WP4: measurements in particle physics experiments
Summary of Wed week 1 session

Patrick Janot (CERN) & Guy Wilkinson (Oxford)

2nd FCC Polarisation Workshop, CERN
22/9/22

Overview

15:30 → 18:30 **WP4: 37/R-022**

Conveners: Guy Wilkinson (University of Oxford (GB)), Patrick Janot (CERN)

15:30 **Luminosity spectrum reconstruction with Bhabhas**
Speaker: Andre Sailer (CERN)
220921_fcc_sailer_...

15:55 **Lessons from ILC applied to FCC-ee**
Speaker: Graham Wilson (The University of Kansas (US))
ECMP_DiMuons_ar... EPOL1.pdf

16:20 **Crossing angle and beam-beam effects**
Speaker: Emmanuel Francois Perez (CERN)
2022_09_21_Beam...

16:45 **Break**

17:00 **Beam energy (spread) measurement with dimuons**
Speaker: Patrick Janot (CERN)
WG4_EnergySpread.... WG4_EnergySpread....

17:25 **Absolute detector alignment with dimuons**
Speaker: Patrick Janot (CERN)
WG4_DetectorAlign... WG4_DetectorAlign...

Overview

15:30 → 18:30 **WP4: 37/R-022**

Conveners: Guy Wilkinson (University of Oxford (GB)), Patrick Janot (CERN)

15:30 **Luminosity spectrum reconstruction with Bhabhas**
Speaker: Andre Sailer (CERN)
220921_fcc_sailer_...

15:55 **Lessons from ILC applied to FCC-ee**
Speaker: Graham Wilson (The University of Kansas (US))
ECMP_DiMuons_ar... EPOL1.pdf

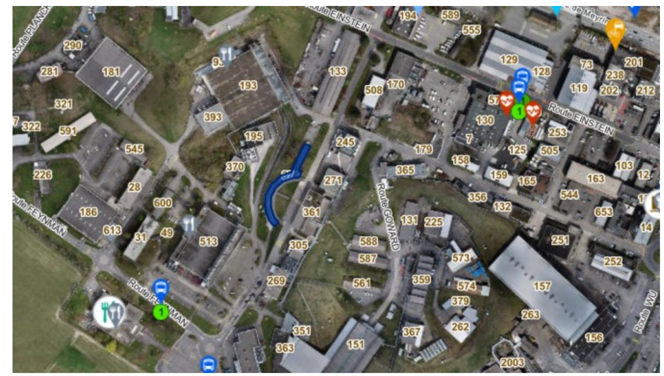
16:20 **Crossing angle and beam-beam effects**
Speaker: Emmanuel Francois Perez (CERN)
2022_09_21_Beam...

16:45 **Break**

17:00 **Beam energy (spread) measurement with dimuons**
Speaker: Patrick Janot (CERN)
WG4_EnergySpread.... WG4_EnergySpread....

17:25 **Absolute detector alignment with dimuons**
Speaker: Patrick Janot (CERN)
WG4_DetectorAlign... WG4_DetectorAlign...

- Task 1 – find the building
- Task 2 – enter the room
- Task 3 – start Zoom



Building 37 is not prime real estate (CERN's flagship future project deserves better). Nevertheless, we now know what we are doing and the session this pm will run smoothly !

Overview

15:30 → 18:30 **WP4: 37/R-022**

Conveners: Guy Wilkinson (University of Oxford (GB)), Patrick Janot (CERN)

- 15:30 **Luminosity spectrum reconstruction with Bhabhas**
  Speaker: Andre Sailer (CERN)
  220921_fcc_sailer_...
- 15:55 **Lessons from ILC applied to FCC-ee**
  Speaker: Graham Wilson (The University of Kansas (US))
  ECMP_DiMuons_ar... | EPOL1.pdf
- 16:20 **Crossing angle and beam-beam effects**
  Speaker: Emmanuel Francois Perez (CERN)
  2022_09_21_Beam...
- 16:45 **Break**
- 17:00 **Beam energy (spread) measurement with dimuons**
  Speaker: Patrick Janot (CERN)
  WG4_EnergySpread.... | WG4_EnergySpread....
- 17:25 **Absolute detector alignment with dimuons**
  Speaker: Patrick Janot (CERN)
  WG4_DetectorAlign... | WG4_DetectorAlign...

WP4's remit: measurement of energy related quantities (*e.g.* E_{CM}, E_{CM} spread etc.) from physics events in experiments.

Much impressive work performed for arXiv:1909.12245 Several talks in session served as reminders of what was done, with encouragement for new blood to take work forward.

However, new results were shown.

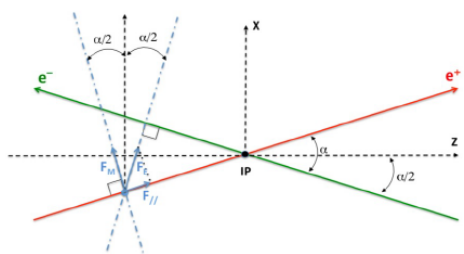
Plus summaries of the impressive work done by our ILC/CLIC friends.

Dimuons – the gift that keeps on giving

Patrick Janot reminded us of the many wonderful things that can be measured with dimuon events, such as E_{CM}, crossing angle, E_{CM} spread, z boost…

Very pedagogical, showing derivations, and also some unsolved problems !

- Beams cross at an angle α in the horizontal plane
  - The horizontal plane is defined as the plane subtended the two beams



$$s = (p_e^+ + p_e^-)^2$$

$$e^+\left(E_e^+ \sin\frac{\alpha}{2}, 0, \; E_e^+ \cos\frac{\alpha}{2}, E_e^+\right)$$

$$e^-\left(E_e^- \sin\frac{\alpha}{2}, 0, -E_e^- \cos\frac{\alpha}{2}, E_e^-\right)$$

$$\sqrt{s} = 2\sqrt{E_e^+ E_e^- \cos\frac{\alpha}{2}}$$

with $E_e^\pm = E(1 \pm \epsilon)$, $\sqrt{s} = 2E\sqrt{1-\epsilon^2}\cos\frac{\alpha}{2}$

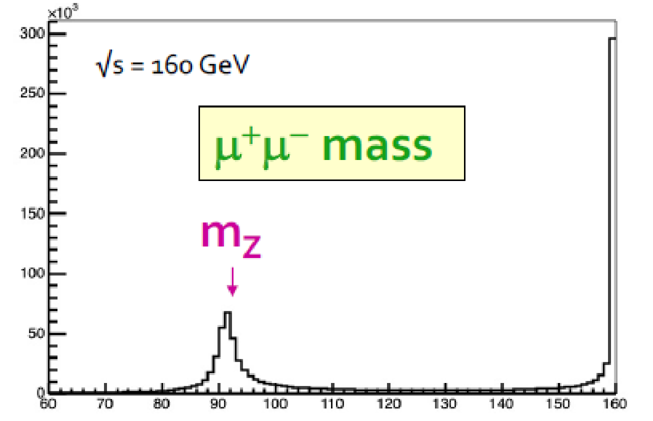
- The z axis is the bisector of the two beam directions
- The y axis is perpendicular to the (x,z) plane
  - → Polar angle θ defined wrt the z axis
  - → Azimuthal angle φ defined in the (x,y) plane

ffbar events are a very rich resource. Plenty of scope for New blood to become involved, to check results with a higher level of realism and to explore new ideas.

Dimuons – the gift that keeps on giving

As already explained by Patrick on Monday, radiative return dimuon events can be used to determine E_{CM}, calibrating from Z mass.

New result this week for running at m_H.



	$\sqrt{s}$	E_γ (GeV)	$N_{\mu\mu}$ (×10⁶)	N_{qq} (×10⁶)	$\sigma_{\sqrt{s}}(\mu\mu)$	$\sigma_{\sqrt{s}}(qq)$	$\sigma_{\sqrt{s}}$ (comb.)	$\sigma_{\sqrt{s}}$ (EPOL)	
6 ab⁻¹	m_H	29	107	173	660 keV	280 keV	225 keV	200 keV ?	NEW !
12 ab⁻¹	$2m_W$	54	47	667	900 keV	340 keV	285 keV	300 keV	
5 ab⁻¹	240 GeV	102	5.6	53	4.2 MeV	2.4 MeV	1.7 MeV	–	
0.2 ab⁻¹	$2m_{top}$	163	0.1	0.3	51 MeV	60 MeV	26 MeV	–	

Looks very promising, but study should be repeated in a 'professional' manner.

Dimuons – the gift that keeps on giving

Generator-level studies performed with dimuons indicates that it should be possible to measure energy spread to required level of precision.

- **Extract from the conclusions of arXiv:1909.12245**

To be revised

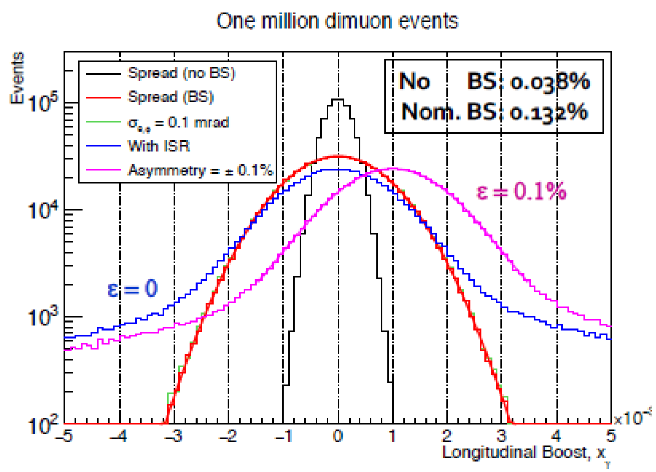
Pseudo Observable	Γ_Z			$\alpha_{QED}(m_Z^2)$		Γ_W	Γ_{top}
Acceptable error	35 keV			10^{-5}		0.5 MeV	18 MeV
$\sqrt{s}$ (GeV)	87.9	91.2	93.8	87.9	93.8	161	350
$\sigma(\delta E)/\delta E$	0.8%	0.2%	0.8%	0.7%		11%	35%
$N_{e^+e^-\to\mu^+\mu^-}$	$5\,10^4$	$8\,10^5$	$5\,10^4$	$6.5\,10^4$		260	25
L ($10^{34}\,cm^{-2}s^{-1}$)	230					28	1.8
$\sigma_{\mu\mu}$ (pb)	185	1450	460	185	460	4.0	0.8
Dimuon rate (Hz)	425	3325	1050	425	1050	1.1	0.015
Time needed	2 min	4 min	$<$ 1 min	3 min	1 min	4 min	30 min

- **All these numbers ought to be checked with professional analysis (gen, sim, reco, ana)**
- **A column for the Higgs direct production at the H pole ($\sqrt{s} = m_H$) must be added**

Dimuons – the gift that keeps on giving

However, the hard work starts only now…

- In real life, we'll deal with a distribution that gathers many effects
  - ISR, angular resolution, √s spread, longitudinal boost
  - Need to disentangle all these effects
    - Master the boost impact
      - → Analytically (best) or numerically
    - Predict ISR with adequate precision
      - → Improvements needed ?
    - Improve statistical uncertainty
      - → All lepton species ?
    - Map angular resolution from data
      - → What precision is needed ?
      - → What mapping is needed ?
      - → What resolution is needed ?

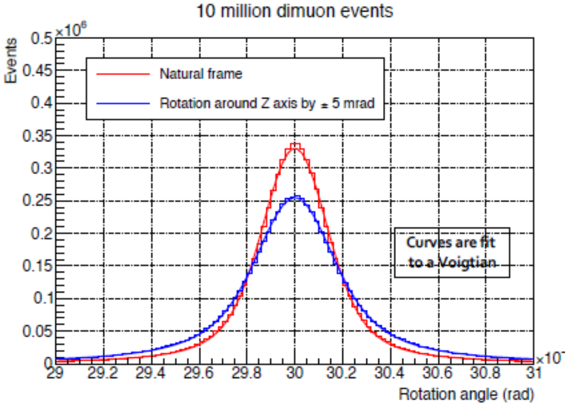


  - Need high-quality generation / simulation

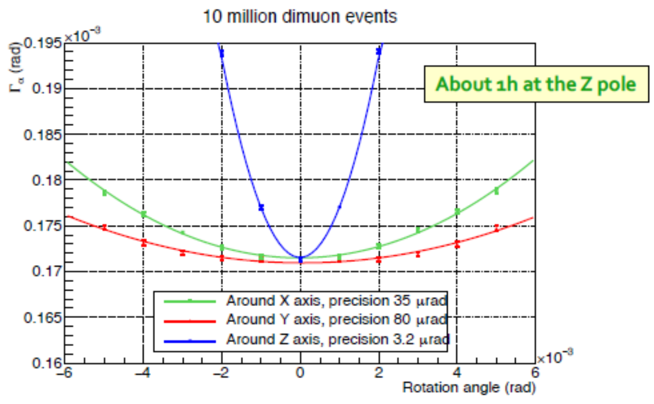
Lots of opportunity to new people to contribute !

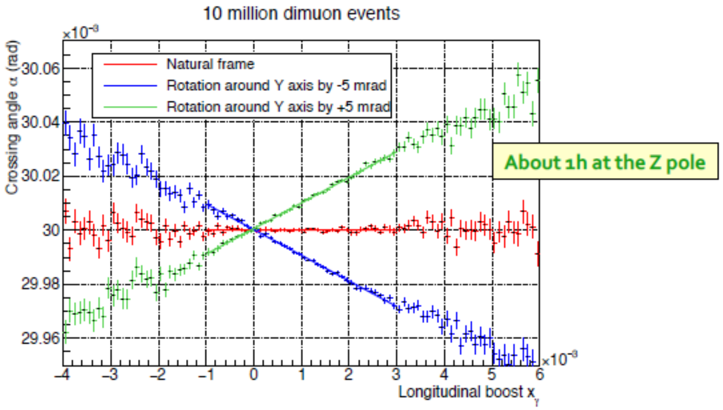
Dimuons – the gift that keeps on giving

New studies from Patrick – dimuon events can also be used to align the detector system w.r.t. the beam coordinate system.



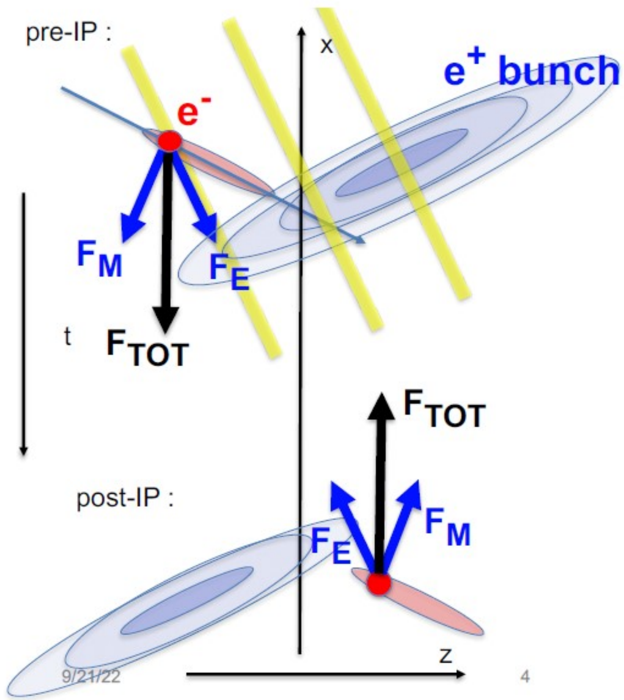
Minimising spread on measured crossing angle, and removing any correlation enables all three Euler angles to be determined !





Crossing-angle & beam-beam effects

Emmanuel Perez, reported on previous work of himself,
P. Janot, D. Shatilov and Y. Voutsinas



$$\sqrt{s} = 2\sqrt{E_+^0 E_-^0}\cos\alpha_0/2 = 2\sqrt{E_+ E_-}\cos\alpha/2,$$

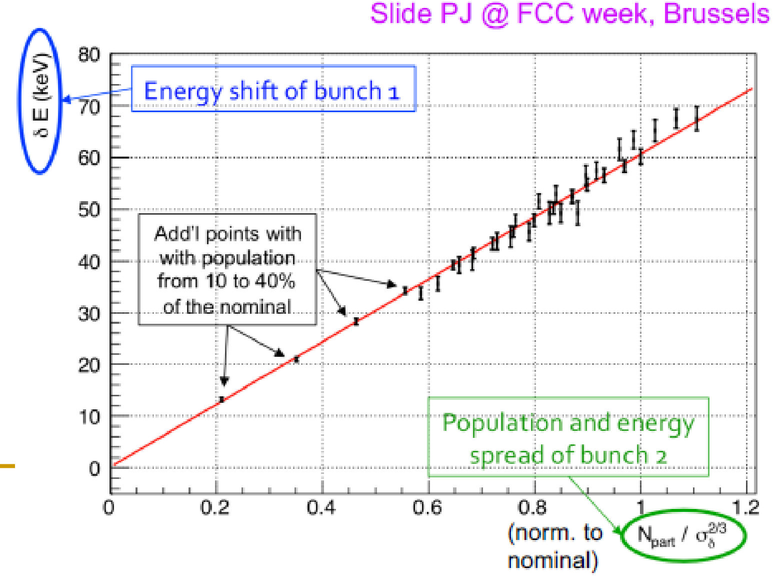
E in absence of BB effects, measured with RDP

??

α with BB effects, measured with dimuons

Need to get at α_0. Can do so by measuring crossing angle with dimuon events as a function of intensity and extrapolating back to zero effect.

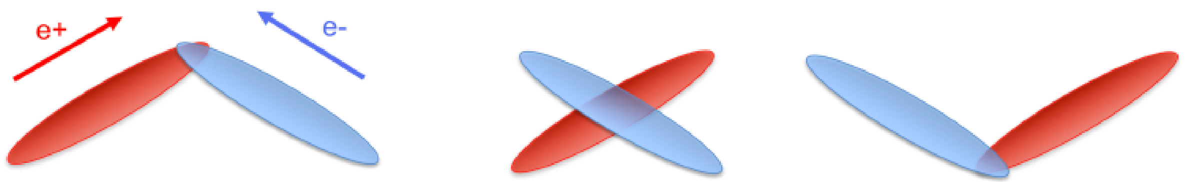
Slide PJ @ FCC week, Brussels



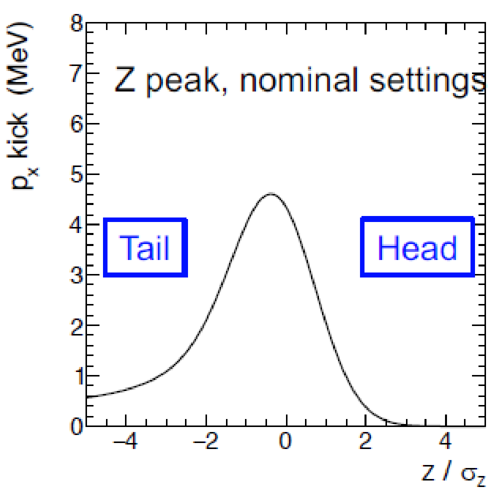
Crossing-angle & beam-beam effects

Alternative techniques – using precise timing information

Due to the xing angle: The longitudinal position (within its bunch) of an interacting e+/- is determined by the time of the interaction (with σ_z = 12 mm, σ_t = 30 ps) :



"early" = head-head   central   "late" = tail-tail



With some measurement of the interaction time (hence of z) : we can exploit the shape of this curve.

The time of the collision can be inferred by measuring the time of the charged particles in final state, e.g. in dedicated timing layer.

12 E.Perez

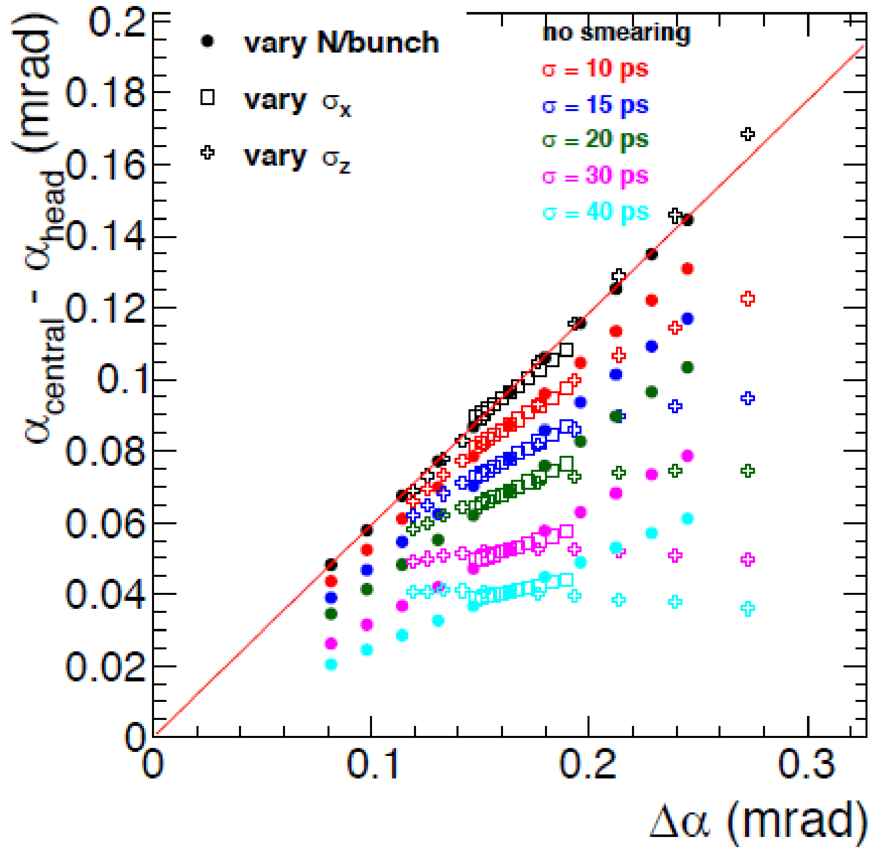
Crossing-angle & beam-beam effects

Alternative techniques – using precise timing information

Seems feasible !

Studies performed for different assumed timing resolutions.

These techniques may have relevance for monochromatisation studies ?



Lessons from our ILC friends

[arXiv:2209.03281]

Center-of-mass energy determination using $e^+e^- \to \mu^+\mu^-(\gamma)$ events at future e^+e^- colliders

Brendon Madison and Graham W. Wilson

Department of Physics and Astronomy, University of Kansas, Lawrence, KS 66045, USA

Abstract

Methods for measuring the absolute center-of-mass energy, $\sqrt{s}$, and its distribution, are investigated for future e^+e^- Higgs-factory colliders using *in situ* e^+e^- collisions. We emphasize the potential of an estimator based on the measurement of muon momenta that we denote $\sqrt{s_p}$. It can be determined with high precision in $e^+e^- \to \mu^+\mu^-(\gamma)$ events while being sensitive to effects from beam energy spread, beamstrahlung, initial-state radiation (ISR), final-state radiation (FSR), crossing angle, and detector resolution. The measurement precision is enabled by a high-precision low-mass tracker; the reported performance estimates are based on full simulation of the tracker response of the ILD detector concept for the ILC operating at $\sqrt{s} = 250$ GeV. The underlying statistical precision is 1.9 ppm for a 2.0 ab^{-1} dataset at ILC. The ultimate utility will depend largely on how well one can calibrate and maintain the tracker momentum scale.

Submitted to the Proceedings of the US Community Study on the Future of Particle Physics (Snowmass 2021)

1. Introduction

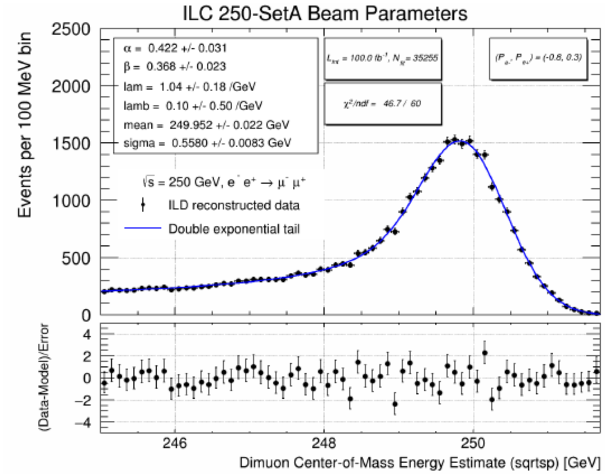
Various e^+e^- collider concepts are under investigation as a potential future "Higgs factory" to explore in detail the physics of the Higgs boson, make precision measurements in the electroweak and top sectors, and to explore potential new physics beyond the Standard Model. This precision e^+e^- program is highly complementary to the continued exploitation in hadron collisions of the LHC that will be enabled with the HL-LHC. The e^+e^- collider concepts vary in maturity, cost, and readiness for construction and include linear collider (ILC, CLIC, C^3, HELEN, and ReLiC) and circular collider (CEPC, FCC-ee, and CERC) concepts. More details and links to documentation are given in [1] and [2]. A key element that enables the physics program of a future e^+e^- collider is the control of the center-of-mass energy ($\sqrt{s}$) scale of the e^+e^- collisions.

Higgs boson physics can start to be thoroughly explored at e^+e^- colliders operating above the nominal ZH threshold of $\sqrt{s} = 216.4$ GeV. In this energy regime, the classic technique of determining the circulating beam energies by measuring the electron/positron precession frequency by resonant depolarization is not expected to work for circular colliders due to the large beam energy spreads[1], and does not apply at all to linear colliders at any center-of-mass energy.

[1] In a circular collider, the beam energy spread, $\sigma_E \sim E_b^2/\rho$ where E_b is the beam energy, and ρ is the ring radius.

Preprint submitted to Snowmass 2021 Proceedings *September 21, 2022*

Impressive work, shown by Graham Wilson, based on dimuon reconstruction.

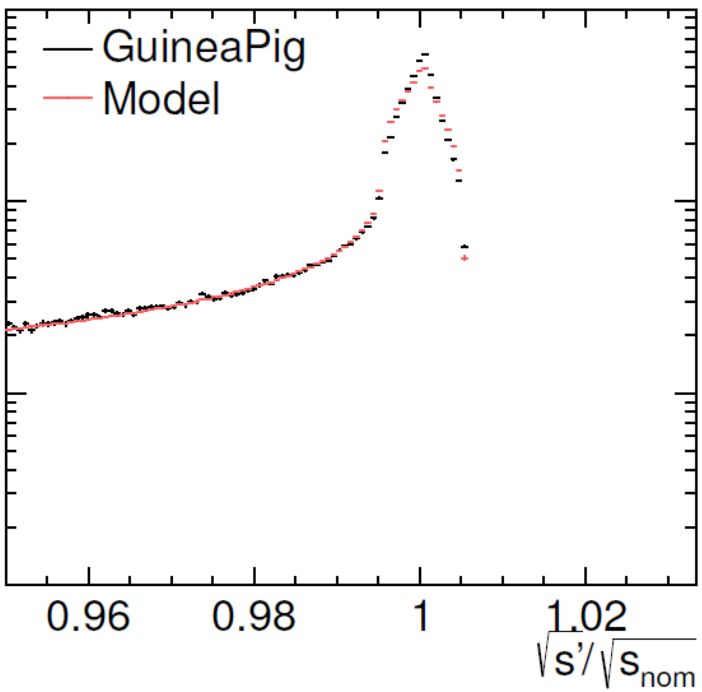


Main difference w.r.t. FCC-ee studies is use of momentum information. Ergo, momentum scale must be very well understood !

See plenary presentation today.

Harnessing Bhabha events

André Sailer showed worked he had performed for CLIC in reconstructing luminosity spectrum (*i.e.* energy spread) with Bhabha events.



Bhabhas should be investigated in FCC-ee context – complementary to dimuons.

WP4 – this afternoon

IMPORTANT ! A tutorial is foreseen on Thursday afternoon (Marcin Chrząszcz)

- Learn how to generate, simulate, analyse dimuon events and more in FCCSW
    - Come with your computer !
- And apply what you have learnt to determine √s, spread, boost, angles, axes, etc.

Lots to do, and great opportunities for high impact work and new ideas !