Beam-spread determination for luminosity measurement @ CEPC

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Overview

- Requirements on beam-spread from $\mathcal{L}$ precision
- Experimental method
- ***s'*** sensitivity to beam-spread
- What do we need to be sensitive to $10^{-1,-2,-3}$ variations of the beam-spread?
- Conclusion

Requirements on beam-spread from $\mathscr{L}$ precision

10^{-3} in $\mathscr{L}$, 240 GeV CEPC, 10^{-4} @ Z^0 pole

Asymmetric bias on beam energy

$|E_+ - E_-| = \Delta E \Rightarrow \beta_z = \Delta E / E_{CM}$

- Longitudinal boost of the CM frame of the colliding particles to the lab frame β_z

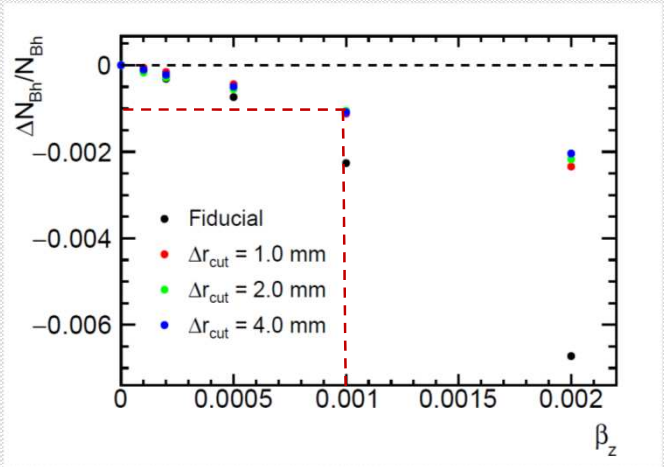
$\Rightarrow$ counting loss due to the loss of colinearity

- Asymmetry in beam energies should be smaller than $10^{-3}(10^{-4})$ for the same $\mathscr{L}$ uncertainty

Effective center of mass energy

- Bhabha cross-section changes as ~1/s $\Rightarrow$ relative uncertainty on (average net) CM energy $< 5 \cdot 10^{-4}$ for $\mathscr{L}$ uncertainty of 10^{-3}
- If there is no asymmetry, there is no impact on counting

One needs to know asymmetry in beam energies as 12.5% of the beam- spread at Z^0 pole (150%@240 GeV)



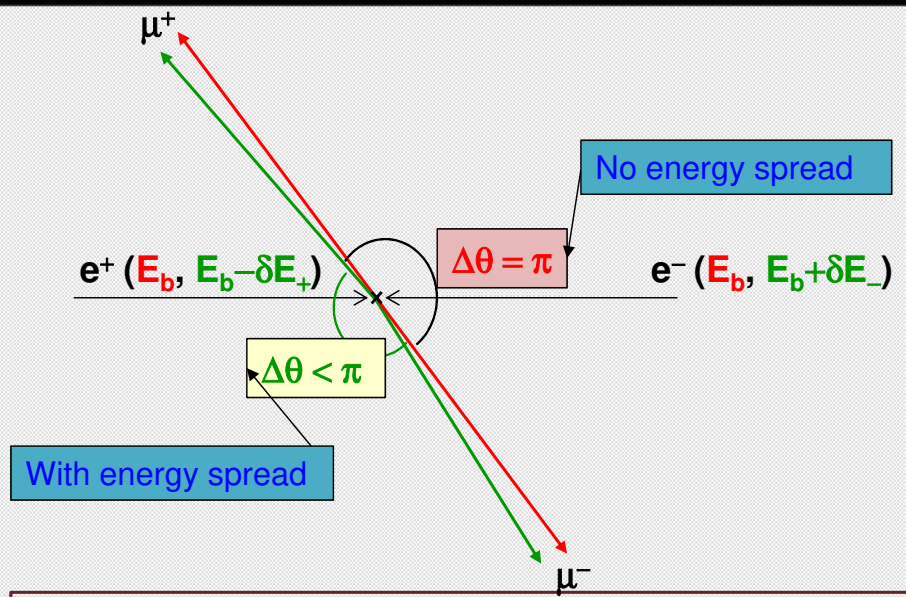
Experimental method

The method:

- ***s'*** can be determined from the reconstructed muons polar angles

$$\frac{s'}{s} = \frac{\sin\theta^+ + \sin\theta^- - |\sin(\theta^+ + \theta^-)|}{\sin\theta^+ + \sin\theta^- + |\sin(\theta^+ + \theta^-)|}$$

- Expected muon polar angle resolution over the whole tracking volume (i.e. 0.1 mrad corresponds to 100 μm position resolution in TPC)
- Method is proposed for FCCee [P. Janot, FCCee polarization WS, 2017]



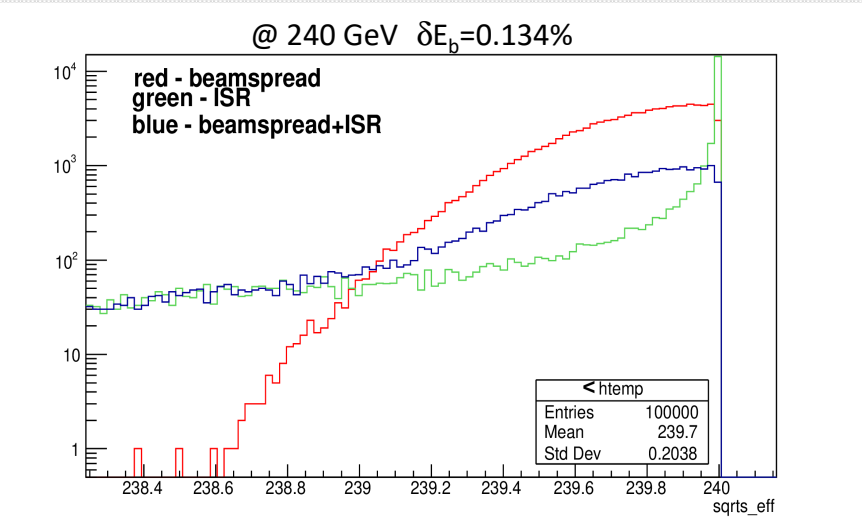
Additional effects:

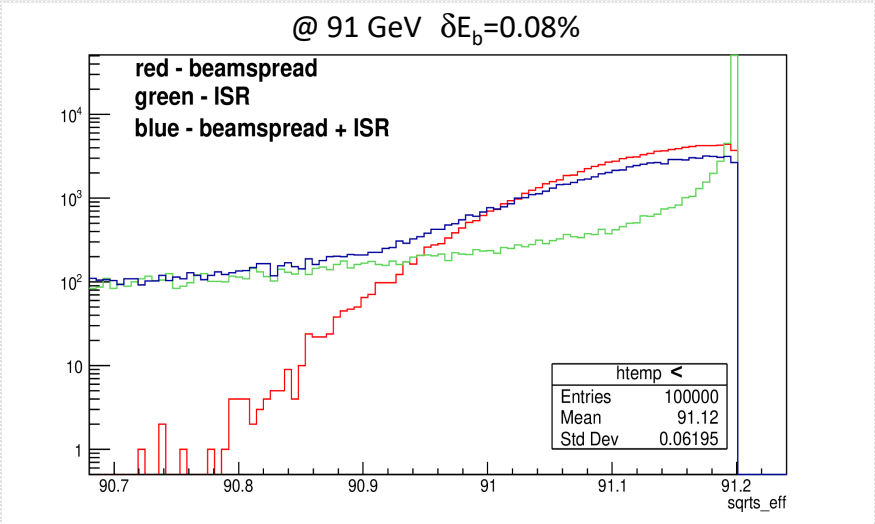
- ISR and FSR
- Beam-beam interactions
- Muon polar angle resolution

We'll try to answer:

- What is the sensitivity (of ***s'***) to beam-spread, additional effects and detector resolution?
- How many muons (what time) one needs to achieve aimed sensitivity?

s' sensitivity to beam-spread

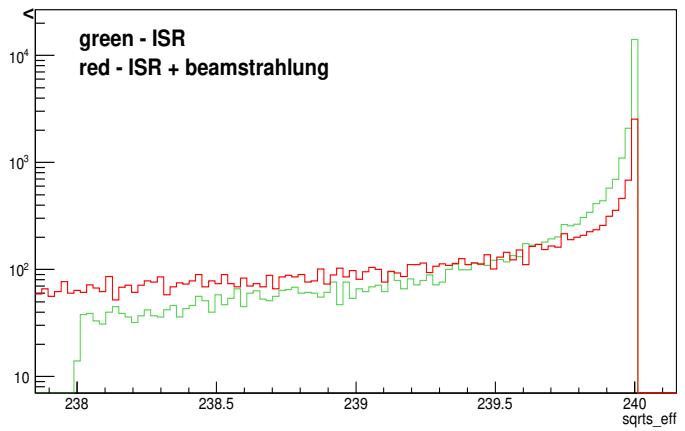


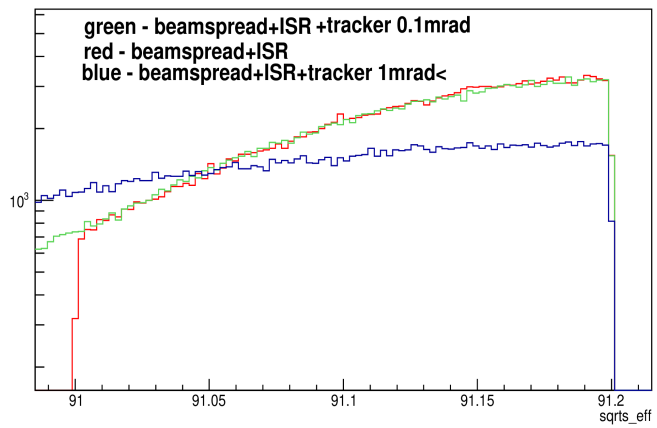


We need:

- Excellent theoretical description of ISR
- Full detector simulation – impact of the resolution
- Presence of backgrounds

s' sensitivity to beam-spread + BS+detector resolution





s' remains sensitive to beam-spread in the presence of ISR and Beamstrahlung

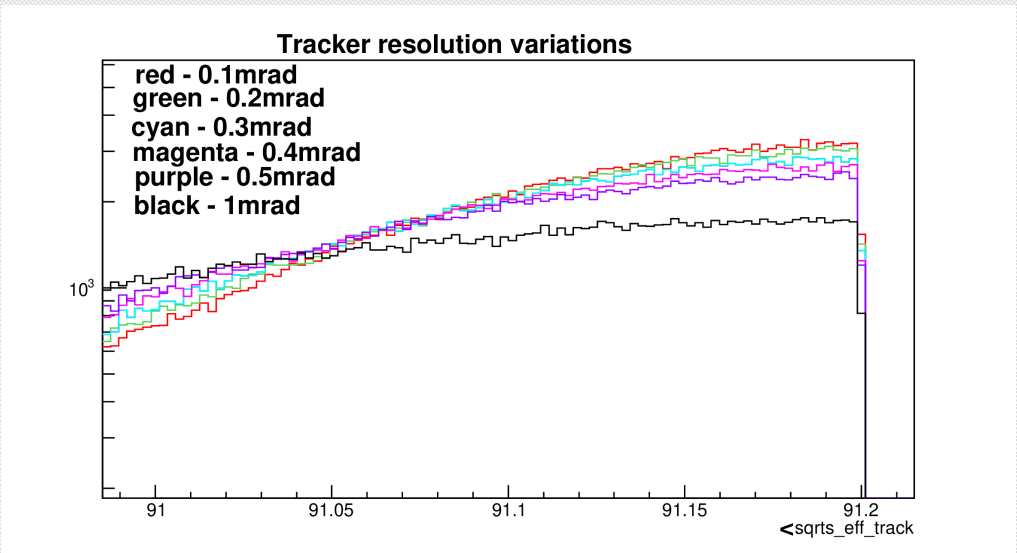
(*this is WHIZARD default parameterization for TESLA beam, should be smaller at CEPC (ongoing study)*)

Impact of estimated 0.1 mrad and 1 mrad detector resolution @ 91 GeV

Apparently, 0.1 mrad (100 µm TPC) doesn't compromise sensitivity to the beam-spread

s' sensitivity to detector resolution

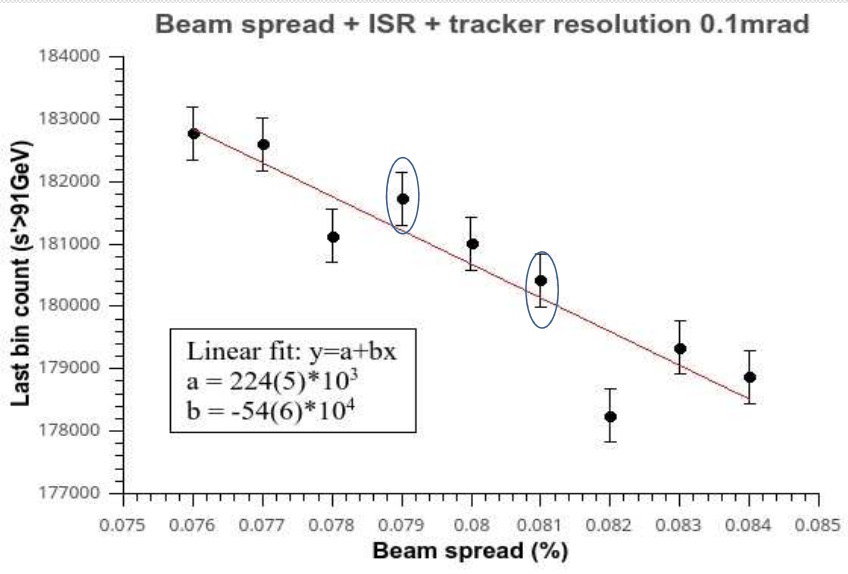
Can the method survive weaker tracking performance?
What is the uncertainty of the tracker resolution?

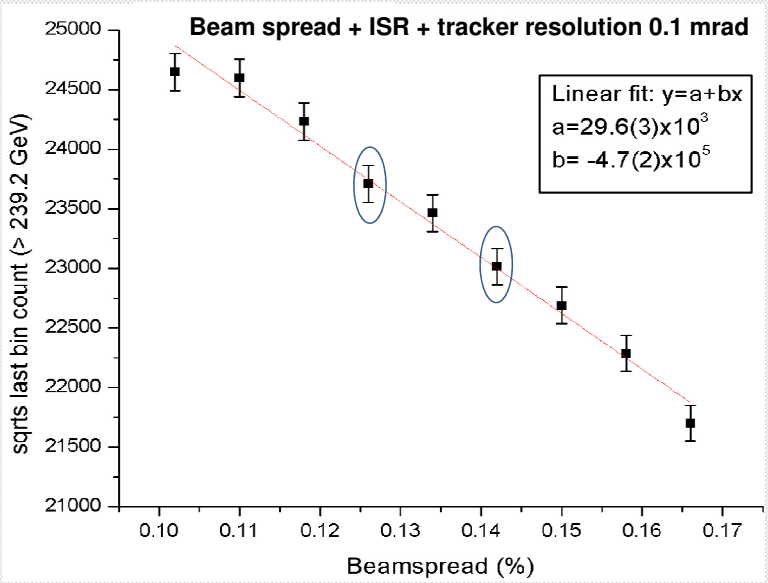


One should stick to the foreseen 0.1 mrad muon angular resolution (100 μm track resolution for TPC) to be known with 0.1 mrad margin

Beam-spread determination from *s'*

s' sensitivity to beam-spread @ 91 GeV (left) and 240 GeV (right)





250 kEvt. at Z^0 pole and 100 kEvt. at 240 GeV are sensitive to the beam-spread variations at 2.5 % (15 %) level, respectively

What do we need to be sensitive to $10^{-1,-2,-3}$ variations of the beam-spread?

Table of assumptions w.r.t. time/statistics

	Luminosity @ IP ($cm^{-2}\,s^{-1}$)	Energy spread (%)	Number of events	Cross-section $e^+e^-\rightarrow\mu^+\mu^-$	Collecting time	Beam-spread variation
Z pole (91.2 GeV)	$32\cdot10^{34}$	0.080	250K	1.5 nb	~ 10 min (2 min for 10^{-4} of $\mathcal{L}$)	$\sim2.5\cdot10^{-2}\cdot\delta E_b$ (900 keV)
Higgs factory (240 GeV)	$3\cdot10^{34}$	0.134	100K	4.1 pb	~ 10 days**	$\sim 0.15\cdot\delta E_b$ (~24 MeV)
FCCee Z pole*	$2.3\cdot10^{36}$	0.132	540 K	1.5 nb	~ 3 min	$\sim2\cdot10^{-3}\cdot\delta E_b$ (~120 keV)

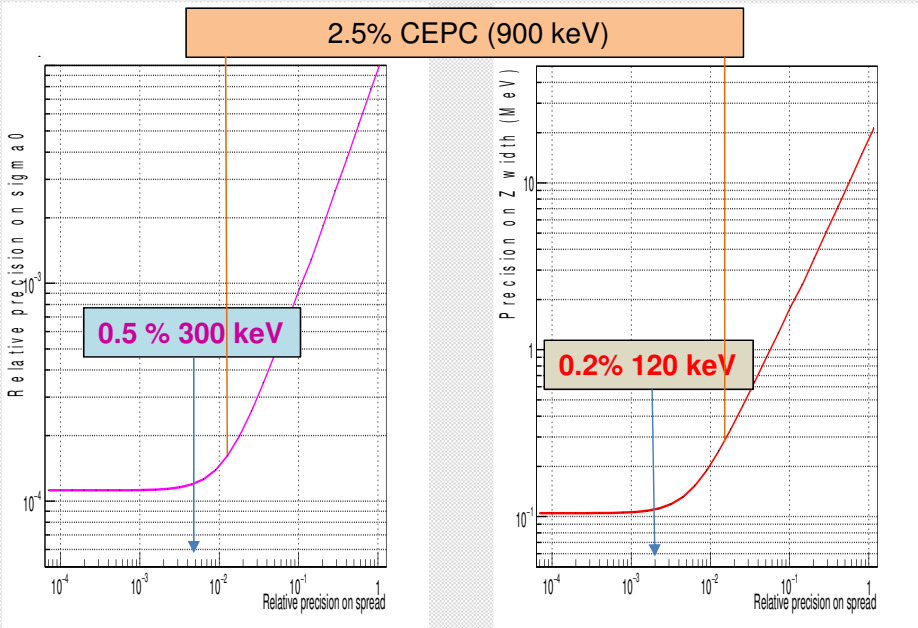
* [P. Janot, FCCee polarization WS, 2017]

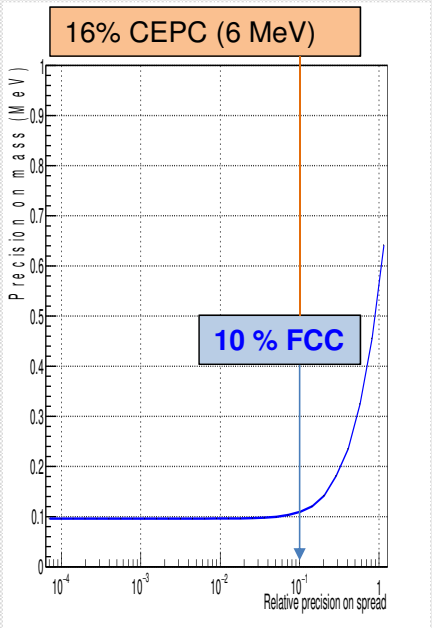
** For $\mathcal{L}$ uncertainty of 10^{-3} we don't need control better than the beam-spread of 0.134% (so the second row is for illustrative purposes)

Further motivation

It is interesting to note that other observables critically depend on the knowledge of the beam-spread (@ Z^0 pole):

- cross-section
- Z^0 total width
- Z^0 mass





* [P. Janot, FCCee polarization WS, 2017]

Conclusions

- Method (proposed for FCCee) of beam-spread determination based on muon polar angle reconstruction **nicely works at low energies** (Z^0 pole), due to high $e^+e^- \rightarrow \mu^+\mu^-$ cross-section and high instantaneous luminosity
- **@ Z^0 pole CEPC, ~2.5% accuracy of the beam spread is feasible (i.e. < 1 MeV)**
- **Integrated luminosity control of 10^{-4} at the Z^0 pole, requires 2 min of data collection**
- @ 240 GeV, beam-energy asymmetry within the existing beam-spread is satisfactory

- Method requires further study: effect of ISR (theoretical) uncertainty, full detector simulation, impact of similar final states backgrounds
- It is also interesting to check if the method is still applicable at ILC Z^0 pole, in the presence of beam-induced effects that are significantly larger than at circular machines