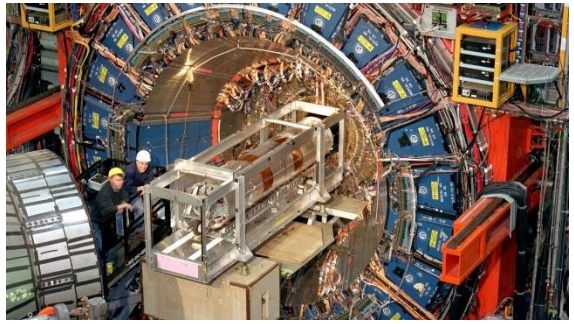
FCC-ee Energy Calibration and Polarization

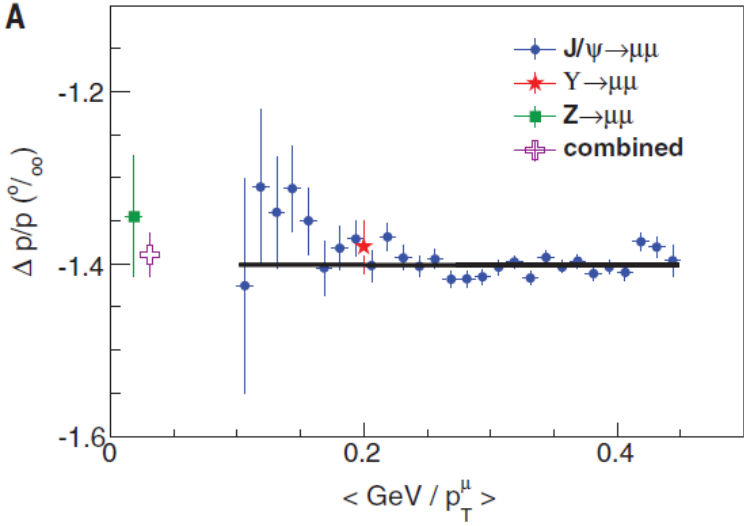


Recent CDF: m_W (MeV)= 80'433.5 $\pm$ 6.4 $_{stat}$ $\pm$ 6.9$_{syst}$ (10^{-4} precision)
-- « could hint at new physics » and surely created a buzz!
-- precision measurements as broad exploration of new physics in quantum corrections, or mixing (SUSY, Heavy neutrinos, etc..)
(-- questions because inconsistent with previous measurements)

CDF measurement is remarkable in two ways:

1. (after 10 years of work)
systematic errors similar to statistical precision

2. relies for the precise calibration on J/ψ, ϒ, Z masses
all measured in e+e- colliders... (VEPP-4M, Doris, LEP= using resonant depolarization!



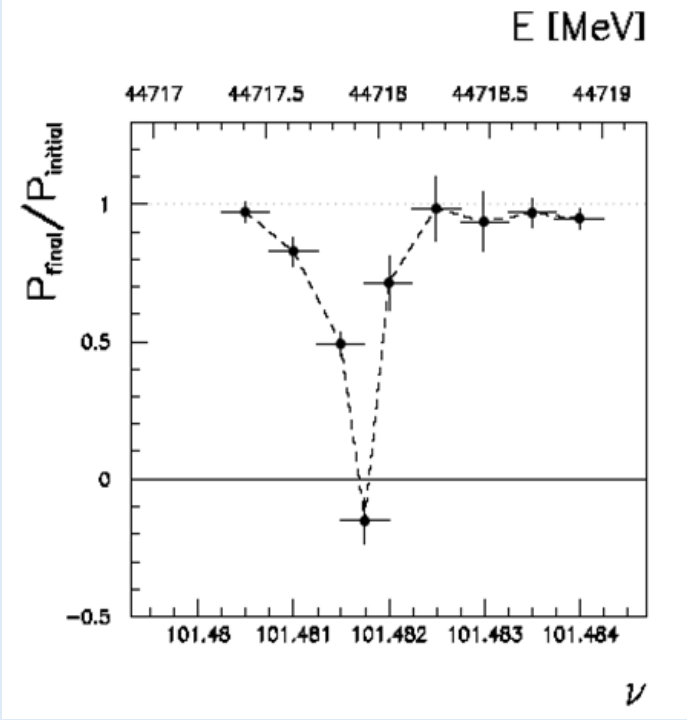
Resonant depolarization is the cornerstone of the precision programme of FCC-ee

factor 500-75 more precise than LEP

~40 times more precise than CDF

➔ Improvement by factor 10-1000 on a long list of EW precision measurements.
e.g. W mass down to ±250 keV, Z mass and width ±4 keV, $\sin^2\theta_W^{eff}$ ± 2.10^{-6} etc..
➔ explore new physics at 10-100 TeV scale, or 10^{-5} mixing with known particles.

Transverse beam polarization provides beam energy calibration by resonant depolarization



→ low level of polarization is required (~10% is sufficient)
→ at Z & W pair threshold comes naturally $\sigma_E \propto E^2/\sqrt{\rho}$
→ at Z use of asymmetric wigglers at beginning of fills
since polarization time is otherwise very long (250h→ ~1h)
→ should be used also at ee → H(126)
→ use 'single' non-colliding bunches and calibrate continuously during physics fills to avoid issues encountered at LEP
→ Compton polarimeters for e+ and e- each
→ should calibrate at energies corresponding to half-integer spin tune
→ must be complemented by analysis of «average E_beam-to-E_CM» relationship

For beam energies higher than ~90 GeV can use ee → Z γ or ee → WW events
to calibrate E_{CM} at ±1-5 MeV level: m_H (~3 MeV) and m_{top} (~10-20 MeV) measts

First set of results obtained in the FCC Design Study:

Polarization and Centre-of-mass Energy Calibration at FCC-ee, arXiv:1909.12245

Table 15: Calculated uncertainties on the quantities most affected by the center-of-mass energy uncertainties, under the final systematic assumptions.

Quantity	statistics	ΔE_{CMabs} 100 keV	$\Delta E_{CMSyst-ptp}$ **40 keV**	calib. stats. 200 keV/$\sqrt{(N^i)}$	σE_{CM} (84) $\pm$ **0.05** MeV	stat/present
m_Z (keV)	**4**	100	**28**	1	–	500
Γ_Z (keV)	**4**	2.5	**22**	1	**10**	400
$sin^2\theta_W^{\rm eff} \times 10^6$ from $A_{FB}^{\mu\mu}$	**2**	–	**2.4**	0.1	–	75
$\frac{\Delta\alpha_{QED}(M_Z)}{\alpha_{QED}(M_Z)} \times 10^5$	**3**	0.1	**0.9**	–	**0.05**	15 (qualitiative!)
m_W(MeV)	**0.250**	-- **0.300** --				40

Next challenges for the feasibility study:

-- **Ascertain the above with integrated simulations** (simulation of polarization and depolarization on real machine)

-- **Match systematic errors with statistics.**

most relevant targets : **the point-to-point systematics, improve the WW energy**

– these are effects that would lead to a deviation from relation between

-- the spin tune as measured by resonant depolarization

-- and the center-of-mass energy.

-- examples: 1. interference between depolarizing resonances and the induced depolarizing resonance because the spin tune varies with energy.

2. effects due to collision offsets folded by opposite sign dispersion

-- designevaluate performance and cost the polarimeter at conceptual level

-- **finalize implementation in the realistic machine, study operational aspects**

Works packages

A- Simulations of spin-tune to beam energy relationship

-- EPFL group obtained funding from CHART for a student and a postdoc (stdies started -- Yi Wu)

-- Ivan Koop now concentrating on res. dep at WW threshold (Qs is now 0.075, *good*!)

B. Simulation of the relationship between beam energies and centre-of-mass energy.

-- control of offsets and vertical dispersion

-- Studied the beamstrahlung monitor but does not work

-- Studies will continue to implement beam deflection scans (AB-Oide-Shatilov-Wenninger)

-- Impact of energy losses (Jacqueline Keintzel)

C. Polarimeter desing and performance

-- now working to build a global collaboration (IJCLAB (Martens), BINP (Muchnoi), CERN (Lefevre), -- others?)

-- Aim to provide integration of polarimeters, wigglers, RF kickers in FCC-ee

-- conceptual design and cost estimate of polarimeter for FCC FS

D. Measurements in Particle Physics Experiments

-- not much work done beyond design study, needs to restart soon

E. Monochromatization

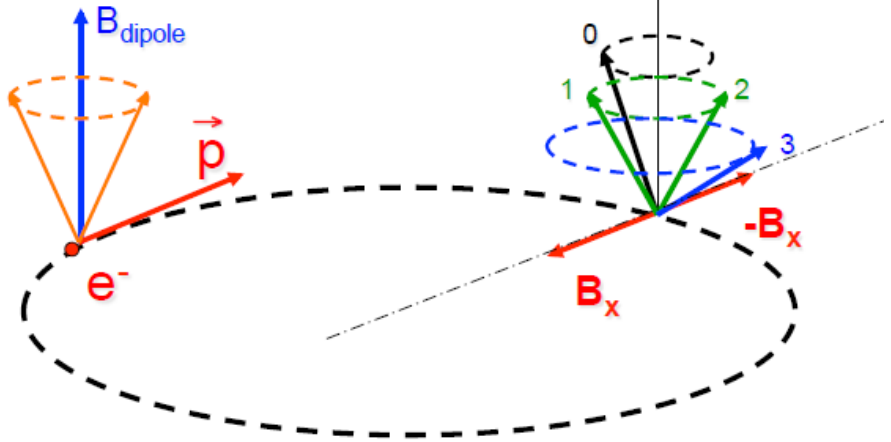
Angeles Faus, Jorg Wenninger, Pantaleo Raimondi, Frank Zimmermann, Dmitry Shatilov

-- new ideas for monochromatization in other dimensions than horizontal (x) axis. (time, z)

-- what its the limit?

SPIN PRECESSION

RESONANT DEPOLARIZATION



(ν is the *spin tune*)

$\delta\theta_{spin} = (g-2)/2 \;.\; E_{beam}/m_e \; \delta\theta_{trajectory}$

$\delta\theta_{spin} = \nu \;.\; \delta\theta_{trajectory}$

$\nu \quad = E_{beam} / 0.4406486$

$\nu \quad = 103.5$ at the Z peak

AMPLIFICATION

➔ high precision

➔ sensitivity to misalignements

-- depolarization

-- spurious spin resonances

Once the beams are polarized, an RF kicker at the spin precession frequency (fractional part thereof) will provoke a spin rotation and depolarization

Simulation of FCC-ee by I. Koop:

can we do as well at W threshold?

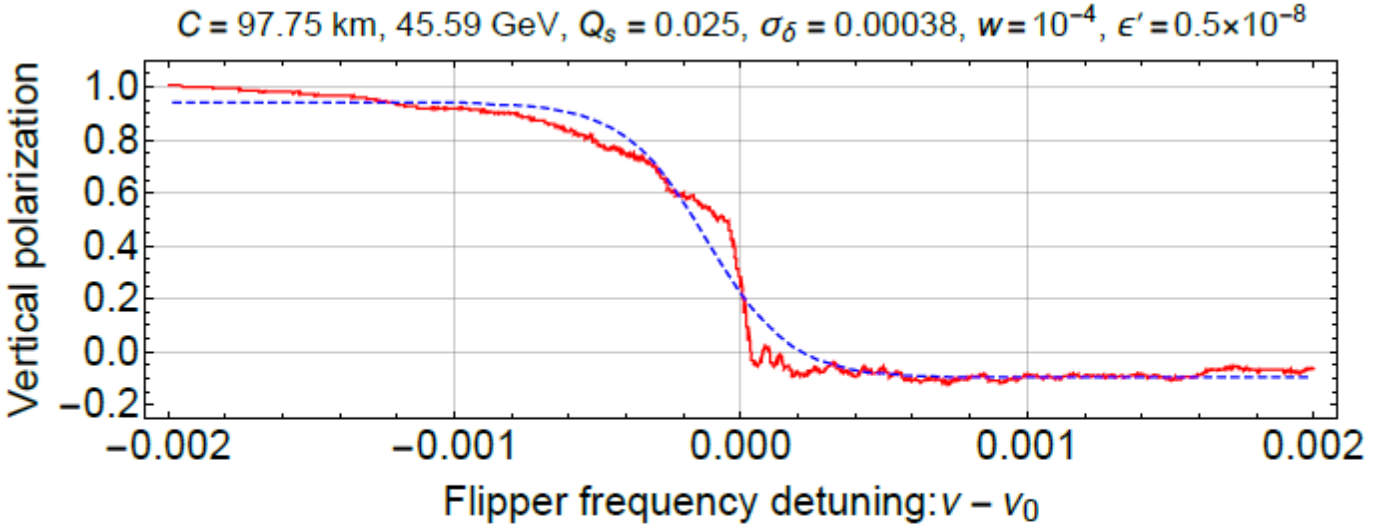


Figure 39. Simulation of a frequency sweep with the depolarizer on the Z pole showing a very sharp depolarization at the exact spin tune value.

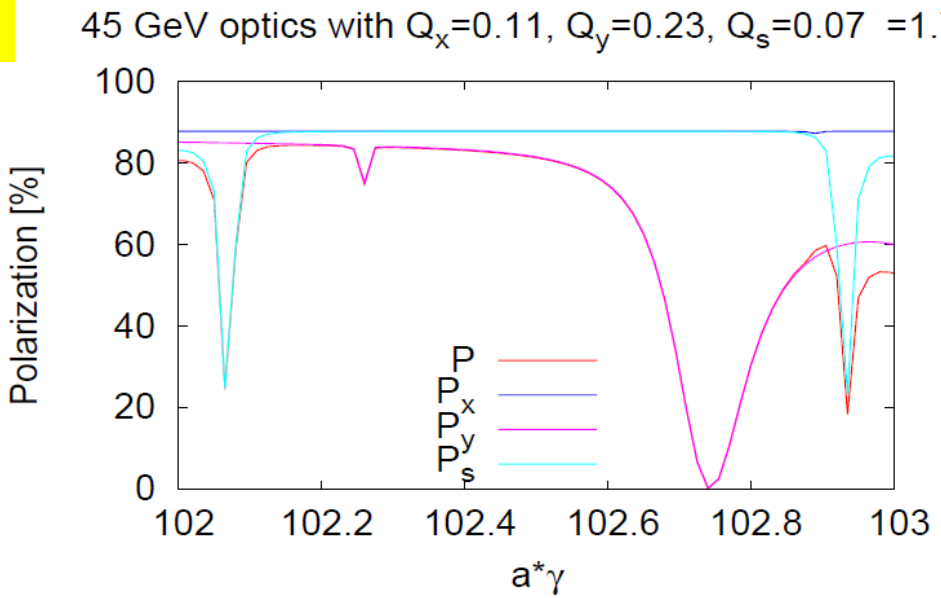
Simulations of self-polarization

Orbit correction leading to similar values for vertical dispersion and vertical emittance than for the luminosity optimization

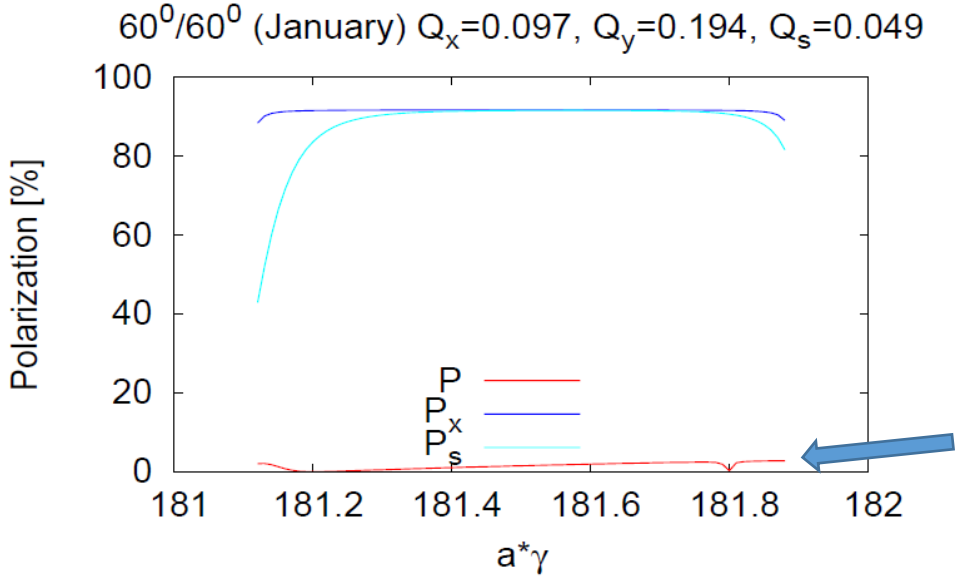
E. Gianfelice

arXiv:1909.12245

@ Z

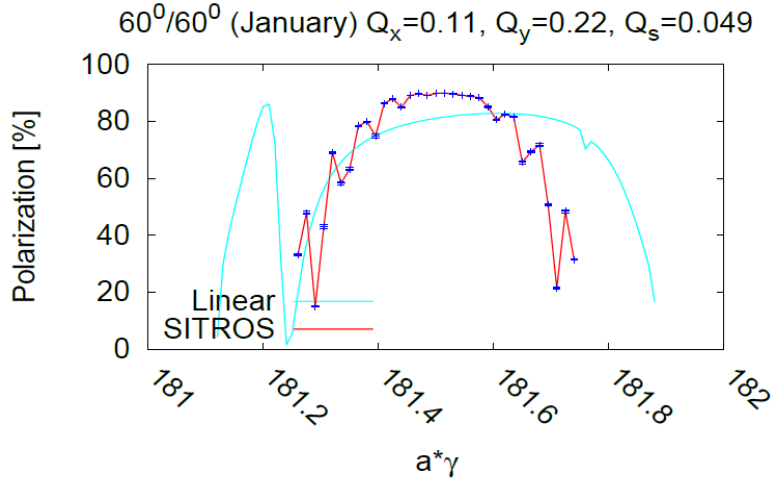


@WW



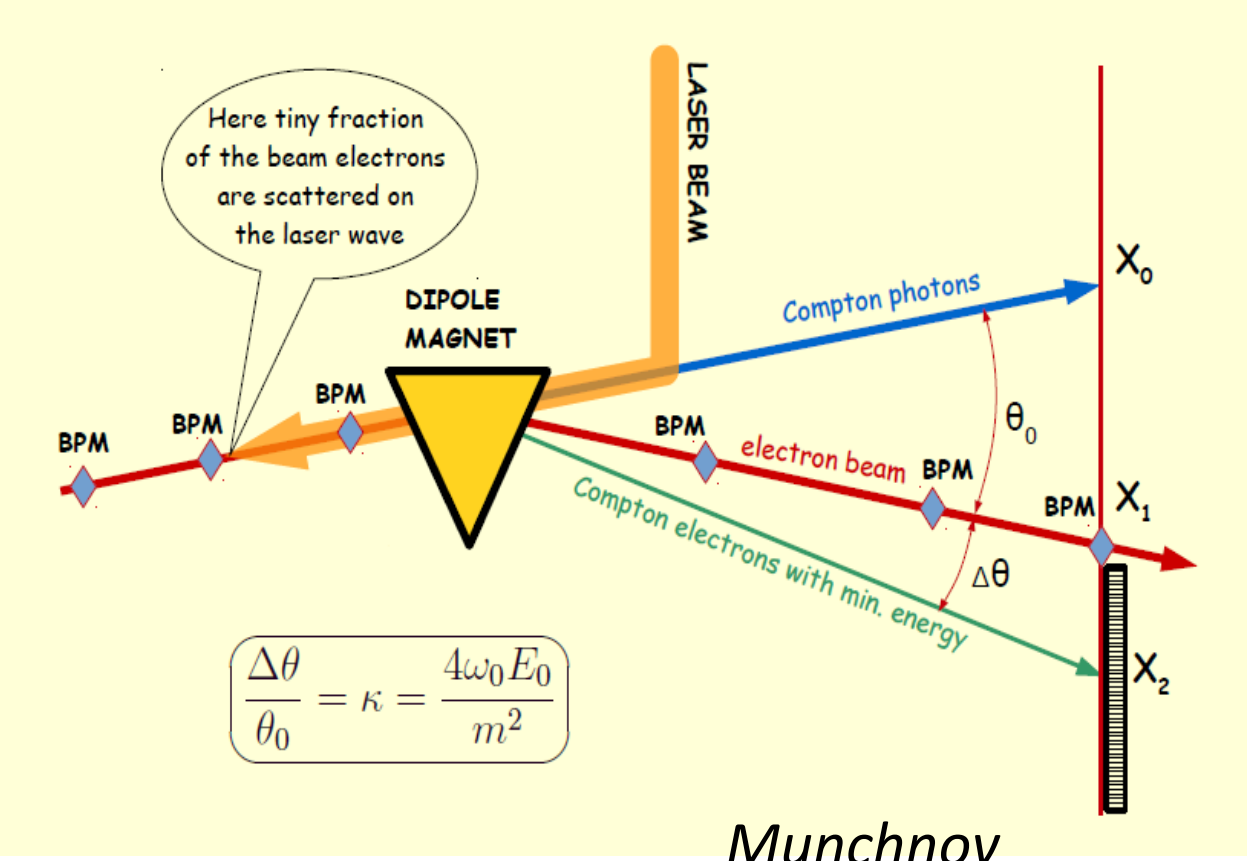
significant impact of spin resonances from vertical orbit @Z **might reduce polarization @W too much**

-- Sufficient level of polarization at Z for machine that is optimized for luminosity.
-- Additional correction of dispersion and
-- harmonic spin matching helps at W *→
-- Effect on resonant depolarization frequency small... but must be simulated
-- These studies will be repeated with simulation on same machine of lumi/polarization ➔ BMAD code by D. Sagan → Yi Wu

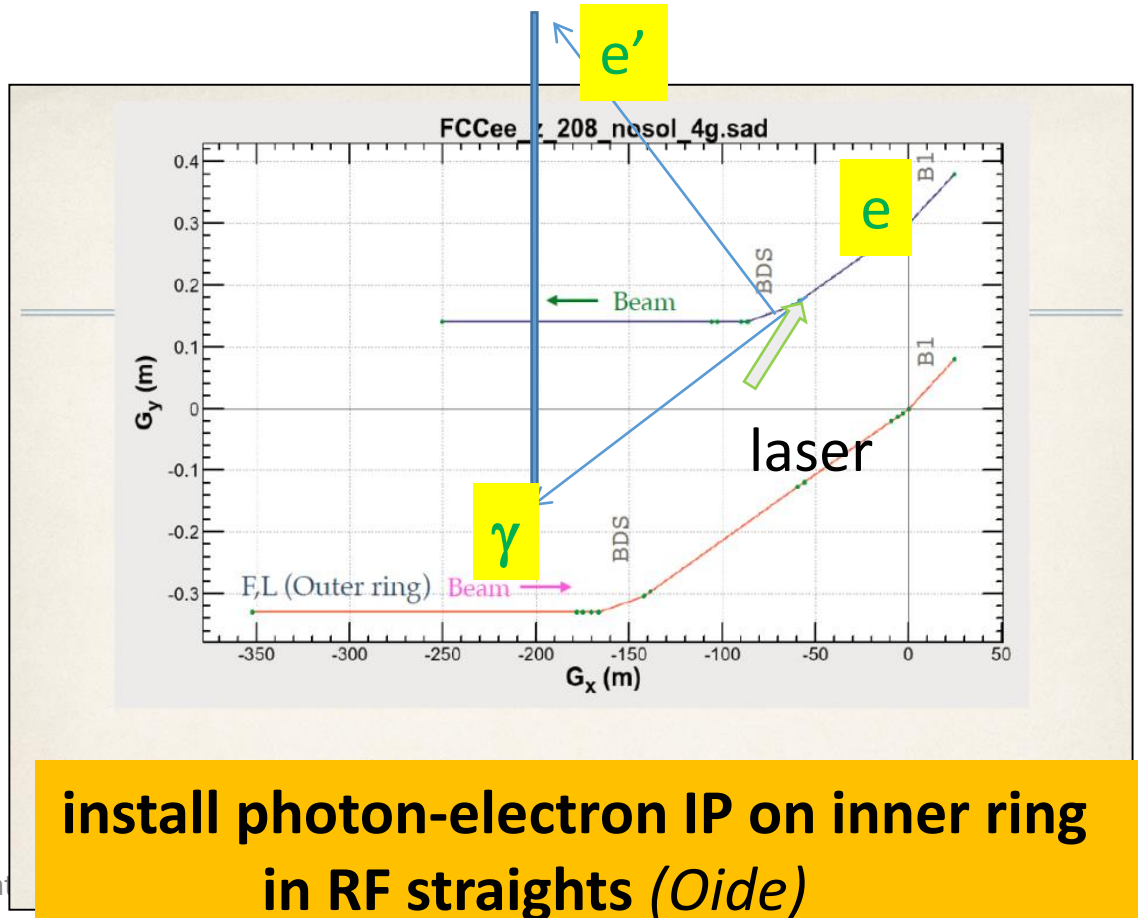


polarimeters

2 Polarimeters, for e+ and e- Use of both electron and photons recoil →measurement of 3D beam polarization
Backscattered Compton γ +e → γ + e 532 nm (2.33 eV) laser; detection of photon and electron.
Change upon flip of laser circular polarization → beam Polarization ±0.01 per second
End point of recoil electron → beam energy monitoring ± 4 MeV per second (Muchnoi, Aurelien Martens)



Munchnoy



install photon-electron IP on inner ring in RF straights *(Oide)*

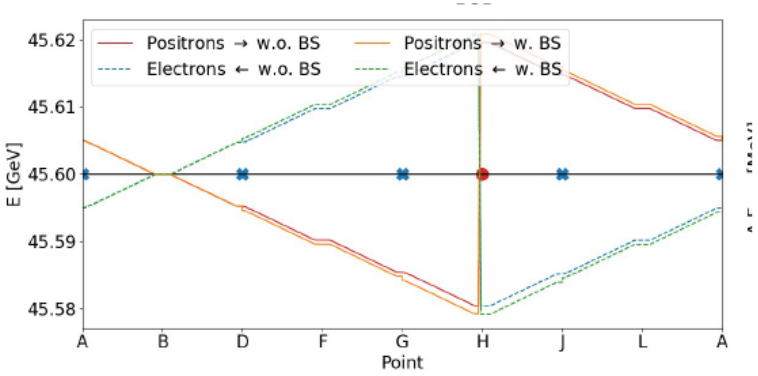
Resonant depolarization frequency vs average beam energy?

Jacqueline Keintzel

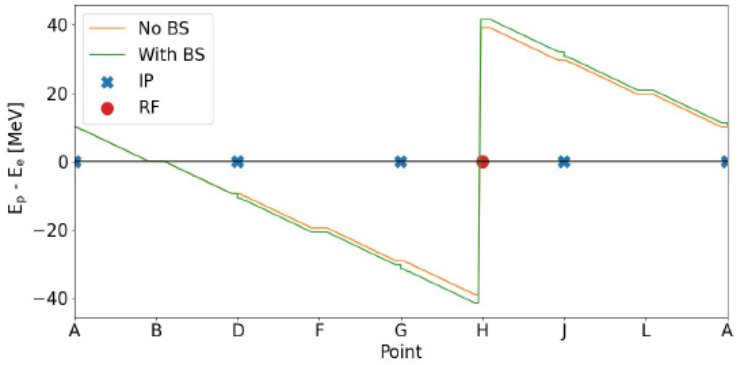
(just because particles have to stay in the ring)
effect of energy losses and gains cancel...

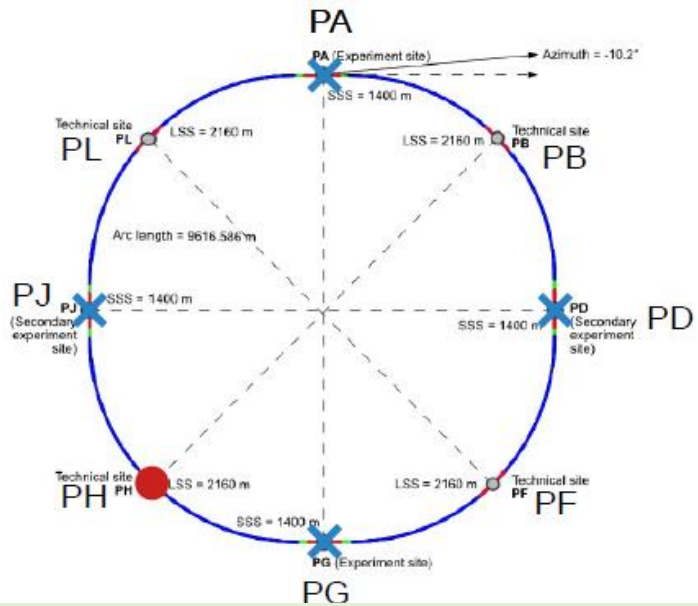
IF there is only one RF section for both e+ and e-

➔ **a strong requirement for the Z, W (and ee➔ H) machines**



Boost: + for e+; - for e-



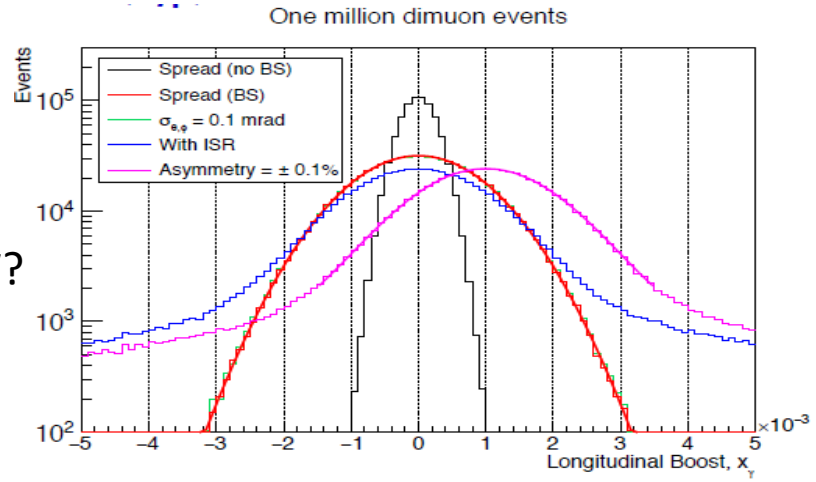


The boosts can be verified with great precision, using muon pairs in the experiments, (±40 keV in 5 minutes). Also, the energy spread can be measured

small (8keV) effect comes from $\Delta E \propto \gamma_{\mathrm{rel}}^4$

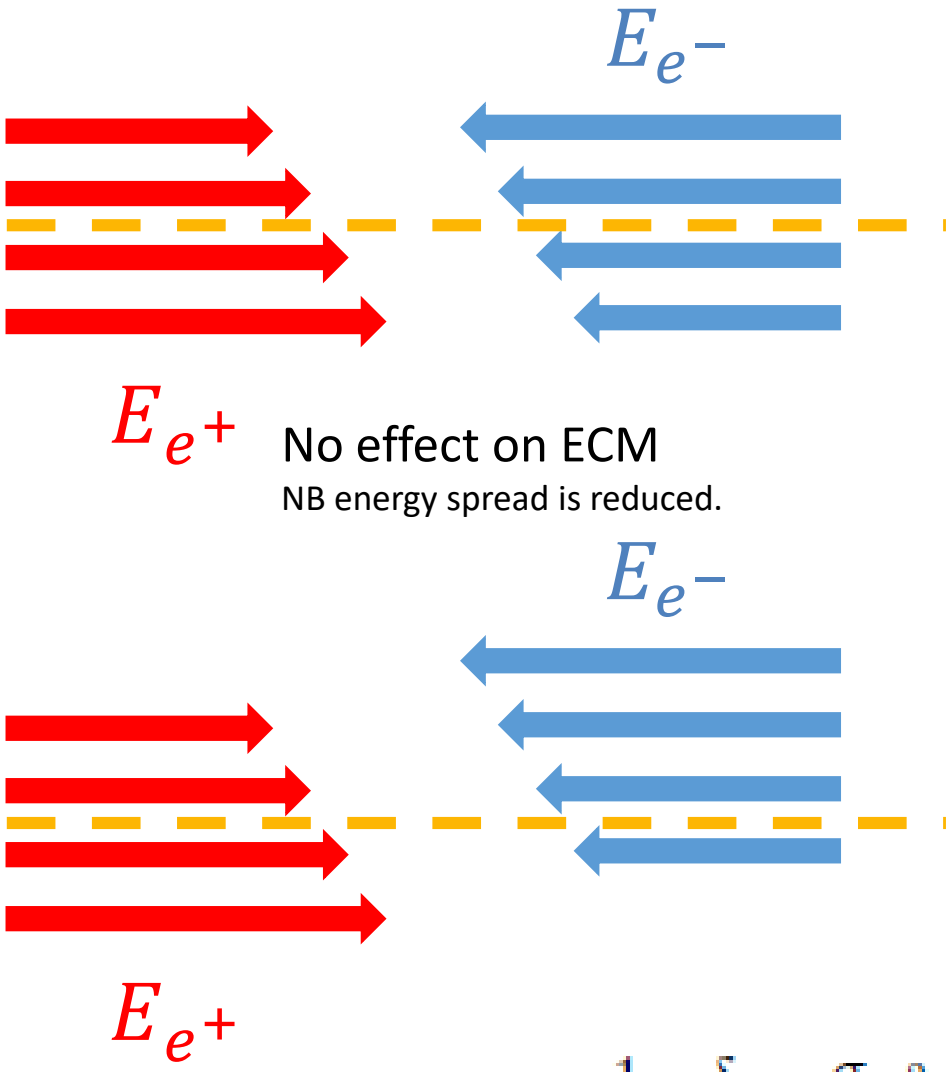
IP	ΔECM [keV]	Boost [MeV]
PA	- 7.851	10.665
PD	- 7.931	- 10.108
PG	0.570	- 30.883
PJ	0.844	31.439

How well does that work for W?



From beam energy to E_{CM}

opposite sign dispersion



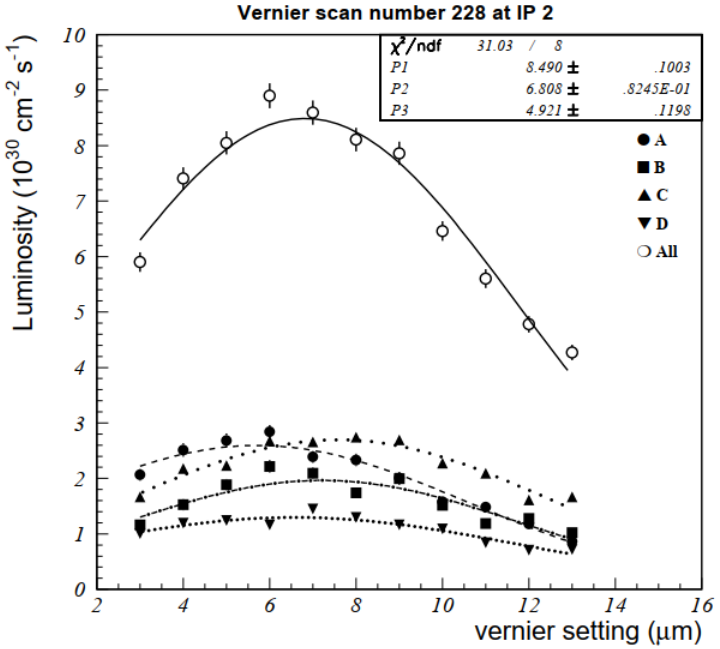
No effect on ECM

NB energy spread is reduced.

ECM lowered: $\Delta E_{\mathrm{CM}} = -\frac{1}{2} \cdot \frac{\delta y}{\sigma_y^2} \cdot \frac{\sigma_{E_{\mathrm{b}}^2}}{E_{\mathrm{b}}} \cdot \Delta D_y^*$

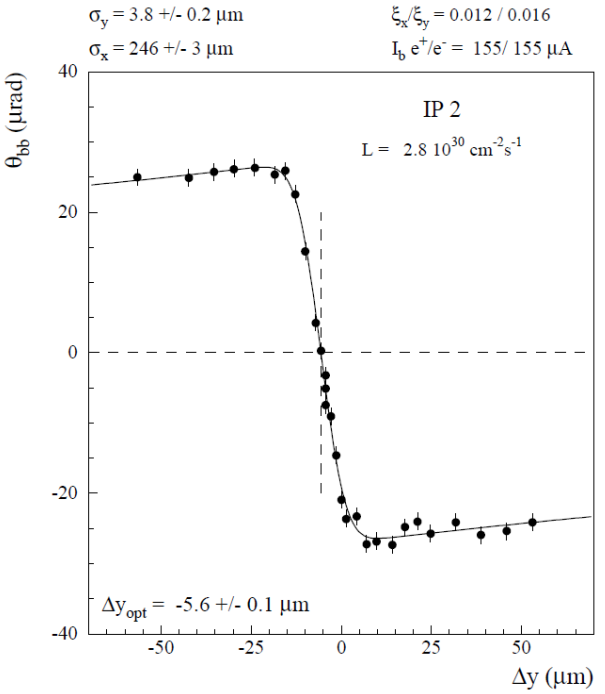
Experience from LEP: Vernier scans

Relative position of beams measured to +- 80 nanometers from one scan



precision requires going far from maximum

➔ loose beam?



Try deflection scans?

EPOL sessions at this FCC week

Wednesday			Thursday			
Parallel 1 Campus Cordeliers room 155 p.	Parallel 2 Campus Cordeliers room 75 p.	Parallel 3 Réfectoire Cordeliers room 100 p.	Parallel 1 Campus Cordeliers room 470 p.	Parallel 2 Campus Cordeliers room 155 p.	Parallel 3 Campus Cordeliers room 75 p.	Parallel 4 Réfectoire Cordeliers room 100 p.
FCC hh accelerator	PED: EPOL	FCCIS WP3 Placement	Reserve	PED/ACC: FCCee EPOL	TI Geodesy alignment	Technology
Chairperson	Chairperson	Chairperson	Chairperson	Chairperson	Chairperson	Chairperson

1. **Wednesday 9:00-10:30**
   -- FCC-ee EPOL The center-of-mass energy calibration and polarization working group (Alain Blondel)
   -- enter-of-mass energy and boosts for various RF-configurations (Jacqueline Keintzel)
   -- Polarimeter & wiggler integration status (Katsunobu Oide)
   -- 3D Polarimeter performance and laser control (Aurelien Martens)

2. **Thursday 9:00-10:30**
   -- Simulations of the Spin Polarization for the Future Circular Collider e+e- using Bmad (Yi Wu)
   -- Study of the depolarization process, possible biases (Ivan Koop)
   -- Control of beam-beam offsets and related ECM biases (Blondel/Oide/Shatilov)
   -- Progress in monochromatization (Angeles Faus-Golfe)