# Transverse profile systems for FCC-ee

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with many thanks to M.Hofer and F. Ewald (ESRF)

# Outline

**Requirements for transverse diagnostics**

**Synchrotron Radiation based systems**

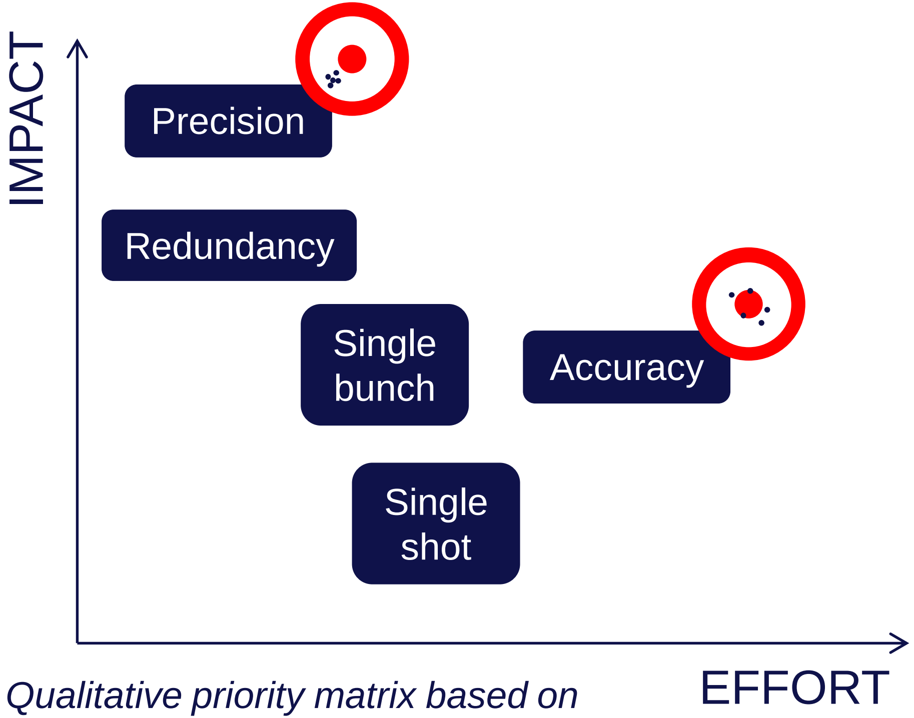
- pinhole camera
- X-ray imaging
- interferometric techniques
- options for SR sources

**Alternatives to Synchrotron Radiation diagnostics**

- laser wire scanner

**Conclusion**

# Requirements for transverse diagnostics




*Qualitative priority matrix based on present understanding of needs*

**Numbers are being defined** but we already have a global picture

**Multiple systems** likely required to meet all specifications

**Real-time precise measurement** is top priority for commissioning

BI specs input spreadsheet

# Pinhole camera


$$\sigma_{eff}^2 = \sigma_{ideal}^2 + \sigma_{PSF}^2$$

$\sigma_{ideal}^2 \rightarrow f(\sigma_{src}, M, \beta, \alpha)$

$\sigma_{PSF}^2 \rightarrow \sigma_{blur}^2 + \sigma_{diff}^2$ ($w_{ph} \uparrow$, $w_{ph} \downarrow$)

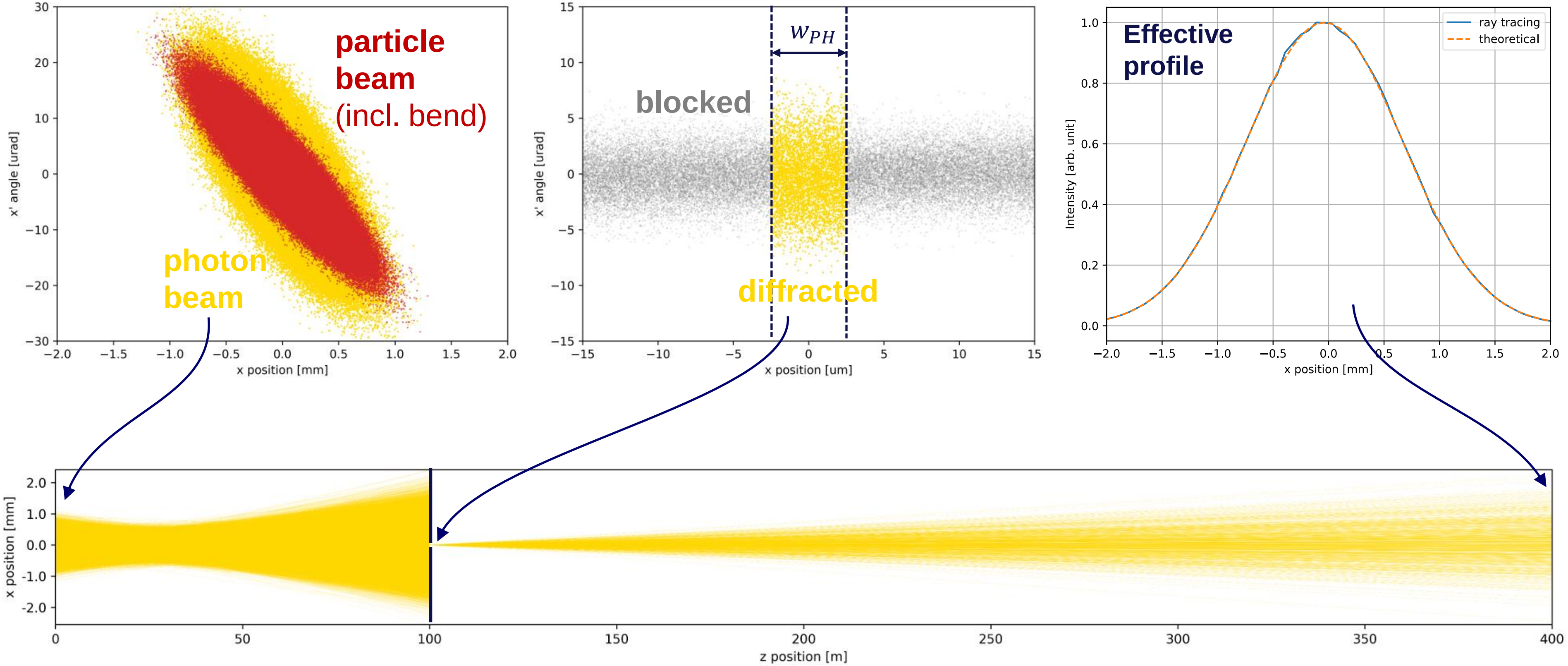
Standard for X-ray diagnostics
- **robust** and minimal system
- good **precision** <2%
- good **accuracy for $\boldsymbol{\sigma > 50\ \mu m}$**

…typically with $\boldsymbol{E_{ph} < 150\ keV}$

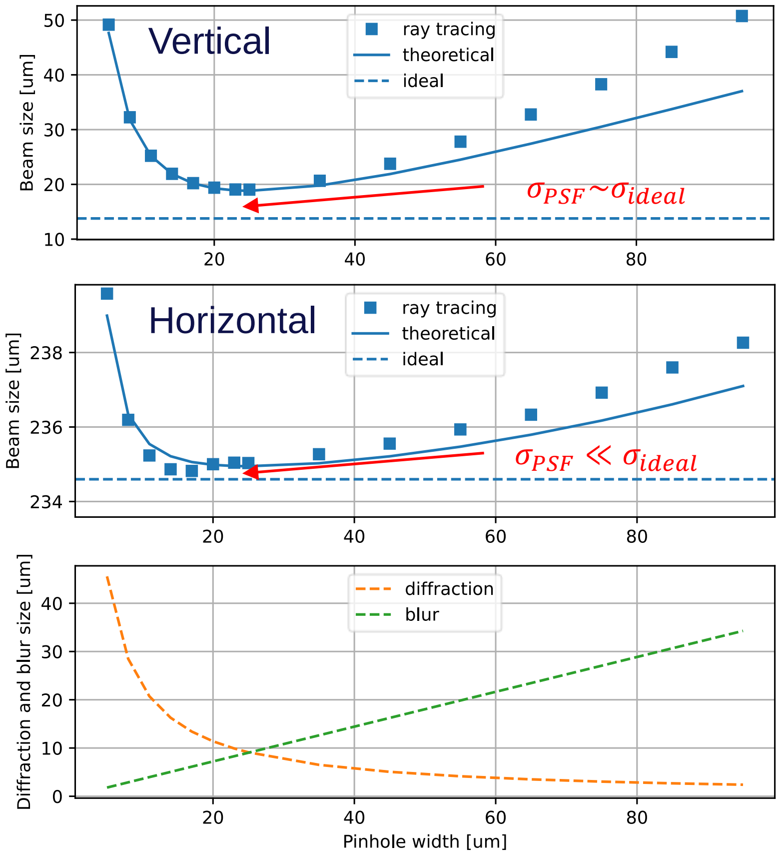
Guess of **parameters for FCC**
- $d \sim 100$ m for beam-light separation
- $D/d \sim 3 - 4$ for magnification
- $w_{PH}$ shall minimize PSF, but $> 10\ \mu$m for manufacturing

Simplified analytical formulae exist → check applicability to FCC case

# Ray tracing


particle beam (incl. bend)
photon beam
x' angle [urad]
x position [mm]
blocked
$w_{PH}$
diffracted
x' angle [urad]
x position [um]
Effective profile
ray tracing
theoretical
Intensity [arb. unit]
x position [mm]
x position [mm]
z position [m]

# Ray tracing



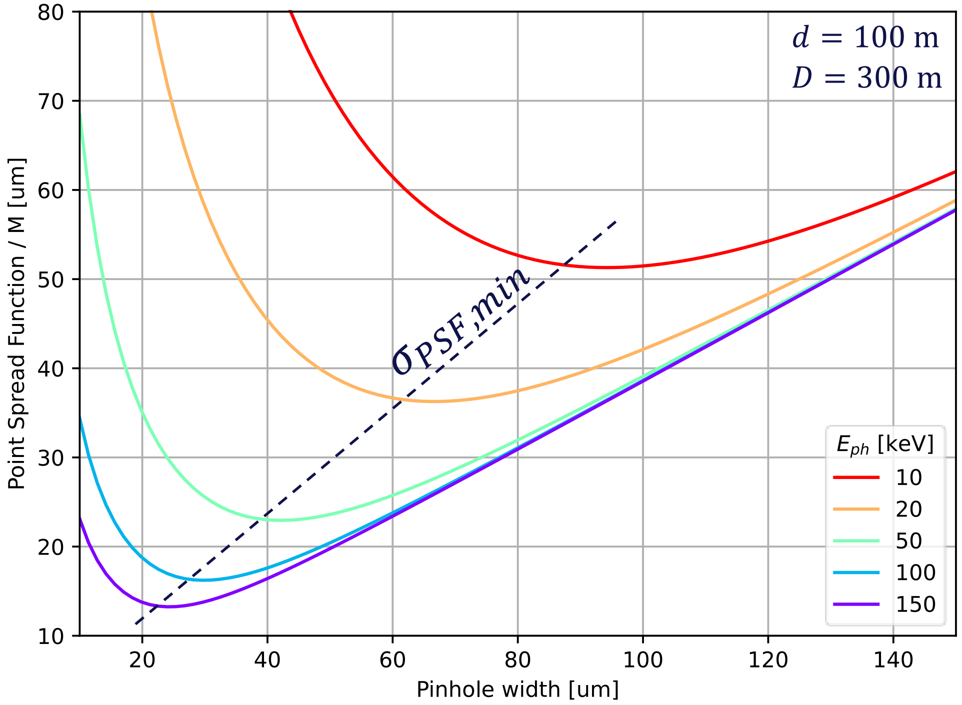

Ray tracing confirms analytical estimation of the Point Spread Function around the optimum $w_{PH}$

Deviations for large $w_{PH}$ because blur is enhanced by large bending radius

$$\sigma_{eff}^2 = \sigma_{ideal}^2 + \sigma_{PSF}^2$$

# Point Spread Function of pinhole camera

Theoretical $\sigma_{PSF}$ computed for realistic range of pinhole widths and photon energy




All scenarios allow resolution of **horizontal** beam sizes

Even at the highest photon energies, **vertical** sizes around 10 μm are hardly resolvable

# Pinhole upgrade: X-ray imaging

Pinhole cameras are **far from diffraction limit** of X-rays $\sigma_{PSF} \xrightarrow{diff\ lim} \frac{\lambda}{4\pi\vartheta_{SR}} \overset{*}{\approx} 0.2\ \mu\text{m}$

**CRLs allow focusing** of an X-ray beam…

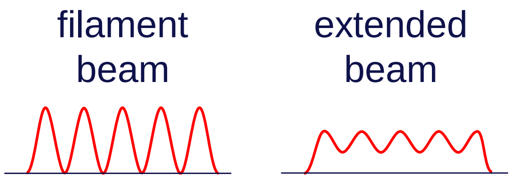

…but are **far from optical quality standard**

- significant chromatic aberrations (monochromator required)
- non-negligible attenuation
- increased setup complexity

*realistic 50 keV photons and $\vartheta_{SR} \approx 0.1\rho^{1/3}\lambda^{2/3} \approx 10\ \mu\text{rad}$

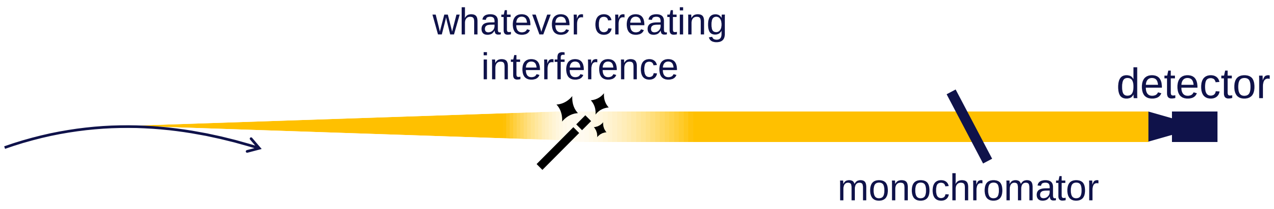
# Alternatives to pinhole: X-ray interferometry

Interferometry is complementary technique to imaging
→ **assess beam size from contrast** of interference fringes




**Variety of targets**
- apertures/slits
- scattering fibers
- nanostructured materials

allow better performance than pinhole...




…but with common **challenges**
- require monochromatic light
- highly sensitive to distortions
- increased setup complexity

Imaging and interferometry can **coexist** on same extraction line, often with same detector

# Options for Synchrotron Radiation sources


**Diagnostics challenges**

- small vertical beam sizes
- high photon energy

**Integration challenges**

- high radiation and power load
- large bending radius (long extraction lines)

Options for SR source

- **arc dipole**: maximum flexibility but harsh environmental conditions
- **Exp/tech site dipoles**: limited choice but more favorable beam sizes

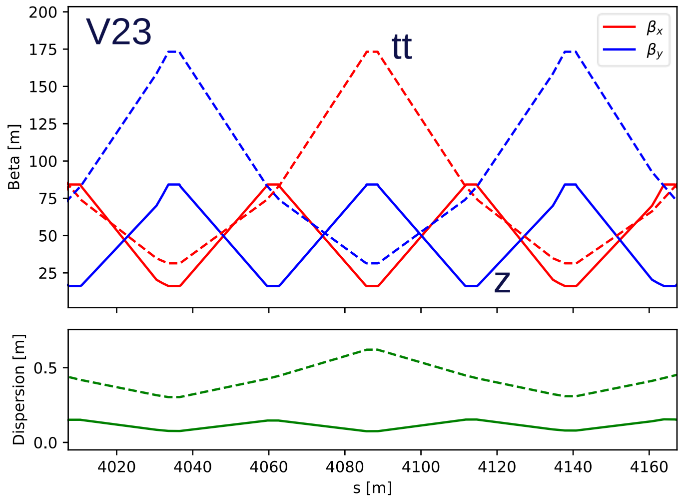
# Arc dipoles

| Parameter | Z | WW | ZH | tt | Unit |
|---|---|---|---|---|---|
| Energy | 45.6 | 80 | 120 | 182.5 | GeV |
| Current | 1280 | 135 | 26.7 | 5 | mA |
| Emittance H / V | 710 / 1.42 | 2170 / 4.34 | 640 / 1.29 | 1490 / 2.98 | pm |
| $\rho$ / $l$ arc dipole | 10000 / ~20 | | | | m |
| $\lambda_c$ / $E_c$ arc dipole | 59.0 / **21.0** | 10.9 / **113.6** | 3.2 / **383** | 0.9 / **1350** | pm / keV |

- **radiation power load** ~8kW/mrad
- **photon energy** beyond diagnostics capabilities and destructive for instrumentation in ttbar
- **challenging beam sizes** due to low beta in arcs

Z: $\beta_y \sim \beta_x \sim 100$ m, $\varepsilon_{(y)} \sim 1.3$ pm, $\sigma_{\min\ (y)} \sim 12$ um

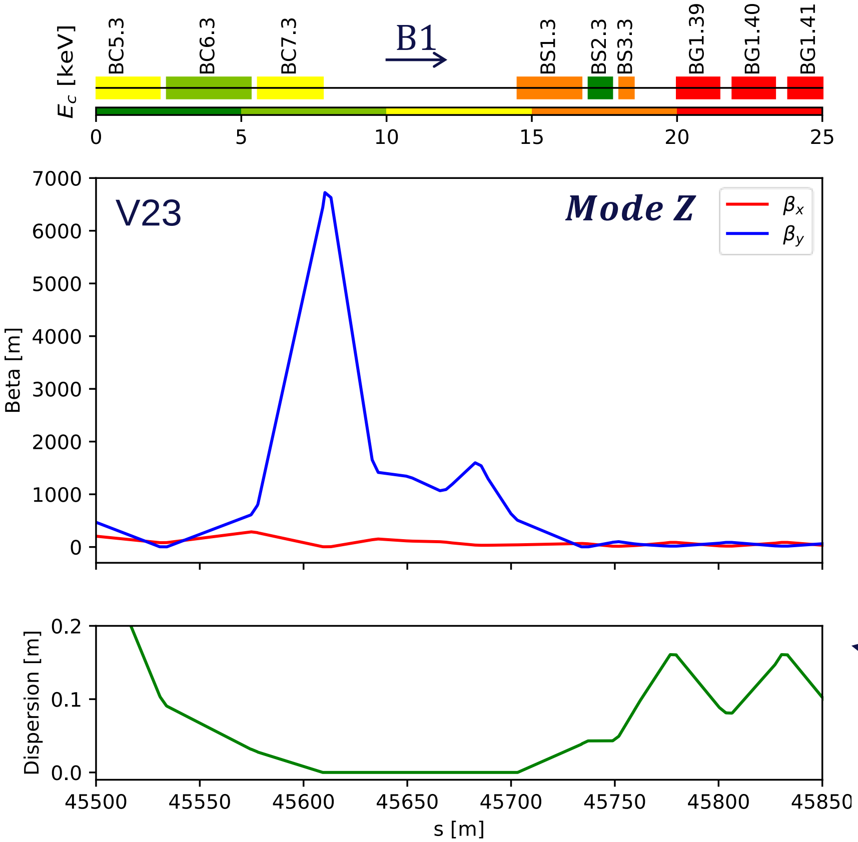
ttbar: $\beta_y \sim \beta_x \sim 50$ m, $\varepsilon_{(y)} \sim 3$ pm, $\sigma_{\min\ (y)} \sim 12$ um



# Dipole magnets around IPs

Pro:
- softer bends
- less SR power
- larger sizes

Cons:
- integration (wigglers?)
- radiation from IP (?)

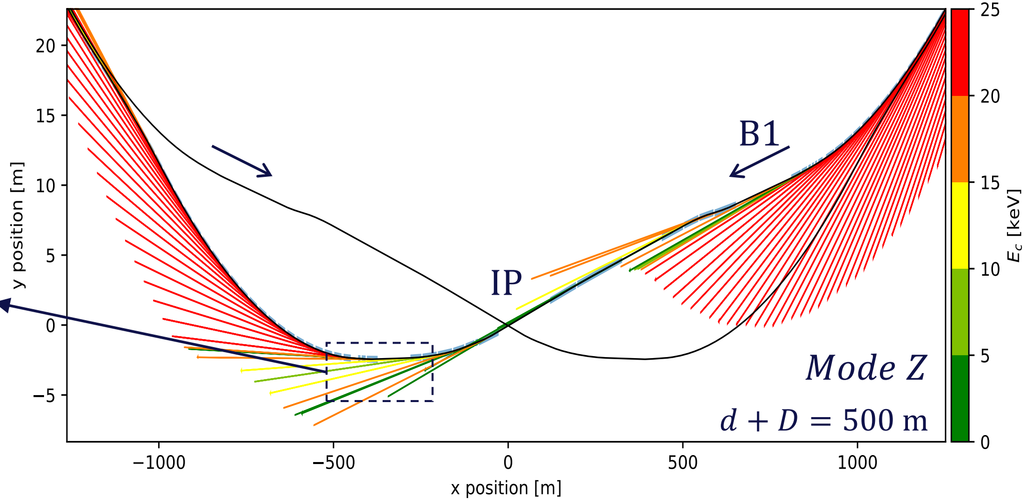



Example centre of BC7

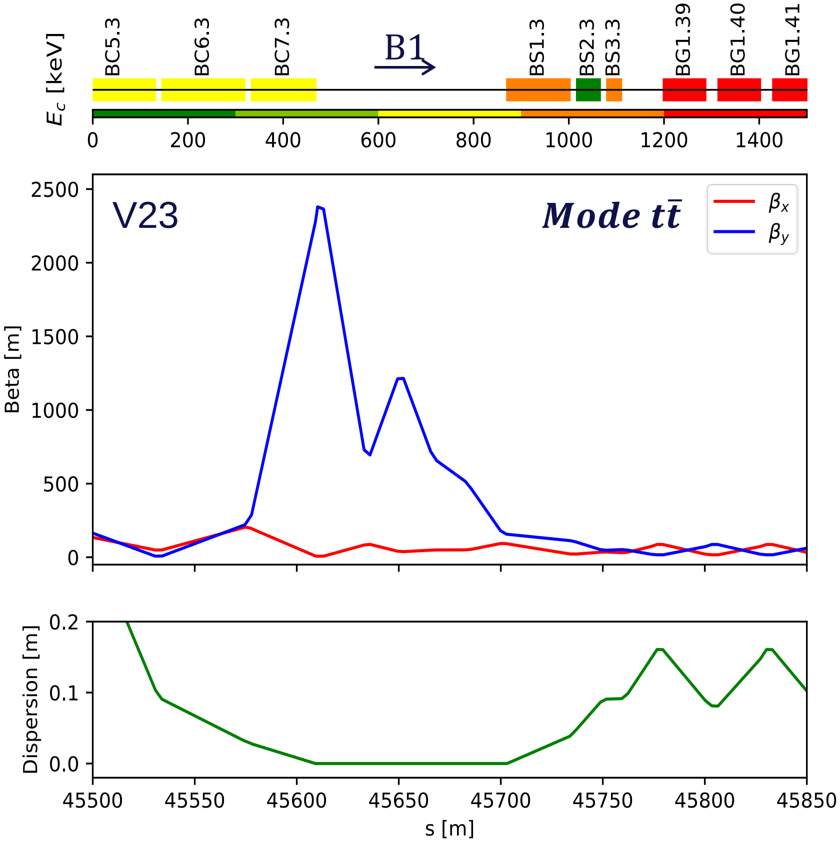
$\beta_y \sim 3000$ m

$\boldsymbol{\sigma_y \sim 80}$ **um**

with $\boldsymbol{\sigma^2_{PSF} \sim 40}$ **µm** for pinhole at $E_c = 15$ keV



# Dipole magnets around IPs (ttbar mode)




Critical energies of most dipoles too high (>1 MeV) for diagnostics at tt mode
→ **working in low frequency tail of spectrum**

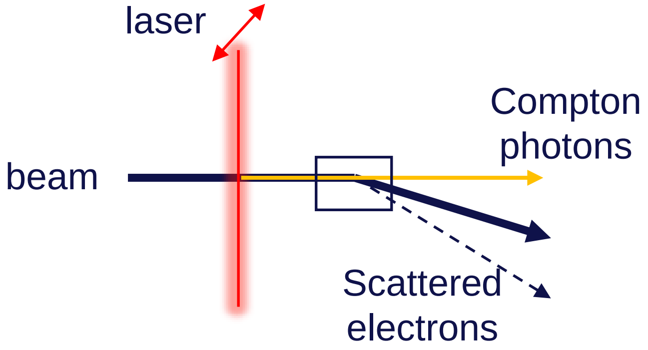
Example centre of BC7 ☺

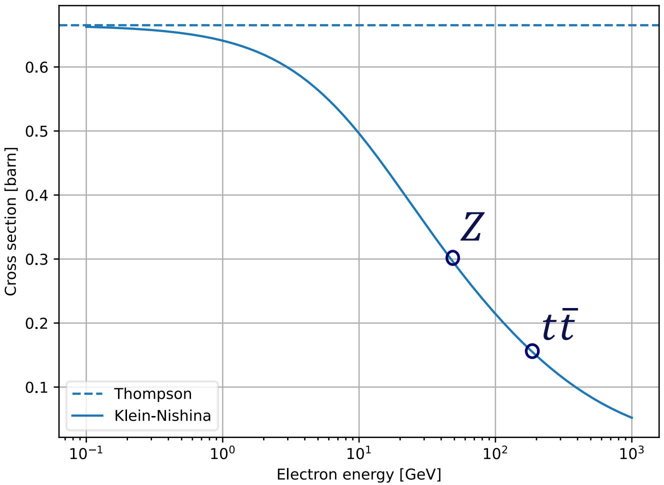
$\beta_y \sim 1500$ m

$\boldsymbol{\sigma_y \sim 50}$ **um**

with $\boldsymbol{\sigma^2_{PSF} \sim 15}$ **µm** for pinhole at $E_{ph} = 150$ keV

# Alternative to SR diagnostics: Laser Wire Scanner




LWS can achieve micrometric resolution
→ suitable for **accurate vertical measurements**

Similar hardware as **polarimeter**
→ possible common **integration**

FCC has very high electron energies
→ **lower cross section** and **higher photon energy** than all present applications

**Laser technology is quickly advancing**
→ higher power laser and better focusing systems likely available by FCC era

# Conclusion

Precise and real-time monitoring is priority for commissioning and operation
→ **pinhole** looks camera more convenient option

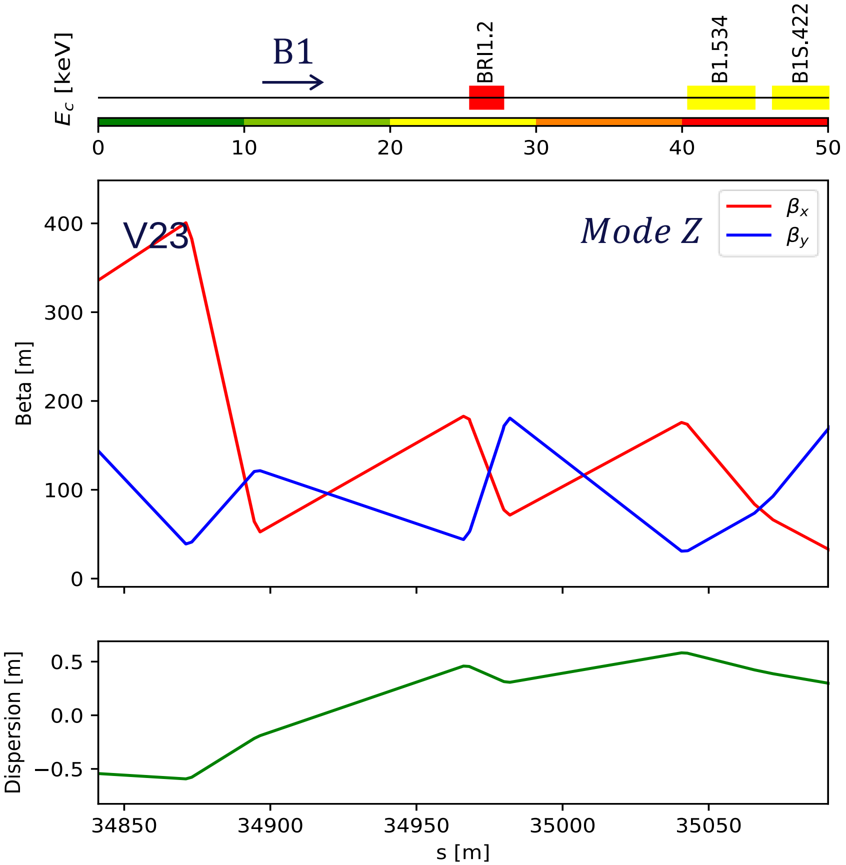
Experimental sites offer more favorable conditions for SR beam size measurements
→ **integration needs to be studied**

Pinhole alone cannot meet accuracy requirement in vertical
→ **X-ray imaging and interferometry** can complement SR-based diagnostics

Alternatives to SR techniques may diversify diagnostics and improve accuracy
→ **Laser Wire Scanner** being considered

# Thank you
# for your attention!

# Dipole magnets around RF




Pro:

- less SR power

Cons:

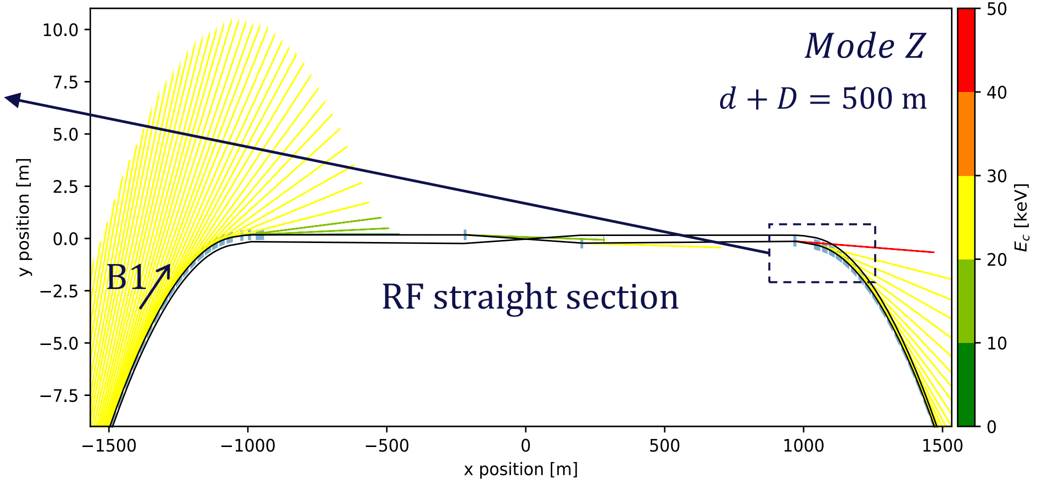
- integration (inside ring and layout changes with mode)
- similar beam sizes as arcs

Example centre of BRI1 ☹

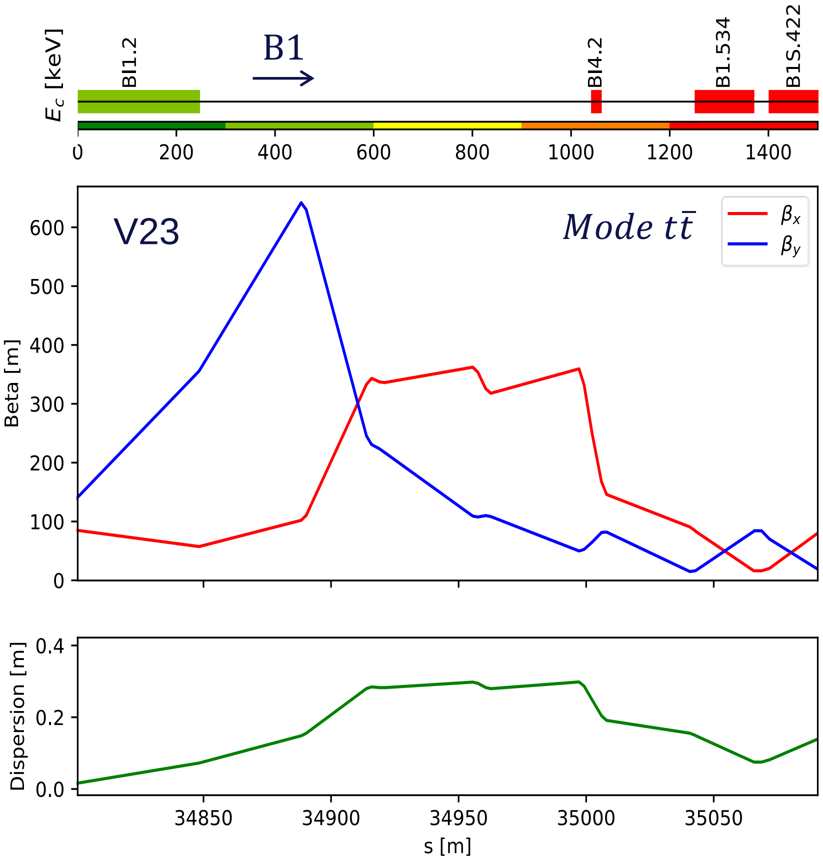
$\beta_y \sim 100$ m

$\boldsymbol{\sigma_y \sim 14}$ **um**

with $\boldsymbol{\sigma_{PSF}^2 \sim 25}$ **µm** for pinhole at $E_c = 50$ keV



# Dipole magnets around RF (ttbar mode)




Example centre of BI1

$\beta_y \sim 250$ m

$\boldsymbol{\sigma_y \sim 20}$ **um**

with $\boldsymbol{\sigma^2_{PSF} \sim 15}$ **µm** for pinhole at $E_{ph} = 150$ keV