



# “La Radioterapia nel cancro della mammella: indicazioni e tecnica”

## NOVITÀ NEL PLANNING

### Radioterapia della mammella e dosi di radiazioni

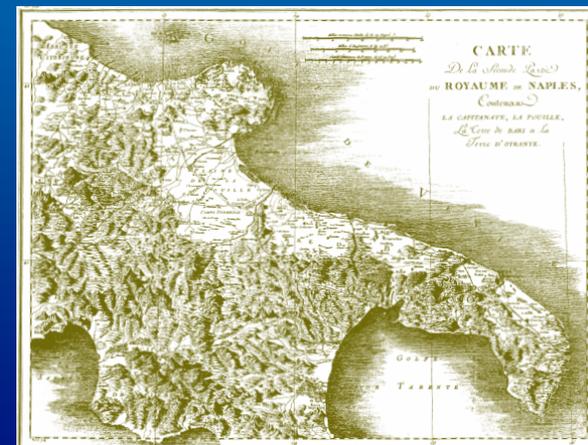
Taranto 19 giugno 2019.

### “NOVITÀ NEL PLANNING” al cuore

*Radioterapia della mammella e  
dosi di radiazioni al cuore*

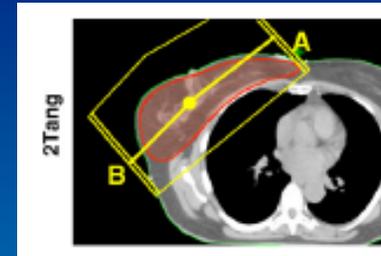
Relatori:

**Luca Grimaldi**

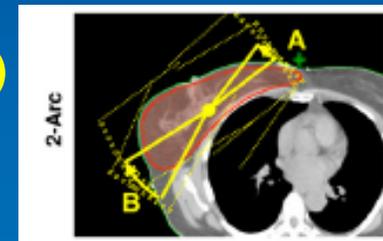


# Le tecniche più utilizzate

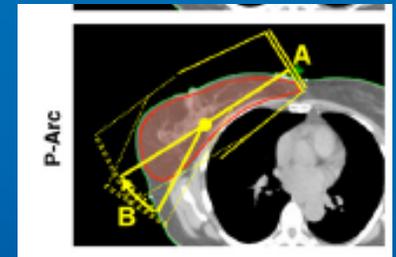
1a – fasci tangenziali a campi filtrati (2Tang)



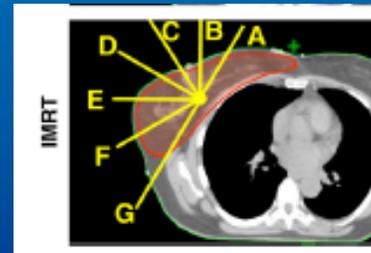
2a – 2-arc (di 20° circa in configurazione 2Tang)



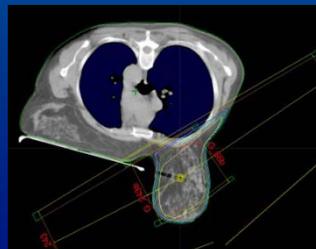
3a – P-arc (partial arc): 1 static field medial + 1 arc lateral



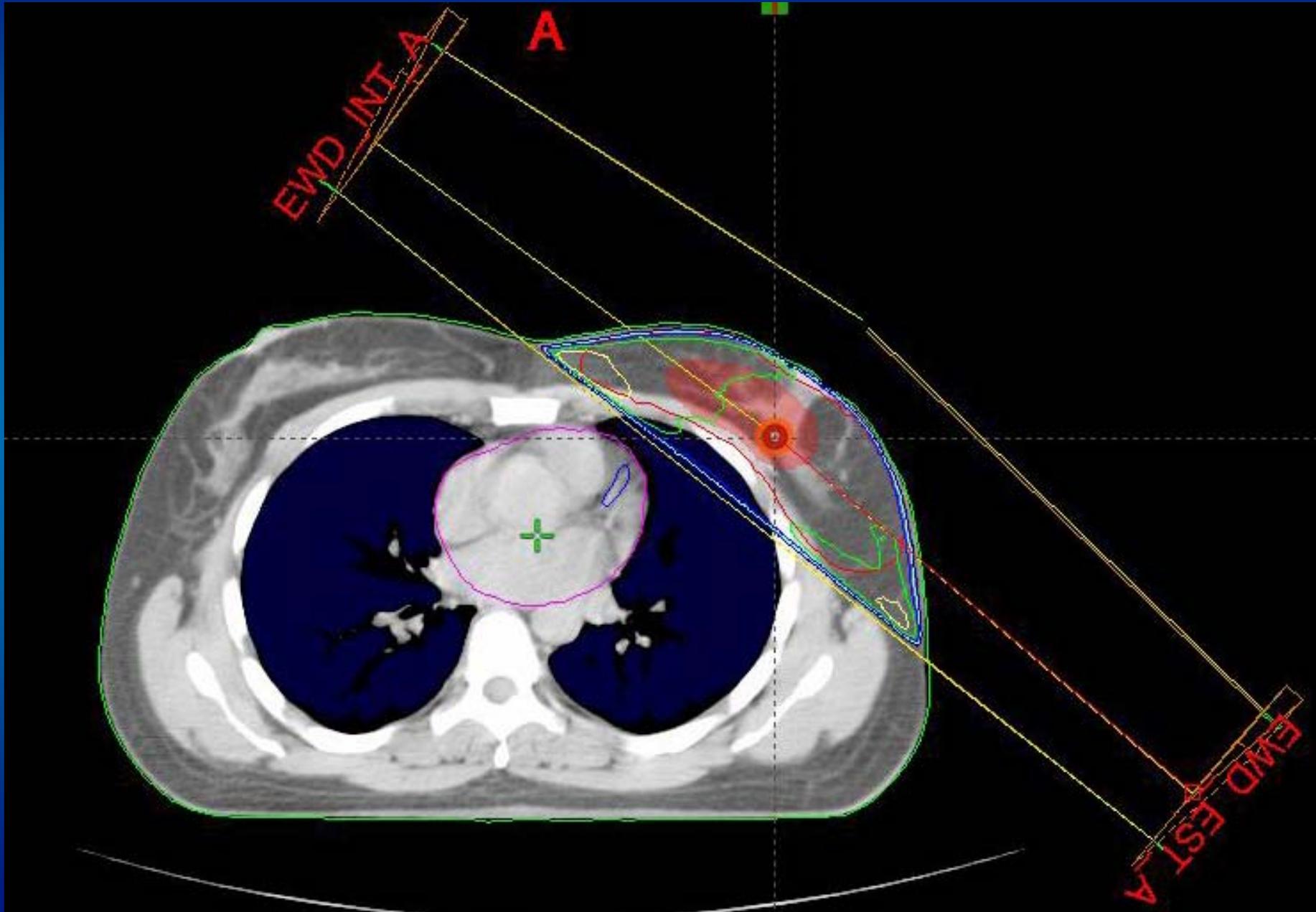
4a – IMRT a 7 fasci equispaziati



5° - Pendulous irradiation



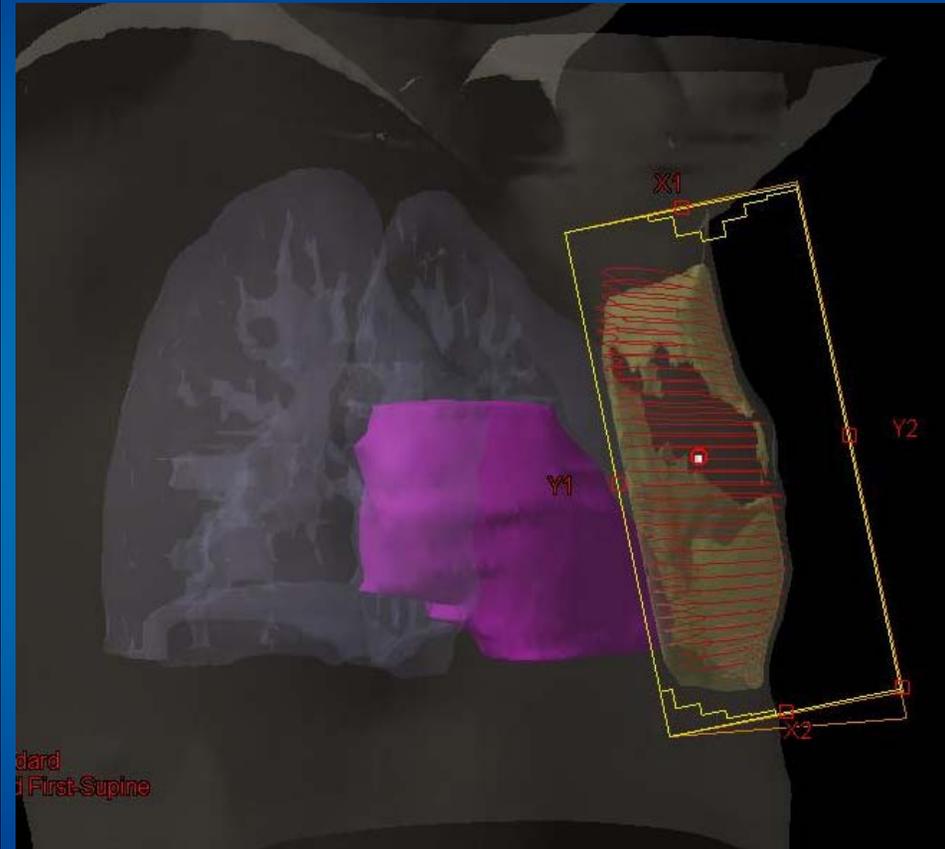
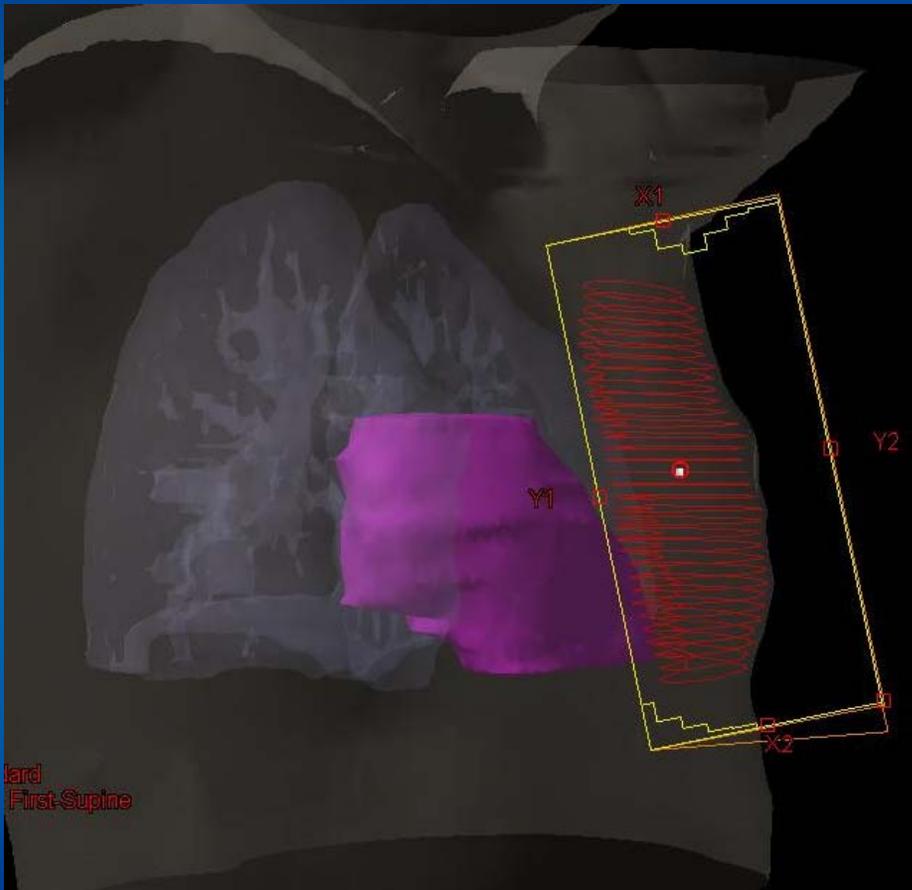
# La tecnica dei campi filtrati



# La tecnica dei campi filtrati

BEV int

BEV int

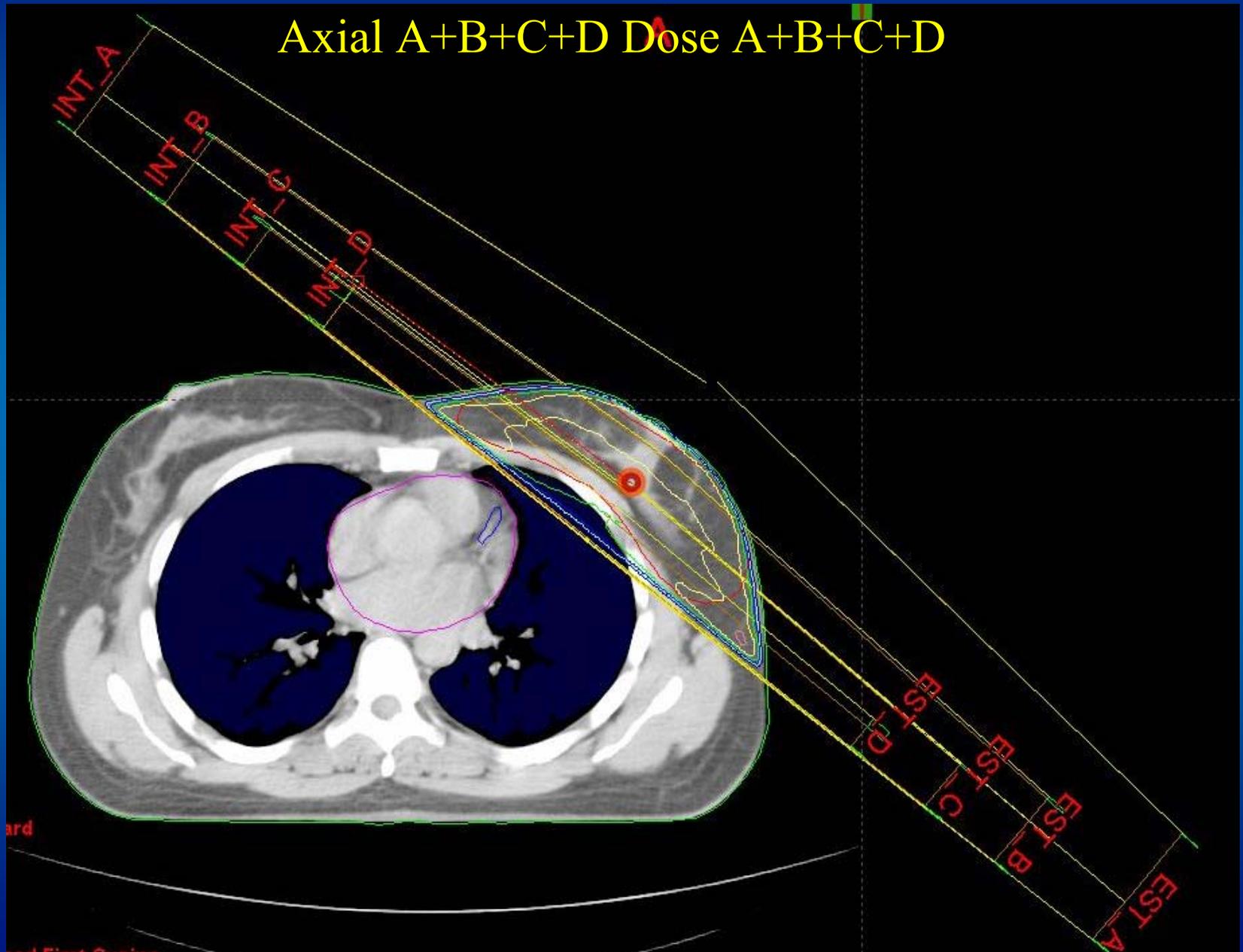


best fit collimator

isodose 100%

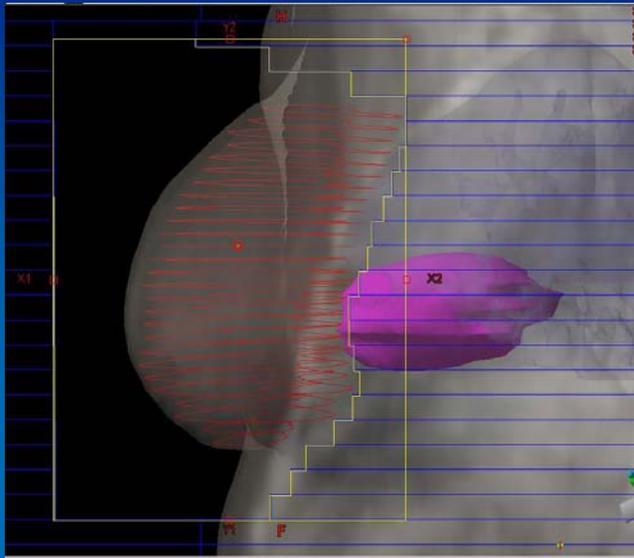
# La tecnica del field in field

Axial A+B+C+D Dose A+B+C+D

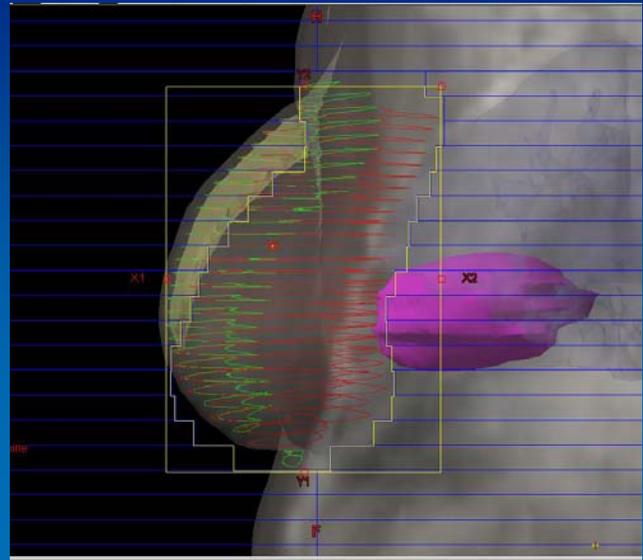


# La tecnica del field in field

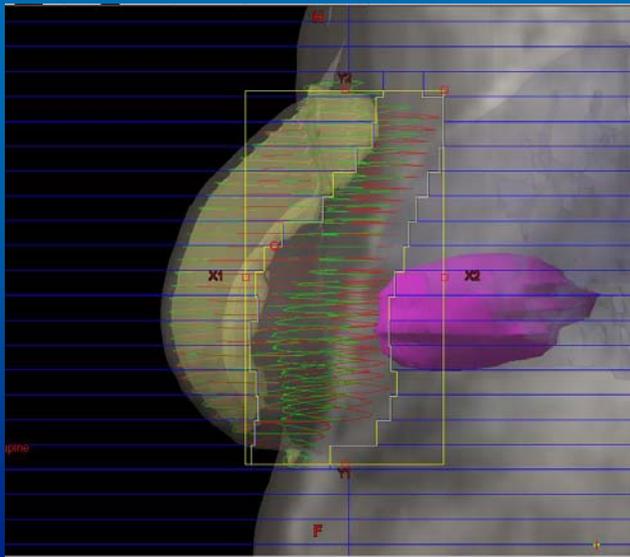
A



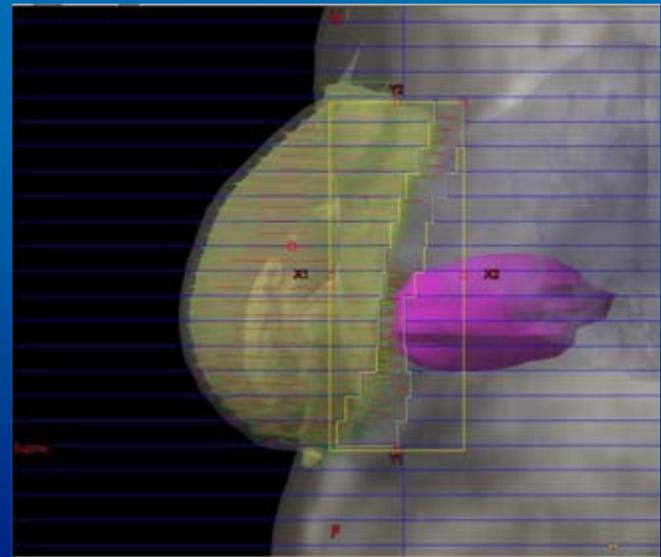
B



C

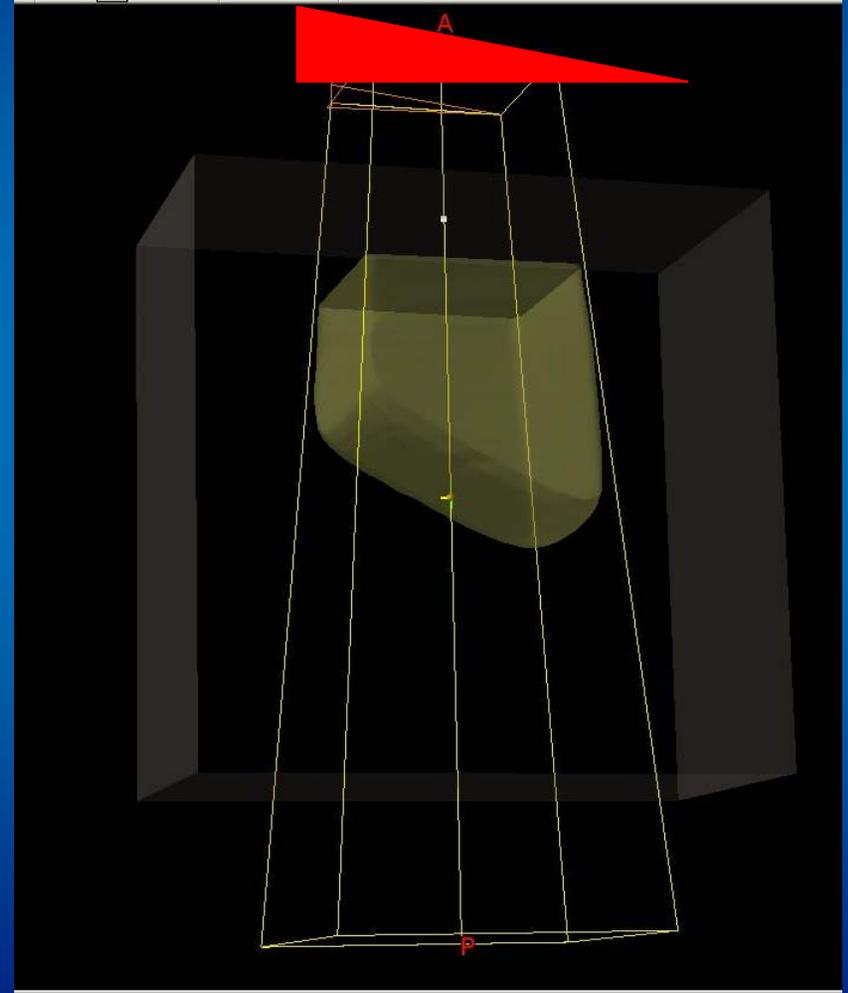
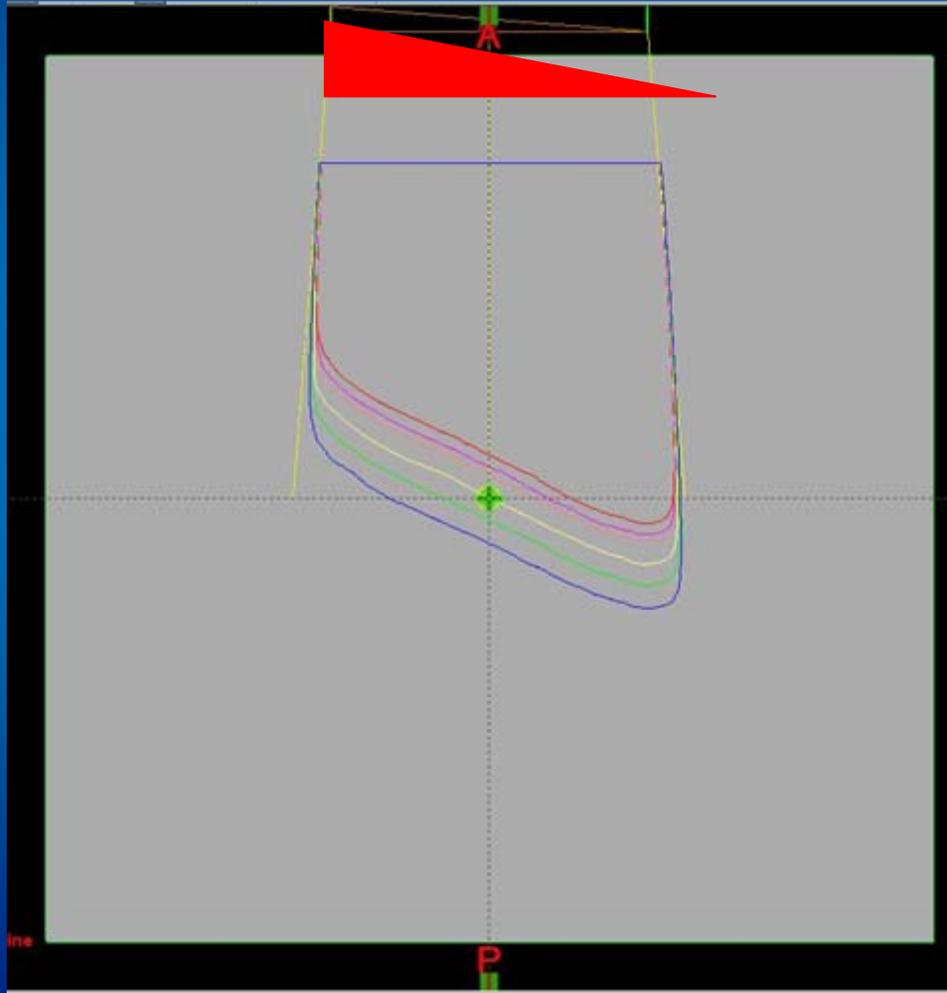


D



# IMRT

Wedge è un esempio di modulazione di fluenza (di energia di particelle)  
ma non di intensità di fluenza (di energia di particelle)



Forward IMRT manual based

Segmento A+B+C+D

Weight **100% 8% 8% 8%**

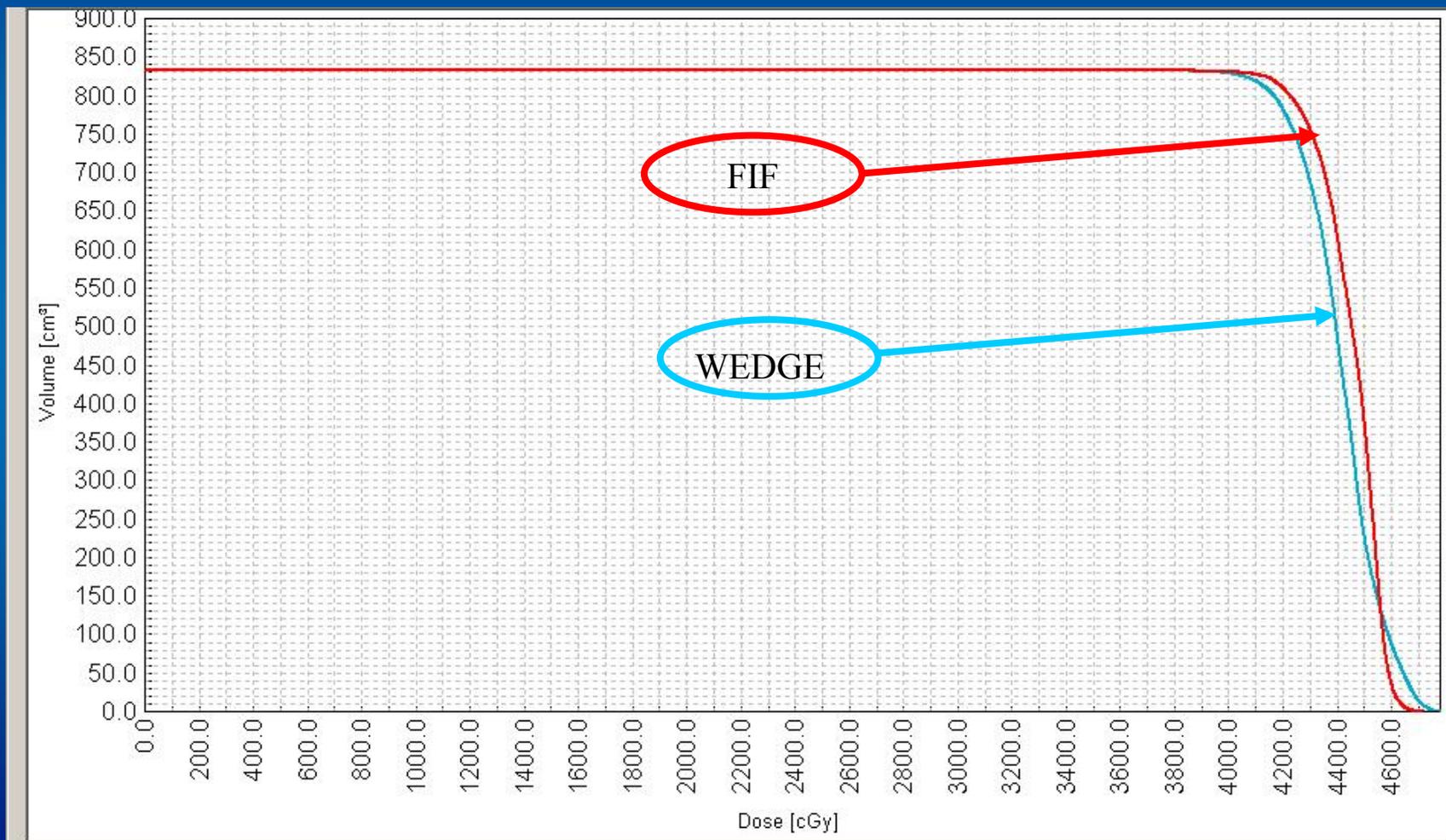


# Indicazioni per l'ottimizzazione

- ✓ sMLC > 5 UM (per evitare le iniziali fluttuazioni del profilo del fascio)
- ✓ stesso angolo del gantry
- ✓ stesso angolo di collimatore
- ✓ peso dei sottocampi pari a 10-20% del peso dei segmenti iniziali
- ✓ evitare campi con S < 4 cm x 4 cm
- ✓  $D_{\max} < 105\%$  durante ottimizzazione
- ✓ N° segmenti da 3 a 5 in base al volume della mammella
- ✓ isocentro a metà spessore attraversato, per facilitare la fase del weighting dei fasci
- ✓ segmenti sempre a coppie
- ✓ **segmenti conformati in BEV sull'isodose del 100% del segmento maggiore**
- ✓ DVH integrale e differenziale

# La tecnica del field in field

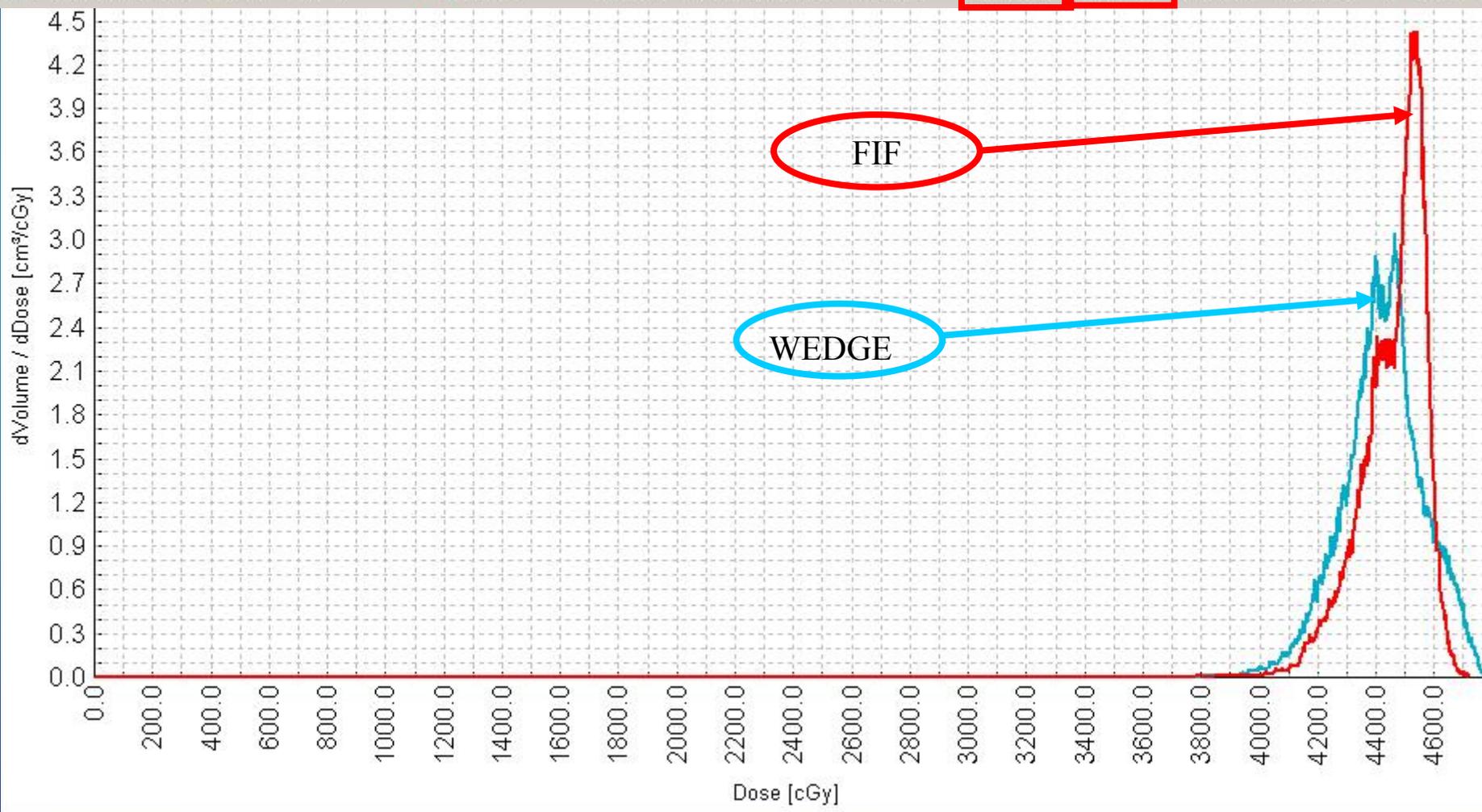
## DVH cumulativo - PTV



# La tecnica del field in field

## DVH differenziale

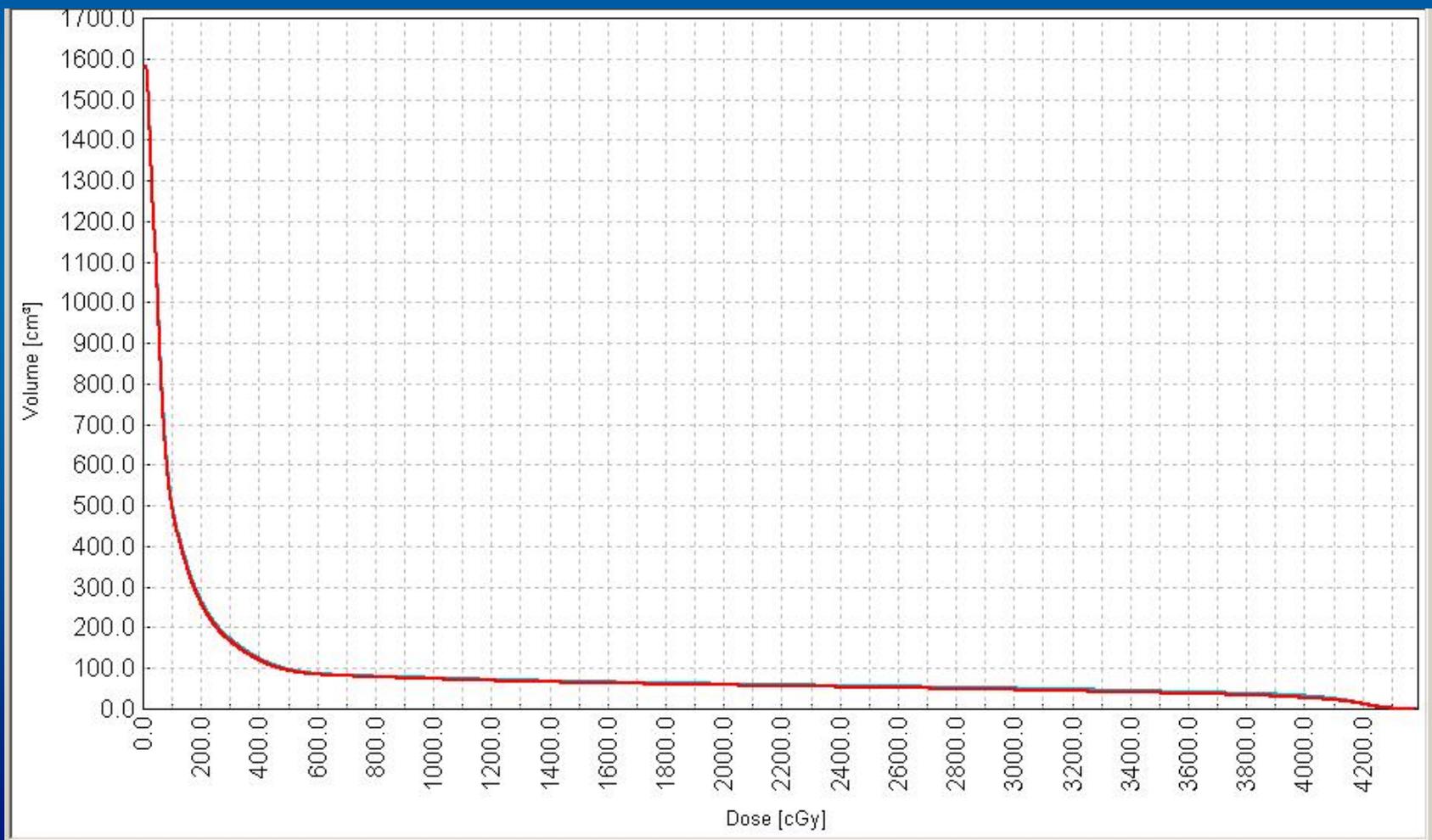
| Plan   | Structure | Prescr. Dose [cGy] | Treat. [%] | Cov. [%] / [%] | Volume [cm <sup>3</sup> ] | Min [cGy] | Max [cGy] | Mean [cGy] | Modal [cGy] | Median [cGy] |
|--|-----------|--------------------|------------|----------------|---------------------------|-----------|-----------|------------|-------------|--------------|
| <input checked="" type="checkbox"/> C1/MML_SN_EWD    | PTV       | 4500.0             | 100.0      | 100.0 / 100.0  | 833.2                     | 3121.7    | 4779.8    | 4425.1     | 4401.4      | 4430.0       |
| <input checked="" type="checkbox"/> C1/provaCOMPLETA | PTV       | 4500.0             | 100.0      | 100.0 / 100.0  | 833.2                     | 3176.6    | 4719.4    | 4461.6     | 4533.7      | 4489.7       |



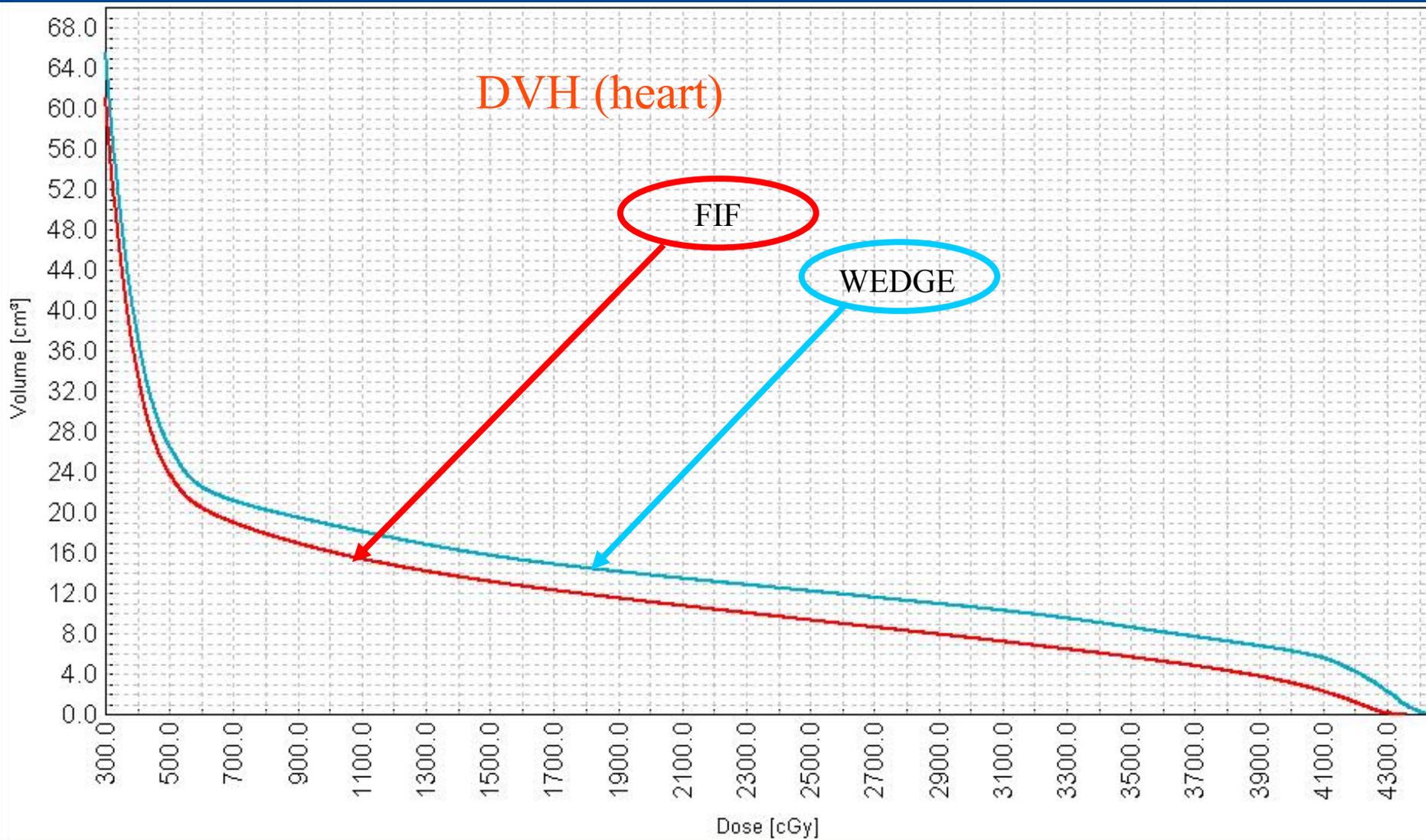
# La tecnica del field in field

## DVH (lung)

| Plan           | Structure | Prescr. Dose [cGy] | Treat. [%] | Cov. [%] / [%] | Volume [cm <sup>3</sup> ] | Min [cGy] | Max [cGy] | Mean [cGy] | Modal [cGy] | Median [cGy] | STD   |
|----------------|-----------|--------------------|------------|----------------|---------------------------|-----------|-----------|------------|-------------|--------------|-------|
| ✓ C1/MML_SN_E  | Lung, NOS | 4500.0             | 100.0      | 77.2 / 100.2   | 2048.6                    | 11.2      | 4388.2    | 254.2      | 15.6        | 66.3         | 724.0 |
| ✓ C1/provaCOMP | Lung, NOS | 4500.0             | 100.0      | 77.2 / 100.2   | 2048.6                    | 11.3      | 4380.1    | 245.4      | 18.2        | 65.4         | 700.8 |

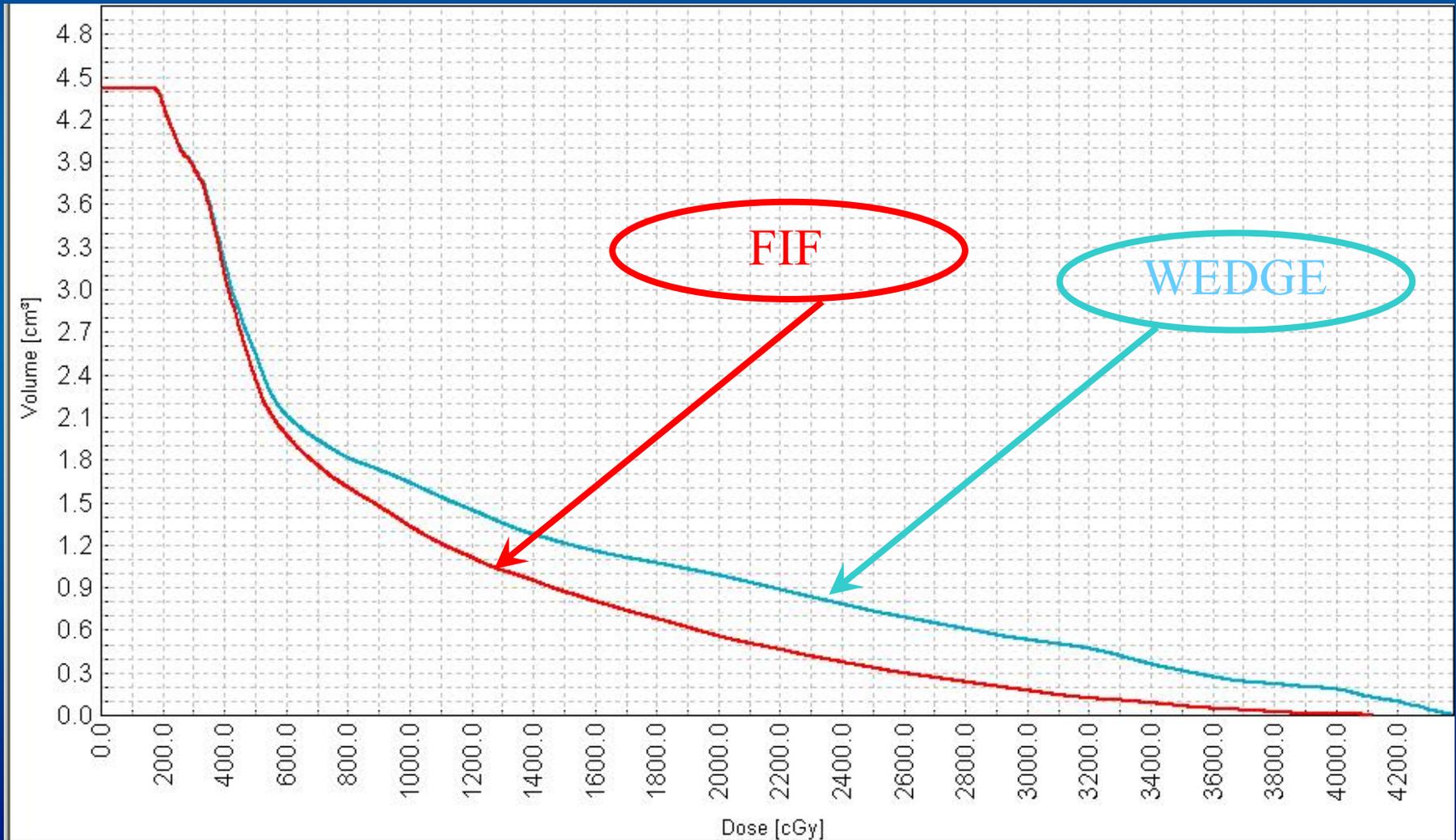


# La tecnica del field in field DVH (heart)



# La tecnica del field in field

## DVH (lad) left anterior descending artery





## FIF vs Wedged

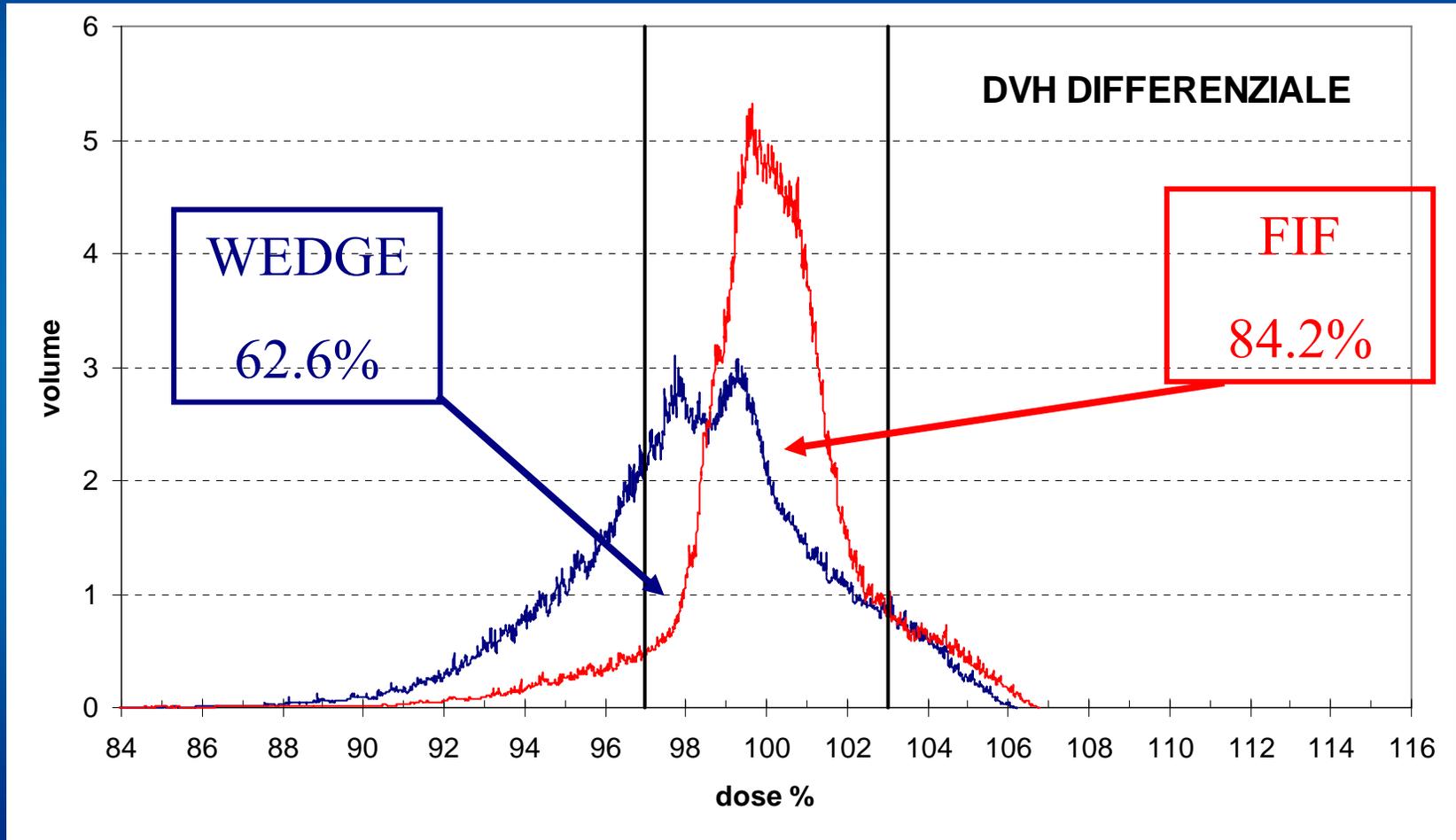


- + maggior uniformità dose
- + riduzione hot spot
- + riduzione dose oar
- + minori UM erogate
- + poco operatore dipendente
- + meno incertezze dosimetriche
- + utilizzo solo una E(6 MV)
- + *no pre-treatment (IMRT)*

- tempo apprendimento tecnica
- tempo irraggiamento (+2-3 min)

Come sono stati interpretati i dati

$$V_{97\%-103\%} = V_{97\%} - V_{103\%} \quad \text{Uniformity Index}$$



$$PTV_{(97\%-103\%)} \text{ FIF}/PTV_{(97\%-103\%)} \text{ WEDGE} = 1.35$$

## I risultati (30 pz)

Guadagno in uniformità:

$$\text{PTV}_{\text{FIF}}(97\%-103\%) / \text{PTV}_{\text{WED}}(97\%-103\%) = \mathbf{1.53}$$

Risparmio degli OAR:

$$D_{\text{media}}_{\text{FIF}}(\text{HEART}) / D_{\text{media}}_{\text{WED}}(\text{HEART}) = \mathbf{0.90}$$

$$D_{2\%}_{\text{FIF}}(\text{HEART}) / D_{2\%}_{\text{WED}}(\text{HEART}) = \mathbf{0.86}$$

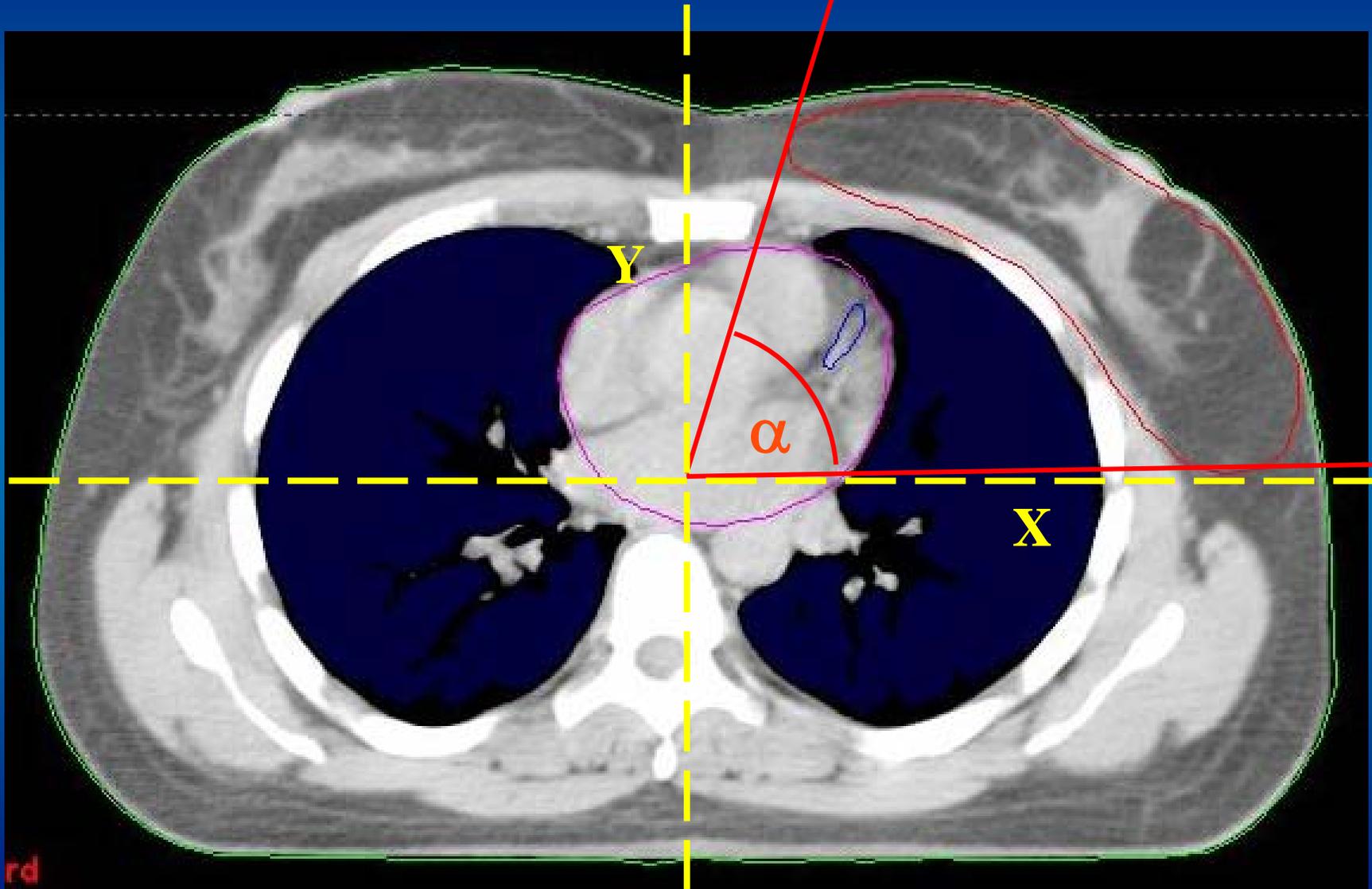
$$D_{\text{media}}_{\text{FIF}}(\text{LAD}) / D_{\text{media}}_{\text{WED}}(\text{LAD}) = \mathbf{0.93}$$

$$D_{2\%}_{\text{FIF}}(\text{LAD}) / D_{2\%}_{\text{WED}}(\text{LAD}) = \mathbf{0.82}$$

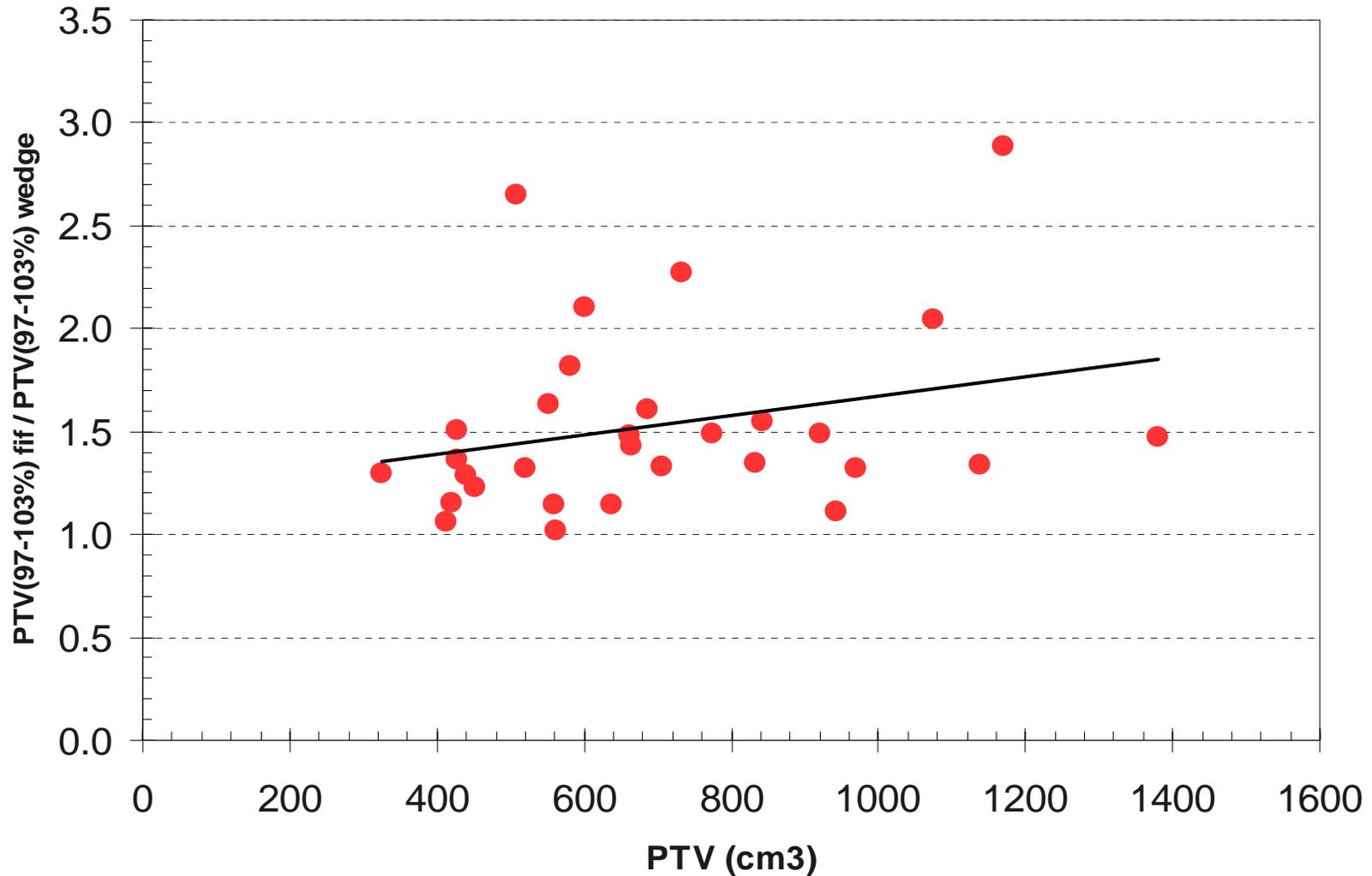
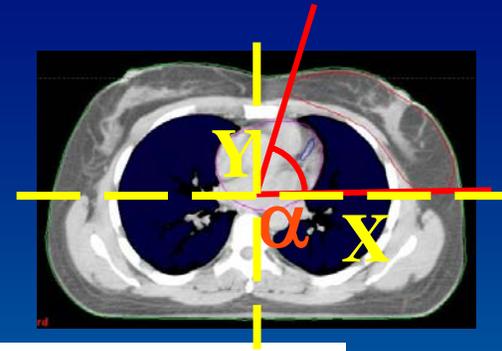
$$D_{\text{media}}_{\text{FIF}}(\text{LUNG}) / D_{\text{media}}_{\text{WED}}(\text{LUNG}) = \mathbf{0.89}$$

$$D_{2\%}_{\text{FIF}}(\text{LUNG}) / D_{2\%}_{\text{WED}}(\text{LUNG}) = \mathbf{0.92}$$

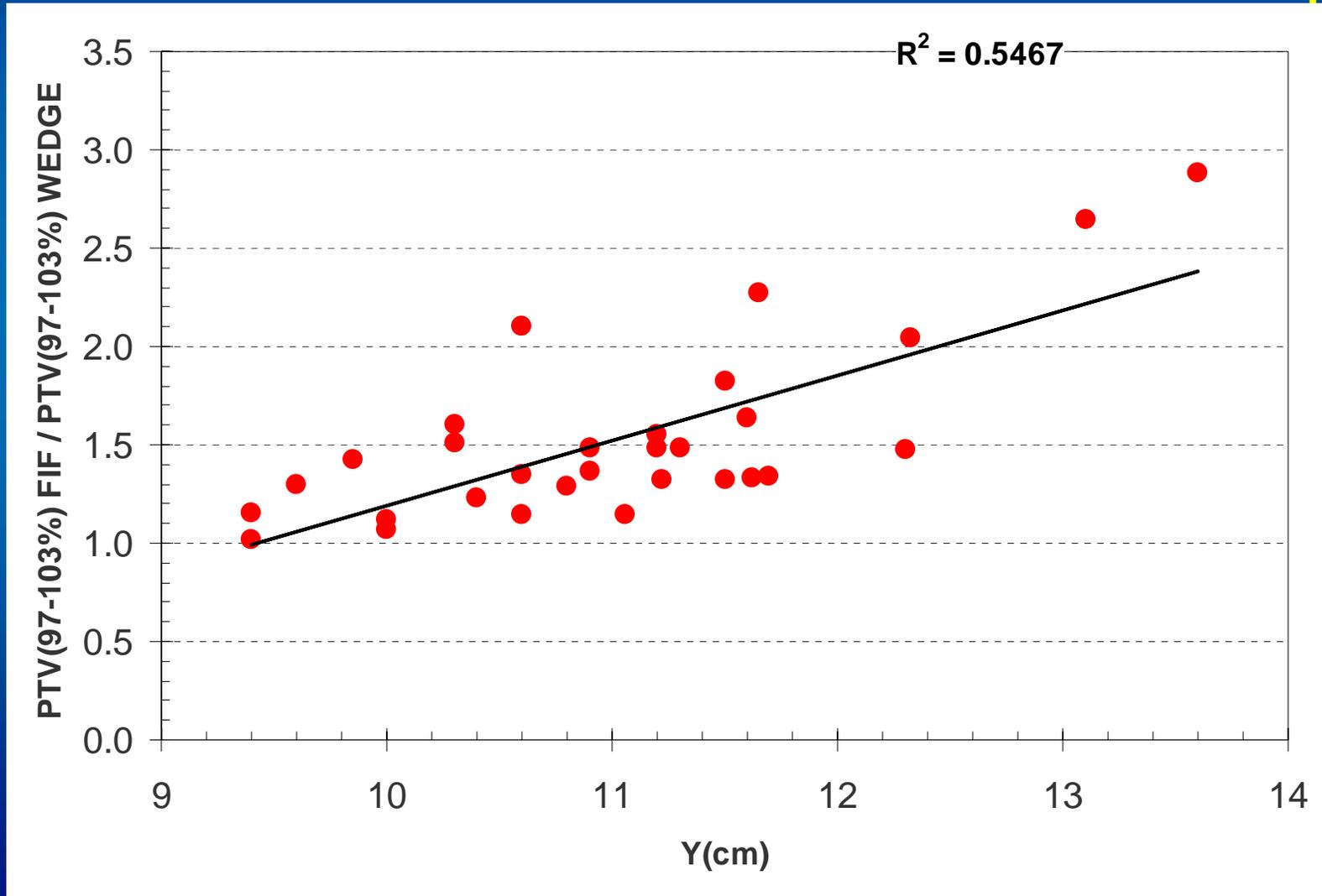
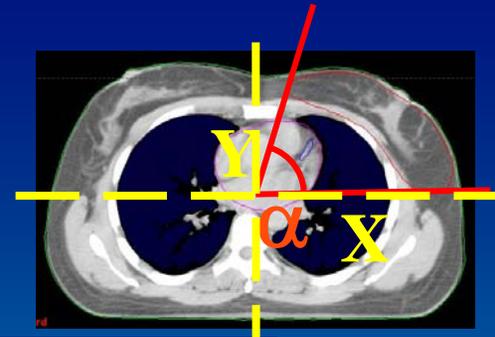
# Parametrizzazione geometrica



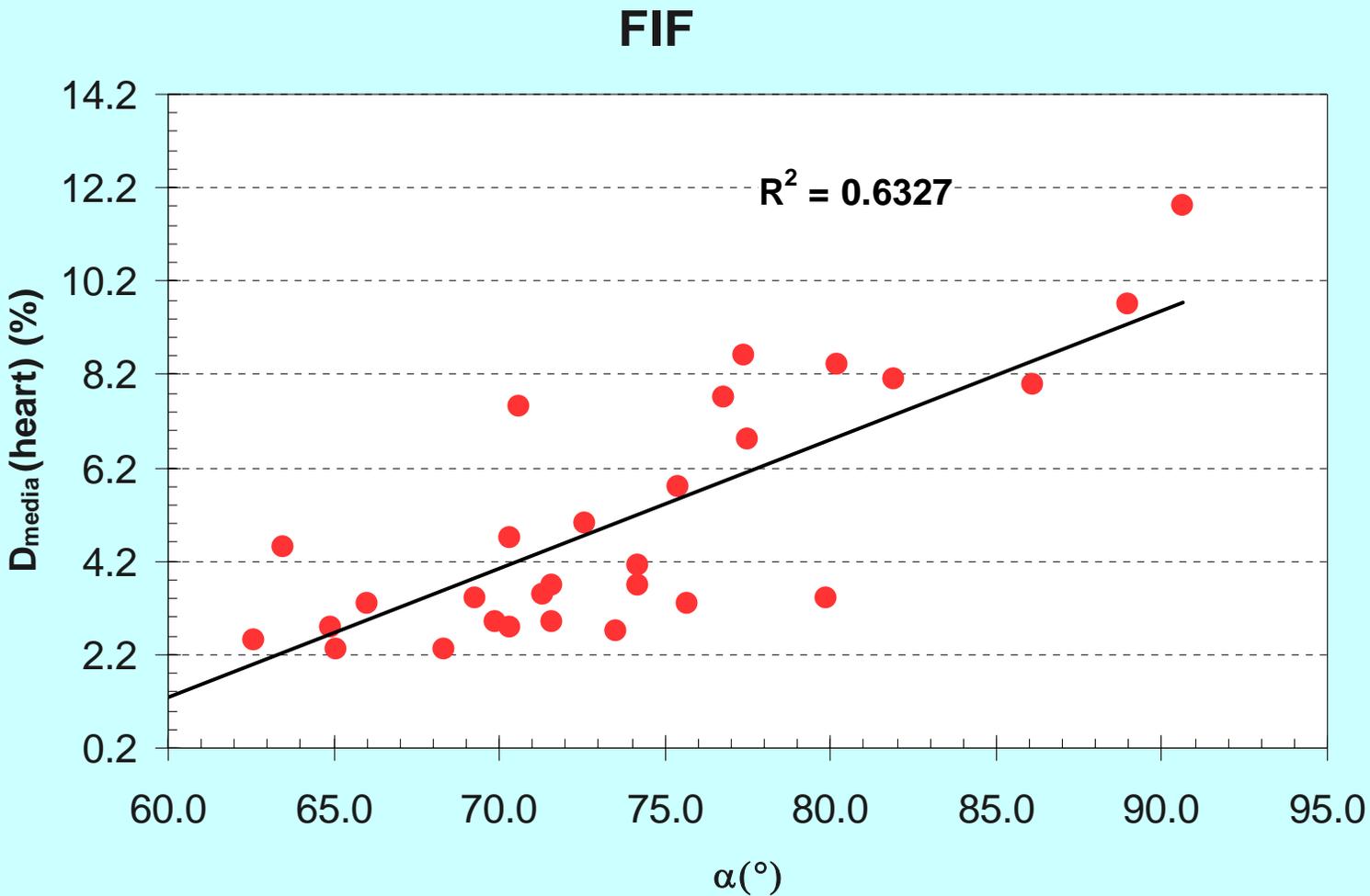
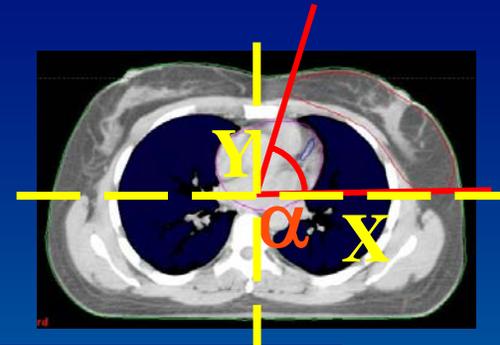
# Indipendenza dal volume del target



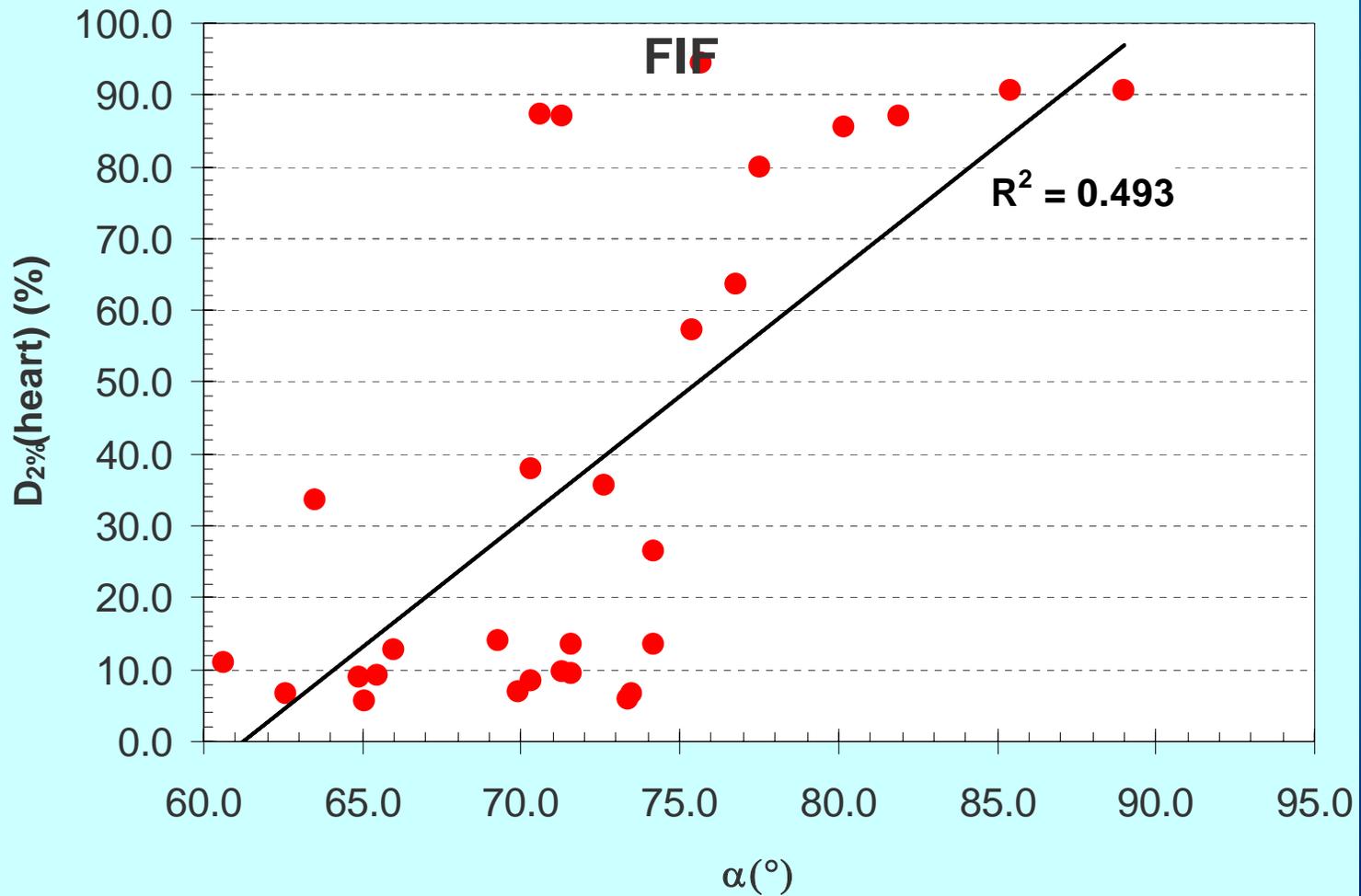
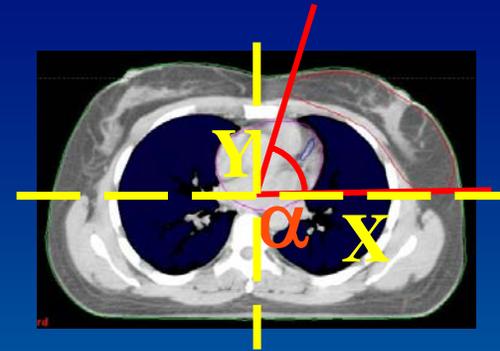
La fif conviene per toraci più spessi



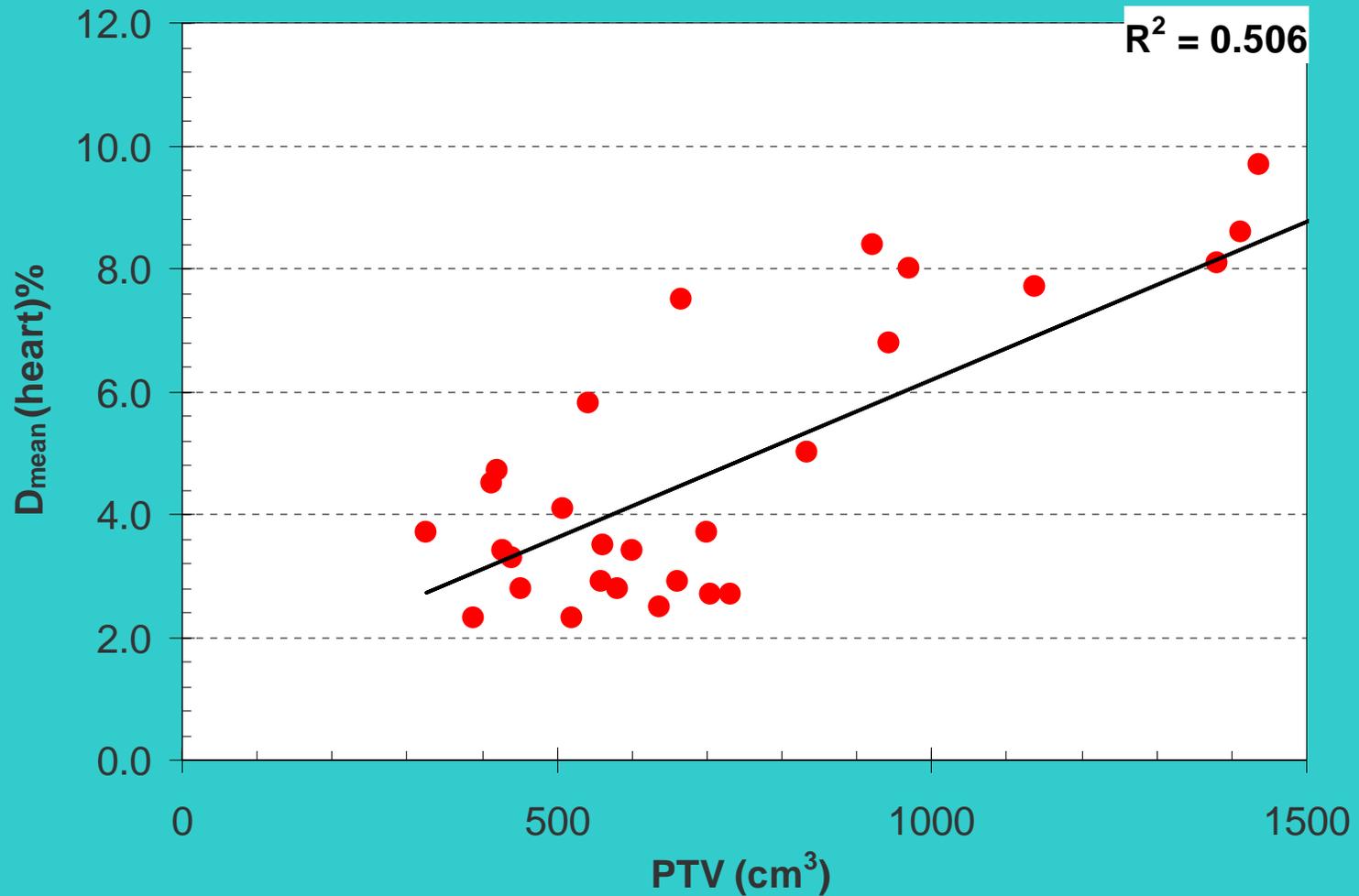
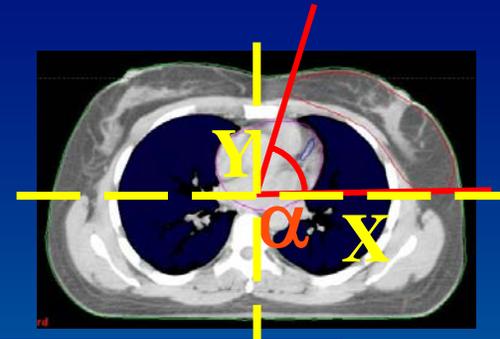
La dose media al cuore aumenta con  $\alpha$



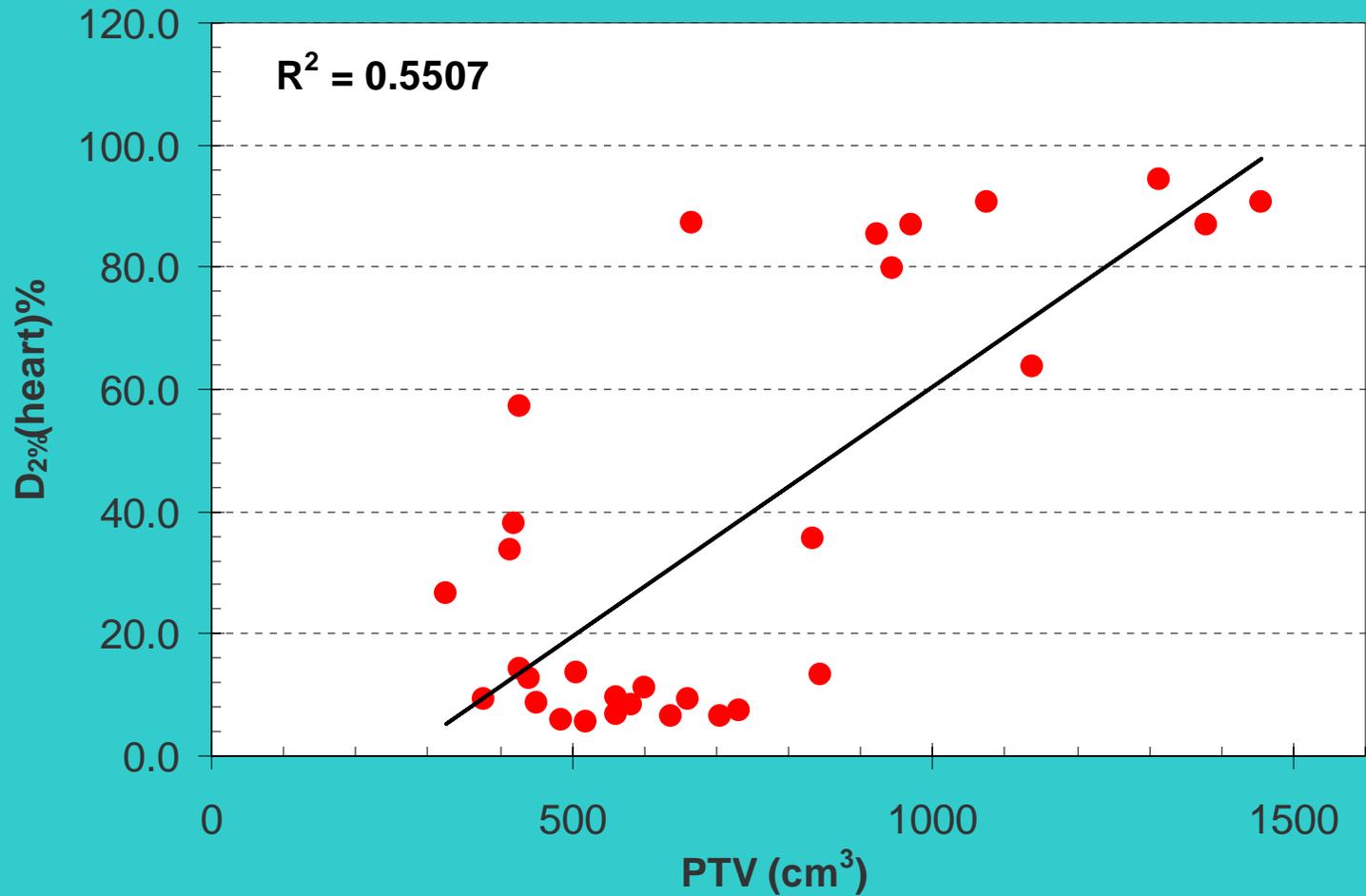
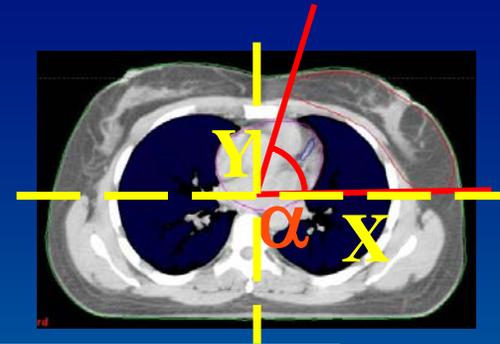
La  $D_{2\%}$  al cuore aumenta con  $\alpha$



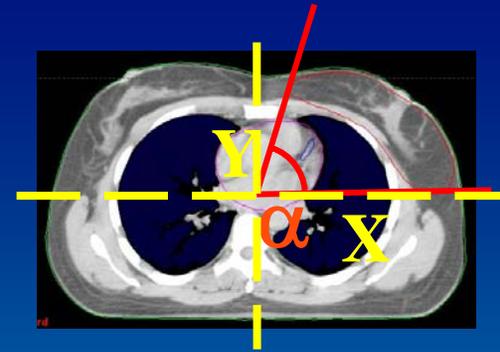
La dose media al cuore aumenta con il volume del PTV



La  $D_{2\%}$  del cuore aumenta con il volume del PTV



# Riassumendo:



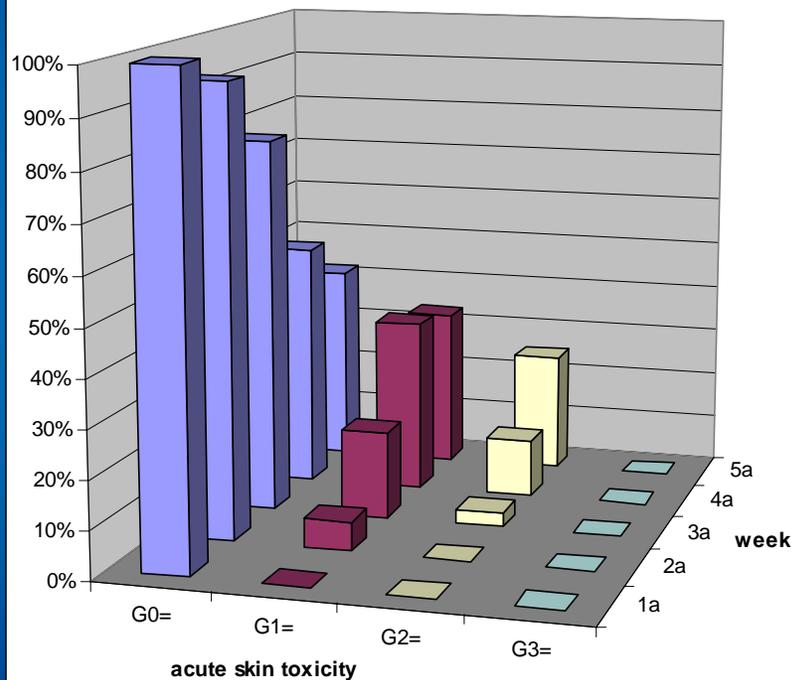
- ✓ Il guadagno in uniformità è indipendente dal volume del target
- ✓ Il guadagno in uniformità aumenta con lo spessore Y del paziente

## OAR

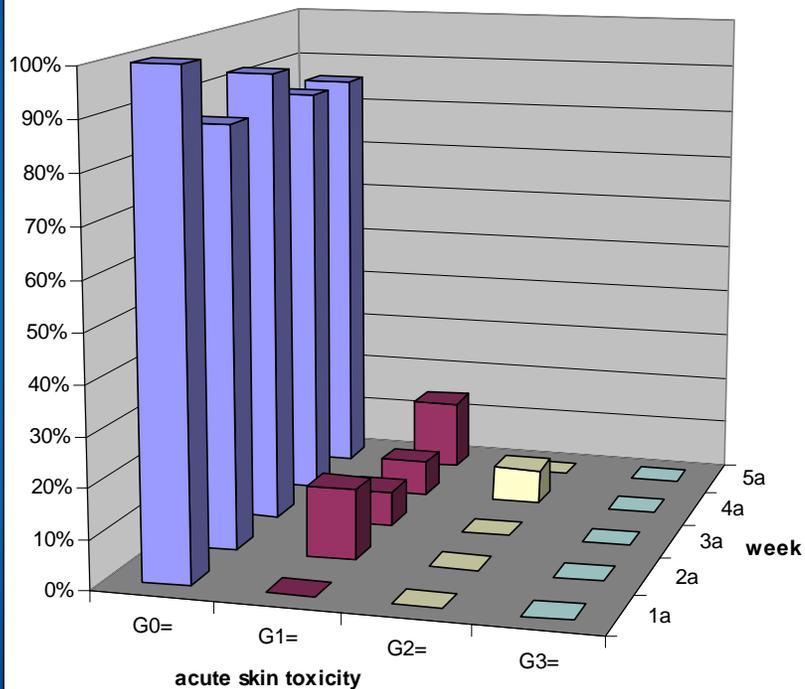
- La  $D_{\text{media}}$  e la  $D_{2\%}$  al cuore aumenta con  $\alpha$  e le dimensioni del PTV

# la tossicità in cute:

wedged beams



field in field



33 pz con WEDGED

30 pz con FIF

## BED = Biological Effective Dose

$$\text{BED} = D \left( 1 + \frac{d}{\alpha/\beta} \right) = nd \cdot \left( 1 + \frac{d}{\alpha/\beta} \right) = nd + \frac{nd^2}{\alpha/\beta}$$

$\alpha$  = radiosensibilità intrinseca;  $\ln N$  cellule danneggiate in modo irreparabile

$\beta$  =  $\ln N$  di cellule danneggiate in modo riparabile per unità di  $\text{Gy}^2$  (capacità di ripopolamento)

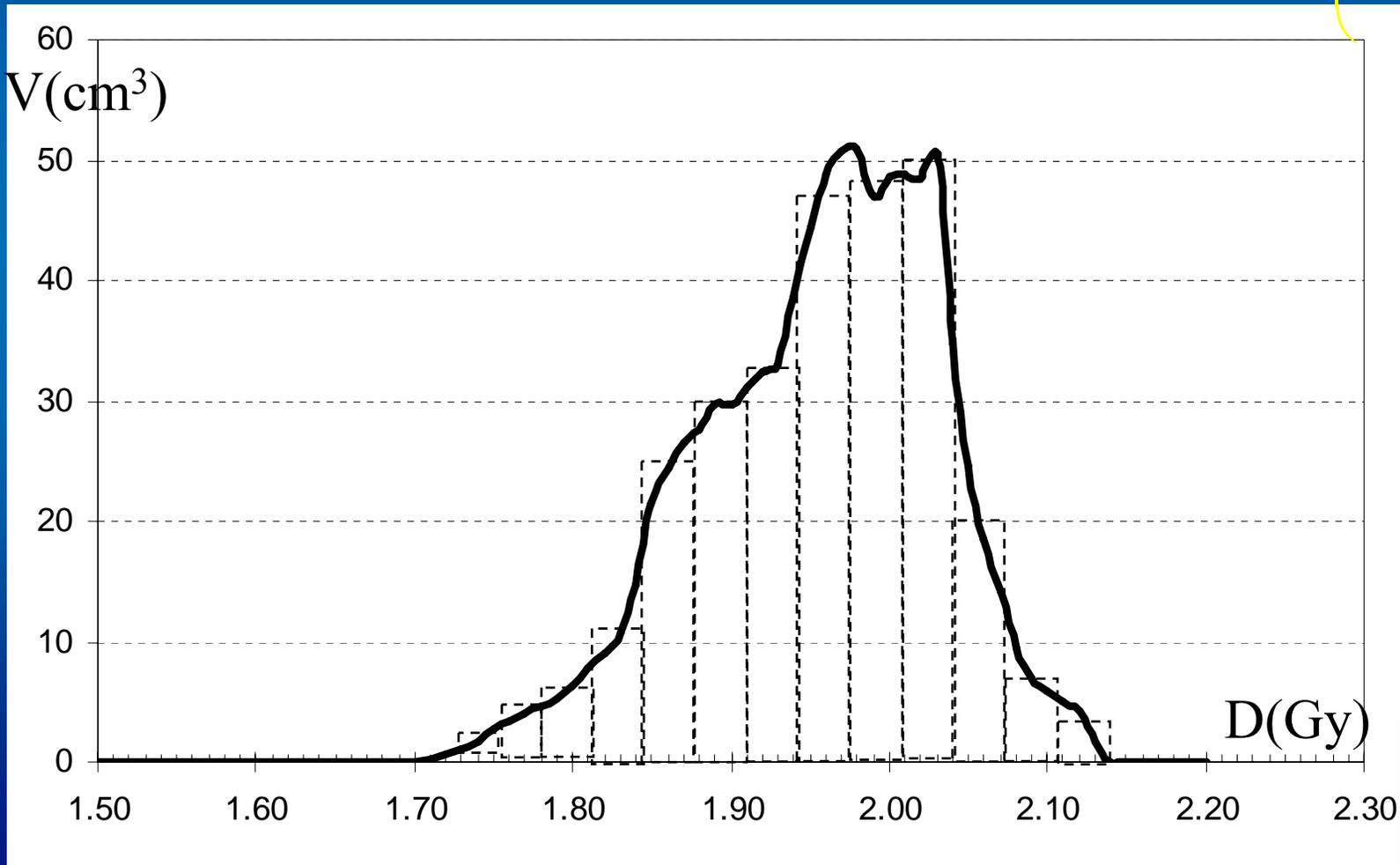
# Equivalent Total Dose

$$D \left( 1 + \frac{d}{\alpha/\beta} \right) = n d \cdot \left( 1 + \frac{d}{\alpha/\beta} \right) = \text{BED} = n' d' \cdot \left( 1 + \frac{2(\text{Gy})}{\alpha/\beta} \right) = D' \cdot \left( 1 + \frac{2(\text{Gy})}{\alpha/\beta} \right) = \text{EQD} \cdot \text{RE}$$

$$\text{EQD} = D \cdot \frac{\left( 1 + \frac{d(\text{Gy})}{\alpha/\beta} \right)}{\left( 1 + \frac{2(\text{Gy})}{\alpha/\beta} \right)} = \frac{\text{BED}}{\text{RE}}$$

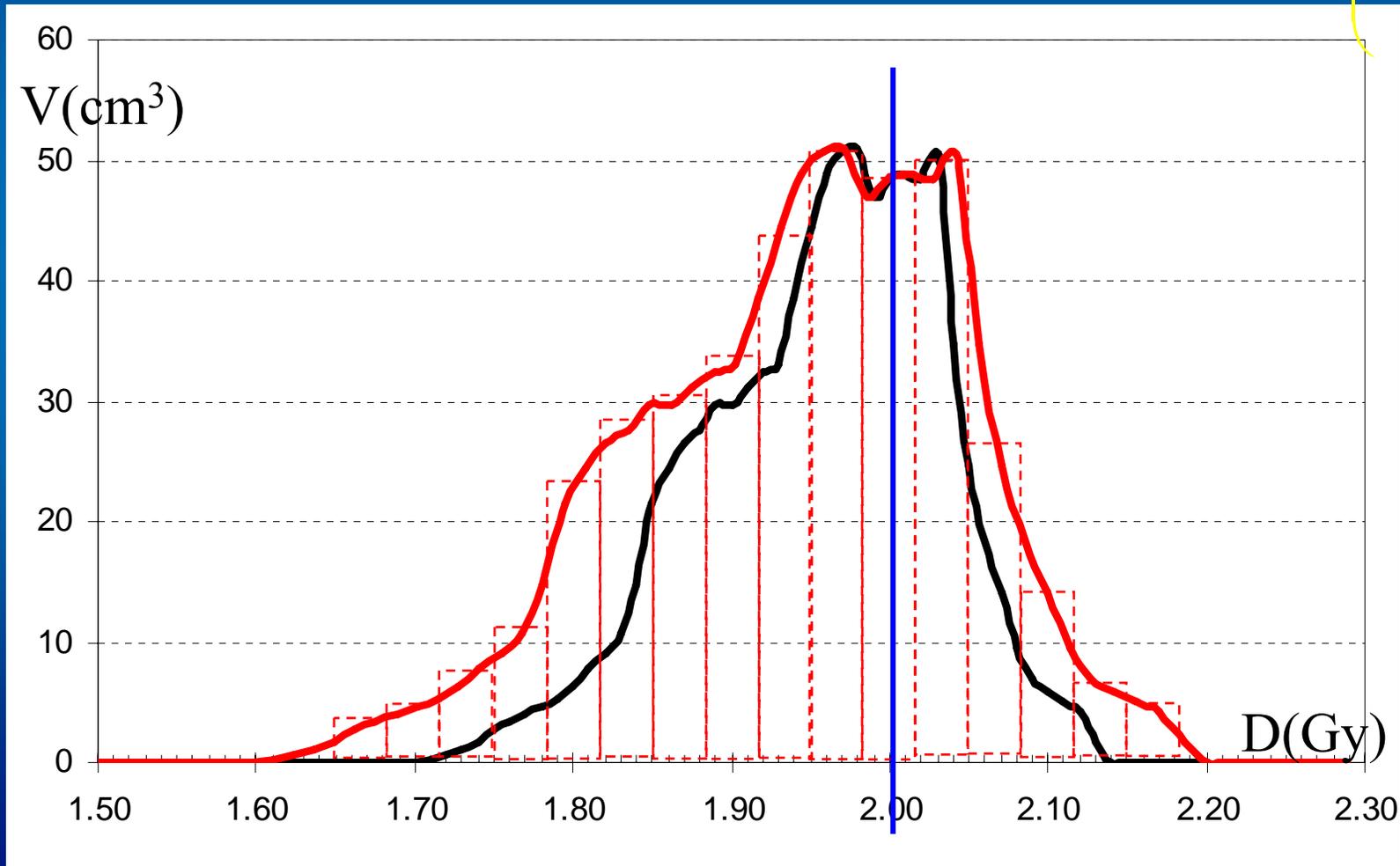
# DVH normalizzato a 2 Gy

$$n' \cdot d'_{i(2\text{Gy})} = n_i d_i \frac{1 + \frac{d_i(\text{Gy})}{\alpha/\beta}}{1 + \frac{2(\text{Gy})}{\alpha/\beta}}$$



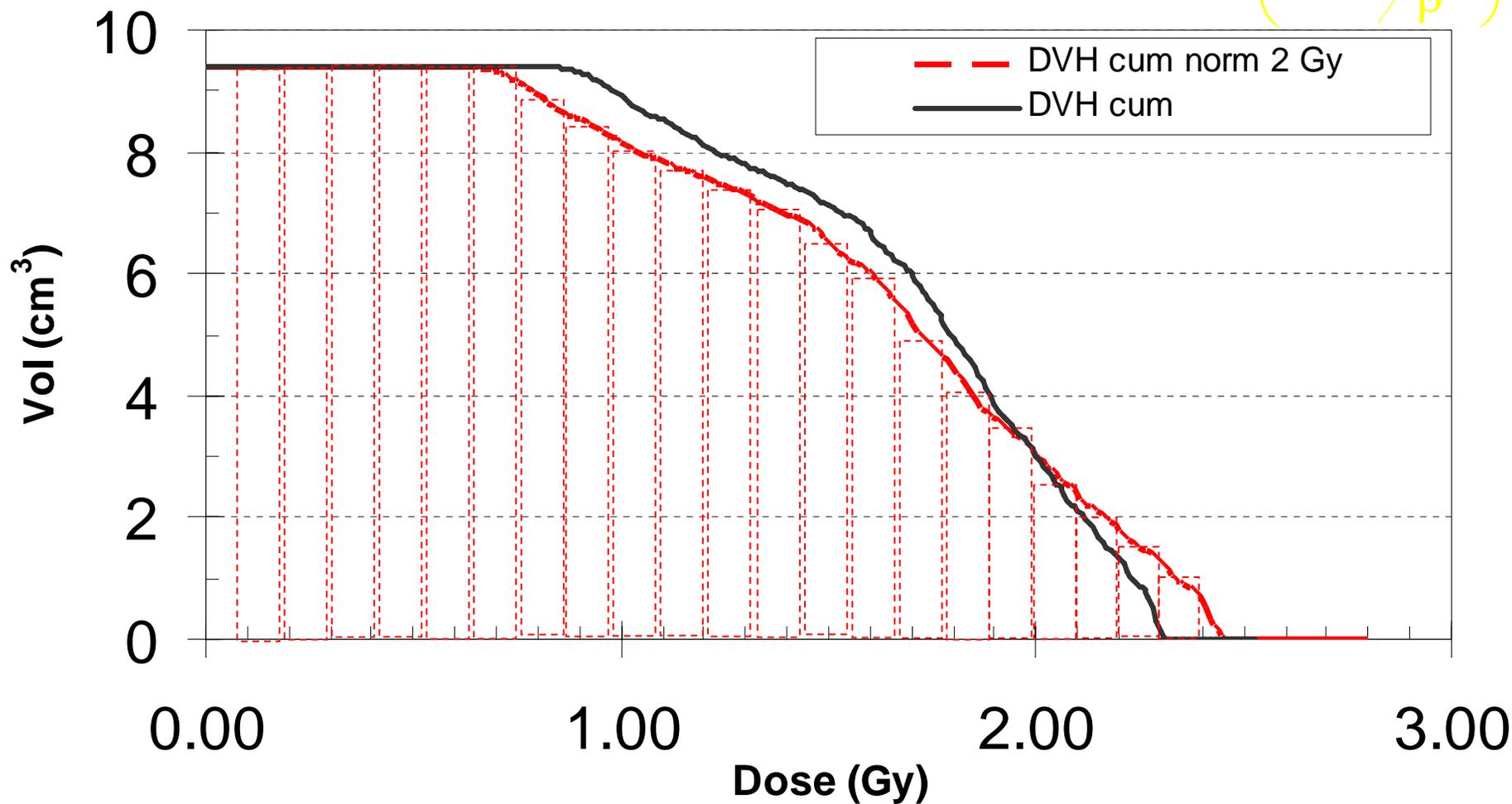
# DVH normalizzato a 2 Gy

$$n' \cdot d'_{i(2\text{Gy})} = n_i d_i \frac{1 + \frac{d_i(\text{Gy})}{\alpha/\beta}}{1 + \frac{2(\text{Gy})}{\alpha/\beta}}$$



DVH normalizzato a 2 Gy

$$n' \cdot d'_{i(2\text{Gy})} = n_i d_i \frac{1 + \frac{d_i(\text{Gy})}{\alpha/\beta}}{1 + \frac{2(\text{Gy})}{\alpha/\beta}}$$



# Modello seriale con parametri di G. Gagliardi

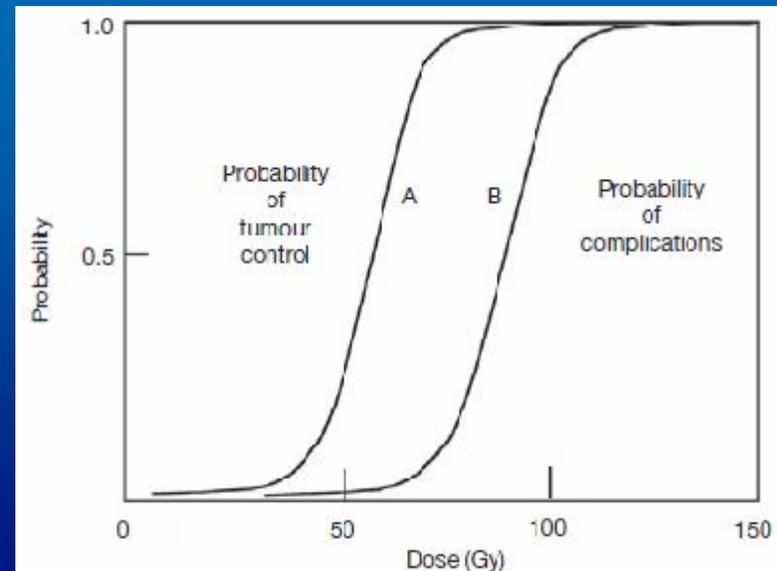
$$P(D) = 2^{-\exp\left[e\gamma\left(1-D/D_{50}\right)\right]}$$

Probabilità per dose uniforme

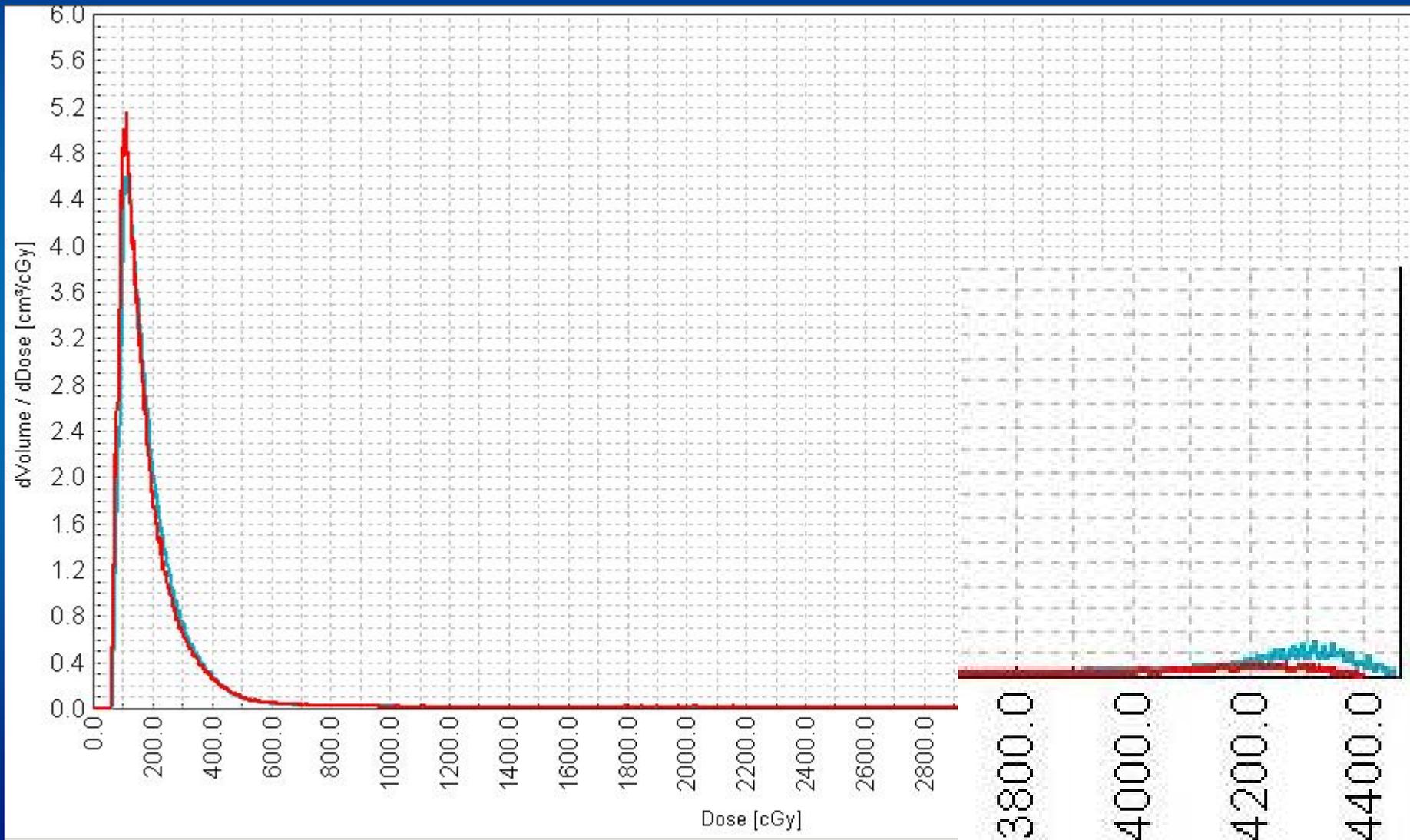
$$P = \left[ 1 - \prod_1^n \left[ 1 - P(D_i)^s \right]^{\Delta v_i} \right]^{\frac{1}{s}} = \left[ 1 - \prod_1^n \left[ 1 - \left( 2^{-\exp\left[e\gamma\left(1-D/D_{50}\right)\right]} \right)^s \right]^{\Delta v_i} \right]^{\frac{1}{s}}$$

$D_{50}$  = 50% complicitance

$\gamma$  = maximum slope



# Il DVH differenziale del PTV + Boost. Picchi grandi e piccoli



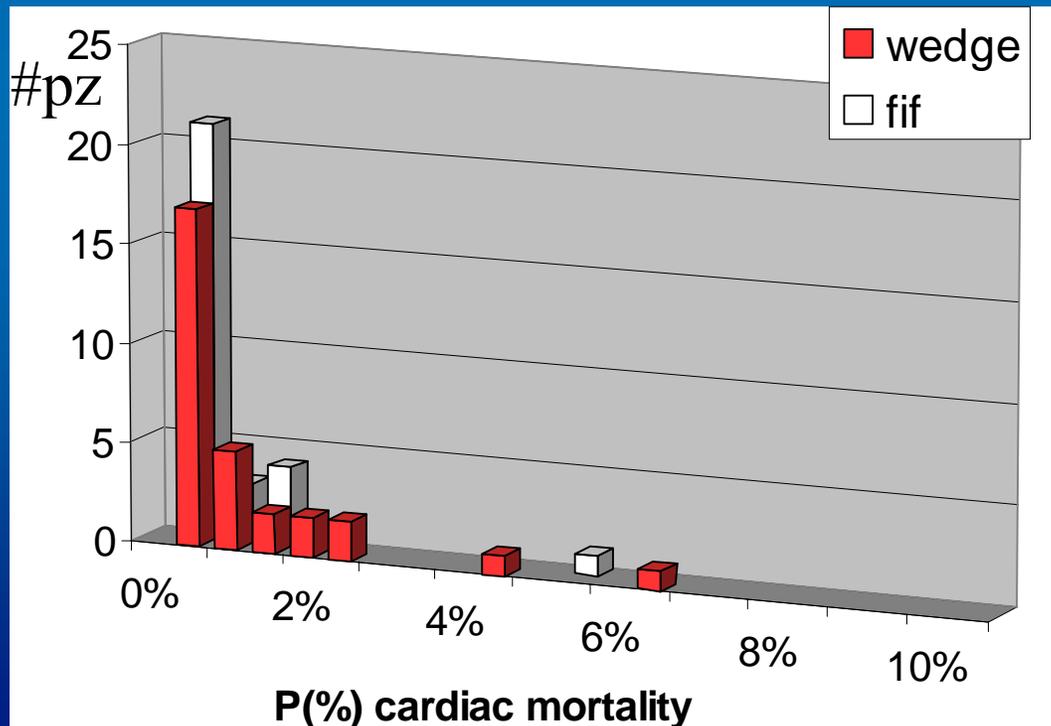
# I primi risultati

Probabilità di morte per infarto miocardico (WEDGE)

$$P_{\text{media}}(\text{WEDGE}) = 0.91\%$$

Probabilità di morte per infarto miocardico (FIF)

$$P_{\text{media}}(\text{FIF}) = 0.53\%$$



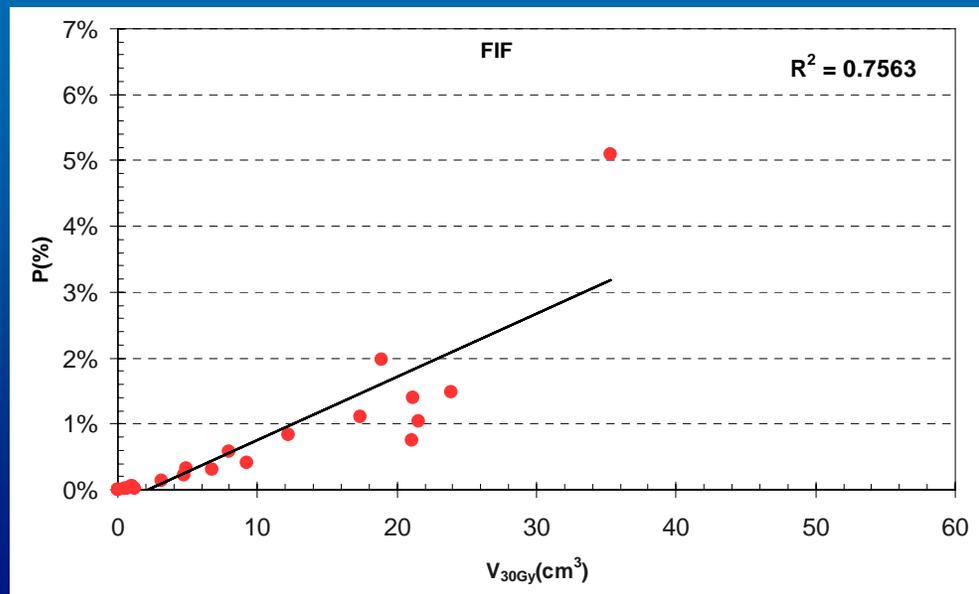
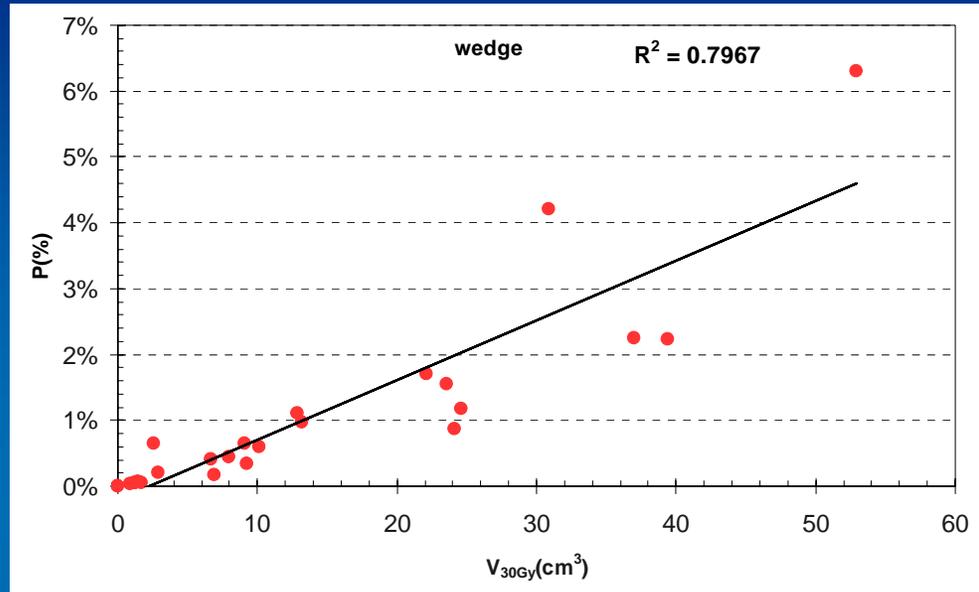
$$R=0.61$$

# Constraint dosimetrici e probabilità di morte per infarto miocardico

$P < 1\%$



$V_{30Gy} < 20\text{cm}^3$

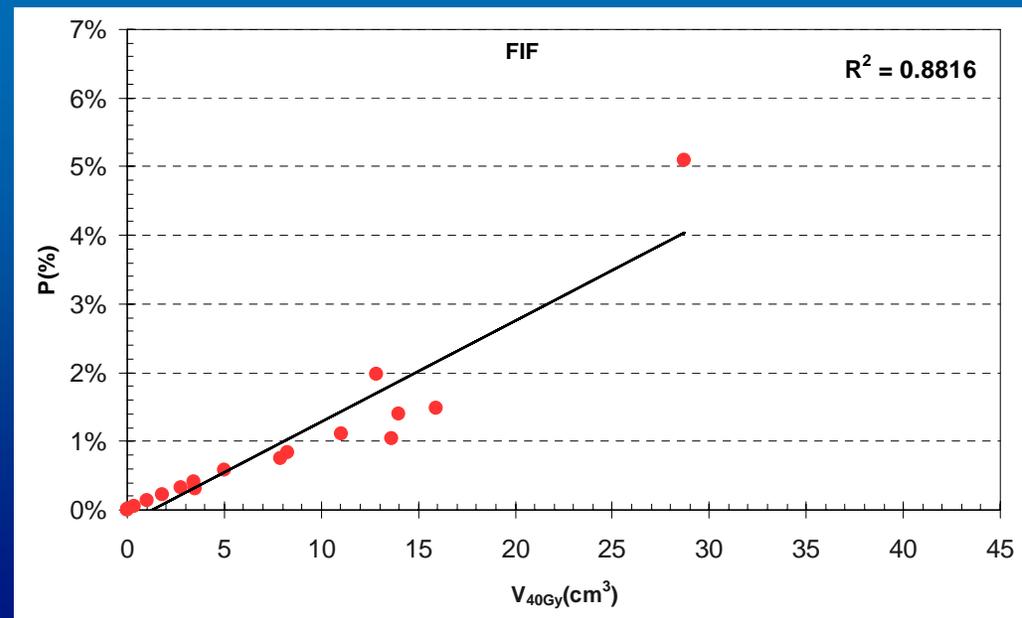
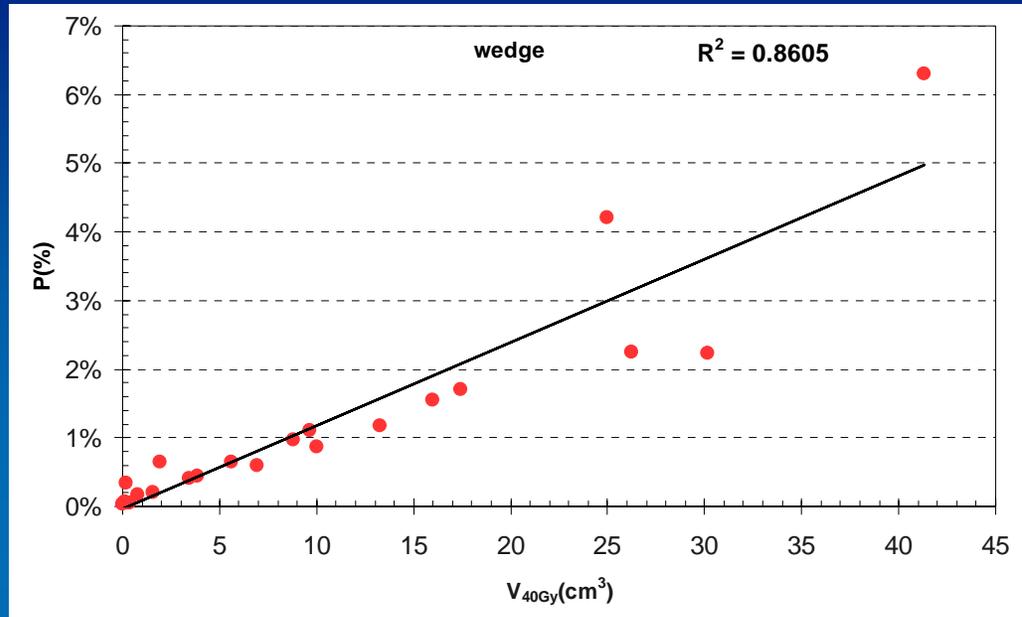


# Constraint dosimetrici e probabilità di morte per infarto miocardico

$P < 1\%$



$V_{40Gy} < 10\text{cm}^3$

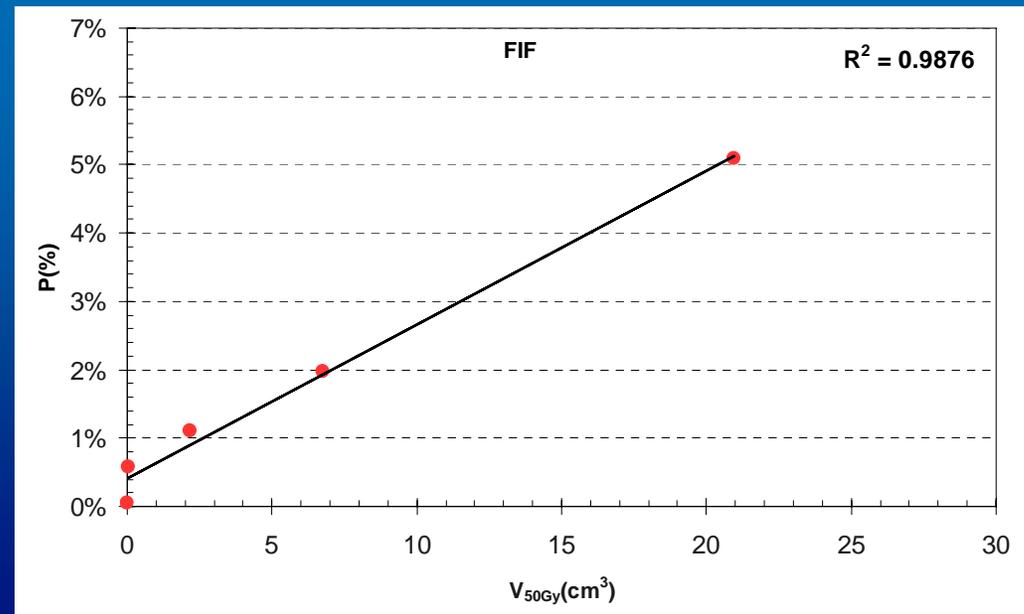
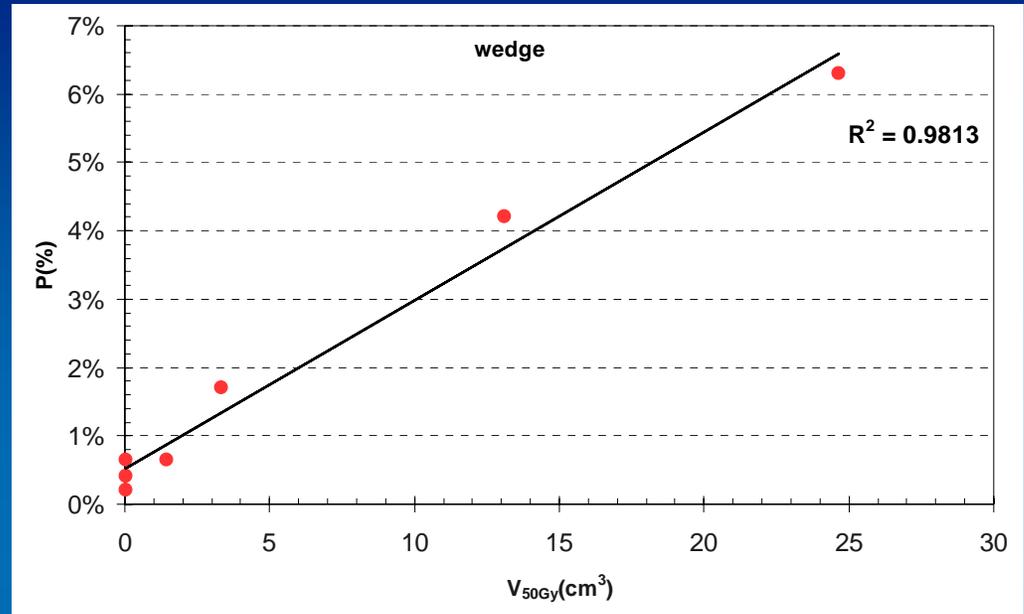


# Constraint dosimetrici e probabilità di morte per infarto miocardico

$P < 1\%$



$V_{50Gy} < 2\text{cm}^3$

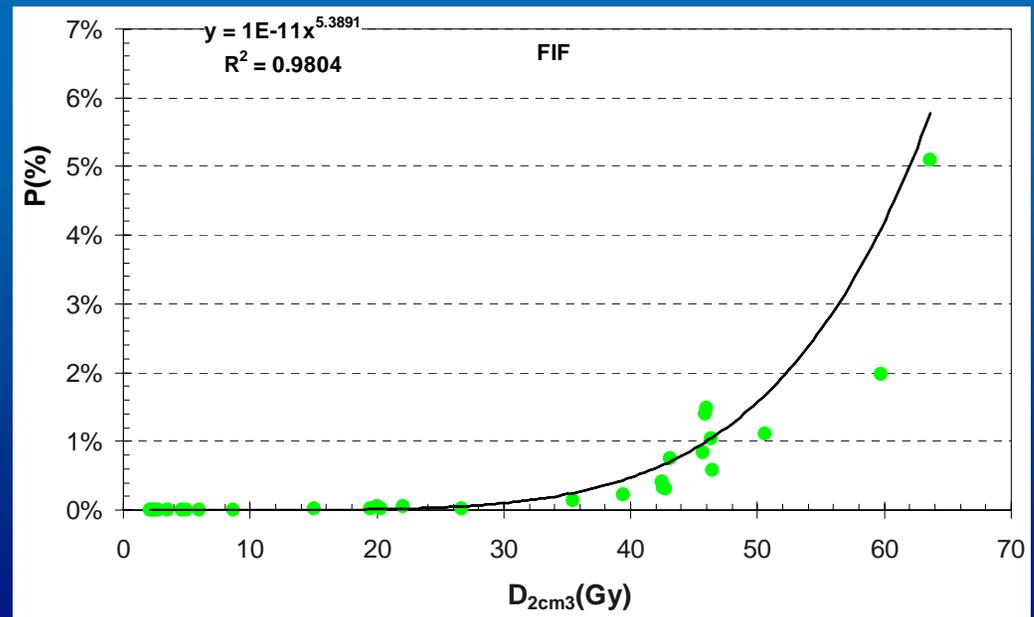
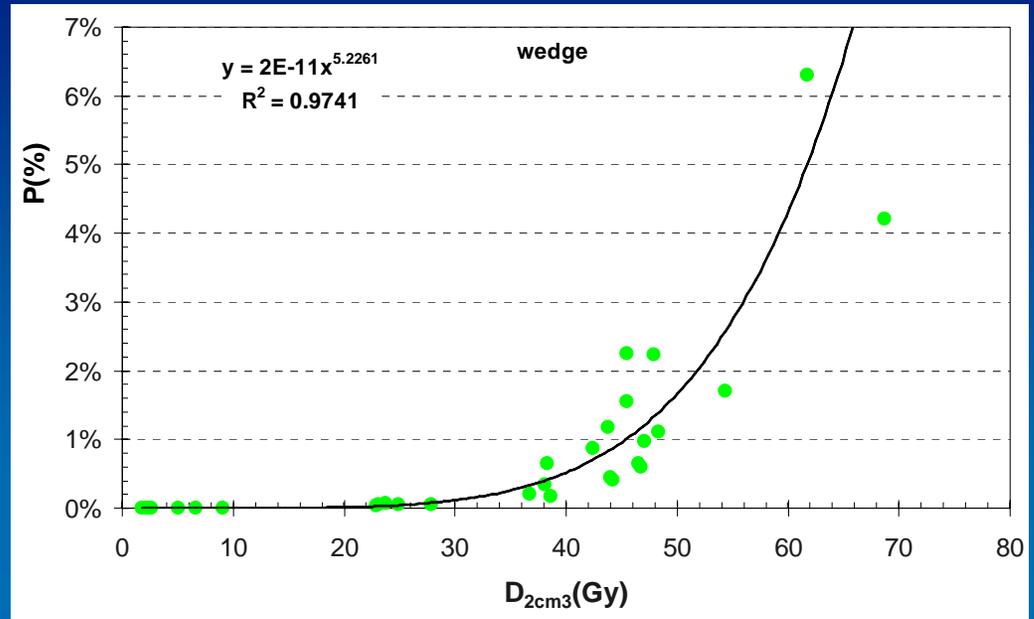


# Constraint dosimetrici e probabilità di morte per infarto miocardico

$P < 1\%$



$D_{2cm3} < 42 \text{ Gy}$



# Constraint dosimetrici e probabilità di morte per infarto miocardico

**P < 1%**



Dose constraints

$$V_{30Gy} < 20cm^3$$

$$V_{40Gy} < 10cm^3$$

$$V_{50Gy} < 2cm^3$$

Volume constraints

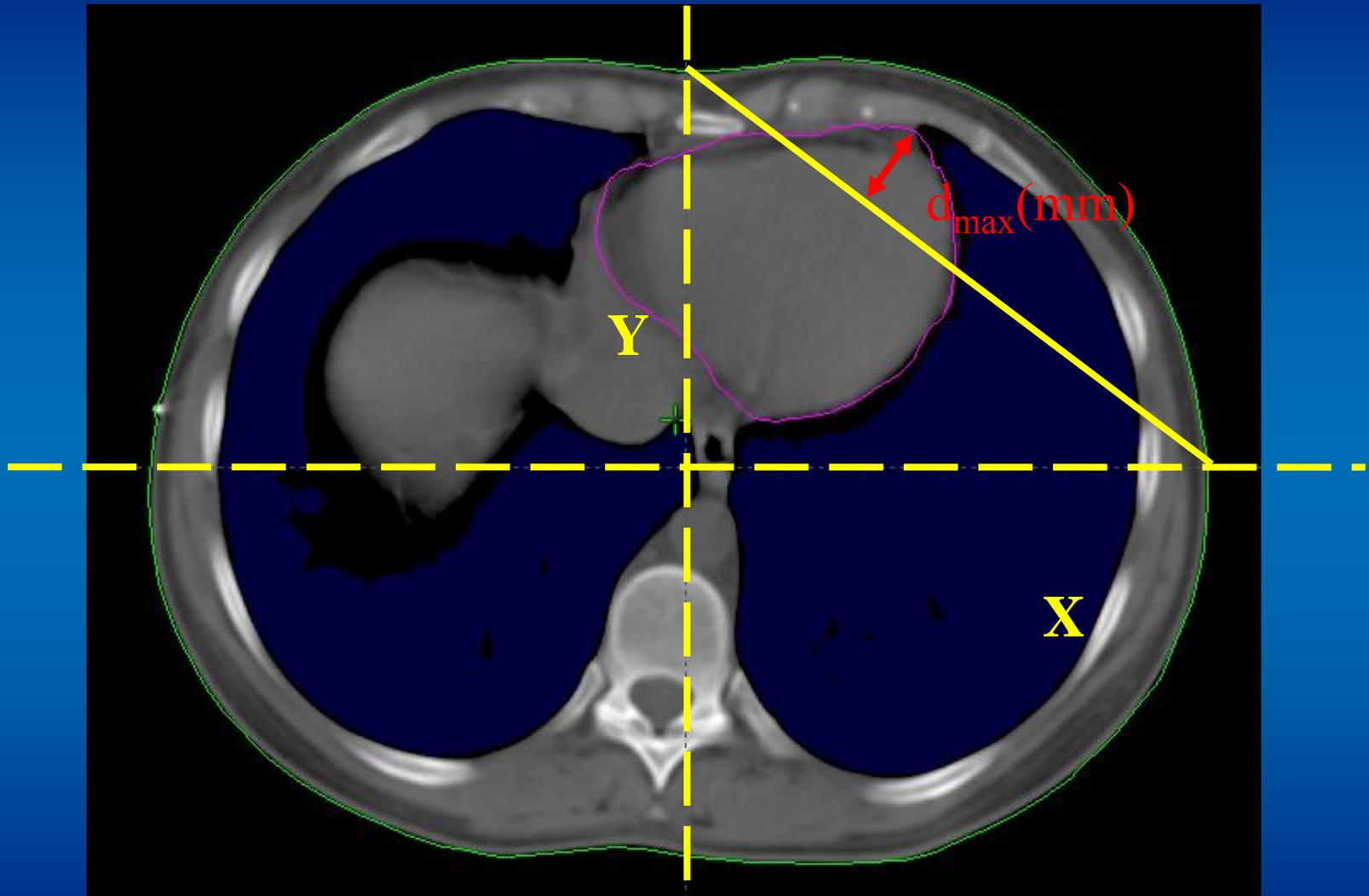
$$D_{2cm^3} < 42Gy$$

$$D_{1cm^3} < 44Gy$$

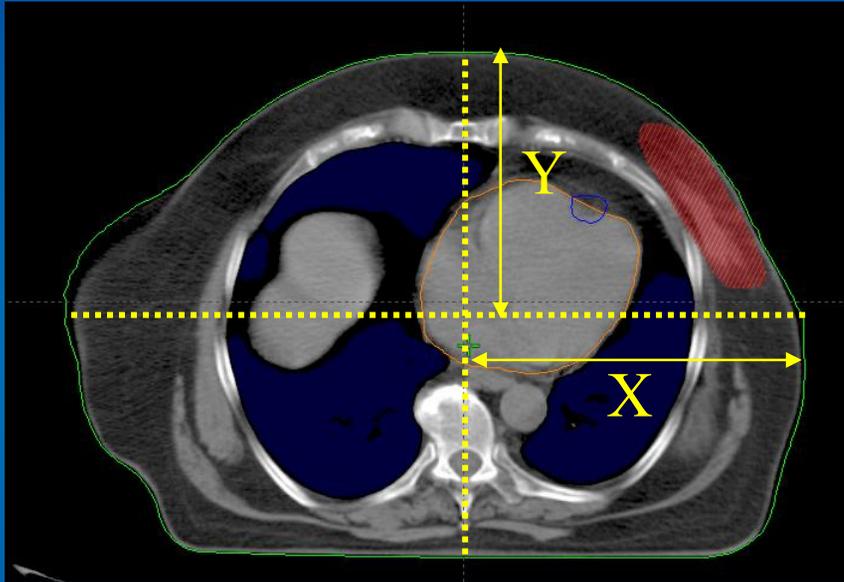
0 10 20 30 40 50 60 70

$D_{1cm^3}(Gy)$

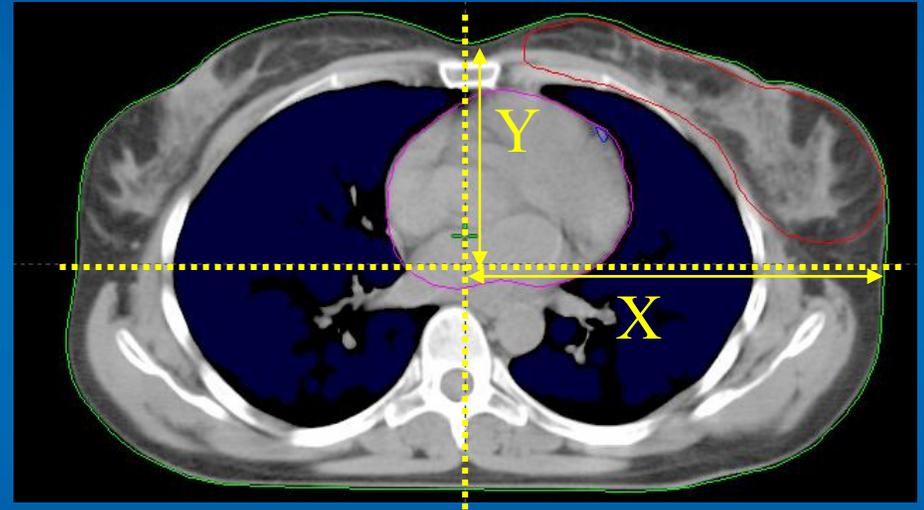
# Stima del danno da radiazioni al cuore e la $d_{max}$



# Toraci e toraci

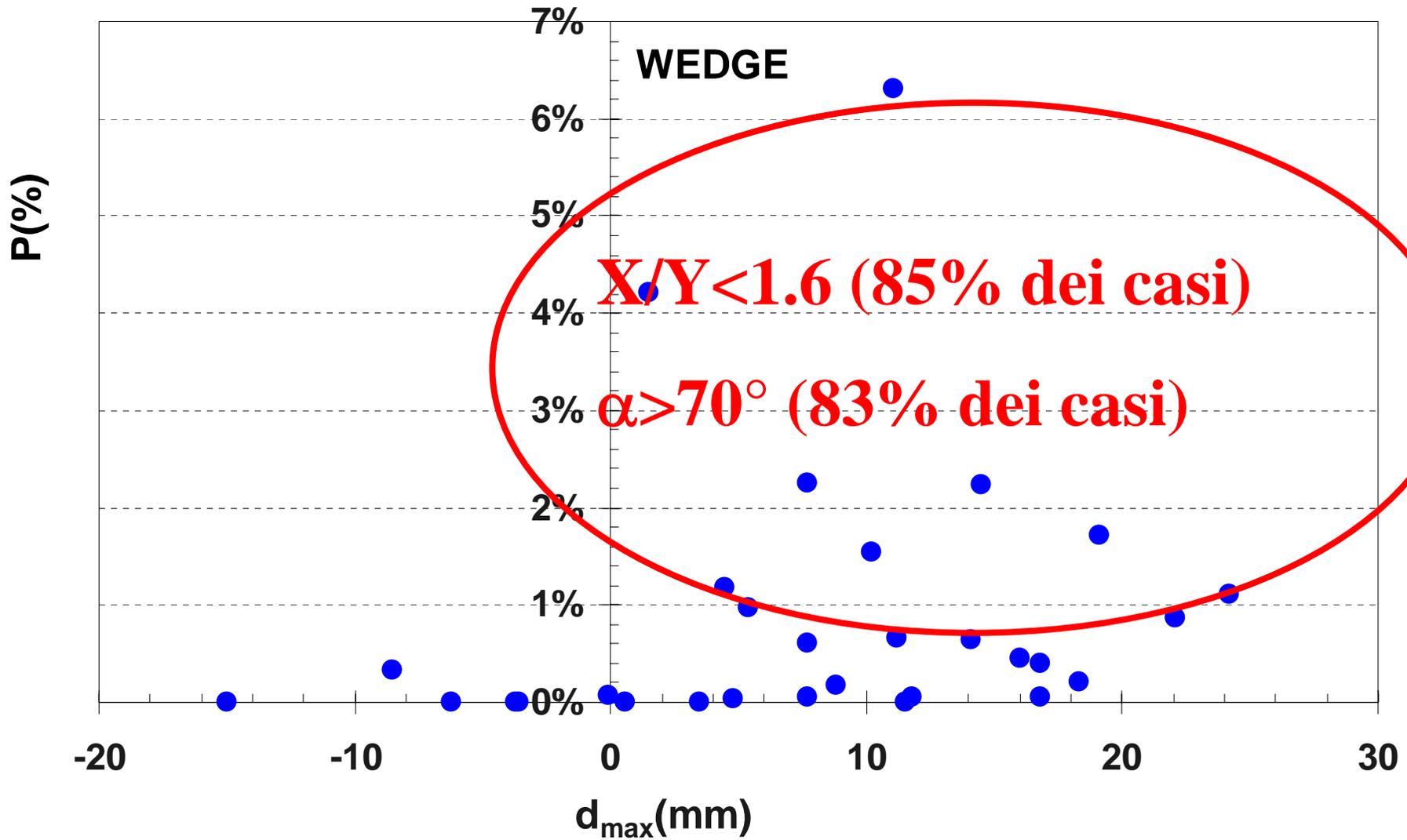


$$X/Y=1.44$$

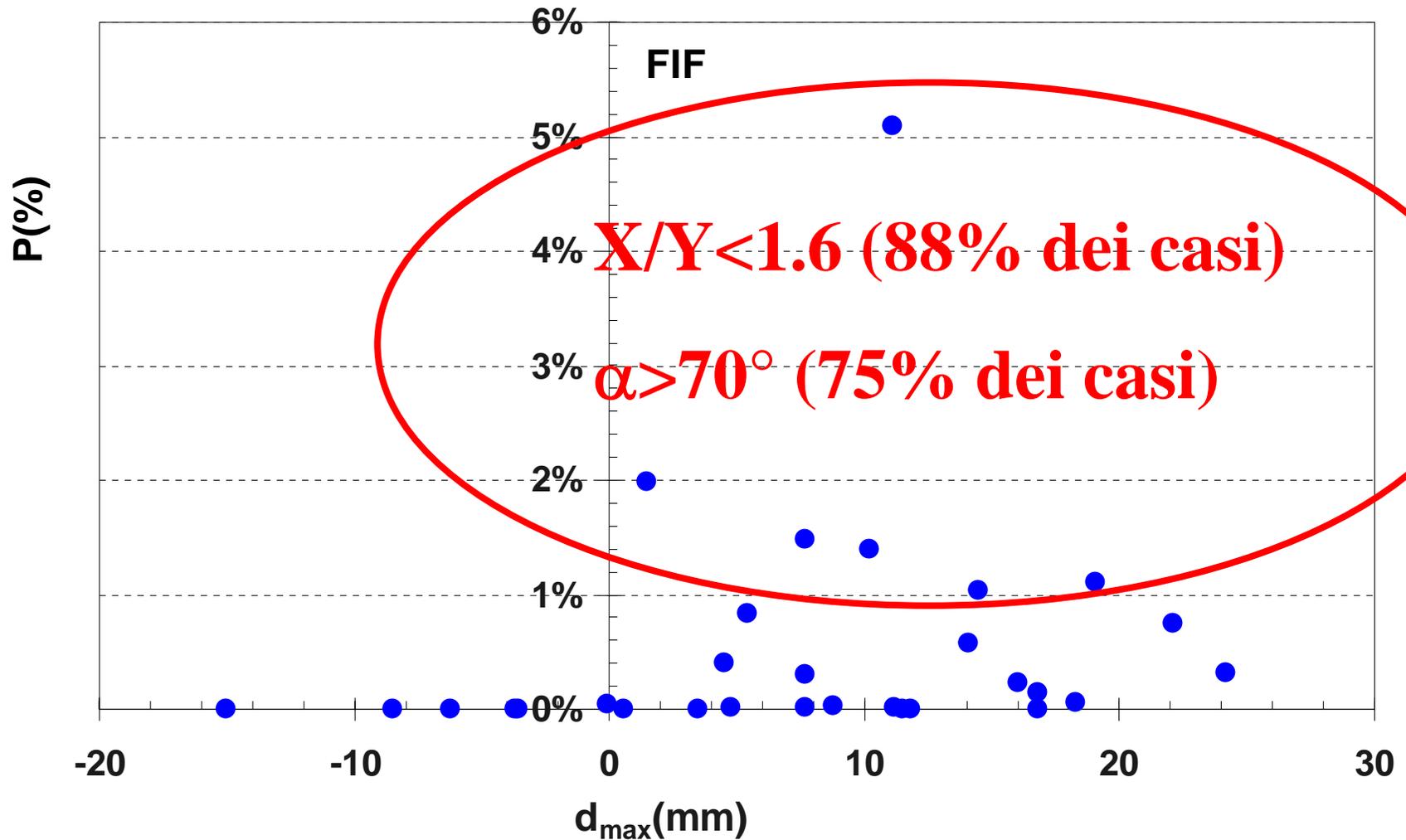


$$X/Y=1.93$$

# Probabilità vs $d_{\max}$



# Probabilità vs $d_{\max}$



## Osservazioni

(*Gagliardi G. et al*, **Radiation Dose-Volume Effects in the heart**, Int. J. Radiation Oncology Biol. Phys (2010), Vol 76, 3, S pp77-85)

La porzione di cuore irradiato è sotto il bordo dei collimatori; l'accuratezza dosimetrica varia a seconda del TPS utilizzato

La correzione per la disomogeneità per la bassa densità del polmone non è valutata correttamente dagli algoritmi di calcolo

La dose calcolata e realmente assorbita dipendono dal set-up

I parametri derivati dai vari modelli sono basati su un numero limitato di dati clinici e le frazioni che sono state utilizzate non coprono un ampio range, ma noi cerchiamo di applicarli anche se siamo nell'era dell'ipofrazionamento



Grazie per l'attenzione  
“Gruppo Regionale AIRO  
APPULO-LUCANO”

Taranto 19 giugno 2010:

NOVITÀ NEL PLANNING

*Radioterapia della mammella e dosi di  
radiazioni al cuore*

Luca Grimaldi – UO Fisica Sanitaria - Brindisi