Bringing Beams Into Collision

- **parameters, observable(s),**
  beam-beam tune shift, Luminosity
- **at which intensity do want to attempt first collisions ?**
- **how to steer into collision ?**
- **communication and signal exchange with experiments**

Commissioning needs

- **start with simple, flexible and robust methods**

- **redundancy !** Can't rely on that everything works fully to spec from day 1

  some systems may not be available at all

  others may work but slower, relying on "expert software" and

  with much increased tolerances, unknown offsets etc.

Several independent measurements and methods will be needed to find errors and to determine uncertainties.

Head-On Beam-beam tune shift

discussed with Werner Herr

$$\xi_x = \frac{r_c\ N\ \beta_x^*}{2\pi\,\gamma\,\sigma_x\ (\sigma_x + \sigma_y)} \qquad \xi_y = \frac{r_c\ N\ \beta_y^*}{2\pi\,\gamma\,\sigma_y\ (\sigma_x + \sigma_y)}$$

calculated, using the classical particle radius, here for the proton $r_c = r_p = 1.5347 \times 10^{-18}\,\mathrm{m}$

In the LHC we have by design round beams with $\sigma = \sigma_x = \sigma_y,\ \beta^* = \beta_x^* = \beta_y^*$

so that $$\xi = \frac{r_c\ N\ \beta^*}{4\pi\,\gamma\,\sigma^2}$$

in terms of the normalised emittance $\sigma = \sqrt{\beta\epsilon_N/\gamma}$ we get simply $$\xi = \frac{r_c\ N}{4\pi\ \epsilon_N}$$

numerically

N	ξ
5×10^9	0.000163
4×10^{10}	0.00130
1.15×10^{11}	0.00374

This is of the same order as the natural tune spread, $\delta Q/Q \approx 10^{-3}$ from $\delta p/p = 4.7 \times 10^{-4}$, $Q' = 2$ and should be observable. "Tune coupling" with excitation was used in HERA to steer collisions, S. Herb, Lauterberg 1992

Comments on some essential measurements: tune, currents, beam size

Measurements are needed per bunch !

We will use 43 or 156 bunches, which may significantly differ in intensity and emittance.

Tune measurements

- **per bunch** to get narrow peaks, see bunch differences, allow for check on Q', $\delta_{x,y}$
- **should be very sensitive, to work without or with tiny excitation** (use BBQ with Shottky like sensitivity and signal)

Beam size measurements:

- **knowing the beam size (at the IP), the currents, and that we collide head-on, allows to predict the absolute luminosity.**

Parameter Range

Single bunch luminosities as relevant for lumi / separation scan statistics

Event rates for σ = 10 mb, which is about the cross section with high energy neutrons in the BRAN

ϵ_N μm	ϵ nm	p GeV/c	β^* m	σ^* μm	N_p	L $\mathrm{cm^{-2}s^{-1}}$	$\dot{N} = L\sigma$ Hz	$\frac{\dot{N}}{f_{\mathrm{rev}}}$	ξ
3.75	7.82	450	18	375.2	5×10^9	1.59×10^{25}	0.158	0.000014	0.000 16
3.75	7.82	450	18	375.2	1.15×10^{11}	8.41×10^{27}	84.1	0.00748	0.003 74
3.75	7.82	450	11	293.3	5×10^9	2.60×10^{25}	0.26	0.000023	0.000 16
3.75	7.82	450	11	293.3	4×10^{10}	1.66×10^{27}	16.64	0.0015	0.001 30
2.5	5.21	450	11	239.4	4×10^{10}	2.49×10^{27}	24.94	0.0022	0.001 95
3.75	7.82	450	11	293.3	1.15×10^{11}	1.37×10^{28}	138	0.0122	0.003 74
3.75	0.503	7000	18	95.14	5×10^9	2.46×10^{26}	2.5	0.00022	0.000 16
3.75	0.503	7000	18	95.14	1.15×10^{11}	1.30×10^{29}	1300	0.116	0.003 74
3.75	0.503	7000	2	31.71	1.15×10^{11}	1.11×10^{30}	11087	0.986	0.003 74
3.75	0.503	7000	0.55	16.63	1.15×10^{11}	3.54×10^{30}	35400	3.15	0.003 74

Commissioning is planned with 43, 156 bunches. No crossing angle

A reasonable goal for first collisions would be ~ 4x10^{10} protons / bunch

Try to get smaller emittances : 2.5 μm maybe achievable for the few bunches of 4x10^{10} protons
Would help in many respects: luminosity, aperture, magnet imperfections (multi-pole errors)

BRAN and first collisions at 450 GeV

Following discussions with Enrico Bravin and Bill Turner

LHC luminosity monitors (BRAN) :

- **optimised for 7 TeV collisions and high luminosity (1e34), with a large dynamic range (1e28 still ok)**

- **commissioning with collisions at 450 GeV was not considered at the time of the specification**
- **the pulse height in the ionisation chambers scales with beam energy**
- **the pulse height / noise ratio and the rates may turn out to be rather marginal.**

Proposal to add a single scintillator on each side of the IP next to the BRAN and use them in L/R coincidence

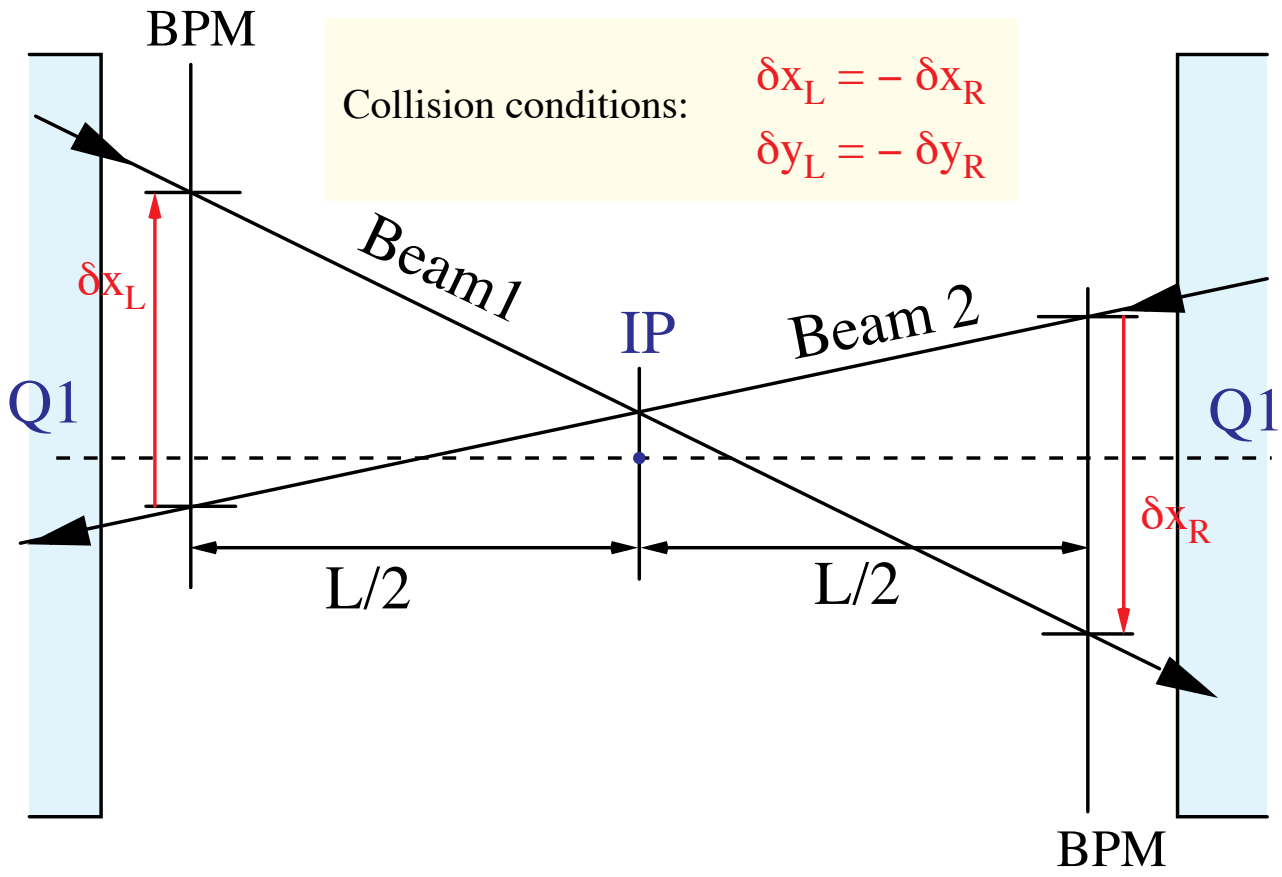
- **very sensitive, no problem with pulse height**
- **excellent background rejection due to coincidences, allows background determination**
- **relatively simple and in-expensive device**
- **also useful for first years at 7 TeV**

References:

- BRAN specification: LHC-B-ES-0007 "MEASUREMENT OF THE RELATIVE LUMINOSITY AT THE LHC" by R. Assmann, J-P. Koutchouk, Massimo Placidi, E. Tsesmelis https://edms.cern.ch/file/347396/1.1
- USLARP http://uslarp.lbl.gov/workshops/

Get beams colliding, tolerances

based on S. Fartoukh LCC 3/2001



Adjust orbits such, that the beam 1 and 2 difference left/right of the IP is the same.

measured with special stripline coupler BPMSW at about 21 m L/R from IP in front of Q1

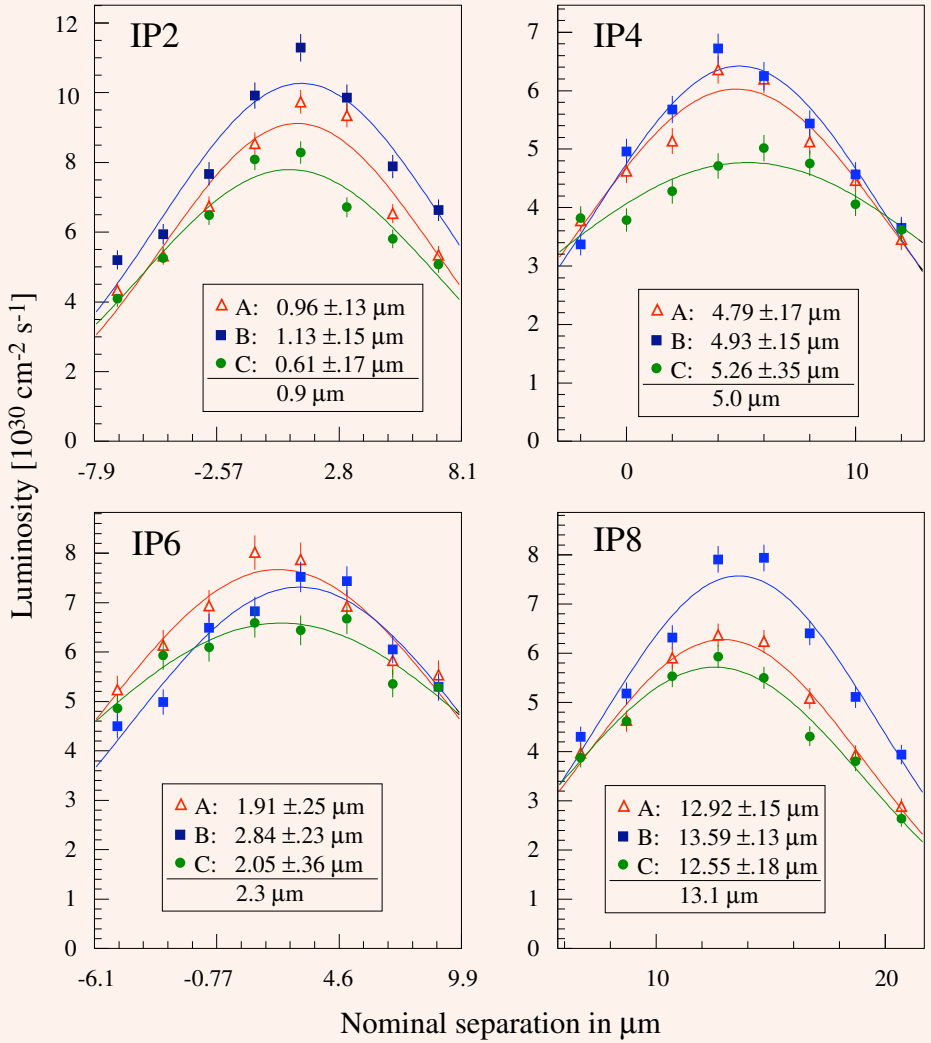
Beams must then collide. This is independent of offsets and crossing angles.

Expected resolution : $\sqrt{2}$ × (50 - 200) µm, say conservatively 300 µm or about 1σ

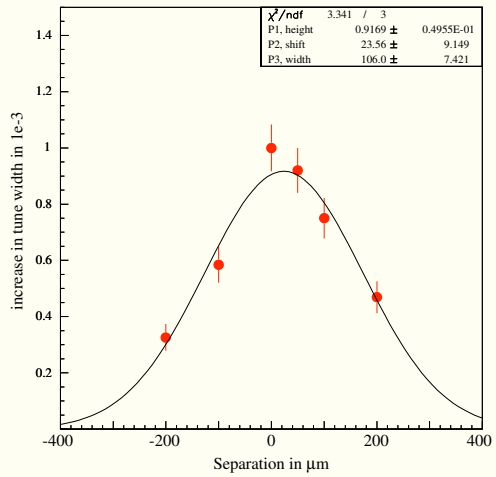
Separation Scan (pioneered by Van der Meer @ ISR)

LEP example:
separation scans using LEP luminosity detectors in operation with 4 bunch trains of each 3 bunches

Time: about 5 min / IP



LHC : hypothetical scan based on increase of tune width



different from LEP, the effect of one beam on the other is really small in LHC (negligible dynamic β effects)

Separation scans in the LHC should allow for reliable beam size measurements at IP in LHC

Separation Scan Strategies

Luminosity with separation

$$\frac{\mathcal{L}}{\mathcal{L}_0} = \exp\left[-\left(\frac{\delta x}{2\sigma_x}\right)^2 - \left(\frac{\delta y}{2\sigma_y}\right)^2\right]$$

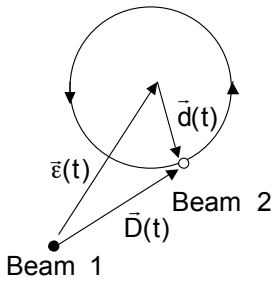
δx	δy	$\frac{\mathcal{L}}{\mathcal{L}_0}$
σ_x	σ_y	
0	0	1
1/2	0	0.9394
1/2	1/2	0.8825
1	0	0.7788
1	1	0.6065
2	0	0.3679
2	2	0.1353

An optimised strategy was proposed by Turner, US LARP Lumi Review, 11 April 2005

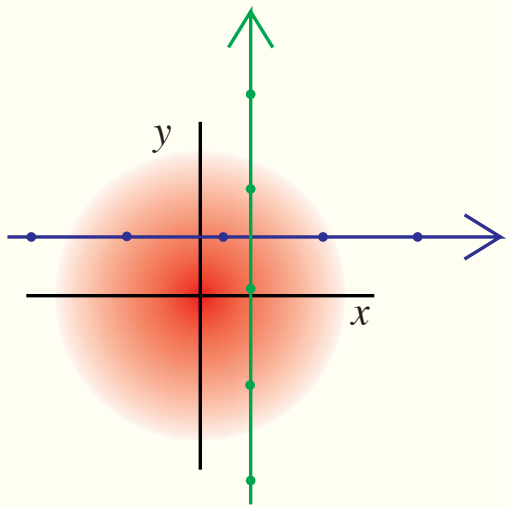
ε = error offset amplitude

d = intentional sweep amplitude

$$L \approx L_0 - L_0 \frac{\varepsilon d}{2\sigma_*^2}\cos(\omega t - \varphi);\ \varepsilon, d << \sigma_*$$



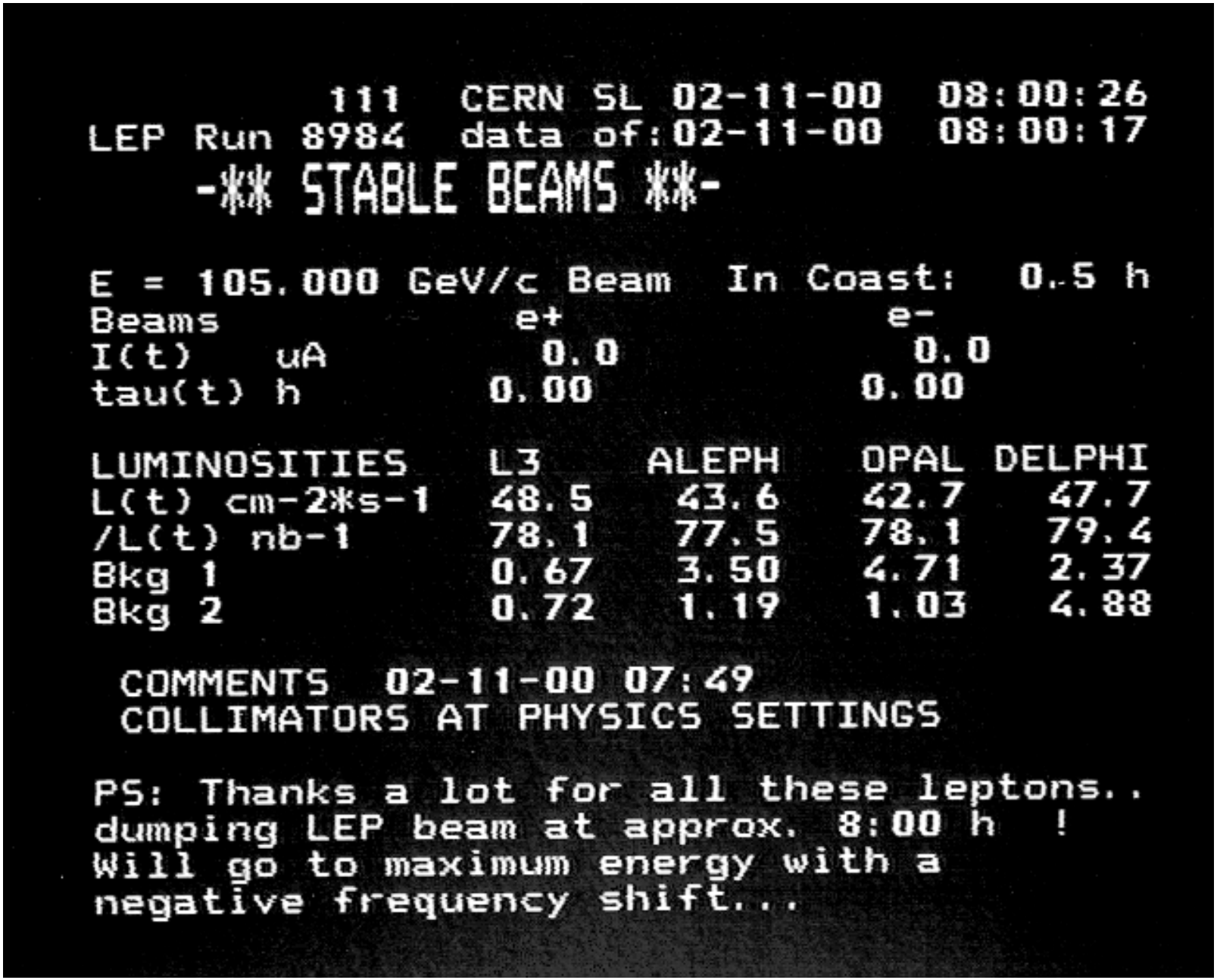
Commissioning : Simple, orthogonal x / y scan



Status and Communication with Experiments

Example of what we used to have in LEP

AB/CO teletext services http://hpslweb.cern.ch/teletext.html



What we may want to have as LHC status page

	111	CERN AB	31-11-07	12:20:26
LHC Run	1234	data of	31-11-07	12:20:16

— ** STABLE BEAMS ** —

E = 0.450 TeV/c	Beam	In Coast	0.5 h	
Beams	Beam 1	Beam 2		
#bun	43	43		
Nprot(t)	1.71e12	1.73e12		
tau(t) h	121	140		

Luminosities	ATLAS	ALICE	CMS	LHC-B
L(t) 1e28 cm-2s-1	5.23	6.23	7.13	5.21
/L(t) nb-1	0.78	0.68	0.78	0.52
BKG 1	1.20	0.52	0.90	0.43
BKG 2	0.85	0.82	0.50	0.80

Comments 31-11-07 11:40:26
COLLIMATORS in coarse settings
Separation Scan in IR1/Atlas

Conclusion

- BPM resolution and beam sizes are similar. Steering into collisions should not be difficult.
- separation scans rely on LHC luminosity detectors BRAN.

  expected performance of current design somewhat marginal for early collisions @ 450 GeV

  ⇨ request for additional Scintillators and left/right coincidences.
- in addition we should also see the effect of collisions in the tune signal
- the expected absolute luminosity for head-on collisions can be predicted from currents and beam sizes.

Experiments are expected to determine themselves the absolute luminosities

- Good machine / experiments communication needed
  - automatic, detailed signal exchange
  - TVscreen summary page with Luminosity & Background
  - regular (schedule) meetings