Last Higgs Catching

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LNF

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A better title would be:

An experimentalist's ongoing adventure

as a Higg's Hunter

or

Higgs, Physics Letters **12**, 132 (1964),

Weinberg, Physical Review Letters **36**, 295 (1976)

a(1.7 MeV), ξ(2.2 GeV), ζ(8.3 GeV),

The Large Hadron Collider-C (1998-2001....)

ATLAS - Tuts, Schamberger, Heintz

CMS - Loveless, Narain.

Higgs and sociology

SSC was justified for its potential for Higgs discovery.

Tevatron CDF and DØ today are dedicated to Higgs.

Current World HEP resources are dominantly spent on Higgs

LHC, ATLAS and CMS (with casts of thousands, 0.1% mine) were designed and are primed for Higgs discovery and study.

Why and How did it come about?
Weak interaction, history

S-wave unitarity:

$$\sigma_\ell = \frac{4\pi}{k^2}(2\ell+1)|a_\ell|^2 \le \frac{4\pi(2\ell+1)}{k^2}$$

$$\sigma_{\ell=0} \sim \frac{1}{s} \qquad \sigma_{\mathrm{F}} = G^2 s$$

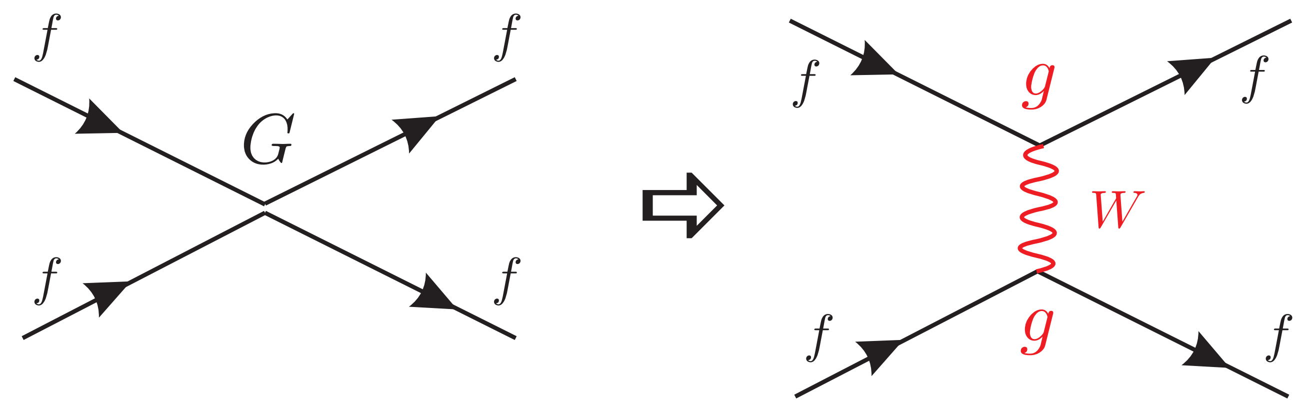
Unitarity bound is violated for:

$$\sigma_{\mathrm{F}} \ge \sigma_{\ell=0} \qquad s \ge \frac{1}{G}$$

$$E \ge \sqrt{1/G} \sim 300 \text{ GeV}$$

π=2=1 above.

But suppose that:



then

$$\frac{\mathrm{d}\sigma}{\mathrm{d}|t|} \propto \frac{g^4}{(M_W^2 - t)^2}$$

instead of $\mathrm{d}\sigma/\mathrm{d}|t| \propto G^2$. Low energy phenomenology ($|t|, s \ll M_W^2$) requires $g^2 \approx G \times M_W^2$.

$g^2 \sim 10^{-5}\ \mathrm{GeV}^{-2} \times 80^2\ \mathrm{GeV}^2 \sim 0.064 \sim \alpha$.

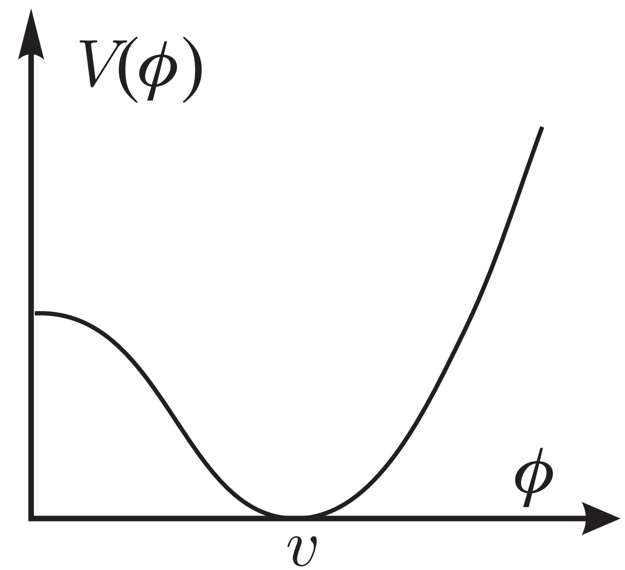
This suggest unifying weak and electromagnetic interactions with the help of vector bosons. $SU(2)_{\mathrm{w-ispin}} \times U(1)_Y$: 4 generators $\Rightarrow$ 4 gauge fields: W^+, W^0, W^- and B^0.

There is also a mixing angle which gets from W^0_μ–B^0_μ to Z^0_μ–A_μ, with A_μ a mass-less field, the photon.

A complex scalar doublet is then introduced in the Lagrangian. The initial symmetry is still there but it can't help spontaneously breaking. The "true" vacuum corresponds to a non zero value of the scalar field ϕ.

One number is well defined,

$$v = \langle\phi\rangle = \sqrt{\frac{1}{\sqrt{2}\,G}} = 246 \text{ GeV}$$



But because the gauge symmetry is local, three of the degrees of freedom of the Higgs field, $\phi^+, \phi^0, \bar{\phi}^0$ and ϕ^- become the zero helicity states of the gauge bosons which thus acquire mass.

The vector boson masses are

$$M_W = \frac{1}{\sin\theta}\left(\frac{\pi\alpha}{\sqrt{2}G}\right)^{1/2} = \frac{37.3}{\sin\theta_W}\ \text{GeV}$$
$$M_Z = \frac{M_W}{\cos\theta_W}$$

One scalar boson survives as an observable elementary particle, it is called the Higgs boson.

So all is left to be done is to find the Higgs.

Searching for Higgs Mass

There is no a priori knowledge about the Higgs mass. But...

In the Lagrangian we find a quartic coupling $\lambda\phi^4$, where λ is an arbitrary dimensionless coupling constant. The Higgs mass is given by $M_H = v\sqrt{\lambda/2}$. What is λ?.

From effective HH coupling, $M_H > \alpha v$

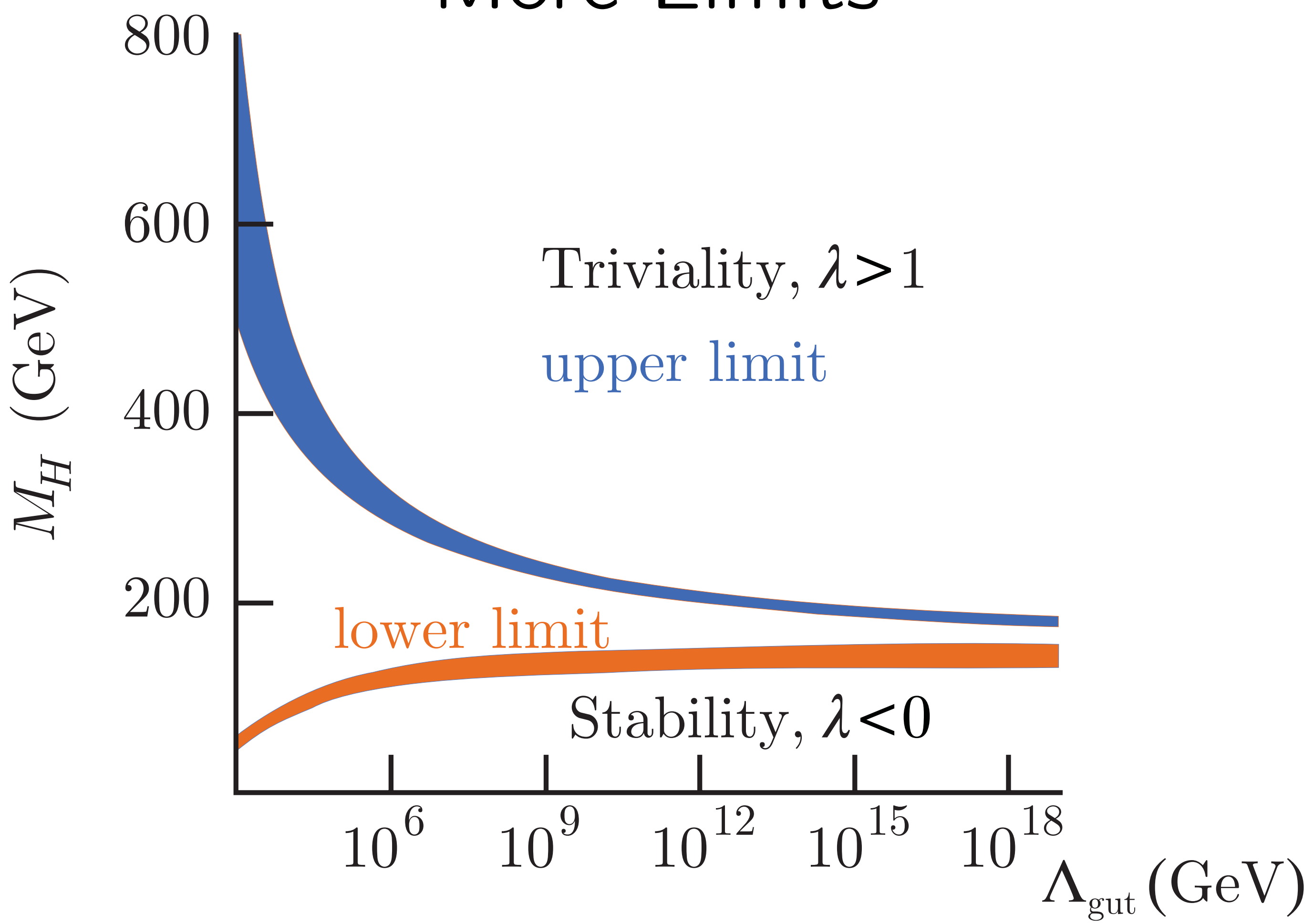
$M_H >$ 7.3 GeV. If $<$, the vacuum becomes unstable...!

In 1976 Weinberg calculated this lower bound to be for $SU(2) \times U(1)$ models, 3.72 GeV; as did Linde.

If $M_H > 1$ TeV than WW scattering exceeds unitarity.

Also for $M_H \sim 1$ TeV, $\Gamma_H \sim 1$ TeV...

More Limits



Higgs mass limit vs new physics scale Λ. Upper unitarity, lower stability.

Many Higgs-bosons

Supersymmetry adds more Higgs. In MSSM just one more complex doublet. No new Higgs is necessary for giving mass to additional gauge boson and we now have 5 physical particles:

1. Two neutral scalars, h^0, H^0
2. One neutral pseudoscalar, A^0
3. Two charged scalars, H^+, H^-

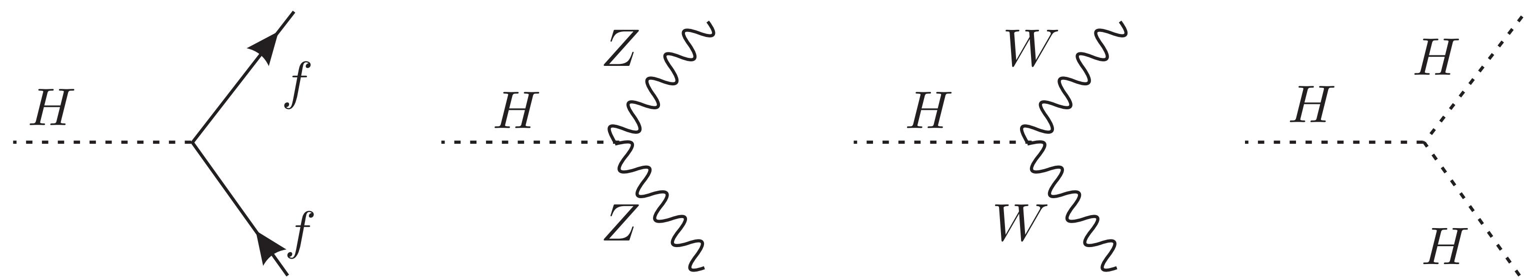
At tree level:

$$M_h \leq M_Z \leq M_H \qquad M_A \leq M_H \qquad M_{H^\pm} \leq M_{W^\pm}$$

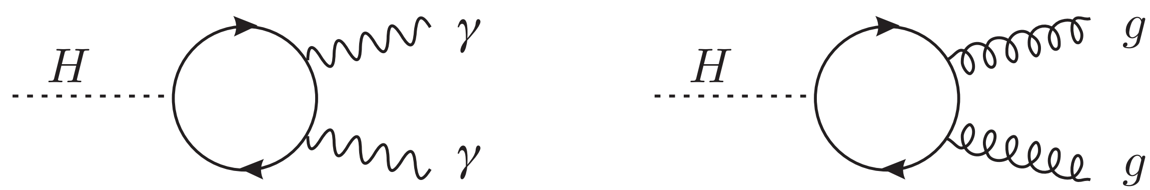
After radiative corrections $M_h \leq 135$ GeV.

Production and decay

The Higgs couples universally to fermion and vector bosons

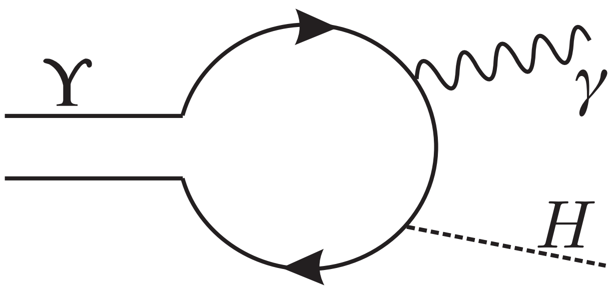


and therefore also to photons and gluons

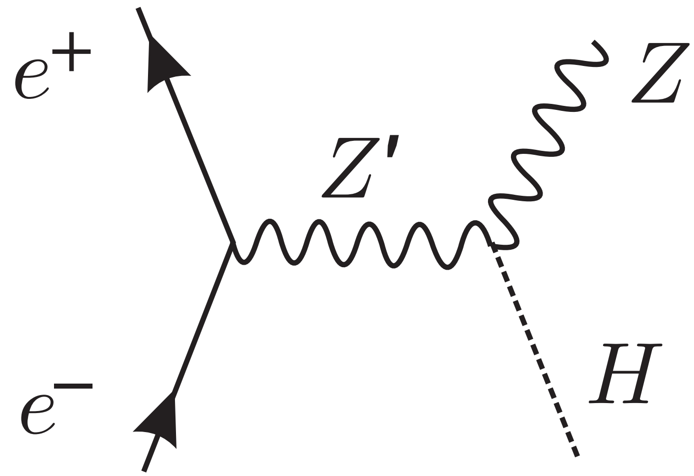


Couplings $\propto$(mass). We can chose the best way to detect it!

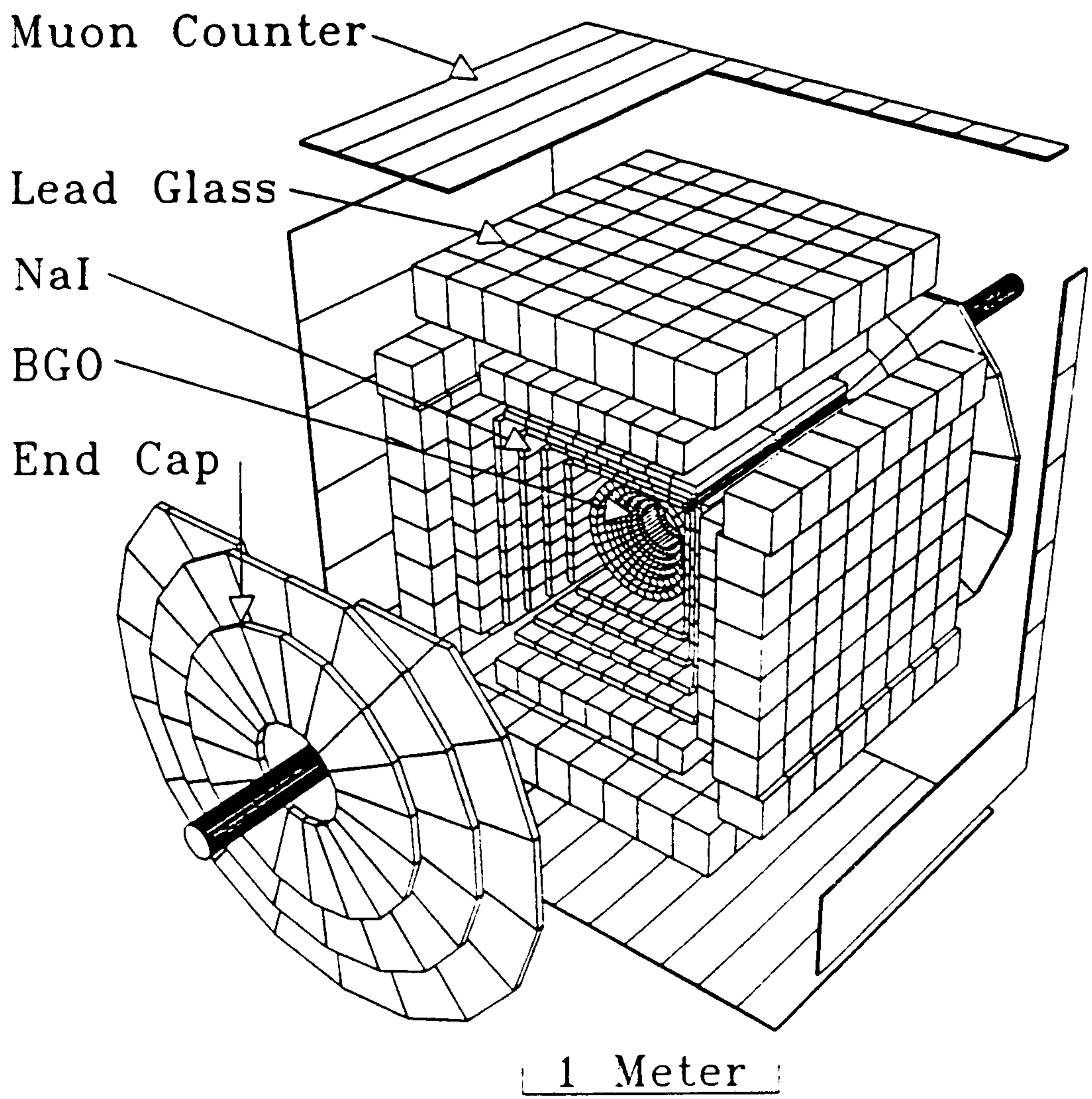
Very light Higgs and axions. Heavy quarks couple more to Higgs. Can search for light Higgs in $\Upsilon \to \gamma + H$. CUSB excluded Higgs with $M_H <$ 3-4 GeV



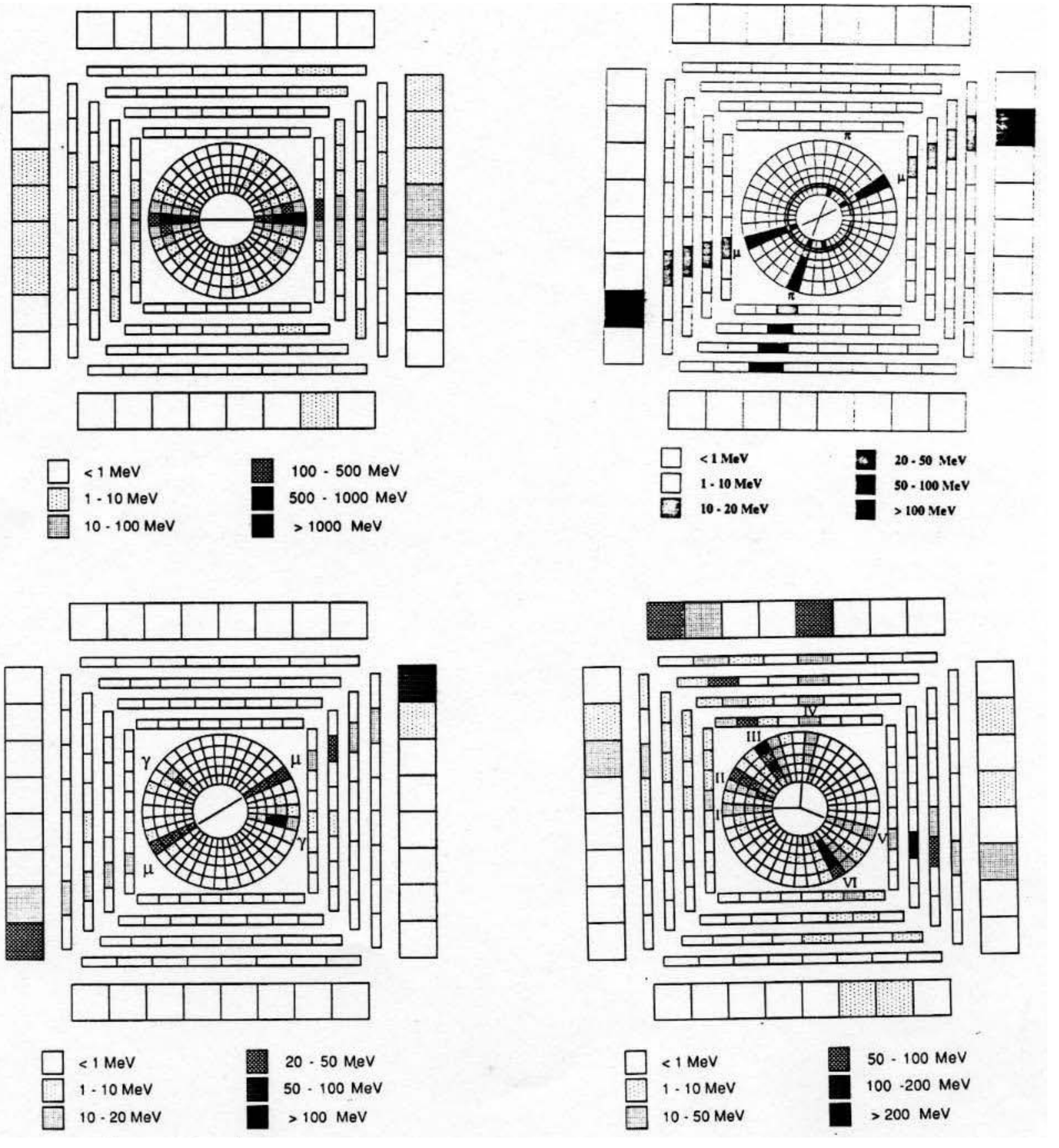
Generic Higgs production at e^+e^- colliders



In 1979 we were given at CESR a tiny interaction region in a pit for detecting the neutral products of the Upsilon decays.



Event Displays in CUSB-II: top-left: Bhabha, top-right: $\pi\pi\mu\mu$, bottom-left $\mu\mu\gamma\gamma$, bottom-right hadronic event



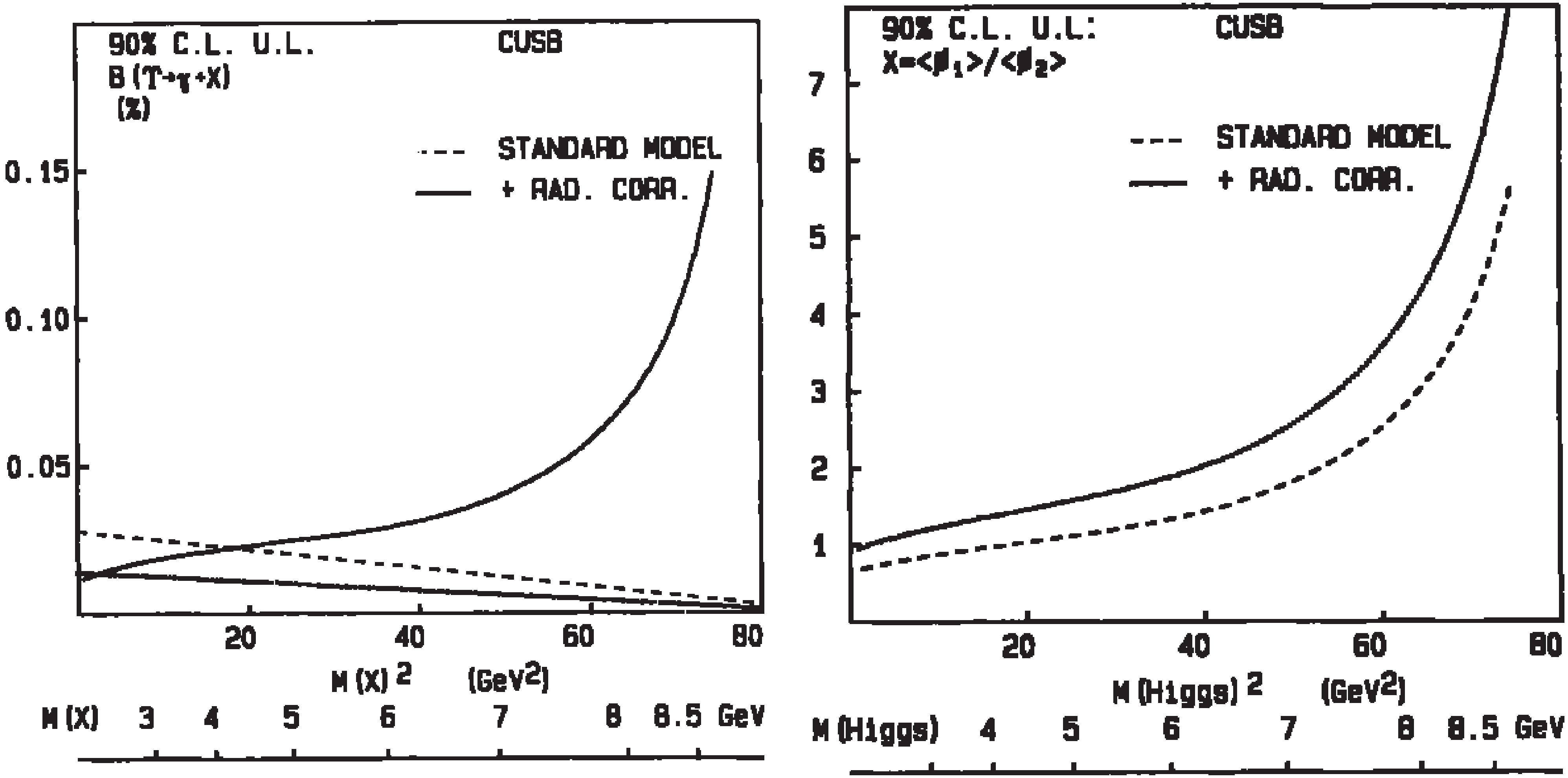
The dominant handle for CUSB's Higgs search is through looking for events containing a monochromatic high energy photon plus any other particles.

The decay rate for the vector meson V to $\gamma + H$ is:

$$\frac{\Gamma(V \to \gamma\, H)}{\Gamma(V \to \mu\mu)} = \frac{G_F M_Q^2}{\alpha\pi\sqrt{2}}\, \frac{1 - M_H^2}{M_V^2}\, x^2$$

($\Gamma(V \to \mu\mu)$, the leptonic width, knows all about the Υ)

CUSB HIGGS LIMITS PRD **35** 2883 1987



- - - Annoying Radiative Corrections!

Beneficial Radiative Corrections

$$M_W = \frac{(\pi\alpha/\sqrt{2}G)^{1/2}}{\sin\theta(1-\Delta r)}$$

where Δr are the $SU(2)\times U(1)$ radiative corrections.

$\Delta r = \Delta r_0 - \rho_t/\tan^2\theta + \mathcal{O}(\log M_H/\Lambda)$

$\Delta R_0 = 1 - \alpha/\alpha(M_Z) = 0.0664$

$\rho_t = \ldots G m_t^2 \ldots = 0.00925 \times (m_t/174.3\ \text{GeV})^2 + \text{logs}$

predicts m_t, partly cancels QED

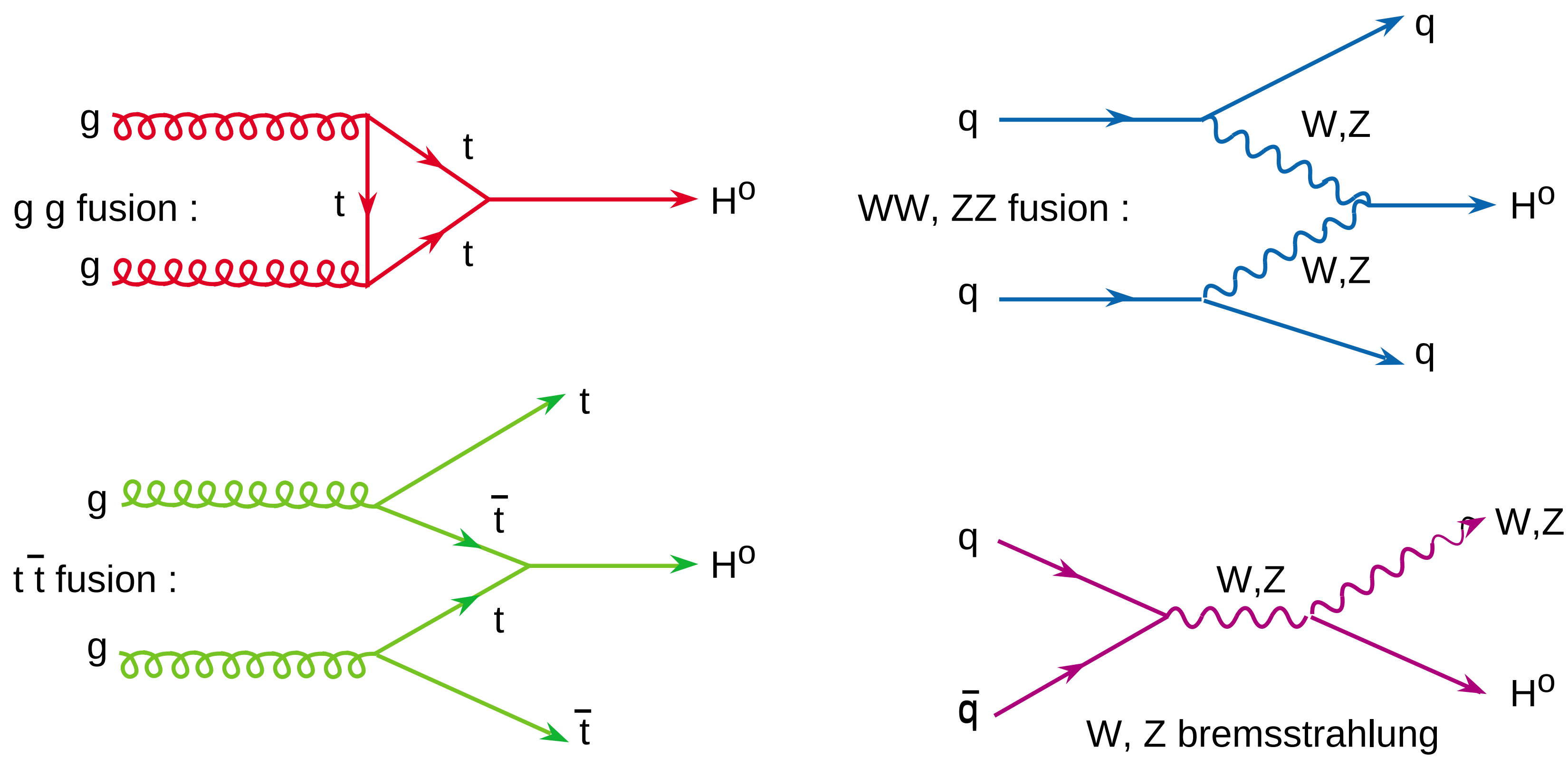
$\Delta r = 0.0350 \pm 0.0019 \pm 0.0002.$ Last error from $\alpha(M_Z)$

From M_Z, M_W, m_t, etc., find M_H.

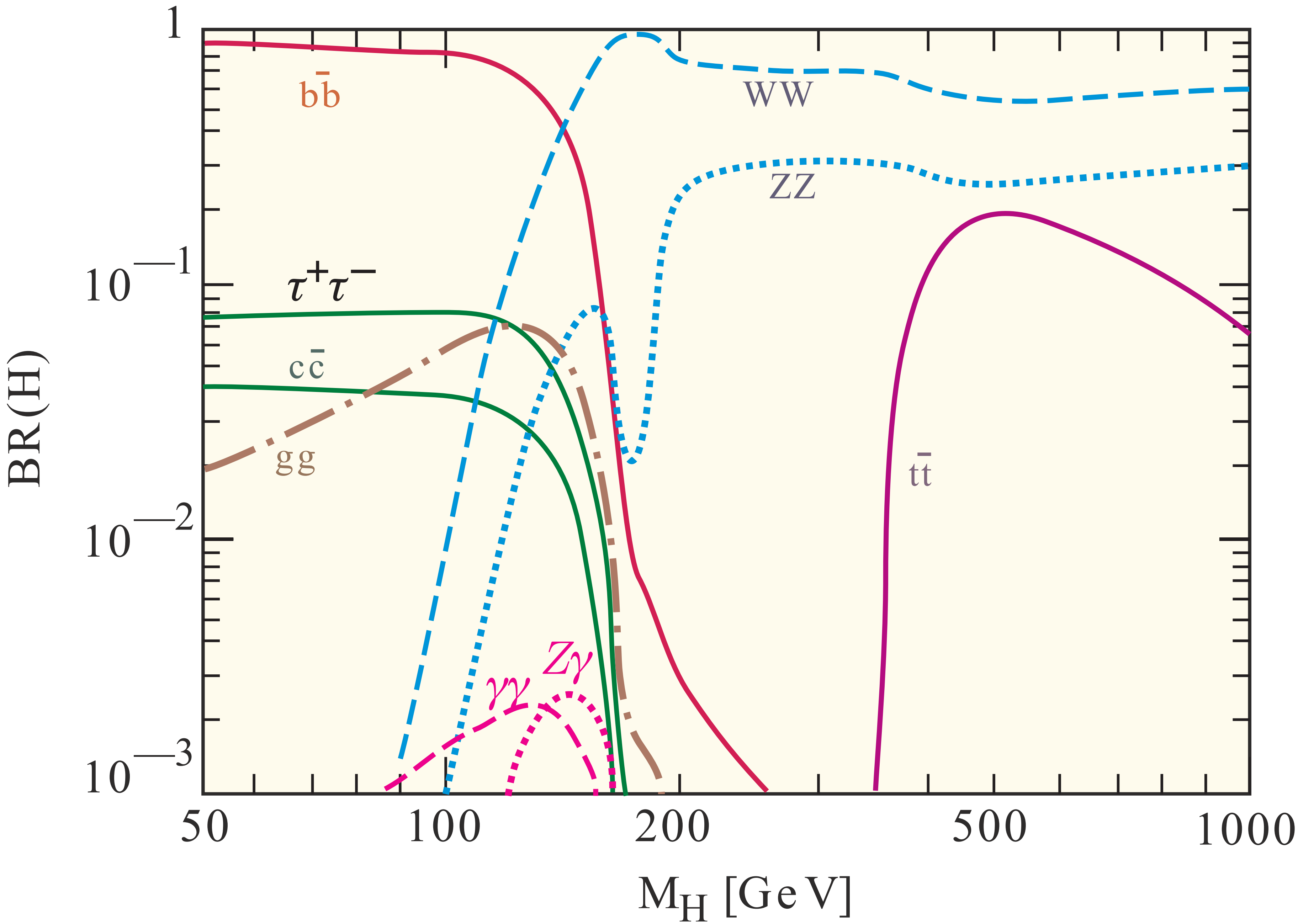
Today I'll skip the middle chapters of LEP, Tevatron and go straight on to 14 TeV.

Higgs production in hadron collisions

A reminder that the production mechanisms are different

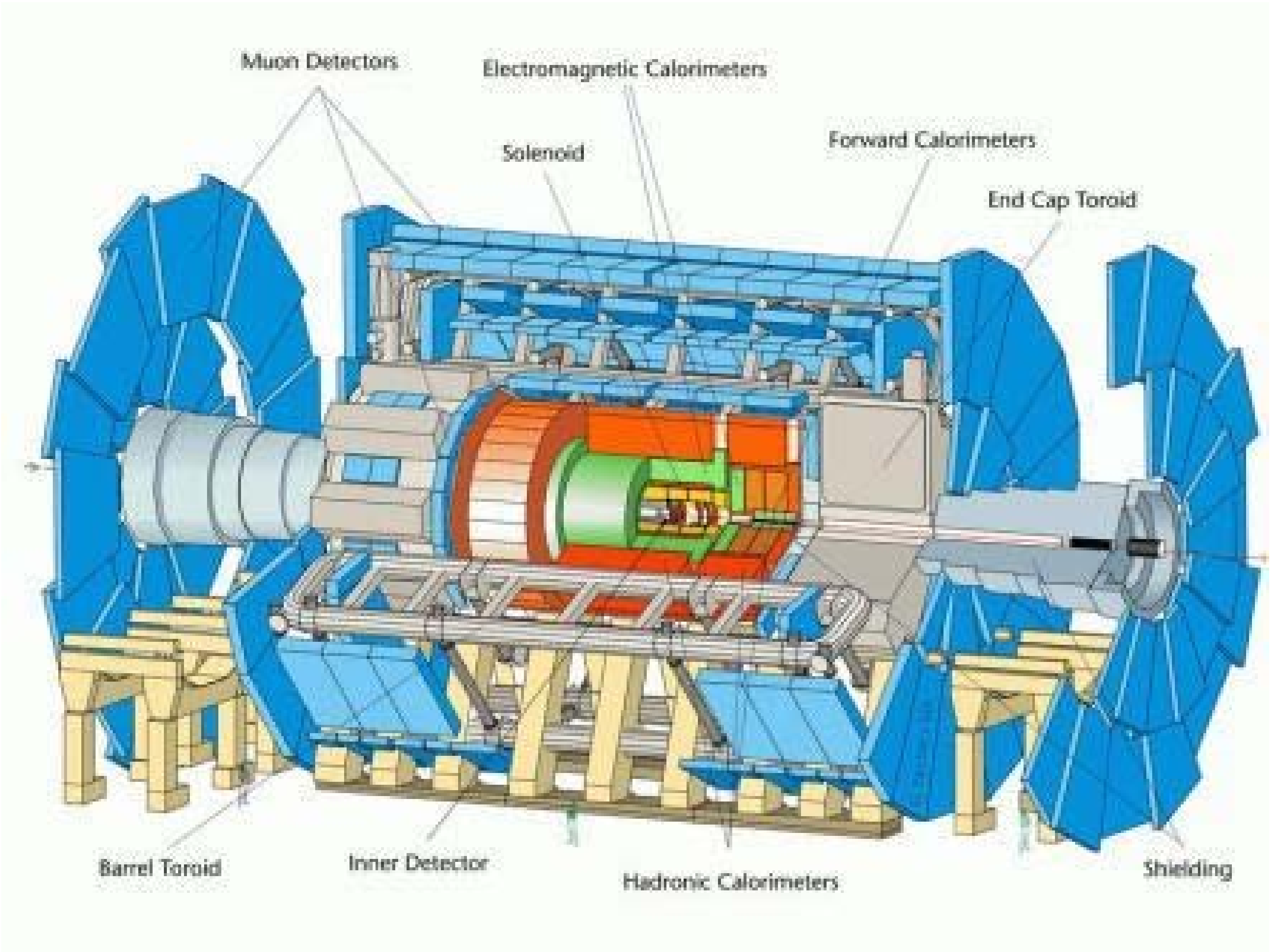


And for heavy Higgs branching ratios to WW, ZZ and tt become dominant.

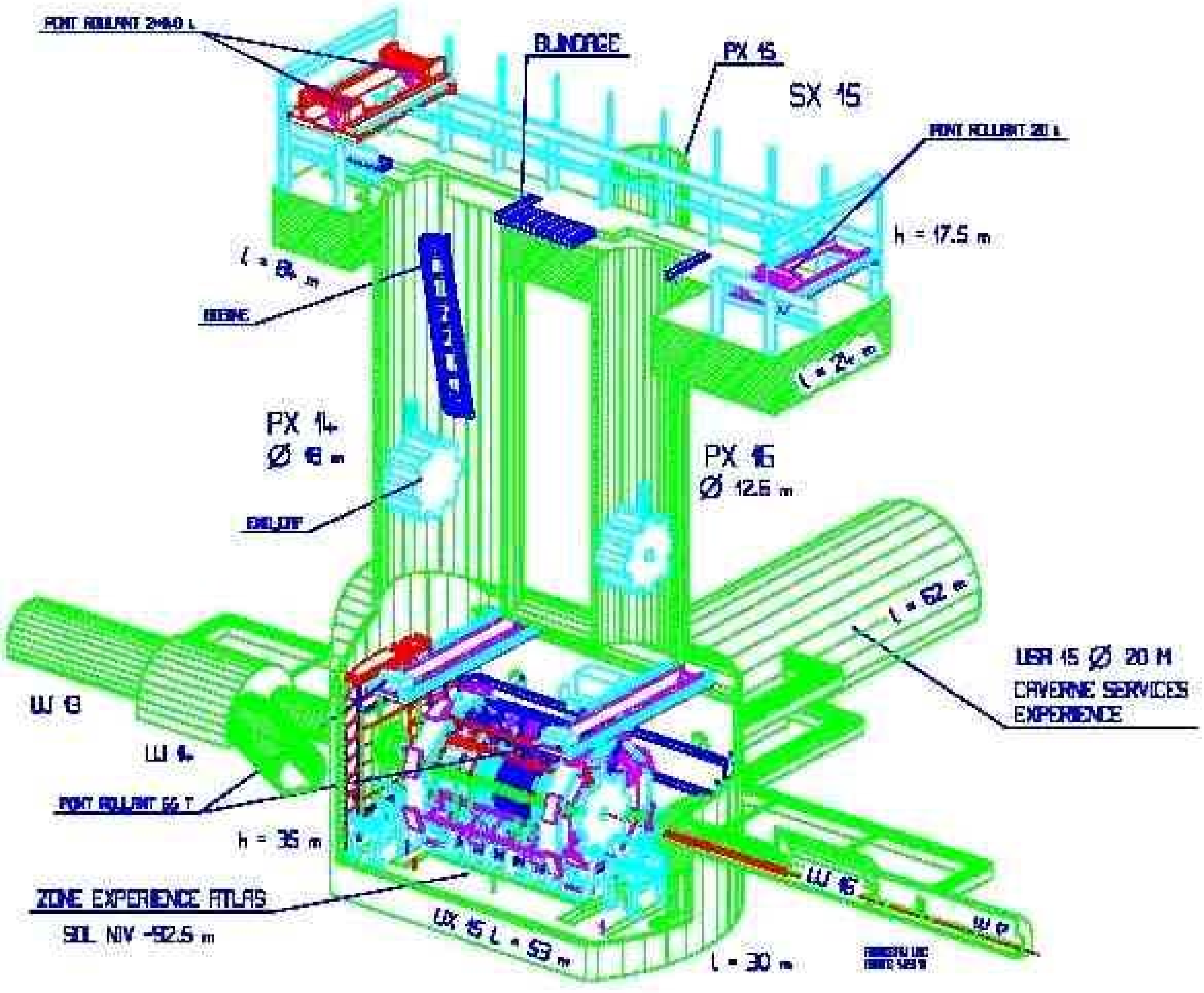


A caveat: tiny window for $\gamma\gamma$,$Z\gamma$ channels.

In 1998 I was summoned to the LHC-C Our charges were checking that the then current designs had no loopholes, my chief concern was ATLAS, 45meters $\times$ 25 meters, 7000 tons



I descended the cavern, much deeper than CUSB's



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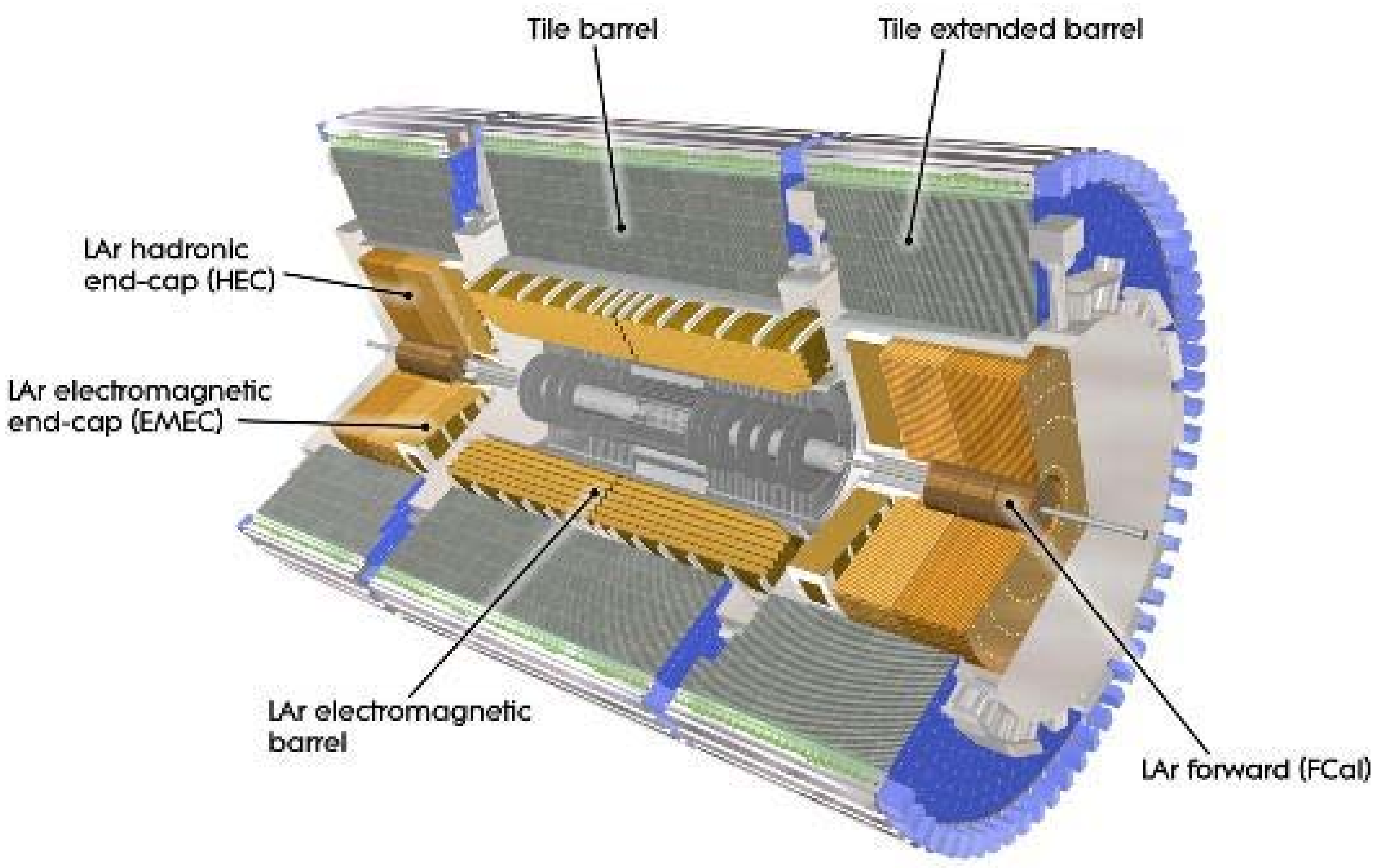
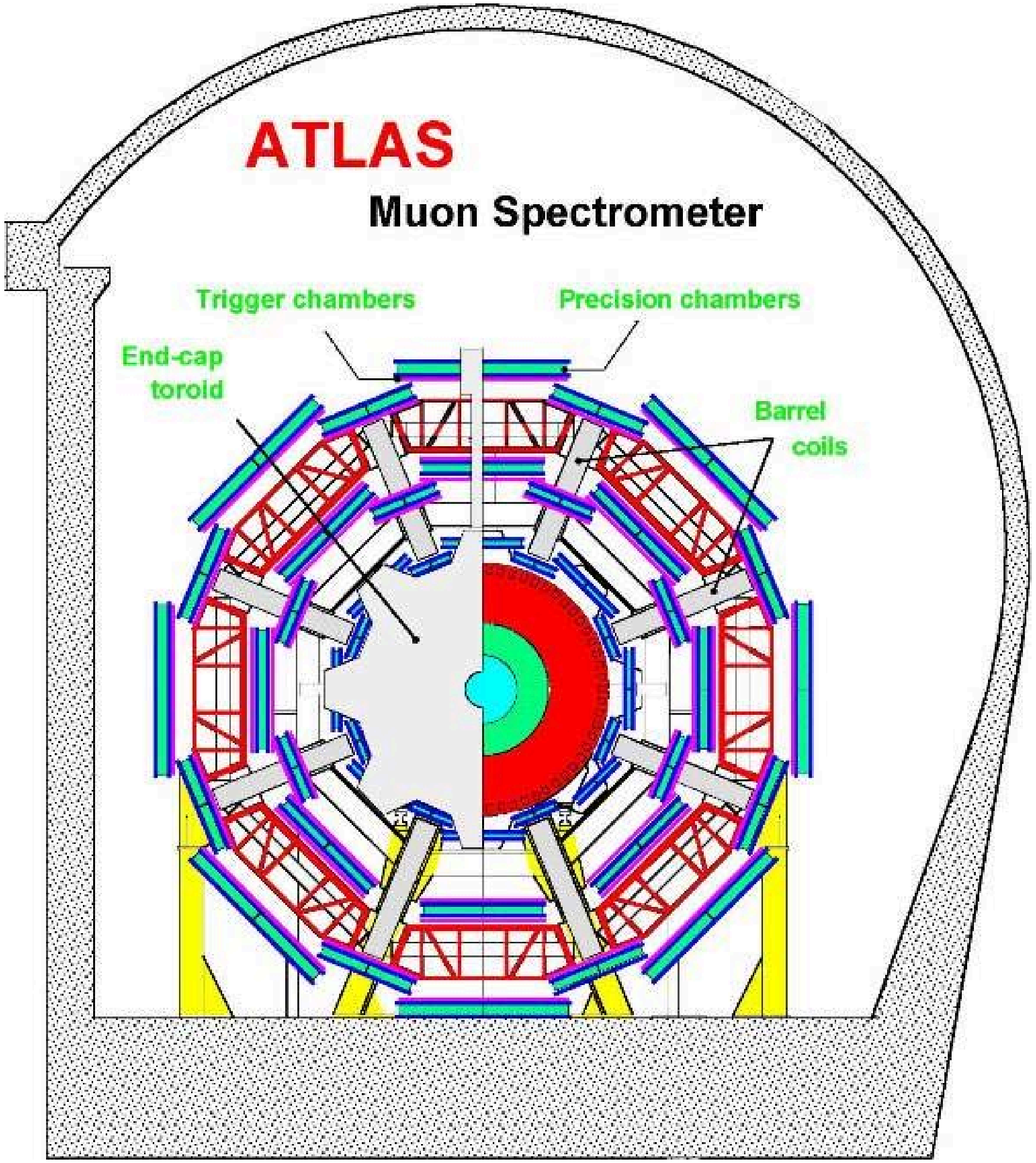
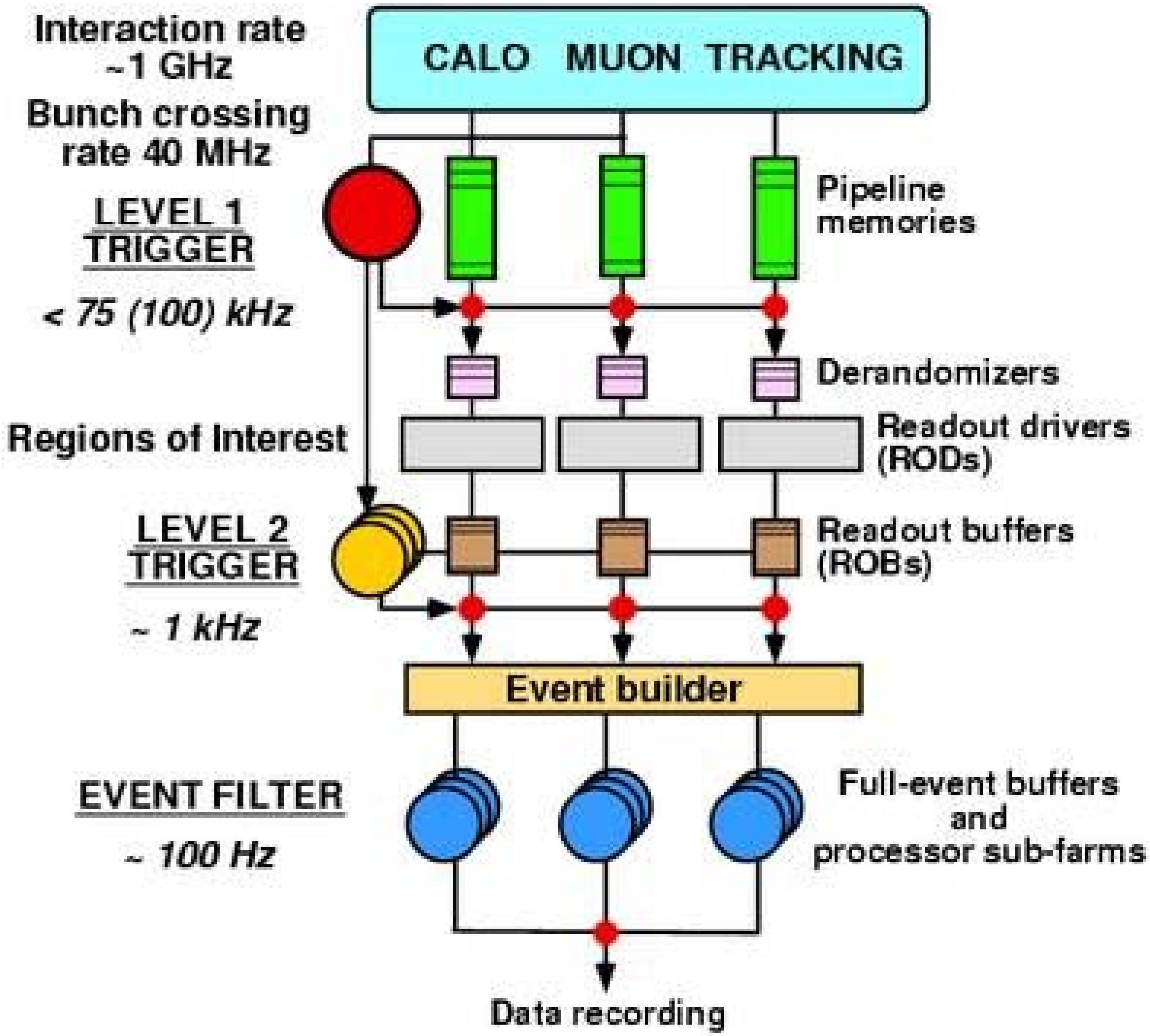
With my past experience at DØ, I was especially intrigued with the em accordion liquid argon calorimeter



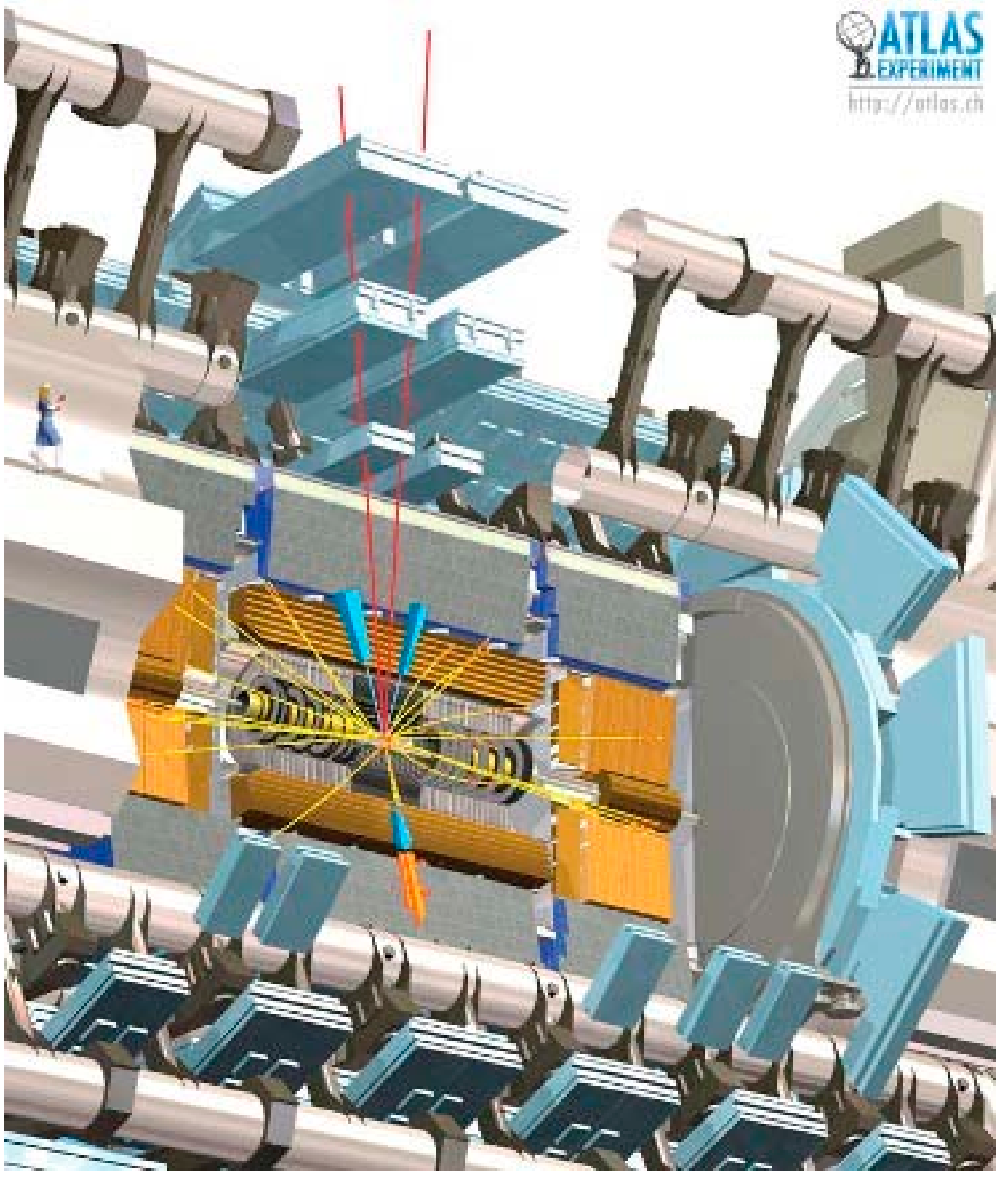
And having seen LNF's and BU's constructions, also the muon system.



I watched with great interest the then nascent trigger development:

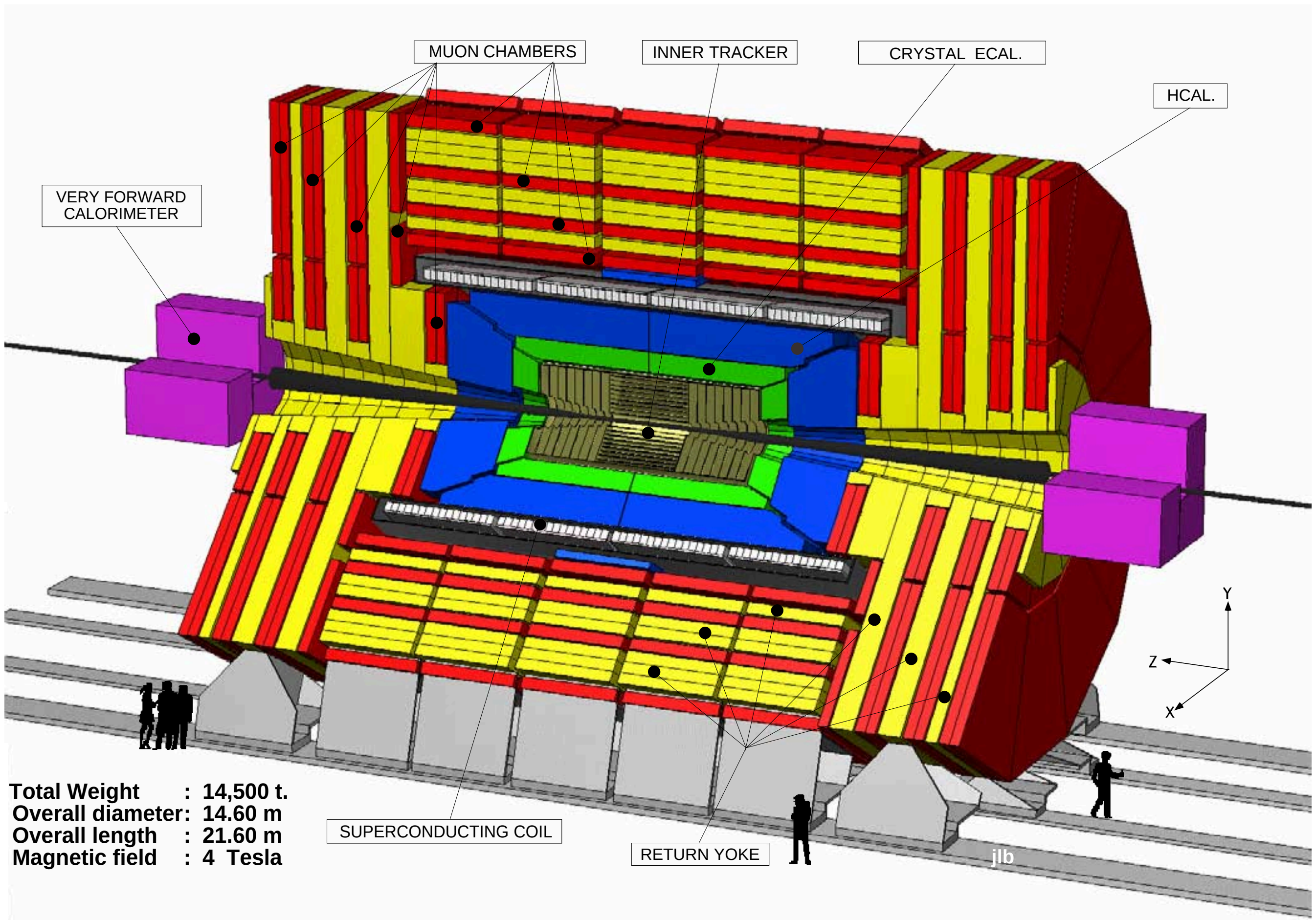


as well as the simulation efforts



In 2001 when we, my LHCC-ohorts, were visiting CMS, I heard a voice from on top of the detector calling me: it was Richard Loveless from Wisconsin, my SB-PhD-1969!

CMS
Compact Muon Solenoidal Detector for LHC



In 2007, Meenakshi Narain moved to Brown University and joined CMS. As you heard from her talk, the simplest Higgs decay event in CMS could look like the following