Y.R. calorimetry meeting, 04/7 2020 O.Tsai (UCLA)

Topics:
- High Resolution HCals
- Compensation.
- ZEUS DU, details

1. All operational high resolution HCals were compensated
Quoted energy resolutions:

ZEUS ~ $35\%/\sqrt{E} \oplus 2\%$ DU/Sc (longitudinal leakages treated with BCAL)
WA80 ~ $33\%/\sqrt{E} \oplus 1.3\%$ DU/Sc (Zero Degree Calorimeter, full absorption)
E864 ~ $34\%/\sqrt{E} \oplus 3.5\%$ Pb/ScFi (full absorption) (copied from R.W. SPACAL)

2. Resolution was dominated by sampling fluctuations.

3. Used high sampling fraction or high sampling frequency (Pb).

4. Compensation were extensively studied at that time.

5. First compensated calorimeter was ZEUS Pb/Sc prototype.

6. There are many factors one has to take into account to achieve compensation.
At zero order, compensation defined by ratio of thickness of passive and active medium,
DU/Sc ~ 1, Pb/Sc ~4

Containment, Longitudinal.

As shown is a bit misleading...

50 GeV – $L_{95} = 4.7\lambda$
100 GeV – $L_{95} = 5.6\lambda$

Absorber:	L_{95}(50 GeV)	L_{95}(100 GeV)
Fe	80 cm	94 cm
Pb	83 cm	99 cm
Cu	72 cm	86 cm
W	47 cm	56 cm
U	52 cm	61 cm

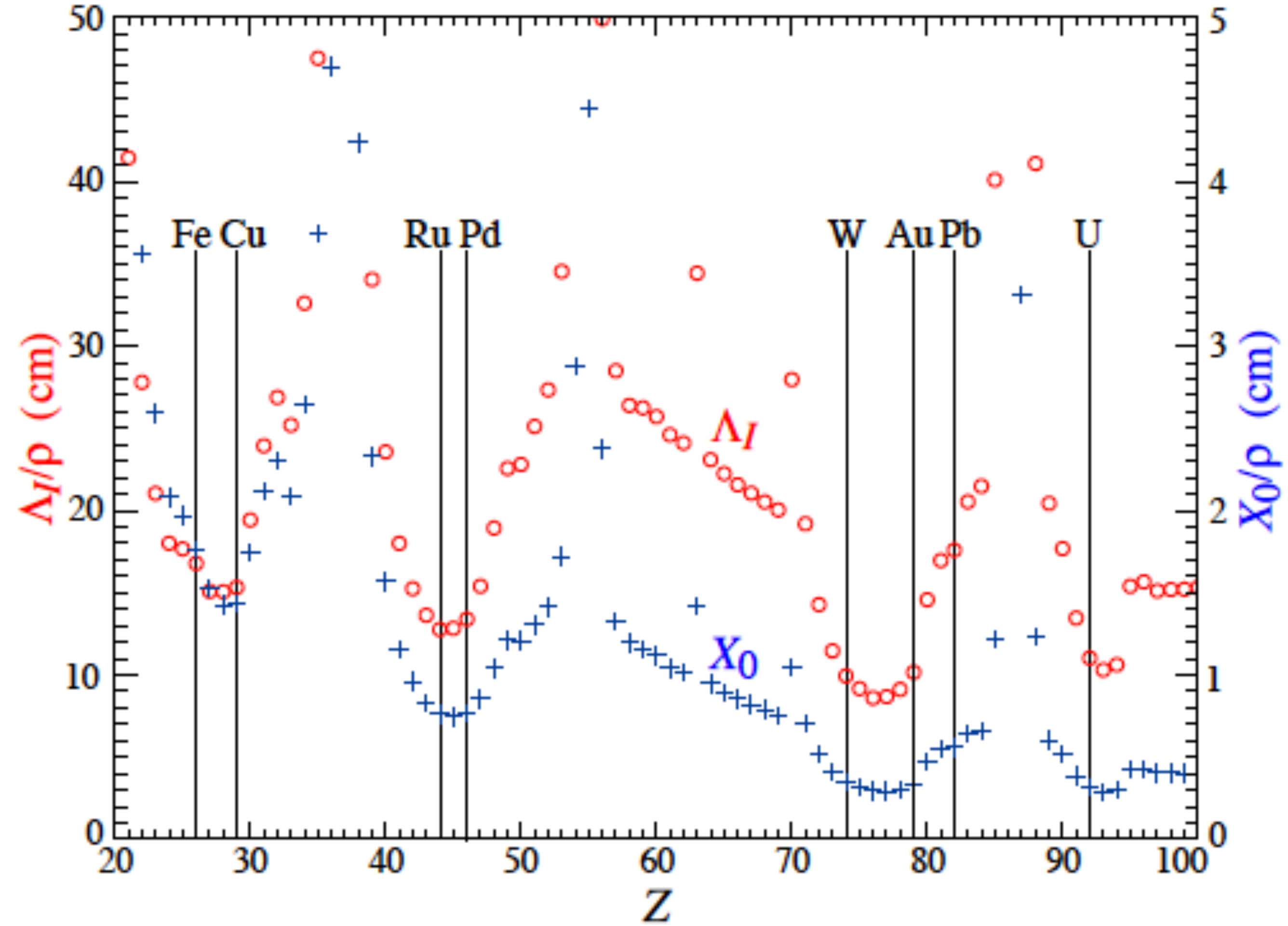


Figure 33.21: Nuclear interaction length λ_I/ρ (circles) and radiation length X_0/ρ (+'s) in cm for the chemical elements with $Z > 20$ and $\lambda_I < 50$ cm.

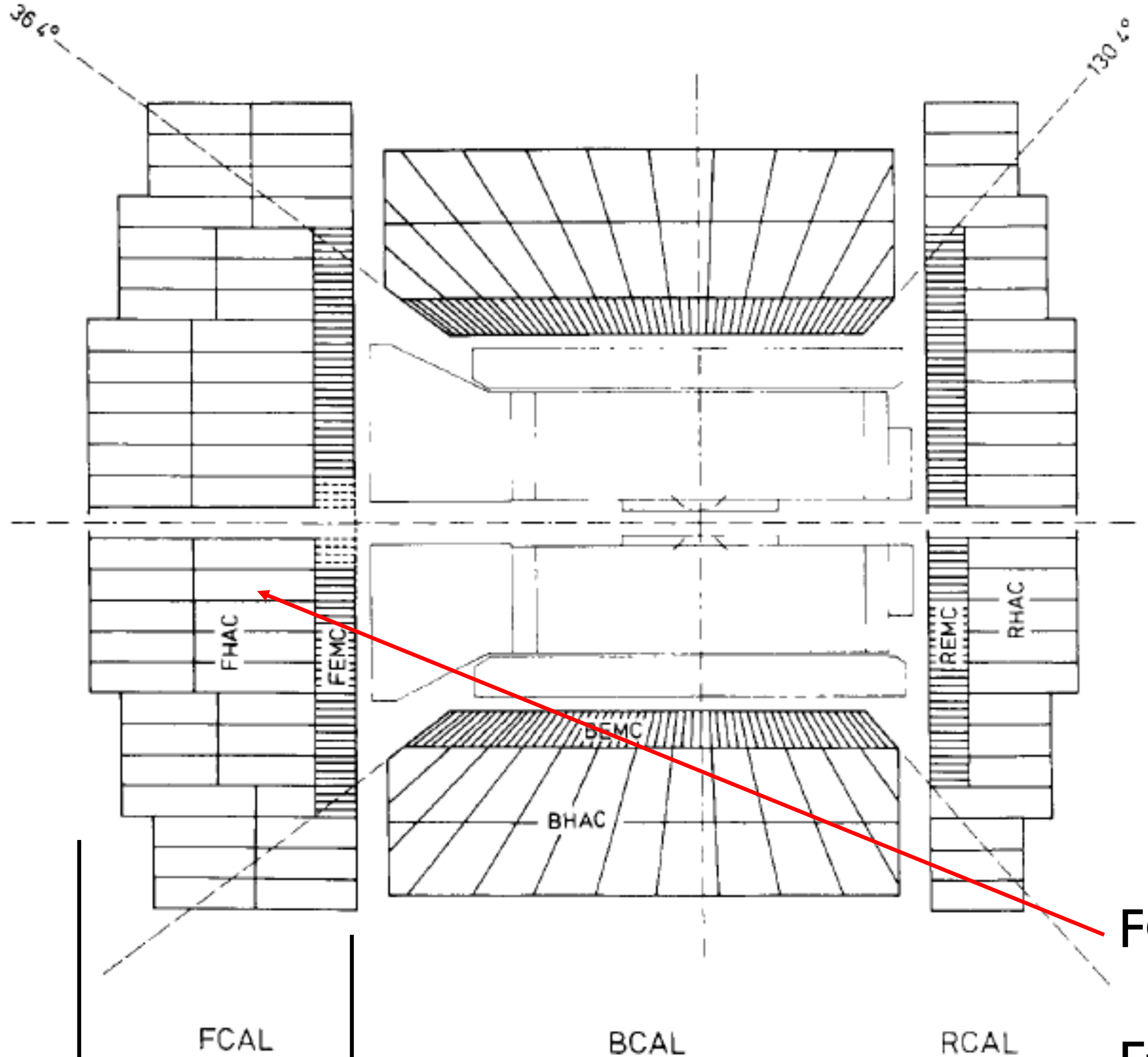
MEGA MILLIONS

or, which is better

CMS Calorimeter

Weight of Fe EndCap for EIC (R~3.5 m, 0.8 m) will be about 180 metric tonnes

ZEUS



171 cm,
or 150 cm

FCAL -7.14λ

Effective λ_{abs} ~ 24 cm

N.B. λ_{abs} includes gaps in the detector, and probably strong back

NIM A257(1987), 488-498

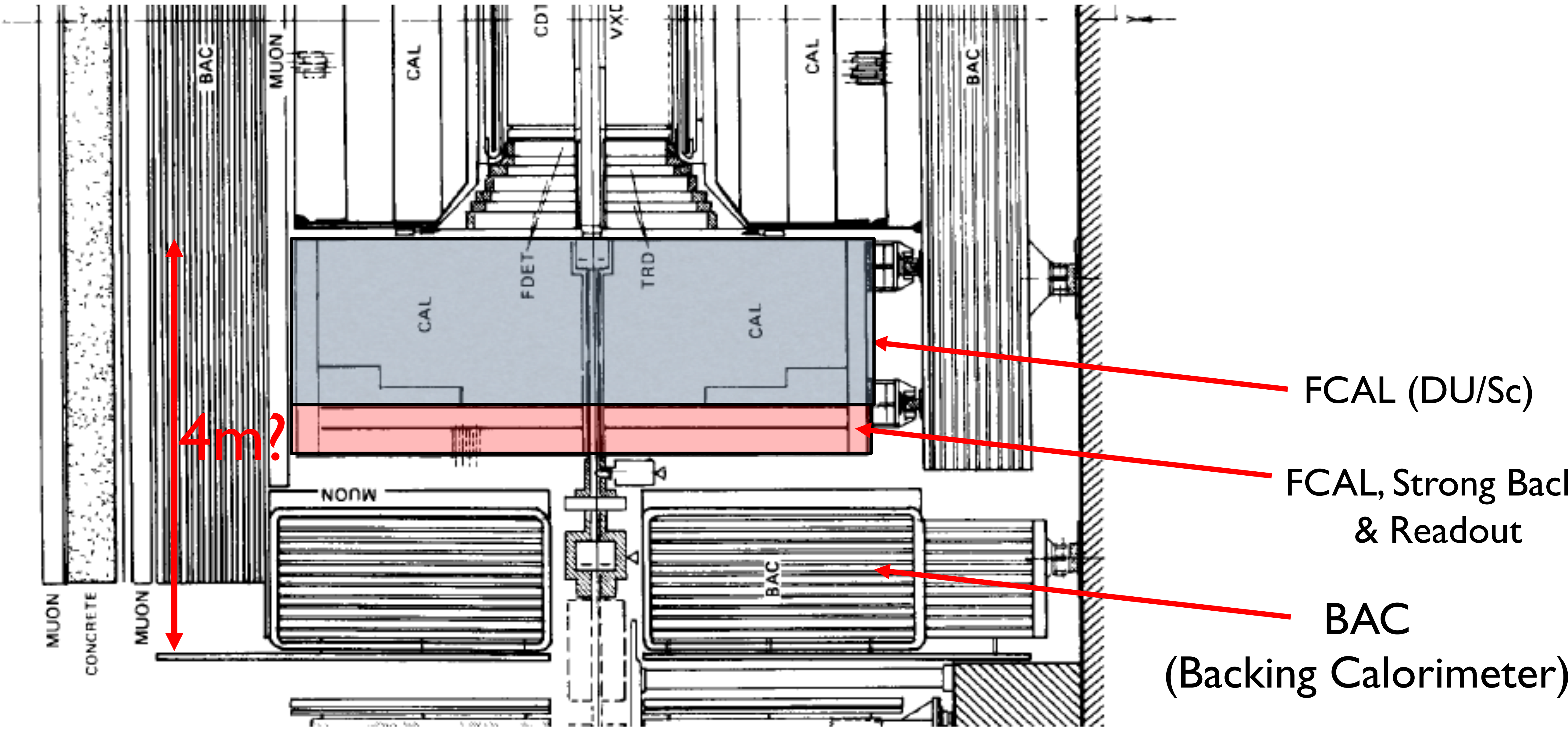


Table 1
Depth of calorimeter necessary to contain 95% of the shower for 90% of the events

Energy (GeV)	10	20	30	40	135	210
Single hadrons jets	5.1λ 4.0λ	5.7λ 4.3λ	6.3λ 4.7λ	6.7λ 4.9λ	7.8λ 6.4λ	8.0λ 6.4

Control leakages with BAC ~ 100%/√(E),
N.B. Quoted energy resolution, and overall detector length

HAC			
steel	0.4	0.023	0.0024
DU	3.3	1.000	0.0305
steel	0.4	0.023	0.0024
paper	0.2		
scintillator	2.6	0.006	0.0033
paper	0.2		
contingency	0.9		
sum	8.0	1.052	0.0386
effective X_0		$0.76\,cm$	
effective λ_{int}		$20.7\,cm$	
effective R_M		$2.00\,cm$	
effective critical energy ϵ_c		$12.3\,MeV$	
effective average density ρ		$8.7\,g/cm^3$	

	FCAL	BCAL	RCAL
total depth EMC or HAC0 [X_0]	25.9	23.8	25.9
total depth EMC or HAC0 [λ_{int}]	0.96	0.87	0.95
total depth HAC1 [λ_{int}]	3.09	1.96	3.09 - 2.32
total depth HAC2 [λ_{int}]	3.09 - 2.32 - 1.54	1.96	-
total # sampling layers	185 - 165 - 145	119	105 - 85
sum of modules	22 + 2x$\frac{1}{2}$	32	22 + 2x$\frac{1}{2}$
sum of 20 x 20 towers	460	-	452
sum of 20 x 28 towers	-	448	-
sum of EMC sections	1056	1696	511
sum of HAC0 sections	196	-	190
sum of HAC1 sections	460	448	452
sum of HAC2 sections	460	448	-
total sum of channels	4344	5184	2306
total DU weight [t]	182.1	230	104.9
total cladding steel weight [t]	17.9	24	9.8
total scintillator weight [t]	8.2	10.2	4.8
total weight [t]	240.2	310	156.6
total # EMC scintillator tiles	27456	40704	13286
total # HAC scintillator tiles	75176	43904	40140
total # DU-plates	4200	3808	2440
total # HAC R580 PM-tubes	2232	5184	2306
total # FEMC XP1911 PM-tubes	2112	-	-

Note: λ_{abs}
20.7 cm vs 24 cm
(λ_{abs} for DU is 10.5 cm)

DU/Sc is not self-supporting.
Mechanics add a lot of dead areas.

- Complicated mechanics.
- Strong back.
- Gaps.

STAR FCS (20mm Fe, 3.4 mm gap)
λ_{abs} ~ 20.16 cm
Self-supporting structure.
Very efficient use of space.

DU absorber, some details.

DU plates production. (185 layers in tower)

- Bare DU plates produced by MSC, Oak Ridge
- DU plates required electron beam welding at Chalk River Lab, Ontario, Canada
- Complete lamination laser welding SS (or SS + magnetic foils)

DU plate handling

- Laminated DU plates has surface activity ~ 50 μSv/h (at 1 m ~ 5 μSv/h).
- Stacking assembly requires robot (stacking at NIKHEF)

Exclusive production methods are expensive.

Compare to Fe absorber plates.

Production
- Machining at any shop which has CNC.
- Plating with Zn, corrosion protection.

Handling
- Don't need robots, we have undergrads.

Some other things:

Mechanical structure is quite complicated because structure is not self-supporting. As many other calorimeters (CDF, STAR, Alice Shashlyk etc. structure is hold by friction, i.e. stack under compression)

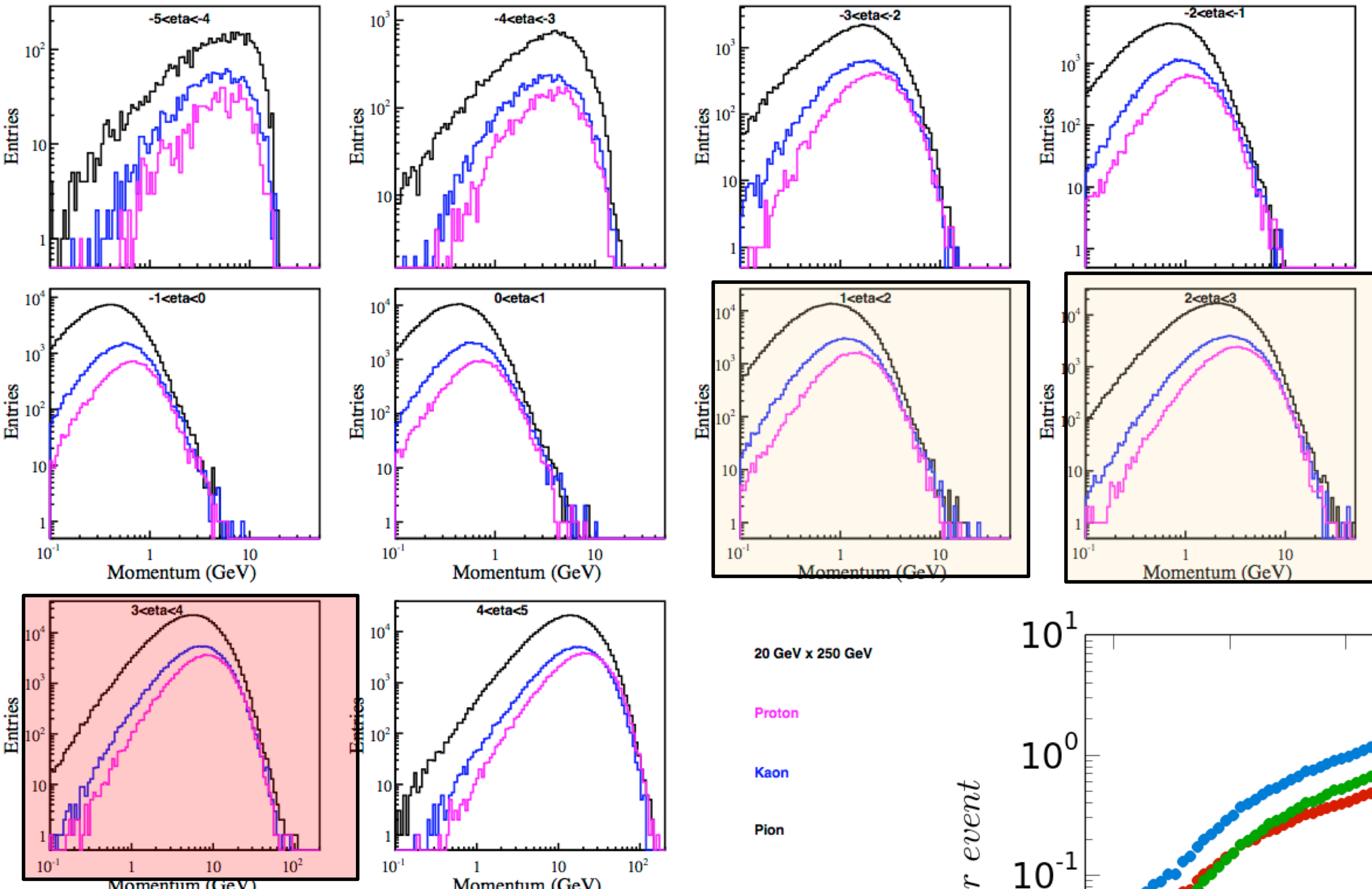
Requires lots of different parts, made with high precision.
Examples:

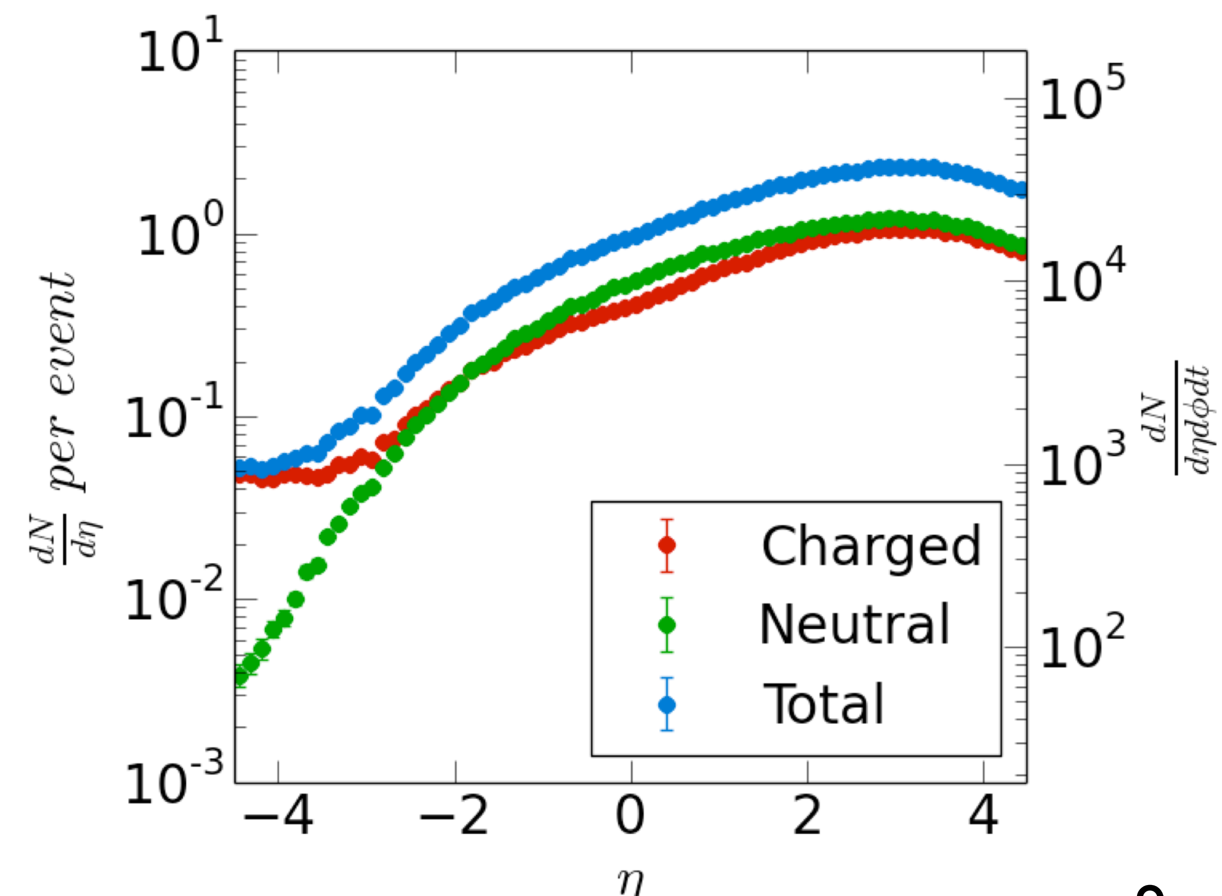
- Tungsten carbide spacers required to keep stack stable under tension with minimal dead space (allocated to spacers) for ZEUS.
- STAR BEMC, 100% QA x-ray defects on laser welded compression straps.

Assembly of modules will require a team of highly trained technicians, i.e. has to be made in one of the National Lab.

Finally, often overlooked, one has to think about generating 200t of radioactive waste …

Energy range, Rates, and Compensation

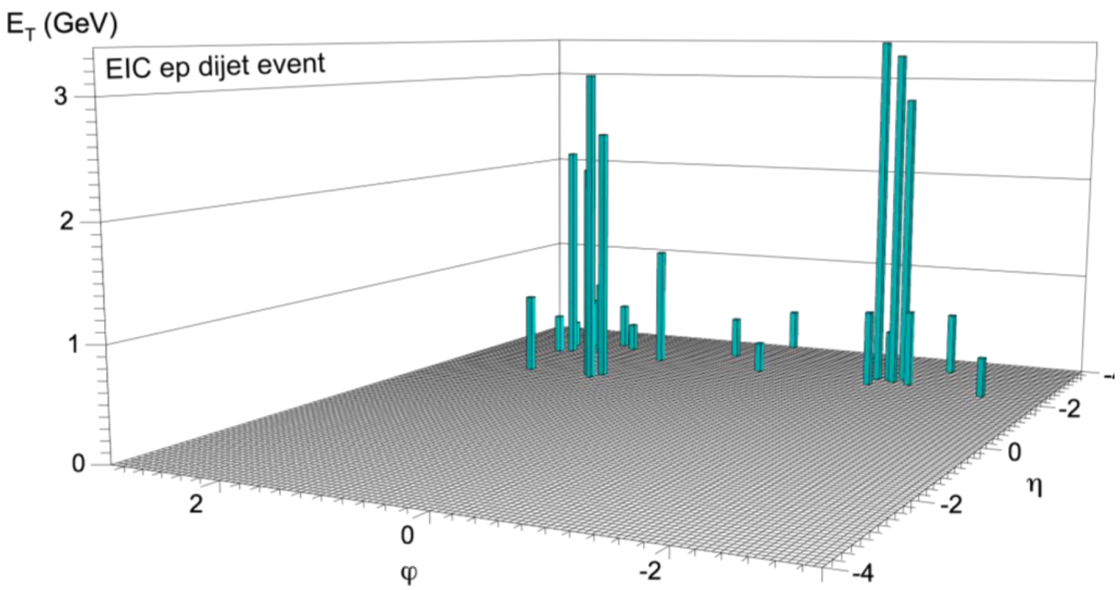


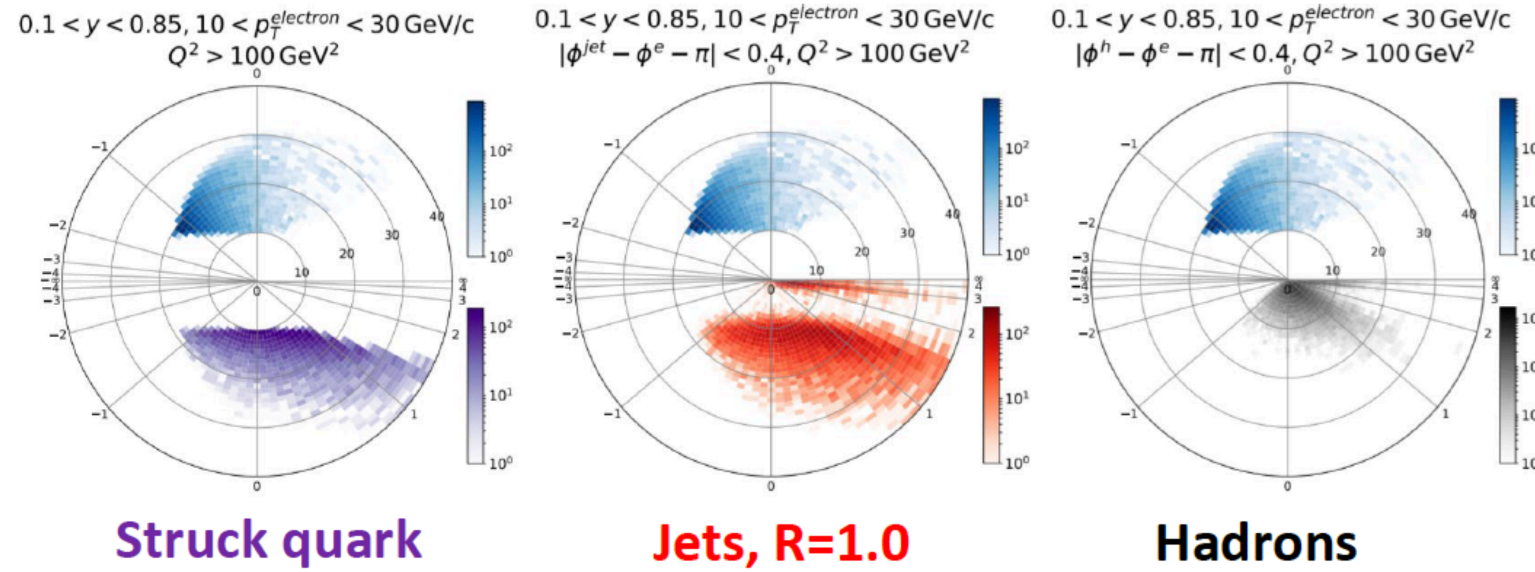


https://wiki.bnl.gov/eic/index.php/Detector_Design_Requirements

Jets at EIC and Compensation

Jets are excellent proxies for quark kinematics





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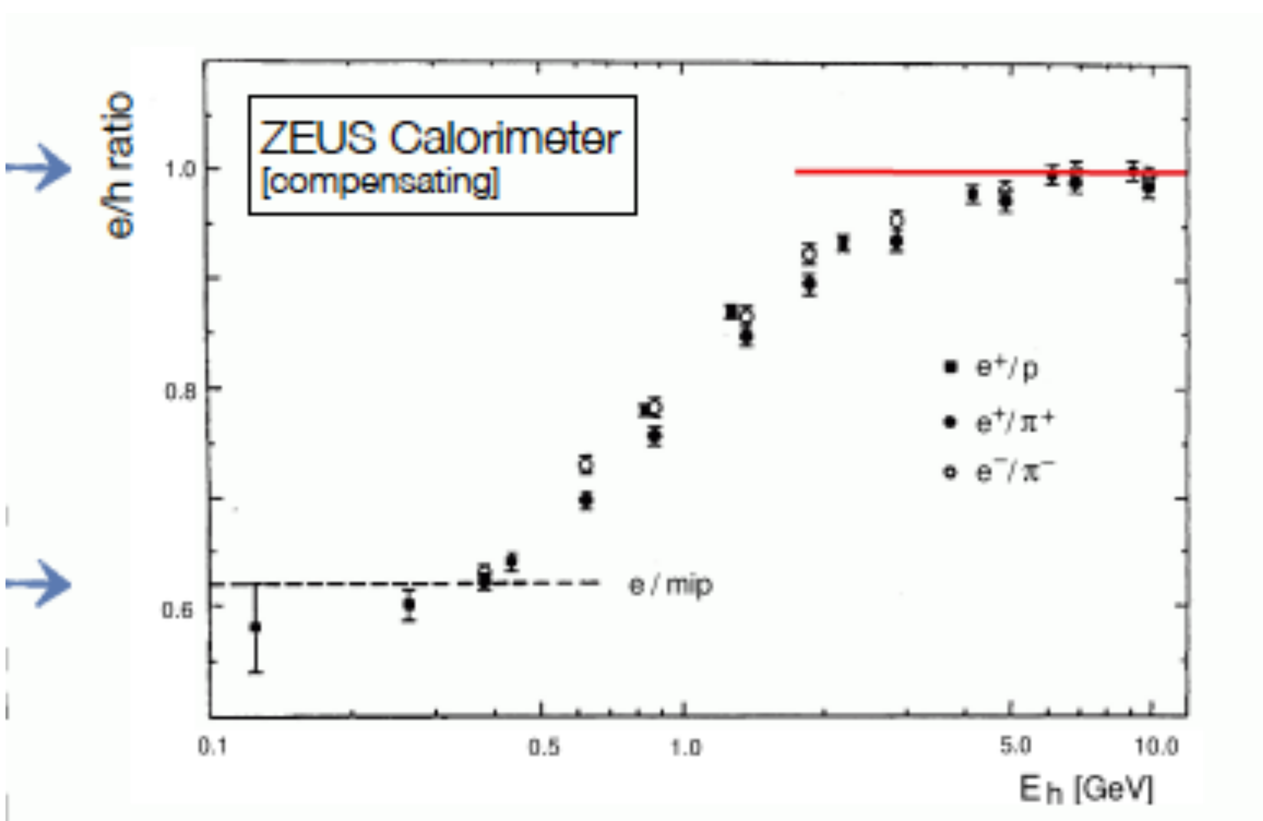


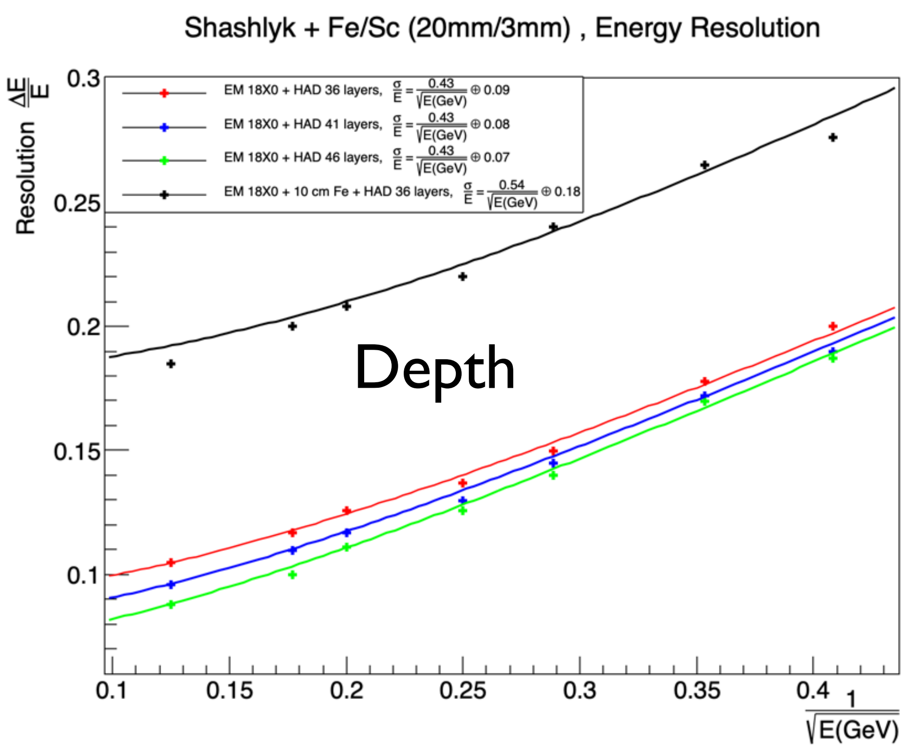
- Compensation is energy dependent. Does not work below 10 GeV.
- I don't know of any solution for that.

Number of Neutrons generated by pions.
U ~ 60/GeV
Pb ~ 20/GeV
Fe* ~ 10/GeV (* somewhat guessed)

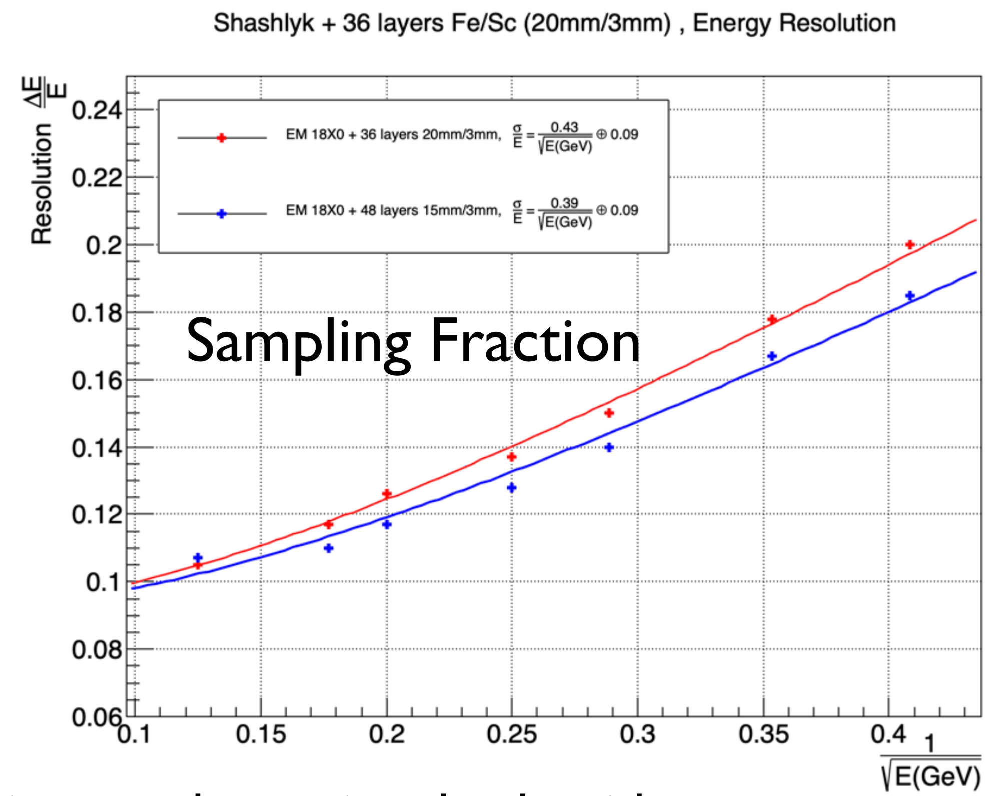
Jet Radius for EIC ~1

Degradation of SiPMs is a concern.

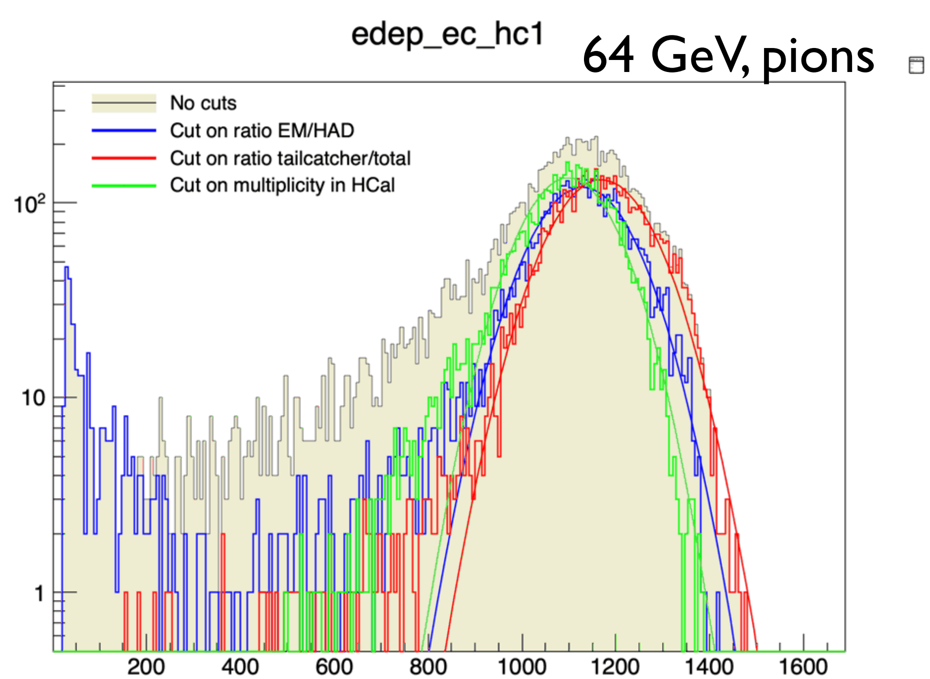
Cost of DU calorimeter. I don't know, guess many times more than Fe/Sc with parameters from handbook. For high resolution HCal one need lot of space and high sampling fraction. As an illustration.

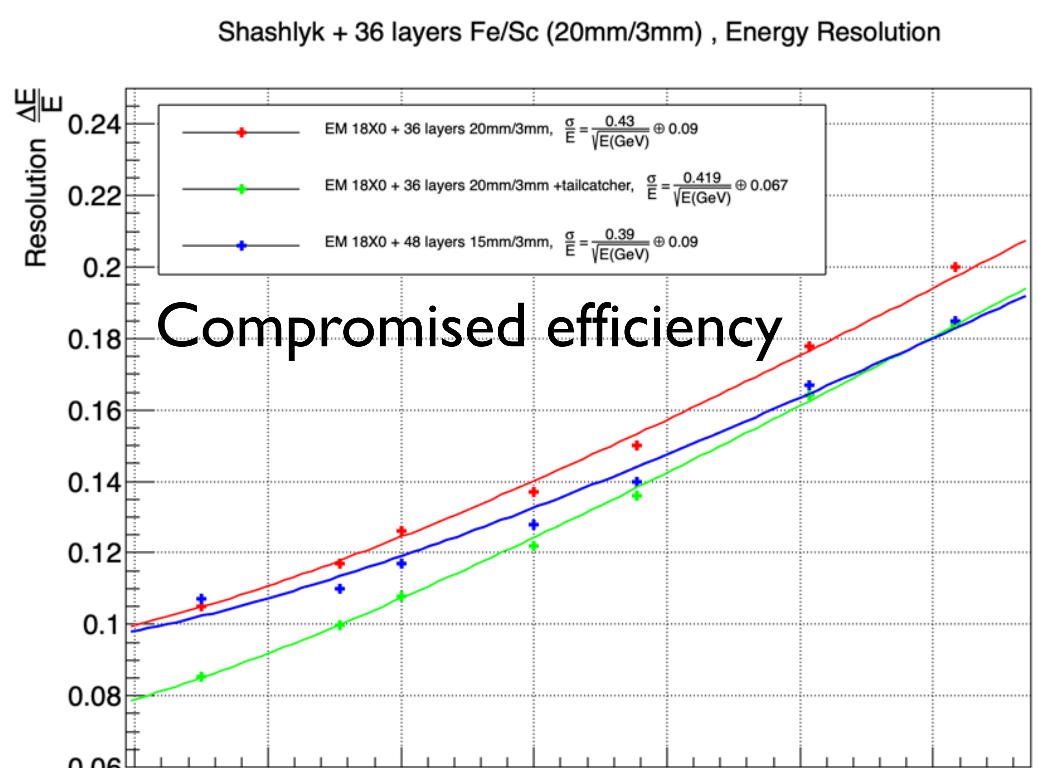


Constant term decreasing slowly with increased depth. log dependence.



Stochastic term decreasing slowly with increased sampling fraction. (10% improvement vs 30% increase in cost)





Trade off. Cheap tail catcher gives same results as improved sampling fraction at low energies, But for the cost of 'efficiency', ~ 90% at 6 GeV drops to 50 % at 64 GeV

Final remarks:

- High resolution HCals are challenging.
- Need both space and money.
- One can think of trade offs like efficiency vs resolution.
- For EIC central detector compensation is not a panacea. For ZDC it is.
- Due to superior trackers, role of calorimeters (HCALs) is different it was ~30 years ago, i.e. we are not talking about CALOR Jets (ZEUS, D0 etc.), it will be PFA... unless one require ‘complimentarity’, i.e. PFA vs CALOR Jets.