MITIGATION BY FAST IP FEEDBACK

A first look

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With thanks to: F. Zimmermann, P. Burrows, K. Oide, D. Shatilov, E. Howling, M. Wendt, T. Lefevre, S. Sai Jagabathuni, V. Gawas and all FCC-ee/FCCIS colleagues

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Outline

Performance Requirements

Sources of Error

Existing Feedback Systems

Hardware Layout

Input Signals

Correctors

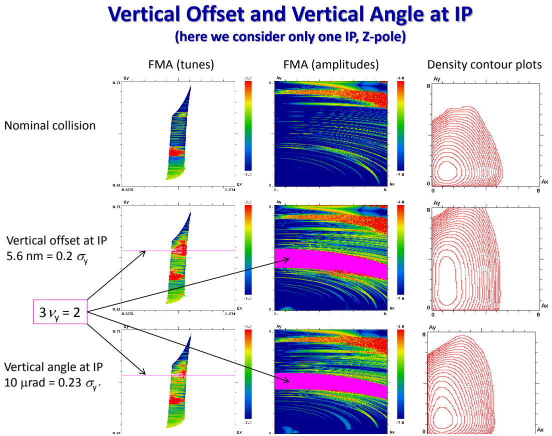
Conclusions

Performance Requirements

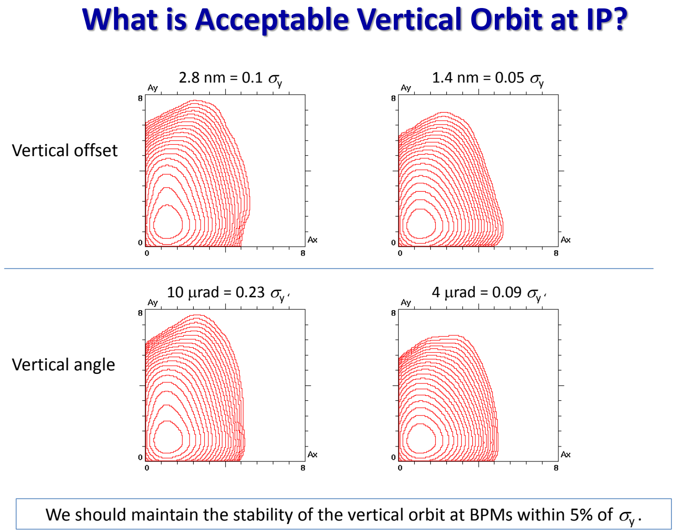
- IP Feedback required to maintain luminosity and lifetime
- Previous studies on acceptable vertical offsets in position and momentum performed by D Shatilov [1], looking at the Z working point

- Previously identified requirements:
  - “We should maintain the stability of the vertical orbit at BPMs within **5% of $\boldsymbol{\sigma_y}$**”

- 5% of σ_y:
  - Z: 1.8nm
  - tt: 2.5nm



D. Shatilov



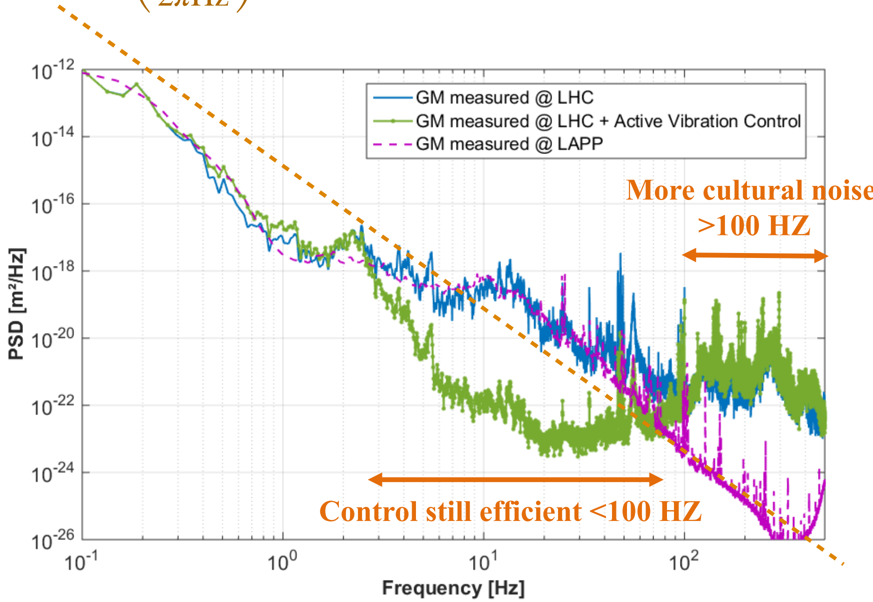
[1] D. Shatilov, Large footprint with 4 IP (can cross half-integer), discussion and mitigation

Sources of Error

- Errors from vibration, due to:
  - Seismic ground motion
  - Machine components (power, cooling)
- Can split into components:
  - Resonant with the betatron frequency
  - Non resonant Vibrations

- Previous studies by K. Oide at Z [2]:
  - Resonant contribution: $\sqrt{\Delta y^{*2}} \sim 13.7\text{pm}$
  - Non-resonant contribution: $\sqrt{\Delta y^{*2}} \sim 32.9\text{nm}$
- Final focus quadrupoles (QC1) produce majority of the non-resonant effect (excluding QC1 5.8nm)
  - May be pessimistic: assumes each quadrupole oscillates independently

$$\sim 10^{-15}\left(\frac{\omega}{2\pi\text{Hz}}\right)^{-4} \text{m}^2/\text{Hz}$$



M. Serluca, et al.

Via K. Oide

[2] K. Oide, Vibrational Orbit Effects

Existing Feedback Strategies

Method	Beam Beam Deflection	Beamstrahlung monitoring	Dithering
Source	Error generated beam offsets	Error generated beam offsets	Induced beam offsets from orbit bumps
Detection Method	Beam Position Monitors	Beamstrahlung photon monitor	Luminometer
Example	SuperKEKB, SLC	SLC	PEP II, SuperKEKB

FCC-ee Beam Beam Effects

- Strength of beam-beam effects quantified by the **Beam Beam Parameter**
- Case very similar for Z, WW, ZH
- Very different situation for tt
  - Beam beam parameter in x comparable to y case for other working points

Parameter	Z	WW	ZH	tt
ξ_x (x1000)	2.2	13	10	73
ξ_y (x1000)	97	128	88	134
ϕ_{pw} (BS)	26.5	3.70	5.40	0.82
Crab Ratio [%]	70	55	50	40

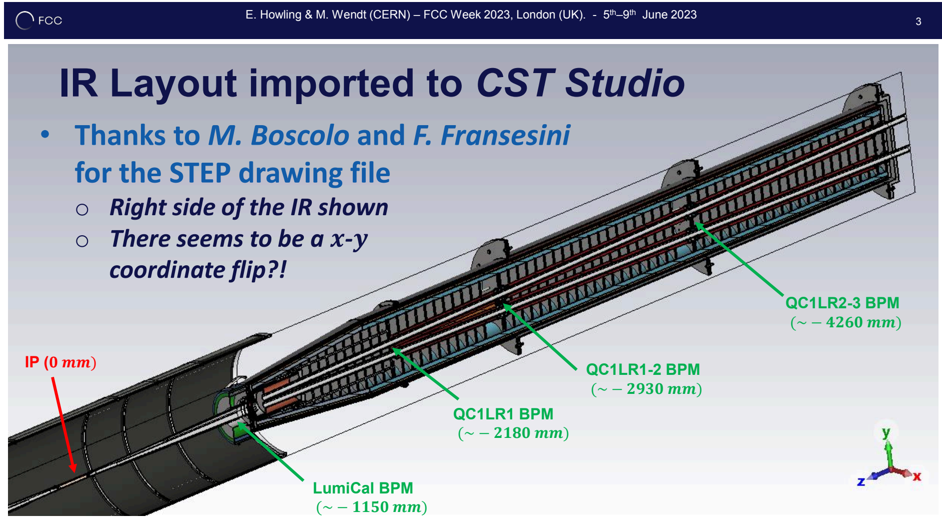
The high beam beam parameters of the tt working point mean different feedback strategies may be required

Piwinski angle of 0.82: more similar to a head on collision

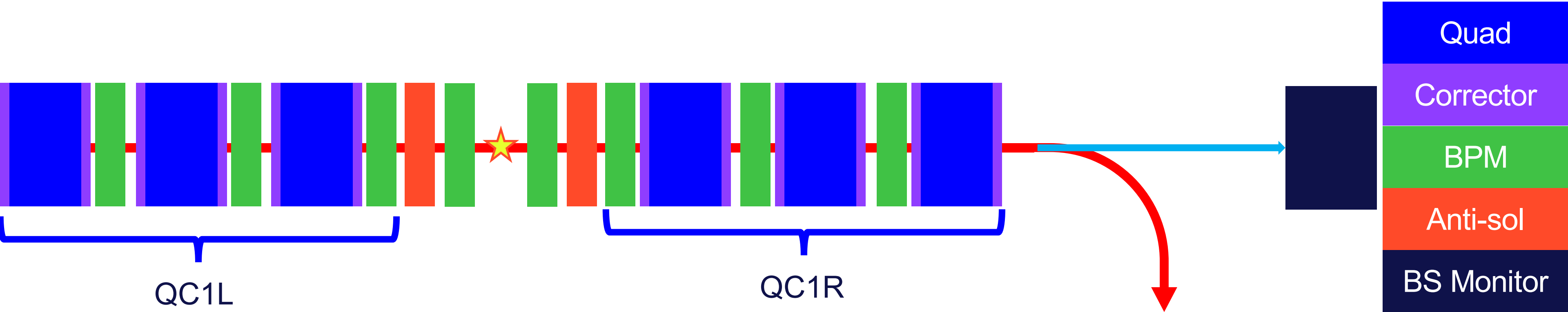
To fully address these beam beam effects (e.g. hourglass 🥜), the PIC solver **GUINEA-PIG** has been used for all simulations

Hardware Layout

- Current system involves only previously proposed elements:
  - Previously BPMs beside LumiCal and in QC1
    - Updated- see talk by E. Howling 15/11
  - BS Monitor downstream
  - Correctors on QC1 elements



E. Howling/ M. Wendt

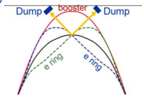


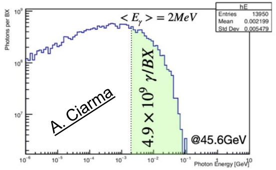
Beamstrahlung Monitoring

- Beamstrahlung photon monitoring currently proposed in the BI plans for FCC-ee
  - **500m downstream of IP**
- Very high power, concentrated in a small area:
  - At Z with 0 offset, 230kW
  - Increases with y offset up to >300kW
- Provides a **per beam** signal
- Previously proposed 2 step approach:
  - Fully characterised photons at low power
  - Analysis of tails, or non-invasive methods during normal operation

Beamstrahlung photons monitoring

- A **significant fluence of photons is generated at the IPs** in the forward direction by different mechanisms (beamstrahlung, radiative Bhabha, SR, etc.)
  - ±2 MeV average, extending up to 100 MeV
  - **~400 kW** in few cm^2
- To be absorbed reliably and safely





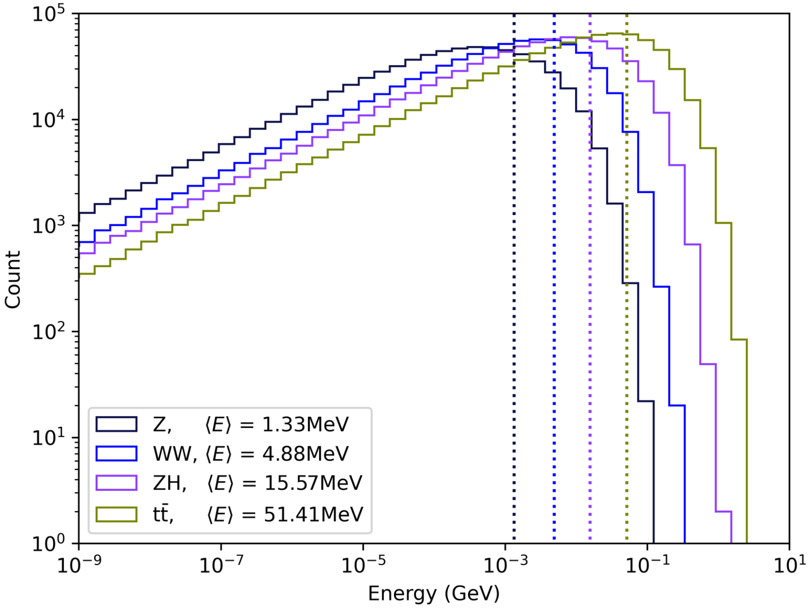
Beamstrahlung photons monitoring

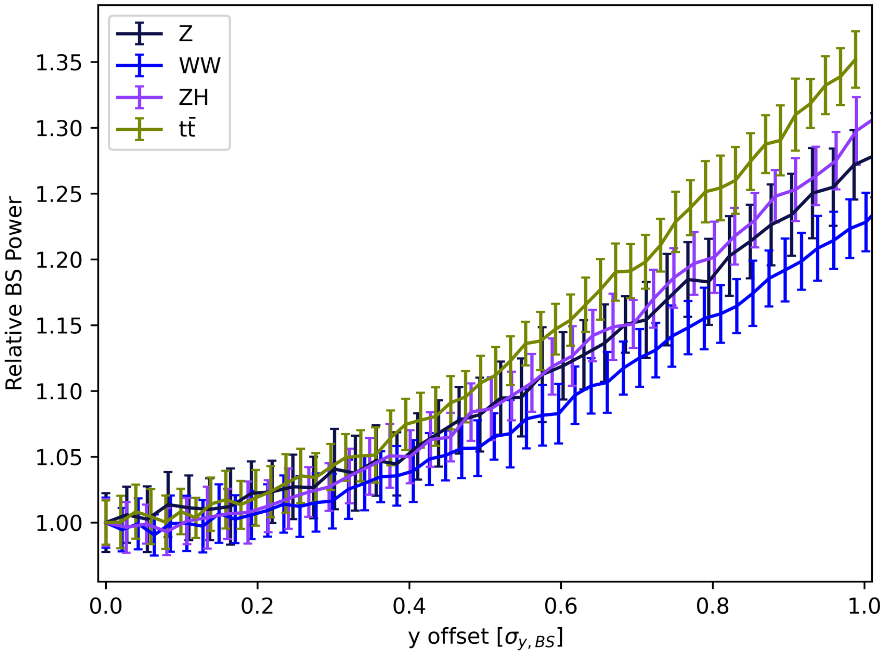
- Measuring the **intensity**, **position** and **size** of high-power densities beamstrahlung photon beams
- Possibly using a **two-step approach** with different diagnostics
  - **Fully characterising the photon beams at low power using, e.g., scintillating screens and cameras (to be studied) that will only be inserted in the photon beam extraction line during single bunch or few bunch operation**
  - Measure the transverse tails of beamstrahlung photon distribution using intercepting sensors (i.e., scintillators, gaseous detectors, pixel detectors..) or developing **fully non-invasive methods** (e.g., using ionisation **or fluorescence of gas jets) that would be able to withstand the full photon beam power**
- Detailed study will start soon..

T. Lefevre

Beamstrahlung Signals

- Beamstrahlung spectra show strongly logarithmic distributions
  - Requires large statistics to model well



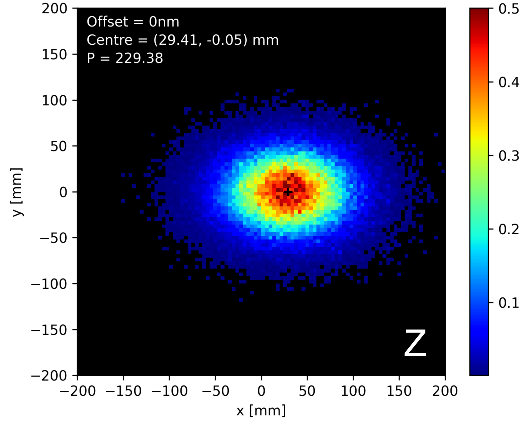


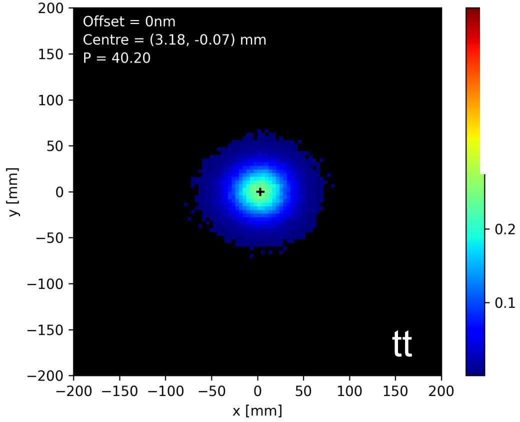
- Photon power increases rapidly with y offset
- Further simulations required with larger numbers of photons for improved statistics

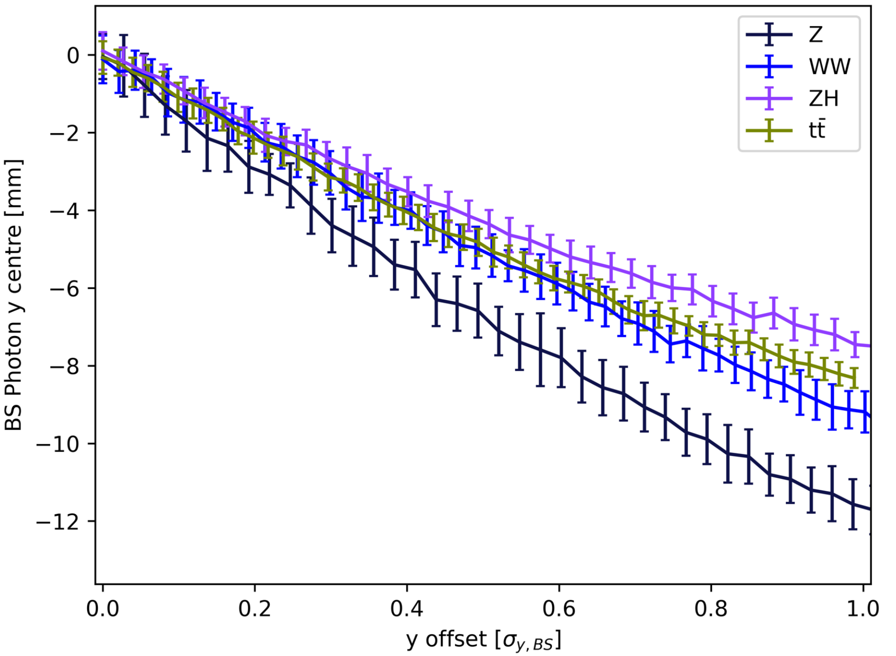
Beamstrahlung Signals

- Monitor ~500m downstream:
  - Photon spot largest at Z
  - Extent is ~25cm in x 20cm in y

- Spot centre position varies with offset:
  - Clear variation with y offset
  - Variation with x offset only for tt



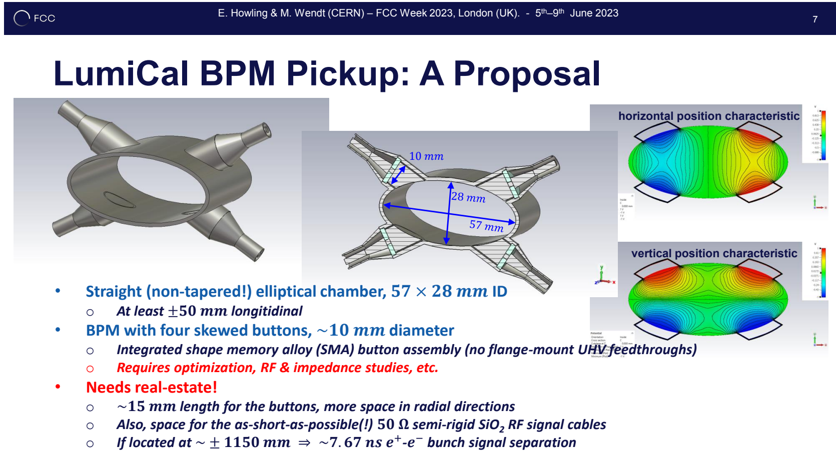


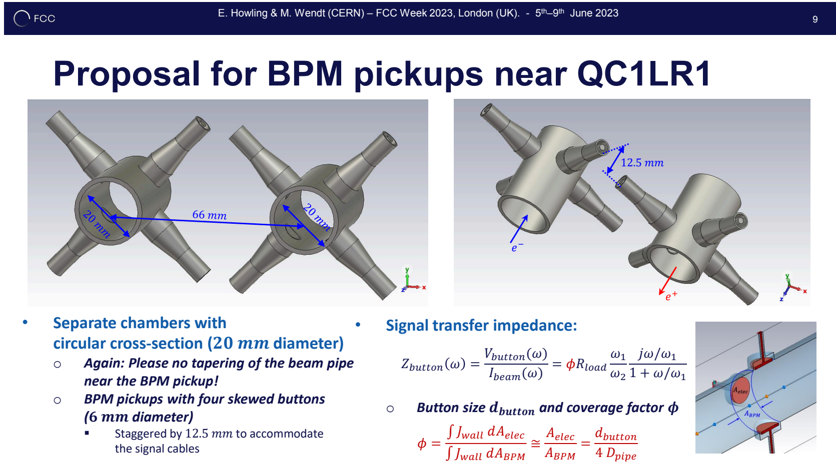


Beam Position Monitors

- Work on IR BPMs ongoing
- Previously proposed locations:
  - LumiCal BPM: 1150mm
  - QC1LR1 BPM: 2180mm
  - QC1LR1-2 BPM: 2930mm
  - QC1LR2-3 BPM: 4260mm

- LumiCal BPM particularly challenging
  - Still on the common beampipe
  - Elliptical cross section





E. Howling/ M. Wendt

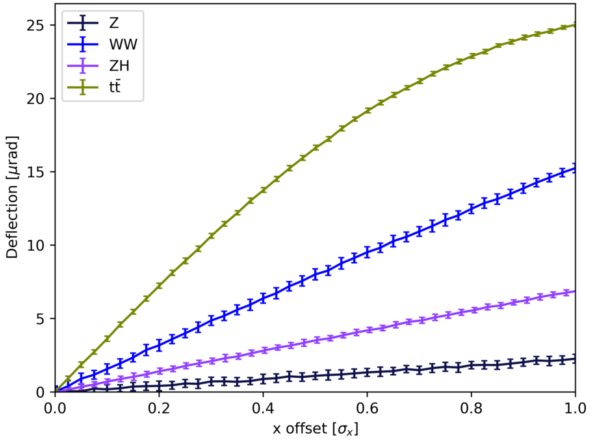
Beam Beam Deflection

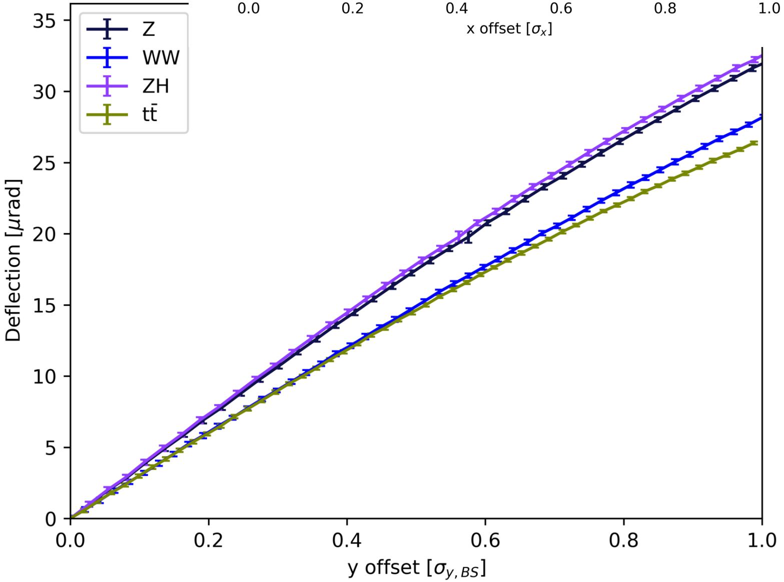
- Clear signal available from beam deflections with y offset

- For an offset of 0.05 sigma, deflection of ~1.5μrad
  - Equates to ~1.7μm at the lumical BPM
  - For system performance, **sub micron resolution**

- Linear beam beam kick model does not adequately describe the results

$$\Delta p_{x,y} = \pm \frac{2\pi\xi_{x,y}}{\beta^*_{x,y}} \Delta_{\mathrm{x,y}}$$

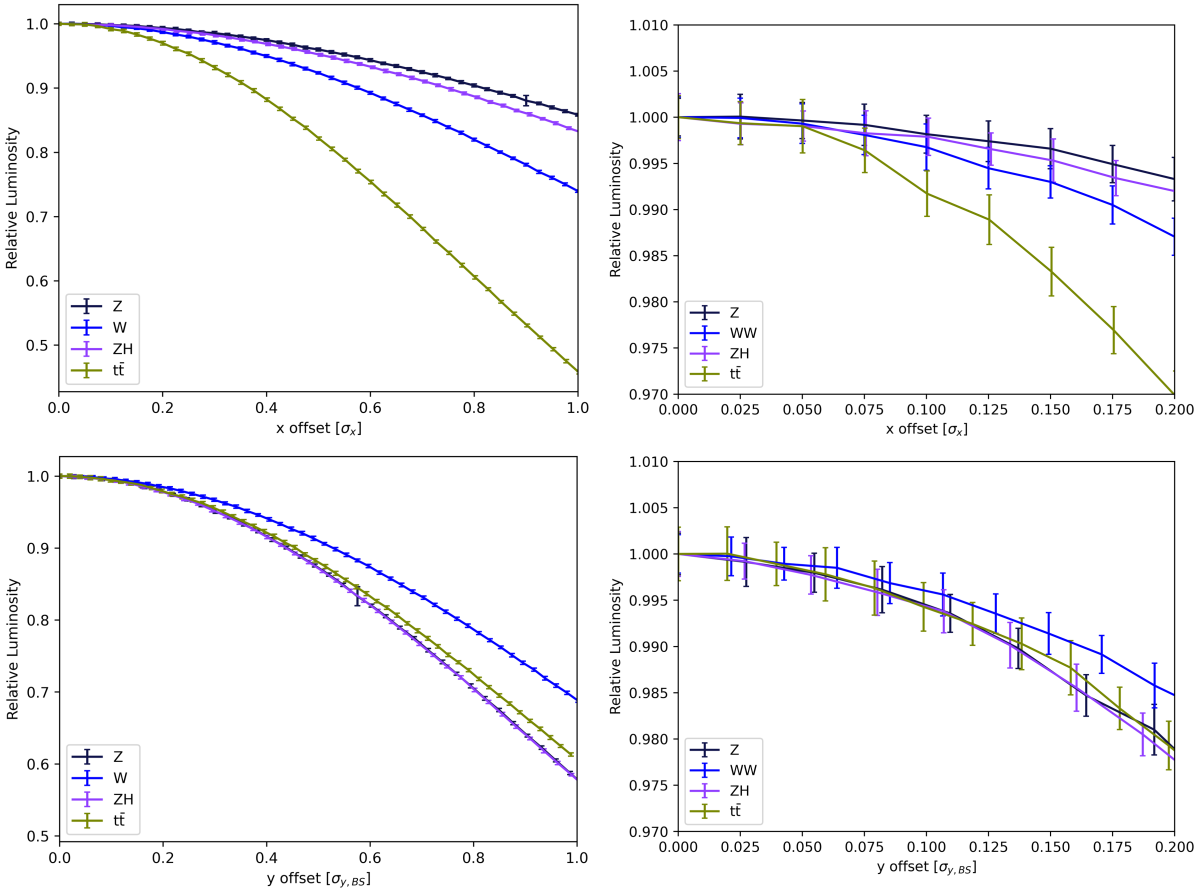




Luminosity

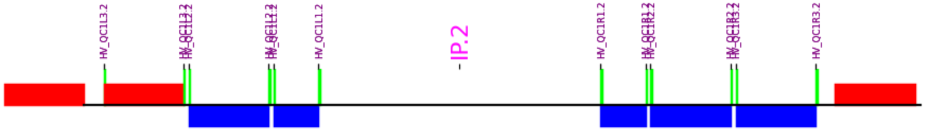
- Luminosity variation with displacement is a key signal for **dithering**
  - Much stronger for tt due to high ξ_x

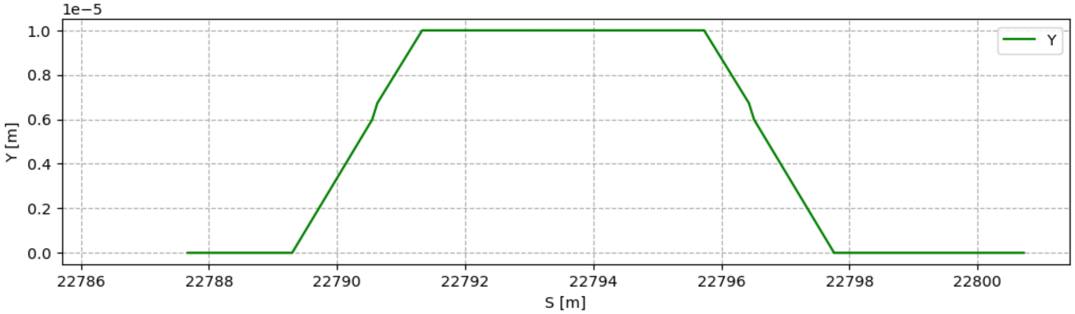
- Monitoring performance strongly dependant on lumical performance:
  - *New Doctoral Student: Vaibhavi Gawas*
  - Due to “examine the FCC-ee luminometer concept and the implied alignment or beam-stability tolerances”



Correctors and Dithering

- IR correctors included in optics repository [3]
- MADX orbit bumps do not include the beam beam effect
- Currently implemented in MADX as thin corrector elements





- Proposed to use these correctors for both dithering and correction
- Low strength requirements allow for fast response
  - Response time may be limited by *shielding of the metal beampipe*
  - **Revolution frequency: 3.3kHz**
  - May need to move kickers away from IP if higher frequencies required

Example orbit bump using MADX correctors
S. Sai Jagabathuni

[3] H. Burkhardt, IR Steering and Possible Consequences

Conclusions

- Current proposed strategy:
  - Dithering to minimise x offset
  - Beamstrahlung monitoring and beam deflection monitoring to minimise y offset
  - These approaches have been used successfully at other accelerators e.g. SuperKEKB

- Hardware performance will be critical:
  - Beamstrahlung monitoring under high radiation power
  - Sub micron resolution of BPMs at the IP

- Strategy applicable to the Z, WW and ZH working points may be different from tt

- All discussion today is with respect to the baseline optics
  - IP tolerances must be checked for alternative optics too

Thank you
for your attention.

APPENDIX

Parameters

Working Point		Z	WW	ZH	$t\bar{t}$
Beam Energy	GeV	45.6	80	120	182.5
Bunch Population	10^{11}	2.14	1.45	1.15	1.55
Bunches/Beam		11200	1780	440	60
RMS Horizontal Emittance ε_x	nm	0.71	2.17	0.71	1.59
RMS Vertical Emittance ε_y	pm	1.9	2.2	1.4	1.6
Horizontal IP Beta β_x	mm	110	220	240	1000
Vertical IP Beta β_y	mm	0.7	1	1	1.6
Energy Spread σ_δ (BS)	%	0.089	0.109	0.143	0.192
Crab Waist Ratio	%	70	55	50	40
Luminosity /IP [Nominal]	10^{34} $cm^{-2}s^{-1}$	140	20	5.0	1.25

Machine parameters used throughout
Assuming layout PA31-3.0, with 4IPs

GP vs Analytic Deflection: x offset

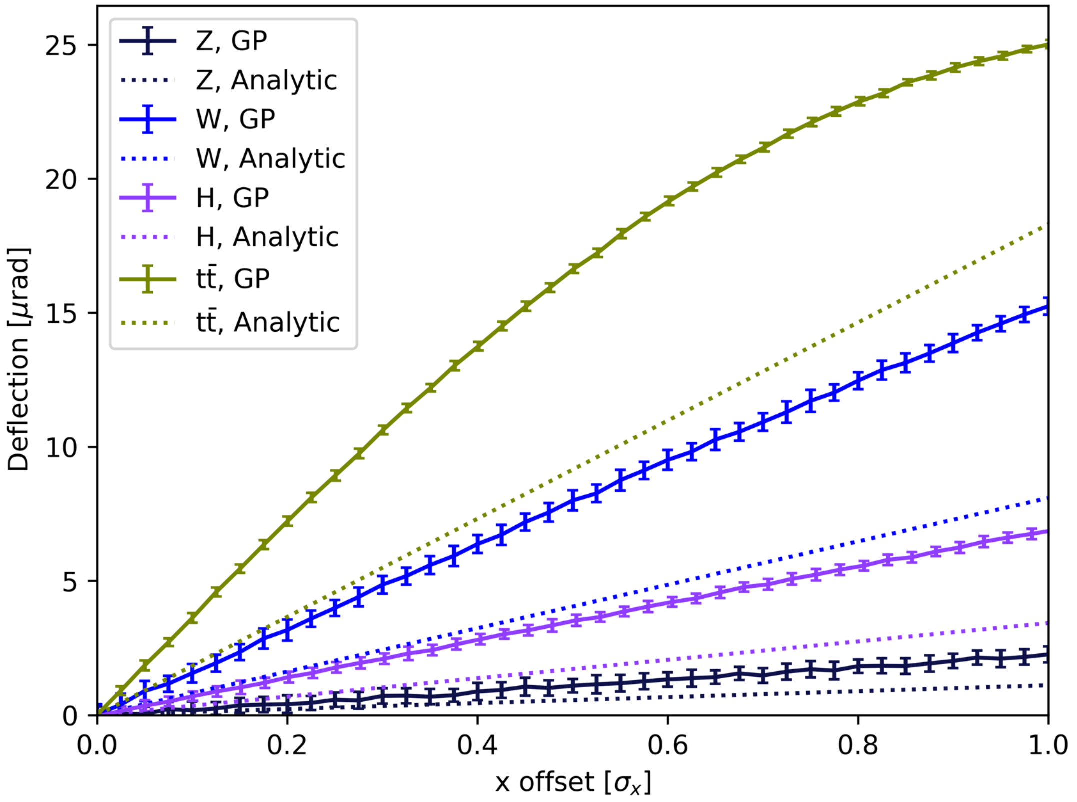
Theory Description:

- Beams with relative vertical offset at the IP by $\Delta_{x,y}$, each beam receive a beam-beam kick at the IP:

$$\Delta p_{x,y} = \pm \frac{2\pi\xi_{x,y}}{\beta^*_{x,y}} \Delta_{x,y}$$

Where ξ_y is the vertical beam beam parameter

- Poor agreements with theory across the board



GP vs Analytic Deflection: y offset

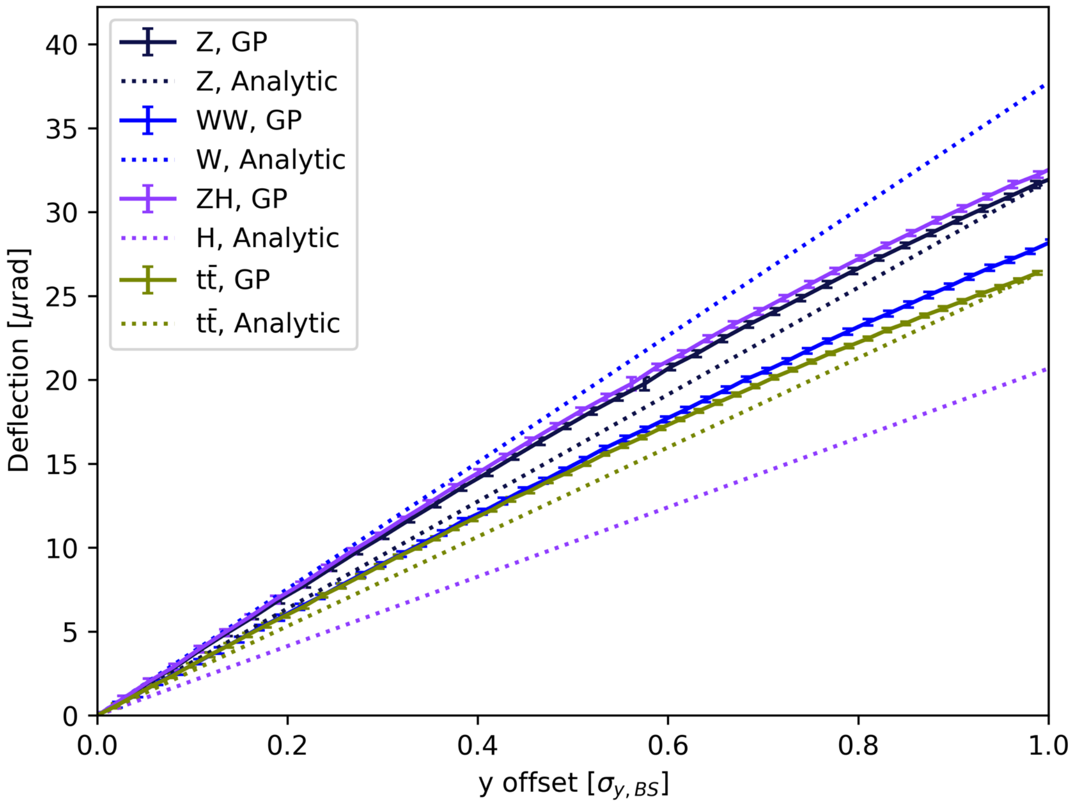
Theory Description:

- Beams with relative vertical offset at the IP by $\Delta_{x,y}$, each beam receive a beam-beam kick at the IP:

$$\Delta p_{x,y} = \pm \frac{2\pi\xi_{x,y}}{\beta^*_{x,y}} \Delta_{x,y}$$

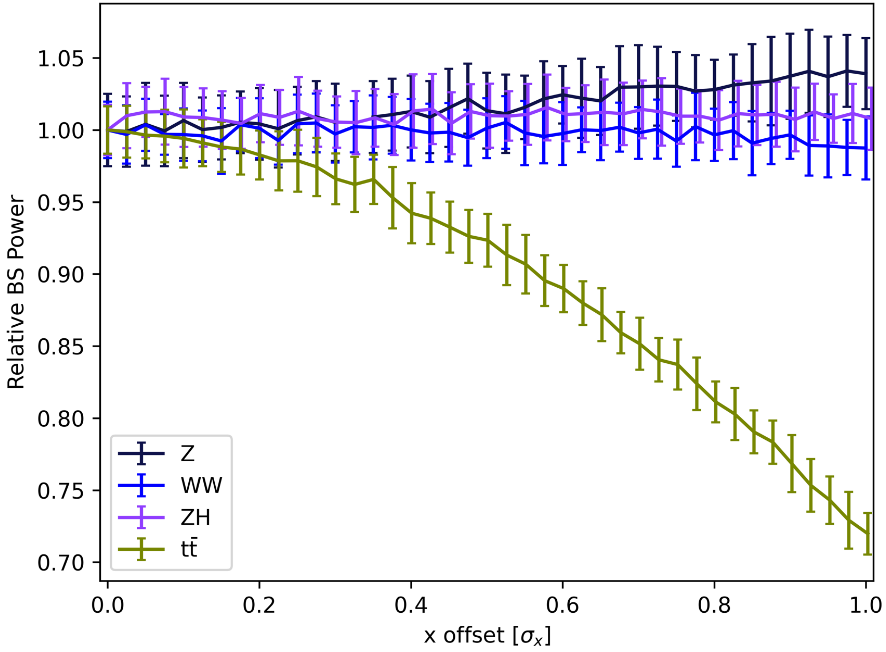
Where ξ_y is the vertical beam beam parameter

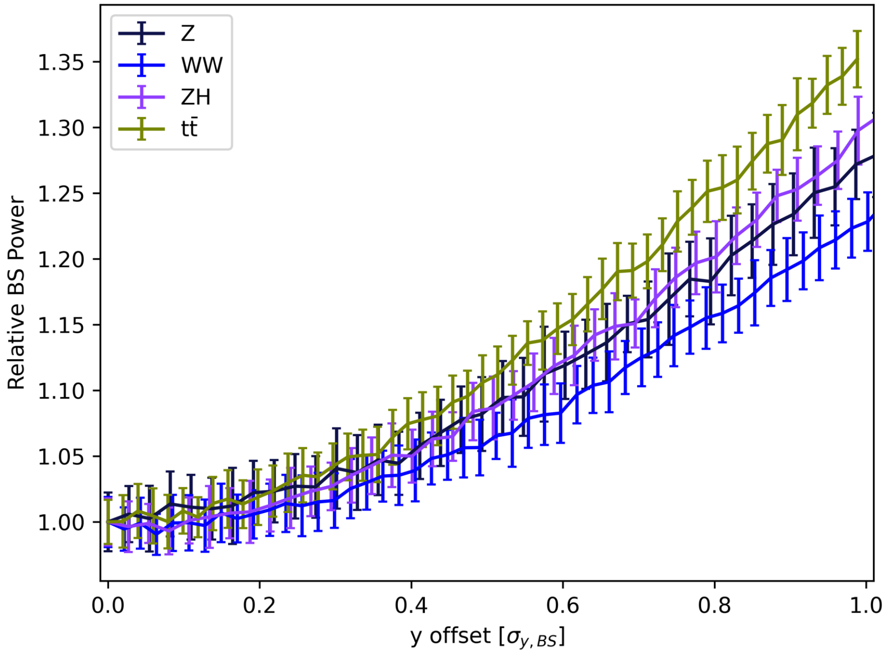
- Theory description agrees well for Z and tt with y offsets, but poor agreement with W and H
- Likely due to high disruption parameters of W and H



BS Photon Power with Offset

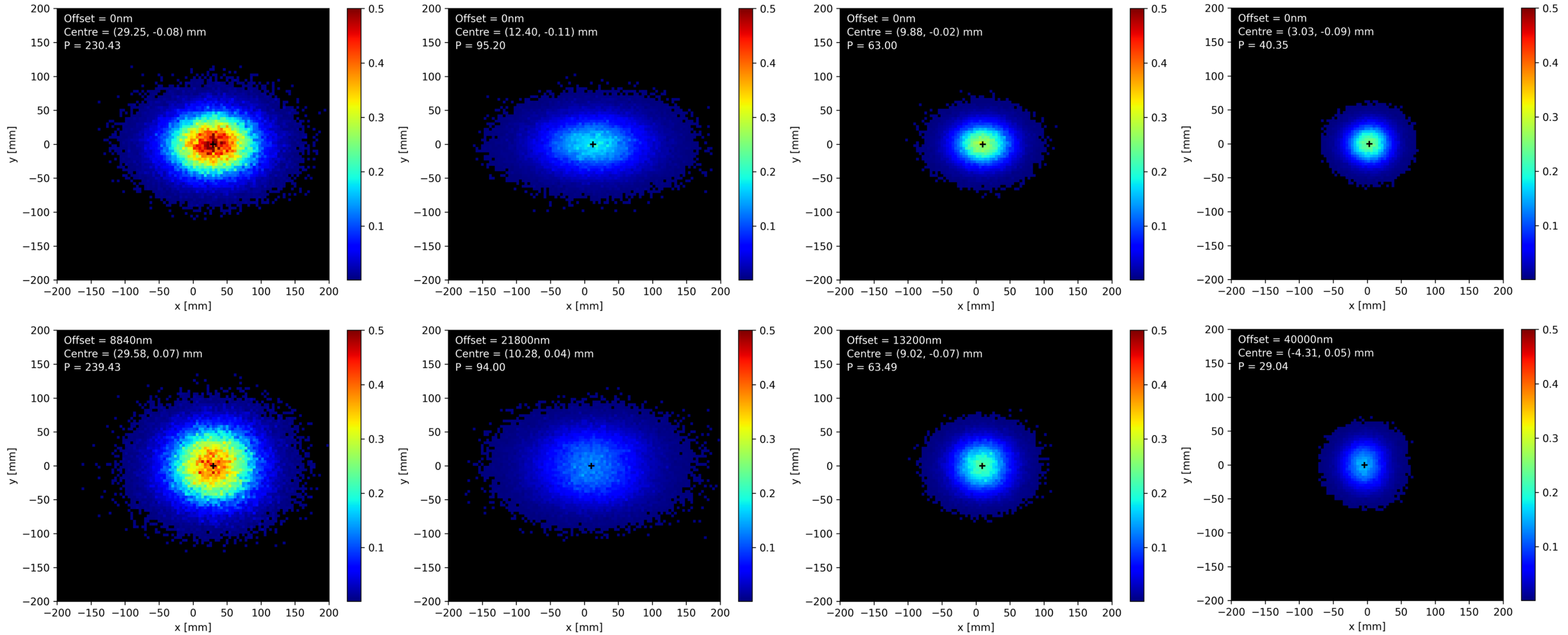
- Offset in x shows variation only for tt due to high beam beam parameter
- Offset in y shows clear variation for all working points





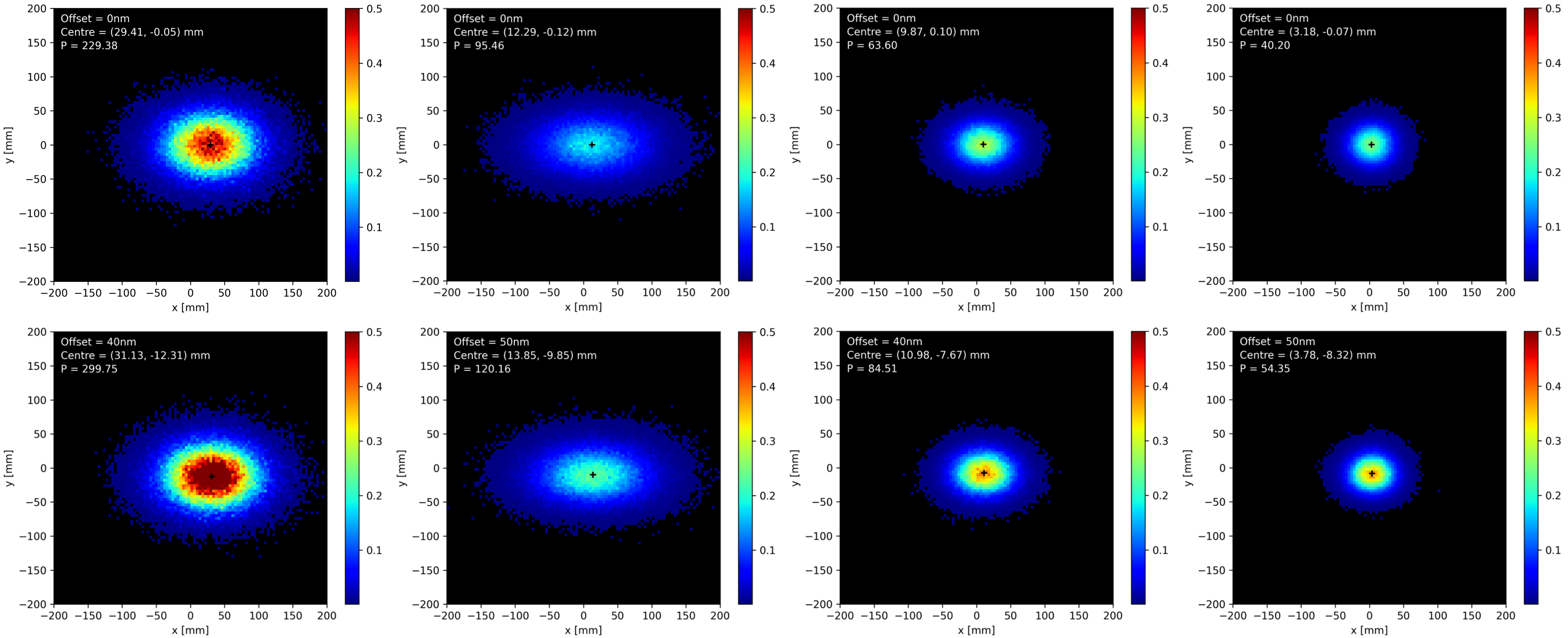
Photon Spots with x offset

- Top plot: 0 offset, lower plot: 1 sigma x offset. Shown for Z, WW, ZH and tt
- No variation observed with x offset



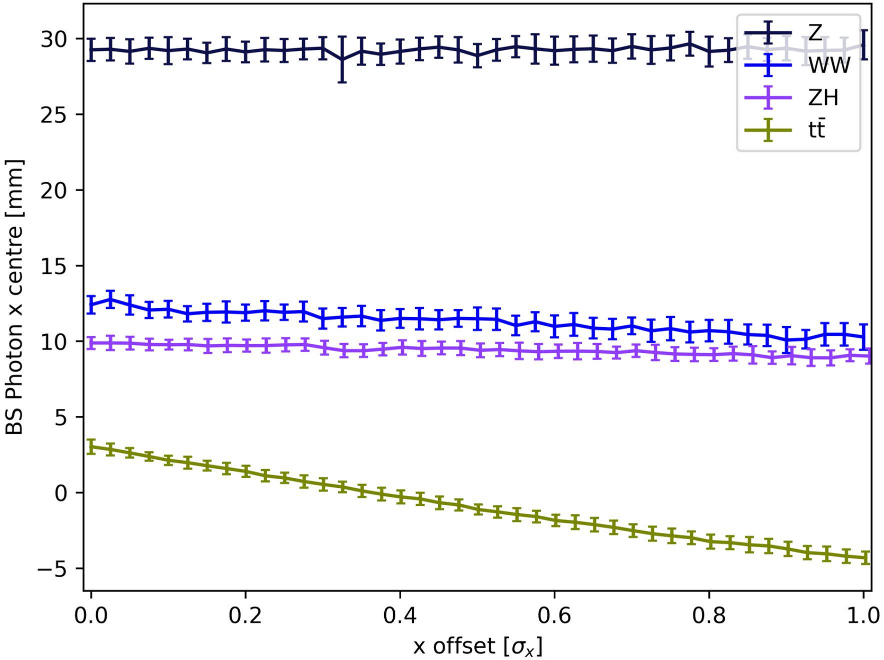
Photon Spots with y offset

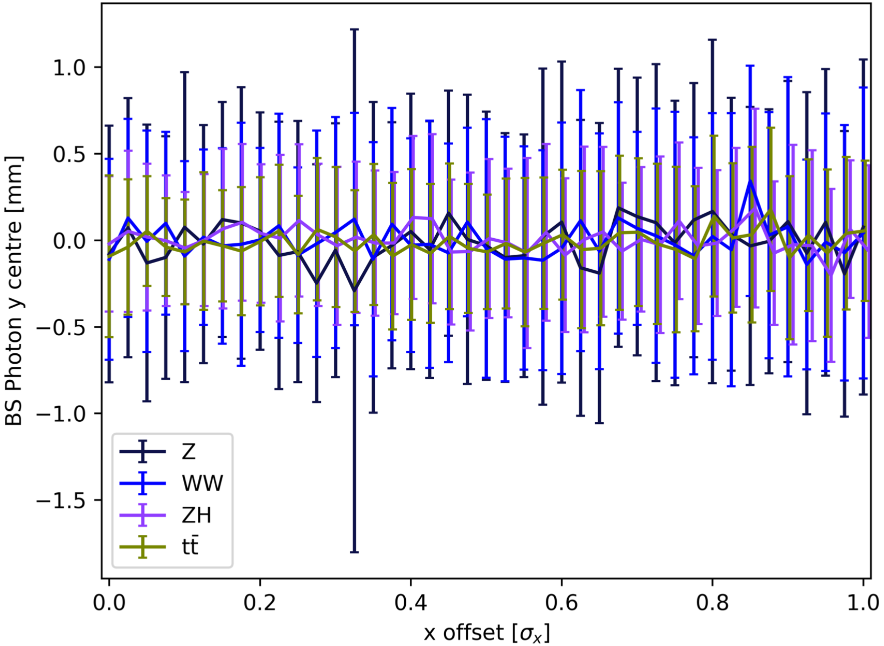
- Top plot: 0 offset, lower plot: 1 sigma y offset. Shown for Z, WW, ZH and tt
- Clear variation observed, but much less than the photon spot size



BS Photon Spot Centroids with x offset

- Variation of x position, correlates with change in energy
- No variation of y centre position with x offset





BS Photon Spot Centroids with y offset

- Variation of x position, correlates with increase in BS photon power
- Strong variation of y centre position with offset