Getting Ready for the LHC: Accelerator, Detectos and Physics

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(Okayama University)

Exploring New Science by Bridging Particle-Matter Hierarchy
The 4th COE Symposium, Tohoku University
June 28-30, 2006

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2. LHC Accelerator and ATLAS Detector
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5. Summary

putting emphases on experimental aspects…

1. Introduction


David Gross


David Politzer


Frank Wilczek

Brief History of Particle Physics


Sheldon Glashow


Abdus Salam


Steven Weinberg

1970's

- Rise of the Standard Model theory (Electroweak and QCD)
- Discovery of J/Ψ (charm quark) in 1974, November Revolution
- Discovery of τ lepton, bottom quark, gluon


Burt Richter


Sam Ting

Never trust a theorist.


Martin Perl

1980's

- Discovery of weak $W^{\pm}$ and Z^0 bosons


Carlo Rubbia


Simon van der Meer

1990's

- Discovery of top quark
- $N_\nu=3$, great success of the Standard Model (gauge theory)
- Discovery of neutrino oscillation

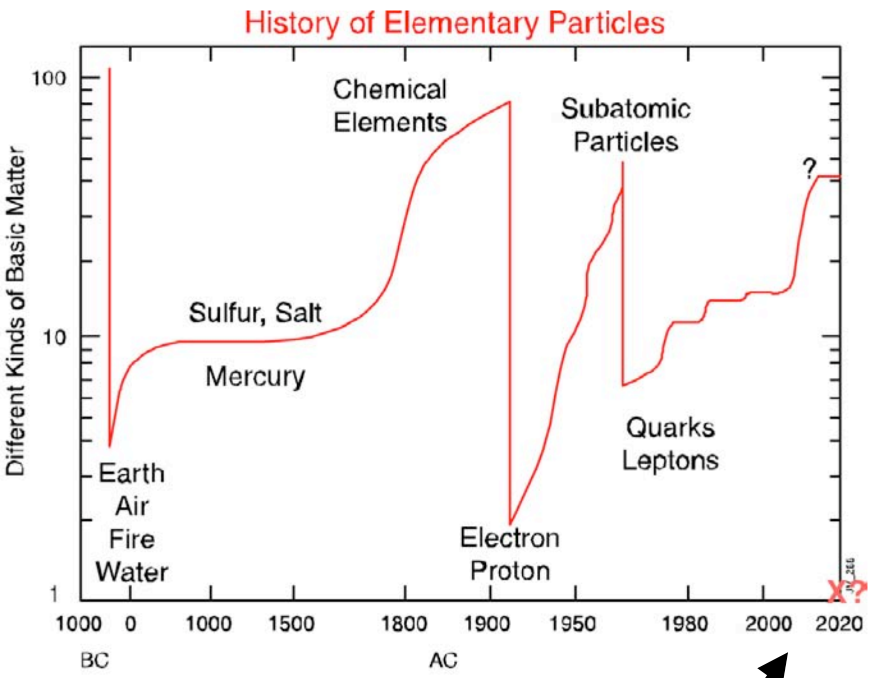

Gerardus 't Hooft


Martinus Veltman

Physics in the 21st century ?

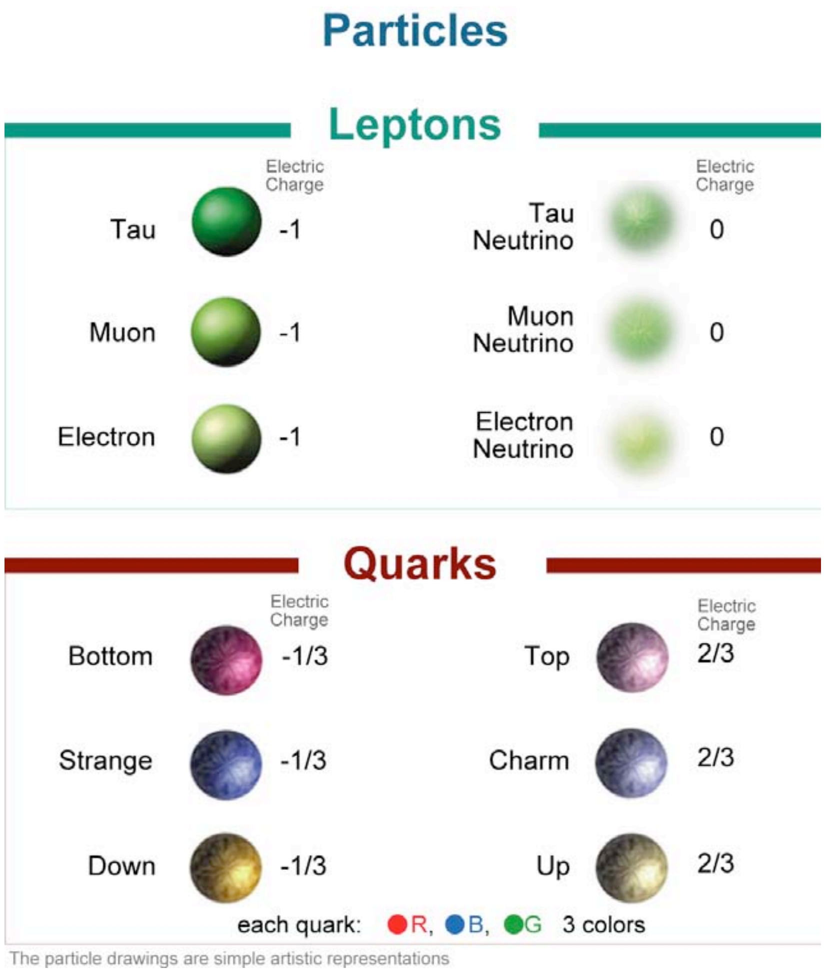
- Find the Higgs particle (last Standard Model particle unobserved)
- Find the TeV scale new physics. → **New Revolution ?**

Elementary Particles


History of Elementary Particles

T. Virdee, ECIS, The Hague, Nov 01

Revolution by LHC in 2009-2010 ?



Particles

Leptons

	Electric Charge		Electric Charge
Tau	-1	Tau Neutrino	0
Muon	-1	Muon Neutrino	0
Electron	-1	Electron Neutrino	0

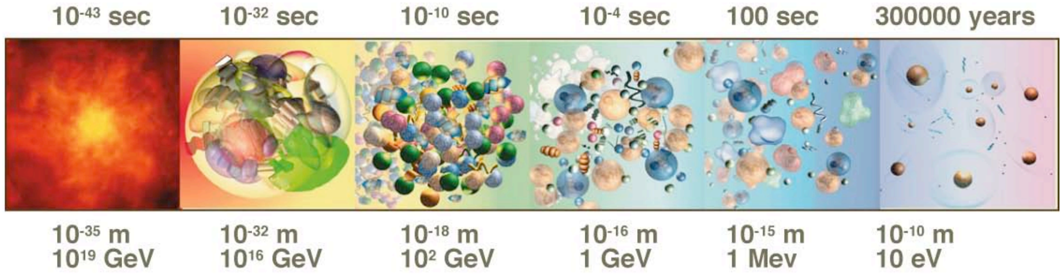
Quarks

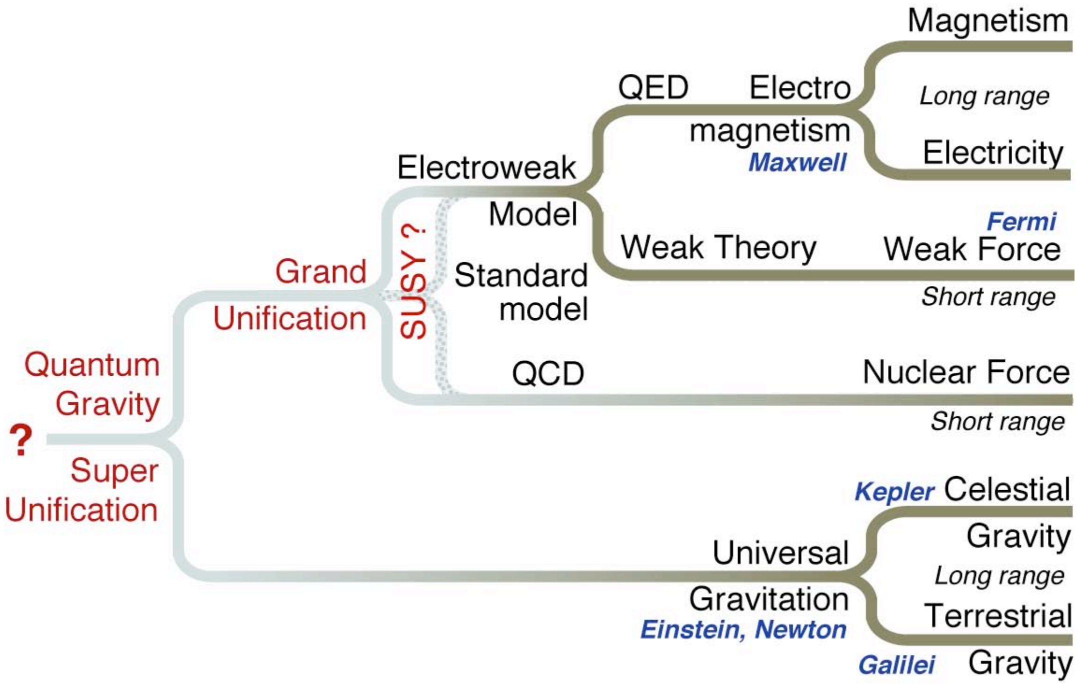
	Electric Charge		Electric Charge
Bottom	-1/3	Top	2/3
Strange	-1/3	Charm	2/3
Down	-1/3	Up	2/3

each quark: ●R, ●B, ●G 3 colors

The particle drawings are simple artistic representations

Forces in Nature





Magnetism
Long range
Electricity
QED Electro magnetism ***Maxwell***
Electroweak Model
Fermi
Weak Theory Weak Force
Short range
Standard model
SUSY ?
Grand Unification
QCD Nuclear Force
Short range
Quantum Gravity
?
Super Unification
Kepler Celestial Gravity
Long range
Terrestrial
Galilei Gravity
Universal Gravitation ***Einstein, Newton***

Theories:

STRINGS? **RELATIVISTIC/QUANTUM** **CLASSICAL**

High Energy Particle Physics

- Hierarchy problem and Naturalness
- Fine tuning: $\frac{M_Z^2}{\Lambda^2} \rightarrow \frac{M_Z^2}{M_{GUT}^2} \approx 10^{-28}$

→ There must be new physics in TeV energy range.

  - Unitarity violation without Higgs above 1TeV (W_L W_L scattering)
  - Prediction of light Higgs with LEP data (M_H<207 GeV@95%C.L).
  - (sub-)TeV WIMP dark matter (SUSY-LSP, axion, $\tilde{\nu}_R$ etc.)

LHC proves directly TeV energy range for the first time!

  - Origin of the electroweak symmetry breaking (EWSB)
    - Higgs, compositeness, Higgsless, others?
  - Unification with quantum gravity, Space-Time structure
    - （super）string theory

Standard Model Lagrangian

R. Barbieri, hep-ph/0410223

$$\mathcal{L} = -\frac{1}{4}F^{a}_{\mu\nu}F^{a\mu\nu} + i\bar{\psi}D\psi$$
$$+\psi_i\lambda_{ij}\psi_j h + h.c.$$
$$+|D_\mu h|^2 - V(h)$$
$$+\frac{1}{M}L_i\lambda^{\nu}_{ij}L_j h^2 \text{ or } L_i\lambda^{\nu}_{ij}N_j$$

	Experiments
The gauge sector	**LEP, SLC, Tevatron**
The flavor sector	**B factories**
The EWSB sector	**LHC, ILC(CLIC)**
The ν−mass sector	**ν factories**

Physics at LHC - main goals for energy frontier machine

1) Probe the origin of the ElectroWeak Symmetry Breaking (EWSB)

2) Search for new physics beyond the Standard Model

Electroweak Symmetry Breaking (EWSB)

Extended Gauge Symmetry

Little Higgs, Higgsless, Left-Right Symmetric Model

Higgs-Gauge Unification

SUSY

(m)SUGRA

GMSB

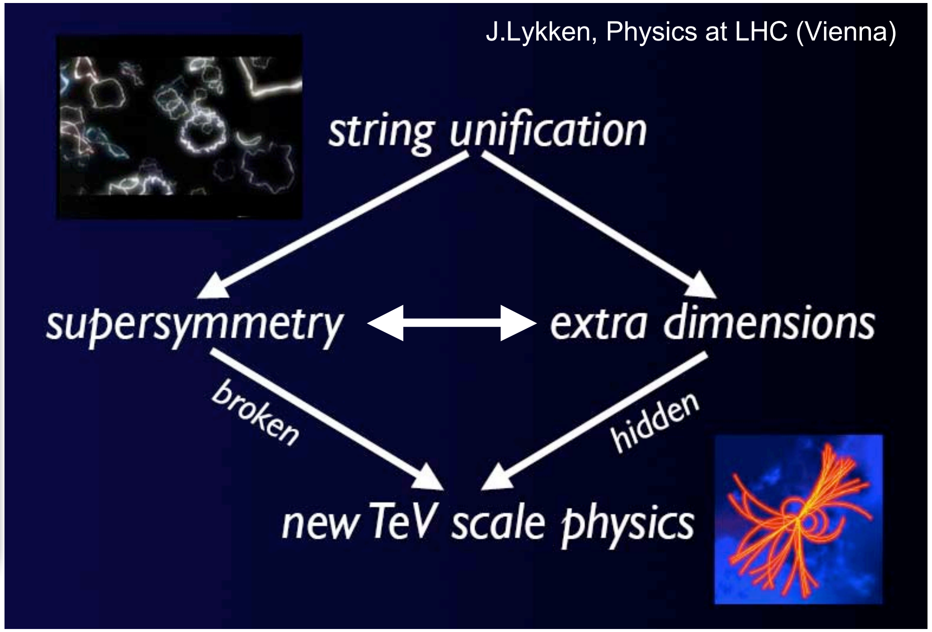
AMSB

Mirage

Split SUSY

RPV

…



J.Lykken, Physics at LHC (Vienna)

Extra-Dimension

LED(ADD)

Randall-Sundrum

Universal ED(KK)

…

Dynamical Symmetry Breaking

Strong EWSB, Chiral Lagrangian, Technicolor,

Composite Higgs, Top-quark Condensation

Precision EW data

Exotics: Compositeness, Lepto-quarks, Monopole …

2. LHC Accelerator and ATLAS Detector

Map of Sendai

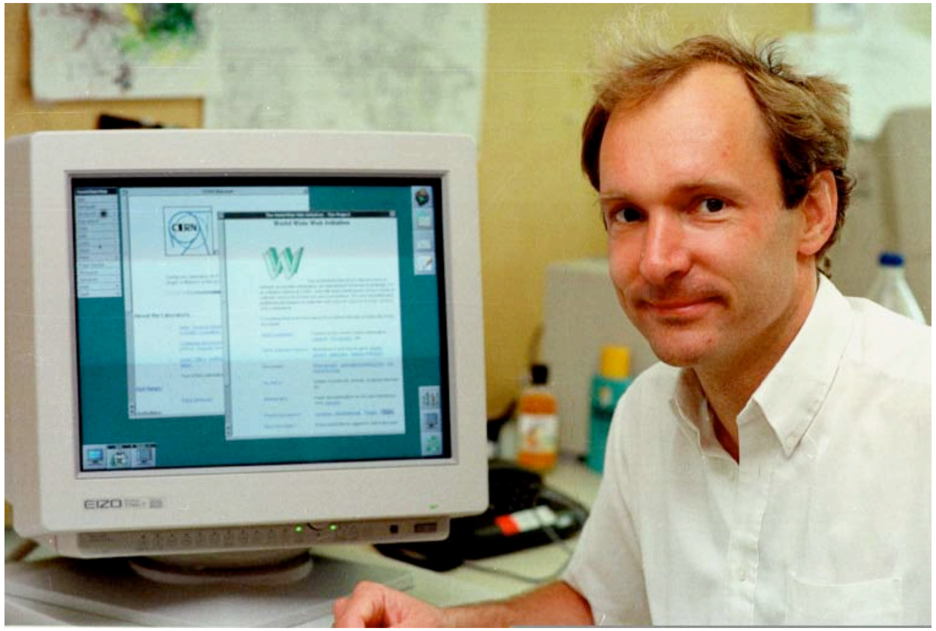
LHC Tunnel
L=27km

CERN

Conseil **E**uropéen pour la **R**echerche **N**ucléaire(1954~)
known also as **European Laboratory for Particle Physics**

- 20 European Member States
- >2500 staff, >6000 users.

Japan became an Observer State in 1995.

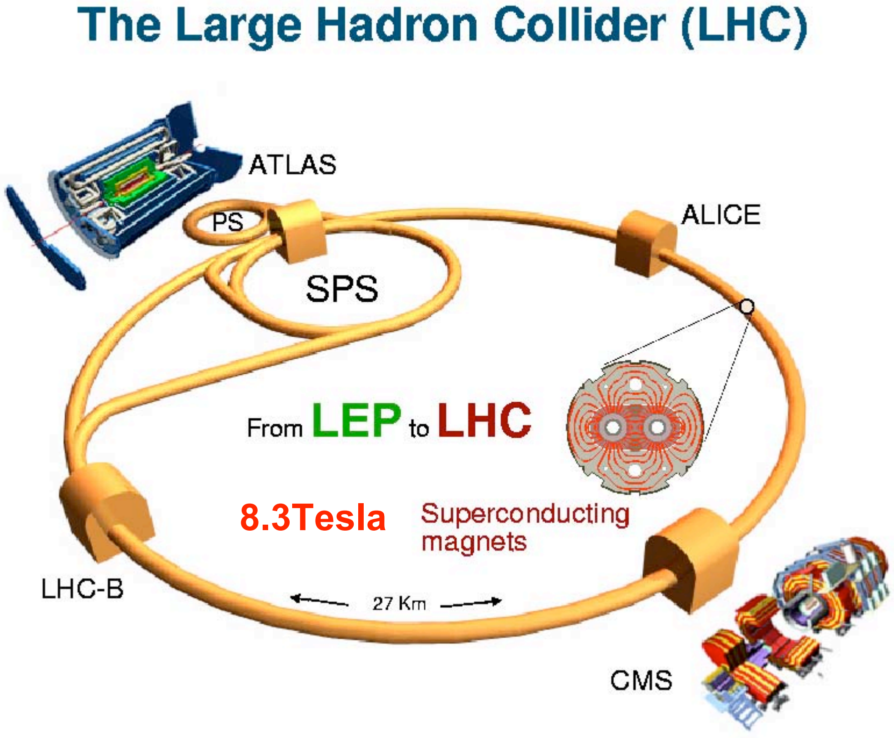


Tim Berners-Lee invented the World-Wide Web.

LHC Accelerator

Proton-Proton Collider

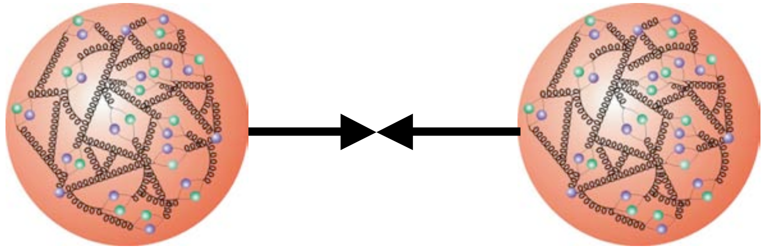
- Centre-of-mass Energy = 14TeV
- Not all energies are available,
- but able to search new particles 3-5TeV.



Proton

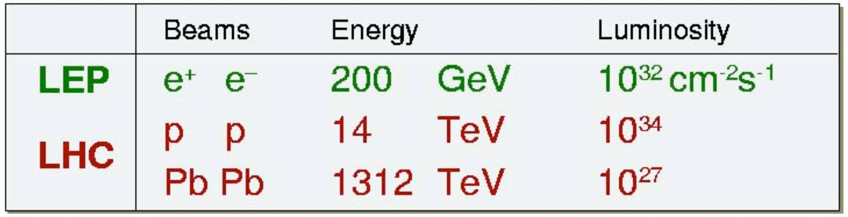
3 valence quarks (uud)

sea quarks + gluons



$$\frac{d\sigma}{dX} = \sum_{j,k}\int_{\hat{X}} f_j(x_1,Q_i)\, f_k(x_2,Q_i)\, \frac{d\hat{\sigma}_{jk}(Q_i,Q_f)}{d\hat{X}}\, F(\hat{X} \to X; Q_i, Q_f)$$

f_i: PDF(Parton Distribution Function)

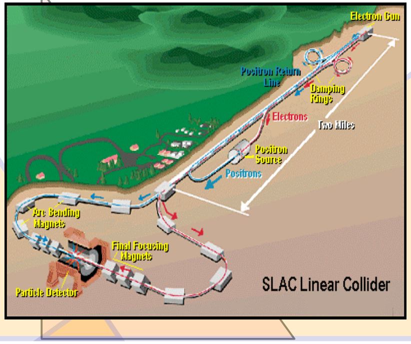


	Beams	Energy		Luminosity
LEP	e^+ e^-	200	GeV	$10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
LHC	p p	14	TeV	10^{34}
	Pb Pb	1312	TeV	10^{27}

Energy Frontier Accelerators

e^+e^- TRISTAN
60 GeV

e^+e^- SLC
91 GeV



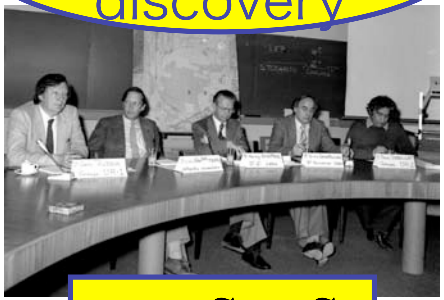
e^+e^- LEP
91-209 GeV

In 2007
LHC starts

e^+e^- ILC
91-1000 GeV

1985 1990 1995 2000 2005 2010 2015 2020

W, Z boson
discovery

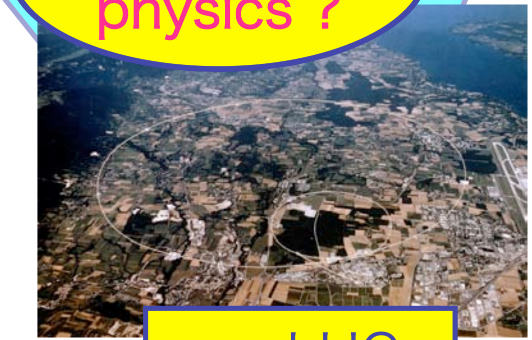


$p\bar{p}$ $Sp\bar{p}S$
600 GeV

Top quark
discovery

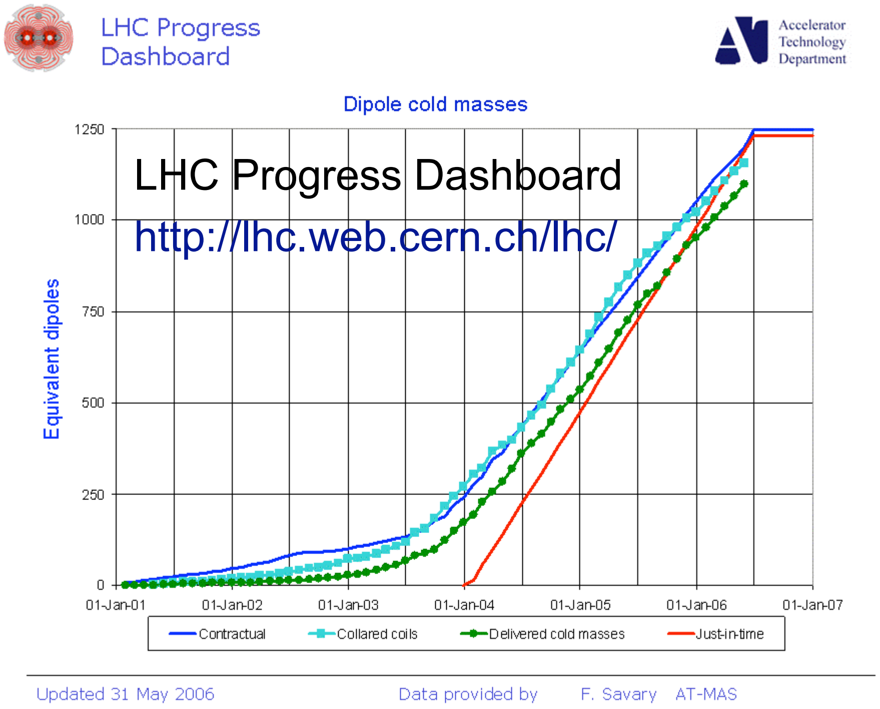
$p\bar{p}$ Tevatron
1.80-1.96 TeV

TeV new
physics ?



pp LHC
14 TeV

CERN Control Centre (CCC)

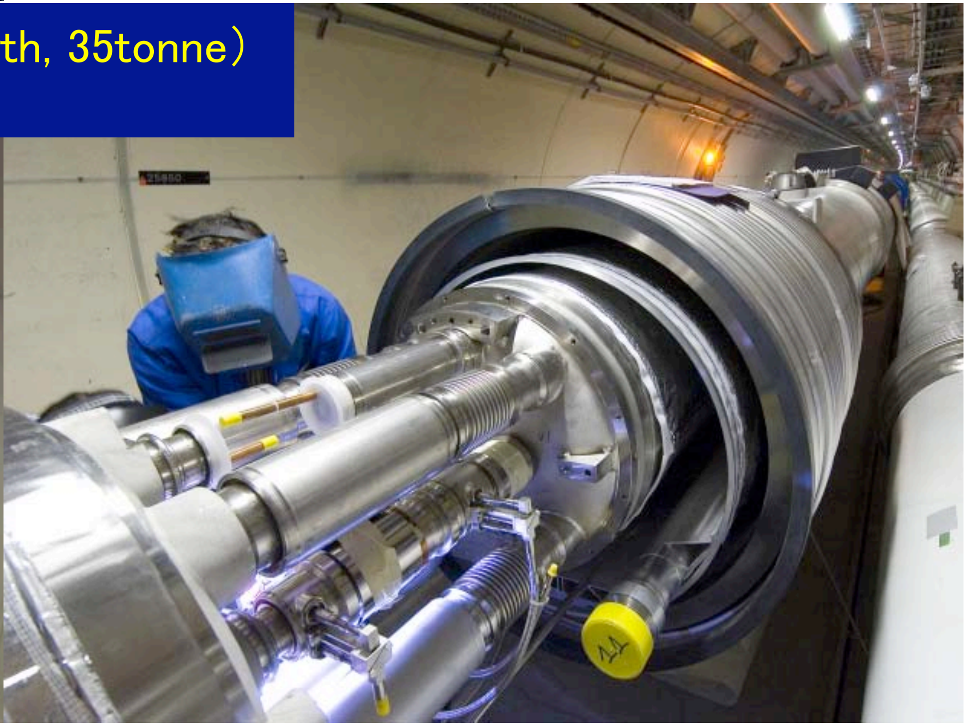


LHC Progress Dashboard

http://lhc.web.cern.ch/lhc/

Updated 31 May 2006 Data provided by F. Savary AT-MAS

1232 SC Dipole Magnets (8.36Tesla, 15m length, 35tonne) installation will finish in March 2007.



LHC Start-up Scenario

Stage 1
Initial Commissioning
43x43 to 156x156, $N=1\text{-}9\times10^{10}$
$L=4\times10^{28}$ - 10^{32}

Stage 2
75ns operation
936x936, $N=4\text{-}9\times10^{10}$
$L=10^{32}$ - 10^{33}

Stage 3
25ns operation
2808x2808, $N=4\text{-}5\times10^{10}$
$L=4\times10^{32}$ - 2×10^{33}

Nominal
25ns operation
$L=10^{34}$

Schedule (CERN Council, June 23, 2006)

Oct. 2006 - Last magnet delivery
Dec. 2006 - Conclude magnet testing
Mar. 2007 - The last magnet installation
Aug. 2007 - Machine closure ready for commissioning
Nov. 2007 - 2 months commissioning@0.9TeV
winter - Commissioning without beam

Spring 2008 - First Physics RUN@14TeV !

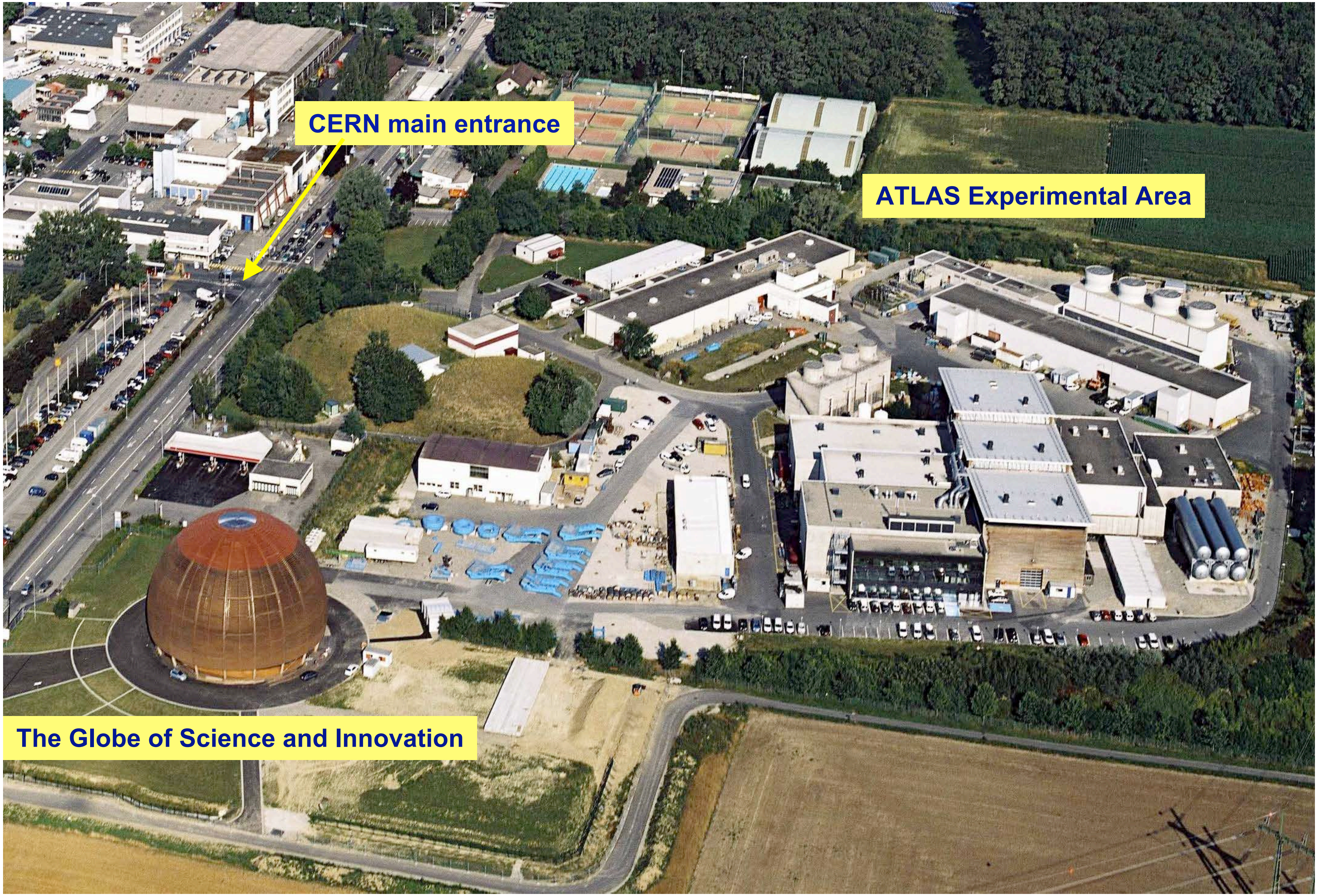
Data collection will continue until a pre-determined amount of data has been accumulated, allowing the experimental collaborations to announce their first results.

The ATLAS Collaboration

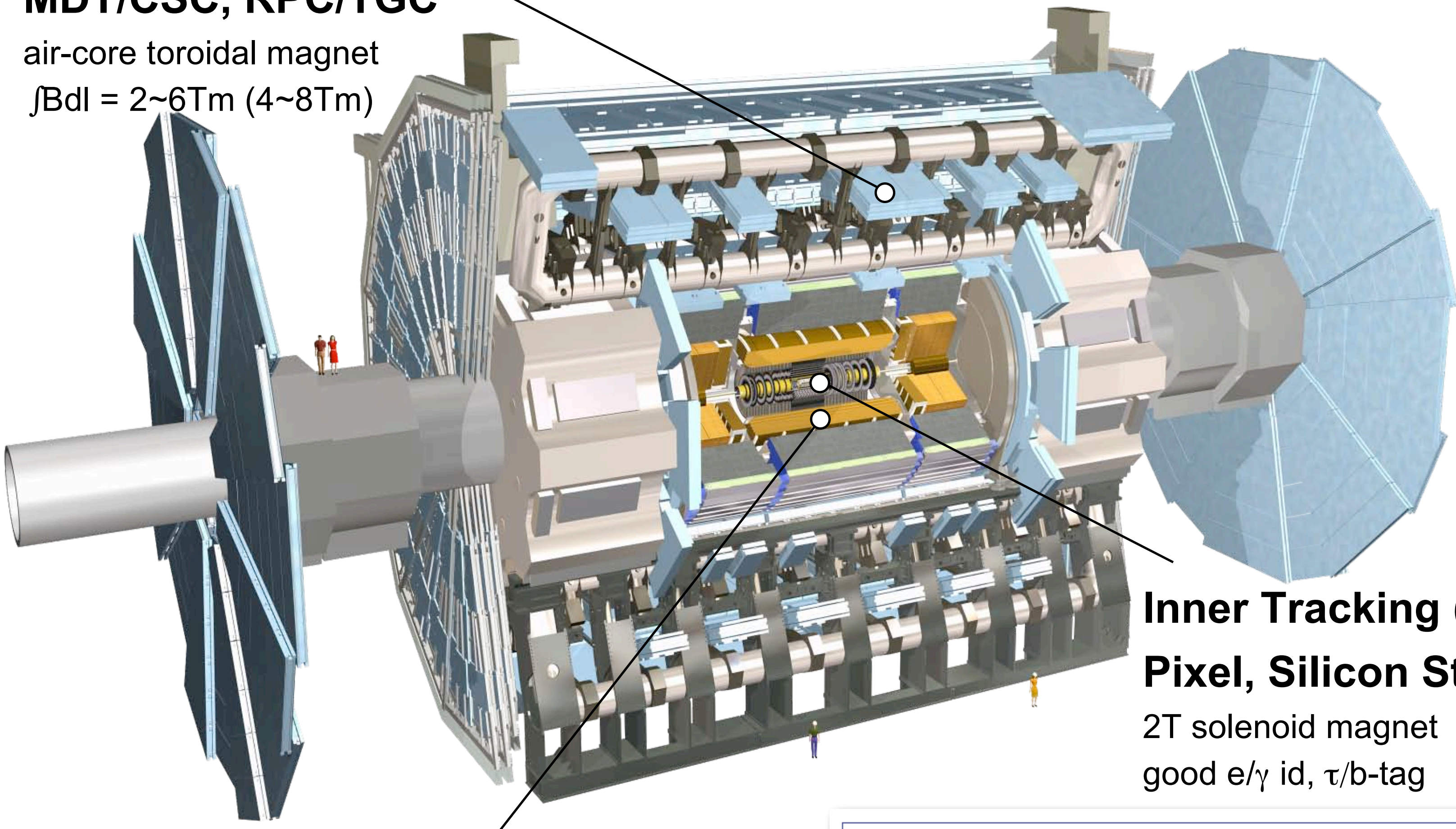
35 nations
158 institutions
~1650 scientists

From Japan
15 institutions (10%)
~60 scientists (5%)
Share 32/468 MCHF (7%)

Albany, Alberta, NIKHEF Amsterdam, Ankara, LAPP Annecy, Argonne NL, Arizona, UT Arlington, Athens, NTU Athens, Baku, IFAE Barcelona, Belgrade, Bergen, Berkeley LBL and UC, Bern, Birmingham, Bologna, Bonn, Boston, Brandeis, Bratislava/SAS Kosice, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, Casablanca/Rabat, CERN, Chinese Cluster, Chicago, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, INP Cracow, FPNT Cracow, Dortmund, TU Dresden, JINR Dubna, Duke, Frascati, Freiburg, Geneva, Genoa, Giessen, Glasgow, LPSC Grenoble, Technion Haifa, Hampton, Harvard, Heidelberg, **Hiroshima**, **Hiroshima IT**, Indiana, Innsbruck, Iowa SU, Irvine UC, Istanbul Bogazici, **KEK**, **Kobe**, **Kyoto**, **Kyoto UE**, Lancaster, UN La Plata, Lecce, Lisbon LIP, Liverpool, Ljubljana, QMW London, RHBNC London, UC London, Lund, UA Madrid, Mainz, Manchester, Mannheim, CPPM Marseille, Massachusetts, MIT, Melbourne, Michigan, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, McGill Montreal, FIAN Moscow, ITEP Moscow, MEPhI Moscow, MSU Moscow, Munich LMU, MPI Munich, **Nagasaki IAS**, Naples, **Naruto UE**, New Mexico, Nijmegen, BINP Novosibirsk, Ohio SU, **Okayama**, Oklahoma, Oklahoma SU, Oregon, LAL Orsay, **Osaka**, Oslo, Oxford, Paris VI and VII, Pavia, Pennsylvania, Pisa, Pittsburgh, CAS Prague, CU Prague, TU Prague, IHEP Protvino, **Ritsumeikan**, UFRJ Rio de Janeiro, Rochester, Rome I, Rome II, Rome III, Rutherford Appleton Laboratory, DAPNIA Saclay, Santa Cruz UC, Sheffield, **Shinshu**, Siegen, Simon Fraser Burnaby, Southern Methodist Dallas, NPI Petersburg, Stockholm, KTH Stockholm, Stony Brook, Sydney, AS Taipei, Tbilisi, Tel Aviv, Thessaloniki, **Tokyo ICEPP**, **Tokyo MU**, Toronto, TRIUMF, **Tsukuba**, Tufts, Udine, Uppsala, Urbana UI, Valencia, UBC Vancouver, Victoria, Washington, Weizmann Rehovot, Wisconsin, Wuppertal, Yale, Yerevan


CERN main entrance
ATLAS Experimental Area
The Globe of Science and Innovation

A Toroidal LHC ApparatuS (ATLAS)



Muon Spectrometer($\eta<2.7$)

MDT/CSC, RPC/TGC

air-core toroidal magnet

$\int Bdl$ = 2~6Tm (4~8Tm)

Inner Tracking ($\eta<2.5$)

Pixel, Silicon Strip, TRT

2T solenoid magnet

good e/γ id, τ/b-tag

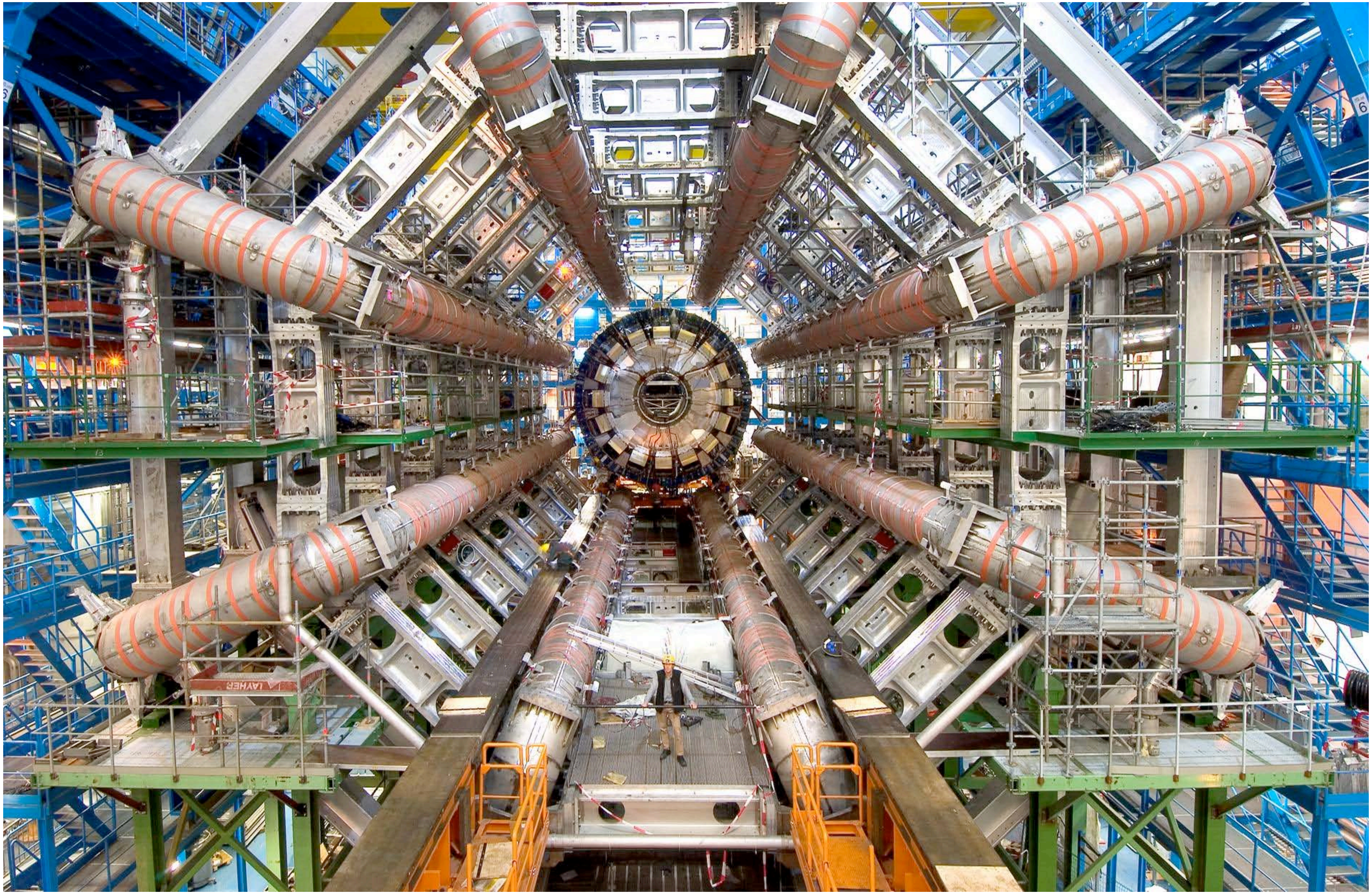
Calorimeter ($\eta<4.9$)

Liq.Ar EM/HAD/FCAL, Tile HAD, FCAL

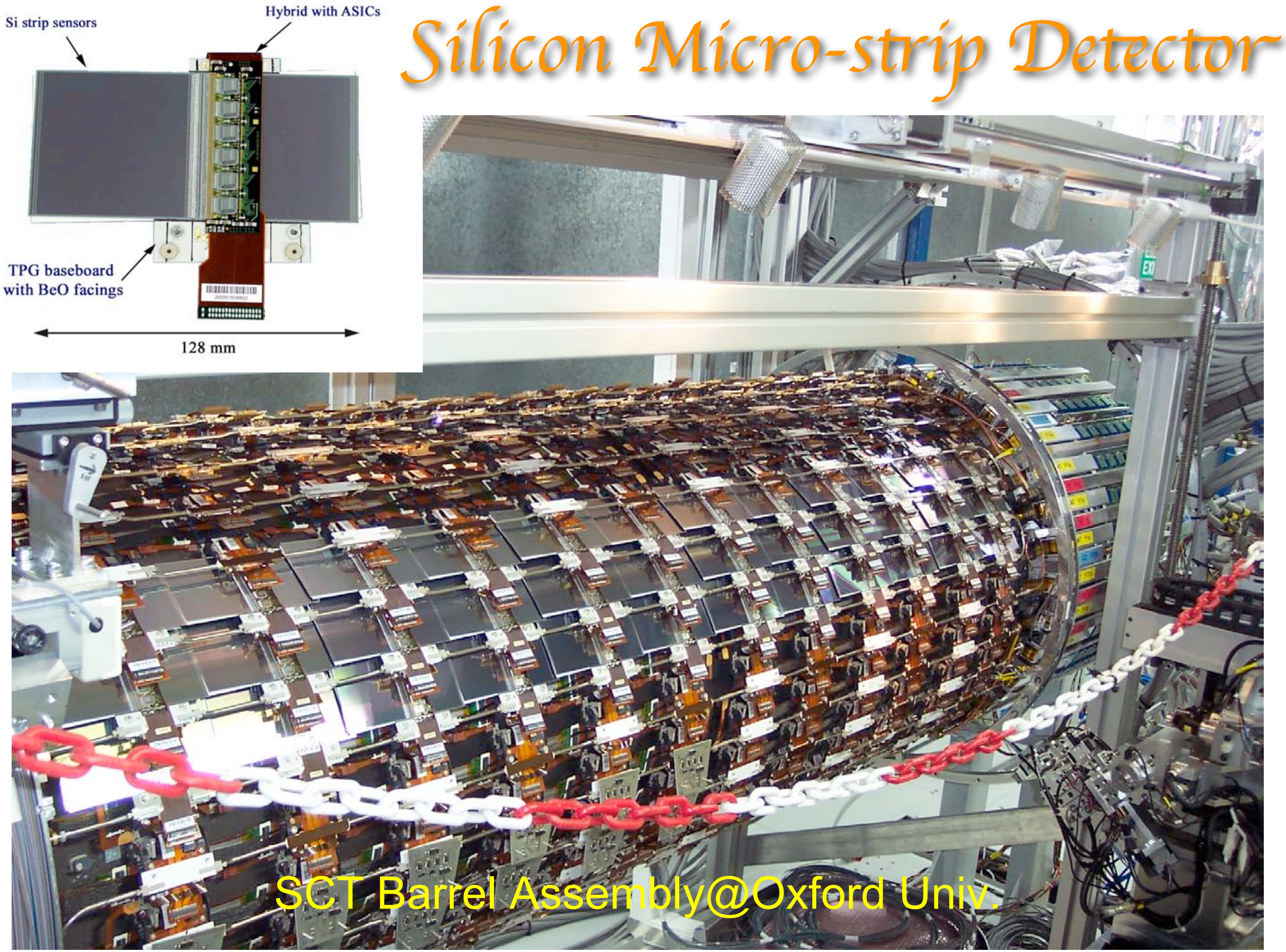
good e/γ id, energy, E_T^{miss}

Diameter	*25 m*
Barrel toroid length	*26 m*
End-cap end-wall chamber span	*46 m*
Overall weight	*7000 Tons*

The ATLAS Detector Nov.2005

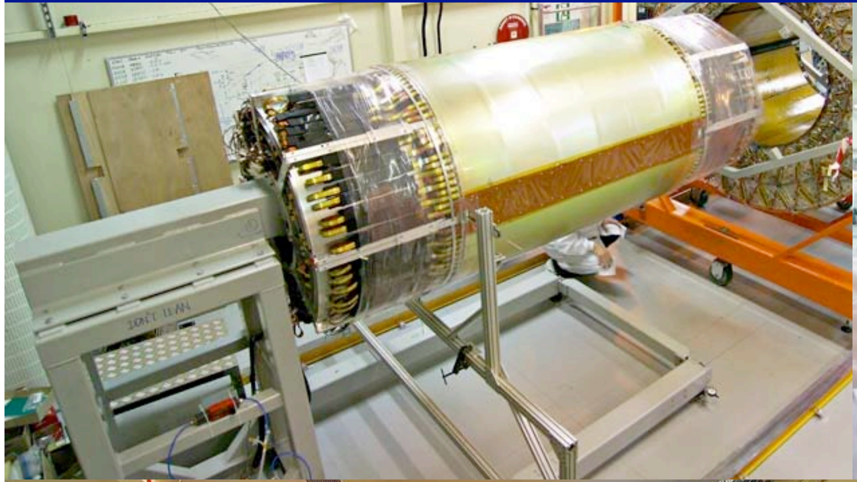


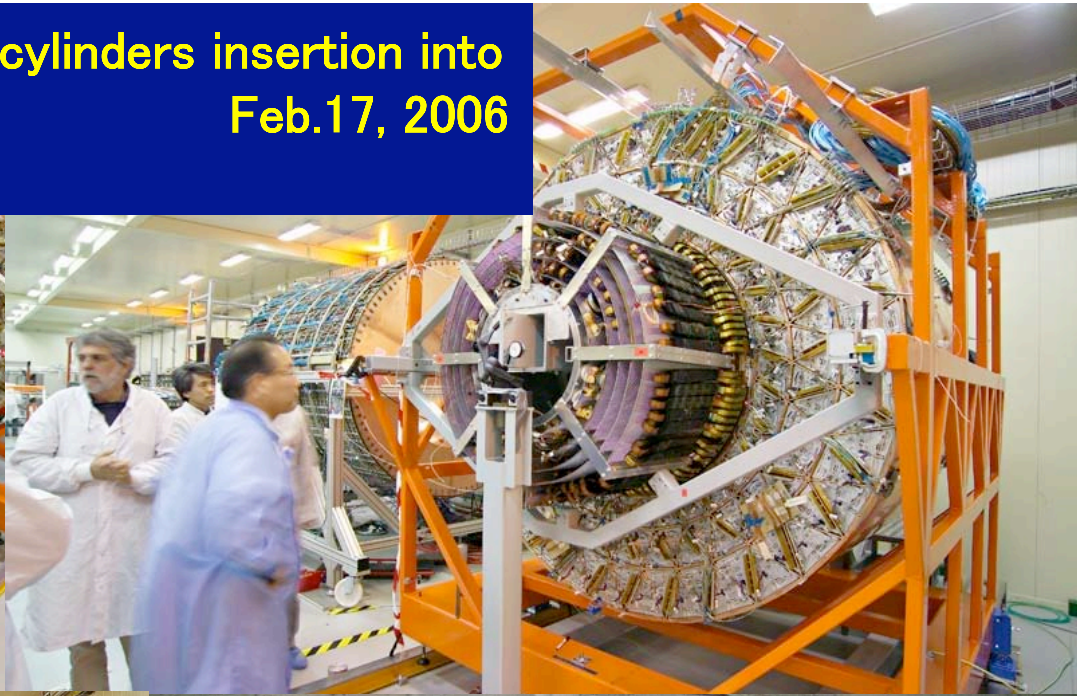
Silicon Micro-strip Detector

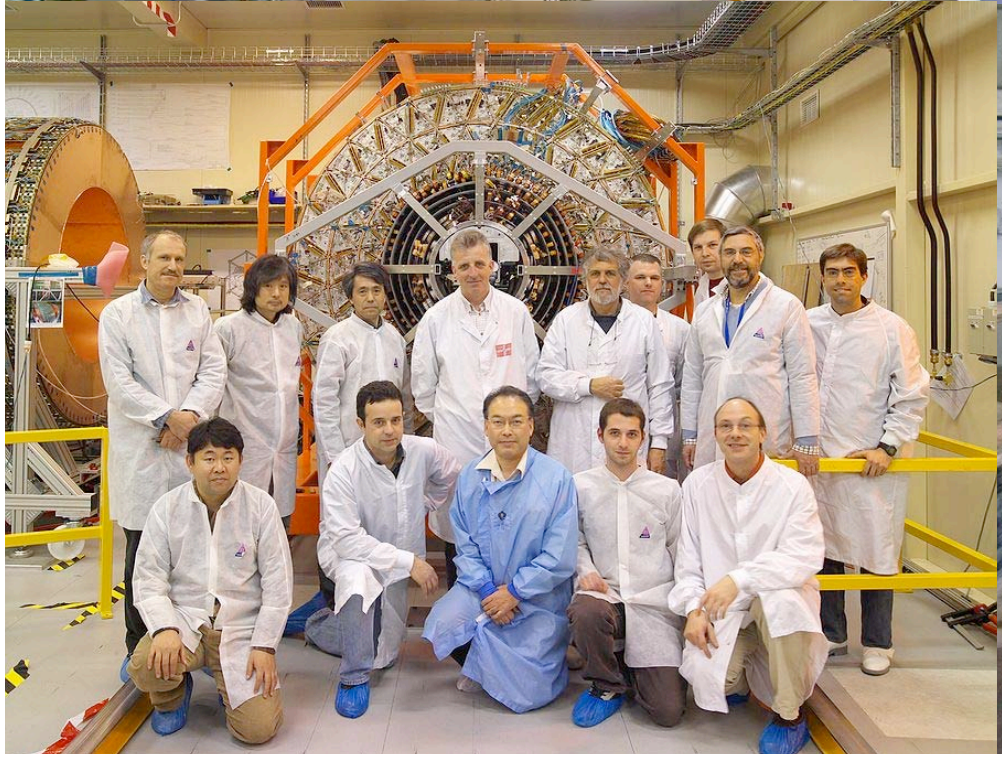


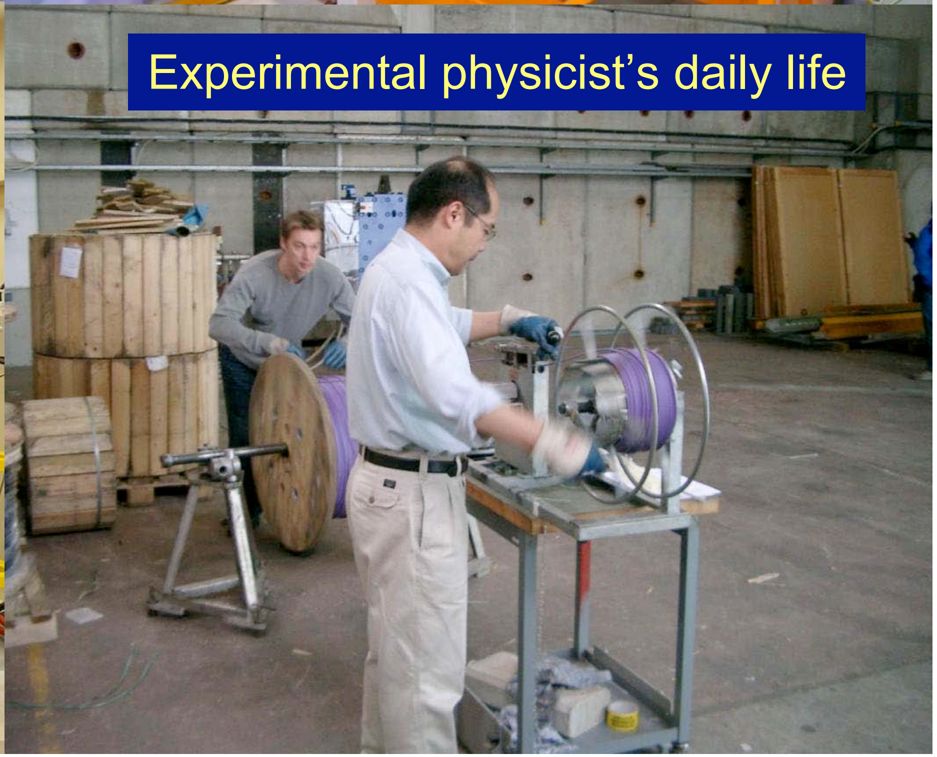
SCT Barrel Assembly@Oxford Univ.

SCT(SemiConductor Tracker) barrel cylinders insertion into TRT(Transition Radiation Tracker) Feb.17, 2006



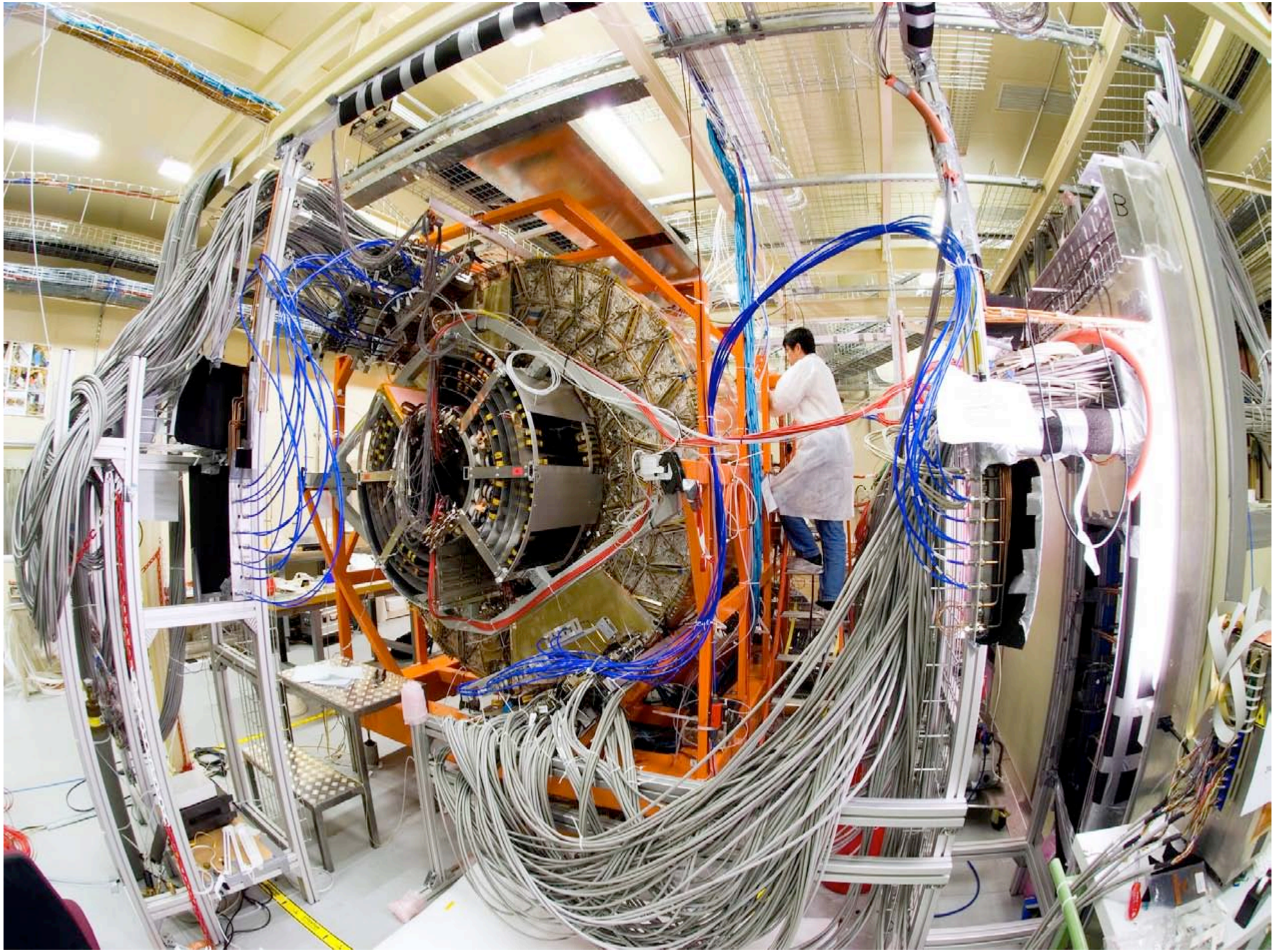






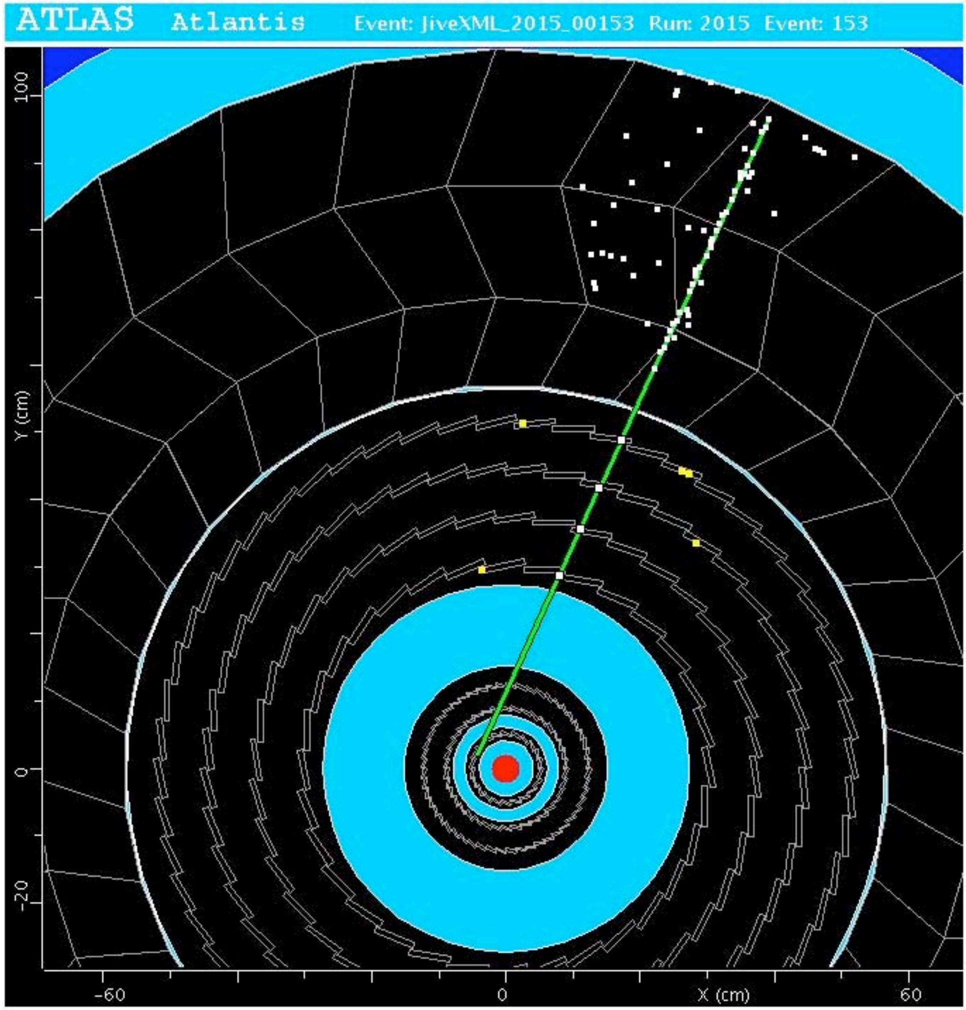
Experimental physicist's daily life

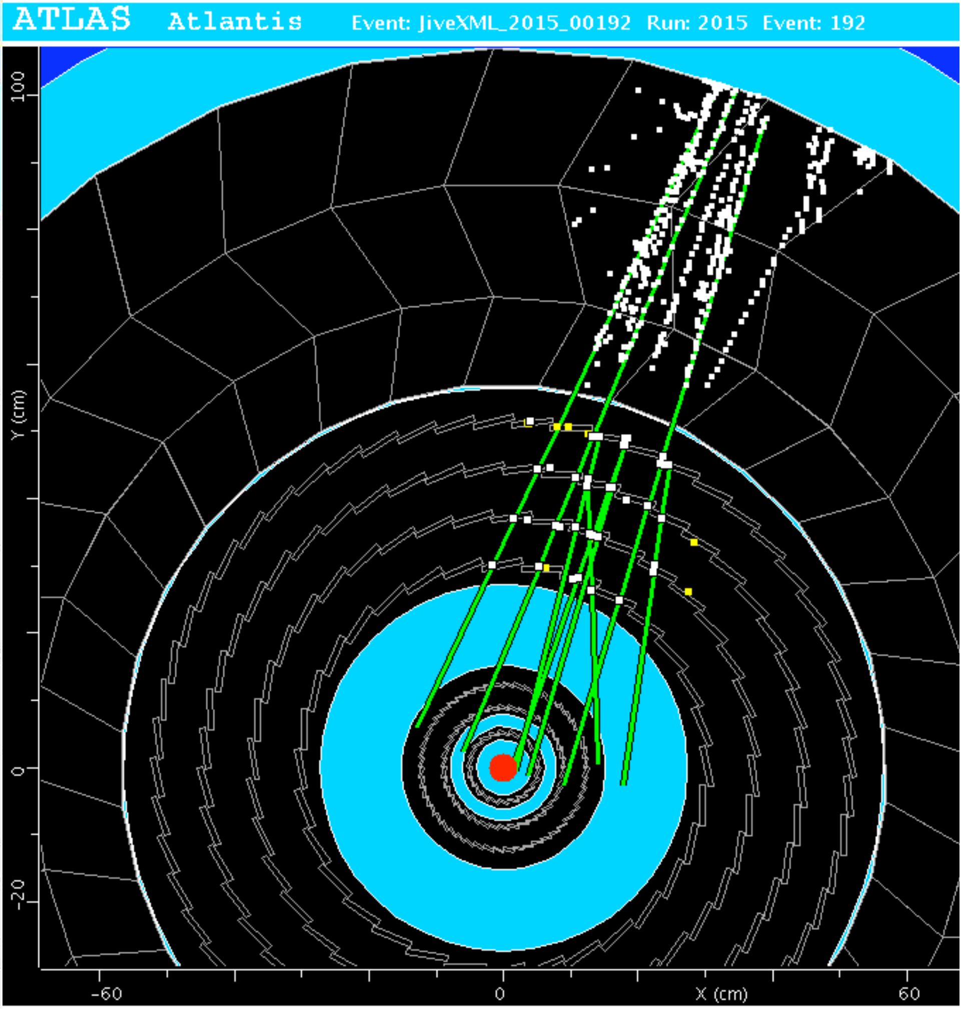
SCT and TRT barrel test



First cosmic events in SCT+TRT

May 2006

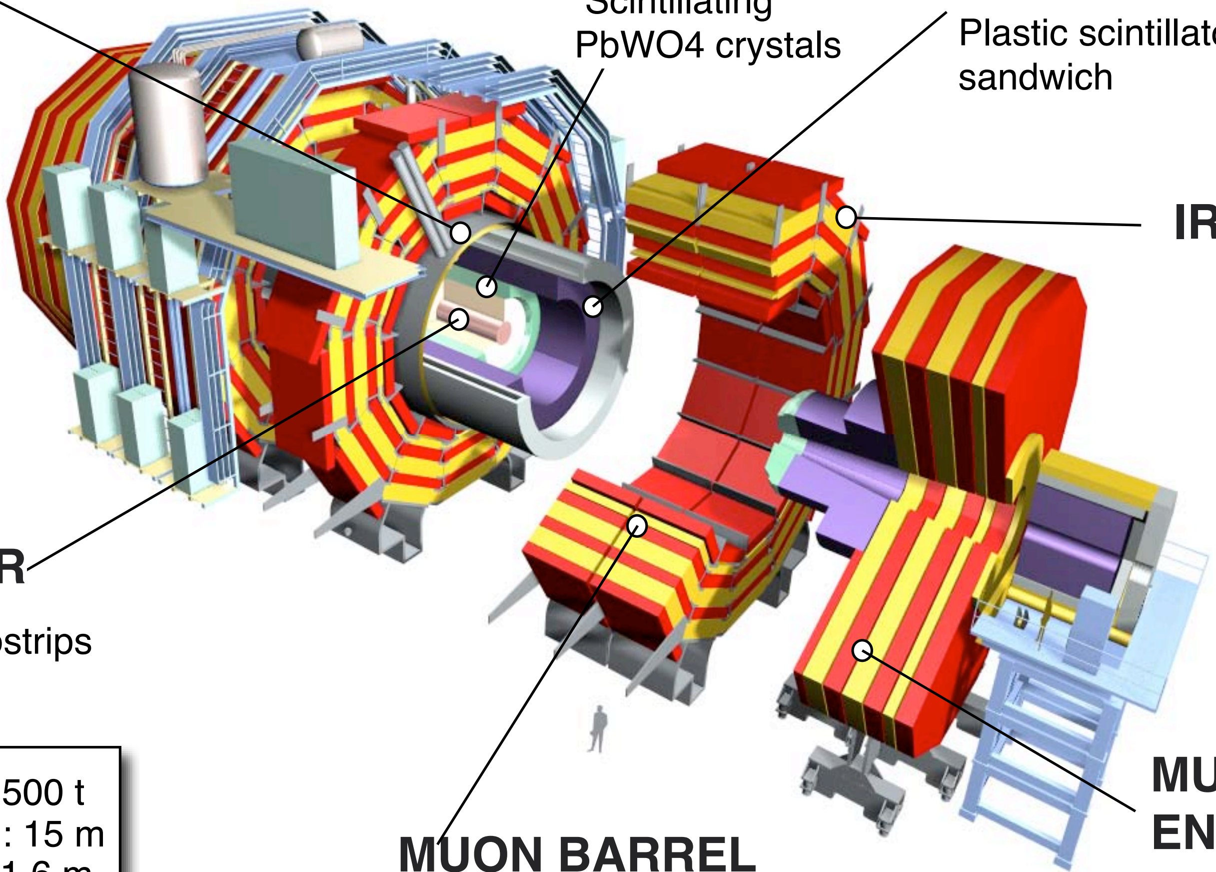




‘Big Wheel’ end-cap muon TGC sector assembled in Hall 180

T.Ogata (Kobe Univ.)

CMS (Compact Muon Spectrometer)



SUPERCONDUCTING COIL

CALORIMETERS

ECAL

Scintillating PbWO4 crystals

HCAL

Plastic scintillator/brass sandwich

IRON YOKE

TRACKER

Silicon Microstrips
Pixels

MUON BARREL

Drift Tube Chambers (**DT**)

Resistive Plate Chambers (**RPC**)

MUON ENDCAPS

Cathode Strip Chambers (**CSC**)

Resistive Plate Chambers (**RPC**)

Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

Event at LHC

A simulated event in ATLAS (CMS) $H \rightarrow ZZ \rightarrow 4\mu$

pp collision at $\sqrt{s}$ = 14 TeV

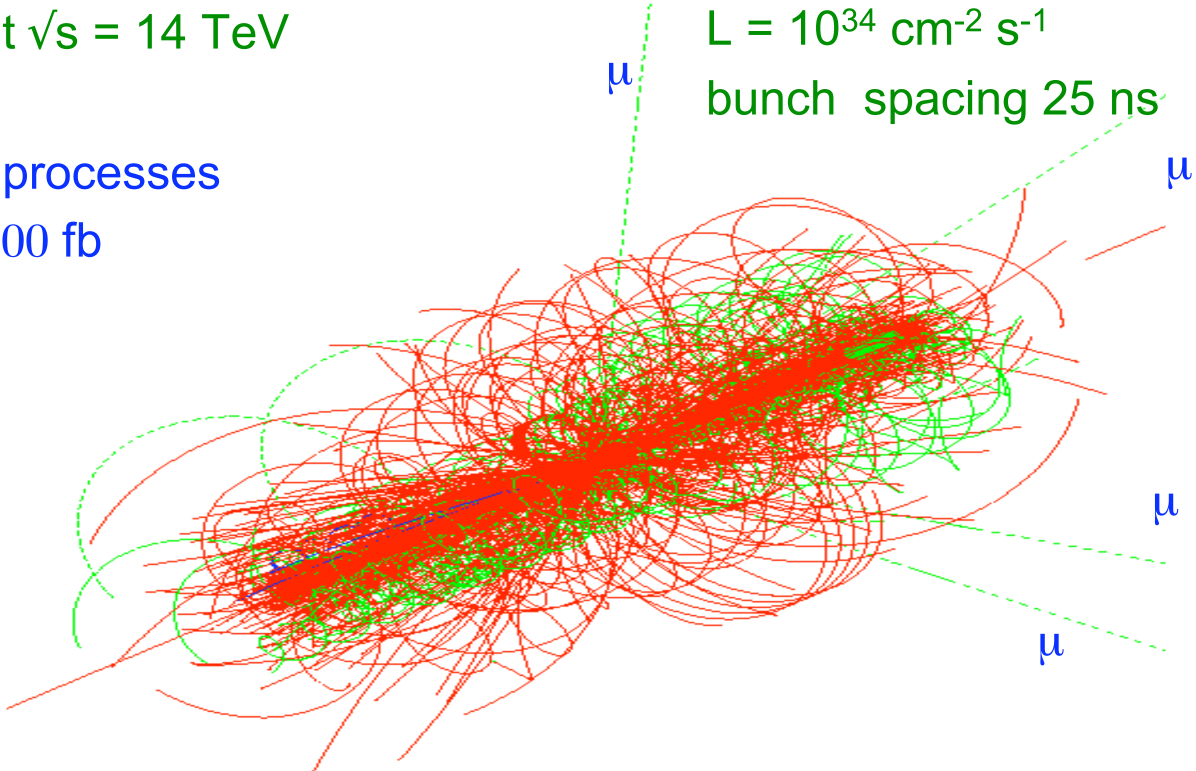
$\sigma_{inel.} \approx$ 70 mb

Interested in processes

with $\sigma \approx 10\text{–}100$ fb

$L = 10^{34}$ cm^{-2} s^{-1}

bunch spacing 25 ns

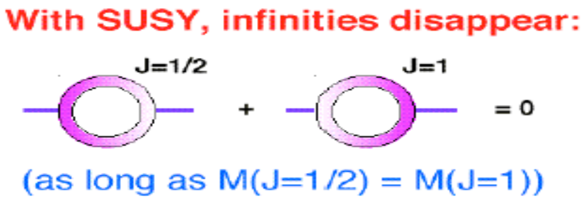


≈ 23 overlapping minimum bias events / Beam Crossing

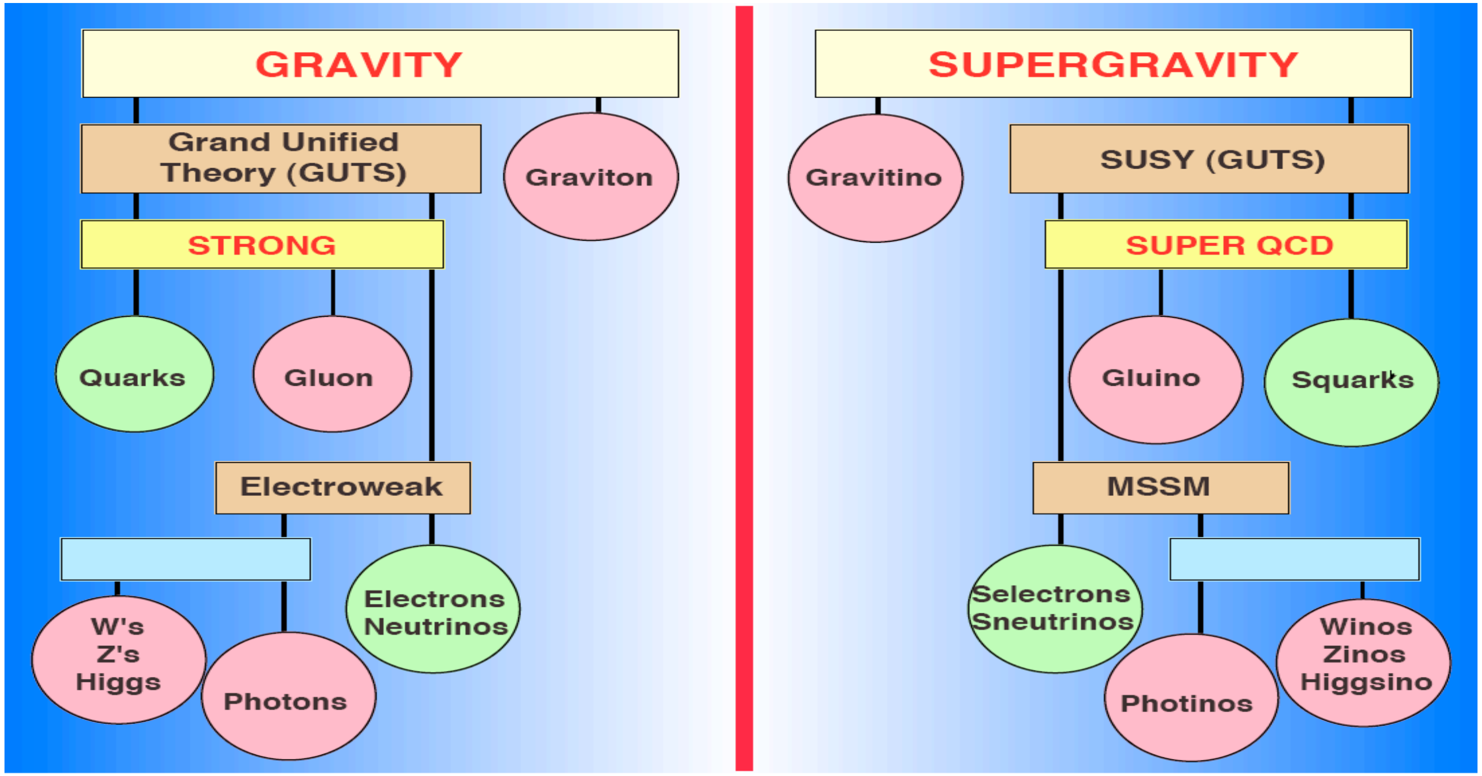
≈ 1900 charged + 1600 neutral particles / Beam Crossing

3. Supersymmetry

Extended Poincaré


With SUSY, infinities disappear:

(as long as M(J=1/2) = M(J=1))


GRAVITY

Grand Unified Theory (GUTS)

Graviton

STRONG

Quarks

Gluon

Electroweak

W's
Z's
Higgs

Photons

Electrons
Neutrinos

SUPERGRAVITY

Gravitino

SUSY (GUTS)

SUPER QCD

Gluino

Squarks

MSSM

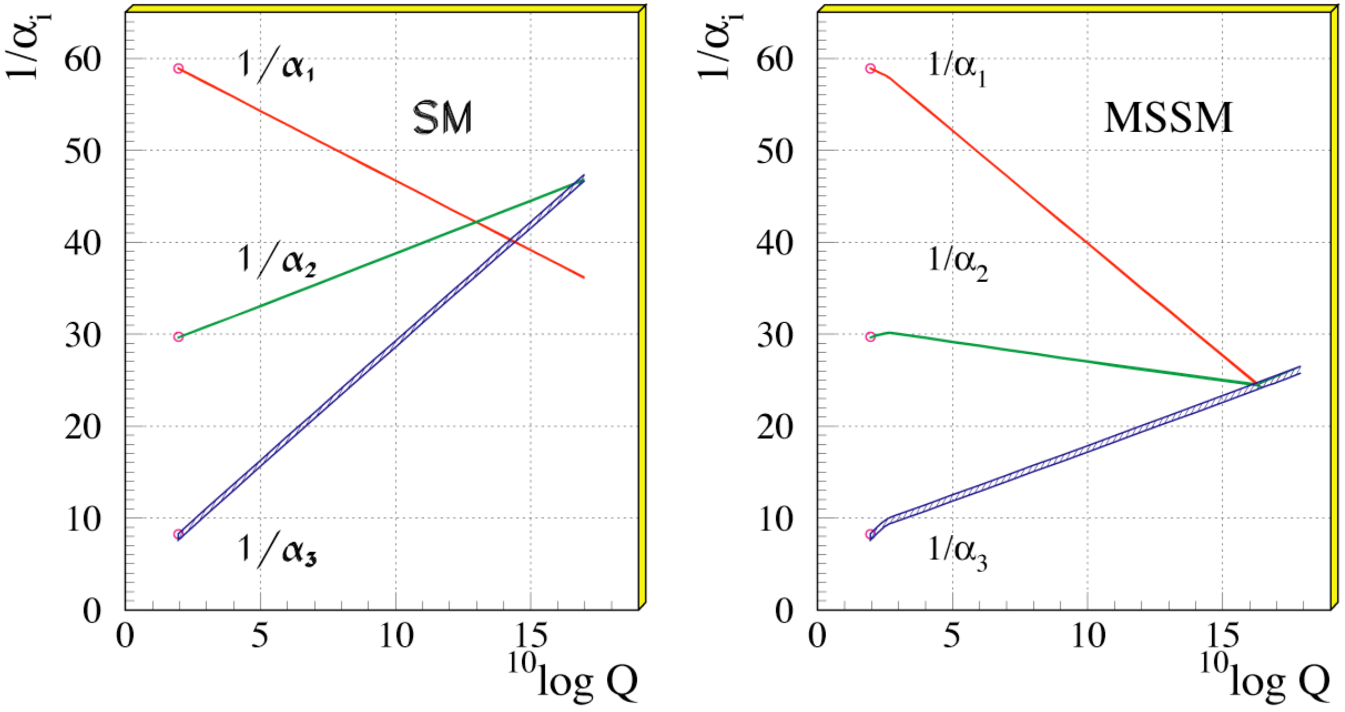
Selectrons
Sneutrinos

Photinos

Winos
Zinos
Higgsino

Indirect evidence of SUSY ?

U. Amaldi, W. de Boer, H.Fürstenau, Phys.Lett.B260(1991)447-455



SUSY particle production at LHC

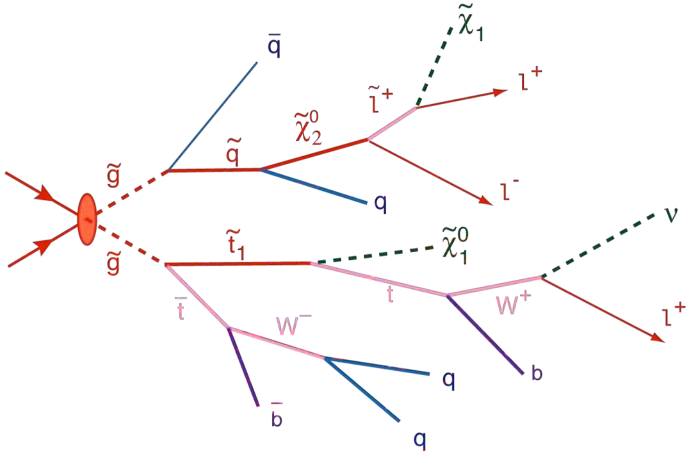
Large cross section via strong interaction

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

$\sigma \approx 3\text{pb for } m(\tilde{q},\tilde{g}) = 1\text{ TeV}$

$\Rightarrow\ 100\text{ events/day@}10^{33}\text{cm}^{-2}\text{s}^{-1}$

Easy discovery M~1TeV within 1 month ?



3 isolated leptons
+ 2 b-jets
+ 4 jets
+ E_t^{miss}

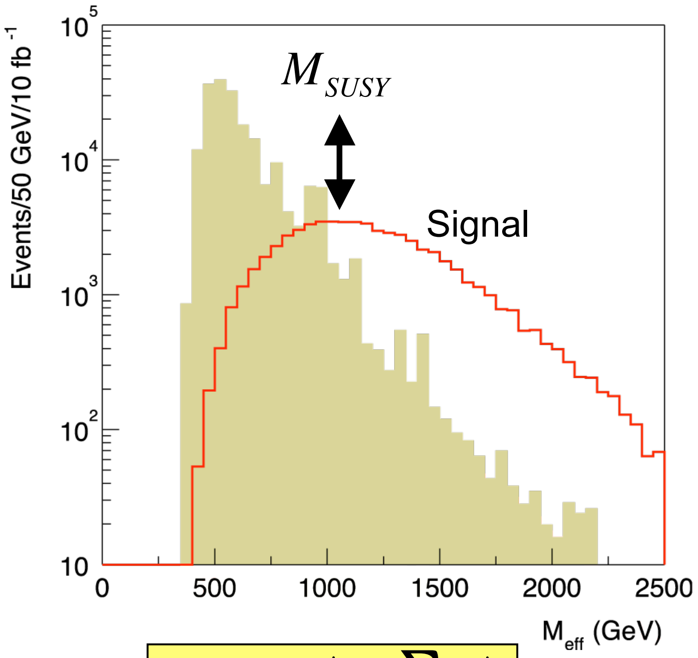
Missing E_T + high p_t jets + Leptons
(Model indep. Analysis, R-parity conserv.)

SUSY Scale

$$M_{SUSY} = min(m(\tilde{q}),m(\tilde{g}))$$

20% accuracy（L=10fb^{-1}, mSUGRA）

Missing E_T is important（calibrate with Z→*ll*+jets)

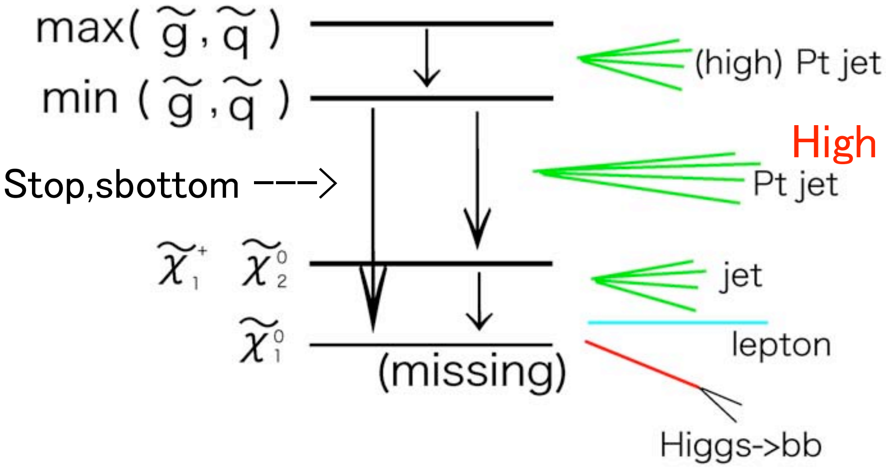


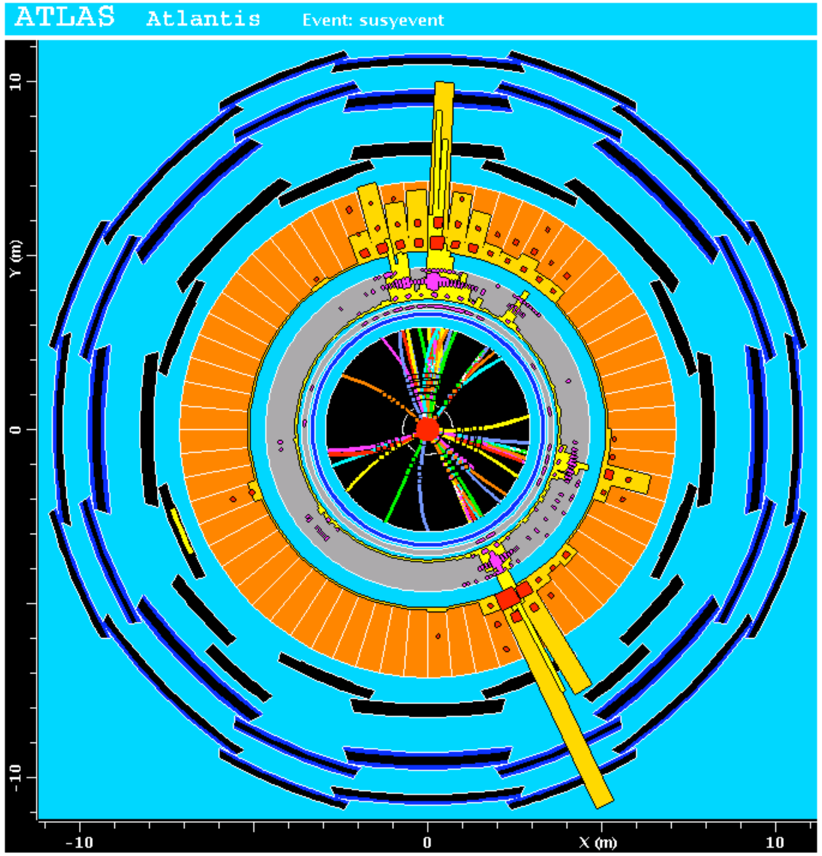
$$M_{eff} = E_T^{miss} + \sum p_T^{jet}$$

J.G. Branson *et al.*, Eur.Phys.J.direct **C4**(2002)N1

SUSY event topology (Gravity- mediation + R-parity)

Gluino/squark are produced copiously,
“Cascade decay” follows after.





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

(1) E_T^{miss} should be controlled in multi-jets topology (N>=4).

(2) High Pt multi-jets are important to estimate SM background contributions and SUSY reconstruction.

N.Kanaya (Kobe)

SUSY inclusive search

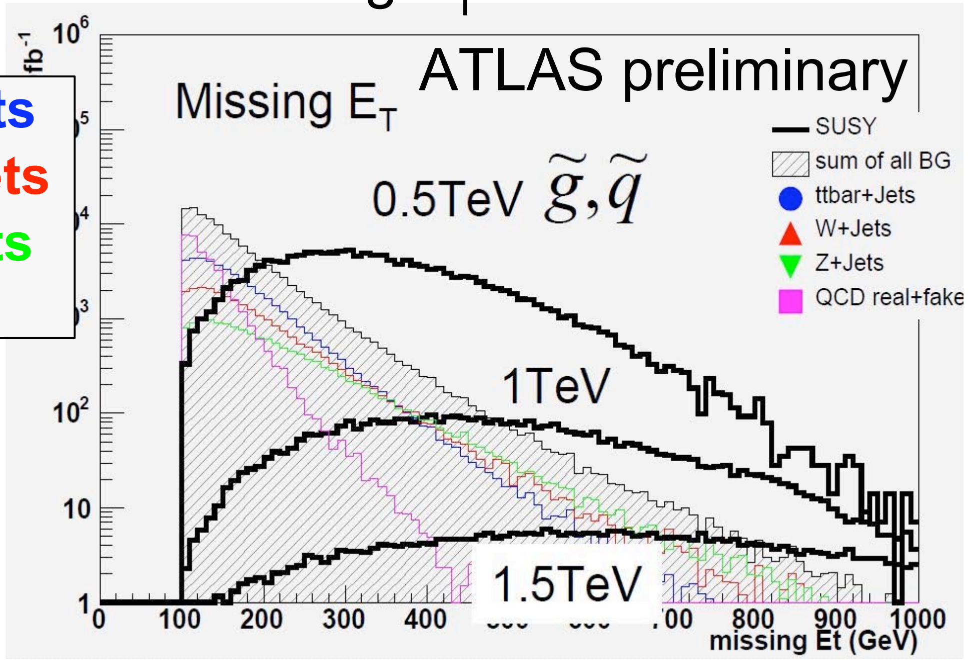
Missing E_T has excellent power
to distinguish signal from SM background.

SUSY standard cut

- Missing E_T > 100GeV
- p_T^{1st}>100GeV, p_T^{4th}>50GeV
- Transverse sphericity>0.2

tt+njets
W+njets
Z+njets
QCD

Missing E_T distribution

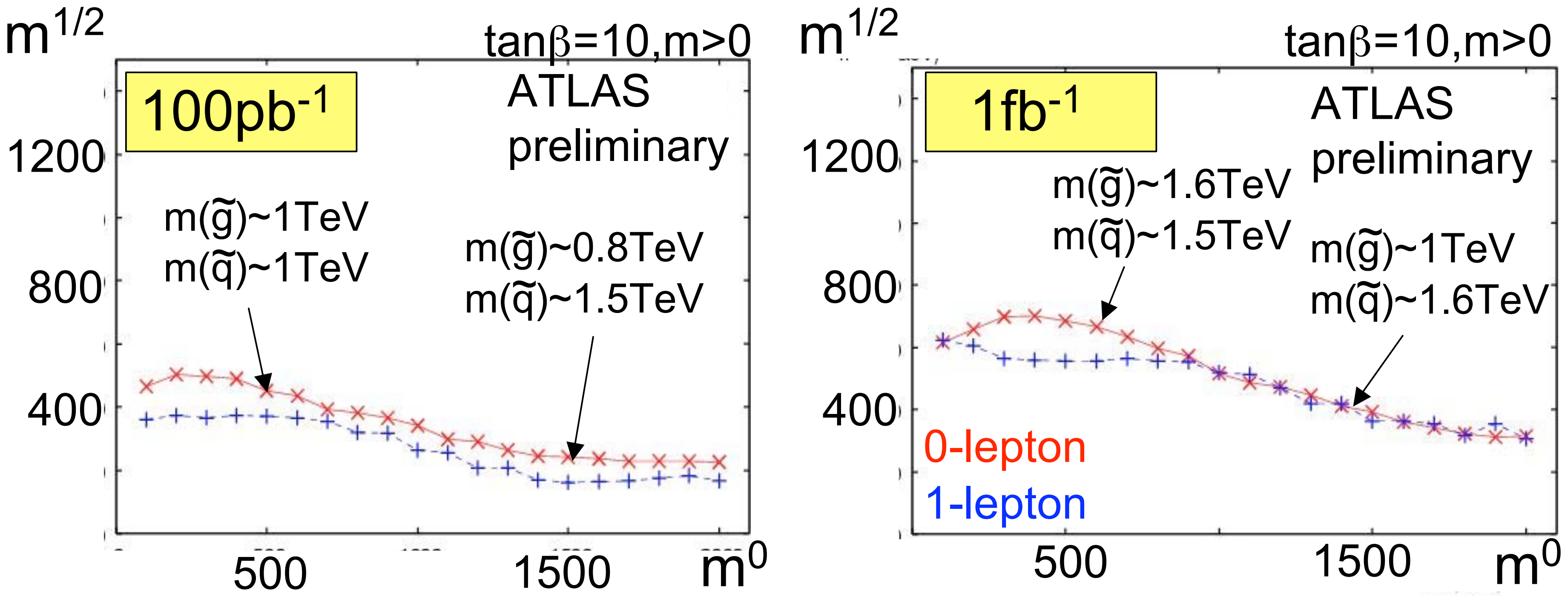


* background is generated by Alpgen MC.

Discovery Potential

N.Kanaya (Kobe)

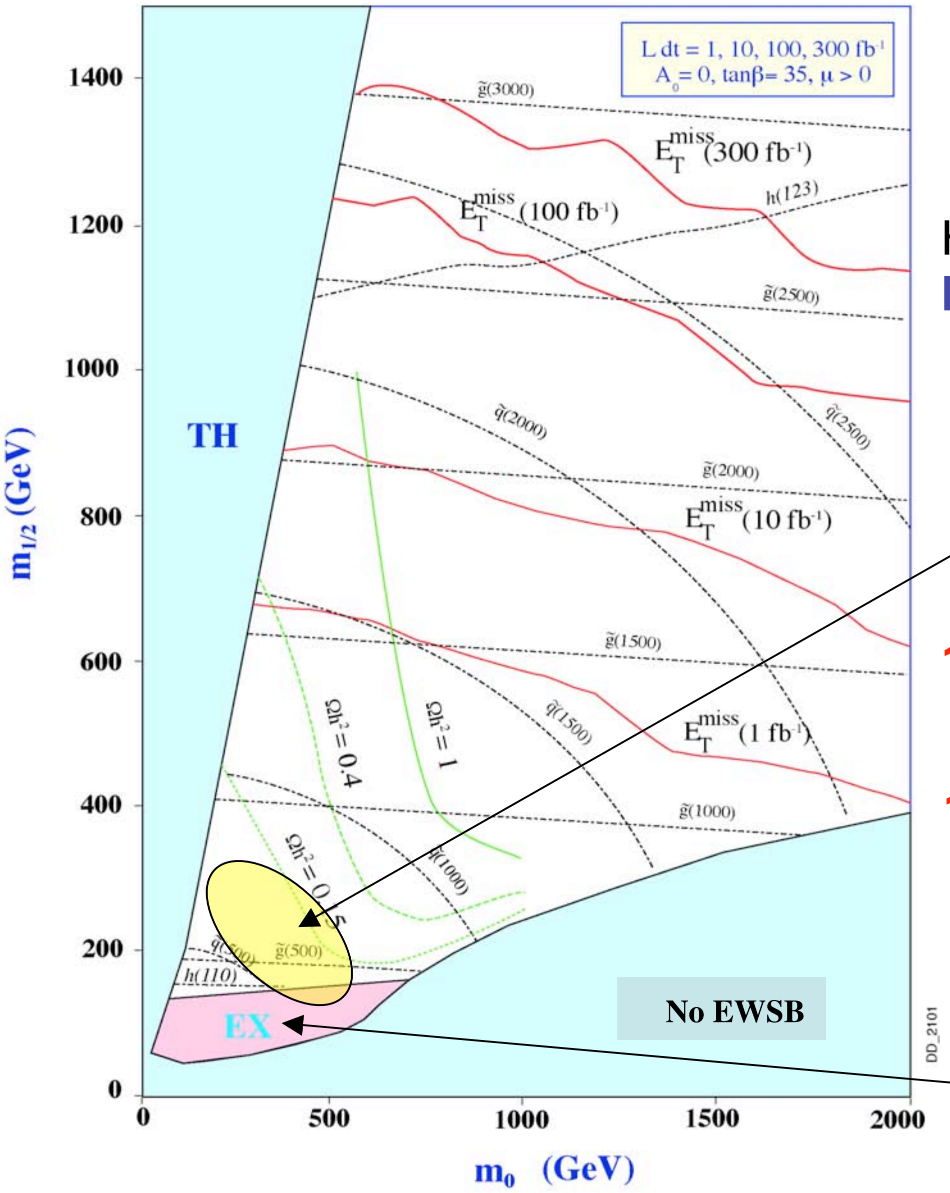
5-sigma discovery potential on m_0-$m_{1/2}$ plane



Fast simulation result
Signal : Isawig/Jimmy
Background : Alpgen

- Only statistical error is included.
- Backgound is estimated by Alpgen.
- 0-lepton mode : More statistics is available.
- 1-lepton mode : Relatively smaller background uncertainty.
  Major background is tt(+njets) is comparatively predictable.

mSUGRA discovery potential



High Lum. 3 year run (L=300fb^{-1})
M≤2.5TeV

Cold Dark Matter
1 week run is enough.

WMAP $0.0094<\Omega_m h^2<0.129$

1 year run (L=10fb^{-1}) **M≤2TeV**

1 month run (L=1fb^{-1})
$m(\tilde{q},\tilde{g})\sim$ **1.5TeV** 5σ discovery

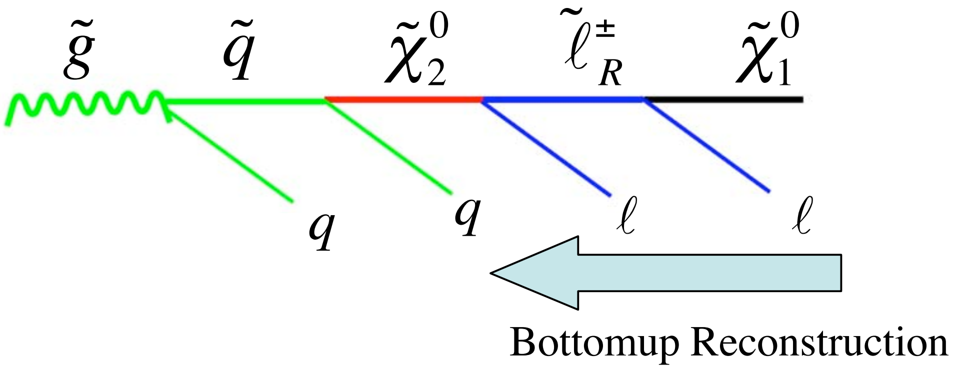
LEP & Tevatron region

Mass Reconstruction

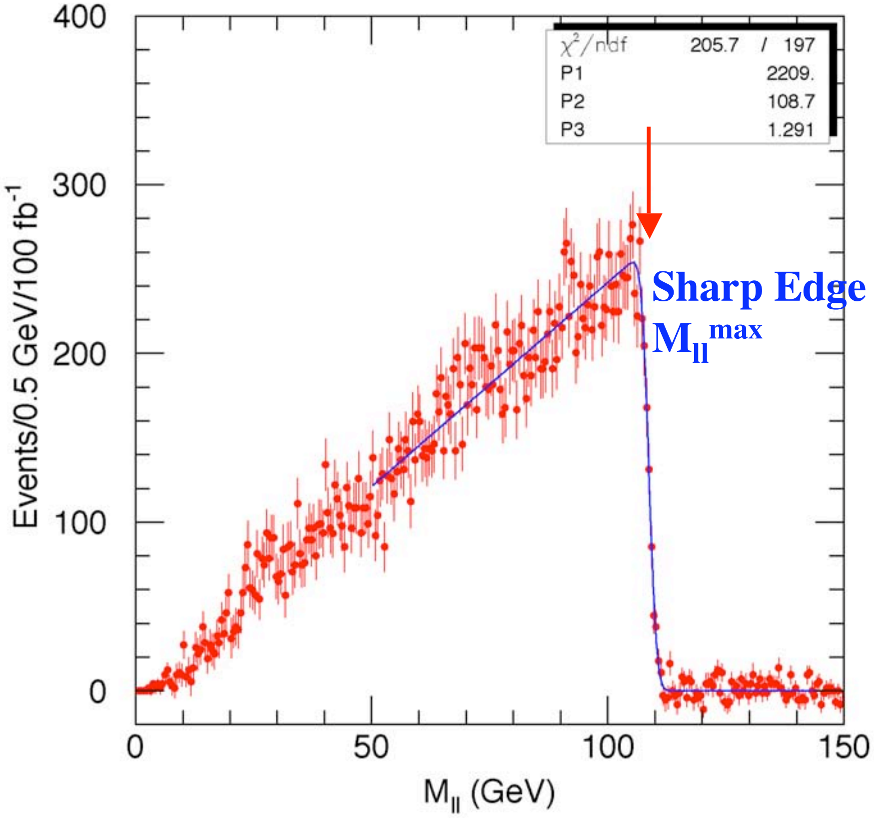
kinematical endpoint

B.C. Allanach *et al.*, JHEP 0009(2000)004

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



Bottomup Reconstruction



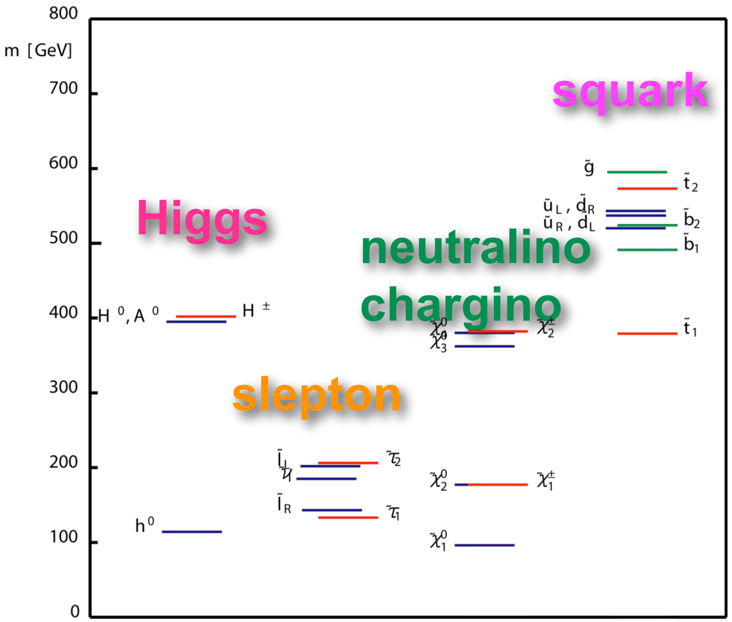
1. Generally under-constrained. Determine mass with help of models.
2. Can determine model independently if 2-body decay chain continues 3 times.
3. Large tan β means more cascade and τ, b.
4. Strong model dependence.
5. Mass uncertainty mostly from LSP's momentum.
6. Determination of spin or Br are difficult.

Supersymmetry vs Extra-Dimension

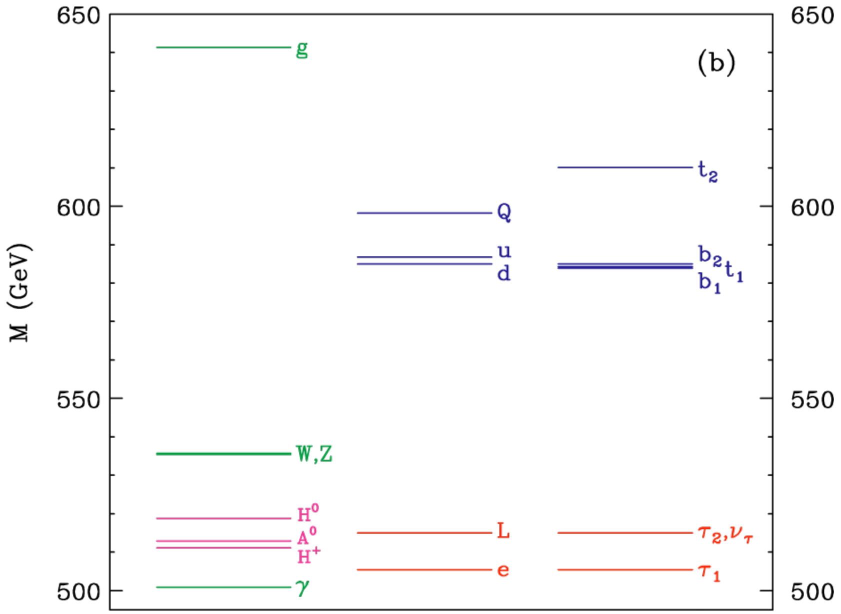
Typical mSUGRA scenario ⟷ Universal Extra-Dimension scenario

Use spin !

B.C.Allanach *et al.*, Eur.Phys.J.**C25**(2002)113



H-C.Cheng *et al.*,
Phys.Rev.**D66**(2002)036005, *ibid.* 056006

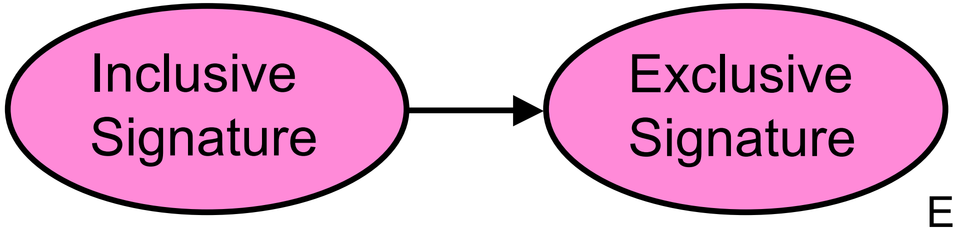


LHC - Higgs, squark/gluino

Testing the underlying theory … not trivial …

- Determination of SUSY model parametres

C.G. Lester, M.A. Parker, M.J. White, JHEP 0601(2006)080



Cross sections

M_{eff}

N_{lepton}

…

Markov chain sampling technique

Inclusive Signature → Exclusive Signature

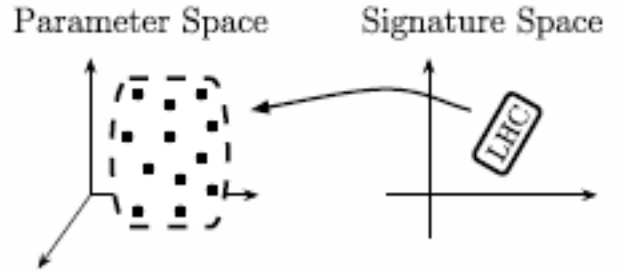
Kinematics

Endpoints(mass)

Easy for theory

- SUSY “inverse map” LHC signatures → theoretical models

N. Arkani-Hamed et al., hep-ph/0512190



15 dimensional parametrization

1808 LHC observables

4. Extra-dimension

- string theory requires 10 dimensions!
  - the only theoretical approach towards a quantum description of gravity: consistency of quantum mechanics and general relativity
  - includes supersymmetry
- the extra dimensions assumed to be compactified.
  - initially the assumption was that compactification radius was order of M_{PL}^{-1}
  - then it was realized that this could be as large as a millimeter !

3 models studied in some detail (there are more !):

1. ADD scenario
2. Randall-Sundrum (RS) model
3. Universal Extra Dimension (KK)

ADD

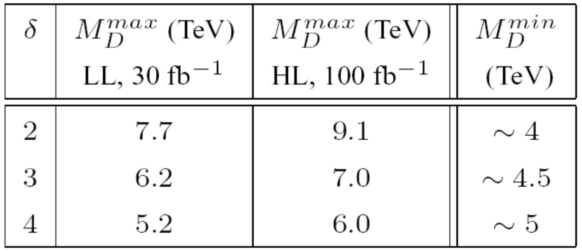
ADD

- Large flat compactified extra dimensions

⇒ conjecture:

- SM particles localized in 4D brane
- gravity propagates in the bulk of higher dimension

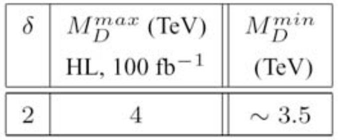
$$M^2_{Pl_{(4)}} = M^{\delta+2}_{Pl_{(4+\delta)}} R^\delta_C \equiv M^{\delta+2}_D R^\delta_C$$



δ	M_D^{max} (TeV) LL, 30 fb^{-1}	M_D^{max} (TeV) HL, 100 fb^{-1}	M_D^{min} (TeV)
2	7.7	9.1	~ 4
3	6.2	7.0	~ 4.5
4	5.2	6.0	~ 5

Uncertainty in σ(*Z+jets*) will lower the reach

Reach in M_D for γG



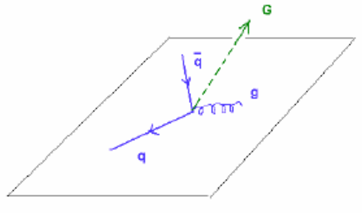
δ	M_D^{max} (TeV) HL, 100 fb^{-1}	M_D^{min} (TeV)
2	4	~ 3.5

Ex. Direct Graviton production at LHC

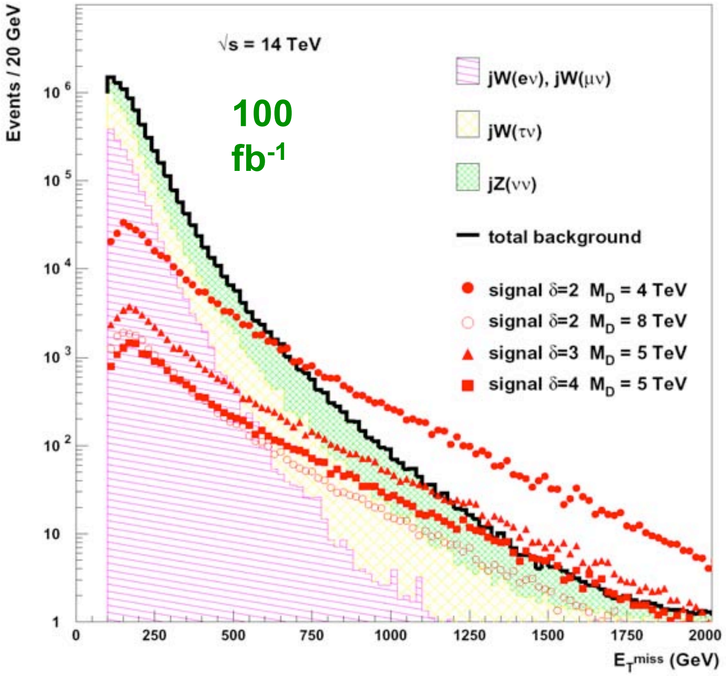
L. Vacavant, I. Hinchliffe, J.Phys.**G27**(2001)1839

Signals in ATLAS:

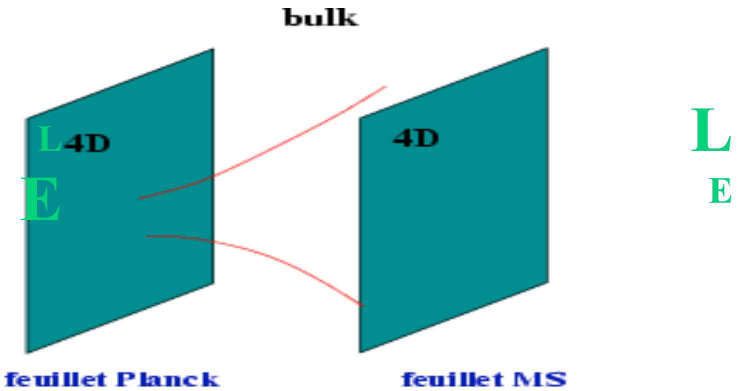
$$\left.\begin{array}{l} \bar{q}q \to gG^{(k)}, \gamma G^{(k)} \\ qg \to qG^{(k)} \\ gg \to gG^{(k)} \end{array}\right\} \text{jets} + \not{E}_T,\ \gamma + \not{E}_T$$



cf. SUSY → Multi-jets



Randall-Sundrum



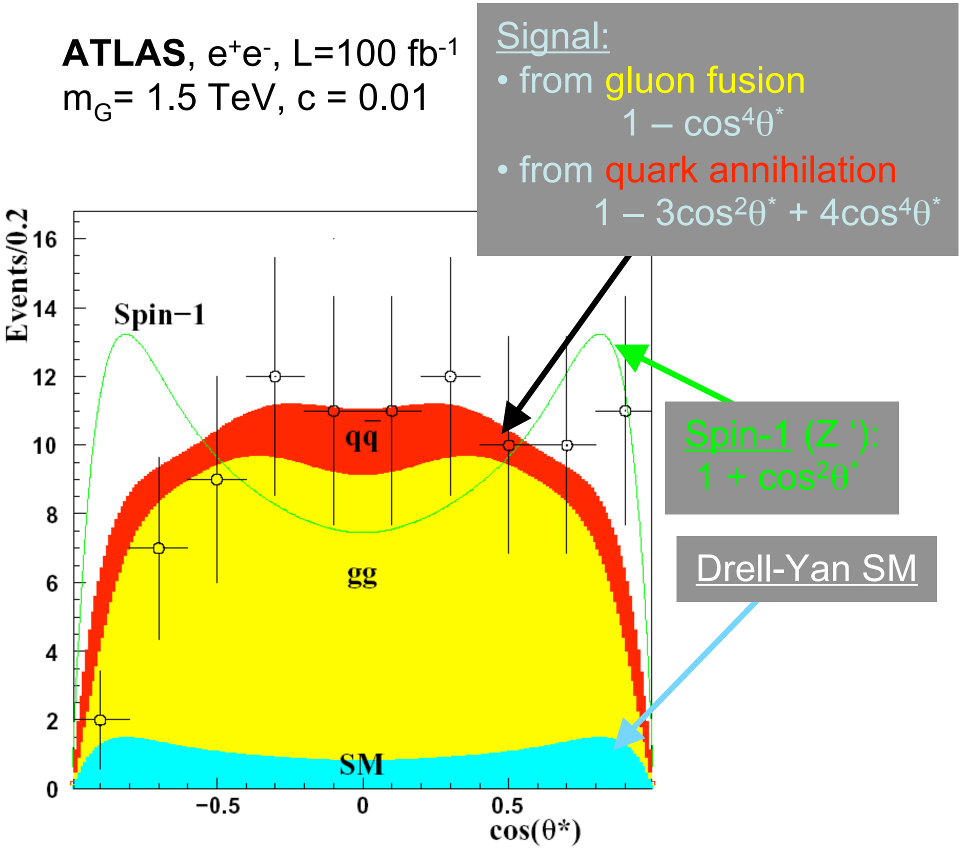
KK graviton excitations $G^{(k)}$

- scale Λ_π
- coupling & width determined by: $c = k/M_{Pl}$
- $0.01 < k/M_{Pl} < 0.1$
- mass spectrum: $m_n = k\, x_n \exp(-k\pi r_c)$

Golden channel: $G^{(1)} \rightarrow e^+e^-$

spin-2 could be determined (spin-1 ruled out) with 90% CL up to graviton mass of 1720 GeV.

ATLAS, e^+e^-, L=100 fb^{-1}
m_G= 1.5 TeV, c = 0.01



Signal:
- from gluon fusion $1 - \cos^4\theta^*$
- from quark annihilation $1 - 3\cos^2\theta^* + 4\cos^4\theta^*$

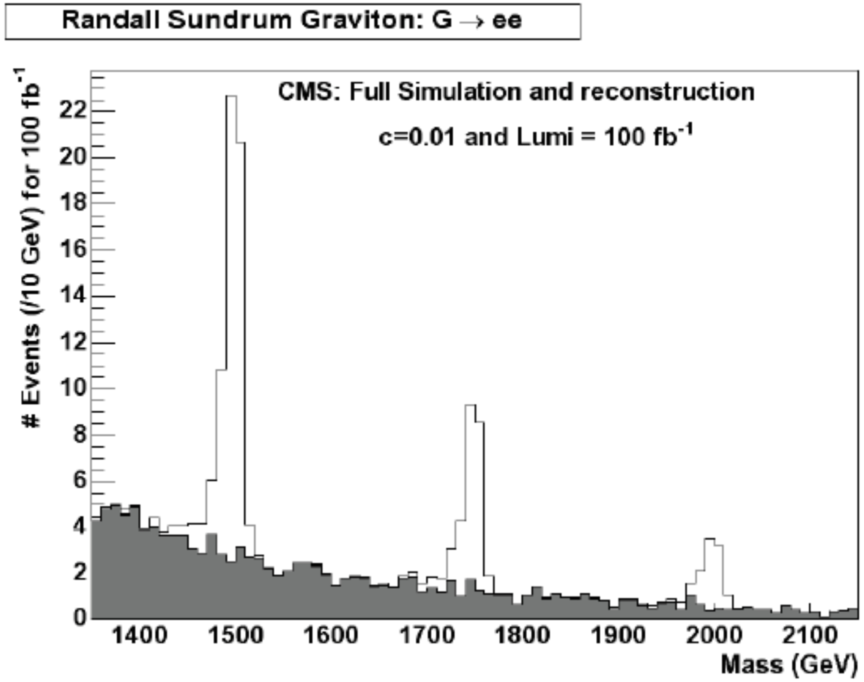
Spin-1 (Z '): $1 + \cos^2\theta^*$

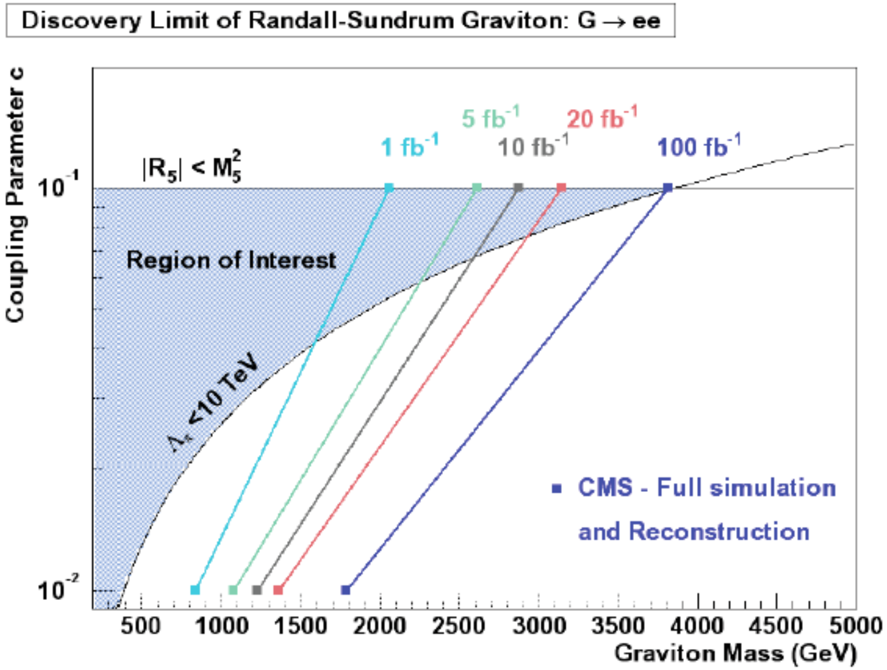
Drell-Yan SM

B.C. Allanach, *et al.*, JHEP**09**(2000)019, *ibid.*​**12**(2002)039

CMS full simulation study

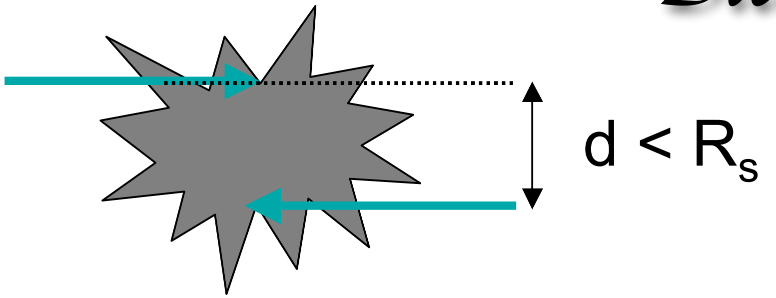
C. Collard and M.C. Lemaire
Eur.Phys.J.C40N5 (2005) 15-21





Black Hole

J.Tanaka et al. Eur.Phys.J.C41(2005) 19-33
C.M.Harris et al. JHEP 0505(2005) 053



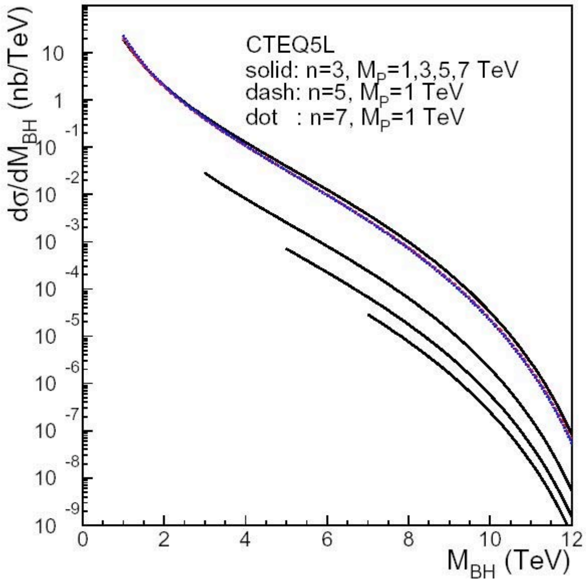
Gravity Scale ~ TeV
Parton collision at d < Schwarzschild radius R_s
→ Black Hole formation
Very large cross section

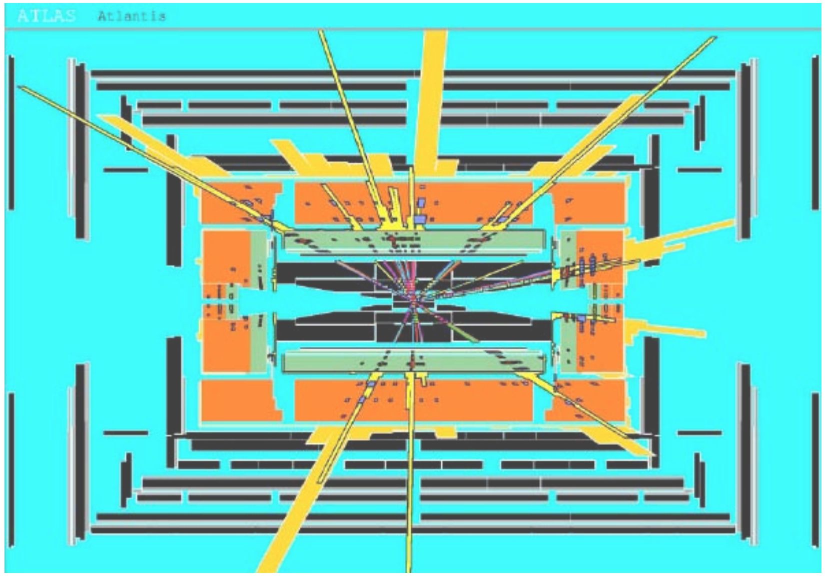
$$R_S = \frac{1}{\sqrt{\pi} M_P}\left[\frac{M_{BH}}{M_P}\left(\frac{8\Gamma(\frac{n+3}{2})}{n+2}\right)\right]^{\frac{1}{1+n}}$$

Parton invariant mass M_{BH}(Black Hole mass)

main phase ? Black body radiation
= Hawking radiation or evaporation
+ ‘Grey-body’ effects (Herwig)
+ Time variation of Hawking temperature
emission of particles

- high multiplicity (a lot of jets)
- “democratic” emission
- spherical distribution



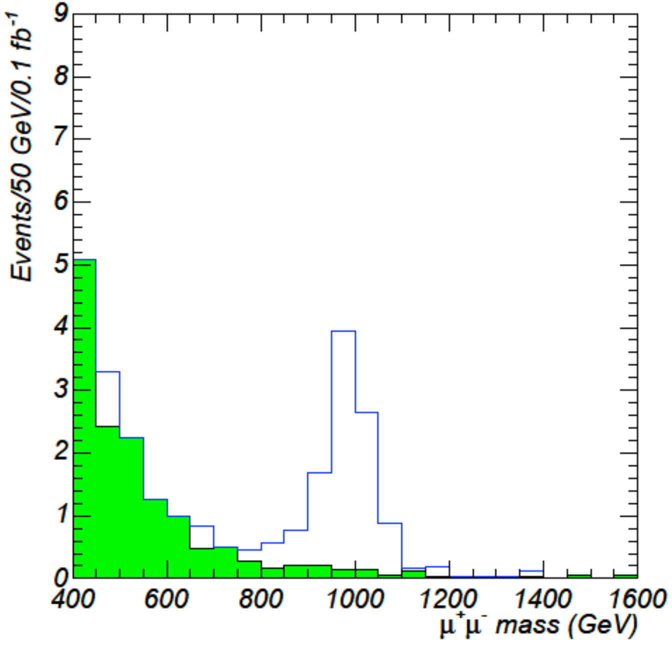


Drell-Yan di-leptons

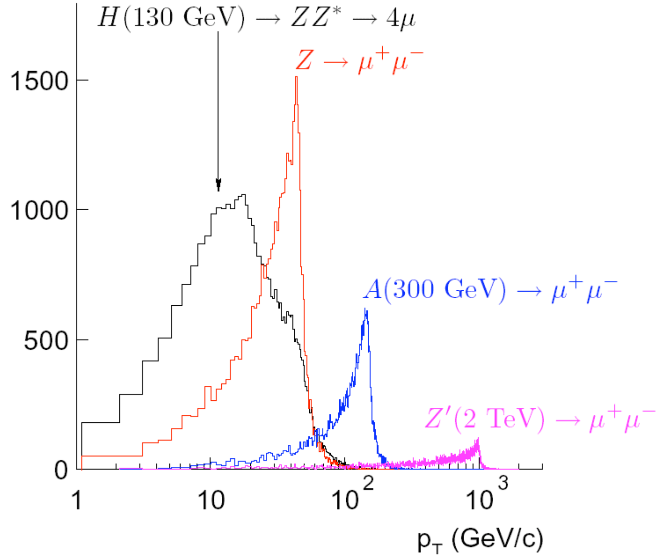
Model independent study

- New gauge bosons: Z’
- Little Higgs: A_H, Z_H
- Large Extra-Dimension(ADD): $G^{(KK)}$
- Randall-Sundrum: $G^{(K)}$
- …

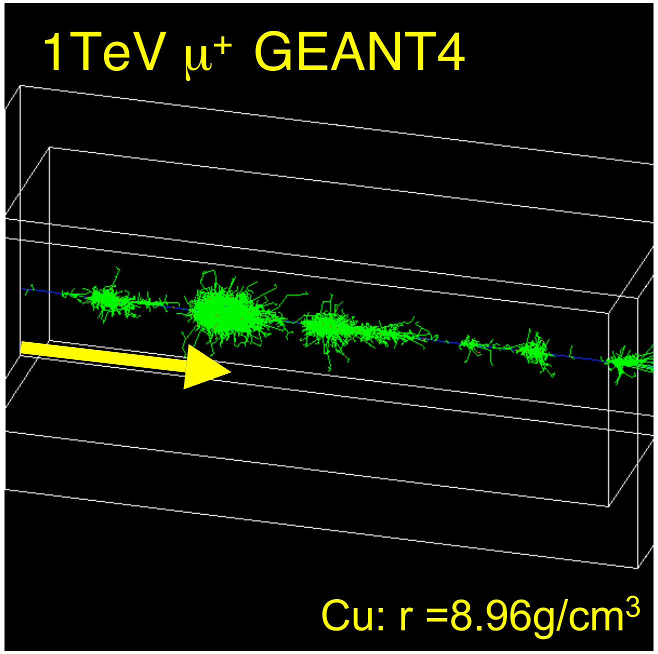
CMS Note 2005/02

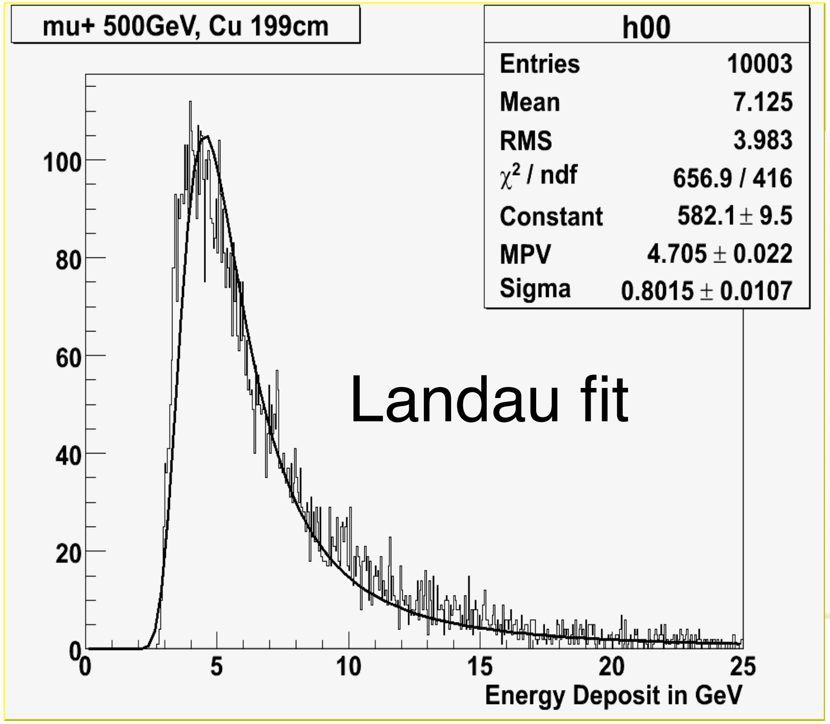


TeV Muons are radiative !



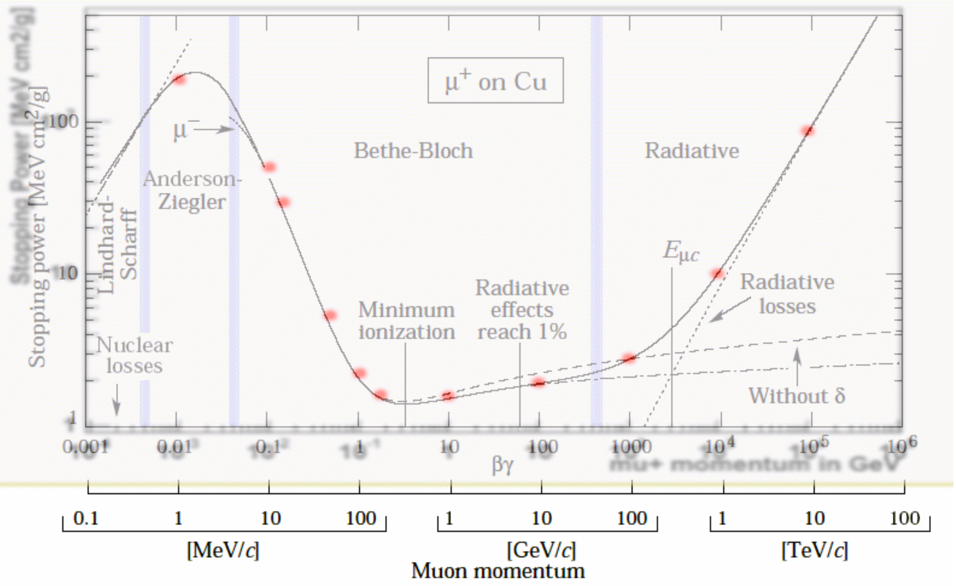
D. Naito
(Okayama)





PDG

D. E. Groom et al., Atomic Data and Nuclear Data Table **78**,183-356(2001)



Detector Commissioning and Physics

Commissioning (2006-2007)

Cosmic Muons, Beam-Halo Muons, Beam-Gas Events

→ initial detector alignment and calibration.

Pilot Run @ 0.9TeV (Nov.-Dec. 2007)

Minimum Bias Events, Di-jet events, Pile-up Events

→ modeling underlying event, jet calibration.

First Physics Runs @ 14TeV (2008~)

- First “good” $10pb^{-1}$ data
  - 20k $W \to l+\nu$, 2.5k $Z \to l+l$, 200 semi-leptonic top-pair
- First “good” $100pb^{-1}$ data
  - W(Z)+jets for jet calibration, missing E_T for SUSY
- From $100pb^{-1}$ to $1fb^{-1}$ data
  - Standard Model process study: top, W/Z, QCD, b-jet
  - Extensive MC tuning

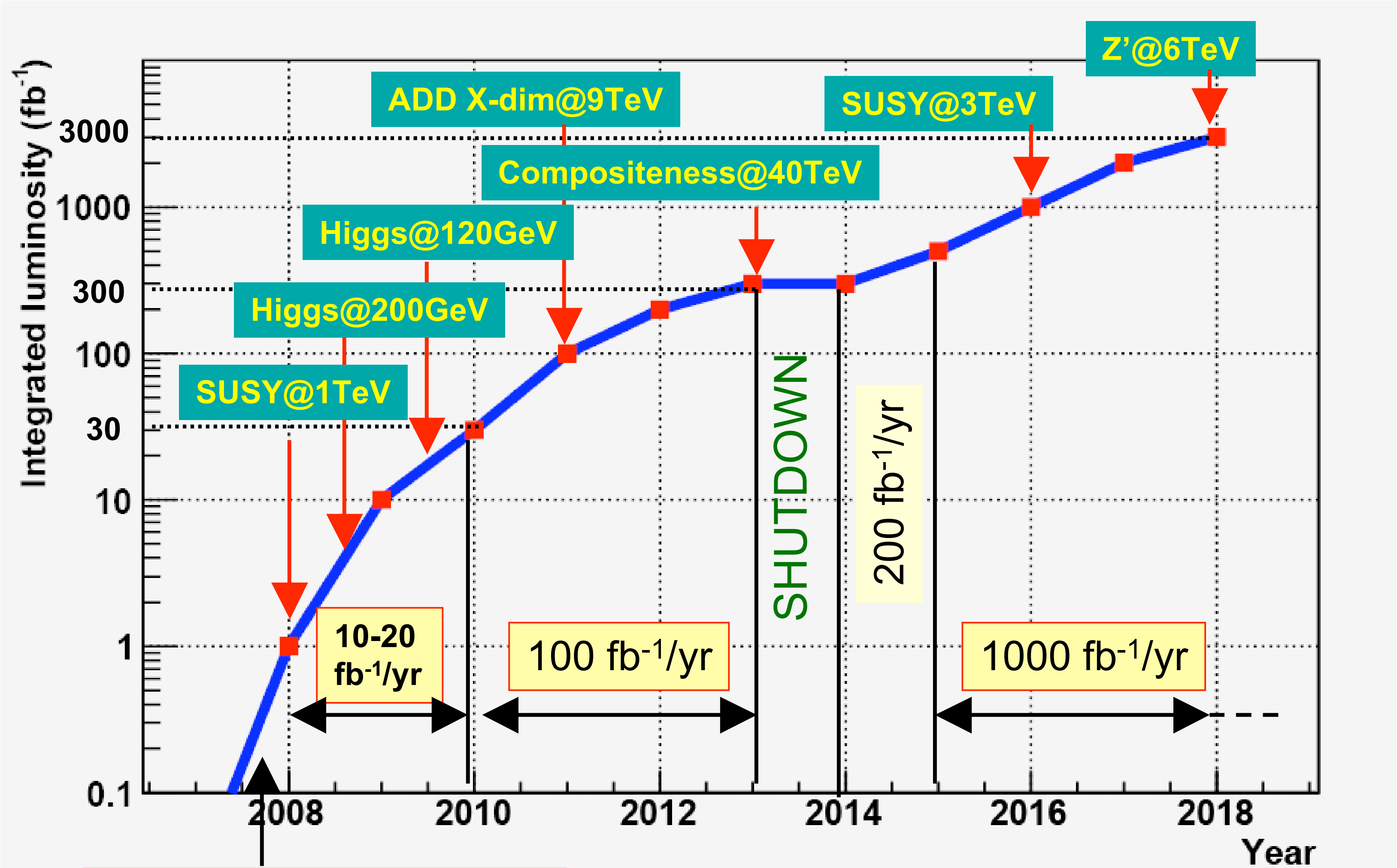
→ early Higgs boson search ($H \to \gamma\gamma$, WW, ZZ).

→ early SUSY-BSM search, missing E_T, di-jet, di-leptons…

LHC Luminosity Profile

Michel Della Negra

$L = 2\times10^{33}$ $L = 10^{34}$ SLHC: $L = 10^{35}$ $(cm^{-2}s^{-1})$



First physics run: $O(1fb^{-1})$

5. Summary

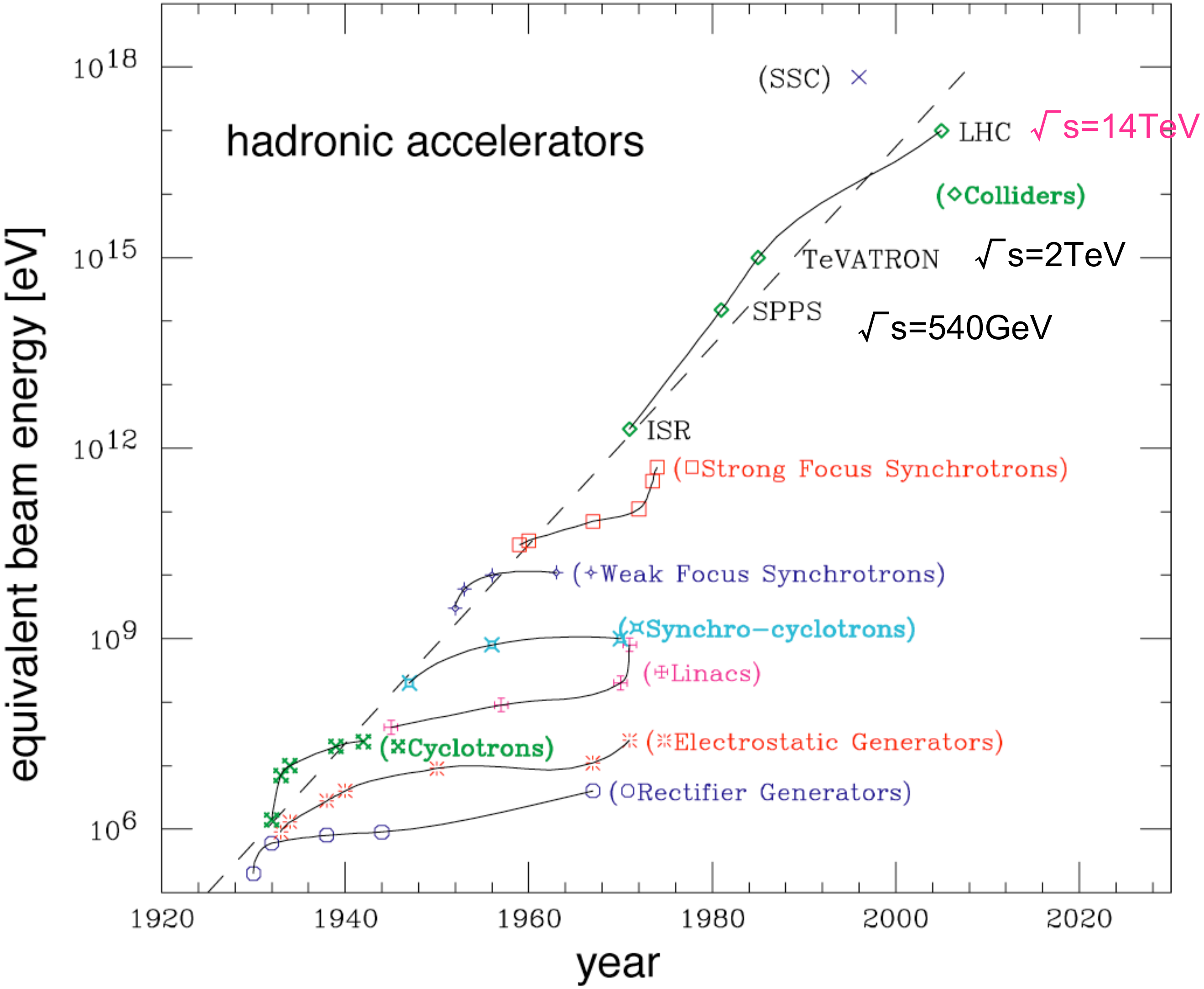
- Discovery first !
- LHC is capable to find new particles (SUSY, ED, Z' etc.) up to 2-3 TeV (up to ~10TeV with interference effect).
- Model discrimination / parametre determination under study.
- Experimental issues: commissioning/calibration
- Needs to understand SM bkg from data and tuned MC.
- Tools: t, b, W/Z and even Higgs!

- We do hope major breakthrough in HEP (SUSY, ED etc.)
- Important decision in 2010 about HEP's future…

backup

History of hadron collider

Livingston plot



LHC Upgrades

CERN Council Strategy Group Open Symposium 2006
January 30 - February 1, 2006 (*LAL - Orsay, France*)
http://events.lal.in2p3.fr/conferences/Symposium06/

Luminosity Upgrade (SLHC)

towards
$L=10^{35} cm^{-2}s^{-1}$

Physics

20-30% increase
in discovery potential
Better stat. precsion

P.Raimondi

parameter	symbol	nominal	ultimate	shorter bunch	longer bunch
no of bunches	n_b	2808	2808	5616	936
proton per bunch	N_b $[10^{11}]$	1.15	1.7	1.7	6.0
bunch spacing	Δt_{sep}[ns]	25	25	12.5	75
average current	I [A]	0.58	0.86	1.72	1.0
normalized emittance	ε_n [µm]	3.75	3.75	3.75	3.75
longit. profile		Gaussian	Gaussian	Gaussian	flat
rms bunch length	σ_z [cm]	7.55	7.55	3.78	14.4
ß* at IP1&IP5	ß* [m]	0.55	0.50	0.25	0.25
full crossing angle	θ_c [µrad]	285	315	445	430
Piwinski parameter	$\theta_c \sigma_z/(2\sigma^*)$	0.64	0.75	0.75	2.8
peak luminosity	L $[10^{34} cm^{-2} s^{-1}]$	1.0	2.3	9.2	8.9
events per crossing		19	44	88	510
luminous region length	σ_{lum} [mm]	44.9	42.8	21.8	36.2

LHC Luminosity Upgrade: tentative milestones

accelerator	WorkPackage	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	after 2015
LHC Main Ring	Accelerator Physics	🟥	🟥	🟨	🟨	🟩	🟩	🟩	🟩	🟩		
	High Field Superconductors	🟥	🟥	🟨	🟨	🟨	🟩	🟩	🟩			
	High Field Magnets		🟥	🟥	🟥	🟨	🟨	🟩	🟩	🟩	🟦	
	Magnetic Measurements			🟥	🟥	🟨	🟨	🟩	🟩	🟩	🟦	
	Cryostats					🟥	🟨	🟨	🟩	🟩	🟦	
	Cryogenics: IR magnets & RF		🟥	🟥	🟥	🟨	🟨	🟩	🟩	🟩	🟦	
	RF and feedback	🟥	🟨	🟥	🟥	🟨	🟨	🟩	🟩	🟩	🟦	
	Collimation & Machine Protection	🟥	🟨	🟨	🟩	🟦	🟥	🟥	🟥	🟥		
	Beam Instrumentation	🟥	🟥	🟥	🟥	🟥	🟨	🟨	🟩	🟩	🟦	
	Power converters					🟥	🟨	🟨	🟩	🟩	🟦	
SPS	SPS kickers			🟥	🟥	🟥	🟨	🟨	🟩	🟦		
	Tentative Milestones	Beam-beam compensation test at RHIC	SPS crystal collimation test	LHC collimation tests	LHC collimation tests	Install phase 2 collimation	LHC tests: collimation & beam-beam			Install new SPS kickers	new IR magnets and RF system	
	Other Tentative Milestones	Crab cavity test at KEKB	Low-noise crab cavity test at RHIC	**LHC Upgrade Conceptual Design Report**		LHC Upgrade Technical Design Report	Nominal LHC luminosity 10^34			Ultimate LHC luminosity 2.3x10^34	beam-beam compensation	Double ultimate LHC luminosity 4.6x10^34

LHC Upgrade Reference Design Report

R&D - scenarios & models	🟥
specifications & prototypes	🟨
construction & testing	🟩
installation & commissioning	🟦

Reference LHC Upgrade scenario: peak luminosity 4.6x10^34/(cm^2 sec)

Integrated luminosity 3 x nominal ~ 200/(fb*year) assuming 10 h turnaround time

new superconducting IR magnets for beta*=0.25 m

phase 2 collimation and new SPS kickers needed to attain ultimate LHC beam intensity of 0.86 A

beam-beam compensation may be necessary to attain or exceed ultimate performance

new superconducting RF system: for bunch shortening or Crab cavities

hardware for nominal LHC performance (cryogenics, dilution kickers, etc) not considered as LHC upgrade

R&D for further luminosity upgrade (intensity beyond ultimate) is recommended: see Injectors Upgrade

LHC Energy Upgrade (DLHC)

- E_b=7 TeV → 14 TeV
- Physics Motivation Eur.Phys.J **C39** (2005) 293-333
  - Higgs self-coupling ~$\lambda\nu$ determination with 20-30% accuracy

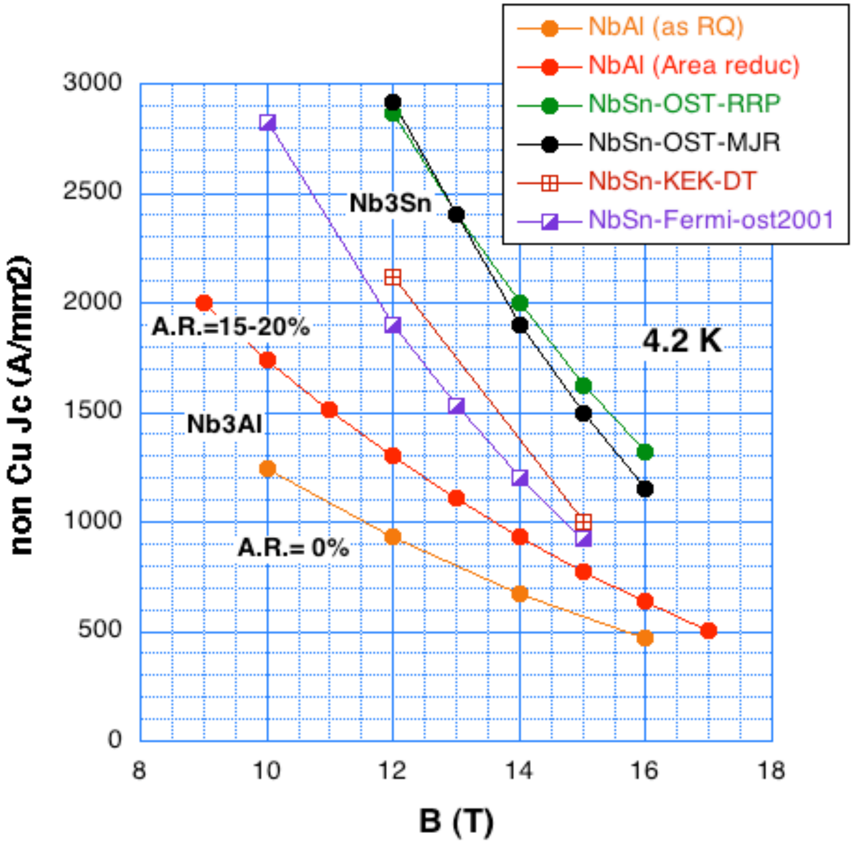
unprecedented dipole field

> 17 Tesla

- Conductor options;

  NbTi, Nb_3Sn, Nb_3Al(KEK)

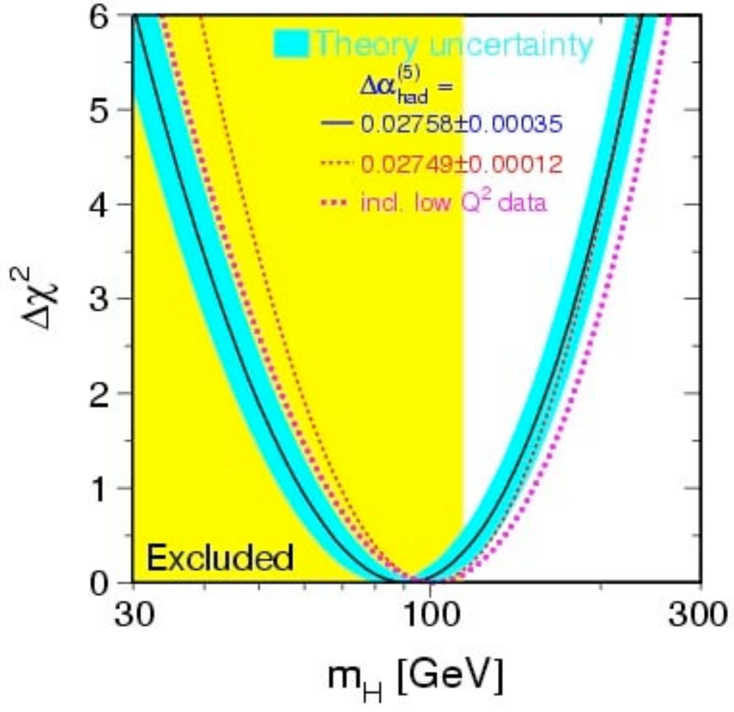
←15-20 year program ?



3. Higgs

Precision measurements at LHC

LEP EW working group, Summer 2005



$$M_H = 91 \pm {}^{45}_{32}\ \text{GeV}\ \ (M_H < 186\ \text{GeV@95\%C.L.})$$

Top quark mass ΔM_{top}

Tevatron RUN-I	Tevatron RUN-II	LHC
178.0±4.3GeV	1.3 GeV	1 GeV

W boson mass ΔM_W

Tevatron + LEP	Tevatron RUN-II	LHC
80.410±0.032GeV	17 MeV	10 MeV

$$M_W \leftarrow M_T^2 = 2 p_T^l p_T^\nu (1 - \cos\Delta\phi)$$

↑ Very challenging !

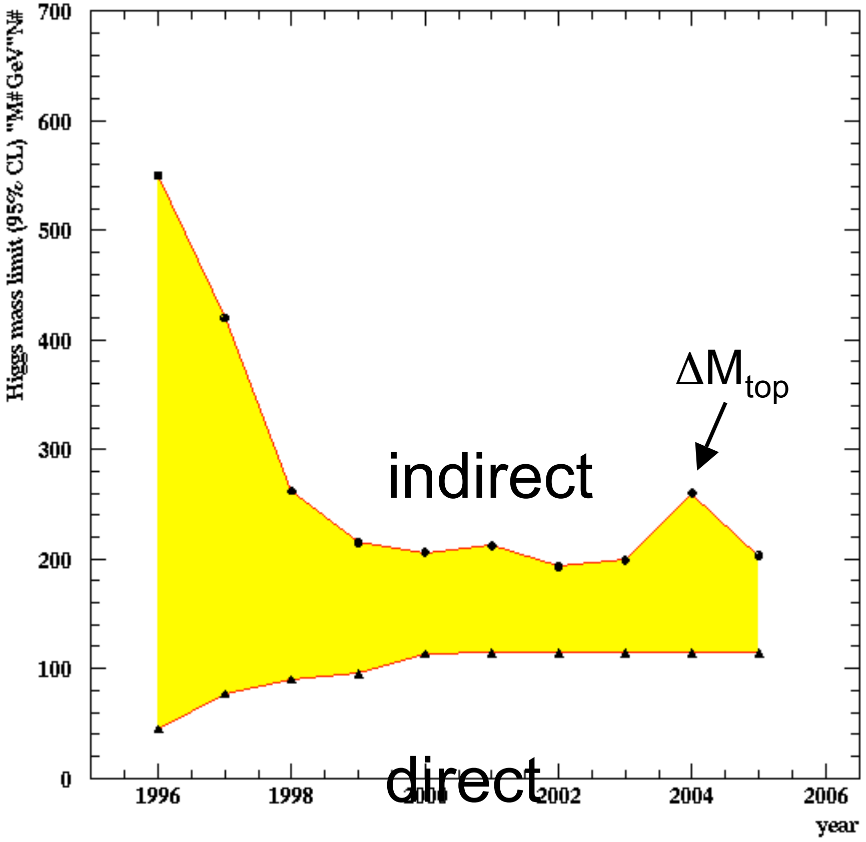
Magnetic filed or momentum resolution

ΔB/B(or Δp/p) < 0.02%,

Tracker Material known to < 1% etc.

Limit on the Higgs mass

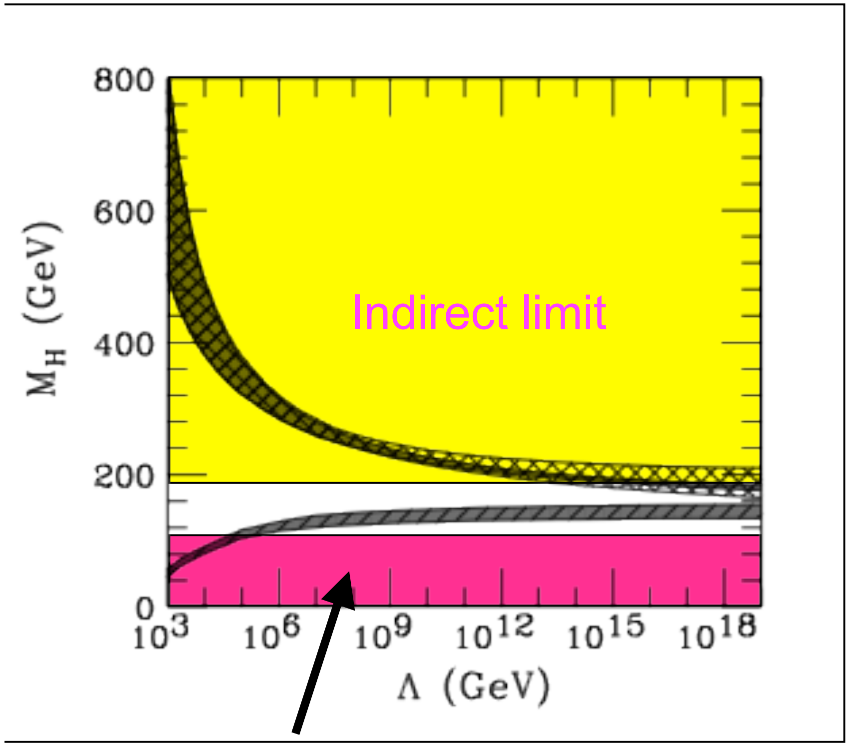
$$V(H) = -\mu_H^2 \, |H|^2 + \lambda \, |H|^4$$



ΔM_{top}

indirect

direct

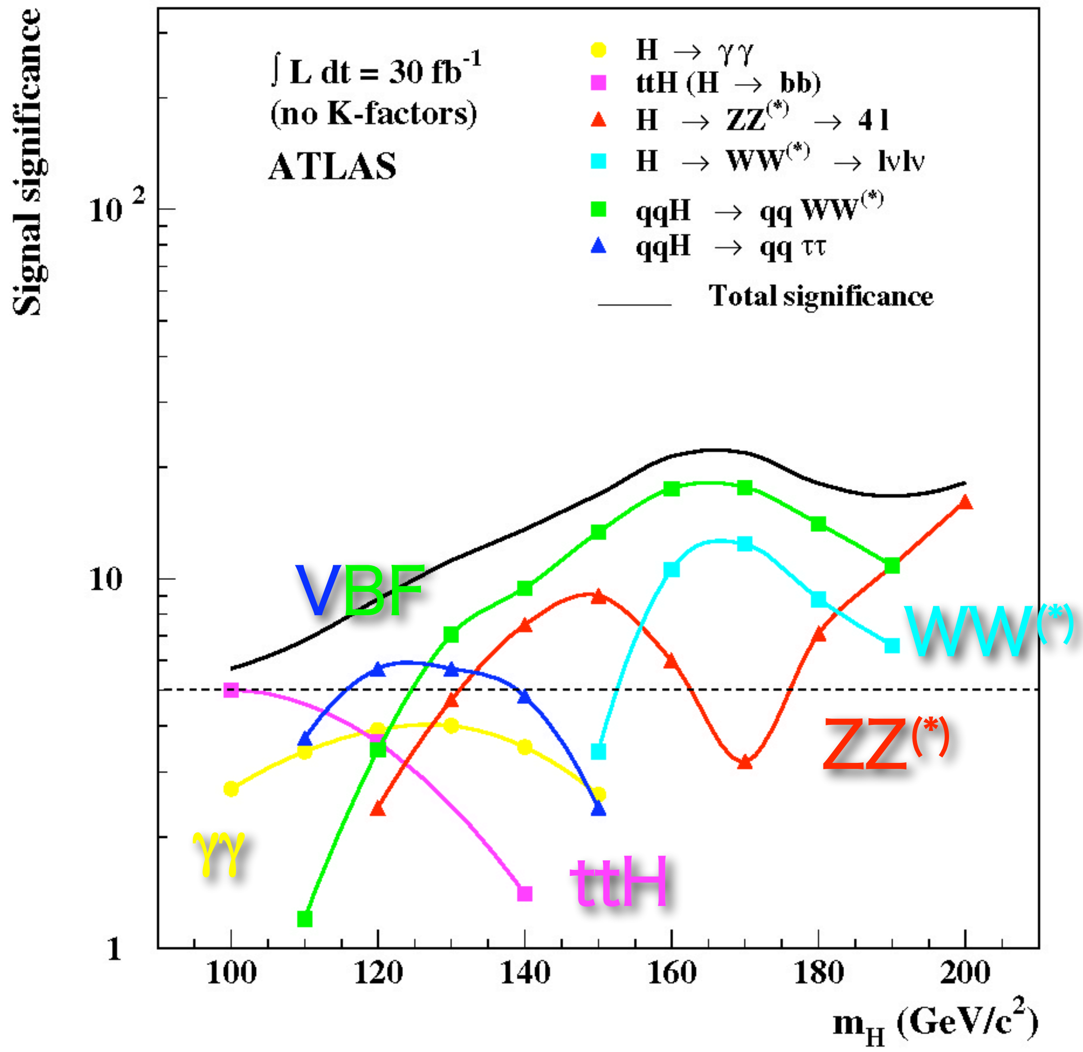


Indirect limit

LEP direct limit

SM Higgs discovery potential

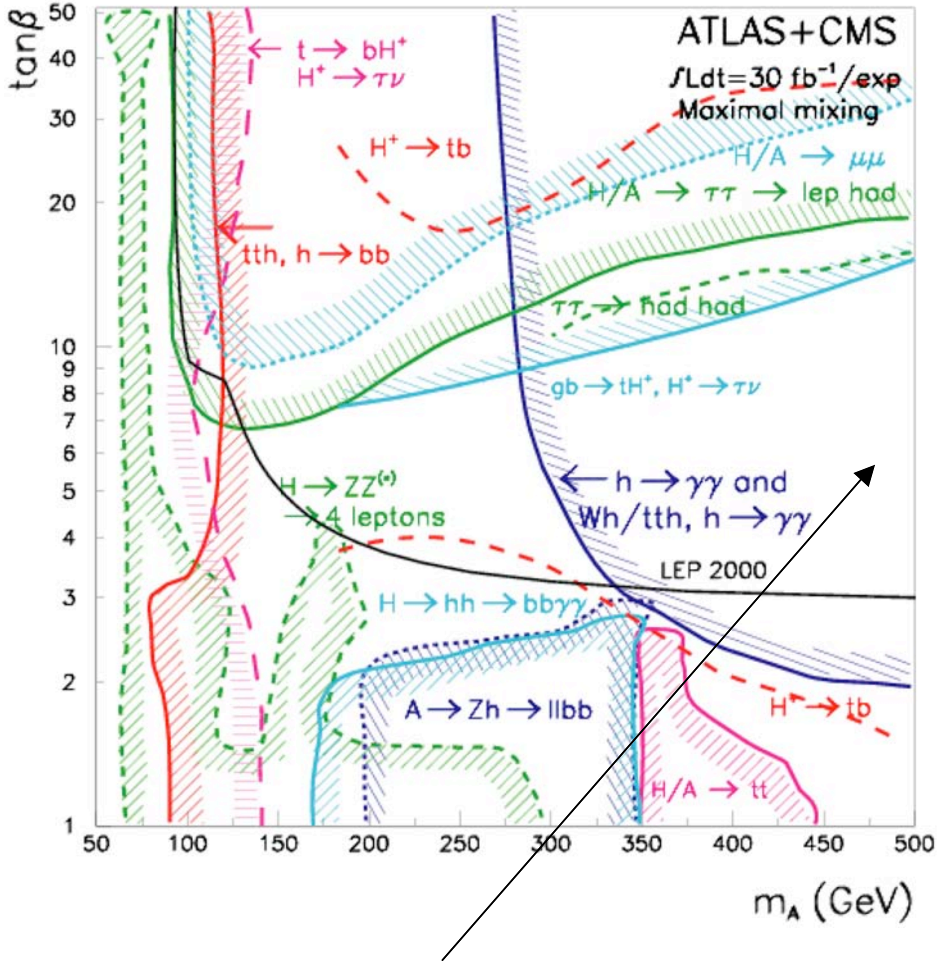
$L=30\text{fb}^{-1}$ >8σ significance
(M_H>114GeV:LEP limit)


S.Asai *et al.*, Eur.Phys.J.direct C32 Suppl. 2 (2004) 19

- Light Higgs VBF・H→ττ
- Heavy Higgs VBF・H→WW
- Multiple discovery modes for M_H<200GeV
- M_H>200GeV
  H→ZZ→4 lepton
  (gold plated) >20σ

$L=10\text{fb}^{-1}$ > 5σ
(99.994%)
→ Discovery after
1year LHC RUN

MSSM Higgs discovery potential



5 Higgs bosons h,H,A,$H^\pm$

Descrive m_A and tanβ at tree level.

Larege bbH/A coupling at large tanβ
H/A→ττ, μμ, bb

μμ channel is important at the beginning of LHC
∵ Commissioning μμ＜ττ＜＜bb

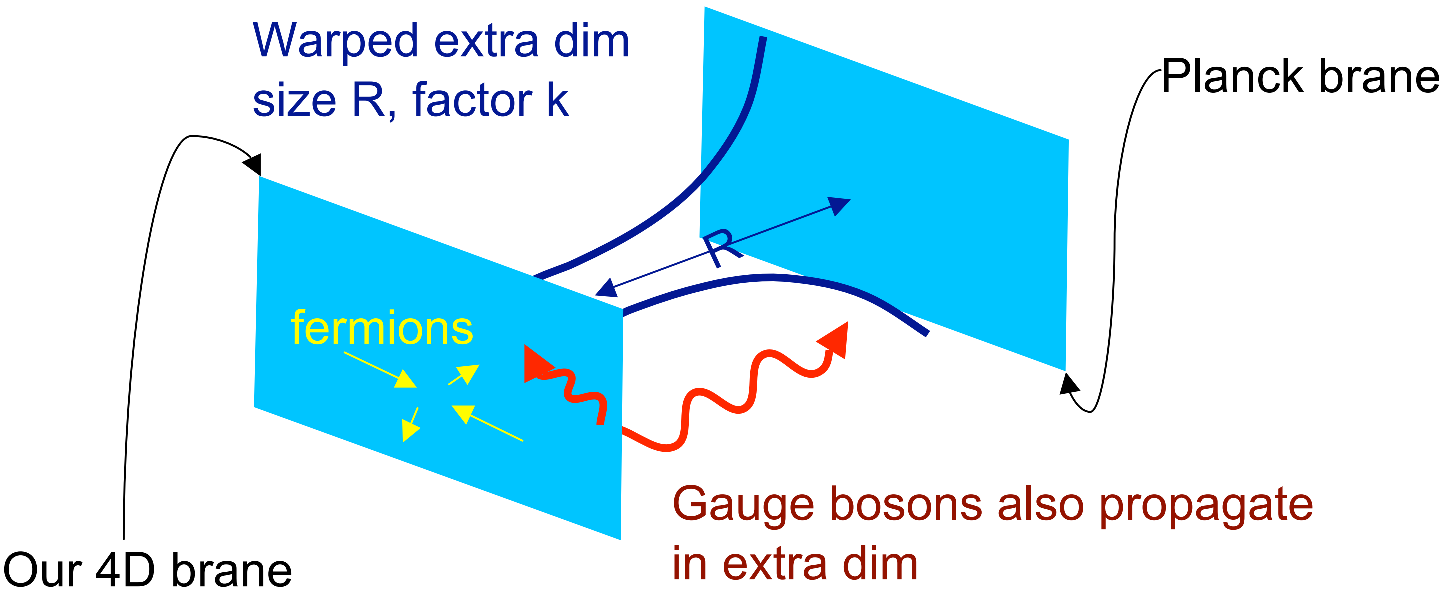
Can observe charged Higgs
via gb→tH^- at tanβ>10

Observe only h similar to H_{SM}.

Cover whole (m_A, tanβ) plane
for MSSM Higgs
with L=30fb^{-1} data

Higgsless Model

C. Csáki *et al.*,
Phys.Rev.**D69**(2004)055006,
Phys.Rev.Lett.**92**(2004)101802



- Gauge group in 5D : $SU(2)_L \times SU(2)_R \times U(1)$
- Different boundaries conditions on branes break SU(2)×U(1) to U(1) : No Higgs needed.
- Z and Z' are KK excitations of the neutral gauge field.
- but strong constraints from EW precision data …

Collider phenomenology:
H. Davoudiasl *et al.*,Phys.Rev.**D70**(2004)015006
T.G. Rizzo, hep-ph/0405094

Little Higgs

Higgs is a pseudo-Goldstone boson from global symmetry breaking.

Higgs acquires a mass radiatively
at the EW scale v.
→ quadratic divergences absent
at one-loop level.
Goldstone bosons
→

Heavy Gauge Bosons

$W^{\pm}_H, Z_H, \gamma_H \sim 1$ TeV

Heavy Top quark

$T \sim 1$ TeV

Triplet Higgs

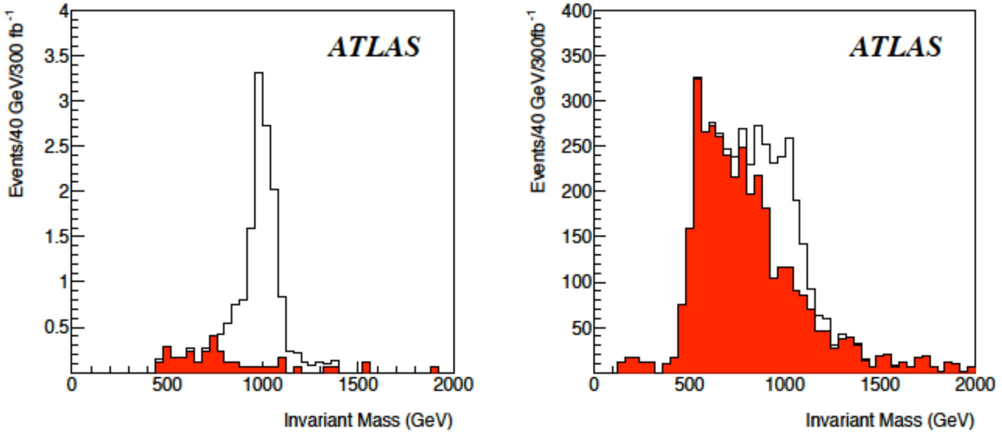
$\varphi^{\pm\pm}, \varphi^{\pm}, \varphi^0 \sim 10$ TeV

N.Arkani-Hamed *et al.,* Phys.Lett.**B513**(2001)232
JHEP**07**(2002)034, *ibid.* **08**(2002)021
Review:
M. Schmaltz, Nucl.Phys.B(Proc.Suppl.)**117**(2003)40
F. del Aguila *et al.,* Acta Phys.Polon.**B35**(2004)2767

Little Higgs signal at LHC

G. Azuelos *et al.,* hep-ph/0402037, Eur.Phys.J.C39S2(2005)13-244

Heavy top T→tZ, bW



Reach $M_T \sim 1\ (2)$ TeV for $x_\lambda = 1\ (2)$.