Educational activities Theory Group

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Athens, June 14, 2021

Discoveries 2010-2020

Higgs

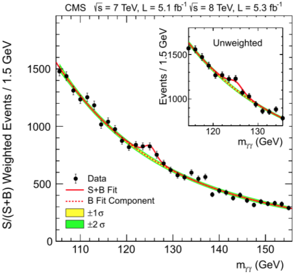


Fig. 3. The diphoton invariant mass distribution with each event weighted by the $S/(S+B)$ value of its category. The lines represent the fitted background and signal, and the coloured bands represent the ± 1 and ± 2 standard deviation uncertainties in the background estimate. The inset shows the central part of the unweighted invariant mass distribution. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this Letter.)

Gravitational wave

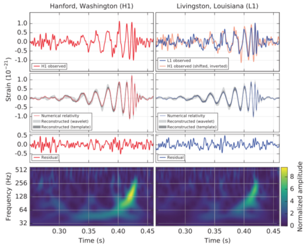
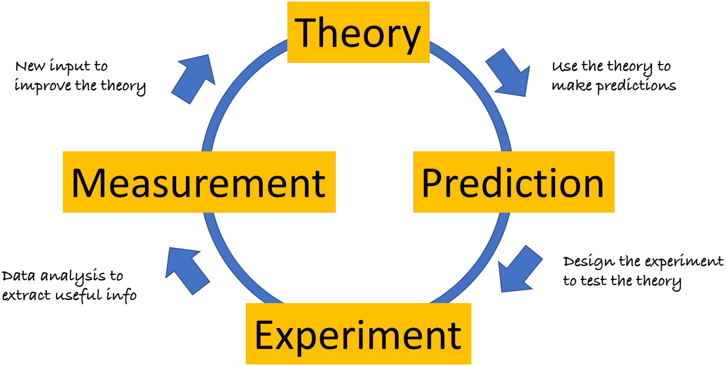


FIG. 1. The gravitational-wave event GW150914 observed by the LIGO Hanford (H1, left column panels) and Livingston (L1, right column panels) detectors. Times are shown relative to September 14, 2015 at 09:50:45 UTC. For visualization, all time series are filtered with a 35–350 Hz bandpass filter to suppress large fluctuations outside the detectors' most sensitive frequency band, and band-reject filters to remove the strong instrumental spectral lines seen in the Fig. 3 spectra. *Top row, left:* H1 strain. *Top row, right:* L1 strain. GW150914 arrived first at L1 and $6.9^{+0.5}_{-0.4}$ ms later at H1; for a visual comparison, the H1 data are also shown, shifted in time by this amount and inverted (to account for the detectors' relative orientations). *Second row:* Gravitational-wave strain projected onto each detector in the 35–350 Hz band. Solid lines show a numerical relativity waveform for a system with parameters consistent with those recovered from GW150914 [37,38] confirmed to 99.9% by an independent calculation based on [15]. Shaded areas show 90% credible regions for two independent waveform reconstructions. One (dark gray) models the signal using binary black hole template waveforms [39]. The other (light gray) does not use an astrophysical model, but instead calculates the strain signal as a linear combination of sine-Gaussian wavelets [40,41]. These reconstructions have a 94% overlap, as shown in [39]. *Third row:* Residuals after subtracting the filtered numerical relativity waveform from the filtered detector time series. *Bottom row:* A time-frequency representation [42] of the strain data, showing the signal frequency increasing over time.

Faint signals; Patience; Theory

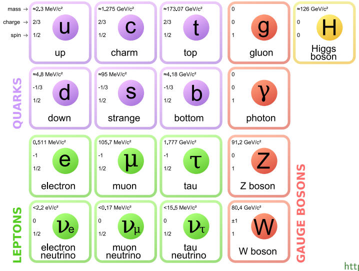
Scientific Knowledge



Quantum Field Theory

Develop theoretical knowledge, algorithms and tools ...

Particle physics today

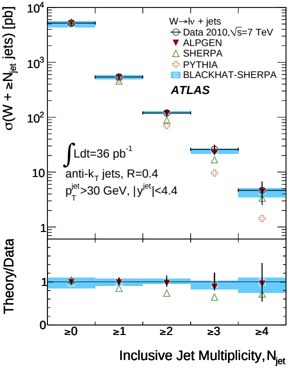


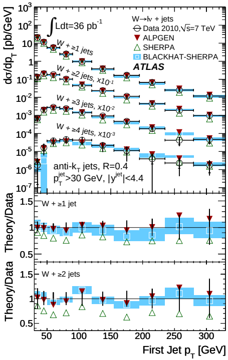
http://en.wikipedia.org

$$\mathcal{L}_{QCD} = i\bar{\psi}_i \left(\left(\gamma^\mu D_\mu\right)_{ij} - m_i \delta_{ij} \right) \psi_j - \frac{1}{4} G^a_{\mu\nu} G^{a\mu\nu}$$

Necessary but not sufficient

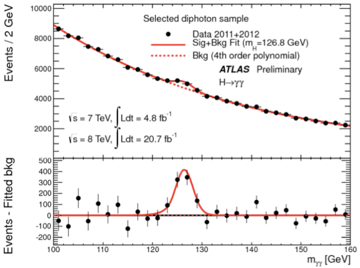
in order to analyse experimental data ...

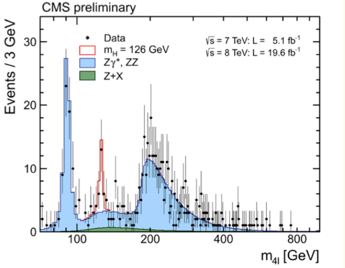




Predictions for all observables

so that discoveries (Higgs) become possible!

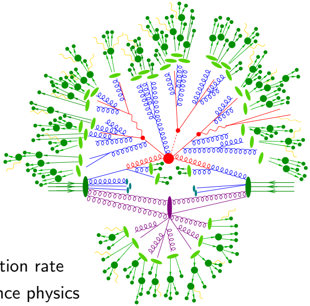




Factorization

Collins,Soper,Sterman'85–'89

- Calculate
  - Scattering probability
  - Gluon emission probability
- Measure
  - Long distance interactions
  - Particle decay rates



Divide et Impera

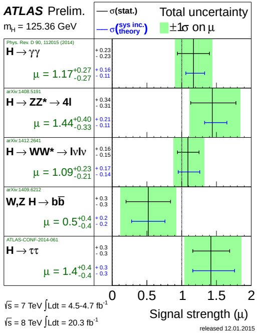
- Quantity of interest: Total interaction rate
- Convolution of short & long distance physics

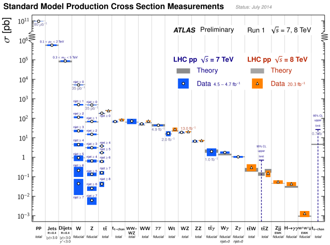
$$\sigma_{p_1 p_2 \to X} = \sum_{i,j\in\{q,g\}} \int \mathrm{d}x_1 \mathrm{d}x_2 \underbrace{f_{p_1,i}(x_1,\mu_F^2) f_{p_2,j}(x_2,\mu_F^2)}_{\text{long distance physics}} \underbrace{\hat{\sigma}_{ij\to X}(x_1 x_2,\mu_F^2)}_{\text{short distance physics}}$$

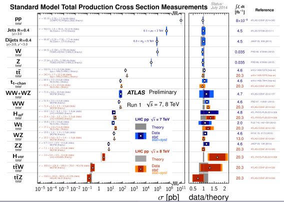
QCD as a perturbative quantum field theory

QCD (N)NLO

Forthcoming experimental precision vs theoretical predictions







Scattering Amplitudes & Precision Calculations

Dr. Konstantinos Papadopoulos – Director of Research
http://old.inspirehep.net/author/profile/C.G.Papadopoulos.1

- Research Associates: G. Bevilacqua, A. Kardos (U. Debrecen, Hungary), M. Czakon, M. Worek (RTWH Aachen, Germany), C. Wever (TUM, Munich, Germany), A. van Hameren, (INP, Cracow, Poland), Alexander V. Smirnov (Lomonosov Moscow State U., Russia), H. Ita (Freiburg U., Germany), Ronald Kleiss (Nijmegen U., IMAPP, The Netherlands), ...
- PhD students: N. Syrrakos, D. Canko

Feynman

PHYSICAL REVIEW VOLUME 76, NUMBER 6 SEPTEMBER 15, 1949

Space-Time Approach to Quantum Electrodynamics

R. P. Feynman
Department of Physics, Cornell University, Ithaca, New York
(Received May 9, 1949)

In this paper two things are done. (1) It is shown that a considerable simplification can be attained in writing down matrix elements for complex processes in electrodynamics. Further, a physical point of view is available which permits them to be written down directly for any specific problem. Being simply a and presumably consistent, method is therefore available for the calculation of all processes involving electrons and photons.

The simplification in writing the expressions results from an emphasis on the over-all space-time view resulting from a study of the solution of the equations of electrodynamics. The relation

D. More Complex Problems

Matrix elements for complex problems can be set up in a manner analogous to that used for the simpler cases. We give three illustrations; higher order corrections to the Møller scatter-

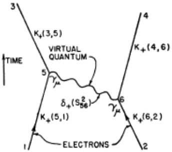
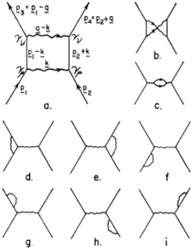
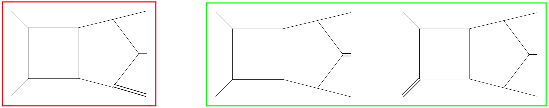


Fig. 1. The fundamental interaction Eq. (4). Exchange of one quantum between two electrons.

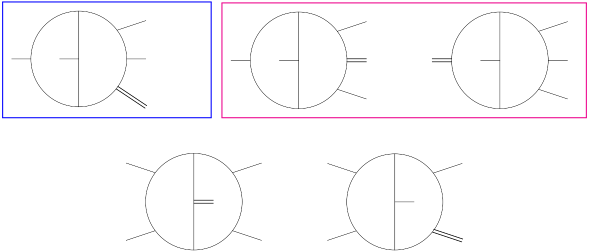


Best today: 5-point - one leg off-shell: all families

C. G. Papadopoulos, D. Tommasini and C. Wever, arXiv:1511.09404 [hep-ph].
C. G. Papadopoulos and C. Wever, JHEP **2002** (2020) 112
S. Abreu, H. Ita, F. Moriello, B. Page, W. Tschernow and M. Zeng, JHEP **2011** (2020) 117
D. D. Canko, C. G. Papadopoulos and N. Syrrakos, JHEP **2101** (2021) 199



The three planar pentaboxes of the families P_1 (left), P_2 (middle) and P_3 (right) with one external massive leg.



The five non-planar families with one external massive leg.

Classical Gravity with Feynman graphs

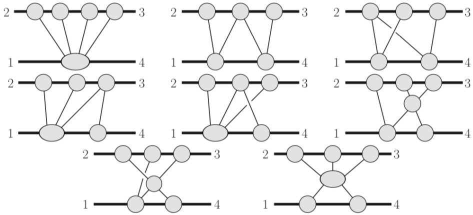


FIG. 1. Generalized unitarity cuts encoding potential-region contributions to binary dynamics. Ovals represent tree amplitudes while exposed lines depict on-shell states. Thin and thick lines denote gravitons and massive scalars, respectively.

Z. Bern, J. Parra-Martinez, R. Roiban, M. S. Ruf, C. H. Shen, M. P. Solon and M. Zeng, Phys. Rev. Lett. **126** (2021) no.17, 171601 [arXiv:2101.07254 [hep-th]].

Dr Minos Axenides – Director of Research

- **Research Associates** : Emer.Prof. M.Floratos, Dr G.Pastras , Dr G.Linardopoulos
- **Ph.D Students** : D.Katsinis –UoA-, I.Sorotonides –UoA-

<u>**Areas of Research + Teaching**</u>:

1) Particle Cosmology , Astroparticle Physics

2) Solitons in Field Theory (Q-Balls) - String & M-Theories

3) Chaotic Dynamics –Classical & Quantum –

- **CO.S.A.Net ; Complex Systems and Applications –** http://cosa.inn.demokritos.gr/contact/

4) Information Theory and the Black Hole Information Paradox

- **Finite Entropy of Quantum Black Hole Puzzle , Hawking Radiation , Models of BH-near Horizon Geometries**

5) Joint (INPP-NTUA-UoA) Quantum Information and Quantum Computation Initiative on Research and Teaching.

<u>***More Detailed Analysis and Information***</u>:

- The Standard Model of Fundamental Interactions
  SU(3) xSU(2) xU(1) x Classical Gravity is incomplete and in tension with the presently popular **standard Cosmological Model (ΛCDM) not accounting for** :
  - Dark Matter (DM) 25% by weight – Non-relativistic (CDM) of positive energy density and pressure in the EOS.
  - Dark Energy(DE) 70% by weight – Non- Diluting with negative pressure and positive energy density in the EOS of the Late Universe.
  - Inflation- Exponentially expanding Phase in the Very Early Universe [> 10^(15) GEV]

Scope of our Early Universe Research : Building Scalar-type Field Theory Models that solves all or any one of the above problems. (e.g. axions , SUSY- Q-balls for Dark Matter , (DM+DE)Hybrid models)

2) **Solitons**

- Supersymmetric Q-balls –Non topological time-dependent finite energy stable solitons due to exact Baryon and Lepton Quantum Numbers in the Minimal Supersymmetric standard Model and supergravity theories originating in the early universe dominate the energy density as Dark Matter.
- Rotating membrane configurations as solutions to higher dimensional (11d) Matrix Model and M-theories. They exhibit chaotic properties and turbulent aspects.

3) **Chaotic Dynamics –Classical and Quantum see**

- The study of low dimensional Systems exhibiting Chaotic properties , deterministic Chaos and onset of Turbulence ***COSA-Net at NCSR-Demokritos offers an Inter-Institute Course with NTUA " Special Topics in Complex System", and Seminars*** -
  http://cosa.inn.demokritos.gr/contact/
- Rapid Information Processing of Black Holes requires both **Chaotic Dynamics , Nonlocality and Quantum Information Methods** of its Microscopic Degrees of Freedom and Near Horizon Geometry Dynamics— (Descritized Models of BH-Horizon Spacetime dynamics)

4) **Quantum Information-Computation Initiative at INPP –NTUA-UoA.**

A joint activity Initiative for the study and research of the Principles of Quantum Information and Quantum Computation is being set up with a

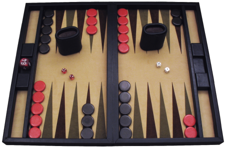
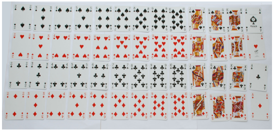
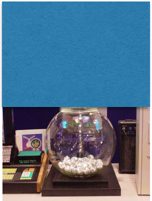
- **joint annual introductory course**
- **joint research towards a Master Degree and Ph.D Degree at NTUA and UoA.**
- **Info at :**
  Dr M.Axenides at INPP (axenides@inp.demokritos.gr)
  Dr M.Floratos at UoA (mforato@physics.uoa.gr)
  Dr G.Varelogianis at NTUA (varelogi@mail.ntua.gr)

MIXMAX Random Numbers Generator

Georgios Savvidis
National Centre for Scientific Research "Demokritos"

Random Number are used from ancient times:

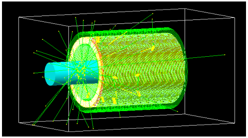
1. Backgammon game - the random numbers generated by dice.
2. Deck of playing cards - the cards are distributed randomly.
3. Lottery Machine - used to generate lucky numbers.
4. Monte Carlo spinning roulette- to determine the winning number and colour.

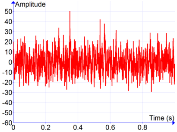




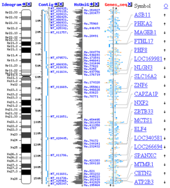

The Monte Carlo Method

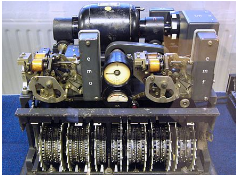
Random Numbers Generator is in the heart of the modern Monte Carlo Method:

1. Used in Manhattan Project
2. To simulate propagation of high energy particle
3. Modelling radiation dosimetry
4. Estimating radiation transmission in medical applications
5. Advanced signal processing and filtering method
6. Computational physics and molecular chemistry
7. Designing detectors
8. Computational biology, computational pharmacology
9. Computational and Statistical Genetics
10. Communication, telecommunication, cryptography, including: electronic commerce,
11. chip-based payment cards, digital currencies, computer passwords and many others..









Development and Implementation of the MIXMAX Technology

1. The MIXMAX Consortium, Marie Sklodowska-Curie Grant Agreement 644121, has developed a cutting-edge theory of the MIXMAX generator.
2. The MIXMAX code in C and C++ was developed by Konstantin Savvidis: https://mixmax.hepforge.org
3. The MIXMAX code generates 64-bit high quality random sequences. It is one of the fastest generators on the market.
4. *http://www.inp.demokritos.gr/~savvidy/mixmax.php*

Implementation of the MIXMAX Generator at CERN

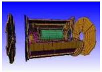
Worldwide acceptance of the open source MIXMAX Technology:

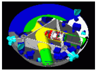
1. The MIXMAX generator has become the default option in Geant4 software at CERN. Its areas of application include high energy, nuclear and accelerator physics, as well as studies in medical and space science: https://geant4.web.cern.ch.
2. The MIXMAX generator has been added in the PYTHIA software at Lund U http://home.thep.lu.se/~torbjorn/doxygen/MixMax_8h_source.html
3. The MIXMAX generator has been implemented into the GSL - GNU Scientific Library https://www.gnu.org/software/gsl/
4. The MIXMAX generator is implemented in the ROOT library at CERN:
5. https://root.cern.ch/doc/master/classTRandom.html
   used among others at the NASA Space Radiation Analyses Group, Johnson Space Centre

GEANT4 A SIMULATION TOOLKIT

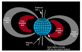
ROOT Data Analysis Framework

LUND UNIVERSITY





GSL
GNU Scientific Library



PYTHIA

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Gravity with perimeter action and gravitational singularities

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ABSTRACT

We consider the perturbation of the Schwarzschild solution by the perimeter action. The asymptotic behaviour of the solution at infinity and at the horizon are calculated and analysed in the first approximation. In the regions far from the matter sources the perturbations are characterised by the ratio of the Plank length to the Schwarzschild radius and are infinitesimally small. At short distances the perturbation is large and there appears a space-time region of the Schwarzschild radius scale that is unreachable by test particles. These regions are located there where the standard theory of gravity has singularities.