Theoretical and phenomenological contexts of measurements for Higgs@LHC

Z. Was,
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Particle physics highlights

The last 50 years of experimental effort created foundation for particle physics.

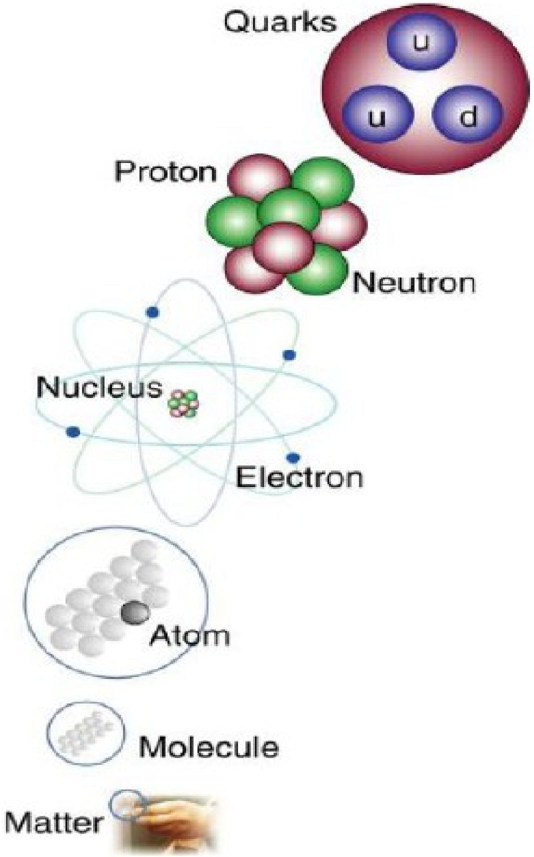
Theory of elementary constituents of matter could be created. Beginning: electrodynamics (QED)– the first ever relativistic quantum field theory

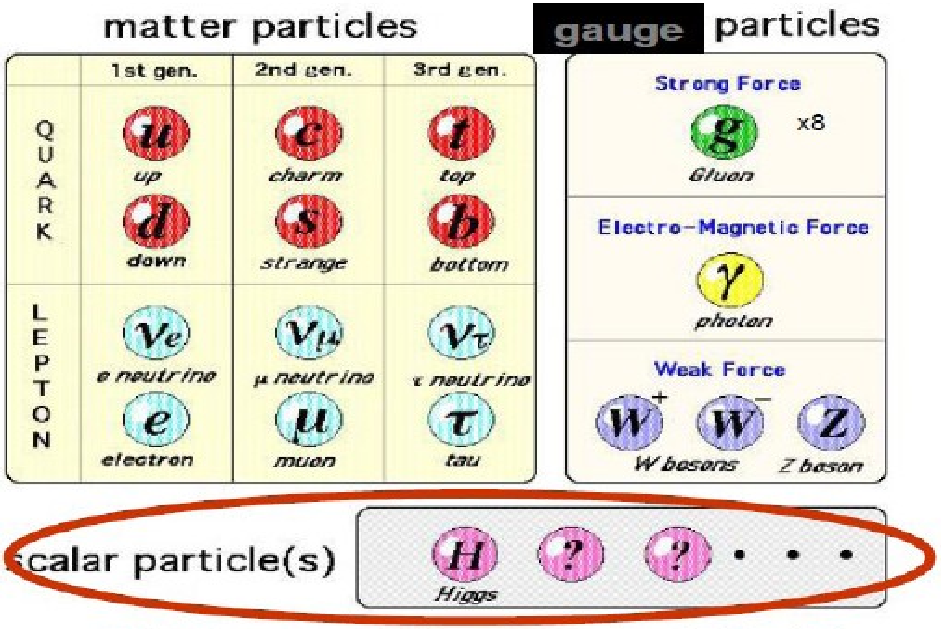
Keystones: **renormalization** and numerous **precision measurements**.

All of particle physics follow this scheme.

The Standard Model is born.

Standard Model describes reasonably well all measurements of today





Elements of the Standard Model

Frozen degrees of freedom

Only u and d quarks, electron, neutrino, photon and gluon fields are needed for description of the matter around us.

Frozen degrees of freedom explain properties of interactions for the *every day matter*, but otherwise remain “spectators”.

W bosons → Fermi interaction → P-parity violation. In macroscopic world not exposed; may have triggered left-handenes of DNA? Beautiful book[1] where such ideas are entertained from mathematical perspective.

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[1] **H. Weyl, *Symmetry*, Princeton University Press, 1952 !already!**

Frozen degrees of freedom

Theoretically motivated field:

it was not possible to construct field theory of weak interactions with massive W-s and Z.

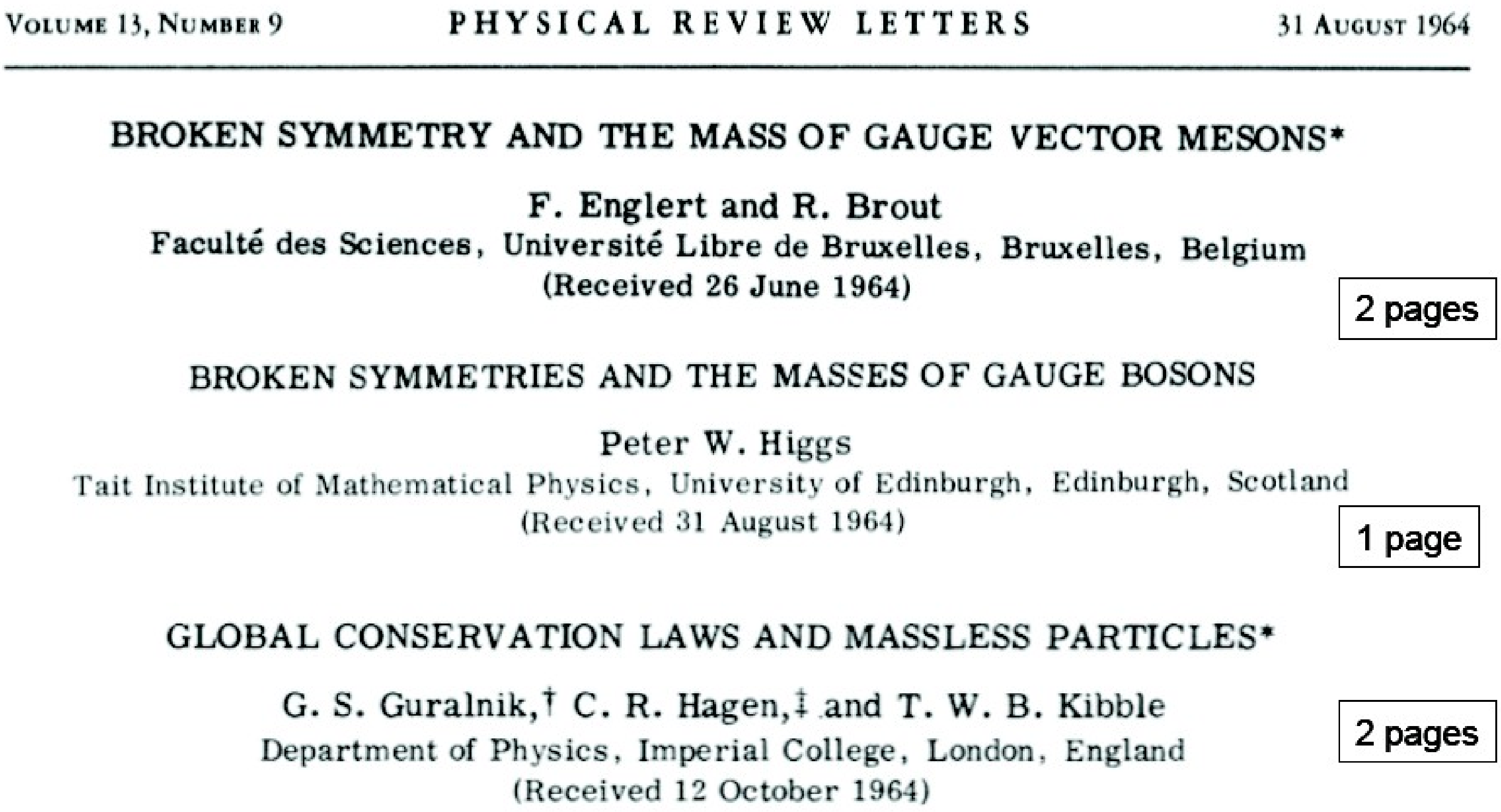
Massless scalar field of 4 degrees of freedom was introduced.

In the mechanism of spontaneous symmetry breaking, 3 degrees are “eaten” into spin 0 components of W+ W- and Z fields. Bosons acquire mass and Standard Model can describe interactions of particle physics.

The last degree of freedom is an **elusive** (until July 2012) **Higgs field**.

Spontaneous Symmetry Breaking (SSB) - Local Symmetry

All the players… in the same PRL issue



VOLUME 13, NUMBER 9 PHYSICAL REVIEW LETTERS 31 AUGUST 1964

BROKEN SYMMETRY AND THE MASS OF GAUGE VECTOR MESONS*

F. Englert and R. Brout
Faculté des Sciences, Université Libre de Bruxelles, Bruxelles, Belgium
(Received 26 June 1964)

2 pages

BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs
Tait Institute of Mathematical Physics, University of Edinburgh, Edinburgh, Scotland
(Received 31 August 1964)

1 page

GLOBAL CONSERVATION LAWS AND MASSLESS PARTICLES*

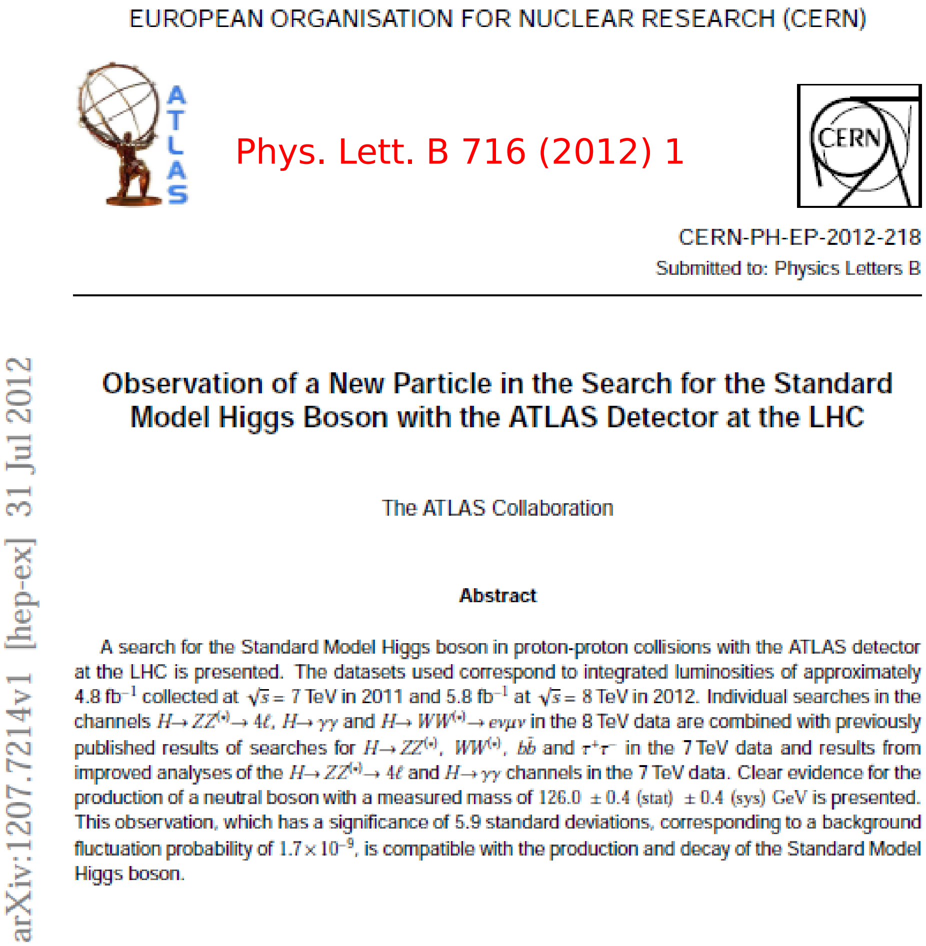
G. S. Guralnik,† C. R. Hagen,‡ and T. W. B. Kibble
Department of Physics, Imperial College, London, England
(Received 12 October 1964)

2 pages

1964 –The Higgs mechanism : How gauge bosons can acquire a mass.

Z. Was, IFJ-PAN

TH. quest: talk by L. Roszkowski …, SUSY etc.



EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

Phys. Lett. B 716 (2012) 1

CERN-PH-EP-2012-218
Submitted to: Physics Letters B

Observation of a New Particle in the Search for the Standard Model Higgs Boson with the ATLAS Detector at the LHC

The ATLAS Collaboration

Abstract

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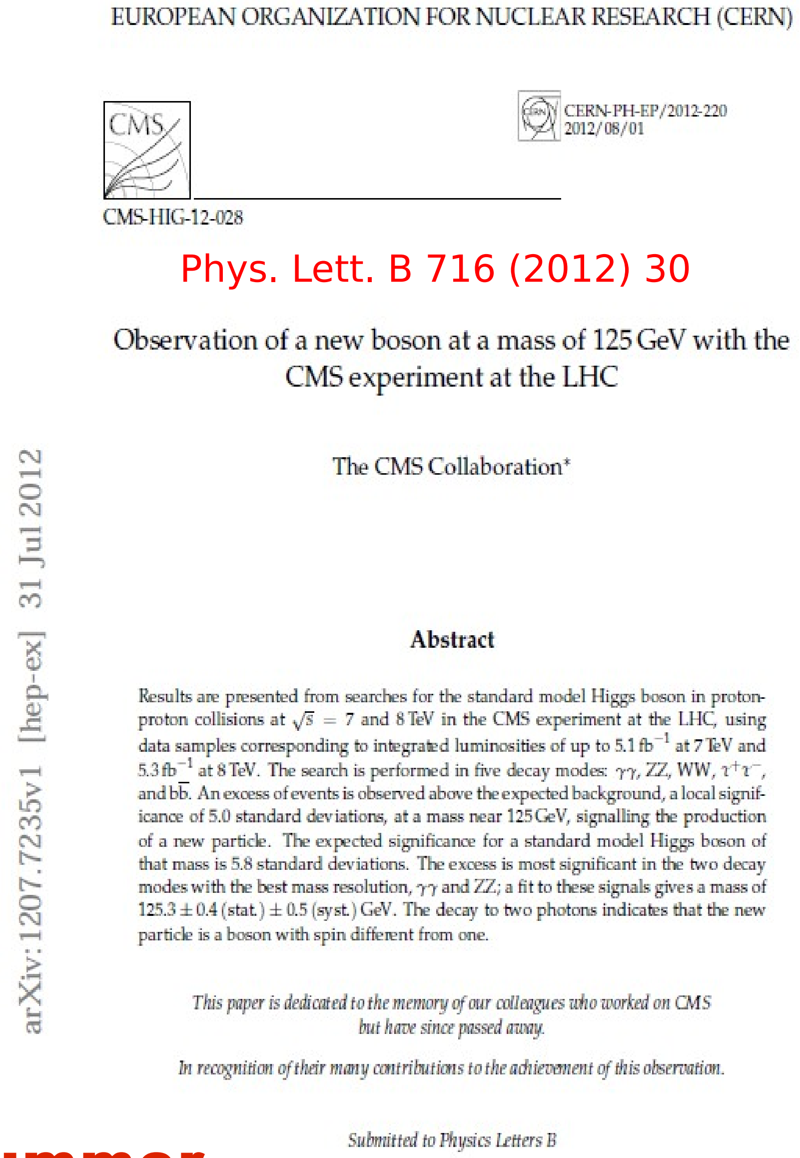


EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP/2012-220
2012/08/01

CMS-HIG-12-028

Phys. Lett. B 716 (2012) 30

Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC

The CMS Collaboration*

Abstract

Results are presented from searches for the standard model Higgs boson in proton-proton collisions at $\sqrt{s} = 7$ and 8 TeV in the CMS experiment at the LHC, using data samples corresponding to integrated luminosities of up to 5.1 fb^{-1} at 7 TeV and 5.3 fb^{-1} at 8 TeV. The search is performed in five decay modes: $\gamma\gamma$, ZZ, WW, $\tau^+\tau^-$, and $b\bar{b}$. An excess of events is observed above the expected background, a local significance of 5.0 standard deviations, at a mass near 125 GeV, signalling the production of a new particle. The expected significance for a standard model Higgs boson of that mass is 5.8 standard deviations. The excess is most significant in the two decay modes with the best mass resolution, $\gamma\gamma$ and ZZ; a fit to these signals gives a mass of $125.3 \pm 0.4\,(\mathrm{stat.}) \pm 0.5\,(\mathrm{syst.})$ GeV. The decay to two photons indicates that the new particle is a boson with spin different from one.

This paper is dedicated to the memory of our colleagues who worked on CMS but have since passed away.

In recognition of their many contributions to the achievement of this observation.

Submitted to Physics Letters B

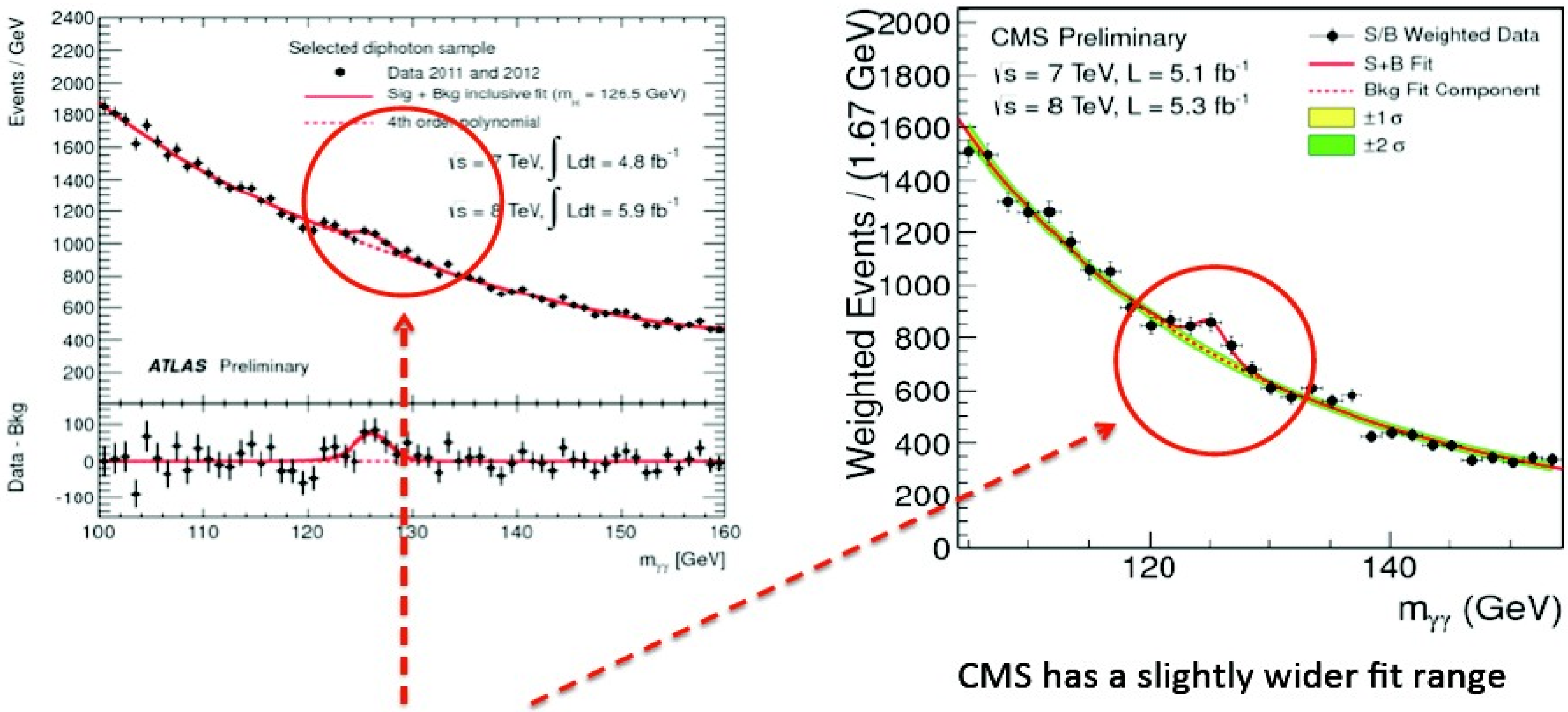
Last Summer ...

5.9 σ ! **discovery**

5.8 σ ! **discovery**

From:
ATLAS presentation, CERN July 4, F. Gianotti
CMS presentation, CERN July 4, J. Incandela

Inclusive/Weighted Mass Spectra



CMS has a slightly wider fit range

Excesses visible in the inclusive mass spectra

It was a challenge, see other talks ...

Breakthrough, but …

Is it Higgs of the Standard Model?

Or may be it is manifestation of unknown (like pions are consequence of quark gluon interactions)?

In 1873 van der Waals defended his doctoral thesis ``Over de Coninuiteit van der Gas en Vloeistoftoestand. It was the first treatment of the properties of the second order phase transition.

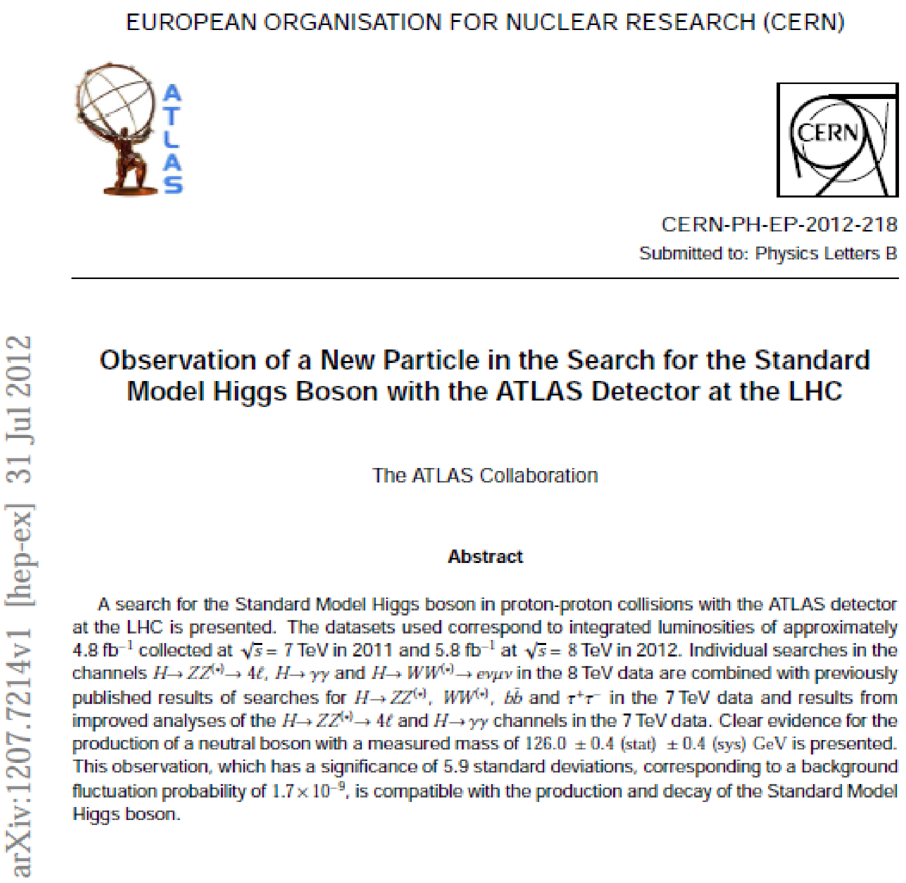
It took more than 80 years before this phenomenon was understood in all of its quantum complexity.

Breakthrough, …

…On the way quantum mechanics had to be established, refined works of theorists on multi-body systems and dynamic of atoms and their interactions had to be developed.

For Higgs we need a lot of further measurements too. May be new theoretical ideas as well.

In the rest of my talk I will discuss examples of details; to demonstrate complexity of the tasks



EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP-2012-218
Submitted to: Physics Letters B

arXiv:1207.7214v1 [hep-ex] 31 Jul 2012

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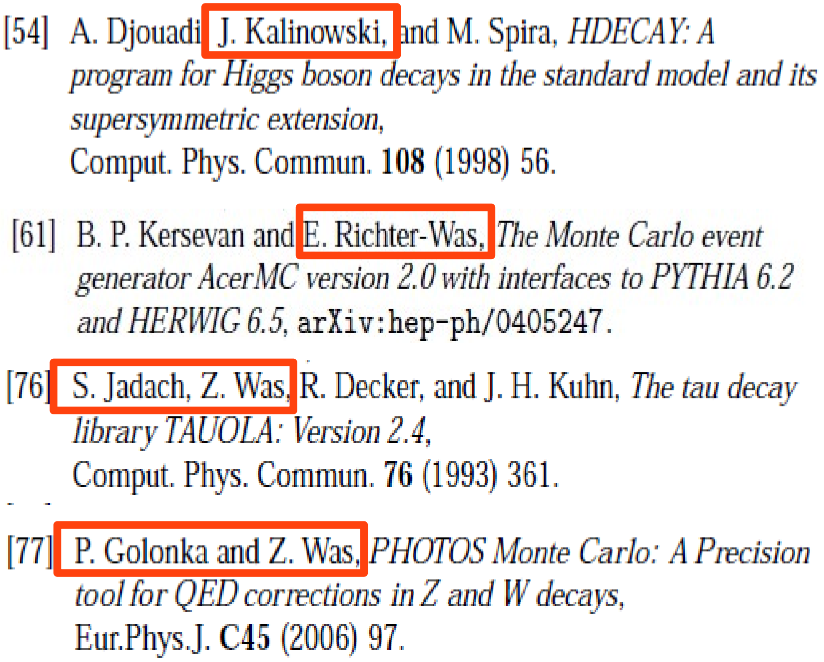


[54] A. Djouadi, J. Kalinowski, and M. Spira, *HDECAY: A program for Higgs boson decays in the standard model and its supersymmetric extension,* Comput. Phys. Commun. **108** (1998) 56.

[61] B. P. Kersevan and E. Richter-Was, *The Monte Carlo event generator AcerMC version 2.0 with interfaces to PYTHIA 6.2 and HERWIG 6.5,* `arXiv:hep-ph/0405247`.

[76] S. Jadach, Z. Was, R. Decker, and J. H. Kuhn, *The tau decay library TAUOLA: Version 2.4,* Comput. Phys. Commun. **76** (1993) 361.

[77] P. Golonka and Z. Was, *PHOTOS Monte Carlo: A Precision tool for QED corrections in Z and W decays,* Eur.Phys.J. **C45** (2006) 97.

ATLAS quoted **four theoretical projects** from Poland

Breakthrough ...

- The title of my talk could suggest that I will discuss all main phenomenological calculations and tools used in H discovery
- It would not be possible, even for cited polish contributions:
  - **[76]** TAUOLA flagship use is simulation for embedded taus in estimation of Higgs searches background
  - **[77]** For PHOTOS it is simulation of bremsstrahlung in 4-lepton final states
  - **[61]** ACERMC of E. Richter-Was et. al., was used e.g. for H backgrounds from single top production.
  - **[54]** HDECAY of J. Kalinowski et.al., was used for H b.r.

Few examples of pheno. tasks needed for Higgs observables

- I have chosen three applications using TAUOLA and PHOTOS MC's:
- H spin measurement in H→ $\tau\tau$ channel.
- Consistency of SM: relation between masses of H, W and top require secondary effects like QED bremsstrahlung to be taken into account in lepton reconstruction in W decays.
- To reduce systematic error of W mass measurement even further: lepton reconstruction in Z decays.

Example 1: TAUOLA

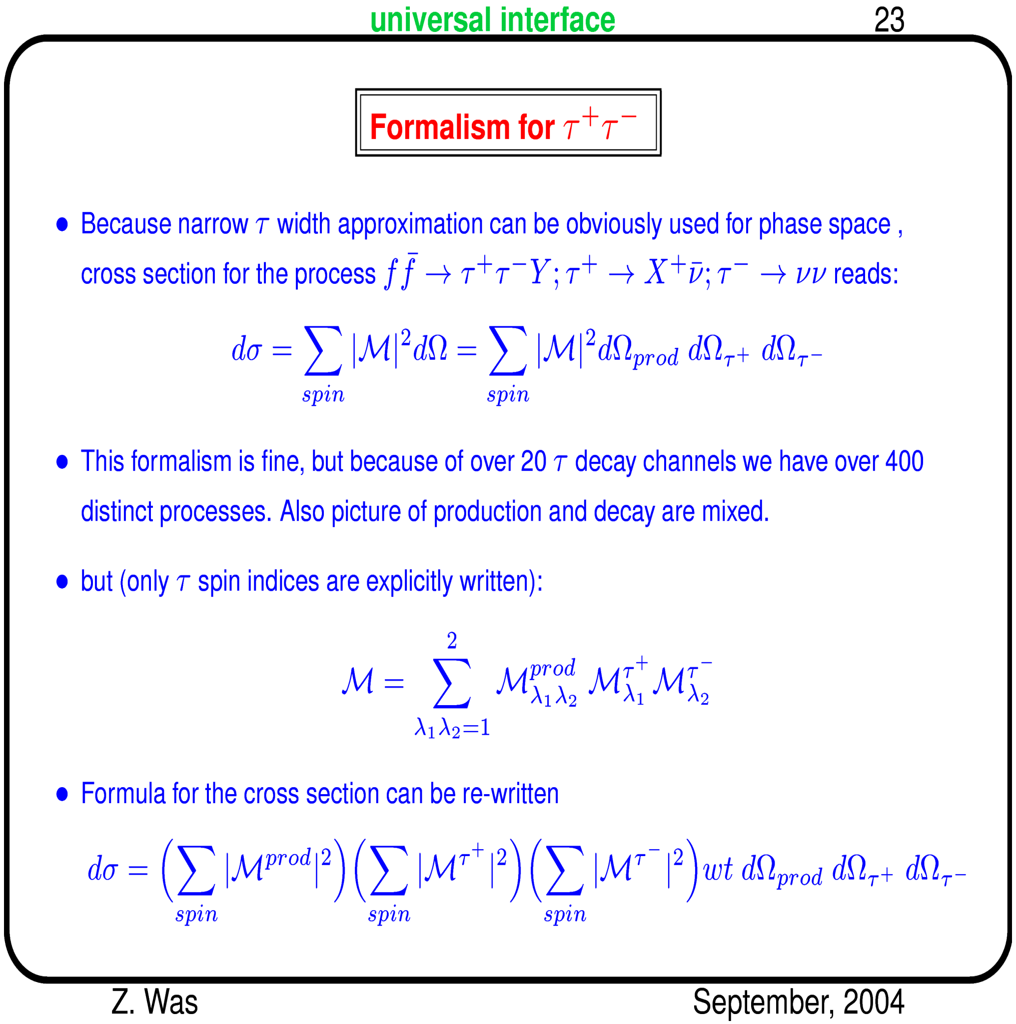
Simulation for H spin=2 hypothesis.

- H → tau tau channel is not central for spin measurement, but may complete the picture

Use of tau spin at LHC

tau decay distribution manifest properties of tau production: spin of W, Z, H, parity etc

properties needed for construction and understanding of observables



universal interface 23

Formalism for $\tau^+\tau^-$

- Because narrow τ width approximation can be obviously used for phase space , cross section for the process $f\bar{f} \to \tau^+\tau^- Y; \tau^+ \to X^+\bar{\nu}; \tau^- \to \nu\nu$ reads:

$$d\sigma = \sum_{spin} |\mathcal{M}|^2 d\Omega = \sum_{spin} |\mathcal{M}|^2 d\Omega_{prod}\, d\Omega_{\tau^+}\, d\Omega_{\tau^-}$$

- This formalism is fine, but because of over 20 τ decay channels we have over 400 distinct processes. Also picture of production and decay are mixed.
- but (only τ spin indices are explicitly written):

$$\mathcal{M} = \sum_{\lambda_1\lambda_2=1}^{2} \mathcal{M}^{prod}_{\lambda_1\lambda_2}\, \mathcal{M}^{\tau^+}_{\lambda_1} \mathcal{M}^{\tau^-}_{\lambda_2}$$

- Formula for the cross section can be re-written

$$d\sigma = \Big(\sum_{spin} |\mathcal{M}^{prod}|^2\Big)\Big(\sum_{spin} |\mathcal{M}^{\tau^+}|^2\Big)\Big(\sum_{spin} |\mathcal{M}^{\tau^-}|^2\Big) wt\; d\Omega_{prod}\, d\Omega_{\tau^+}\, d\Omega_{\tau^-}$$

Z. Was September, 2004

Use of tau spin at LHC

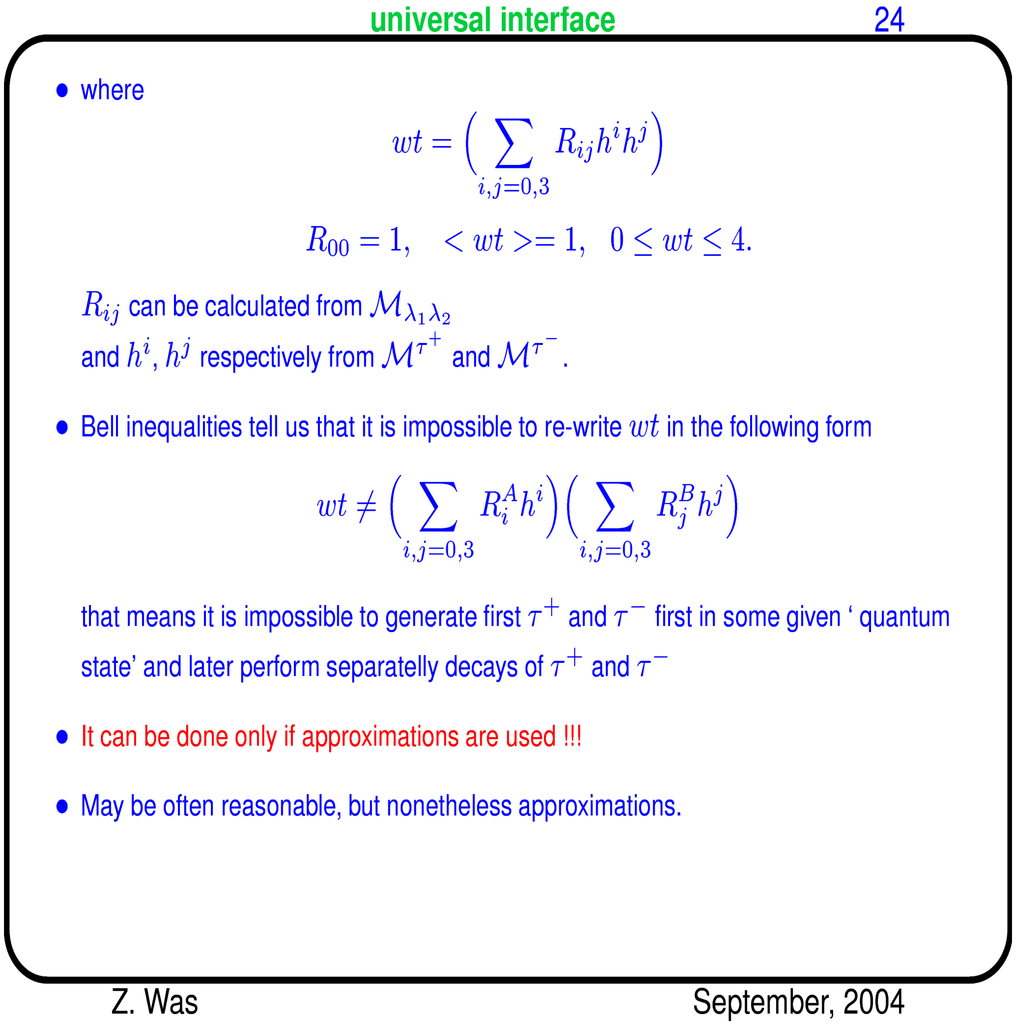
General form of density matrix is universal.

For Higgs R_{33}=1 for Z/gamma* R_{33}=-1 also R_{30} R_{03} representing tau polarization is non-zero.

In ultrarelativistic approximation all other elements of R are zero.

In general case,

beautiful parity observables can be studied.



universal interface 24

- where

$$wt = \Big(\sum_{i,j=0,3} R_{ij} h^i h^j \Big)$$

$$R_{00} = 1, \quad < wt >= 1, \quad 0 \leq wt \leq 4.$$

R_{ij} can be calculated from $\mathcal{M}_{\lambda_1 \lambda_2}$
and h^i, h^j respectively from $\mathcal{M}^{\tau^+}$ and $\mathcal{M}^{\tau^-}$.

- Bell inequalities tell us that it is impossible to re-write wt in the following form

$$wt \neq \Big(\sum_{i,j=0,3} R^A_i h^i \Big) \Big(\sum_{i,j=0,3} R^B_j h^j \Big)$$

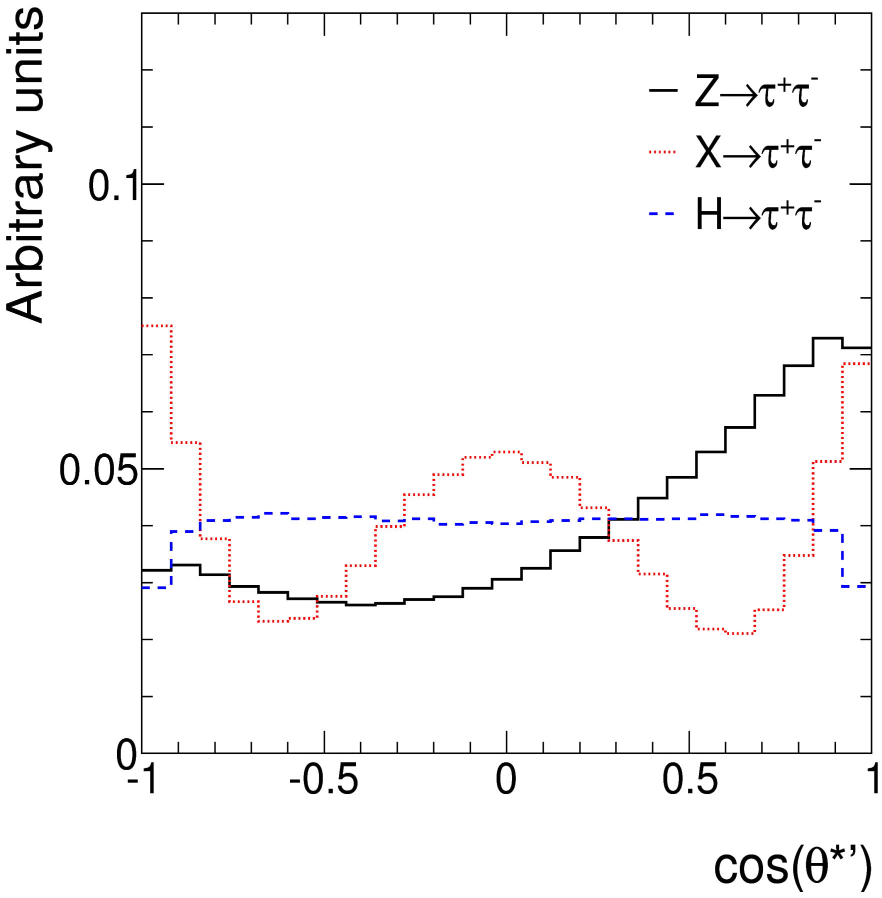
that means it is impossible to generate first τ^+ and τ^- first in some given ' quantum state' and later perform separatelly decays of τ^+ and τ^-

- It can be done only if approximations are used !!!
- May be often reasonable, but nonetheless approximations.

Z. Was September, 2004

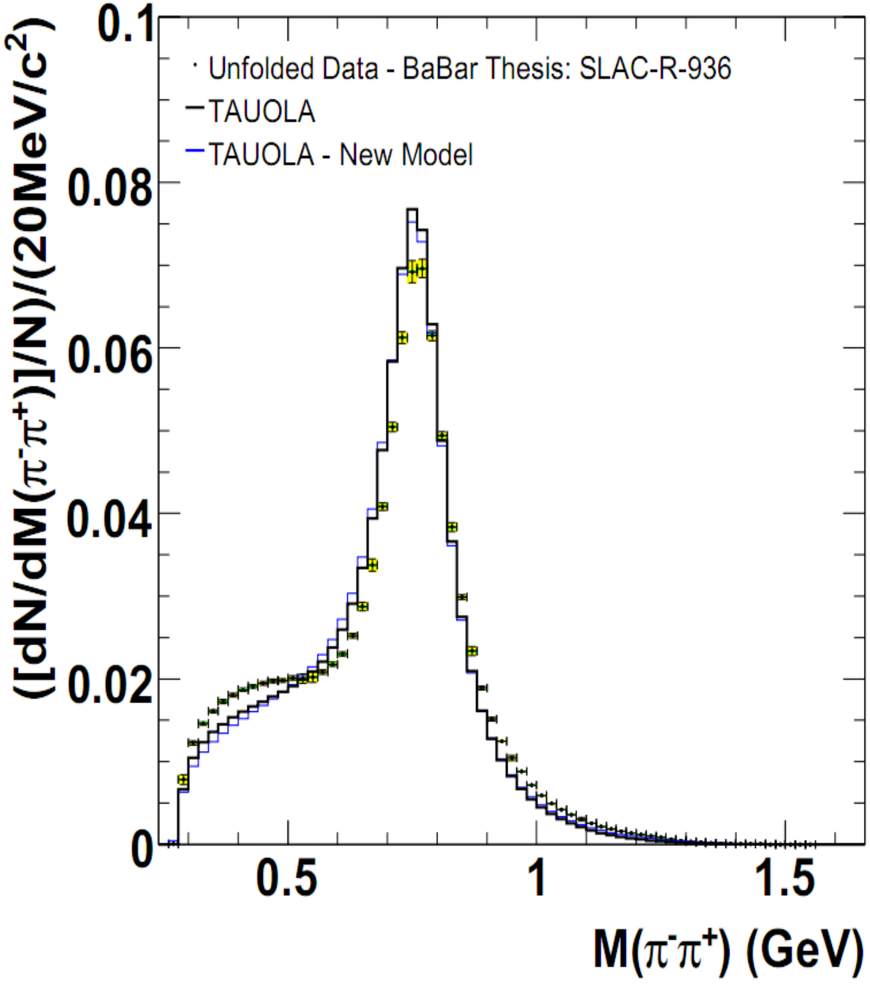
TAUOLA → TauSpinner → recent results → useful to improve measurement of Higgs spin?

- We need to distinguish signal of New Physics from Background
- Shape of multidimensional distributions depend on properties of New Physics and how it differs from SM background
- It depends on effects due to detector acceptance as well.
- Finally on properties of tau decays.
- S. Banerjee, J. Kalinowski, W. Kotlarski, T. Przedzinski and ZW, An example figure from *Ascertaining the spin for new resonances decaying into tau⁺ tau⁻ at Hadron Colliders*, CERN-PH-TH-2012-347, Dec 2012



TAUOLA need low energy experiments

- Details of tau decays need to be modeled on the basis e.g. of Resonance Chiral Lagrangian approach
- Fits to the Belle BaBar data must follow.
- Work started 2 decades ago by S. Jadach, M. Jezabek and ZW



SM Higgs sector consistency test

One of the important relation of SM is the one between three masses:

- top quark mass
- W mass
- Higgs mass

Precision measurements for this relation are pursued:

Consistency test in SM Higgs Sector

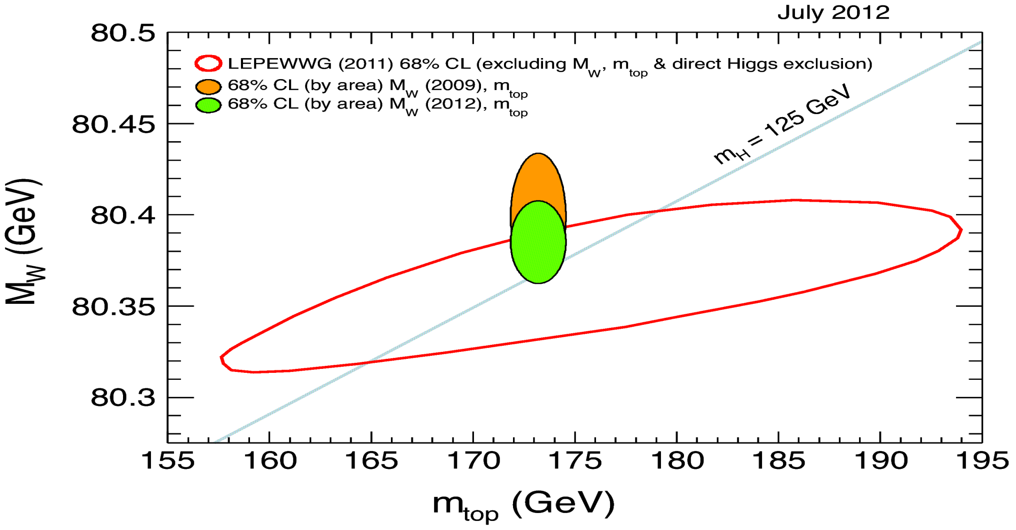
CDF: PRL **108**,151803 (2012), D0: PRL **108,** 151804 (2012)

Standard model fit

With $M_W = 80385 \pm 15$ MeV

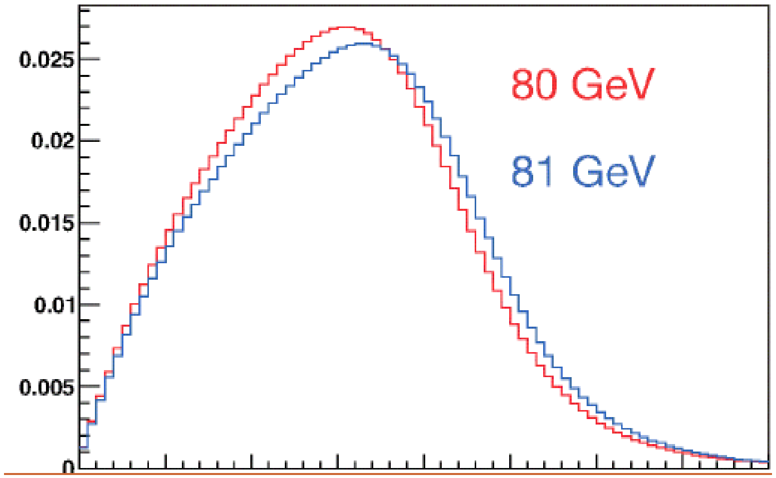
$M_H = 94^{+29}_{-24}$ GeV
$M_H < 152$ GeV @95% CL

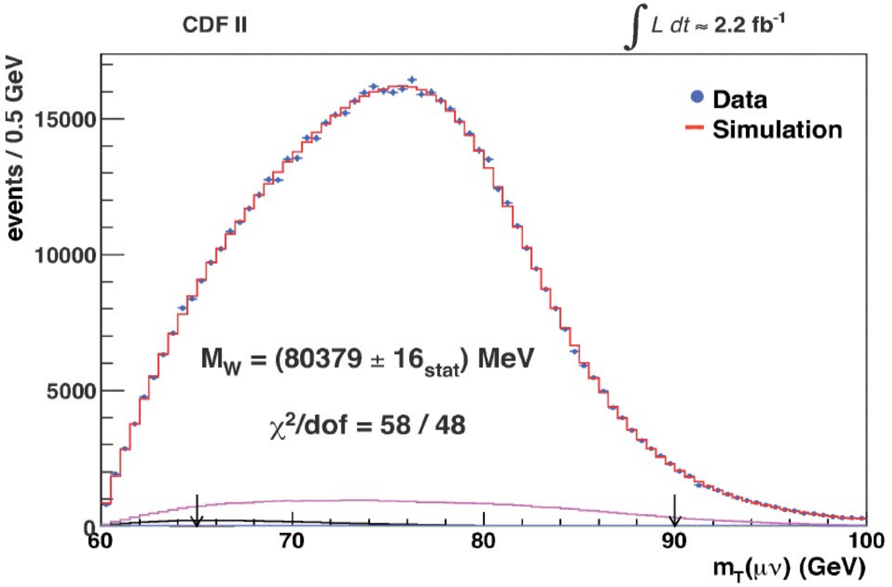
LEPEWWG/ZFitter



Now Higgs mass is known: improve precision for W mass measurement

High precision in MC needed:





$$m_T = \sqrt{2 p_T^{\ell} p_T^{\nu} (1 - \cos \Delta\theta_{\ell\nu})}$$

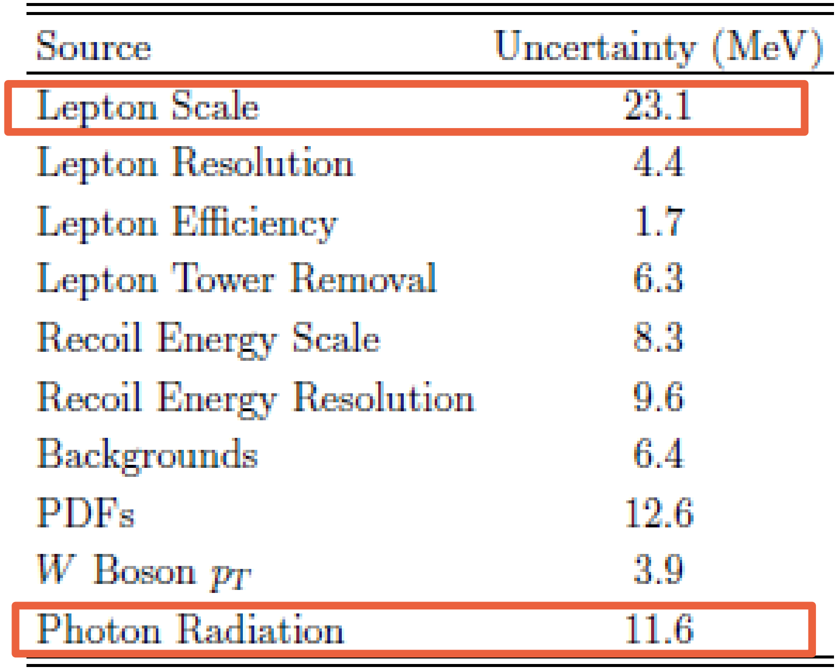
Note: how tiny is effect of 15 MeV

This improvement was achieved by experimental and theoretical efforts

Main achievements: Lepton resolution and QED FSR

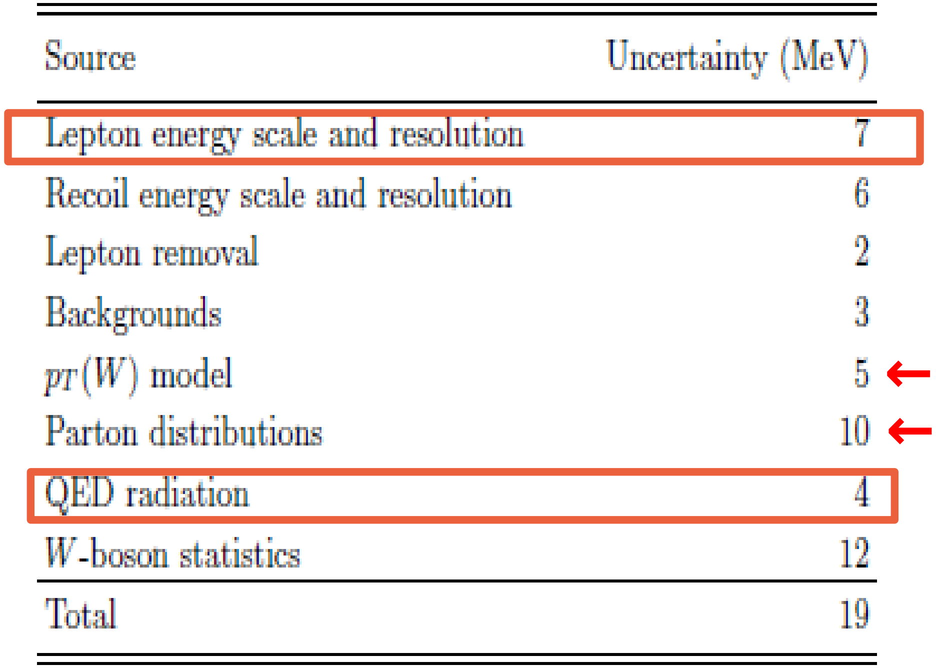
Now PDF's and p_T(W) main TH systematic err. → see later

CDF: 200pb^{-1} measurement (2008) **CDF: 2.2fb^{-1} measurement (2012)**



Source	Uncertainty (MeV)
Lepton Scale	23.1
Lepton Resolution	4.4
Lepton Efficiency	1.7
Lepton Tower Removal	6.3
Recoil Energy Scale	8.3
Recoil Energy Resolution	9.6
Backgrounds	6.4
PDFs	12.6
W Boson p_T	3.9
Photon Radiation	11.6

Phys. Rev. D77, 112001 (2008)



Source	Uncertainty (MeV)
Lepton energy scale and resolution	7
Recoil energy scale and resolution	6
Lepton removal	2
Backgrounds	3
$p_T(W)$ model	5 ←
Parton distributions	10 ←
QED radiation	4
W-boson statistics	12
Total	19

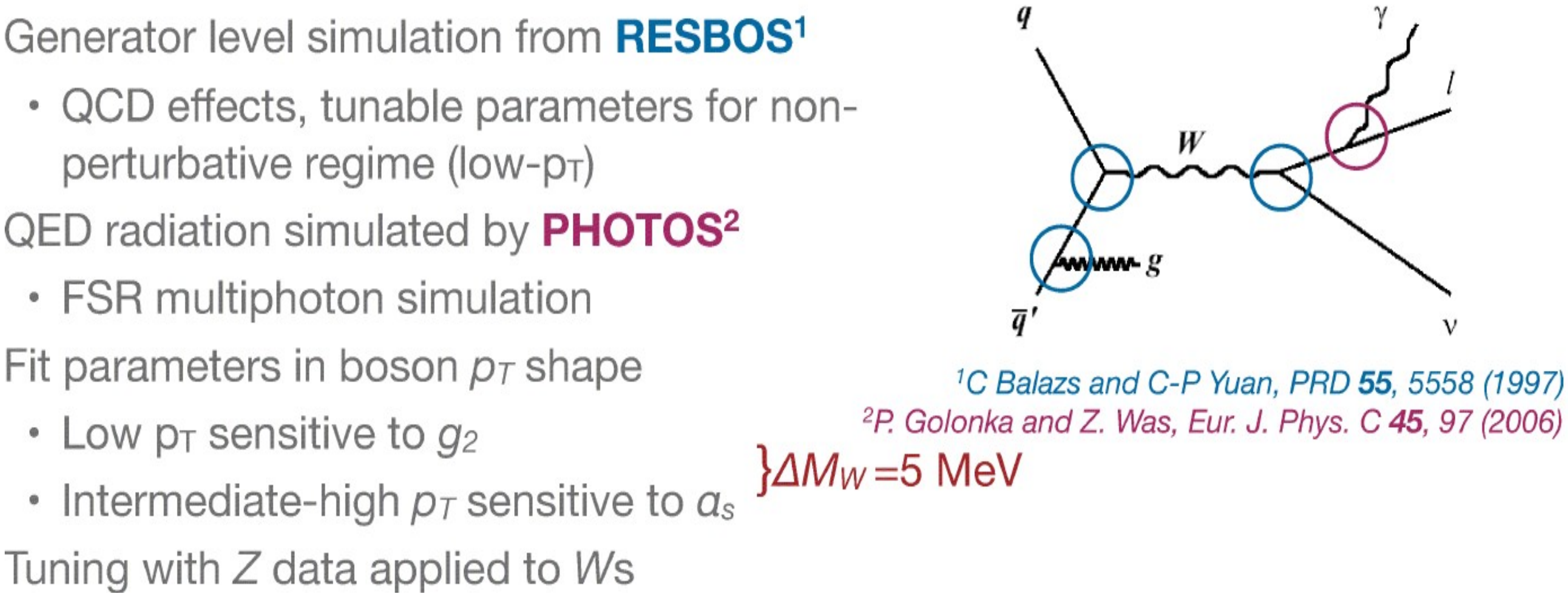
Phys. Rev. lett. 108, 151803 (2012)

Example 2: PHOTOS for M_T

QED bremsstrahlung is of importance for this measurement.

PHOTOS is used to simulate bremsstrahlung in decays (as one of the alternatives).

Simulation in CDF divided into blocks



Generator level simulation from **RESBOS**[1]

- QCD effects, tunable parameters for non-perturbative regime (low-p_T)

QED radiation simulated by **PHOTOS**[2]

- FSR multiphoton simulation

Fit parameters in boson p_T shape

- Low p_T sensitive to g_2
- Intermediate-high p_T sensitive to α_s

$\}\Delta M_W = 5$ MeV

Tuning with Z data applied to Ws

[1] *C Balazs and C-P Yuan, PRD* ***55****, 5558 (1997)*

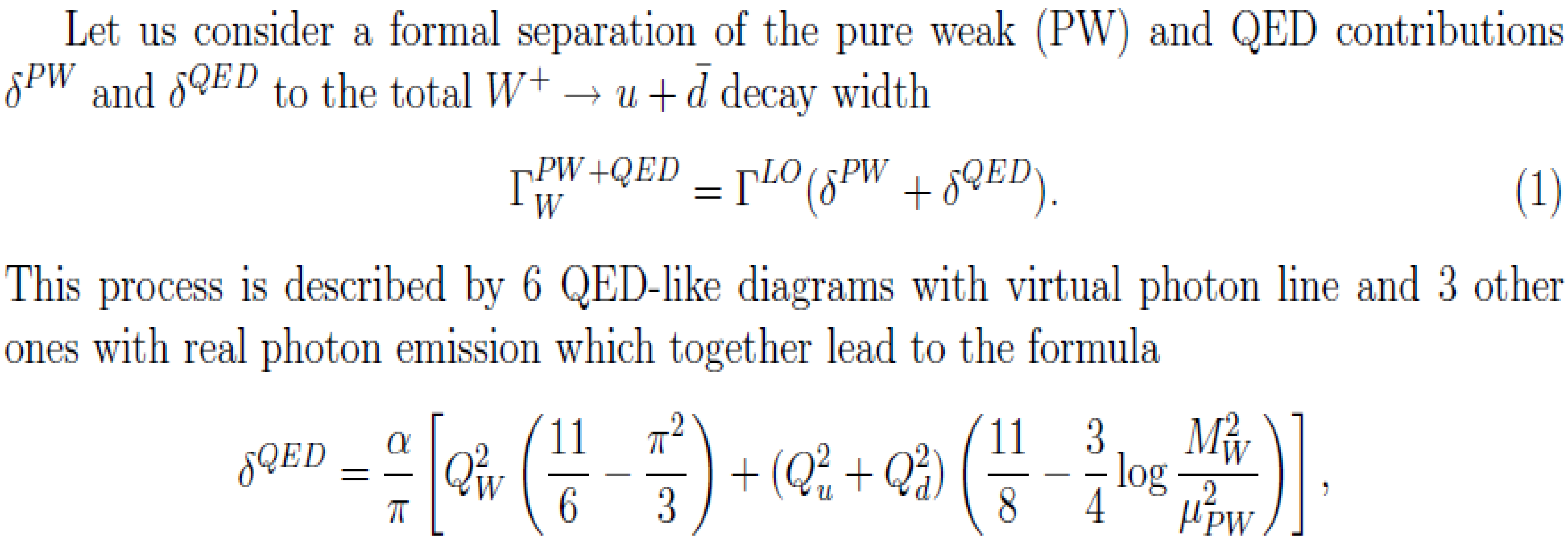
[2] *P. Golonka and Z. Was, Eur. J. Phys. C* ***45****, 97 (2006)*

QED FSR was generated with PHOTOS

PHOTOS principle of use

- Since 1989 PHOTOS (by E.Barberio, B. van Eijk, Z. W., P. Golonka) is used to simulate QED radiative corrections in decays.
- Full events of complicated tree structure for production and cascade decays are fed in.
- At every event tree branching (decay) , PHOTOS intervene. With calculated by algorithm probability extra photon(s) are added and kinematics of other particles is adjusted.
- Such algorithm can be controlled to a very high precision.

Separation PW-QED in W decay



Let us consider a formal separation of the pure weak (PW) and QED contributions δ^{PW} and δ^{QED} to the total $W^+ \to u + \bar{d}$ decay width

$$\Gamma_W^{PW+QED} = \Gamma^{LO}(\delta^{PW} + \delta^{QED}). \qquad (1)$$

This process is described by 6 QED-like diagrams with virtual photon line and 3 other ones with real photon emission which together lead to the formula

$$\delta^{QED} = \frac{\alpha}{\pi}\left[Q_W^2\left(\frac{11}{6} - \frac{\pi^2}{3}\right) + (Q_u^2 + Q_d^2)\left(\frac{11}{8} - \frac{3}{4}\log\frac{M_W^2}{\mu_{PW}^2}\right)\right],$$

For high precision in PHOTOS use electroweak corrections have to be separated into pure weak (PW) and QED. This was done for SANC tests. This has to be followed in practical use in experiments as well.

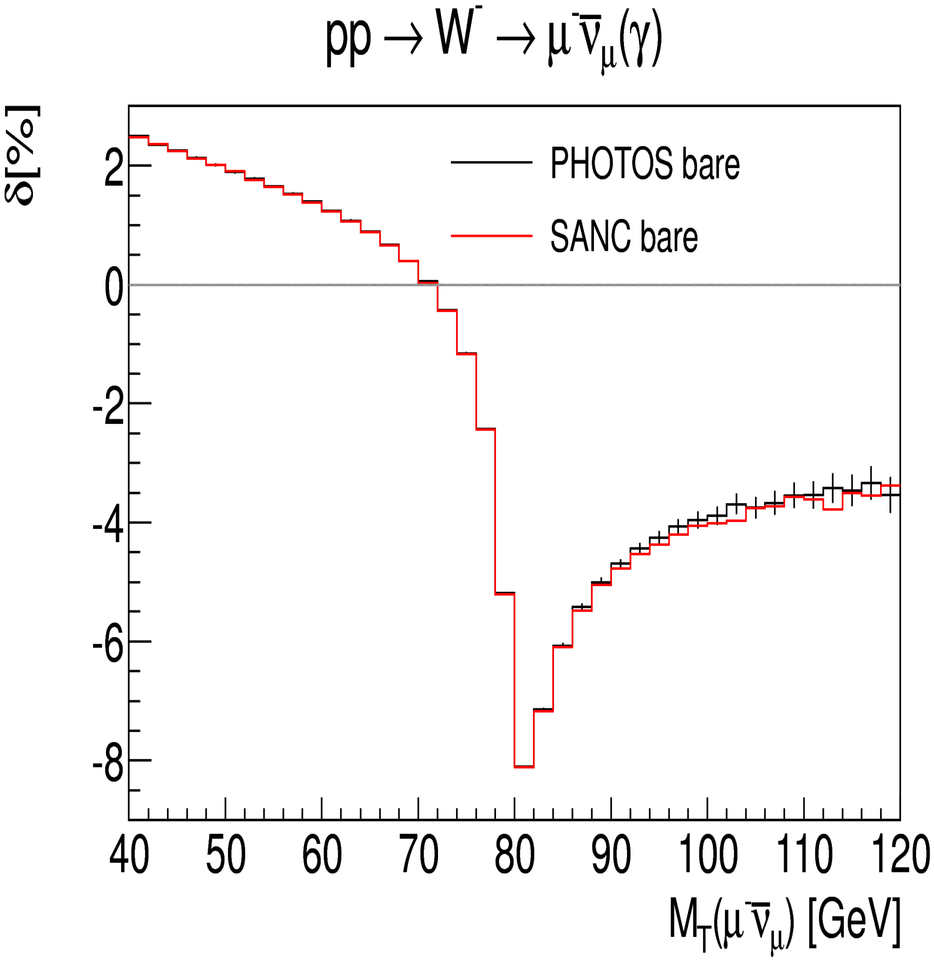
PHOTOS technical tests in $M_T(W)$:

QED FSR corrections for transverse mass M_T.

Test and comparison PHOTOS vs. SANC.

This is technical test. Also we show QED FSR in W decays is properly disentangled from complete EW effects.

A. Arbuzov, R. Sadykov, ZW, *QED bremsstrahlung in decays of electroweak bosons*, CERN-PH-TH/2012-354, Dec 2012



Example 3: PHOTOS and ϕ^*

- Already at present, dominant th. systematic error in W mass measurement is due to PDF's and uncertainties for $p_T(W)$.
- To control better PDF's and $p_T(W)$ measurements of Z production @LHC are optimized.
- Instead of measuring $p_T(Z)$, it is better to use ϕ^* constructed from directions of leptons in $Z \rightarrow l^+ l^-$ decay
- Lepton directions are measured precisely!

$\phi^* \sim p_T(Z)/M_Z$

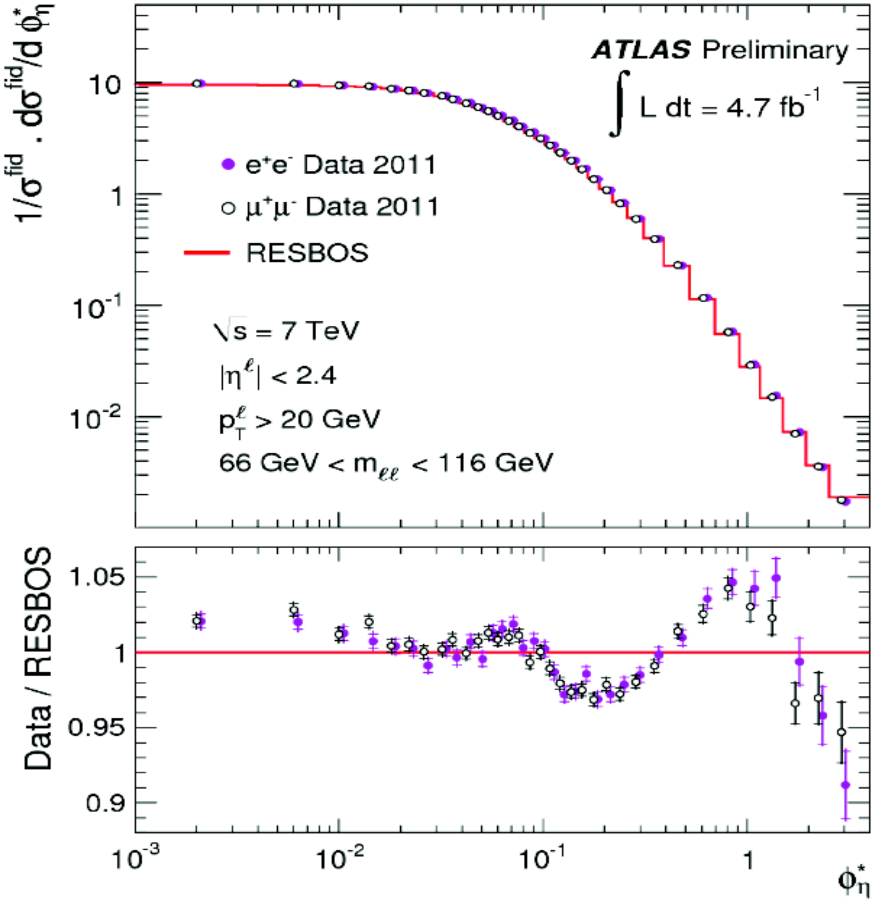
arXiv:1211.6899

First measurement is published now, progress is continued.

We attempt to be helpful with theoretical side.

Tests with KKMC and Winhac are on going: Oanh Doan, S. Jadach, W. Placzek, ZW

At present systematic error on QED FSR is estimated from comparison PHOTOS SHERPA



Summary

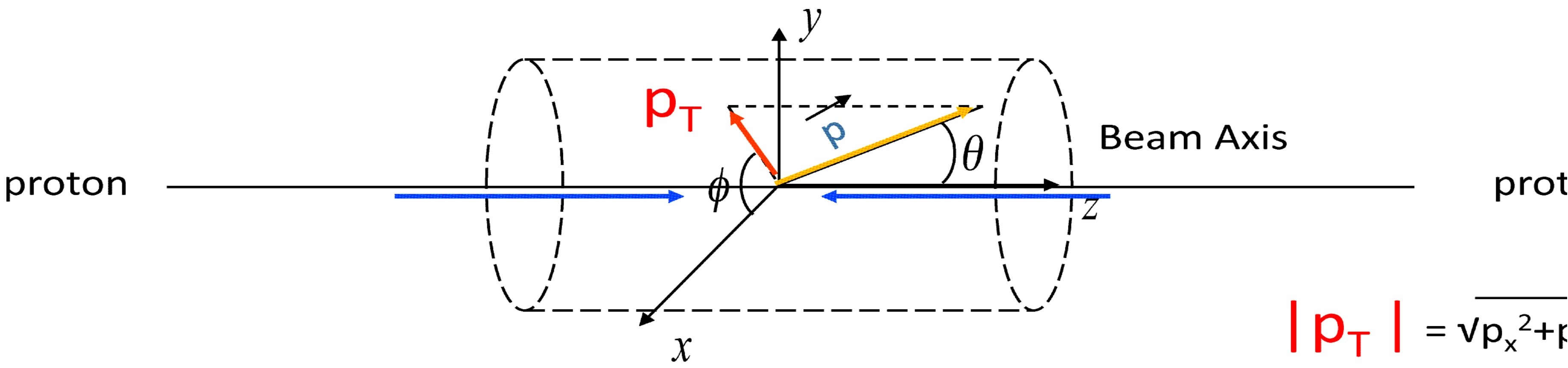
I have shown examples of phenomenological work for Higgs@LHC. I could profit from activities and expertise of HEP community:

- QED and tau decays at LEP time
- Expertise on parton showers and matrix element calculations in pp collisions
- Expertise on Higgs signatures.
- Advices on experimental needs and capabilities.

That was and hopefully is going to be fascinating, often unexpected adventure, which could grow on combination of new challenges, laborious efforts and previous expertise.

I hope my talk could send such a message.

Extra slides

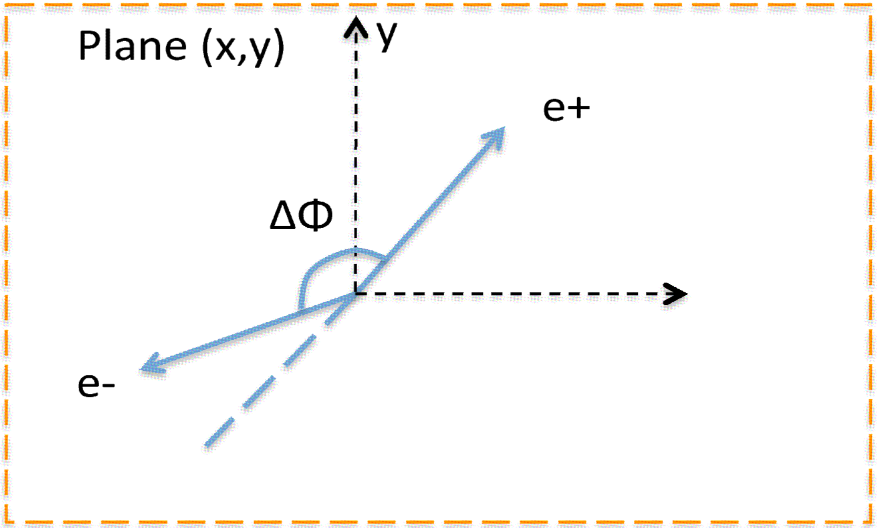


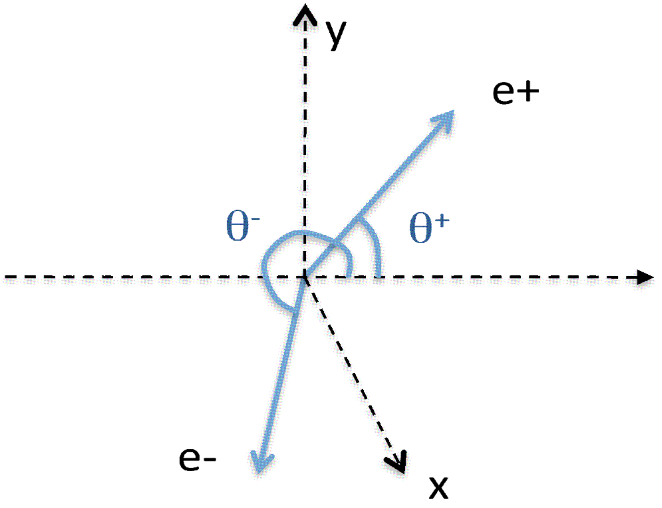
$|p_T| = \sqrt{p_x^2+p}$

- rapidity $$Y = \frac{1}{2} \ln \frac{E+p_z}{E-p_z}$$
- pseudorapidity $$\eta = -\ln\left(\tan\frac{\theta}{2}\right)$$

Fiducial region:
Electron p_T > 20 GeV, Positron p_T > 20 GeV
$|\eta|$ Electron < 2.4, $|\eta|$ Positron < 2.4
66 GeV < M_{Zboson} < 116 GeV

Phi* instead of Z boson p_T





$$\phi_{\text{acop}} = \pi - \Delta\phi.$$

$$\phi^* \equiv \tan(\phi_{\text{acop}}/2)\sin(\theta^*)$$

$$\cos(\theta^*_\eta) = \tanh\left(\frac{\eta^- - \eta^+}{2}\right),$$

$$\eta^- = -\ln\left(\tan\frac{\theta^-}{2}\right)$$

$$\eta^+ = -\ln\left(\tan\frac{\theta^+}{2}\right)$$

We want to measure dσ(Z->l+l-)/dΦ* at Born level in the fiducial region and need to k the uncertainty on the Φ* distribution (dN(Z->l+l-)/dΦ*) due to the approximations on in PHOTOS calculations (l = e, μ)

TAUOLA PHOTOS main references

TAUOLA

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