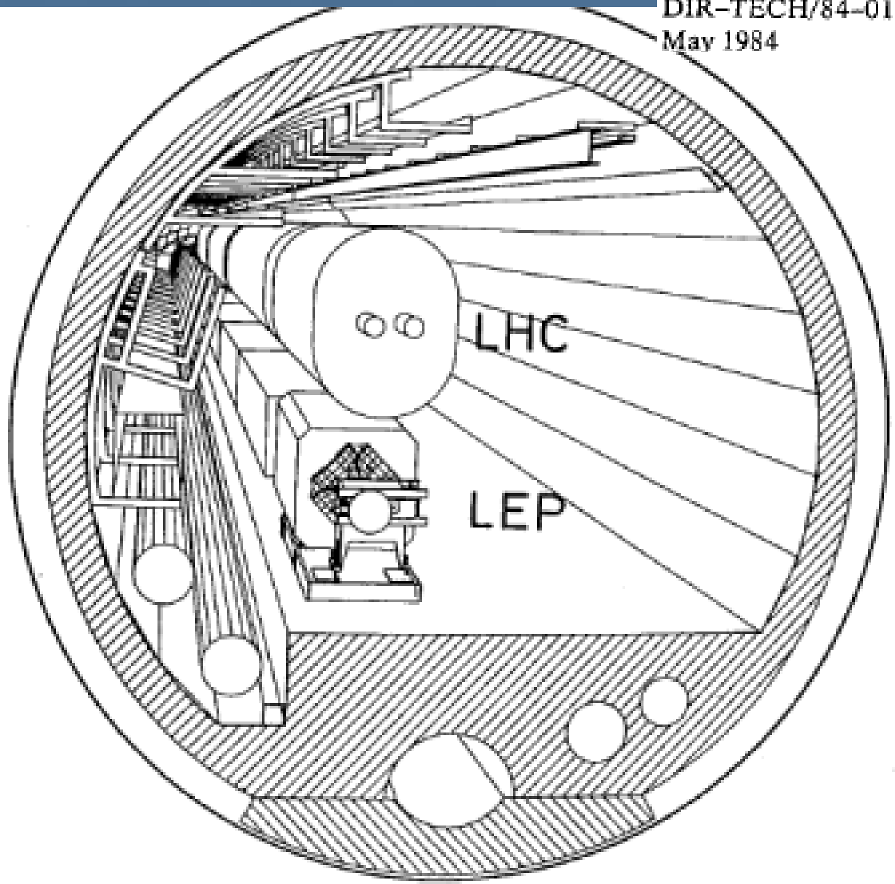
First year at LHC

A.Zaitsev

IHEP, Protvino

DIR-TECH/84-01
May 1984



LARGE HADRON COLLIDER
IN THE LEP TUNNEL

A feasibility study of possible options

by

The CERN Machine Group

- 1984 : first studies
- 1990 : Aachen workshop
- Summer 1992 :Evian workshop
- End 1992:
ATLAS and CMS Letters Of Intent
- No very significative
change of detector design since
- 1994 The CERN Council approves the construction of the LHC
- 1998 The first prototype magnet with a 15 metre nominal length is tested

1981 International Symposium on Lepton and Photon Interactions at High Energies

Bonn, August 24-29, 1981

PARTICLE PHYSICS PROSPECTS: AUGUST ' 81

L.B. OKUN

At present the scalarland exists only in the dreams of theoreticians, who describe it in many ways, which are quite far from being selfconsistent. The aim of this talk is to urge experimentalists and accelerator builders to join their efforts in discovering this land, which lies below and not far above 1 TeV.

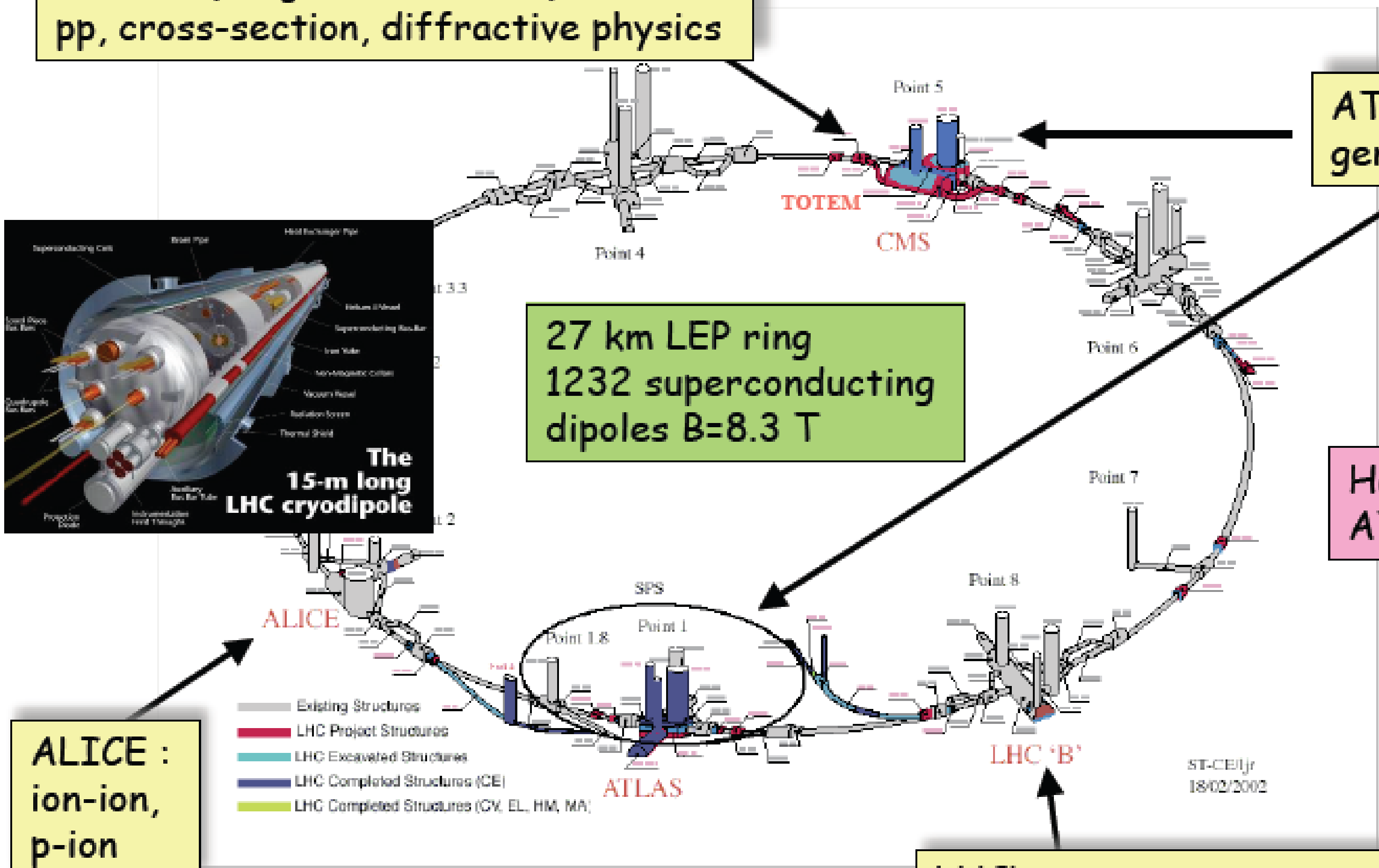
During the last 50 years physicists solve problems by inventing hypothetical particles, which eventually become real. It took 14 years to discover the first hypothetical spinless particle: the pion. It is now precisely 14 years that we live with a new type of hypothetical spinless bosons. Isn't it about time to discover them?

LHC

- pp $\sqrt{s}$ = 14 TeV $L_{design} = 10^{34}\ cm^{-2}\ s^{-1}$ (after 2009)
  $L_{initial} \leq$ few x $10^{33}\ cm^{-2}\ s^{-1}$ (until 2009)
- Heavy ions (e.g. Pb-Pb at $\sqrt{s}$ ~ 1000 TeV)

TOTEM (integrated with CMS):
pp, cross-section, diffractive physics

ATLAS and CMS :
general purpose



27 km LEP ring
1232 superconducting
dipoles B=8.3 T

Here:
ATLAS and CMS

ALICE :
ion-ion,
p-ion

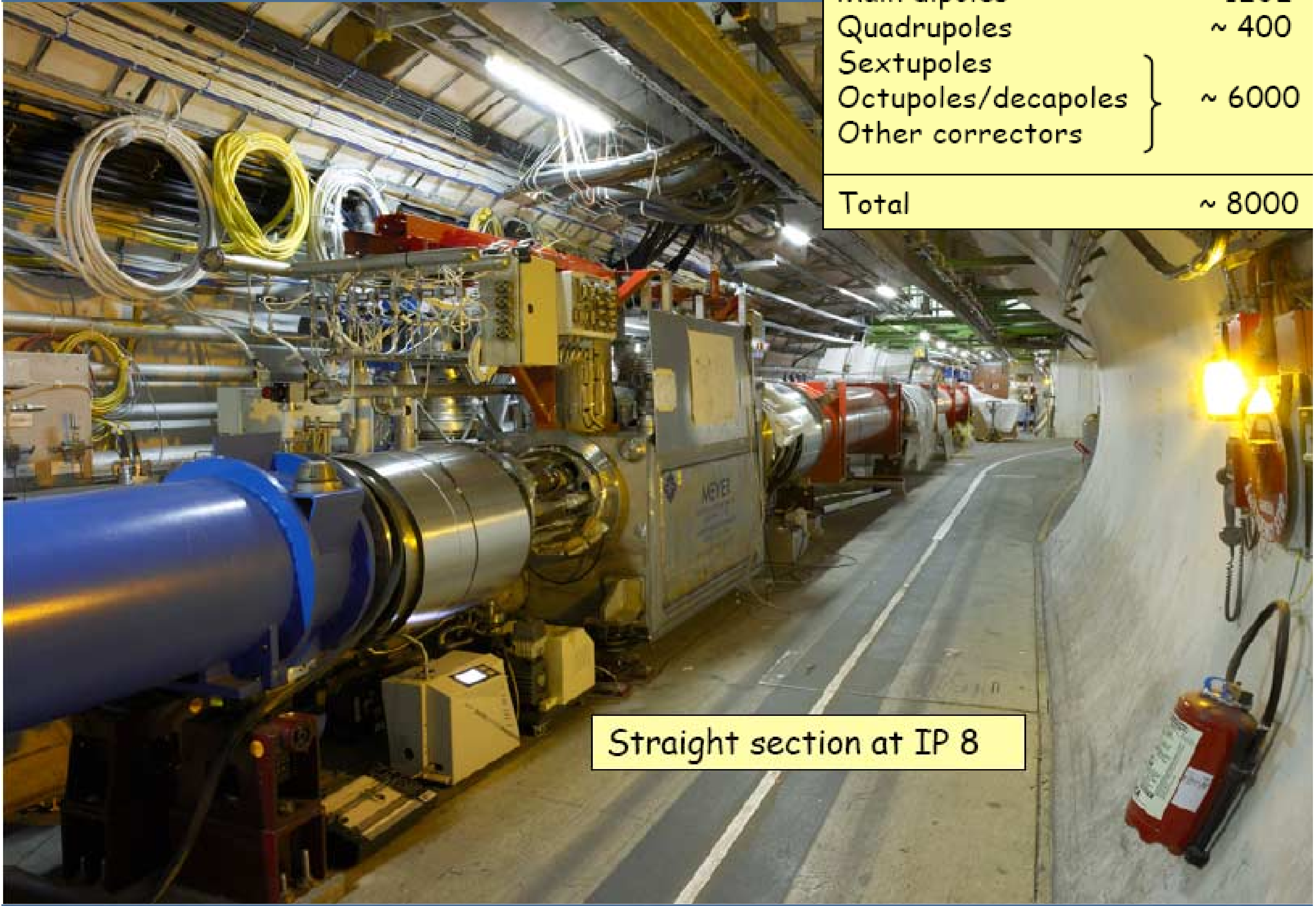
LHCb :
pp, B-physics, CP-violation

Russian Institutions in LHC

- Russian Center "Kurchatov Institute"
- Russian Academy of Sciences
  - Budker INP (Novosibirsk)
  - Lebedev PI (Moscow)
  - Konstantinov PNPI (St.Petersburg)
  - INR (Moscow)
- Agency of Atomic Energy
  - IHEP (Protvino)
  - ITEP (Moscow)
  - RFNC "VNIIEF" (Sarov)
- Moscow State University
  - Skobeltsyn INP (Moscow)
- Ministry of Education and Sciense
  - MEPhI (Moscow)
  - St.-Petersburg State University (St.Petersburg)

JINR (Dubna) in close cooperation with RF Institutes

Main dipoles	1232
Quadrupoles	~ 400
Sextupoles Octupoles/decapoles Other correctors	~ 6000
Total	~ 8000



Straight section at IP 8

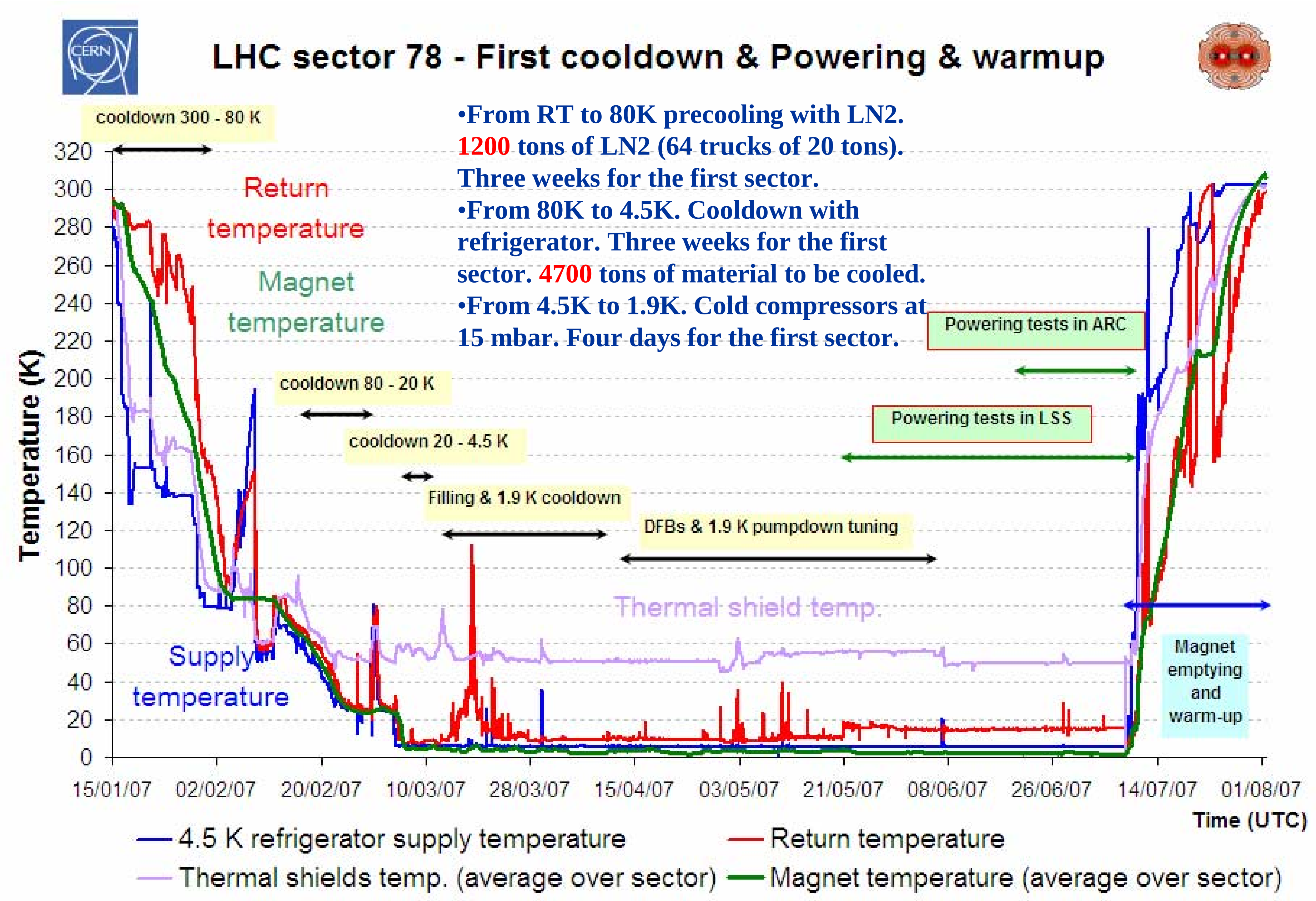

Straight section at IP 1

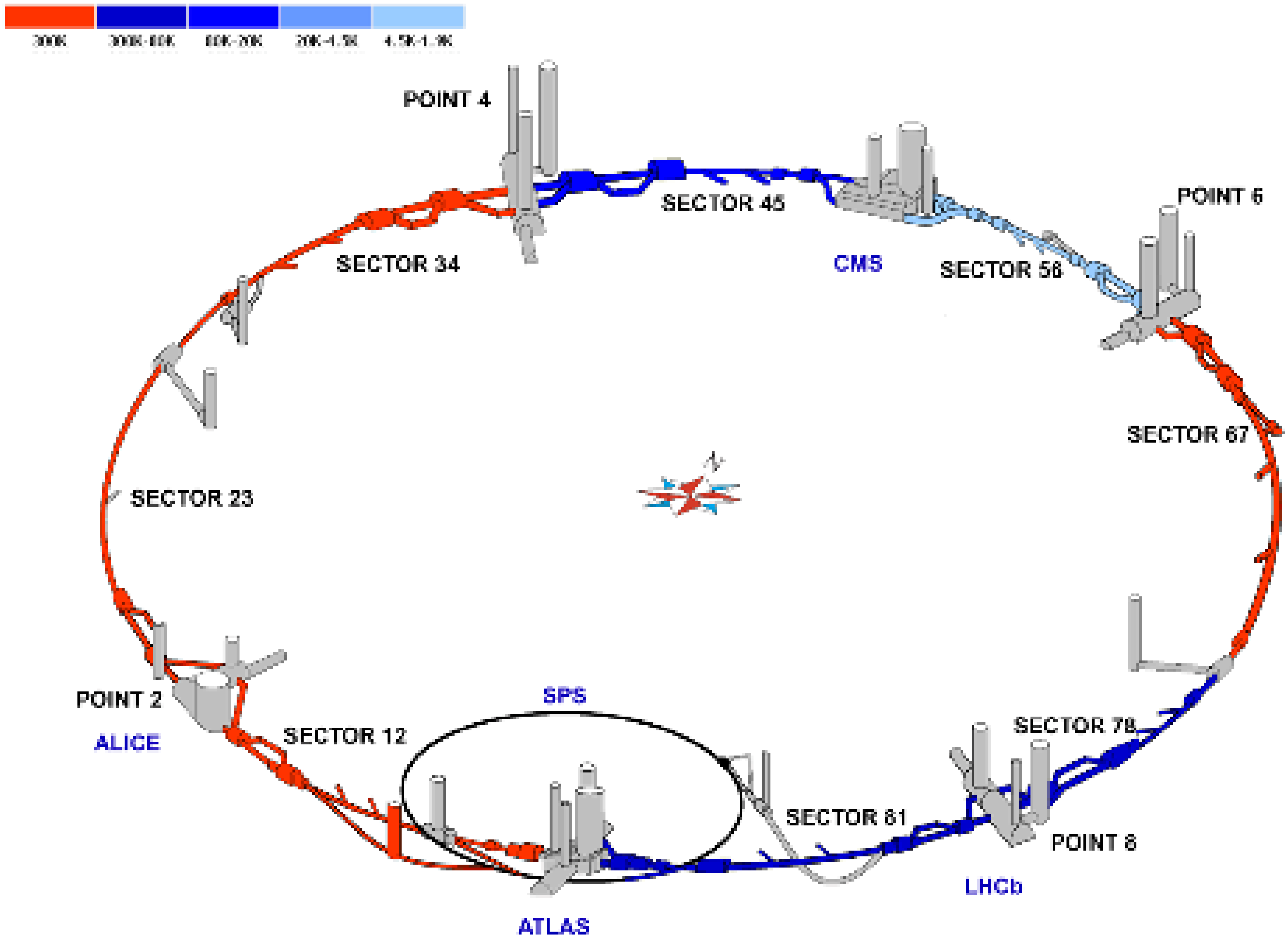

RF cavities
28.09.2006

Descent of the last magnet, 26 April 2007

30'000 km underground at 2 km/h!

First cooldown and warm up of Sector 7-8




POINT 4
SECTOR 45
CMS
POINT 6
SECTOR 34
SECTOR 56
SECTOR 67
SECTOR 23
SPS
POINT 2
ALICE
SECTOR 12
SECTOR 78
SECTOR 81
POINT 8
LHCb
ATLAS

- **The whole ring will be closed and pressure tested by mid December. Cooldown of 4 sectors started before the end of the year.**

- **May-July 2008: Beam commissioning to 7 TeV**

I. Pilot physics run

- First collisions
- 43 bunches, no crossing angle, no squeeze, moderate intensities
- Push performance (156 bunches, partial squeeze in 1 and 5, push intensity)
- Performance limit 10^{32} cm-2 s-1

II. 75ns operation

- Establish multi-bunch operation, moderate intensities
- Relaxed machine parameters (squeeze and crossing angle)
- Push squeeze and crossing angle
- Performance limit 10^{33} cm-2 s-1 (event pileup)

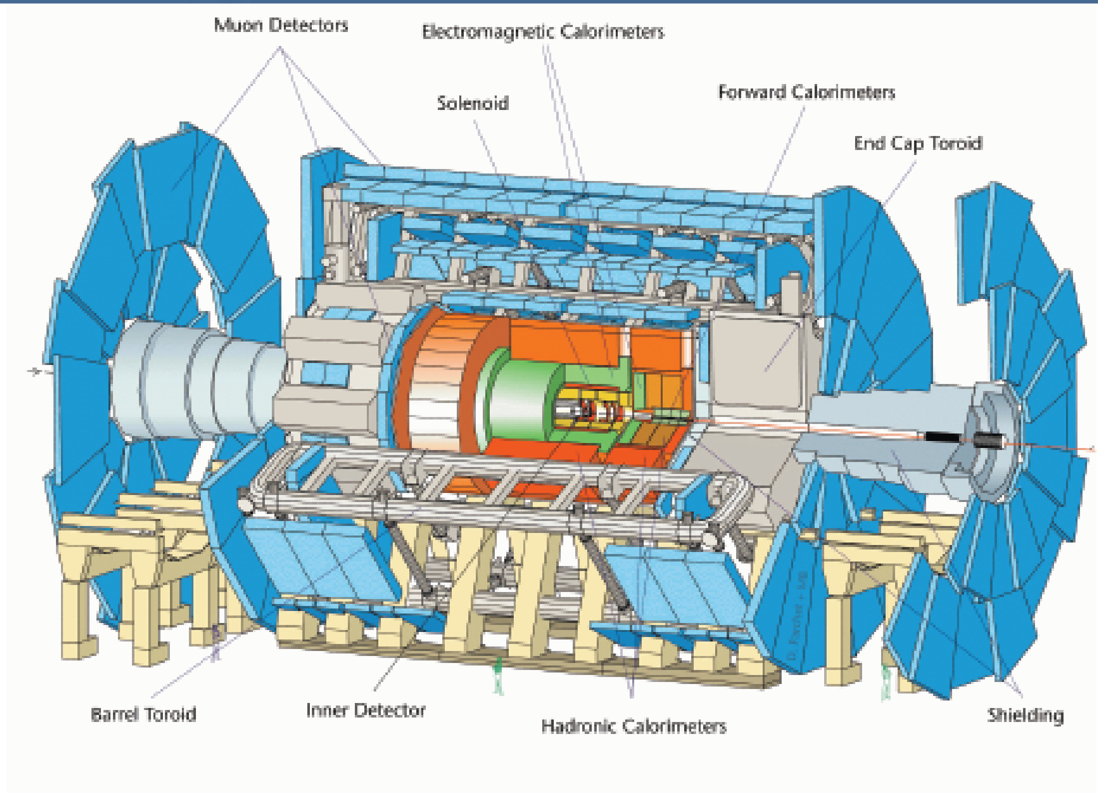
III. 25ns operation I

- Nominal crossing angle
- Push squeeze
- Increase intensity to 50% nominal
- Performance limit 2 10^{33} cm-2 s-1

IV. 25ns operation II

- Push towards nominal performance

ATLAS

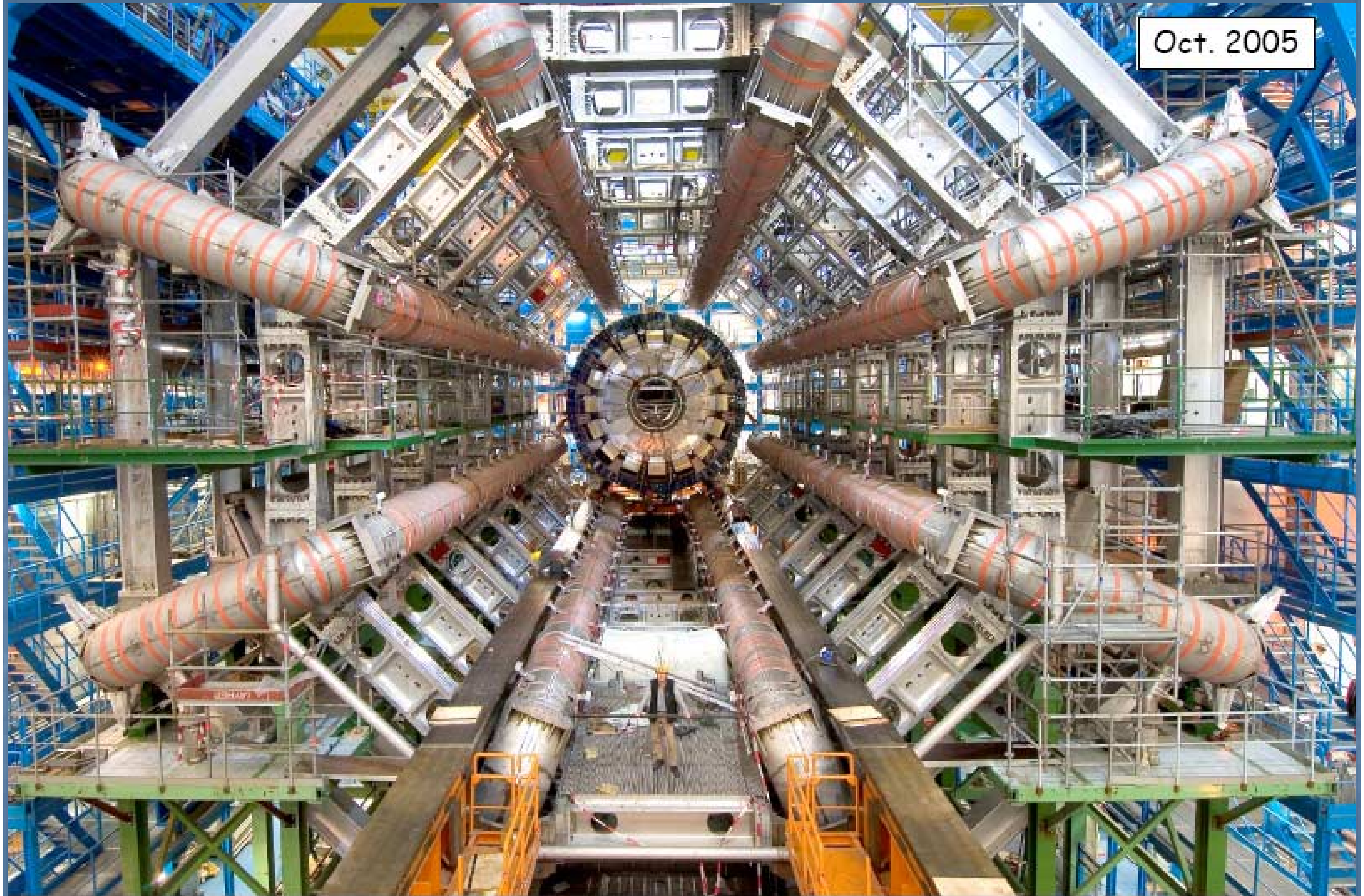


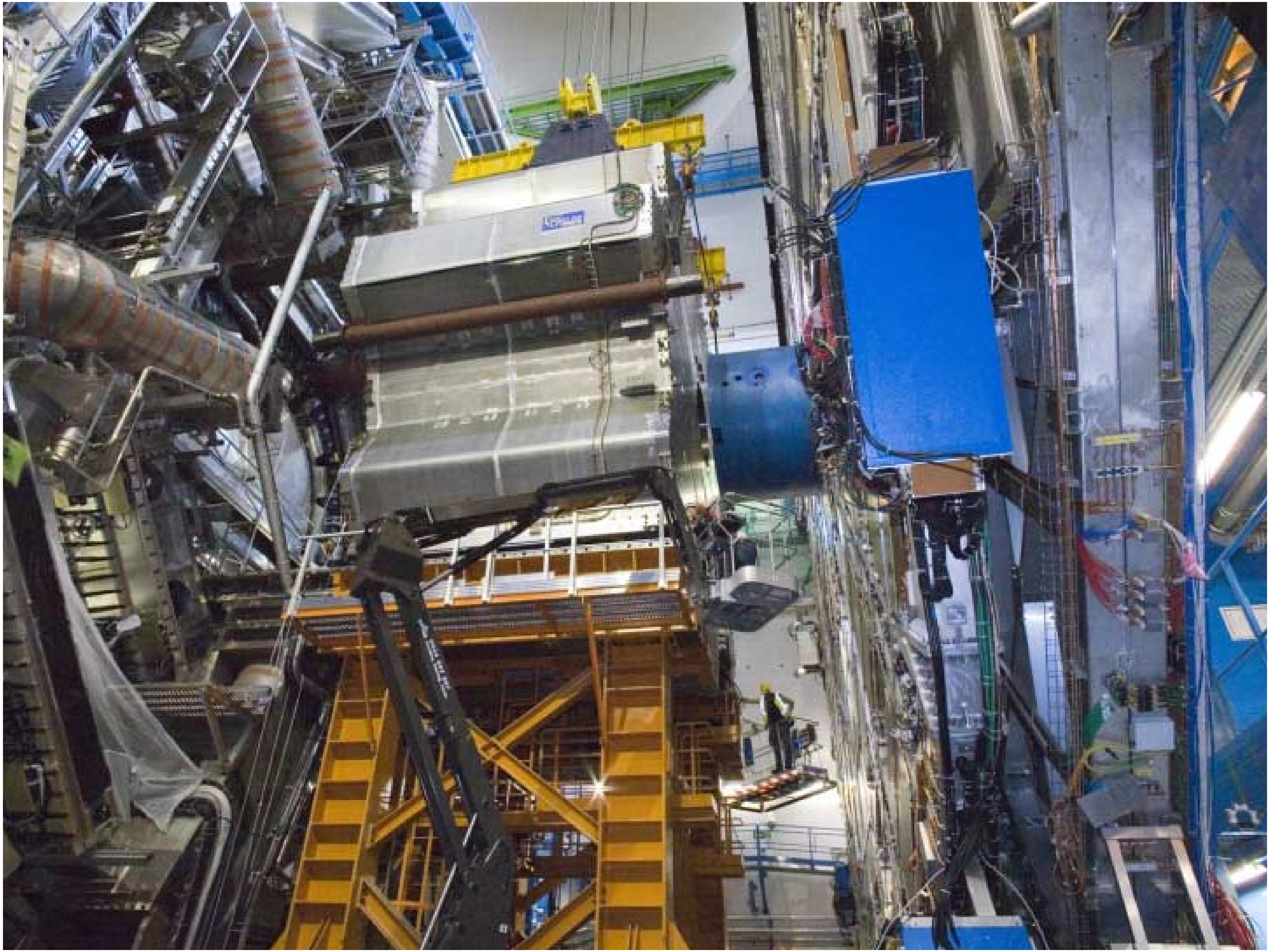
Length : ~45 m
Radius : ~12 m
Weight : ~ 7000 tons
Electronic channels : ~ 10^8
~ 3000 km of cables

- Tracking ($|\eta|<2.5$, B=2T) :
  -- Si pixels and strips
  -- Transition Radiation Detector (e/π separation)

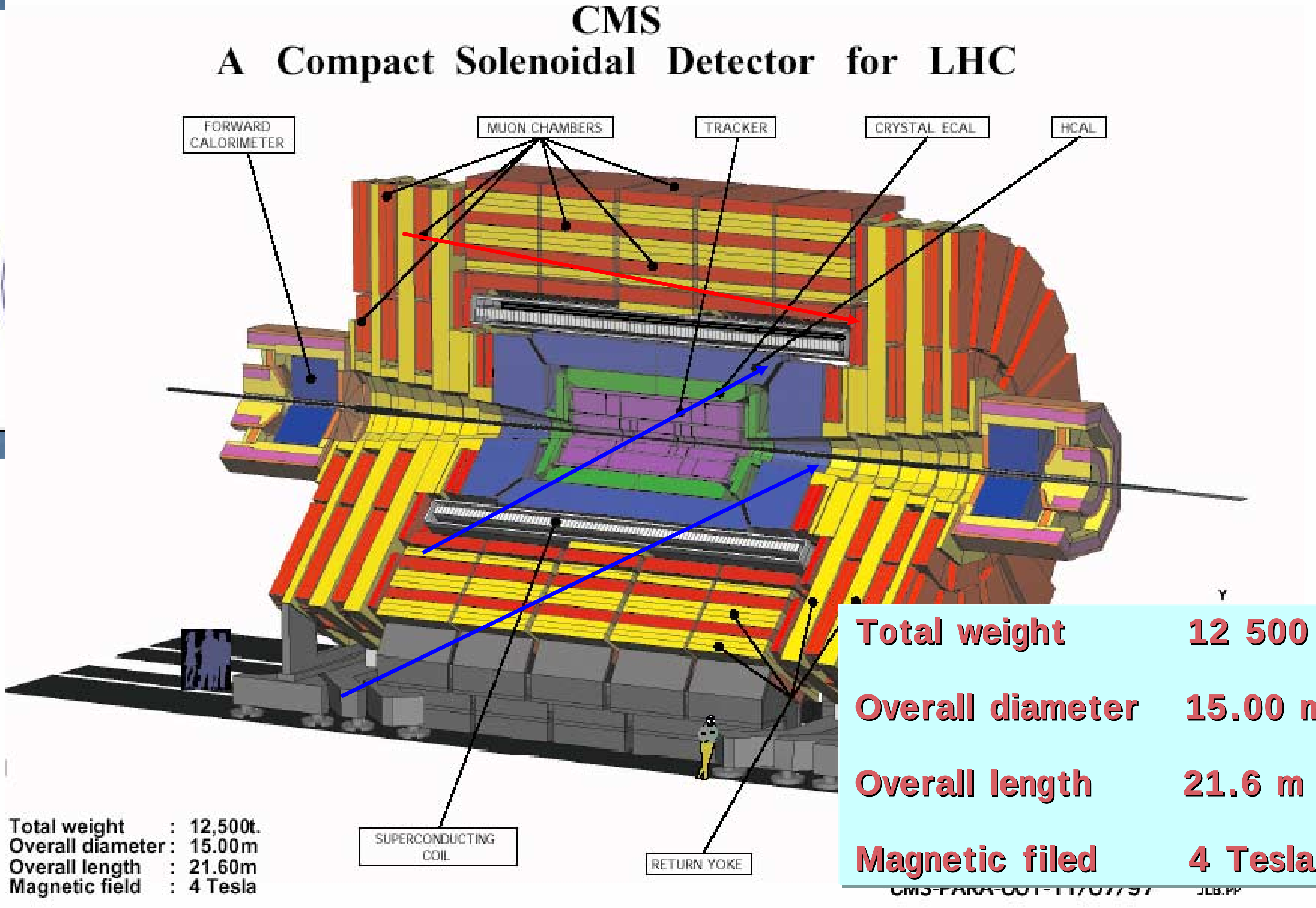
- Calorimetry ($|\eta|<5$) :
  -- EM : Pb-LAr with Accordion shape
  -- HAD: Fe/scintillator (central), Cu/W-LAr (fwd)

- Muon Spectrometer ($|\eta|<2.7$) :
  air-core toroids with muon chambers


Oct. 2005



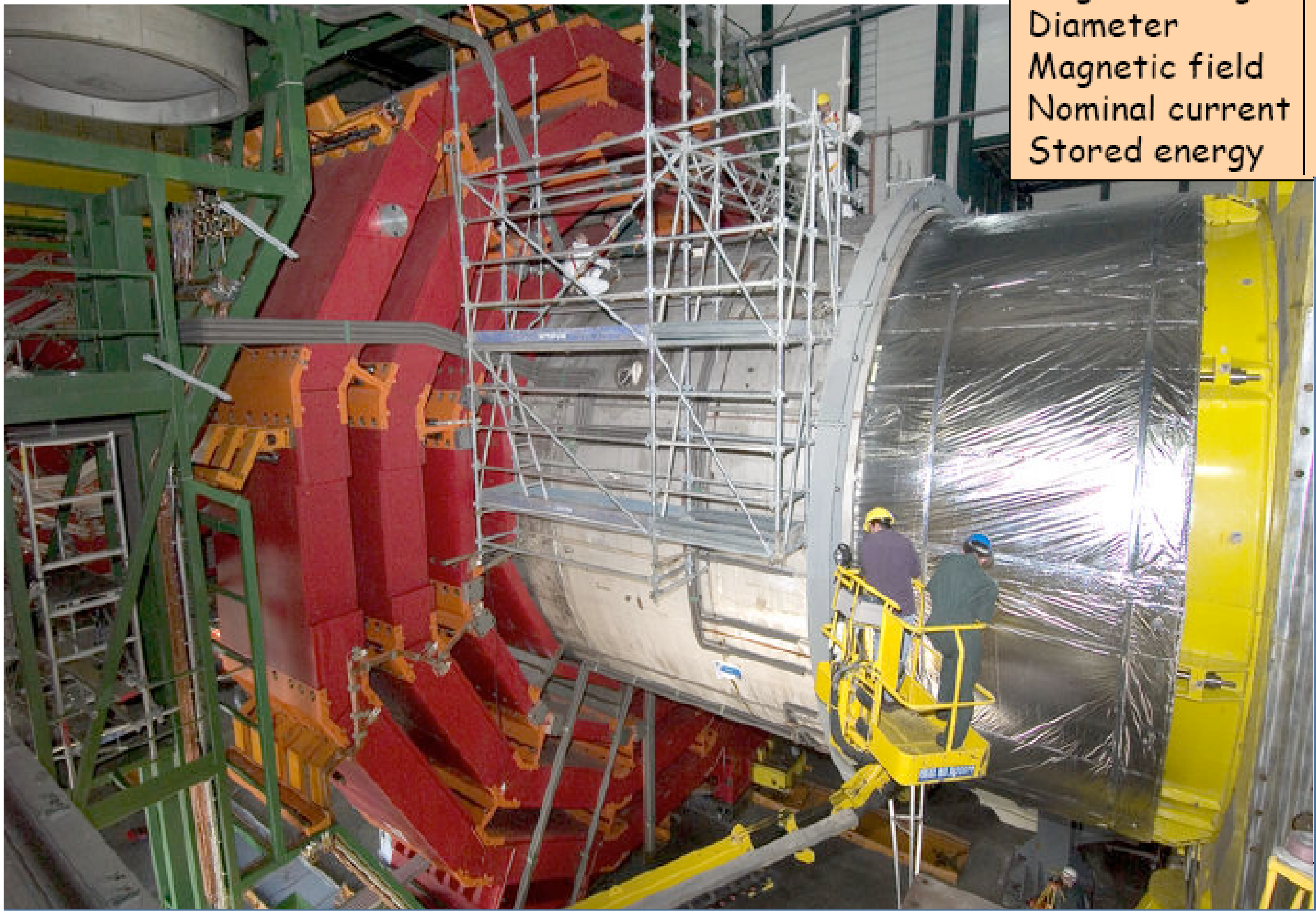
The Compact Muon Solenoid



Total weight	12 500 t
Overall diameter	15.00 m
Overall length	21.6 m
Magnetic filed	4 Tesla

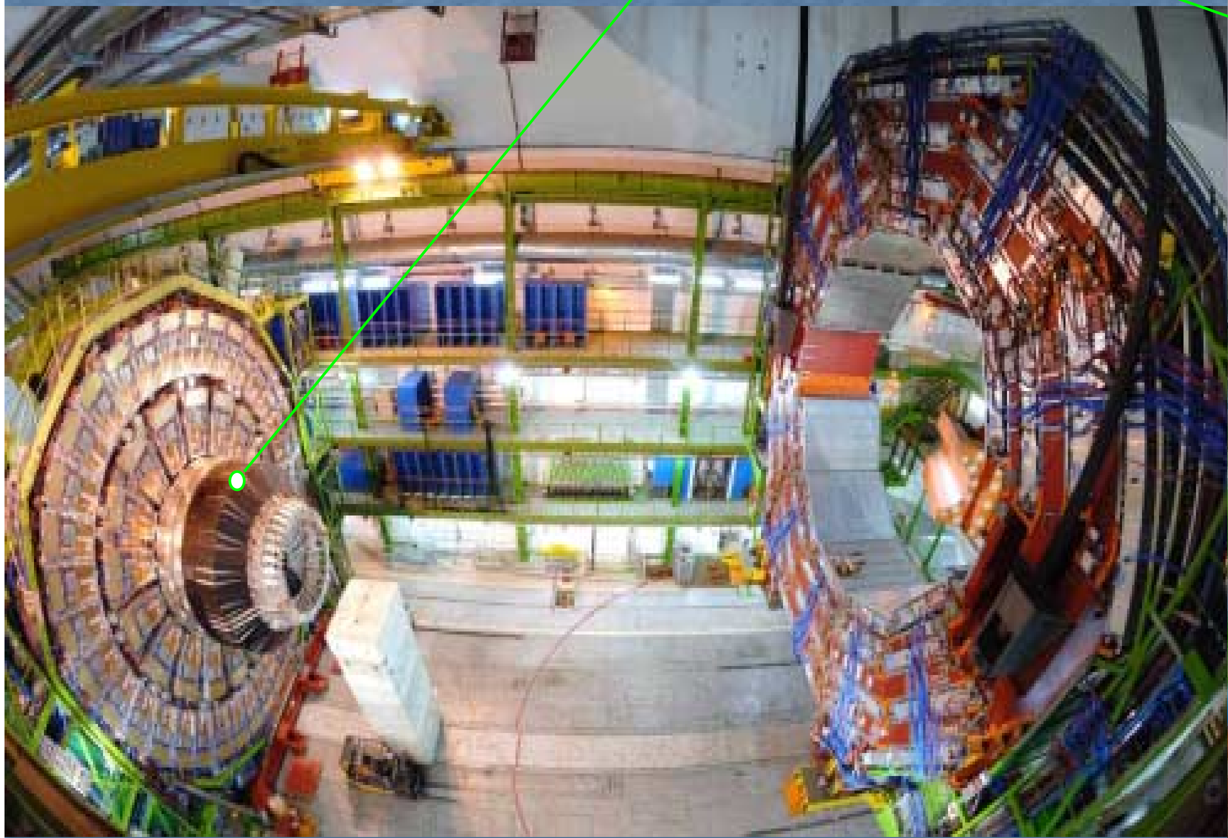
At the surface, solenoid inserted on 14 Sept. 2005;
cooled down to 4.5 K in February 2006;
ramping up the current, now at 12.5 kA (2.5 T)
→ magnetic test/field map starting Aug./Sept. 2006 (MTCC)

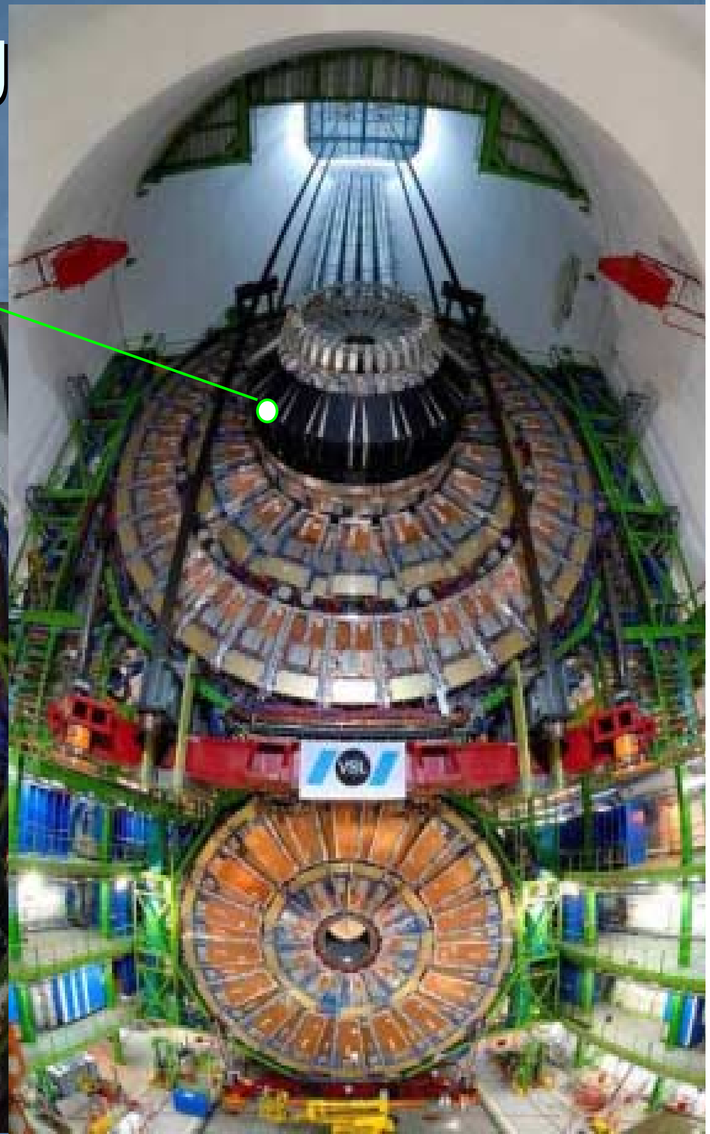
Magnetic length	12.5 m
Diameter	6 m
Magnetic field	4 T
Nominal current	20 kA
Stored energy	2.7 GJ



ENDCAP Hadron calorimeter HE+ and Forward MUON ME+1/1 at YE+1 disk

CMS UX5 Lowering





	ATLAS	CMS
MAGNET (S)	Air-core toroids + solenoid in inner cavity 4 magnets Calorimeters in field-free region	Solenoid Only 1 magnet Calorimeters inside field
TRACKER	Si pixels+ strips TRT → particle identification B=2T $\sigma/pT \sim 5x10^{-4}$ pT □ 0.01	Si pixels + strips No particle identification B=4T $\sigma/pT \sim 1.5x10^{-4}$ pT □ 0.005
EM CALO	Pb-liquid argon $\sigma/E \sim 10\%/\sqrt{E}$ uniform longitudinal segmentation	$PbWO_4$ crystals $\sigma/E \sim 2\text{-}5\%/\sqrt{E}$ no longitudinal segm.
HAD CALO	Fe-scint. + Cu-liquid argon (10 λ) $\sigma/E \sim 50\%/\sqrt{E}$ □ 0.03	Cu-scint. (> 5.8 λ +catcher) $\sigma/E \sim 100\%/\sqrt{E}$ □ 0.05
MUON	Air → $\sigma/pT \sim 7$ % at 1 TeV standalone	Fe → $\sigma/pT \sim 5\%$ at 1 TeV combining with tracker

With the first physics run in 2008 ($\sqrt{s}$ = 14 TeV) ....

1 fb^{-1} (100 pb^{-1}) ≡ 6 months (few days) at L= 10^{32} $cm^{-2}s^{-1}$
with 50% data-taking efficiency
→ may collect a few fb^{-1} per experiment by end 2008

Channels (examples ...)	Events to tape for 100 pb^{-1} (per expt: ATLAS, CMS)	Total statistics from some of previous Colliders
$W \to \mu\nu$	~ 10^6	~ 10^4 LEP, ~ 10^6 Tevatron
$Z \to \mu\mu$	~ 10^5	~ 10^6 LEP, ~ 10^5 Tevatron
$tt \to W b W b \to \mu\nu + X$	~ 10^4	~ 10^4 Tevatron
QCD jets p_T > 1 TeV	> 10^3	---
$\tilde{g}\tilde{g}$ m = 1 TeV	~ 50	---

With these data:

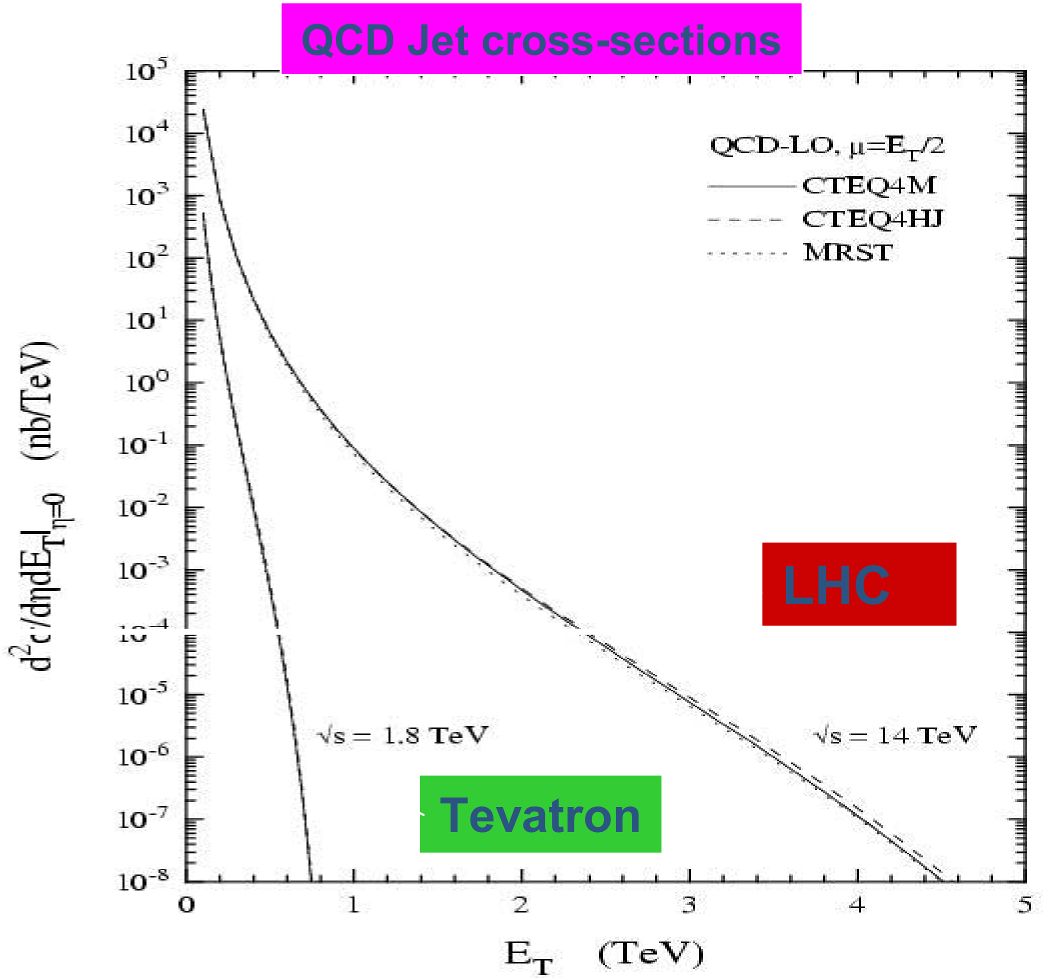
- Understand and calibrate detectors in situ using well-known physics samples
  e.g. - $Z \to ee, \mu\mu$ tracker, ECAL, Muon chambers calibration and alignment, etc.
  - $tt \to bl\nu\ bjj$ jet scale from $W \to jj$, b-tag performance, etc.

- Measure SM physics at $\sqrt{s}$ = 14 TeV : W, Z, tt, QCD jets ...
  (also because omnipresent backgrounds to New Physics)

Prospects for physics in 2008-2009 (examples …)

We will jump immediately into a new territory …

10 events with 100 pb^{-1}



The first measurements and underlying events

➢Candidate for very early measurement

few 10^4 events enough to get charged and energy density ⇒

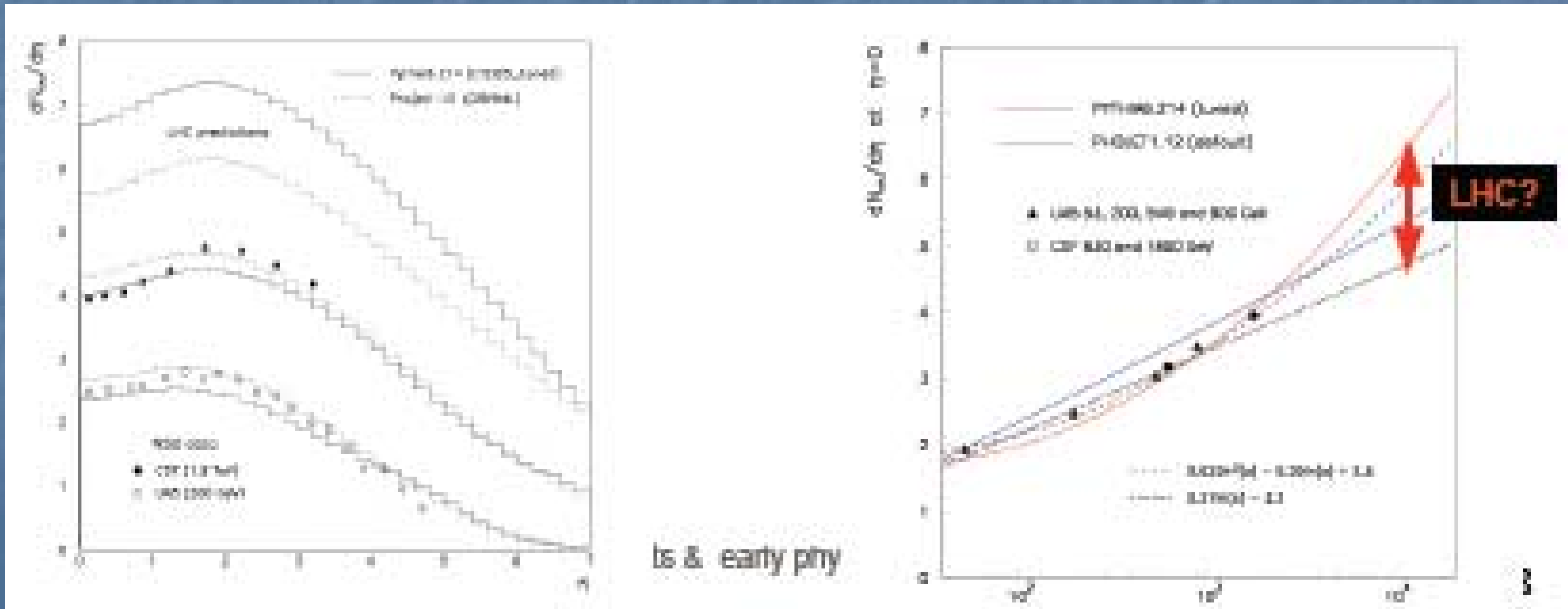
15 minutes of good data !

- ✓ **Topological structure of p-p collision from charged tracks**
- ✓ **The leading jet defines a direction in the ϕ plane**

Main observables:

+ $dN/d\eta d\phi$, charged density

+ $d(PT_{sum})/d\eta d\phi$, energy density



QCD Studies

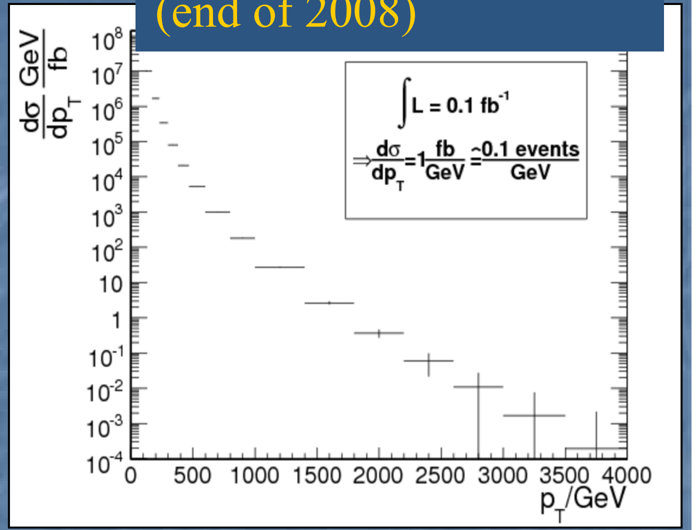
Aims:

- **Measurements of α_s**
- **Information on PDF's at small-x and large-Q^2**
- **Study QCD dynamics at small-x**
- **Measurements of jet shapes and jet fragmentation function**
- **Calibration by physics processes**

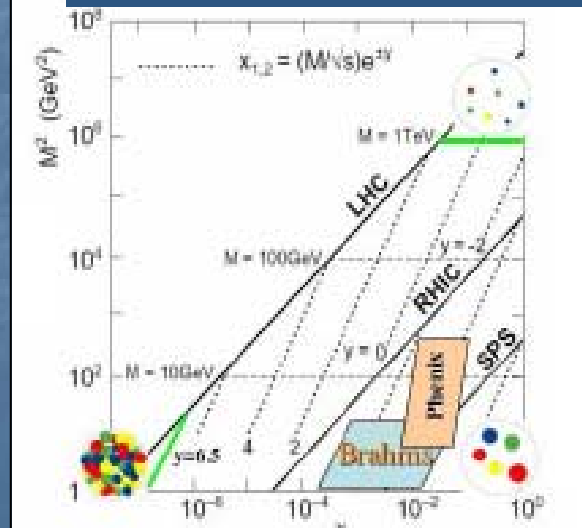
Observables

- ✓ **inclusive jet and dijets**
- ✓ **γ + jet and diphotons**
- ✓ **Z + jets**
- ✓ **bbbar jets**

Jet x-section with 0.1 fb^{-1} (end of 2008)



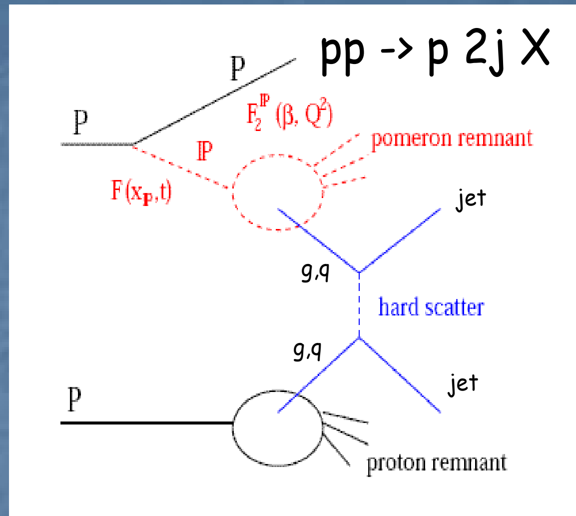
Q^2- and x- region at CMS



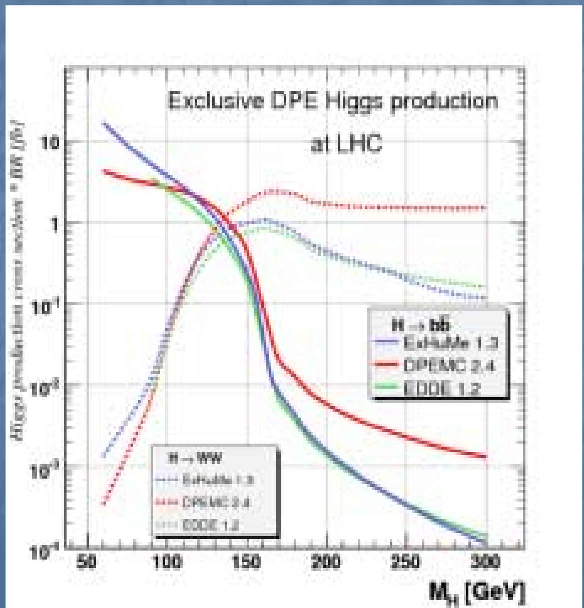
JINR, ITEP, MSU, PNPI

Diffraction/Forward Physics

- **Study of 2 jet production in hard single diffraction (one pomeron exchange)**
- **Study of 2 jet production in central diffraction (double pomeron exchange)**
- **Study of the underlying event in diffractive topologies**



IHEP, MSU, PNPI



EWK Physics

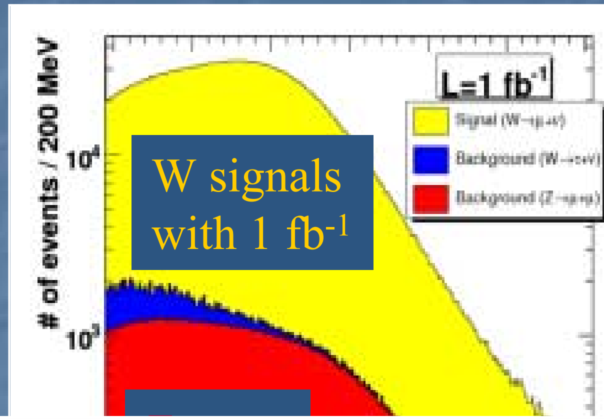
Large W (Z) cross section: 10 nb (1 nb) and clean leptonic signatures

- **Can be easily selected with high efficiency/purity**
  - 60% efficiency for Z->ee and 52% efficiency for Z->μ μ
  - contamination < 1%
- **Uncertainties with 1 fb^{-1} in the muon channel in detector**

$$\frac{\Delta\sigma}{\sigma}(pp \to Z + X \to \mu^+\mu^- + X) = 0.13\,\% \pm 2.3\,\% \pm \text{lumi uncert.}$$

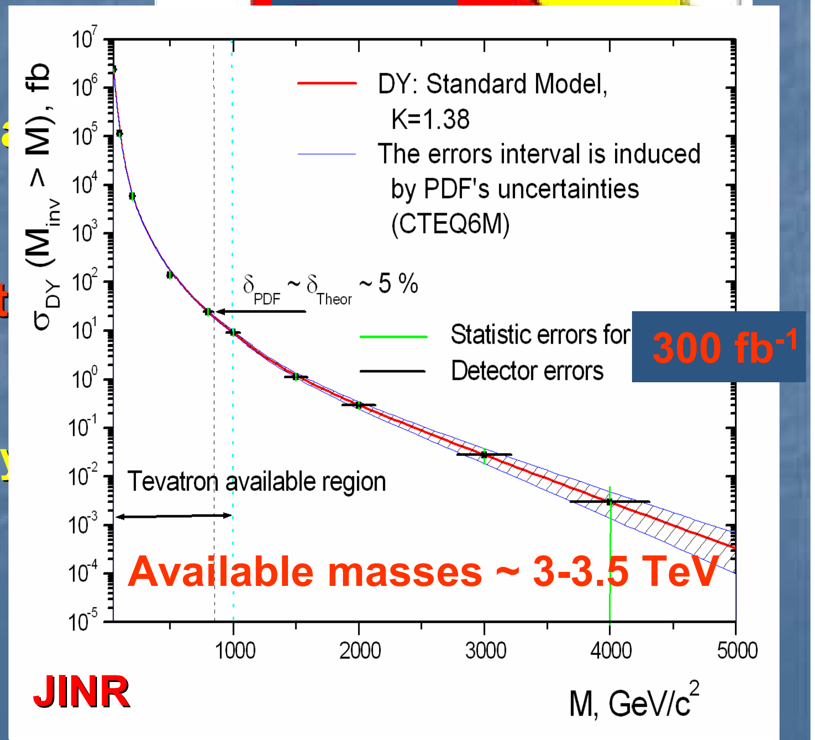
$$\frac{\Delta\sigma}{\sigma}(pp \to W + X \to \mu\nu + X) = 0.04\,\% \pm 3.3\,\% \pm \text{lumi uncert.}$$

- **6%- 7% accuracy on the luminosity seems fe**



Study of Drell-Yan processes up to the large invariant masses inaccessible at other accelerat

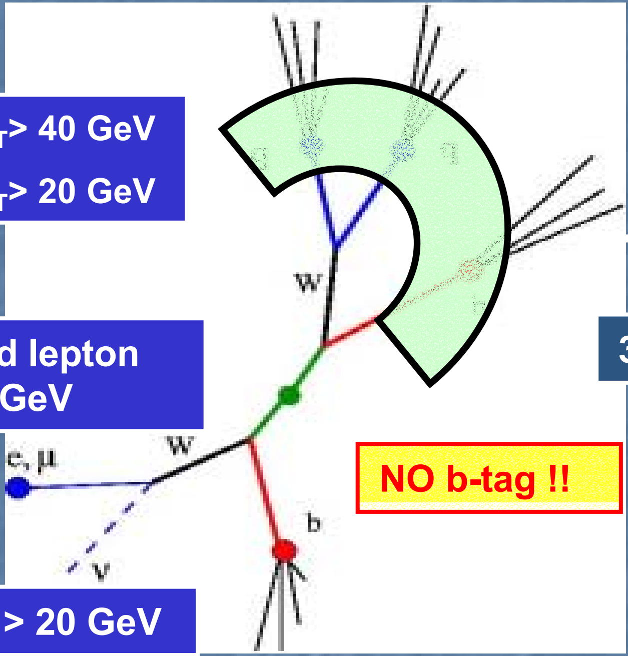
- **Important benchmark process**
- **Deviations from SM cross section indicate new phy**
  - cross-section measurements
  - extraction of muon forward-backward asymmetry
  - exploration of helicity structure of these process

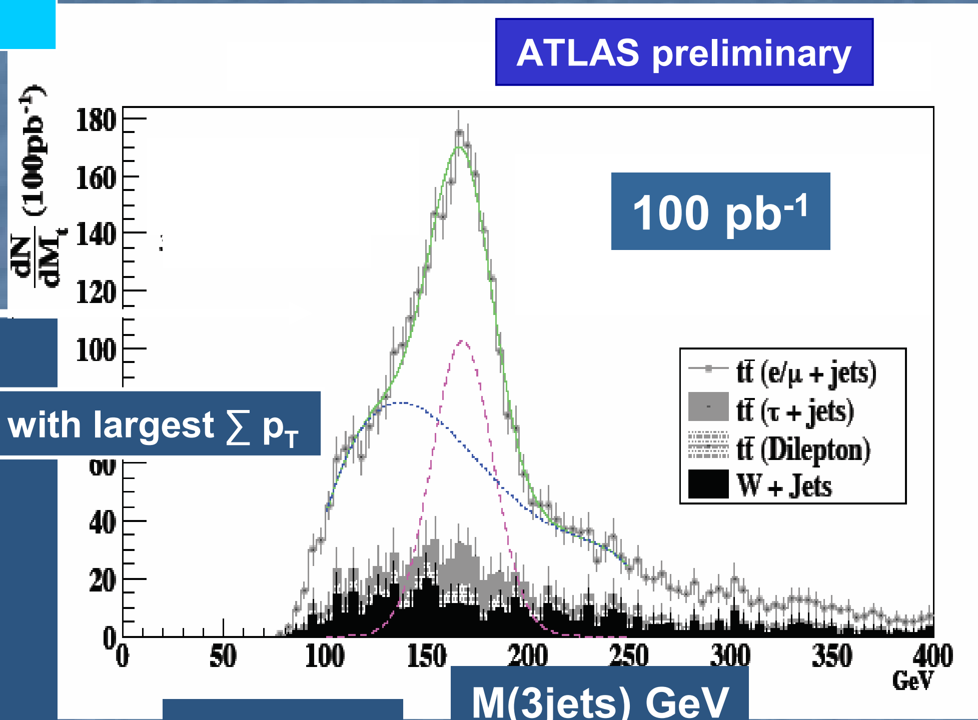


The first top quarks in Europe

A top signal can be observed quickly, even with limited detector performance and simple analysis …. and then used to calibrate the detector and understand physics

$\sigma_{tt} \approx 250$ pb for tt → bW bW → blν bjj





Top signal observable in early days with no b-tagging and simple analysis
(~3000 evts for 100 pb^{-1}) → measure σ_{tt} to ~20%, m_t to <10 GeV with 100 pb^{-1}?
(ultimate LHC precision on m_t: ~ 1 GeV)

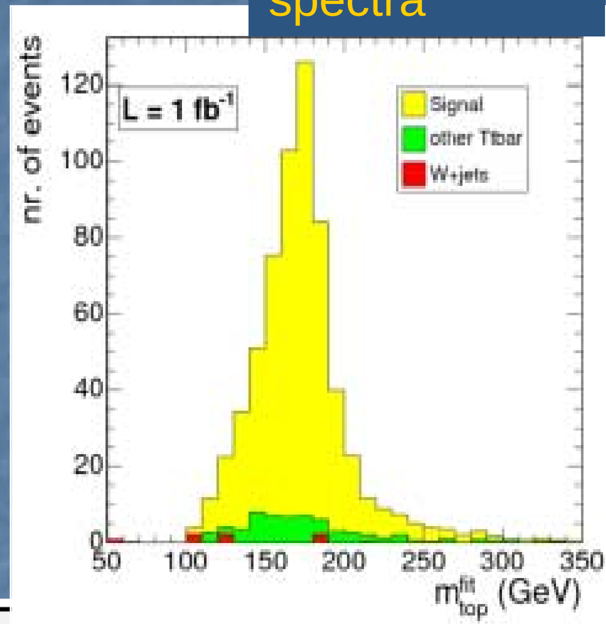
In addition, excellent sample to:

- **commission b-tagging, set jet E-scale using W → jj peak, …**
- **understand / constrain theory and MC generators using e.g. p_T spectra**

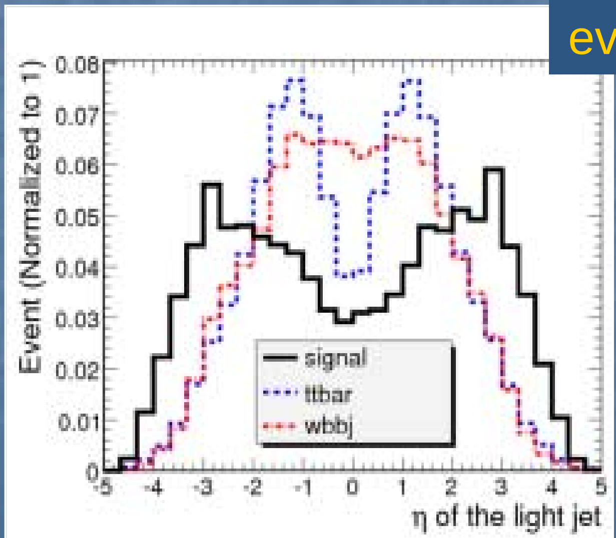
Top Physics

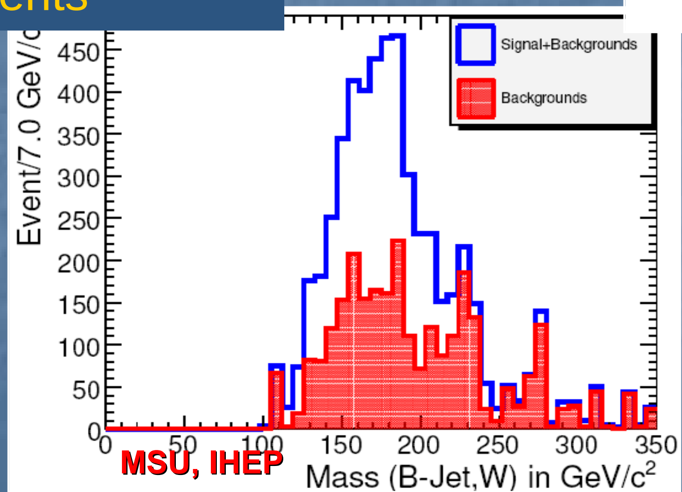
- ✓ **Make initial direct measurement of top mass**
- ✓ **Measure total and differential ttbar cross section a**
  - test of pQCD calculations (predicted at ~ 10%)
  - sensitive to new physics
- ✓ **Measure single top production (t-channel)**
- ✓ **Polarization in ttbar and single top systems**
- ✓ **FCNC**

Top mass spectra



single top events

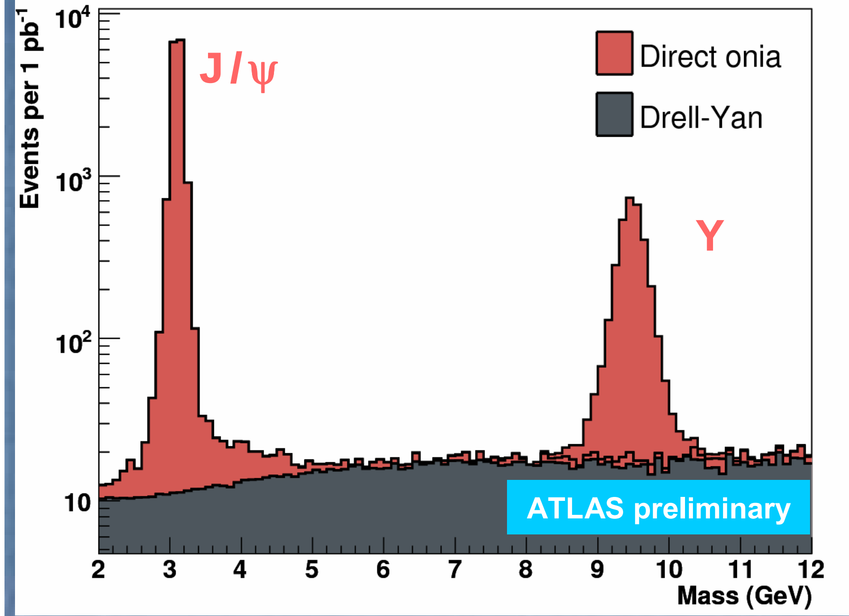




Expected total mass error for 10 fb^{-1}: 1.2 GeV !!

The first peaks …

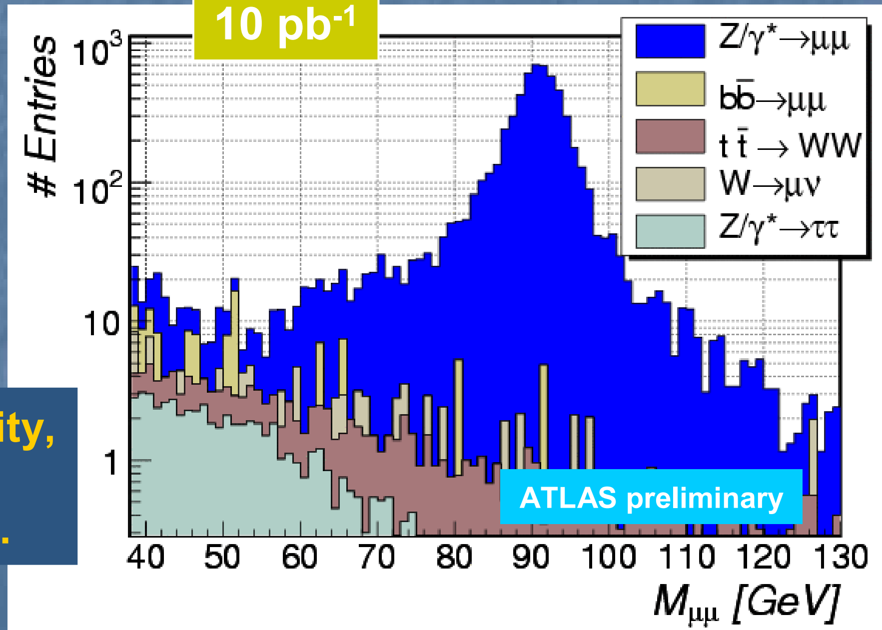
1 pb^{-1} ≡ 3 days at 10^{31} at 30% efficiency



After all cuts:
~ 4200 (800) J/ψ (Υ) → μμ evts per day at L = 10^{31}
(for 30% machine x detector data taking efficiency)
~ 15600 (3100) events per pb^{-1}

→ tracker momentum scale, trigger performance, detector efficiency, sanity checks, …

10 pb^{-1}



After all cuts:
~ 160 Z → μμ evts per day at L = 10^{31}
~ 600 events per pb^{-1}

→ Muon Spectrometer alignment, ECAL uniformity, energy/momentum scale of full detector, lepton trigger and reconstruction efficiency, …

Precision on σ (Z→μμ) with 100 pb^{-1}: <2% (experimental error), ~10% (luminosity)

An ideal candidate for an early discovery:

A narrow resonance with mass ~ 1 TeV decaying into e^+e^-

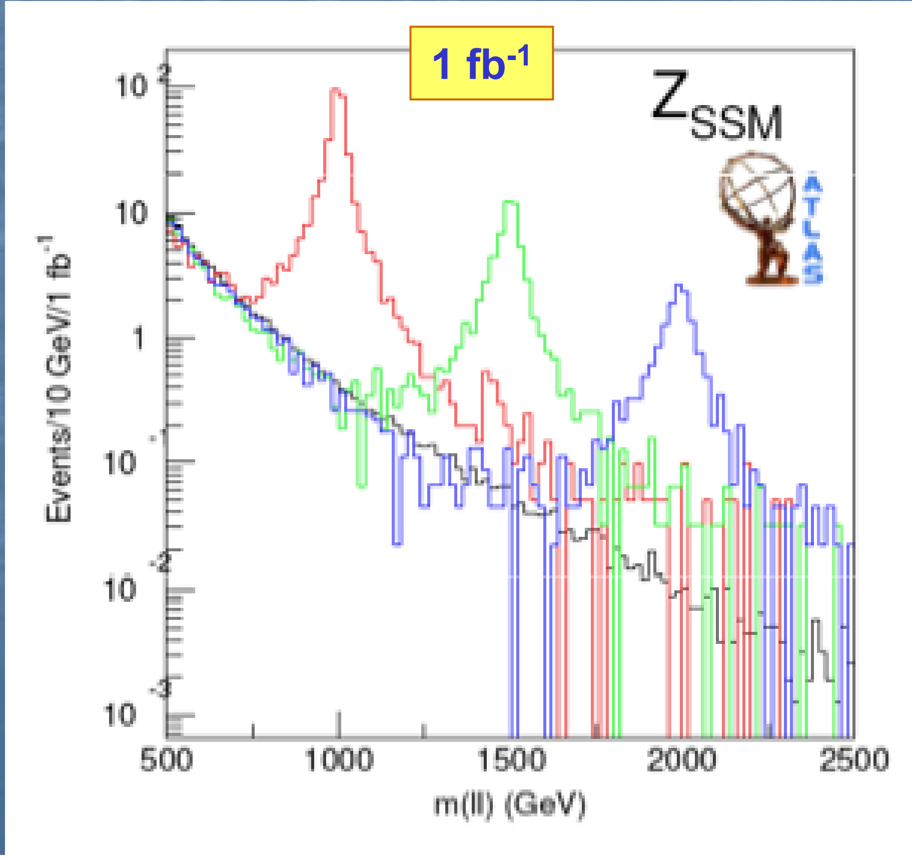
$Z' \rightarrow e^+e^-$ with SM-like couplings (Z_{SSM})

Mass	Expected events for 1 fb^{-1} (after all analysis cuts)	Integrated luminosity needed for discovery (corresponds to 10 observed evts)
1 TeV	~ 160	~ 70 pb^{-1}
1.5 TeV	~ 30	~ 300 pb^{-1}
2 TeV	~ 7	~ 1.5 fb^{-1}

- with 100 pb^{-1} large enough signal for discovery up to m > 1 TeV
- signal is (narrow) mass peak on top of small Drell Yan background
- ultimate calorimeter performance not needed

Is it a Z' or a Graviton ? From angular distribution of e^+e^- can disentangle Z' (spin=1) from G (spin=2)
Requires more data (~ 100 fb^{-1})

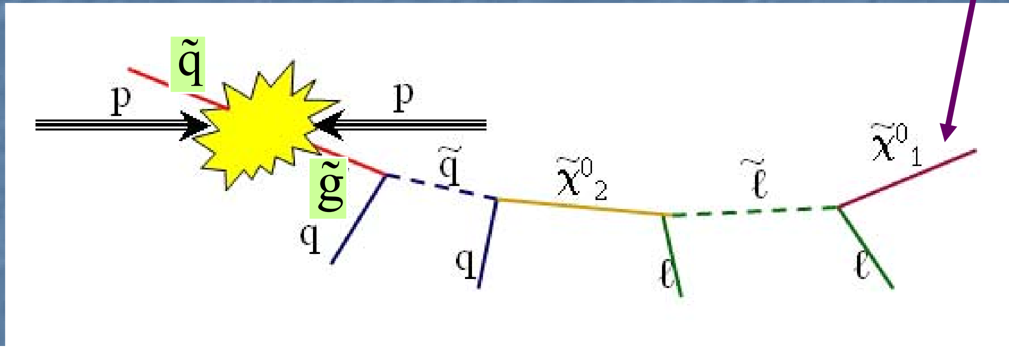
Ultimate ATLAS reach (300 fb^{-1}): ~ 5 TeV



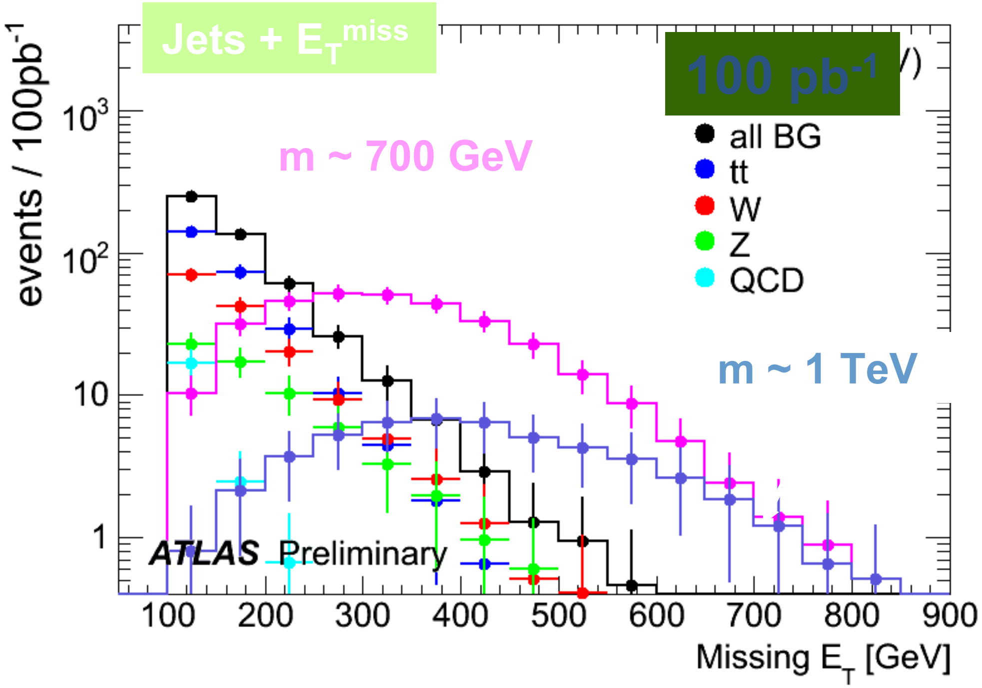
Another example: Supersymmetry

If it is at the TeV scale, it should be found "quickly" …. thanks to:

- large (strong) cross-section for $\tilde{q}\tilde{q}, \tilde{g}\tilde{q}, \tilde{g}\tilde{g}$ production
- spectacular signatures (many jets, leptons, missing E_T)



For $m(\tilde{q},\tilde{g}) \sim 1$ TeV expect 10 evts/day at $L=10^{32}$

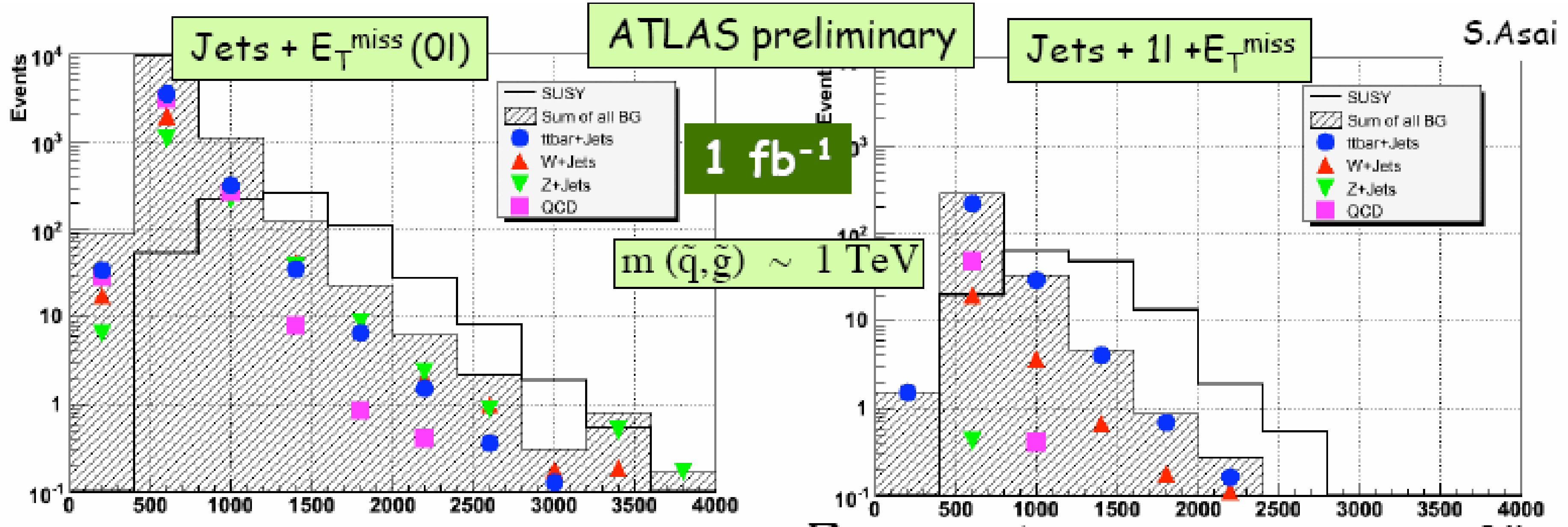


LHC reach for gluino mass

∫Ldt of well understood data	Discovery (95% C.L. exclusion)
0.1-1 fb^{-1} (2009)	~1.1 TeV (1.5 TeV)
≥1 fb^{-1} (2009-2010)	~1.7 TeV (2.2 TeV)
300 fb^{-1} (ultimate)	up to ~ 3 TeV

Hints with only 100 pb^{-1} up to m~1 TeV, but understanding backgrounds requires ~1 fb^{-1}

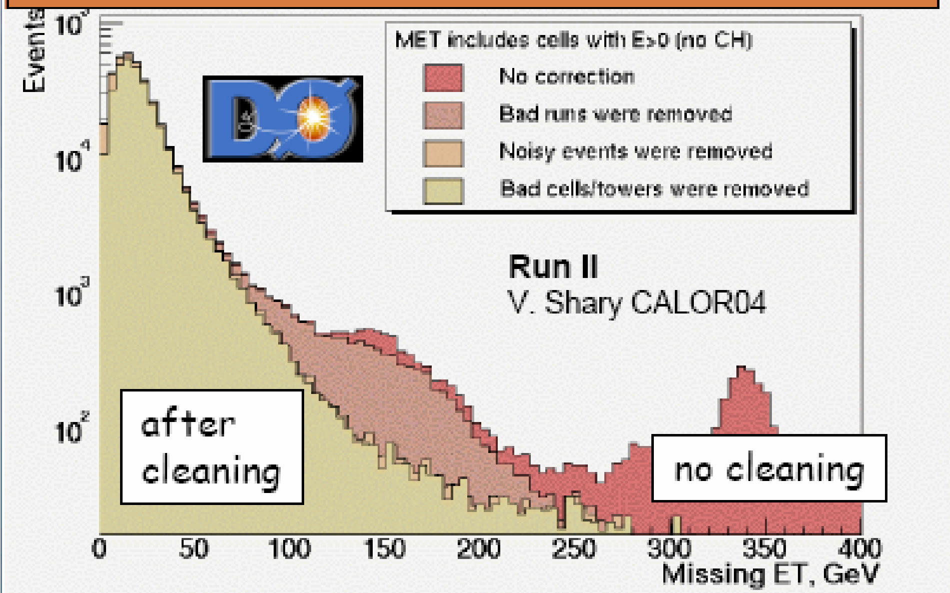
Planning for future facilities would benefit a lot from quick determination of scale of New Physics. With ~ 1 fb^{-1} LHC could tell if "standard" SUSY accessible to $\sqrt{s} \leq 1$ TeV ILC.

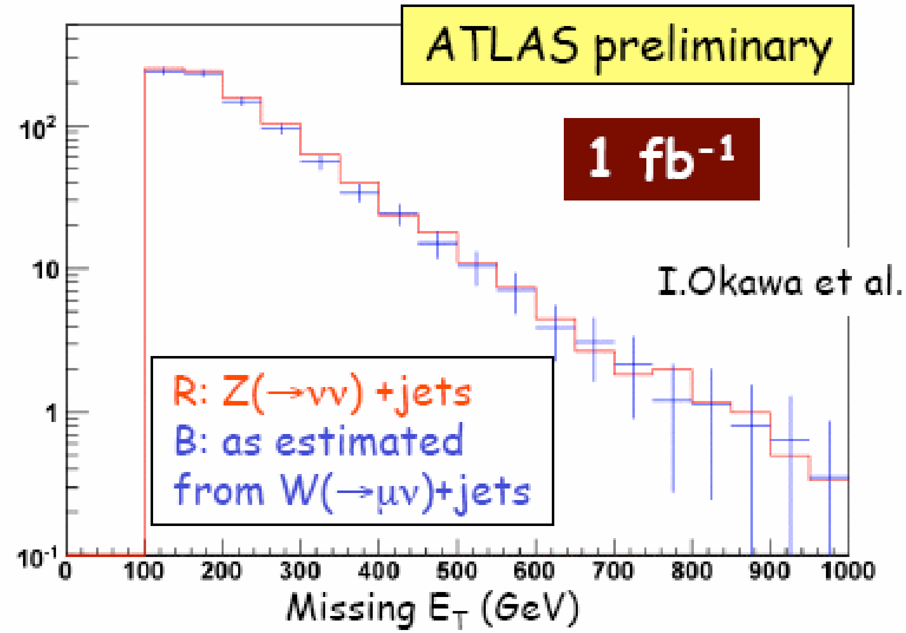


$$M_{eff}\ (GeV) = \sum_{i=1,4} E_T\ (i) + E_T^{miss}$$

Estimate physics backgrounds using data (control samples)

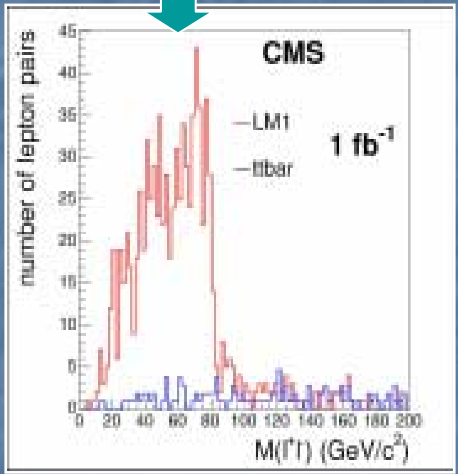
E_T^{miss} spectrum contaminated by cosmics, beam-halo, machine/detector problems, etc.



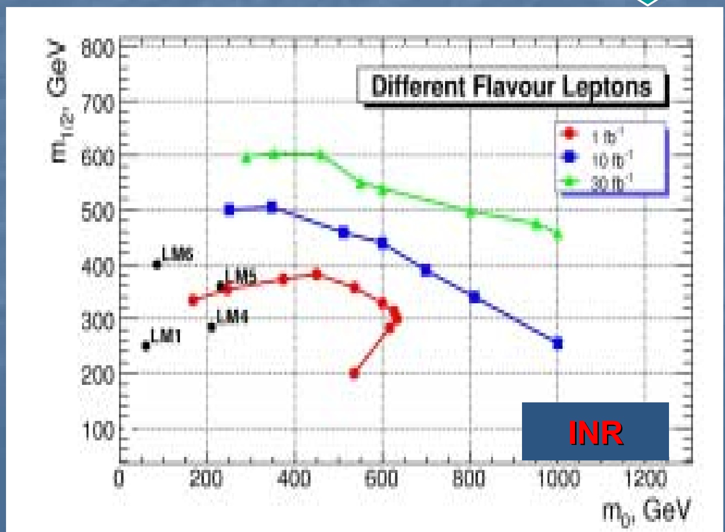


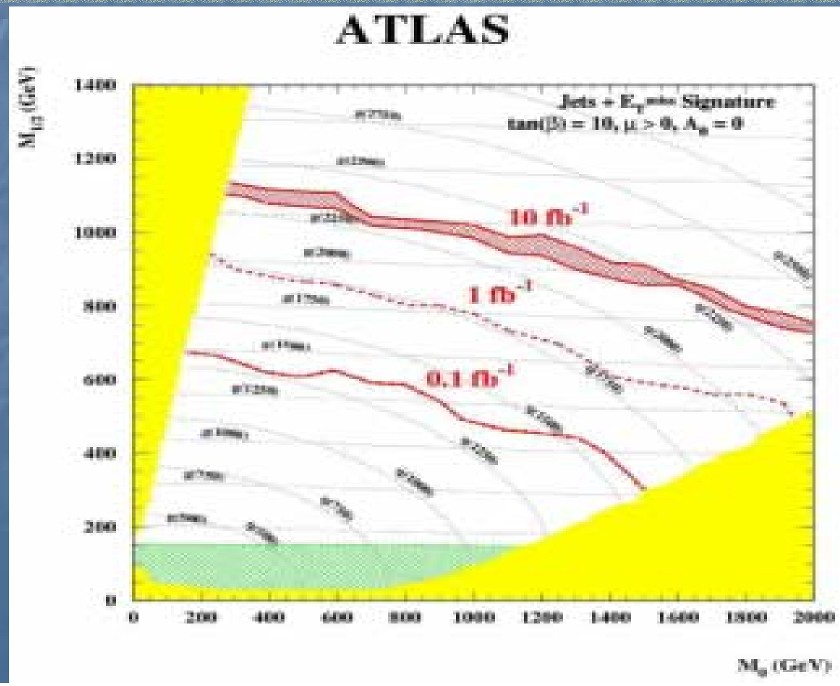
SUSY Searches

- **In some case the possible SUSY signature is striking even at low luminosity.**
  - MET from the LSP pair escaping the detector + leptons & jets from the cascade



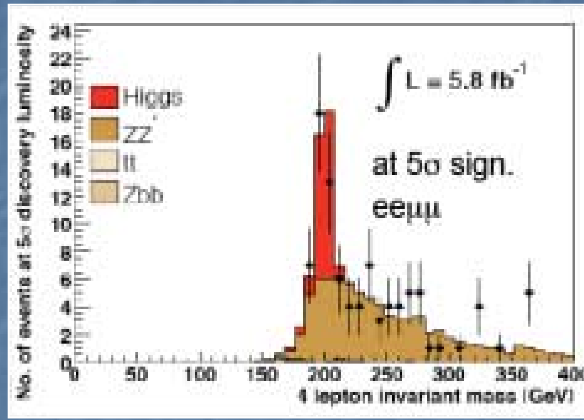
- Search for sleptons using the $l^+ l^- + E_T^{miss}$ + jet veto signature
  - CMS will be able to detect sleptons for a total luminosity 10 fb^{-1}
- Search for neutralino using the e^{+-} mu^{-+} + E_T^{miss} signature
  - study of lepton flavour violation
  - CMS test points LM1 - LM9 for integral luminosity 1 fb^{-1}



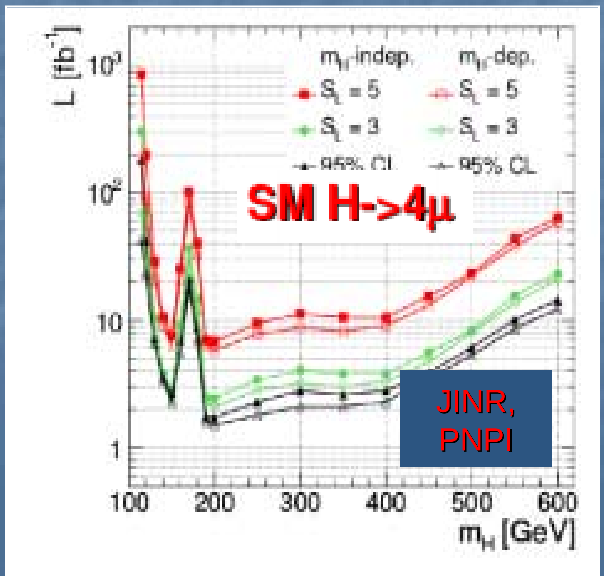


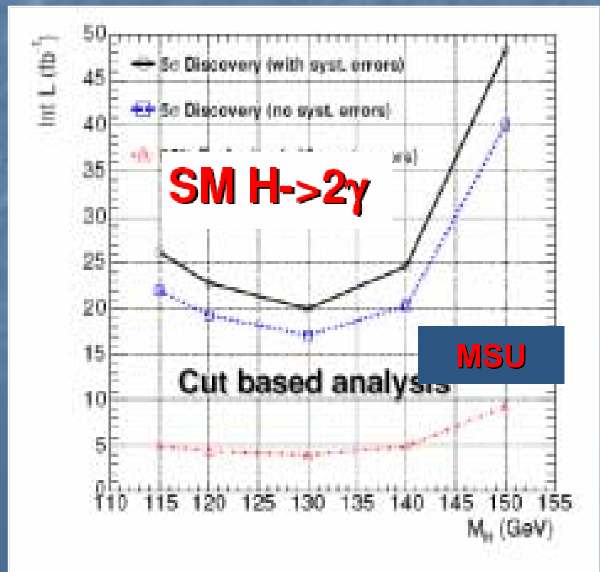
SM Higgs Bosons Searches

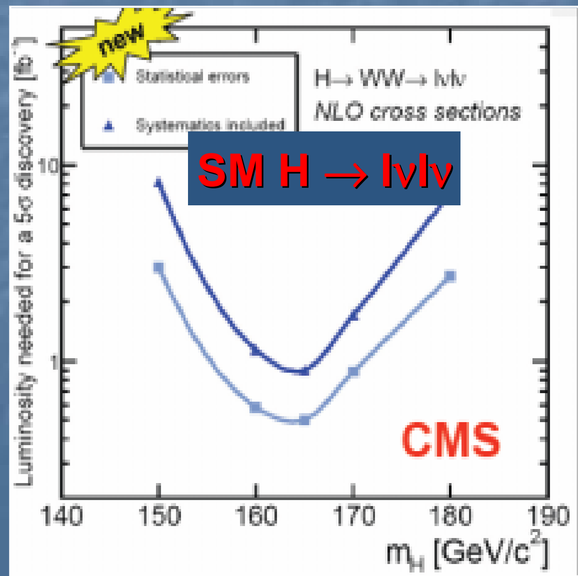
- Search for Higgs bosons is one of the first priority tasks of CMS and ATLAS Physics program
- Benchmark channels for SM Higgs are
  - $H \to ZZ \to 4l$ ("golden" decay)
  - $H \to \gamma\gamma$
  - $H \to ZZ \to 2l + 2jet$
  - $H \to WW \to 2l + 2\nu$



- The discovery mass range is from 85 GeV up to 1 TeV

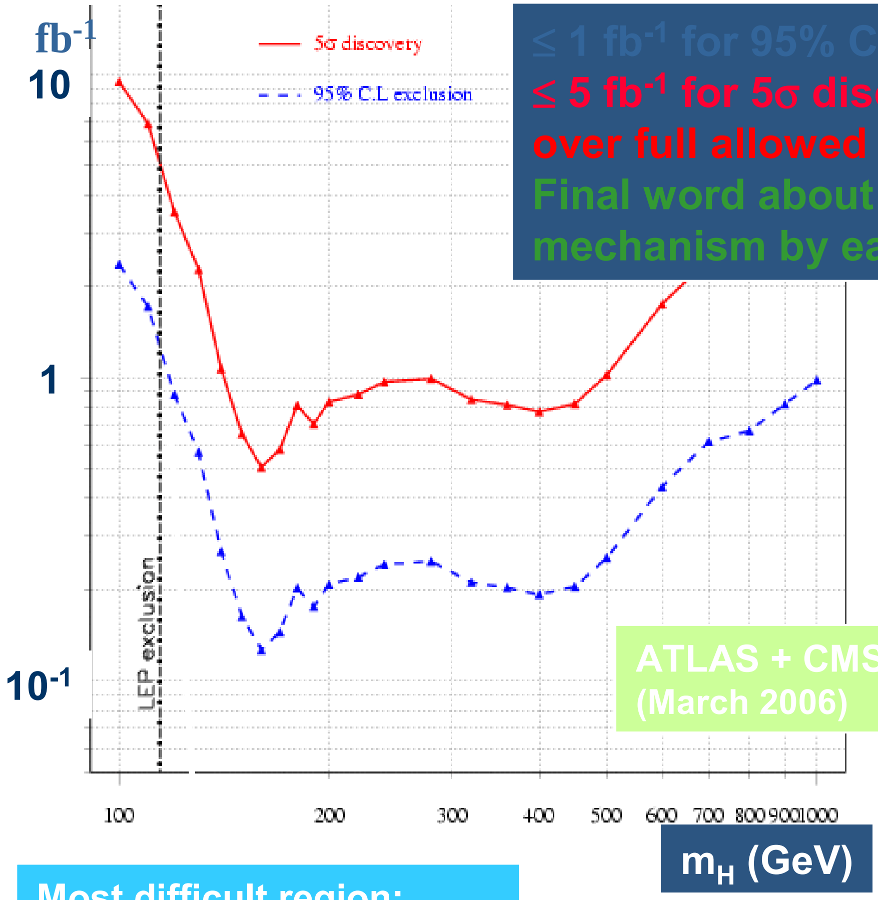




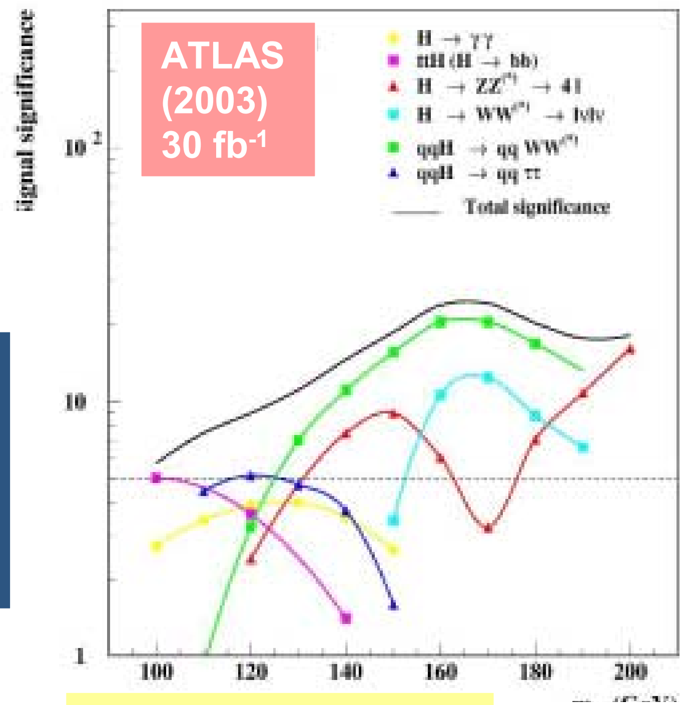


The more difficult case: *light Higgs boson*

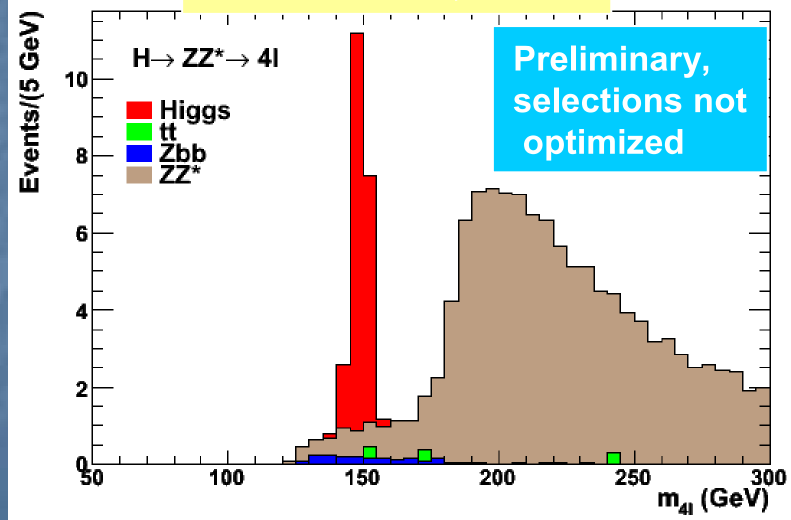
Need ∫Ldt of several fb^{-1} of well-understood data per experiment



≤ 1 fb^{-1} for 95% C.L. exclusion
≤ 5 fb^{-1} for 5σ discovery over full allowed mass range
Final word about Higgs mechanism by early 2010 ?



H → ZZ* → 4l, 10 fb^{-1}



Most difficult region: need to combine many channels (e.g. H → γγ, qqH→qqττ) with small S/B

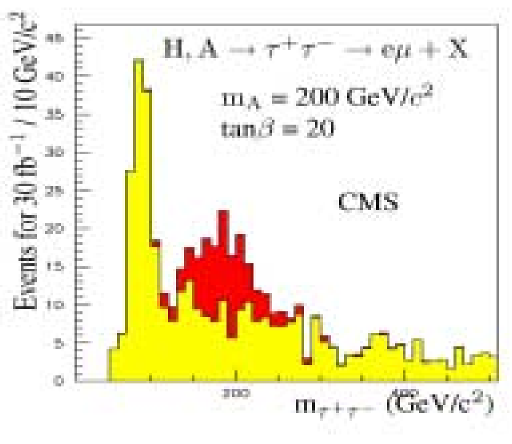
For m_H > 140 GeV discovery easier with H → ZZ(*) → 4l (narrow mass peak, small B). H → WW → lνlν (dominant at 160-175 GeV) is counting experiment (no mass peak)

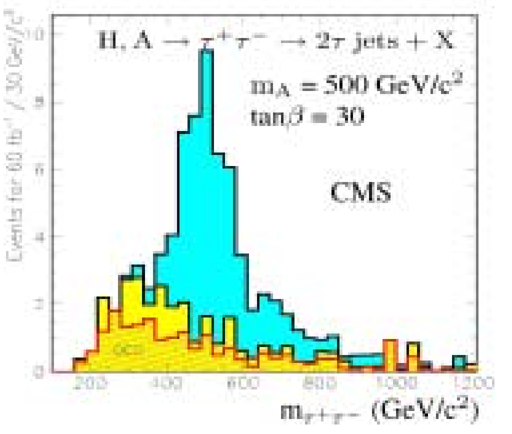
MSSM Higgs Bosons Searches

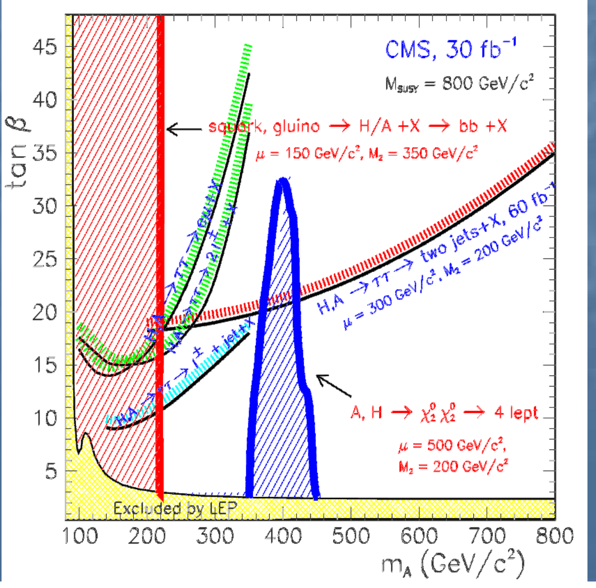
- **Benchmark channels for MSSM Higgs are**
  - A/H → ττ
  - A/H → μμ
  - A/H → bb/ μμ
  - $H^{\pm}$ → τν
  - $H^{\pm}$ → tb

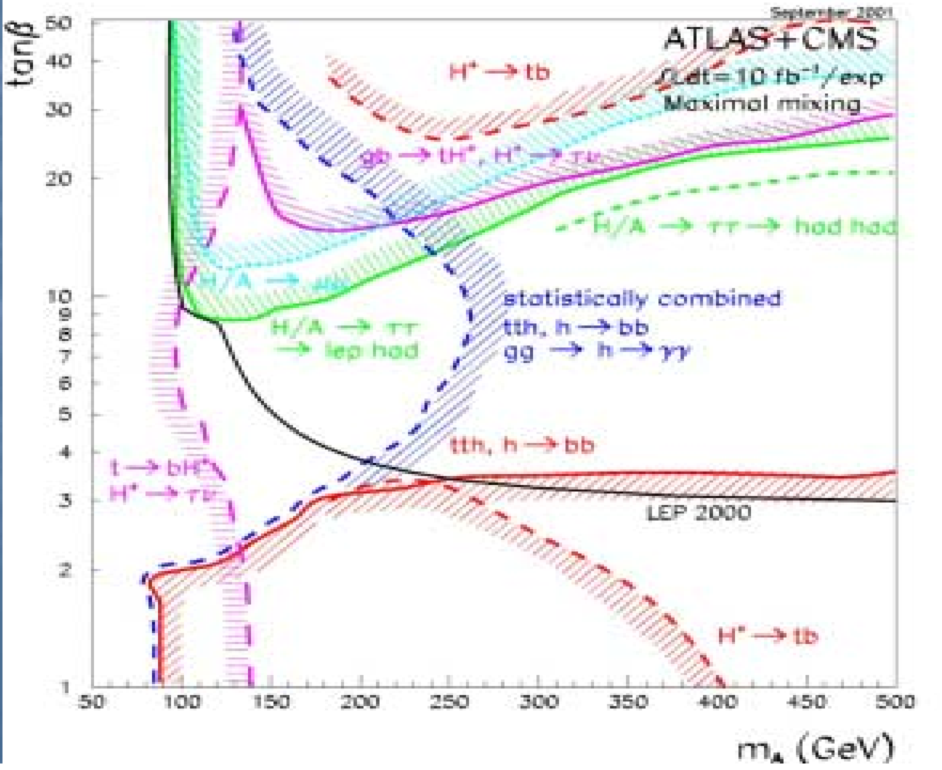
- **At low tan β, we may exploit the sparticle decay modes:**

  - A, H → $\chi_2^0 \chi_2^0$ → $4l$ + E_T^{miss}
  - A, H in cascade decays of s particles



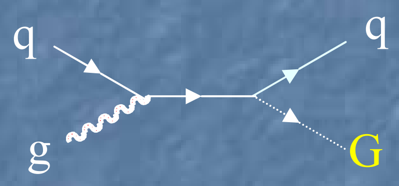






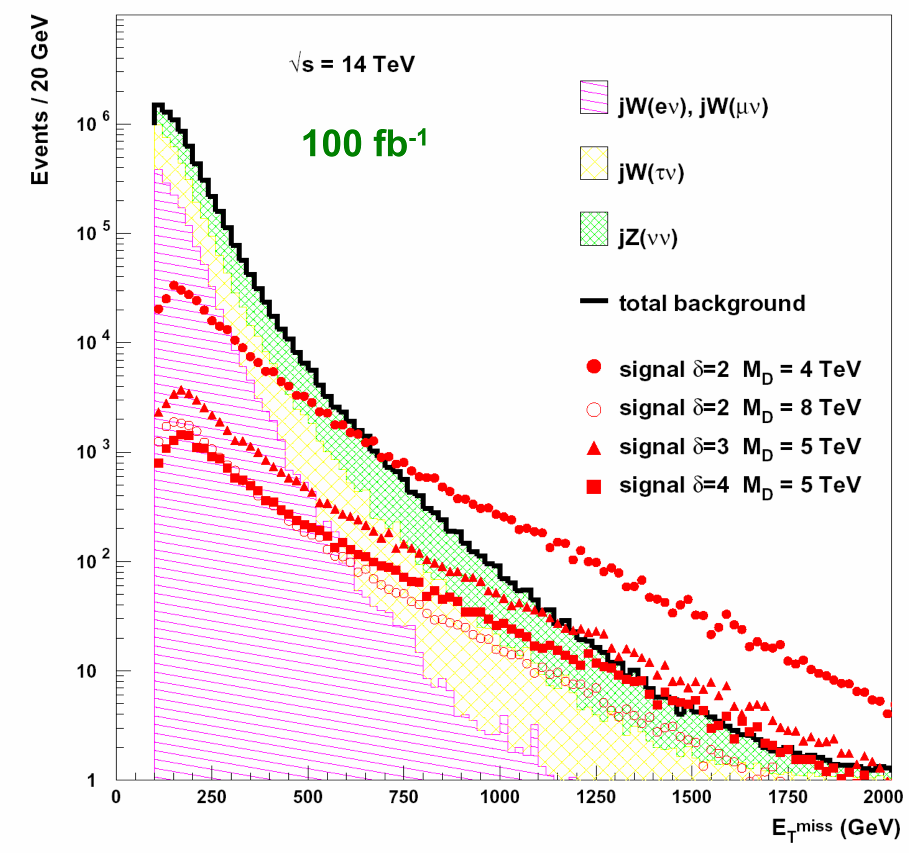
Extra Dimensions

- Many different theoretical variants exist:
  - **Large extra dimensions (ADD)**
  - **Randall-Sundrum models with "warped" extra dimensions**
  - **Strong gravity at the TeV scale (with Black Hole production!)**
  - **…**
- ADD example:



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

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



IHEP

LHC accelerator and ATLAS/CMS on track for 14 TeV p-p collisions in 2008

Continuous understanding/ debugging/ calibrating effort
since several years :

- o Test beams□Cosmics□beam gas/halo□collision
- o In addition to « as-built » large scale simulation

Data collected in year 2008 can bring first physics results even discoveries

This will only be possible with continued work on understanding the detector with ever increasing accuracy and level of details

• What breaks EW symmetry (origin of mass) ?

• Whether existing indications for unification and supersymmetry point to right direction ?

• If indeed the superworld opens up, is it the dark matter ?

• Whether new exotic phenomena exist at EW scale, like Hidden sectors, extradimensions, new particles, fields and interactions ?

Soon we will know!

Back up slides

With the first collision data (1-100 pb-1) at 14 TeV

Understand detector performance in situ in the LHC environment,
and perform first physics measurements:

- Measure particle multiplicity in minimum bias (a few hours of data taking …)
- Measure QCD jet cross-section to ~ 30% ?
(Expect >10^3 events with ET (j) > 1 TeV with 100 pb-1)
- Measure W, Z cross-sections to 10% with 100 pb-1?
- Observe a top signal with ~ 30 pb-1
- Measure tt cross-section to 20% and m(top) to 7-10 GeV with 100 pb-1 ?
- Improve knowledge of PDF (low-x gluons !) with W/Z with O(100) pb-1 ? •
- First tuning of MC (minimum-bias, underlying event, tt, W/Z+jets, QCD jets,…)

And, more ambitiously:

Discover SUSY up to gluino masses of ~ 1.3 TeV ?
Discover a Z‘ up to masses of ~ 1.3 TeV ?
Surprises ?

F. Gianotti

Calibration with real data

Standard model processes:

o $Z \rightarrow ee$ (~ 6 x 10^4 evts/day after cuts): ECAL inter-calibration, absolute E-scale, etc.

o $Z \rightarrow \mu\mu$ (~ 6 x 10^4 evts/day after cuts): p-scale in tracker and Muon Spectrometer, etc.

o $tt \rightarrow bl\nu\ bjj$ (~ 1 x 10^4 evts/day after cuts) : absolute jet-scale from $W \rightarrow jj$, b-tag performance, reconstruction of complex final states (for ttH),etc.

 Inclusive processes (dedicated prescaled trigger)

o Minimum-bias events : pp interaction properties, MC tuning, LVL1 efficiency,timing, radiation background in Muon chambers, etc.

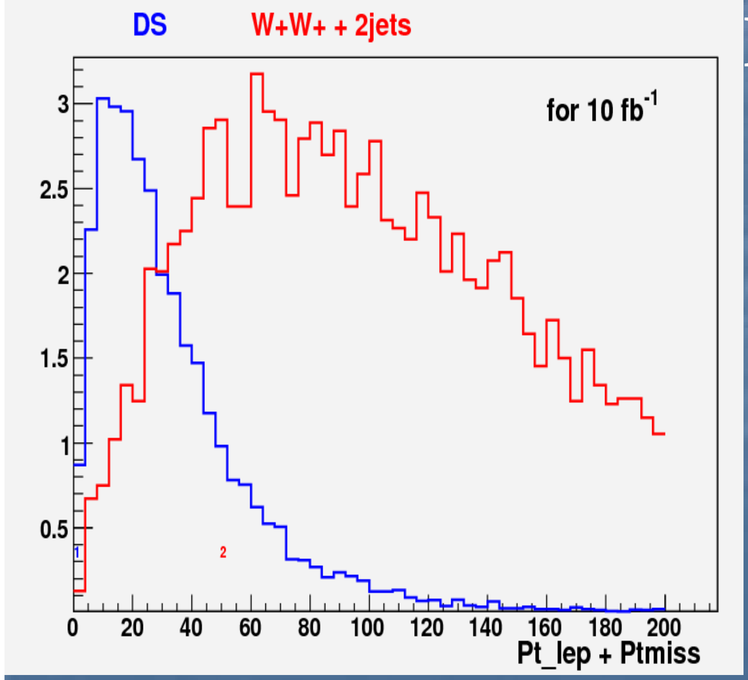
o QCD : QCD cross-sections and MC tuning, trigger efficiency, calorimeter inter-calibration, jet algorithms, background to Higgs, SUSY,etc.

o Inclusive $e^\pm$ pT > 10 GeV : trigger efficiency, ECAL calibration, ID alignment, E/p, $e^\pm$ reconstruction at low-pT, etc.

o Inclusive $\mu^\pm$ pT > 6 GeV : trigger efficiency, $\mu^\pm$ reconstruction at low-pT,E-loss in calorimeters, ID alignment, etc.

Standard model

Precision calculations Drell-Yan process for PDF measurements. (JINR)
Development of the theoretical and experimental methods for PDF evaluations. (IHEP)



Multiparton interactions (IHEP)

New type of the reactions, could give the background to many processes (f.e. Higgs to bbar).

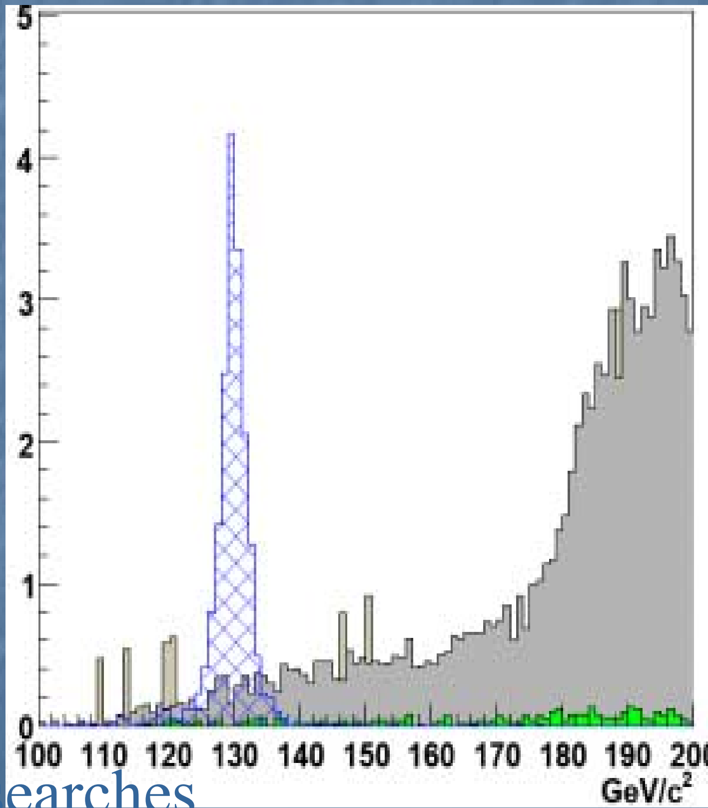
The cross section can be measured by ATLAS in the reaction of same sign vector boson production.

Search for the SM Higgs boson via decay $H \rightarrow 4\mu$.

"Gold plated" channel
for Higgs discovery
at LHC

G.Chelkov, I.Boyko, K.Nikolaev
(JINR)

Reconstructed mass
of 4-muon systemR



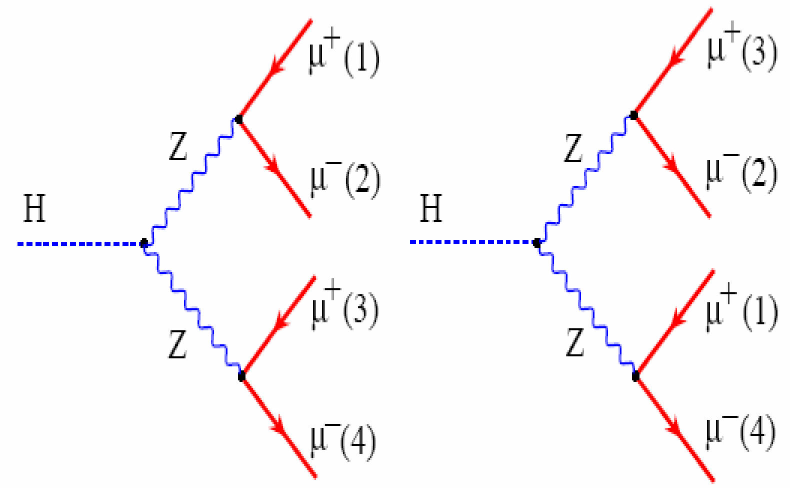
ITEP take part in VBF Higgs searches

SANC

Project SANC (Support of Analytical and Numerical Calculations for Experiments at Colliders). http://brg.jinr.ru/

D.Bardin, *L.Kalinovskaya, P.Christova, et al (DLNP, JINR), A.Arbuzov, S.Bondarenko (BLTP, JINR).*

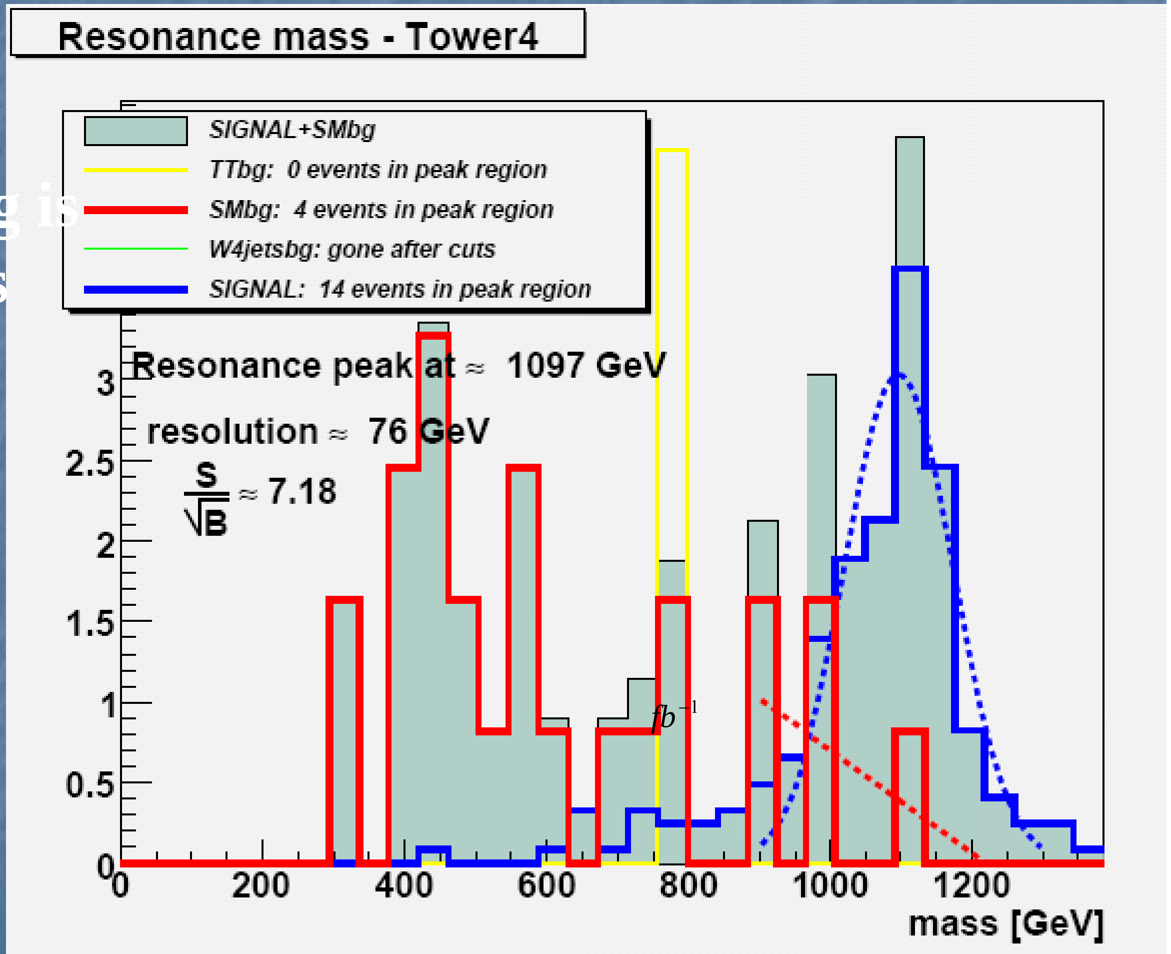
New Monte-Carlo generator $H \to 4\mu$ at single resonance approximation was created, taking into account both 1-loop corrections and identity effects that was never done before.
This generator was tranferred for use to JINR ATLAS muon group.



Vector resonance in WZ channel

Electroweak symmetry breaking is still NOT understood.

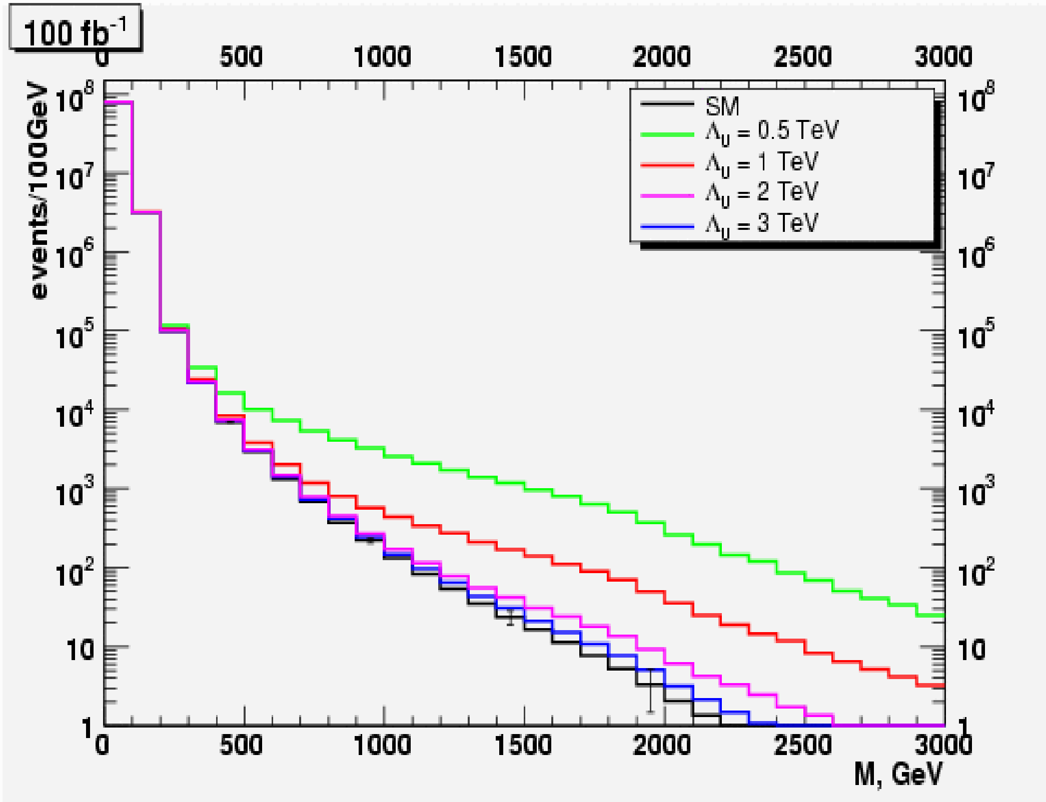
The vector boson scattering is sensitive to the new physics



From talk of A.Myagkov on “Hadron structure-07” conference

Exotic phenomena at high masses of dileptons (IHEP)

The deviations in dilepton invariant mass distribution may be a signal for existence of extra space dimensions of effect of unparticle physics.



Unparticle stuff looks like a non-integral number of invisible particles.

Virtual exchange of virtual gravitons increase the cross sections at high masses

- **New, rich phenomenology**

Russian Institutions in LHC

- Russian Center "Kurchatov Institute"
- Russian Academy of Sciences
  - Budker INP (Novosibirsk)
  - Lebedev PI (Moscow)
  - Konstantinov PNPI (St.Petersburg)
  - INR (Moscow)
- Agency of Atomic Energy
  - IHEP (Protvino)
  - ITEP (Moscow)
  - RFNC "VNIIEF" (Sarov)
- Moscow State University
  - Skobeltsyn INP (Moscow)
- Ministry of Education and Sciense
  - MEPhI (Moscow)
  - St.-Petersburg State University (St.Petersburg)

JINR (Dubna) in close cooperation with RF Institutes

Physics Studies in ATLAS (I)

- **Top-quark** **(JINR, BNPI)**
  - **Important test of SM (charge, mass, etc)**
  - **Background for SUSY, Exotics, etc**
  - **Energy calibration, etc**
- **QCD @ Standard Model Physics** **(JINR, IHEP, LPI)**
  - **Parton DF**
  - **Gamma/Z-jet events and Gluon DF**
  - **Multiparton interactions**
  - **Cherenkov in QCD**
- **Higgs Physics** **(JINR, ITEP)**
  - **$H \to 4\mu$**
  - **$H \to bb$, $H \to \tau\tau$, $H \to Z\gamma$**
- **SUSY Physics** **(JINR)**
  - **"the first observed" SUSY-particle in the other SUSY-channels**
  - **SUSY is background for SUSY**
  - **Stop, Gluinos, Same-sign dileptons**

Physics Studies in ATLAS (II)

- **Exotics Physics** **(IHEP, JINR, MEPhI)**
  - **SUSY R-hadrons (travel ATLAS without decays)**
  - **SUSY long-living Staus, Stops, etc**
  - **Extra dimensions, unparticles**
  - **WW, WZ and ZZ rezonances**
  - **Monopoles, etc**
  - **Rare tau-lepton decays**
  - **Z′ $\rightarrow$tt**
- **b-quarks** **(MSU, LPI)**
  - **Rare decays**
  - **Production**
- **Heavy Ions Physics** **(JINR, MEPhI)**
  - **QGP jet quenching via Z-jet events,**
  - **ultraperipheral interactions**

CMS Physics Analysis

Physics analysis in CMS Collaboration is going on in 8 physics group:

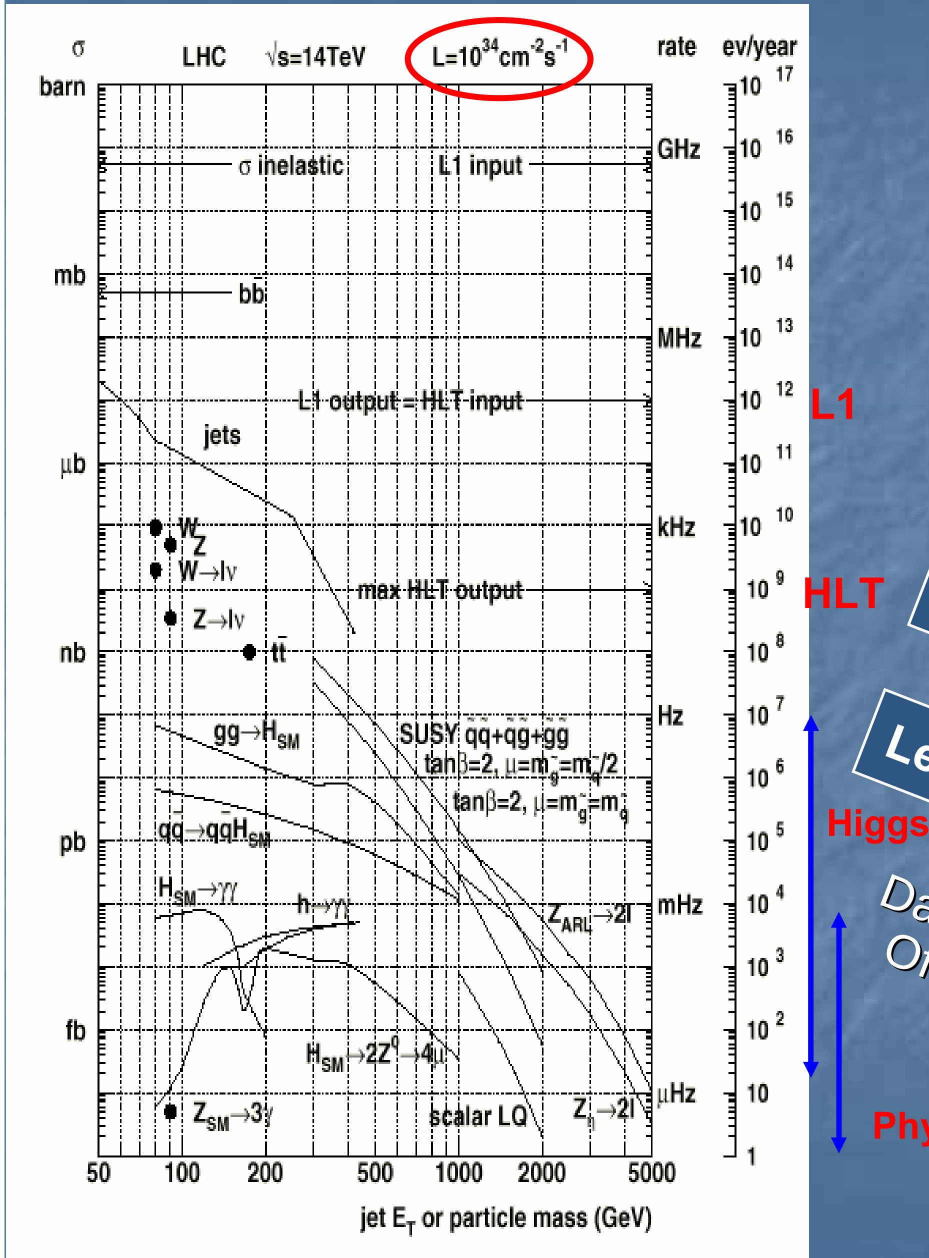
- **QCD**
- **EWK (electroweak)**
- **Physics of Top quark**
- **B-physics**
- **Higgs**
- **SUSY**
- **Exotic**
- **Heavy Ions**

All the time of CMS project side by side with detector assembly and installation the physicists from Russian and Duba Member State (RDMS) Institutions focused their efforts at development of CMS Physics Research Program.

The overall CMS strategy for early physics with 0.1-1 fb^{-1} (2008-beginning of 2009)

- Alignment and calibration by physics processes (γ + jet, Z + jet, Z^0 etc)
- Triggering
  - Early trigger performance
  - Prescaled trigger & overall strategy
- Studies of Standard Model (W/Z, jest, B-physics, top, diffraction) at new energy scale
- Search for new physics signals (Higgs, SUSY, Exotic) with 0.1 fb^{-1}

The data flows from CMS



2008 – beginning of 2009:

10^{32} physics run ⇒ 100 pb^{-1} – 1 fb^{-1}

The first measurements and underlying events

- ➢ Checks of theory:

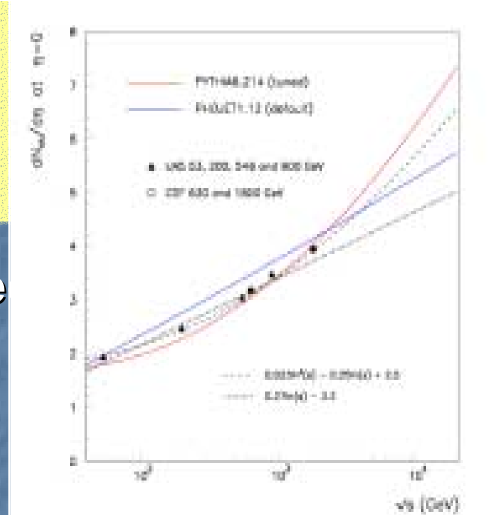
W, Z cross sections at ~3%, ttbar cross section at ~10%

Main observables:
+ $dN/d\eta d\phi$, charged density
+ $d(PT_{sum})/d\eta d\phi$, energy density

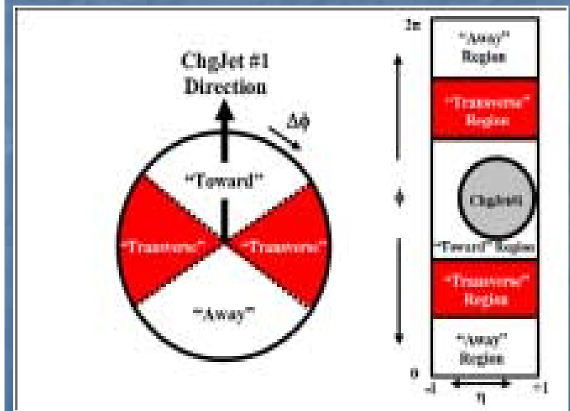
- ➢ Candidate for very early measurement

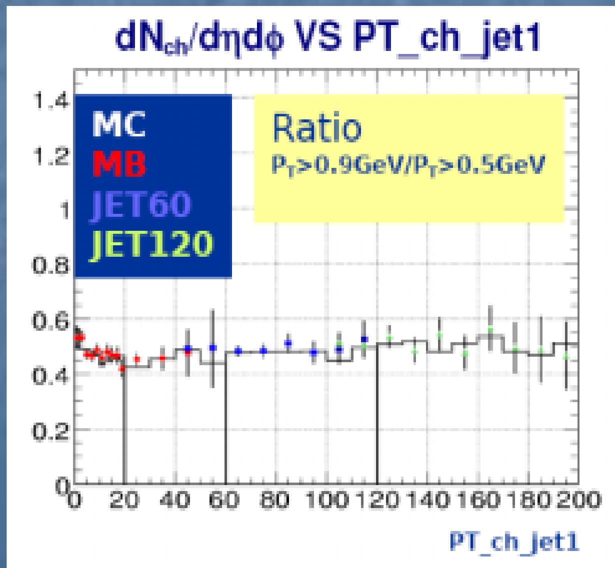
few 10^4 events enough to get charged and energy density ⇒

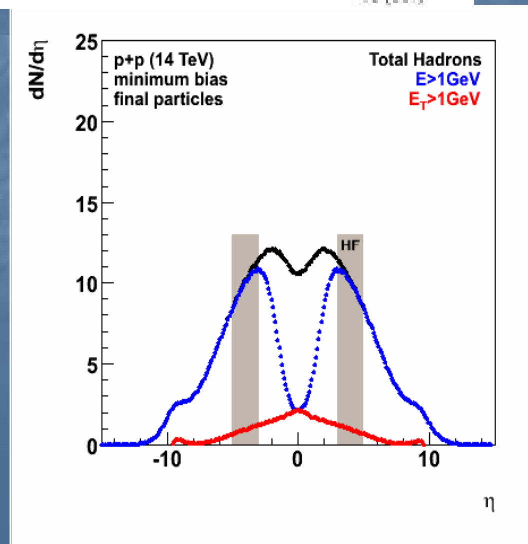
15 minutes of good data !



- ✓ **Topological structure of p-p collision from charge**
- ✓ **The leading jet defines a direction in the ϕ plane**
- ✓ **Transverse region particularly sensitive to UE**







Exotics (Beyond the Standard Model)

- Extended gauges models (Z' and W')
- Compositeness
- Large flat Extra-Dimensions (ADD model)
  - Extra dimensions are flat and could be as large as a few µm
  - SM particles restricted to 3D brane and only accessible to gravity
- Randall-Sundrum (RS1 – two branes)
  - Small extra spatial dimensions
  - Curved bulk space (AdS_5 - slice)
  - Well separated graviton mass spectrum
- TeV^{-1} Extra dimension Model
  - Bosons could also propagate in the bulk
  - Fermions are localized at the same (opposite) orbifold point: destructive (constructive) interference between SM gauge bosons and KK excitations
- Universal Extra Dimensions
  - All SM particles propagate in Extra Dimensions
  - often embedded in large Extra Dimensions

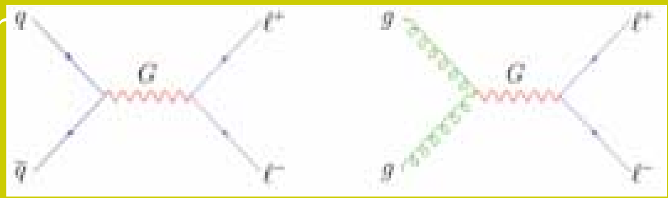
Exotics (Beyond the Standard Model)

- Di-lepton, di-jets and di-photon resonance states (new particles) in RS1-model (RS1-

  graviton) and TeV^{-1} extra dimension model (Z_{KK}) or ex

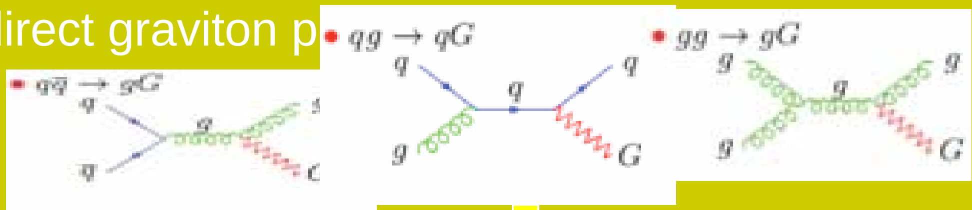
- Di-leptons, di-jets continuum modifications

  (virtual gravitor … nes



- Single Jets/Single Photons + Missing E_T

  (direct graviton p



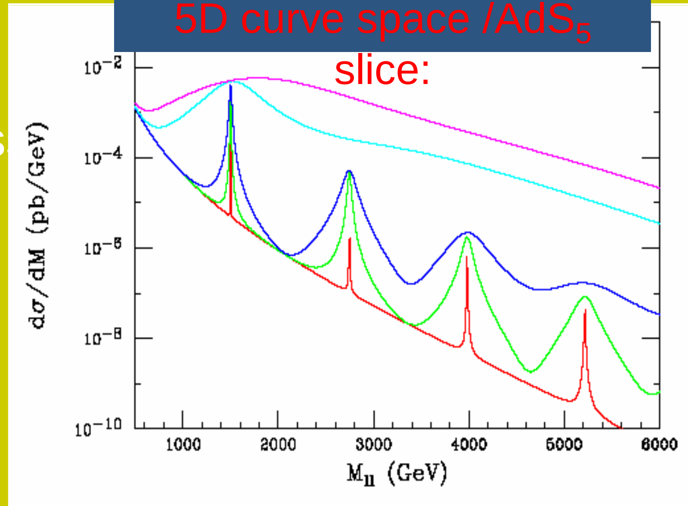
- Single Leptons + missing E_T in W_{KK} decays

  in TeV^{-1} extra dimension model (W_{KK})

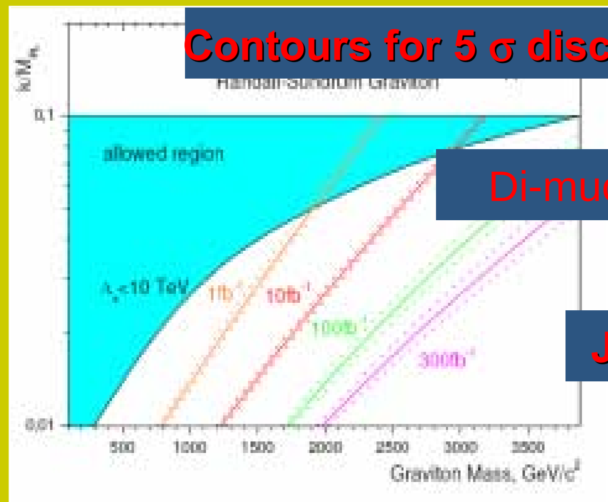
- Back-to-back energetic jets + Missing E_T (UED)

- 4 jets + 4 leptons + Missing E_T (mUED)

Di-muon continuum in 5D curve space /AdS$_5$ slice:



Contours for 5 σ discovery



Di-muons

JINR