Standard Model theory in Poland
(EW, QCD, MC generators, etc.)

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Outline:

- Standard Model theory
- Topics
- Monte Carlo generators
- SM theory centres in Poland
- Human resources
- Details on SM theory centres
- Conferences and workshops
- International projects
- Summary

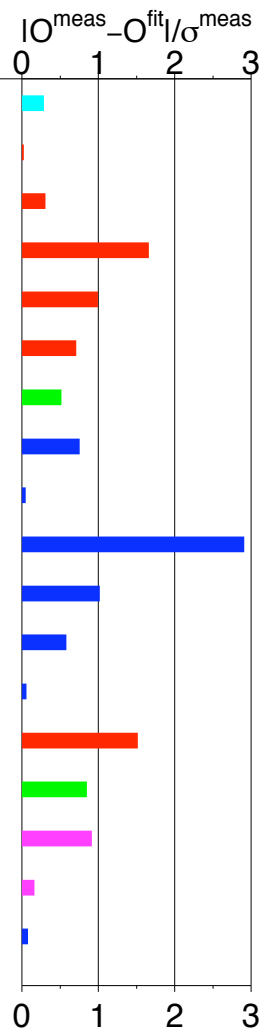
Standard Model theory

- Theory of electroweak (EW) and strong interations of elementary particles (leptons and quarks).
- Quantum field theory with gauge symmetry based on non-abelian Lie product group: $\mathbf{SU(3)_c \times SU(2)_L \times U(1)_Y}$.
- Masses of electroweak bosons ($W^{\pm}$ and Z) and fermions generated by the Higgs mechanism through spontaneous symmetry breaking: $\mathbf{SU(2)_L \times U(1)_Y \rightarrow U(1)_Q}$.
- Prediction of (yet undiscovered) scalar particle, called the **Higgs boson**.
- Description of **P** and **CP** violation in weak interactions, quark mixing, FCNC, etc.
- Asymptotic freedom of strong interactions – **pQCD**.
- Neutrino mixing and masses can be added by a simple extension (preferably see-saw mechanism) → **Extended Standard Model (ESM)**.

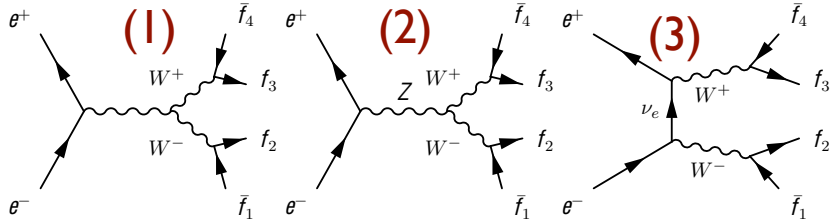
➢ Good agreement with (almost) all experimental data!

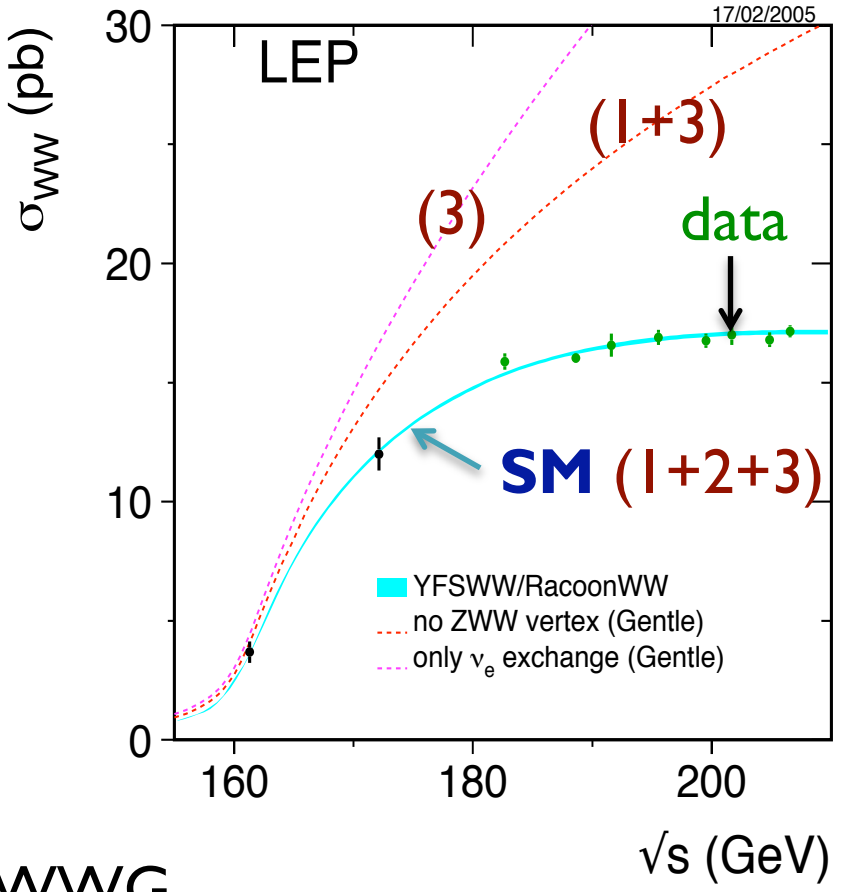
SM vs. experimental data

	Measurement	Fit	$\lvert O^{meas} - O^{fit} \rvert / \sigma^{meas}$
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02750 ± 0.00033	0.02759	
m_Z [GeV]	91.1875 ± 0.0021	91.1874	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959	
σ^0_{had} [nb]	41.540 ± 0.037	41.478	
R_l	20.767 ± 0.025	20.742	
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01646	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1482	
R_b	0.21629 ± 0.00066	0.21579	
R_c	0.1721 ± 0.0030	0.1722	
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1039	
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0743	
A_b	0.923 ± 0.020	0.935	
A_c	0.670 ± 0.027	0.668	
A_l(SLD)	0.1513 ± 0.0021	0.1482	
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.399 ± 0.023	80.378	
Γ_W [GeV]	2.085 ± 0.042	2.092	
m_t [GeV]	173.20 ± 0.90	173.27	



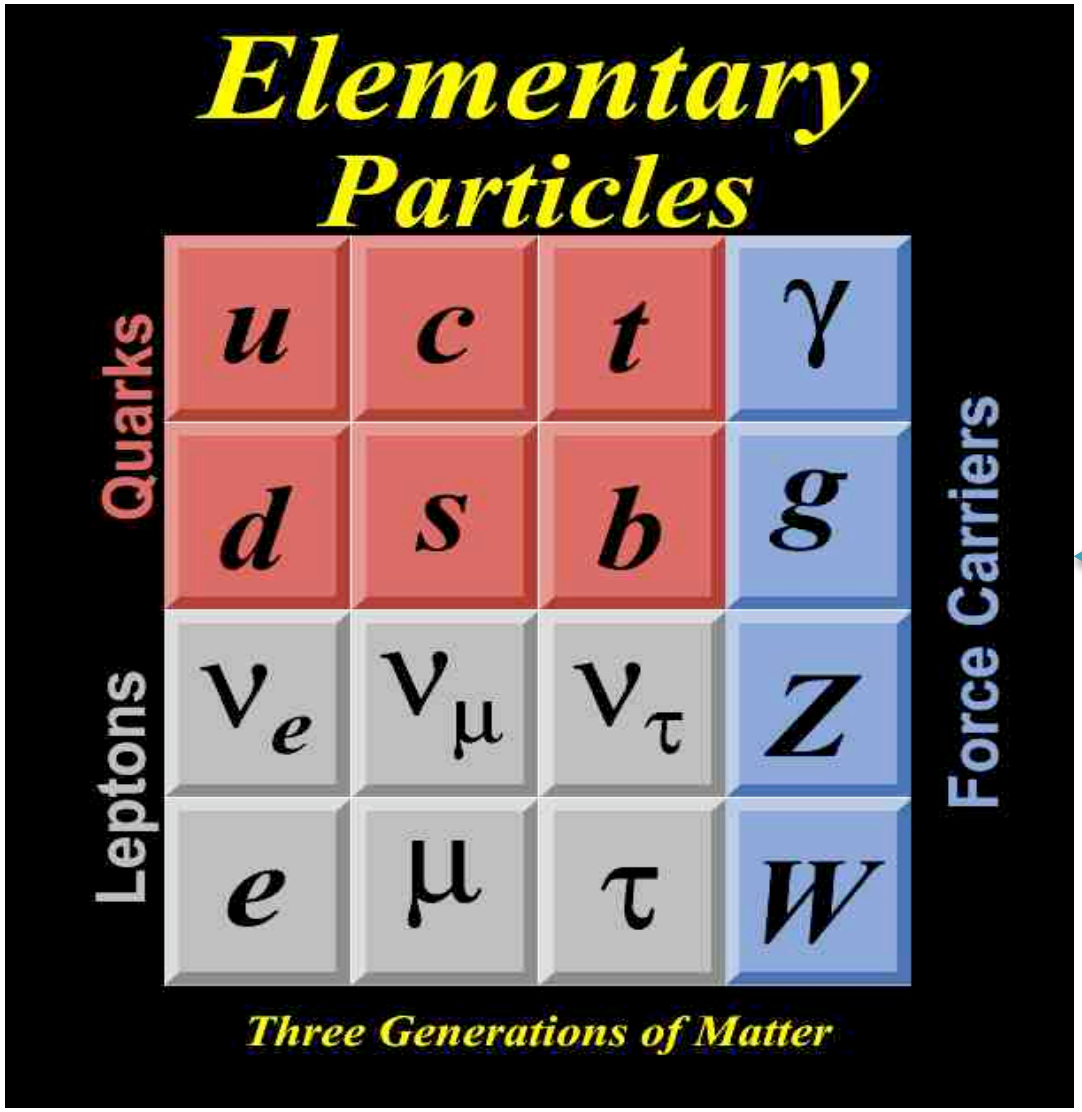
July 2011





LEP EWWG

Standard Model theory



Higgs boson (scalar)

H ?

LHC 2012

⇓

Crucial test of SM

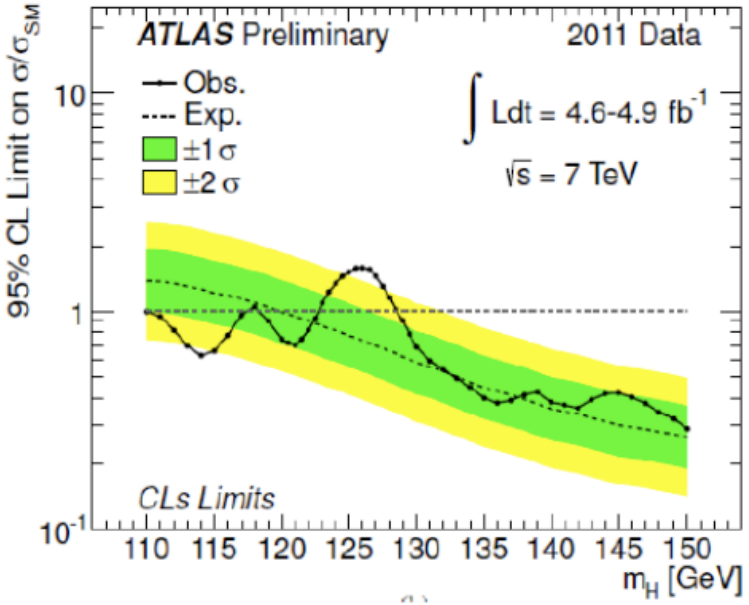
Topics: EW

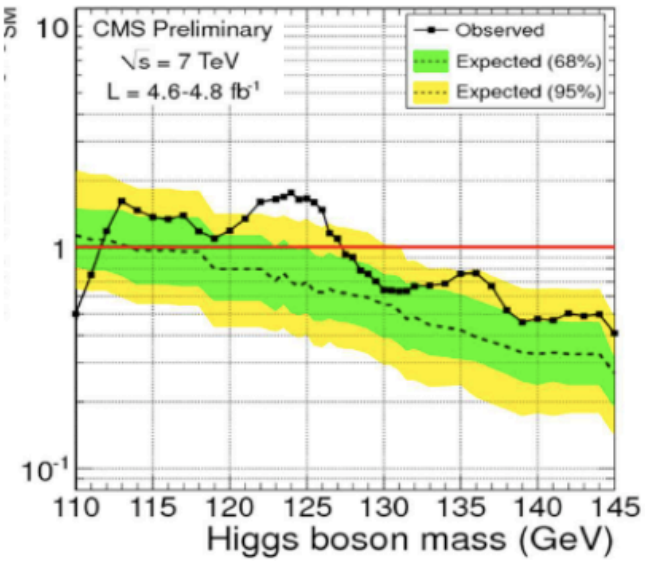
- Higgs boson physics:
  - direct searches for Higgs boson,
  - W-boson and top-quark mass measurements → indirect search for Higgs boson → consistency test of SM,
  - measurements of Higgs-boson partial decay widths → SM or non-SM Higgs boson.
- Measurements of electroweak parameters and cross sections → further precision tests of SM.
- SM processes as background for "New Physics".
- Some SM processes may serve as "standard candles" for other processes at HEP colliders.

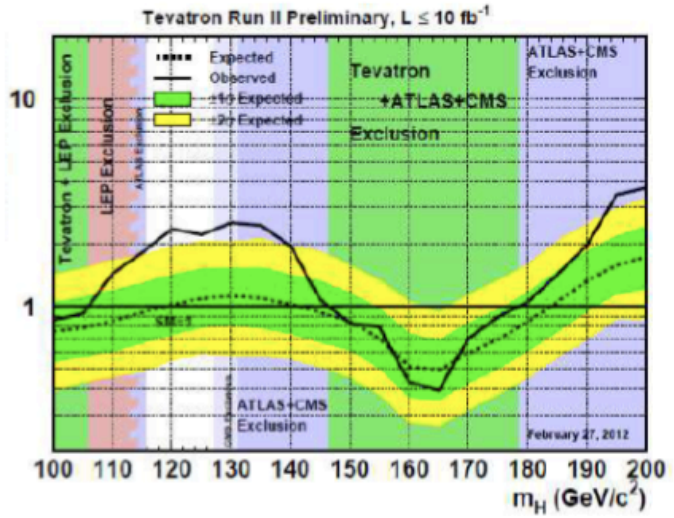
➢ All this needs precise theoretical predictions including higher-order quantum corrections!

Direct Higgs searches

The Higgs







95% exclusion
ATLAS:
110-117.5, 118.5-122.5, 129-539 GeV
CMS:
127.5- 600 GeV

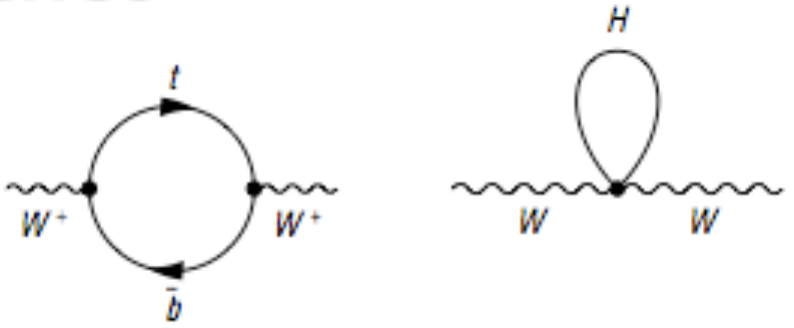
All experiments see some excess at ~ 122 - 128 GeV

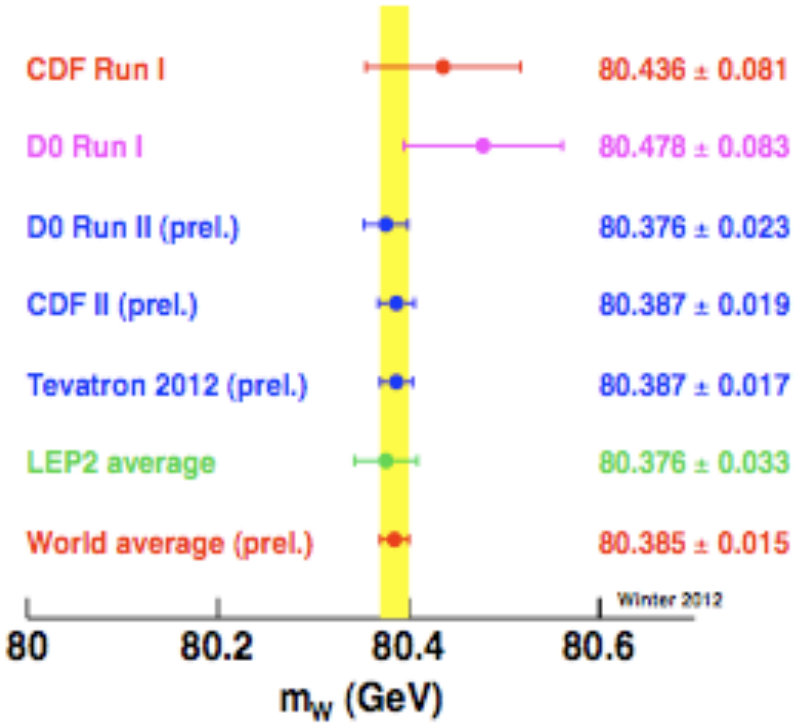
G. Altarelli, Moriond 2012

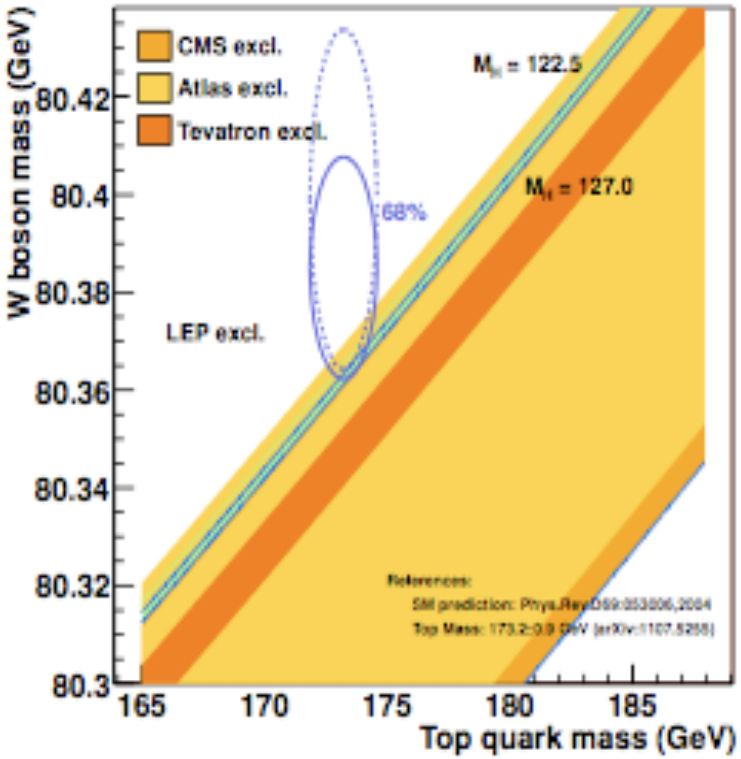
Indirect Higgs searches

SM loop corrections to m_W:

$\Delta r(m_t, M_H, \ldots)$



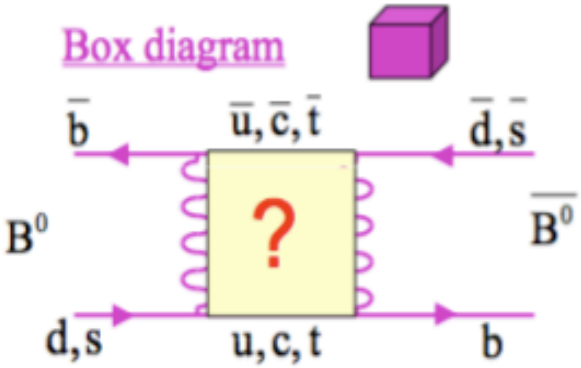




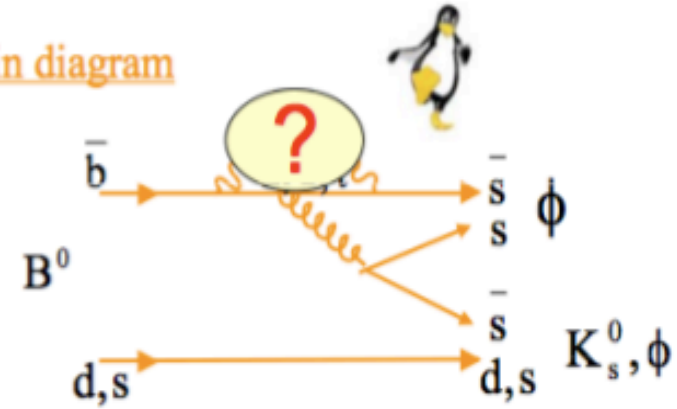
R. Lopes de Sa, Moriond 2012

SM as background for New Physics

Search for deviations from Standard Model predictions due to ***virtual contributions of new heavy particles in loop processes***



New Physics



measure:

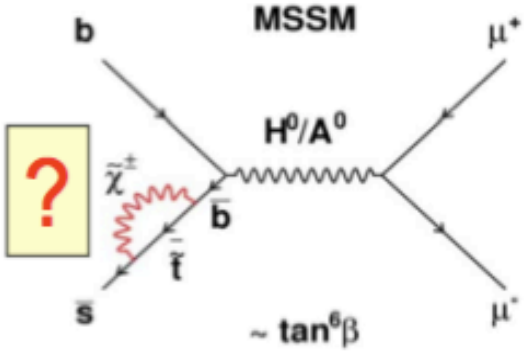
- ***CP violating phases*** in mixing and decay
- ***Rare Decays*** of heavy quarks

compare:

- to ***very precise predictions*** of the SM

→ discovery potential for ***New Physics*** extending to mass scales far in excess of the LHC centre-of-mass energy

$B_s \rightarrow \mu^+\mu^-$ "s-channel penguin"



A. Schopper, Moriond 2012

Topics: QCD

- Perturbative QCD predictions for hard processes at NLO, NNLO, …
- Parton shower generators at NLO.
- Matching the above.
- Jet algorithms.
- Structure functions, PDFs, spin.
- Low x physics: BFKL, CCFM, saturation, etc.
- Diffraction, higher-twist effects, etc.
- Heavy flavours, hadron models, etc.
- Non-perturbative regime: lattice QCD, effective models, AdS/CFT, etc.
- Relativistic heavy-ion collisions: quark-gluon plasma, etc.

Monte Carlo generators

✓ Indispensable tools in HEP collider experiments!

- Electron-positron colliders:
  - Bhabha: BHLUMI, BHWIDE.
  - 2f (f ≠ e): KKMC.
  - hadrons: PHOKHARA, EKHARA.
  - WW, ZZ, 4f: YFSWW, YFSZZ, KoralW.
  - multiparticle final states: carlomat, ee4f γ , eett6f.
- Hadron colliders:
  - SM background processes at LHC: AcerMC.
  - Drell-Yan CC and NC processes: WINHAC, ZINHAC.
  - NLO parton shower for ISR, FSR: CMC, MMC.
- Universal:
  - Higgs decays: HDECAY.
  - Tau-lepton decays: TAUOLA.
  - QED radiation in particle decays: PHOTOS.
- Dedicated to heavy ion collisions:
  - THERMINATOR, THERMINATOR 2, GLISSANDO.

Disclaimer

- Based mainly on info from Web pages and partly on personal contacts:
  - Complete?
  - Accurate?
  - Up-to-date?
- Difficult to draw strict border-lines between:
  - SM and Beyond SM,
  - SM and formal QFT, and mathematical physics,
  - Phenomenology and experiment.

  ➢ Numbers probably a bit overestimated and partly overlap with BSM theory and experiment!
- Sorry if not sufficient justice given to all!

SM theory centres in Poland

Human resources (staff + PhD students)

Sum: 131+65

Details on SM theory centres

Warsaw University – Institute of Theoretical Physics:

1. Chair for Theory of Particles and Elementary Interactions (head: Stefan Pokorski)
2. Chair for Theory of Strong and Electroweak Interactions (head: Maria Krawczyk)

- Human resources: 18 staff + 23 PhD students.
- Topics:
  - EW quantum corrections for SM processes, including minimal and non-minimal Higgs mechanism.
  - Structure of hadrons, photons and bound states of heavy quarks with the use of advanced renormalization group procedures and computer methods.
  - Broad spectrum from phenomenological studies within the Standard Model to formal aspects of string theory.

Details on SM theory centres

National Centre for Nuclear Research (NCBJ), Warsaw/Świerk

1. Department of Theoretical Physics (head: Grzegorz Wilk):

- Human resources: 25 staff + 1 PhD student.
- Topics:
  - Multiparticle production, statistical methods (in particular Bayes fits), Bose-Einstein correlations.
  - QCD models of Pomeron and Odderon, hard diffraction.
  - Strangelets, mesoatoms, hybrid mesons, low energy.

Details on SM theory centres

Jagiellonian University, Krakow – Institute of Physics

1. Dept. of Particle Theory (head: Michał Praszałowicz)
2. Dept. of Applied Computing Methods (head: W. Słomiński)
3. Dept. of Complex Systems (head: Jerzy Jurkiewicz)
4. Dept. of Field Theory (head: Henryk Arodź)
5. Dept. of Discrete Field Theory (head: Andrzej Kotański)

- Human resources: 31 staff + 18 PhD students.
- Topics:
  - Phenomenology of SM processes, including quantum corrections.
  - Monte Carlo generators for HEP colliders (LHC, LHeC, ILC/CLIC).
  - Perturbative and non-perturbative QCD, including lattice QCD.
  - Heavy ion collisions, multiparticle production and quark-gluon plasma.
  - PDFs, diffraction, geometrical scaling, higher twist effects.
  - Hadron models, chiral dublers, pentaquarks.
  - Instantons, non-comutative geometry, mathematical foundation of quantum field theory.

Details on SM theory centres

Institute of Nuclear Physics, Polish Academy of Sciences (IFJ PAN), Krakow – Division of Theoretical Physics (head: Stanisław Jadach):

1. Dept. of Particle Theory (head: Maciej Skrzypek)
2. Dept. of Theory of Structure of Matter (head: Piotr Bożek) [partly Rzeszów Univ. and J. K. Univ. in Kielce]

- Human resources: 20 staff + 7 PhD students.
- Topics:
  - QED, EW and QCD quantum corrections for SM processes.
  - QED/EW/QCD Monte Carlo generators for HEP colliders: LHC, LHeC, ICL, CLIC, BELLE, DAFNE, BEPC, VEPP, etc.
  - QCD phenomenology (evolution, diffraction, saturation).
  - Effective models of strong interactions.
  - Relativistic heavy ion collisions.
  - Meson production, interaction and decay.

Details on SM theory centres

University of Wrocław – Institute of Theoretical Physics:

1. Dept. of Elementary ParticleTheory (head: Ludwik Turko)
2. Dept. of Field Theory (head: Zbigniew Haba)
3. Dept. of Neutrino Physics (head: Jan Sobczyk)

- Human resources: 14 staff + 7 PhD students.
- Topics:
  - Physics of ultra-relativistic heavy ion collisions, astrophysical implications.
  - Low energy neutrino physics, CP(T) violation, polarised neutrino beams
  - Pion production in neutrino scattering off nucleons and nuclei.
  - Nuclear effects in neutrino interactions, nucleon form factors.
  - Statistical data analysis, neural computation in particle physics, Monte Carlo simulations.

Details on SM theory centres

University of Silesia, Katowice – Institute of Physics:

1. Dept. of Field Theory and Elementary Particles (head: Marek Zrałek)

- Human resources: 7 staff + 6 PhD students.
- Topics:
  - Properties of neutrinos: nature, masses, mixing, CP violation.
  - Multiparticle SM processes in HEP colliders (LHC, ILC) including electroweak bosons, Higgs boson and top quark.
  - Automation of cross section computations for reactions with many particles.
  - Real and virtual radiative corrections for high and low energy processes, in particular the Bhabha process.
  - Application of differential equations and Mellin-Barnes transformation in multiloop calculations.
  - Radiative return method and Monte Carlo tools for precision hadronic physics.

Details on SM theory centres

Jan Kochanowski University in Kielce – Institute of Physics:

1. Dept. of Theoretical Physics (head: Stanisław Mrówczyński)
2. Dept. of Computer Physics (head: Wojciech Broniowski)

- Human resources: 5 staff + 1 PhD student.
- Topics:
  - Relativistic heavy ion collisions, quark-gluon plasma.
  - Equilibrium and non-equilibrium systems of quantum fields, particularly in QCD.
  - Effective chiral quark models of mesons.
  - Non-perturbative methods in quantum field theory.

Details on SM theory centres

University of Zielona Góra – Institute of Physics:

1. Dept. of Theory of Fundamental Interactions (head: Anatol Nowicki)

- Human resources: 6 staff + 1 PhD student.
- Topics:
  - Kaon physics, unstable particles, CPT symmetry.

University of Białystok – Faculty of Physics:

1. Dept. of Field Theory (head: Jerzy Przeszowski)

- Human resources: 5 staff + 1 PhD students.
- Topics:
  - Quantum field theory on light-cone, QED.
  - High-spin particles, spin-mass coupling.

Conferences and workshops

- Warsaw
  - FLATVIAnet Topical Workshop, Kazimierz Dolny, 23-27 July 2009.
  - Seventh Workshop on Particle Physics and Cosmology, Warsaw, 3-6.02.2010.
  - Conference "Scalars 2011", Warsaw, 25-29.08.2011.
  - Conference "Planck 2012", Warsaw, 28.05-1.06.2012.
- Krakow
  - EPS HEP Conference, 16-22.07.2009.
  - Cracow Epiphany Conference, annual (★1995), January.
  - Cracow School of Theoretical Physics in Zakopane, annual, May/June (52nd this year).
  - Workshop "Tau lepton decays: hadronic currents from data of Belle and BaBar and new physics signatures at LHC", 14-19.05.2012, IFJ PAN.
- Krakow–Warsaw Workshop on LHC Physics, monthly.

Conferences and workshops

- Wroclaw
  - "Neutrino interactions: from theory to Monte Carlo simulations", Lądek Zdrój, 2-11.02.2009.
  - "Three Days of Strong Interactions", Wrocław, 9-11.07.2009.
  - "Relativistic Heavy-Ion Collisions at High Barion Number Density ", Wrocław, 5-6.12.2009.
  - "Three Days on Quarkyonic Island", Wrocław, 19-21.05.2011.
  - "Cosmic Matter in Heay-Ion Collision Laboratories", Lądek Zdrój, 4-11.02.2011.
- Katowice
  - International Conference of Theoretical Physics "Matter to the deepest", Ustroń, bi-annual (35th in 2011).
- Kielce
  - V Polish Workshop on Relativistic Heavy Ion Collisions "SHIN(E)ing Physics", Kielce, 6-7.12.2008.
  - International Symposium on Multiparticle Dynamics, ISMD2012, Kielce, 16-21.09.2012

International projects

- EC FP6 Marie Curie Action ToK, "Calculational tools and methods for physics at Large Hadron Collider" CAMTOPH, 2004-2008, IFJ PAN Krakow, coordinator: S. Jadach.
- EC FP6 Marie Curie Action ToK, "Correlations in Complex Systems" COCOS, 2005-2009, JU Krakow, coordinator: J. Jurkiewicz.
- EC FP6 Marie Curie Research Training Network ENRAGE, 2005-2009, JU Krakow, coordinator: J. Jurkiewicz.
- EC FP6 Marie Curie Research Training Network FP6-2005-MOBILITY-1, MRTN-CT-2006-035505 HEPTOOLS, 2006-2010, Polish node: IFJ PAN Krakow (coordinator: E. Richter-Wąs).
- EC FP6 Marie Curie Research Training Network FP6-2005-MOBILITY-1, MRTN-CT-2006-035482 FLAVIAnet, 2006-2010, Polish node: Katowice-Krakow-Warsaw (coordinator: H. Czyż).

International projects

- EC FP6 Marie Curie Action ToK MTKD-CT-2005-029466, "Particle Physics and Cosmology: the Interface", 2006-2010, Warsaw U., coordinator: S. Pokorski.
- EC FP7 Marie Curie ITN "UNILHC", PITN-GA-2009-237920, 2009-2013, coordination: CERN, Polish team: Warsaw U. (coordinator: S. Pokorski).
- EC FP7 Integrated Activity: "Study of Strongly Interacting Matter: HadronPhysics2", 2009-2012, Polish team: Wroclaw U., US Katowice.
- EC FP7 Marie Curie ITN "LHCPhenoNet", PITN-GA-2010-264564, 2011-2014, Polish team: US Katowice (coordinator: J. Gluza).
- French-Polish cooperation between IN2P3 and COPIN (consortium of 7 Polish physics institutes), 2007-2010, 2010-2014, coordination: IFJ PAN Krakow.

Summary – ups:

- Most current theoretical aspects of Standard Model investigated in Poland.
  - Strong in Monte Carlo generators for HEP colliders.
  - Substantial contribution to heavy ion physics.
- Well-integrated with European and world-wide theoretical particle physics, with active international collaboration.
- Participation in and coordination of international research networks.
- Participation in organizing committees, advisory boards, working groups.
- Organisation of international conferences, workshops, schools.

Summary – downs:

- Demographic problems:
  - Aging staff.
  - Decreasing number of (good) students.
- Low financing:
  - One of the lowest budgets for research in Europe.
  - Basic science not among research priorities.
  - Low staff salaries and PhD student stipends.
- Losing in competition with other fields of science (bio-, nano-, info-) and industry, particularly IT.
  - Particle physics not very attractive in recent years – no big experimental discoveries as well as theoretical breakthroughs!
  - Difficult to attract bright students!
- More and more, worse and worse bureaucracy!

➢ Breaking discoveries at LHC strongly needed!