Skip to slide 15,16, and 29

# FCC-ee beam polarization and Energy Calibration Workshop

https://indico.cern.ch/event/669194/

**EPOL group:**

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M Hildreth, Notre-Dame USA
I Koop , N Muchnoi, A Bogomyagkov, S. Nikitin, D. Shatilov BINP; NOVOSIBIRSK

**see my other slides and the workshop site for summary and complete info**

# Conclusions

We had a very sucessful workshop and unveiled and number of aspects of the question of energy calibration that are of great interest.

Several good news
-- running scenario, pilot bunches Touschek limited to ~few $10^{10}$ e+- /bunch
-- wigglers (8 3-pole-units per beam)
-- polarimeter/spectrometer set-up (new)
-- polarization levels at Z and W
-- direct measurements of energy spread and energy asymmetries
-- smallness of effect of beamstrahlung and RF
-- etc. etc.
**-- started writing the CDR! 25 pages and typing!**

**some difficulties**

-- opposite sign vertical dispersion
-- possible difficulty with depolarizer.

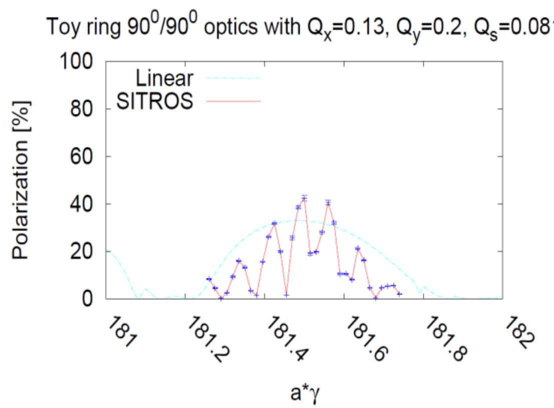
**THANK YOU!**

see all the slides for more information!

# The Qs issue

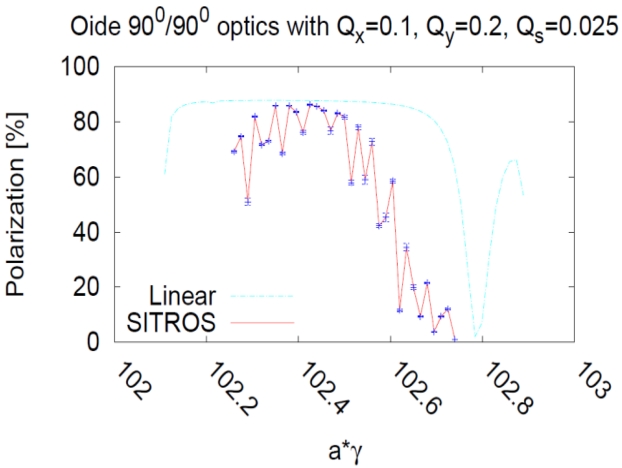
There is a concern that low Qs value will make Qs resonances so close that (de)polarization disappears. Eliana and Ivan independently checked the possible effect.

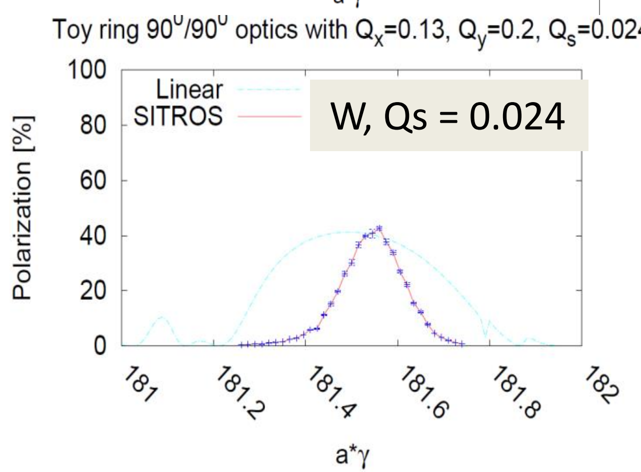
at the W with Qs = 0.08 ➔

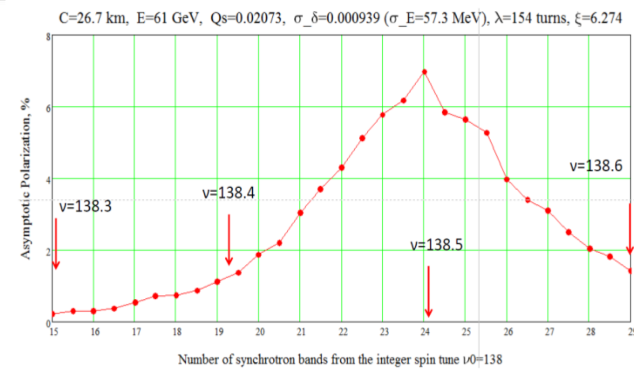



Eliana, at the Z Qs=0.025

Ivan K, at 61GeV Qs=0.02

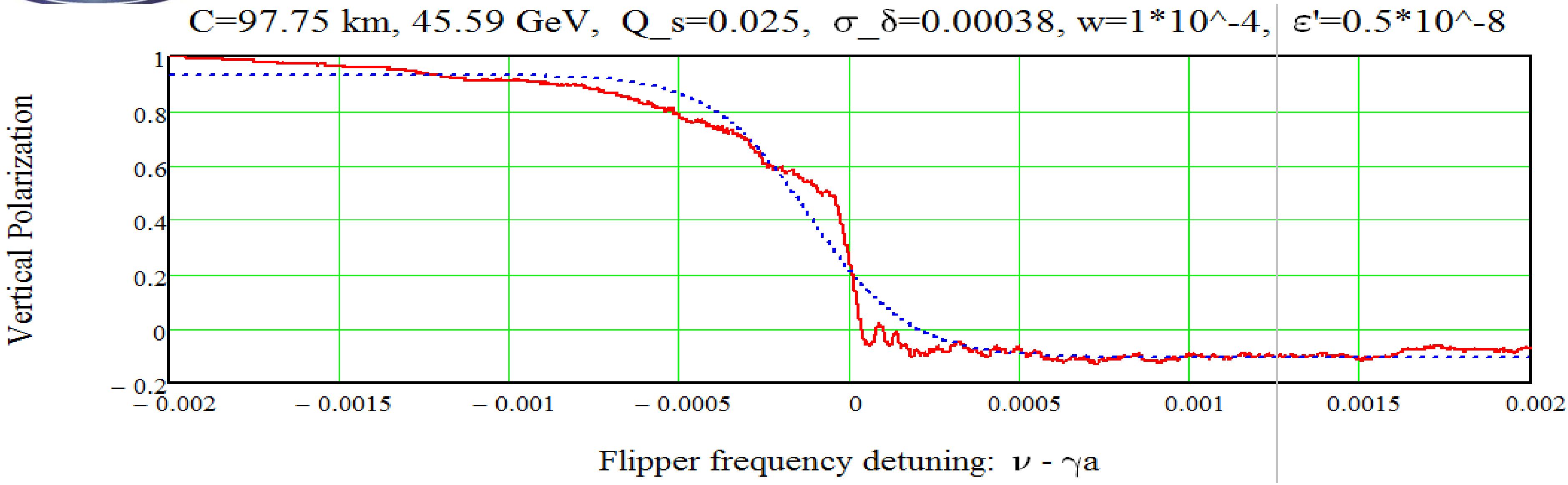



➔ Similar polarization level, smoother curves.

# FCC-ee at 45.6 GeV, Qs=.025, w=1·10$^{-4}$, dv=0.5·10$^{-8}$




$\nu_0 = 103.461$

$w^2/\varepsilon' = 2$

$(w \cdot J_0(\xi))^2/\varepsilon' = 0.46$

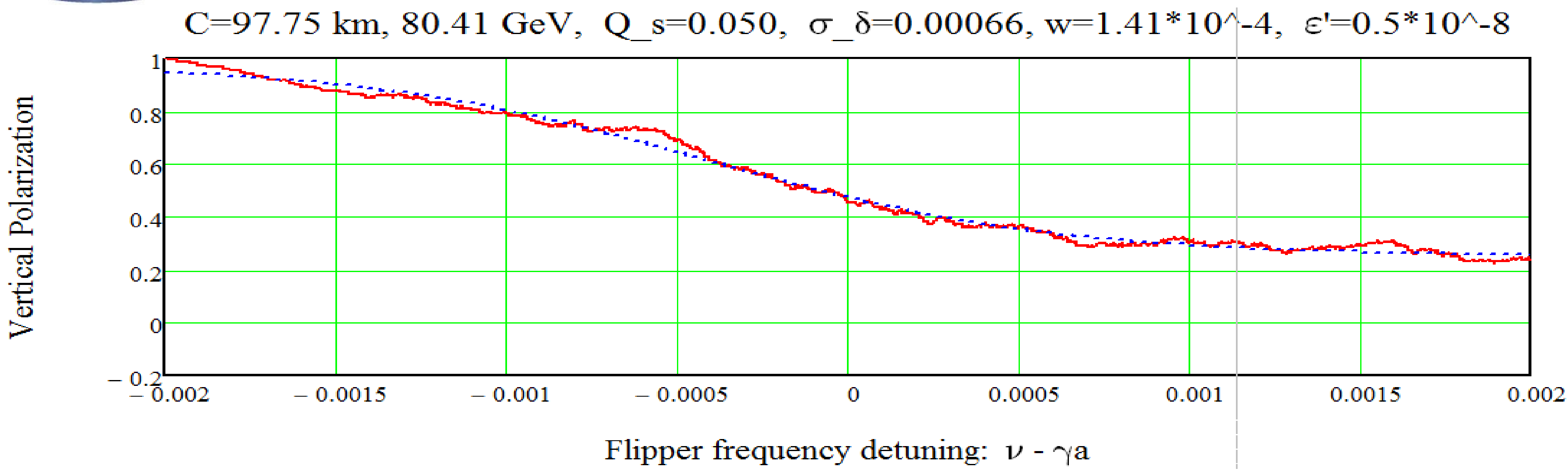
$\xi = \nu_0 \sigma_\delta / Q_s = 1.556$

Scan time: $T$= 260.8 s

With nominal Qs=.025 at Z. And with strong depolarizer w=1·10$^{-4}$.

My simple fit gives the resonance frequency with an error Δv= -0.00011. But, in fact, the transition zone here is very narrow and is centered to the right spin tune value very well.

# FCC-ee at 80.41 GeV, Qs=.05, w=$1.41\cdot10^{-4}$, dν=$0.5\cdot10^{-8}$




$\nu_0 = 182.481$

$w^2/\varepsilon' = 4$

$(w \cdot J_0(\xi))^2/\varepsilon' = 0!$

$\xi = \nu_0\sigma_\delta/Q_s = 2.4$

Scan time: $T$= 260.8 s

Try to increase the depolarizer strength up to w=$1.41\cdot10^{-4}$. But not clear, trustable picture we see. Simple fit gives the resonance frequency with an error Δν= - 0.0004.

I think, the last two plots show that the synchrotron tune at W should be made much higher. Its minimal acceptable value is Qs=.075, or even higher!

# Hardware requirements: wigglers

Given the long polarization time at Z, wigglers will be necessary.
An agreement was reached on a set of **8 wiggler units per beam**

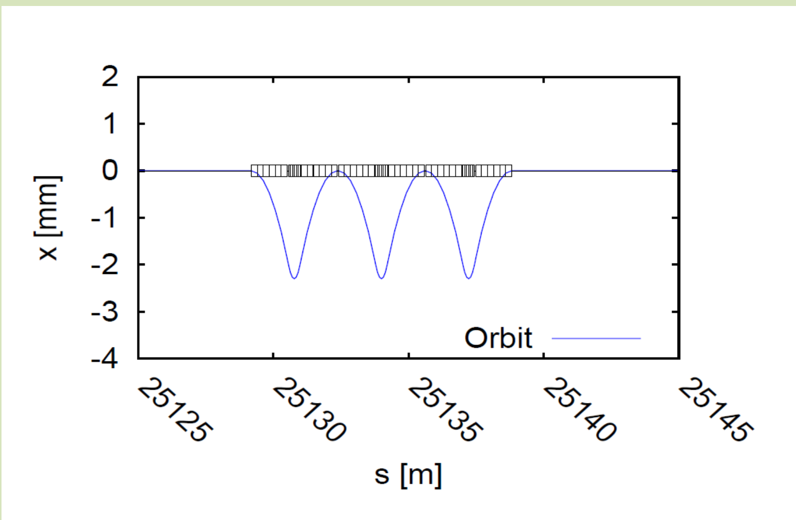
## Polarization wigglers

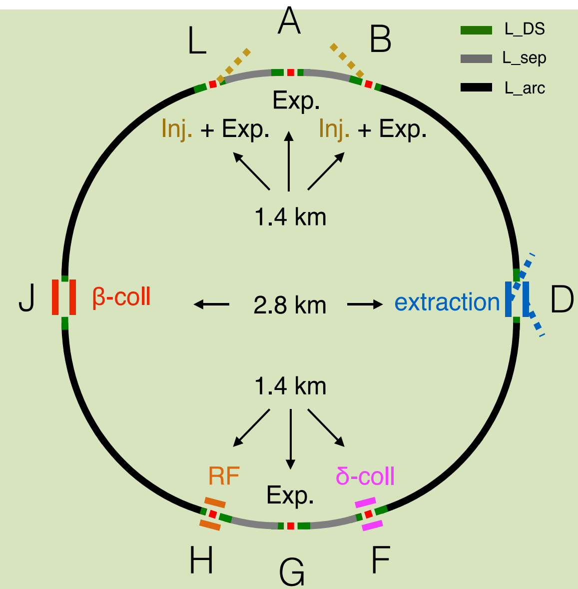
**8 units per beam,** as specified by Eliana Gianfelice

$B+=0.7$ T  $L+ = 43$cm $L-/L+ = B+/B- = 6$

at $E_b = 45.6$ GeV and $B+ = 0.67$ T

=> $P=10\%$ in 1.8H $\sigma_{Eb} = 60$ MeV $E_{crit}=902$ keV




**placed e.g. in dispersion-free straight section H and/or F**

# Hardware requirements: polarimeters

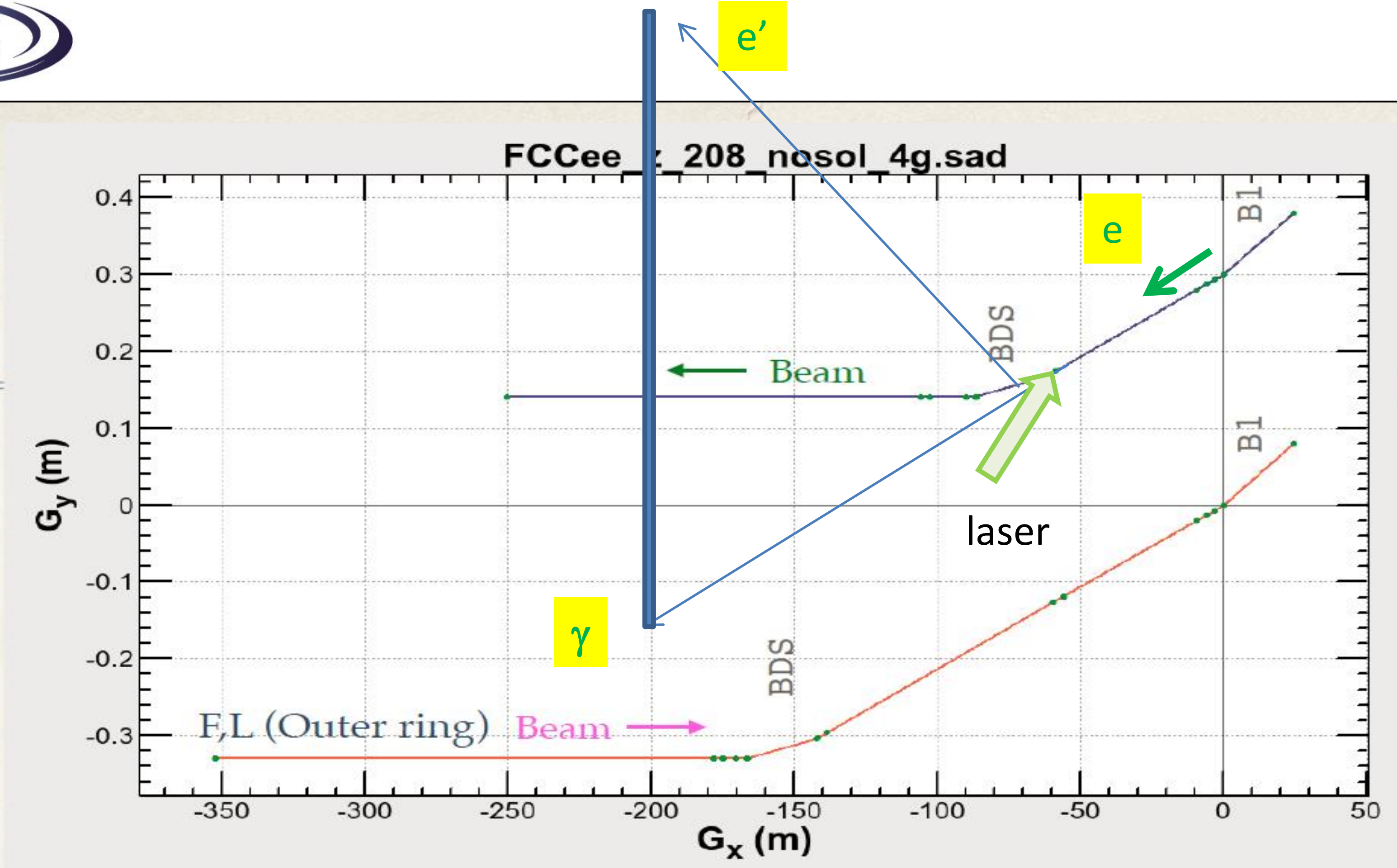
Efficient polarimeter is necessary.

**2 Polarimeters, one for each beam**

Backscattered Compton $\gamma$ +e $\rightarrow$ $\gamma$ + e   **$\gamma$ from 532 nm (2.33 eV) laser**

Nickolai Muchnoi pointed out that scattered electron contains anti-correlated information on e-beam polarization and gives information on beam energy

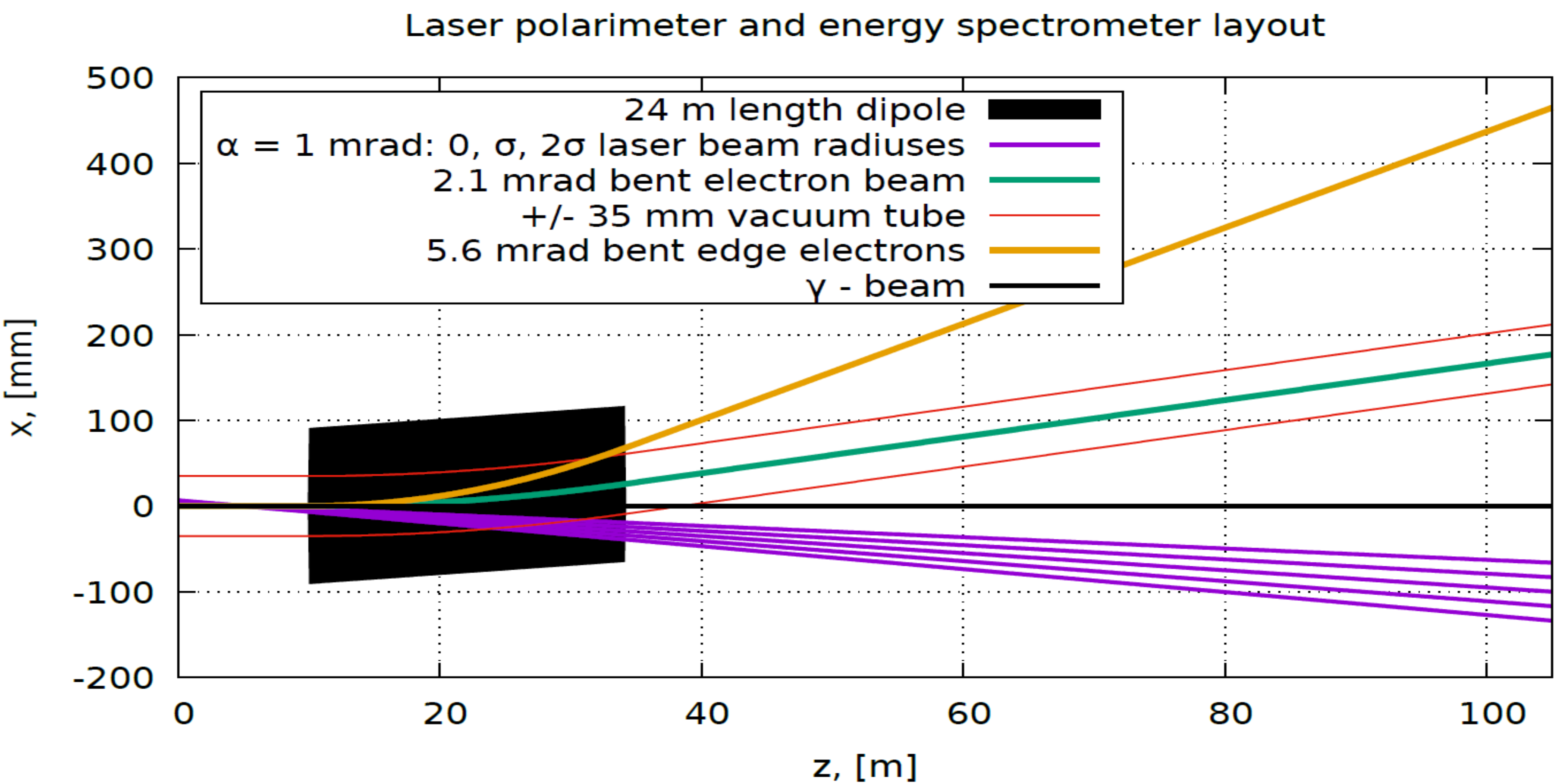
Practical arrangement similar to LEP for the detection of the photon,
but complemeted with an electron spectrometer



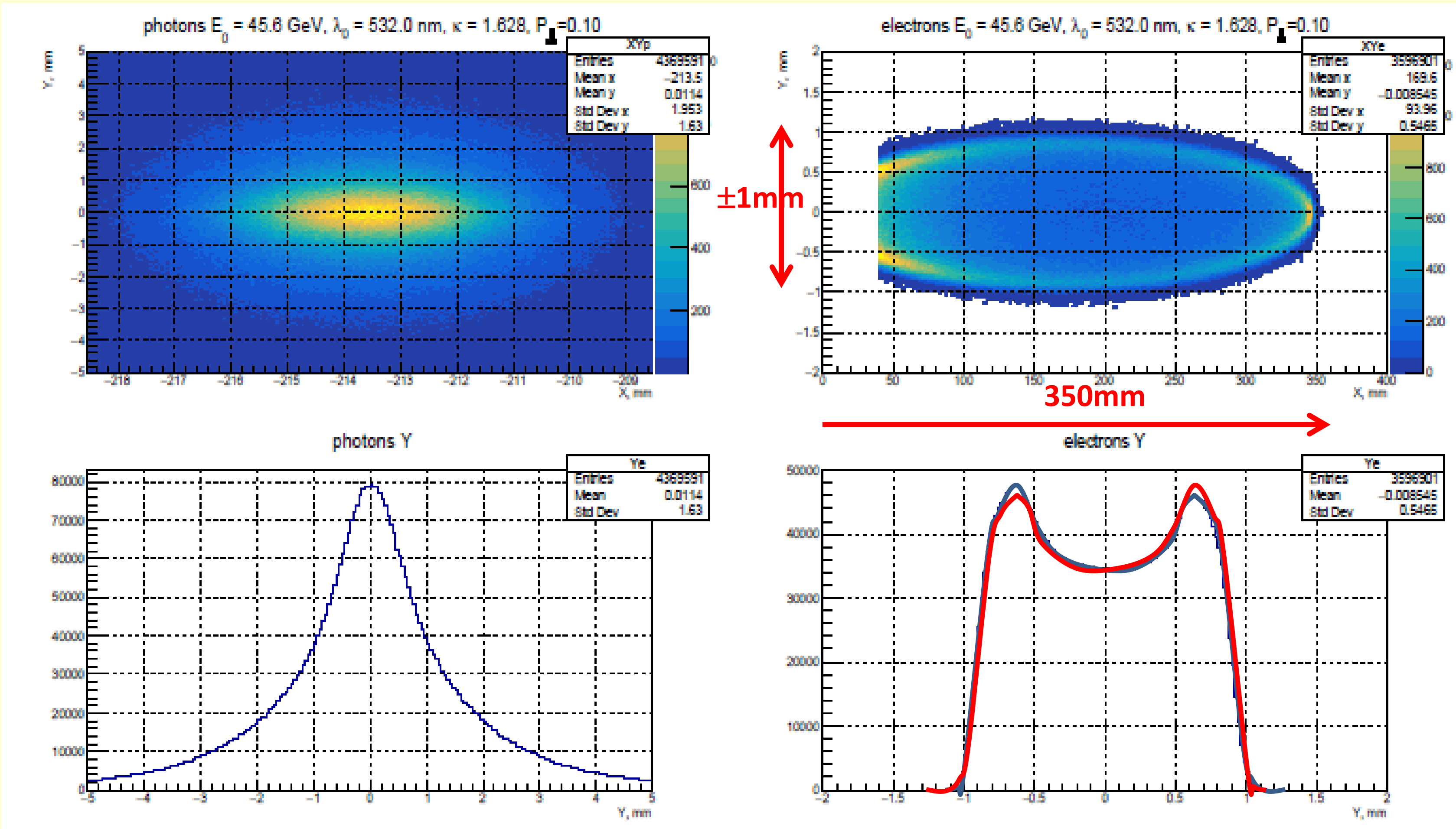

**Require that there is no quadrpole on the trajectory of the outgoing electrons of the lowest energy**

The dispersion suppressor dipole (BDS):

```
;
 BEND    BDS       =(L =24.119925292770883   ANGLE =.002134100603580931     E1 =.5     E2 =.5 )
```

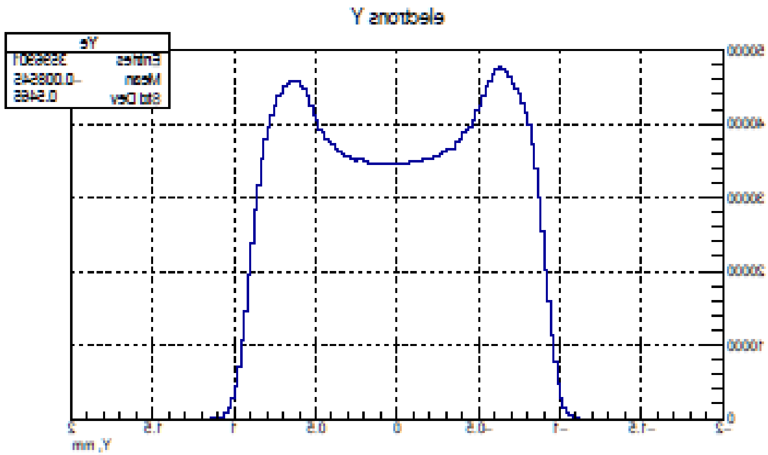


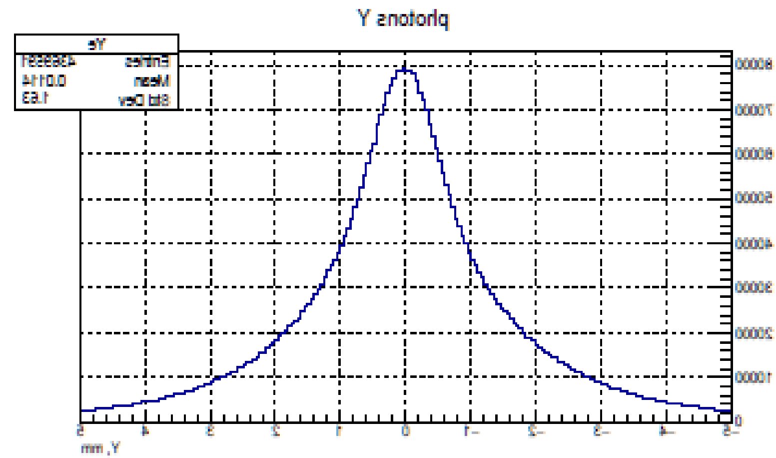
Laser polarimeter and energy spectrometer layout
24 m length dipole
α = 1 mrad: 0, σ, 2σ laser beam radiuses
2.1 mrad bent electron beam
+/- 35 mm vacuum tube
5.6 mrad bent edge electrons
γ - beam
500
400
300
200
100
0
-100
-200
x, [mm]
0
20
40
60
80
100
z, [m]




statistical precision: in 3 seconds of data taking

Fit results: $\chi^2$/NDF = 19607.8/19336. Prob = 0.0839. E = 45.60005 ± 0.00033 GeV. $P_\perp$ = 0.10343 ± 0.00332




it is expected that beam polarization can be measured to P ± 1% (absolute)
in a few seconds. (if the level is 5%, this is 5σ). To be verified with improved fitter (Nickolai)

# polarimeter-spectrometer situated 100m from end of dipole.

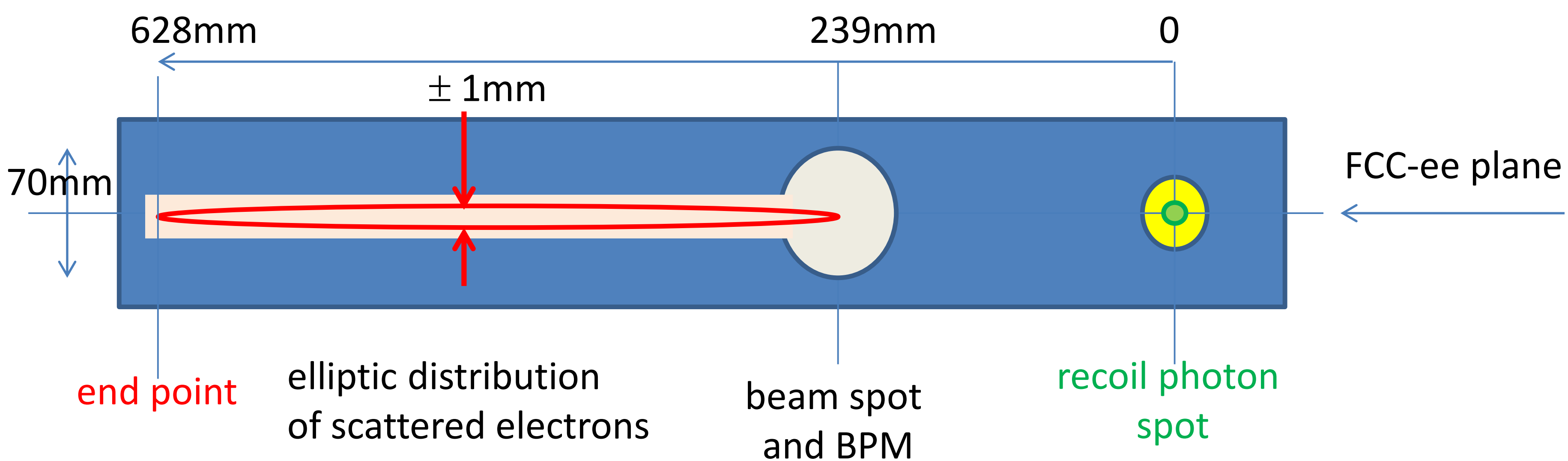
Using the dispersion suppressor dipole with a lever-arm of **100m** from the end of the dipole, one finds

-- minimum compton scattering energy at 45.6 GeV is 17.354 GeV

-- distance from photon recoil to Emin electron is 0.628m

| | laser (eV) | beam (GeV) | mc2(MeV) | B field | R | LM | theta | L | true beam |
|---|---|---|---|---|---|---|---|---|---|
| | 2.33 | 45.6 | 0.511 | 0.013451 | 11300 | 24.119 | 0.002134 | 100 | 45.60005 |
| nominal kappa = 4. E_laser.Ebeam_nom/mc2 | 1.627567296 | | | | | | | | |
| true kappa = 4. E_laser.Ebeam_true/mc2 | 1.627568924 | | | | | | | | |
| nominal Emin | 17.35445561 | | | | | | | | |
| true Emin | 17.35446221 | | | | | | | | |
| position of photons | 0 | | | | | | | | |
| nominal position of beam (m) | 0.239182573 | | | | | | | | |
| true position of beam (m) | 0.239182334 | 2.39182E-07 | | | | | | | |
| nominal position of min (m) | 0.628468308 | | | | | | | | |
| true position of min (m) | 0.628468069 | 2.39182E-07 | | | | | | | |

mouvement of beam and end point are the same:
0.24microns for $\delta Eb/Eb=10^{-6}$ ($\delta Eb$=45keV)



# Energy gains (RF) and energy losses (Arcs and Beamsstrahlung)

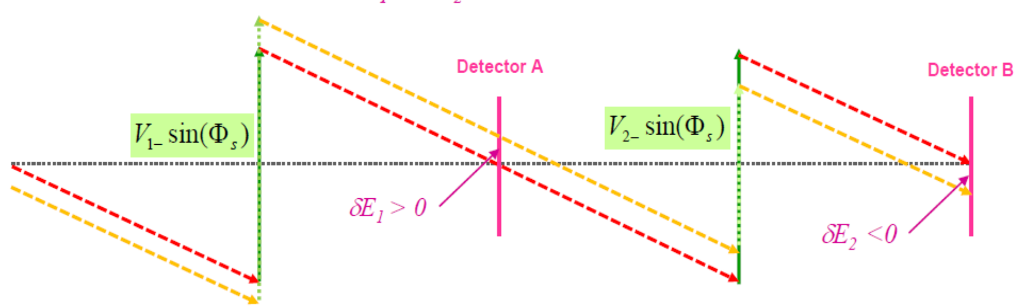
At LEP the disposition of the RF units on each side of the experiments had the effect that any asymmetry in the RF would change the energy of the beams at the IP, but not the average energy in the arcs.

**At FCC-ee, because the sequence is RF – energy loss – IP – energy loss- RF such errors have little effect on the relationship between average energy in the arcs and that at the IP.**
**They can induce a difference between e+and e- (can be measured in expt!)**

## RF errors

- If the RF voltage or phase changes in one RF group, the local energy gain will change, the difference must be compensated by the second group → strong correlation of changes / errors between the 2 RF groups.
- To first order the energy change has opposite signs at the 2 experiments !

$$\delta E_1 + \delta E_2 \approx 0$$




- By averaging the Z mass of the 2 experiments one can cancel out some of the RF errors (is that 'legal'?).
  - This correlation could also be observed by other means (event asymmetries etc).

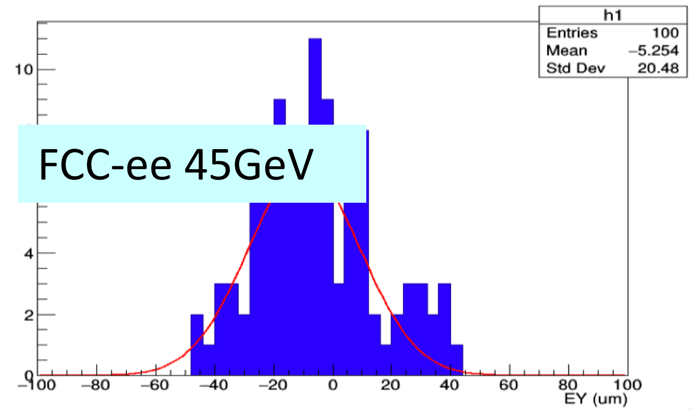
**-- need to understand the possible uncertainty in energy loss in the arcs (9 MeV per arc @Z) and that due to impedance**

# Opposite sign dispersion at IP

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

For FCC-ee at the Z we have:

- Dispersion of e+ and e- beams at the IP is 20um (uncorrelated average) –the difference in dispersion matters in this calculation –m'ply by SQRT(2), so $\Delta D_y^* = 28\mu m$.
- Sigma_y is 30nm
- Sigma_E is 0.132%*45000MeV=60MeV
- Delta_ECM is therefore **4MeV** for a 10% offset
- Note that we cannot perform Vernier scans like at LEP, we can only displace the two beams by ~10%sigma_y
- Assume each Vernier scan accurate to 1% sigma_y
- We need 100 vernier scans to get an $E_{CM}$ accuracy of 40keV – suggestion: vernier scan every hour




Dima El Khechen

**Determination of impact parameter between beams at IP**

-- at LEP Vernier*) scans allowed a precision of <30nm out of 4 microns beam size (<1%)

-- any issue doing this at FCC-ee?

**Dispersions for e+ and e- separately.**

-- determination by extrapolation from measurements in the ring what is the best optics group can come up with?

-- experiments can determine the IR position to about 10nm every second in the transverse directions (x and y) would that be useful?

NB can also measure the luminous region length in ext with a somewhat larger error

# Summary of requirements to optics group

As it happened in LEP, the demands from energy calibration and polarization lead to understanding the accelerator in new details. Thus the following shopping list.

1. At this point we do not have a unified description of the machine that allows to perform, with the same (realistic and corrected) accelerator, calculations of luminosity and polarization
2. integration of the polarization wigglers in the lattice
3. integration of the polarimeter/spectrometer in the lattice
4. design and integration of the depolarizing kicker(s) in the machine
5. evaluation of uncertanties in the energy losses (esp. difference between colliding and non colliding bunches)
6. BI requirements for energy spread, dispersion measurements, Vernier scans, design of dedicated knobs for polarization, vertical dispersion in ring, and at IR.
7. How much luminosity would we lose, should we have to increase Qs to 0.1 at the W?
8. Should include the information that can be obtained from the collisions
   -- energy spread, energy differences, transverse mouvements & position, z&$\sigma_z$, of IR

**Also:**

1. to which precision do we expect/should the two beams be of equal energy?
 10-4 difference between e+ and e- → spin tunes of 103.45 vs 103.44
 this is probably acceptable and should be reproducible.
 10-3 would clearly be not acceptable.

2. A thorough monitoring system will need to be foreseen, since the variation of energy with time will be considerable if not corrected.
RF needs to follow the tides and correctors need to follow the orbit measurements for orbit and dispersion corrections and spin matching.
How many NMRs do we need?

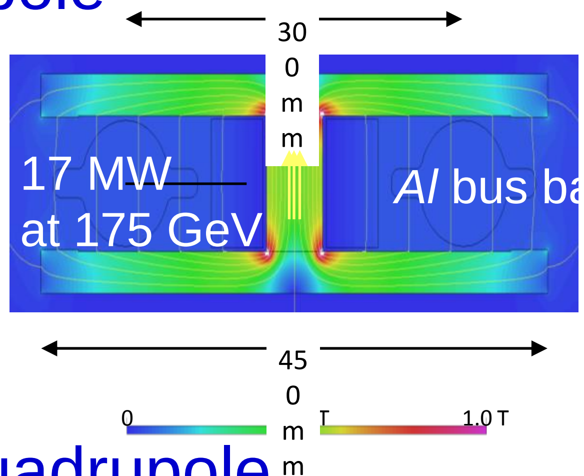
3. quantities having a n impact or sensitivity to beamstrahlung should be recorded. Which ones?
4. any other?

5. The exact time and sizes of all these changes will need to be recorded.

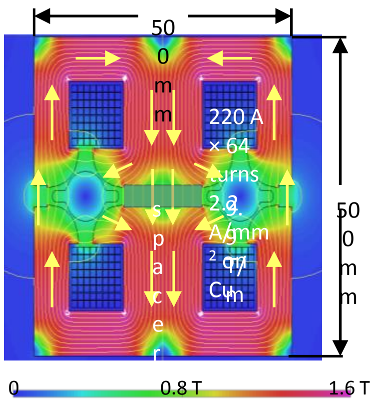
# FCC-ee dual aperture main magnets

## **low-power low-cost designs** - factor 2 power saving by dual aperture

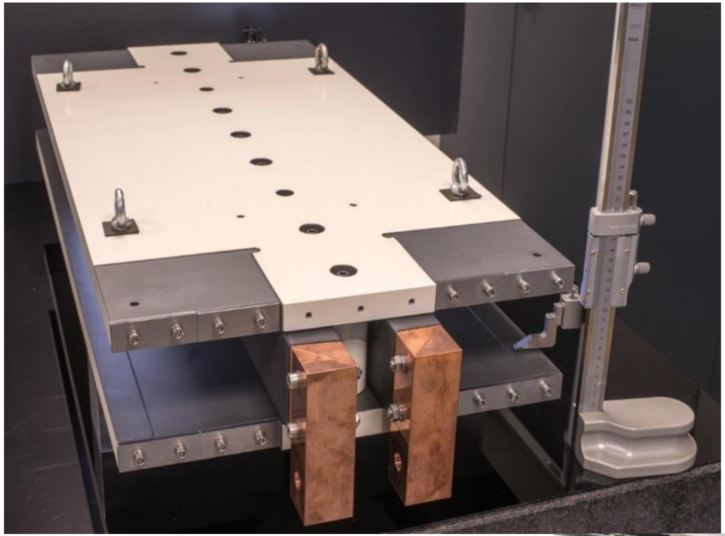
dipole




quadrupole




22 MW at 175 GeV with *Cu* coil



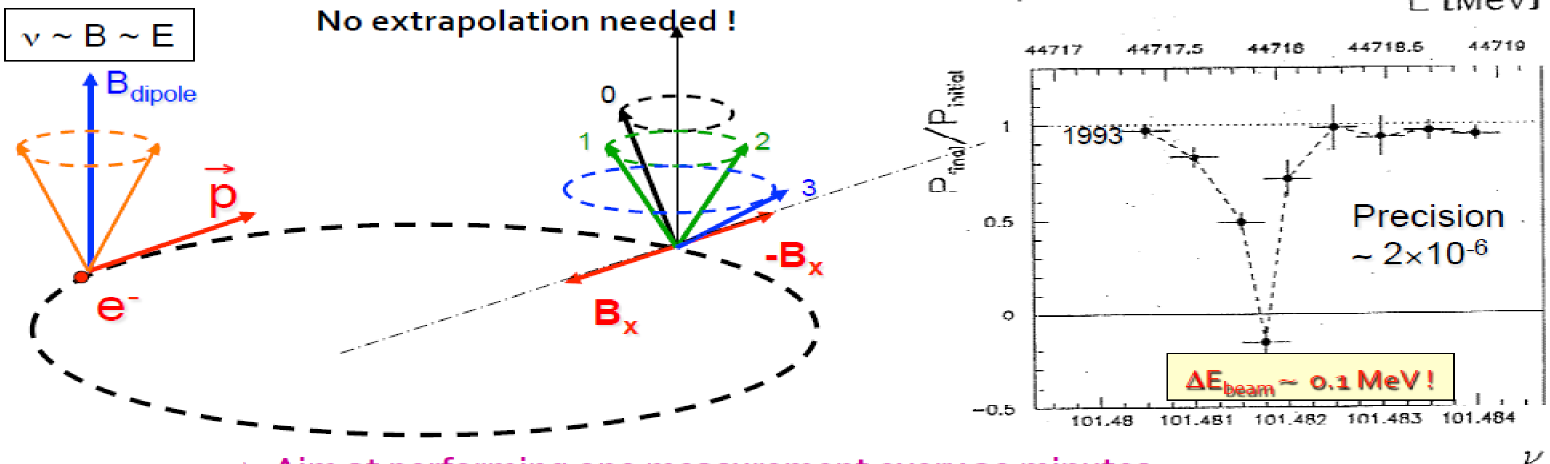
**construction of main dipole and quadrupole models (~1 m units)**

magnetic measurements ongoing

- Natural beam transverse polarization up to $\sqrt{s} \sim 2\ m_W$
  - Exquisite beam energy measurement with resonant depolarization, unique to rings
    - Precision limited to 2 MeV at LEP1 by the extrapolation to collision conditions
      - ➨ At TLEP, can use few single bunches (out of 4400 at the Z pole)

... and no e+ polarimeter!

No extrapolation needed !



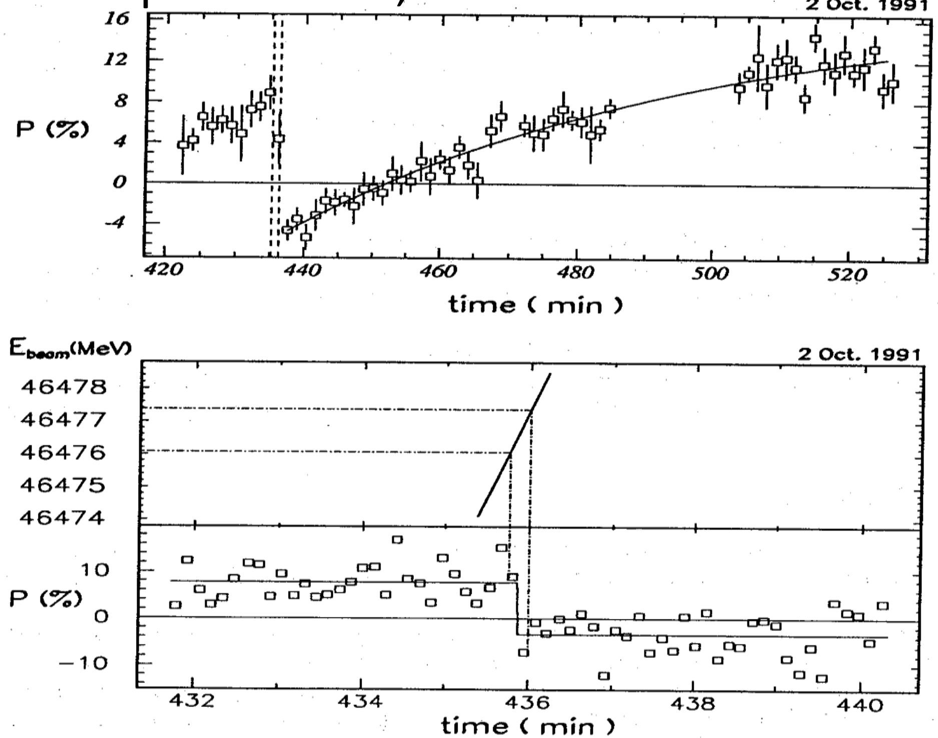

- ➨ Aim at performing one measurement every 20 minutes

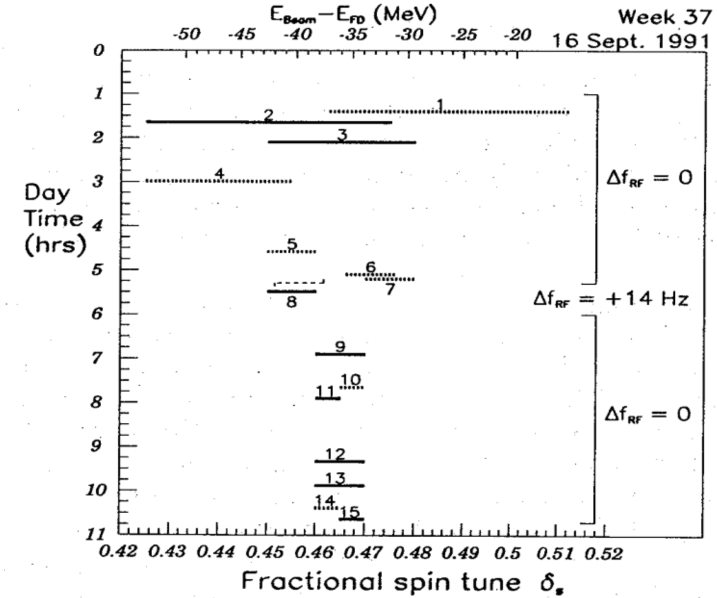
Ultimate precision better than 50 keV for $m_Z$ and $m_W$ measurements

- For $\sqrt{s}$ above $2m_W$ : use accurate W or Z masses in $e^+e^- \to Z(\gamma)$, WW, ZZ

should revisit the uncertainty and the method to understand how much better we can do.
Also how practical is it to co-exist
'polarized single bunches' with 'top-off injection'

# Resonant depolarization, 1991




variation of Rf frequency to eliminate half integer ambiguity

$E_{beam} = 46{,}466.6 \pm 0.6$ MeV, e.g. precise to $\pm\, 1.5\ 10^{-5}$.

**Figure 20:** Polarization signal on 2 October 1991, showing the localization of the depolarizing frequency within the sweep.
Top: display of data points, with the frequency sweep indicated with vertical dashed lines. The full line represents the result of a fit with starting polarization $(-4.9 \pm 1.)\%$, polarization rise-time $(60 \pm 13)$ minutes, asymptotic polarization $(18.4 \pm 4.1)\%$.
Bottom: expanded view of the sweep period, with the individual data sets displayed (there are 10 sets per point); The frequency sweep lasted 7 data sets. The corresponding beam energy is shown in the upper box. Spin flip occurred between the two vertical dash-dotted lines.

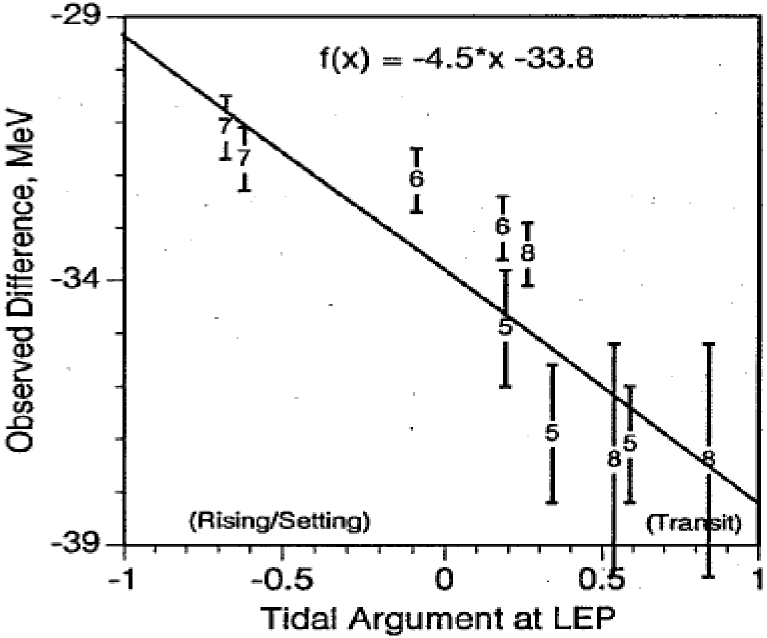



**Figure 22:** Correlation between the energy measured with resonant depolarization in 1991 and the earth tide amplitude. The numbering on the measurements represents their sequence in time, and the error bars give the range in beam energy within which resonant depolarization was observed.

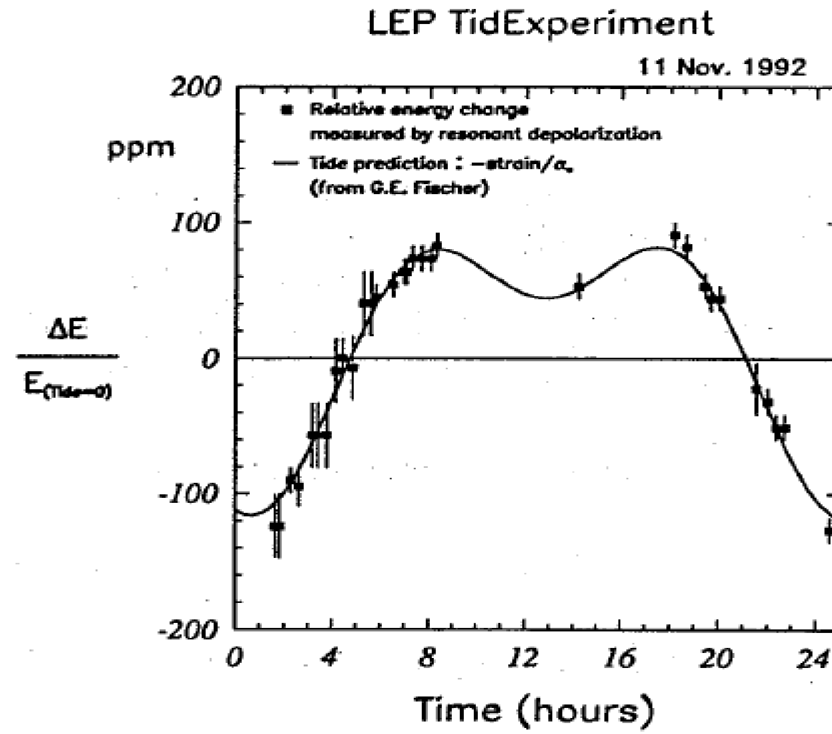



**Figure 23:** Beam energy variations measured over 24 hours compared to the expectation from the tidal LEP deformation.

We want 1 part per million. Swing will be 10 times larger at FCC-ee than at LEP **BUT** we will measure every 10-15 minutes. Will this work?

still after corrections for tides there were large fluctuations.

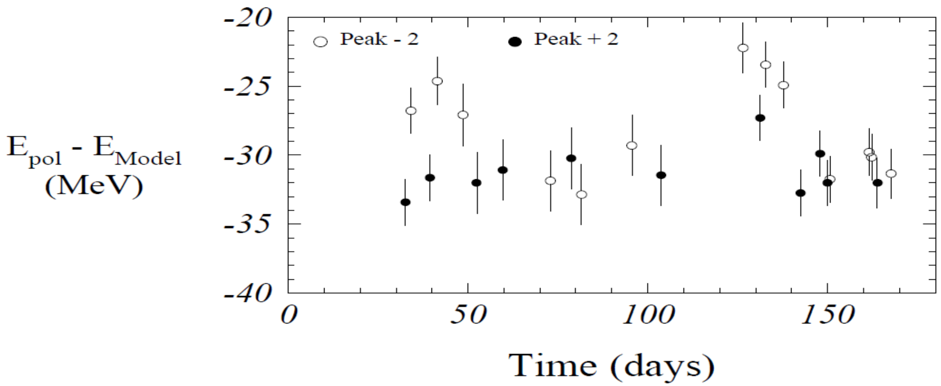
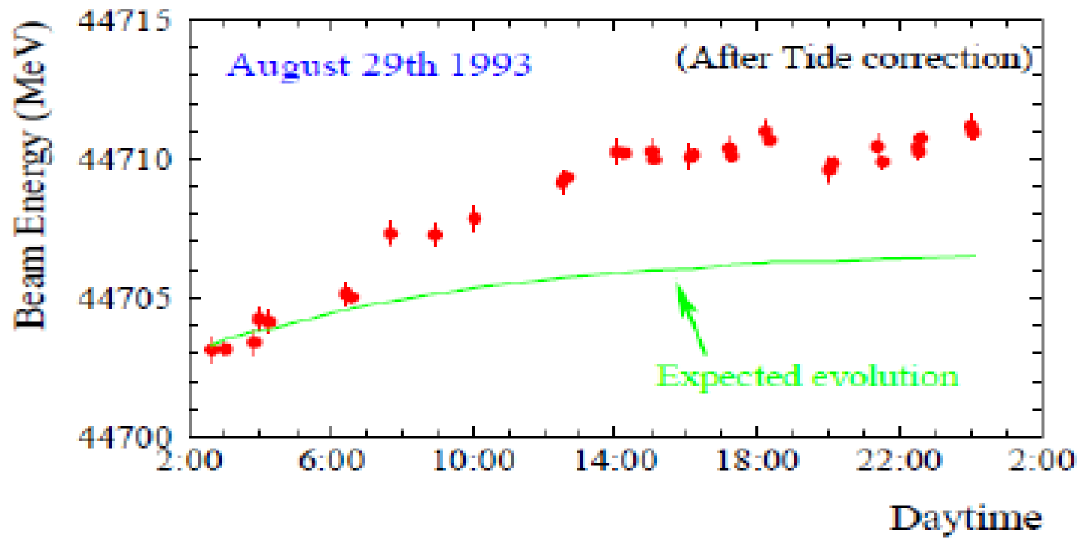
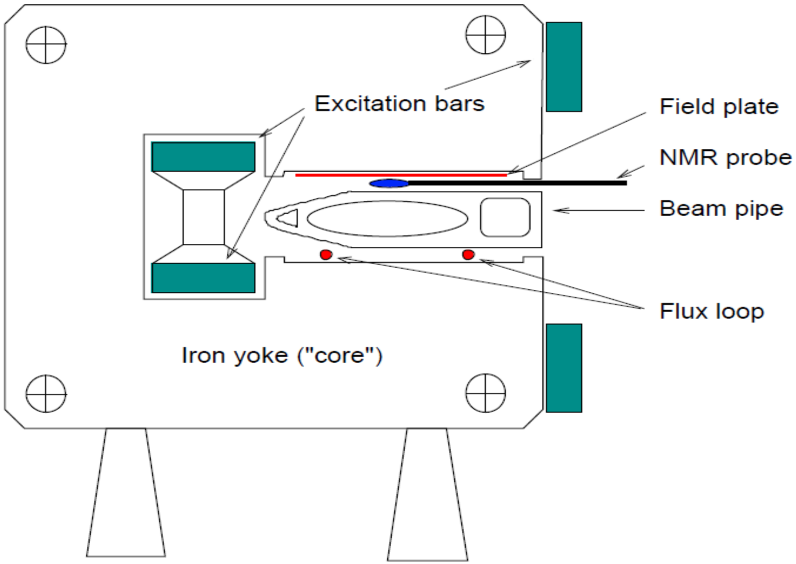


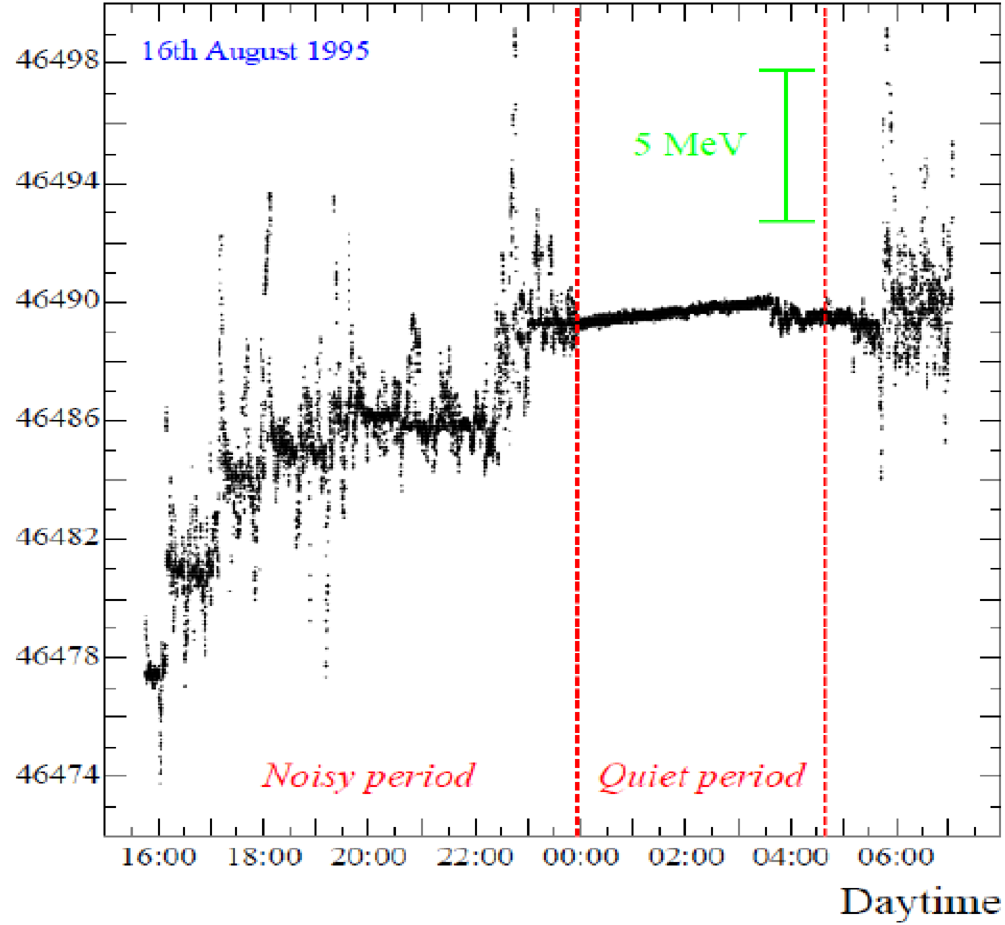

Figure 3: Evolution of the electron beam energy during the 1993 scan after correction of periodic effects (tides), dipole temperature changes and radial orbit movements.

-- Level of the Lake Geneva pulls the accelerator
-- Rain or snow on the Jura

a drift during a long MD fill
-- beyond tides –
was cause of concern
for 2 years….






in 1995 NMR probes were installed inside two magnets on the ring and the observations were striking: the field rises during the fills!

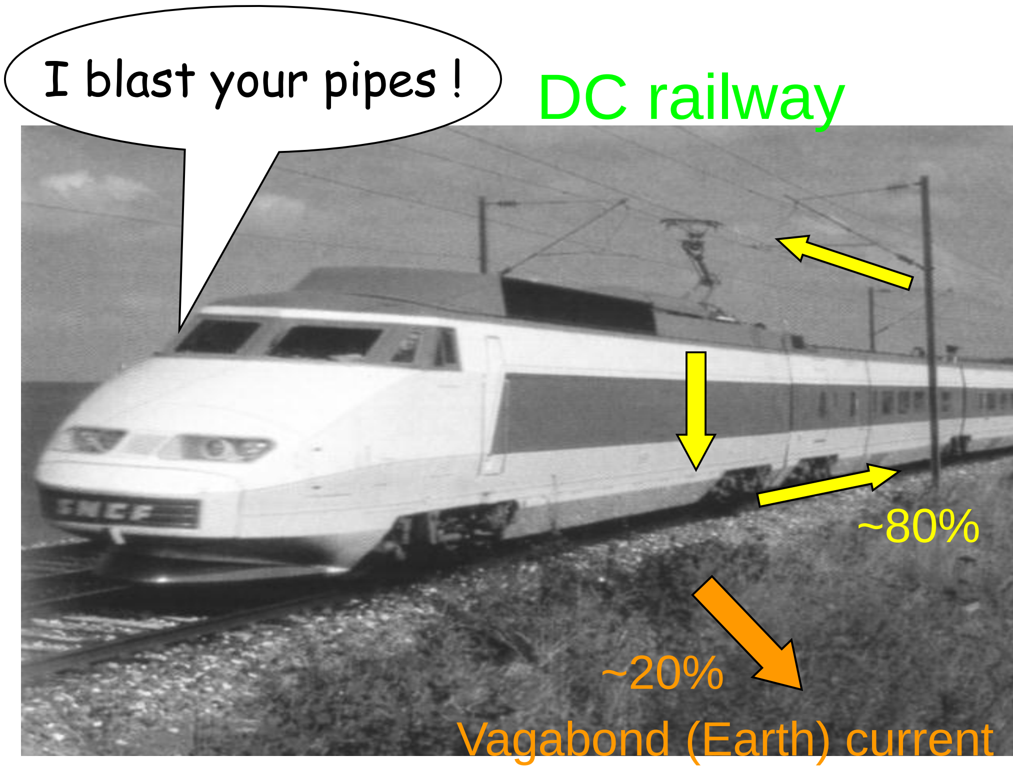
in 1996 14 more NMRs were installed
→ two per octant

# Pipebusters

The explanation was given by the Swiss electricity company EOS...

**Vagabond currents from trains and subways**

Source of electrical noise and corrosion (first discussed in …1898 !)



Measurements
of the current flowing
on the LEP beam pipe
showed a strange
correlation pattern
as if current
flowed from point 1
to point 6 in the two
arcs at the same time

The culprit was found
to be the TGVs

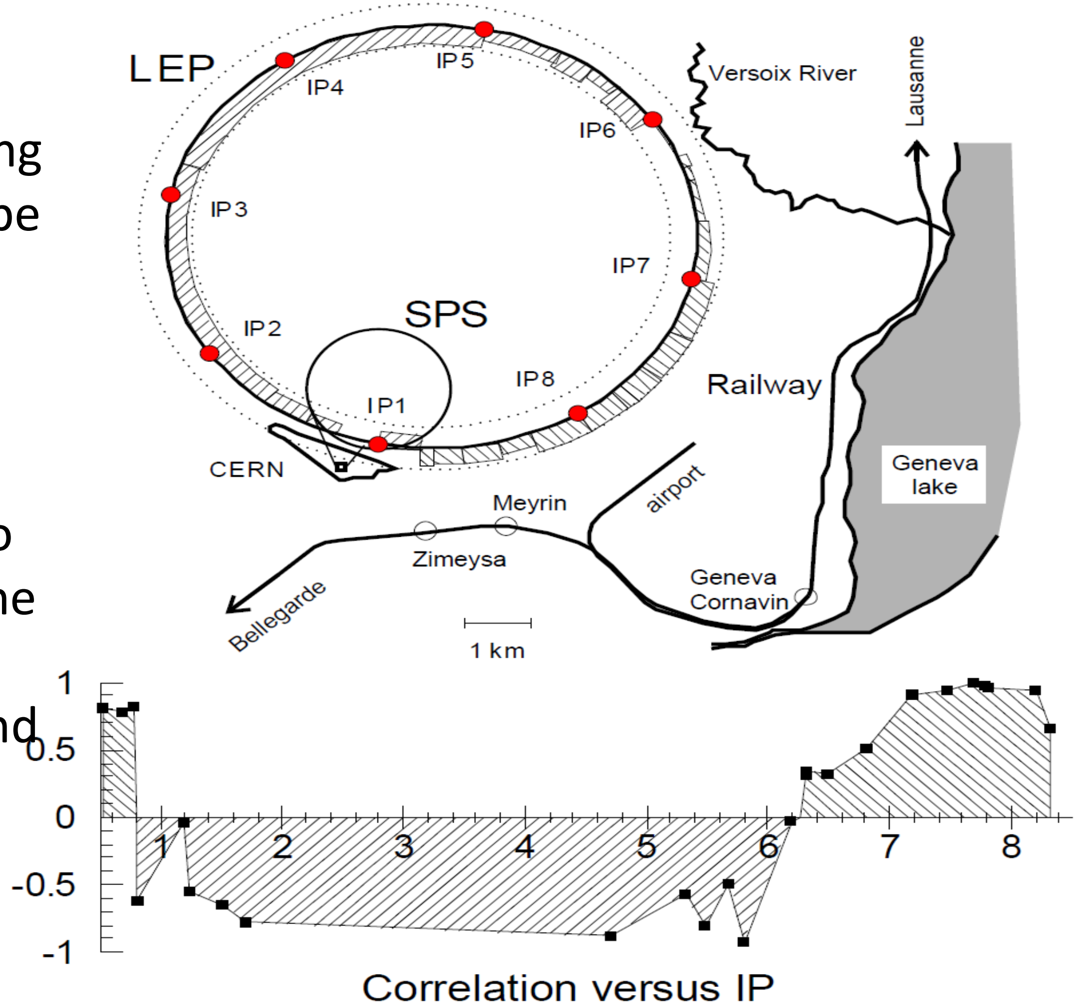



Figure 4: Diagram of CERN accelerators and surroundings. The measured correlation pattern of the parasitic currents along the ring is shown, proving that they enter and leave LEP near IP6 and IP1.

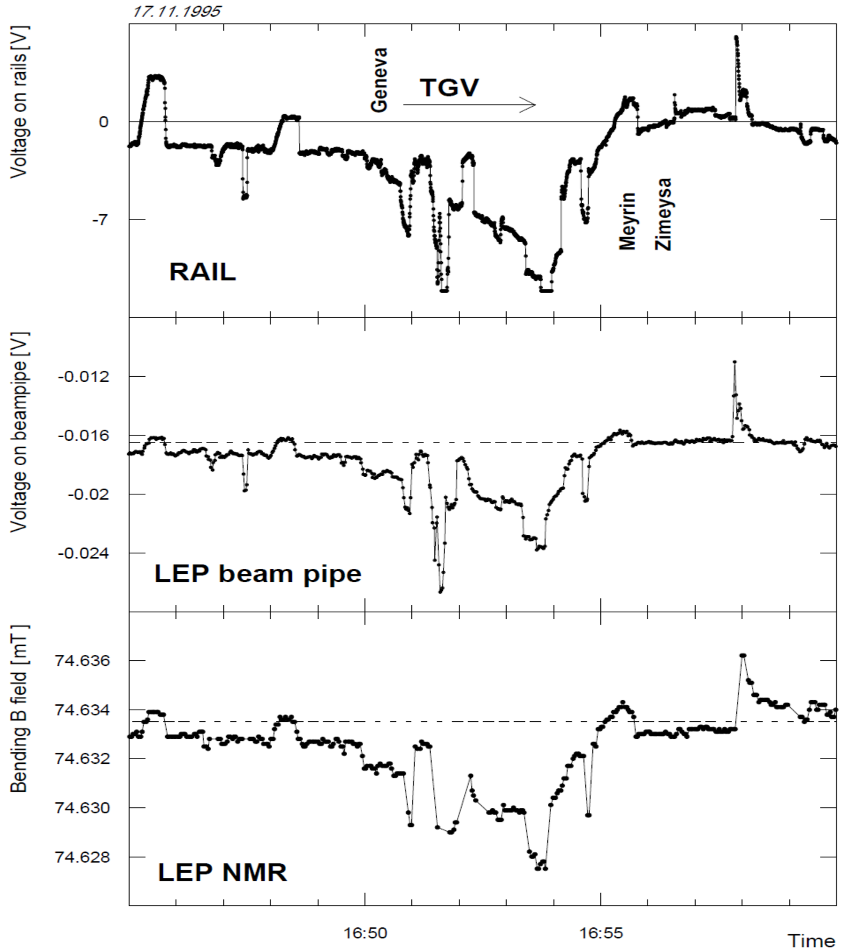
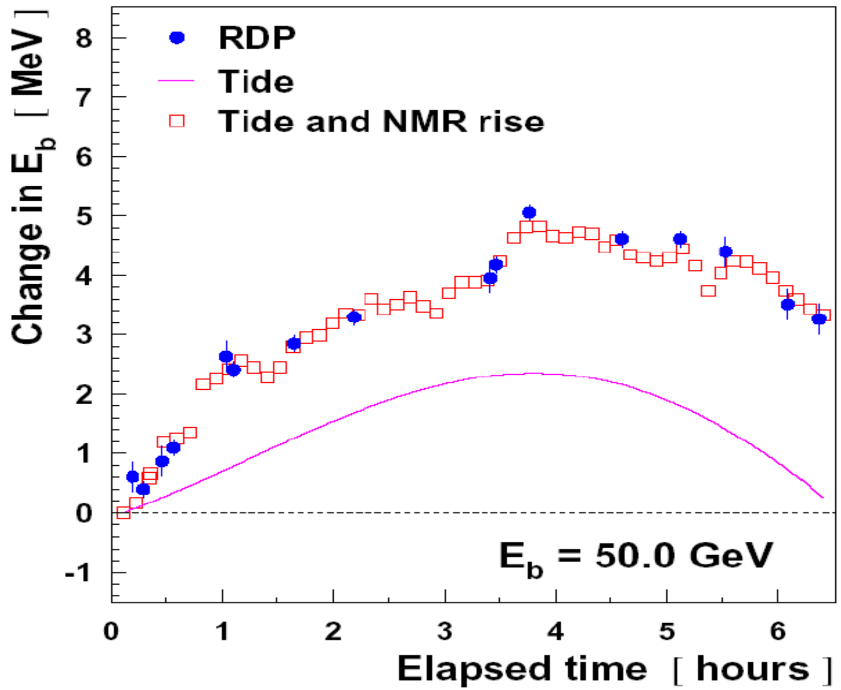



Figure 5: The synchronous measurement of the voltage difference between ground and the train rails (top), the voltage difference between the LEP beam pipe and ground (middle) and the NMR readings (bottom). The correlation is obvious. The label 'Geneva' marks the time of the departure of the TGV ('Train à Grande Vitesse') from Geneva central station. The label 'Zimeysa' indicates the time when the TGV went past the measuring device.

Modelling of energy rise by (selected) NMR sampling of B-field is excellent !




(Experiment from 1999)

by 1999 we had an excellent model of the energy variations…
but we were not measuring the Z mass and width anymore
– we were hunting for the Higgs boson!

**Today**

# XIth FCC-ee Energy Calibration and Polarization WG meeting

Thursday 30 Nov 2017, 14:45 → 17:00 Europe/Zurich

376-1-020 (CERN)

Alain Blondel (Universite de Geneve (CH)) , Jorg Wenninger (CERN)

**Description** follow up on workshop and preparation of CDR

**Videoconference Rooms** FCC-ee_EPOL Join 376-1-

**14:45** → 15:10 **connection and Follow-up from workshop** 25m
**Speaker**: Alain Blondel (Universite de Geneve (CH))

**15:10** → 15:40 **Effect of beamstrahlung on coliision energy (energy loss energy spread and their relationship)** 30m
**Speaker**: Dmitry Shatilov

**15:40** → 16:00 **Energy collision bias from residual vertical dispersions** 20m
**Speakers**: Dima El Khechen (CERN) , Katsunobu Oide (High Energy Accelerator Research Organization (JP)) , Katsunobu Oide , m Koratzinos (Universite de Geneve (CH))

**16:00** → 16:10 **Optics for compton polarimenter** 10m
**Speakers**: Katsunobu Oide (High Energy Accelerator Research Organization (JP)) , Katsunobu Oide
Optics_Oide_Compt... Optics_Oide_Compt...

**16:15** → 16:35 **a.o.b.** 20m

# Next meetings

**14 December 16:00-18:00**

can we make it in the morning (e.g. 10-14:00 CERN time)?

I have penciled the following presentations:

Anton: update on syst. errors in spin tune to ECM extrapolation

Ivan update on W depolarization parameters

Eliana possible update on simulation of depolarization etc…?

**11 January 16:00-18:00**

I have penciled in a presentation by Tobias & Jorg on saw-toothing and RF effects

what else?

We should foresee presentations on BI, NMR's?