Particle Physics in Transition

Physics and Projects

Max Klein

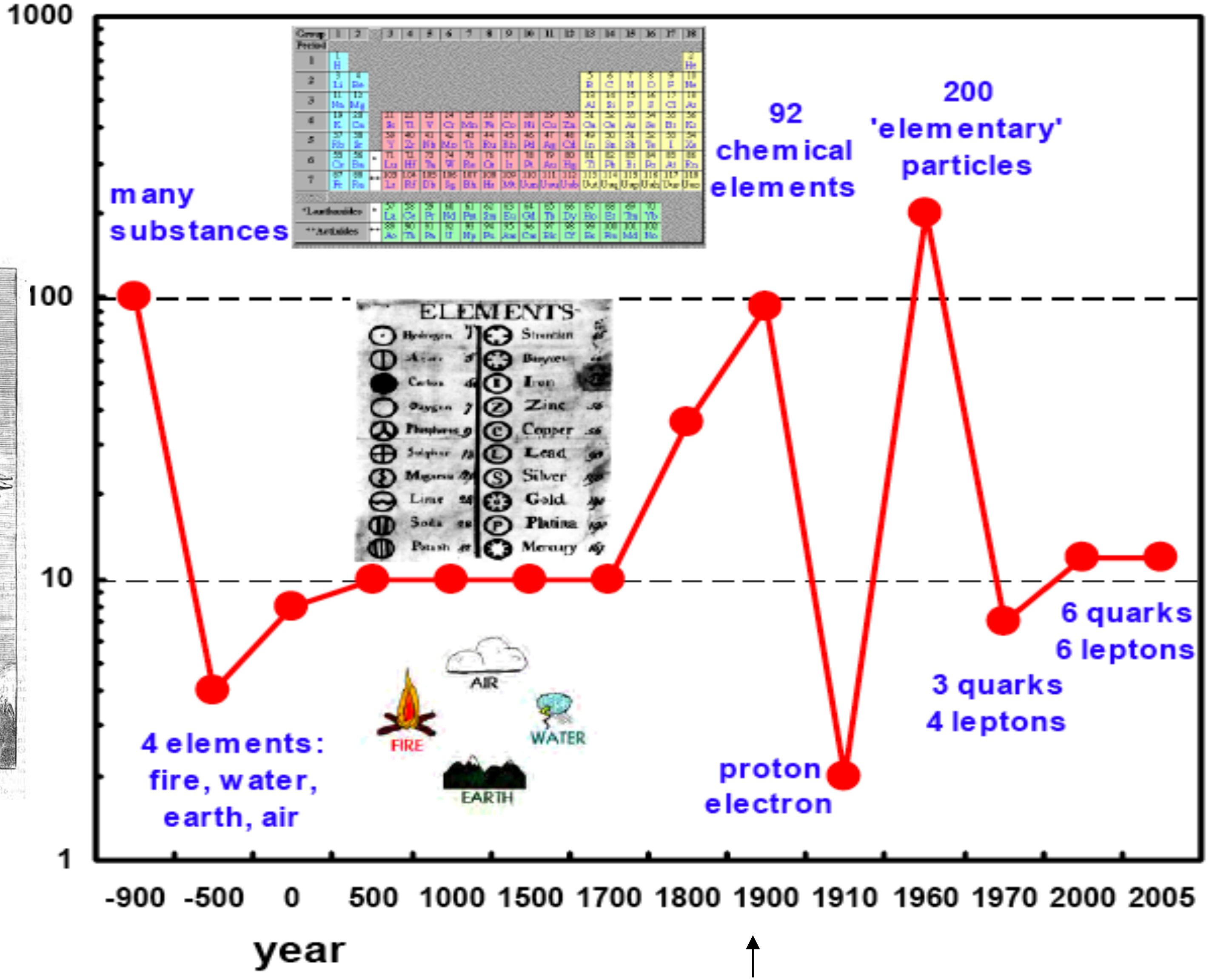
UNIVERSITY OF LIVERPOOL

Colloquium at Prague 11th of January 2012

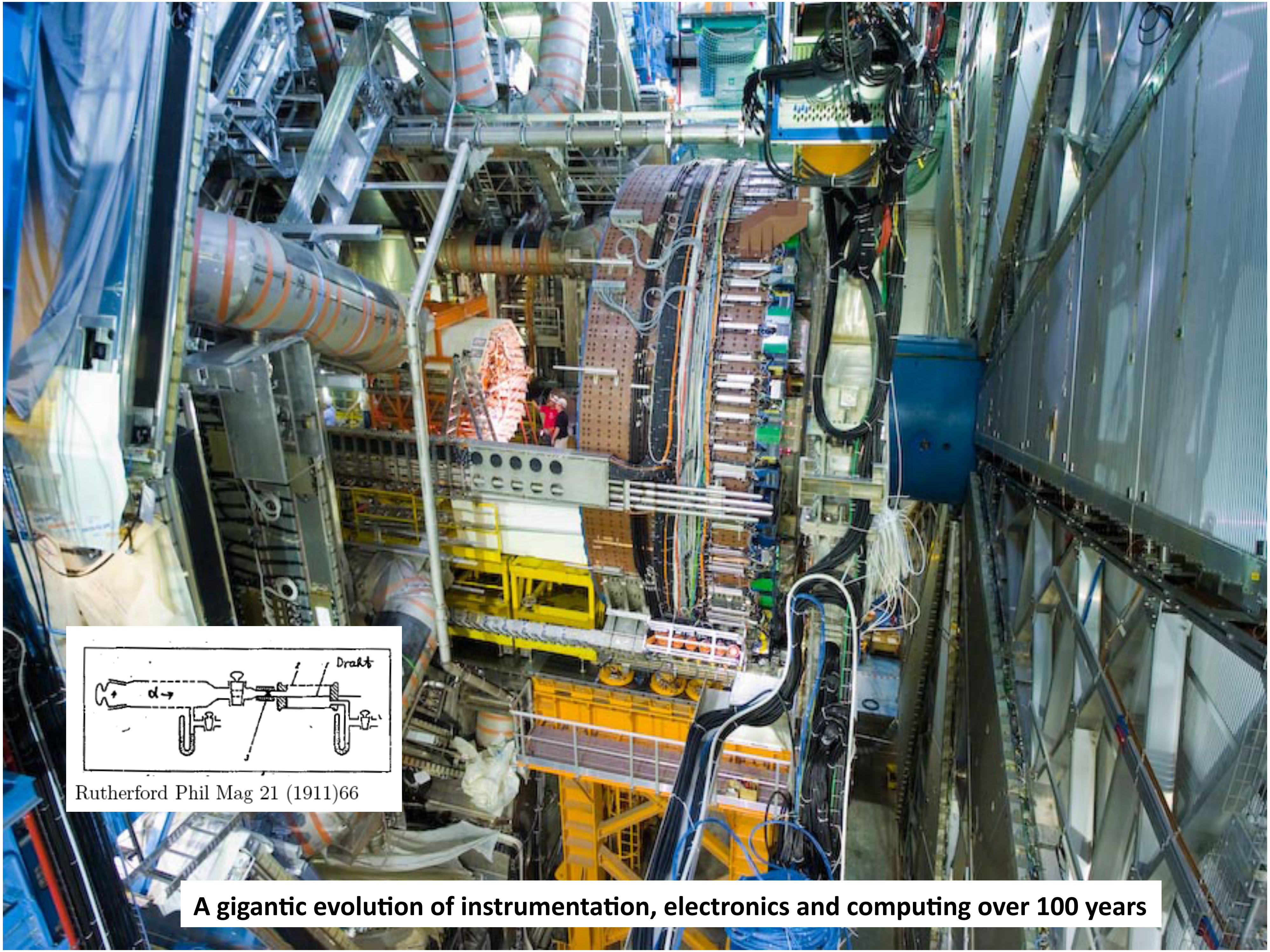
From Empedoclez to today

490-430 BC, Sicily

Four elements
and two forces
(love and strife)



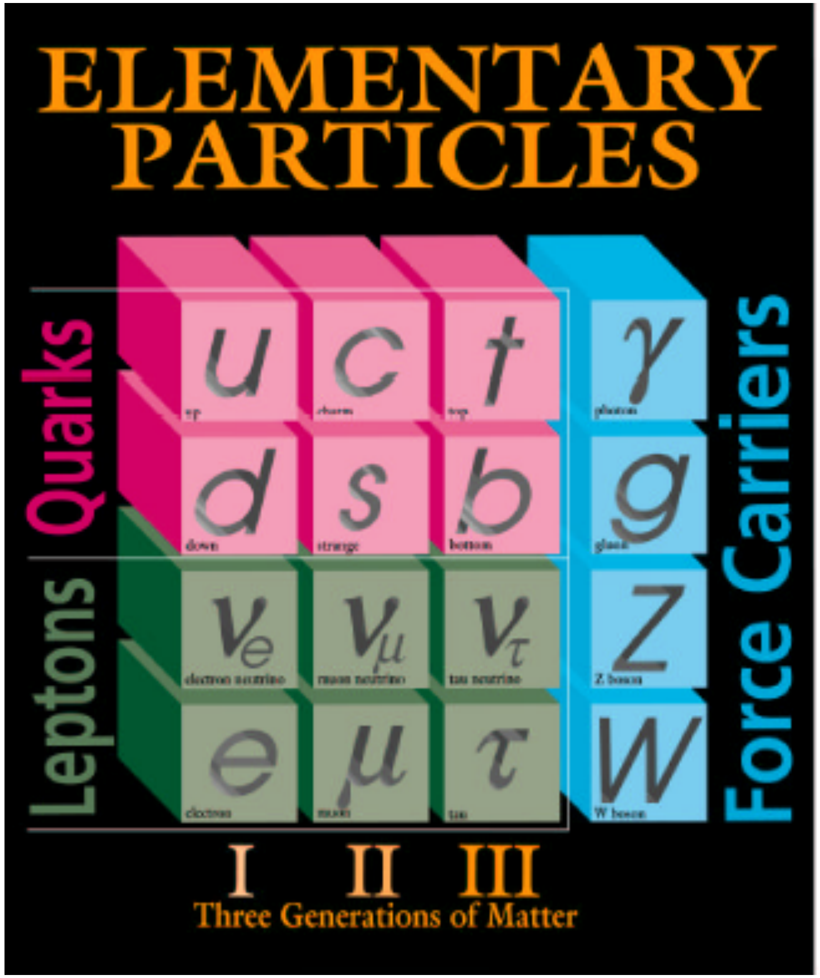
Lord Kelvin: There is nothing new to be discovered in physics.
All that remains is more and more precise measurement.



Rutherford Phil Mag 21 (1911)66

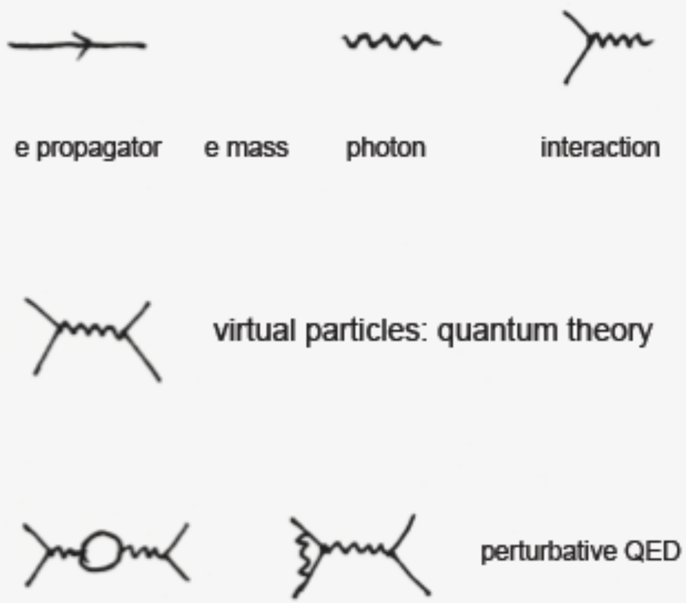
A gigantic evolution of instrumentation, electronics and computing over 100 years

The Standard Model



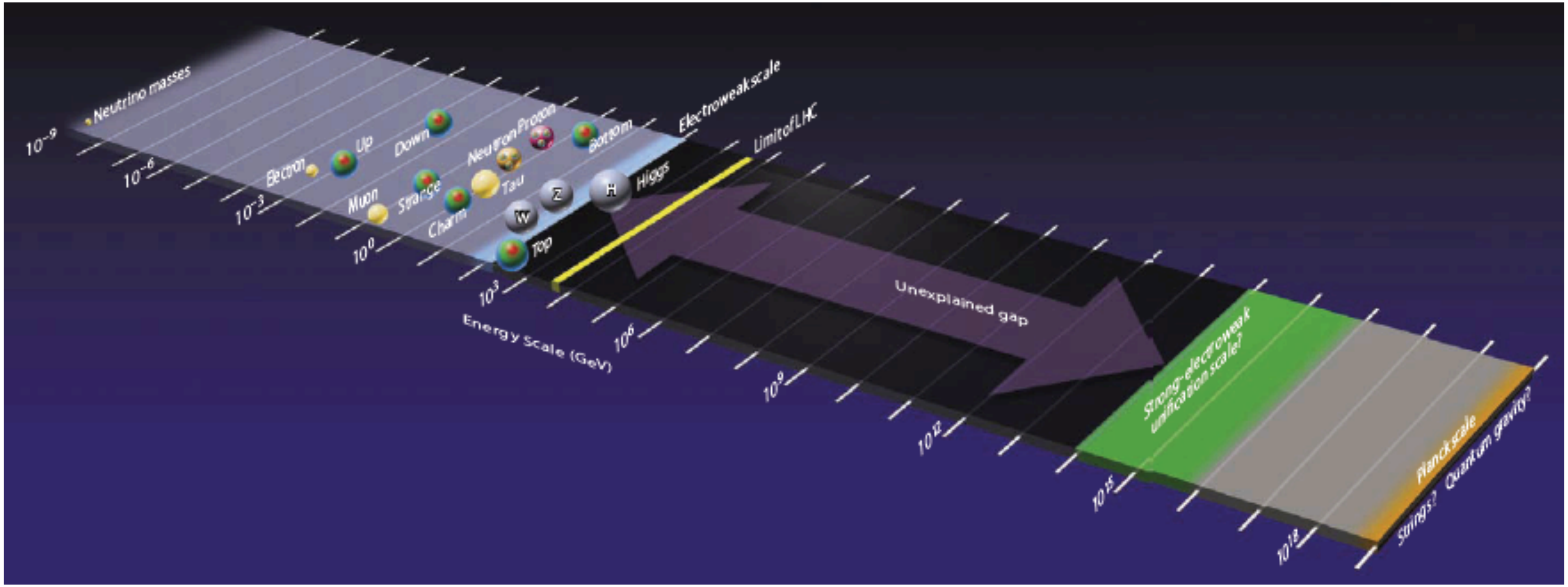
Renormalisable gauge field theory of the electromagnetic, strong and weak interaction.

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



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

The energy frontier



C.Quigg

With ingenuitive accelerators of the past century we have used beams of 5 MeV→ 4 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

Neutrinos

Photo: AIP, Emilio Segrè Visual Archives

Wolfgang Pauli

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

Abschrift

Physikalisches Institut
der Eidg. Technischen Hochschule
Zürich

Zürich, 4. Dez. 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 Grossenordnung 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.

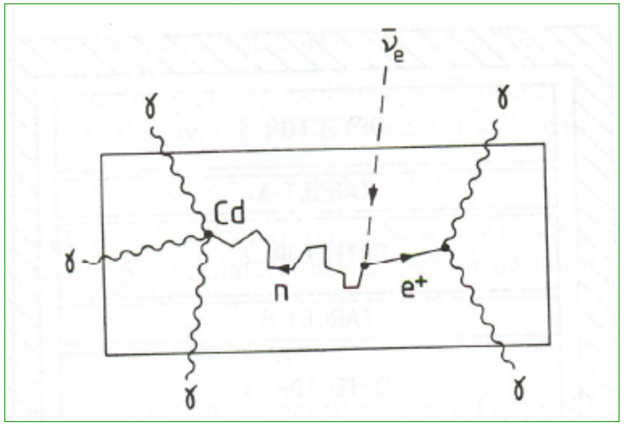
$n \rightarrow p\, e\, \nu$

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

Early Neutrino Physics

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

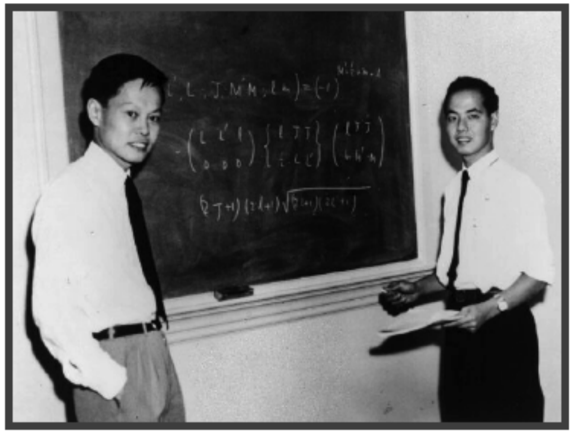
Discovery of the neutrino



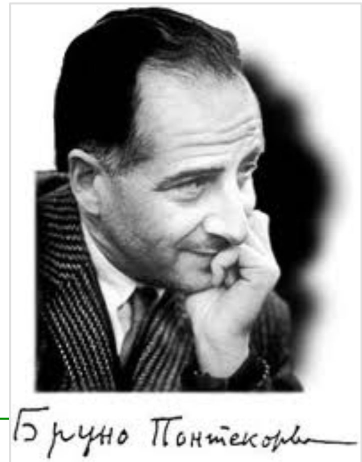
E_ν = 1 MeV. 2 events / hour

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")



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}

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

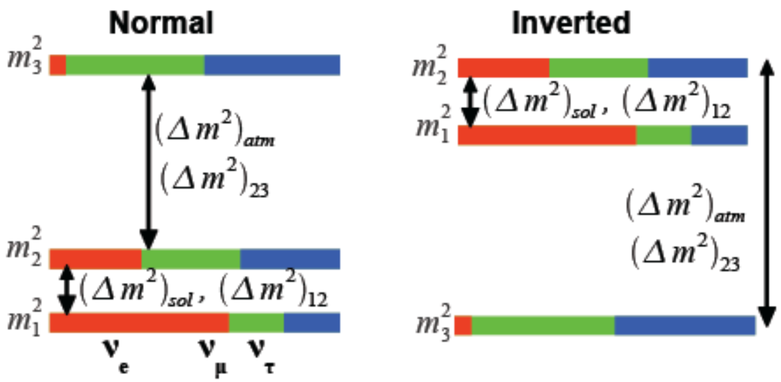
θ_{13}

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

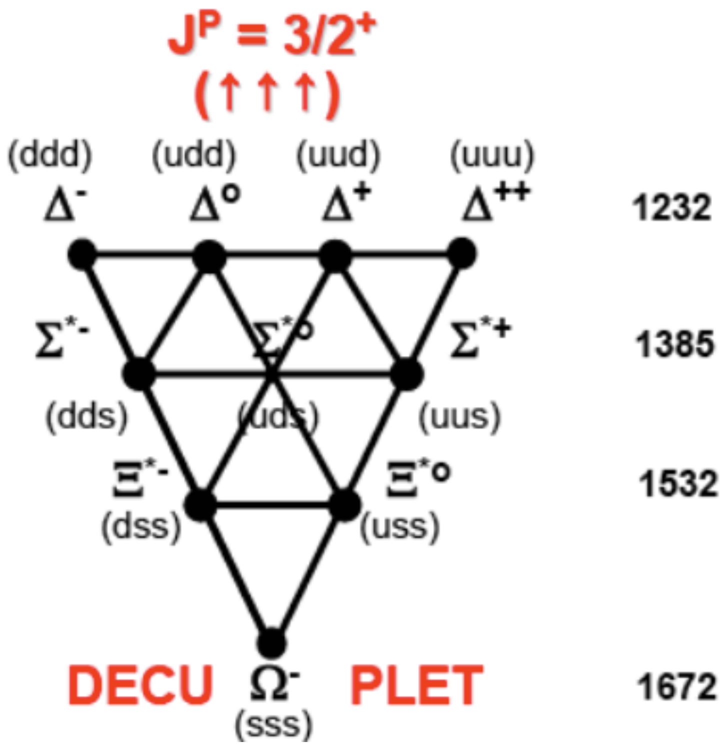


Most urgent points:

- $\sin^2 2\theta_{13} > 0.01$ 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 ?

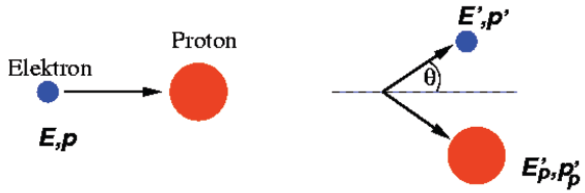
Early Quark-Parton Physics

[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

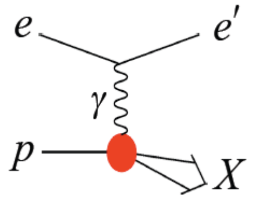
Hofstadter 1955



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

Deep Inelastic ep Scattering

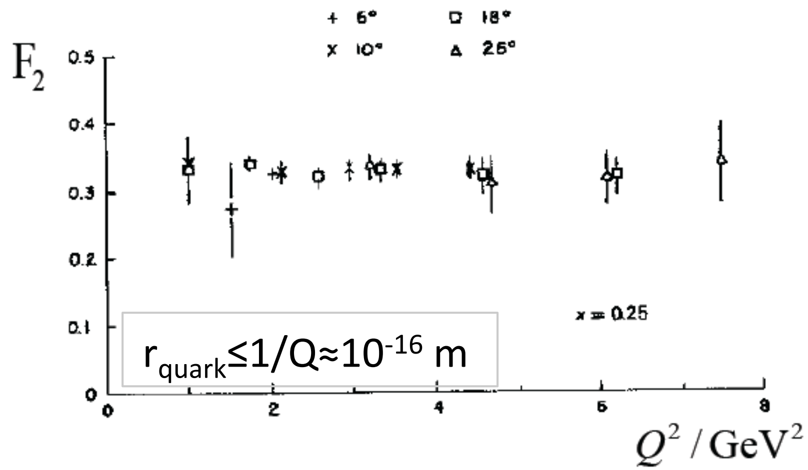
SLAC 1969
Friedman
Kendall
Taylor et al.



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

$\theta = 6° \ldots 26°$

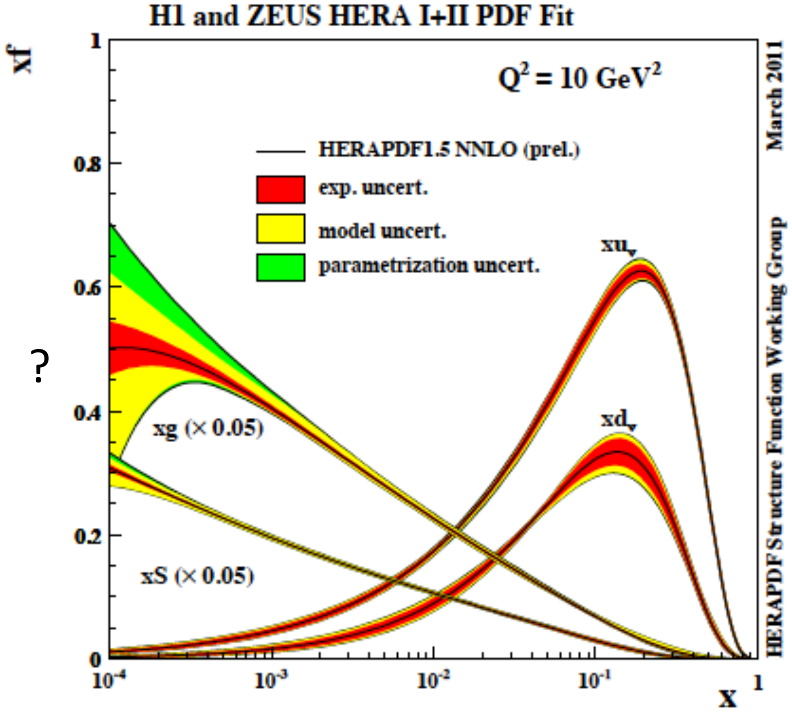
$Q^2 = 1 \ldots 7\,\mathrm{GeV}^2$



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

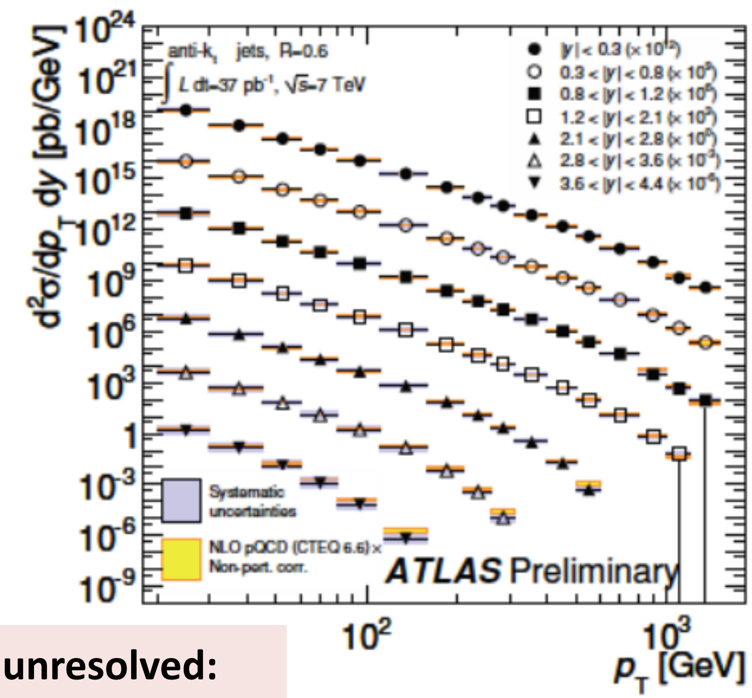
Partons to explain scaling behaviour

The standard picture of quark-parton dynamics



?

Universal? parton distributions



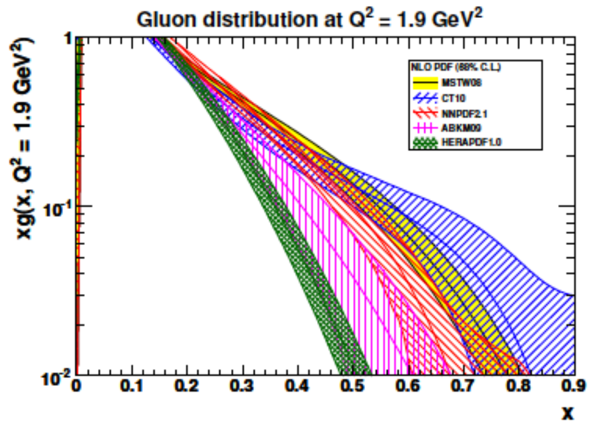
$$\mu\frac{dg(\mu)}{d\mu} = \beta(g(\mu))$$ RGE

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

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

Asymptotic Freedom: perturbative QCD

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, Englert, Kibble, Hagen, Guralnik]

["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**.

2010 Sakurai Prize Winners - (L to R) Kibble, Guralnik, Hagen, Englert, Brout and Higgs (not on this photo)

Remarks on the Higgs particle

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

Gauge field Lagrangian a la QED

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

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 $\eta=\sqrt{(-\mu^2/2\lambda)}$

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

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

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

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!

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

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)]

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

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

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

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

$$M_\gamma = 0$$

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

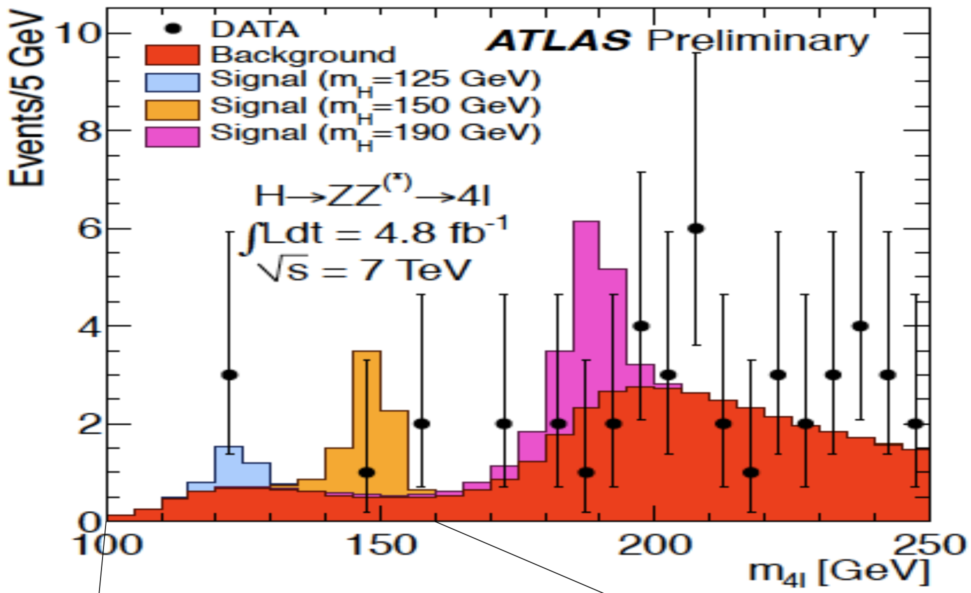
All of this has been beautifully confirmed by experiment: W, Z, sinΘ, mass relations.

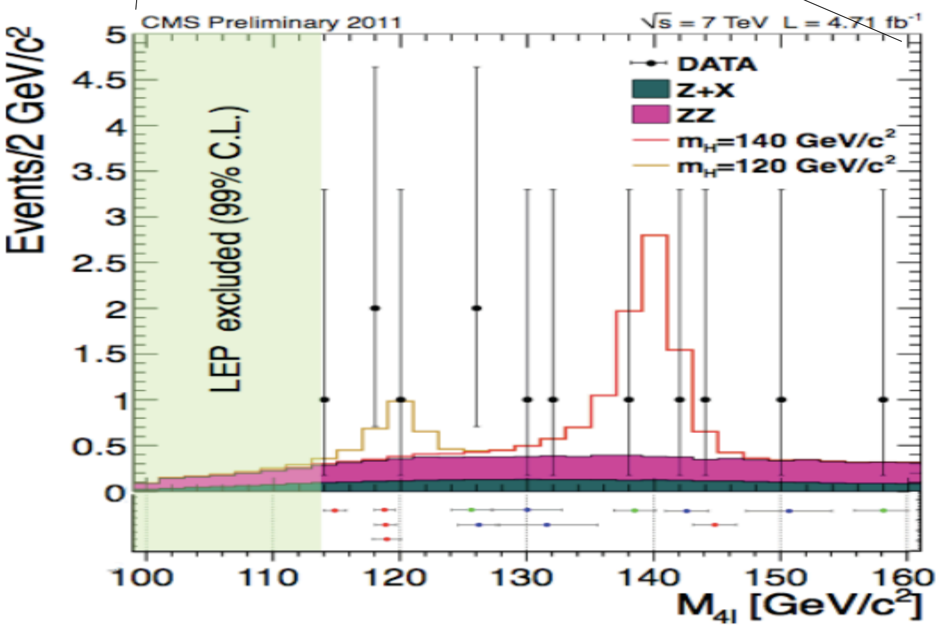
We don't know how large λ is and whether this choice of the Higgs mechanism is real.

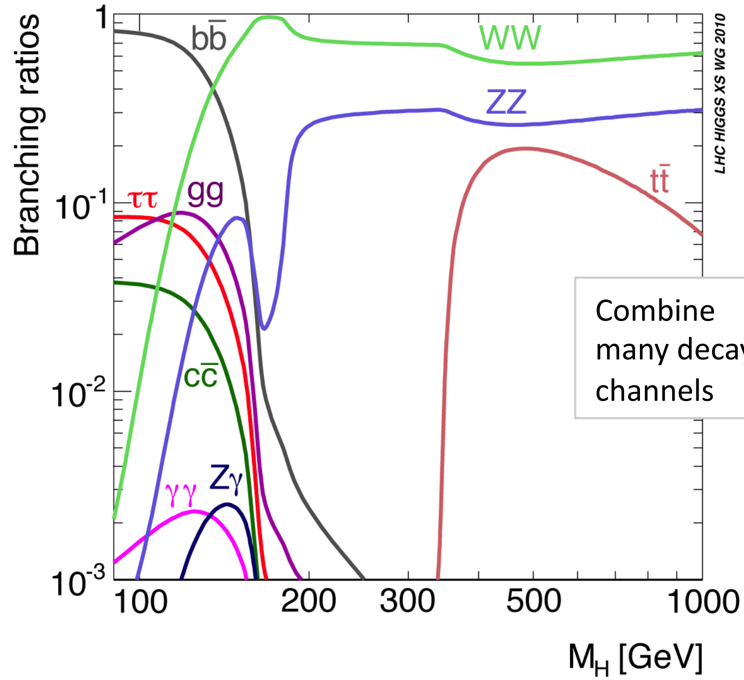
Search for the Higgs Particle

[13.12.2011]

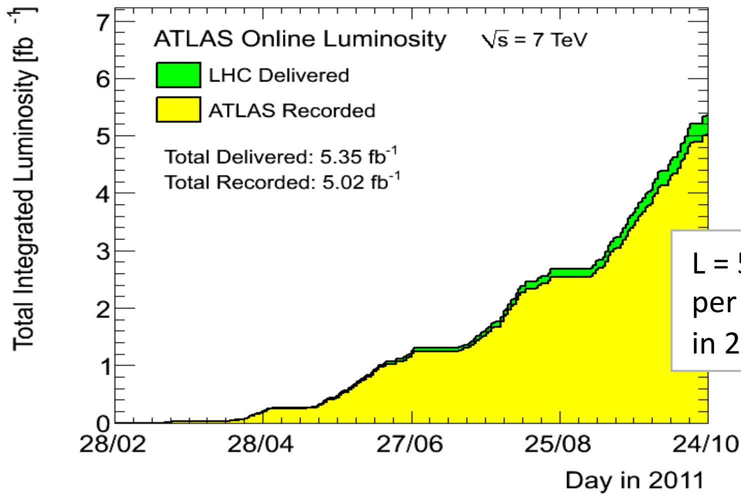
Cleanest channel: H → ZZ* → 4l







Combine many decay channels

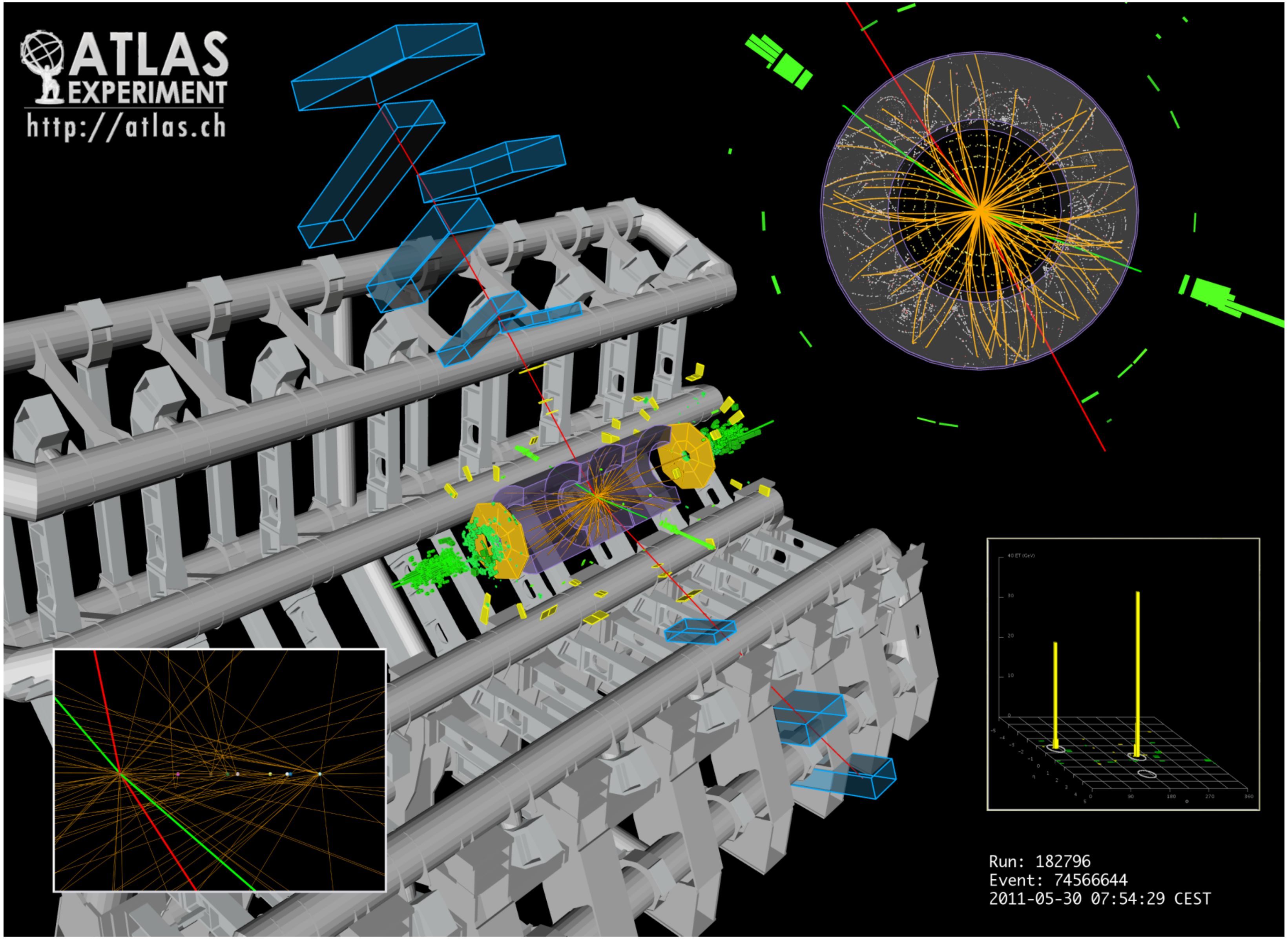


L = 5fb^{-1} per exp in 2011

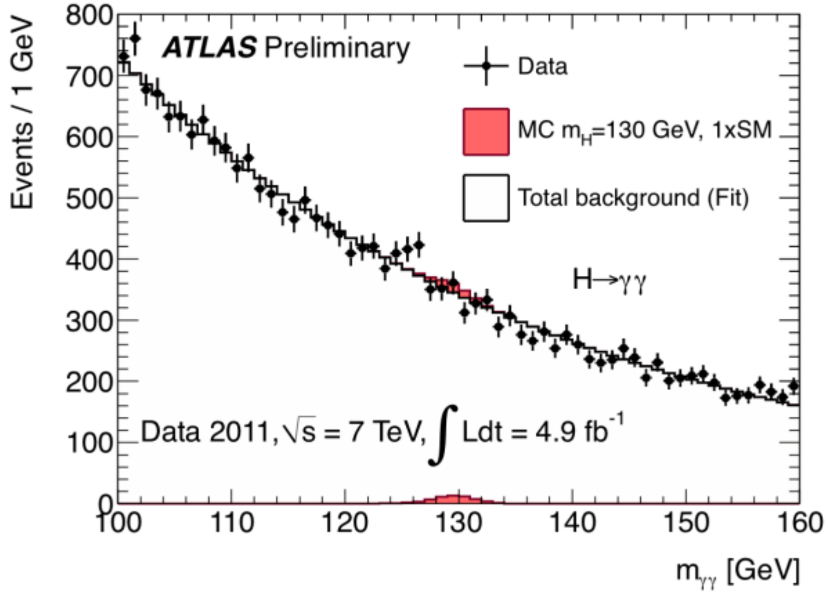
$H \rightarrow ZZ^{(*)} \rightarrow ee\mu\mu$

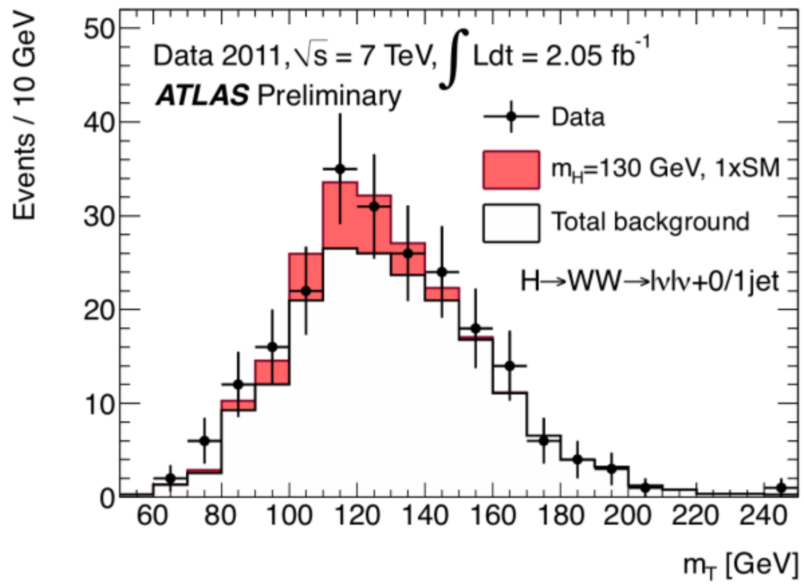
2e2μ candidate with $m_{2e2\mu}$= 124.3 GeV

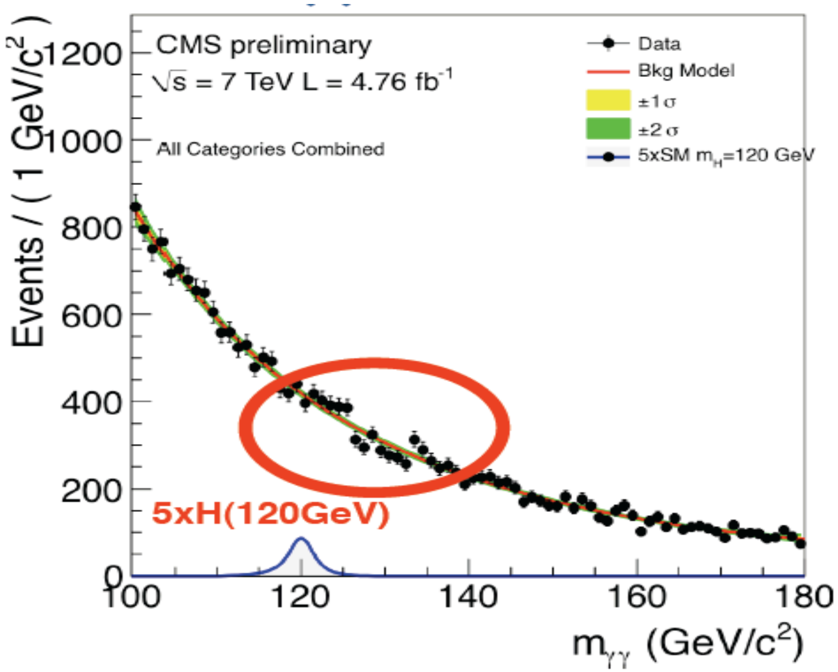
p_T (e^+, e^-, μ^-, μ^+)= 41.5, 26.5, 24.7, 18.3 GeV
m (e^+e^-)= 76.8 GeV, m($\mu^+\mu^-$) = 45.7 GeV

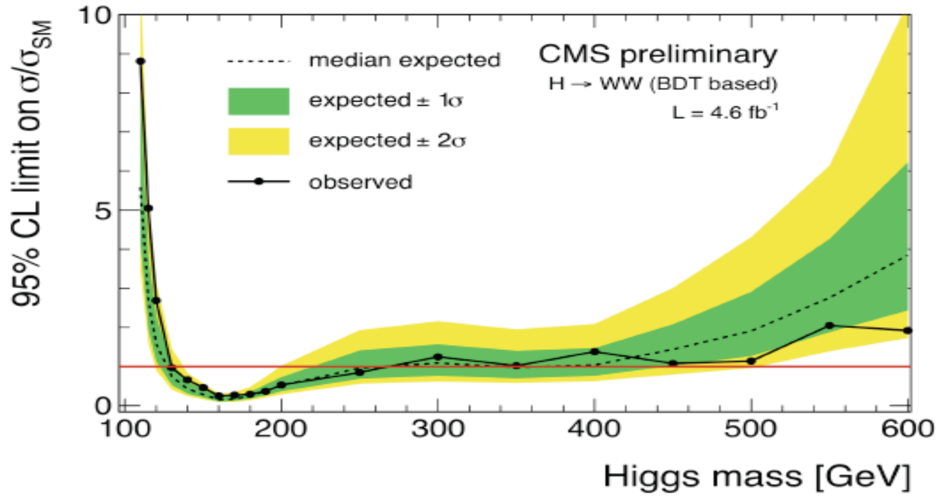


γγ and WW channels

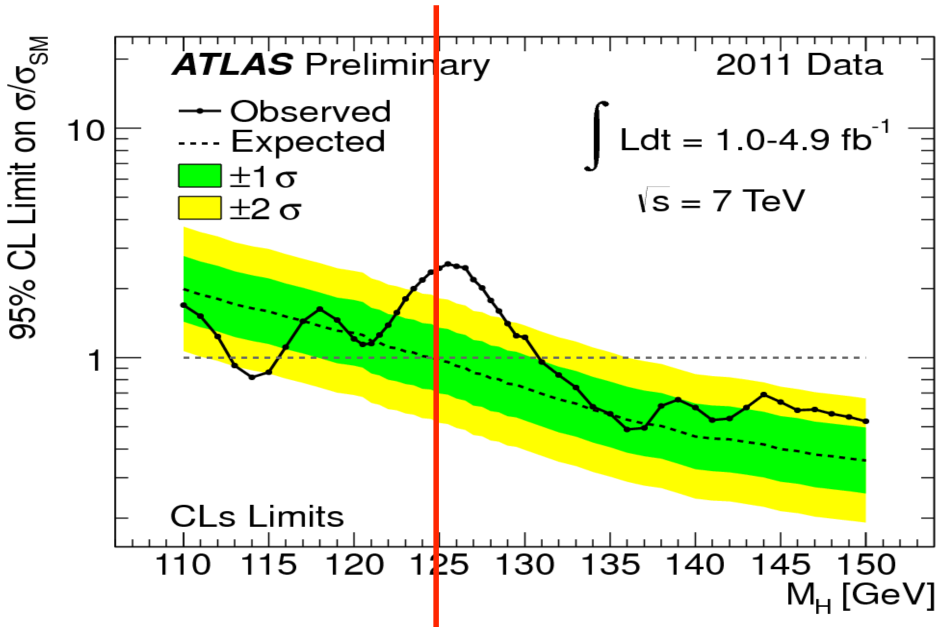


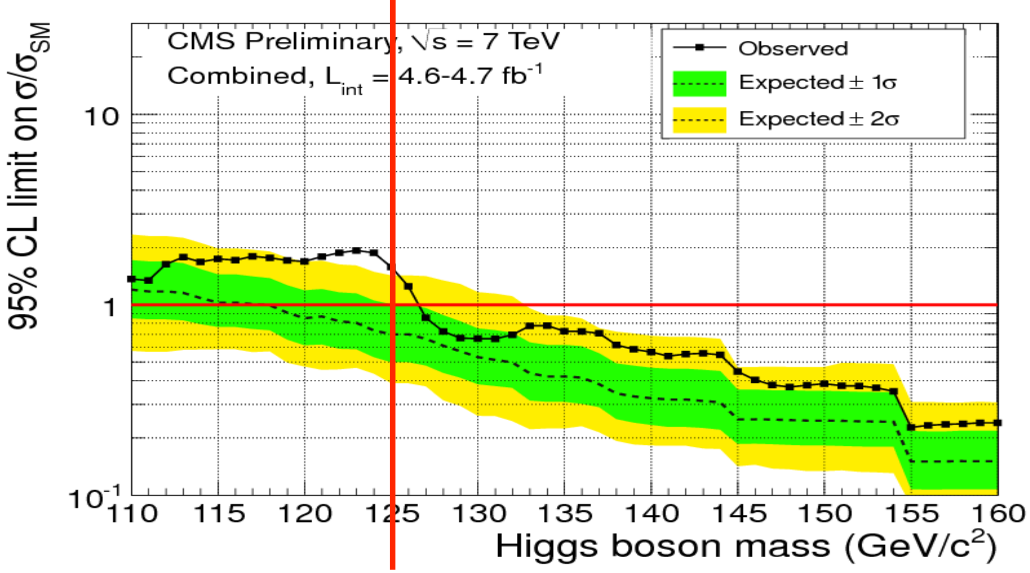


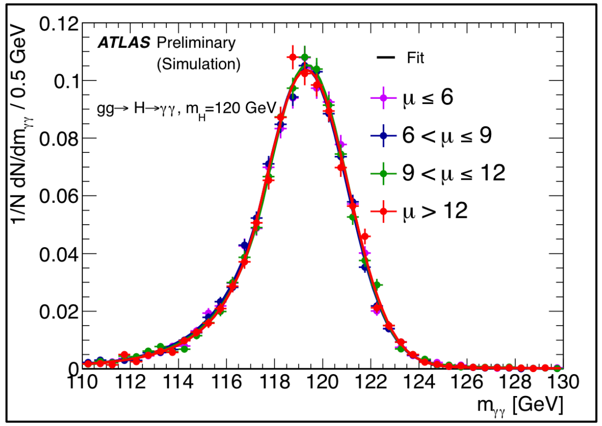




Higgs on December 13th,2011







simulated SM Higgs → γγ in ATLAS

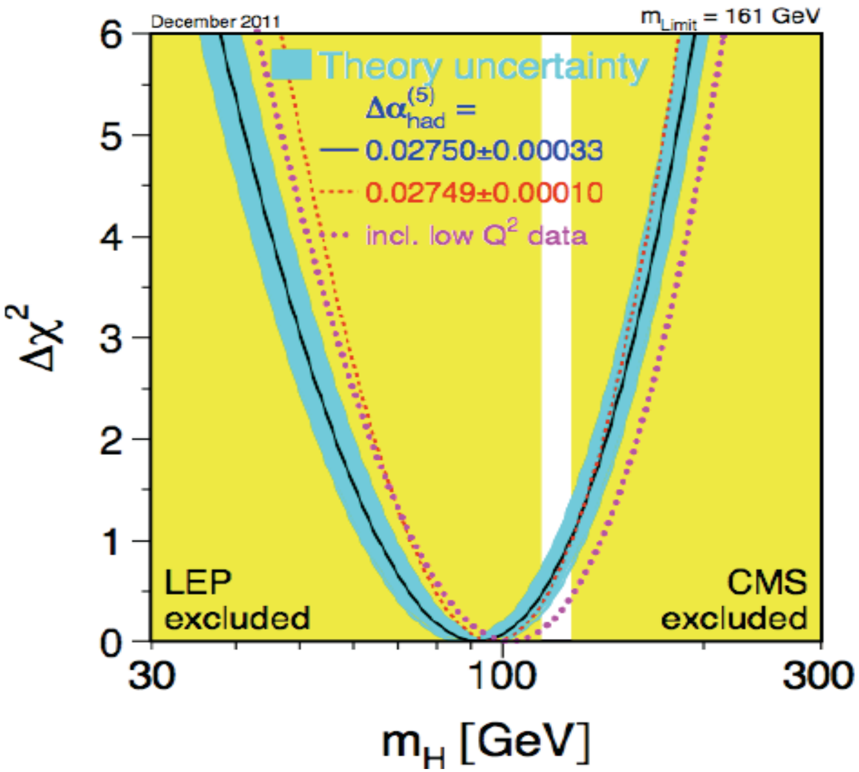
The “excesses” are about 2 GeV apart, probably just compatible

The Higgs is NOT god’s particle and may (not) exist. I don’t think it is more important than the proton, the up/down quark, the gluon, ν or the W… BUT sth is missing and the H exciting for sure.

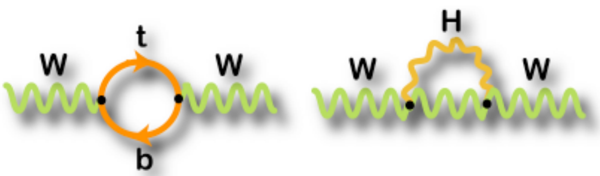
We expect $16 fb^{-1}$ at 4TeV for 2012. It thus is likely that the existence of the SM Higgs can be (dis)proven within the course of next year.


LHC Tunnel 2002

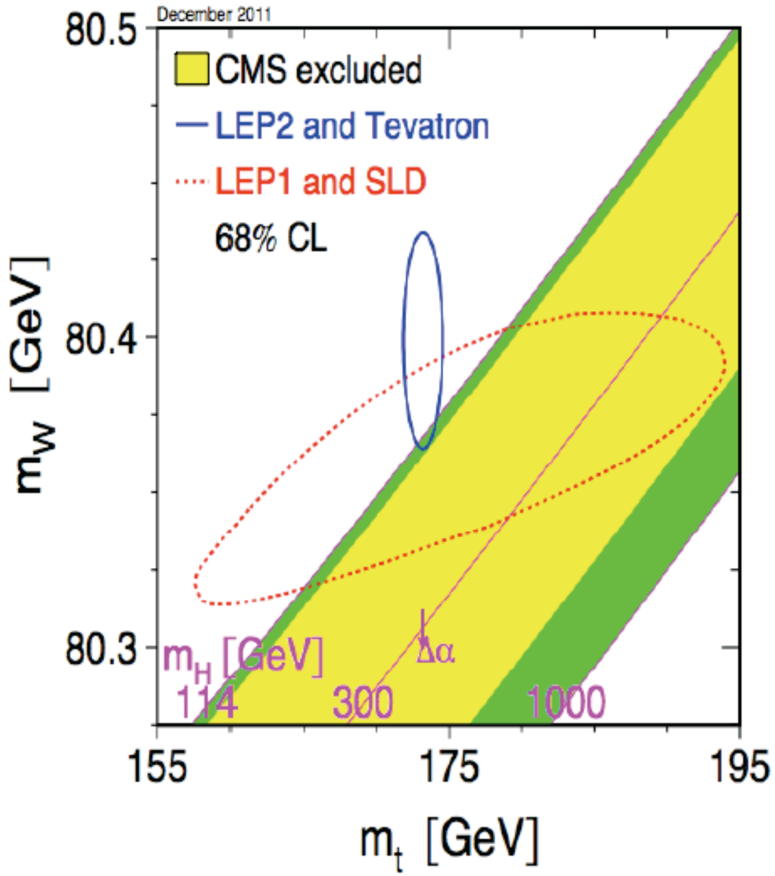
Search for the Higgs Particle [indirect]



Determination of M_H within exploiting loop corrections

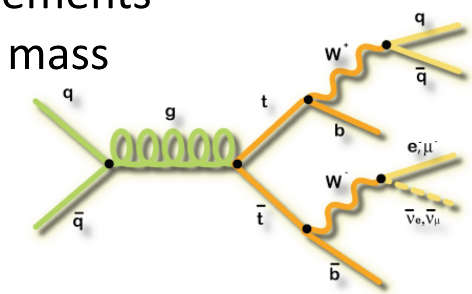


Successful example: prediction of top mass using e^+e^- data

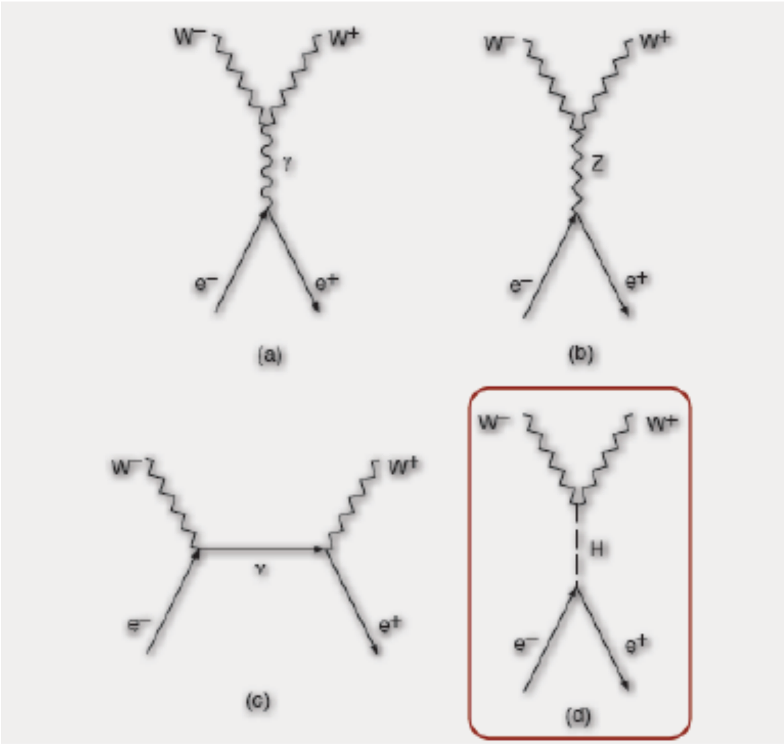


Challenging measurements of W and top quark mass

m_W=80.399±0.023
m_t=173.1±1.3



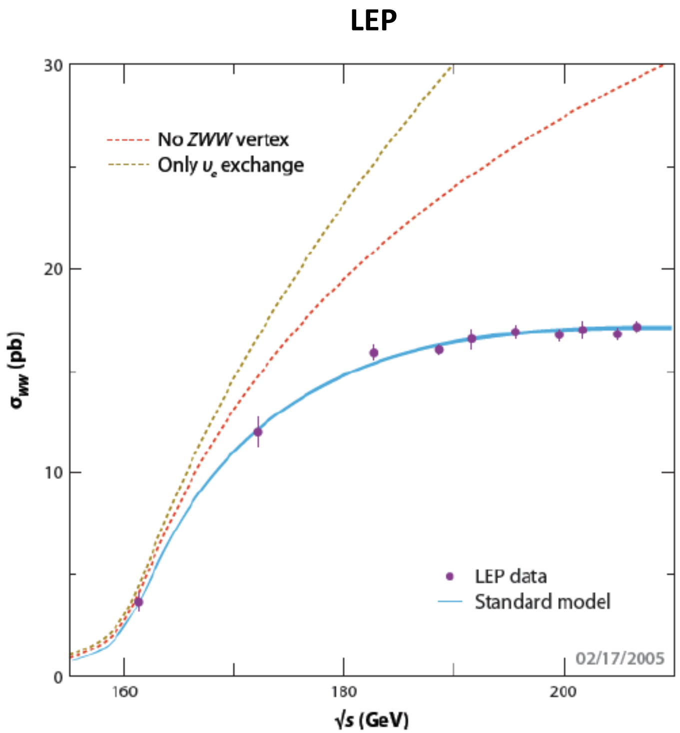
No Higgs?

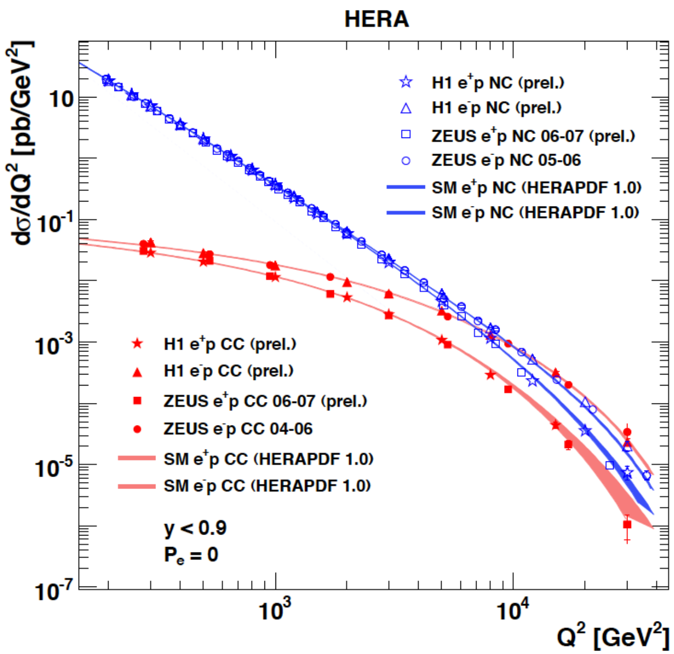


W and Z/γ behave as predicted

LEP:ZWW

HERA:NC≈CC



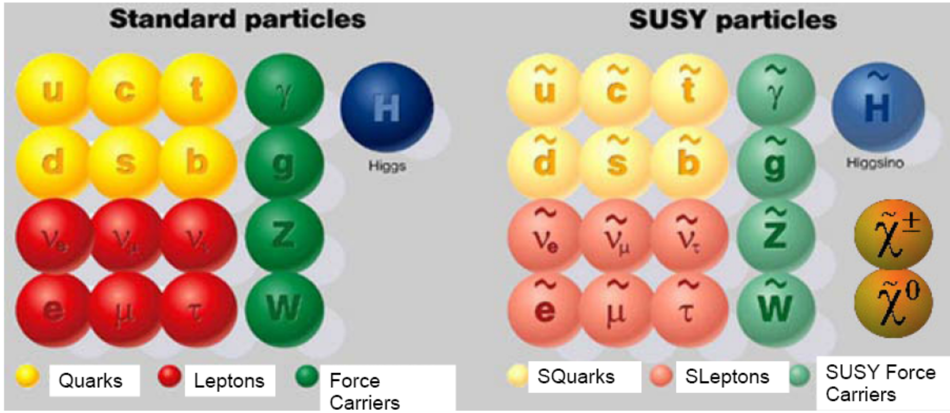


The W damps the rise of the 4fermion cross section.

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

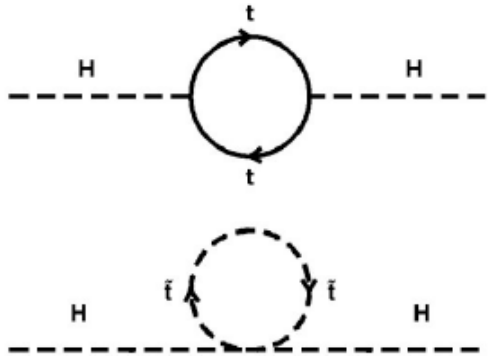
SUperSYmmetry*)

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)

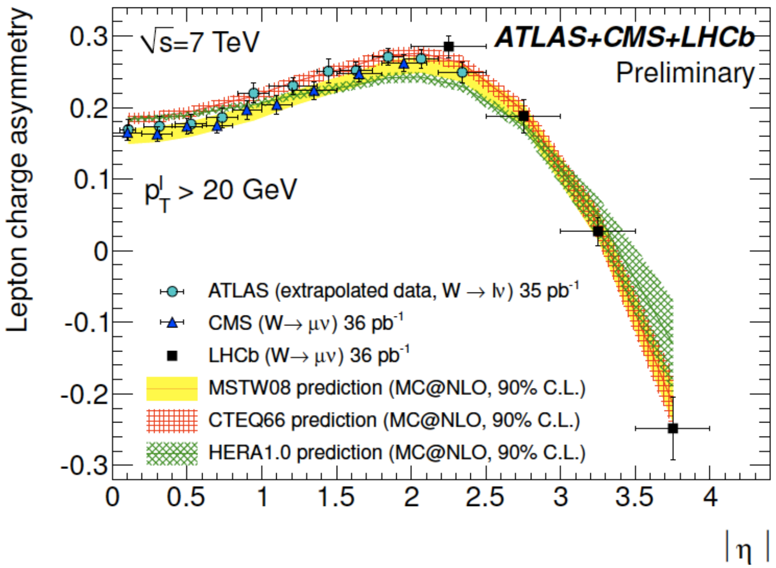


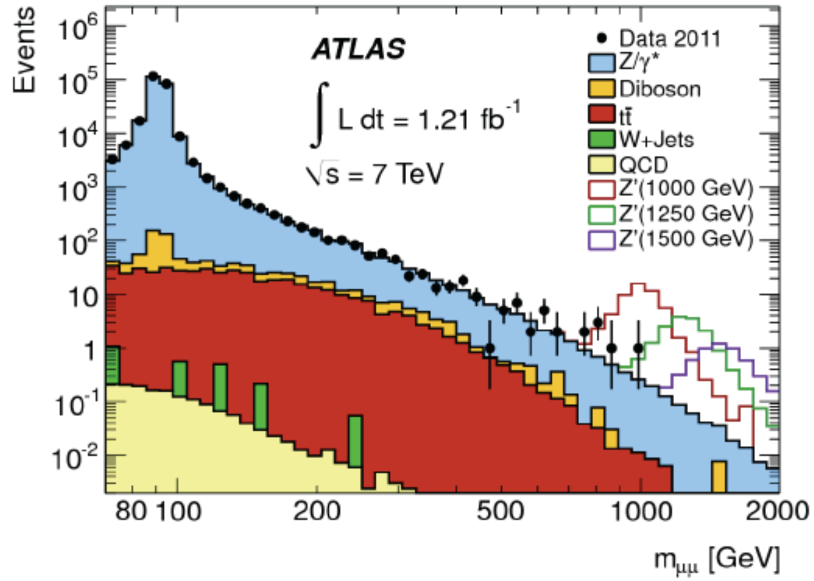
*) Y.Golfand, E.Likhtman, JETP Letters 13(1971)323
"Extension of the Algebra of Poincare Group Generators and Violation of P Invariance"
D.Volkov, V.Akulov, Phys.Lett. 46B (1973)109 "Is the Neutrino a Goldstone Particle?"
J.Wess, B.Zumino, Nucl.Phys. B70(1974)39 "Supergauge Transformations in 4 Dimensions"

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

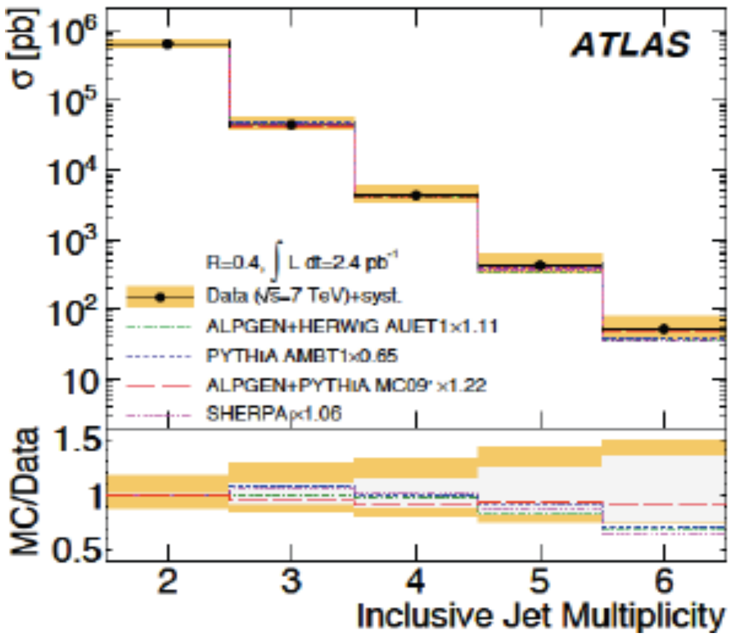
LHC- Standard Model Measurements [~400 papers/preliminary results in 2010/11]

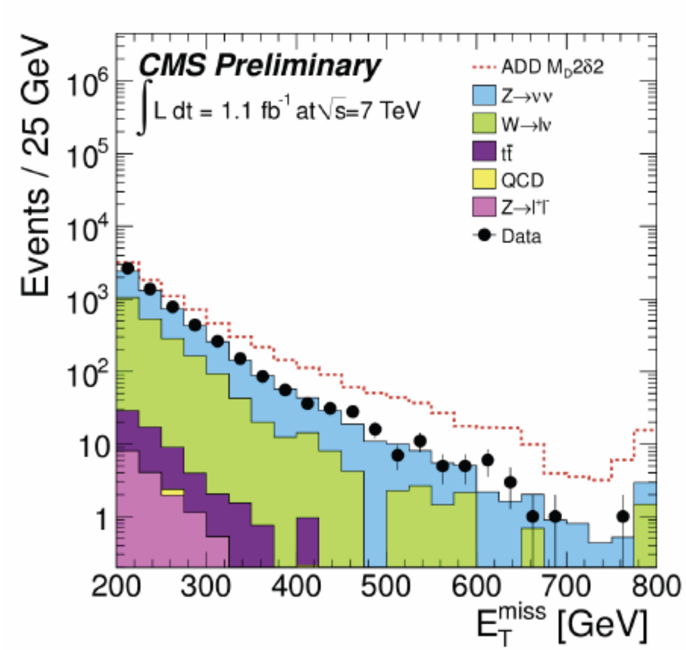




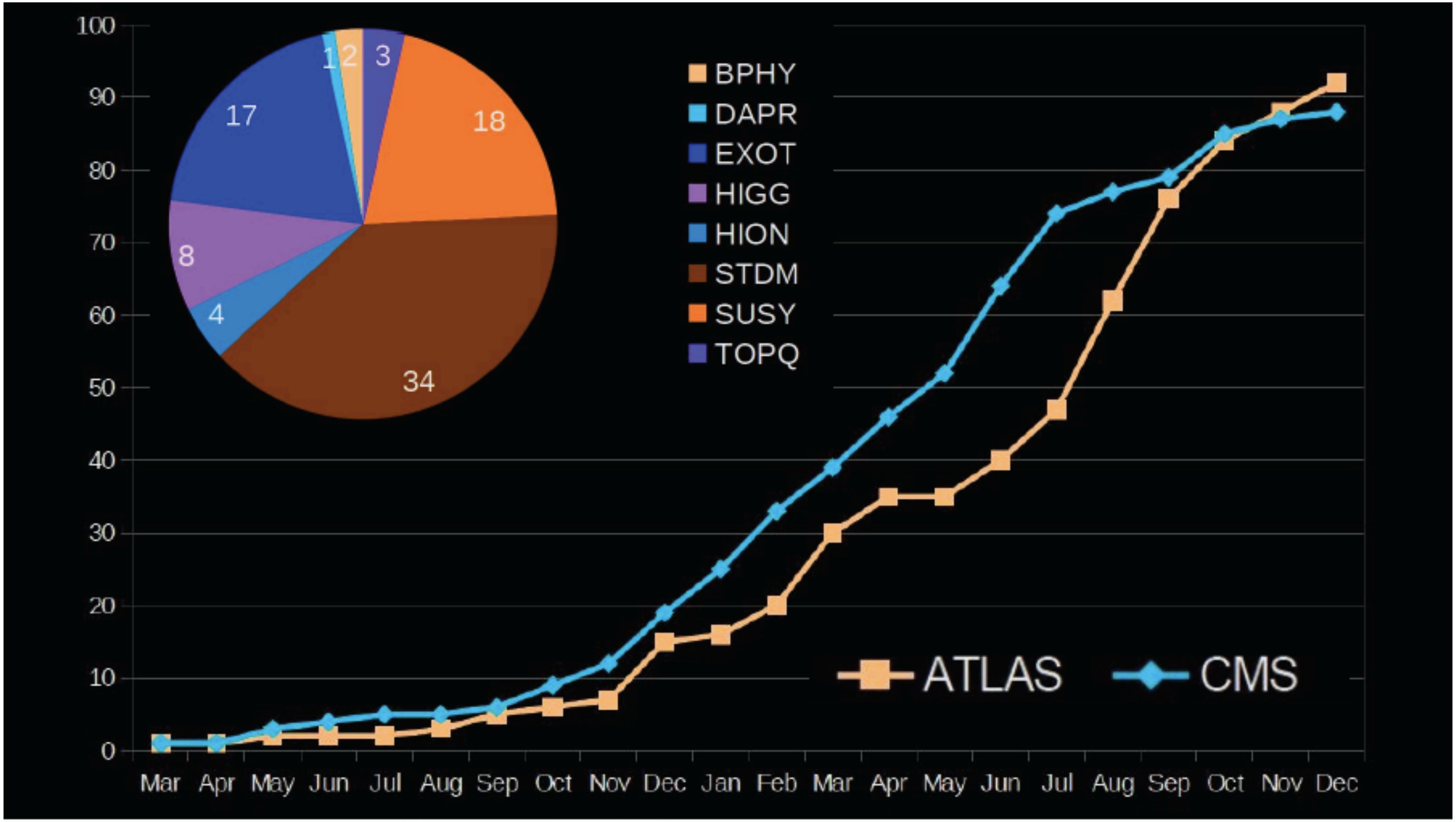
No sign for Z' nor W' below about 2 TeV

Explore proton+QCD in new region





No large missing energy of unknown origin

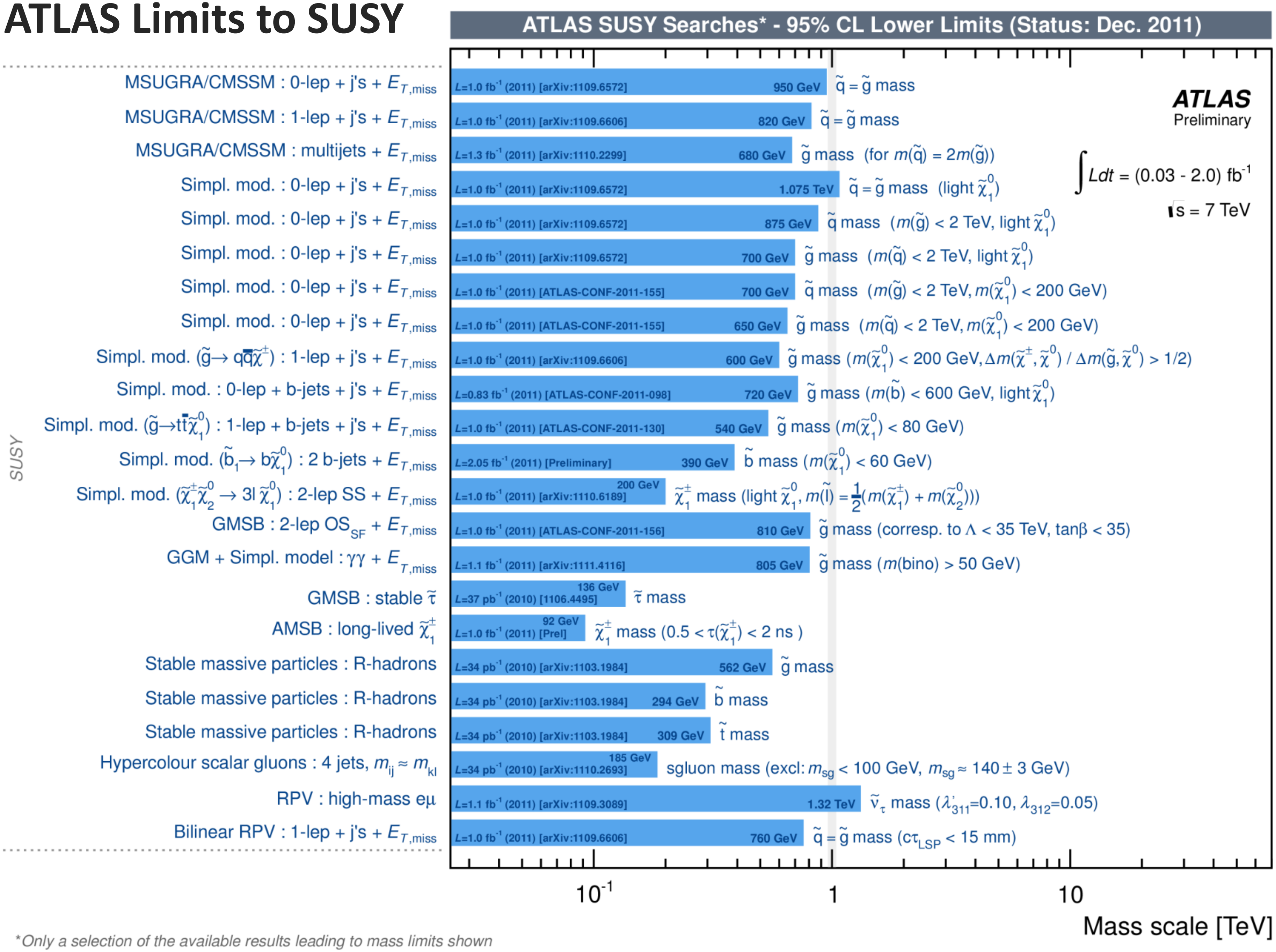


(19/12/11)

Publications

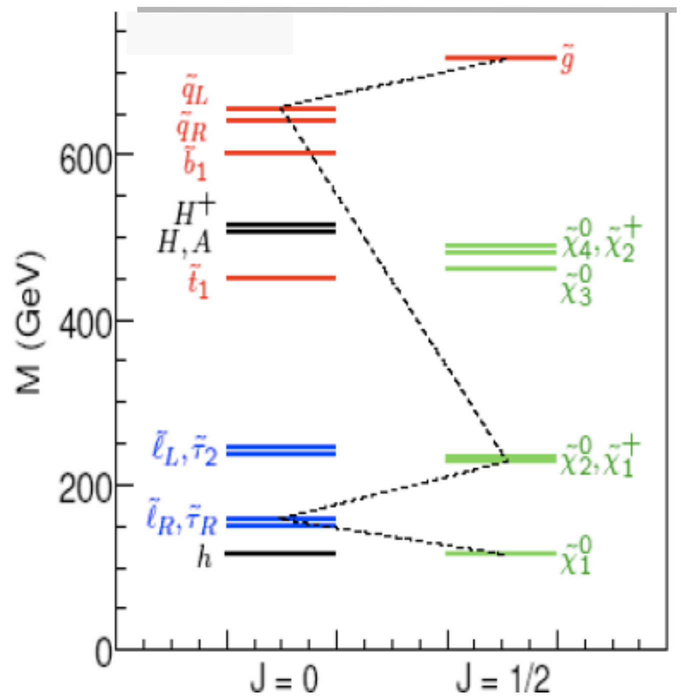
http://atlasresults.web.cern.ch/atlasresults/

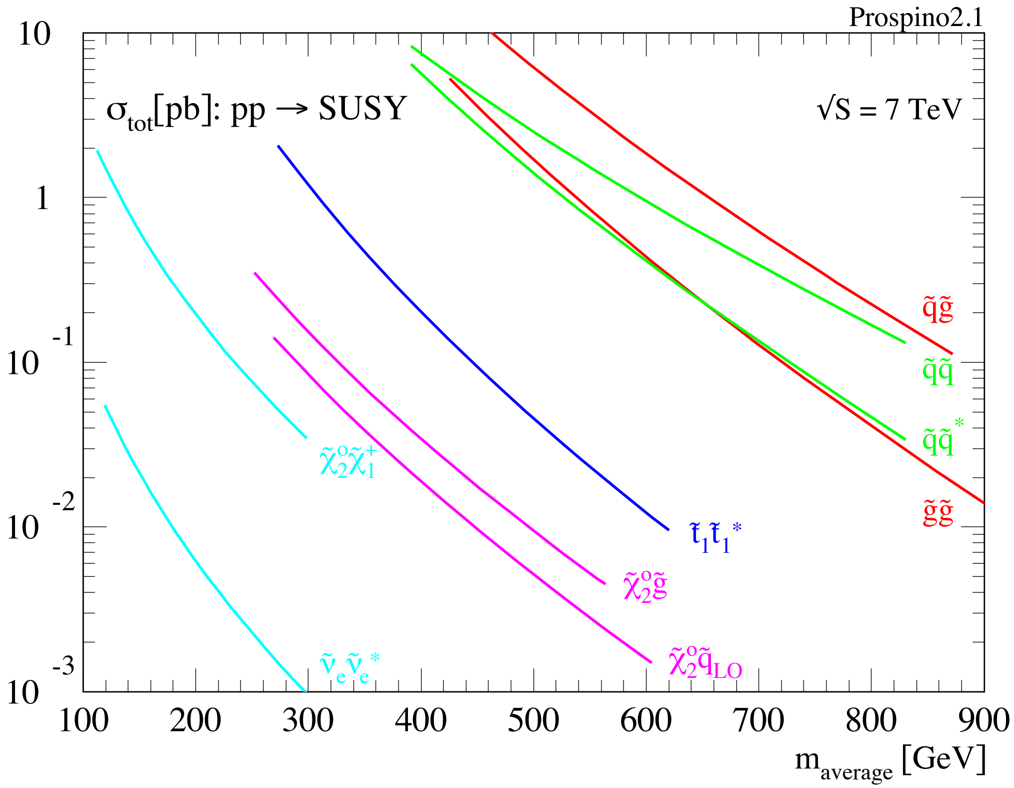
ATLAS Limits to SUSY



SUSY Before and Now?

A SUSY spectrum before 2011





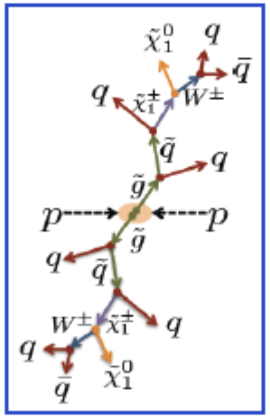
T.Plehn

Look for

3rd, lighter generation

RPV SUSY [ep, DM?]

Extended decay chains



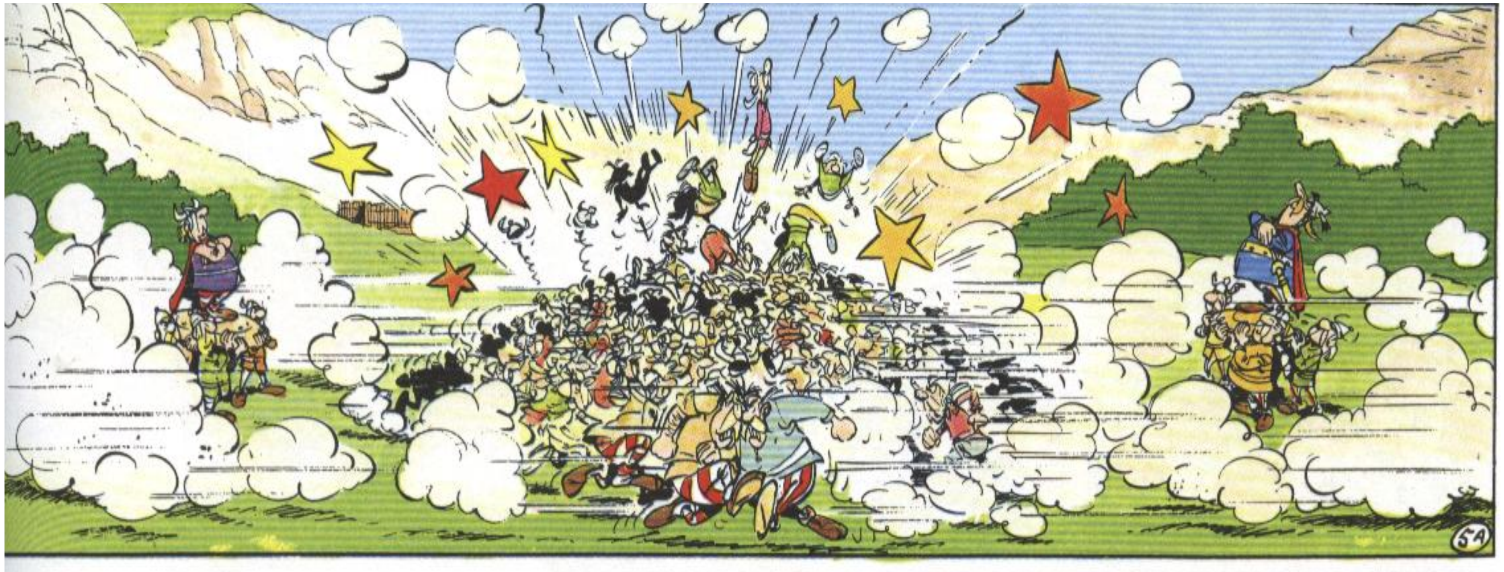
R-parity = $(-1)^{2J+3B+L}$

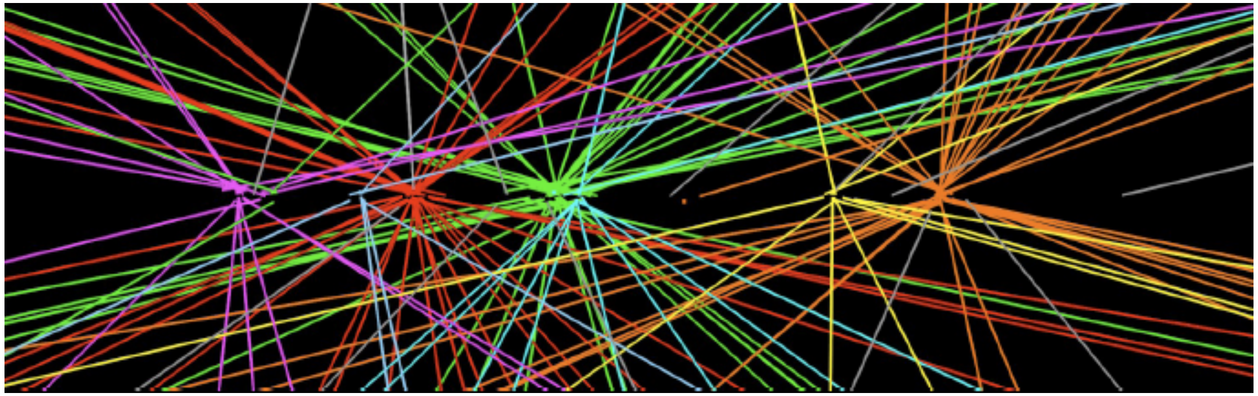
= 1 for SM particles, = -1 for SUSY partners

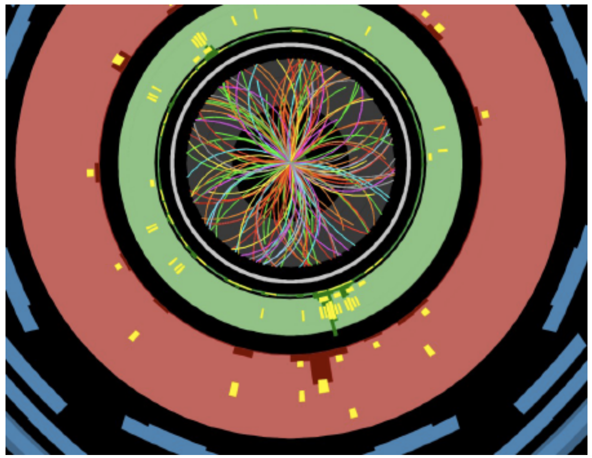
IF SUSY exists and IF R is conserved then the lightest SUSY particles are a candidate for DM

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

An unprecedented experimental challenge





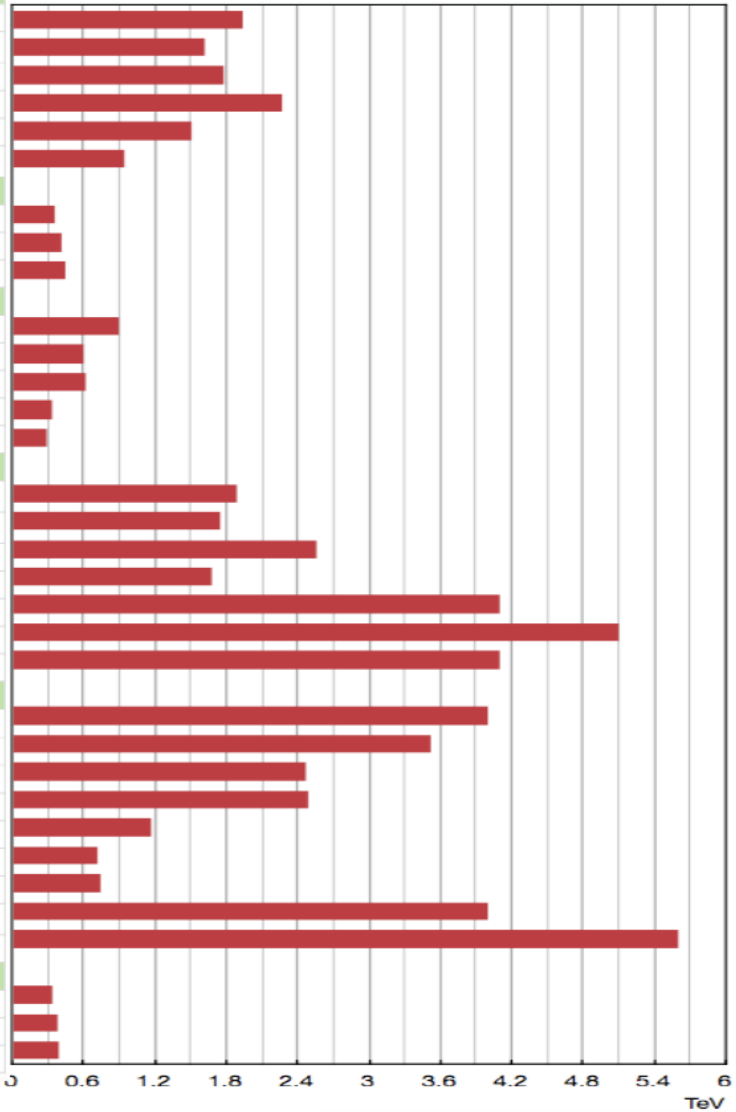


Mean pileup about 10 at $L=10^{33} cm^{-2}s^{-1}$

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

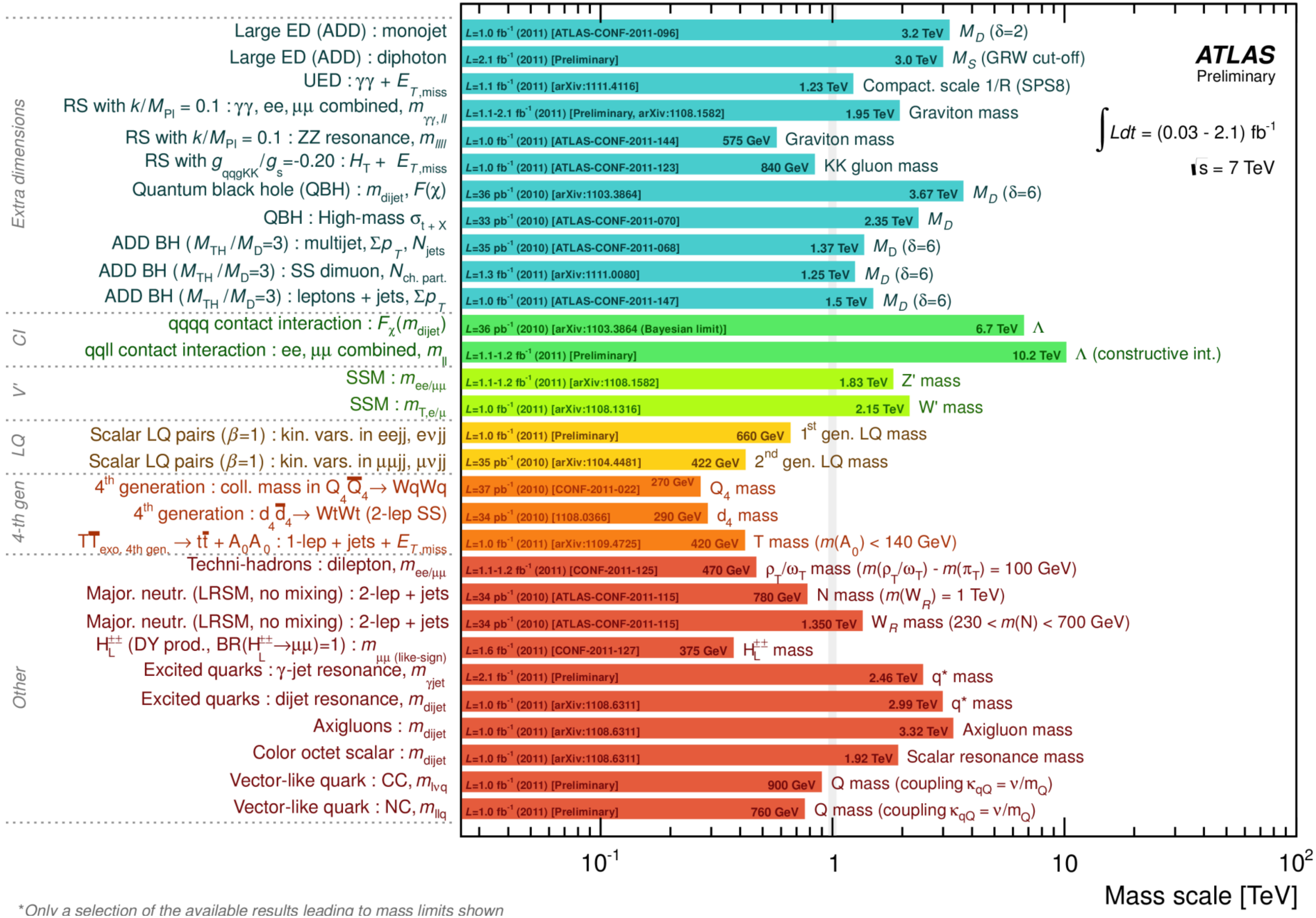
CMS - Limits to Exotic Physics

	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	



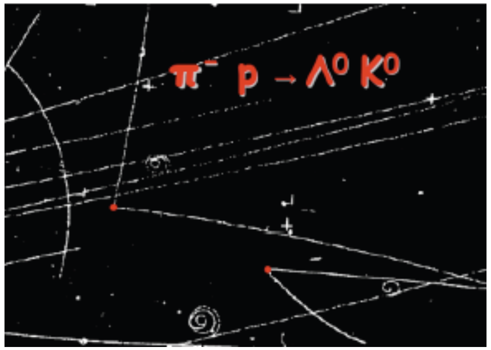
ATLAS Exotics Limits

ATLAS Exotics Searches* - 95% CL Lower Limits (Status: Dec. 2011)



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

Early Quark Mixing Physics



$$\tau(K_s^0 \rightarrow 2\pi) = 0.9 \cdot 10^{-10} s$$
$$\tau(K_L^0 \rightarrow 3\pi) = 0.5 \cdot 10^{-7} s$$
$$CP|K^0\rangle = |\overline{K^0}\rangle$$
$$|K_S^0\rangle = \sqrt{\frac{1}{2}}(|K^0\rangle + |\overline{K^0}\rangle), CP = +1$$
$$|K_L^0\rangle = \sqrt{\frac{1}{2}}(|K^0\rangle - |\overline{K^0}\rangle), CP = -1$$

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

$$\begin{pmatrix} u \\ d' \end{pmatrix}$$
$$d' = d\cos\theta_c + s\sin\theta_c$$
$$K^+(\bar{s}u) \rightarrow \pi^0(\bar{u}u)e^+\nu_e$$
$$\pi^+(\bar{d}u) \rightarrow \pi^0(\bar{u}u)e^+\nu_e$$
$$\frac{\Gamma(K^+ \rightarrow \pi^0 e^+ \nu_e)}{\Gamma(\pi^+ \rightarrow \pi^0 e^+ \nu_e)} \propto \tan^2\theta_c$$

Suppression of strangeness changing weak neutral currents

Glashow, Iliopoulos, Maiani (GIM) 1970

$$\begin{pmatrix} u \\ d' \end{pmatrix}, \begin{pmatrix} c \\ s' \end{pmatrix}$$
$$d' = d\cos\theta_c + s\sin\theta_c$$
$$s' = -d\sin\theta_c + s\cos\theta_c$$
$$\frac{\Gamma(D^+ \rightarrow K^-\pi^+\pi^+)}{\Gamma(D^+ \rightarrow K^+\pi^-\pi^+)} \propto \frac{T(c \rightarrow \bar{s}ud)}{T(c \rightarrow \bar{d}us)} \propto \tan^2\theta_c$$

Introduction of 4th quark
Charm decays

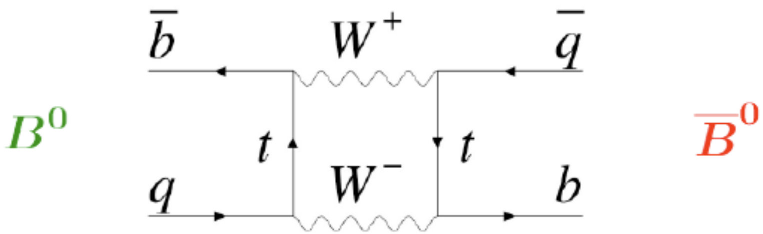
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} \equiv \hat{V}_{\text{CKM}} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

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



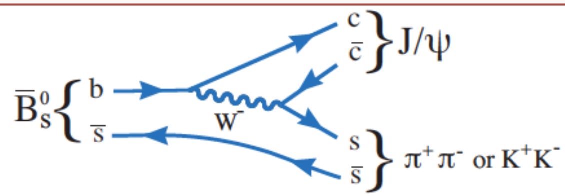
Discovered by ARGUS 1987

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

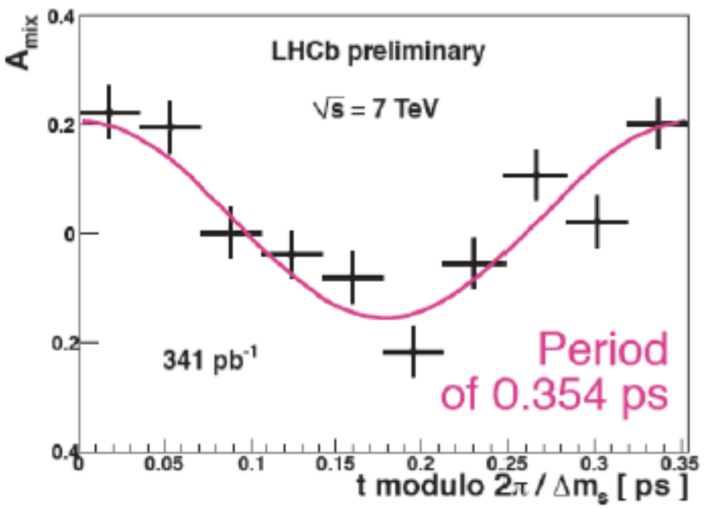
B→K^*ll FB asymmetry: LHCb: SM ok (÷Belle09)

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

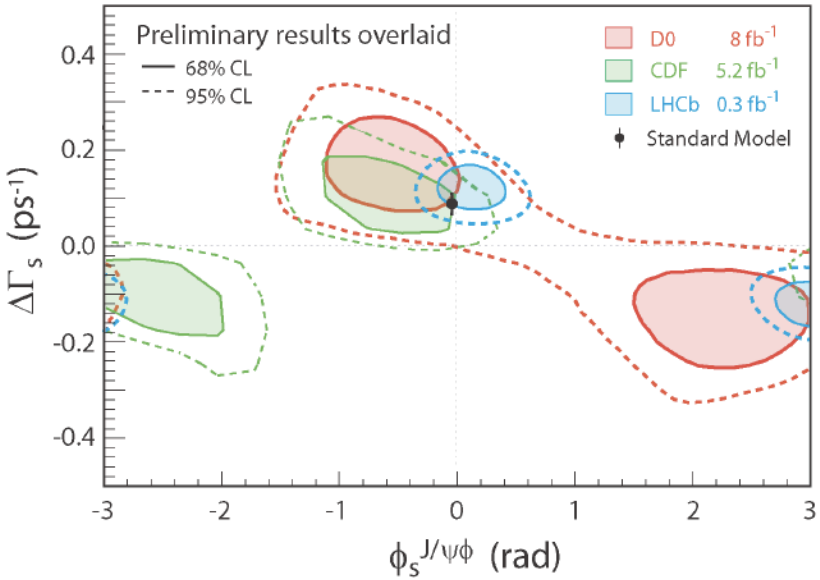
Some tension between Br(B → τν) and sin2β



LHCb: δρ=300μm, δt=50fs

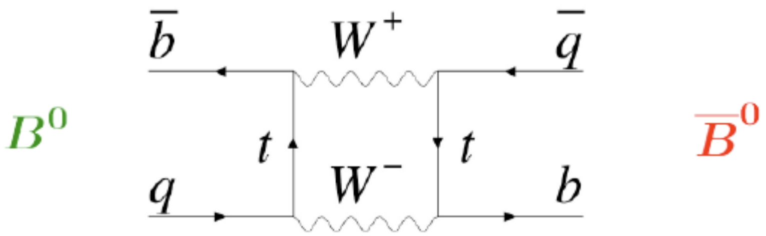


CP violating phase Φ in B^0_{s}bar decays



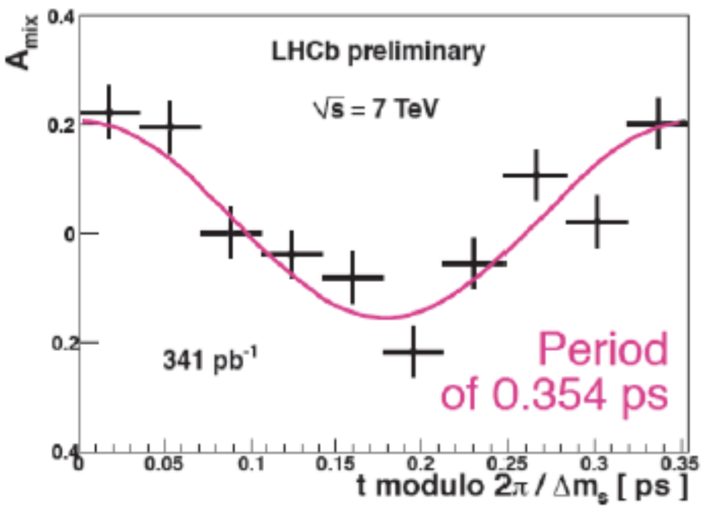
B_s mixing measured ok with SM
best measurement of Δm_s

Future B Physics



Discovered by ARGUS 1987

LHCb: δρ=300μm, δt=50fs



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D0: (-0.787 +-0.172 +-0.093)% 3.9σ above SM
LHCb: to come

Some tension between Br(B → τν) and sin2β

To be studied (with high precision):

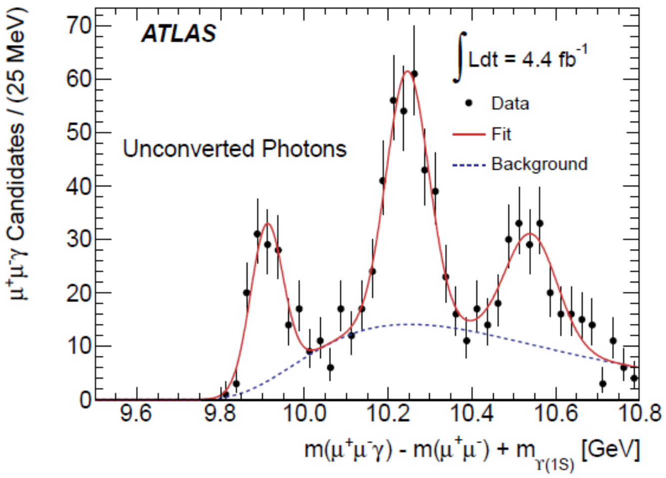
- γ from tree (B → DK, ...)
- $|V_{ub}|$ from exclusive semilept. B decays
- $B_{s,d} \to \mu\mu$
- CPV in B_s mixing
- $B \to K^*\mu\mu$ (angular analysis)
- $B \to \tau\nu, \mu\nu$
- $K \to \pi\nu\nu$
- CPV in D mixing

New B factories in Japan and near Rome

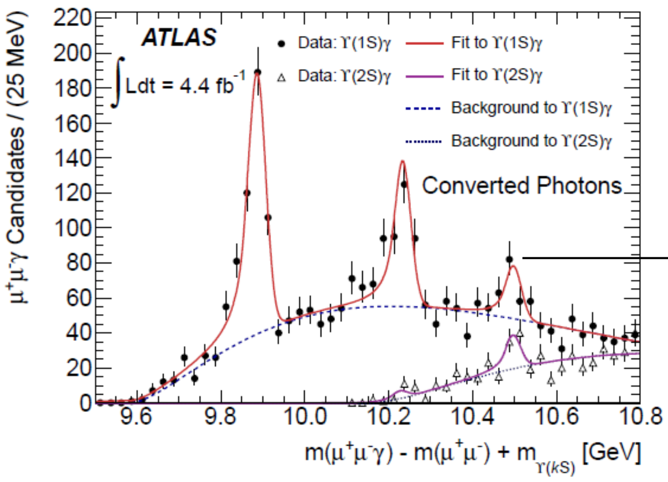
NA62

G.Isidori ICFA11

Christmas present: Discovery of $\chi_b(3p) \rightarrow \Upsilon(1s), \Upsilon(2s) + \gamma$



(a)

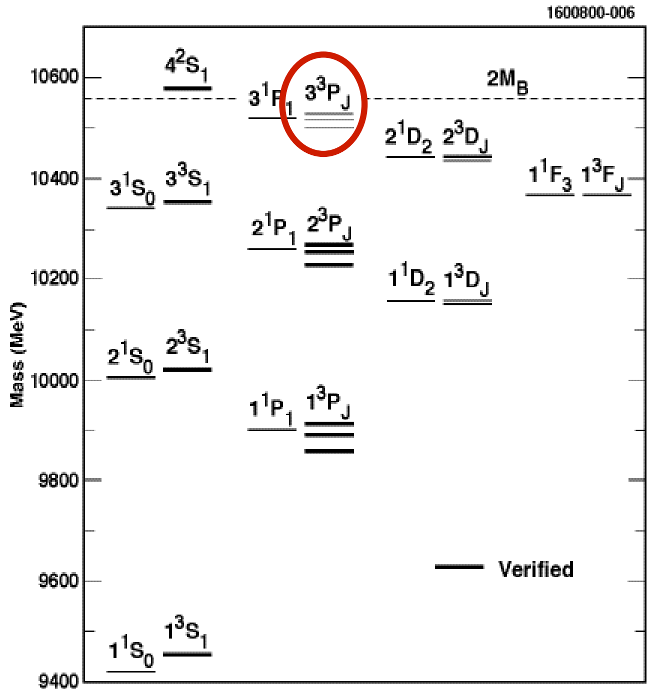


(b)

arXiv:1112.5154v1

- Simplest strongly interacting system
- QCD equivalent of positronium
- Non-relativistic for heavy quarks (QQ) $\beta^2 \sim 0.08$
- Tests potential models, $V(r) = -4/3\ \alpha_s/r + k\ r$
- Tests Lattice QCD calculations

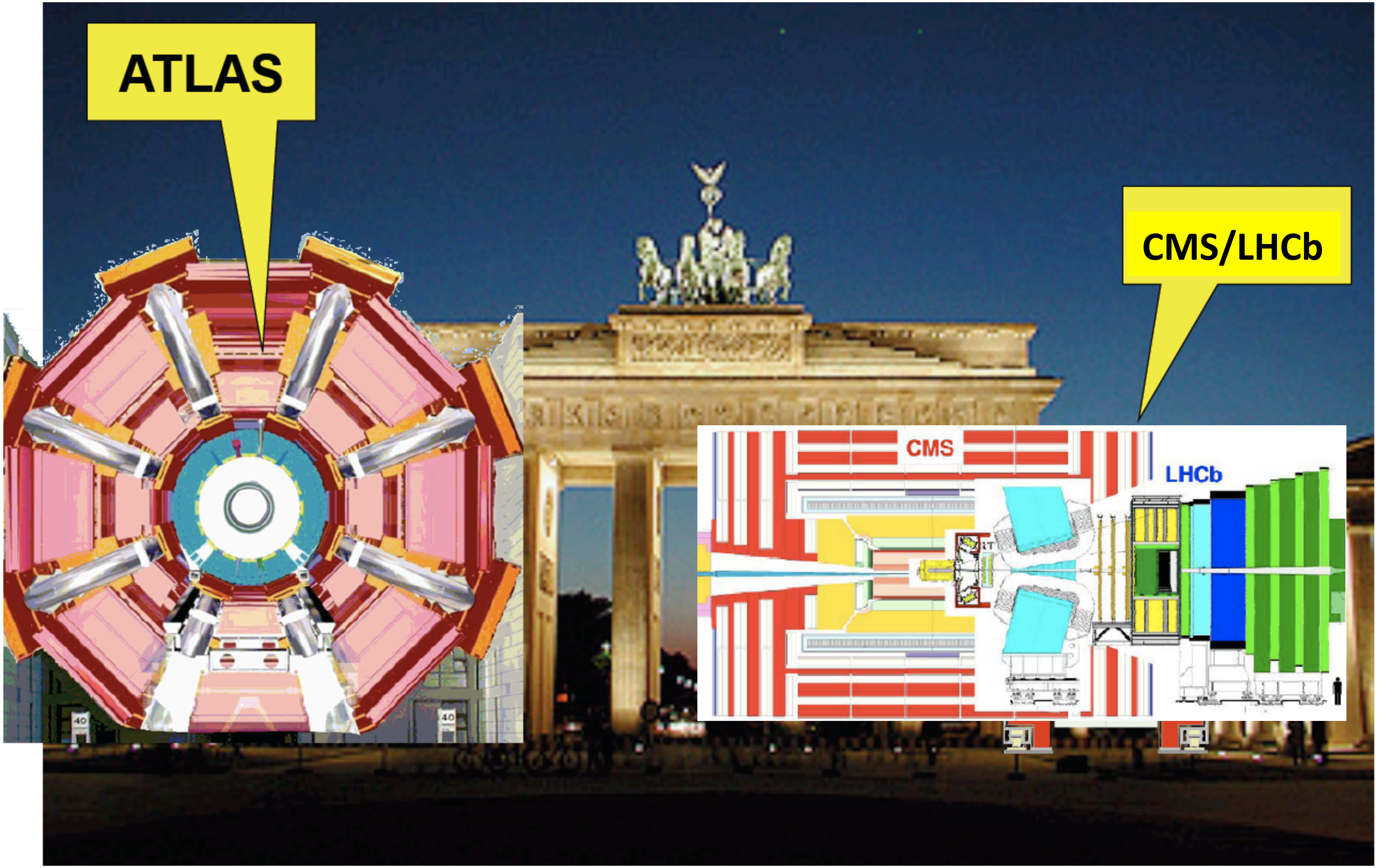
Slide of T.Doyle



State	Model predictions [3, 4] [MeV]	Fitted masses [MeV] Unconverted Photons	Converted Photons
$\chi_b(1P)$	9900	9910 ± 6 (stat.) ± 11 (syst.)	Fixed to χ_{b1} = 9892.78 & χ_{b2} = 9912.21 [9]
$\chi_b(2P)$	10260	10246 ± 5 (stat.) ± 18 (syst.)	Fixed to χ_{b1} = 10255.46 & χ_{b2} = 10268.65 [9]
$\chi_b(3P)$	10525	10541 ± 11 (stat.) ± 30 (syst.)	10539 ± 4 (stat.) ± 8 (syst.)

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

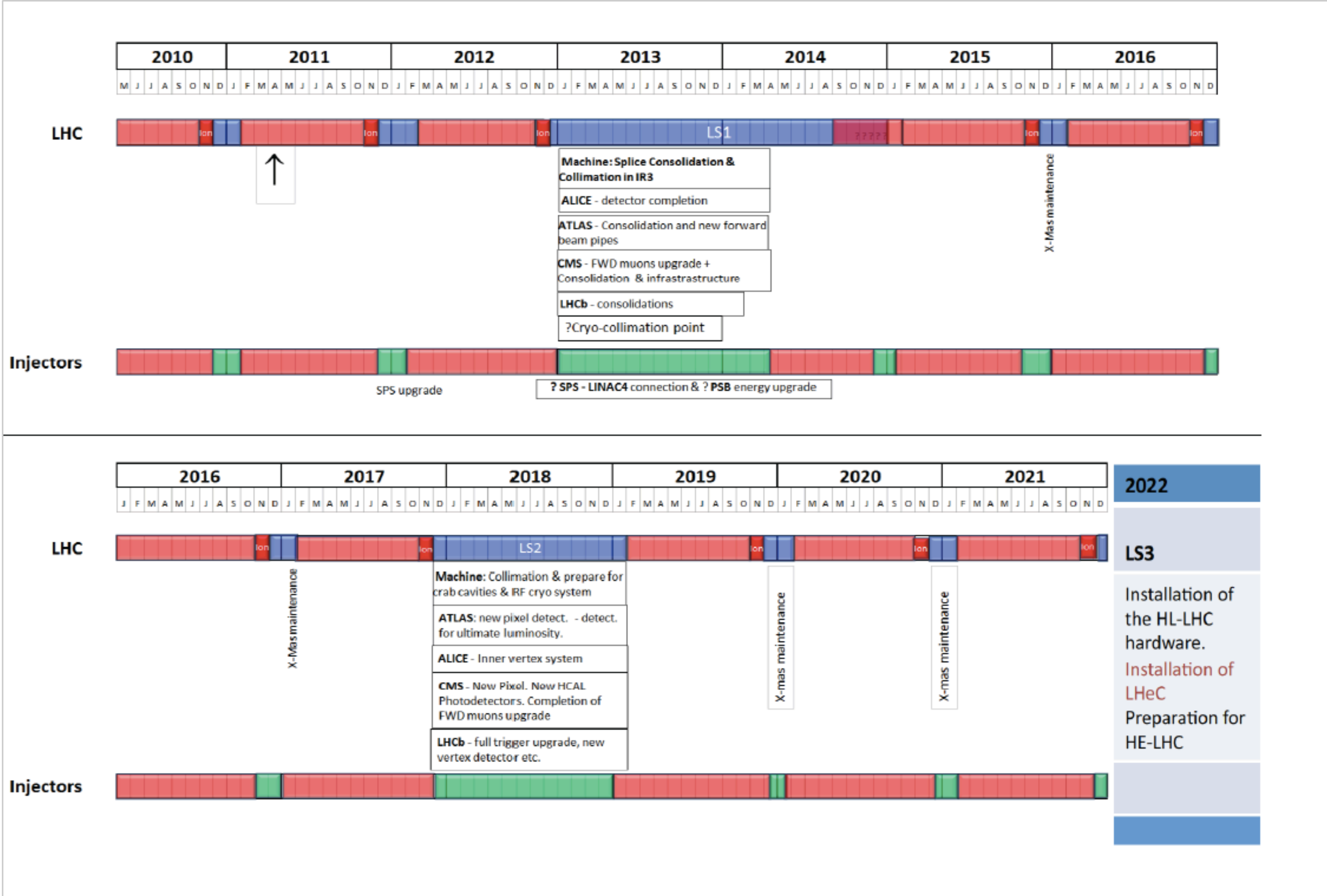
S.Myers EPS11 Grenoble

Goals for 25ns bunch crossing

$2\ 10^{11}$ p/bunch
$\beta^* = 0.15$ 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



S.Myers EPS11

The Large Hadron electron Collider

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

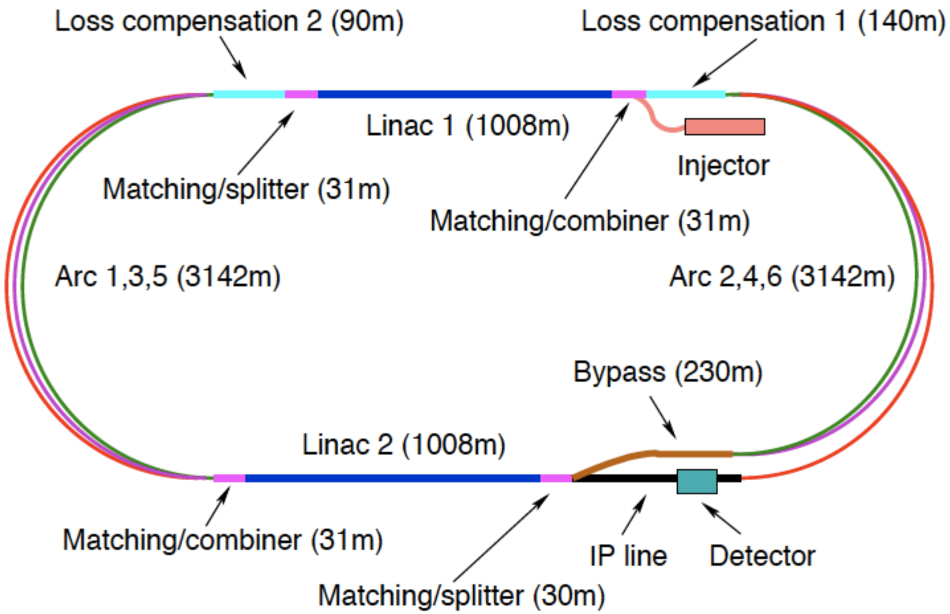
$$N_p = 1.7 \cdot 10^{11}, \varepsilon_p = 3.8\,\mu m, \beta^* = 0.2 m, \gamma = 7000/0.94$$

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

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

Table 2: Components of the Electron Accelerators

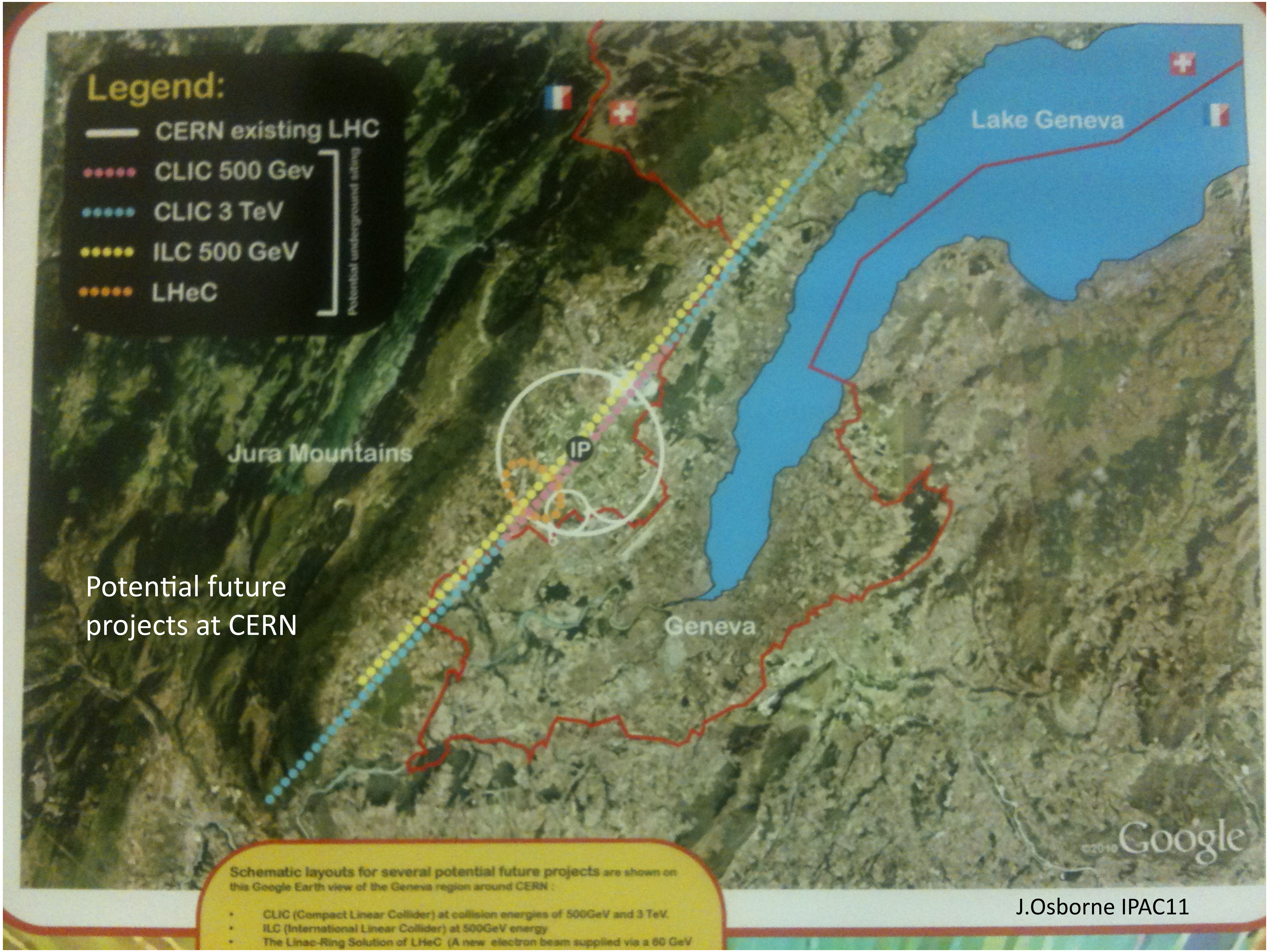
	Ring	Linac
magnets		
beam energy	60 GeV	
number of dipoles	3080	3600
dipole field [T]	0.013 – 0.076	0.046 – 0.264
total nr of quads	866	1588
RF and cryogenics		
number of cavities	112	944
gradient [MV/m]	11.9	20
RF power [MW]	49	39
cavity voltage [MV]	5	21.2
cavity R/Q [Ω]	114	285
cavity Q_0	–	$2.5\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



- **TeV scale ep collider [60x7000]GeV²**
- 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

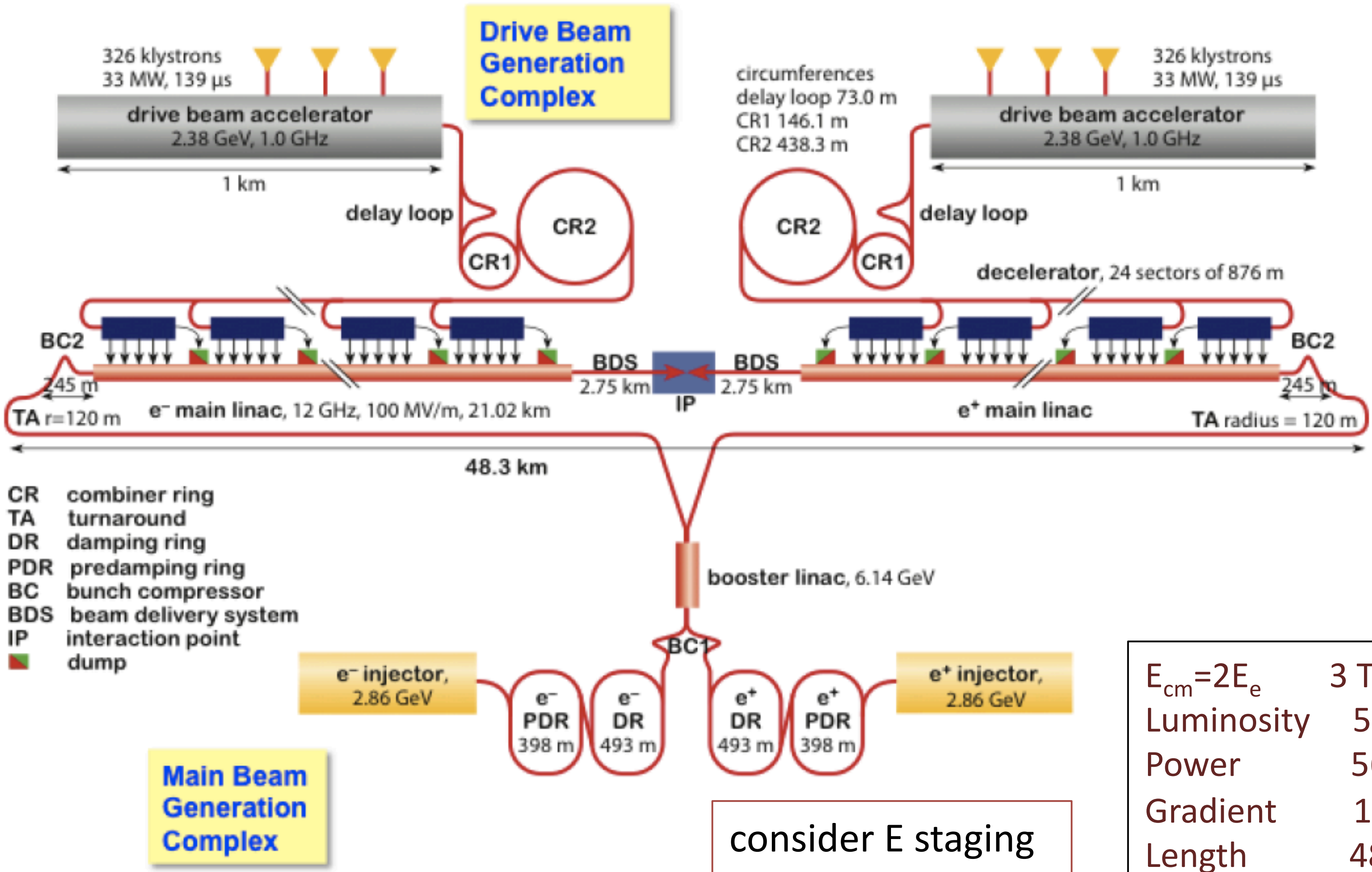
→ Seminar tomorrow on LHeC



Potential future projects at CERN

J.Osborne IPAC11

Compact Linear Collider - CLIC



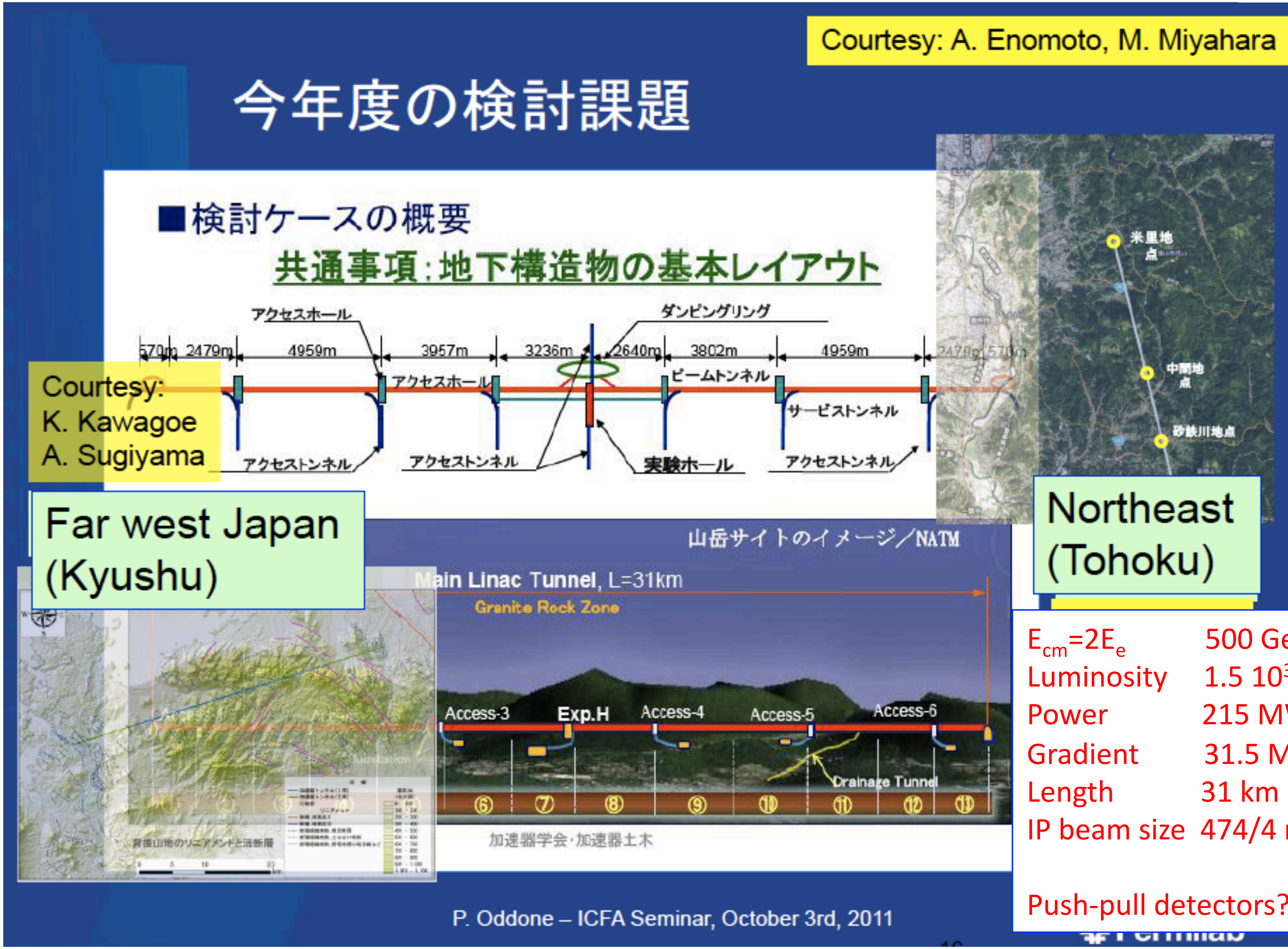
consider E staging
depending on LHC:
0.5 TeV 14km
1-2 TeV 20-34km

$E_{cm}=2E_e$	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



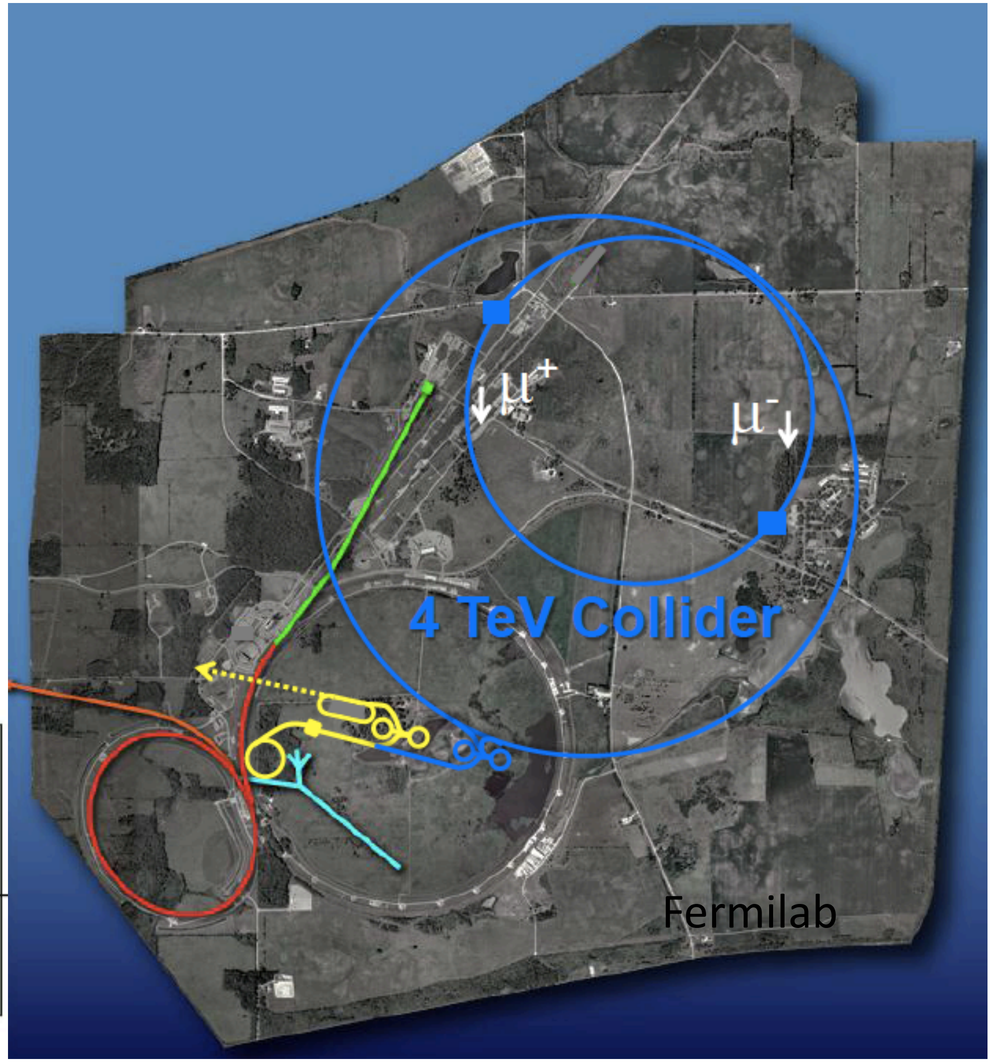
$E_{cm}=2E_e$	500 GeV
Luminosity	1.5 10^{34}
Power	215 MW
Gradient	31.5 MV/m
Length	31 km
IP beam size	474/4 nm

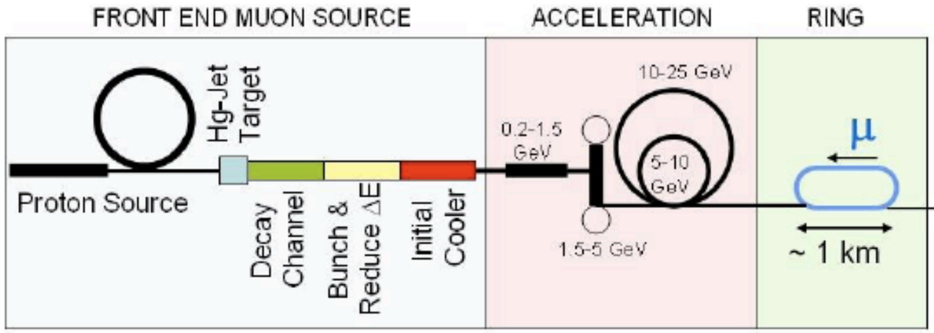
Push-pull detectors?

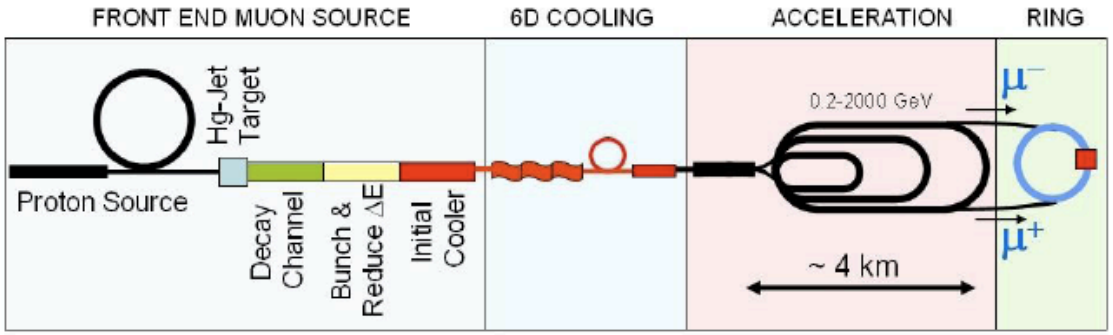
Muon Collider

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 = 2×10^{12}
δp/p = 0.1%

S.Geer ICFA11

THEORY

M.Froissart ICHEP ("Rochester") 1966

H.Murayama – ICFA11

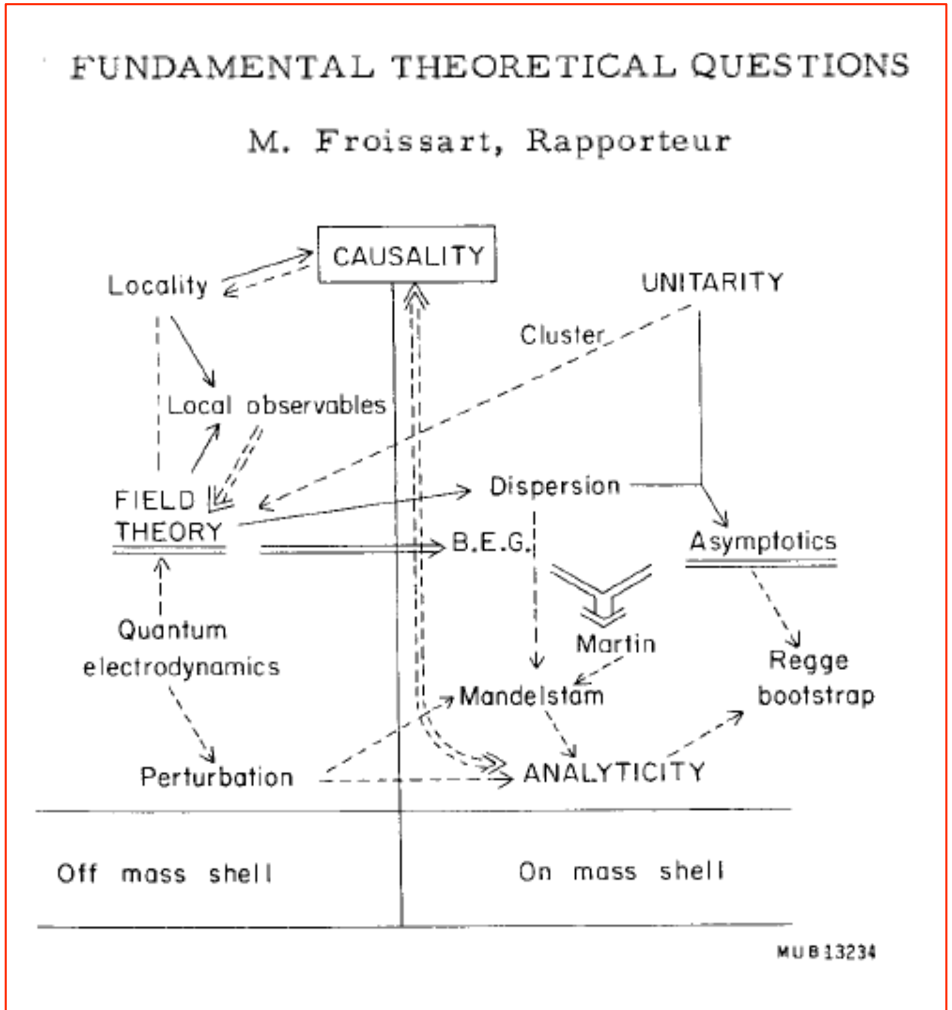
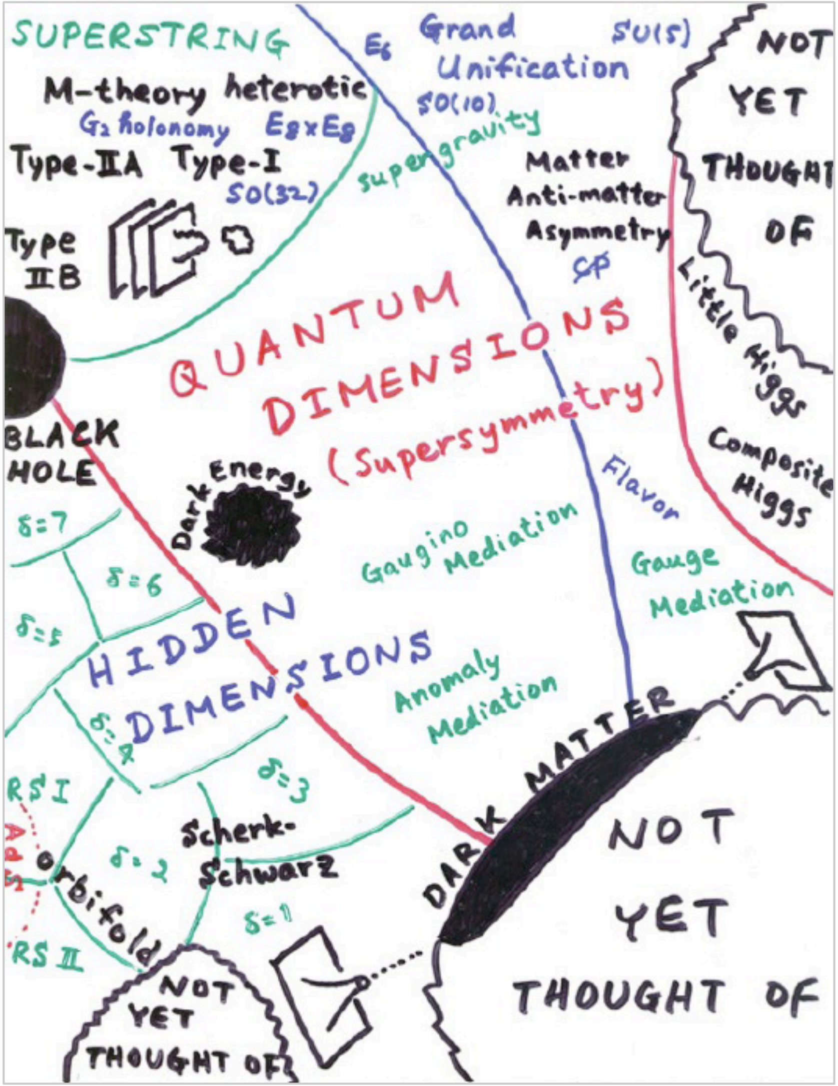


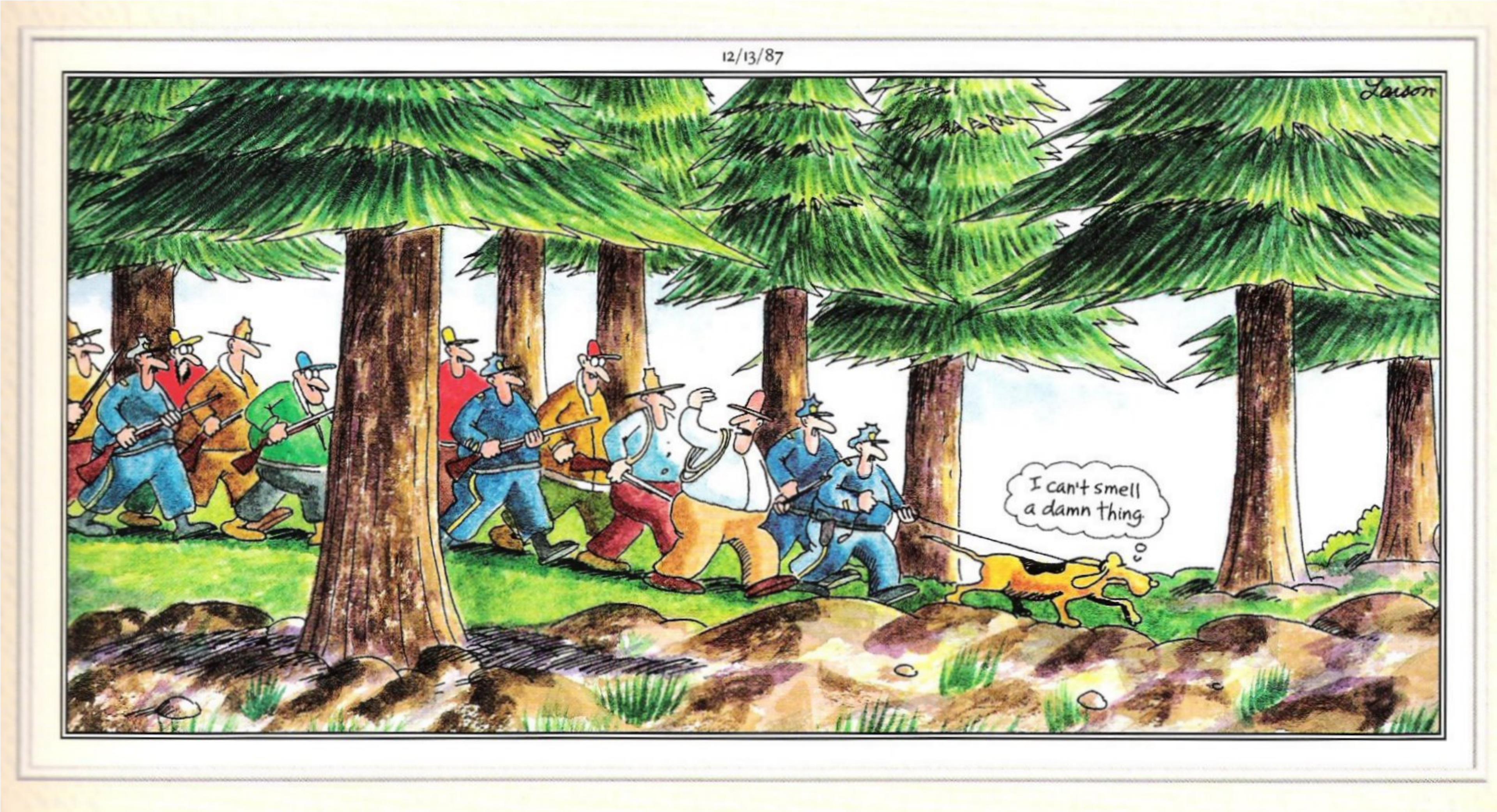
Fig. 1-1. Logical map of "Fundamental" concepts.



→ Quarks in 1969

→ ?in 2014?

Providing Direction



Slide of T.Doyle

H.Murayama – ICFA11

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

HEP has a bright future if we don’t narrow the scope to too few questions and devices