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INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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SUMMER SCHOOL IN HIGH ENERGY PHYSICS AND COSMOLOGY

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FUTURE AVENUES OF RESEARCH IN PARTICLE PHYSICS AT CERN

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Future Avenues of Research in Particle Physics at CERN

CERN's long term strategy based on:

a broad complementary experimental programme, that emphasizes, however, CERN's responsibility to provide the facilities for exploring the next high energy frontier

❶ full exploitation of LEP, including its high energy upgrade (LEP**2**) × 100 GeV

❷ commissioning of the LHC as soon as possible (2002) × 1 TeV

❸ a few high quality, unique, precision experiments at the SPS

to be carried out within a tight financial envelope and tight manpower constraints

➡ a high threshhold for what programmes to continue and an inevitable need to stop programmes which near completion (LEAR, Ω spectrometer)

☛ CERN's long term strategy

The LHC injection complex

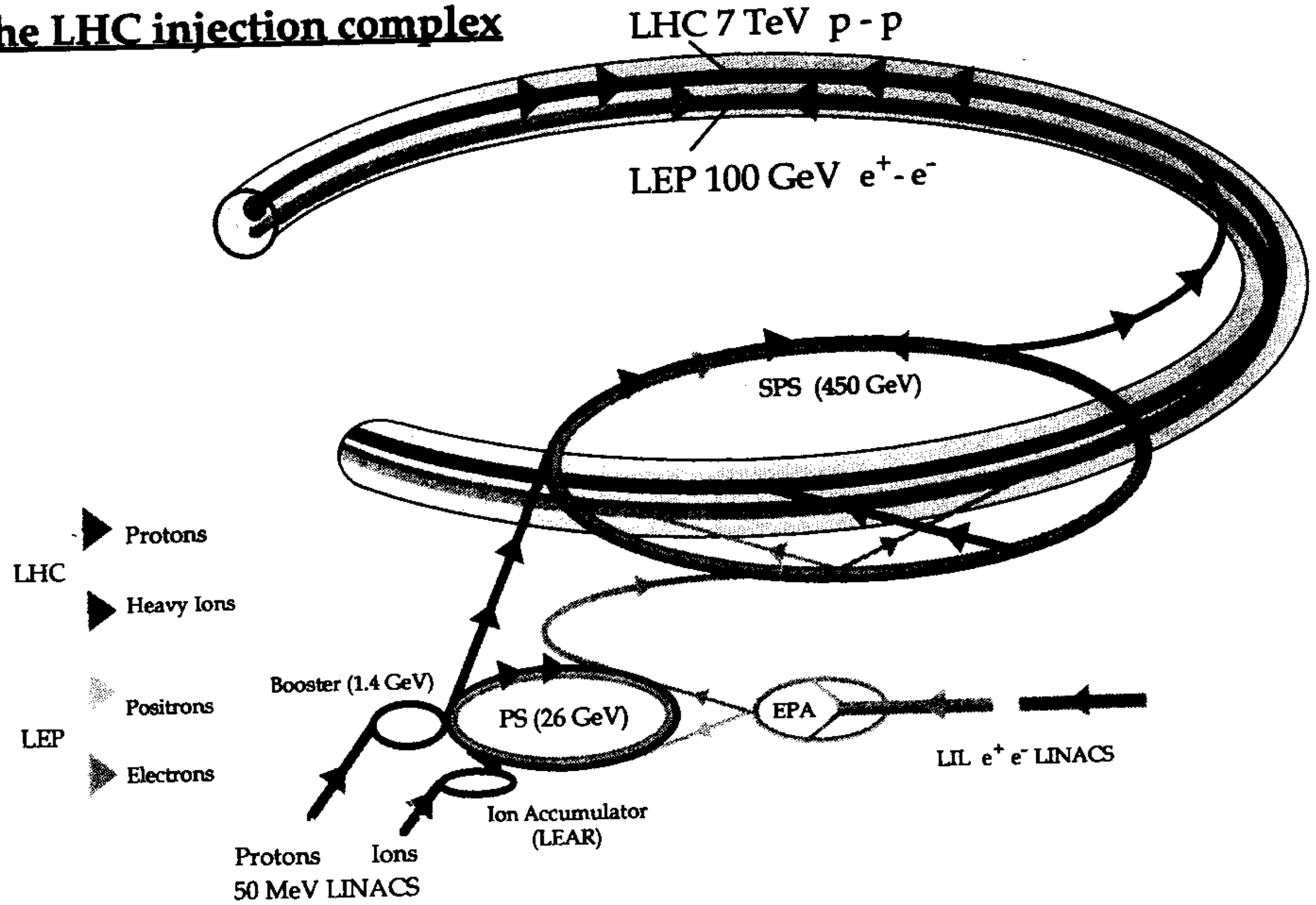
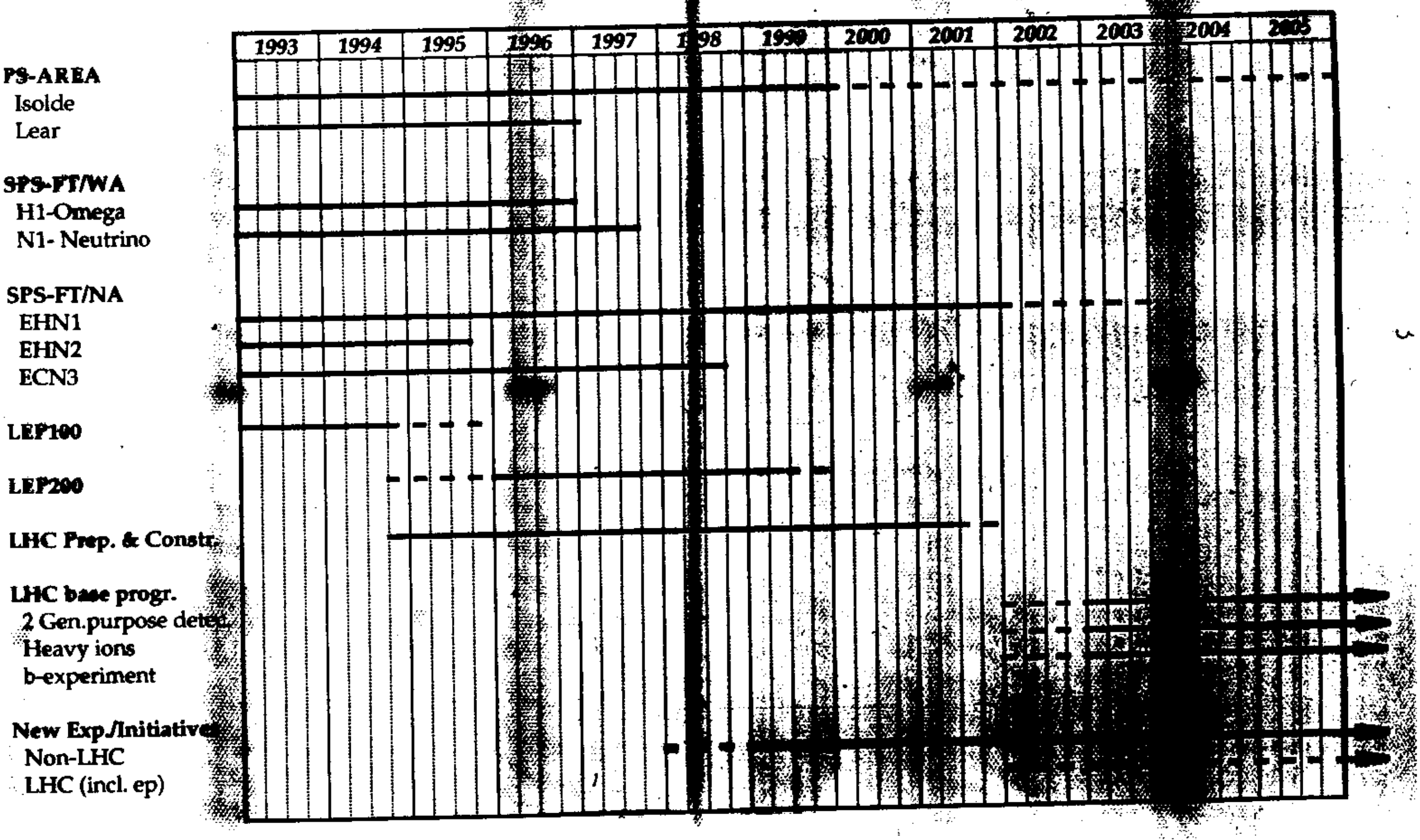


Figure 1

MODEL FOR THE SCIENTIFIC PROGRAMME



LEP ultimate machine to test SM. No deviations from SM predictions.

Main open questions in Particle Physics should be covered in framework of such a broad diversified experimental programme, provided CERN has a unique rôle to play.

- the mechanism of electroweak symmetry breaking, i.e. Higgs, longitudinal W-W interactions, gauge cancellations
  - ☛ LEP, LHC
- the existence of new forms of matter signalling higher symmetries than those of the SM i.e. supersymmetric particles, leptoquarks, excited leptons, compositeness, new gauge bosons
  - ☛ LEP, LHC
- the nature and origin of CP-violation in both K- and B-systems
  - ☛ SPS (K), LHC(B)
- phenomenology of heavy fermions, bottom, top
  - ☛ LEP, LHC
- the way in which QCD operates in the non-perturbative regime and in complex systems, QCD thermodynamics, hadron spectroscopy
  - ☛ SPS, LHC
- origin of dark matter, e.g. neutrino mass/oscillations
  - ☛ SPS, LHC

SPS programme

- ν's discussed by K. Winter at this workshop. Assumed to continue up till end '97
- NA48 CP-violation experiment intends to improve on accuracy of measuring direct CP-violation. Present (CERN, NA31) value $\varepsilon'/\varepsilon = (2.3 \pm 0.7)\ 10^{-3}$. To improve accuracy to typically 2×10^{-4} reduction of systematics ➡ two nearly collinear K_S and K_L beams.

☛ NA48 lay out

Final installation early 1996. Five years of running.

- Heavy ion experiments. Several ready to take date with Pb-beams. WA97 (Strange baryons in Ω spectr.) and WA98 (γ-production) to be completed after 1996 run,

NA44 (HBT interferometry)
NA50 (J/Ψ suppression)
NA49 (TPC) up till 1998, step towards LHC

Pb-ion programme to start November. Initial success: 13 μA beam of Pb^{53+} ions injected into PS Booster 15 June.

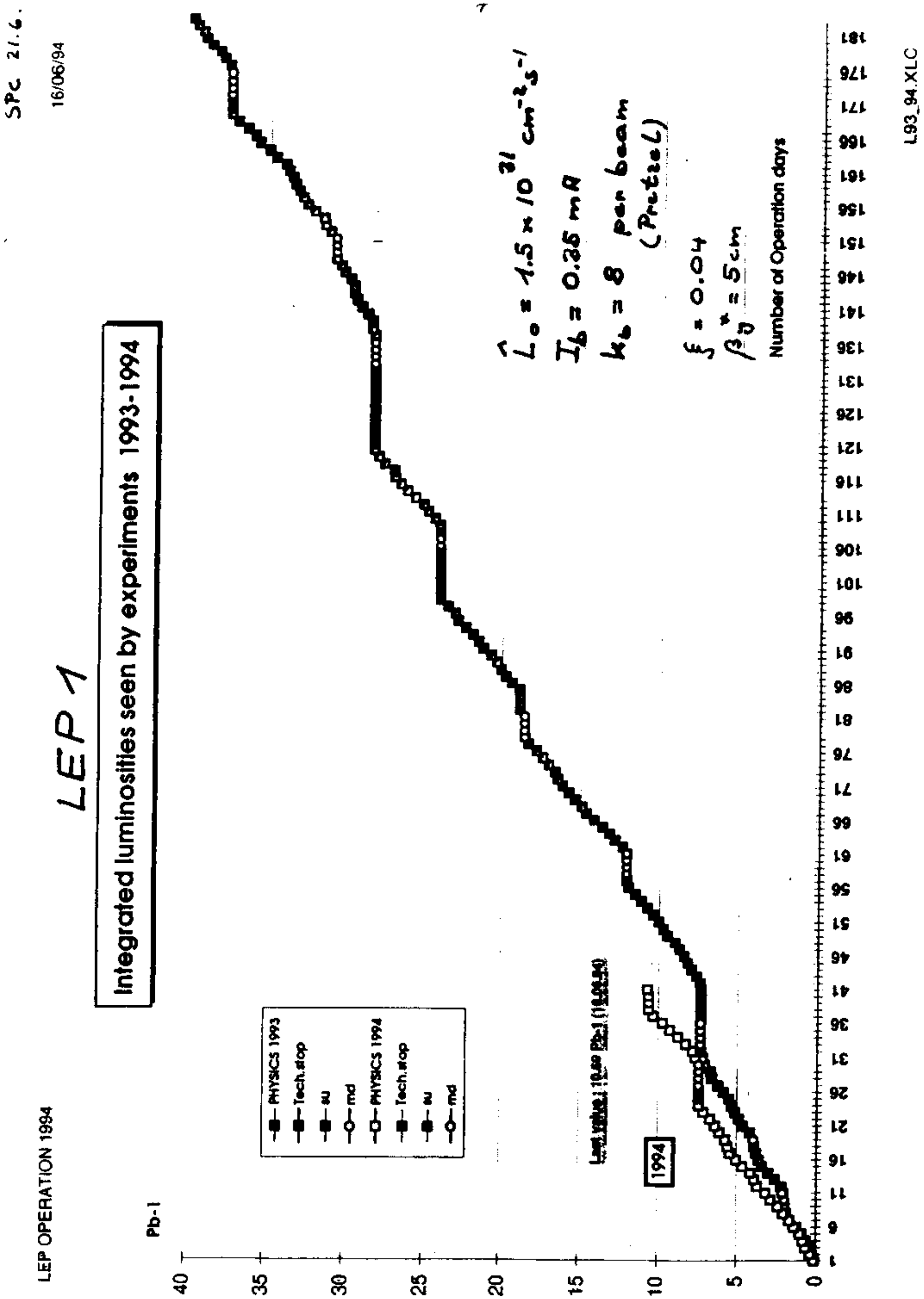
LEP programme

LEP is the ultimate machine for high precision tests of the Standard Model. Peak luminosity now exceeding the design luminosity. Further improvements foreseen particularly important for next phase LEP2.

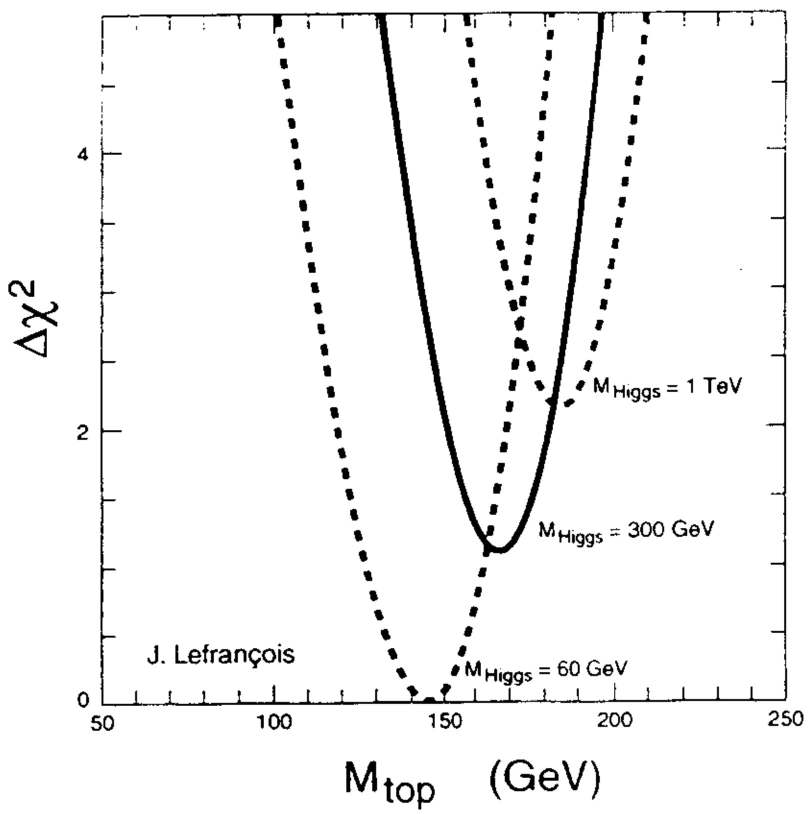
LEP will run up till 1995 at the Z^0 peak. By the end of 1994 LEP an integrated luminosity expected of about 150 pb^{-1}. In 1995, with some luck a significant further increase in statistics.

From 1996 onwards it is hoped that the machine will operate at energies above the W-pair threshhold (LEP2), in principle for three years. Unless there are major arguments (physics scheduling) to continue LEP will be put in mothballs from the year 2000 to possibly reemerge later when ep collsions at the LHC are wanted.

➩ At the present there are no further developments of LEP foreseen i.e. no further addition of Superconducting cavities to increase the energy and no installation of spin rotators to get longitudinally polarized beams. Inconsistent with present long range scientific and financial planning.



TOP QUARK MASS AT LEP



Original schedule for commisioning of LEP2 had to be modified due to slower industrial production rate of SC cavities and problems with the RF couplers. Both production of cavities and problems with couplers seem now to be under control.

June situation:

Phase I cavities (24 Nb + 8 Nb-film) for Pt 2 all at CERN and waiting for final couplers.

Phase II cavities (160 Nb film); 59% of cavities accepted with production to be ended by mid '95. 29% of modules (4 cavities) accepted with 43% delivered to be installed end "95

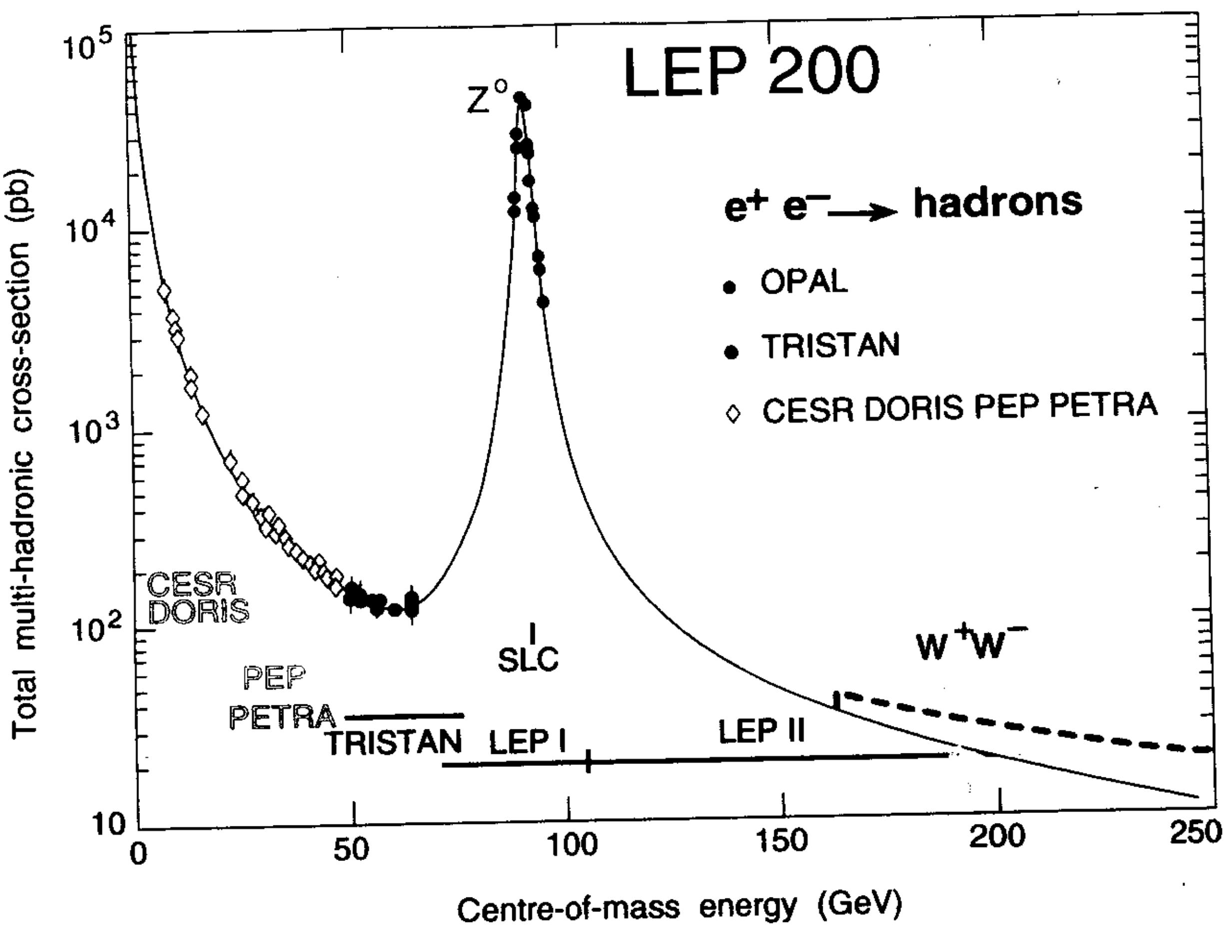
Phase III cavities (32 Nb-film) to replace final Cu-cavities, reduce tranverse impedance and thus increase luminosity on order.

Especially at LEP2 luminosity of crucial importance. Physics planning based on assumption of $_{3y}\int L dt = 500\ pb^{-1}$ @ 90 GeV beam energy.

➪ sets target for the required luminosity. For 150 days of running at overall efficiency $\int L dt / L_{peak}.T = 0.18$ (LEP1) a peak luminosity $L = 7 \times 10^{31}$ is necessary.

Promising development: concept of bunch trains. 4 trains of 2 (3) bunches would allow bunch current of 1 mA to be achieved corresponding to luminosity of $6 \times 10^{31} cm^{-2} s^{-1}$. Tests being carried out end '94. Possibly implementation already for '95 LEP1 running with 4 x 4 bunches would give peak luminosity to $6 \times 10^{31} cm^{-2} s^{-1}$.

Also LEP detectors progressively upgraded in the past years, in particular by installing precise vertex detectors and improved luminosity monitors.



Physics menu at LEP2

- Precise measurement of W-mass.
- Extended range for Higgs search
- Triple boson vertex coupling
- Search for new particles e.g. SUSY
- QCD tests e.g. running α_s

Rates at LEP2 typically two orders of magnitude smaller than at LEP1. ∫Ldt target of 500 pb^{-1} ➨ 8000 W-pairs per experiment (all decay modes).

❶ Expected precision on W-mass using full statistics and complete kinematical reconstruction:

$$\Delta M_W = 60 \text{ MeV per experiment (50 MeV combined)}$$

at present $M_W = 80.22 \pm 0.26$ GeV; at Tevatron expected $\Delta M_W = 100$ MeV.

Using cross section behaviour near threshold an accuracy of 100 MeV could be obtained for a significantly smaller integrated luminosity.

➪ Precise W-mass measurement constrains significantly Higgs mass once top mass is precisely measured

☛ graph

❷ Higgs search

Mass range accessible both for SM Higgs and Higgs predicted in MSSM roughly given by:

$$\sqrt{s} \approx M_H + M_Z + 10\,\text{GeV}$$

➡ push for highest E_B. Mass limit 82 (93) GeV for $\sqrt{s}$ = 175 (190) GeV

❸ Triple Boson Vertex

With ≈ 10000 W-pairs it will be possible to do detailed checks on the γW^+W^- and $Z^0W^+W^-$ couplings by studying decay angular distributions. Couplings determined, imposing C, P and T invariance, by 3 independent form factors of which one is the coupling constant and two parameters related to the magnetic and the electric quadrupole moment of the W.

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$$\mu_\gamma = e/2M_W\,[1 + \kappa_\gamma + \lambda_\gamma] \qquad Q_\gamma = -e/M^2_W\,[\kappa_\gamma - \lambda_\gamma]$$

SM values: $\kappa_\gamma, \kappa_Z = 1; \lambda_\gamma, \lambda_Z = 0$

Accuracy at LEP2 in measuring these parameters of the order 10-20% @ E_B = 90 GeV; 5-10% @ E_B = 95 GeV

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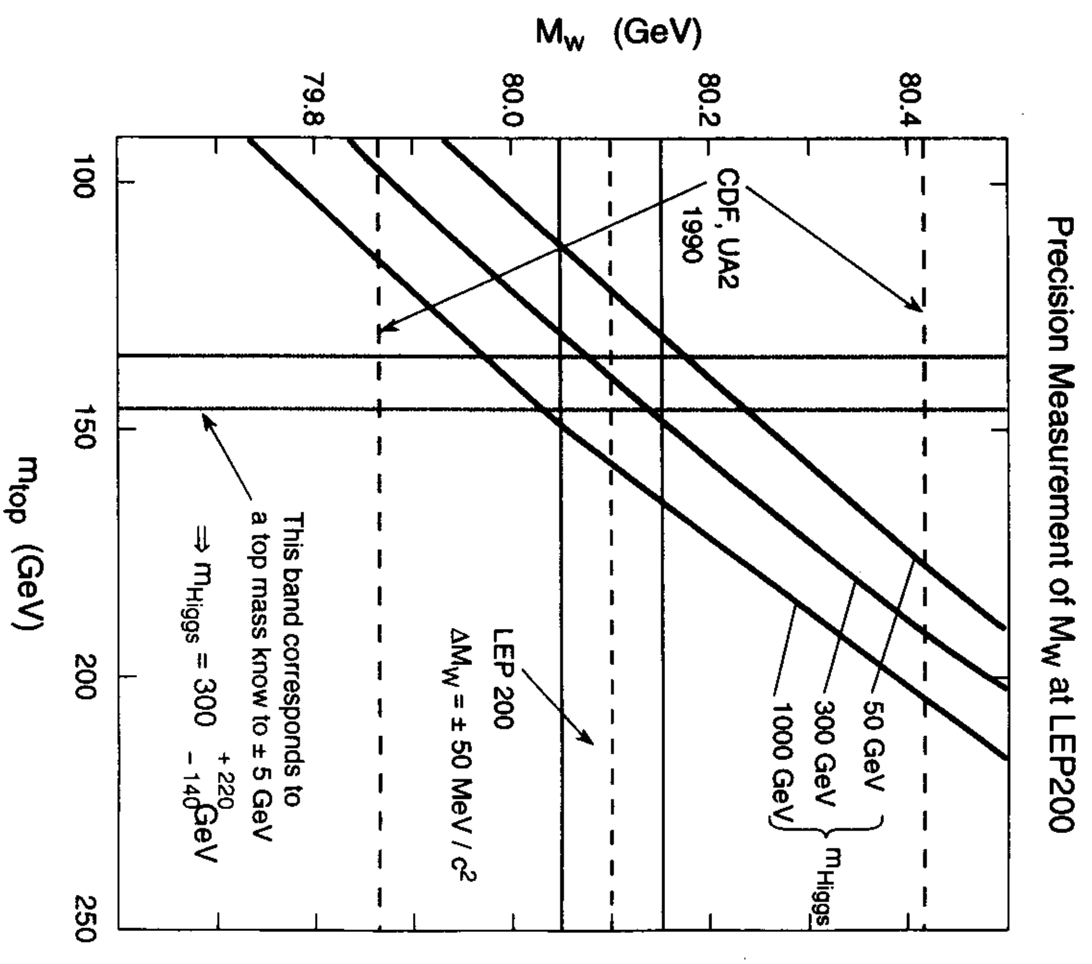
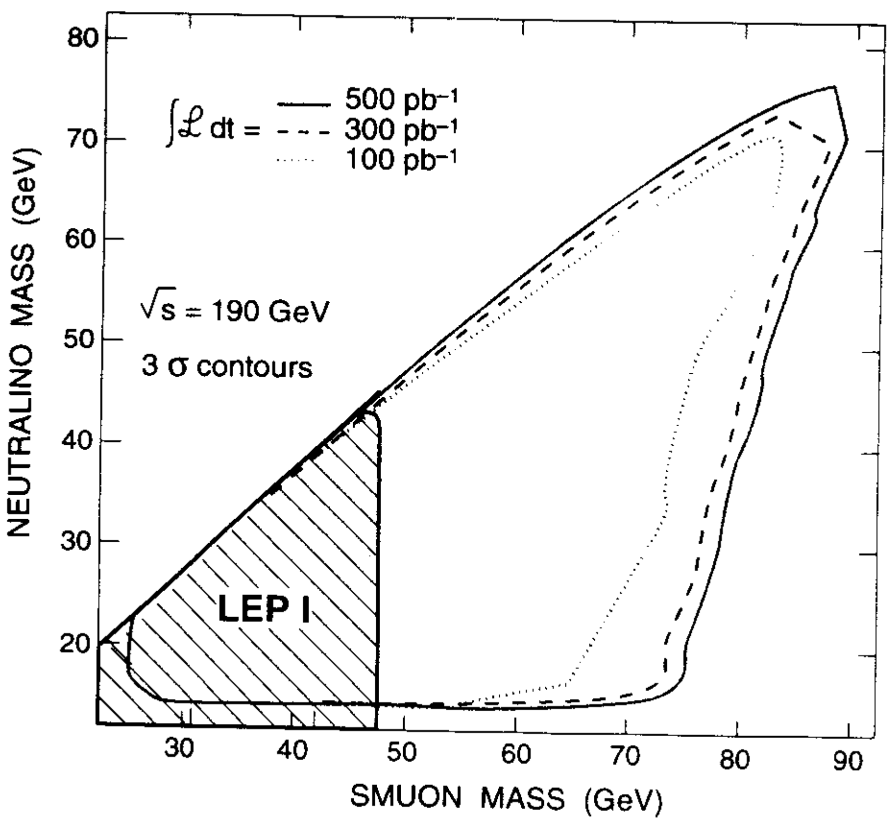


❹ New particle searches

Sleptons could be found up to ≈ 0.8 x E_B. Chargino's $\chi^{\pm}$ up to kinmatical limit through decay into lightest neutralino and $q\bar{q}$ or $l\nu$.

Also increased limits set on new heavy leptons, leptoquarks etc..

SEARCH FOR SUPERSYMMETRIC MUONS (smuons) AT LEP 200



LHC programme

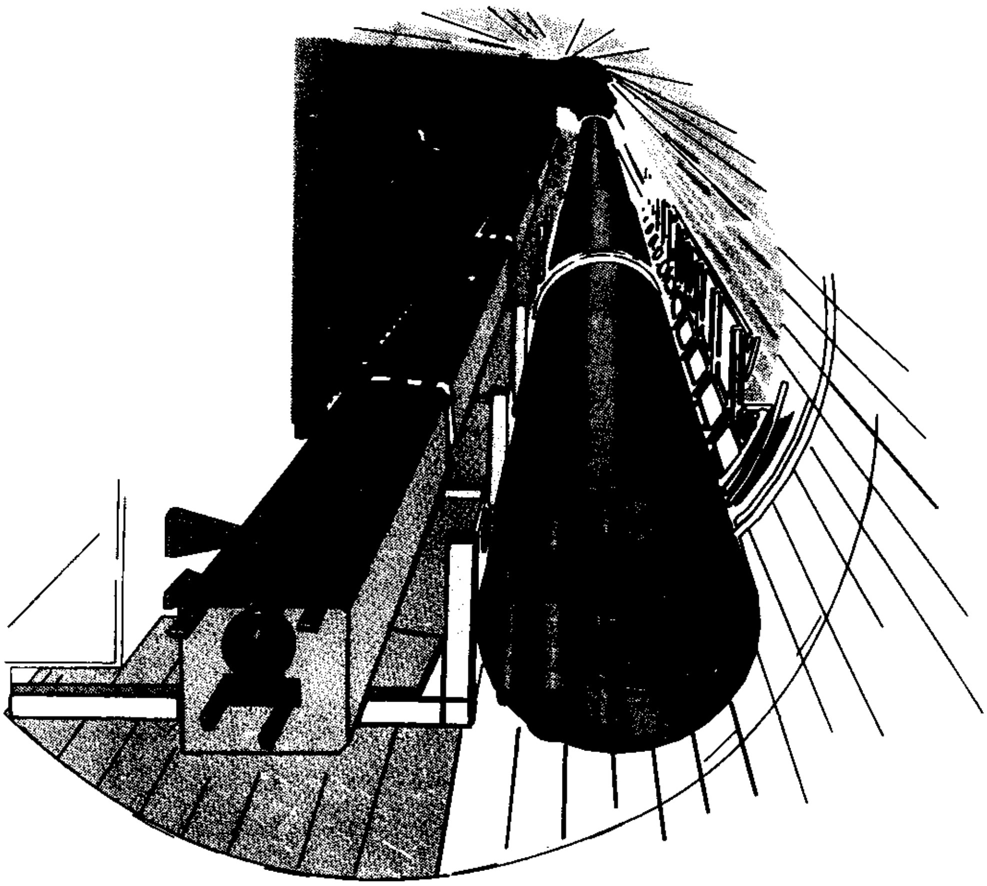
The LHC will extend CERN's tradition of providing its user community with frontier facilities, spanning a broad, diversified physics programme, based on the following elements:

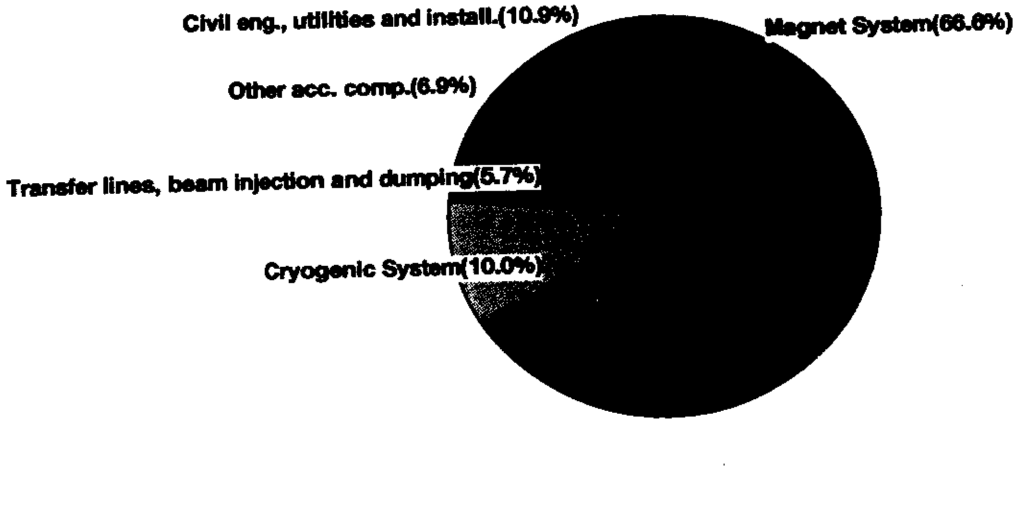
- High energy, high luminosity **proton-proton** collisions ($\sqrt{s}$ = 14 TeV, L ≥ 10^{34} $cm^{-2}s^{-1}$) ➨ the next high energy ("1 TeV") frontier
- **Heavy ion** collisions (Lead) ($\sqrt{s}$ = 1150 TeV, L ~ 10^{27} $cm^{-2}s^{-1}$) ➨ Strong Interaction Thermodynamics, with rapidly increasing interest of Nuclear Physics community
- **Non- mainstream proton experiments (colliding mode or fixed target) for beauty and neutrino physics** ➨ continuing at high energy programme presently carried out at SPS
- **electron-proton** collisions ($\sqrt{s}$ = 1.36 TeV, L= 2.8 x10^{32} $cm^{-2}s^{-1}$), at later stage ➨ important input to be provided by HERA

☛ LHC machine lay out and parameters

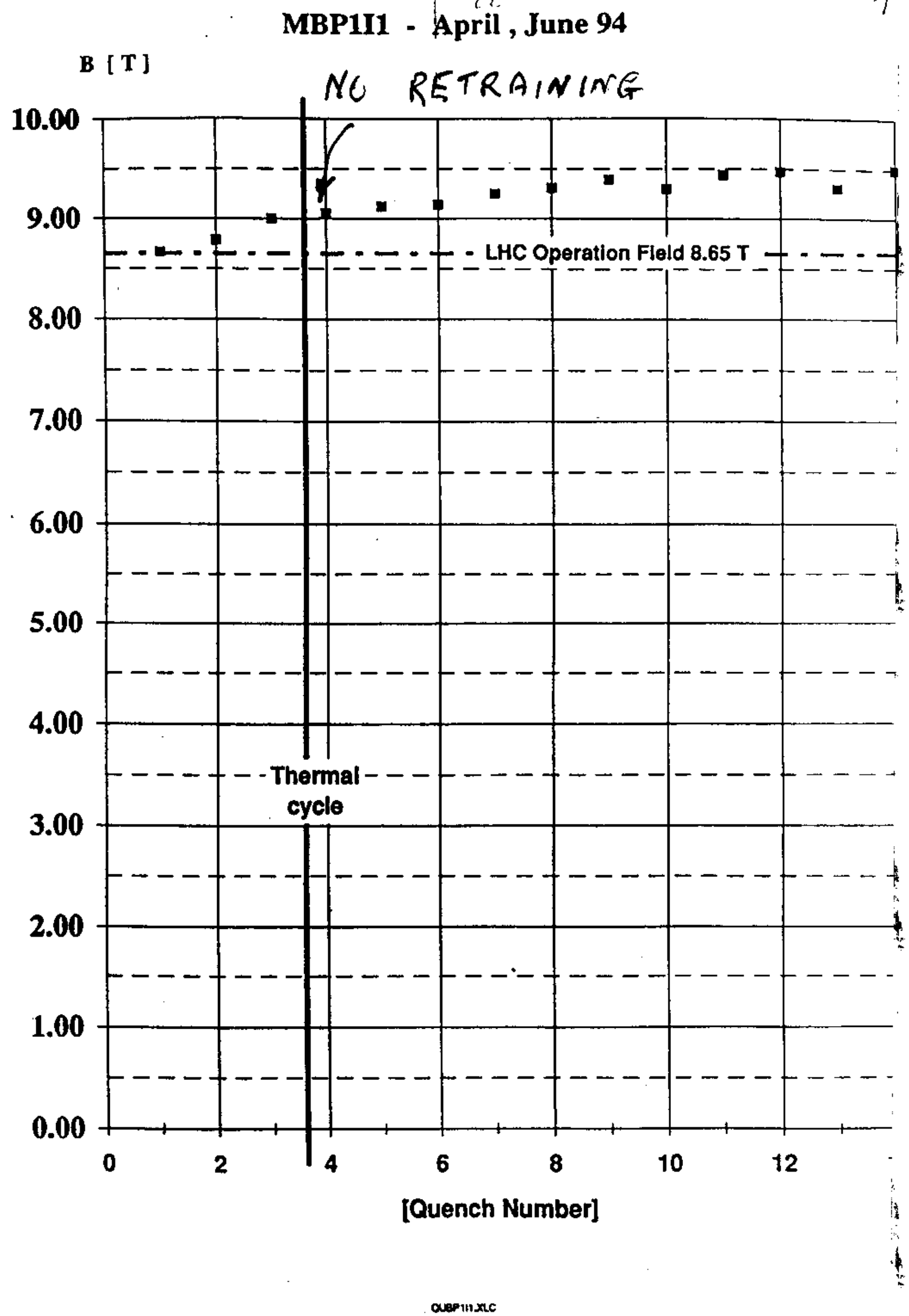
LHC Main Parameters

Collisions		p-p	Pb-Pb
Operational Energy	[TeV]	14	1148
Dipole Field	[T]	8.65	8.65
Nominal Luminosity	[$cm^{-2}s^{-1}$]	10^{34}	10^{27}
Luminosity @ beam-beam limit	[$cm^{-2}s^{-1}$]	2.5 10^{34}	
Bunch Spacing	[m] | [ns]	7.5 | 25	40.5 | 135
Particles/Bunch		10^{11}	10^{8}
Particles/Beam		2.8 10^{14}	4.7 10^{10}
Number of Experiments		2	1
β* at interaction point	[m]	0.5	0.5
r.m.s. radius at interaction point	[μm]	15	15
r.m.s. collision length	[cm]	5.3	5.3
Crossing Angle	[μrad]	200	<100





Total Machine Cost: 2230 MCHF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Status LHC Experimental Programme

		EoI	LoI	Prov. OK	Techn. Proposal	Date for subm.
ATLAS	pp gen. purp.	March '92	Oct. '92	April '93	Nov. '93	Dec. 94
CMS	pp gen. purp.	March '92	Oct. '92	April '93	Nov. '93	Dec. 94
L3P	pp gen. purp.	March '92	Oct. '92			
ALICE	ion gen. purp.	March '92	March '93	Nov. '93	April '94	Dec. 95
COBEX	ded. beauty	March '92	Oct. '93	One	Forward	
LHB	ded. beauty	March '92	Oct. '93	Collider	Experim.	
GAJET	ded. beauty	March '92	Oct. '93	June 94		
TOTEM	σ(tot)	March '92	✓			
ν(Chorus)	ν-expt	March '92	✓			
ν(Nomad)	ν-expt	March '92	✓			

➪ **Physics objectives and considerations**

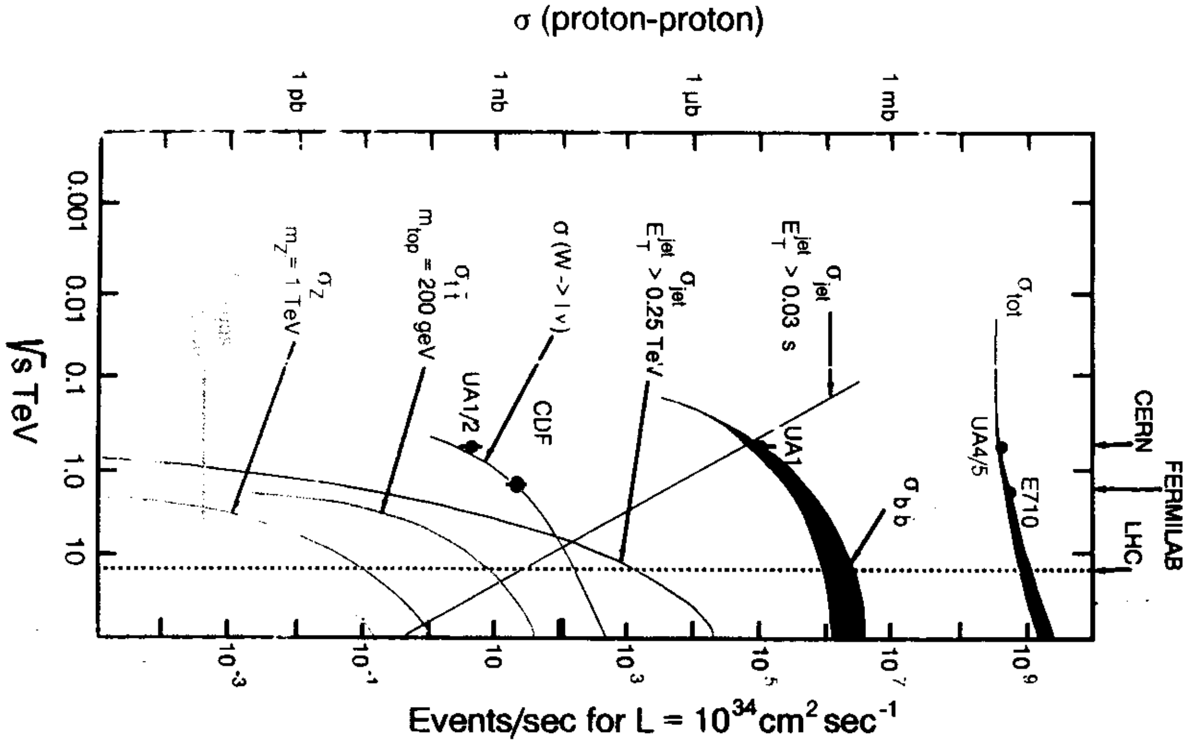
The LHC will address four main fundamental physics issues.

❶ Origin of Electroweak Symmetry breaking and the mass generating mechanism

❷ Supersymmetry

❸ Existence of quark-gluon plasma phase

❹ CP symmetry violation (B-physics)



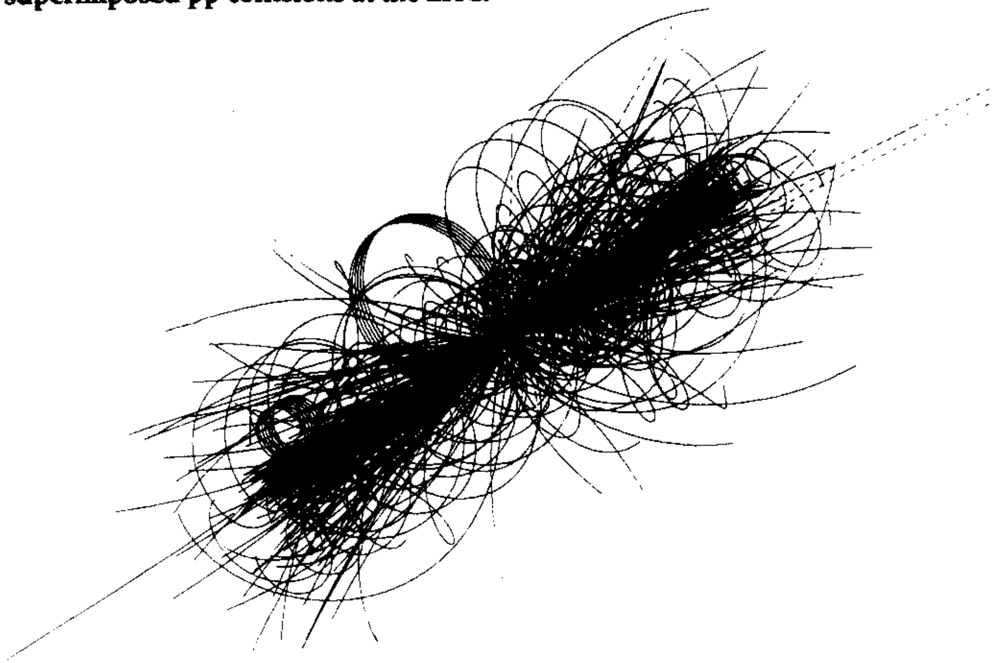
Experimentation at LHC not trivial

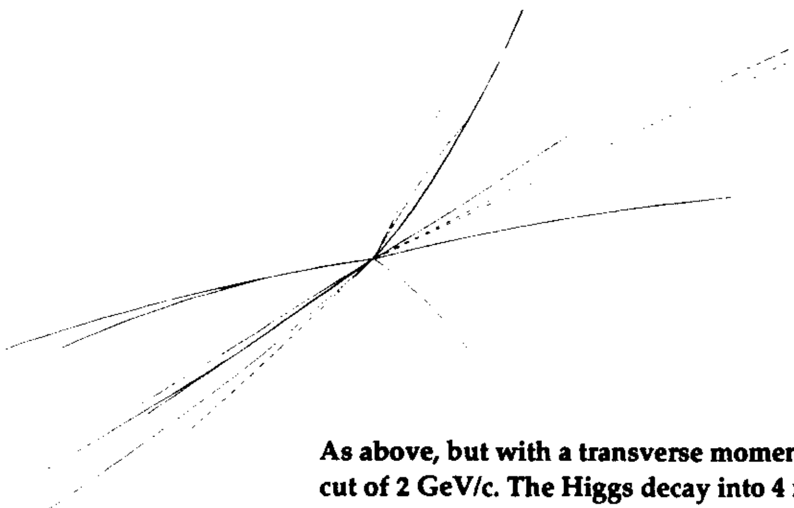
- small signals/large background
- bunch crossing frequency 40 MHz
- O (20) overlapping interactions/bunch crossing for 10^{34} $cm^{-2}s^{-1}$
- large particle multiplicities O (100)/interaction ($dn_{ch}/d\eta \approx 6$ per unit of rapidity)
- large radiation doses in particular in forward direction up to 10 MRad

⇨ Extensive Detector R&D programme carried out in past 4 years confirming experimental feasibility of detectors

- fast detectors to prevent pile up
- high granularity of detectors ➡ many read-out channels
- pipelined front-end electronics
- spohisticated triggering systems, with parallel processing capabilities
- radiation resistant electronics

All charged particles (hadrons in red, muons in green) produced by 12 superimposed pp collisions at the LHC.





As above, but with a transverse momentum cut of 2 GeV/c. The Higgs decay into 4 muons

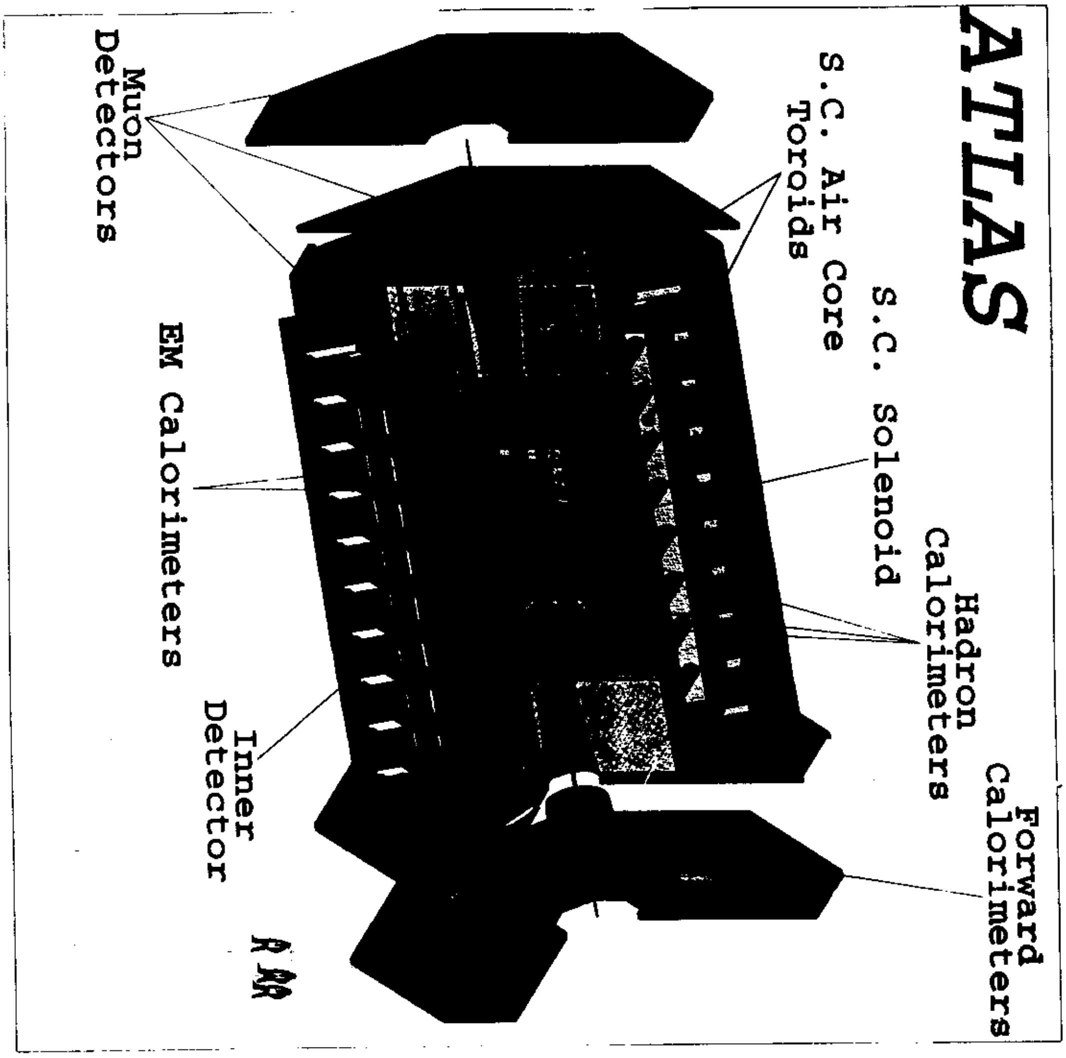
Physics goals of the LHC involve the observation of a wide range of possible new particles and phenomena around electroweak mass scale

➡ detectors should aim for the observation of high p_T and "centrally" produced experimental signatures such as

- $\mu^{\pm}$
- $e^{\pm}$ and γ
- jets
- missing Energy/Momentum

Main detector functions to be considered:

- tracking and vertex detection
- calorimetry
- electron identification
- muon measurements
- triggering and data acquisition



<u>ATLAS</u>

❑ General purpose pp detector for LHC able

- to pursue the physics issues at the initial lower luminosity
- to perform safely at the highest possible luminosities
- exploring all possible signatures i.e. e, γ, μ, jet and missing E_T , with the largest possible acceptance in rapidity and transverse momentum
- remaining within realistic cost constraints

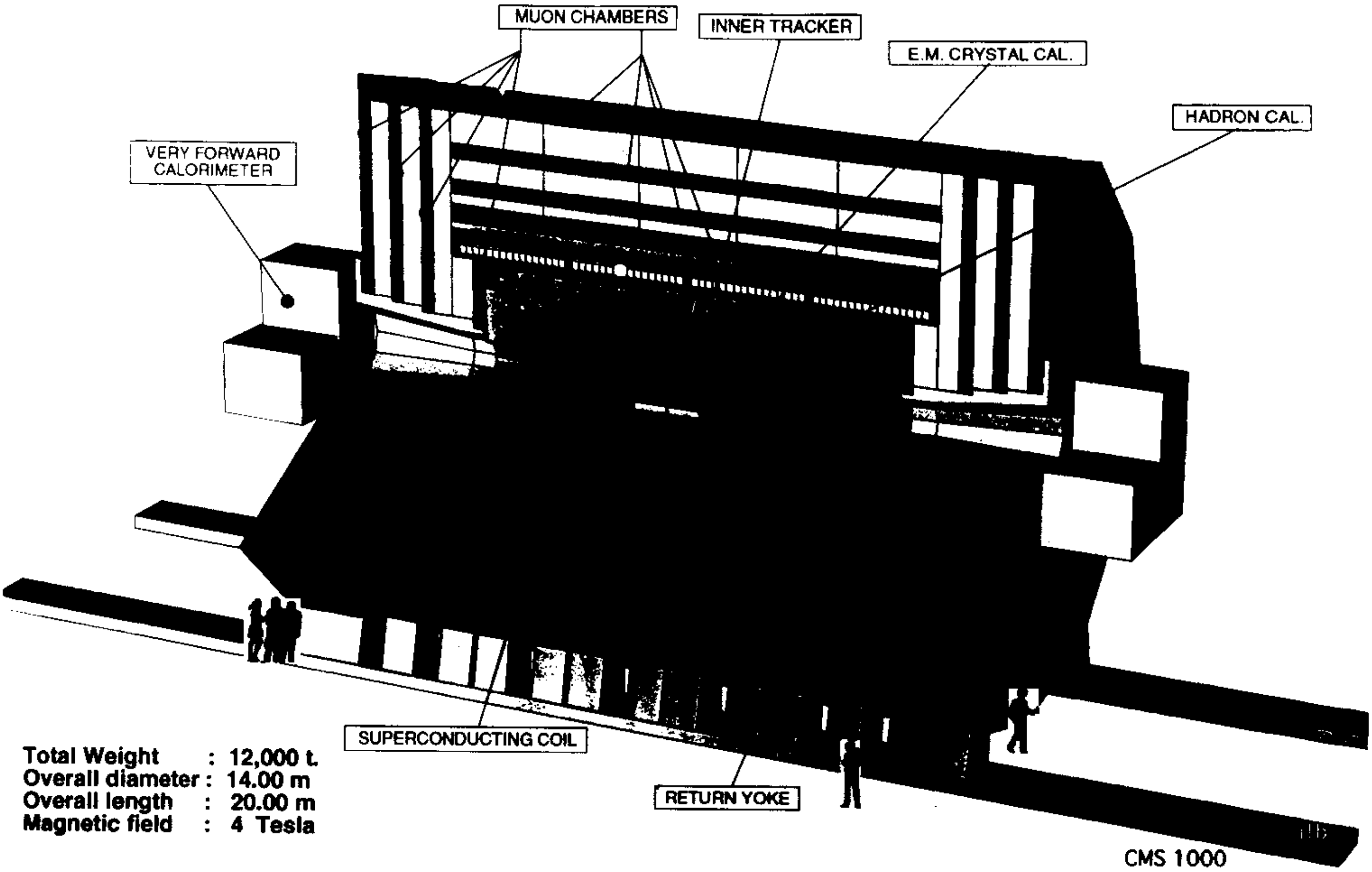
➡ inner detector in 2 T central solenoid for measurement of isolated leptons and electron identification for $-2.5 < \eta < 2.5$, high precision vertex detector for low luminosity operation
Discrete layers of Si μ-strip and MSGC, continuous TRT tracker

➡ High quality sampling calorimetry combined with fine-granularity preshower detection for e's and γ's
Liq. Ar/Pb

➡ Hermetic hadron calorimetry $-5 < \eta < 5$
Liq. Ar, sc. tiles

➡ 8 coil air-core toroidal magnet $-3 < \eta < 3$ for muon detection

CMS
A Compact Solenoidal Detetor for LHC



Total Weight : 12,000 t.
Overall diameter : 14.00 m
Overall length : 20.00 m
Magnetic field : 4 Tesla

CMS (Compact Muon Spectrometer)

❑ General purpose pp detector for LHC optimizing

- muon detection at highest possible luminosity
- electron/γ detection
- muon studies in ion collisions

➡ long solenoidal magnet (14 m); 5.9 m bore; 4T field with rapidity coverage $-2.5 < \eta < 2.5$ and excellent momentum resolution for muons

➡ innner tracking with Si μ-strip and Microstrip gas chambers (MSGC)

➡ high resolution crystal (CeF_3, $PbWO_4$) em calorimeter for $H \to \gamma\gamma$ or Pb/Scintillator plates using WLS fibres for read out $-2.5 < \eta < 2.5$

➡ Cu-sc. hadron calorimeter; in very forward direction Fe and (gaseous) Parallel Plate Chambers, $-5 < \eta < 5$

➡ Different options for the muon detection system: Drift Tube chambers; Wall-less Drift Chambers; Honeycomb Strip Chambers

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❑ proton collider

Constituent c.o.m. energy in p-p collisions a continuous distribution

➡ no strict kinematic limit

⇨ Both energy and luminosity are important variables
  - ➡ aim for highest possible luminosity

⇨ The LHC at $\sqrt{s}$ = 14 TeV and L = 10^{34} $cm^{-2}s^{-1}$ will indeed have the required discovery potential for the "next generation" machine, with discovery range/limits:

- SM Higgs ≈ 80 GeV - 1 TeV
- WW, WZ, ZZ scattering resonances (like ρ-like and ω-like vector bosons of technicolour) 2-2.5 TeV
- Gluinos and squarks 1.5 TeV
- New Gauge Bosons 3 TeV - 5 TeV
- New Heavy quarks 1 TeV

⇨ At lower luminosity as in the initial commissioning phase
  - top quark and b-quark phenomenology
  - 3-gauge coupling $q\bar{q} \to WWZ/\gamma$
    % accuracies thanks to large number of events and high masses.

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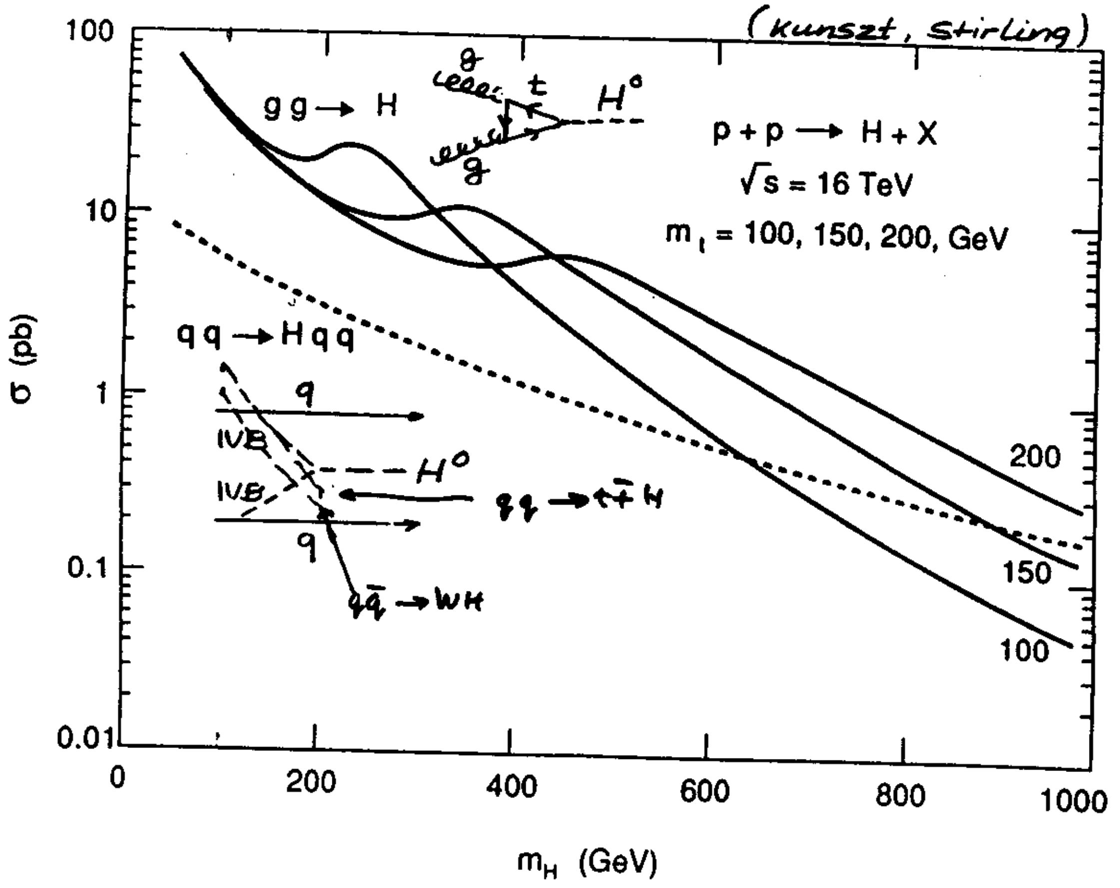
the two main production processes:

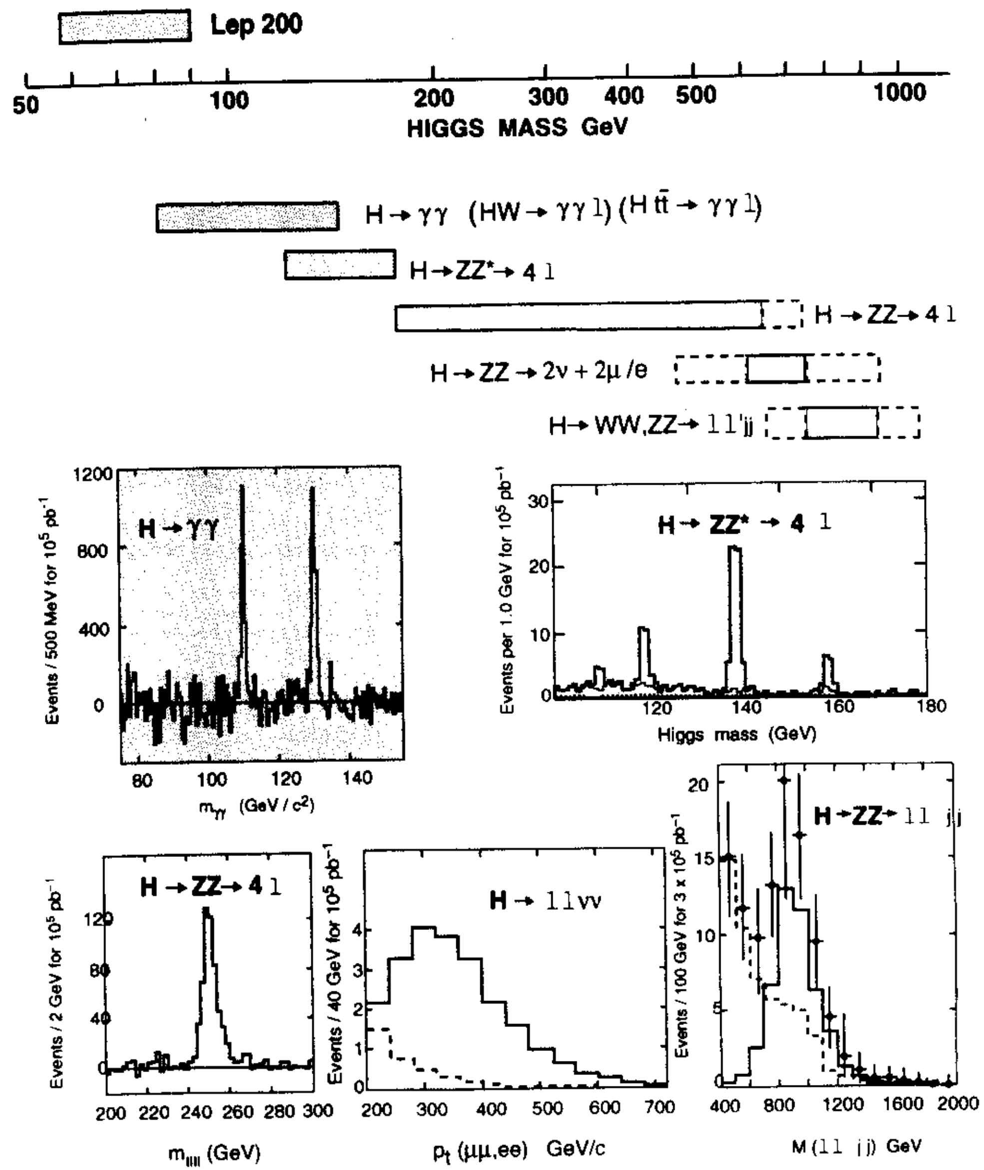


Higgs sector

Major benchmark process with a variety of possible channels most of which are sensitive to the detector performance

final states	mass range (GeV)	characteristics
SM Higgs		
$\gamma\gamma$	80 - 150	γ - identification vs π^0 and e mass resolution
ZZ* -> l l l l	130 - 2 m_Z	mass resolution, lepton isolation at high luminosity
ZZ -> l l $\nu\bar{\nu}$	400 - 800	calorimeter hermeticity forward jet tagging
WW -> l ν jj and ZZ -> l l jj	> 600	high-p_T W, Z -> jj forward jet tagging
SUSY Higgs		
h -> $\gamma\gamma$		high luminosity
A, H -> $\tau\tau$ with eμ or l + hadron and plus missing E_T		low luminosity τ-identification b-tagging to veto $t\bar{t}$-backg. calorimeter hermeticity
t -> bH$^+$ with H$^+$ -> $\tau\nu$ with H$^+$ -> c$\bar{s}$		as above jet mass resolution

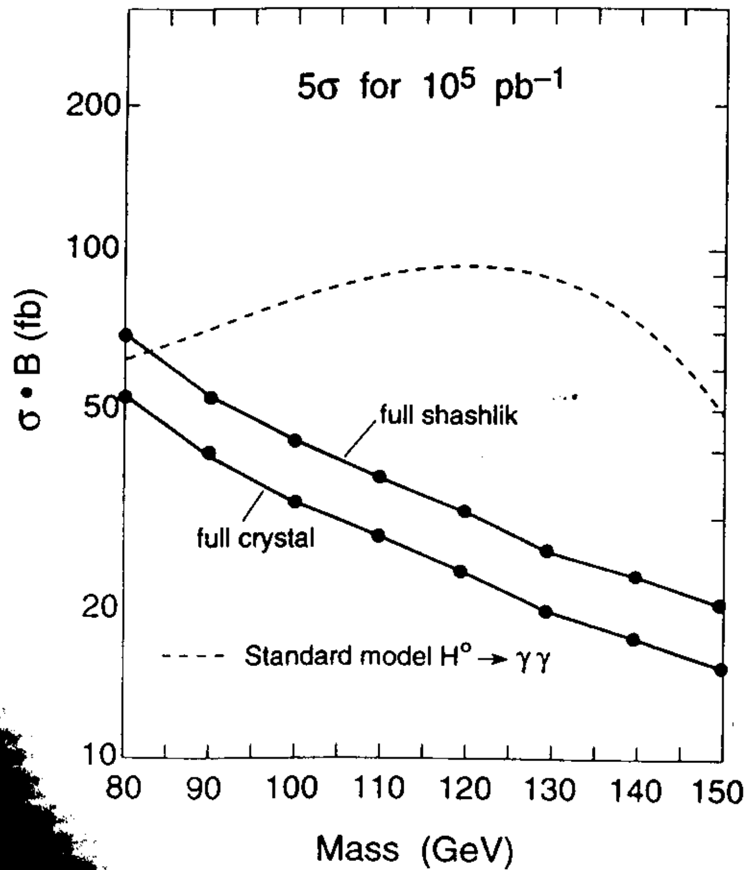
Search for the Higgs in CMS



$H \rightarrow \gamma\gamma$

[illegible]

- Detector complete



$H \rightarrow \gamma\gamma$

[illegible]

- Shashlik complete

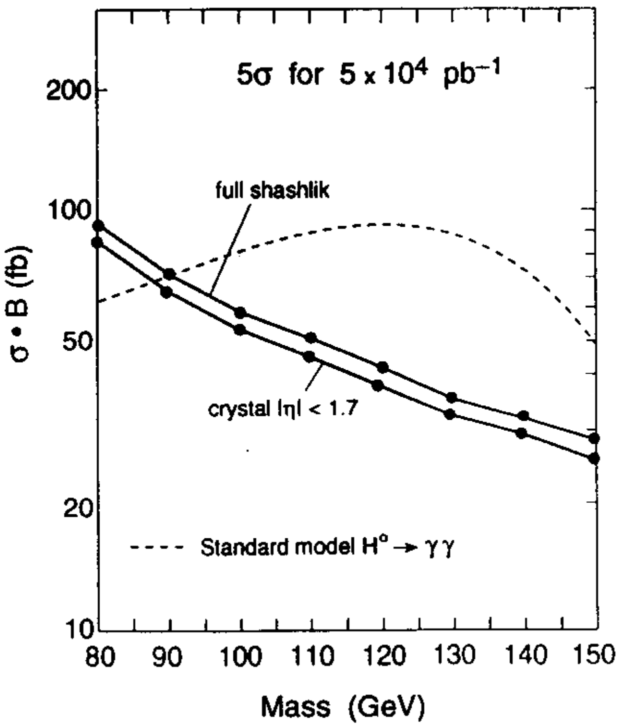
  $8\%/\sqrt{E} \oplus 1\% \oplus 0.300/E$

  $70\ \mathrm{mrad}/\sqrt{E}$

- Crystal barrel $|\eta| < 1.7$

  $2\%/\sqrt{E} \oplus 0.5\% \oplus 0.150/E$

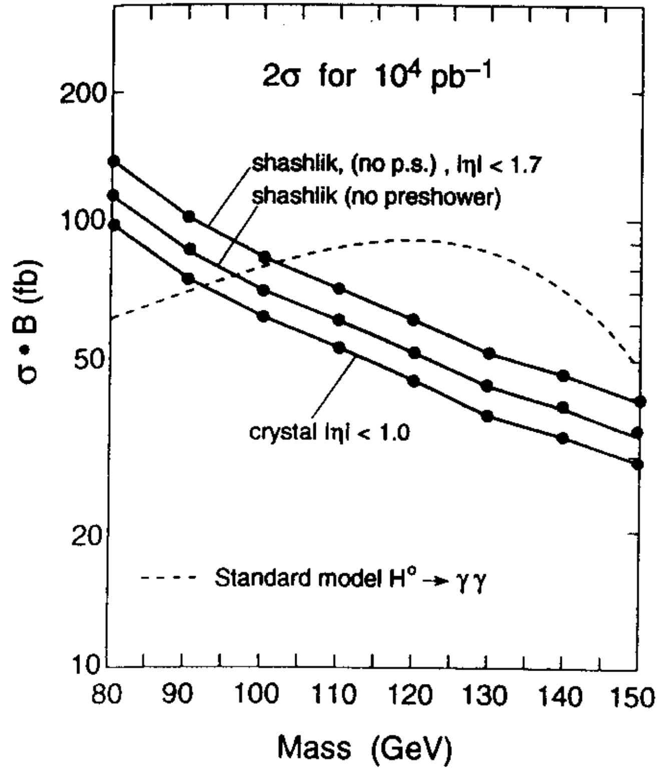
  $60\ \mathrm{mrad}/\sqrt{E}$



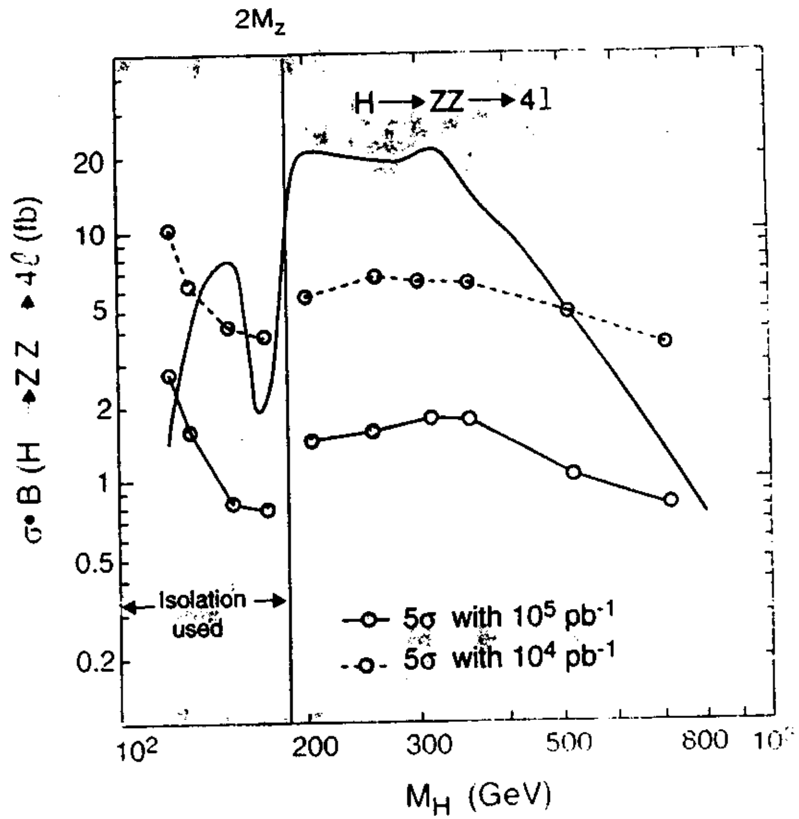
$H \to \gamma\gamma$

0 - 2 years, $10^{32} \to 10^{33}$

- No pre-shower means background x 2 for Shashlik
- Photon direction using vertex
- 2σ: 95% CL limits for $H \to \gamma\gamma$

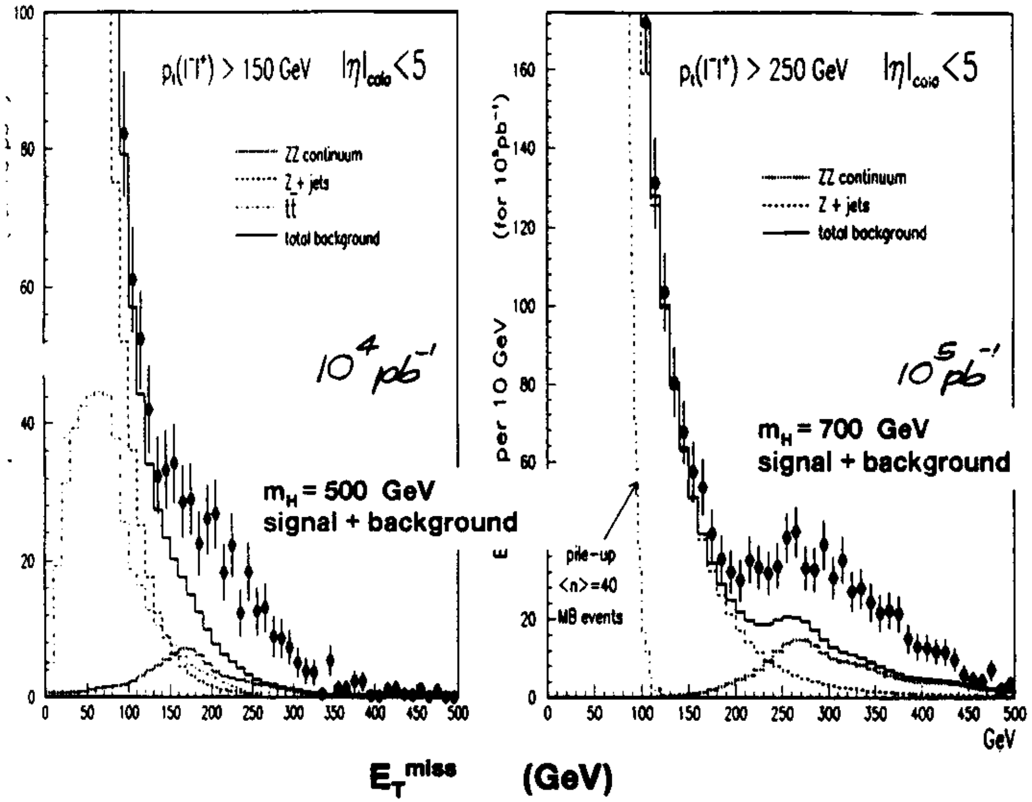


$H \to ZZ^*$ and $H \to ZZ$



- For 4 charged leptons:
  - Need good tracking momentum resolution;
  - Full geometric acceptance.

H -> ZZ -> ll $\nu\bar{\nu}$



Careful study of E_T^{miss} tail performed => for E_T^{miss} > 100 GeV:

- crack effects increase tail by ~ 10%
- calorimeter resolution has small impact
- coverage is crucial to reduce Z + jet background
- pile-up effects (min-bias, rare processes) are small

Jet tagging strongly reduces the background

H -> ZZ -> ll$\nu\bar{\nu}$ may well extend the reach of H -> ZZ -> llll searches, both at low and high luminosities

Higgs sector in SUSY (MSSM)

Combine searches for neutral (h, H, A) and charged ($H^{\pm}$) Higgs

Main sensitivity beyond LEP II from:

- h -> $\gamma\gamma$

- needs high luminosity
- usually depressed in rate with respect to SM Higgs
- m_h not far from m_Z

A, H -> $\tau\tau$ with at least one τ decay to leptons

- nee is low luminosity and good calorimeter coverage to rec nstruct well $\tau\tau$ mass
- incl de hadronic τ decays to increase sensitivity

- Sear 1 for $H^{\pm}$ from top decays

- can be done at low luminosity
- b and τ-tagging help substantially
- sensitivity improves for larger m_{top}

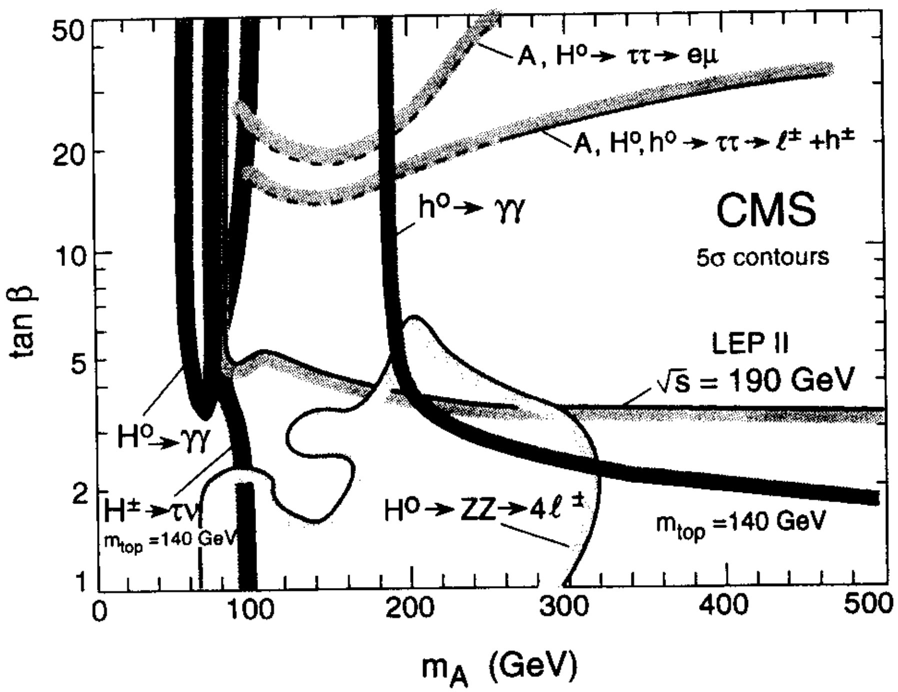
-> $ZZ^{(*)}$ -> 4 charged leptons

ited due to depressed H -> $ZZ^{(*)}$ rate

Regions of the MSSM parameter space (m_A, tgβ) explorable through various SUSY Higgs channels

$h^o \to \gamma\gamma$; $H^o \to \gamma\gamma$; $H^o \to ZZ \to 4\ell^\pm$ for 10^5 pb^{-1}

$H^\pm \to \tau\nu$; A,H,h $\to \tau\tau \to \ell\ell'$ or ℓh for 10^4 pb^{-1}



Top quark physics

Exciting field at LHC start-up

- ***measurement of the mass m_t***
- ***search for non-standard top decays***

Very large rates even at low luminosity

for L = 10^{32} $cm^{-2}s^{-1}$ and m_t = 140 GeV one expects
- **~ 20 $t\bar{t}$ pairs produced per minute**
- **~ 300 reconstructed $t\bar{t}$ -> (lν) (jjb) per day**
- **~ 30 clean isolated e-μ pairs per day**

Measurement of m_t with a precision of about < 5 GeV can be achieved (similar to indirect ultimate LEP measurements)

Sensitivity to t -> bH^+ decays over the full kinematically accessible ($m_{H^\pm}$,tanβ) range

- **$H^+ \to \tau^+\nu_\tau$ decays with τ -> hadron(s)**
- **$H^+ \to c\bar{s}$**

Measurement of m_t

m_{jjb} (for $t \to jjb$)

Full reconstruction of m_t

Reduction of backgrounds and experimental systematic errors using b-tagging

Precision limited by systematics (partially theoretical)

For 10^3 pb^{-1}:	statistical error	$\pm$ 1 GeV
	systematic error	$\pm$ 6 GeV

$m_{l\mu}$ (for $t \to bl\nu$, $b \to c\mu\nu$)

Very clean channel with almost no experimental systematic errors

For 10^4 pb^{-1}:	m_t = 140	200 GeV
statistical error	$\pm$ 1.2	$\pm$ 1.9 GeV
systematic error	$\pm$ 4.0	$\pm$ 5.0 GeV

$t\bar{t} \to Wb\ Wb$, $W \to \mu\nu$, $m(2j) = m_W \pm 20$ GeV

ATLAS

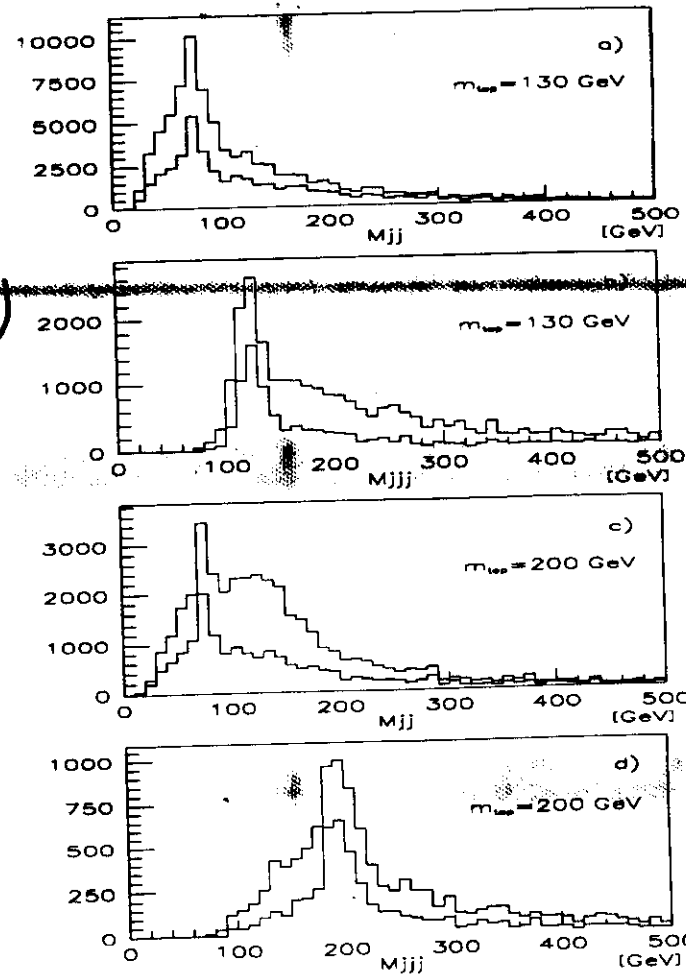
Reconstruction of hadronic top quark decays

- lepton tag with p_T > 40 GeV
- at least 3 jets within $|\eta| < 2$, p_T^{j} > 50 GeV, $p_T^{j2,j3}$ > 40 GeV in the hemisphere opposite to the lepton tag
- b-jet tagging (shaded histograms): at least one charged track with p_T > 2 GeV and impact parameter larger than 200 μm

m_t = 130 GeV

events per 10^4 pb^{-1} (1 year @ 10^{33} cm^{-2}s^{-1})

m_t = 200 GeV



For 10^4 pb^{-1} σ_{stat} = 1 GeV

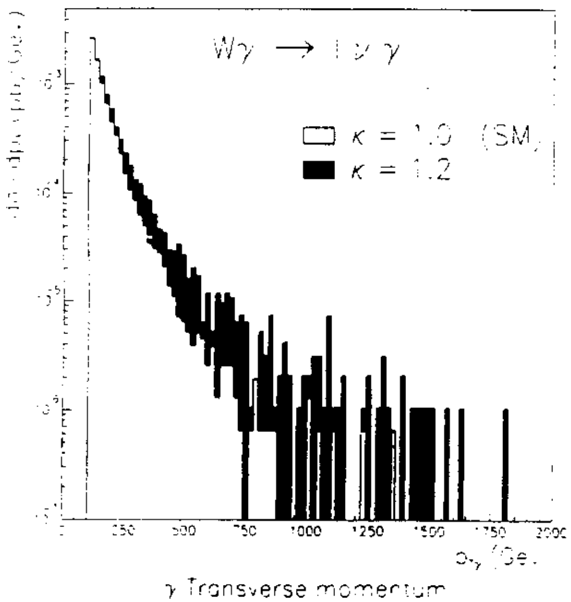
Gauge boson pair production

Essential test of electroweak theory through three vector-boson coupling
Expect to improve LEP II measurements at LHC

Example: Wγ production

($p_T^{\gamma} > 100$ GeV, $p_T^{l} > 25$ GeV)

- need good photon identification: for $R^{jet} \sim 10^4$ expect 17000 reconstructed W -> lν + γ events for ~ 4000 background events from $t\bar{t}$ and W+jets
- $t\bar{t}\gamma$ remains dominant background sources (~10000 events) after lepton isolation cuts against $b\bar{b}\gamma$ background



Good sensitivity to κ

(160 excess photons with $p_T^{\gamma} > 300$ GeV above a total background of ≤ 1000 events for κ = 1.1)

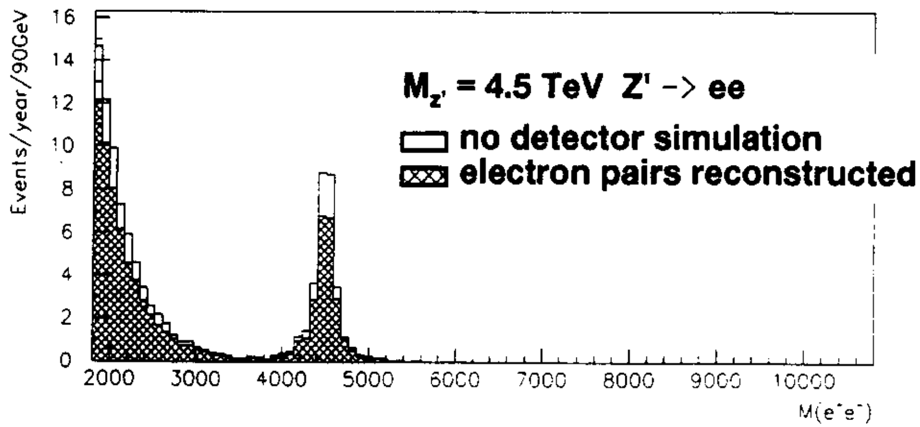
Search for new vector bosons

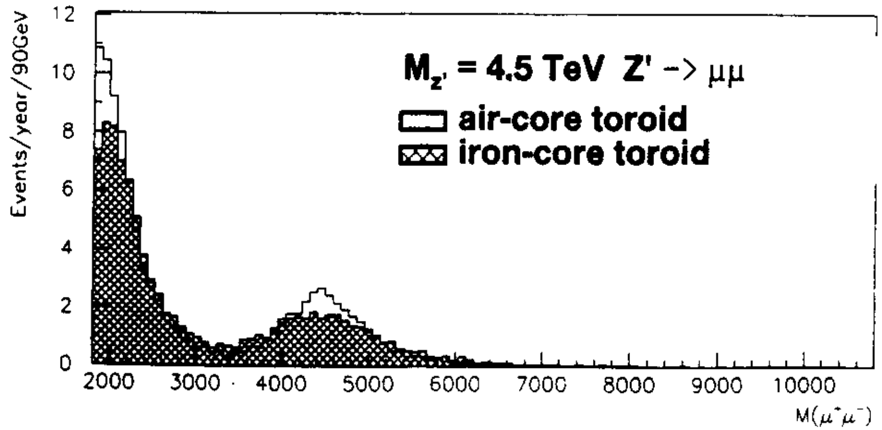
The detector is sensitive to Z' -> ee, μμ, jj
and to W' -> eν, μν, jj

Best reach is achieved through Z' -> ee and W' -> eν

example: Extended Gauge Model ($\Gamma_{Z'} = \Gamma_Z \bullet M_{Z'} / M_Z$)

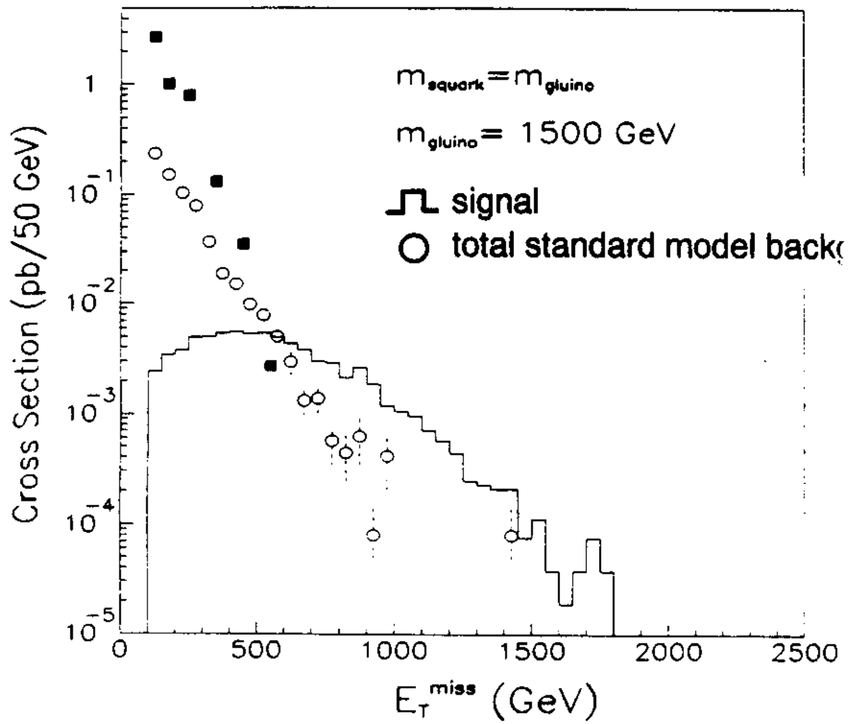
good sensitivity for $m_{Z'} \leq 5.0$ (4.0) TeV for 10^5 (10^4) pb^{-1}
similar sensitivity for $m_{W'} = m_{Z'} + 0.5$ TeV





Gluinos and squarks in E_T^{miss} + jets channel

Cuts: 3 jets with $p_T > 200$ GeV
a fourth jet with $p_T > 100$ GeV
circularity, $S_T > 0.2$



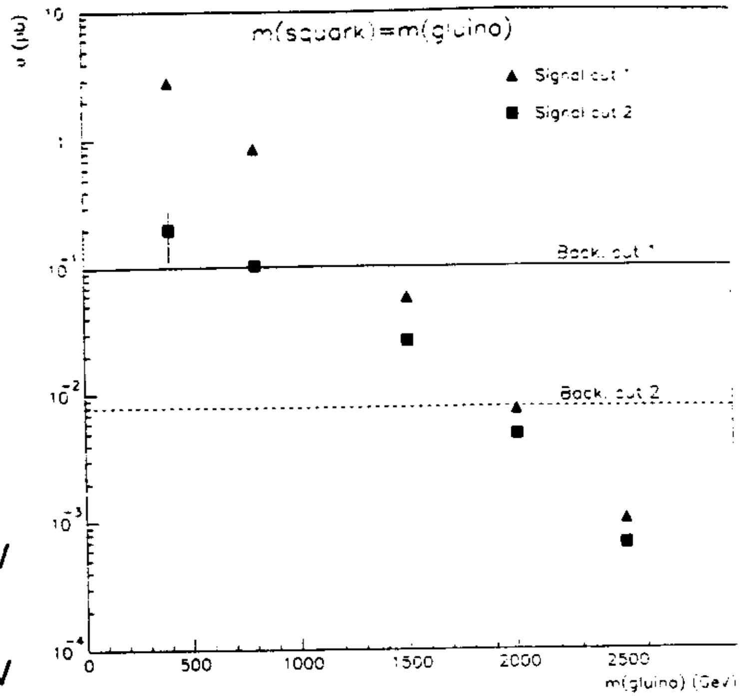
Black squares show $d\sigma/dp_T$ for 5-jet events where at least 4 jets pass the cuts and the 5th jet falls in the calorimeter crack region end-cap / forward ($\Delta\eta = 0.1$ at $|\eta| = 3$)

==> Instrumental background is not a problem for $E_T^{miss} > 300$ GeV

Gluinos and squarks in E_T^{miss} + jets channel

$\tan\beta = 2$, $\mu = -440$ GeV, $m_t = 140$ GeV, $m_{H^+} = 500$ GeV

Cross section for signal and backgrounds (pb)



common mass (GeV)

Cuts as above plus:

Cut 1:
$E_T^{miss} > 300$ GeV

Cut 2:
$E_T^{miss} > 600$ GeV

Mass reach ($S/\sqrt{B} > 5$)

		10^3 pb^{-1}	10^4 pb^{-1}	10^5 pb^{-1}
$m(\tilde{g}) \approx m(\tilde{q})$:	$m \leq$	1.6 TeV	2.0 TeV	2.3 TeV
$m(\tilde{q}) = 2 \cdot m(\tilde{g})$:	$m(\tilde{g}) \leq$	1.0 TeV	1.25 TeV	1.4 TeV
$m(\tilde{g}) = 2 \cdot m(\tilde{q})$:	$m(\tilde{q}) \leq$	0.75 TeV	1.0 TeV	1.2 TeV

For any mass-relation squarks and/or gluinos can be seen with a significance >> 10 down to 300 GeV for 10^3 pb^{-1}

- ☐ ion collider

Study of strongly interacting matter at extreme densities

➡ demonstrate the transition from hadronic matter to a plasma of deconfined quarks and gluons (QGP).

LHC will have a unique potential in this field. It will be a natural extension of the ion programme presently carried out at the SPS.

The LHC will provide

- higher energy densities
- over larger volumes
- in a new baryonic-free region

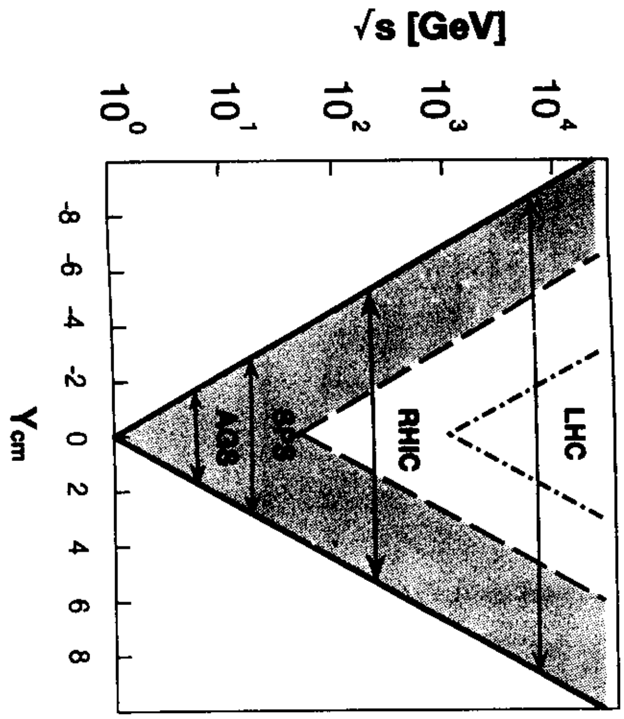
$\varepsilon_o \approx (dE_T/dy) / (\pi r_o^2 A^{2/3} \tau) \approx \ln s$

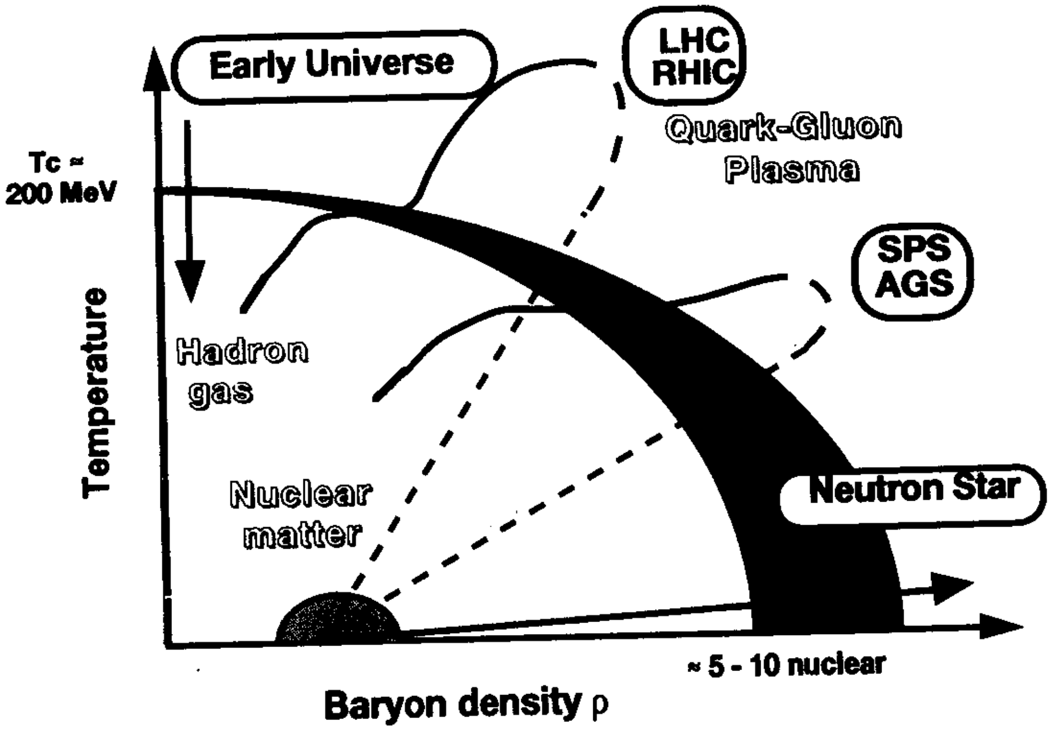
$\pi r_o^2 A^{2/3}$: 150 fm² in Pb-Pb

τ: length of $\Delta y \approx 1$, i.e. formation time ≈ 1 fm

$V_c = V_o\, \varepsilon_o / \varepsilon_c$

$V_f = V_o\, \varepsilon_o / \varepsilon_{n.m.}$



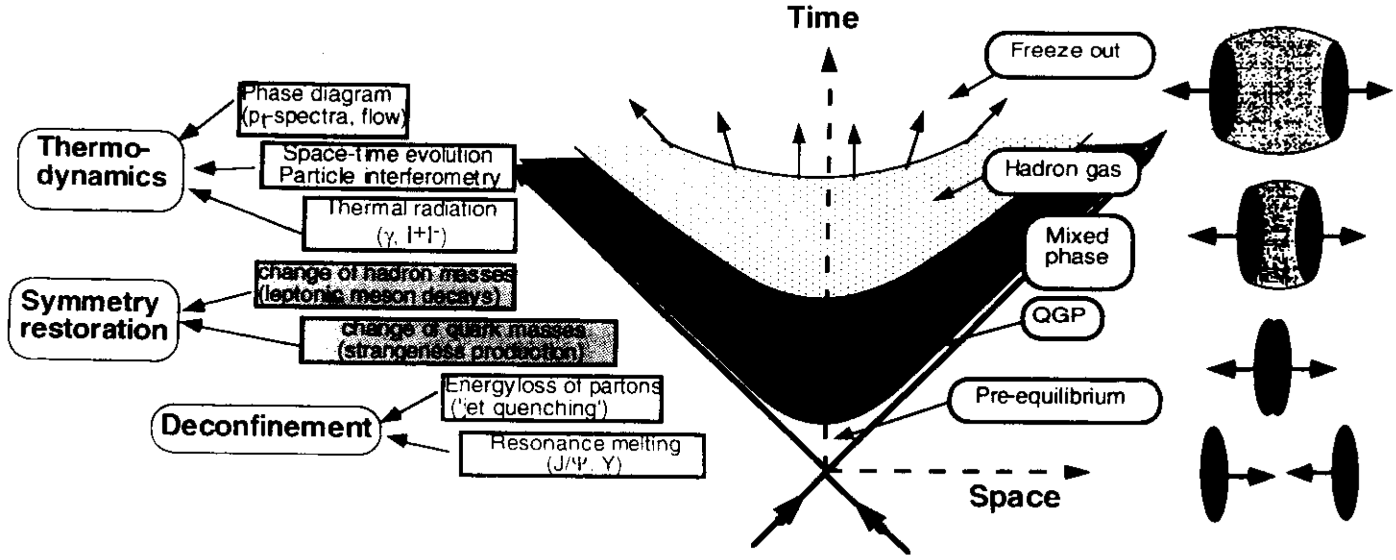


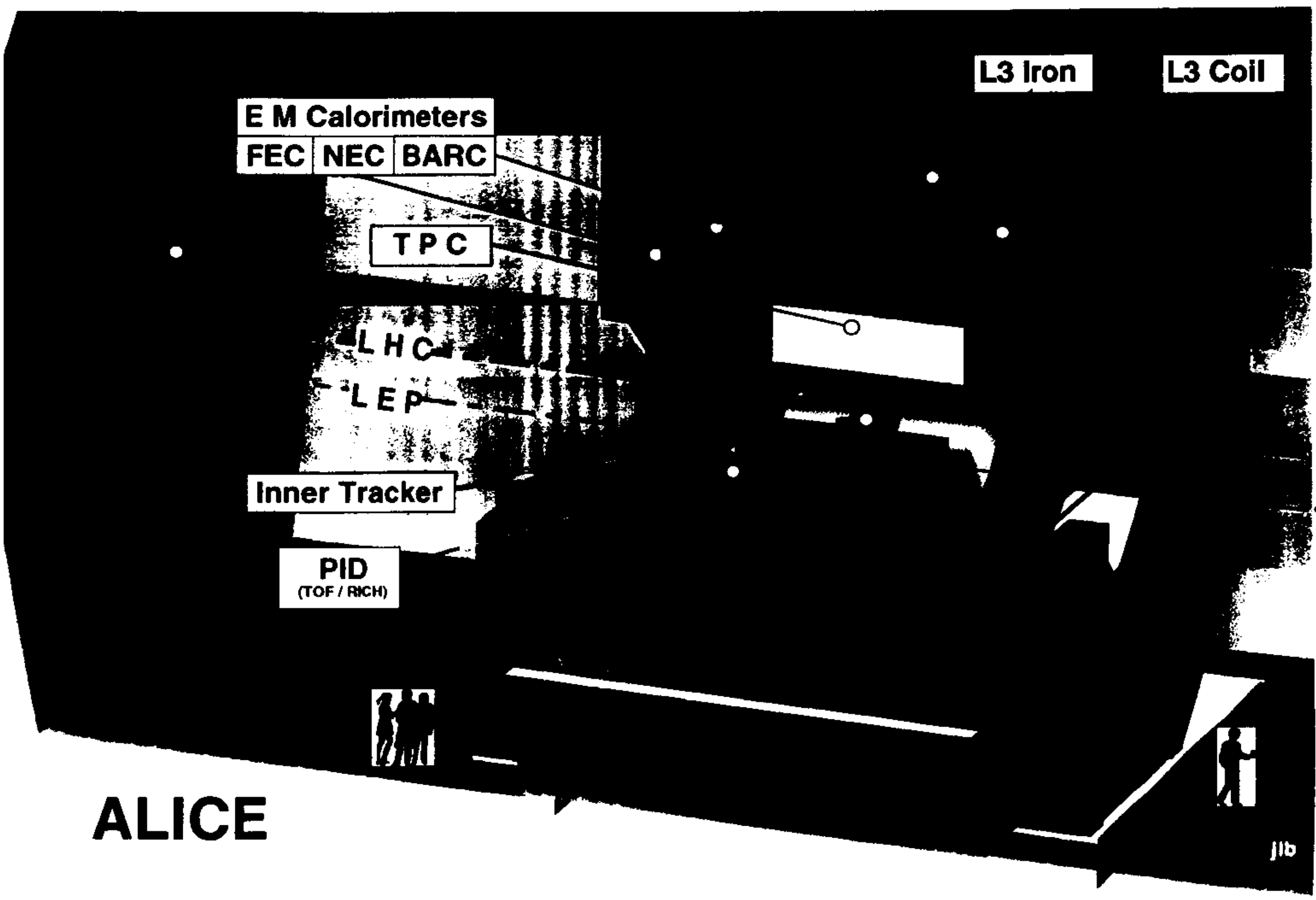
$\sqrt{s}$	dn/dy	ε [GeV/fm³]	T [MeV]	V_c [fm²]	T_c [fm/c]	V_f [fm³]	R_f [fm]
17 (SPS)	800	2.5	190	150	1	3×10^4	14
200 (RHIC)	1500	4.7	220	600	3	8×10^4	18
6300 (LHC)	2500	7.8	250	1200	5	2×10^5	25

➪ LHC will safely provide the energy densities and temperatures of nuclear matter required for the transition to a QGP. How to prove ?

Heavy quark vector mesons are the most promising probes for the primordial QGP state. The suppression of J/Ψ production in heavy ion collisions was predicted and observed at the SPS. Alternative explanations, however, cannot be ruled out Comparing J/Ψ, Ψ ', Y , Y' and X states can decide between the QGP explanation and the other ones. LHC in this respect unique. Only place where the required statistics for Y and Y' can be achieved.

Signals


Time
Space
Freeze out
Hadron gas
Mixed phase
QGP
Pre-equilibrium
Thermo-dynamics
Symmetry restoration
Deconfinement
Phase diagram (p_T-spectra, flow)
Space-time evolution Particle interferometry
Thermal radiation (γ, l^+l^-)
change of hadron masses (leptonic meson decays)
change of quark masses (strangeness production)
Energyloss of partons ('jet quenching')
Resonance melting (J/Ψ, Υ)


L3 Iron
L3 Coil
E M Calorimeters
FEC
NEC
BARC
T P C
L H C
L E P
Inner Tracker
PID
(TOF / RICH)
ALICE
jlb

ALICE

First referee reports (Kajantie, London, Pretzl)

Average central event ($\Delta y=1$)

$\approx 1000\ \pi^+$ (but predictions between 600-4000)		Energy flow
$\approx 1000\ \pi^-$		Interferometry
$\approx 2000\ \gamma$		
≈ 10 e		
$\approx 200\ K^-$		Hadron gas
$\approx 70\ \bar{p}$		
$\approx 20\ \Lambda$		
$\approx 1\ \Xi$		
≈ 0.5 direct γ		Thermal emission
$\approx 0.01\ \rho, \omega, \phi$ -> ee	↑	Chiral symmetry
≈ 0.002 jets E_T =50 GeV		Propagation of q's
$\approx 0.002\ J/\Psi$	ALICE	Color screening
$\approx 2.10^{-5}\ Y$	pp experiments	
$4\ 10^{-7}\ M_{\mu\mu} = 10$	↓	

Ion physics = single event physics ⇨ first 10 events will teach a lot

⇨ B-meson physics a very interesting part of the LHC programme

- measurements of three angles of the CKM unitary triangle
- measurement of x_s
- rare decays ($B^o \rightarrow \mu^+\mu^-; \mu^\pm$ e)

ATLAS and CMS can make significant contributions in particular in measuring sin 2β ($B^o \rightarrow J/\Psi\ K^o_s$), tracking close to beam pipe increaes potential for sin 2α ($B^o \rightarrow \pi\pi$) . However, a dedicated experiment can do significantly better i.e particle ID and better vertex measurement.

⇨ Dedicated Beauty experiments

Three approaches:

- COBEX forward angle colliding beam expt (10-600 mrad)
- LHB extracted beam (bend Si crystal) on Cu target (≤75 mrad)
- GAJET fixed H_2 gasjet target (3.5-87 mrad)

Recent decision by Research Board to ask three collaborations (GAJET, LHB, COBEX) to come with a new Letter of Intent based on a forward colliding beam detector because of intrinsic advantage of higher cross section σ(bb) = 500 μb instead of 1μb and better signal to background ratio ($\sigma(bb)/\sigma_{tot,\ inel.} = 1/140$)

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□ Beauty Physics

Hadron machines prolific sources of heavy quark states. High production rates for beauty particles ➡ dedicated Beauty experiment.

Main goal of such an experiment: CP-violation in the b-quark system. Experimental goal: to define asymmetry

$$A = [N(B^o \to f) - N(\bar{B}^o \to f)]/[N(B^o \to f) + N(\bar{B}^o \to \bar{f})] = \sin 2\phi \cdot \sin(x_q . t/\tau)$$

f is a decay channel which is a CP eigenstate. In particular $B_d^o \to \Psi K_s^o$, $B_d^o \to \pi^+\pi^-$; $B_s^o \to \rho K^o$, $B_s K^+$; $B^{\pm,0} \to DK$ measure three angles of the Cabibbo-Kobayashi-Maskawa matrix unitarity triangle.

LHC asset ➡ large number of BB events

- coll. beam mode ⇨ N(bb) ≈ 5 10^{12}/year
- fixed target mode ⇨ N(bb) ≈ 10^{11}/year

  compared to CESR: 10^6/year, LEP 10^5/year, BMF 10^7/year

But: $\sigma(bb)/\sigma_{tot}$ small and high particle multiplicities in particular for FT experiment. ➡ lower trigger and tagging efficiency at LHC than at BMF (≈ 10^{-4} ATLAS/CMS; ≈10^{-2} ded. Beauty expts; 0.25 BMF)

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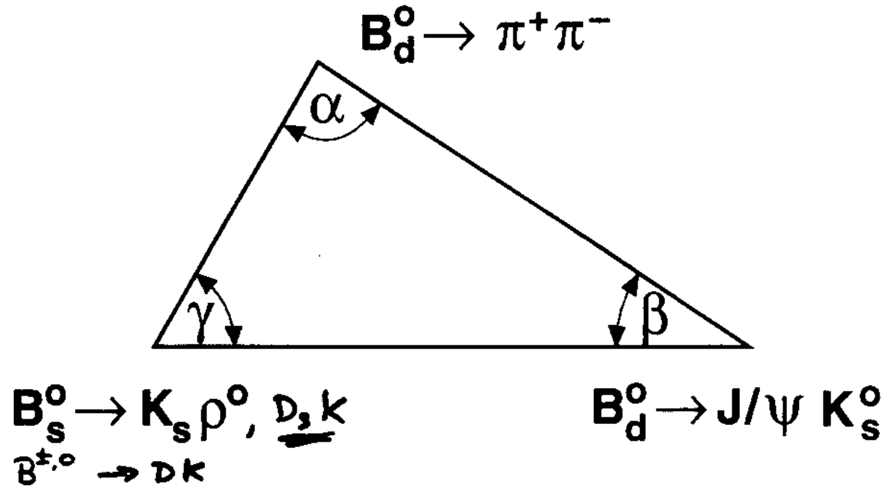
CP - Violation in the B $\bar{\textbf{B}}$ System

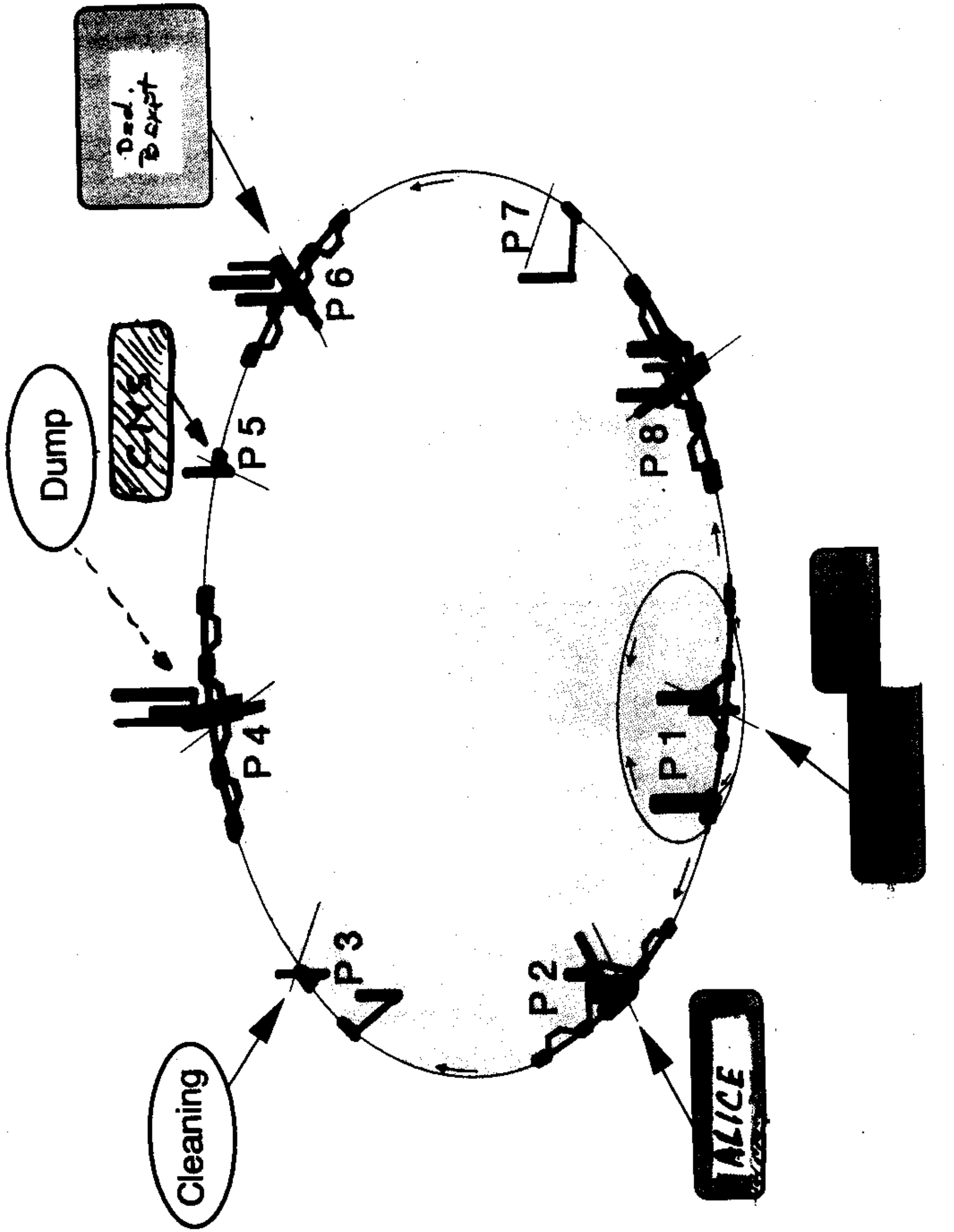
CKM Unitary Triangle



expected error on angle measurement

	Δ sin2α	Δ sin2β	Δ sin2γ	x_s
ATLAS	0.[illegible]	0.035	–	<35
CMS	0.08	0.040	–	?
COBEX	0.02	0.019	0.07 ($D_s K$)	60±.04
GAJET	0.03	0.038	0.10	50±.0[illegible]
LHB	0.04	0.027	0.08 ($D_s K$)	40±.0

y151Pauss



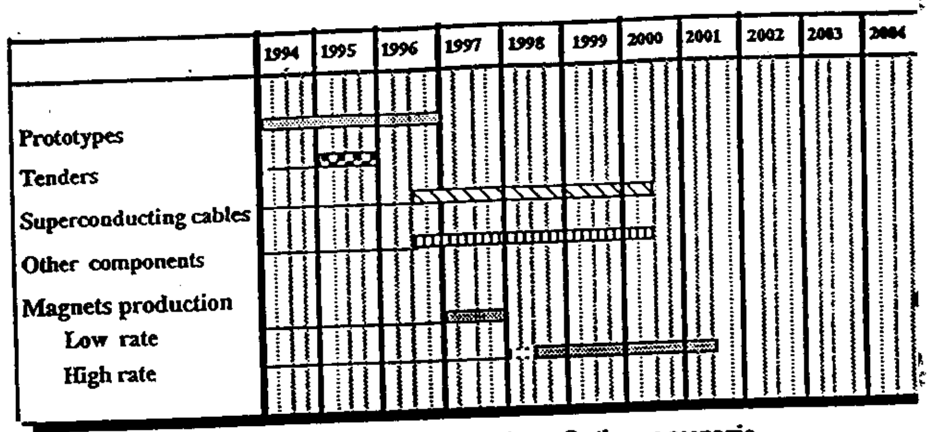


Figure 1 - LHC Dipole fabrication planning - Optimum scenario

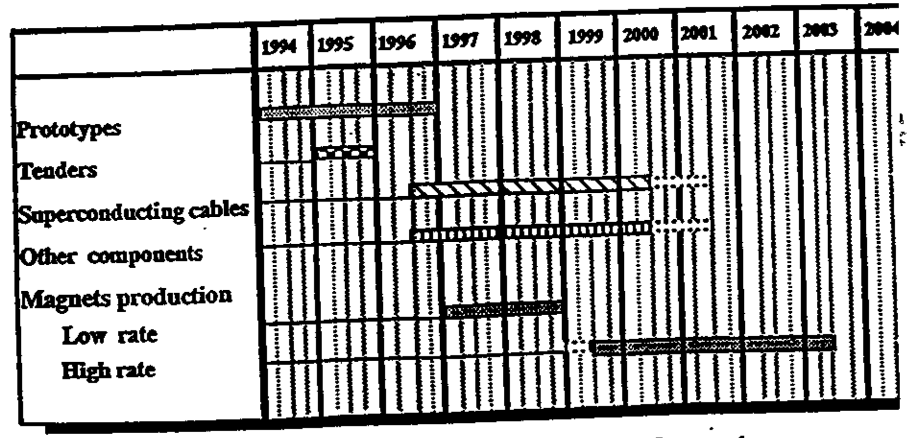


Figure 2 - LHC Dipole fabrication planning - Stretched scenario