Experiments desiderata

- How much data is useful at $s^{1/2}$ = 900GeV ?
  - 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

ACKNOWLEDGEMENTS

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_{high})

Time to high energy collisions

Stage A: Initial commissioning to pilot physics

Aim: 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):

		Ring factor	Total Time [days] both rings	Comments
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	Single beam initially, performed following successful ramp
A12	Commission experimental magnets			
A10	Setup for collisions - 7 TeV	1	1	
	Physics un-squeezed	1	-	
	TOTAL to first collisions		**31**	
A11	Commission squeeze	2	6	
A5	Increase intensity	2	6	
	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.

900 GeV Collisions: update from report in 2007-15 LTC

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 $k_b = 2$, β^* = injection value, $N = \sim 9\times10^{10}$

for info: about $10^{28}\text{cm}^{-2}\,\text{s}^{-1}$
$\times10^{5}$ s = ~ 1 nb^{-1}
(~5×10^{7} inelastic interactions)

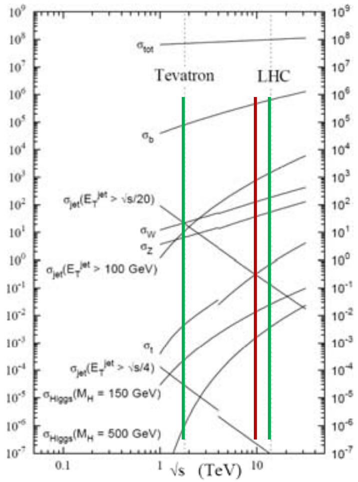
To do what ?

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

if lumi measued
(fast separation scan?)

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 ⇒ at least 2 bunches per beam should be used

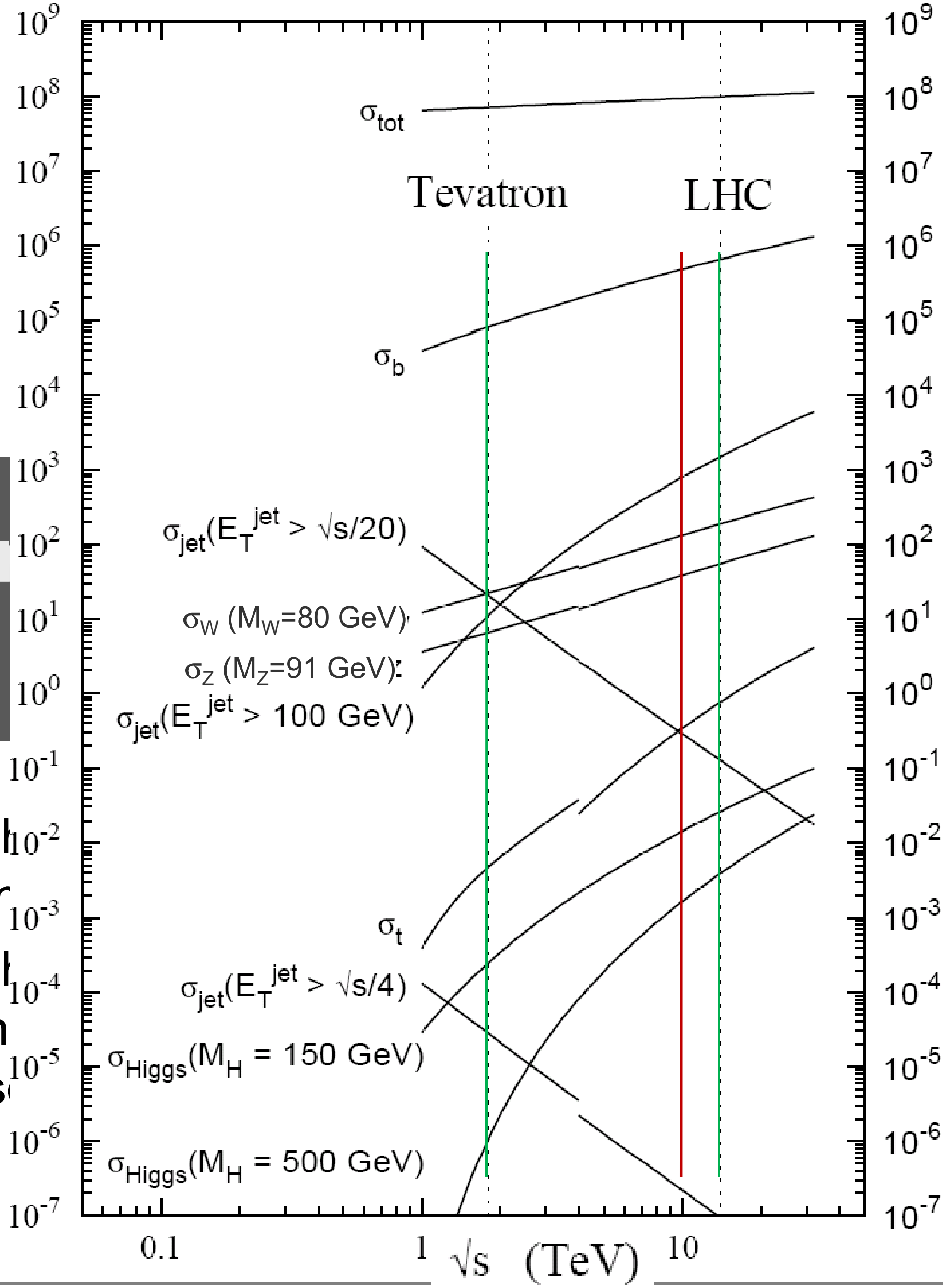


Integrated luminosity × cross section versus energy

- 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

Integr... section



- Wh... which air...
- Wh... en... ics run us... eV)

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.)

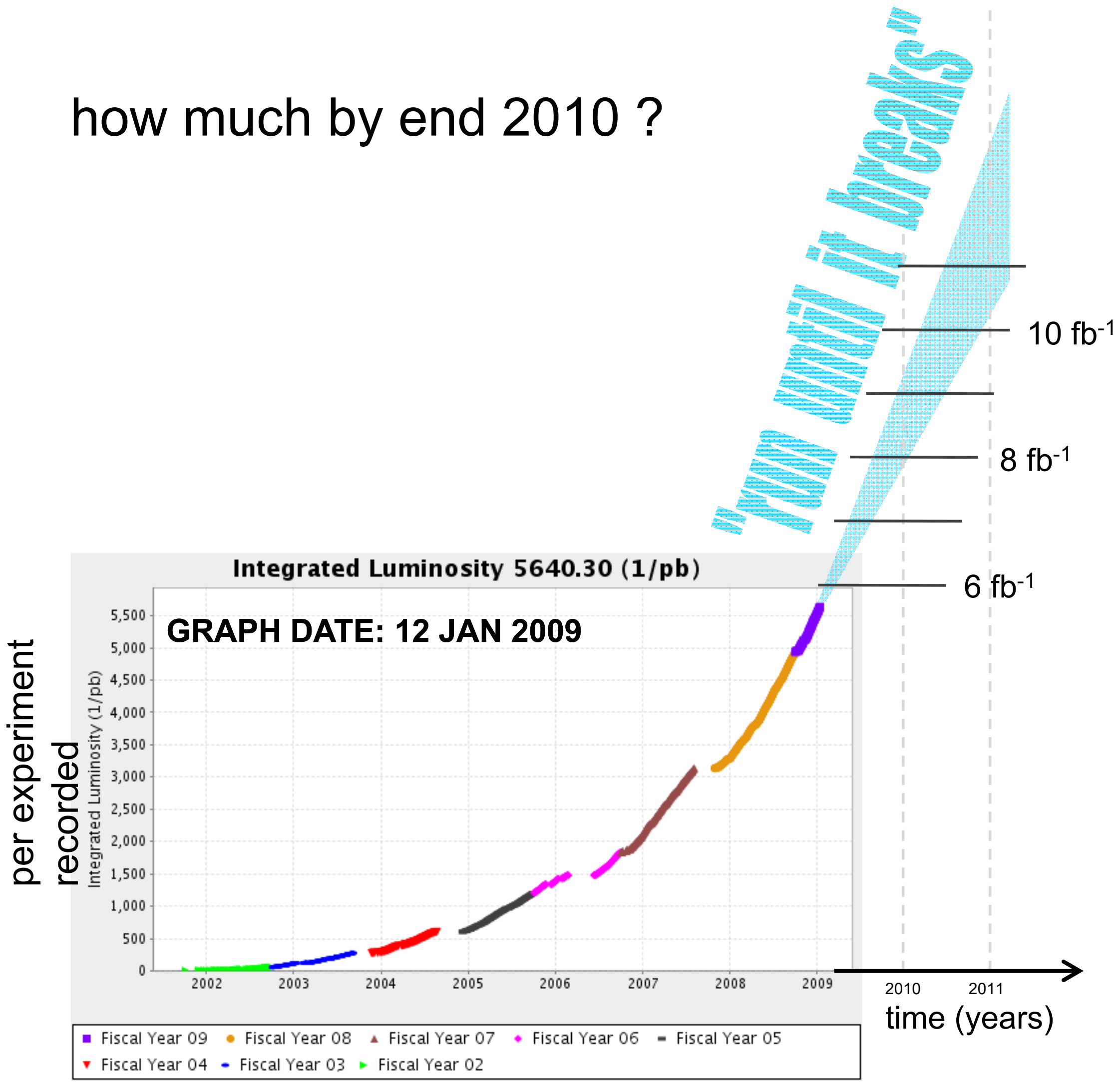
Let’s not forget that

- Understanding the detector performance will take time
- There will be operation inefficiencies, down time, etc.

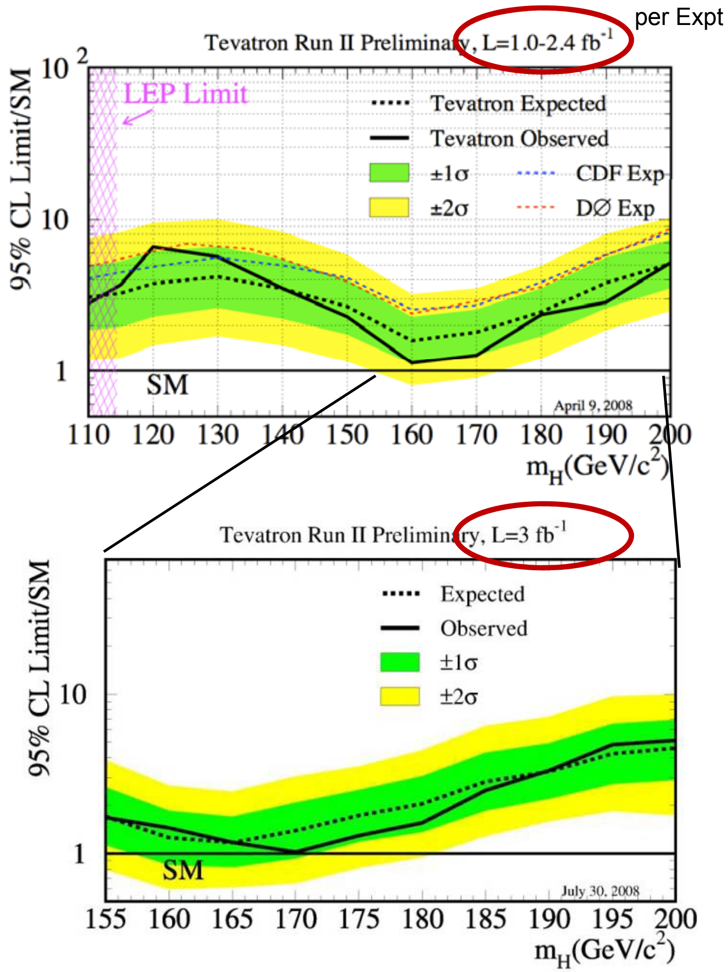
State of the Art: Tevatron

Projected integrated lumi

how much by end 2010 ?

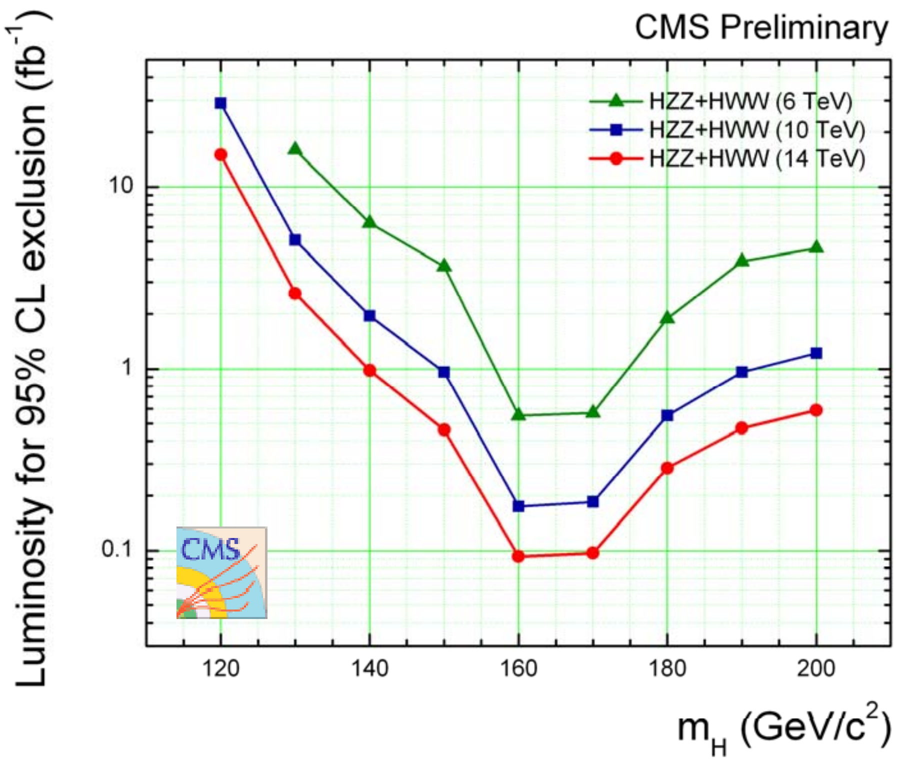


There is more than just one paranoia at CERN...



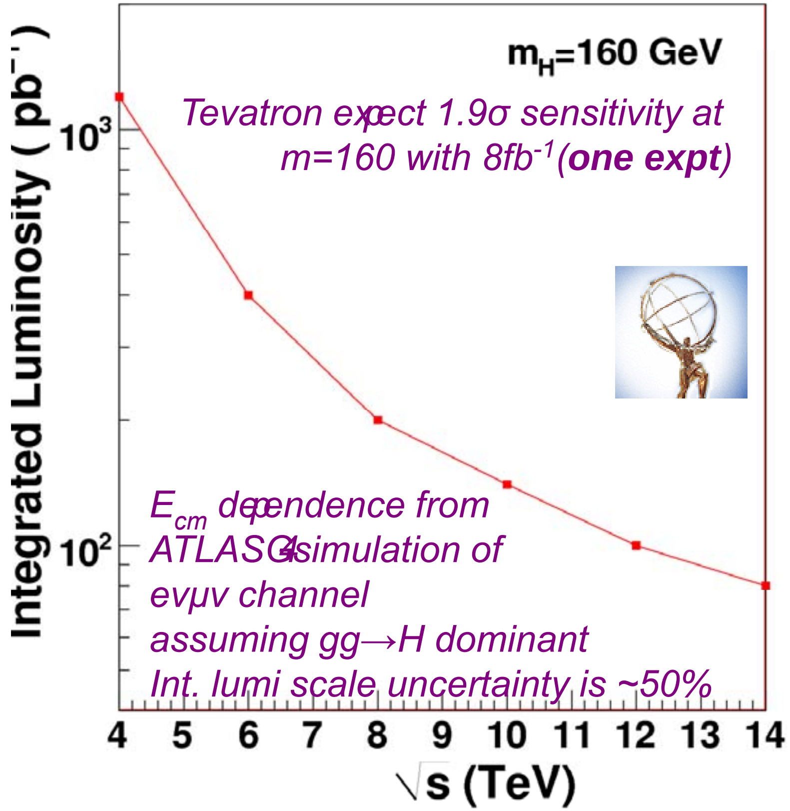
Higgs 95% CL at LHC GPD , H→ weak bosons, indicative

Combined H→WW + H→ZZ: lumi for 95% CL



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

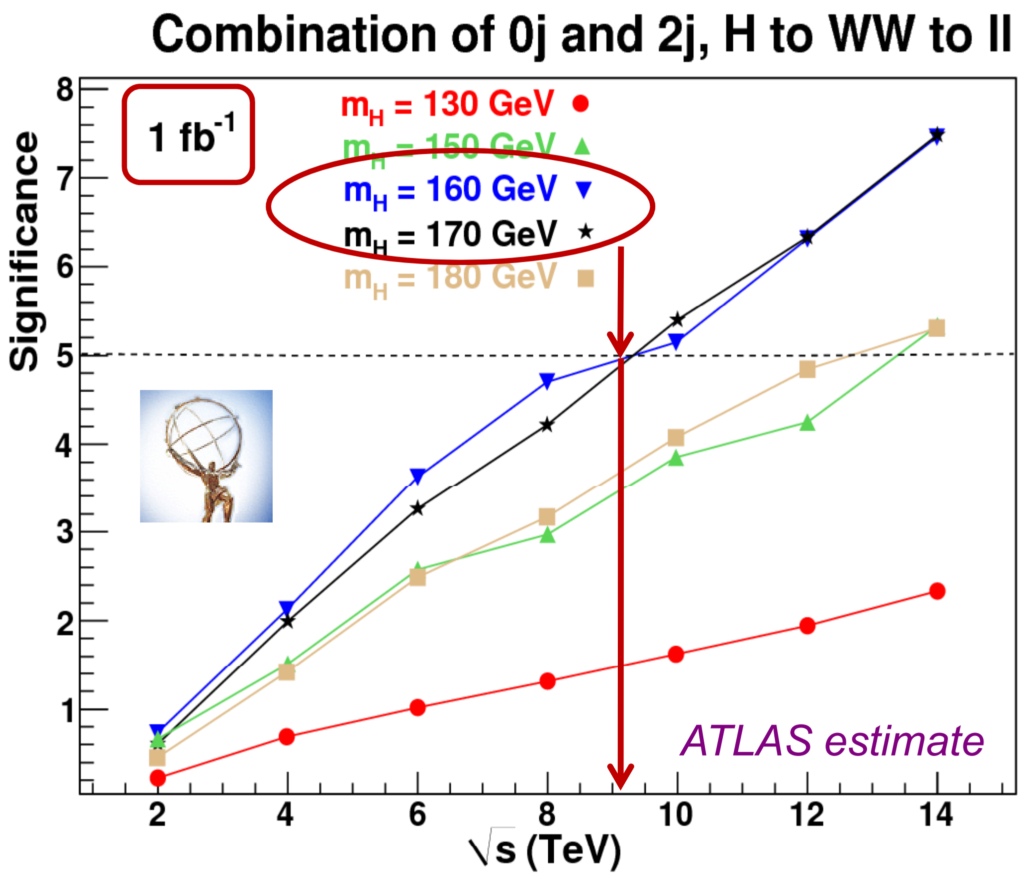
Compare sensitivity to Tevatron with 8 fb^{-1} (only H→WW→ $\ell\nu\ell\nu$)



- Massive loss of sensitivity below 6 TeV

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

Higgs 5σ discovery, indicative



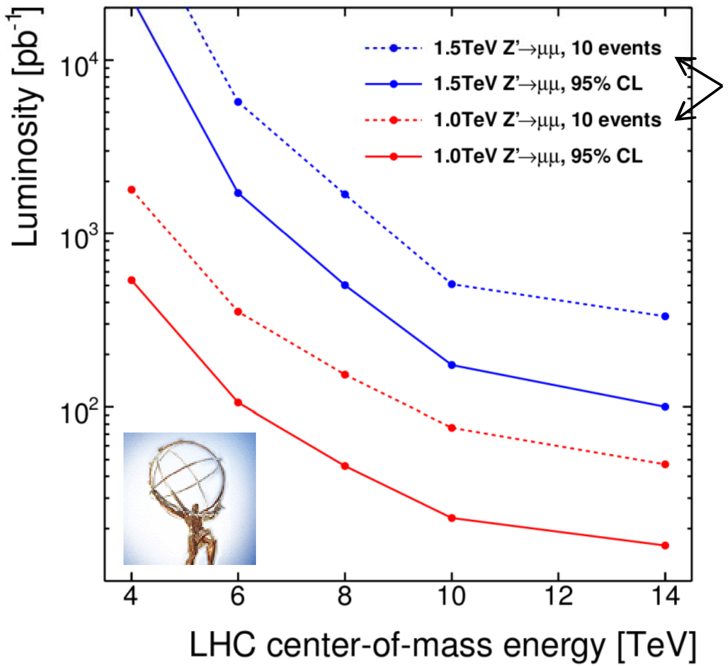
5σ discovery for m_H ~160 GeV is possible with
$s^{1/2}$ = 8-10 TeV and **~1fb^{-1} g.d.**

Z' resonance

Z': Heavy partner of the Z (SSM)

- Very clean experimental signal: Z'→ℓℓ
- Tevatron 95% CL limit at $m_{Z'}$ =1 TeV

ATLAS fast simulation

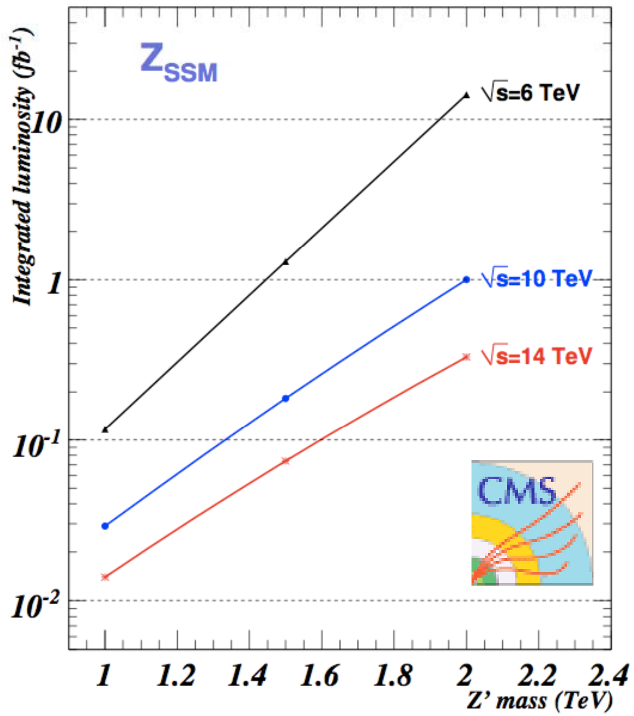


5σ discovery

Needed luminosity for 95%CL exclusion at $m_{Z'}$ = 1 TeV :

$s^{1/2}$: 14 → 10 → 6 TeV

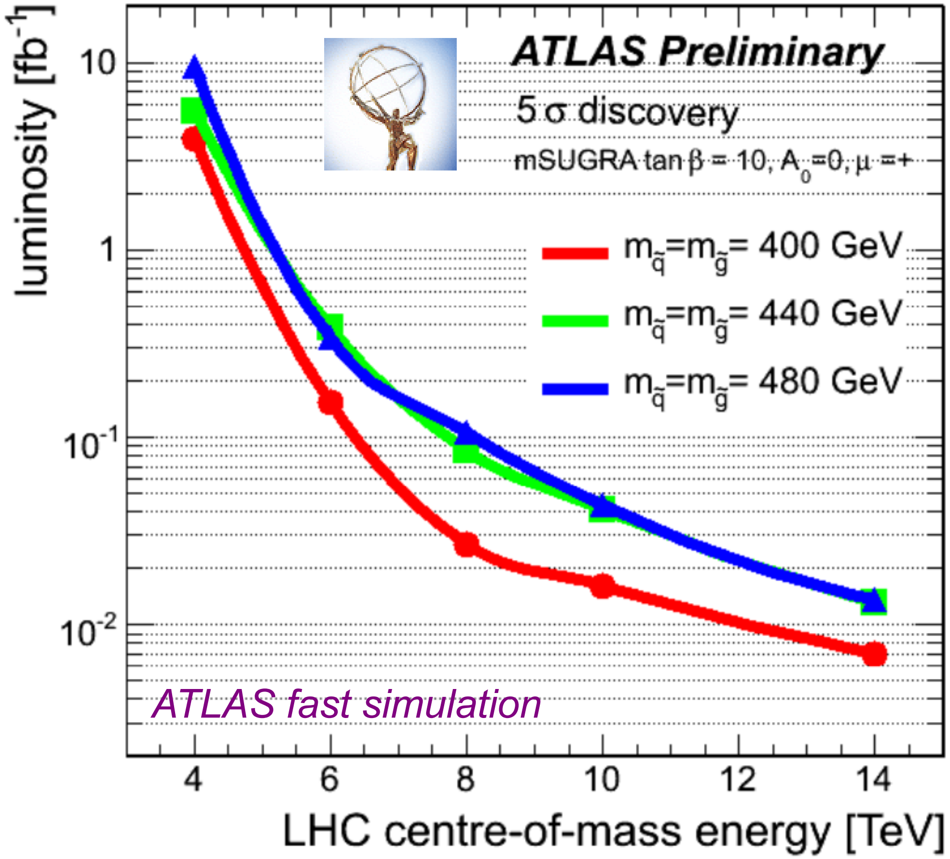
Lumi: 13 → 30 → 110 pb^{-1}



for $m_{Z'}$ ~1TeV, with **$s^{1/2}$ = 10 TeV** <
95% CL limit with **~30 pb^{-1} g.d.**
5σ discovery possible with **~100 pb^{-1}g.d.**

SUSY , an example

- ℓ+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}≈8 TeV, the sensitivity collapses



5σ discovery beyond current Tevatron limits is possible with
$s^{1/2}$ = 8-10 TeV and **~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)

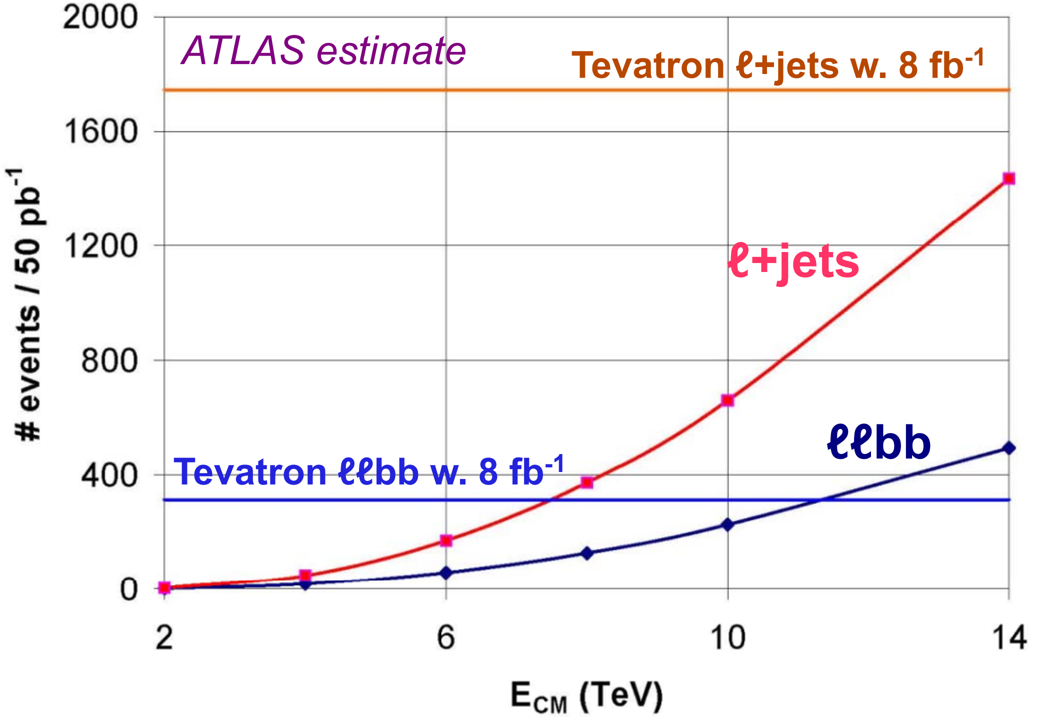
CDF Note 9506

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 addiction 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

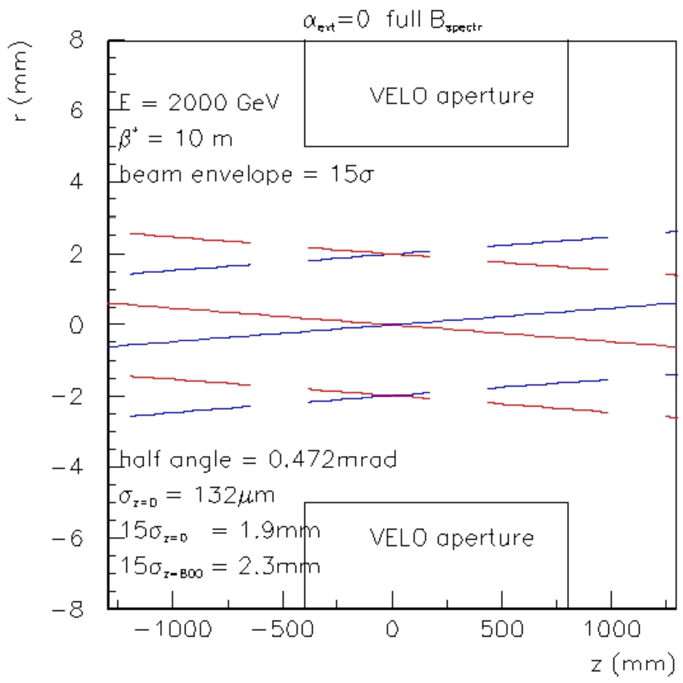
- LHCb
- ALICE
- TOTEM
- LHCf

LHCb in summary

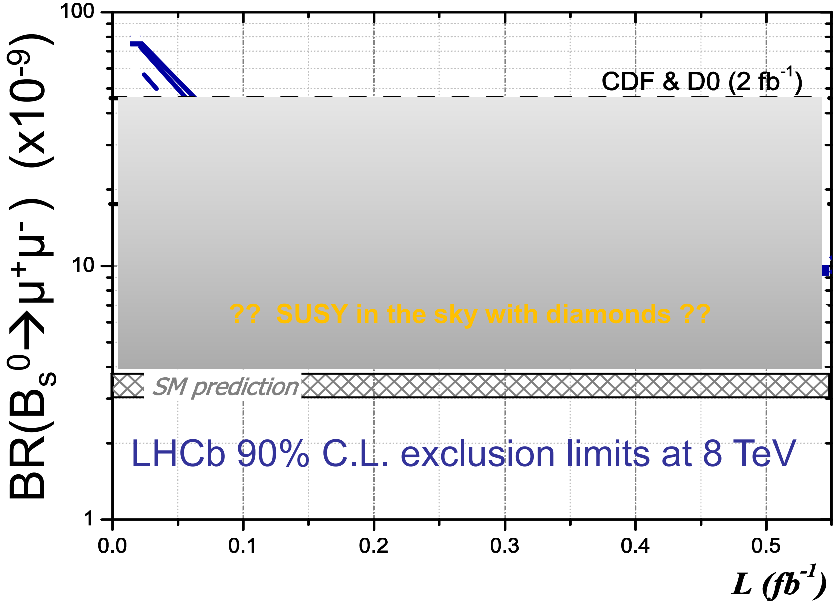
- B cross section does not vary as drastically as for high mass objects. Thus, the request to go to highest possible energy is milder
- Need **0.3-0.5 fb^{-1}** at **s$^{1/2} \geq$ 8 TeV** to surpass Tevatron in B_s physics
- Need at least 5 pb^{-1} at s$^{1/2} \geq$ 4 TeV to collect good sample of J/psi

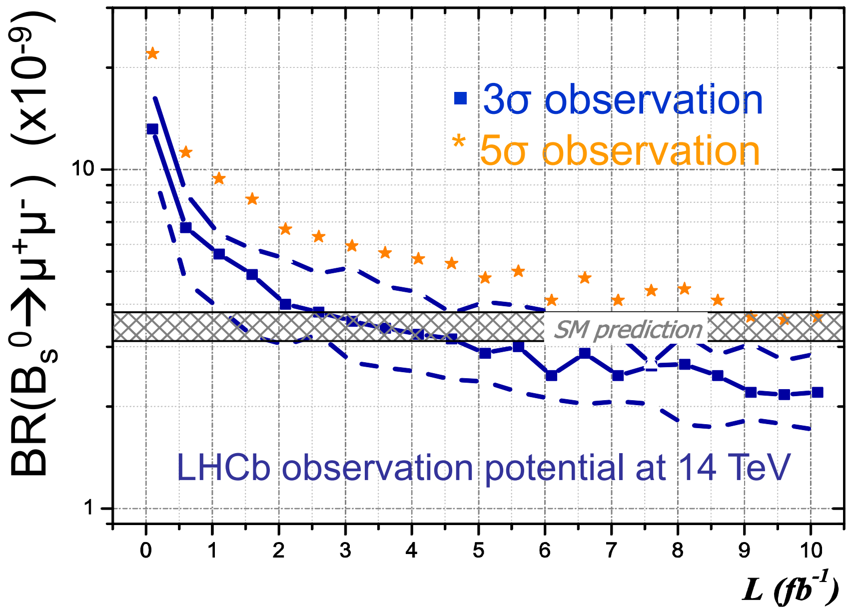
NB:

- If E ≤ 2 TeV, LHCb will not take the risk to close the VELO (if with full B_{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 β* ⇒ exploit smallest possible β* in 2009 and 2010 (what is β^*_{min} with full B_{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 **~0.3-0.5 fb^{-1} g.d.** to improve on expected Tevatron limit

Collect ~3 fb^{-1} for 3σ observation of SM value

ALICE and *pp* running, in a few words

- ALICE not as strongly interested as GPDs in reaching the highest possible energy for *pp*
- What about $s^{1/2}$ = 5.5 TeV ? (the *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 ~10^{29} cm^{-2} s^{-1} (opt) or 3×10^{30} cm^{-2} s^{-1} (max)
- Physics program includes also runs with smallest possible β^*: beam axis used as vertex constraint (would like beam size $\sigma_{x,y}$ < ~40 um which, at 5TeV means β^* < ~ 2.25 m)
  - 2m ? 3m ? what is the minimum possible β^* at the given energy in 43x43 or 156x156 ? (while remaining at desired luminosity, and with full B_{spectr})
- ALICE particularly interested in “symmetric shift” filling schemes and in 50ns (as opposed to 25ns), see later slides
- Heavy ions => see later slides

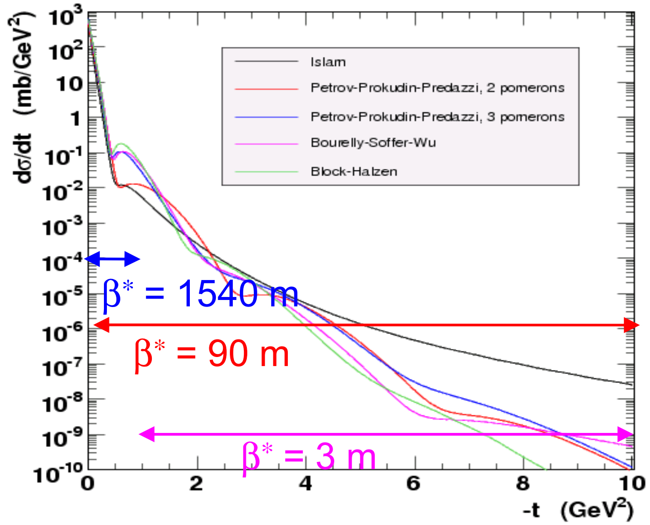
TOTEM (IP5)

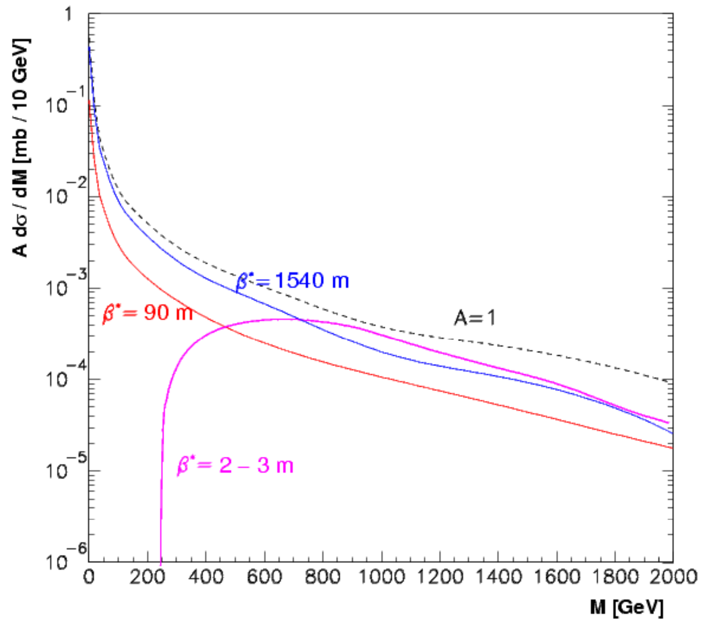
- T1, T2, all RP220 and some RP147 will be ready
- **TOTEM will operate under all running conditions**
- Programme at $s^{1/2}$ = 900 GeV:

Move RPs to 15σ

- 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 (β^* = 3 m): large |t| elastic scattering, central diffraction
- As soon as technically feasible: request β^* = 90 m optics (or a gradual unsqueezing from β^* = 3 m to higher values)
  → first measurement of σ_{tot} with Optical Theorem using T1, T2, RP (~ 5 %)





LHCf (IP1)

- 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 $L>10^{3?}\ cm^{-2}\ s^{-1}$
- 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 ~10^{29} cm^{-2} s^{-1} (opt) or 3×10^{30} cm^{-2} s^{-1} (max)
- LHCb: highest possible till reaches ~5×10^{32} cm^{-2} s^{-1}, then prefer minimizing pile-up at same luminosity

Filling schemes / bunch patterns

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

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 accomodate 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 Werner Herr's talk

Luminosity limits for 75, 50, 25 ns (2010, ...)

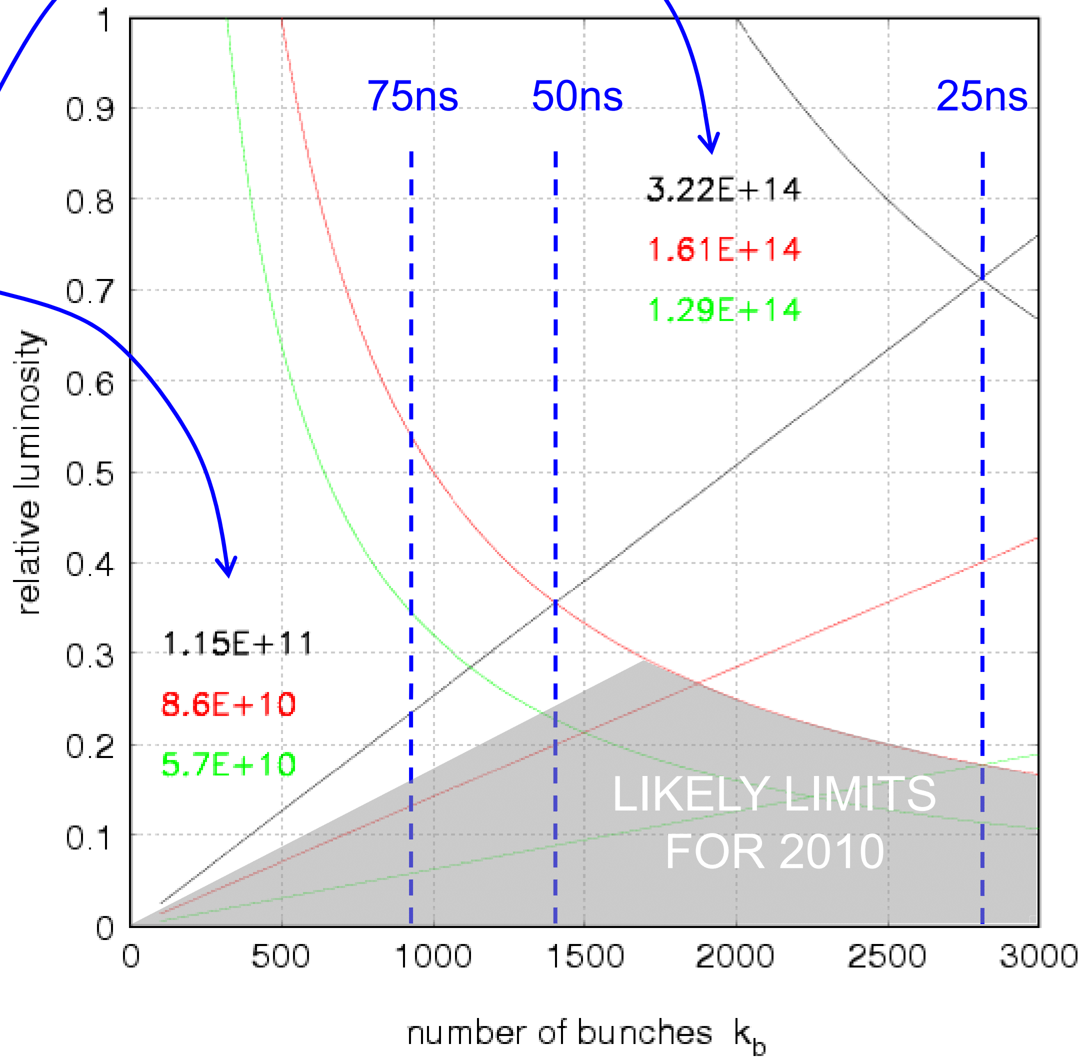
$$L = \frac{f\, k_b\, N^2}{4\pi\sigma^2} F$$

- Simplified limits:
  - I_{max} ($I = k_b N$)
  - N_{max}

straight slopes

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

hyperbolas

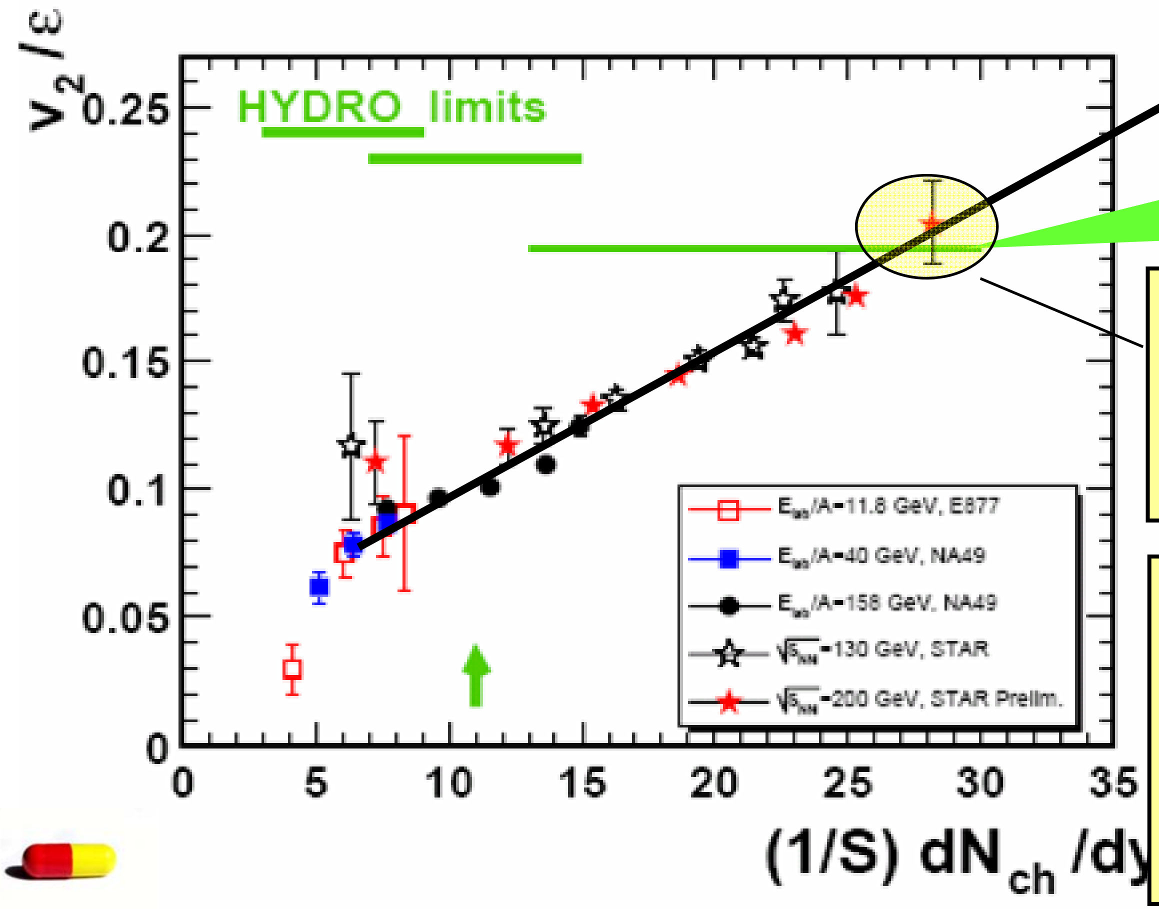


Heavy Ions: Flow at LHC

- one of the first and most anticipated answers from LHC
  - 2[nd] RHIC paper: Aug 24, 22k MB events, **flow surprise** (v_2)
    - Hydrodynamics: modest rise (Depending on EoS, viscosity, speed of sound)

LHC ?

increase of flow



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

……………………..

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,

    β^*=1m , 62b $\times$ 7$\times 10^7$Pb, α=0, thus ~ 5$\times 10^{25}$ cm^{-2}s^{-1}

See John Jowett's talk

- 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 p @ E_{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 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

$$L = \frac{f\, k_b\, N^2\, \gamma}{4\pi\, \varepsilon_N \beta^*} F$$

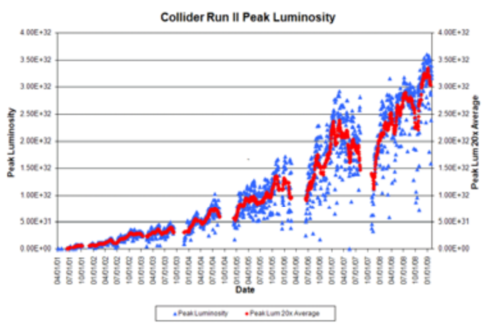
β^*=3m

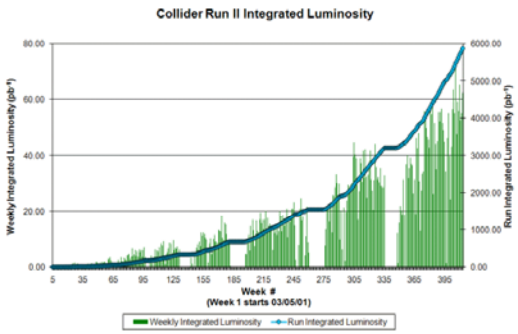
N=10^{11}

Assume (somewhat arbitrarily)
a "Hübner factor" of 0.2

k_b=156	$\Rightarrow$	6×10^{31} cm^{-2} s^{-1}	$\Rightarrow$	~ 1 pb^{-1} / day
k_b=1404	$\Rightarrow$	5×10^{32} cm^{-2} s^{-1}	$\Rightarrow$	~ 8 pb^{-1} / day

$\alpha \neq 0$

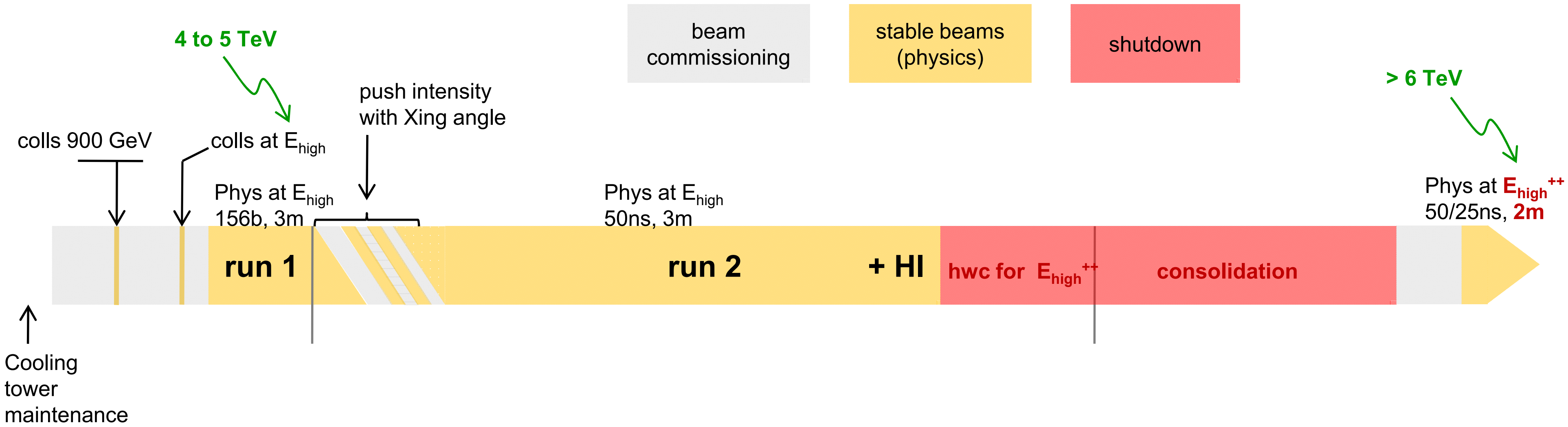




Note: Tevatron is cruising at
~3×10^{32} cm^{-2} s^{-1}
(8 pb^{-1}/day , 2 fb^{-1} / year)
$\Rightarrow$ we need high energy!

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)

Conclusion

- 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)

PAQ 1

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!

PAQ 2

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)

PAQ 3

Do the experiments need a 2009/2010 winter shutdown ?

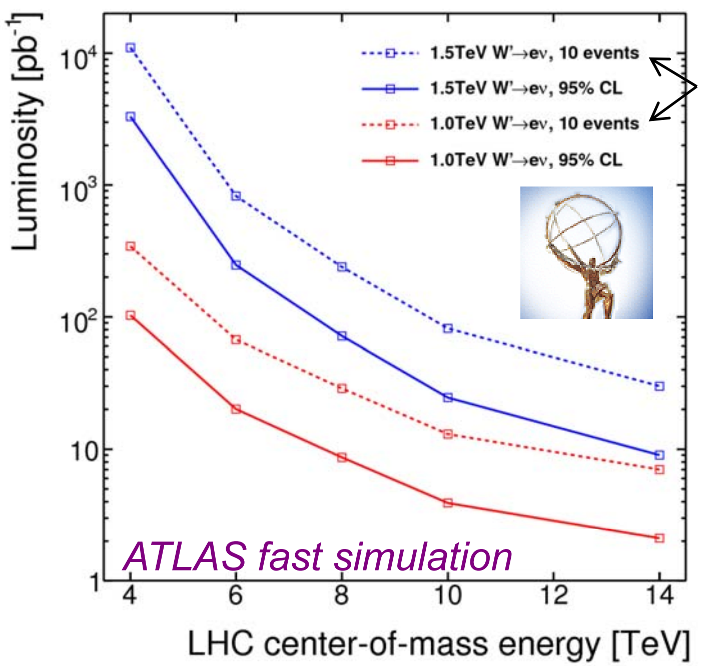
- No!
- Experiments will be ready to start when the machine is ready to start, any time, and ready to continue as long as is needed to achieve first physics results

Further slides

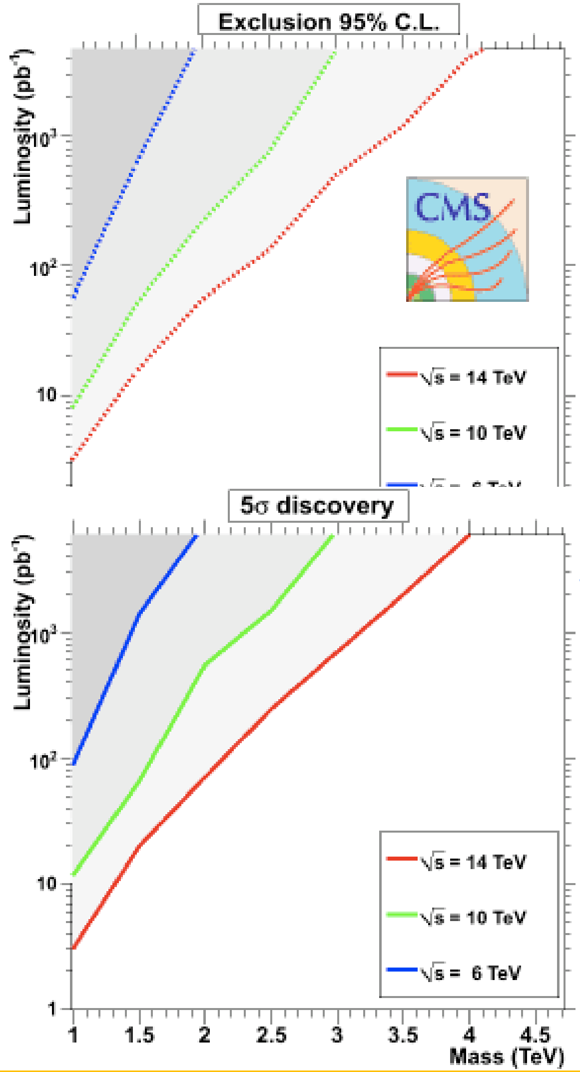
W' resonance

W' $\rightarrow e\nu$**:**

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



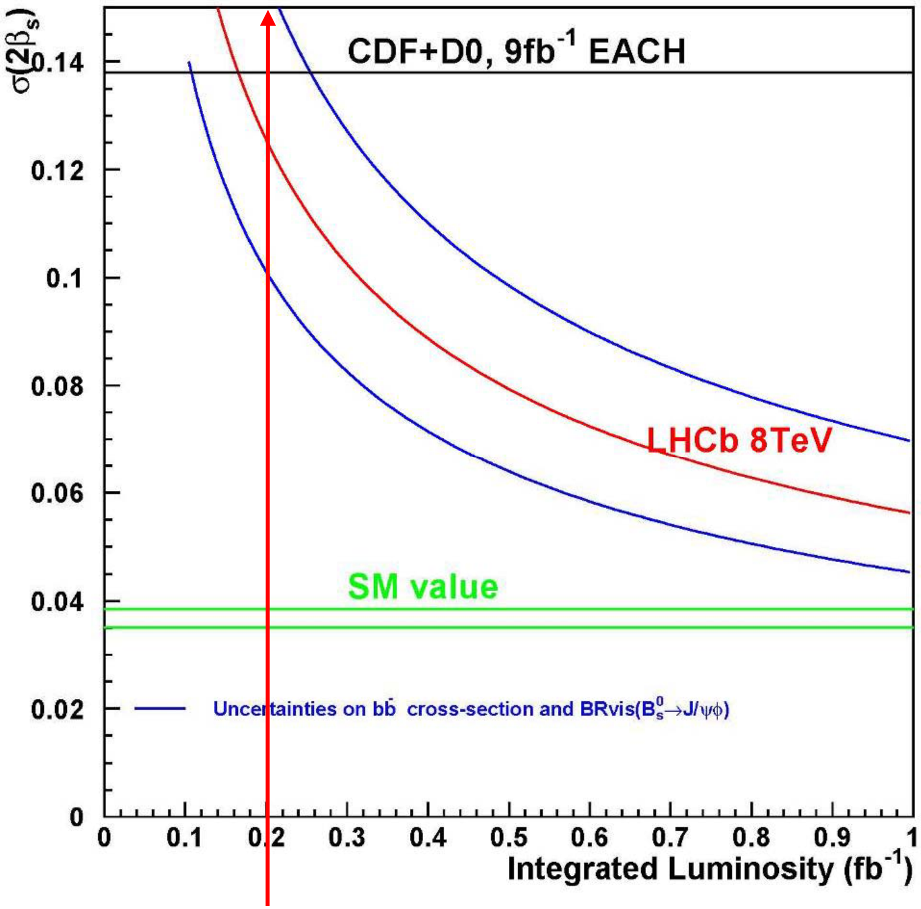
5σ discovery

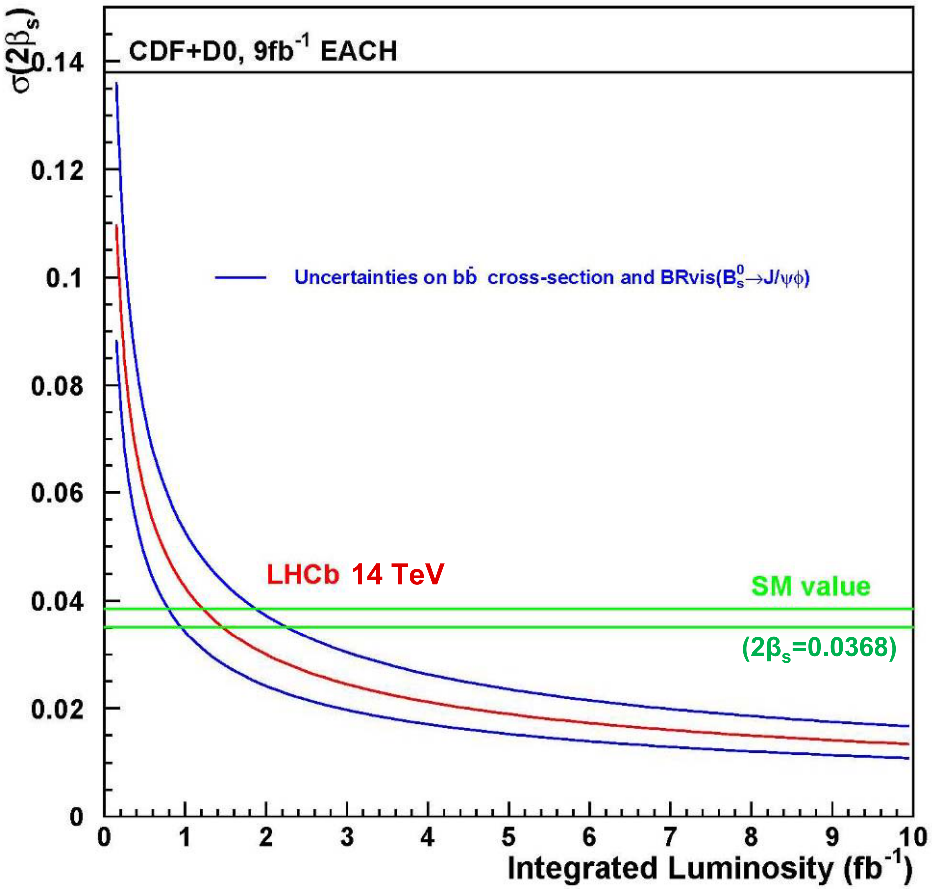


for $m_{W'}$ ~1TeV, with $\mathbf{s^{1/2} = 10}$ **TeV** <
95% CL limit with **~5 pb^{-1} g.d.**
5σ discovery possible with **~15 pb^{-1}g.d.**

Physics reach for $2\beta_s$

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



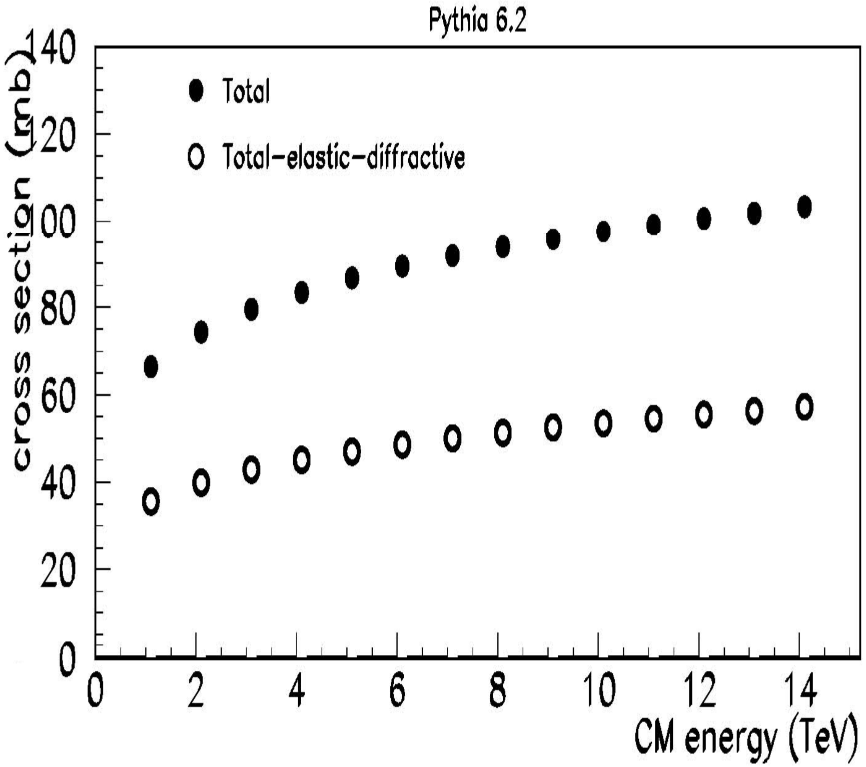


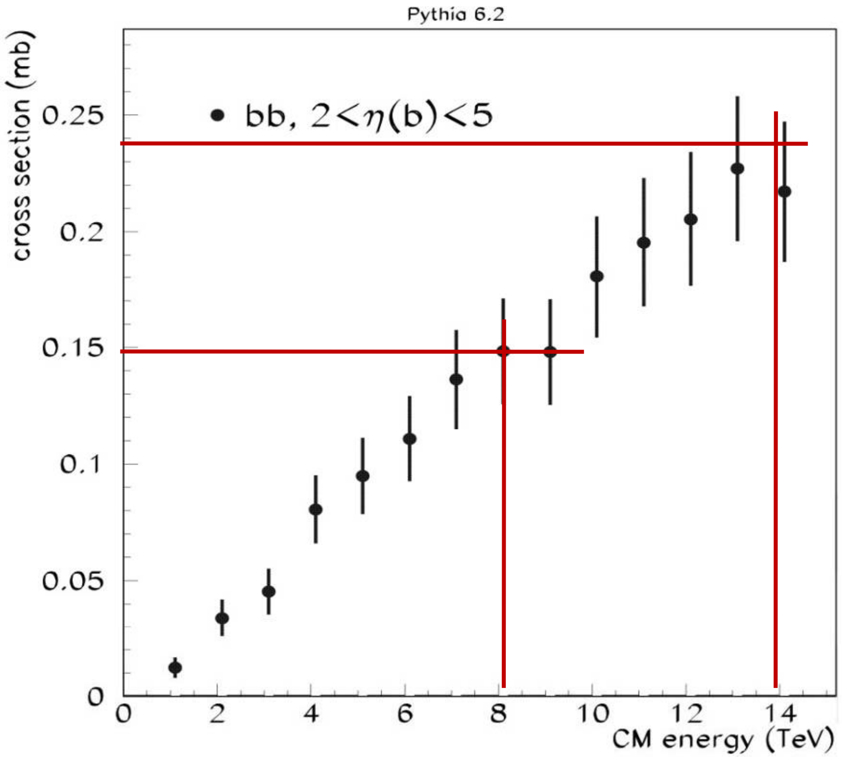
0.2 fb^{-1} = threshold introducing fit instabilities

Collect at least **~0.3-0.5 fb^{-1} g.d.** to improve on expected Tevatron limit with 9 fb^{-1}

→ Collect ~3 fb^{-1} for 3σ observation of SM value

Energy dependence: LHC as a B factory

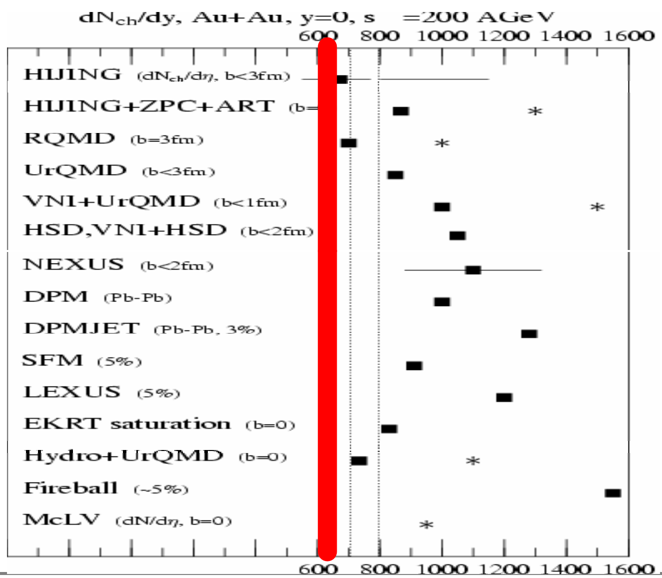


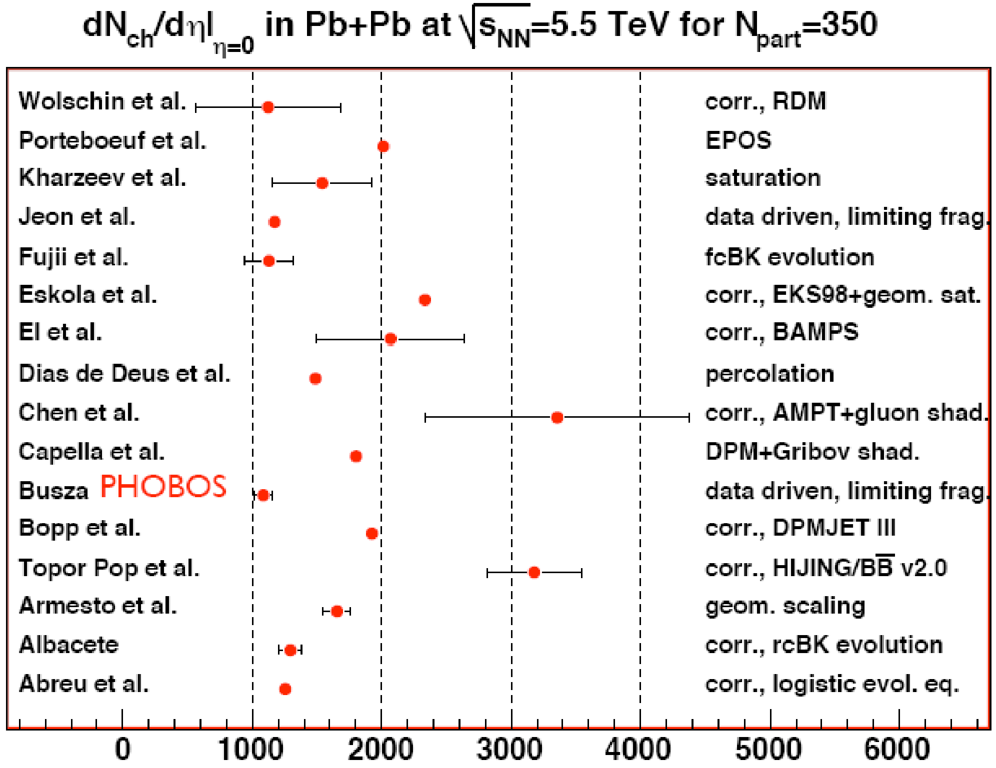


- B-yield in LHCb acceptance has about linear dependence with energy (i.e. loosing a factor 1.75 going from 14 to 8 TeV CM energy)

Heavy Ions: ‘The First 3 Minutes'

- **Huge jump in energy from RHIC (200 GeV) to LHC: x 30 !**
  - for many important observables, **$\sigma \sim \sigma_{tot}$ (barn!)**, so <u>within hours</u> of collisions:
    - significant new results are guaranteed
    - discoveries are likely
    - surprises are possible
- **RHIC in 2000:** collisions June 12
  - 1st paper July 19, dNch/dη
    - excluding 90% of predictions
    - **6366 MB (382 central)** events,
    - LHC: seconds at 1% design Lumi





“last call for predictions” workshop (CERN, 2007)
N Armesto et al., J. Phys. G 35 (2008) 054001
N Armesto, J. Phys. G 35 (2008) 104042