Detectors and Physics Working Group

A. De Roeck & Yannis Karyotakis

CLIC Workshop 08

Physics and Detector

The numbers

- 4 sessions/21+6 talks
  - Physics and simulation
  - Detectors I (Calorimeter & Partcile Flow)
  - Detectors II (Tracker, Timing)
  - Common Session with MDI
- On average 25-30 participants at all times, 50-60 in total.
  - More than a factor 2 increase wrt. CLIC07
- Excellent exchange with ILC friends.
  - already started earlier in 2008

Since CLIC07

- Since February 08: Startup engagement in PH department for LC detector studies (available from September '08 onwards)
  - PhD students
  - 1 Fellow
  - 1 Scientific associate
  - (+ ≥4 part time PH staff)
  - Some resources available for visitors for LC detector studies
  - Collaboration with several other institutes
- Since February 08: ILC/CLIC collaboration (machine and detectors)

Since CLIC07

- Interests
  - At start: simulation studies to identify critical areas
    - Fast tracking (time stamping), in connection with pixel group
    - TPC studies: usable @CLIC?
    - MDI/FCAL studies. Redesign the MDI area
    - Calorimetry/particle flow, especially for high densities
- Grand plan
  - CLIC CDR by 2010, including a section on detector options
    - Capitalize on working with ILC Detector groups
  - Start-up with studies with SiD-like (ILD) detectors

Physics and Simulation

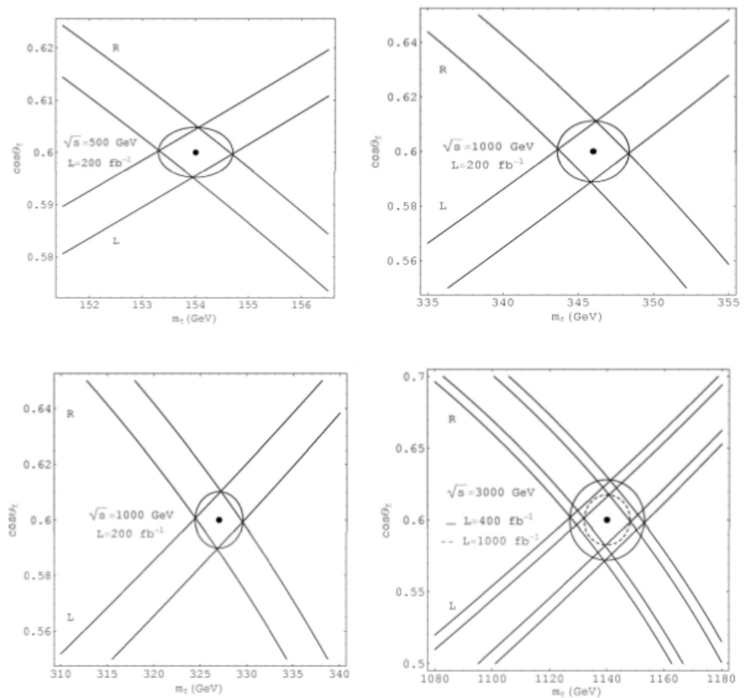
Stau Particle Production (SUSY)

Meta-stable Staus

O Cakir

The coresponding values of $\beta\gamma<0.4$ for staus stopping in different detector parts for the benchmark points ε, ζ, η and θ

$\sqrt{s}$(GeV)	500	1000	3000	Optimal for	Maximal including
L_{int}(fb^{-1})	200	200	400(1000)	pair prod'n	other prod'n processes
ϵ	34	4	4(10)	1500	1700
ζ	-	12	4(10)	254	700
η	-	10	4(10)	370	600
θ	-	-	8(20)	56(140)	140(350)



Polarization

e- %90

e+ %60

accuracies on the measure:

$(\Delta m_{\tilde{\tau}_1}, \Delta\cos\theta_{\tilde{\tau}})$

(0.7, 0.005) for ε

(2.4, 0.01) for ζ, η

at Ecm=1000 GeV;

(8, 0.02) for θ

at Ecm=3000 GeV

Reminder that polarization is important!

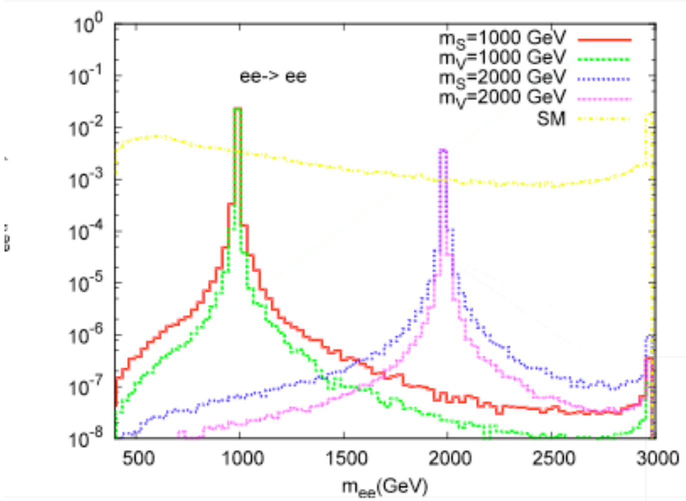
To what precision do we Need to know the polarization?

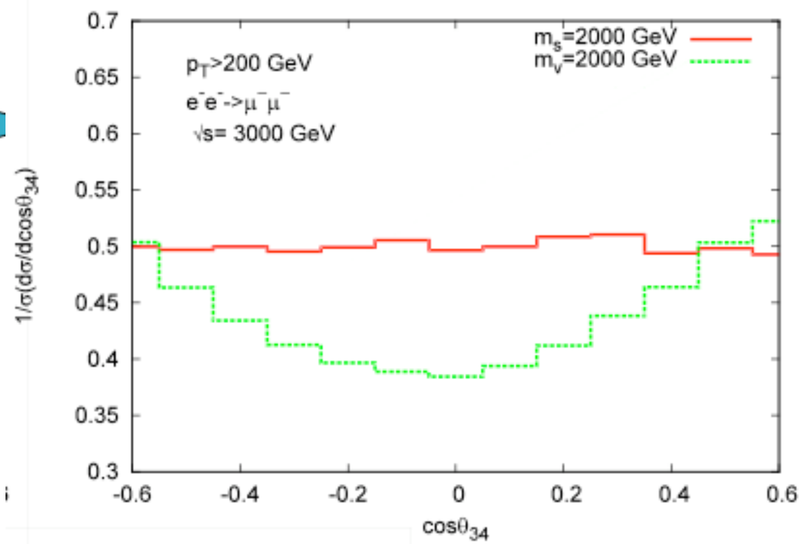
Bileptons

I Turk Cakir

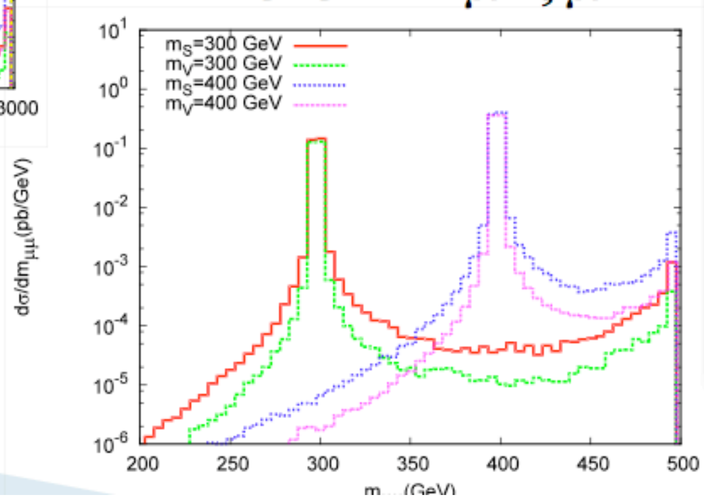
INVARIANT MASS

$$e^- e^- \rightarrow e^-, e^-$$

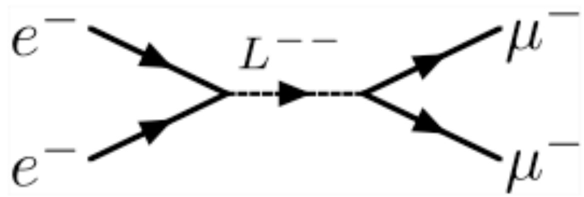




$$e^- e^- \rightarrow \mu^-, \mu^-$$



Angular correlation



Reminder: not to forget the e-e- mode

Excited Lepton Production

A Ozansoy

Analysis : $e^+e^- \to e\nu W$

Acceptance cuts:

$p_T^e > 20\ GeV \quad \not{p}_T > 20\ GeV$

$|\eta_e| < 2.5$

↓

σ_B=0.463 pb for $e^+e^- \to e\nu W$

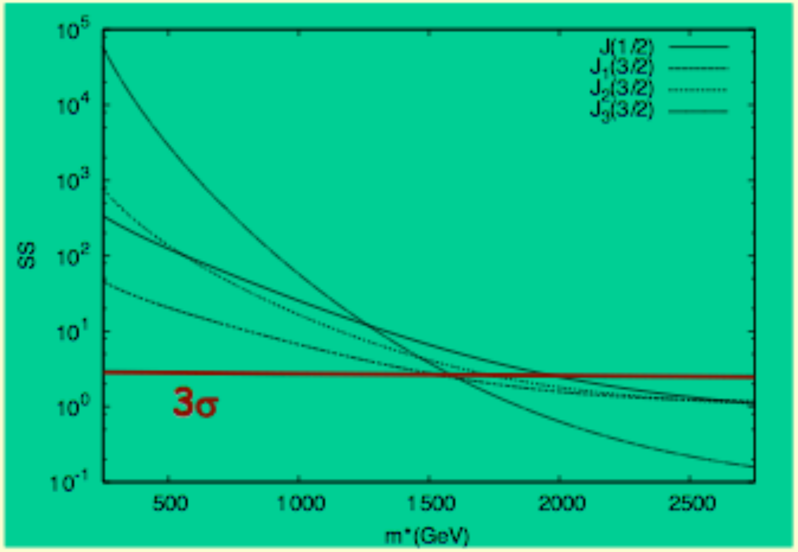
+

Further cuts: $W \to jj$

$|m_{ejj} - m^*| < 25\,\mathrm{GeV} \quad for\ 0.1 < m^* < 1.5\mathrm{TeV}$

$m_{ejj} > 1\,\mathrm{TeV} \quad \mathrm{for} \quad m^* > 1.5\mathrm{TeV}$

↓



m^*(GeV)	σ_B (pb)
250	1.96×10^{-2}
500	1.69×10^{-2}
1000	1.00×10^{-2}
1500	6.32×10^{-3}
2000	1.83×10^{-1}
2500	1.83×10^{-1}
2750	1.83×10^{-1}

$$SS = \frac{\sigma_S}{\sqrt{\sigma_B}} \sqrt{\varepsilon . L_{int}}$$

$$L_{int} = 400\,fb^{-1}$$

SS>3 → m ~ 1.5 TeV for* $c_V^W = c_A^W = 0.05$

A. Ozansoy,CLIC08 17

Reminder that egamma option can have larger reach

Detection possible over the full kinematic range ~ 1.5 TeV

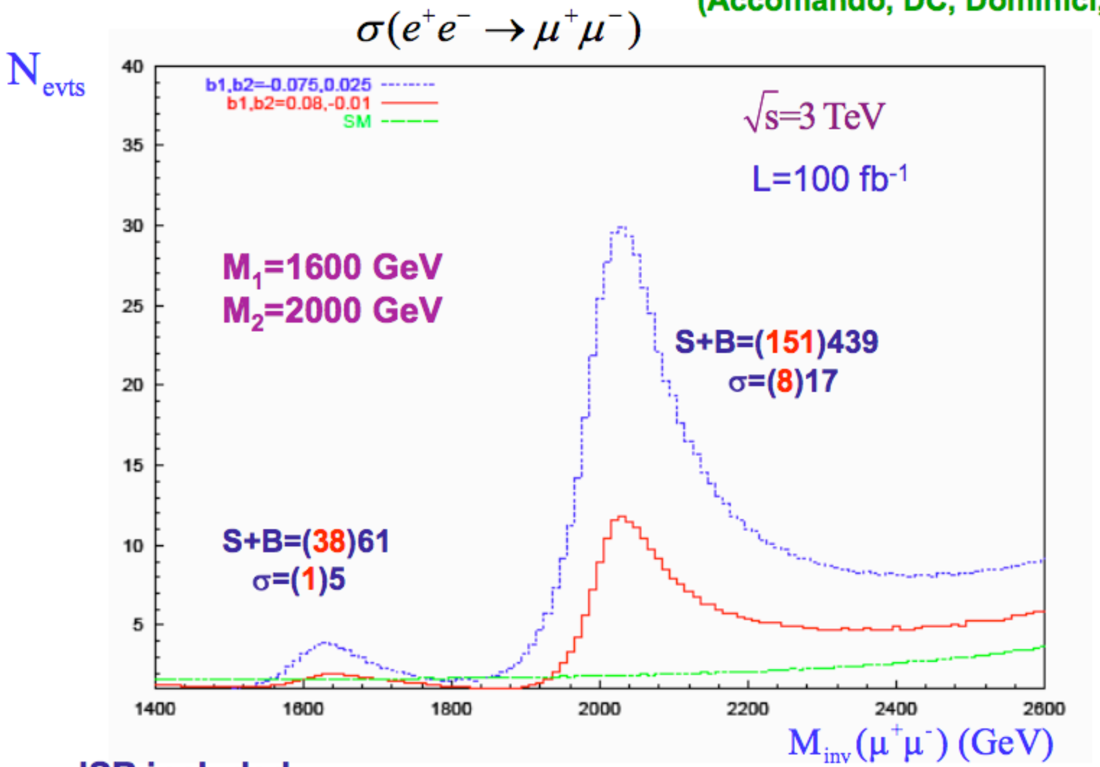
Models with multiple new gauge bosons

Eg. Higgsless Linear Moose Model

S. De Curtis

4-site at CLIC (preliminary)

(Accomando, DC, Dominici, Fedeli)



ISR included
BS not included

S+B=#evts(M±Γ)
σ=S/(S+B)

24

Gain wrt LHC
couplings &
precision measurements
of the parameters

(to be quantified)

Also: Higgs Self coupling as a flagship measurement for a LC

P. Gay

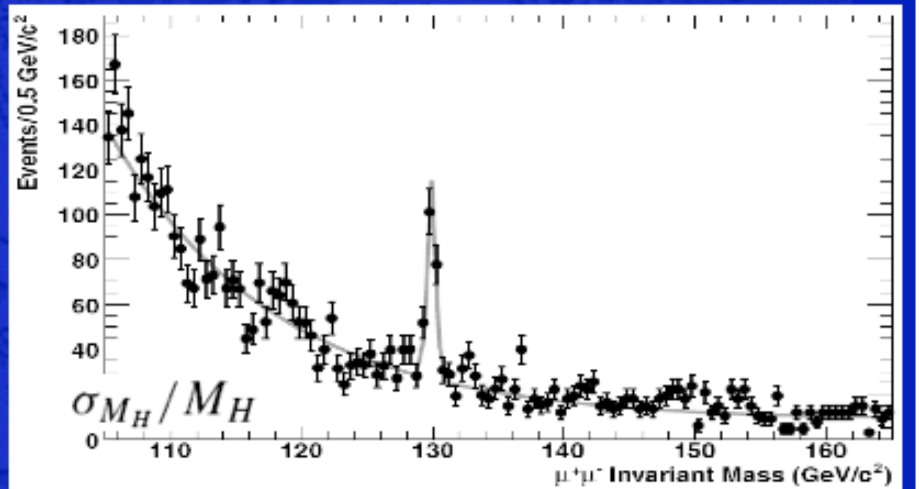
Detector Simulation for CLIC

SiD study of H→μμ production with MOKKA/Marlin

M. Battaglia

$\sigma_{M_H}/M_H = 0.0034$

$\pm 2\,\sigma_{M_H}$ signal window

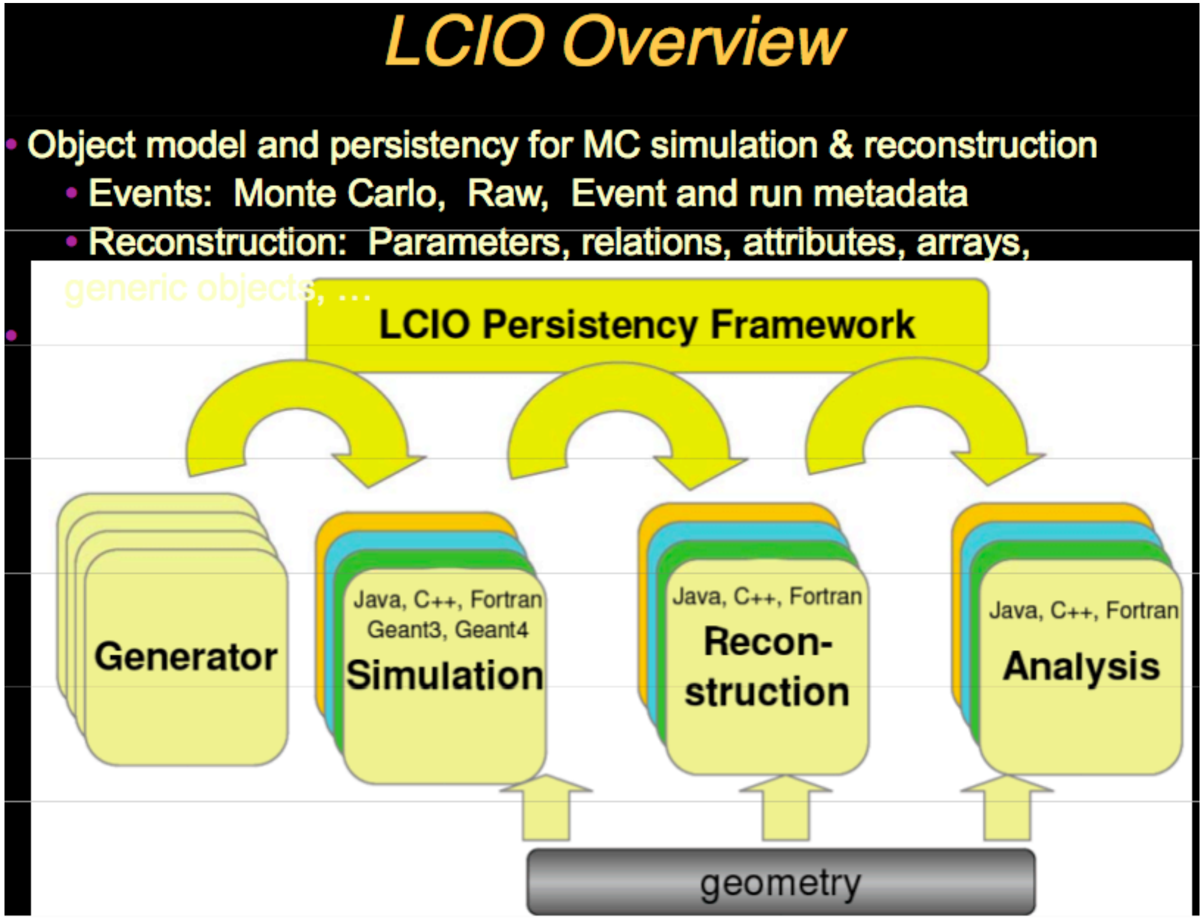


Results for 5 ab^{-1}

M_H (GeV)	Nb. signal evts.	Nb. bkg. evts.	$S/\sqrt{B}$	$\delta BR/BR$
120	229.6	161.1	18.1	0.086
130	153.1	88.1	16.3	0.101
140	103.2	64.3	12.9	0.125
150	68.1	58.1	9.5	0.160
155	68.1	58.0	5.2	0.253
160	12.1	33.0	2.1	

Detector Simulation

- Start with LC Detector full simulation of SiD (Slic)
- Keep eyes open also for the European framework (Marlin)

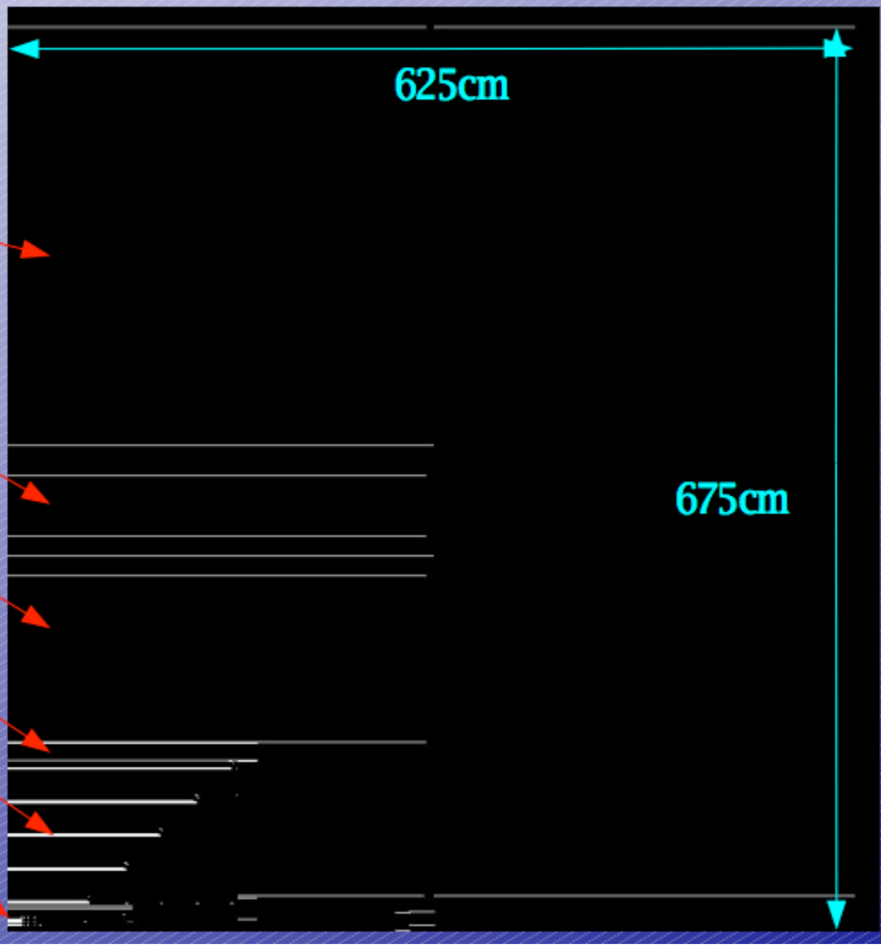


N. Graf

CLIC000

Initial CLIC detector study starting from SiD with changes for High TeV Collisions (first vertex layer moved out, calorimeter deeper (9λ),...)

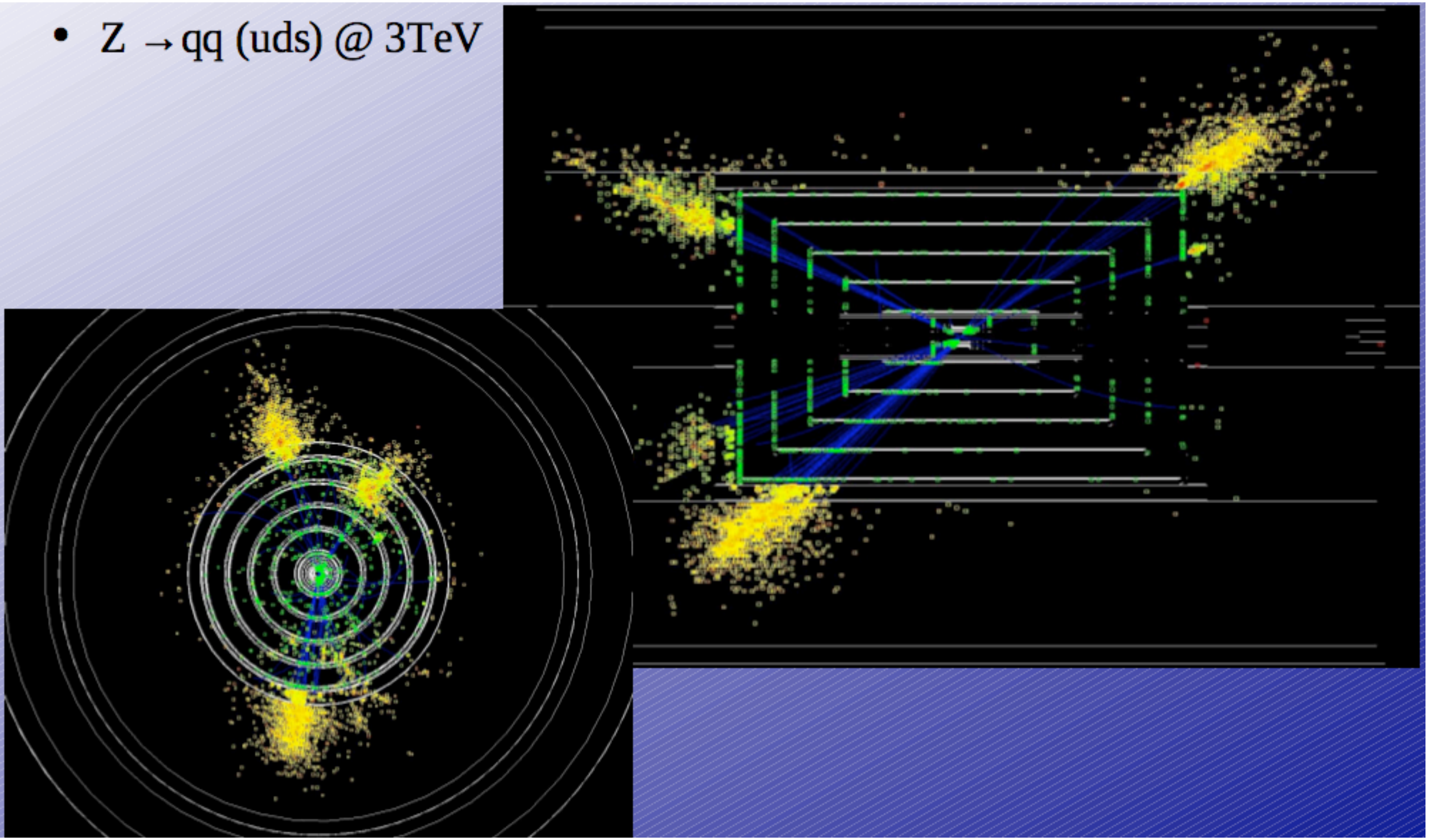
- Cut through CLIC 000 (drawn by JAS3)
  - Myon system
  - Solenoid
  - HCAL
  - ECAL
  - Tracker
  - Vertex detector



P. Speckmayer

CLIC00O

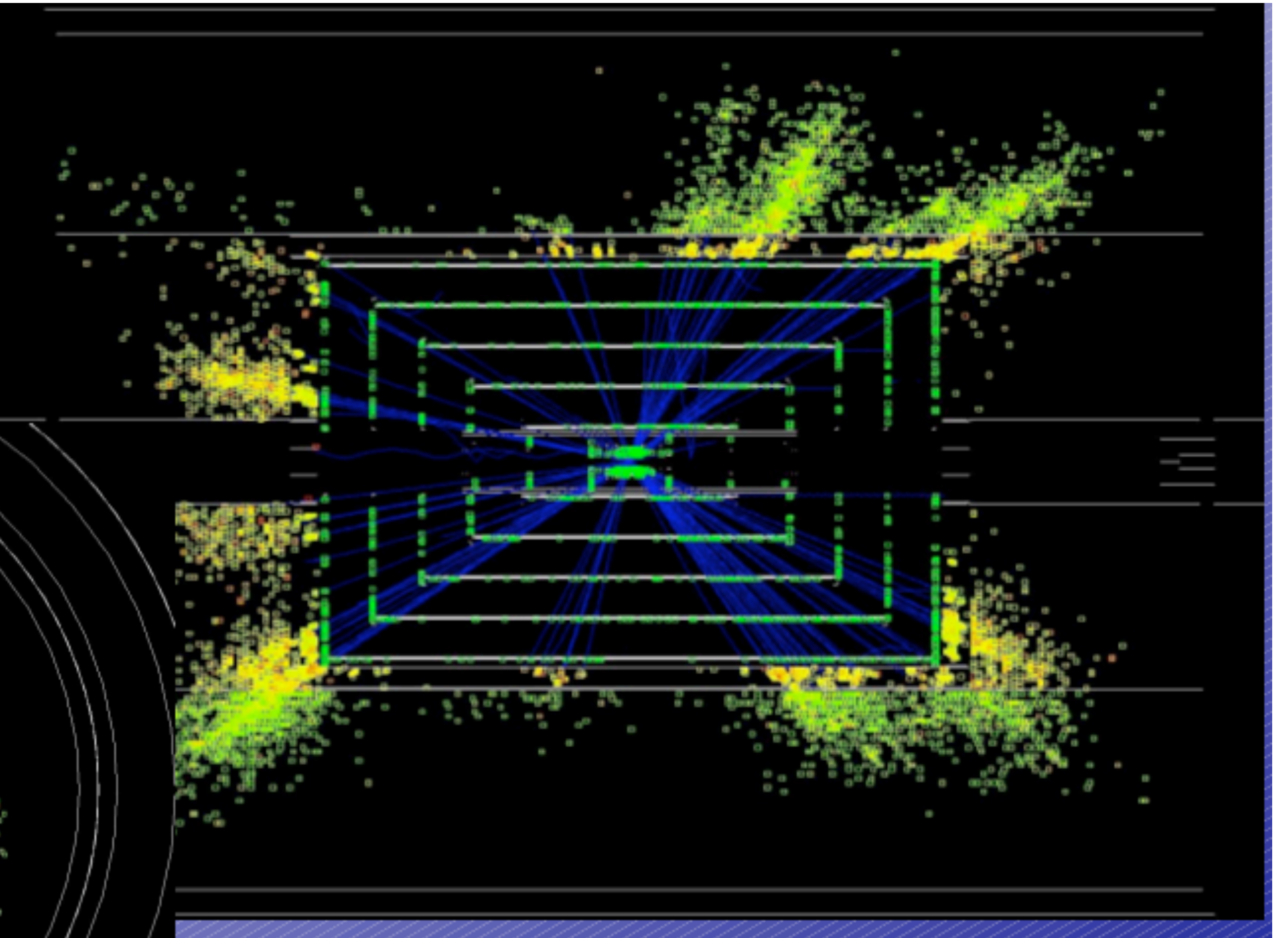
- Z →qq (uds) @ 3TeV

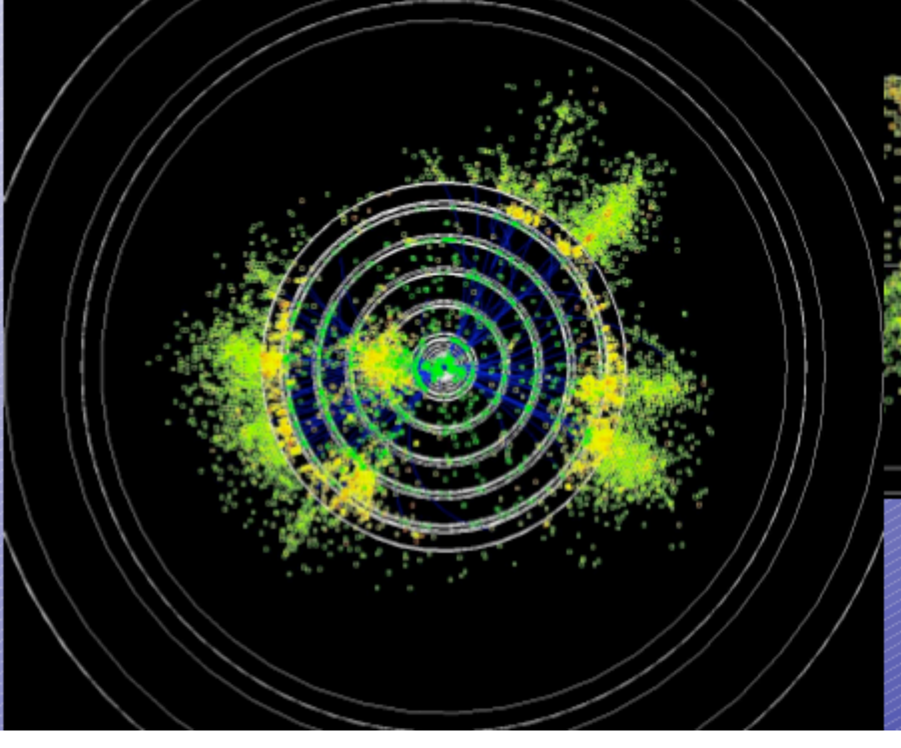


Tungsten calorimeter now, but not to stay…

CLIC000

- WW →qqqq @ 3TeV





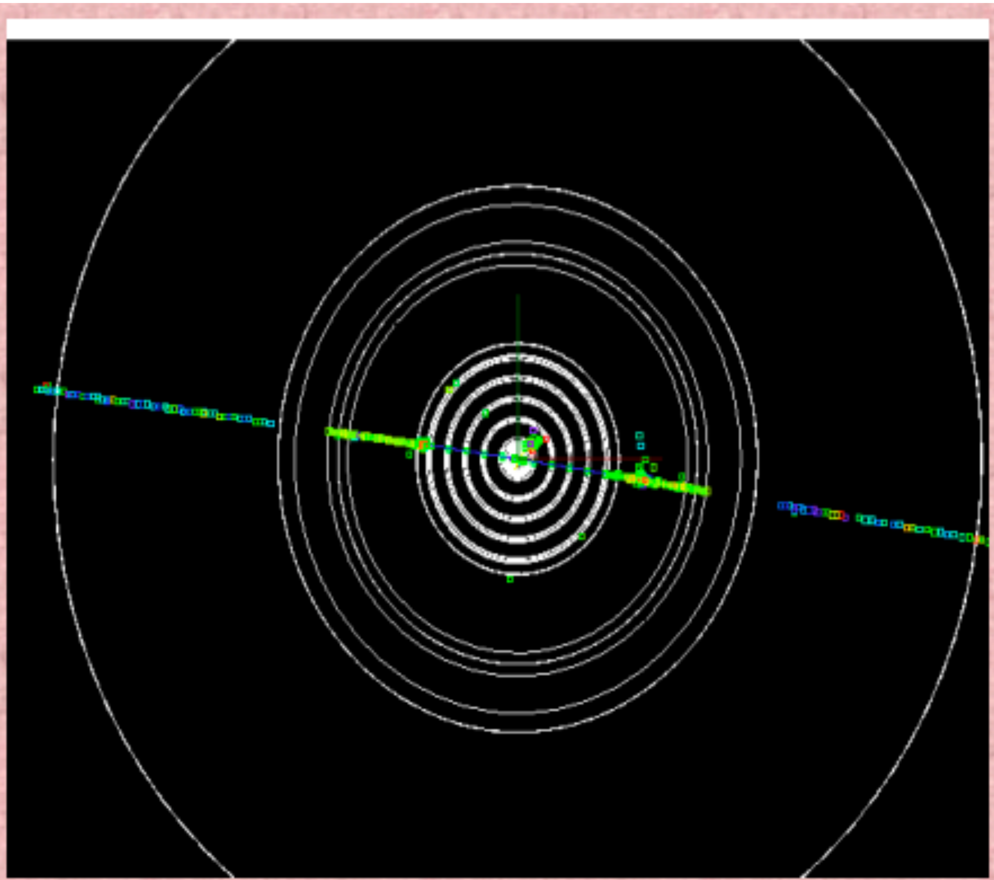
Startup Studies

A Ozansoy

$$e^+e^- \to \gamma / Z \to q\bar{q} \quad (q = u,d,s)$$
$$\to \gamma / Z \to l^+l^- \quad (l = e,\mu)$$
$$\to \gamma / Z \to t^+t^-$$

$$e^+e^- \to ZZ\,(Z \to l^+l^-, Z \to 2j, Z \to \nu\bar{\nu})$$
$$\to WW\,(W \to 2j, W \to l\nu)$$

$$e^+e^- \to \gamma / Z / Z' \to \mu\bar{\mu} \quad (sequential \quad Z')$$
$$e^+e^- \to \tilde{\mu}_L\tilde{\mu}_L \to \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$$



$Z' \to \mu\mu$ event as seen at CLIC000

Processes on the list for studies

Benchmarks processes to be defined (meeting this afternoon)

Examples of possible Benchmarks

ADR/M. Battaglia

1- WWnunu/ZZnunu at 1 TeV and 3 TeV (W/Z separation, fwd)

2- KK/Z' resonance scan at 3 TeV (beamstrahlung, tracking)

3- HHnunu, M_H = 120 GeV (H/Z/W separation, fwd, b tagging)

4- qq (q=c,b,t) at 1 and 3 TeV (xsec, AFB, ALR) (tagging at highest energy, q charge, boosted jets)

5- Smuon or staus at some high mass (such as K' ?) (Fwd, beamstrahlung)

6- Some SUSY processes with complex final states (eg H+H-, HA, heavy charginos decaying into Z and W)

For discussion /start with a few of these processes

Detectors

Detector Overview Talks

- Excellent overview talks on the state of the art of the detector R&D from our ILC friends
  - AHCAL F. Sefow
  - DHCAL J. Blaha
  - ECAL N. Watson
  - Pixel detectors M. Stanitzki
  - Silicon detectors A. Savoy-Navarro
  - TPCs R. Settles
  - Particle Flow M. Thomson
  - 4th Concept C. Gatto
- Extremely useful input for our studies and collaborative work

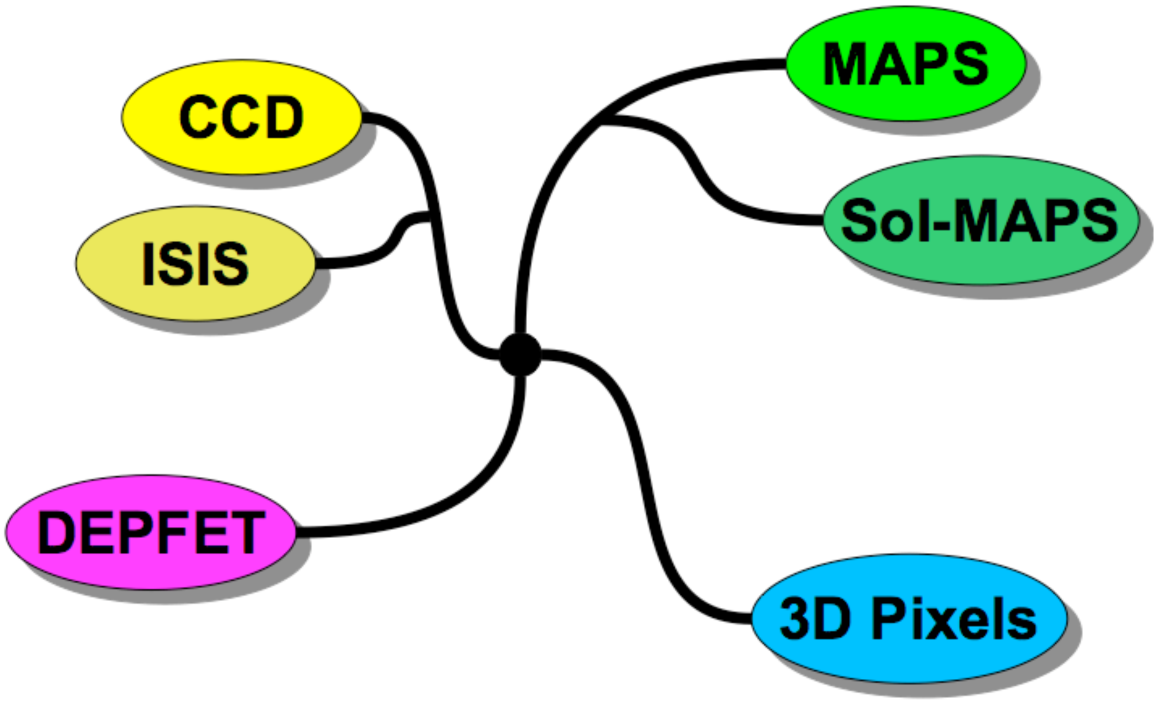
Pixel Detectors

- Detector implications
  - Calorimeter granularity
  - Pixel size
  - Material budget, central
  - Material budget, forward

- Detector implications
  - Need factor ~200 better than LHC
  - Need factor ~20 smaller than LHC
  - Need factor ~10 less than LHC
  - Need factor ~ >100 less than LHC

M. Stanitzki

Pixel Technology Tree



Silicon trackers

The SiLC R&D collaboration is one of the sub-detector "transversal" R&D collaboration that tackles all these issues for the ILC proposed detectors,
with strong synergy with the LHC Si tracking builders (legacy) and future LHC upgrades.
The requests of the CLIC tracking are indeed starting to be also taken into account by this collaboration.

A. Savoy-Navarro

Some important parameters for trackers: CLIC vs ILC

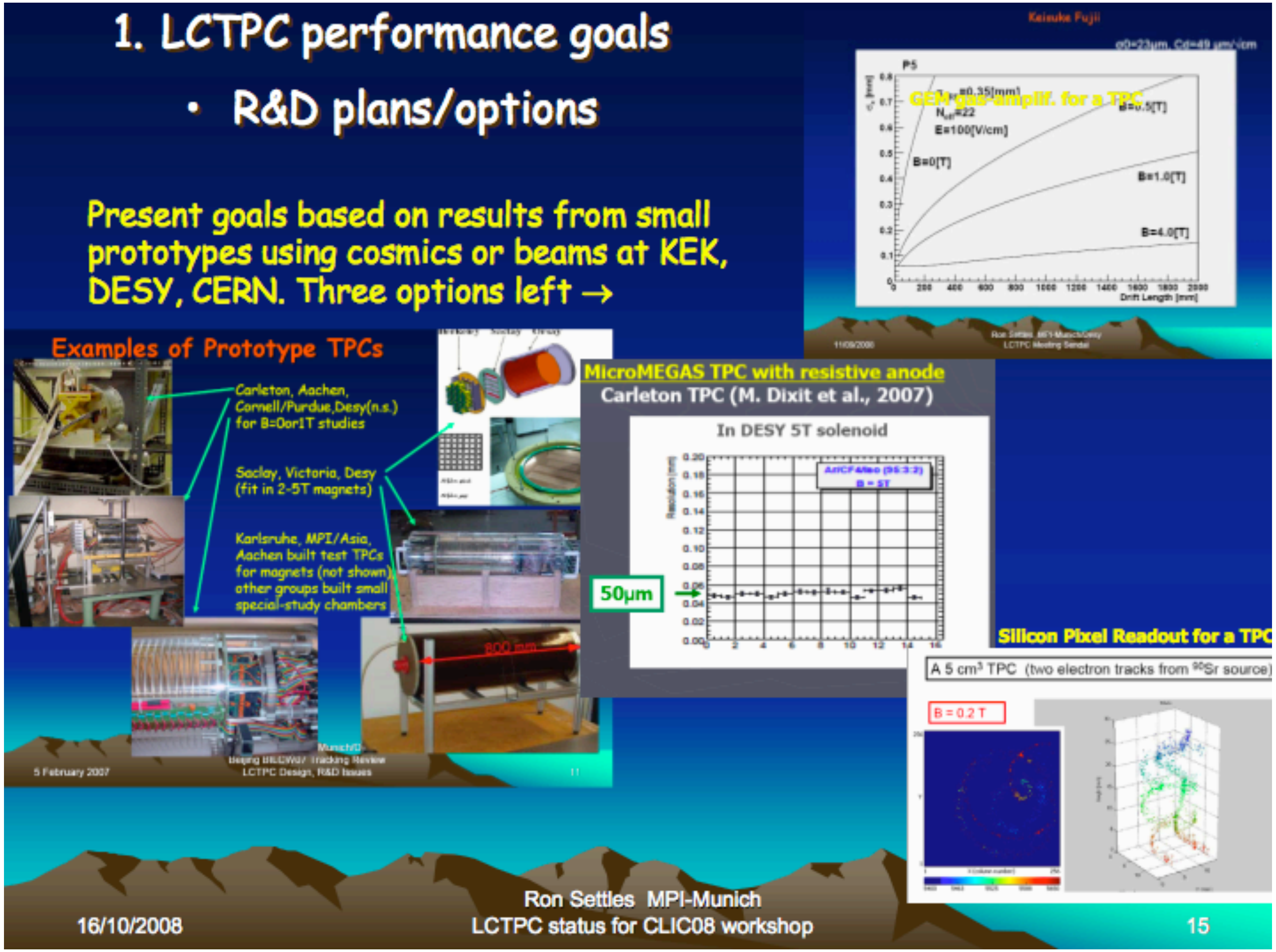
parameters	ILC	CLIC
Time stamping	O(100 ns) (achievable by Si	O(100-200ps) (special layers?)
Shaping time	LONG: 0.5 to 1.5 μs	SHORT: O (150ns)
Power cycling: Y/N? (inter bunch train /reduction factor	YES (OK) (200ms/~ 70)	YES? (20ms/to be studied)
Double track recognition	YES (OK)	YES-YES (OK)
$\sigma(\delta p_T/p^2_T)$	a few 10^{-5} (c/GeV)	idem
Spatial resolution	4 to 7 μm (OK)	idem
Material budget/layer	~ 0.7-0.8% X0 (OK)	idem

TPCs

Still an option for CLIC/Needs to be studied

R. Settles

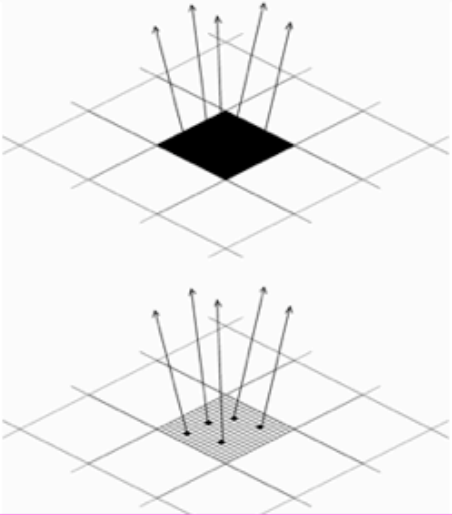
Maybe Si+TPC?



Digital ECAL

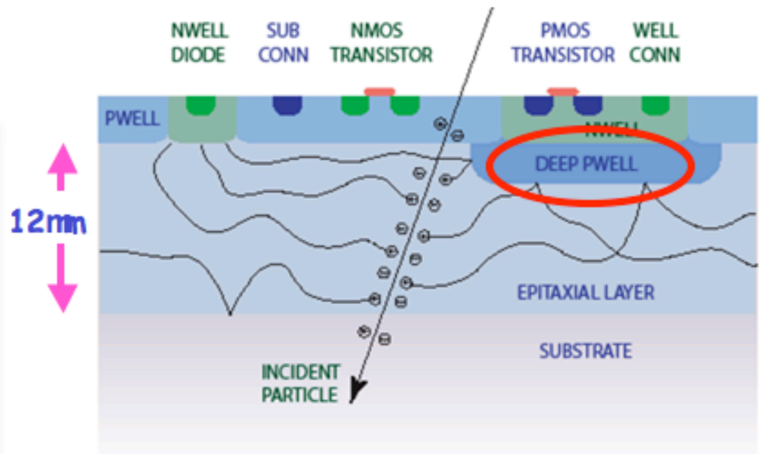
N. Watson

MAPS ECAL: Option Summary



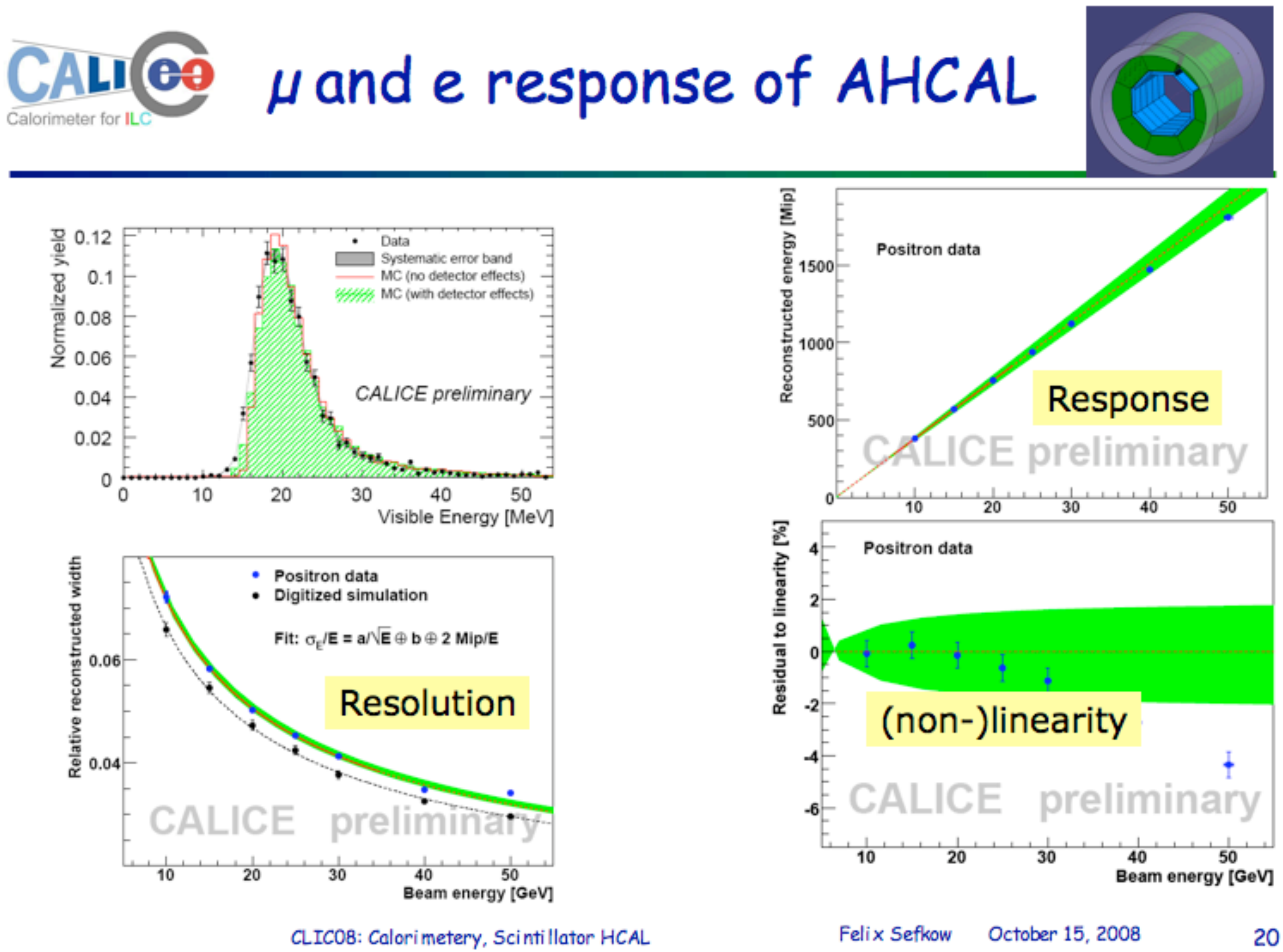
- Swap ~0.5x0.5 cm^2 Si pads with small pixels
  - "Small" := at most one particle/pixel
  - 1-bit ADC/pixel, i.e. **Digital ECAL**

- How small?
  - EM shower core density at 500GeV is ~100/mm^2
  - Pixels must be < 100×100mm^2
  - Our baseline is 50×50mm^2
  - Gives ~10^{12} pixels for ECAL – "Tera-pixel APS"
  - Mandatory to integrate electronics on sensor



Analog HCAL

F. Sefkow



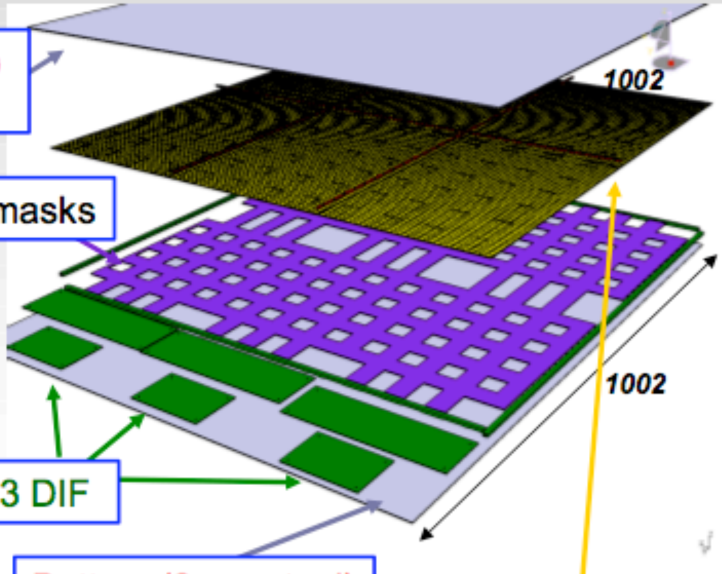
Digital HCAL

J. Blaha

M² µMegas prototype

M² prototypes:

- ~10 000 channels !
- Prototypes to be ready for test beam 2009!
- Performance studies towards the technology for m³



M² µMegas design

- 6 bulks (50x32 pads each)
- Hardroc or dirac readouts
- DAQ
  - USB + PC
  - CALICE DAQ2

Next step: m³ with ~ 400 000 readout channels

Similar work (m²/m³) is underway with RPC (US and EU)

Building Big Magnets

Capitalizing on the CMS experience

A. Herve

The CMS design would suit *any new 3.5* or *4-Tesla coil*.

A 5-Tesla large thin coil, respecting all parameters considered safe today, would be a *natural extrapolation of the CMS design, with the possible use of an improved conductor* using cold drawn Al-0.1wt%Ni alloy as stabilizer.

Reaching 5T requires to launch an R&D program (*being already discussed between Saclay, Genova and CERN*) to:

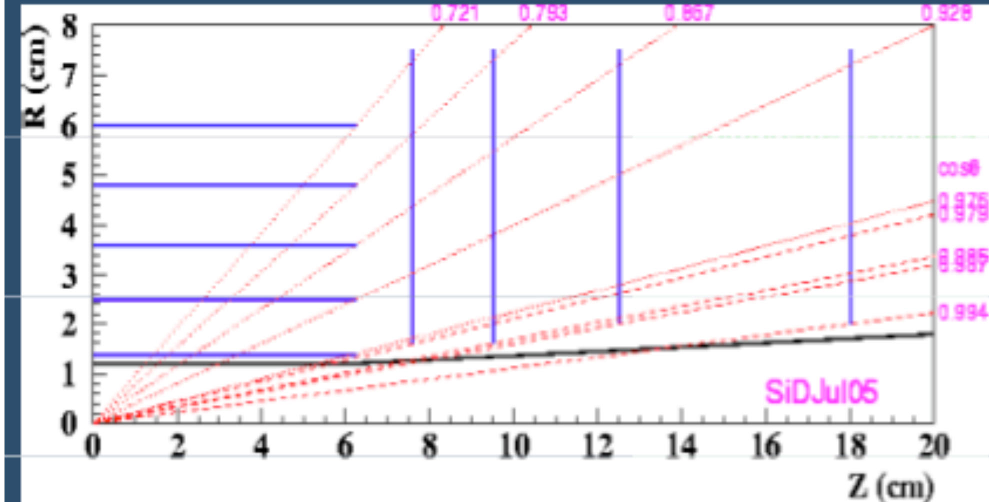
- Check possibility of using "Yamamoto's alloy" in a reinforced conductor à la CMS.
- Find an easier and less expensive technique to replace EB welding to attach the reinforcement.
- Secure a safe industrial solution for the co-extrusion of the sc cable.

Fast Timing in the tracker

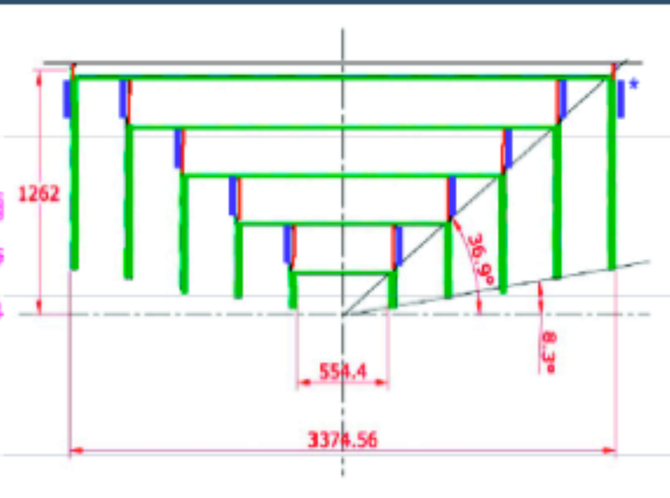
P. Jarron

- Choice of the timing implementation in the tracking system
  - Radius, number of timing-tracking planes
  - Outer tracker barrels look more attractive if background rejection needed
    - Tracking geometry might be strip or macropixel
  - Timing in vertex possible if coherent pairs rate affordable
    - What is the benefit in terms of tracks reconstruction?

ILC SiD vertex layout



ILC SiD tracking layout

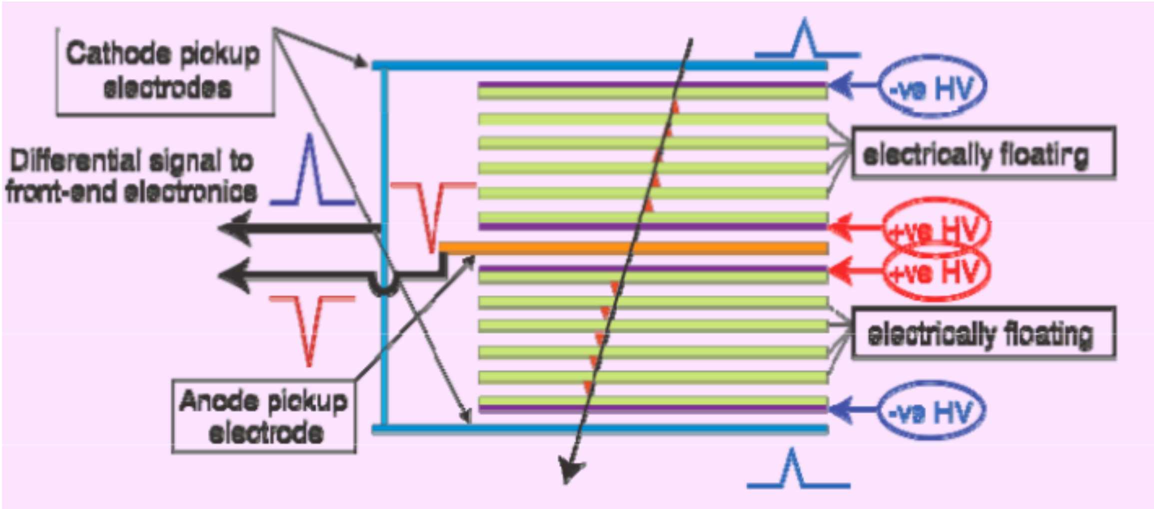


Many questions need to be answered through studies
Timing from vertec detector needed, heat load, data estimate, calorimeter..

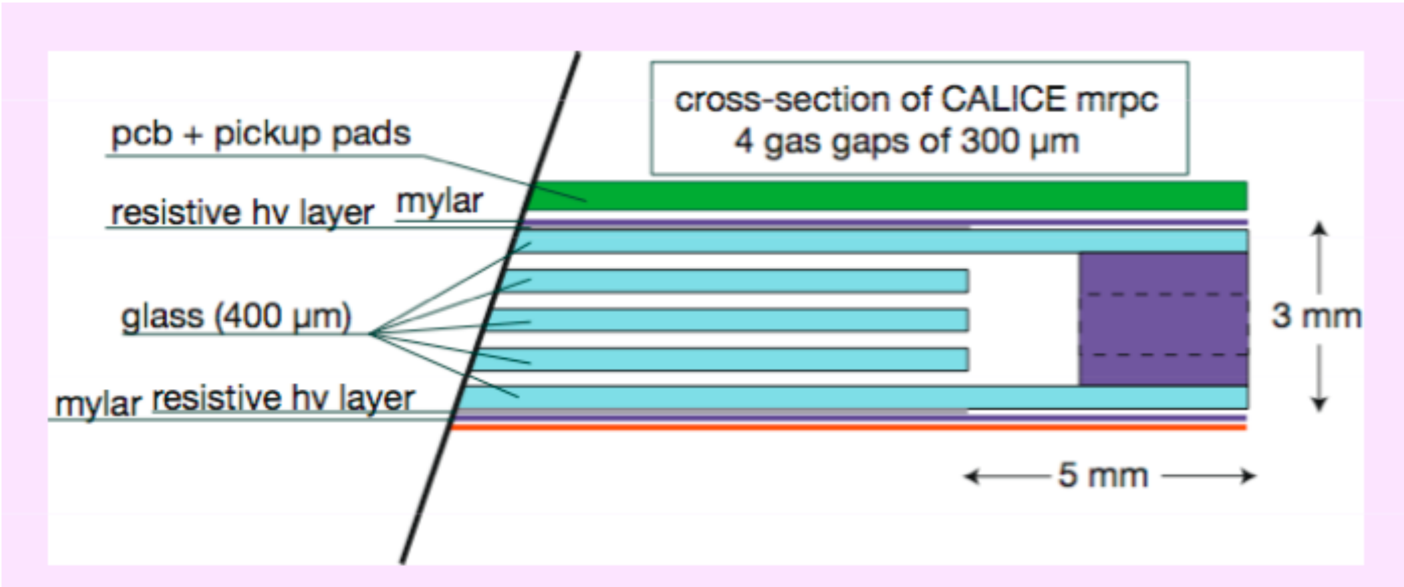
ALICE TOF

40 ps timing precision with RPCs

D. Hatzifotiadou



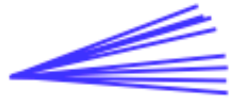
For DHCAL?
Timing ~ 150 ps



❷ The Particle Flow Paradigm

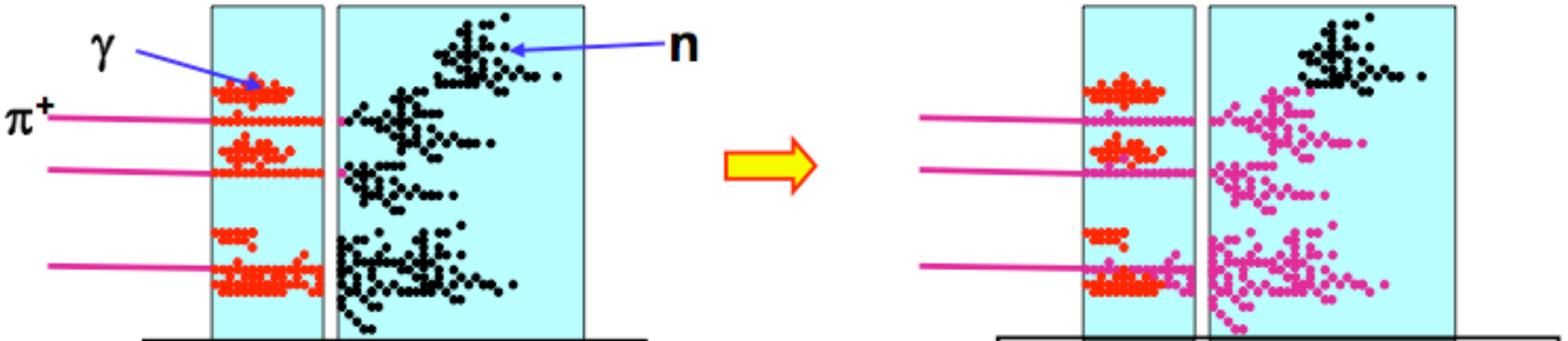
★ **In a typical jet :**

- **60 %** of jet energy in charged hadrons
- **30 %** in photons (mainly from $\pi^0 \rightarrow \gamma\gamma$)
- **10 %** in neutral hadrons (mainly n and K_L)



★ **Traditional calorimetric approach:**

- Measure all components of jet energy in ECAL/HCAL !
- **~70 %** of energy measured in HCAL: $\sigma_{\mathrm{E}}/\mathrm{E} \approx 60\,\%/\sqrt{\mathrm{E(GeV)}}$
- Intrinsically "poor" HCAL resolution limits jet energy resolution



$E_{JET} = E_{ECAL} + E_{HCAL}$ $\quad$ $E_{JET} = E_{TRACK} + E_{\gamma} + E_{n}$

★ **Particle Flow Calorimetry paradigm:**

- charged particles measured in tracker (essentially perfectly)
- Photons in ECAL: $\sigma_{\mathrm{E}}/\mathrm{E} < 20\,\%/\sqrt{\mathrm{E(GeV)}}$
- Neutral hadrons (ONLY) in HCAL
- Only 10 % of jet energy from HCAL ⟹ much improved resolution

Particle Flow Observations

M. Thomson

- With slight optimization: seems not to work to badly for jet energies up to 500 GeV
- Calorimeter depth important at high energies
- High field less important. Large R is more important
- Clever algorithm that can smoothly change from particle flow to energy flow to pure calorimetric measurements needs to be developed
- CLIC will also have to deal with "ILC energy jets" where PF should help
- If CLIC runs at lower energies (< 1 TeV) then ~ ILC situation
- Excellent area for studies and collaboration with ILC experts

In backup slides…

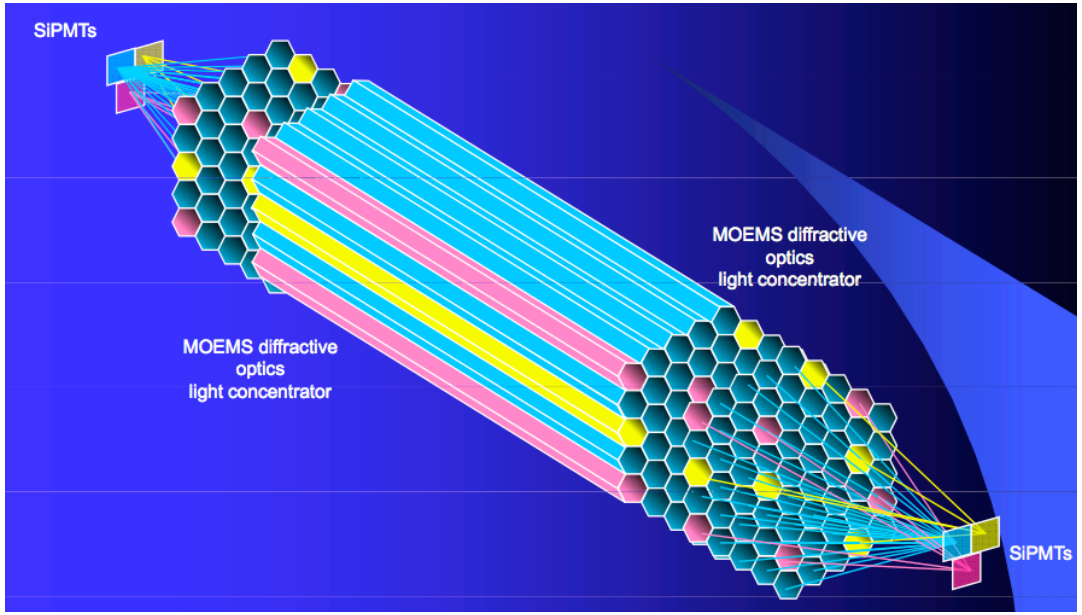
Homogenous Dual Readout Calorimetry

- New technologies in the production of heavy scintillators open interesting perspectives in:
  - Design flexibility: detector granularity
  - Functionality: extract more information than simple energy deposit
- The underlying concept of this proposal is based on metamaterials
  - Scintillating cables made of heavy scintillating fibers of different composition ⇨ quasi-homogeneous calorimeter
  - Fiber arrangement in such a way as to obtain 3D imaging capability
  - Fiber composition to access the different components of the shower

P. Lecoq

Alternative to particle flow

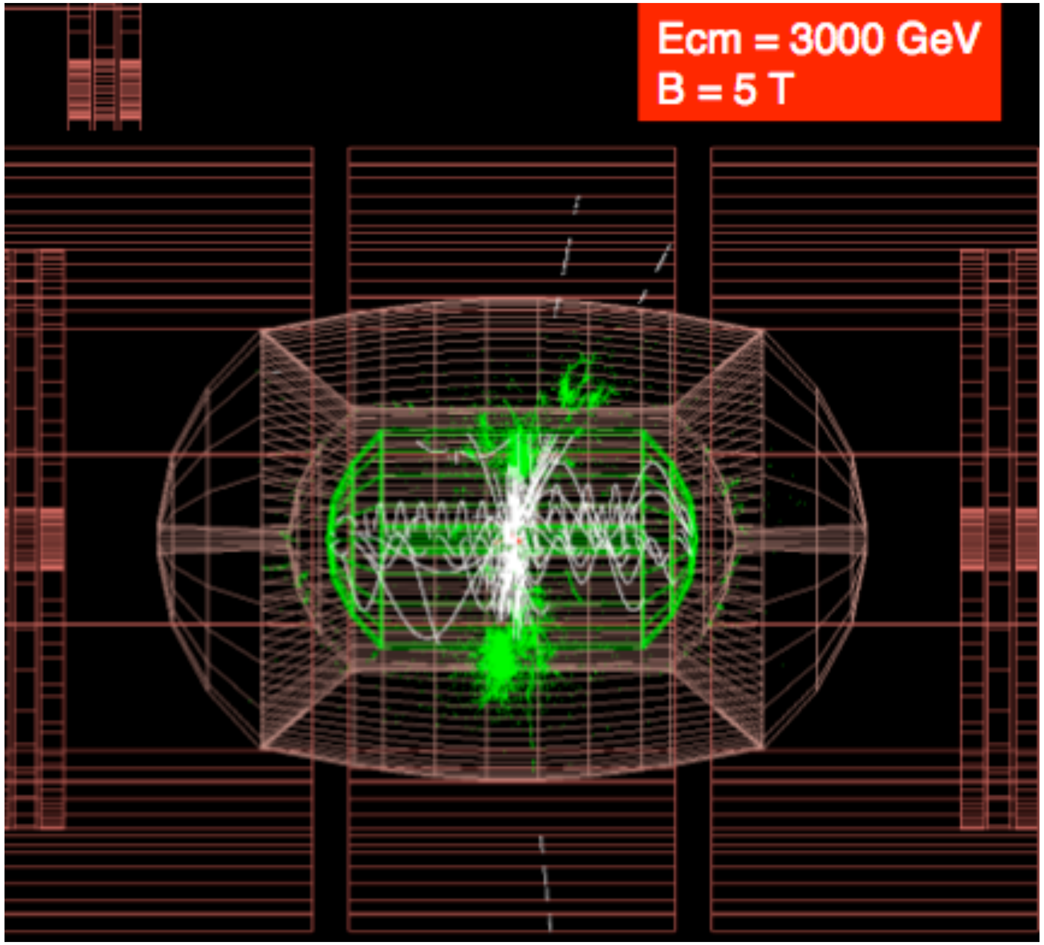
Testbeam Sstudies ongoing..

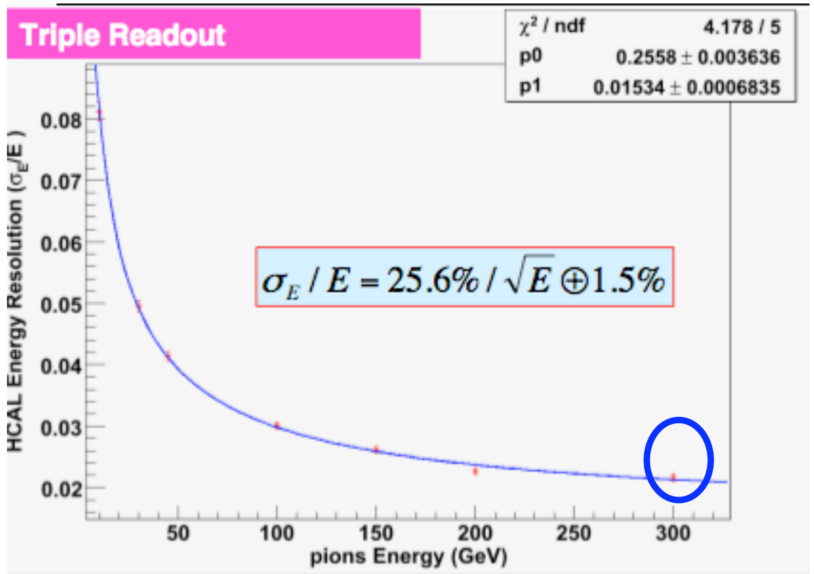


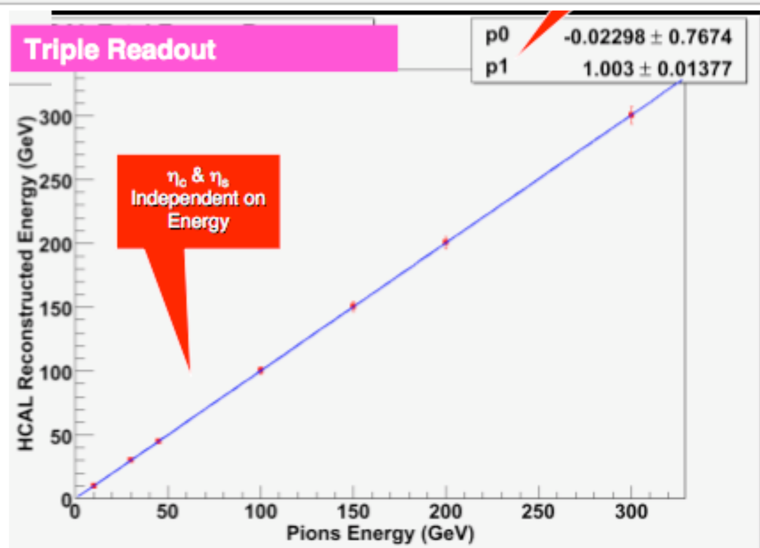
4th Concept ILC Detector

ttbar->6 jets events

C. Gatto







Common Session with the MDI

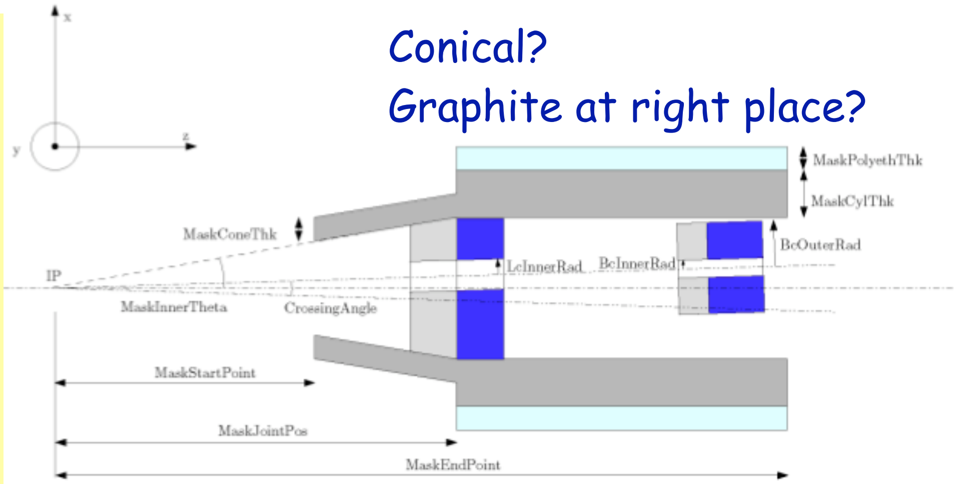
I should be over time now...

Common Session with MDI

- MDI group E Tsesmelis
  - Technical items of common interest
  - Luminosity considerations
- Mask Studies L. Linssen
  - Revisite of the Mask (a la ILC)
- L* of 8m instead of 3.5 m A. Seryi
  - Stability feasible now? Simpler MDI, easier FD design etc… 20% lumi loss?
  - Maybe startup scenario, upgrade later to 3.5?
- New parameters, backgrounds, Lumi Spectrum etc D. Schulte
  - New sets for 500 GeV. Conservative and nominal sets for 3 TeV/500 GeV
  - Background files available now.
- Backgrounds a 500 GeV A. Vogel
- Post Collision line K. Elsener

Conical?

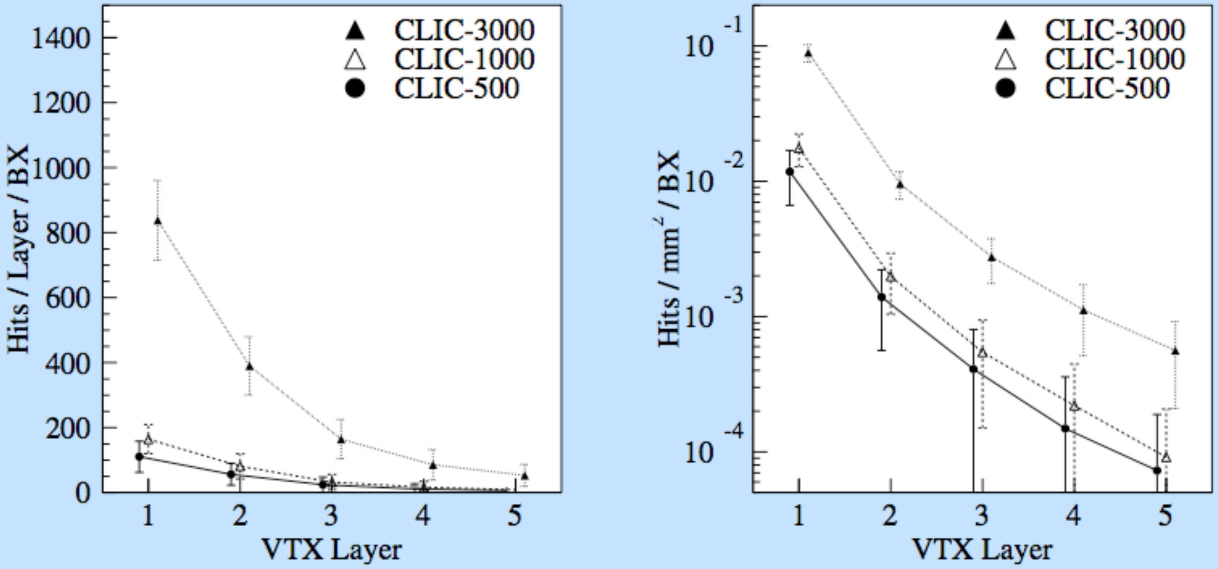
Graphite at right place?



CLIC Background in "LDC"

A. Vogel

VTX Hits – LDC Without Forward Mask



Over-optimistic: no BeamCal, no magnets at all
But: still with 4 T and 15 mm innermost VTX

CLIC-3000 vs. ILC-NOM-500 (with LDC geometry)

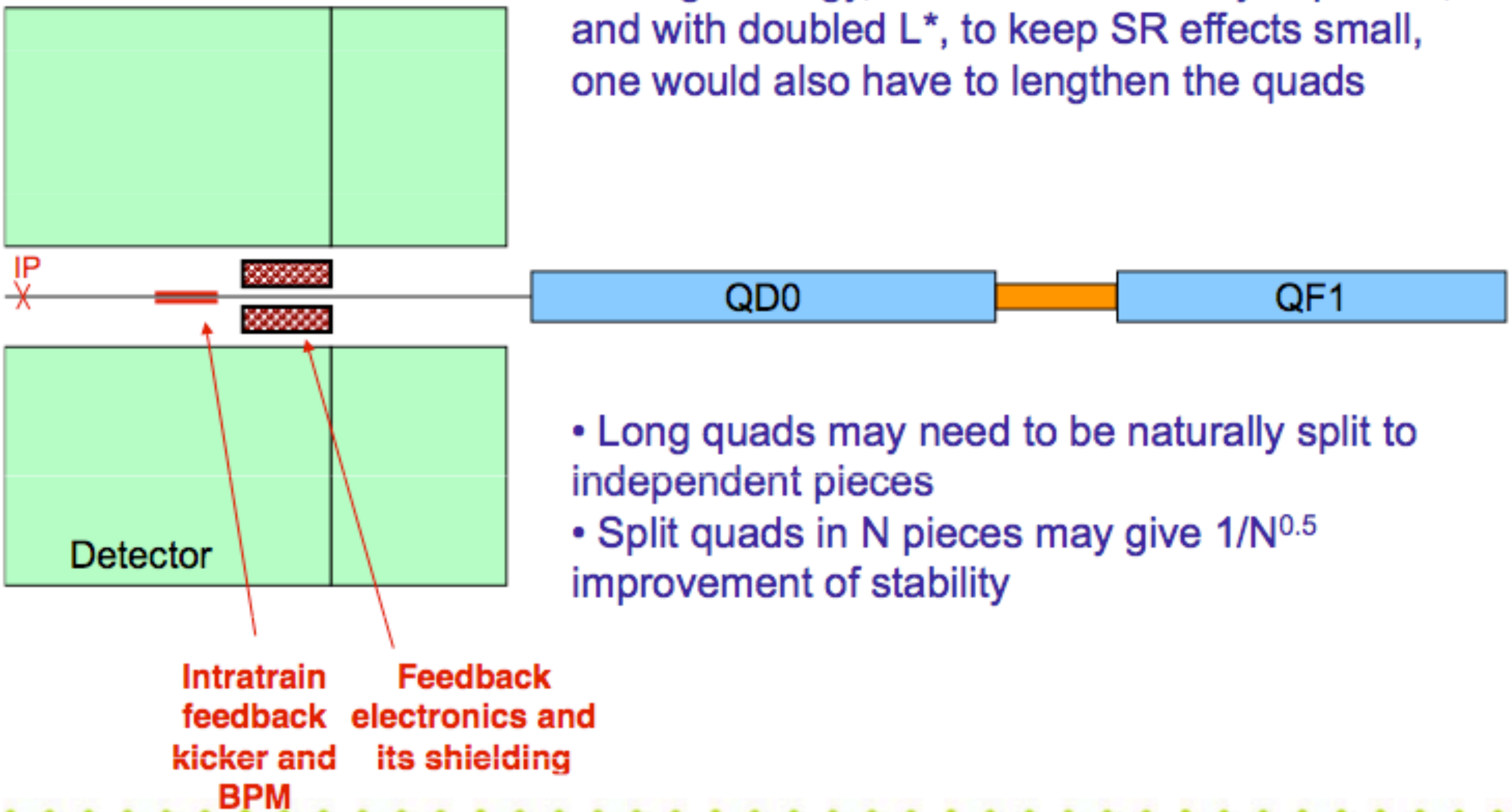
- VTX: $\mathcal{O}(10)$ times more backgrounds per readout
- TPC: $\mathcal{O}(30)$ times more backgrounds per readout
- modification of the mask may help (approx. 50 %)

Challenging, but not hopeless!

CLIC IR discussion…

A. Seryi

• At high energy, the SR in FD is very important, and with doubled L*, to keep SR effects small, one would also have to lengthen the quads



• Long quads may need to be naturally split to independent pieces

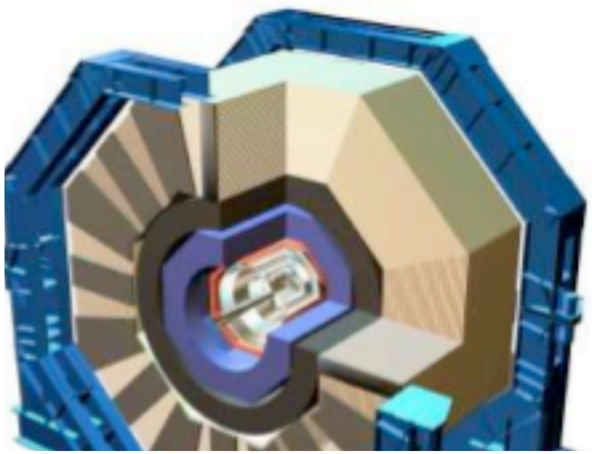
• Split quads in N pieces may give $1/N^{0.5}$ improvement of stability

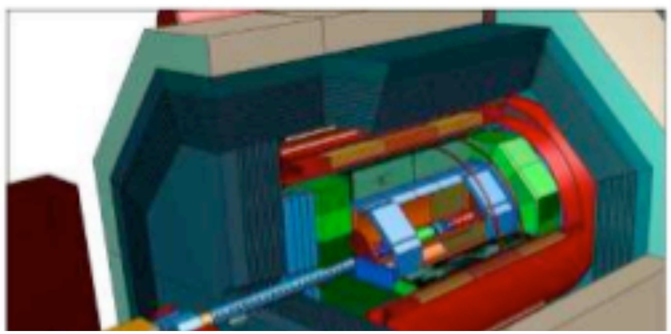
Conclusions: CLIC08

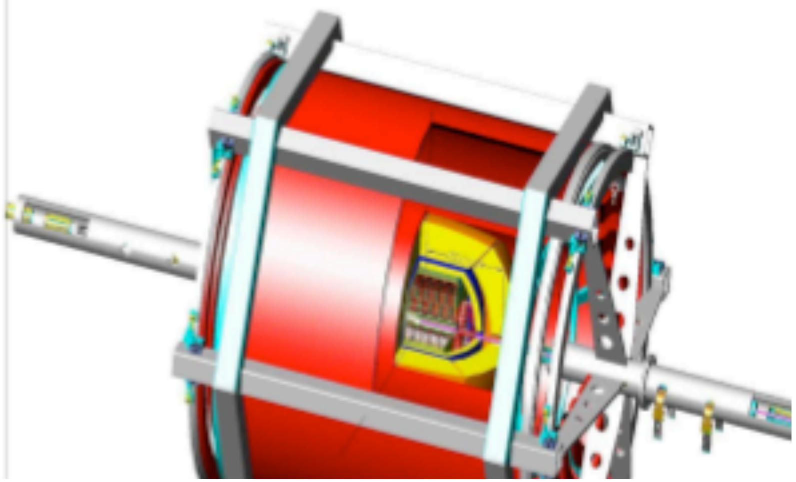
- A few new physics channels studied
- CLIC detector design studies are taking shape.
  - Thanks to help from ILC SW/Det. experts
  - Have to keep, if not increase, momentum…
- Excellent ILC/CLIC interaction this week.
  - Detector issues/updates
  - New studies eg on particle flow
  - Have to pursue this line of collaborative work
- In all, it has been an very interesting week for the physics and detector studies…

Thanks to all speakers!!

	ILD	SiD	4-th
VTX	Si-pixels	Si-pixels	Si-pixels
Tracker	TPC + Si-strip	Si-strip	DC with Clust. Counting
Calorimeter	PFA Rin=2.1m	PFA Rin=1.27m	Compensating Rin=1.5m
B	3-4T	5T	3.5T/-1.5T No return yoke
BR^2	10.2-13.2 Tm^2	8.1 Tm^2	(non-PFA)
E_{store}	1.6-1.6 GJ	1.4 GJ	2.7 GJ
Size	R=6.0-7.2m IZI=5.6-7.5m	R=6.45m IZI=6.45m	R=5.5m IZI=6.4m







Particle Flow

★ Traditional calorimetry $\sigma_E/E \approx 60\%/\sqrt{E/\mathrm{GeV}}$

★ Does not degrade significantly with energy (but leakage will be important at CLIC)

★ Particle flow gives much better performance at "low" energies
- very promising for ILC

rms90 PandoraPFA v03-β

E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$	σ_E/E_j
45 GeV	23.8 %	3.5 %
100 GeV	29.1 %	2.9 %
180 GeV	37.7 %	2.8 %
250 GeV	45.6 %	2.9 %
500 GeV	84.1 %	3.7 %
500 GeV	64.3 %	3.0 %

63 layer HCAL (8 λ_I)
B = 5.0 Tesla

<u>What about at CLiC ?</u>

★ PFA perf. degrades with energy

★ For 500 GeV jets, current alg. and ILD concept:

$$\sigma_E/E \approx 85\%/\sqrt{E/\mathrm{GeV}}$$

★ Crank up field, HCAL depth…

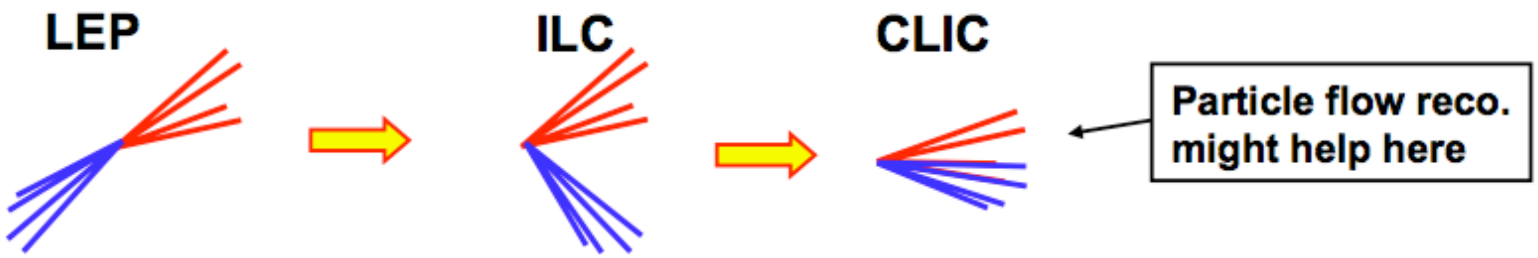
$$\sigma_E/E \approx 65\%/\sqrt{E/\mathrm{GeV}}$$

★ Algorithm not tuned for very high energy jets, so can probably do significantly better

<u>Conclude:</u> for 500 GeV jets, PFA reconstruction not ruled out

Particle Flow

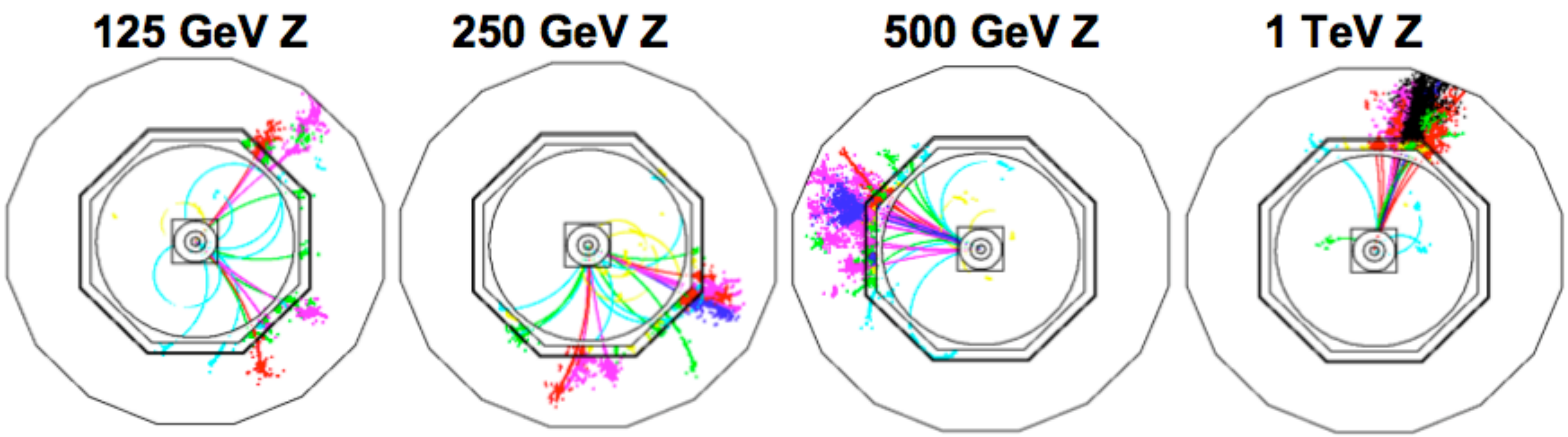
★On-shell W/Z decay topology depends on energy:



★A few comments:

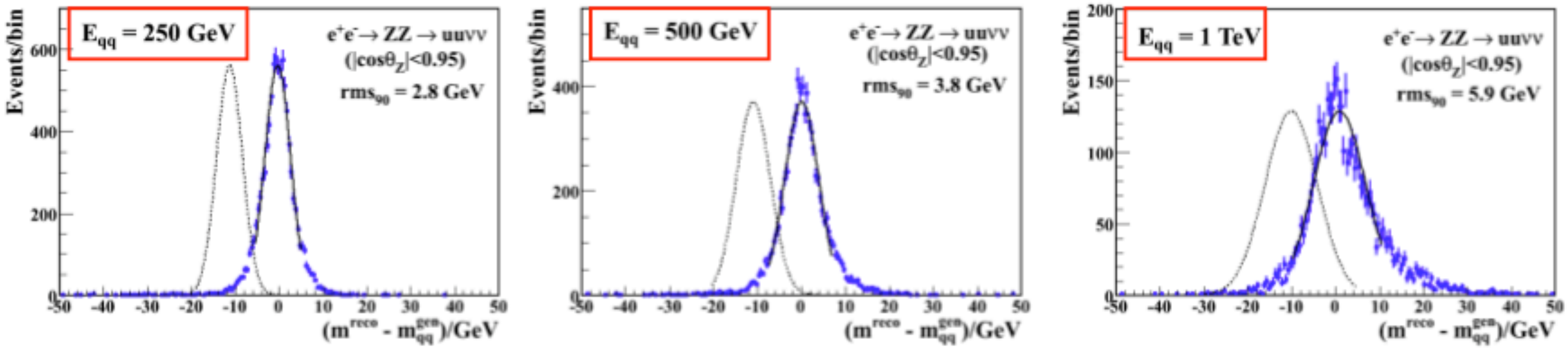
- Particle multiplicity does not change
- Boost means higher particle density
- PFA could be better for “mono-jet” mass resolution

★PandoraPFA + ILD performance studied for:



Particle Flow

★ Study Z mass resolution as function of E_Z with ILD detector (TPC based, B=3.5 T, 6 λ_I HCAL)



rms90 PandoraPFA v03-β

E_Z	σ_E/E	σ_m/m
125 GeV	2.4 %	2.7 %
250 GeV	2.5 %	3.1 %
500 GeV	3.1 %	4.1 %
1 TeV	4.2 %	6.2 %
1.5 TeV	5.6 %	8.2 %

Particle Flow

- ★ CLIC energies will push limits of Particle Flow Calorimetry
- ★ Particle Flow argues more strongly for large **R** rather than high **B**
- ★ For high energy jets, estimate (based on ILC/ILD studies)

R: 1.25m → 2.0m : +60 % improvement
B: 5.0 T → 3.5 T : +13 % improvement

Argument for high B-field is not Particle Flow !

B impacts inner radius of Vertex Detector ← Dependence not strong $r_{\text{inner}} \propto \sqrt{B}$

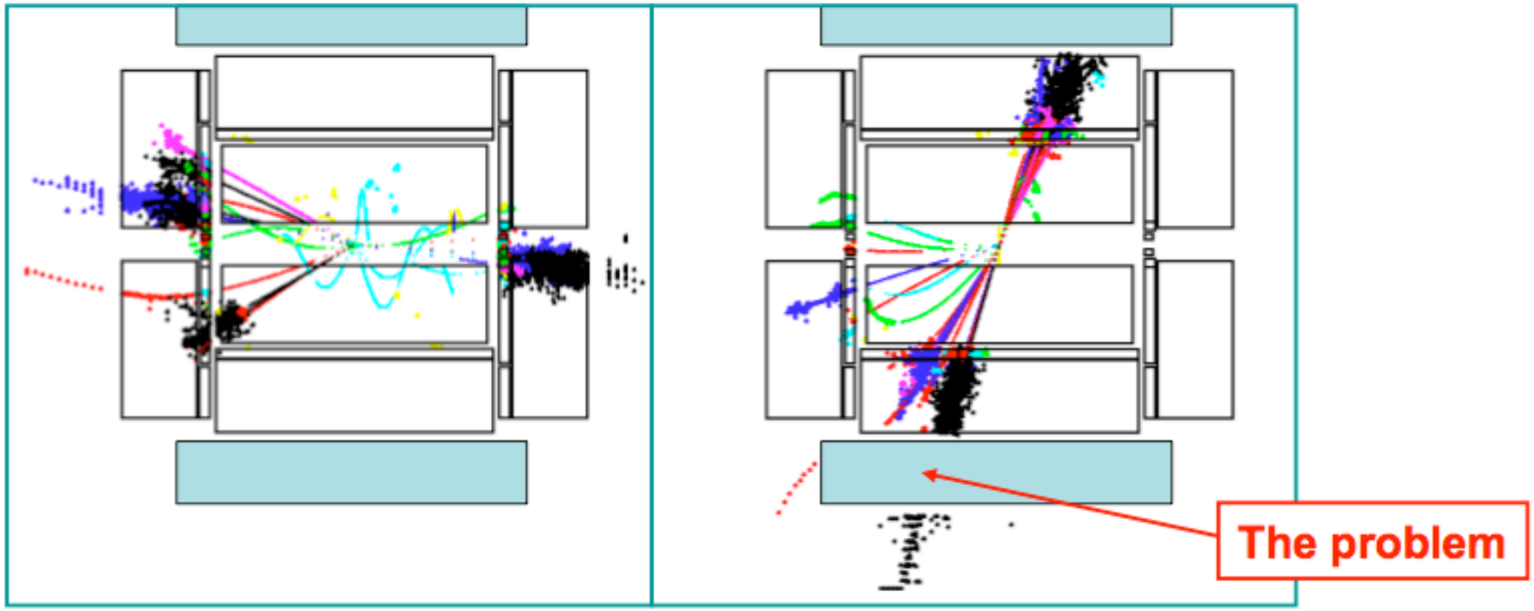
Particle Flow

Two interesting questions:

★ How important is HCAL leakage ?
- vary number of HCAL layers

★ What can be recovered using MUON chambers as a "Tail catcher"
- PandoraPFA now includes MUON chamber reco.
- Switched off in default version
- Simple standalone clustering (cone based)
- Fairly simple matching to CALO clusters (apply energy/momentum veto)
- Simple energy estimator (digital) + some estimate for loss in coil

e.g.



Particle Flow

Not much data:

E_{JET}	HCAL	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$	σ_E/E_j
500 GeV	6 λ_I	84.1 %	3.7 %
500 GeV	8 λ_I	~70 %	3.4 %

63 layer HCAL (8 λ_I) B = 5.0 T, corrected to B = 3.5 T

For 3 TeV machine: 6 λ_I not sufficient

For 3 TeV machine: 8 λ_I ?

Needs study

Particle Flow

★ Particle Flow at the ILC

Now have a proof of principle of Particle Flow Calorimetry

⇨ Unprecedented Jet Energy Resolution

- Based on full simulation/reconstruction (gaps and all) of ILD detector concept

★ Particle Flow at CLIC

Particle Flow Calorimetry certainly not ruled out

- Need to consider in context of the full CLIC physics programme
  - what drives jet energy resolution goals at CLIC ?
- For Higgs + threshold studies, CLIC would be likely to run at lower energy: here there is a strong argument for PFA
- For mono-jet mass resolution, PFA may help at high energies (needs study)
- Perhaps surprisingly, ILD detector concept looks like it will give "OK" performance for 500 GeV jets and 1 TeV Zs: i.e. TPC, 3.5 T, 6 λ_I

Particle Flow

★ A Particle Flow Detector for CLIC

- Tracker should be as large as possible
  - r = 1.25 m, almost certainly too small for CLIC
- Argument for high B is not from Particle Flow
  - momentum resolution/vertex tagging
- Argument for B = 5 T at CLIC may not be that strong
- From ILD studies, no evidence (yet) for problems related to a TPC, don't rule it out yet

★ A Particle Flow Development for CLIC

- Not *a priori* obvious that Particle Flow is the right approach for CLIC
- Will require study/development
  - correcting for leakage
  - evolution from PFlow to EFlow to pure calorimetry
  - understanding of jet mass reconstruction…

Requires new effort