Early Physics with the CMS detector at LHC

HLPW2008
6. – 8. March 2008
Spa, Belgium

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Outline

- Status and schedule
  - CMS
  - LHC
- Early data analyses:
  - The roadmap to discovering new physics
  - Calibration and Alignment
  - Underlying event
  - Physics with dijet events
  - W/Z $\rightarrow$ leptons
  - Top pair production

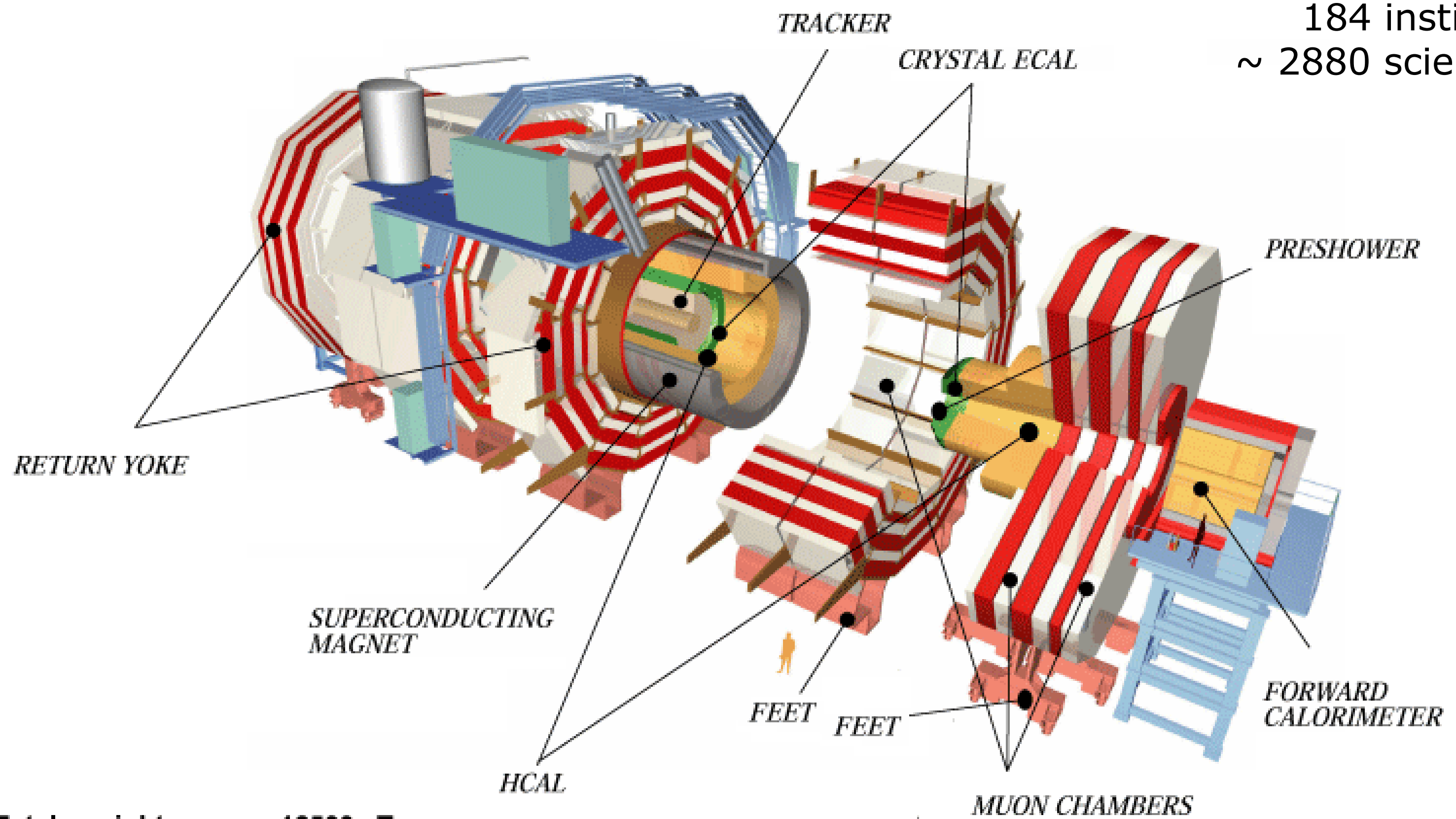
Physics studies results taken from CMS recent physics results page:

https://twiki.cern.ch/twiki/bin/view/CMS/PhysicsResults

and from the CMS Physics Technical Design Report
J. Phys. G: Nucl. Part. Phys. **34** 995-1579

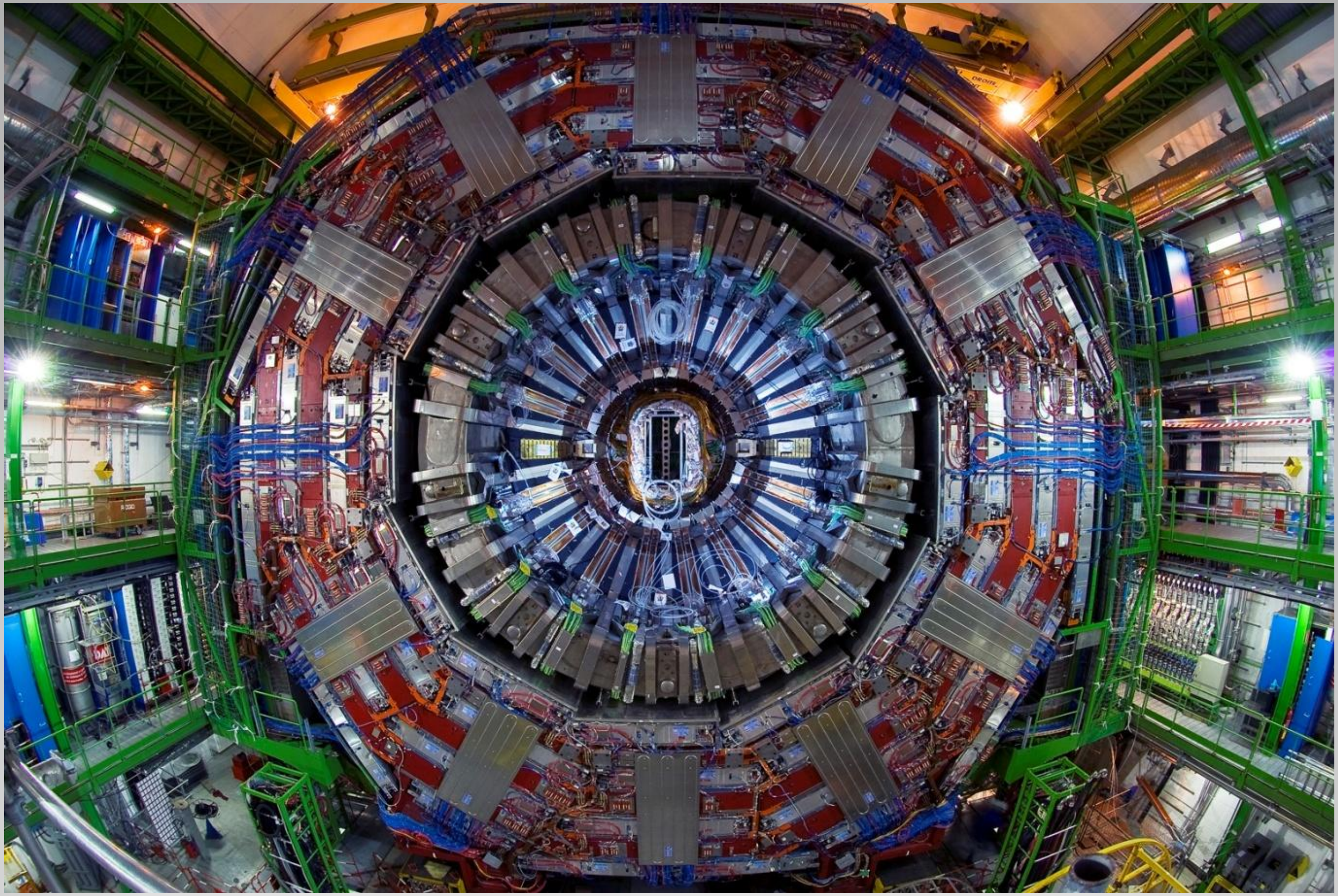
The CMS detector

184 institutes
~ 2880 scientists



Total weight	:	12500 T
Overall diameter	:	15.0 m
Overall length	:	21.5 m
Magnetic field	:	4 Tesla

CMS status and schedule



Tracker inserted in January

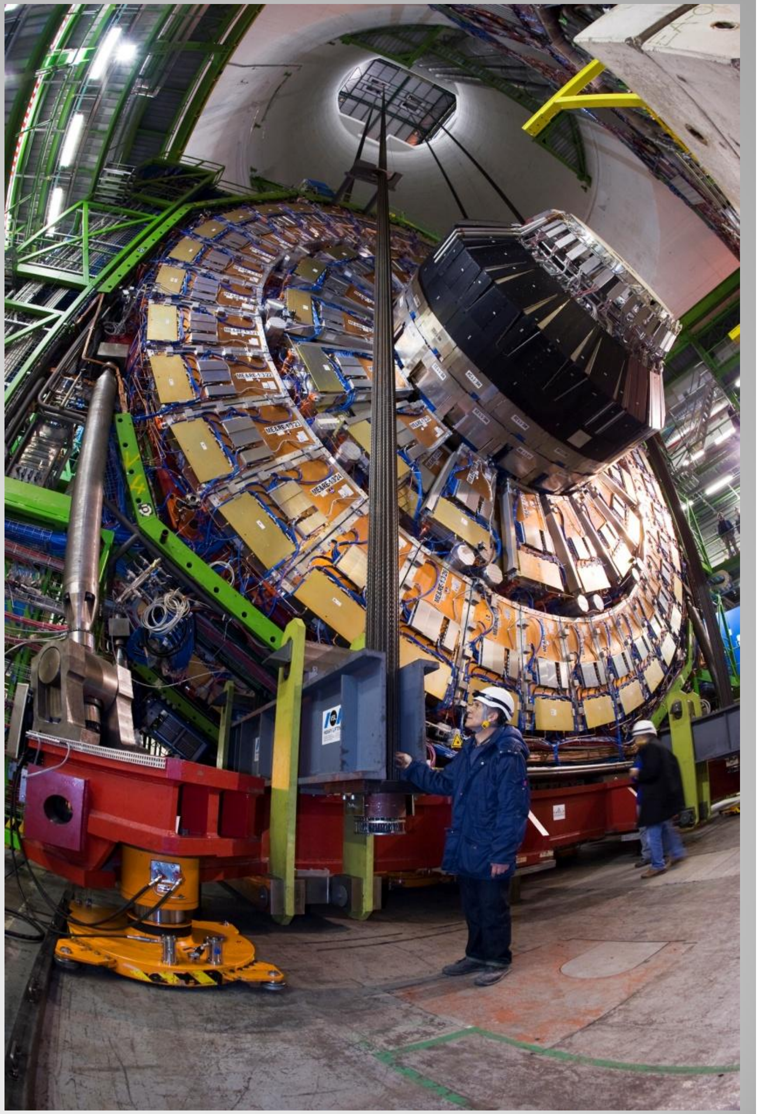
CMS status and schedule

- Descent of the last endcap disc in January
- All barrel wheels and endcap discs now underground

- Next steps:

Date	Event
End of March	Cosmic data taking without magnetic field
End of April	Beam pipe closed and baked out Pixel detector installed
End of May	CMS detector closed
June	Cosmic run with full magnetic field* Ready for beam

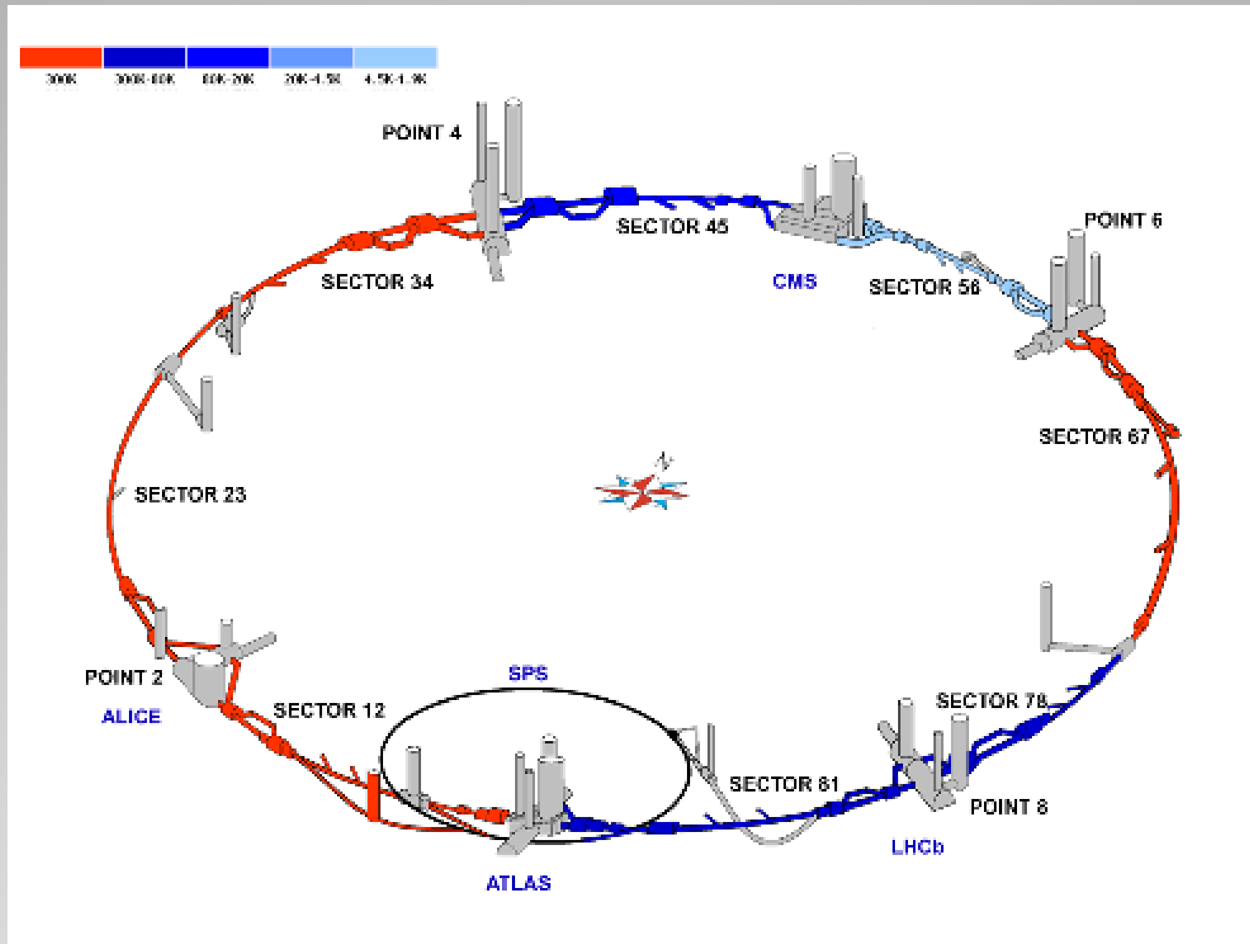
*a slice of the detector has been used to record cosmic data on the surface at nominal magnetic field in 2006



LHC status

http://cern.ch/lhc

2008-03-02



One out of eight sectors cooled down to < 2 K

LHC schedule

http://cern.ch/lhccwg/overview_index.htm

Stage	Year	Program	Luminosity (target/limit) [$cm^{-2}s^{-1}$]	Integ. Lumi (week/month) for target [pb^{-1}]
A	2008	**Pilot physics run:** physics aim 43 x 43 bunches maximum 156 x 156 bunches.	$6.12 \cdot 10^{30}$/ $1.12 \cdot 10^{32}$	3.7 / 16.1
B	2009	**Intermediate physics run:** physics aim 75 ns bunch spacing possible initial physics aim 96 x 96 bunches (bunch intensity 1 x 10^{10}) maximum aim 936 x 936 bunches (maximum 9 x 10^{10})	$1.28 \cdot 10^{32}$/ $1.24 \cdot 10^{33}$	77.4 / 337
C	2009	**25 ns run I:** intensity per bunch 5 x 10^{10} protons (initial 1 x 10^{10}); physics aim 2808 x 2808 bunches	$1.13 \cdot 10^{33}$/ $1.91 \cdot 10^{33}$	683 / 2972
D	After 2009	**25 ns run II:** push towards nominal performance	$3.65 \cdot 10^{33}$/ $1.01 \cdot 10^{34}$	2208 / 9599

Roadmap to new physics

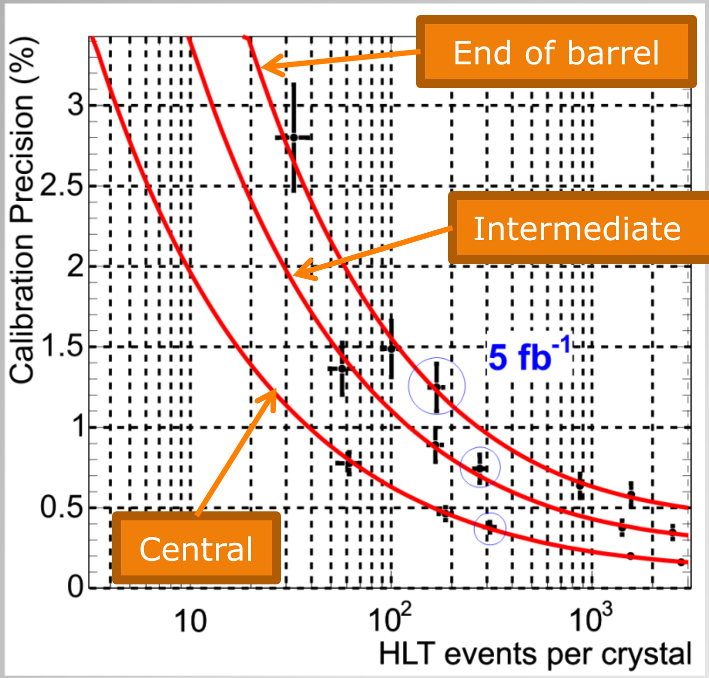
- Reminder:
  - The roadmap to discovering new physics is the following:

1. Understand data acquisition, trigger and detector behaviour
2. Validate event reconstruction
3. Calibrate calorimeters and align tracking chambers
4. Measure Standard Model cross sections and distributions
5. Look for peaks on top of known processes

Calibration and Alignment

Calorimeters need to be calibrated

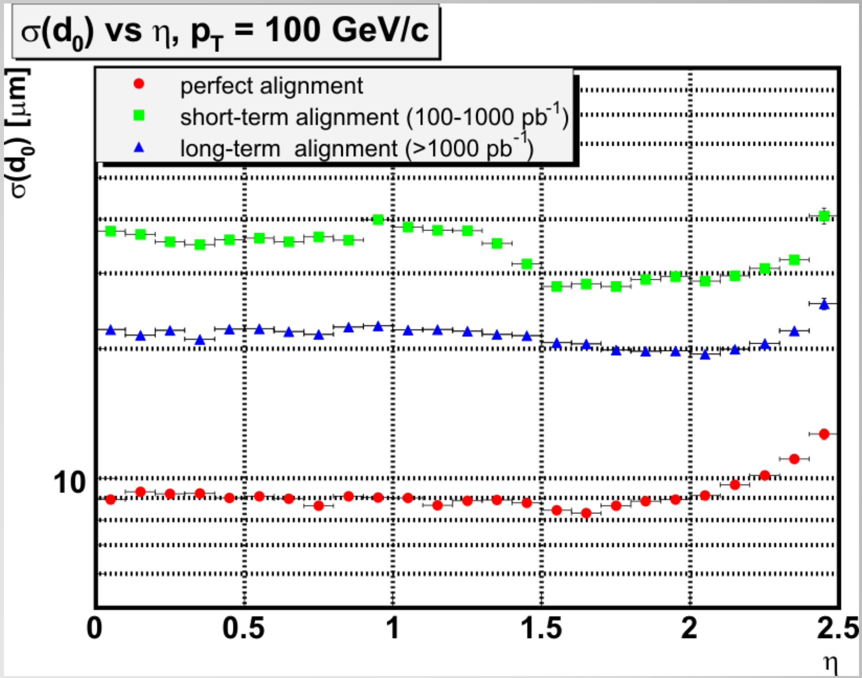
CMS Physics TDR Vol. I



ECAL calibration uncertainty
For different detector regions

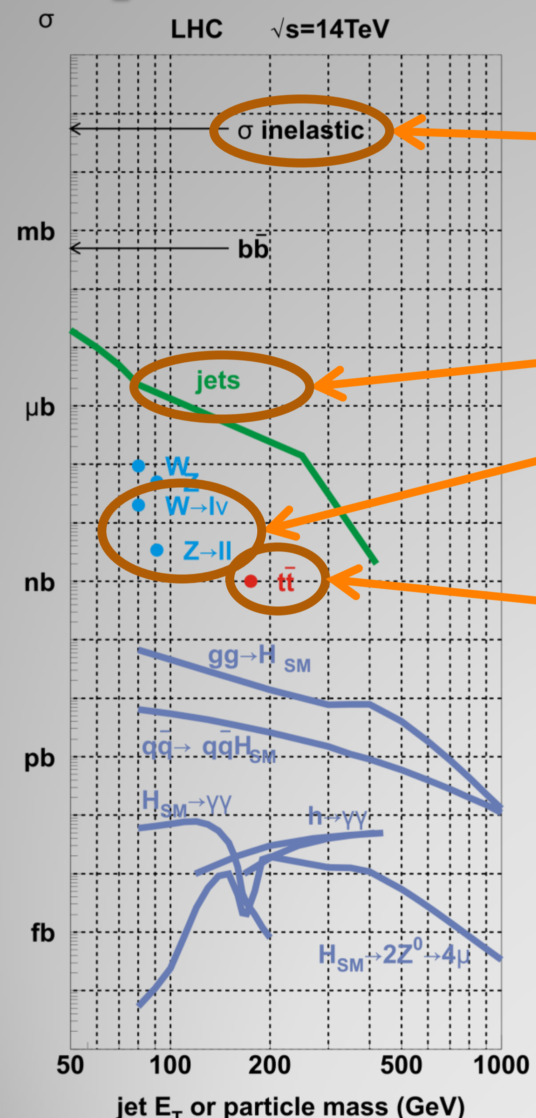
Tracking chambers need to be aligned

CMS Note 2006/029



Transverse impact parameter resolution for different misalignment scenarios

Physics Processes at LHC



Underlying event ($\int Ldt$ = 1-100 pb^{-1})

Dijets ($\int Ldt$ = 10-1000 pb^{-1})

W/Z $\rightarrow$ e/μ ($\int Ldt$ = 10 pb^{-1})

Top pairs ($\int Ldt$ = 20–1000 pb^{-1})

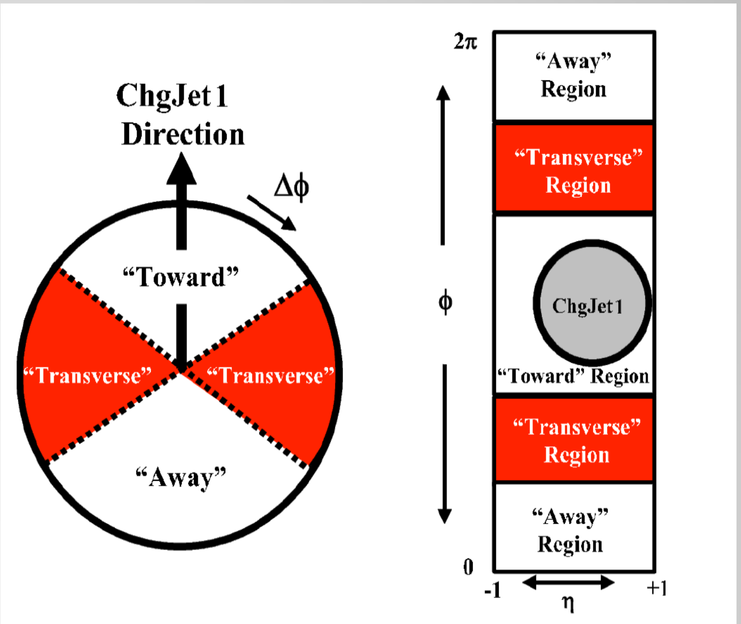
Physics analyses for the near future (2008 and early 2009 runs)

Underlying event

CMS PAS QCD_07_003

- Several models for describing the non-hard-scattering part of a proton-proton collision (underlying event) exist
- Models tuned with measurements at the TEVATRON but still give significantly different predictions for LHC
- Experimentally important for
  - calculating jet energies
  - particle isolation
  - Multiple hard interactions

- Strategy: Look for charged particle activity in the plane transverse to the leading charged particle jet and compare different models



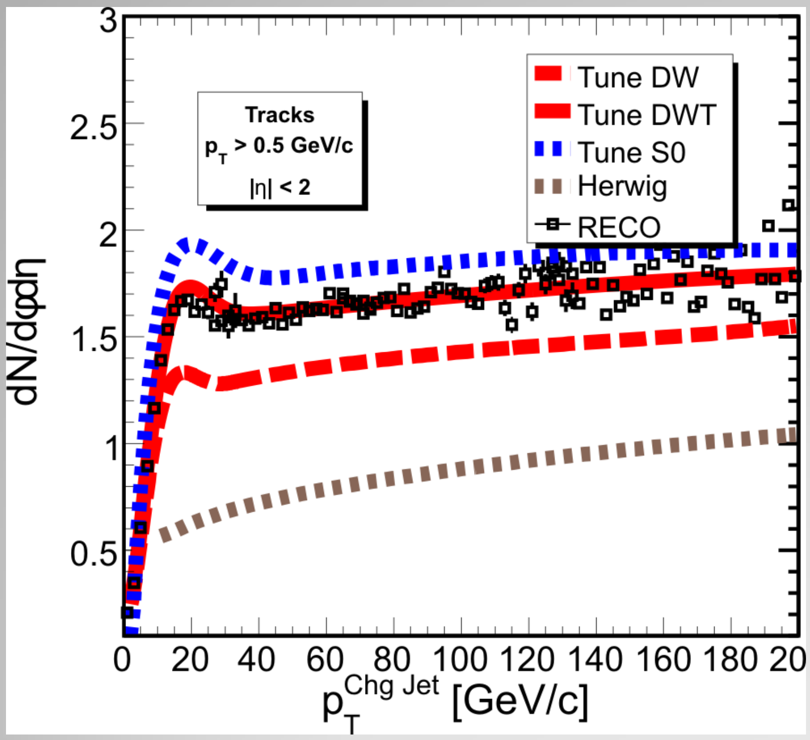
CMS CR 2007/064

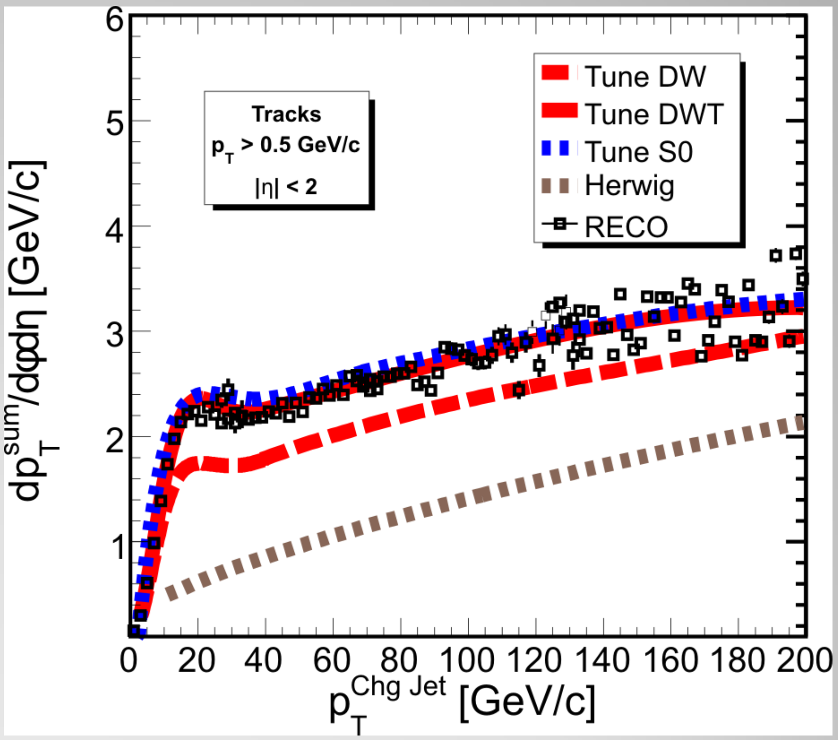
Underlying event

CMS PAS QCD_07_003

100 pb^{-1}

In region transverse to leading track jet





charged particle multiplicity

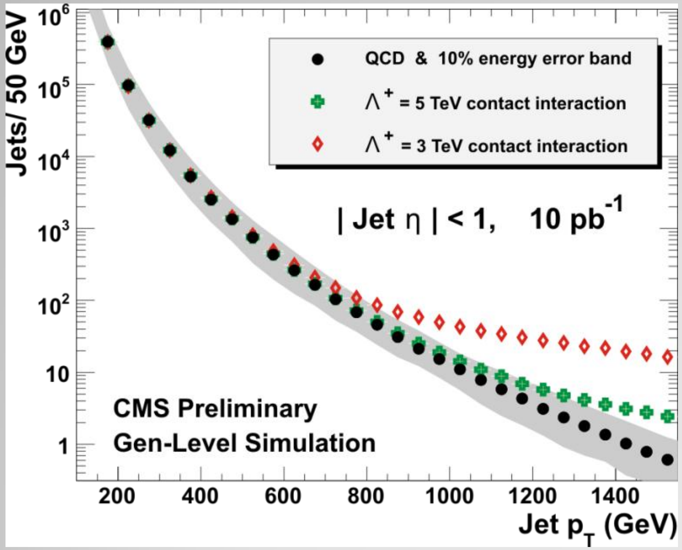
charged particle momentum sum

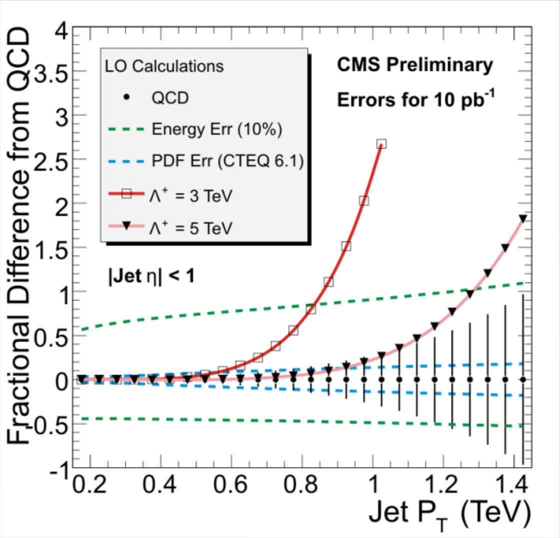
underlying event models differ significantly !

Physics with dijet events

CMS PAS SBM_07_001

- Reconstruct jets with an iterative cone algorithm (cone size R = 0.5)
- Take the two jets with largest transverse momentum
- Require
  - central jets
  - missing E_T / (scalar E_T sum) < 0.3





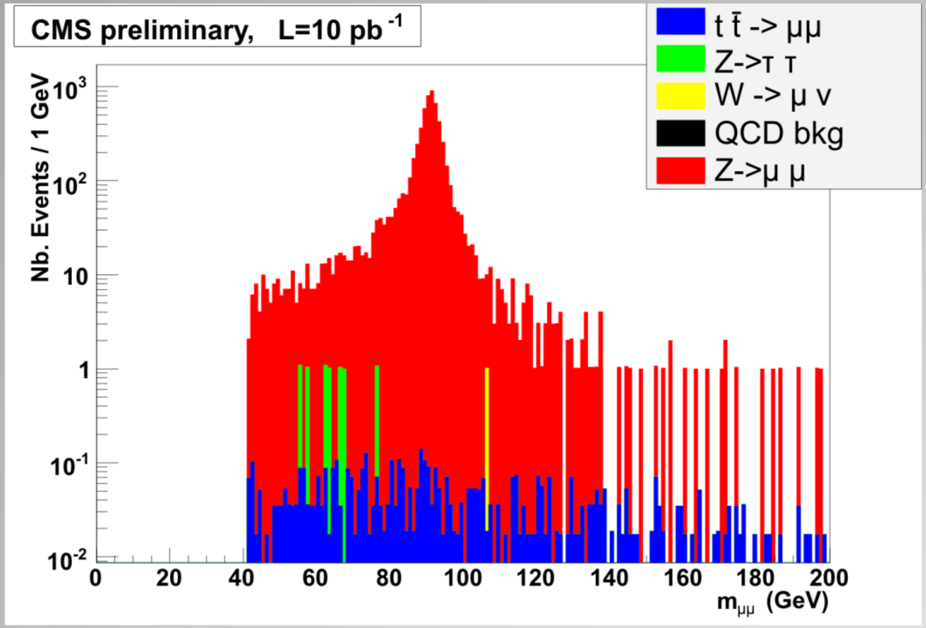
Sensitivity to contact interactions: Λ^+= 3 TeV observable with 10 pb^{-1}
(Current TEVATRON limit: 2.7 TeV)

W/Z → electrons/muons

- High cross section
- Half of the Feynman diagram is electroweak
  - well understood theoretically
    - fully differential calculations available at NNLO QCD (Melnikov, Petriello Phys.Rev.D74:114017,2006)
    - Theoretical scale uncertainty less than 1%
  - Measured to high precision at previous colliders
- Can be used to calibrate electromagnetic calorimeter and muon detectors in situ
- Can be used to check lepton reconstruction efficiencies with data
- Can be used to cross check PDFs
- Background to a number of searches

W/Z → muons

CMS PAS 2007/002



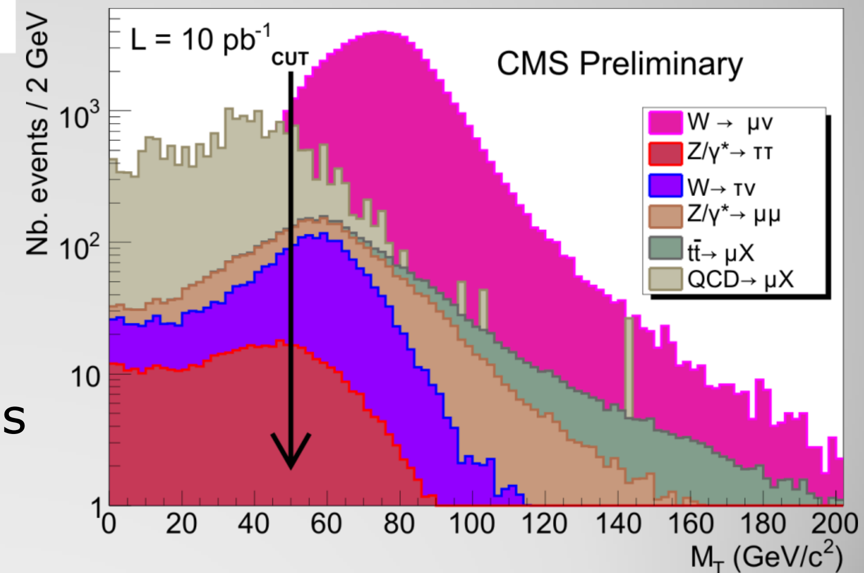
μμ invariant mass for Z/γ^* events

Estimate backgrounds from fit to sidebands

Low backgrounds !

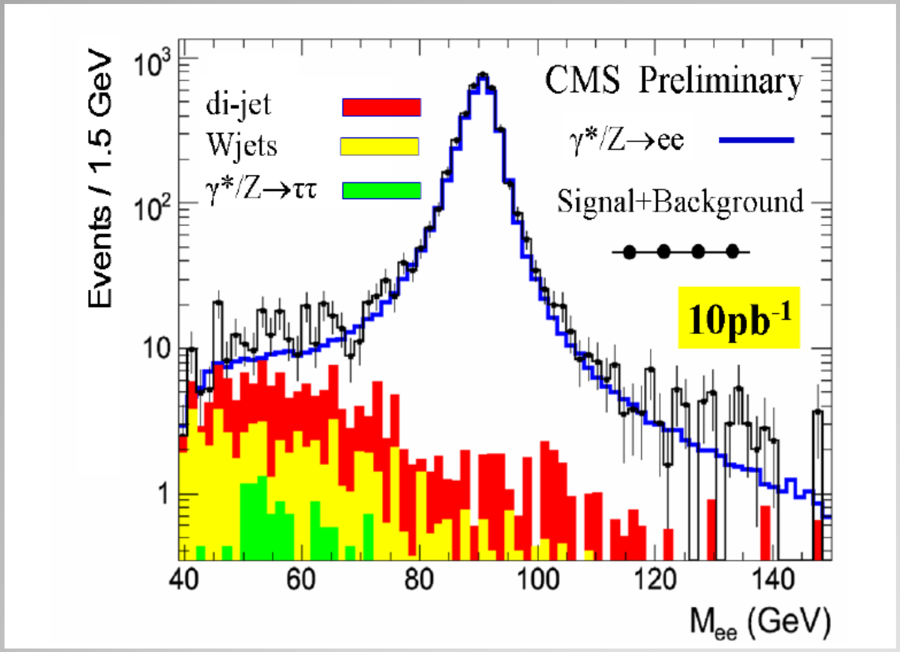
Muon trigger proven to work with cosmic muons

$\mu + E_T^{miss}$ transverse mass for W events



W/Z → electrons

CMS PAS EWK-07-001

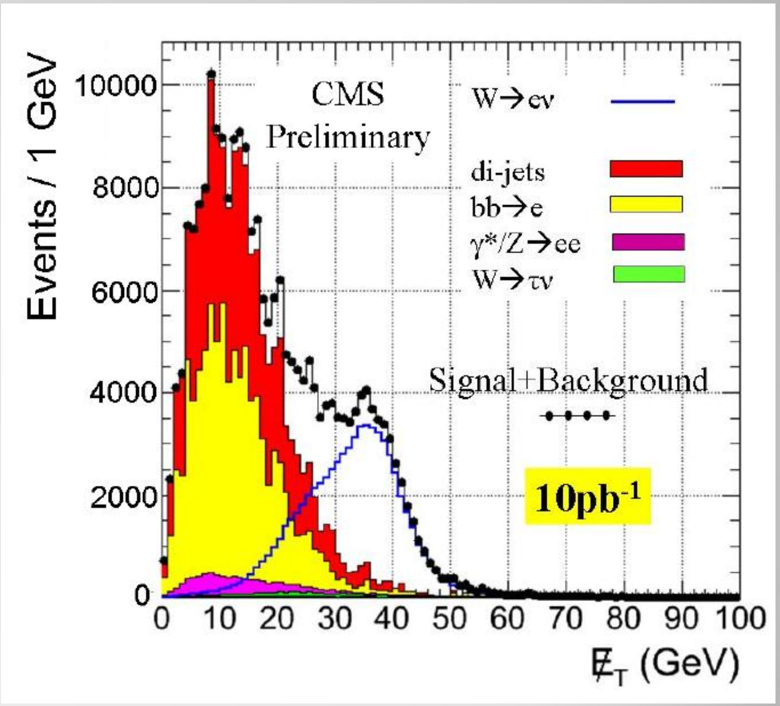


ee invariant mass mass for Z/γ^* events

Background
(in peak region) ~ 1%

Low backgrounds !

E_T^{miss} for W events



W/Z → electrons

CMS PAS EWK-07-001

- Backgrounds:
  - $W \to e\nu$
    - QCD background: determine from data
    - Z/γ^* decays to electrons (3%)
    - W/Z decays to taus (2%)
  - $Z \to e^+e^-$
    - Light and b di-jet production
    - About 1% total
- Expected uncertainties for 10 pb^{-1}:

Source/Nature	$W \to e\nu$
Systematic (BG subtraction, efficiency, acceptance, higher order calculations, renormalization scale etc.)	few %
Luminosity	10%
Statistical	~ 1%

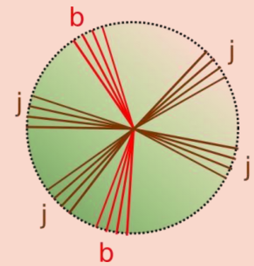
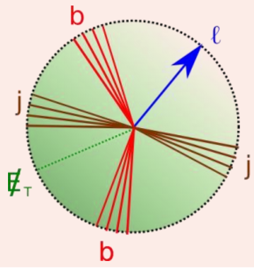
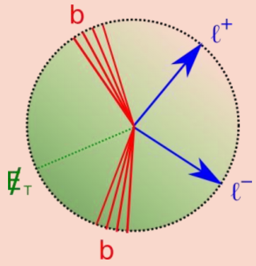
Luminosity is the dominant uncertainty
→ use this measurement to determine the parton luminosity

Top pair physics

- Large number of tops will be produced at LHC
  - $\sigma_{NLO} \approx 830$ pb
  - Cross section more than 100 times larger than at the Tevatron
- All kinds of reconstruction aspects need to be understood/can be tested:
  - Lepton reconstruction and identification
  - Jet reconstruction
  - Lepton energy/jet energy/missing E_T scales
  - Secondary vertices, b-tagging

Top pair physics

- Experimental signatures:

Decay Mode	Branching ratio	Experimental signature
hadronic	46%	
Semi-leptonic	44% (29% e/μ)	
dilepton	10% (5% e/μ)	

Top pair physics

- Start with di-lepton and semi-leptonic (lepton = e/μ) channels
- With $20pb^{-1}$:
  - About 800 di-lepton and 4700 semi-leptonic (e/μ) events produced
  - Observe top pair events
  - Look for a mass peak (semi-leptonic channel)
- With $200pb^{-1}$:
  - Estimation of background rates from data
  - Measurement of cross section
  - Measurement of m_{top}
  - Measurement of first differential distributions (m_{top}, m_{top}^{T}, p_T,…)
  - Observation of events involving tau decays
  - Checks of inclusive jet energy scale, b-tag efficiency, missing E_T reconstruction, m_{top} - $m_{antitop}$

Top pair physics

CMS Physics TDR Vol. II

1000 pb^{-1}

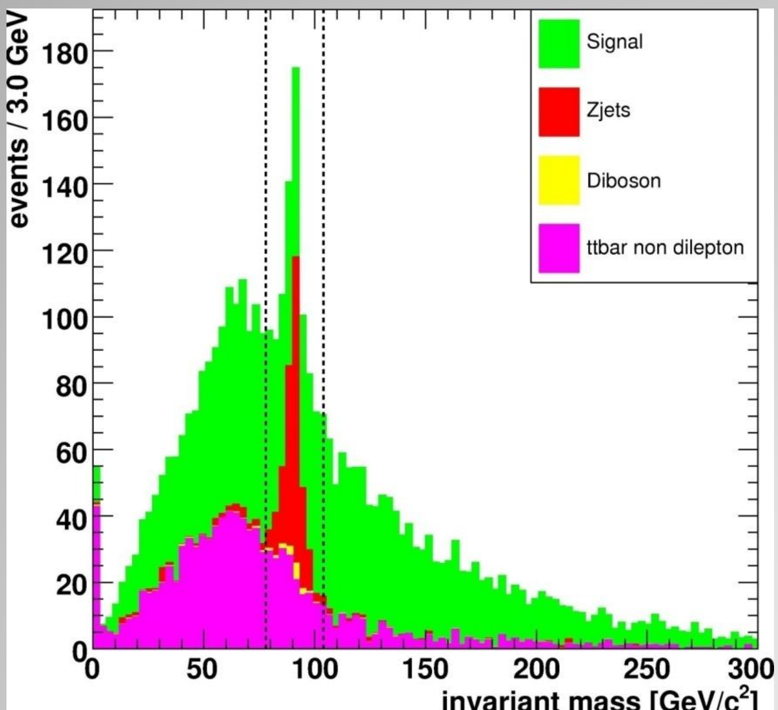
- Di-lepton channel:
  - Require
    - Lepton trigger
    - At least two jets
    - Two oppositely charged leptons with p_T > 20 GeV
    - Lepton isolation (tracks and calorimeter hits)
    - E_T^{miss} > 40 GeV
  - Select two b jets
    - Discrimination based on jet p_T, jet mass (from tracks), secondary vertex (distance and relative energy) etc.
  - Apply kinematic fit imposing W mass
  - Efficiency = 1.2%, S/B = 12:1

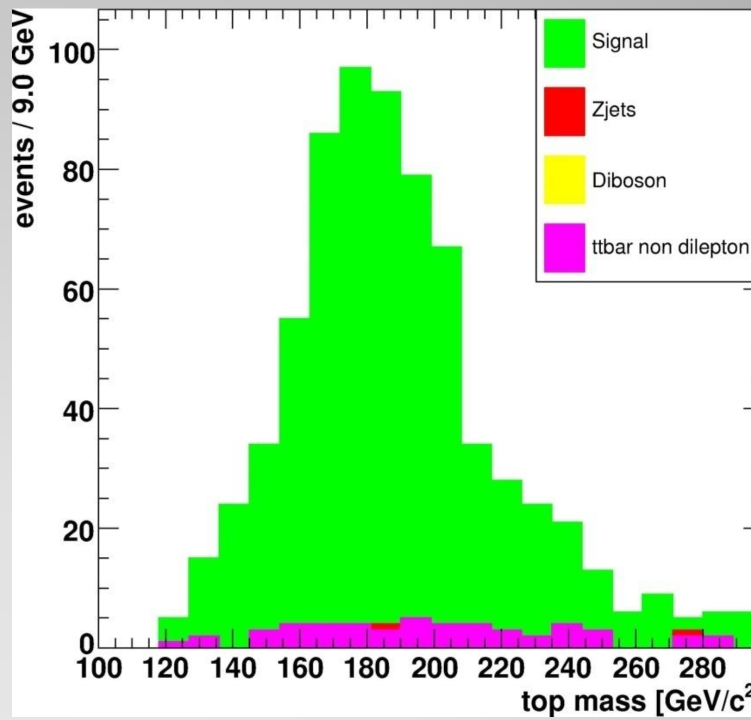
Top pair physics

CMS Physics TDR Vol. II

1000 pb^{-1}

Di-lepton channel





Di-lepton invariant mass

Reconstructed top mass after Kinematic fit (final selection)

Top pair physics

CMS Physics TDR Vol. II

$1000\ pb^{-1}$

- Semi-leptonic channel (muons only):
  - Require
    - Single muon trigger
    - At least four jets
    - A muon with p_T > 20 GeV
    - Lepton isolation (tracks and calorimeter hits)
    - E_T^{miss} > 30 GeV
  - Select two b jets
    - Discrimination based on jet p_T, jet mass (from tracks), secondary vertex (distance and relative energy) etc.
  - Apply kinematic fit imposing W mass
  - Efficiency = 6.28±0.04%, S/B = 26.7:1
  - Cross section measurement uncertainties ($1\ fb^{-1}$): ± 1.2%(stat) ±9.2%(syst) ± 10% (luminosity)

Conclusion and outlook

Several interesting physics topics to be looked at with the very first LHC collisions were presented

Looking forward to recording proton-proton collisions soon !

Backup Slides

Top pair physics

- Systematic uncertainties (di-lepton channel, 10 fb^{-1})

Effect	Effect on cross section measurement
Jet Energy Scale	3.6%
b-tag efficiency	3.8%
Lepton reconstruction	1.6%
E_T^{miss}	1.1%
ISR and FSR	2.5%
Pile-Up	3.6%
Underlying Event	4.1%
Heavy quark fragmentation	5.1%
PDF uncertainties	5.2%
Statistical uncertainty	0.9%
Integrated luminosity	3%

Top pair physics

- Accepted cross sections (di-lepton channel, LO cross section in pb^{-1}):

Stage	Signal	τ	WW	WZ	ZZ	Z + jets	Other top pair
Before selection	24.3	30.4	7.74	0.89	0.11	3912	438
Level-1 + HLT	19.4	15.1	4.4	0.37	0.07	657	92
2 jets E_T > 20 GeV	11.5	9.8	0.6	0.012	0.006	23.9	73.1
E_T^{miss} > 40 GeV	9.6	8.1	0.5	0.01	0.003	5.8	53.6
Two opp. charged leptons	3.2	0.42	0.04	0.001	0.001	1.17	0.12
b-tag of two highest E_T jets	1.12	0.15	0.002	$\sim 10^{-4}$	$\sim 10^{-5}$	<0.01	0.05

Top pair physics

- Systematic uncertainties (semi-leptonic channel, 10 fb^{-1})

Effect	Effect on cross section measurement
Simulation samples (ε_{sim})	0.6%
Simulation samples (F_{sim})	0.2%
Jet Energy Scale (light quarks) (2%)	1.6%
Jet Energy Scale (heavy quarks) (2%)	1.6%
b-tagging (5%)	7.0%
Background level	0.9%
Radiation (Λ_{QCD}, $Q^2{}_0$)	2.6%
Pile-Up (30% On-Off)	3.2%
Underlying Event	0.8%
Fragmentation (Lund b,σ_q)	1.0%
Parton Density Functions	3.4%
Statistical uncertainty	0.4%
Integrated luminosity	3%
Total Systematic Uncertainty	9.7%
Total Uncertainty	9.7%

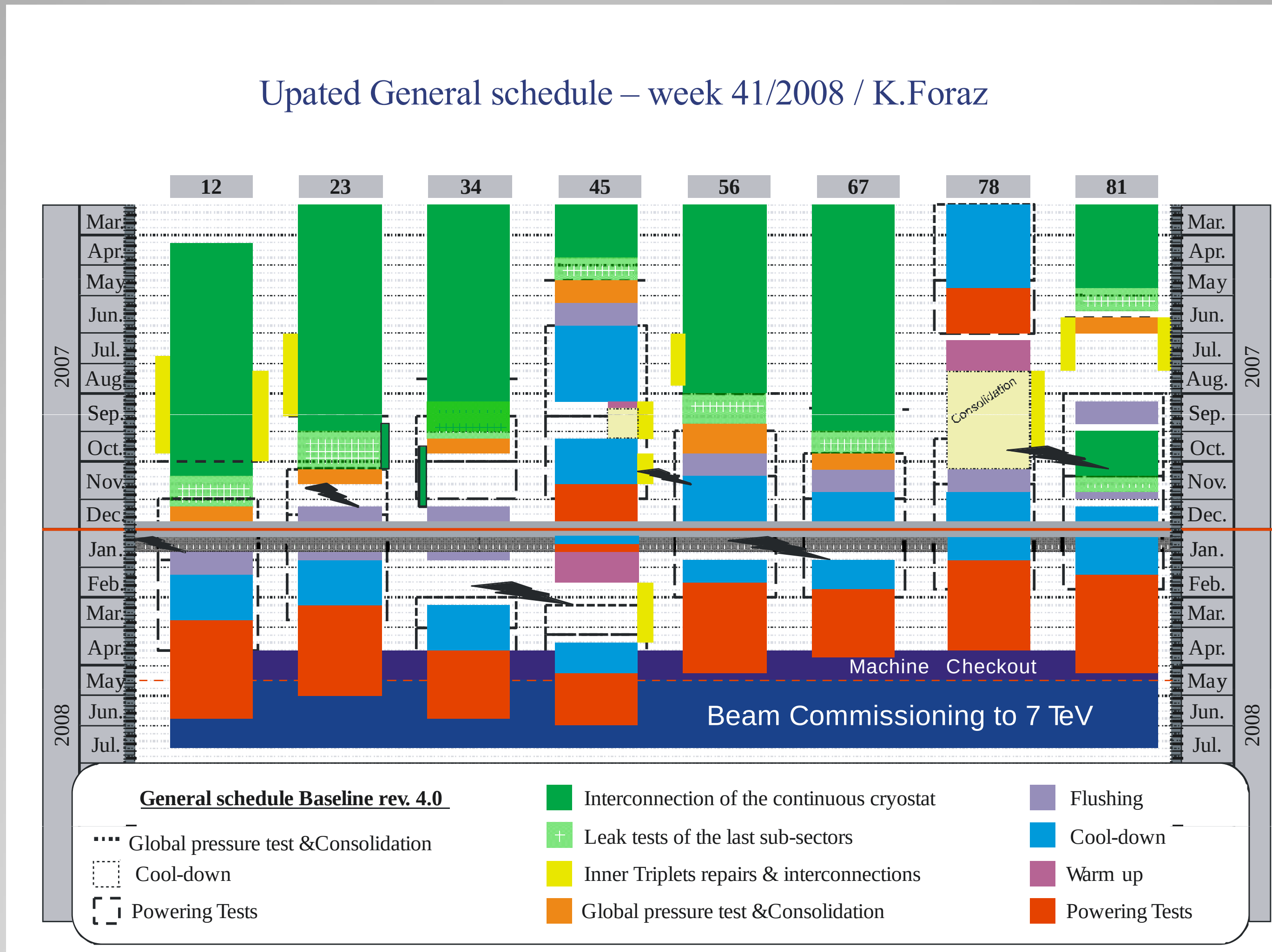
Top pair physics

- Efficiencies (semi-leptonic channel, LO cross sections for S/B and accepted cross section):

Stage	Semi-lept. top pair	Other top pair	W + 4jets	Wbb + 2jets	Wbb + 3jets	S/B
Level-1 + HLT	62.2%	5.30%	24.1%	8.35%	8.29%	7.8
four jets E_T > 30 GeV	25.4%	1.01%	4.1%	1.48%	3.37%	9.9
p_T^{lepton} > 20 GeV	24.8%	0.97%	3.9%	1.41%	3.14%	10.3
b-tag criteria	6.5%	0.24%	0.064%	0.52%	0.79%	25.4
Kinematic fit	6.3%	0.23%	0.059%	0.48%	0.72%	26.7
Selected cross section (pb)	5.21	1.10	0.10	0.08	0.05	
Scaled to L = 1 fb^{-1} (events)	5211	1084	104	82	50	

LHC schedule

http://cern.ch/foraz/schedule.pdf

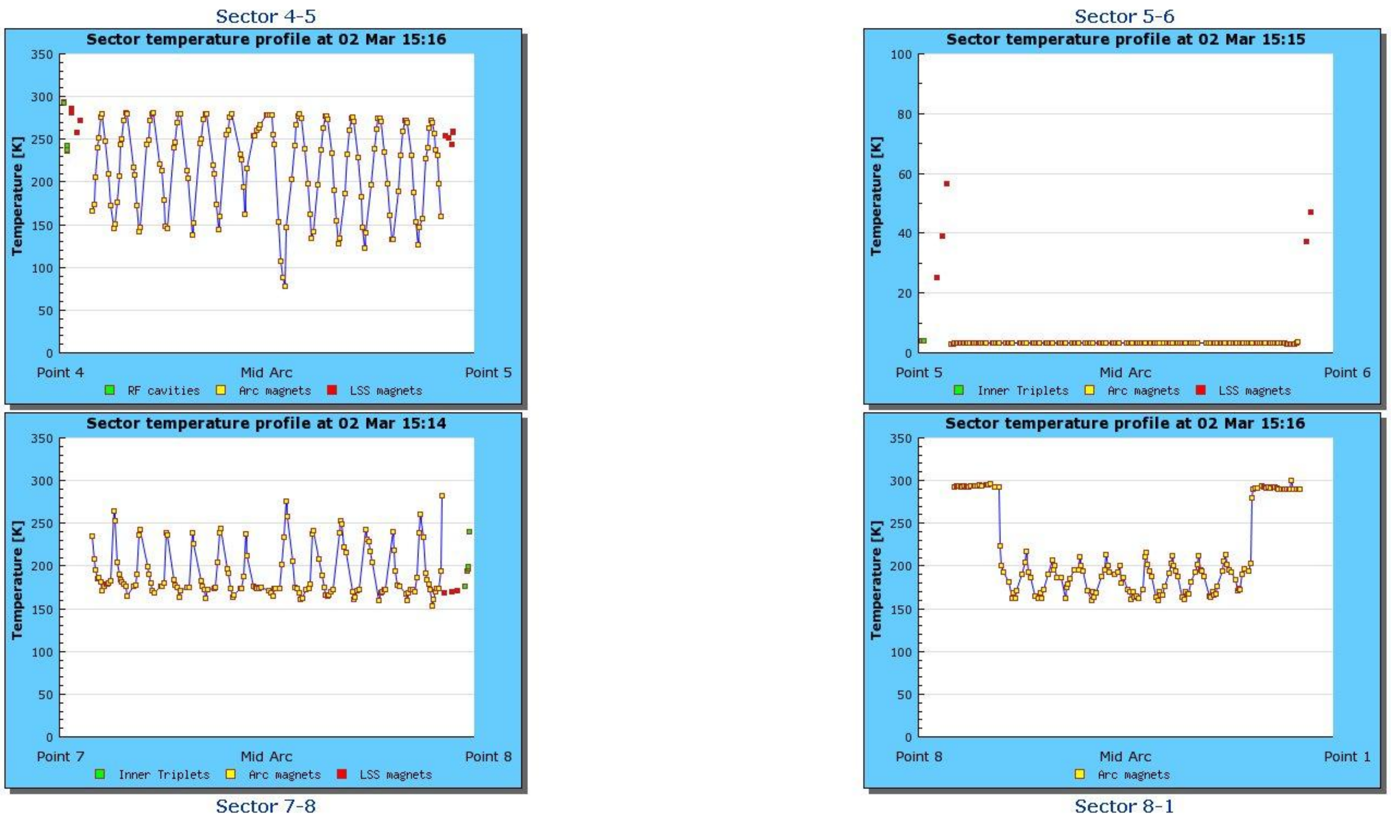


Expect beam commissioning in July

LHC status

http://cern.ch/lhc 2008-03-02

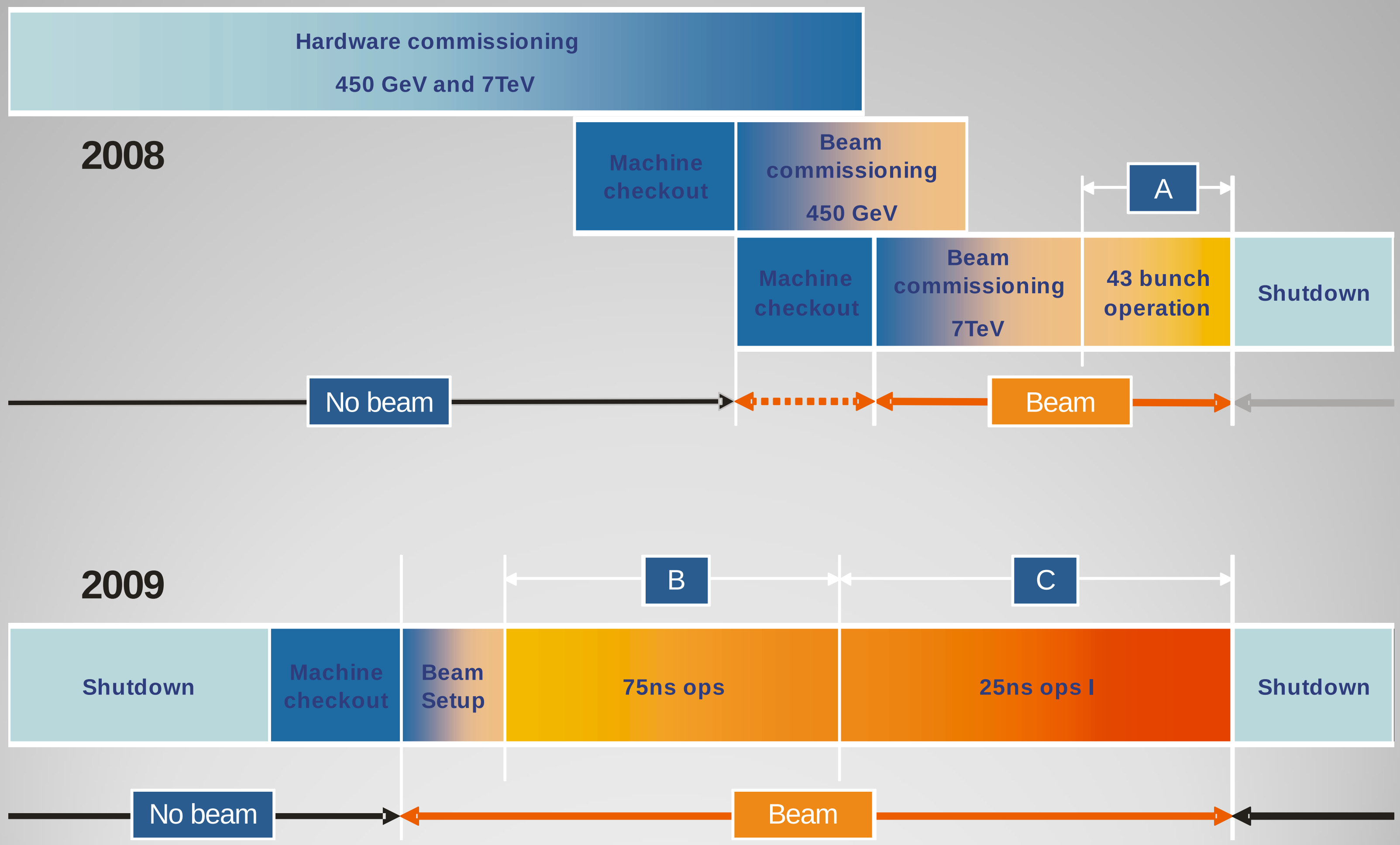
Cooldown status



LHC Hardware Commissioning home page

LHC schedule

R.Bailey, Physics at the Terascale
DESY, December 2007



LHC schedule

<u>Stage A</u>	**Pilot physics run:** physics aim 43 x 43 bunches; maximum 156 x 156 bunches.
<u>Stage B</u>	**Intermediate physics run:** physics aim 75 ns bunch spacing; possible initial physics aim 96 x 96 bunches (bunch intensity 1 x 10^{10}), maximum aim 936 x 936 bunches (maximum 9 x 10^{10}).
Stage C	**25 ns run I:** intensity per bunch 5 x 10^{10} protons (initial 1 x 10^{10}); physics aim 2808 x 2808 bunches
Stage D	**25 ns run II:** push towards nominal performance

Machine parameters		450GeV		Stage A		Stage B		Stage C			Stage D	
		Target		Target	Limit	Target	Limit	Target	Limit		Target	Limit
spacing	ns	2021		2021	566	75	75	25	25		25	25
bunch length	m	0.1124		0.0755	0.0755	0.0755	0.0755	0.0755	0.0755		0.0755	0.0755
crossing angle	urad	0		0	0	250	250	285	285		285	285
bunch intensity		4.00E+10		4.00E+10	9.00E+10	4.00E+10	9.00E+10	5.00E+10	5.00E+10		9.00E+10	1.15E+11
bunches		43		43	156	936	936	2808	2808		2808	2808
energy	eV	4.50E+11		7.00E+12	7.00E+12	7.00E+12	7.00E+12	7.00E+12	7.00E+12		7.00E+12	7.00E+12
F		1.00		1.00	1.00	0.96	0.92	0.90	0.84		0.90	0.84
normalised emittance	cm	3.75E-04		3.75E-04	3.75E-04	3.75E-04	3.75E-04	3.75E-04	3.75E-04		3.75E-04	3.75E-04
beta*	cm	1100	**Commission hardware for high energy operation**	200	200	200	100	100	55	**Installation of phase II collimators and full beam dump diluters**	100	55
luminosity	/cm2s	7.16E+28		6.12E+30	1.12E+32	1.28E+32	1.24E+33	1.13E+33	1.91E+33		3.65E+33	1.01E+34
total inel cross section	cm2	6.00E-26		6.00E-26	6.00E-26	6.00E-26	6.00E-26	6.00E-26	6.00E-26		6.00E-26	6.00E-26
event rate per cross		0.01		0.76	3.85	0.73	7.09	2.14	3.63		6.94	19.18
protons per beam		1.72E+12		1.72E+12	1.40E+13	3.74E+13	8.42E+13	1.40E+14	1.40E+14		2.53E+14	3.23E+14
current per beam	mA	3.09E+00		3.09E+00	2.53E+01	6.74E+01	1.52E+02	2.53E+02	2.53E+02		4.55E+02	5.81E+02
energy per beam	Joules	1.24E+05		1.93E+06	1.57E+07	4.19E+07	9.43E+07	1.57E+08	1.57E+08		2.83E+08	3.62E+08
beam size	um	293.3		31.7	31.7	31.7	22.4	22.4	16.6		22.4	16.6