b'-quarks @ b4

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Disclaimer:

Not all content of this talk is entirely serious

But some of it is

Questions

- Under which circumstances is a fourth generation still allowed?

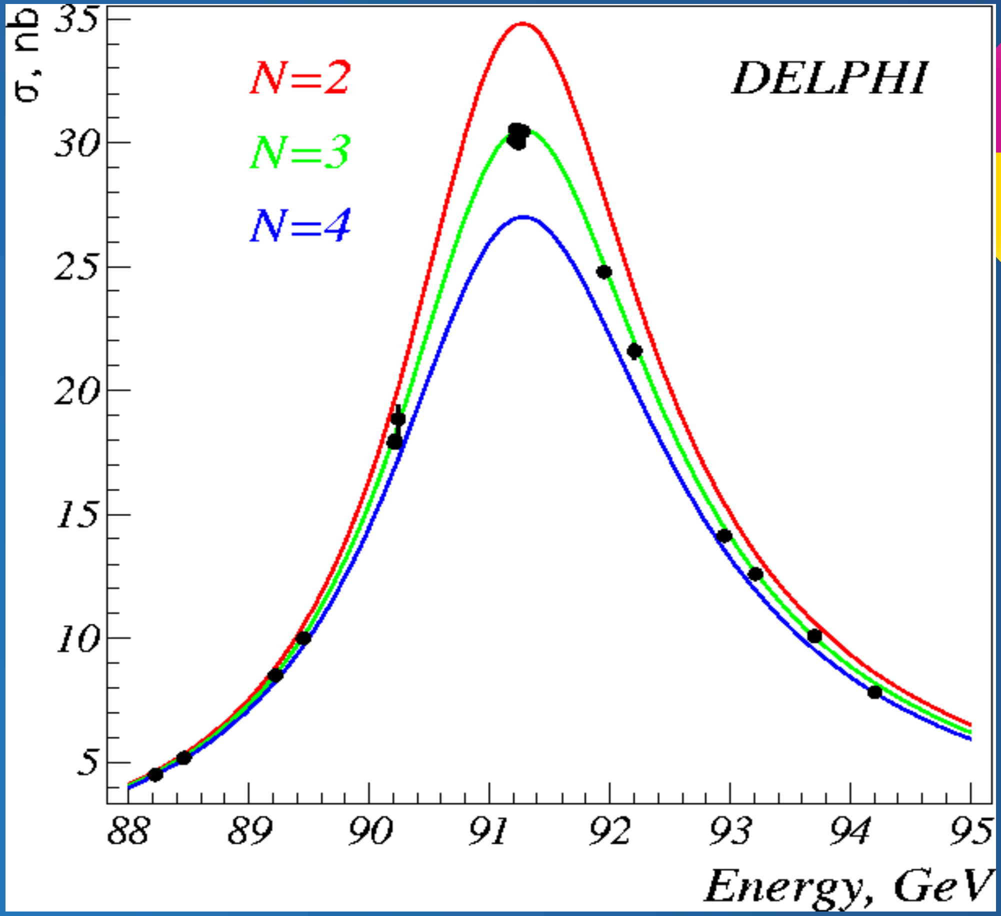
- If a b’-quark is discovered at 850 GeV/c^2, what experiment would you perform to study its properties?

Part I

the physics

Ancient LEP results:
Only 3 generations of neutrinos

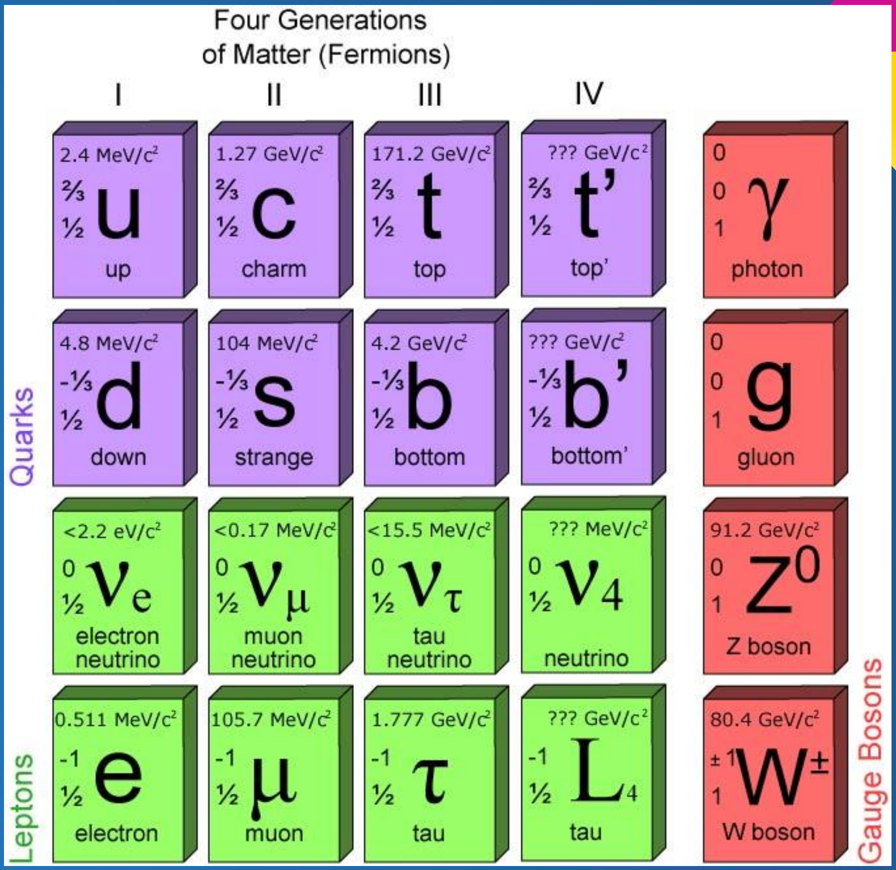
- "Normal" neutrinos lighter than $m_z/2$ are disallowed from LEP (Z lineshape)
- Window between $m_z/2$ and $m_H/2$ open
- Above $m_H/2$: depends on Higgs model



SM with 4 generations (SM4)

The simplest model accommodating the 4th generation quark

- SM + 1 chiral family of fermions
- one Higgs doublet
- Yukawa couplings
- Dirac neutrinos



Disfavored by current experimental observations !

Higgs doesn't like 4th gen quarks

How the Higgs production cross section changes:

- In the SM, the dominant Higgs production process is the gluon-gluon fusion process (Fig 1)
- In a fourth generation with two additional heavier quarks (Fig 2), the Higgs production cross section is enhanced wrt SM (Fig 3) up to a factor ~ 9

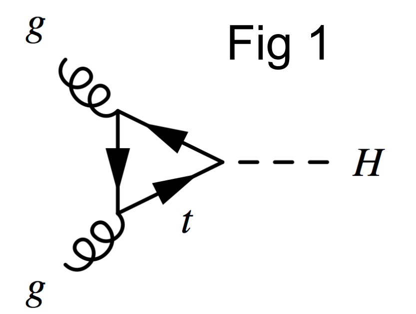


Fig 1

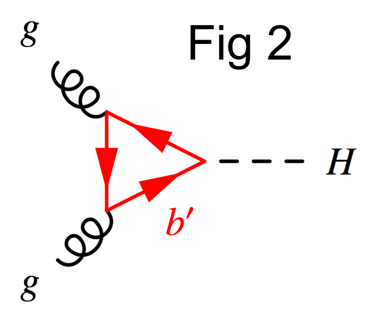


Fig 2

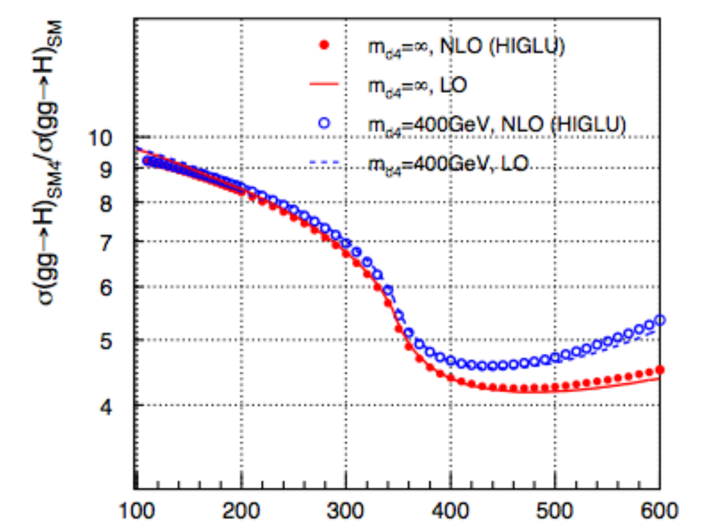
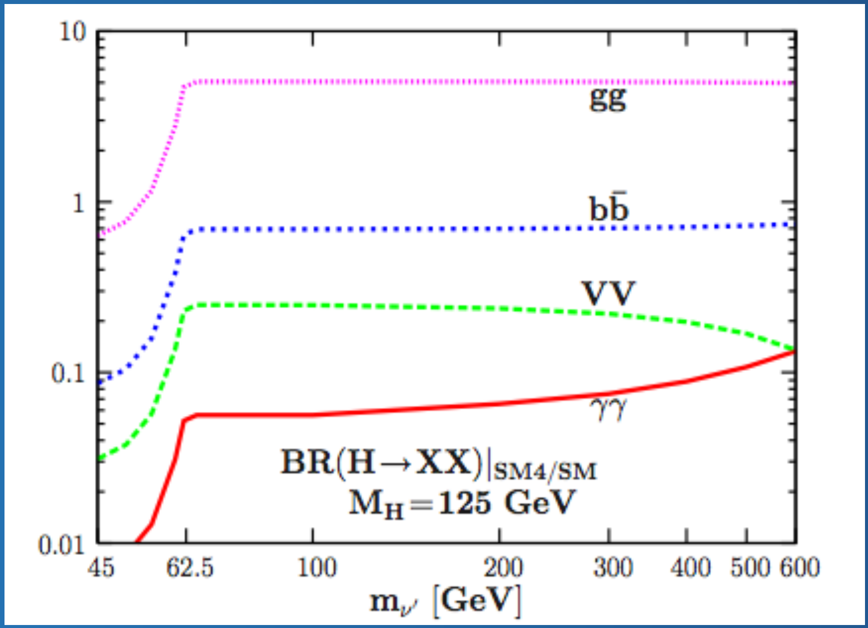


Fig 3

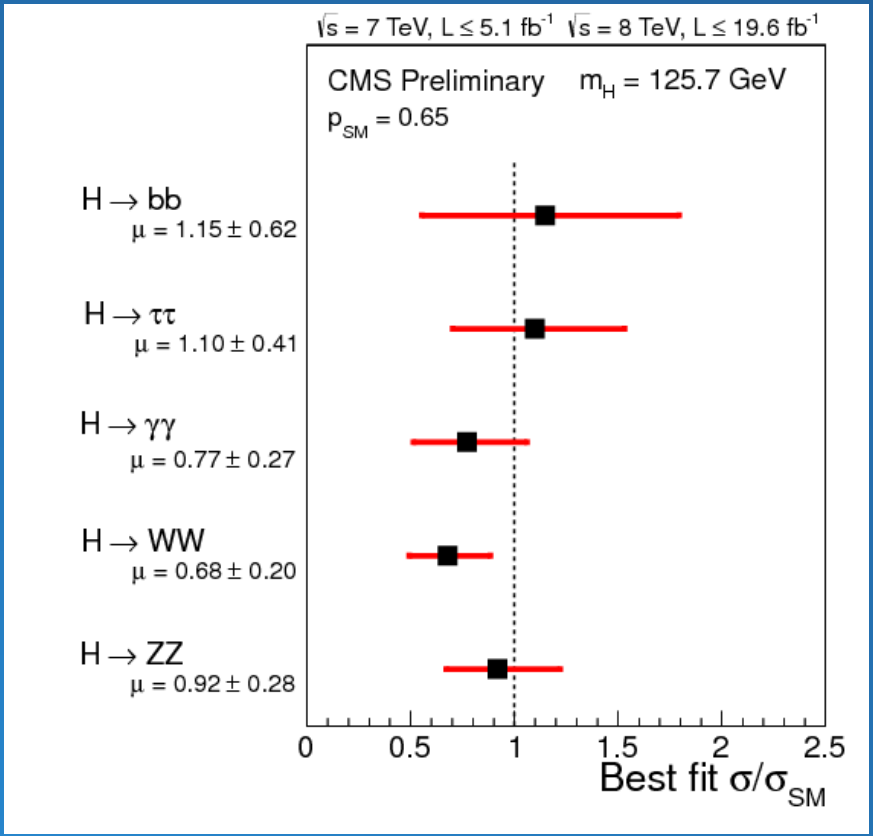
Higgs still doesn't like 4th gen

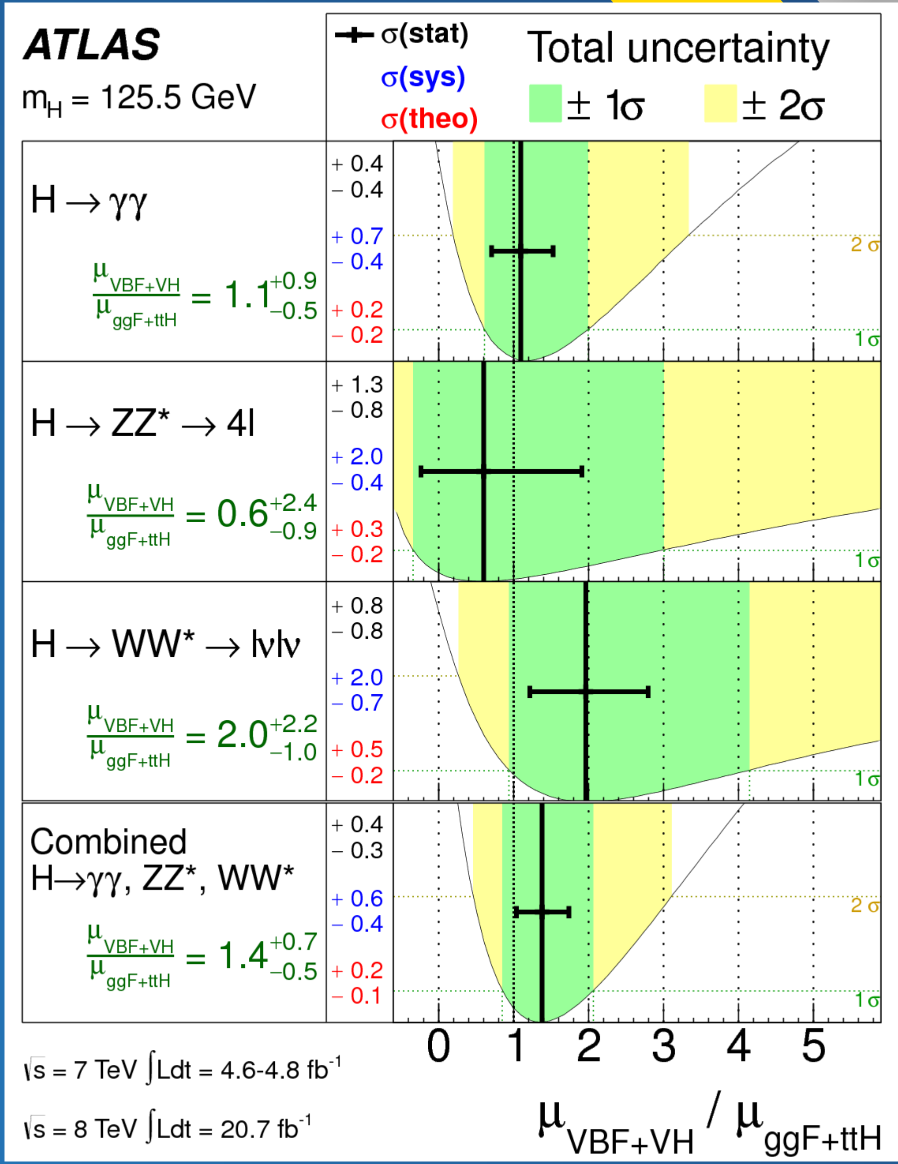
How the Higgs branching ratios change:

- in the case of a light neutrino, the Higgs boson will also decay into a neutrino pair and the branching ratio BR($H \to \nu'\bar{\nu}'$) can be sizable enough to suppress the rates for the visible channels
- the rates for the $H \to ZZ$ and $H \to \gamma\gamma$ decays are strongly suppressed by a factor that is larger than the one which enhances the $gg \to H$ cross section.



Higgs still doesn't like 4th gen





Bottom line: results cannot accommodate SM4

So what is allowed?

The SM4 can survive with small modifications if

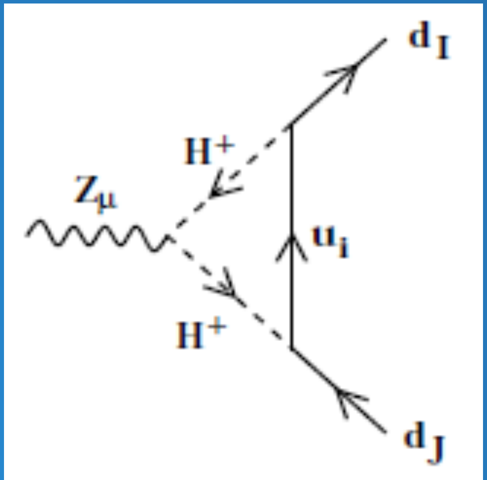
- we extend Higgs sector, e.g. 2 Higgs doublets (2HDM)
  - allows us to save *chiral* SM4 (4th generation decoupled from others)

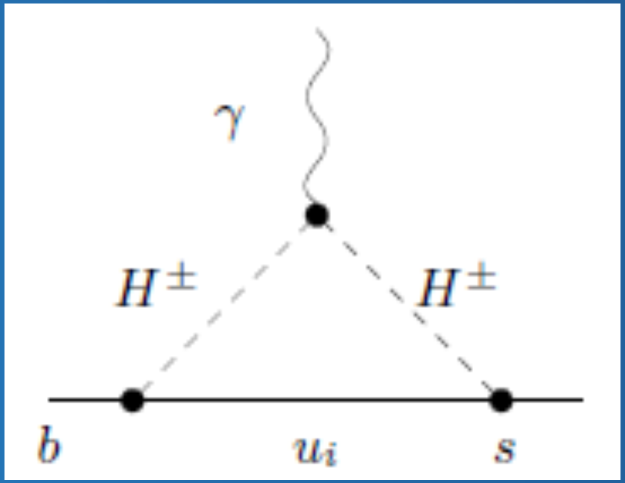
  and/or

- the additional quarks are vector-like (VLQs)
  - no Higgs mechanism required for mass generation of such quarks

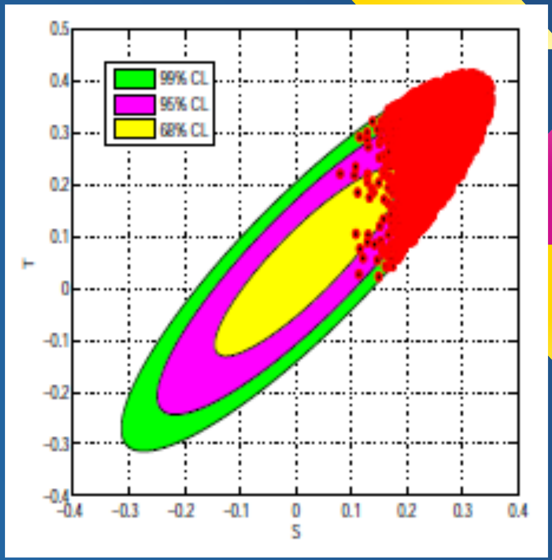
Two Higgs Doublet Model

- LHC Higgs results exclude chiral 4th gen.
  ⇨ only holds for SM Higgs (single doublet) !!!
- More complex Higgs sector possible, e.g. two Higgs doublets (2HDM)
- Effects on electroweak and flavor physics, e.g.:





Two Higgs Doublet Model



- Consequences discussed in
  http://arxiv.org/abs/1208.3195
- Two Higgs doublets coupling to 'light' and 'heavy' fermions
- Assuming 2HDM:
  - 4th gen. still fits to electroweak and flavor observables
  - **4th gen. viable with recent Higgs results !!!**
- Relaxed search bounds due to further decay channels (e.g. $t' \rightarrow ht$ or $t' \rightarrow H^{+}b$)
- Higgs field(s) could be condensates of 4th gen fermions
  → dynamical electroweak symmetry breaking

Vector-like quarks (VLQ)

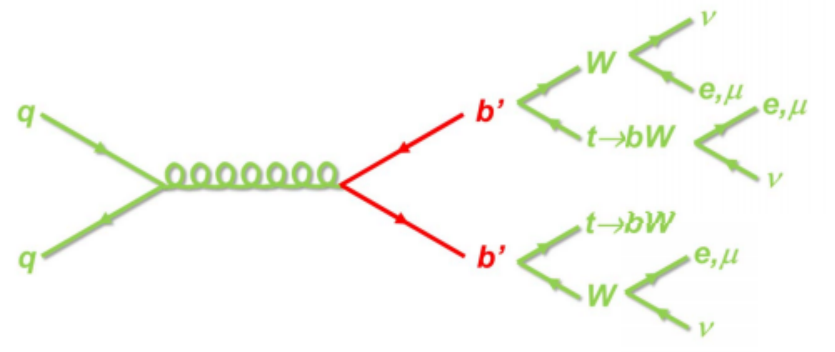
- Vector-like fermions have their left and right components transforming in the same way
- The $\bar{\psi}_L \psi_R$ mass terms are not forbidden by symmetry
- The resonances associated to such Lagrangian terms do not affect the current formulation of the theory, but intervene merely as a higher order NP effect

Vector-like quarks (VLQ)

- Once produced, vector-like fermions are expected to decay by the exchange of Z, W and H, with decay rates and modes almost completely constrained by the fact that the phase space that does *not* affect the SM is small.

- Down-like 4th generation quarks should appear as a $b'\bar{b}'$ state with

$$b' \to t(\to bW)W$$

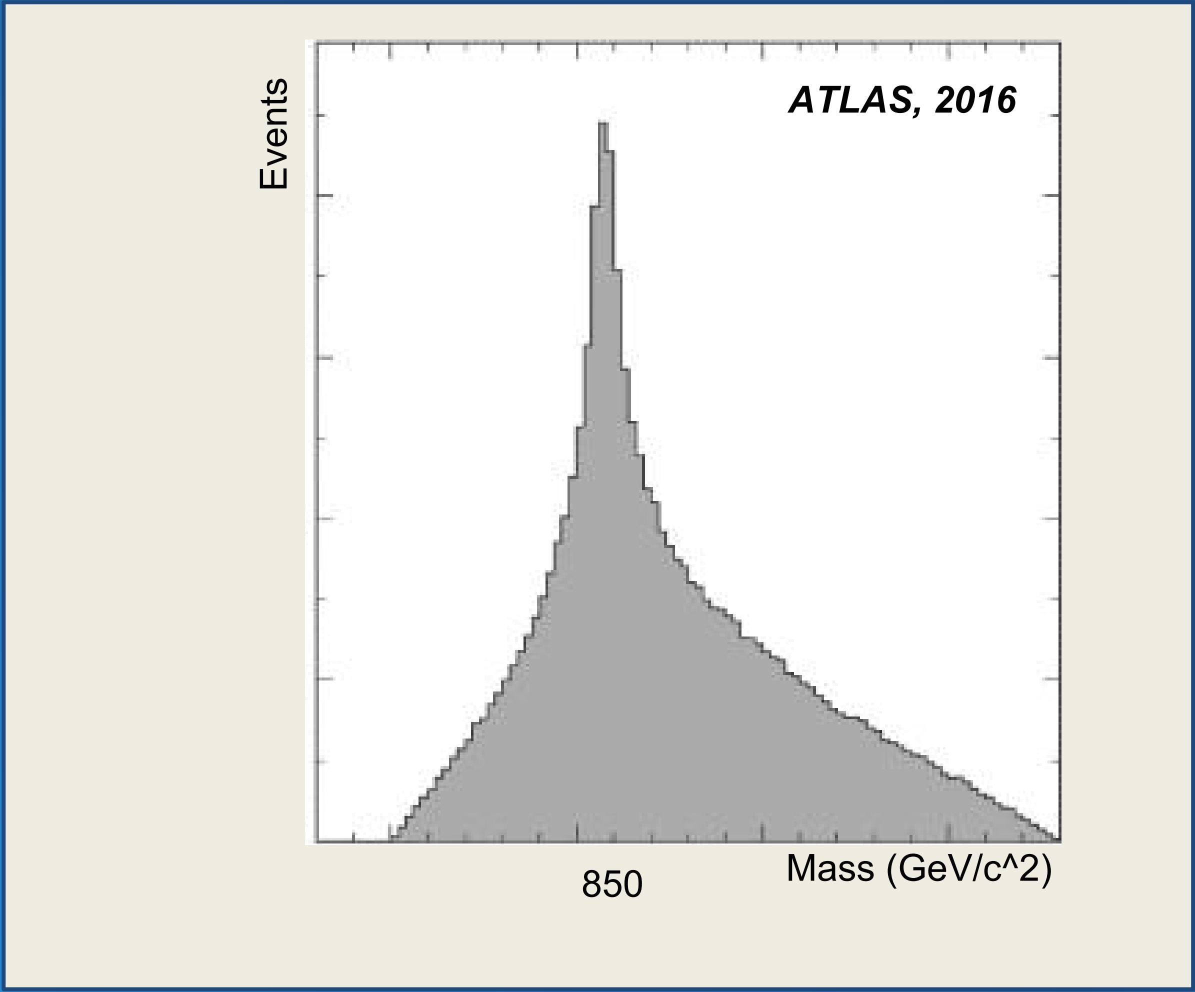


- These events would be characterized by large transverse energy, at least 6 jets (at least 2 from b quarks) and a lepton in the final state

Part II

the experiment

Look, a b'-quark!



The b'-factory

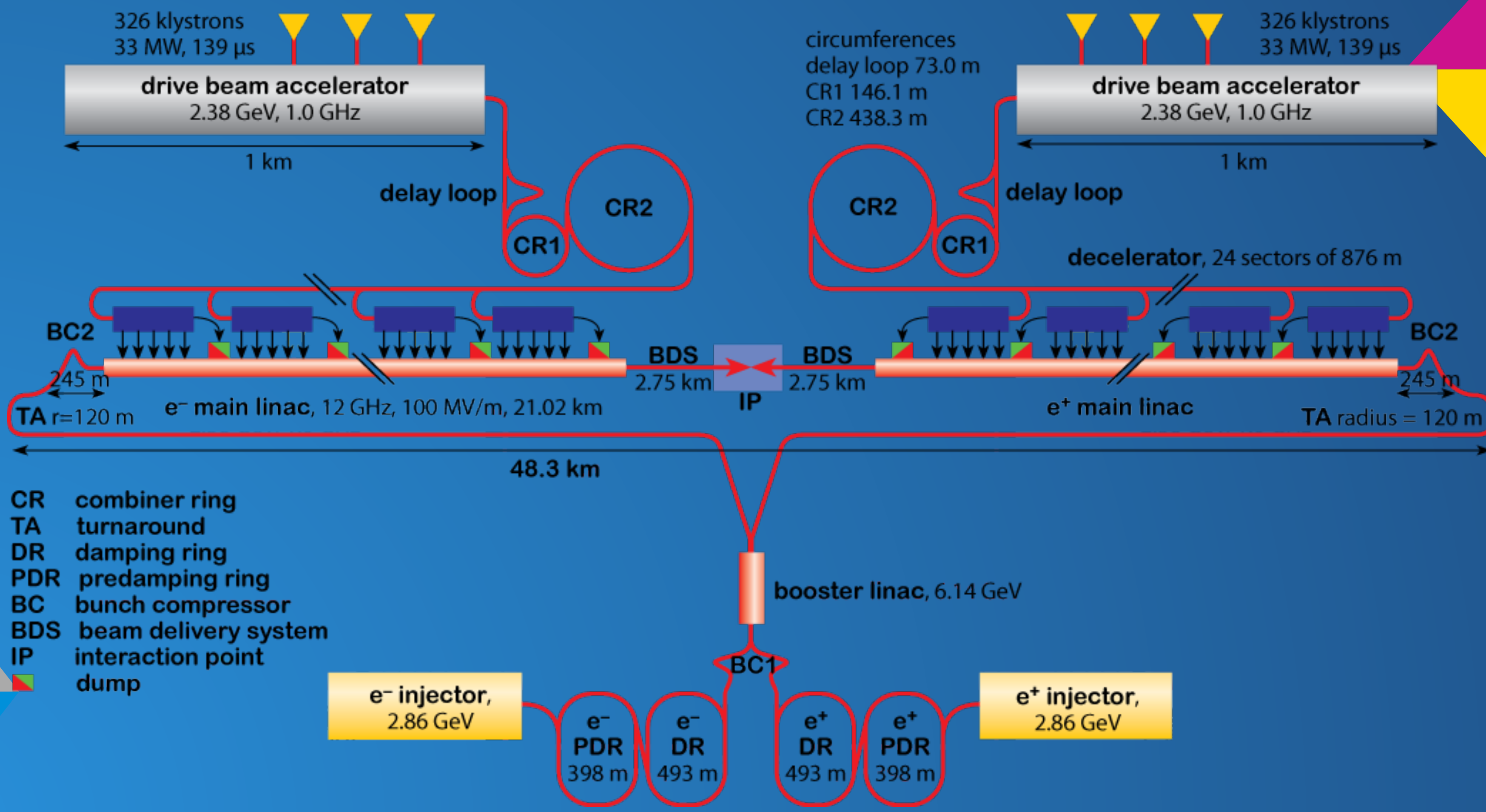
- Produce many b'-quark pairs
- Do so in a clean environment

⟶ lepton collider!

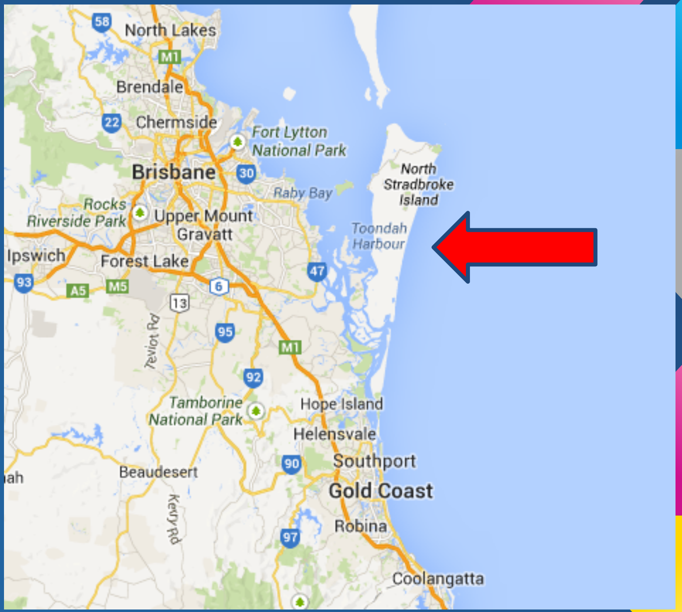
  - low background
  - knowledge of initial energy
  - tuneable center of mass energy

Requires: center of mass energy = 1700 GeV

Ready made plans:



Choosing a building site:
North Stradbroke Island

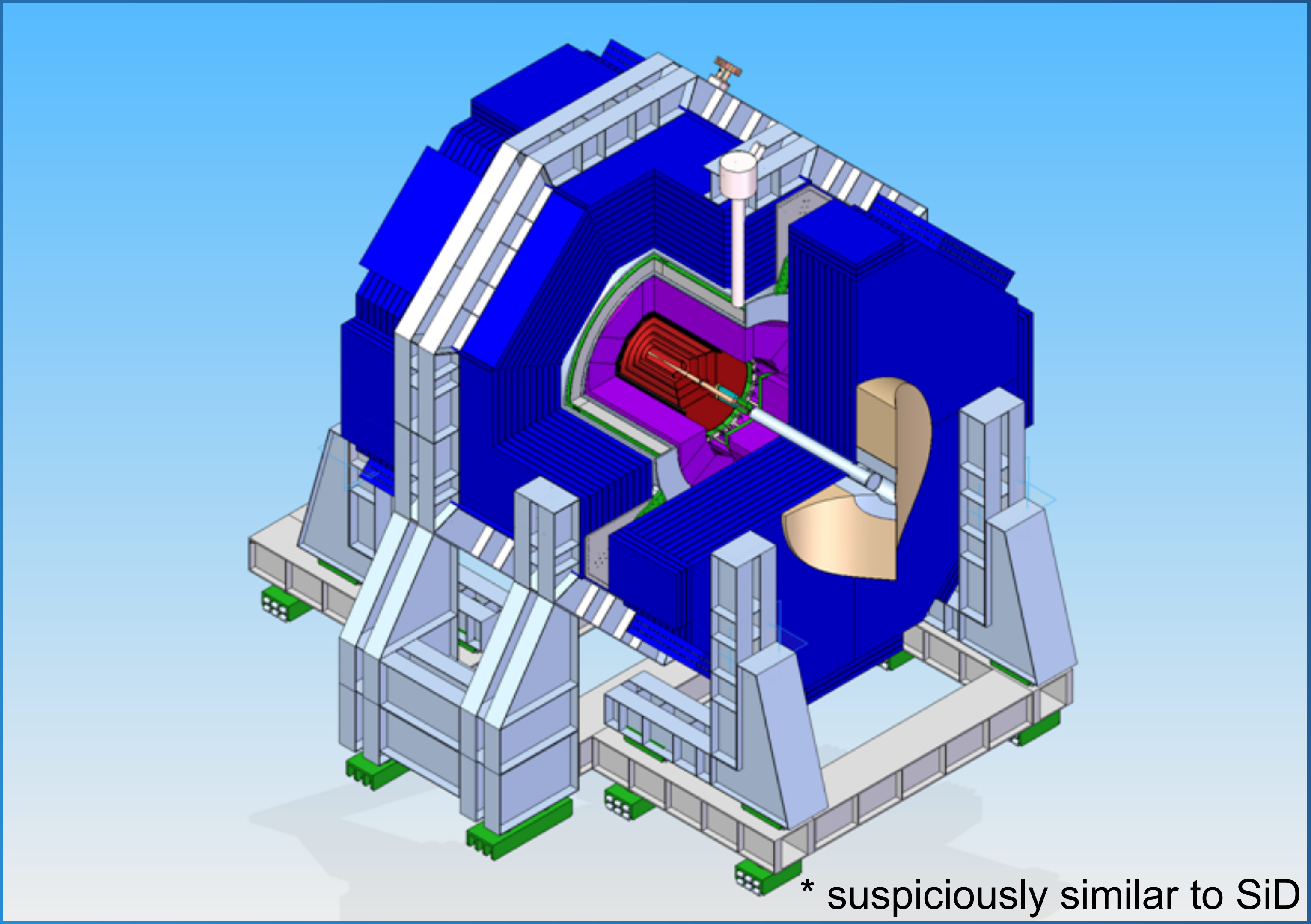


Perfect ...

- ... size (38 km)
- ... climate
- ... beaches
- ... travel options

Unfortunately, hardly any nightlife

Detector Concept*: b4



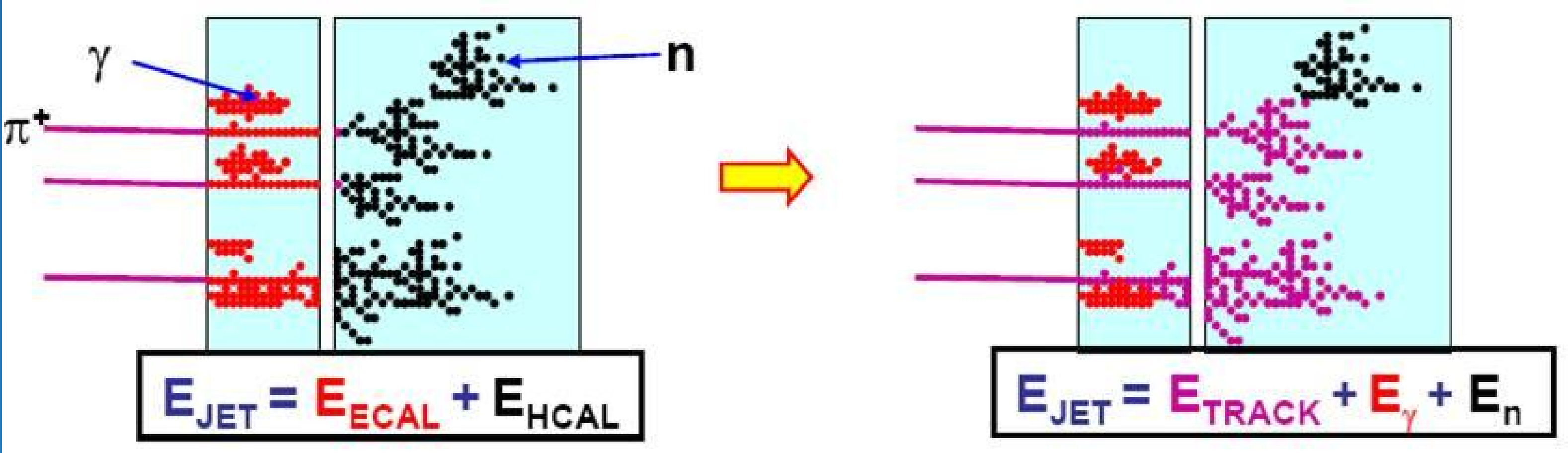
* suspiciously similar to SiD

Detector Subsystems

- Vertex detector/Tracker: Silicon pixels/strips
- EM calorimeter: Silicon/Tungsten
- Hadron Calorimeter: RPC/Steel
- Magnet: 5T solenoid
- Muon system: Scintillator/Steel

⇨ Detector design optimized for "Particle Flow" calorimetry. (highly segmented, etc.)

The "Particle Flow Algorithm"



- conventional: $E_{jets} = E_{ECAL} + E_{HCAL}$
- particle flow: use superior resolution of tracker to measure energy of charged particles --

$$E_{jets} = E_{tracks} + E_{\gamma} + E_{n}$$

can balance total event energy

→ "**total** missing energy"

Analysis strategies, 1

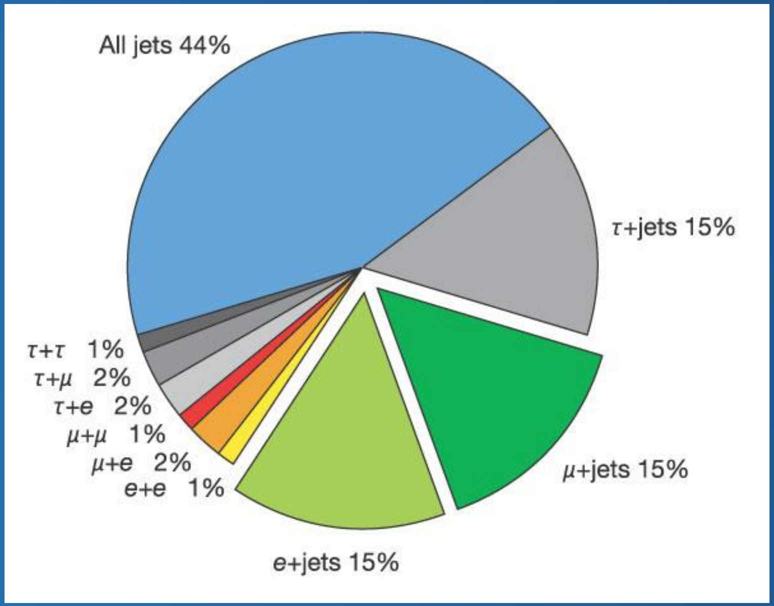
an analog b'-detector:

energy resolution... not great.

Analysis strategies, 2

- $e^+e^- \rightarrow Z \rightarrow$ b'bbar' $\rightarrow$ tW tbarW
- search in all-hadronic channel, to make use of the excellent energy resolution of the detector
    - each tW:
      b + (had.) + (had.)

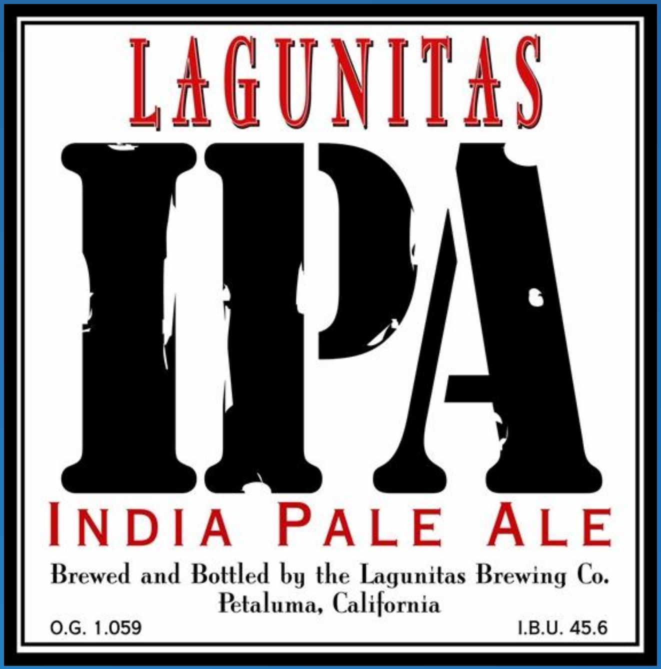
top decays



Summary

- Barely any scenarios left that allow for a b'-quark
- Should we discover one, we need a linear collider to study its properties
- CLIC is eminently suitable for this purpose by virtue of its design energy
- The SiD detector is an excellent example of the kind of detector we would need for precise measurements of the properties of a b'-quark

Credits



- Dennis
- Geert-Jan
- Giovanni
- Huilin
- Liza
- Lucia
- Michela
- Rogier

Backup slides

Why we need a dutch mountain

Please ask Stefan (in the audience)

And now: beer


BREWING COMPANY
DESCHUTES
Big Sky Brewing
SNAKE RIVER BREWING CO.
JACKSON HOLE, WYOMING
BIG DOG'S BREWING COMPANY
LAS VEGAS
UINTA BREWING
AVERY BREWING
UPSTREAM BREWING COMPANY
MILLSTREAM
BREWING CO.
MARBLE BREWERY
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Or what?