HIGH INTENSITY ISSUES IN THE CERN PSB & PS

R CAPPI / CERN-PS

- INTRODUCTION
  - WHAT ARE PSB & PS ?
  - MAIN PARAMETERS
  - PRESENT PERFORMANCE

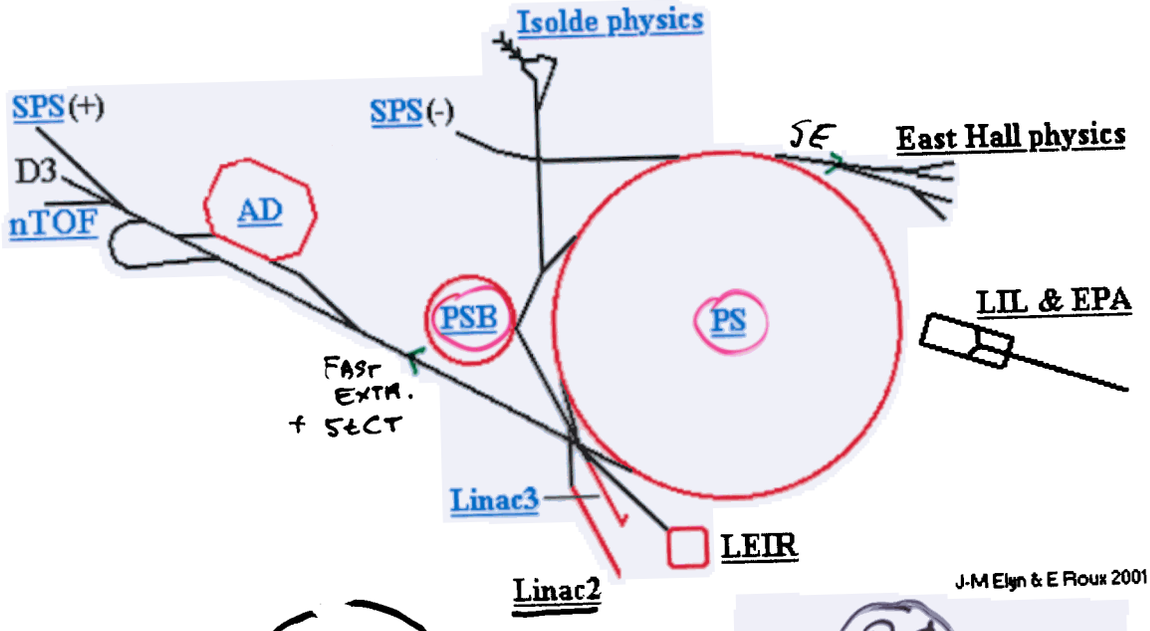
- HIGH INTENSITY ISSUES
  - CURRENT PROBLEMS
  - CURES

→ FUTURE PROSPECTS
  - THE NEW STORNCT
  - USER 'REQUIREMENTS'
  - PLANS FOR STUDIES & EXPERIMENTS

- CONCLUSION

Snowmass 2001

WHAT ARE PSB & PS ?

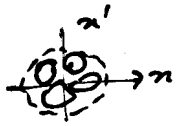


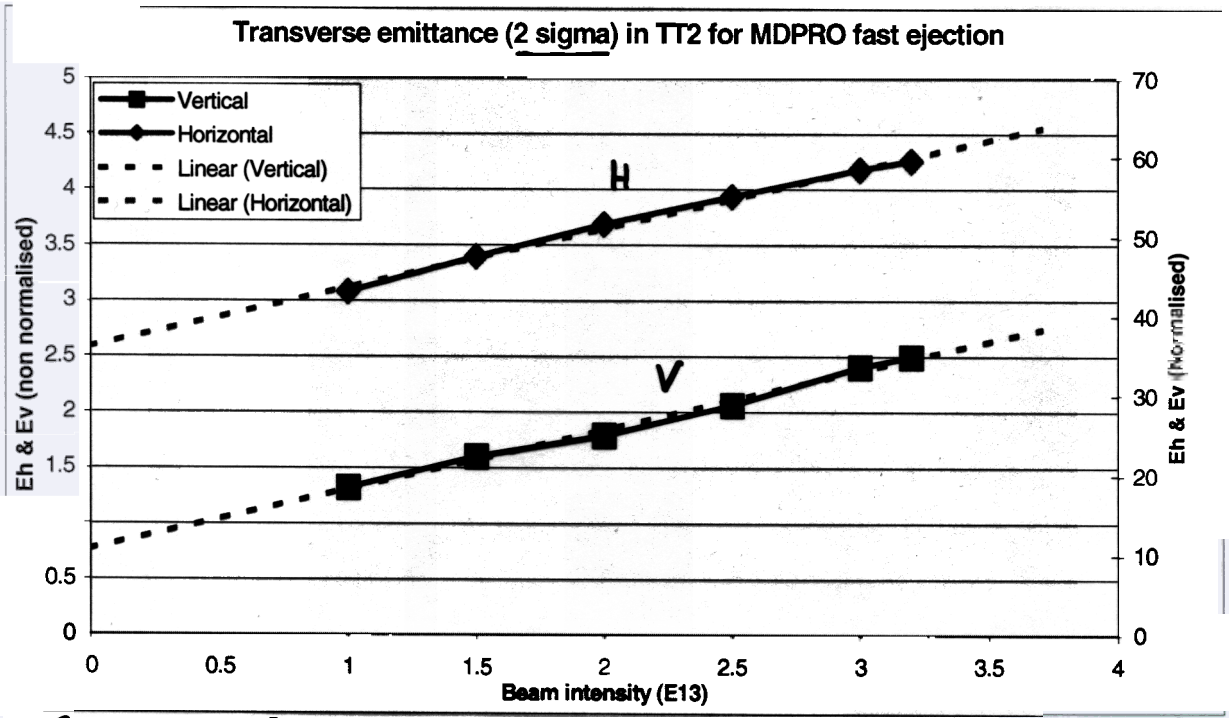
	PSB	PS
ENERGY RANGE	50 MeV - 1.4 GeV	1.4 GeV - 27 GeV
RADIUS (m)	25 (4 rings)	100
REP. RATE	1/1.2 s	1/ 1.2, 2.4, 3.6 s
PARTICLES	... O_2, He, p, Pb ... $e^{\pm}$, $\bar{p}$, ...	
h	1, 2	8, 16, 20, 21, ..., 84, ..., 420
$N_{t\,max}$	$3.8 \cdot 10^{13}$ p/p	$3.3 \cdot 10^{13}$ p/p
$N_{b\,max}$	$1 \cdot 10^{13}$ p/b	$0.7 \cdot 10^{13}$ p/b ($\sigma_t = 6$ ns)
Brilliance: $\frac{N_t}{\varepsilon^*_{x,y}}$ 1σ	$1.2 \cdot 10^{12}$ / 2.5 μm	$1 \cdot 10^{13}$ / 3 μm
Remarks	PPM mode double harm. cav. ctrl long. b.v. bunch splitting flat bunches fast extr. only ...	PPM mode single or double batch injection Long. bunch splitting (x 2, x 3) or merging, deb., neb., ... γ_{tr} jump bunch compressions FAST extraction SLOW extraction 5 turn Continuous Transfer ...

PERFORMANCE

μ^c NTE SITE vs x, y

PSB | PROTON MULTITURN (1-12) INJECTION





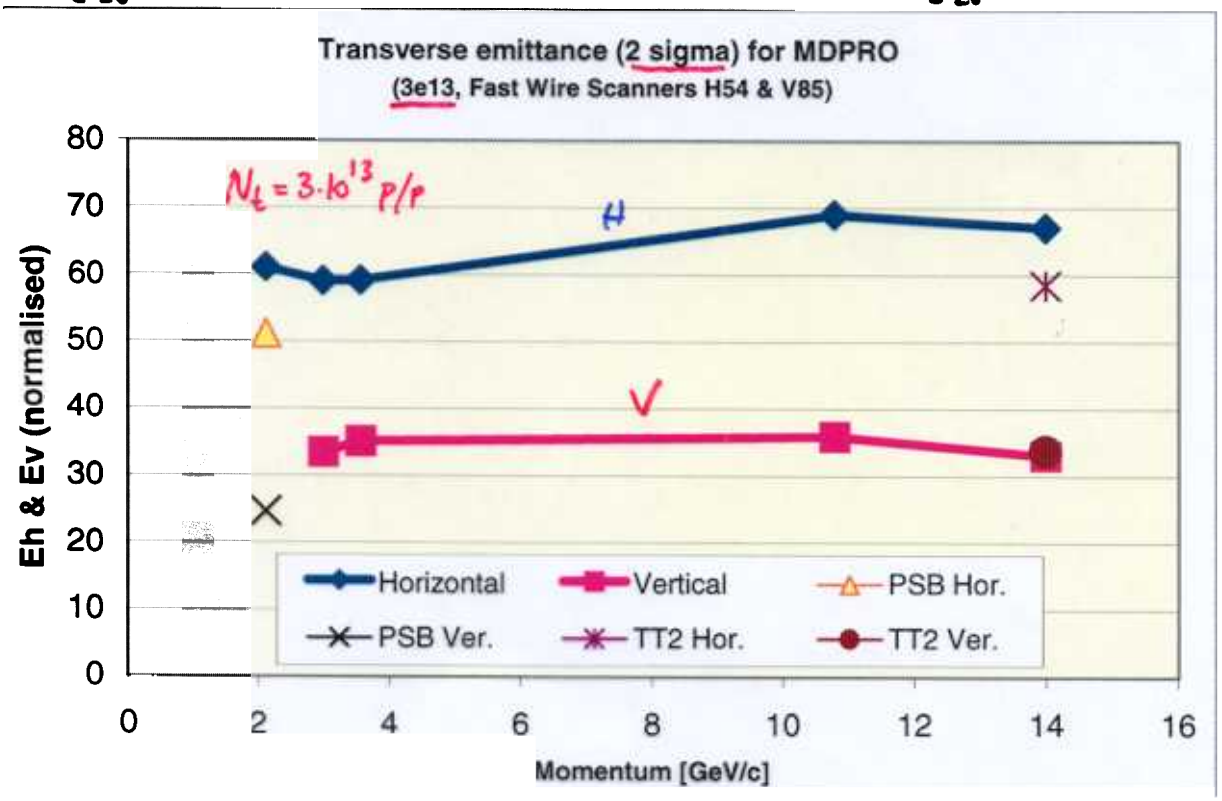
Fittings

$\varepsilon_{x_{2\sigma}} \simeq 0.57 \cdot N_t + 2.5$

$\varepsilon_{y_{2\sigma}} \simeq 0.53\, N_t + 0.8$

$\varepsilon^*_{x_{2\sigma}} \simeq 8.45\, N_t + 37$

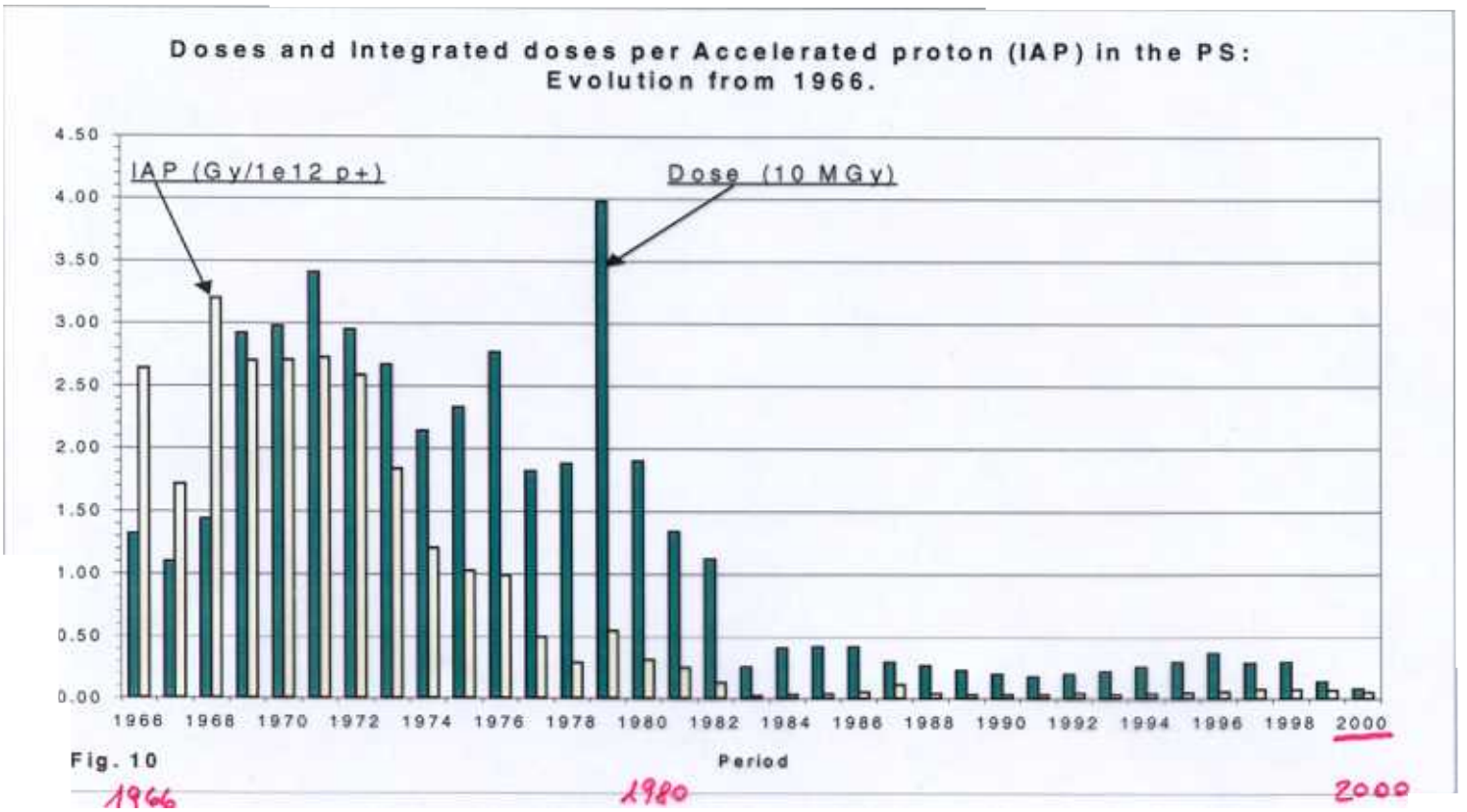
$\varepsilon^*_{y_{2\sigma}} \simeq 7.85\, N_t + 11.8$



Courtesy R. Steerenberg

EFFORTS TO REDUCE MACHINE IRRADIATION

AND OPTIMIZE RELIABILITY ($\eta \simeq 95\%$ over the year)



POINT IS HOW TO WORK AT HIGH INTENSITY

i.e. ~ 1 – 3 10^{13} p/p KEEPING LOW LOSSES i.e. ~ $0.2 \cdot 10^{13}$ p/p

~ 10%

COURTESY D. MANGUNKI

MAIN HIGH INTENSITY ISSUES IN PS

→ AT LOW ENERGY

- SPACE CHARGE — in PSB: $\Delta Q \simeq -0.5$
  PS: $\Delta Q \simeq -0.3$
- PS ACCEPTANCE — $A_x = 60\ \mu m$, $A_y \simeq 20\ \mu m$
- H-T & COUPL. BUNCH TRANSV INSTAB.
  Cured with: x-y coupling or octupoles or transv. feedback + ξ control

→ AT TRANSITION (6.2 GeV/c):

- γ_t-jump: $\Delta\gamma_t \simeq \pm 1$, $\Delta t \simeq 1$ ms
- $\xi_{x,y}$ CHANGE: $-1 \rightarrow +0.1$ in ~5 ms
- BBU INSTABILITY (SINGLE BUNCH) → see picture
  cured by long. blow-up, e.g. $\begin{cases} N_b = 0.7 \cdot 10^{13}\ p/b \\ \varepsilon_\ell > 2.2\ eVs \end{cases}$

→ DURING ACCELERATION

- COUPL. BUNCH LONG. INSTAB.
  Cured with (long. feedbacks) + HOM's damping + Landau damping
- H-T INSTAB.
  Cured by careful control of $\xi_{x,y}$
- LONG. μW INSTAB. during some long. gymnastics (e.g. debunching - rebunching)
  Cured by increasing ε_ℓ

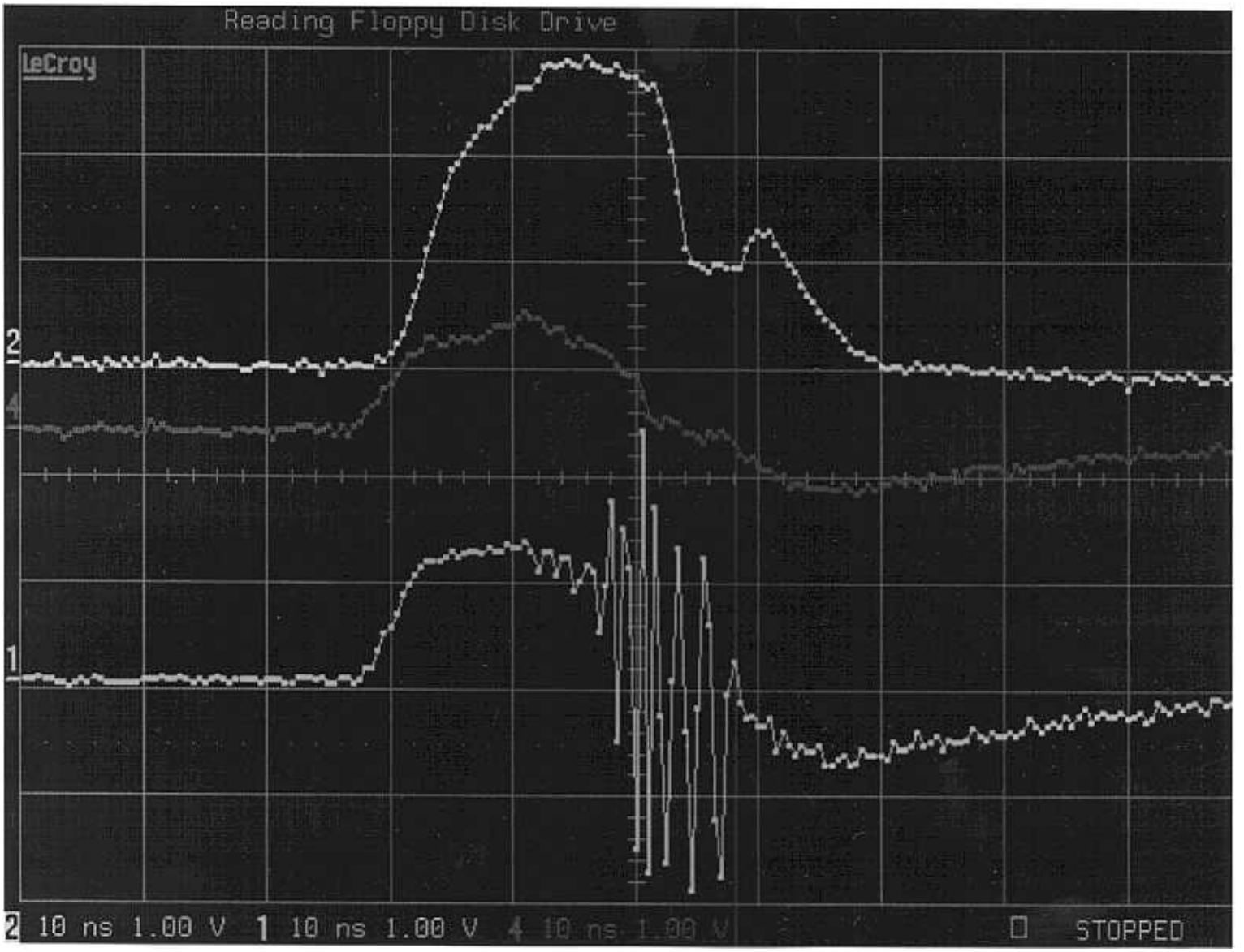
→ AT EXTRACTION

- FAST EXTRACTION (single turn)
  no problems ($\eta > 98\%$)
- SLOW EXTRACTION
  only for low intensity beams ($< 10^{12}$ p/p)

⇒ • 5 turn CONTINOUS TRANSFER → lossy operation
at 14 GeV/c — see next transp. ..

Beam Break Up instability near injection

$f\,\varepsilon_e$ vs



N_b ~ 10^{13} p/b 10 m d

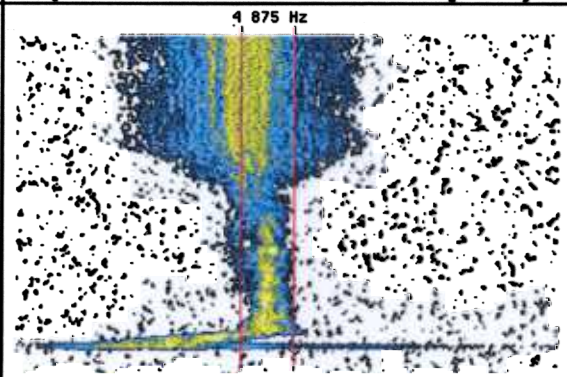
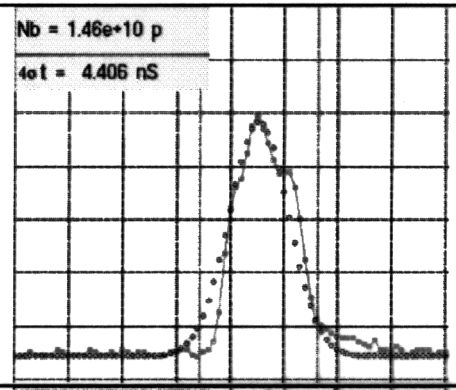
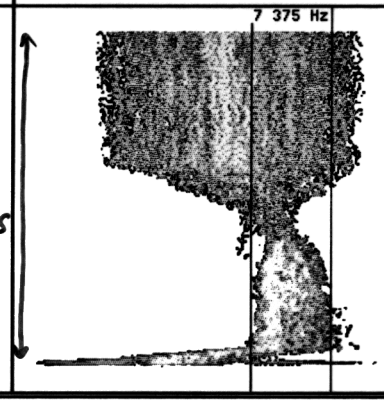
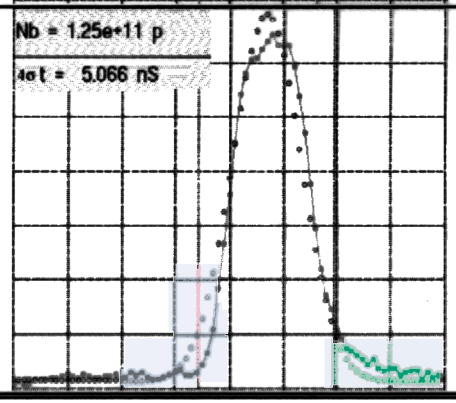
ΔV

4 ΔR

1 Σ

μW instability on debunched beam (LHC):

Z/n~17 Ω measured by 1) quadr. freq. shift, 2) e- bunch lengthening and 3) transv. tune shift

H^+ / bunch	$E_L(h=16)$	Schottky spec. @ 26 GeV/c (395 MHz – 50 kHz span)	Bunch @ ejection
~ 1×10^{10} H^+ @ ejection	0.85 eVs		
~ 10×10^{10} H^+ @ ejection	1.15 eVs ~ 200 ms		

$\frac{dp}{p} \simeq 10^{-}$

COURTESY R. GAROBY

at 14 GeV/c

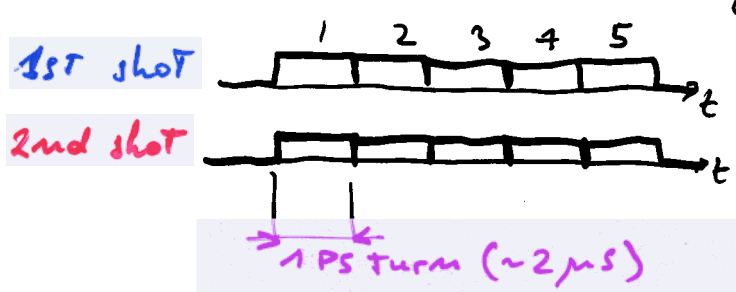
THE 5 TURN CONTINOUS TRANSFER

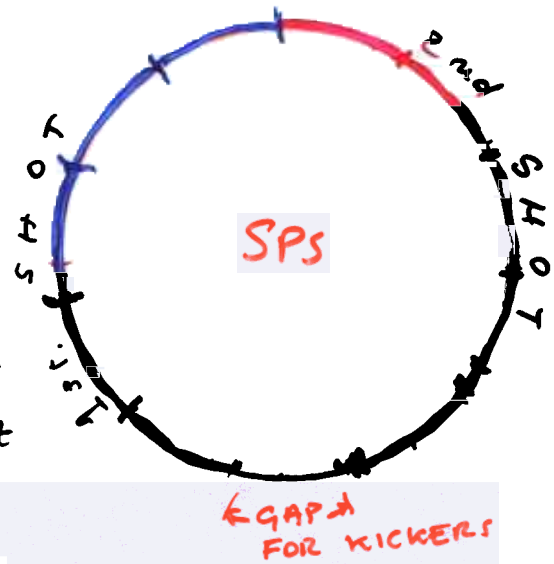
for SPS filling

- WHY ?

$$L_{SPS} = 11 \times L_{PS}$$

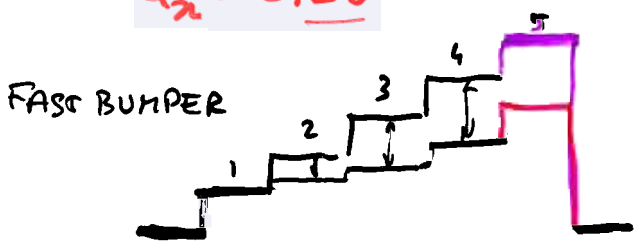
the PS fills the SPS with 2 shots of a 5 turn extraction

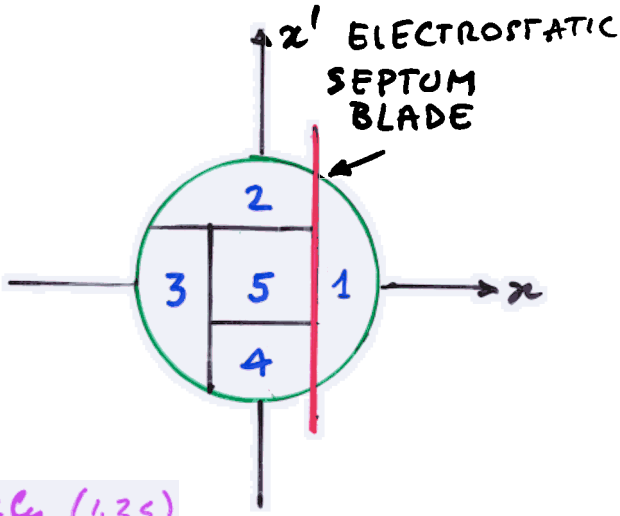




- HOW

$Q_x = 6.25$





- ADVANTAGES : $\varepsilon_{x\,SPS} = \frac{1}{5}\,\varepsilon_{x\,PS}$
  - it fills SPS quickly (1,2 s)
- DISADVANTAGES :
  - IN REALITY $\varepsilon_{x\,SPS} \simeq \frac{1}{3}\,\varepsilon_{x\,PS}$
  - ε_x different for each turn
  - different distributions
  - difficult to match

Lossy operation (~ 10% losses on ES)

difficult to do it at 26 GeV/c

Conclusion : If we want to increase the intensity and keep low losses we have to invent a new method

VERY PRELIMINARY

IDEAS FOR A NEW STCT

BASIC RECIPE :

3) CREATE WITH SEXT. & OCT. A 4th ORDER RESONANCE
CHANGE THE TUNE IN THE MACHINE IN ORDER THAT THE BEAM SWEEPS THROUGH THIS RESONANCE
THE SWEEPING MUST BE A GIVEN FUNCTION OF TIME TO ACHIEVE AN ADIABATIC CAPTURE IN THE TRANSVERSE PLANE

4) ONCE THE BEAM IS SPLIT IN 5 EQUAL PARTS, EXTRACT AS IN PREVIOUS CT

THIS SHOULD PROVIDE LOWER LOSSES AND BETTER MATCHING, EMITTANCE CONSERVATION WITH MAYBE A SMALL INVESTMENT

STATUS :

PRELIMINARY SIMULATIONS GIVE ENCOURAGING RESULTS (*)

WE ARE PLANNING SOME EXPERIMENTS FOR NEXT YEAR

(*) ... HOWEVER WE CANNOT SAY YET IF IT IS A GOOD IDEA ...

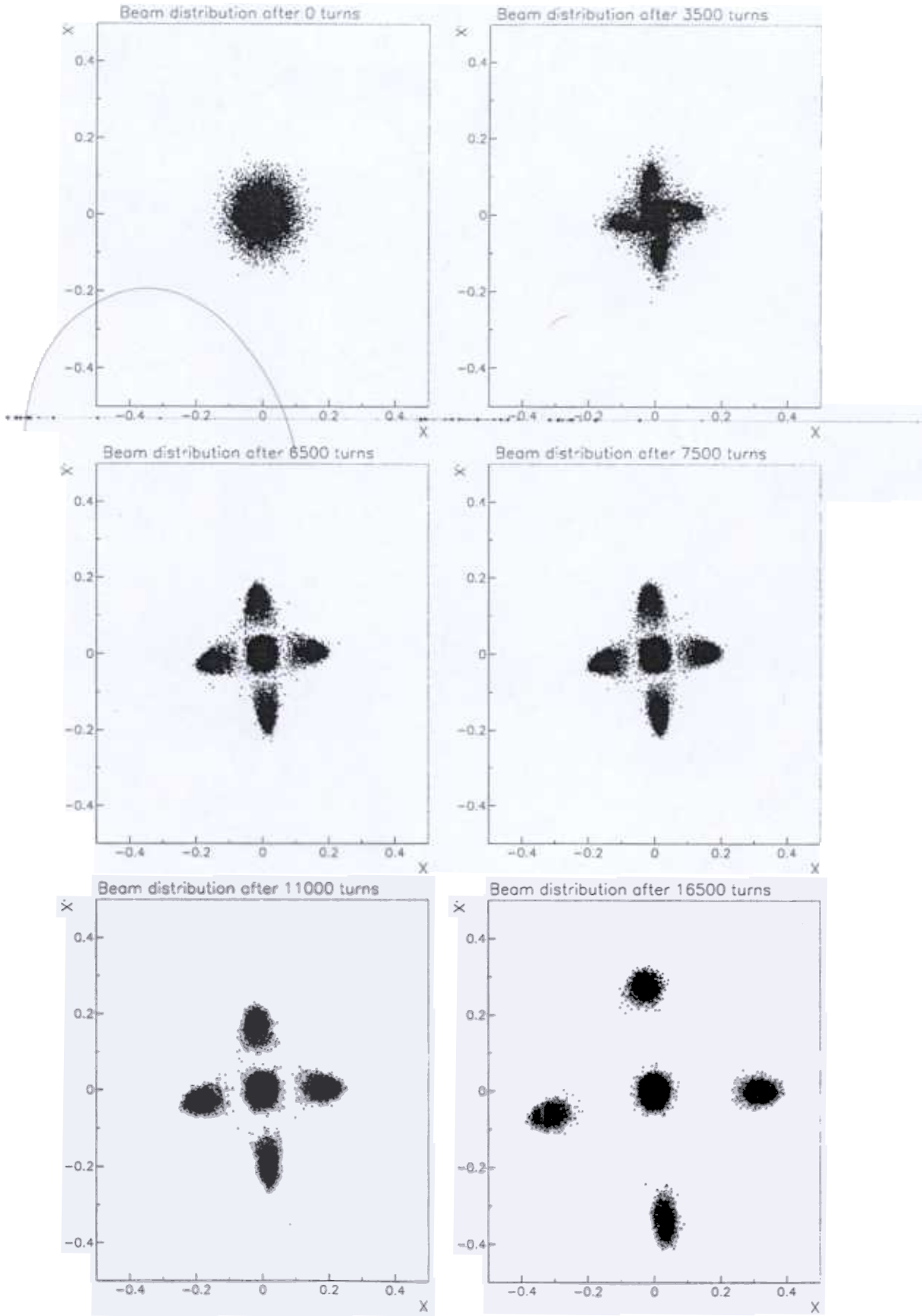
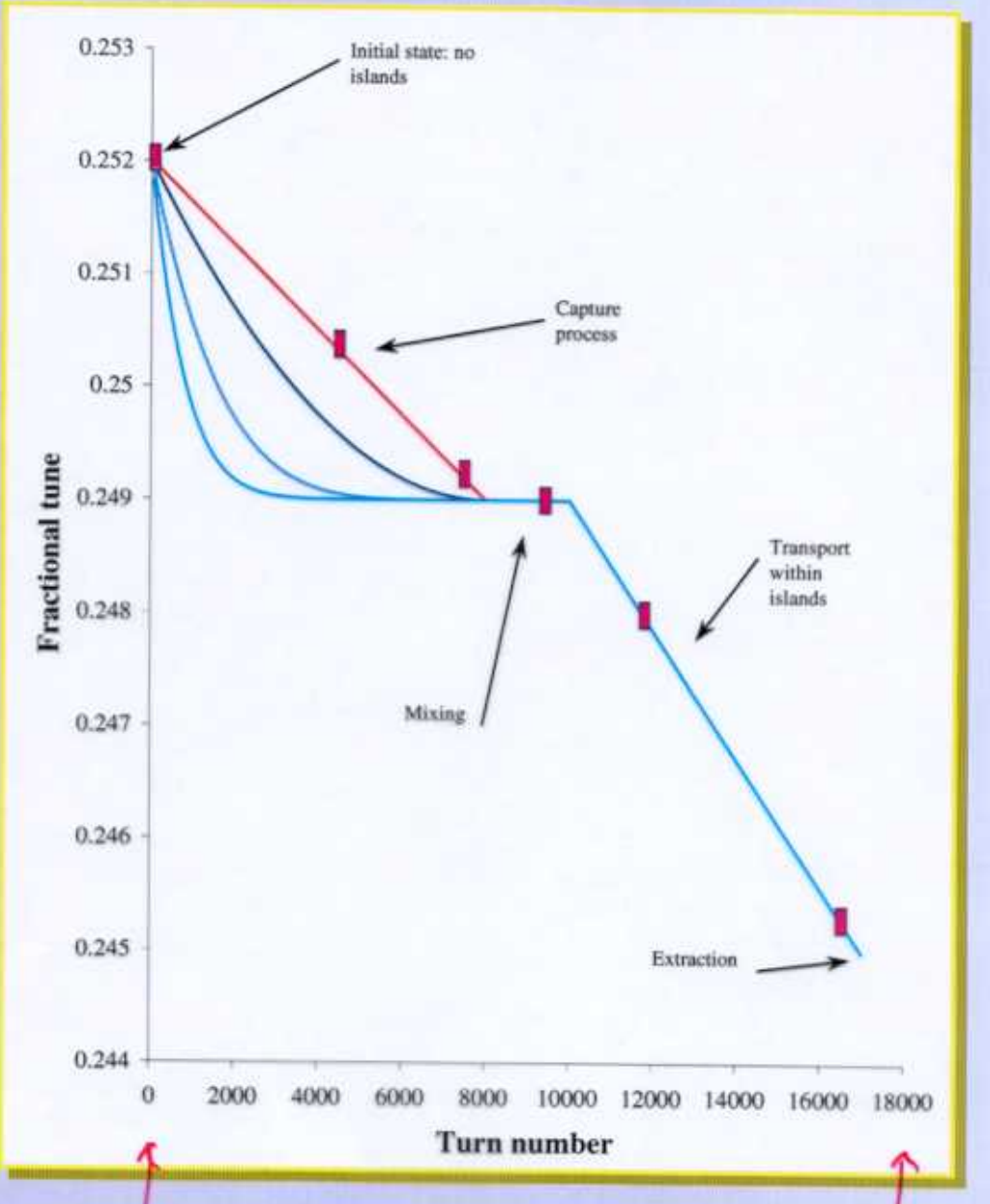


Figure 6: Evolution of the beam distribution during the trapping process. The different plots correspond to tune values represented by solid squares in Fig. 2. Each plot represents 2.25×10^4 points. The initial Gaussian distribution has $\mu = 0$ and $\sigma = 0.04$.

Tune evolution

- The model: linear machine + sextupole + octupole.
- The red curve (linear tune variation vs time) has been used in numerical simulations.



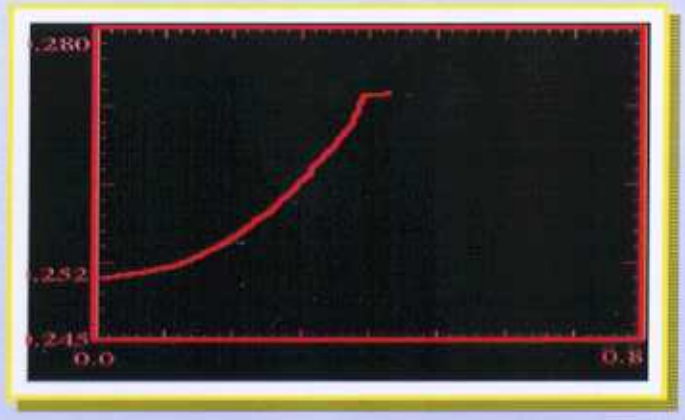
0

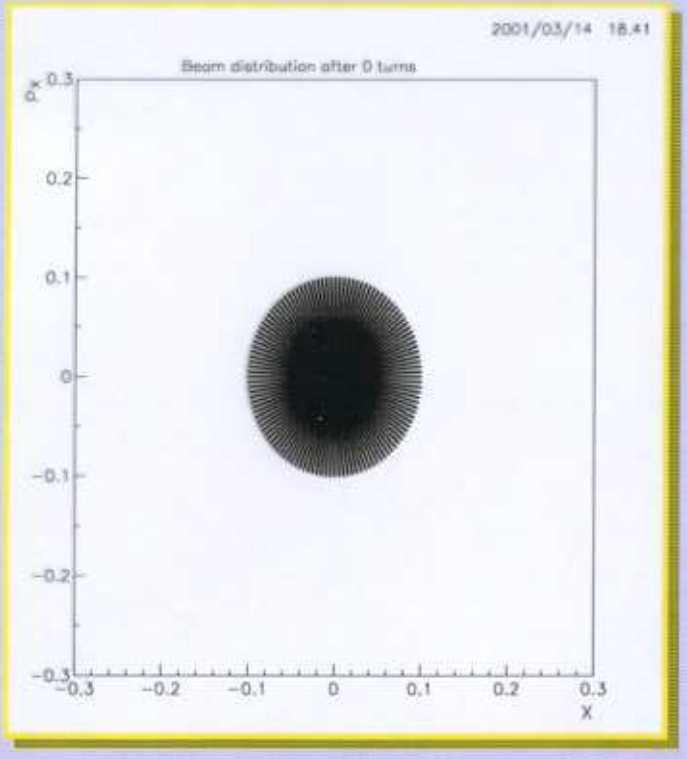
~ 40 ms

COURTESY M. GIOVANNOZZI

Phase space topology, beam distribution

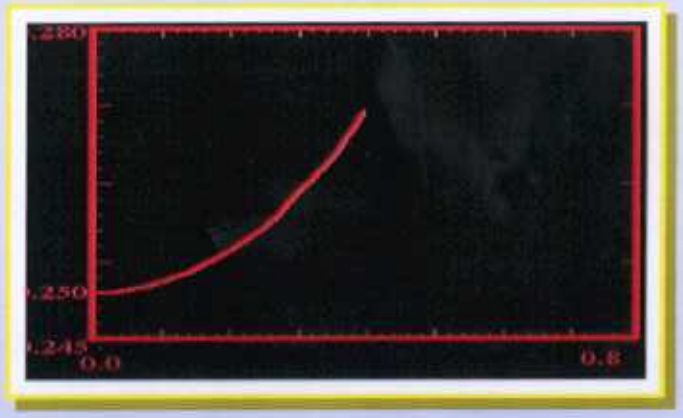
- Parameters:
  - $\nu_H = 0.2520.$
  - Turn number: $0.$
- Scale of phase portrait: $[-1, 1], [-1, 1].$

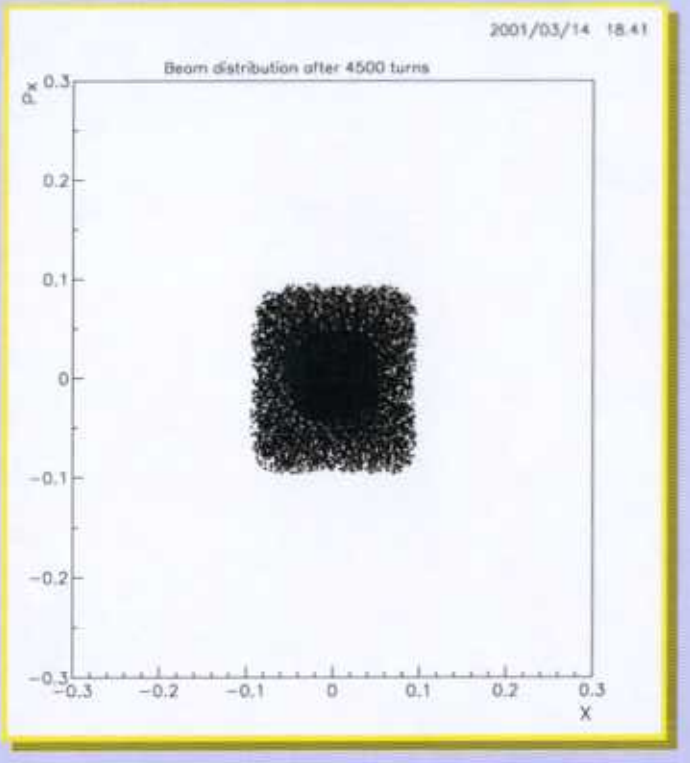




Phase space topology, beam distribution

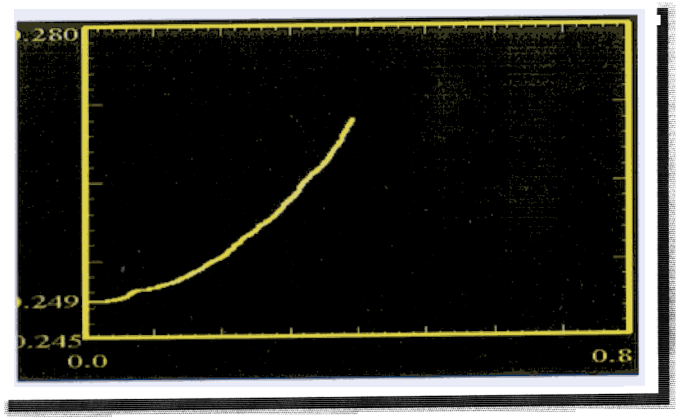
- Parameters:
  - $\nu_H = 0.2503.$
  - Turn number: $4500.$
- Scale of phase portrait: $[-1, 1], [-1, 1].$

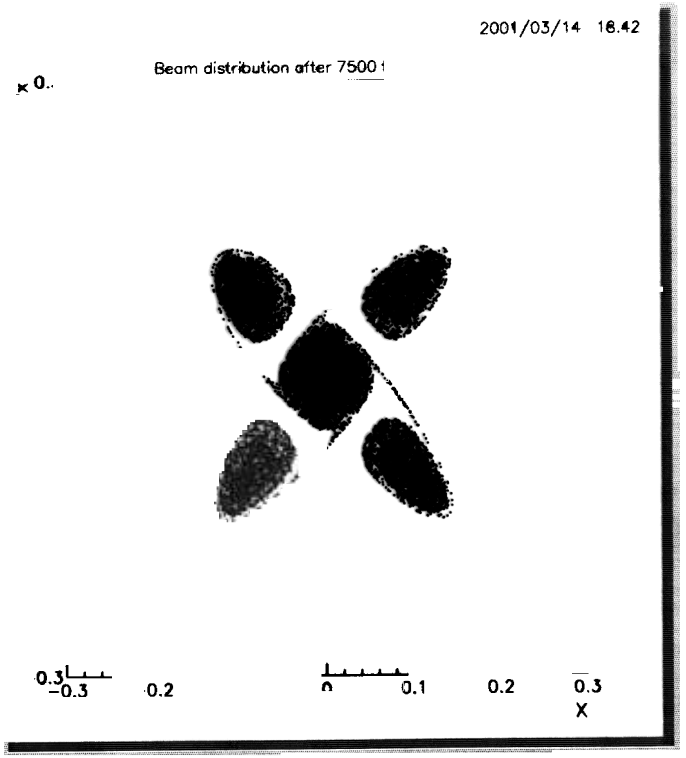


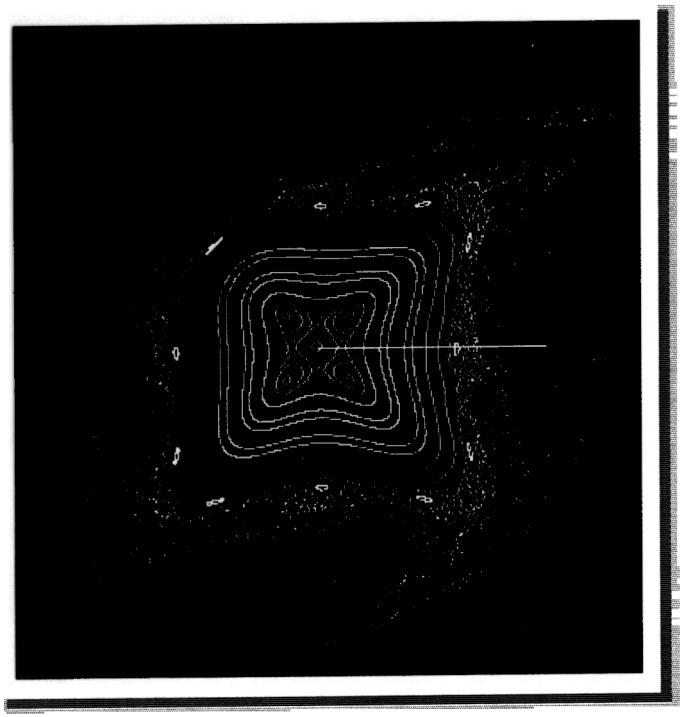


Phase space topology, beam distribution

- Parameters:
  - $\nu_H = 0.2492.$
  - Turn number: 7500
- Scale of phase portrait: $[-1, 1]$ $[-1, 1]$

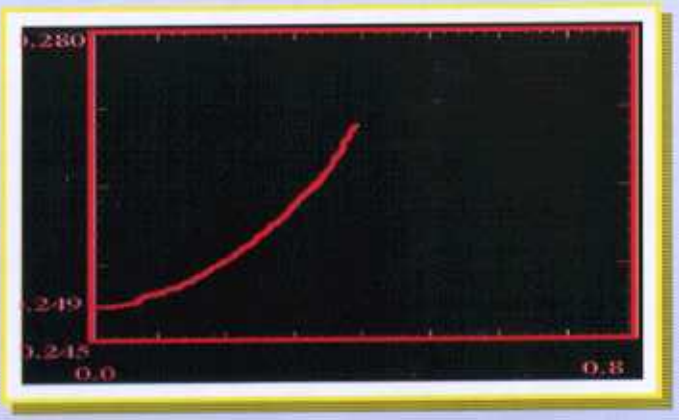


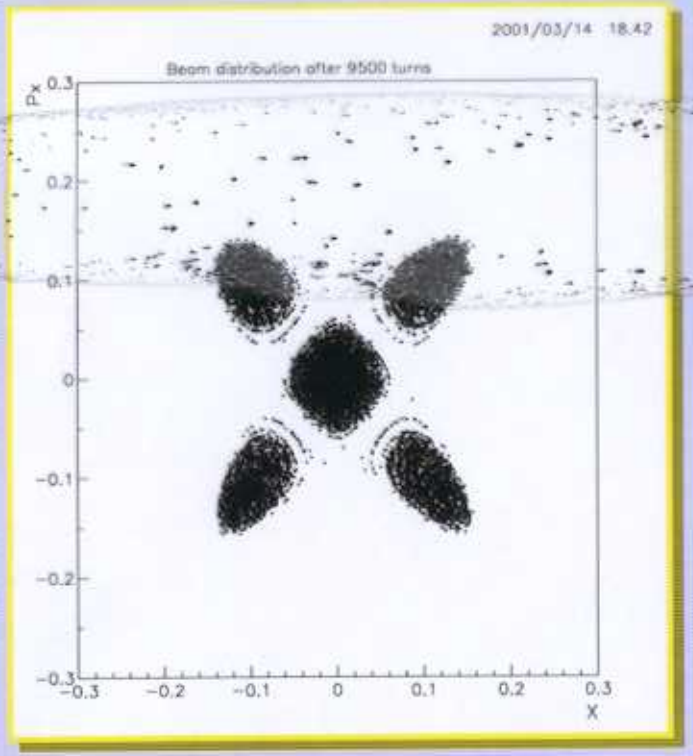




Phase space topology, beam distribution

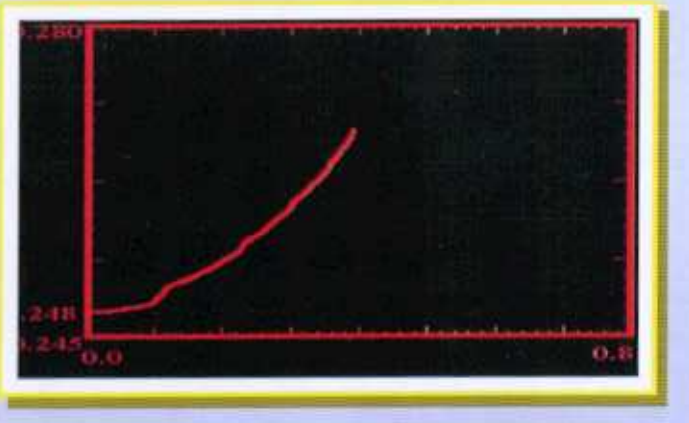
- Parameters:
  - $\nu_H = 0.249$.
  - Turn number: 9500.
- Scale of phase portrait: $[-1, 1], [-1, 1]$.

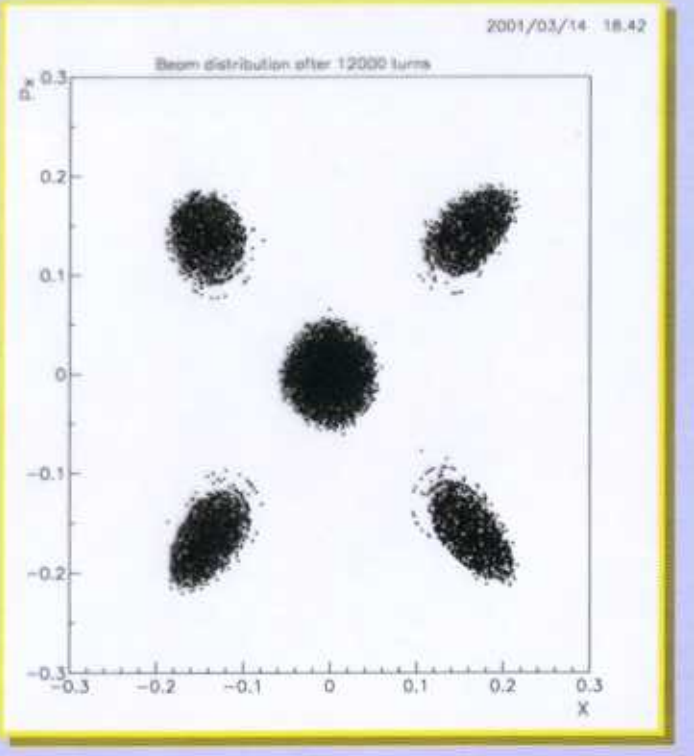




Phase space topology, beam distribution

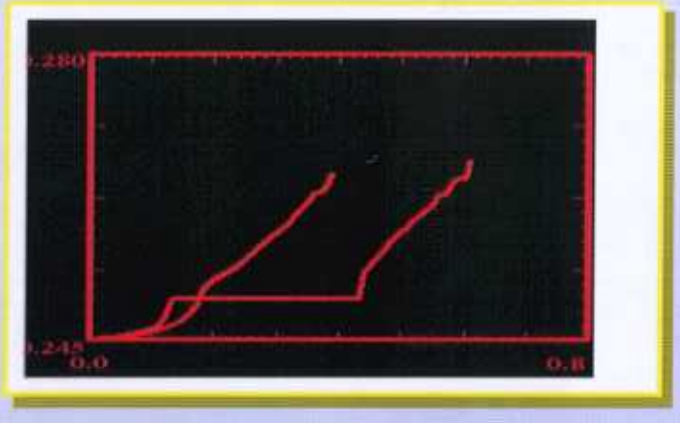
- Parameters:
  - $\nu_H = 0.2479.$
  - Turn number: 12000.
- Scale of phase portrait: $[-1, 1], [-1, 1]$.

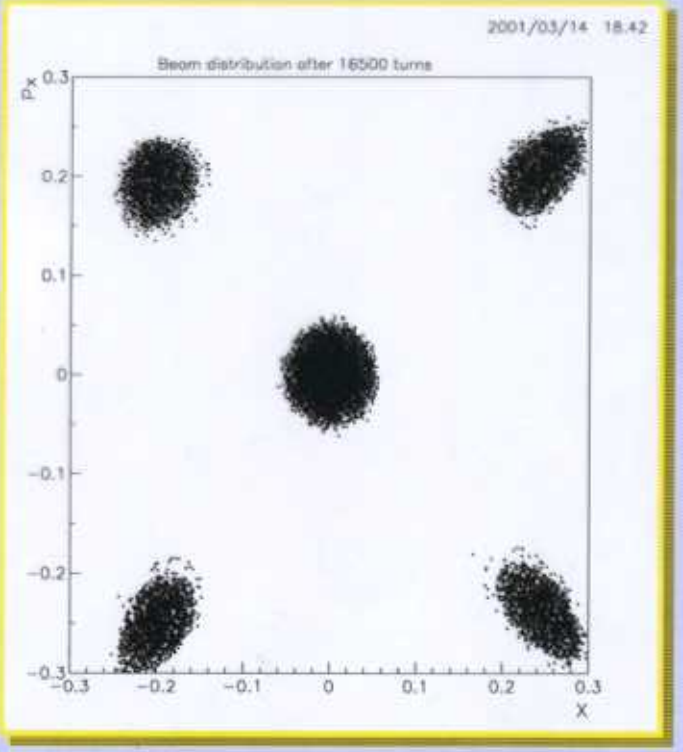




Phase space topology, beam distribution

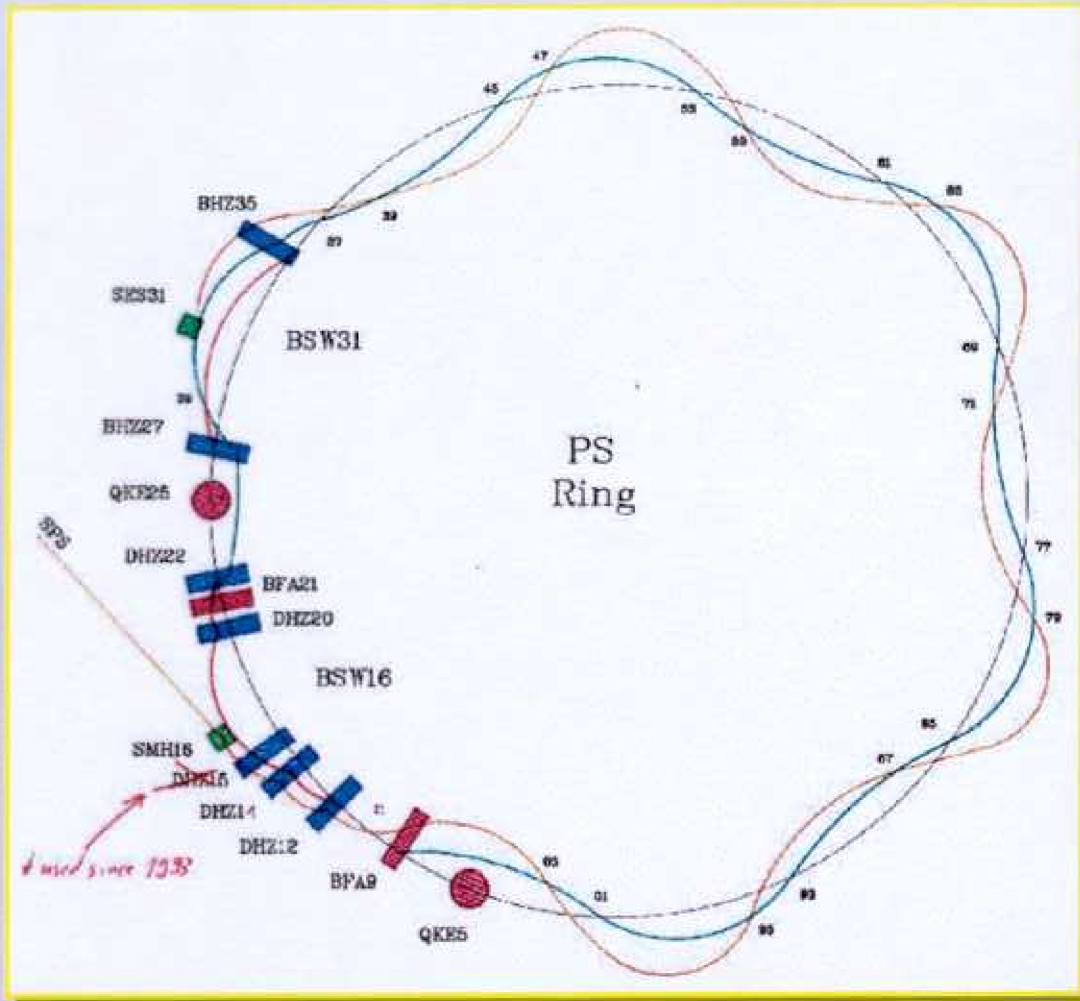
- Parameters:
  - $\nu_H = 0.2453.$
  - Turn number: 16500.
- Scale of phase portrait: $[-1, 1], [-1, 1]$.





Extraction

- Based on local bump around septum 16.
- The slow bump is the standard one (bump 16, elements in sections: 12, 14, 20, 22).
- The fast bump could be generated (to be checked) by BFAs (present location in sections 9, 21).
- Key point: The nonlinear elements should not be located in the bump region (low-order effects due to off-axis traversal).
- Problem: Sextupole (slow extraction) in section 19 and octupoles in section 20.



USER REQUIREMENTS

TOWARDS HIGHER INTENSITIES $\times 2?, \times 3?$

CNGS(ν), LHC, MTOF, SOLDE, etc

STUDIES ARE GOING ON on

- new STCT
- DOUBLE BATCH INJECTION AT HIGH INTENSITIES
- $ DOUBLE PSB REP. RATE 1/1.2 s → 1/0.6 s
- H^-. 120 MeV new LINAC
- $$$ SUPERCOND. Proton LINAC at 2.2 GeV

A F INCREASING CNGS (ν) INTENS

$N_{PS} = \frac{N_{SPS}}{2}$

#	Denomination	N sps [10^{13}p/p]	POT flux ϕ [10^{13}p/s]	Gain = ϕ / 0.8	Cost (ord. of mag.) [MCHF]	Remarks
0	present nominal scheme	4.8	4.8 / 6 = 0.8	1	0	Already difficult
1.1	**=0 + double batch PS inj.**	**7.7**	**7.7 / 7.2 = 1.07**	**1.34**	**1**	**Higher N_{sps} but longer cycle** (cost without 200MHz SC cav.)
1.1a	1.1 + PSB @ 0.6s	7.7	7.7 / 6.6 = 1.17	1.46	3	Important HW modifications (?) Improvements to ISOLDE
1.2	**1.1 + new5-turnCT**	**8.6**	**8.6 / 7.2 = 1.19**	**1.49**	**2**	**Better transfer efficiency (lower losses)**
1.2a	1.2 + PSB @ 0.6s	8.6	8.6 / 6.6 = 1.30	1.63	4	Best of group 1 ?
1.3	1.2 + 26GeV/c	8.6	8.6 / 8.4 = 1.02	1.28	3	No transition in SPS CT @ 26GeV/c ?
1.3a	1.3 + displaced & shortened PSB cycle	8.6	8.6 / 7.2 = 1.2	1.5	3	Very interesting
2.1	**1.2 + a new H^- 120MeV Linac**	**8.6**	**8.6 / 6 = 1.43**	**1.79**	**70**	**Improvements also for LHC, ISOLDE,...**
3.1	SPL at 2.2GeV + new 5-turnCT at 14GeV/c	23	23 / 6 = 3.83	4.79	300	Extremely high coll. effects =>UNREALISTIC

Table 2. A list of various schemes (the arrows indicate the "selected schemes"). They are listed in 3 groups 1.n, 2.n and 3.n, where 1, 2 and 3 are the number of digits in the cost figure. "Nsps" is the p intensity / pulse in the SPS. "POT flux" is the proton on target flux, i.e. Nsps / SPS cycle duration with cycle duration = 4.8s + time between two PS extractions (actually the varying parameter). "Gain" is the ratio of POT flux / present nominal flux . "Cost" is a very approximate cost evaluation (order of magnitude).

CONCLUSION

- IN THE PSB – PS – SPS CHAIN THERE IS NOT A SINGLE LIMITATION UNFORTUNATELY

- CONCERNING CNGS (ν) p FLUX A GAIN OF 1.5 SEEMS ATTAINABLE (THOUGH DIFFICULT) AT MODERATE COST

- WITH A NEW H^- 20 MEV LINAC THE GAIN COULD BE 1.8. 'LHC ULTIMATE' BEAM, ISOLDE & nTOF COULD ALSO BENEFIT

  ↳ the first stage for a 2.2 GeV SPL

A GAIN OF 3 SEEMS UNREALISTIC EVEN WITH A 2.2 GeV SPL, DUE TO EXTREME COLLECTIVE EFFECTS IN PS & SPS

HOWEVER FOR AN "LHC ULTIMATE X2" (i.e. $\mathcal{L} \simeq 10^{35}\ cm^{-2}s^{-1}$) IT COULD BE (USEFUL) NECESSARY