Physics From LEP

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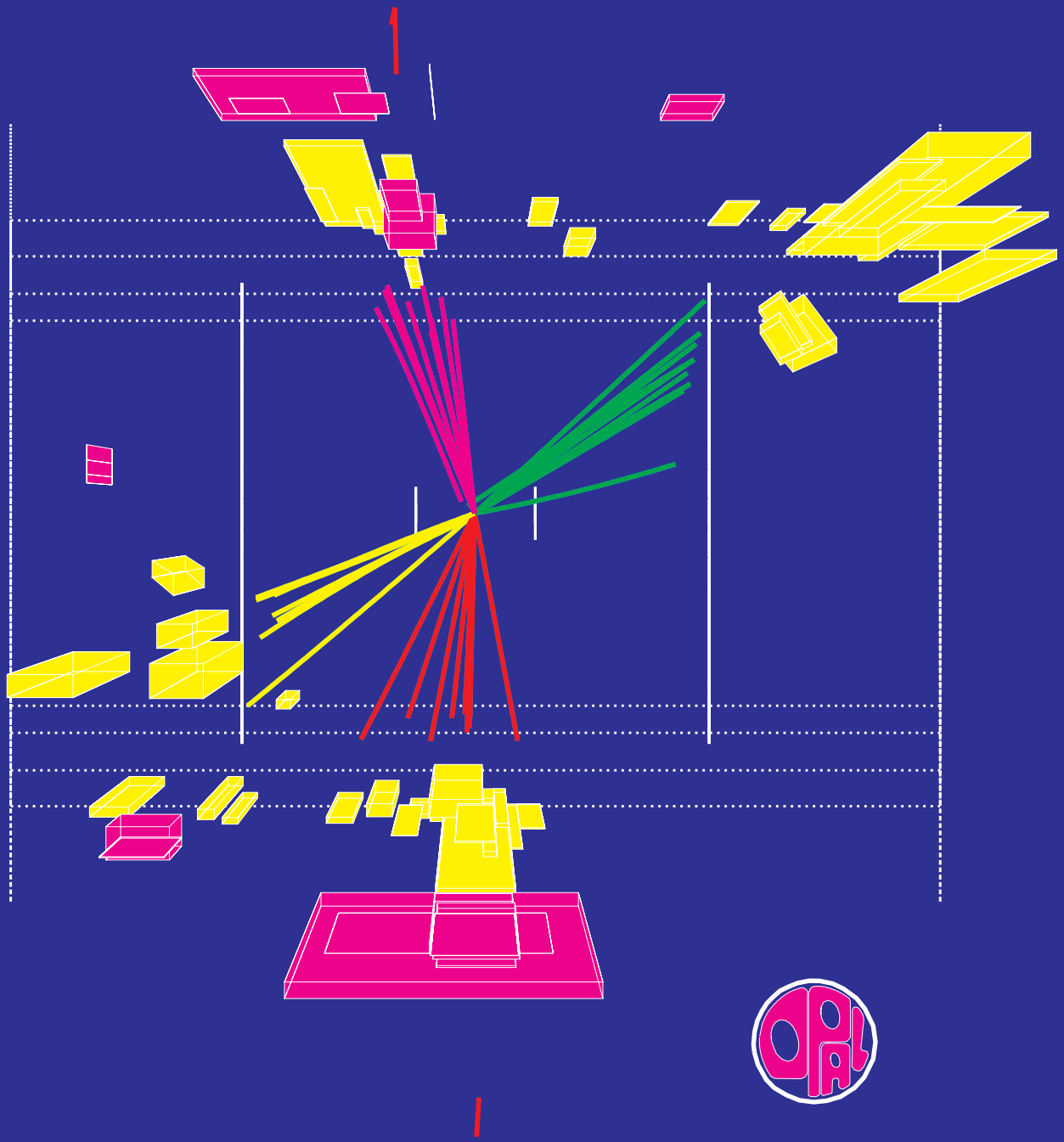
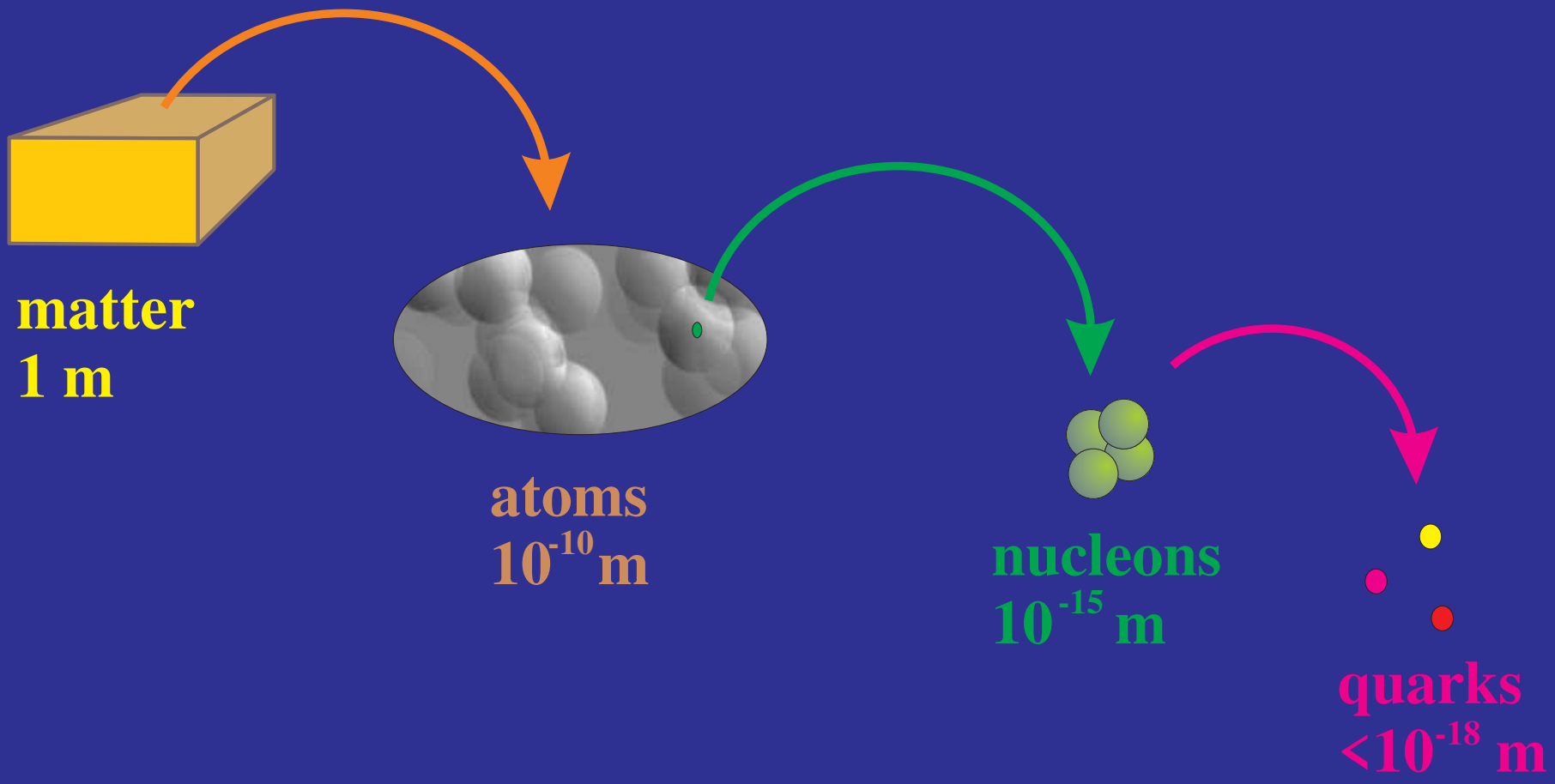
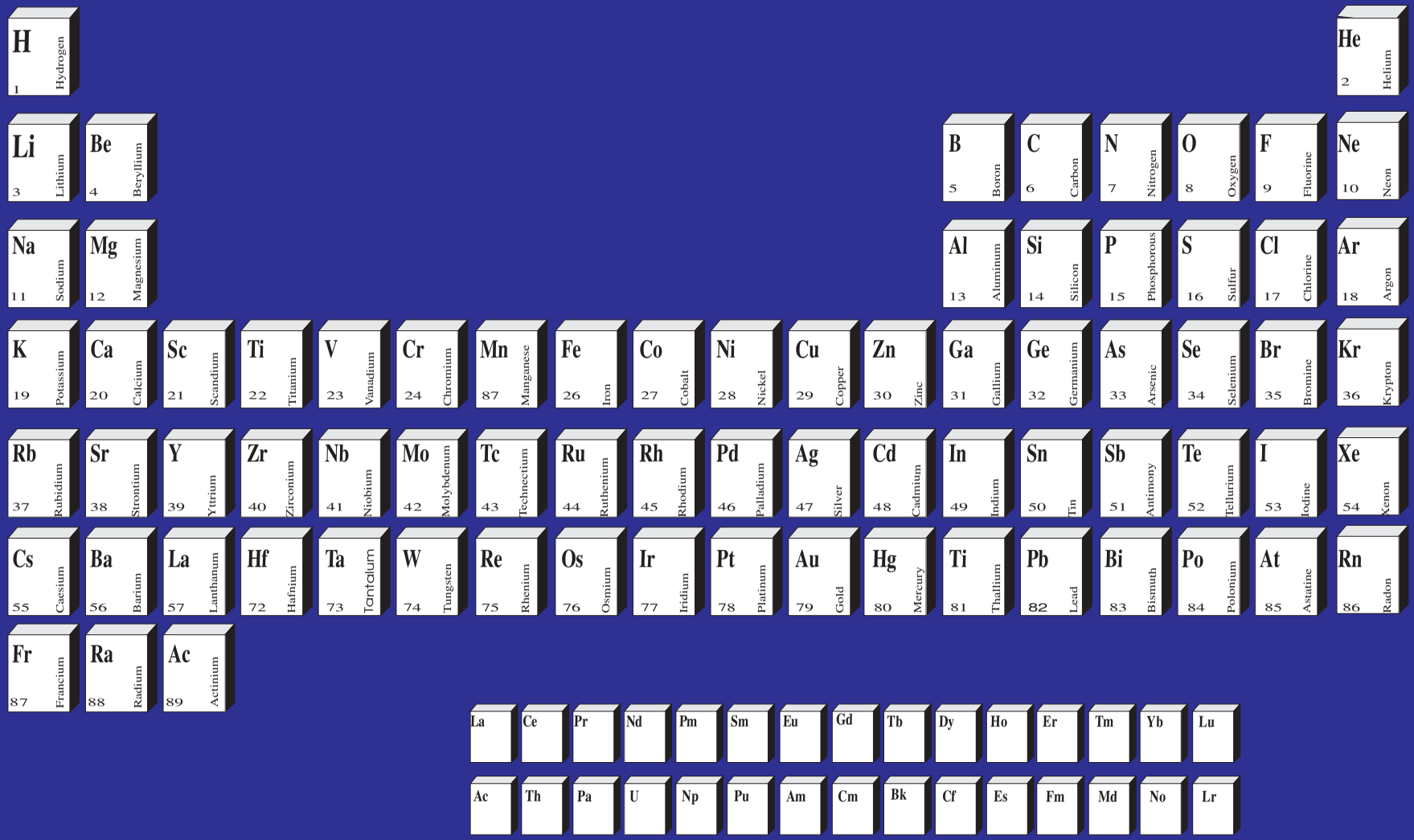


Particle Physics is the study of matter and its interactions at the most fundamental level.



Chemistry has a table of 110 "elements"



Particle Physics has only 12×2 "elements" to deal with:

		charge (e)	mass (GeV/c^2)
quarks	u: up quark	+2/3	0.4
	d: down quark	-1/3	0.4
	c: charm quark	+2/3	1.8
	s: strange quark	-1/3	0.6
	t: top quark	+2/3	175
	b: bottom quark	-1/3	4.5
leptons	e: electron	-1	5×10^{-4}
	ν_e: e neutrino	0	$<7\times10^{-9}$
	μ: muon	-1	0.1
	ν_μ: μ neutrino	0	$<3\times10^{-4}$
	τ: tau	-1	1.8
	ν_τ: τ neutrino	0	$<3\times10^{-2}$

Leptons exist on their own;
Quarks combine to form hadrons:

baryons	proton	uud	0.938
	anti proton	$\bar{u}\,\bar{u}\,\bar{d}$	0.938
	neutron	udd	0.940
	Λ	uds	1.116
mesons	π^+	$u\,\bar{d}$	0.140
	K^+	$u\,\bar{s}$	0.494

Forces between elementary particles:

	acts on	relative strength *
Gravitational	all	10^{-41}
Weak	quarks leptons	10^{-4}
Electromagnetic	charged particles	1
Strong	quarks only	60

* between two u quarks in a hadron

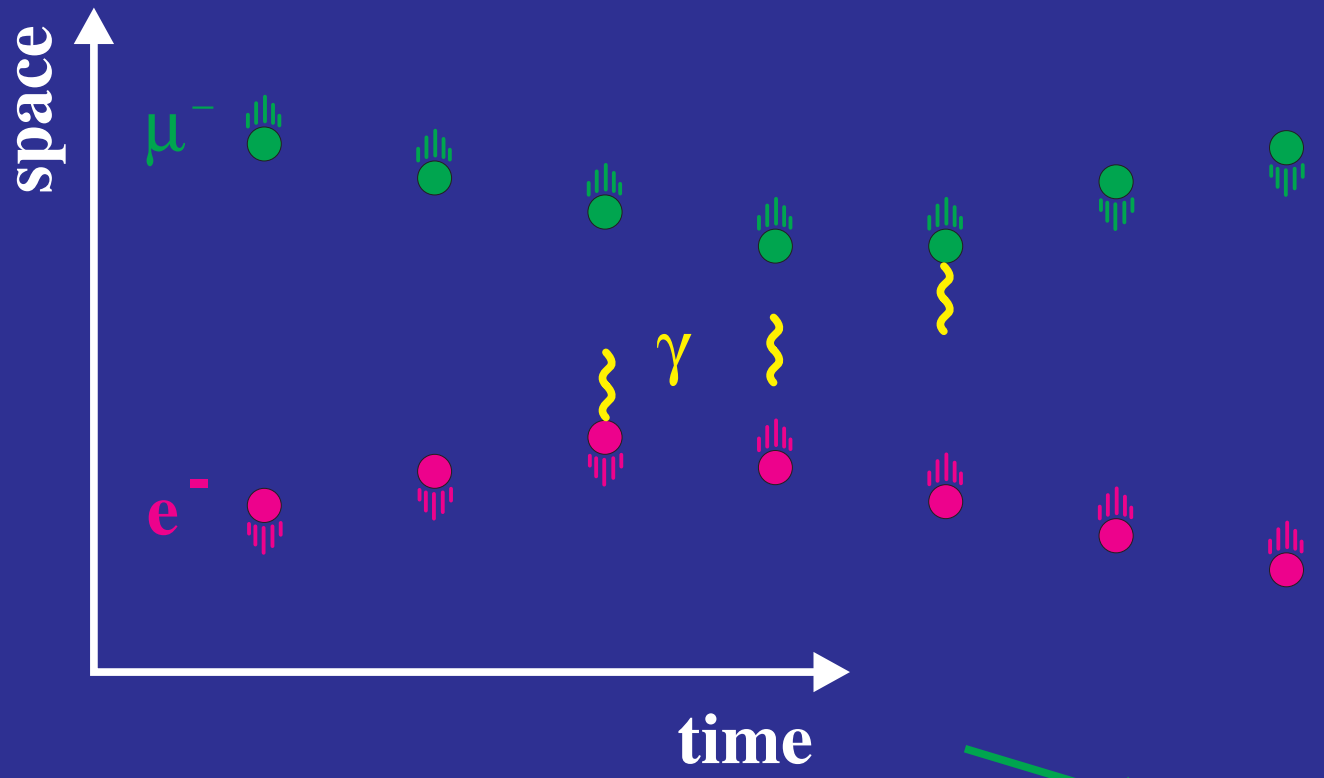
The Standard Model

describes the "big" 3 forces in a uniform way

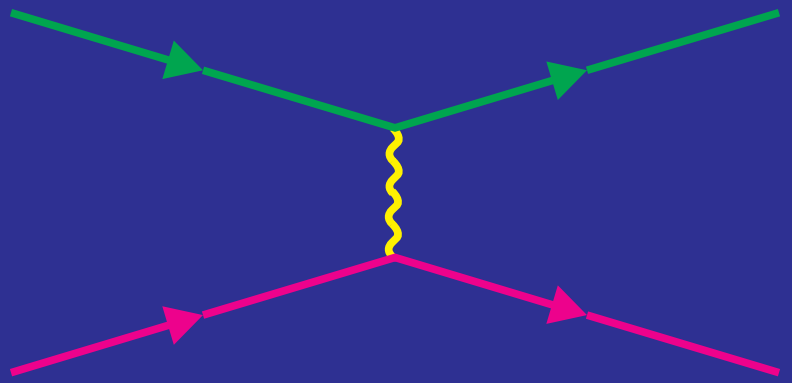
these interactions arise from the exchange of other particles: the Gauge Bosons

the exchanged particles are "virtual" ... they owe their existence to
Heisneberg's Uncertainty Principle

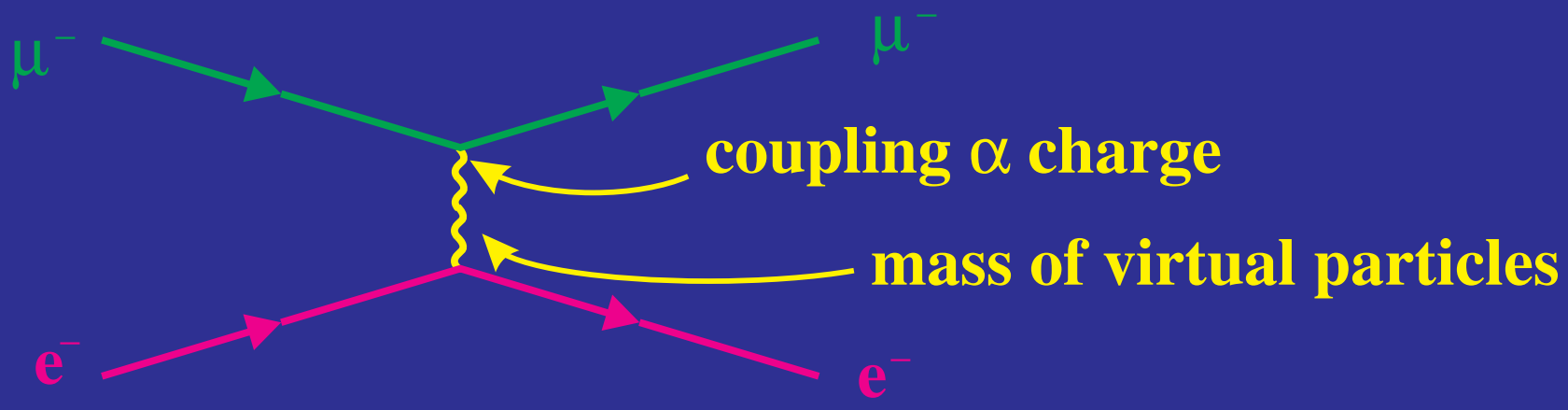
An electromagnetic interaction



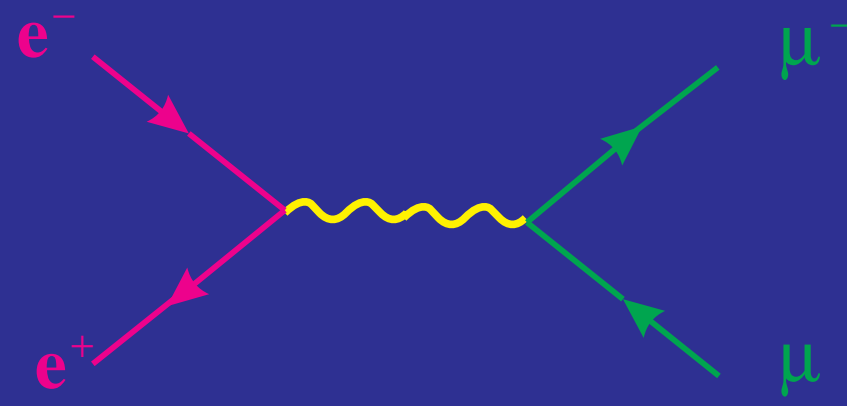
Feynman's Shorthand:



Quantum electrodynamics (QED) calculates the probability of an interaction on the basis of:



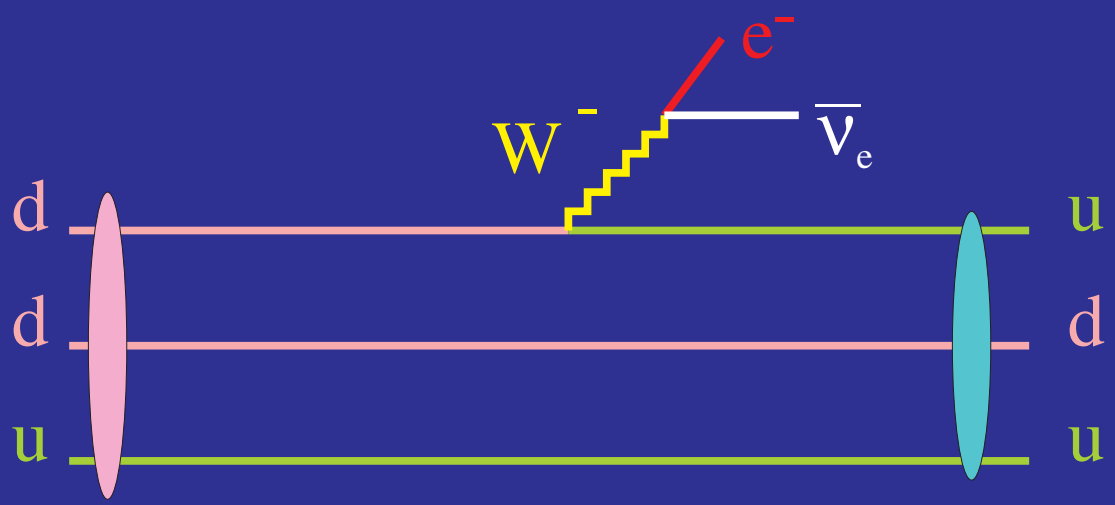
QED says that you can rotate these diagrams:



ie. $e^+ e^- \rightarrow \mu^+ \mu^-$

Weak interactions are via the heavy W^- W^+ and Z^0

the weak force allows quarks and leptons to change flavour, for example in neutron decay:



The weak force is weak because its bosons are massive

Why are weak bosons heavy?

SM → a complex scalar field partly eaten by weak bosons

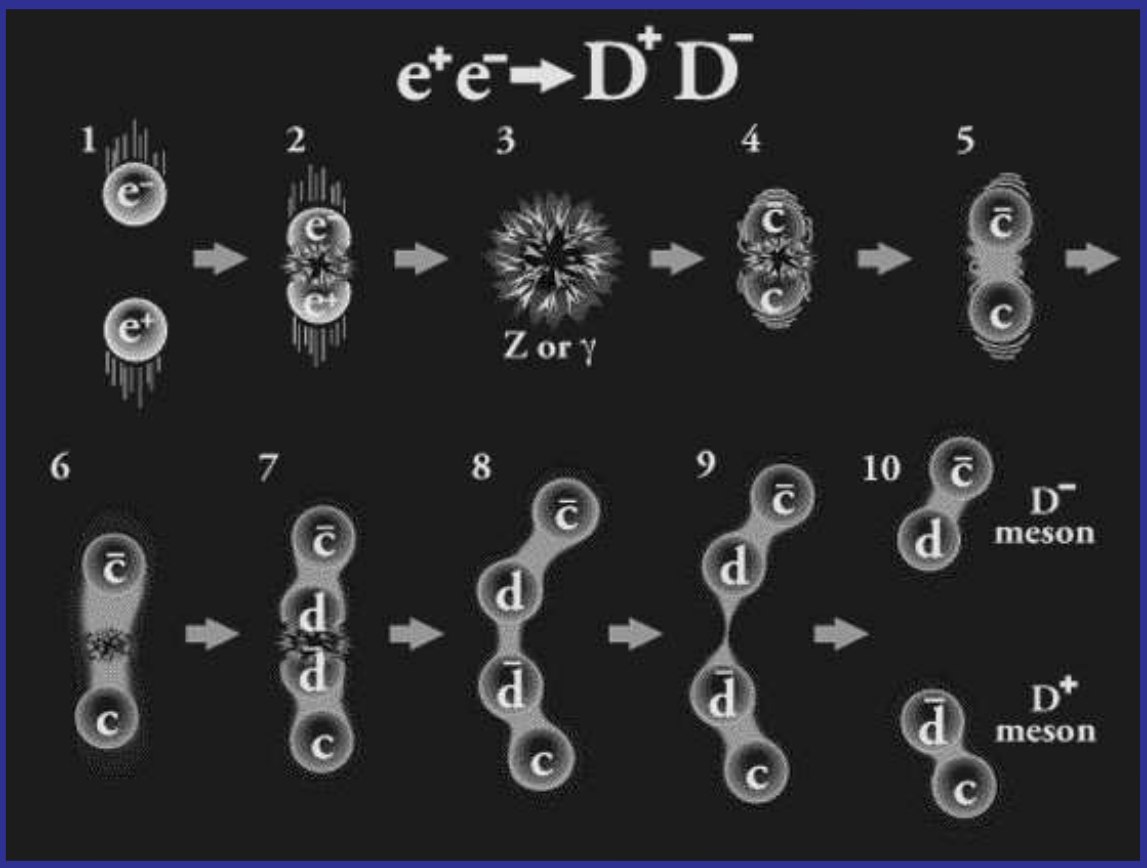
As a consequence a Higgs boson predicted to exist

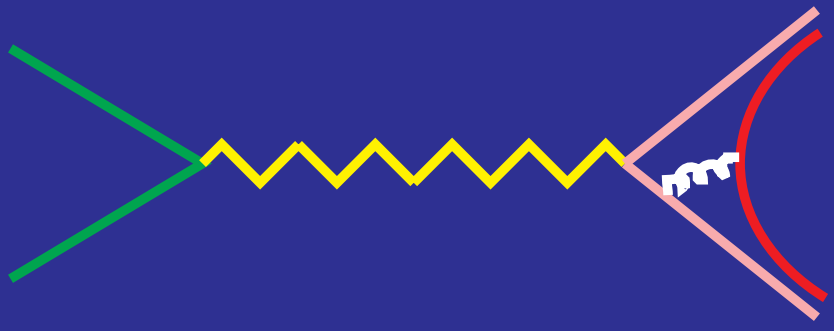
- responsible for all fermion masses
- unknown mass

The strong force

acts only on quarks

strength increases with distance





Successes of the Standard Model

- large number of predictions verified by experiment
- no result in serious disagreement with the model

Problems with the Standard Model

- a large number of arbitrary parameters
- fine tuning and heirarchy problems
- does not explain why three generations

The Standard Model is thought to be a low energy approximation of a more complete theory (much like Newtonian Mechanics and Special Relativity)

What lies beyond the SM?

Perhaps "Supersymmetry"

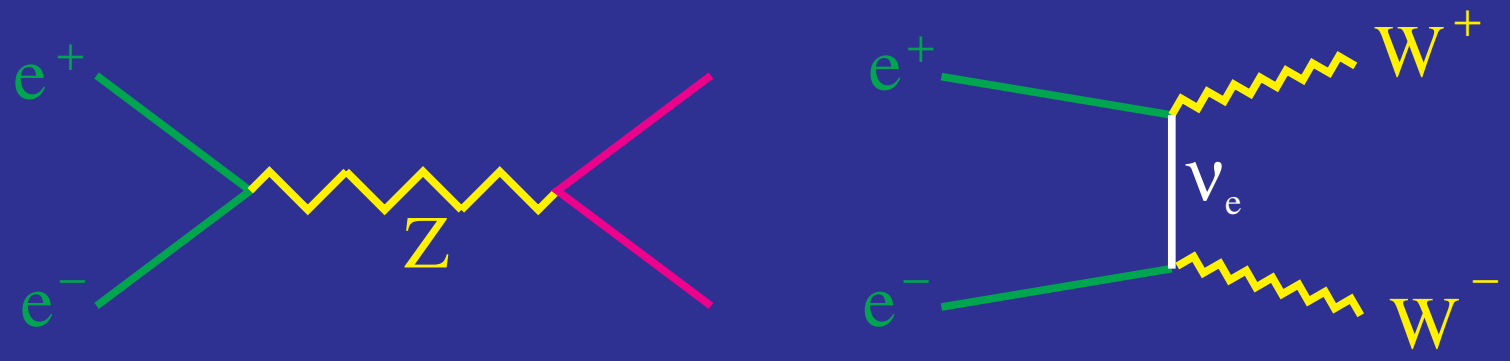
- solves some of the problems with the SM
- predicts many new particles to be discovered

Perhaps something else

- some direction is needed
- deviations from SM predictions could provide the clues

Experimental program at LEP

detailed study of the Standard Model

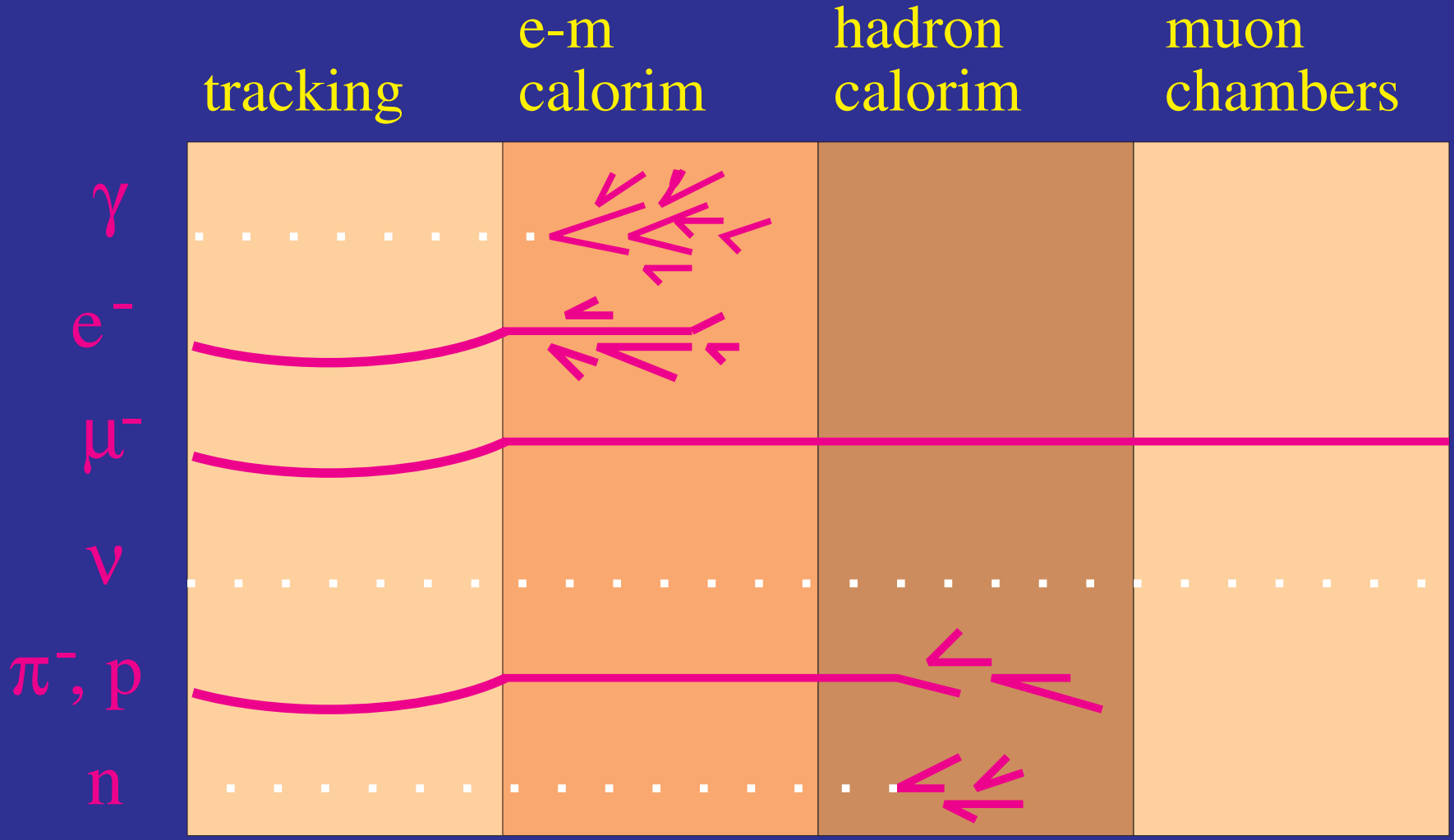


all known particles produced

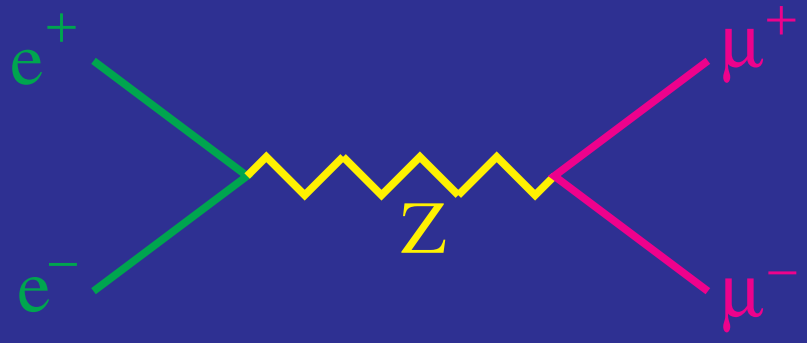
all three forces involved

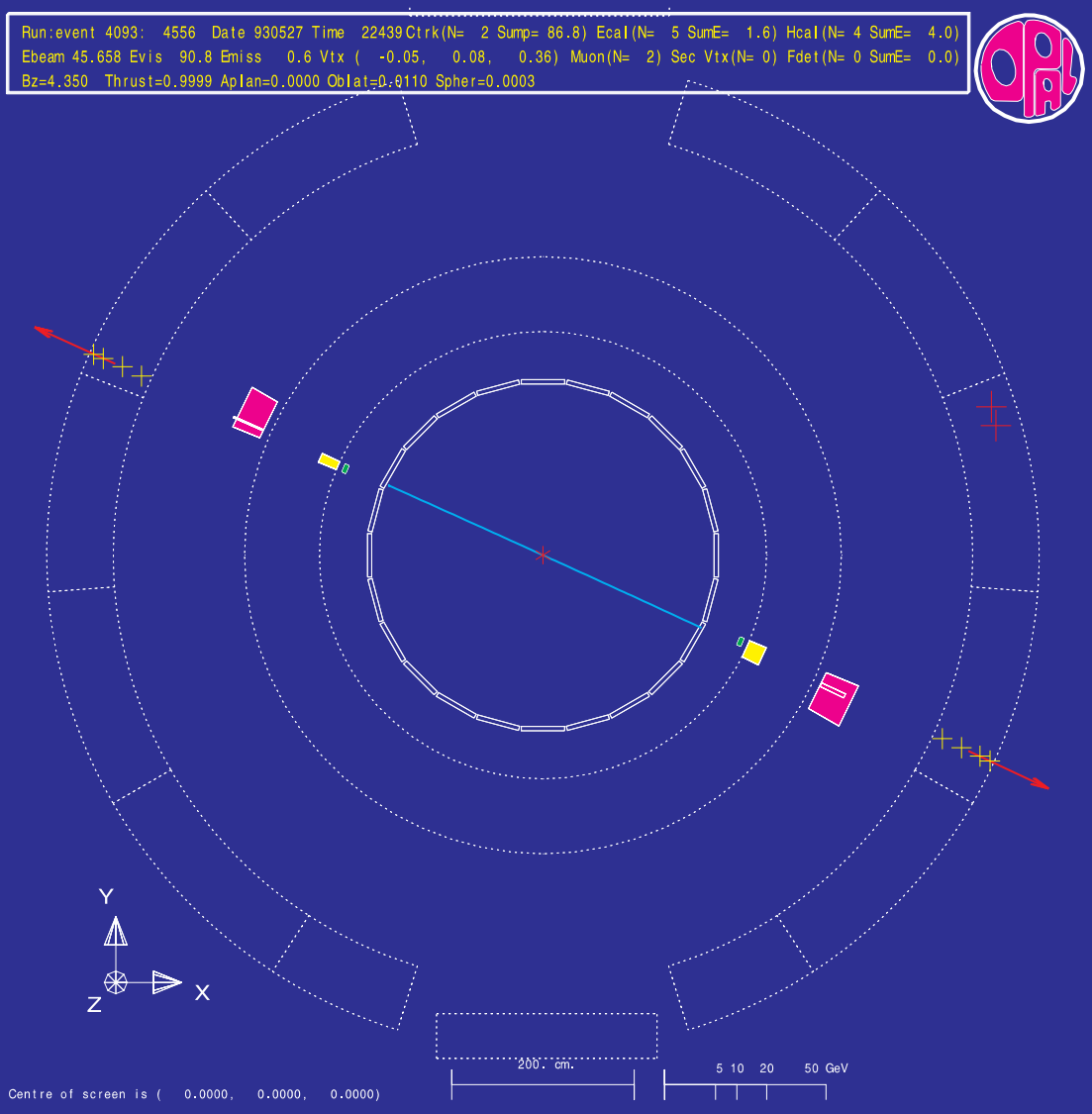
search for effects beyond the Standard Model

Components of the OPAL detector

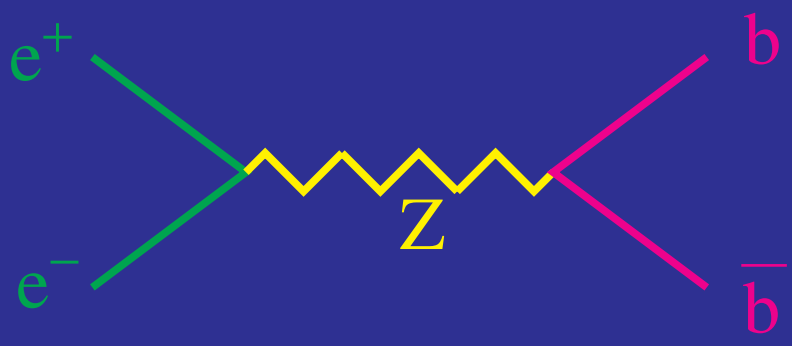


An $e^+e^- \rightarrow \mu^+\mu^-$ event





An $e^+e^- \rightarrow b\ \bar{b}$ event



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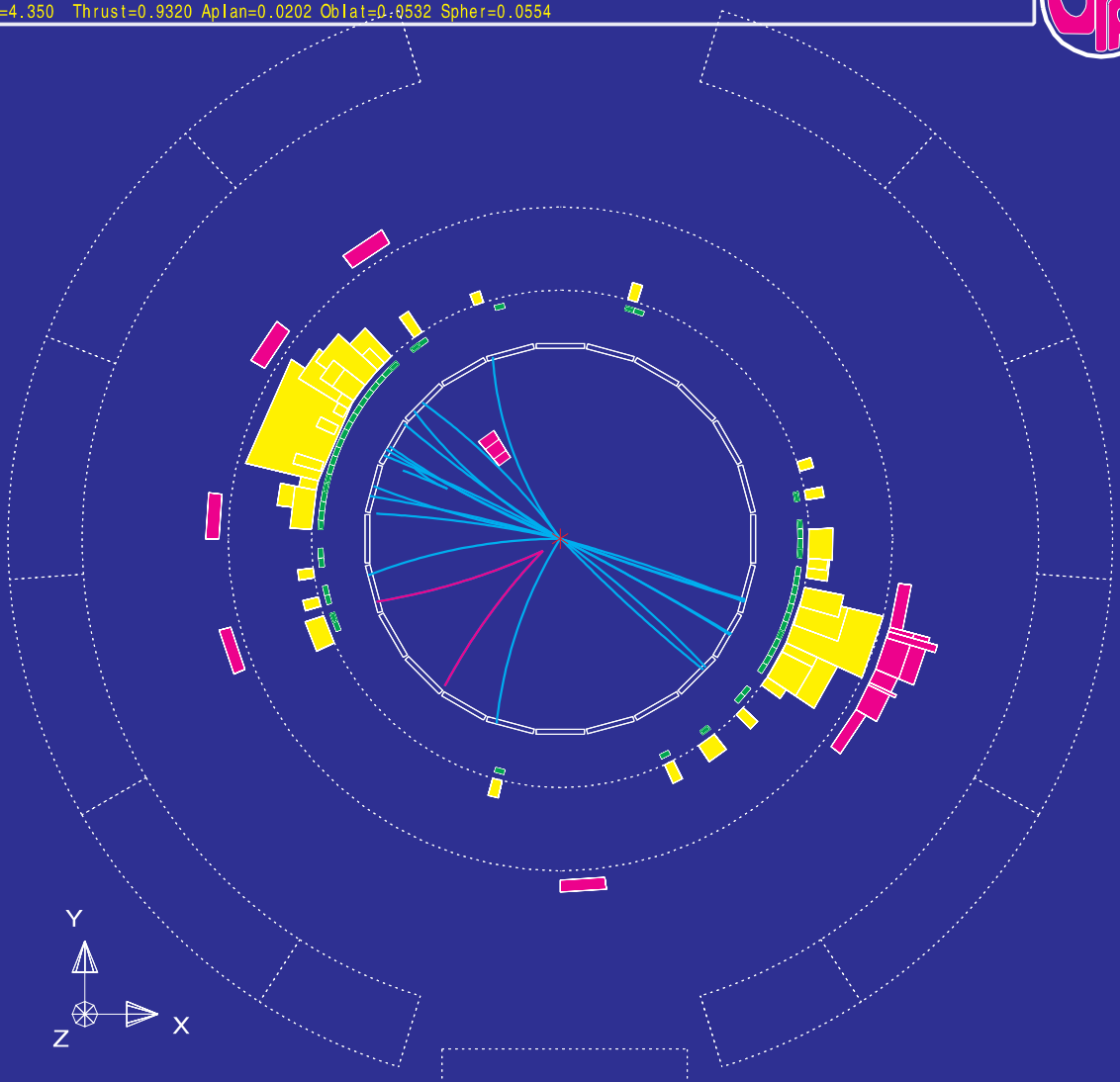
Ebeam 45.623 Evis 89.3 Emiss 2.0 Vtx (-0.10, 0.16, -0.10) Muon(N= 0) Sec Vtx(N= 3) Fdet(N= 0 SumE= 0.0)
Bz=4.350 Thrust=0.9320 Aplan=0.0202 Oblat=0.0532 Spher=0.0554

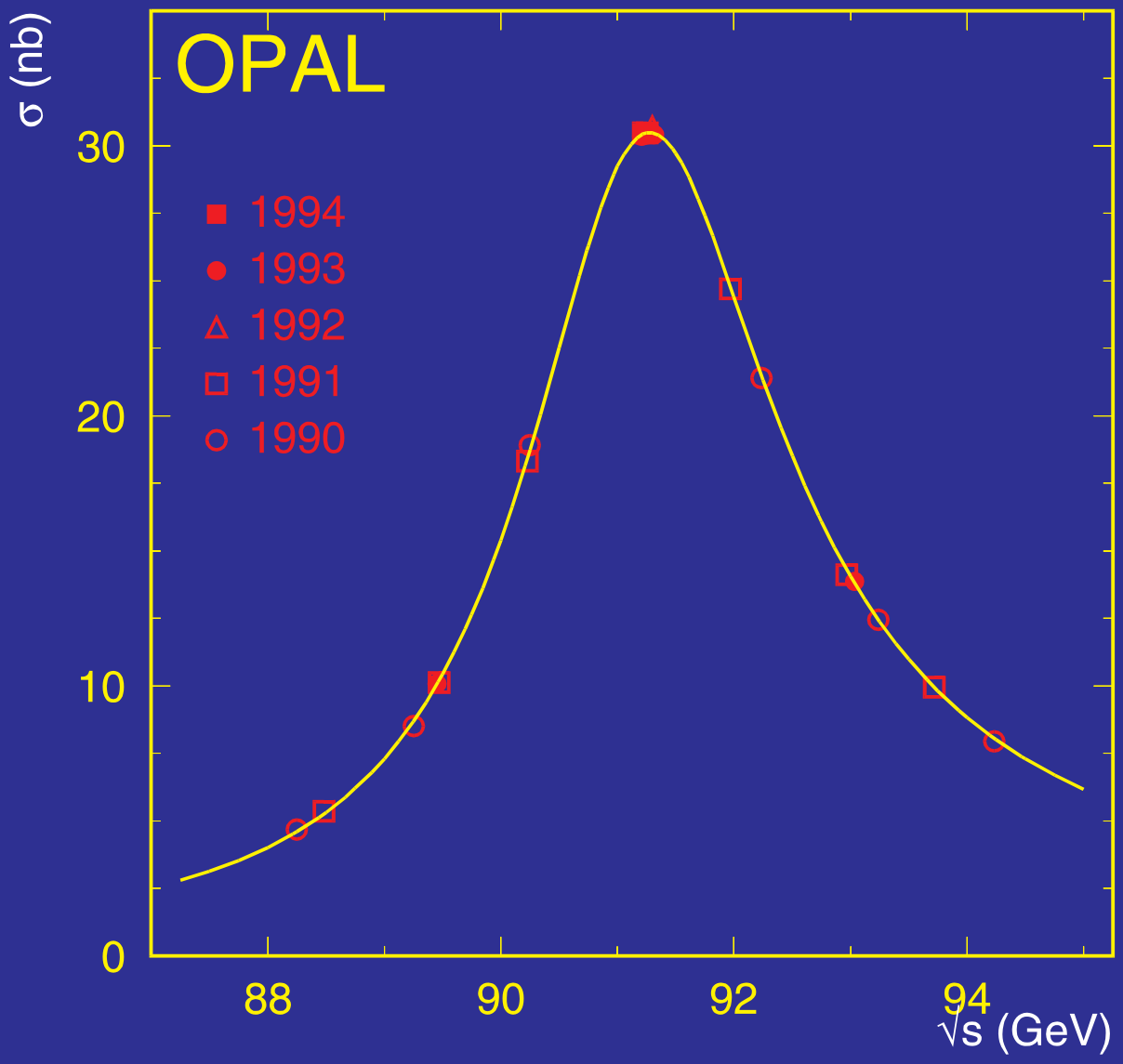


Centre of screen is (0.0000, 0.0000, 0.0000)

Z^0 lineshape

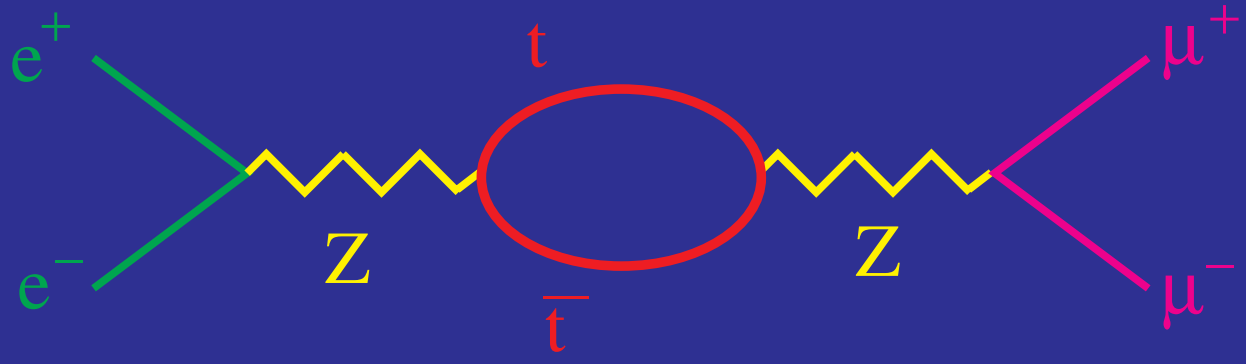
Determines the number of generations:

$n_\nu = 2.989 +/- 0.012$



Many measurements made (individual production rates, asymmetries)... all in agreement with the Standard Model.

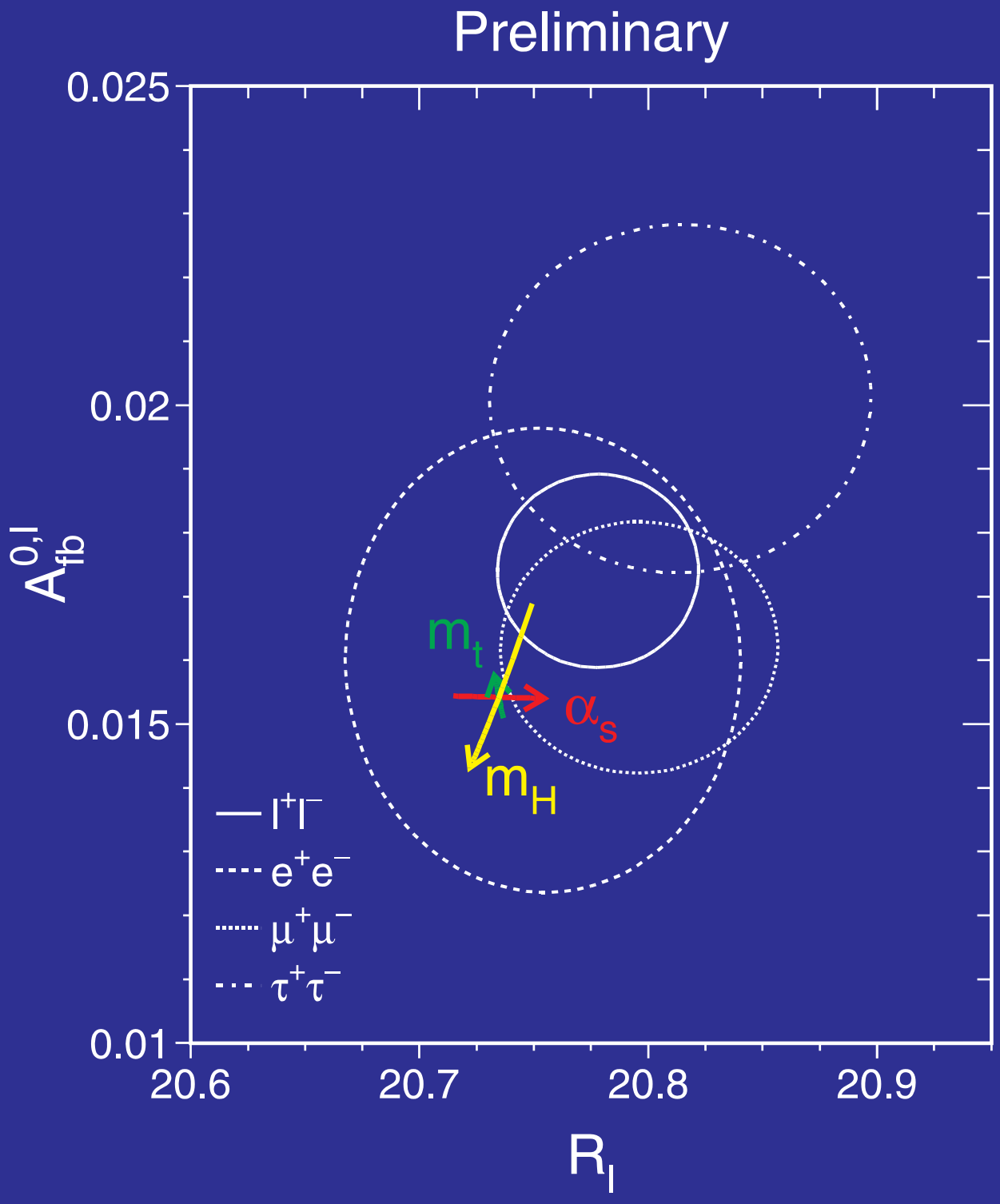
Virtual processes give information about the top quark:



LEP determined top quark mass before the top quark was discovered!

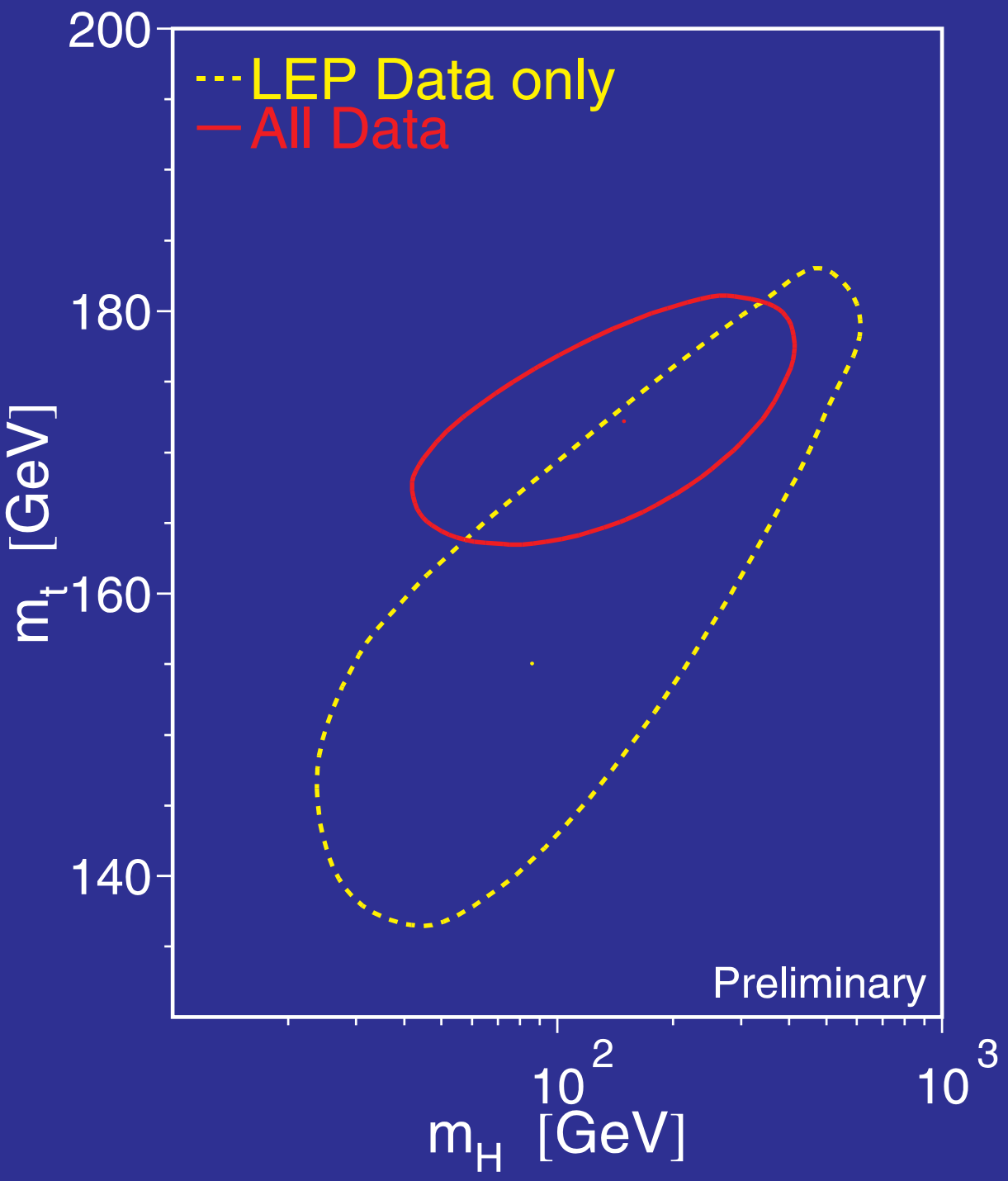
LEP 170 +/– 20 CDF/D0 175 +/– 6 GeV/c^2

For example:
The decay rate and asymmetry for leptons



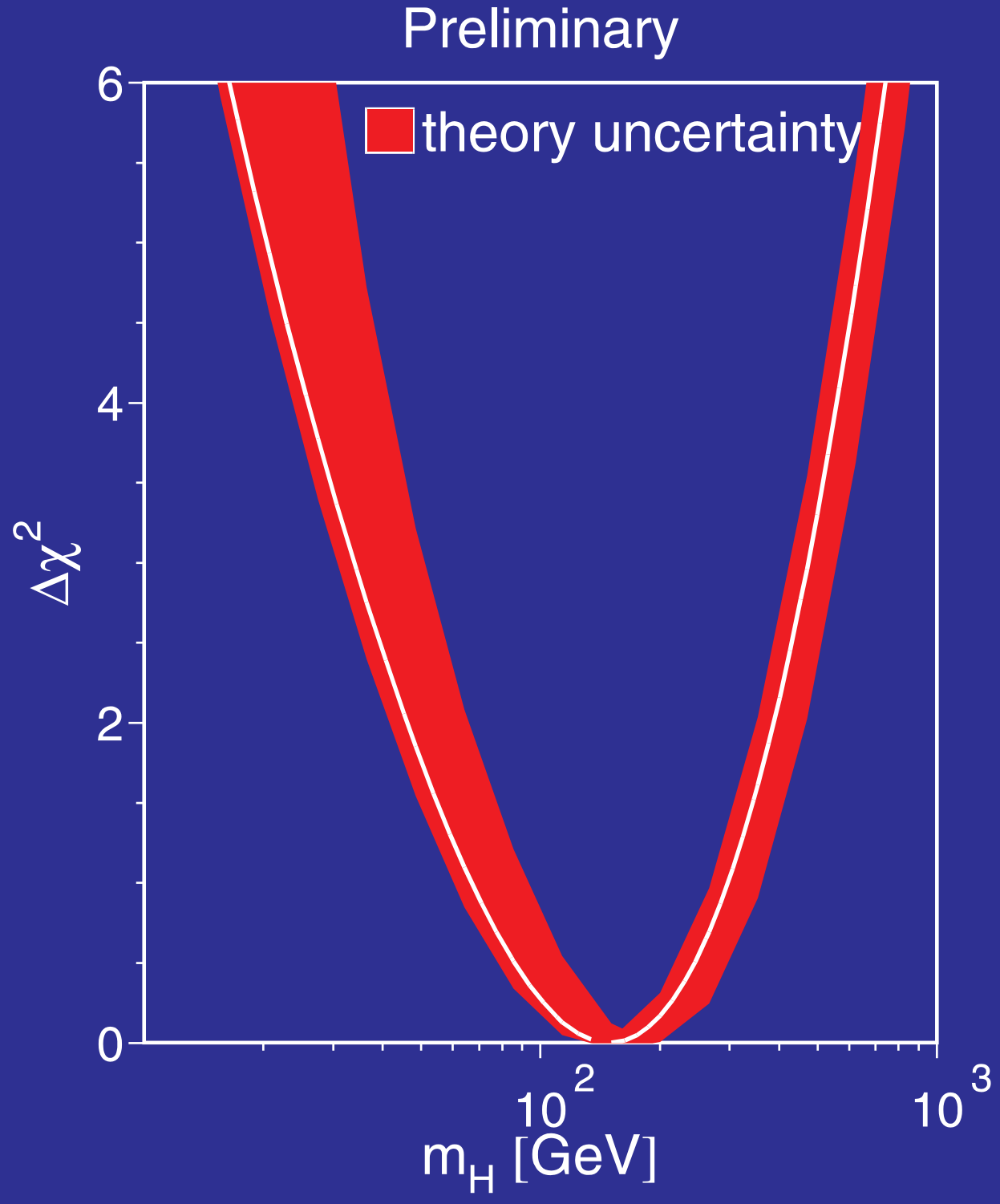
Combining all LEP cross section and asymmetry measurements, yields the 68 % CL contours for m_t and m_H

Red curve includes CDF/D0 m_t

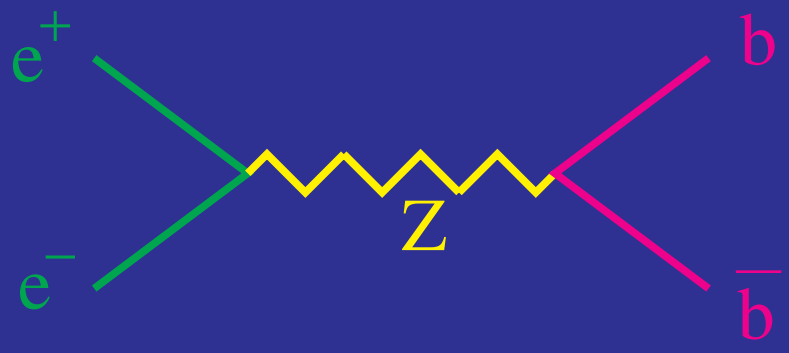


Overall limit on Higgs mass

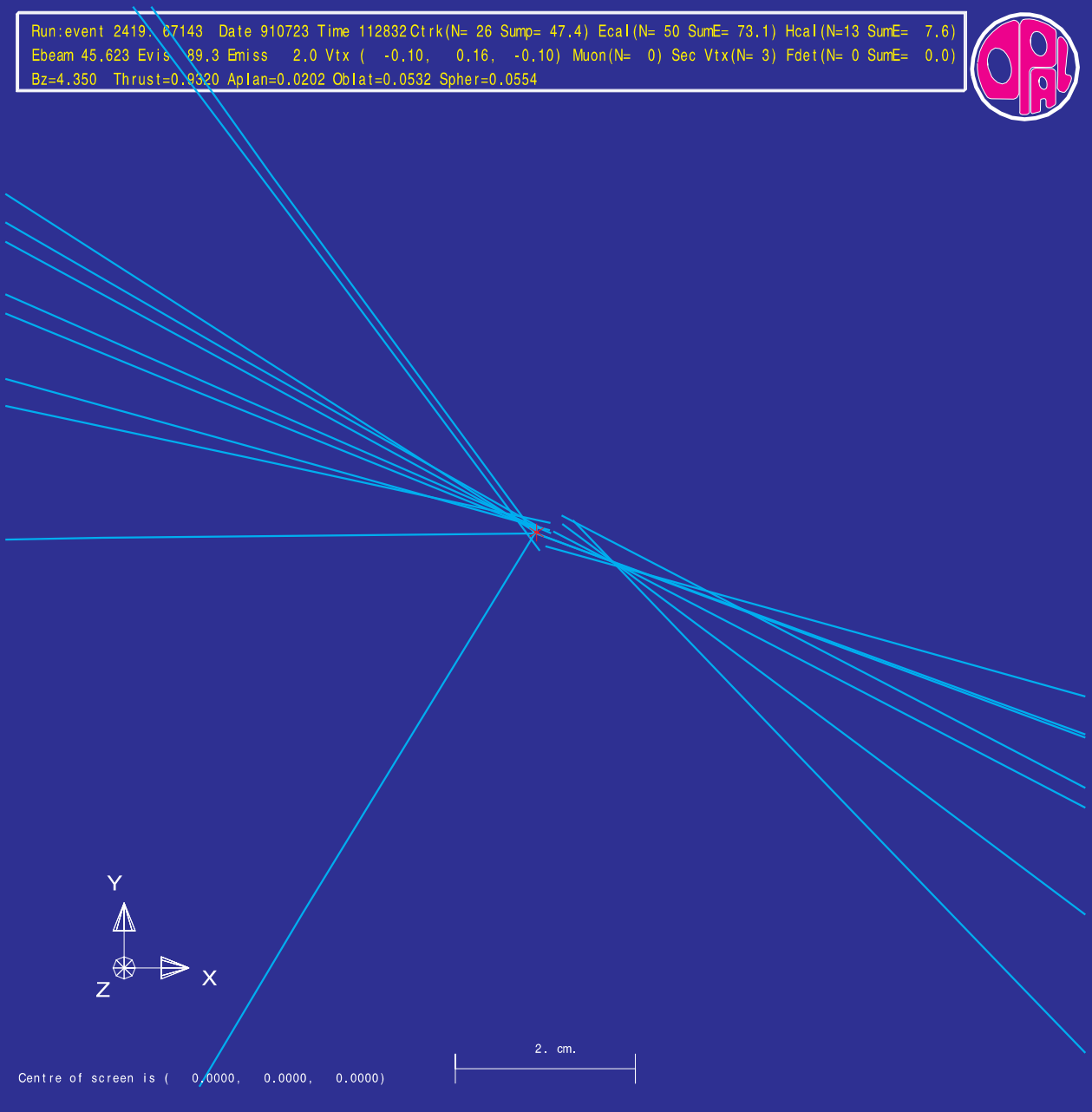
theory error: missing higher order corrections



b quark measurements



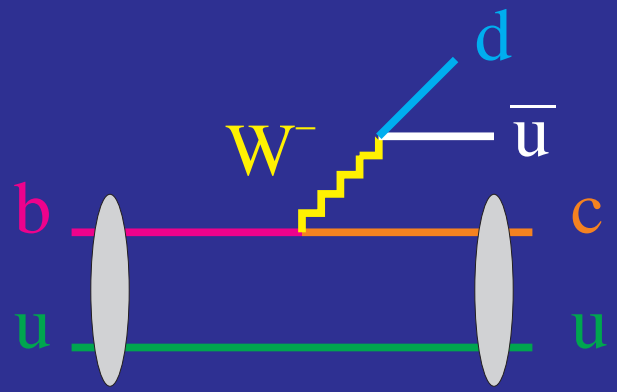
$$\tau = 1.5 \times 10^{-12}\,\mathrm{s} \quad \beta\gamma c\tau = 3\ \mathrm{mm}$$

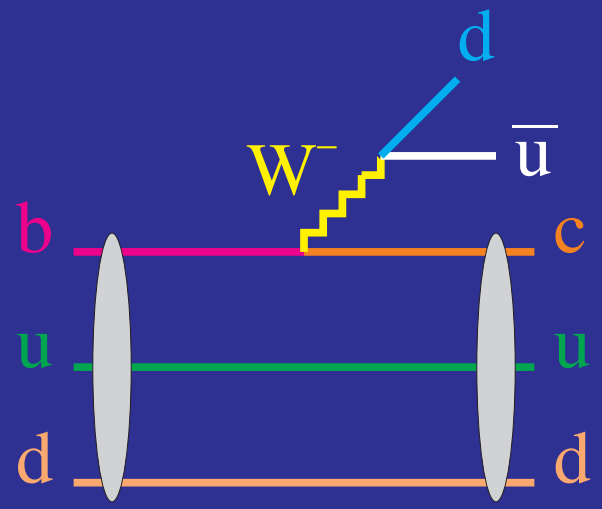


B hadron lifetimes

Fit the "proper" decay times of different species to

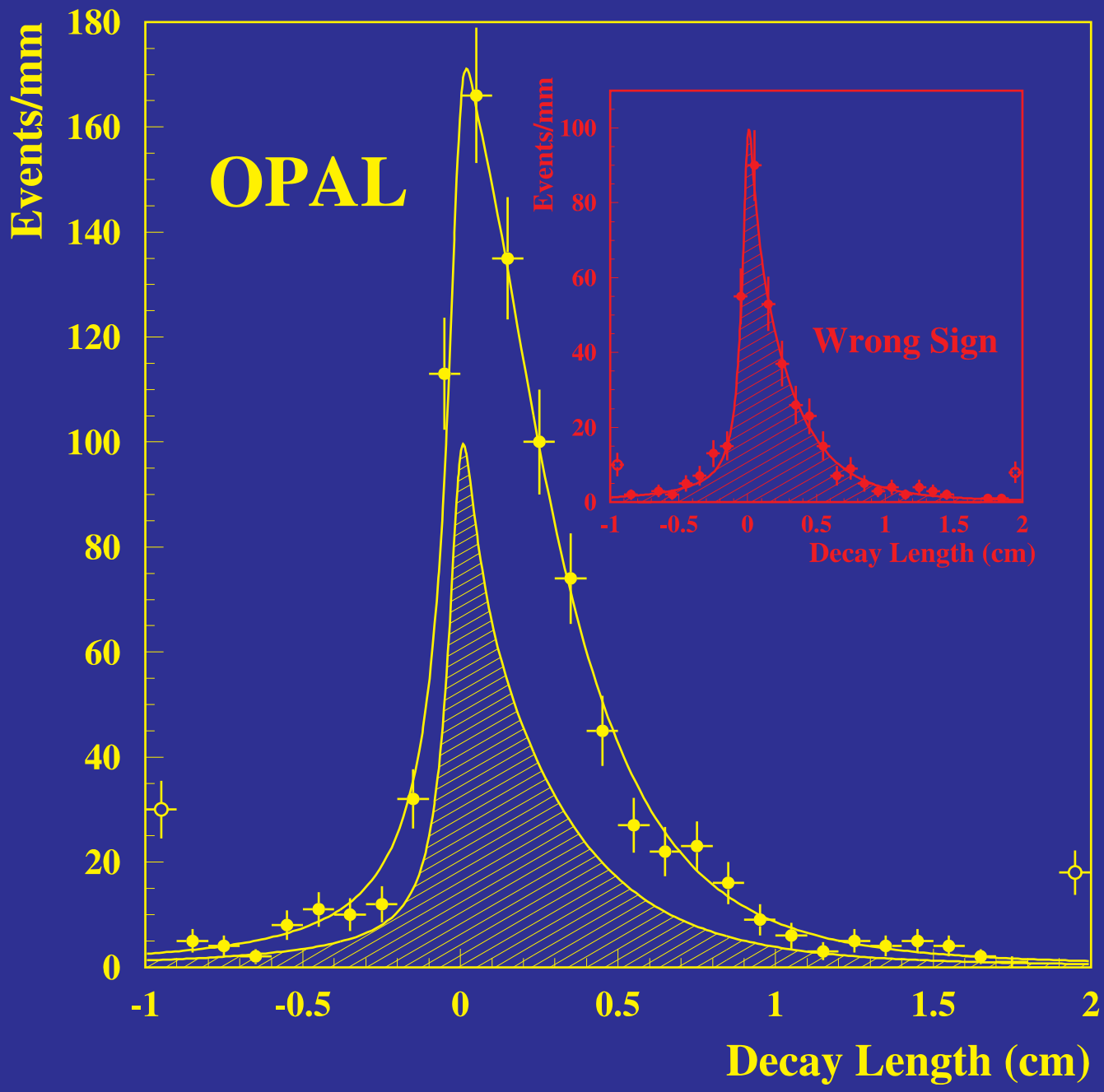
$$p(t) = e^{-t/\tau} / \tau$$





Expect τ(meson) = τ(baryon) to about 10%

Example:
Average b baryon lifetime fit



LEP avg: $t_{\Lambda_b} = 1.21 +/- 0.06$ ps

The result...

$\tau(\text{baryon}) / \tau(\text{meson}) = 0.78 \pm 0.04$

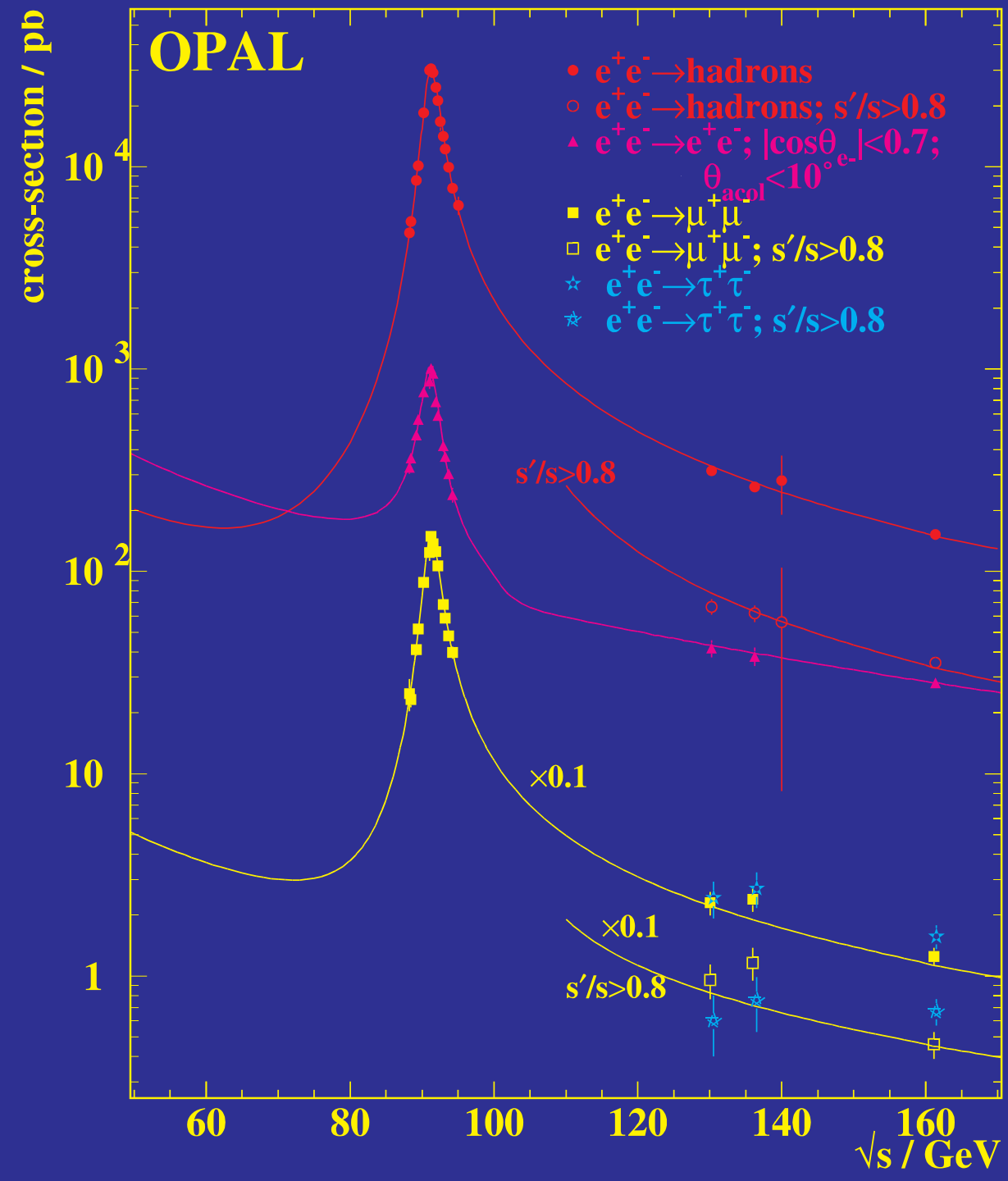
(Predicted to be between 0.9 and 0.99)

About 3σ from the expected result

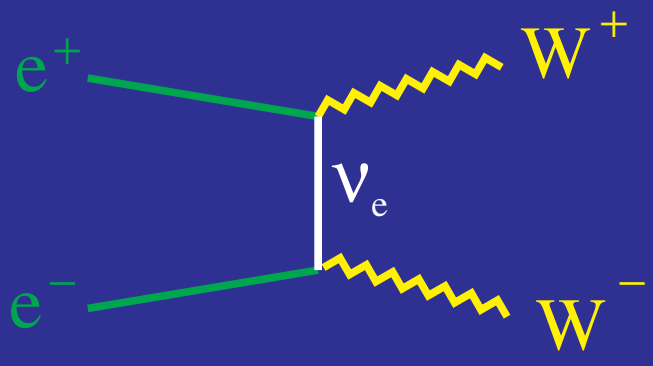
Possible source of confusion: Influence of strong interactions are difficult to calculate. Wait for more theoretical work on this before making conclusions.

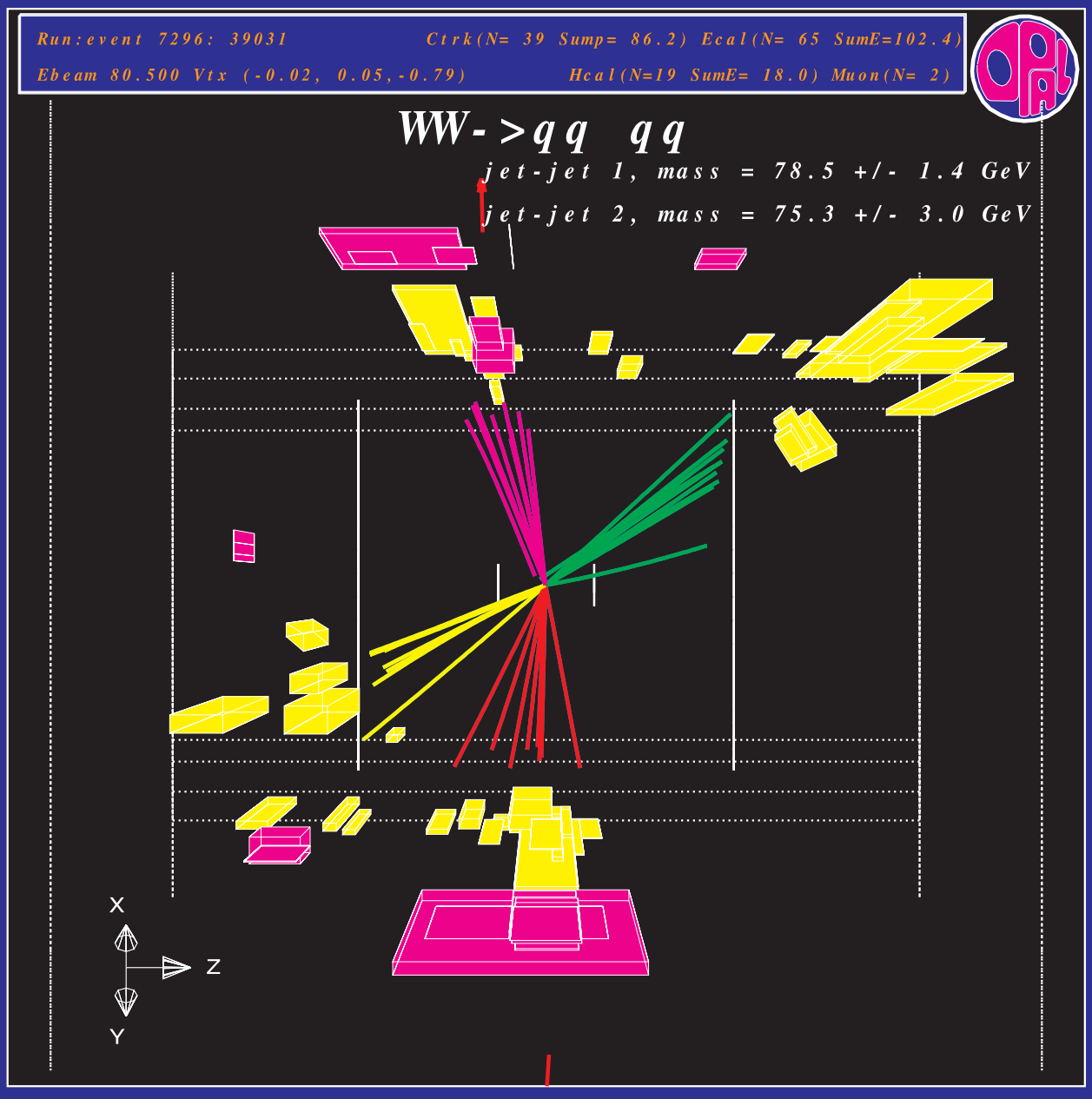
Phase II of LEP:

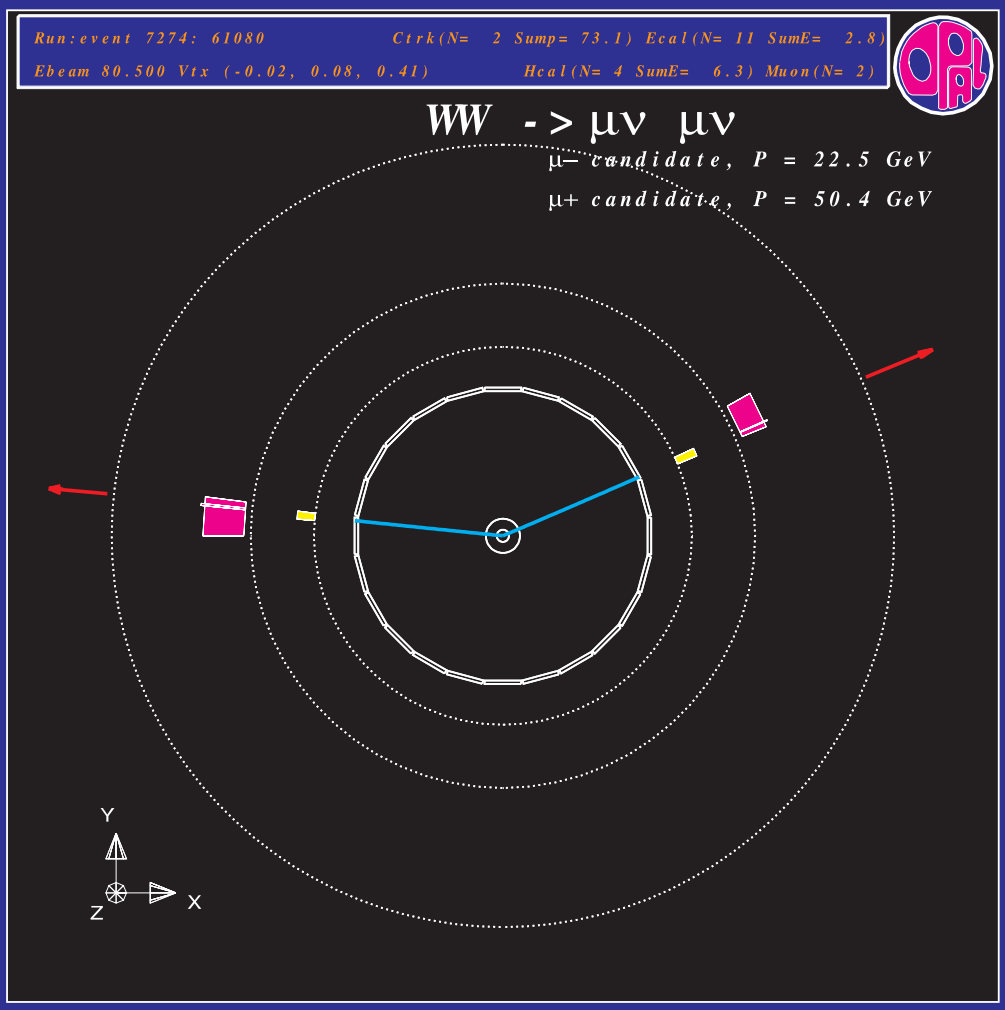
Above the Z^0

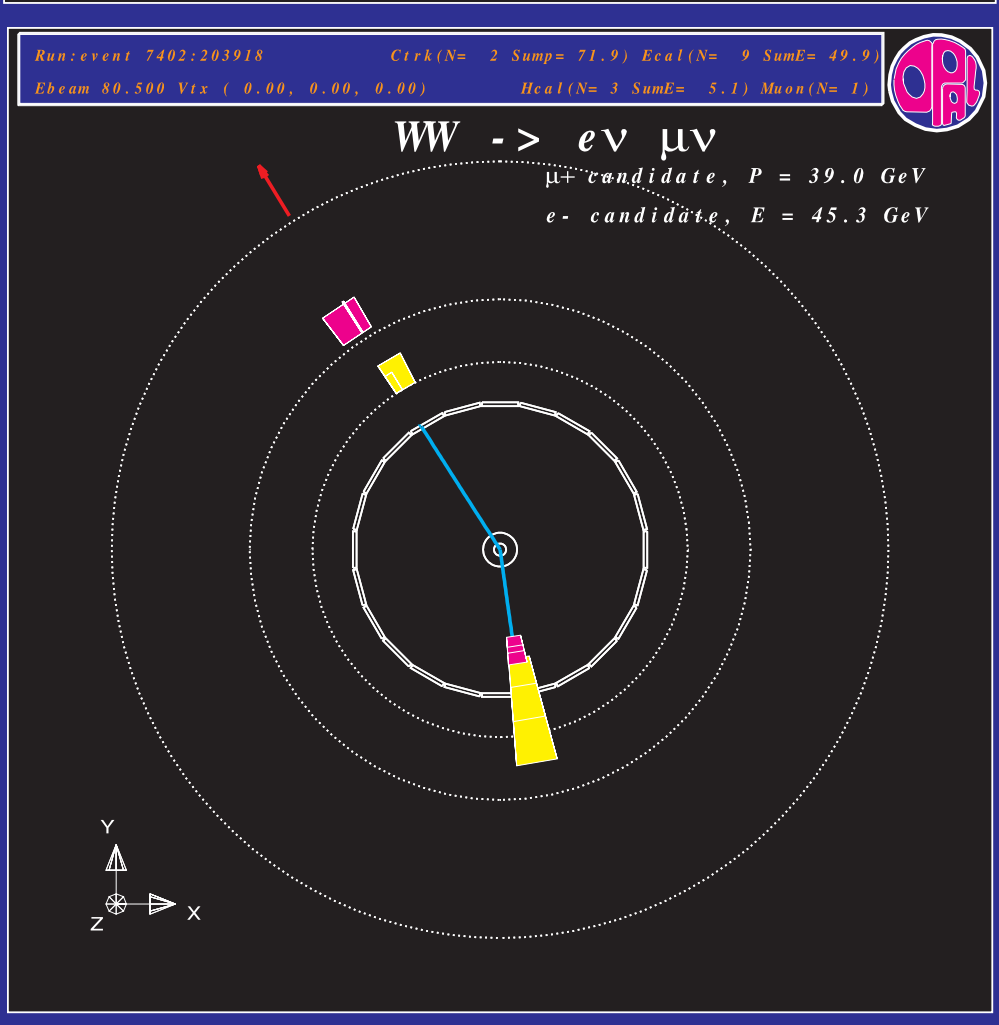


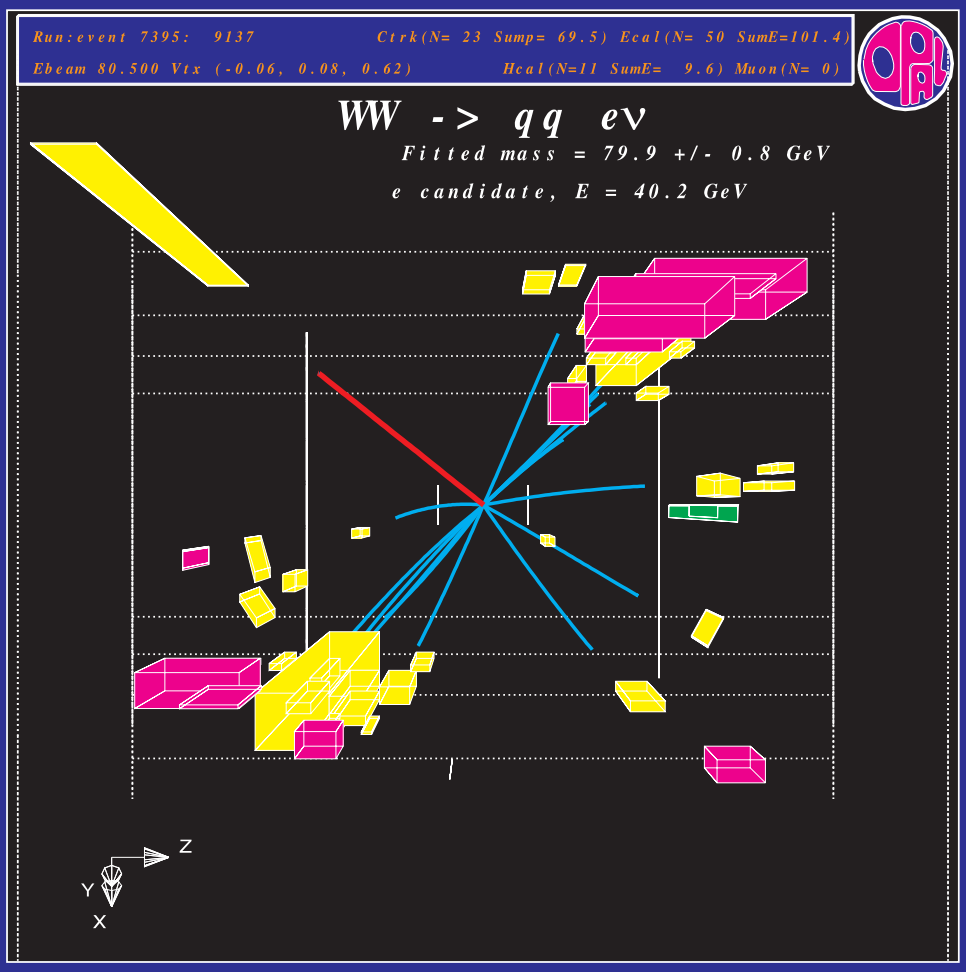
Above the W pair production threshold

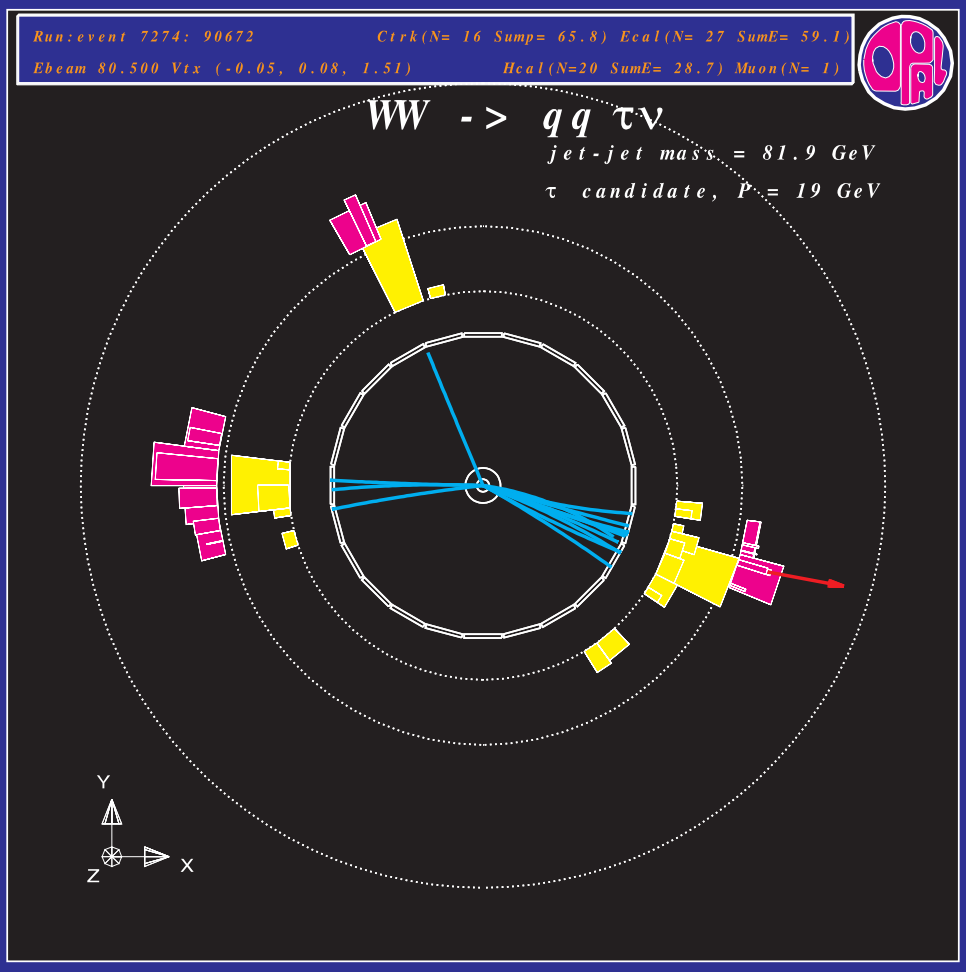




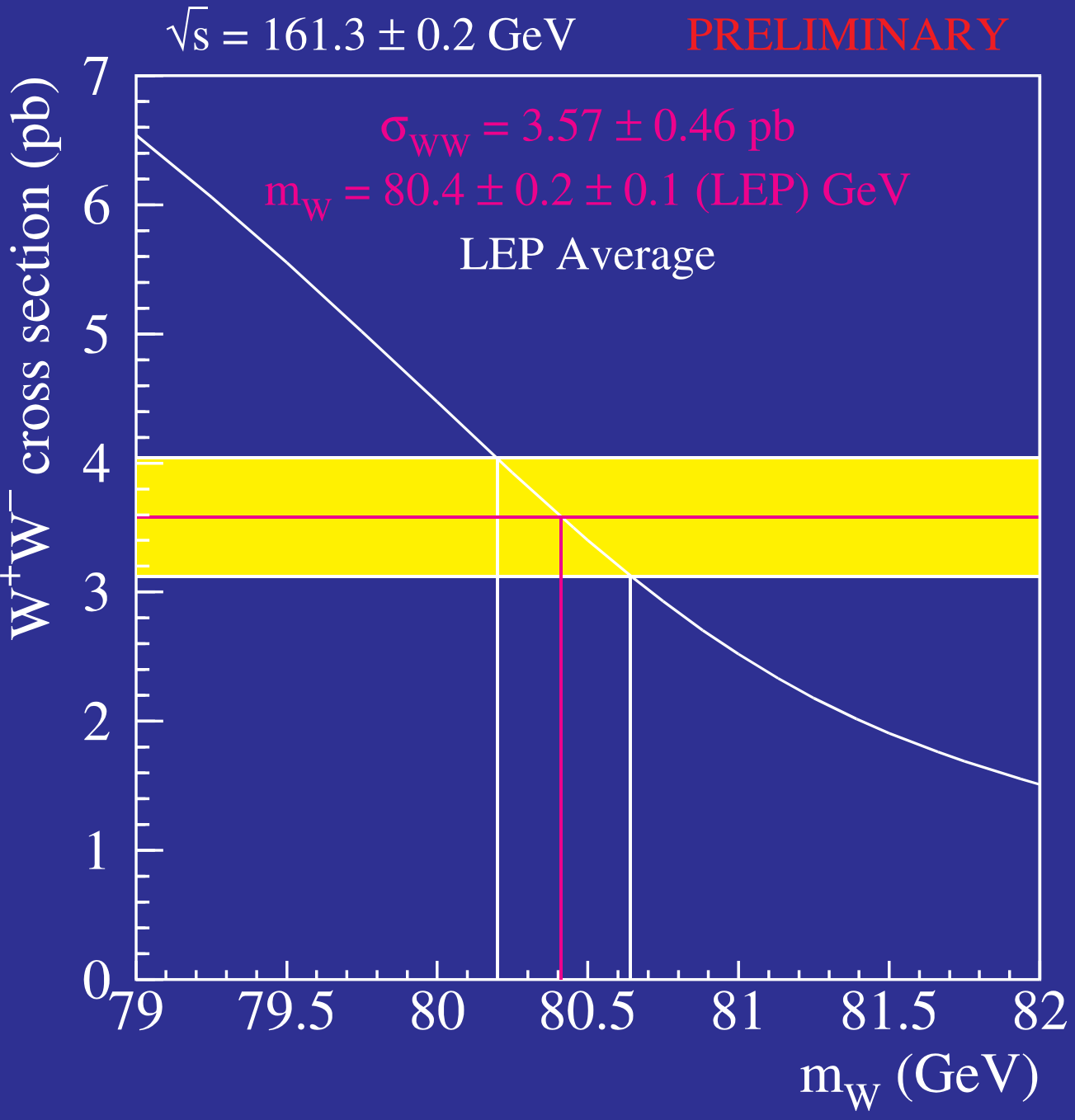

Run:event 7274: 61080 Ctrk(N= 2 Sump= 73.1) Ecal(N= 11 SumE= 2.8)
Ebeam 80.500 Vtx (-0.02, 0.08, 0.41) Hcal(N= 4 SumE= 6.3) Muon(N= 2)
WW -> μν μν
μ- candidate, P = 22.5 GeV
μ+ candidate, P = 50.4 GeV
Y
Z
X


Run:event 7402:203918 Ctrk(N= 2 Sump= 71.9) Ecal(N= 9 SumE= 49.9)
Ebeam 80.500 Vtx (0.00, 0.00, 0.00) Hcal(N= 3 SumE= 5.1) Muon(N= 1)
WW -> eν μν
μ+ candidate, P = 39.0 GeV
e- candidate, E = 45.3 GeV
Y
Z
X


Run:event 7395: 9137 Ctrk(N= 23 Sump= 69.5) Ecal(N= 50 SumE=101.4)
Ebeam 80.500 Vtx (-0.06, 0.08, 0.62) Hcal(N=11 SumE= 9.6) Muon(N= 0)
WW -> qq eν
Fitted mass = 79.9 +/- 0.8 GeV
e candidate, E = 40.2 GeV
Z
Y
X


Run:event 7274: 90672 Ctrk(N= 16 Sump= 65.8) Ecal(N= 27 SumE= 59.1)
Ebeam 80.500 Vtx (-0.05, 0.08, 1.51) Hcal(N=20 SumE= 28.7) Muon(N= 1)
WW -> qq τν
jet-jet mass = 81.9 GeV
τ candidate, P = 19 GeV
Y
Z
X

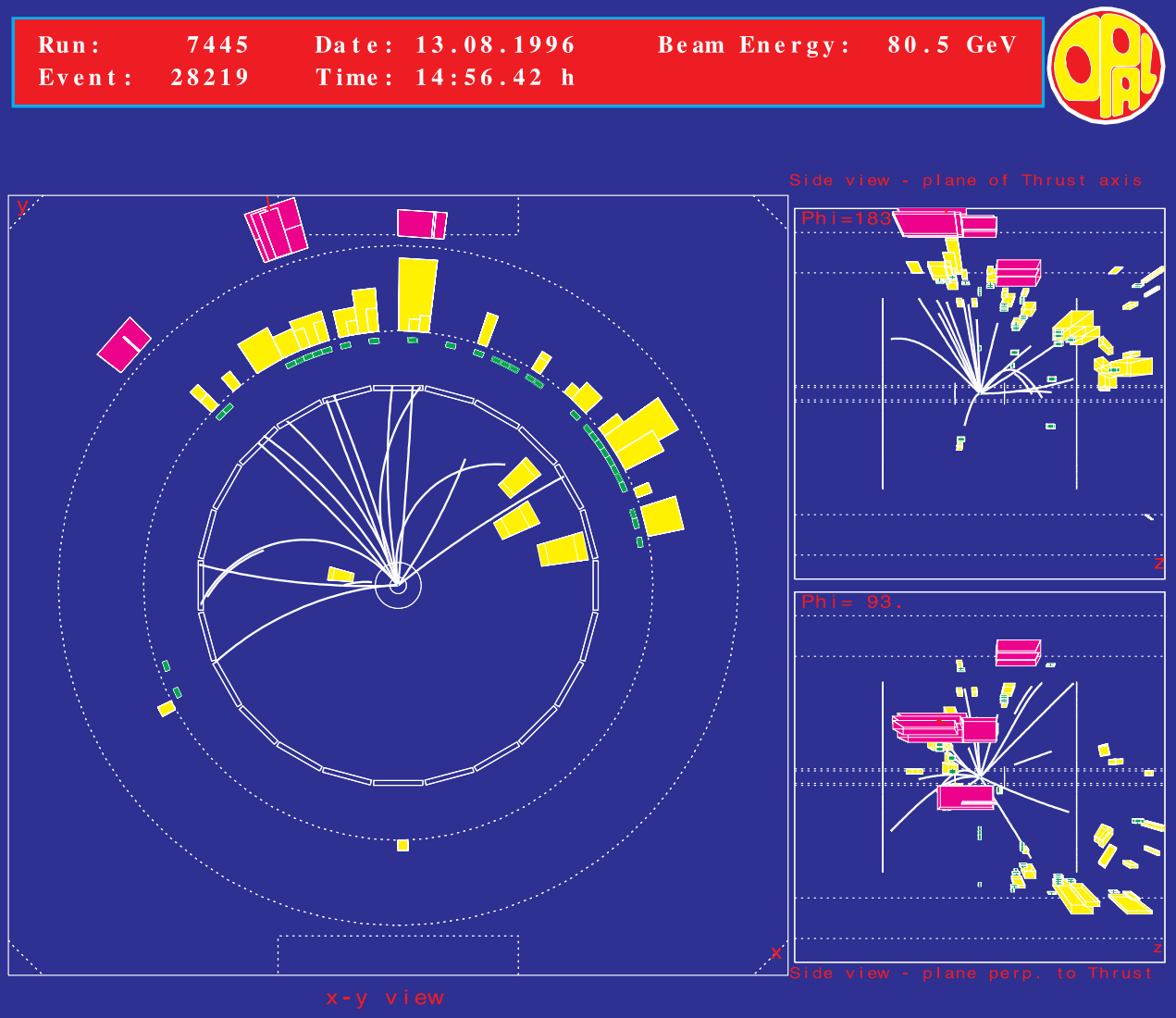
WW cross scction near threshold
depends on mass ⟶ measure m_W



CDF/D0 : m_W = 80.36 +/– 0.13 GeV

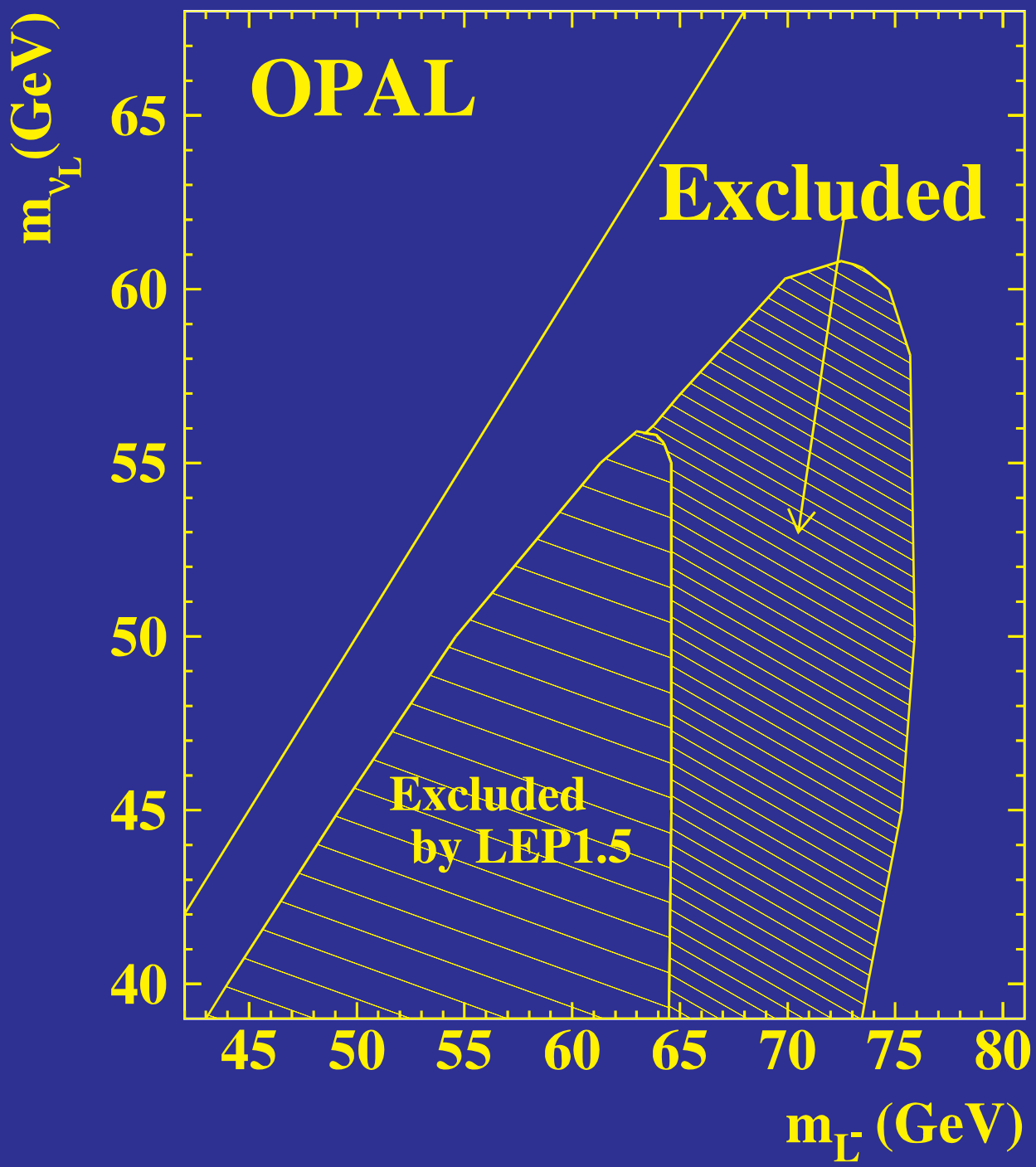
LEP I : m_W = 80.34 +/– 0.04 GeV

Search for unusual topologies ⟶ new particles?

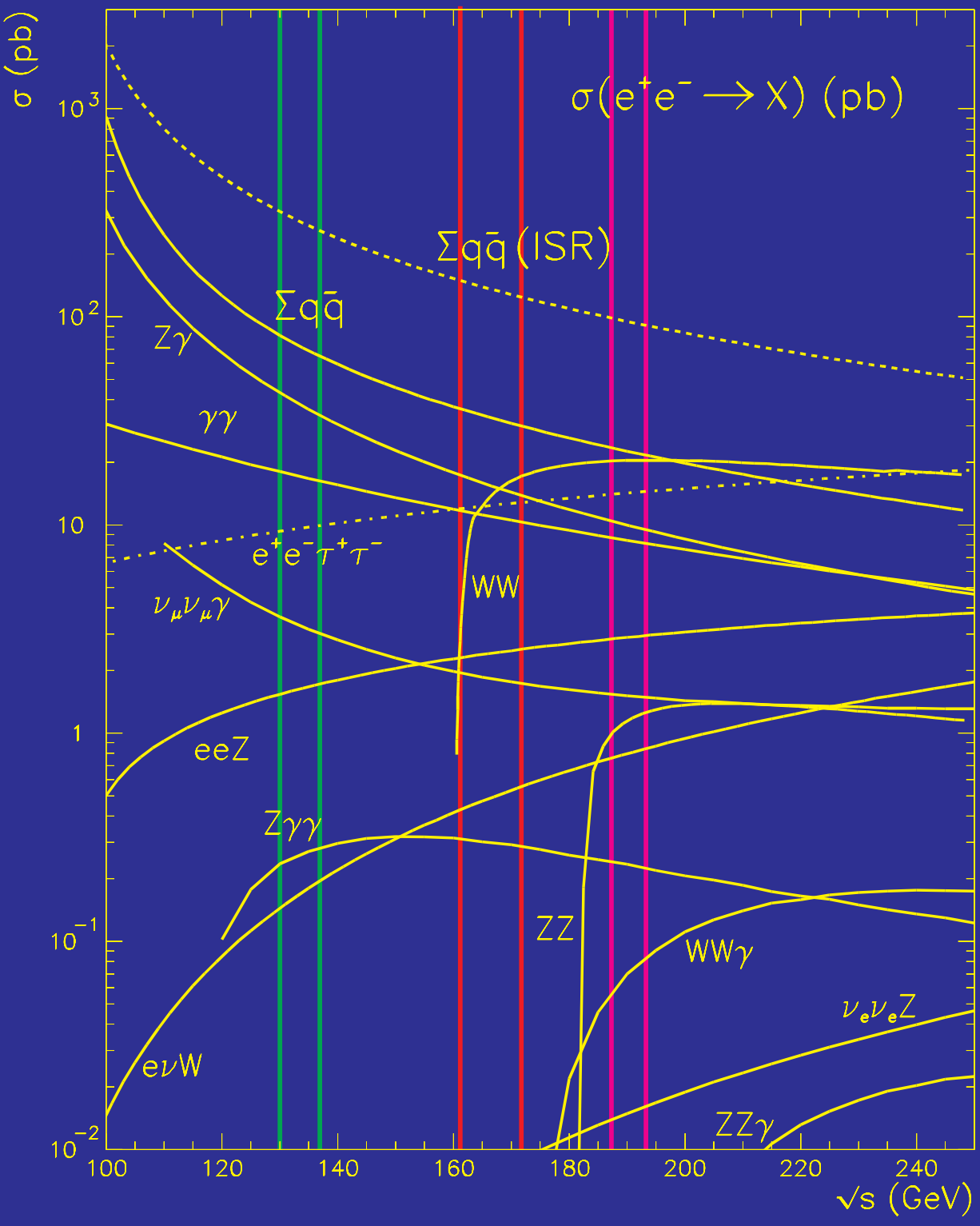


So far... nothing unexpected seen

Can only set exclusion regions, such as:



Future energies and Standard Model processes:



Summary

The Standard Model has successfully passed the detailed examination by the experiments at the first phase of LEP.

Perhaps in phase II of LEP, experiments will crack the Standard Model and get a glimpse at what is beyond...