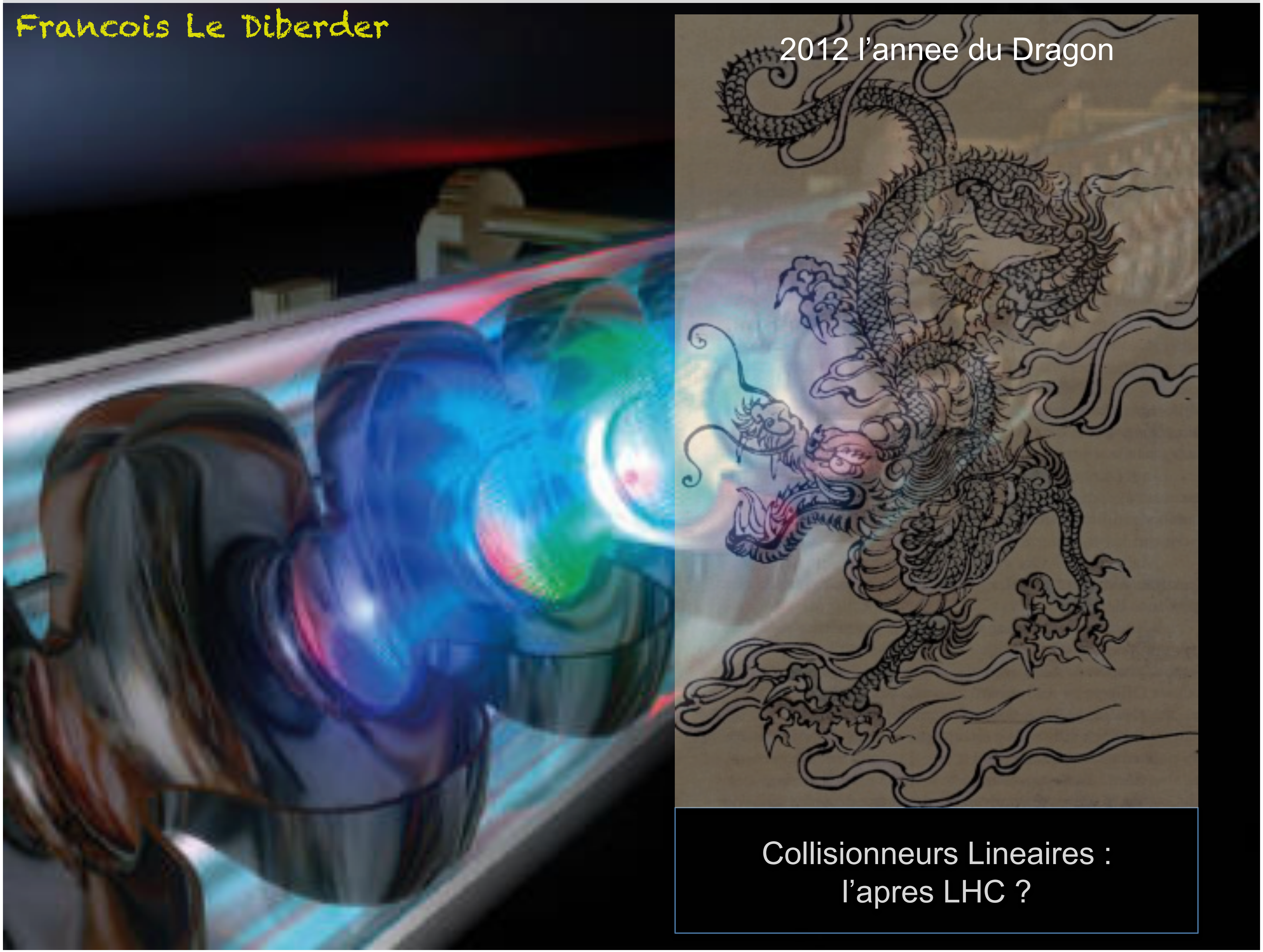
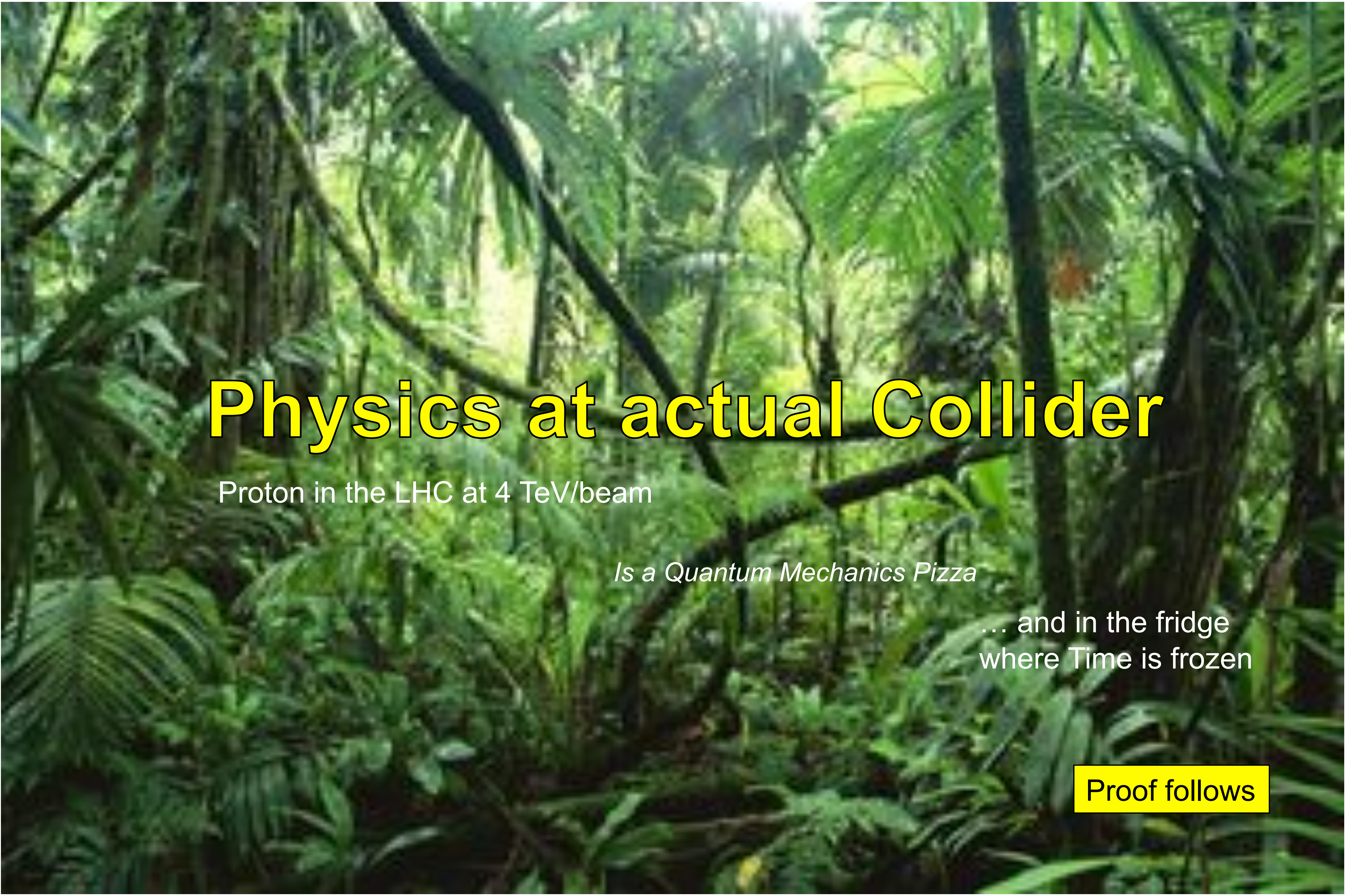
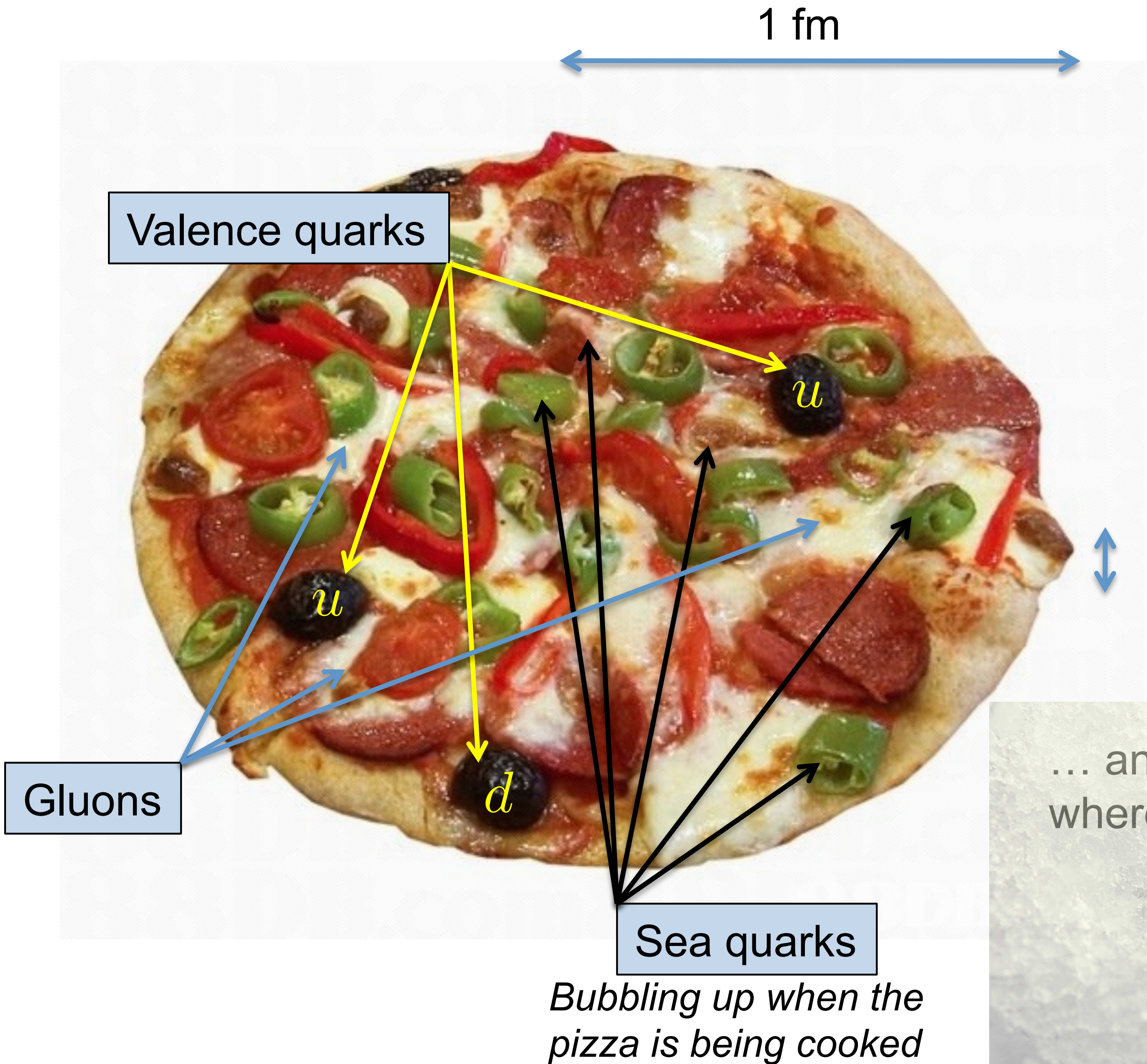


Francois Le Diberder
2012 l'annee du Dragon
Collisionneurs Lineaires :
l'apres LHC ?


Physics at actual Collider
Proton in the LHC at 4 TeV/beam
Is a Quantum Mechanics Pizza
… and in the fridge
where Time is frozen
Proof follows

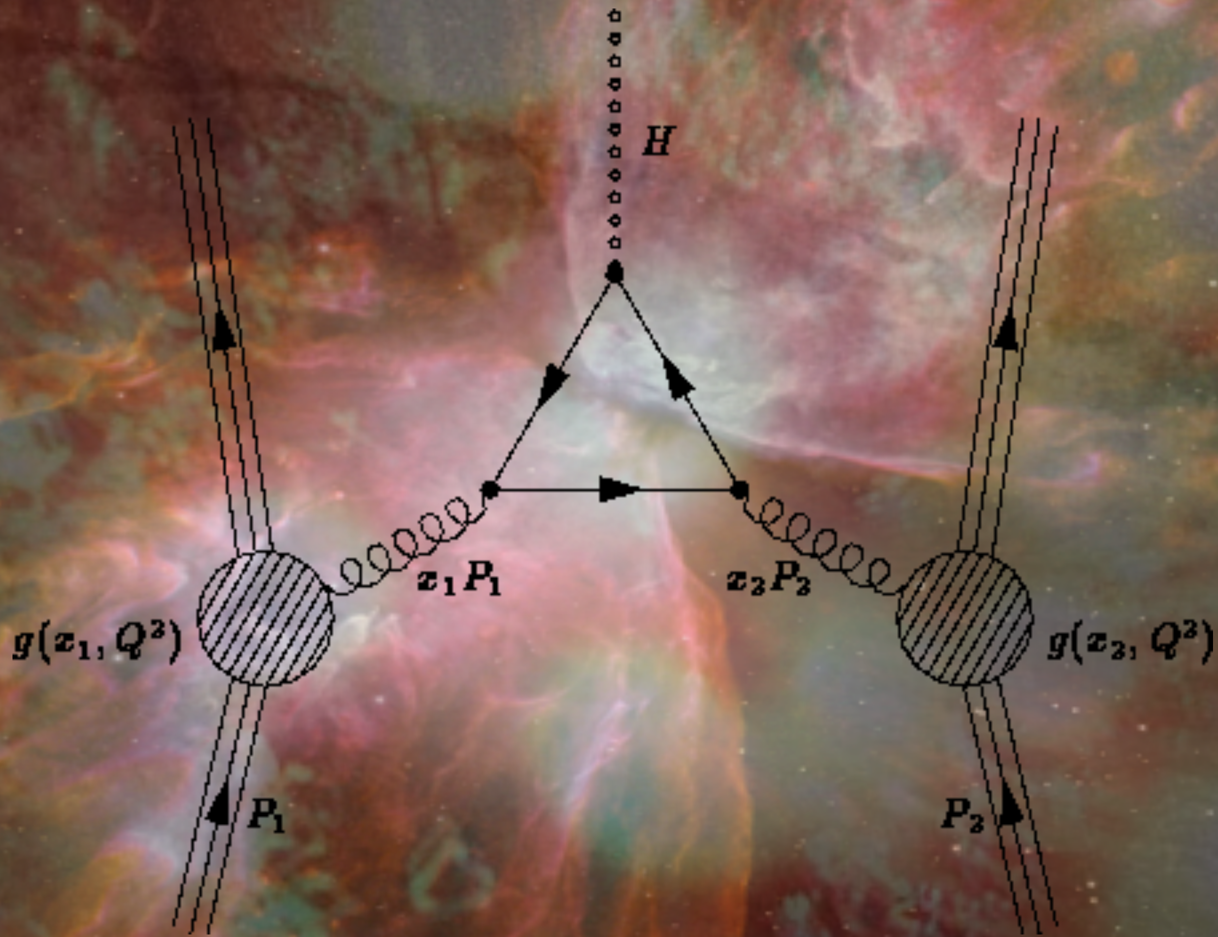
Proton in the LHC at 4 TeV/beam *Is a Quantum Mechanics Pizza*





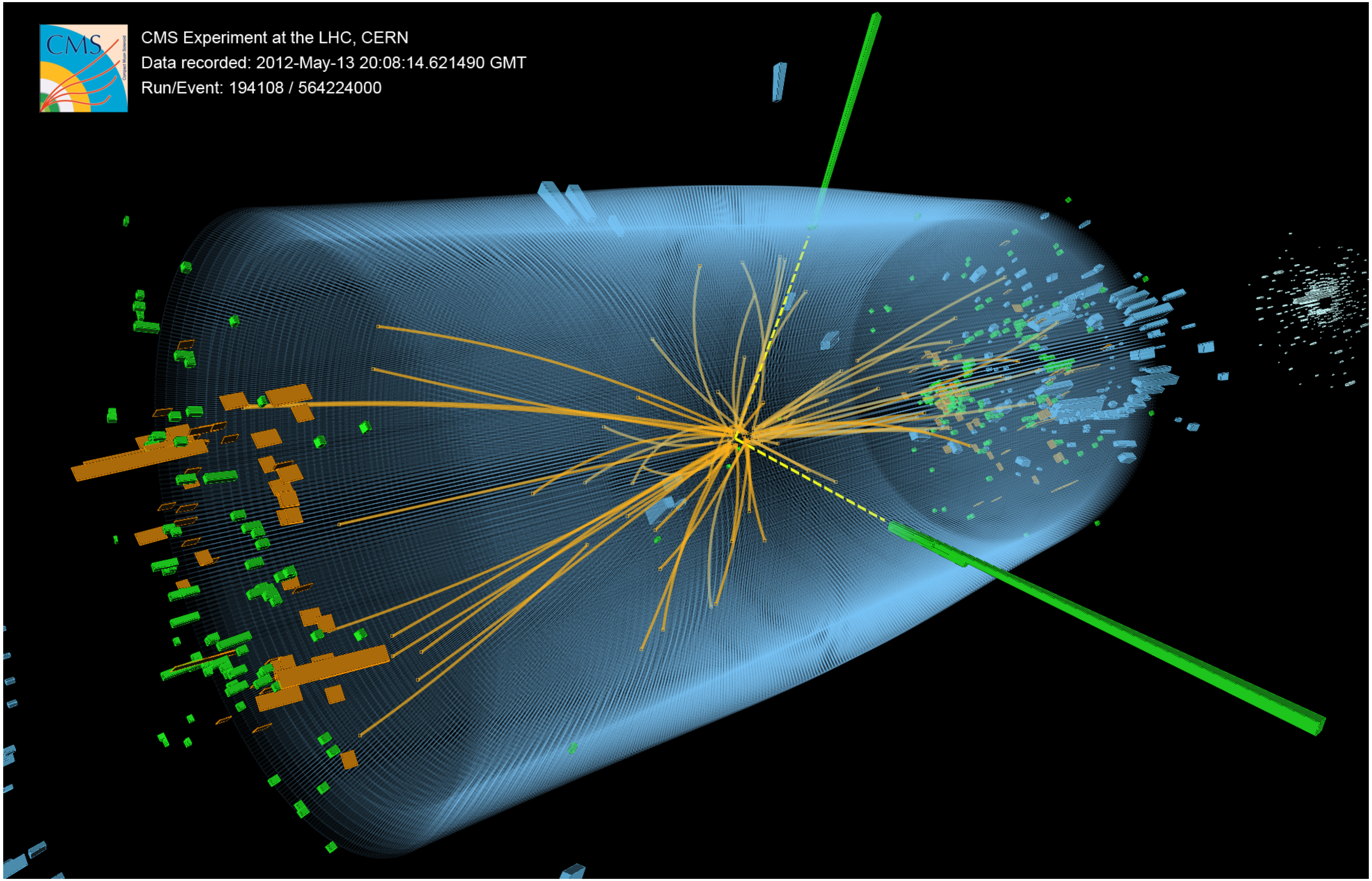
Pizza Pizza collisions

When two pizzas touch : they interact (violently)
the total cross-section is close to the geometrical cross-section



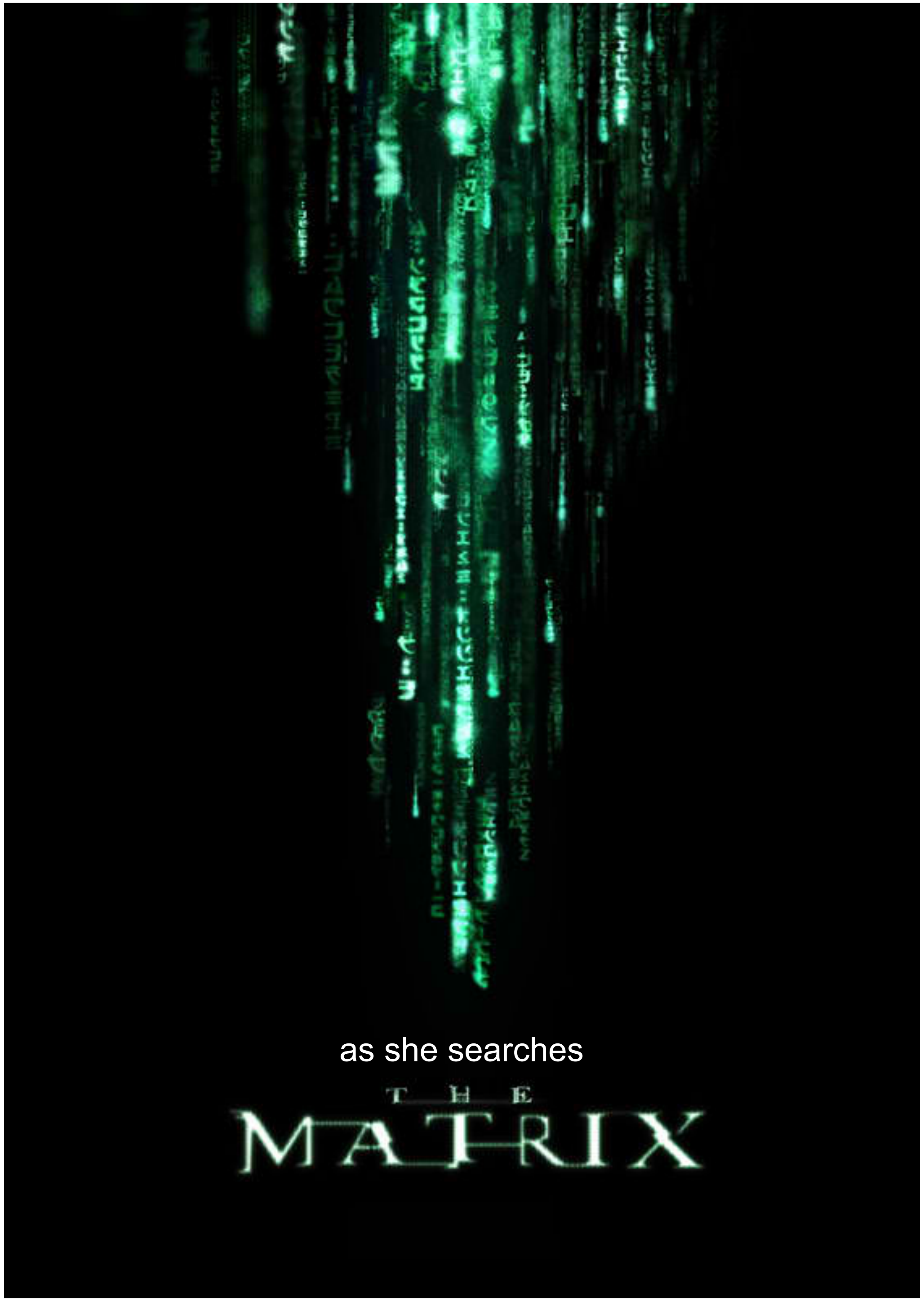

**A rare pizza-pizza collision**
**where a "hard" scattering took place**

How an event looks like, one properly massaged to please the eyes




For the physicist it looks much less simple

For the PhD student it looks like an hopeless hyperbunch of raining numbers she has to crunch endlessly on the Grid

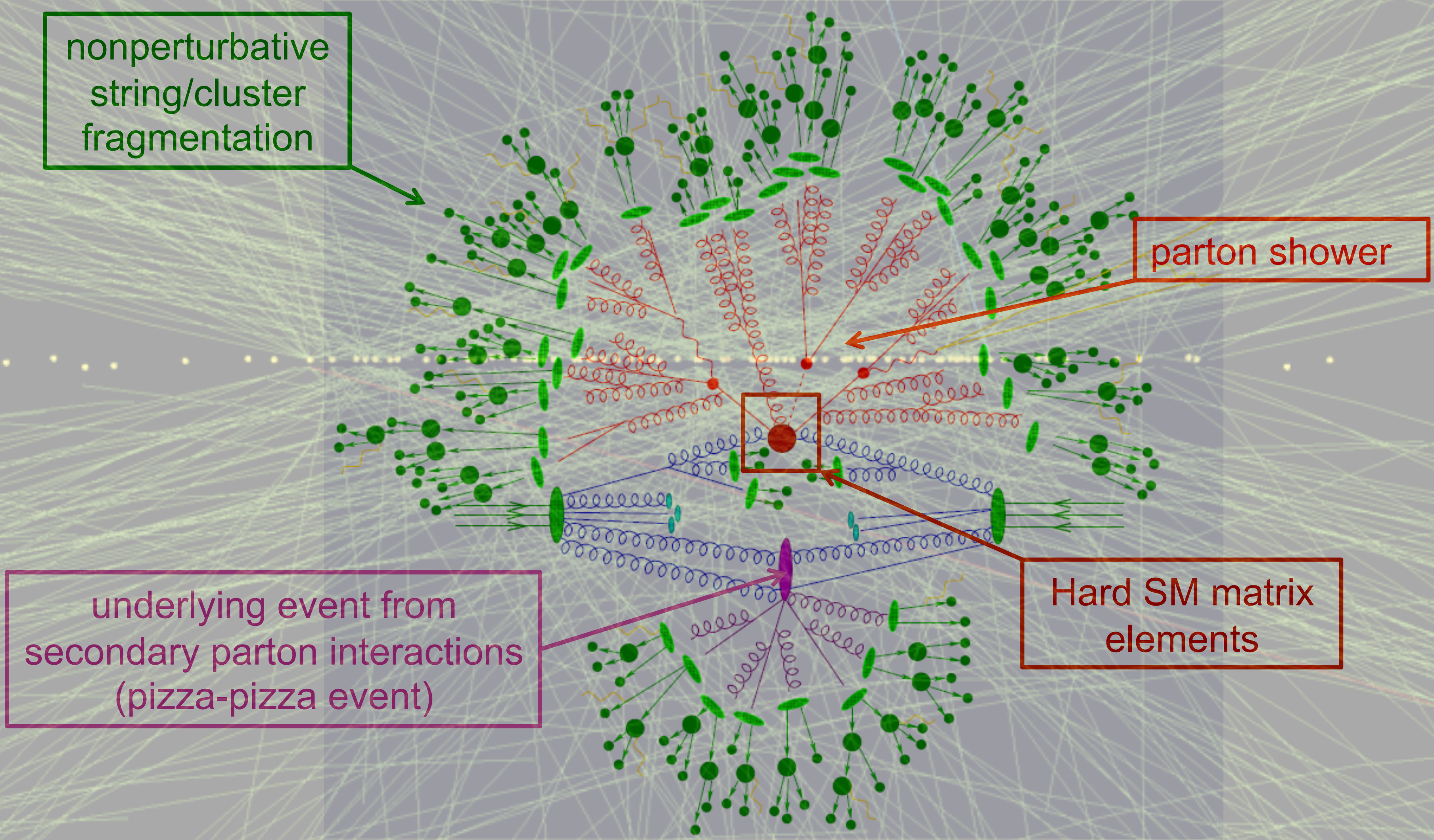


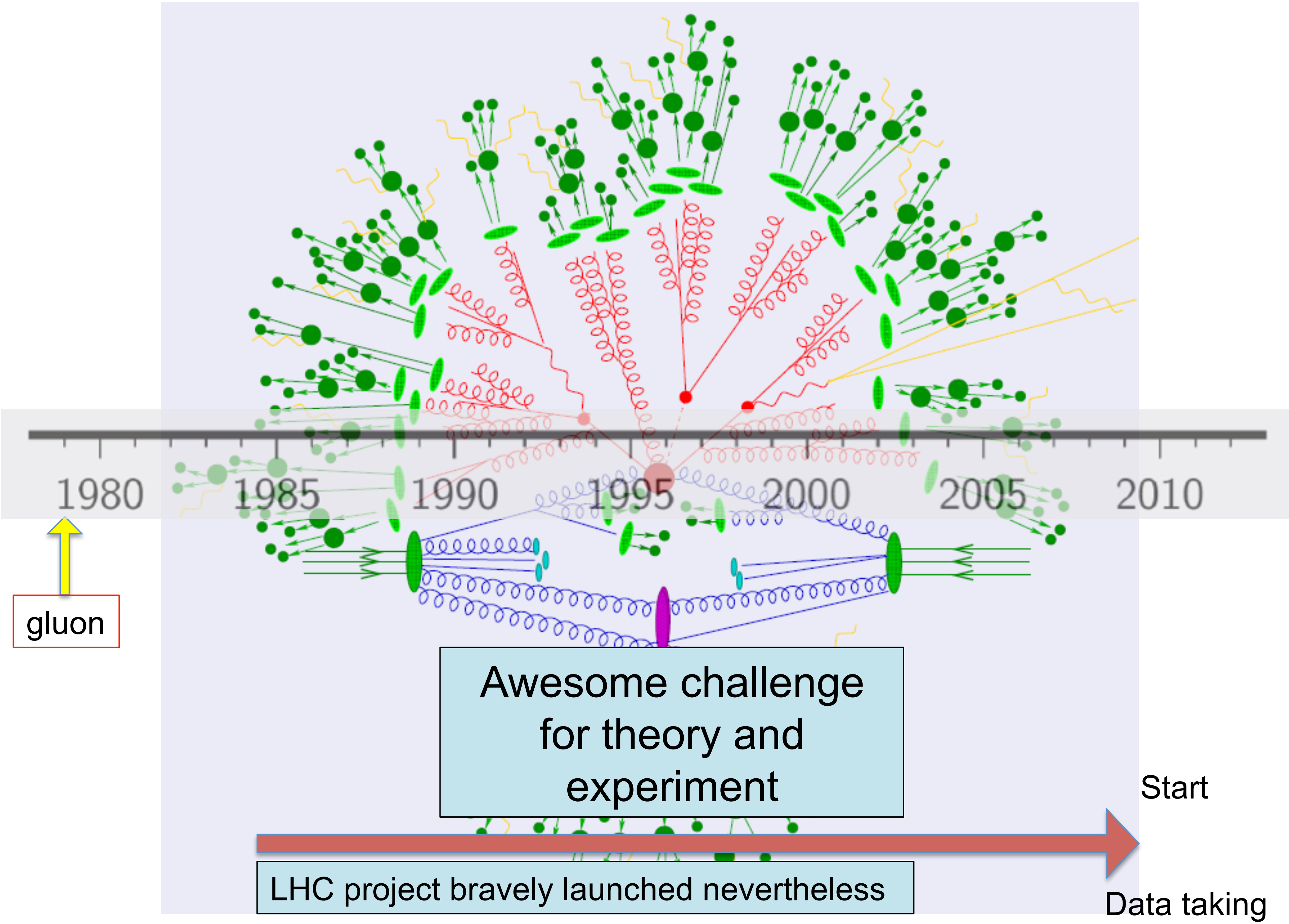

as she searches

that will help her to invert the detector and pizza effects

**to reach Physics**

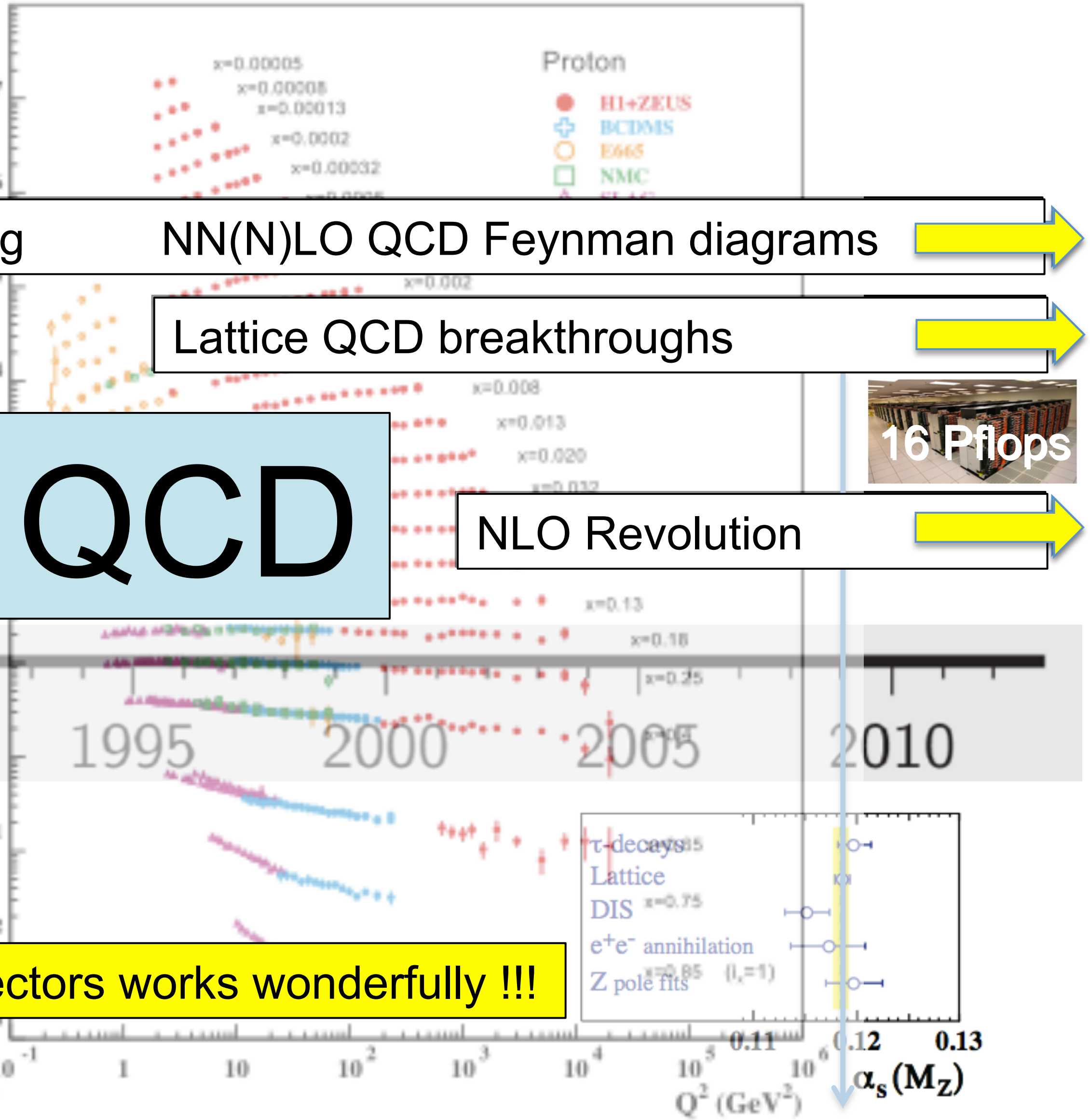
# “Typical” hadron collider event




1980
1985
1990
1995
2000
2005
2010
gluon
Awesome challenge for theory and experiment
Start
Data taking
LHC project bravely launched nevertheless

✦ uncertainties from scale variation and PDF+strong coupling

| | | σ (8 TeV) | uncertainty |
|---|---|---|---|
| NNLL QCD +NLO EW | gg→H | 19.5 pb | 14.7% |
| | VBF | 1.56 pb | 2.9% |
| NNLO QCD +NLO EW | WH | 0.70 pb | 3.9% |
| | ZH | 0.39 pb | 5.1% |
| NLO QCD | ttH | 0.13 pb | 14.4% |




Cracking

NN(N)LO QCD Feynman diagrams

Lattice QCD breakthroughs

# Mastering QCD

NLO Revolution

1980 1985 1990 1995 2000 2005 2010

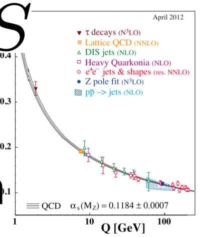
gluon

Machine and detectors works wonderfully !!!

$\alpha_S$

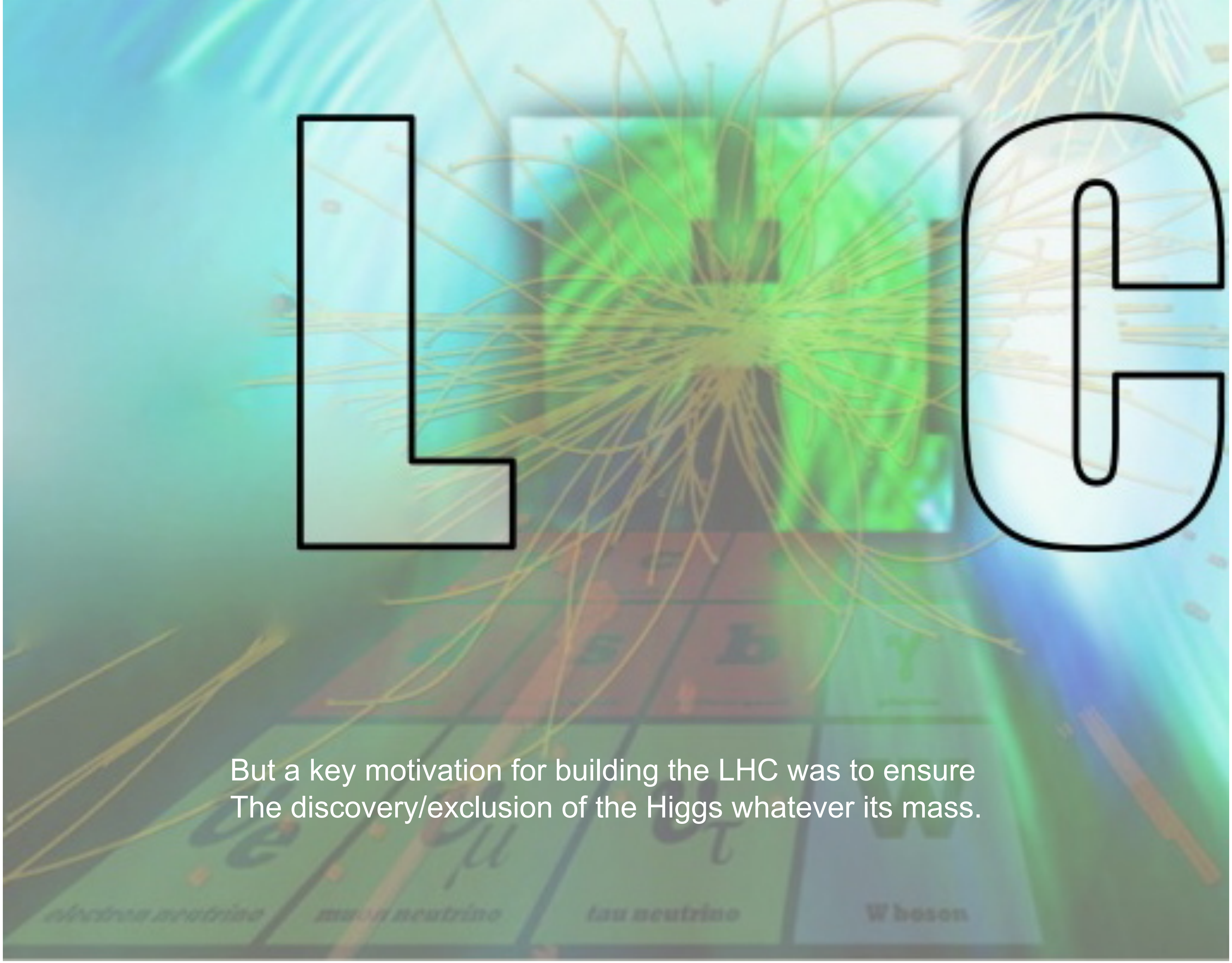
$\alpha_S$

$$\alpha_s(M_Z^2) = 0.11844 \pm 0.00059$$



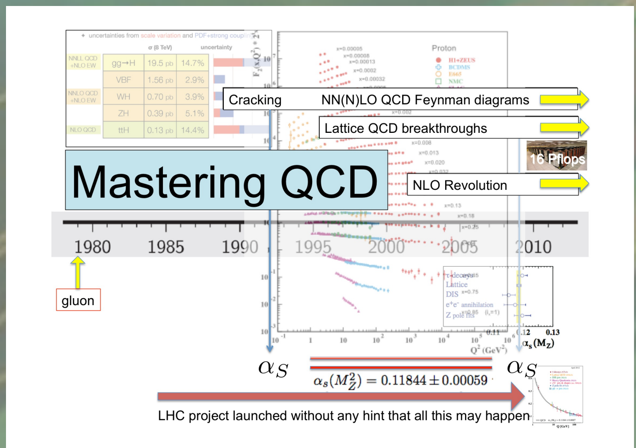

LHC project launched without any hint that all this may happen


LHC pushing the limits on new phenomena BSM
ATLAS SUSY Searches* - 95% CL Lower Limits (Status: ICHEP 2012)
ATLAS
Preliminary
Mass scale [TeV]
With an unexpected strenght
so far no big surprise, to our big disappointment

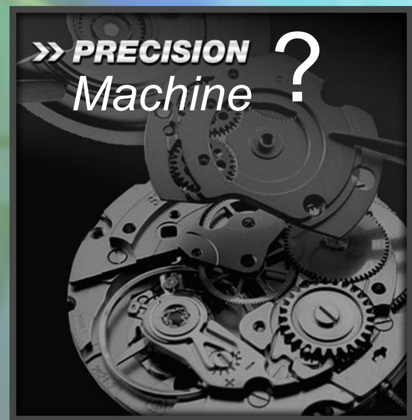


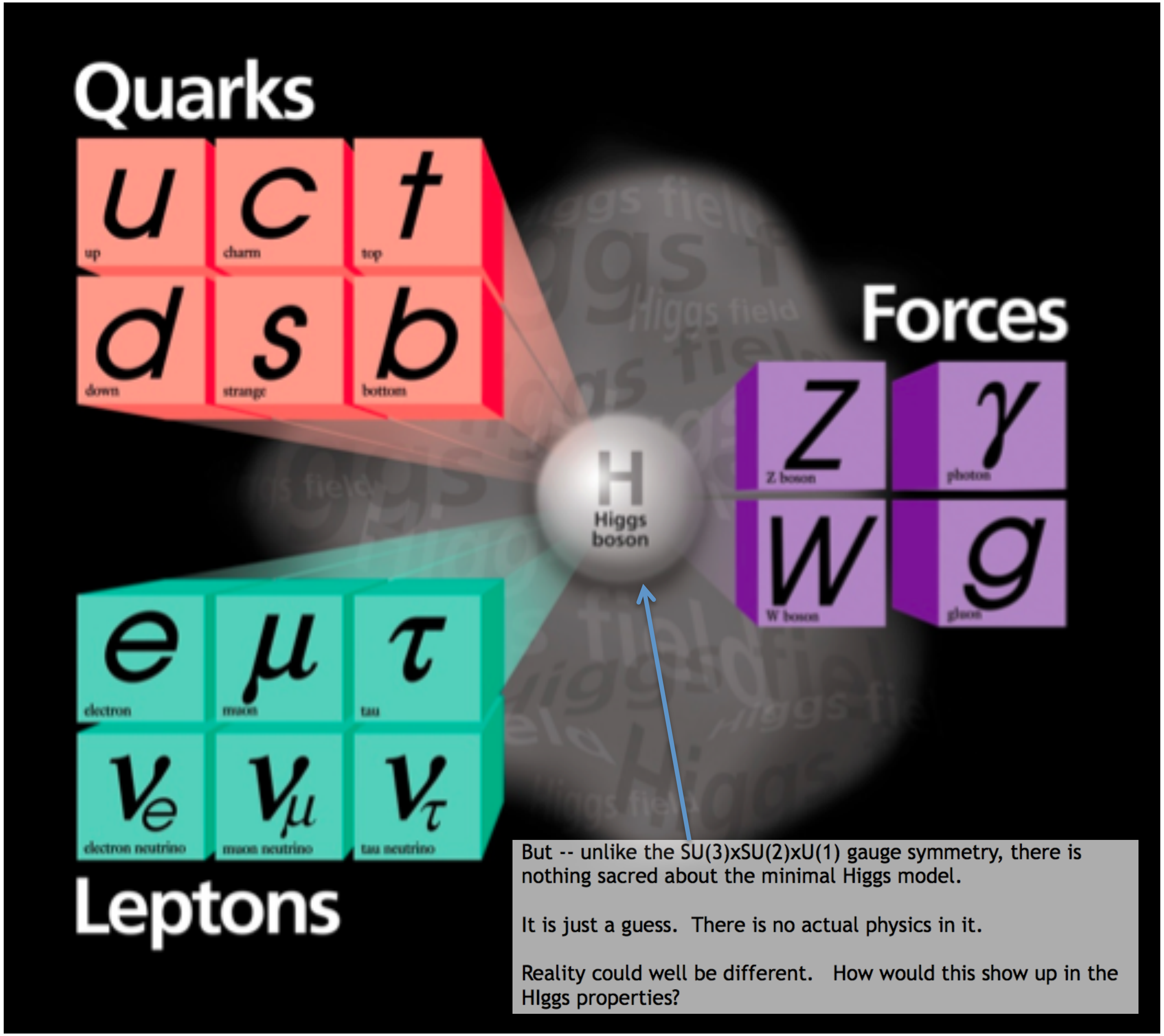

But a key motivation for building the LHC was to ensure
The discovery/exclusion of the Higgs whatever its mass.

# LHC



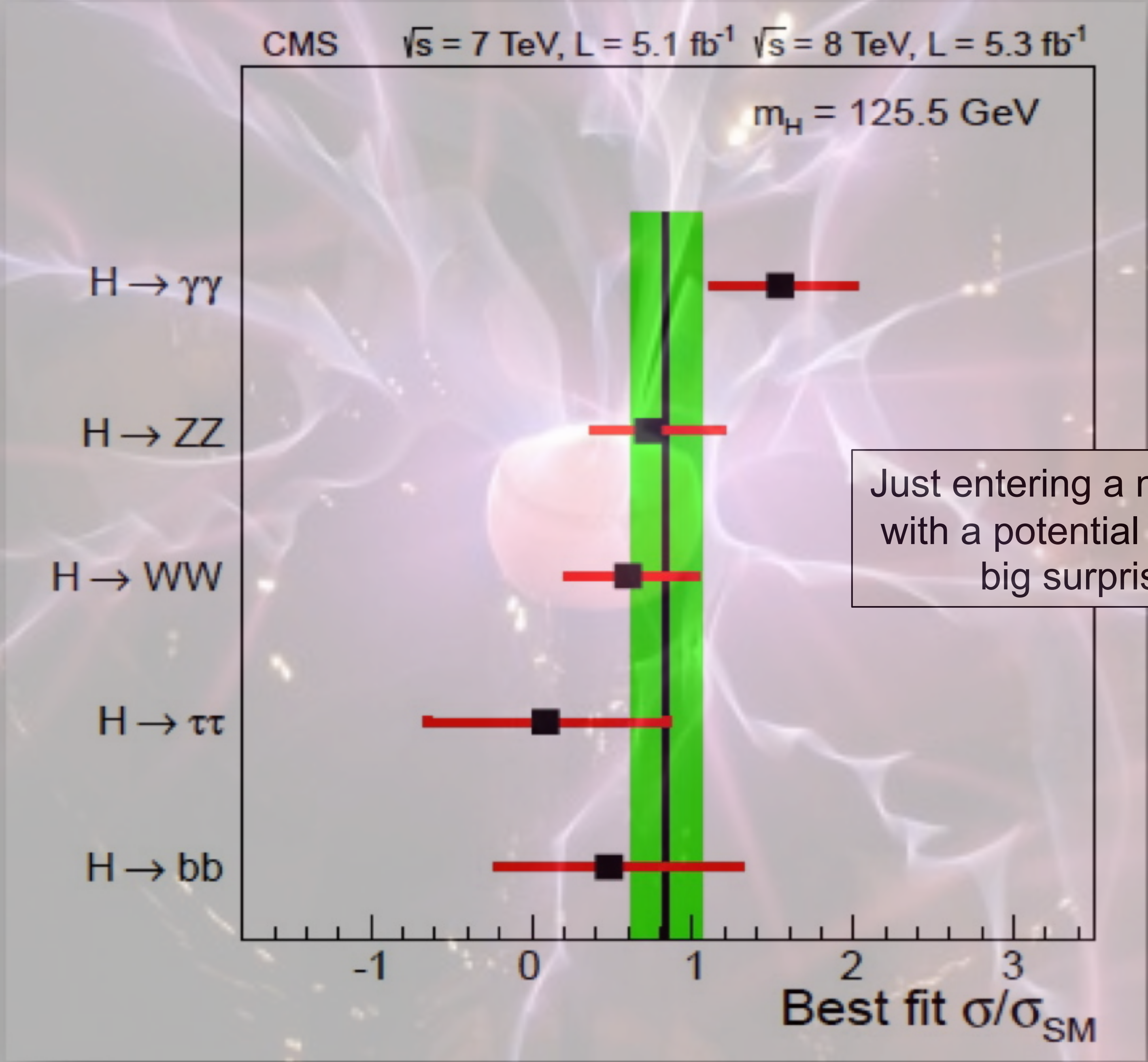

- Now 7 but 13 TeV soon
- Higher Luminosity
- Detectors upgrades
- Know how improving





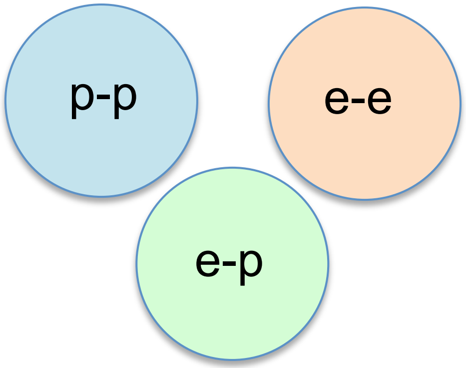
Quarks
u
up
c
charm
t
top
d
down
s
strange
b
bottom
Forces
Z
Z boson
γ
photon
W
W boson
g
gluon
H
Higgs boson
e
electron
μ
muon
τ
tau
$\nu_e$
electron neutrino
$\nu_\mu$
muon neutrino
$\nu_\tau$
tau neutrino
Leptons
But -- unlike the SU(3)xSU(2)xU(1) gauge symmetry, there is nothing sacred about the minimal Higgs model.
It is just a guess. There is no actual physics in it.
Reality could well be different. How would this show up in the HIggs properties?


We should stay open-minded and filled with
intense curiosity:
Exploration of Planet Higgs just began.




Just entering a new world
with a potential for many
big surprises

## Three types of machines, so far

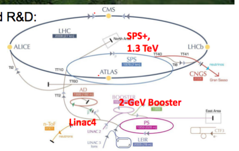




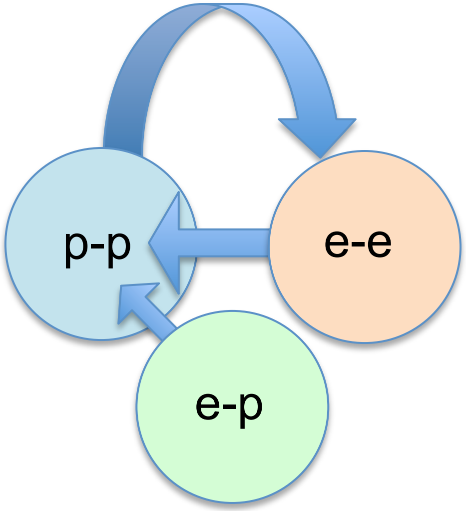
History tought us that the interplay between
p-p & e-e & e-p colliders is intrumental
in allowing progresses
in our understanding of Physics

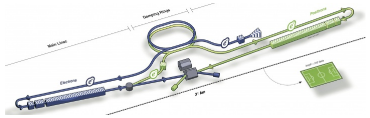
The future must be prepared well in advance

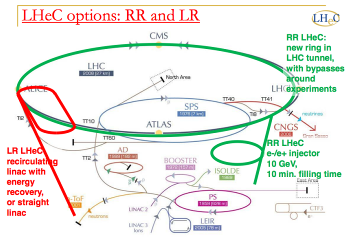
HE-LHC – main Issues and R&D:




- High-field 20T dipole magnets based on $Nb_3Sn$, $Nb_3Al$, and HTS
- High-gradient quadrupole magnets for arc and IR
- Fast cycling SC magnets for ~1.3 TeV injector
- Emittance control in regime of strong SR damping and IBS
- Cryogenic handling of SR heat load (first analysis; looks manageable)
- Dynamic vacuum

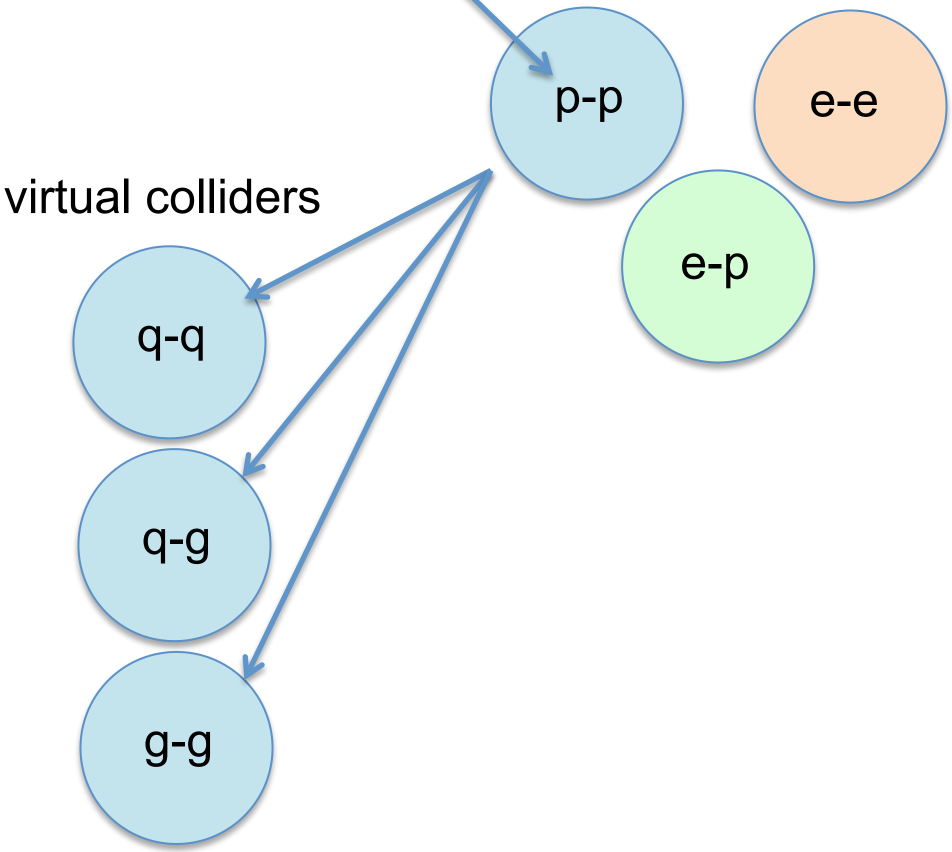


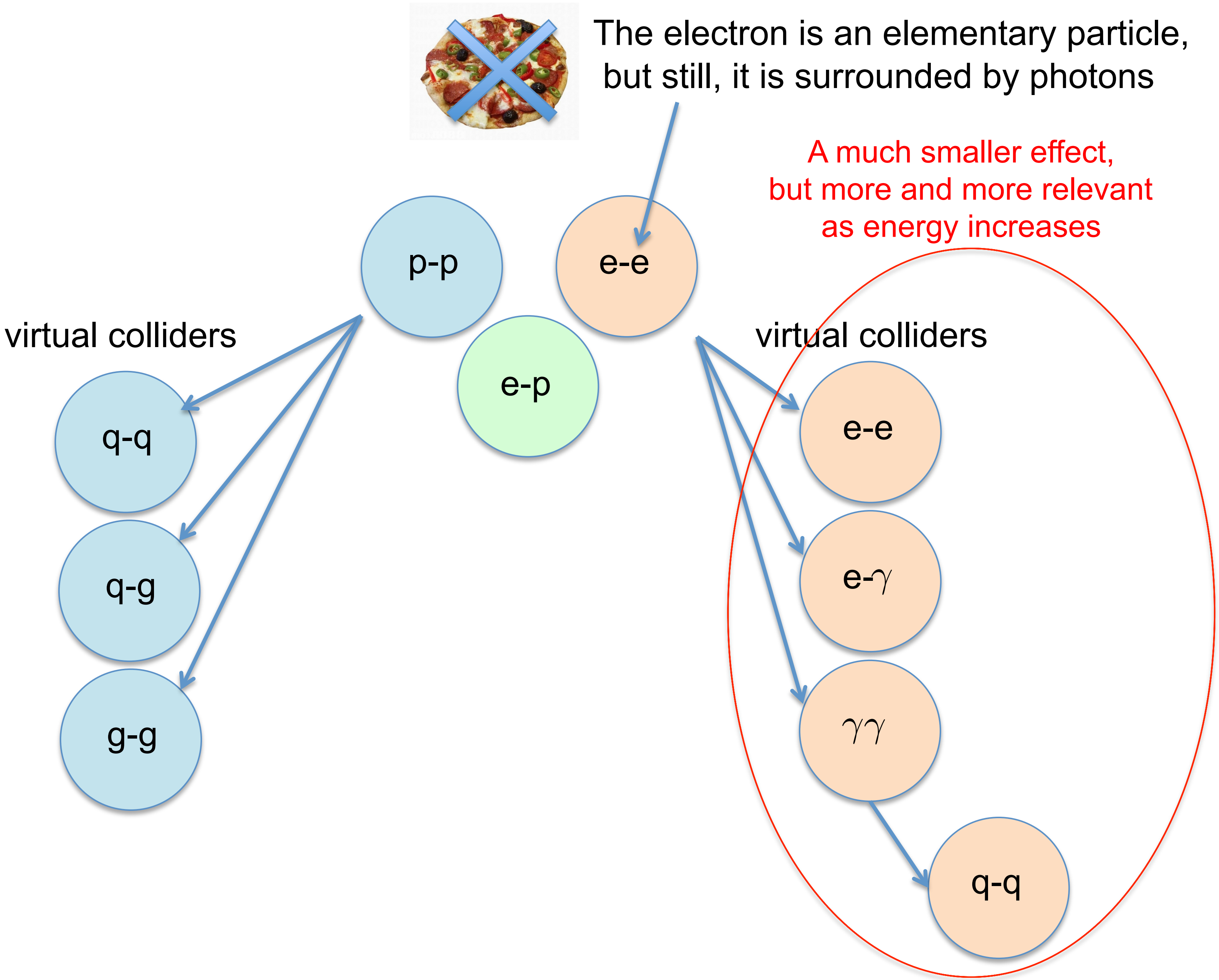




History tought us that the interplay between
p-p & e-e & e-p colliders is intrumental
in allowing progresses
in our understanding of Physics

The proton is not an elementary particle




The electron is an elementary particle,
but still, it is surrounded by photons
A much smaller effect,
but more and more relevant
as energy increases
p-p
e-e
e-p
virtual colliders
q-q
q-g
g-g
virtual colliders
e-e
e-$\gamma$
$\gamma\gamma$
q-q

# Muon Collider Conceptual Layout

Serious thoughts on the Next-to-Next Possible colliders started long ago: where US are betting for the long term.

**Project X**
Accelerate hydrogen ions to 8 GeV using SRF technology.

**Compressor Ring**
Reduce size of beam.

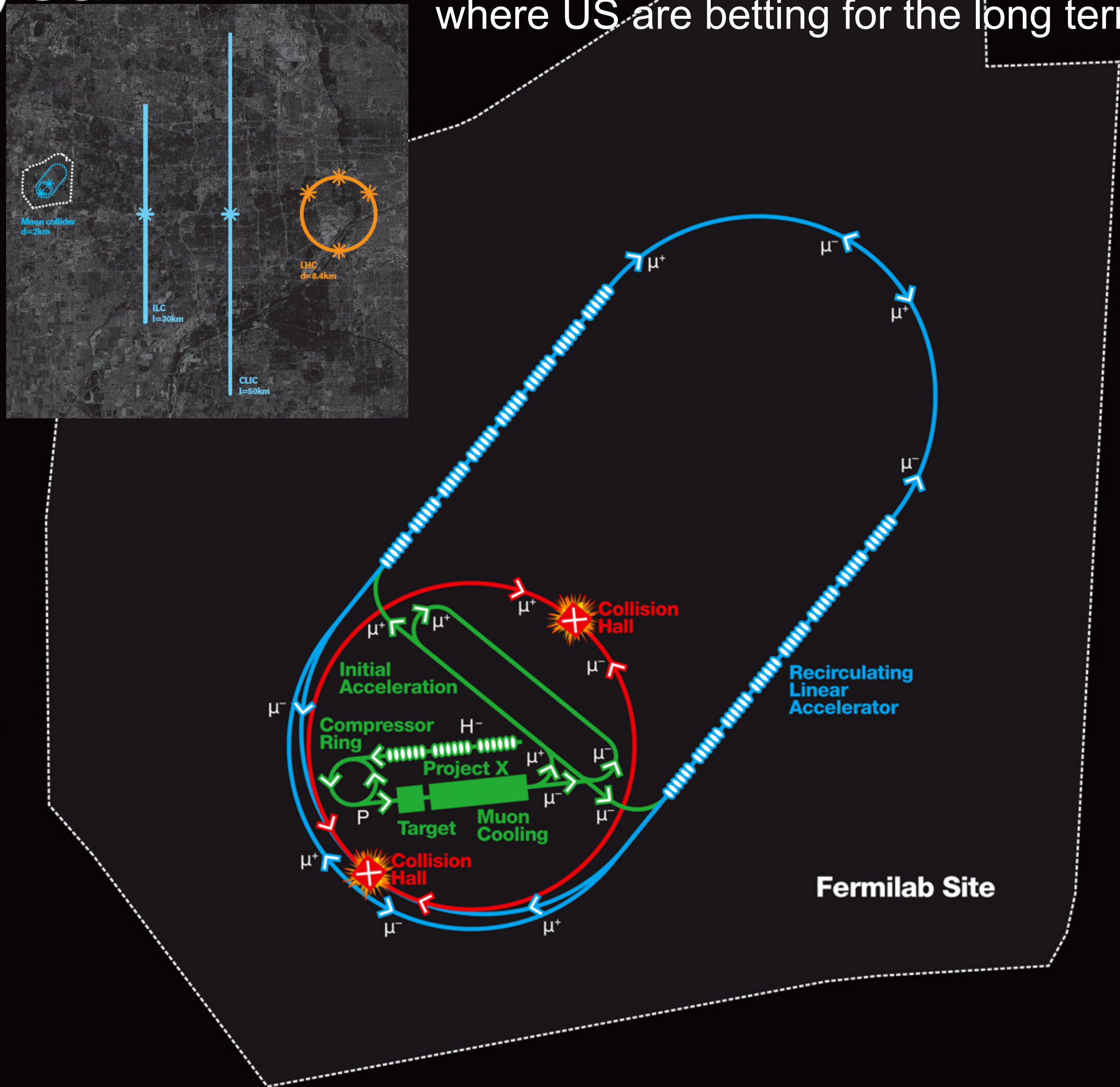
**Target**
Collisions lead to muons with energy of about 200 MeV.

**Muon Capture and Cooling**
Capture, bunch and cool muons to create a tight beam.

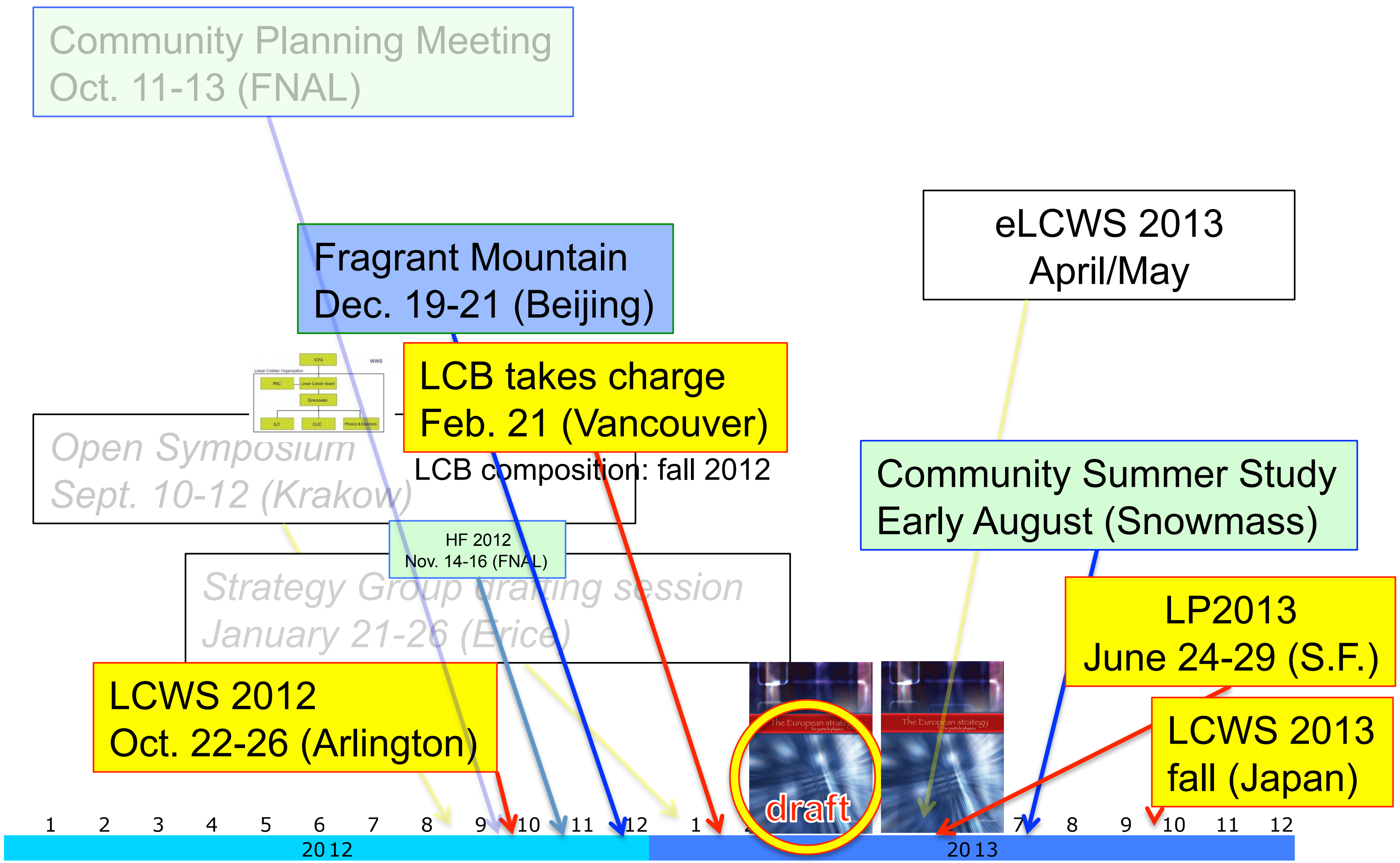
**Initial Acceleration**
In a dozen turns, accelerate muons to 20 GeV.

**Recirculating Linear Accelerator**
In a number of turns, accelerate muons up to 2 TeV using SRF technology.

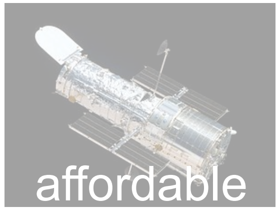
**Collider Ring**
Bring positive and negative muons into collision at two locations 100 meters underground.



# Timeline for HEP Global roadmap: 12 busy months ahead



# The dream-machine




flexibility

Clean Luminosity


Mature technology

$SU(2)_L$

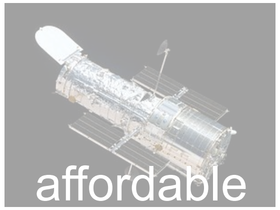
Full SM reach

# The dream-machine

e-e collider

flexibility

Clean Luminosity





Mature technology

$SU(2)_L$

Full SM reach

e-e collider

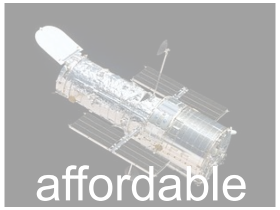
# The dream-machine

LC collider

flexibility

e-e collider

Clean Luminosity





Mature technology

LC collider

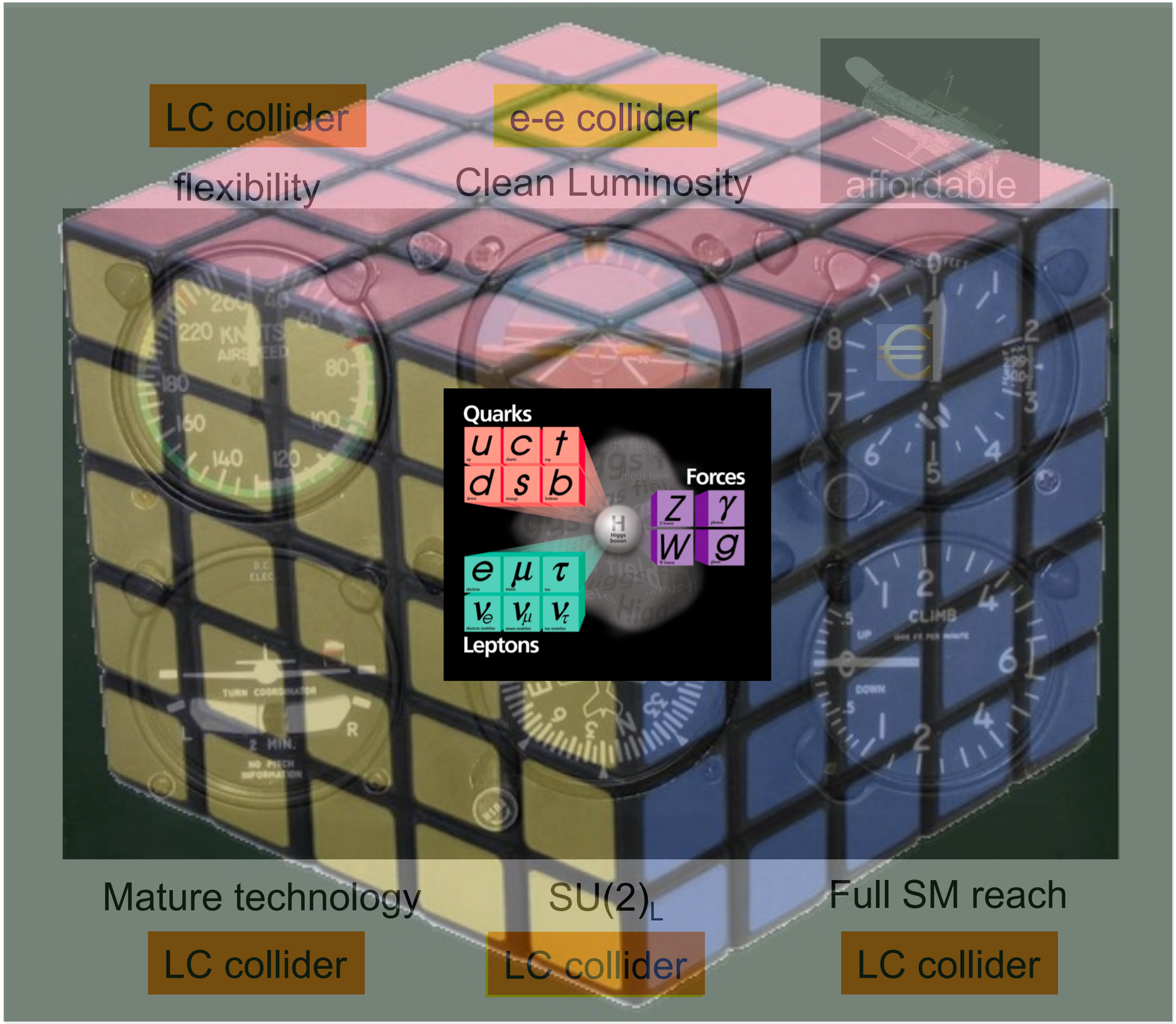
$SU(2)_L$

LC collider

Full SM reach

LC collider

# The dream-machine



# The dream-machine

LC collider

flexibility

e-e collider

Clean Luminosity



Mature technology

LC collider

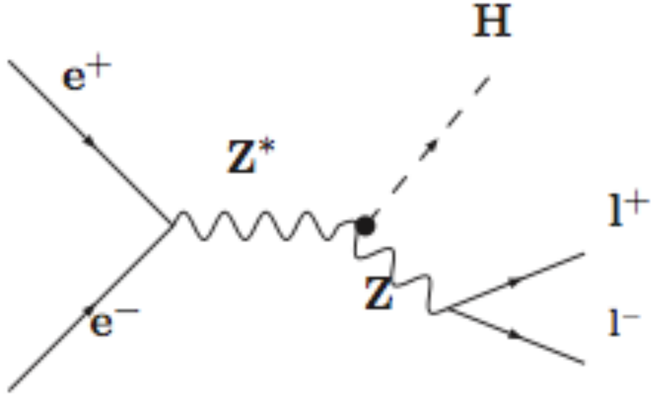
$SU(2)_L$

LC collider

Full SM reach

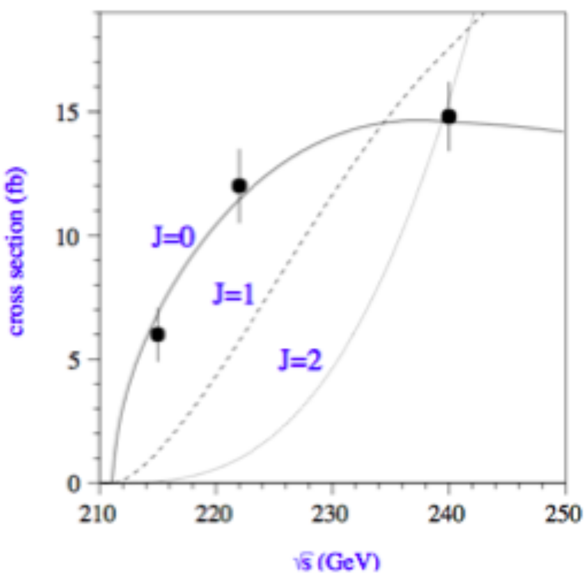
LC collider

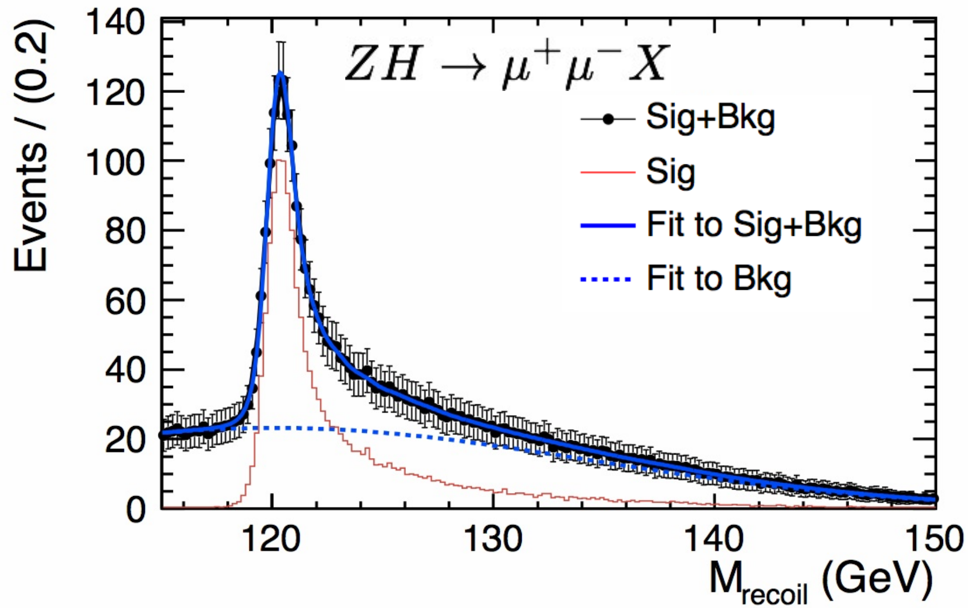
## Higgs-strahlung Process:




$$M_H^2 = (\sqrt{s} - E_Z)^2 - P_Z^2$$

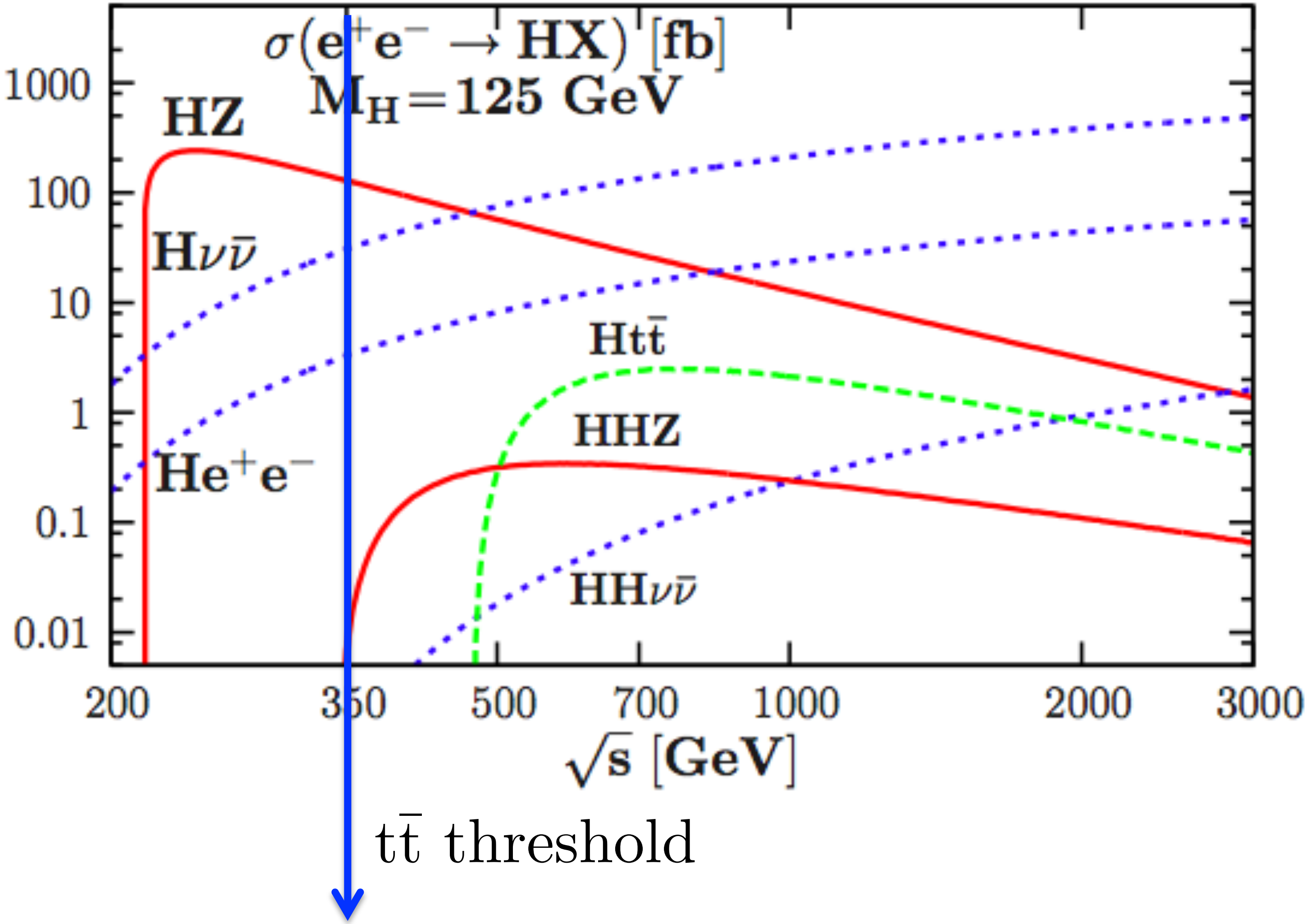
$$g_{ZZH}^2 \propto \sigma = N/L\epsilon$$



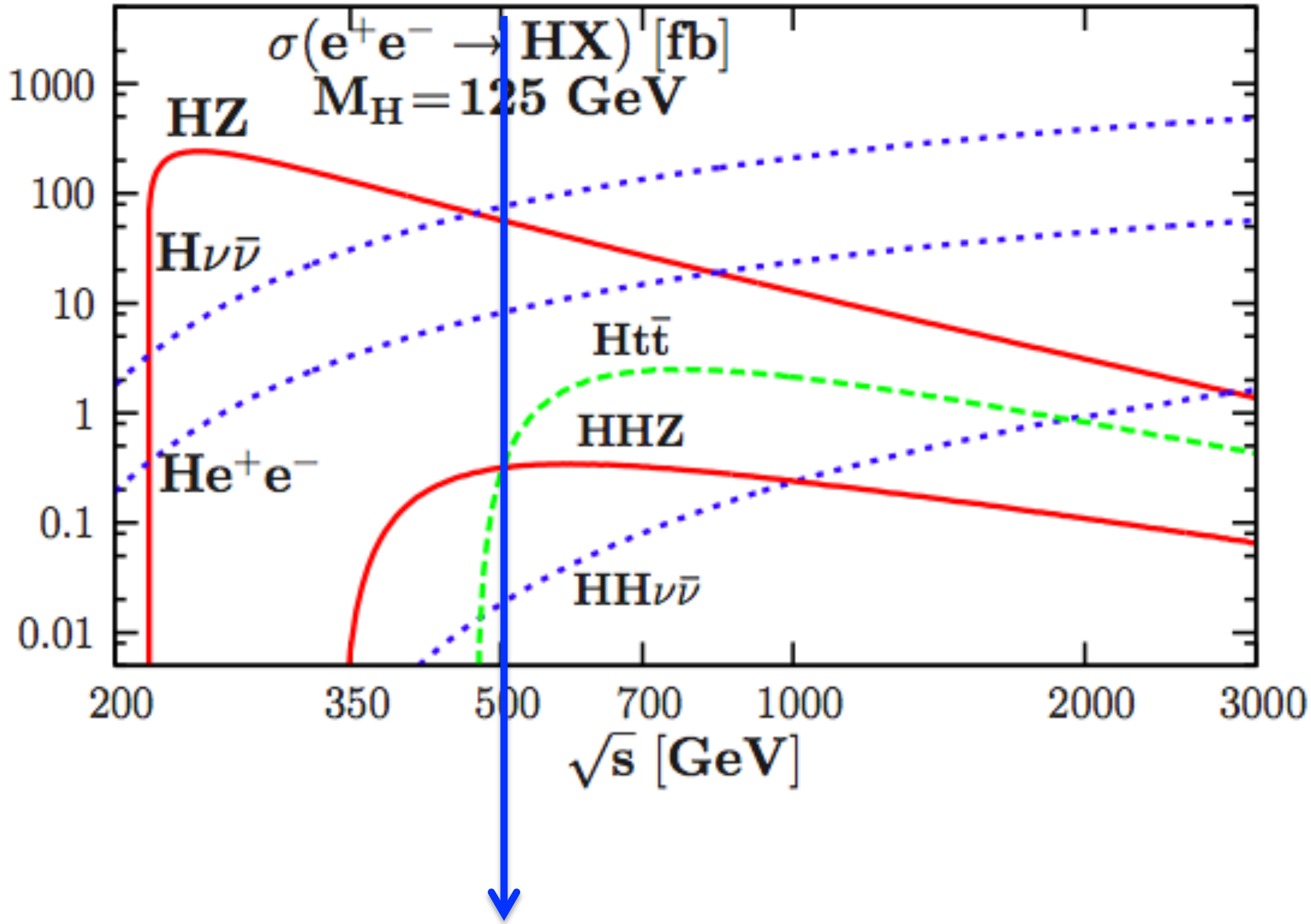




Invisible Higgs decays are made visible!

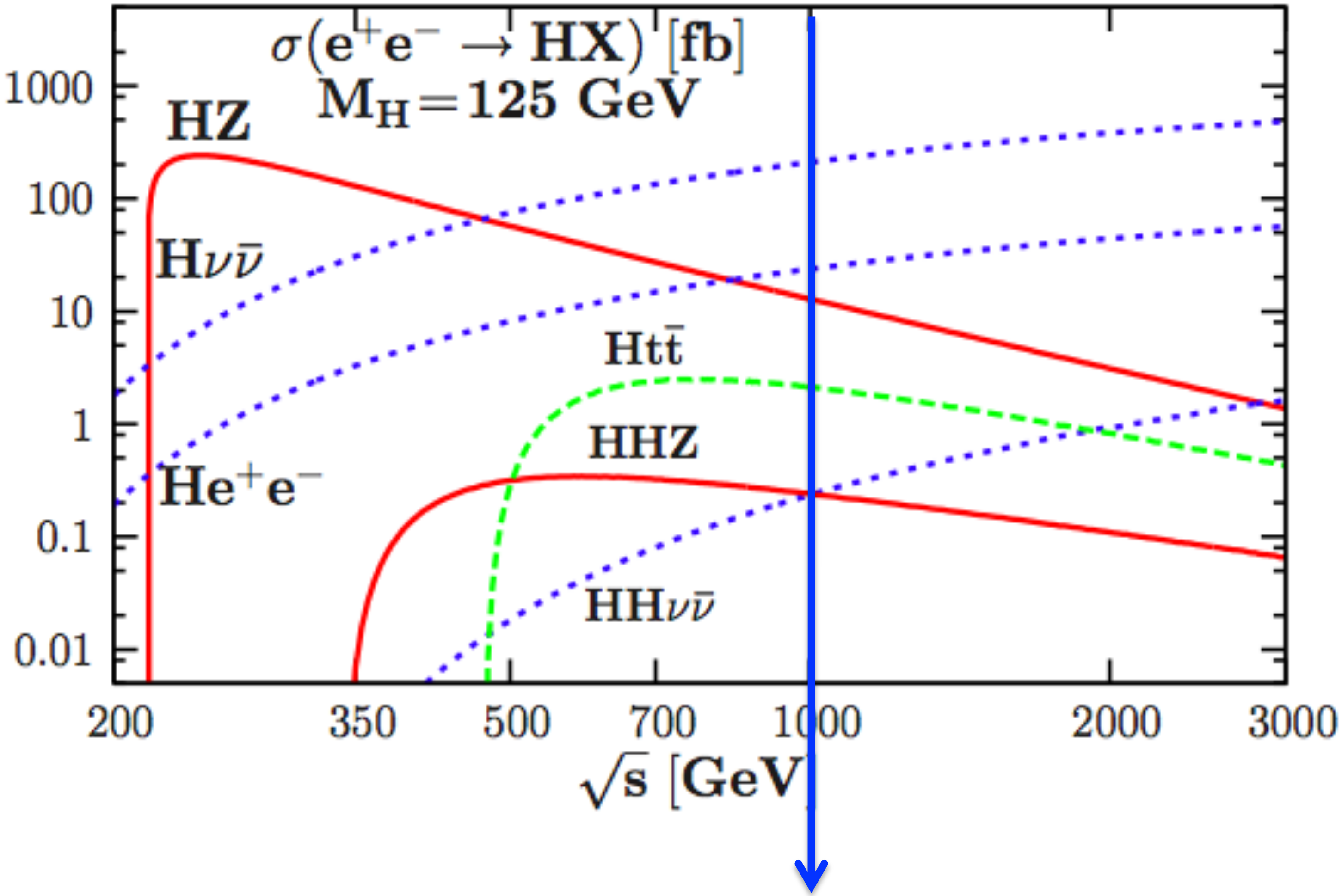
Two simultaneous thresholds : $t\bar{t}$ and $HHZ$



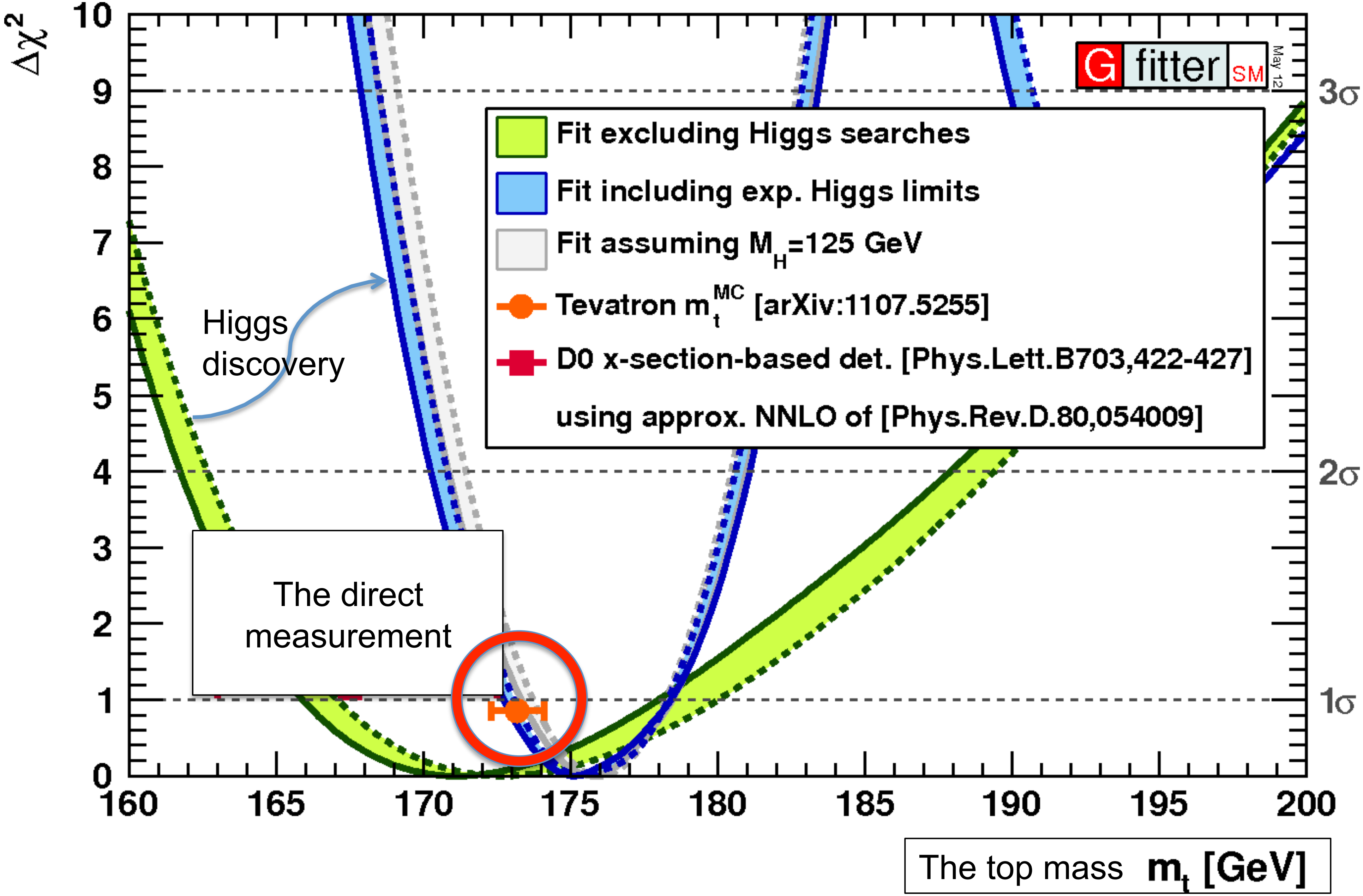

350 GeV is the entrance to top world



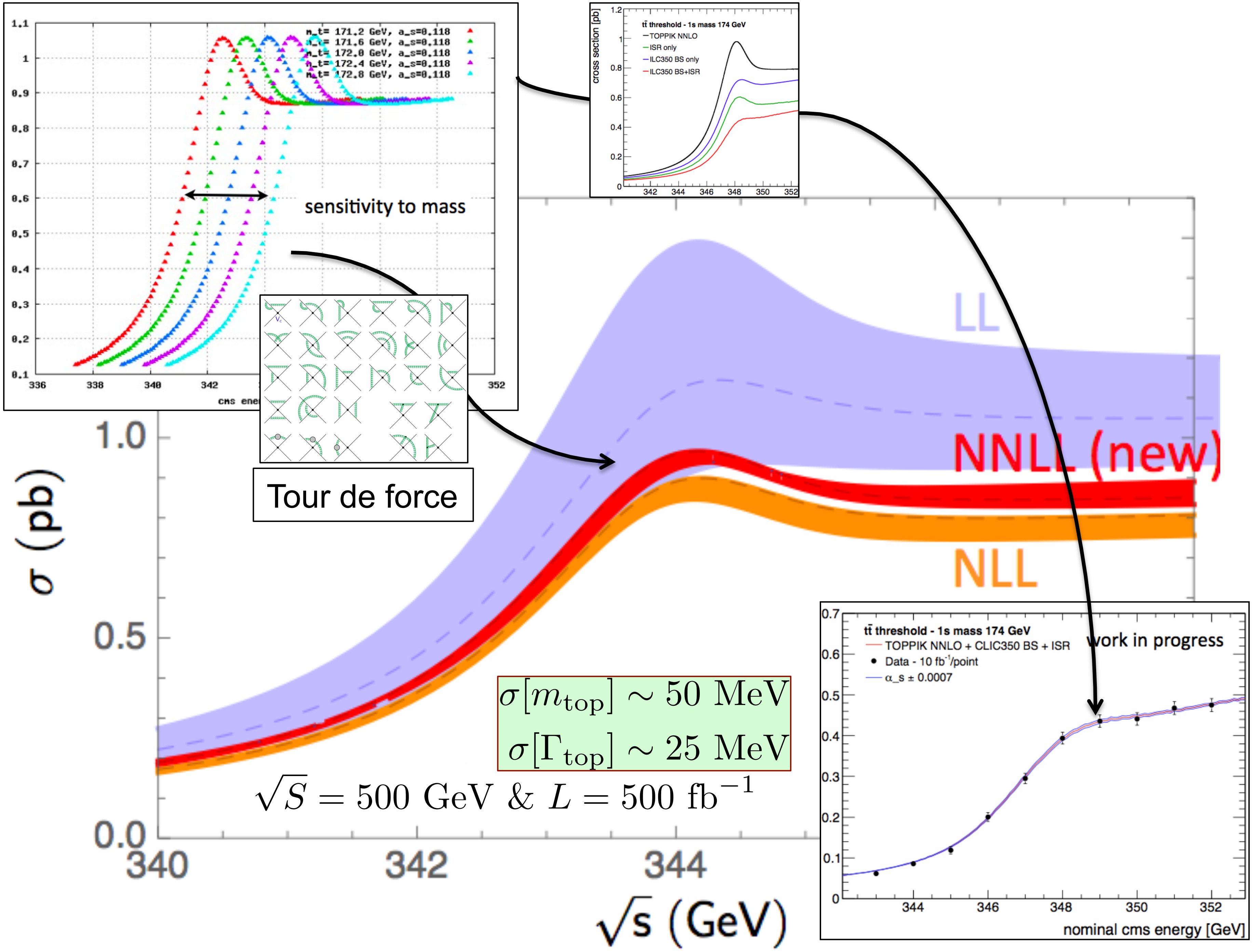

500 GeV is the portal to the whole SM



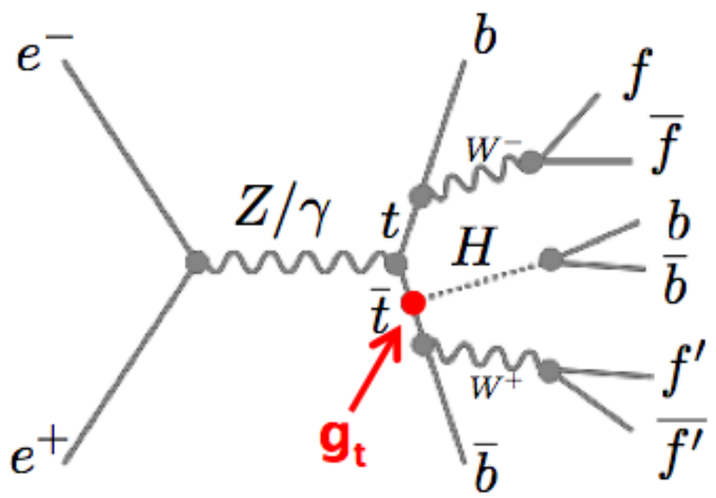

1000 GeV is the Vector-Vector world

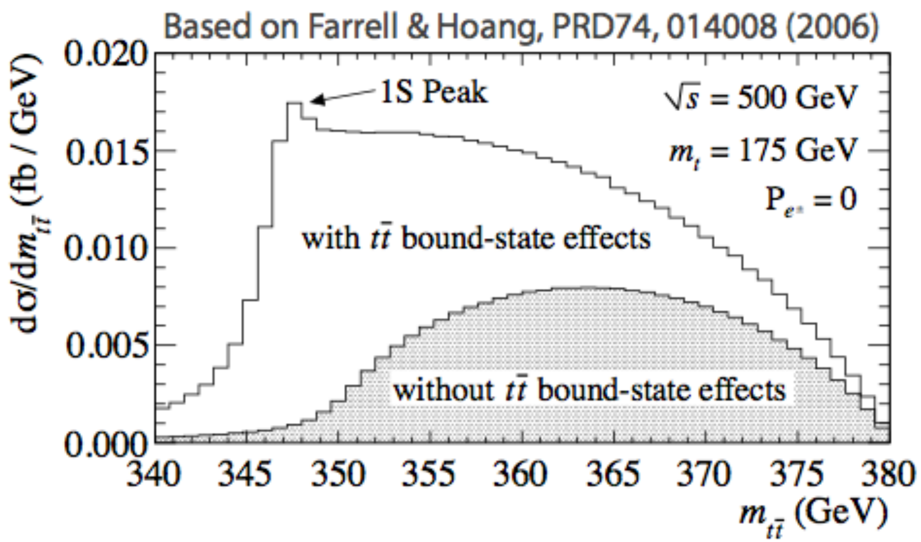


Δχ²
10
9
8
7
6
5
4
3
2
1
0
160
165
170
175
180
185
190
195
200
3σ
2σ
1σ
G fitter SM
May 12
Fit excluding Higgs searches
Fit including exp. Higgs limits
Fit assuming M_H=125 GeV
Tevatron m_t^MC [arXiv:1107.5255]
D0 x-section-based det. [Phys.Lett.B703,422-427]
using approx. NNLO of [Phys.Rev.D.80,054009]
Higgs discovery
The direct measurement
The top mass m_t [GeV]



m_t= 171.2 GeV, a_s=0.118
m_t= 171.6 GeV, a_s=0.118
m_t= 172.0 GeV, a_s=0.118
m_t= 172.4 GeV, a_s=0.118
m_t= 172.8 GeV, a_s=0.118
sensitivity to mass
tt̄ threshold - 1s mass 174 GeV
TOPPIK NNLO
ISR only
ILC350 BS only
ILC350 BS+ISR
cross section [pb]
Tour de force
LL
NNLL (new)
NLL
$\sigma$ (pb)
$\sqrt{s}$ (GeV)
$\sigma[m_{\rm top}] \sim 50$ MeV
$\sigma[\Gamma_{\rm top}] \sim 25$ MeV
$\sqrt{S} = 500$ GeV & $L = 500$ fb$^{-1}$
tt̄ threshold - 1s mass 174 GeV
TOPPIK NNLO + CLIC350 BS + ISR
Data - 10 fb$^{-1}$/point
α_s ± 0.0007
work in progress
nominal cms energy [GeV]

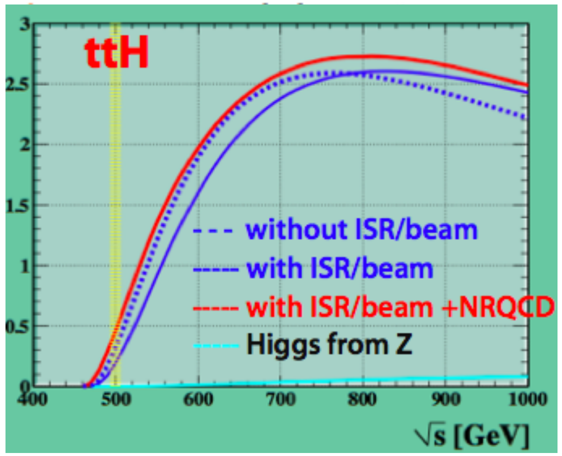


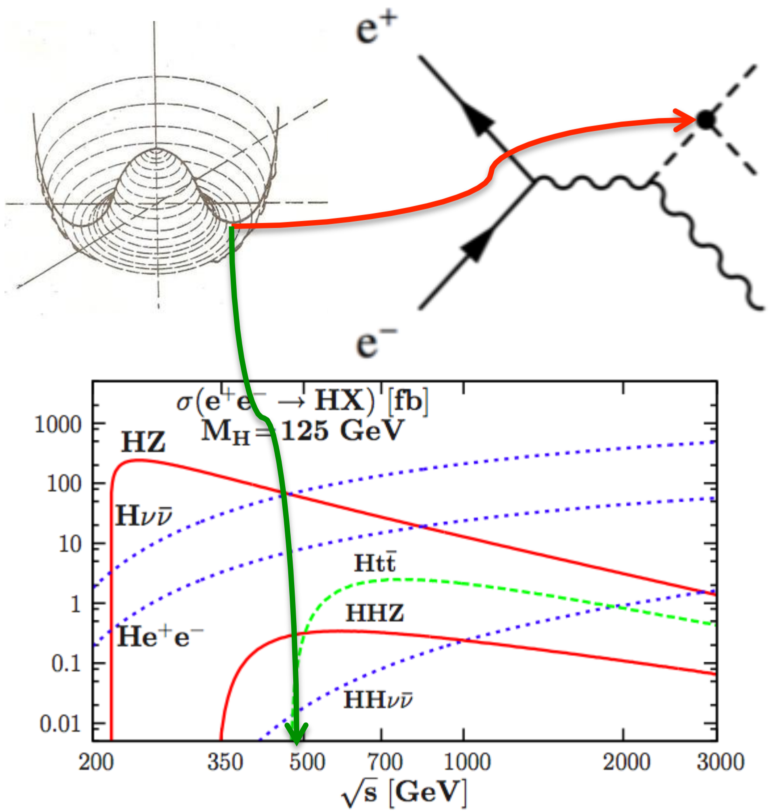

## 6-jet + lepton cut flow

L = 1 ab$^{-1}$, polarized beams

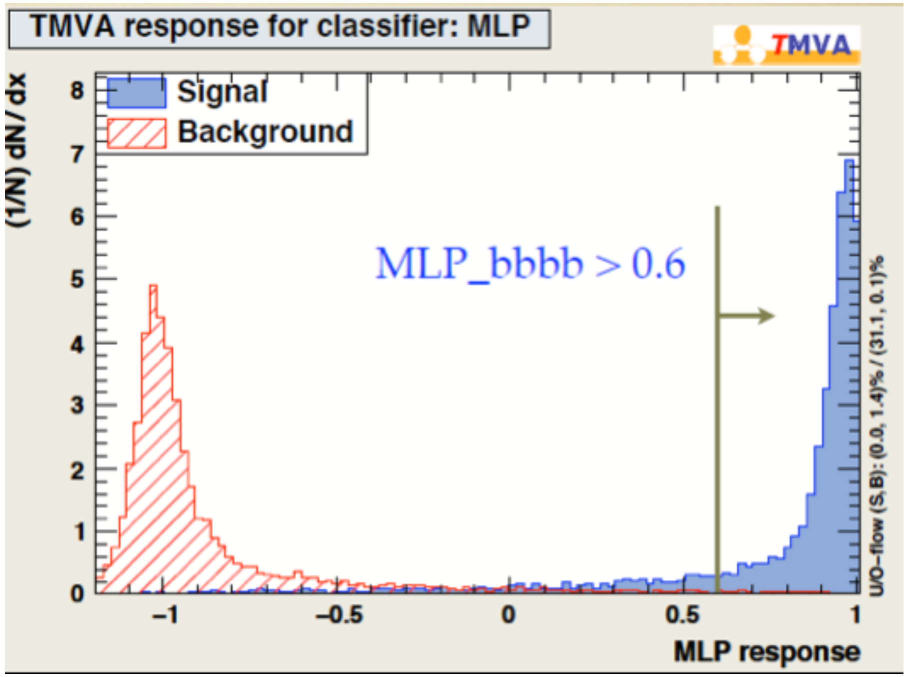
| cut \ sample | ttH (6J) | ttH (8J/4J) | tt | ttZ | ttg*-> ttbb | significance |
|---|---|---|---|---|---|---|
| no cuts | 282. | 358. | 980739. | 2407. | 1160. | 0.3 |
| # isolated lepton = 1 | 180. | 49.0 | 340069. | 791. | 398 | 0.3 |
| thrust < 0.77 | 146. | 37.7 | 144999. | 617. | 266. | 0.4 |
| $Y_{5\to4}$ > 0.005 | 126. | 25.8 | 12298. | 416. | 114. | 1.1 |
| 4x btag | 49.0 | 4.2 | 173. | 53.3 | 37.8 | 2.8 |
| mass cuts | 39.5 | 1.6 | 23.0 | 33.9 | 13.2 | 3.7 |




Coupling Htt at about 10%



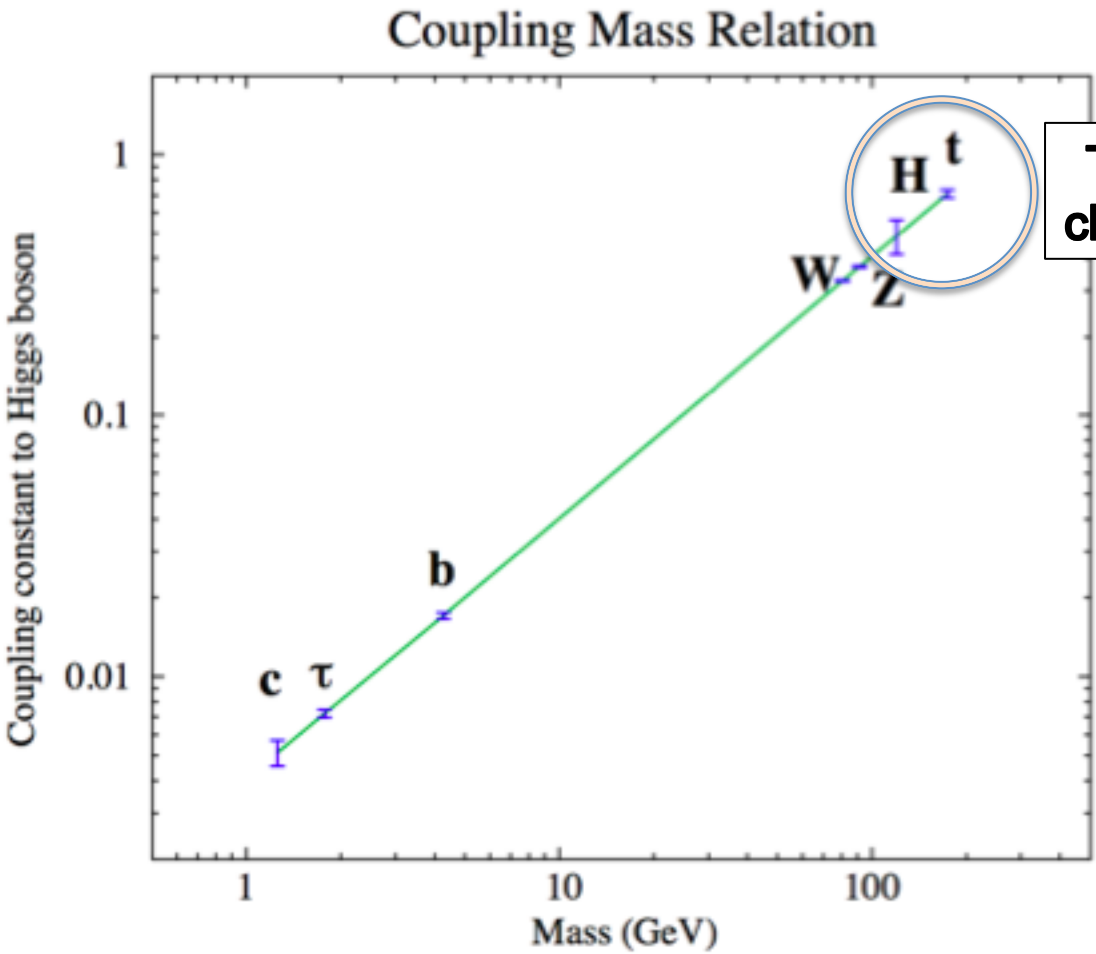

| Decay mode | BR. | # events in 1 ab-1 |
|---|---|---|
| qqbbbb | 32% | 146 |
| ννbbbb | 9% | 42 |
| qqbbWW*->qqbbqqqq | 6% | 28 |
| llbbbb | 4% | 19 |
| qqbbWW*->qqbbqqlν | 3% | 14 |
| qqbbWW*->qqbblνqq | 3% | 14 |
| others | 43% | 194 |
| tt -> bbqqqq | | ~800,000 |
| ZZZ, ZZH -> qqbbbb | | ~600 |




| Energy (GeV) | Modes | signal | background | significance | |
|---|---|---|---|---|---|
| | | | | excess (I) | measurement (II) |
| 500 | $ZHH \to (l\bar{l})(b\bar{b})(b\bar{b})$ | 6.4 | 6.7 | 2.1σ | 1.7σ |
| 500 | $ZHH \to (\nu\bar{\nu})(b\bar{b})(b\bar{b})$ | 5.2 | 7.0 | 1.7σ | 1.4σ |
| 500 | $ZHH \to (q\bar{q})(b\bar{b})(b\bar{b})$ | 8.5 | 11.7 | 2.2σ | 1.9σ |
| | | 16.6 | 129 | 1.4σ | 1.3σ |

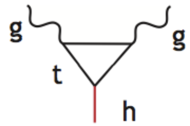
Coupling HHH at about 20%

A 500+ GeV Linear Collider can cover most accessible Higgs couplings




**The most challenging**

$\Gamma_{gg}$




$\Gamma_{\gamma\gamma}$

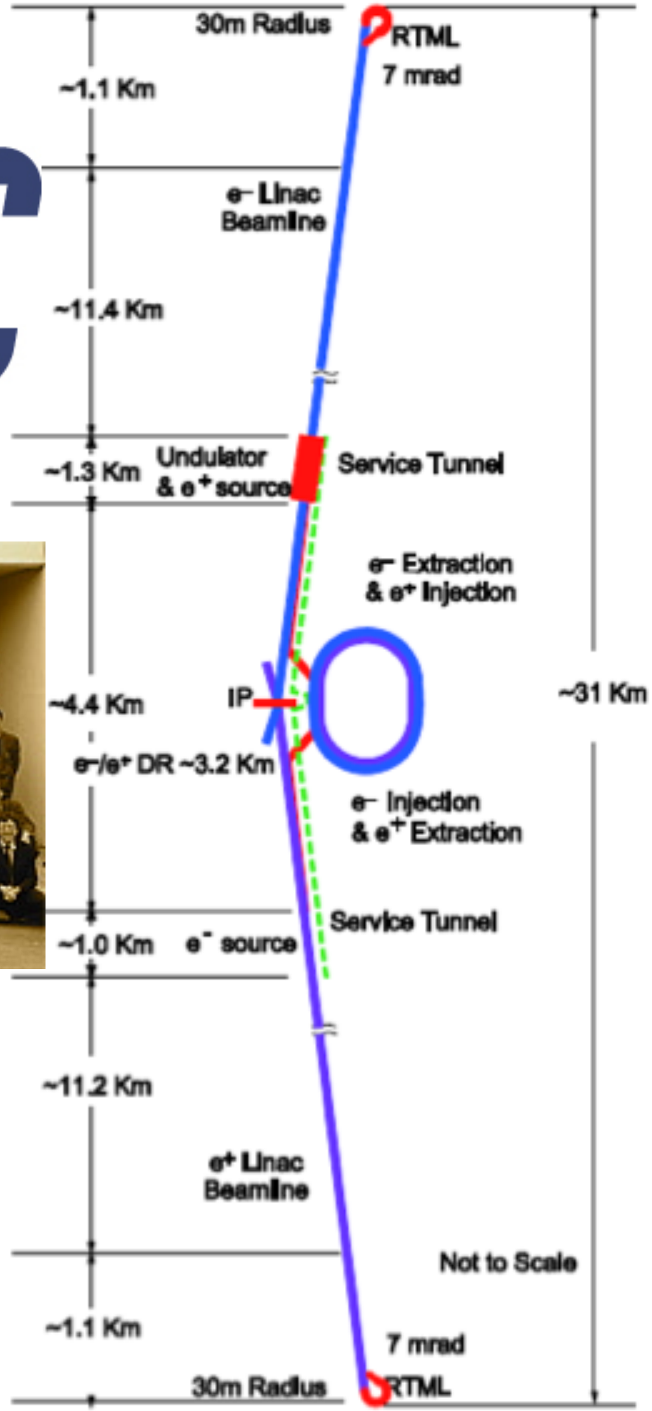
$\Gamma_{tot}$

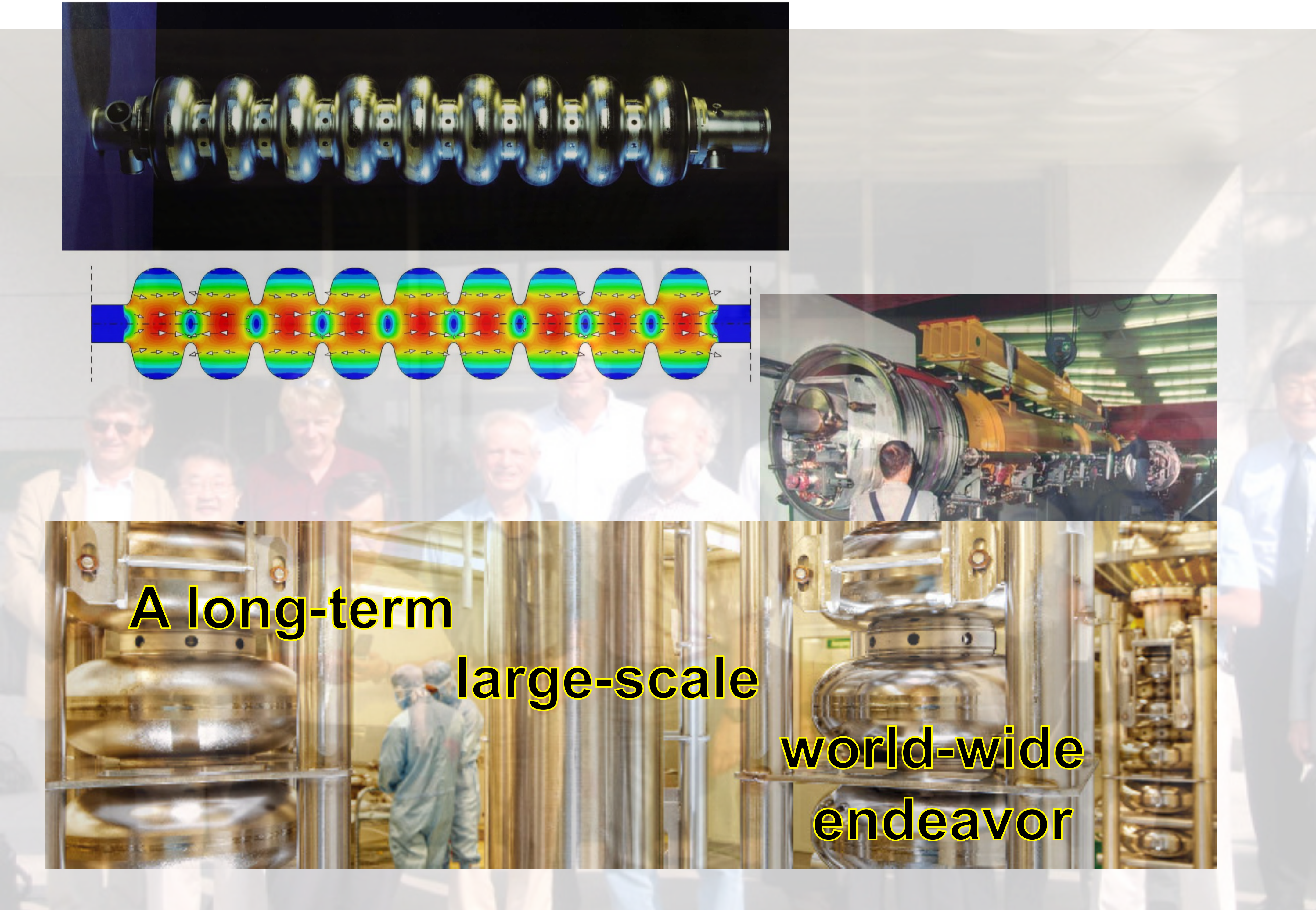
$\Gamma_{invisible}$

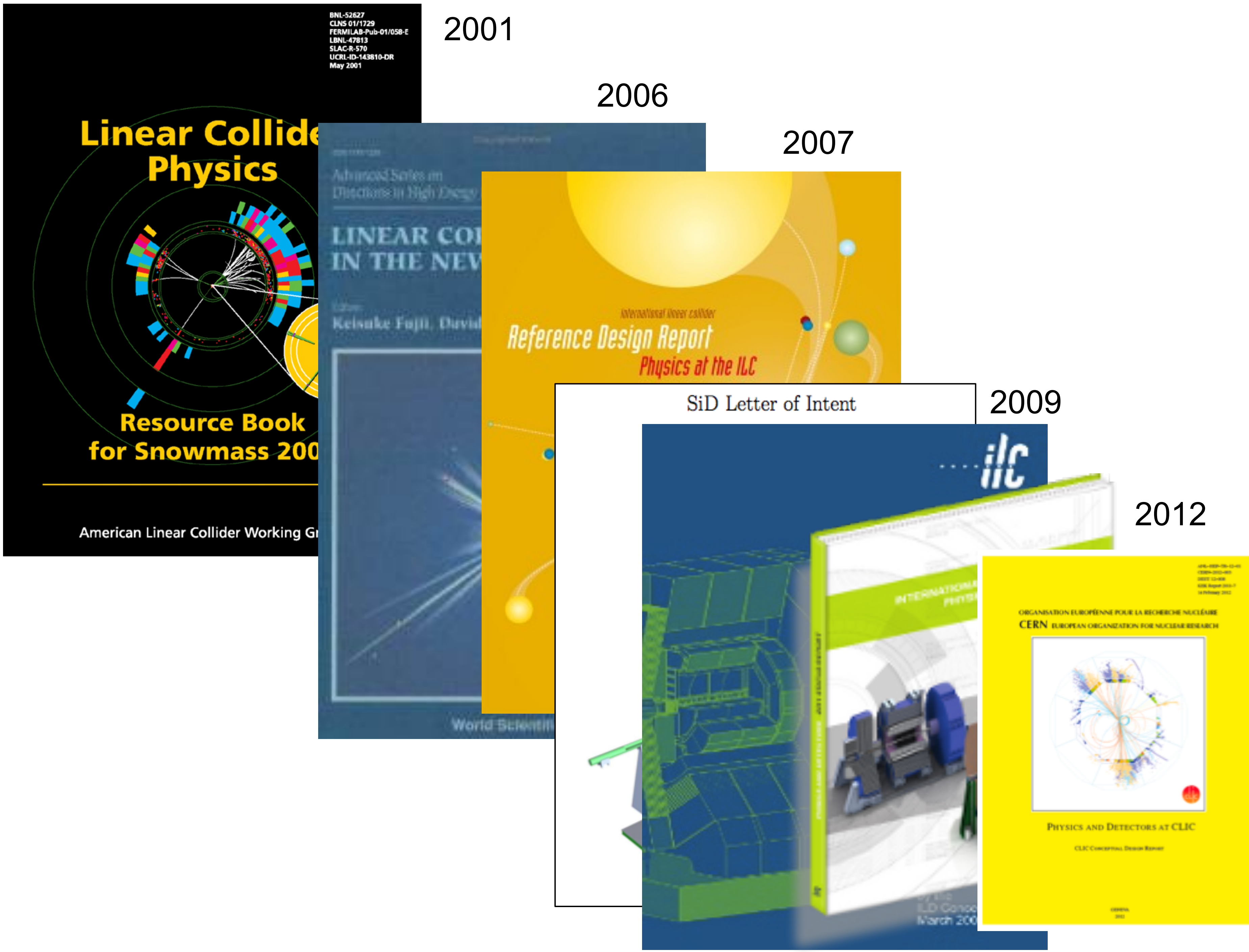
August 2004

November 2004

March 2005

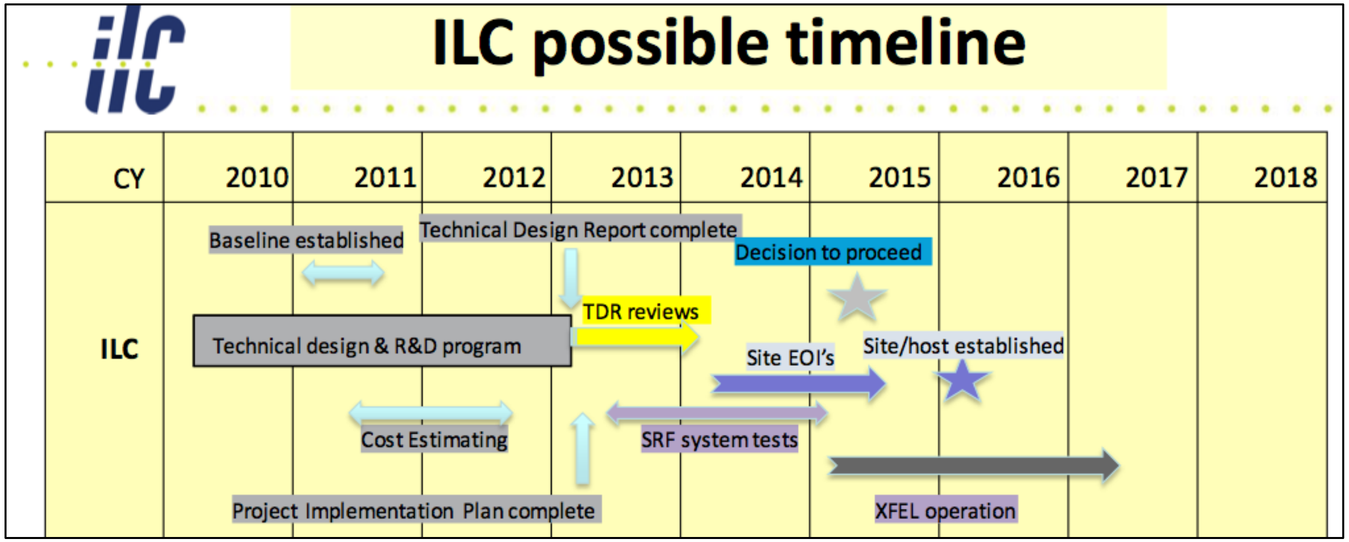


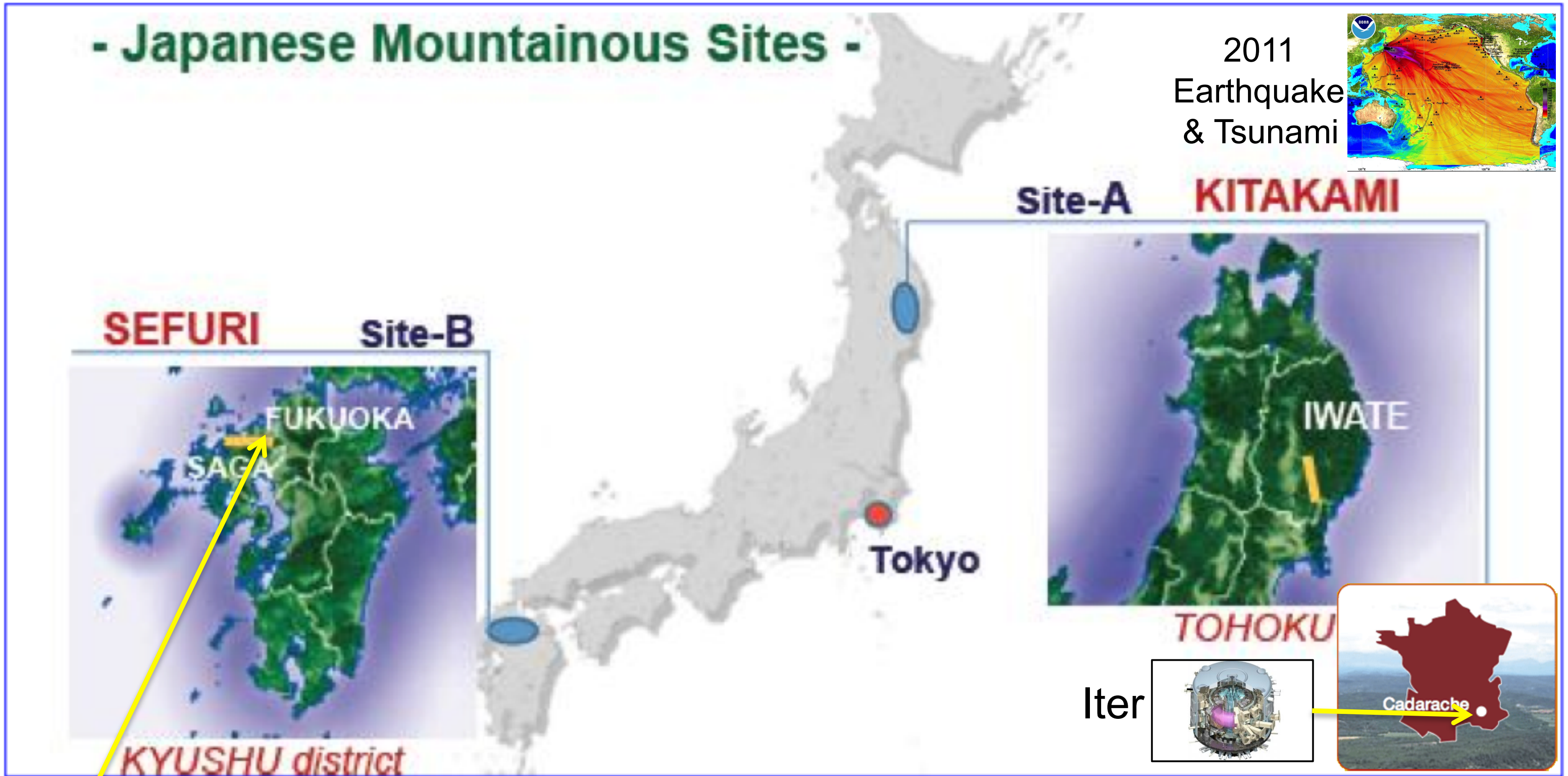

A long-term
large-scale
world-wide
endeavor



2001
BNL-52627
CLNS 01/1729
FERMILAB-Pub-01/058-E
LBNL-47813
SLAC-R-570
UCRL-ID-143810-DR
May 2001
Linear Collide
Physics
Resource Book
for Snowmass 200
American Linear Collider Working Gr
2006
LINEAR CO
IN THE NEW
Keisuke Fujii, David
2007
International linear collider
Reference Design Report
Physics at the ILC
SiD Letter of Intent
2009
ilc
2012
CERN
Physics and Detectors at CLIC
CLIC Conceptual Design Report

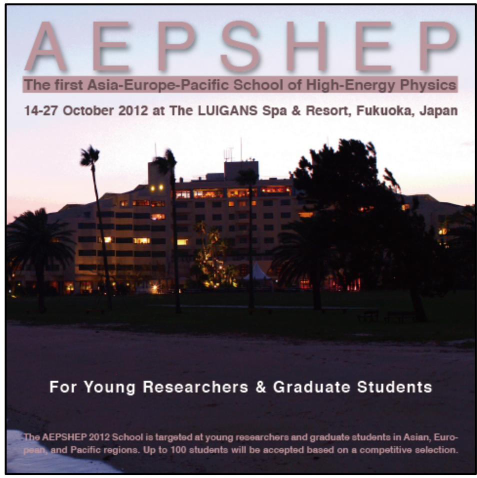

- Japanese Mountainous Sites -
Site-A
KITAKAMI
IWATE
TOHOKU district
Tokyo
SEFURI
Site-B
FUKUOKA
SAGA
KYUSHU district


ILC possible timeline
CY
2010
2011
2012
2013
2014
2015
2016
2017
2018
ILC
Baseline established
Technical Design Report complete
Decision to proceed
TDR reviews
Technical design & R&D program
Site EOI's
Site/host established
Cost Estimating
SRF system tests
Project Implementation Plan complete
XFEL operation



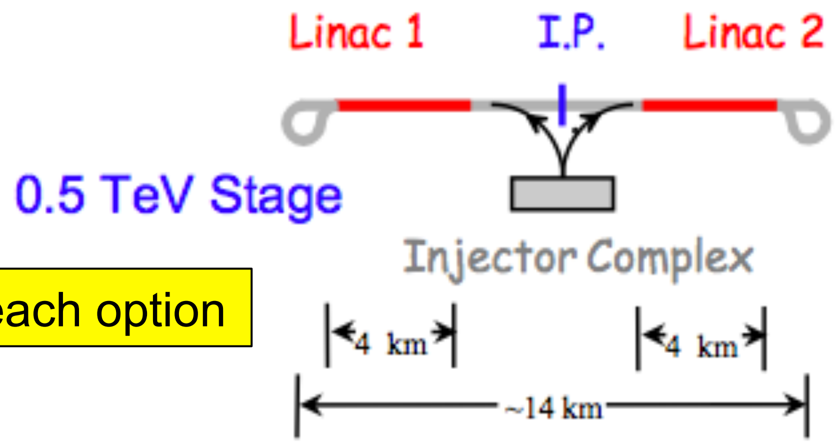

**The first School Euro-Asian is being Held right now in a Fukuoka resort**

DG of CERN will come



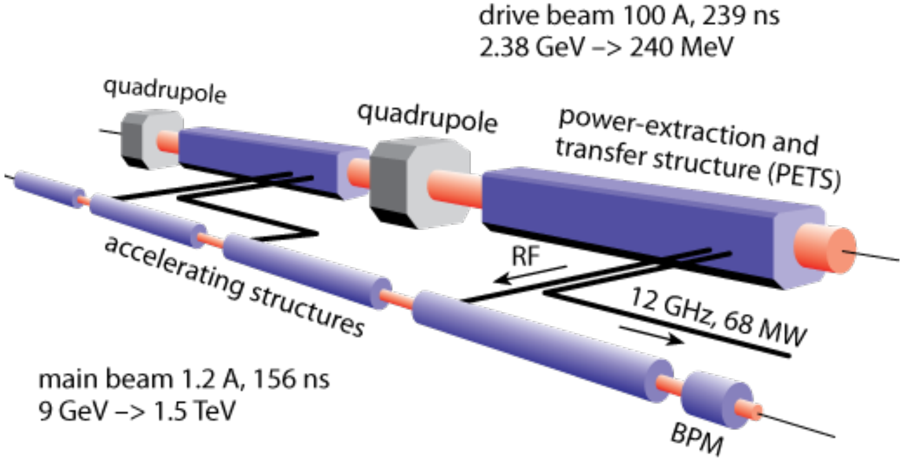

Co-organized by CERN And France as the daughter Of the French-Asia initiative launched in 2006 for LC

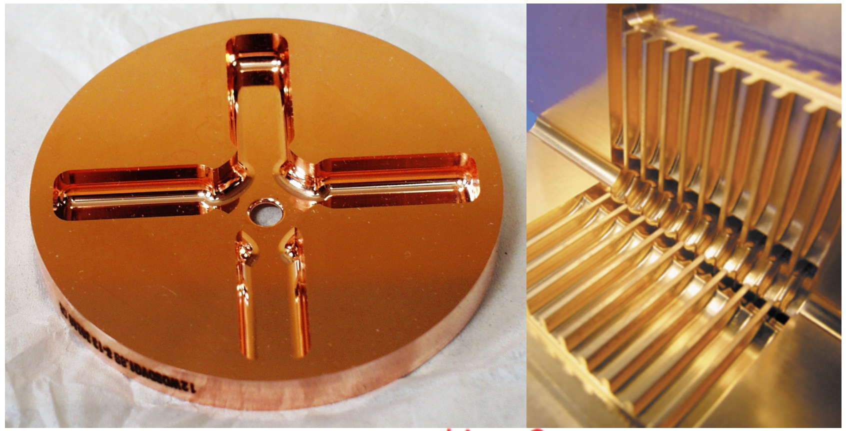
**France is in a very good position, we should maintain**

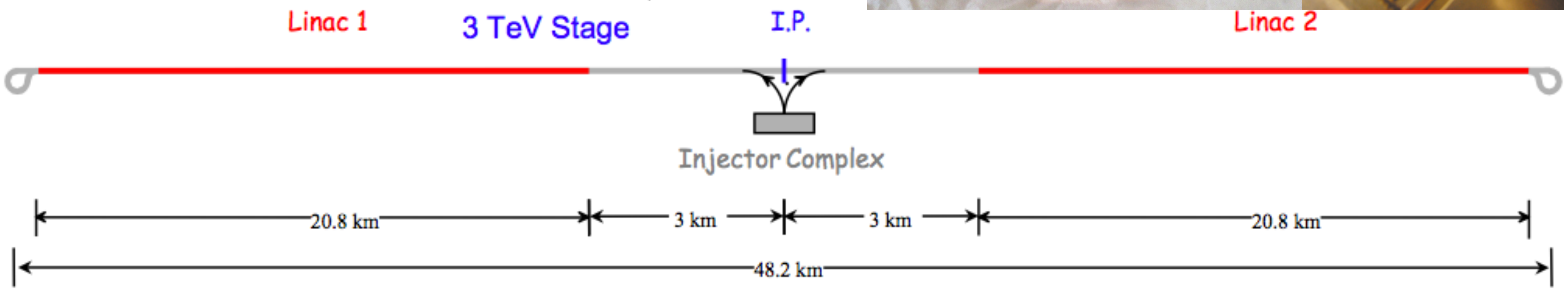




Higher energy reach option

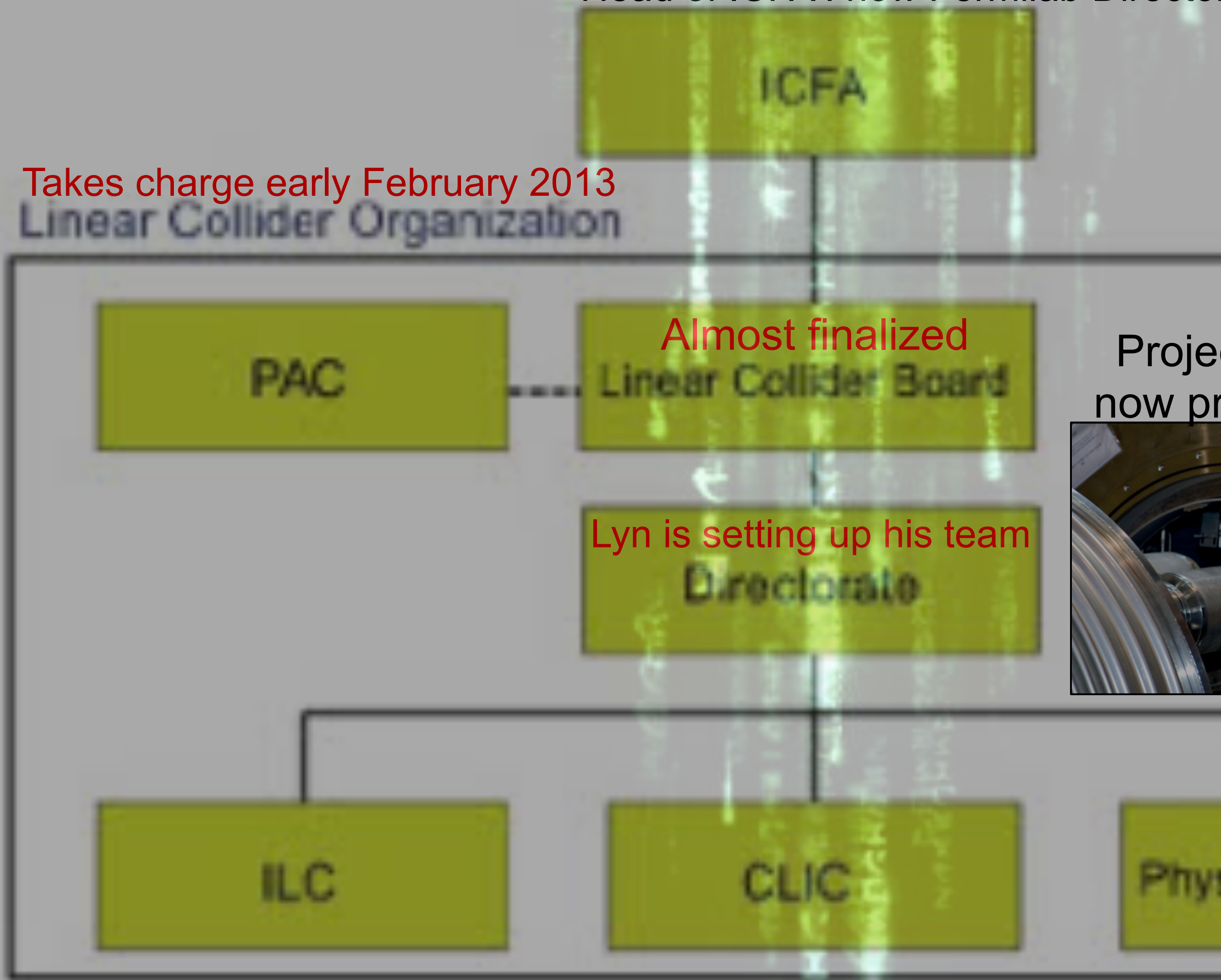




Head of ICFA : now Fermilab Director

Takes charge early February 2013




Almost finalized

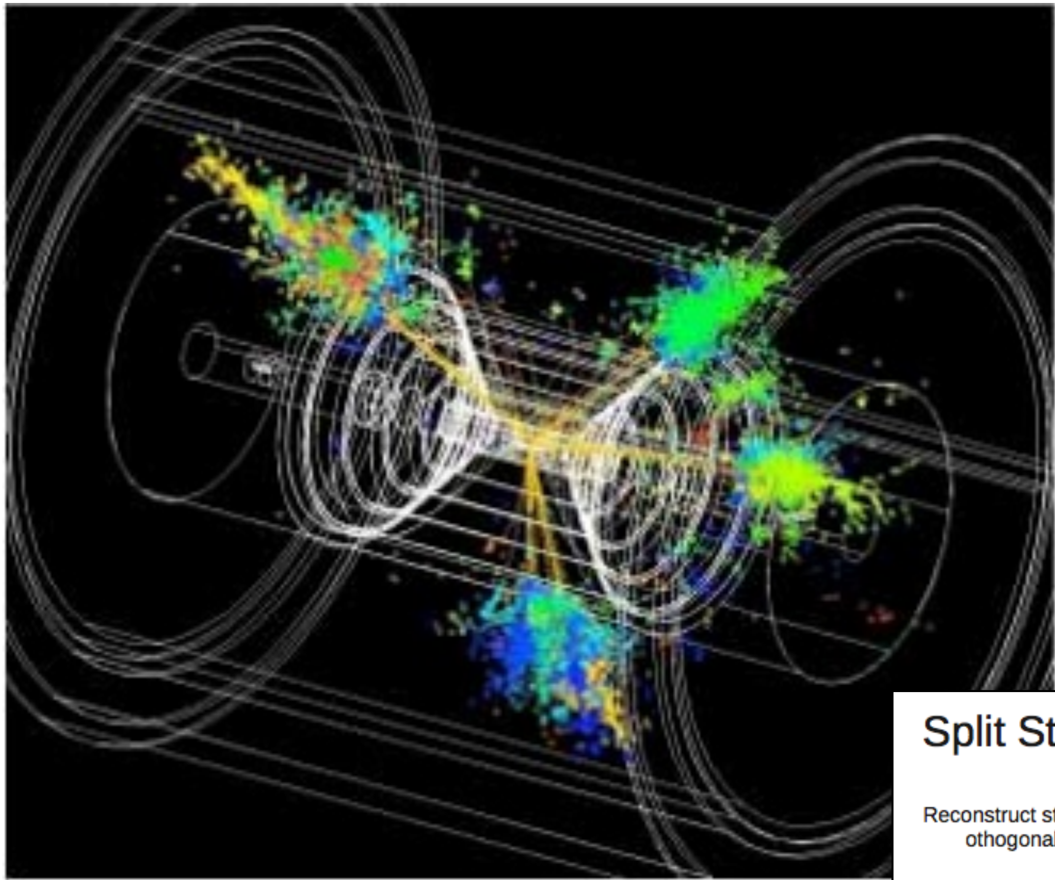
Lyn is setting up his team

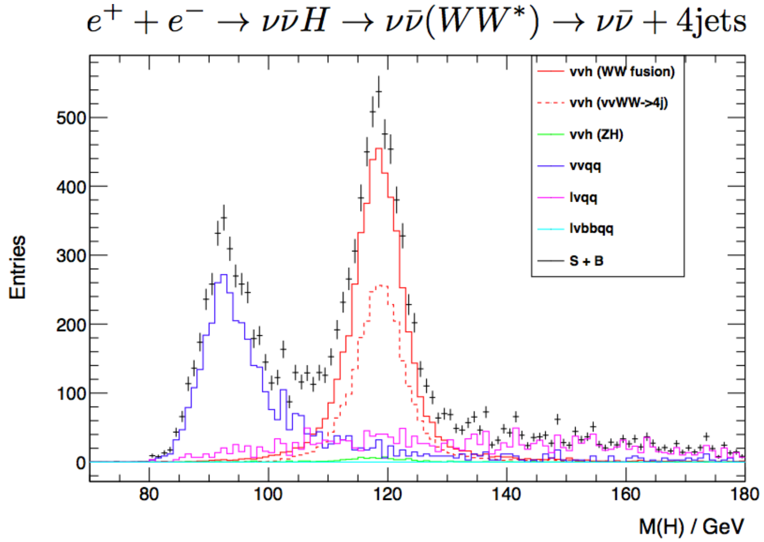
**Lyn Evans**
Project Leader of LHC
now project leader of LC

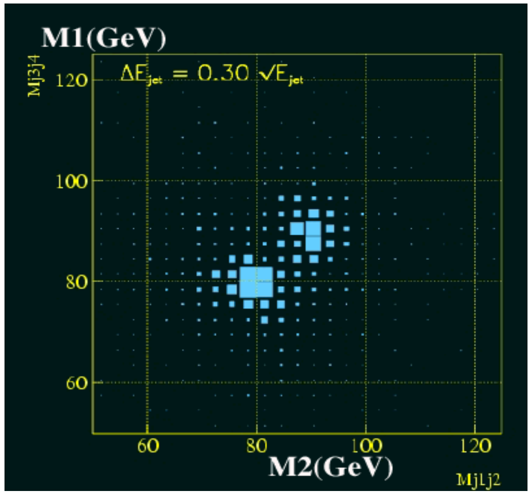
Technical Design Report
Final review December 2012

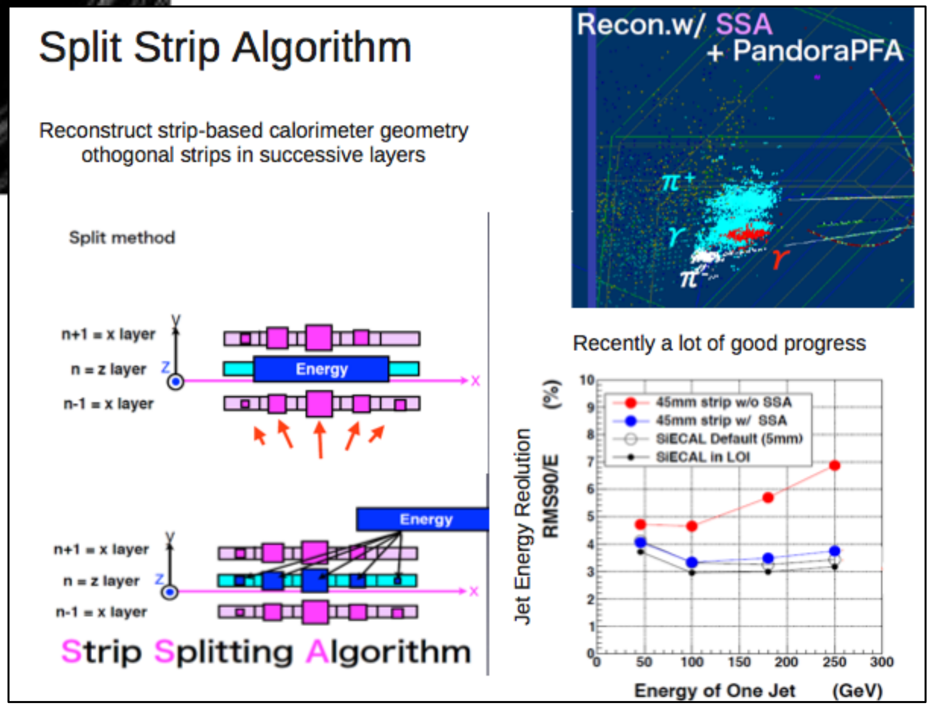
Conceptual Design Report
major milestone in 2012

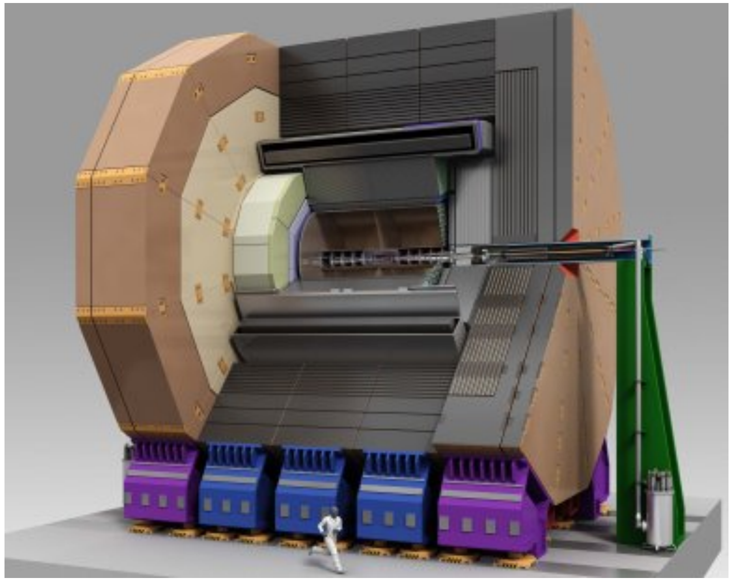
Detailed Baseline Design
Final review December 2012

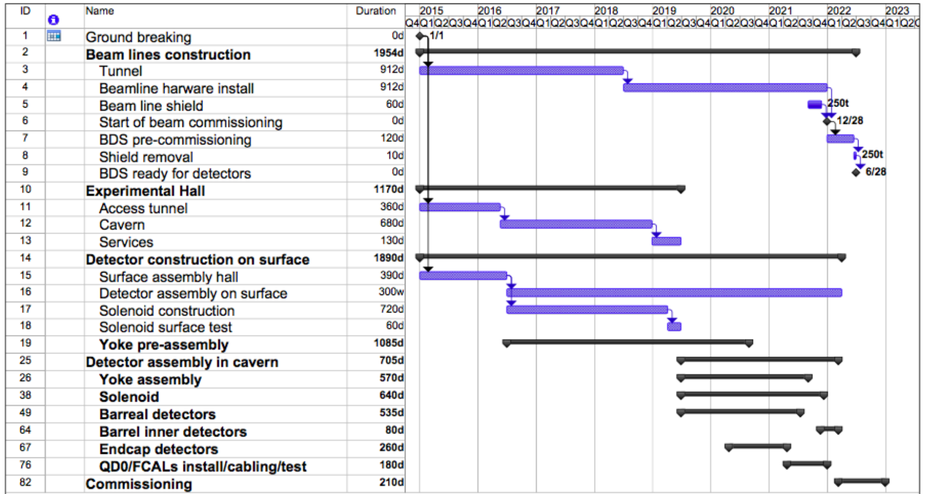



$e^+ + e^- \to \nu\bar{\nu}H \to \nu\bar{\nu}(WW^*) \to \nu\bar{\nu} + 4\text{jets}$
Entries
M(H) / GeV
vvh (WW fusion)
vvh (vvWW->4j)
vvh (ZH)
vvqq
lvqq
lvbbqq
S + B


M1(GeV)
Mj3j4
$\Delta E_{jet} = 0.30\sqrt{E_{jet}}$
M2(GeV)
Mj1j2


Split Strip Algorithm
Reconstruct strip-based calorimeter geometry
othogonal strips in successive layers
Split method
n+1 = x layer
n = z layer
n-1 = x layer
Energy
Strip Splitting Algorithm
Recon.w/ SSA
+ PandoraPFA
Recently a lot of good progress
45mm strip w/o SSA
45mm strip w/ SSA
SiECAL Default (5mm)
SiECAL in LOI
Jet Energy Reolution
RMS90/E
(%)
Energy of One Jet (GeV)



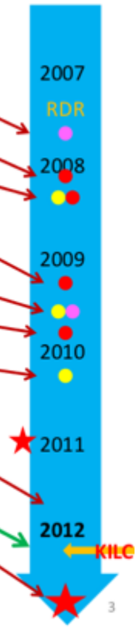



- Total construction time: ~8 years
- Detector underground construction: ~3 years

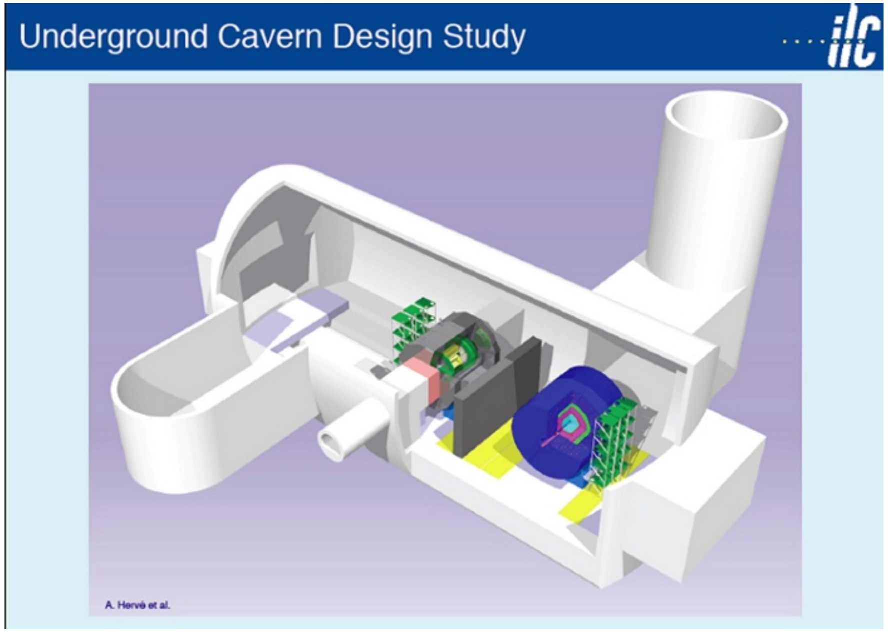
Detectors status, S. Yamada, KILC 2012

## The time line of the LOI process

- **Oct. 2007: Call for LOIs was made by ILCSC**
- Jan. 2008: Detector management was formed
- Mar.2008: IDAG formed, 3 LOI groups known
- **Mar.2009: 3 LOIs submitted**
- Summer 09: **IDAG recommendation for validation and ILCSC's approval**
- Oct 2009: Work plan of the validated groups
- **Mar:2009: IDAG began monitoring the progress**
- End 2010: Interim report completed
- ***DBD outline to be monitored***
- End 2012: **Detailed Baseline Design Report**




2012/4/24 Sakue Yamada @ KILC12 @Daegu 3



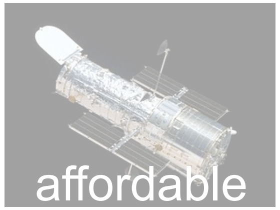
# The dream-machine

LC collider

flexibility

e-e collider

Clean Luminosity





Mature technology

LC collider

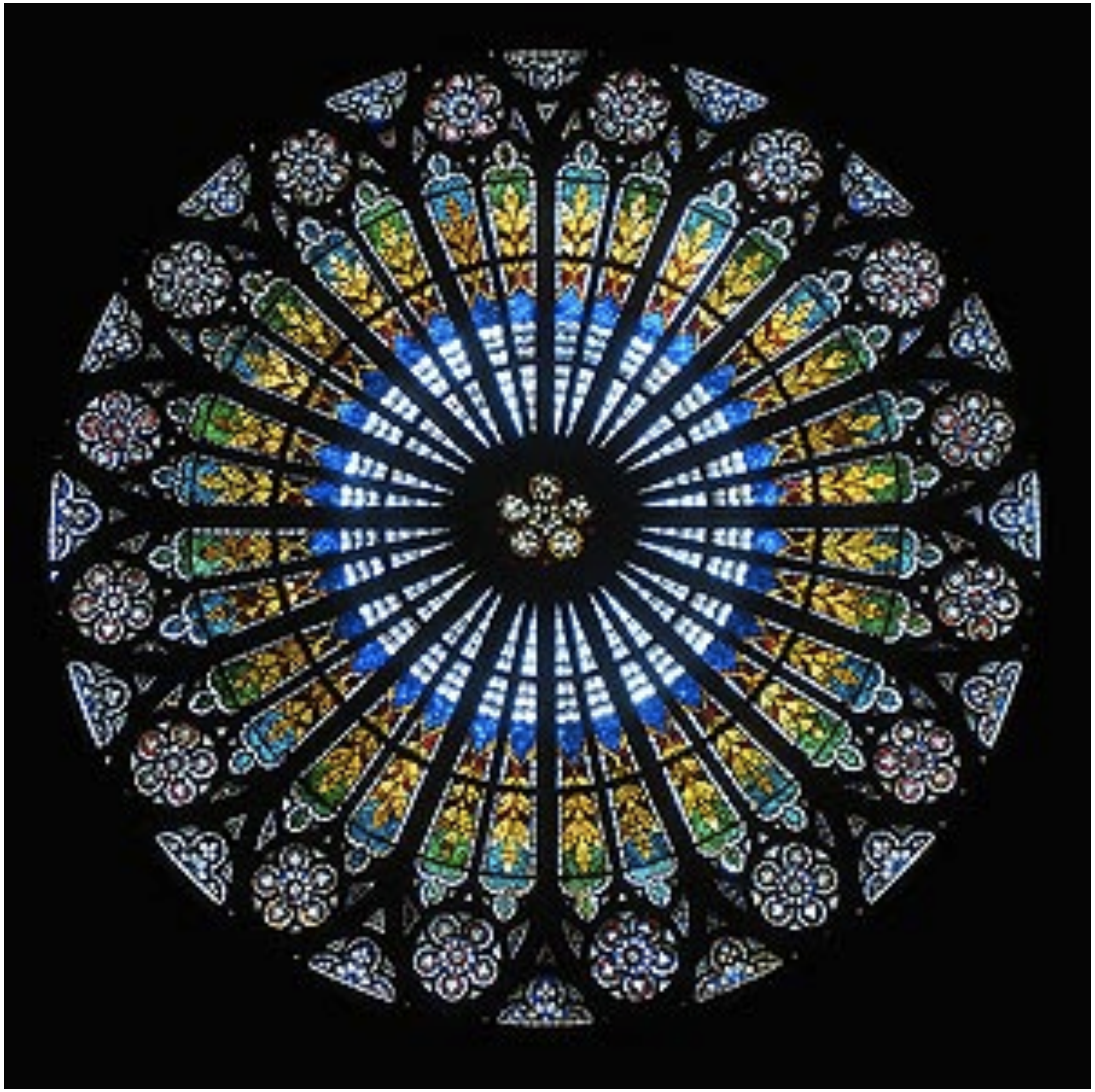
$SU(2)_L$

LC collider

Full SM reach

LC collider

It took more than 250 years to build Strasbourg Cathedral

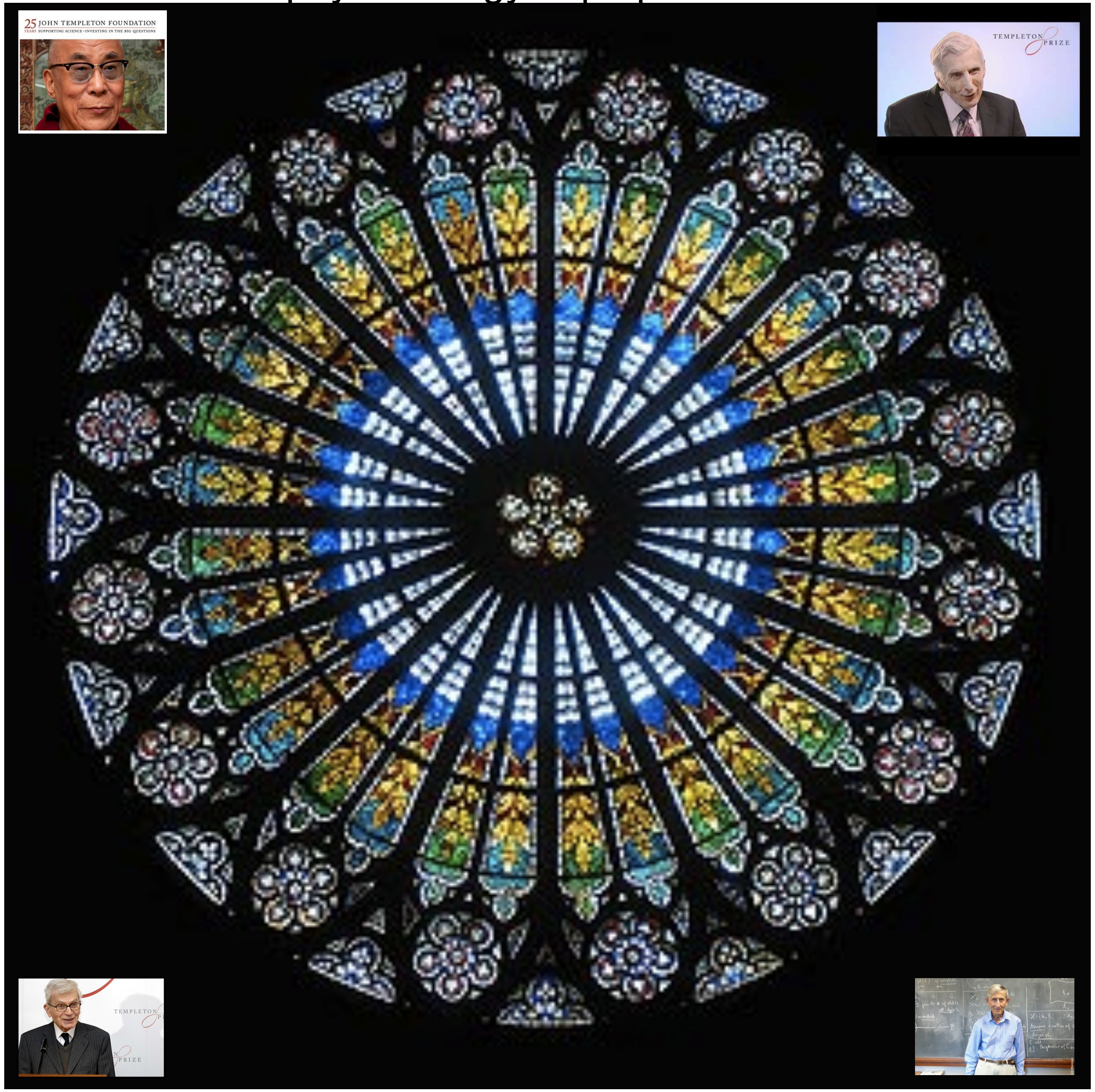


More than 10 years to go before the Linear Collider runs

Enthousiastic mail this morning (19 10 2012) from DG of CERN:

15-18 Oct 2012 Science Philosophy Theology http://public.web.cern.ch/Public/Welcome.html

Templeton Prize
2012 Dalai Lama



Templeton Prize
2011 Rees

Templeton Prize
2009 D’espagnat

Templeton Prize
2000 Dyson

We must keep our ambitions up to what humanity means

We must dare!