Experiments desiderata

- How much data is useful at $s^{1/2} = 900$GeV?
  - build on LTC 2007-15, with update in light of current situation
- Integrated luminosity $\times$ cross section vs. energy
  - What is the minimum amount of data at given energy that is needed to make the 2009 run useful?
  - What do we need to do to pass the Tevatron, which aims for $9$ fb$^{-1}$ by 2010?
- Non-GPD (non General Purpose Detectors)
  - ALICE and LHCb
  - TOTEM and LHCf
  - Ions
- Scheduling / scenarios
to the representatives of the LHC experiments who helped me preparing this presentation (Federico Antinori, Austin Ball, Sergio Bertolucci, Tiziano Camporesi, Dave Charlton, Christophe Clement, Mario Deile, Fabiola Gianotti, Andrei Golutvin, Peter Jenni, Paul Kuijer, Daniela Macina, Marzio Nessi, Werner Riegler, Andreas Schopper, Jurgen Schukraft, Paris Sphicas, Jim Virdee, Thorsten Wengler, Werner Witzeling, etc.)

and

to the many brave physicists who, hidden behind the overshadowing « LHC Collaborations », worked hard to produce the relevant physics graphs and numbers, some of which will be shown here.

Many thanks
How much data is useful at 450GeV?

- In what conditions?
- To do what?

- Assumption: "on the way" to high energy ($E_{\text{high}}$)
Stage A: Initial commissioning to pilot physics

Aims: initial commissioning with the goal to bring moderate intensities into collision for the first time, including the the commissioning the LHC cycle with low intensity beam to high energy, and the move to two-beam operation. See Chamonix XIV presentation for outline.

We aim to minimize the risk of quenches (reduced beam current and possibly reduced energy); decouple the commissioning of the various systems; minimize the pile-up in the experiments; and maximize the integrated luminosity.

- Phases - breakdown of the phases of the commissioning process with well-defined prerequisites and goals for each phase. The required functionality of the accelerator equipment and instrumentation for each is listed.
- Breakdown in terms of estimated time of tasks making up the constituent phases
- Luminosity performance

Stage A: How Long?

Assume we slice commissioning procedures to the minimum required to get 2 pilot++ beams to 7 TeV and collide them unsqueezed. From scratch (no sector test, no 450 GeV run):

<table>
<thead>
<tr>
<th></th>
<th>Ring factor</th>
<th>Total Time [days] both rings</th>
<th>Comments</th>
</tr>
</thead>
</table>
| A1 | Injection and first turn | 2 | 4 | ✓ done! :-)
| A2 | Circulating beam | 2 | 2 |
| A3 | 450 GeV initial commissioning | 2 | 4 |
| A4 | 450 GeV optics measurements | 2 | 5 | Priority 1 measurements only
| A6 | 450 GeV - two beams | 1 | 1 | Low intensity all
| A7 | Collisions at 450 GeV | 1 | 2 | Performance - Bring CMS solenoid on before - measure and correct coupling
| A8 | Snapback and ramp | 2 | 10 | Single and then two beams
| A9 | 7 TeV flat top checks | 2 | 2 |
| A10 | Commission experimental magnets | 1 | 1 |
| A11 | Setup for collisions - 7 TeV | 1 | 1 |
| A10 | Physics unsqueezed | 1 | - |
| **TOTAL to first collisions** | 31 |
| A11 | Commission squeeze | 2 | 6 |
| A5 | Increase intensity | 2 | 6 |
| A5 | Set-up physics - partially squeezed. | 1 | 2 |
| **Pilot physics run** | |

We are assuming around 30 days of beam time to get first collisions. With an operational efficiency of 50%, it would take something like 2 months elapsed time. This will be followed by a period of pilot physics interleaved with further machine development.
Is it useful?
- Yes! Contrary to a year ago: Expts do request a 900 GeV runlet.
- All Expts wish to make use of 2 or 3 shifts of stable colliding beams, still in the noise of the beam commissioning schedule

When?
- As soon as possible!
  - integrated luminosity not so relevant. More important: beam conditions and the organization/scheduling of the 900 GeV stable_beams periods.
  - insertion into commissioning plan to be done "on the fly"
  - probably: one physics fill, then back to beam commissioning, then another physics fill, etc.
  - no need to wait for high intensities, happy with $k_b = 2$, $\beta^* =$ injection value, $N = \sim 9 \times 10^{10}$

To do what?
- Mainly: time alignment, space alignment
- Also: physics cross check (a few basic distributions, cross section)

In what conditions?
- Safe beam conditions, stable beams (interlocks!) ... two small issues
- Request: take the data with solenoids ON ... and also OFF, if possible (ALICE)
- Expt dipoles OFF is acceptable (and even requested by LHCb, unless net crossing angle is adjusted)
- All experiments are interested $\Rightarrow$ at least 2 bunches per beam should be used

for info: about $10^{26} \text{cm}^{-2} \text{s}^{-1} \\times 10^5 \text{s} = \sim 1 \text{nb}^{-1} \\
(\sim 5 \times 10^7$ inelastic interactions)
What do we need to do to pass the Tevatron, which aims for 9 fb\(^{-1}\) by 2010?

What is the minimum amount of data at given energy that is needed to make the 2009 physics run useful? (assuming CM energy \(8 < s^{1/2} < 10\) TeV)

See also Jim Virdee in Chamonix XII, p. 257
What do we need to do to pass the Tevatron, which aims for 9 fb⁻¹ by 2010? What is the minimum amount of data at a given energy that is needed to make the 2009 physics run useful? (assuming CM energy $8 < \sqrt{s} < 10$ TeV)

See also Jim Virdee in Chamonix XII, p. 257
GPD physics: Two families

Discovery channels:
- Higgs
- $W'$, $Z'$
- SUSY
- Exotic particles

Try to express these as:
1. Lumi needed to make a better (exclusion) measurement than Tevatron
2. Lumi needed to make a discovery

Standard Model channels
- $W$, $Z$
- top
- QCD

An excellent understanding of these is an essential step toward discoveries

NB: In the following slides, when talking about integrated luminosity (“so many pb⁻¹”), we really mean data taken with good beam and detector conditions (i.e. “good data” or g.d.)

Let’s not forget that
- Understanding the detector performance will take time
- There will be operation inefficiencies, down time, etc.
State of the Art: Tevatron

Projected integrated lumi

how much by end 2010?

There is more than just one paranoia at CERN...
Higgs 95% CL at LHC GPD, $H \rightarrow$ weak bosons, indicative

Combined $H \rightarrow$ WW $+$ $H \rightarrow$ ZZ: lumi for 95% CL

CMS Preliminary

- Energy $s^{1/2}$: 14 $\rightarrow$ 10 $\rightarrow$ 6 TeV
- Lumi needed: 0.1 $\rightarrow$ 0.2 $\rightarrow$ 0.6 fb$^{-1}$

To challenge Tevatron with $s^{1/2} = 8-10$ TeV, we need $\sim$300-200 pb$^{-1}$ g.d.

Tevatron expect 1.9σ sensitivity at $m=160$ with 8fb$^{-1}$ (one expt)

$m_H=160$ GeV

Massive loss of sensitivity below 6 TeV

Int. lumi scale uncertainty is $\sim$50%

Energy dependence from ATLAS@simulation of $e^{+}e^{-}\nu\bar{\nu}$ channel assuming $gg \rightarrow H$ dominant
Higgs $5\sigma$ discovery, indicative

5\sigma discovery for $m_H \sim 160$ GeV is possible with $s^{1/2} = 8-10$ TeV and $\sim 1$fb$^{-1}$ g.d.
Z' resonance

Z': Heavy partner of the Z (SSM)
- Very clean experimental signal: Z' → ℓℓ
- Tevatron 95% CL limit at m_{Z'} = 1 TeV

Needed luminosity for 95%CL exclusion at m_{Z'} = 1 TeV:
\[ s^{1/2} : 14 \rightarrow 10 \rightarrow 6 \text{ TeV} \]
Lumi: 13 → 30 → 110 pb^{-1}

for m_{Z'} \sim 1\text{ TeV}, with \( s^{1/2} = 10 \text{ TeV} \),
\[ 95\% \text{ CL limit with } \sim 30 \text{ pb}^{-1} \text{ g.d.} \]
5σ discovery possible with \( \sim 100 \text{ pb}^{-1} \text{ g.d.} \)
SUSY, an example

- $\ell$+jets+missing-$E_T$ channel
  - Not most sensitive, but will be usable before inclusive jets+missing-$E_T$ analysis
- Tevatron limit currently is 380 GeV in this model ($m_{\tilde{q}} = m_{\tilde{g}}$)
  - plot shows 3 masses above this
- We will be sensitive to a region overlapping with ultimate Tevatron reach
- Below $E_{cm} \approx 8$ TeV, the sensitivity collapses

5σ discovery beyond current Tevatron limits is possible with $s^{1/2} = 8-10$ TeV and $\sim 30-15$ pb$^{-1}$ g.d.
Susy in the Sky with Diamonds

Search for Gluino-Mediated Sbottom Production in the MET+b-jet Sample

The CDF Collaboration
URL http://www-cdf.fnal.gov
(Dated: September 12, 2008)

CDF Note 9506

INTRODUCTION

Supersymmetry (SUSY) is one of the primary theories for physics beyond the Standard Model (SM). SUSY proposes a symmetry between fermions and bosons and predicts a superpartner for all standard model particles. The superpartner for a standard model particle differs from it only by a half-unit of spin. With the addition of this symmetry, SUSY offers solutions to the fine-tuning problem and a possible mechanism for electroweak symmetry breaking (EWSB). It also makes possible for a unification of the gauge couplings at about the Planck scale \(10^{19}\) GeV.
Top quarks

- Background to new physics searches – must measure cross-section & properties in data
- Expected Tevatron statistics provide a benchmark:
  - Cross-section statistical precision will then be comparable to other uncertainties
  - High-precision top physics will be underway

~50 pb⁻¹ @ 14 TeV would match full Tevatron sample
- lose ~factor 2 in cross-section dropping to 10 TeV
- lose ~another factor 2 dropping to 8 TeV

Below 8 TeV samples will be rather small, with a few tens of pb⁻¹

Catch up with Tevatron with \( s^{1/2} = 8-10 \) TeV and \(~200-100\) pb⁻¹ g.d.
Non-GPD

- LHCb
- ALICE
- TOTEM
- LHCf
LHCb in summary

- B cross section does not vary as drastically as for high mass objects. Thus, the request to go to highest possible energy is milder.
- Need **0.3-0.5 fb\(^{-1}\) at \(s^{1/2} \geq 8\ TeV\)** to surpass Tevatron in \(B_s\) physics.
- Need at least 5 \(pb^{-1}\) at \(s^{1/2} \geq 4\ TeV\) to collect good sample of J/psi.

NB:
- If \(E \leq 2\ TeV\), LHCb will not take the risk to close the VELO (if with full \(B_{\text{spectr}}\) and uncorrected crossing angle). Hence, disfavour a hypothetical "Tevatron energy run".
- LHCb assumes that TCTVs will all be present, so that there is no limitation in IP8 to \(\beta^*\) ⇒ exploit smallest possible \(\beta^*\) in 2009 and 2010 (what is \(\beta^*_{\text{min}}\) with full \(B_{\text{spectr}}\) and 50ns ??)
- LHCb wishes to take some TED calibration runs about 1 month before beam arrives into LHC (LHCb detector is set up horizontally and lacks cosmics, especially in VELO detector).
Physics reach for $BR(B_s^0 \rightarrow \mu^+\mu^-)$

- as function of integrated luminosity (and comparison with Tevatron)

At $s^{1/2} = 8$ TeV, need $\sim 0.3-0.5$ fb$^{-1}$ g.d. to improve on expected Tevatron limit

Collect $\sim 3$ fb$^{-1}$ for $3\sigma$ observation of SM value
ALICE and \textit{pp} running, in a few words

- ALICE not as strongly interested as GPDs in reaching the highest possible energy for \textit{pp}
- What about $s^{1/2} = 5.5$ TeV? (the \textit{NN} equivalent in PbPb@14TeV)
  - not so crucial at this stage, but yes, would request to choose $E=2.75$ TeV if a beam energy between 2 and 3 TeV was being considered
- Will collect data at $\sim 10^{29}$ cm$^{-2}$ s$^{-1}$ (opt) or $3\times 10^{30}$ cm$^{-2}$ s$^{-1}$ (max)
- Physics program includes also runs with smallest possible $\beta^*$: beam axis used as vertex constraint (would like beam size $\sigma_{x,y} < \sim 40$ um which, at 5TeV means $\beta^* < \sim 2.25$ m)
  - 2m? 3m? what is the minimum possible $\beta^*$ at the given energy in 43x43 or 156x156? (while remaining at desired luminosity, and with full $B_{\text{spectr}}$)
- ALICE particularly interested in “symmetric shift” filling schemes and in 50ns (as opposed to 25ns), see later slides
- Heavy ions => see later slides
TOTEM (IP5)

- T1, T2, all RP220 and some RP147 will be ready
- **TOTEM will operate under all running conditions**
  - Programme at $s^{1/2} = 900$ GeV:
    - Poor acceptance for elastic scattering
    - RP alignment using beam halo and diffractive protons
    - Study of surviving protons with momentum losses $\xi = \Delta p/p > 0.1$
    - Study of event topologies with T1, T2 (pseudorapidity distributions, multiplicities)
    - relative cross-sections for different event topologies
  - Programme at $s^{1/2} = 10$ TeV:
    - Early optics ($\beta'^* = 3$ m): large $|t|$ elastic scattering, central diffraction
    - As soon as technically feasible: request $\beta'^* = 90$ m optics (or a gradual unsqueezing from $\beta'^* = 3$ m to higher values)
    - first measurement of $\sigma_{tot}$ with Optical Theorem using T1, T2, RP (~ 5 %)
Aim: study of energy distribution of particles emitted in very forward region for understanding of cosmic ray phenomena

Interested in all c.m. energies, including 900 GeV
- but of course the goal is to measure at 14 TeV

Integrated lumi: few nb\(^{-1}\) at 14 TeV, or order 10 nb\(^{-1}\) if somewhat lower than 14 TeV

Lumi limitation: degradation of non rad-hard components after few pb\(^{-1}\) in data taking position
- move out by 10 cm when L>10\(^{30}\) cm\(^{-2}\) s\(^{-1}\)
- dismount & remove detector when L>10\(^{37}\) cm\(^{-2}\) s\(^{-1}\)

Preferred operating conditions:
- 2x2 and 43x43, L= 10\(^{29}\) cm\(^{-2}\) s\(^{-1}\), crossing angle 0 and 140 urad (enhanced acceptance)
- 156x156 introduce pile-up (2us electronics)

Potentially interested in HI run data taking (interferences to be checked)
Luminosity and Filling schemes

Requests

- **ATLAS/CMS**: highest possible luminosity
- **ALICE**: need $\sim 10^{29} \text{ cm}^{-2} \text{ s}^{-1}$ (opt) or $3 \times 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$ (max)
- **LHCb**: highest possible till reaches $\sim 5 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$, then prefer minimizing pile-up at same luminosity
Filling schemes / bunch patterns

First collisions

- use 2x2 ⇒ each Expt gets 1 colliding pair
  - You save my neck

Many bunches, no crossing angle (43x43, 156x156)

- the «symmetric shift» schemes are generally preferred by Expts
  - ALICE: low lumi becomes easier by reducing number of colliding bunches rather than by displacement or defocusing
  - Can accommodate in IP8 (LHCb) about 50% of IP1&5 luminosity without reducing ATLAS & CMS luminosity
    - 43x43: with 2 or 4 colliding pairs in ALICE, about 19 in LHCb
    - 156x156: with 8 or 16 colliding pairs in ALICE, about 68 in LHCb

Many more bunches, with crossing angle (75, 50, 25ns)

- 50ns seems more suitable than 75 ns for the Expts:
  - easy to include a few colliding pairs for ALICE (no need of lateral displ. or defocusing), while other three IPs get O(1400) colliding bunches
- possibly, 50ns is also more luminous than 25ns while intensity is limited to ~50% of nominal (but some negative effect for LHCb ⇒ more pile-up)

See details in LTC 2008-05 and in LHC Project Notes 323, 415

See Werner Herr's talk
Luminosity limits for 75, 50, 25 ns (2010, ...)

\[ L = \frac{f \, k_b \, N^2}{4\pi\sigma^2} \, F \]

- **Simplified limits:**
  - \[ I_{\text{max}} \quad (I = k_b \, N) \]
  - \[ N_{\text{max}} \]

- For simplicity, assume here the same \( \sigma \) and \( F \) for all high \( k_b \) schemes (75, 50 and 25 ns)

---

For the diagram:

- Hyperbolas
- Straight slopes

---

**LIKELY LIMITS FOR 2010**

- 75ns: \[ 3.22 \times 10^14 \]
- 50ns: \[ 1.61 \times 10^14 \]
- 25ns: \[ 1.29 \times 10^14 \]

---

**Number of bunches vs. luminosity**

- **0** to **3000**
- **0** to **1**

---

1st LHC Performance Workshop 6-February-2009 Chamonix Massimiliano Ferro-Luzzi 24
Heavy Ions: Flow at LHC

- one of the first and most anticipated answers from LHC
  - 2nd RHIC paper: Aug 24, 22k MB events, flow surprise (v₂)
    - Hydrodynamics: modest rise (Depending on EoS, viscosity, speed of sound)
- BNL Press release, April 18, 2005:
  Data = ideal Hydro
  "Perfect" Liquid
  New state of matter more remarkable than predicted – raising many new questions
- LHC will either confirm the RHIC interpretation (and measure parameters of the QGP EoS)
  OR
  ..........................................

1st LHC Performance Workshop 6-February-2009 Chamonix Massimiliano Ferro-Luzzi 25
Heavy Ion Run

- Keep option open
  - Injectors and LHC should be compatible with the possibility of a HI run
  - Note that even 1 day @ early scheme is enough to surpass RHIC, $\beta^* = 1 \text{m} , 62b \times 7\times10^7 \text{Pb}, \alpha=0, \text{ thus } \sim 5\times10^{25} \text{ cm}^{-2}\text{s}^{-1}$

- Would a HI run only at injection energy be of interest?
  - No, only interesting if ramped energy
  - Then, which high energy?
    => For simplicity, start with same magnetic machine as for $\sqrt{s_{\text{NN}}}=\text{p@E}_{\text{high}}$

- When there is a HI run, ATLAS and CMS assume same conditions in their IP as for ALICE (whereas LHCb has no HI program)

- Short run in 2009? ... seems no longer possible.
Putting it all together

- scenario for 2009, 2010
Discovery channels for GPD, in summary

- Typically, with **50-100 pb⁻¹ good data** at 10-8 TeV ⇒ many new limits set on hypothetical particles (some more stringent than Tevatron), or even discoveries possible!

- With **200-300 pb⁻¹ g.d. at 10-8 TeV** ⇒ start competing with Tevatron for Higgs masses around 160 GeV

- With **1 fb⁻¹ g.d. at 10 TeV** ⇒ find Higgs if around 160 GeV mass

- The higher the energy, the faster it goes...

- Note: below ~20-40 pb⁻¹ g.d. at 10-8 TeV, or at any lower energy, one would probably start talking about an "engineering run"
  (can still be very useful, but perhaps not in terms of immediate physics results)

A run at \( s^{1/2} = 8-10 \text{ TeV} \) and at least 100-50 pb⁻¹ of good data would already be a FANTASTIC run with major physics impact
Luminosities at $s^{1/2} = 10$ TeV

\[ L = \frac{f k_b N^2 \gamma}{4\pi \varepsilon_{Nf}\beta^*} F \]

\[ \beta^* = 3m \]
\[ N = 10^{11} \]

Assume (somewhat arbitrarily) a “Hübner factor” of 0.2

\[ k_b = 156 \quad \Rightarrow \quad 6 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1} \quad \Rightarrow \quad \sim 1 \text{ pb}^{-1} / \text{ day} \]

\[ k_b = 1404 \quad \Rightarrow \quad 5 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1} \quad \Rightarrow \quad \sim 8 \text{ pb}^{-1} / \text{ day} \]

Note: Tevatron is cruising at
\[ \sim 3 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1} \]
(8 pb\(^{-1}\)/day , 2 fb\(^{-1}\) / year)
\[ \Rightarrow \text{we need high energy!} \]
The Preferred Scenario

Start the LHC as soon as possible and run for one year

Scenario with greatest flexibility

- Can adapt our goals to evolving circumstances
  - Increase 8 => 12 TeV in the course of 2010?

- Heavy Ion run at the end of 2010
  - adjust end date (start of shutdown)
- THE EXPERIMENTS ARE READY TO TAKE DATA

- LET’S START AS SOON AS YOU CAN  (november?)

- LET’S RUN FOR A YEAR
Probably Asked Questions

(PAQ)
Would the (GPD) experiments be happy to run at $s^{1/2} = 8$ TeV rather than 10 TeV?

a) Short run, sensibly less than 100 pb$^{-1}$:
   – that would be considered an engineering run

b) Long run, 100 pb$^{-1}$ or more:
   – Grossly speaking, we would need to run twice as long as with $s^{1/2} = 10$ TeV, for similar physics impact
   – So, if it fits in a year, yes, let’s do it without waiting!
Would the experiments be favourable to training all sectors to 6 TeV this year, before making a first physics run?

- No.
  - Of course 12 TeV is better than 10 TeV, which is better than 8 TeV, which… but the latter is already a good energy to achieve first physics
  - 6+6 TeV training could fit in sometime in 2010, “gradual increase of energy” (after having secured some data)
Do the experiments need a 2009/2010 winter shutdown?

- No!

- Experiments will be ready to start when the machine is ready to start, any time, and ready to continue as long as is needed to achieve first physics results
Further slides
**W' resonance**

**W' → ev:**
- Tevatron 95% CL limit also at $m_{W'} = 1\,\text{TeV}$
- We will be sensitive to a region overlapping with ultimate Tevatron reach

For $m_{W'} \sim 1\,\text{TeV}$, with $s^{1/2} = 10\,\text{TeV}$, 95% CL limit with $\sim 5\,\text{pb}^{-1}\,\text{g.d.}$, 5σ discovery possible with $\sim 15\,\text{pb}^{-1}\,\text{g.d.}$
Physics reach for $2\beta_s$

- as function of integrated luminosity (and comparison with Tevatron)

0.2 fb$^{-1}$ = threshold introducing fit instabilities

Collect at least $\sim0.3-0.5$ fb$^{-1}$ g.d. to improve on expected Tevatron limit with 9 fb$^{-1}$

$\Rightarrow$ Collect $\sim3$ fb$^{-1}$ for 3σ observation of SM value
B-yield in LHCb acceptance has about linear dependence with energy (i.e. loosing a factor 1.75 going from 14 to 8 TeV CM energy)
Heavy Ions: ‘The First 3 Minutes’

- **Huge jump in energy from RHIC (200 GeV) to LHC:** x 30!
  - for many important observables, $\sigma \sim \sigma_{\text{tot}}$ (barn!), so within hours of collisions:
    - significant new results are guaranteed
    - discoveries are likely
    - surprises are possible

- **RHIC in 2000:** collisions June 12
  - 1st paper July 19, $dN_{\text{ch}}/d\eta$
  - excluding 90% of predictions
  - 6366 MB (382 central) events,
  - LHC: seconds at 1% design Lumi

```
\begin{align*}
\text{d}N_{\text{ch}}/\text{d}\eta & \mid_{\eta=0} \text{ in Pb+Pb at } \sqrt{s_{NN}}=5.5 \ \text{TeV for } N_{\text{part}}=350
\end{align*}
```

```
\begin{tabular}{ll}
Wolechin et al. & \text{cor.}, RDM \\
Porteboeuf et al. & EPOS \\
Kharzeev et al. & saturation \\
Jeon et al. & data driven, limiting frg. \\
Fujii et al. & fKB evolution \\
Eskola et al. & corr., EKS98+geom. sat. \\
El et al. & corr., BAMPS \\
Dias de Deus et al. & percolation \\
Chen et al. & corr., AMPT+gluon shad. \\
Capella et al. & DPM+Gribov shad. \\
Busza & data driven, limiting frag. \\
\textbf{PHOBOS} & corr., DPM/JET III \\
Bopp et al. & corr., HIJING/BB v2.0 \\
Topor Pop et al. & geom. scaling \\
Armesto et al. & corr., rCBK evolution \\
Albacete & corr., logistic evol. eq. \\
Abreu et al. &
\end{tabular}
```

“last call for predictions” workshop (CERN, 2007)