton collisions, but with reduced pile-up background. The scheme proposed in this paper, if confirmed by the future Gamma Factory proof-of-principle experiment, could be implemented at CERN with minor

The consequences of a missing PDF input

2007

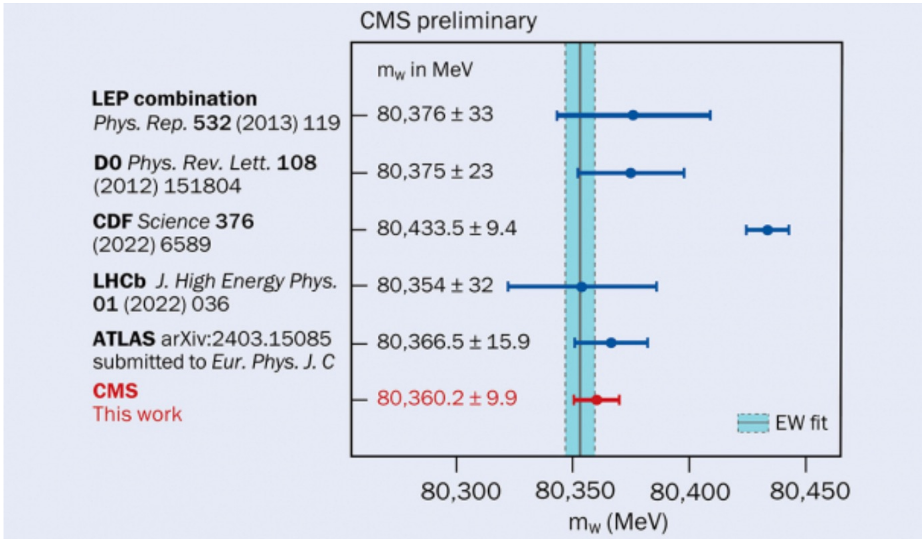
Expected biases in the measured values of M_W

$u^{(v)}, d^{(v)}$	$u^{(v)}_{\rm max} = 1.05\, u^{(v)}$, $d^{(v)}_{\rm min} = d^{(v)} - .05\, u^{(v)}$	79
	$u^{(v)}_{\rm min} = 0.95\, u^{(v)}$, $d^{(v)}_{\rm max} = d^{(v)} + .05\, u^{(v)}$	−64
	$u^{(v)}_{\rm min} = 1.02\, u^{(v)}$, $d^{(v)}_{\rm max} = d^{(v)} - .02\, u^{(v)}$	32
	$u^{(v)}_{\rm min} = 0.98\, u^{(v)}$, $d^{(v)}_{\rm max} = d^{(v)} + .02\, u^{(v)}$	−18
	$u^{(v)}_{\rm max} = 1.02\, u^{(v)}$, $d^{(v)}_{\rm min} = 0.92\, d^{(v)}$	48
	$u^{(v)}_{\rm min} = 0.98\, u^{(v)}$, $d^{(v)}_{\rm max} = 1.08\, d^{(v)}$	−32

Expected biases in the measured values of M_W

s, c	$c_{\rm min} = 0.8\, c$, $s_{\rm max} = s + 0.2\, c$	257
	$c_{\rm max} = 1.2\, c$, $s_{\rm min} = s - 0.2\, c$	−237
	$c_{\rm min} = 0.9\, c$, $s_{\rm max} = s + 0.1\, c$	148
	$c_{\rm max} = 1.1\, c$, $s_{\rm min} = s - 0.1\, c$	−111
	$c_{\rm min} = 0.95\, c$, $s_{\rm max} = s + 0.05\, c$	78
	$c_{\rm max} = 1.05\, c$, $s_{\rm min} = s - 0.05\, c$	−58

2025



Three PDF degrees of freedom will remain unconstrained by the LHC data alone (a cure: EW programme with isoscalar ion collisions)

The precision luminosity measurement at LHC

Four principal reasons to push the precision frontier as much as possible:

- ***Measurement of the cross sections ratios at different CM-energies***
  (EW physics, Primakoff processes, Higgs searches, etc…)

- ***Measurement of the cross section ratios with different beam species***
  (use ions to modify the medium effects in hard EW and QCD processes)

- ***Relative normalization of the cross sections measured in different phase-space regions*** *(e.g. ATLAS/CMS versus LHCb in the measurement of $\sin^2\theta_W$)*

- ***Relative normalization of cross sections measured at the LHC and Tevatron***
  (precision unfolding of the flavour and sea/valence structure of the proton)

The precision luminosity measurement at LHC

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment
Volume 584, Issue 1, 1 January 2008, Pages 42-52

Luminosity measurement method for LHC: The theoretical precision and the experimental challenges ☆

M.W. Krasny [a], J. Chwastowski [b c], K. Słowikowski [b]

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment
Go to Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment on ScienceDirect
Volume 729, 21 November 2013, Pages 949-961

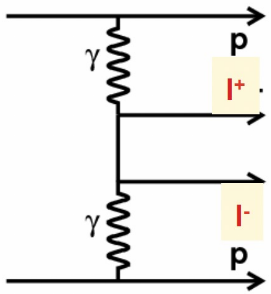
Luminosity measurement method for the LHC: The detector requirement studies ☆

M.W. Krasny [a], J. Chwastowski [b c], A. Cyz [c], K. Słowikowski [c]

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment
Volume 729, 21 November 2013, Pages 934-948

Luminosity measurement method for the LHC: Event selection and absolute luminosity determination ☆

M.W. Krasny [a], J. Chwastowski [b c], A. Cyz [c], K. Słowikowski [c]



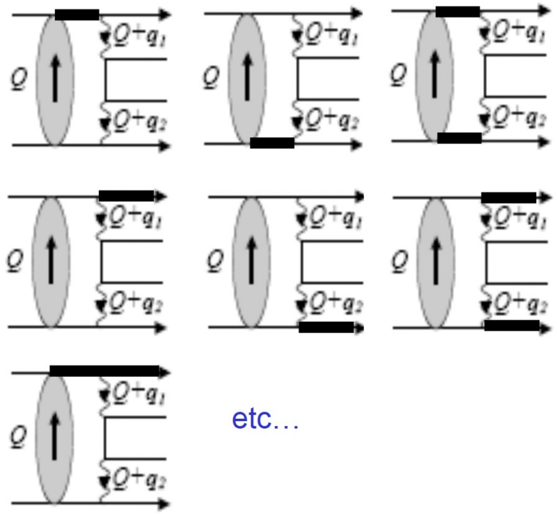
… to achieve <1% control of the cross sections either the p_t^{thr} must be low:

$p_t^{thr} < O(1)$ *GeV /c*

…or the transverse momentum of the lepton pair must be reconstructed with a precision/resolution:

$\delta(p_t^{pair}) < O(100)$ *MeV /c*

Unrealistic for (p_t^{thr} = 6 GeV/c), easy for (p_t^{thr} < 0.6 GeV/c)



V.A. Khoze[a], A.D. Martin[a], R. Orava[b] and M.G. Ryskin[a,c]

Eur.Phys.J.C19:313-322,2001

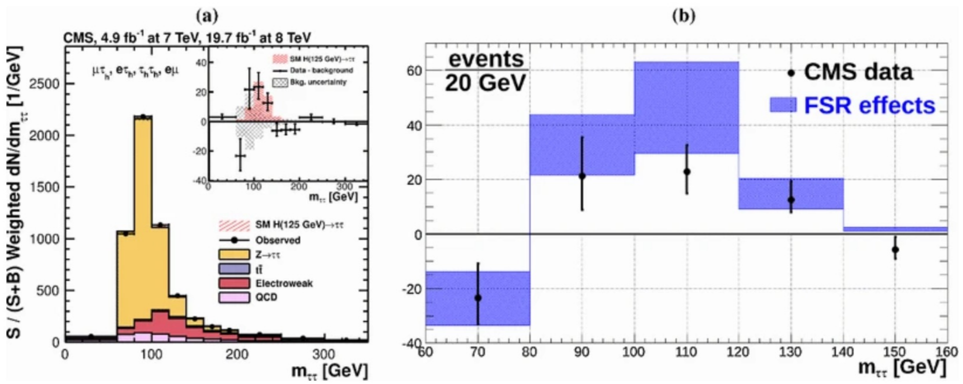
Photon emissions by muons and τ-leptons and the “evidence” for the H→ ττ decays

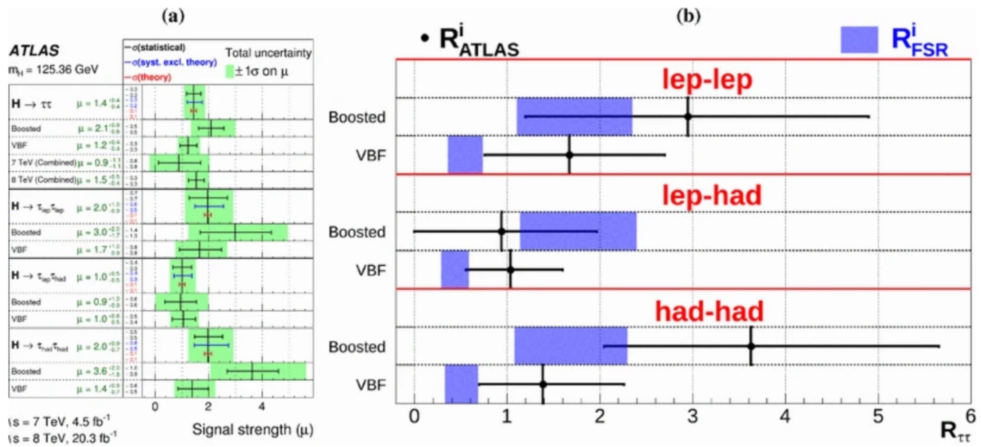
Home › The European Physical Journal C › Article

QED radiative corrections and their impact on $H \to \tau\tau$ searches at the LHC

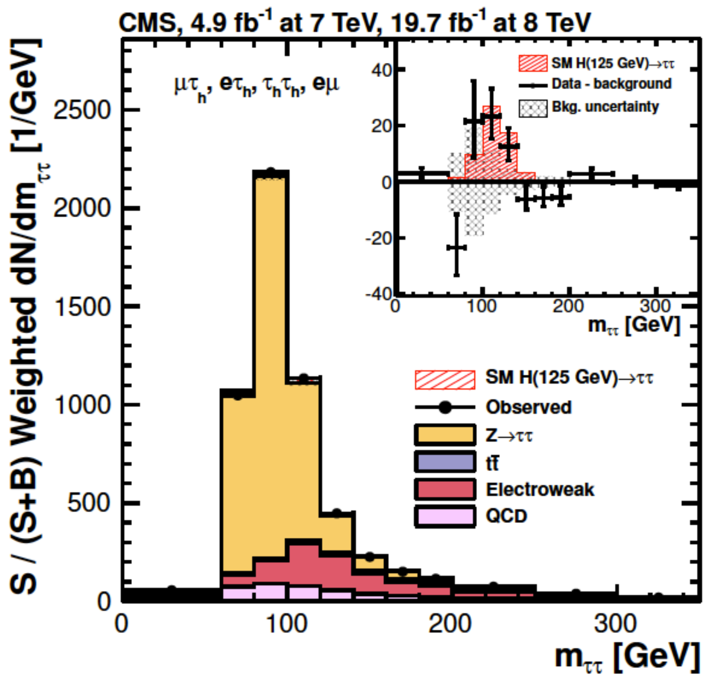
Regular Article – Experimental Physics | Open access | Published: 09 April 2016
Volume 76, article number 194, (2016) Cite this article

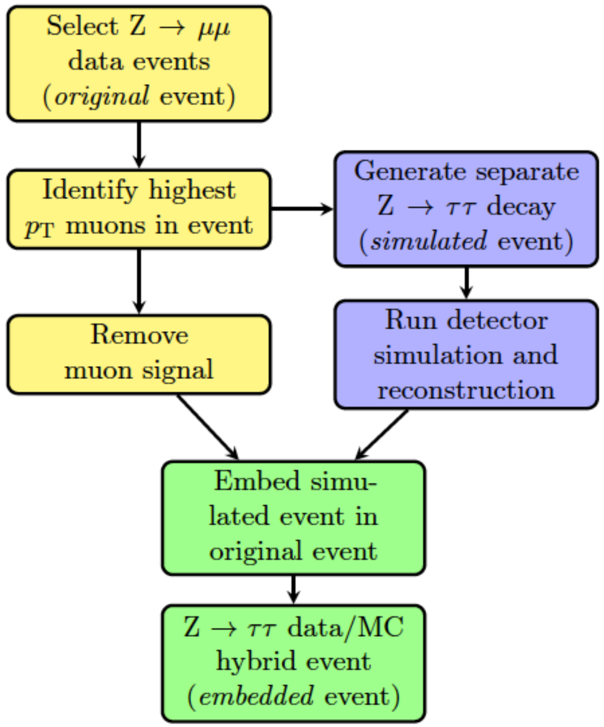
Mieczyslaw Witold Krasny, Stanisław Jadach & Wiesław Płaczek





The dominant background to H→$\tau\tau$ decays comes from the Z→$\tau\tau$ decays. This background is determined using the ***Z→$\mu\mu$*** *data (rather than MC event simulation) by the "embedding procedure" in which the detector response to the muons is replaced by the simulated response to the τ-leptons*



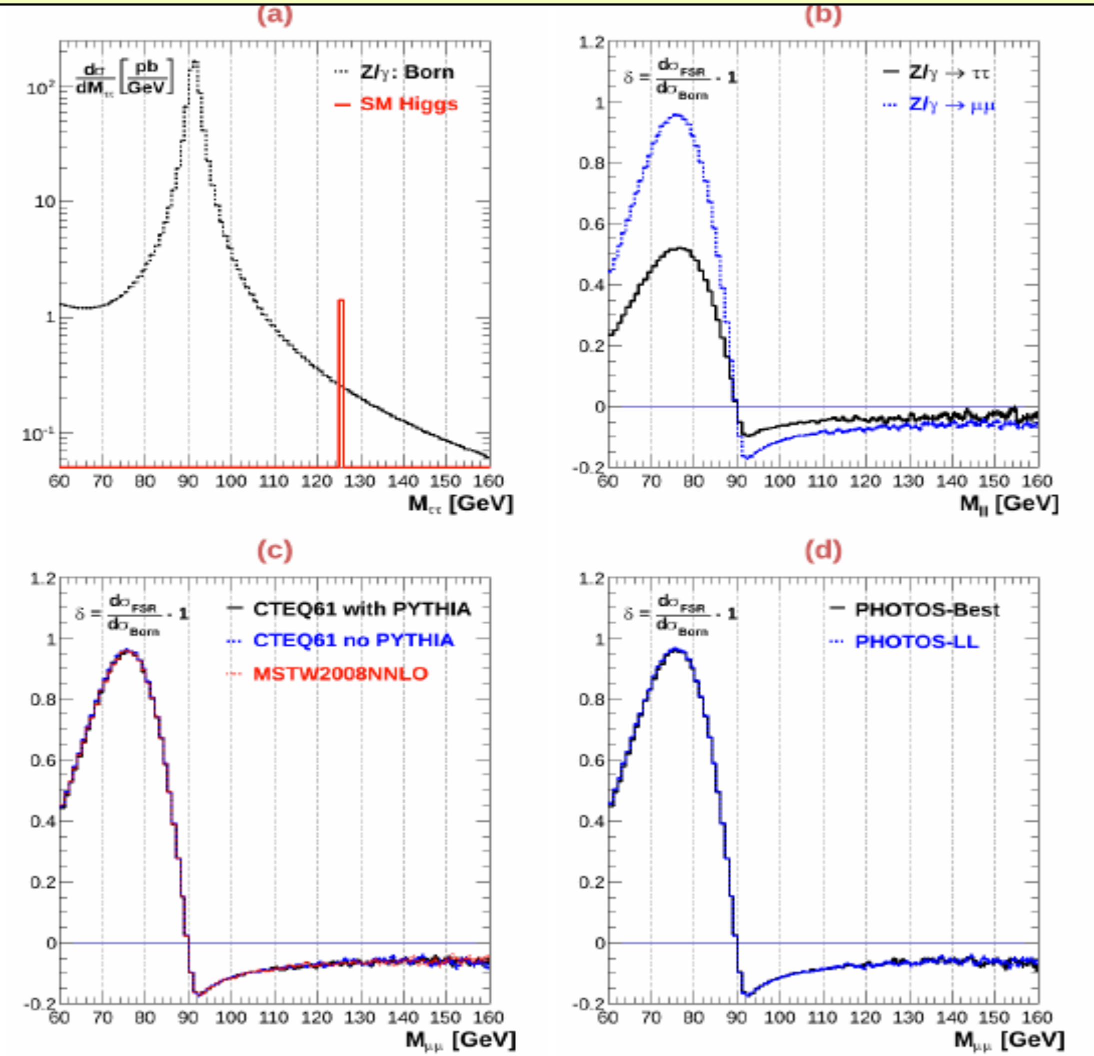


The principal comment back in 2014 (at the time of the preparation of the $H \rightarrow \tau\tau$ discovery papers:

“The ratio of the $Z \rightarrow \tau\tau$ to $H \rightarrow \tau\tau$ cross section is ~ 1000 to 1…

… If you embed tautau decays into mumu environment with O(~1%) ***precision you must consider*** *the differences in the photon radiation strength from muons and taus (they radiate with different strength ~* $\alpha/\pi \, ln((m\mu/m\tau)^2)$*. You do not write anything in the papers on the procedure how you took this effect into account. Reconstructed muon track momenta will be smaller that those of "Born" muons (..or equivalent taus)*
So, while replacing muons by taus you will underestimate, in the MC, the large mass tail of the Z->tau-tau events thus increasing artificially (or maybe even creating), of what you call, the Higgs signal. Have you studied this effect?”

Classical radiative corrections to Z→ττ leptonic decays:



The necessity of taking into account the radiative corrections to the embedding procedure has its origin in the interplay of the following three effects:

- in the embedding procedure bare muons are replaced by dressed τ-leptons,
- the measurement resolution of the mass of two opposite charge τ-leptons is comparable to the difference of masses of Z-boson and the Higgs boson,
- the inclusive cross section for Z/γ^*-bosons decaying into leptons is by three orders of magnitude higher than that for the Higgs boson.

The Higgs adventure

BACKGROUND TO HIGGS-BOSON SEARCHES FROM INTERNAL CONVERSIONS OF OFF-SHELL PHOTONS ASSOCIATED WITH Z/γ^*-BOSON PRODUCTION AT THE LHC* **

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(Received December 22, 2014; revised version received March 11, 2015)

This paper presents the studies of the background contribution to the $H \to 4l$ searches originating from the processes of off-shell (virtual) photon emissions and their conversions into lepton pairs accompanying the production of Z/γ^*-bosons at the LHC. They extend the analyses of the irreducible background presented in the ATLAS and CMS Higgs papers [*Phys. Lett.* **B716**, 1 (2012); *Phys. Lett.* **B726**, 88 (2013); *Phys. Rev.* **D90**, 052004 (2014); CERN-PH-EP-2014-170, to appear in *Phys. Rev.* **D**; *Phys. Lett.* **B716**, 30 (2012); *Phys. Rev.* **D89**, 92007 (2014)] by taking into account the emissions of off-shell photons by parton showers. Including these effects does not change significantly the Higgs-searches background level, provided that the transverse momentum of each of the final-state leptons is restricted to the range of $p_{\mathrm{T},l} > 7$ GeV. In the kinematical region extended towards

** The work is partly supported by the Programme of the French–Polish Coo… between IN2P3 and COPIN No. 05-116, and by the Polish National Cen… grant No. DEC-2011/03/B/ST2/00220.

Vol. 46 (2015) ACTA PHYSICA POLONICA B No 5

BACKGROUND TO HIGGS-BOSON SEARCHES FROM INTERNAL CONVERSIONS OF OFF-SHELL PHOTONS ASSOCIATED WITH Z/γ^*-BOSON PRODUCTION AT THE LHC* **

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Vol. 45 (2014) …A POLONICA B No 1

…CESS OF FOUR-LEPTON EVENTS …RETED AS HIGGS-BOSON SIGNAL: BACKGROUND FROM DOUBLE DRELL–YAN PROCESS?* **

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(Received October 23, 2013)

We construct a simple model of the Double Drell–Yan Process (DDYP) for proton–proton collisions and investigate its possible contribution to the background for the Higgs-boson searches at the LHC. We demonstrate that under the assumption of the predominance of short range, $\mathcal{O}(0.1)$ fm, transverse-plane correlations of quark–antiquark pairs within the proton, this contribution becomes important and may even explain the observed excess of the four-lepton events at the LHC — the events interpreted as originating from the Higgs-boson decays: $H \to ZZ^* \to 4l$ and $H \to WW^* \to 2l2\nu$.

DOI:10.5506/APhysPolB.45.71
PACS numbers: 14.80.Bn, 13.38.Be, 13.38.Dg, 13.85.Qk

Vol. 47 (2016) ACTA PHYSIC…

ON THE CONTRIBUTION OF T… DRELL–YAN PROCESS TO WW… ZZ PRODUCTION AT THE LH… **

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(Received January 20, 2015; revised version November 2, 2015)

In this paper, we investigate consequences of an assumption that the discrepancy of the predicted and observed W^+W^- production cross sections at the LHC is caused by the missing contribution of the double Drell–Yan process (DDYP). Using our simple model of DDYP [*Acta Phys. Pol. B* **45**, 71 (2014)], we show that inclusion of this production mechanism leads to a satisfactory, parameter-free description of the two-lepton mass distribution for 0-jet W^+W^- events and the four-lepton mass distribution for ZZ events. In such a scenario, the Higgs-boson contribution is no longer necessary to describe the data. An experimental programme to prove or falsify such an assumption is proposed.

DOI:10.5506/APhysPolB.47.1045

Vol. 42 (2011) ACTA PHYSICA POLONICA B No 10

ASCERTAINING THE ORIGIN OF THE $l\nu l\nu$ EXCESS EVENTS AT THE LHC BY A CHANGE OF BEAM ENERGY

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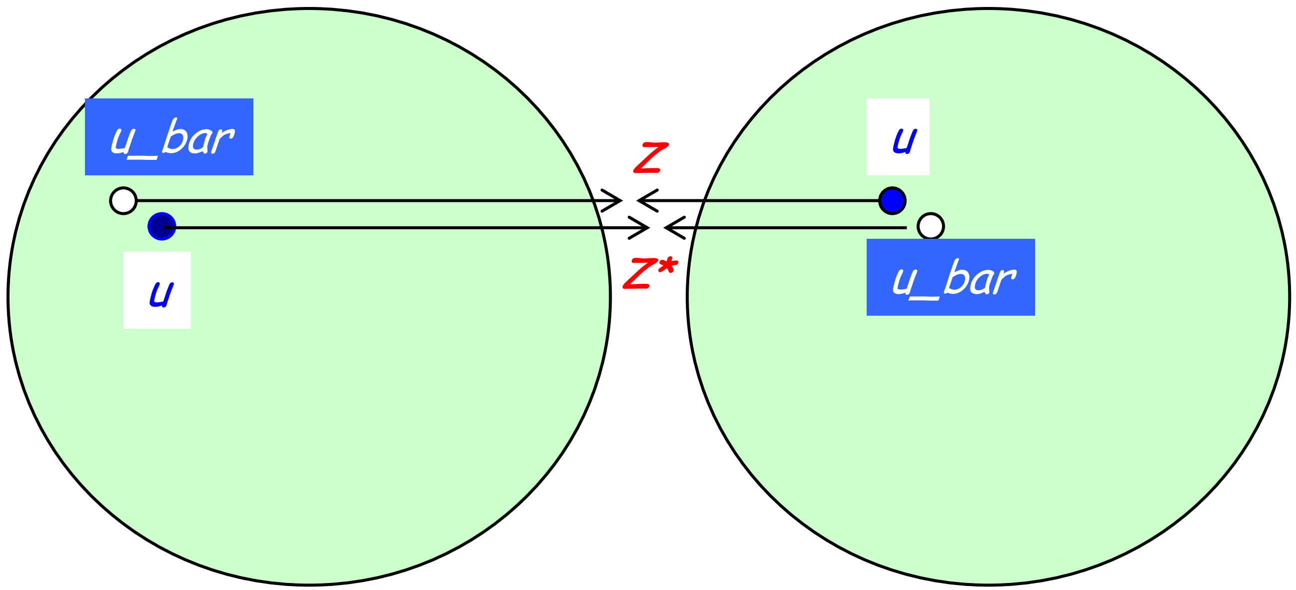
(Received September 6, 2011)

A higher than predicted rate of two leptons plus missing transverse energy events, reported at the summer HEP conferences, can originate from a decay of the Higgs boson into a $WW^{(*)}$ pair, a misjudgement of the rate of SM background processes or a statistical fluctuation. In this paper we discuss a way to resolve this three-fold ambiguity.

DOI:10.5506/APhysPolB.42.2133
PACS numbers: 14.70.Fm, 14.80.Bn, 13.85.Rm

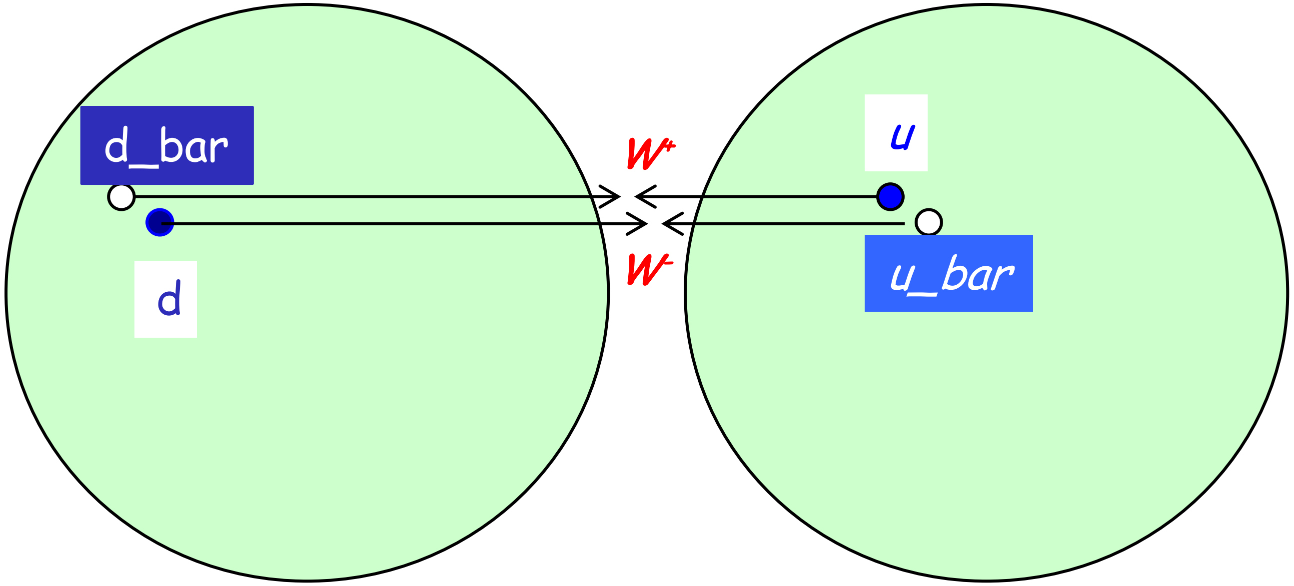
Enhanced ZZ (ZZ*) production in DDYP



The correlation length of the uubar and ddbar pairs are the same (strong isospin symmetry – the excess of ZZ and WW events correlated (mimicking the custodial symmetry)*

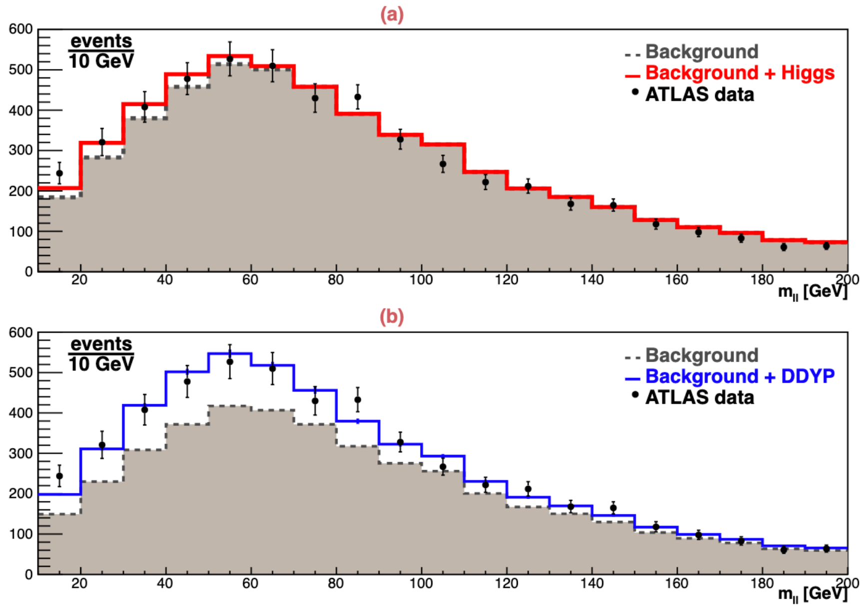
***Note:* – spin ZZ (ZZ*) = 0 (higgs like)**

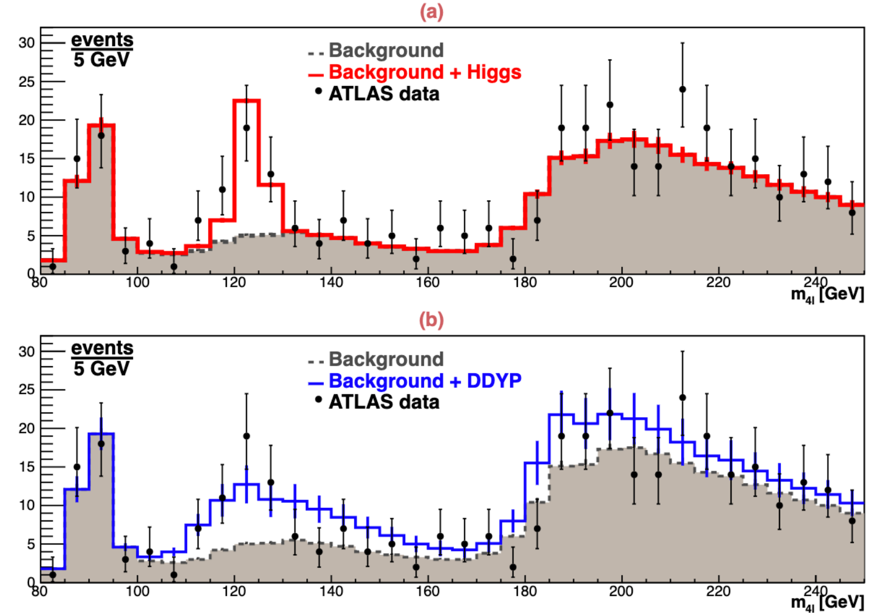
Enhanced WW production in DDYP

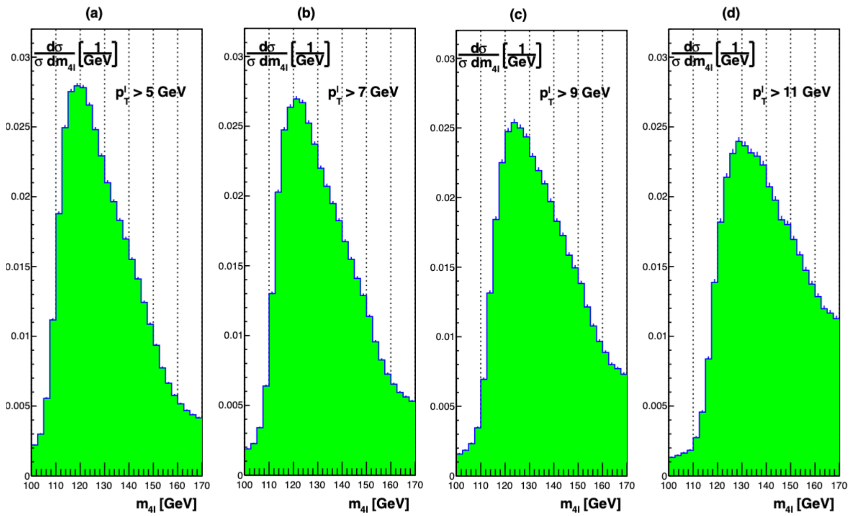


The presence of an antiquark enhances the probability of finding the same flavour quark nearby.

<u>Note (local helicity compensation):</u> spin WW = 0 (higgs like)


(a)
events / 10 GeV
Background
Background + Higgs
ATLAS data
m_ll [GeV]
(b)
events / 10 GeV
Background
Background + DDYP
ATLAS data
m_ll [GeV]


(a)
events / 5 GeV
Background
Background + Higgs
ATLAS data
m_4l [GeV]
(b)
events / 5 GeV
Background
Background + DDYP
ATLAS data
m_4l [GeV]


(a)
(b)
(c)
(d)
dσ / σ dm_4l [1/GeV]
p_T^l > 5 GeV
p_T^l > 7 GeV
p_T^l > 9 GeV
p_T^l > 11 GeV
m_4l [GeV]