Comparison of W and Fe HCal at Multi-TeV-Energies

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Outline

- Motivation
- HCal stack simulation studies
- Simulations with CALICE AHCal module
- Particle Flow Performance
- Future Plans

ILC HCal Parameters

- SiD (LoI version)
  - HCAL
    - R_{min} = 141 cm, R_{max} = 253 cm
    - 40 layers of Steel/Gas (2.0 cm + 0.8 cm)
    - λ = 5.1 , X_0 = 46.5
    - Readout: 1.0 cm x 1.0 cm digital
    - 12 fold
  - Coil
    - R_{min} = 255 cm, R_{max} = 338 cm
    - B = 5.0 T

- ILD (LoI version)
  - HCAL
    - R_{min} = 206 cm, R_{max} = 333 cm
    - 48 layers of Fe/Scint (2.0 cm + 0.5 cm)
    - λ = 6.0 , X_0 = 55.3
    - Readout: 3.0 cm x 3.0 cm analog
    - 16 fold (outside), 8 fold (inside)
  - Coil
    - R_{min} = 344 cm, R_{max} = 419 cm
    - B = 3.5 T

Why Tungsten?

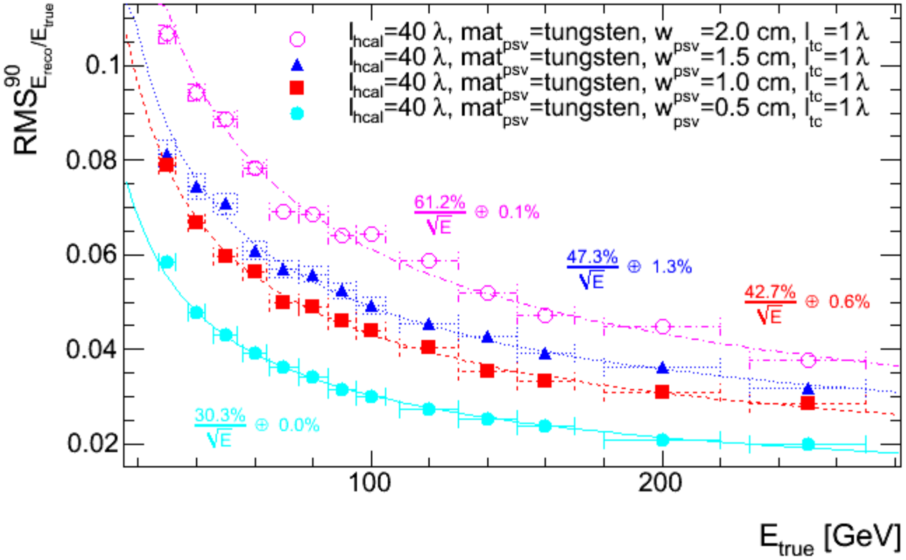
- Need shorter longitudinal shower size
    - High energetic jets require more HCal material in terms of interaction lengths – to achieve better containment
    - Strong constraints by coil – cost and feasibility
- Need smaller lateral shower size
    - High energetic jets are more boosted
    - PFA performance is decreasing because of overlapping showers
- Tungsten might solve both problems
- We consider tungsten only for the HCal barrel since space constraints for the endcaps are not severe

HCal-Stack Simulations

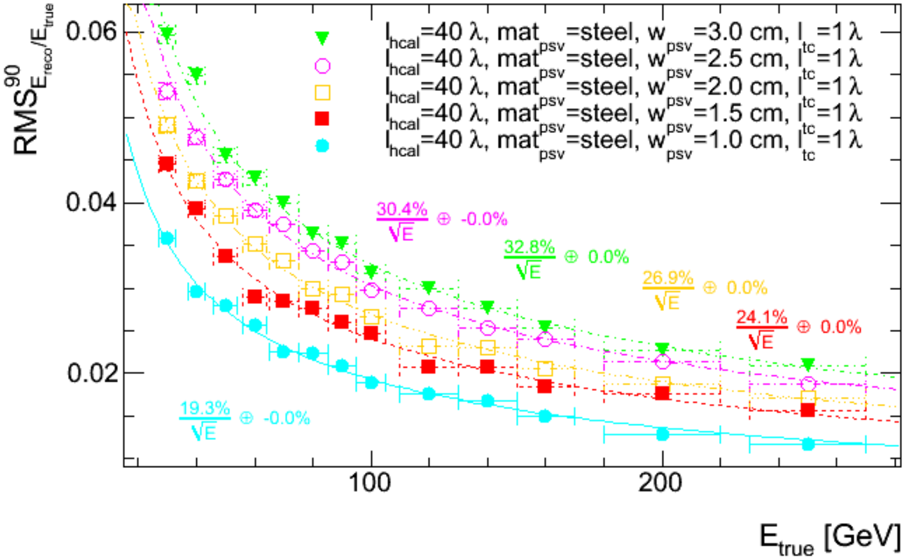
- Simple HCal geometry to investigate materials and sampling ratios
- Materials: tungsten, steel, steel-tungsten-sandwich (various thicknesses)
- Constant gap size: 5.0 mm Scint + 2.5 mm G10
- Dimensions: 5x5m and more than 25 λ in depths to guarantee shower containment
- Simulated 100k π^+ between 1 GeV and 300 GeV for each geometry
  - This should cover the energy range of jet main constituents of events with #jets ≥ 4 @ 3 TeV
- Defined active and dead layers during reconstruction – corresponding to different HCal, coil and tailcatcher sizes
- Reconstruction with a neural network (TMVA)
- Using simple shower variables: width, length, center, energy density, etc.

HCal-Stack Simulations

- “extremely deep”-HCal performance



Tungsten

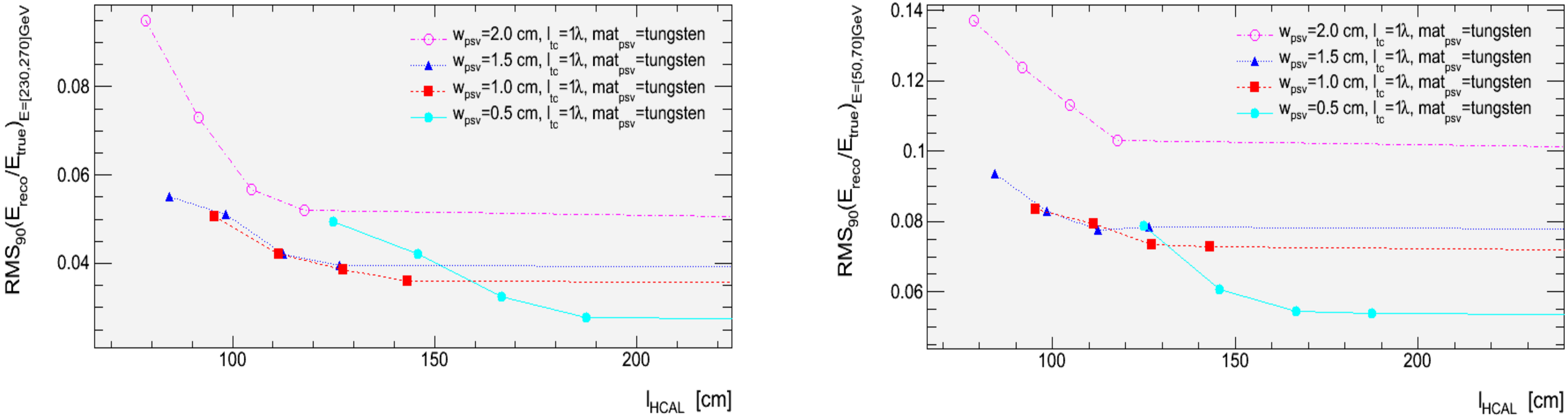


Steel

- Linearity is better than 2% (not shown)
- “extremely deep”-case:
  - Finer passive layers are better
  - Steel performs better than tungsten

HCal-Stack Simulations

- Performance vs HCal depth (tungsten)



E_{MC} ~ 250 GeV

E_{MC} ~ 60 GeV

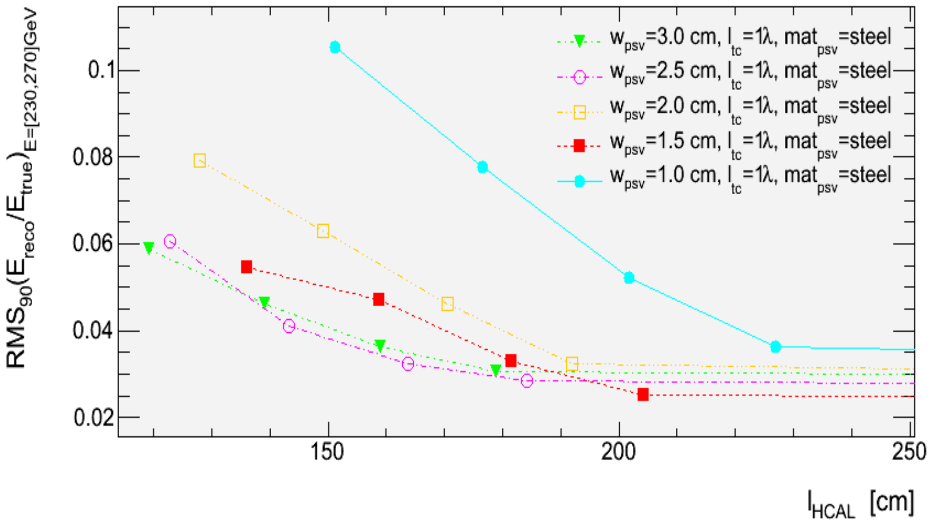
The 4 points of each graph correspond to 6, 7, 8 and 9 λ total calorimeter material

- For an HCal depth of around ~ 140 cm an absorber thickness of ~ 1 cm tungsten seems optimal
- This corresponds to ~ 8 λ; taking into account 1 λ of ECal, a 7 λ HCal appears to be sufficient for CLIC energies
- Stay away from the steep areas where leakage becomes the dominating factor

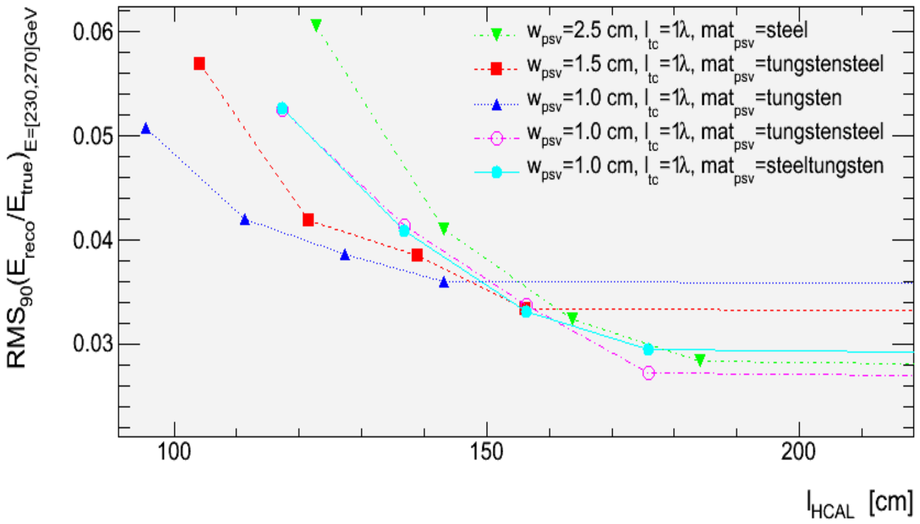
HCal-Stack Simulations

- Performance vs HCal depth (tungsten vs steel)

Steel



Steel, Tungsten, Steel & Tungsten

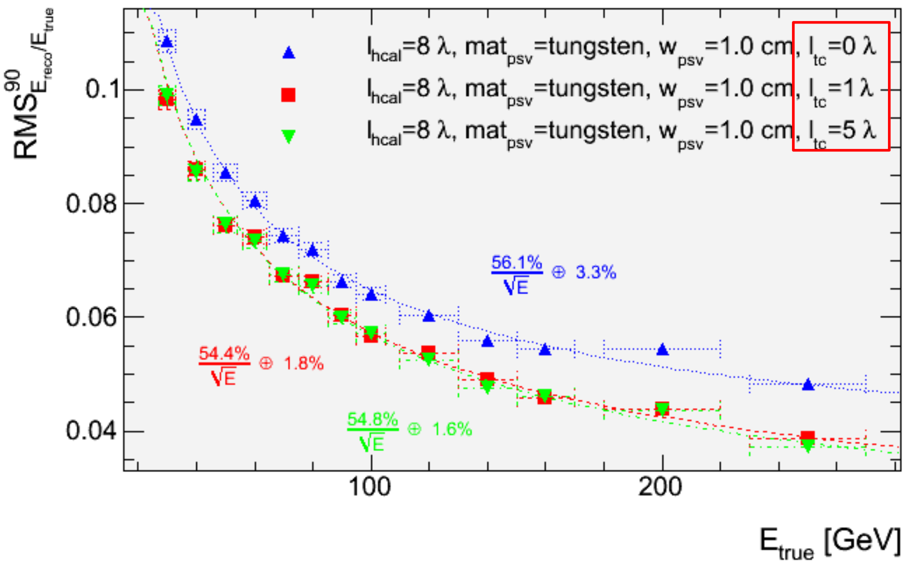


- Steel can perform better than tungsten, but only at a significantly bigger HCal size

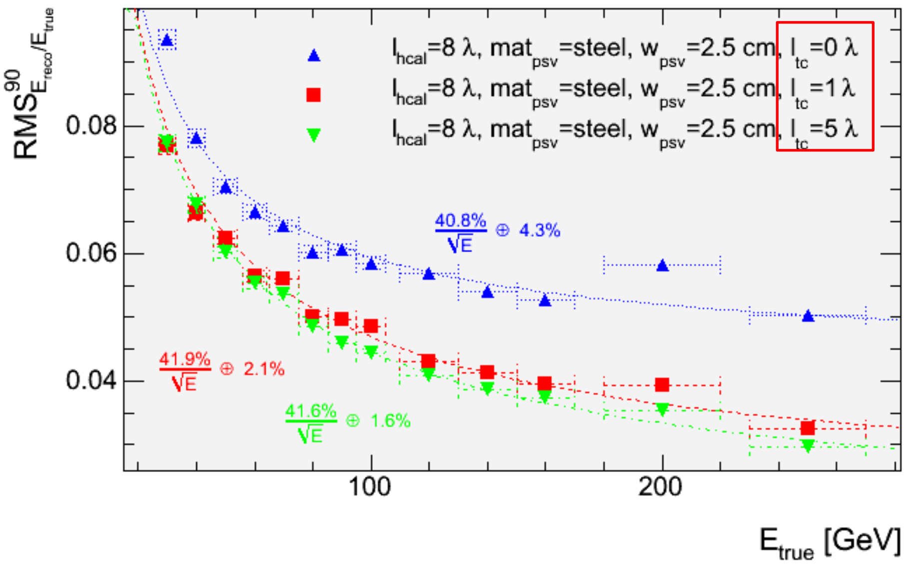
HCal-Stack Simulations

- Impact of a Tailcatcher

Tungsten



Steel

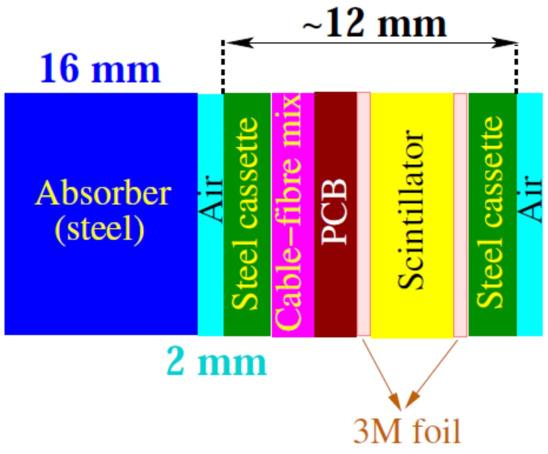


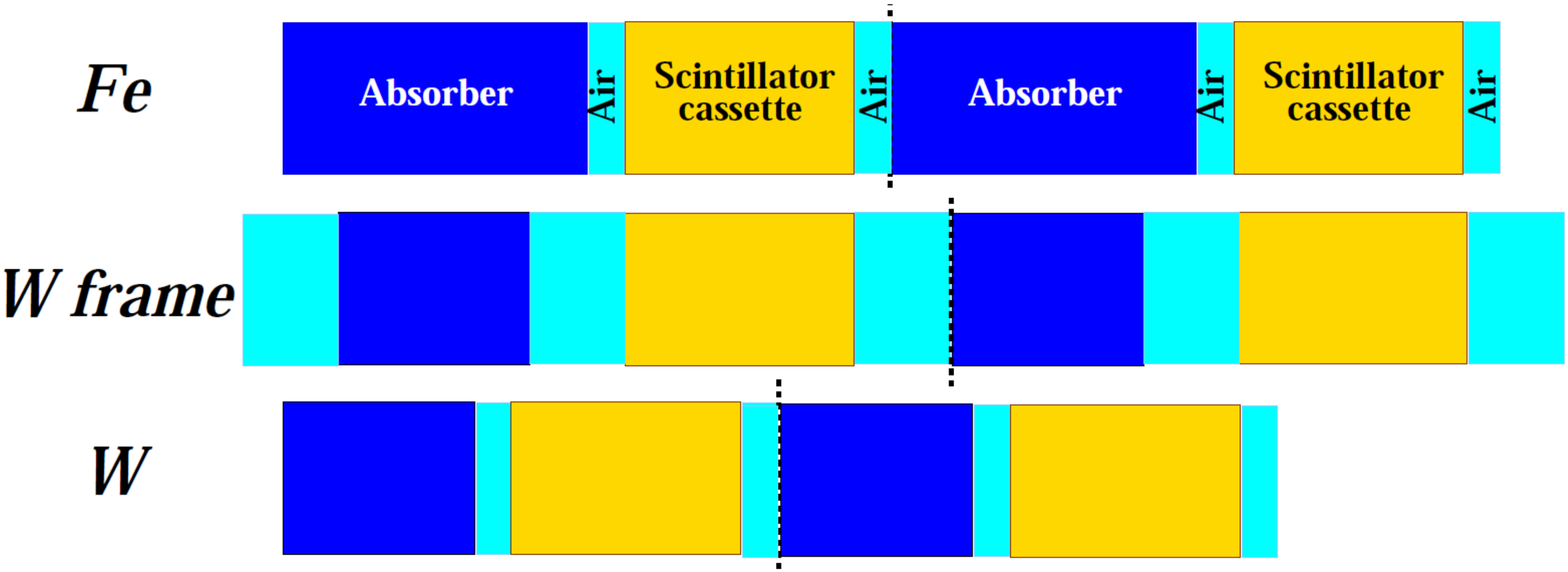
- Resolution is improved by adding a tailcatcher of ~1 λ
- The effect of a bigger tailcatcher is negligible
- In this case: 0 λ implies no active material after the coil

Simulations with CALICE AHCal Module

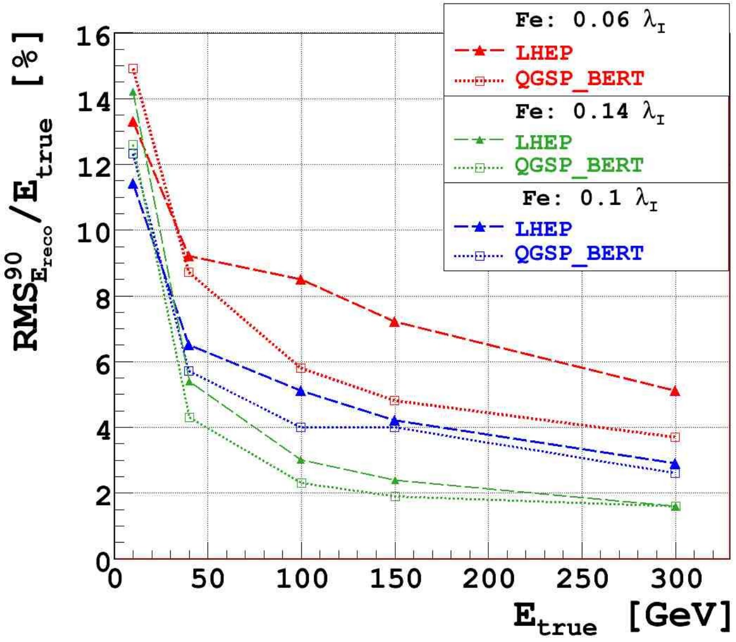
- In a possible tungsten HCal prototype the existing active modules would be re-used
- Current electronics require the full 30mm pitch
- Additional air gaps in the HCal

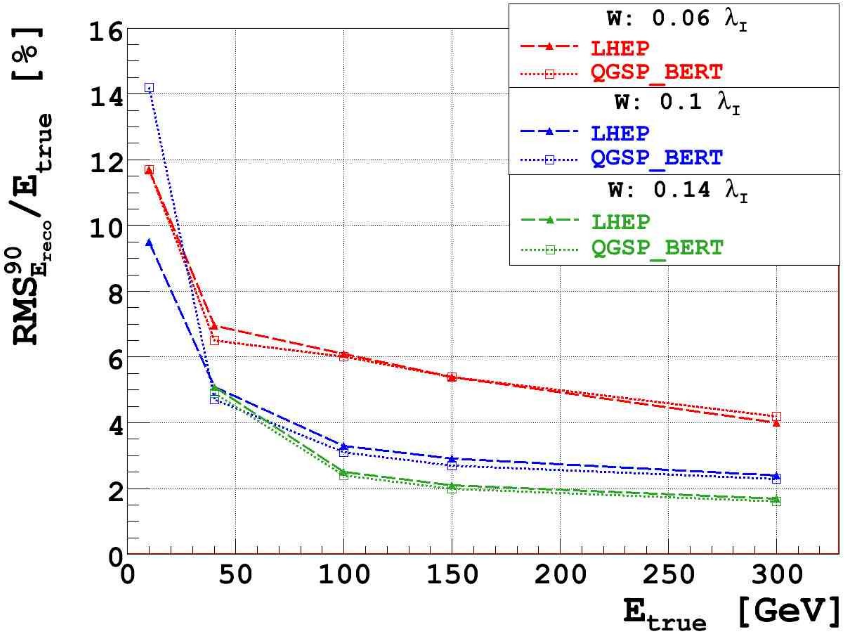
AHCAL module

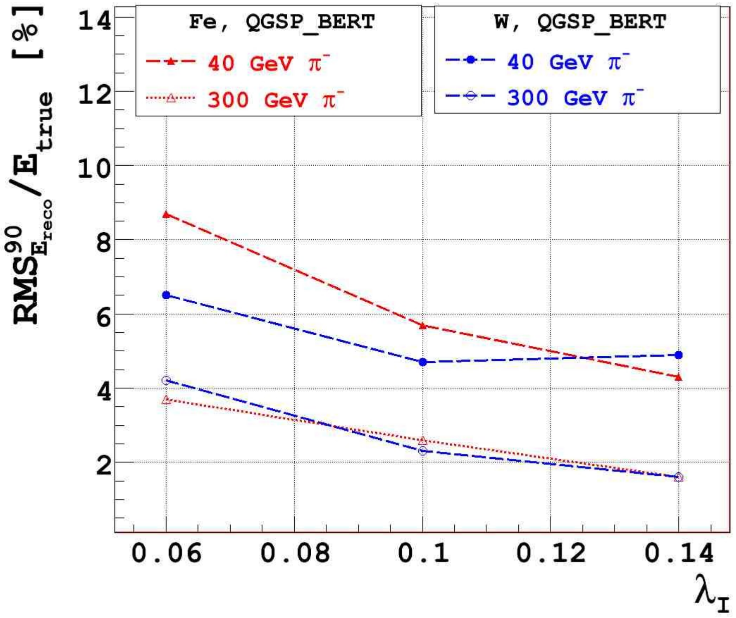




Energy Resolution

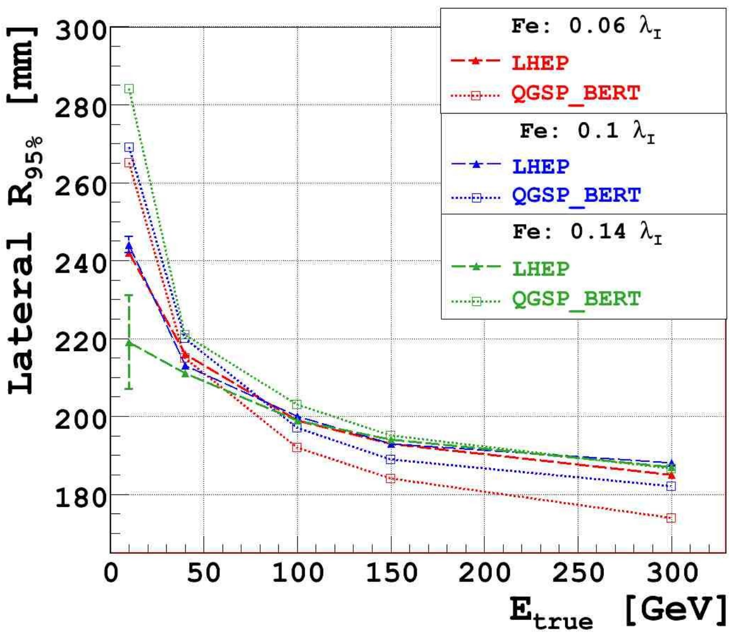


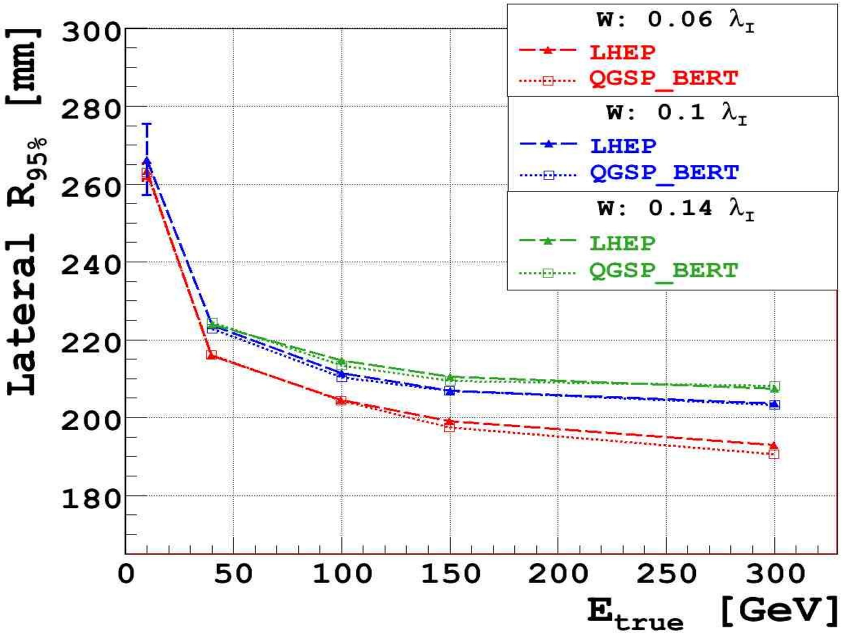


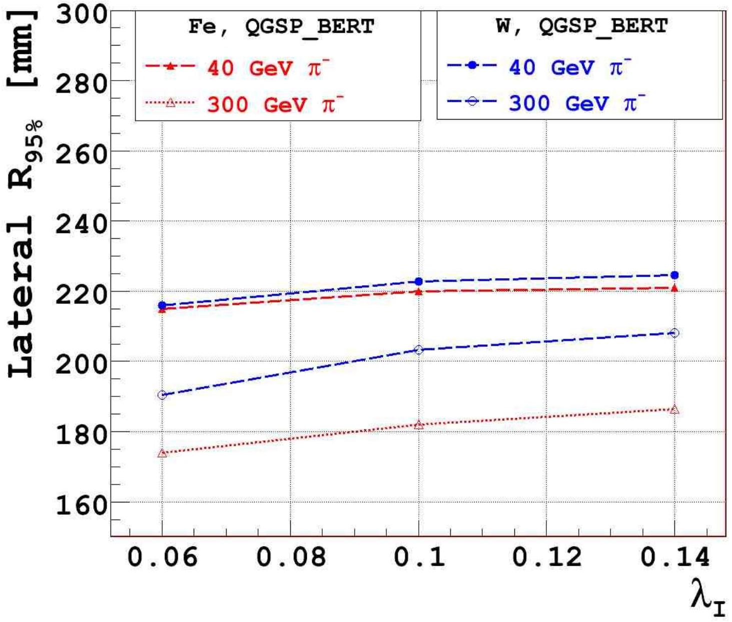


- 40 GeV π^- : better resolution with W
- 300 GeV π^- : comparable results for both

Lateral Shower Containment

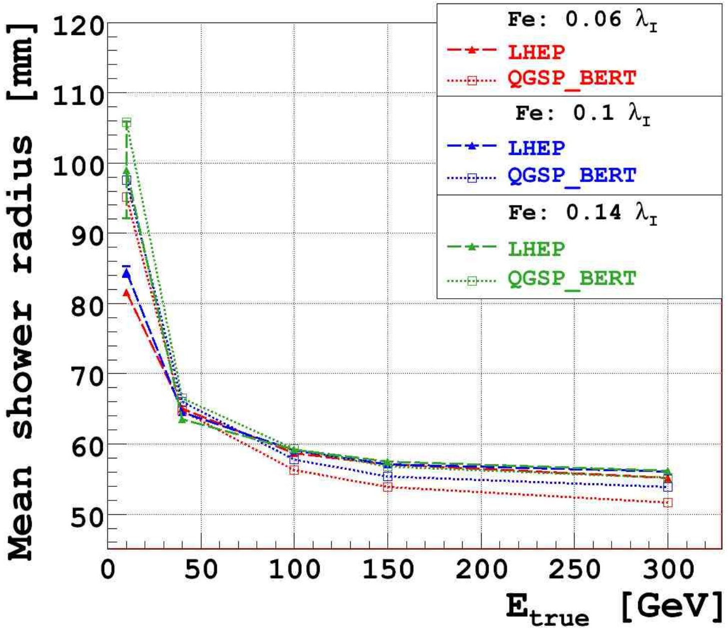


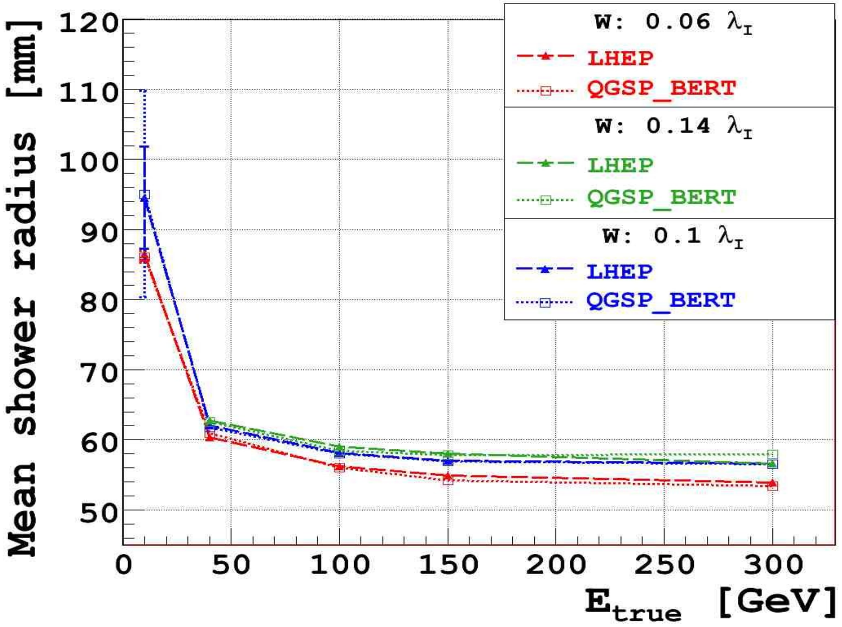


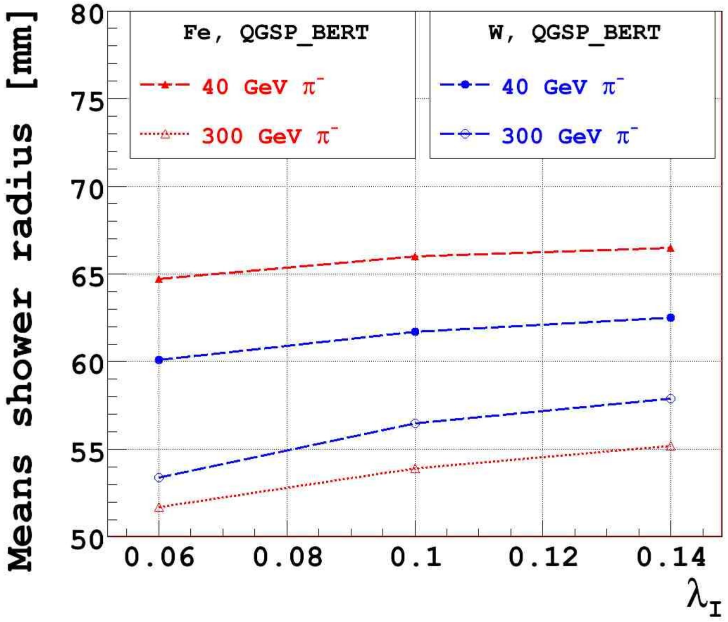


- 40 GeV π^- : $R_{95\%} \approx$ 22cm for W and Fe
- 300 GeV π^- : 95% containment at smaller radius for Fe

Mean Shower Radius



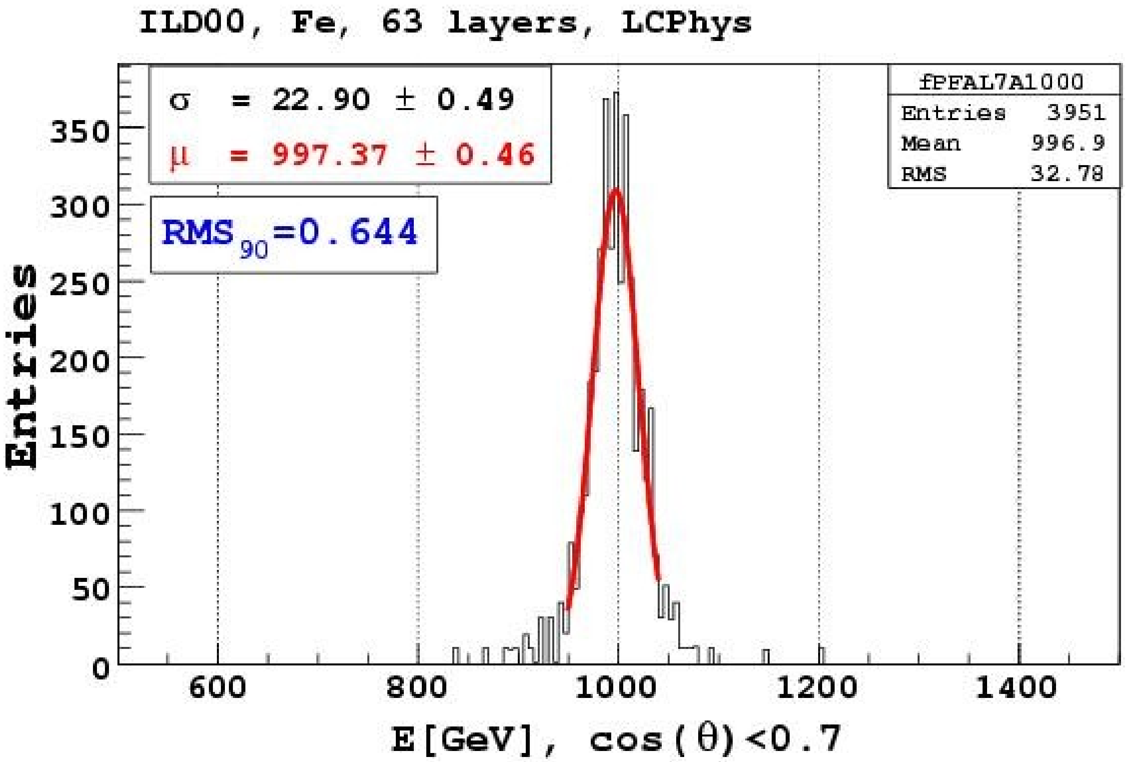




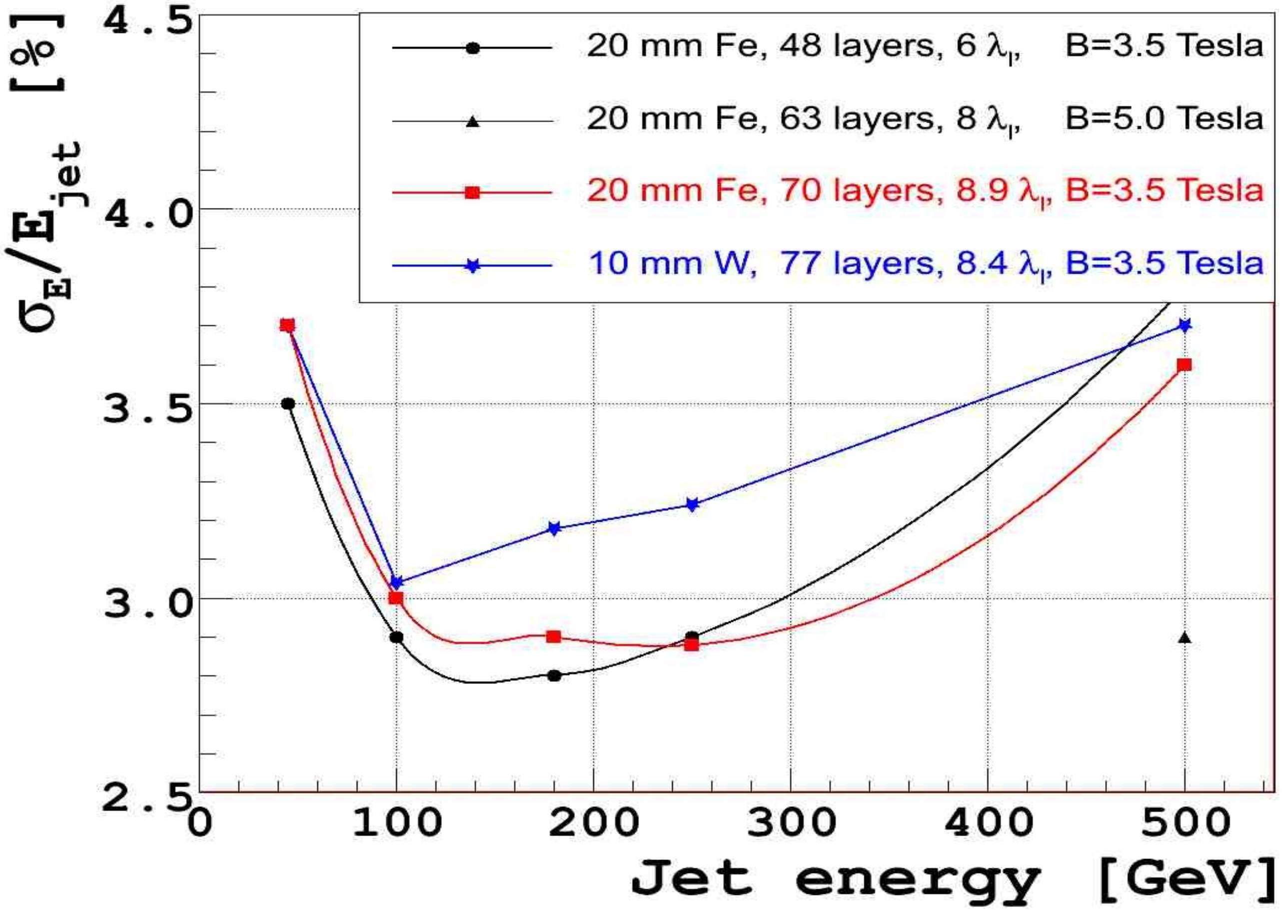
- 40 GeV π^- : smaller radius for W
- 300 GeV π^- : smaller radius for Fe

Particle Flow Performance

- Modified ILD detector
  - 77 layers of 10mm W + 5mm Scint ≈ 8.4 λ
  - 70 layers of 20mm Fe + 5mm Scint ≈ 8.9 λ
- Use Pandora PFA (without special tuning)
- Example for 8.0 λ HCal, Fe absorber, B = 5 T : $\sigma_E/E \approx 64\%/\sqrt{E/\text{GeV}}$
- Consistent with M. Thomsons results



Particle Flow Performance



- Jet energy resolution comparable for W and Fe for low energies
- W performance degrades for higher energies
- No tuning of Pandora PFA

Plans for W HCal Prototype

- Verify simulation results with a tungsten HCal prototype
- Re-use existing active modules (scintillator, micromegas, …)
- Re-use existing mechanical support structure
- Very productive workshop on September 24 at LAPP
  - http://indico.cern.ch/conferenceDisplay.py?confId=68025
- Possible dimensions:
  - 40 layers
  - Between 60x60 cm^2 and 80x80 cm^2 W plates in Fe or Al frame
- Possible timeline
  - 2010 – start of W plate production
  - 2011 – first beam tests

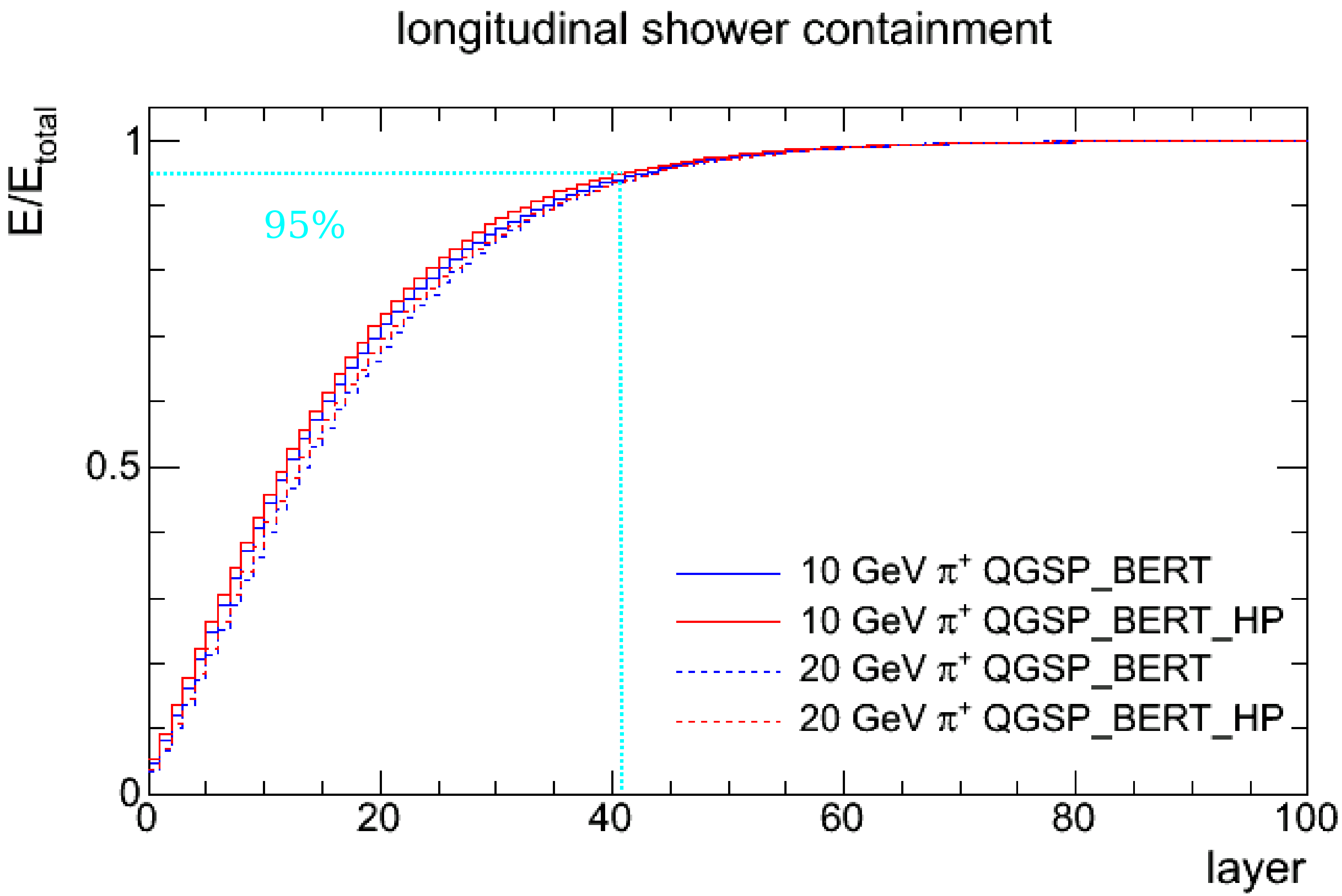
Conclusion & Outlook

- W HCal is a viable option at CLIC energies because of the strong constraints imposed by the coil radius
- Further simulation studies are needed, especially for PFA performance
- A prototype is needed to verify simulations
- Construction of a W HCal prototype is planned within CALICE

Thank You

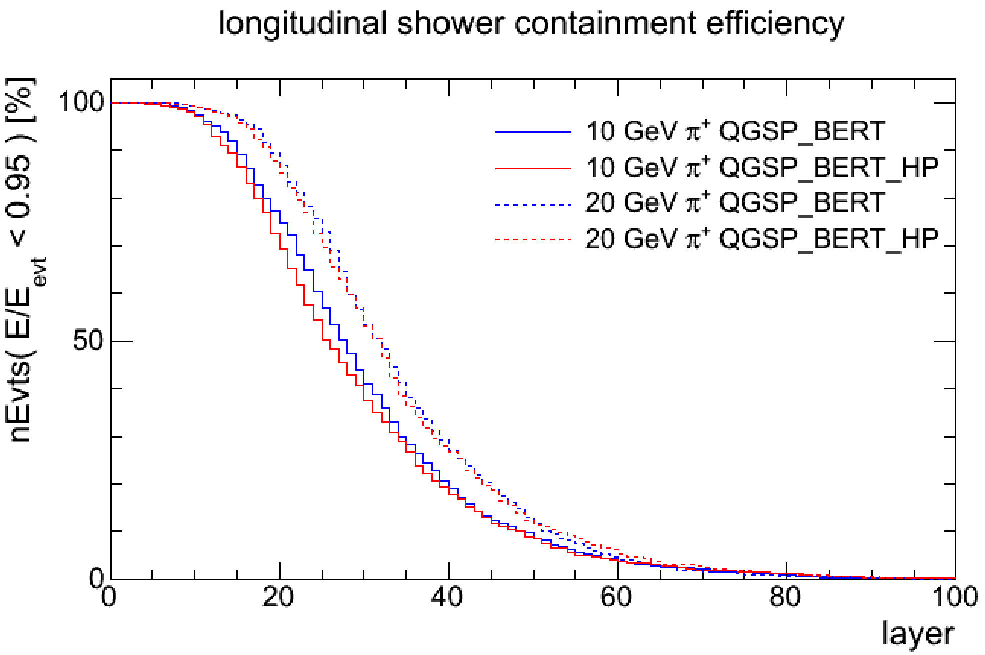
Backup Slides

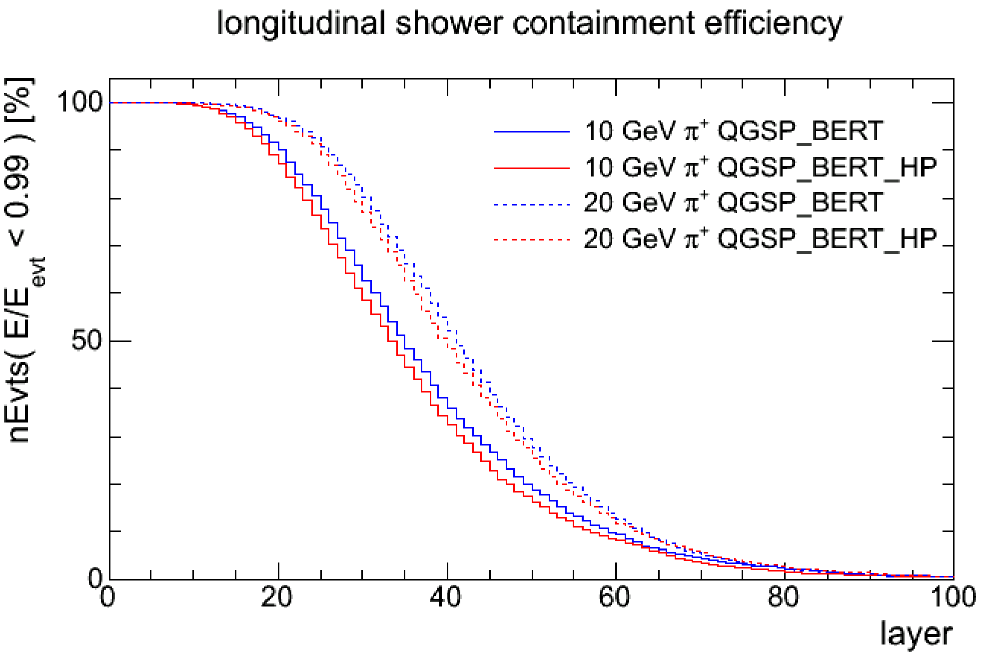
Longitudinal Shower Size



12 mm tungsten + scint

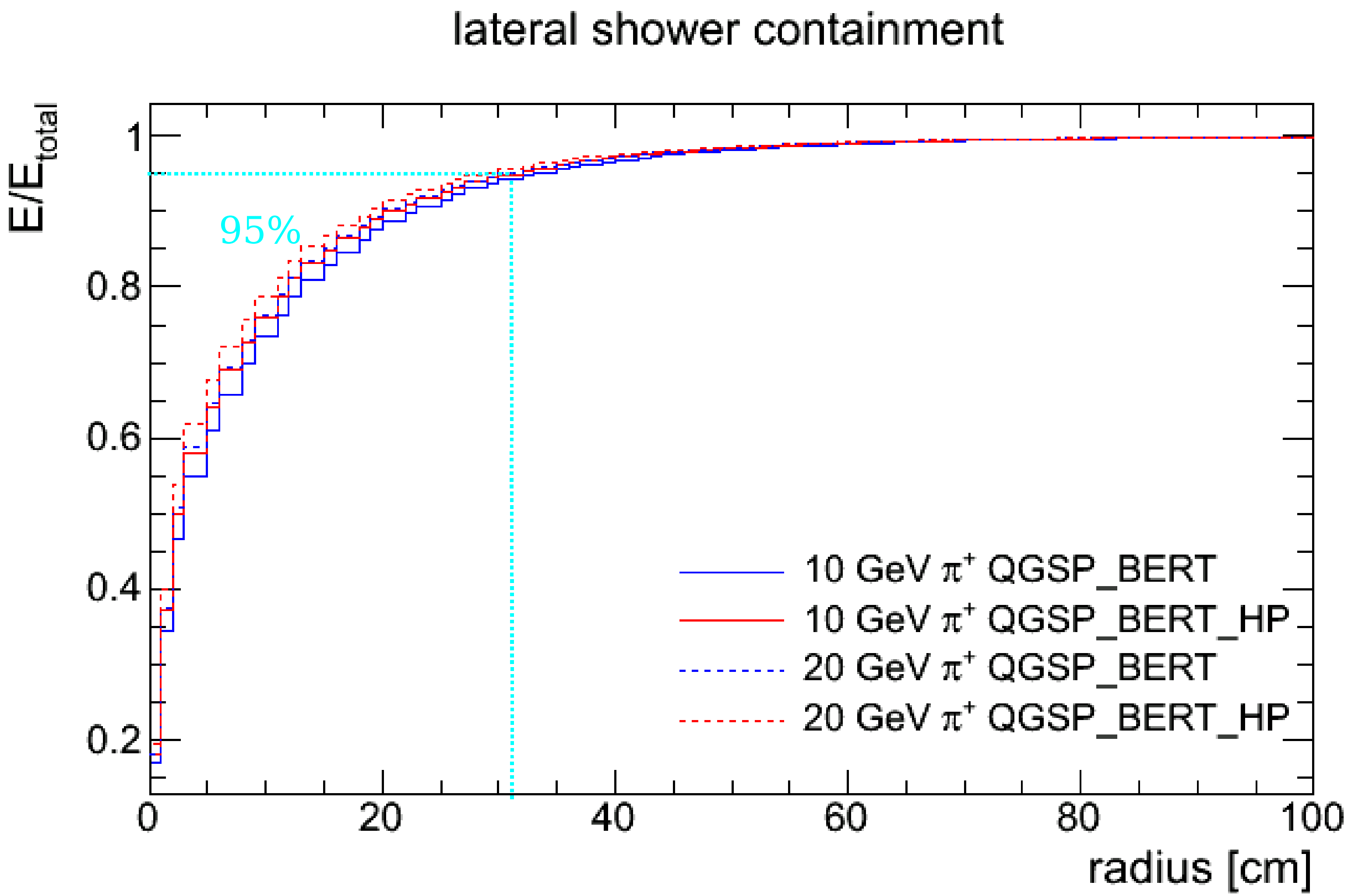
Longitudinal Containment Efficiency





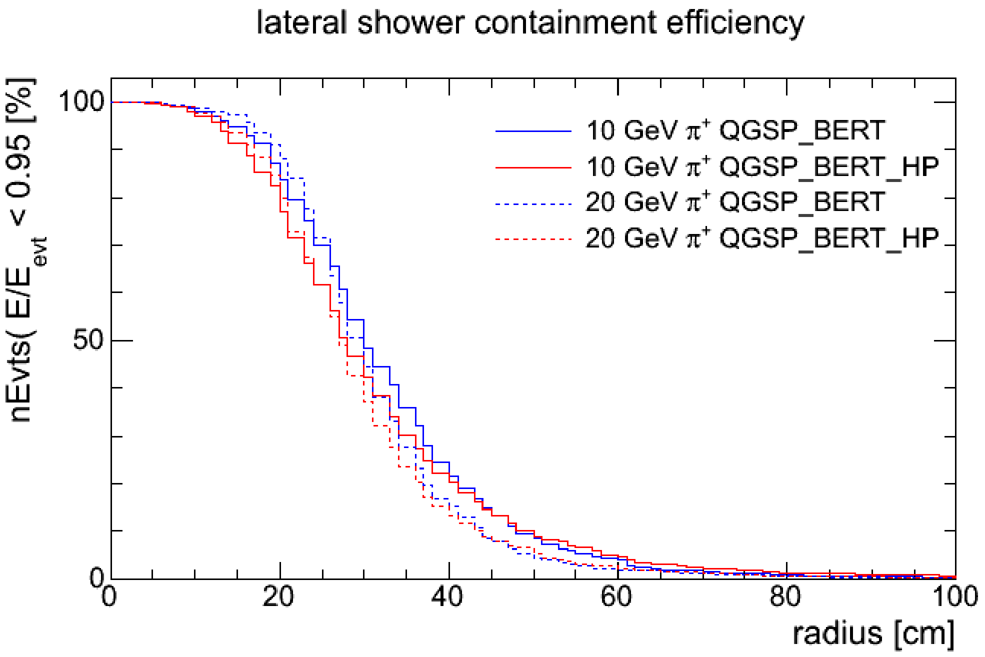
12 mm tungsten + scint

Lateral Shower Size

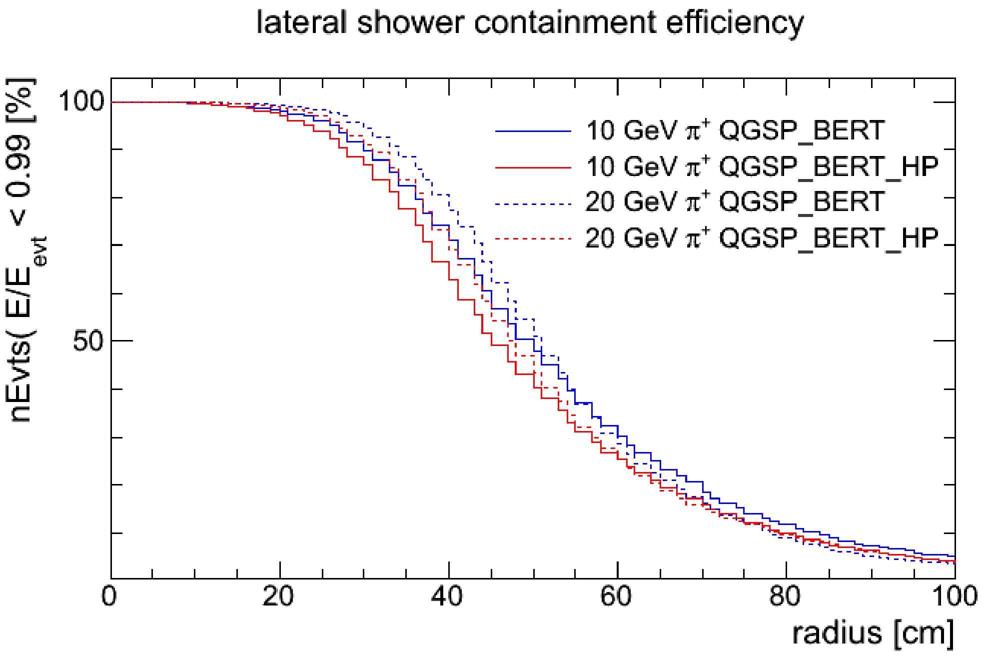


12 mm tungsten + scint

Lateral Containment Efficiency



lateral shower containment efficiency

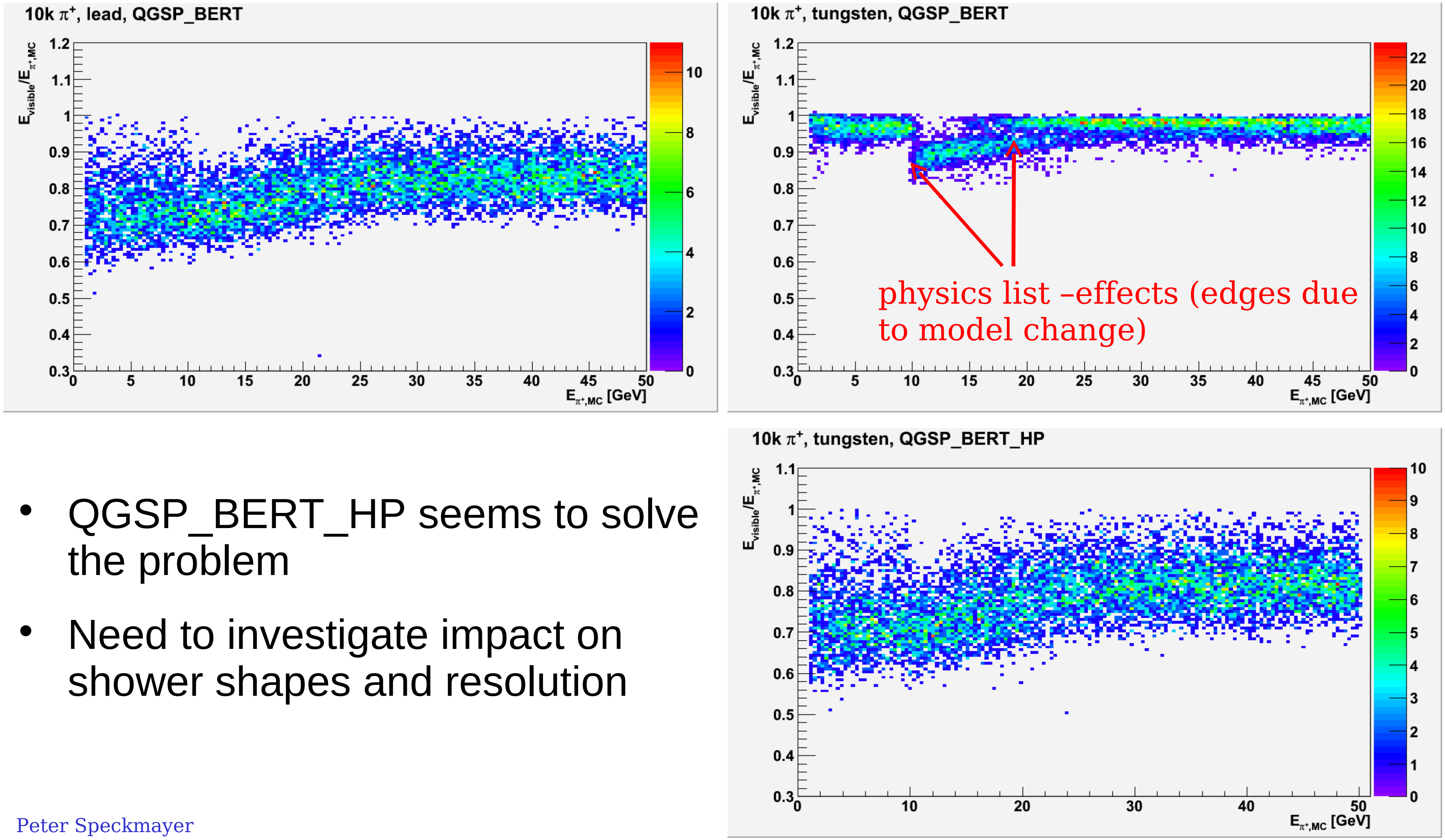


lateral shower containment efficiency

12 mm tungsten + scint

Possible Errors in Simulation

- GEANT4 treatment of neutrons spoils visible energy simulation

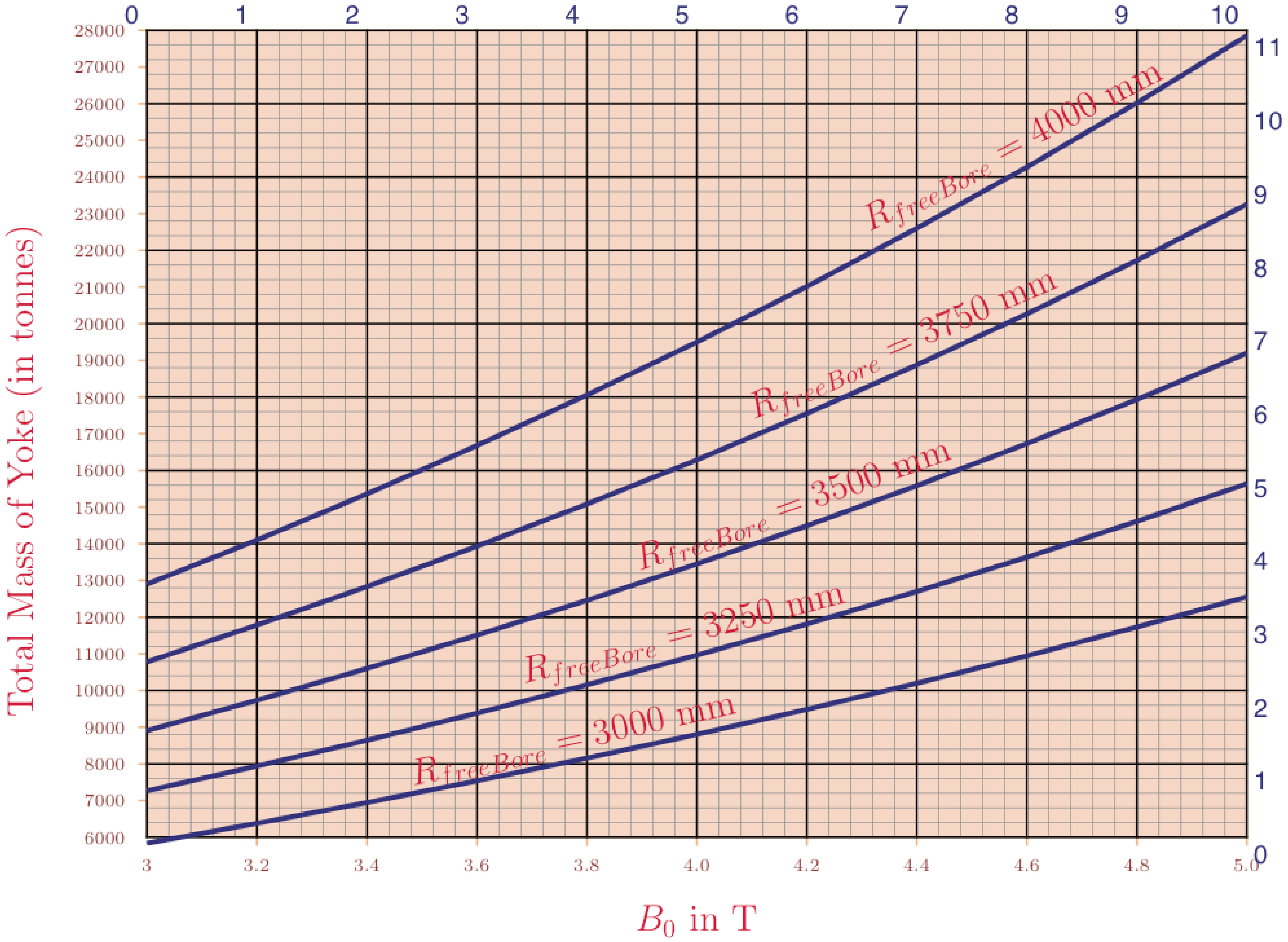


physics list –effects (edges due to model change)

- QGSP_BERT_HP seems to solve the problem
- Need to investigate impact on shower shapes and resolution

Peter Speckmayer

Coil Parametrization



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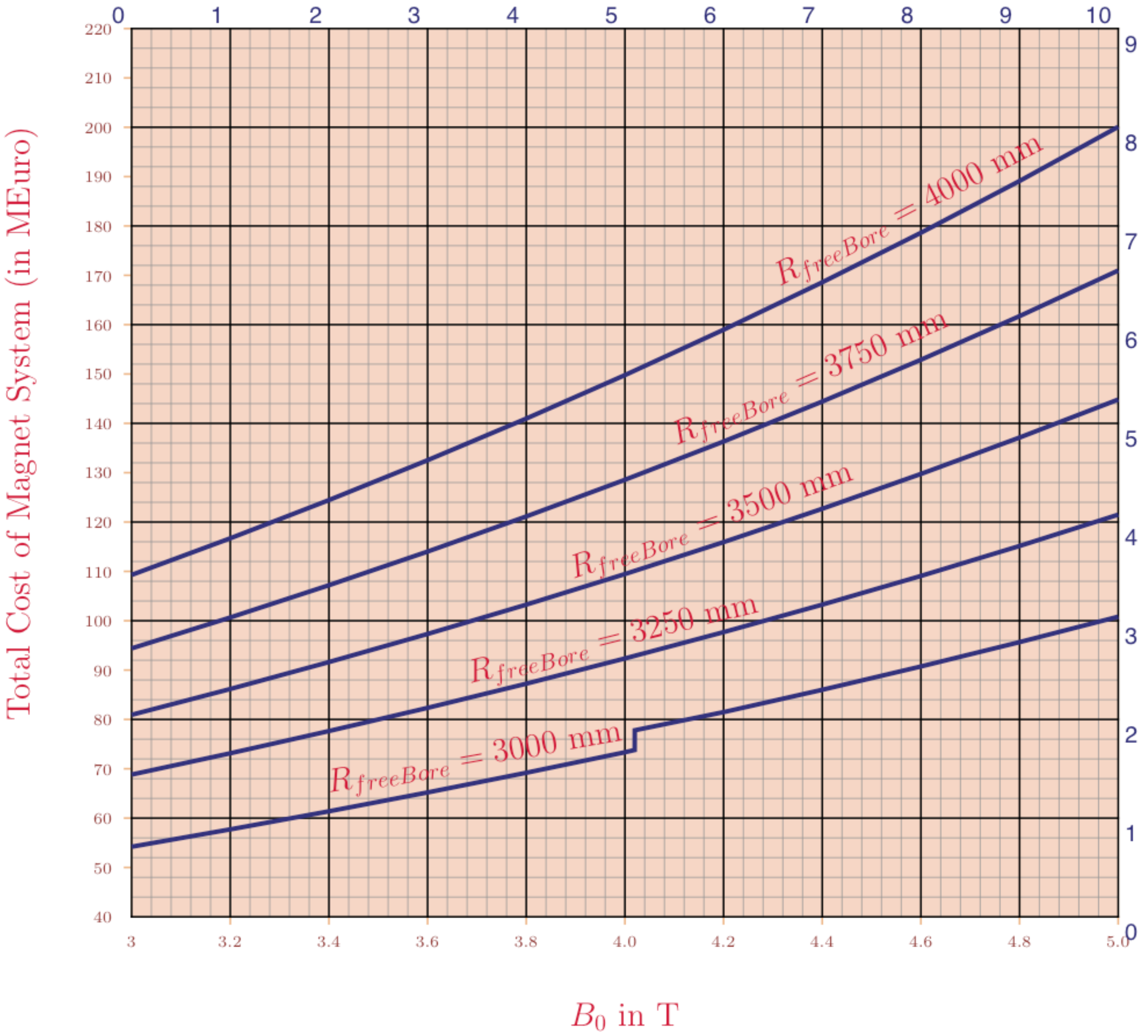
Coil Parametrization



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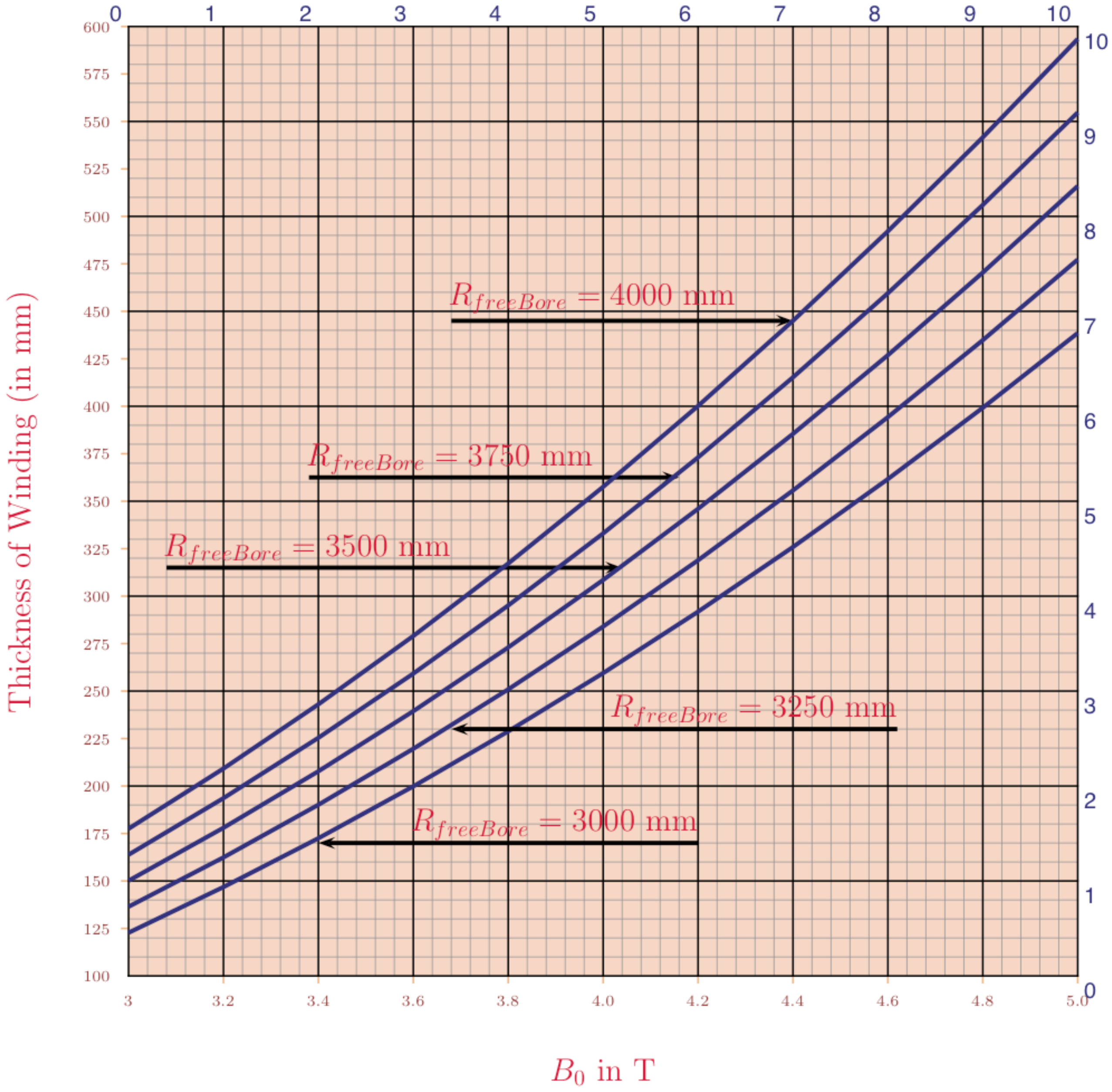
Coil Parametrization



Alain Hervé

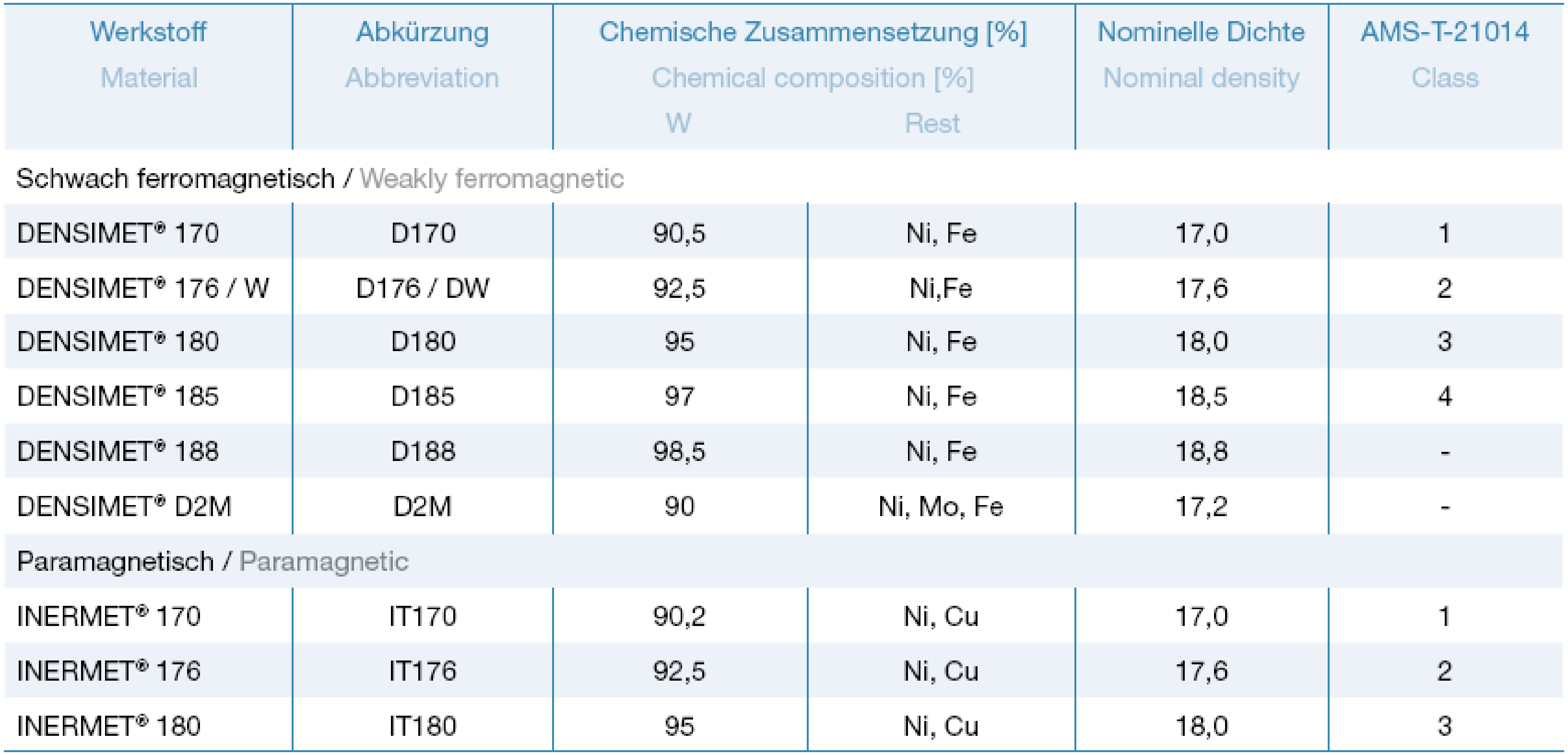
Tungsten Properties

- Pure tungsten
  - $\rho = 19.3\ \mathrm{g/cm^3}$
  - $\lambda = 9.94$ cm, $X_0 = 0.35$ cm
  - brittle and hard to machine

- Tungsten alloys with W > 90% + Cu / Ni / Fe
  - $\rho = 17 - 19\ \mathrm{g/cm^3}$
  - $\lambda \approx 10$ cm, $X_0 \approx 0.4$ cm
  - Well established production procedure
  - Easy to machine
  - Price ~ 70 Euro/kg (without machining)

Tungsten Alloys

- Tungsten is usually used in alloys for better mechanical properties and machinability
- Several ferromagnetic (W,Ni,Fe) or paramagnetic (W,Ni,Cu) alloys are available



Werkstoff Material	Abkürzung Abbreviation	Chemische Zusammensetzung [%] Chemical composition [%]		Nominelle Dichte Nominal density	AMS-T-21014 Class
		W	Rest		
Schwach ferromagnetisch / Weakly ferromagnetic					
DENSIMET® 170	D170	90,5	Ni, Fe	17,0	1
DENSIMET® 176 / W	D176 / DW	92,5	Ni,Fe	17,6	2
DENSIMET® 180	D180	95	Ni, Fe	18,0	3
DENSIMET® 185	D185	97	Ni, Fe	18,5	4
DENSIMET® 188	D188	98,5	Ni, Fe	18,8	-
DENSIMET® D2M	D2M	90	Ni, Mo, Fe	17,2	-
Paramagnetisch / Paramagnetic					
INERMET® 170	IT170	90,2	Ni, Cu	17,0	1
INERMET® 176	IT176	92,5	Ni, Cu	17,6	2
INERMET® 180	IT180	95	Ni, Cu	18,0	3

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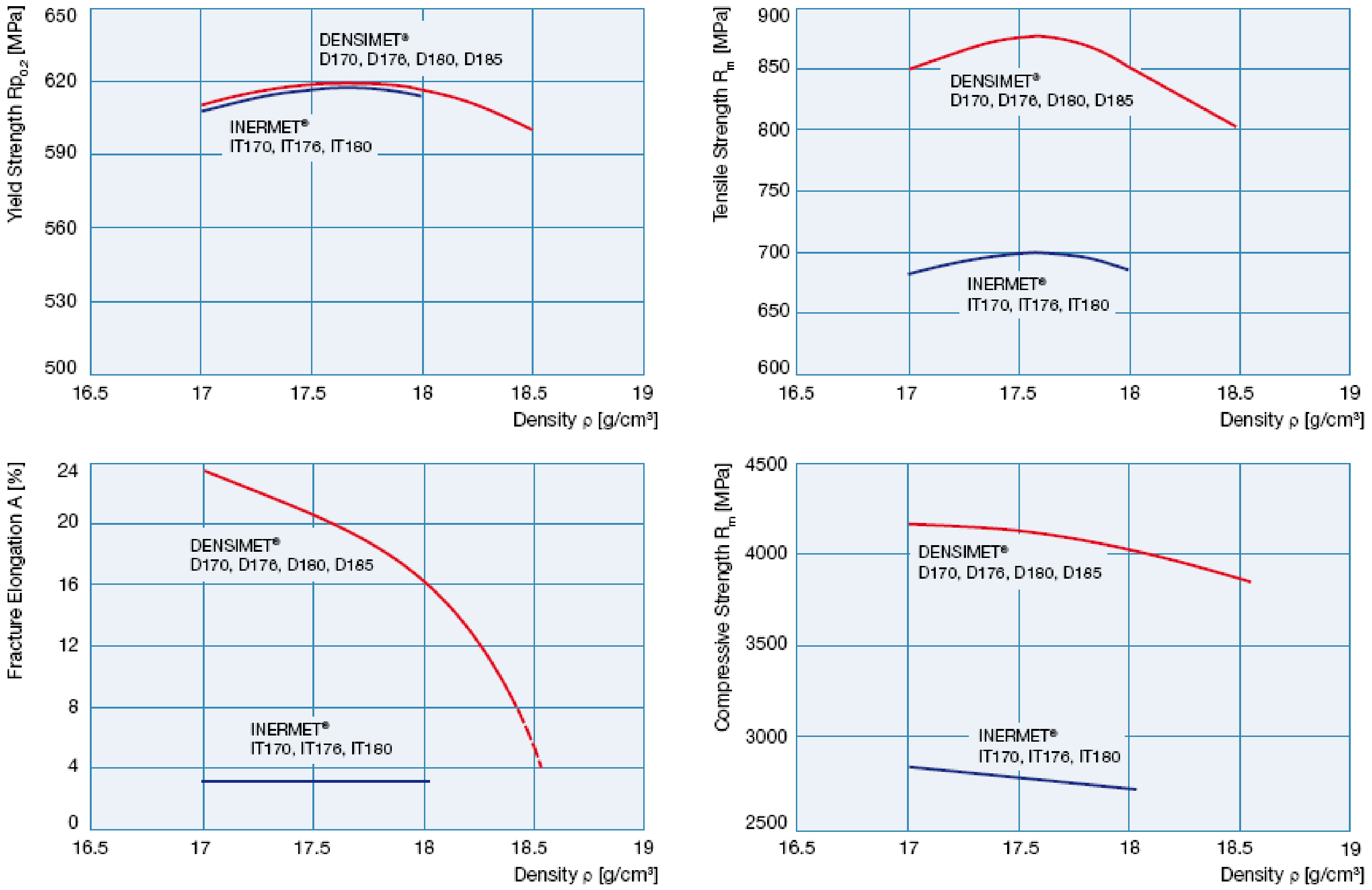
Tungsten Alloys

	D170	IT170	D176 / W	IT176	D180	IT180	D185
Elastizitätsmodul E [GPa] Young‘s modulus E [GPa]	340	330	360	350	380	360	385
Schubmodul G [GPa] Modulus of rigidity G [GPa]	140	125	145	135	150	140	160



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