CLICdp Detector Optimization:
Status and Trends

Nikiforos Nikiforou
CERN/LCD
On behalf of the CLICdp Collaboration

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Introduction - Outline

- At CLICdp we are working towards an **updated simulation model** for the CLIC detector: **aim to have a model by the end of this year**
  - **Will be used for next round of physics studies**

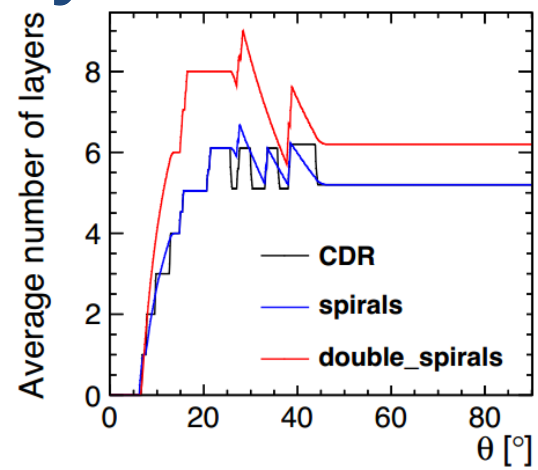
- **Projected characteristics of the new simulation model:**
  - **All-Silicon** tracker to cope with the high occupancy of the CLIC environment
  - **Dimensions and B-field defined by particle flow performance**
  - Optimize forward acceptance of trackers and calorimeters

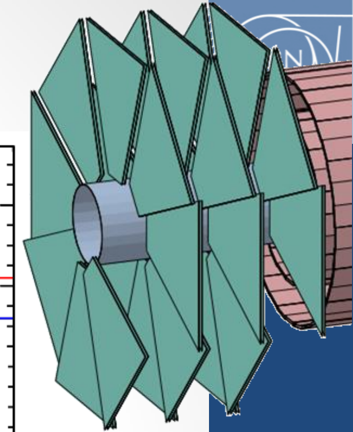
- Incorporate updated input from engineering/material studies, cost projections
- Ongoing optimization studies to help determine optimal detector parameters (this talk)

- Will mainly summarize the studies for the **Vertex Detector, Tracker**, **ECal** and **HCal**
- Briefly mention some of the open points not covered today

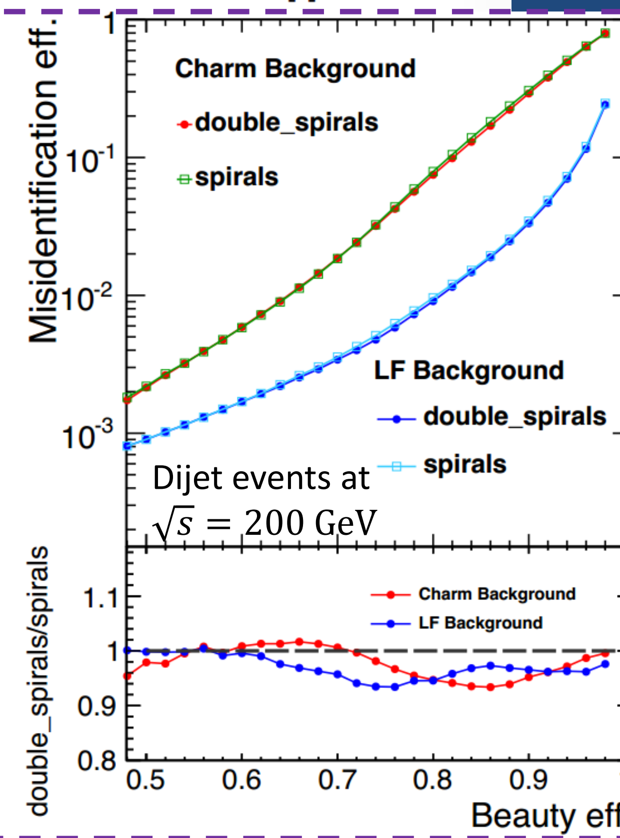
Vertex Detector: double layers

- $0.18\% \; X_0$ per double-layer in simulation
- Spiral Geometry (better airflow)
- Barrel: 5 single-layers ⇒ 3 double-layers
- Endcap: 4 single-layers ⇒ 3 double-layers

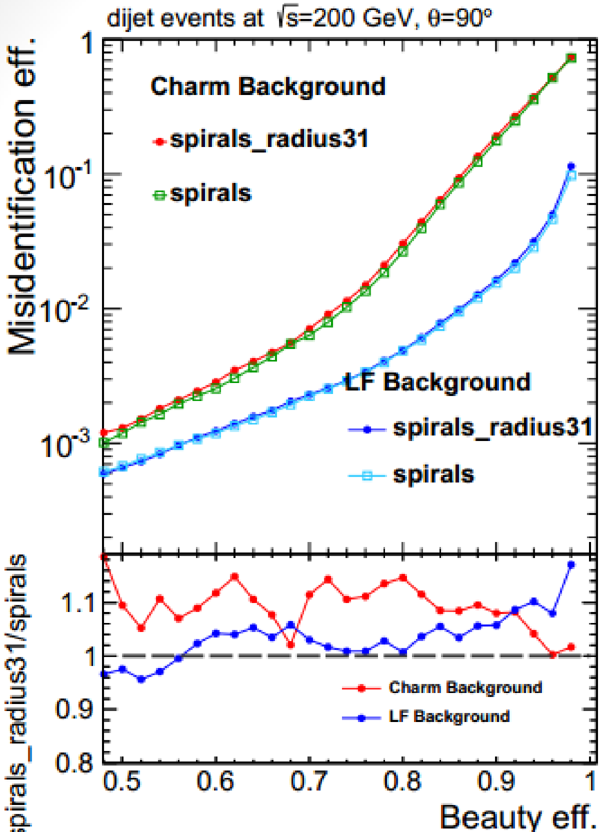




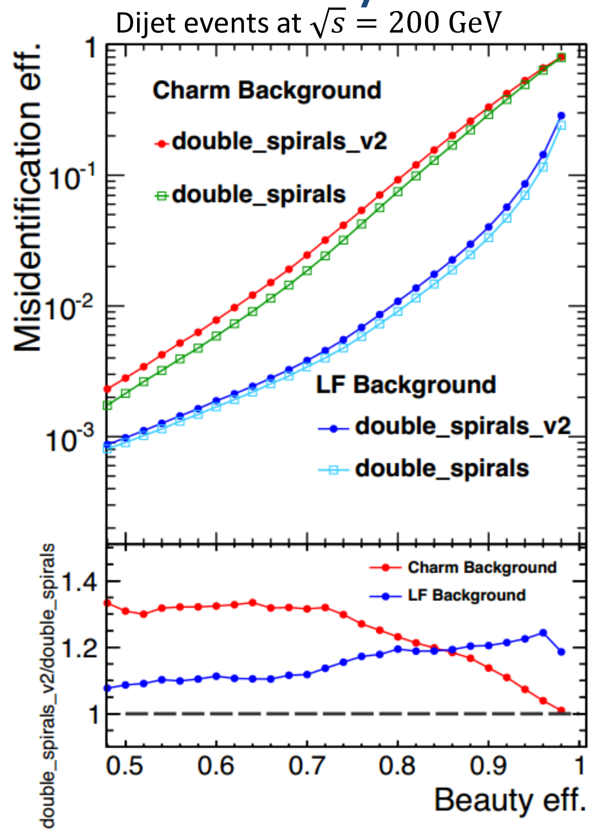
- Estimate changes in performance due to layout by studying the **flavor-tagging performance** (N. Alipour Tehrani, P. Roloff [2])
- b-quark misidentification as a function of b-quark Identification efficiency with a background rich in c-quarks (Top lines) or **L**ight-**F**lavored quarks (bottom lines). Similar study performed for c-tagging
- Lower panel shows ratio of double-layer over the single-layer geometries
  - **Almost the same as single-layer layout**



Vertex Detector : Effect of Inner Radius /Material



(N.Alipour Tehrani, P. Roloff [2])

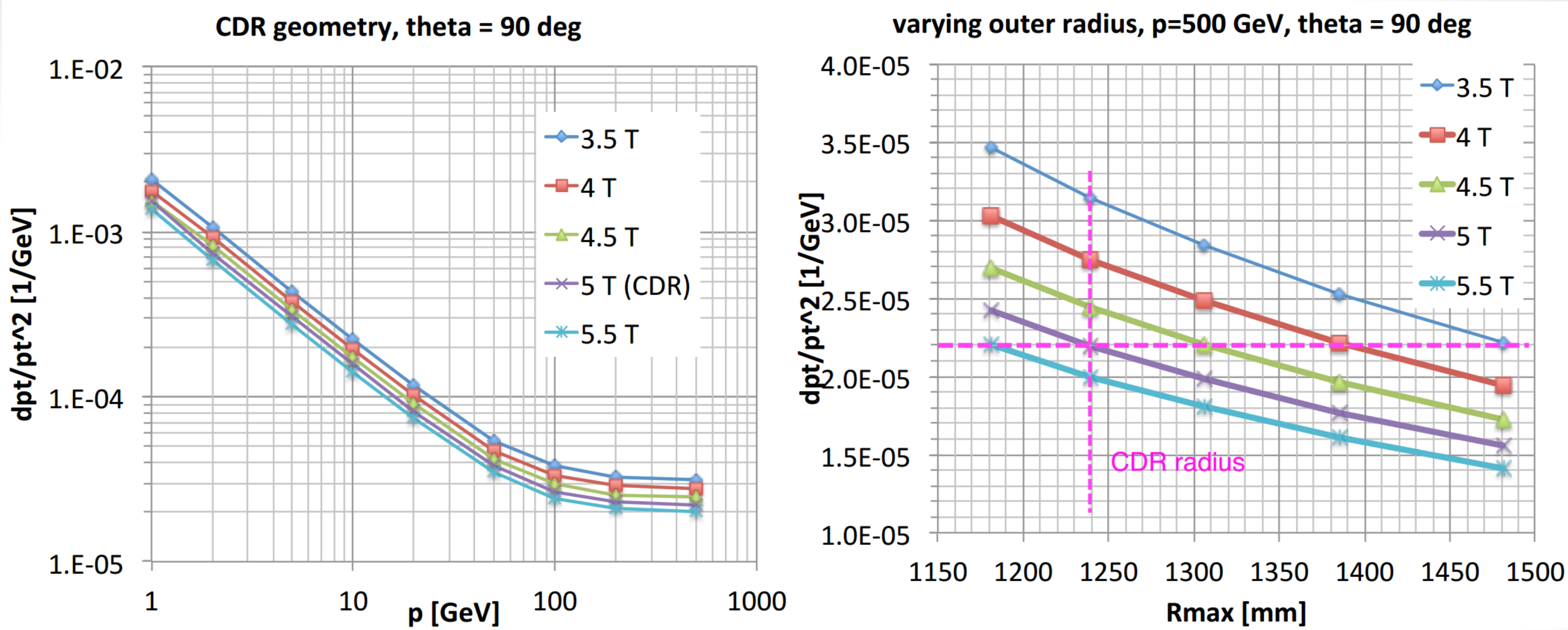


- Inner Radius from 27 mm to **31 mm**
- Compensates for increase in the rate of Incoherent e-pair background if B-field is reduced
- **Small effect in flavor-tagging performance**

- Double-layer modules were simulated with twice as much material
- Extra material leads to undesirable increase of fake rate

In the new detector model: Use double layers with spirals and modules with $0.2\%X_0$ per (single) layer

Silicon Tracker Optimization



Fast simulation study (LicToy) with CLIC_SID_CDR geometry (D. Dannheim et al. [3])

- Tracking performance depends on tracker **radius** and **magnetic** field

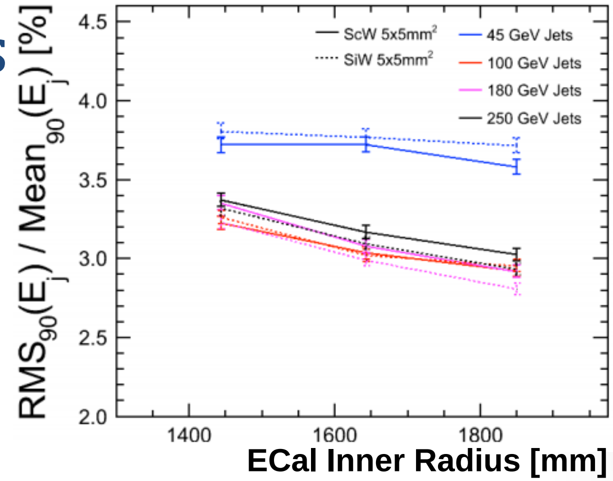
$$\frac{\sigma(p_T)}{p_T^2} \propto \frac{\sigma^{meas}}{\sqrt{N}\boldsymbol{B} \cdot \boldsymbol{R^2}}$$

Stronger dependence on R

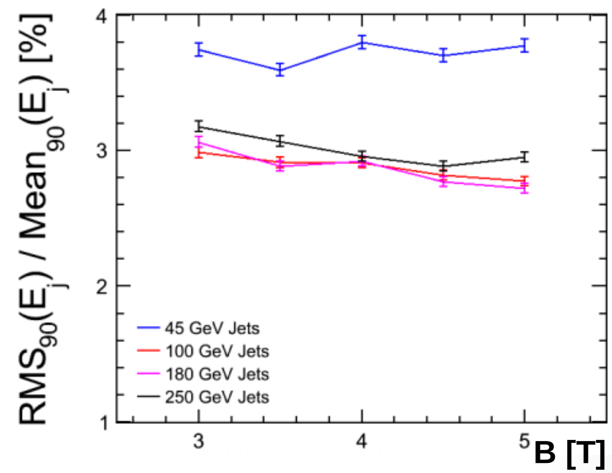
- **Can compensate reduction of B in new detector by rescaling R by $\sqrt{B_{nom}/B}$**
- Aim to **increase** from 1.3 m (CLIC_SID) but not much gain by going to 1.8 m (CLIC_ILD)

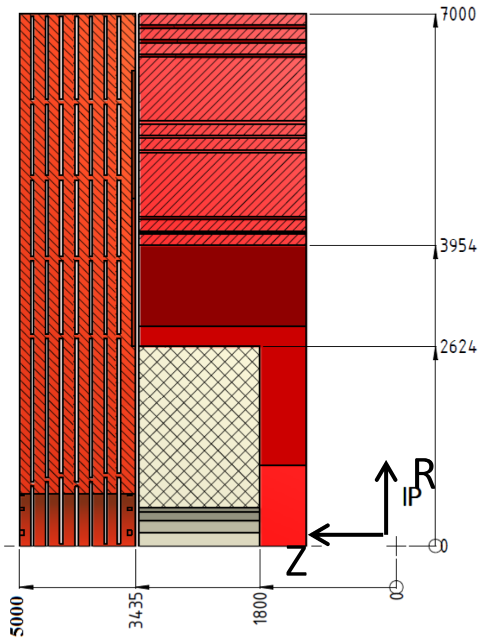
Silicon Tracker: Conclusions and Plans

- **B-Field and R affect PFA Performance**
  - Previous ILD studies by M. Thomson and J. S. Marshall [4,5]
- **Aiming for an outer tracking radius of 1.5 m**
- A magnetic field strength of up to 4.5 T should be technically feasible
  - **Will need to make a decision on 4 Vs 4.5 T**



- **Effects of non-uniform magnetic field currently under investigation**
  - Implementation of more realistic field map underway
  - Changes in tracking software





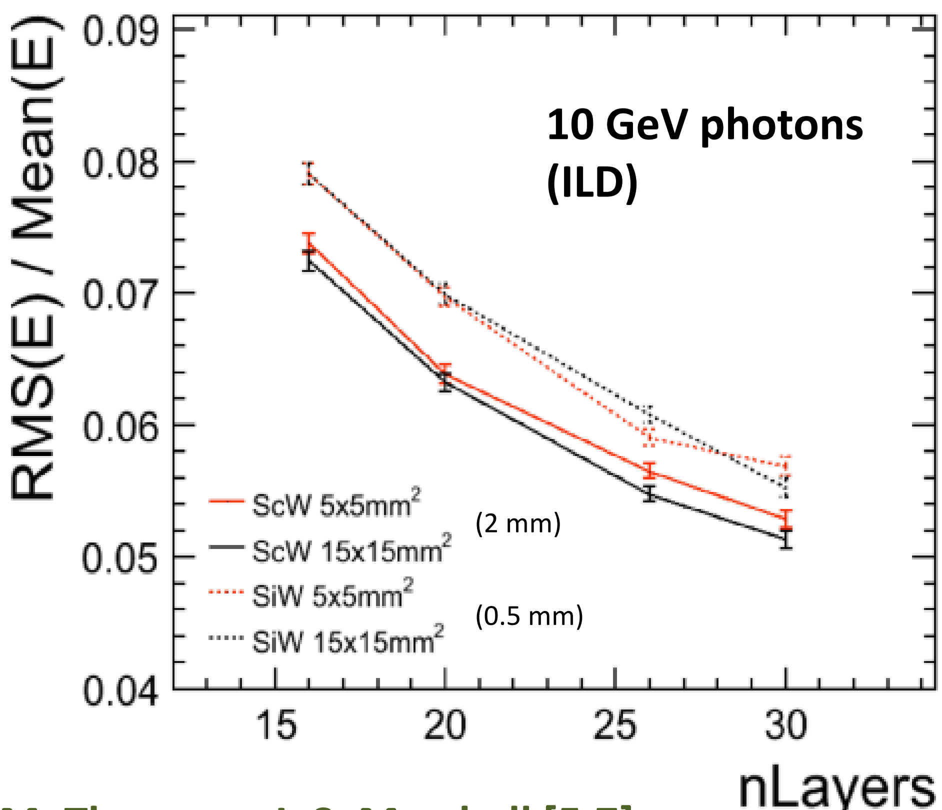
B. Cure [6]

- **Tracker length: at least ~CLIC_ILD (4.6 m)**
  - Considering reducing Endcap Yoke thickness by ~1.2 m and employing End coils

ECal Optimization: Active Material, Number of Layers, Granularity

ILD-based baseline model: **SiW ECal with 29 layers** (23 X_0 / 1 λ_I):

- Tungsten absorber: **20x2.1 mm + 9x 4.2 mm**
- Silicon Active material, **500 µm** thickness, **5x5 mm²** cells

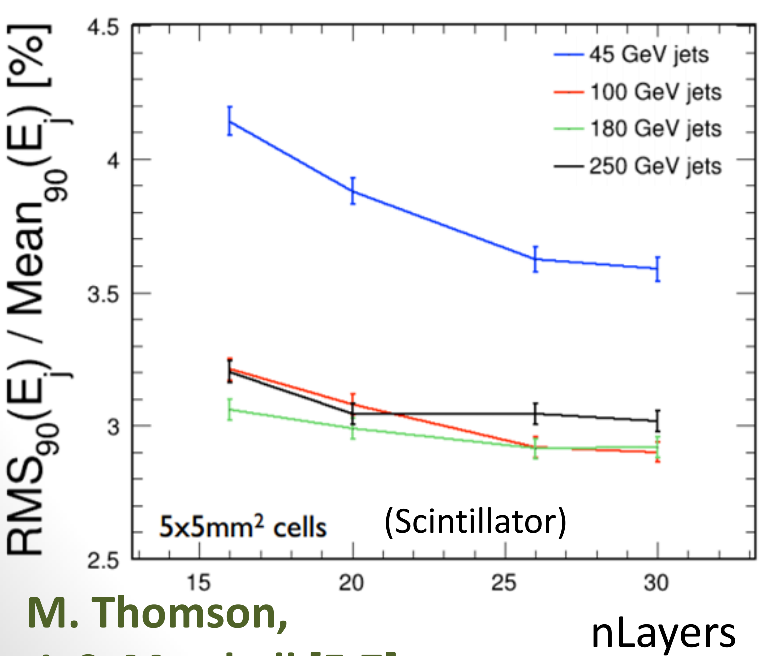


M. Thomson, J. S. Marshall [5,7]

- Scintillator instead of silicon may give a slightly better resolution
  - Depends on active element thickness
  - Also considered Si/Sc combinations
- **Stronger dependence on number of layers ($\sim 1/\sqrt{N}$)**

ECal Optimization: Jet Energy Resolution

- **Si vs Sc:** No significant effect on JER
- **# Layers:** Not very important for higher energy jets (PFA confusion dominates): **Not much more improvement from 25 to 30 layers**
- **Cell size:** Becomes important for higher energy jets (where confusion dominates)
  - JER **degradation** from 3% to ~3.5% when increasing cell size to 15x15 mm^2
  - Combinations of different granularities in layers considered
    - No significant gain for the extra complexity



M. Thomson, J. S. Marshall [5,7]

Working hypotheses for the simulation model:

- **Silicon active material, Tungsten absorber**
- **Decrease number of layers to 25 while keeping the same depth in #X_0 (scale absorber thickness accordingly)**
- **Use 5x5 mm^2 cells throughout**

HCal Optimization: Introduction

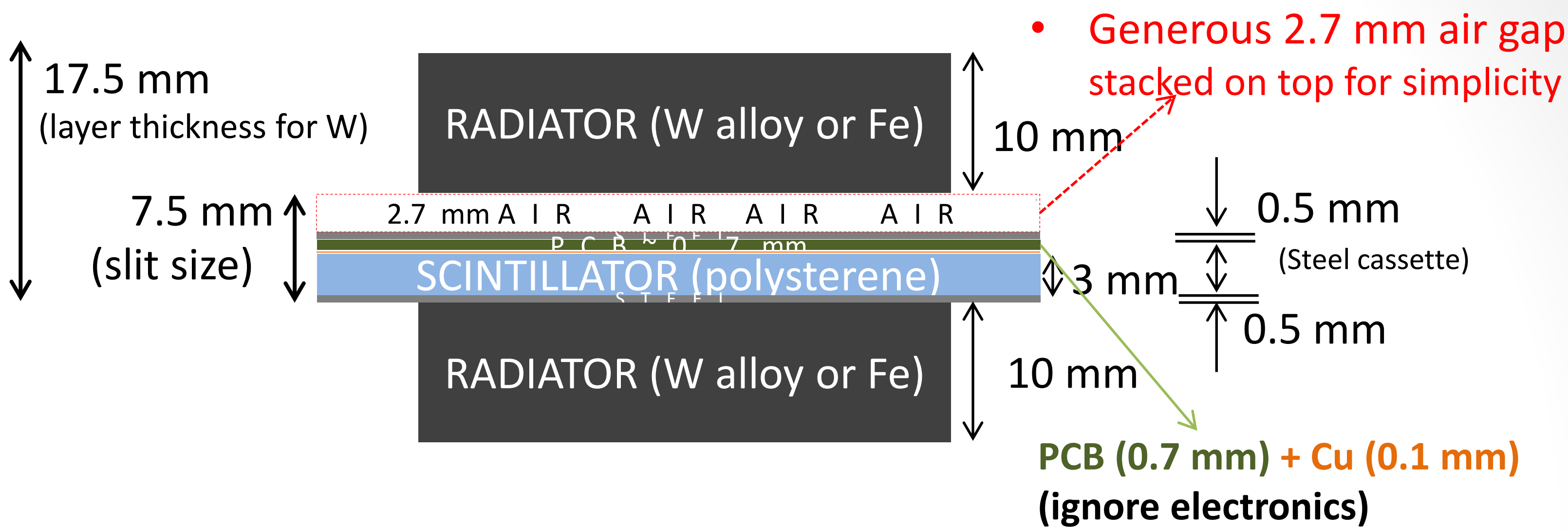
- Will need to provide input to ongoing engineering studies for feasibility of **HCal Barrel assembly** and **magnet construction:**
  - Granularity (especially number of layers)
  - Choice of absorber material (W or Fe) and thickness
  - Thickness and assembly of active layer (cassette)
    - Try to reduce thickness of active layer, while keeping a realistic assembly scenario
- Assume $R_{outer}^{tracker} = 1500$ mm -> $R_{inner}^{HCal} = 1750$ mm (for 29L ECal)

- Previously estimated optimal depth of HCal for CLIC at $\sim\mathbf{7.5\lambda_I}$
  - Variation of parameters around that central value
  - Limits options in granularity/number of layers

  } Drive R_{outer}^{HCal} and **solenoid inner bore** requirements

- For the HCal Endcap, use Steel absorber, 60 layers x 20 mm, keep constant for these studies

HCal Barrel in the new CLIC Detector Model

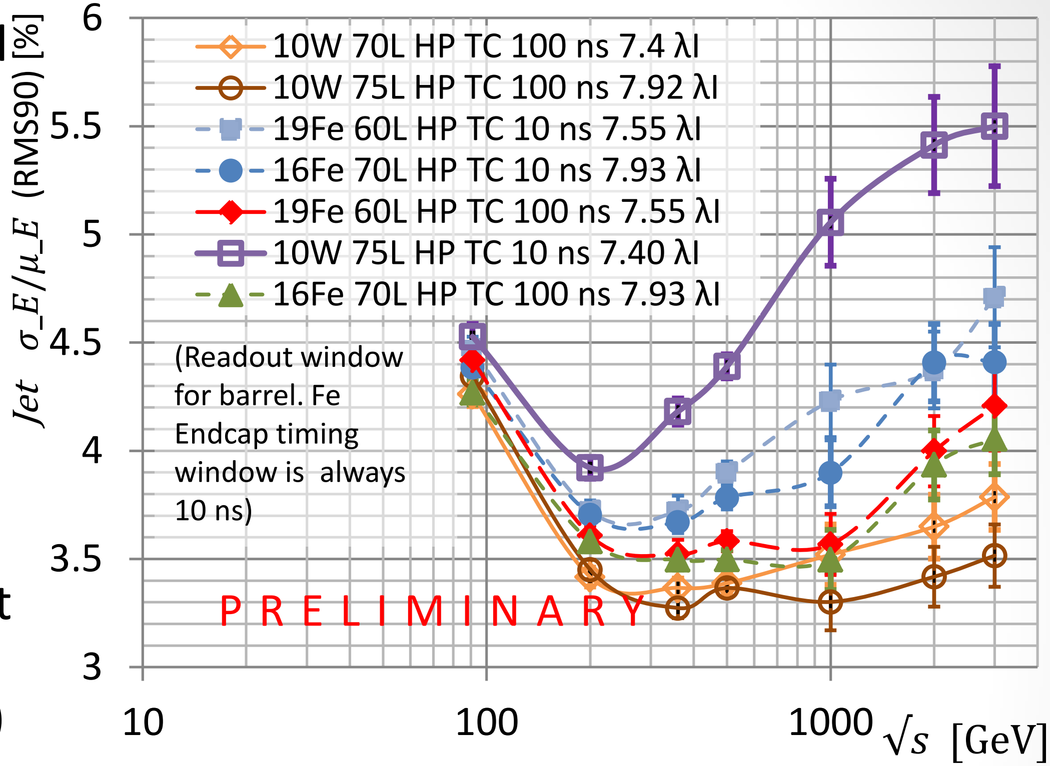


- Adapted ILD cassette, with steel explicitly included
  - Not assumed part of absorber
- Investigating the following model variations:

Detector	# Layers	Abs Thick	Cass. Thick	Air	Total Depth	Total Thickness	Inner R	Outer Face Position	Outer Radius
		mm	mm	mm	#λI	mm	mm	mm	mm
CLIC_ILD_CDR	75	10	5* (*Scint)	1.5	7.42	1237.5	2058	3295.5	3341.2
CLIC_SID_CDR						1237.5	1447	2684.5	2721.7
W + cassette	75	10	4.8	2.7	7.92	1322.5	1750	3072.5	3115.1
W + cassette	**70**	**10**	**4.8**	**2.7**	**7.40**	**1235**	**1750**	**2985**	**3026.4**
Fe + cassette	**60**	**19**	**4.8**	**2.7**	**7.55**	**1609**	**1750**	**3359**	**3405.6**
Fe + cassette	70	16	4.8	2.7	7.93	1661	1750	3411	3458.3

HCal Optimization: *W* vs *Fe*

- Studying JER for each model as a function of $\sqrt{s}$ for $Z \rightarrow uds$ events
- Digitization/PFA Calibration using procedure from Cambridge (with γ, μ, K_L^0)
- **Show also effect of timing cuts on models**
- Generally, W needs a larger readout window for readout (response for W plateaus at ~ 100 ns vs ~ 10 ns for Fe)



- Preliminary results show that tungsten performs very well for a 100 ns-wide readout window and offers a **compact** HCal, therefore is a very attractive option
- **However, tungsten cost, availability, properties, machinability are also equally important points to be considered**
- **Will soon have to make a decision on the material to be used in simulation model, taking everything into consideration**

Open Points – Not Covered Today

- Optimization of the **forward region**
  - Is extension of coverage (especially HCal) **feasible?**
  - Is there a justifiable **benefit** over the background in potential physics analyses?
- **Position of Final Focusing Quadrupole (QD0): Inside** Vs **Outside**
  - Significant challenges for assembly and support (esp. if Inside)
  - Need to review impact on luminosity (esp. if Outside)
- Ongoing implementation of new CLICdp detector in **DD4hep**
  - Going well! The various subdetectors are being implemented
  - Dedicated presentation during the software part …

Summary and Conclusions

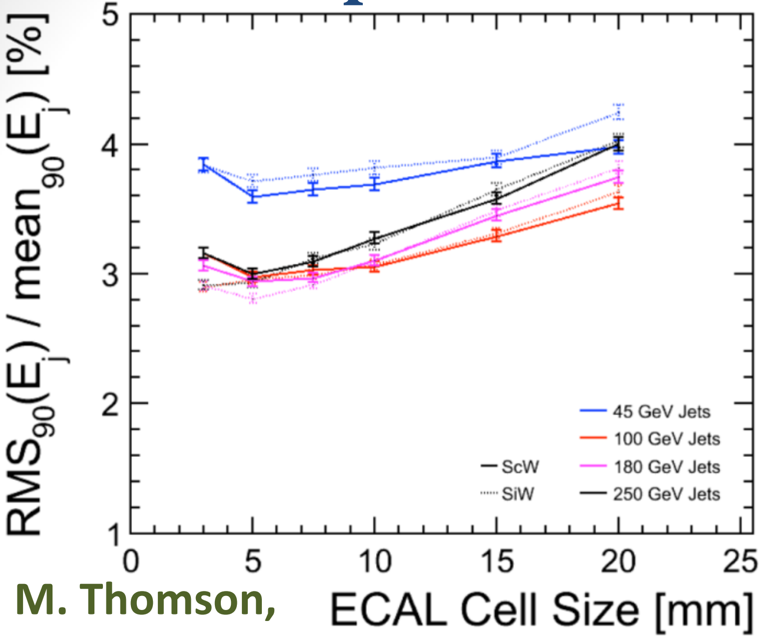
- Working on a new CLIC detector simulation model *by end of year*
- Some of the projected parameters as of today
  - **B-field: $\mathbf{4 - 4.5\ T}$** T.B.D.
  - **Double-layer** vertex detector modules with **spiral** layout
  - **All-silicon** tracker
  - $\boldsymbol{R^{tracker}_{outer} \sim 1.5\ \mathrm{m},\ L^{tracker} \gtrsim 4.6\ \mathrm{m}}$
  - **SiW** ECal: **25** layers/5x5 mm^2 cells, 23 X_0 / 1 λ_I
  - HCal: Use 3 mm scintillator
    - **HCal Barrel: W vs Fe** absorber **T.B.D.,** aim for $\sim$7.5 λ_I
    - HCal Endcap: **20 mm Fe** absorber, 60 layers
- Some additional important open points
  - Position and integration of QD0
  - Optimization of forward region
- Detector geometry is already being put together in **DD4hep**

References

1. *A. Miyamoto et al.*, ***Physics and Detectors at CLIC : CLIC Conceptual Design Report***, CERN-2012-003
2. *N.Alipour Tehrani and P. Roloff*, ***Optimisation Studies for the CLIC Vertex-Detector Geometry***, CLICdp-Note-2014-002
3. *D. Dannheim et al.,* Slides at https://indico.cern.ch/event/309925/contribution/2/material/slides/0.pdf
4. *M. Thomson, Nucl.Instrum.Meth. A611 (2009)*
5. *J. Marshall*, Slides at http://indico.cern.ch/event/309926/contribution/1/material/slides/0.pdf
6. *B. Cure*, Slides at https://indico.cern.ch/event/314325/contribution/1/material/slides/1.pdf
7. *M. Thomson,* Slides at http://indico.cern.ch/event/309926/contribution/1/material/slides/0.pdf

BACKUP MATERIAL

ECal Optimization: Jet Energy Resolution



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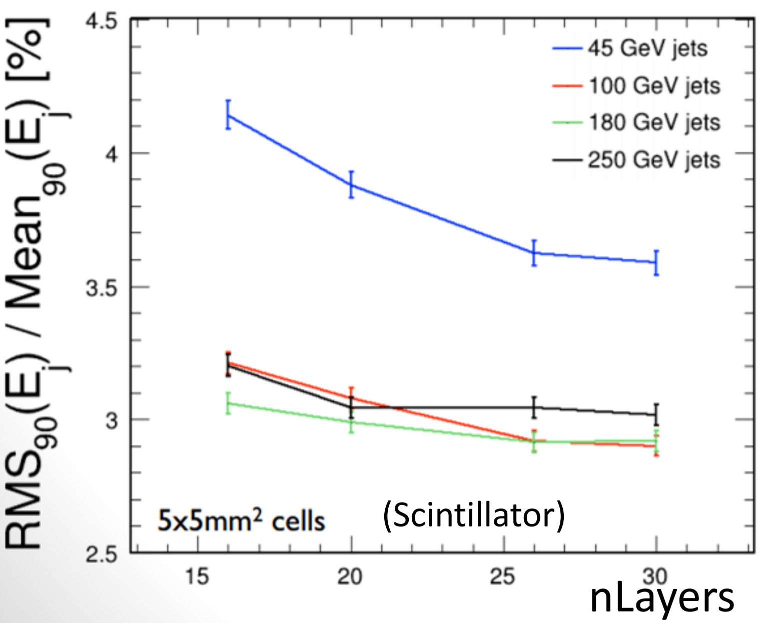
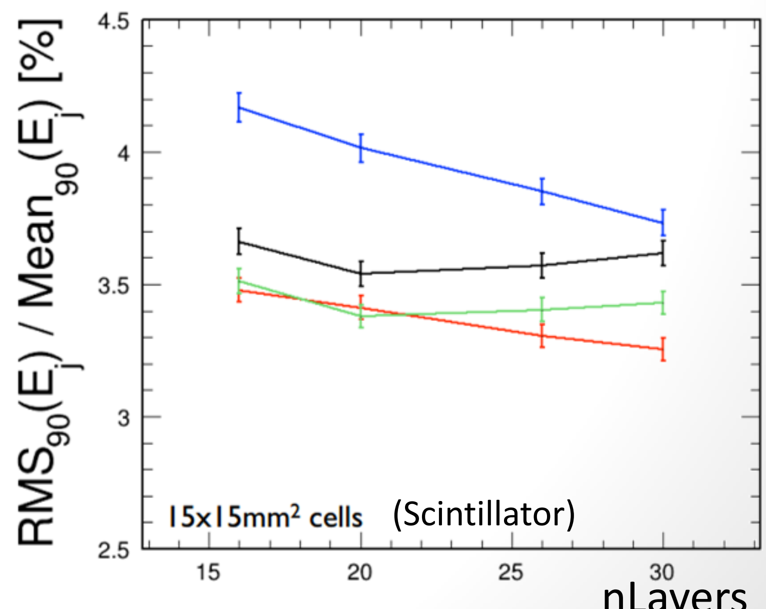
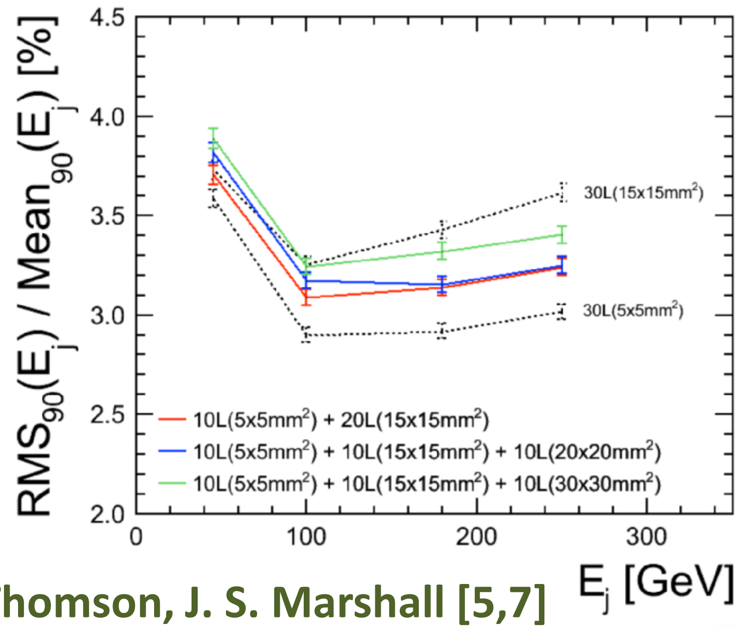
M. Thomson, J. S. Marshall





ECal: Final Thoughts and Conclusions

- Combinations of different cell sizes in layers were considered
  - Increased complexity
  - Only modest improvement over 30L@15x15 mm^2 option
- 30L@5x5 mm^2 still appears to be the most attractive solution



M. Thomson, J. S. Marshall [5,7]

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CLIC_ILD_CDR Material Scan in φ

- Geometry

Parameters:

(from CDR and http://www-flc.desy.de/ldcoptimization/tools/mokkamodels.php?model=CLIC_ILD_CDR)

HCAL BARREL	SHcalSc02
Number Of Layers	75
Number Of Sides	(8) 16
Inner Radius	2058 mm
Outer Radius	**3341 mm**
Z Length	4700 mm
Section Phi	0.52 radians
Cell Size U	30.0 mm
Cell Size V	30.0 mm
Layers 0 - 74	
10 mm	Tungsten
5 mm (sensor)	**Polystyrene**
1.5 mm	Air

- No realistic cassette implemented in this model
- For optimization studies, implement a cassette (adapted from ILD) and simulate models by modifying ILD_o1_v06 (next slide)

Scan using Mokka/Geant4