# Optimising and standardising non-destructive imaging and spectroscopic methods to improve the determination of body composition and meat quality in farm animals

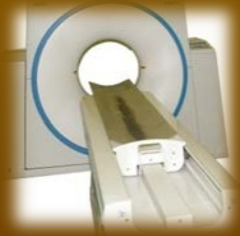
**FA 1102**

**Start date: 20/11/2011**

**End date: 20/11/2015**

**Farm Animal Imaging**

www.cost-faim.eu




**Lutz Bunger**

Chair

**Senior Researcher /Section Leader - SRUC UK**



COST is supported by the EU Framework Programme

European Science Foundation — ESF provides the COST Office through a European Commission contract

# Non-invasive measurement of body and carcass composition in livestock by Computer Tomography, Dual Energy X-Ray Absorptiometry, Magnetic Resonance Imaging, and Ultrasound Scanning

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# OUTLINE

-INTRODUCTION

-HISTORY

-NON-INVASIVE TECHNIQUES FOR BODY/CARCASS COMPOSITION MEASUREMENTS

- -CT + DXA
- -MRI
- -US

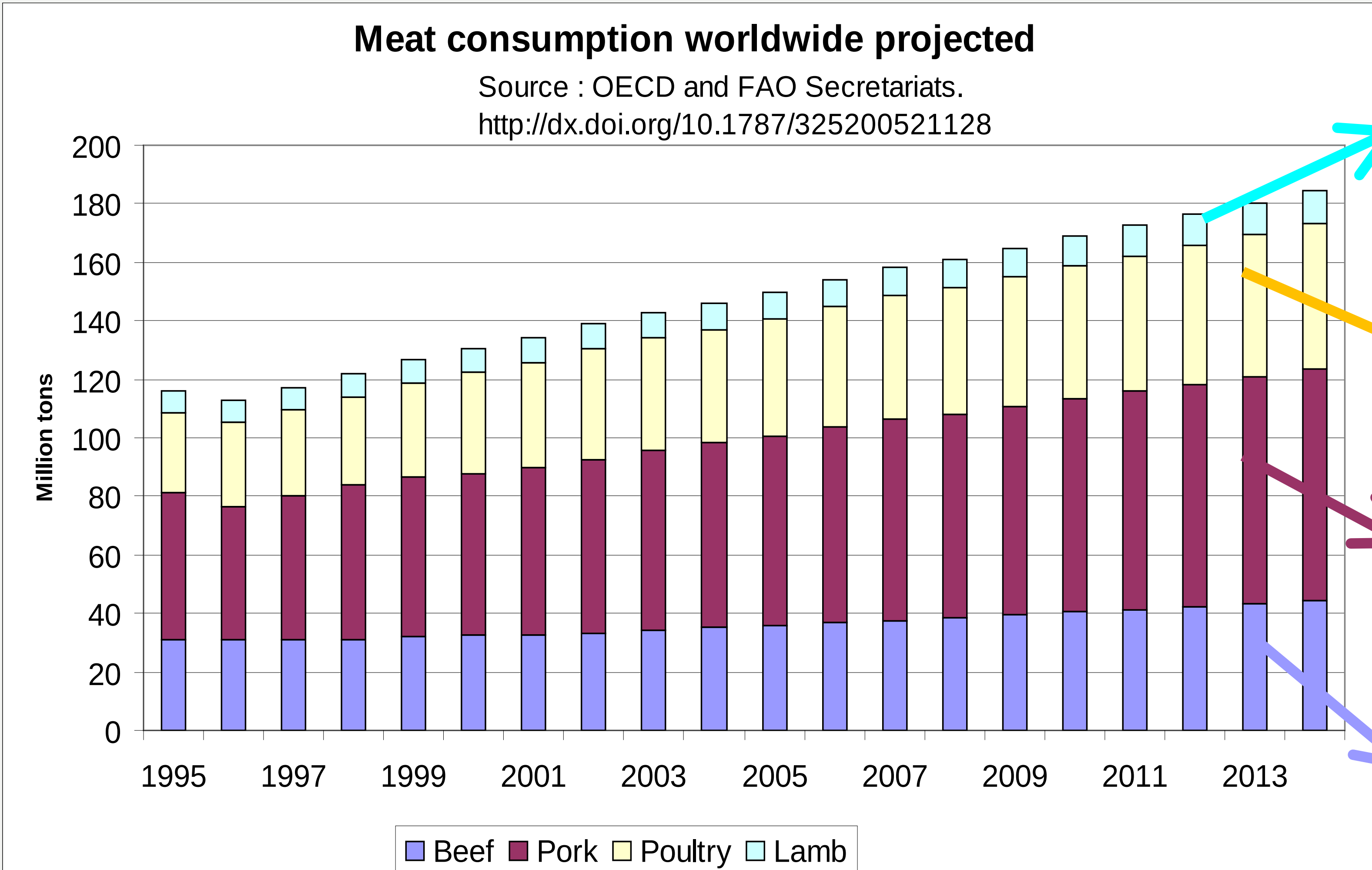
-COMPARISON of TECHNIQUES

-CONCLUSIONS

-FUTURE DEVELOPMENTS

# INTRODUCTION

## Europe: ~3 kg/head/a




~22 kg/head/a

~45 kg/head/a

~20 kg/head/a

# INTRODUCTION

Ability to accurately measure

-body composition or

-carcass composition

→ important applications for PHENOTYPING

- performance testing and selection in breeding programmes,
- (*standardization of*) grading and payment
- of course scientific studies

→growth/nutrition/genetics/housing/behaviour…

→not alone for meat producing animals

e.g beef cattle, sheep, swine or poultry, and also fish…

# INTRODUCTION

4 Genetics | Pig International

**FARM ANIMAL GENETICS**

is all about sustainable profitability


*Changes in global pig production are creating new sales opportunities for genetics.*

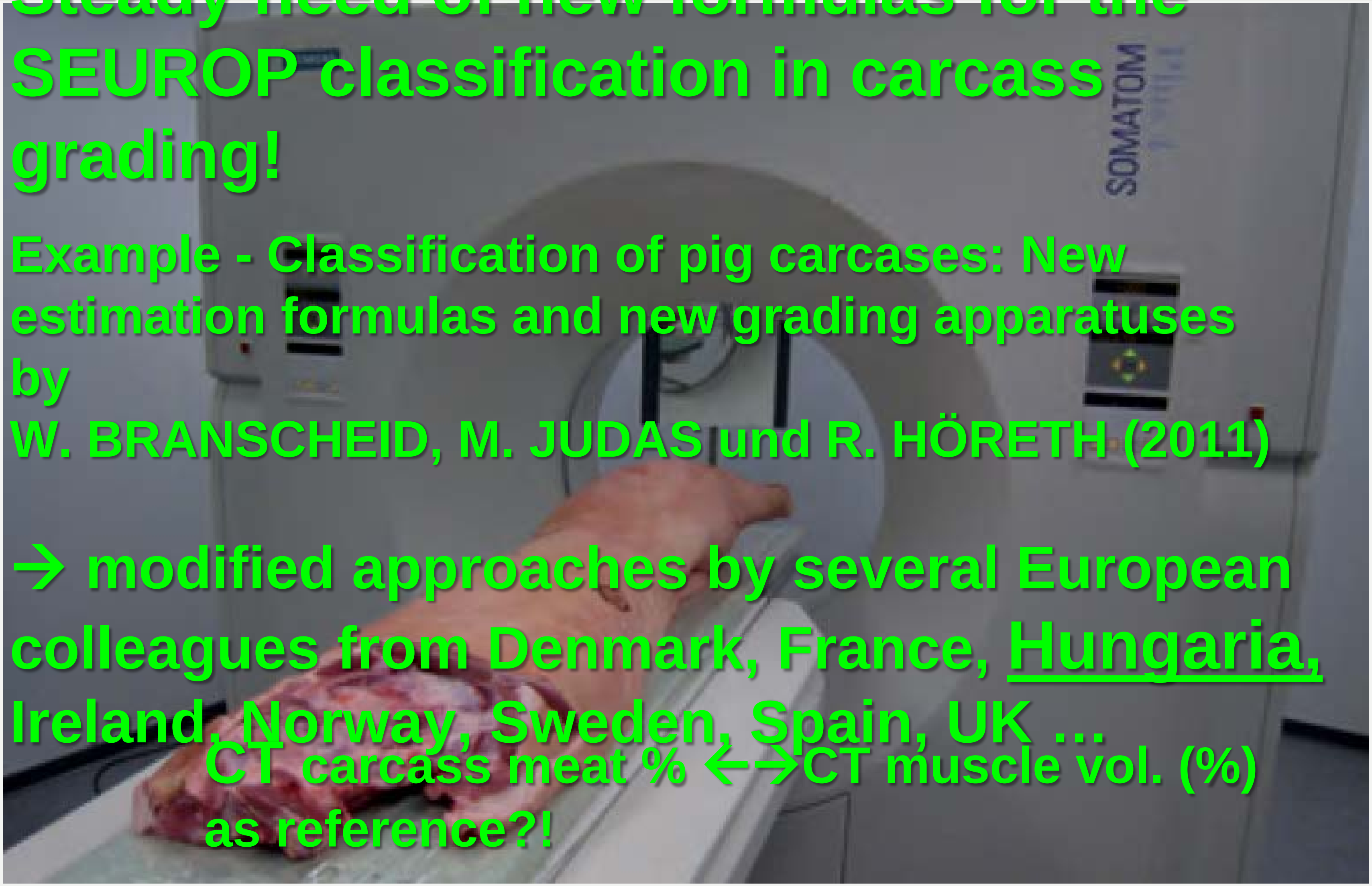
*CT scanning is part of routine genetic selection programs in modern times.*

By Colin Ley,
European farming and food journalist, leycj@aol.com

www.WATTAgNet.com | March/April 2013

CT scanning is part of routine genetic selection programs in modern times!

# INTRODUCTION




## Steady need of new formulas for the SEUROP classification in carcass grading!

**Example - Classification of pig carcases: New estimation formulas and new grading apparatuses by W. BRANSCHEID, M. JUDAS und R. HÖRETH (2011)**

**→ modified approaches by several European colleagues from Denmark, France, <u>Hungaria,</u> Ireland, Norway, Sweden, Spain, UK …**

**CT carcass meat % ←→CT muscle vol. (%) as reference?!**

# INTRODUCTION

Determination of the true lean meat yield (%)
by magnetic resonance imaging for performance testing

**Institute of Animal Breeding, Mariensee → now FLI**

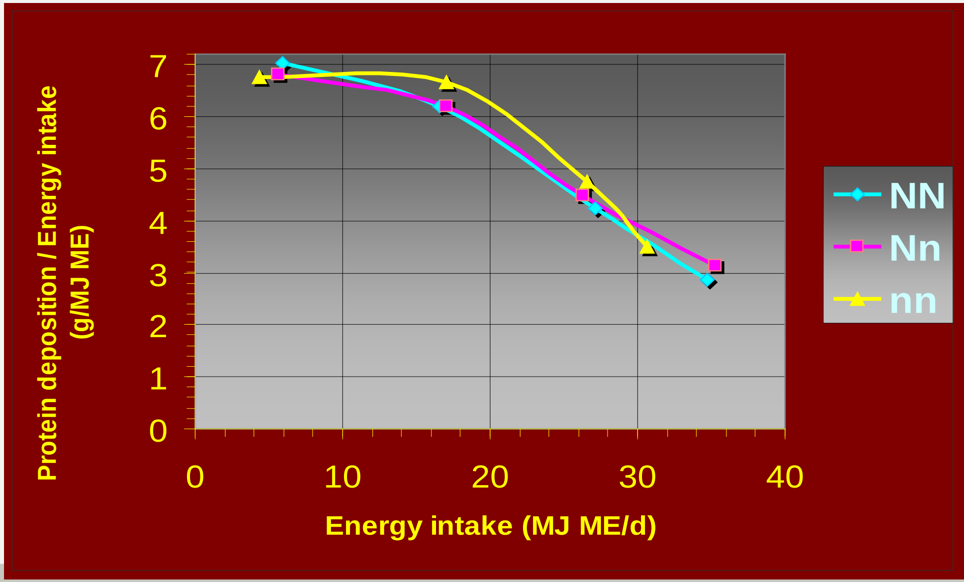
# HISTORY

## Mitchell 2007:

"Fundamental to progress in the study of animal growth and nutrition has been the **ability to measure body composition**.

The most **direct method** for measuring body composition is to completely **dissect** it into viscera, skin, bones, muscle, and fatty tissue."

→ Dissection, however, is no real option for individual growth studies.




→ It is still the standard!

# HISTORY?


The Royal Show, Stoneleigh Park
Subjective appraisal → alone the system changed in comparison with domestication
Large Black
01/07/2007
13:12:38

# History of Body Composition Analysis for Livestock Selection/Payment

QMR

2000

DNA-Analysis (*RyR1, RN, LEP* ...)

**CT, MRI (NMRS), DXA,** TOBEC, BIA ← Skjervold et al., 1981 - CT; Groeneveld, 1983 - MRI

SPA, DPA, VIA

Near Infrared Spectroscopy

Neutrone activation, **Ultrasound** ← Claus, 1957...

1950 „Ruler“, K-40 counting

Body density

smart ideas by Bloch, Purcell, Cormack, Hounsfield … (1910-1972)

$D_2O$ tracer, **X-Ray Radiography** ← Kronacher and Hogreve (1936 - 1938)

Calorimetry

Blood volume

1900 Fat free body mass

X-Strahlen: Wilhelm Conrad Röntgen (1895)

Piezo-electric effect: J. und P. Curie (1880)

„Chemical“ Analysis

Dissection ← **Lawes and Gilbert (1859)** Rothamsted Experiments

Visual and tactile

Exterieur appraisal ← **Subjective evaluation by our ancestors**

Domestication

# Overview -- Imaging Methods

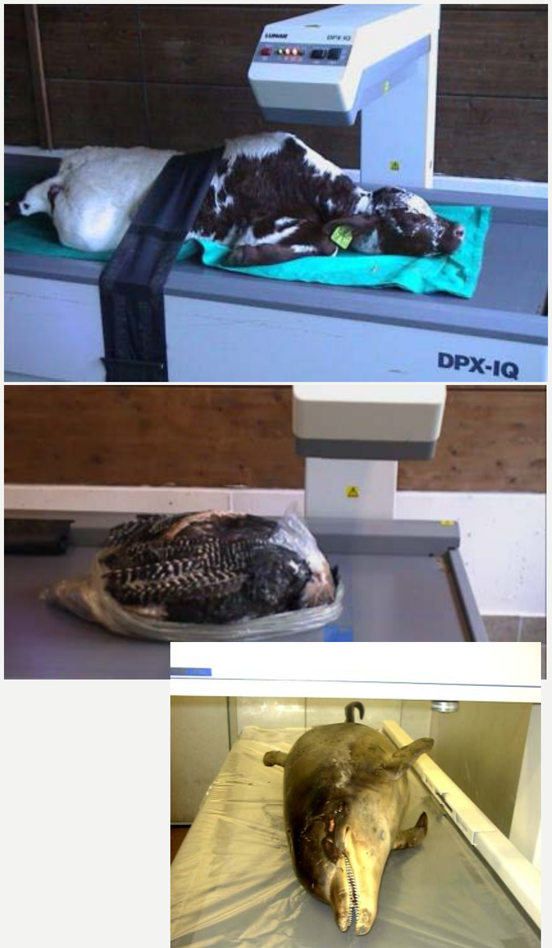
## (Electromagnetic) Frequencies (Hz)

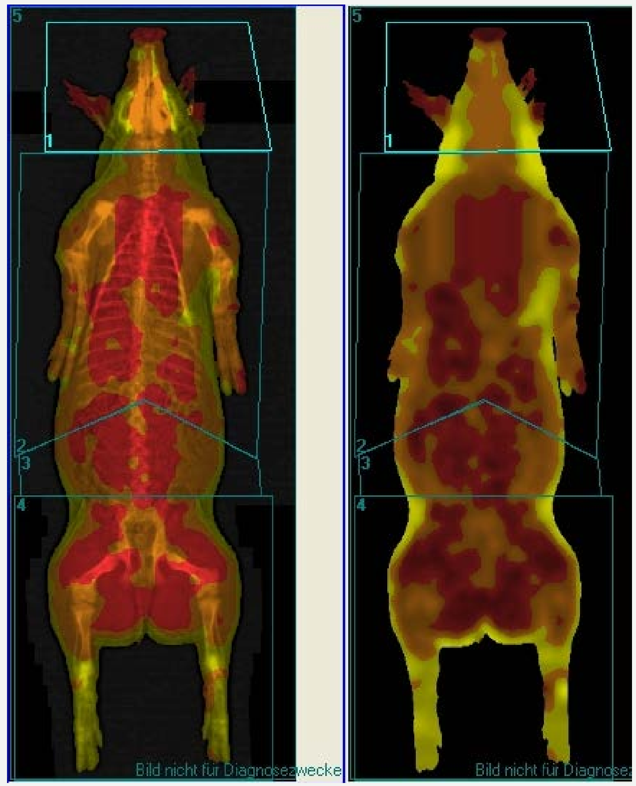
*Signal source*

| | | | | |
|---|---|---|---|---|
| | *(NAA)* *(PET)* | | Gamma rays | Radioactive Isotopes |
| | | $10^{18}$ | | |
| Ionisation | *(CT/ DXA)* | | X-rays | **„X-ray“ photons; attenuation** |
| | | $10^{16}$ | | |
| | | | Ultra Violet | |
| | | $10^{14}$ | Visible Light | Photon intensity, Light reflexion |
| No Ionisation | | | | |
| | | $10^{12}$ | Infrared Light | |
| | | | Microwave | |
| | | $10^{10}$ | | |
| | | | (Hyper sound) | |
| | | $10^{8}$ | Radio | **Net magnetisation, Proton density, Relaxation times** |
| | *(MRT/ MRS)* | | Frequency | |
| | | $10^{6}$ | waves | |
| | *(mechanical energy - US)* | $10^{4}$ | Ultra sound | **Speed of sound** |

# Dual Energy X-ray Absorptiometry

Pencil Beam

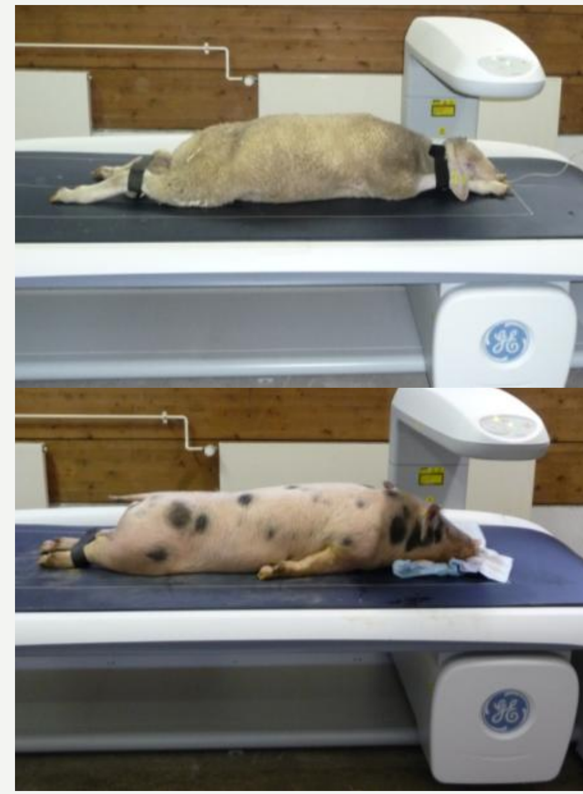



Bone mineral (density)

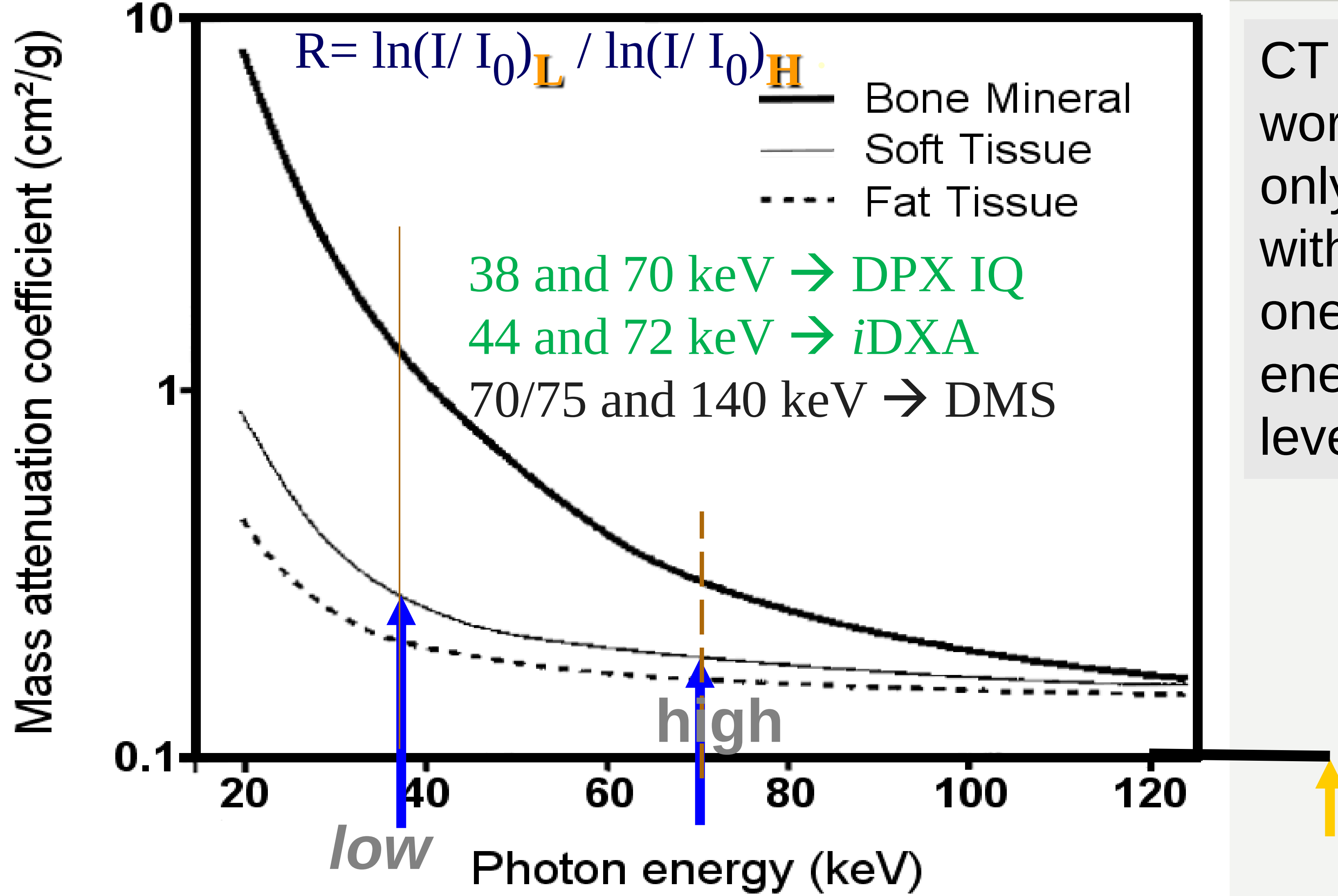
Soft tissue (fat/non-fat)

Fan Beam



+ CT (3D) = DECT

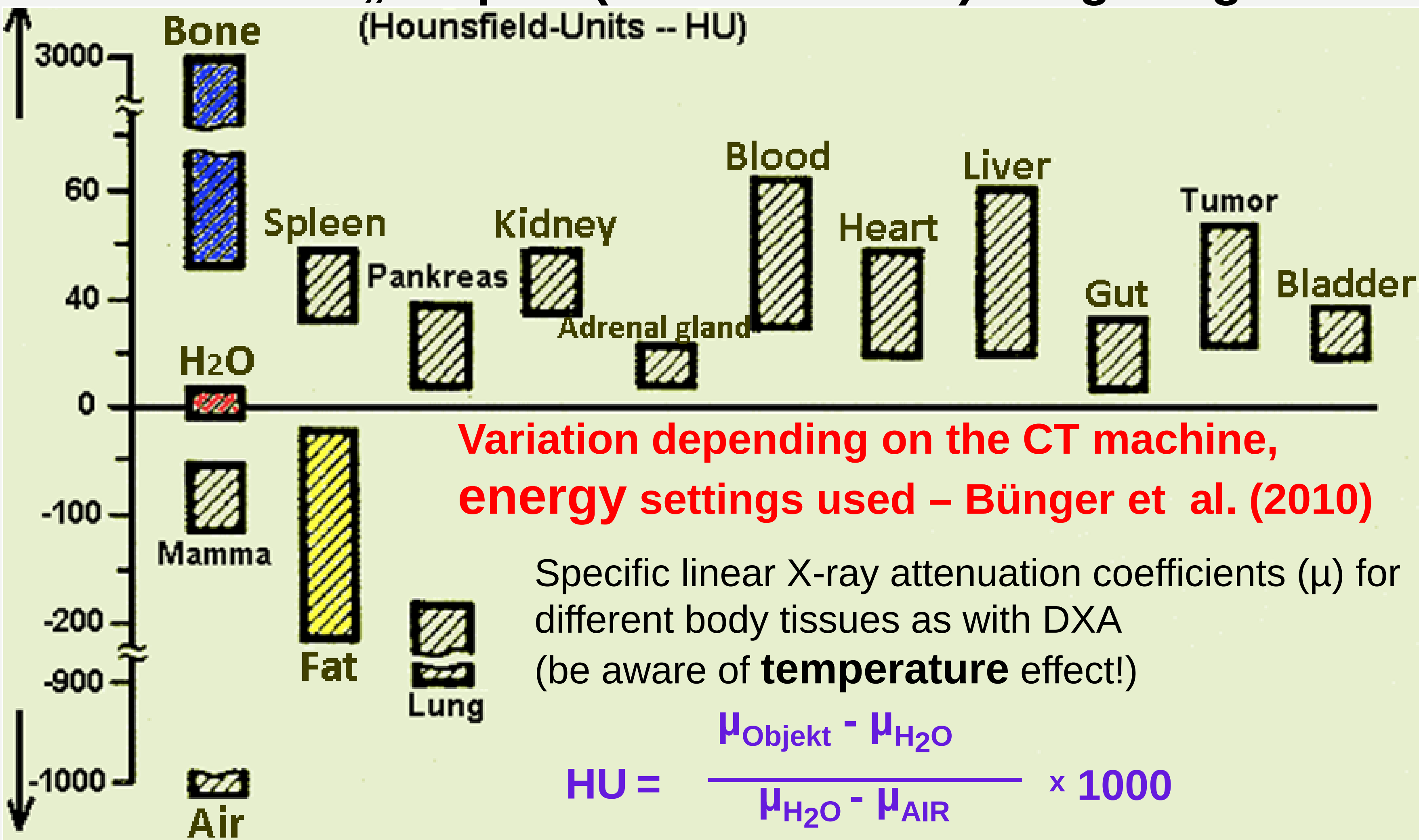
# DXA/CT - DECT principle




CT works only with one energy level !

# Computer Tomography

## → „simple" (almost unified) image segmentation




**Variation depending on the CT machine, energy settings used – Bünger et al. (2010)**

Specific linear X-ray attenuation coefficients (µ) for different body tissues as with DXA (be aware of **temperature** effect!)

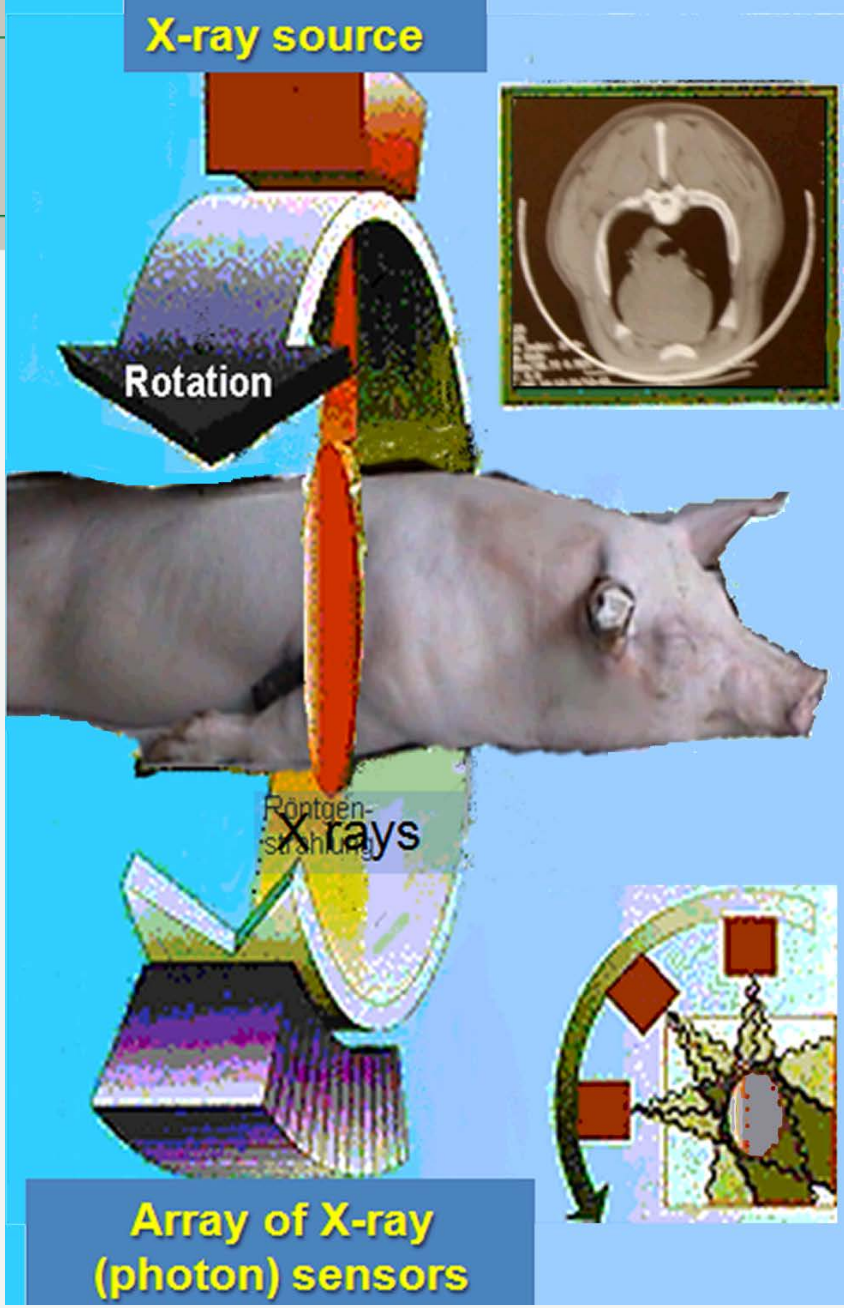
$$HU = \frac{\mu_{Objekt} - \mu_{H_2O}}{\mu_{H_2O} - \mu_{AIR}} \times 1000$$

# X-ray Computer Tomography (CT)

## Principle (now) rotating –Spiral CT

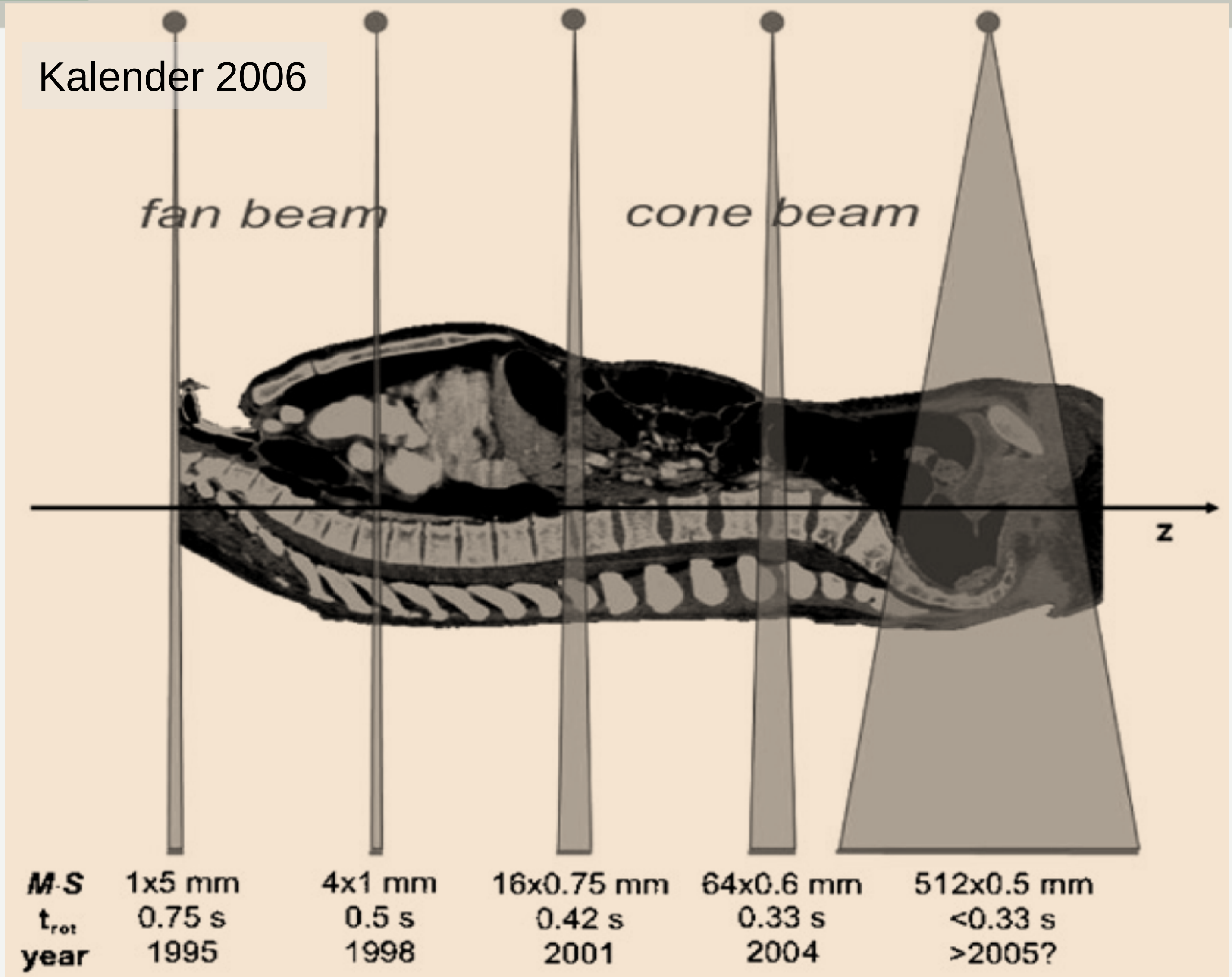
Duroc boar

(KONGSRO – NORSVIN 2012)




modified from Knoflach et al. (2000)

# Computer Tomography: slice and speed race




M=number of slices
S=slice thickness

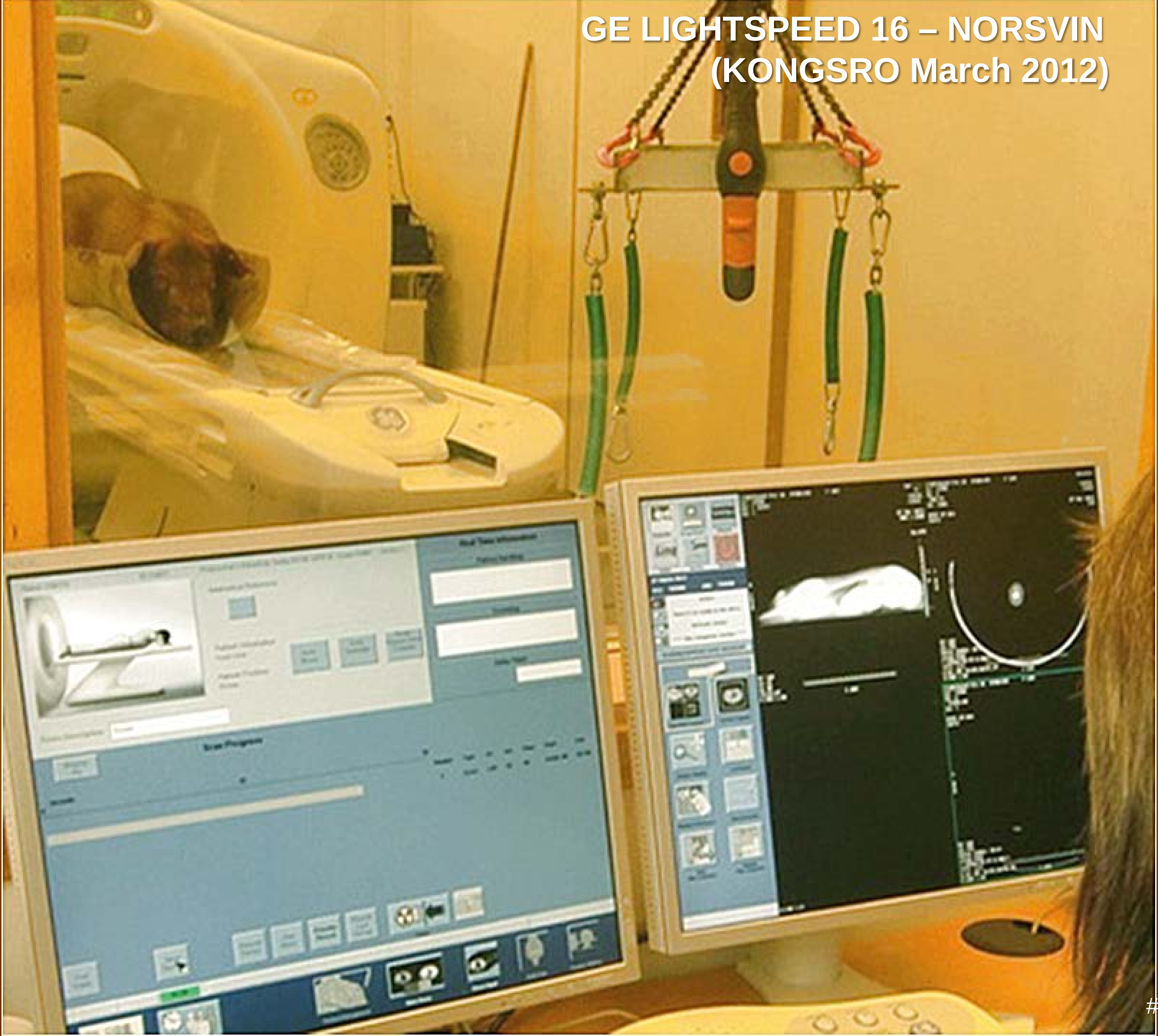
**Region covered: 6,7 mm/s 8 mm/s 28,6 mm/s 116,4 mm/s >850 mm/s**

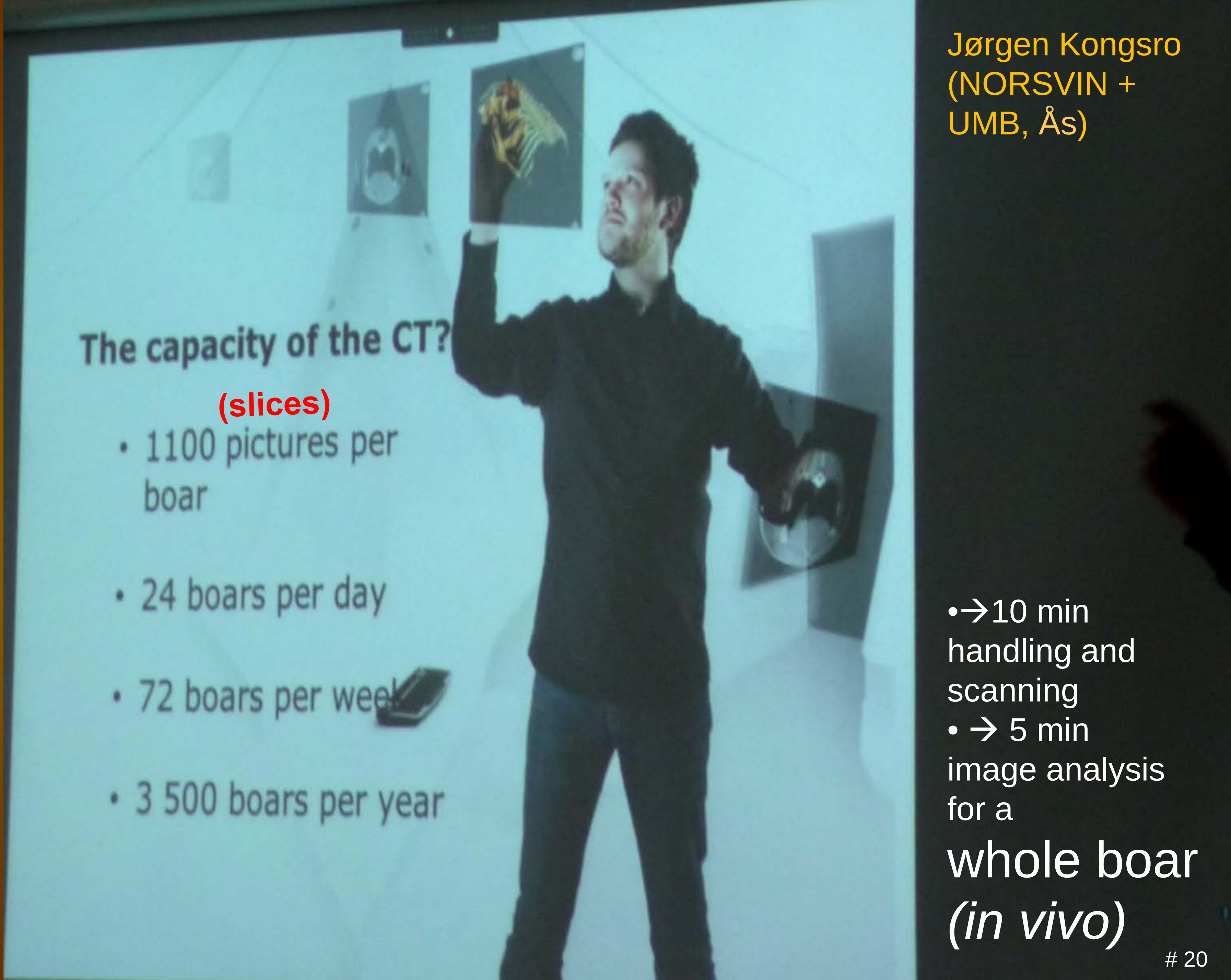
# Computer Tomography: size race

Meanwhile the bore size increased also up to 90 cm diameter.

→ Larger animals will fit in.

# GE LIGHTSPEED 16 – NORSVIN (KONGSRO March 2012)






(slices)

Jørgen Kongsro (NORSVIN + UMB, Ås)

•→10 min handling and scanning
• → 5 min image analysis for a

whole boar

*(in vivo)*

# CT Phenotyping

## Automatic Image Analysis with Matlab

- Body composition
  - Lean meat
  - Fat
  - Bone
  - Primal cuts
  - Carcass weight
  - Live weight
  - Yield (carcass / live)


GE LIGHTSPEED 16 – NORSVIN
(KONGSRO March 2012)

# SRUC → former SAC

COLUMBIA-SCHAF

NATURFARBENES SCHAF

KATAHDIN-HAARSCHAF

**SCHAU DER SCHAFE**
*Schon diese Auswahl an Schafen auf einer Landwirtschaftsmesse in den USA zeigt die Vielfalt der über Jahrtausende gezüchteten Rassen. Rechts: In Großbritannien bringen Bauern ihre Schafe zur Landwirtschaftshochschule in Edinburgh. Ein Computertomograf vermisst sie, auf dass nur die allerbesten für die Zucht ausgewählt werden.*

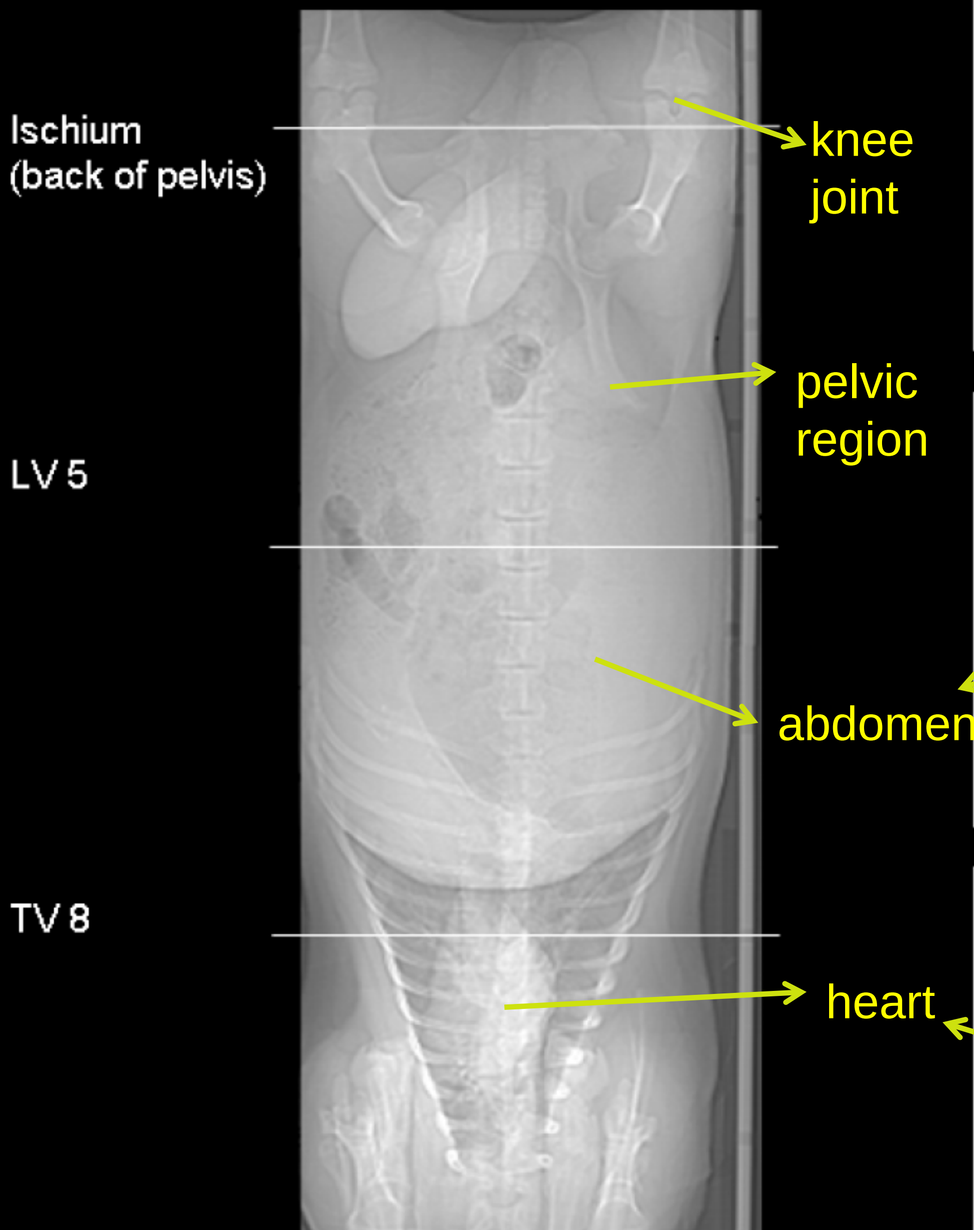
NORTH COUNTRY CHEVIOT

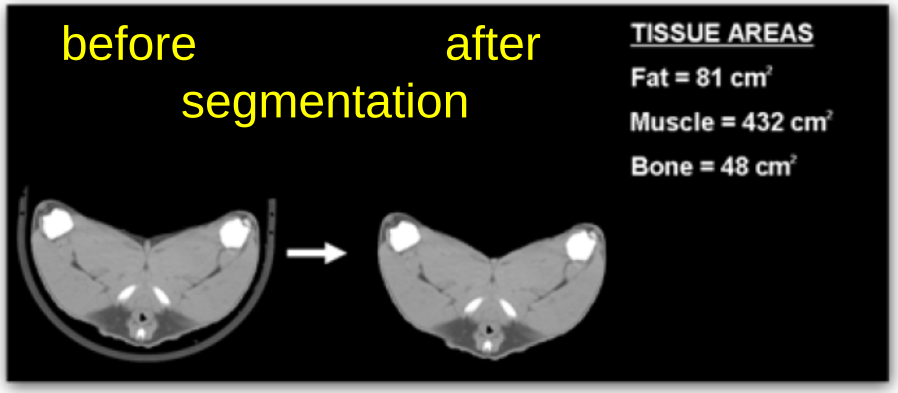
KATAHDIN-HAARSCHAF

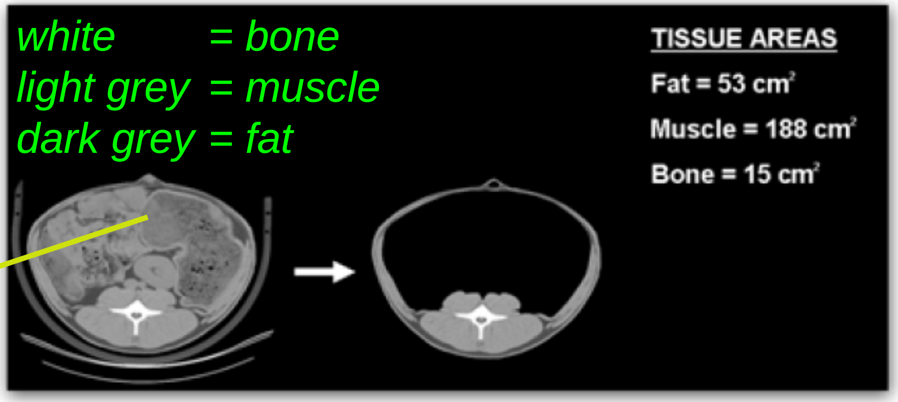
86

National Geographic, April 2011

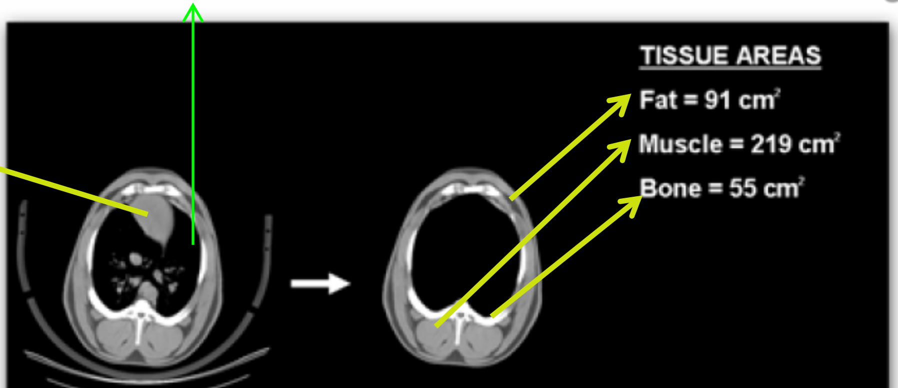
# SRUC – CT Scan images – BÜNGER ´13



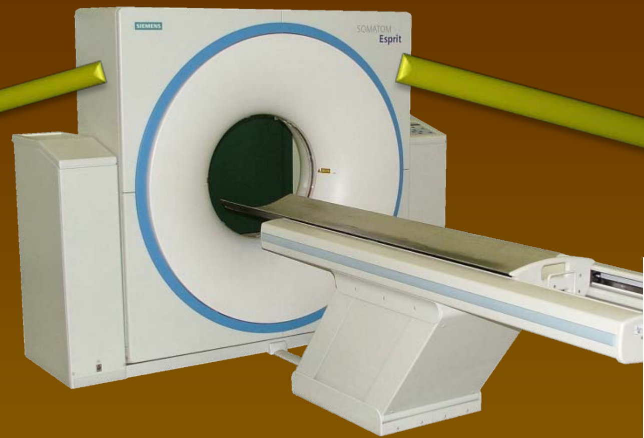




*black = air → in the middle of the animal = lung*

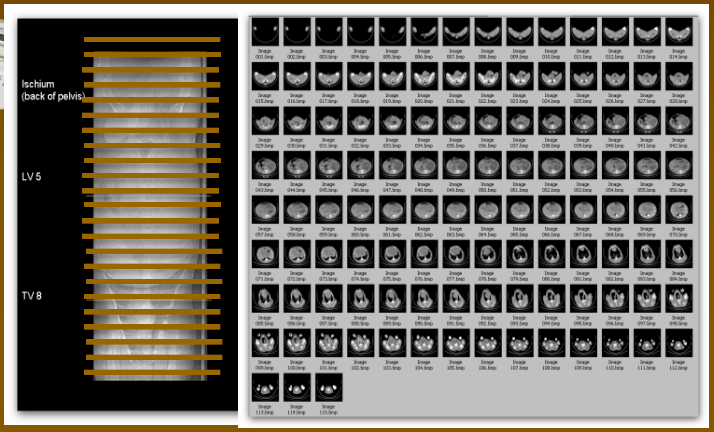


# "Old" and new **traits** for carcass value, meat quality, and other traits.



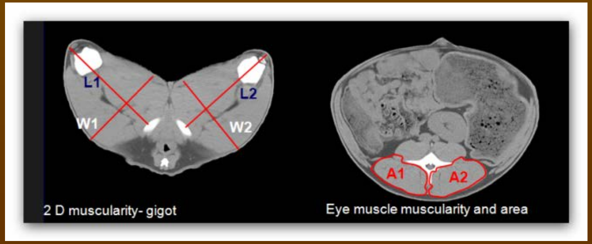

Reference scanning


Spiral scanning – whole body




- Pred. Carcass and tissue weights(M, F, B)
- Pred. Tissue proportions
- Pred. Killing out %
- 2D- Gigot muscularity,
- EM-area and 2D-EM- muscularity

- **Meas.** Carcass and tissue weights(M, F, B)
- **Meas.** Tissue proportions
- **Meas.** Killing out %
- **3D**- Gigot muscularity,
- EM-area and **3D**-EM- muscularity




BÜNGER 2013

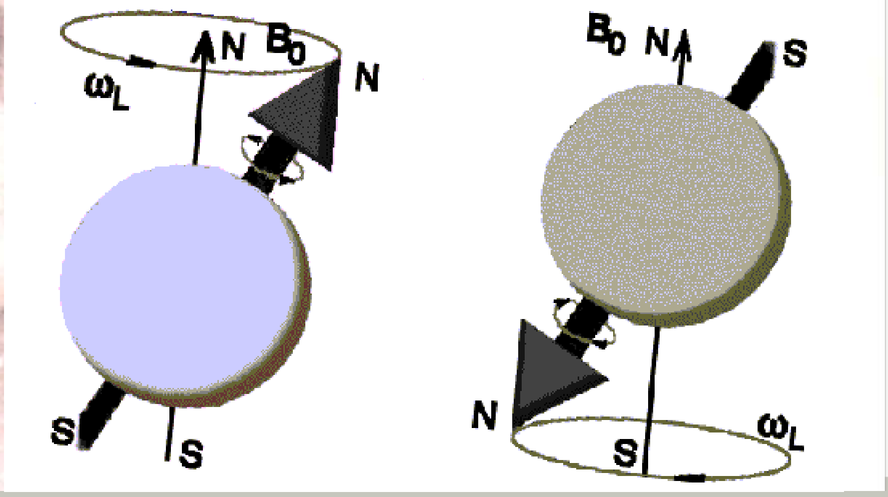
→ WAIT FOR THE FUTURE!

# $^{1}$H Magnetic Resonance Imaging

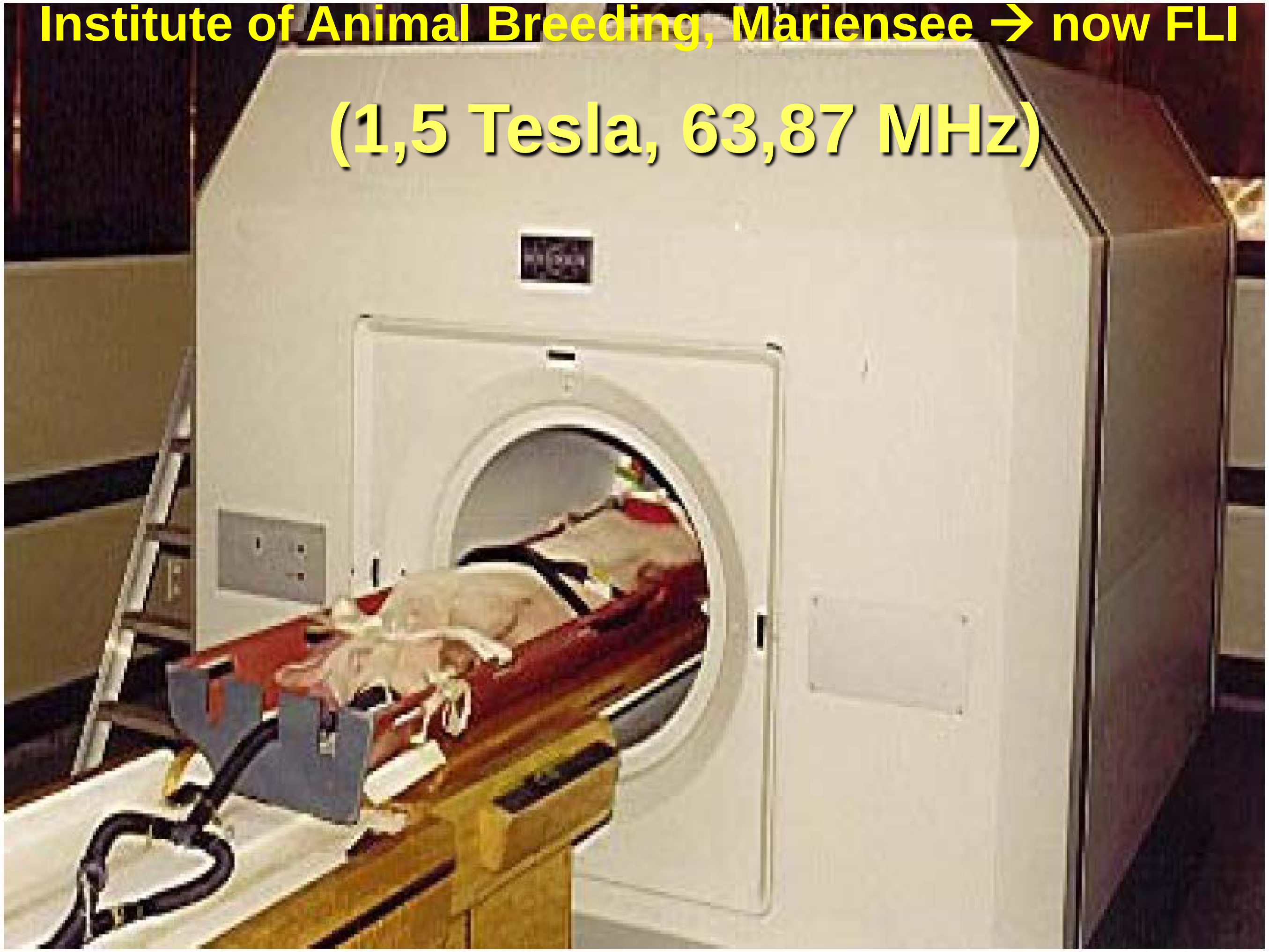
Spin system + high (radio) frequency waves
⇓
3D local gradients
⇓
signal by time (TE, TR)
⇓
Fourier transformation
⇓
Spectral / Fourier signal by Voxel (T1, T2, PD dependent)
⇓
Signal Intensity → Grey Value
⇓
Image (x,y, z)

**Principle: Net magnetization of nuclei with uneven Proton and Neutron number**

**→induced 3D coded voltage readings with tissue specific „relaxation times“**



# $^{1}$H Magnetic Resonance Imaging/Spectroscopy




Baulain, Groeneveld, Henning, Kallweit → since 1983/88

# 1.5 Tesla Tomograph (63.87 MHz)

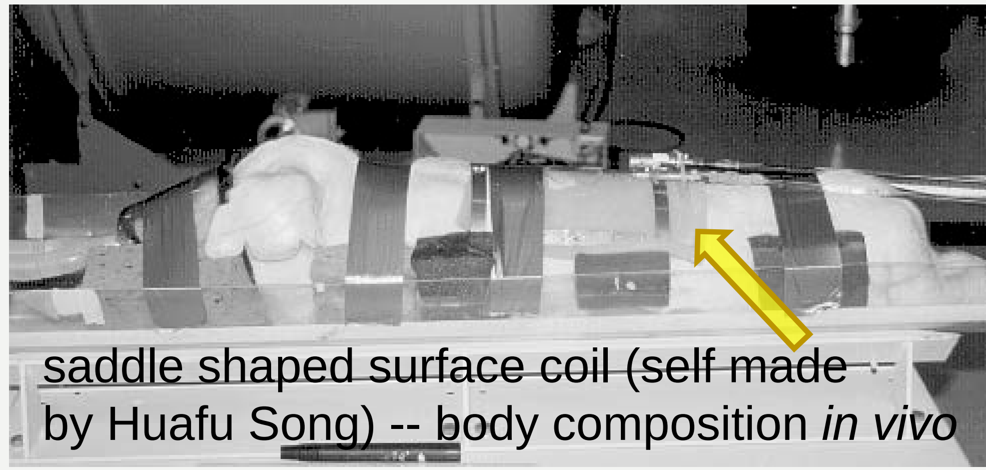
## for humans + animals up to 130 kg BW

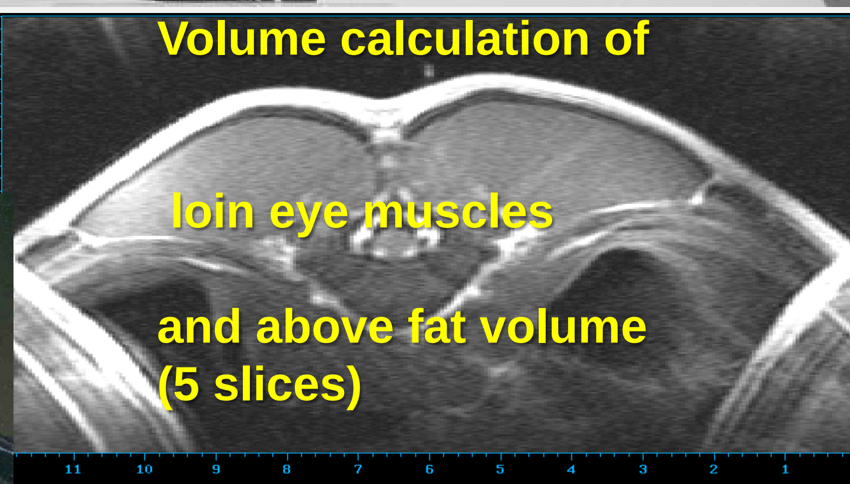

Howard University – Washington, DC (Department Chair: Paul Wang)

# $^{1}$H Magnetic Resonance Imaging/Spectroscopy

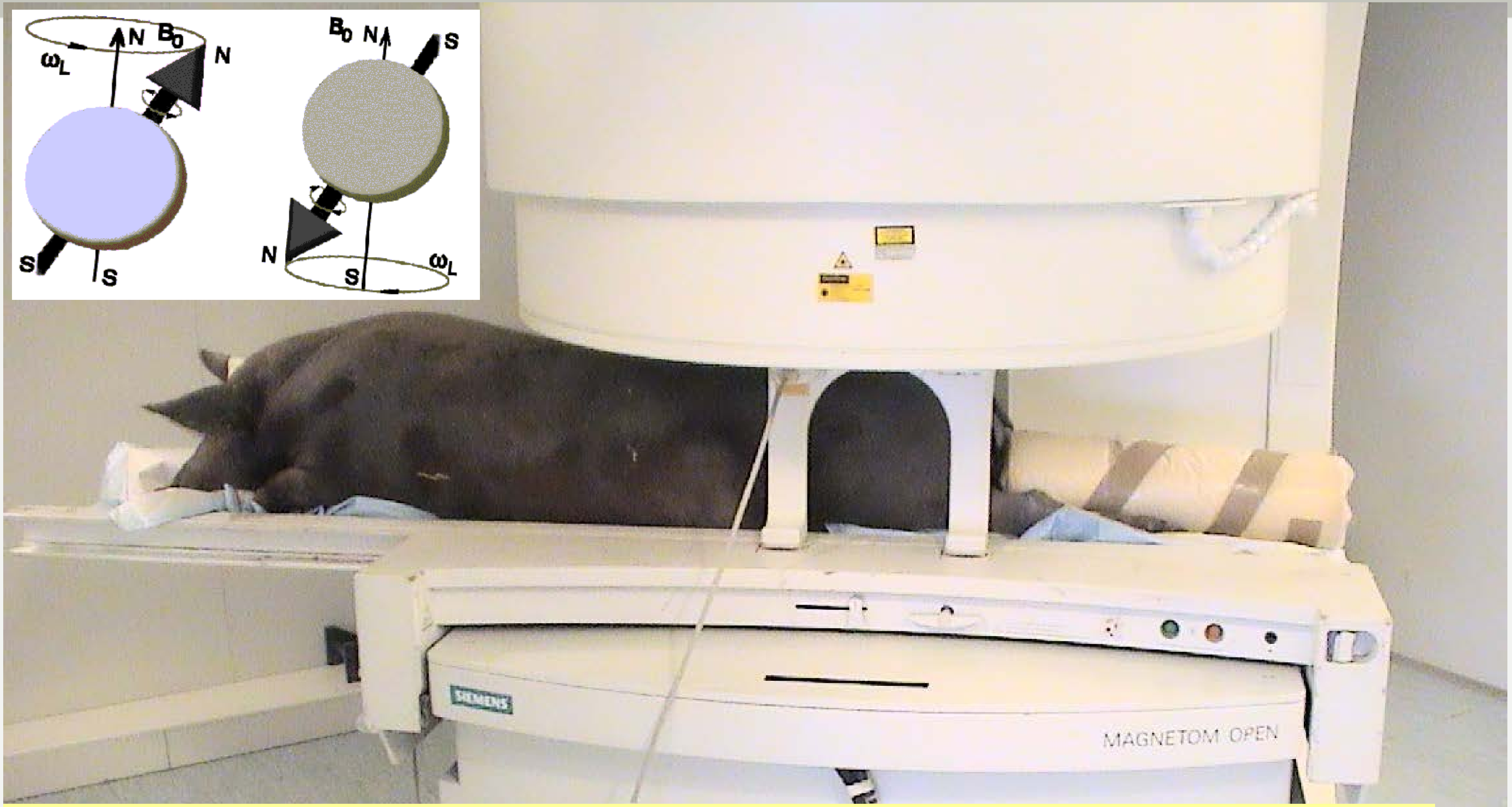
# $^{1}$H Magnetic Resonance Imaging/Spectroscopy

Howard University – Washington, DC (Department Chair: Paul Wang)


# $^{1}$H Magnetic Resonance Imaging




**~0.2 Tesla → Larmor frequency ~ 8.24 MHz for $^{1}$H**

*In vivo* Magnetic Resonance Imaging
since 2007 at the Livestock Center Oberschleissheim

# Characteristics of different nuclei

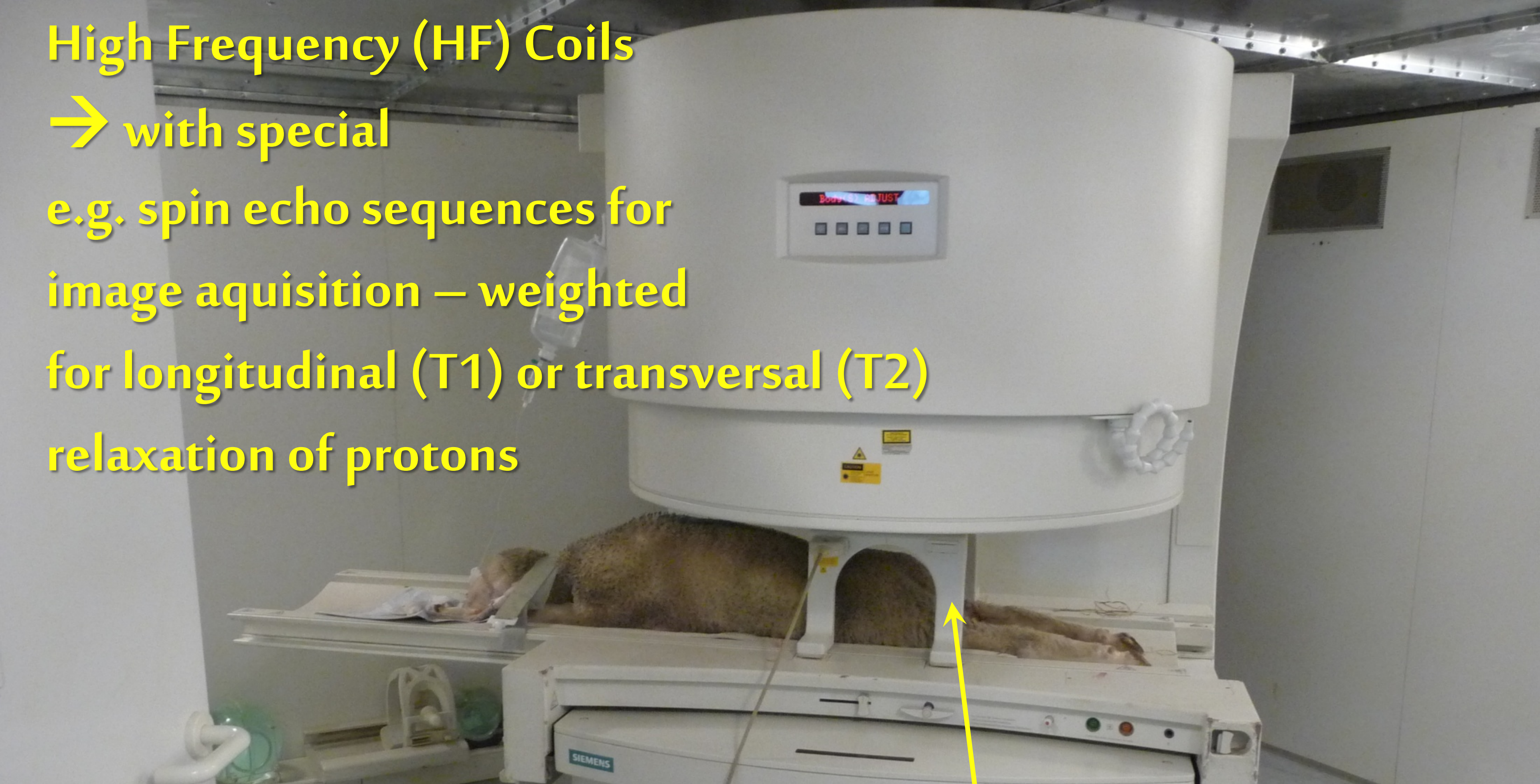
| Isotope | Spin | Resonance frequency at 4.7 T [MHz] | Natural frequency % | Relative sensitivity % |
|---|---|---|---|---|
| **$^{1}$H*** | **1/2** | **200.11** | **99.985** | **100** |
| $^{2}$H | 1 | 30.72 | 0.015 | 0.96 |
| $^{3}$H | 1/2 | 213.45 | - | 121.36 |
| $^{12}$C | 0 | - | 98.89 | 0 |
| **$^{13}$C** | **1/2** | **50.33** | **1.11** | **1.59** |
| **$^{31}$P** | **1/2** | **80** | **100** | **6.63** |

- $^{1}$H Resonance (Larmor) frequency (MHz)
  4.7 T: 200.11
  1.5 T: 63.87
  0.2 T: 8.24

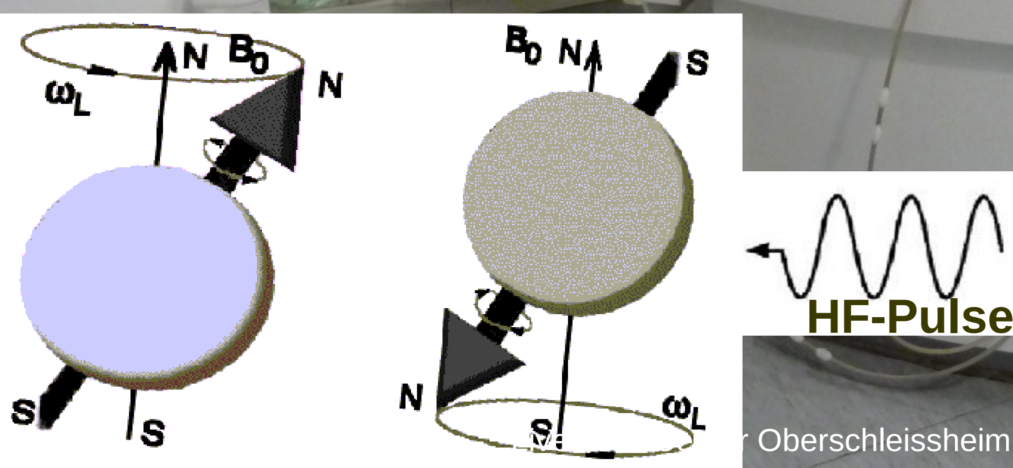
# High Frequency (HF) Coils

→ with special

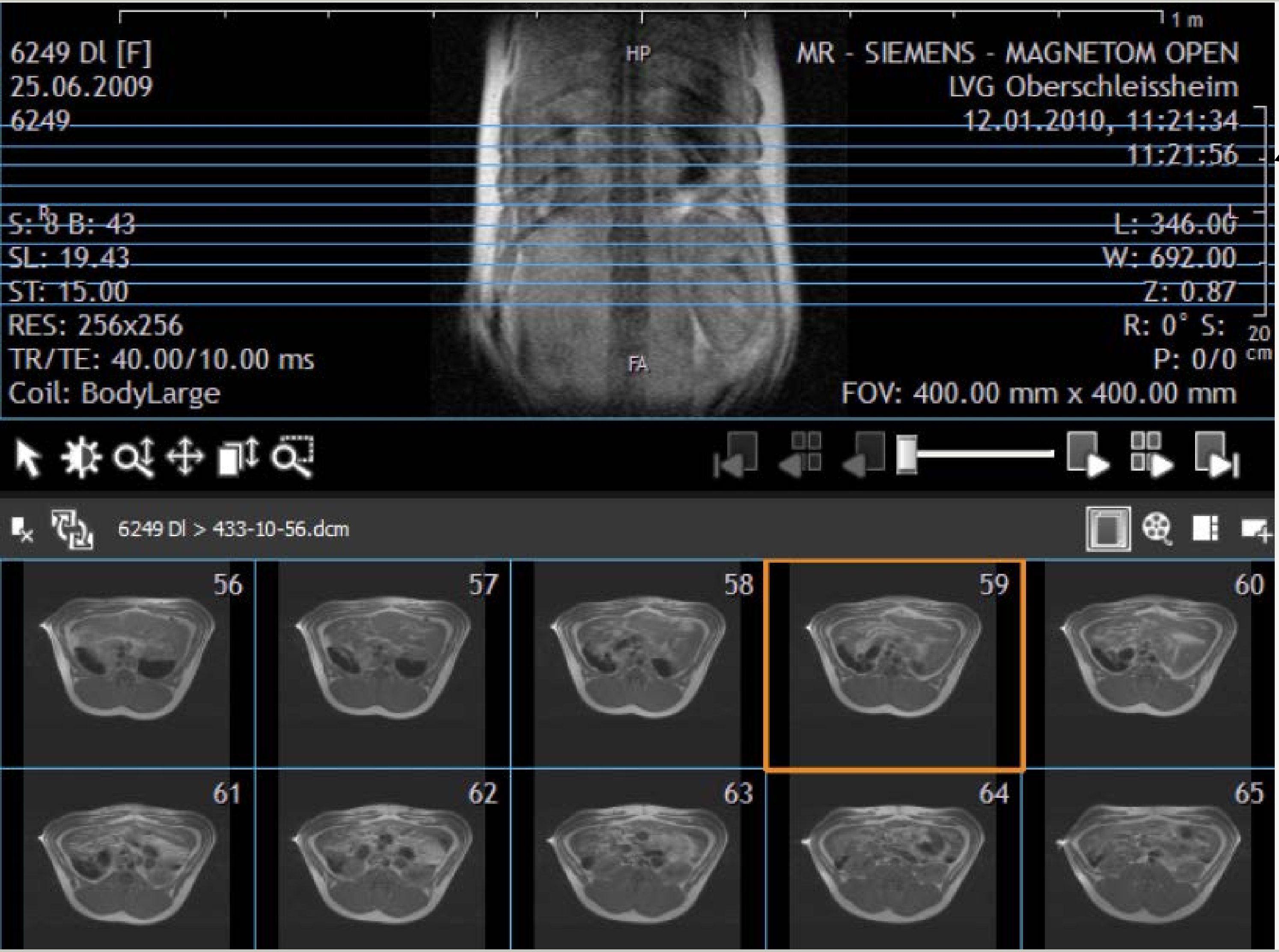
e.g. spin echo sequences for image aquisition – weighted for longitudinal (T1) or transversal (T2) relaxation of protons




„Body Coil“ (large or small) for open magnet systems



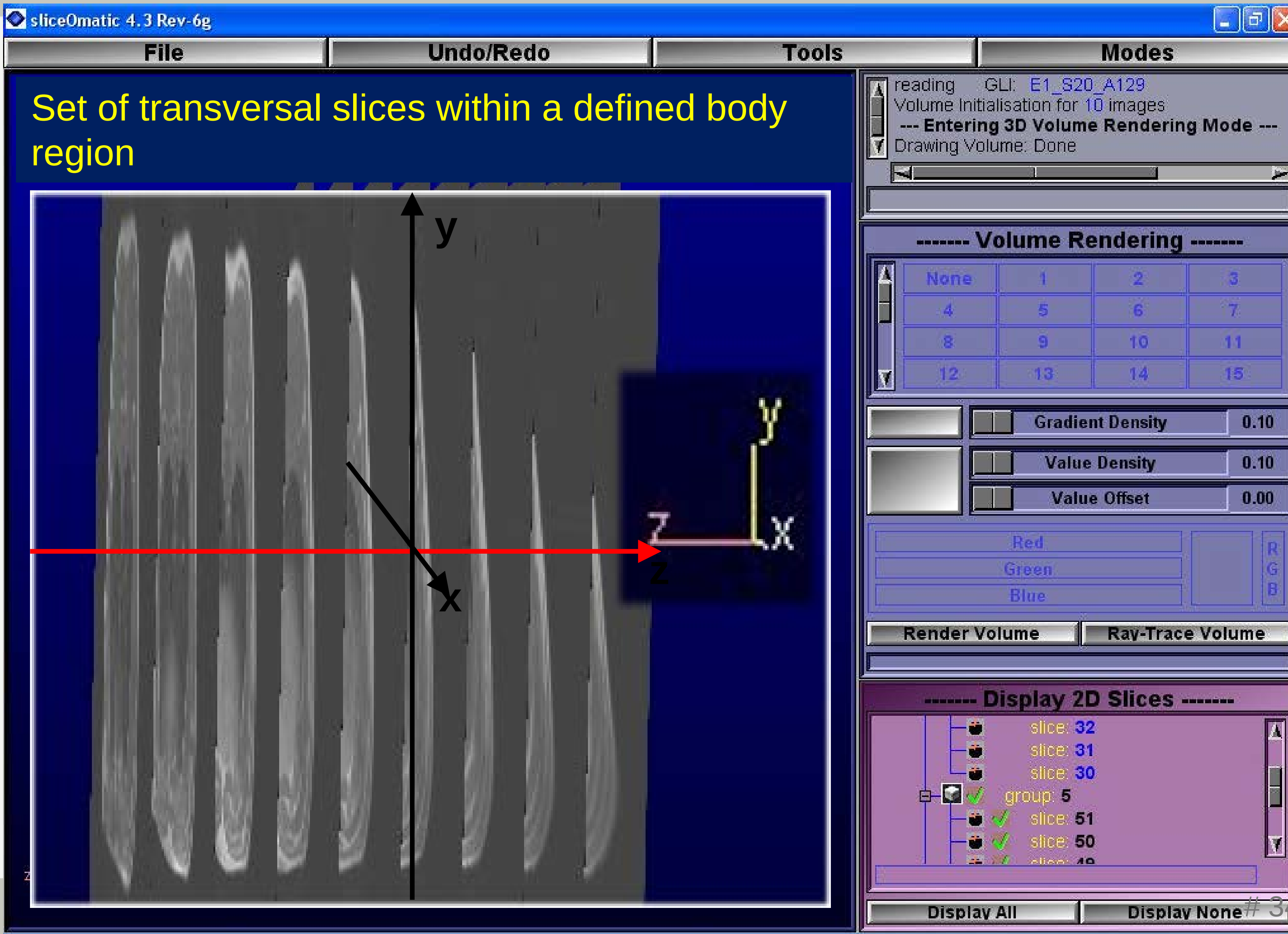
# $^1$H Magnetic Resonance Imaging




Localizer or Scout scan

# $^{1}$H Magnetic Resonance Imaging

Set of transversal slices within a defined body region



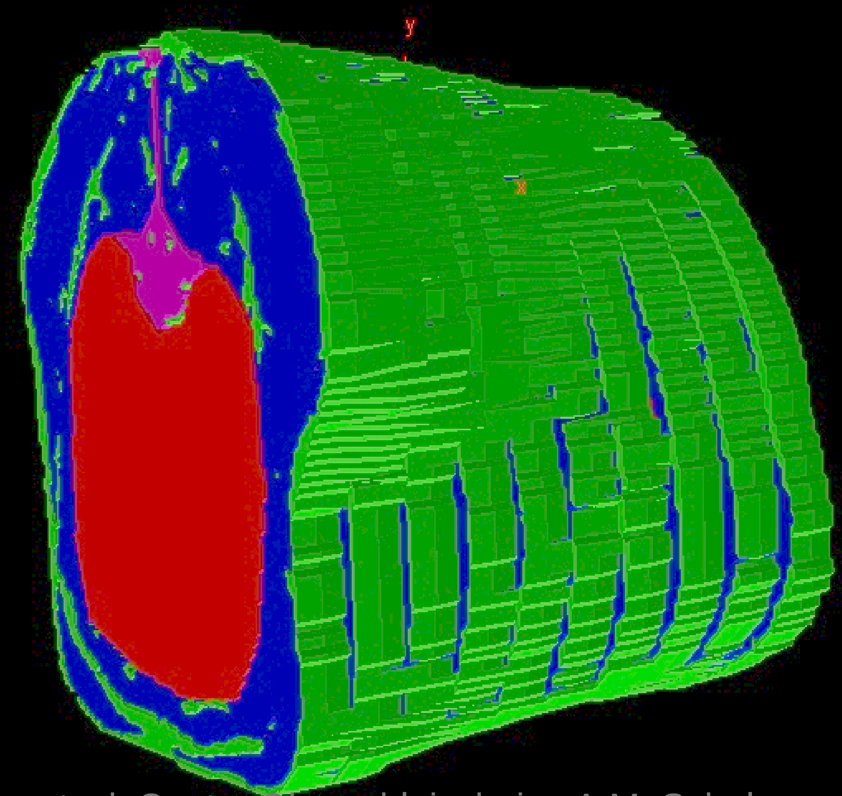
# $^{1}$H Magnetic Resonance Imaging

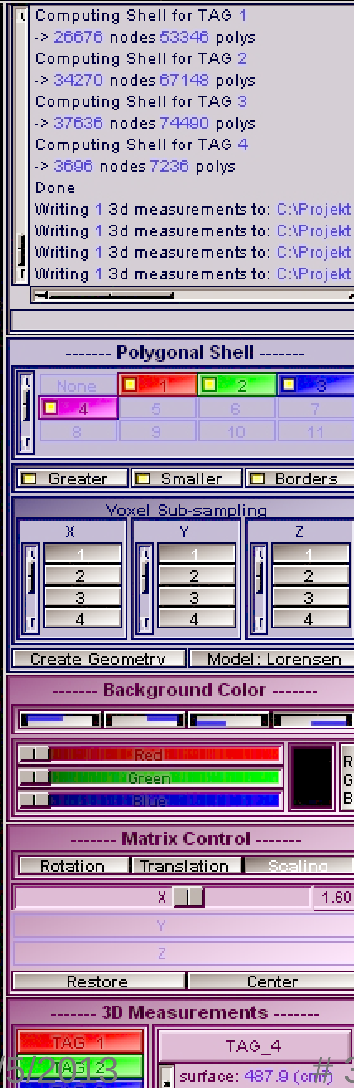
sliceOmatic 4.3 Rev-6i

File | Undo/Redo | Tools | Modes

→ automatic, semi-automatic or manual segmentation into muscle, fat or bone volumes

→ no "unique" signal intensities



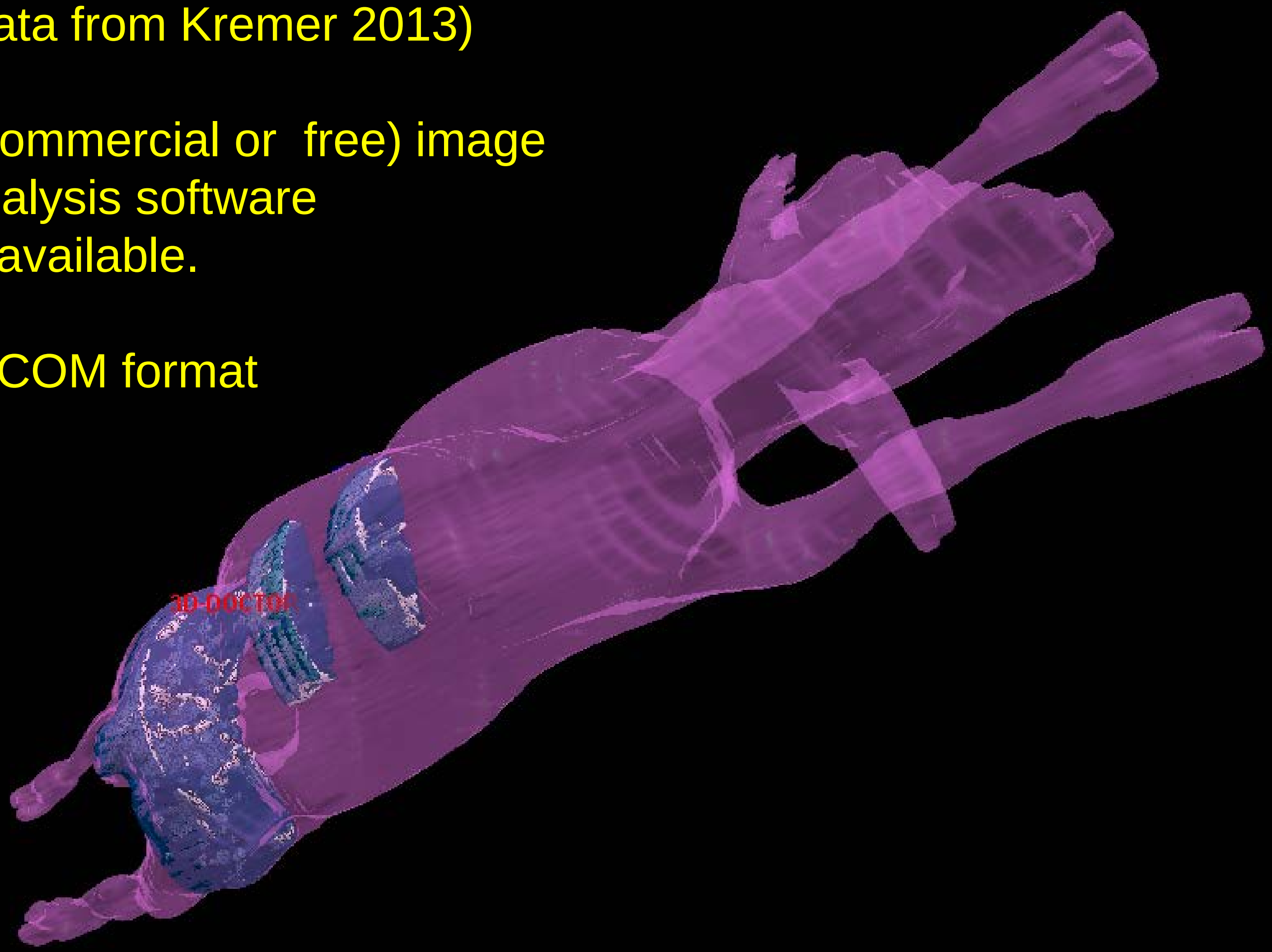


# $^1H$ Magnetic Resonance Imaging

Virtual dissection of a lamb
(data from Kremer 2013)

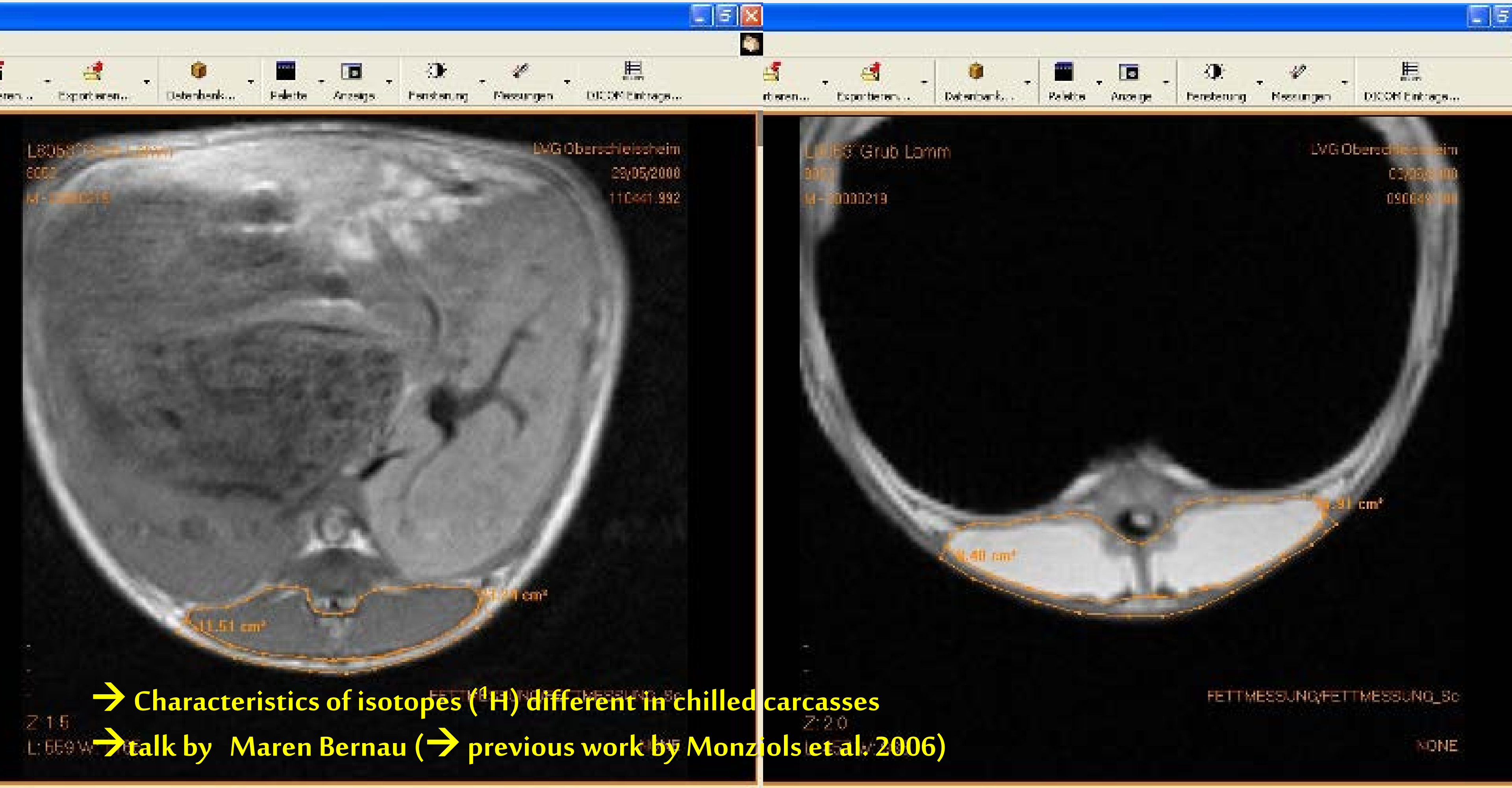
(Commercial or free) image
analysis software
is available.

DICOM format



# $^{1}$H Magnetic Resonance Imaging

*in vivo* *carcass*




→ Characteristics of isotopes ($^{1}$H) different in chilled carcasses

→ talk by Maren Bernau (→ previous work by Monziols et al. 2006)

T1 weighted sequence

# Carcass study MRI

M. Monziols et al. / Meat Science 72 (2006) 146–154 151

Table 4
Prediction of weight or proportion of muscle, total fat and subcutaneous fat in the half carcass from MRI images of one, two, three [illegible]

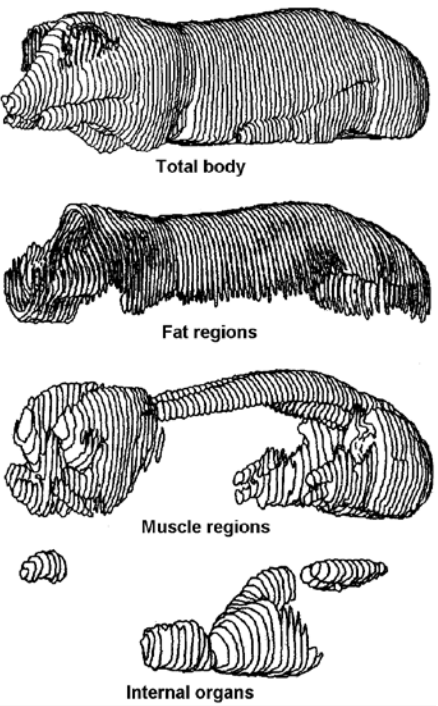
| Predicting variables[a] obtained in | Predicted variables | | | | | |
|---|---|---|---|---|---|---|
| | Muscle | | Total fat | | [illegible] fat | |
| | Weight | %[b] | Weight | %[b] | [illegible] | %[b] |
| $R^2$ | | | | | | |
| Loin | 0.973 | 0.965 | 0.907 | [illegible] | 0.931 | 0.972 |
| Loin & Ham | 0.993 | 0.976 | [illegible] | 0.982 | 0.960 | 0.983 |
| Loin & Belly | 0.984 | 0.975 | [illegible] | 0.983 | 0.984 | 0.988 |
| Loin, Ham & Belly | 0.996 | [illegible] | [illegible] | 0.986 | 0.988 | 0.991 |
| The four cuts | 0.996 | [illegible] | 0.986 | 0.986 | 0.994 | 0.993 |
| Residual standard deviation (g or %) | | | | | | |
| Loin | [illegible] | 1.65 | 1015 | 1.41 | 727 | 1.19 |
| Loin & Ham | [illegible] | 1.39 | [illegible] | [illegible] | [illegible] | [illegible] |
| Loin & Belly | [illegible] | 1.43 | [illegible] | [illegible] | [illegible] | [illegible] |
| Loin, Ham & Belly | 287 | 1.31 | [illegible] | [illegible] | [illegible] | [illegible] |
| The four cuts | 284 | 1.28 | [illegible] | [illegible] | [illegible] | [illegible] |

[a] Pi[illegible]ges of the cut, corresponding to the tissue of the predic[illegible]t and propor[illegible]ue in the half carcass, respectively).
[b] Tissue proportion, relative to half carcass weight.

The more cuts (slices) the higher is the accuracy !

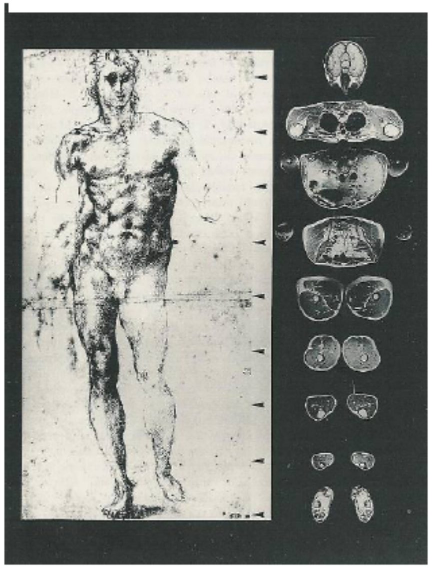
Not always !
Baulain et al. 2010

# Method of volume estimation




Mitchell et al. (2001)
- MRI

## Bonaventura Cavalerius (1598-1647)



(Roberts et al., 1993)

$$est_1 V = T\,(A_1 + A_2 + \dots A_n)$$

$A_1, A_2, \dots A_n$ → section areas
$T$ → sectioning interval
n → consecutive sections

*(T needs to be thin for exact estimates)*

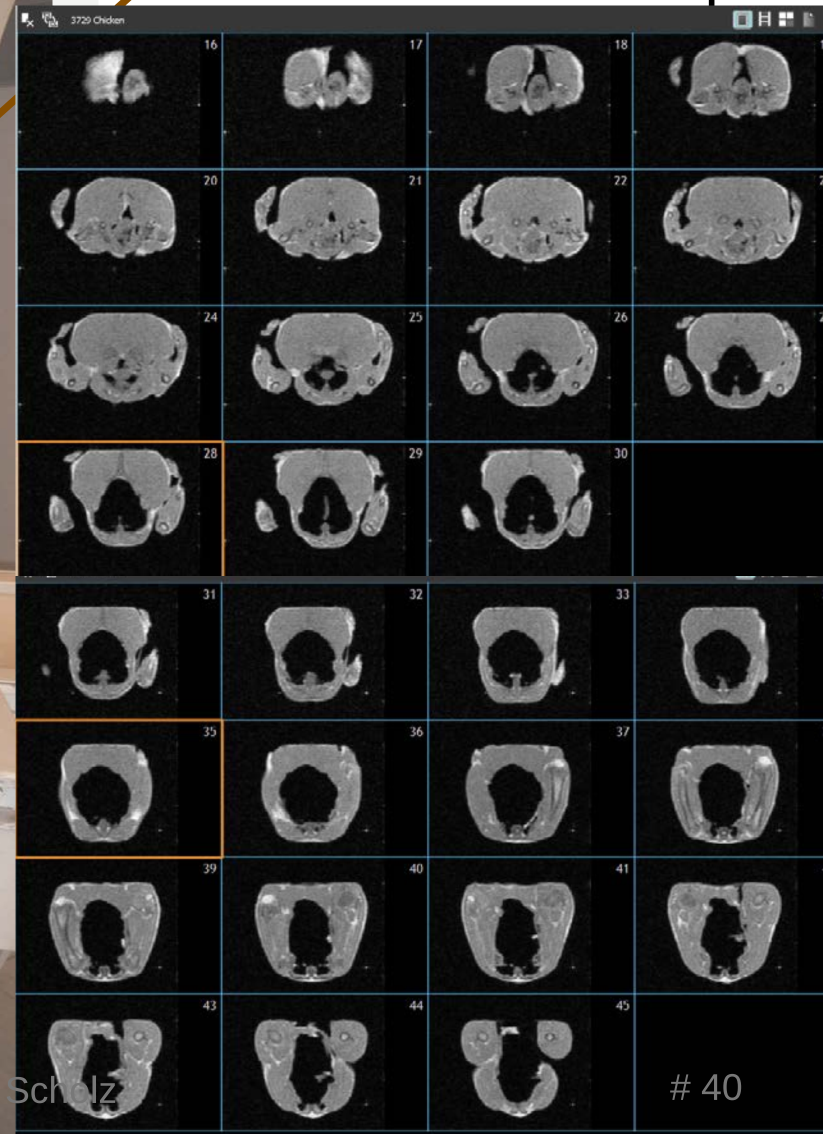
⇩

unbiased estimation

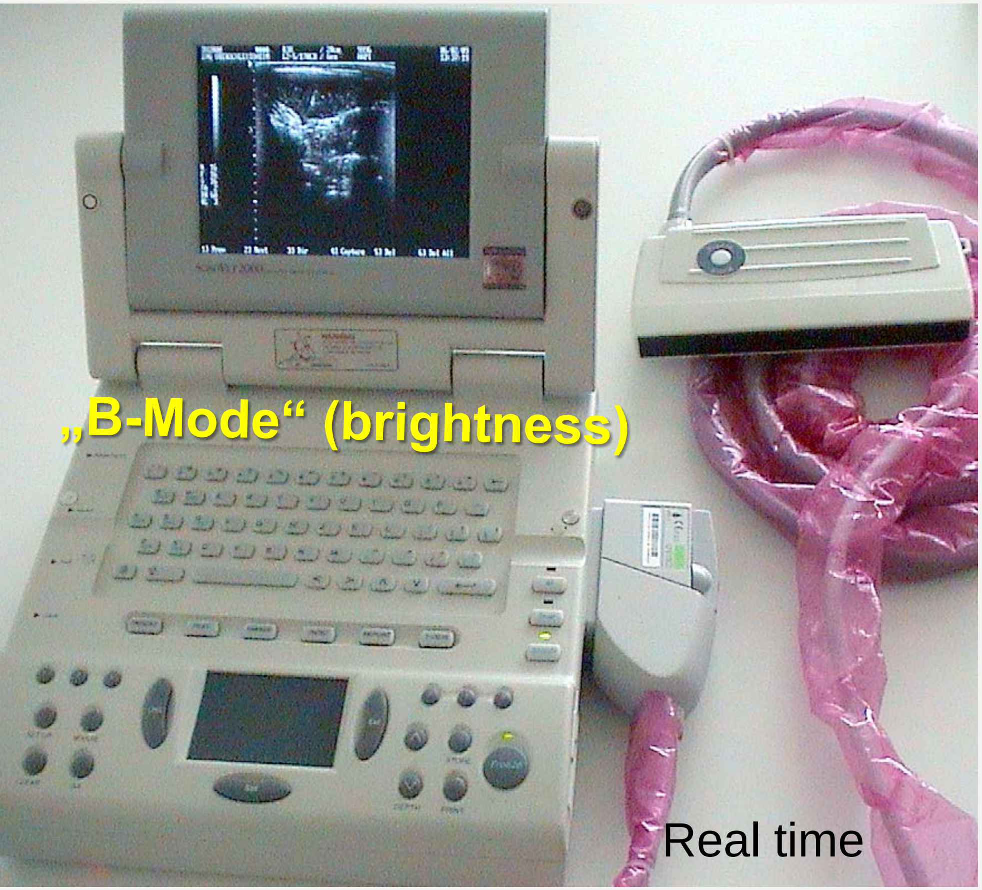
e.g. used: by; Glasbey & Robinson (2002) - CT; Tholen et al. 2003 → MRI

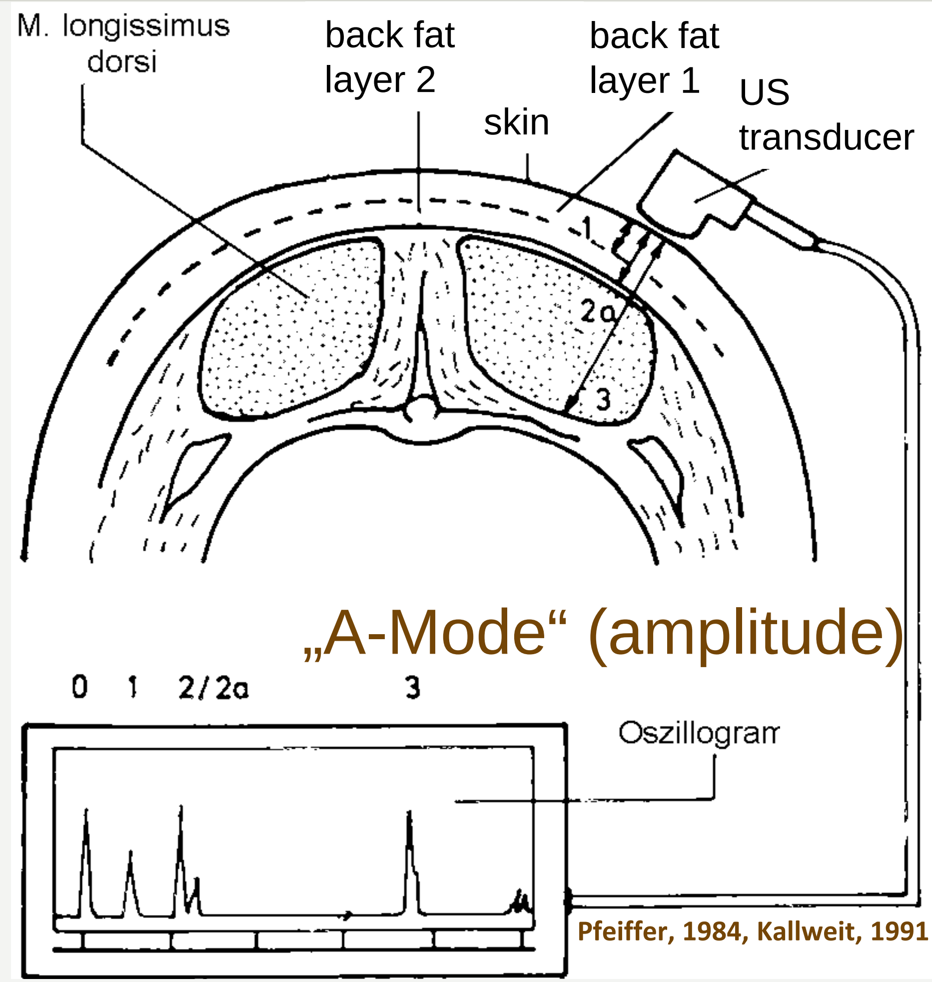
MRI/DXA broiler chicken (project 2013)
-whole Carcass
45 slices – three steps





# Ultrasound Imaging/Scanning




Pfeiffer, 1984, Kallweit, 1991

Principle: reflection of sound waves from the interface between different media and/or body tissues (> 20 kHz) → emitter + receiver=piezo-electric elements (quarz, cristalls)

# Speed of sound waves in „Tissue“ (m/s)*

| | |
|---|---|
| Air | 330 |
| Blood | 1549 - 1570 |
| Fat | 1460 - 1480 |
| Connective T. | 1545 |
| Water | 1524 |
| Skeletal Muscle | |
| Longitudinal | 1592 |
| Cross-Sectional | 1545 |
| Bone | 3406 – 4030 |

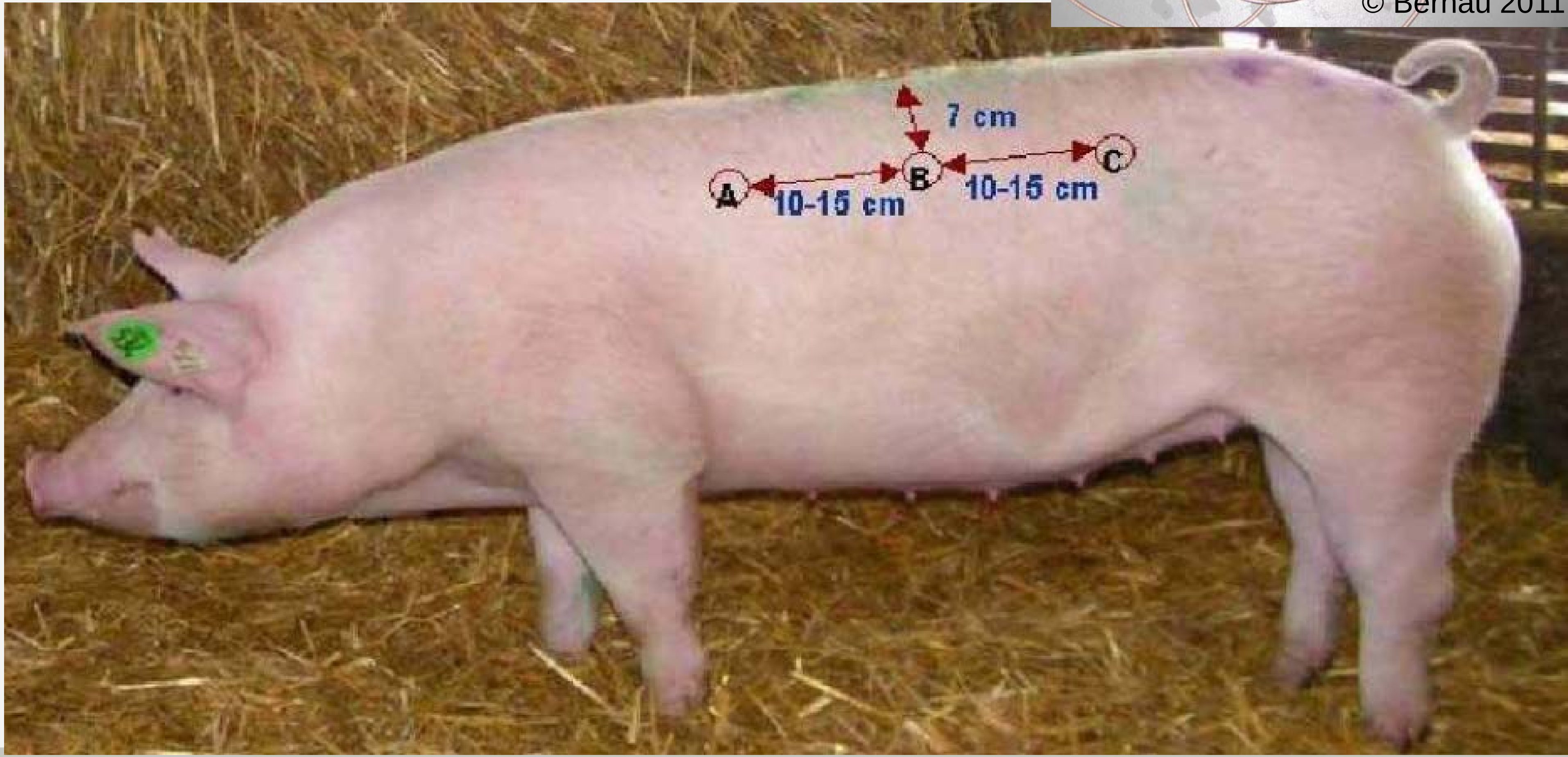
→* depends on surrounding temperature

# Ultrasound Imaging/Scanning


Beef cattle scanning (Stouffer 2004)

# Ultrasound Imaging/Scanning

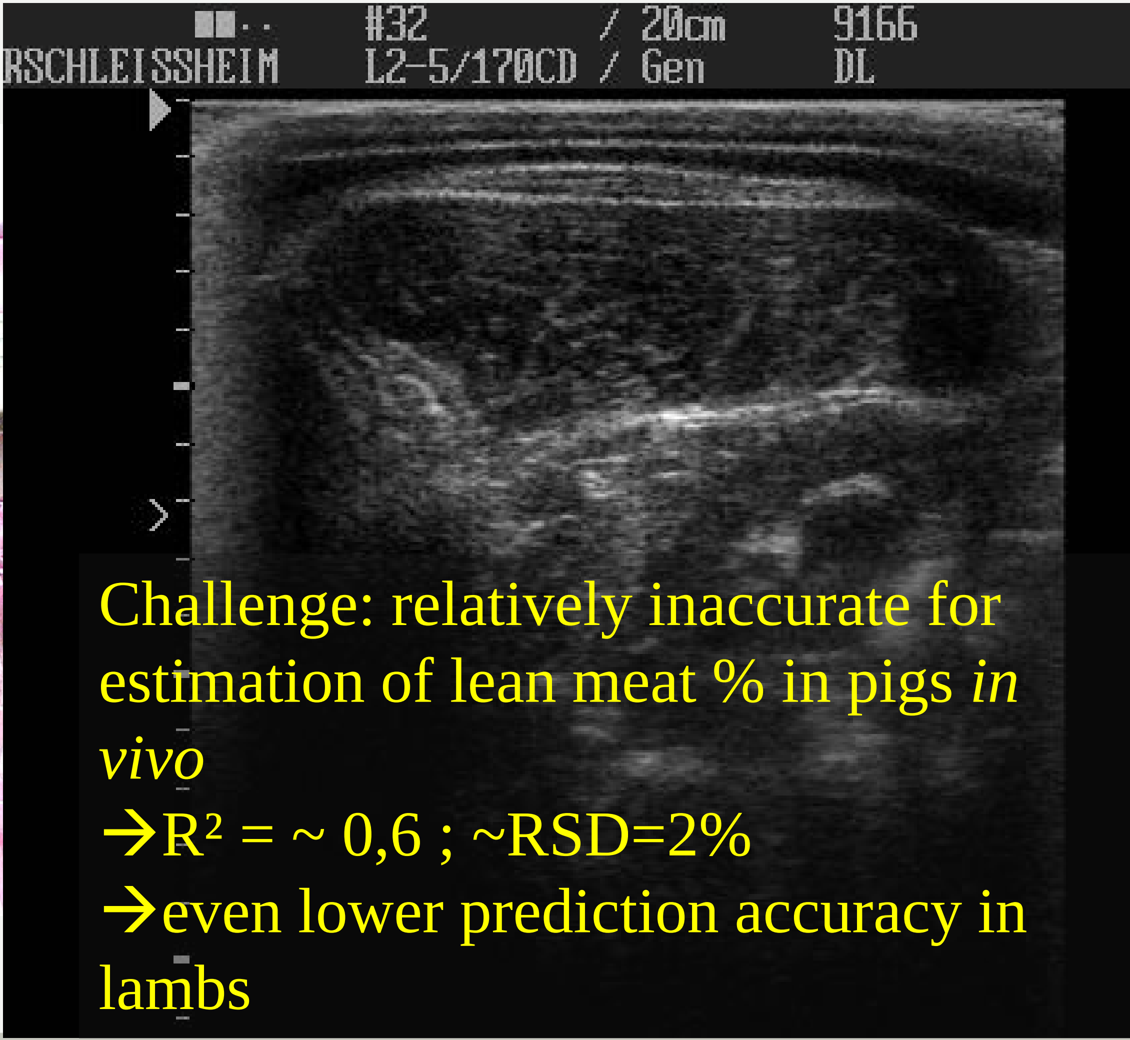

Boar and gilt performance test (Germany, ZDS 2005)
Back Fat measures A (SpA), B (SpB) und C (SpC).
A-mode



# Ultrasound-Imaging

## Individual Performance testing *in vivo:*
## → Breeding value

B mode system

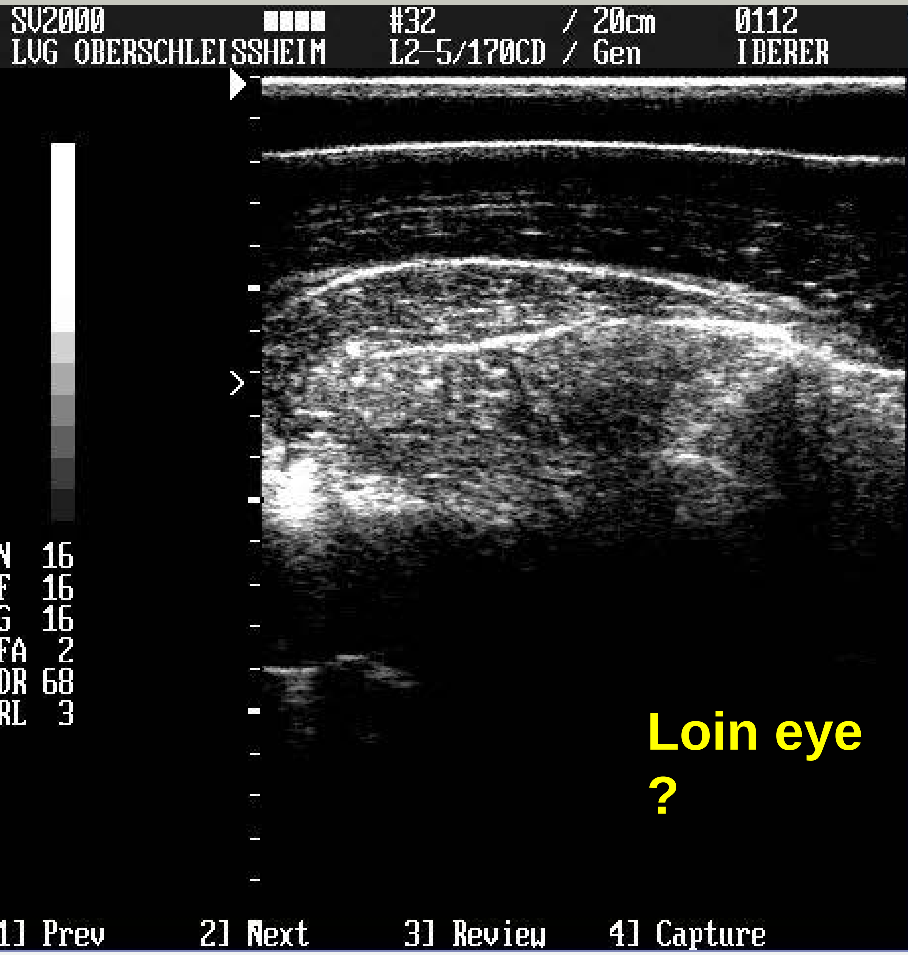


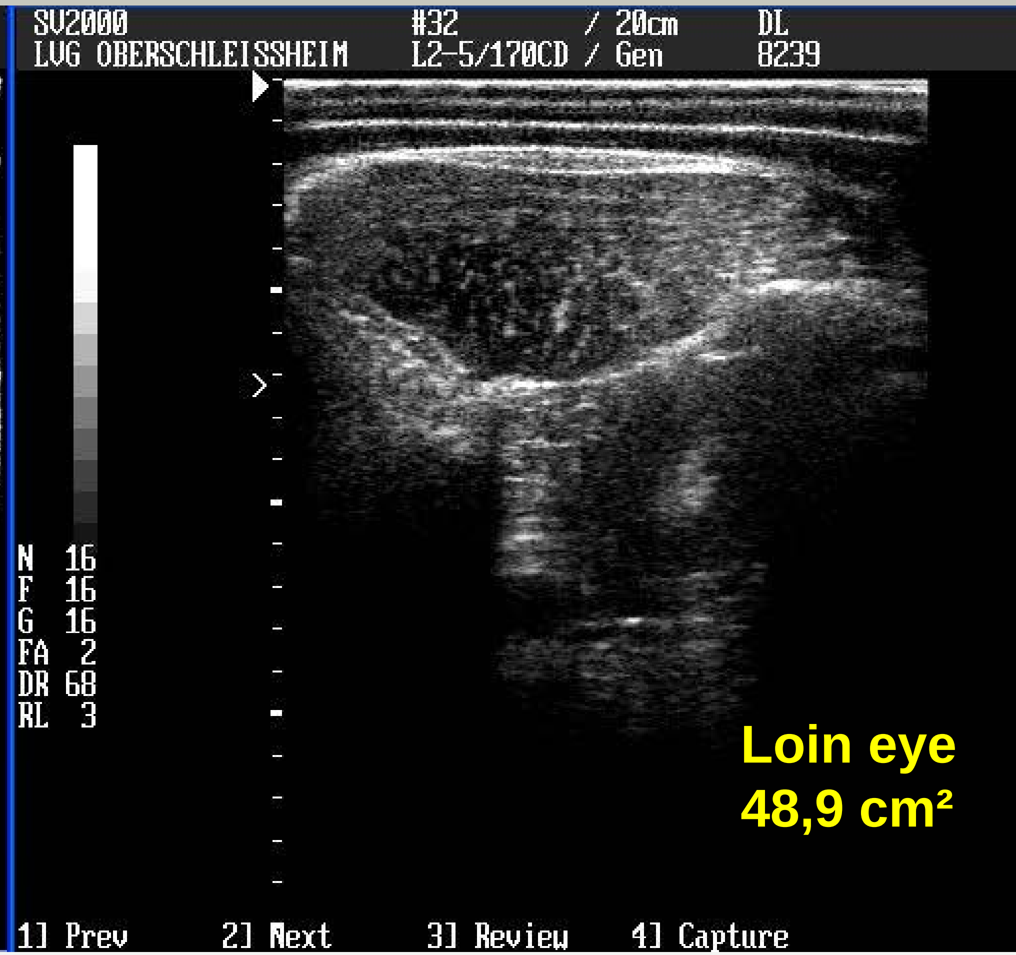

Challenge: relatively inaccurate for estimation of lean meat % in pigs *in vivo*

→$R^2$ = ~ 0,6 ; ~RSD=2%

→even lower prediction accuracy in lambs

# Ultrasound-Imaging




**Cerdo Iberico**
Fat depth: ~ 50 mm
Muscle depth: ~ 45 mm?

**German Landrace**
Fat depth: ~20 mm
Muscle depth: ~50 mm

# Ultrasound Imaging/Scanning

# Comparison of techniques

| Method | Reference tissue from dissection/ chemical analysis | Accuracy Pigs ≥ Sheep ≥ Poultry $R^2$ | RSD | Scan Time Whole Body | X-radition exposure (mrem) |
|---|---|---|---|---|---|
| CT | Lean Meat (%) | <0,92 | >0,30 | 5-30 sec | 9 -15 |
| MRI | Lean Meat (%) | <0,87 | >0,38 | 15-30 min | none |
| DXA | Lean Meat (%) | <0,82 | >0,50 | 7-13 min | 0,03-0,06 |
| US* | Lean Meat (%) | <0,77 | >0,70 | - | none |

*no whole body information with present technology (here carcass data, Branscheid et al. 2011, Judas 2011)

# Comparison of techniques

| | Advantages | Disadvantages |
| --- | --- | --- |
| Computer Tomography (CT) | - very high anatomical resolution<br>- High speed<br>- Whole Body – 3D data<br>- Automatic data analysis | - X-radiation exposure<br>- expensive |
| Dual Energy X-ray Absorptiometry (DXA) | -Easy handling<br>-low radation<br>-medium prize<br>-quick data analysis<br>-regional data analysis | - alone 2D information (so far)<br>- no direct data for lean meat (in vivo) |
| **Magnetic Resonance Imaging (MRI)** | - Excellent soft tissue differentiation<br>- Whole Body – 3D data<br>- Functional Imaging | - expensive<br>- rather slow (whole body)<br>- availability (farm animal sector) |
| Ultrasound Imaging (UI) | - Portable, extensive database for some species,<br>- reasonably prized<br>- no radiation<br>- Real time, on line<br>- No size limit , no anesthesia | - Less accurate anatomical resolution<br>- Image analysis not easily automated<br>- no whole body information |

# Conclusion for imaging methods

If sufficient automatic procedures are available, the "***Cavalieri"* method** is the preferred imaging procedure,

→ because a whole body information **does not require breed, species, or age/weight-specific prediction equations.**

- **Baulain et al. (2010b) -- MRI**
- **Norsvin (Kongsro 2012) -- CT**
- **partially Kremer (2013) -- MRI**

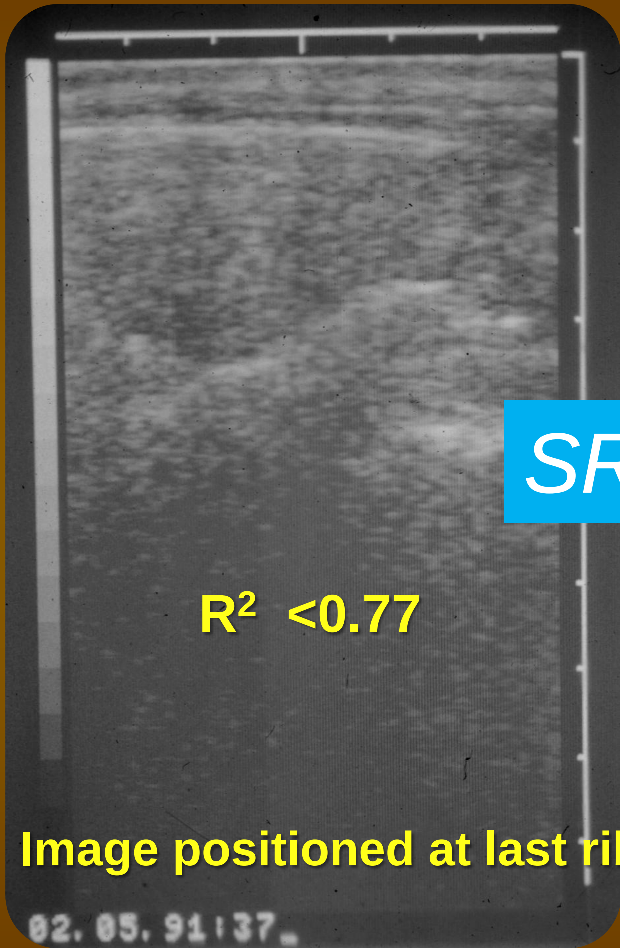
# Conclusion for imaging methods (performance testing)

- If radiation and the high investment price is not an issue, then use a „New Generation“ CT for the measurement of body/carcass composition.
- If a 3D information is not required use DXA.
- If radiation is an issue, use MRI.
  - You will need anesthesia in most cases!

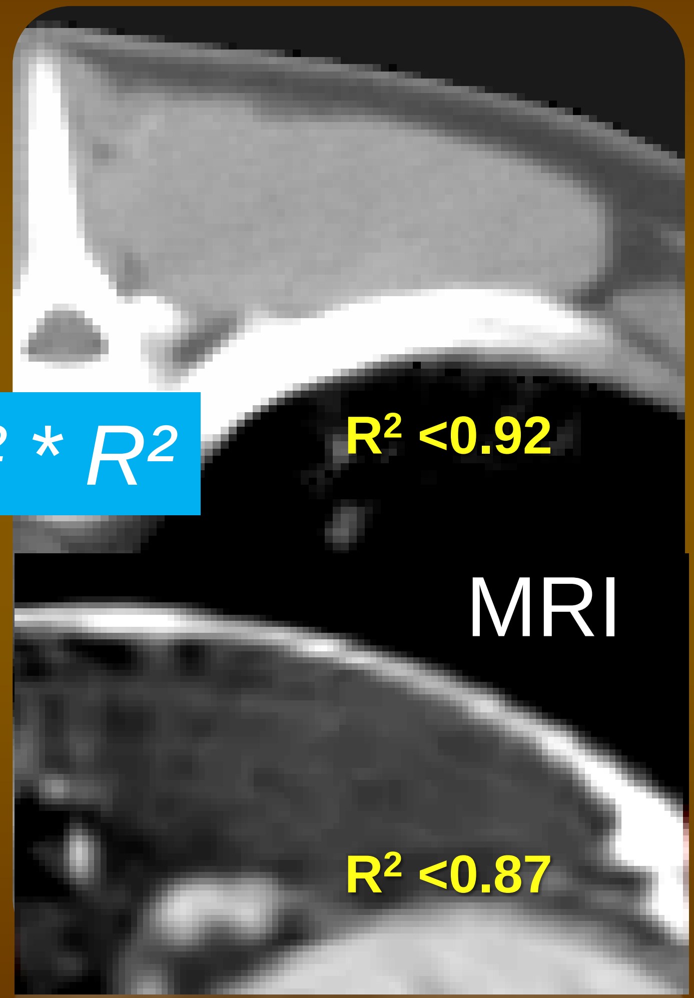
- If a „quick“ and „easy“ answer is the objective, use A-mode ultrasound – for little more B-mode.
  - In all cases, a scale is very useful!

## Accuracy for Lean Meat Yield (%) in (**sheep**)

# Ultrasound vs. X-ray CT




$$SR = SD * h^2 * R^2$$




→ US is good but CT/MRI is better → and together is best!

Data: Streitz et al. 1995, Stanford et al. 1998, McFarlane et al. 2009, Bünger 2013, Kremer 2013#

# Conclusion for imaging methods (generally)

## Kallweit 1993:

"There are advantages and disadvantages of individual systems in their present state.

The rapid progress in technical development may lead to further improvements in the future."

→ 20 years later: Nothing has changed !

# Outlook into the Future

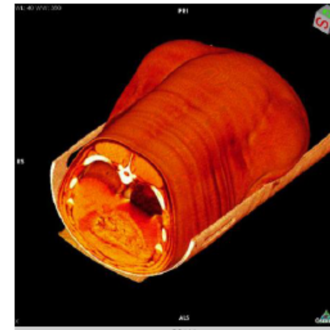
## Non-Invasive Measurement of

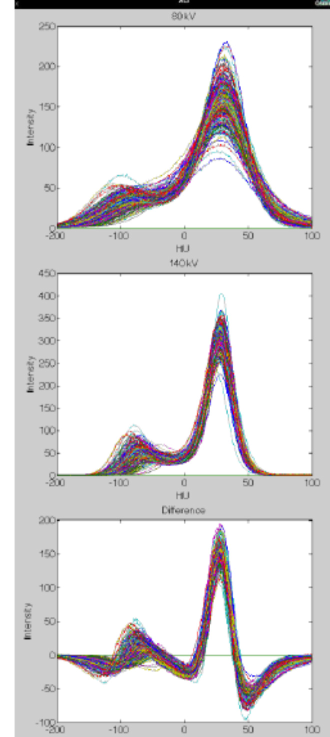
## new „PHENOTYPES“

# Outlook into the Future

NORSVIN (KONGSRO March 2012)

## CT Phenotyping



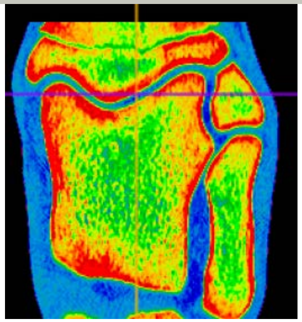



- Meat and fat quality
  - IMF
  - Water content in fat

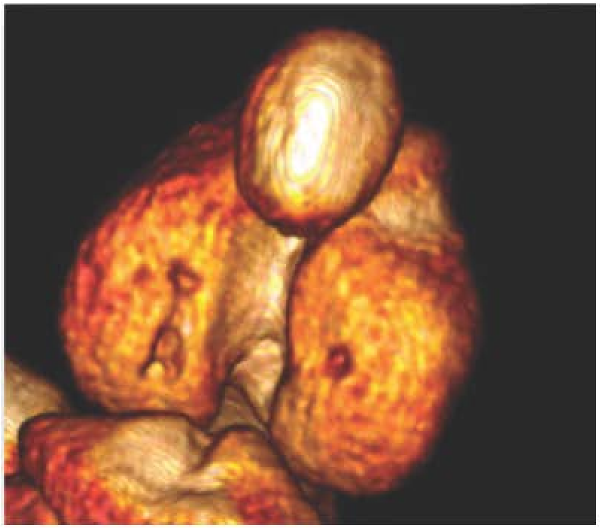
Make calibration between CT and NIR on carcass.

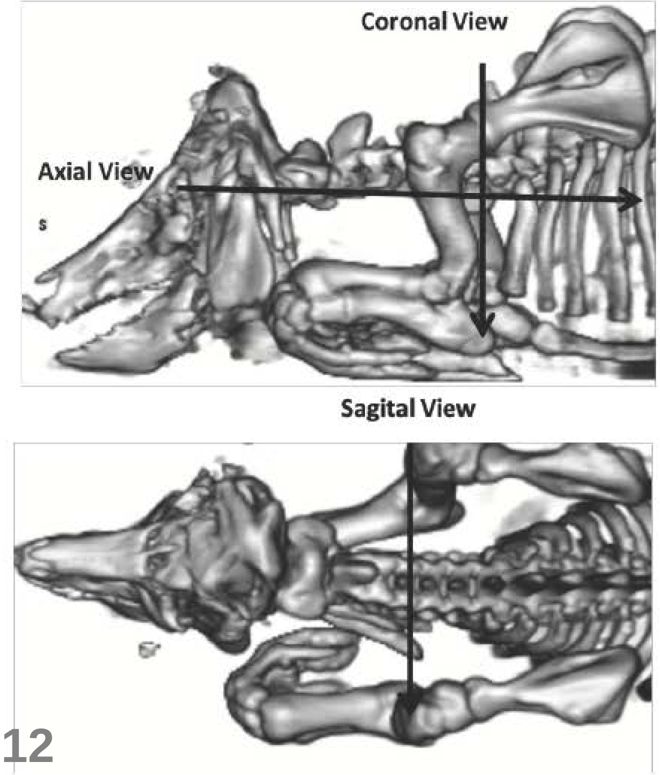
The FOSS FoodScan Tm near infrared spectrophotometer

# CT Phenotyping



- Leg weakness score
  - Osteochondrosis (0-4)

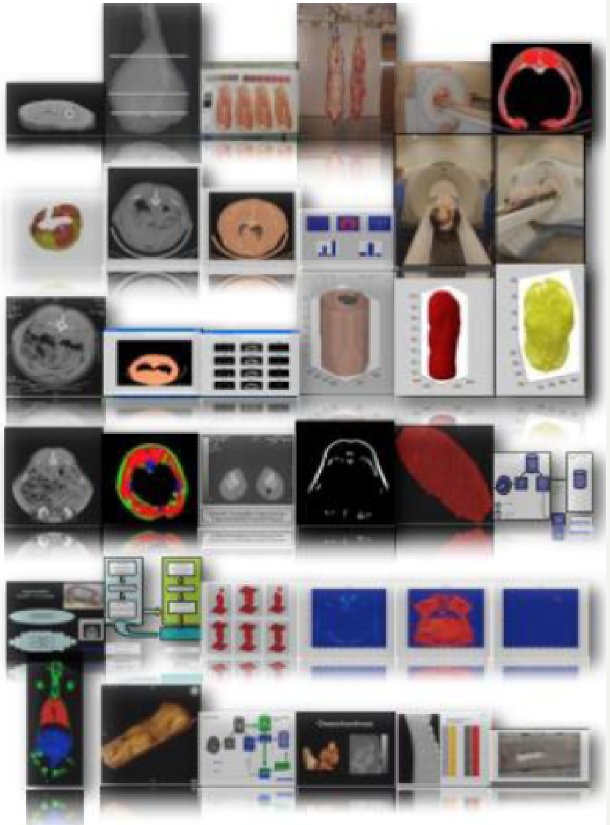





**Results published: Aasmundstad et al. 2012**

# Phenotyping – new traits under development

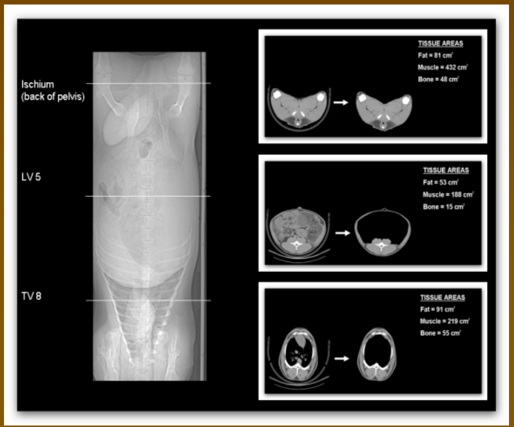
- Bone mineral content
- Internal organs – breeding for an improved «engine»
- Other morphological traits



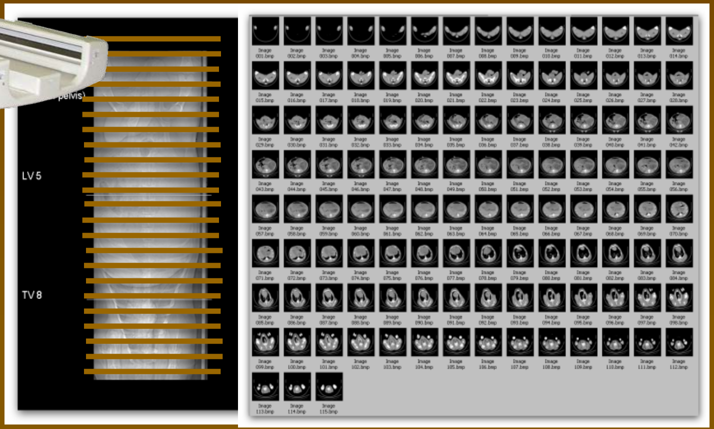
NORSVIN (KONGSRO March 2012)

# “Old” and **new traits** for carcass value, meat quality, and other traits.


Reference scanning

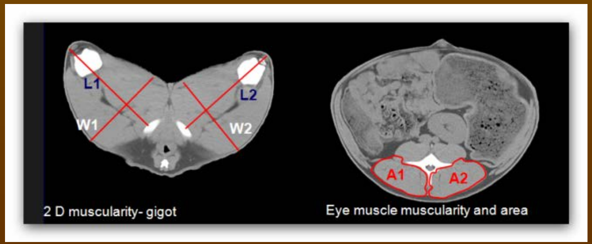



Spiral scanning – whole body




- Pred. Carcass and tissue weights(M, F, B)
- Pred. Tissue proportions
- Pred. Killing out %
- 2D- Gigot muscularity,
- EM-area and 2D-EM- muscularity

- **Meas.** Carcass and tissue weights(M, F, B)
- **Meas.** Tissue proportions
- **Meas.** Killing out %
- **3D**- Gigot muscularity,
- EM-area and **3D**-EM- muscularity




- Spine characteristics (after CD’s PhD)
- Muscle density ~ IMF ~ taste (after NC PhD)
- Pred. Killing out %
- 3D- Gigot muscularity,
- EM-area and 3D-EM- muscularity
- (Gut size→ methane; pelvic dimensions→ lambing

BÜNGER 2013

# THANK YOU FOR YOUR ATTENTION