BEAM-BEAM DESIGN CRITERIA

FOR LHC

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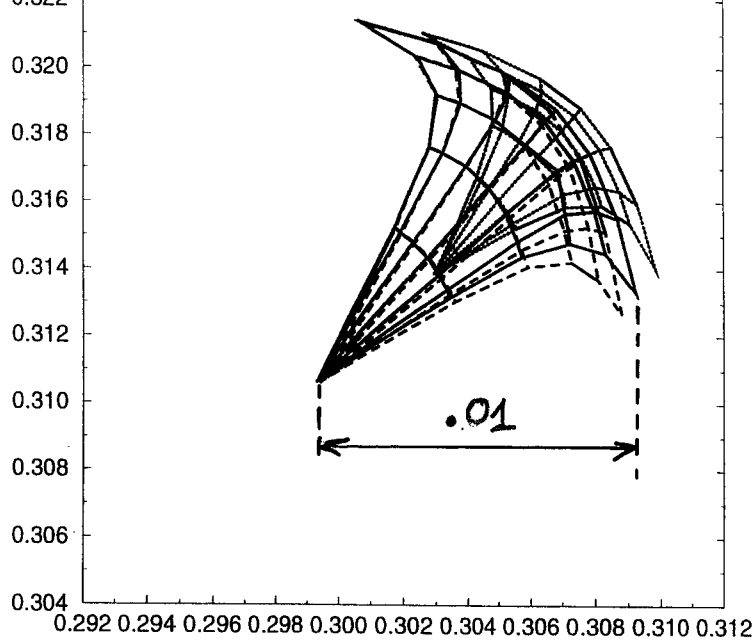
1) The LHC and its 4 experiments

- Lumi, β^*, Xing angle
- Bunch schedule _ pacman _ superpacman
- Footprints

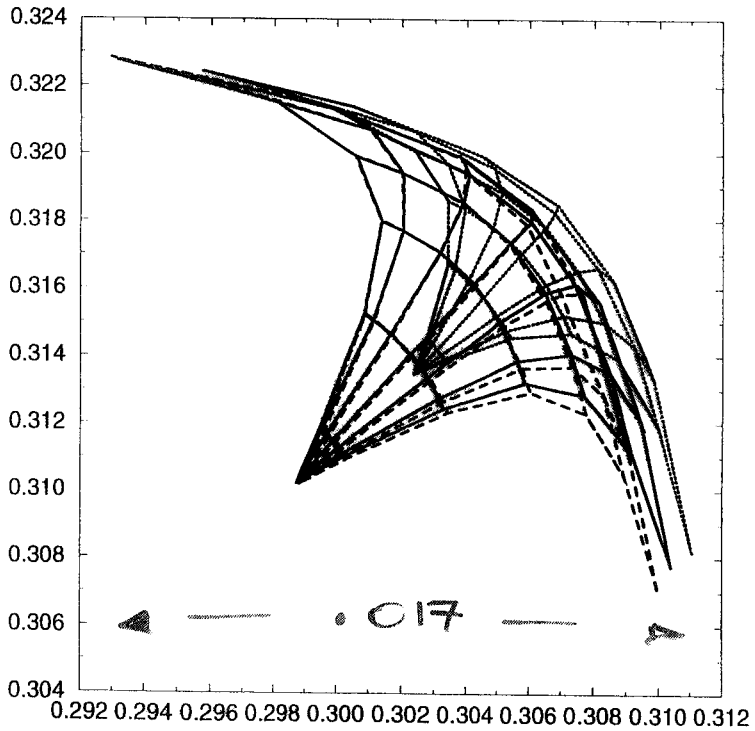
2) Assumptions, past experience _ Recipe for LHC

3) Questions _ LHC specific



± 150 μrad

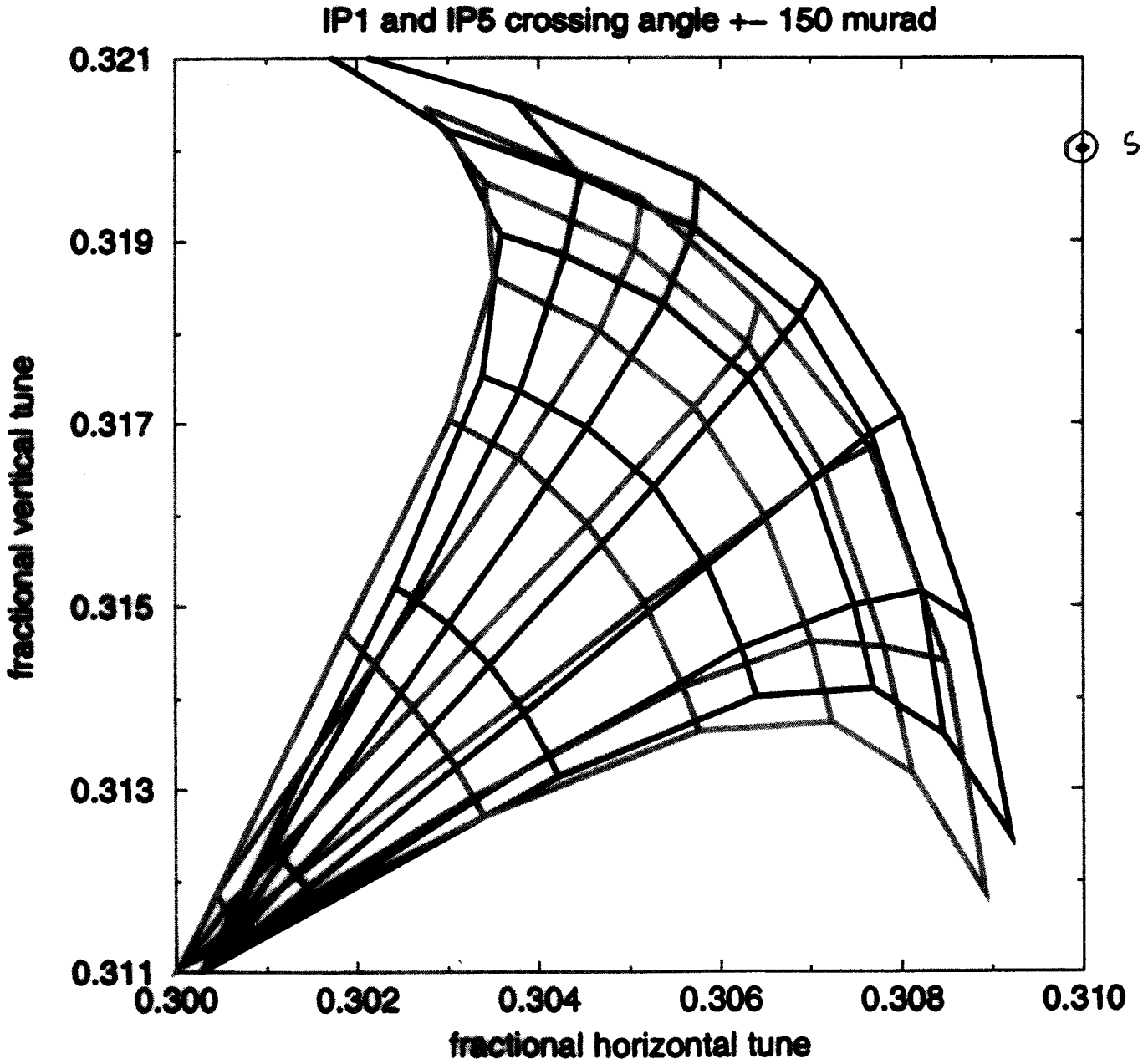
gure 9: Vertical-horizontal (IP1, IP5) plus IP8 collision (solid) versus the same plus halo lision at IP2 (dashed) at $\pm 150 \mu rad$. For comparison: nominal machine (dotted).



± 125 μrad

gure 10: Vertical-horizontal (IP1, IP5) plus IP8 collision (solid) versus the same plus halo lision at IP2 (dashed) at $\pm 125 \mu rad$. For comparison: nominal machine (dotted).

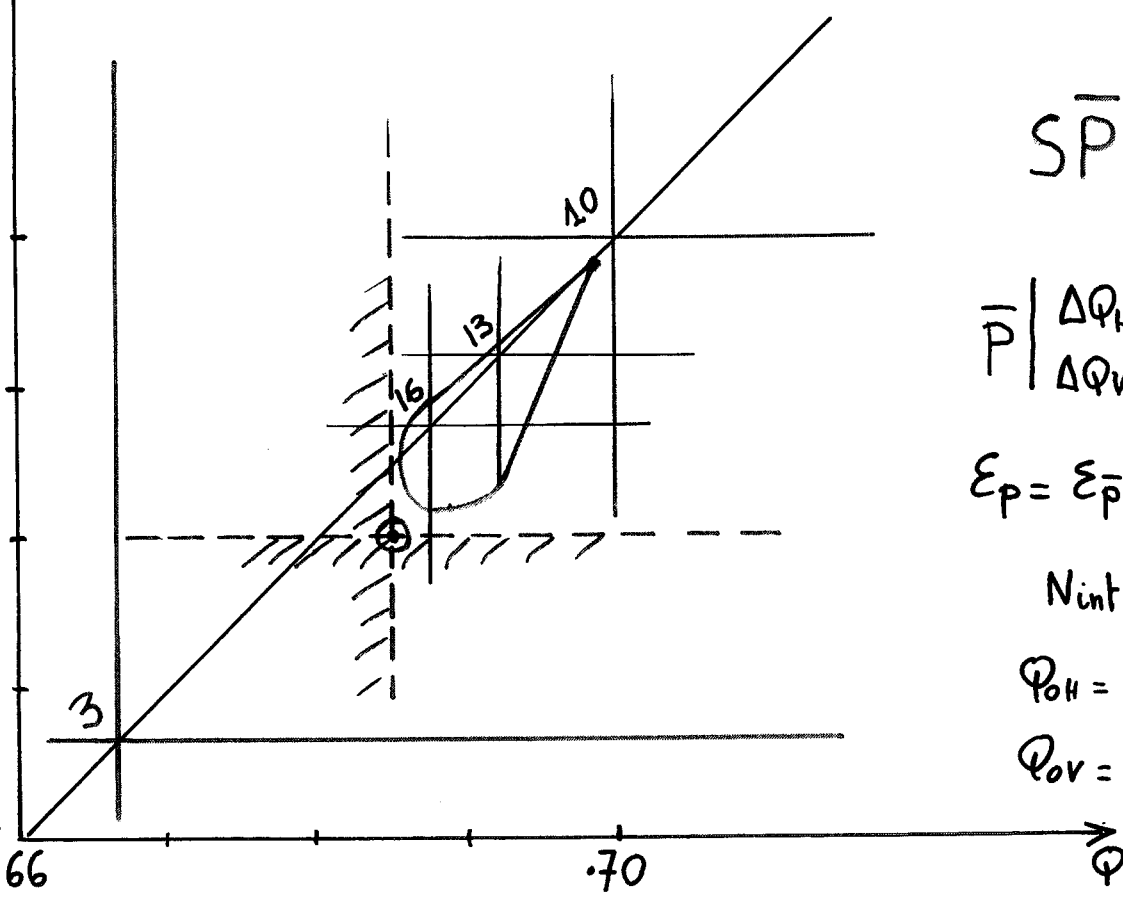
Footprints $0 \rightarrow 6\sigma$



⊙ single beam

0–6σ tune footp

$\Delta Q \sim .01$



$S\bar{P}PS$

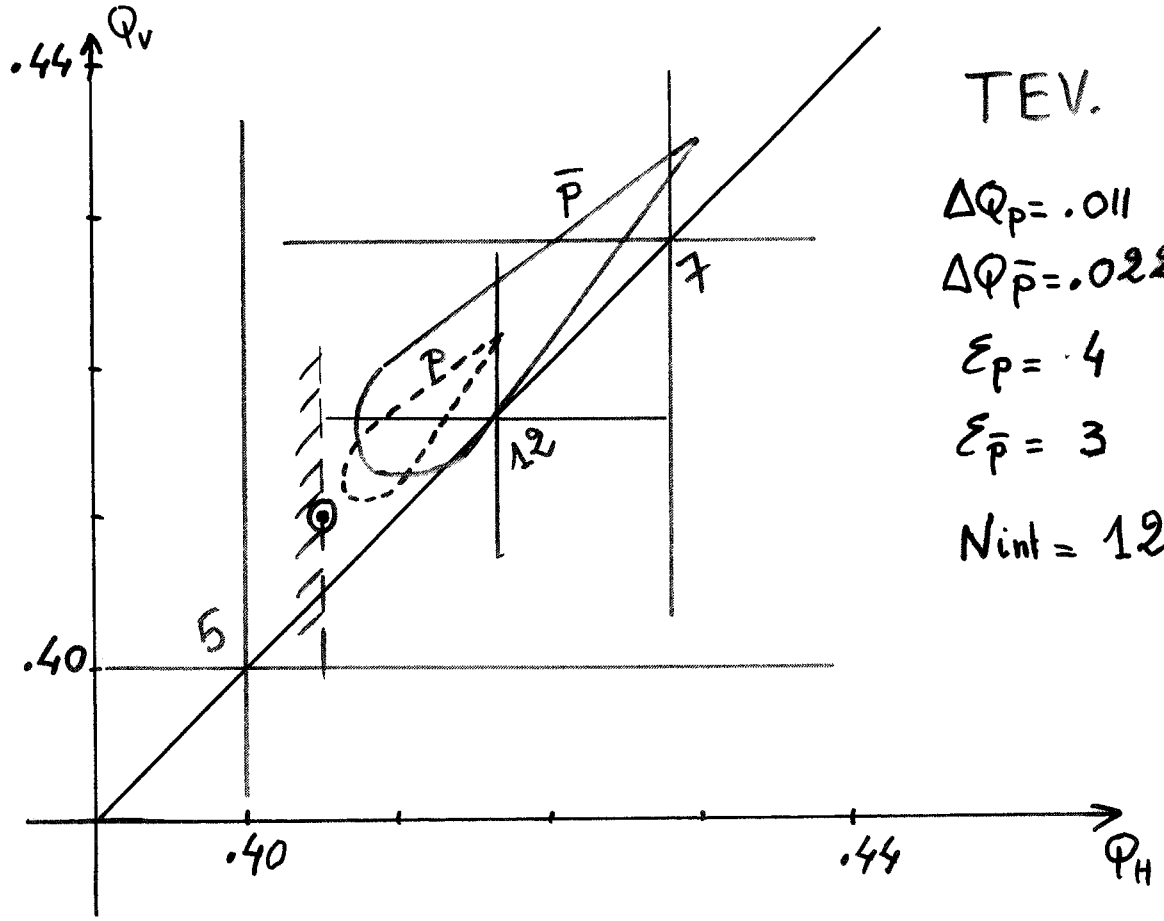
$\bar{P}$ | $\Delta Q_H = .013$
$\Delta Q_V = .018$

$\varepsilon_p = \varepsilon_{\bar{p}} = 2.75\ 10^{-6}$

$N_{int} = 3$

$Q_{oH} = .685$

$Q_{oV} = .680$



TEV.

$\Delta Q_p = .011$

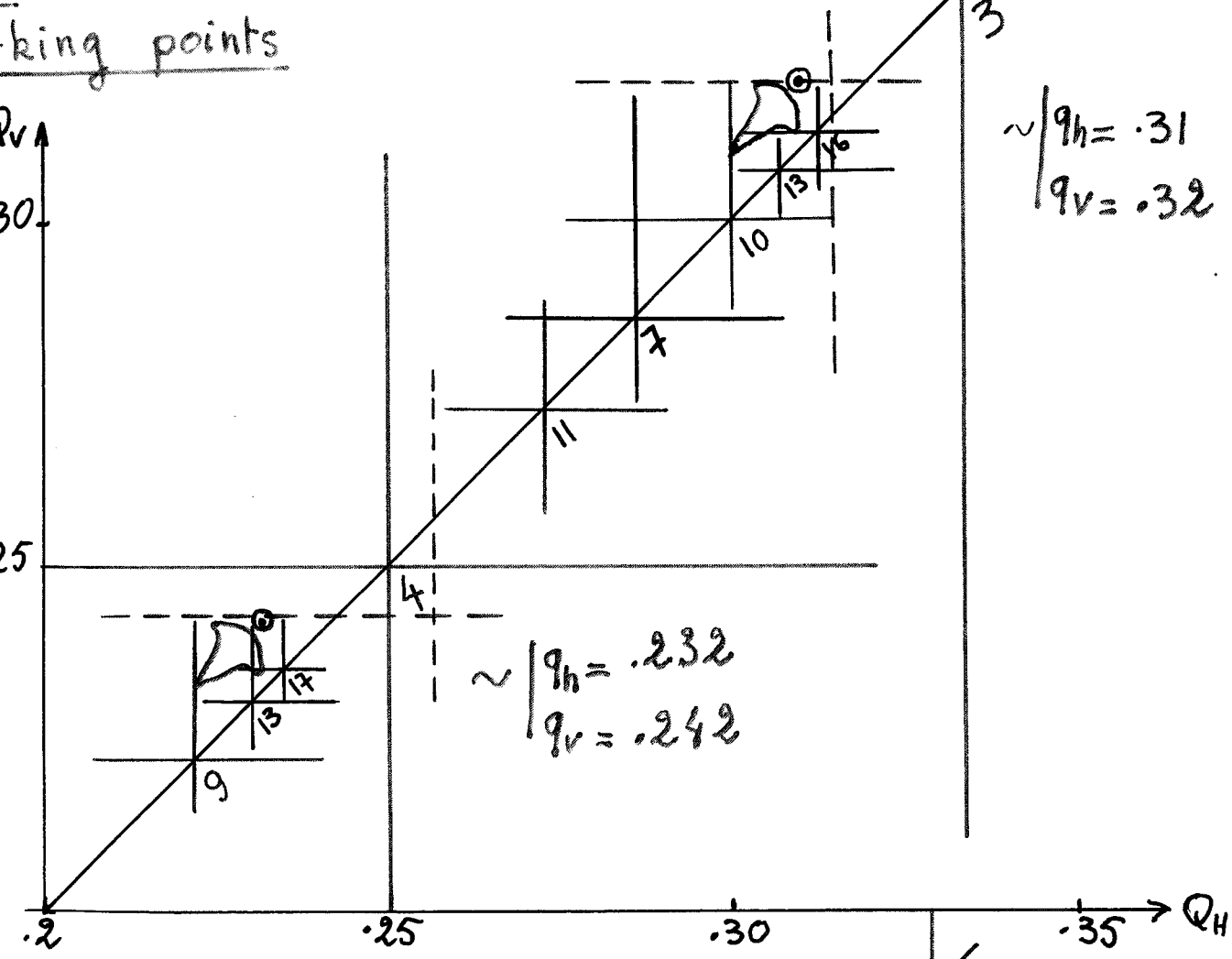
$\Delta Q_{\bar{p}} = .022$

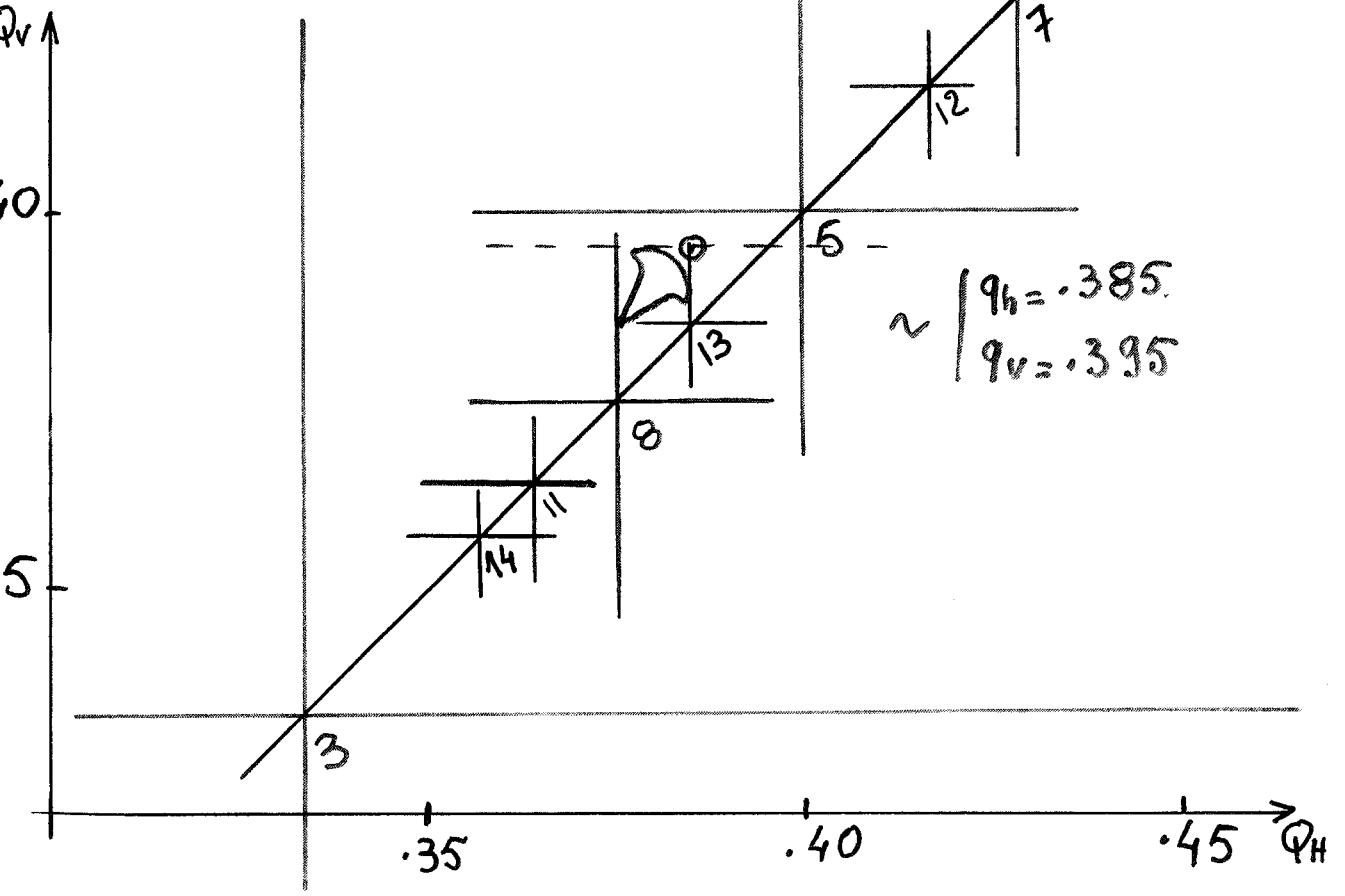
$\varepsilon_p = 4$

$\varepsilon_{\bar{p}} = 3$

$N_{int} = 12$

-king points


Q_V
30
25
.2
.25
.30
.35
Q_H
3
10
7
11
4
9
13
17
13
16
$\sim \begin{cases} q_h = .31 \\ q_v = .32 \end{cases}$
$\sim \begin{cases} q_h = .232 \\ q_v = .242 \end{cases}$


Q_V
40
5
.35
.40
.45
Q_H
3
7
12
5
8
13
11
14
$\sim \begin{cases} q_h = .385 \\ q_v = .395 \end{cases}$

Recipe for LHC

1) Avoid resonances $N \leq 12$

2) $q_h - q_v = .01$

$\rightarrow$ $\Delta Q \leq .01$ to $.012$

Nominal
10^{34}

2b) $q_h - q_v = .005$

$\rightarrow$ $\Delta Q \leq .015$ to $.017$

"Ultimate"
$2.3\ 10^{34}$.

Quiet space to accomodate b.b. tune footprint

- Influence of triplet errors
- Long-range interactions

→ specify Xing angle □
triplet quality □

) 13th order resonance

- strength – $S\bar{p}pS$ experience
  – excitation by Xing angle □
    Dispersion (Leunissen)
  – partial separation
- Effect (due to tune ripple, slow drifts ...)
  → lifetime ? background ?

) Coherent modes

- LEP, SPS, TEV □
- LHC □ → π mode <u>not</u> damped ?
  influence of long range ?

DYNAMIC APERTURE STUDIES DURING COLLISIONS IN THE LHC

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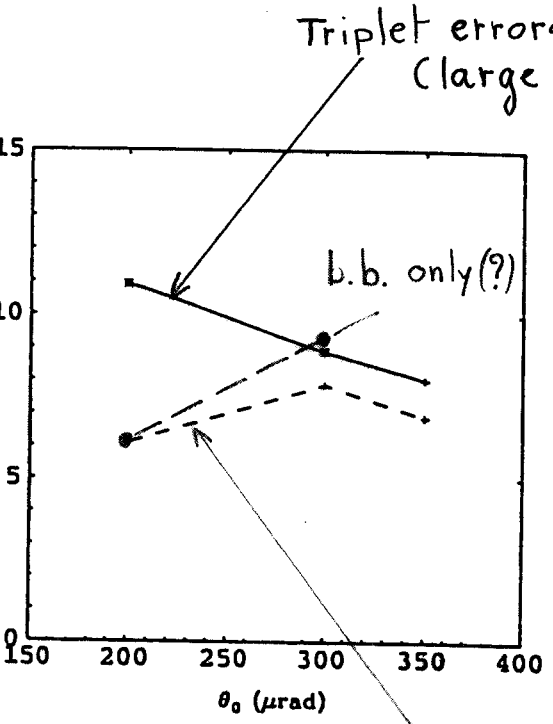


namic aperture *vs.* crossing angle:
(10^5 turns)
$\beta^* = 0.5$ m

+ 2 Hi Lumi experiments ($\beta^* = 0.5$m) : Head-on + Long rang
($\mathcal{L} = 10^{34}$ cm^{-2}s^{-1})
+ 2 Low Lumi experiments : Head-on only.

SPECIFICATION OF TRIPLET

• D.A. for 10^5 turns = | 12σ average
                          | 10σ minimum

Xing angle $\pm 150\,\mu rad$

for nominal Working point | $Q_H = .31$
                          | $Q_V = .32$

(check other WPs ?)

2. ΔQ @ $6\sigma \leq 0.001$

→ achieved through careful design
+ corrections

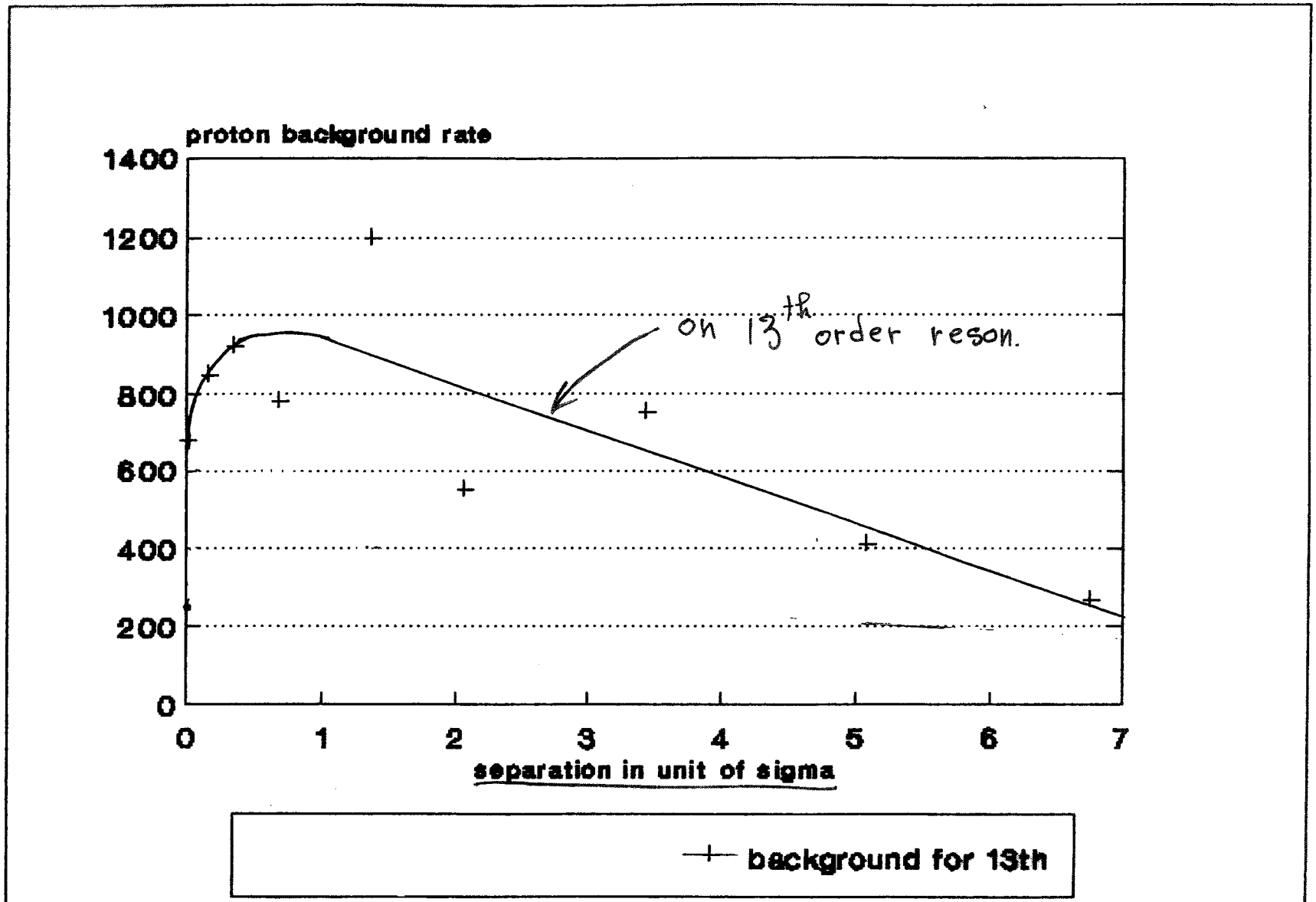
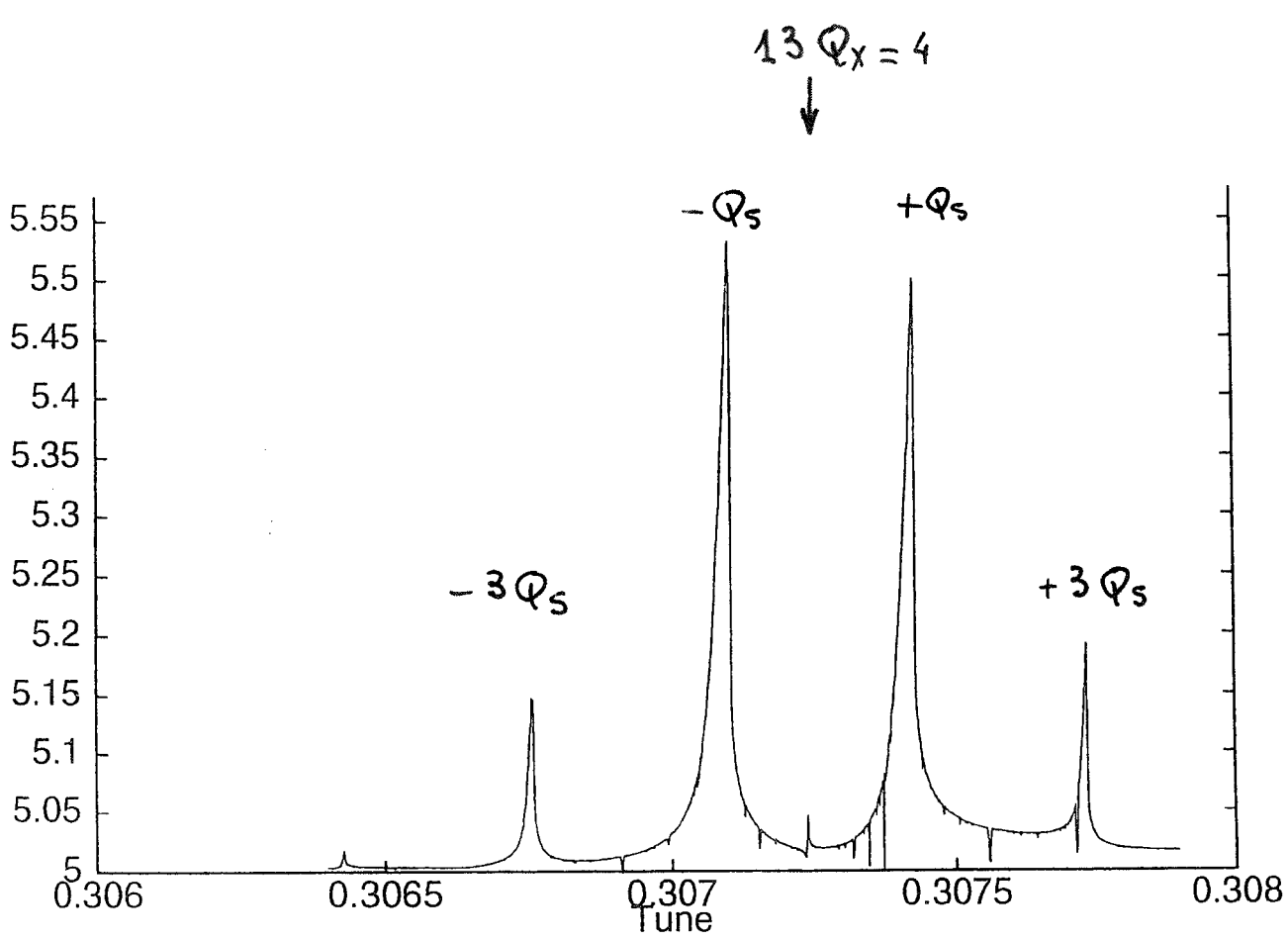
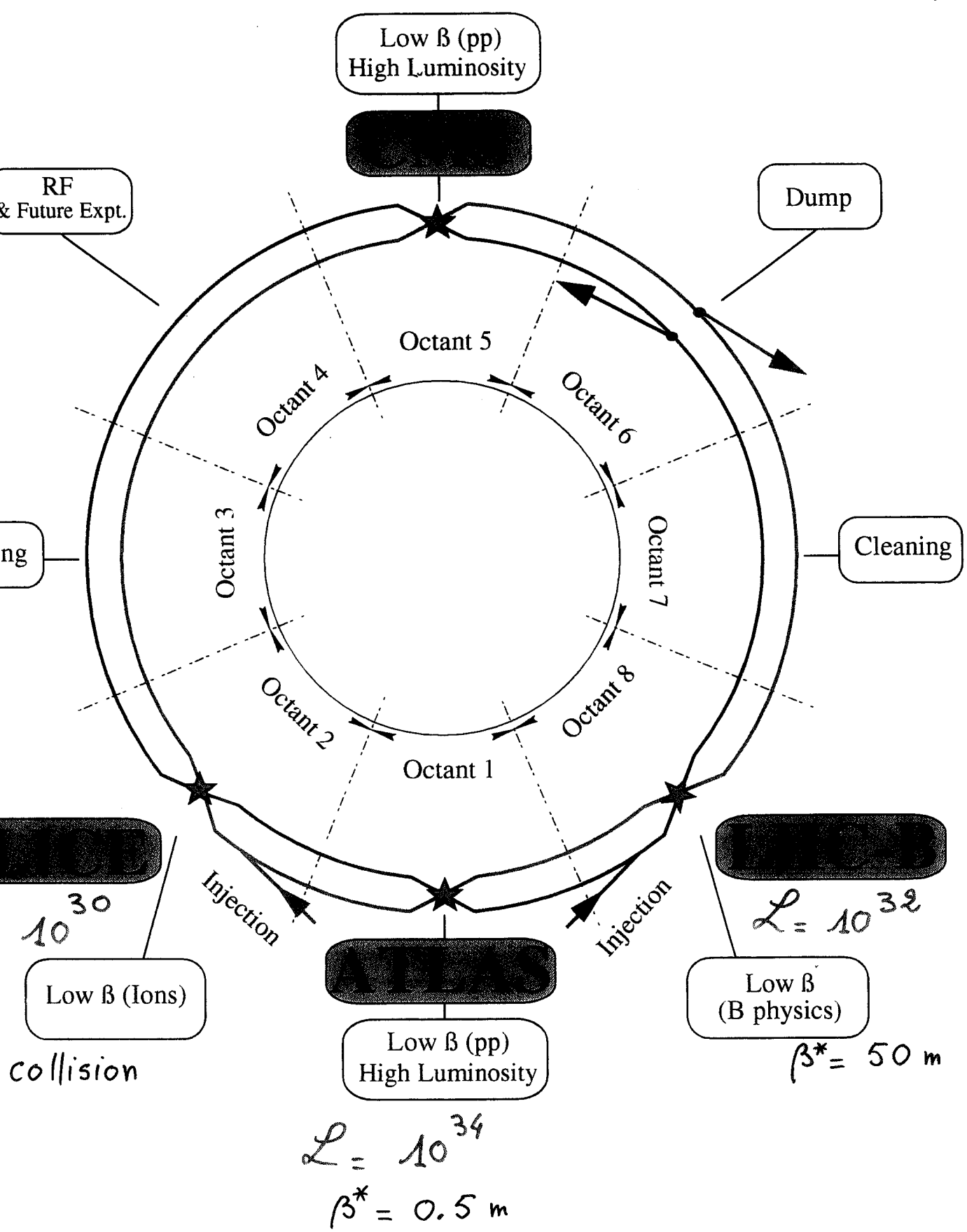

proton background rate
1400
1200
1000
800
600
400
200
0
0
1
2
3
4
5
6
7
separation in unit of sigma
on 13th order reson.
background for 13th

fig. 8



Tune scan around $13 Q_x = 4$ $a_0 = 5\sigma$.

crossing angle $\phi = \pm 150$ μrad.



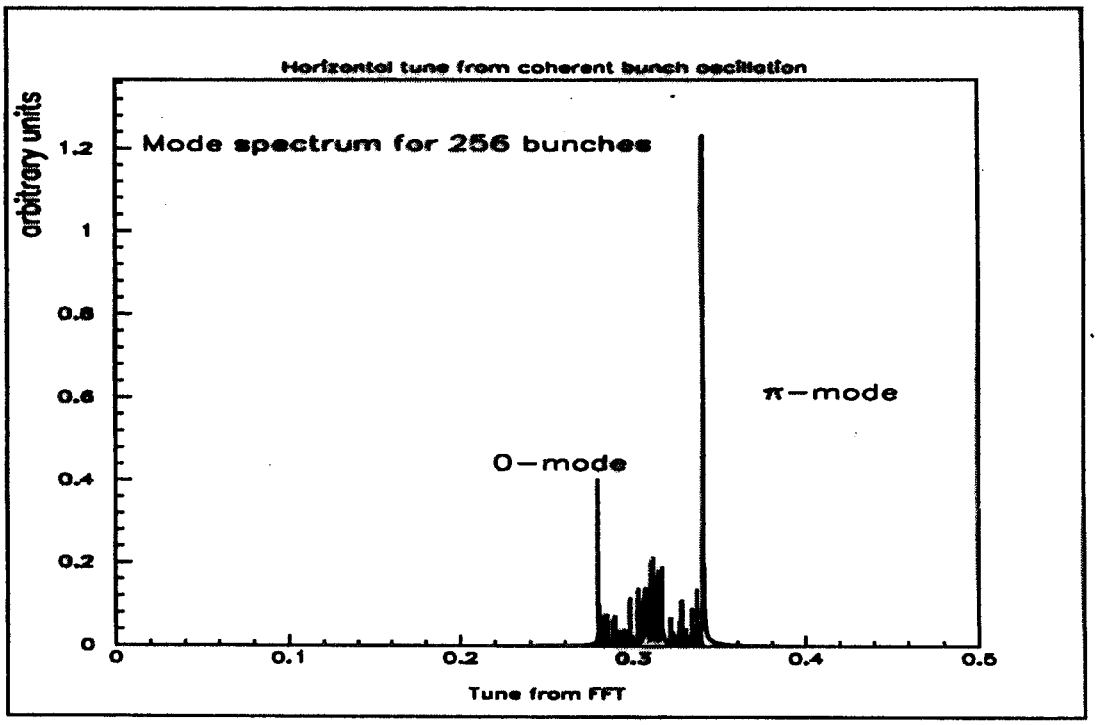
LHC layout

HF239 EXP.

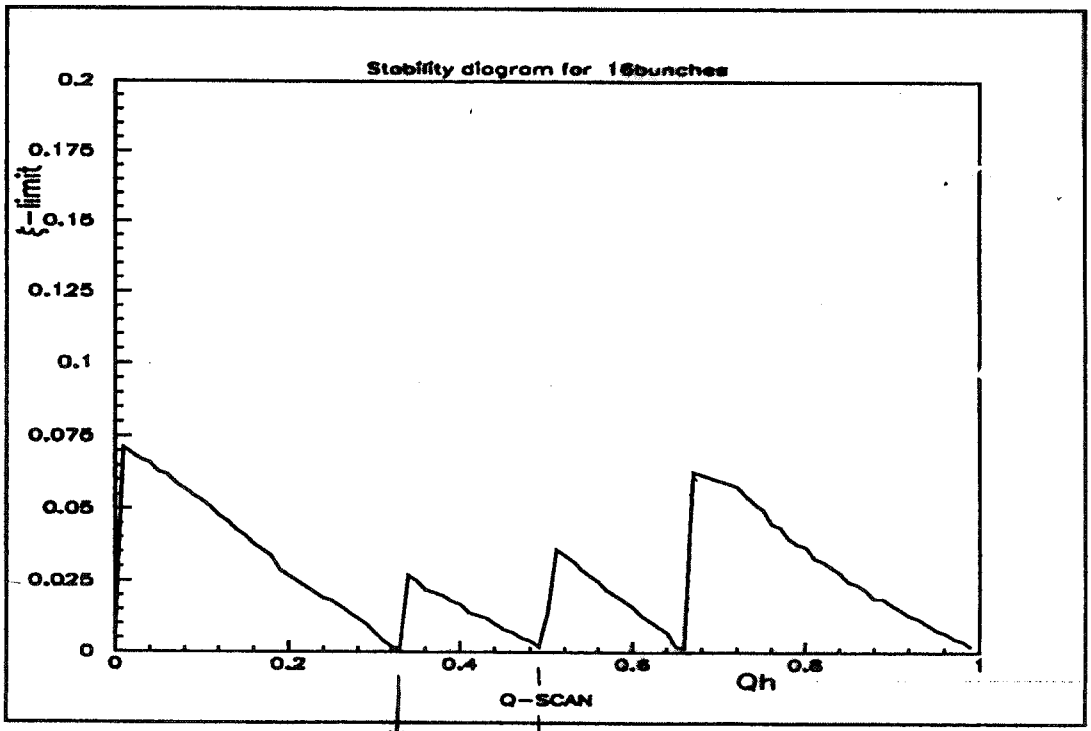
Coherent Beam-beam

(here dominated by long-range int.)

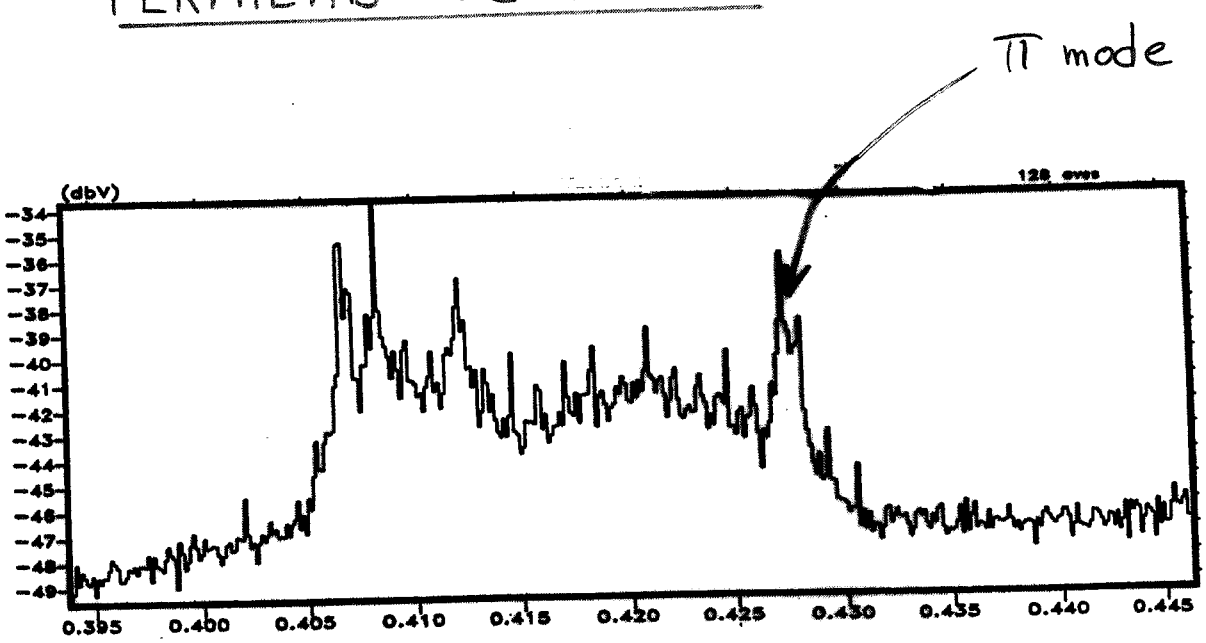
Clustered IP



$Q_\pi - Q_0 \simeq 7.5\,\xi$ (3 IP's)



FERMILAB TEVATRON



colliding beam spectrum at 150 GeV.

Schottky spectrum

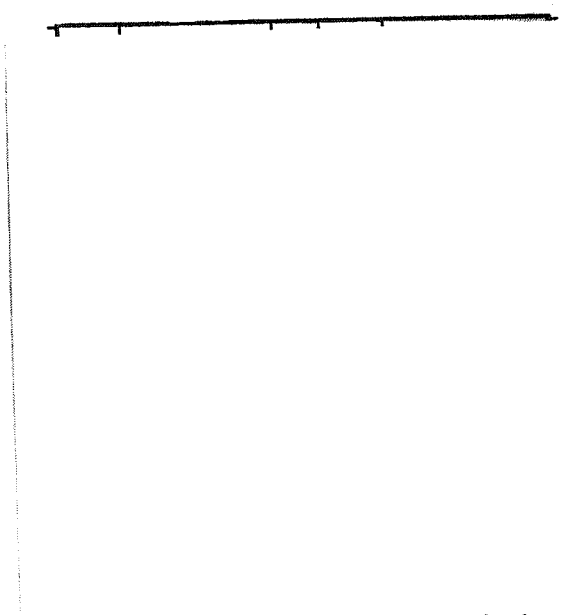


Figure 9: Calculated tune density distribution which produced the transfer function in figure 8.

Challenges of LHC:

- **High field**
- **<u>High Luminosity</u>** $= 10^{34}\text{cm}^{-2}\text{s}^{-1}$

$$L = \frac{\gamma}{4\pi e}\frac{1}{\beta^*}\left[\frac{N}{\varepsilon_n}\right][Nkfe]$$

ε_n: *Transverse density*

$Nkfe$: *beam current I*

I = 0.56 A

N = $1.1\ 10^{11}$ } $\sim 3.10^{14}$ p

k = 2835

ε_n = $3.75\ 10^{-6}$ m

β^* = 0.5 m

N : particles/bunch

k : number of bunches

f : revolution freq.

ε_n : normalized emittance

$$= \frac{\sigma^2}{\beta}\gamma$$

$Q_{bb} = .01$

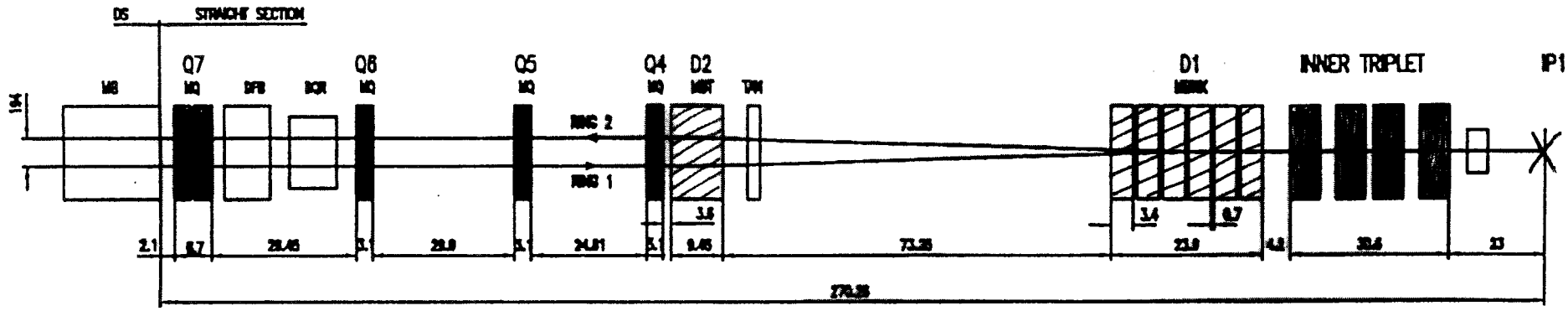
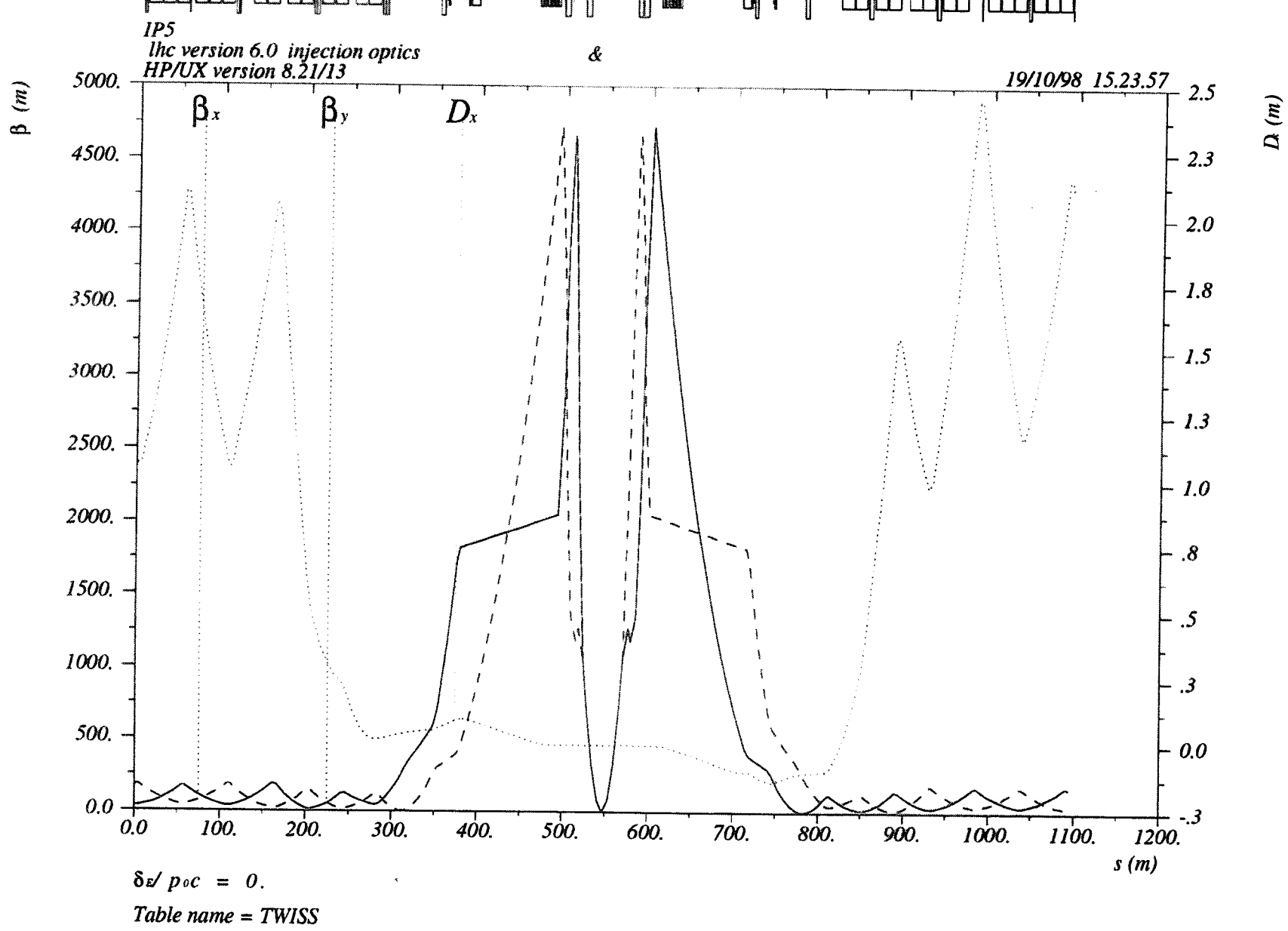


Figure 1: Schematic layout of the left half of the LHC high luminosity insertion. The layout is symmetrical with respect to the IP, and is identical for the ATLAS and CMS experiments.

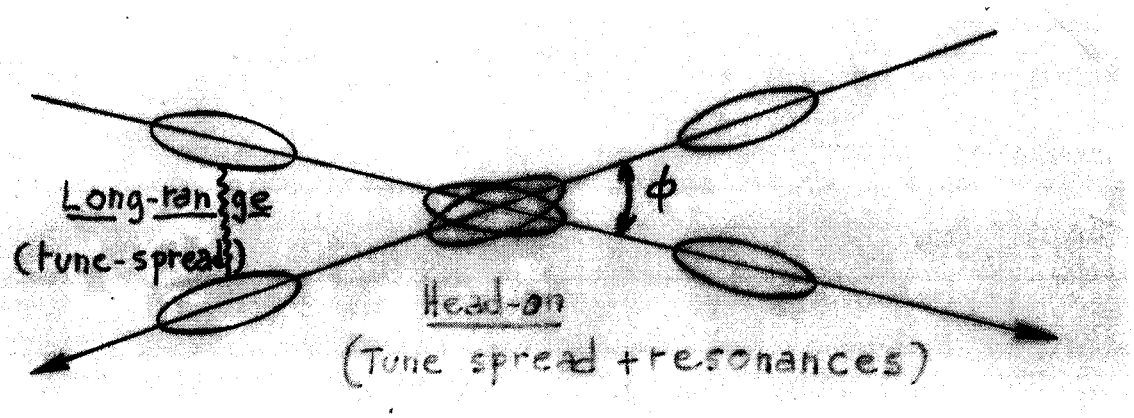


Betatron Functions at IP5 in collision: notice the "enormous" distortion compared to arc functions >> in

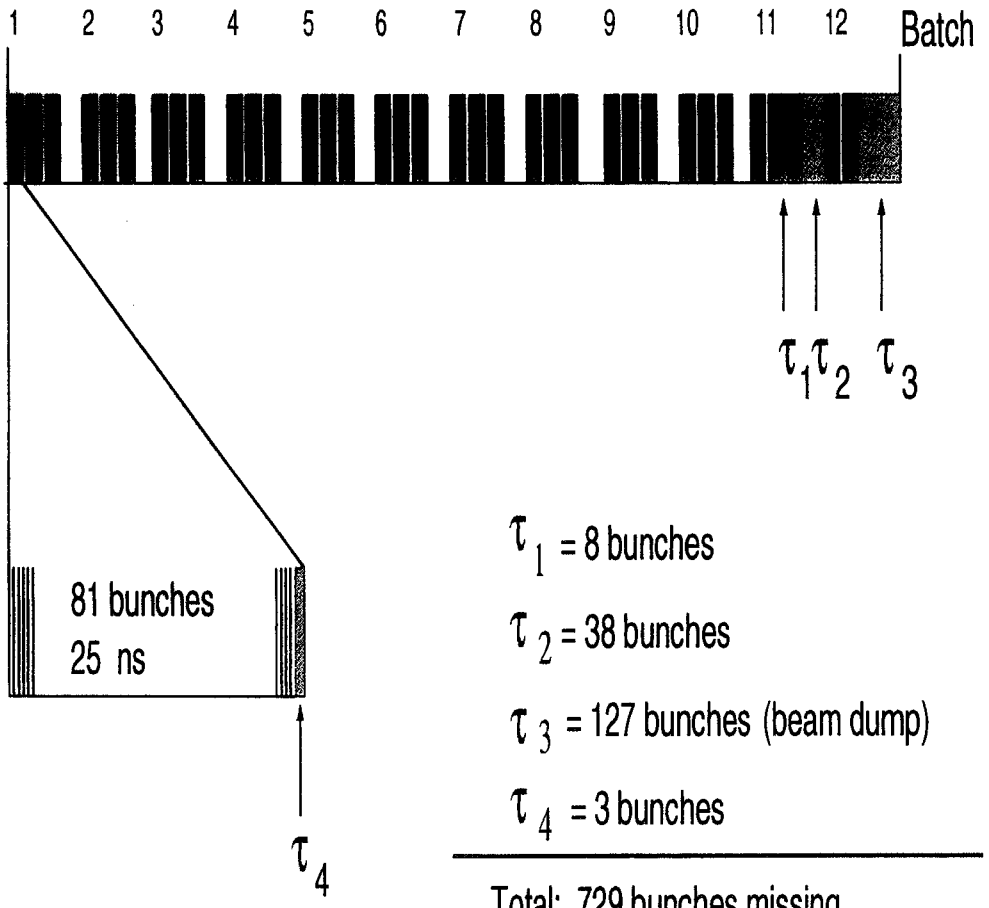
Beam-beam related effects for the LHC

(Relevant for LHC performance)

- Long range and head-on interactions
- Beam-beam induced synchrobetatron resonances
- Coherent beam-beam effects
- Beam-beam induced orbit effects



PACMAN bunches due to gaps



- **"Holes" meet "holes" at the interaction point**

→ **No short range interaction**

- **When a bunch meets a "hole" in the common part**

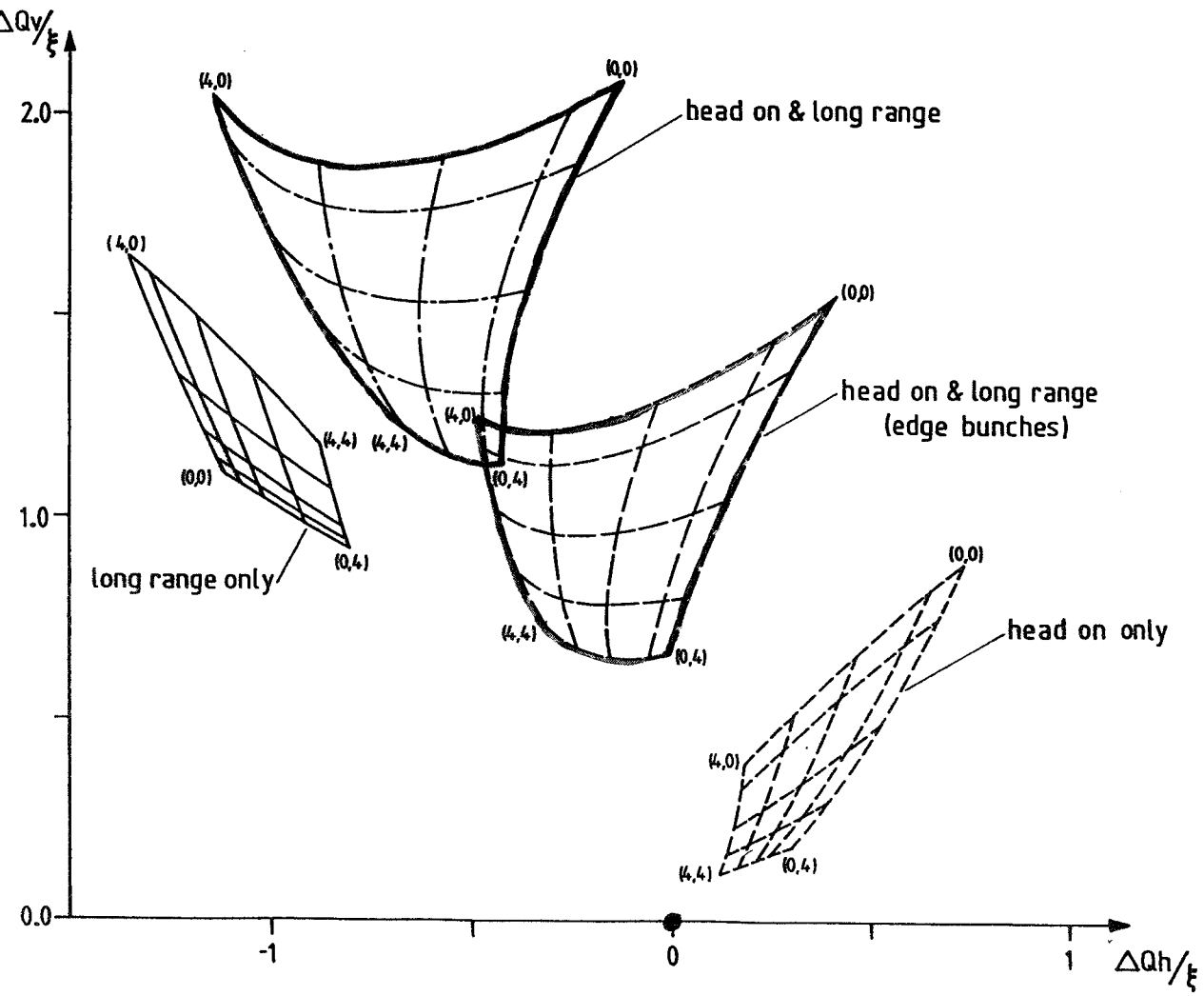
→ **No long range interaction, PACMAN bunches**

⟶ **Those see fewer interactions in total**

⟶ **Different integrated beam-beam effect**

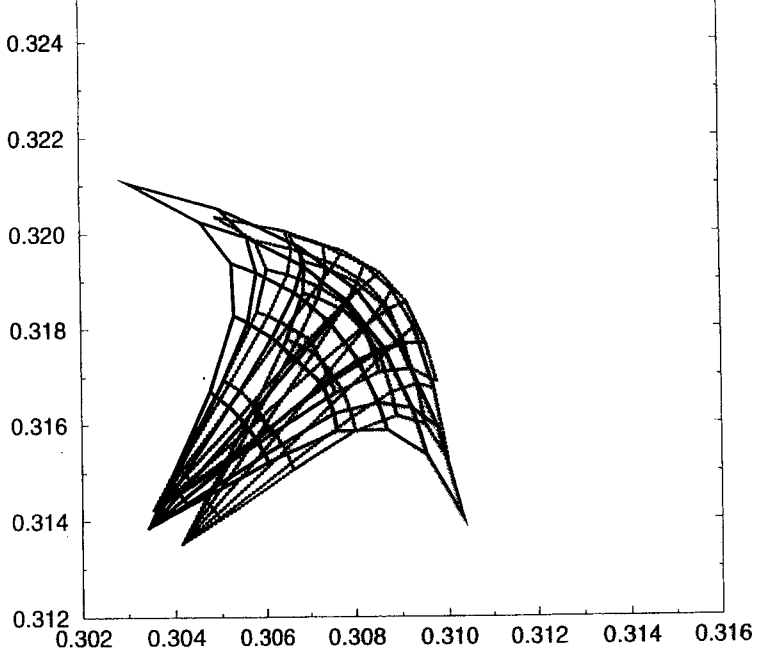
⟶ **Implication for periodicity !!!**

Tune footprint for single interaction regions

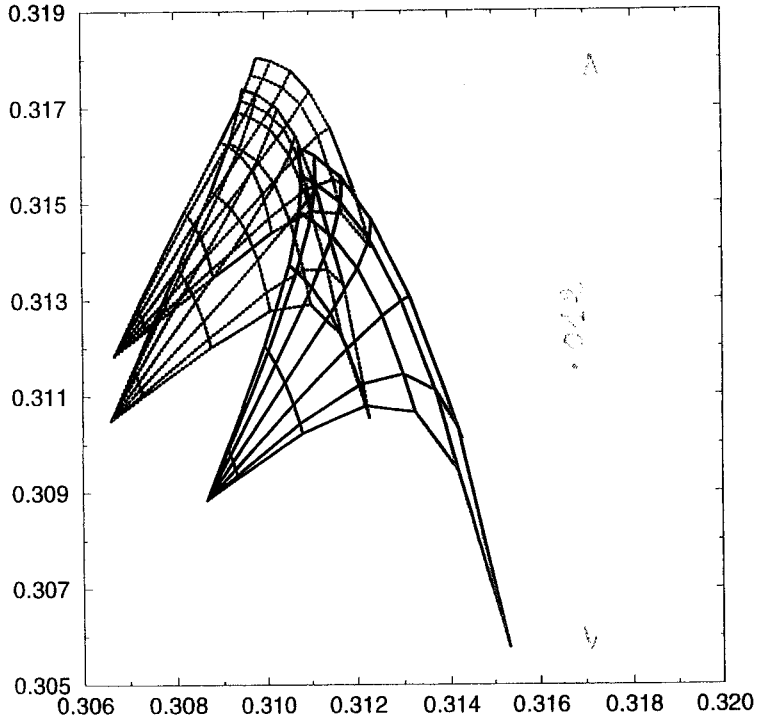


- **Footprint of PACMAN bunches shifted compared to nominal bunches**
  → increased tune spread !

- **Tune shift negative in horizontal plane**
  → NO compensation !



igure 5: Vertical-horizontal: no pacman (solid) versus pacman on left resp. right side of IPs lotted) at $\pm 150 \mu rad$.



'igure 6: Horizontal-horizontal: no pacman (solid) versus pacman on left resp. right side of Ps (dotted) at $\pm 150 \mu rad$.