ALICE ZDC and TCTTVB Tertiary Collimators

- Zero-degree calorimeters in the heavy-ion experiments (ALICE, CMS, ATLAS) are crucial for physics measurements
  - Measure energy carried away by non-interacting (spectator) beam nucleons
  - D1 separator magnet separates spectator protons and neutrons to two distinct calorimeters 92 m from IP
  - Neutron calorimeter also measures neutrons from electromagnetic dissociation (1 and 2 n)
- Physics measurements affected:
  - The energy mean value and resolution
    - centrality determination
  - The ϕ azimuthal angle distribution
    - measurement of the reaction plane in nuclear collisions and therefore measurement of the directed flow
- Angular spread of spectator neutrons from nuclear Fermi momentum

Transverse divergence of spectator neutrons

Nuclear radius: $R_A \approx (1.25 \text{ fermi}) A^{1/3}$

Nucleon density: $n \approx \dfrac{A}{\frac{4}{3}\pi R_A^{\,3}}$

Fermi energy: $E_f = \dfrac{\hbar^2}{2m_n}\left(\dfrac{3\pi^2 n}{2}\right)^{2/3} \approx 30 \text{ MeV}$

Fermi momentum: $p_f = \sqrt{2m_n E_f} \approx 240 \text{ MeV}$

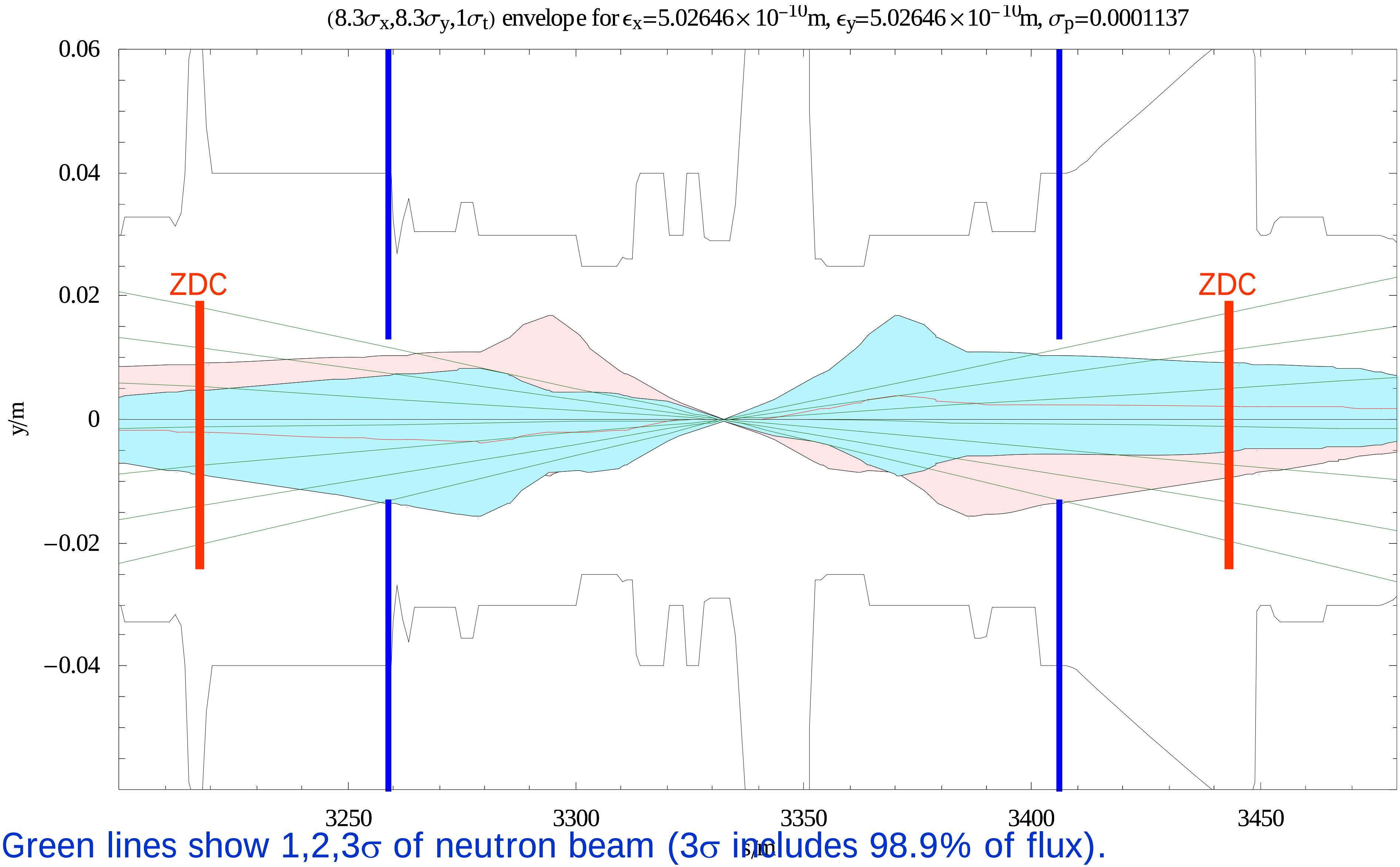
RMS neutron angle: $\sigma_\theta = \dfrac{p_f}{2\, p_{\text{beam}} / A} = 44\ \mu\text{rad}$ (ALICE ZDC Monte Carlo gives 51 μrad)

Compare collisional beam at IP: $\sigma_{p_y} = \sqrt{\dfrac{\varepsilon_{\text{n}}}{2\beta^* \sqrt{2\gamma^2 - 1}}} \approx 22.5\ \mu\text{rad}$

Neutrons are not focussed in straight sections (no strong sextupoles!).

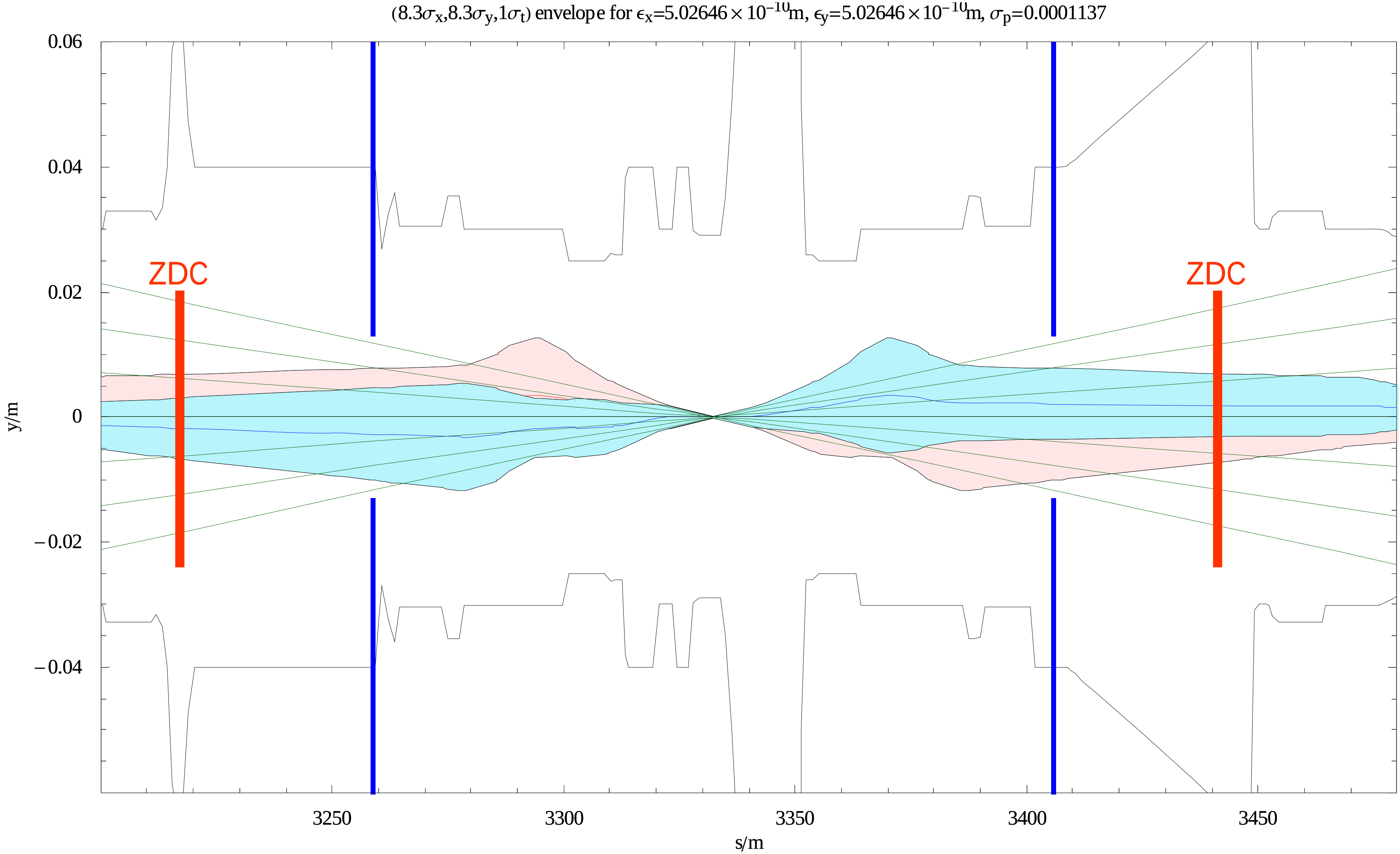
In electromagnetic dissociation, mean transverse momentum is less, 27 MeV/c.

Nominal ion collision optics (with 10 μrad crossing angle)



Green lines show 1,2,3σ of neutron beam (3σ includes 98.9% of flux).
Pink is vertical beam envelope of Beam 1, pale blue is Beam 2.

Early Ion Collision optics (with zero μrad crossing angle)



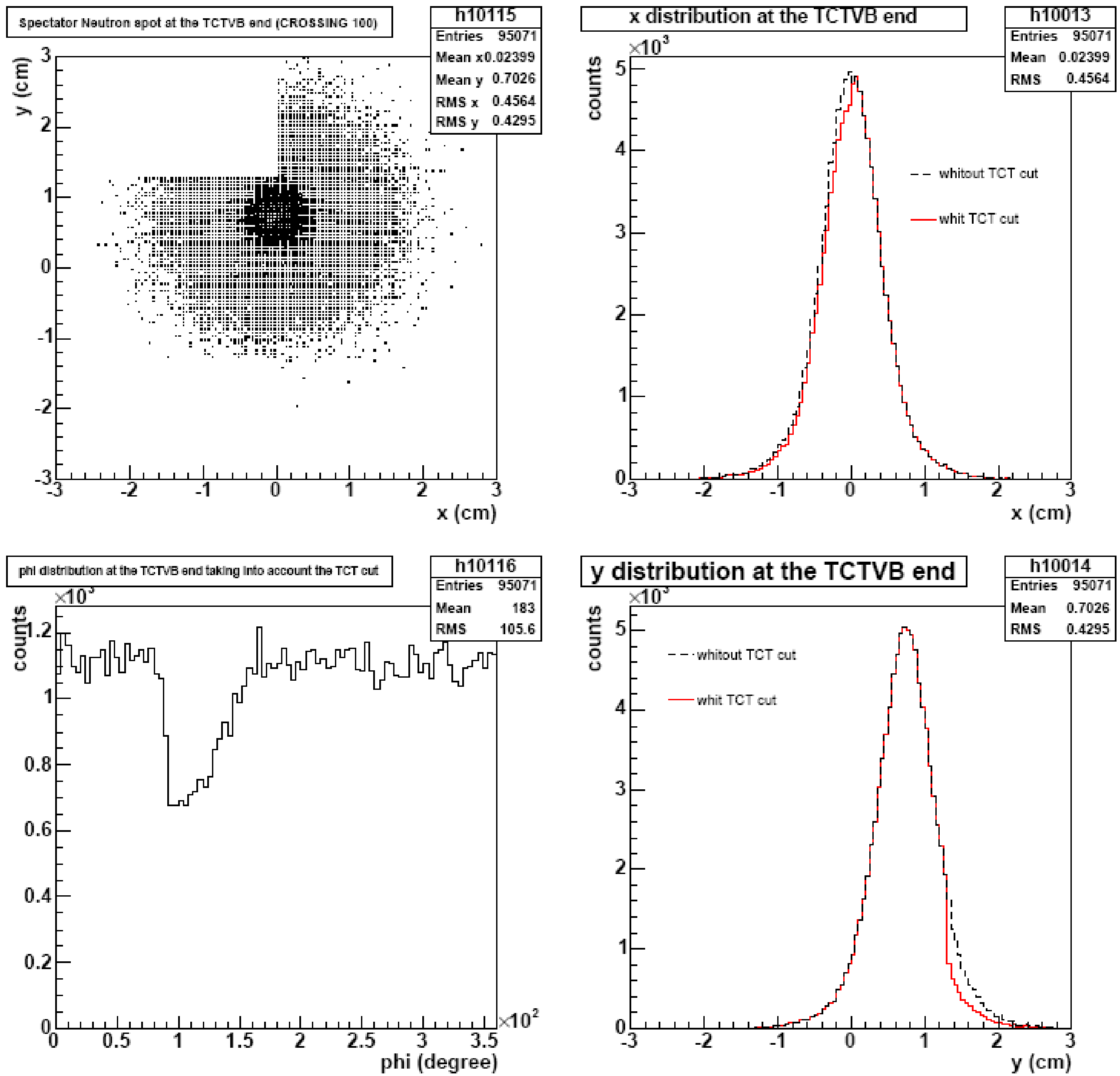
Green lines show 1,2,3σ of neutron beam (3σ includes 98.9% of flux).

Pink is vertical beam envelope of Beam 1, pale blue is Beam 2.

TCTVB neutron shadow on ZDC for 100 μrad crossing angle

100 microrad crossing angle at IP2 with 30 microrad beam divergence (larger than we are likely to use in heavy-ion operation).

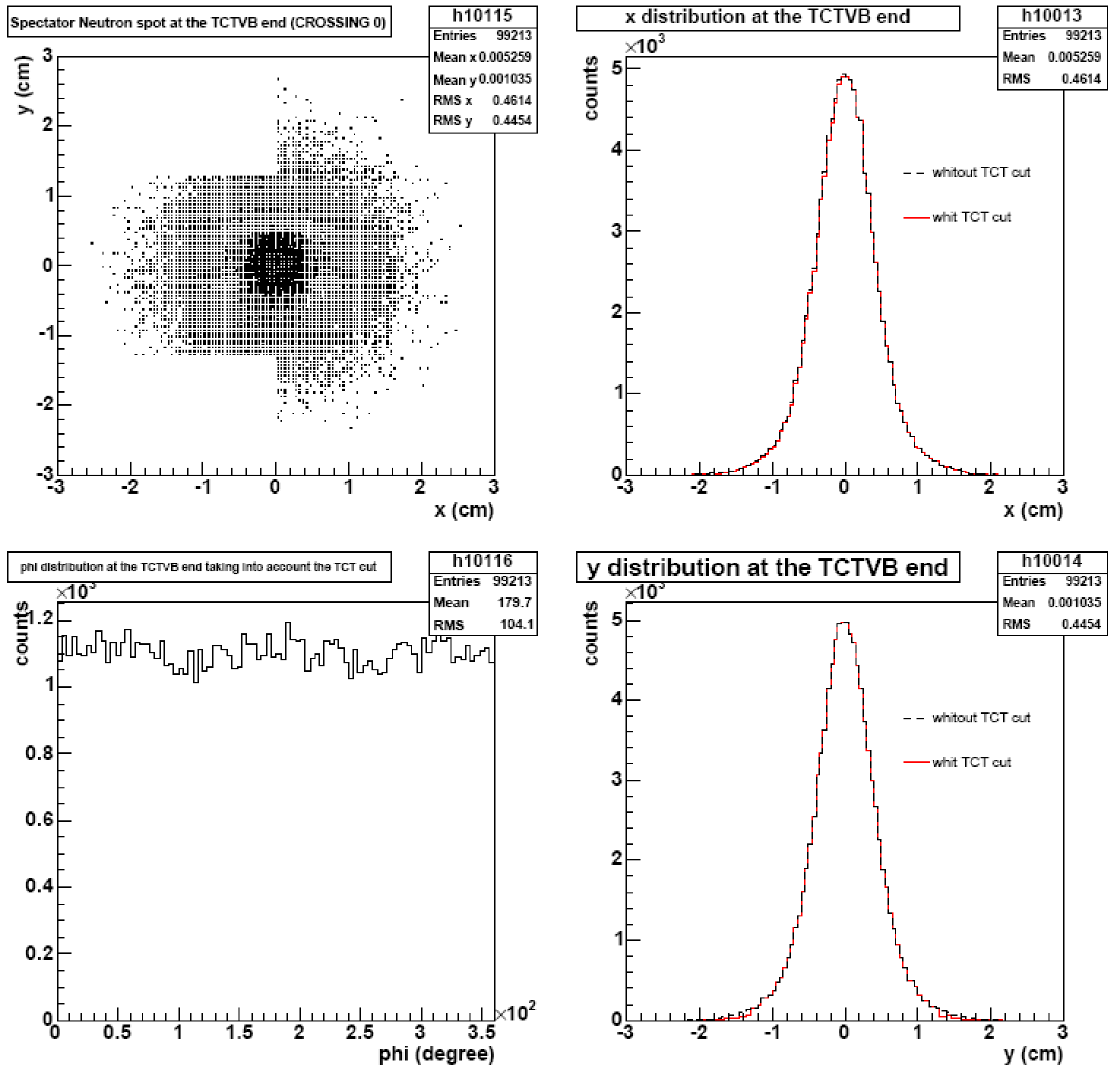
The number of spectator neutrons hitting the jaws is 5% and the ϕ distribution is not flat



From M. Gallio et al

TCTVB neutron shadow on ZDC for zero crossing angle

Zero crossing angle at IP2 with 30 microrad beam divergence. The number of spectator neutrons hitting the jaws is 0.8% and the ϕ distribution appears flat.



From M. Gallio et al

Conclusion

- With 0-10 μrad crossing angle, the proposed half-gap settings are just OK for ZDC physics
  - Our estimates consistent with ALICE Monte-Carlo.
- Larger crossing angles will not work but are probably not needed for heavy-ion physics
- This provides some protection for triplet quadrupoles.
- May still be worthwhile to look at additional tertiary collimators for ion runs ?
  - New collimators would be further away from IP
  - Daniela Macina has identified possible locations