Hunting for Pseudoscalars and Scalars:
…with nuclei as search tools and with Wit's wit

This talk is a tribute to Wit Busza's wit – with my admiration for his quest for searching simplicity in complex phenomena with both humility and the same time a strength of intellectual honesty

… and my gratefulness for all the discussions we had over the last 26 years on physics …and on the rest of the world

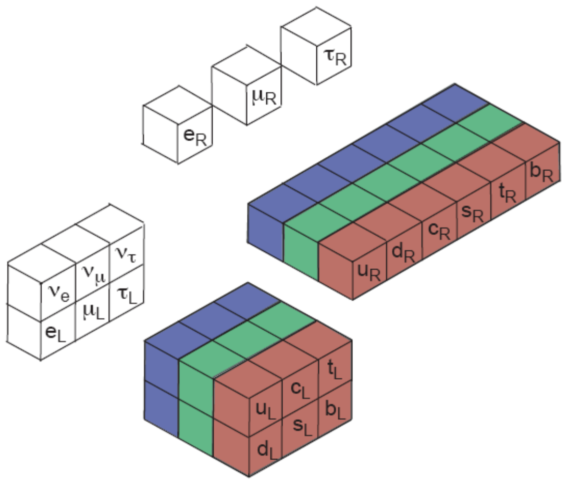
Mieczyslaw Witold Krasny
LPNHE, University Pierre and Marie Curie, Paris

- **A prelude**

The Standard Model

spin ½ particles as building bricks and spin 1 particles as force carriers

Pointlike ($r \lesssim 10^{-18}$ m) **quarks** and **leptons**



Where are the elementary pseudoscalars and scalars?

with interactions specified by

$$\mathbf{SU(3)_c} \otimes \mathbf{SU(2)}_L \otimes \mathbf{U(1)}_Y$$

gauge symmetries . . .

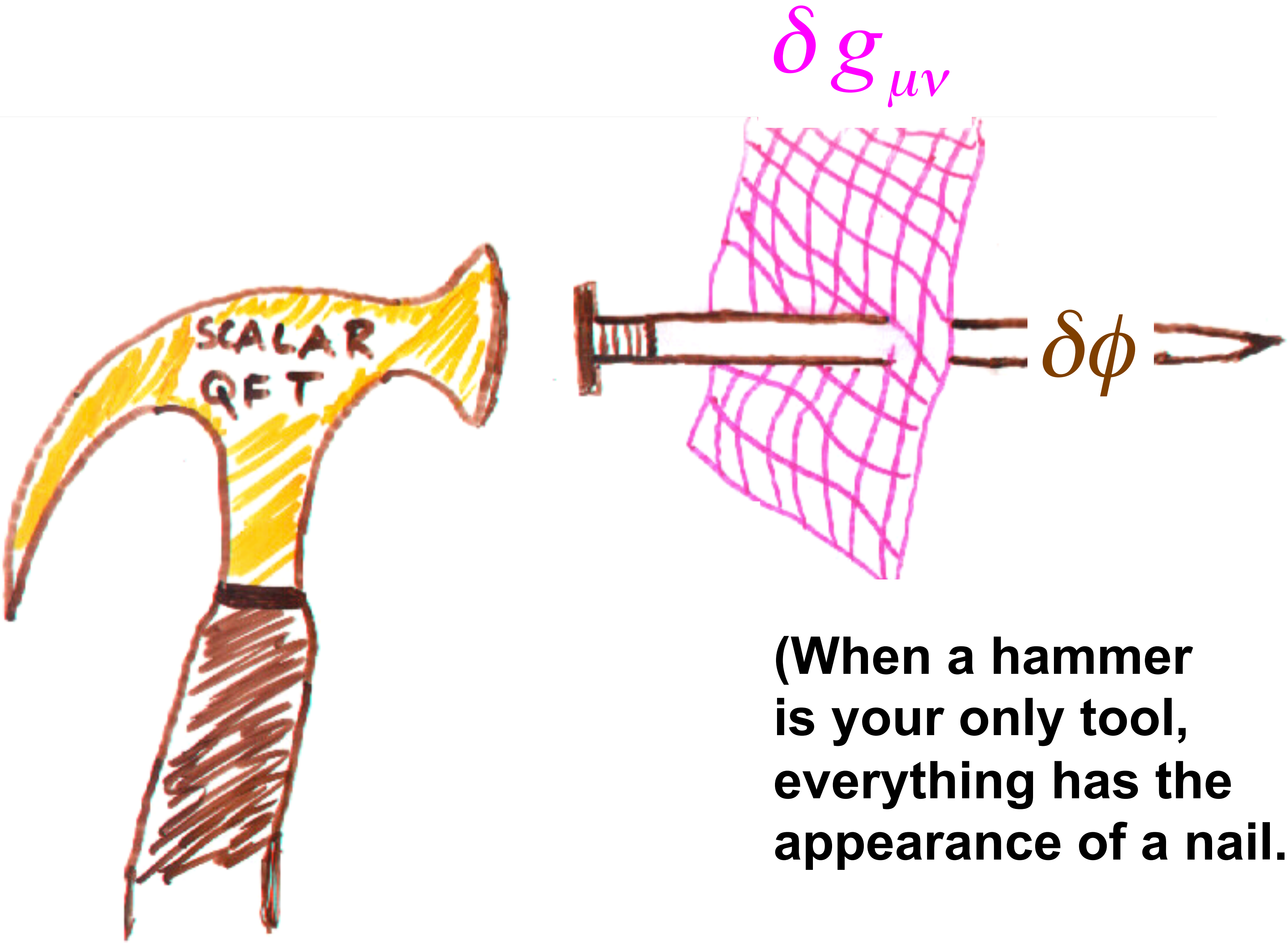
Badly wanted:

elementary scalar and pseudo-scalar fields:

quintessence, k-essence, inflatons, dilatons, axion, higgs…

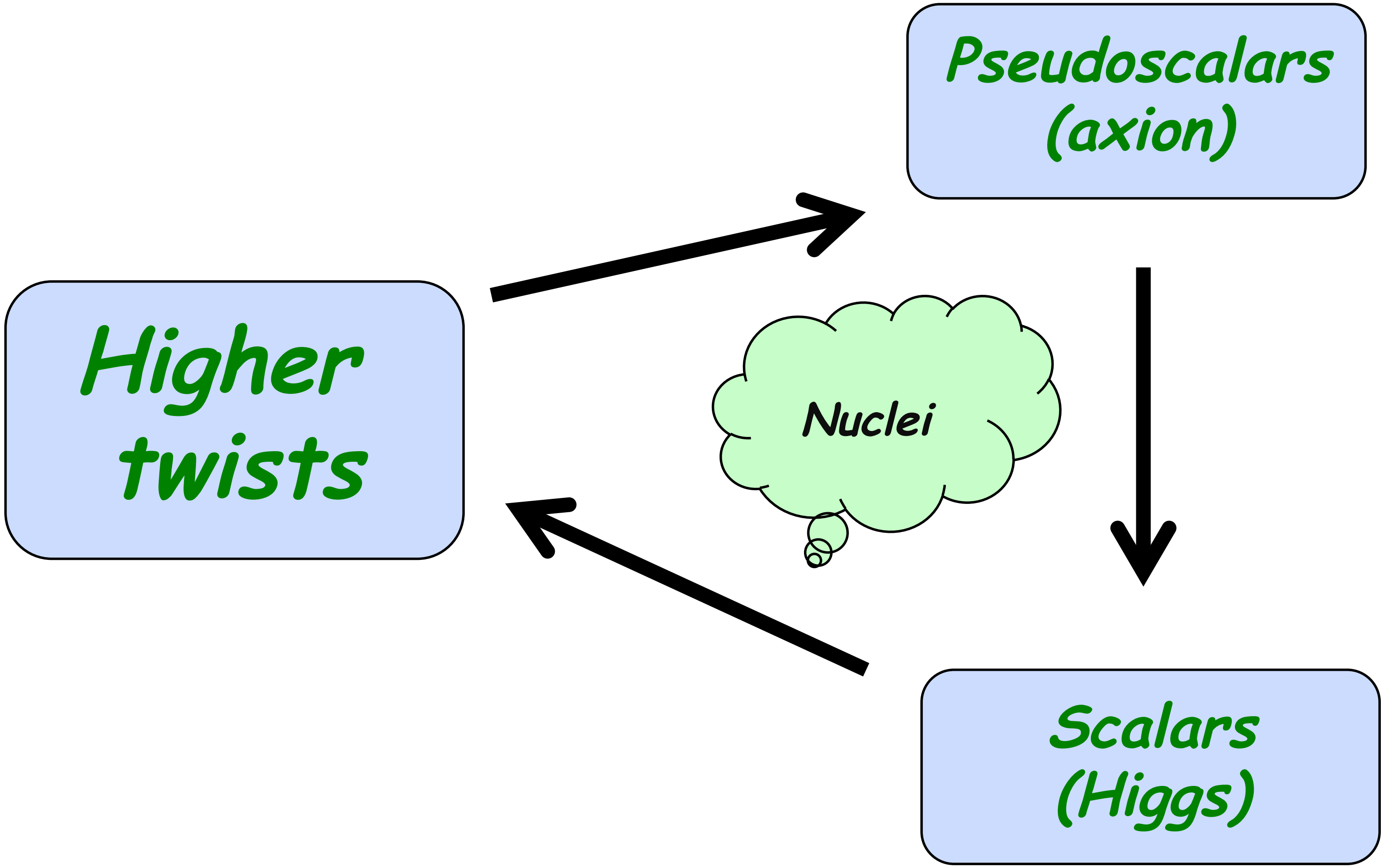
DO THEY EXIST, OR ARE THEY JUST REPRESNTING A CONVENIENT WAY OF HIDING UNKNOWN WITHIN THE LOCAL QUANTUM FIELD THEORIES PARADIGMS…

R. Kollb ⟶



(When a hammer is your only tool, everything has the appearance of a nail.)

The 1986 and 2013 snapshots – -two "encounters" with Wit

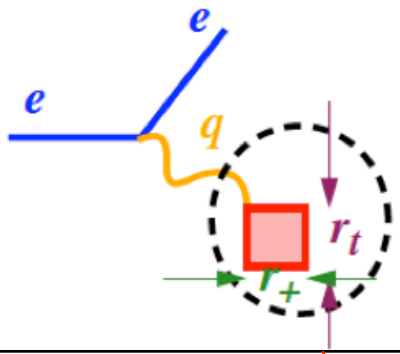


- the year 1986

the "axion time"

Search for charged scalar partons (E140 exp.) …and the role of nuclei

Probing point-like structure of protons and nuclei with transversely and longitudinally polarized virtual photons



$R = \sigma_L/\sigma_T = 0$ - *for spin ½ partons*

$R = \sigma_L/\sigma_T = \infty$ - *for spin 0 partons*

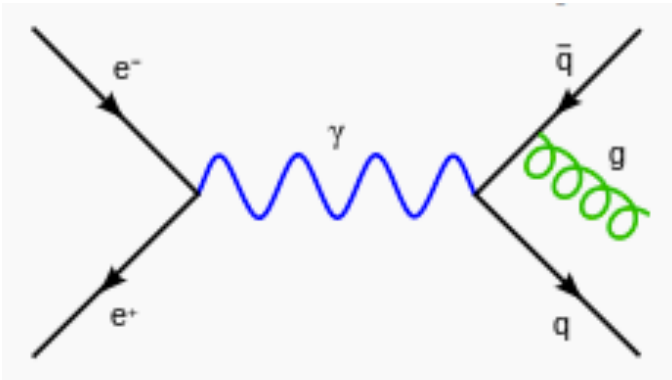
… a possible mechanisms

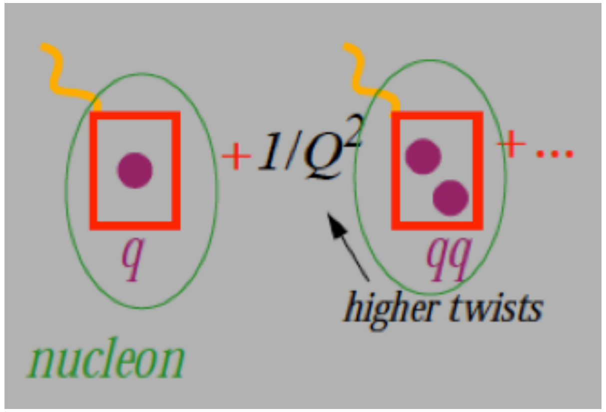
$s^{+(-)}$	$(ud)^{1/3}$

… is an observation of R ≠ 0 a sufficient condition to claim the discovery of scalar partons?

Search for charged scalar partons (E140 exp.) …and the role of nuclei

No, the precision measurement of R must be complemented by a comprehensive analysis of all the QCD effects, including Higher Twists (HT)…

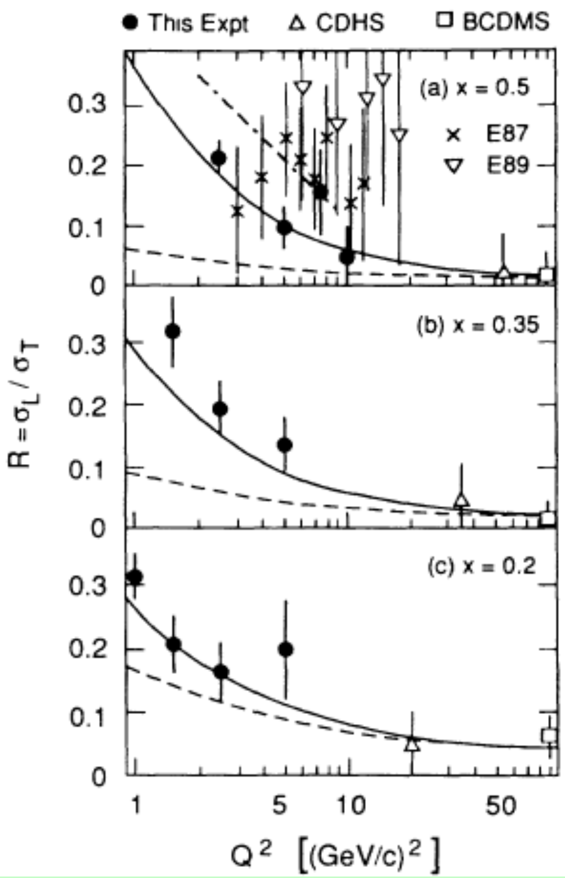


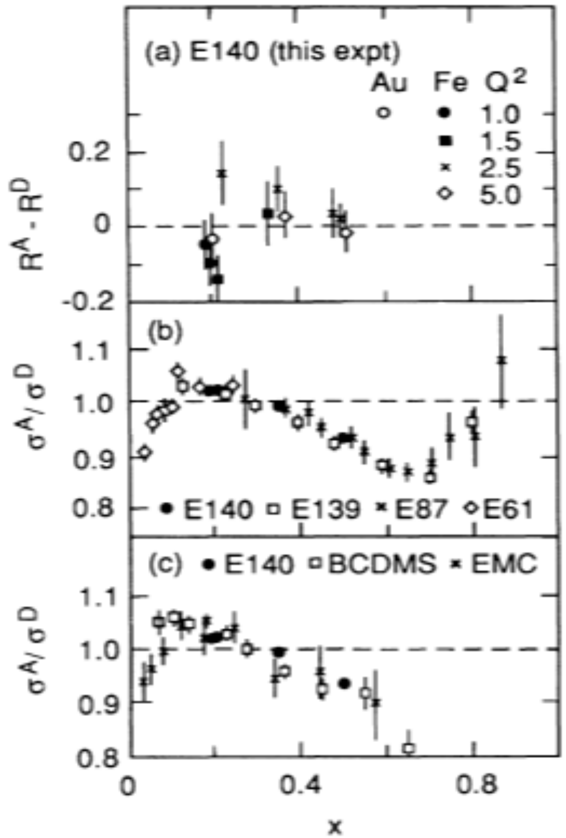


$R_{QCD} = \sim \alpha_s log(Q^2/\Lambda^2)G(2x,Q^2)$

$R_{HT} = \sim 1/Q^2$

The E140 experiment results (1986)





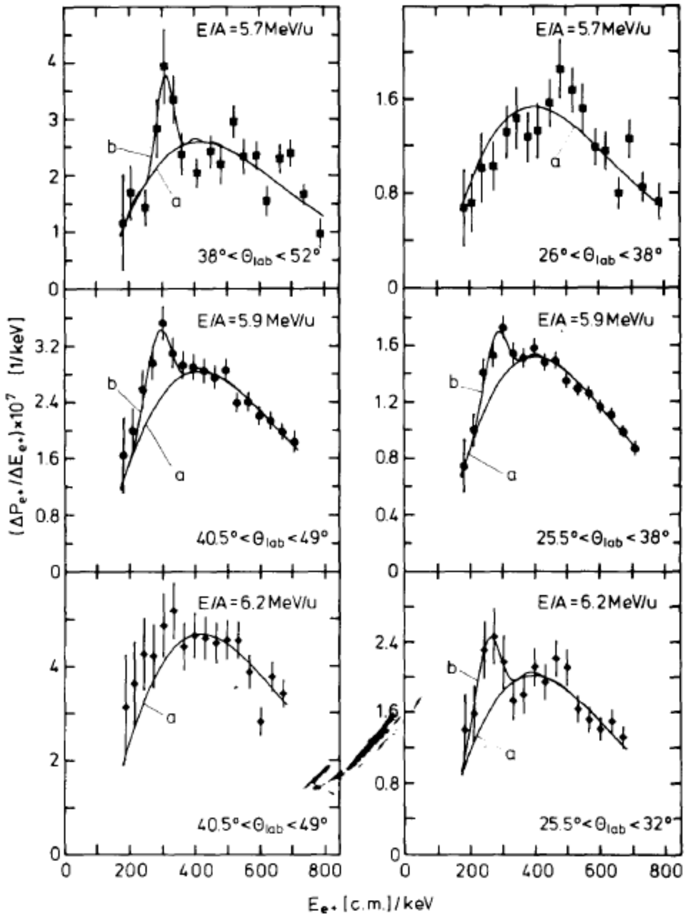
No scalar partons:
significant QCD and HT contribution

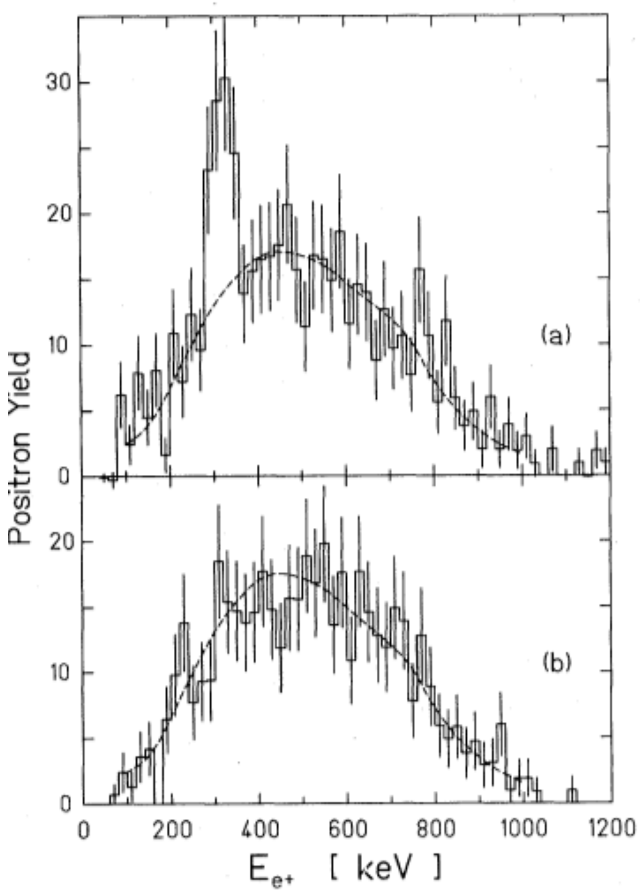
The role of nuclei:
"scalar-like" processes confined to short-range, sub-nucleon distances

1986 - GSI peaks -heavy ion collisions

sparking of the vacuum:

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

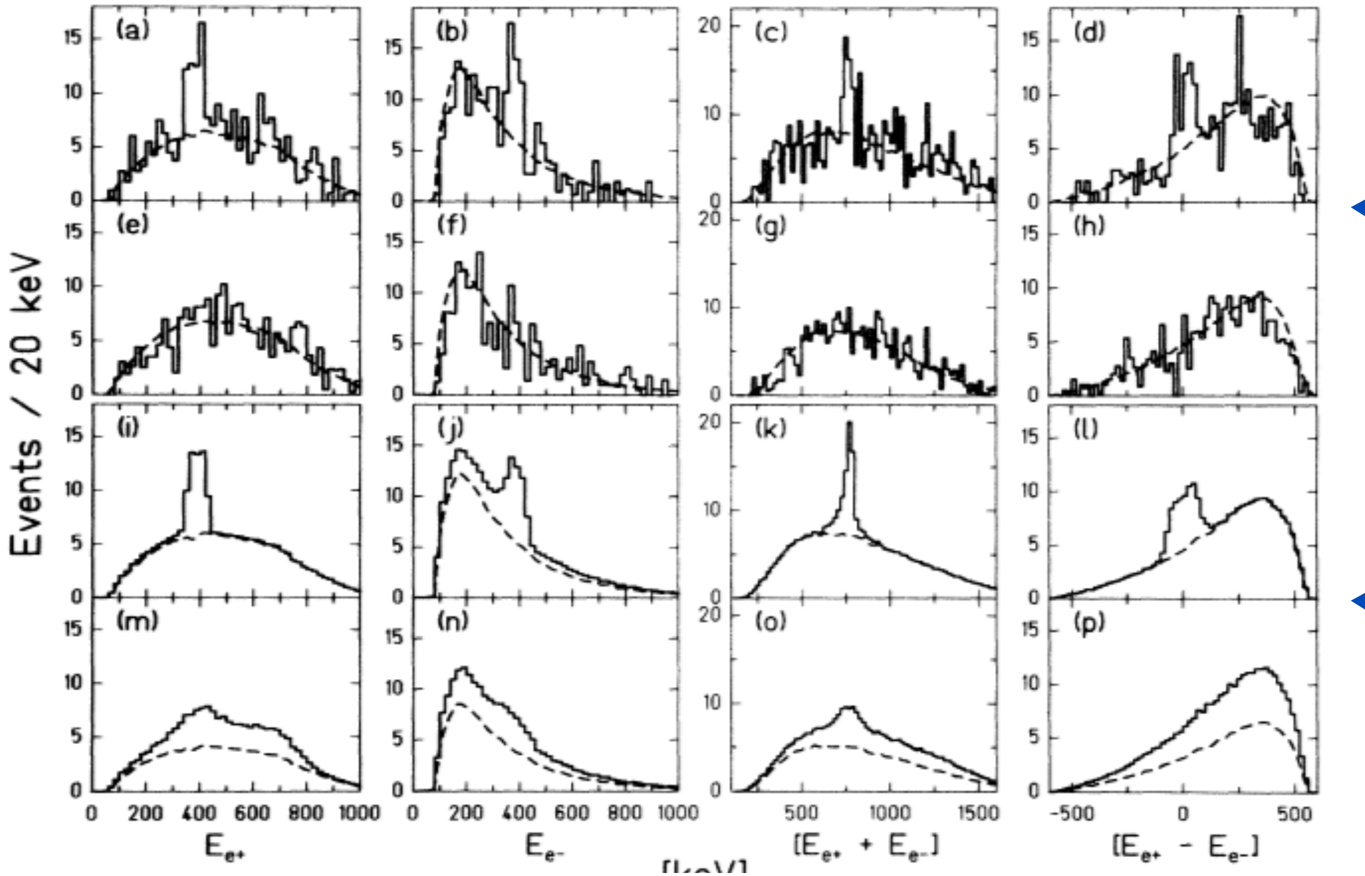




Found peaks in the positron and electron spectra
…

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 1.8 MeV scalar (pseudoscalar) particle



exp.data

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

Why so exciting?: CP violation in strong interactions

$$\frac{1}{32\pi^2}\bar{\theta}\,\frac{1}{2}\varepsilon_{\mu\nu\rho\sigma}F^{\mu\nu}F^{\rho\sigma}=\bar{\theta}\,\{F\tilde{F}\}$$

$$\bar{\theta}=\theta_{QCD}+\theta_{weak},\quad \theta_{weak}=\arg.Det.M_q$$

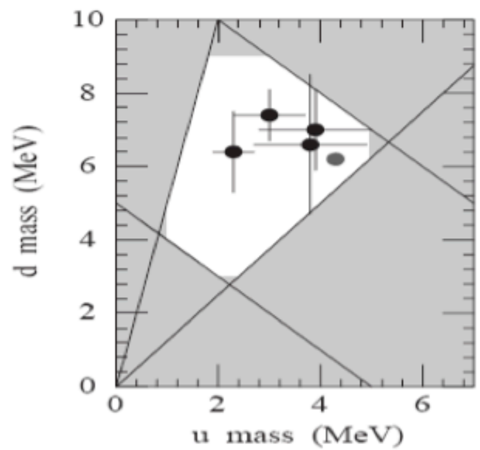
Here theta-bar is the final value taking into account the electroweak CP violation. Weak interactions can contribute O(10-17) [George-Randall]. For QCD to become a correct theory, this CP violation must be sufficiently suppressed.

If masses of the quarks were zero theta
Is not a physical quantity and there
Is no strong CP problem:

$$q\rightarrow e^{i\gamma_5\alpha}q \quad : \quad \int(-m\bar{q}q+\frac{\theta}{32\pi^2}F\tilde{F})$$

$$\rightarrow\int(-m\bar{q}e^{2i\gamma_5\alpha}q+\frac{\theta-2\alpha}{32\pi^2}F\tilde{F})$$

… but apparently this not the case…



Particle Data (2006), p.510

The E141 experiment at SLAC

SLAC-E-141 Experiment UPDATE

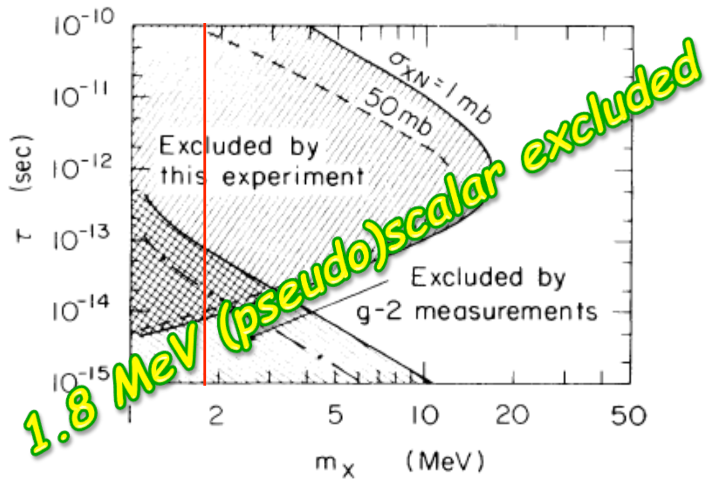
SEARCH FOR SHORT-LIVED NEUTRAL BOSONS FROM A BEAM DUMP

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

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

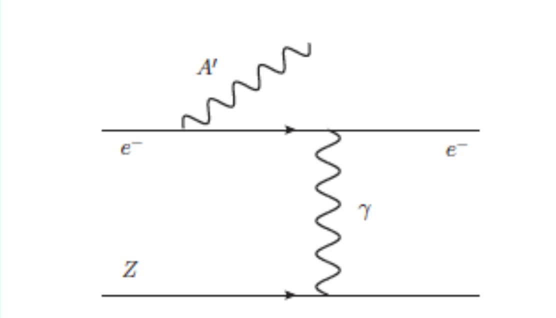
E141 proposal by M.W. Krasny, K. Lang, A.Para, M. Riordan, with a big help from Bj

Wit Busza and J. Dorfan referees



THE REFEREE'S COURAGE:

SIMPLE CONCEPT:



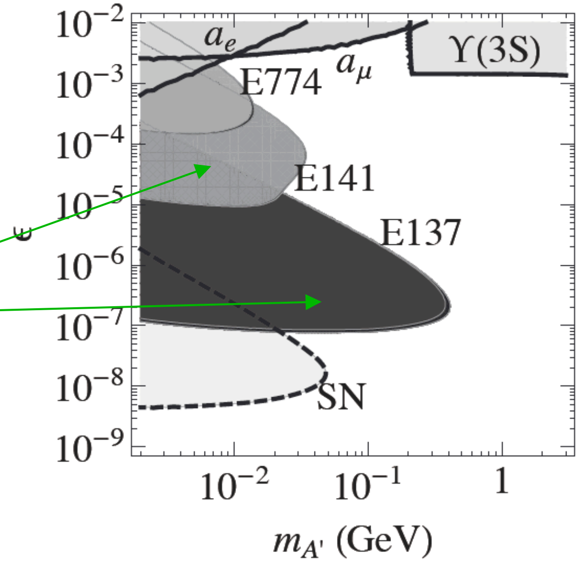
...BUT:

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

The impact of E141 on constraining the "Dark Gauge Forces" – present status

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \epsilon_Y F^{Y,\mu\nu} F'_{\mu\nu} + \frac{1}{4} F'^{,\mu\nu} F'_{\mu\nu} + m^2_{A'} A'^{\mu} A'_{\mu}, \quad (3)$$

where $\mathcal{L}_{\rm SM}$ is the Standard Model Lagrangian, $F'_{\mu\nu} = \partial_{[\mu} A'_{\nu]}$, and A' is the gauge field of a massive dark $U(1)'$ gauge group [1]. The second term in (3) is the kinetic



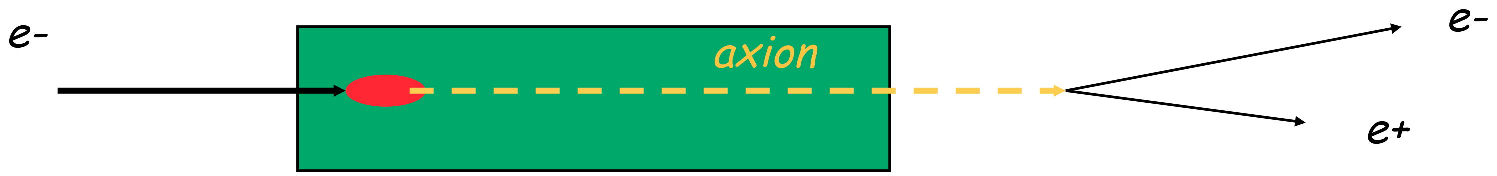
Rejection regions of SLAC Experiments in the 80-ties

J.D. Bjorken et al :

SLAC-PUB-13650

SU-ITP-09/22

Experimental search for axions



For $\tau \sim 10^{-13}$ s the target lengths must be O(10) cm:
One must use highest Z target for optimal S/B (Tungsten)

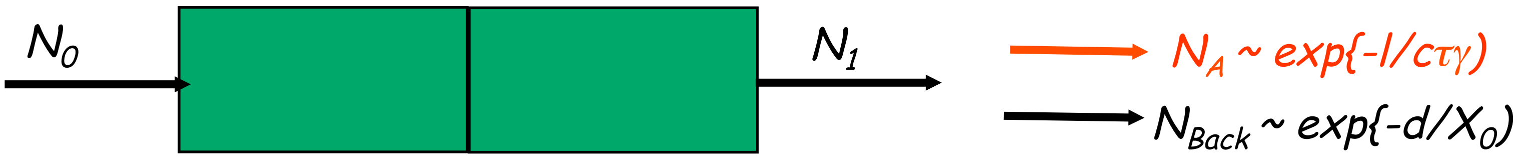
Canonical procedure:

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

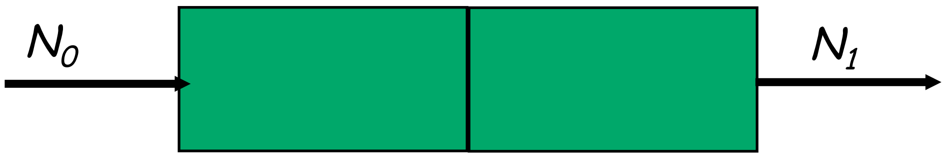
…dedicated precision measurement method obligatory

Dedicated, precision searches



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

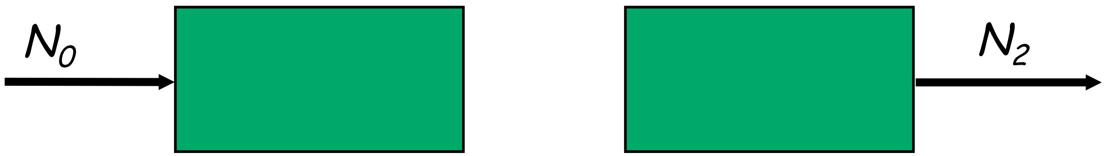
Dedicated, precision searches



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

$N_{Back} \sim exp\{-d/X_0\}$

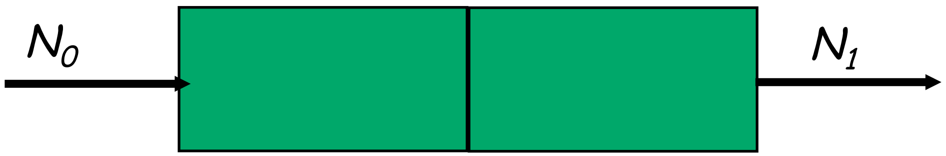
Run 1: dump thickness $d=d_1$, length $l=l_1$, $\gamma_{beam} = \gamma_0$, $B_{spectr} = B$



if $(N_2 < N_1)$-discovery

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

Dedicated, precision searches



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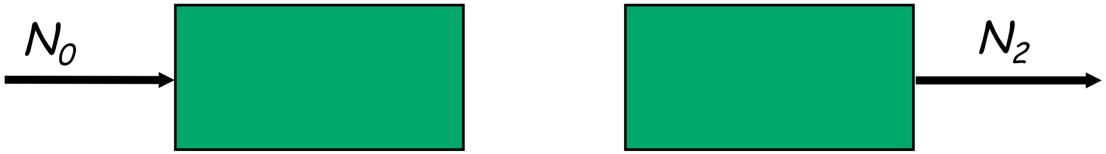

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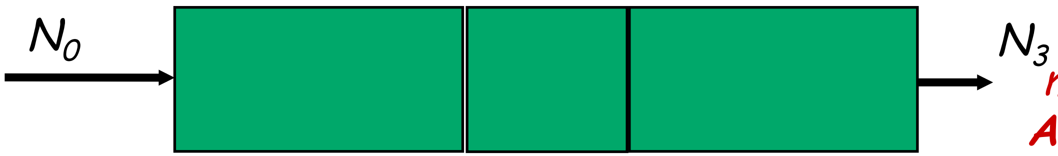
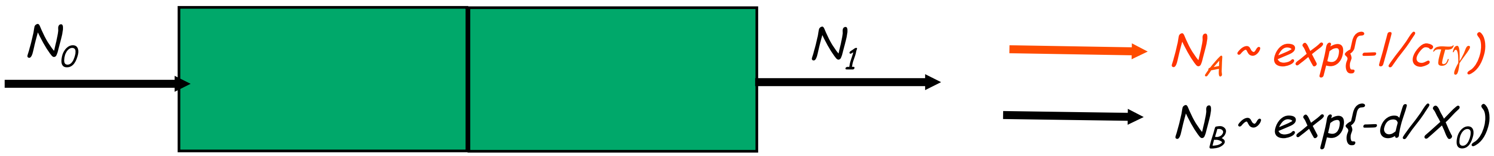


measure $(N_1-N_3)/(N_1-N_2)$

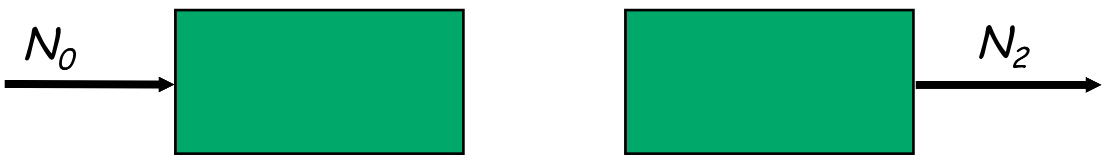
A' absorption cross-section

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

Dedicated, precision searches



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' absorbtion cross-section

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

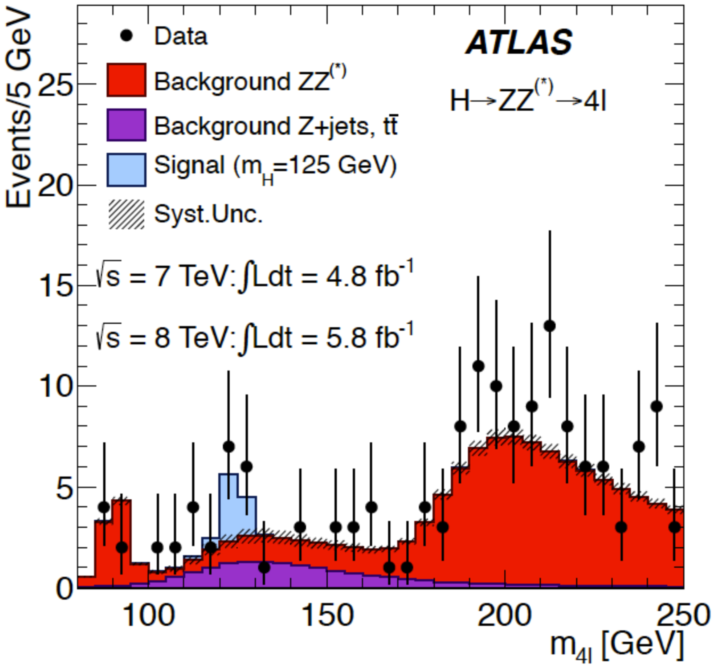
Repeat Run 1-3: for B ---> -B and $\gamma_{beam} = 2\gamma_0$
to verify the hypothesis of a decay of a neutral particle

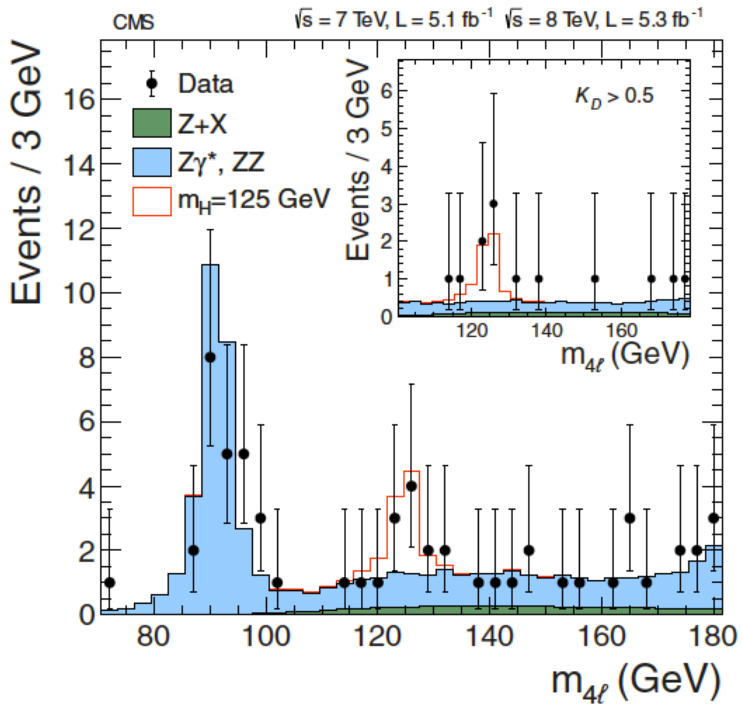
- **Today's encounter with Wit**

the "Higgs time"

I skip the "lepto-quark time" -- 1996 at DESY and the "Higgs time" at LEP

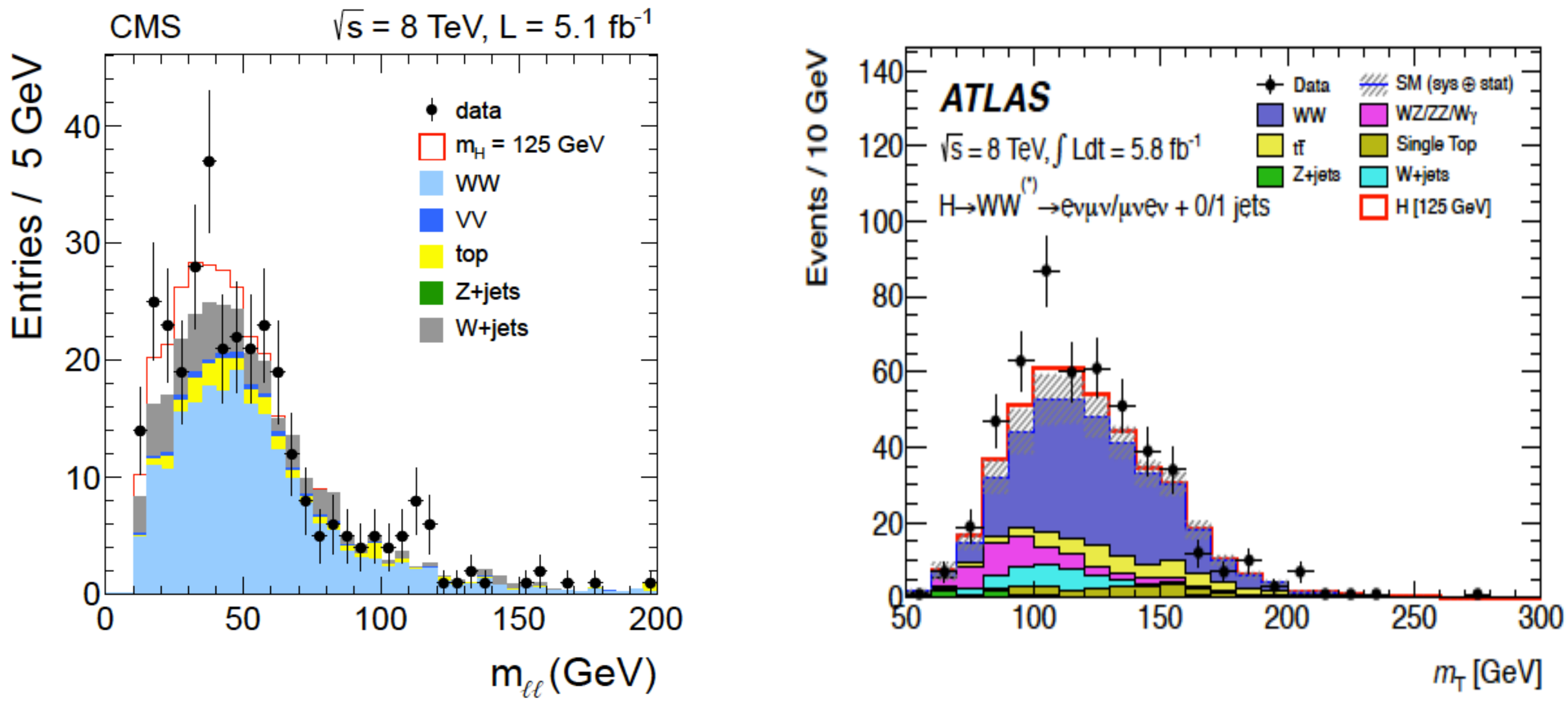
The 2012 CERN peaks





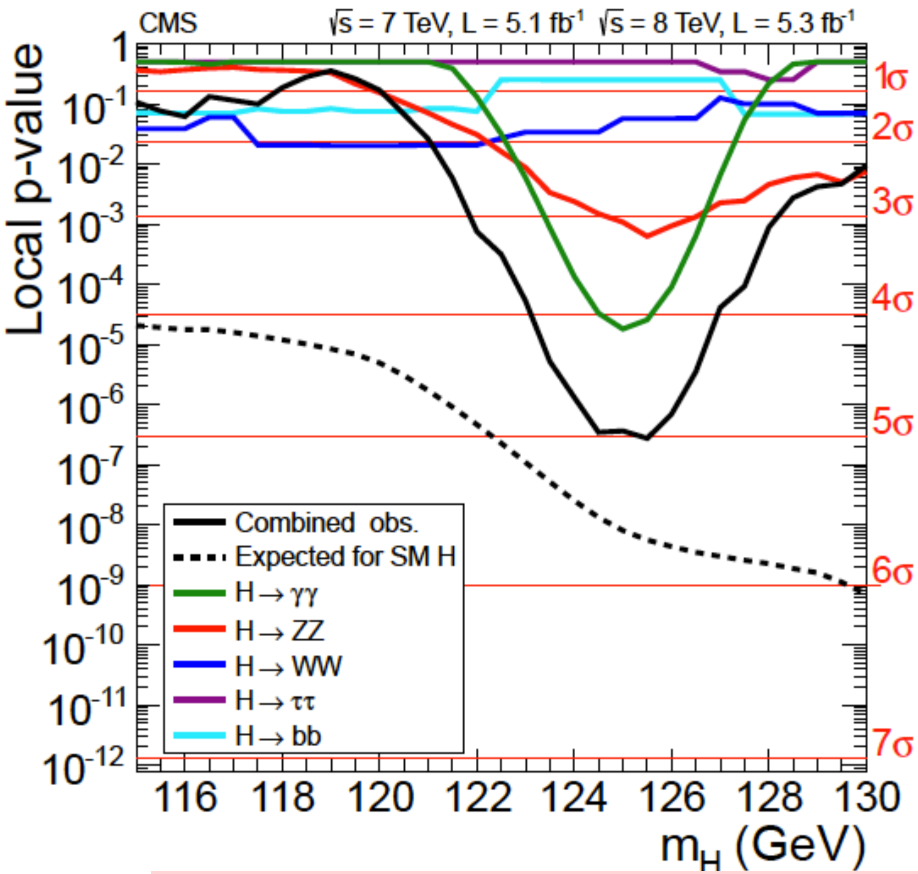
Peak in the 4l mass spectrum at ~125 GeV observed by ATLAS and CMS

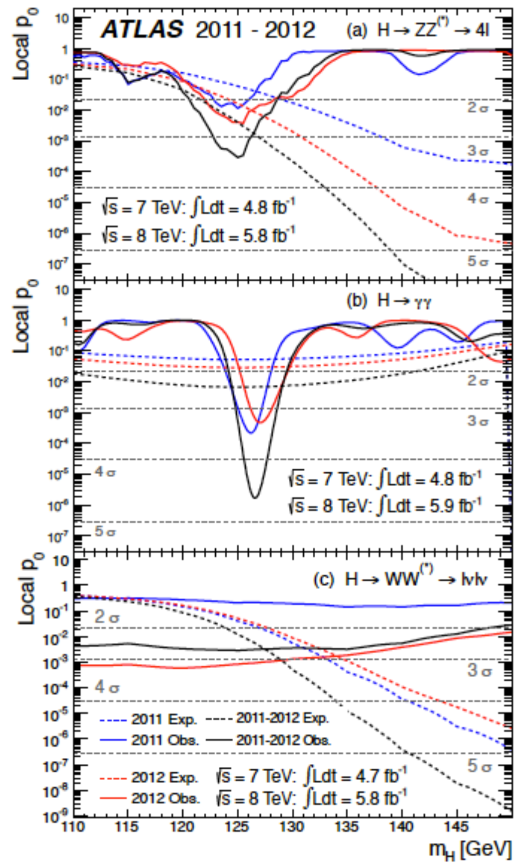
The 2012 CERN peaks



*An excess of 2l2ν events at low invariant masses of the two charged lepton system compatible with the 4l peak assuming decays of a 125 GeV 'HIGGS-LIKE" particle H → WW**

The 2012 CERN peaks

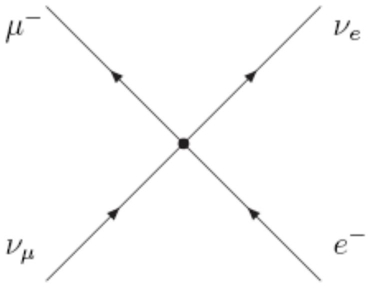




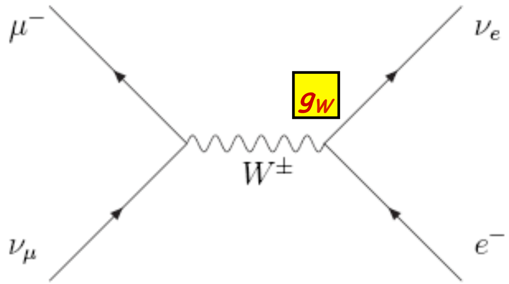
July 2012, CERN announces a discovery of a new Higgs-like particle

Why so exciting? The Higgs particle story in 4 chapters

Chapter 1 - CC/NC-interactions and the need for massive charged bosons



$\Longrightarrow$



$$\mathcal{L} = \frac{G_F}{\sqrt{2}} \left[\bar{\nu}_\mu \gamma_\lambda (1 - \gamma_5) \mu\right] \left[\bar{e} \gamma_\lambda (1 - \gamma_5) \nu_e\right]$$

$$f_0[\nu_\mu e^- \rightarrow \mu^- \nu_e] \rightarrow \frac{G_F s}{2\sqrt{2}\pi} \frac{M_W^2}{M_W^2 - s}$$

$$f_0[\nu_\mu e^- \rightarrow \mu^- \nu_e] = \frac{G_F s}{2\sqrt{2}\pi}$$

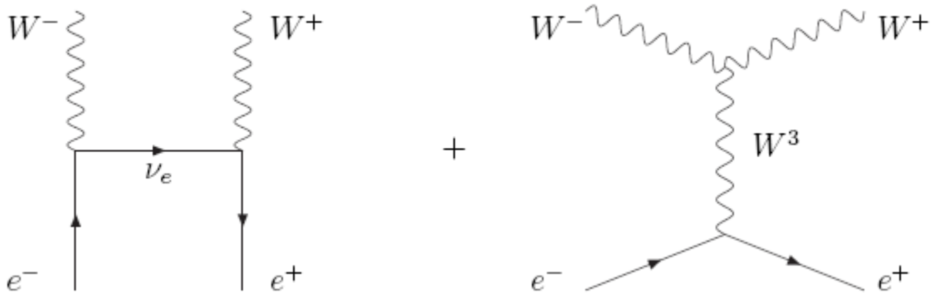
define $G_F/\sqrt{2} = g_W^2/8M_W^2.$

If $Re(f_0) < 0.5$ (unitarity limit) then the theory breaks down for $s < (600\ GeV)^2$

The theories equivalent for $s \ll (600\ GeV)^2$
If $g_W \sim e$ (coupling democracy) then $M_W \sim 100\ GeV$

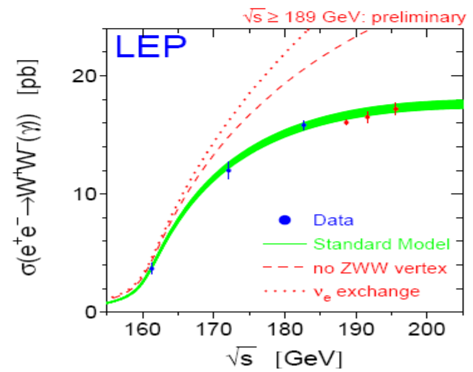
The Higgs particle story in 4 chapters

Chapter 2 - self couplings of the massive bosons



This amplitude breaks the unitarity limit – grows like ***s*** at high energies (production of longitudinally polarized W-bosons)

Cure: The simplest way to dump the divergence is to exchange a doubly charged lepton in the u-channel or a neutral W boson in the s-channel



...under the following condition:

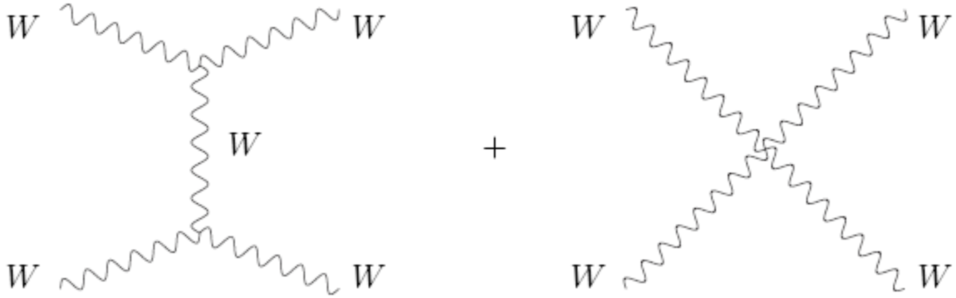
$$[I^k, I^l] = i\varepsilon_{klm} I^m$$

for the couplings g_W I^k_{ab} between the leptons a,b and the W boson k, note:

$$W^{\pm} = (W^1 \mp iW^2)/\sqrt{2}$$

The Higgs particle story in 4 chapters

Chapter 3 - quadrilinear coupling of EW bosons



The amplitude for elastic W boson collisions (the contribution due to virtual W-exchanges to collisions of longitudinally polarized W-bosons) grows as s^2 at high energies and breaks the unitarity limit at the TeV scale.

Cure: Cancellation of the leading divergence by introducing a quadrilinear coupling among the W boson, which must be quadratic in the coupling g_W

…the following condition must be fulfilled:

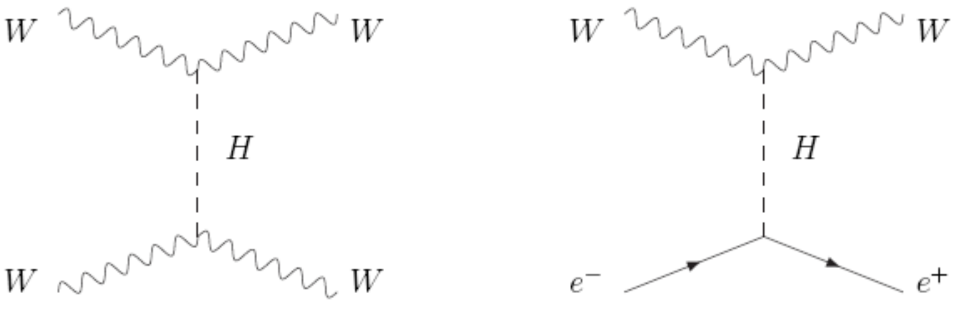
$$\lambda_{klmn} = g_W^2 \varepsilon_{klp'} \varepsilon_{p'mn}$$

for the couplings of the W bosons: k,l,m,n.

Unitarity is however not fully restored!!! (the amplitude grows as s at high energies) … but all theory-intrinsic mechanisms exhausted –need a mechanism which is external to the field theory of massive vector bosons…

The Higgs particle story in 4 chapters

Chapter 4 - the birth of the Higgs boson



The **simplest** way of canceling the remaining divergence (~s) is to introduce a massive scalar "Higgs" boson (destructive interference of the W-exchange and H-exchange diagrams)

The amplitude of fermion-anifermion annihilation to longitudinally polarized W-bosons diverges as: $m_f s^{0.5}$ – this divergence is regularized by coupling of the Higgs boson to fermions (~m_f coupling)

Asymptotic limit of the W scattering amplitude :

$$f_0[W_L W_L \to W_L W_L] \to \frac{G_F M_H^2}{4\sqrt{2}\pi}$$

…provided that Higgs boson couples to W as: $g_W M_W$. …

…and it is not too heavy…

…the unitarity arguments for processes involving 1,2,3,4 Higgs bosons allow to determine the minimal model for the quartic WH interactions and the self-interaction of H…

Can one claim the Higgs discovery… beyond any doubt ?

The Higgs boson decays describe successfully majority of the excess even characteristics…

…but, are there any other mechanisms which may produce the observed excess of events (and their characteristics) which cannot be a priori rejected?

(a reminder: all the characteristics of the GSI peaks were explained fully by the axion decays)

The LHC excess of four-lepton events interpreted as Higgs-boson signal: background from Double Drell-Yan processes?

Mieczyslaw Witold Krasny[a], Wiesław Płaczek[b]

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Paper submitted to Phys. Lett. this weekend

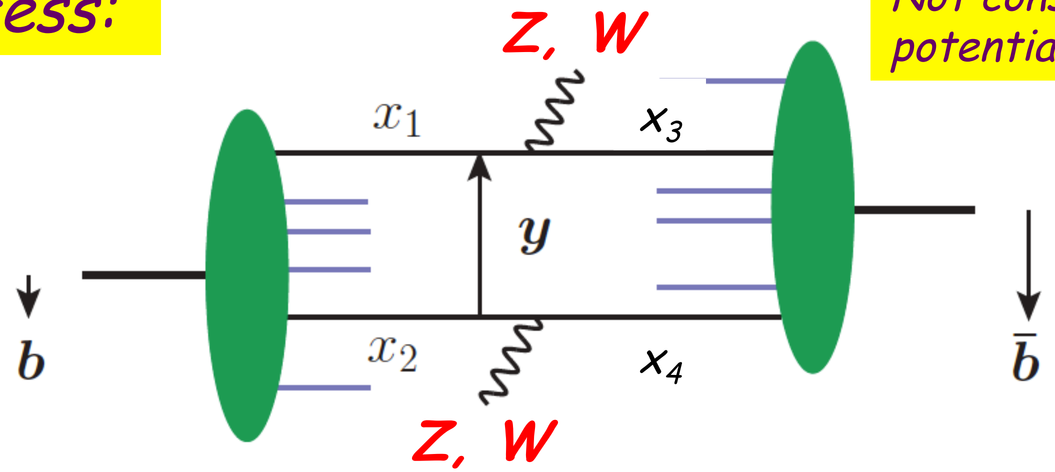
Abstract

We construct a simple model of 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 $H \to WW^* \to 2l2\nu$.

The Double Drell-Yan Process (DDYP)

HT process:

Not considered so far as the potential background source



Model approximations

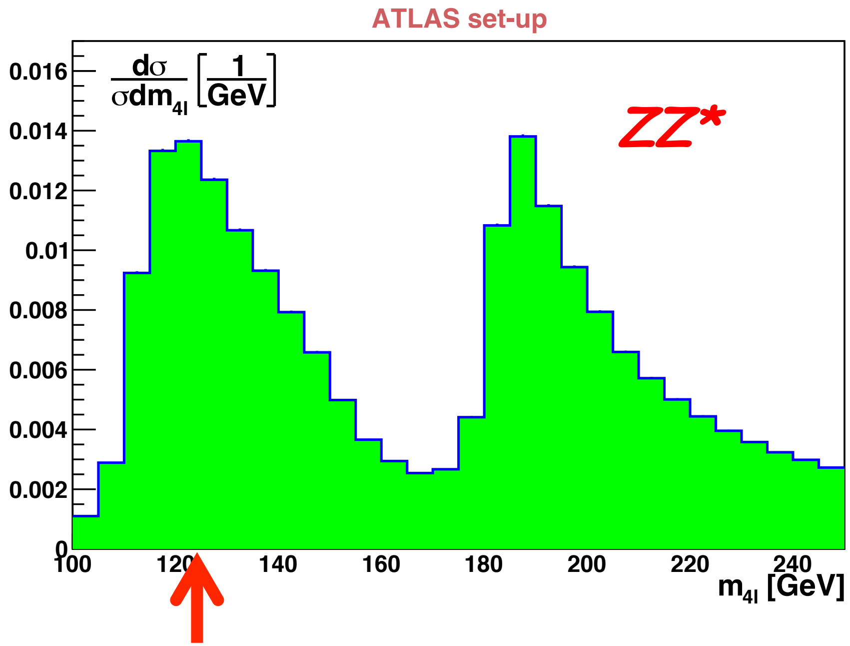
$$\sigma^{\rm DDYP}(p_1,p_2,p_3,p_4) = \frac{\sigma^{\rm SDYP}(p_1,p_2)\,\sigma^{\rm SDYP}(p_3,p_4)}{S_{qq}},$$ S_{qq} - effective. transverse plane correlation area

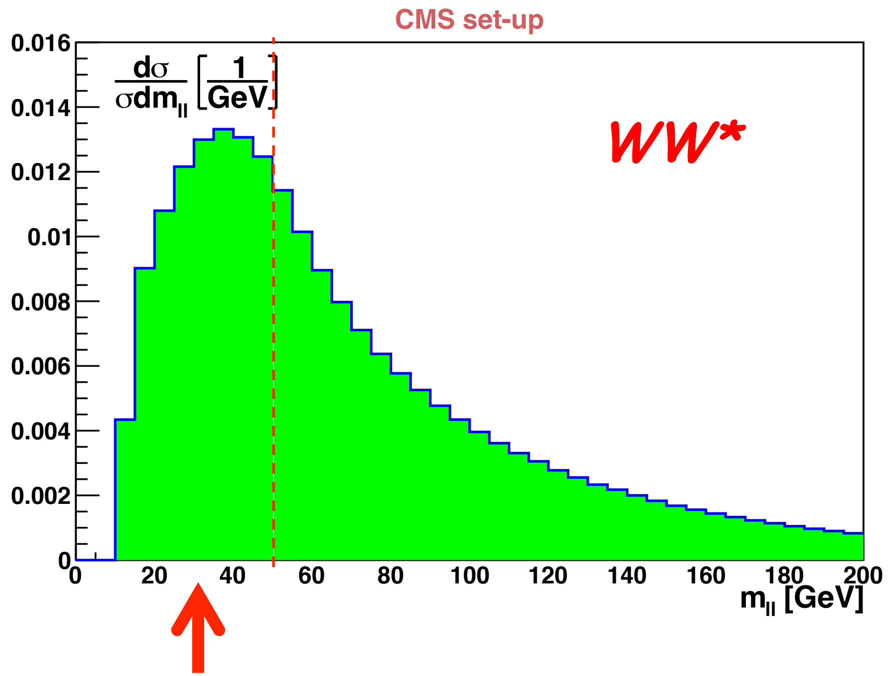
$$D_q(x_1,x_2,m_1^2,m_2^2)D_q(x_3,x_4,m_1^2,m_2^2) = q(x_1,m_1^2)q(x_3,m_1^2)q(x_2,m_2^2)q(x_4,m_2^2)$$

Neglected: amplitude formalism and interferences, colour, spin and flavour correlations, correlations between the transverse plane positions of annihilating quarks and their respective longitudinal momenta

The parameter free prediction of the DDYP model – using its "WINHAC" implementation

Mass spectra

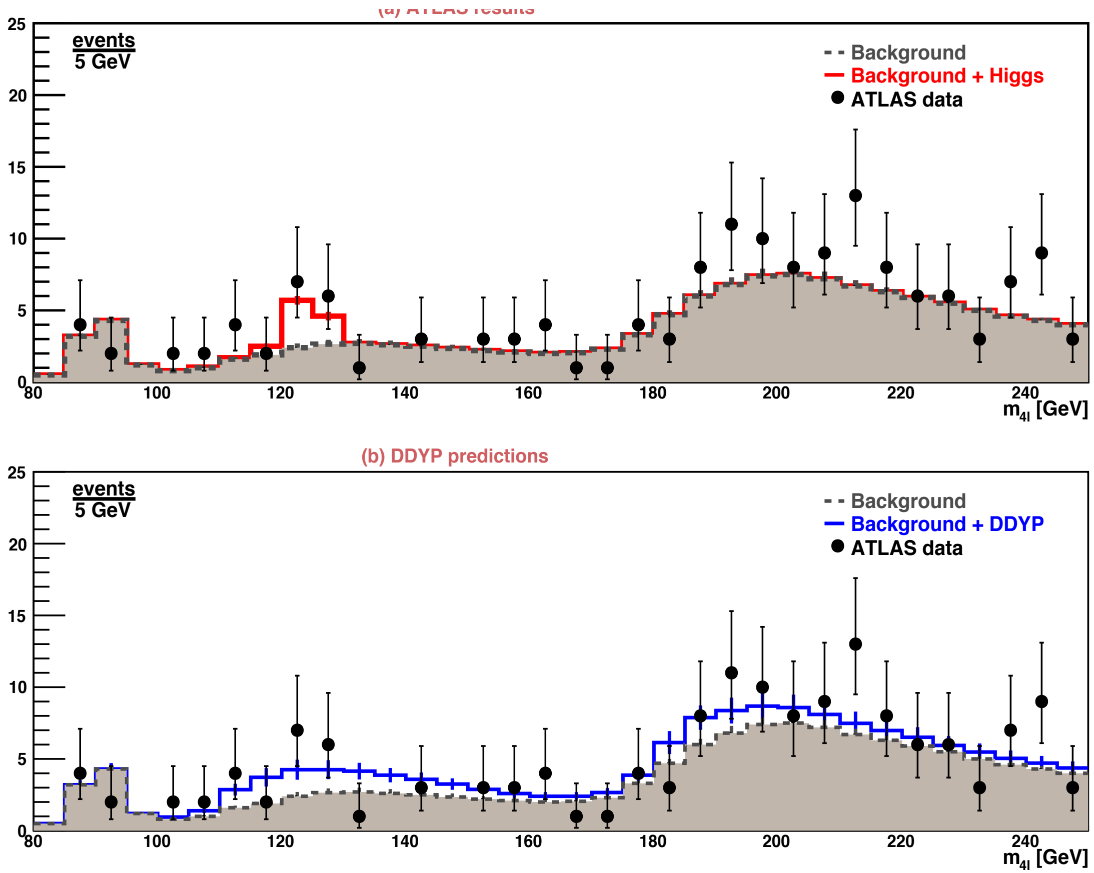




A peaking behaviour of the 4l mass spectrum un the model with a peak at ~ 125 GeV

A dominant contribution in the region of small m_{ll} where the Higgs signal is expected to appear

The description of the observed 4l mass spectra by the Higgs model and by the DDYP



$$\chi^2/\mathrm{dof} = 1.14$$
$$p_0 = 0.25$$

$$\chi^2/\mathrm{dof} = 1.04$$
$$p_0 = 0.41$$

$$S_{a\bar{a}}^{ZZ} = 0.14 \pm 0.07\,\mathrm{mb}$$

An excess of the WW events also satisfactorily explained – the transverse plane correlation area found to be compatible for ZZ* and WW**

No, one cannot. This should be verified experimentally… two approach lines:

1. Investigation of the properties of the excess events
Higgs vs. DDYP

Similarities:

- *Mass peak*
- *ZZ (WW) spin*
- *CM energy dependence*
- *Custodial symmetry*

Differences

- *Invariance/variance of the peak position with exp. cuts*
- *Excess in the ~125 GeV region accompanied by the excess in the $2M_Z$ region*
- *The peak width*
- *The p_T spectra of opposite charge lepton pairs*

No, one cannot. This should be verified experimentally… two approach lines:

2. Using both the proton and the ion beams

The charge dependence:

Look at W^+W^+ (W^-W^-) versus W^+W^- to filter out the quark-quark and quark-antiquark correlations

***Filtering the short range and long range quark-antiquark correlations in pA collisions** (SLAC 1986 approach)*

Short range correlation:

$$\sigma^{DDYP} \sim A$$

Long range correlation:

$$\sigma^{DDYP} \sim A^{4/3}$$

Messages to be taken out:

- *A discovery of at least one elementary (point-like) scalar(pseudoscalar) would change profoundly our understanding how Nature works at both the subatomic and cosmological scales*

- *The first traces of a scalar have been seen at CERN – It is however premature to claim its discovery (a lesson from ζ, GSI-axion, DESY-lepto-quark, Higgs@LEP stories)*

- *It does not hurt to "swing" your apparatus to ask new physics questions…*

- *Higher Twists (a largely forgotten QCD aspect) are important not only for the strong interaction phenomena) – they may mimic as well the signals of the scalar (pseudoscalar) particles interacting weakly*

- *Higher Twists may explain a majority of the (semi) hard phenomena attributed to the QGP (jet quenching, ridge, …) The relationship between pp, pA, AA and eA is pivotal to filter out the standard and non-standard QCD effects … in particular if the analysis tools are not confined to the existing Leading Twist MC, generators …*

  ….but,are based on Wit's wit…

Extra transparencies

A solution: axions

… Peccei and Quinn proposed another way of "rotating out" the theta parameter by introducing the Field H_u which couples only to up-type Quarks and H_d which couples to down-type quarks…

$$L = \bar{q}_L u_R H_u + \bar{q}_L d_R H_d - V(H_u, H_d) + \cdots$$

The Lagrangian is invariant under changing $\Theta \to \Theta - 2\alpha$. Thus, it seems that Θ is not physical, since it is a phase of the PQ transformation. But, Θ is physical, which can be seen from the free energy dependence on $\cos\Theta$. At the Lagrangian level, there seems to be no strong CP problem. But $\langle H_u \rangle$ and $\langle H_d \rangle$ breaks the PQ global symmetry and there results a Goldstone boson, axion *a* [Weinberg,Wilczek]. Since Θ is made field, the original $\cos\Theta$ dependence becomes the potential of the axion *a*.

If its potential is of the $\cos\Theta$ form, always $\Theta = a/Fa$ can be chosen at 0 [Instanton physics,PQ,Vafa-Witten]. So the PQ solution of the strong CP problem is that the vacuum chooses

$$\theta = 0$$

Mass, gauge phases and quantum mechanics

What if the masses of point-like particles are also the result of a "collaborative" effort?. Nambu, Lassino example:

Dirac particle: a mixture bare fermions With opposite chirality's but the same charge

$$E\psi_1 = \sigma \cdot p\psi_1 + m\psi_2,$$
$$E\psi_2 = -\sigma \cdot p\psi_2 + m\psi_1,$$
$$E_p = \pm(p^2 + m^2)^{\frac{1}{2}},$$

Cooper "Particle": a mixture of a particle and a hole of the same spin

$$E\psi_{p+} = \epsilon_p \psi_{p+} + \phi\psi_{-p-}{}^*,$$
$$E\psi_{-p-}{}^* = -\epsilon_p \psi_{-p-}{}^* + \phi\psi_{p+},$$
$$E_p = \pm(\epsilon_p{}^2 + \phi^2)^{\frac{1}{2}}.$$

$$\phi \approx \omega \exp[-1/\rho],$$

ω- the energy bandwidth around the Fermi surface
ρ – the average interaction energy

?

The mass as indirect consequence of 'dark" lattice-vibration energy. Coherence of gauge phases allows to create a rigid quantum-coherent structure in which gauge bosons appear as massive particles.

Why axion solution of the strong was attractive for cosmologists?

… allows for adjustments of the of cosmological parameters using low-mass cold dark matter

Axion field values right after inflation can take any value between [0,π]. So Ω_a may be at the required value by an appropriate misalignment angle for any F_a in the new inflation scenario. [Pi(84)]

The axion potential is of the form

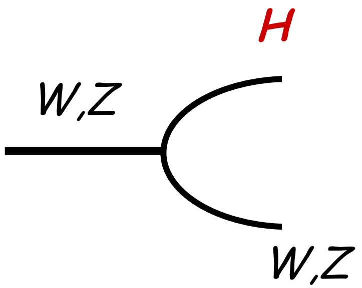
The vacuum stays there for a long time, and oscillates when the Hubble time(1/H) is larger than the oscillation period($1/m_a$)

$$H < m_a$$

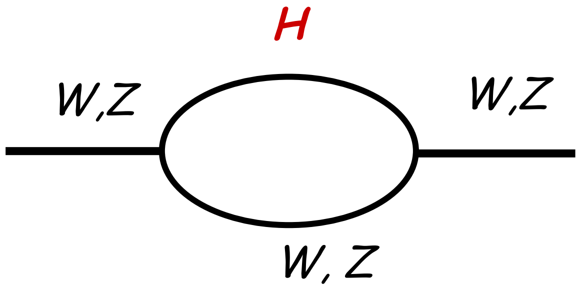
This occurs when the temperature is about 1 GeV.

Trees and loops

What to look at?



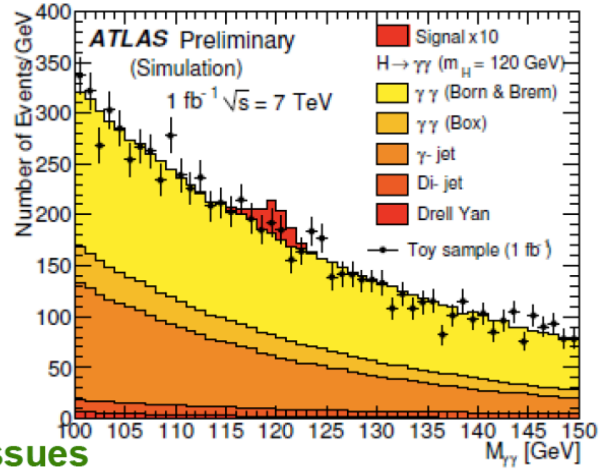
Where to look?



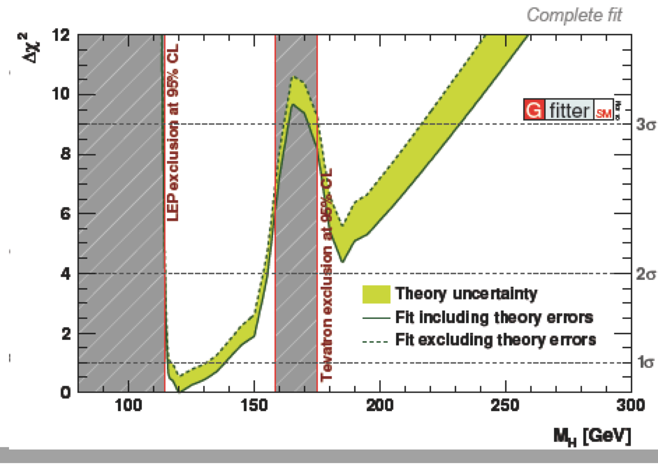
Loop corrections modify the interrelationship between the SM parameters

α, M_Z, G_F → M_W, $\sin^2(\theta_W)$, Γ_W,…

Example:



sues



Higgs mechanism (paradigms and prejudices)

The Higgs mechanism of electroweak gauge-symmetry breaking is attractive both for theorists (perturbative QFT methods) and for experimentalists (allows to link the EW experimental data over a large domain of s, using only one parameter: M_H ``measured" via radiative loop corrections)…

Higgs mechanism (paradigms and prejudices)

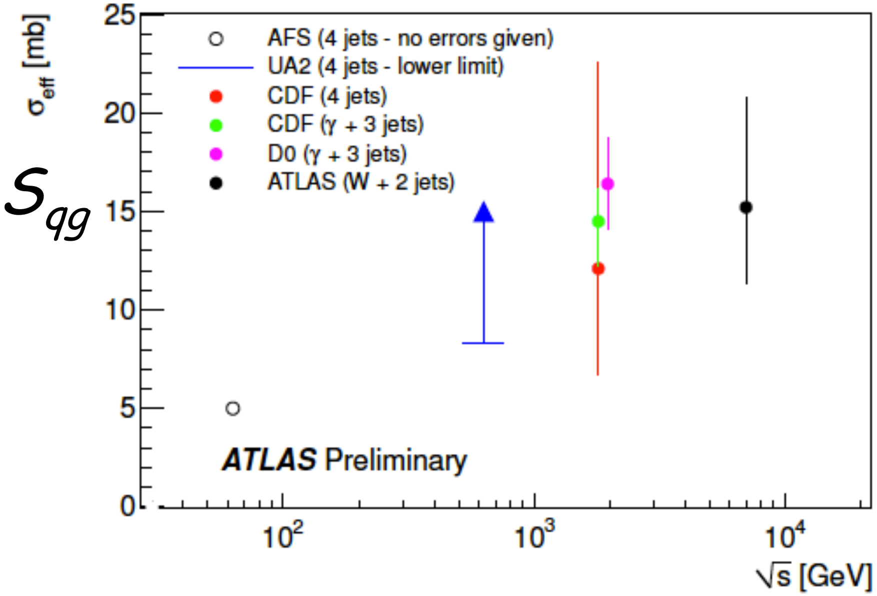
…but

…the Higgs mechanism rephrases (accommodates), rather then explains, the origin of masses of fermions (dozens of adjustable parameters, mass-to-coupling-constant-trade-off is very ugly and provisional) dark matter candidates (WIMPS, axions, etc.) are massive but their masses are unrelated to Higgs mechanism,

.

The question: are there short range correlation of quarks in the proton?

S_{qg}



The average gluon-gluon and gluon-quark transverse-plane correlation length is of the order of the nucleon size.

Can one neglect the DDYP contribution because it requires the quark-antiquark correlation length to be ~10 times smaller, than that for qg and gg i.e of the order of ~0.1 fm ???

(note: $S_{qq'}$ ~$1/\Gamma_{Z,W}$, ~$1/k_T^q$, ~instanton size, pQCD onset scale)

The GSI peaks in heavy ion collisions

VOLUME 51, NUMBER 25 PHYSICAL REVIEW LETTERS 19 DECEMBER 1983

Observation of a Peak Structure in Positron Spectra from U+Cm Collisions

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(Received 8 November 1983)

A narrow peak structure has been observed in positron spectra from U + Cm collisions at bombarding energies near the Coulomb barrier whose origin cannot be associated with established dynamic mechanisms of positron production involving Rutherford trajectories only. The peak's energy is centered at 316 ± 10 keV. Its width of ~ 80 keV, dominated by Doppler broadening, implies that the emitting system exists for longer than $\sim 10^{-20}$ sec.

PACS numbers: 12.20.Fv, 25.70.Ef