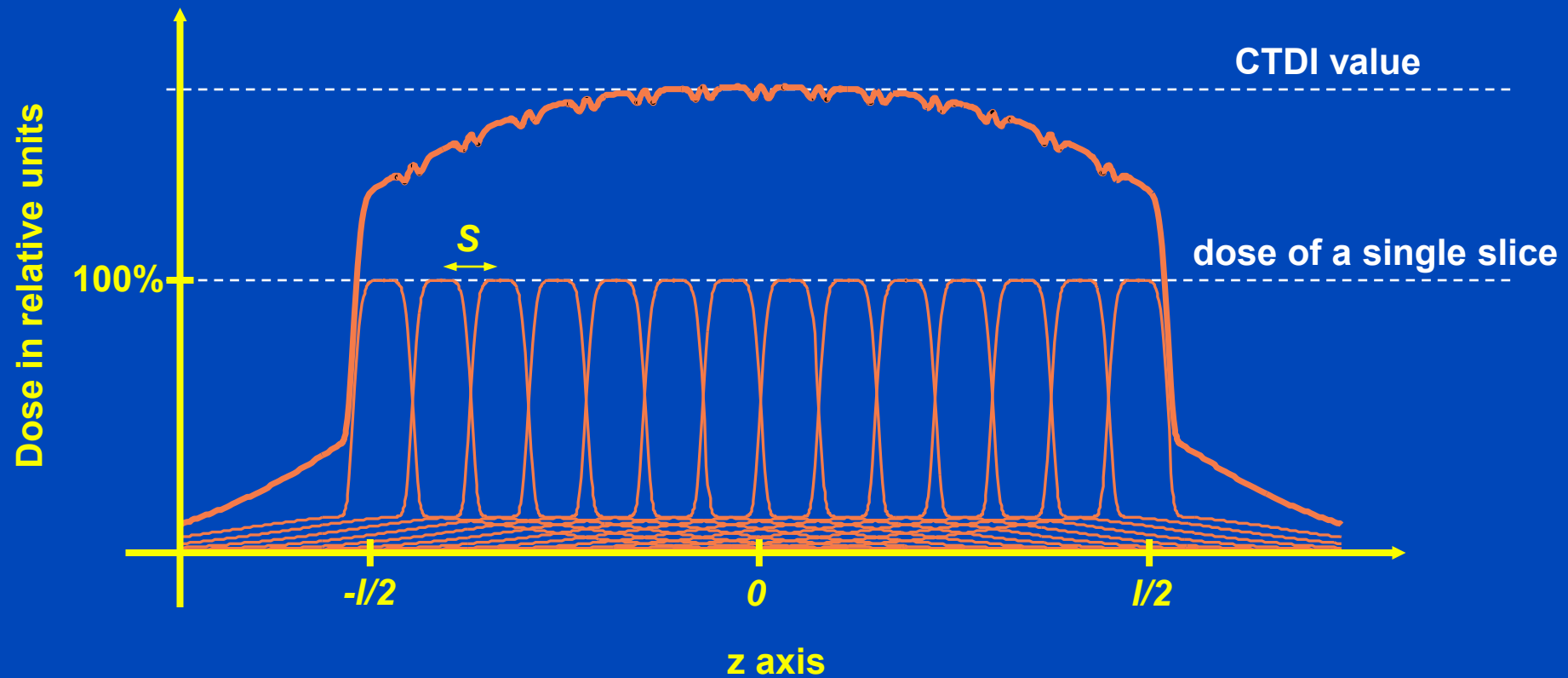


Beyond Circle CTDI: Assessing Spiral Acquisition Alternatives for Routine CT Dose Quantification

**Stefan Sawall, Philipp Oelze, Moritz Herb,
and Marc Kachelrieß**

**German Cancer Research Center (DKFZ)
Heidelberg, Germany
www.dkfz.de/ct**

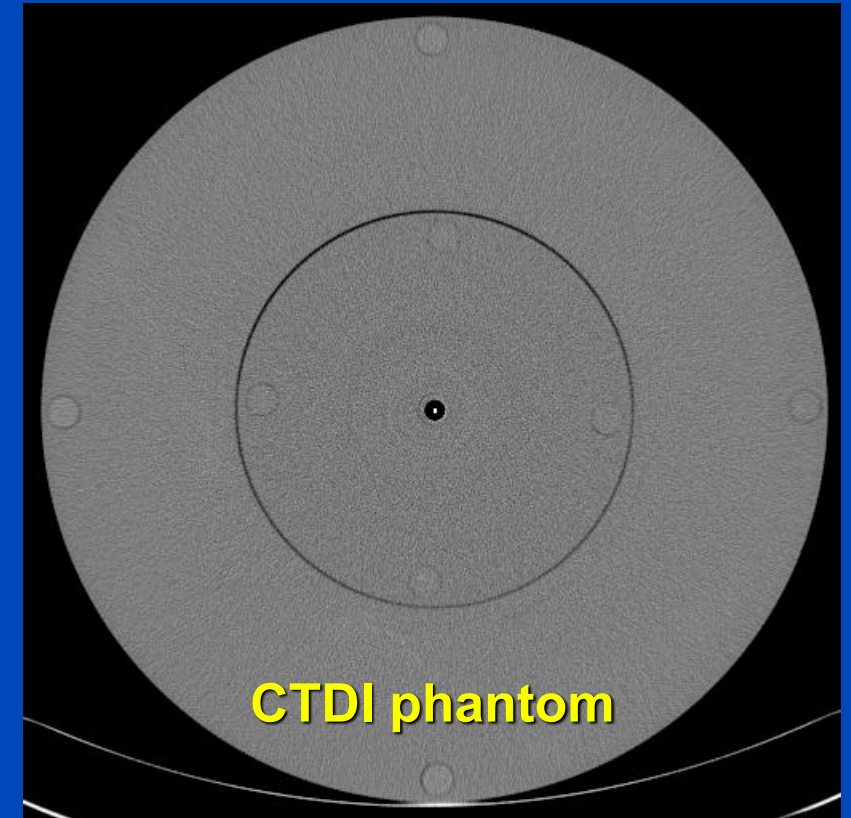
Dose Distribution $D(z)$



CT Dose Index (CTDI)

$$\text{CTDI} = \frac{1}{C} \int_{-\infty}^{\infty} dz D(z)$$

$$\text{CTDI}_{100} = \frac{1}{N} \int_{-50 \text{ mm}}^{50 \text{ mm}} dz D(z) = \frac{\overbrace{\bar{D} \cdot 100 \text{ mm}}^{\text{Dosimeter reading}}}{\underbrace{N}_{\text{normalization}}}$$



$$\text{CTDI}_w = \frac{1}{3} \text{CTDI}_{100}^{\text{central}} + \frac{2}{3} \text{CTDI}_{100}^{\text{peripheral}}$$

Typically normalized to 100 mAs.

Background CTDI

- CTDI = CT dose index.
- Standardized measure of radiation dose output of a CT scanner.
- Allows to compare radiation output of different CT scanners.
- Conventional CTDI measurements are based on circle scans: cCTDI.
- CTDI is measured with a 10 cm pencil-shaped ionization chamber in a homogeneous cylindrical 16 or 32 cm PMMA phantom.
- Many clinical CT protocols use spiral scanning.
- Using the traditional method for spiral protocols requires to define axial protocols that are “CTDI-equivalent” to the existing spiral protocols.
- **Defining spiral-equivalent circle protocols is hardly possible in user mode.**
- **Assessing CTDI directly from spiral scans is desired (and proposed^{1,2}).**
- **However: Large collimations are typically available only for circle scans**
 - E.g. Canon, GE and United's 100 mm to 160 mm

¹Leon et al. The helically-acquired CTDI_{vol} as an alternative to traditional methodology. J. Appl. Clinical Medical Physics 21(8):263-271, 2020.

²Barreto et al. Estimating the CTDI_{vol} with helical acquisitions: Results from a national generalizability study. Med. Phys. 52(3):1823-1832, 2024.

CTDI Versions

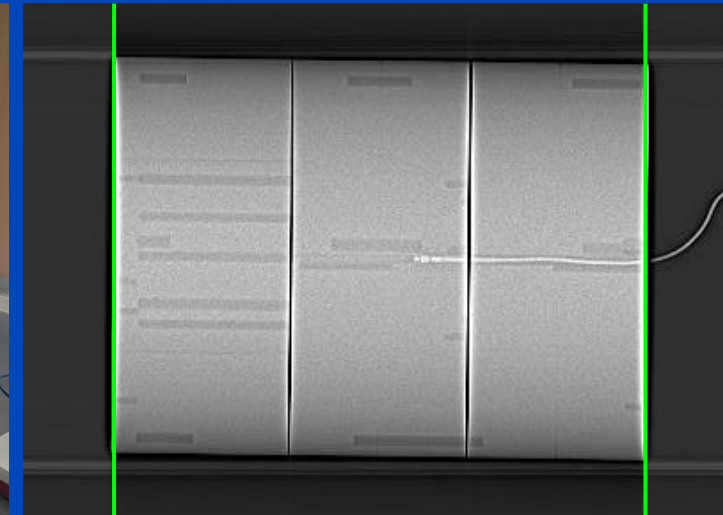
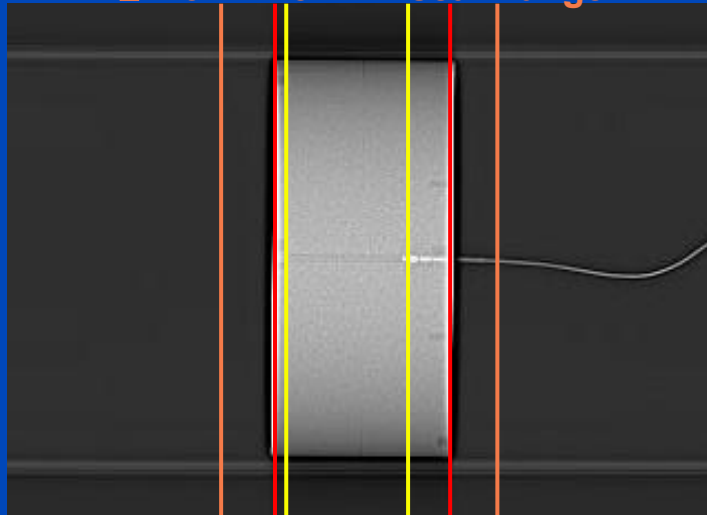
- cCTDI = conventional / circle (axial) CTDI, with $S = 0$ and $P = 15$ cm.
- sCTDI = proposed spiral CTDI, with $S = 10$ cm and $P = 15$ cm.
- eCTDI = proposed spiral CTDI, with $S = 15$ cm and $P = 15$ cm.
- oCTDI = overscan CTDI, with $S \geq P + 2C$ (air on both sides), $P = 15$ cm.
- xCTDI = extra long CTDI, with $S = P = 45$ cm
- vCTDI = vendor's CTDI value (presumably measured like cCTDI)

=100 mm sCTDI scan range

=145 mm eCTDI scan range

≥245 mm oCTDI scan range

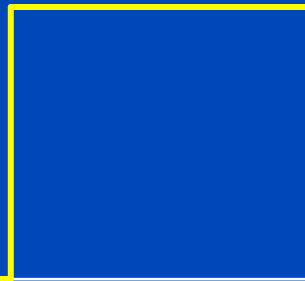
≥450 mm xCTDI scan range



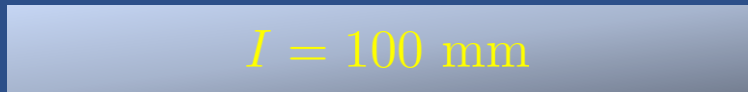
Circle Scan with $C < I$

$$\text{CTDI} = \frac{1}{C} \int_{-I/2}^{I/2} dz D(z)$$

$C = 40 \text{ mm}$



$I = 100 \text{ mm}$



Circle Scan with $C < I$

$$\text{CTDI} = \frac{1}{C} \int_{-I/2}^{I/2} dz D(z)$$

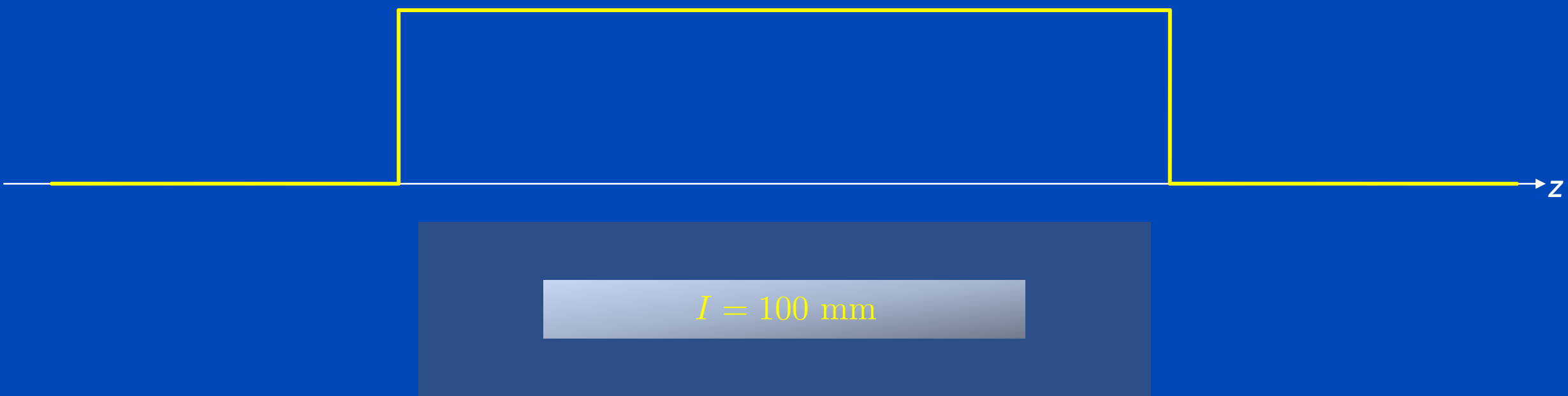
$$C = 80 \text{ mm}$$

$$I = 100 \text{ mm}$$

Circle Scan with $C > I$

$$\text{CTDI} = \frac{1}{I} \int_{-I/2}^{I/2} dz D(z)$$

$$C = 160 \text{ mm}$$

$$I = 100 \text{ mm}$$


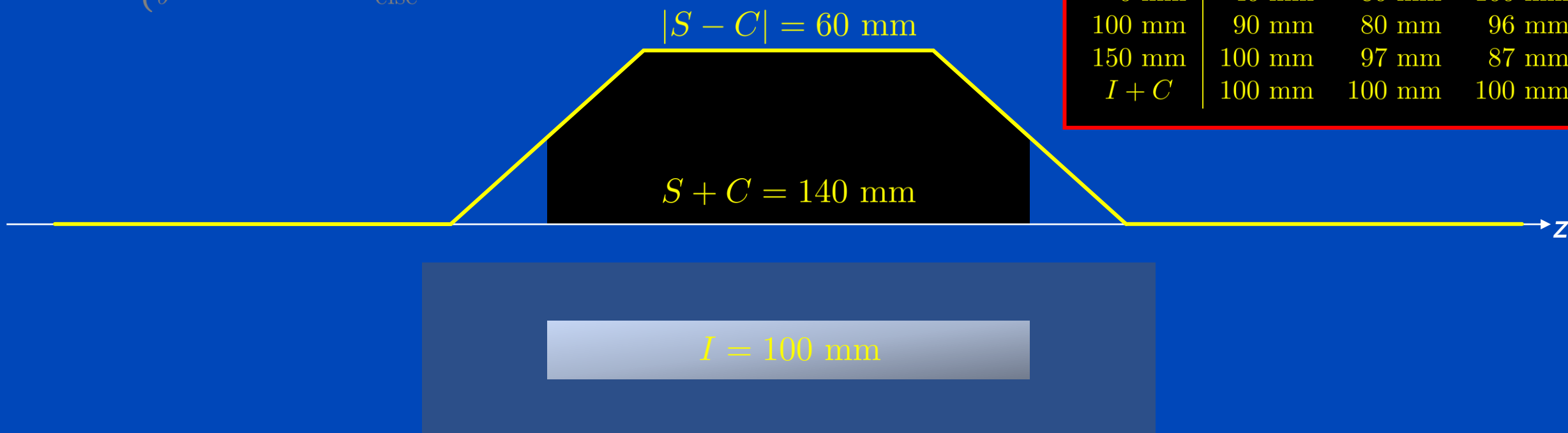
$S = 100$ mm (i.e. sCTDI) and $C = 40$ mm

$$N(S, C, I) = f(\min(S, C), \max(S, C), I) \quad \text{CTDI} = \frac{1}{90 \text{ mm}} \int_{-50 \text{ mm}}^{+50 \text{ mm}} dz D(z)$$

$$f(a, b, I) = \begin{cases} I & \text{if } I < b - a \\ b - \frac{(a + b - I)^2}{4a} & \text{if } I < b + a \\ b & \text{else} \end{cases}$$

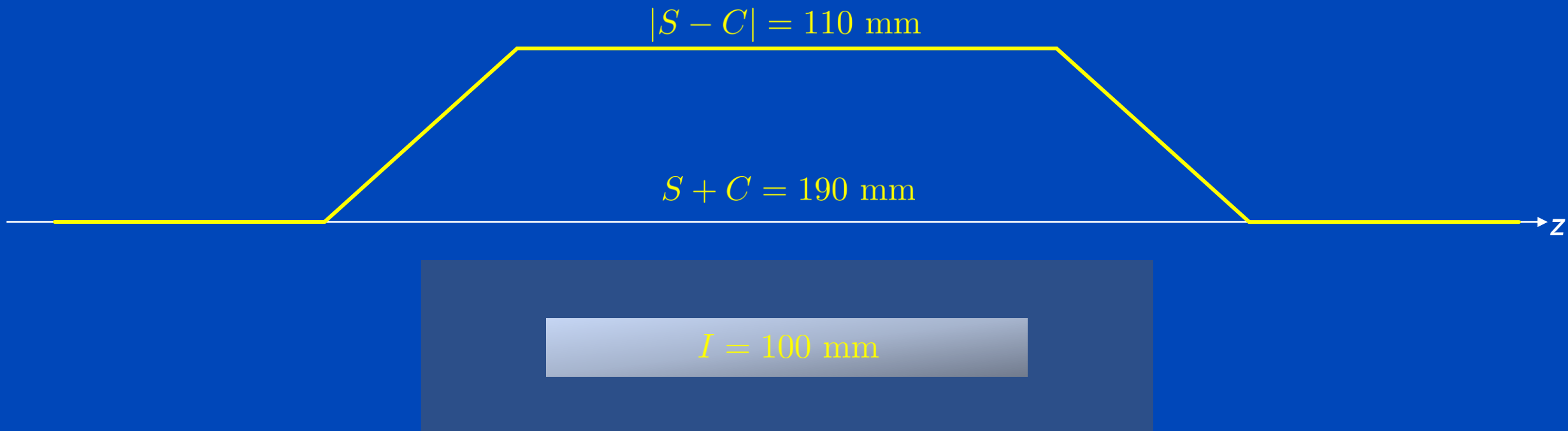
$$N = N(S, C, I) = \int_{-I/2}^{I/2} dz \text{ImagingPrimary}(z)$$

	C		
S	40 mm	80 mm	160 mm
0 mm	40 mm	80 mm	100 mm
100 mm	90 mm	80 mm	96 mm
150 mm	100 mm	97 mm	87 mm
$I + C$	100 mm	100 mm	100 mm



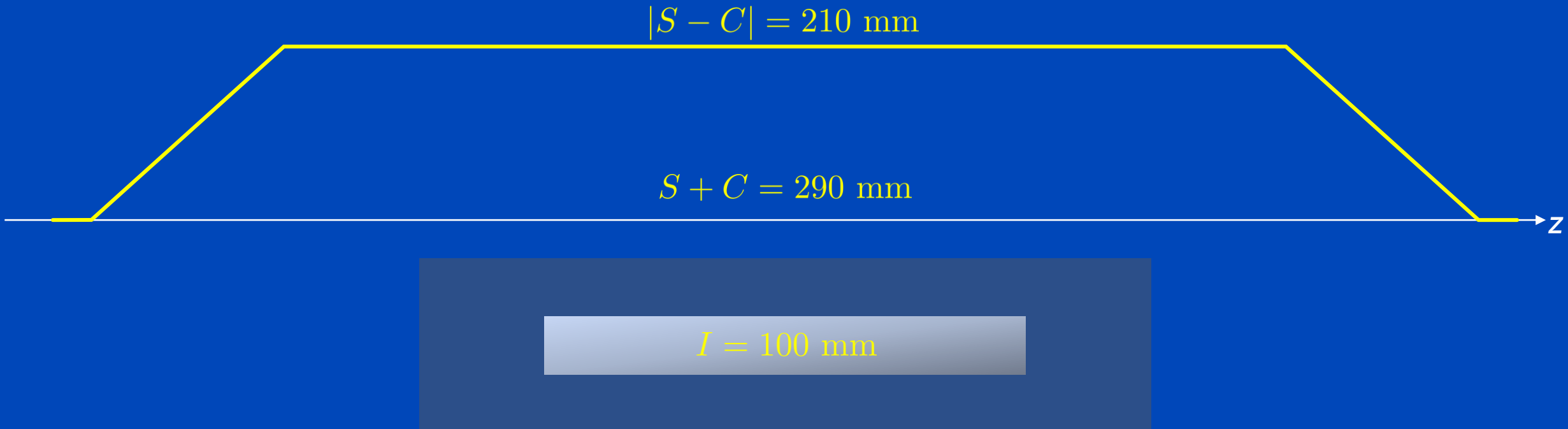
$S = 150$ mm (i.e. eCTDI) and $C = 40$ mm

$$\text{CTDI} = \frac{1}{100 \text{ mm}} \int_{-50 \text{ mm}}^{+50 \text{ mm}} dz D(z)$$



$S = 250$ mm (i.e. oCTDI) and $C = 40$ mm

$$\text{CTDI} = \frac{1}{100 \text{ mm}} \int_{-50 \text{ mm}}^{+50 \text{ mm}} dz D(z)$$



$S = 450 \text{ mm}$ (i.e. xCTDI) and $C = 40 \text{ mm}$

$$\text{CTDI} = \frac{1}{100 \text{ mm}} \int_{-50 \text{ mm}}^{+50 \text{ mm}} dz D(z)$$

$$|S - C| = 410 \text{ mm}$$

$$S + C = 490 \text{ mm}$$

→ z

$$I = 100 \text{ mm}$$

Measurement Results (120 kV, 100 mAs)

- Somatom Definition Flash** ($C = 64 \times 0.6 \text{ mm} = 38.4 \text{ mm}$):

	Central/mGy	Peripheral/mGy	Weighted/mGy	Diff. to ^{6.45 mGy} cCTDI	Diff. to ^{6.75 mGy} vCTDI
sCTDI	4.20 ± 0.16	7.40 ± 0.12	6.33 ± 0.12	-1.9 %	-6.2 %
eCTDI	4.67 ± 0.08	7.75 ± 0.08	6.72 ± 0.06	+4.2 %	-0.4 %
oCTDI	4.80 ± 0.05	7.82 ± 0.08	6.81 ± 0.06	+5.6 %	+0.9 %
xCTDI	6.71 ± 0.32	8.77 ± 0.16	8.09 ± 0.19	+25.4 %	+19.9 %

×1.2, roughly

- Naeotom Alpha** ($C = 96 \times 0.6 \text{ mm} = 57.6 \text{ mm}$):

	Central/mGy	Peripheral/mGy	Weighted/mGy	Diff. to ^{7.94 mGy} cCTDI	Diff. to ^{7.90 mGy} vCTDI
sCTDI	4.94 ± 0.15	8.26 ± 0.26	7.16 ± 0.21	-9.8 %	-9.4 %
eCTDI	5.39 ± 0.10	8.39 ± 0.34	7.39 ± 0.22	-6.9 %	-6.5 %
oCTDI	5.47 ± 0.08	8.47 ± 0.28	7.47 ± 0.18	-5.9 %	-5.4 %
xCTDI	7.98 ± 0.22	9.82 ± 0.34	9.21 ± 0.29	+16.0 %	+16.6 %

×1.2, roughly

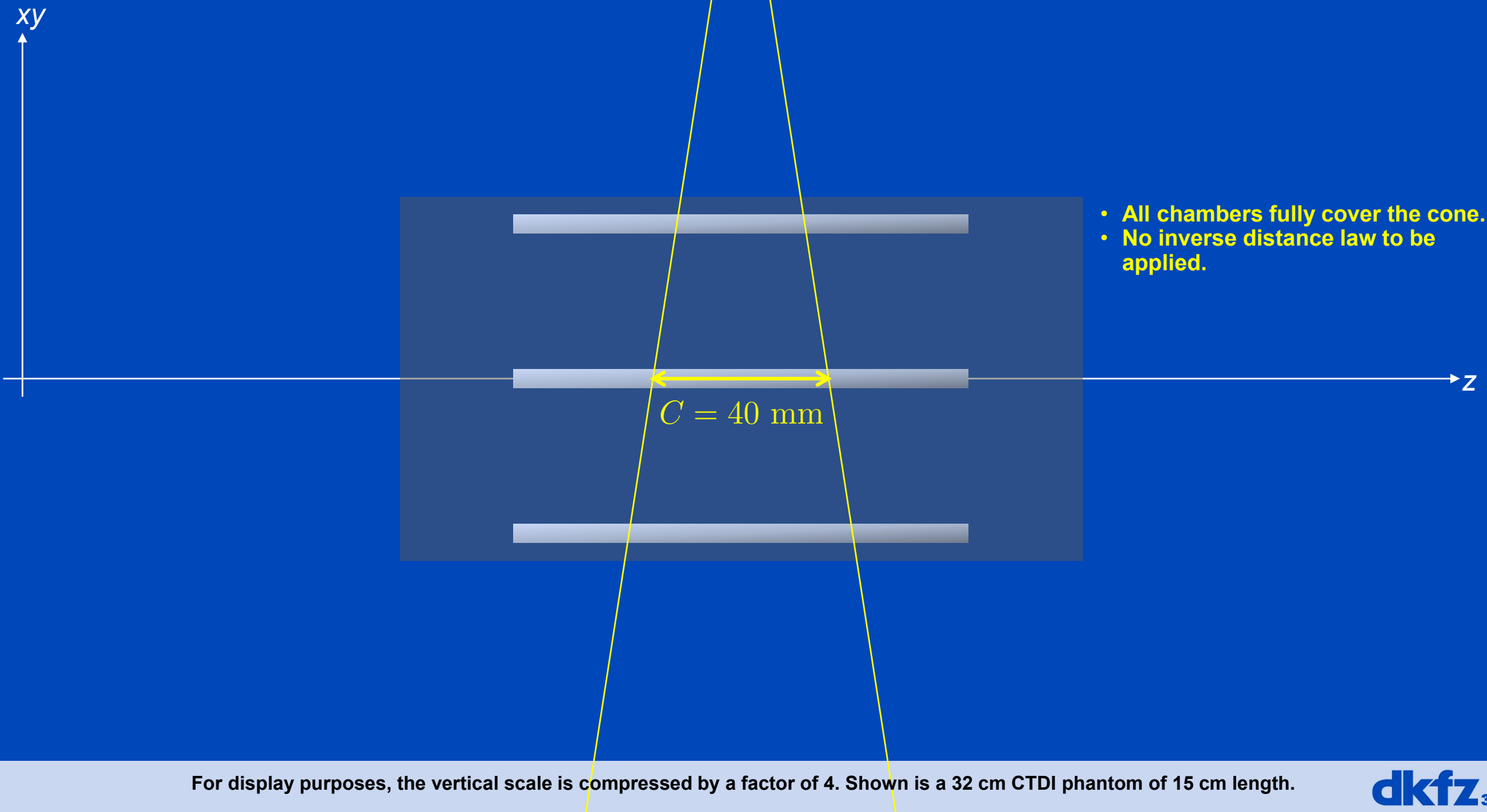
- As expected, values increase with increasing S and P .
- But sCTDI, eCTDI and oCTDI behaviour is inconclusive.
- From oCTDI to xCTDI seems to be a factor of ≈ 1.2 .

{ cCTDI vs. vCTDI = ???
 scan vs. recon range = ???
 scan start+end handling = ???

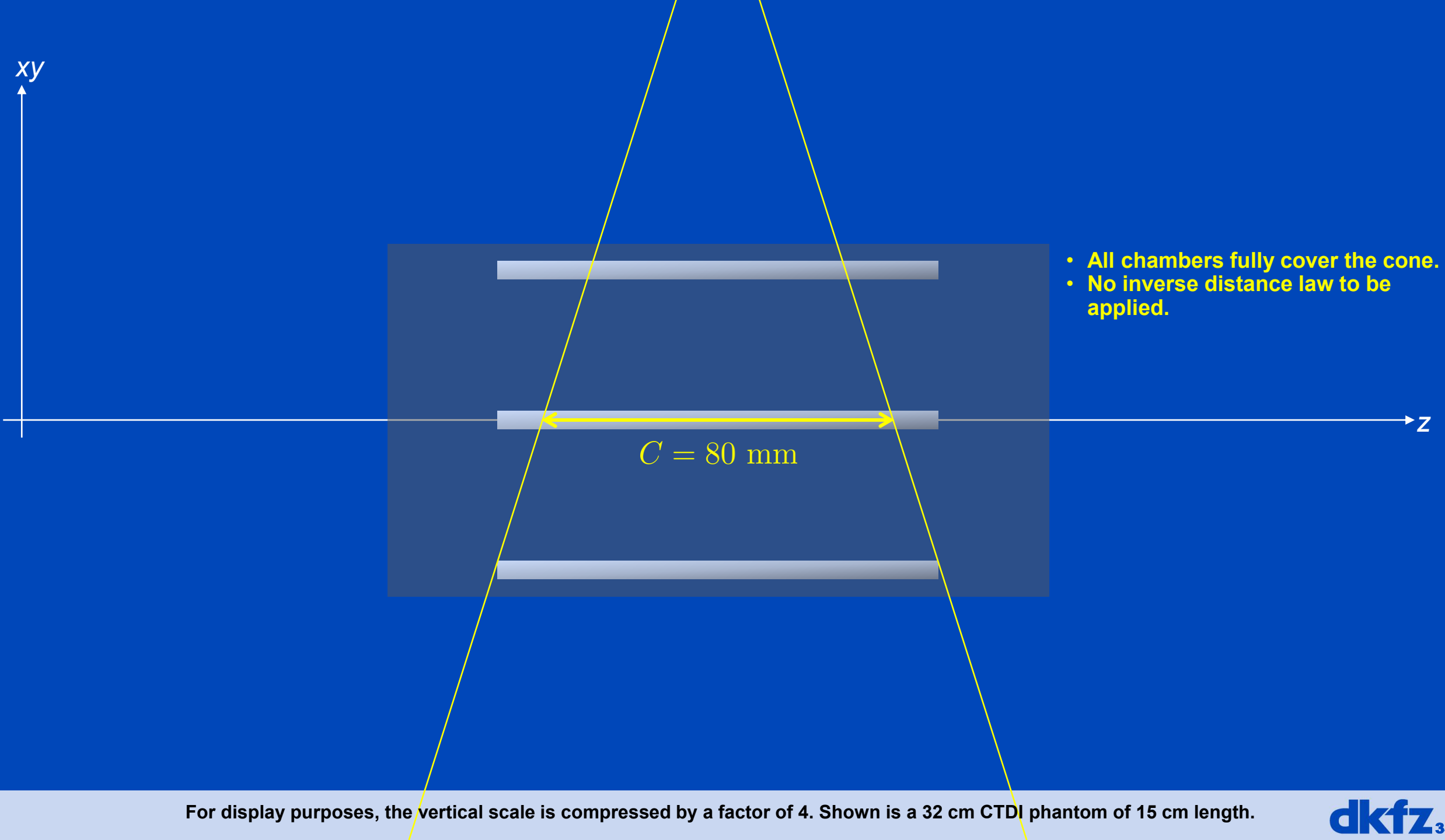
Simulation Parameters for rcs::CMonteCarlo¹

- PMMA cylinder with 32 cm diameter.
- $R_F = 595$ mm.
- $R_{FD} = 1085.6$ mm.
- Tube potential 70 kV and 120 kV
- Bowtie similar to Flash scanner.
- $C = 40, 80$ and 160 mm.
- $P = 150, 300, 450$ mm, and ∞ .
- $S = 0, 100, 150, P + 2C$, and ∞ . $S = 0$ is the circle scan.

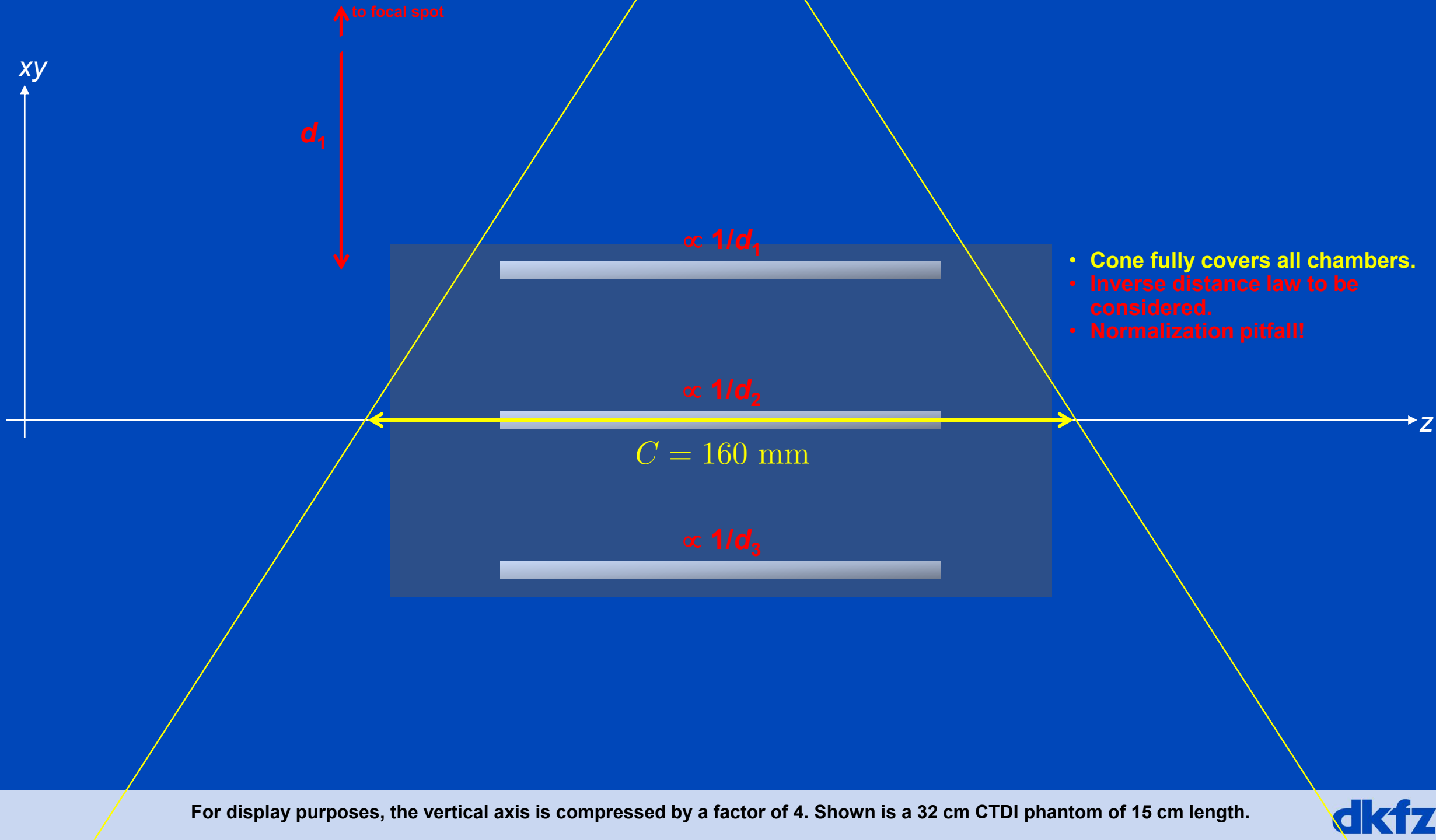
¹M. Baer, M. Kachelrieß. Phys. Med. Biol. 57, 6849–6867 (2012).



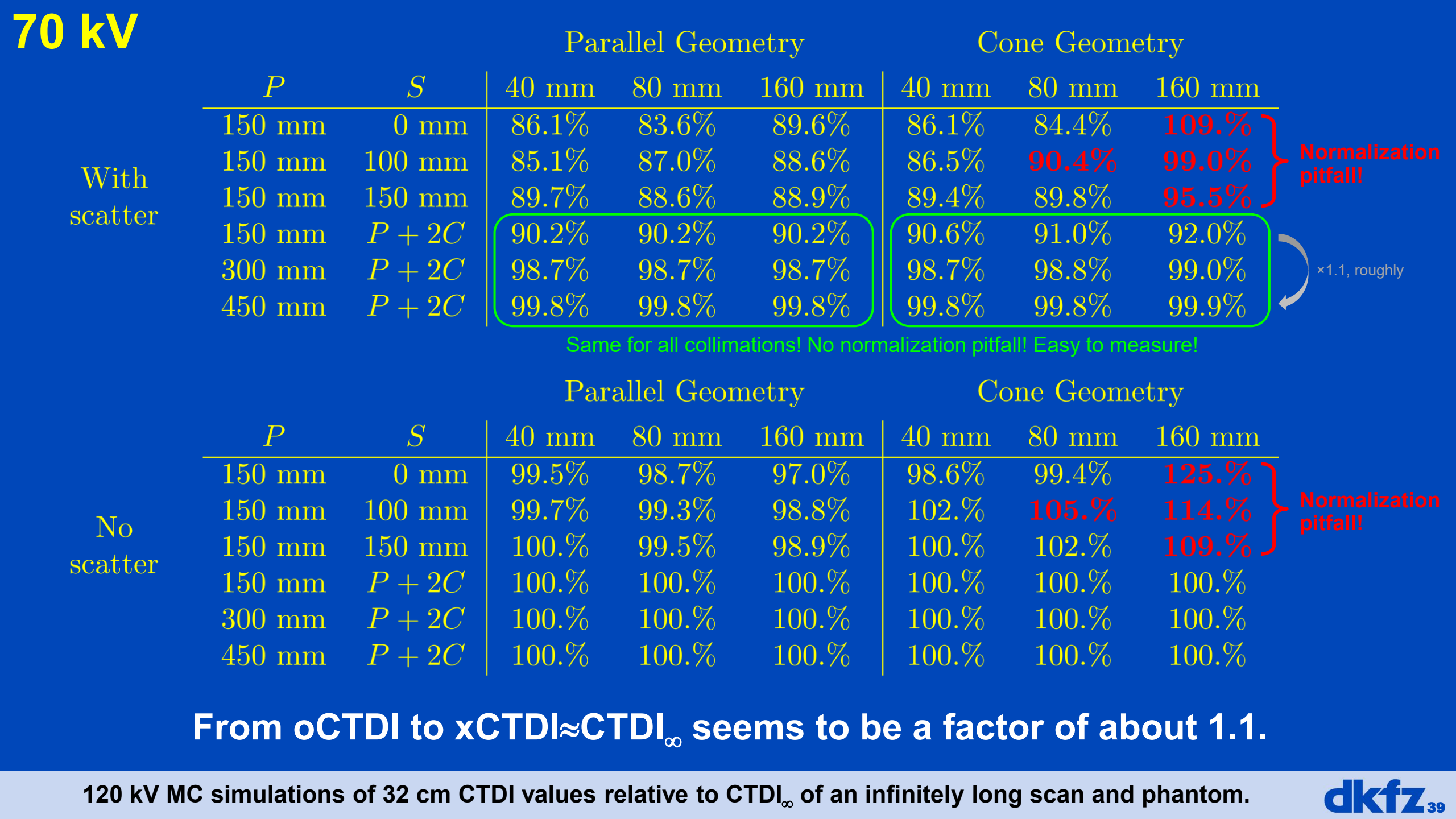
For display purposes, the vertical scale is compressed by a factor of 4. Shown is a 32 cm CTDI phantom of 15 cm length.



For display purposes, the vertical scale is compressed by a factor of 4. Shown is a 32 cm CTDI phantom of 15 cm length.



For display purposes, the vertical axis is compressed by a factor of 4. Shown is a 32 cm CTDI phantom of 15 cm length.



With
scatter

		Parallel Geometry			Cone Geometry			
P	S	40 mm	80 mm	160 mm	40 mm	80 mm	160 mm	
150 mm	0 mm	79.7%	77.1%	85.5%	79.9%	78.2%	99.2%	Normalization pitfall!
150 mm	100 mm	78.9%	81.2%	83.4%	79.9%	83.8%	91.6%	
150 mm	150 mm	84.1%	82.9%	83.6%	83.8%	83.8%	88.7%	
150 mm	$P + 2C$	84.8%	84.8%	84.8%	85.3%	85.7%	86.9%	×1.2, roughly
300 mm	$P + 2C$	97.4%	97.3%	97.4%	97.4%	97.5%	97.7%	
450 mm	$P + 2C$	99.5%	99.5%	99.5%	99.5%	99.5%	99.6%	

Same for all collimations! No normalization pitfall! Easy to measure!

No
scatter

		Parallel Geometry			Cone Geometry			
P	S	40 mm	80 mm	160 mm	40 mm	80 mm	160 mm	
150 mm	0 mm	99.1%	99.0%	98.7%	99.2%	99.3%	123.9%	Normalization pitfall!
150 mm	100 mm	99.9%	99.8%	99.8%	102.9%	105.9%	113.9%	
150 mm	150 mm	100.0%	99.8%	99.7%	100.0%	102.9%	108.9%	
150 mm	$P + 2C$	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	
300 mm	$P + 2C$	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	
450 mm	$P + 2C$	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	

From oCTDI to xCTDI $\approx$ CTDI $_{\infty}$ seems to be a factor of about 1.2.

Recommendation and Conclusion

- Use oCTDI, which is the spiral scan with $S \geq P + 2C$.
 - Spiral protocols can be used for oCTDI.
 - Standard 16 and 32 cm CTDI phantoms of 150 mm length can be used.
 - Standard 100 mm ionization chambers can be used.
 - The scan range is easy to set (even without topogram), as it extends beyond the phantom.
 - Invariance under vendor-specific proprietary behaviour of collimator and reconstruction technology at scan start and scan end.
 - Theoretically independent of the collimation. This allows intra- and inter-scanner comparisons for protocols differing in C .
 - Most simple normalization of the meter reading: Simply divide by 100 mm.
- The choice of the phantom diameter (16 or 32 cm) and the calculation of the weighted CTDI remain unchanged.
- **Overscan CTDI provides a practical and robust approach for quality assurance under clinically relevant acquisition conditions.**
 - What about protocols that exist only as circle scans (e.g. those for $C \geq 100$ mm)?

Thank You!



The 10th International Conference on Image Formation in X-Ray Computed Tomography

July 10 – July 14, 2028, Oberstdorf, Germany
www.ct-meeting.org



Conference Chair
Marc Kachelrieß, German Cancer Research Center (DKFZ), Heidelberg, Germany

This presentation will soon be available at www.dkfz.de/ct.

Parts of the reconstruction software were provided by RayConStruct® GmbH, Nürnberg, Germany.