Beam-beam limits

W. Herr (for MD teams, OP crews)

What are beam-beam limits - HEAD-ON ? (I)

- Lepton colliders:
  - → Increase of equilibrium emittance with intensity at well defined threshold
  - → Well quantified by tune shift ΔQ (but not ξ !)
  - → Luminosity increase slower that N^2
  - → Depends strongly on damping properties
  - → Q very important
- Good chance to get reasonable estimate

What are beam-beam limits - HEAD-ON ? (II)

- **Hadron colliders:**
  - → **No clear criteria, can be (under certain conditions):**
    - **(Slow) emittance increase**
    - **Reduction of dynamic aperture (rarely)**
    - **Particle losses, life time and tails**
    - **Coherent effects**
  - → **But: when does any of these become a problem ?**
- **Tune shift ΔQ only (small) part of the story**
- **Rather an "operational limit", sensitive to distortions (noise, ripple, small excitations, ...)**
- **Can hope to estimate (and minimize) the various effects**

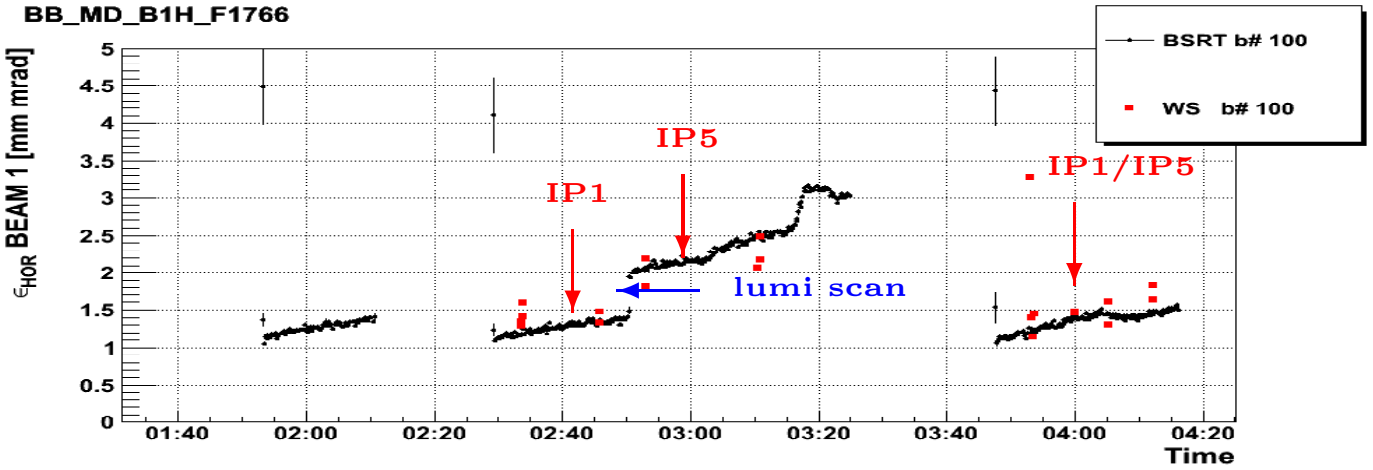
What are beam-beam limits - LONG RANGE ?

- **Effects (problems !) much better defined, will be:**
  - **Reduction of dynamic aperture (mostly)**
  - **Particle losses and tails**
  - **PACMAN effects (orbit, tune and chromaticity)**
  - **Coherent effects**
  - **..**
- **Evaluation (and minimization) more successful**

First head-on MD

- **Main purpose: explore whether there is a "tune shift limit"**
- **Performed at 450 GeV**
  - **Bunch intensities initially around 1.8 10^{11} p/b, $\epsilon_n \approx 1.2\ \mu$m**
  - **Reached $\Delta Q \geq 0.017$ per IP, $\Delta Q \geq 0.035$ for 2 IPs**
  - **Reasonable life time, large tune shift mainly due to small emittances**

Emittance evolution



→ **all fills with single bunches, beam 1, horizontal**

Emittances - with and without collisions

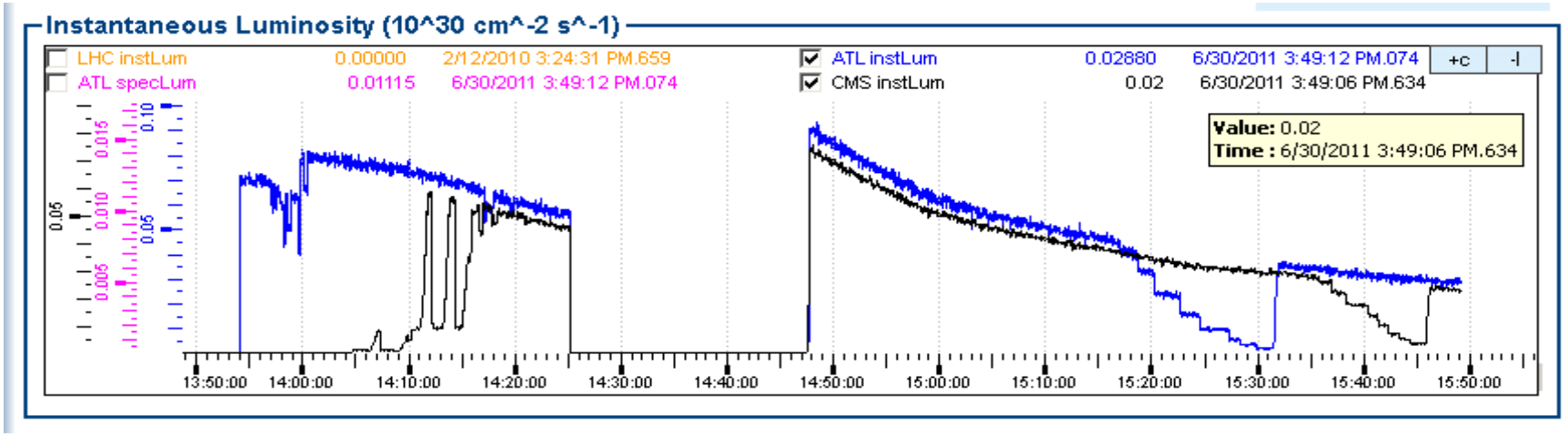
collisions	B1b1 ϵ_x	B1b1 ϵ_y	B2b1 ϵ_x	B2b1 ϵ_y
no coll	1.15 μm	1.2 μm	1.45 μm	1.6 μm
IP: 1	1.3 μm	1.2 μm	1.5 μm	1.5 μm
IP: 1, 5	1.25 μm	1.3 μm	1.6 μm	1.6 μm

- **Bunch intensity: 1.85 10^{11}**
- **Beam-beam parameters: 0.015/0.017 per IP**

Second head-on MD

- **Main purpose: explore what intensities we can collide, plus more detailed measurements (orbit, tune,...)**
  - **Bunch intensities initially above 2.2 10^{11} p/b, $\epsilon_n \approx 1.7\ \mu$m**
  - **Reached $\Delta Q \approx 0.015$ per IP, $\Delta Q \approx 0.030$ for 2 IPs**
  - **No visible emittance blowup**
  - **Life time worse, order of 1 - 2 hrs, (but larger initial emittances than 1st MD ?)**
- **Proposal: redo with more collisions (2 on 2) and at 3.5 TeV !**

ATLAS luminosity*)



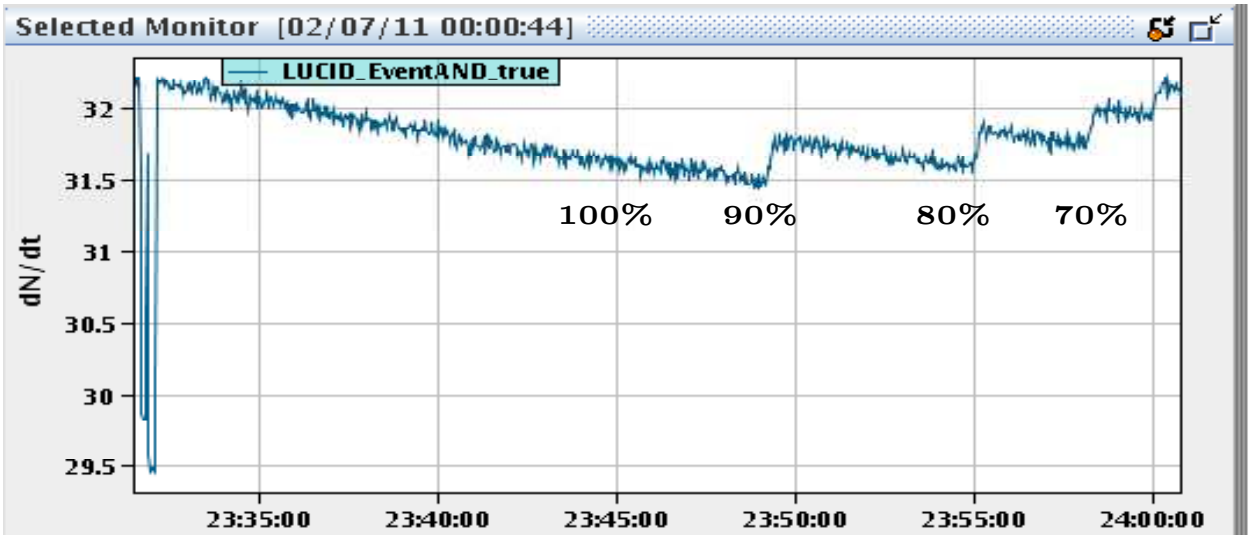
→ **Luminosity in ATLAS during 2nd head-on MD**

*) **Courtesy Witold Kosanecki**

Long range MD

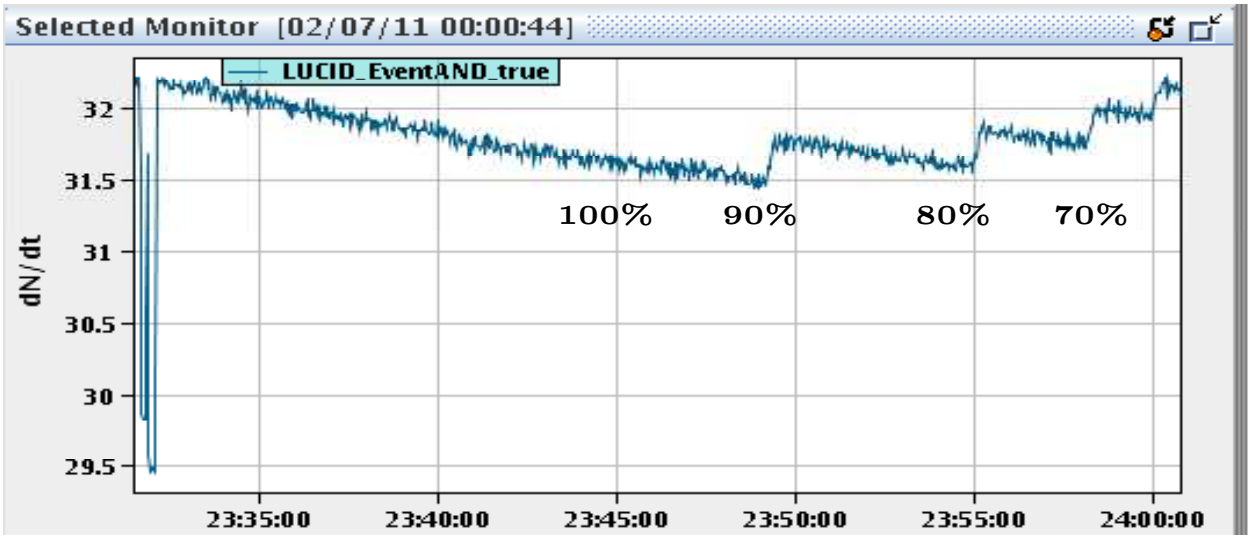
- **Beam conditions:**
  - **Bunch intensities and emittances standard operational conditions**
  - **One batch (36 bunches) per beam (no time for second fill)**
  - **Squeezed to 1.5 m at 3.5 TeV**
  - **Reduced crossing angle (from $\pm$ 120 μrad) in steps (first IP1, then IP5)**
  - **Adjust collimator settings at every step**

Scan of crossing angle



- Luminosity as function of crossing angle IP1
- Reduction factor exactly as calculated !

Scan of crossing angle



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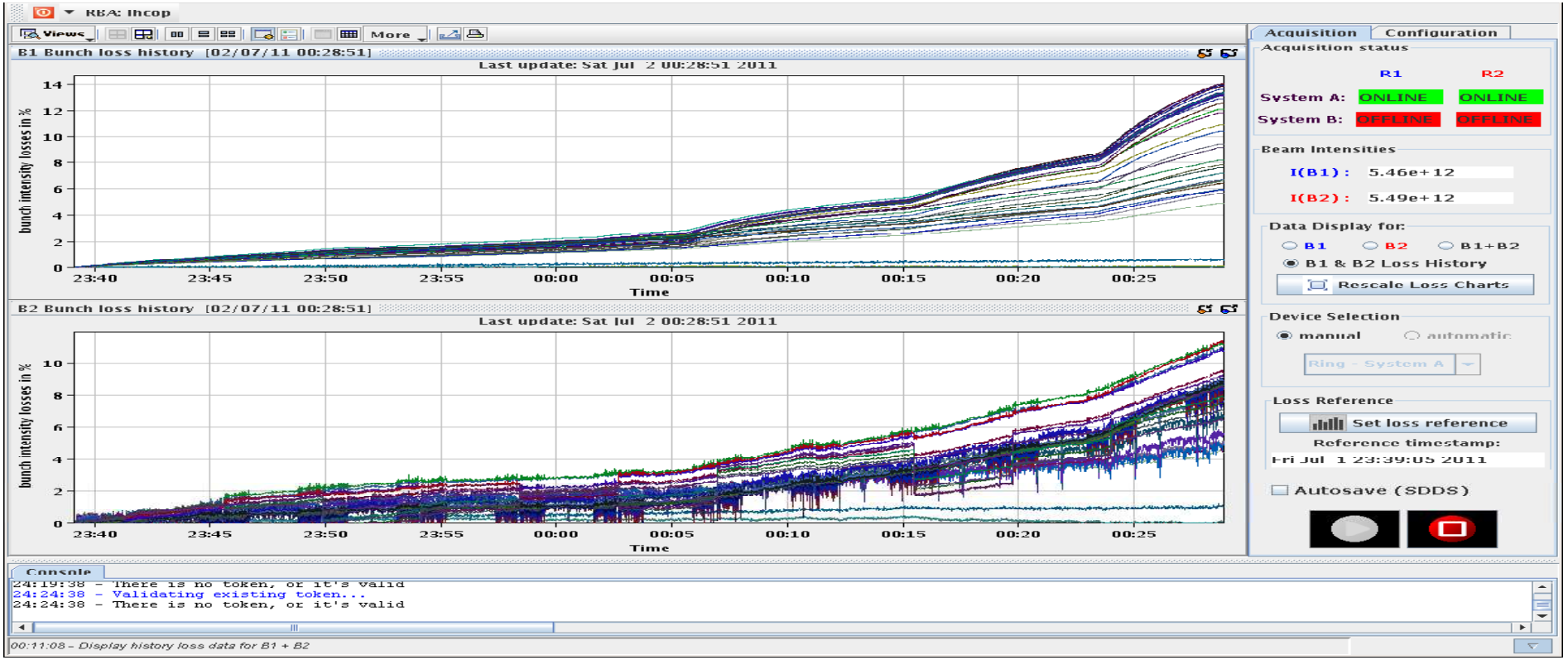
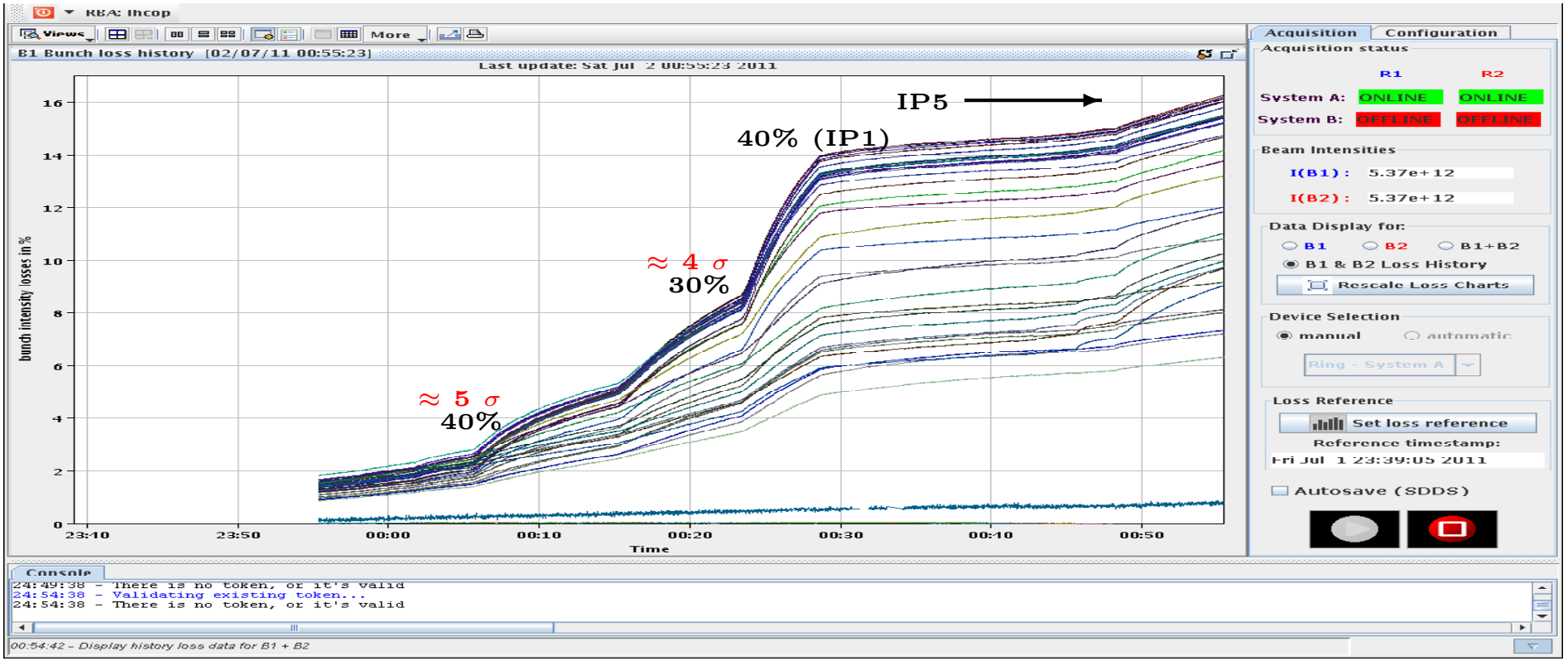
”Levelling” with crossing angle

Scan of crossing angle



→ **Loss as function of crossing angle (IP1 and IP5)**

Scan of crossing angle

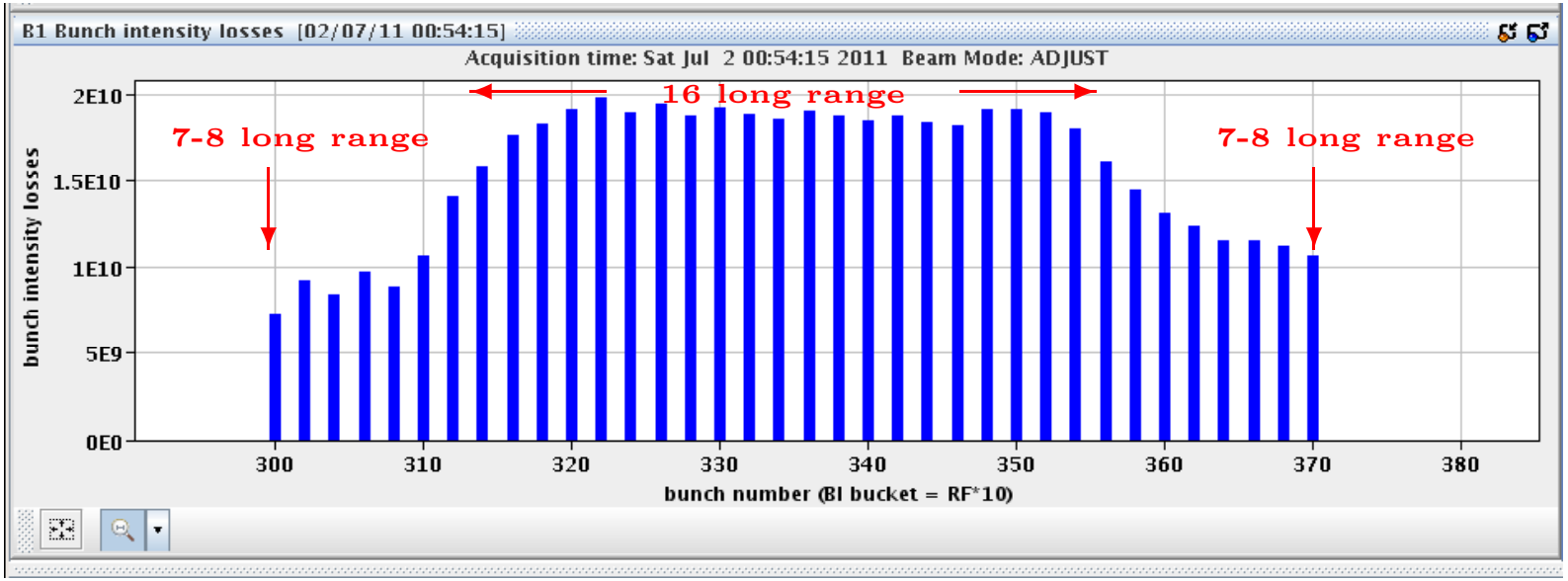


➡ **Loss as function of crossing angle (IP1 and IP5)**

Scan of crossing angle

- **Observations:**
  - **Losses start after some threshold**
  - **Different bunches have different threshold !**
  - **Strong evidence for PACMAN effects**

PACMAN effects



→ **Losses of the bunches in a batch**

Long range observations

- **Very clear observations:**
  - **Threshold effect around 4 - 5 σ**
  - **Threshold depends on number of long range encounters !!**
  - **Very strong effect on number of long range encounters !!**

→ **Bunches with half the long range:**
$\approx$ 1 σ more "dynamic aperture"

Long range observations

- **Very clear observations:**
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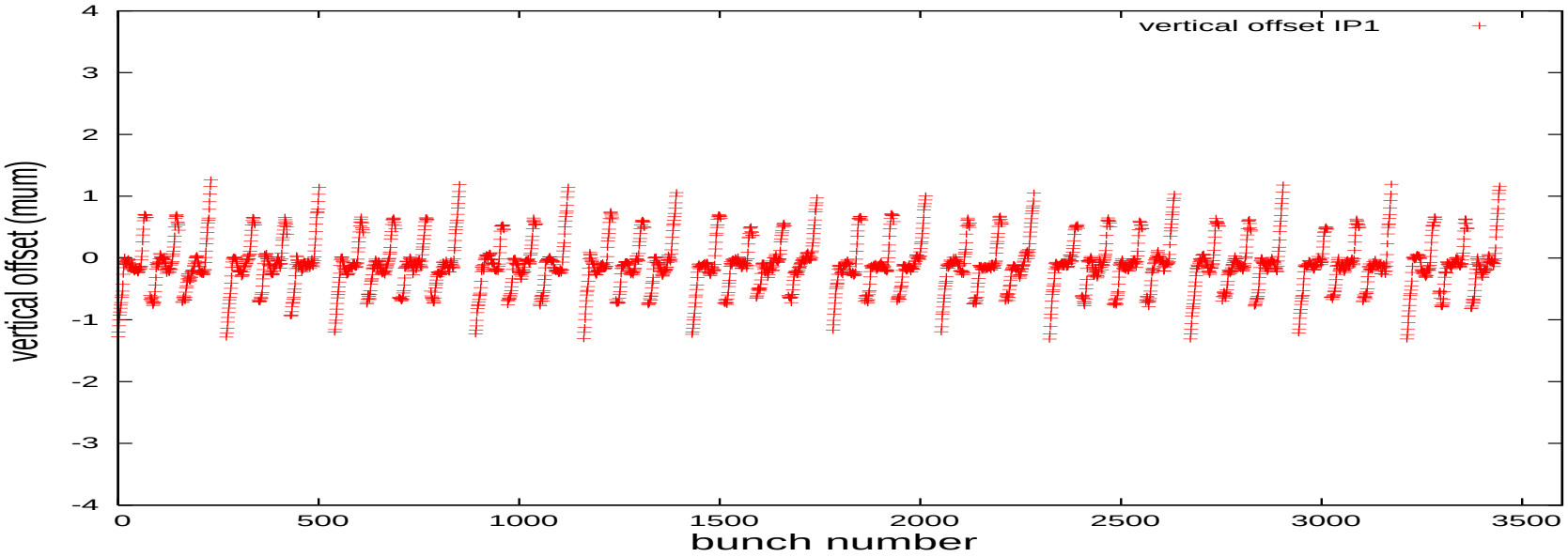
→ **Bunches with half the long range:**
$\approx$ 1 σ more "dynamic aperture"

→ **Do we expect other PACMAN effects ?**

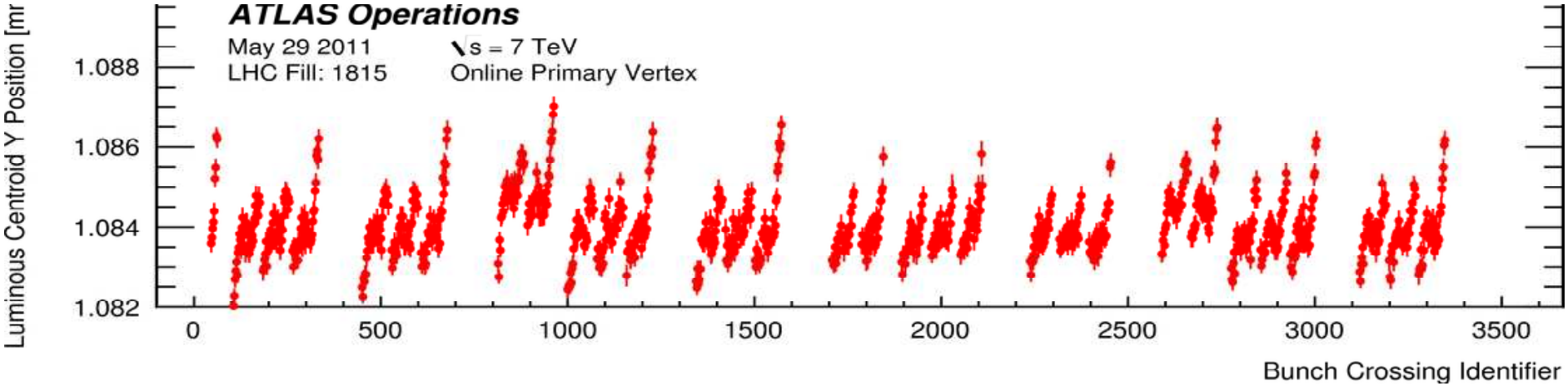
PACMAN Orbit effects



- **Expectations from self-consistent computation (TRAIN)**
- **Not identical (but comparable) configuration**

PACMAN Orbit effects

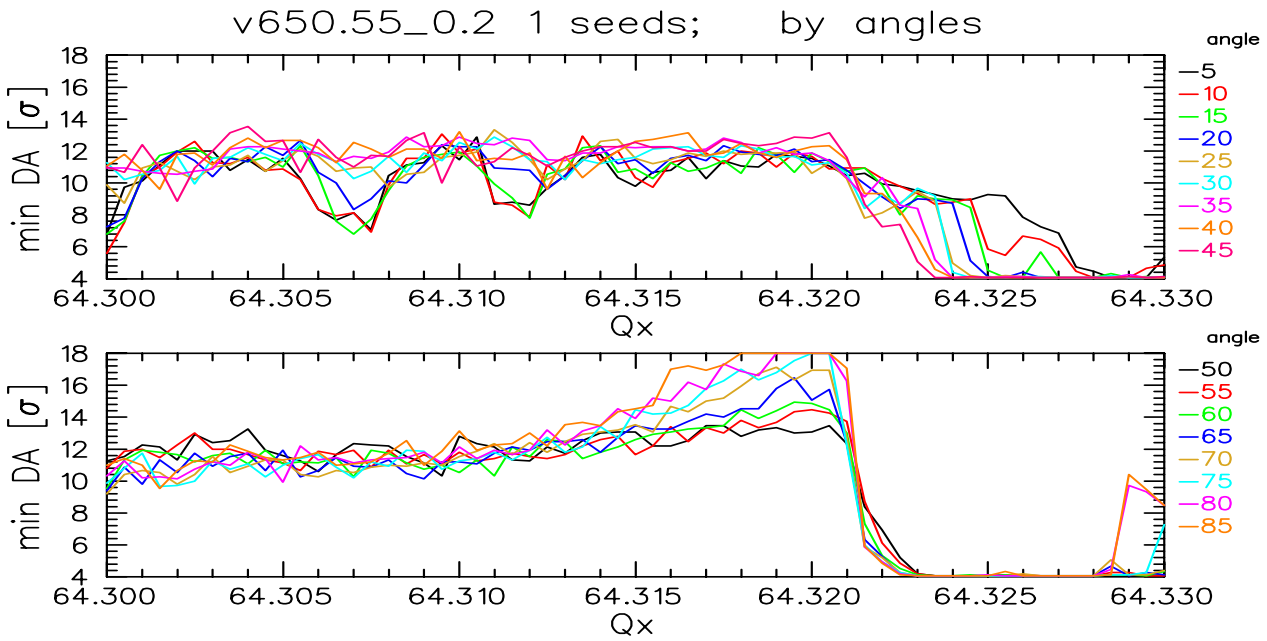
2011-07-05 file:///afs/cern.ch/user/z/zwe/Desktop/PNG/bcid_vs_posY_pm_posYErr.png #1



- **Bunch centroid as measured by ATLAS**
- **Behaviour follow exactly the expectations ... !**

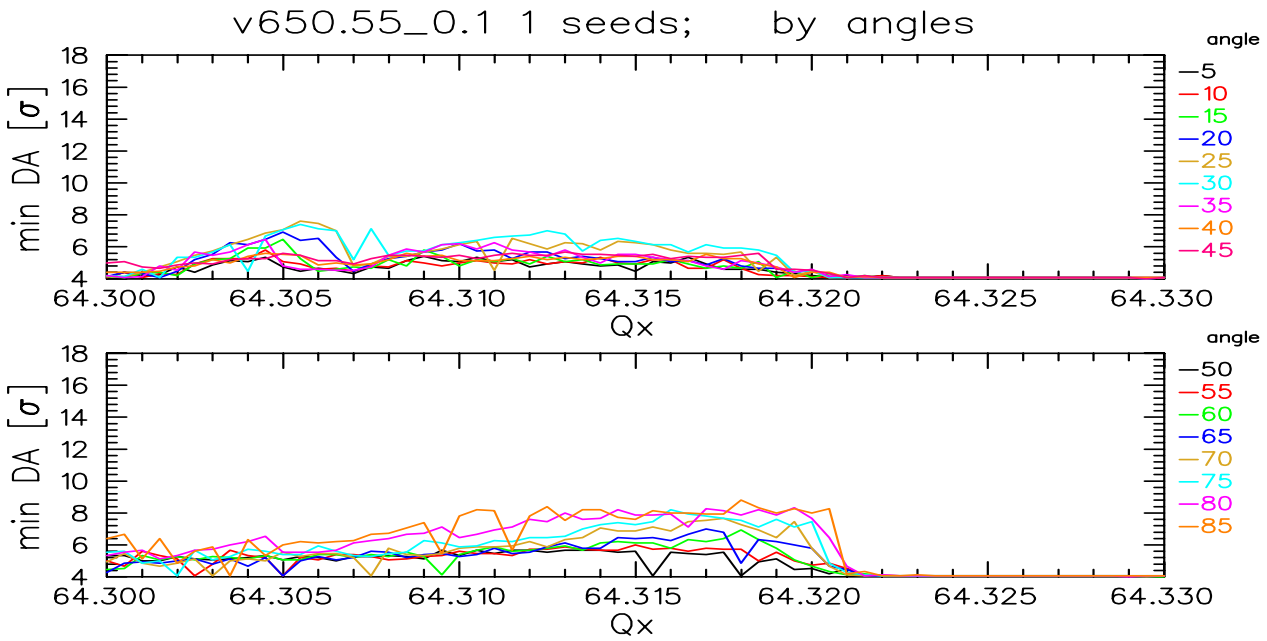
*) **Courtesy Witold Kosanecki, Josh Cogan**

Expected dynamic aperture



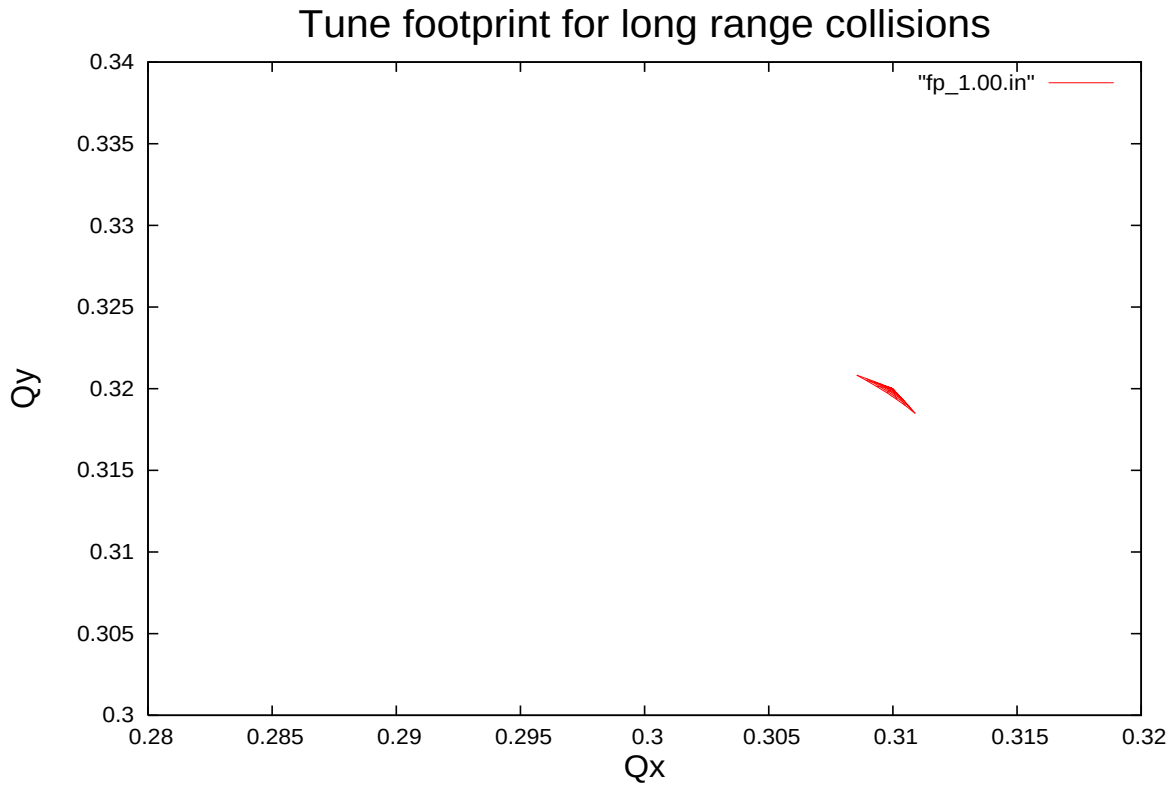
- **Tune scan, Project Note 416 (W. Herr, D. Kaltchev)**
- **For 7 TeV, 25ns, but separation about 12 σ**

Expected dynamic aperture



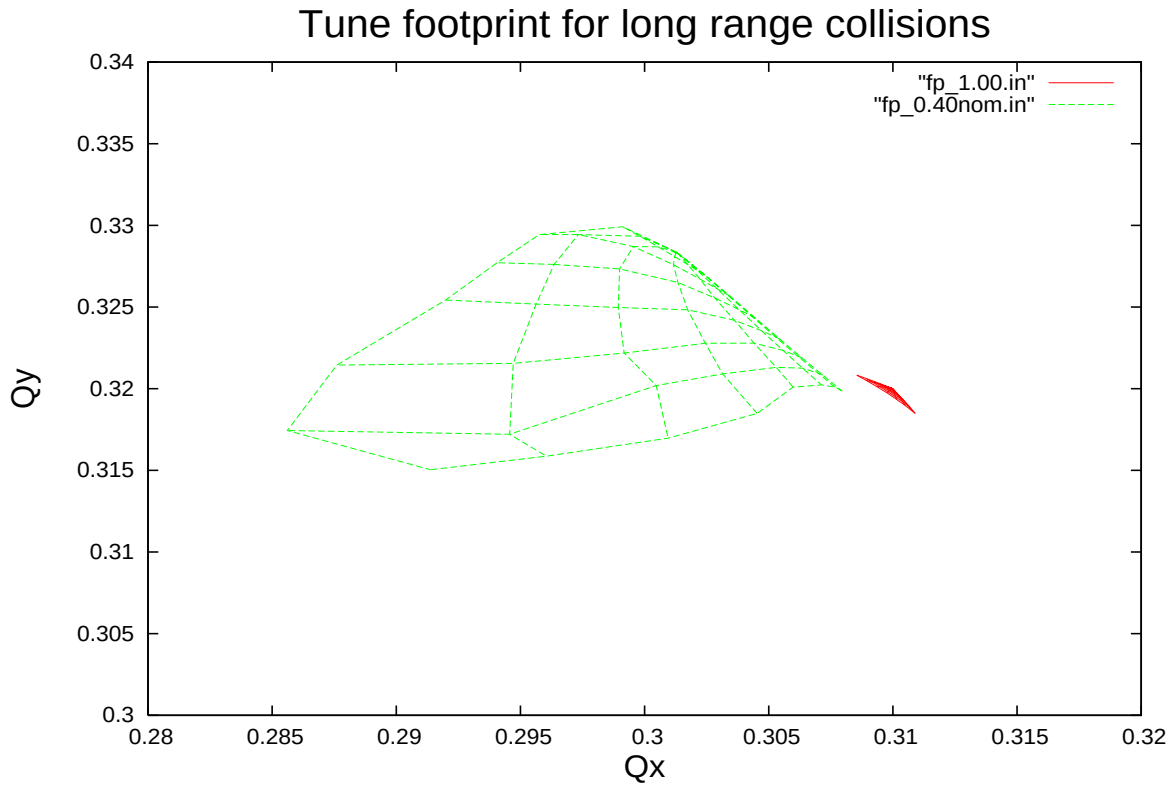
- Tune scan, Project Note 416 (W. Herr, D. Kaltchev)
- For 7 TeV, 25ns, but separation about 6 σ

Footprints during scans



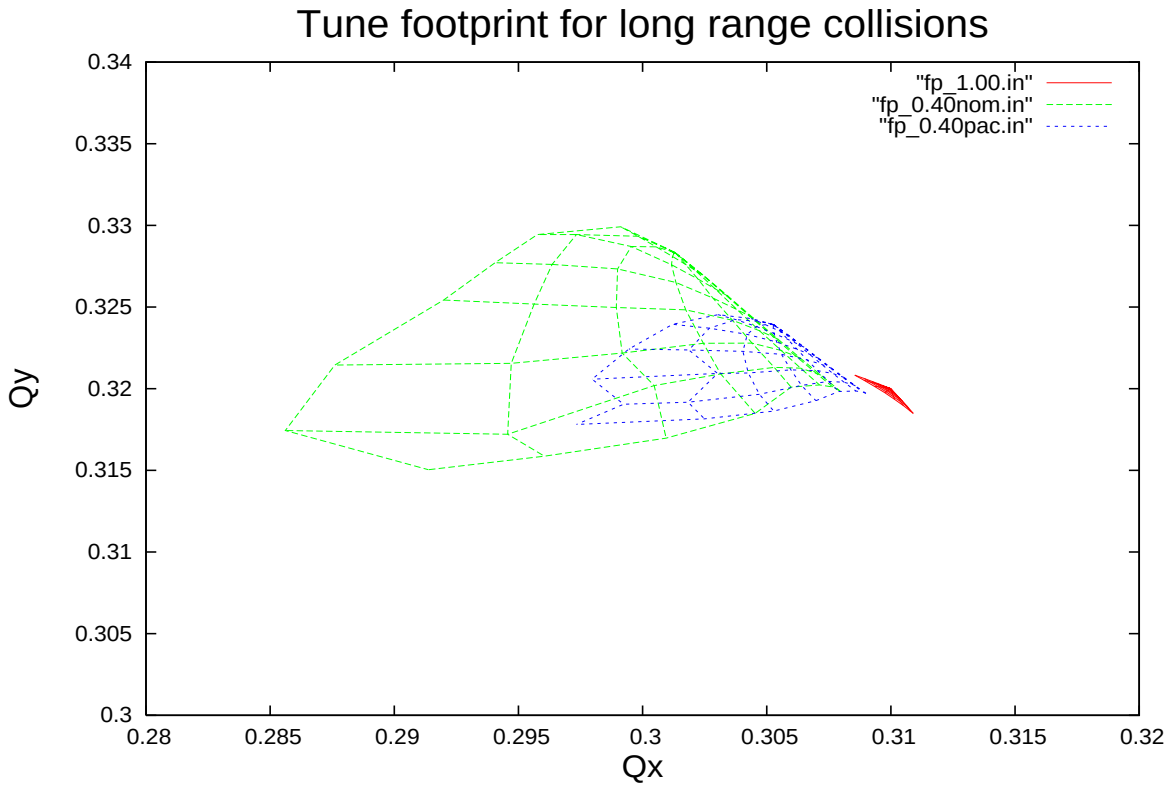
→ **Beams at 12 σ**

Footprints during scans



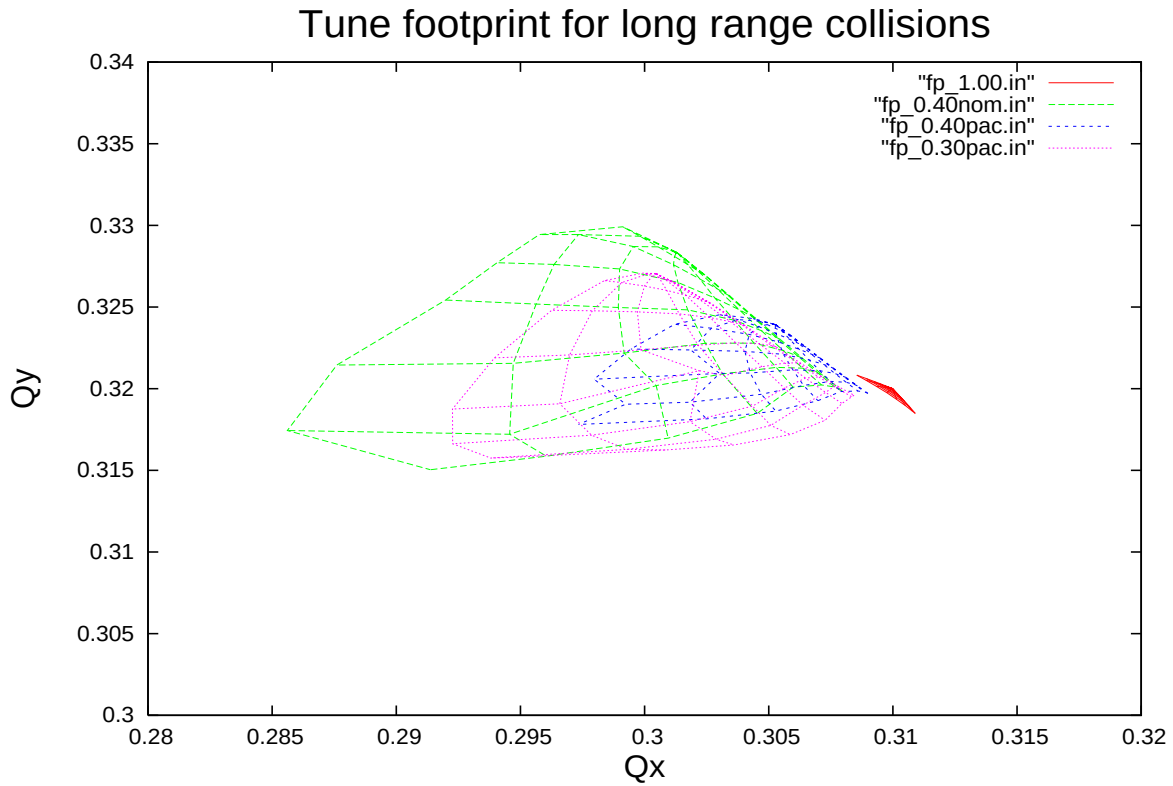
→ **Beams at 5 σ (40%)**

Footprints during scans



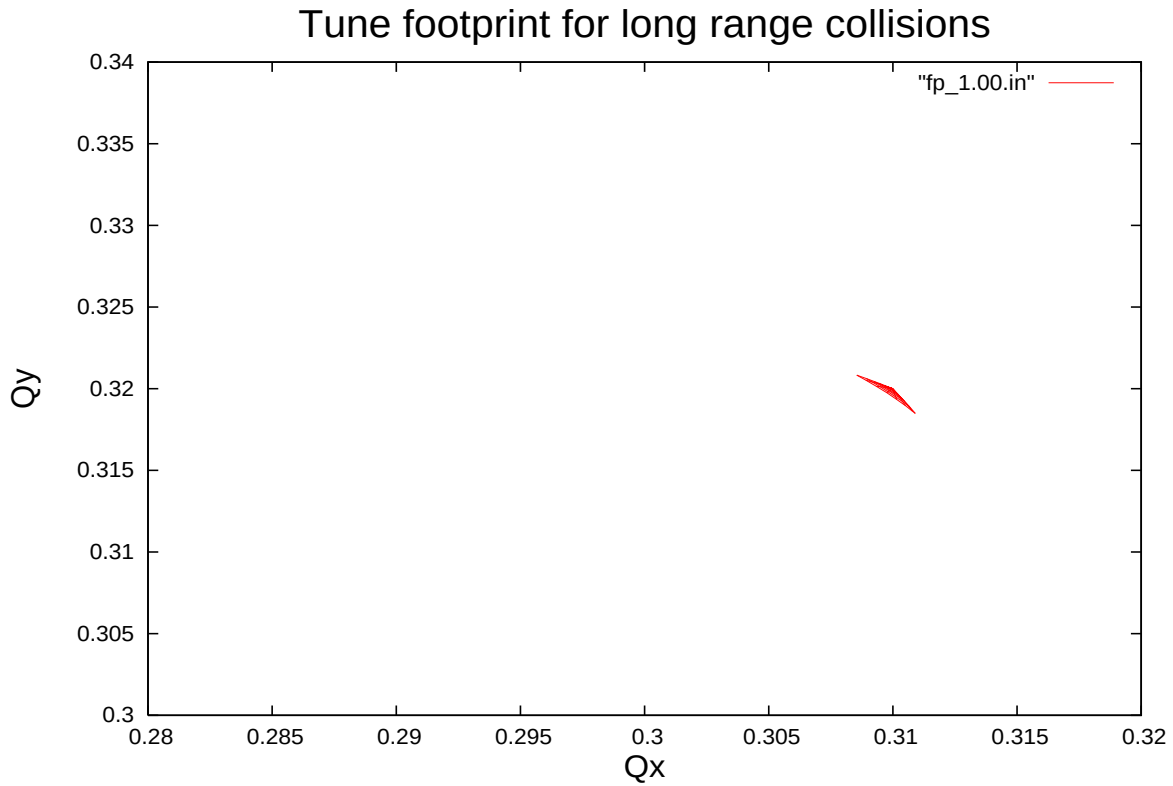
→ **Beams at 5 σ (40%), PACMAN bunches !**

Footprints during scans



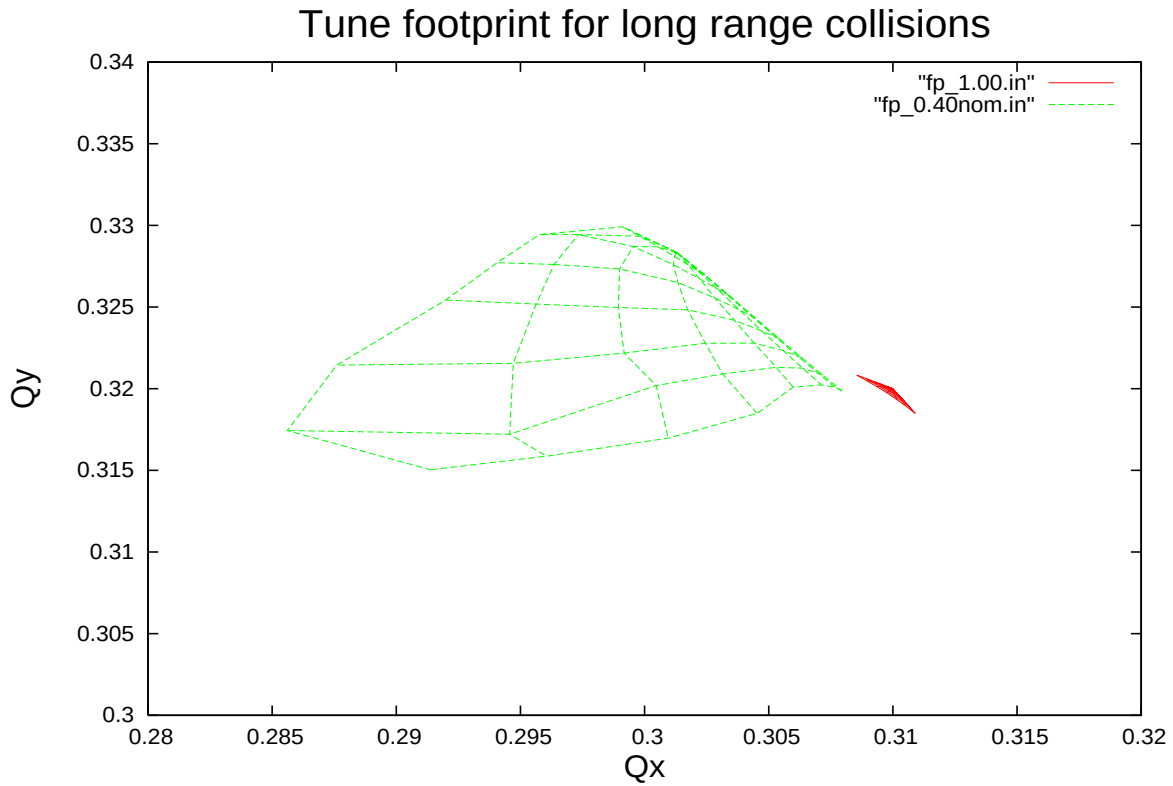
→ **Beams at $\leq 4\ \sigma$ (30%), PACMAN bunches !**

Footprints during scans



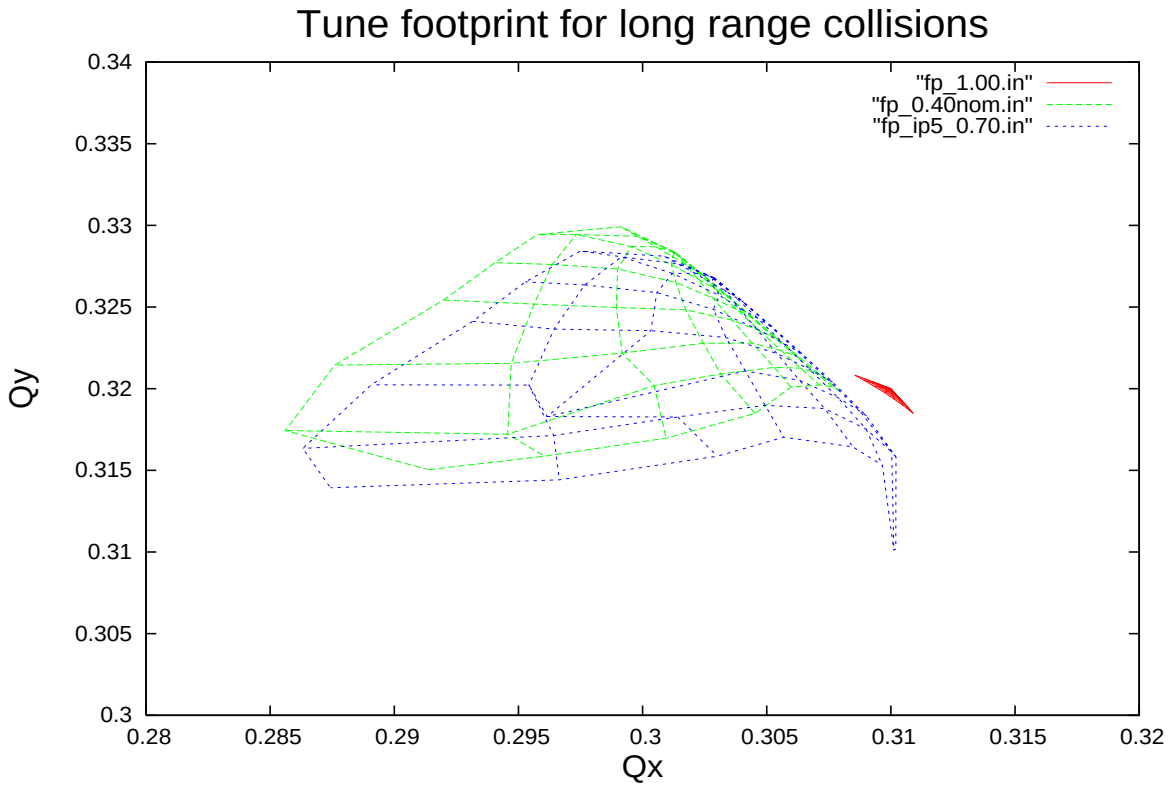
→ **IP1 at 100%**

Footprints during scans



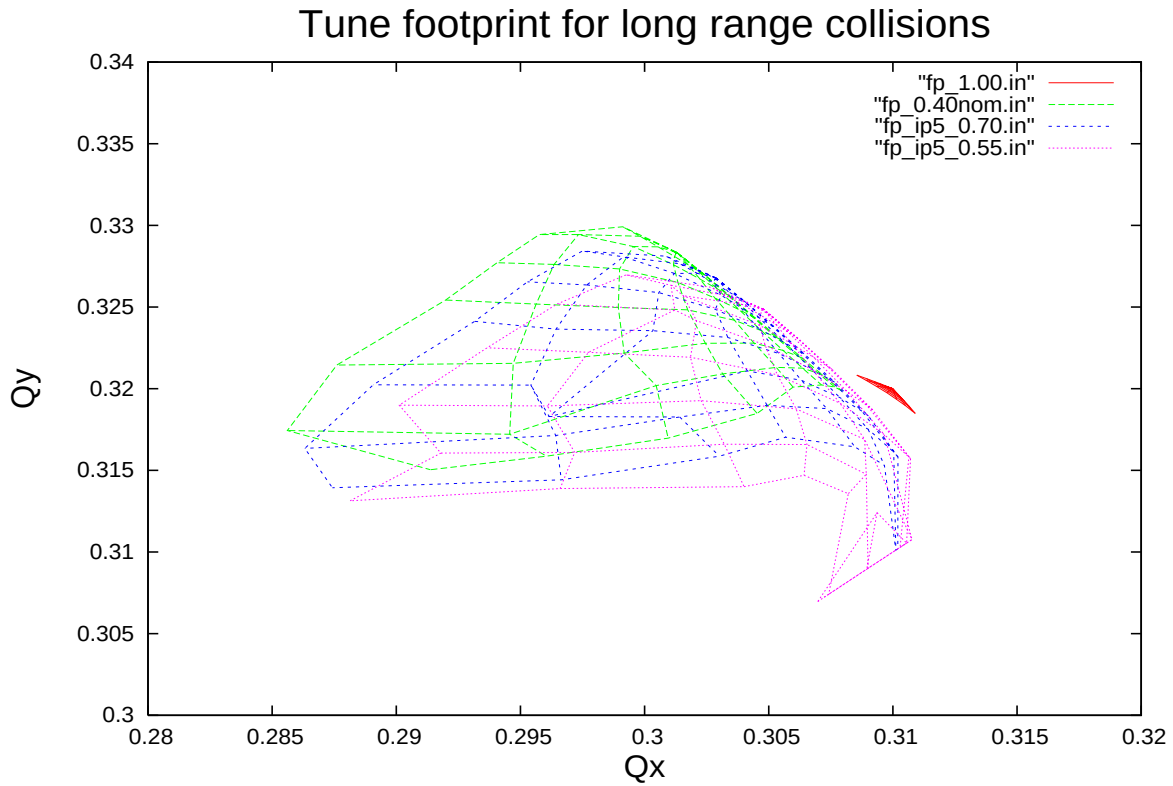
→ **IP1 at 40%, IP5 at 100%**

Footprints during scans



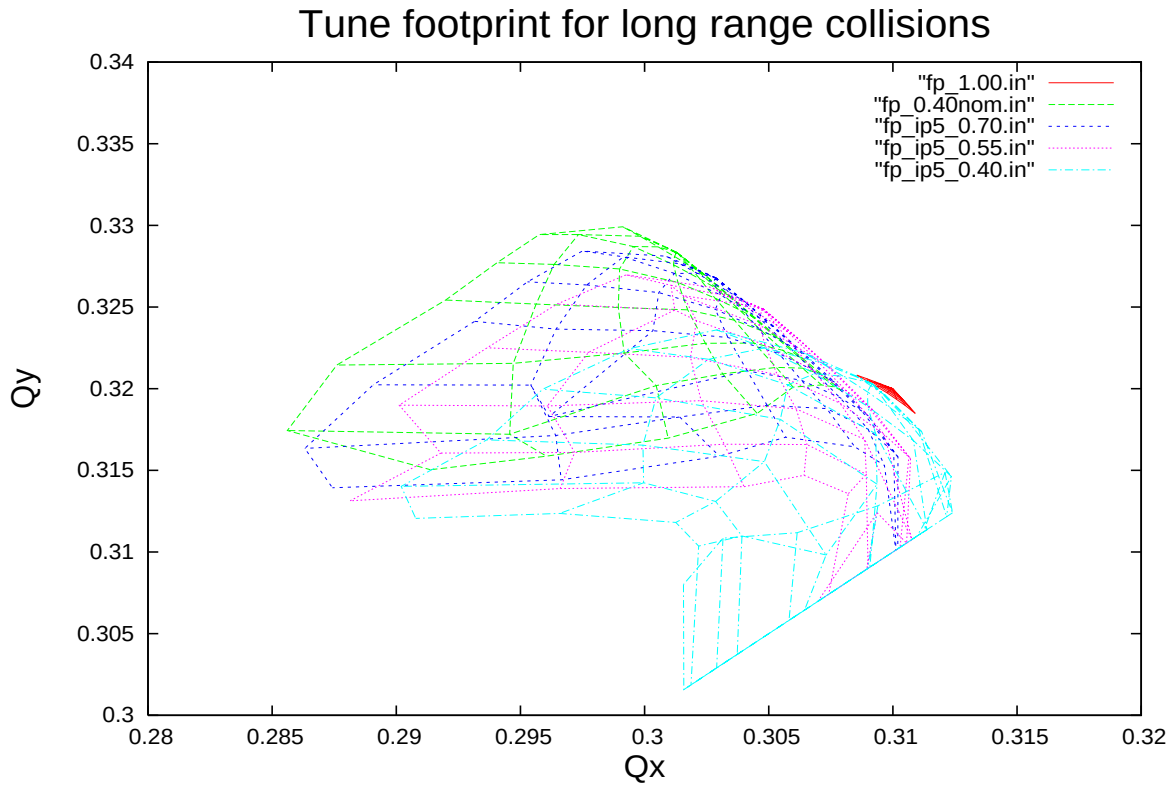
→ **IP1 at 40%, IP5 at 70%**

Footprints during scans



→ **IP1 at 40%, IP5 at 55%**

Footprints during scans



→ **IP1 at 40%, IP5 at 40%**

Long range observations

- Remember: we had collisions only in IP1 and IP5 (no IP2/8)
- Double the number for 25 ns → lower threshold (i.e. at larger separation)
  - → For larger number of long range encounters: larger separation
- For reasonable condition: should aim for 8σ minimum separation

What do we learn for: head-on beam-beam

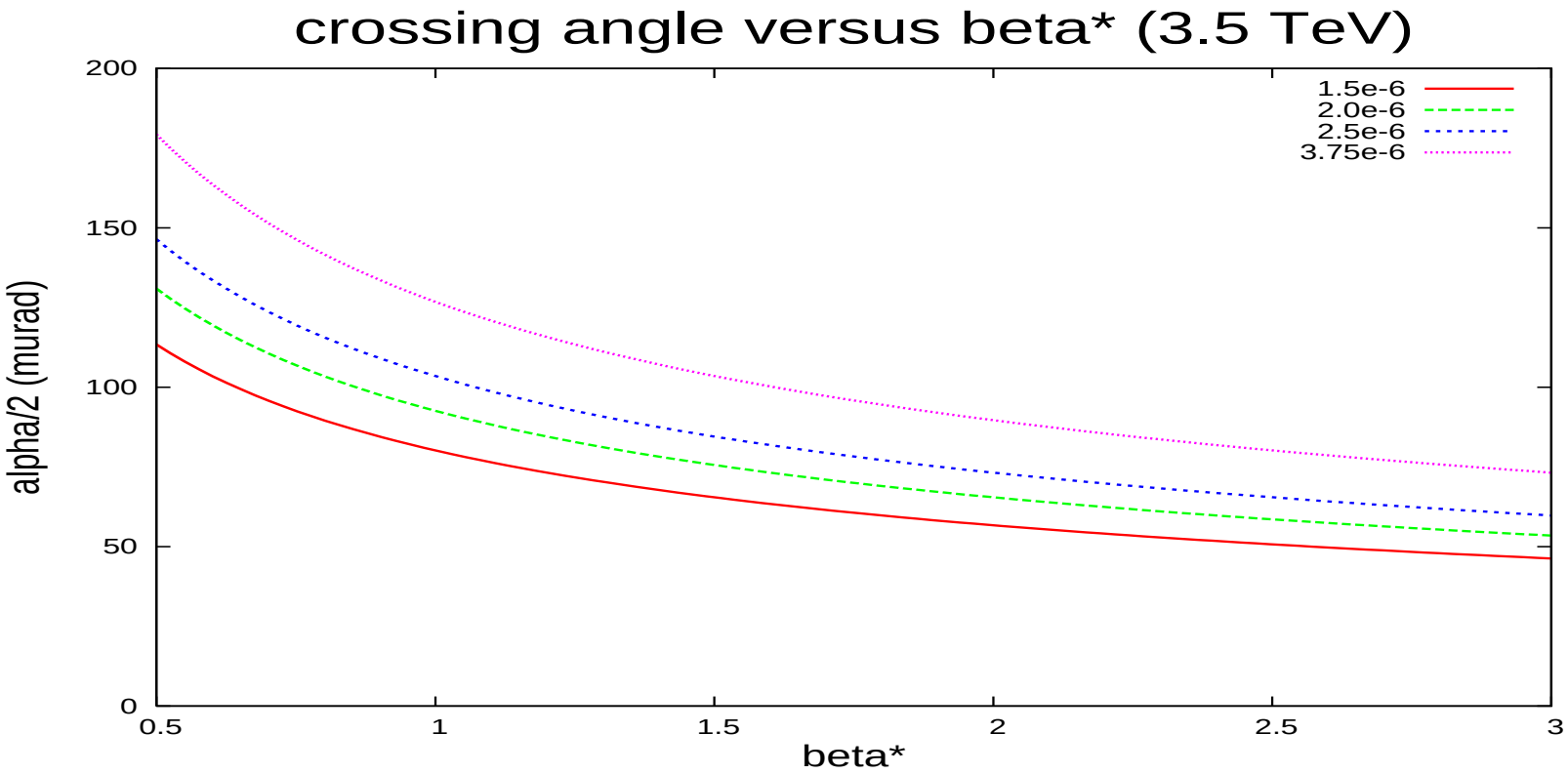
- **Main conclusions**
  - **Can achieve tune shifts (total and per IP) well above the nominal**
  - **New aim should be: $\Delta Q \geq$ 0.01 per IP**
  - **Can collide higher bunch intensities**
  - **Small emittances preferred**

⚠ **Head-on beam-beam different in presence of long range !**

What do we learn for: long range beam-beam

- **Lessons:**
  - **Dynamic aperture reduced as expected**
  - **All PACMAN effects observed (tune, orbit, losses, ...)**
  - **Sufficient separation important, some margin for 50 ns**
  - **Number of bunches (i.e. parasitic encounters) very important**
- **Keep the separation large enough, in particular for many bunches and higher intensities**
- **Keep the emittances small**

Required crossing angle - 8 sigma



- **Required (half) crossing angle for 8 σ separation**
- **Different emittances assumed**

How far can we push it ?

- **Aim at:**
  - **Separation not smaller than 8 σ**

    possible for β^* around 1 m (1.5 m)
  - **Small emittances preferred (smaller than $\epsilon_n \leq$ 2.5 μm)**
  - **Bunch intensities around or above 2.0 10^{11}**

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- **Aim at:**
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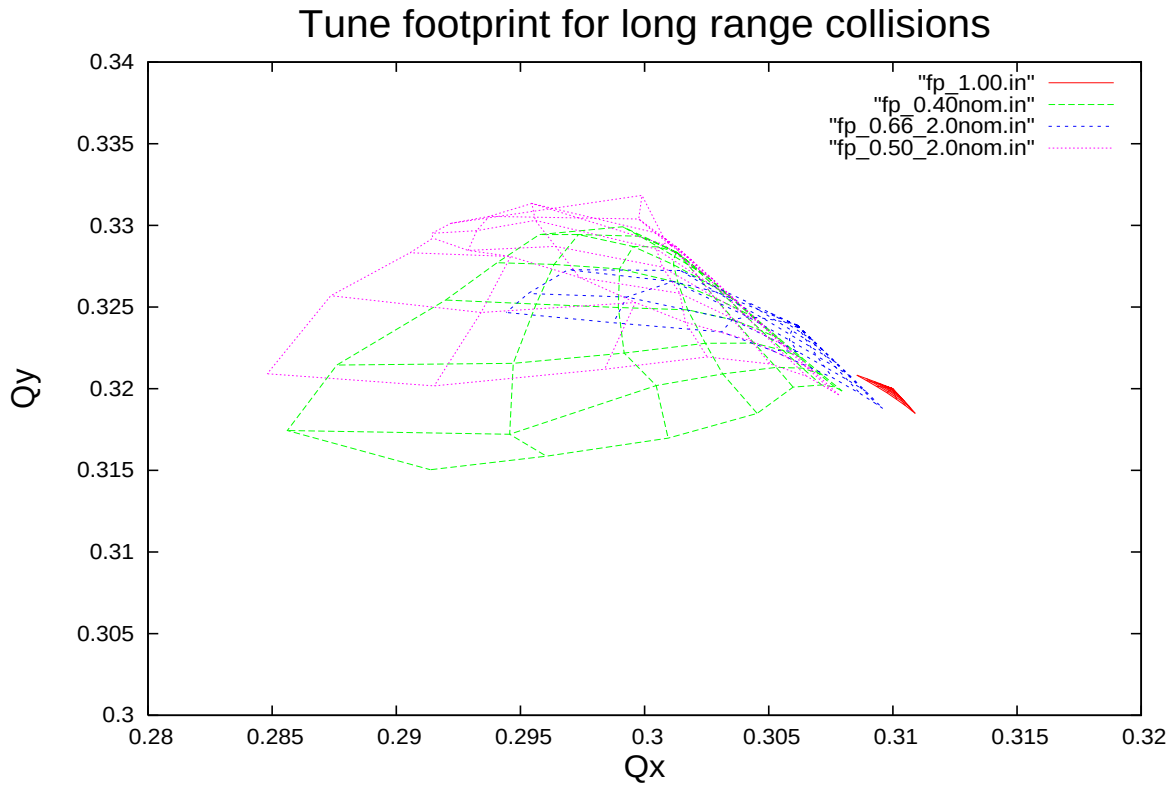
    possible for β^* around 1 m (1.5 m)
  - **Small emittances preferred (smaller than $\epsilon_n \leq$ 2.5 μm)**
  - **Bunch intensities around or above 2.0 10^{11}**
- **For 50 ns:** $\mathcal{L} \approx 6-7\ (4-5) 10^{33} \mathrm{cm}^{-2}\mathrm{s}^{-1}$

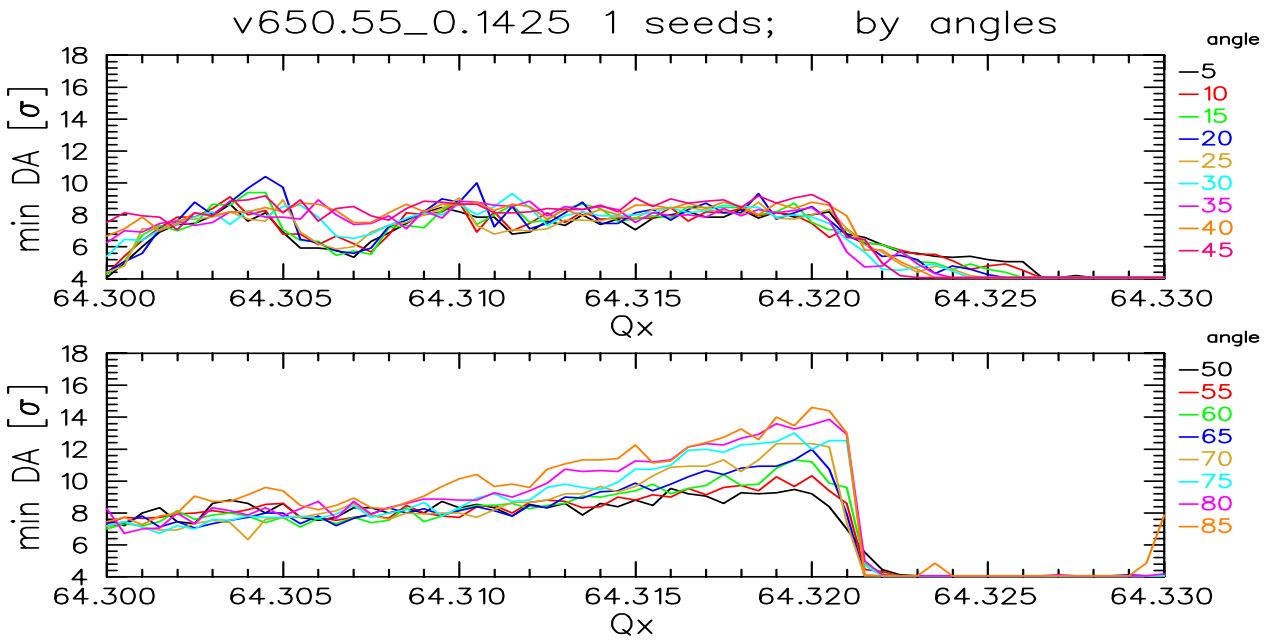
- BACKUP SLIDES -

Footprints during scans



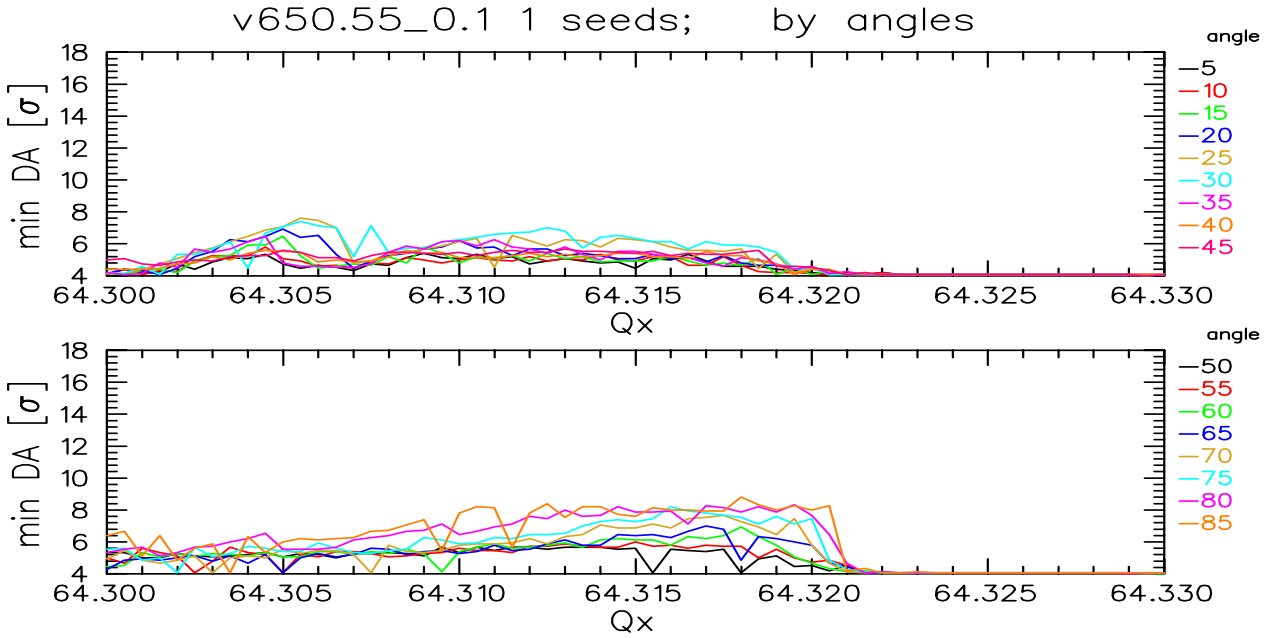
→ **Beams at $\leq$ 6 σ (50%) IP1, N = 2.0 10^{11}**

What about 7 TeV, 25 ns ?



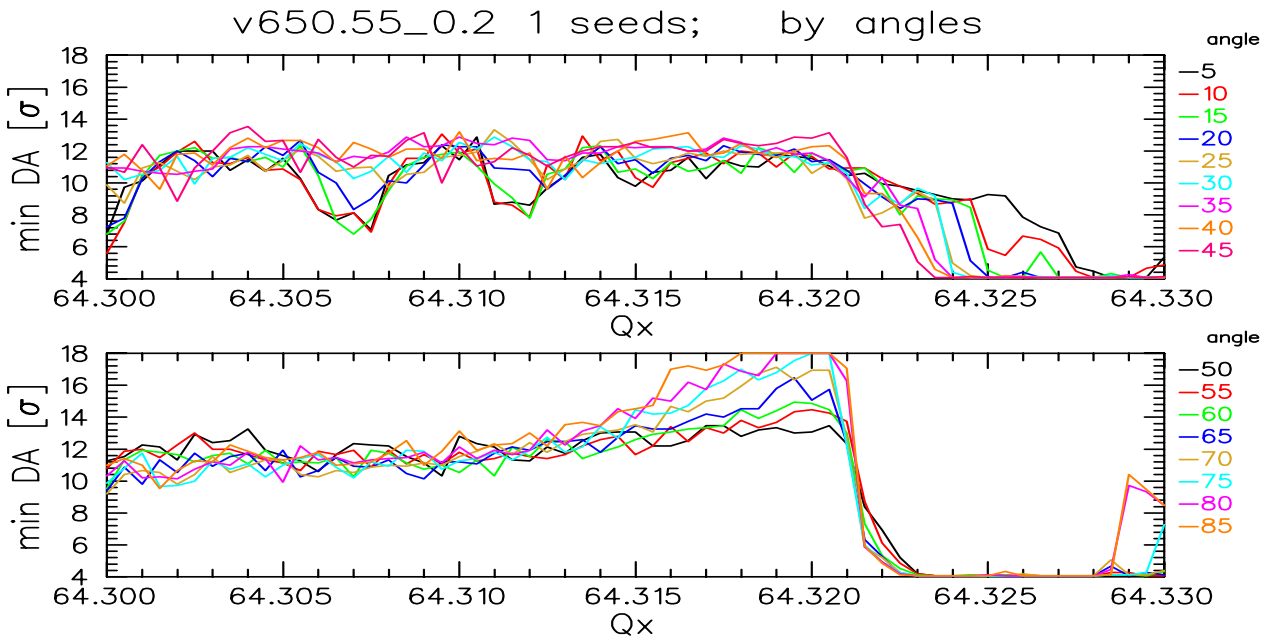
- **Tune scan, Project Note 416 (W. Herr, D. Kaltchev)**
- **$\beta^* = 0.55$ m, angle $= \pm 142.5$ μrad**

What about 7 TeV, 25 ns ?



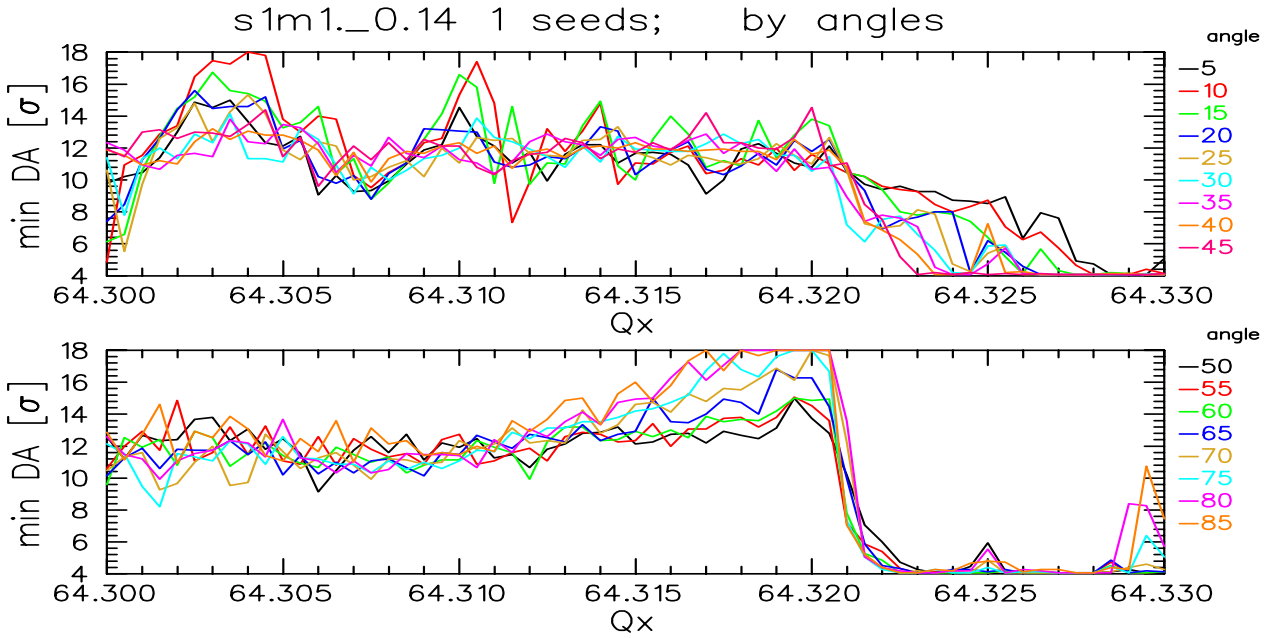
- **Tune scan, Project Note 416 (W. Herr, D. Kaltchev)**
- **$\beta^* = 0.55$ m, angle $= \pm 100$ μrad**

What about 7 TeV, 25 ns ?



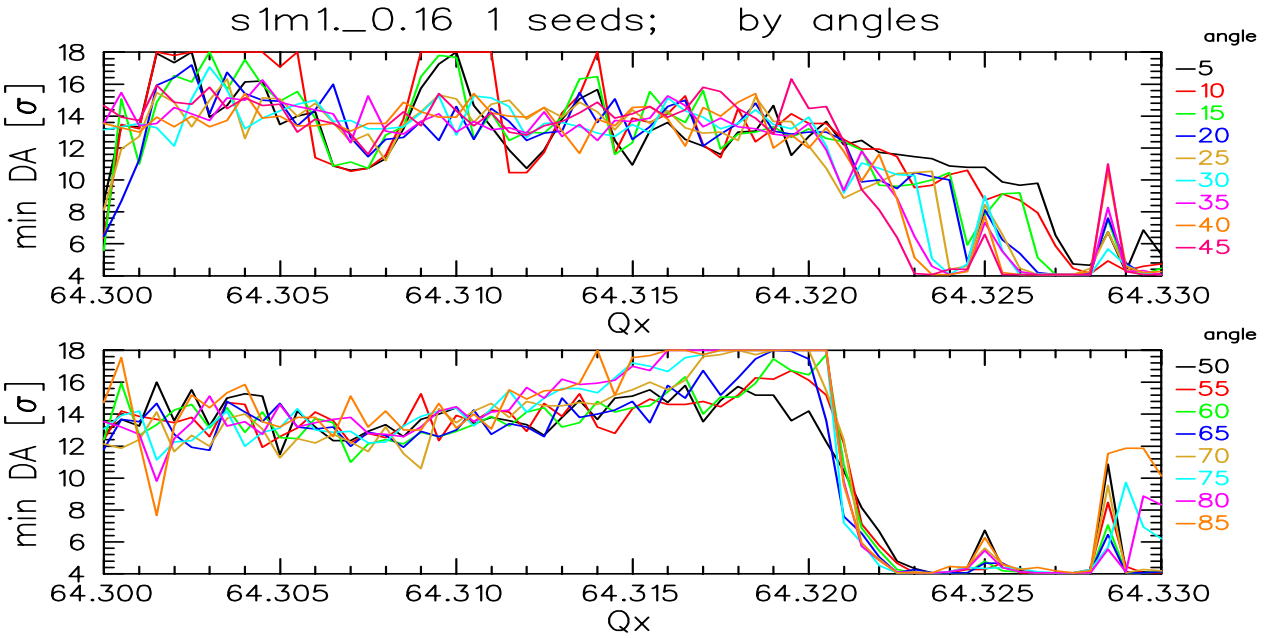
- **Tune scan, Project Note 416 (W. Herr, D. Kaltchev)**
- **$\beta^* = 0.55$ m, angle $= \pm 200.0$ μrad**

What about 7 TeV, 25 ns ?



- **Tune scan, Project Note 416 (W. Herr, D. Kaltchev)**
- $\beta^* = 1.00$ **m, angle** $= \pm 140.0$ μ**rad**

What about 7 TeV, 25 ns ?



- **Tune scan, Project Note 416 (W. Herr, D. Kaltchev)**
- **$\beta^* = 1.00$ m, angle $= \pm 160.0$ μrad**