# Applications of fast timing in $E_{CM}$ related tasks

- crossing-angle studies (E. Perez)
- monochromatization studies

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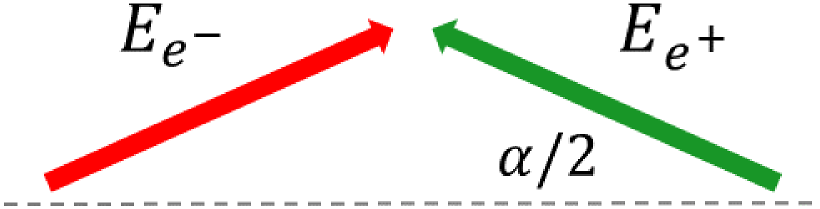
# $E_{CM}$ determination and crossing angle

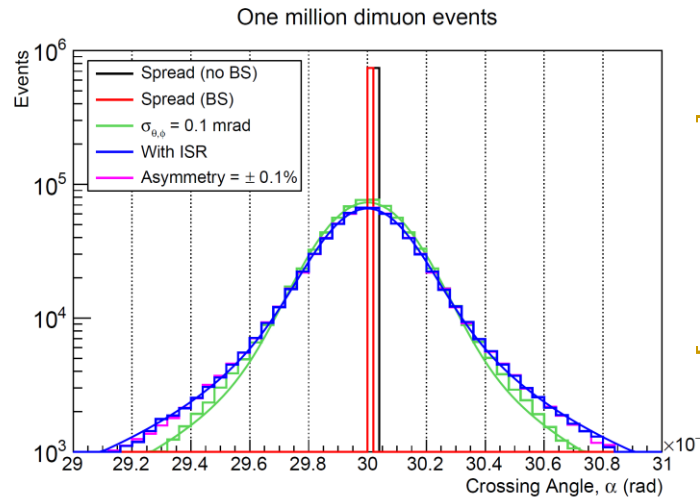
We determine average beam energies from resonant depolarization and then correct for *e.g.* synchrotron losses to obtain local $E_{e-}$ and $E_{e+}$ at interaction point. If crossing angle α is known, we can then calculate $E_{CM}$ (in this discussion neglecting other effects related to opposite-sign dispersion and collision offsets).




$$\sqrt{s} = 2\sqrt{E_{e^+}E_{e^-}}\cos\alpha/2$$

Collision angle can be determined by experiments through radiative dimuon events with very high statistical precision.

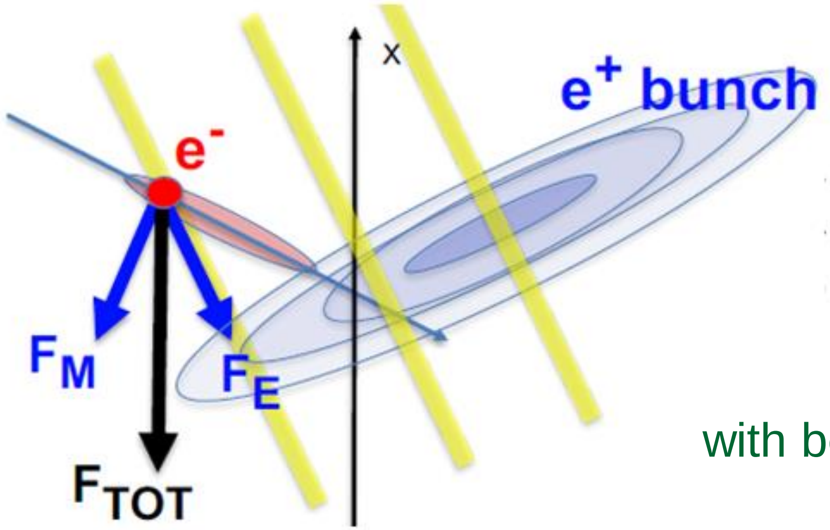
Measure with $10^{-5}$ statistical precision with $10^6$ dimuons, which is 10 mins of data taking at Z [arXiv:1909.12245].




[P. Janot *et al.*]

# Complications – the beam-beam kick

Particles in one bunch experience an electric & magnetic force of equal magnitude from particles in other bunch. Net force has a component along the particle trajectory, increasing (decreasing) energy before (after) collision, & a perpendicular component, which kicks beams & increases (decreases) crossing angle before (after) collision...




…but ECM unmodified.

known from RDP

$$\sqrt{s} = 2\sqrt{E^0_{e^+}E^0_{e^-}}\cos\alpha_0/2$$

$$= 2\sqrt{E_{e^+}E_{e^-}}\cos\alpha/2$$

with beam-beam effects

$$\alpha = \alpha_0 + \Delta\alpha$$

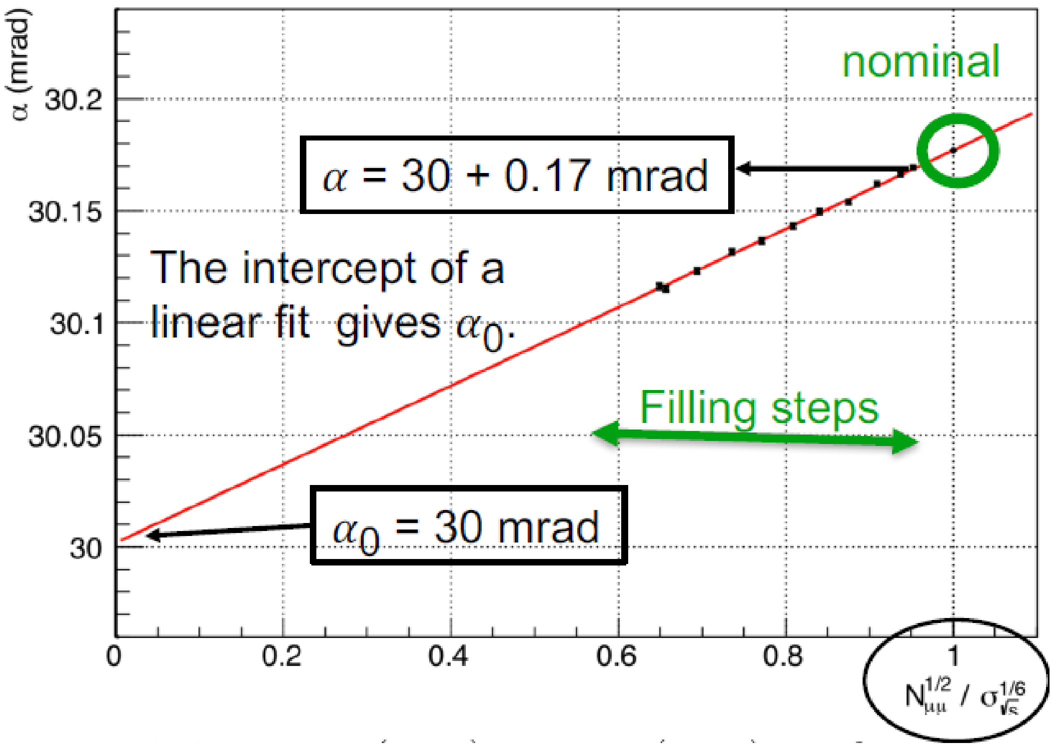
$\alpha_0 = 30$ mrad

$\Delta\alpha \approx 0.17$ mrad

Solution: measure α and Δα, & hence determine $\alpha_0$. Require <10% precision on Δα.

# Measuring Δα during filling

Δα depends on both bunch intensity and energy spread, hence can be determined through bending-angle measurements as machine is being filled.

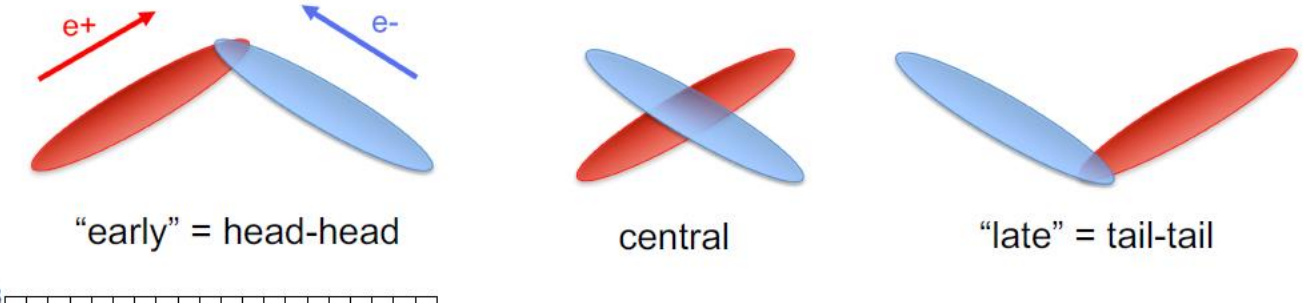



[P. Janot, E. Perez]

Seems to work well, but there may be practical limitations (*e.g.* stability during filling). Desirable to find complementary method, if only to provide redundancy.

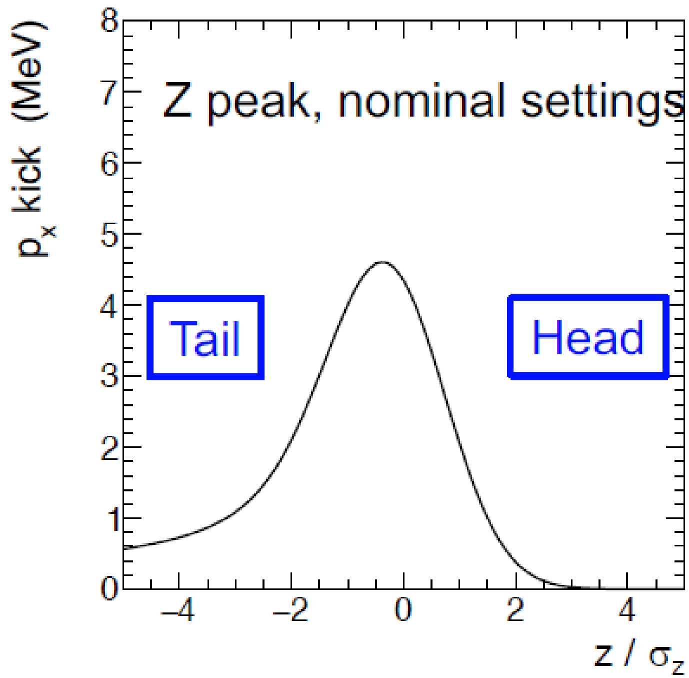
# Measuring Δα through timing info

Crossing angle leads to a correlation between position in bunch & interaction time.




$\sigma_z$ ~ 12 mm
$\sigma_t$ ~ 30 ps

The size of the kick varies with the position of the particle in the bunch, and therefore depends on the time of the interaction.




here z = 0 is in middle of bunch

# Measuring Δα through timing info

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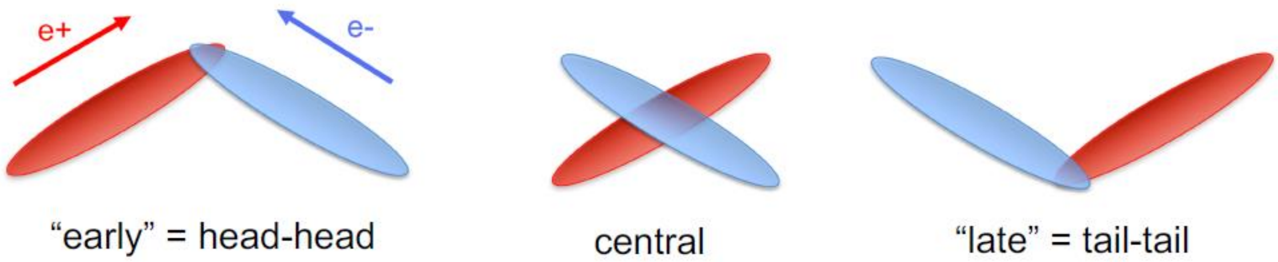
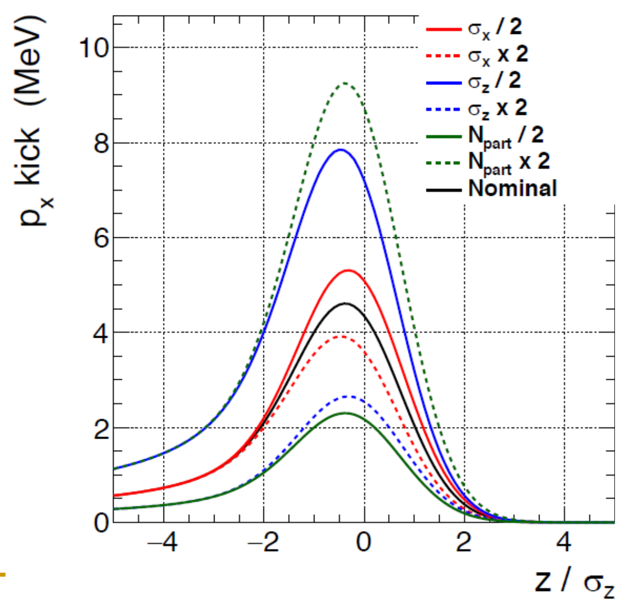
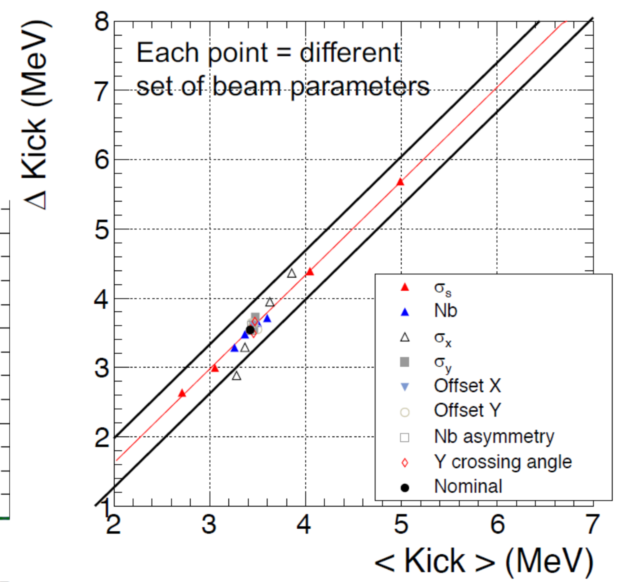



$\sigma_z \sim 12$ mm
$\sigma_t \sim 30$ ps

Look a Δ kick, *difference* of size of kick at z = 0 and z = 1σ. Difference is correlated to mean size of kick, as can be seen if we compare the two for a variety of bunch parameters.

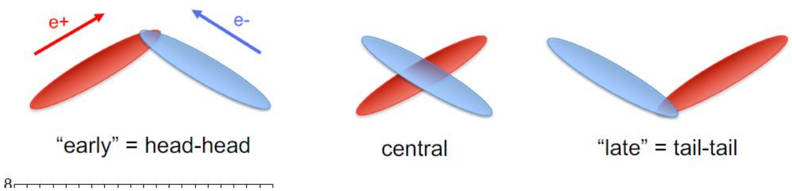



[E. Perez]

# Measuring Δα through timing info

We can effectively measure Δ kick in the experiment by measuring change in α for head (early) & central collisions.

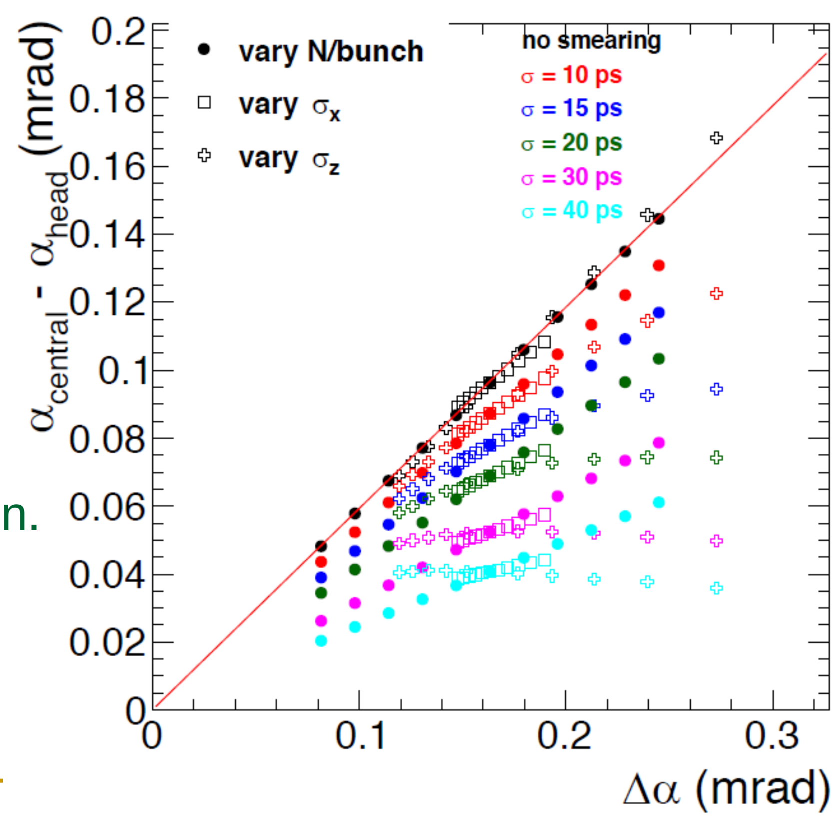



We expect $\alpha_{central} - \alpha_{head}$ to be correlated to Δα – what we want to find !

Making such a measurement requires precise timing information.

Indeed this correlation is found, here simulated for several timing resolutions, again scanning over different beam parameters to make manifest the correlation.

Very strong correlation seen for resolution of 10 ps, with some dependence still evident when this is degraded to 40 ps.

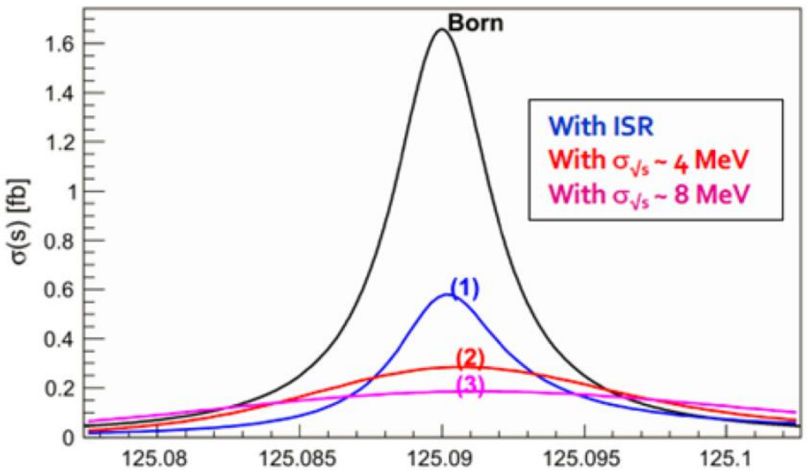


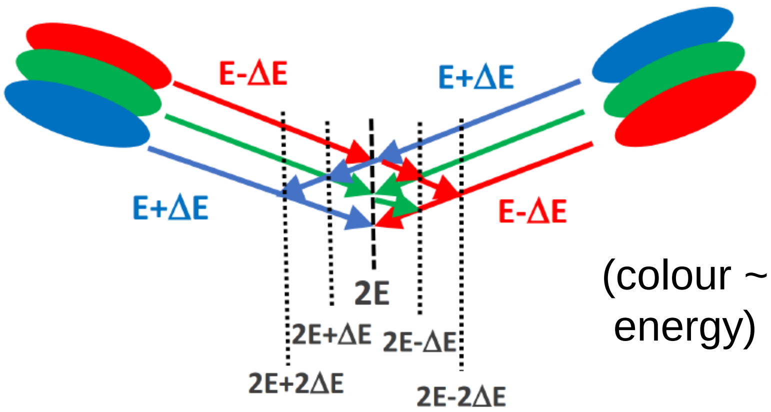

[E. Perez]

# Monochromatization for $e^+e^- \rightarrow H$

Any attempt to run at $E_{CM}$=125 GeV in order to measure the electron-Yukawa coupling requires monochromatization to reduce the energy spread, ideally < $\Gamma_H$.

Until now (see *e.g.* EPJ+ 137 (2022) 31), monochromatization schemes have been based on the possibility of introducing opposite-sign horizontal dispersion, and having collisions without (*i.e.* using crab cavity) or with a crossing angle.




[A. Blondel]

For illustrated scheme to be useful, events must be analysed differentially in bins of (x,z) and energy spread and mean boost must be measured in each.

# Monochromatization for $e^+e^- \rightarrow H$

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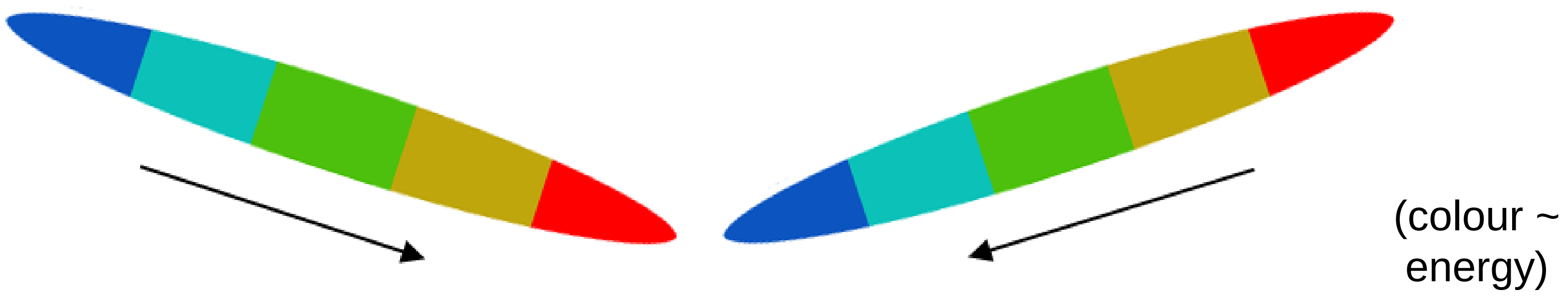


Alternative / complementary possibility – introduce longitudinal dispersion.

In this case it would be necessary to perform differential analysis in bins of interaction time. What resolution is necessary? Depends on exact pattern of dispersion. Dedicated study required. Most extreme case maybe 3 ps ?