Luminosity Considerations for the LHC (Ions)

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Introduction

- **Average Luminosity and Luminous region**
- **Hourglass not needed**
- **Calculations for the LHC (ions)**
- **Some results**
- **Conclusions**

Average Luminosity and Luminous Region

- **Simplest case** $\rightarrow \mathcal{L} = \dfrac{N_1 N_2 f B}{4\pi\sigma_x\sigma_y}$

- **Luminous region** ($\pm s$) $\rightarrow \mathcal{L}(s) = \int_{-s}^{+s} \mathcal{L}(s')ds'$

- **Integrated luminous region** ($\pm s$) $\rightarrow$

$$\mathcal{L}_{\mathrm{av}}(s) = \frac{1}{T}\int_0^T \int_{-s}^{+s} \mathcal{L}(s',t)ds'dt$$

- **Crossing angle**

Hourglass not needed

- $\sigma_z = \sigma_z^* \sqrt{1 + \left(\frac{s}{\beta^*}\right)^2} \rightarrow$ hourglass
- **Not needed for LHC ion parameters**
- $N_1 = N_2 = 7.0 \times 10^7$ **particles/bunch**
- 592 **bunches/beam,** $f = 11.2455$ kHz
- $\phi = 100$ (CMS) – 300 (ALICE) μrad **(total** $\times$ $\angle$**)**
- $\beta_x^* = \beta_y^* = 1.0 \rightarrow 0.5$ m (squeeze), or
- $\beta_x^* = \beta_y^* = 0.5$ m $\sigma_x^* = \sigma_y^* = 15.9$ μm (no squeeze)
- $\sigma_x^* = \sigma_y^* = 22.5$ μm $\rightarrow 15.9$ μm, $\sigma_s = 7.7$ cm

Calculations for the LHC

- **Bunch length increases linearly by** 30 % **in** 10 **hours for protons (P. Baudrenghien)**

- **For ions: (IBS)** $\rightarrow$ **several cases:** 20%**,** 30 %**,** 40 %**,** 50 % **in** 3.5/6.6/13 **hours**

- **Worst case shown for non squeezing scenarios**

- **Intensity falls off as**

$$N = N_0 \exp\left(-\frac{t}{3.5/6.6/13hr.}\right)$$

(O. Brüning - protons)

No Squeeze, 2 Experiments, 30% b.l.increase:

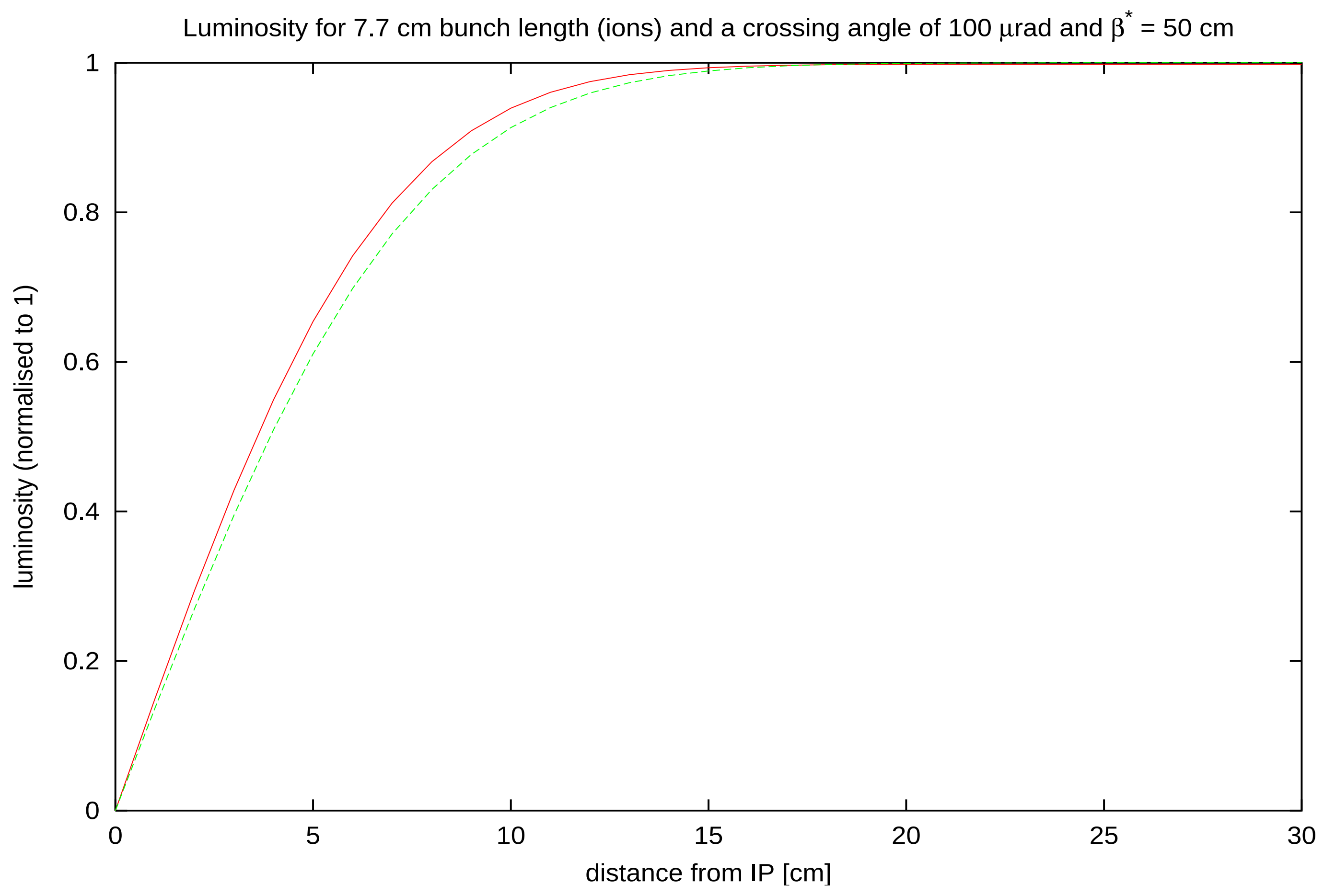

Figure 1: $\beta^* = 0.5\text{m},\ \phi = 100\ \mu\text{rad}$

Results: 30% bunch length increase, $\phi = 100\ \mu$rad

- $\mathcal{L} = 1.0 \times 10^{27}\ \text{cm}^{-2}\text{s}^{-1},\ 4.29 \times 10^{26}$ after 6.6 hours
- 100% **lumi** $\rightarrow\ \ s = \pm\ 20$ cm $\longrightarrow\ \ s = \pm\ 20$ cm
- 95% **lumi** $\rightarrow\ \ s = \pm\ 11$ cm $\longrightarrow\ \ s = \pm\ 12$ cm
- 90% **lumi** $\rightarrow\ \ s = \pm\ 8.5$ cm $\longrightarrow\ \ s = \pm\ 9.5$ cm
- 85% **lumi** $\rightarrow\ \ s = \pm\ 8$ cm $\longrightarrow\ \ s = \pm\ 8.5$ cm
- 80% **lumi** $\rightarrow\ \ s = \pm\ 7$ cm $\longrightarrow\ \ s = \pm\ 7.5$ cm

No Squeeze, 2 Experiments, 30% b.l.increase:

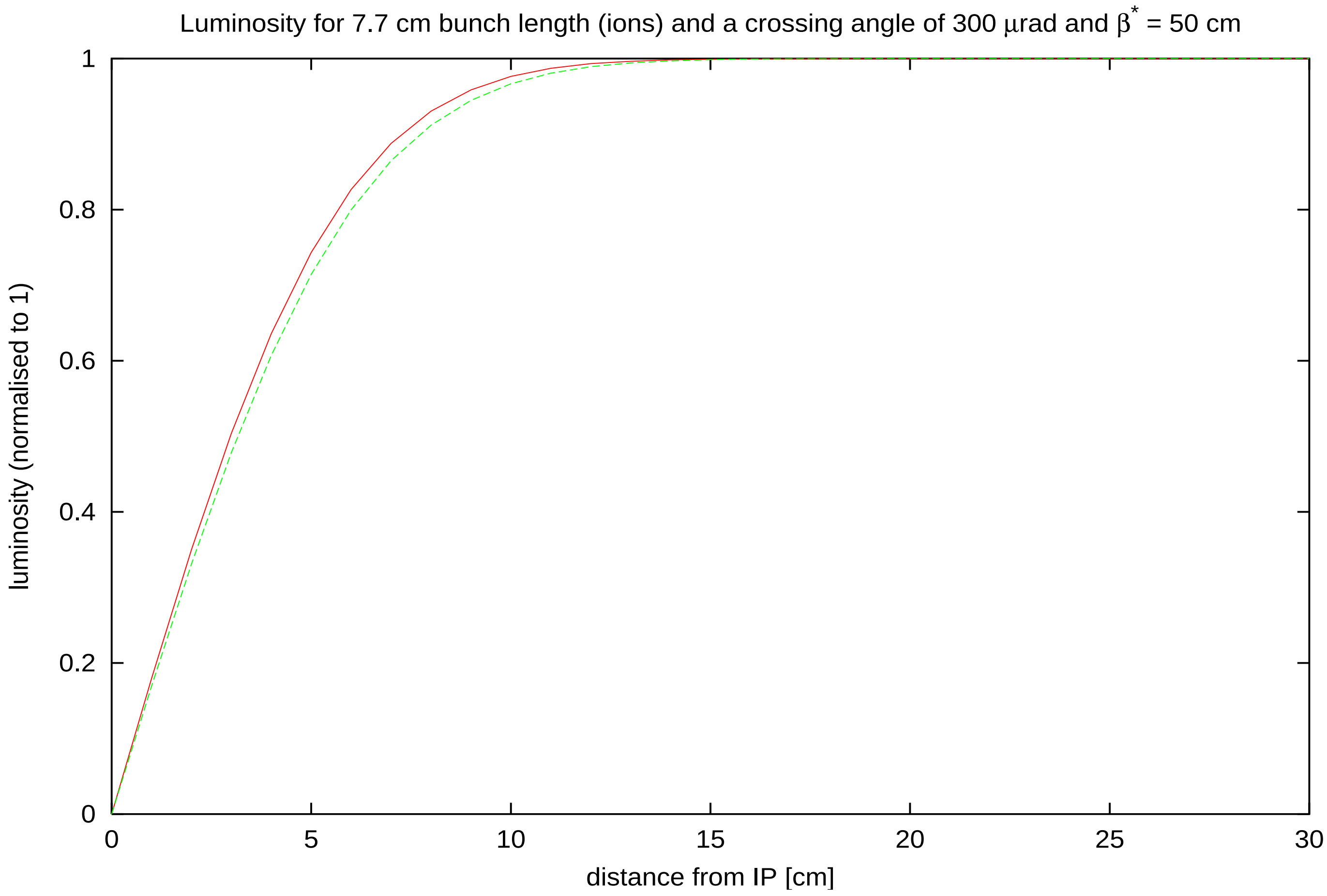

Figure 2: $\beta* = 0.5$m, $\phi = 300\ \mu$rad

Results: 30% bunch length increase, $\phi = 300\ \mu\text{rad}$

- $\mathcal{L} = 8.31 \times 10^{26}\ \text{cm}^{-2}\text{s}^{-1},\ \ 3.91 \times 10^{26}$ after 6.6 hours
- 100% **lumi** $\rightarrow\ \ s = \pm\ 14\ \text{cm} \longrightarrow\ \ s = \pm\ 14\ \text{cm}$
- 95% **lumi** $\rightarrow\ \ s = \pm\ 9\ \text{cm} \longrightarrow\ \ s = \pm\ 9.5\ \text{cm}$
- 90% **lumi** $\rightarrow\ \ s = \pm\ 7.5\ \text{cm} \longrightarrow\ \ s = \pm\ 8\ \text{cm}$
- 85% **lumi** $\rightarrow\ \ s = \pm\ 7\ \text{cm} \longrightarrow\ \ s = \pm\ 7.5\ \text{cm}$
- 80% **lumi** $\rightarrow\ \ s = \pm\ 6\ \text{cm} \longrightarrow\ \ s = \pm\ 6.5\ \text{cm}$

No Squeeze, 3 Experiments, 20% b.l.increase:

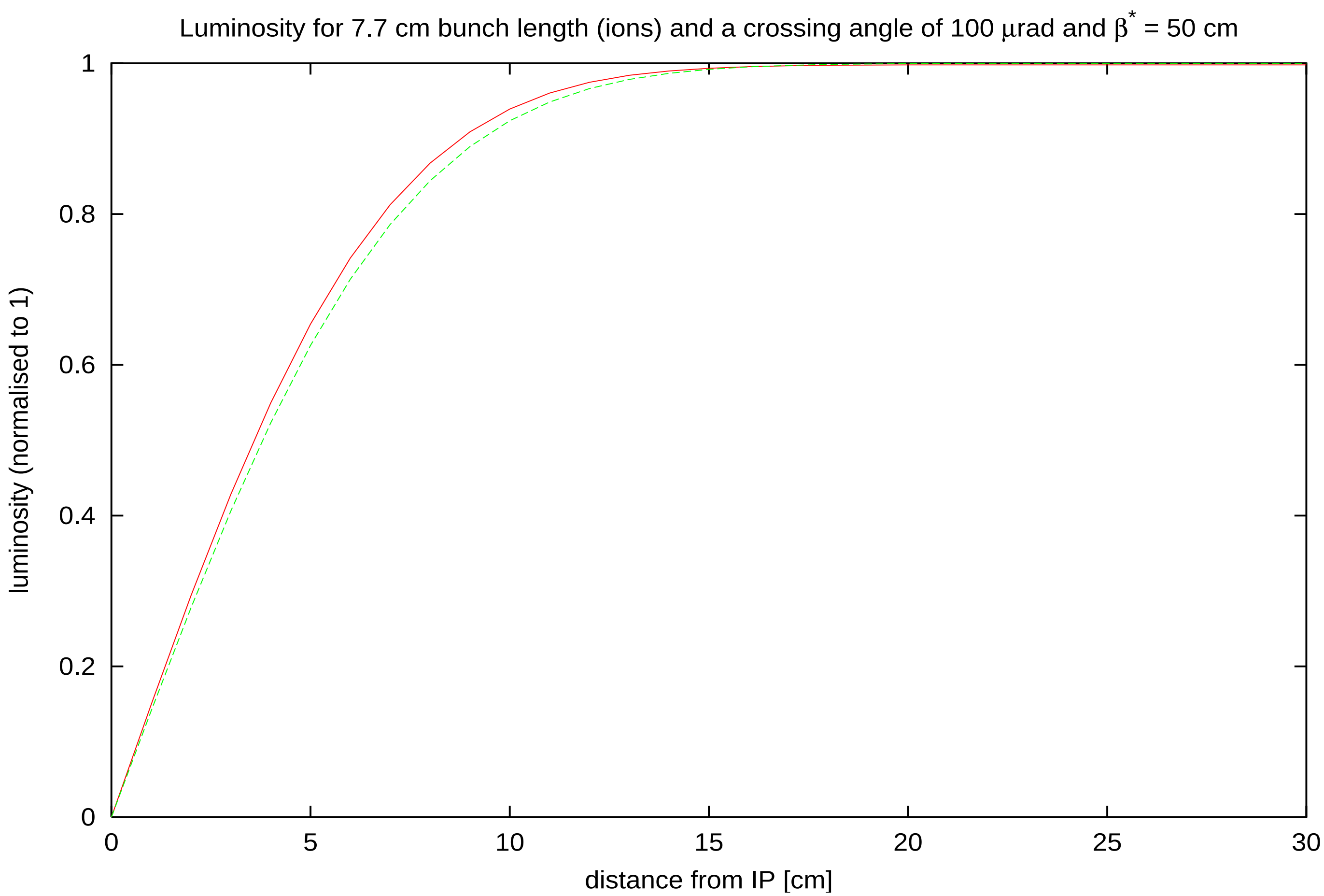

Figure 3: $\beta* = 0.5\text{m},\ \phi = 100\ \mu\text{rad}$

Results: 20% **bunch length increase,** $\phi = 100\ \mu$rad

- $\mathcal{L} = 1.0 \times 10^{27}\ \text{cm}^{-2}\text{s}^{-1},\ 4.3 \times 10^{26}$ after 3.5 hours
- 100% **lumi** $\rightarrow\ \ s = \pm\ 20$ cm $\longrightarrow\ \ s = \pm\ 20$ cm
- 95% **lumi** $\rightarrow\ \ s = \pm\ 11$ cm $\longrightarrow\ \ s = \pm\ 11.5$ cm
- 90% **lumi** $\rightarrow\ \ s = \pm\ 8.5$ cm $\longrightarrow\ \ s = \pm\ 9$ cm
- 85% **lumi** $\rightarrow\ \ s = \pm\ 8$ cm $\longrightarrow\ \ s = \pm\ 8.5$ cm
- 80% **lumi** $\rightarrow\ \ s = \pm\ 7$ cm $\longrightarrow\ \ s = \pm\ 7.5$ cm

B. Murato

No Squeeze, 3 Experiments, 20% b.l.increase:

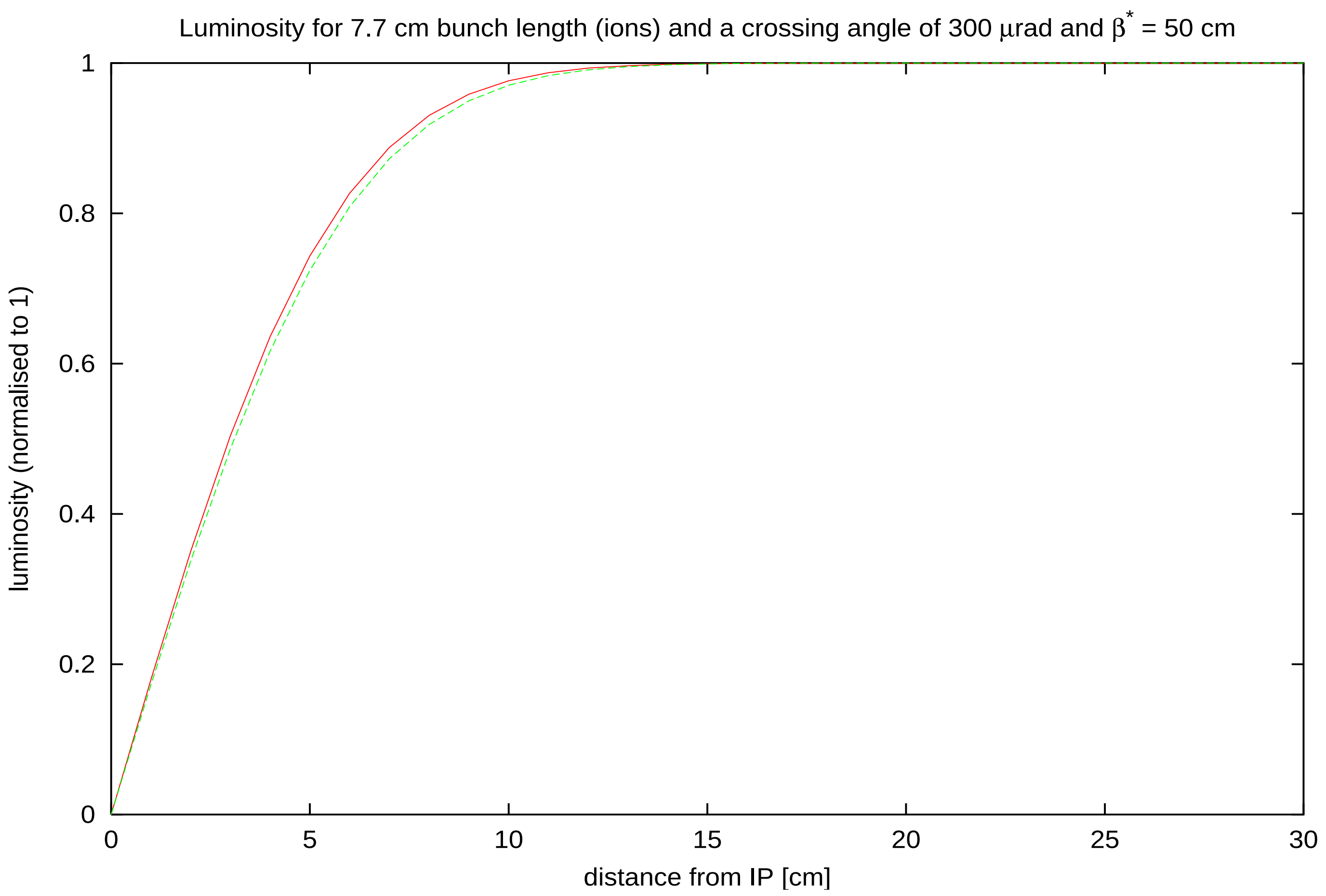

Figure 4: $\beta* = 0.5\text{m}, \ \phi = 300 \ \mu\text{rad}$

Results: 20% bunch length increase, $\phi = 300\ \mu\text{rad}$

- $\mathcal{L} = 8.31 \times 10^{26}\ \text{cm}^{-2}\text{s}^{-1},\ 3.57 \times 10^{26}$ after 3.5 hours
- 100% **lumi** $\rightarrow\ s = \pm\ 14\ \text{cm} \longrightarrow\ s = \pm\ 14\ \text{cm}$
- 95% **lumi** $\rightarrow\ s = \pm\ 9\ \text{cm} \longrightarrow\ s = \pm\ 9\ \text{cm}$
- 90% **lumi** $\rightarrow\ s = \pm\ 7.5\ \text{cm} \longrightarrow\ s = \pm\ 7.5\ \text{cm}$
- 85% **lumi** $\rightarrow\ s = \pm\ 7\ \text{cm} \longrightarrow\ s = \pm\ 7\ \text{cm}$
- 80% **lumi** $\rightarrow\ s = \pm\ 6\ \text{cm} \longrightarrow\ s = \pm\ 6\ \text{cm}$

Squeeze

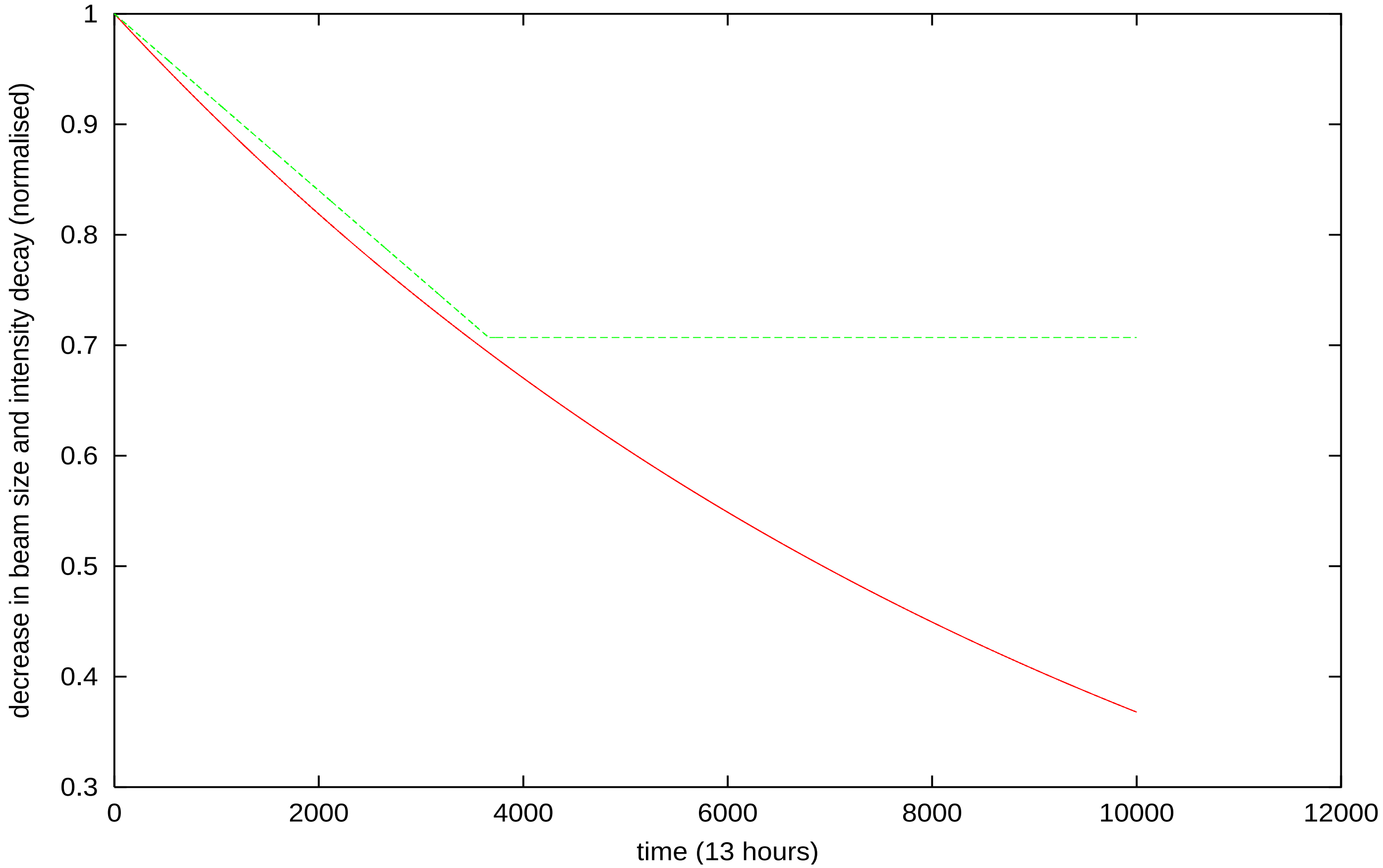

Figure 5: Intensity decay & squeezing of $\sigma_{x,y}$

Squeeze

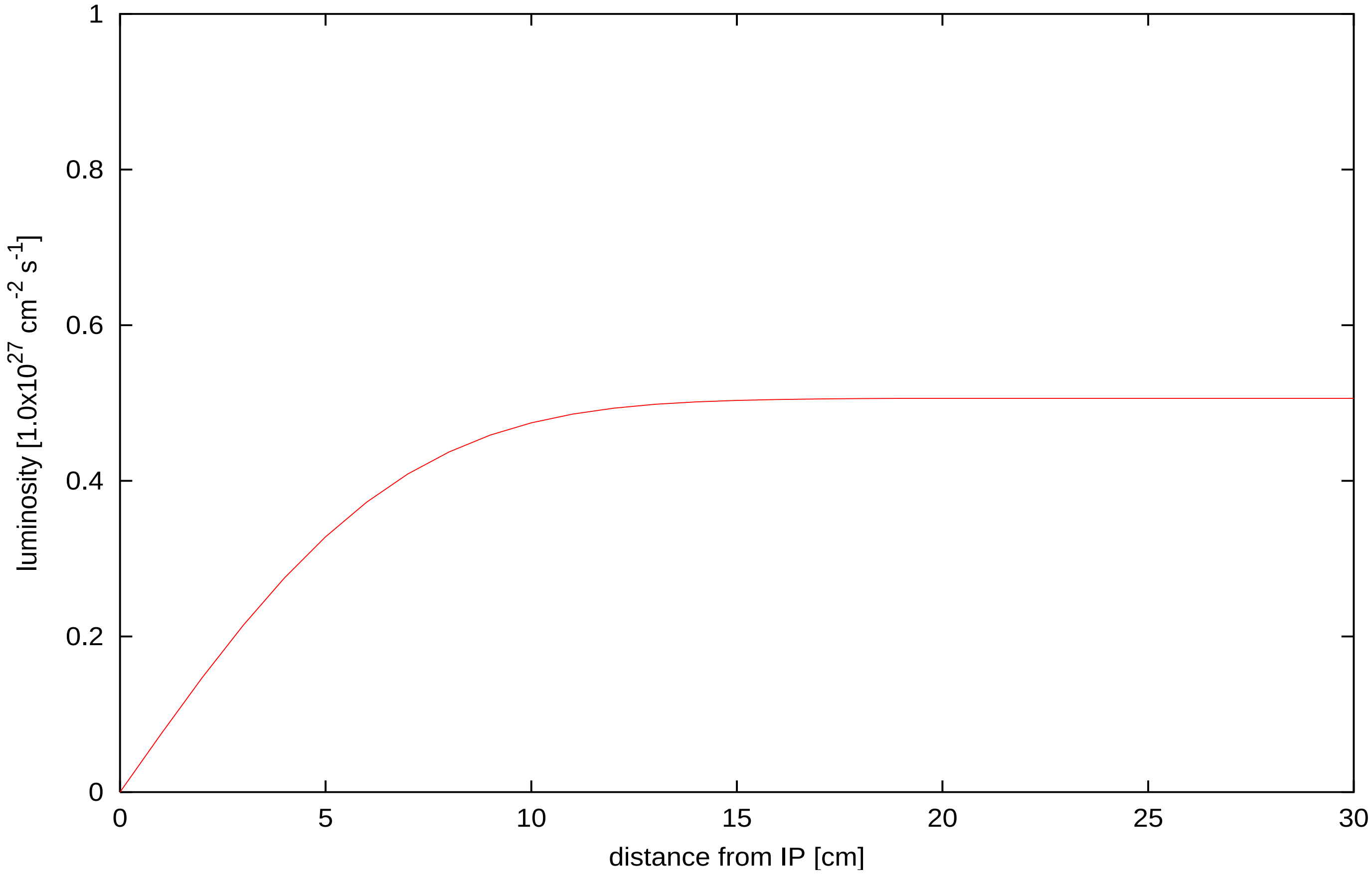

Figure 6: L. region for $\phi = 100$ μrad, $\beta^* = 100$ cm, bunch l. 7.7 cm

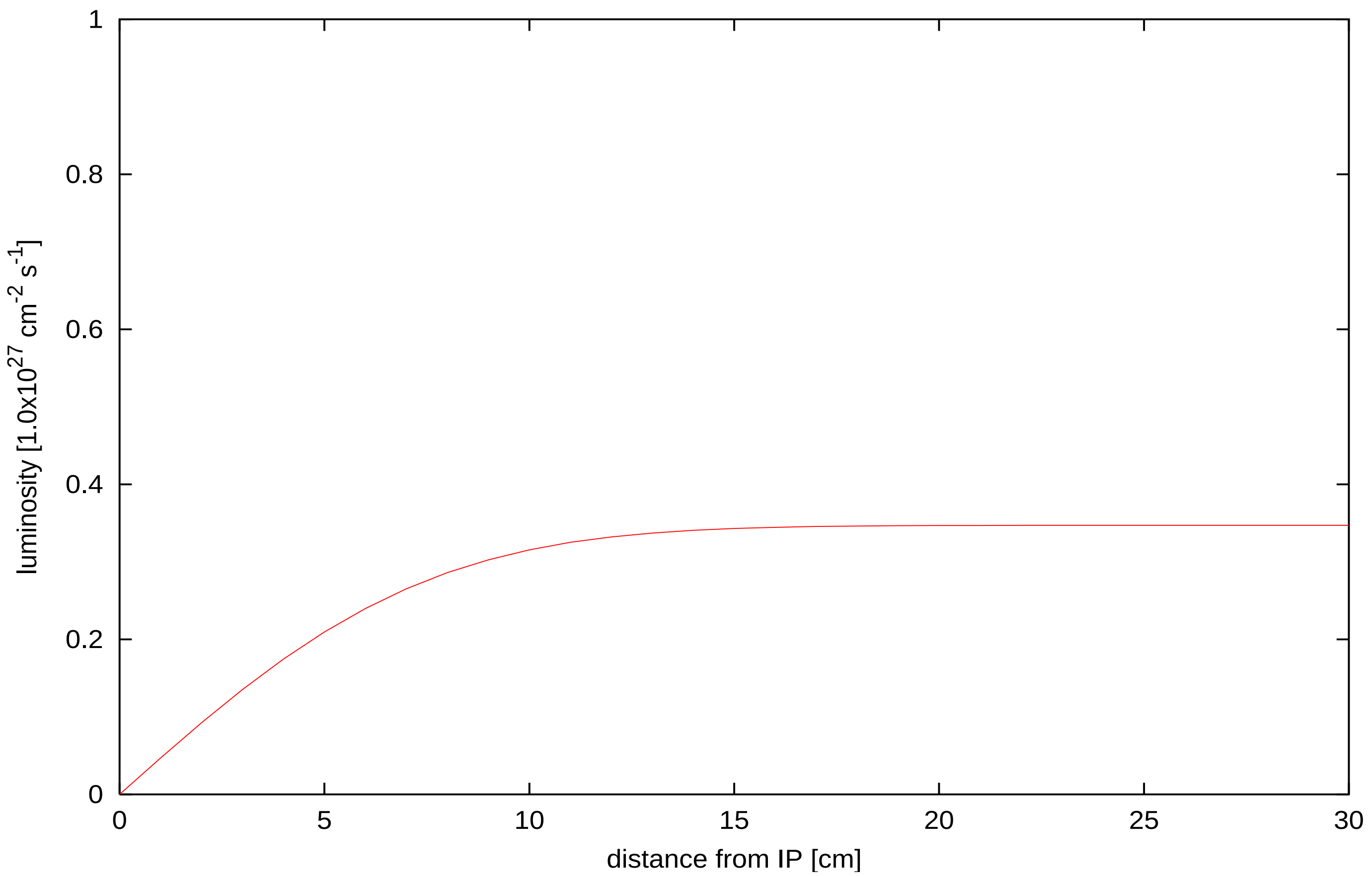

Figure 7: Same after 13hr. coast (30% b.l.i. & int. decay, $\beta^* = 50$ cm)

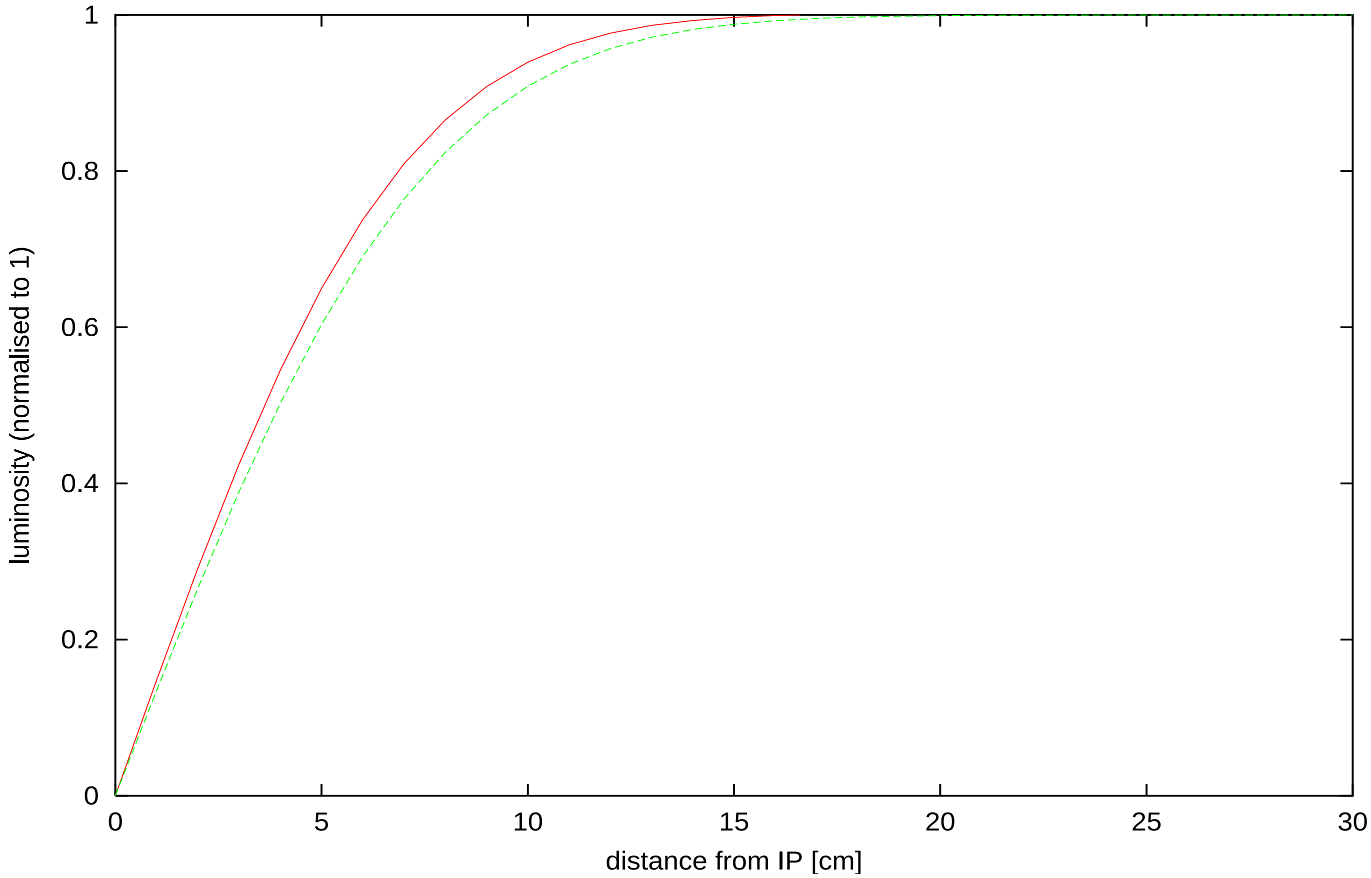

Figure 8: Both, normalised, ($\phi = 100\ \mu$rad $\beta^* = 100\ \rightarrow\ 50$ cm)

Results: 30% bunch length increase, $\phi = 100\ \mu$rad

- $\mathcal{L} = 5.05 \times 10^{26}\ \mathrm{cm}^{-2}\mathrm{s}^{-1},\ 3.47 \times 10^{26}$ after 13 hours
- 100% **lumi** $\rightarrow\quad s = \pm\ 15$ cm $\longrightarrow\quad s = \pm\ 20$ cm
- 95% **lumi** $\rightarrow\quad s = \pm\ 10.5$ cm $\longrightarrow\quad s = \pm\ 12$ cm
- 90% **lumi** $\rightarrow\quad s = \pm\ 9$ cm $\longrightarrow\quad s = \pm\ 10$ cm
- 85% **lumi** $\rightarrow\quad s = \pm\ 7.5$ cm $\longrightarrow\quad s = \pm\ 8$ cm
- 80% **lumi** $\rightarrow\quad s = \pm\ 7$ cm $\longrightarrow\quad s = \pm\ 7.5$ cm

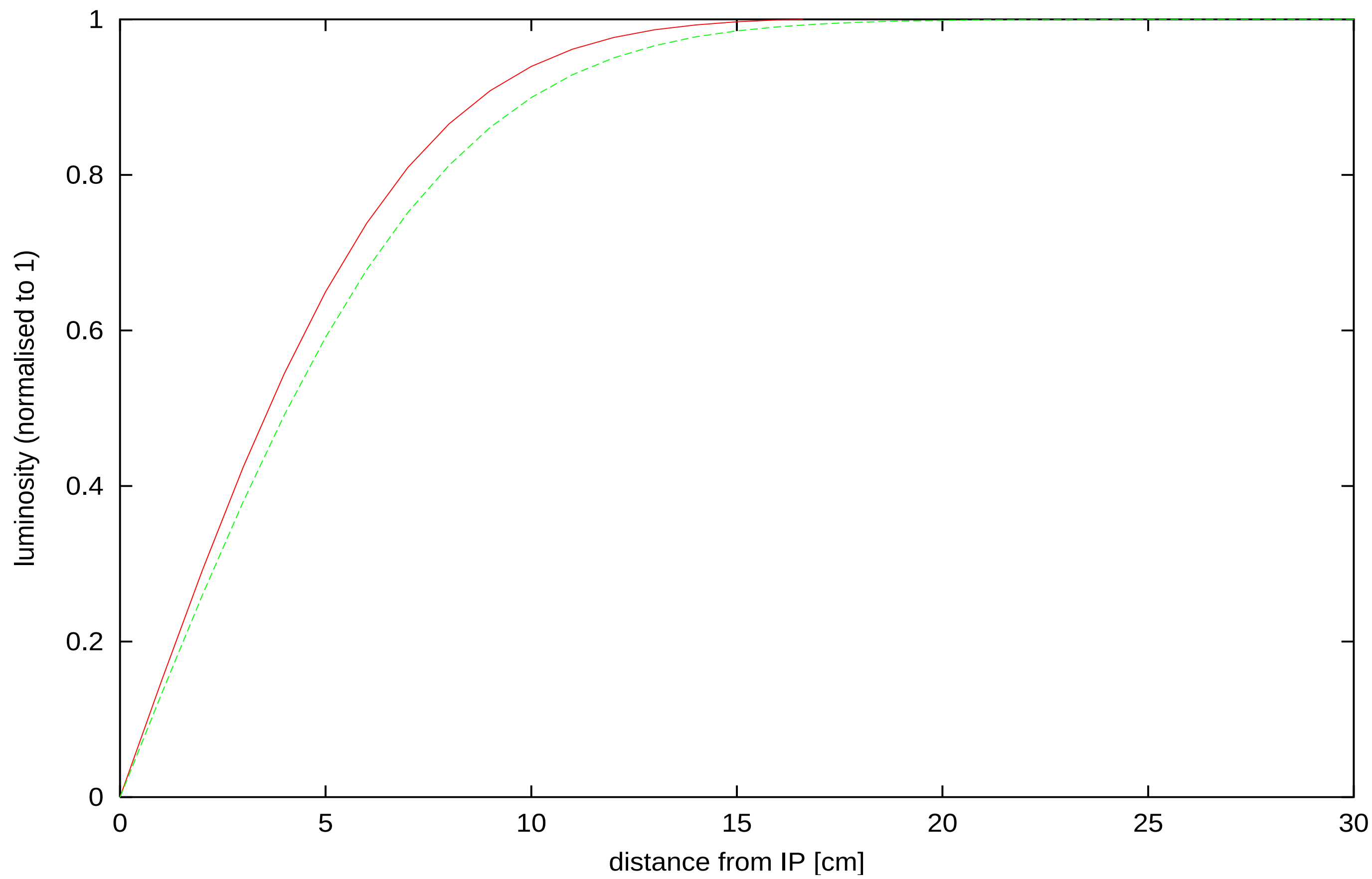

Figure 9: 40% b.l.i., normalised, ($\phi = 100$ μrad $\beta^* = 100 \ \rightarrow \ 50$ cm)

Results: 40% bunch length increase, $\phi = 100\ \mu$rad

- $\mathcal{L} = 5.05 \times 10^{26}\ \mathrm{cm}^{-2}\mathrm{s}^{-1},\ 3.46 \times 10^{26}$ after 13 hours
- 100% **lumi** $\rightarrow\ s = \pm\ 15$ cm $\longrightarrow\ s = \pm\ 21$ cm
- 95% **lumi** $\rightarrow\ s = \pm\ 10.5$ cm $\longrightarrow\ s = \pm\ 12.5$ cm
- 90% **lumi** $\rightarrow\ s = \pm\ 9$ cm $\longrightarrow\ s = \pm\ 10.5$ cm
- 85% **lumi** $\rightarrow\ s = \pm\ 7.5$ cm $\longrightarrow\ s = \pm\ 8.5$ cm
- 80% **lumi** $\rightarrow\ s = \pm\ 7$ cm $\longrightarrow\ s = \pm\ 8$ cm

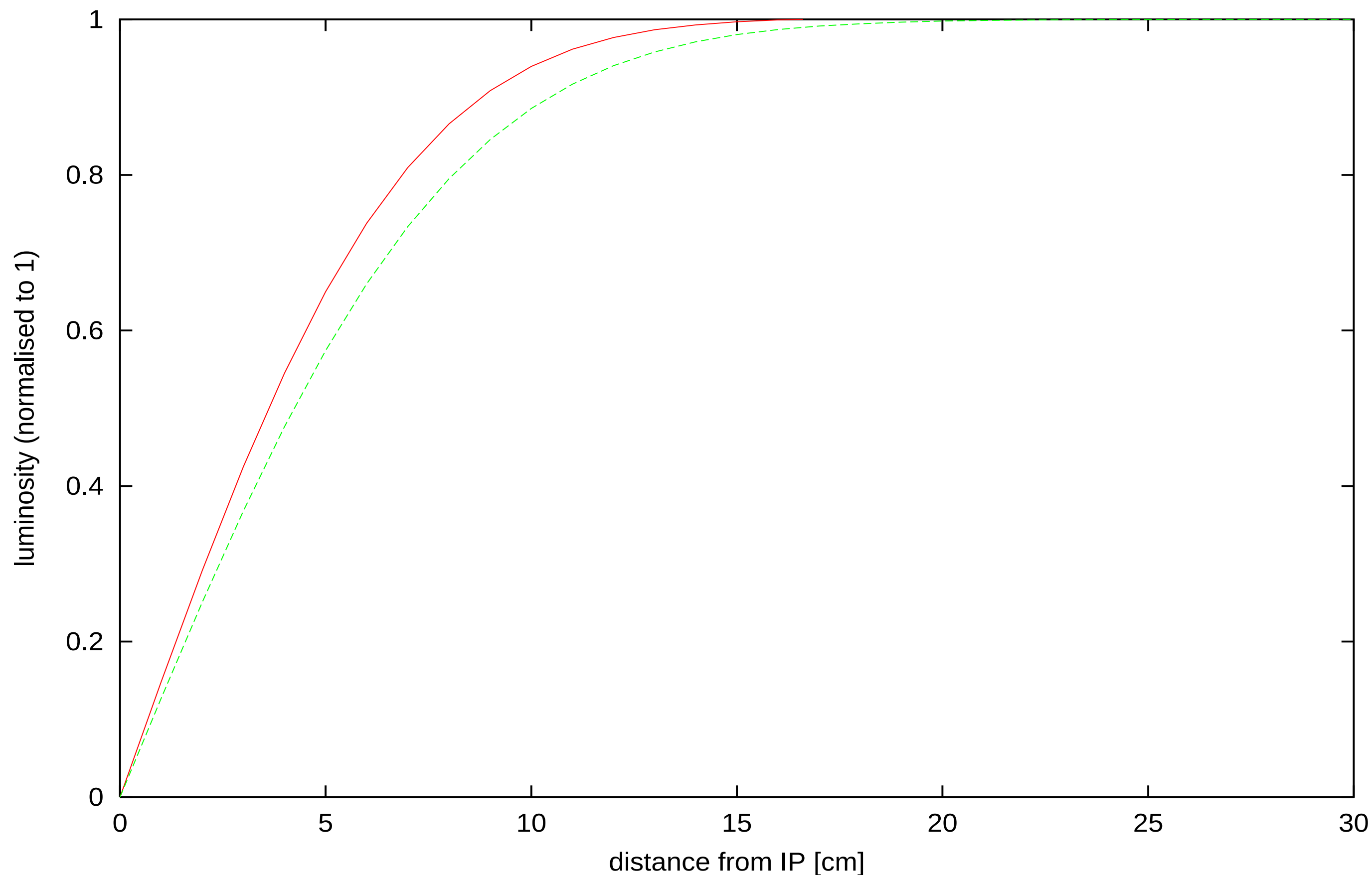

Figure 10: 50% b.l.i., normalised, ($\phi = 100\ \mu$rad $\beta^* = 100\ \rightarrow\ 50$ cm)

Results: 50% bunch length increase, $\phi = 100\ \mu$rad

- $\mathcal{L} = 5.05 \times 10^{26}\ \mathrm{cm}^{-2}\mathrm{s}^{-1},\ 3.45 \times 10^{26}$ after 13 hours
- 100% **lumi** $\rightarrow\ s = \pm\ 15$ cm $\longrightarrow\ s = \pm\ 22$ cm
- 95% **lumi** $\rightarrow\ s = \pm\ 10.5$ cm $\longrightarrow\ s = \pm\ 13$ cm
- 90% **lumi** $\rightarrow\ s = \pm\ 9$ cm $\longrightarrow\ s = \pm\ 11$ cm
- 85% **lumi** $\rightarrow\ s = \pm\ 7.5$ cm $\longrightarrow\ s = \pm\ 9$ cm
- 80% **lumi** $\rightarrow\ s = \pm\ 7$ cm $\longrightarrow\ s = \pm\ 8$ cm

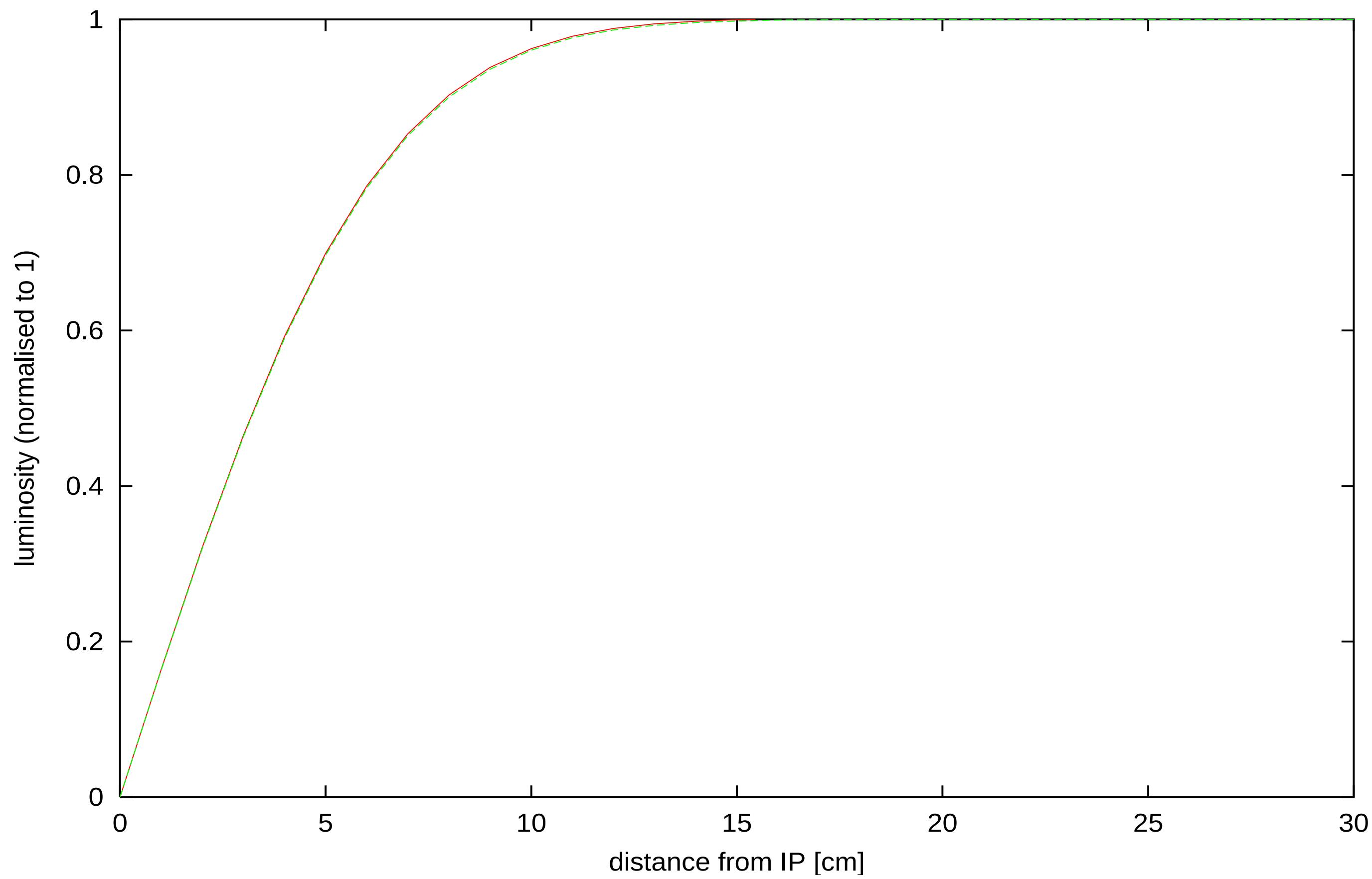

Figure 11: 30% b.l.i., normalised, ($\phi = 300\ \mu$rad$\beta^* = 100\ \rightarrow\ 50$ cm)

Results: 30% bunch length increase, $\phi = 300\ \mu$rad

- $\mathcal{L} = 4.56 \times 10^{26}\ \mathrm{cm^{-2}s^{-1}},\ 2.86 \times 10^{26}$ after 13 hours
- 100% **lumi** $\rightarrow\ s = \pm\ 15$ cm $\longrightarrow\ s = \pm\ 15$ cm
- 95% **lumi** $\rightarrow\ s = \pm\ 10$ cm $\longrightarrow\ s = \pm\ 10$ cm
- 90% **lumi** $\rightarrow\ s = \pm\ 8.5$ cm $\longrightarrow\ s = \pm\ 8.5$ cm
- 85% **lumi** $\rightarrow\ s = \pm\ 7$ cm $\longrightarrow\ s = \pm\ 7$ cm
- 80% **lumi** $\rightarrow\ s = \pm\ 6.5$ cm $\longrightarrow\ s = \pm\ 6.5$ cm

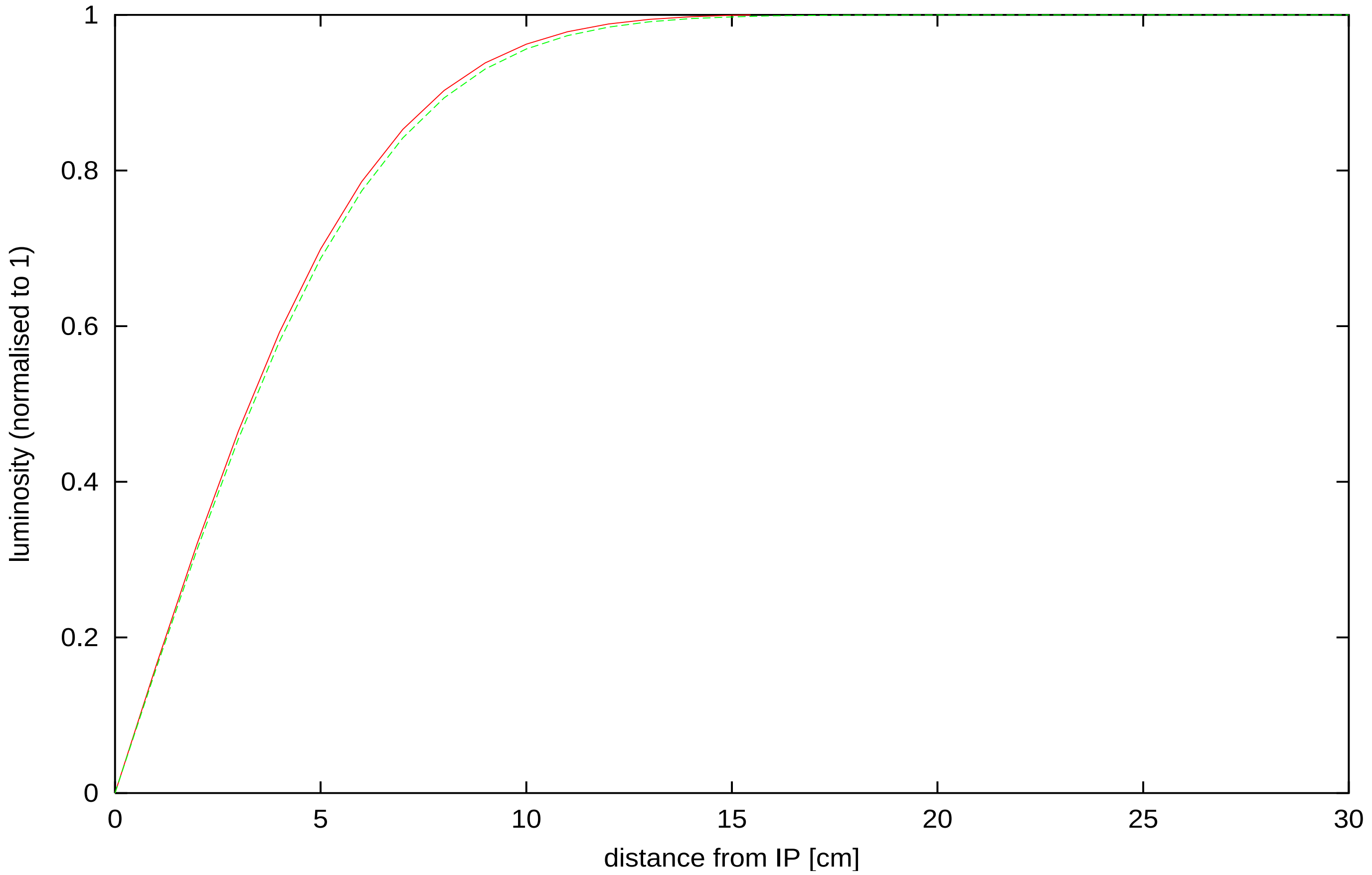

Figure 12: 40% b.l.i., normalised, ($\phi = 300\ \mu$rad $\beta^* = 100 \ \rightarrow\ 50$ cm)

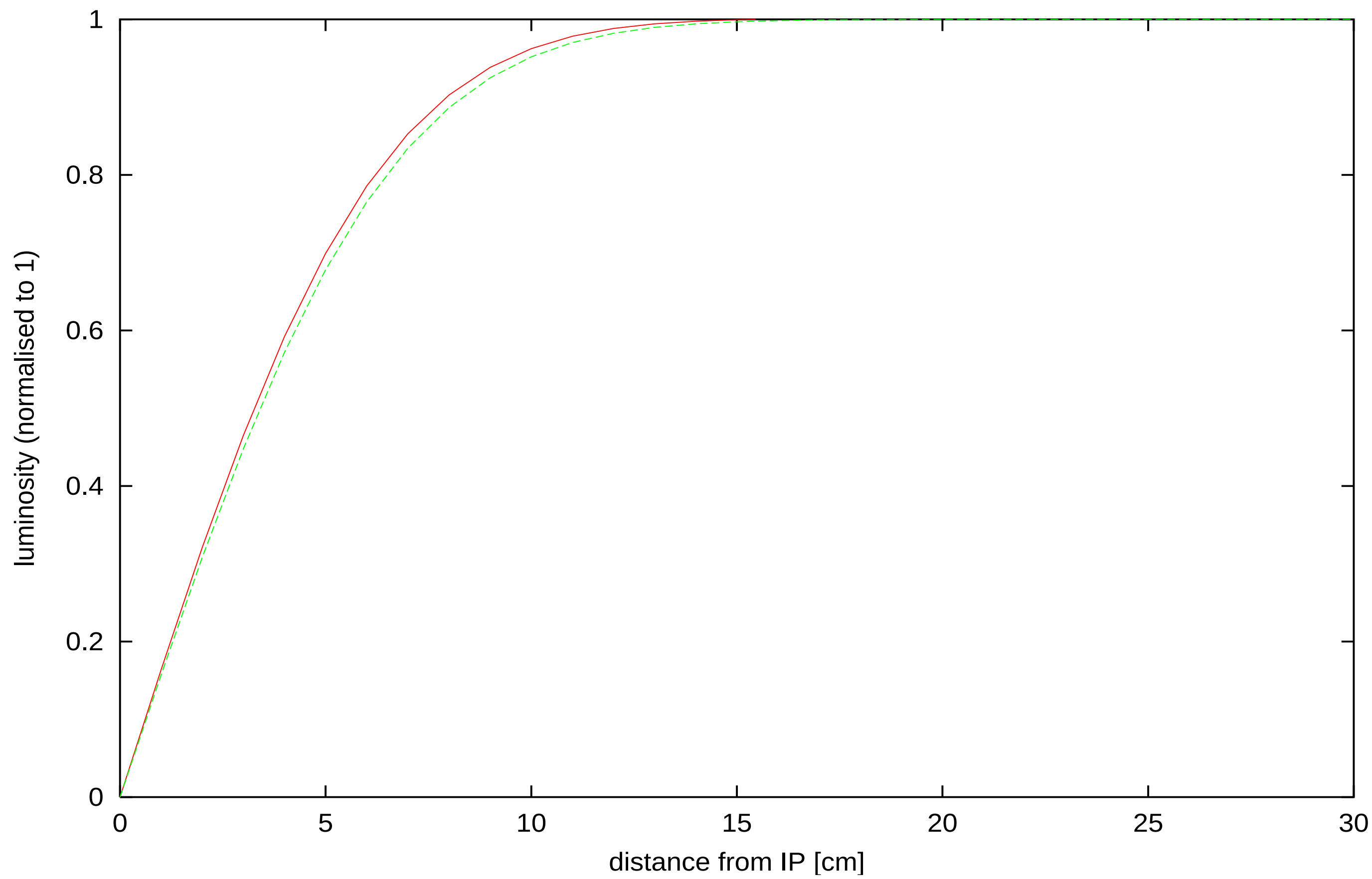

Figure 13: 50% b.l.i., normalised, ($\phi = 300\ \mu$rad $\beta^* = 100 \ \rightarrow\ 50$ cm)

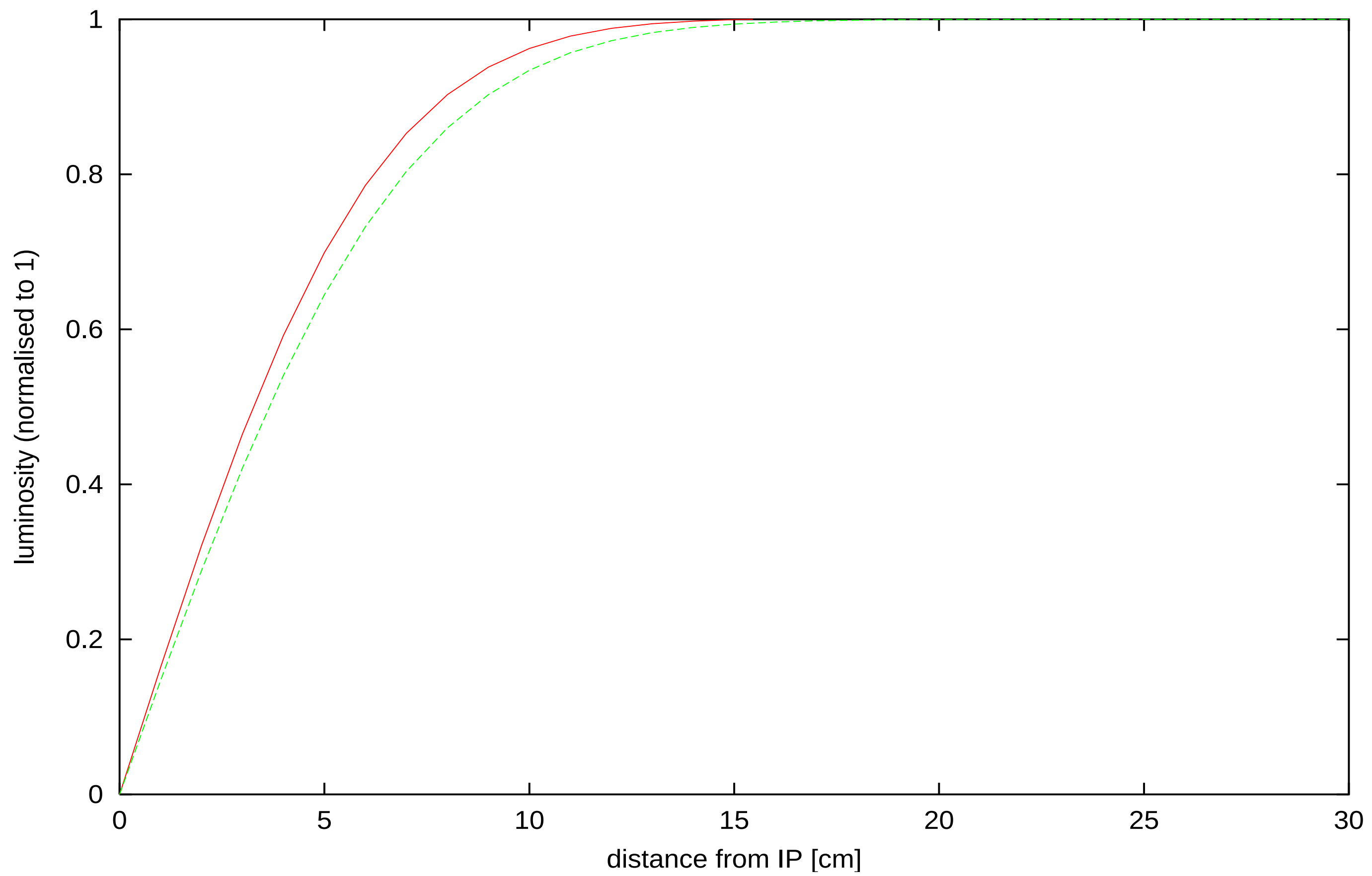

Figure 14: 100% b.l.i. normalised, ($\phi = 300\ \mu$rad $\beta^* = 100\ \rightarrow\ 50$ cm)

Conclusions

- **Detailed results will be available**

  /afs/cern.ch/user/b/bmurator/public/lumi/ions/

- **Hourglass not important for $\mathcal{L}$ with current settings $\rightarrow$ ignored**

- **Luminosity changes dramatically**

- **Luminous region changes for CMS/ALICE**