UNIVERSITY OF LIVERPOOL

Fröhlich Lecture Series in Physics 2011/2012

“Particle Physics in Transition”

Professor Max Klein
Department of Physics
University of Liverpool

16.00 Wednesday 26th October 2011
Rotblat Lecture Theatre, Chadwick Building

The Fröhlich Lectures are presentations by research leaders which are intended to be accessible to a general audience at the advanced undergraduate level.

Abstract

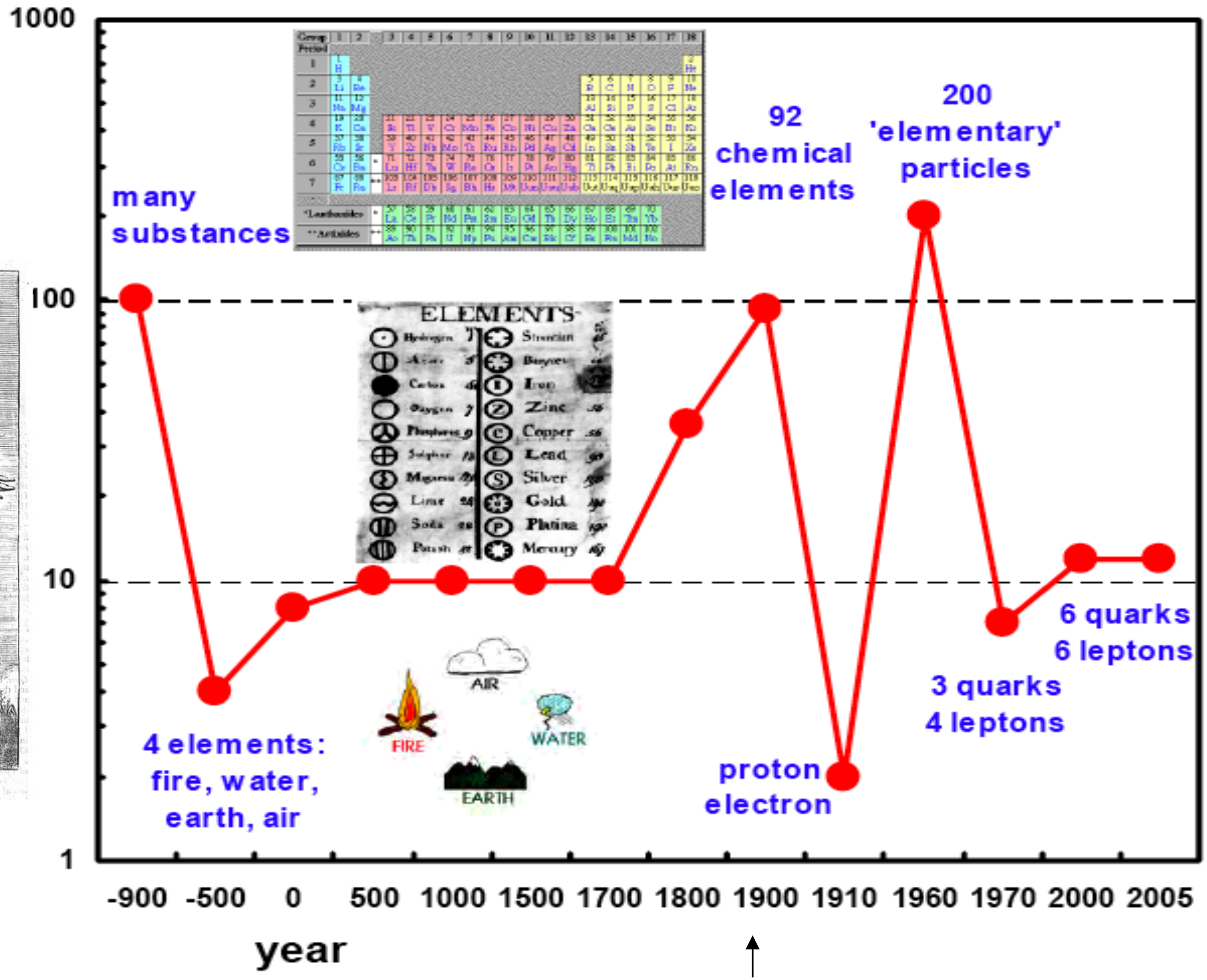
Elementary particle physics is now about a hundred years old. A variety of experimental discoveries has supported its Standard Model, a quantum field theory of the interactions of leptons and quarks, as the adequate description of phenomena at the Fermi energy scale. With the Large Hadron Collider at CERN and a number of further energy frontier and high precision accelerator projects we expect to be at the eve of changes and likely surprises in the persisting endeavour to resolve the smallest dimensions of nature.

Physics Projects

From Empedoclez to today

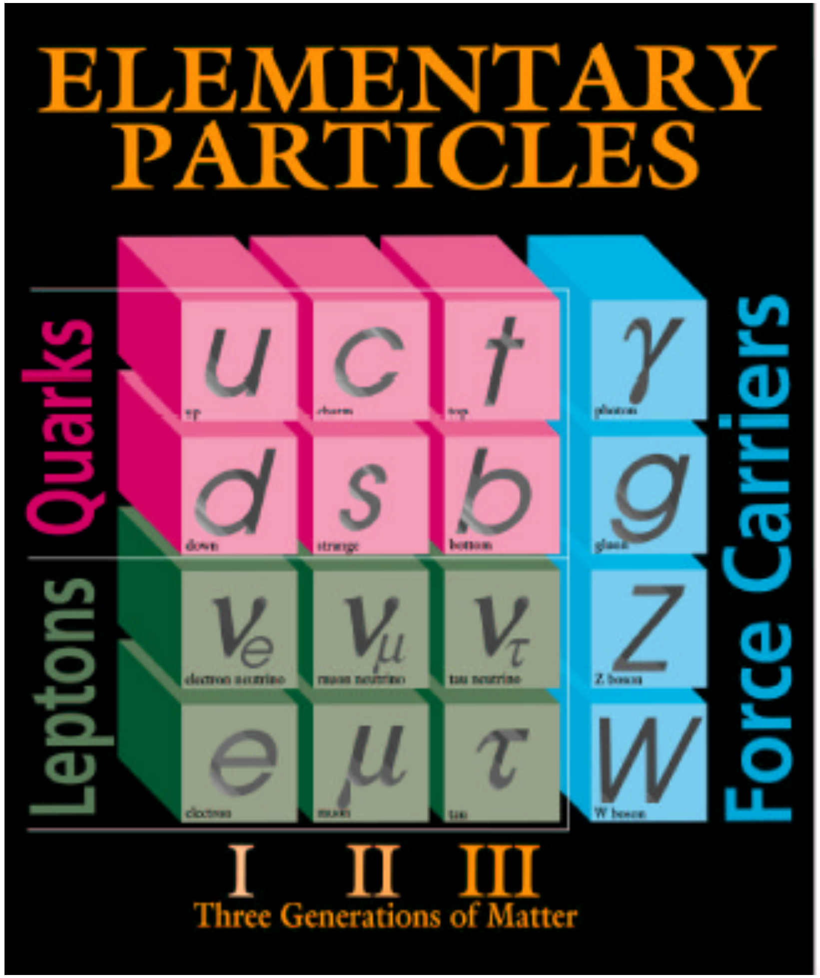
490-430 BC, Sicily

Four elements
and two forces
(love and strife)

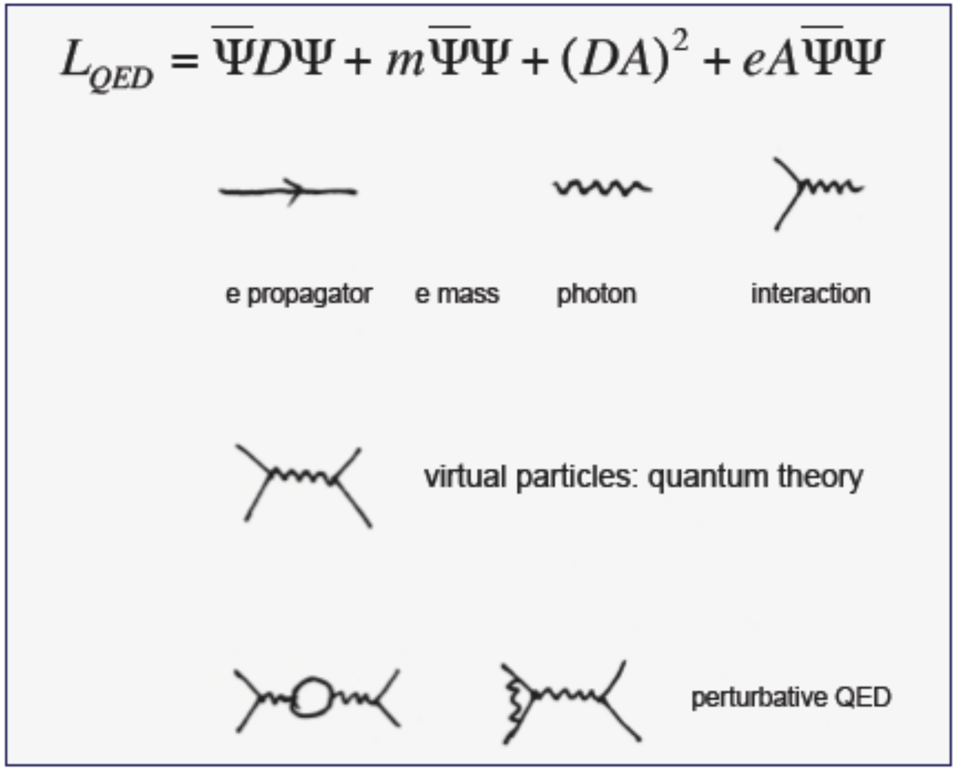


Lord Kelvin: There is nothing new to be discovered in physics.
All that remains is more and more precise measurement.

The Standard Model



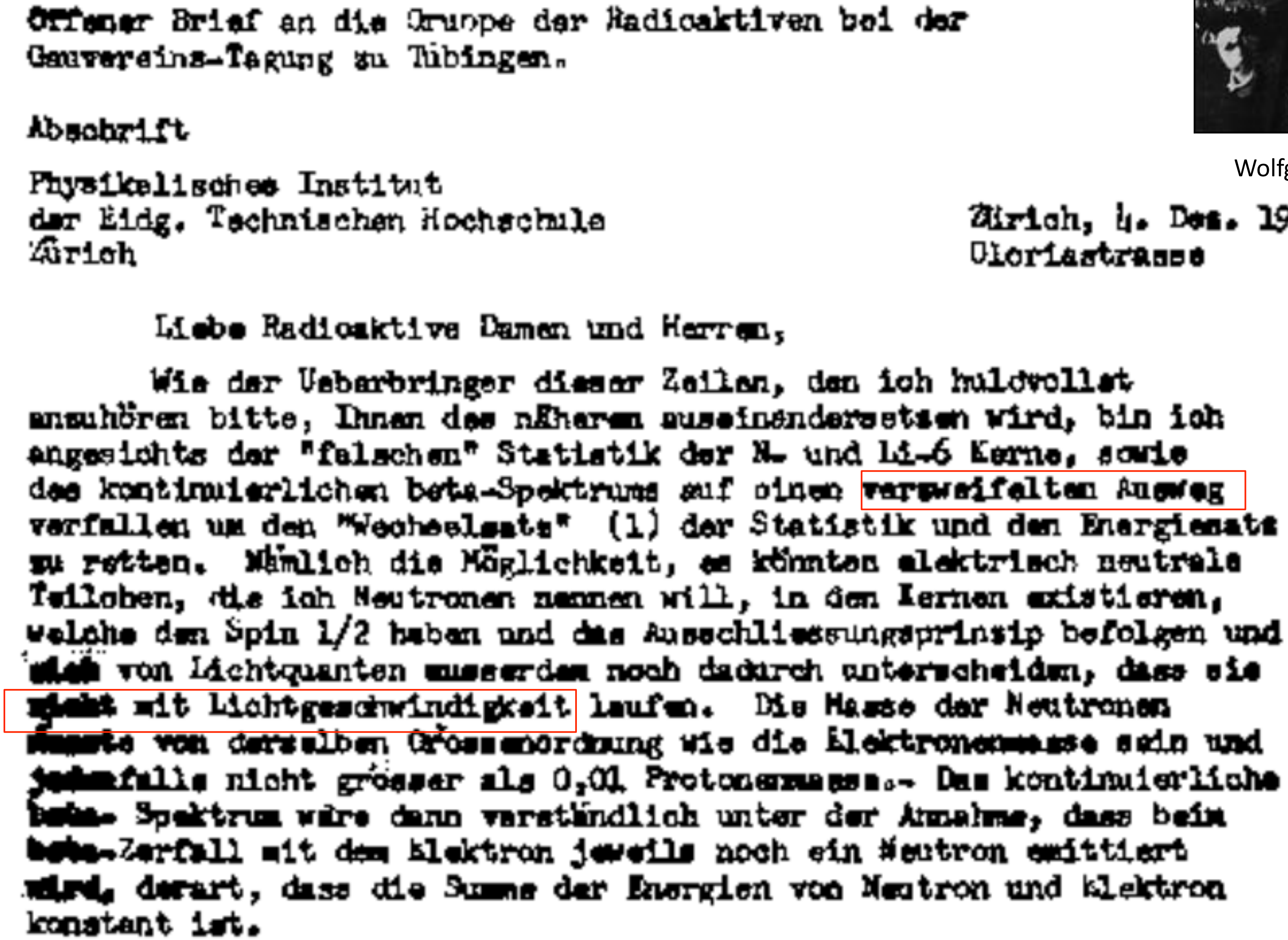
Renormalisable gauge field theory of the electromagnetic, strong and weak interaction.



$$L_{QED} = \overline{\Psi}D\Psi + m\overline{\Psi}\Psi + (DA)^2 + eA\overline{\Psi}\Psi$$

Higgs mechanism to damp divergence of WW cross section. H the “god” particle, a scalar.

Neutrinos



Offener Brief an die Gruppe der Radioaktiven bei der Gauvereins-Tagung zu Tübingen.

Abschrift

Physikalisches Institut
der Eidg. Technischen Hochschule
Zürich

Zürich, 4. Des. 1930
Gloriastrasse

Liebe Radioaktive Damen und Herren,

Wie der Ueberbringer dieser Zeilen, den ich huldvollst anzuhören bitte, Ihnen des näheren auseinandersetzen wird, bin ich angesichts der "falschen" Statistik der N- und Li-6 Kerne, sowie des kontinuierlichen beta-Spektrums auf einen verzweifelten Ausweg verfallen um den "Wechselsatz" (1) der Statistik und den Energiesatz zu retten. Nämlich die Möglichkeit, es könnten elektrisch neutrale Teilchen, die ich Neutronen nennen will, in den Kernen existieren, welche den Spin 1/2 haben und das Ausschliessungsprinzip befolgen und sich von Lichtquanten ausserdem noch dadurch unterscheiden, dass sie nicht mit Lichtgeschwindigkeit laufen. Die Masse der Neutronen müsste von derselben Grössenordnung wie die Elektronenmasse sein und jedenfalls nicht grösser als 0,01 Protonenmasse.- Das kontinuierliche beta- Spektrum wäre dann verständlich unter der Annahme, dass beim beta-Zerfall mit dem Elektron jeweils noch ein Neutron emittiert wird, derart, dass die Summe der Energien von Neutron und Elektron konstant ist.

Photo: AIP, Emilio Segrè Visual Archives

Wolfgang Pauli

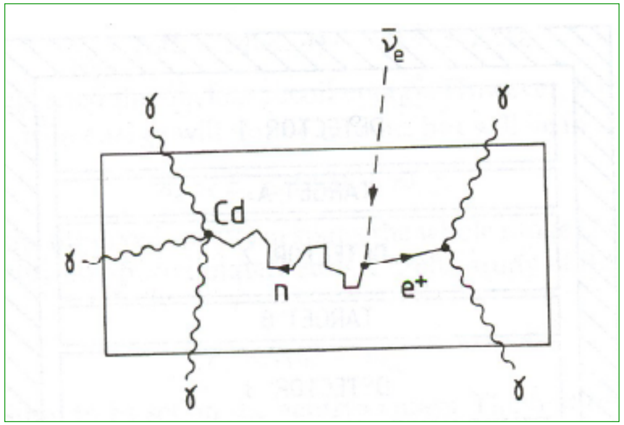
$n \rightarrow p\ e\ \nu$

Pauli in a letter to the “radioactive ladies and gentleman” postulates the neutron/ino
Too immature an idea to publish and o busy a man to participate in the workshop..

Early Neutrino Physics

Fred Reines, Clyde Cowan
Savannah River Reactor
$\nu p \rightarrow n e^+$ 1956

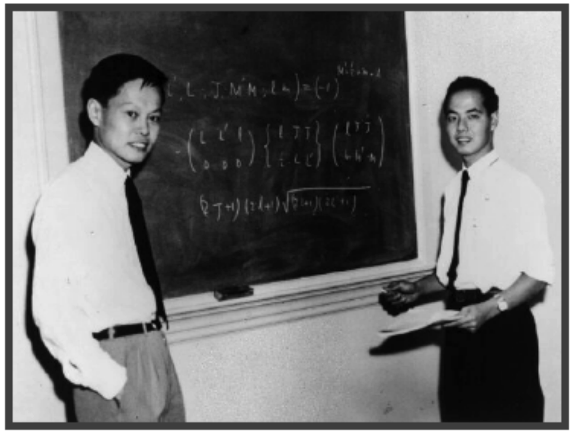
Discovery of the neutrino



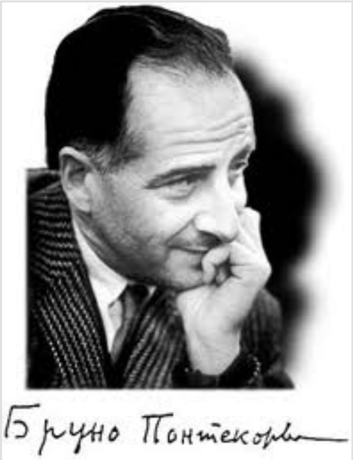
E_ν = 1 MeV. 2 events / hour

Parity violation.
Mme Wu et al., 1957

$$^{60}Co \rightarrow {}^{60}Ni^{*} e^{-} \overline{\nu}_e$$



Parity predicted to be violated
by T.D.Lee and C.N. Yang in 1956
(“θ-τ puzzle”)



Бруно Понтекорво

Bruno Pontecorvo
Inverse beta processes and nonconservation of lepton charge
Sov.Phys.JETP 7 (1958) 172-173.
The foundation of neutrino oscillation physics.

The standard picture of three neutrino mixing

- flavor oscillation described by PNMS matrix
- parametrized by 3 mixing angles and CP-violating phase δ_{CP}

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \cdot \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13} e^{-i\delta_{CP}} \\ 0 & 1 & 0 \\ -\sin\theta_{13} e^{-i\delta_{CP}} & 0 & \cos\theta_{13} \end{pmatrix} \cdot \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

“atmospheric sector”

θ_{23}

$\lvert\Delta m^2_{31}\rvert$	$(2.40^{+0.12}_{-0.11})\ 10^{-3}\ \mathrm{eV}^2$
$\sin^2\theta_{23}$	$0.50^{+0.07}_{-0.06}$

θ_{13}

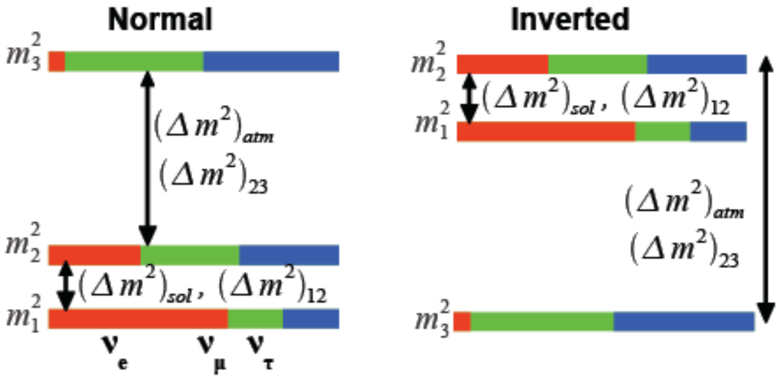
new

$\sin^2\theta_{13}$	$0.013^{+0.007}_{-0.005}$ $0.016^{+0.008}_{-0.006}$
δ	$\left(-0.61^{+0.75}_{-0.65}\right)\pi$ $\left(-0.41^{+0.65}_{-0.70}\right)\pi$

“solar sector”

θ_{12}

Δm^2_{21}	$(7.65^{+0.23}_{-0.20})\ 10^{-5}\ \mathrm{eV}^2$
$\sin^2\theta_{12}$	$0.304^{+0.022}_{-0.016}$

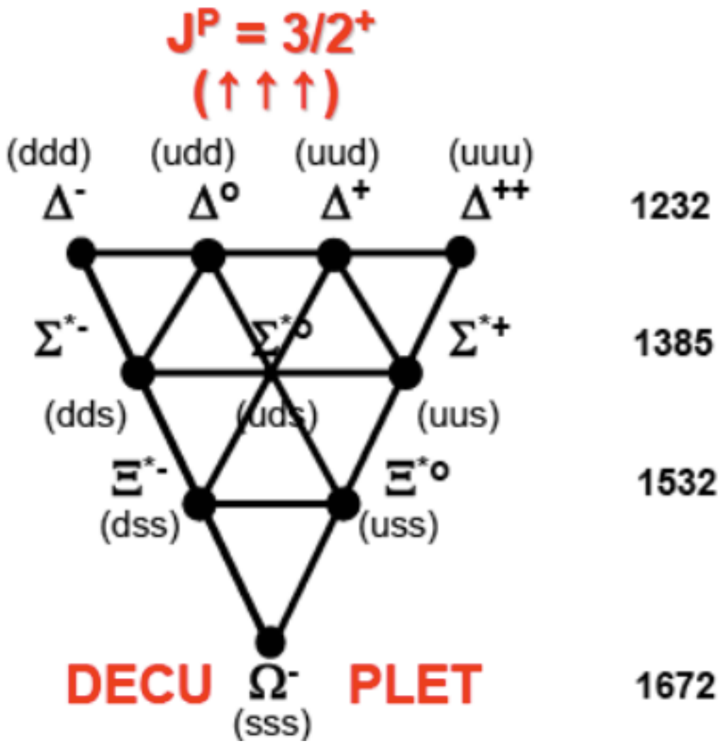


Most urgent points:

- $\sin^2 2\theta_{13} > 0.01$ at $>5\sigma$ significance ?
- Mass hierarchy $\Delta m_{31}^2>0$?, $\Delta m_{31}^2<0$?
- CP-phase $\delta \neq 0, \pi$ at $>3\sigma$ significance, δ true ?
- Unitarity ? tri-bimaximal ? differences between quark and lepton sectors ?

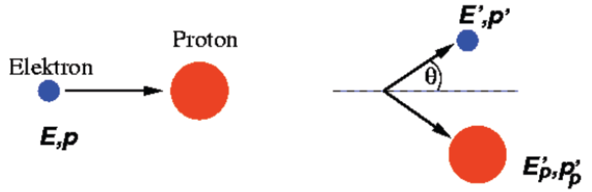
Early Quark-Parton Physics

[Three] quarks to explain the
proliferation of particles



Ω^- predicted 1962: Gell-Mann M=1685 MeV
observed at BNL 1964 at M=1686±12 MeV

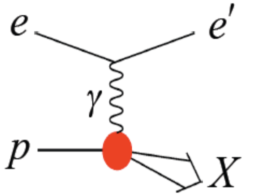
Hofstadter 1955



$$r_{\text{Proton}} = (0.74 \pm 0.24) \cdot 10^{-15}\,\text{m}$$

Deep Inelastic ep Scattering

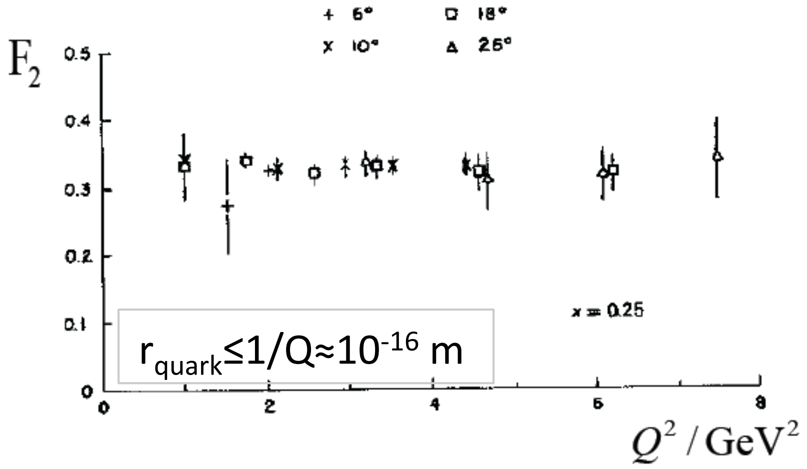
SLAC 1969
Friedman
Kendall
Taylor et al.



$E_e = 1.5 \ldots 20\,\text{GeV}$

$\theta = 6° \ldots 26°$

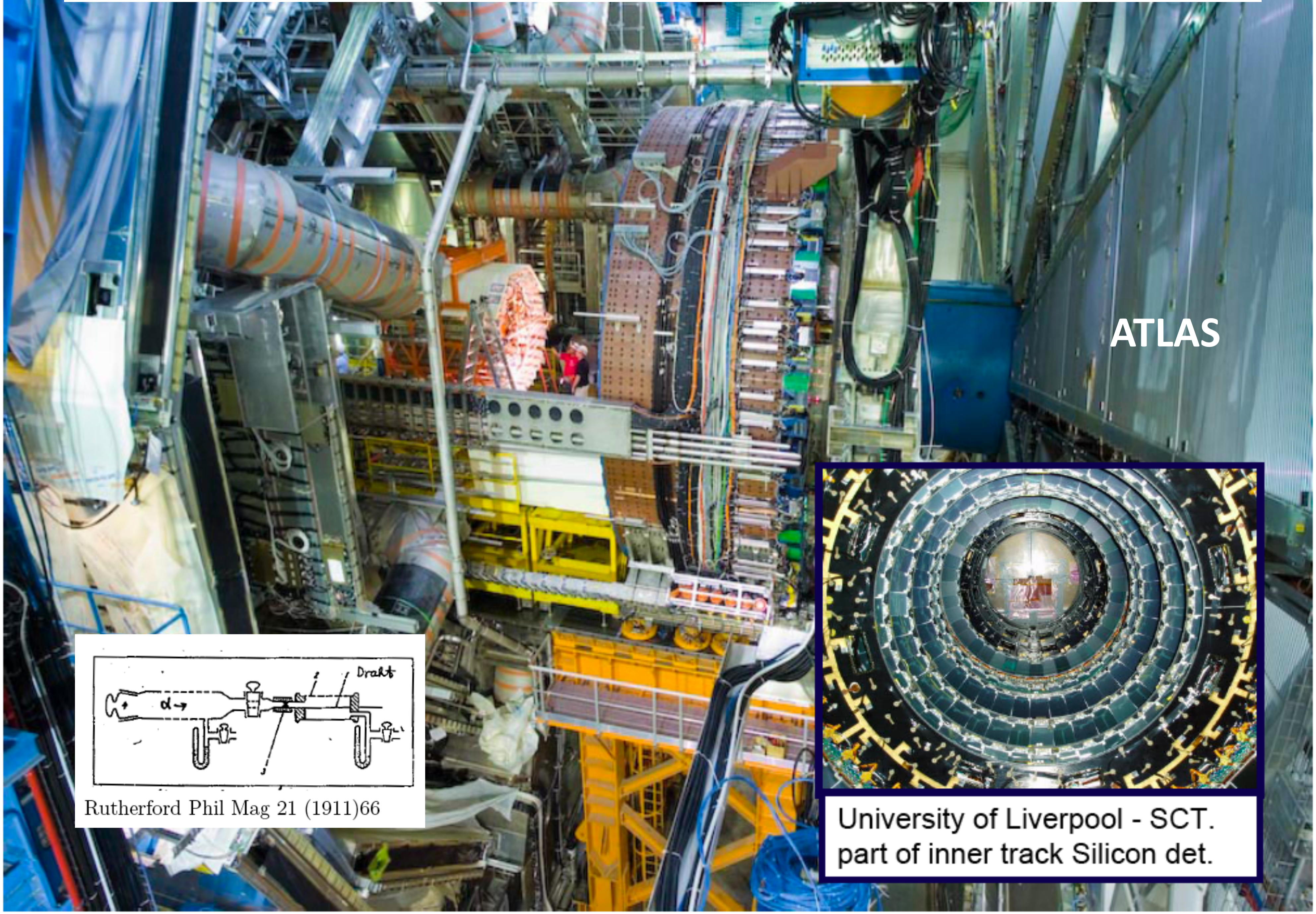
$Q^2 = 1 \ldots 7\,\text{GeV}^2$



$r_{\text{quark}} \leq 1/Q \approx 10^{-16}$ m

Partons to explain scaling behaviour

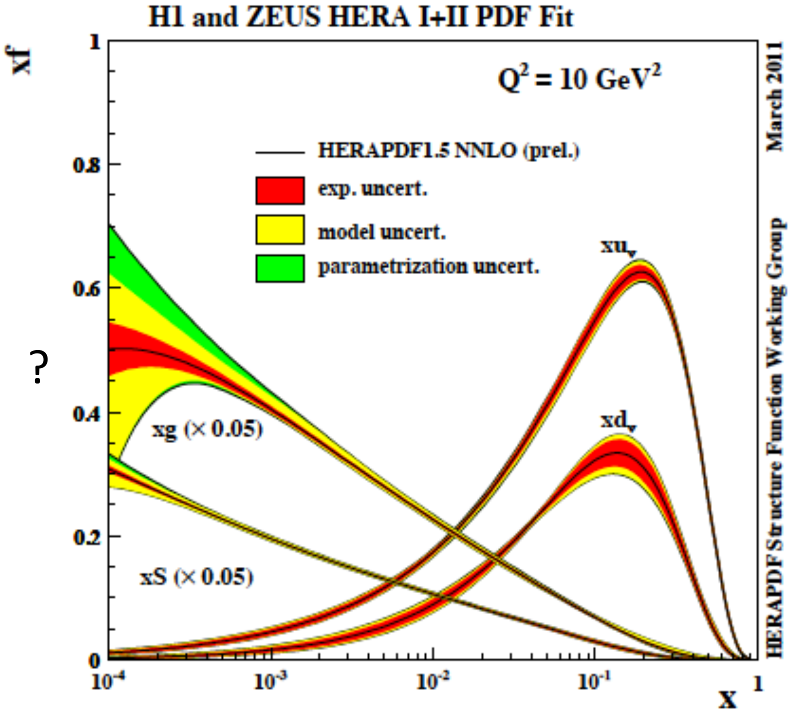
A gigantic evolution of instrumentation, electronics and computing over 100 years



Rutherford Phil Mag 21 (1911)66

University of Liverpool - SCT.
part of inner track Silicon det.

The standard picture of quark-parton dynamics



?

$$\mu\frac{dg(\mu)}{d\mu} = \beta(g(\mu))$$

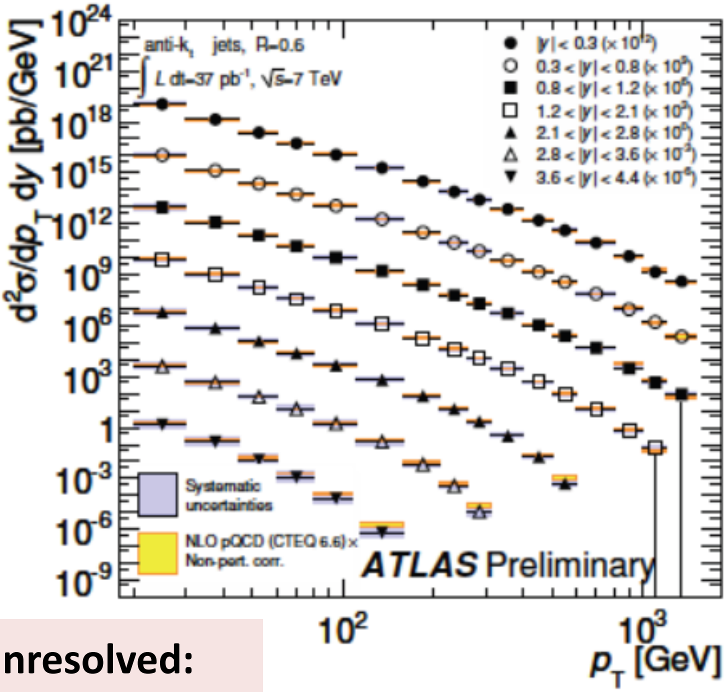
RGE

$$\beta(g) = -g\left[\frac{\alpha_s}{4\pi}\beta_1 + \left(\frac{\alpha_s}{4\pi}\right)^2\beta_2 + \ldots\right]$$

$$\frac{\alpha_s}{4\pi} = \frac{1}{\beta_1\ln(\mu^2/\Lambda^2)} - \frac{\beta_2\ln(\ln\mu^2/\Lambda^2)}{\beta_1^3\ln^2(\mu^2/\Lambda^2)} + \ldots$$

Asymptotic Freedom: perturbative QCD

Universal? parton distributions



Yet unresolved:

Gluon at high x/M

GUT (α_s to 0.1%)

QPM symmetries

Saturation

Axions, Odderons

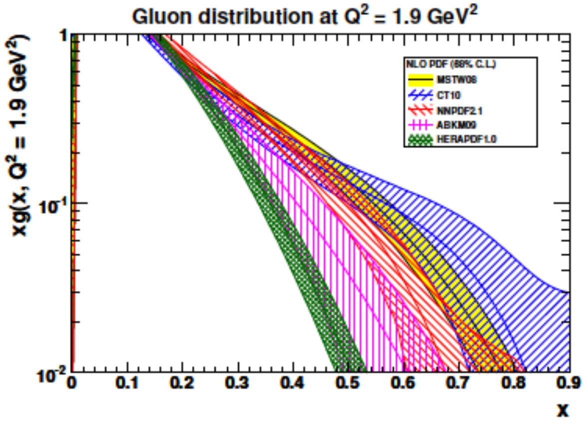
Instantons

Initial QGP state

N-PDFs

QCD-String-SUSY

Substructure..



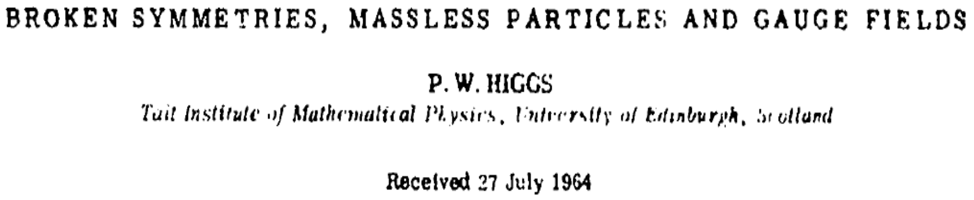
The Higgs Mechanism

Broken Symmetry (as in $M_p \neq M_n$):
non-invariant terms in L or [Nambu] L is symmetric but the ground state isn't

Spontaneous breaking of a global symmetry leads to the existence of massless scalar bosons [Goldstone]

Spontaneous breaking of a locally symmetric gauge theory [Yang Mills] implies:
Goldstone bosons disappear, massless gauge bosons become massive
and a massless scalar particle appears [Higgs, Brout, Engler, Kibble, Hagen..]

["The gauge fields have eaten the Goldstone bosons and grown heavy" Coleman]

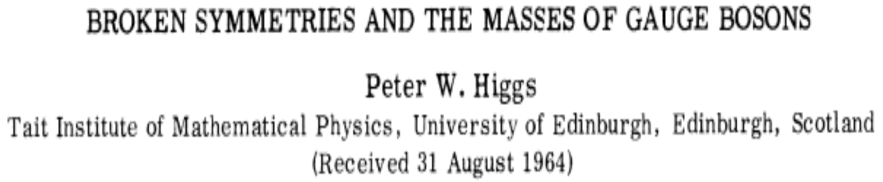


BROKEN SYMMETRIES, MASSLESS PARTICLES AND GAUGE FIELDS

P. W. HIGGS
Tait Institute of Mathematical Physics, University of Edinburgh, Scotland

Received 27 July 1964

Phys.Lett.12(1964)132-133



BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs
Tait Institute of Mathematical Physics, University of Edinburgh, Edinburgh, Scotland
(Received 31 August 1964)

Phys.Rev.Lett.13(1964)508-509

5+5 since 58

In the SM have 4 gauge fields ($A^{1,2,3}$,B) and the Higgs field (φ). The gauge fields are transformed to the mass eigenstates: Z, $W^{\pm}$ and the photon. **The masses of the weak interaction bosons are determined by the VEV of the Higgs potential**.

Remarks on the Higgs particle

$$L = (D_\mu\varphi)^+(D_\mu\varphi) - V(\varphi^+\varphi) - \frac{1}{4}F^a_{\mu\nu}(F^a)^{\mu\nu} - \frac{1}{4}G_{\mu\nu}G^{\mu\nu}$$

$$D_\mu = (\partial_\mu + igA^a_\mu\frac{\varepsilon_a}{2} + ig'B_\mu\frac{1}{2}), \varphi = \begin{pmatrix} 0 \\ \eta + \sigma(x)/\sqrt{2} \end{pmatrix}$$

$$(D_\mu\varphi)^+(D_\mu\varphi) = \frac{1}{2}(\partial_\mu\sigma)(\partial^\mu\sigma)$$

$$+\frac{1}{2}\left(\frac{g^2\eta^2}{2}\right)(A^1_\mu A^{1\mu} + A^2_\mu A^{2\mu})$$

$$+\frac{1}{2}\eta^2(gA^3_\mu - g'B_\mu)(gA^{3\mu} - g'B^\mu) + h.c.$$

$$\begin{pmatrix} Z_\mu \\ A_\mu \end{pmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & +\cos\theta \end{pmatrix}\begin{pmatrix} A^3_\mu \\ B_\mu \end{pmatrix}, \tan\theta = \frac{g'}{g}$$

$$W^\pm_\mu = \frac{1}{\sqrt{2}}(A^1_\mu \pm iA^2_\mu)$$

$$M_{W^+} = M_{W^-} = \frac{g\eta}{\sqrt{2}}$$

$$M_Z = \frac{M_W}{\cos\theta}$$

$$M_\gamma = 0$$

$$M_H = \sqrt{-2\mu^2} = 2\eta\cdot\sqrt{\lambda}$$

Gauge field Lagrangian a la QED

Covariant Derivative including four gauge fields transforming according to SU(2) [$A^{1,2,3}$] and U(1) B

φ is a specific choice of the Higgs field, η is its VEV. For $V=-\mu^2\,\varphi^+\varphi - \lambda\,(\varphi^+\varphi)^2$ it follows $\eta=\sqrt{(-\mu^2/2\lambda)}$

The explicit calculation of the 'DD' term yields a squared, i.e. mass term for an A^1,A^2 combination and, after rotation, for Z and A^3 , the photon!

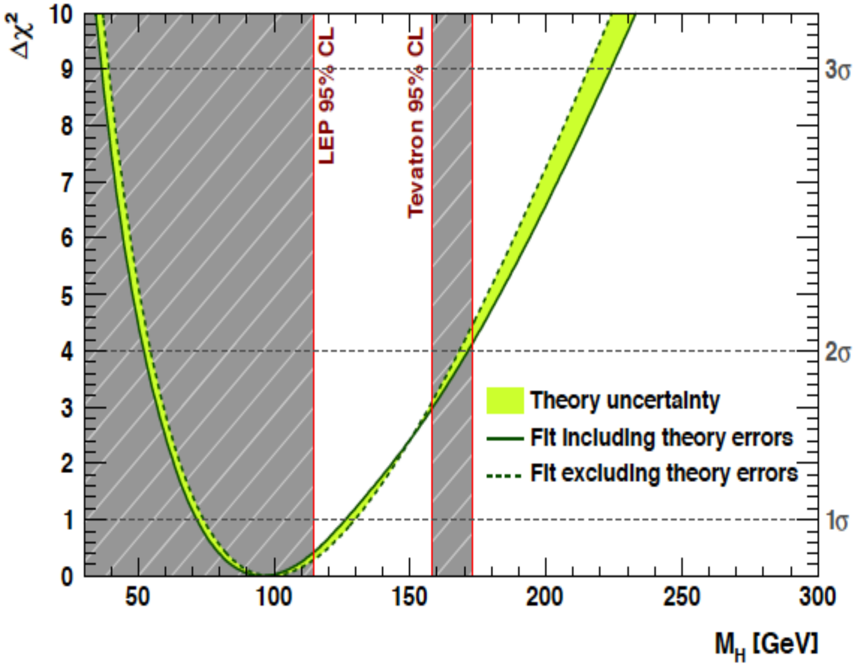
The weak and electromagnetic couplings g', g get related via the rotation (the "Weinberg") angle. Specifically one has e=g sinΘ. [data:sinΘ=0.23116(13)]

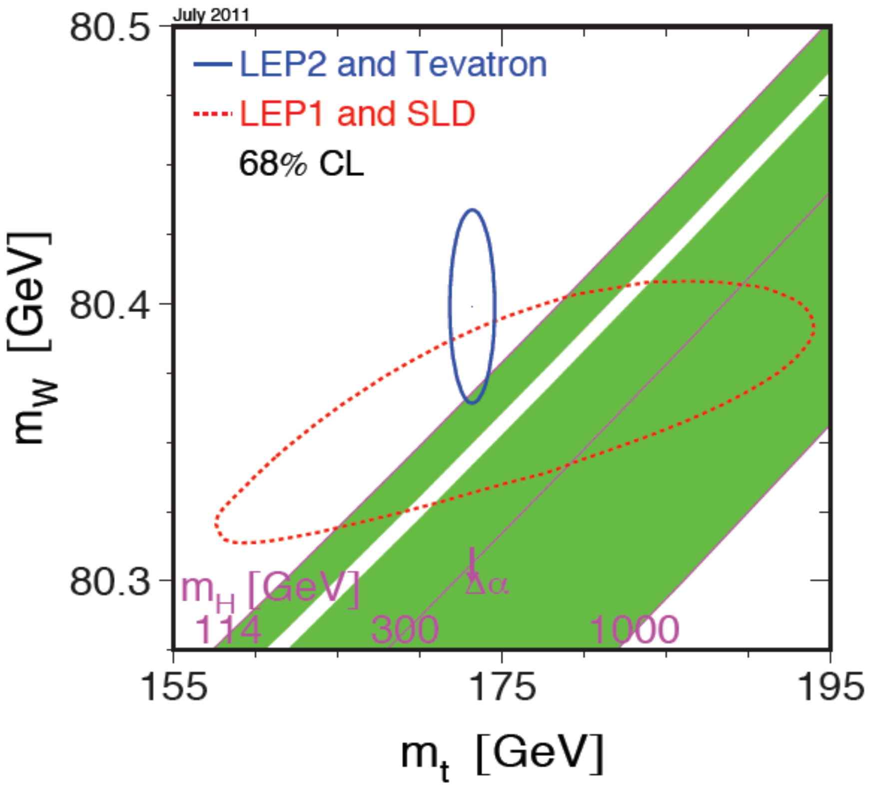
The masses are related to the VEV of the Higgs field.

All of this has been beautifully confirmed by experiment: W, Z, sinΘ, mass relations.

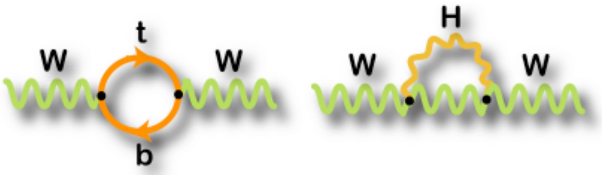
We don't know how large λ is and whether this choice of the Higgs mechanism is real.

Search for the Higgs Particle - indirect





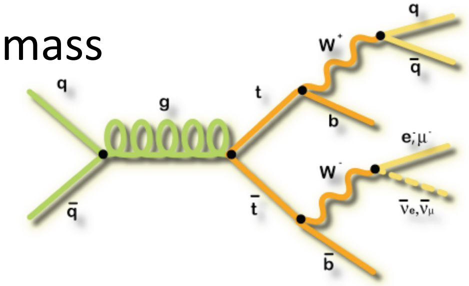
Determination of M_H within exploiting loop corrections



Successful example: prediction of top mass using e^+e^- data

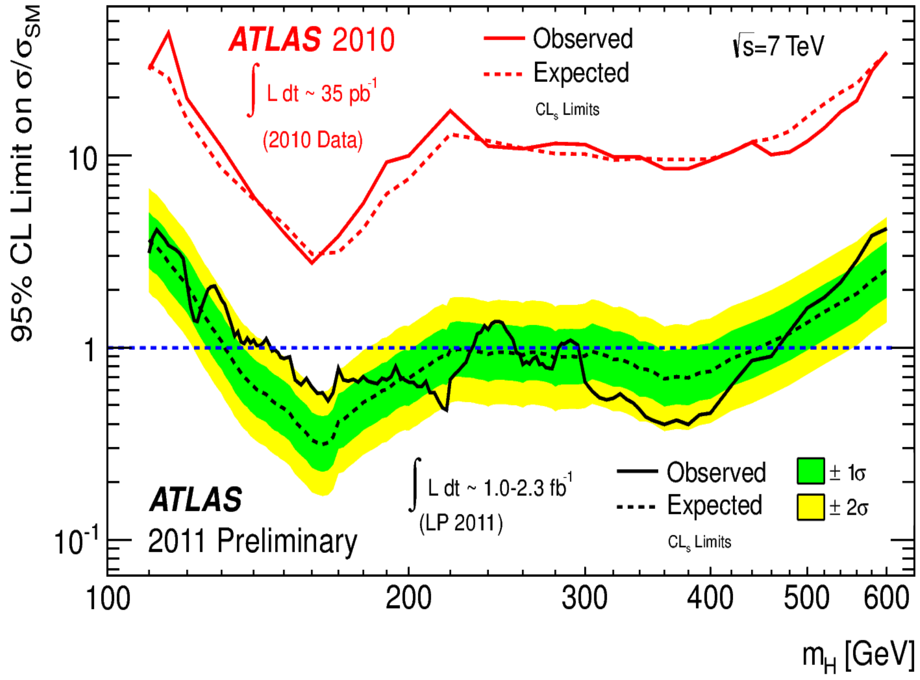
Challenging measurements of W and top quark mass

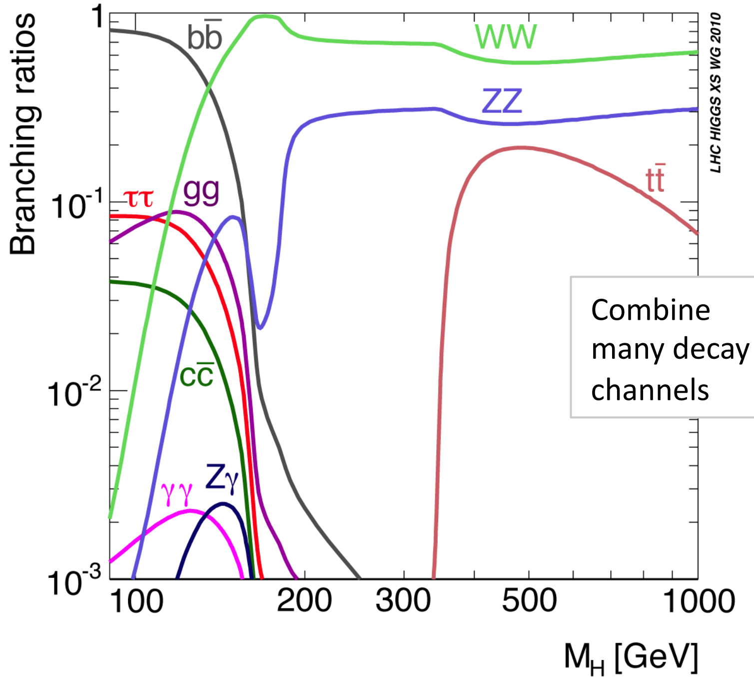
m_W=80.399±0.023
m_t=173.1±1.3



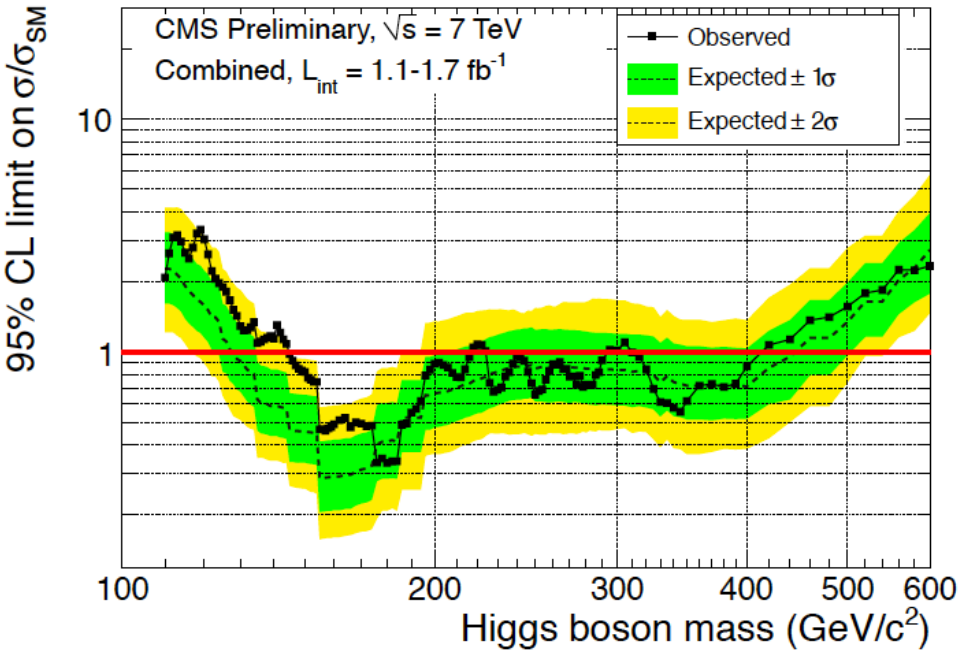
Search for the Higgs Particle

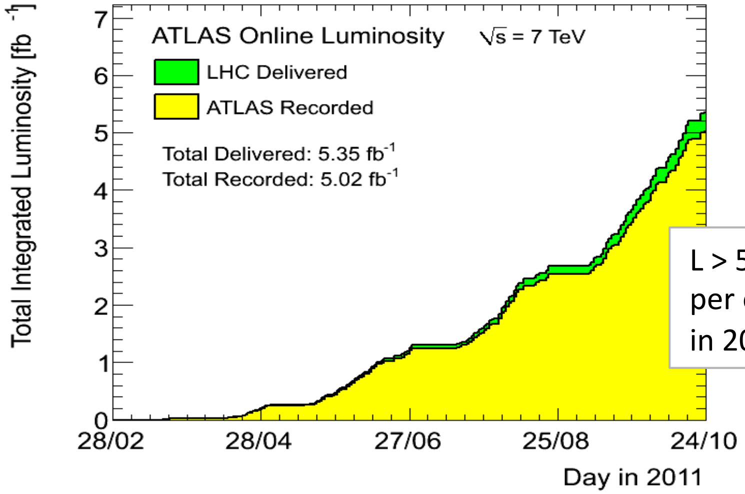
Direct [August 2011]





Combine
many decay
channels

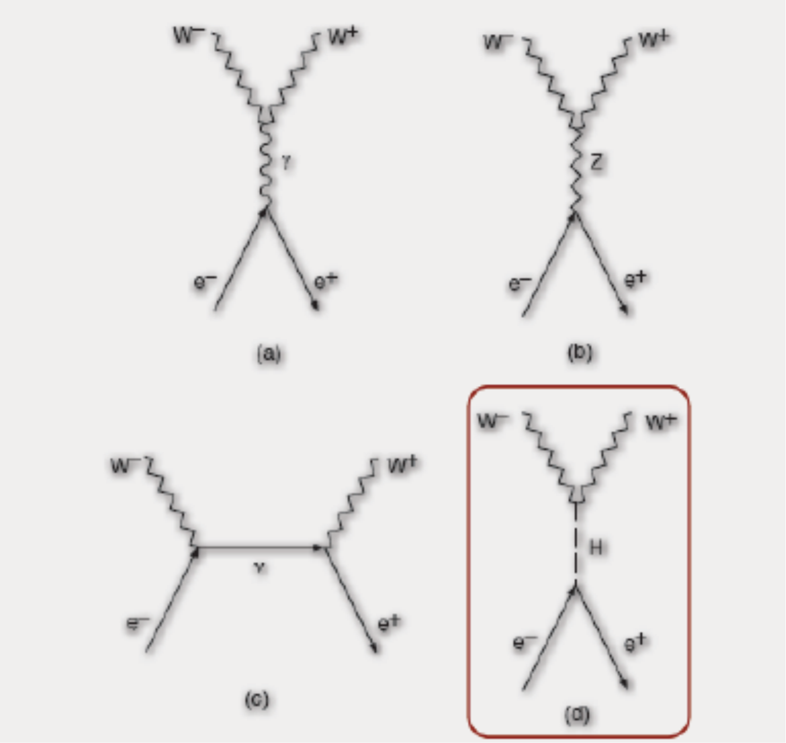




L > $5fb^{-1}$
per exp
in 2011

LHC Tunnel 2002

No Higgs?

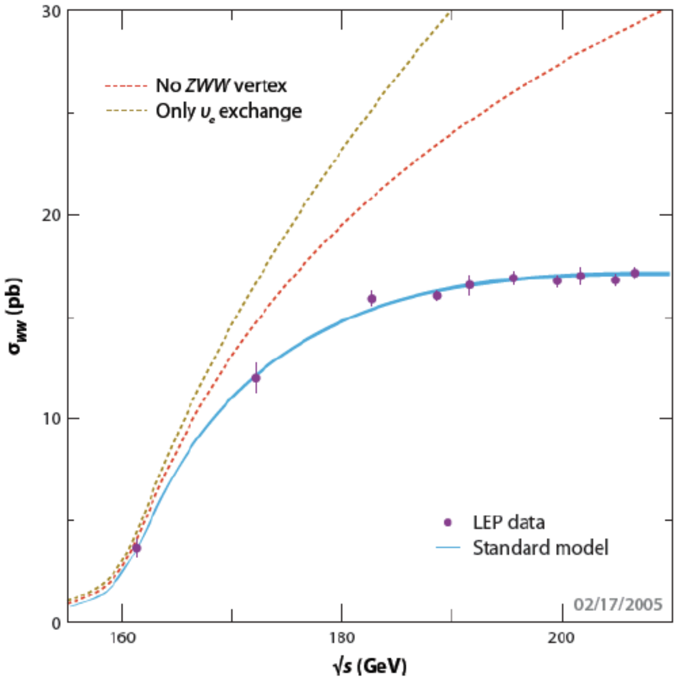


W and Z/γ
behave as
predicted

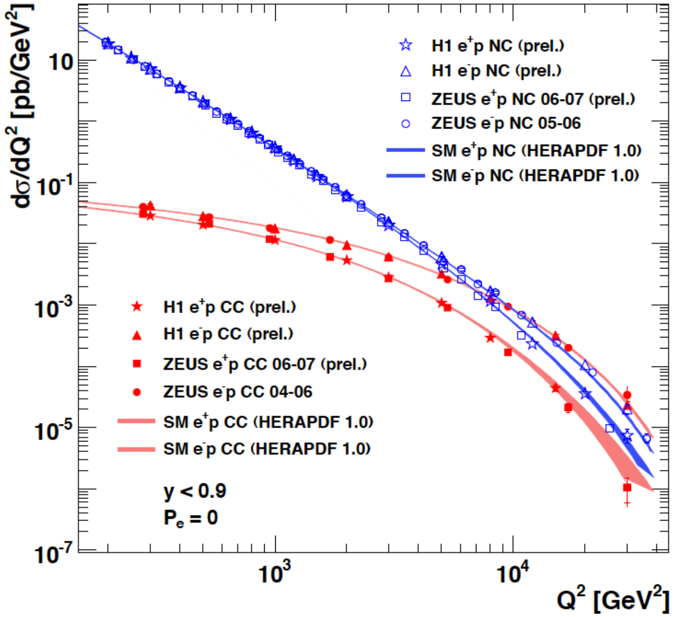
LEP:ZWW

HERA:NC≈CC

LEP



HERA



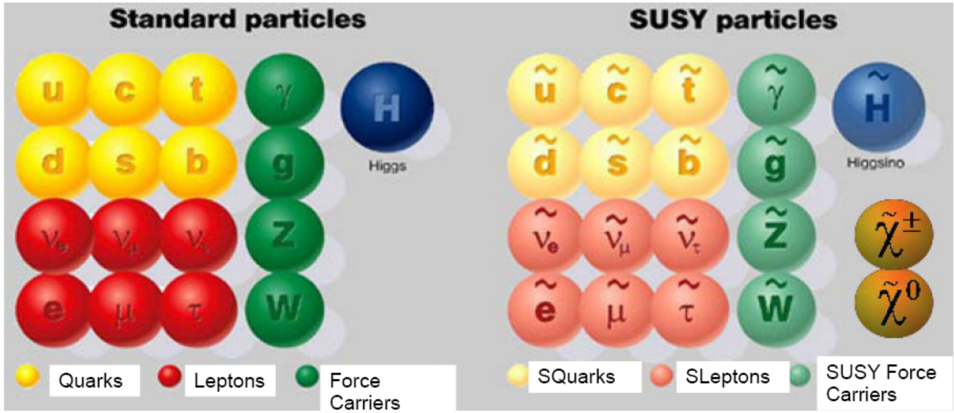
The W damps the rise of the 4fermion cross section.

The H has been expected to give mass to the W,Z
but also to damp the rise of the WW cross section.

It is a major Christmas present if H was indeed excluded.

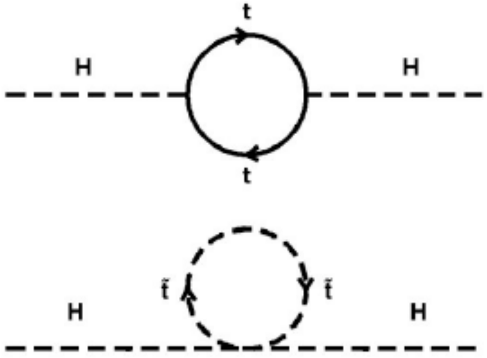
SUperSYmmetry*)

J=1/2 J=1 J=0 J=0 J=1/2 J=1/2



A beautiful theory:

- scalars become normal particles
- divergences are compensated
- matter and field get united (massless photon and massive photino)
- internal (isospin, colour) symmetries get united with space-time symmetry (generalisation of Poincaré group)



*) Y.Golfand, E.Likhtman, JETP Letters 13(1971)323
“Extension of the Algebra of Poincare Group Generators and Violation of P Invariance”
D.Volkov, V.Akulov, Phys.Lett. 46B (1973)109 “Is the Neutrino a Goldstone Particle?”
J.Wess, B.Zumino, Nucl.Phys. B70(1974)39 “Supergauge Transformations in 4 Dimensions”

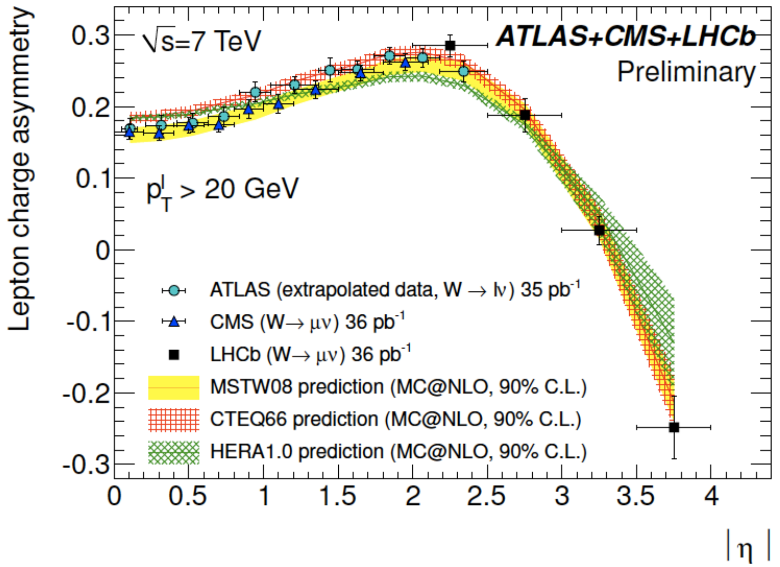
SUSY needs “light” Higgs (most of it)

Technicolor:

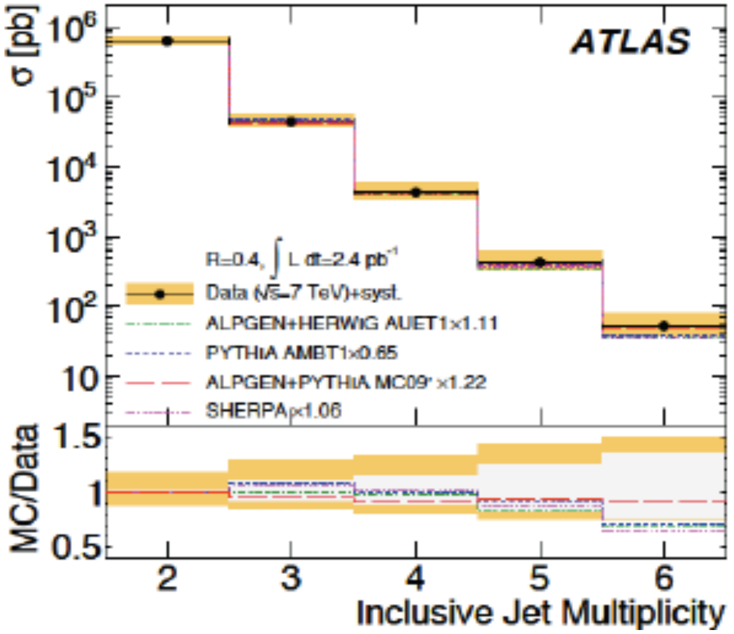
“We argue that the existence of fundamental scalar fields constitutes a serious flaw of the Weinberg-Salam theory. A possible scheme without such fields is described. The symmetry breaking is induced by **a new strongly interacting sector whose natural scale is of the order of a few TeV.”**

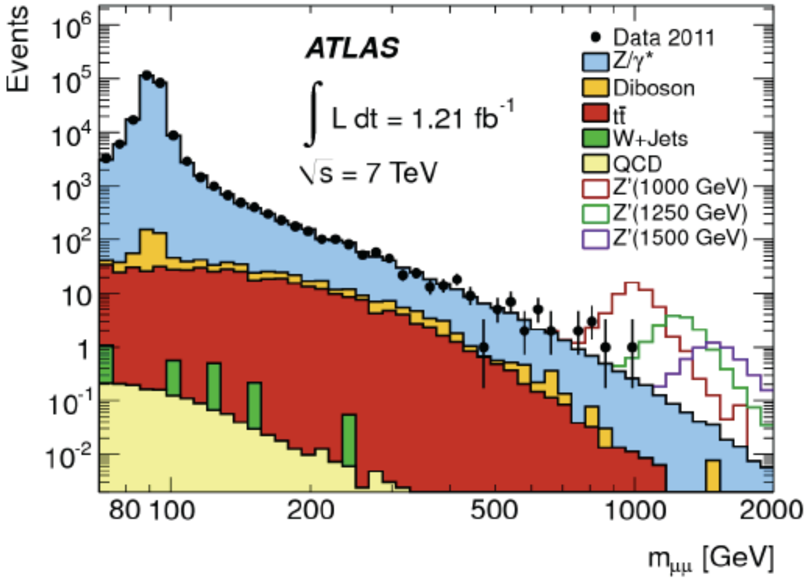
L.Susskind, Dynamics of Spontaneous Symmetry Breaking in the Weinberg Salam Theory. Phys D20 (1979) 2619-2625
Dimopoulos,Susskind: Mass Without Scalars NP. B155 (1979) 237 Farhi, Susskind: Technicolor Phys.Rept. 74 (1981) 277

LHC- Standard Model Measurements [~400 papers/preliminary results in 2010/11]

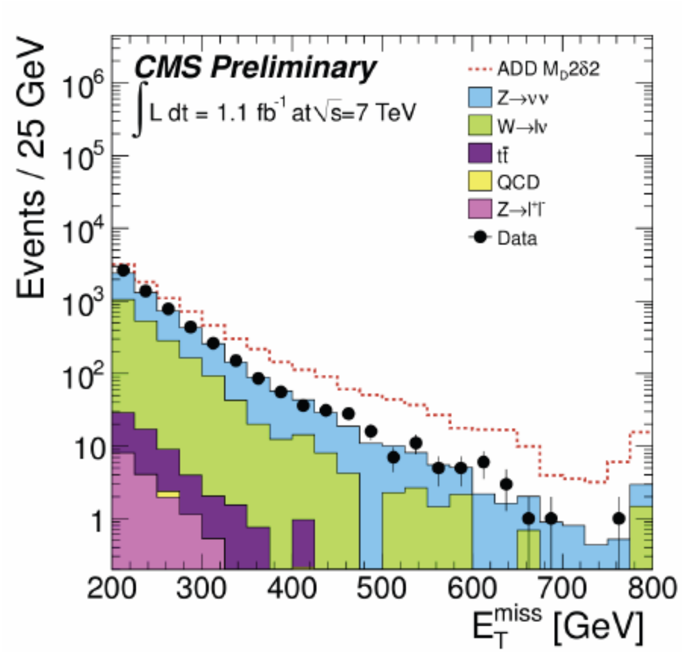


Explore proton+QCD in new region



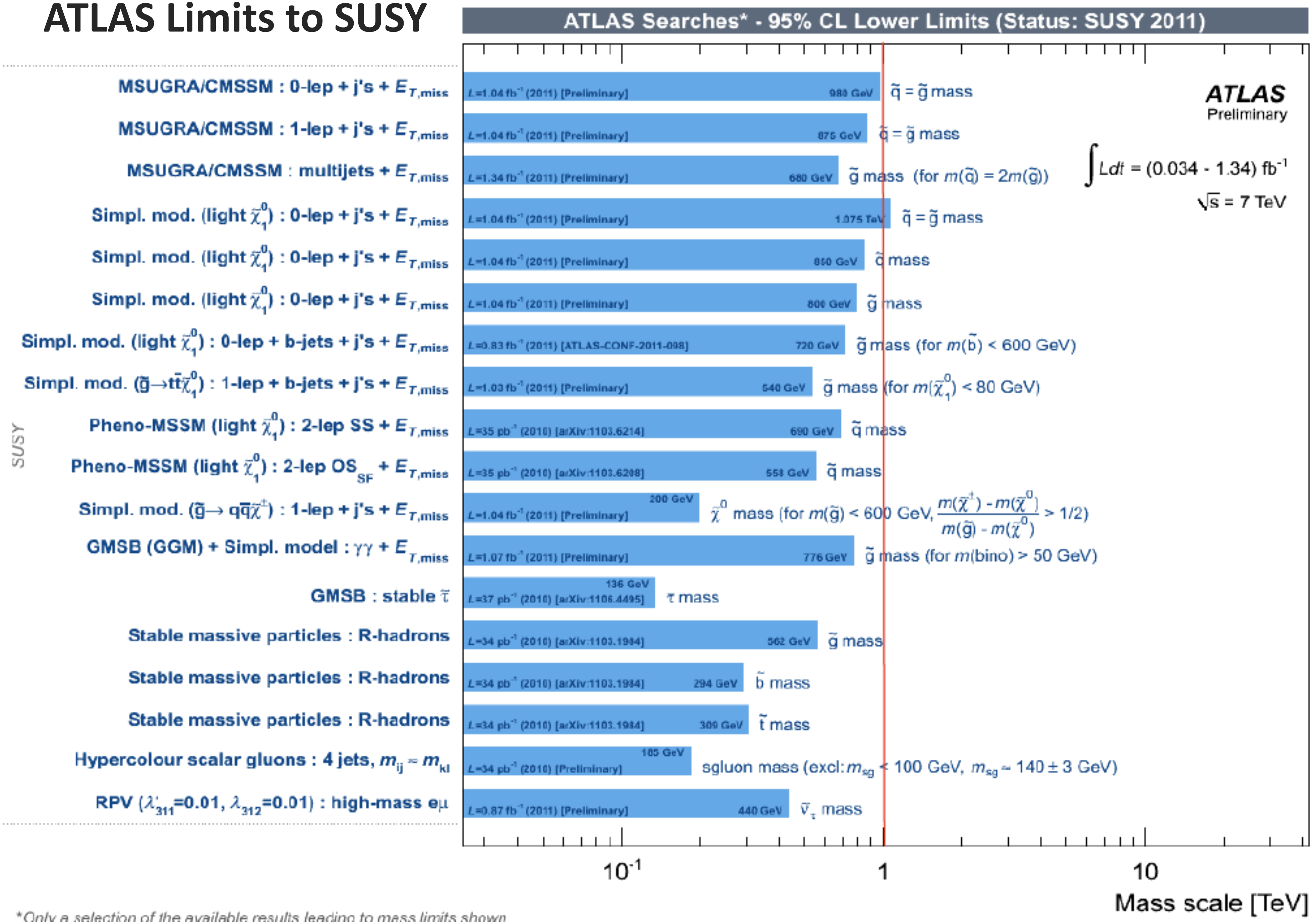


No sign for Z' nor W' below about 2 TeV



No large missing energy of unknown origin

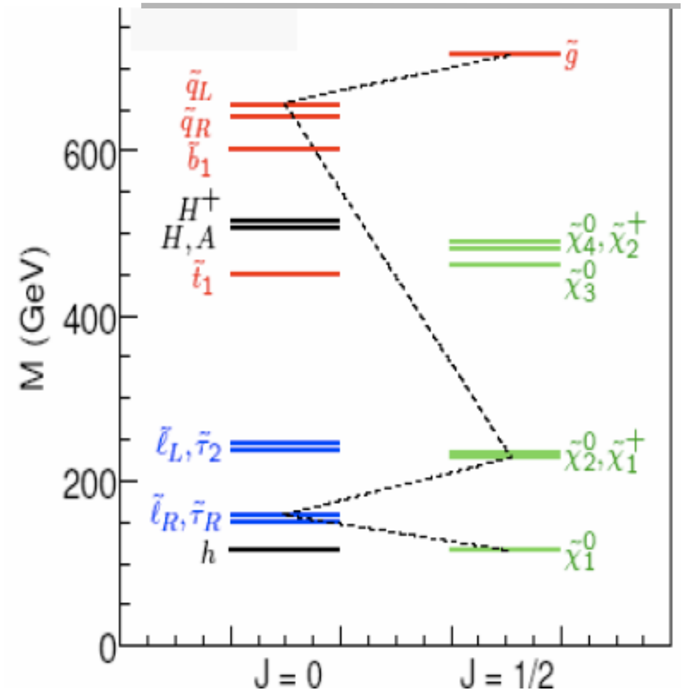
ATLAS Limits to SUSY

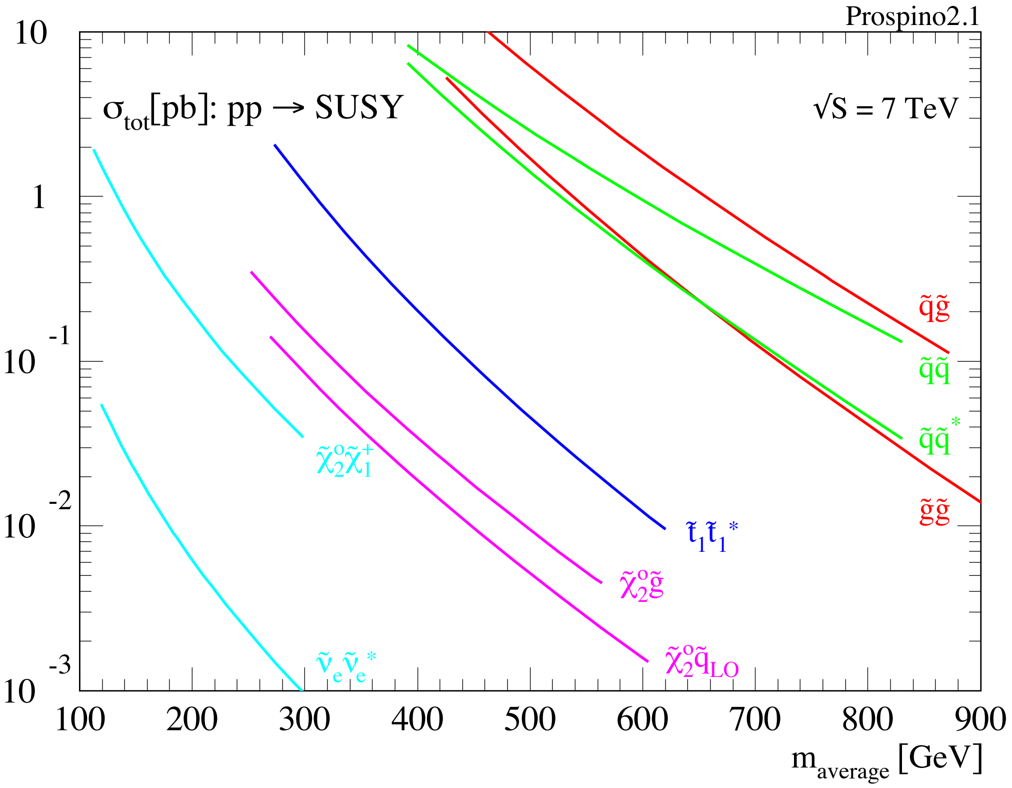


*Only a selection of the available results leading to mass limits shown cf Sakuarai seminar today

SUSY Before and Now?

A SUSY spectrum before 2011





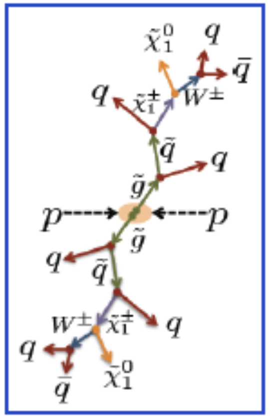
T.Plehn

Look for

3rd, lighter generation

RPV SUSY [ep, DM?]

Extended decay chains



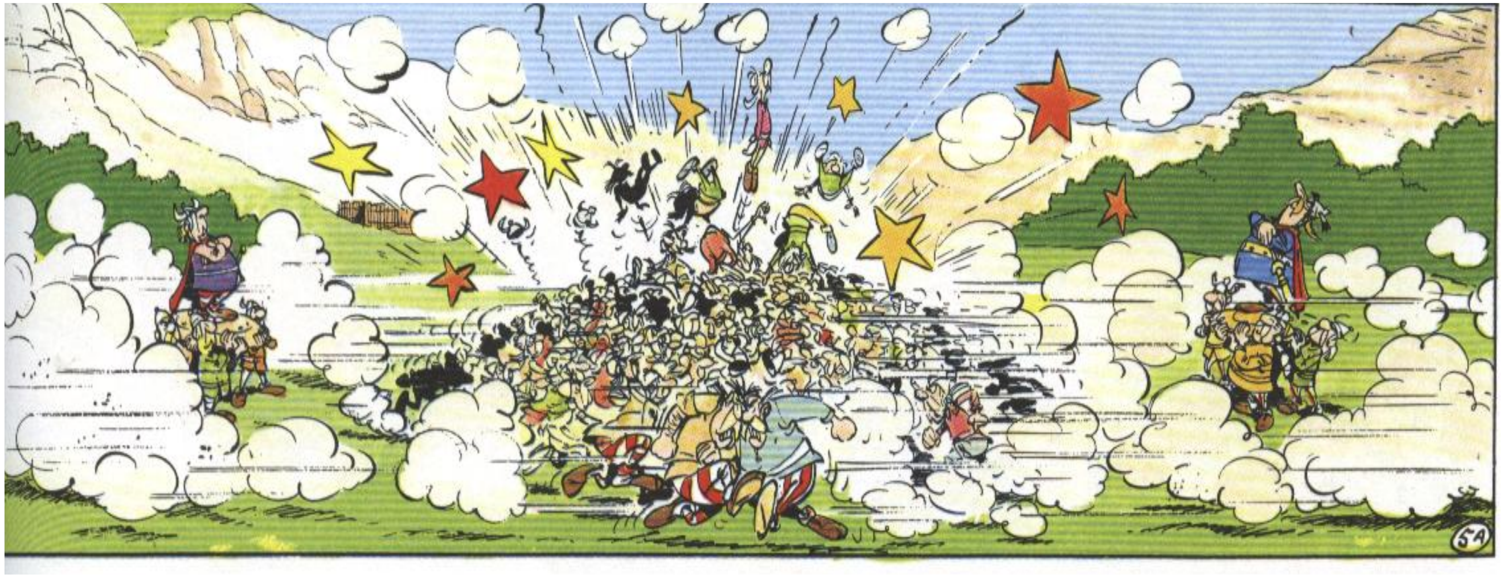
R-parity = $(-1)^{2J+3B+L}$

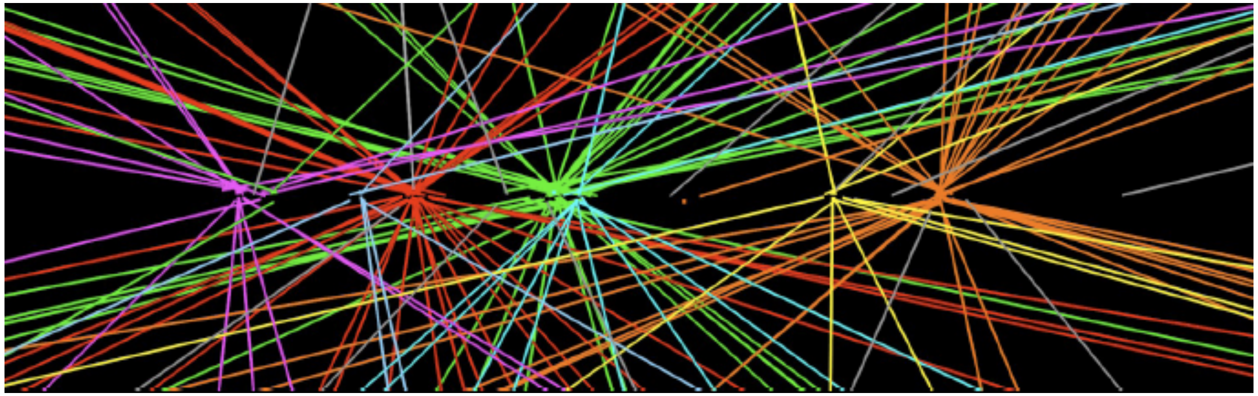
= 1 for SM particles, = -1 for SUSY partners

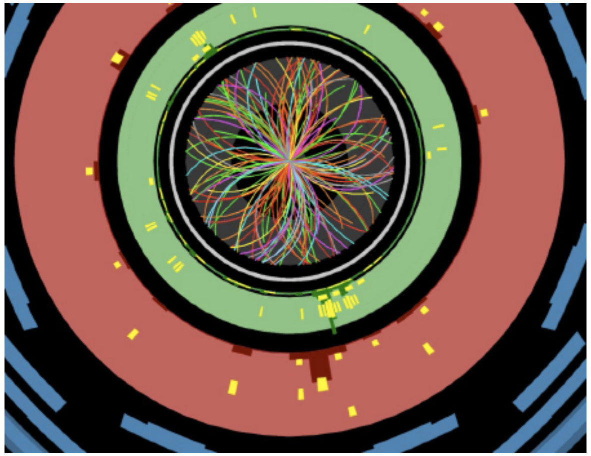
IF SUSY exists and IF R is conserved then the lightest SUSY particles are a candidate for DM

[proton decay violates R parity; R ad hoc in MSSM but natural in SO(10) GUT]

An unprecedented experimental challenge





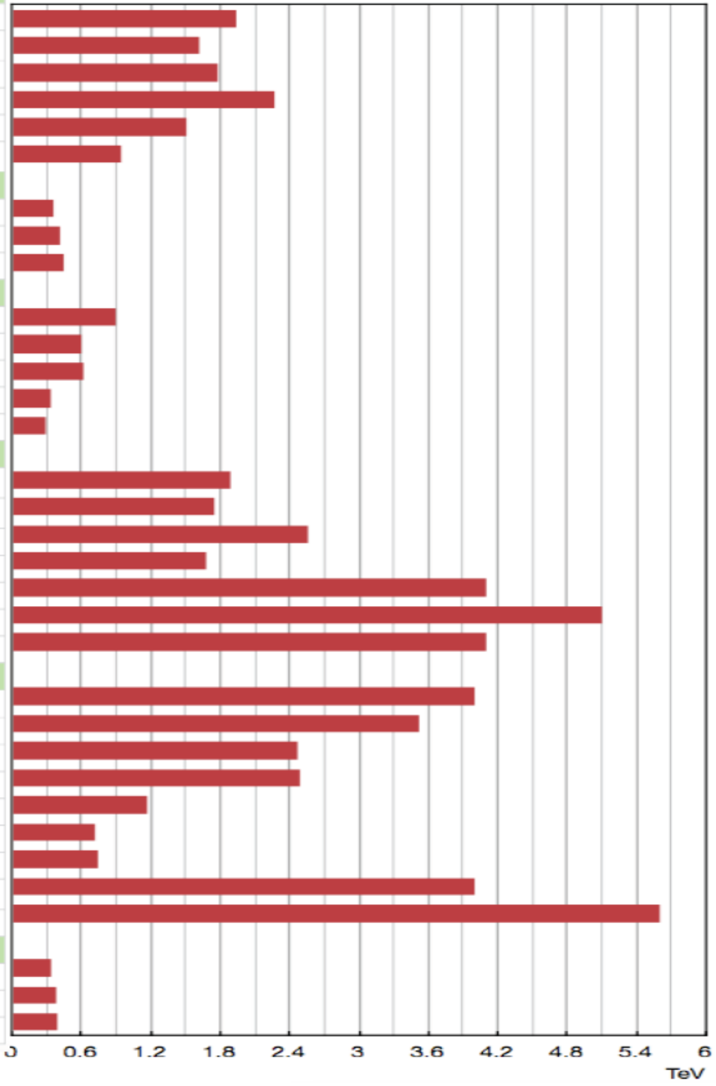


Mean pileup about 10 at L=10^{33}cm^{-2}s^{-1}

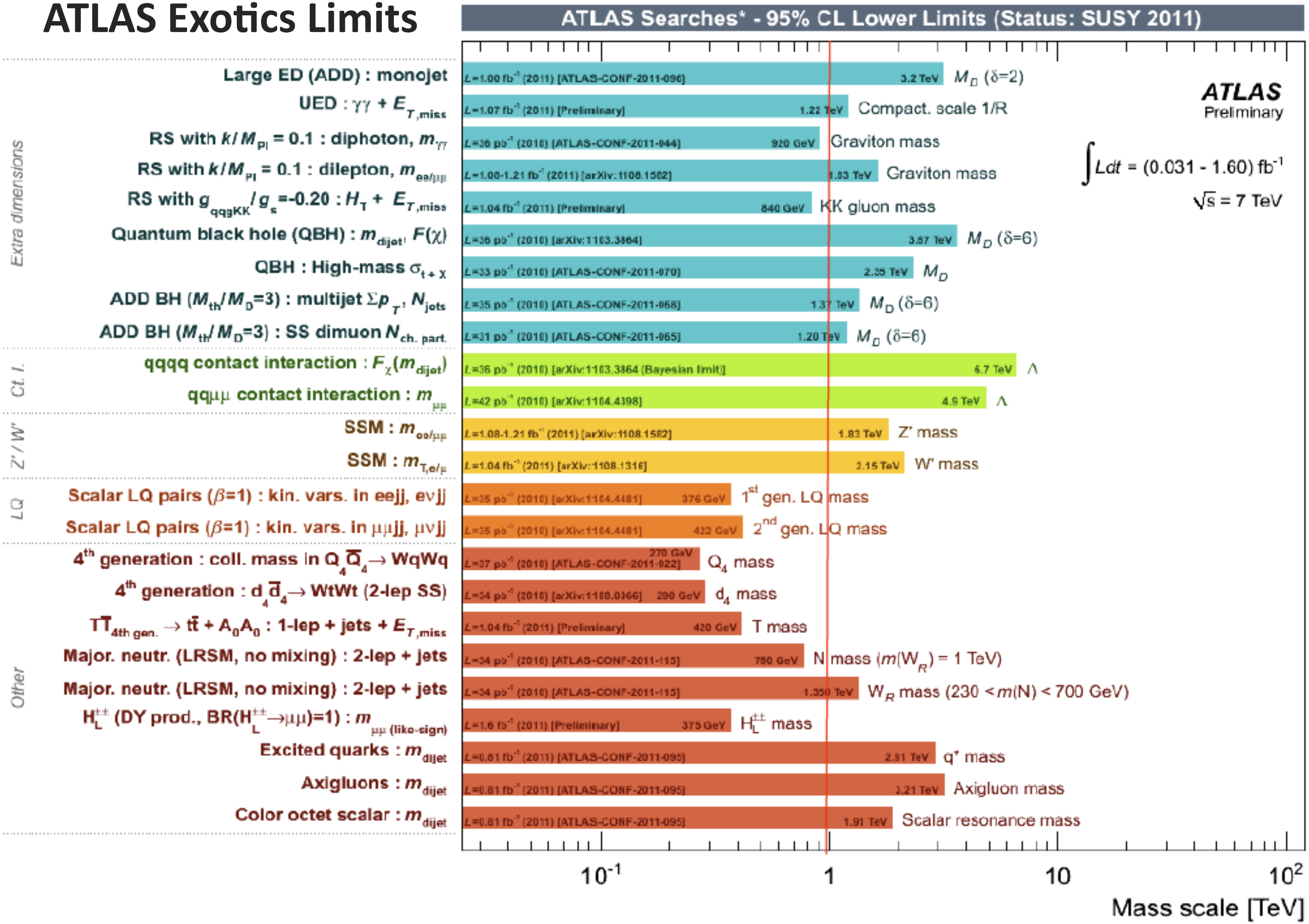
Need full replacement of inner ATLAS tracker for 5 10^{34}

CMS - Limits to Exotic Physics

	Limits in TeV	
		Heavy Bosons
Z'_{SSM} ll	1.94	2011
Z'_{Ψ} ll	1.62	2011
G_{KK} ll k/M = 0.1	1.78	2011
W' lν	2.27	2011
W' dijet	1.51	2011
G_{KK} γγ k/M = 0.1 (2010)	0.945	2010
		4th Generation
$M_{b'}$, b' ⇒ tW (2010)	0.361	2010
$M_{t'}$, t' ⇒ tZ (100%)	0.417	2011
$M_{t'}$, t' ⇒ bW (100%), l+jets	0.45	2011
		Heavy Stable Particles
M_{gluino}, HSCP	0.899	2011
M_{gluino}, Stopped Gluino	0.601	2011
M_{stop}, HSCP	0.620	2011
M_{stop}, Stopped Gluino	0.337	2011
M_{stau}, HSCP	0.293	2011
		Large Extra Dimensions
M_s, γγ, GRW (2010)	1.89	2010
M_s, μμ, GRW (2010)	1.75	2010
M_D, monojet, n_{ED} = 2 (2010)	2.56	2010
M_D, monojet, n_{ED} = 6 (2010)	1.68	2010
M_{BH}, rotating, M_D=3.5 TeV, n_{ED} = 2	4.1	2011
M_{BH}, non-rot, M_D=1.5 TeV, n_{ED} = 6	5.1	2011
String Ball M, M_D=2.1, M_s=1.7, g_s=0.4	4.1	2011
		Compositeness and Contact Interactions
String Resonances	4.0	2011
E_6 diquarks	3.52	2011
Axigluon/Coloron	2.47	2011
q^* , dijet	2.49	2011
q^* , boosted Z	1.17	2010
e^*, Λ = 2 TeV	0.720	2010
μ^*, Λ = 2 TeV	0.745	2010
C.I. Λ , dijet mass (3 pb^{-1})	4.0	2010
C.I. Λ , X analysis	5.6	2010
		LeptoQuark
LQ1, β=0.5 (2010)	0.340	2010
LQ1, β=1.0 (2010)	0.384	2010
LQ2, β=1.0 (2010)	0.394	2010

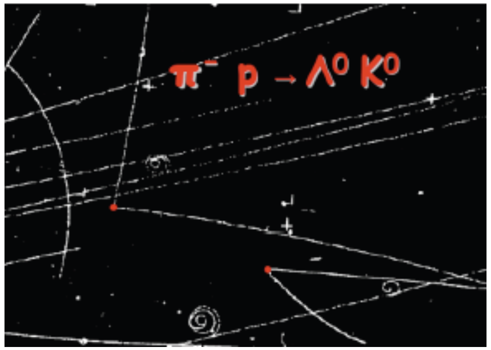


ATLAS Exotics Limits



Note: LHC is for ~1000fb^{-1} at 14 TeV to be compared with 1fb^{-1} at 7 TeV now

Early Quark Mixing Physics



$$\tau(K_s^0 \to 2\pi) = 0.9 \cdot 10^{-10}\, s$$

$$\tau(K_L^0 \to 3\pi) = 0.5 \cdot 10^{-7}\, s$$

$$CP|K^0\rangle = |\overline{K^0}\rangle$$

$$|K_S^0\rangle = \sqrt{\frac{1}{2}}(|K^0\rangle + |\overline{K^0}\rangle), CP = +1$$

$$|K_L^0\rangle = \sqrt{\frac{1}{2}}(|K^0\rangle - |\overline{K^0}\rangle), CP = -1$$

Strangeness oscillations: m_L-m_S=3.5 10^{-6} eV
(Gell-Mann and Pais, 1955)

Regeneration of K_s component (Pais et al. 1956)

Rare decay of K_L into 3 pions: CP violation
(Cronin and Fitch 1964)

Suppression of strangeness changing weak charged currents

Cabibbo 1963

$$\begin{pmatrix} u \\ d' \end{pmatrix}$$

$$d' = d\cos\theta_c + s\sin\theta_c$$

$$K^+(\bar{s}u) \to \pi^0(\bar{u}u)e^+\nu_e$$

$$\pi^+(\bar{d}u) \to \pi^0(\bar{u}u)e^+\nu_e$$

$$\frac{\Gamma(K^+ \to \pi^0 e^+ \nu_e)}{\Gamma(\pi^+ \to \pi^0 e^+ \nu_e)} \propto \tan^2\theta_c$$

Suppression of strangeness changing weak neutral currents

Glashow, Iliopoulos, Maiani (GIM) 1970

$$\begin{pmatrix} u \\ d' \end{pmatrix}, \begin{pmatrix} c \\ s' \end{pmatrix}$$

$$d' = d\cos\theta_c + s\sin\theta_c$$

$$s' = -d\sin\theta_c + s\cos\theta_c$$

$$\frac{\Gamma(D^+ \to K^-\pi^+\pi^+)}{\Gamma(D^+ \to K^+\pi^-\pi^+)} \propto \frac{T(c \to \bar{s}ud)}{T(c \to \bar{d}us)} \propto \tan^2\theta_c$$

Introduction of 4th quark
Charm decays

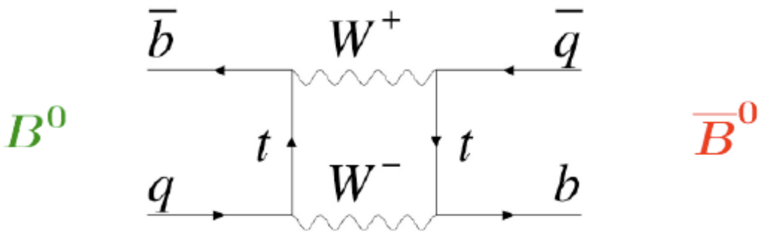
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} \equiv \hat{V}_{\text{CKM}} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

CP violating phase → 3rd family

Makoto Kobayashi, Toshihide Maskawa

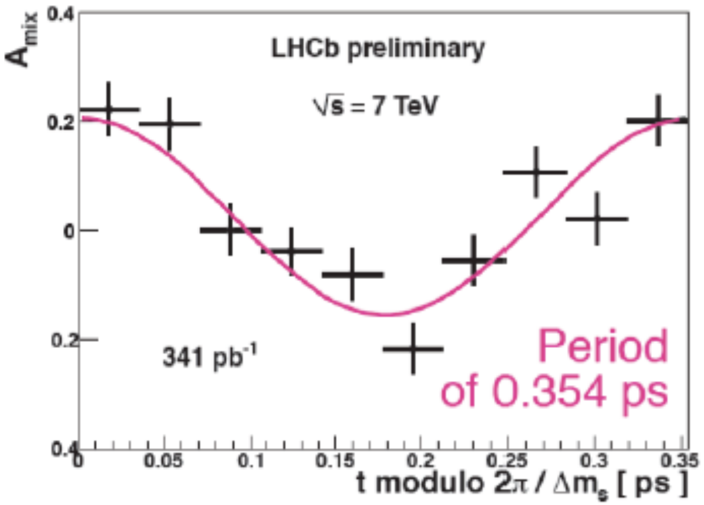
CP Violation in the Renormalizable Theory of Weak Interaction
Prog. Theor. Phys. 49 (1973) 652-657. [6416 citations]

Recent B Physics



Discovered by ARGUS 1987

LHCb: δρ=300μm, δt=50fs



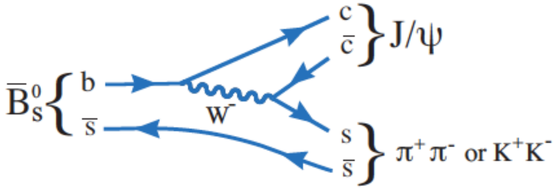
B_s mixing measured ok with SM
best measurement of Δm_s

Br(Bs → μμ) < 1.1 10^{-8} [3.4 * SM]
LHCb+CMS do not confirm CDF excess

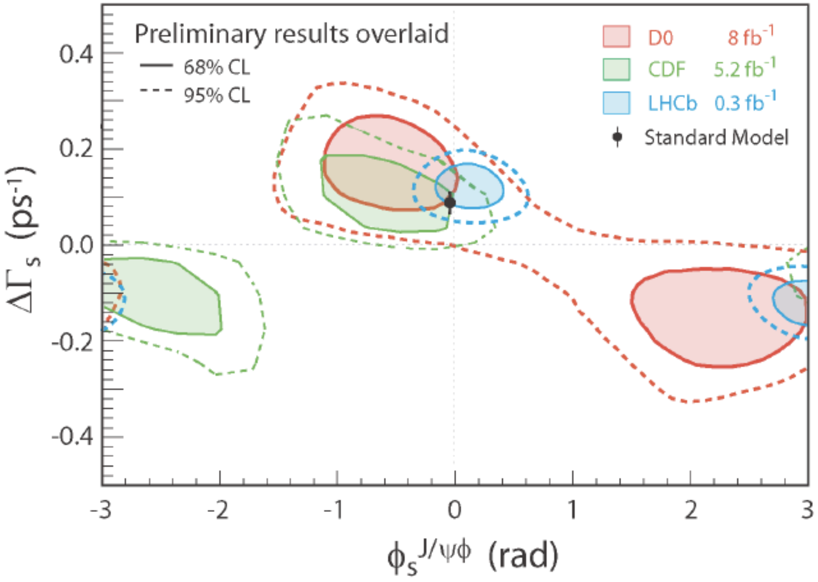
B→K^*ll FB asymmetry: LHCb: SM ok (÷Belle09)

Like sign di-muon asymmetry
D0: (-0.787 +-0.172 +-0.093)% 3.9σ above SM
LHCb: to come

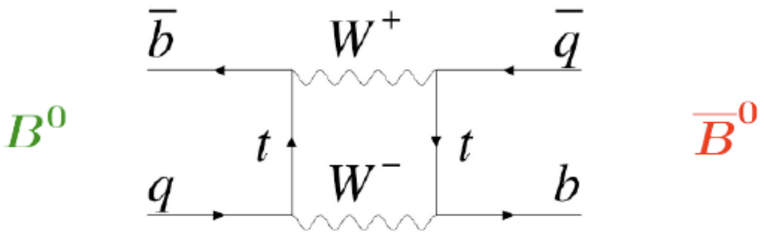
Some tension between Br(B → τν) and sin2β



CP violating phase Φ in B^0_{sbar} decays

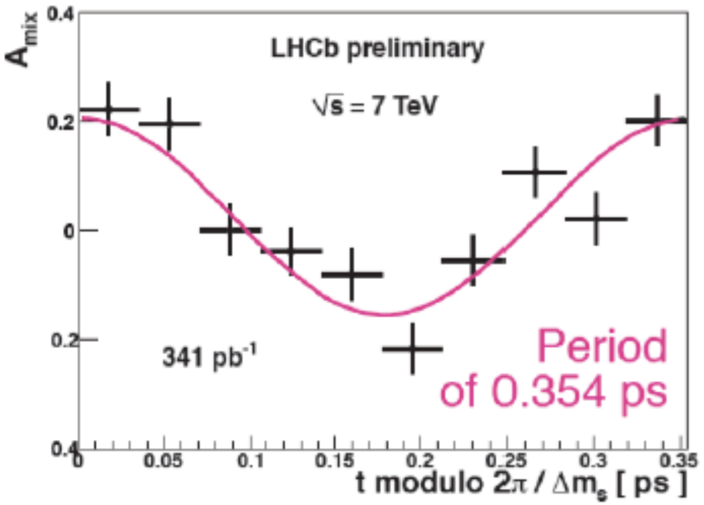


Future B Physics



Discovered by ARGUS 1987

LHCb: δρ=300μm, δt=50fs



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LHCb: to come

Some tension between Br(B → τν) and sin2β

To be studied (with high precision):

- γ from tree (B → DK, ...)
- $|V_{ub}|$ from exclusive semilept. B decays
- $B_{s,d} \rightarrow \mu\mu$
- CPV in B_s mixing
- B → K*μμ (angular analysis)
- B → τν, μν
- K → πνν
- CPV in D mixing

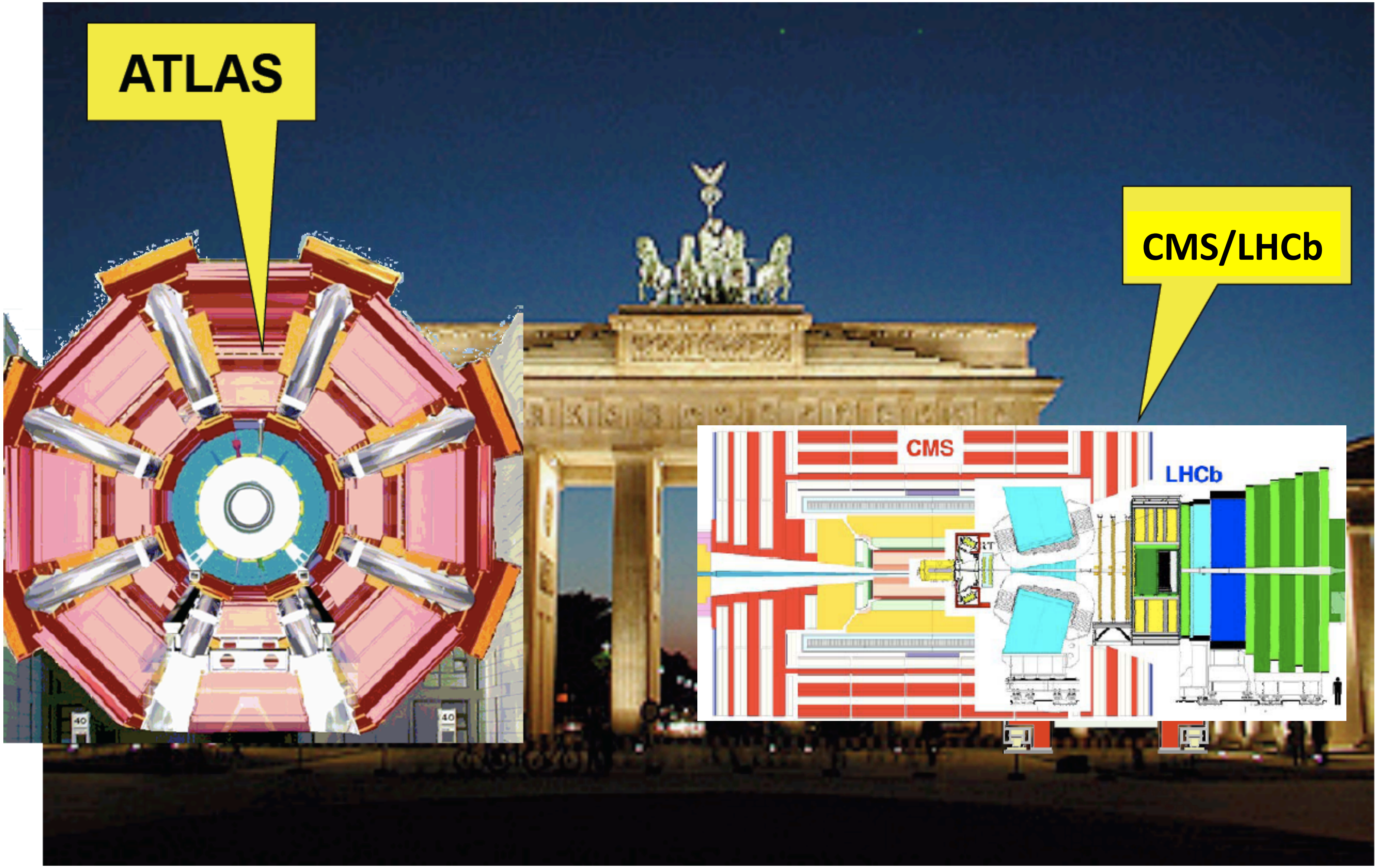
New B factories in Japan and near Rome

NA62

G.Isidori ICFA11

Projects

Projects



The LHC Upgrades

	2013	2023	2033+
	LHC	HL-LHC	HE-LHC
Collision energy [TeV]	14	14	33
Peak/leveled luminosity [10^{34} $cm^{-2}s^{-1}$]	1.0	7.9/5.0	2.0/2.0
integrated luminosity per year (1900h) [fb^{-1}]	57	250	100
events per crossing	19	150	76
# bunches / beam	2808	2808	1404
bunch population [10^{11}]	1.15	1.7	1.29
Beam current [A]	0.58	0.86	0.32
Luminosity leveling	no	θ_c , V_{crab} or β^*	$\varepsilon_{x,y}$
initial transverse normalized emittance [μm]	3.75	3.75	3.75 (x),1.84 (y)
number of IPs contributing to tune shift	3	3	2
maximum total beam-beam tune shift	0.01	0.01	0.01
IP beta function [m]	0.55	0.14	1.0 (x), 0.43 (y)
full crossing angle [μrad]	285 (9.5 $\sigma_{x,y}$)	0 (509)	175 (12 σ_{x0})
dipole field [T]	8.33	8.33	20
dipole coil aperture [mm]	56	56	40-45
stored beam energy [MJ]	362	504	479
SR power per ring [kW]	3.6	5	62.3
longitudinal SR emittance damping time [h]	12.9	12.9	0.98
luminosity lifetime [h]	23	4	13

The LHC Luminosity Upgrade

- New high field insertion quadrupoles
- Upgraded cryo system for IP1 and IP5
- Upgrade of the intensity in the Injector Chain (LIU)
- Crab Cavities to take advantage of the small beta*
- Single Event Upsets
  - SC links to allow power converters to be moved to surface
- Misc

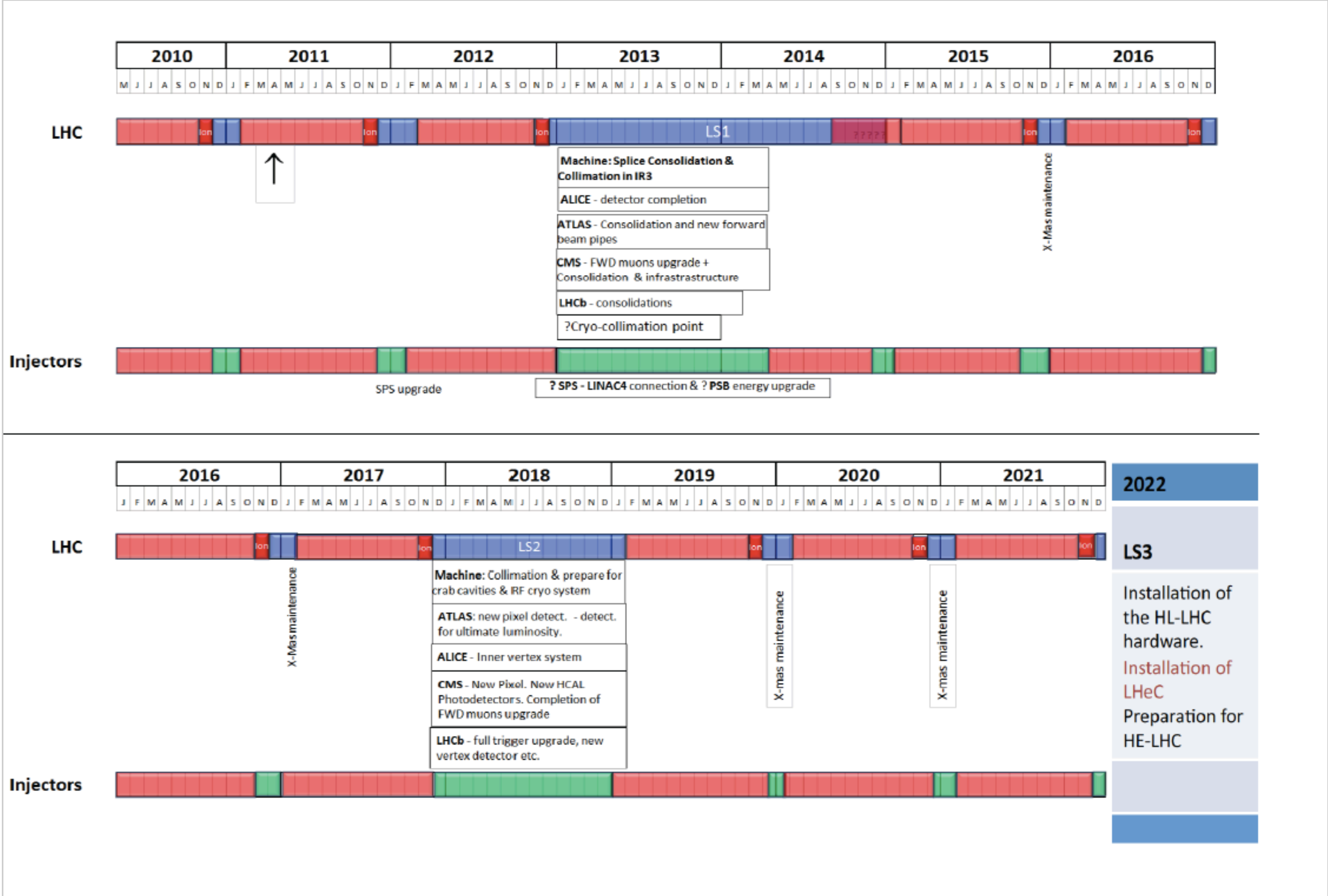
S.Myers EPS11 Grenoble

Goals for 25ns bunch crossing

2 10^{11} p/bunch
β^* =0.15 m
L = 7 10^{34} leveled to 5 10^{34} $cm^{-2}s^{-1}$
Integrated L = $3ab^{-1}$ by 2030+

Corresponding detector upgrades:
ATLAS $150m^2$ strips, $10m^2$ pixels
Trigger, muons..

The coming LHC decade -DRAFT



Machine: Splice Consolidation & Collimation in IR3

ALICE - detector completion

ATLAS - Consolidation and new forward beam pipes

CMS - FWD muons upgrade + Consolidation & infrastrastructure

LHCb - consolidations

?Cryo-collimation point

? SPS - LINAC4 connection & ? **PSB** energy upgrade

Machine: Collimation & prepare for crab cavities & RF cryo system

ATLAS: new pixel detect. - detect. for ultimate luminosity.

ALICE - Inner vertex system

CMS - New Pixel. New HCAL Photodetectors. Completion of FWD muons upgrade

LHCb - full trigger upgrade, new vertex detector etc.

Installation of the HL-LHC hardware.

Installation of LHeC

Preparation for HE-LHC

The Large Hadron electron Collider

$$L = \frac{1}{4\pi}\cdot\frac{N_p}{\varepsilon_p}\cdot\frac{1}{\beta^*}\cdot\gamma\cdot\frac{I_e}{e}$$

$$N_p = 1.7\cdot 10^{11}, \varepsilon_p = 3.8\mu m, \beta^* = 0.2m, \gamma = 7000/0.94$$

$$L = 8\cdot 10^{31} cm^{-2}s^{-1}\cdot\frac{N_p 10^{-11}}{1.7}\cdot\frac{0.2}{\beta^*/m}\cdot\frac{I_e/mA}{1}$$

$$I_e = mA\frac{P/MW}{E_e/GeV}$$

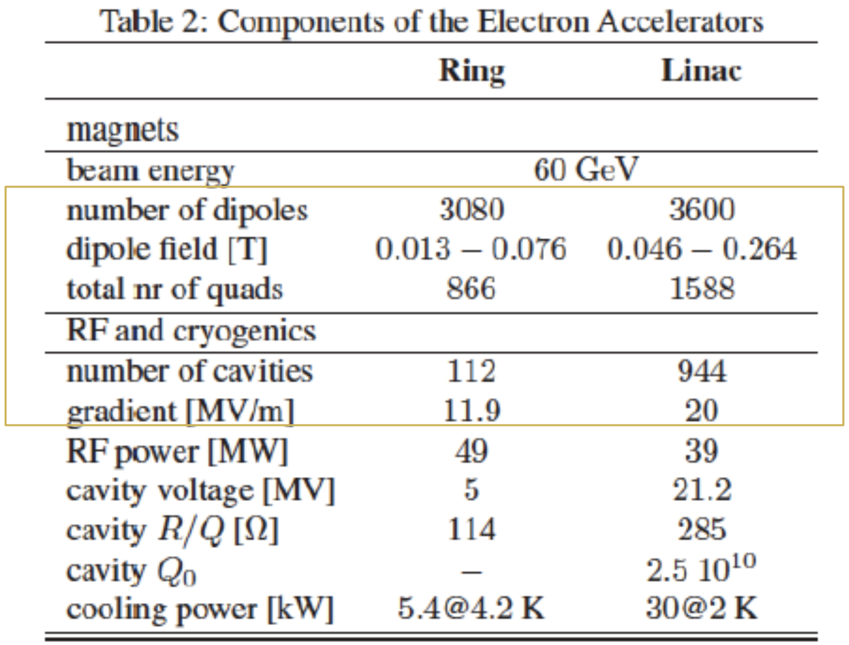
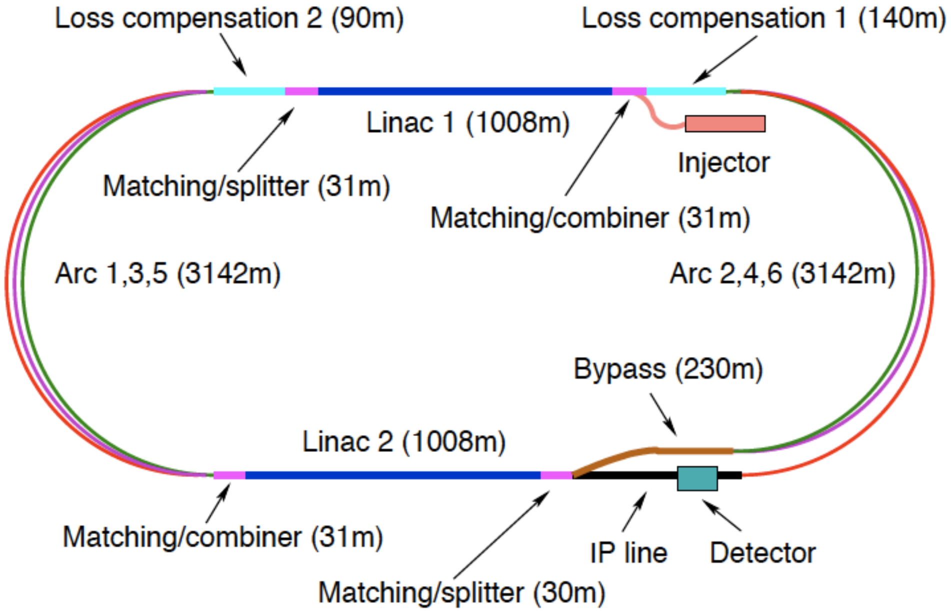


Table 2: Components of the Electron Accelerators

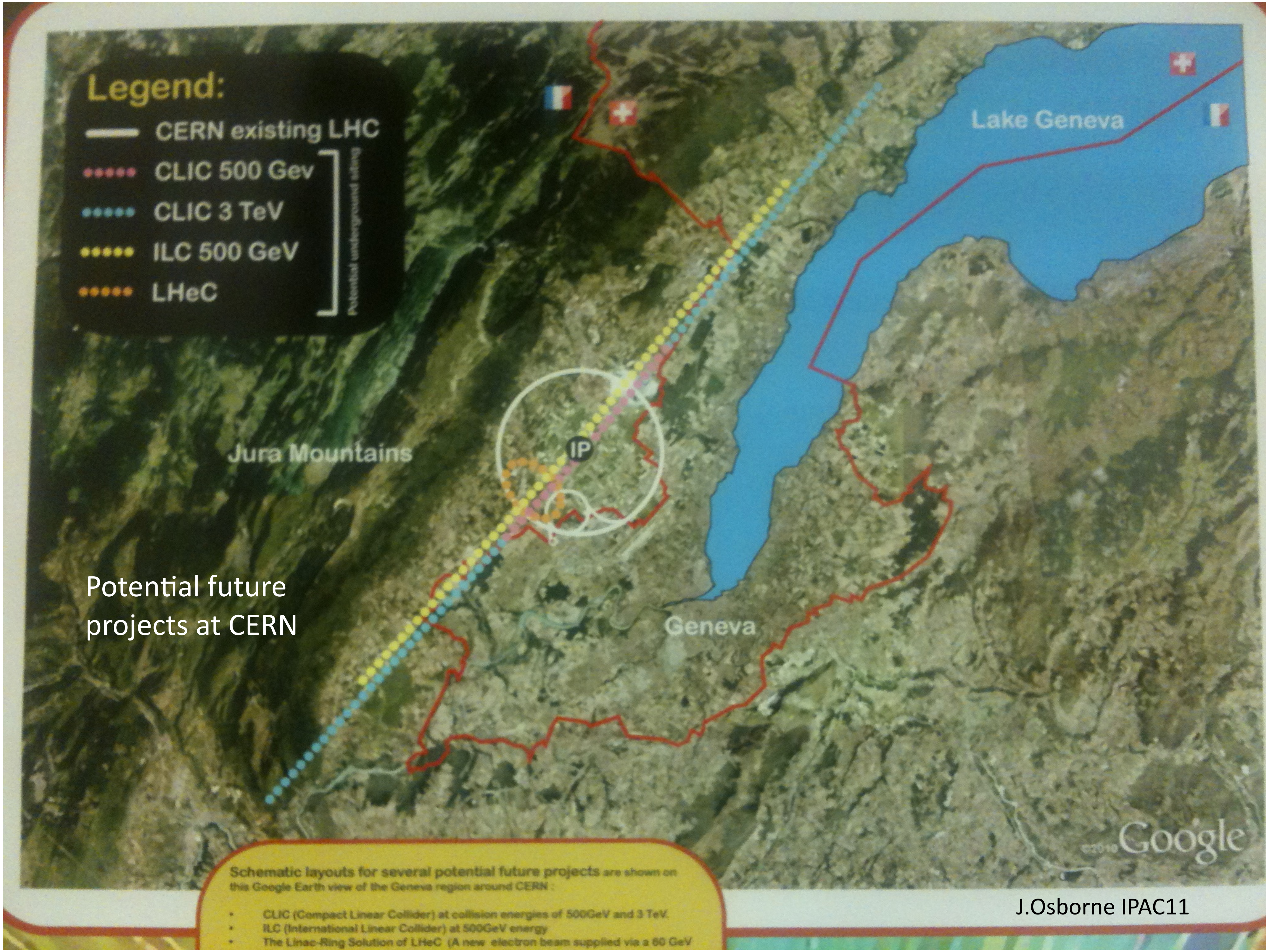
	Ring	Linac
magnets		
beam energy	60 GeV	
number of dipoles	3080	3600
dipole field [T]	0.013 – 0.076	0.046 – 0.264
total nr of quads	866	1588
RF and cryogenics		
number of cavities	112	944
gradient [MV/m]	11.9	20
RF power [MW]	49	39
cavity voltage [MV]	5	21.2
cavity R/Q [Ω]	114	285
cavity Q_0	–	$2.5\ 10^{10}$
cooling power [kW]	5.4@4.2 K	30@2 K



- -TeV scale ep collider [60x7000]GeV^2
- - ep and eA collisions using LHC
- - synchronous ep and pp operation
- - 100 times HERA luminosity
- - 100 MW wall plug power
- - Energy recovery allows GW power

DRAFT Design

Potential future projects at CERN

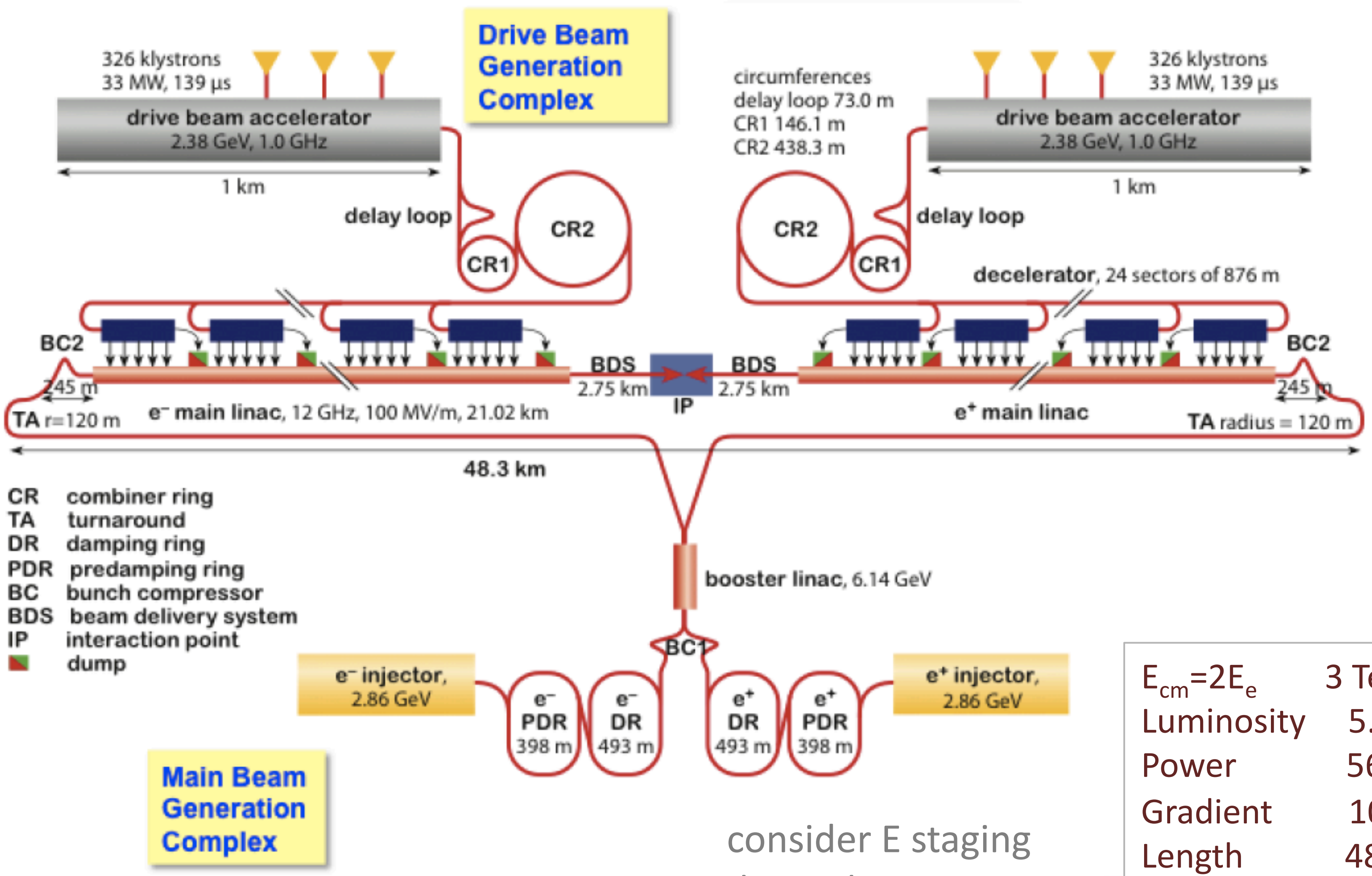


Schematic layouts for several potential future projects are shown on this Google Earth view of the Geneva region around CERN :

- CLIC (Compact Linear Collider) at collision energies of 500GeV and 3 TeV.
- ILC (International Linear Collider) at 500GeV energy
- The Linac-Ring Solution of LHeC (A new electron beam supplied via a 60 GeV

J.Osborne IPAC11

Compact Linear Collider - CLIC



CR	combiner ring
TA	turnaround
DR	damping ring
PDR	predamping ring
BC	bunch compressor
BDS	beam delivery system
IP	interaction point
🟥	dump

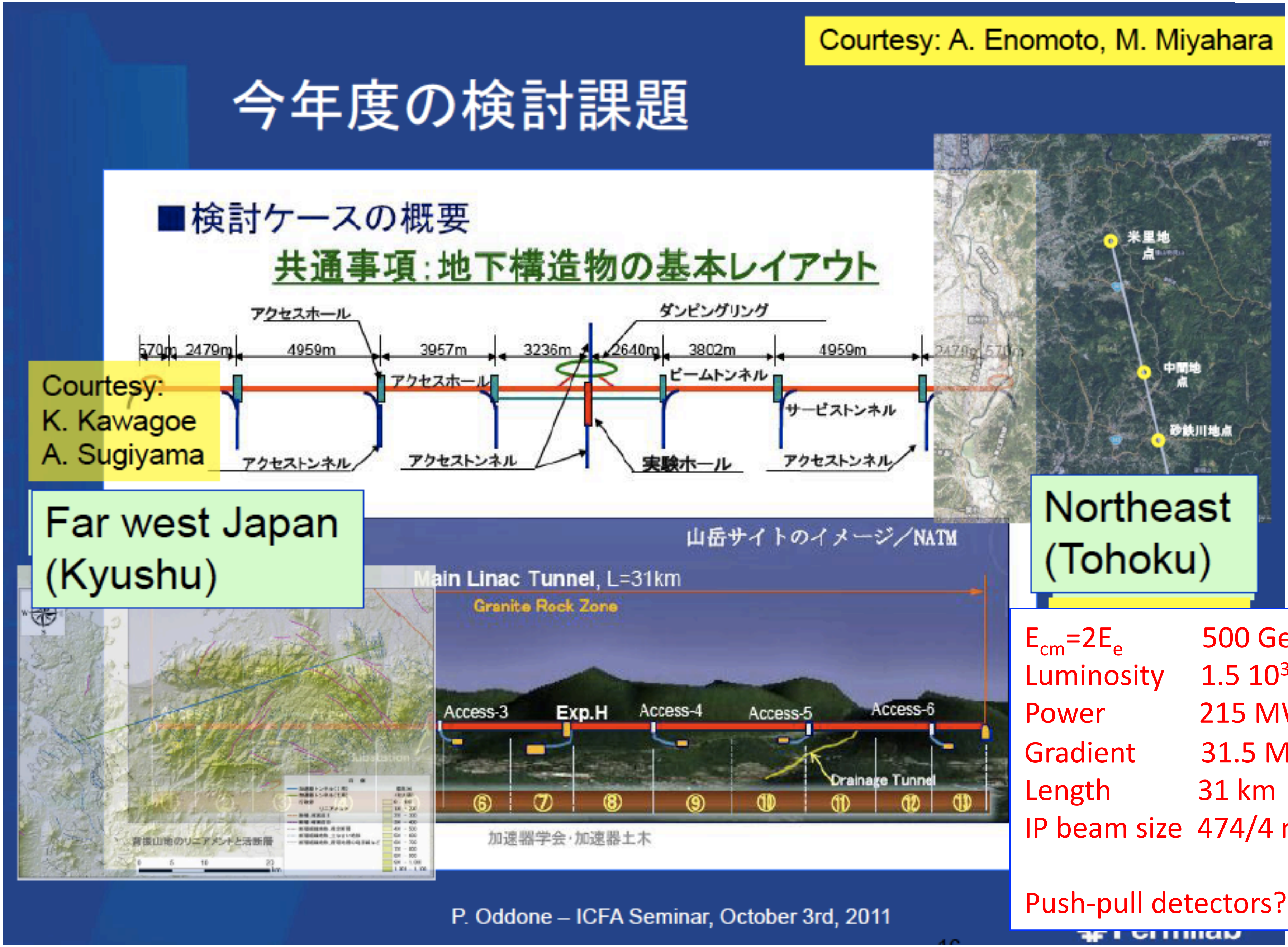
consider E staging depending on LHC:
0.5 TeV 14km
1-2 TeV 20-34km

$E_{cm}=2E_e$	3 TeV
Luminosity	5.9 10^{34}
Power	560 MW
Gradient	100 MV/m
Length	48 km
IP beam size	40/1 nm

Push-pull detectors?

S. Stapness ICFA11

The International Linear Collider



Courtesy: A. Enomoto, M. Miyahara

今年度の検討課題

■検討ケースの概要

共通事項：地下構造物の基本レイアウト

Courtesy:
K. Kawagoe
A. Sugiyama

Far west Japan
(Kyushu)

Northeast
(Tohoku)

山岳サイトのイメージ／NATM

加速器学会・加速器土木

P. Oddone – ICFA Seminar, October 3rd, 2011

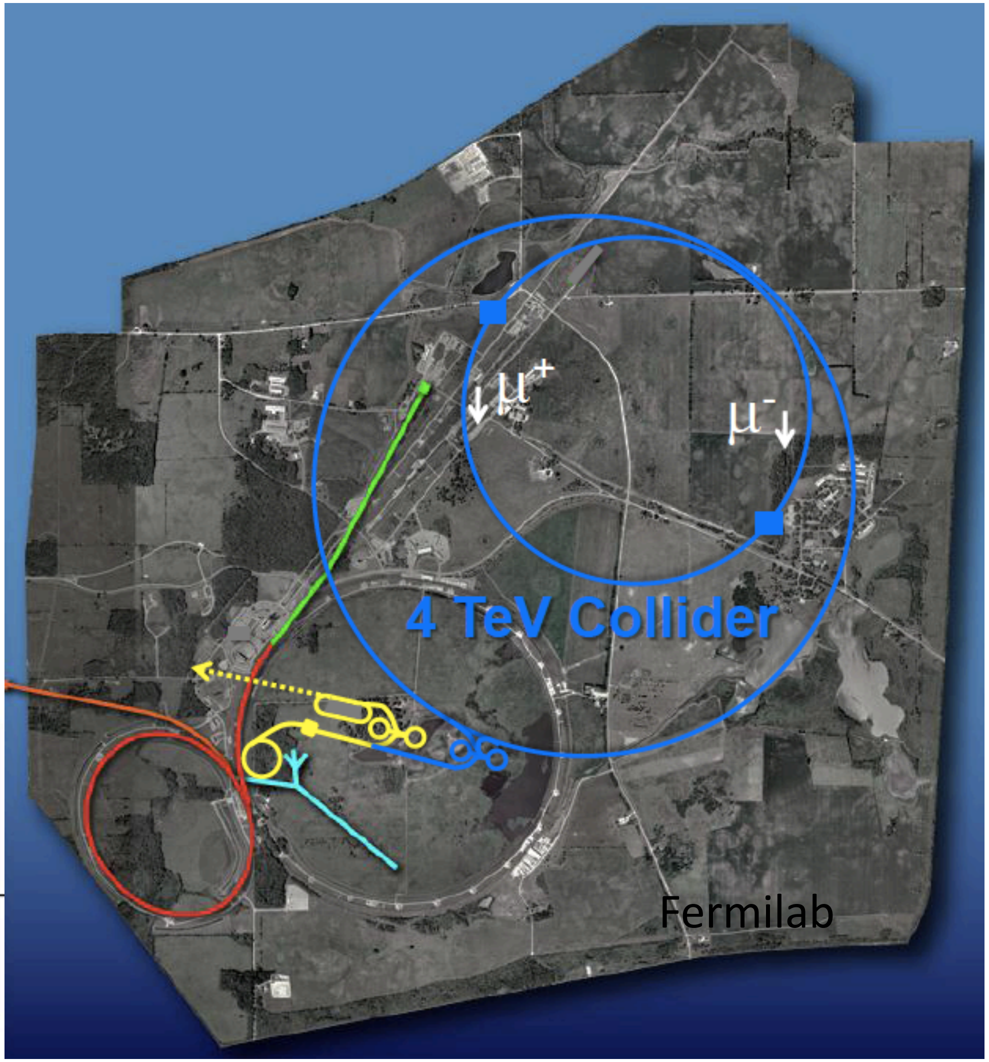
$E_{cm}=2E_e$	500 GeV
Luminosity	$1.5\ 10^{34}$
Power	215 MW
Gradient	31.5 MV/m
Length	31 km
IP beam size	474/4 nm

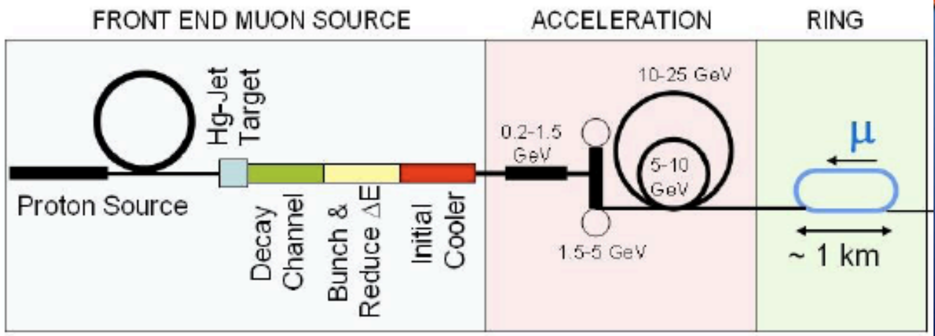
Push-pull detectors?

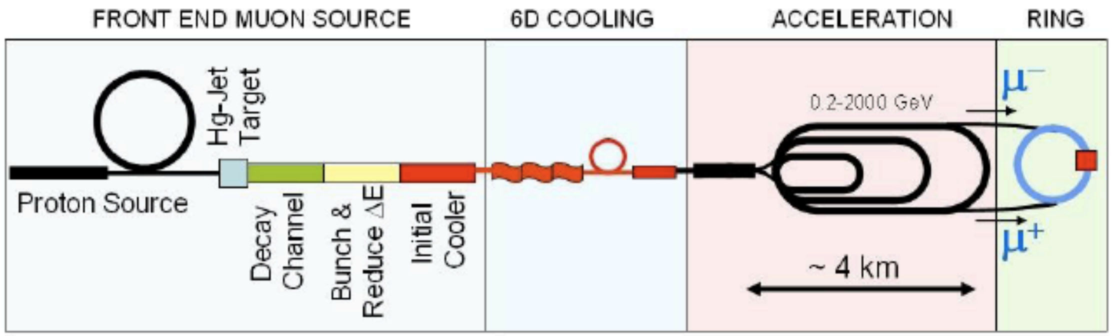
Muon Collider

A Future for Fermilab:
ProjectX, Neutrino Factory, Muon Collider

3 Proposals for ν Factories:
JPARC,CERN, FNAL based. Detector R+D







MUON COLLIDER

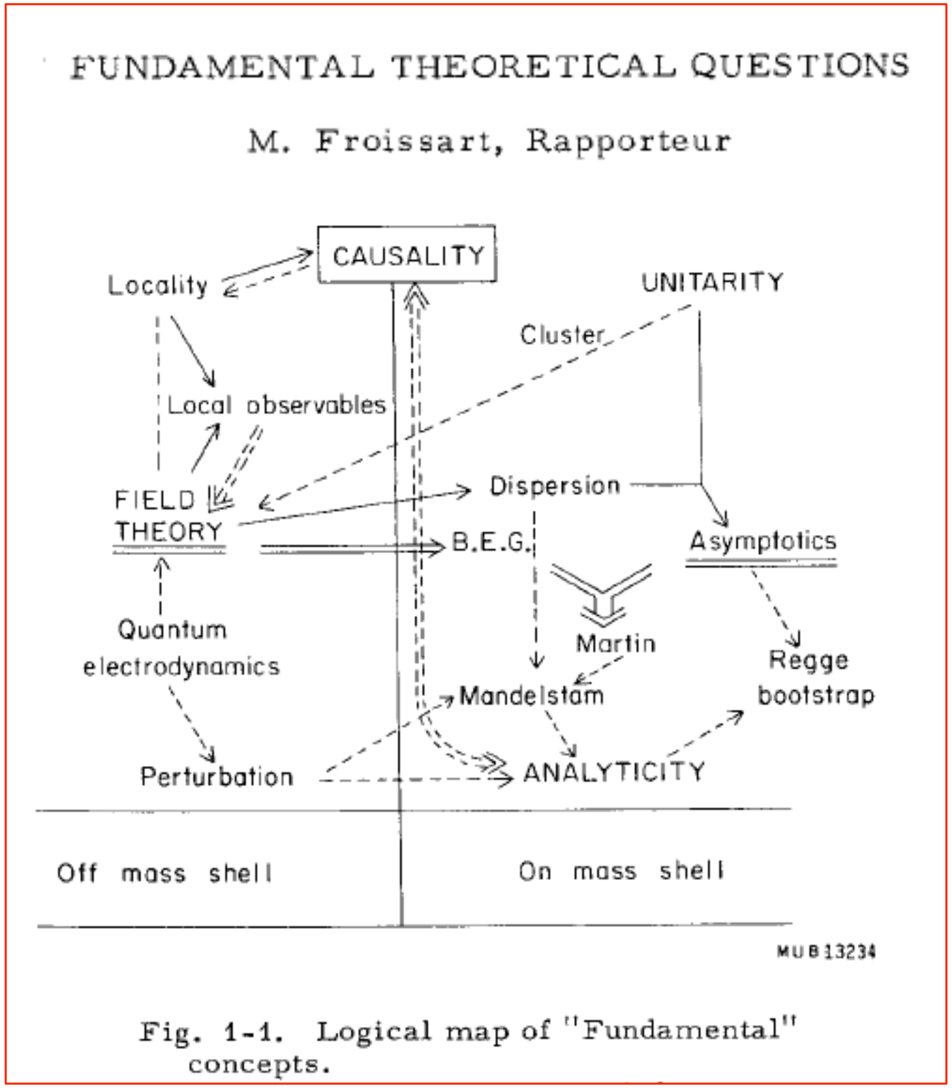
Circumference = 4.5km
$L = 3\times10^{34}$ cm^{-2}s^{-1}
μ/bunch = $2\text{x}10^{12}$
δp/p = 0.1%

S.Geer ICFA11

M.Froissart ICHEP (“Rochester”) 1966

THEORY

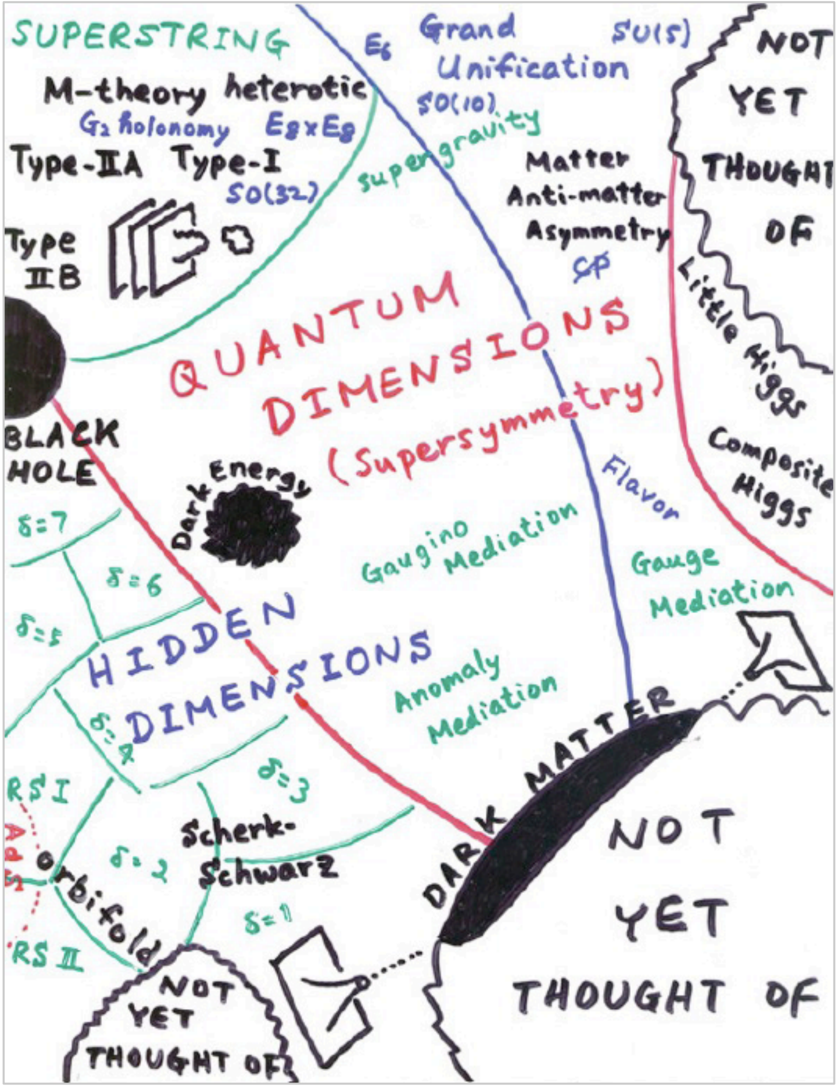
H.Murayama – ICFA11



FUNDAMENTAL THEORETICAL QUESTIONS

M. Froissart, Rapporteur

Fig. 1-1. Logical map of "Fundamental" concepts.



→ Quarks in 1969

→ ?in 2014?

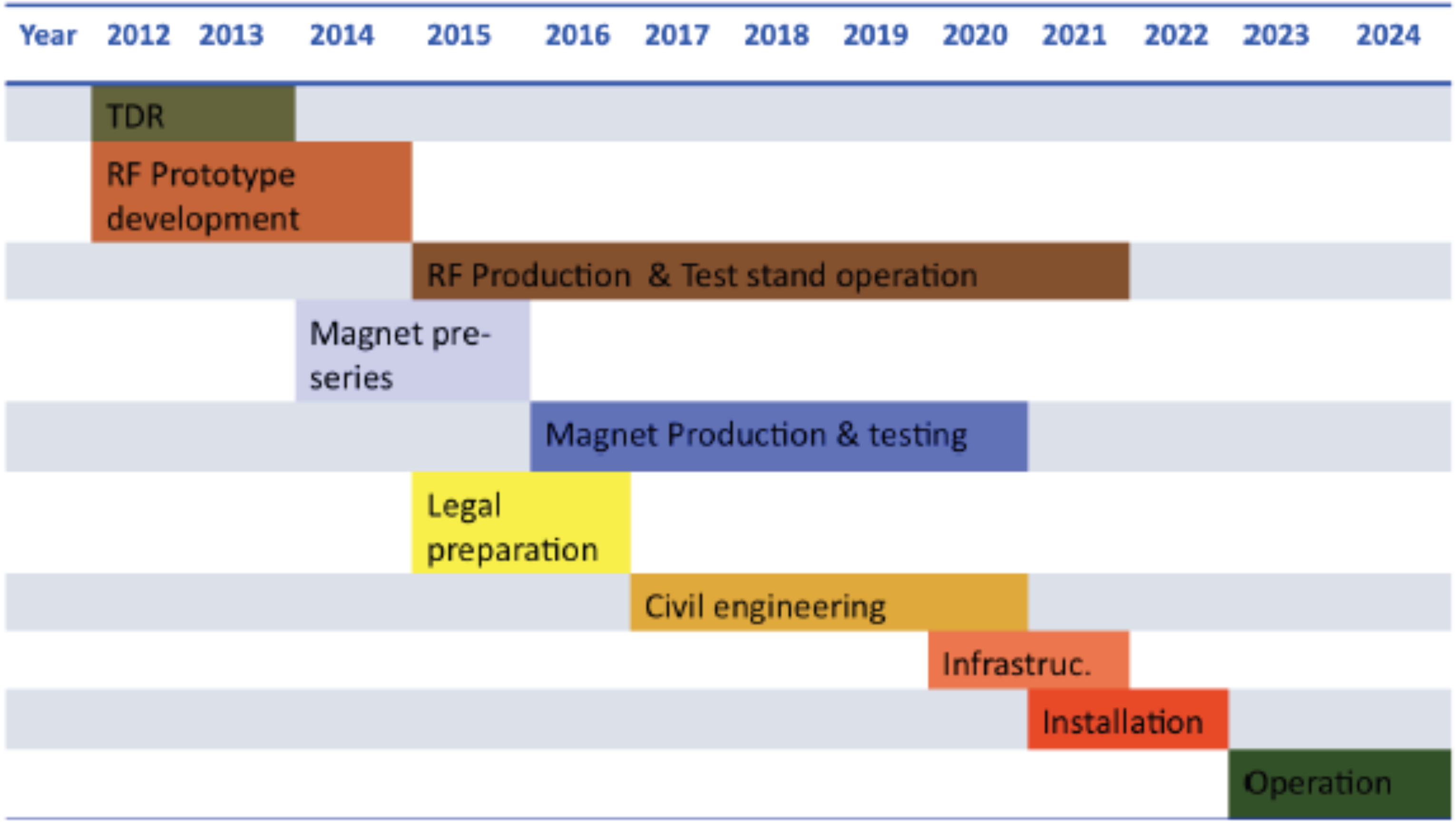
H.Murayama – ICFA11

“We like to see particle physics as driven by experiment…” Burt Richter 2009 at CERN

Liverpool HEP: ATLAS, ATLASupgrade, LHCb, LHCbupgrade, T2K,νFactory, NA62, LHeC + AstroPP

backup

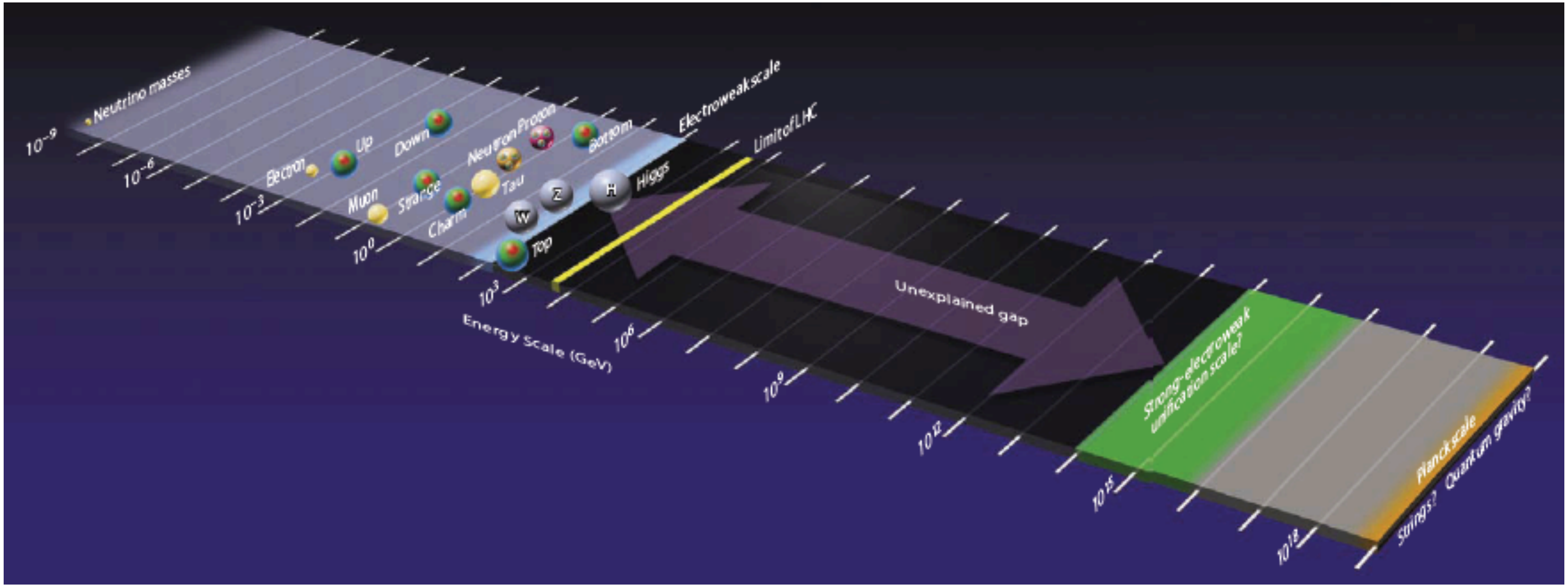
LHeC Tentative Time Schedule



LS3 --- HL LHC →

We base our estimates for the project time line on the experience of other projects, such as (LEP, LHC and LINAC4 at CERN and the European XFEL at DESY and the PSI XFEL)

The energy frontier



C.Quigg

With ingenuitive accelerators of the past century we have used beams of 5 MeV→ 1 TeV, an increase of six orders of magnitude in 100 years. We have no idea how to achieve a similar gain in this century. Theory is not certain as to what lies above or around the TeV scale. Three decades ago SU(5) predicted 'the desert', but it contradicted experiment

title

title