Precyzyjne obliczenia i eksperymenty w fizyce cząstek elementarnych

Janusz Gluza

XLVII Zjazd Fizyków i Fizyczek Polskich

19-23.09.2021, Bydgoszcz

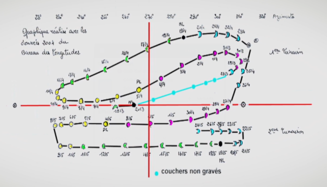
Narodowe Centrum Nauki

Polskie Towarzystwo Fizyczne
Societas Physicorum Poloniae
Experimento et mente
1920

Precyzja, początki

- Tycho de Brahe ($\sim$ 1601) orbita Marsa, tablice rudolfińskie;

  $\longrightarrow$ Johannes Kepler ($\sim$ 1609) - prawa ruchu planet;
  $\longrightarrow$ Isaac Newton ($\sim$ 1686) - grawitacja



Kość z Abri Branchard ($\sim$ 30 000 lat),
Alexander Marschack, ‘Cognitive Aspects of Upper Paleolithic Engraving’ Current Anthropology (1972),
Interpretacja: Chantal Jegues-Wolkiewicz - prawdopodobnie pierwszy księżycowy kalendarz
Podobnie szkice, jaskinie w Lascaux, $\sim$ 17 000 pne.

Precyzja, wybrane zagadnienia

- Albert Michelson, Edward Morley (1881) - stała prędkość światła (~~eter~~);
  $\longrightarrow$ A. Einstein (1905) - ?
  - $\longrightarrow$ A. Eddington (1919) OTW (zakrzywienie promieni światła);
- O. Lummer, E. Pringsheim, H. Rubens, and F. Kurlbaum (1900) - rozkład promieniowania ciała doskonale czarnego
  $\longrightarrow$ M. Planck (1900) - kwanty;
- **Anomalny moment magnetyczny** (i) elektronu (Rabi et al, 1947, Schwinger, 1948) (ii) mionu;
- M. Veltman (1977) ρ-parametr $\sim m_t^2$;
  $\longrightarrow$ Tevatron (1994) - odkrycie top-u;
- LEP era: bozony W, Z, cząstka Higgsa (poprawki elektrosłabe);
  $\longrightarrow$ Eksperymenty LEP, SLAC, **LHC**;
- **Neutrina** (masy, kąty, fazy CP);
- Fale grawitacyjne;
- ...
- **Planowane eksperymenty w niskich i wysokich energiach.**

Dlaczego zależy nam na coraz większej precyzji?

- Zwiększenie precyzji pozwala nam na dojrzenie subtelniejszych sygnałów;
  1. w ramach znanej fizyki (anomalie);
  2. nowe procesy, zjawiska;

- Ogólniej - ustalenie nowych standardów;
- Konsekwencje
  - Historia, ekonomia, nauki społeczne, polityka, badania podstawowe.

Kontekst: redefinicja jednostki masy, 2018

"The revision of the SI- the result of three decades of progress in metrology"
https://iopscience.iop.org/article/10.1088/1681-7575/ab0013
"The CODATA 2017 values of h, e, k, and N_A for the revision of the SI" -
https://iopscience.iop.org/article/10.1088/1681-7575/aa950a

Prawo według "miary, liczby, wagi"

"To be just was precisely to use balance."

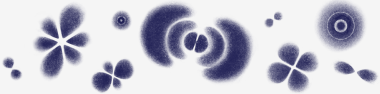
Przypowieści Salomona:

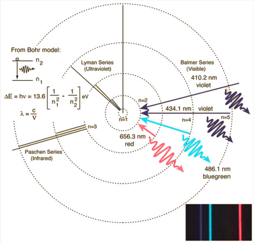
"Dwojakie odważniki są ohydą dla Pana, a fałszywe wagi, to rzecz niedobra"

Kodeks Hammurabiego 1772 pne - śmierć oszukującym na wadze

Różnorakie drogi do precyzyjnej fizyki cząstek, zaczynając od skal atomowych

Ostatni zjazd PTF w Krakowie, 2019,
prof. Krzysztof Pachucki "Elektrodynamika kwantowa lekkich atomów Krzysztof i czasteczek" (QED)





Z.Ligeti

Aside: factor-of-2 improvements can matter!

Search for $K_L \to \pi\pi$

ANNALS OF PHYSICS: 5, 156–181 (1958)

Long-lived Neutral K Mesons*

M. Bardon, K. Lande, and L. M. Lederman

Columbia University, New York, New York, and Brookhaven National Laboratories, Upton, New York

and

William Chinowsky

Brookhaven National Laboratories, Upton, New York

set an upper limit <0.6% on the reactions

< 0.6%

$$K_2^0 \to \begin{cases} \mu^\pm + e^\mp \\ e^+ + e^- \\ \mu^+ + \mu^- \end{cases}$$

and on $K_2^0 \to \pi^+ + \pi^-$.

Volume 6, Number 10 PHYSICAL REVIEW LETTERS May 15, 1961

DECAY PROPERTIES OF K_2^0 MESONS*

D. Neagu, E. O. Okonov, N. I. Petrov, A. M. Rosanova, and V. A. Rusakov
Joint Institute of Nuclear Research, Moscow, U.S.S.R.
(Received April 20, 1961)

Combining our data with those obtained in reference 7, we set an upper limit of 0.3% for the relative probability of the decay $K_2^0 \to \pi^- + \pi^+$. Our

< 0.3%

"At that stage the search was terminated by administration of the Lab."

[Okun, hep-ph/0112031]

Volume 13, Number 4 PHYSICAL REVIEW LETTERS 27 July 1964

EVIDENCE FOR THE 2π DECAY OF THE K_2^0 MESON*†

J. H. Christenson, J. W. Cronin,‡ V. L. Fitch,‡ and R. Turlay§
Princeton University, Princeton, New Jersey
(Received 10 July 1964)

= 0.2 ± 0.04 %

We would conclude therefore that K_2^0 decays to two pions with a branching ratio $R = (K_2 \to \pi^+ + \pi^-)/(K_2^0 \to \text{all charged modes}) = (2.0 \pm 0.4) \times 10^{-3}$ where the error is the standard deviation. As empha-

Nowy wynik (2020)

REPORT

Measurement of the fine-structure constant as a test of the Standard Model

Richard H. Parker[1,*], Chenghui Yu[1,*], Weicheng Zhong[1], Brian Estey[1], Holger Müller[1,2,†]
+ See all authors and affiliations

Science 13 Apr 2018:
Vol. 360, Issue 6385, pp. 191-195
DOI: 10.1126/science.aap7706

Article | Published: 02 December 2020

Determination of the fine-structure constant with an accuracy of 81 parts per trillion

Léo Morel, Zhibin Yao, Pierre Cladé & Saïda Guellati-Khélifa

Nature **588**, 61–65(2020) | Cite this article

$\alpha^{-1}(Cs)$= 137.035 999 046(27)

$\alpha^{-1}(Rb)$= 137.035 999 206(11)

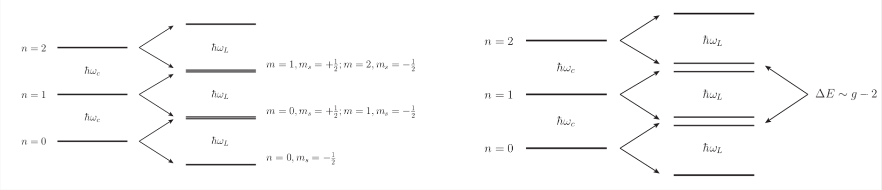
$\alpha^{-1}(a_e)$= 137.035 999 139(31)

Uwaga: (i) nowy wynik już odchylenie od SM w kierunku jak dla $(g-2)_\mu$, (ii) duża rozbieżność z Cs ($\sim 5.4\sigma$).

Guellati-Khélifa poprawiała eksperyment 22 lata
https://www.nature.com/articles/s41586-020-2964-7 [02 December 2020]

$$R_\infty = \frac{\alpha^2 m_e c}{4\pi\hbar} \longrightarrow \alpha^2 = \frac{R_\infty}{c} \times \frac{h}{m_e} \longrightarrow \frac{h}{m_e} = \frac{u}{m_e}\frac{M_X}{u}\frac{h}{M_X}$$

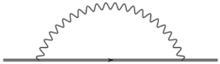
Przesunięcie Lamba $\longrightarrow$ stała Rydberga.

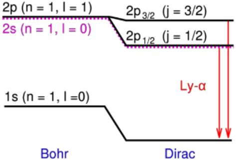


PHYSICAL REVIEW VOLUME 72, NUMBER 4 AUGUST 15, 1947

The Electromagnetic Shift of Energy Levels

H. A. Bethe
Cornell University, Ithaca, New York
(Received June 27, 1947)





$$\Delta E_{2S-2P} \sim \frac{\alpha}{\pi}(Z\alpha)^4 \ln(Z\alpha) \sim 1057 \text{ MHz}$$

ELSEVIER
Physics Letters B
Volume 795, 10 August 2019, Pages 432-437

The Lamb shift of the 1*s* state in hydrogen: Two-loop and three-loop contributions

Robert Szafron $\longrightarrow$ Savely G. Karshenboim [a, b, c], Akira Ozawa [b], Valery A. Shelyuto [d, c], Robert Szafron [e], Vladimir G. Ivanov [c]

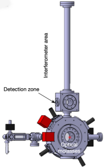
Czy pomiar α ma wpływ na niestandardowe modele (BSM)?

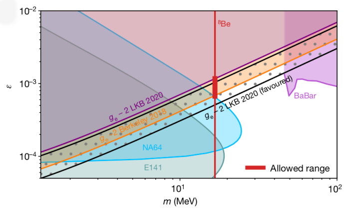
Table 1 | Error budget on α

Source	Correction ($\times 10^{-11}$)	Relative uncertainty ($\times 10^{-11}$)
Gravity gradient	−0.6	0.1
Alignment of the beams	0.5	0.5
Coriolis acceleration		1.2
Frequencies of the lasers		0.3
Wave-front curvature	0.6	0.3
Wave-front distortion	3.9	1.9
Gouy phase	108.2	5.4
Residual Raman light shift	2.3	2.3
Index of refraction	0	<0.1
Internal interaction	0	<0.1
Light shift (two-photon transition)	−11.0	2.3
Second-order Zeeman effect		0.1
Phase shifts in Raman phase-lock loop	−39.8	0.6
Global systematic effects	**64.2**	**6.8**
Statistical uncertainty		**2.4**
Relative mass of ^{87}Rb[a]: 86.9091805310(60)		3.5
Relative mass of the electron[b]: $5.48579909065(16) \times 10^{-4}$		1.5
Rydberg constant[b]: 10,973,731.568160(21) m^{-1}		0.1
Total: α^{-1} = 137.035999206(11)		**8.1**

For each systematic effect, more discussion can be found in Methods.
[a]From ref. [13].
[b]From https://pml.nist.gov/cuu/Constants/.

Morel, L., Yao, Z., Cladé, P. et al. Determination of the fine-structure constant with an accuracy of 81 parts per trillion. Nature 588, 61–65 (2020).



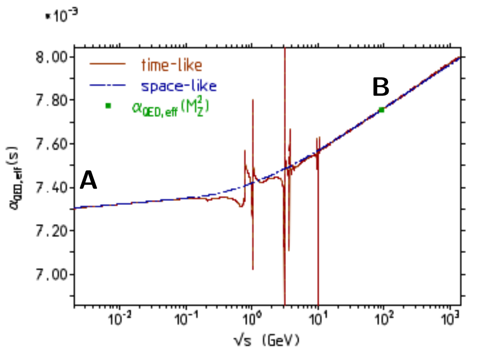


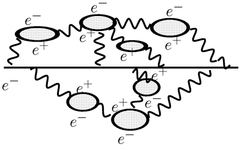
Podstruktura: m^*, rozmiar $L = \hbar/(m^* c) \longrightarrow$ dodatkowa modyfikacja rzędu $\delta a_e \simeq m_e/m^*$
stąd wykluczone:

$$m^* < 520 \text{ GeV} \equiv L > 2 \times 10^{-18}/4 \times 10^{-19} \text{ m}$$

Eksperyment ma polepszyć dokładność δa_e o rząd w następnych latach, będzie na poziomie czułości $(g-2)_\mu$.

$\alpha_{QED}(s)$, polaryzacja próżni

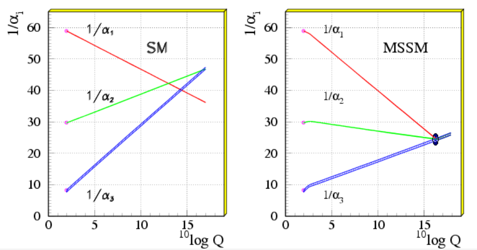


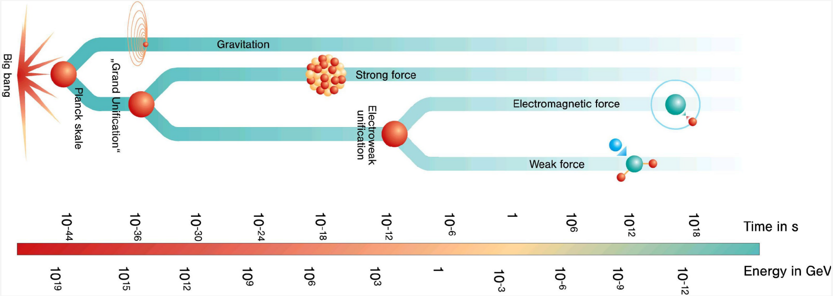


F. Jegerlehner, http://dx.doi.org/10.23731/CYRM-2020-003.9

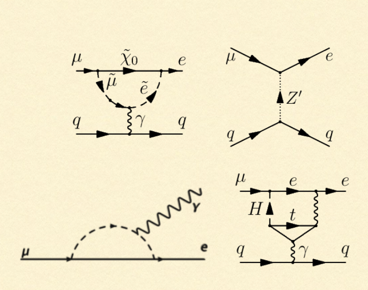
$$\mathbf{A}: \alpha_{\mathbf{QED}}(\mathbf{0}) \simeq \mathbf{1/137},\ \mathbf{B}:\ \alpha_{\mathbf{QED}}(\mathbf{M_Z^2}) \simeq \mathbf{1/128}.$$

Unifikacja oddziaływań





Komplementarność poszukiwań: niskie energie, LFV: $\mu \to e\gamma$, konwersja $\mu \to e$



$m_\mu \sim 200\ m_e$

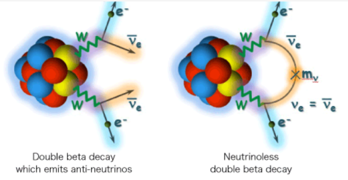
$R^{\mu\to e} < 7 \cdot 10^{-13}$, oczekiwana poprawa precyzji 4 rzędów,

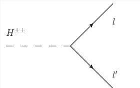
Wrażliwość na nowe efekty: $\sim$ 10 000 TeV!

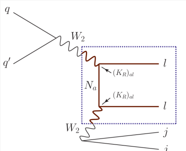
Łamanie liczby leptonowej, neutrina Majorany, $H^{\pm\pm}$, ...

Proces	Obecne ograniczenie	Oczekiwany limit	Eksperyment
$\mu^+ \to e^+\gamma$	$< 4.2 \times 10^{-13}$	5×10^{-14}	MEG II
$\mu^+ \to e^+e^-e^+$	$< 1.0 \times 10^{-12}$	10^{-16}	Mu3e
$\mu^-\mathrm{Al} \to e^-\mathrm{Al}$	$< 6.1 \times 10^{-13}$	10^{-17}	Mu2e, COMET
$\mu^-\mathrm{Si/C} \to e^-\mathrm{Si/C}$	–	5×10^{-14}	DeeMe
$\tau \to e\gamma$	$< 3.3 \times 10^{-8}$	5×10^{-9}	Belle II, FC
$\tau \to \mu\gamma$	$< 4.4 \times 10^{-8}$	10^{-9}	Belle II, FC
$\tau \to eee$	$< 2.7 \times 10^{-8}$	5×10^{-10}	Belle II, FC
$\tau \to \mu\mu\mu$	$< 2.1 \times 10^{-8}$	5×10^{-10}	Belle II, FC
$\tau \to e\ \mathrm{had}$	$< 1.8 \times 10^{-8}$	3×10^{-10}	Belle II, FC
$\mathrm{had} \to \mu e$	$< 4.7 \times 10^{-12}$	10^{-12}	NA62
$h \to e\mu$	$< 3.5 \times 10^{-4}$	3×10^{-5}	HL-LHC, FC
$h \to \tau\mu$	$< 2.5 \times 10^{-3}$	3×10^{-4}	HL-LHC, FC
$h \to \tau e$	$< 6.1 \times 10^{-3}$	3×10^{-4}	HL-LHC, FC

Asymetria materia-antymateria! $\eta = \frac{n_B - n_{\bar{B}}}{n_\gamma} \simeq \frac{n_B}{n_\gamma} \simeq 10^{-10}$







Neutrina, własności

Kilkanaście lat temu (PDG, 1996):

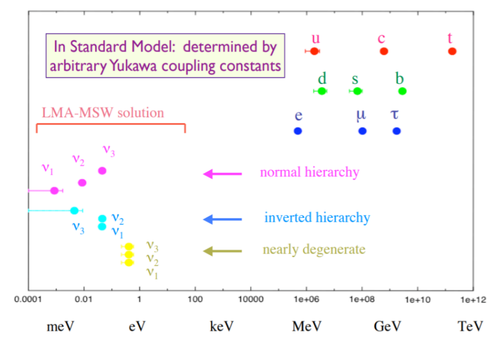
1. $m_{\nu_e} < 15$ eV;
2. $m_{\nu_\mu} < 170$ keV;
3. $m_{\nu_\tau} < 24$ MeV;

$$U_{PMNS} \approx U_{TB} = \begin{bmatrix} \sqrt{\frac{2}{3}} & \frac{1}{\sqrt{3}} & 0 \\ -\frac{1}{\sqrt{6}} & \frac{1}{\sqrt{3}} & -\frac{1}{\sqrt{2}} \\ -\frac{1}{\sqrt{6}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}} \end{bmatrix}$$

Mechanika kwantowa!

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = V_{\mathtt{PMNS}} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix},$$

Biswajit Karmakar, MTTD2021

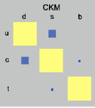


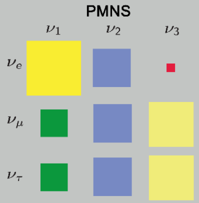
Neutrina, własności i konsekwencje

Super-K, Hyper-K, T2K, NOvA, Antares, KM3NeT, Juno, Dune, SNO+, Daya Bay, Double Chooz, RENO, ...

$$U_{PMNS} = \begin{pmatrix} \{0.810, 0.829\} & \{0.539, 0.562\} & \{0.147, 0.169\} \\ \{-0.485, -0.479\} & \{0.467, 0.563\} & \{0.669, 0.743\} \\ \{0.278, 0.339\} & \{-0.683, -0.626\} & \{0.647, 0.728\} \end{pmatrix}$$

$$\theta_{12} = 33.9^o \pm 1.0^o$$
$$\theta_{23} = 36^o - 54^o$$
$$\theta_{13} = 9.12^o \pm 0.63^o$$
$$\Delta m^2_{21} = (7.53 \pm 0.18) \times 10^{-5}\ [\text{eV}^2]$$
$$\Delta m^2_{32} = (2.44 \pm 0.06) \times 10^{-3}\ [\text{eV}^2]$$

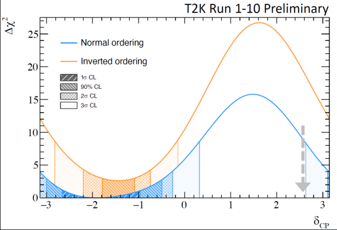


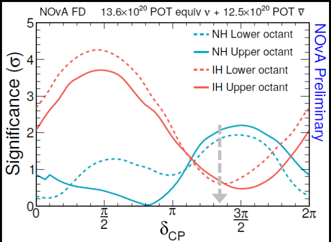


Wniosek: Fizyka neutrin wkroczyła w erę precyzji.

Do 2030: hierarchia mass, δ_{CP} (może), absolutne masy, Majorana-Dirac, L. Wen, EPS2021.

The CP Phase



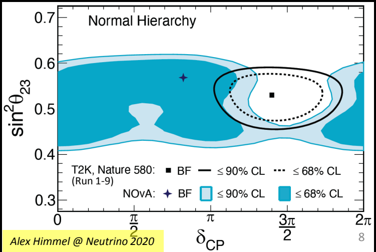


T2K
- δ = - π/2 favored
- Large range of values of δ_{CP} around +π/2 are excluded at 99.7%

NOvA
- Best-fit δ = 0.82 π
- Exclude **IH** δ = π/2 at >3σ
- Disfavor NH δ = 3π/2 at ~2σ

Clear tension exists

NOvA + T2K joint analysis is underway

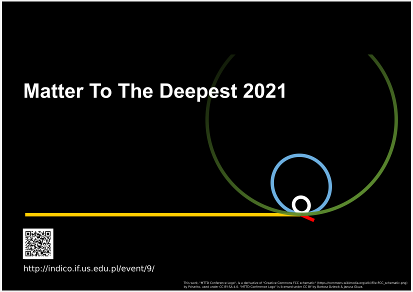


Alex Himmel @ Neutrino 2020

8

FUTURE COLLIDERS

HL-LHC,
HE-LHC,
FCC-hh,
Ion, Ion-e,
LHeC/FCC-eh,
b/c/tau,
muon,
CEPC,
SppC,
FCC-ee,
ILC,
CLIC,
...



SLAC - 3.2 km, Tevatron - 6.2 km, LEP/LHC/HL-LHC - 27 km, ILC/CLIC - 50 km, FCC/CEPC - 100 km

EPPSU Briefing Book

arXiv.org > hep-ex > arXiv:1910.11775

Search...

Help | Ad

High Energy Physics - Experiment

Physics Briefing Book

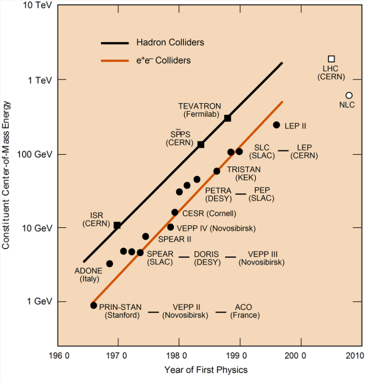
European Strategy for Particle Physics Preparatory Group

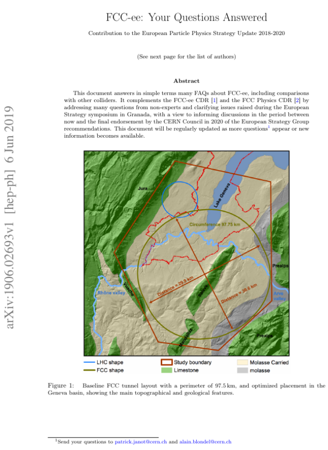
(Submitted on 25 Oct 2019)

The European Particle Physics Strategy Update (EPPSU) process takes a bottom-up approach, whereby the community is first invited to submit proposals (also called inputs) for projects that it would like to see realised in the near-term, mid-term and longer-term future. National inputs as well as inputs from National Laboratories are also an important element of the process. All these inputs are then reviewed by the Physics Preparatory Group (PPG), whose role is to organize a Symposium around the submitted ideas and to prepare a community discussion on the importance and merits of the various proposals. The results of these discussions are then concisely summarised in this Briefing Book, prepared by the Conveners, assisted by Scientific Secretaries, and with further contributions provided by the Contributors listed on the title page. This constitutes the basis for the considerations of the European Strategy Group (ESG), consisting of scientific delegates from CERN Member States, Associate Member States, directors of major European laboratories, representatives of various European organizations as well as invitees from outside the European Community. The ESG has the mission to formulate the European Strategy Update for the consideration and approval of the CERN Council.

Comments: 254 p
Subjects: **High Energy Physics - Experiment (hep-ex)**; High Energy Physics - Phenomenology (hep-ph)
Report number: CERN-ESU-004
Cite as: arXiv:1910.11775 **[hep-ex]**

Historia, przyszłość





FCC-ee: Your Questions Answered

Contribution to the European Particle Physics Strategy Update 2018-2020

(See next page for the list of authors)

arXiv:1906.02693v1 [hep-ph] 6 Jun 2019

Abstract

This document answers in simple terms many FAQs about FCC-ee, including comparisons with other colliders. It complements the FCC-ee CDR [1] and the FCC Physics CDR [2] by addressing many questions from non-experts and clarifying issues raised during the European Strategy symposium in Granada, with a view to informing discussions in the period between now and the final endorsement by the CERN Council in 2020 of the European Strategy Group recommendations. This document will be regularly updated as more questions[1] appear or new information becomes available.

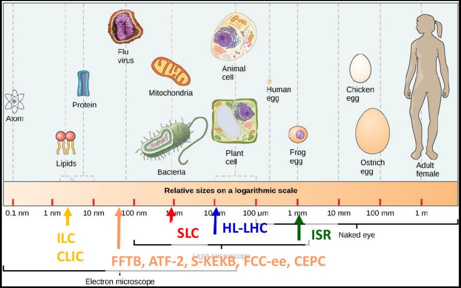
Figure 1: Baseline FCC tunnel layout with a perimeter of 97.5 km, and optimized placement in the Geneva basin, showing the main topographical and geological features.

[1] Send your questions to patrick.janot@cern.ch and alain.blondel@cern.ch

F. Zimmermann, 11th FCC-ee Workshop, CERN, January 2019

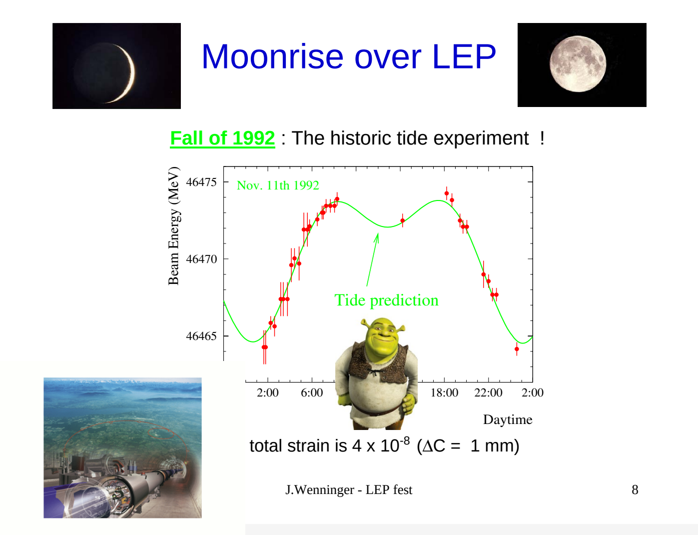
https://indico.cern.ch/event/766859

vertical spot size challenge



FCC-ee in the regime of FFTB, ATF-2, and especially SuperKEKB

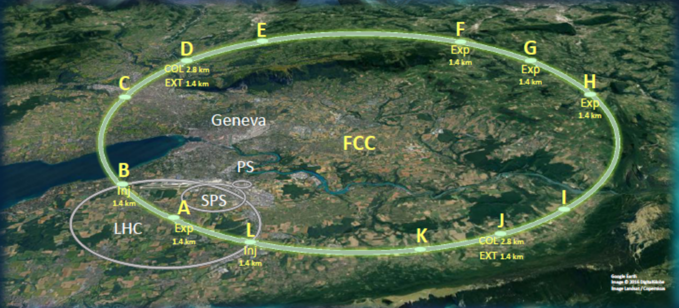
J. Wenninger, LEP Fest 2000, https://indico.cern.ch/event/408341/



Future Circular Collider – A key to new physics

The Future Circular Collider (FCC) study is an international collaboration aimed at designing the particle accelerator that will replace the LCH once it has completed its operational lifetime. The FCC will expand the current energy and luminosity frontiers in order to help answer the most fundamental questions in science: What is dark matter? Are there extra dimensions in the universe? Are there other forces in nature?

The FCC collaboration, hosted by CERN, is open to universities, research institutes and high-tech companies. A conceptual design will be delivered before the end of 2018, in time for the next update of the European Strategy for Particle Physics.



FCC-hh – A discovery machine

The 100 TeV proton-proton collider (FHC-hh) will have an energy seven times higher than the LHC. Such a collider will give access to the smallest scales and the most energetic phenomena in nature.

New fundamental forces and particles can be discovered, extending the reach for searching dark matter particles, supersymmetric partners of quarks and gluons, and possible substructure inside quarks.

Billions of Higgs bosons and trillions of top quarks will be produced, creating new opportunities for the study of rare decays, flavor physics, and the mechanism of electroweak symmetry breaking.

The FCC-hh collider provides also the opportunity to push the exploration of the collective structure of matter at the most extreme density and temperature conditions to new frontiers through the study of heavy-ion collisions.

FCC-ee – A machine for precision

The second scenario of the FCC design study (FCC-ee) is a high-luminosity, high-precision electron-positron collider with center-of-mass collision energies between 90 and 350 GeV. Located in the same 100 km long tunnel as the FCC-hh it is considered a potential intermediate step towards the realization of the hadron facility, and complementary to it.

Clean experimental conditions give electron-positron colliders the capability to measure known particles with the highest precision.

FCC-ee would measure the properties of the Z, W, Higgs and top particles with unequalled accuracy, offering the potential for discovering dark matter or heavy neutrinos. The FCC-ee could enable profound investigations of electroweak symmetry breaking and open a broad indirect search for new physics over several orders of magnitude in energy.

FCC-he – New opportunities

With the huge energy provided by the 50 TeV proton beam and the potential availability of an electron beam with energies of the order of 60 GeV, new horizons open up for the physics of deep inelastic electron-proton scattering.

The FCC-he collider would be both a high-precision Higgs factory and a powerful microscope to discover new particles. It would be the most accurate tool for studying quark-gluon interactions, possible substructure of matter and unprecedented measurements of strong and electroweak interaction phenomena. The hadron-electron collider is a unique complement to the exploration of nature at high energies within the FCC complex.

The FCC study explores three different scenarios: a hadron-had collider (FCC-hh), an electron-positron collider (FCC-ee), an hadron-lepton (FCC-he) collider. The hadron-hadron collider def the overall infrastructure for the FCC. With a target center-of-n energy of 100 TeV, and 16-Tesla bending magnets, such a mach will have a circumference of 100 km.

Main parameters and geometrical aspects

	LHC	FCC
Circumference [km]	26.7	100
Dipole field [T]	8.33	16
Straight sections	8 × 528 m	6 ×1400 m + 2 × 4200 m
Number of IPs	2 + 2	2 + 2
Injection energy [TeV]	0.45	3.3

FCC-hh compared with LHC and High-Luminosity LI

	LHC	HL-LHC	FCC-hh baseline		FCC-hh ultim	
Energy at center of mass [TeV]	14	14	100		100	
Bunch spacing [ns]	25	25	25	5	25	[illegible]
Number of bunches	2808	2808	10600	53000	10600	53
Transverse emittance [mm]	3.75	2.5	2.2	0.44	2.2	0.
Beam current [A]	0.584	1.12	0.5		0.5	
Peak luminosity [10^{34} $cm^{-2}s^{-1}$]	1.0	5.0	5.0		< 30.0	

FCC-ee compared with the Large Electron-Positron collider (LEP2)

The main center-of-mass operating points with strong physics interest for FCC-ee a 91 GeV (Z pole), 160 GeV (W pair production threshold), 240 GeV (Higgs resonance and 350 GeV ($t\bar{t}$ threshold).

	LEP2	FCC-ee				
		Z		W	H	t
Energy at center of mass [GeV]	208	91		160	240	3
Bunch spacing [ns]	247 / 494	7.5	2.5	50	400	40
Number of bunches	4	30180	91500	5260	780	8
Emittance (horizontal) [nm]	22	0.2	0.09	0.26	0.61	1
Emittance (vertical) [pm]	250	1		1	1.2	2
Beam current [mA]	3.04	1450		152	30	6
Peak luminosity (for 2 IPs) [10^{34} $cm^{-2}s^{-1}$]	0.012	207	90	19.1	5.1	1

Contacts and further information

FCC - FCC Office
fcc.office@cern.ch

EuroCirCol - Prof. Carsten P. Welsc
carsten.welsch@cockcroft.ac.uk

UNIVERSITY OF LIVERPOOL

http://fcc.web.cern.ch

http://www.eurocircol.eu

This project has received funding from the European Union's Horizo research and innovation programme under grant No 654305. The infor herein reflects only the views of its authors and the Research Executive is not responsible for any use that may be made of the information con

~ 50 lat fizyki bozonu Z – dwustronicowa praca

S. Weinberg, 'A model of leptons'

VOLUME 19, NUMBER 21 PHYSICAL REVIEW LETTERS 20 NOVEMBER 1967

and

$$\varphi_1 \equiv (\varphi^0 + \varphi^{0\dagger} - 2\lambda)/\sqrt{2} \quad \varphi_2 \equiv (\varphi^0 - \varphi^{0\dagger})/i\sqrt{2}. \qquad (5)$$

The condition that φ_1 have zero vacuum expectation value to all orders of perturbation theory tells us that $\lambda^2 \cong M_1^2/2h$, and therefore the field φ_1 has mass M_1 while φ_2 and φ^- have mass zero. But we can easily see that the Goldstone bosons represented by φ_2 and φ^- have no physical coupling. The Lagrangian is gauge invariant, so we can perform a combined isospin and hypercharge gauge transformation which eliminates φ^- and φ_2 everywhere[6] without changing anything else. We will see that G_e is very small, and in any case M_1 might be very large,[7] so the φ_1 couplings will also be disregarded in the following.

The effect of all this is just to replace φ everywhere by its vacuum expectation value

$$\langle\varphi\rangle = \lambda\binom{1}{0}. \qquad (6)$$

The first four terms in $\mathfrak{L}$ remain intact, while the rest of the Lagrangian becomes

$$-\tfrac{1}{8}\lambda^2 g^2[(A_\mu{}^1)^2 + (A_\mu{}^2)^2] - \tfrac{1}{8}\lambda^2(gA_\mu{}^3 + g'B_\mu)^2 - \lambda G_e \bar{e}e. \qquad (7)$$

We see immediately that the electron mass is λG_e. The charged spin-1 field is

$$W_\mu \equiv 2^{-1/2}(A_\mu{}^1 + iA_\mu{}^2) \qquad (8)$$

and has mass

$$M_W = \tfrac{1}{2}\lambda g. \qquad (9)$$

The neutral spin-1 fields of definite mass are

$$Z_\mu = (g^2 + g'^2)^{-1/2}(gA_\mu{}^3 + g'B_\mu), \qquad (10)$$

$$A_\mu = (g^2 + g'^2)^{-1/2}(-g'A_\mu{}^3 + gB_\mu). \qquad (11)$$

Their masses are

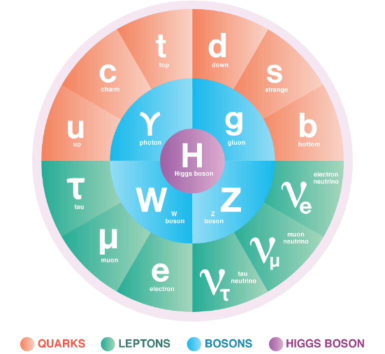
$$M_Z = \tfrac{1}{2}\lambda(g^2 + g'^2)^{1/2}, \qquad (12)$$

$$M_A = 0, \qquad (13)$$

so A_μ is to be identified as the photon field. The interaction between leptons and spin-1 mesons is

$$\frac{ig}{2\sqrt{2}}\bar{e}\gamma^\mu(1+\gamma_5)\nu W_\mu + \text{H.c.} + \frac{igg'}{(g^2+g'^2)^{1/2}}\bar{e}\gamma^\mu e A_\mu + \frac{i(g^2+g'^2)^{1/2}}{4}\left[\left(\frac{3g'^2-g^2}{g'^2+g^2}\right)\bar{e}\gamma^\mu e - \bar{e}\gamma^\mu\gamma_5 e + \bar{\nu}\gamma^\mu(1+\gamma_5)\nu\right]Z_\mu. \qquad (14)$$

LEP ($W^{\pm}, Z$), LHC (H^0) - ukształtowanie Modelu Standardowego



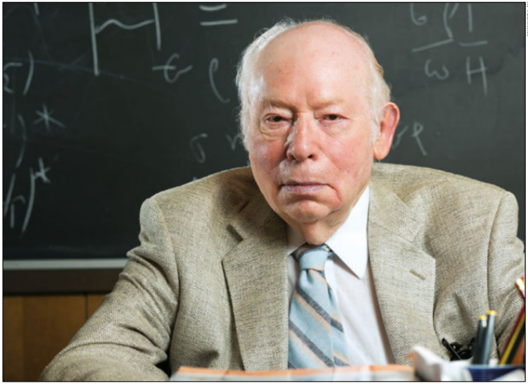
LEP ($W^{\pm}, Z$), LHC (H^{0}) - ukształtowanie Modelu Standardowego

Steven Weinberg 1933–2021

A mind to rank with the greatest

Steven Weinberg, one of the greatest theoretical physicists of all time, passed away on 23 July, aged 88. He revolutionised particle physics, quantum field theory and cosmology with conceptual breakthroughs that still form the foundation of our understanding of physical reality.

Weinberg is well known for the unified theory of weak and electromagnetic forces, which earned him the Nobel Prize in Physics in 1979, jointly awarded with Sheldon Glashow and Abdus Salam, and led to the prediction of the Z and W vector bosons, later discovered at CERN in 1983. His breakthrough was the realisation that some new theoretical ideas, initially believed to play a role in the description of nuclear strong interactions, could instead explain the nature of the weak force. "Then it suddenly occurred to me that this was a perfectly good sort of theory, but I was applying it to the wrong kind of interaction. The right place to apply these ideas was not to the strong interactions, but to the weak and electromagnetic interactions," as he later recalled. With his work, Weinberg had made the next step in the unification of physical laws, after Newton understood that the motion of apples on Earth and planets in the sky are governed by the same gravitational force, and Maxwell understood that electric and magnetic phenomena are the expression of a single force.



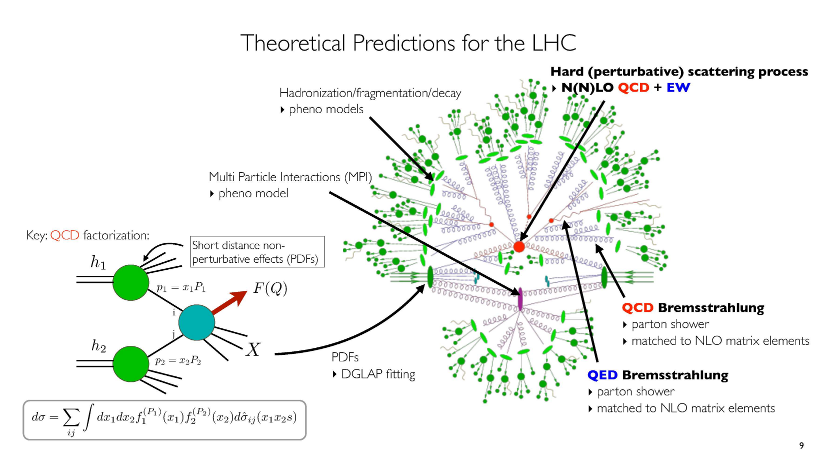
Al Valentine

Steven Weinberg radically changed the way we look at the universe.

In my life, I have built only *one* model

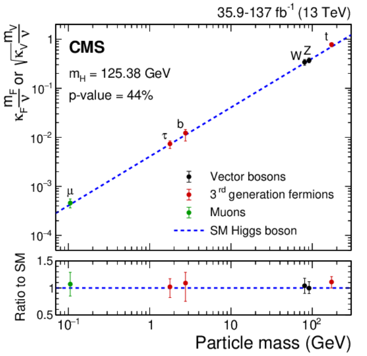
physicists, and will certainly continue to serve future generations.

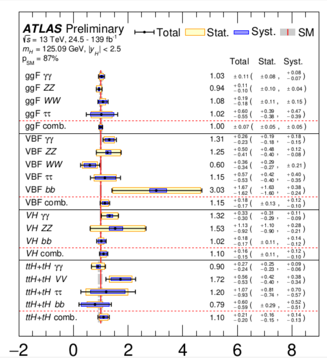
Steven Weinberg is among the very few individuals who, during the course of the history



"Standard Model Theory, Jonas M. Lindert, EPS 2021,
https://indico.desy.de/event/28202

Od 2012: coraz większa precyzja, szerokie spektrum procesów

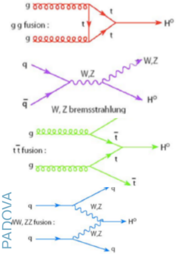


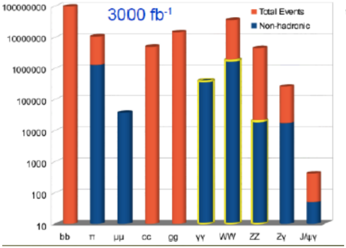


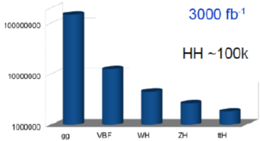
ATLAS 2020: https://cds.cern.ch/record/2725733
CMS 2020: http://cds.cern.ch/record/2730058

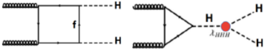
HL-LHC IS A HIGGS FACTORY

- At HL-LHC, we expect to produce ~170M Higgs Bosons, including ~120k of pair produced events
- Over 1Million for each of the main production mechanisms, spread over many decay modes





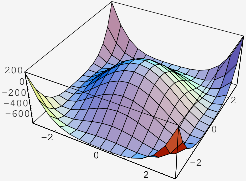


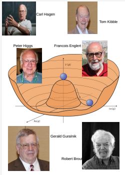


- Enables a broad program:
  - Precision O(few%) measurements of couplings across broad kinematics
  - Exploration of Higgs potential (hh production)
  - Sensitivity to rare decays involving new physics
  - extend BSM Higgs searches (extra scalars, BSM Higgs resonances, exotic decays…)

Czy "krajobraz" potencjału może być tak prosty? Góra Mayon

(Znana jako "doskonały stożek")

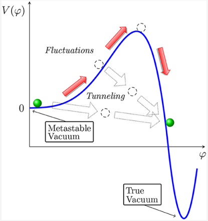


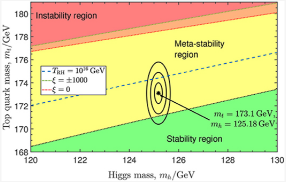


$$\Phi \equiv \Phi_{SM} = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$$

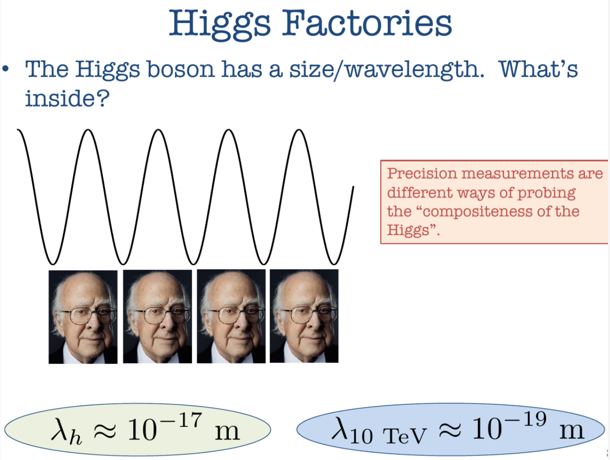
$$V = -\mu^2 \Phi^\dagger \Phi + \lambda (\Phi^\dagger \Phi)^2$$

$$V_{min} = v/\sqrt{2}, v = \sqrt{\mu^2/\lambda} \simeq 250 \text{ GeV}$$





Compositeness - testing substructures of elementary particles

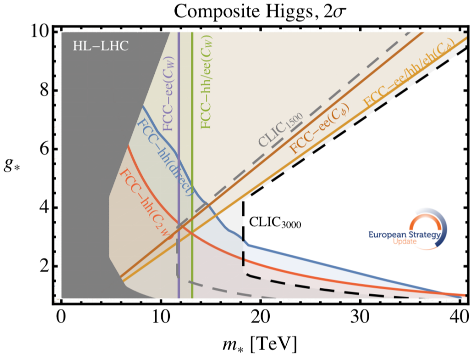


PTF2021 + Matthew Philip Mccullough, Oxford 2019,

https://indico.cern.ch/event/783429/contributions/3305140/attachments/1829729/2996092/CEPC.pdf

Is the Higgs Fundamental?

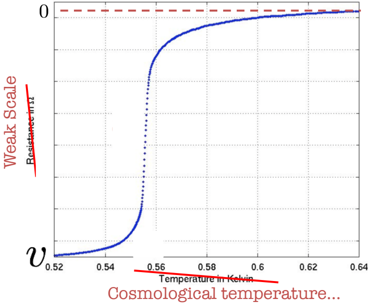
Including direct searches for the associated composite-sector mesons



provides valuable complementary information.

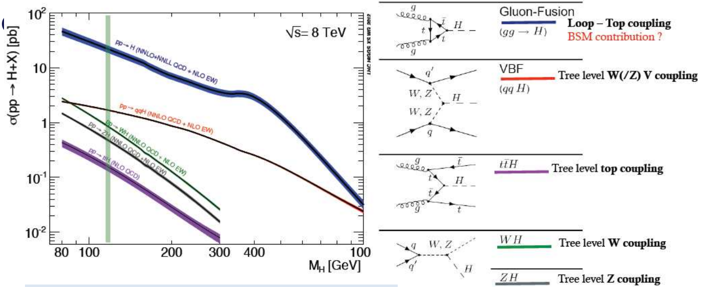
The Electroweak Phase Transition

The EW phase transition only happened once, a long long time ago. How can we tell what happened,



and study the details of the phase transition?

Alain Blondel, Epiphany 2021 https://indico.cern.ch/event/934666



THE LHC is a Higgs Factory…BUT

~100 Million Higgs already produced… more than most "Higgs factory" projects.

$$\sigma_{i\to f}^{\text{observed}} \propto \sigma_{prod} \frac{(g_{Hi})^2 (g_{Hf})^2}{\Gamma_H}$$

relative error scales with 1/purity and 1/√efficiency of signal

We don't know this until measured directly

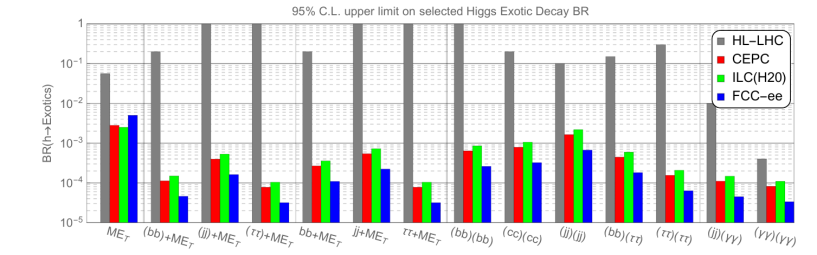
difficult to extract the couplings because σ_{prod} uncertain and Γ_H is unknown (invisible+ unmeasured channels) → must do physics with ratios.

LHC/HL-LHC nie wyjaśni wielu kwestii w SM/BSM

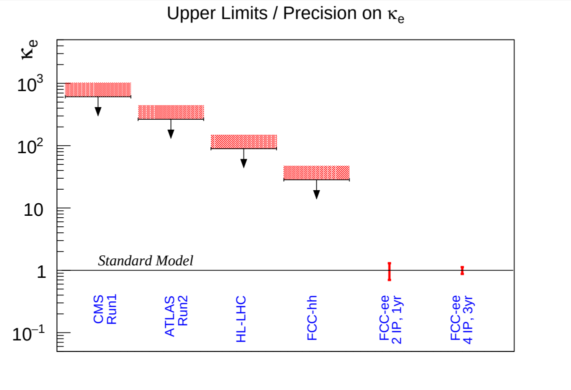
Jakie skale energii możemy badać (TeV)? Jakie zderzacze?

Przykład: rozpady egzotyczne bozonu Higgsa, 1612.09284

'Exotic decays of the 125 GeV Higgs boson at future e^+e^- lepton colliders' by Liu, Wang, Zhang.



Czułość FCC-ee, porównania, Blondel & Janot inspires



Sprzężenie Higgsa do elektronów: He^-e^-

Jorgen D'Hondt, "Strategies and plans for particle physics in Europe",

Epiphany 2021, https://indico.cern.ch/event/934666

e^+e^- Higgs Factories (incl. B/c/τ/EW/top factories)

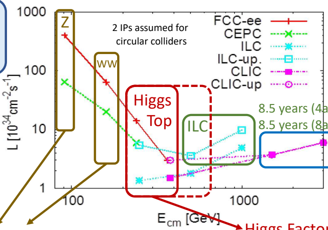
precision frontier — circular colliders

synchrotron radiation

for the same power, less luminosity at higher E_{cm}

(Energy Recovery Linac technology might mitigate this & allow to go to higher E_{cm})

linear colliders — energy frontier



8.5 years (4ab^{-1} @ 0.5 TeV)
8.5 years (8ab^{-1} @ 1 TeV)

7 years (2.5ab^{-1} @ 1.5 TeV)
8 years (5ab^{-1} @ 3 TeV)

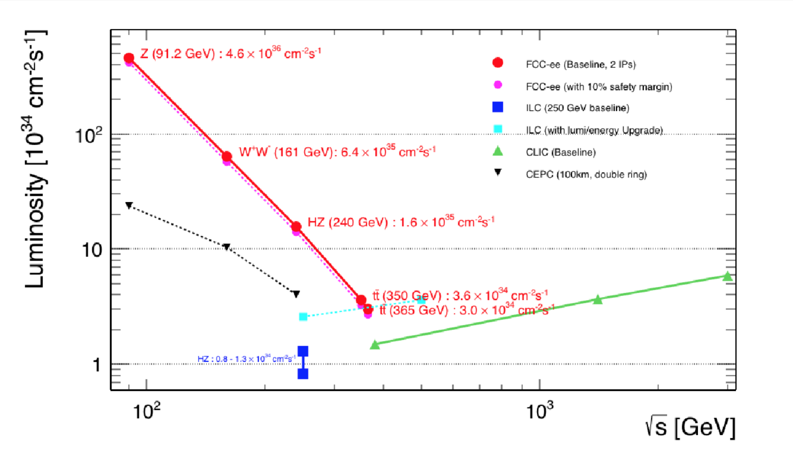
B/c/τ/EW Factories

per detector in e^+e^-	# Z	# B	# τ	# charm	# WW
LEP	4 x 10^6	1 x 10^6	3 x 10^5	1 x 10^6	2 x 10^4
SuperKEKB	-	10^{11}	10^{11}	10^{11}	-
FCC-ee	2.5 x 10^{12}	7.5 x 10^{11}	2 x 10^{11}	6 x 10^{11}	1.5 x 10^8

Higgs Factories with complementarity

- g_{HZZ} (250GeV) versus g_{HWW} (380GeV)
- top quark physics
- beam polarization for EW precision tests

(transverse polarization in circular e^+e^- colliders only at lower E_{cm} while longitudinal polarization at linear colliders)

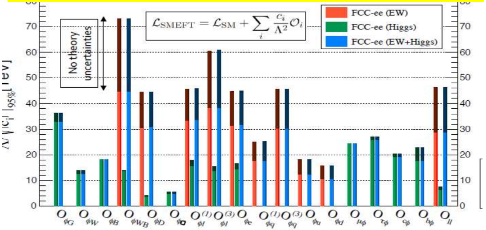

Luminosity [10^34 cm^-2s^-1]
Z (91.2 GeV) : 4.6 × 10^36 cm^-2s^-1
W+W- (161 GeV): 6.4 × 10^35 cm^-2s^-1
HZ (240 GeV) : 1.6 × 10^35 cm^-2s^-1
tt̄ (350 GeV) : 3.6 × 10^34 cm^-2s^-1
tt̄ (365 GeV) : 3.0 × 10^34 cm^-2s^-1
HZ : 0.8 - 1.3 × 10^34 cm^-2s^-1
FCC-ee (Baseline, 2 IPs)
FCC-ee (with 10% safety margin)
ILC (250 GeV baseline)
ILC (with lumi/energy Upgrade)
CLIC (Baseline)
CEPC (100km, double ring)
10^2
10
1
10^2
10^3
√s [GeV]

Alain Blondel, Epiphany 2021 https://indico.cern.ch/event/934666

The opportunities **The challenges**

Observable	present value ± error	FCC-ee Stat.	FCC-ee Syst.	Comment and leading exp. error
m_Z (keV)	91186700 ± 2200	**4**	100	From Z line shape scan Beam energy calibration
Γ_Z (keV)	2495200 ± 2300	**4**	25	From Z line shape scan Beam energy calibration
$\sin^2\theta_W^{eff}(\times 10^6)$	231480 ± 160	**2**	2.4	from $A_{FB}^{\mu\mu}$ at Z peak Beam energy calibration
$1/\alpha_{QED}(m_Z^2)(\times 10^3)$	128952 ± 14	**3**	small	from $A_{FB}^{\mu\mu}$ off peak QED&EW errors dominate
R_ℓ^Z $(\times 10^3)$	20767 ± 25	**0.06**	0.2-1	ratio of hadrons to leptons **acceptance for leptons**
$\alpha_s(m_Z^2)$ $(\times 10^4)$	1196 ± 30	**0.1**	0.4-1.6	from R_ℓ^Z above
σ_{had}^0 $(\times 10^3)$ (nb)	41541 ± 37	**0.1**	4	peak hadronic cross section luminosity measurement
$N_\nu(\times 10^3)$	2996 ± 7	**0.005**	1	Z peak cross sections Luminosity measurement
R_b $(\times 10^6)$	216290 ± 660	**0.3**	< 60	ratio of $b\bar{b}$ to hadrons stat. extrapol. from SLD
$A_{FB}^b, 0$ $(\times 10^4)$	992 ± 16	**0.02**	1-3	b-quark asymmetry at Z pole from jet charge
$A_{FB}^{pol,\tau}$ $(\times 10^4)$	1498 ± 49	**0.15**	<2	τ polarization asymmetry τ decay physics
τ lifetime (fs)	290.3 ± 0.5	**0.001**	0.04	radial alignment
τ mass (MeV)	1776.86 ± 0.12	**0.004**	0.04	momentum scale
τ leptonic $(\mu\nu_\mu\nu_\tau)$ B.R. (%)	17.38 ± 0.04	**0.0001**	0.003	e/μ/hadron separation
m_W (MeV)	80350 ± 15	**0.25**	0.3	From WW threshold scan Beam energy calibration
Γ_W (MeV)	2085 ± 42	1.2	0.3	From WW threshold scan Beam energy calibration
$\alpha_s(m_W^2)(\times 10^4)$	1170 ± 420	**3**	small	from R_ℓ^W
$N_\nu(\times 10^3)$	2920 ± 50	**0.8**	small	ratio of invis. to leptonic in radiative Z returns
m_{top} (MeV/c^2)	172740 ± 500	**17**	small	From $t\bar{t}$ threshold scan QCD errors dominate
Γ_{top} (MeV/c^2)	1410 ± 190	45	small	From $t\bar{t}$ threshold scan QCD errors dominate
$\lambda_{top}/\lambda_{top}^{SM}$	1.2 ± 0.3	**0.10**	small	From $t\bar{t}$ threshold scan QCD errors dominate
ttZ couplings	± 30%	0.5 – 1.5%	small	From $\sqrt{s} = 365$ GeV run

Precision EW measurements:
is the SM complete?



-^- EFT D6 operators (some assumptions)

-^- Higgs and EWPOs are complementary

-^- top quark mass and couplings essential!

(the 100km circumference is optimal for this)

<-- systematics are preliminary

(aim at reducing to systematics)

<-- tau, b, and c observables still to be added

<-- complemented by high energy FCC-hh

Theory work is critical and initiated *1809.01830*

Expected precision in 2040

Conclusion of the 2018 Workshop

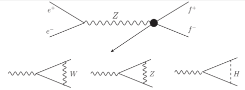
J. Gluza

"We anticipate that, at the beginning of the FCC-ee campaign of precision measurements, the theory will be precise enough not to limit their physics interpretation. This statement is however conditional to sufficiently strong support by the physics community and the funding agencies, including strong training programmes".

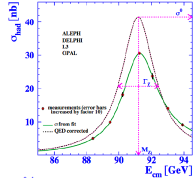
- **Numerical evaluation with three-loops calculations:** arXiv:1901.02648

	$\delta\Gamma_Z$ [MeV]	δR_l $[10^{-4}]$	δR_b $[10^{-5}]$	$\delta \sin^{2,l}_{eff}\theta$ $[10^{-6}]$
Present EWPO theoretical uncertainties				
EXP-2018	2.3	250	66	160
TH-2018	0.4	60	10	45
EWPO theoretical uncertainties when FCC-ee will start				
EXP-FCC-ee	~~0.1~~ 0.025	10	$2 \div 6$	~~6~~ 3
TH-FCC-ee	0.07	7	3	7

- **500 person-years needed over 20 years – Recognized as strategic priority.**



Cross section : Z mass and width

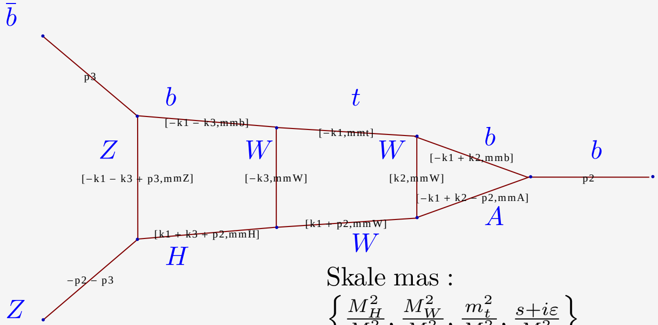


- ~30% QED corrections (ISR)

Collider Physics at the Precision Frontier G. Heinrich, 2009.00516

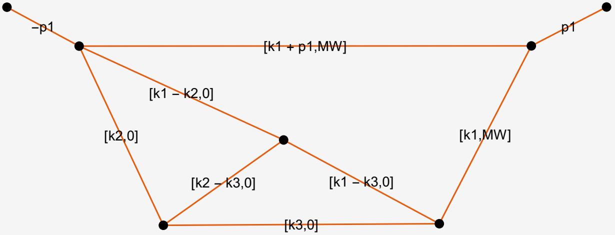
	analityczne	numeryczne
kasowanie biegunów	dokładne	z niepewnościa numeryczna
kontrola całkowalnych osobliwości	kontynuacja analityczna	mniej bezpośrednie
szybka i stabilna ewaluacja	tak (przeważnie)	zależy
rozszerzenie na wiecej skal/petli	trudne	obiecujace
automatyzacja	trudne	mniej trudne

Mocne i słabe strony analitycznych i numerycznych metod obliczeniowych dla całek petlowych.



Skale mas :

$$\left\{ \frac{M_H^2}{M_Z^2}, \frac{M_W^2}{M_Z^2}, \frac{m_t^2}{M_Z^2}, \frac{s+i\varepsilon}{M_Z^2} \right\}$$



Metoda	Wynik	Błąd absolutny
MBnumerics	-18.77940696**2** - 6.3907850**27** $\cdot i$	$10^{-9} + 10^{-9} \cdot i$
pySecDec	-18.78**7167067** - 6.38**4327811** $\cdot i$	0.00**93** + 0.00**97** $\cdot i$

$$\int \frac{\frac{d^D k_1}{i\pi^{D/2}} \frac{d^D k_2}{i\pi^{D/2}} \frac{d^D k_3}{i\pi^{D/2}}}{[(p_1+k_1)^2]^{a_1}[(k_1-k_2)^2]^{a_2}[k_2^2]^{a_3}[-M_W^2+(k_2-k_3)^2]^{a_4}[(k_1-k_3)^2]^{a_5}}$$

$$\frac{1}{[k_3^2]^{a_6}[k_1^2]^{a_7}[(p_1+k_2)^2]^{a_8}[(p_1+k_3)^2]^{a_9}}$$

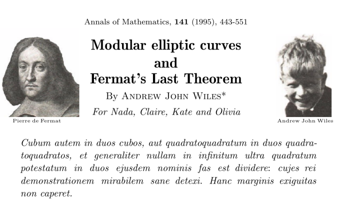
$$D = 4 - 2\epsilon.$$

Klasyfikacja diagramów złożoność obliczeń

$Z \to b\bar{b}$			
Liczba topologii	1 pętla	2 pętla	3 pętla
	1	5	50
Liczba diagramów	15	1114	120187*
Pętle fermionowe	0	150	**17580**
Pętle bozonowe	15	964	102607
QCD / EW	1 / 14	98 / 1016	10405 / 109782

∗ diagramy tensorowe w dekompozycji "rozmnażają" się w różny sposób w zależnosci od stosowanej metody obliczeń.

Fizyka zderzaczy to w gruncie rzeczy ... magia świata matematyki!



Annals of Mathematics, **141** (1995), 443-551

Modular elliptic curves and Fermat's Last Theorem

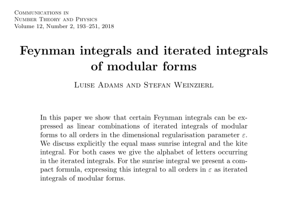
By Andrew John Wiles*

For Nada, Claire, Kate and Olivia

Pierre de Fermat

Andrew John Wiles

Cubum autem in duos cubos, aut quadratoquadratum in duos quadratoquadratos, et generaliter nullam in infinitum ultra quadratum potestatum in duos ejusdem nominis fas est dividere: cujes rei demonstrationem mirabilem sane detexi. Hanc marginis exiguitas non caperet.



Communications in Number Theory and Physics
Volume 12, Number 2, 193–251, 2018

Feynman integrals and iterated integrals of modular forms

Luise Adams and Stefan Weinzierl

In this paper we show that certain Feynman integrals can be expressed as linear combinations of iterated integrals of modular forms to all orders in the dimensional regularisation parameter ε. We discuss explicitly the equal mass sunrise integral and the kite integral. For both cases we give the alphabet of letters occurring in the iterated integrals. For the sunrise integral we present a compact formula, expressing this integral to all orders in ε as iterated integrals of modular forms.

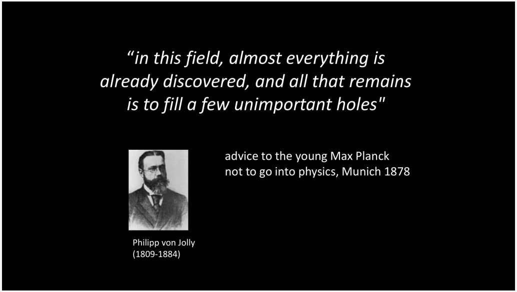
Analityczne rozwiązania dla wielopętlowych "masywnych" całek opisujących rozpraszania cząstek wykraczają poza funkcje eliptyczne 

Podsumowanie

Kilka fundamentalnych problemów związanych z precyzyjnymi badaniami w fizyce cząstek elementarnych:

- Potencjał Higgsa, cząstki skalarne;
- Jaki model BSM w przypadku anomalii?
- Asymetria CP (kwarki, neutrina, skalary);
- Mieszanie zapachów, hierarchii mas kwarków, neutrin, typ neutrin;
- Zagadnienia astro i kosmologiczne.

Przyszłość fizyki



Prorokowanie jest trudne.

Albert Michelson (1894):

`"It seems probable that most of the grand underlying principles have been firmly established (...) the future truths of physical science are to be looked for in the sixth place of decimals"`

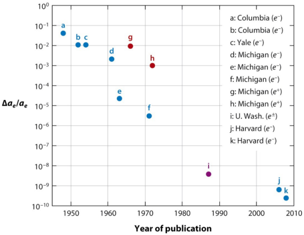
Q: Dear Albert: What about special and general relativity, and quantum mechanics, particle physics, ...?

Dziękuję za uwagę.

Człowiek rozsądny dostosowuje się do świata. Człowiek nierozsądny usiłuje dostosować świat do siebie. Dlatego wielki postęp dokonuje się dzięki ludziom nierozsądnym. George Bernard Shaw

Dodatkowe slajdy

$(g-2)_e$, poprawki kwantowe



Commins ED. 2012.
Annu. Rev. Nucl. Part. Sci. 62:133–57

$$a_e = c_1\left(\frac{\alpha}{\pi}\right) + c_2\left(\frac{\alpha}{\pi}\right)^2 + c_3\left(\frac{\alpha}{\pi}\right)^3 + c_4\left(\frac{\alpha}{\pi}\right)^4 + c_5\left(\frac{\alpha}{\pi}\right)^5 + a_{\rm had} + a_{\rm EW} + \ldots$$

$$\begin{aligned} c_1 &= 0.5 \\ c_2 &= -0.328\ldots \\ c_3 &= 1.181\ldots \\ c_4 &= -1.912\ldots \\ c_5 &= 7.79(34) \\ a_{\rm had} &= 1.7\times 10^{-12} \\ a_{\rm EW} &= 3.0\times 10^{-14} \end{aligned}$$

[Karplus, Kroll (1950); Petermann (1957); Sommerfield (1957)]
[Laporta, Remiddi (1996); Kinoshita (1995)]
[Kinoshita et al. (2007) , Laporta (2017)]

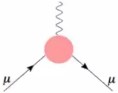
[CODATA 2014]

Compositeness - testowanie podstruktur cząstek elementarnych

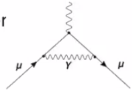
The magnetic moment of charged leptons (e, μ, τ): $\vec{\mu} = g \frac{e}{2m} \vec{S}$

Dirac: $g = 2$

quantum effects



Julian Schwinger
[1948]



$$g = 2\left(1 + \frac{\alpha}{2\pi}\right)$$

$$\alpha \approx \frac{1}{137}$$

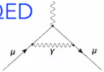
Anomalous magnetic moment:

$$a \equiv \frac{g-2}{2} = 0.00116\ldots$$

Compositeness - testowanie podstruktur cząstek elementarnych, $(g-2)_\mu$

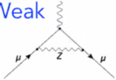
$$\boxed{a_\mu = a_\mu(\mathrm{QED}) + a_\mu(\mathrm{Weak}) + a_\mu(\mathrm{Hadronic})}$$

QED



$+\ldots$ $\quad 116\,584\,718.9\,(1) \times 10^{-11}$ $\quad$ 0.001 ppm

Weak

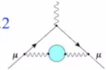


$+\ldots$ $\quad 153.6\,(1.0) \times 10^{-11}$ $\quad$ 0.01 ppm

Hadronic...

...Vacuum Polarization (HVP)

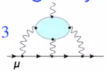
α^2



$+\ldots$ $\quad 6845\,(40) \times 10^{-11}$ [0.6%] $\quad$ 0.37 ppm

...Light-by-Light (HLbL)

α^3



$+\ldots$ $\quad 92\,(18) \times 10^{-11}$ [20%] $\quad$ 0.15 ppm

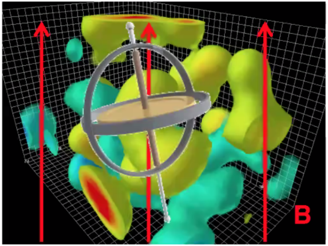
Compositeness - badanie próżni, https://youtu.be/81PfYnpuOPA

New physics search

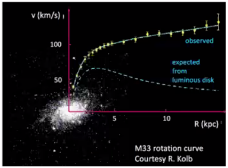
Image Credits: Derek Leinweber

- Measuring the precession tells us the muon magnetic moment
- The high precision allows us to ‘see’ if new particles or forces are contributing to the anomaly!

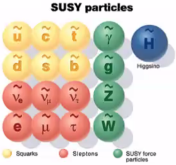
$$a_\mu = \frac{g-2}{2}$$



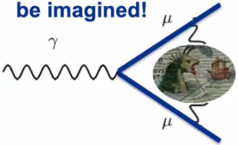
Dark matter!



SUSY!



Monsters yet to be imagined!

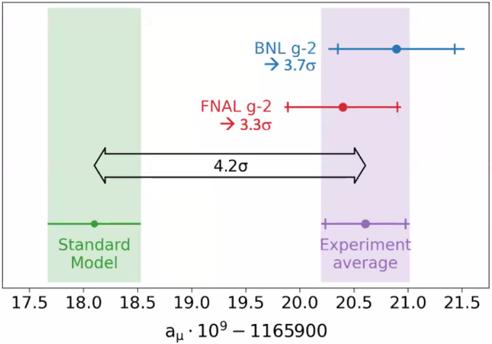


Fermilab

Nowy wynik Fermilab 2021

Comparison to SM prediction

$a_\mu(SM) = 0.00116591810(43) \rightarrow 368$ ppb



- Individual tension with SM
  - BNL: 3.7σ
  - FNAL: 3.3σ

$a_\mu(Exp) - a_\mu(SM) = 0.00000000251(59) \rightarrow 4.2\sigma$

Fermilab

Elektromagnetyzm: atomy, chemia, biologia

$$F = k\frac{qQ}{r^2} \equiv \frac{1}{4\pi\epsilon_0}\frac{qQ}{r^2} \quad \to \alpha \equiv \frac{\phi \mathbf{e}}{\mathbf{mc^2}} = \frac{\frac{\mathbf{e^2}}{\mathbf{4}\pi\epsilon_\mathbf{0}\mathbf{L}}}{\mathbf{mc^2}} = \frac{\mathbf{e^2}}{\mathbf{4}\pi\epsilon_\mathbf{0}\hbar\mathbf{c}},\ L = \frac{\hbar}{mc}$$

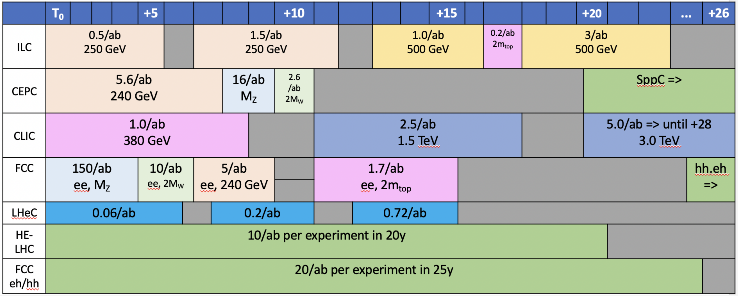
Stała struktury subtelnej α wynosi liczbowo około 1/137 [137.035999206(11)]

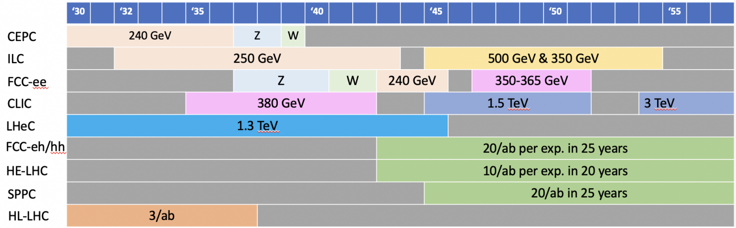
Czy 1/136 lub 1/138 robi różnicę?

Procentowe zmiany w wartości α implikuja czerwone lub niebieskie gwiazdy ("Gravitation", Misner, Thorne, Wheeler)

https://www.nature.com/articles/s41586-020-2964-7 [02 December 2020]

Ramy czasowe startu planowanych przyszłych dużych eksperymentów





FCC

τ-lepton properties and Lepton Universality

Snowmass2021 - Letter of Interest

Tau lepton properties and lepton universality measurements at the FCC-ee

Thematic Areas:

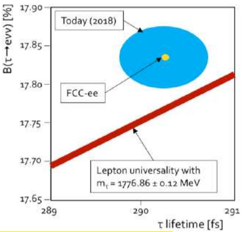
- EF04: EW Physics: EW Precision Physics and constraining new physics
- EF03: EW Physics: Heavy flavor and top quark physics

Contact Information:
Mogens Dam (Niels Bohr Institute, Copenhagen University) [dam@nbi.dk]

Authors:
Alain Blondel[1], Mogens Dam[2], Patrick Janot[3]

Abstract:
The FCC-ee is a frontier Higgs, Top, Electroweak, and Flavour factory. It will be operated in a 100-km circular tunnel built in the CERN area, and will serve as the first step of the FCC integrated programme towards $\geq$ 100-TeV proton-proton collisions in the same infrastructure [1]. With its huge luminosity at Z-pole energies, unrivalled samples of 5×10^{12} Z decays will be produced at multiple interaction points. The five orders of magnitude larger statistics than at LEP opens the possibility of much improved measurements of τ-lepton properties—lifetime, (leptonic) branching fractions, and mass—in $\tau^+\tau^-$ final states. Such measurements provides interesting tests of lepton universality, in effect probing whether the Fermi coupling constant is the same in τ decays as in μ decays. The ultimate goal, that experimental errors match the statistical accuracy, leads to highly demanding requirements on detector design. This Letter of Interest describes some of the many challenges presented by this benchmark measurement.

a) Mass
b) Lifetime
c) Leptonic branching fractions



This measurement is sensitive to heavy neutrino mixing with the ν_τ

Flavour physics numbers for FCC-ee

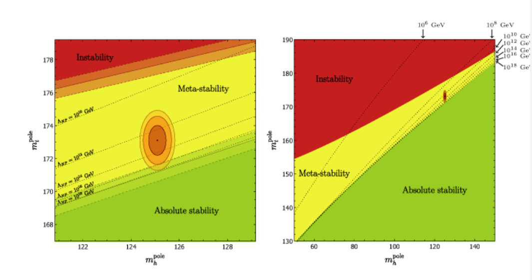
Table 7.1: Expected production yields of heavy-flavoured particles at Belle II (50 ab^{-1}) and FCC-ee.

Particle production (10^9)	B^0 / $\overline{B}^0$	B^+ / B^-	B^0_s / $\overline{B}^0_s$	Λ_b / $\overline{\Lambda}_b$	$c\overline{c}$	$\tau^+\tau^-$
Belle II	27.5	27.5	n/a	n/a	65	45
FCC-*ee*	1000	1000	250	250	550	170

Table 7.2: Comparison of orders of magnitude for expected reconstructed yields of a selection of electroweak penguin and pure dileptonic decay modes in Belle II, LHCb upgrade and FCC-ee experiments. Standard model branching fractions are assumed. The yields for the electroweak penguin decay $\bar{B}^0 \rightarrow K^{*0}(892)e^+e^-$ are given in the low q^2 region.

Decay mode	$B^0 \rightarrow K^*(892)e^+e^-$	$B^0 \rightarrow K^*(892)\tau^+\tau^-$	$B_s(B^0) \rightarrow \mu^+\mu^-$
Belle II	$\sim$ 2 000	$\sim$ 10	n/a (5)
LHCb Run I	150	-	$\sim$ 15 (–)
LHCb Upgrade	$\sim$ 5000	-	$\sim$ 500 (50)
FCC-ee	$\sim$ 200000	$\sim$ 1000	$\sim$1000 (100)

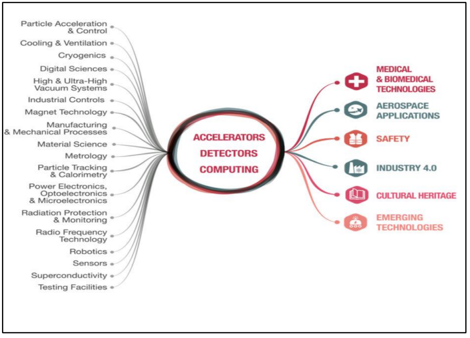
The ‘universe’ stability fate phase diagram, https://arxiv.org/abs/1707.08124

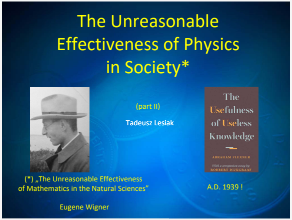


Dotted lines indicating the scale at which the addition of higher-dimension could stabilize the SM (one of possible BSM scenarios). Is BSM needed there?

‘The Standard Model of Particle Physics as a Conspiracy Theory and the Possible Role of the Higgs Boson in the Evolution of the Early Universe’, F. Jegerlehner, 2106.00862

DG Fabiola Gianotti, CERN vision and goals until next strategy update, → pdf

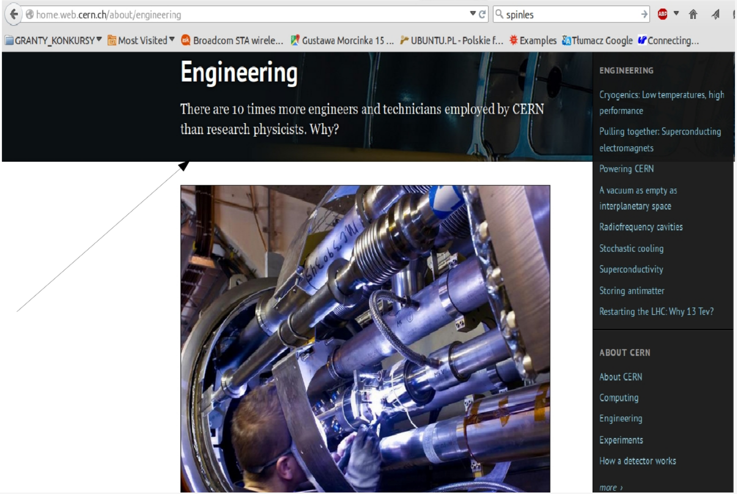




Tadeusz Lesiak Polish Physical Society (pdf): Nieracjonalna użyteczność fizyki dla społeczeństwa"

German Rodrigo, MTTD2021, The future of particle physics

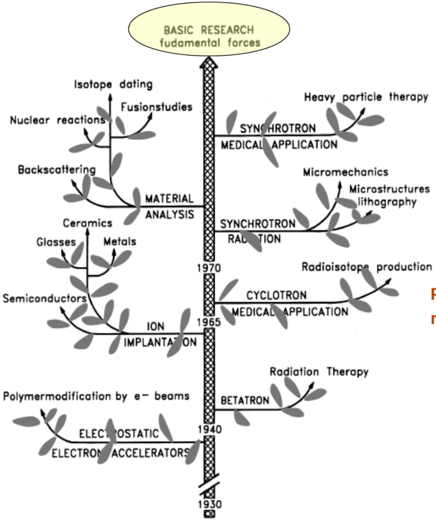
https://inspirehep.net/literature/1425942


home.web.cern.ch/about/engineering
spinles
GRANTY_KONKURSY
Most Visited
Broadcom STA wirele...
Gustawa Morcinka 15 ...
UBUNTU.PL - Polskie f...
Examples
Tłumacz Google
Connecting...
Engineering
There are 10 times more engineers and technicians employed by CERN than research physicists. Why?
ENGINEERING
Cryogenics: Low temperatures, high performance
Pulling together: Superconducting electromagnets
Powering CERN
A vacuum as empty as interplanetary space
Radiofrequency cavities
Stochastic cooling
Superconductivity
Storing antimatter
Restarting the LHC: Why 13 Tev?
ABOUT CERN
About CERN
Computing
Engineering
Experiments
How a detector works
more ›

Fizyka jądrowa, fuzje, datowanie

Nadprzewodniki

Modyfikacja polimerów



Terapia ciężkimi jonami

litografia

Produkcja radioizotopów

WHAT'S THE USE OF BASIC SCIENCE?

Christopher Llewellyn Smith,
Director-General of CERN from 1994-1998

by C.H. Llewellyn Smith,
former Director-General of CERN
Original: The use of basic science

Content:

Video: https://cds.cern.ch/record/388110?ln=en

https://www-zeuthen.desy.de/ jknapp/JK/Reading_files/basic_science.html

Znaczenie "basic science"

Faraday... anegdota - podatki.
Dyr. Fermilabu pytany przez kongresmenów USA:
Q: "What will your lab contribute to the defence of the US?"
A: "Nothing, but it will make it worth defending"
Ekonomia, aplikacje:
Casimir o uzasadnianiu badań podstawowych: "I have heard statements that the role of academic research in innovation is slight. It is about the most blatant piece of nonsense it has been my fortune to stumble upon"
"Słyszałem stwierdzenia, że rola nauki akademickiej w inowacjach jest niewielka. Jest to najbardziej rażący kawałek bzdury na który miałem szczęście się natknąć" ...
One might ask even whether induction coils in motor cars might have been made by enterprises which wanted to make motor transport and whether then they would have stumbled on the laws of induction. But the laws of induction had been found by Faraday many decades before that.

Accelerators[1]

- semiconductor industry
- sterilisation - food, medical, sewage
- radiation processing
- non-destructive testing
- cancer therapy
- incineration of nuclear waste
- power generation (energy amplifier)?
- source of synchrotron radiation (biology, condensed matter physics...)
- source of neutrons (biology, condensed matter physics...)

Particle detectors

- Crystal Detectors[2]
  - medical imaging
  - security
  - non-destructive testing
  - research
- Multiwire Proportional Chambers
  - container inspection
  - research
- Semi-conductor Detectors
  - many applications at the development stage

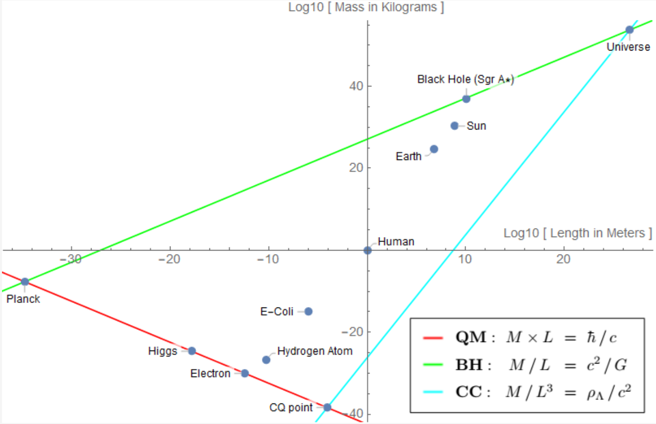
Informatics

- World Wide Web[3]
- Simulation programmes
- Fault diagnosis
- Control systems
- Stimulation of parallel computing

Superconductivity

- Particle physics
- multifilamentary wires/cables
- nuclear magnetic resonance imaging
- many others (cryogenics, vacuum, electrical engineering, geodesy...)

Gdzie jesteśmy: wymiary i skale



'A democratic Cosmos', Y. Yargic, G. Franzmann
https://arxiv.org/abs/1910.00481