Recent ECAL Optimisation Studies and Plans

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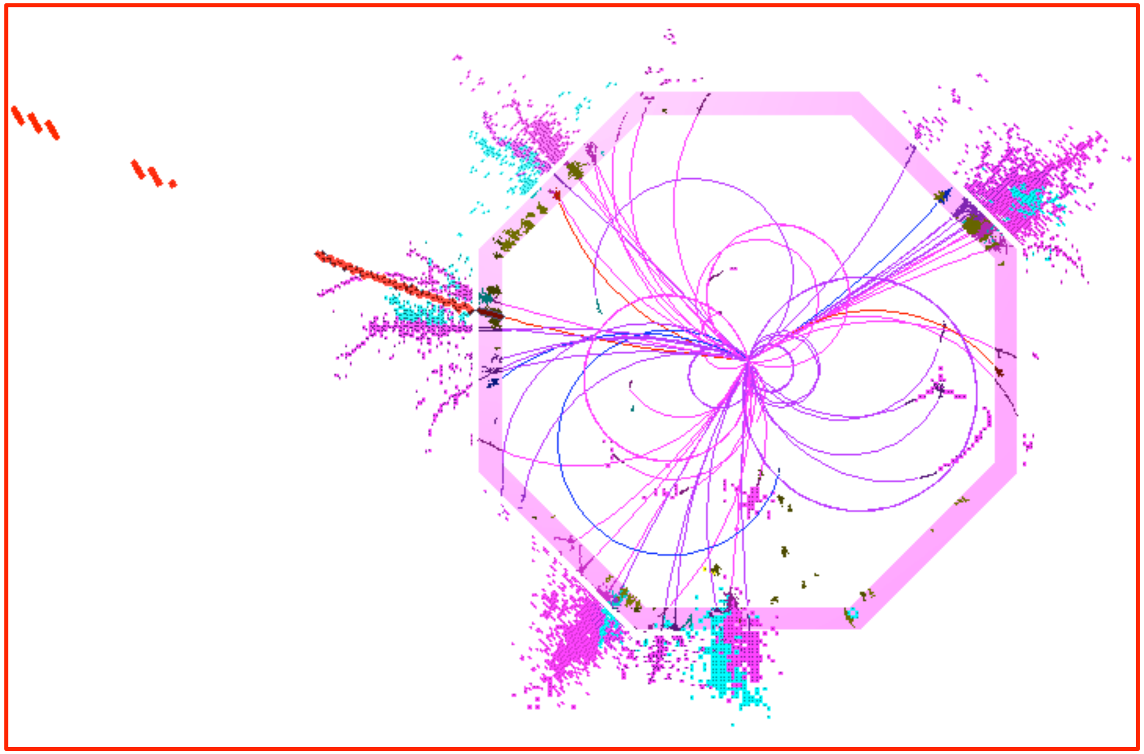


Overview

★ **This talk:**

- Summarize key ECAL results/issues
  - Based on detailed studies from John Marshall
- "Optimal" answer depends on the question…
  - Cost ?
  - Risk - technological challenges
- Will only present physics arguments…

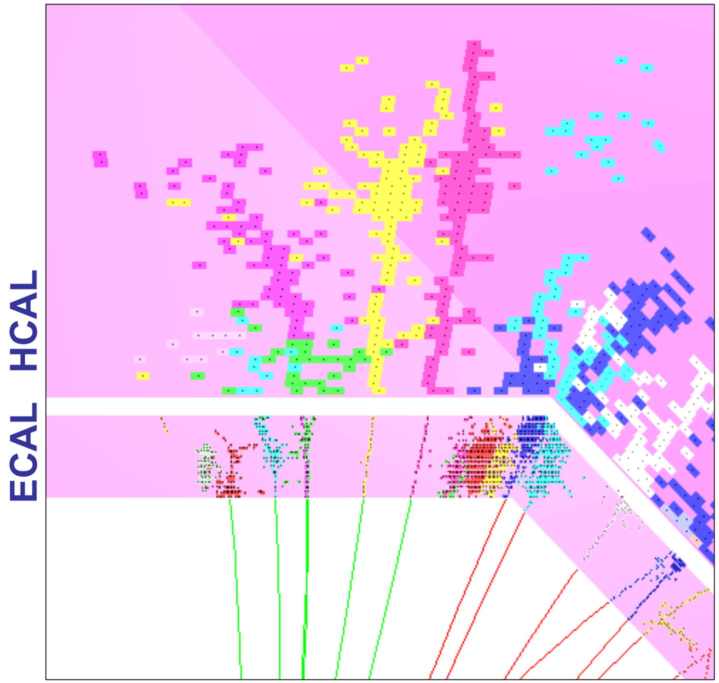
★ **Starting point:**

- SiW ECAL
  - 29 layers
  - 5 x 5 mm^2 high-resistivity silicon cells
  - Silicon thickness: 500 μm

Study context

★ **Basic assumption: Particle Flow Calorimetry**

- To 1st order: ECAL measures **photons/electrons**
- NLO: ECAL measures start of **neutral hadronic showers**
- NNLO: pattern recognition capability ⟹ **confusion**



★ **For jets:**

- ECAL is not main driver of jet energy resolution
- For E_{JET} < 70 GeV
  - HCAL energy res.
- For E_{JET} > 70 GeV
  - Confusion – **hadrons**

Study scope

★ **Physics Models:**
- SiW ECAL
- ScW with 2mm Scintillator

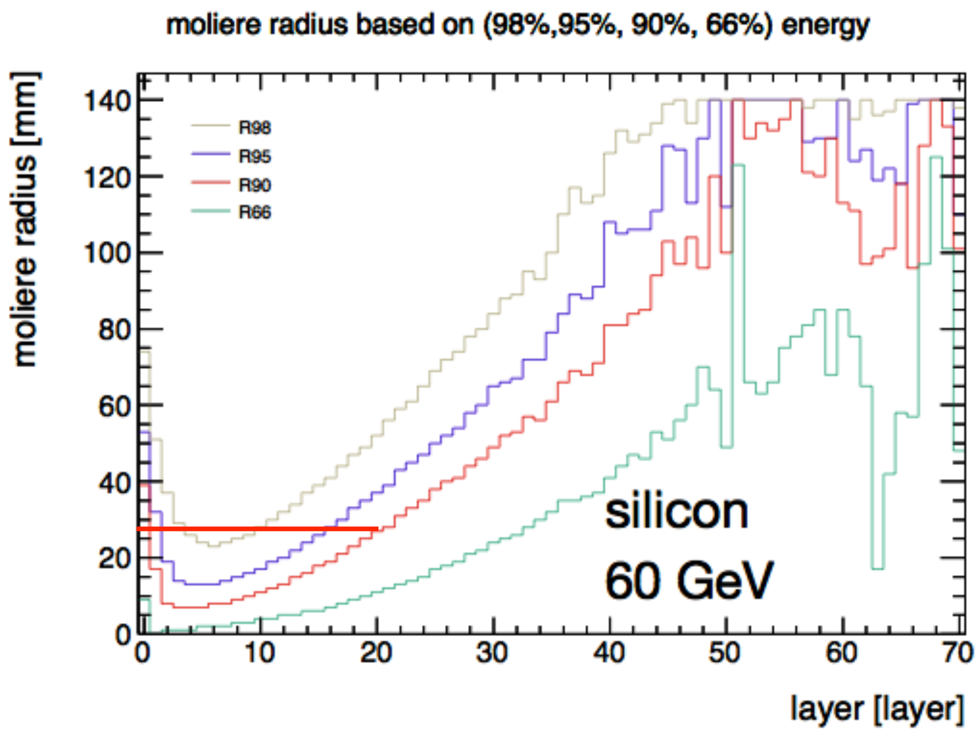
vs

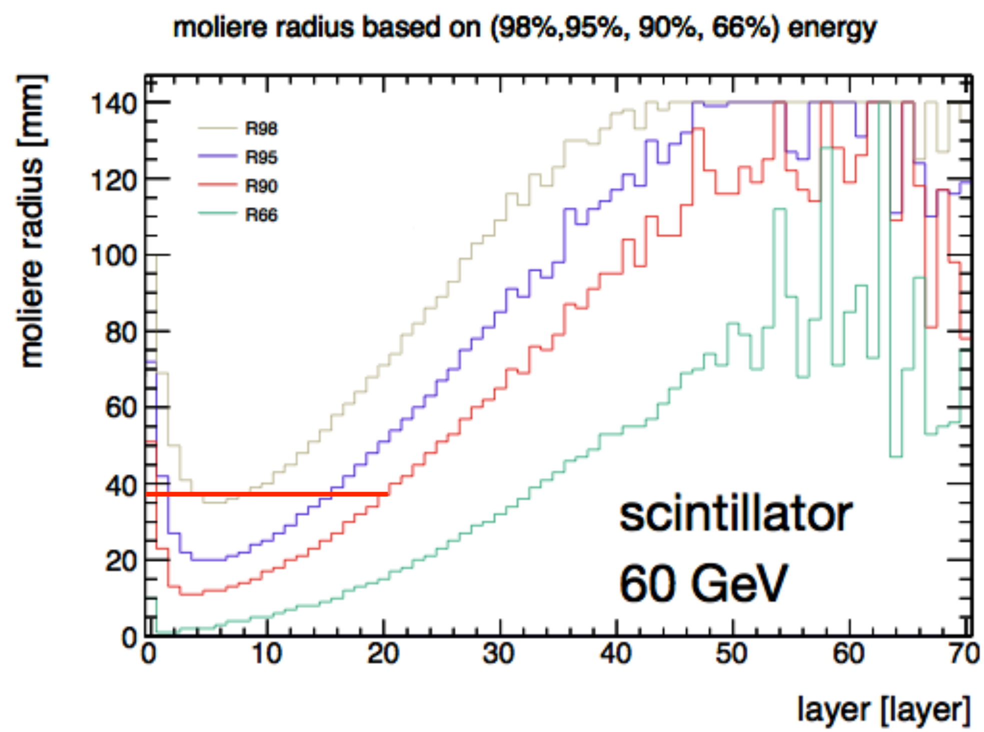
★ Not making arguments which is best

★ Use detector models to probe physics/performance sensitivity

Molière Radius

- Moliere radius is a crude measure of shower width
  - in a high-granularity calorimeter, sample in depth…
  - showers broaden as they develop
  - Broader in SiW than ScW

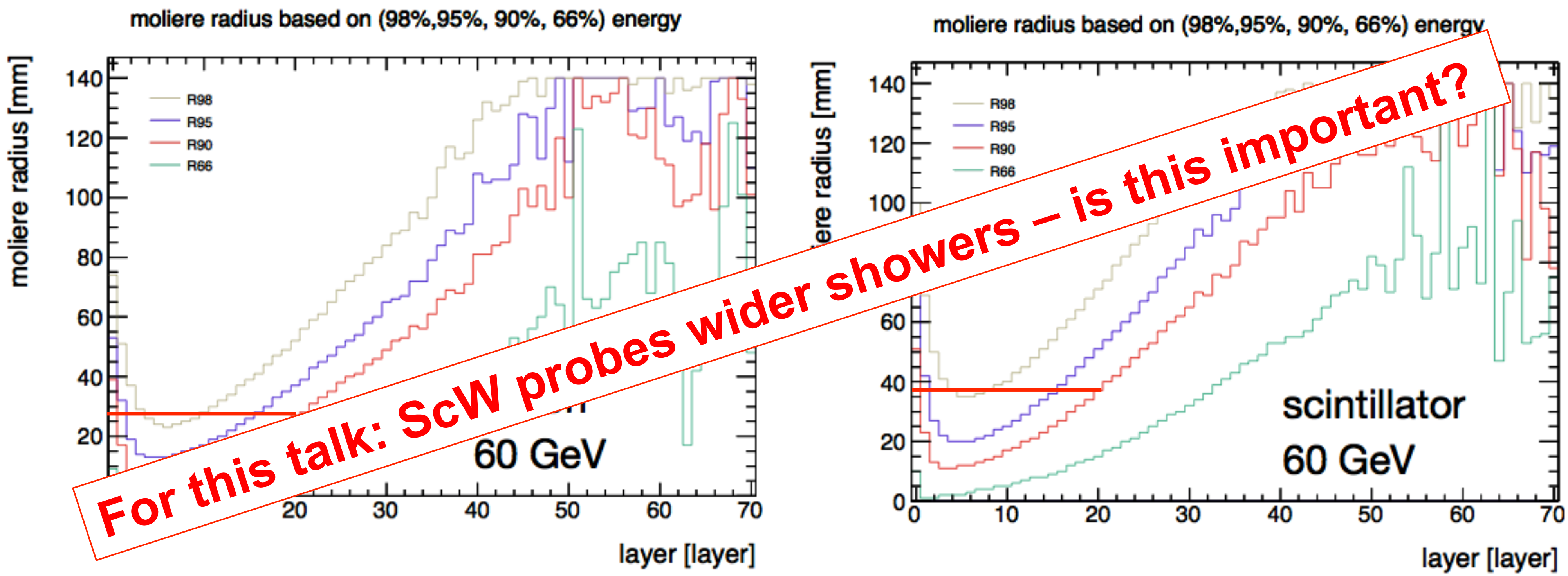




D. Schoke, F. Simon

Molière Radius

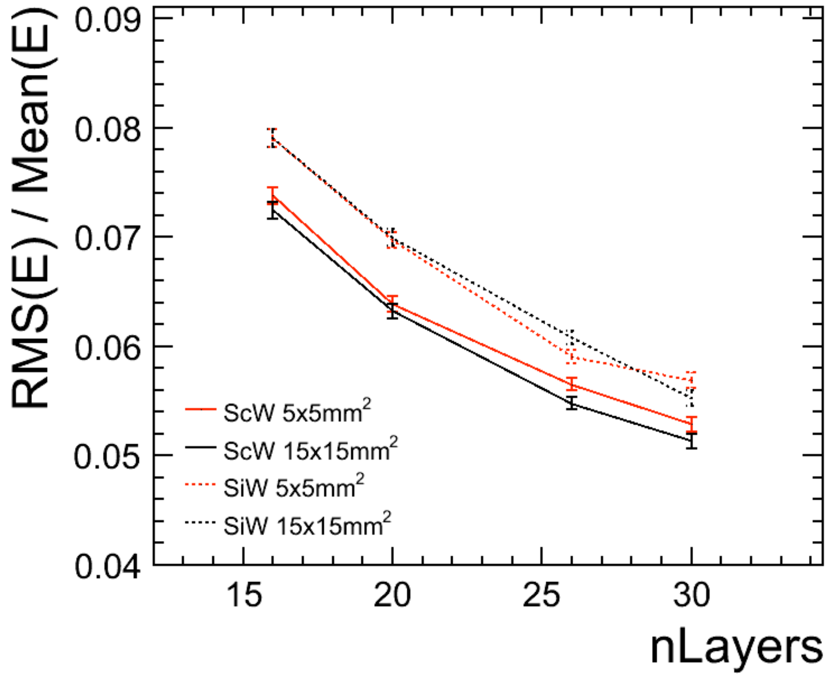
- ★ **Moliere radius is a crude measure of shower width**
  - **in a high-granularity calorimeter, sample in depth…**
  - **showers broaden as they develop**
  - **Broader in SiW than ScW**



D. Schoke, F. Simon

Single Particle Performance

★ **Energy resolution for 10 GeV photons:**

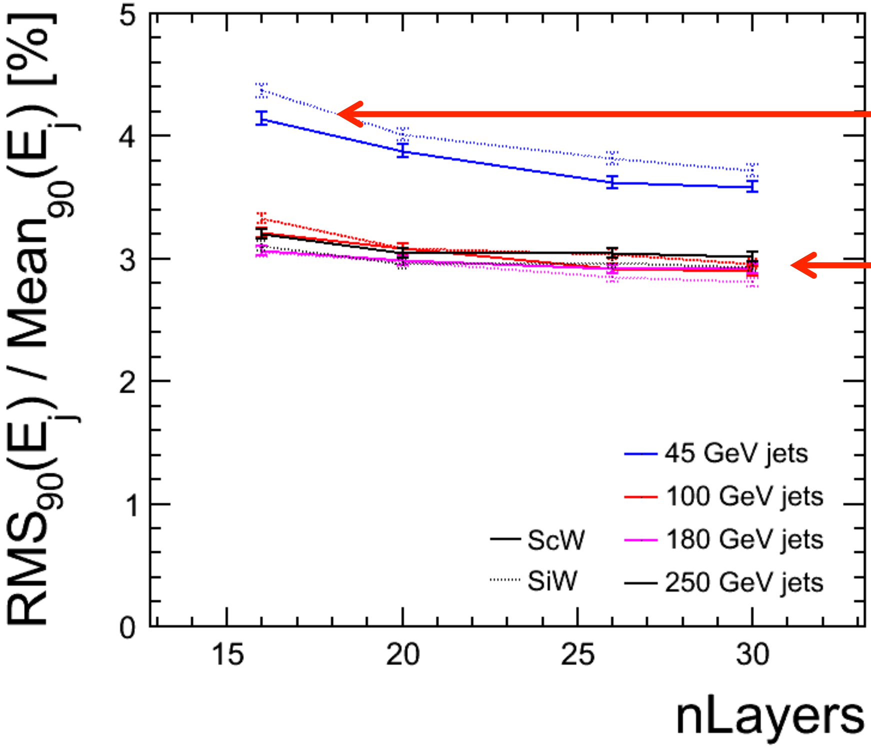


$25\,\%/\sqrt{E(\mathrm{GeV})}$

$16\,\%/\sqrt{E(\mathrm{GeV})}$

- ScW slightly better than SiW (but depends on Sc or Si thickness)
- Number of layers (samples) is a much bigger effect
  - Resolution ~ $1/\sqrt{N_{layers}}$
- No clear “physics requirement” on ECAL resolution for $\gamma, e^{\pm}$
  - 15 layers of SiW is a pretty poor ECAL

Jet Energy Resolution



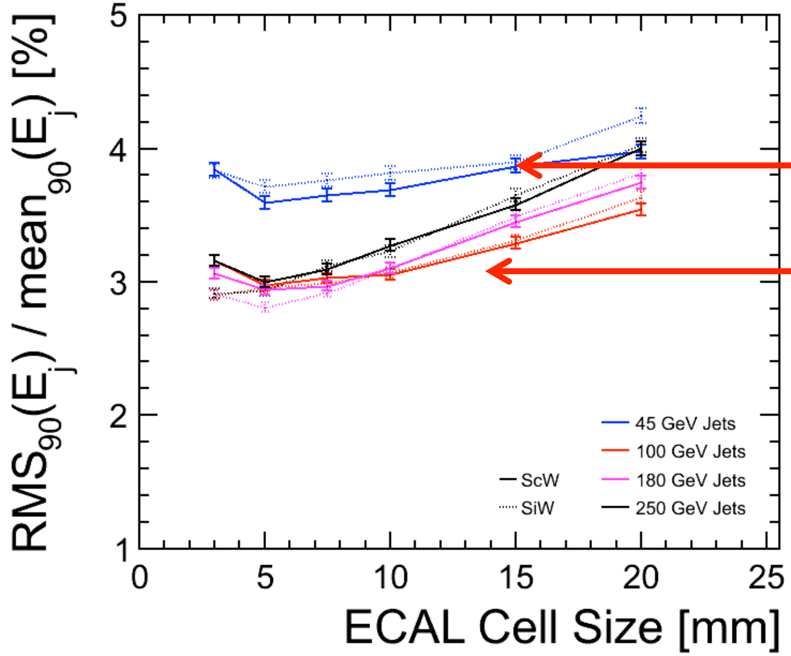
ECAL energy res. becomes important

Confusion dominates "pattern recognition"

- ScW vs SiW: no big difference (i.e. from change in Moliere radius)
- # of layers – "important" for lower energy jets (resolution dominates)
- For higher energy jets (where confusion dominates) number of layers makes little difference

Transverse segmentation

★ **Jet energy resolution**



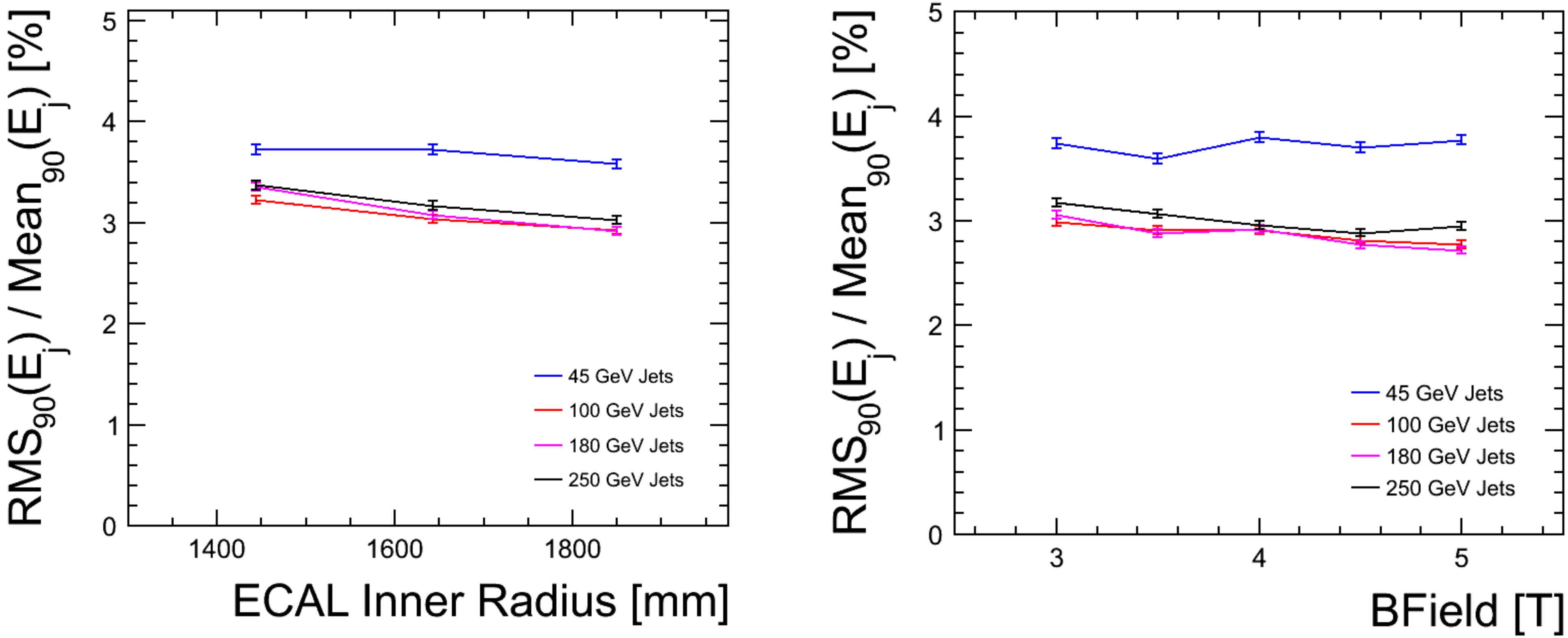
"Easy" for pattern recog.
~ no confusion

Challenging for patrec
~ segmentation matters

- ScW vs SiW: again no big difference (Moliere radius)
- Cell size – not very important for lower energy jets (simple for reco)
- For higher energy jets (where confusion dominates) more important
  - 5 x 5 mm^2 → 15 x 15 mm^2 ⇨ JER: 3 % → ~3.5 %

B-field & ECAL Radius

★ 5 x 5 mm^2 ScW



★ **Rather shallow dependences**

- **Smaller/lower-field options are viable for jet E perf.**

Other considerations

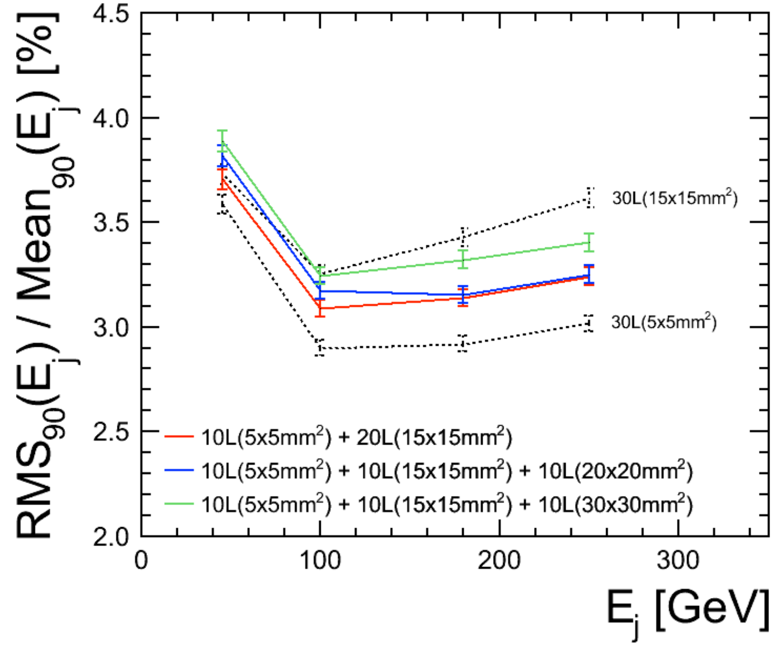
★ **Technology:**

- Is an ECAL with small scintillator cells practical ?
- Relative costs of ScW and SiW ?
- Relative ease of calibration ?
- Cheaper options for SiW sensors ?
- Should we consider hybrid options ?

  e.g. 10 layers of 5 x 5 mm² SiW

  +20 layers 15 x 15 mm² ScW

  - is this really practical?



★ **Cost:**

- How important is cost at the moment ?
- How well do we understand costs?
- Clearest cost reduction through numbers of layers & radius

Impact on Physics ???

★ **Jet Energy Resolution:**

- Impact of JER diluted by:
  - Jet-finding
  - Combinatorics in associating jets to bosons in e.g. **WW→qqqq**
  - Beam related backgrounds
- But to date, no/few quantitative study (see next slides)
- Do all models give adequate performance?
  - 5 x 5 mm^2 → 15 x 15 mm^2
  - 30 layers → 15 layers

  } (and/or)

★ **Electron/Photon Resolution:**

- No quantitative studies – selectrons?
  - My bias: want inherent ECAL performance $< 20\,\%/\sqrt{E(\mathrm{GeV})}$

★ **Hadronic Tau decays:**

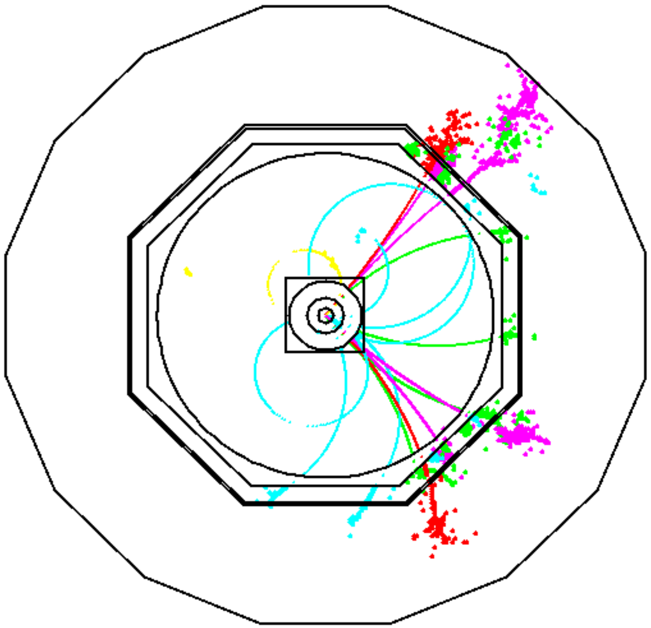
- Potential probe of spin-structure and CP through tau polarization
- Cell size will impact ability to identify hadronic tau decay modes
  - Studies not mature

Physics Optimisation

★ New study "invisible Higgs" (Kelvin Mei, M.Phil, Cambridge)

- Simple final state: HZ (H→invis)(Z →qq)
- Two main variables: di-jet Z mass, recoil mass
- Most direct probe of jet energy resolution?

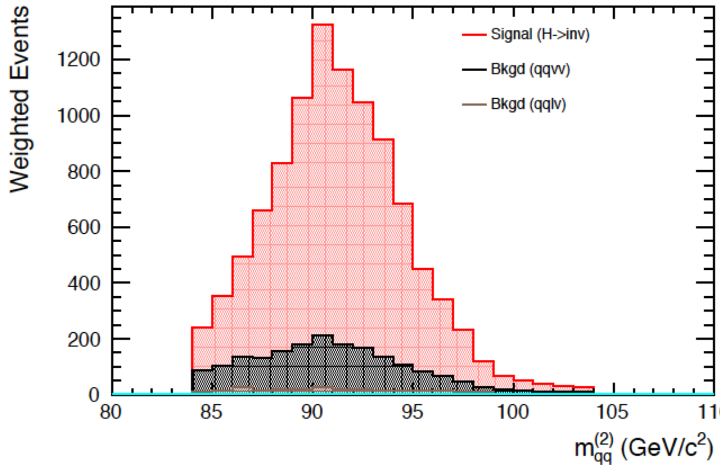
★ Use ECAL parameters as proxy for jet energy



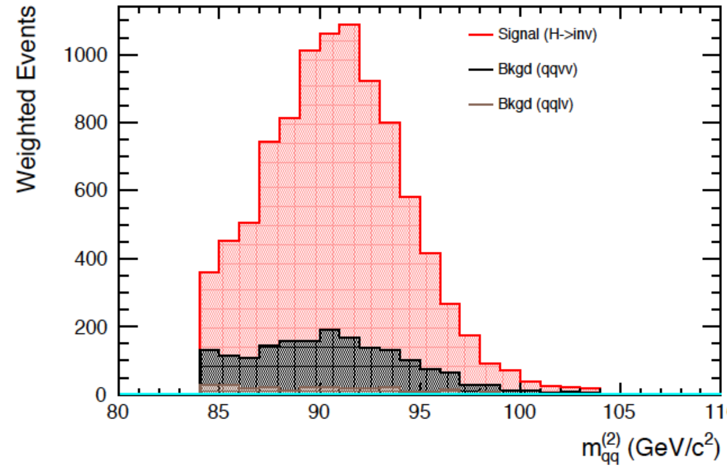
Not trivial - a number of steps:

- Select 4 ECAL models
  - 4 different jet E res.
- Simulate main samples
  - study physics sensitivity
- Map back to jet energy resolution

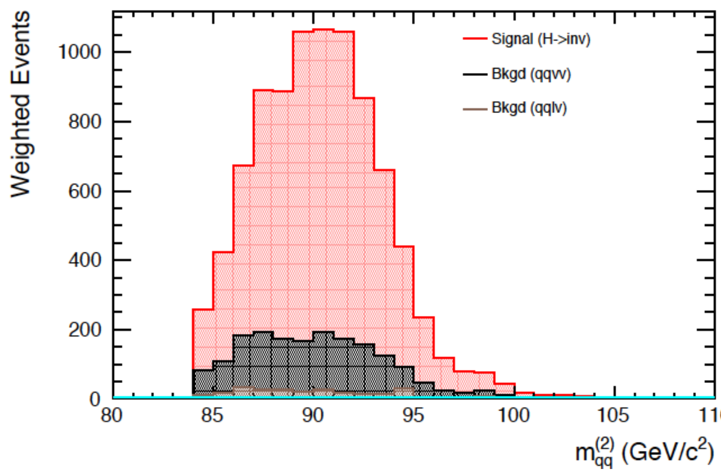
e.g. di-jet mass



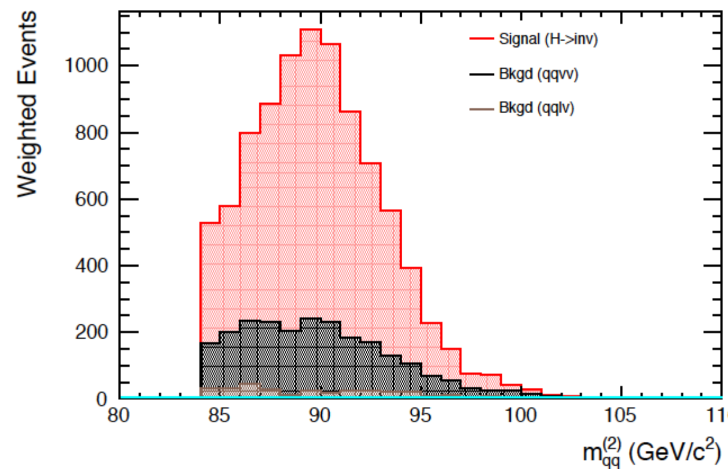
30 layers: 5x5 mm^2



30 layers: 15x15 mm^2



15 layers: 5x5 mm^2



15 layers: 15x15 mm^2

Physics Dependency

★ **Full simulation studies**

- **Full analysis performed (ILC 350 GeV) for ILD**
- **For alternatives (and comparison):**
  - **Signal + main background (qqvv)**
- **BDT based selections – tuned for each model**

Model	$\Delta\sigma_{inv} / \sigma_{SM}$	σ_E /E
30 layers: 5 x 5		
30 layers: 15 x 15		
15 layers: 5 x 5		
15 layers: 15 x 15		

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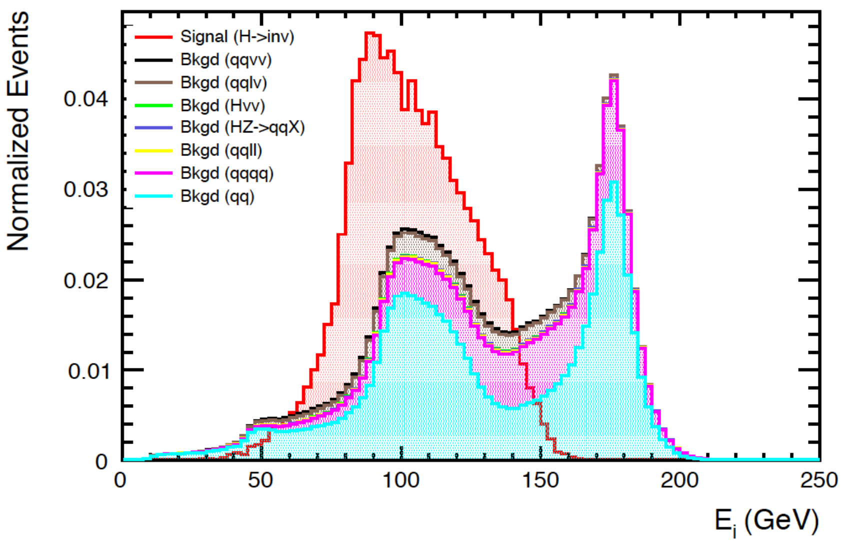
Model	$\Delta\sigma_{inv} / \sigma_{SM}$	σ_E /E
30 layers: 5 x 5	0.43 %	
30 layers: 15 x 15	0.45 %	
15 layers: 5 x 5	0.45 %	
15 layers: 15 x 15	0.48 %	

Connect to jet resolution

Highest energy jet in event



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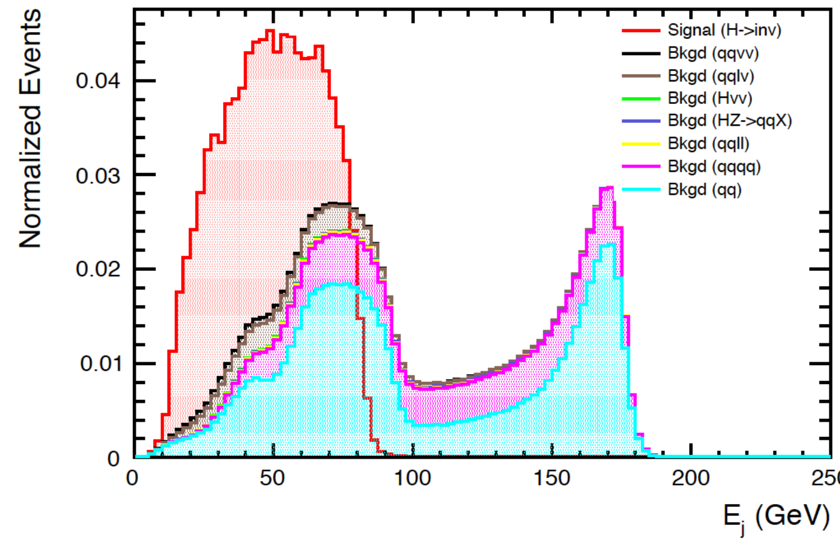
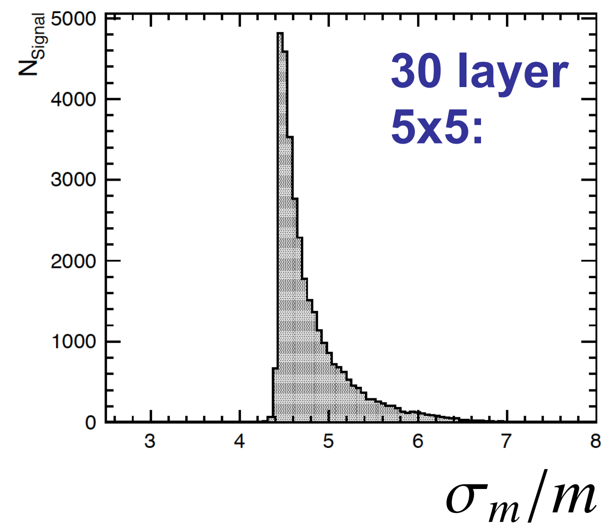
Lowest energy jet in event



+ knowledge of jet energy resolution vs energy (for each model)

$$\frac{\sigma_m}{m} = \sqrt{\left(\frac{\sigma_{E_1}}{E_1}\right)^2 + \left(\frac{\sigma_{E_2}}{E_2}\right)^2}$$

⇨



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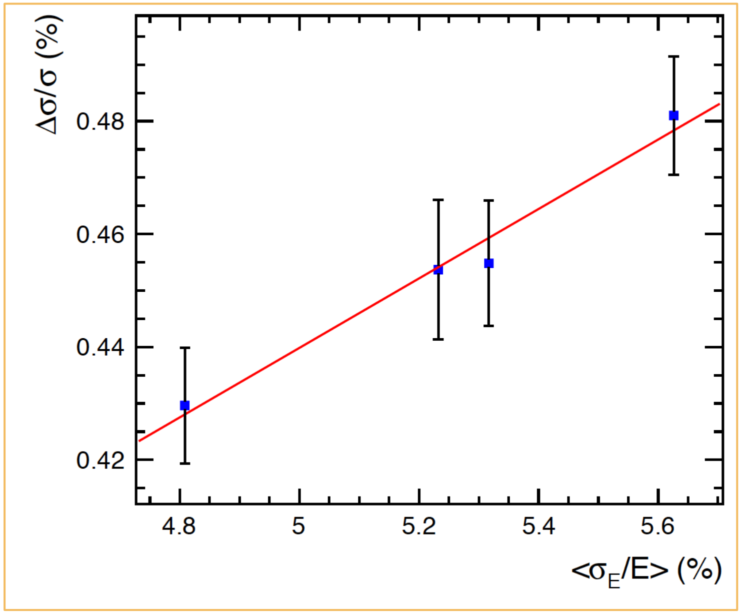
Physics Dependency

Model	$\Delta\sigma_{inv} / \sigma_{SM}$	σ_m /m	< σ_E /E >
30 layers: 5 x 5	0.43 %	4.8 %	3.4 %
30 layers: 15 x 15	0.45 %	5.3 %	3.8 %
15 layers: 5 x 5	0.45 %	5.2 %	3.7 %
15 layers: 15 x 15	0.48 %	5.6 %	4.0 %



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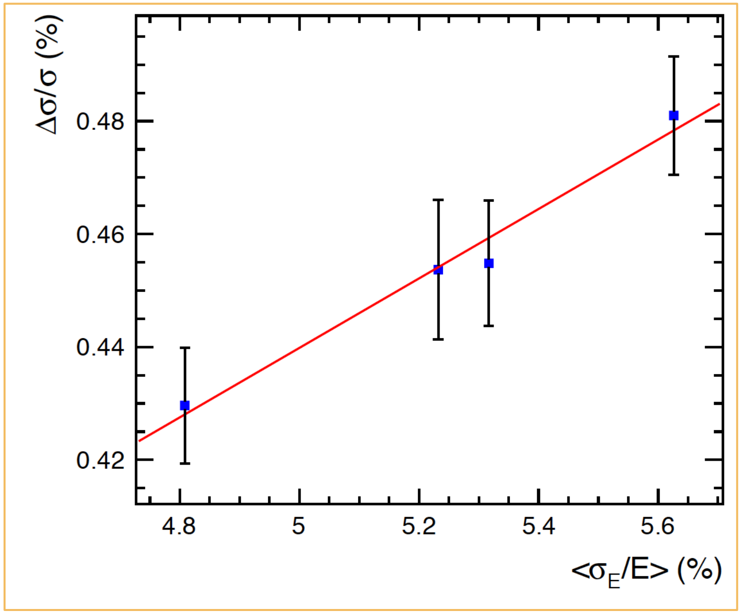

17 % increase in jet E resolution

- **12 ± 3 % decrease in sensitivity**
- **17 ± 4 % decrease in integrated luminosity**

Conclusions

★ **ECAL optimisation**
- in principle, SiW & ScW give similar performance
- cost reduction options (jet energy resolution):
  - reduce ECAL radius
  - reduce number of layers

    price = poorer EM resolution

★ **Physics optimisation**
- comparison of specific models ~ easy
- connecting back to "performance" goals is
  much harder