Probing Electroweak Symmetry Breaking at LHC : Higgs Physics with CMS Detector

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University partner:
Prof. Thomas Müller, University of Karlsruhe

Scientific Career

- Undergraduate studies at Minsk State University (1990-1995)
- Junior researcher at NCPHEP Minsk (1995-1999)
  - prototyping CMS hadron calorimeter
  - hadron physics at Serpukhov accelerator
- Ph.D. studentship , DESY-Zeuthen, HU Berlin (1999-2002) [2 years at CERN]
  - searches for neutral Higgs boson with L3 experiment at LEP/CERN
- DESY Fellowship, Hamburg (2002-2005)
  - studies of ILC physics potential (Higgs & SUSY physics)
  - design and simulation of hadron calorimeter prototype for ILC
- Post doc at MPI Munich (2005-now)
  - development of reconstruction tools for the ILC detector (tracking algorithms)
  - physics studies for ILC (Higgs and top quark physics)
  - study of the proton structure in e-p collisions at HERA/DESY
- Supervision of 1 Ph.D. student and 1 diploma student
- Convener of the world-wide ILC Higgs Working Group

Standard Model

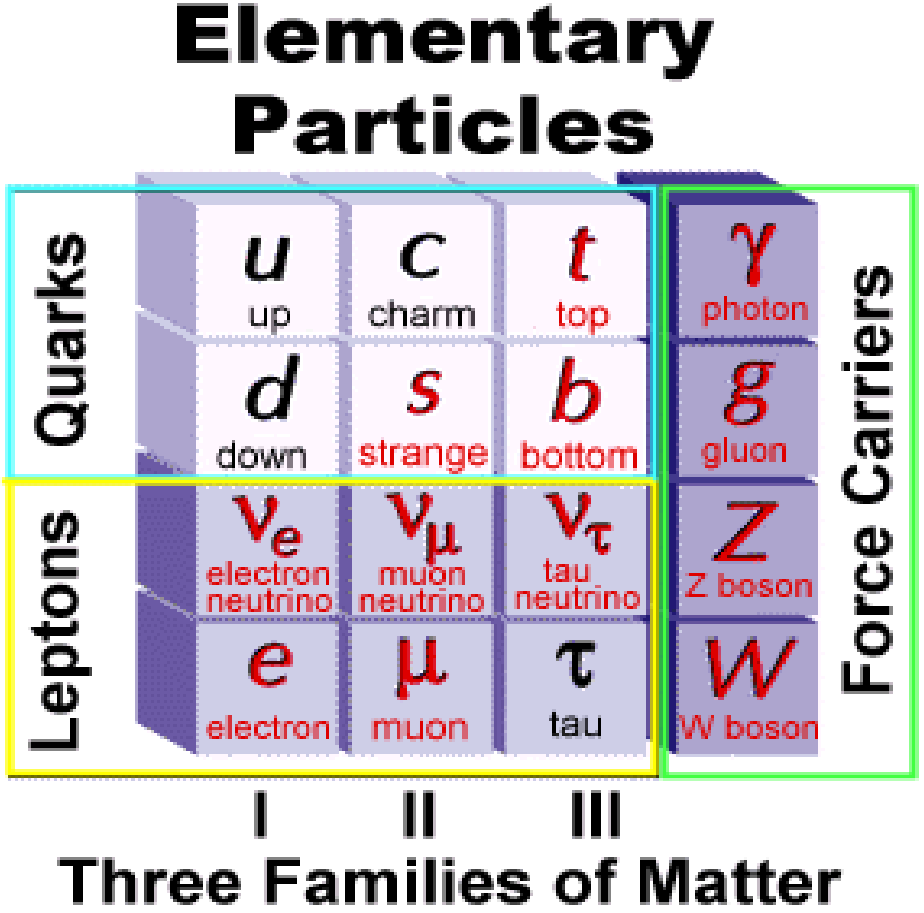
Ingredients ⇒
- elementary particles
- gauge interactions

Aesthetic feature ⇒

- ***SU(3) x SU(2)xU(1) gauge symmetry***

SU(3) – strong interactions :
8 massless gluons

SU(2)xU(1) – electroweak interactions
γ massless, $W^{\pm}$,Z massive



SM has been extensively tested at SPS, HERA, LEP, Tevatron...!

- But... W and Z masses violate gauge symmetry ⇒ mechanism is needed which explains electroweak symmetry breaking

Higgs mechanism

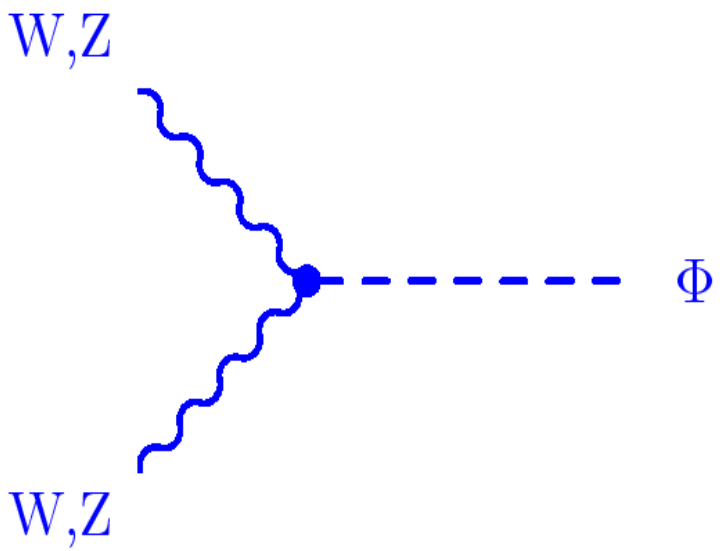
- new field : complex scalar doublet

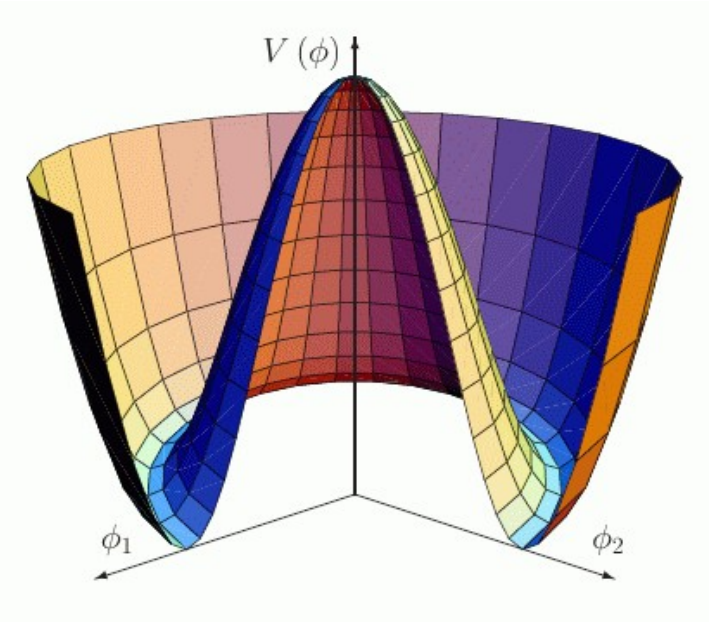
$$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$$

- with specific potential

$$V(\Phi^\dagger\Phi) = \lambda\left(\Phi^\dagger\Phi - \frac{v^2}{2}\right)^2$$

⇒ ground state (vacuum) with non-zero value of Higgs field





W and Z bosons [as well as other massive particles] acquire mass via interaction with “Higgs vacuum”

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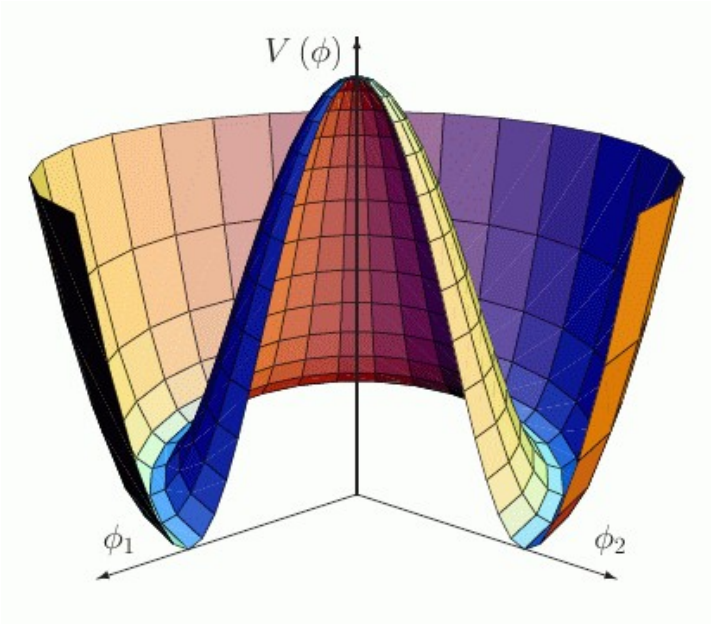

W and Z bosons [as well as other massive particles] acquire mass via interaction with "Higgs vacuum"

"Radial" excitation of ground state

$$\Phi = \begin{pmatrix} 0 \\ \frac{v+H}{\sqrt{2}} \end{pmatrix}$$

gives rise to one more physical state

Higgs mechanism

- new field : complex scalar doublet

$$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$$

- with specific potential

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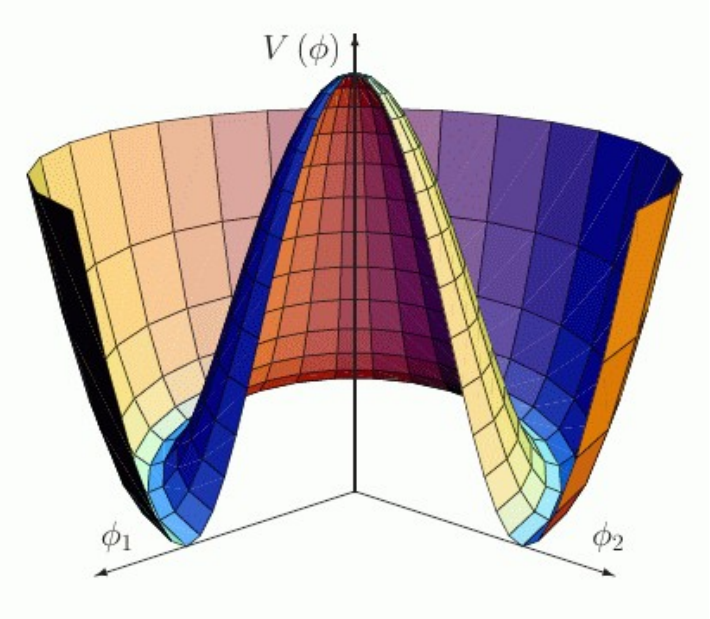


W and Z bosons [as well as other massive particles] acquire mass via interaction with "Higgs vacuum"

Higgs sector in SUSY

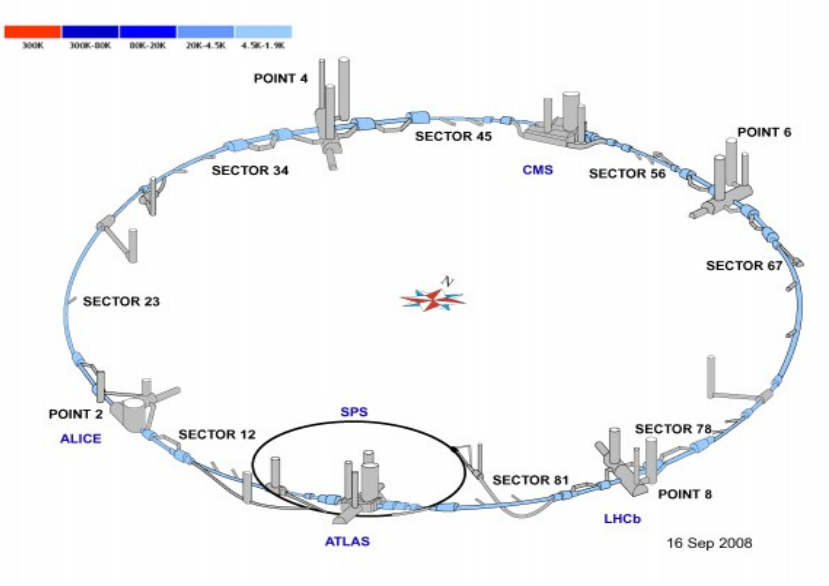
2 doublets ⇒ five physical states
h, H, A (neutral) $H^\pm$ (charged)

enriched Higgs phenomenology

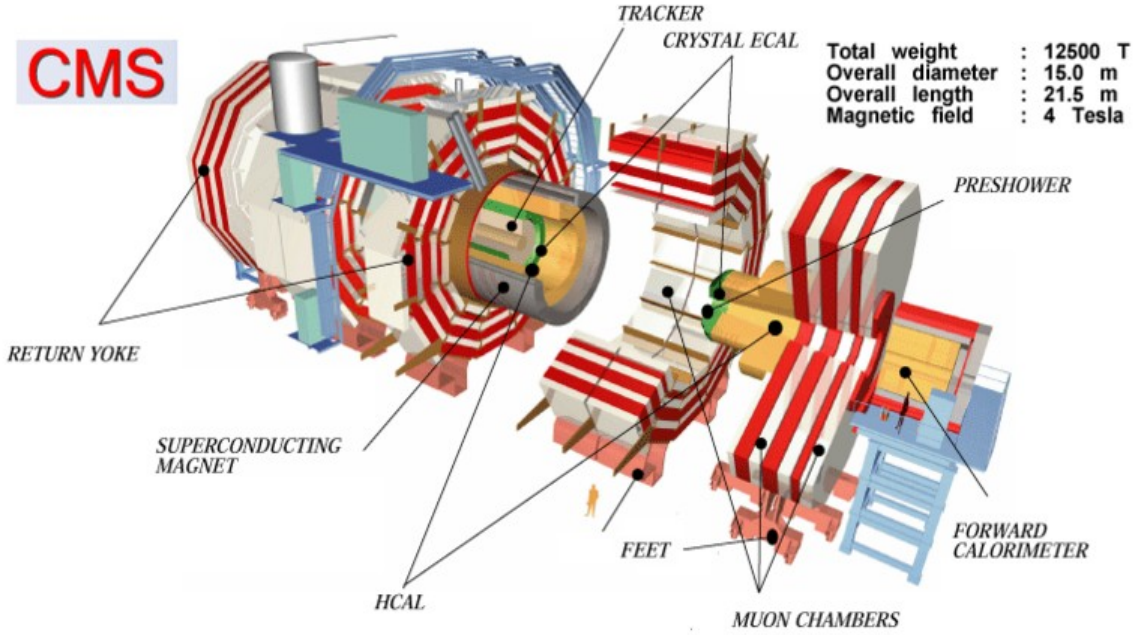
Crucial parameter : tanβ = v_1/v_2

Extended Higgs sector expected in theories beyond the SM, e.g. Supersymmetry (SUSY)

Large Hadron Collider
Place of Future Quest for Higgs Boson



- 27 km storage ring
- two colliding proton beams @ energy 7 TeV, $\sqrt{s}$ = 14TeV (also heavy ion beams)
- few Higgs bosons per minute will be produced
- four experiments : ATLAS, CMS, ALICE, LHCb

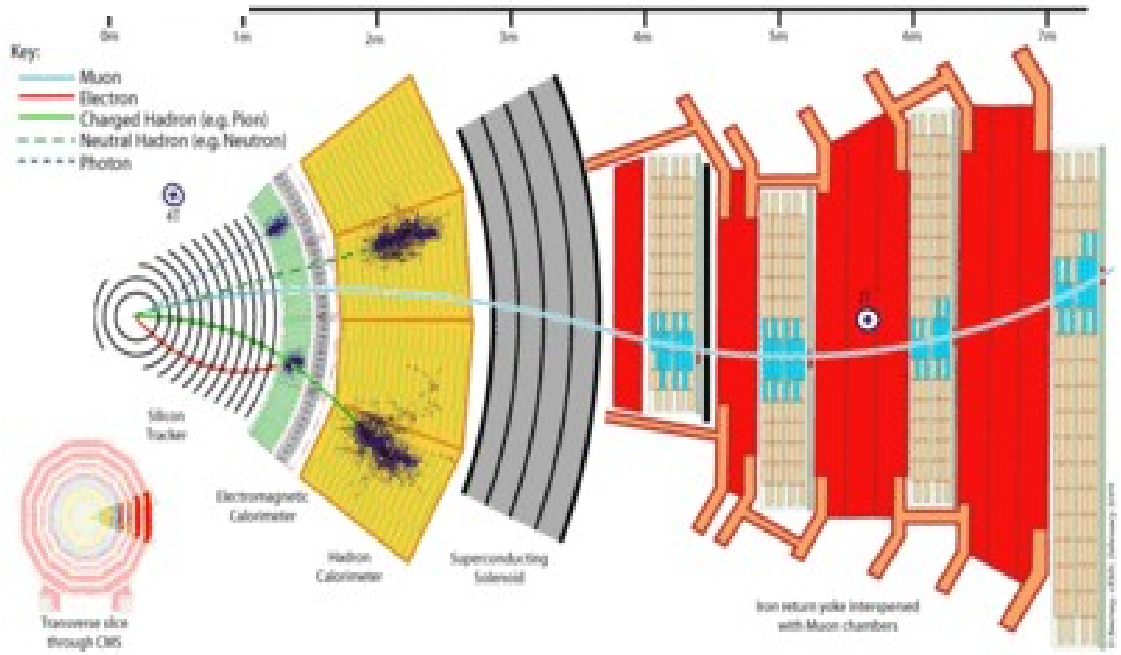


Compact Muon Solenoid

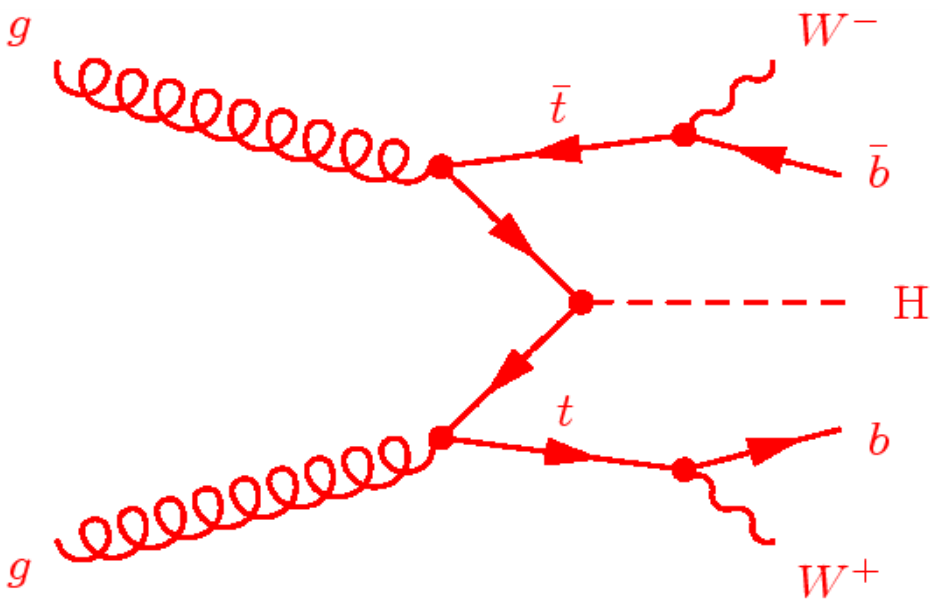
- **Main purpose : reconstruction of particles resulting from decays of heavy states (*H, W, Z etc*) produced in pp collisions**
- **Consists of components each specialized for certain task**

Design features

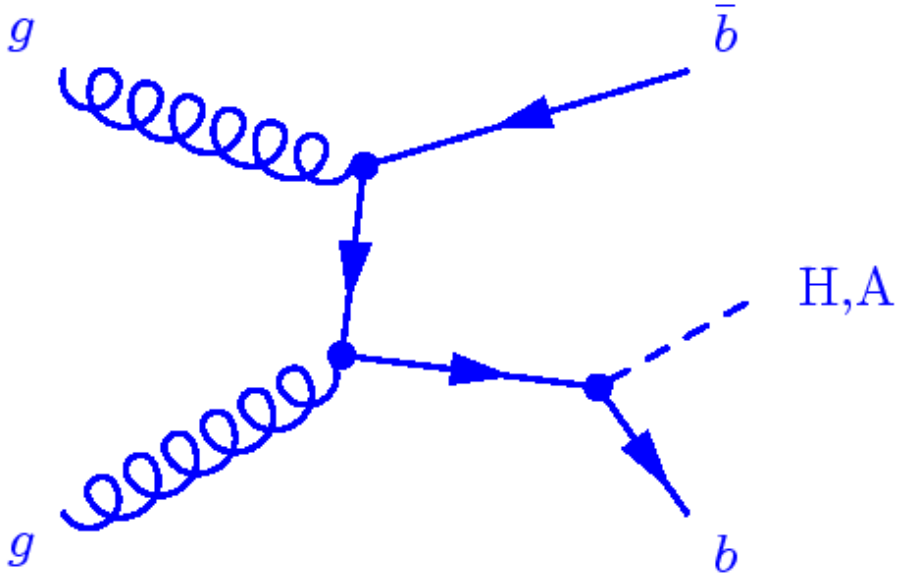
- universality
- hermeticity
- high granularity
- excellent EM calorimetry
- precise vertexing
- radiation hardness



Channels to be Studied by YIG



- moderate rate in SM
  enhanced rate in SUSY at low *tanβ*
- promising channel : *Htt→bbbbqqℓν*



- vanishing rate in SM
  enhanced rate in SUSY at high *tanβ*
- promising channel : *H(A)bb→ττbb*

Probe of Higgs couplings to heaviest fermions!

Signal Signatures	**Analysis prerequisites**
multi-jet final states	⇒ excellent jet reconstruction
presence of b hadrons	⇒ precise vertexing (b-jet tagging)
isolated leptons (e,μ,τ)	⇒ efficient lepton identification

Goals of YIG

- Physics commissioning (pre-analysis tasks)
  - improvement of Monte Carlo event generators
  - calibration/tuning of b-tagging with reference SM processes
  - calibration of jet energy with reference SM processes
- Design of analysis tools to detect *Htt and H(A)bb*
  - optimization of electron and muon and τ-lepton identification
  - optimization of jet clustering algorithm
  - elaboration of event selection procedure
- Measurements of physical observables : Higgs mass, cross sections
- Phenomenological interpretation of physical observables $\Rightarrow$ constraints on new models

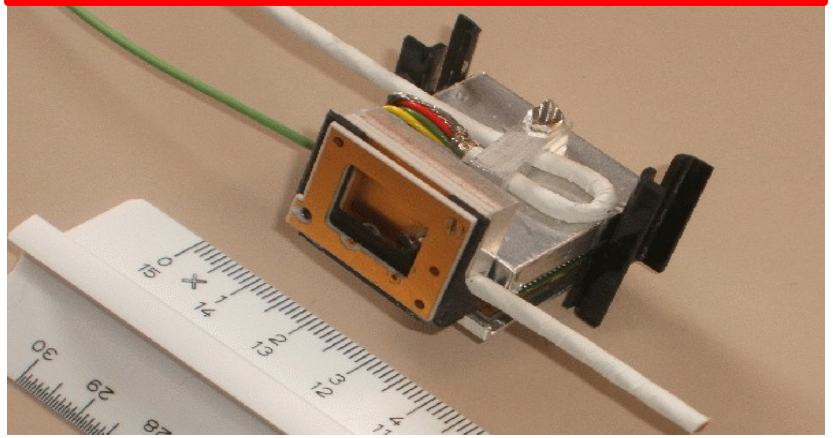
Hardware Contribution of YIG

- LHC detectors will operate in hostile radiation environment

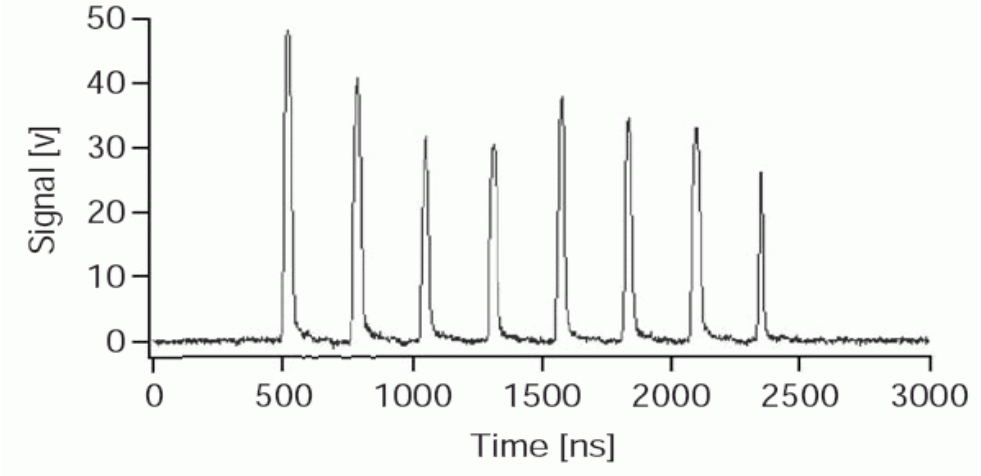
⇒ radiation hard Beam Condition Monitor

  - provides fast diagnostics of beam condition to ensure safe operation
  - measures beam halo flux and generates beam abort signal if flux exceeds acceptable level

element of BCM based on Chemical Vapour Deposited Diamond



Response of BCM sensor to 8 bunches of ~ 10^8 protons/cm^2 (testbeam @ CERN PS)

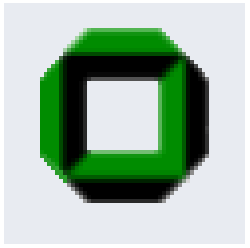


planned group activities

- participation in operation of BCM
- participation in R&D of radiation hard fast sensors for luminosity upgrade of LHC [superLHC] and future e^+e^- linear collider

Structure of Group and Networking

Collaborative work,
seminars, teaching



YIG of Dr. Melzer-Pellmann

collaboration on jet energy calibration

Alexei Raspereza
(Group Leader)
Post doc + 2 Ph.D. students

- Jet calibration
- Improvement of MC event generators
- *gg→Hbb* analysis
- SUSY parameter analysis based on observables in the Higgs sector
- BCM operations and R&D

U. Karlsruhe
Prof. T. Müller
1 Ph.D. student

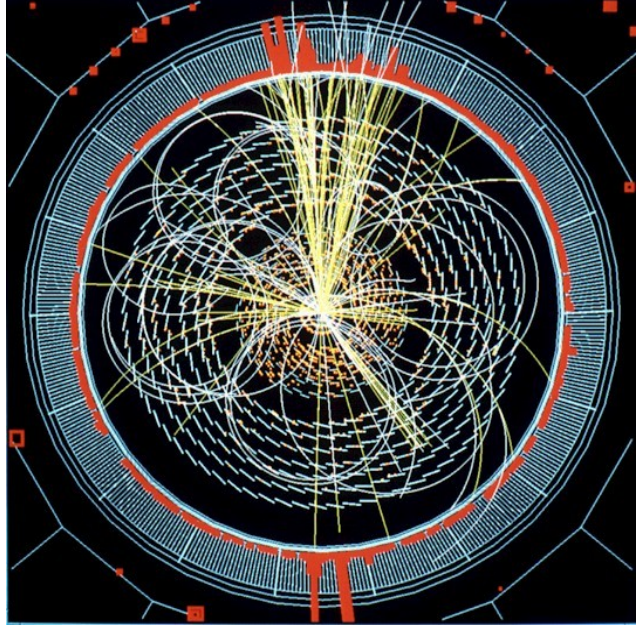
- B-tag calibration
- *gg→Htt* analysis
- BCM operations, R&D

Theory Group at DESY

collaboration on the Higgs boson phenomenology

Helmholtz Alliance Analysis Center at DESY

collaboration on improvement of MC event generators



Elucidating EW Symmetry Breaking Mechanism at LHC will be the next step in our understanding of the fundamental structure of matter.

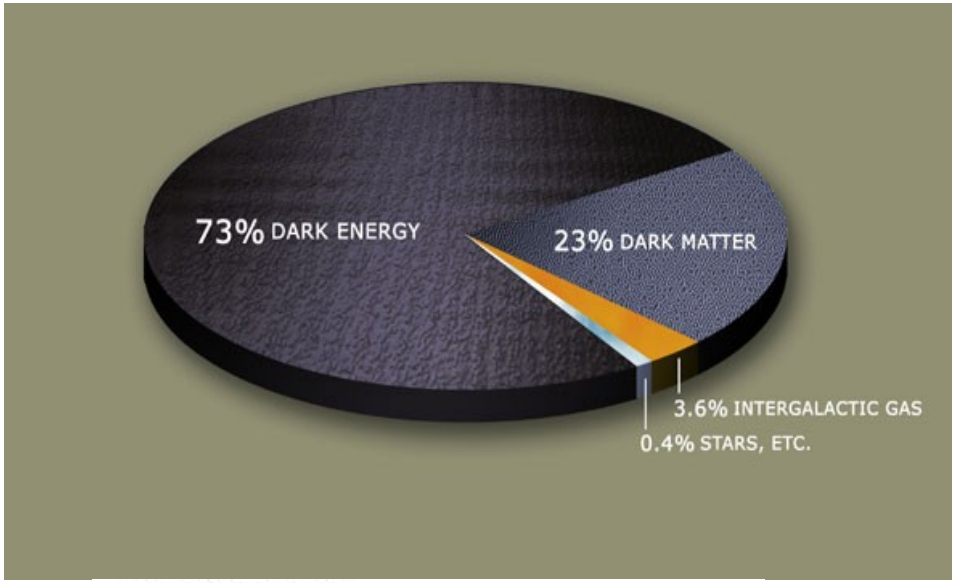
DESY

CERN

Backup slides

Higgs sector in Supersymmetry

- Astrophysics : SM describes only 4% of matter in universe

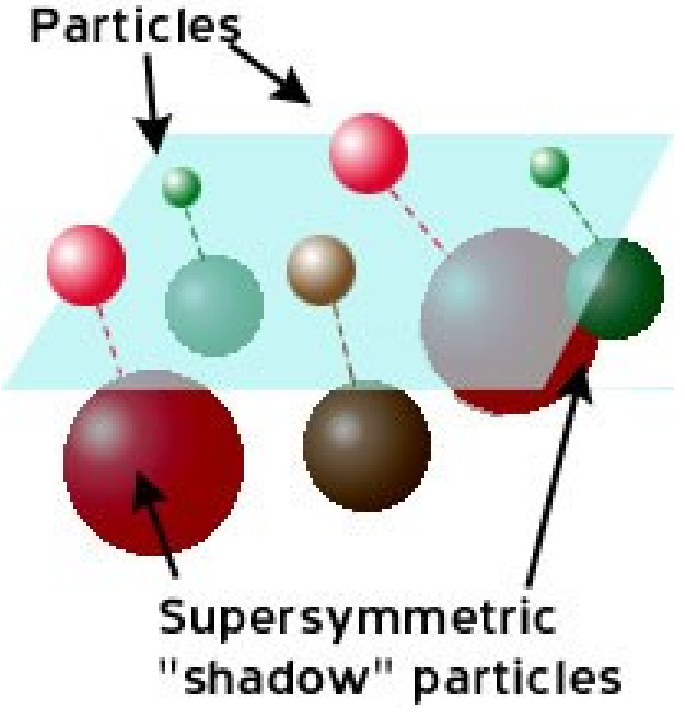


- Supersymmetry – bosons ⇔ fermions

⇒ attractive extension of SM

- ✔ explains dark matter
- ✔ paves road to unification of forces
- ✔ overcomes some flaws of SM

- ✔ SUSY particles – mirror reflection of SM particles at heavier mass scale



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2 doublets five physical states

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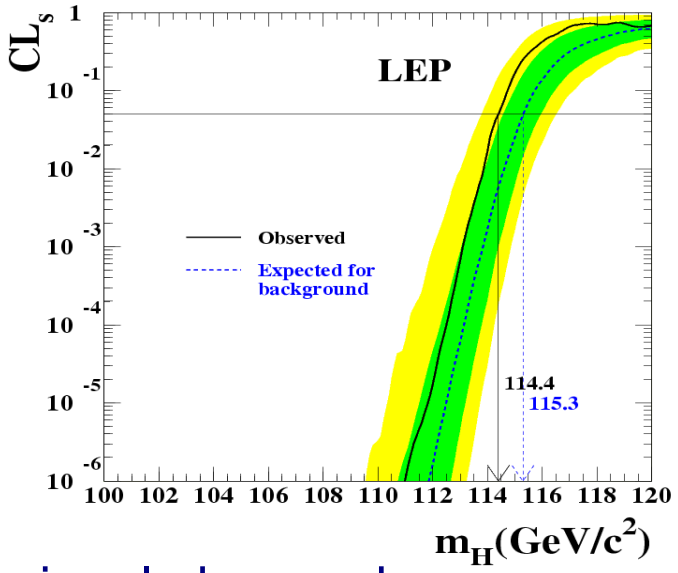
enriched Higgs phenomenology!

Searches for Higgs Boson

Higgs mass not predicted by SM => Higgs boson search

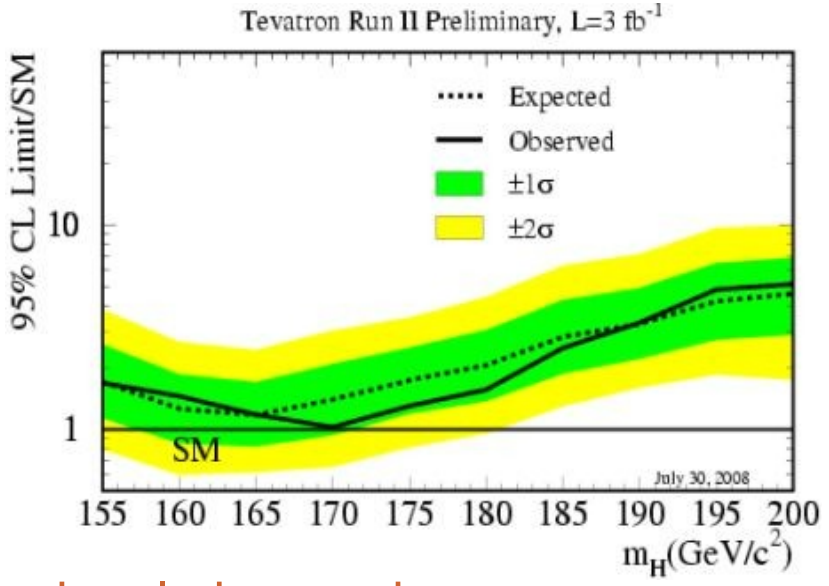
- production of the Higgs boson
- detection of its decay products

- LEP : e+e- collisions at 209 GeV
- Main production mechanism ee→ZH
- Investigated decays : H→bb,$\tau\tau$



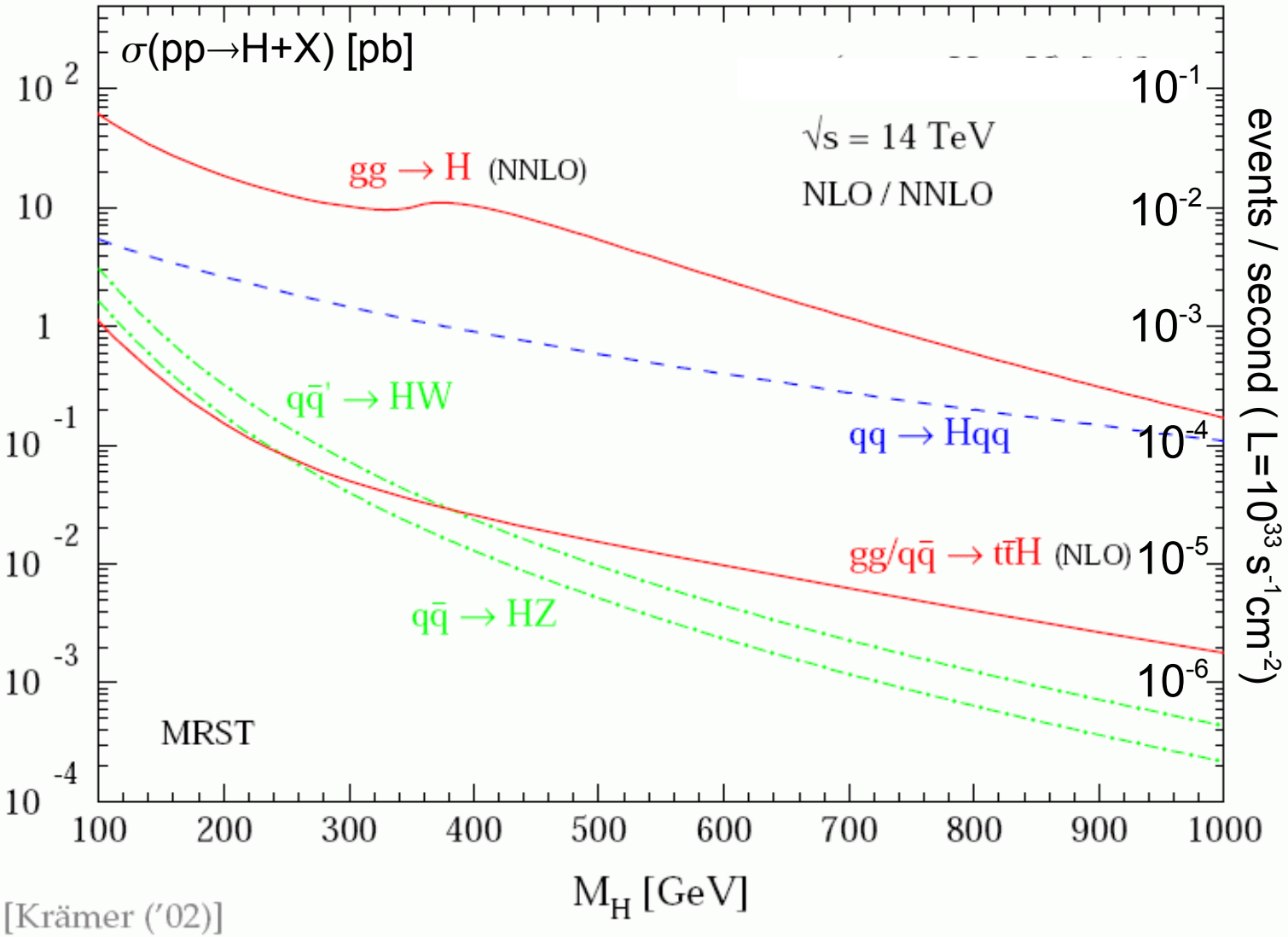
No signal observed
Insufficient energy? Higgs boson might be too heavy for production at LEP

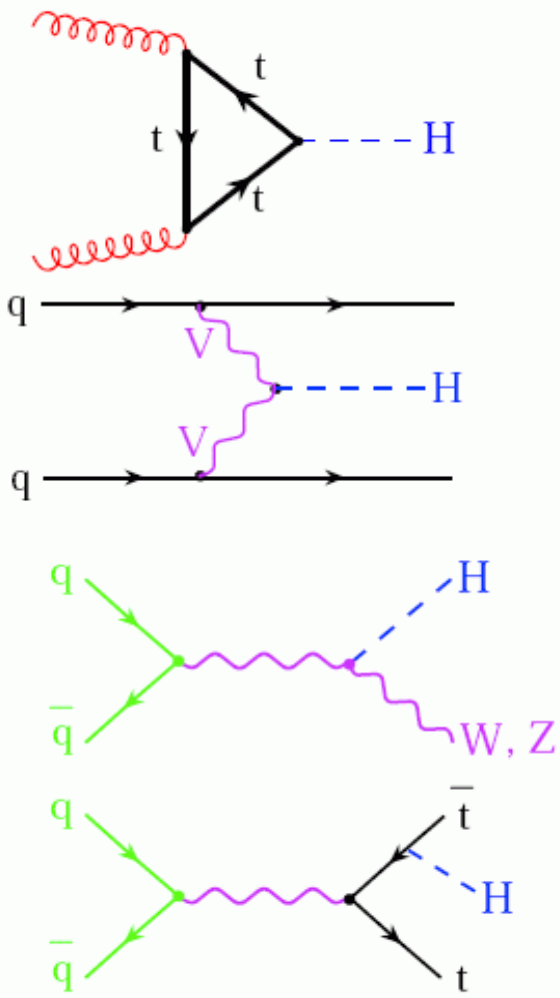
Tevatron : pp collisions at 2 TeV
Production mechanisms qq→WH, gg→H
Investigated decays : H→bb,WW



No signal observed
Insufficient statistics? There might be too few produced Higgs bosons to be distinguished from background

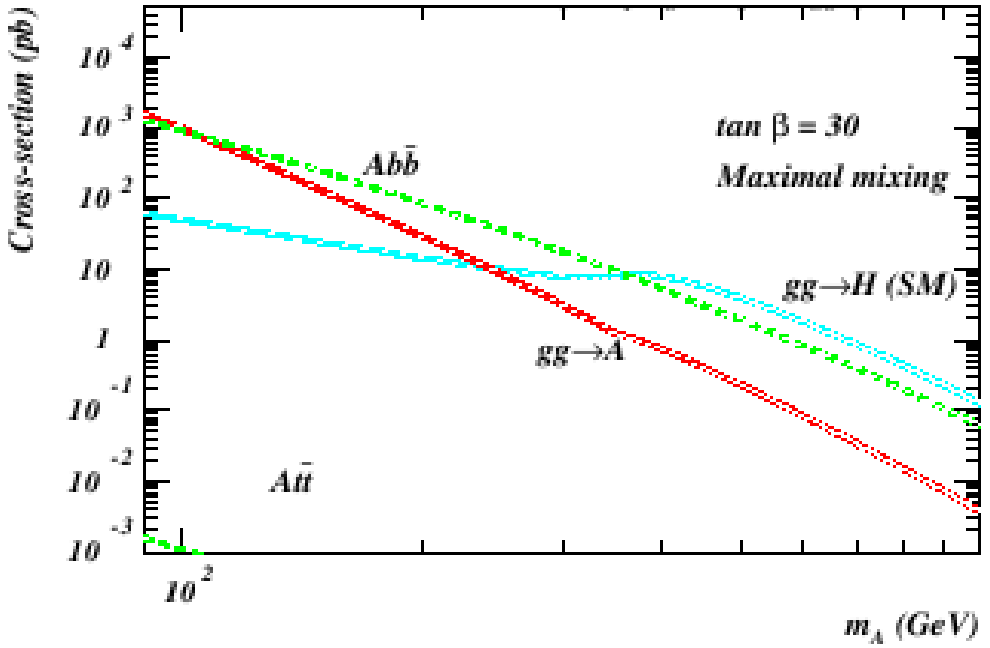
SM Higgs Production at LHC



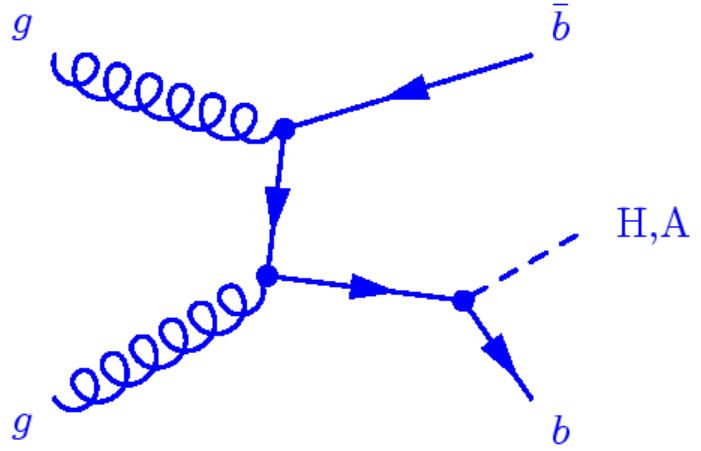


[Krämer ('02)]

MSSM Higgs Production at LHC

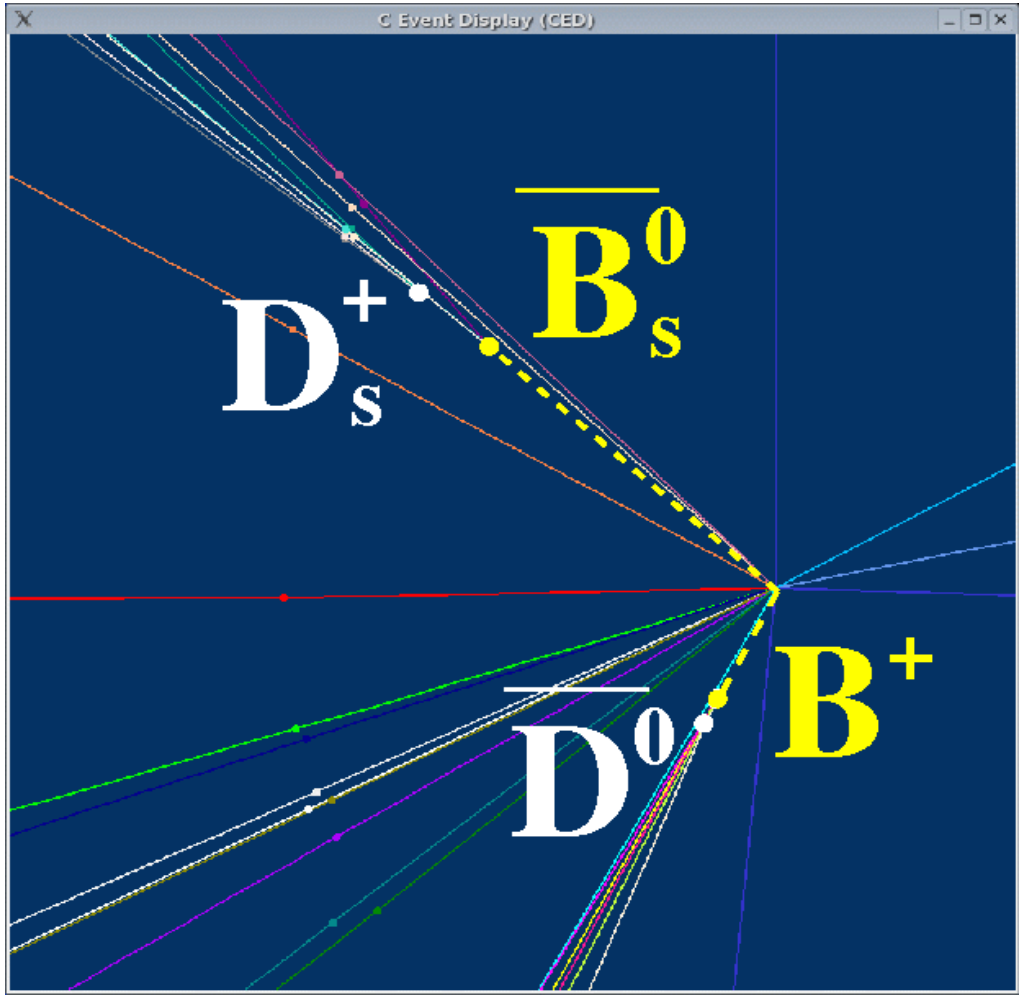


Yukawa Production of SUSY Higgs bosons at high *tanβ*



Signal rate may be larger than for *gg→H* in the SM !
(large *Hbb, Abb* couplings @ high *tanβ*)

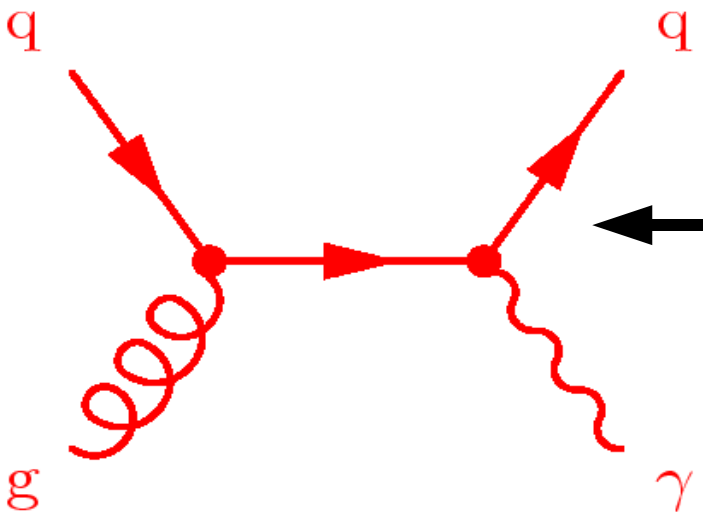
B-Tagging : Tool for Higgs Searches (major contribution of YIG)



- jets from b-quarks contain B-mesons ($\gamma\beta c\tau$ = few mm)
  - secondary vertices, m~m
  - tracks with large impact parameters
  - presence of leptons
- reliable prediction of backgrounds requires accurate calibration of b-tagging
- dedicated calibration sample enriched with b-hadrons, e.g. $t\bar{t} \rightarrow bbWW \rightarrow bbqq\ell\nu$

Jet Energy Calibration

- Calibration of jet energy will be done with $gq \rightarrow qZ(q\gamma)$ samples



$E_{T,\,jet} = E_{T,\,\gamma}$

ECal as calibrator

$E_{T,\,jet} = E_{T,\,\mu\mu}$

Si Tracker and muon system as calibrator