What Will LHC Bring Us:
Higgs, SUSY, ---, or Surprises?

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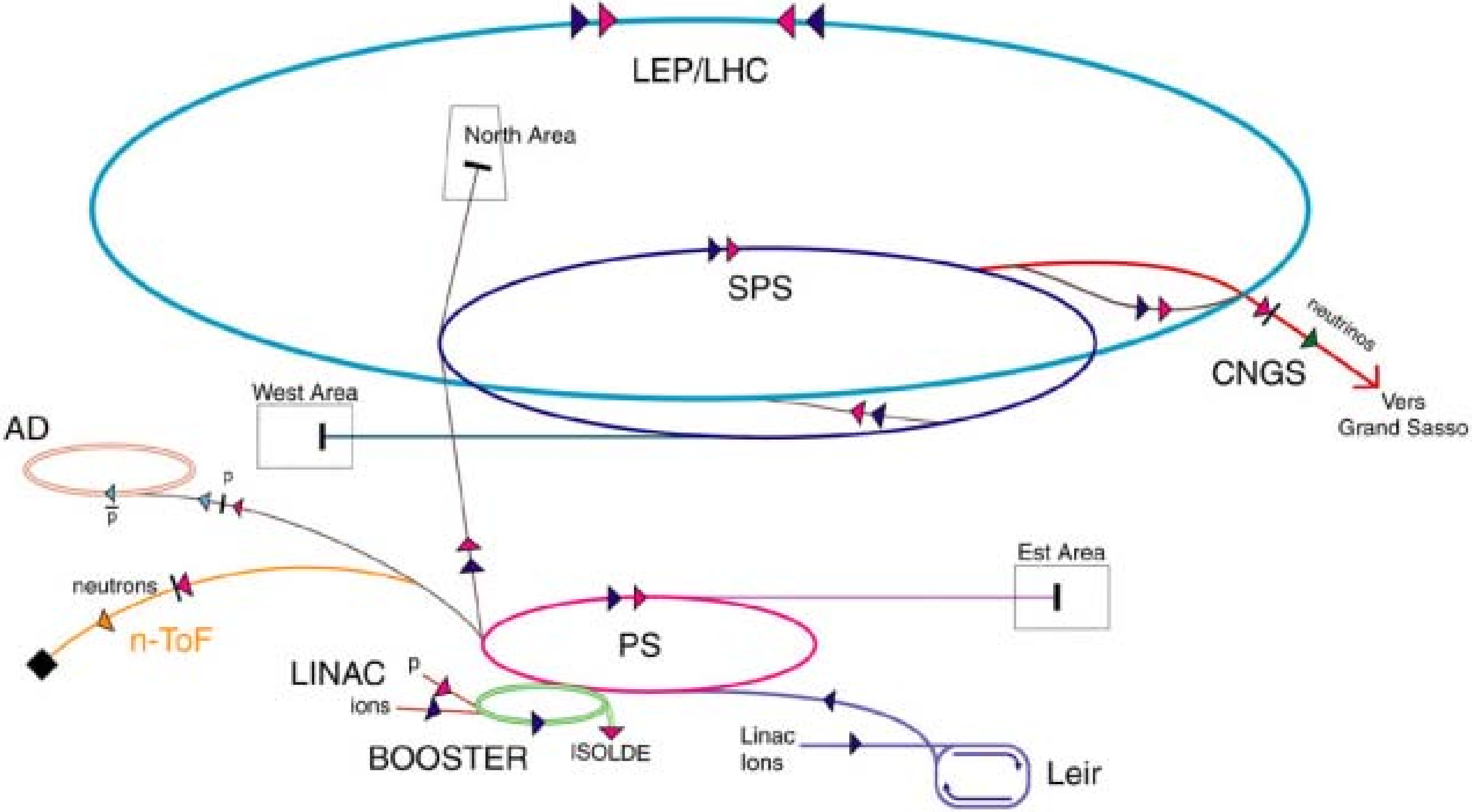
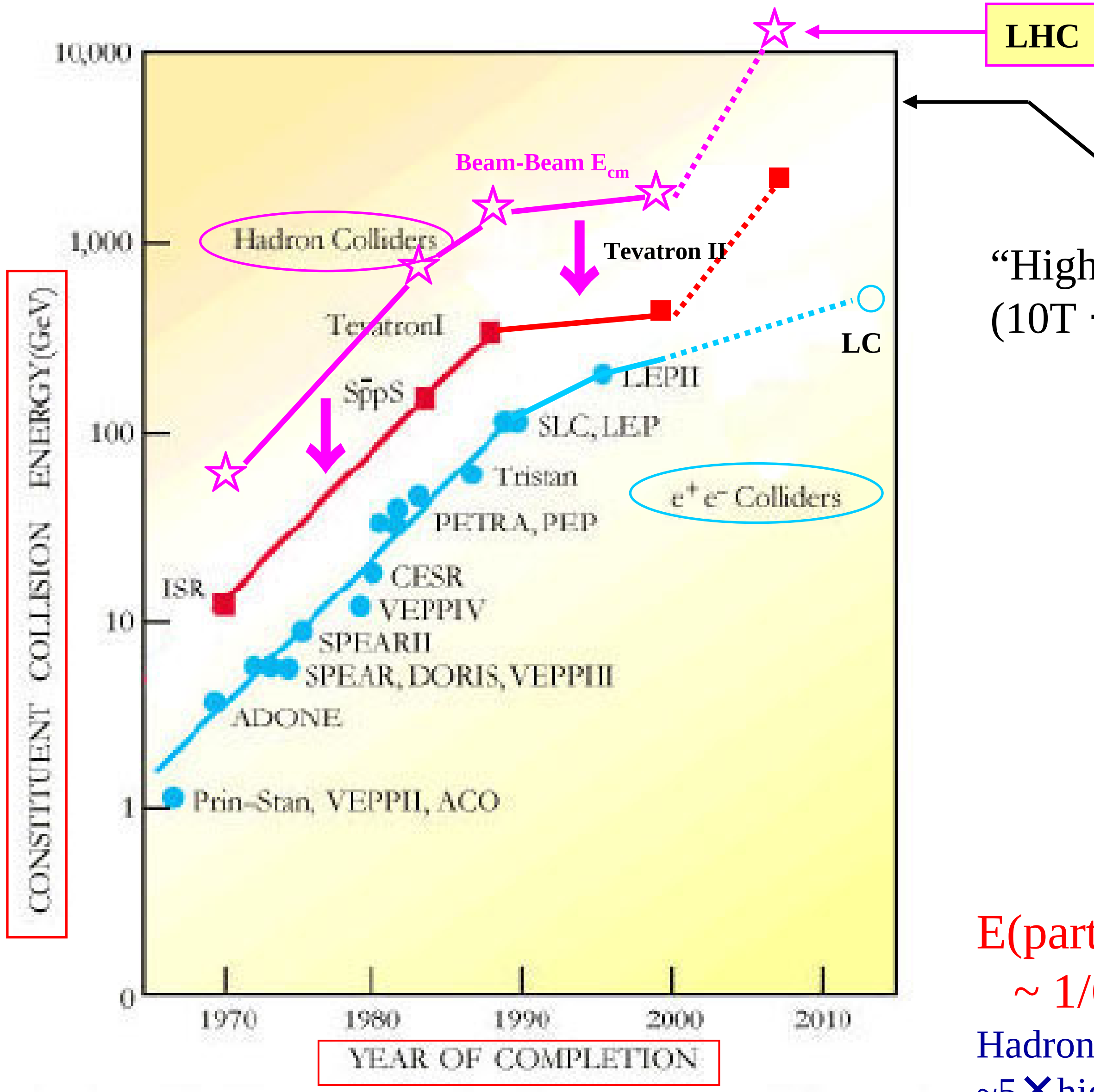
1. Introduction
2. LHC Project
3. Physics Expected at LHC
4. Summary

18.Feb.2004
Quests-COE-WS

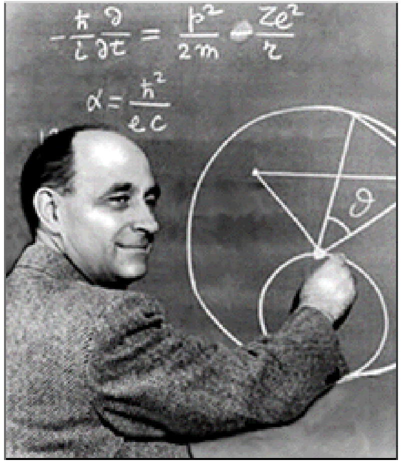
1. Introduction



History of Colliders



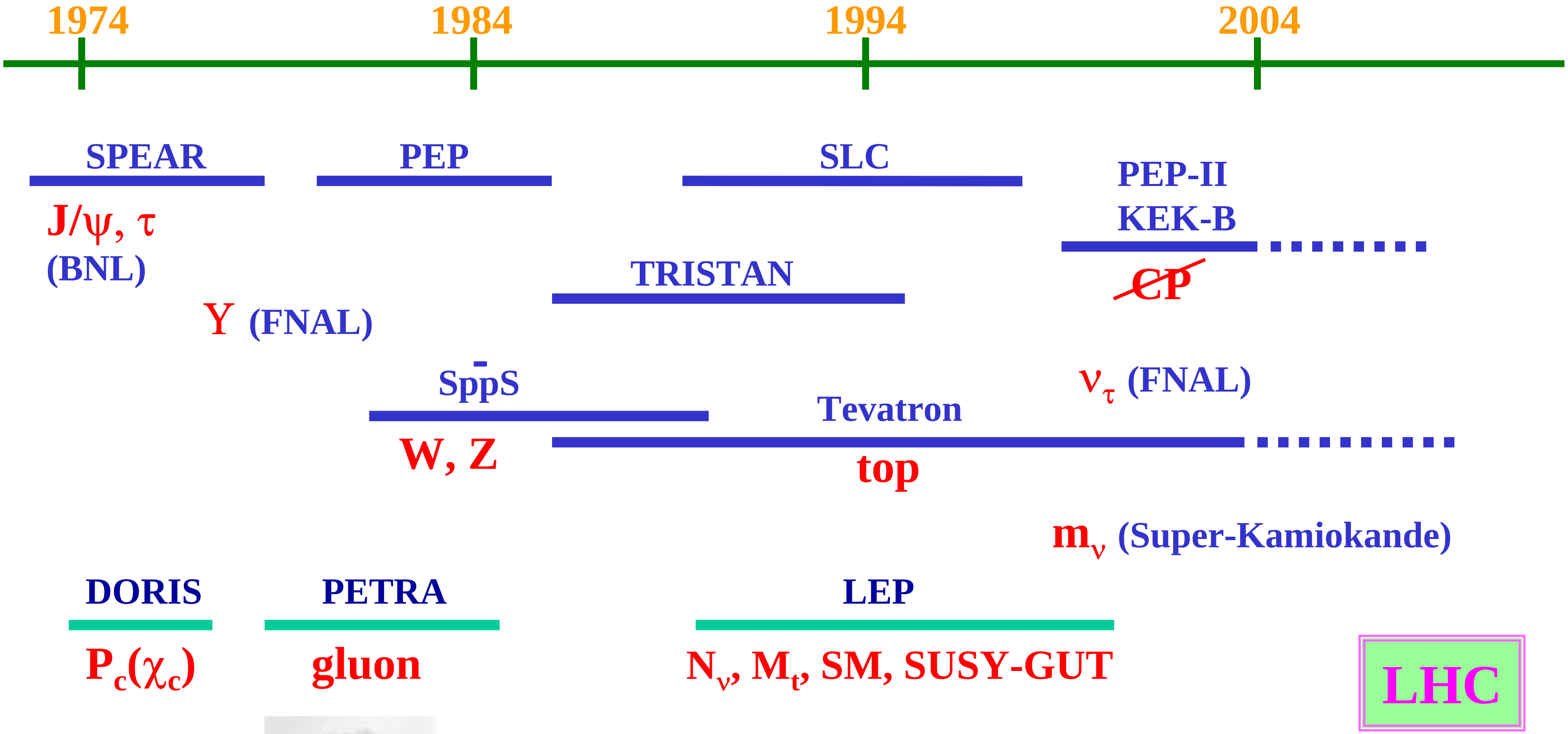
"Highest energy on the Earth"
(10T → 20PeV → E_{cm} ~ 6TeV)



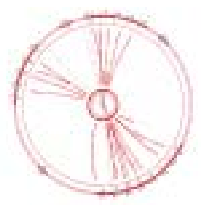
E(parton-parton)
~ 1/6 ✕ E(proton-proton)

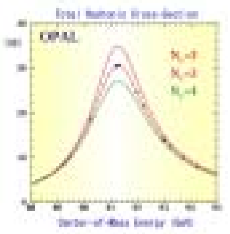
Hadron colliders giving effectively
~5✕higher energies than e^+e^- colliders

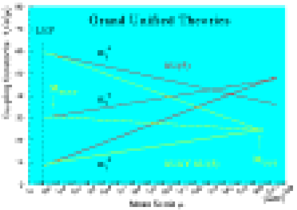
Brief History of Particle Physics in the Last 30 Years



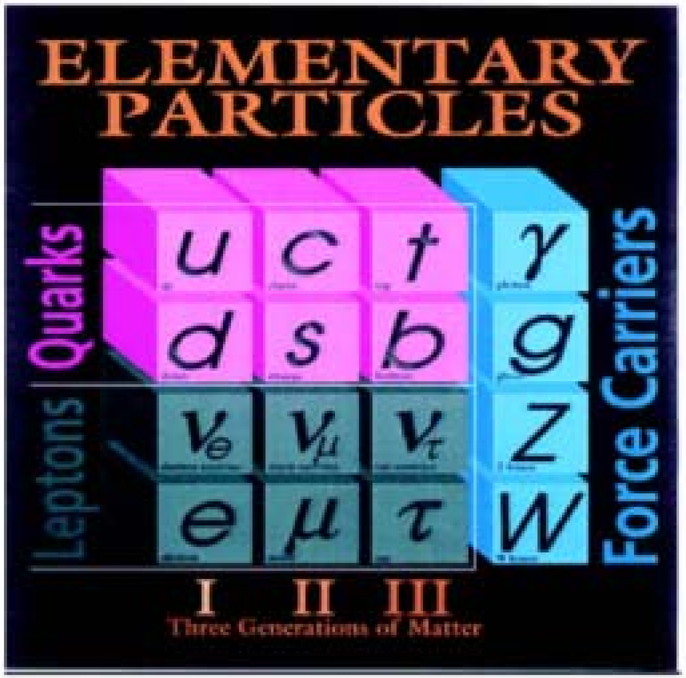
ICEPP was established

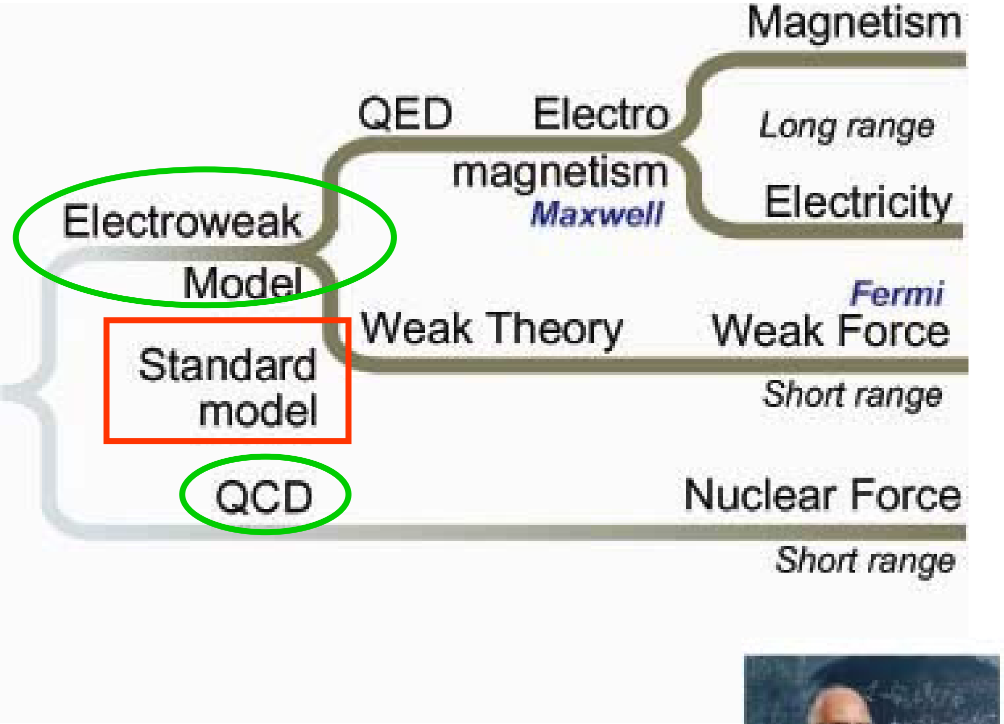






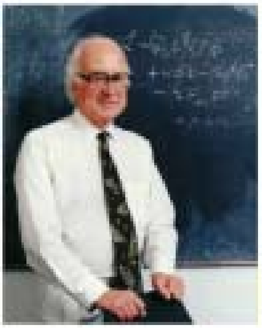
The Standard Model





SM : checked with <1% accuracy, but

- Higgs not yet found (“Missing link” of SM)
- $m_\nu \neq 0$
- sign of SUSY-GUT
- Why 3 families?
- gravity?
- SM is not an ultimate theory, ---

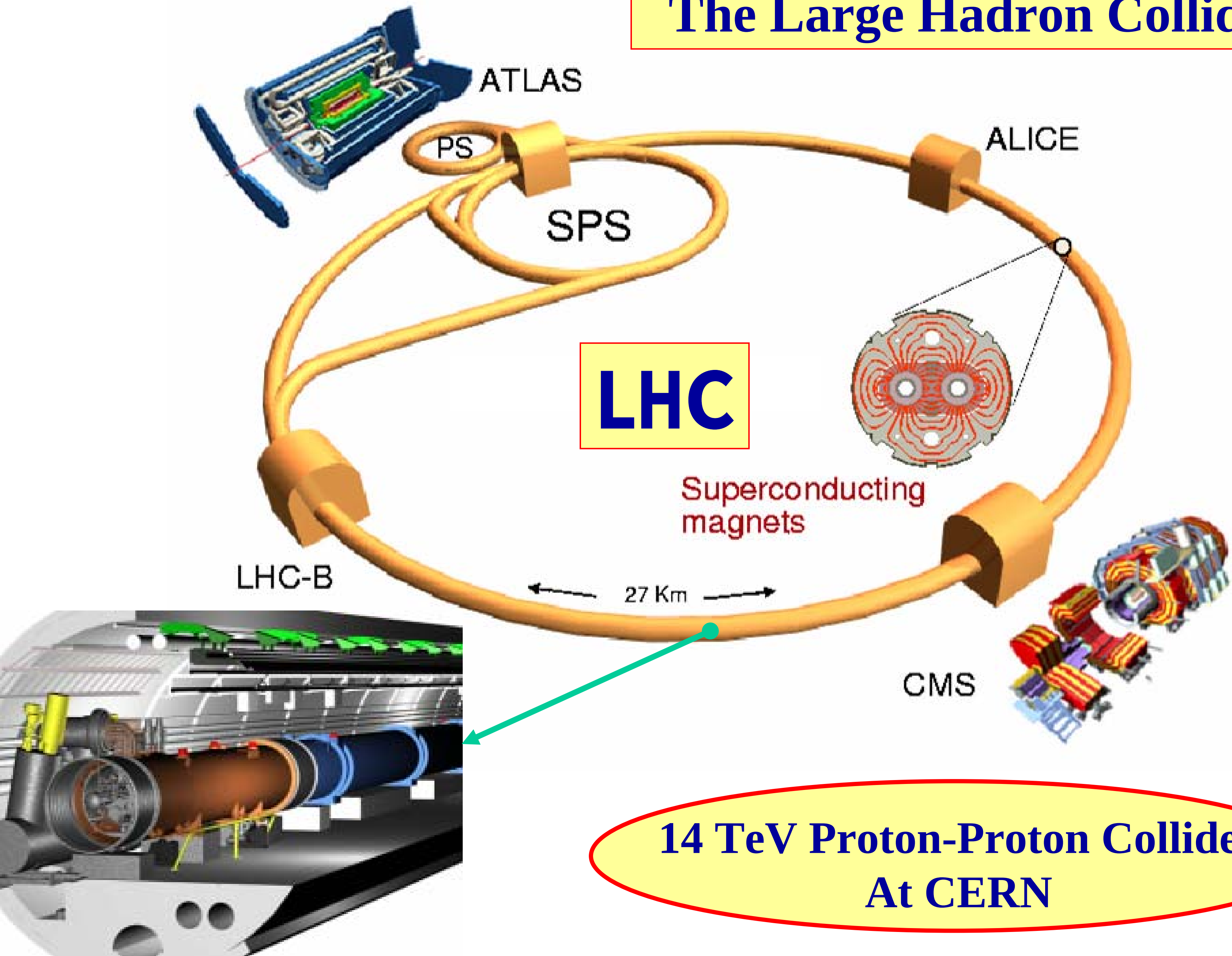


- Find Higgs
- Look for something beyond SM

2. LHC Project

Accelerator and Detectors

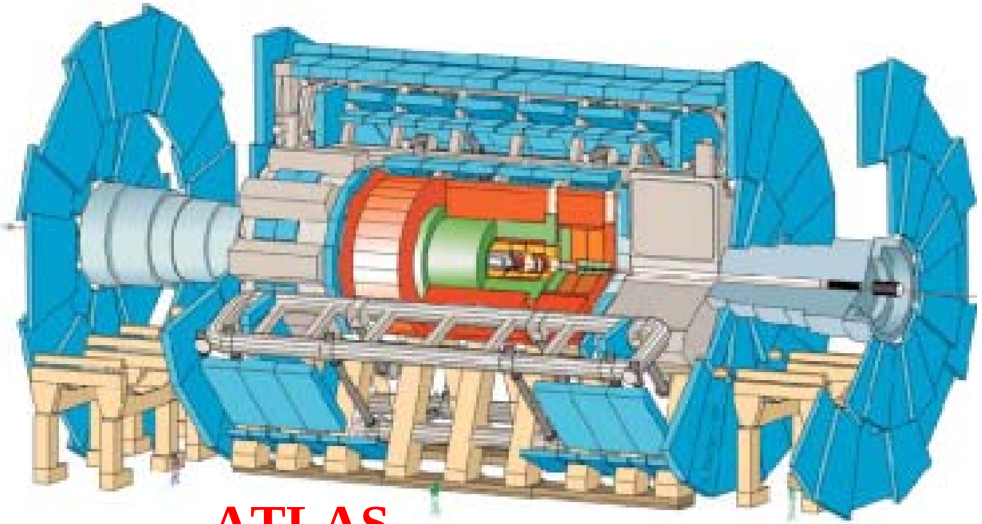
The Large Hadron Collider



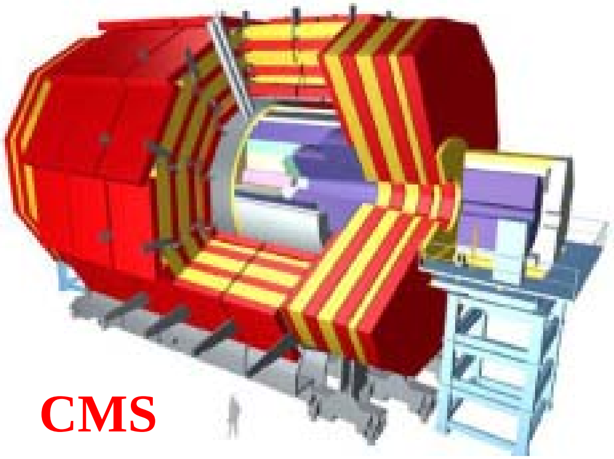
14 TeV Proton-Proton Collider
At CERN

LHC Experiments

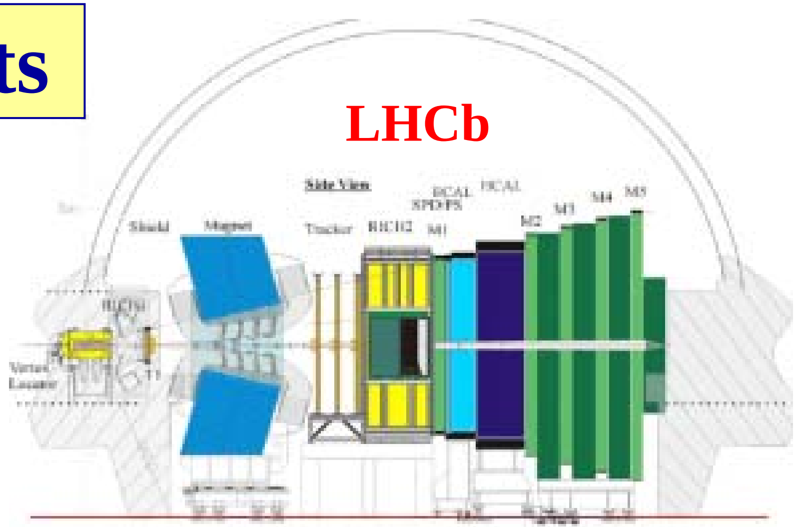
General-purpose pp experiments



ATLAS

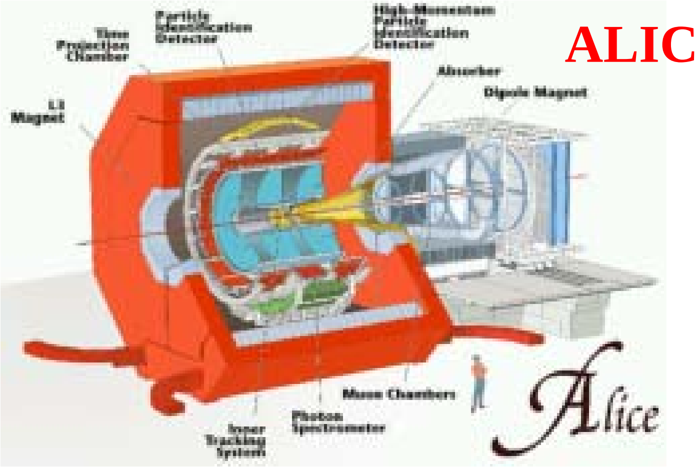


CMS



LHCb

- pp experiment dedicated to b-quark physics
- Single-arm forward spectrometer



ALICE

- Heavy-ion experiment (Pb-Pb collisions) at ~6 TeV/nucleon
- Quark-gluon plasma studies

LHC Machine Parameters

Proton-Proton Collider

Circumference: 26.7 km (using LEP tunnel)

Beam Energy: **7 TeV** (Injection E: 450 GeV, PS→SPS→LHC)

1232 MR dipoles **B=8.33 Tesla**, L=14.3m, 1.9K (**2-in-1 magnets**)

368 MR quads B'=223 T/m, L=3.1m

No. of Bunches: 2808

Bunch spacing: 24.95 ns

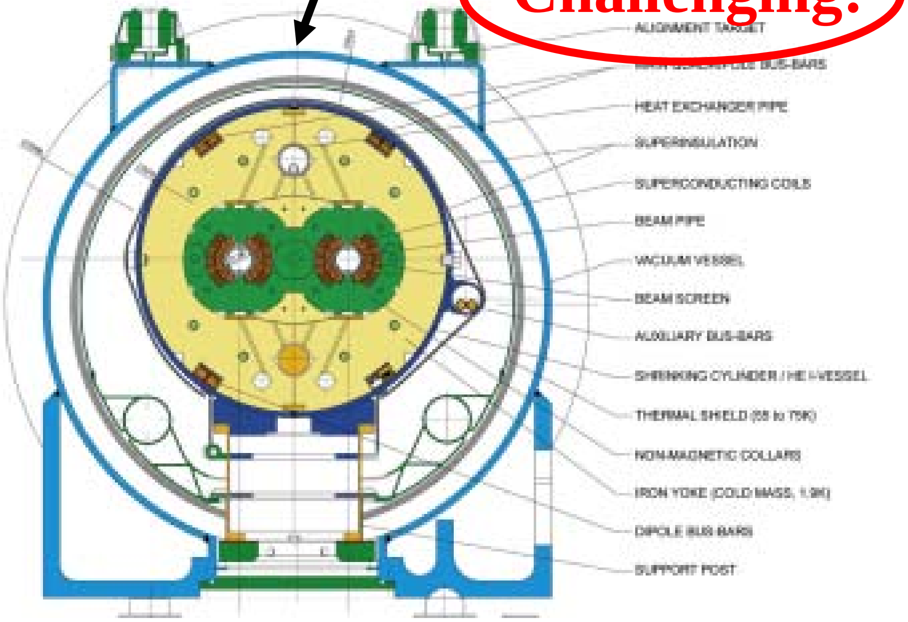
Bunch size at IP: 16 μ m

Bunch length at IP: 77 mm

Half crossing angle: 160 μ rad

Luminosity: **10^{34} cm^{-2}s^{-1}**

Challenging!



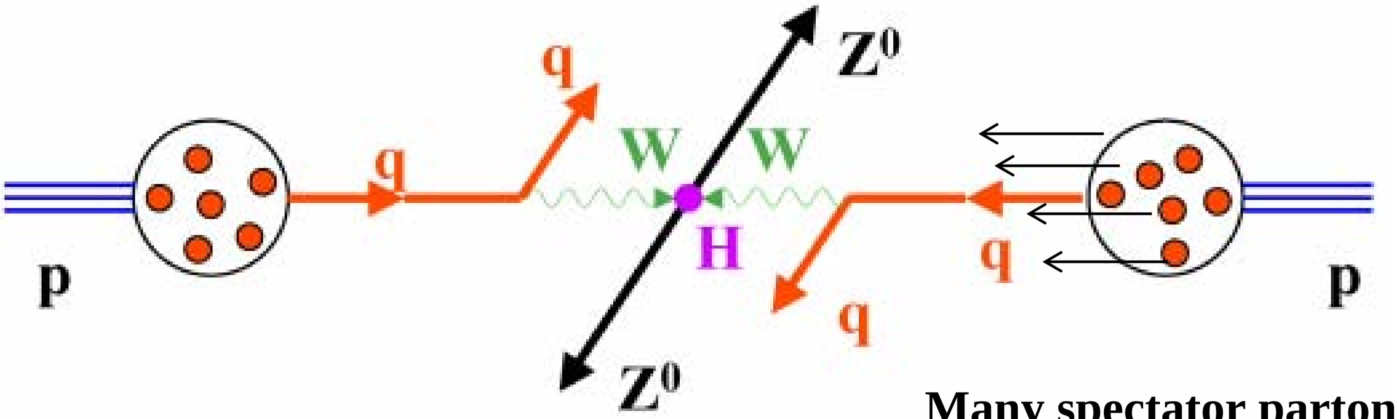
Heavy Ion Collider

Pb-Pb E_{cm} : 1312 TeV

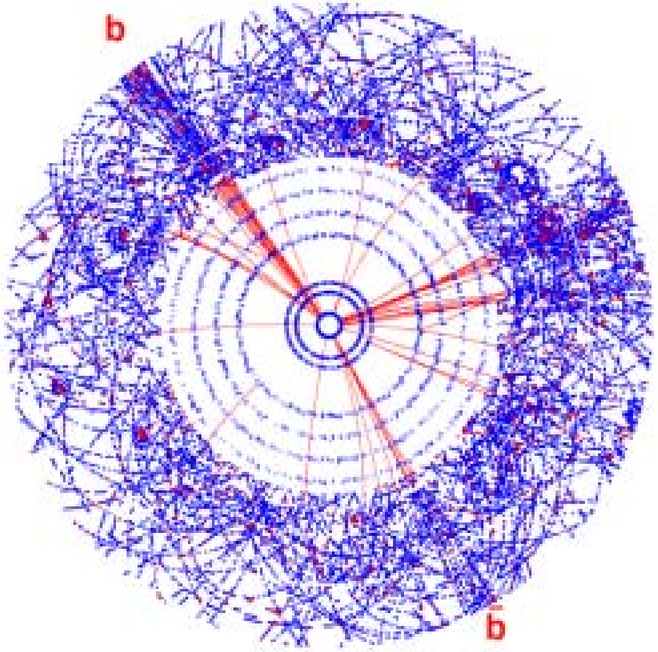
Pb-Pb Luminosity: $2x10^{27}$ cm^{-2}s^{-1}

~23 pp collisions/crossing

LHC: Proton-Proton Collider at E_{CM} = 14 TeV



Many spectator partons
→ large BG



High collision energy → New physics
Large BG → Analysis is not easy.

Discovery potential ☺

Precision measurement ?

LHC Experimental Challenge

- High Interaction Rate

  40MHz beam crossing

  first trigger decision, fast electronics

  data recorded at ~100 Hz

- Large Particle Multiplicity

  ~20 superposed events in each bunch crossing (min. bias events)

  ~1000 tracks emerge into the detector every 25 nsec

  ➔ need highly granular detectors, i.e. large number of channels

- High Radiation Level

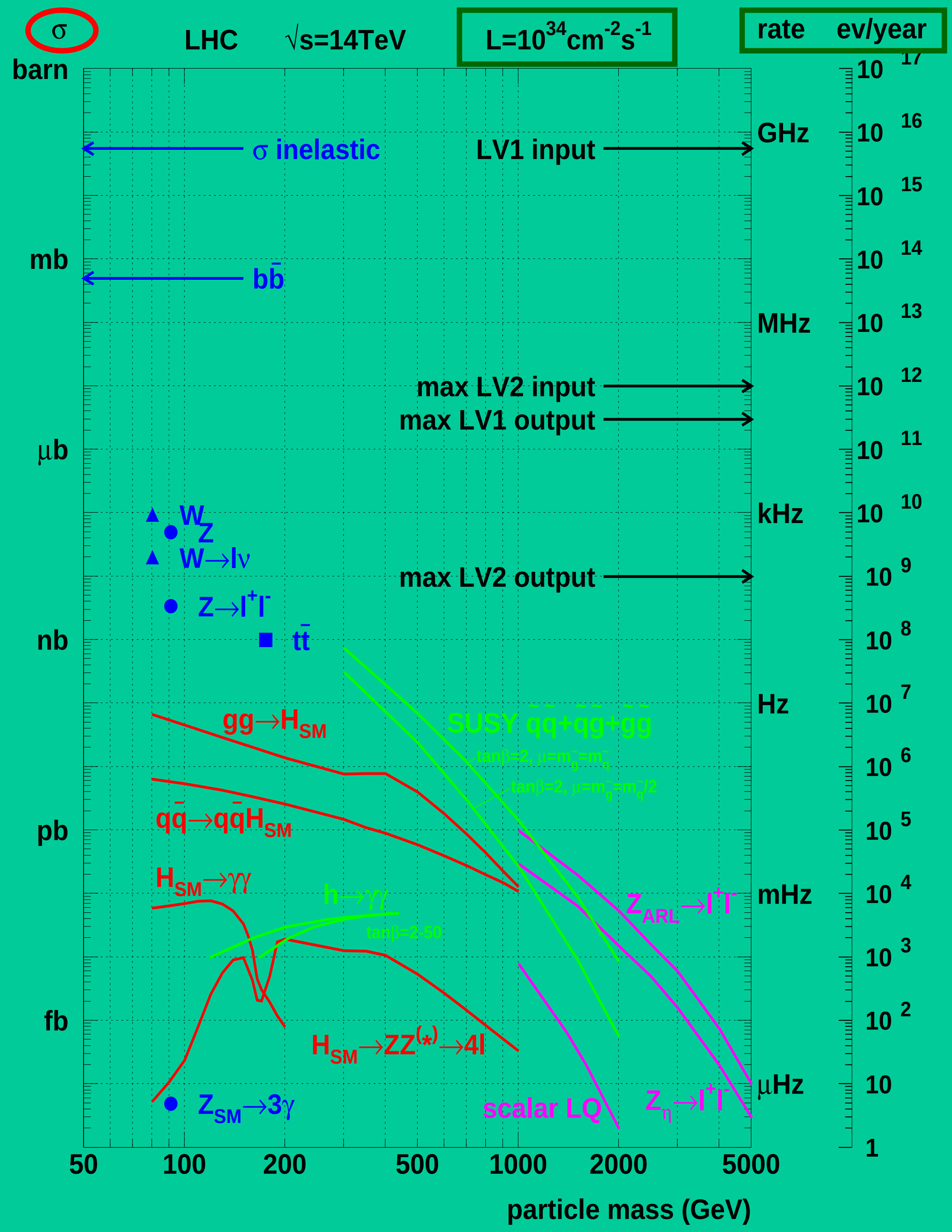
  neutrons, **γ** ’s

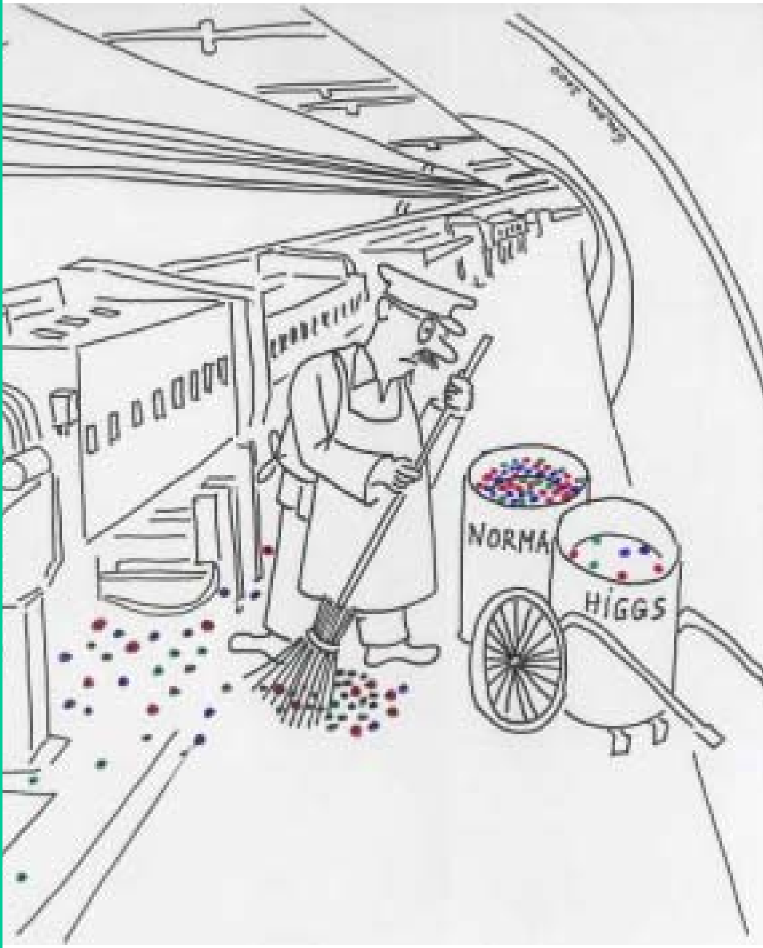
  ➔ radiation hard detectors and electronics

- Huge Amount of Data

  ➔ World-wide computing grid (for data analysis and storage)

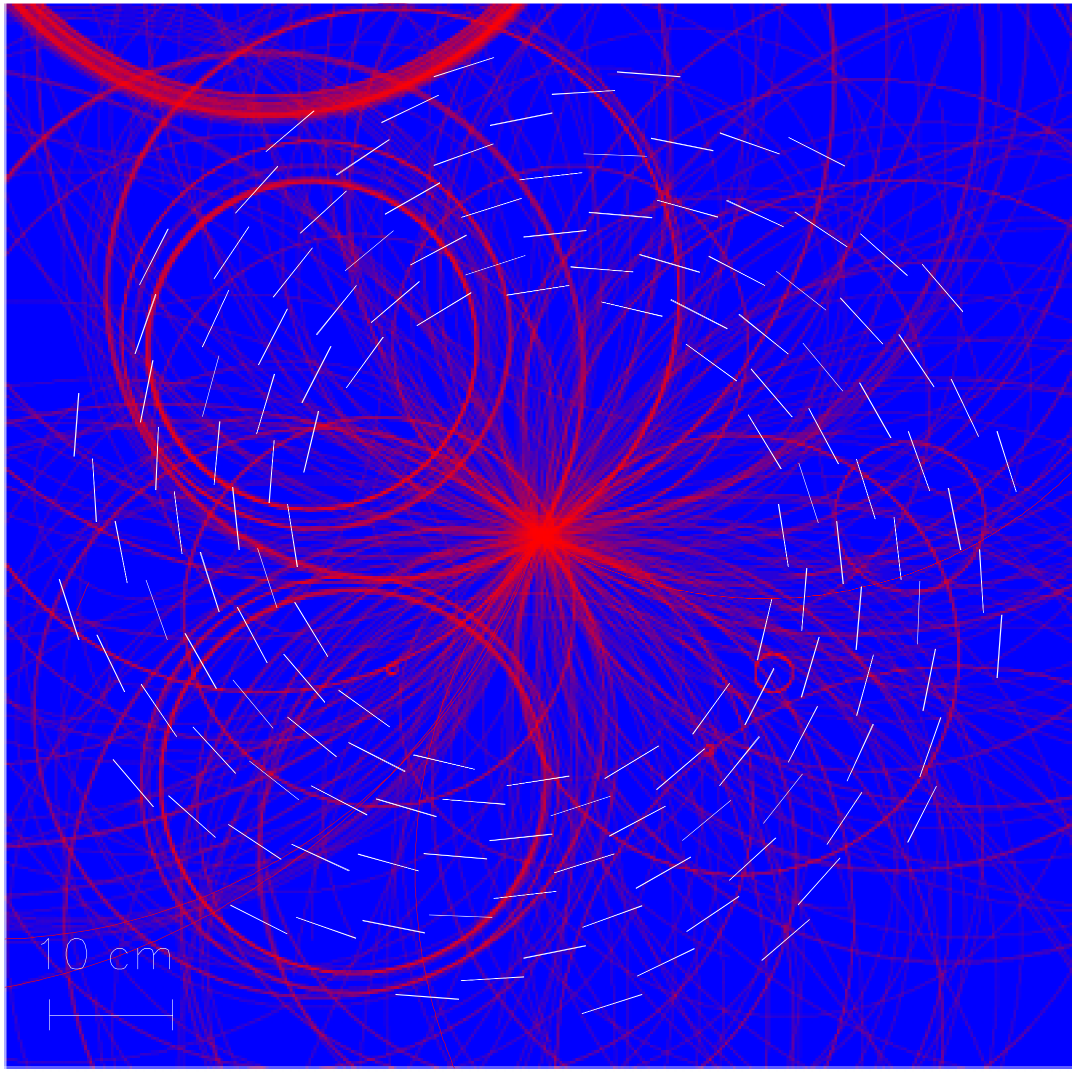
Cross Section vs Particle Mass at LHC





➔ Puzzle in the next slide

Puzzle



Find 4 straight tracks.

Challenges for sub-detector system

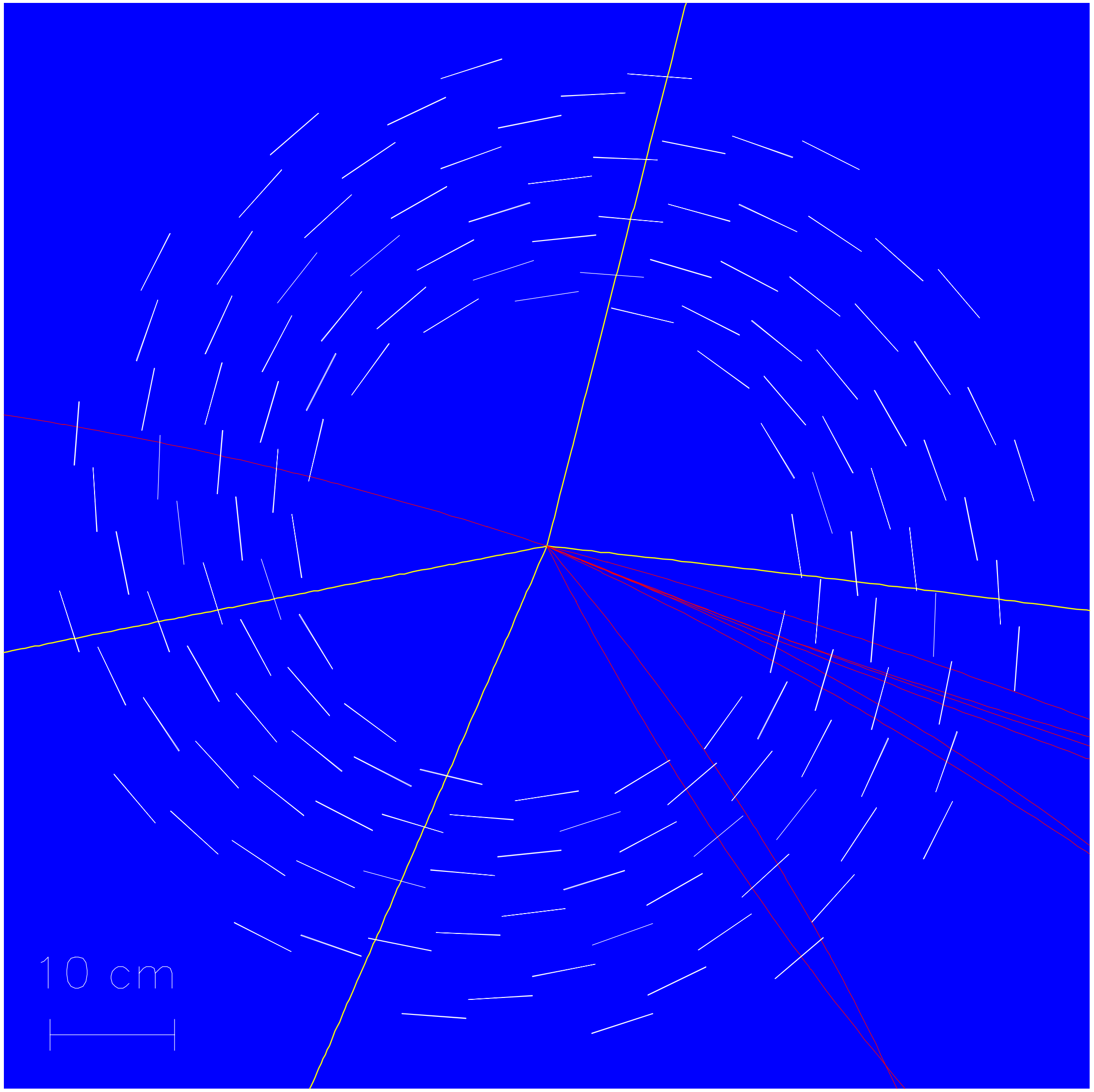
(Tracking in Inner Detector)

←Such an event every 25 nsec without Higgs!

“Searching a needle in a haystack”

(H→ZZ→4 μ)

Answer



Make a “cut” on the transverse momentum of the tracks: $p_T > 2$ GeV

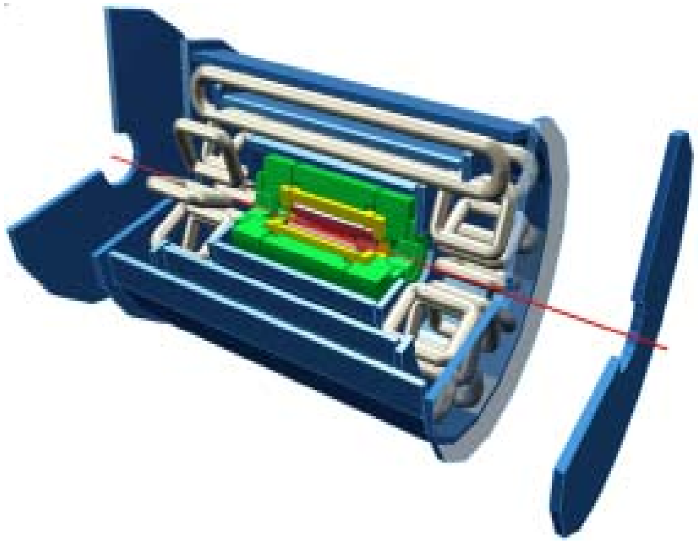
• • or

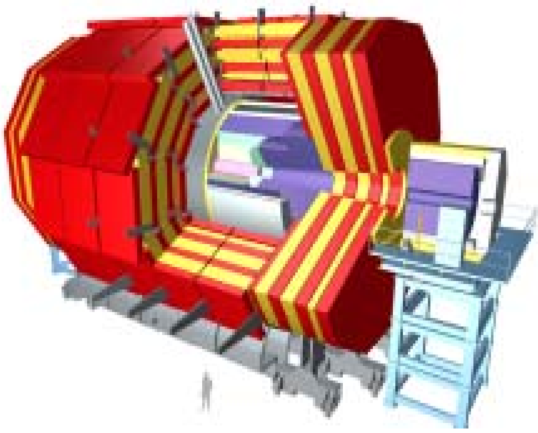
find muon tracks.

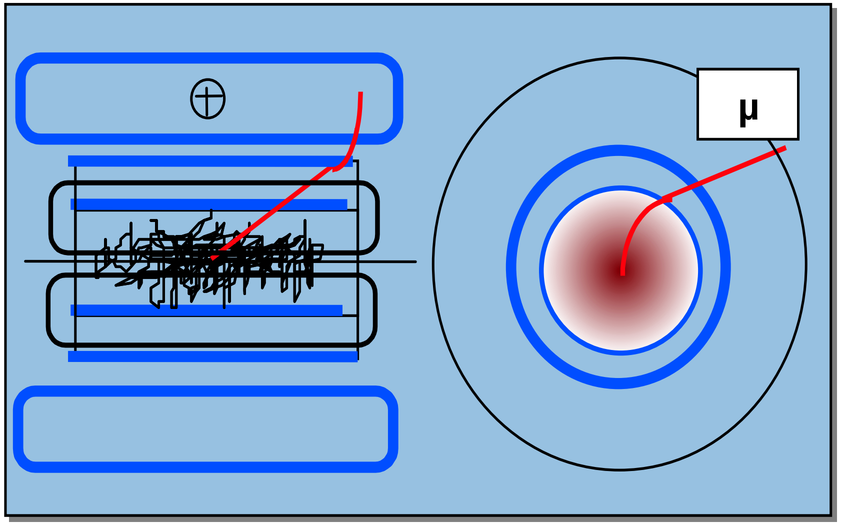
Muon Detection and Magnet System

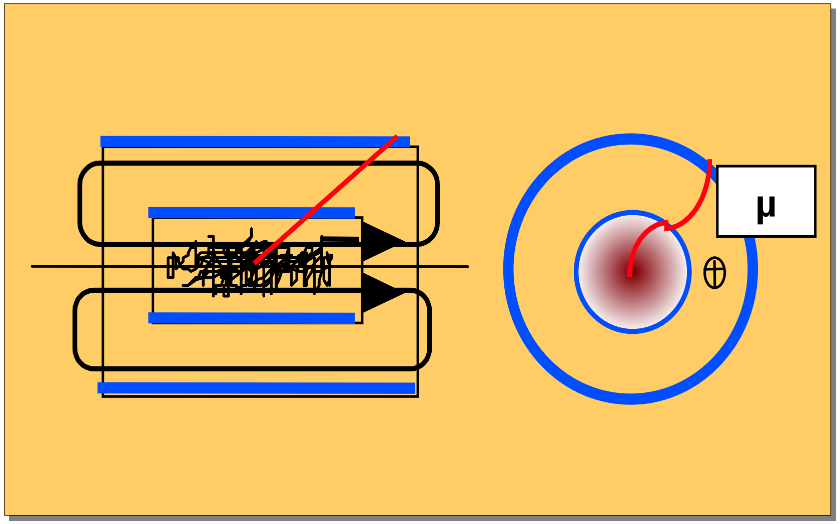
ATLAS A Toroidal LHC ApparatuS

CMS Compact Muon Solenoid

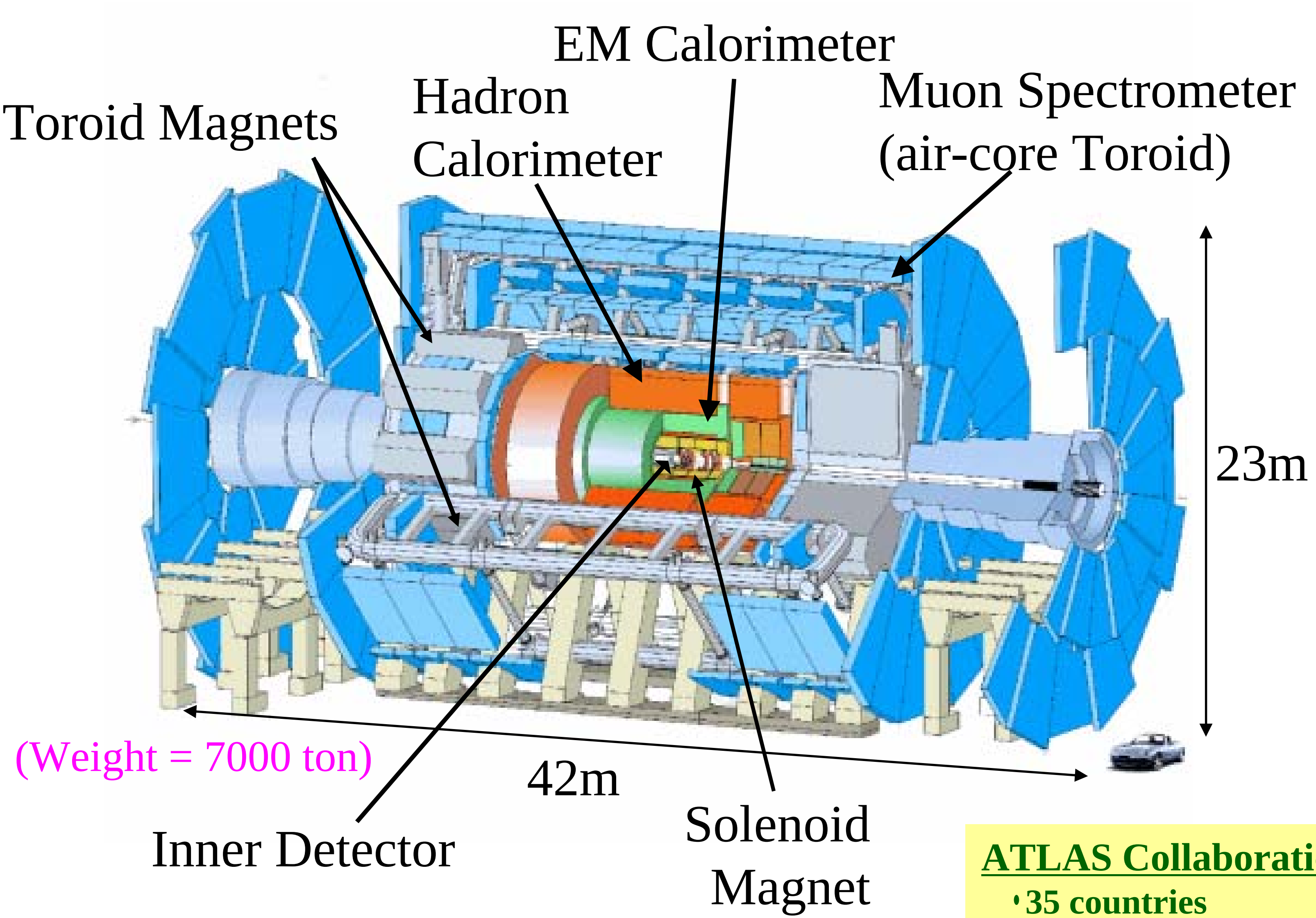








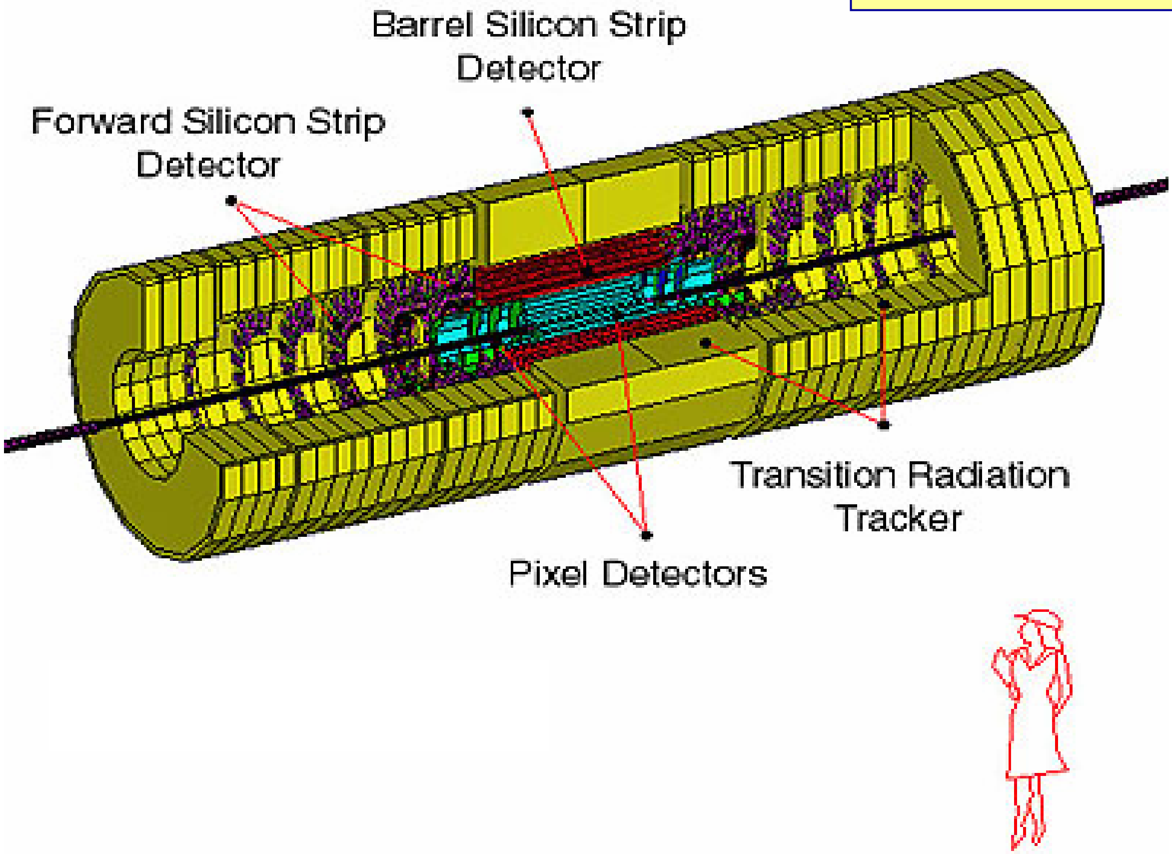
ATLAS Detector

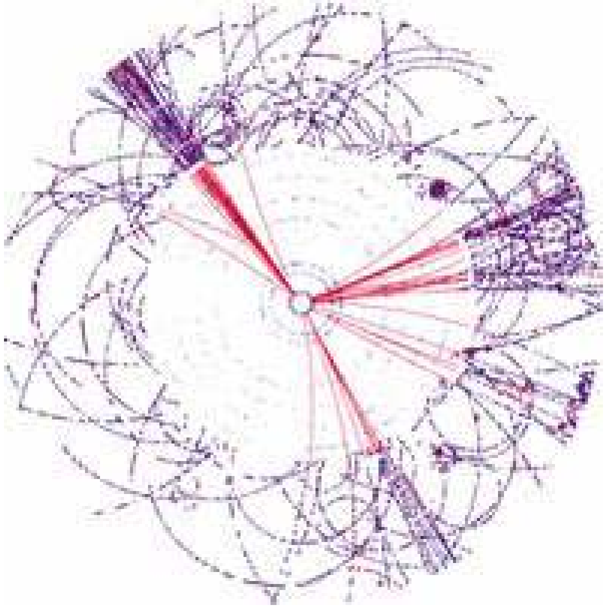


ATLAS Collaboration

- **35 countries**
- **150 institutions**
- **1800 physicists (incl. engineers)**

ATLAS Inner Detector

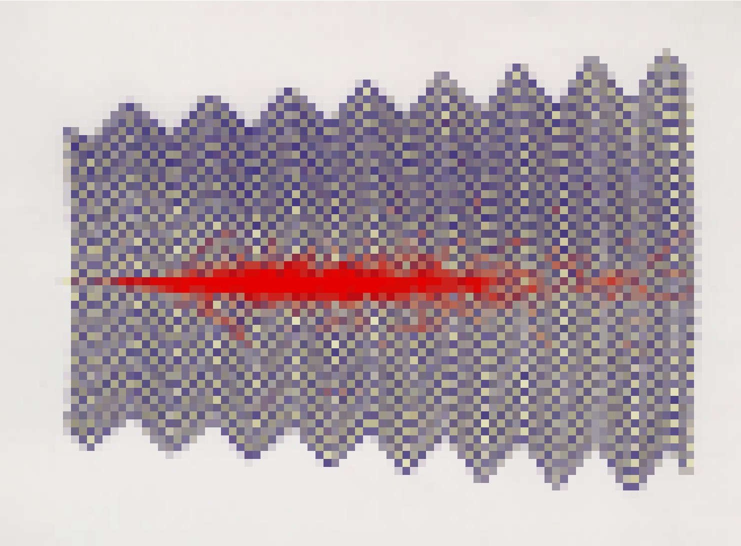




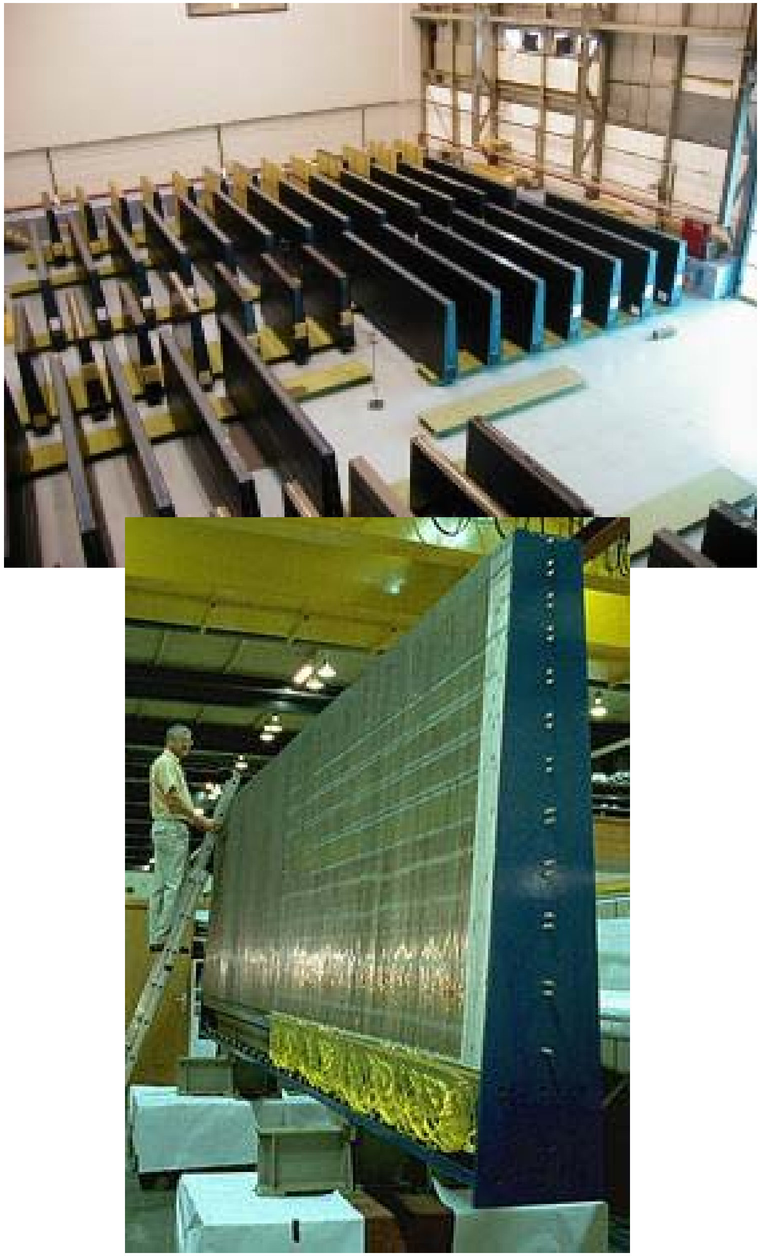
- **Solenoid Magnet (2T field)**
- Pixel Detectors $\sigma(r\phi)=12\mu m$ (1.4×10^{8}channels)
- Strip Detectors $\sigma(r\phi)=16\mu m$ (6×10^{6} channels)
- Transition Radiation Tracker $\sigma(r\phi)=170\ \mu m$/straw (5×10^{5} channels)

➔ $\sigma(p_T)/p_T \sim 0.4\ p_T$ (p_T in TeV)

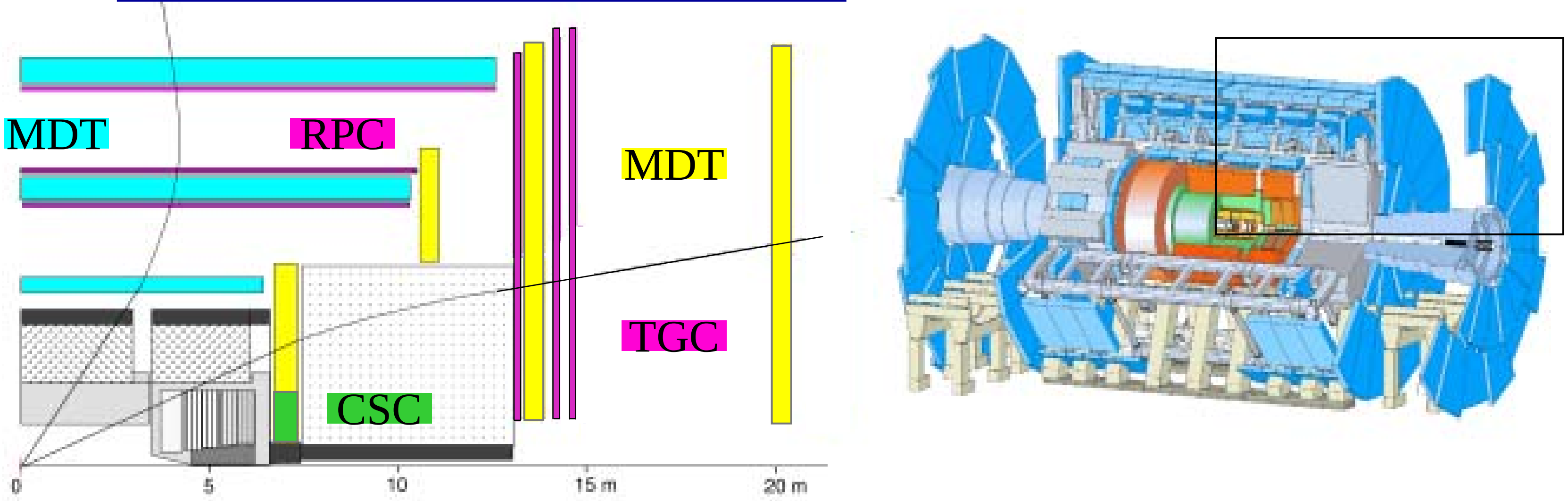
ATLAS Liq. Ar ECAL



ATLAS HCAL (lead+Scinti.)



Muon Detector



Precision chambers

Monitored **D**rift **T**ubes (| η | < 2)

with a single wire resolution of 80 μm

Cathode **S**trip **C**hambers (2 < | η | < 2.7)

at higher particle fluxes

Trigger chambers

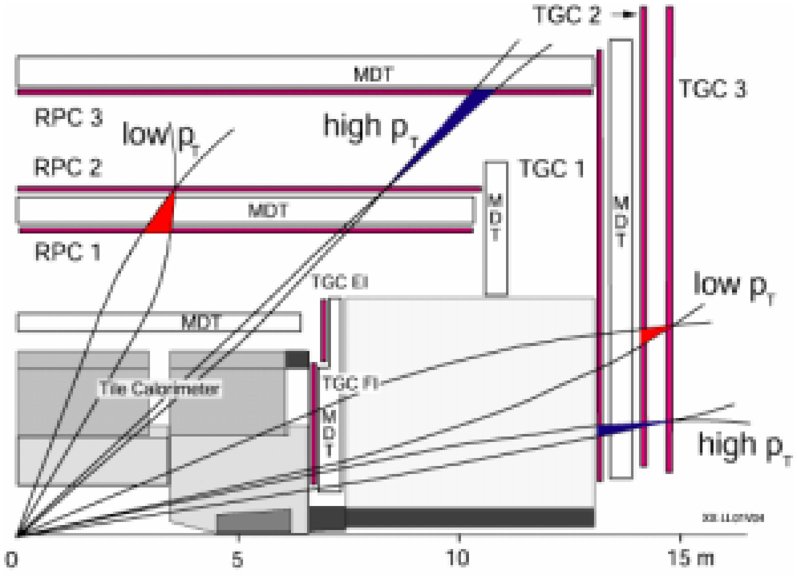
Resistive **P**late **C**hambers (| η | < 1.05)

with a good time resolution of 1 ns

Thin **G**ap **C**hambers (1.05 < | η | < 2.4)

at higher particle fluxes

ATLAS Magnet System

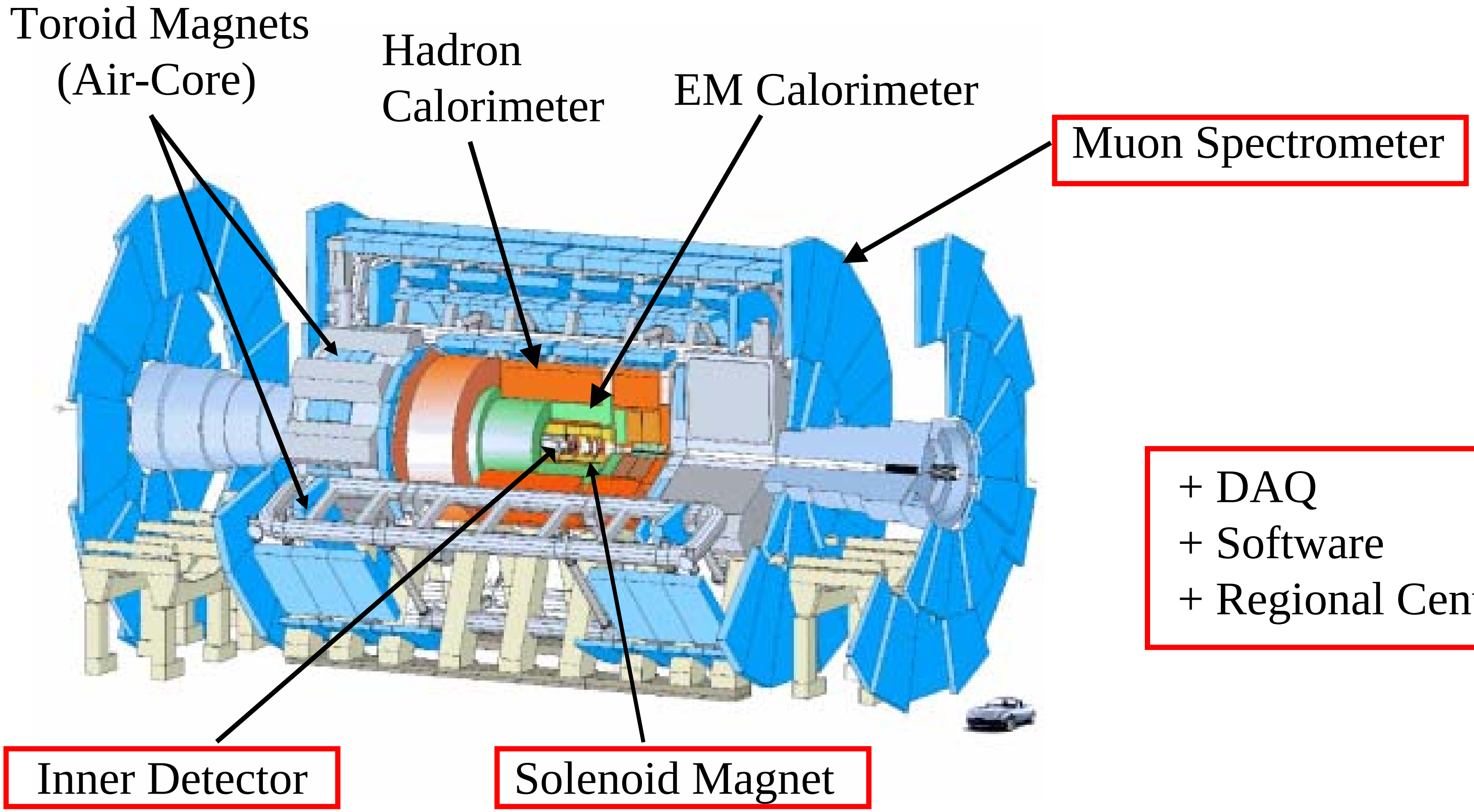


5m × 26m barrel s.c. toroid

Activities of ATLAS-Japan Group

15 Institutions (UT/ICEPP, KEK, Tsukuba, TUAT, TMU, Shinshu, Ritsumeikan, Kyoto, KUE, Kobe, NUE, Okayama, Hiroshima, HIT, NIAS)

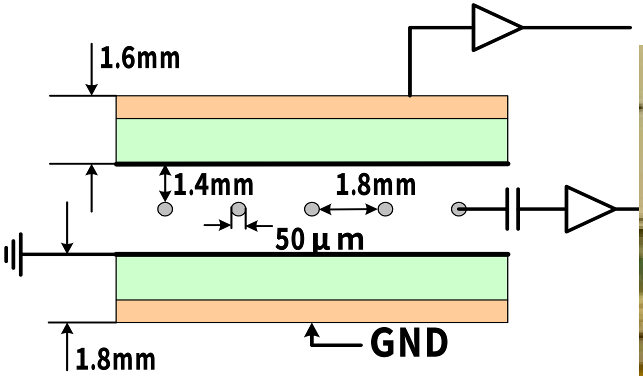
~50 Staffs (+ Students)

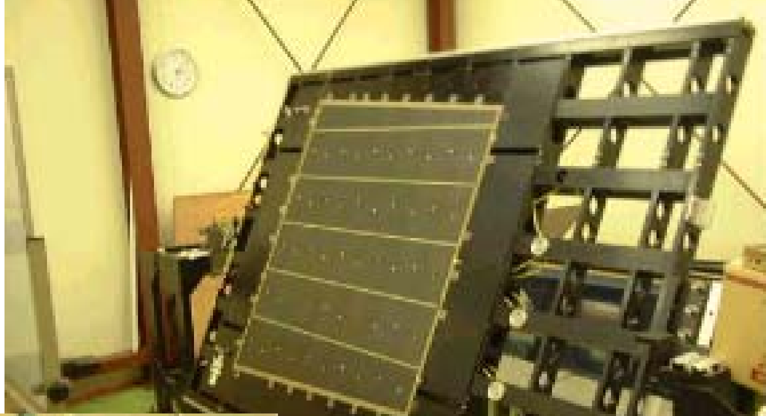


+ DAQ
+ Software
+ Regional Center

Thin Gap Chambers

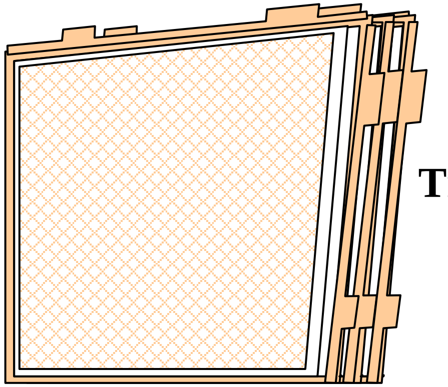
for Muon Triggering in Endcap Region (1.05 < | η | < 2.4)





TGC production
@ KEK

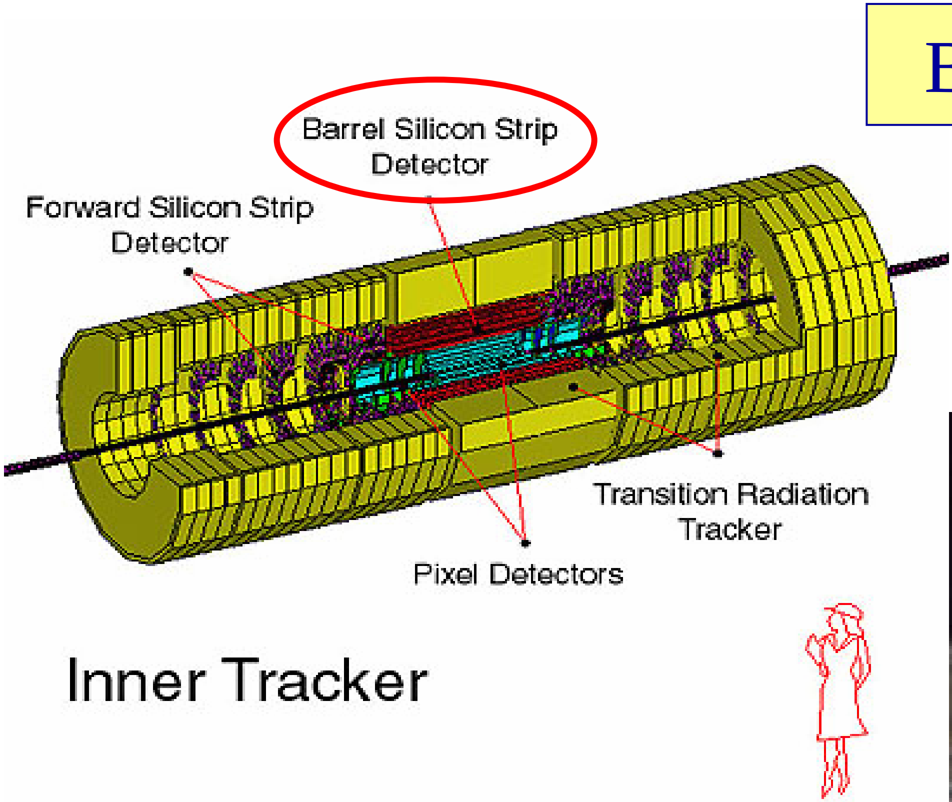
Japanese group is making
- 1056 / 3600 chambers
- all the electronics



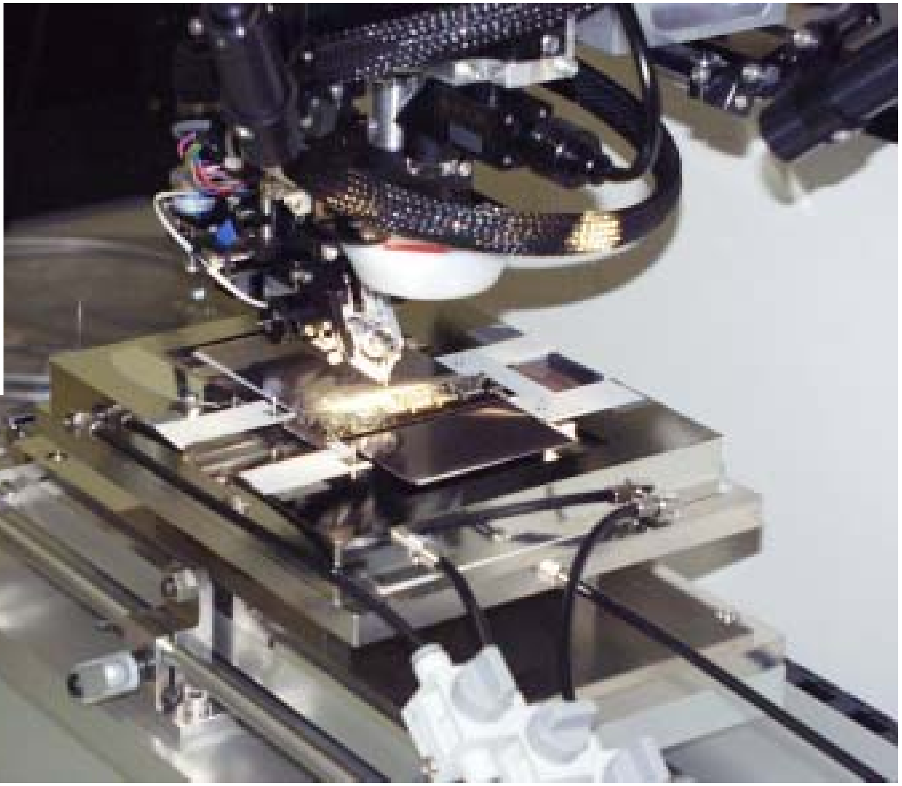
1.6m × 1.2m
Triplet chamber

TDC/TMC for MDT is also a Japanese contribution.

Barrel Silicon Strip Modules

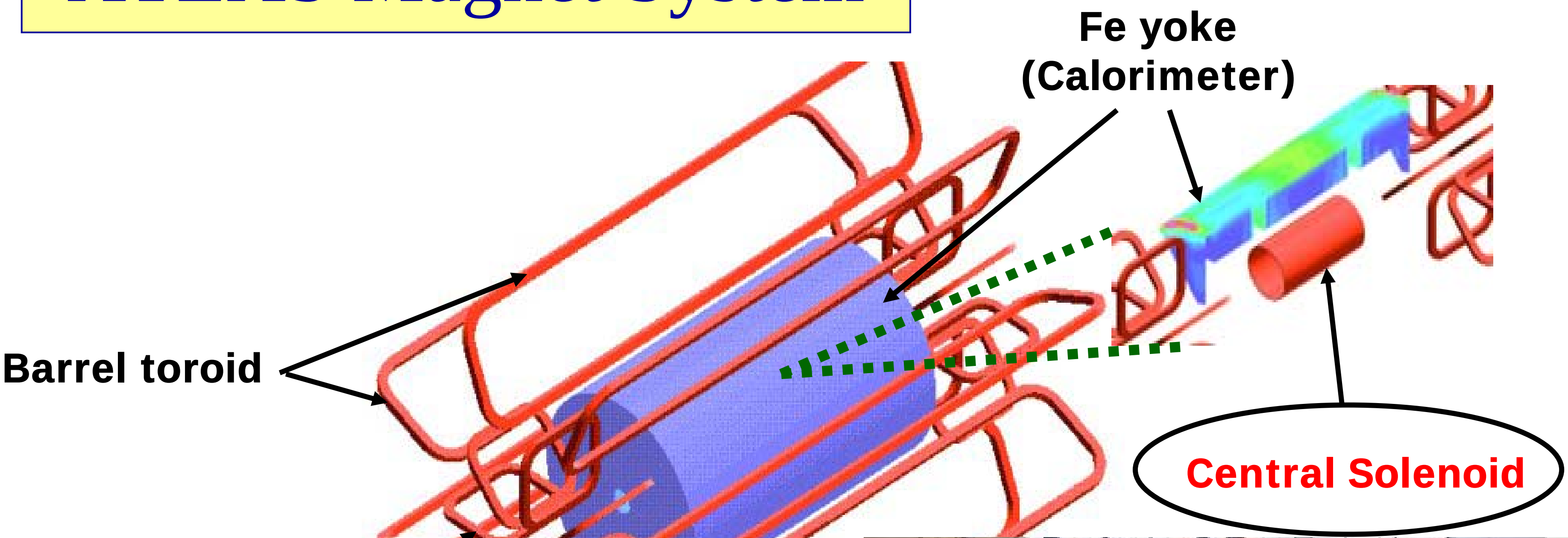


- Japanese Share of the Work
  - 6000/10600 Detectors
  - 2500/2500 Hybrid Boards
  - 980/2220 Modules
- Production Schedule
  - Sep. 2004 Modules Ready
  - End 2004 Cylinders Ready



Wire-Bonding of the Module

ATLAS Magnet System



Fe yoke
(Calorimeter)

Barrel toroid

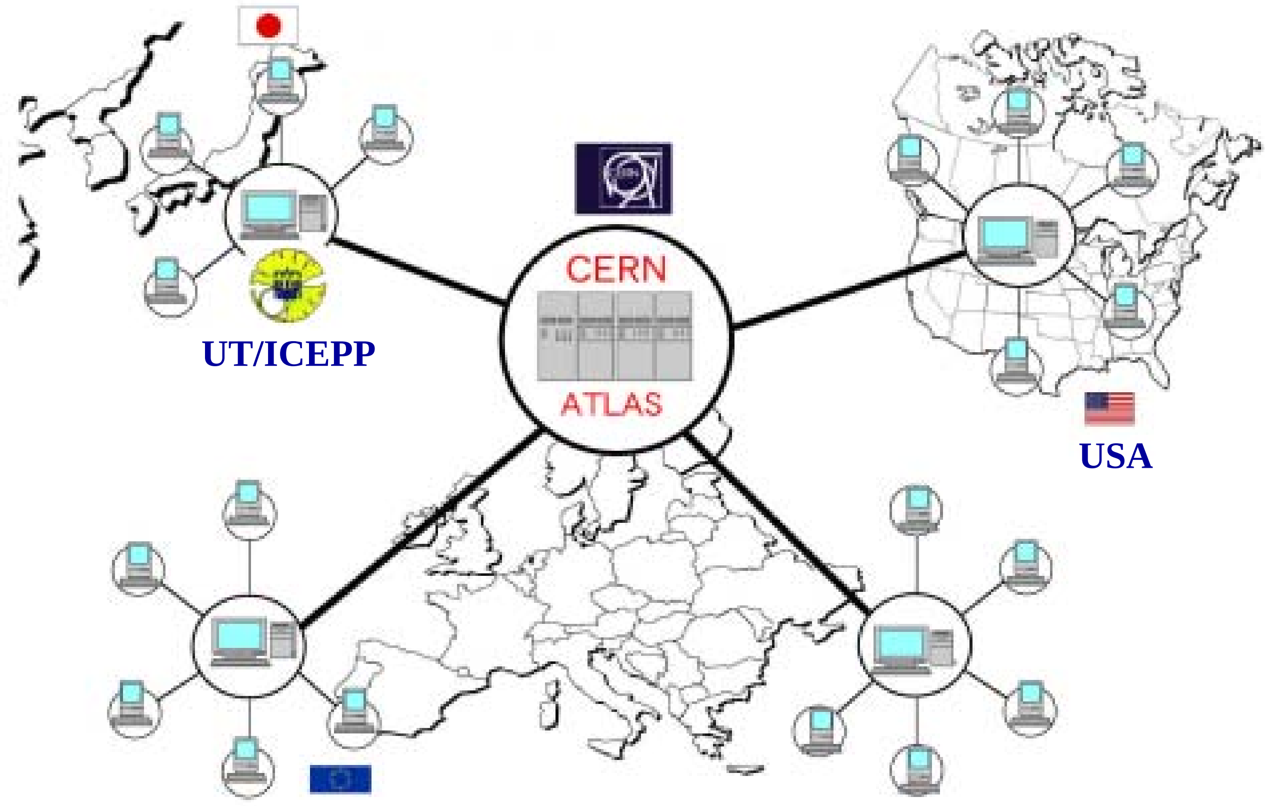
End-cap toroid

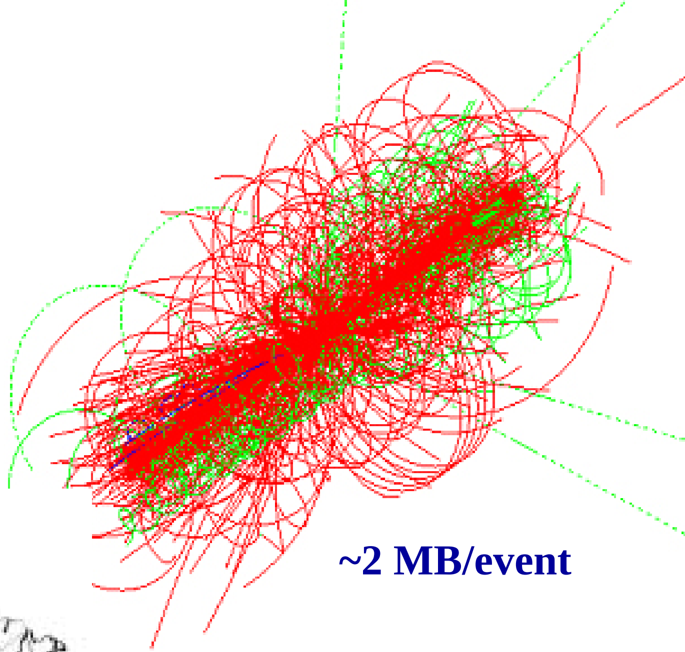
Central Solenoid

Superconducting Central Solenoid
(2T, L=5m, 10mϕ, 0.8X_0)

Data Analysis System

Regional centers and world-wide network
for LHC data analysis





~2 MB/event

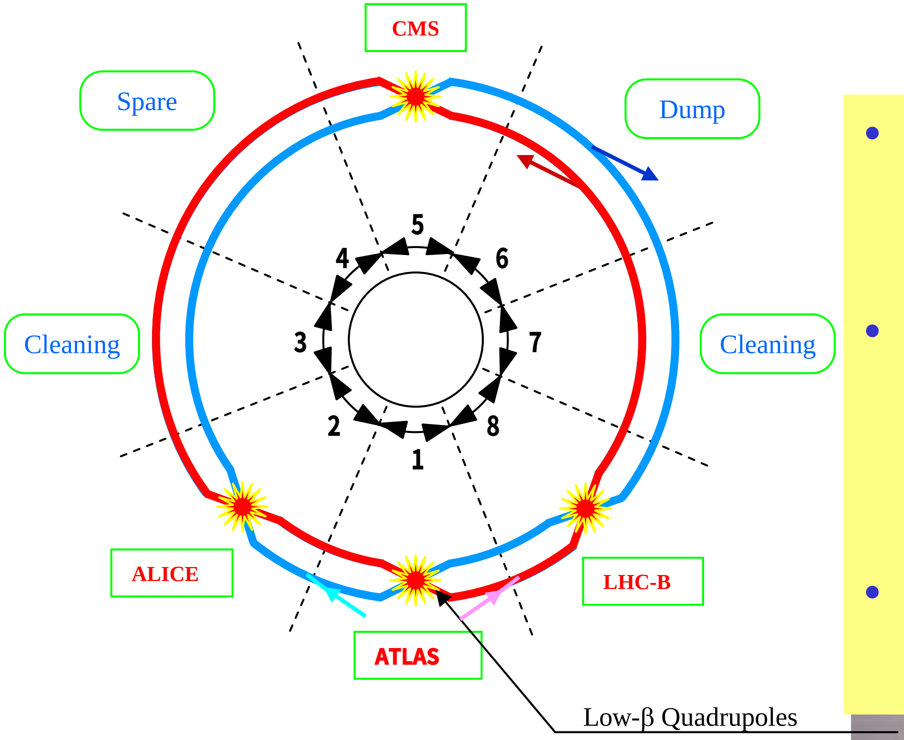
ATLAS raw data:
2.8 PB/year → 4M CD-R's

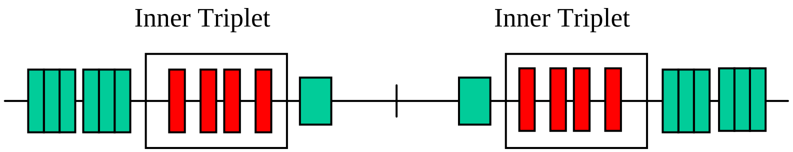
For all LHC experiments, need
- **CPU: 2000k SI95**
  (⇒ 100,000 PCs)
- **Disk: 2600 TB**
- **Tape: 20 PB**

Regional Centers
Computing GRID / LCG

Low-β Quadrupoles

- **Production in progress**
  - 16 of 18 (incl. 2 spares) Quads. Completed
  - Production to be completed, early 2004
- **Test at KEK**
  - 14 magnets tested
  - Acceptable Training
  - Good field quality and stability
- **Delivery to Fermilab for cryostating**
  - 13 Quads delivered





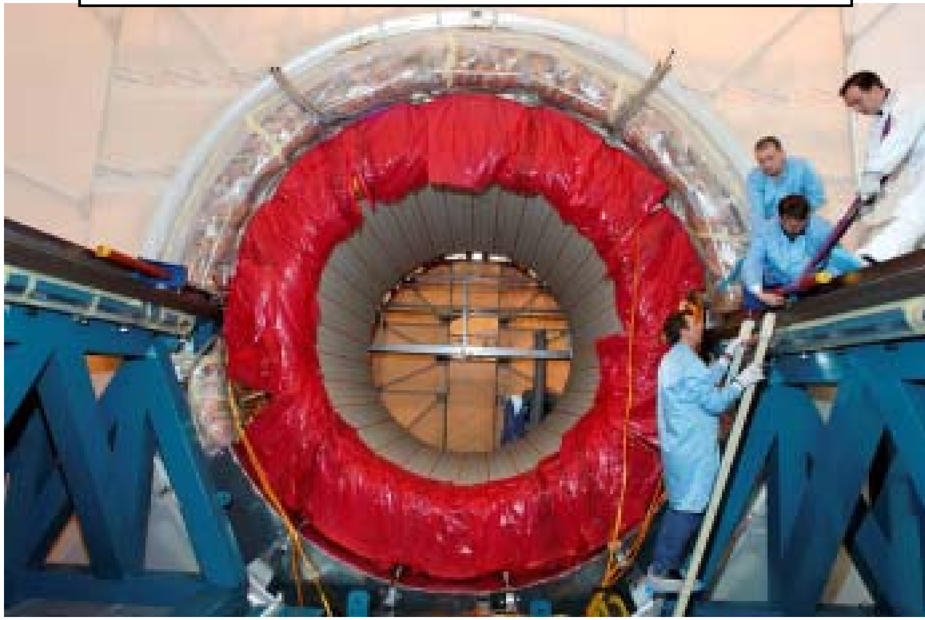
Cross Section

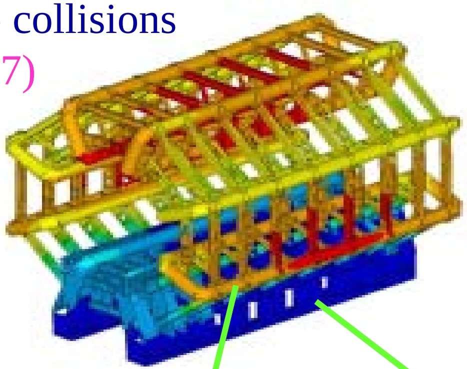
Tests at KEK Warm measurement

ATLAS Status and Schedule

- Detector parts under construction
- Experimental hall ready (June 2003)
- Detector installation in the pit (by end 2006)
- Detector commissioning (beginning 2007)
- Single beam injection (Apr. 2007)
- Start experiment with pp collisions
  (from summer 2007)

EM calorimeter inside the cryostat





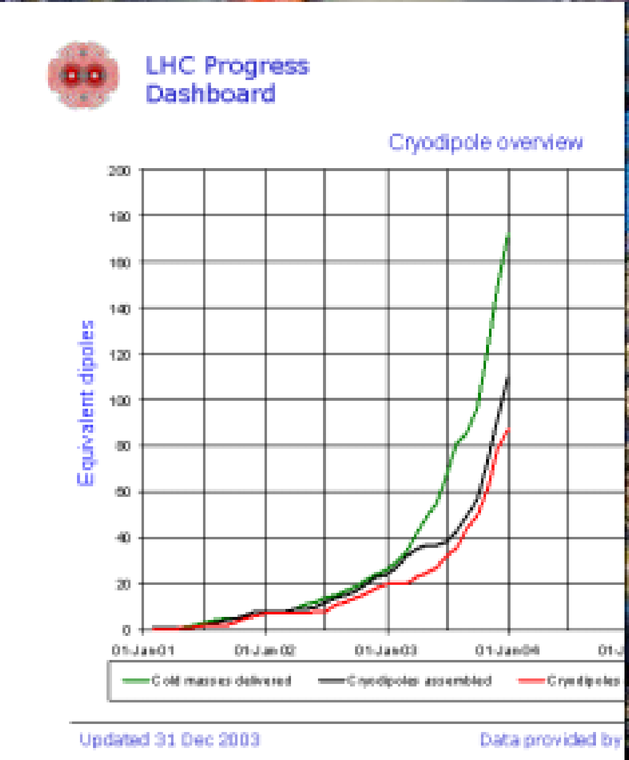
Barrel toroid cryostat

Webcam
(29.Jan.'04)

LHC Status and Schedule

- First beam transfer line magnet installed (Dec.2003)
- 154 SC dipole magnets (= first octant) delivered (Dec. 2003)

- LHC ring closed (end 2006)
- Cooling LHC (beginning 2007)
- Beam commissioning (Apr.2007)
- Start pp collisions (June 2007)



Tests of 14m magnets

Test of handling system with the first cryodipole in LHC tunnel (27.Jan.04)

“CERN/LHC Budget Crisis?”

Former DG

In 2001, it became apparent:

- cost increase for LHC completion
- tight schedule

In 2002, ERC recommended:

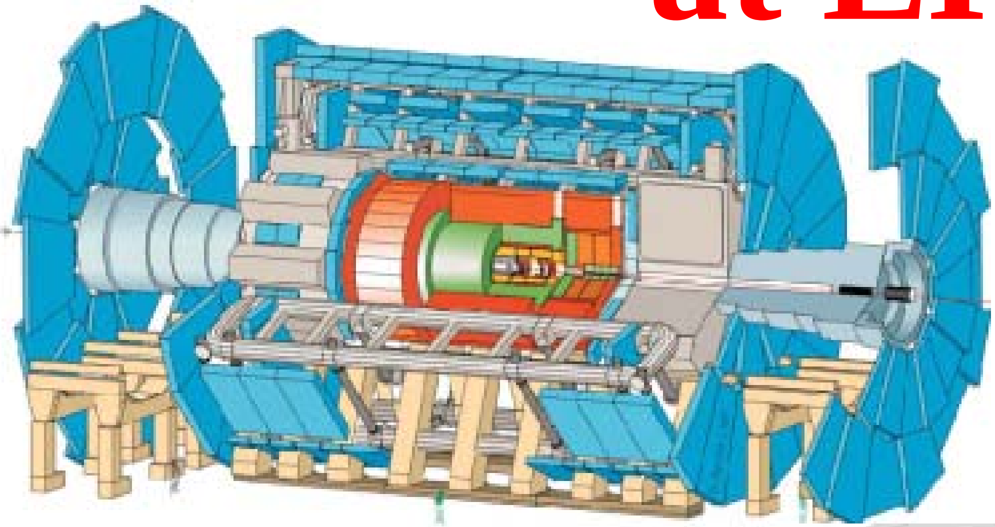
- cut non-LHC activities
- delay the schedule → start-up in 2007

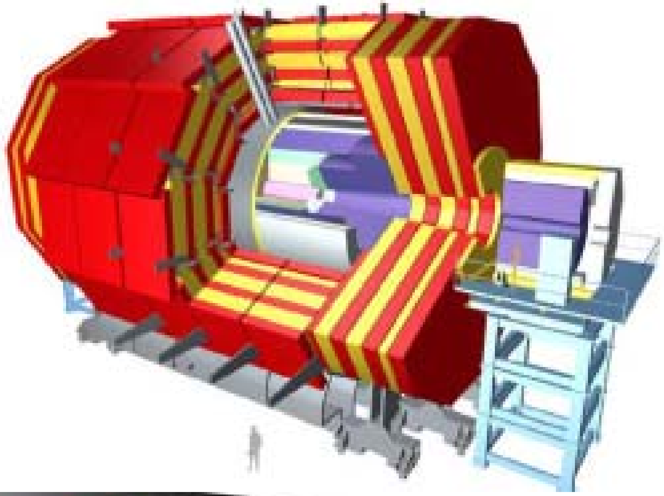
ERC Chair → New DG

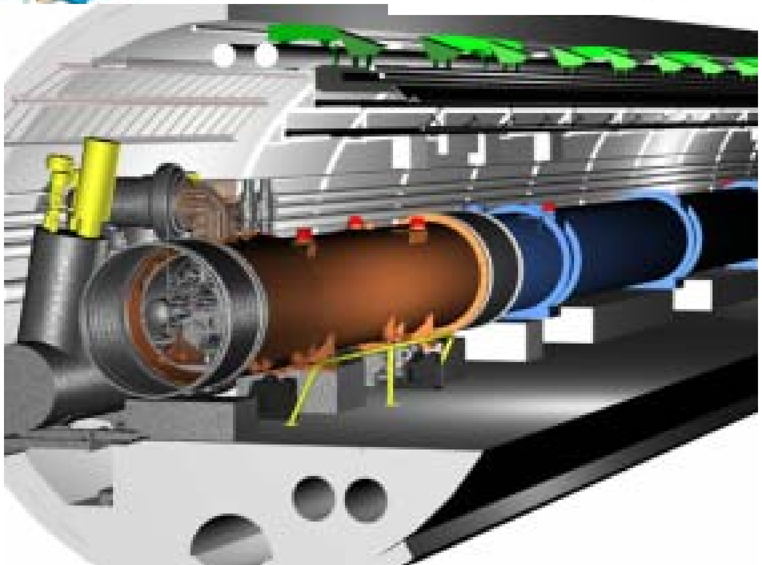
“Old concerns have been overcome ··
·· the project’s cost is stable and its schedule unchanged, foreseeing first beam in April 2007 with first collisions following in June.” (Council, Dec.2003)

"··LHC is the utmost priority of CERN."

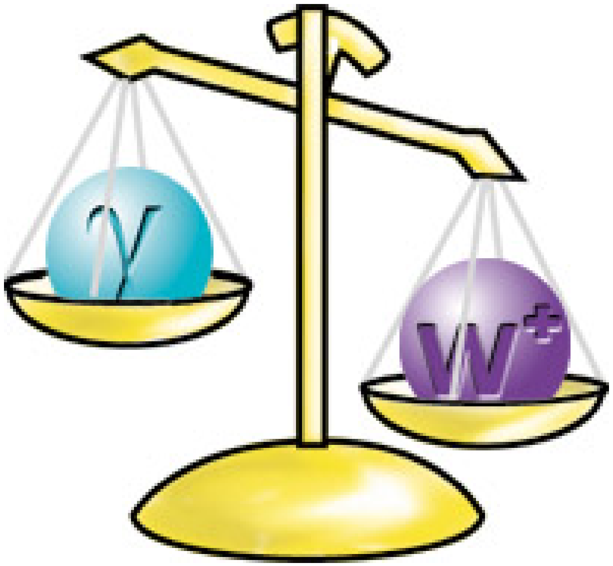
3. Physics Expected at LHC

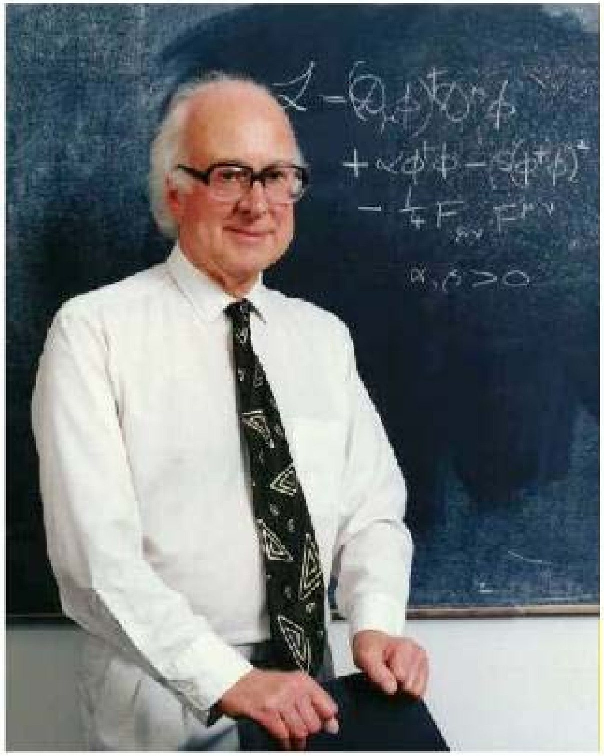




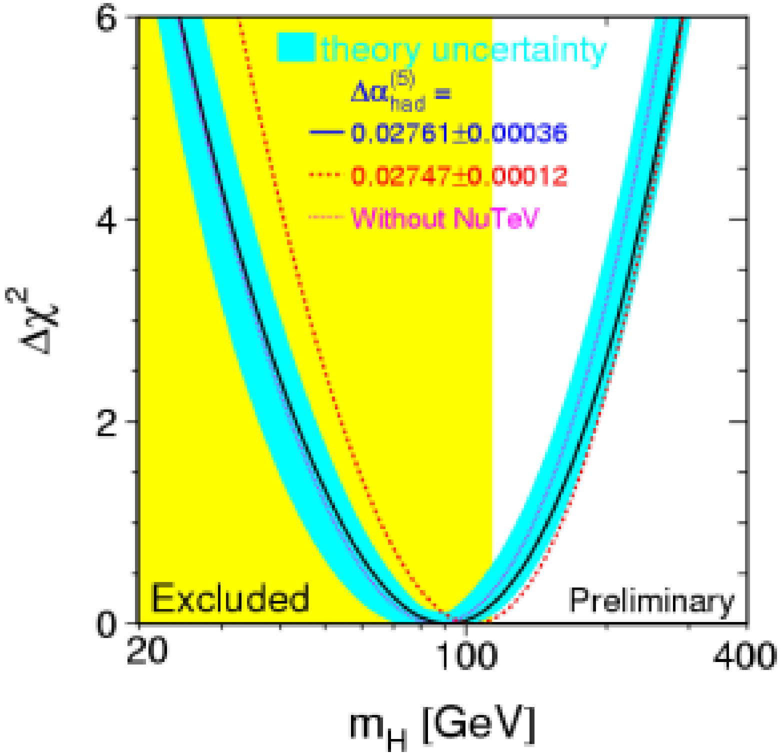


SM Higgs





What do we know today about it ?



- Needed in SM to generate particle masses
- Mass not predicted by theory except that
  $m_H < 1000$ GeV (from Unitarity)
  → tighter constraint from the argument of
  Landau pole and vacuum stability

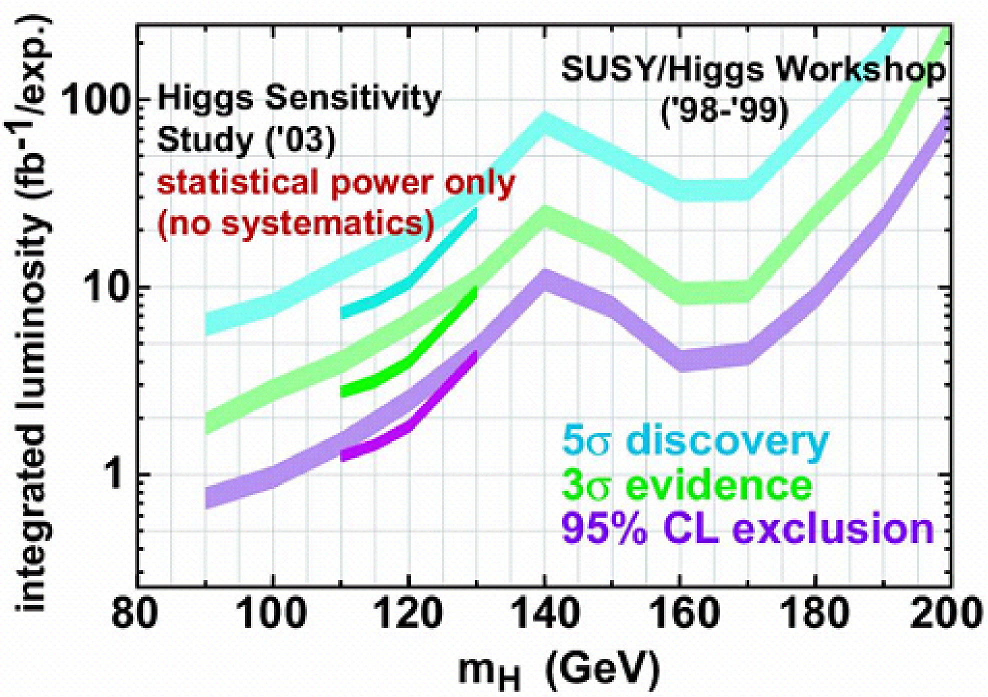
- $m_H > 114.4$ GeV   from direct searches at LEP
- Indirect limits from fit of SM to:
  -- LEP1/SLD precise measurements at $\sqrt{s} = m_Z$
  -- m_W measurement LEP2/Tevatron
  -- m_{top} measurement at Tevatron

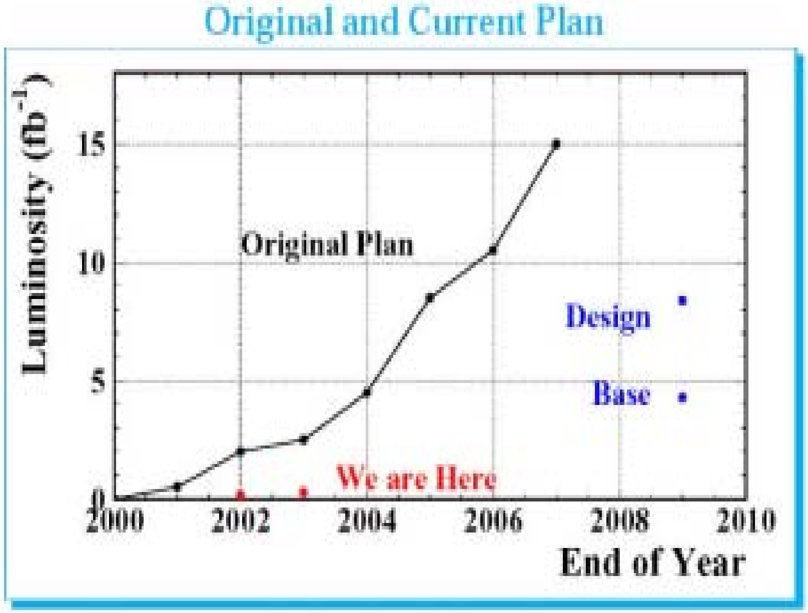
Best fit of SM to data
(minimum χ^2) found for
$m_H = 91^{+58}_{-37}$ GeV

$m_H < 219$ GeV (95% C.L.)

→ Higgs could be just around the corner !

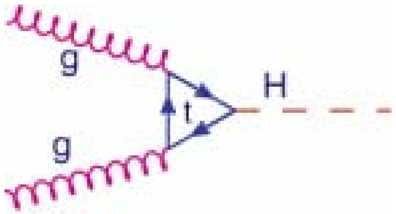
Higgs at Tevatron Run-II?



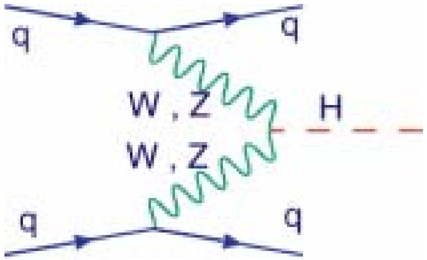


M_H < 120 GeV at 3σ by 2007 (?)

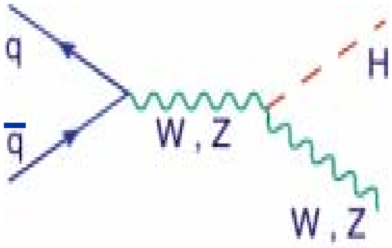
Higgs Production at LHC



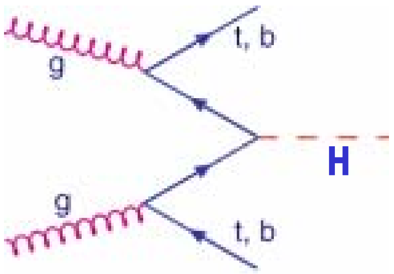
Gluon Fusion



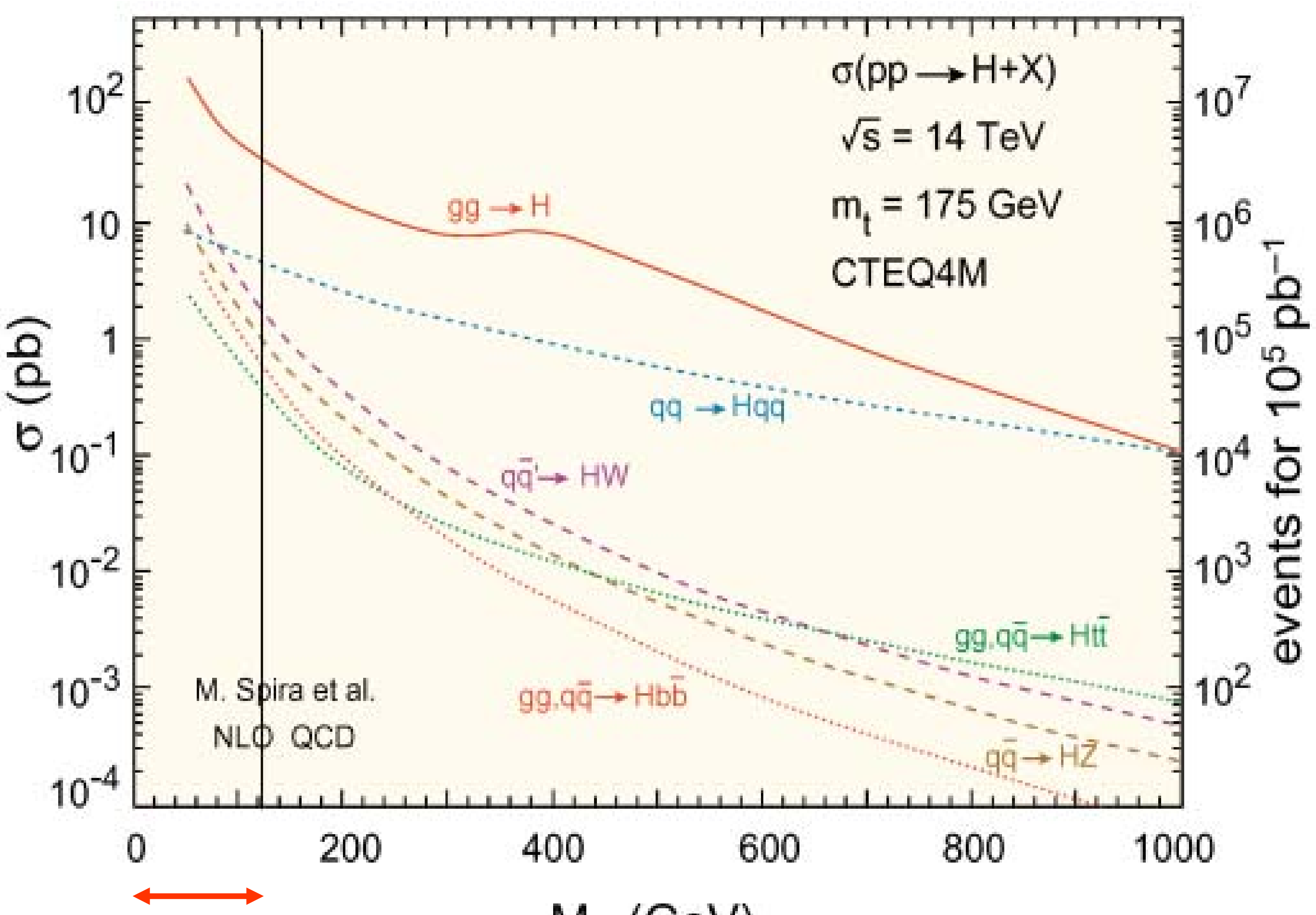
VBF



Asoc. Prod. with W/Z

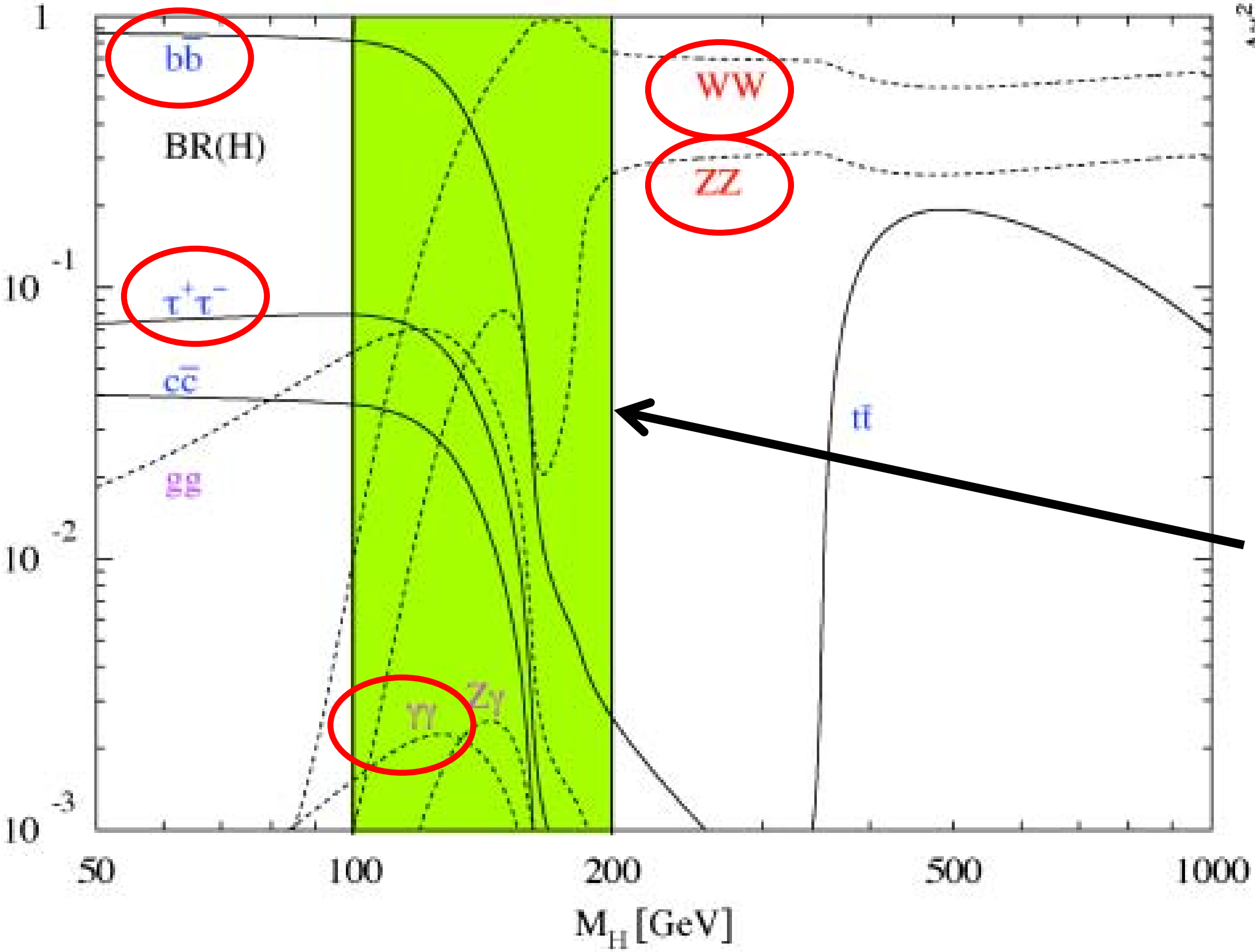


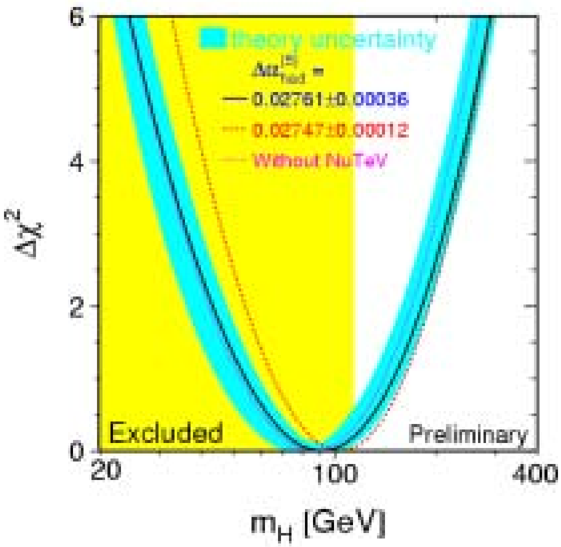
Asoc. Prod. with t/b



Excl. by LEP

Higgs Decay Process





5 important decay modes in the mass region indicated by LEP

Observation of multiple decay modes
→ Detailed study of Higgs properties

Promising channels for SM Higgs boson (H<140GeV)

Decay modes

Production modes

	bb	τ τ	γ γ	WW	ZZ
gg→H	×	×	Mass	×	------
VBF	? (Y_b)	**Discovery** Y_{τ} Gw	**?** **(Discovery)**	**Discovery** Gw^2	------
ttH	$Y_t Y_b$	$Y_t Y_{\tau}$	------	------	------
WH	×	×	------	------	------

× : BG too high ----- : σ or Br too small

Blue: we can measure couplings and mass

Promising channels for SM Higgs boson (H>140GeV)

Decay modes

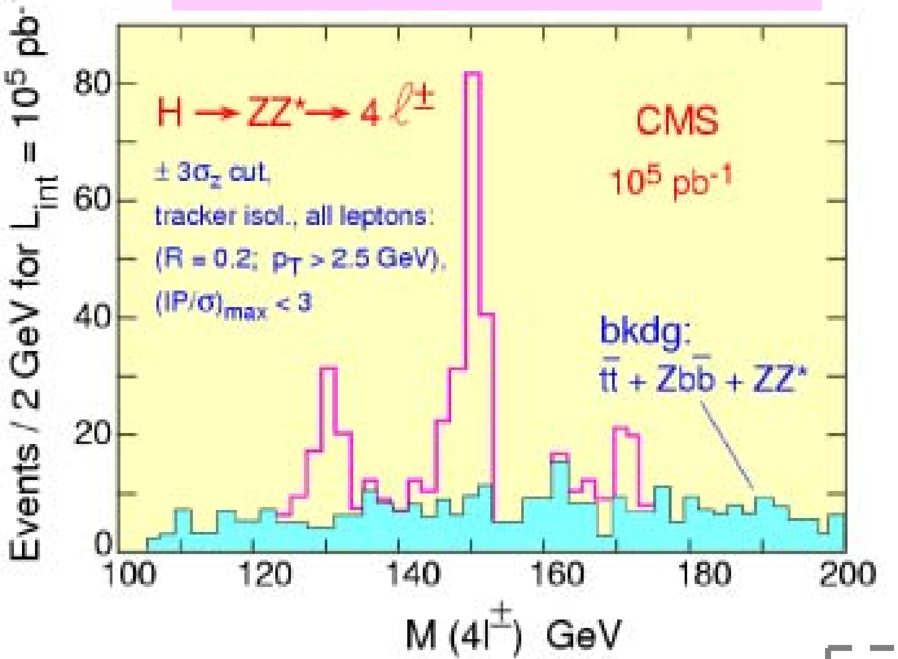
Production modes

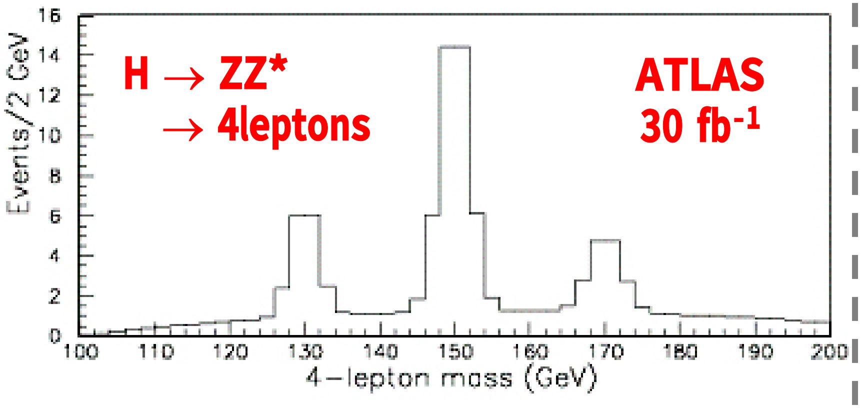
	bb	$\tau\ \tau$	$\gamma\ \gamma$	WW	ZZ
gg→H	×	-----	-----	**Discovery**	**Discovery** **Mass, spin**
VBF	×	-----	-----	**Discovery** **Gw^2**	**GwGz**
ttH	-----	-----	-----	**GwY_t** **(<180GeV)**	------
WH	-----	-----	-----	**Discovery**	------

× : BG too high ----- : σ or Br too small

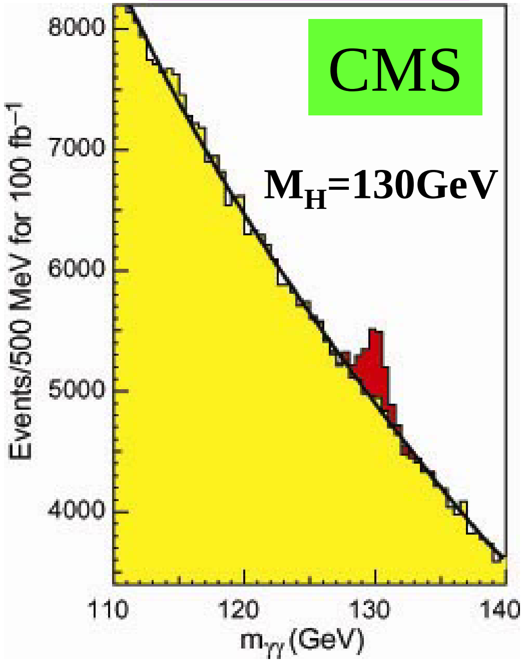
Blue: we can measure couplings and mass

$H \rightarrow ZZ^* \rightarrow 4$leptons



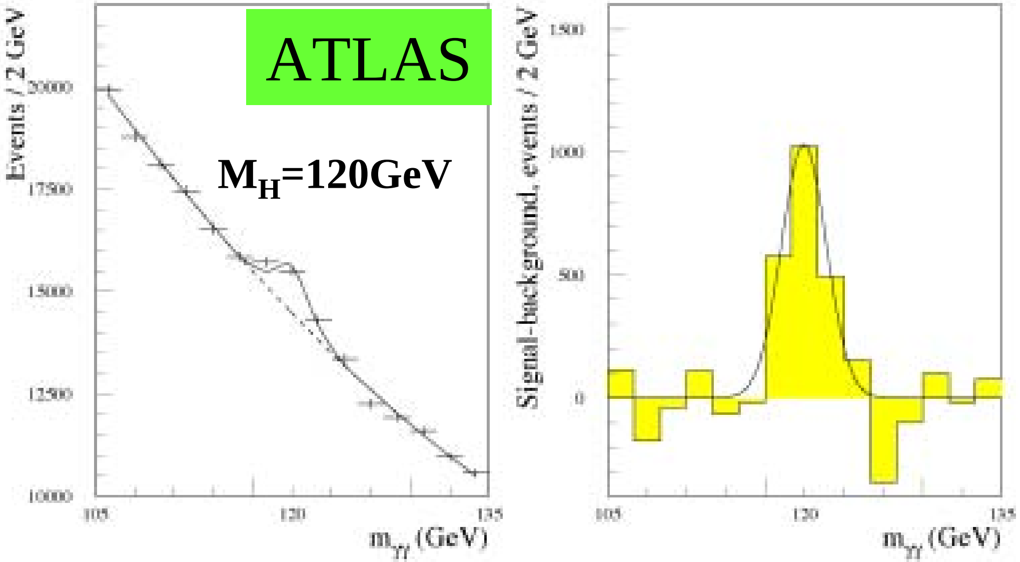


$H \rightarrow \gamma\ \gamma$



CMS

M_H=130GeV



ATLAS

M_H=120GeV

VBF

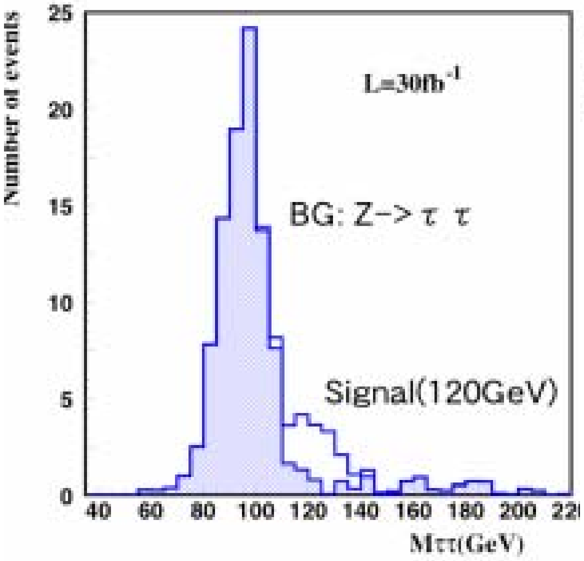
$M_{\tau\tau}$ Dist. for H→ττ

M_T Dist. for H→WW

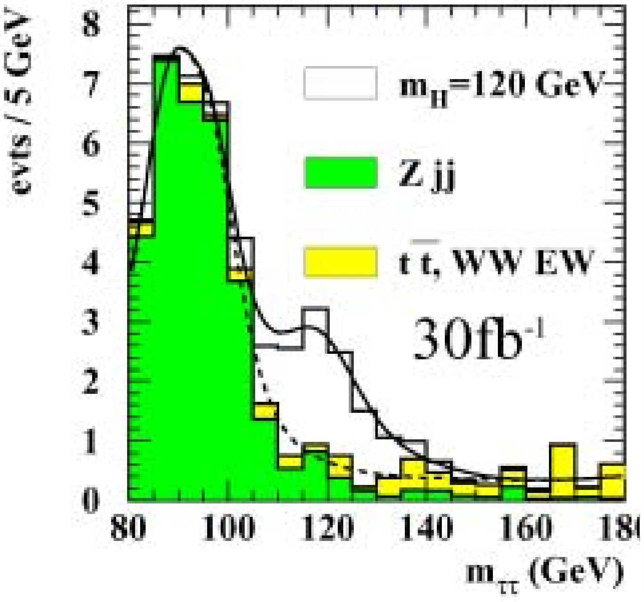
M_H=120GeV

M_H=160GeV

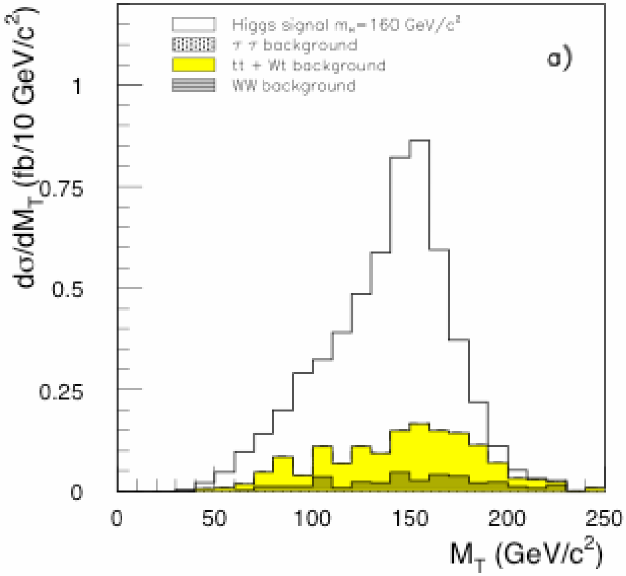
$$\tau^+\tau^- \to h\nu_\tau \ell \nu_\tau \nu_\ell$$



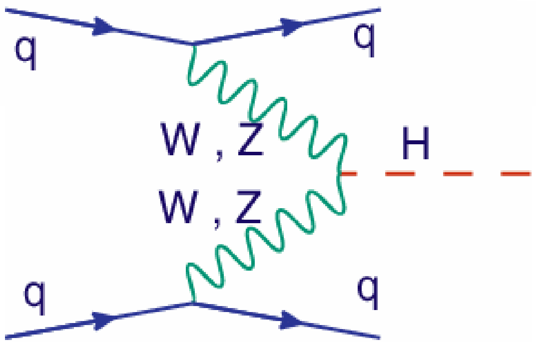
$$\tau^+\tau^- \to \ell\ell 4\nu$$



$$W^+W^- \to \ell\nu\ell\nu$$



>5σ for 140<M_H<200 GeV
with 10 fb^{-1}

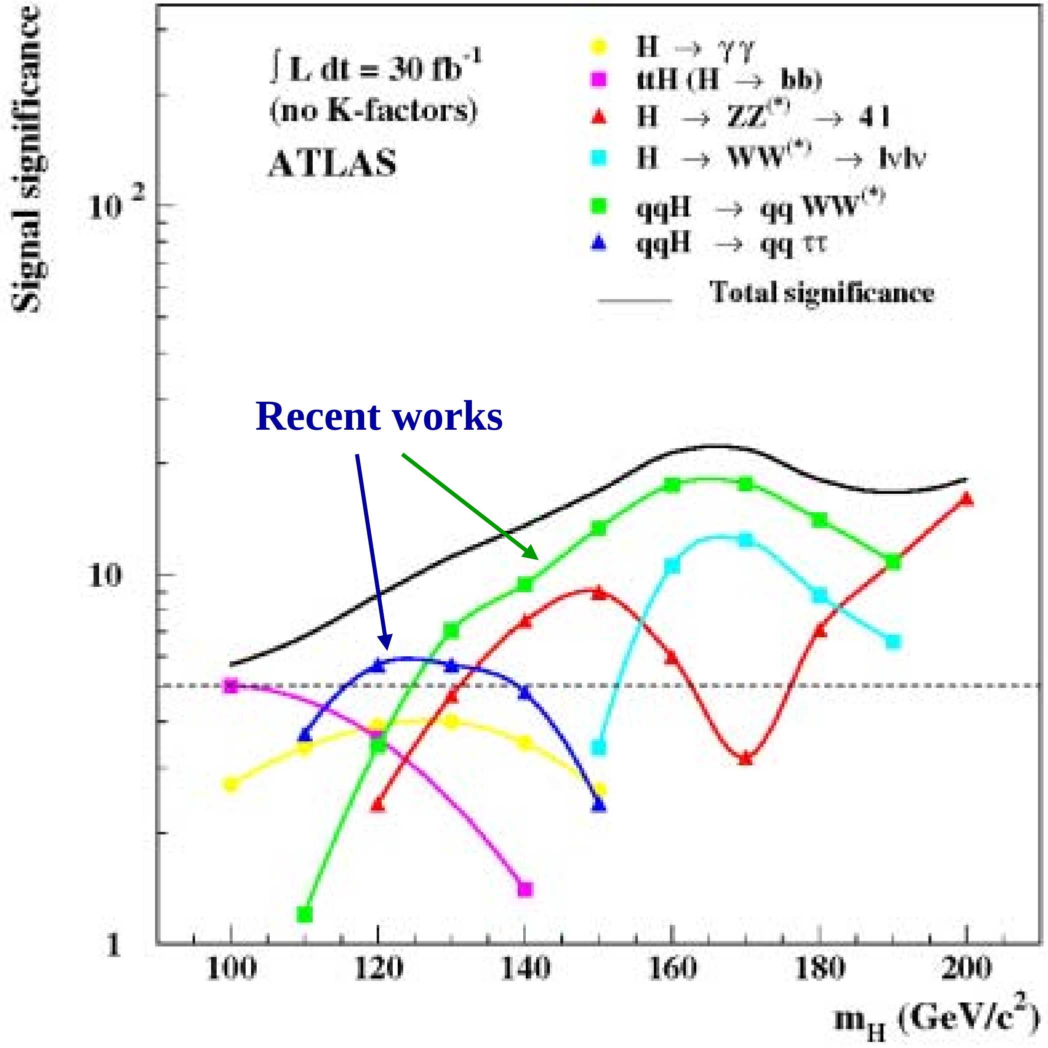


Feature of VBF Process:

- High Pt jet in the forward region
- Higgs decay products observed in the central rapidity gap (no color flow)

→ **Large reduction of background**

Discovery Potential of SM Higgs



Recent works

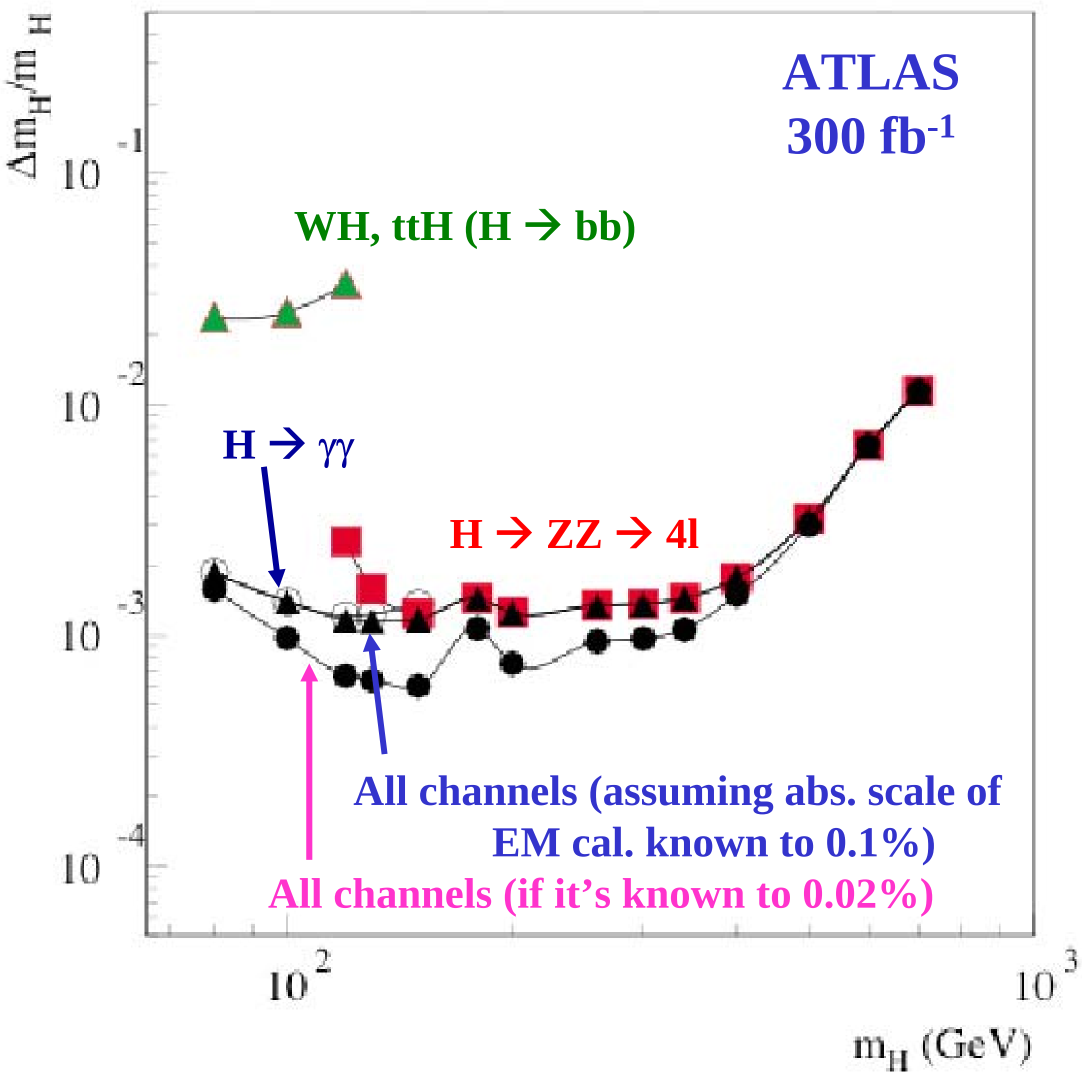
For the int. lumi. of 30 fb^{-1},
> 8 σ discovery
(M_H>114GeV:LEP limit)

Light Higgs : VBF・τ τ
Heavy Higgs : VBF・WW
M_H < 200 GeV : mult. decay mode
M_H > 200 GeV : > 20 σ with
H→ZZ→4lepton

SM Higgs would be discovered within one year after LHC start (10 fb^{-1}) with > 5 σ.

➔ And what's more?

Measurement of Higgs Mass



ATLAS
300 fb^{-1}

WH, ttH (H → bb)

H → γγ

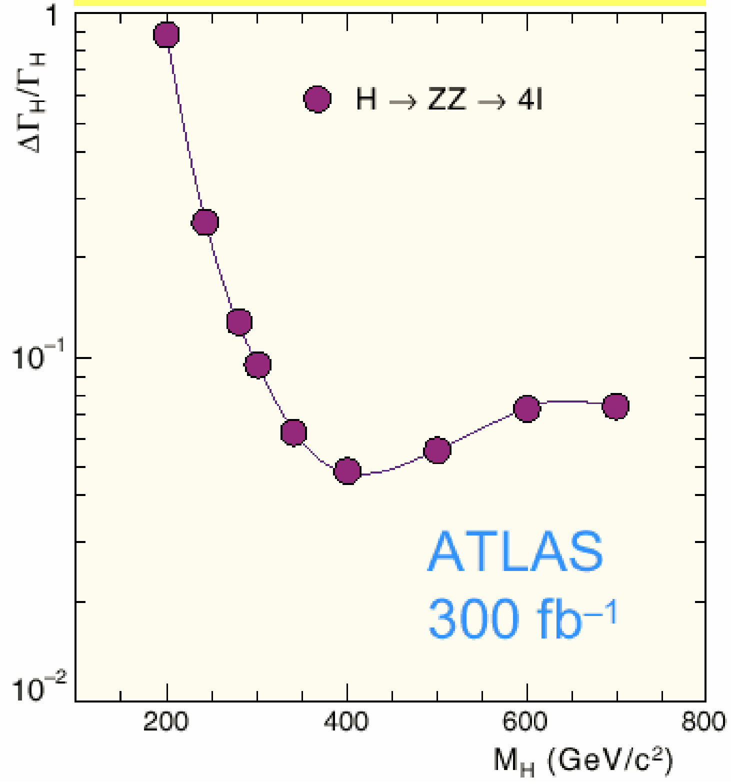
H → ZZ → 4l

All channels (assuming abs. scale of EM cal. known to 0.1%)

All channels (if it's known to 0.02%)

→ $\Delta m_H/m_H \sim 0.1\%$

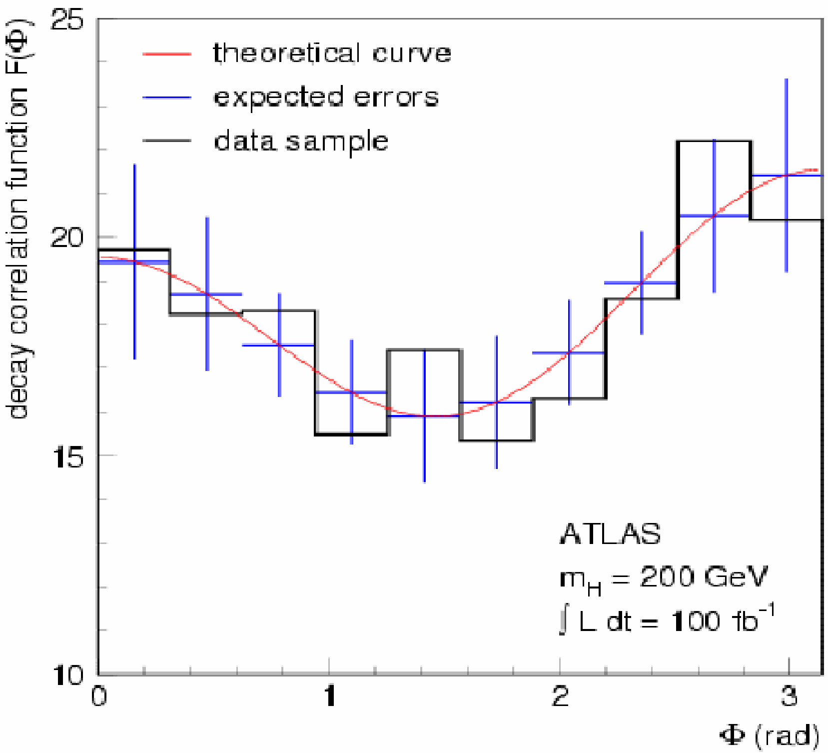
And its decay width ・・

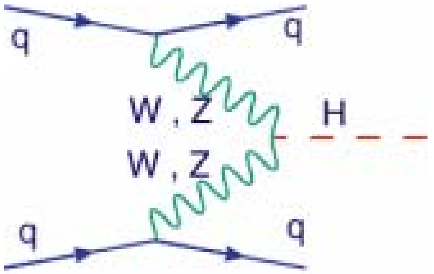


Higgs Spin and CP

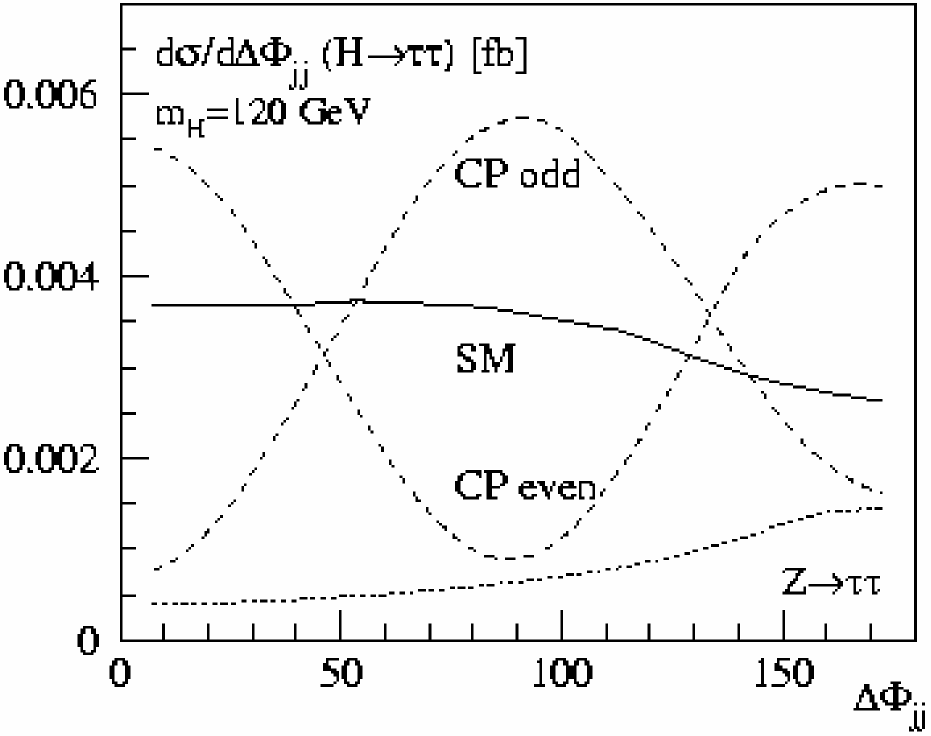
From angular distributions of decay products in H→ZZ→4*l*

➔ Angle between decay planes of two Z's from Higgs decay





Azimuthal angle distribution of two forward tagging jets in VBF

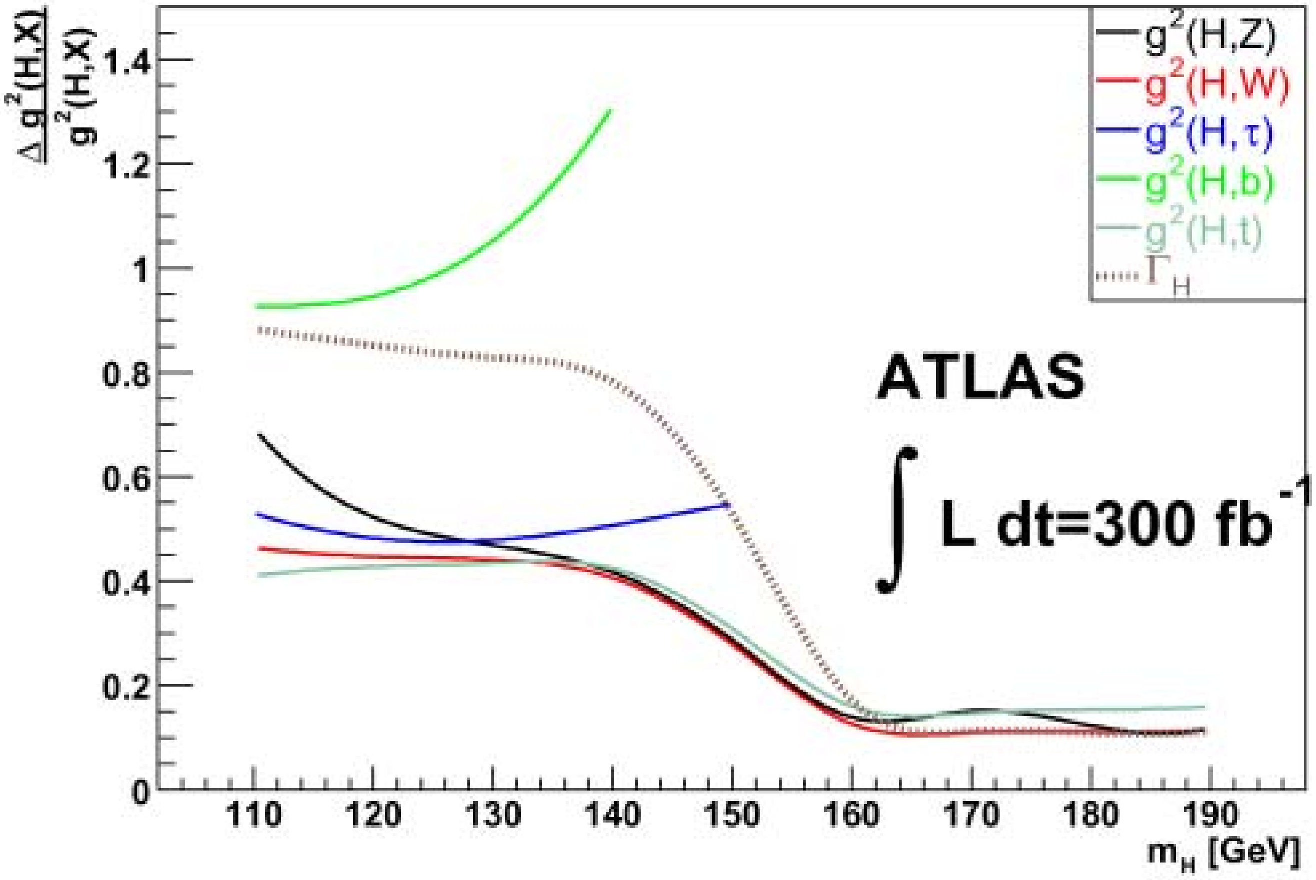


Measurement of Coupling Constants

Reconstruction, Detector		
L	5 %	Luminosity
ϵ_D	2 %	Detector eff.
ϵ_L	2 %	Lepton reconstr.
ϵ_γ	2 %	Photon reconstr.
ϵ_b	3 %	b-tag
ϵ_{Tag}	5 %	tag-jets
ϵ_{Iso}	5 %	Lepton isolation

Backgr. normalization $\Delta N_{i,B}$	
sharp Mass-peak:	1 %
all other:	10 %

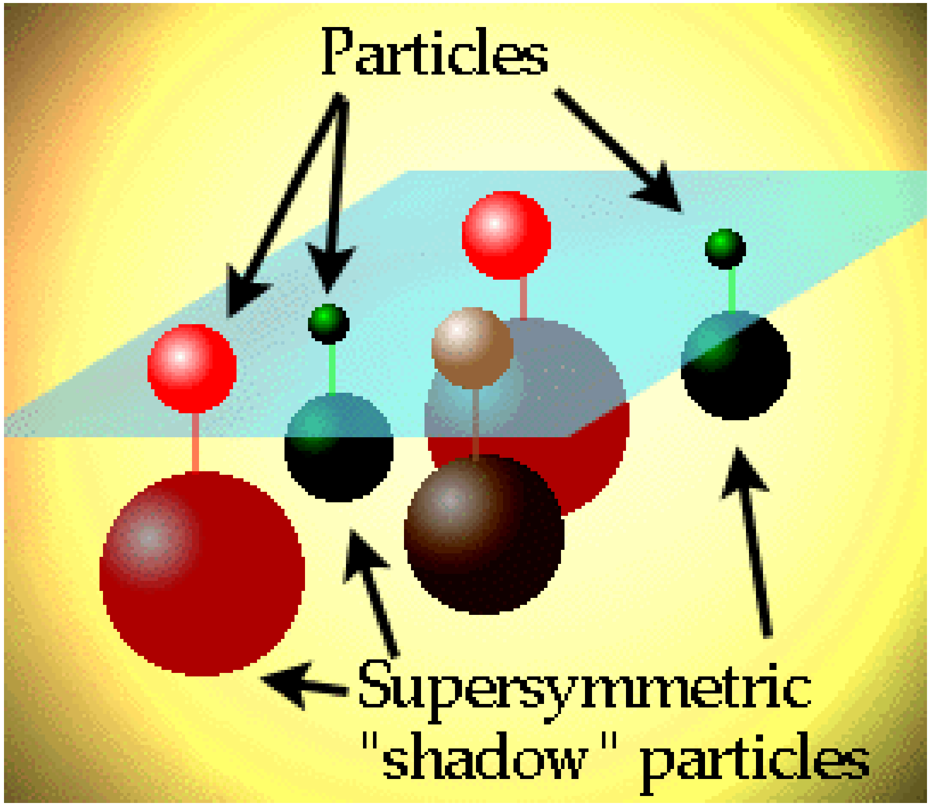
Background cross sections $\Delta\left(\sigma \cdot \mathrm{BR}\right)_j$
between 10 % and 40 %



Major error source is BG (10 – 40 %)
→ Need study of QCD/MC

y_t、y_τ、g_{ZZH}、g_{WWH} will be determined with ∼20 % accuracy.
($M_H = 115 – 140$ GeV)

SUSY

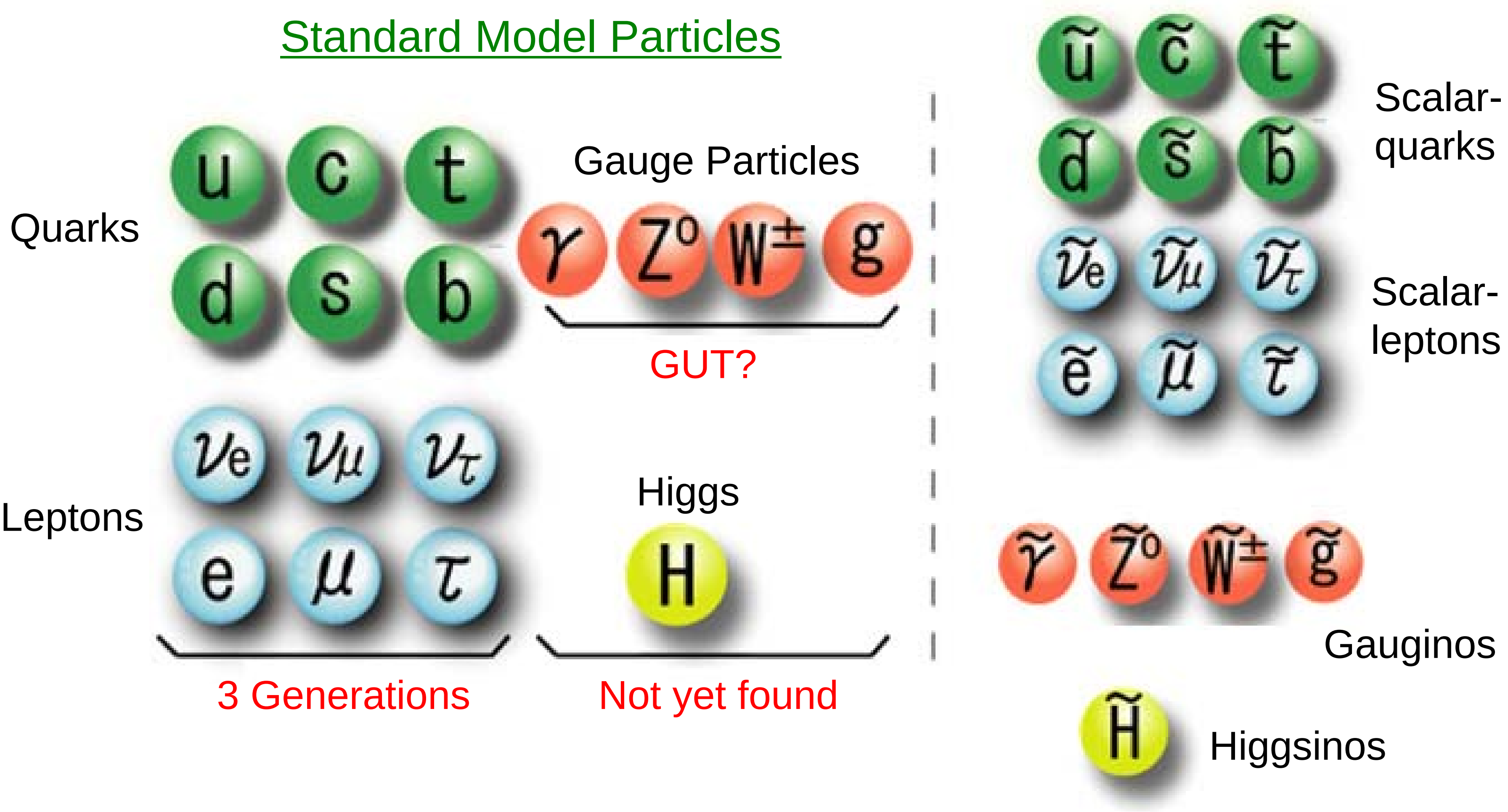


Super Symmetry

Symmetry between fermions (matter) and bosons (forces)

SUSY Particles

Standard Model Particles



Quarks

Leptons

Gauge Particles

GUT?

Higgs

3 Generations

Not yet found

Scalar-quarks

Scalar-leptons

Gauginos

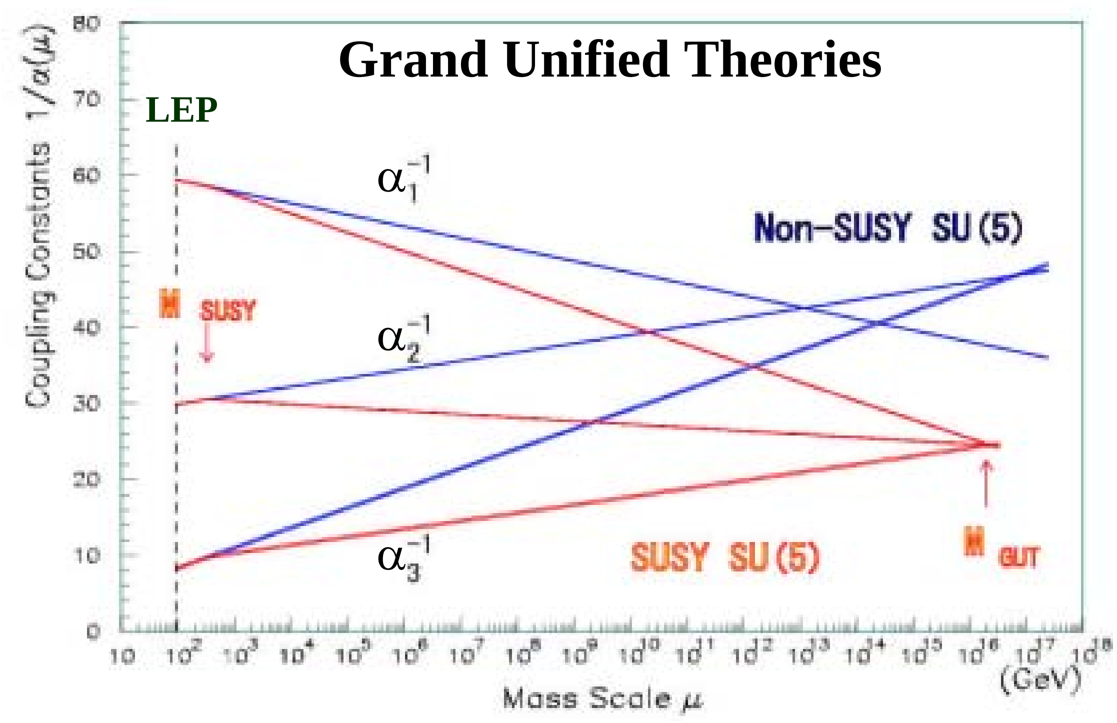
Higgsinos

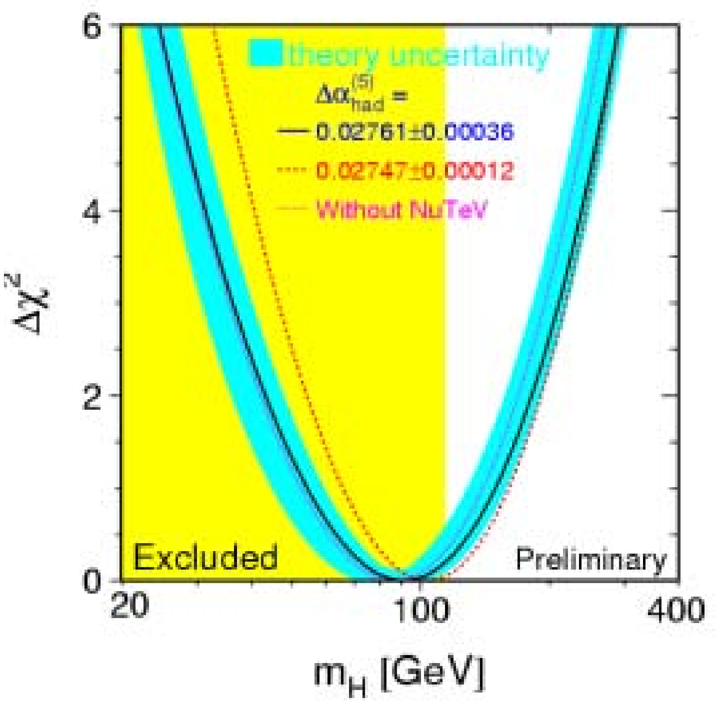
Motivations for SUSY

- Solution for the hierarchy problem (protect m_H from divergence)
- Unification of all the forces including gravity
- Provides an important candidate for Dark Matter

Experimental indications:

- Gauge coupling unification (with low E SUSY)
- low mass Higgs





SUSY Phenomenology

Minimal Supersymmetric extension of the Standard Model (MSSM) which has minimal particle content (two Higgs doublets)

But still it predicts many new particles and many new parameters! (SUSY is not a perfect symmetry.)

MSSM particle spectrum :

5 Higgs bosons : h, H, A, $H^{\pm}$

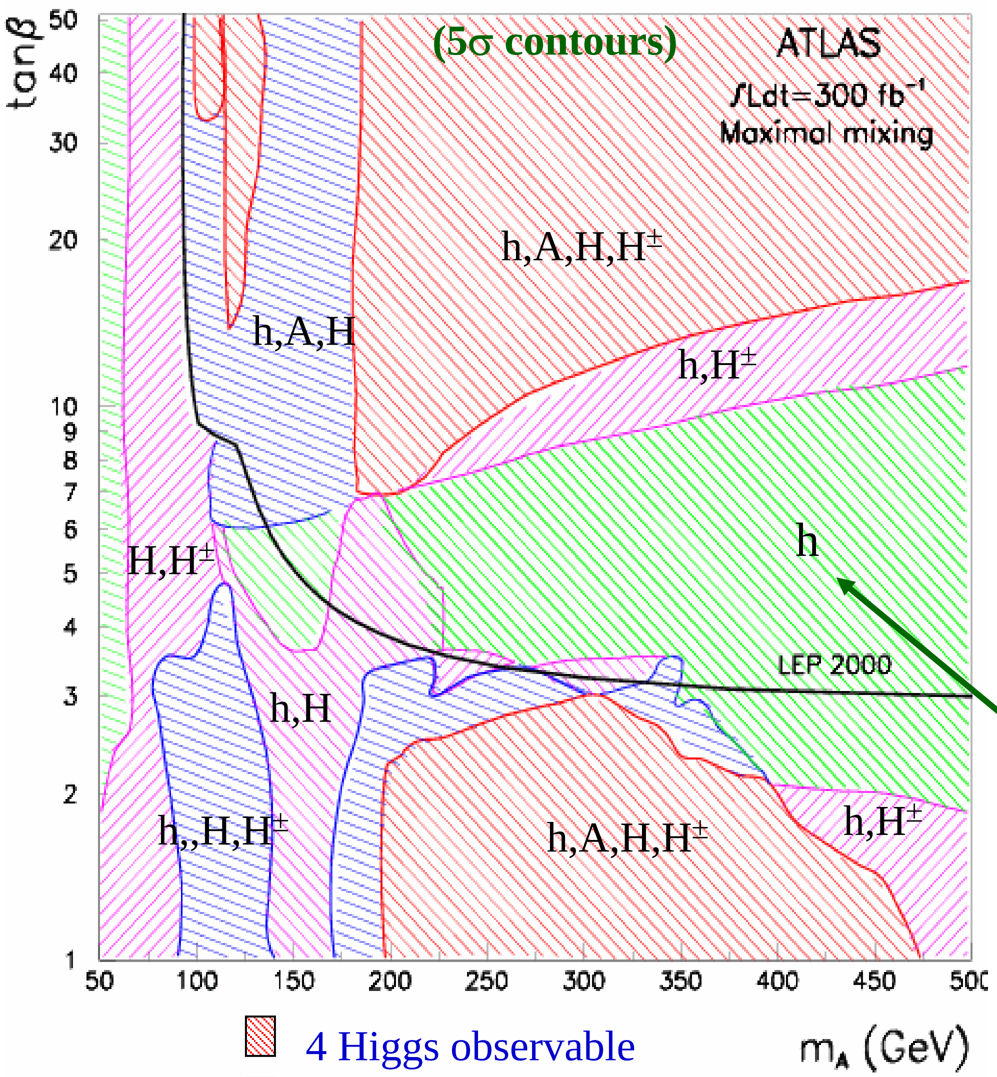
quarks	→	squarks	$\tilde{u}, \tilde{d}$, etc.
leptons	→	sleptons	$\tilde{e}, \tilde{\mu}, \tilde{\nu}$, etc.
$W^{\pm}$	→	winos	$\to \chi^{\pm}_{1}, \chi^{\pm}_{2}$ 2 charginos
$H^{\pm}$	→	charged higgsino	
γ	→	photino	$\to \chi^{0}_{1,2,3,4}$ 4 neutralinos
Z	→	zino	
h, H	→	neutral higgsino	
g	→	gluino	$\tilde{g}$

R-parity conservation

- **R=+1 for SM particles**
- **R=-1 for SUSY particles**

→LSP (χ^{0}_{1}) is a good candidate of Cold Dark Matter

MSSM Higgs sensitivity at LHC



▨ 4 Higgs observable

▨ 3 Higgs observable

▨ 2 Higgs observable

▨ 1 Higgs observable

- h, H^0, A^0, H^{+-}
- described by 2 parameters (M_A , tan β) in tree level
  (tan $\beta = v_u / v_d$)

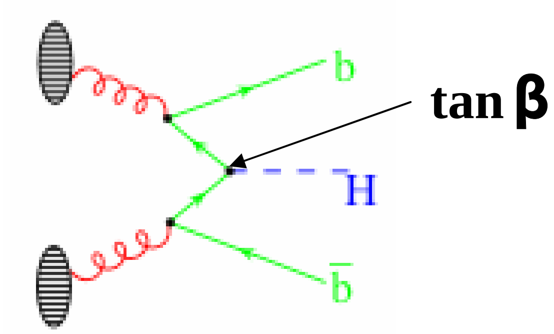
- **large tan β → bbH/A coupling becomes large.**
  H/A→ τ τ , μ μ ,bb

- **charged Higgs in gb→tH^- for tan β >10**

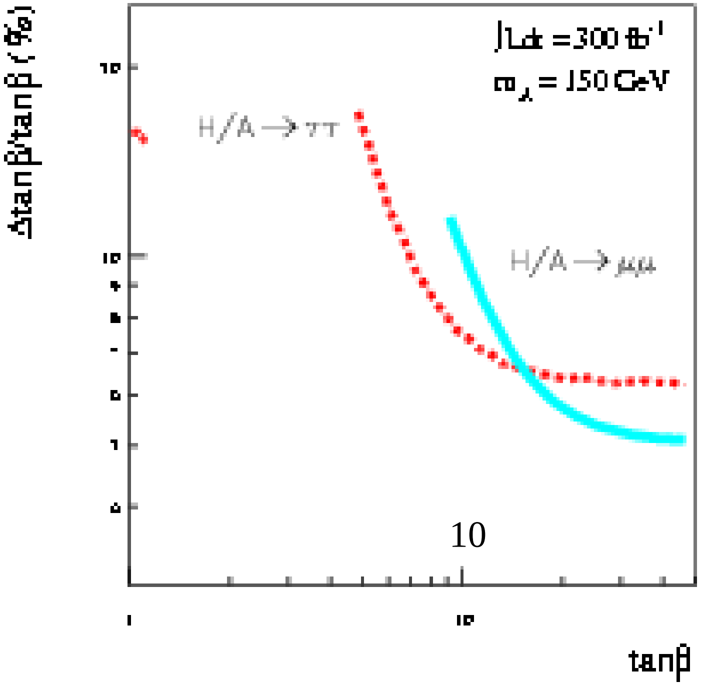
$h \sim H_{SM}$

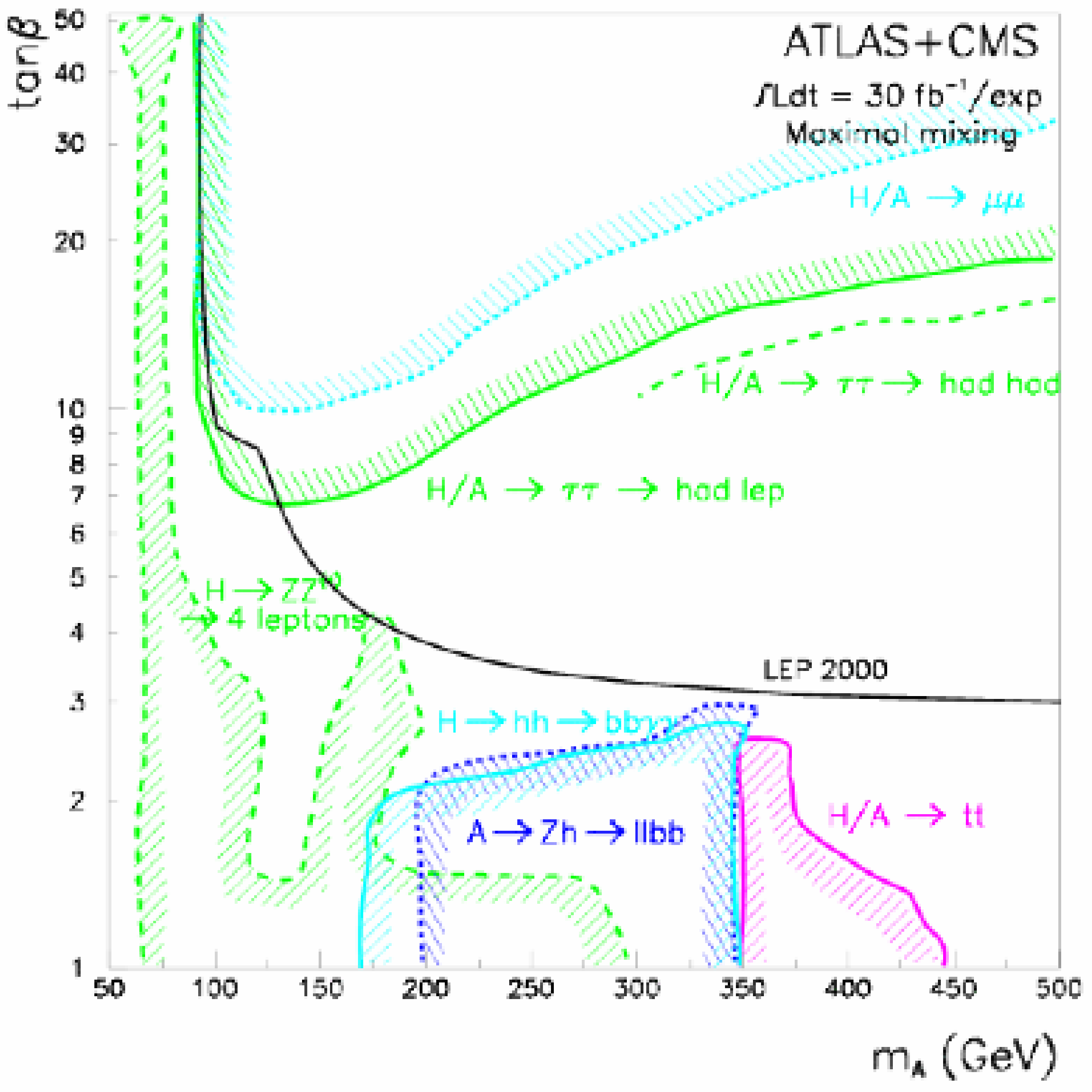
Most region will be covered with 30fb^{-1}

H/A Production



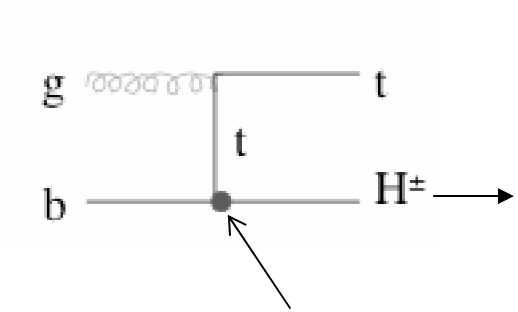
gg → bbH/A → ττ, μμ, bb





→ Important channel to determine tan **β**

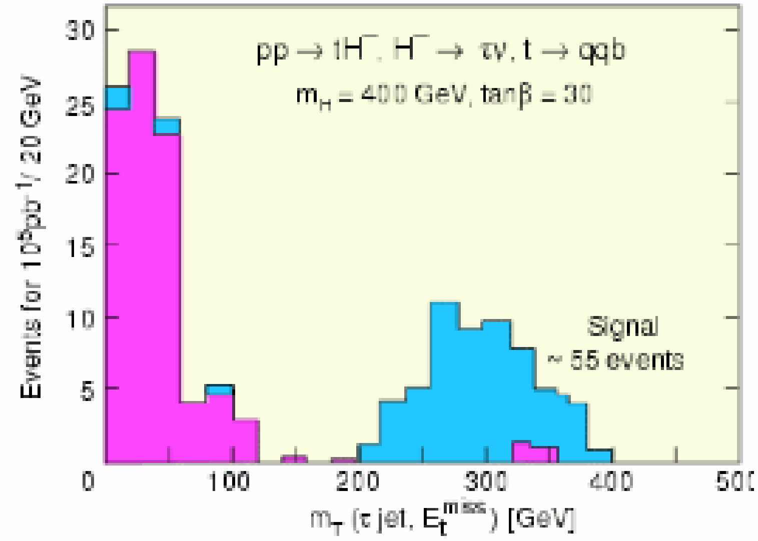
H^{+-} Production

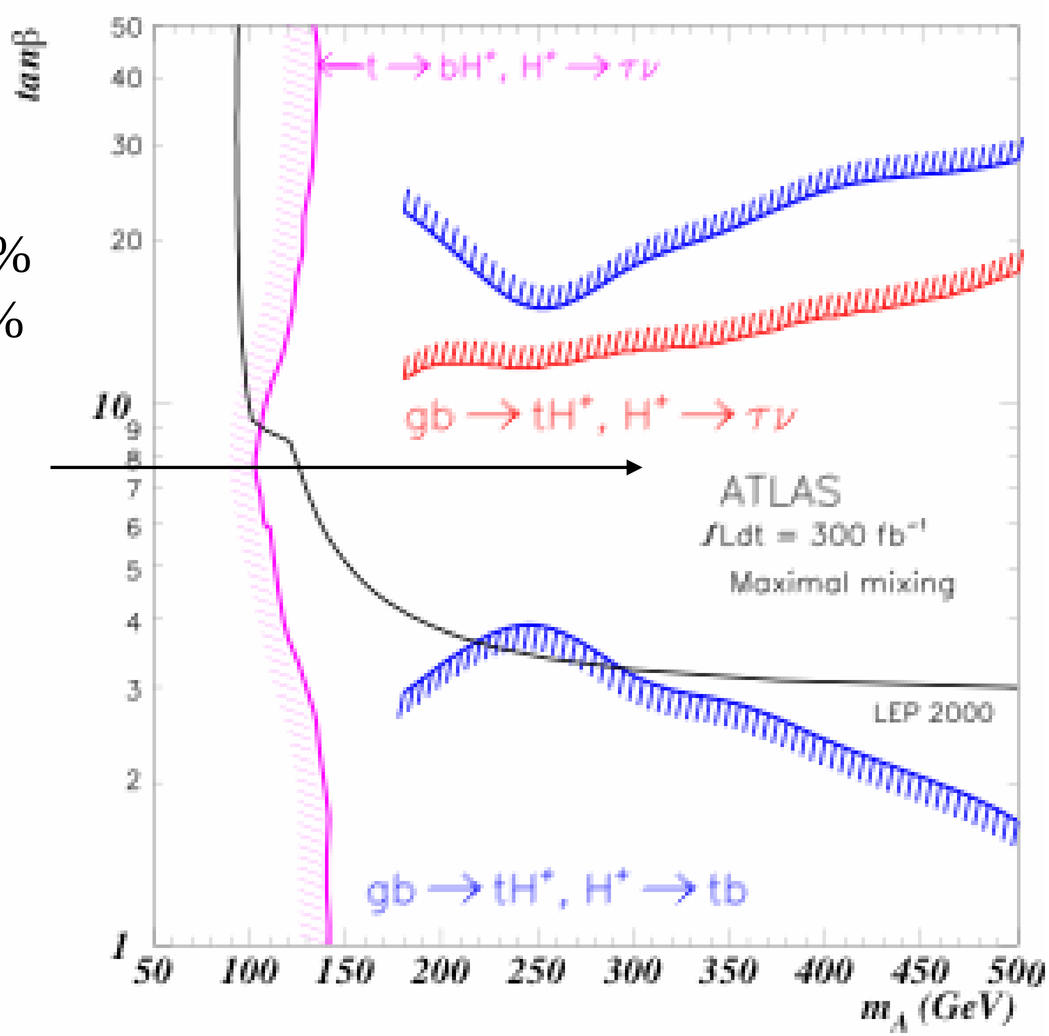


(t,b) Br=90%
(τ,ν) 10%

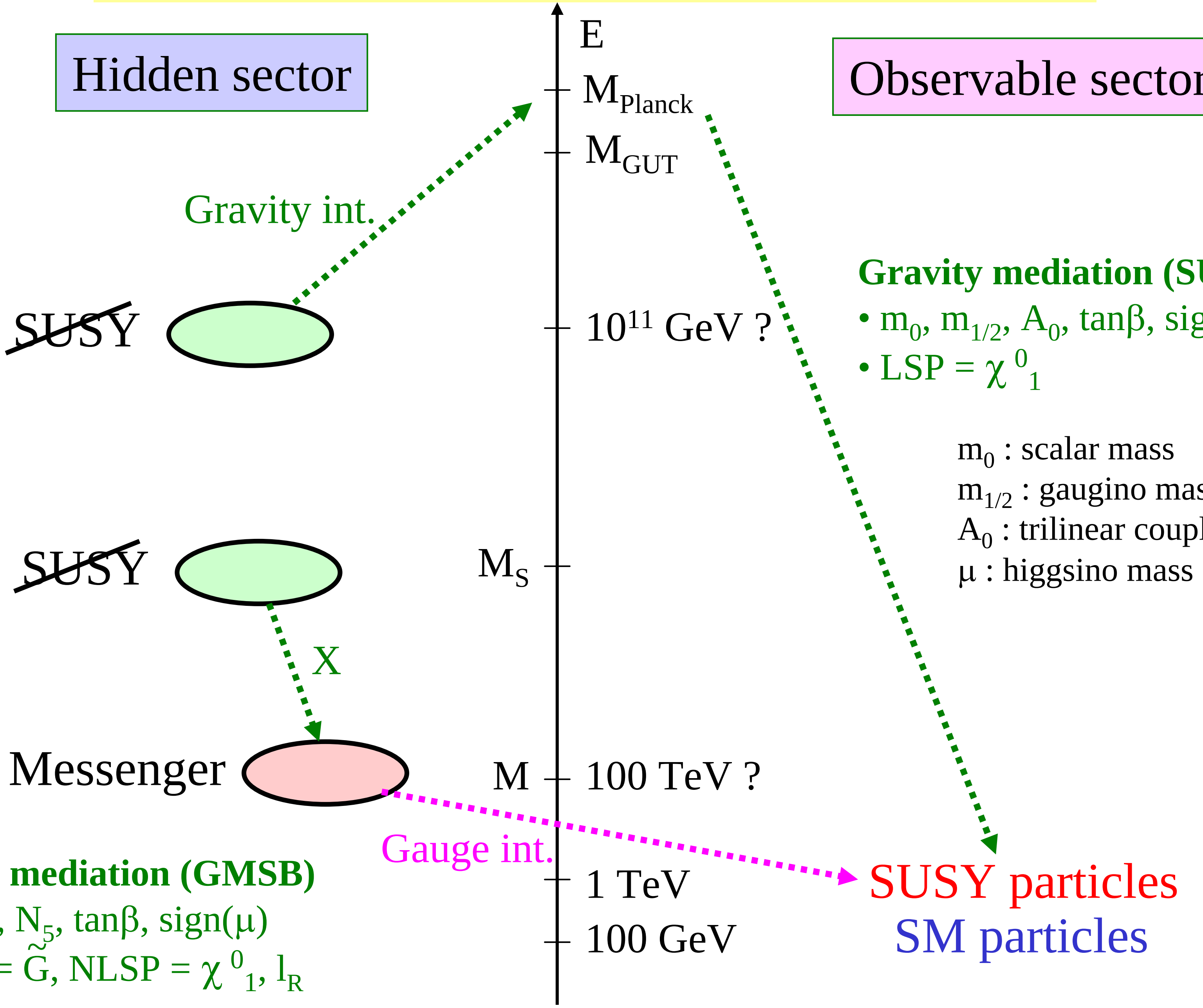
suppressed at $tan\beta \approx \sqrt{m_t / m_b}$

CMS 100 fb^{-1}





Mediation of SUSY Breaking



Gravity mediation (SUGRA)

- m_0, $m_{1/2}$, A_0, tanβ, sign(μ)
- LSP = χ^0_1

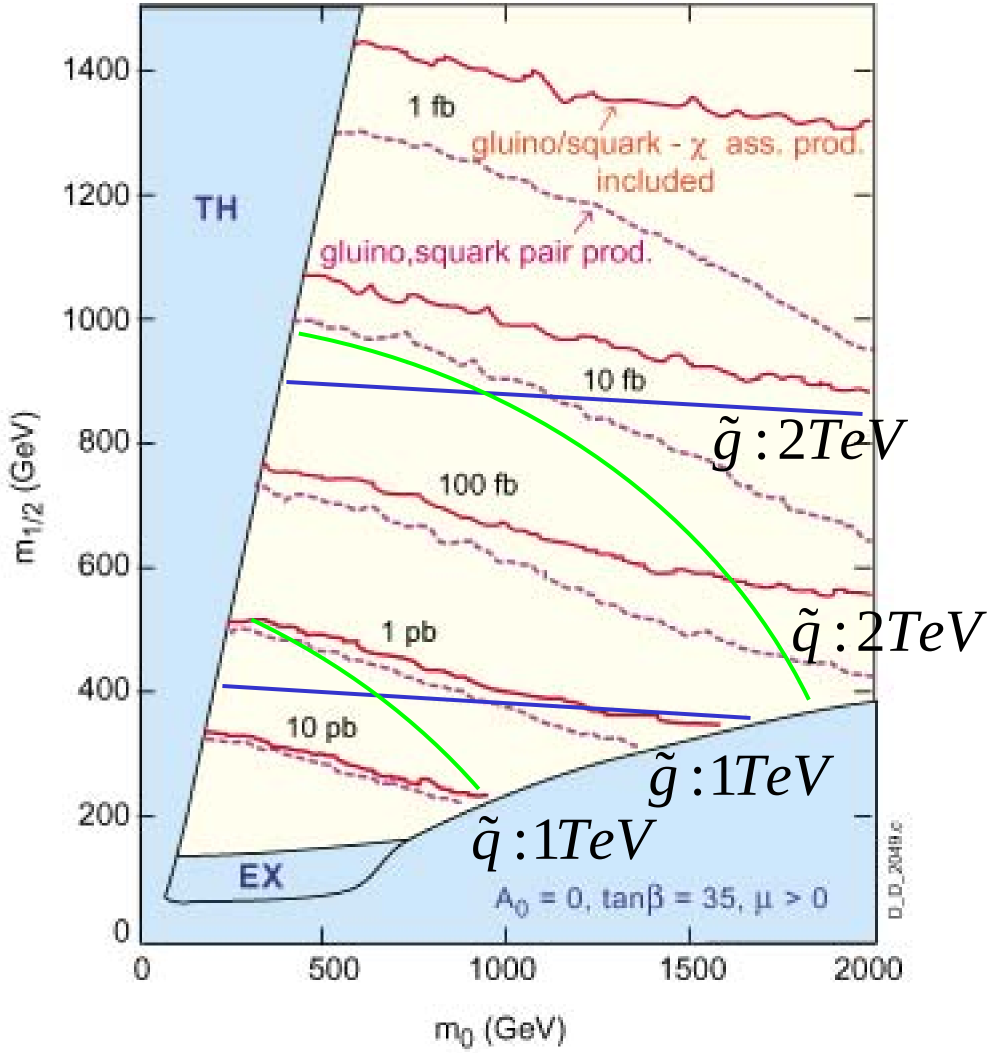
m_0 : scalar mass
$m_{1/2}$: gaugino mass
A_0 : trilinear coupling const.
μ : higgsino mass

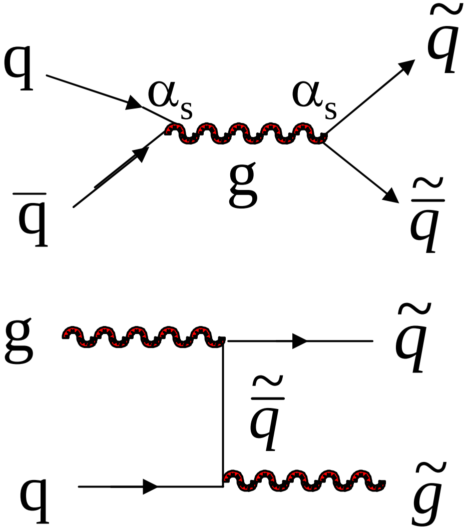
Gauge mediation (GMSB)

- M, Λ, N_5, tanβ, sign(μ)
- LSP = $\tilde{G}$, NLSP = χ^0_1, l_R

Production cross section of SUSY particles at LHC

mSUGRA model

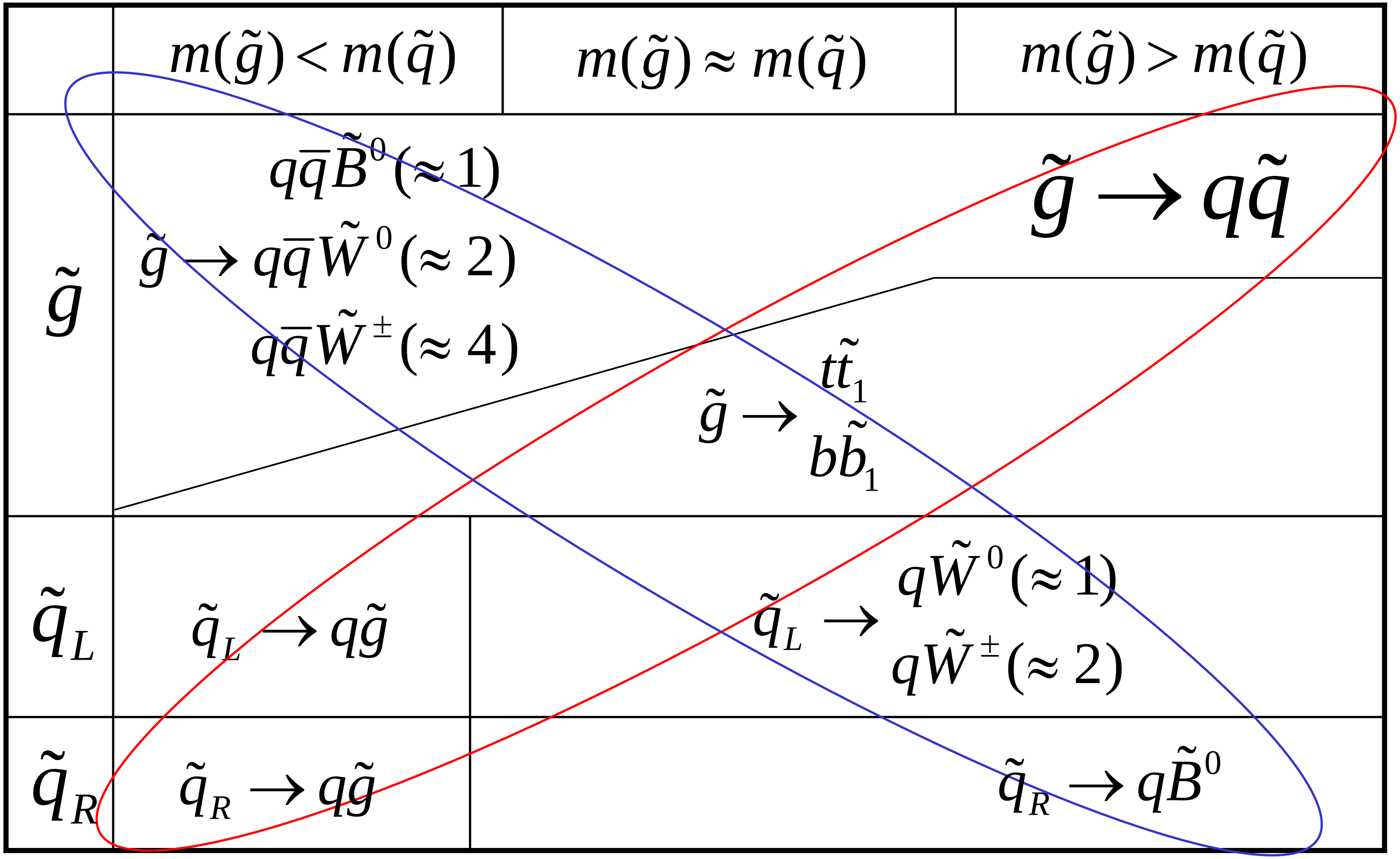




$(\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{q}\tilde{q})$ produced via strong processes

- large cross section
- not much dependent on SUSY parameters

$\tilde{g}, \tilde{q}$ Decay Processes

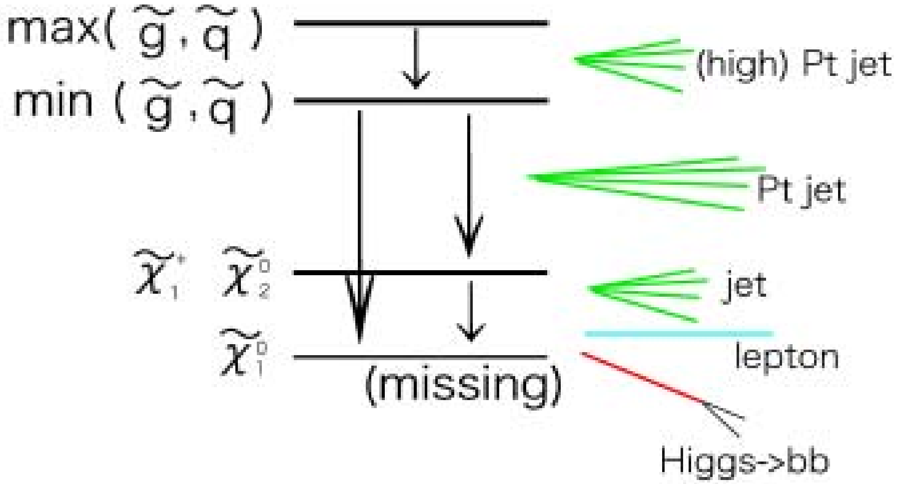


	$m(\tilde{g}) < m(\tilde{q})$	$m(\tilde{g}) \approx m(\tilde{q})$	$m(\tilde{g}) > m(\tilde{q})$
$\tilde{g}$	$\tilde{g} \to q\bar{q}\tilde{B}^0(\approx 1)$ $q\bar{q}\tilde{W}^0(\approx 2)$ $q\bar{q}\tilde{W}^\pm(\approx 4)$	$\tilde{g} \to t\tilde{t}_1$ $b\tilde{b}_1$	$\tilde{g} \to q\tilde{q}$
$\tilde{q}_L$	$\tilde{q}_L \to q\tilde{g}$	$\tilde{q}_L \to q\tilde{W}^0(\approx 1)$ $q\tilde{W}^\pm(\approx 2)$	
$\tilde{q}_R$	$\tilde{q}_R \to q\tilde{g}$	$\tilde{q}_R \to q\tilde{B}^0$	

Strong interaction

EW interaction

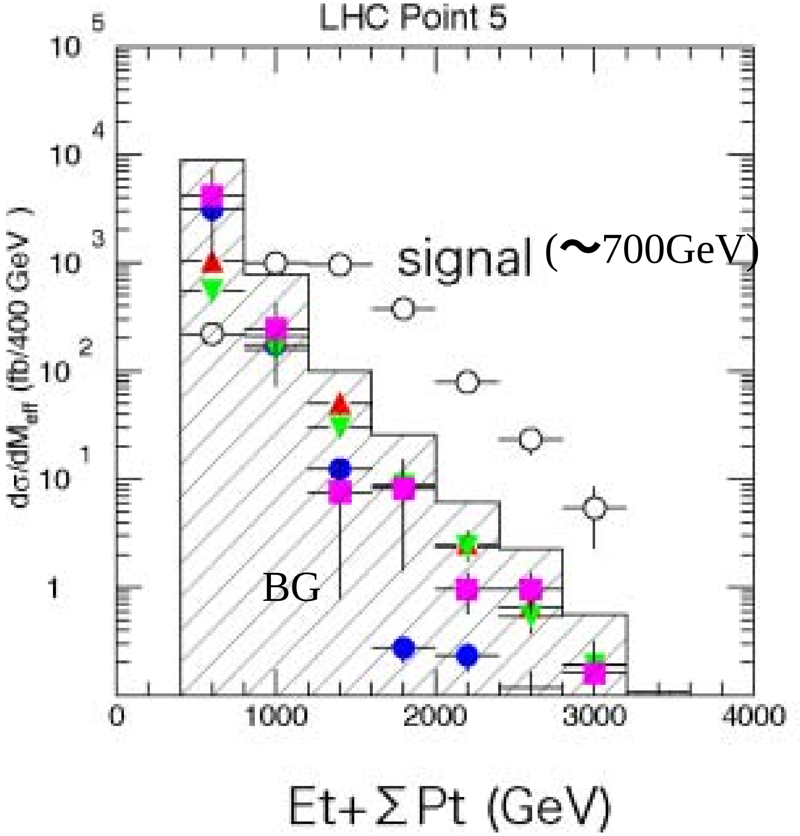
SUSY Signals



Expected event topology

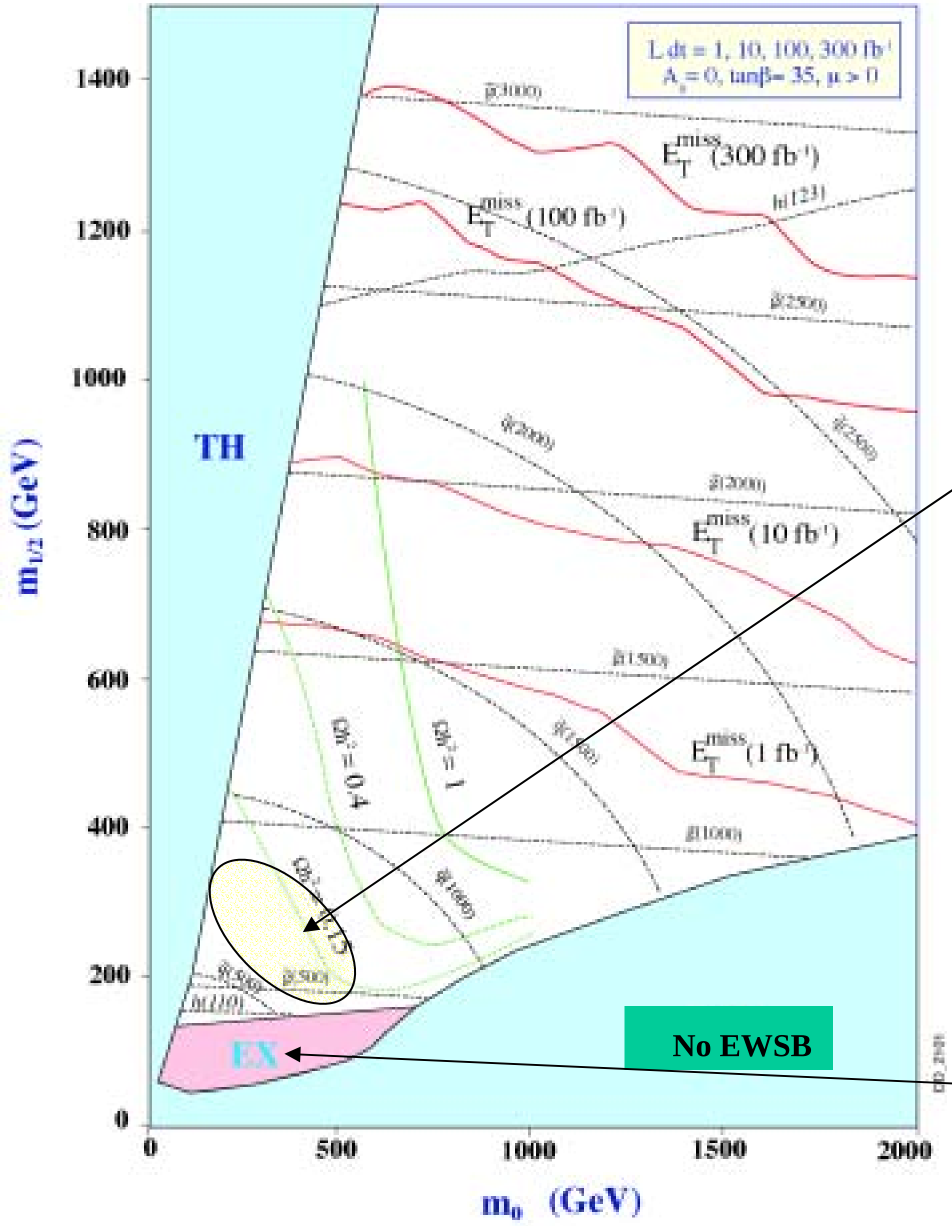
multi leptons
$\not{E}_T$ + High P_T jets + b-jets
τ -jets

BG --- tt, QCD, Z+njets, W+njets



- **Discovery would be easy.**
- **To study further details, SUSY itself would become BG.**

Discovery Potential of SUSY(mSUGRA)



10 years (300fb^{-1}) → **~ 2.5 TeV**

1 week run would be sufficient to cover the interesting region for Cold DM.

1 year run (L=10fb-1) → **~ 2TeV**

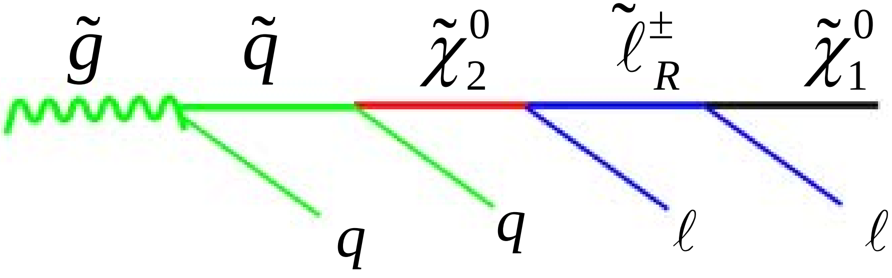
1 month run (L=1fb^{-1}) → **~1.5TeV**
(5 σ)

LEP-II / Tevatron-II search region

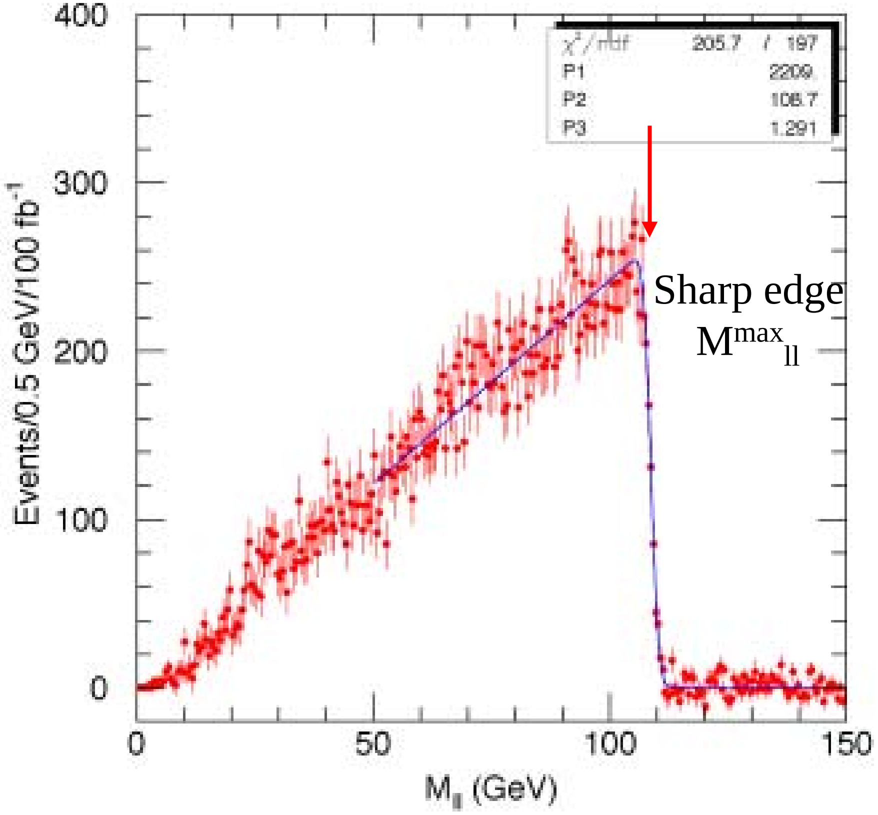
What more can one study on SUSY at LHC ?

In some cases, ---

- **model dependent**
- **chain of 2-body decays**

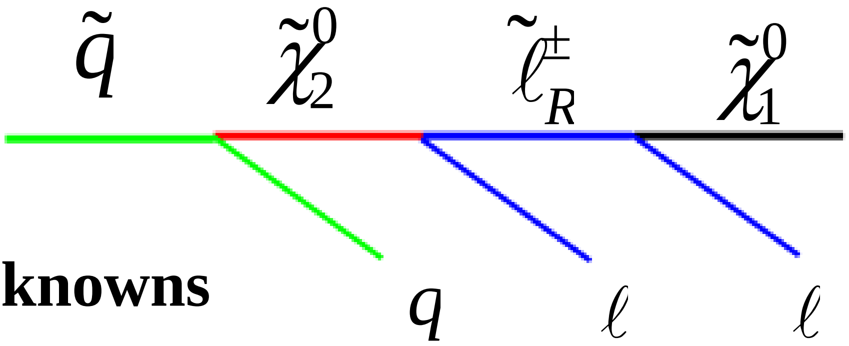


$$M_{\ell\ell}^{\max} = m(\tilde{\chi}_2^0)\sqrt{1-\left(\frac{m(\tilde{\ell}_R^{\pm})}{m(\tilde{\chi}_2^0)}\right)^2}\sqrt{1-\left(\frac{m(\tilde{\chi}_1^0)}{m(\tilde{\ell}_R^{\pm})}\right)^2}$$

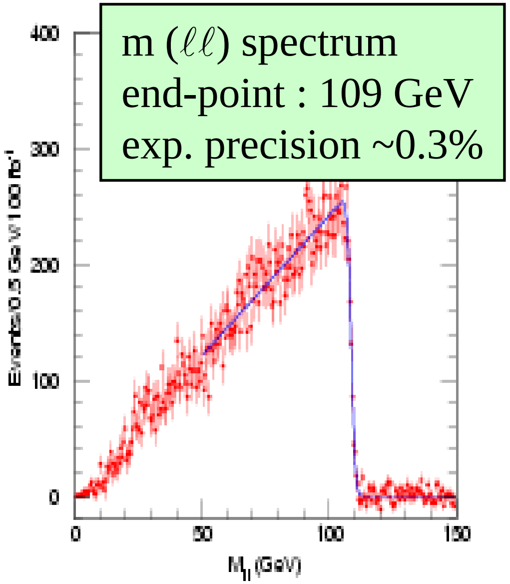


→ Constraint on mass reconstruction

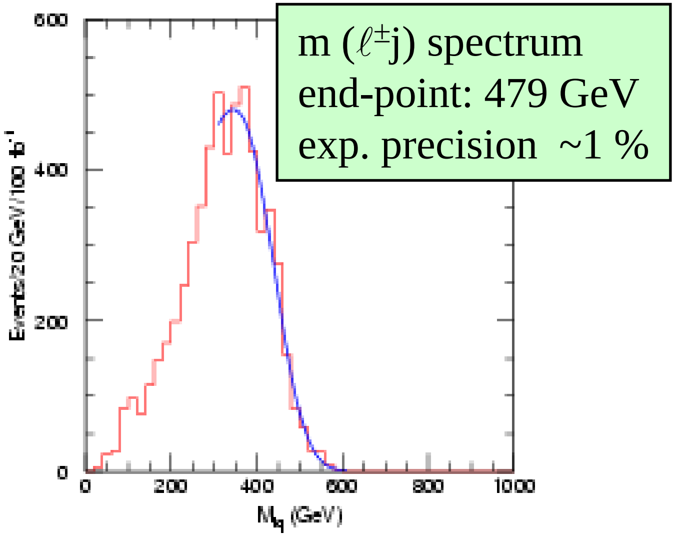
If we are lucky, ---



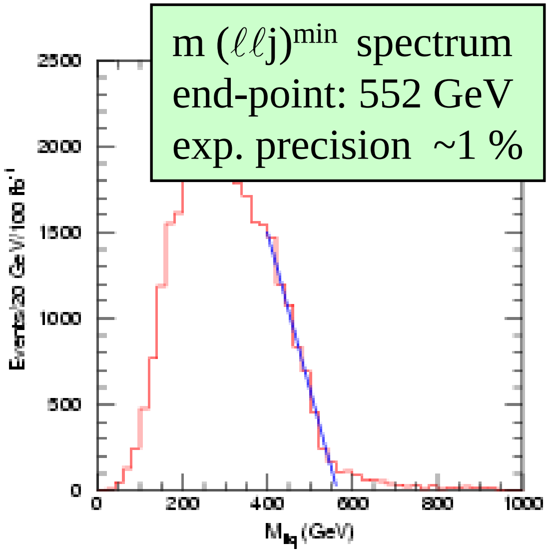
4 unknowns



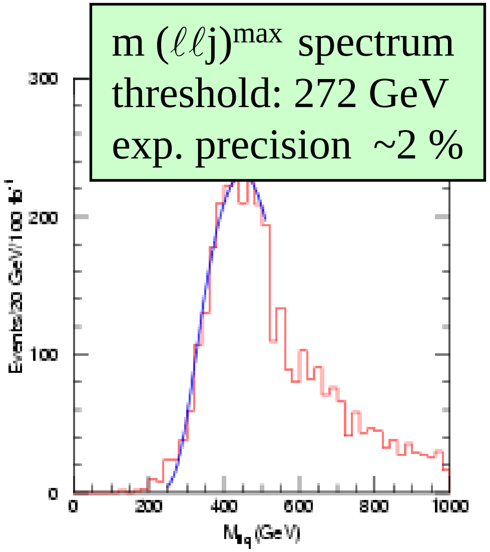
m ($\ell\ell$) spectrum
end-point : 109 GeV
exp. precision ~0.3%



m ($\ell^{\pm}$j) spectrum
end-point: 479 GeV
exp. precision ~1 %



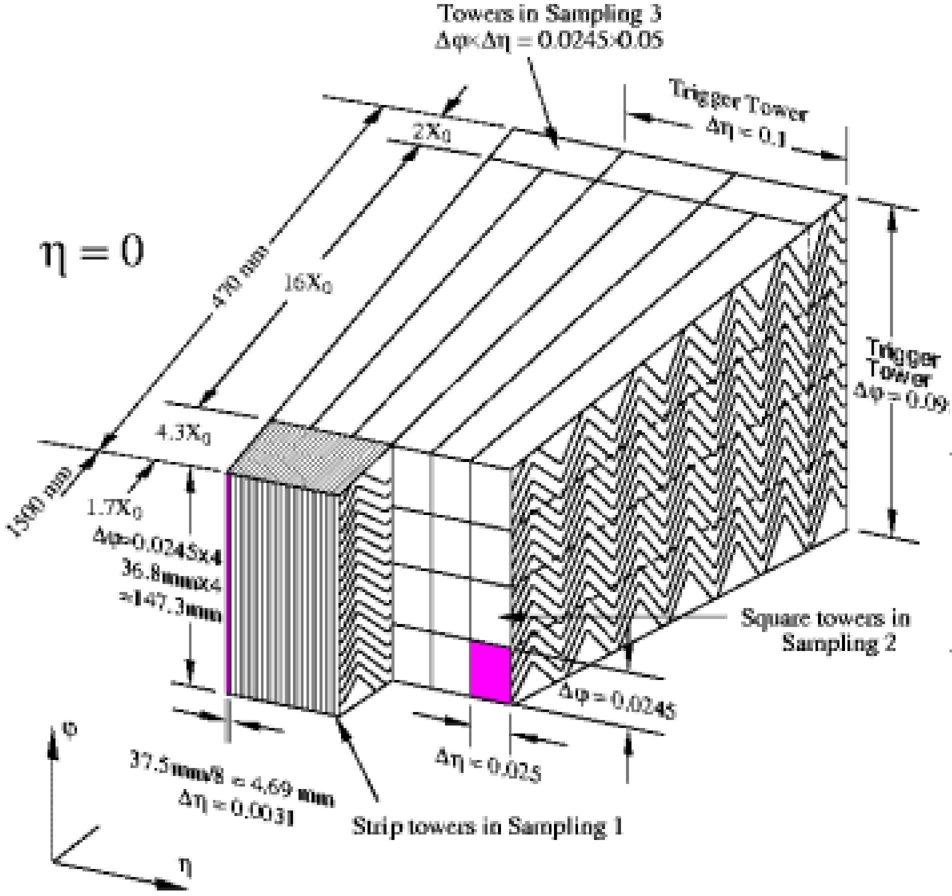
m ($\ell\ell$j)$^{\text{min}}$ spectrum
end-point: 552 GeV
exp. precision ~1 %

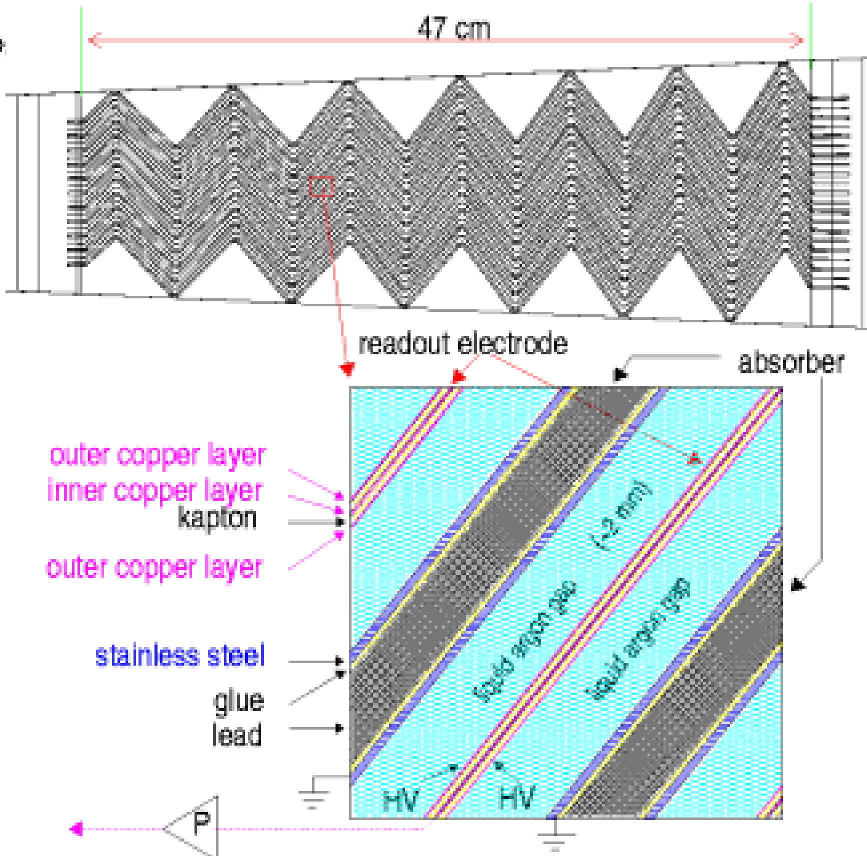


m ($\ell\ell$j)$^{\text{max}}$ spectrum
threshold: 272 GeV
exp. precision ~2 %

4 constraints → We can determine the masses.
(3-12% for 700-800 GeV squark, gluino)

ATLAS EM Calorimeter



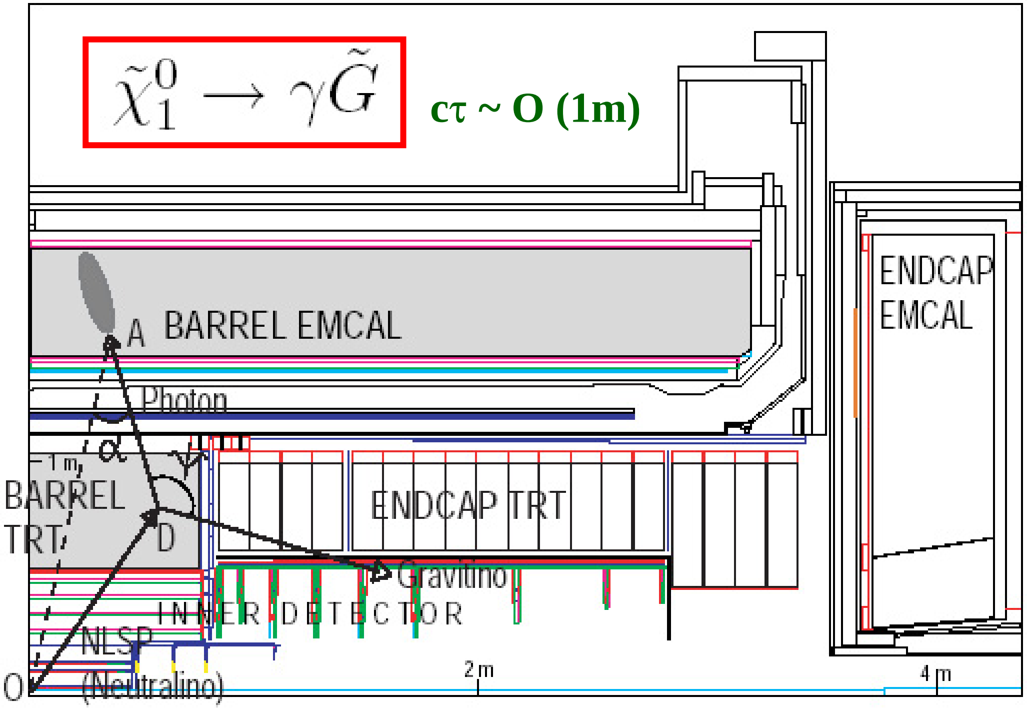


$\sigma_E / E = 10\ \% / \mathrm{sqrt}(E)$

$\sigma_\theta = 60\ \mathrm{mrad} / \mathrm{sqrt}(E)$

$\sigma_t \sim 100\ \mathrm{ps}$

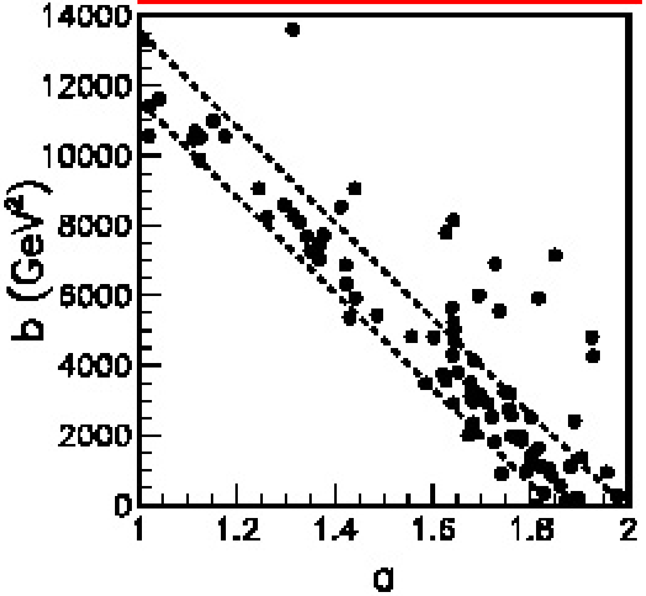
A Possible Gauge Mediation Signal



$\tilde\chi^0_1 \to \gamma\tilde G$

cτ ~ O (1m)

$\tilde\ell \to \ell\tilde\chi^0_1 \to \ell\gamma\tilde G$



$$
\begin{aligned}
\cos\psi &= \frac{1-\xi^2}{1+\xi^2}\,, \\
\text{where}\quad \xi &\equiv \frac{ct_\gamma - L\cos\alpha}{L\sin\alpha}
\end{aligned}
$$

$$
\begin{aligned}
m^2_{\tilde\ell} &= (p_\gamma + p_{\tilde G} + p_\ell)^2 \\
&= 2E_\gamma E_{\tilde G}(1-\cos\psi) + 2E_\ell E_{\tilde G}(1-\cos\theta_{\ell\tilde G}) \\
&+ 2E_\ell E_\gamma(1-\cos\theta_{\ell\gamma}) \\
&= \underbrace{\left(1+\frac{E_\ell(1-\cos\theta_{\ell\tilde G})}{E_\gamma(1-\cos\psi)}\right)}_{a} m^2_{\tilde\chi^0_1} + \underbrace{2E_\ell E_\gamma(1-\cos\theta_{\ell\gamma})}_{b}
\end{aligned}
$$

(hep-ph/0309031)

~100 lγ events ➔ σ_M/M (slepton, neutralino) ~ 3%

In some cases ---

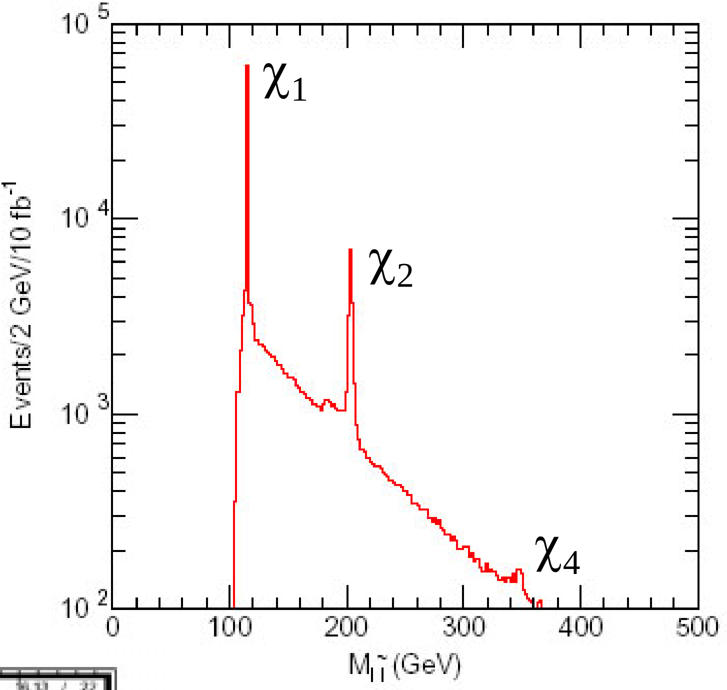
GMSB G2b point

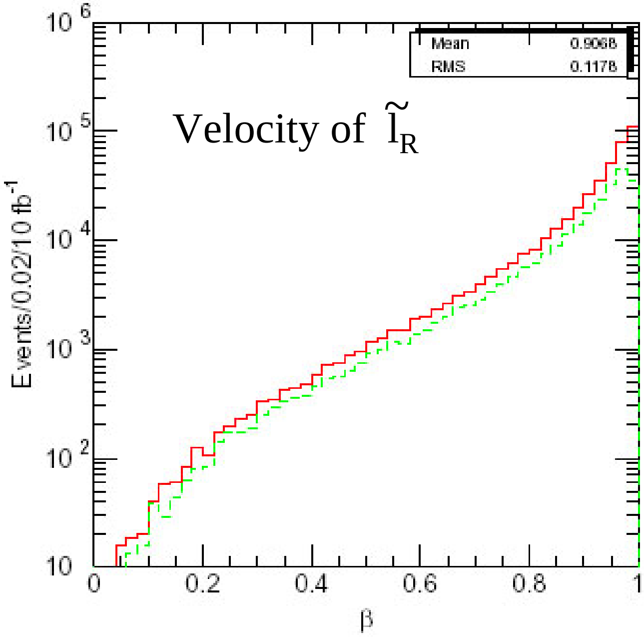
NLSP = $\tilde{\tau}_1$ and $c\tau \approx 1\,\mathrm{km}$

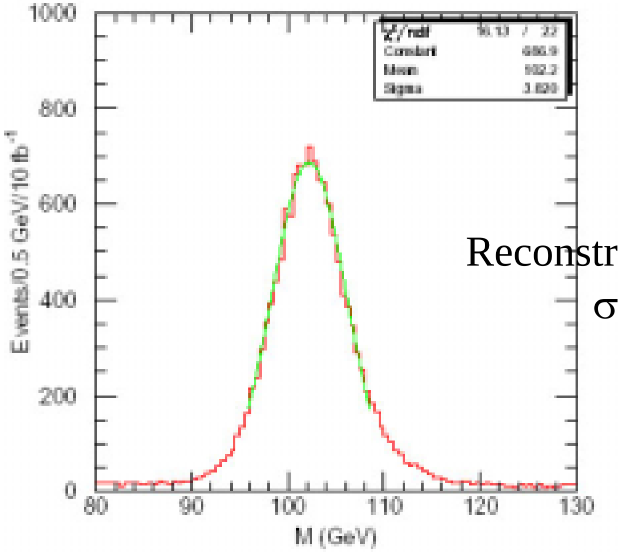
$\tilde{e}_R$ and $\tilde{\mu}_R$ are also long-lived

➔ stable heavy charged leptons

$\tilde{\chi}_i^0 \rightarrow \tilde{\ell}_R \ell$



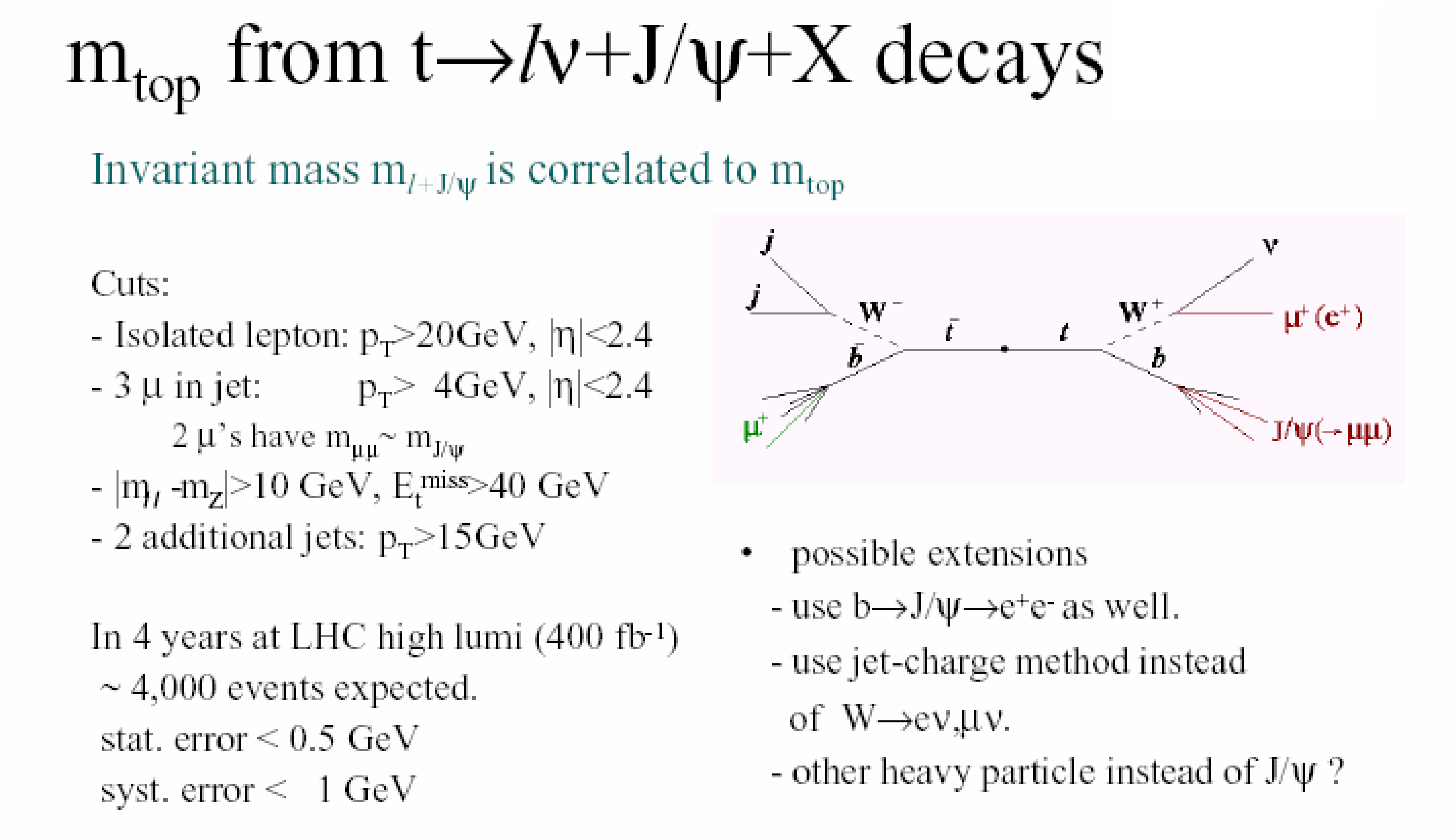




Reconstructed slepton mass
$\sigma_M / M \sim 4\%$

ATLAS MDT ➔ $\sigma_t \sim$ 1ns

Top and B Physics



m_{top} from $t \rightarrow l\nu + J/\psi + X$ decays

Invariant mass $m_{l+J/\psi}$ is correlated to m_{top}

Cuts:

- Isolated lepton: $p_T > 20$GeV, $|\eta| < 2.4$
- 3 μ in jet: $p_T >$ 4GeV, $|\eta| < 2.4$
    2 μ's have $m_{\mu\mu} \sim m_{J/\psi}$
- $|m_l - m_Z| > 10$ GeV, $E_t^{miss} > 40$ GeV
- 2 additional jets: $p_T > 15$GeV

In 4 years at LHC high lumi (400 fb^{-1})
~ 4,000 events expected.
stat. error < 0.5 GeV
syst. error < 1 GeV

- possible extensions
  - use $b \rightarrow J/\psi \rightarrow e^+e^-$ as well.
  - use jet-charge method instead of $W \rightarrow e\nu, \mu\nu$.
  - other heavy particle instead of J/ψ ?

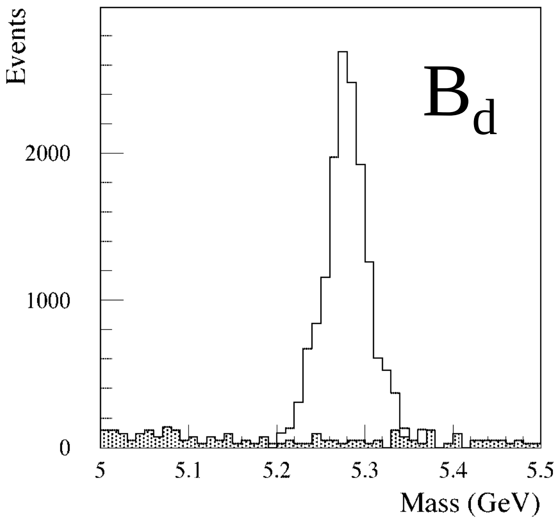
B-physics at ATLAS/LHCb

(1) Measurement of **sin2 β** using $B_d \to J/\psi(\mu^+\mu^-)K_S^0(\pi^+\pi^-)$

ATLAS

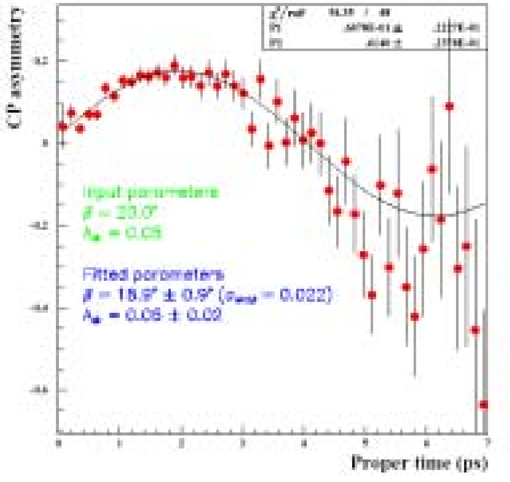
- data rate ～ 10Hz (2 **μ** , Pt > 6GeV)
- reconstruction of J/ψ, K^0_S → B_d (S/B=32)
- high statistics: 250k event/30fb^{-1}

→ **Δ**sin2 **β** =0.016 (stat.) +-0.005(sys.)
～2% accuracy (3 years low lumi. run)



LHCb

- low Pt trigger
- **π**, e, **μ** separation by RICH
- ～2% accuracy with 119k events / 2 fb^{-1}



(2) Physics of B_s meson

Δm_s from $B_s \to D_s\ \pi$ and $B_s \to D_s\ a_1$

- detectable up to30ps^{-1} (LHCb 58ps^{-1})
- measurable up to 0.05ps^{-1} **$\Delta m_s \sim 12$ps^{-1}**

(3) Rare decays

Br (SM) --- 3.5×10^{-9} 1.5×10^{-10}

	Signal $B^0_s \to \mu^+\mu^-$	Signal $B^0_d \to \mu^+\mu^-$	BG
1 year $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	92	14	660
3 years at $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	27	4	93

↓

5σ signal

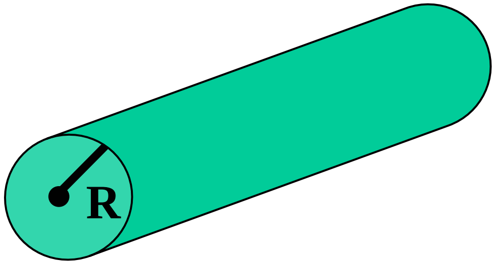
Extra Dimensions

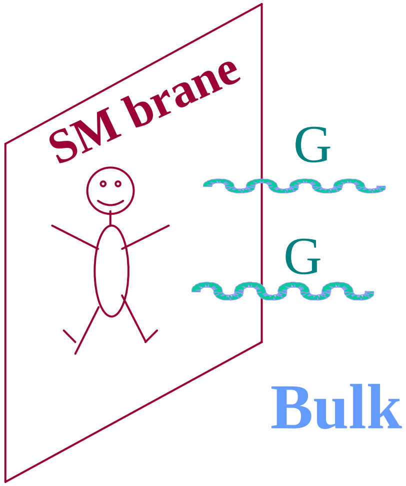
Concept of ED is not unfamiliar.

- **Kaluza-Klein**
- **Quantum Gravity**
- **Superstring**
- **M-theory**

  → **10 or 11 dimensional space-time**

Is it anything to do with LHC ?





- ED must be compactified.

  → But how large, and how are ED compactified?
- Various models
- Some ED may be fairly large. (Exp. not excluded)
- If gravity propagates in 4+n dimensions, quantum gravity scale as low as **$M_D \approx$ 1 TeV** is possible.

  → No hierarchy problem!
- Graviton becomes massive. (KK excitations)
- Gravity becomes strong.

  → Effects of Q.G./string may be observed at LHC.

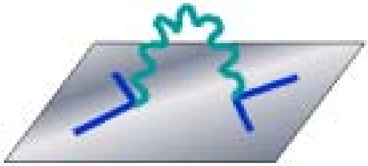
Some models:

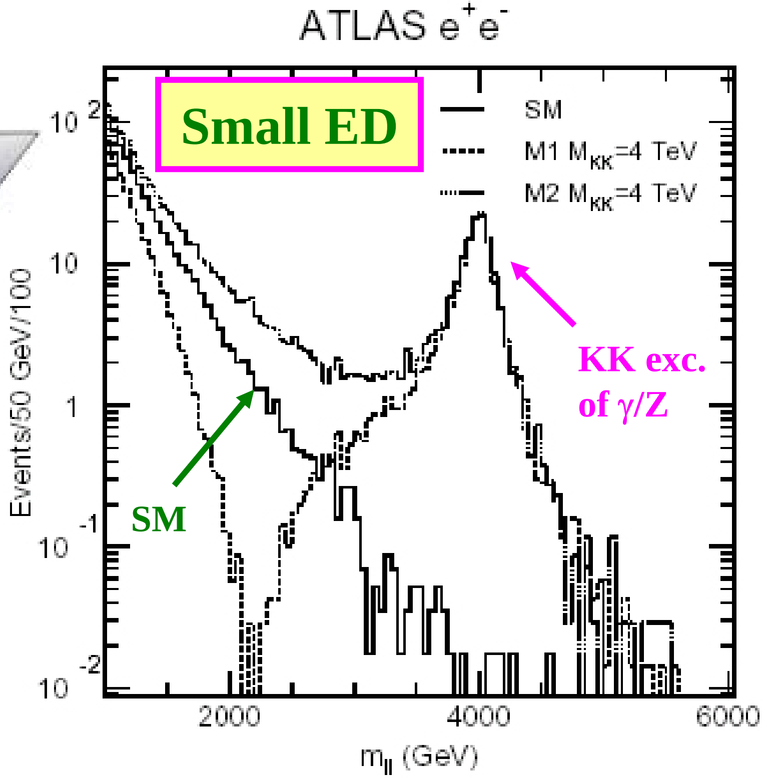
- Large ED (ADD model) --- $R_C >> 1\ \mathrm{TeV}^{-1}$ ➔ Graviton KK excitations
- Small ED (variation of ADD) --- $R_C \approx 1\ \mathrm{TeV}^{-1}$

  ➔ KK excitations of SM gauge bosons
- Warped ED (RS model) ➔ Gravitons and Graviscalars(radions)

  (Radion ≈ SM Higgs; They mix; SM Higgs search at LHC may be confused.)

Large ED Signals

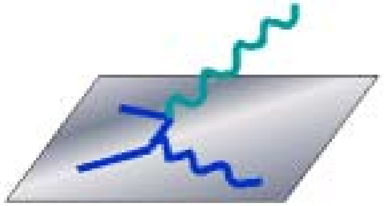


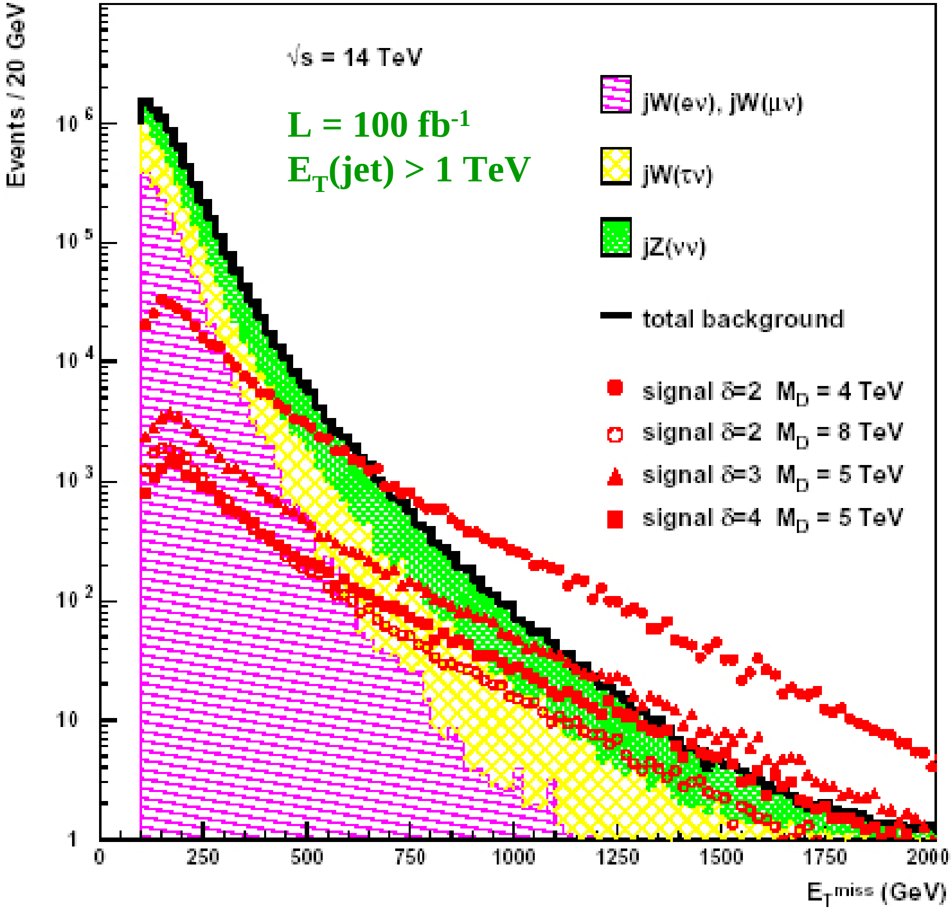


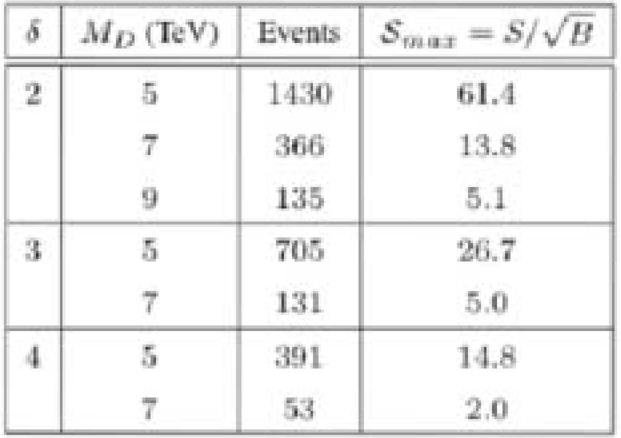
KK graviton production :

gg→gG

(mono-jet + missing-E_T)







δ	M_D (TeV)	Events	$S_{max} = S/\sqrt{B}$
2	5	1430	61.4
	7	366	13.8
	9	135	5.1
3	5	705	26.7
	7	131	5.0
4	5	391	14.8
	7	53	2.0

Large ED signal events

$jZ(\nu\nu)$	$jW(\tau\nu)$	$jW(e\nu)$	$jW(\mu\nu)$
523	151	12	14

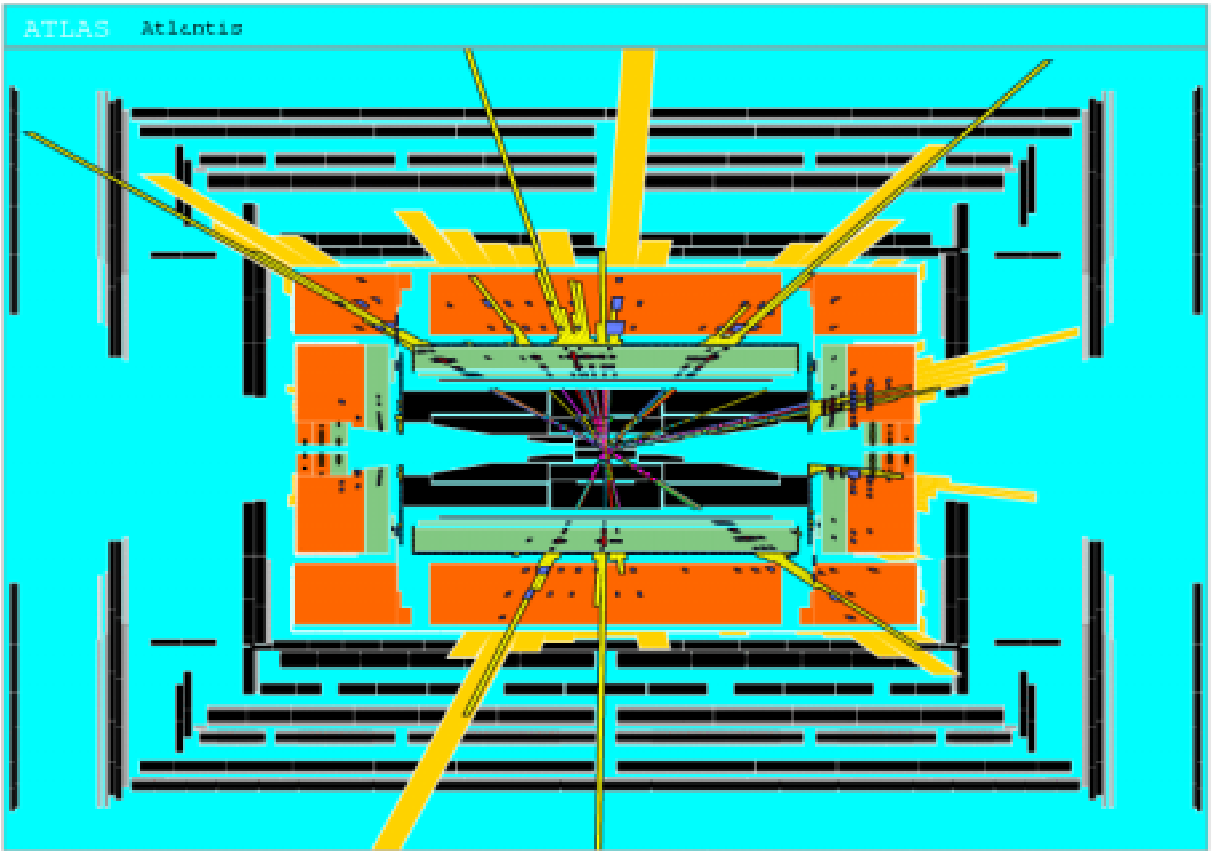
SM BG events

Black Hole Production

If the Planck scale in ~TeV region: can expect Black Hole production

Simulation of a black hole event with M_{BH} ~ 8 TeV in ATLAS

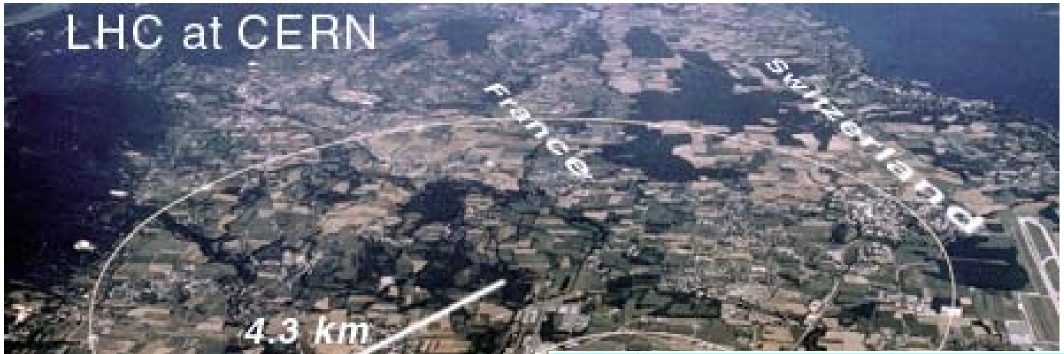
(M_D ~ 1 TeV, n=6)

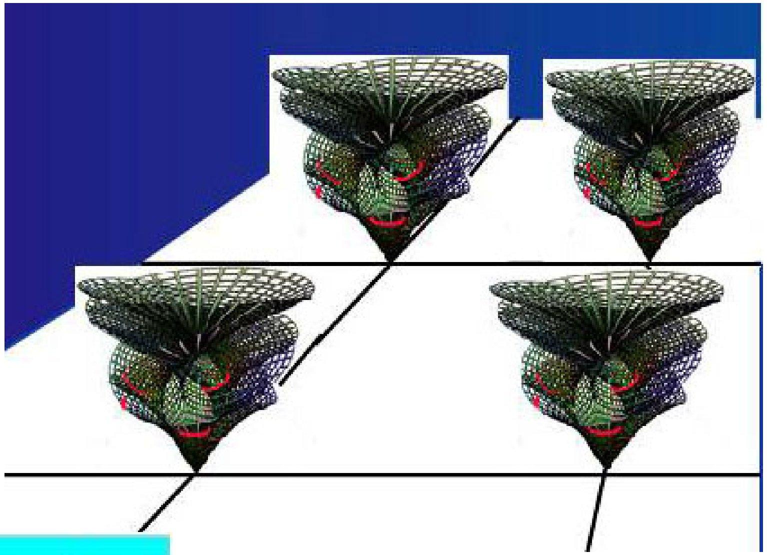


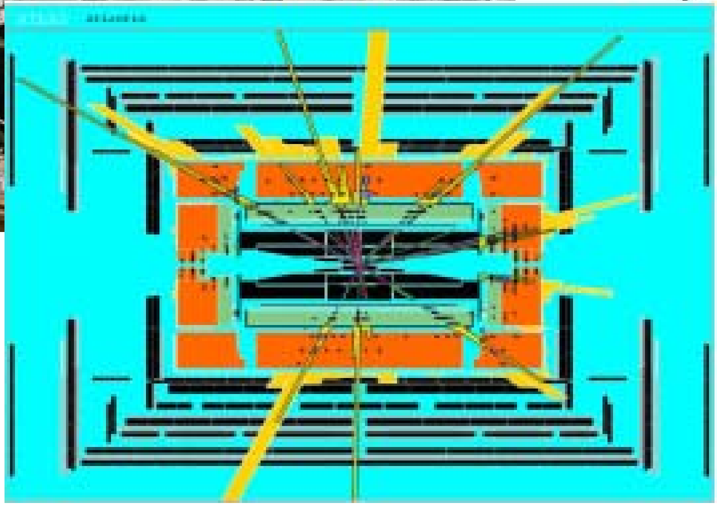
- Large cross section
- ~Spherical events
- Many high energy jets, leptons, photons etc.

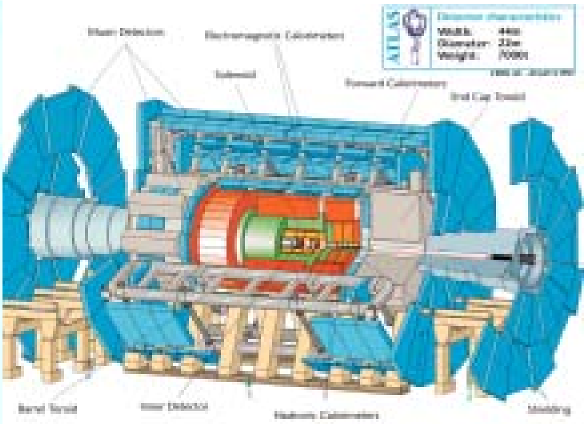
Ecological comment:
BH's will decay within ~10^{-26} secs, so that the detector (and rest of the world) is safe!

Brane New World









“ • • It might be possible that BH is produced at LHC.
It will then disappear immediately by Hawking radiation.
And I will get the Nobel Prize.”

Summary of LHC New Physics Reach

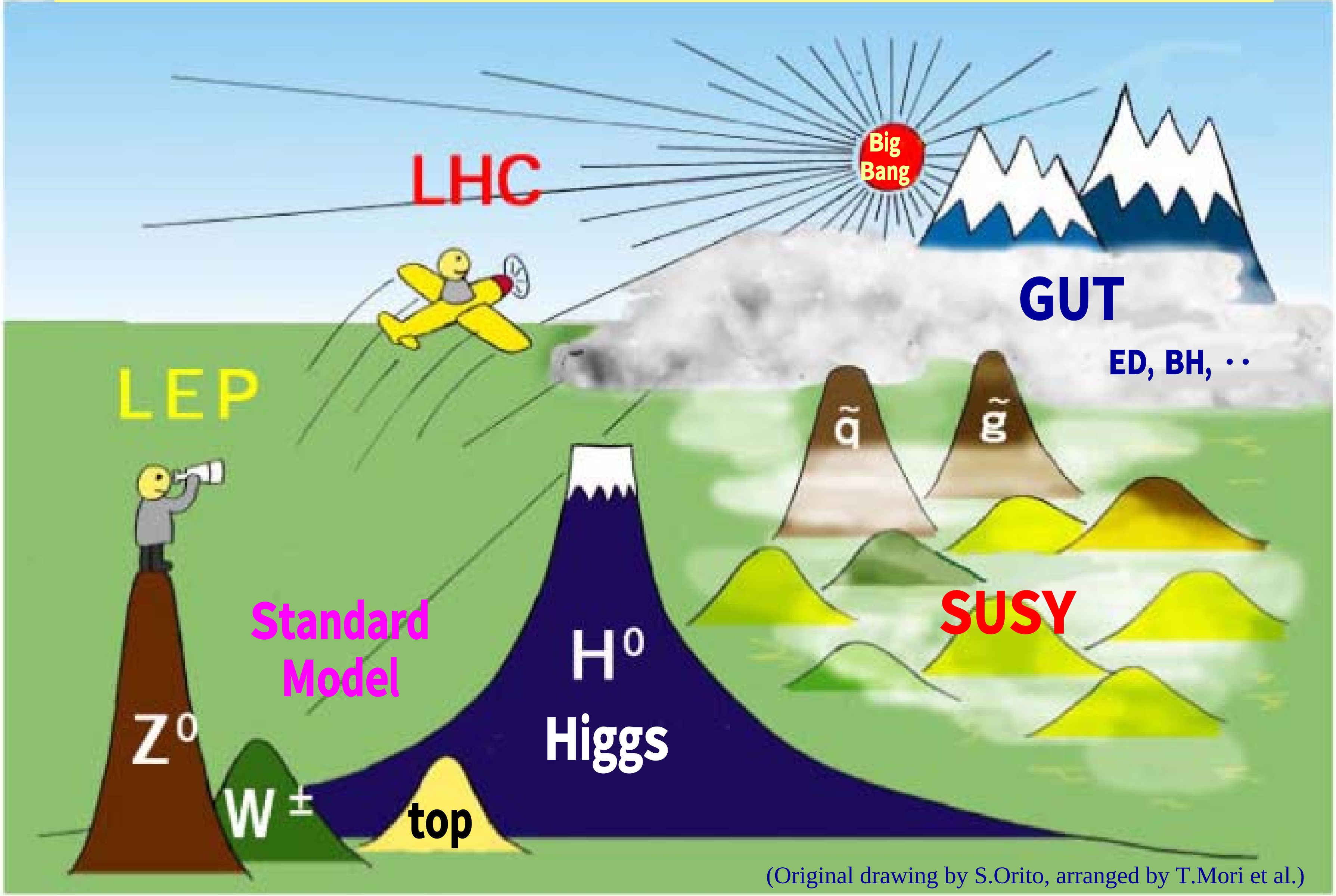
SM Higgs	100 GeV ~ 1 TeV
MSSM Higgs	covers full (m_A, tanβ)
SUSY (squark, gluino)	< 2 TeV (100 fb^{-1})
New gauge bosons (Z’)	< 4.5 TeV (100 fb^{-1})
Quark substructure (Λ_C)	< 25/40 TeV (30/300 fb^{-1})
q*, l*	< 6.5/3.4 TeV (100 fb^{-1})
Large ED (M_D for n=2,4)	< 9/5.8 TeV (100 fb^{-1})
Small ED (M_C)	< 5.8 TeV (100 fb^{-1})
Black holes	< 6 ~ 10 TeV
M(top quark)	σ_M ~ 1 GeV (~ 0.5 %)
M_W	σ_M ~ 15 MeV
CP-violation in B-decay	$\sigma(\sin 2\beta)$ ~ 0.016 (30 fb^{-1})
Rare B-decay ($B_S \rightarrow \mu\mu$)	~ 5σ (130 fb^{-1})

Discovery for sure
+ some measurements

can say “final word”
about (low E) SUSY

Any one of those will change the understanding of our universe !

LHC Looking Down at New Phenomena in the TeV Region



(Original drawing by S.Orito, arranged by T.Mori et al.)