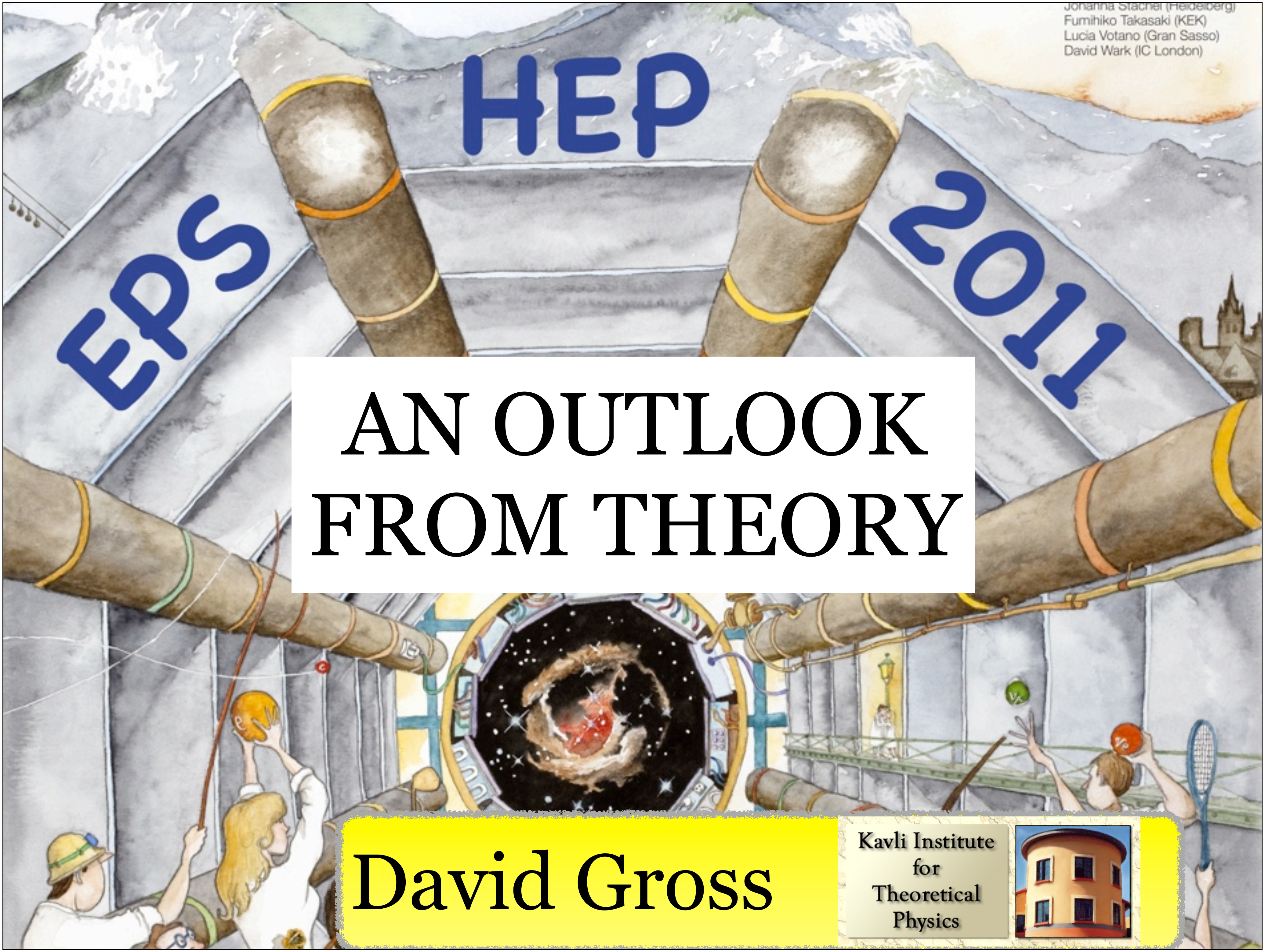


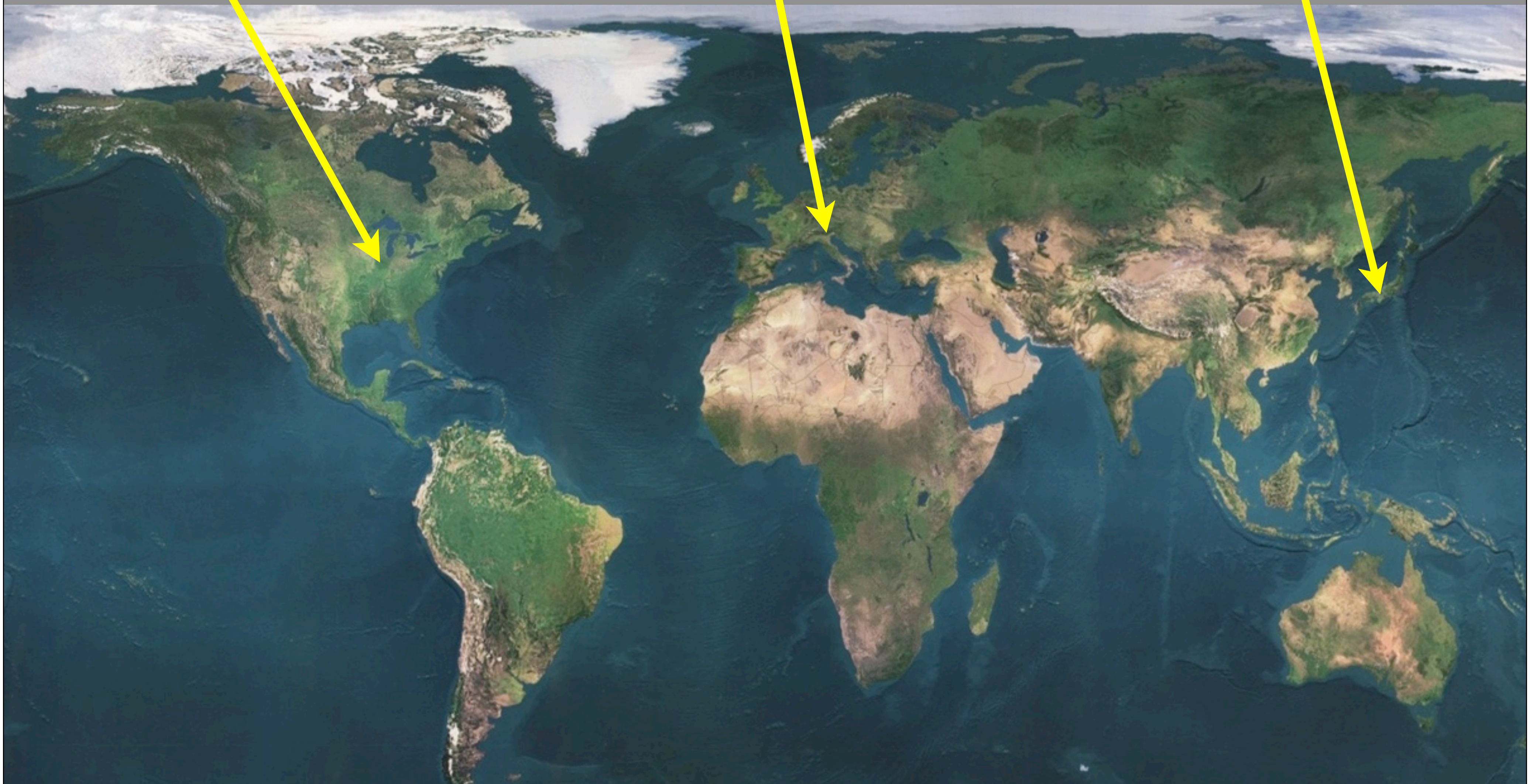
AN OUTLOOK FROM THEORY

David Gross

Kavli Institute for Theoretical Physics

A OUTLOOK FROM

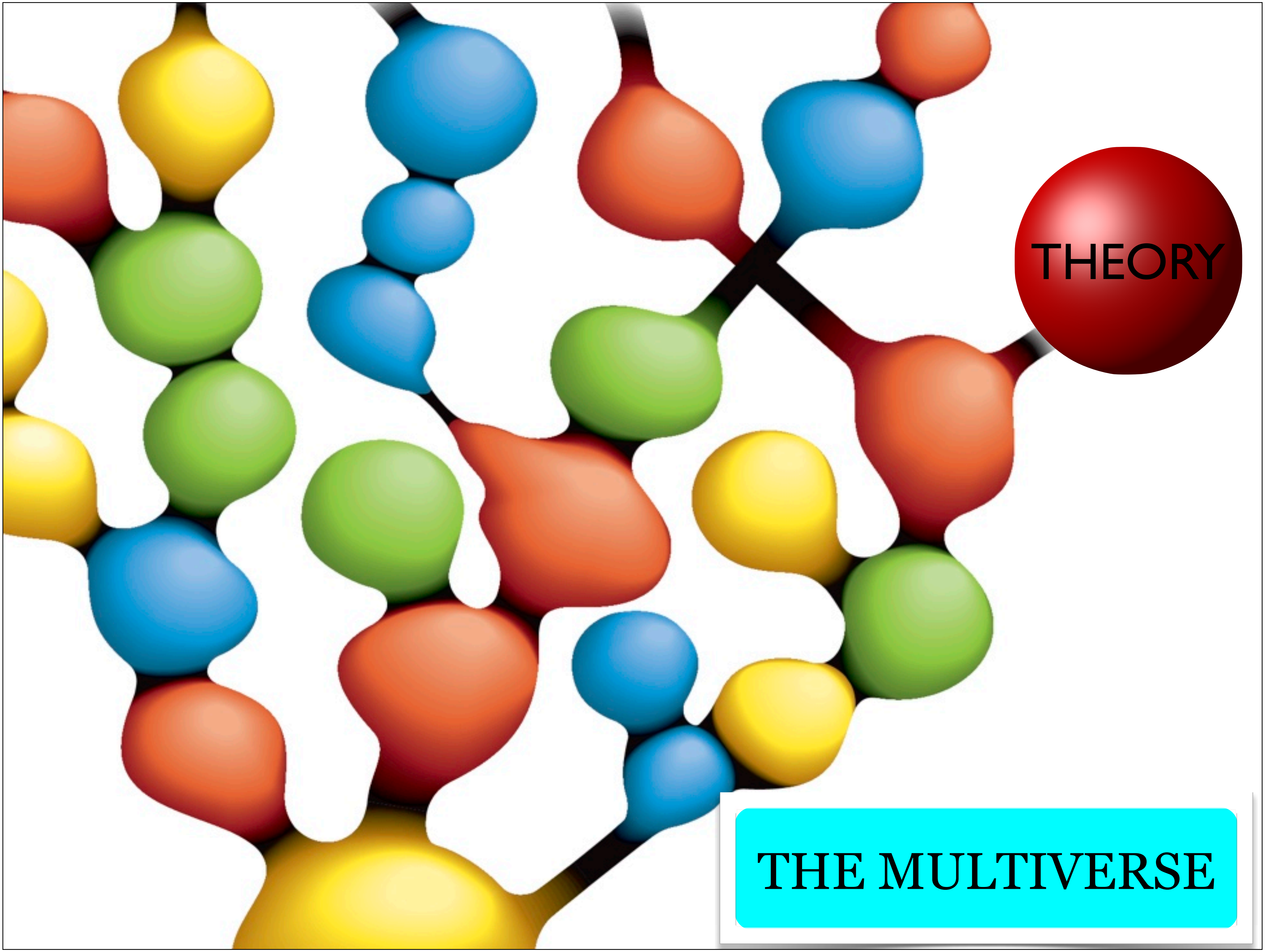
AMERICA EUROPE ASIA



WHERE IS THEORY ?

WHERE IS THEORY ?


THEORY


THEORY
THE MULTIVERSE

THE STANDARD THEORY

$\mathcal{L} =$ ELECTROWEAK QCD

$$-\frac{1}{4g'^4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4g^2}W^a_{\mu\nu}W^{\mu\nu a} - \frac{1}{4g_s^2}G^a_{\mu\nu}G^{\mu\nu a}$$

$$+\bar{Q}_i i\not{D} Q_i + \bar{u}_i i\not{D} u_i + \bar{d}_i i\not{D} d_i + \bar{L}_i i\not{D} L_i + \bar{e}_i i\not{D} e_i$$

$$+(Y_u^{ij}\bar{Q}_i u_j \tilde{H} + Y_d^{ij}\bar{Q}_i d_j H + Y_l^{ij}\bar{L}_i e_j H + c.c.)$$

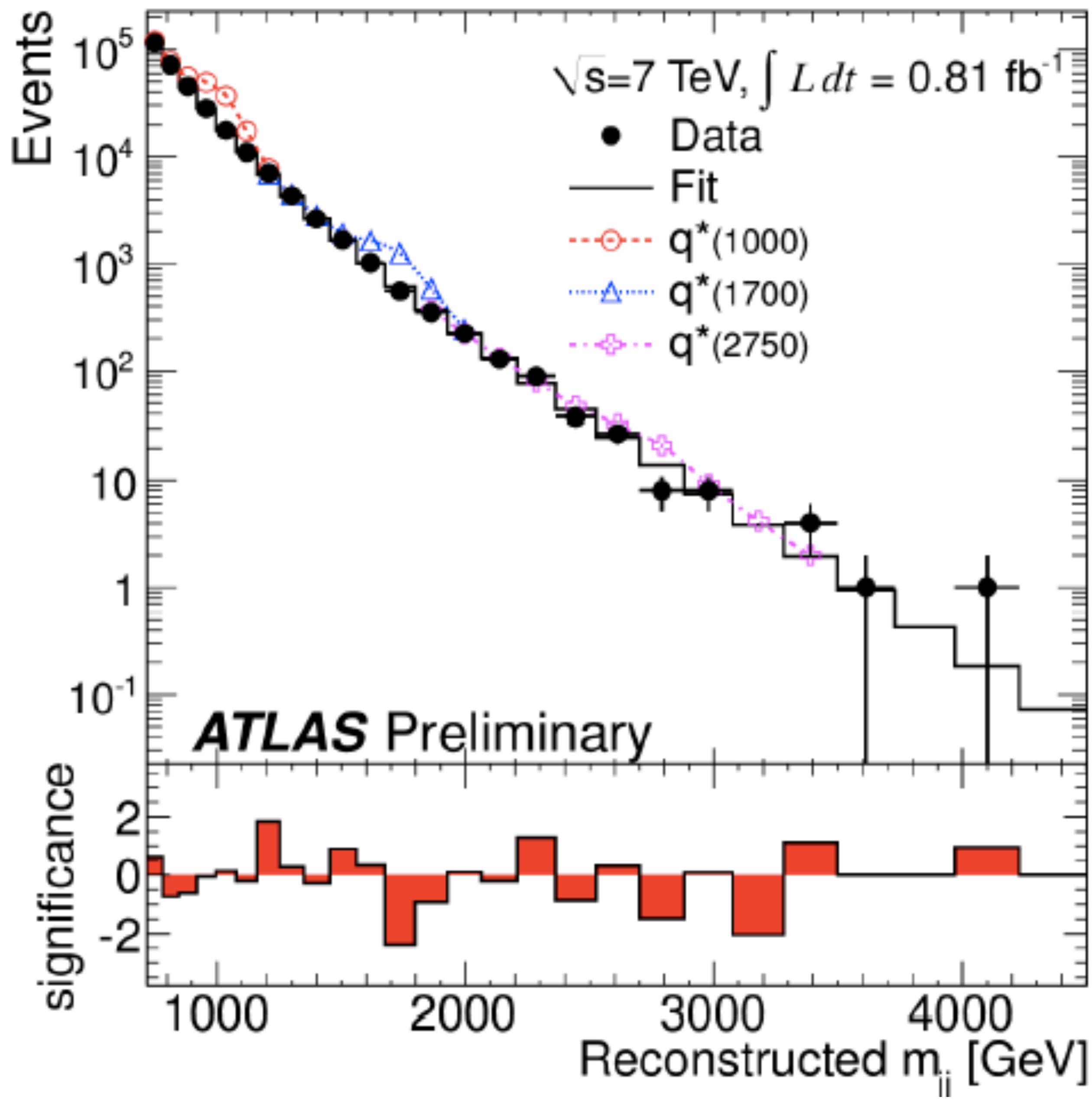
$$-\lambda(H^\dagger H)^2 + \lambda v^2 H^\dagger H + \frac{\theta}{64\pi^2}\epsilon^{\mu\nu\rho\sigma}G^a_{\mu\nu}G^a_{\rho\sigma}$$

1

UNBELIEVABLY SUCCESSFUL

DI-JET CROSS SECTION

ATLAS-CONF-2011-095; 0.81 fb^{-1} of 2011 data

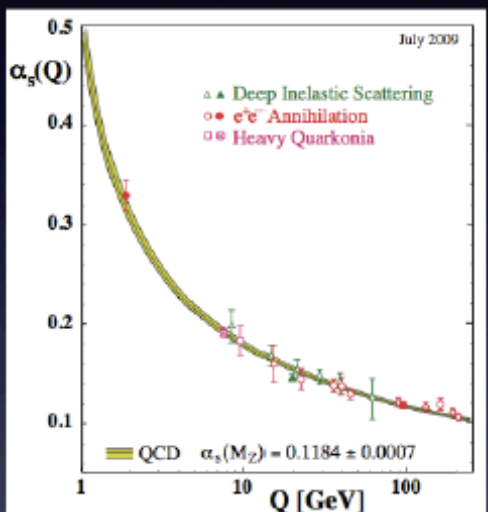


α_s in year 2011

dedicated workshop in Munich in February 2011
Courtesy of S. Bethke

2009 world summary

$\alpha_s = 0.1184 \pm 0.0007$



Very preliminary July 2011 # : $\alpha_s = 0.1183 \pm 0.0010$

	Process	Q [GeV]	$\alpha_s(M_{Z^0})$	excl. mean $\alpha_s(M_{Z^0})$	std. dev.
	τ-decays	1.78	0.1197 ± 0.0016	0.1180 ± 0.0011	0.9
	DIS [F_2]	2 - 170	0.1142 ± 0.0023	0.1186 ± 0.0013	1.7
	DIS [e-p $\rightarrow$ jets]	6 - 100	0.1198 ± 0.0032	0.1182 ± 0.0010	0.5
	Lattice QCD	7.5	0.1183 ± 0.0008	0.1182 ± 0.0017	0.1
	Υ decays	9.46	$0.119^{+0.006}_{-0.005}$	0.1183 ± 0.0010	0.1
new	e^+e^- [jets & shps]	14 - 44	0.1172 ± 0.0051	0.1183 ± 0.0010	0.2
→	$p\bar{p}$ incl. jets	50-145	0.1161 ± 0.0045	0.1183 ± 0.0010	0.4
	e^+e^- [ew prec. data]	91.2	0.1193 ± 0.0028	0.1182 ± 0.0010	0.4
→	e^+e^- [jets & shps]	91 - 208	0.1208 ± 0.0038	0.1182 ± 0.0011	0.7
→	e^+e^- [5-jet]	91 - 208	$0.1155^{+0.0041}_{-0.0034}$	0.1183 ± 0.0010	0.6

Giulia Zanderighi
University of Oxford & STFC

ElectroWeak Theory

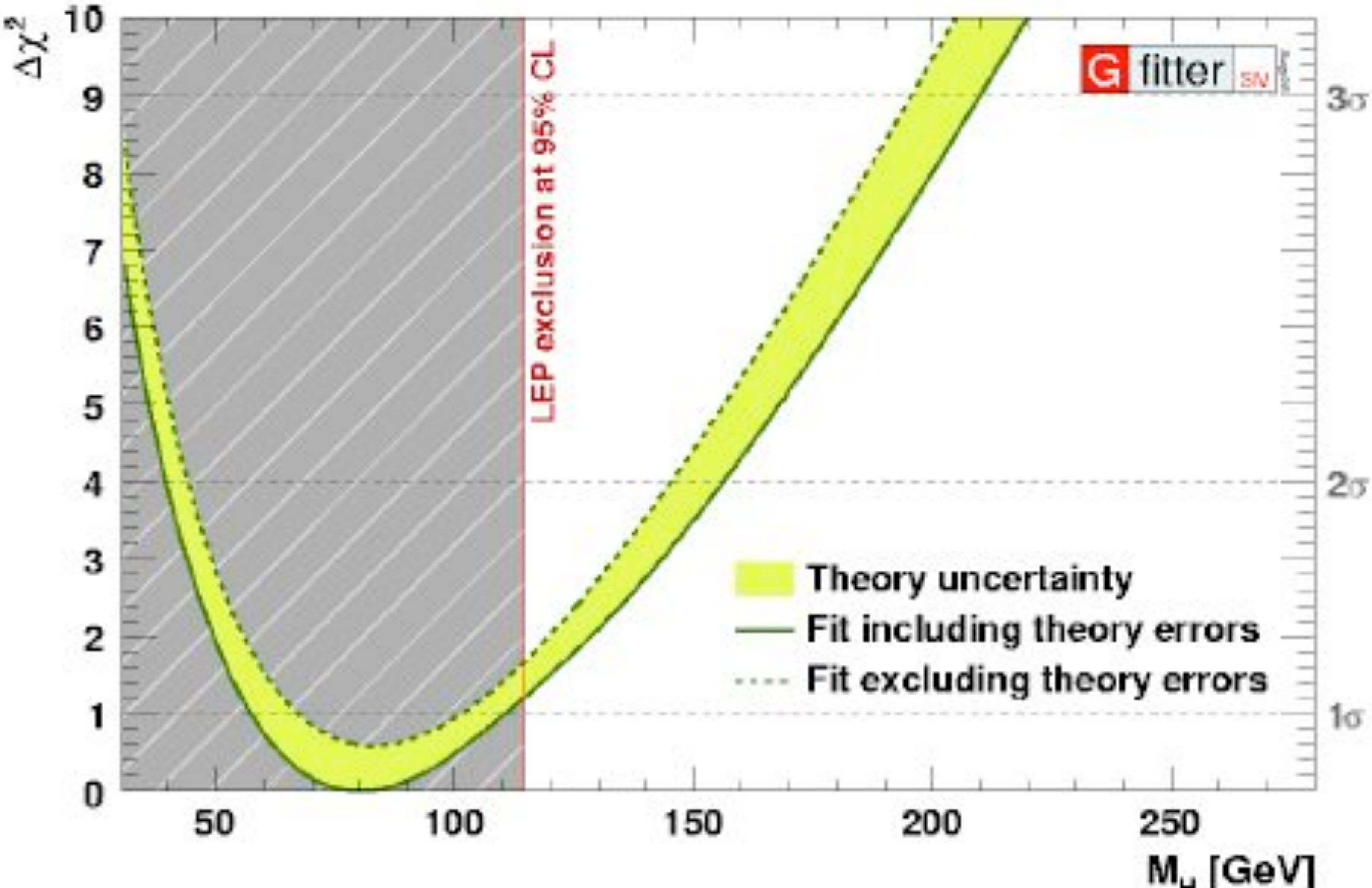
2

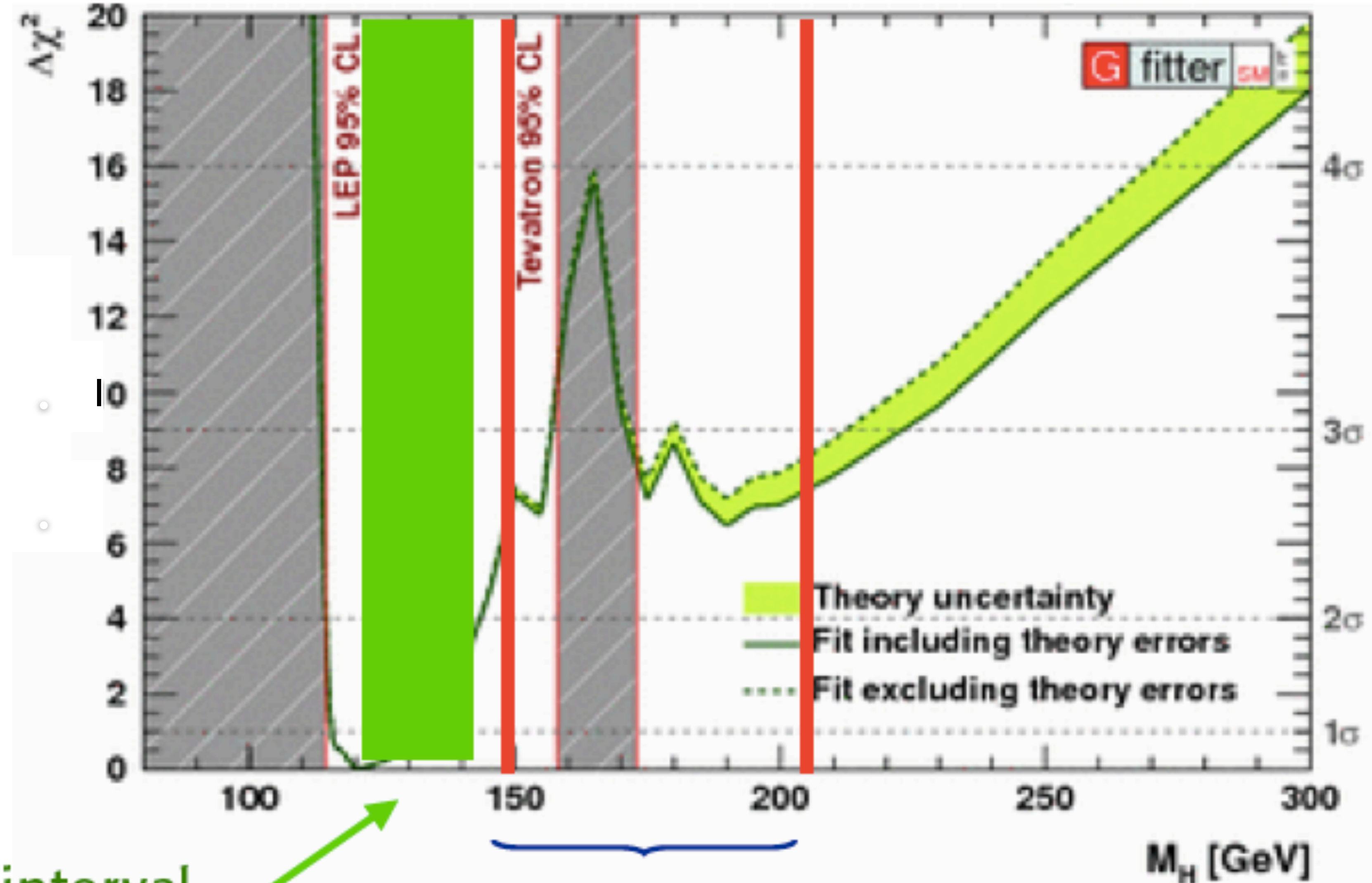
We Are Rapidly Closing In On The **HIGGS**

LARGE MASS HIGGS EXCLUSION

TANTALIZING HINTS OF LOW MASS (120-150) HIGGS

SM as well as SUSY suggest a light Higgs





interval
with excess
~2.5 σ

Excl. by ATLAS/CMS

also 300 < m_H < 450 GeV
is excluded

Guido Altarelli

BEYOND THE SM

- Dark Matter ✓
- Neutrino Masses
- Baryon Asymmetry
- Cosmic Acceleration
- Unification ✓
- Electroweak scale, "hierarchy" ✓
- Flavor masses, mixings, generations
- Cosmology, inflation, vacuum energy

Exp

TEV

Th

SUSY= QUANTUM DIMENSIONS of SPACE TIME

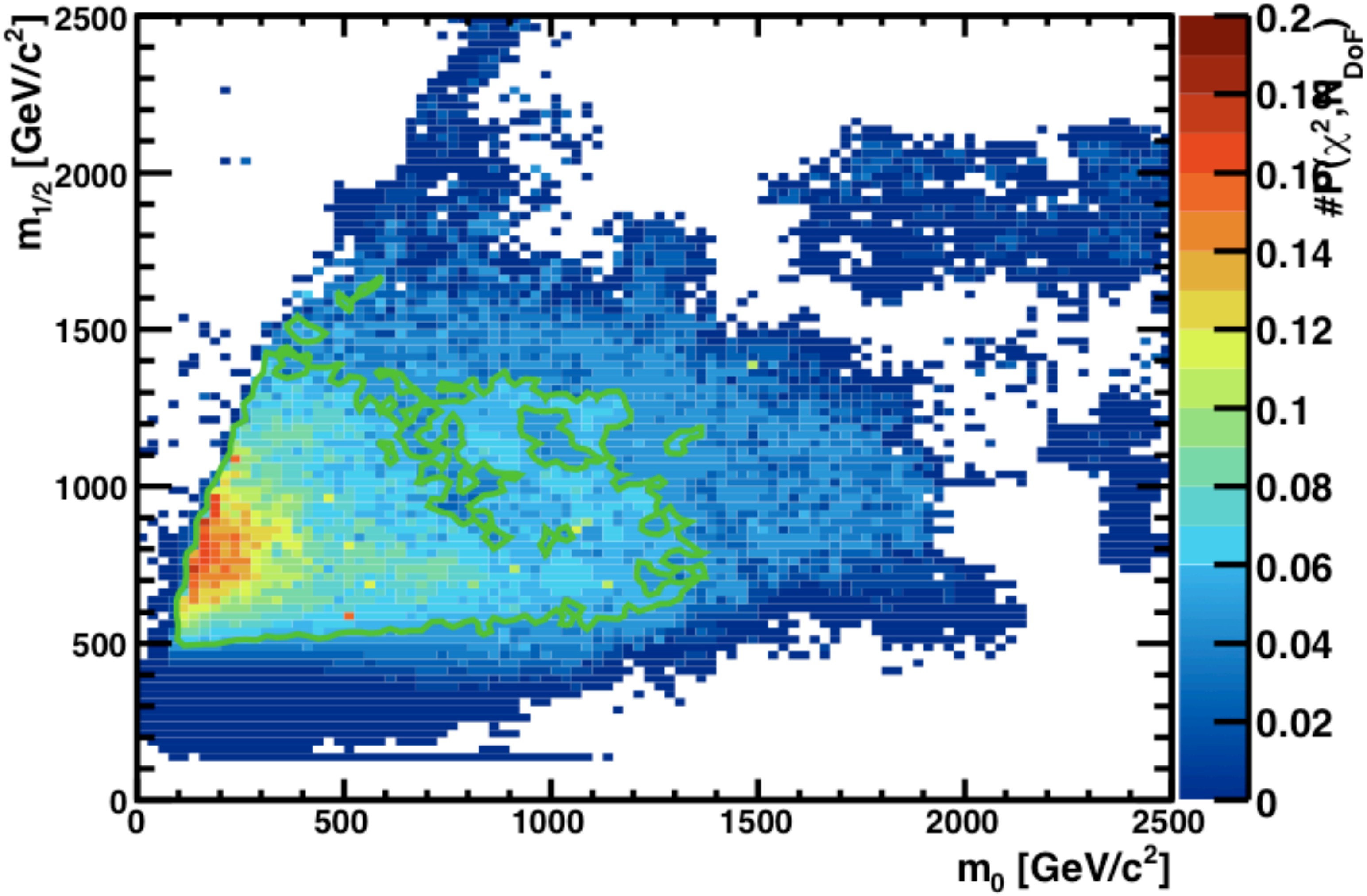
SUPERSYMMETRY IS BEAUTIFUL AND PREDICTIVE: GAUGE COUPLINGS, SPECTRUM

SUPERSYMMETRIC MODELS ARE NOT !

3

COLORED SPARTICLES ARE NOT AROUND THE CORNER

MasterCode Collaboration



CMMSM IS ON LIFE SUPPORT

THE CMSM

THE CONSTRAINED MINIMAL STANDARD MODEL

$$\alpha_1,\ \alpha_2,\ \alpha_3$$

$$M_{\mathrm{QUARKS}} = M_q$$

$$M_{\mathrm{LEPTONS}} = M_l$$

DARK MATTER = Neutrinos

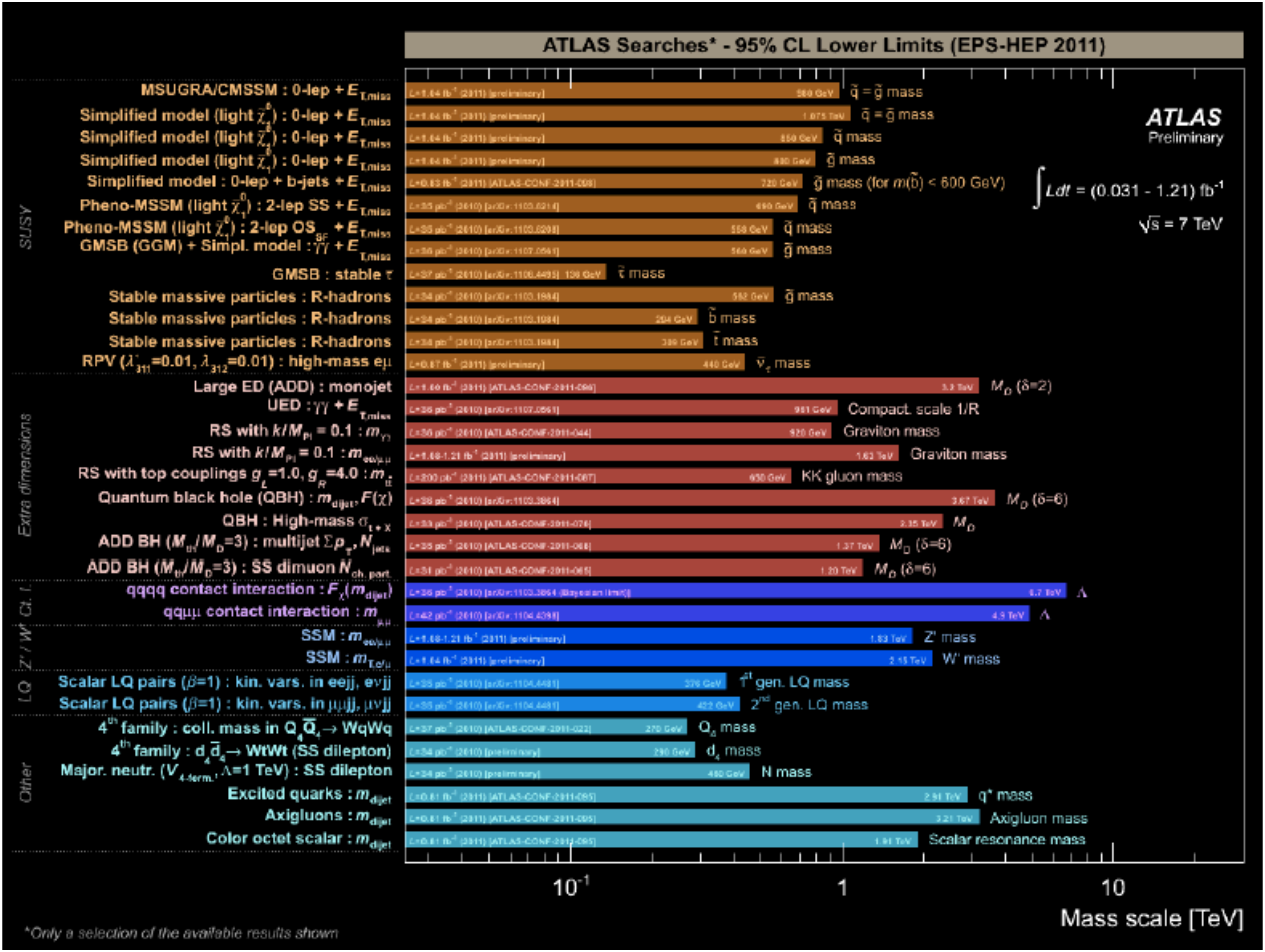
INFLATON = Higgs

4

NO SIGN OF

(Easily Discoverable)

NEW PHYSICS



ATLAS Searches* - 95% CL Lower Limits (EPS-HEP 2011)
ATLAS
Preliminary
$\int L dt$ = (0.031 - 1.21) fb^{-1}
$\sqrt{s}$ = 7 TeV
SUSY
MSUGRA/CMSSM : 0-lep + $E_{T,miss}$
Simplified model (light $\tilde{\chi}_1^0$) : 0-lep + $E_{T,miss}$
Simplified model (light $\tilde{\chi}_1^0$) : 0-lep + $E_{T,miss}$
Simplified model (light $\tilde{\chi}_1^0$) : 0-lep + $E_{T,miss}$
Simplified model : 0-lep + b-jets + $E_{T,miss}$
Pheno-MSSM (light $\tilde{\chi}_1^0$) : 2-lep SS + $E_{T,miss}$
Pheno-MSSM (light $\tilde{\chi}_1^0$) : 2-lep OS$_{SF}$ + $E_{T,miss}$
GMSB (GGM) + Simpl. model : $\gamma\gamma$ + $E_{T,miss}$
GMSB : stable $\tilde{\tau}$
Stable massive particles : R-hadrons
Stable massive particles : R-hadrons
Stable massive particles : R-hadrons
RPV (λ'_{311}=0.01, λ_{312}=0.01) : high-mass eμ
$\tilde{q} = \tilde{g}$ mass
$\tilde{q} = \tilde{g}$ mass
$\tilde{q}$ mass
$\tilde{g}$ mass
$\tilde{g}$ mass (for $m(\tilde{b})$ < 600 GeV)
$\tilde{q}$ mass
$\tilde{q}$ mass
$\tilde{g}$ mass
$\tilde{\tau}$ mass
$\tilde{g}$ mass
$\tilde{b}$ mass
$\tilde{t}$ mass
$\tilde{\nu}_\tau$ mass
Extra dimensions
Large ED (ADD) : monojet
UED : $\gamma\gamma$ + $E_{T,miss}$
RS with k/M_{Pl} = 0.1 : $m_{\gamma\gamma}$
RS with k/M_{Pl} = 0.1 : $m_{ee/\mu\mu}$
RS with top couplings g_L=1.0, g_R=4.0 : $m_{t\bar{t}}$
Quantum black hole (QBH) : m_{dijet}, $F(\chi)$
QBH : High-mass σ_{t+X}
ADD BH (M_{th}/M_D=3) : multijet Σp_T, N_{jets}
ADD BH (M_{th}/M_D=3) : SS dimuon $N_{ch. part.}$
M_D (δ=2)
Compact. scale 1/R
Graviton mass
Graviton mass
KK gluon mass
M_D (δ=6)
M_D
M_D (δ=6)
M_D (δ=6)
Ct. I.
qqqq contact interaction : $F_\chi(m_{dijet})$
qqμμ contact interaction : $m_{\mu\mu}$
Λ
Λ
Z' / W'
SSM : $m_{ee/\mu\mu}$
SSM : $m_{T,e/\mu}$
Z' mass
W' mass
LQ
Scalar LQ pairs (β=1) : kin. vars. in eejj, eνjj
Scalar LQ pairs (β=1) : kin. vars. in μμjj, μνjj
1st gen. LQ mass
2nd gen. LQ mass
Other
4th family : coll. mass in $Q_4\bar{Q}_4 \rightarrow WqWq$
4th family : $d_4\bar{d}_4 \rightarrow WtWt$ (SS dilepton)
Major. neutr. ($V_{4\text{-ferm.}}$, Λ=1 TeV) : SS dilepton
Excited quarks : m_{dijet}
Axigluons : m_{dijet}
Color octet scalar : m_{dijet}
Q_4 mass
d_4 mass
N mass
q* mass
Axigluon mass
Scalar resonance mass
10^{-1}
1
10
Mass scale [TeV]
*Only a selection of the available results shown

NO SIGN OF

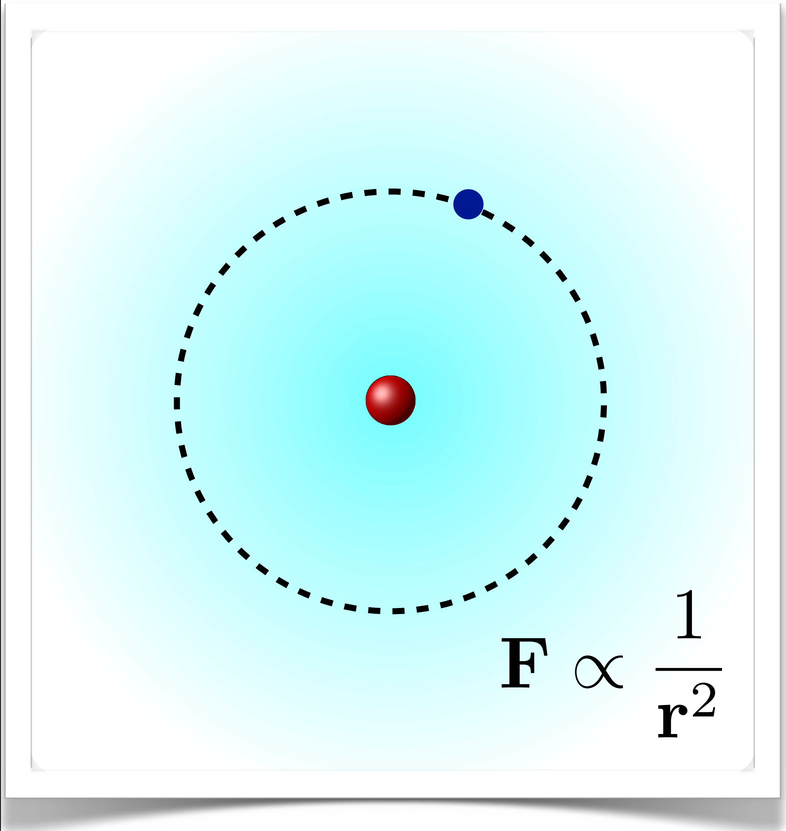
(Easily Discoverable)

NEW PHYSICS

WE NEVER SAID IT
WOULD BE EASY

MEANWHILE IN THEORY.....

WE HAVE FOUND THE HYDROGEN ATOM OF QUANTUM FIELD THEORY



An Integrable Model That Is A Good Approximation To The Real World

- ➔ Classical Mechanics
- ➔ Bohr Model
- ➔ Non Relativistic QM
- ➔ Dirac Equation
- ➔ Relativistic QM--QED

WE HAVE FOUND THE HYDROGEN ATOM OF QUANTUM FIELD THEORY

Asymptotically Free QCD

An Integrable Model That Is A Good Approximation To The Real World

For large momenta:

Free Theory of Quarks And Gluons

We Can Usefully Expand In $\alpha_s(p)$

To Calculate LHC Backgrounds

WE HAVE FOUND THE HYDROGEN ATOM OF QUANTUM FIELD THEORY

N=4
SUSY
GAUGE
THEORY
$N_C = \infty$

An Integrable Model That Is A Good Approximation To The Real World

To make contact with QCD we need to:

Break SUSY
Put in Quarks

AdS/CFT: Dual to a string theory in 10 dim.

NOT ONLY BEAUTIFUL

BUT USEFUL

QCD SCATTERING AMPLITUDES

QUARK GLUON LIQUID

MANY BODY THEORY

NOT ONLY USEFUL

BUT IMPORTANT

Connects To Many Of The Deepest Issues We Encounter In Our Attempts To Understand:

Quantum Gravity

(Black Holes, The Big Bang, Emergent Space)

String Theory & Field Theory

Theory Summary and Future Directions

LEPTON + PHOTON / 1993

50%

PREDICTIONS

I shall end this talk with a set of predictions. Since this conference is thirty years old I thought I might predict thirty years into the future—but that is much too far. So I will predict halfway, say fifteen years into the future, to the year 2008. First, ten experimental predictions, in order of likelihood:

1. The top quark will be old news and will have a mass of 160 ± 20 Gev. ✓

2. ϵ'/ϵ will finally be measured and will not be zero. In addition the three B-factories will have found new manifestations of CP violations. ✓

3. At least 2 light Higgs particles will be found after a few years of running at the SSC. ✗

4. There will be convincing evidence for the existence of supersymmetric particles. ✗

5. The astrophysicists will finally have determined that $\Omega = 1$ with an accuracy of 10%. Particle physicists will understand that this mass density is composed of a combination of baryons, axions, neutrinos and neutralinos with various weights (some of which could be zero.) ✓

6. The observation of neutrino oscillations will verify the MSW mechanism and be consistent with the solar neutrino problem. ✓

7. There will be evidence of the quark gluon plasma and of a chiral phase transitions in heavy ion collisions. ✓

8. Some number of new Z-mesons will be discovered. ✗

9. There will be cloudy evidence of superstrings. ✗

10. Finally, the most surprising and strange of all predictions—there will be a real surprise! ✓

Λ

Ten more predictions for theory:

1. Lattice gauge theory, armed with Mega-Tera-flop computers, will calculate the hadronic spectrum from QCD with 1% precision.

2. Analytic treatments in QCD will developed to describe small x physics, Regge behavior and hadronic fragmentation functions.

3. A nonperturbative treatment of QCD based on the $1/N_c$ expansion and/or stringy QCD will be developed. AdS/CFT

4. There will exist a quantitative understanding of the cosmological origin of baryons.

5. There will exist a quantitative understanding of the cosmological origin of density fluctuations leading to the large scale structure of the universe.

6. String field theory will begin to be a useful tool and will illuminate the underlying symmetries of the theory.

7. New mechanisms of string supersymmetry breaking will be discovered leading to new and definitive low energy models.

8. The conceptual revolution arising from the nonperturbative formulation of string theory will be in full swing, revolutionizing the concepts of space-time geometry.

9. The fate of evaporating black holes will be understood without modifing the basic principles of quantum mechanics.

10. And, most unlikely, we will understand why the cosmological constant is zero.

45%

NEW PREDICTIONS (10 years)

1. QCD tests & applications will greatly improve, incorporating NLO, NNLO,...and a theory of fragmentation and hadronization.
2. Atlas and CMS will discover a candidate Higgs particle.
3. There will be convincing evidence for Susy particles.
4. Plans will be underway to build a LC (at Cern) to explore the superworld and the US will join CERN.
5. There will be direct detection of the Dark Matter wind.
6. Alice will see a crossover to the perturbative quark-gluon plasma.
7. Some new Z mesons will be discovered.
8. Gravitational waves and B modes will be observed.
9. String theory will start to be a **theory** with predictions.
10. We will have a plausible explanation of why Λ is so small.

THE REAL HEROES OF THIS CONFERENCE

THE REAL HEROES OF THIS CONFERENCE

THE LEADERSHIP OF CERN AND THE GOVERNMENTS OF EUROPE WHO PERSEVERED AND PREVAILED

THE ACCELERATOR PHYSICISTS WHO BUILT THE LHC

THE PARTICLE PHYSICISTS WHO BUILT THE DETECTORS AND ARE ANALYZING THE DATA


C
D

Keep up the hard work.

BE PATIENT

1 FB^{-1} DOWN

2999 FB^{-1} TO GO

ENJOY

THE
FUN
IS JUST
BEGINNING