Tungsten as HCal-material for a LC at multi-TeV energies

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Outline

- Hcal with tungsten: simulation studies @ CERN
- Tungsten as HCal material
- Plans for a tungsten HCal prototype

Why Tungsten?

- CLIC @ 3TeV
- 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
- Smaller Lateral Shower Size
  - High energetic jets are more boosted
  - PFA performance is decreasing
- Tungsten might solve both problems

Tungsten HCal Simulations

- Investigate what modifications are needed for the ILC-detector concepts in a CLIC-scenario
- For calorimeters this means calorimetric performance and in particular PFA performance
- Questions to answer:
  - How many interaction lengths do we need?
  - Which sampling frequency is optimal?
  - Full detector and PFA studies (to be done)
    - Readout cell sizes?
    - Change magnetic field?
    - Change aspect ratio of the detector?

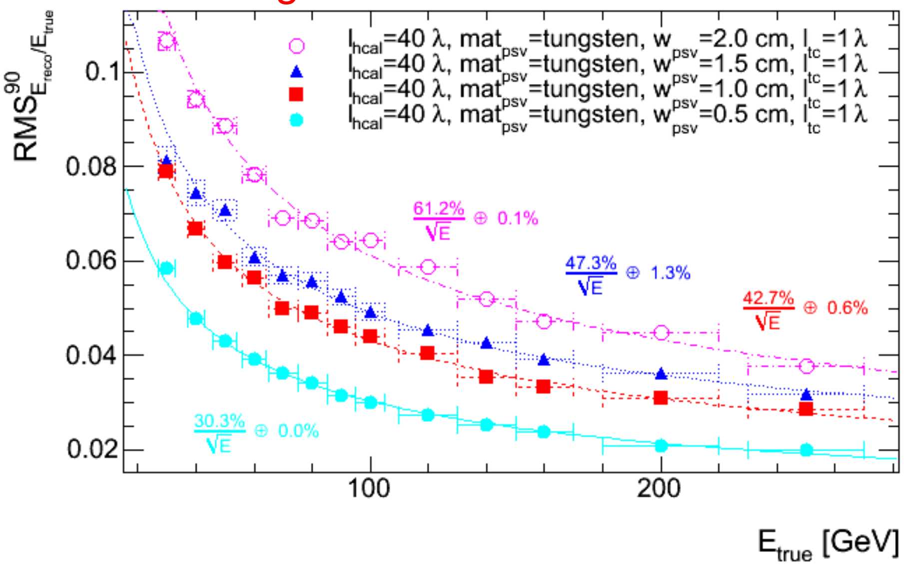
HCal-Stack Simulations

- Many different HCal-geometries with tungsten, steel and a combination of both, without changing the active parts (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 – corresponding to different HCal, coil and tailcatcher sizes
- Defined simple shower variables: width, length, center, energy density, etc.
- Used a neural network (TMVA) to reconstruct the π^+ energy

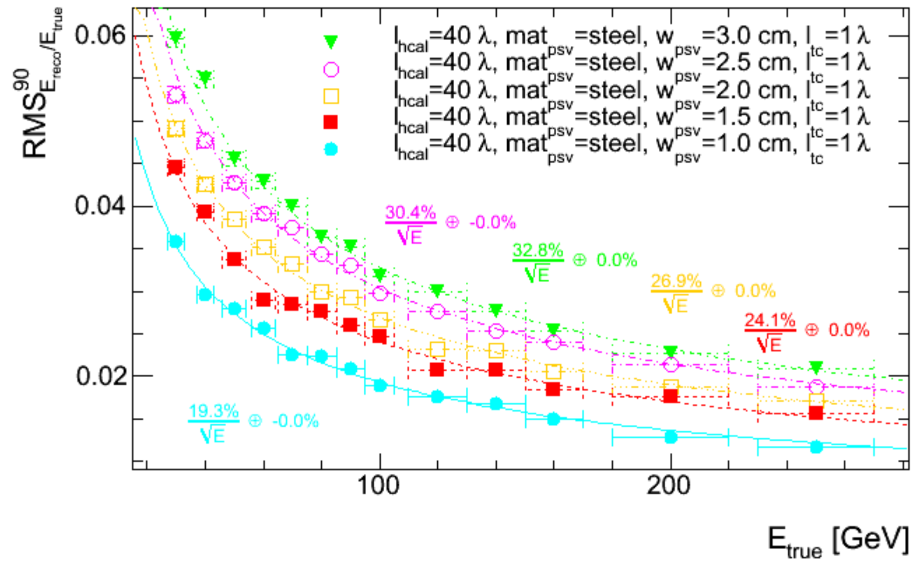
HCal-Stack Simulations

- “extremely deep”-HCal performance

Tungsten



Steel

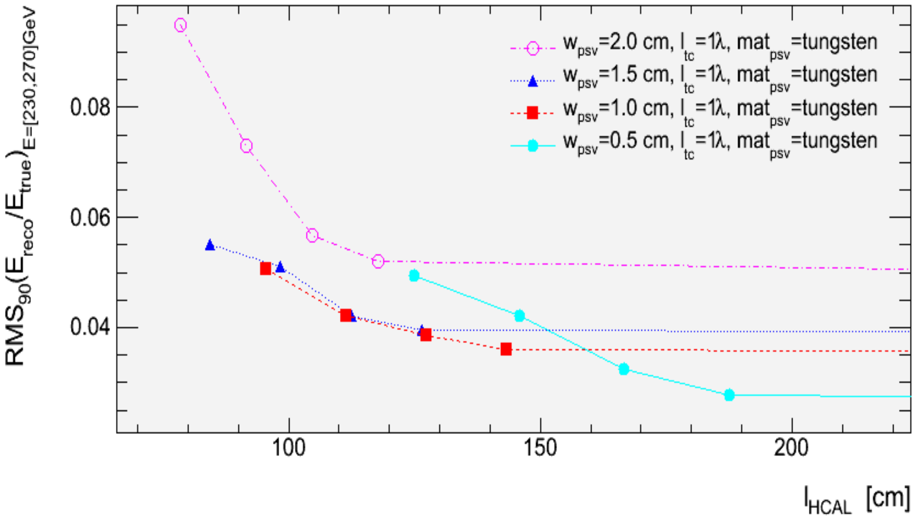


- Linearity is better than 2% (not shown)
- “extremely deep”-case:
  - Finer passive layers are better
  - Steel performs better than tungsten

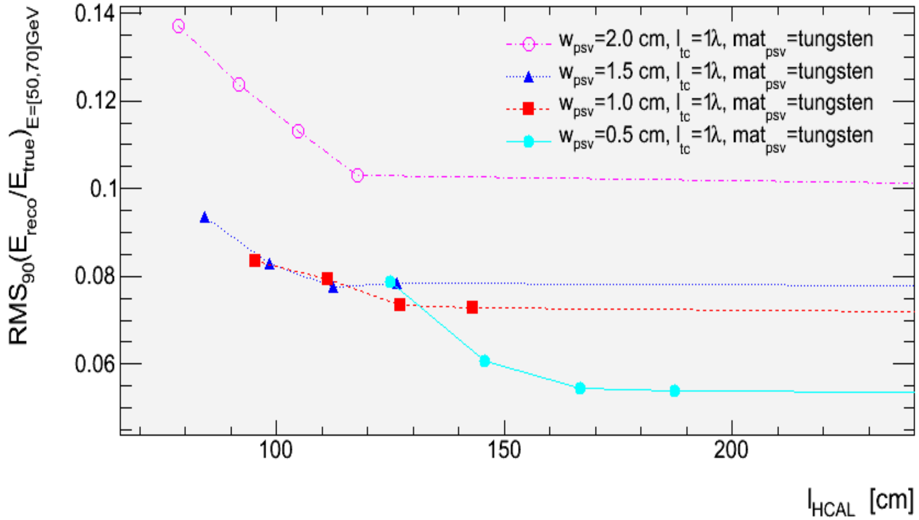
CLIC-PH-Note, Speckmayer & Grefe (in preparation)

- Performance vs HCal depth (tungsten)

E_{MC} ~ 250 GeV



E_{MC} ~ 60 GeV



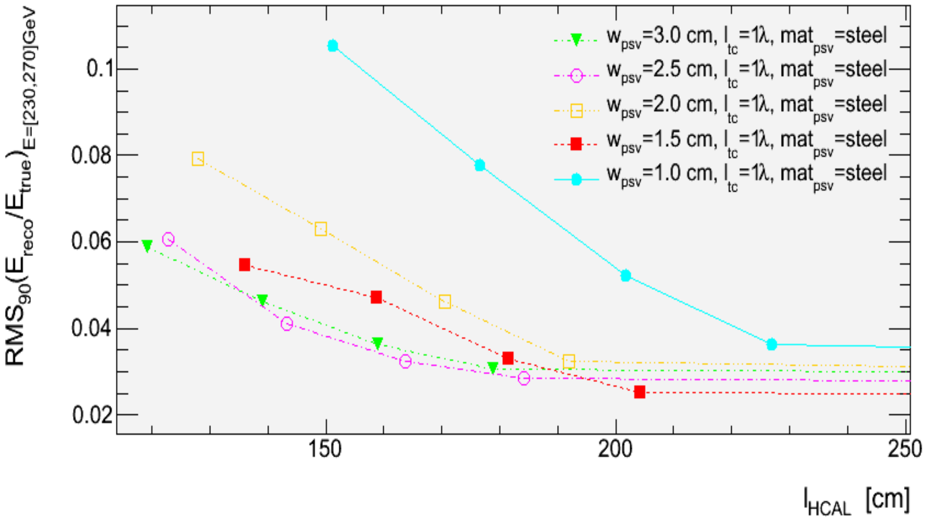
The 4 points of each graph correspond to 6, 7, 8 and 9 λ

- 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

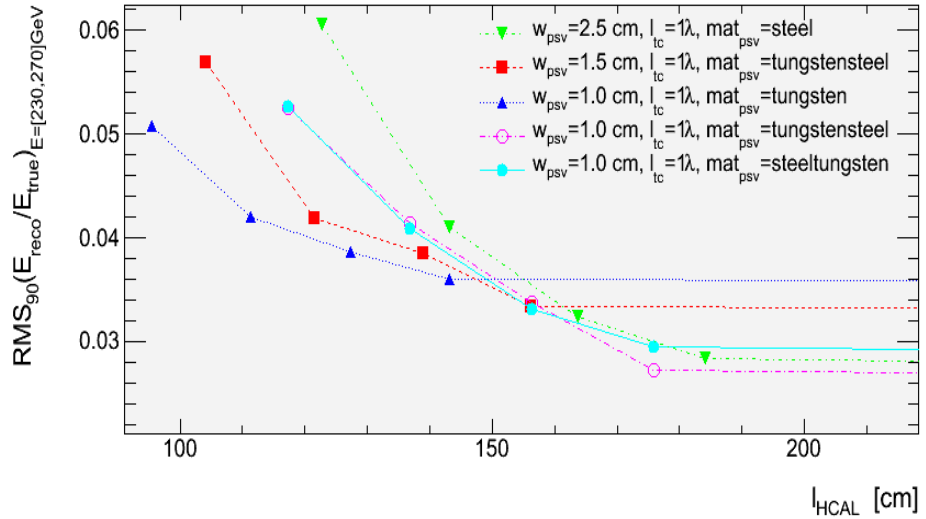
CLIC-PH-Note, Speckmayer & Grefe (in preparation)

- Performance vs HCal depth (tungsten vs steel)

Steel



Steel, Tungsten, Steel & Tungsten

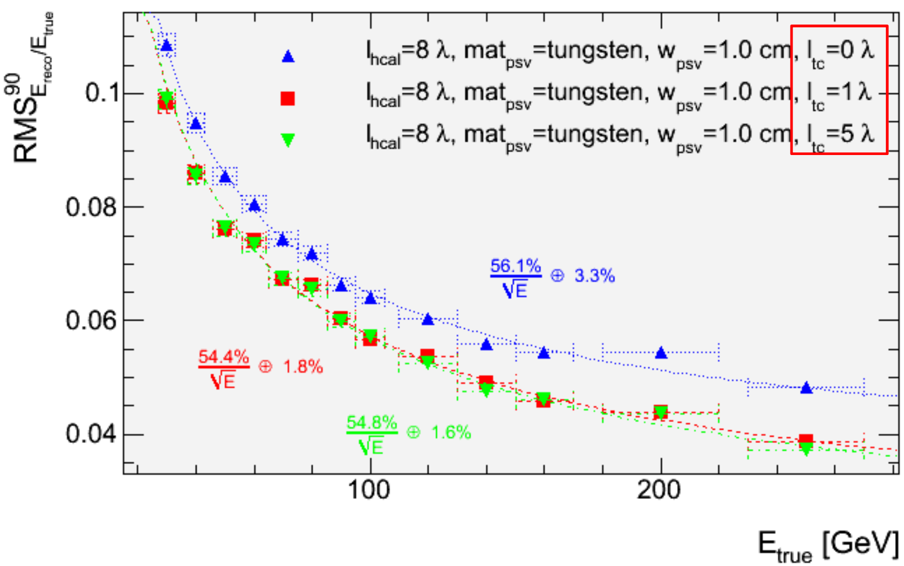


- Steel yields a better performance than tungsten, but only for a significantly deeper HCal
- For a tungsten-steel sandwich structure (50% thickness each), the W-Fe-Scint case performs slightly better than the Fe-W-Scint case, because more of the electromagnetic signal reaches the active layers

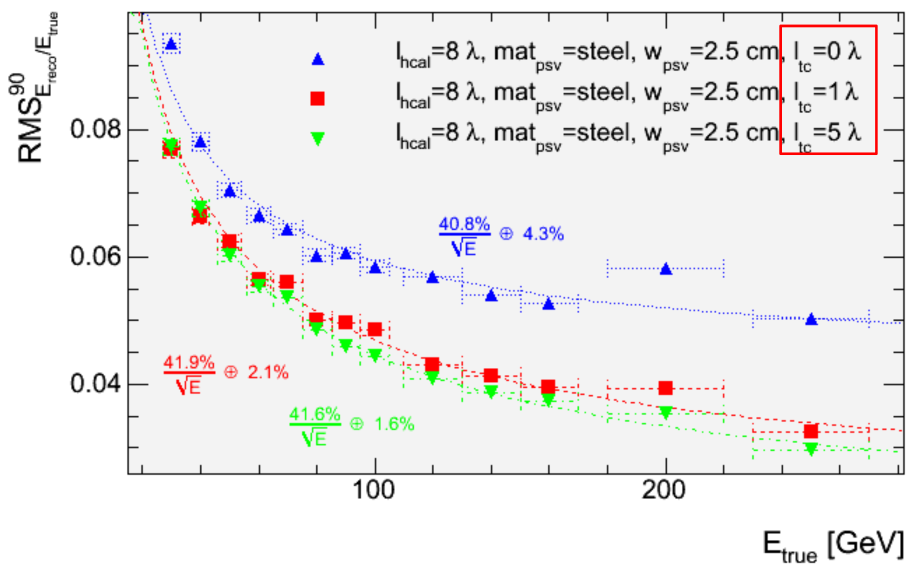
CLIC-PH-Note, Speckmayer & Grefe (in preparation)

- Impact of a Tailcatcher

Tungsten



Steel



- 0 λ implies no active material after the coil
- While the resolution is improved by adding a tailcatcher of ~1 λ the effect of an even bigger tailcatcher is negligible

CLIC-PH-Note, Speckmayer & Grefe (in preparation)

HCal Barrel Dimensions

calculated for 18 fold symmetry	ILD-flavor		SiD-flavor	
	10mm W	20 mm Fe	10 mm W	20 mm Fe
layers	70	60	70	60
R_{min} [cm]	200	200	141	141
R_{max} [cm]	320	370	270	310
Length [cm]	540	540	364	364
weight [t]	1200	930	650	500
Channels (1cm x 1cm)	$3.4*10^6$	$3.2*10^6$	$1.8*10^6$	$1.7*10^6$
Channels (3cm x 3cm)	$3.8*10^5$	$3.5*10^5$	$2.0*10^5$	$1.9*10^5$
λ	7.6	7.6	7.7	7.7
X_0	200	70	200	70

Properties of Tungsten

Tungsten Properties

- Pure tungsten
  - $\rho = 19.3\ g/cm^3$
  - $\lambda = 9.94$ cm, $X_0 = 0.35$ cm
  - brittle and hard to machine
- Tungsten alloys with W > 90% + Cu / Ni / Fe
  - $\rho = 17 – 19\ g/cm^3$
  - $\lambda \approx 10$ 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 [%] W	 Rest	Nominelle Dichte Nominal density	AMS-T-21014 Class
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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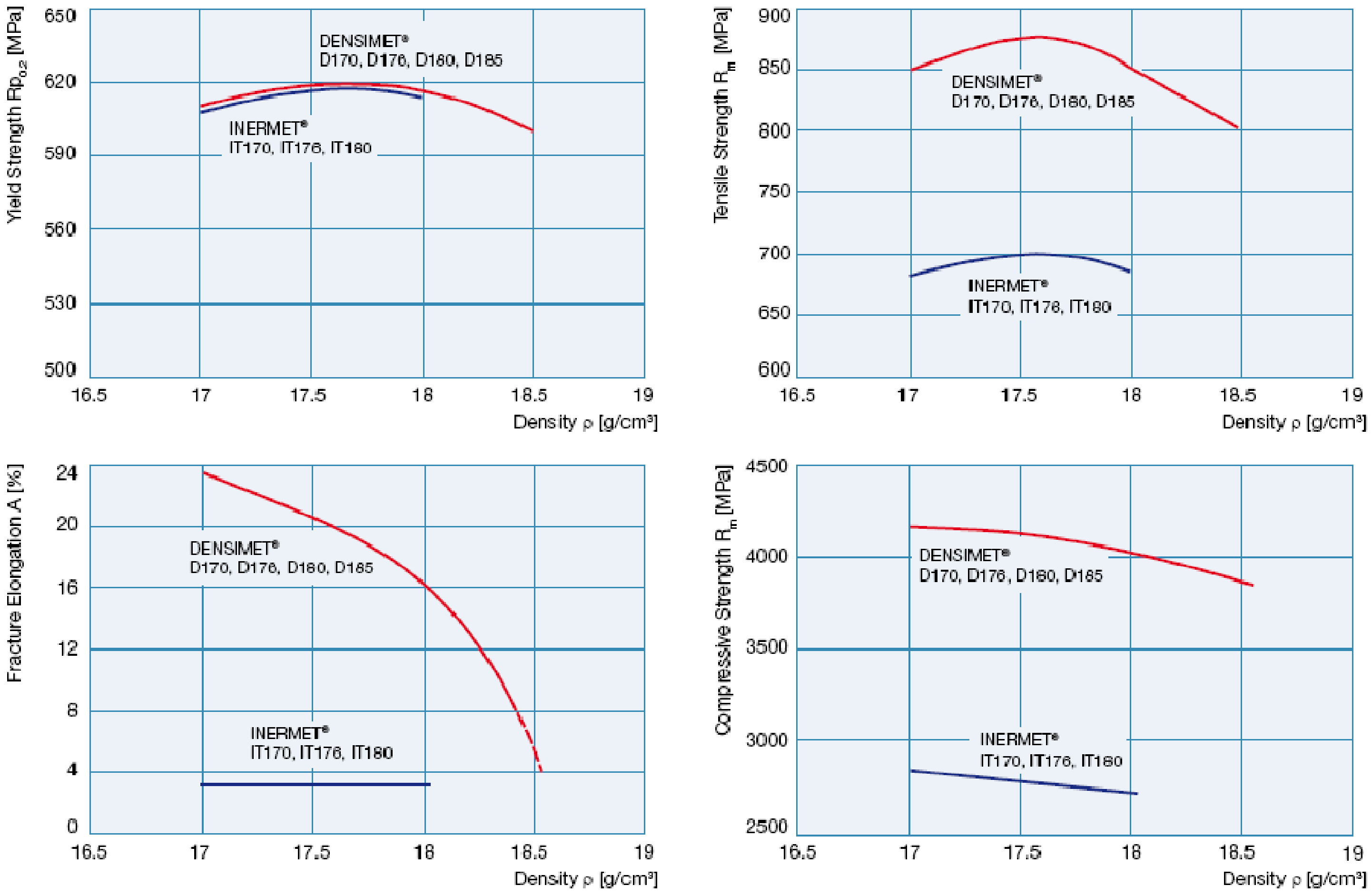
Tungsten Alloys

	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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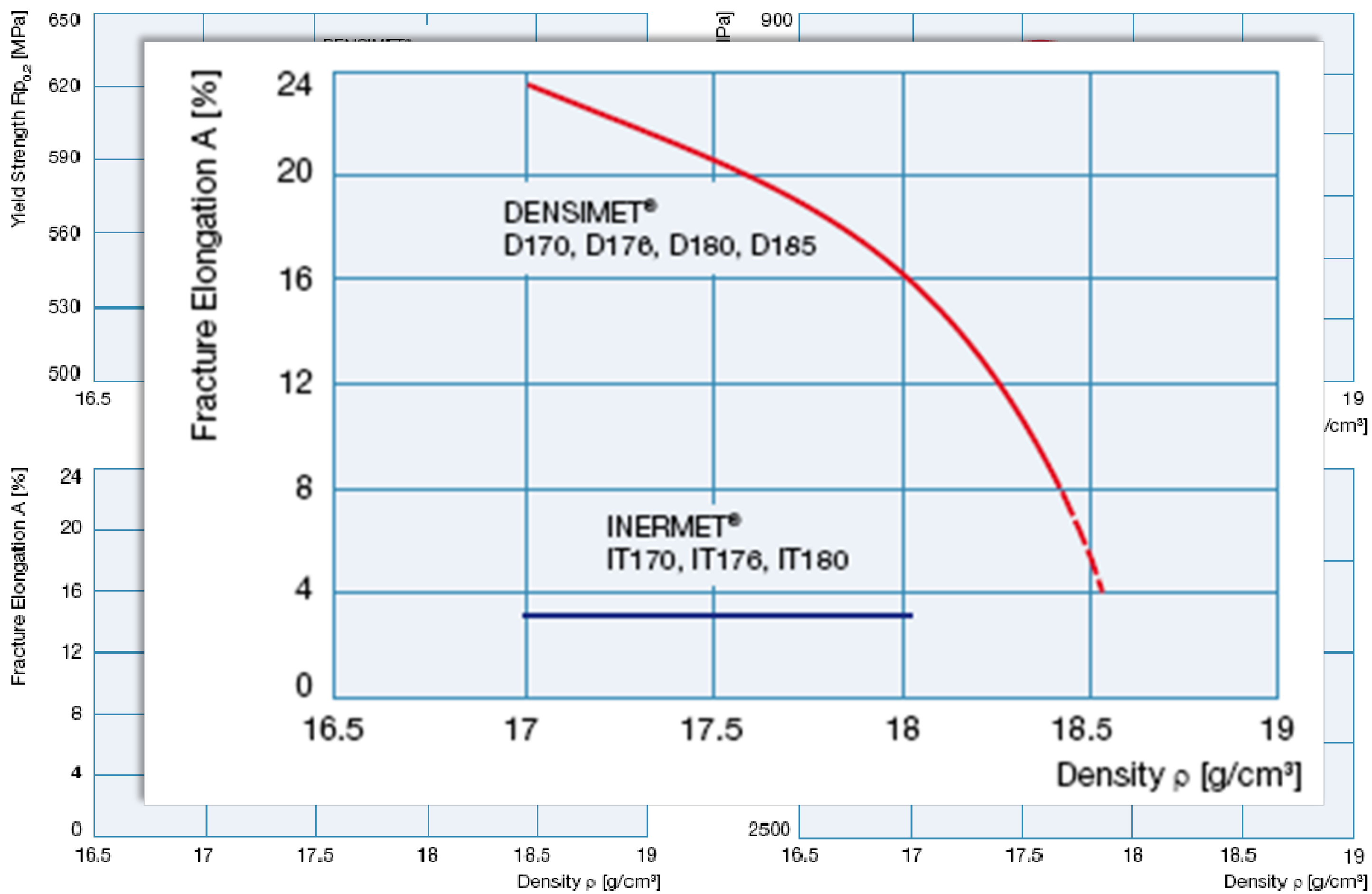

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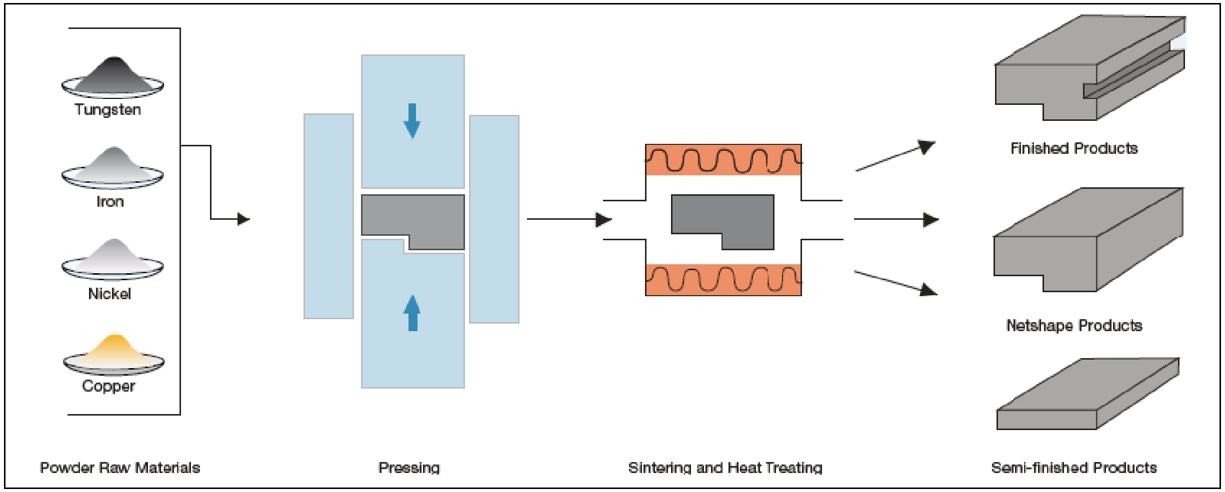
Tungsten Production

- Starting from powder, the metal mixture is first pressed and then scintered and finally machined
- Each production step increases the density
- The main limitations are:
  - Plate size – limited by the size of the oven
  - Thin plates – it has to be somehow stable after pressing
  - todays limitations are around 10 x 500 x 800 mm^3
- We are in contact with Industry to address these issues



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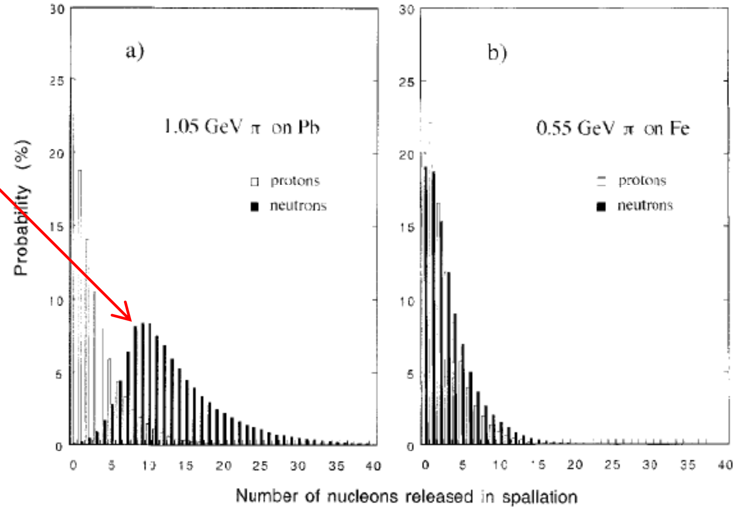
Tungsten HCal Prototype

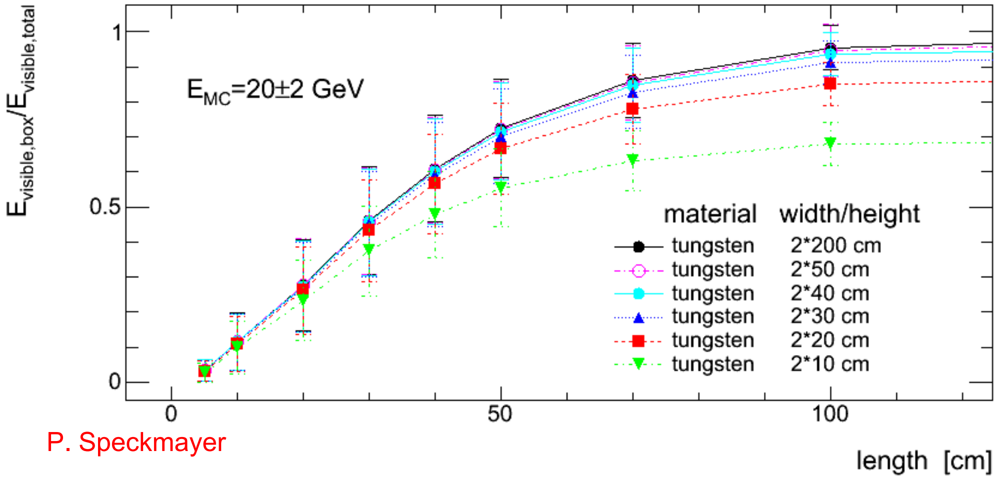
- Some questions can not be answered by simulations and need a real prototype:
- Physics performance:
  - Verify GEANT4 simulations (resolution, etc.)
  - Include noise terms – do slow neutrons spoil the signal?
  - Test PFA performance



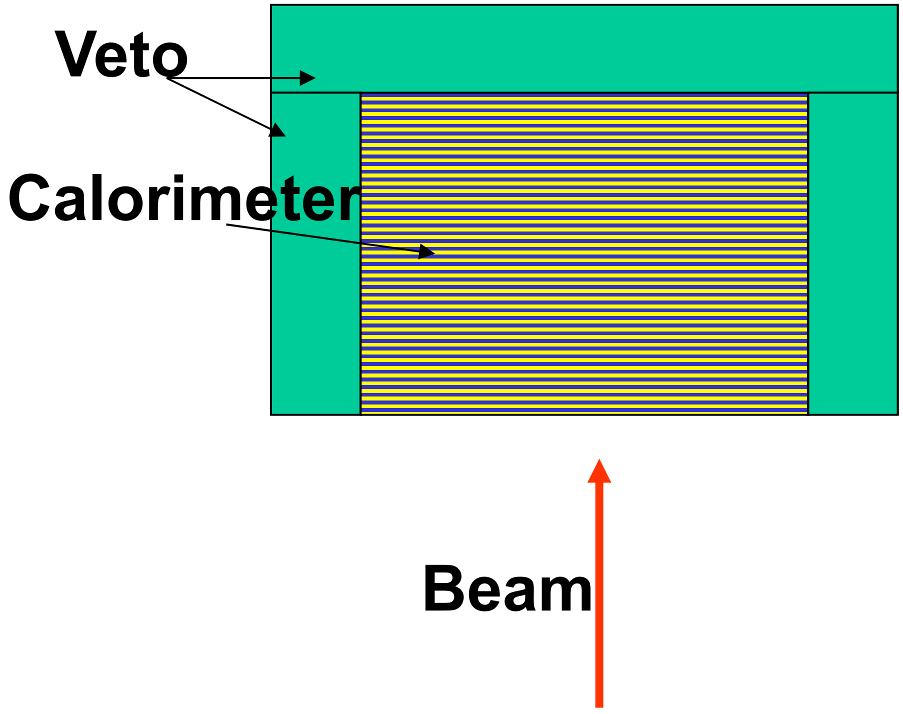
- Tungsten plate production process:
  - Production of large and thin plates
  - Quality of machining? Flatness of plates?
- Mechanical questions:
  - Test assembly in view of a full HCal segment

- If possible use existing CALICE active modules
  - Test Scintillator and RPC together with tungsten
- Start with a smaller prototype (less than 1x1 m^2 plate-size)
- Fill up unused space with Steel plates to have a veto signal and use only fully contained showers

20 GeV π+ using 10 mm W plates



P. Speckmayer



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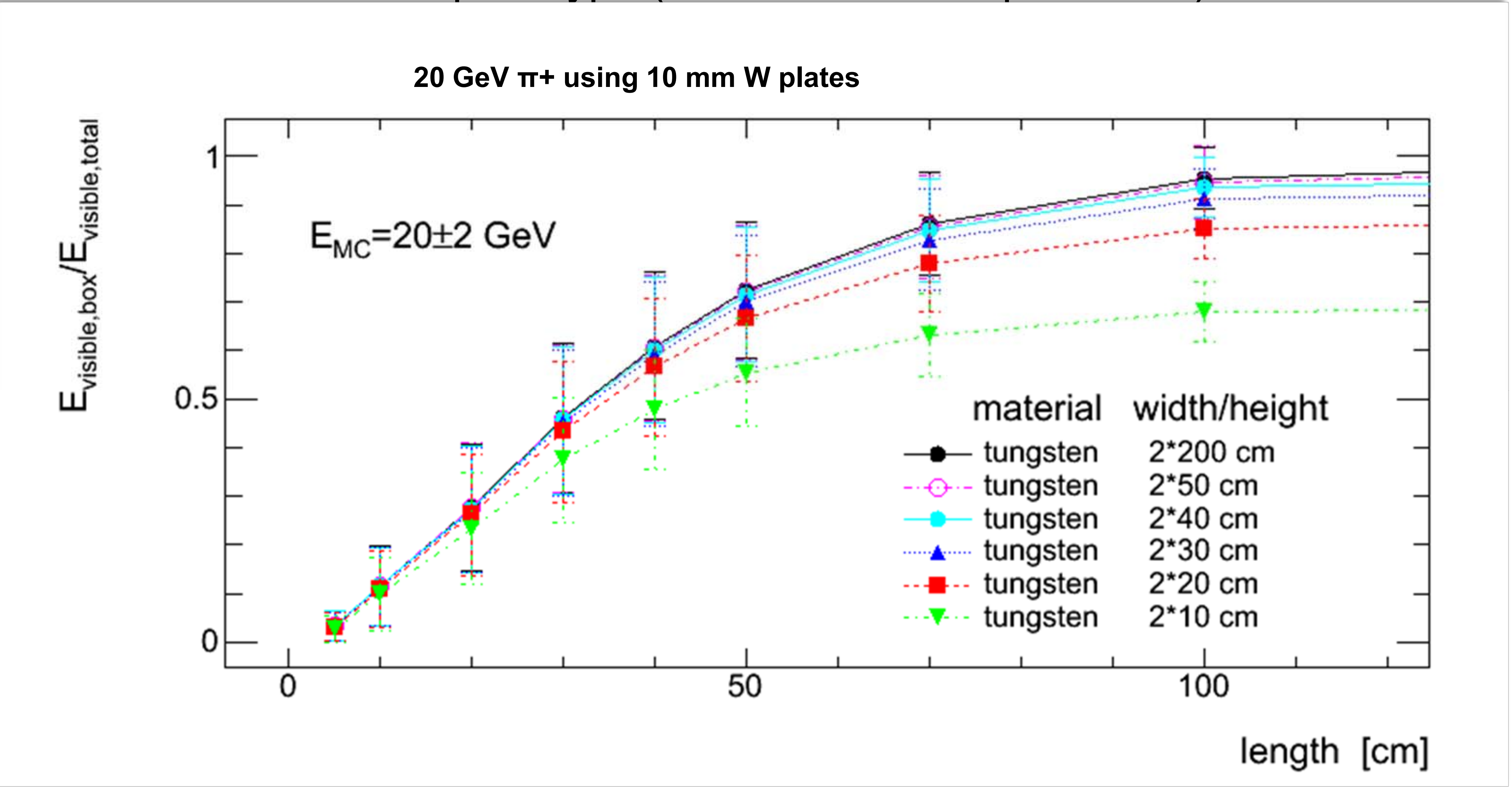

Tungsten HCal Prototype

- Cutting on the shower size biases the physics:
- Small showers means high electromagnetic fraction, but we want to investigate hadronic performance!
- Getting the lateral size right is more important than getting the depth right
  - Can select by first interaction without bias on the hadronic part of the shower
  - Easy to add more layers
- Need to understand correlation of shower content and shower size

  → ongoing studies
- Some rough numbers:
  - Minimum plate size seems to be 50x50 cm^2 (low energy tests)
  - Minimum length ~50 cm

Conclusion

Conclusion and Outlook

- Simulations with tungsten
  - 8 - 9 λ total (ECal + HCal) seem to be sufficient for π^+ up to 300 GeV
  - For the given HCal dimensions an ~10mm W-absorber seems optimal
  - 1 λ Tailcatcher is useful
  - Estimations based on "conventional" calorimetry and leakage
  - Need to verify with PFA performance
- Production of the tungsten plates seems possible
- Tungsten HCal prototype
  - If we seriously want to investigate a tungsten HCal option a prototype is necessary
  - Possible extension for CALICE-program
  - Strong interest from CERN – We need your help!