Impressions from FCCee Polarisation and Energy Calibration Workshop

Jenny List
12th Future Colliders @ DESY meeting
23 September 2022

2nd FCC Energy Calibration, Polarization and Mono-chromatisation WS

… a two week workshop…

- started this Monday, runs til end of next week => 60% of the WS still to come!
- 1st week: focus on beam polarisation, joined with EIC
- structured sessions every day 13:00-18:00:
  - 13:00 - 15:00 plenary
  - 15:30 - 18:00 parallel sessions
- parallel sessions organised by WPs
  - WP1: Polarization simulations and spin-tune to beam energy relationship, wigglers and kickers
    (Eliana Gianfelice, Ivan Koop, Tatiana Pieloni)
  - WP2: Simulation of the relationship between average beam energy and centre-of-mass energies
    (Jörg Wenninger, Katsunobu Oide)
  - WP3: Polarimeter design, performance and integration
    (Aurelien Martens, Dave Gaskell, Thibaut Lefevre)
  - WP4: Measurements in particle physics experiments
    (Guy Wilkinson, Patrick Janot)
  - WP5: Monochromatization
    (Angeles Faus-Golfe, Frank Zimmermann)

This is not a summary…

… rather a personal choice of highlights

General Impressions

… from the first 4 days

- organisers did an excellent job to invite experts on the various topics from past, present and future:
  - LEP: Jörg Wenninger
  - SLC: Mike Woods
  - HERA: Stefan Schmitt, Fabian Zomer
  - JLab: Dave Gaskell, Alexandre Camsonne
  - SuperKEK-B: Mike Rooney
  - VEPP: Stepan Zakharov
  - LUXE: Louis Hélary, Gianluca Sarri
  - EIC: Ferdinand Willeke, Vadim Ptitsyn, Ciprian Gal
  - ILC: Graham Wilson, Aurelien Martens, JL
  - CLIC: Andre Sailer
  - CEPC: Zhe Duan, Tao Chen
- many talks are very interesting resources if you want to dig into the subject of polarisation & beam energy - and its history!
- no exact counting, but <50%, maybe ~30%, talks on FCCee itself
- 110 registrants, typical plenary attendance: ~15 in person, ~ 15 on zoom (@dinner: 19 :-))

Polarisation, Resonant Depolarisation and Beam Energy

Jacqueline Keintzel

- ultra-precise beam energy knowledge to measure M_Z to 100keV, width to 25 keV
- technique: resonant depolatisation
  - build-up polarisation
  - induce RF kick
  - when hitting the right frequency, resonance occurs
  - translate resonance frequency to energy

  => not that easy - see many talks at WS
- Sokolov-Ternov takes TIME, many hours
- beam-beam interaction (Bhabhas!) burns beams O(1 minute)

=> continuous top-up injection for colliding bunches, use non-colliding pilot bunches to build-up polarisation

- Lepton beams polarize naturally transversely over time → Sokolov-Ternov-Effect
- Depolarization naturally from synchrotron radiation, resonances, etc.
- Maximum polarization at about 92.4 % in lepton storage rings

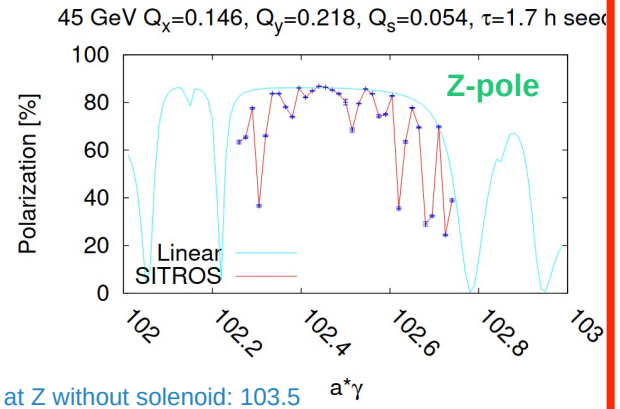
Strong unexpected resonance found for SITROS simulations

$$\underbrace{\tau^{-1}}_{\text{Effective polarization rate}} = \tau_{bks}^{-1} + \underbrace{\tau_{dep}^{-1}}_{\text{Depolarization rate}}$$

Baier-Katkov-Strakhovenko polarization rate

$$\tau_{bks}^{-1} = \frac{5\sqrt{3}}{8}\frac{\hbar r_e \gamma^5}{m_e C}\oint ds \frac{1-\frac{2}{9}(\hat{n}_0(s)\cdot\hat{s})^2}{|\rho(s)|^3}$$

Polarization direction in ŷ for planar ring



- Resonances with transverse and longitudinal axis

Q_x … horizontal tune
Q_y … vertical tune
Q_s … synchrotron tune
m_i, k … integer
a … gyromagnetic moment
γ … relativistic gamma

$$\underbrace{a\gamma}_{\text{Spin tune for ideal machine}} + \underbrace{m_x Q_x + m_y Q_y}_{\text{Transverse planes}} + \underbrace{m_s Q_s}_{\text{Longitudinal plane}} = k$$

Y. Wu: indico.cern.ch/event/1119730/

aγ at Z without solenoid: 103.5

E. Gianfelice-Wendt, indico.cern.ch/event/727555/contributions/3468285, 2019.

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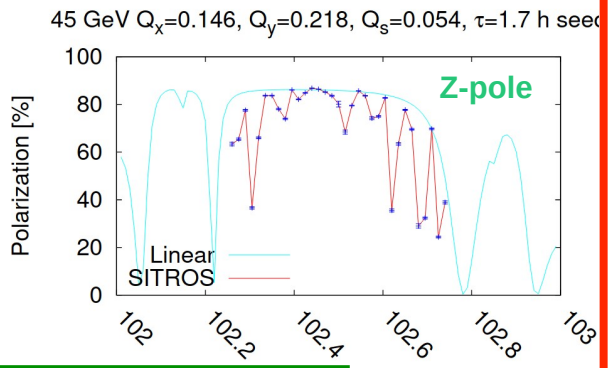

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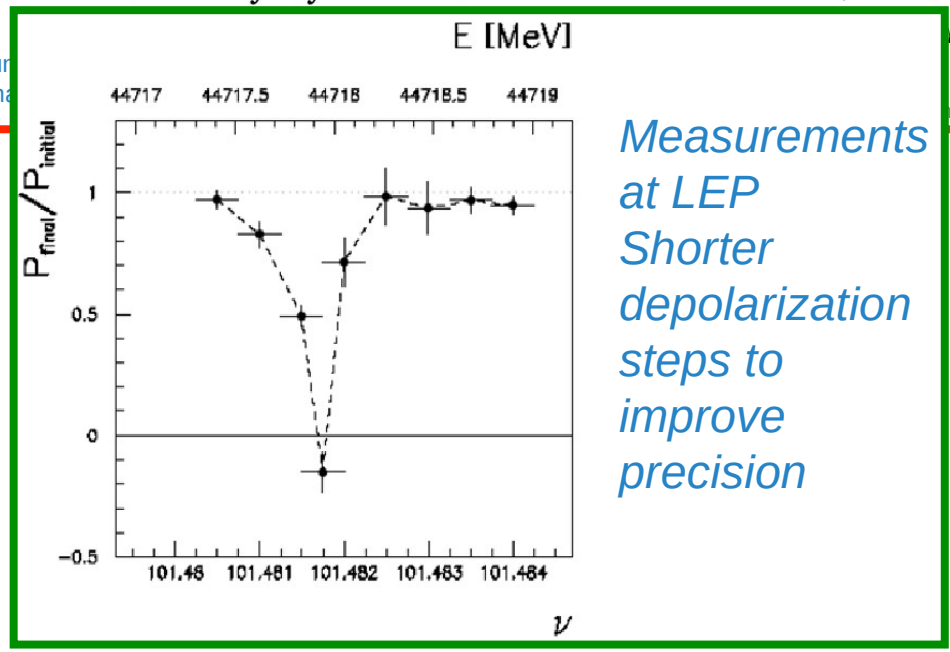

Measurements at LEP Shorter depolarization steps to improve precision

s/3468285, 2019.

Physics Motivation

Christophe Grojean

2

The precise values of the Higgs couplings control the structure of matter/Universe

m_W, m_Z ↔ Higgs couplings ✓

lifetime of stars

(why $t_{Sun} \sim t_{life\ evolution}$?)

m_e, m_u, m_d ↔ Higgs couplings ?

size of atoms — nuclei stability

EW @ $t \sim 10^{-10}$s ↔ Higgs self-coupling ?

matter/anti-matter ↔ CPV in Higgs sector ?

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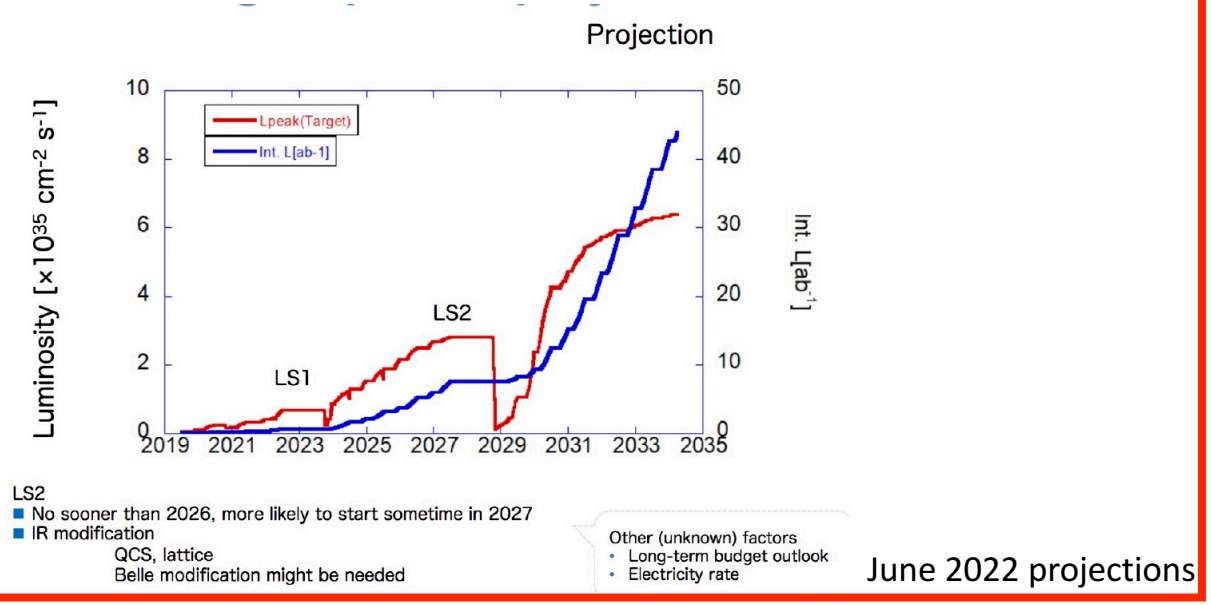
matter/anti-matter ↔ CPV in Higgs sector ?

=> essential that we sharpen messages like these, to reach other scientists,
and to develop them even further into exciting stories for the general public & policy makers!

Polarisation Upgrade of SuperKEK-B

Mike Roney

- Would aim to start to install polarization in Long Shutdown 2 (LS2) for new final focus ~2027, or later
- Polarization upgrade R&D in MEXT KEK Roadmap 2021-26



June 2022 projections

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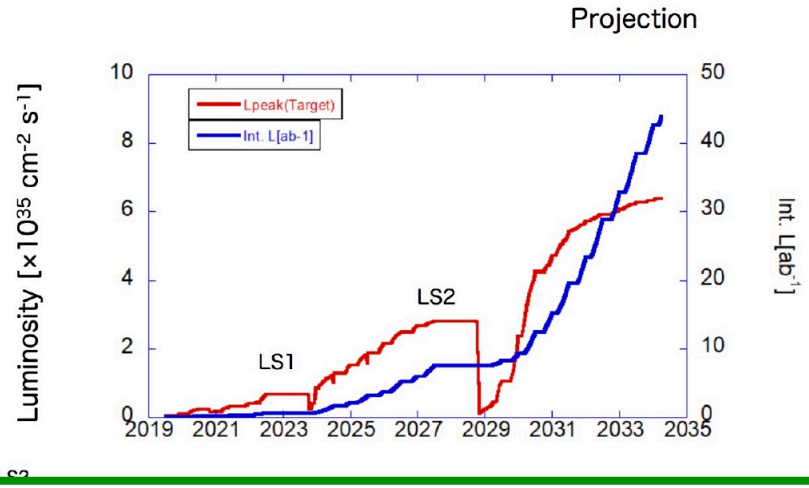
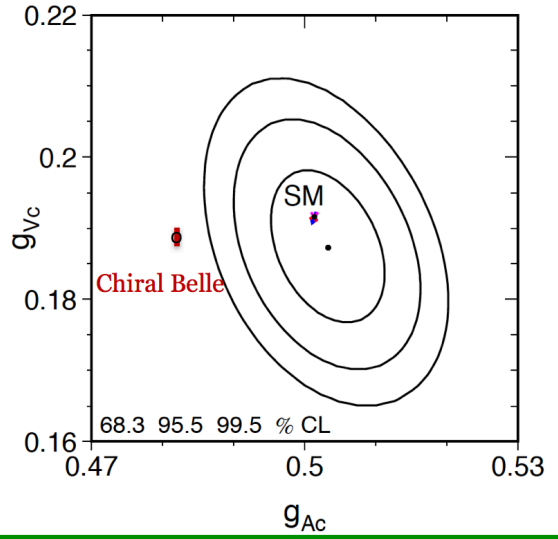
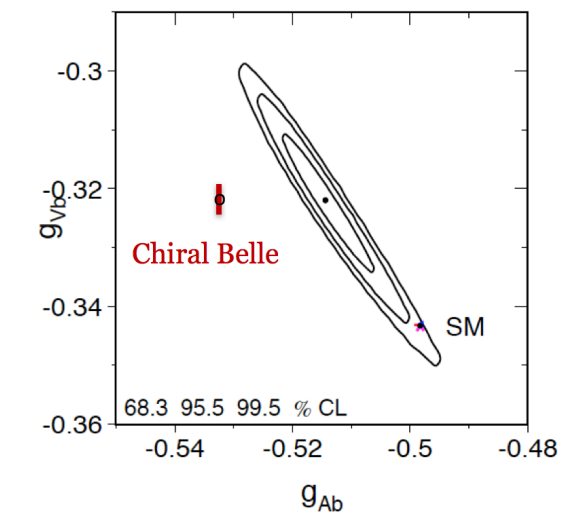


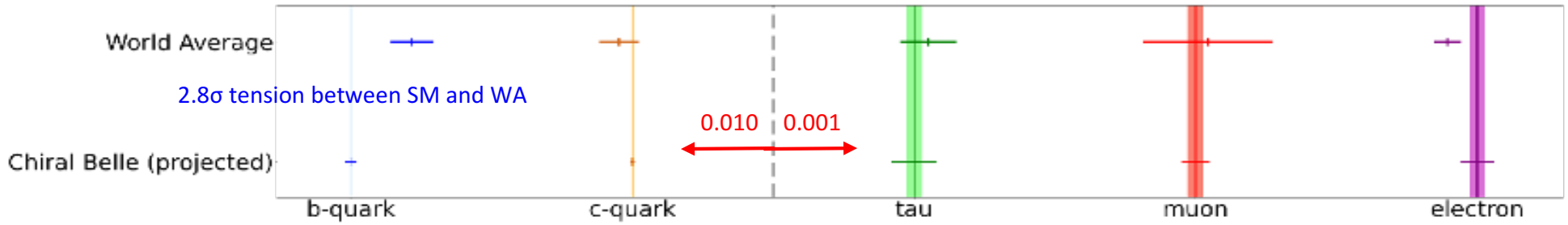
c-quark:
Chiral Belle ~7 times more precise



b-quark:
Chiral Belle ~4 times more precise
with 20 ab^{-1}



Combined analysis (assuming universality) : $\sigma(g_V^f) = 0.00033_{stat} \pm 0.00018_{sys}$ [*cf.* SM error of ±0.0003]



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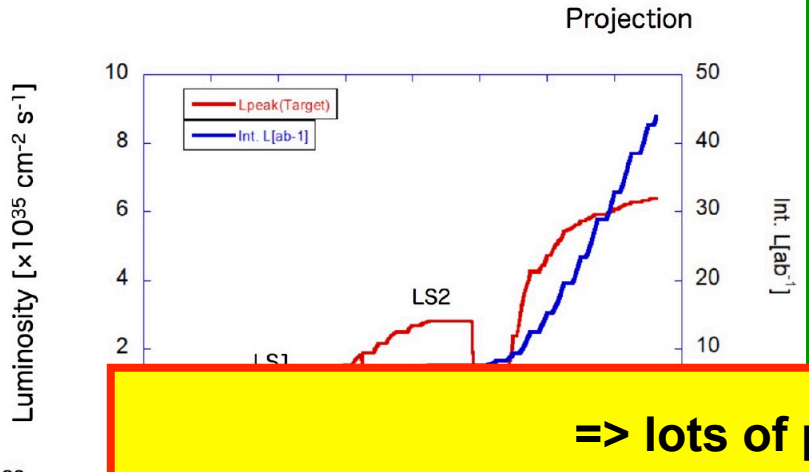

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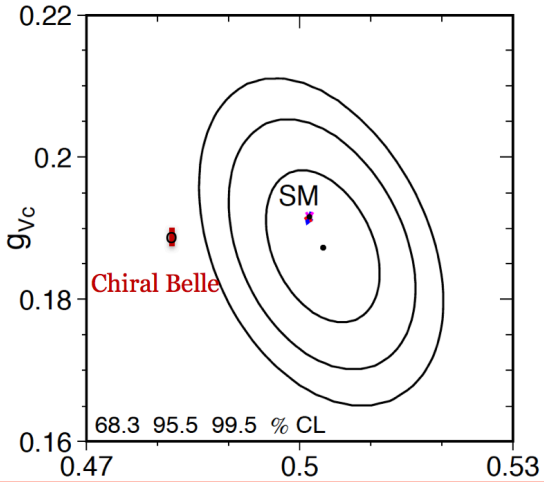

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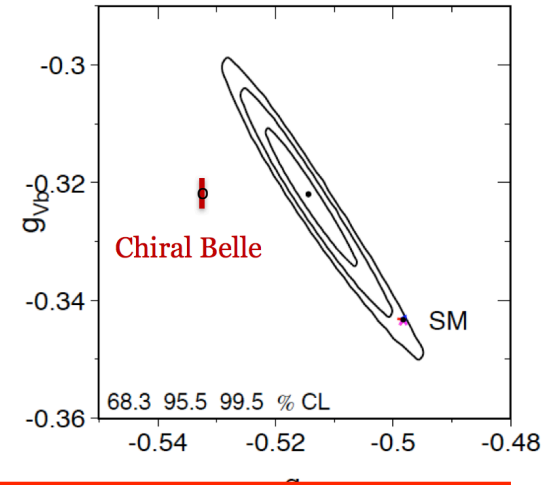
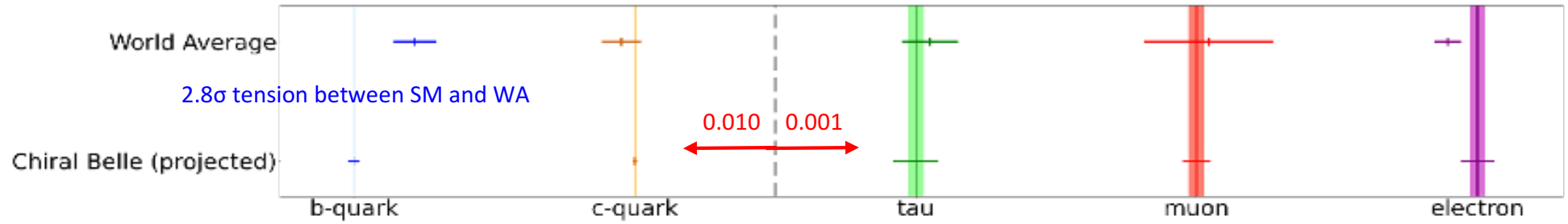


=> lots of progress reported on all aspects
- source, spin rotators, spin tracking, minimal changes to lattice, polarimetry, …

Combined



Residual Longitudinal Polarisation

Guy Wilkinson

Any residual longitudinal-polarisation will bias cross sections & forward-backward asymmetries (indeed, high longitudinal polarisation is actually useful, but we assume we are not in that regime – rather longitudinal polarisation is a nuisance).

Consider forward-backward asymmetry of $b\bar{b}$ at *Z* pole: $A_{\mathrm{FB}}^{b} = \frac{3}{4}\mathcal{A}_e\mathcal{A}_b$

where in the SM $\mathcal{A}_e \approx 0.15, \quad \mathcal{A}_b \approx 0.95 \Longrightarrow A_{\mathrm{FB}}^{b} \approx 0.11$

Now, if there is longitudinal polarisation, asymmetry becomes: $\left(A_{\mathrm{FB}}^{b}\right)' = \frac{3}{4}\mathcal{A}_e'\mathcal{A}_b$

where $\mathcal{A}_e' = -\left(\frac{\mathcal{A}_e - P}{1 - \mathcal{A}_e P}\right)$ with $P = \frac{(P_z)_{e^-} - (P_z)_{e^+}}{1 - (P_z)_{e^-}(P_z)_{e^+}}$

and $(P_z)_{e^\pm}$ the longitudinal polarisation of the $e^\pm$.

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Consider forwa

where in the S

Now, if there is

where $\mathcal{A}_e' = -$

and $(P_Z)_{e^\pm}$ the

So, if $(P_Z)_{e^-} = (P_Z)_{e^+}$ (no reason to be so) = 10^{-5} (ballpark guess)

$$P = 2 \times 10^{-5} \implies \frac{(A_{FB}^b)' - A_{FB}^b}{A_{FB}^b} = 1.3 \times 10^{-4}$$

Statistical uncertainty on A_{FB}^b around 2 x 10^{-5} (relative), and QCD uncertainty which will probably be larger. Still, to be safe we would want to control P_Z to < 10^{-5}.

How is this to be done ? Measurements must be made on colliding bunches, where scattering rates are lower. Can we sample all bunches ? Will it prove necessary to depolarise the physics bunches ? If so, we will still need to monitor residual effects.

Note also, that calculations required to transport the measurement of 3-vector at polarimeter to P_Z value at the interaction points. How can this be cross checked ?

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=> limitations from residual polarisation of nominally unpolarised beam is something we've been pointing out since several years (cf PhD thesis Robert Karl, Jakob Beyer)

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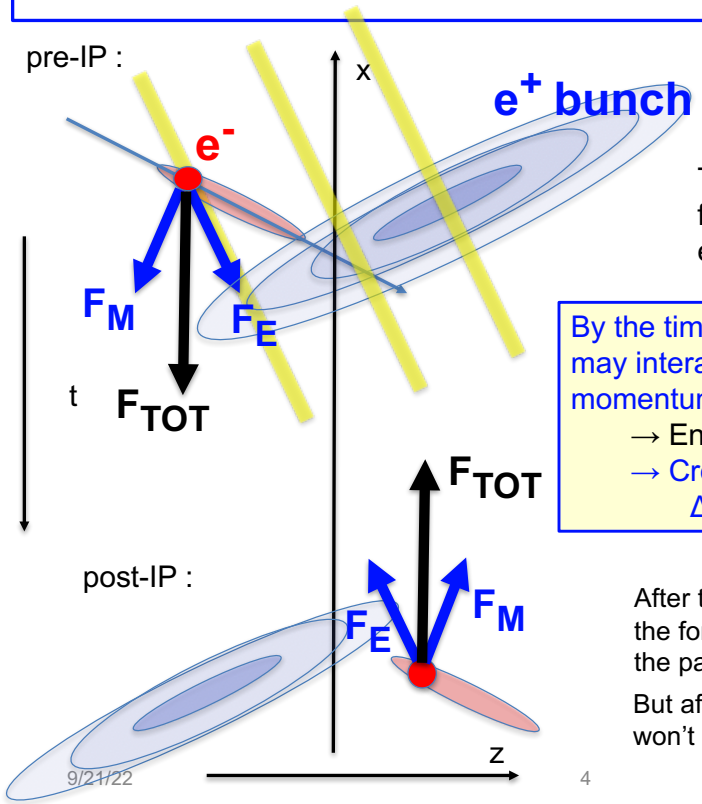
Application for Fast Timing Detectors ?

Emmanuel Perez

Beam-beam effects complicate the picture…



Before it reaches the IP :
The Lorentz force felt by the electron
is along the x axis,
pointing downwards.

The particle is accelerated by this force along -x, and it gains energy.

By the time the particles reach the IP and may interact, they have acquired a net momentum ("kick") along (-) x.

→ Energy increases $\Delta E = \text{Kick} \times \sin\alpha/2$

→ Crossing angle increases:

$\Delta(\alpha/2) = \text{Kick} / E_e$

After the IP :
the force is in the other direction,
the particle is decelerated and looses energy.

But after it has crossed the IP, the particle won't be able to collide anymore in this BX.

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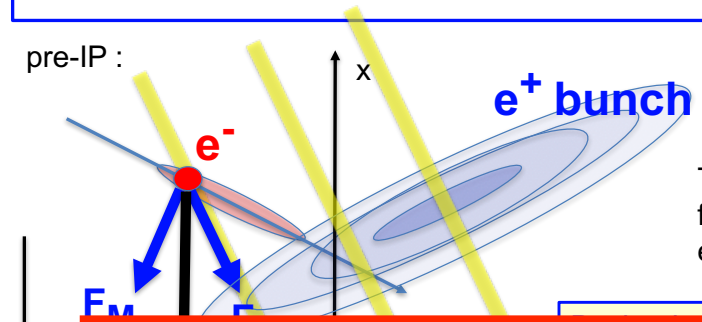
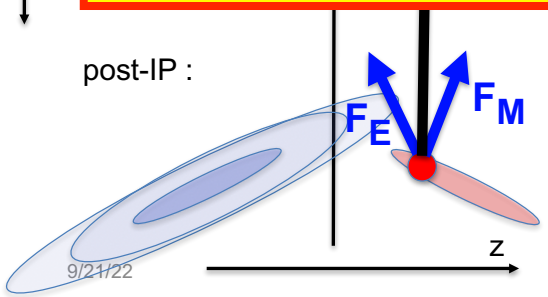


The particle is accelerated by this force along -x, and it gains energy.

Interplay of crossing angle & beam-beam effects
=> Collision energy and transverse kick depend on position of colliding particles in bunch



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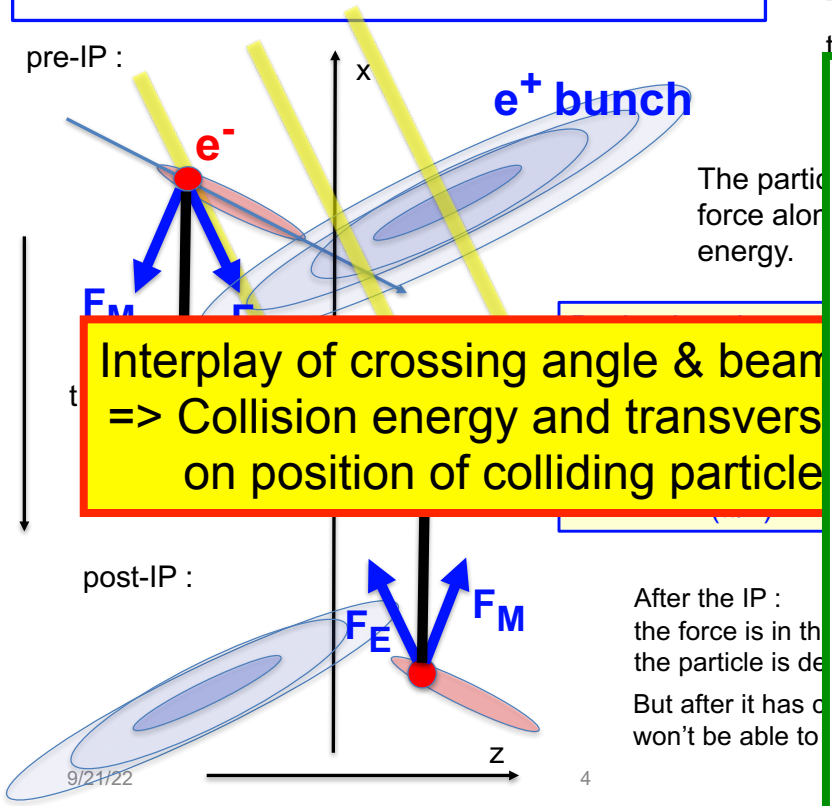

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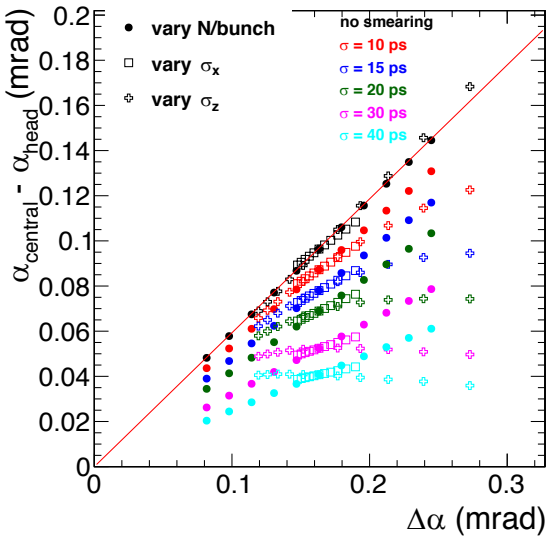
Assume that we can bin the dimuon events according to the timing :

- Measure the effective crossing angle separately for the "head" and the "central" collisions
- $\alpha_{central} - \alpha_{head} = (\alpha_{central} - \alpha_0) - (\alpha_{head} - \alpha_0) = \Delta Kick$ of the previous slide
- From the correlation shown on the previous slide:
  - the measurement of $\alpha_{central} - \alpha_{head}$ (i.e. of $\Delta kick$) gives the average kick (i.e. the average $\Delta\alpha$, i.e. α_0)
- Can be a complementary check of the method described in the paper (does not require bunches with different intensities).

Plugging in some timing resolution:

- With a worse and worse resolution: $\alpha_{central} - \alpha_{head}$ decreases as expected (resolution washes out the difference)
- Effect of resolution is bad when σ_z is decreased (expected)
- Apart for large σ_z variations, linear correlation is maintained and $\alpha_{central} - \alpha_{head}$ remains large enough to be measured, even with a resolution of tens of ps.

May be worth pursuing a bit… ?



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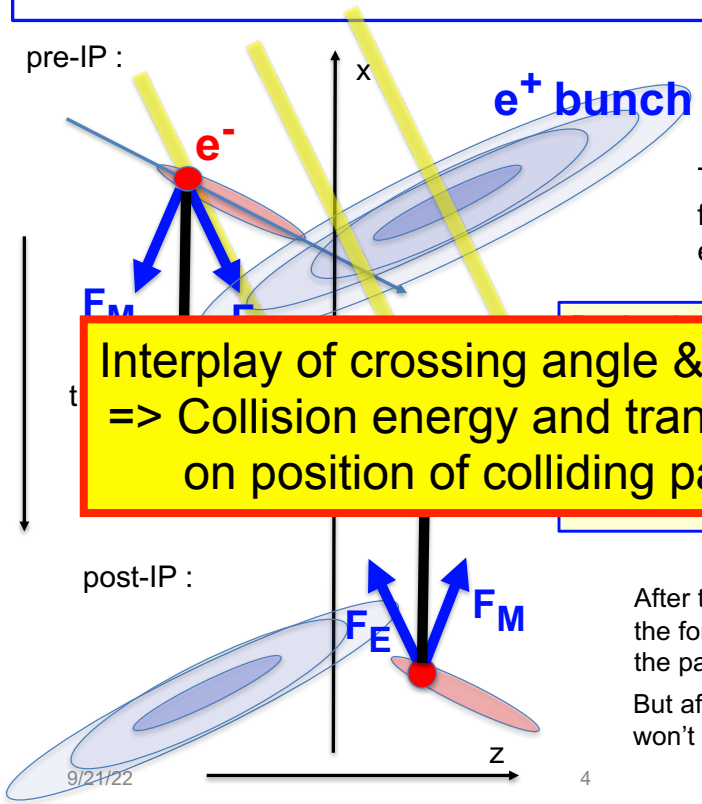
pre-IP :



post-IP :

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After the IP : the force is in th… the particle is de…

But after it has c… won't be able to…

9/21/22 4

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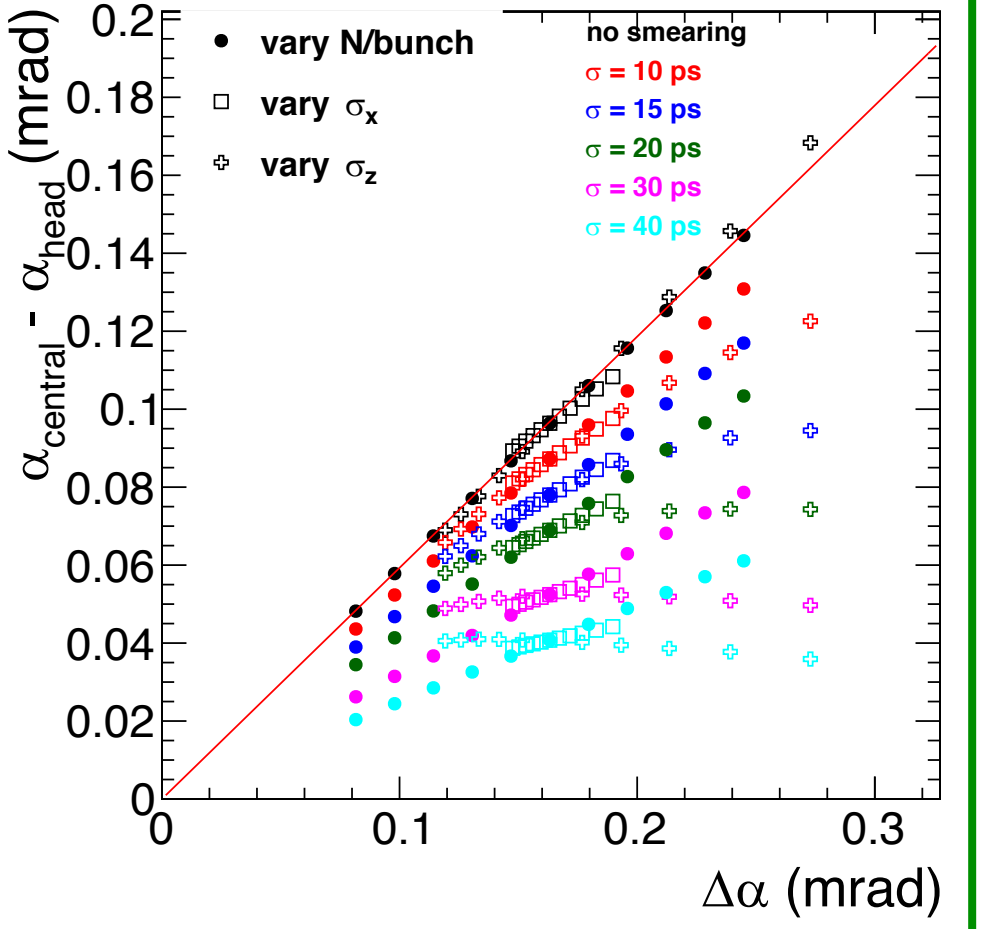

Summary

… of a non-summary :)

- interesting workshop
- very nice to bring again the experts from past / present / future accelerators
- will continue this afternoon and this week
- there are many challenges still ahead until the FCCee ambitions are substantiated…
- https://indico.cern.ch/e/EPOL