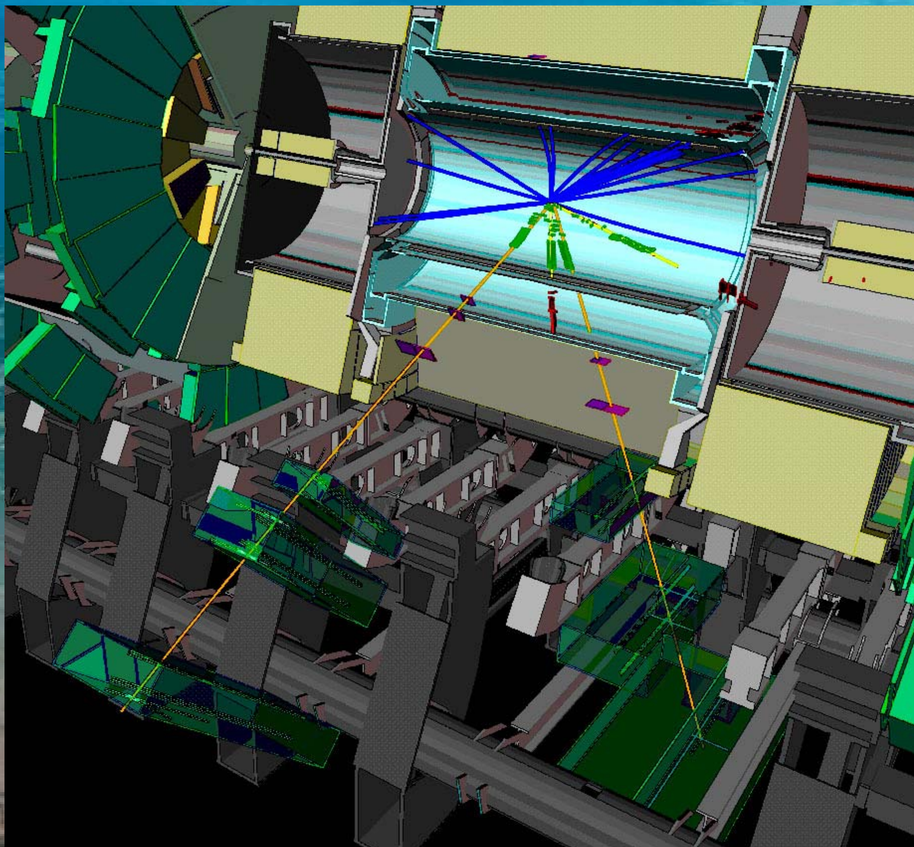
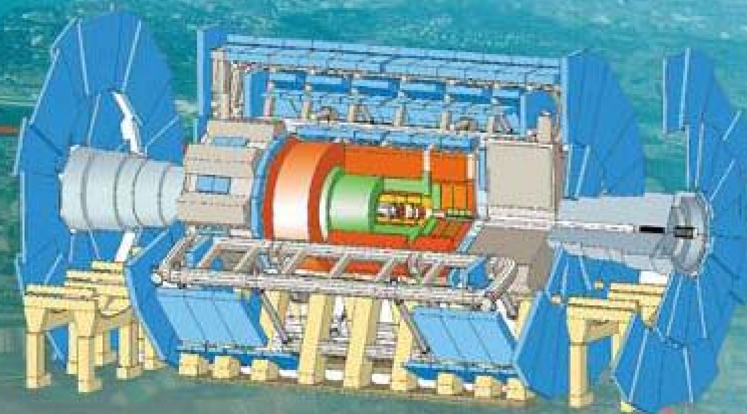
LHCにおけるヒッグス粒子探索

LHC実験の現状と予定
SMヒッグス粒子探索の展望
Non-SMヒッグス粒子の場合
まとめ



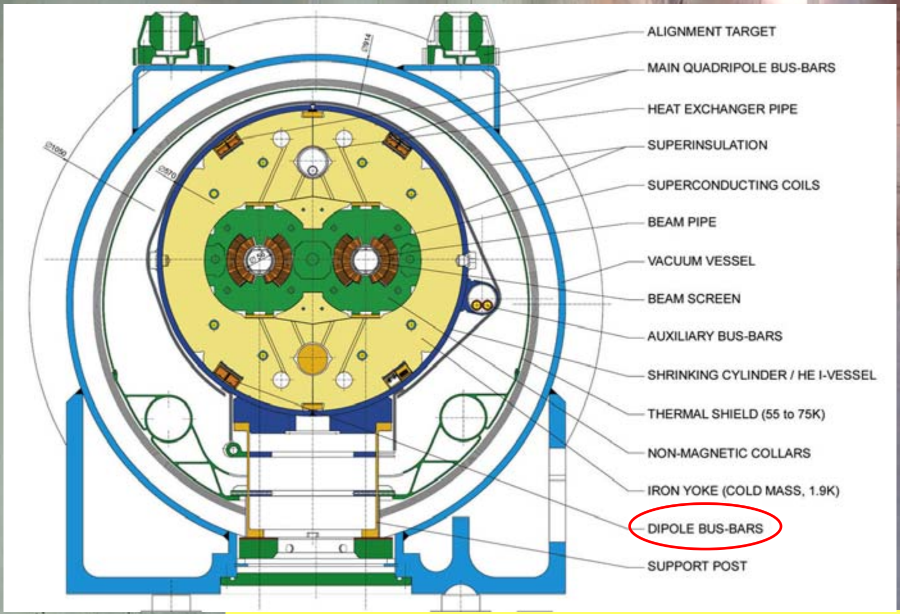


27. Mar. 2009
日本物理学会(立教大)
小林富雄
(東大素粒子センター)

Large Hadron Collider (LHC) at CERN

- 14 TeV の陽子・陽子衝突型加速器
- LEPトンネルを利用
- 建設に14年
- 総建設費は約5000億円
- 2008年9月10日first beam周回に成功

＊CERNのLEP(e^+e^-)は 200 GeV
＊米国フェルミ研究所のTevatron($p\bar{p}$)は 2 TeV

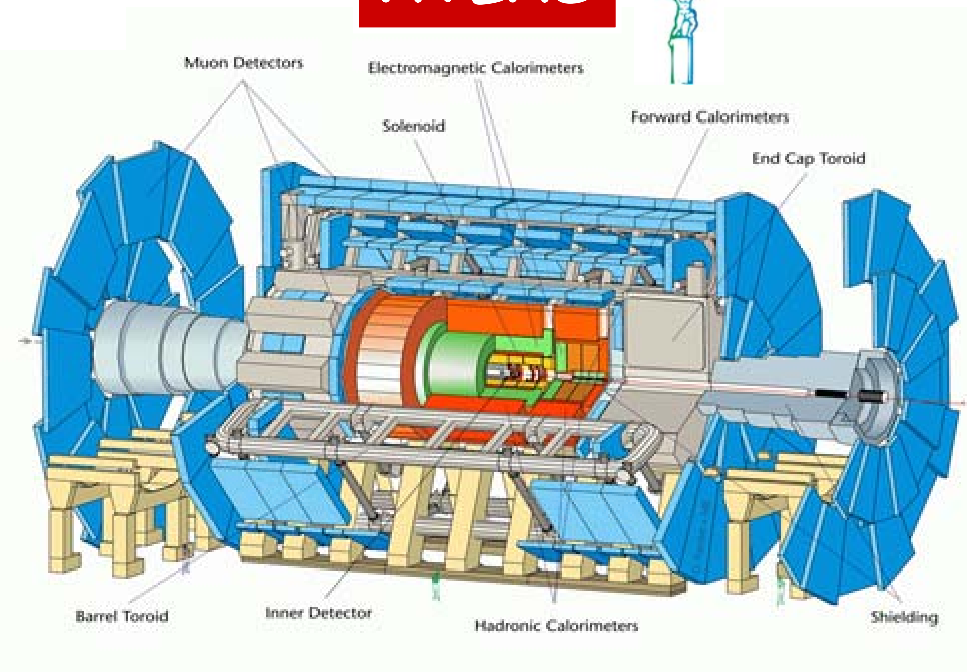


2-in-1超伝導ダイポールマグネット:
磁場強度 8.3T、超流動ヘリウム温度 1.9K、長さ 14.3m、1232台

General purpose detectors for pp collisions

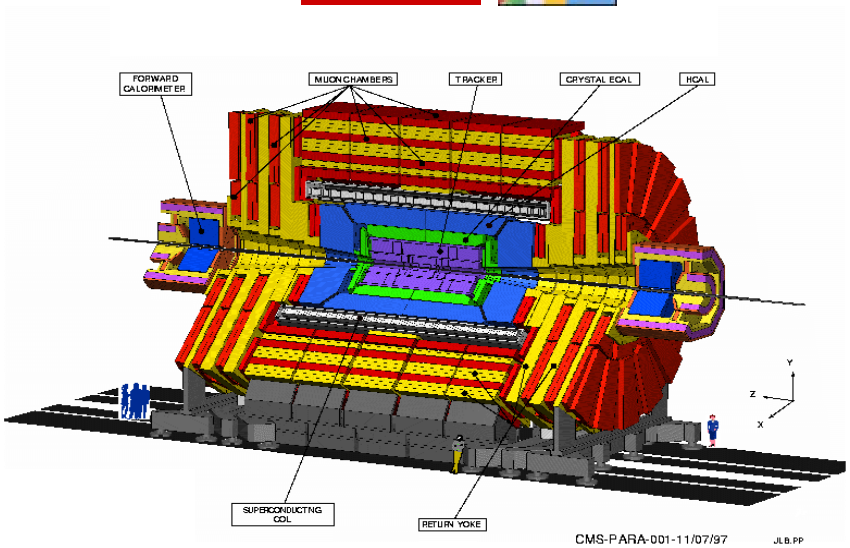
+ LHCb, ALICE, TOTEM, LHCf

ATLAS



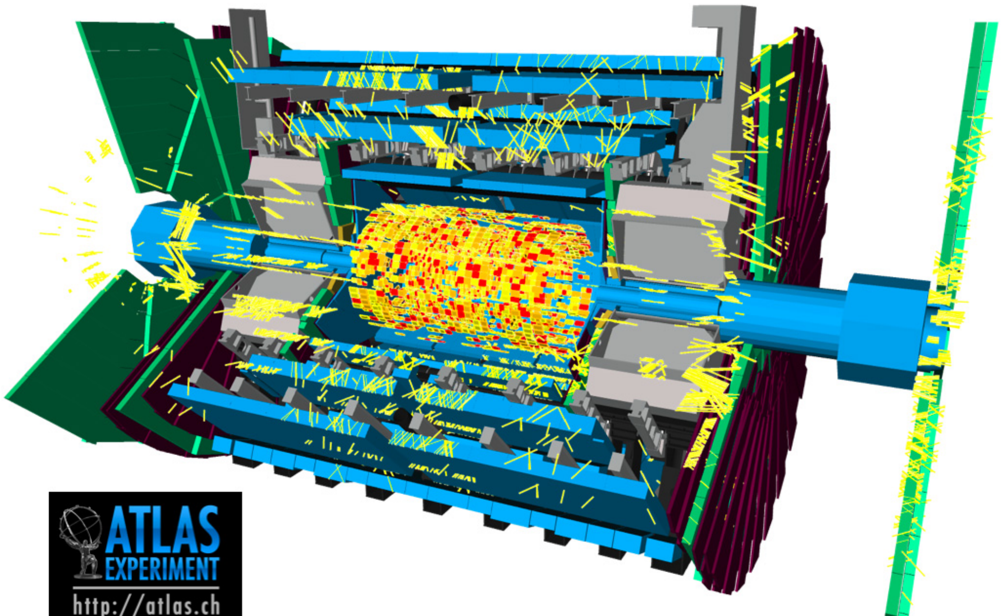
Length : ~45 m
Diameter : ~24 m
Weight : ~ 7,000 tons
Electronic channels : ~ 10^8
Solenoid : 2 T
Air-core toroids

CMS

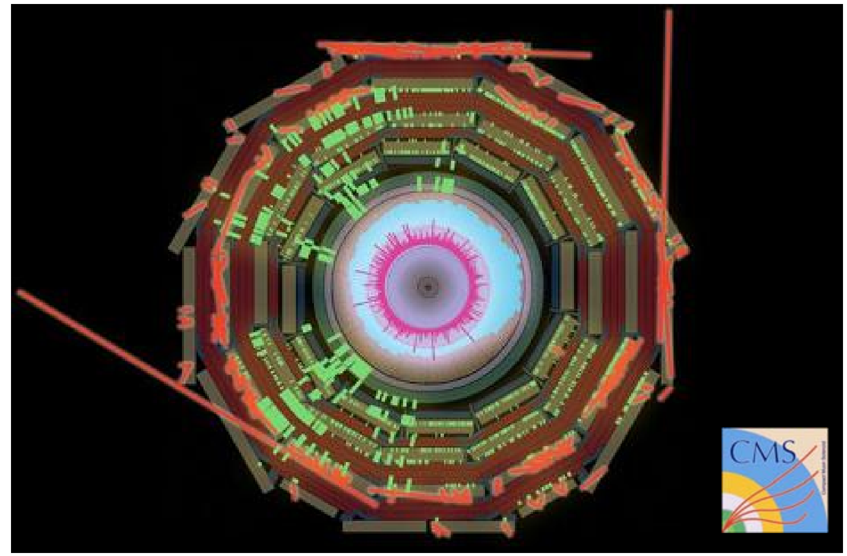


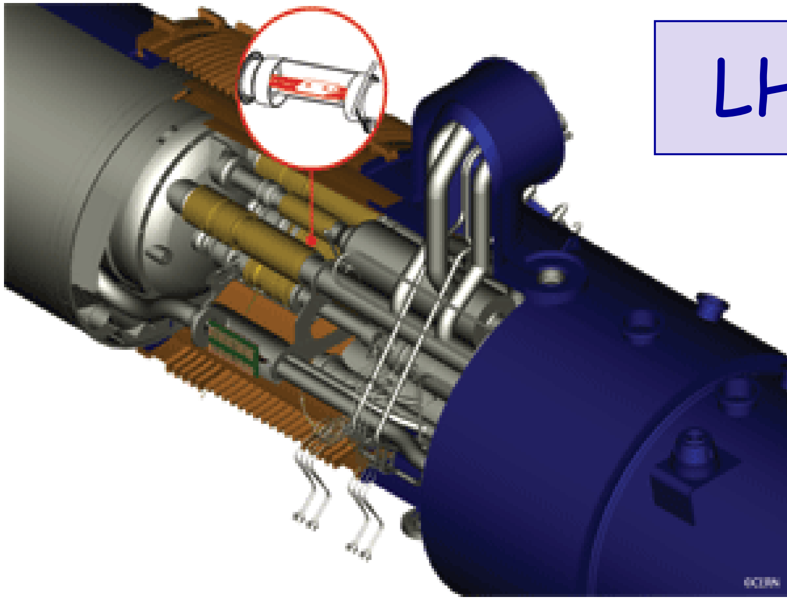
Length : ~22 m
Diameter : ~14 m
Weight : ~ 12,500 tons
Solenoid : 4 T
Fe yoke
Compact and modular

Splash events on Sep.10, 2008
(LHC first beam circulation)



first beam event seen in ATLAS

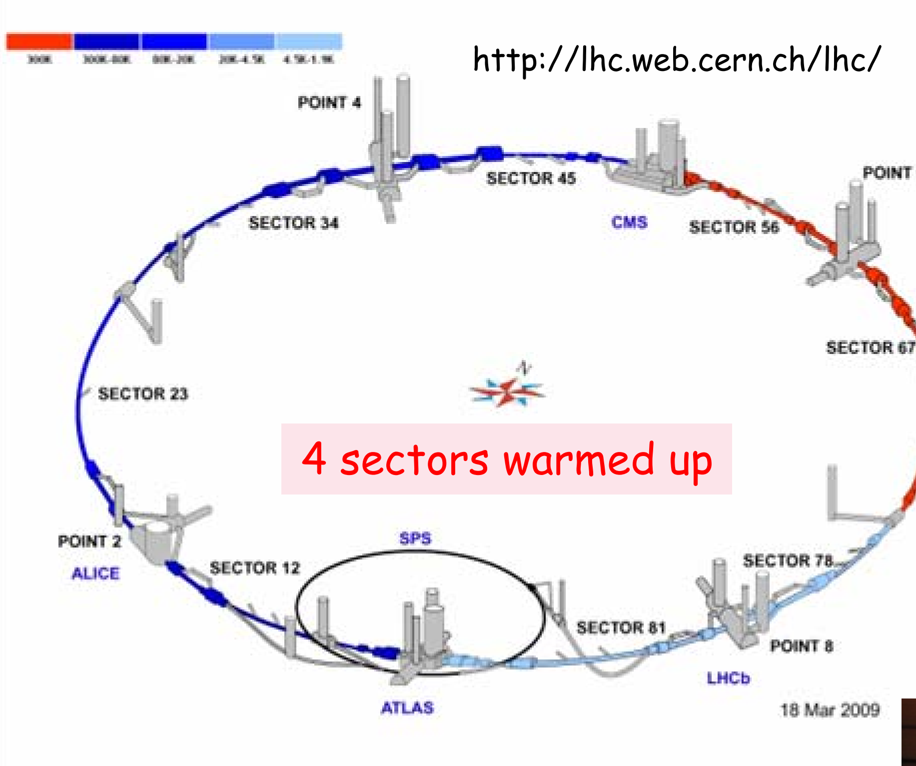




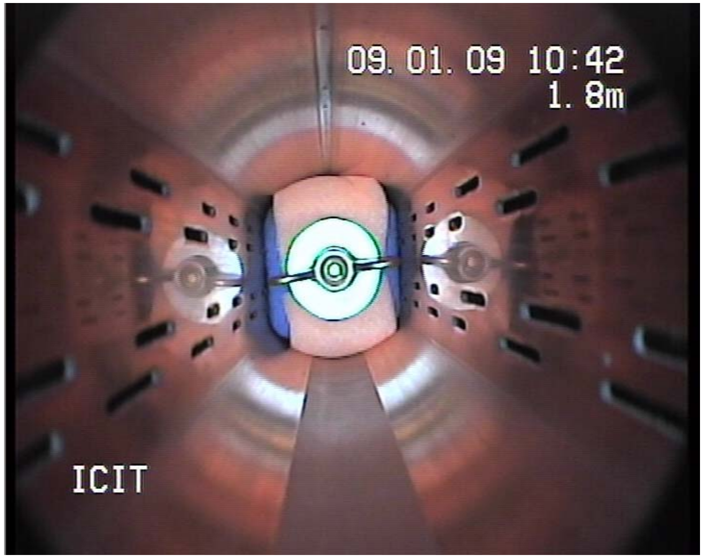
LHC Incident (19 Sept. 2008)

1. Sector34のパワーテスト中、dipoleとQ-magnetの
   超伝導ケーブルバス結線部の抵抗値が増加
   → 温度上昇 → クエンチ → クエンチ保護回路作動
2. 電源トリップが作動したものの、アーク放電が発生
   → 真空（断熱）容器に穴
3. 真空容器内およびビームパイプ内にヘリウムが流出
   → shock wave
4. 減圧排気バルブが開放されたが、
   → 真空隔壁が破壊、いくつかのマグネットが動かされ
   → 6トンのヘリウムがトンネル内に流出（15t/sector）

対策



- 53台のマグネット
  （39 diploles +14 quadrupoles）
  を地上に持ち出して修理・チェック
- クエンチ検出、異常な電圧や熱の
  検出システムの改善
- 安全開放バルブの容量と数を増強
- ビームパイプの掃除
- 真空隔壁を備えたQ−magnetの
  サポートを強化



LHC Inauguration (21.Oct.2008)

(23.Jun.1995)

今年・来年の予定

CERN DG: … foresee first beams in the LHC at the end of Sept. this year, with collisions in late October. A short technical stop over Christmas. Then run through to autumn next year, … possibility of lead ion collisions in 2010.

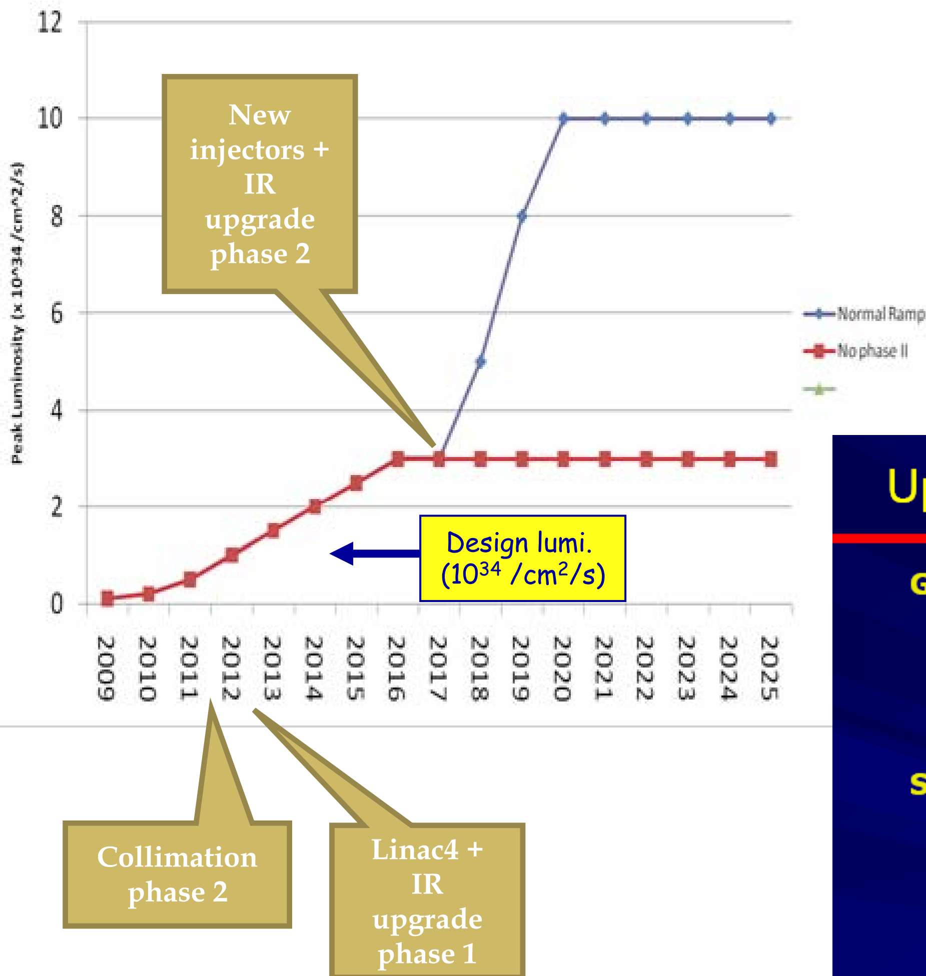
Year	2009											2010														
Month	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
Baseline	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH		SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	SH	SH	SH	SH
	24 weeks physics possible																									
Base '	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	SH	SH	SH	SH	SH	SH
	44 weeks physics possible																									
Delay (4W)	SH	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	SH	SH	SH	SH	SH
Delay (8W)	SH	SH	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	SH	SH	SH	SH

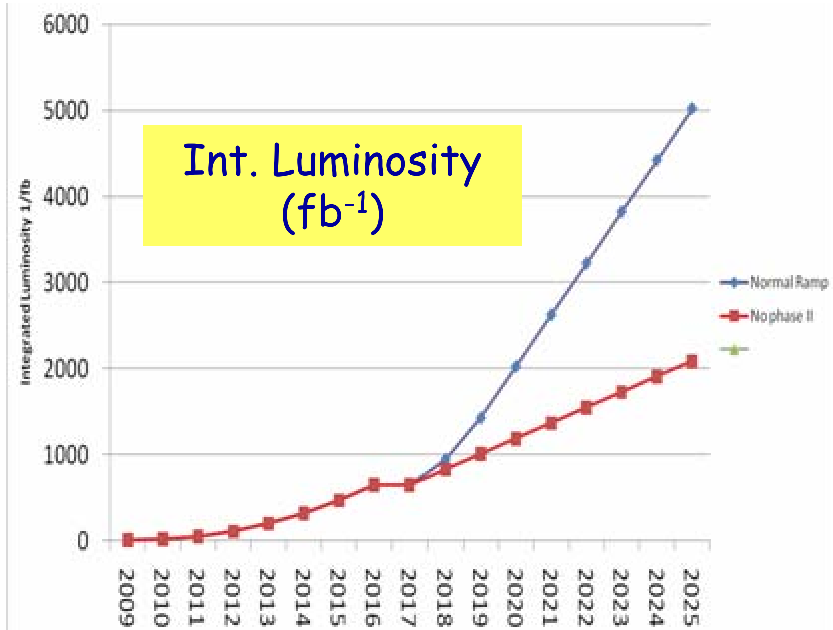
Gain 20 weeks of physics in 2010 by running during winter months

HIGH price Electricity

E_{cm} = 10 TeV
Int. lumi. ~ 200 pb^{-1}

Peak Luminosity
(2008年夏の時点での予想)





2011年: 14TeVでO(1) fb^{-1} (?)
2012年: O(10) fb^{-1} (?)

Upgrade of the LHC insertions: "Phase I"

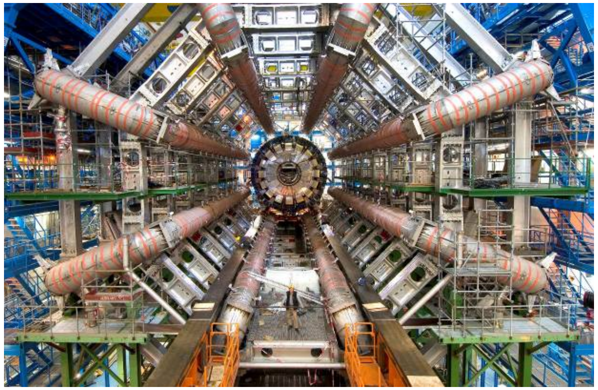
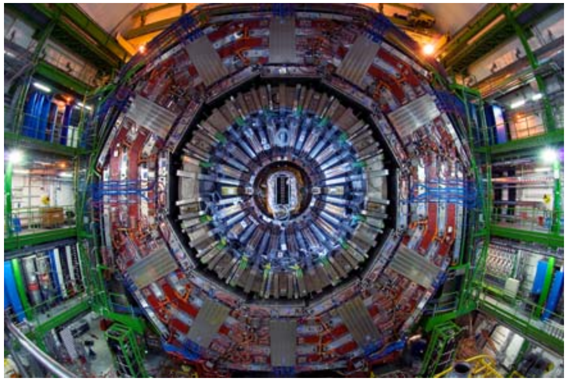
Goal of "Phase I" upgrade:

Enable focusing of the beams to β^*=0.25 m in IP1 and IP5, and reliable operation of the LHC at 2 10^{34} $cm^{-2}s^{-1}$ on the horizon of the physics run in 2013.

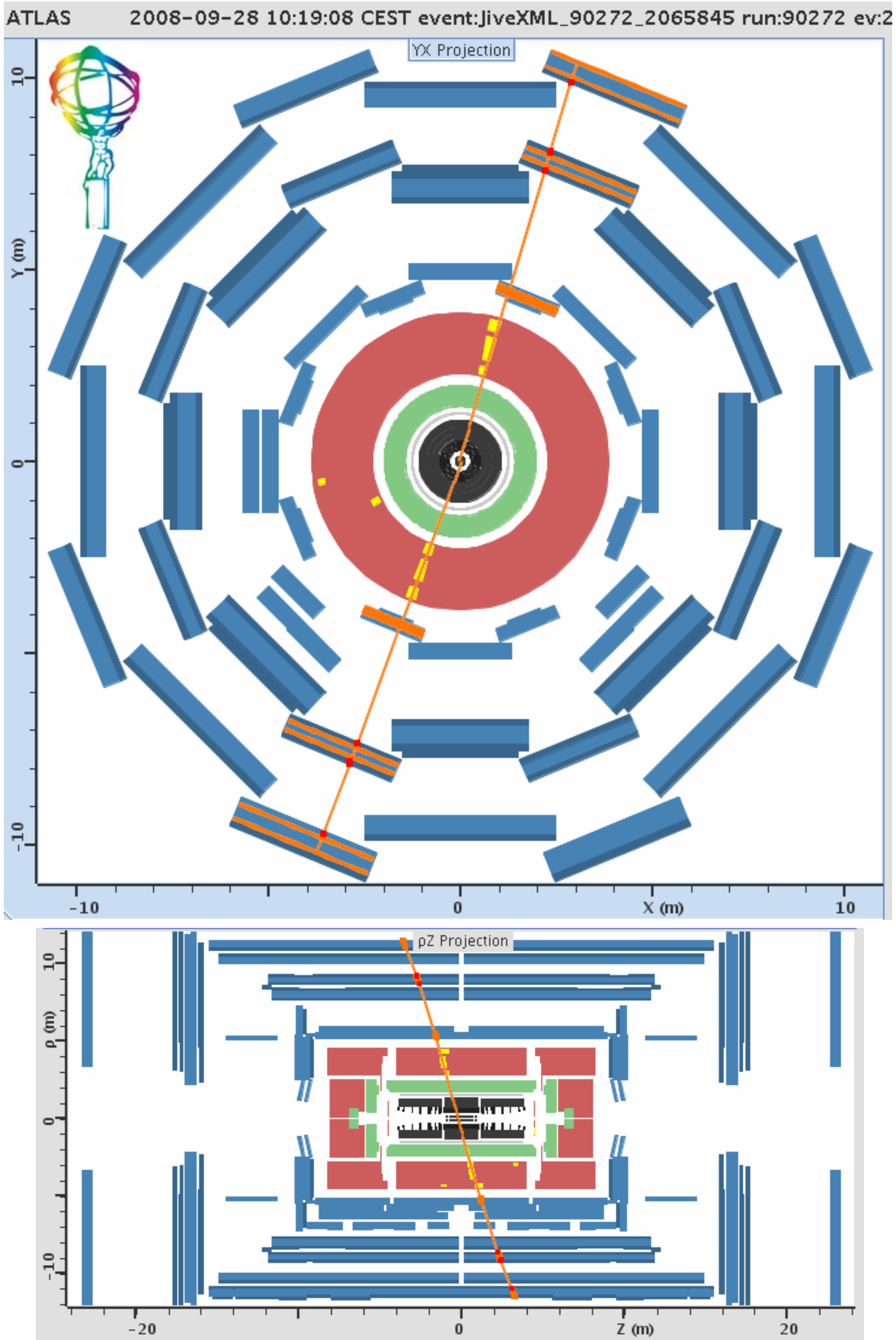
Scope of "Phase I" upgrade:

1. Upgrade of ATLAS and CMS experimental insertions. The interfaces between the LHC and the experiments remain unchanged at ± 19 m.
2. Replace the present triplets with wide aperture quadrupoles based on the LHC dipole cables (Nb-Ti) cooled at 1.9 K.
3. Upgrade the D1 separation dipole, TAS and other beam-line equipment so as to be compatible with the inner triplet aperture.
4. The cooling capacity of the cryogenic system and other main infrastructure elements remain unchanged.
5. Modifications of other insertion magnets (e.g. D2-Q4) and introduction of other equipment in the insertions to the extent of available resources.

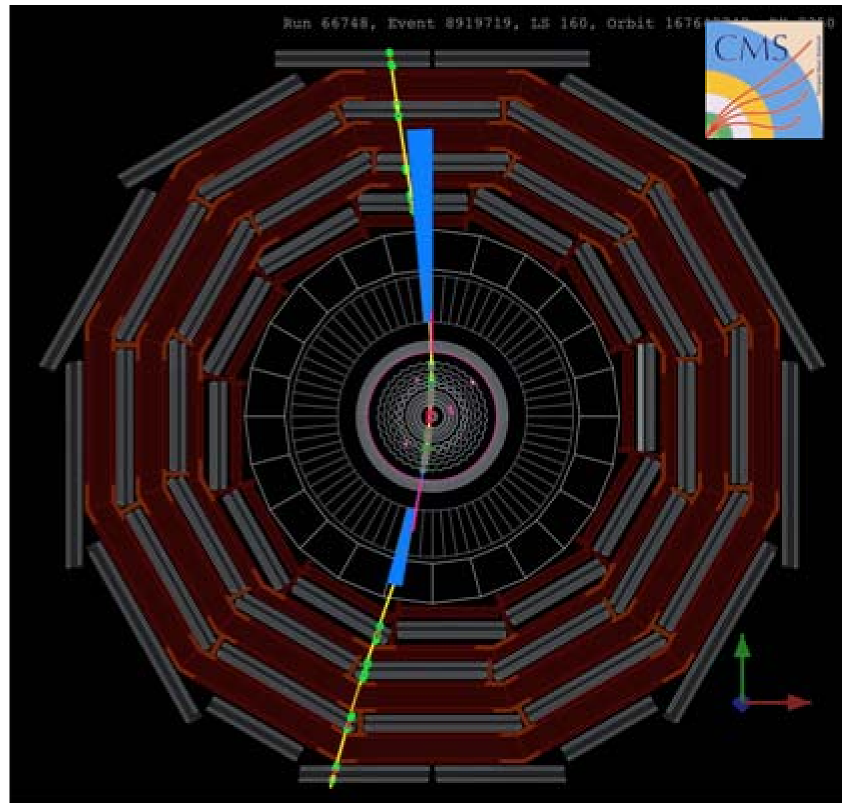
(R.Aymar, Plenary ECFA)

	ATLAS	CMS
TRACKER	Si pixels + strips TRT → particle identification $\sigma/p_T \sim 4\times10^{-4}\, p_T \oplus 0.01$	Si pixels + strips No particle identification $\sigma/p_T \sim 1.5\times10^{-4}\, p_T \oplus 0.005$
EM CALO	Pb-liquid argon $\sigma/E \sim 10\%/\sqrt{E}$ uniform longitudinal segmentation	$PbWO_4$ crystals $\sigma/E \sim 2\text{-}5\%/\sqrt{E}$ no longitudinal segmentation
HAD CALO	Fe-scint. + Cu-liquid argon ($\geq 10\ \lambda$) $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$	Brass-scint. ($\geq 5.8\ \lambda$ + catcher) $\sigma/E \sim 100\%/\sqrt{E} \oplus 0.05$
MUON	MDT, CSC, RPC, TGC $\sigma/p_T \sim 7\%$ at 1 TeV standalone	DT, CSC, RPC $\sigma/p_T \sim 5\%$ at 1 TeV combining with tracker

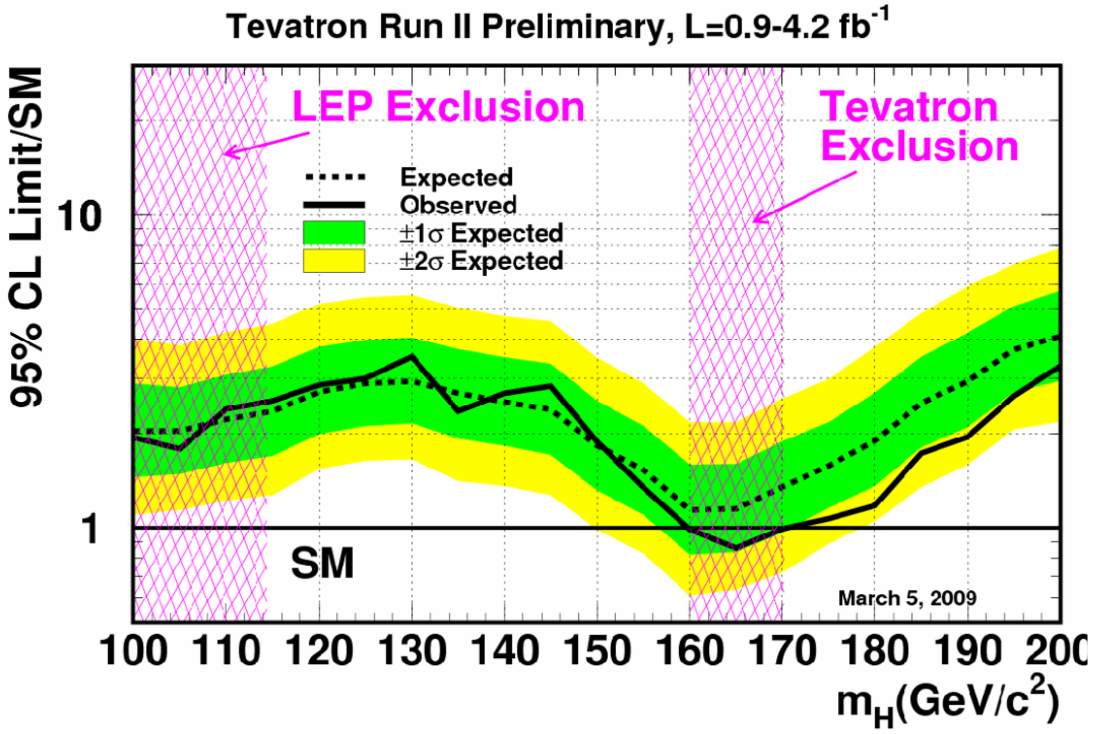


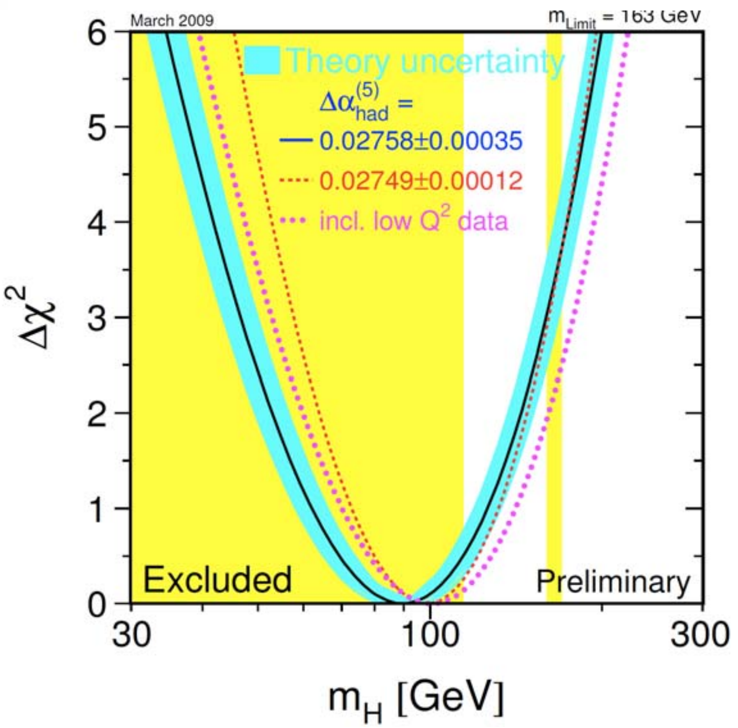
Data taking using cosmics



SM Higgs粒子質量の実験的制限

Moriond Conf.
(Mar.2009)



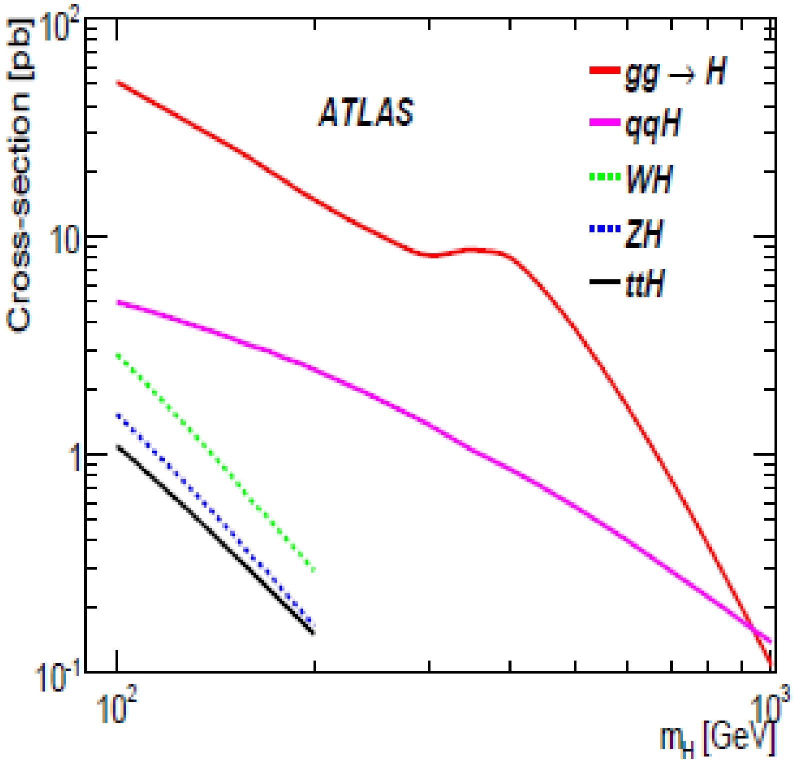


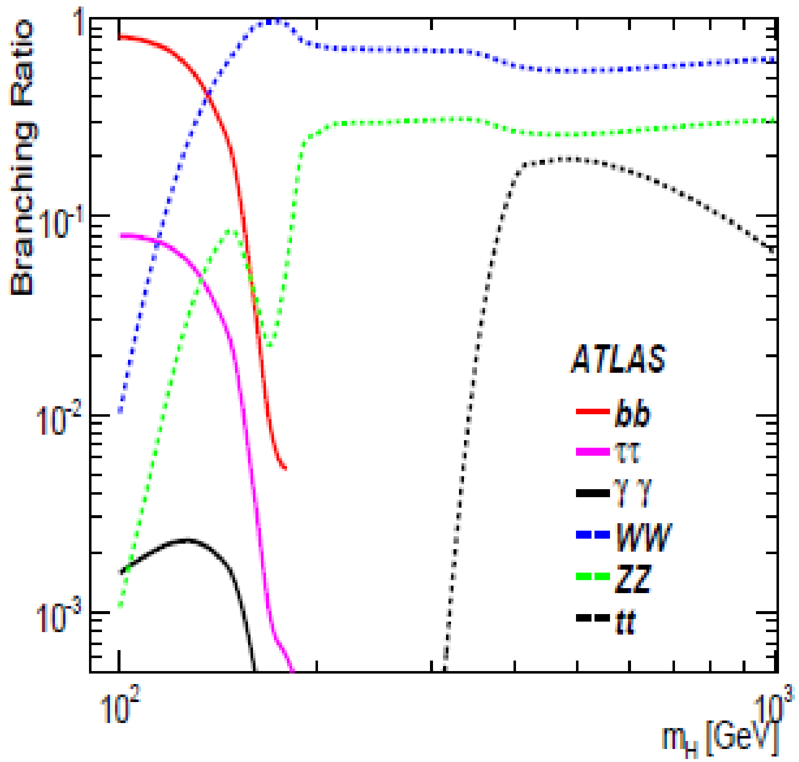
SM Higgs excluded in the mass range 160-170 @ 95% c.l.

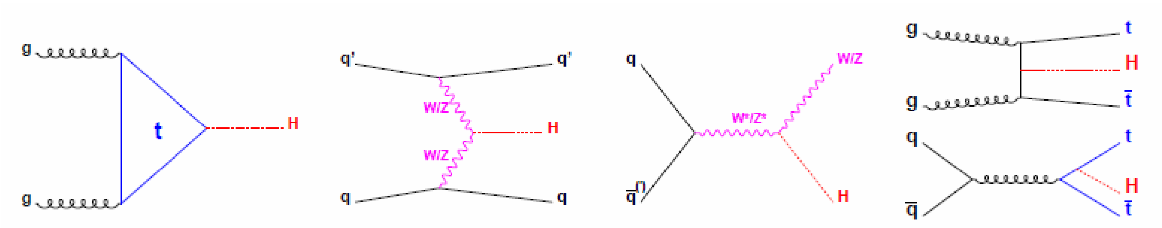
Global E&W fit with latest averages of M_t and M_W

⇨ $114.4 < M_H < 160$ (GeV)

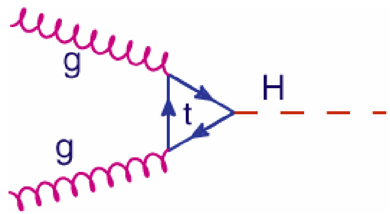
LHCでのSM Higgs 生成と崩壊モード



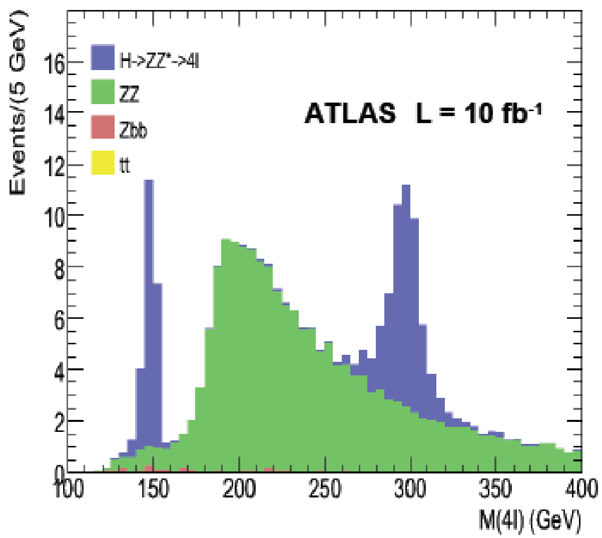


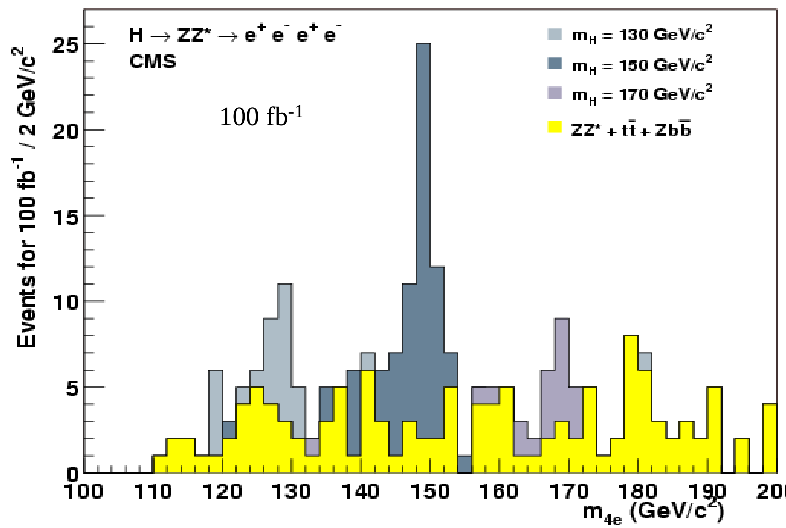


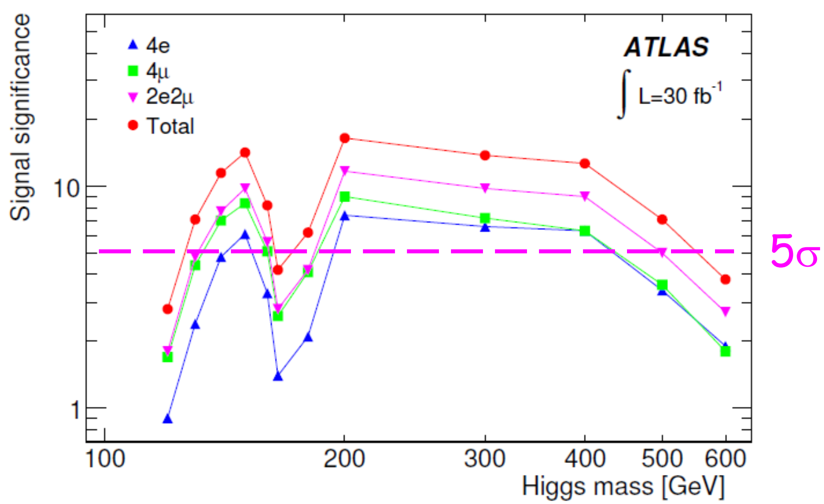
Higgsと各種粒子とのCouplingの研究が可能

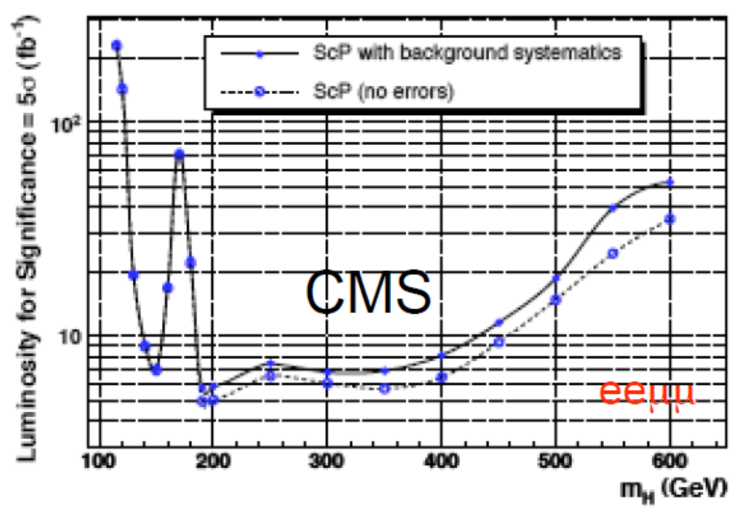


$H \rightarrow ZZ^{(*)} \rightarrow 4l$
$(l = e, \mu)$



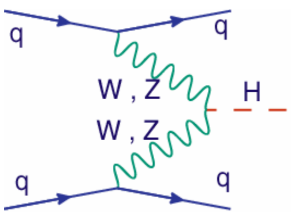






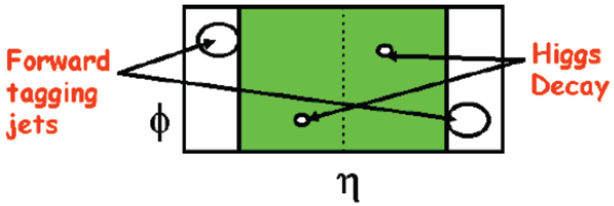
Vector Boson Fusion Process

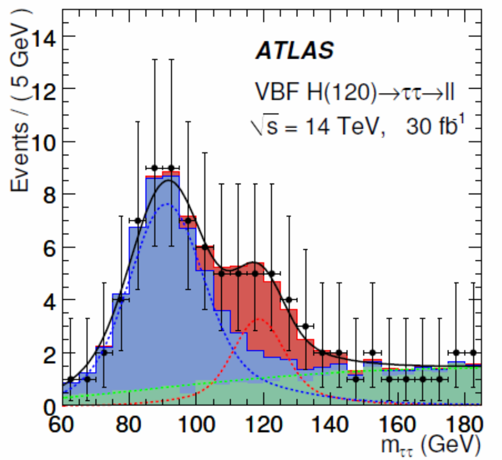
D.L.Rainwater, D.Zeppenfeld, K.Hagiwara (1999)

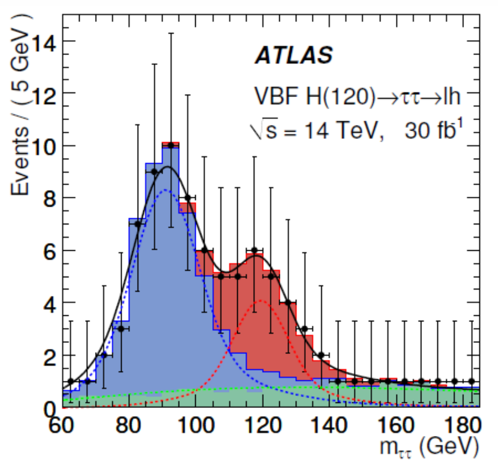


- Cross-section is lower than the gluon fusion process
- High P_T jet in the forward region
- Higgs decay products observed in the central rapidity gap (no color flow)

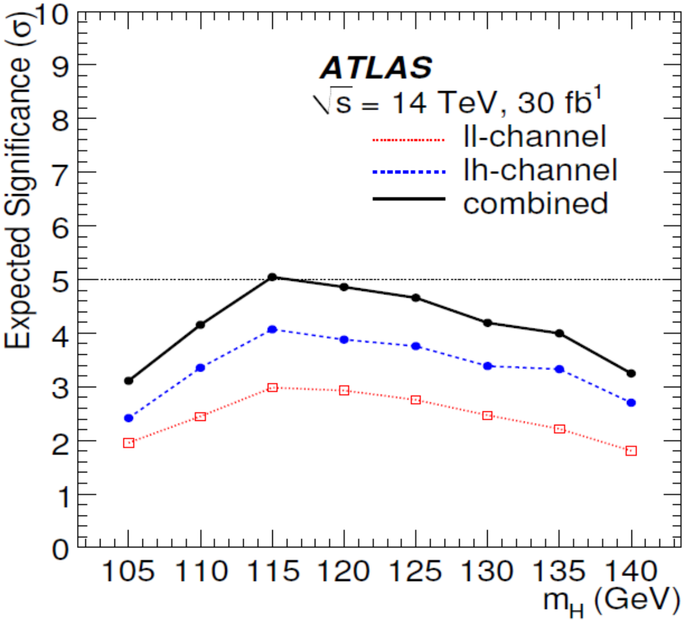
➔ Large reduction of background



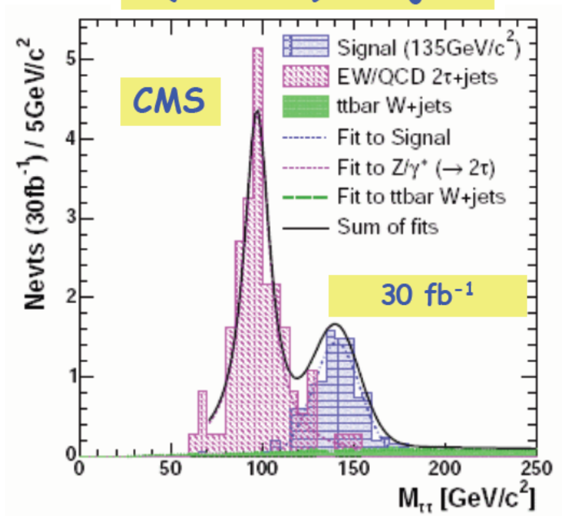


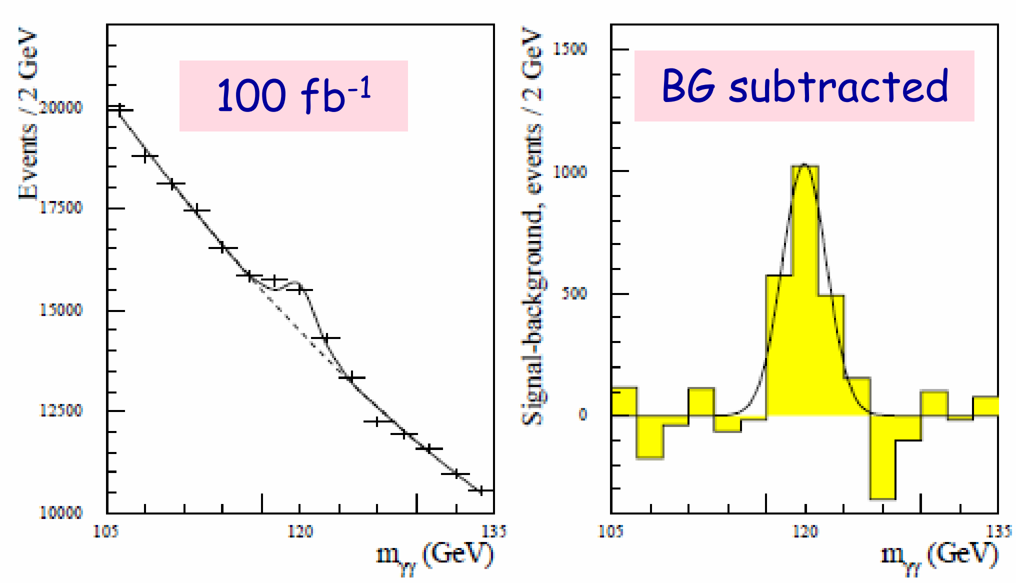


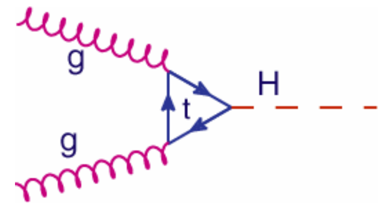
$H \to \tau\tau \to ll, lh$



H(→ττ→lh) +≥2jets

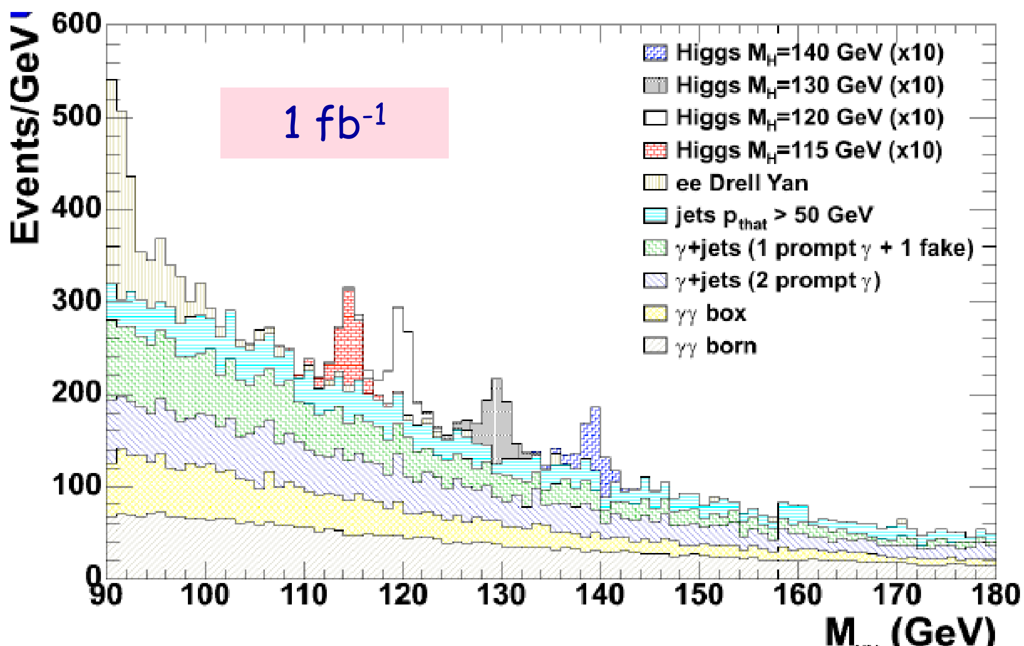




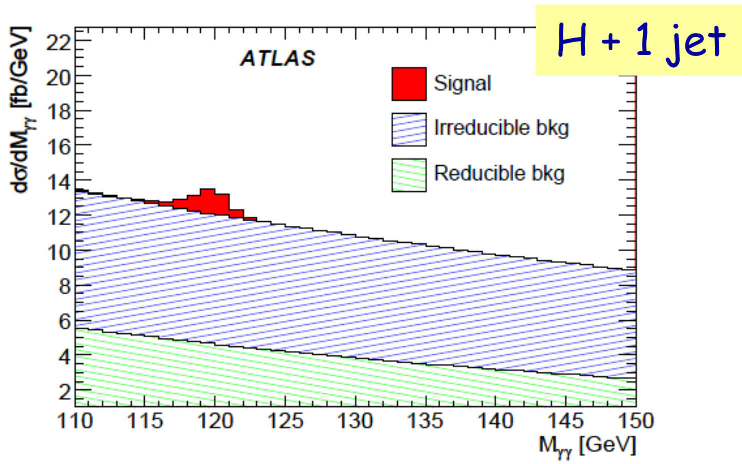


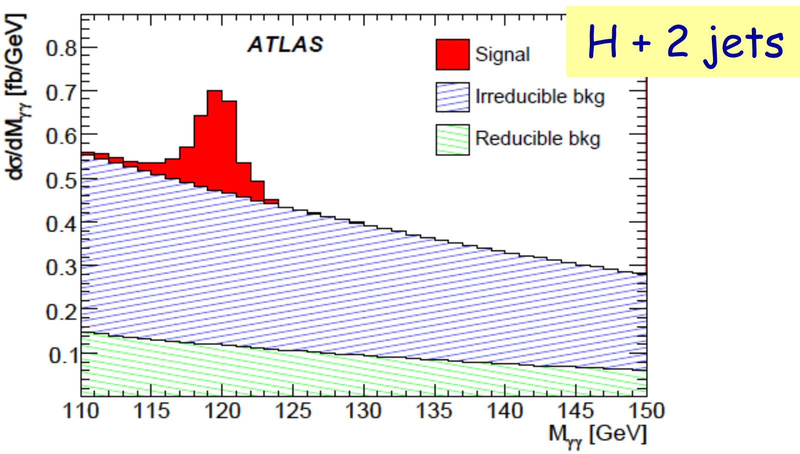
$H \rightarrow \gamma\gamma$

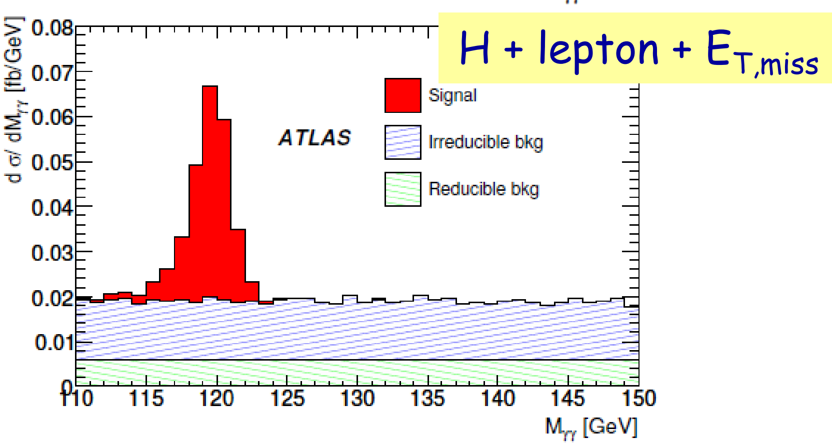
ATLAS Physics TDR (May 1999)

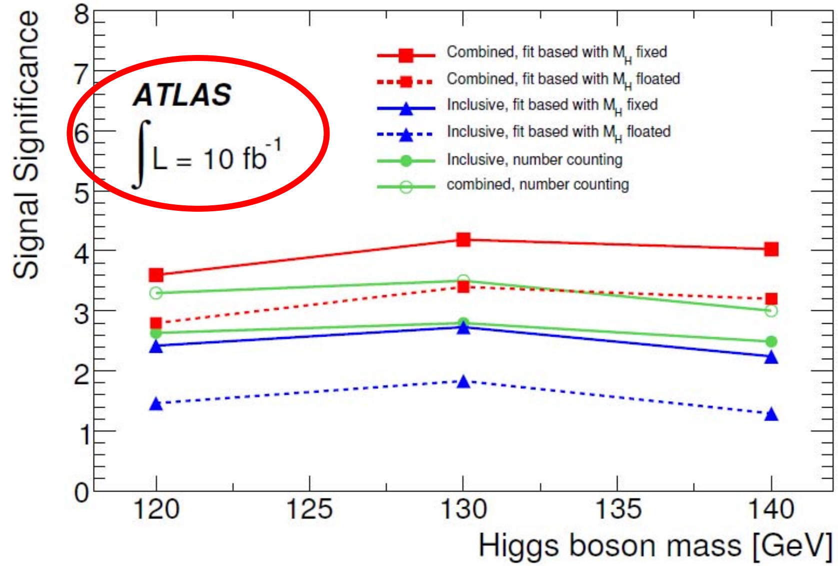


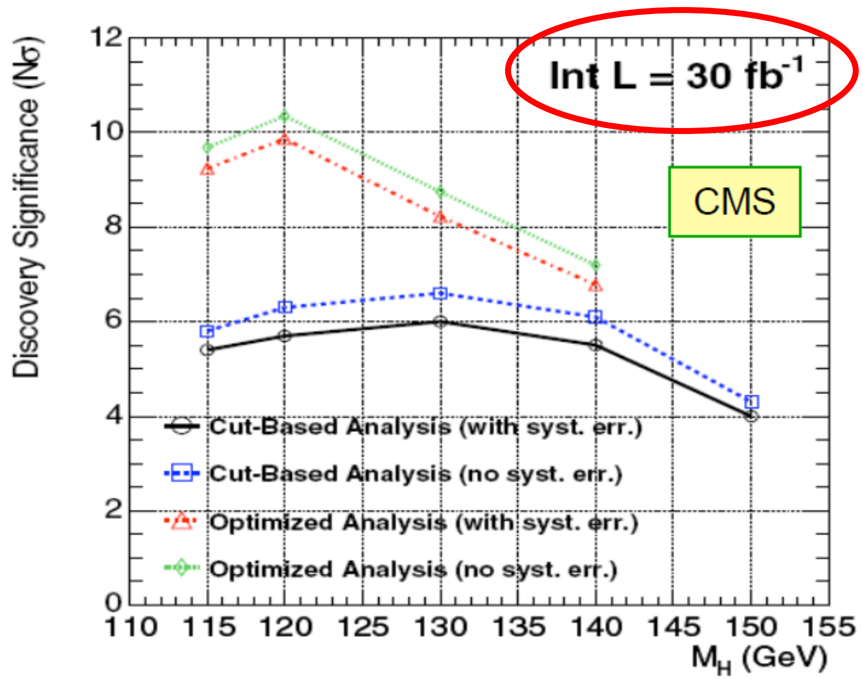
CMS Physics TDR (June 2006)

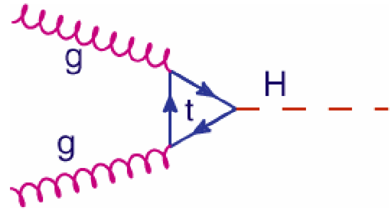

H + 1 jet
ATLAS
Signal
Irreducible bkg
Reducible bkg
dσ/dM_γγ [fb/GeV]
M_γγ [GeV]


H + 2 jets
ATLAS
Signal
Irreducible bkg
Reducible bkg
dσ/dM_γγ [fb/GeV]
M_γγ [GeV]


H + lepton + E_T,miss
ATLAS
Signal
Irreducible bkg
Reducible bkg
d σ/ dM_γγ [fb/GeV]
M_γγ [GeV]

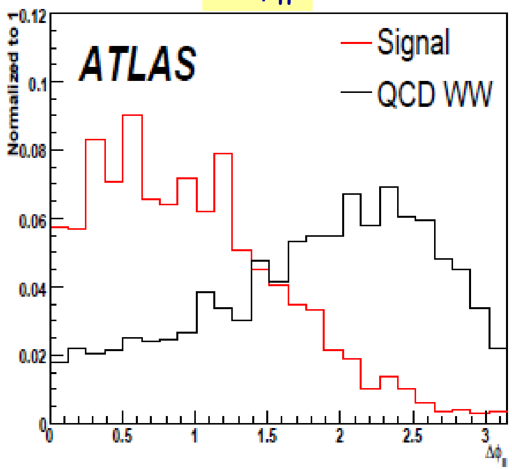

ATLAS
∫L = 10 fb^-1
Combined, fit based with M_H fixed
Combined, fit based with M_H floated
Inclusive, fit based with M_H fixed
Inclusive, fit based with M_H floated
Inclusive, number counting
combined, number counting
Signal Significance
Higgs boson mass [GeV]


Int L = 30 fb^-1
CMS
Cut-Based Analysis (with syst. err.)
Cut-Based Analysis (no syst. err.)
Optimized Analysis (with syst. err.)
Optimized Analysis (no syst. err.)
Discovery Significance (Nσ)
M_H (GeV)

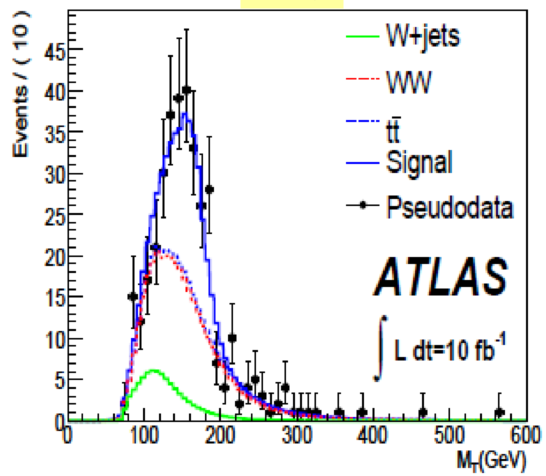


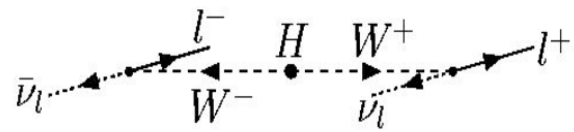
$H \rightarrow WW \rightarrow l\nu l\nu$

$\Delta\phi_{ll}$

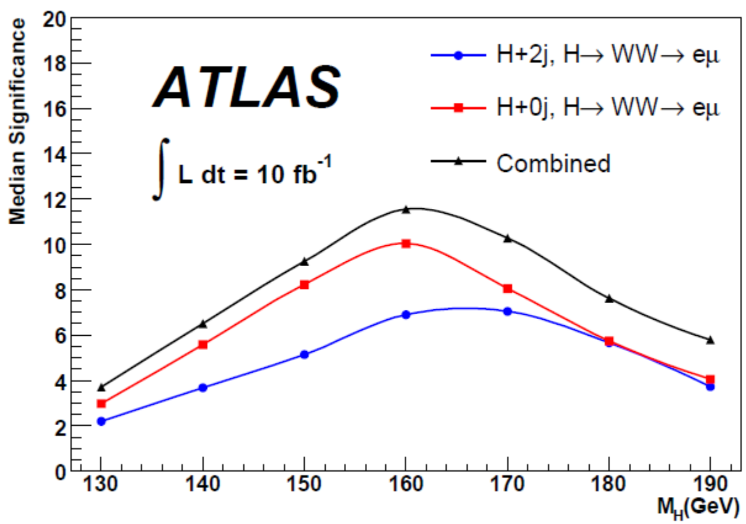


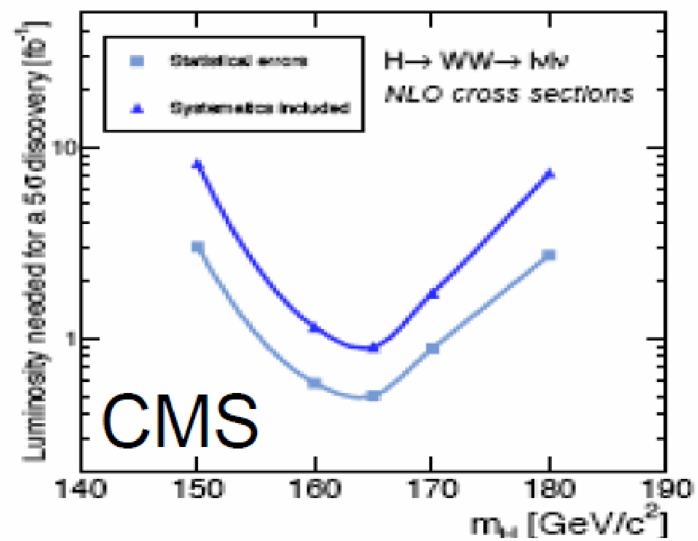
M_T



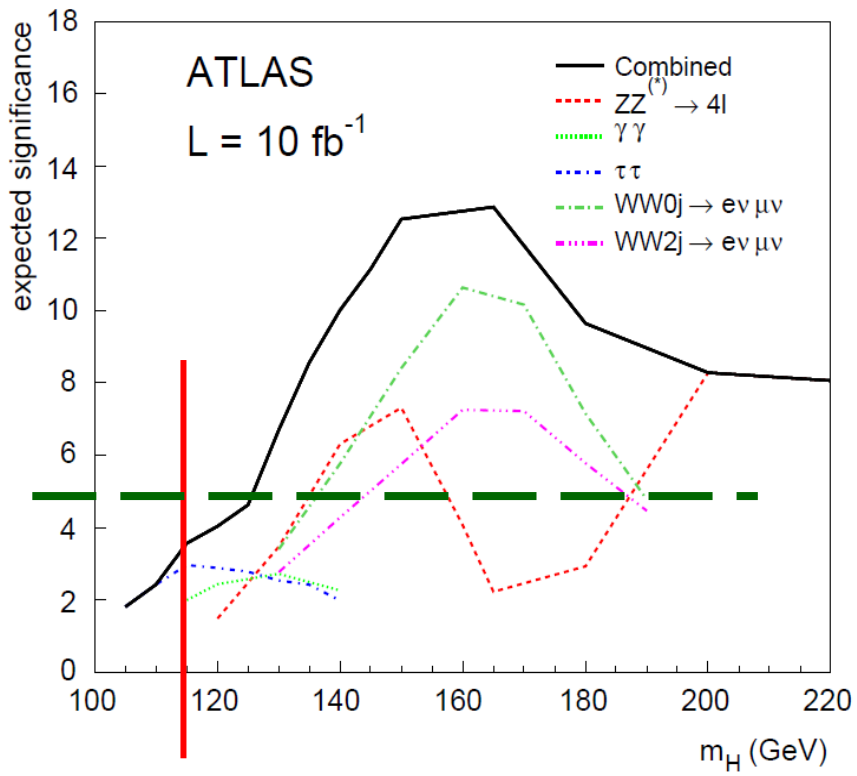


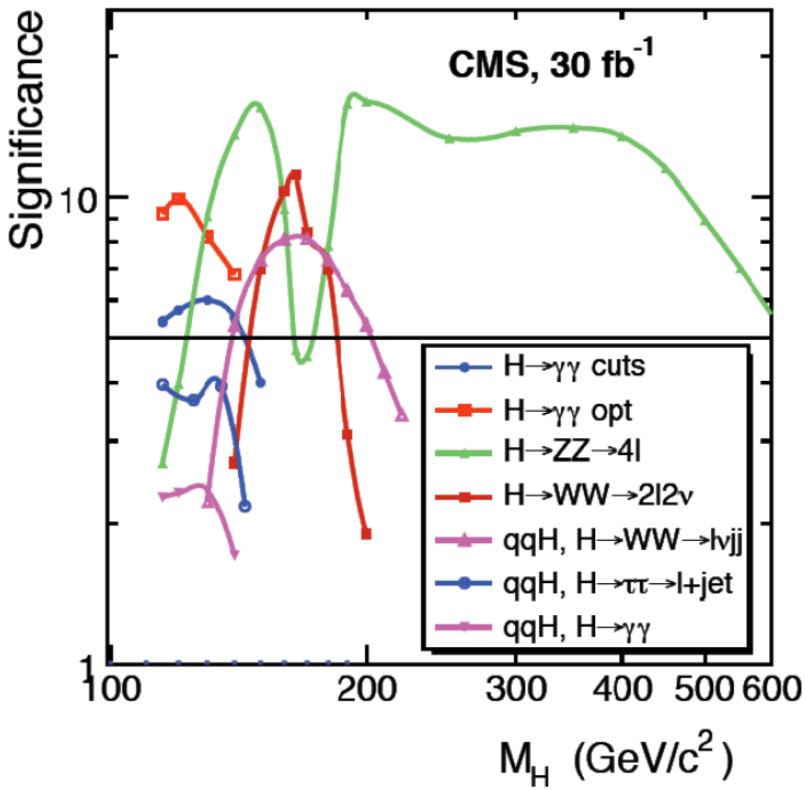
$$M_T = \sqrt{(E_T^{ll} + E_T^{\nu\nu})^2 - (\vec{p}_T^{\,e\mu} + \vec{p}_T^{\,miss})^2}$$





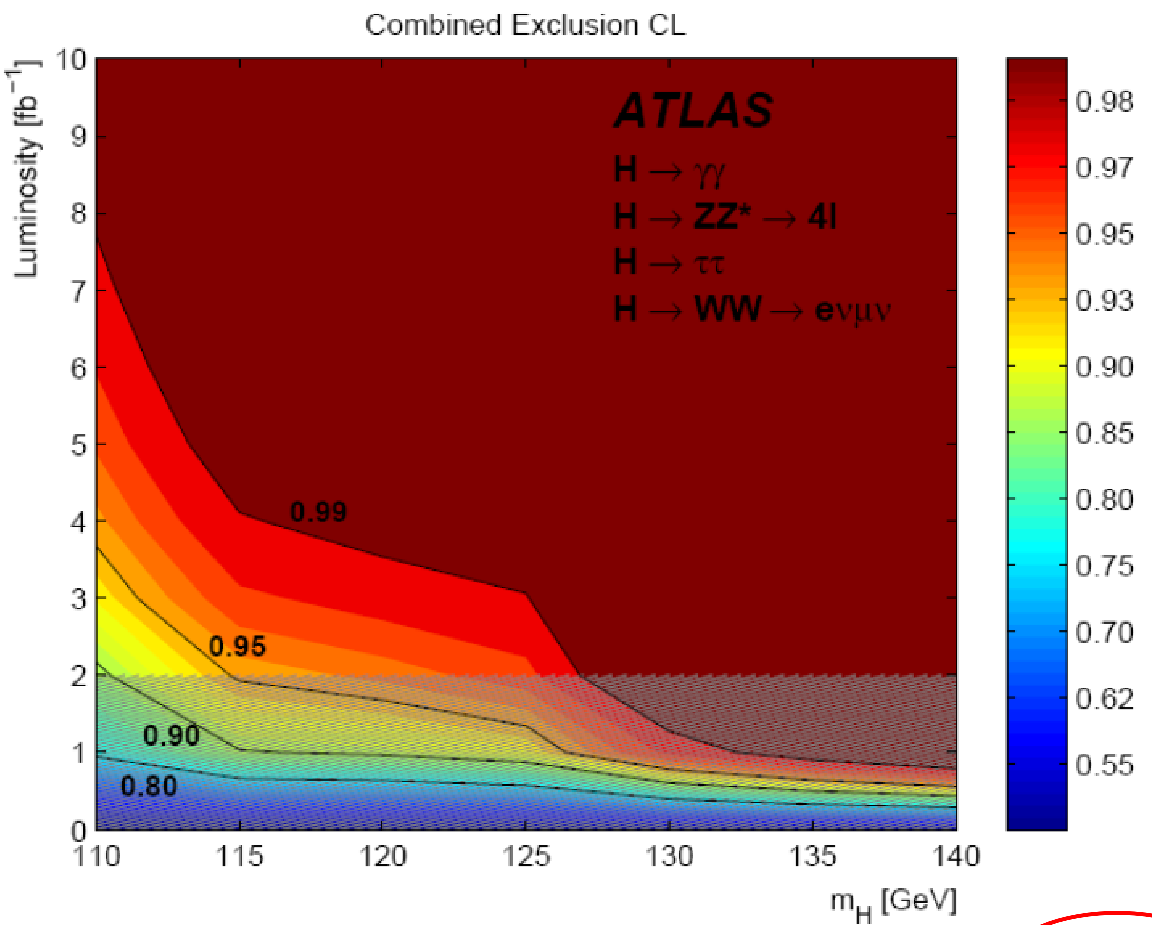
LHC discovery potential (SM Higgs)





2012～2013年頃までには…

SM Higgs が存在しない場合

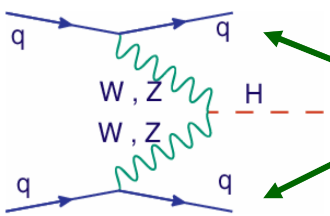


ATLAS: 95% CL sensitivity from 115 GeV with 2 fb^{-1}

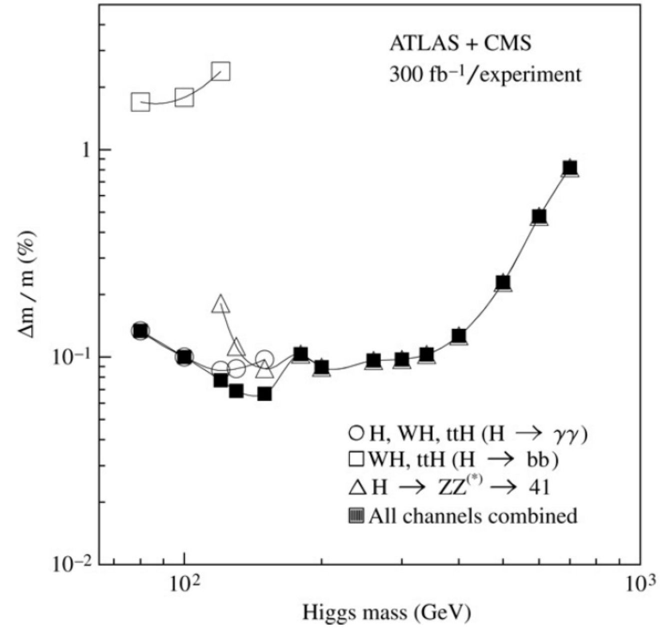
2011年中にも…

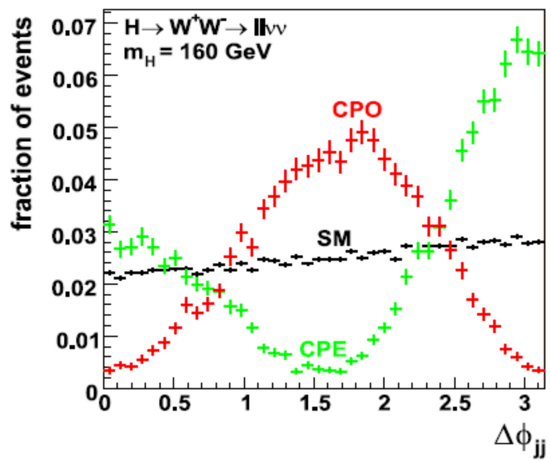
Higgs粒子（らしきもの）が発見されたら

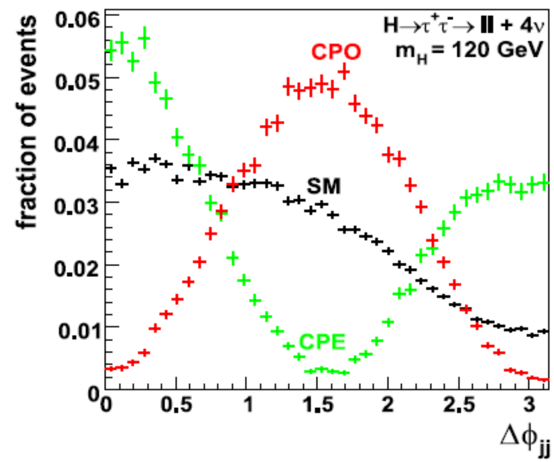
- ・質量の測定
- ・スピン/CPの測定
- ・Hとfermion/VBとの
  coupling測定（次ページ）
- ・Higgs self coupling
  （→ LHCでは難しそう）



$\Delta\phi_{jj}$





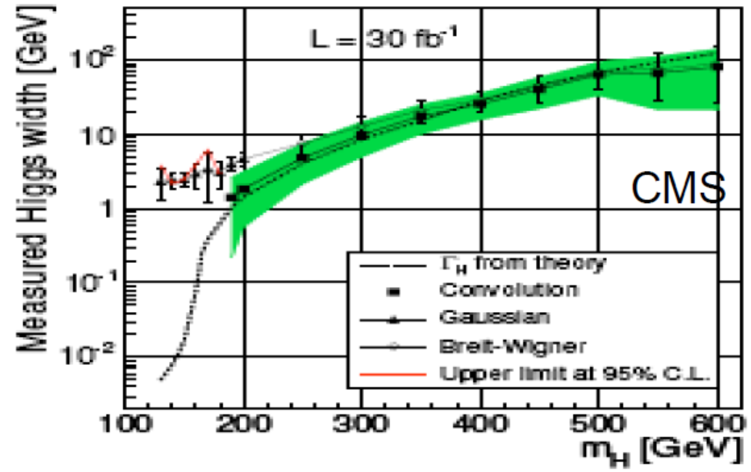


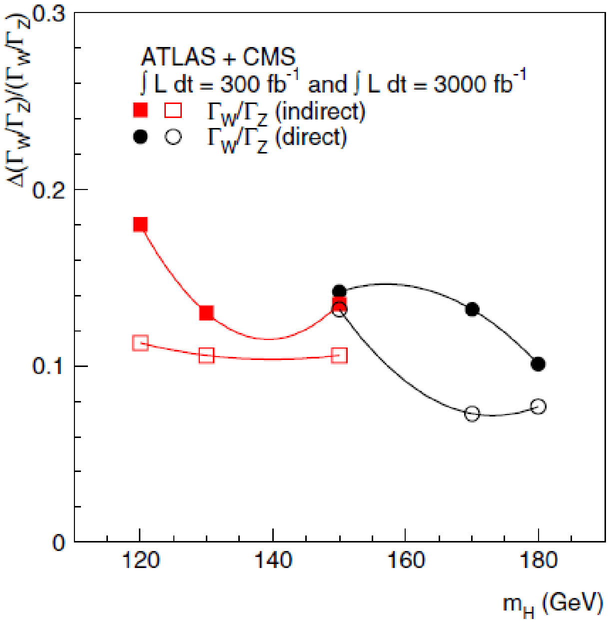
Anomalous couplings can be excluded at 5σ (2σ) for m_H = 160 (120) GeV with 10 (30) fb^{-1}

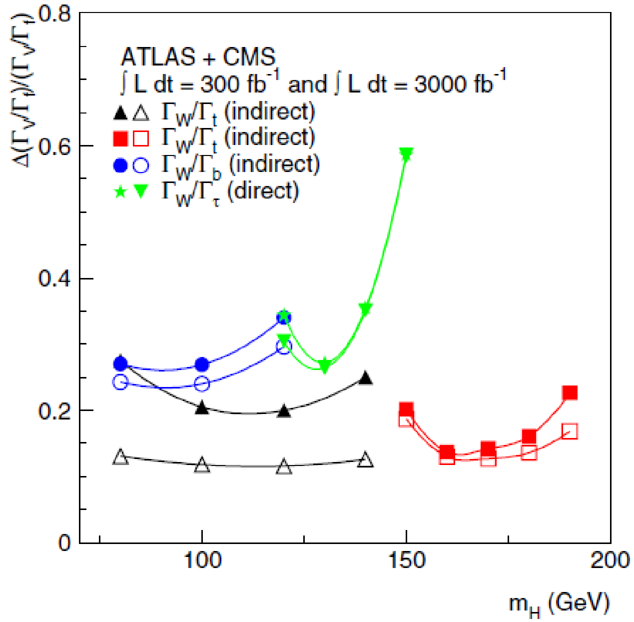
Higgs couplings to fermions and bosons

$$\sigma_{yy \to H} \cdot BR(H \to xx) \sim \Gamma_y \cdot \Gamma_x / \Gamma_H$$

だが、Γ_H の測定は m_H<200GeV では難しい



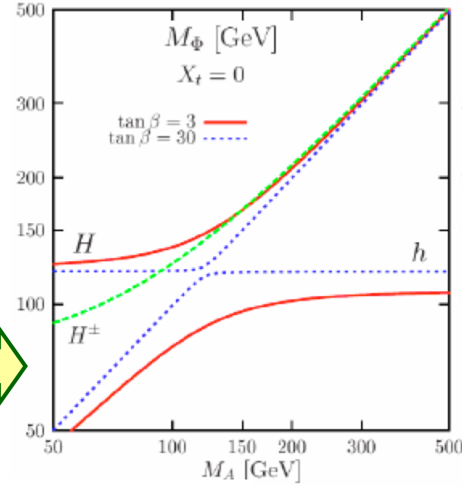


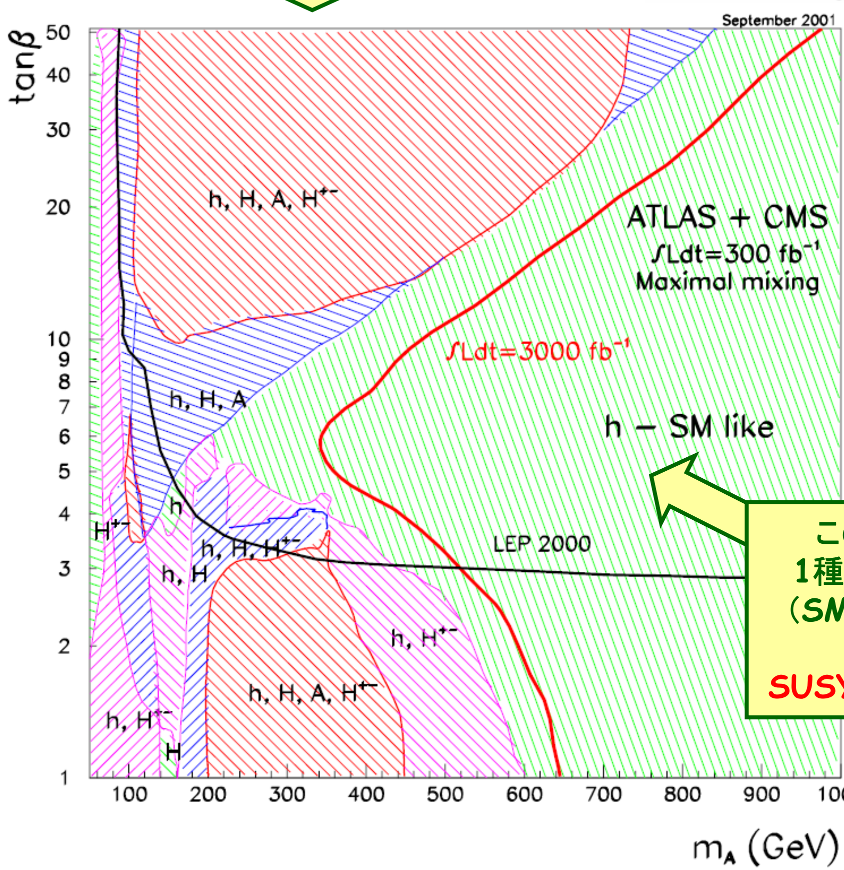


Coupling の比は ~10% の精度で測定可能

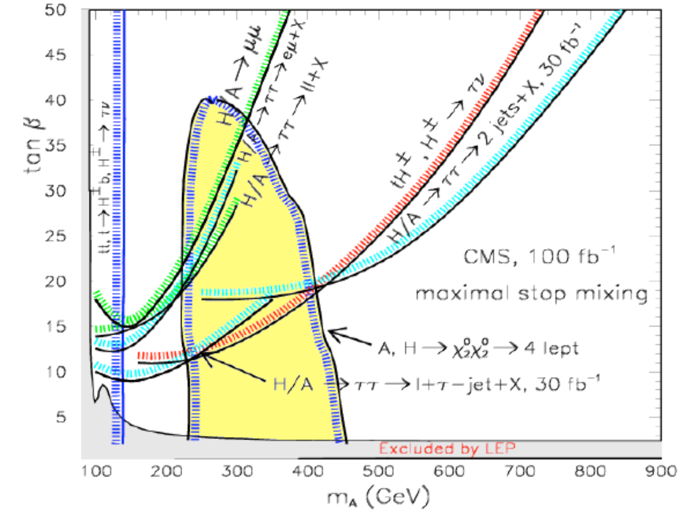
Higgsは
1種類だけか？

MSSM model の場合



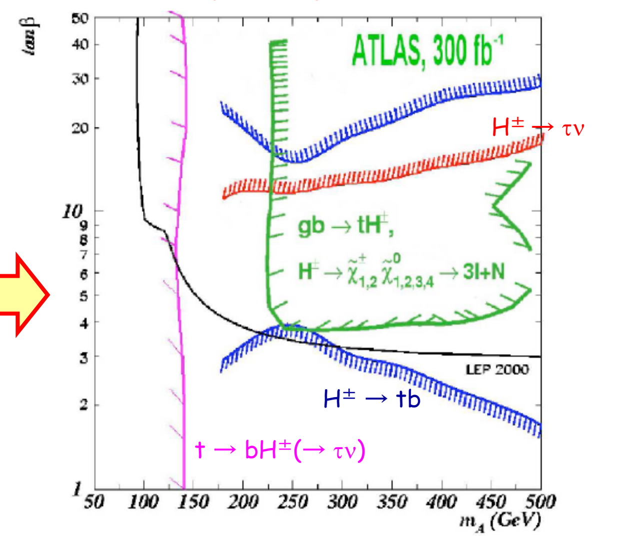


$H/A \rightarrow \chi^0_2\chi^0_2 \rightarrow \ell\ell\chi^0_1\ \ell\ell\chi^0_1$



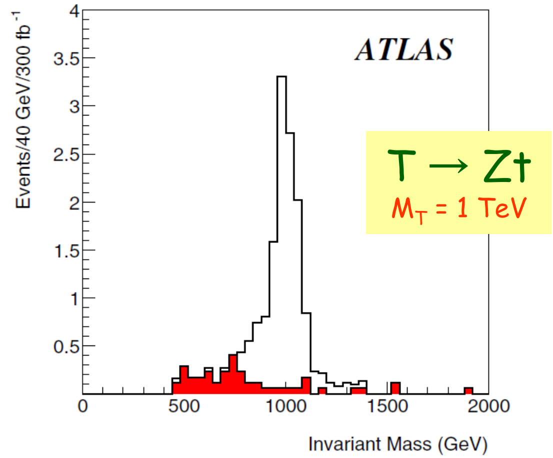
$gb \rightarrow tH^+,\ H^\pm \rightarrow \chi_{2,3}{}^0\ \chi_{1,2}{}^\pm \rightarrow 3\ell + E_T^{miss}$

この領域はLHCでは
1種類しか見つからない
（SM粒子への崩壊では）
…が、
SUSY粒子への崩壊も可能

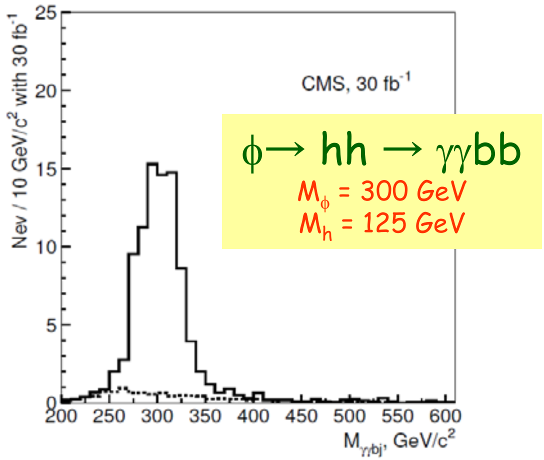


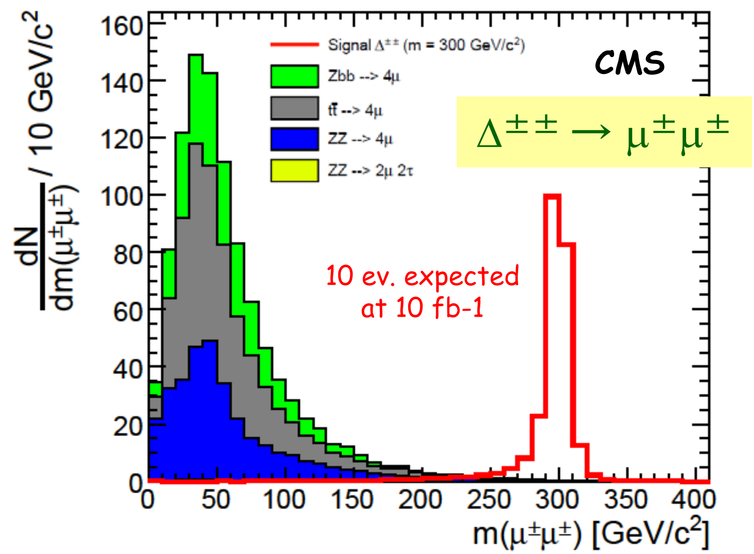
SM Higgs, SUSY Higgsでない場合も
（新しいEWSB mechanismの可能性）

・Little Higgs model
(Arkani-Hamed et al., 2002)
→ new heavy gauge boson (W', Z')
heavy quark (T)
doubly charged Higgs boson ($\Delta^{\pm\pm}$)
(triplet Higgs Δ generating Majorana mass to ν)



・5D Randall-Sundrum model
→ radion (ϕ) がHiggs (h) とmixing





Higgsがない場合

・Higgsless model → new heavy gauge boson (W', Z') が存在
(C.Csaki, C.Grojean, H.Murayama, et al., 2004)
・V_L-V_L scattering → non-resonantの場合、(S)LHCでは難しそう

Higgs粒子は基本粒子か、複合粒子か？
南部先生の東大物理教室談話会講演より、1992(3?)

Histories of

Superconductivity		Weak Interaction
K.Onnes (1911) 超伝導の発見 (Hg)	↔	A.H.Becquerel (1896) 放射能の発見 (U)
F.London, H.London (1935) 現象論的な方程式	↔	E.Fermi (1934) β-decay の理論 (effective theory)
V.L.Ginzburg, L.D.Landau (1950) 量子力学 自発的対称性の破れによる相転移	↔	S.L.Glashow, A.Salam, S.Weinberg (1967) Standard EW theory (Higgs 粒子)
J.Bardeen, L.N.Cooper, J.R.Schriefer (1957) Cooper pair による凝縮 (e^-e^-) ~ Bose 粒子	↔	?

4.
私が対称性の自発的破れ (SSB) の概念を見つけたのは偶然のできごとであるが，私が東大時代に培われた物性論への興味と，BCS 理論の生誕地がたまたま近くにあったおかげでもあったと思う．

南部陽一郎「素粒子物理の青春時代を回顧する」
日本物理学会誌 Vol.57, No.1, 2002 より

- top condensation?
- technicolor?
- compositeness …

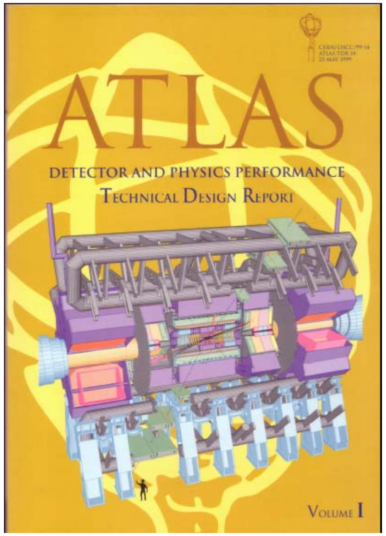
  or
- SUSY …

  or
- Little Higgs, Higgsless, …

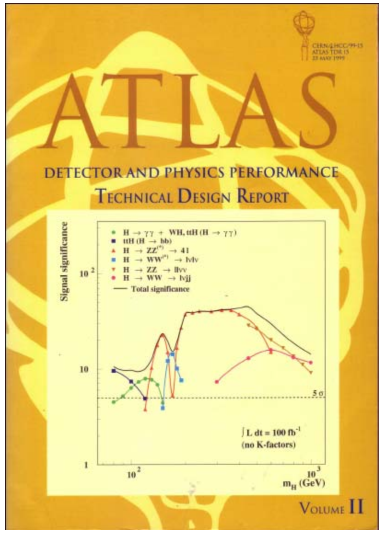
⇒

- LHCで発見
  ＋何らかの測定
- LCで更に詳細な研究を

参考文献：Physics TDRs



May 1999
（460ページ）

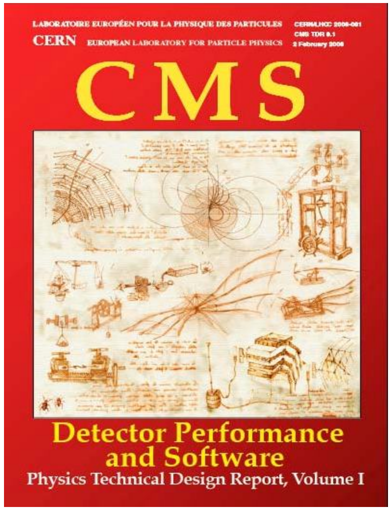


May 1999
（500ページ）

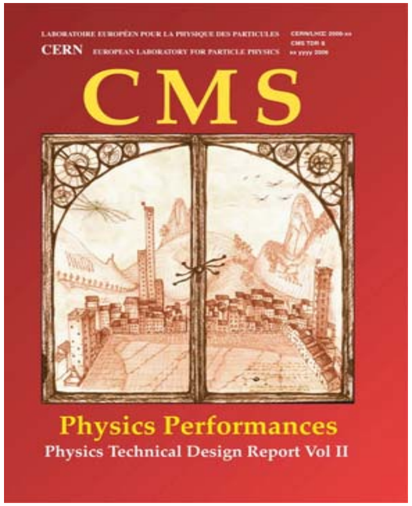
CSC (Computing System Commissioning) book
Expected Performance of the ATLAS Experiment
- Detector, Trigger and Physics

arXiv:0901.0512

Jan.2009
（1830ページ）



Feb.2006
（510ページ）



Jun.2006
（640ページ）

http://cmsdoc.cern.ch/cms/cpt/tdr/