MODERN TRENDS IN PARTICLE PHYSICS

RuPAC2012
Peterhof, September 24, 2012

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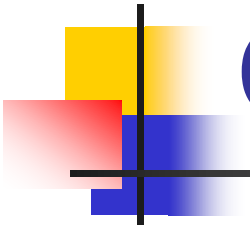


OUTLINE

- Fundamental vs Effective interactions
- HIGGS!!?
- Testing SM – high and low energies
- QCD – hadron (spin) structure
- QCD matter – heavy ions

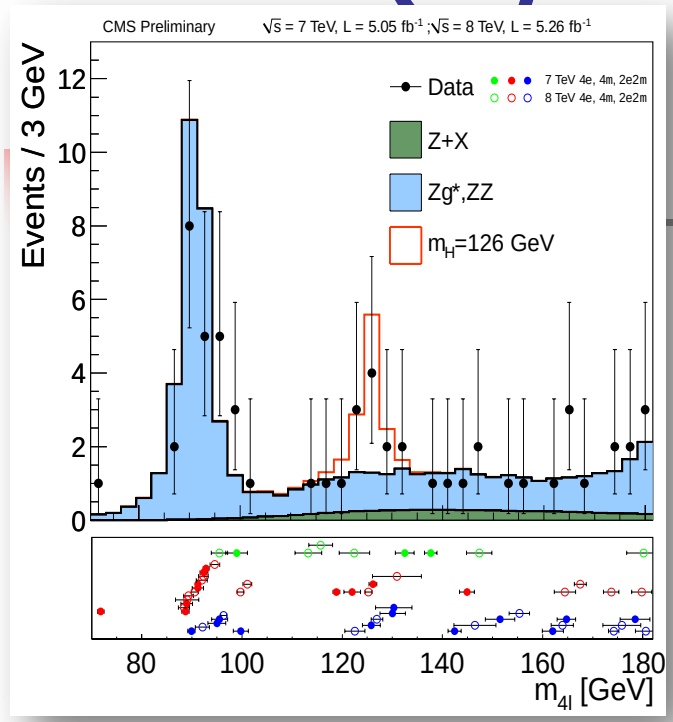
Two faces of particle physics

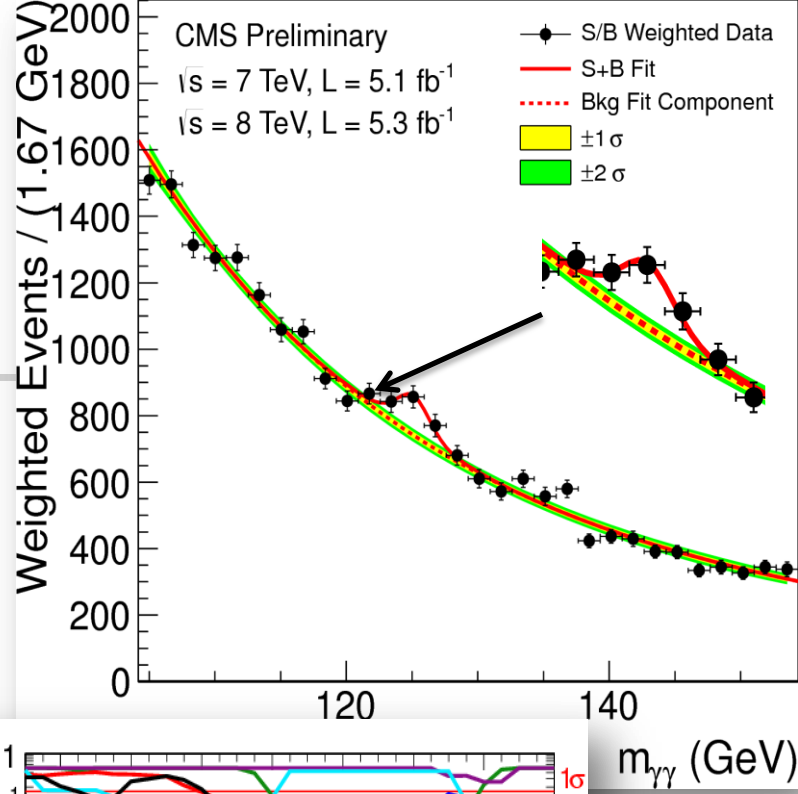
- Basic constituents and fundamental interactions:
- QED, EW, pQCD; Higgs – source of ~1% of visible Universe mass – e,(current)q
- Effective (emergent) interactions: NPQCD - source of ~100% of visible Universe mass –p,n; QCD matter)
- Complicated ; relation to fundamental laws - difficult
- Cf – simple Navier-Stokes eqs. – long-term weather forecast is not possible because of turbulence
- Confinement and turbulence are both "Millenium problems" of Clay Institute

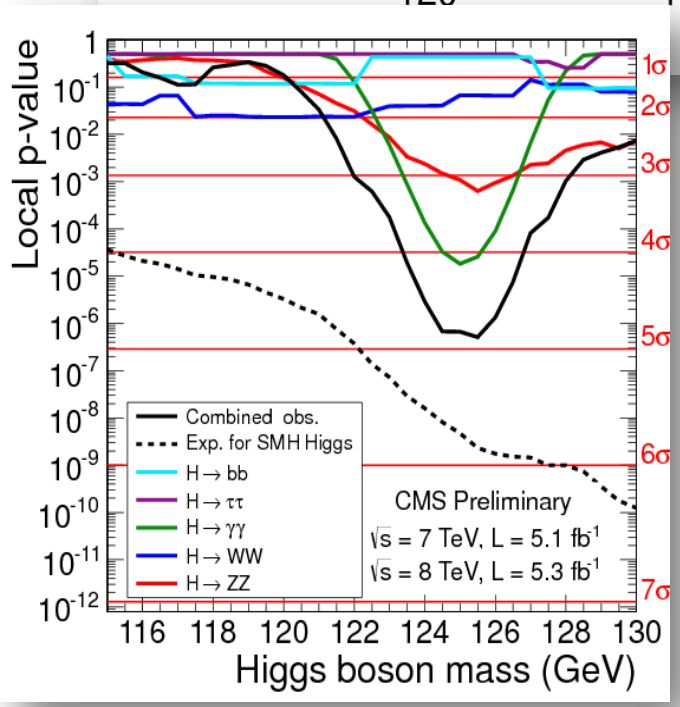
Higgs@LHC

- The missing ingredient of SM: field providing the mass to all FUNDAMENTAL particles
- SCALAR Condensate (occupying the whole space) – generation of universal scalar quantity – mass
- Cf. Vector EM field – change of momentum

CMS(4/07/12)







We have observed a new boson with a mass of

125.3 ± 0.6 GeV

at

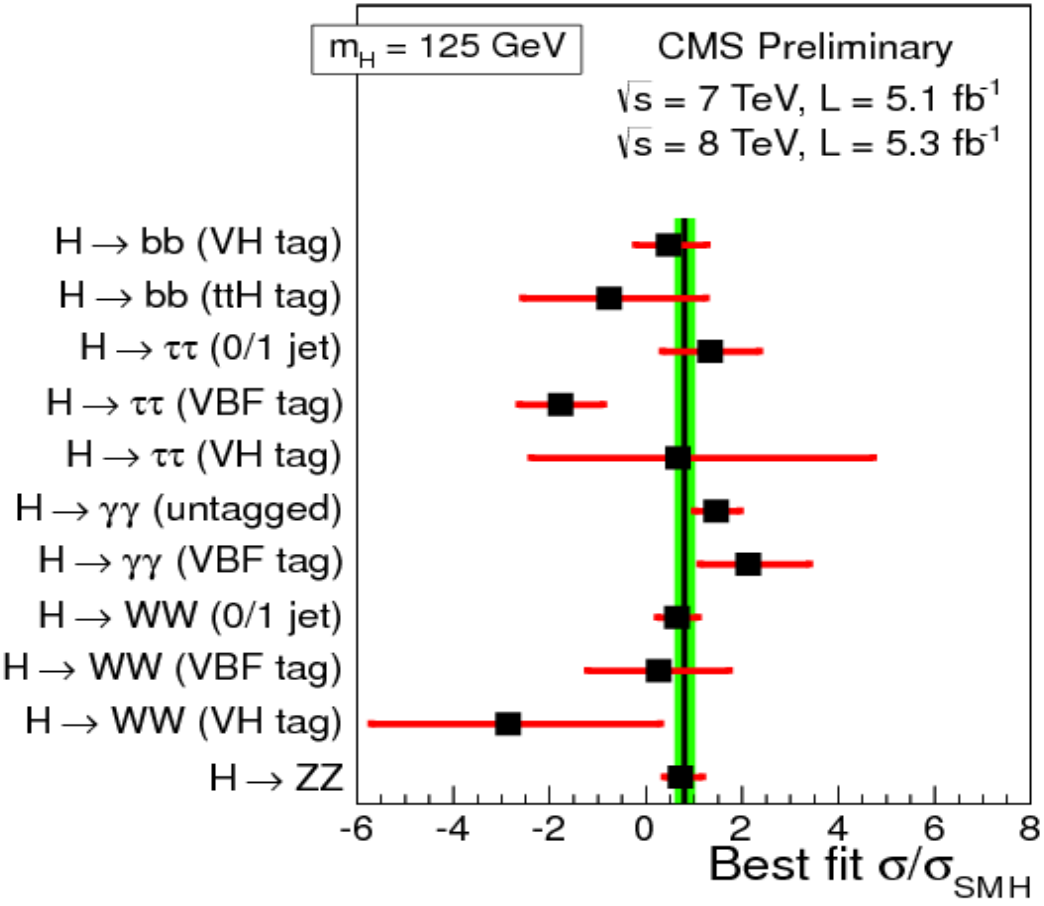
4.9 σ significance !

Is it really a SM Higgs?

- Looks very much like Higgs – similarity of cross-section in MANY channels – coincidence unprobable
- BUT – excess in some channels (2 photons) and deficit in other (taus) – see next slides from CMS
- More statistics is required and expected

Compatibility with SM Higgs boson event yields in different modes

- Event yields in different production times decay modes are self-consistent
  - albeit many modes have not yet reached sensitivity to distinguish SM from Background



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Testing the SM and Fundamental Symmetries

- LHC : New heavy particles, if existed, may be produced: SUSY, (Extradimensional – if discovered - most exciting since Copernicus!) Graviton, new gauge bosons…
- BUT – HUGE backgrounds
- Lower energies: new particles only virtual
- Special observables (spin-related asymmetries), decay modes…

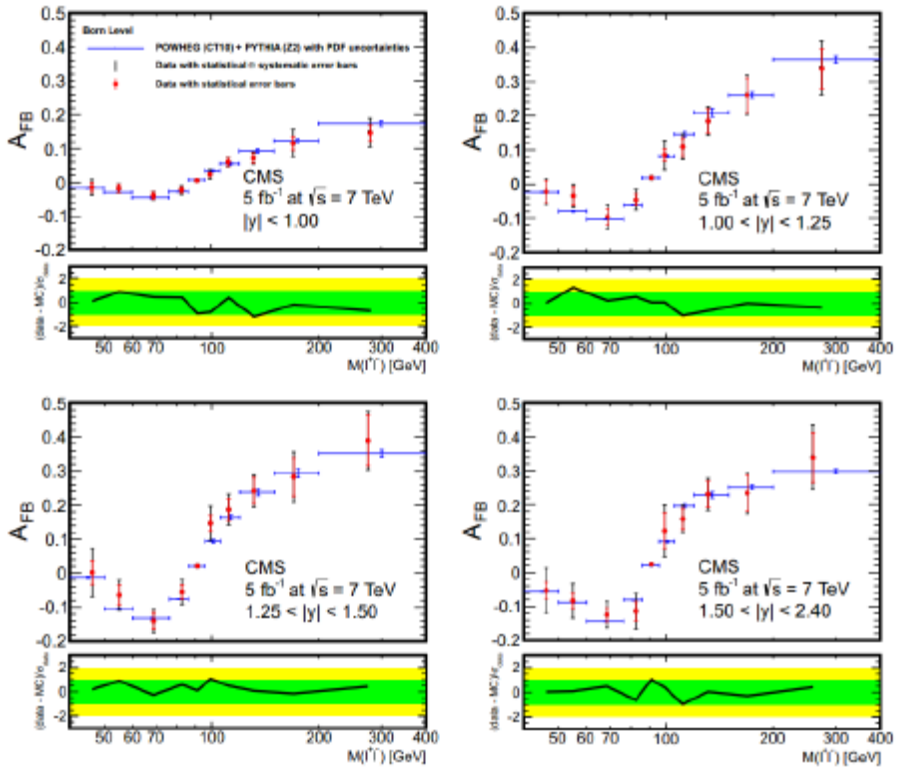
Polarization data has often been the graveyard of fashionable theories.
If theorists had their way, they might just ban such measurements altogether out of self-protection.

J.D. Bjorken, 1987

Forward-backward asymmetry of Drell–Yan lepton pairs in pp collisions at $\sqrt{s} = 7\,\mathrm{TeV}$

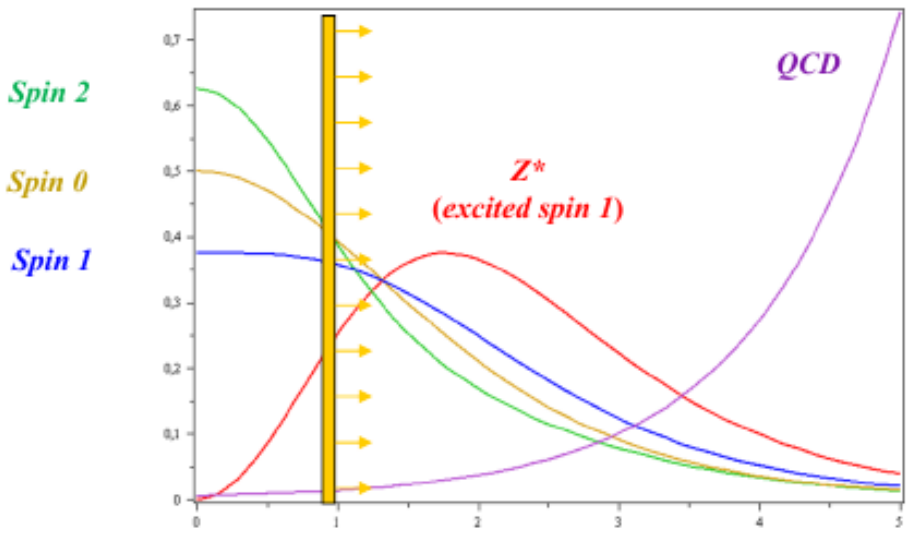
The CMS Collaboration*

CMS Results with 5 fb^{-1}



- A_{FB} measured in 4 different |y| bins as a function of invariant mass M_{ll}
- Unfolded to Born level
- e^+e^- and $\mu^+\mu^-$ channels combined
- Good agreement to SM prediction

Search for excited Z* bozon@ATLAS

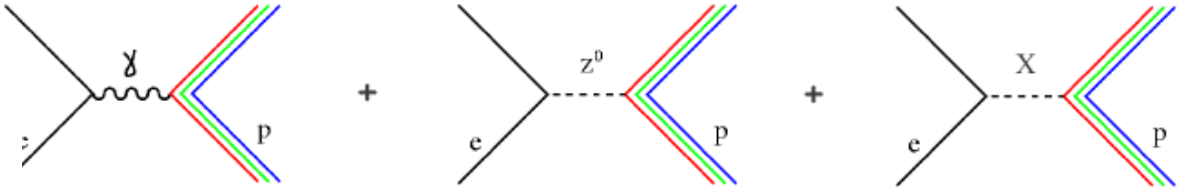


Due to Z* unique angular distribution, the additional selection, suppressing SM backgrounds can be introduced.

Additional cut for final leptons $|\eta_1-\eta_2|>0.9$ is expected to bring 10-15% increase of the signal over SM background statistics.

New physics – also at GeV experiments: Qweak@JLAB

Indirect Probe of New Physics



Electromagnetic force -- proton's electric charge

$$Q^p = 2\left(+\frac{2}{3}\right)+1\left(-\frac{1}{3}\right)=+1$$

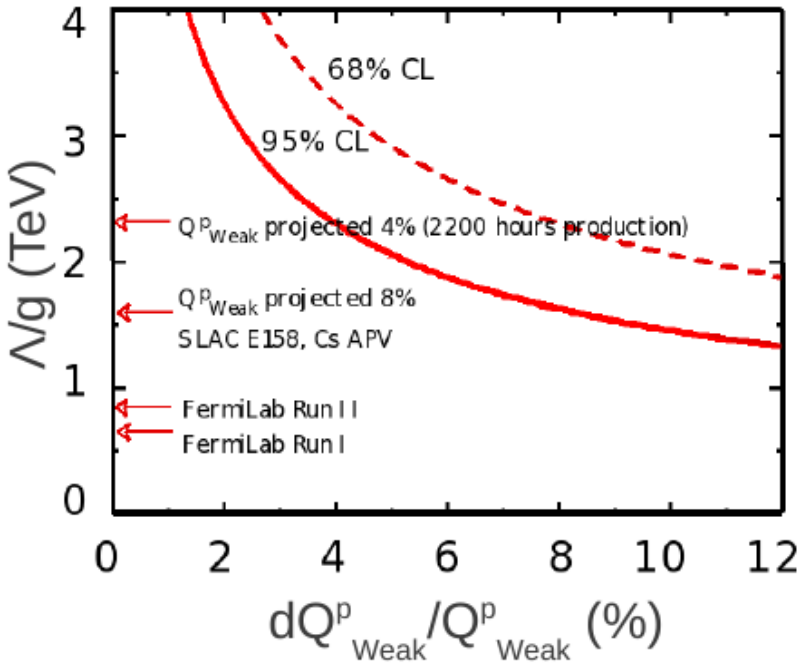
Weak force -- proton's neutral weak charge - Q_{weak}

$$Q^p_{weak} = 2\left(1-8/3\sin^2\theta_W\right)+1\left(-1+4/3\sin^2\theta_W\right)$$
$$= 1-4\sin^2\theta_W \approx 0.07$$

A 4% Q^p_{Weak} measurement probes with 95% confidence level for new physics at energy scales to:

$$\frac{\Lambda}{g} \sim \frac{1}{2\sqrt{\sqrt{2}G_F\left|dQ^p_W\right|}} \sim 2.3\ TeV$$

If LHC uncovers new physics, then precision low Q^2 measurements will be needed to determine charges, coupling constants, etc.



EDM&g-2

- Special cases for new physics searches
- Precise measurements of spin precession; dedicated rings
- Muon's g-2 stays ~3 sigmas away from SM for years
- Few new experiments at sight: BNL, COSY, J-PARC
- Some projects – long-term spin coherence, Earth rotation effect may be seen!
- Spin rotation as classical rotator – test of Post-Newtonian equivalence principle!

Equivalence principle

- Newtonian – "Falling elevator" – well known and checked (also for elementary particles)
- Post-Newtonian – gravity action on SPIN – known since 1962 (Kobzarev and Okun'); rederived from conservarion laws - Kobzarev and Zakharov
- Anomalous gravitomagnetic (and electric-CP-odd) moment iz ZERO or
- Classical and QUANTUM rotators behave in the SAME way
- - not checked on purpose but in fact checked in atomic spins experiments at % level (obtained by reanalysis: Silenko,OT'07)

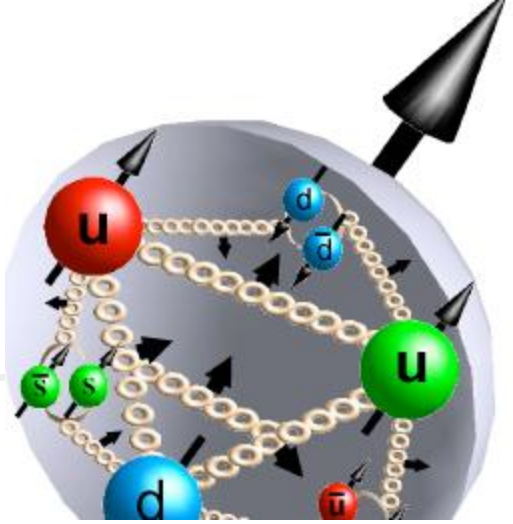
(NP)QCD and hadron structure

- Search of new physics in hadronic reactions requires:
- To know pQCD background
- NPQCD Pdf's with a good accuracy (% @LHC
- Complicated processes – new parton distributions: unintegrated, spin- and transverse momentum dependent, generalized…

Interplay of high/low energies

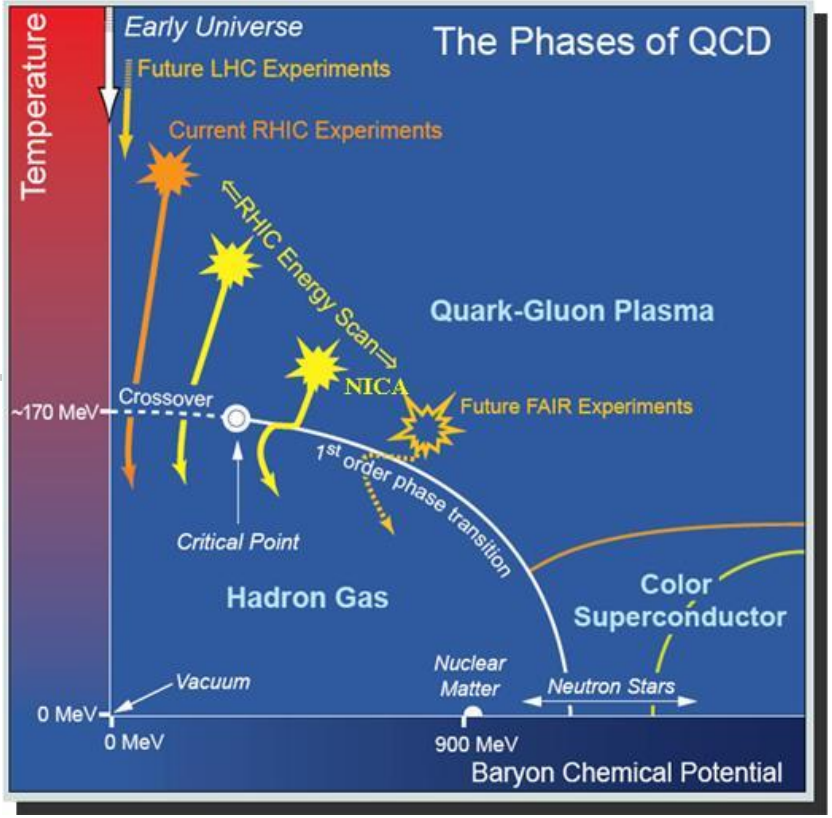
- LHC: PDfs at large scale/small x
- Related by QCD evolution to low scale/large x
- At ~ GeV scale – low x unaccessible
- Testing of sum rules (e.g. Bjorken) using very accurate Jlab data includes low x extrapolation and indirectly probes also corresponding physics

Nucleon spin structure



- $<L_q + S_q/2 + L_G + S_G> = 1/2$
- Small quark spin contribution
- Gluon anomaly: simplest interpretation: gluon polarization ->HERMES, RHIC, COMPASS -> small
- Anomaly-> strangeness polarization(OT'09)
- Orbital angular momentum ->GPDs, TMDs (Jlab)
- Various NPQCD methods, models, lattice

QCD matter



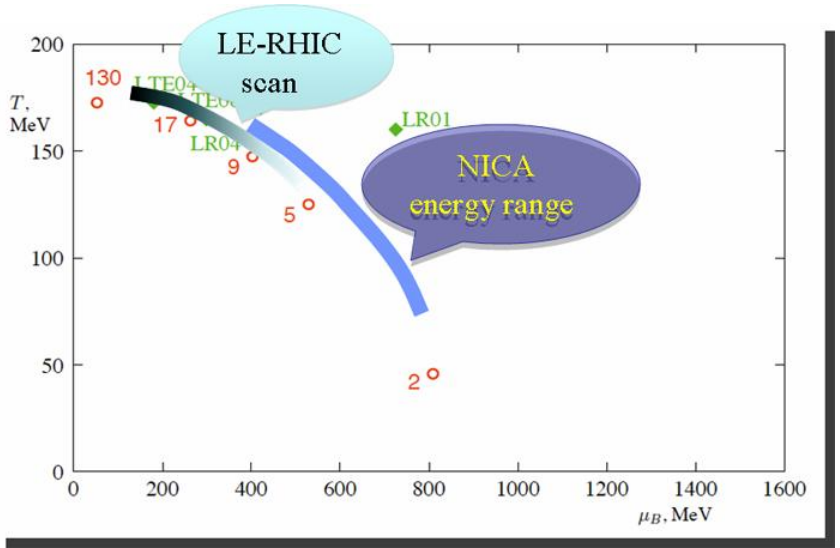
- Another emergent phenomenon (2 Millenium mathematical problems – confinement and turbulence - meet)
- Very notion of QCD phases – highly nontrivial – short existence time – how equilibration happens?!

QCD matter

- Temperature may be effective
- Exponential behaviour appears, say in Regge theory also
- Statistical models of pdfs
- Hagedorn mass spectrum – hadrons produced already in "equilibrium"

Temperature vs density

- High T – high energy- RHIC,LHC
- High density (important for astrophysics – compact stars)- moderate energy ->RHIC low energy scan, FAIR, NICA



(C)P – violation in QCD matter

- QCD CP-odd topological effects may be probed by magnetic field and vorticity of medium
- H – highest ever possible (D. Kharzeev –next slide)
- Vorticity – of the same order, model estimates in progress

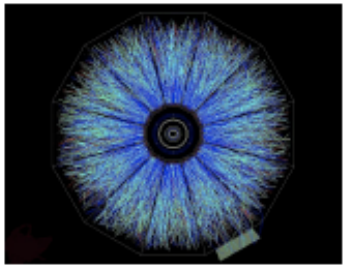
Comparison of magnetic fields

The Earths magnetic field	0.6 Gauss
A common, hand-held magnet	100 Gauss

The strongest steady magnetic fields achieved so far in the laboratory	4.5×10^5 Gauss
The strongest man-made fields ever achieved, if only briefly	10^7 Gauss

Typical surface, polar magnetic fields of radio pulsars	10^{13} Gauss
Surface field of Magnetars	10^{15} Gauss

http://solomon.as.utexas.edu/~duncan/magnetar.html



At BNL we beat them all!

Off central Gold-Gold Collisions at 100 GeV per nucleon

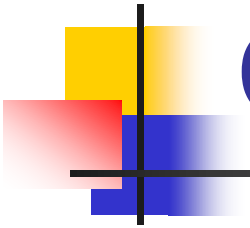
$$e\,B(\tau = 0.2\,\mathrm{fm}) \;=\; 10^3 \sim 10^4\ \mathrm{MeV}^2 \sim 10^{17}\,\mathrm{Gauss}$$

Chiral Magnetic Effect

- Correlation between electric current and magnetic field (resembles EDM)
- Positive and negative pions move predominantly in deifferent directions
- Sign of topological QCD field unknown

-> pairs of same charge fly predominantly together

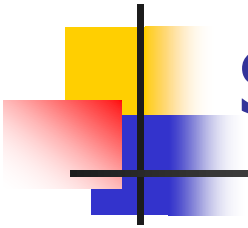
Observed but many other sources and many features cannot be explained...

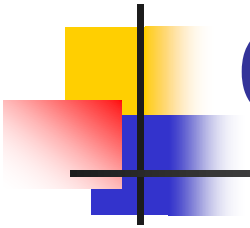


CONCLUSIONS

- Exciting time for search of final ingredient of SM
- New physics at various energies
- The growing role of emergent phenomena in particle physics like NPQCD and QCD matter
- Spin : tool and aim
- Interplay of various accelerator (also - needlsess to say - non-accelerator!) experiments

Extra slides: anthropic selection





Outline

- Anthropic coincidences:Shift of (Dirac) Paradygm?
- Cosmological constant and acceleration

- Anthropic coincidences for QCD – nucleon masses
- Improbable initial conditions in terms of quark/gluon momentum fractions – possible signal of randomness

"Mesoscopic" Antropic Principle

- Solar eclipses and elliptic orbits
- Biological evolution and anthropic principle

Anthropic reasoning

- S. Weinberg

Living in the Multiverse

Opening Talk at the Symposium "Expectations of a Final Theory" at Trinity College, Cambridge, September 2, 2005; to be published in *Universe or Multiverse?*, ed. B. Carr (Cambridge University Press).

Steven Weinberg
Physics Department, University of Texas at Austin

Most advances in the history of science have been marked by discoveries about nature, but at certain turning points we have made discoveries about science itself. These discoveries lead to changes in how we score our work, in what we consider to be an acceptable theory.

For an example look back to a discovery made just one hundred years ago. As you recall, before 1905 there had been numerous unsuccessful efforts to detect changes in the speed of light due to the motion of the earth through the ether. Attempts were made by Fitzgerald, Lorentz, and others to construct a mathematical model of the electron (which was then conceived to be the chief constituent of all matter), that would explain how rulers contract when moving through the ether in just the right way to keep the apparent speed of light unchanged. Einstein instead offered a symmetry principle, which stated that not just the speed of light but all the laws of

V. Rubakov at ICHEP06

- "Naturalness"?

Our world is not that natural

- Quite a number of friendly fine-tunings
  - Cosmological constant $\sim (10^{-3}\ eV)^3$
    Just right for galaxies to form
    Linde' 87; Weinberg' 87
  - Light quark masses and α_{EM}
    Just right for $m_n > m_p$
    but stable nuclei
  - Primordial density perturbations $\frac{\delta\rho}{\rho} \sim 10^{-5}$
    Just right to form stars
    but not supermassive galaxies w/o planets
    Tegmark, Rees' 97

Anthropic principle

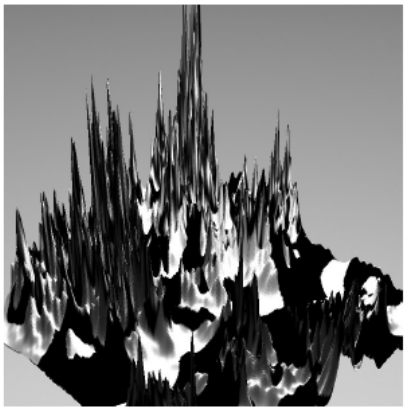
- Started long ago

Anthropic principle/environmentalism

"Our location in the Universe
is neccessarily priviledged to
the extent of being compatible
with our existence as observers"
Brandon Carter'1974

Recent support from
"string landscape"

We exist where couplings/masses
are right

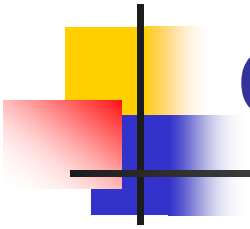


A.Linde, D.Linde, A.Mezhlumian' 93

Problem: never know which parameters are environmental and which derive from underlying physics

Disappointing, but may be true

“Dirac” Paradygm: pro and contra



- Fundamental physics is the realization of mathematical beauty BUT
- If we would even be able to derive everything from math WHY it is so suited for our life (Lee Smolin) ??
- Mathematics is infinite, reality is finite
- Are any probes of Multiverse INCIDE our Universe possible?!

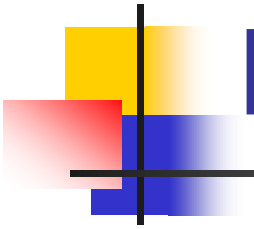
Is acceleration explainable by AP?

- Weinberg: cosmological constant cannot be too large

> But anthropic arguments provide not just a bound on ρ_V; they give us some idea of the value to be expected: ρ_V should be not very different from the mean of the values suitable for life. This is what Vilenkin[6] calls the "principle of mediocrity." This mean is positive, because if ρ_V were negative it would have to be less in absolute value than the mass density of the universe during the whole time that life evolves, since otherwise the universe would collapse before any astronomers come on the scene,[7] while if positive ρ_V only has to be less than the mass density of the universe at the time when most galaxies form, giving a much broader range of possible positive than negative values. In 1997-8 Martel, Shapiro, and I[8] carried out

- Vilenkin: mediocrity principle
- Linde: chaotic inflation

Nucleon mass



- p/n must be fine-tuned with ~1% accuracy to avoid neutron and hydrogen universes
- Can we see the traces of mediocrity in QCD??
- Suggestion: probe the momentum fractions carried by quarks and gluons

Momentum fractions of quarks and gluons

- Fundamental notions – matrix elements of energy momentum tensors
- Evolution towards UV fixed point
- If scale of matrix elements is defined by the temperature of the universe – backward evolution
- No nucleons at large scales – photons (or quantum states in QGP – similarity of momentum fractions in various hadrons ?)

Evolution of momentum fractions

- Asymptotically at large scale Q
- <xq>/<xG> ->3N/16=9/8
- Deviation from asymptotic value
- $d(Q)/d(Q_0) = (a(Q)/a(Q_0))^c$
- c=2(16/3+N)/(33-2N)
- =68/63 (N=6)
- =62/69 (N=5)
- =56/75 (N=4)
- =50/81 (N=3)

Low scale

- d(1GeV) – related to QCD scale and therefore to nucleon mass - is not far from asymptotics for nucleons, pions, transverse rho's
- Why?
- Suggestion – positivity of d plays a role

Positivity (of density matrix) and scale arrows

Physics Reports 470 (2009) 1–92

Contents lists available at ScienceDirect

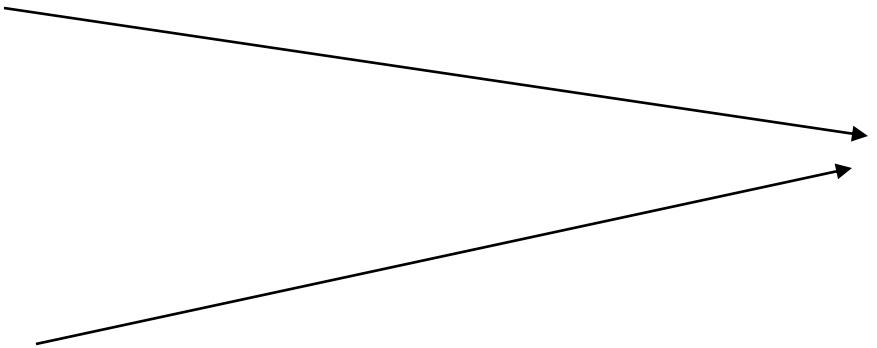
Physics Reports

journal homepage: www.elsevier.com/locate/physrep

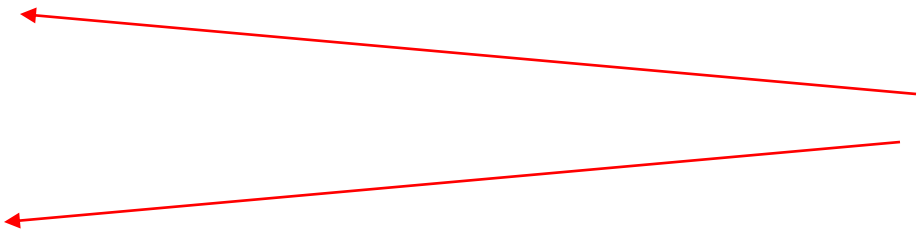
Spin observables and spin structure functions: Inequalities and dynamics

Xavier Artru [a], Mokhtar Elchikh [b], Jean-Marc Richard [c,*], Jacques Soffer [d], Oleg V. Teryaev [e]

- Direct (kinetic) – positivity(0<d<1) is preserved



- Backward (antikinetic) – may be violated



Initial conditions

- Evolution of d put the positivity bound

for QCD coupling as $d(Q)/d(Q_0) = (a(Q)/a(Q_0))^c$

- Initial conditions cannot deviate too much from asymptotic values
- But why they are close to asymptotical at low scale?
- 1st possibility: Strong NP evolution down to Q~0 – requires d(1GeV) be close to asymptotical in order to remain positive at Q~0
- 2nd possibility – pure statistical effect – seen in simulations of positivity constraints

Positivity constraints

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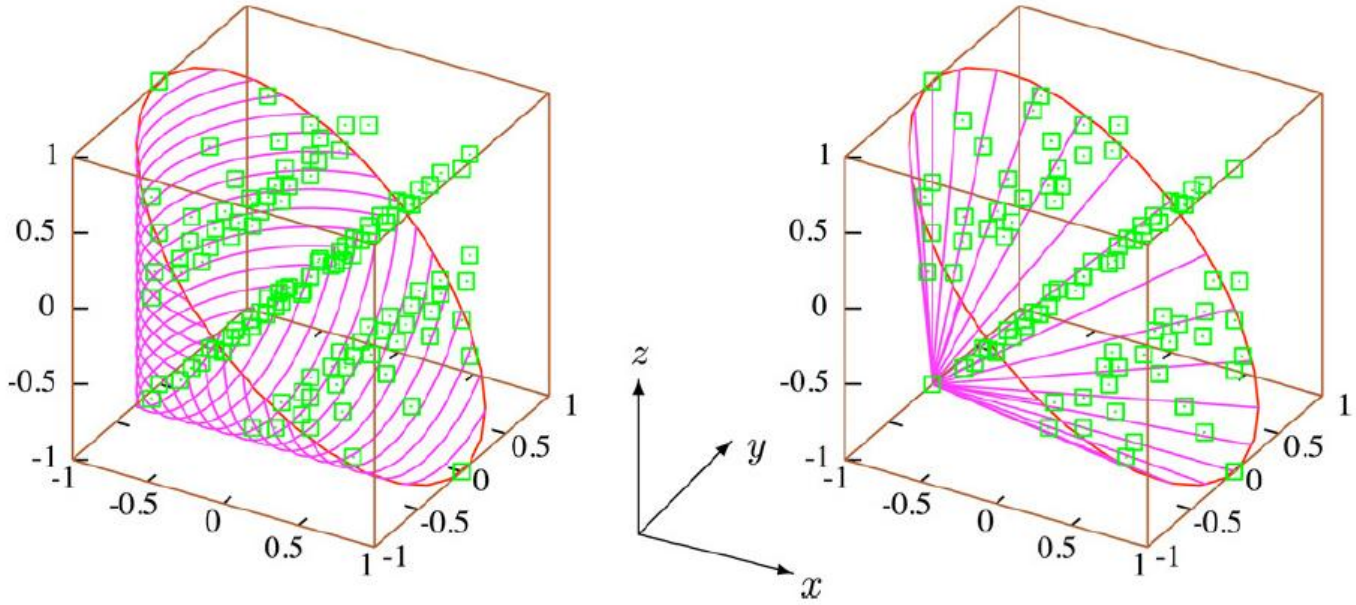
- Random simulation – typically far from saturation



QCD scale and proton mass

- In terms of d – requires improbable initial condition
- May be achieved by random probes
- Closeness to asymptotic values – NP evolution or statistiacl effect or…?
- Arguments in favour or against randomness of proton mass MAY BE found in principle
- Experimental/NP tests of momentum fractions

Probability and compensation

- Required valued are rather unprobable
- Should be compensated by a large number of trials
- “Event generator”: for cosmology/particle physics – chaotic (ethernal) inflation
- Similar problem of improbable initial condition – rather common (cf talk of P.Fiziev and D. Shirkov)

MWI&AP

The old and new Concepts of Physics
An open-dialogue journal
www.uni.lodz.pl/concepts

Many-worlds interpretation of quantum theory and mesoscopic anthropic principle.

Alexander Yu. Kamenshchik, (Bologna U. & INFN, Bologna & Landau Inst.) , Oleg V. Teryaev, (Dubna, JINR) . May 2007. 11pp.
Published in **Concepts Phys.V:575-592,2008**.
e-Print: **arXiv:0705.2494** [quant-ph]

MANY-WORLDS INTERPRETATION OF QUANTUM THEORY AND MESOSCOPIC ANTHROPIC PRINCIPLE

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(Received 28 June 2008; accepted 14 July 2008)

Abstract

We suggest to combine the Anthropic Principle with Many-Worlds Interpretation of Quantum Theory. Realizing the multiplicity of worlds it provides an opportunity of explanation of some important events which are assumed to be extremely improbable. The Mesoscopic Anthropic Principle suggested here is aimed to explain appearance of such events which are necessary for emergence of Life and Mind. It is complementary to Cosmological Anthropic Principle explaining the fine tuning of fundamental constants. We briefly discuss various possible applications of Mesoscopic Anthropic Principle including the

Concepts of Physics, Vol. V, No. 4(2008)
DOI: 10.2478/v10005-007-0045-4

Can we find non-cosmological test of AP?

- Yes, if it is extended to include non-cosmological coincidences
- Life even in suitable universe is still VERY unprobablel
- "Event generators" ?!

- Very large Universe – answer to Hawking's argument against AP -"our Solar system is certainly a prerequisite for our existence… But there does not seem any necessity for other galaxies to exist"
- But – no SMOOTH variations required to reach "fine-tuned" coincidence
- "Many worlds interpretation of quantum mechanics – extremely efficient "Universes generator"

Planetary coincidences

- Solar eclipse – due to coincidence of Moon and Sun angular size
- Follows from AP if Eclipse was necessary for life emergence (OT, 2000)– testable in principle…
- Recent discovery – extra-Solar planets – many with non-circular orbits – surprise
- "Natural" explanation – AP: non-circular – more probable (in reality about 20% with $e < 0.1$)
- Other Solar planets circular – because it is not possible for one circular and other non-circular planets to emerge

AP and biological evolution

- Life appears only in one (few) of Universes in many-world interpretation (McFadden, 2000)
- Life is unique in Universe – both in space and time
- Natural extension – "directed" evolution – problem ever since Darwin discovered ADAPTIVE evolution – explained by AP: only in very rare places of Multiverse complexity is increasing
- Support – punctuated equilibrium, irreversibility in brain formation, "Out of Africa", "Mitochondrial Eve"
- Quantum mechanics is necessary as "event generator"

So what happens?

- Very general paradygm of fundamental physics may be changed
- May lead to dramatic consequences to other sciences
- May also strongly influence the public understanding of science and life