Beam-beam effects & the "px-kick"

In the context of studies pertaining to the luminosity measurement (see later) : we realised that, due to Beam-beam effects, all events get a "px-kick".

Nothing much new here. These effects have been already studied in the energy calibration WG. E.g. had been presented e.g. by Dmitry Shatilov more than one year ago:
https://indico.cern.ch/event/687643/contributions/2821791/attachments/1575955/2488613/de_by_bs.pdf

Here I show what comes out from the tools that we use:
- Our main tool: Guinea-Pig
- Also have an independent calculation based on standard formula for the fields
    - https://indico.cern.ch/event/798359/contributions/3318866/attachments/1795160/2926035/2019_02_13_analytical_model.pdf

Bhabha events tracked through Guinea-Pig

Guinea-Pig reads Bhabha events (e.g. generated by BHWIDE).

1) Modification of the initial state : Prior to interacting, the initial state e- and e+ feel the EM field of the opposite bunch
   - Angular deflection ("pinch effect"), beamstrahlung

2) Modification of the final state : After the interaction, the final state e- and e+ (outgoing, towards the LumiCal) also feel this field
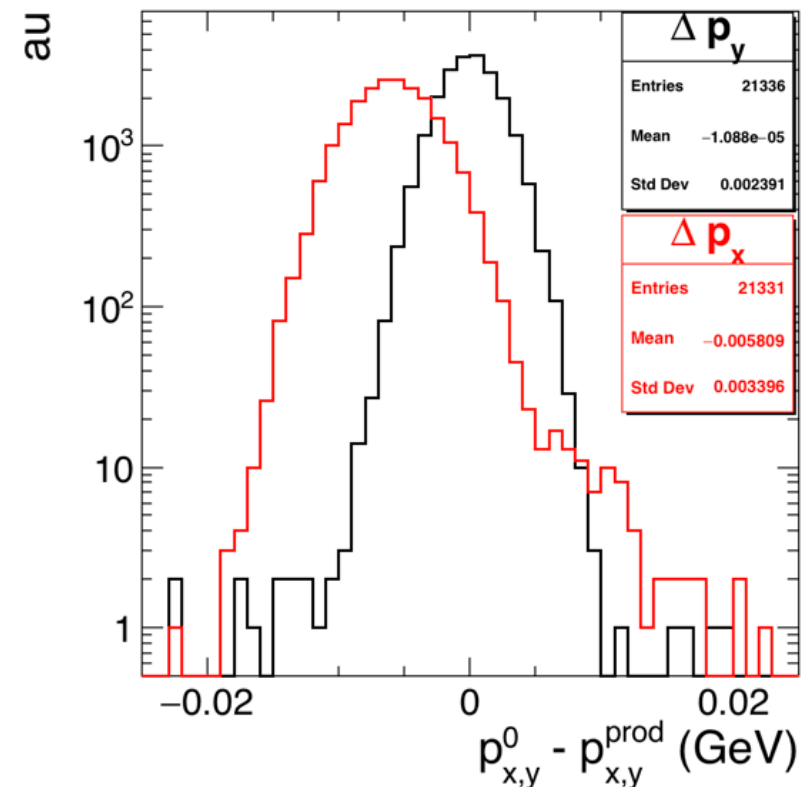
We have access to the kinematics after step 1).
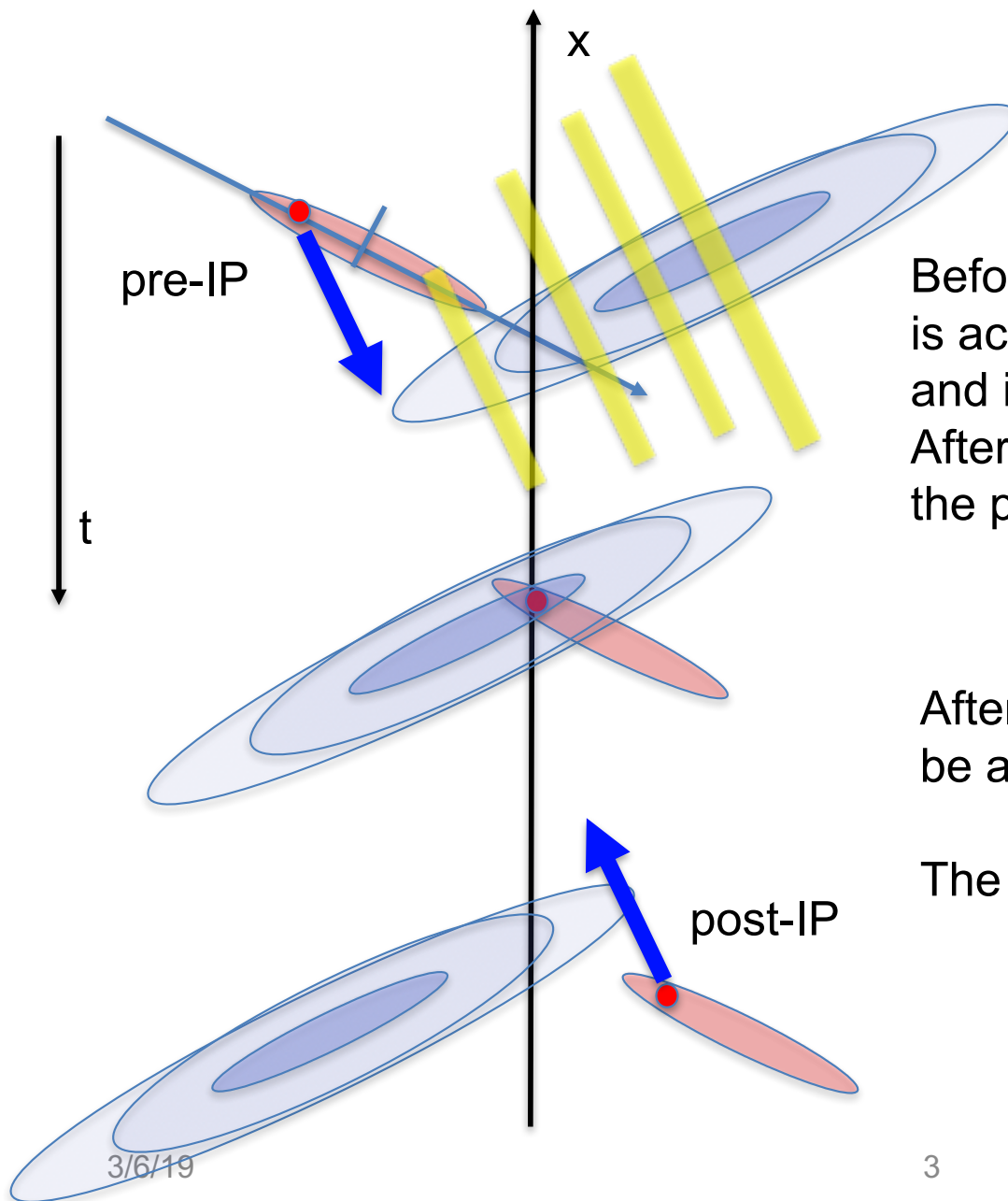
The plot shows the difference in

$$p_{x,y}{}^{tot} = p_{x,y}\,(e\text{-}) + p_{x,y}\,(e\text{+})$$

between step-1 and the generator level.

We see a "kick" in px of about 6 MeV.
(studied here with Bhabhas, but all events from all processes equally affected).

$\Delta\,p_y$	
Entries	21336
Mean	−1.088e−05
Std Dev	0.002391

$\Delta\,p_x$	
Entries	21331
Mean	−0.005809
Std Dev	0.003396

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$p^0_{x,y}$ - $p^{prod}_{x,y}$ (GeV)

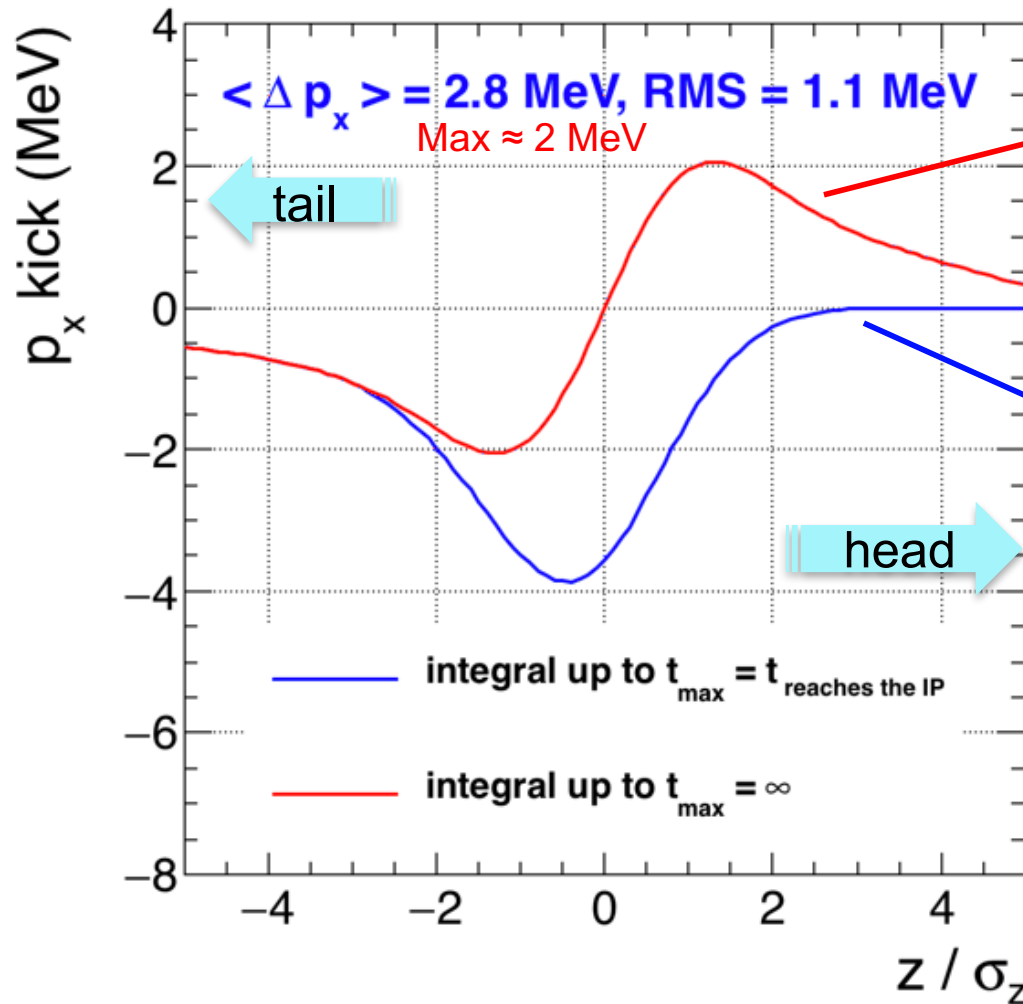# Beam-beam effects on the initial state particles

x

pre-IP

t

Before it reaches the IP : the particle is accelerated by the force along -x, and it gains energy.
After the IP, the force is in the other direction, the particle is decelerated and loose energy.

After it has crossed the IP, the particle won't be able to collide anymore.

The "kick" is built by the pre-IP forces.

post-IP

Beam-beam effects on the initial state particles: px-kick

Plot labels:
- y-axis: p_x kick (MeV)
- x-axis: z / σ_z
- $<\Delta p_x> = 2.8$ MeV, RMS = 1.1 MeV
- Max ≈ 2 MeV
- tail
- head
- —— integral up to $t_{max} = t_{reaches\ the\ IP}$
- —— integral up to $t_{max} = \infty$

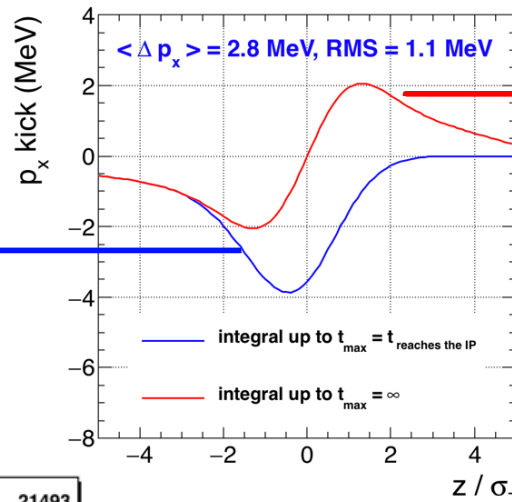Integration up to t = ∞. The averaging over all particles in the bunch is zero.

Kick integrated by the particles up to the time when they won't be able to collide anymore.
Average = 2.8 MeV.
Consistent with the kick of
6 MeV (per event) / 2 seen in GP.

z
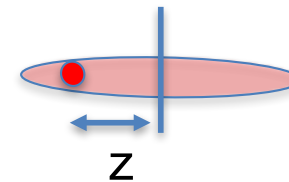
Particles in the head: most of the force is after they crossed the IP, and Fx > 0.
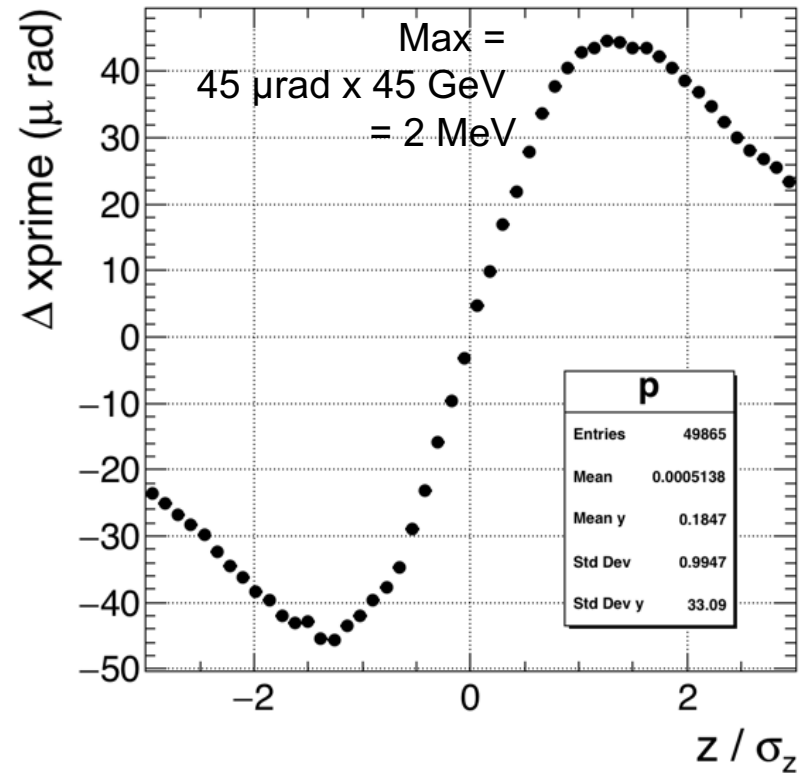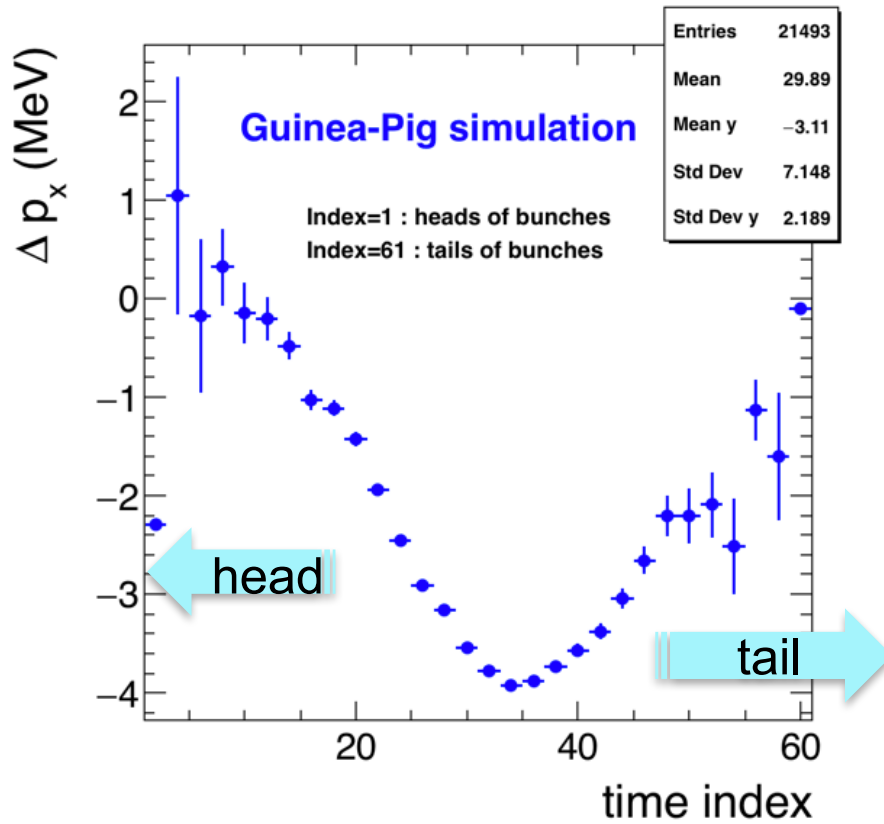Particles in the tail : most of the force is before they crossed the IP, and Fx < 0.

BB effects on the initial state particles: comparison with GP
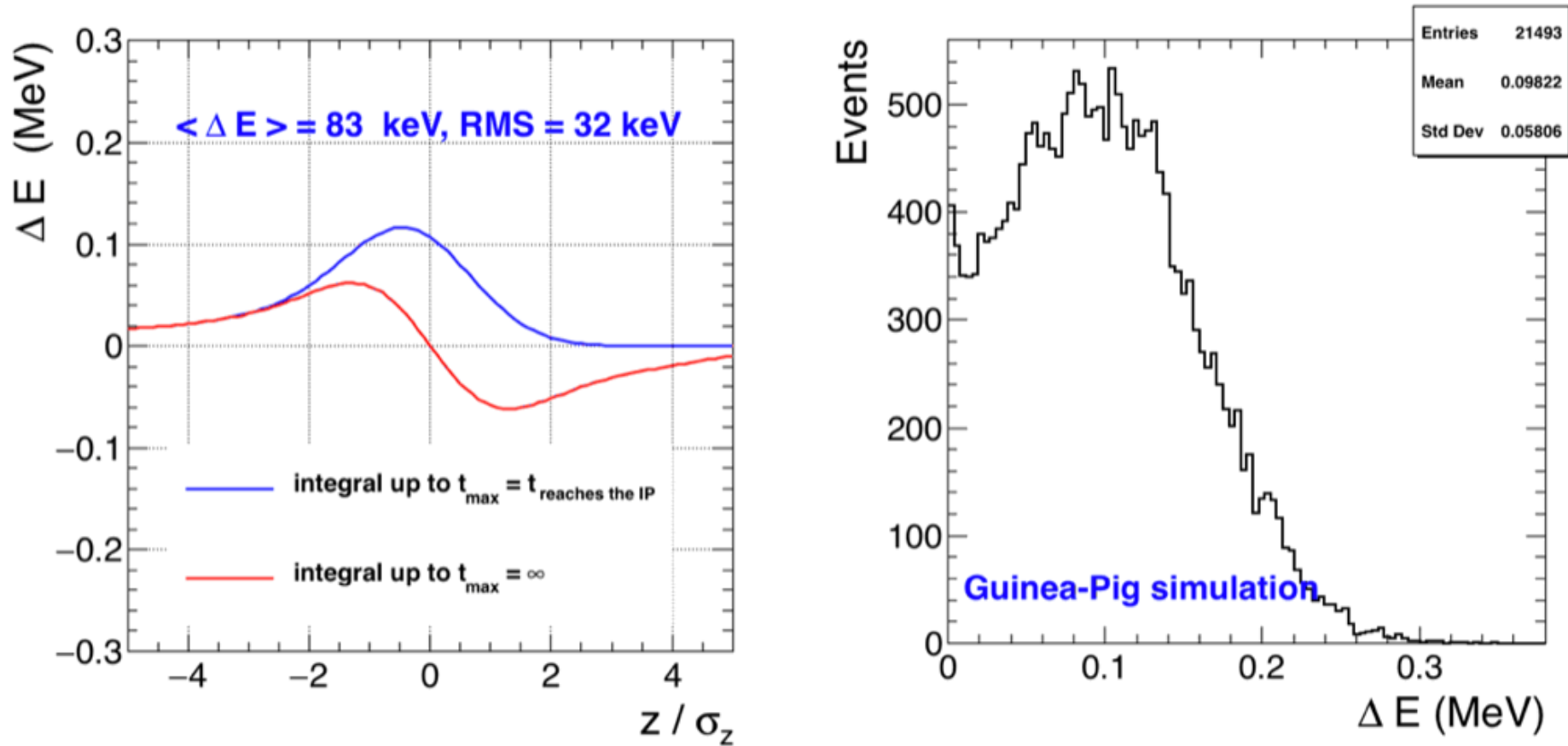
Bhabha events through GP.

$<\Delta p_x> = 2.8$ MeV, RMS = 1.1 MeV

Max ≈ 2 MeV

integral up to $t_{max} = t_{reaches\ the\ IP}$

integral up to $t_{max} = \infty$

p_x kick (MeV)

z / σ_z

"dump" the beams in Guinea-Pig :

Guinea-Pig simulation

Index=1 : heads of bunches
Index=61 : tails of bunches

Entries	21493
Mean	29.89
Mean y	−3.11
Std Dev	7.148
Std Dev y	2.189

Δp_x (MeV)

head

tail

time index

Max = 45 µrad x 45 GeV = 2 MeV

Δ xprime (µ rad)

p	
Entries	49865
Mean	0.0005138
Mean y	0.1847
Std Dev	0.9947
Std Dev y	33.09

z / σ_z

Seen as ΔE

The px-kick affects the energy of the particles prior to the collision and sqrt(s) :

$<\Delta E> = 83$ keV, RMS = 32 keV

integral up to $t_{max} = t_{reaches\ the\ IP}$

integral up to $t_{max} = \infty$

Guinea-Pig simulation

Entries 21493
Mean 0.09822
Std Dev 0.05806

A bit larger than Dmitry's result (60 keV).

ΔE from Guinea-Pig: obtained from Δpx, as GP includes Beam-strahlung (ΔE = Δpx * sin (30 mrad))

- Qualitative agreement with what Dmitry had shown earlier

- Not perfect numerical agreement, but :

  - Currently chasing numerical caveats in my analytical code

  - And checking how the results from Guinea-Pig vary with several steering parameters (grid size, slicing, etc.)

  - Also, using here the FCC parameters as given in the param. table; apart from σ_z, these are apparently not the dynamical values

  - So the numerical values shown here may still vary…

- The next talk will show that it can anyway be precisely measured in-situ.