CepC detectors

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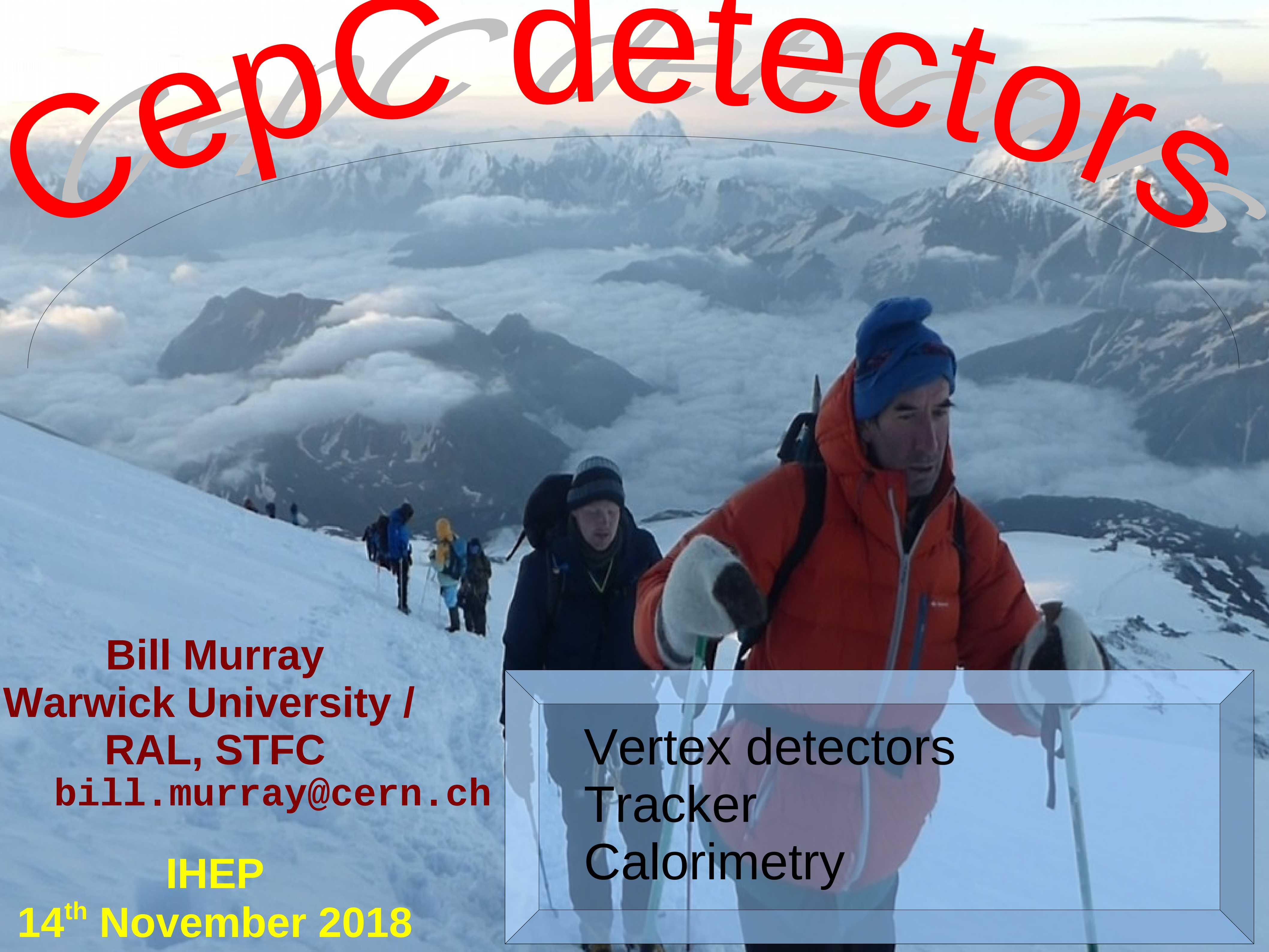
Vertex detectors
Tracker
Calorimetry

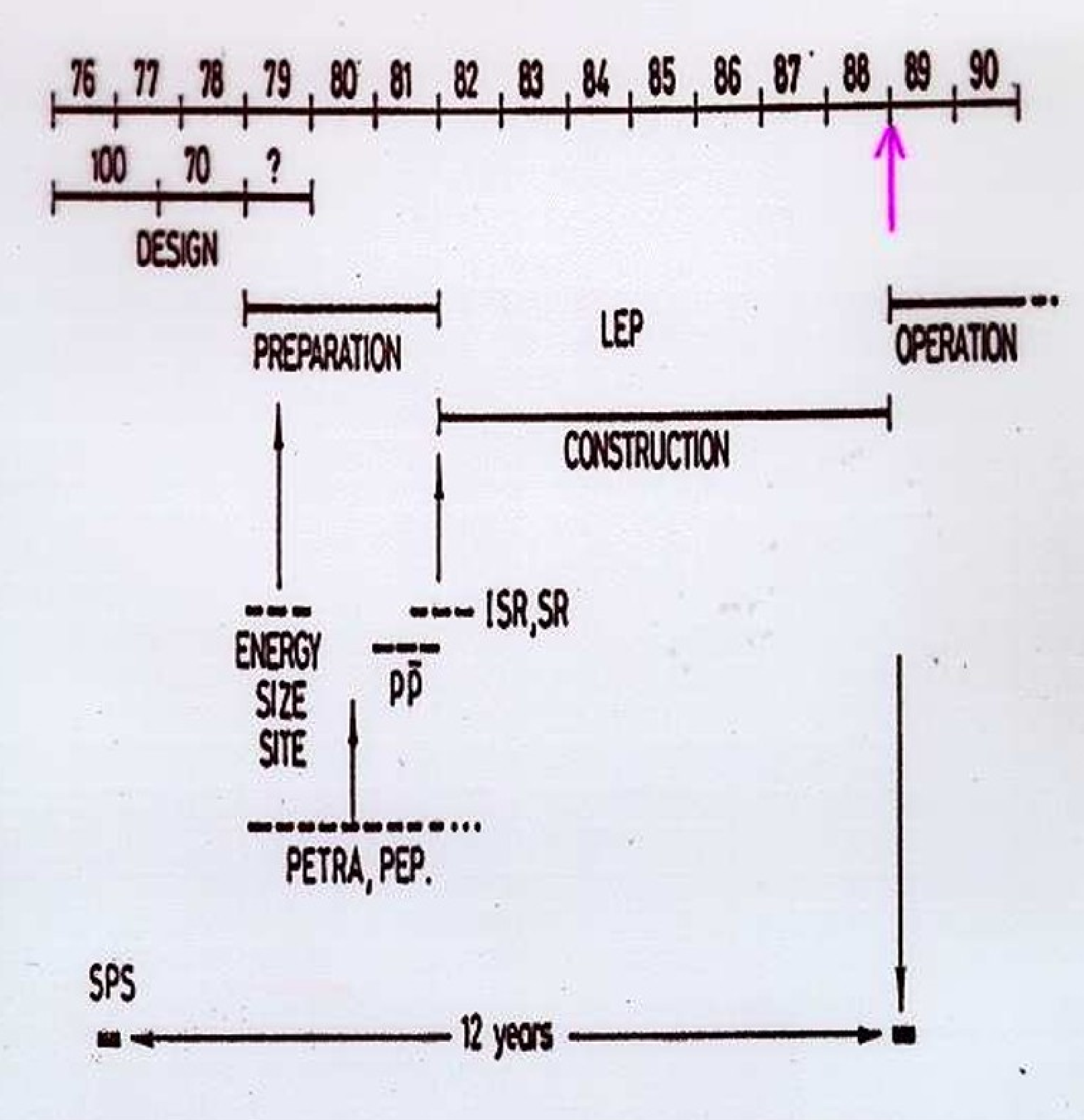


Disclaimer

- These are my personal views and not those of Warwick University, STFC, UK Research and Innovation or any other body
- I have tried to summarize what I can from this exciting workshop, but there is too much to even follow
  - This is really a good sign
- A thousand apologies if I missed your/your favourite work
- Mistakes are all mine

Planning accelerators

- John Adams LEP planning, Les Houches 1979
  - LEP turned on in 89!
  - As predicted
- But LHC:
  - In mid 1980s LHC was 17TeV machine, $10^{33}cm^{-2}s^{-1}$
  - 10^{34} was `high-lumi' option in 1987
  - Turn on 1998



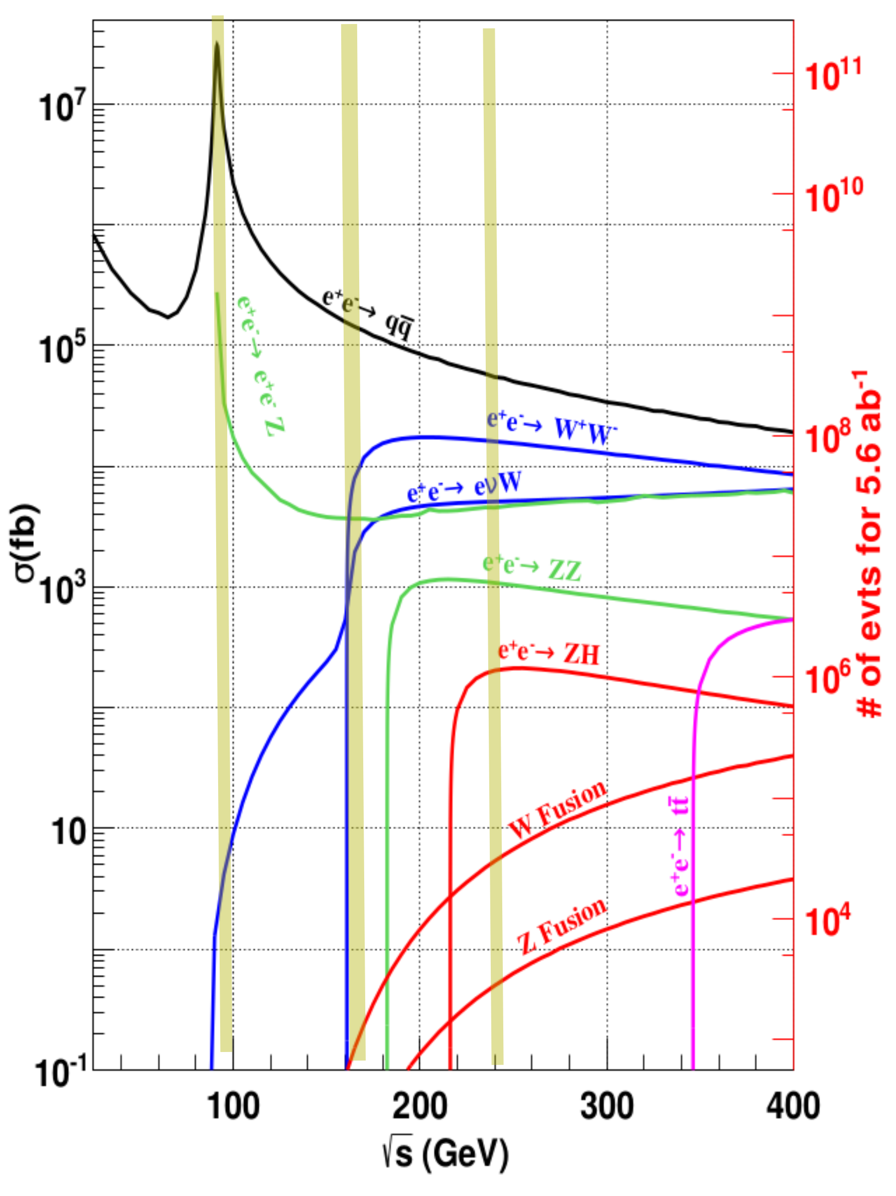
Running scenario

Operation mode	√s (GeV)	L per IP $10^{34}cm^{-2}s^{-1}$	Years	Total ∫L ab^{-1},2 IPs	Event yields
H	240	3	7	5.6	$1x10^6$ +$3x10^8$ qq
Z	91.2	32	2	16	$7x10^{11}$
WW	158-172	10	1	2.6	$2x10^7$

- Running at ZH gives O(20M) events / year / IP
  - But the Z peak yields 30,000M, 1000 times more
  - Z running stresses DAQ/storage, space charge, Radiation. 30KHz Z's
- Tracking precision (momentum & d_0 resolution) requirements are toughest for Higgs physics
  - Numbers aboove assume 2T field for Z run

Cross-sections

- Running at 240 GeV maximises ZH
  - But qq σ is 300 times larger than ZH
- Removing background requires good detector performance
  - Of course, s/b is about 10^7 times better than LHC
- Presumably all ee→qq will be kept
  - Its only 0.1% of the Z data!



Detector concepts

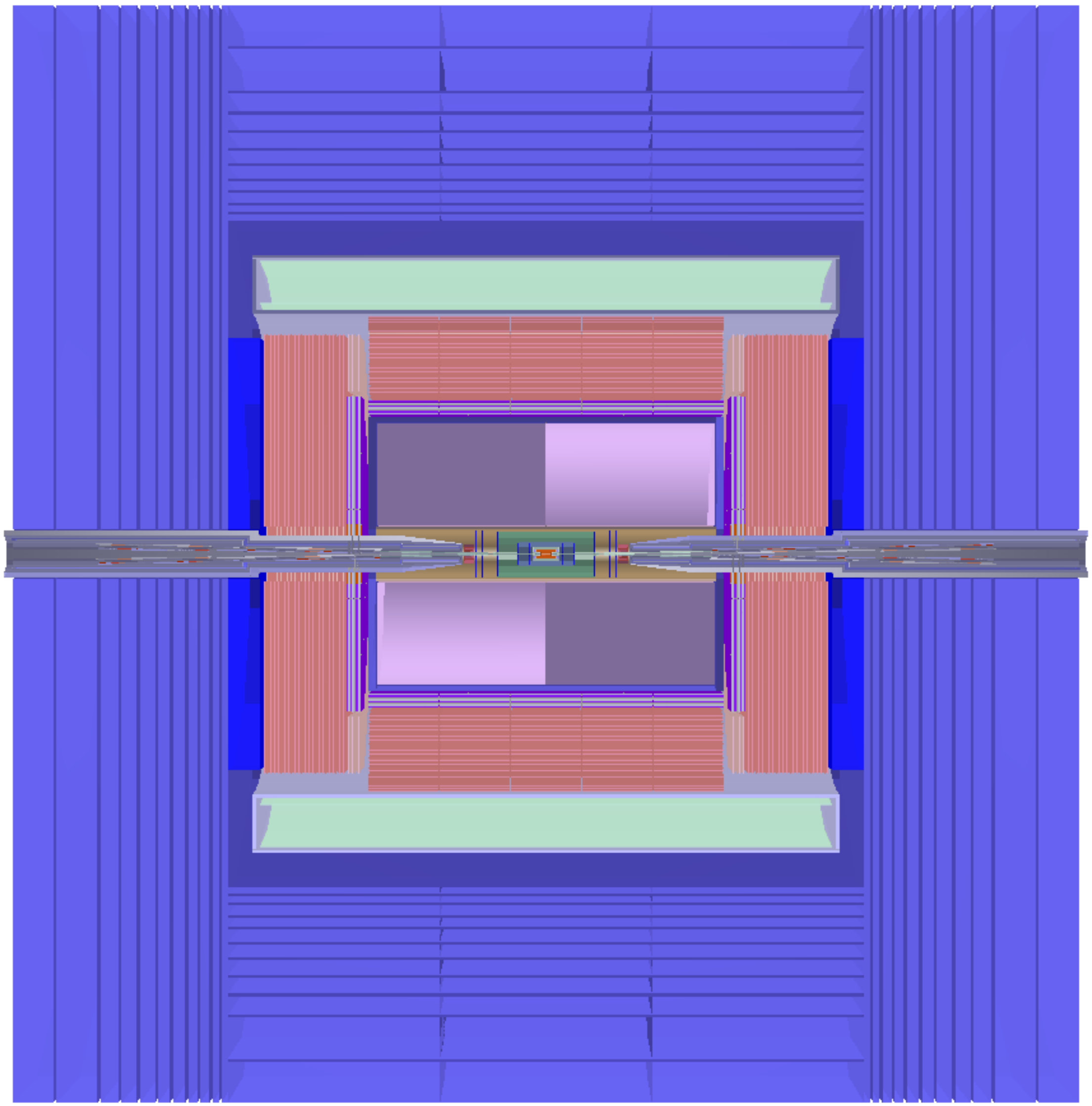
- In an ideal world requirements would come first...but...

CepC detectors

- Three concepts in CDR:
  - Two Leaning heavily on ILC work
    - SiD & ILD adapted for lower energy
    - Both with 3T solenoids
    - Thinner HCAL, lower granularity
    - Concern about the TPC charge buildup at Z luminosity
    - But TPC would offer 3σ p-K separation...possible B phys?
    - 10μs readout for silicon vtx, 30KHz Z's → triggerless?
    - Power load in silicon major concern. Material may suffer
  - IDEA: wirechamber, 2T solenoid, calorimeter outside
    - 90% He wirechamber...(Kloe/MEG++) 10% occupancy?
    - DREAM dual-readout
    - Solenoid upgrade with HTS for 30% thinner coil?

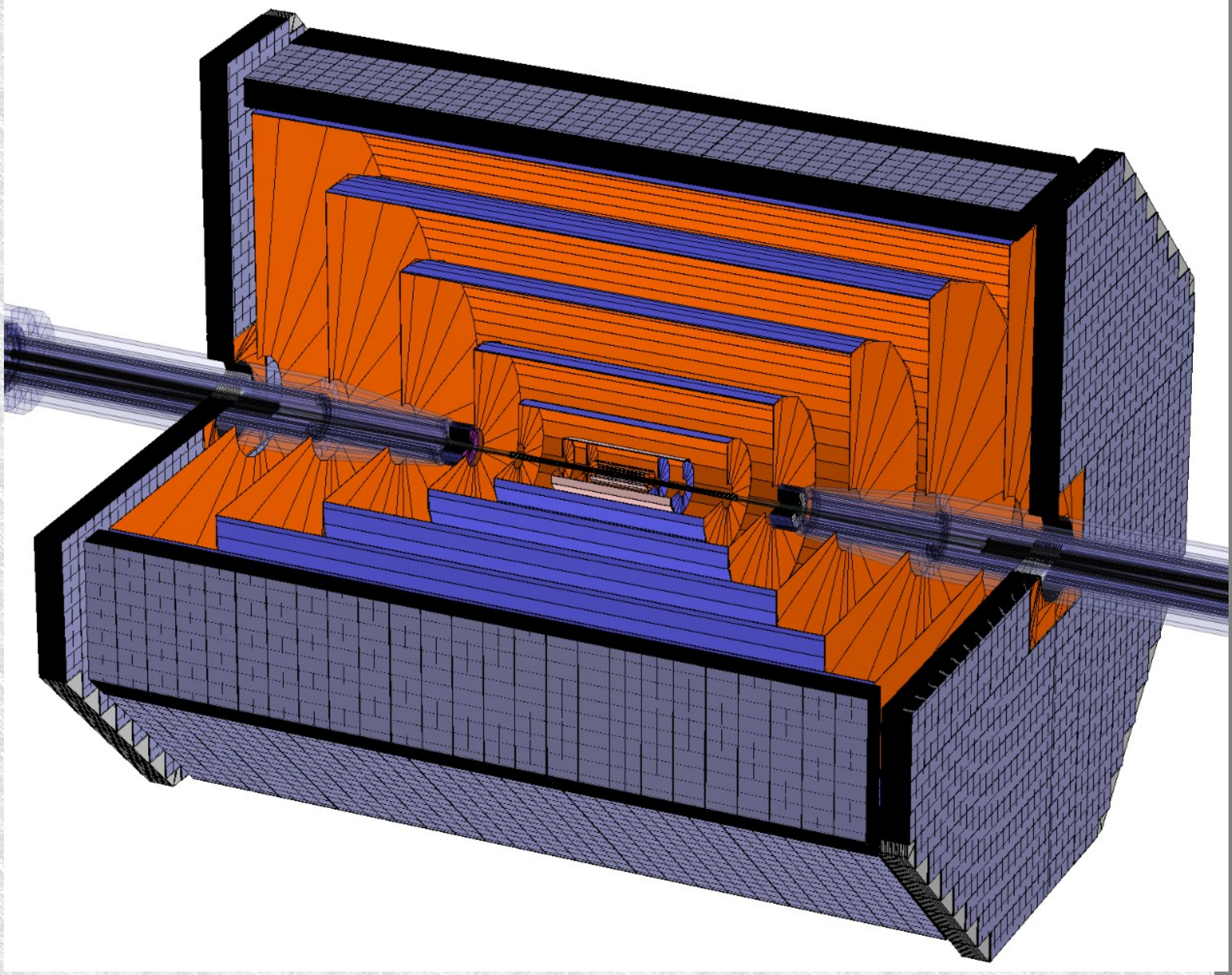
Baseline design

- Son of ILD
- 3T 3m radius solenoid
- Containing:
  - Si Vertex detector
  - TPC
    - 1.8m radius
  - Silicon External Tracker
  - Si-W ECAL
  - HCAL
- Return yoke outside
  - Including muon system



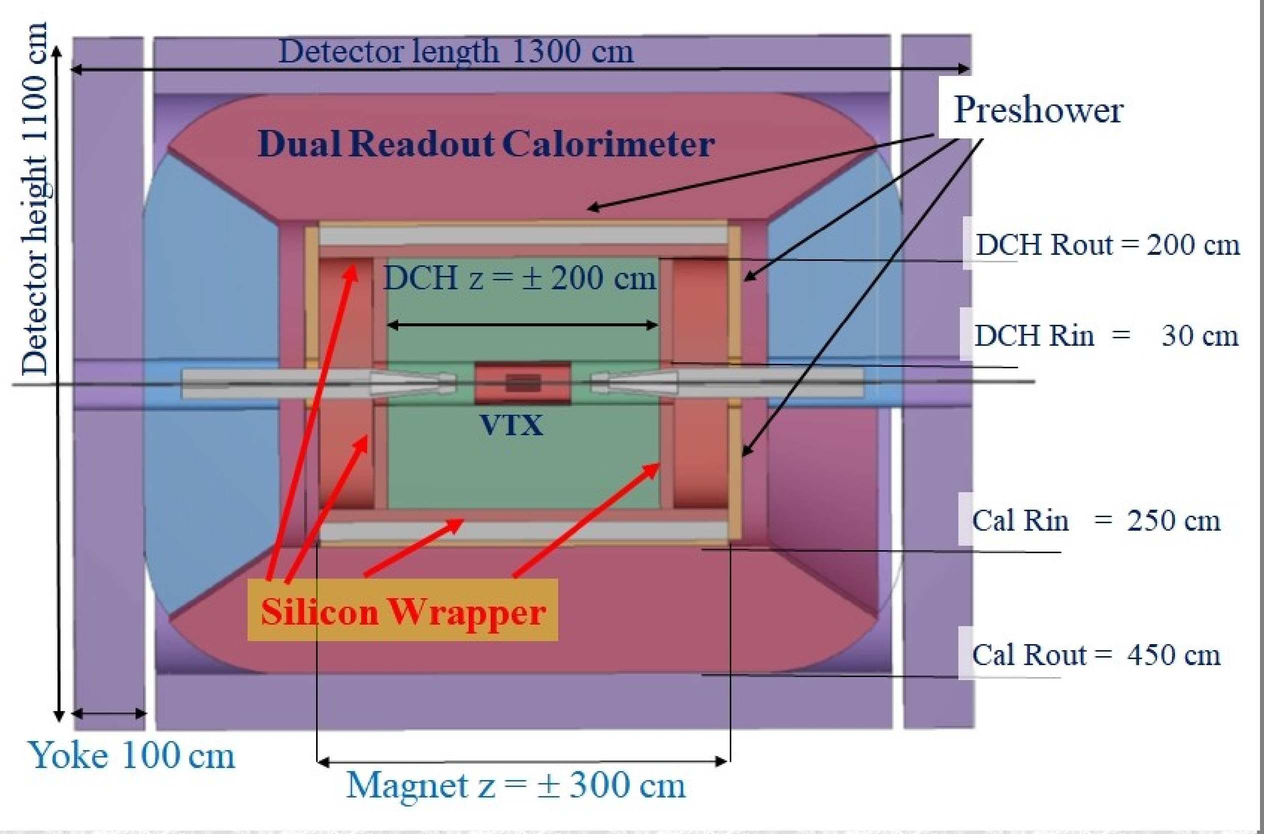
Full Silicon Tracker

- Much like concept I
- But with all-silicon tracker
  - Lacks dE/dx particle ID
  - Higher material budget
  - But stable, rate capable.
- Daughter of SID



IDEA: 2nd Detector concept

- Thin, 2m R, 2T solenoid
- Containing
  - Si vertex detector
  - Drift chamber
    - a la MEG
  - Silicon outer layer
    - Resolution?
- Surrounded by
  - DREAM EM+HCAL calorimeter
  - Instrumented return yoke



Detector Requirements

Tracker specification

$$\sigma(1/p_T) = 2.10^{-5} \oplus \frac{10^{-3}}{p_T \sin\theta}$$

$$\sigma(d_0) = 5 \oplus \frac{10}{p \sin^{3/2}\theta} \mu m$$

- Aiming for an order of magnitude better than LHC

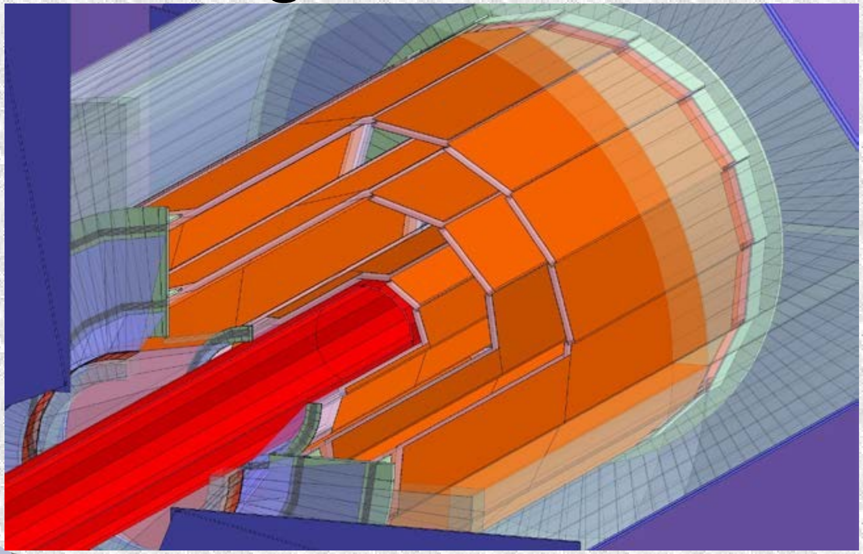
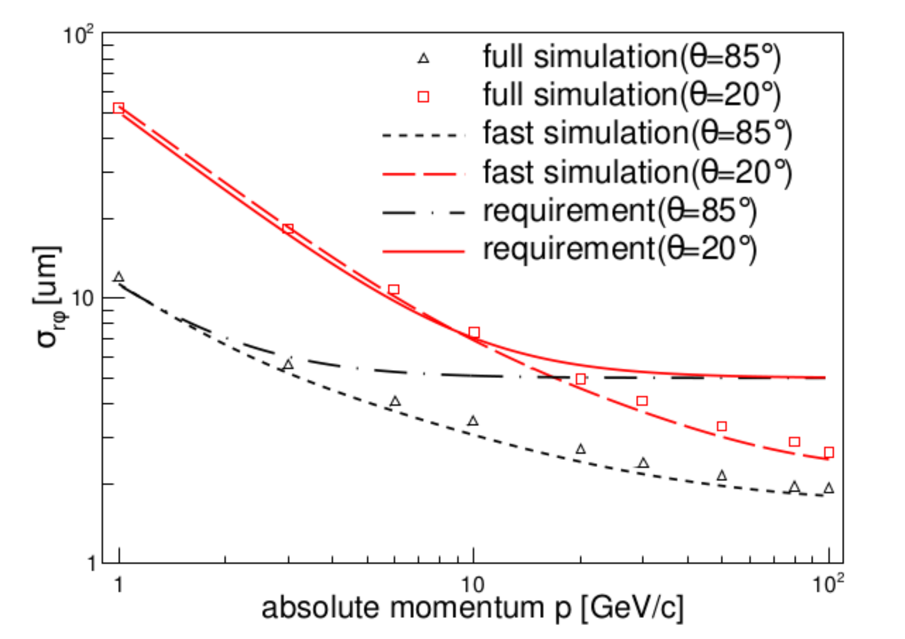


Table 1. Design parameters of the CEPC vertex system.

	R(mm)	| Z |(mm)	$\sigma(\mu m)$	material budget
Layer 1	16	62.5	2.8	$0.15\%/X_0$
Layer 2	18	62.5	6	$0.15\%/X_0$
Layer 3	37	125.0	4	$0.15\%/X_0$
Layer 4	39	125.0	4	$0.15\%/X_0$
Layer 5	58	125.0	4	$0.15\%/X_0$
Layer 6	60	125.0	4	$0.15\%/X_0$

Impact parameter resolution

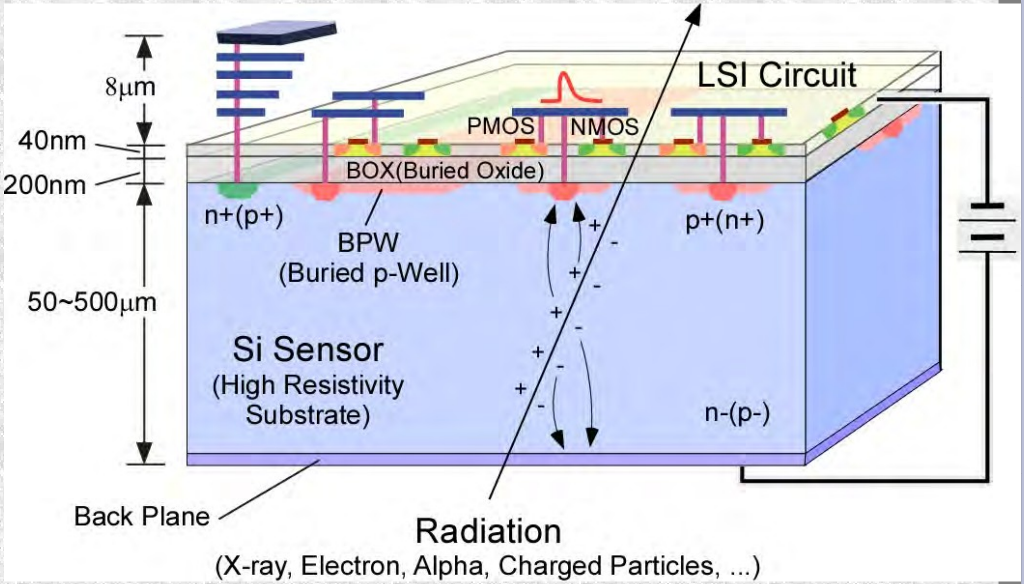
- High p spec is exceeded
- But at low p is only just reached
  - Trackers have a history of underestimating material at CDR
- Consider 3 scenarios:

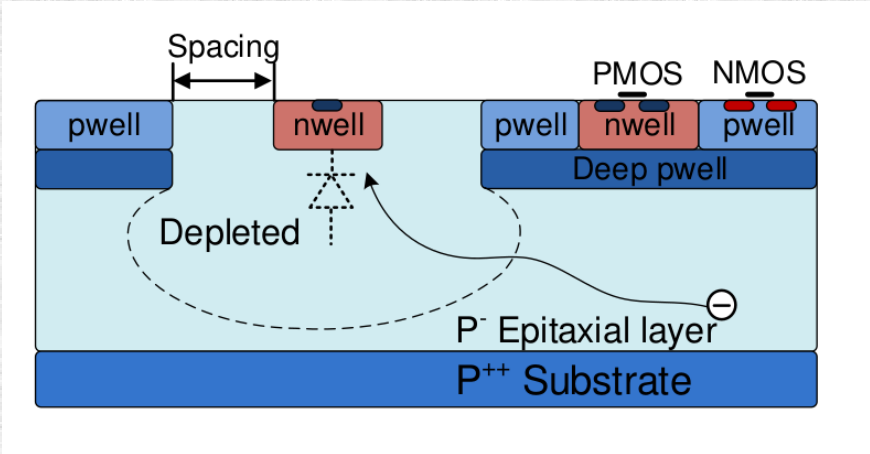


	Aggressive	Nominal	Conservative
Material per layer, X0	0.075	0.15	0.3
Resolution, μm	1.4-3	2.8-6	5-10.7
Radius, mm	8	16	23
$H \rightarrow bb$ ε*P	0.925	0.914	0.900
$H \rightarrow cc$ ε*P	0.133	0.095	0.078

Pixel developments

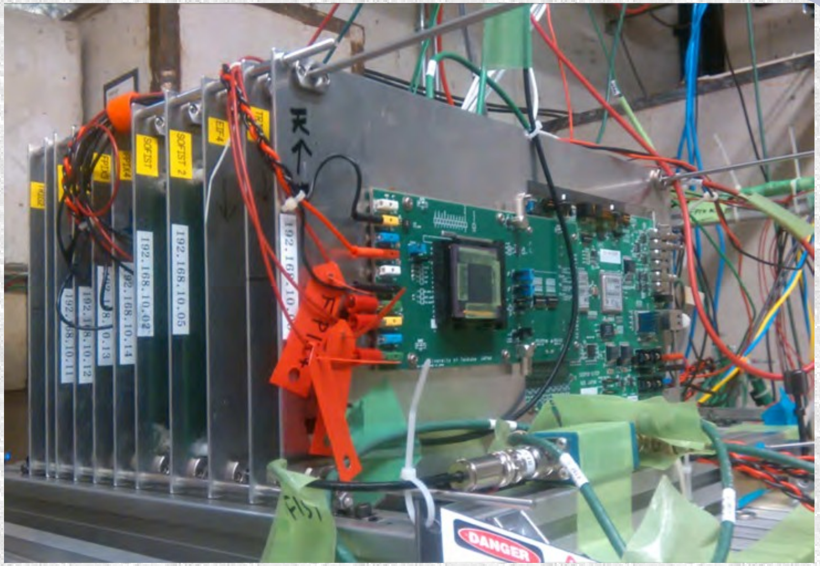
- Very active research area
- ILC solutions use time structure to save power
  - Adaption to CepC needed
- Alpide chip (ALICE) is close to spec already
- CMOS has great potential for easy assembly
  - ARCADIA process in INFN aims for demonstration in 2020

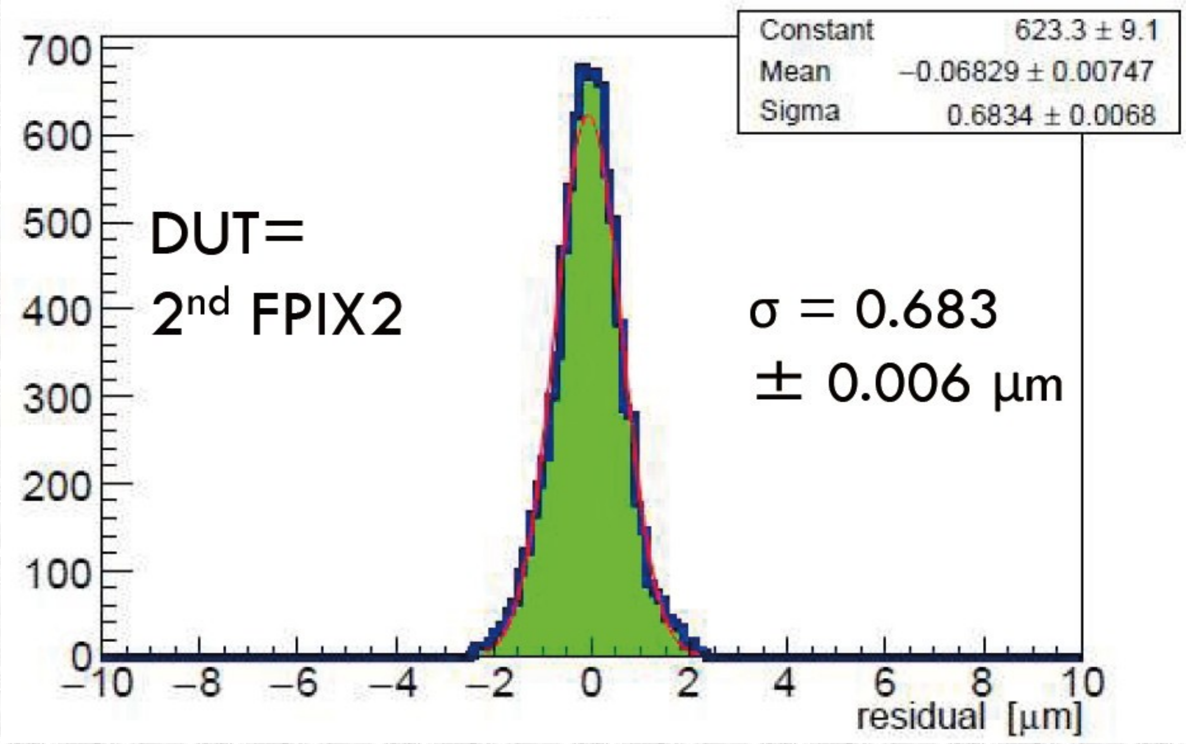




Pixel resolution

- DSOI FPIX2 detector 8μm²
- Beam test at Fermilab
  - Telescope 5 FPIX2 plus SOFIST (20 μm²)

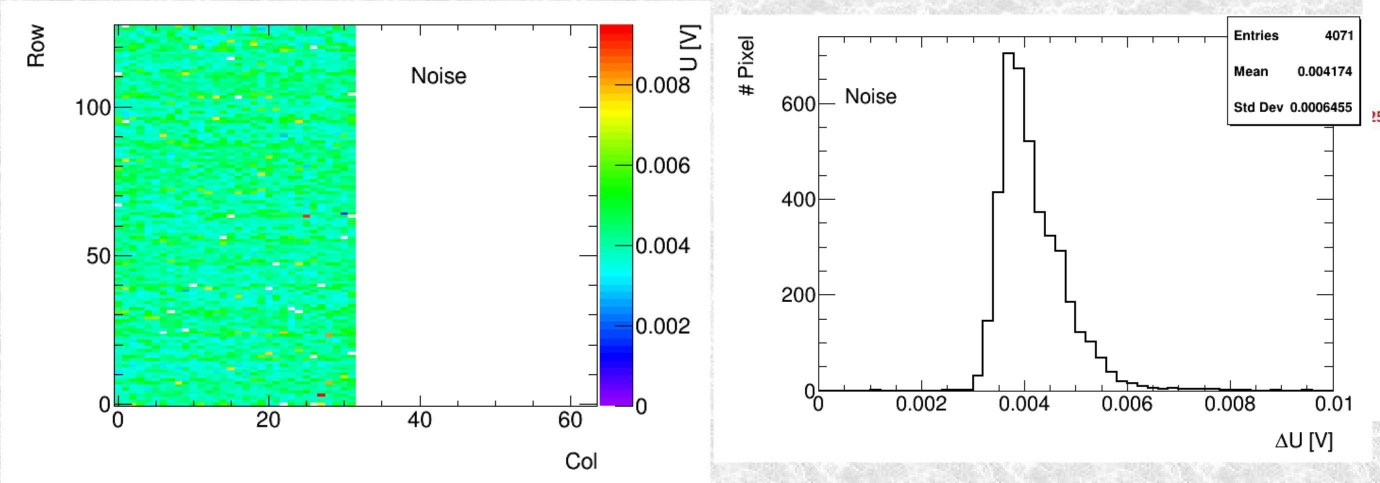


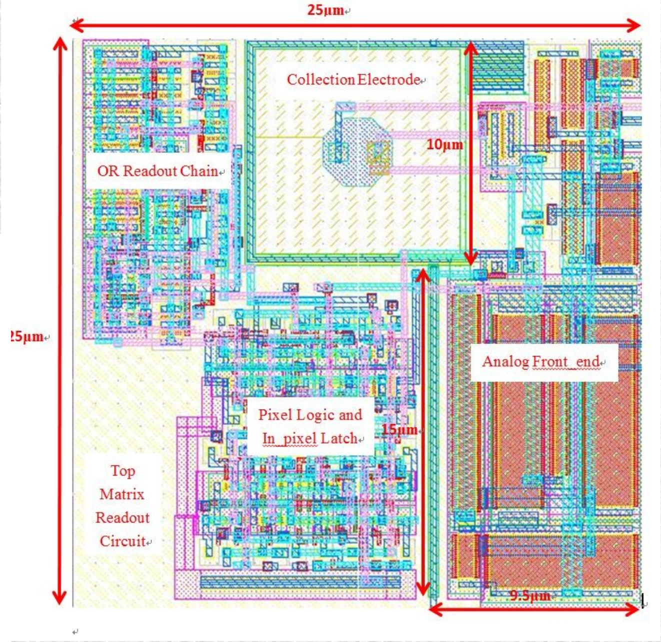


- Resolution of 0.68μm is world record

Example CepC CMOS: MIC4

- MIC4 25μm^2 pixel, high-speed integrated link
- Front end from ALPIDE
  - Duration < 3μs
- Low and uniform noise





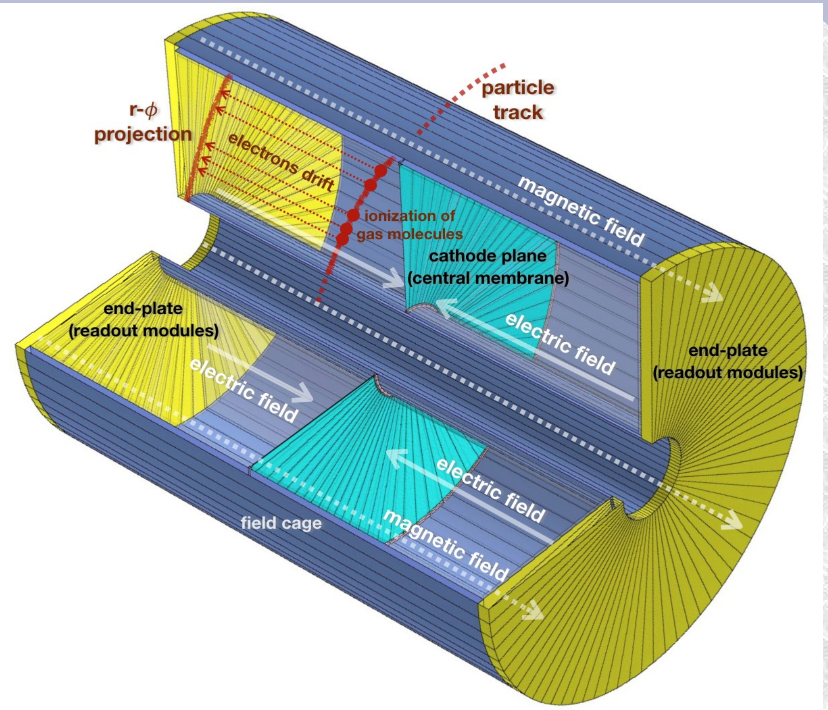
- SOI developments (CPV2) also very promising
  - Resolution below 3um demonstrated

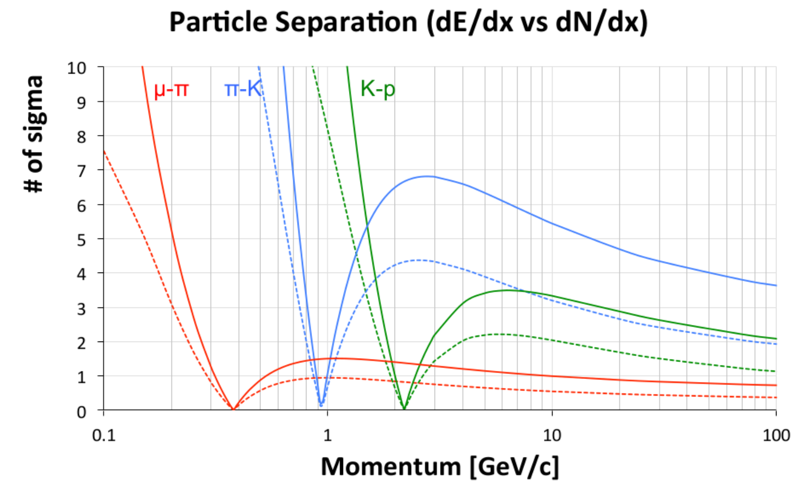
Vertex detector status

- A challenging detector
  - But with much active work
- Existing technology is close to providing solutions

TPC status

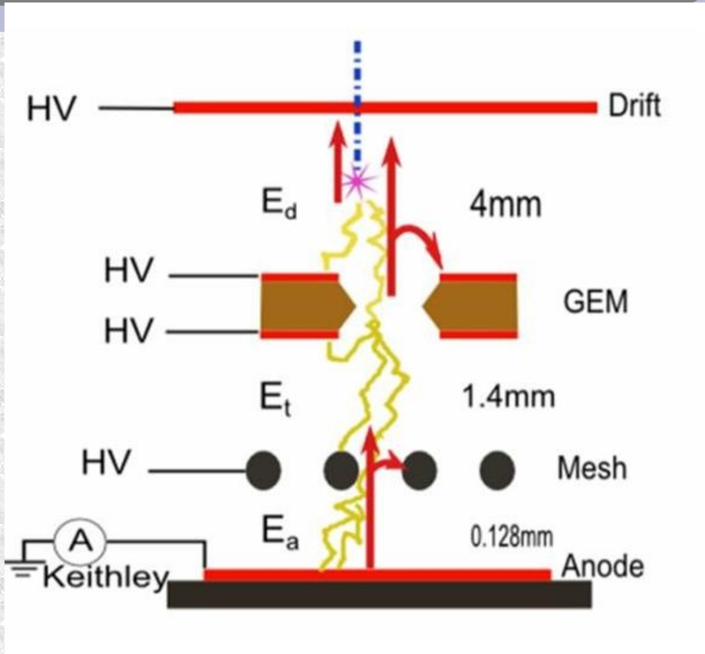
- Radius: 0.3m to 1.8m
- Length: 4.7m
- Electrons drift to MPGD's
  - 30μs drift time
    - Same as (Z rate)$^{-1}$
  - 220 space points
  - 3T field suppresses diffusion
    - 100μm resolution
- Laser alignment
- 1% X0 in central region
  - 10% in endcaps (including cabling)

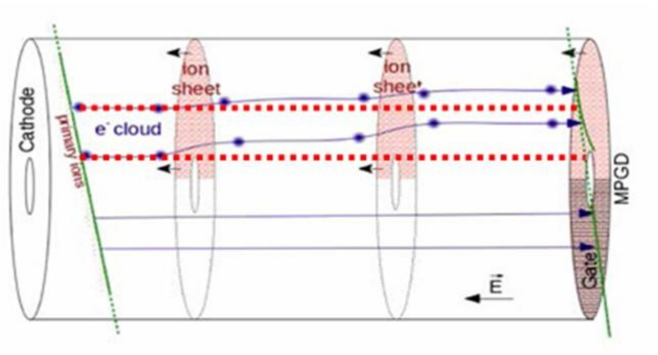


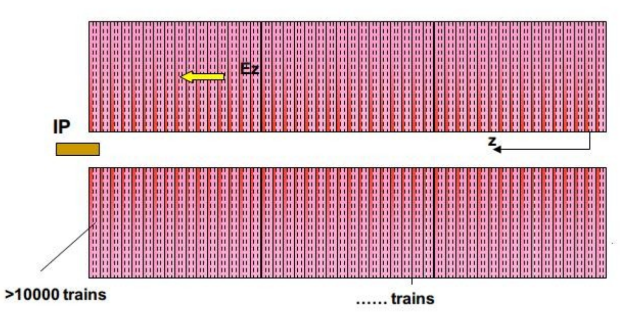


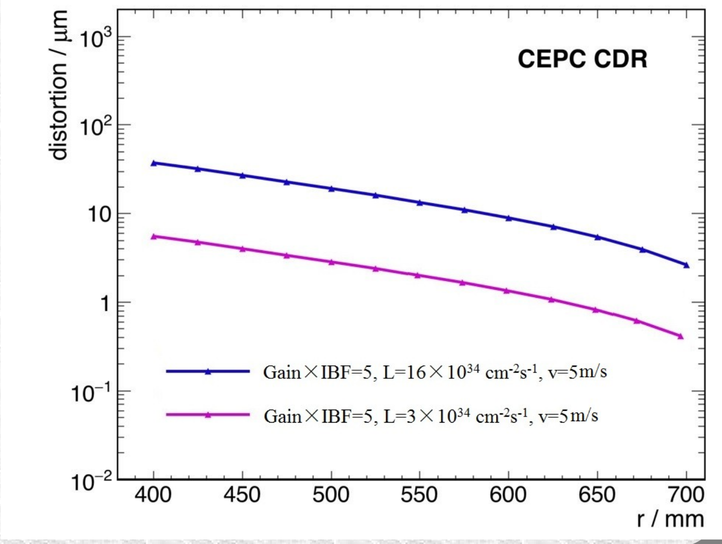
Distortion from ion backflow

- Gas gain in GEM leaves ions
  - Drift back to cathode 5μm/μs
- Each event produces a disc of ions
  - Which deflect electrons
- 40μm distortion @ 3 10^{34}
- c/f 100



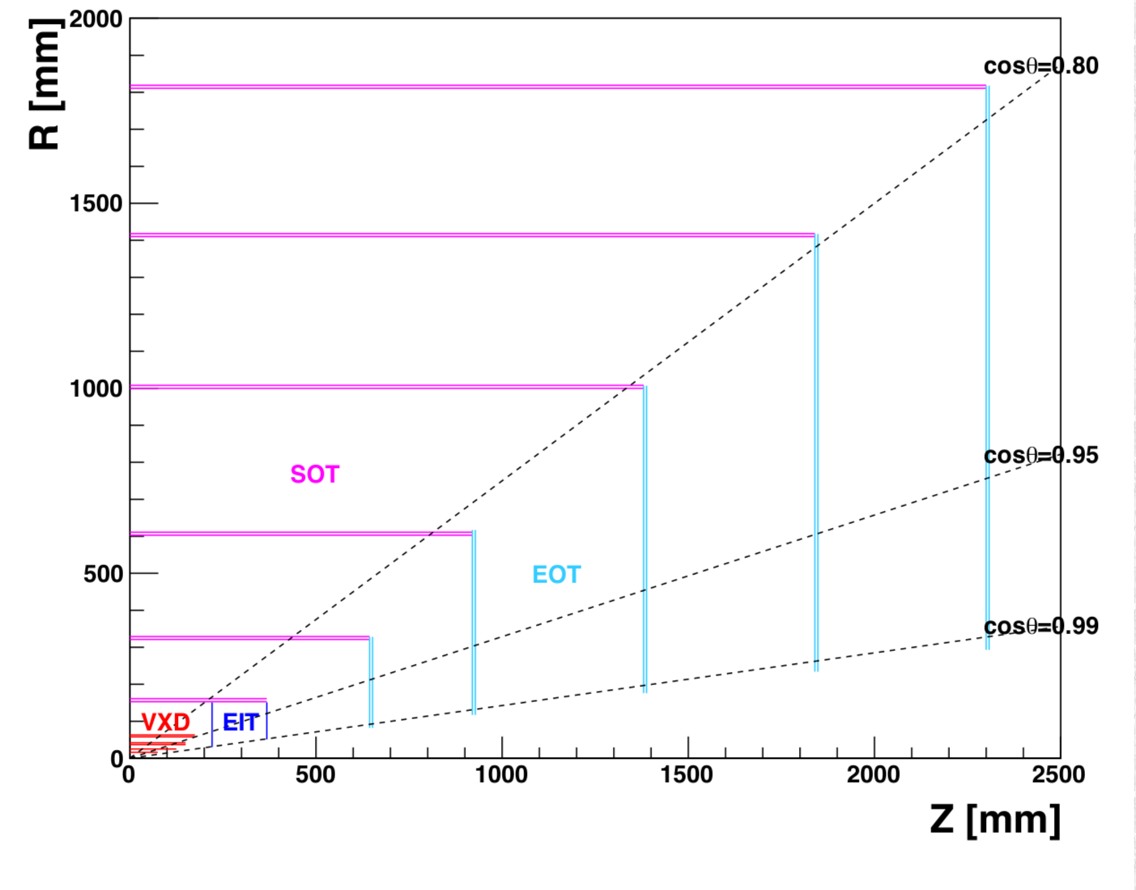






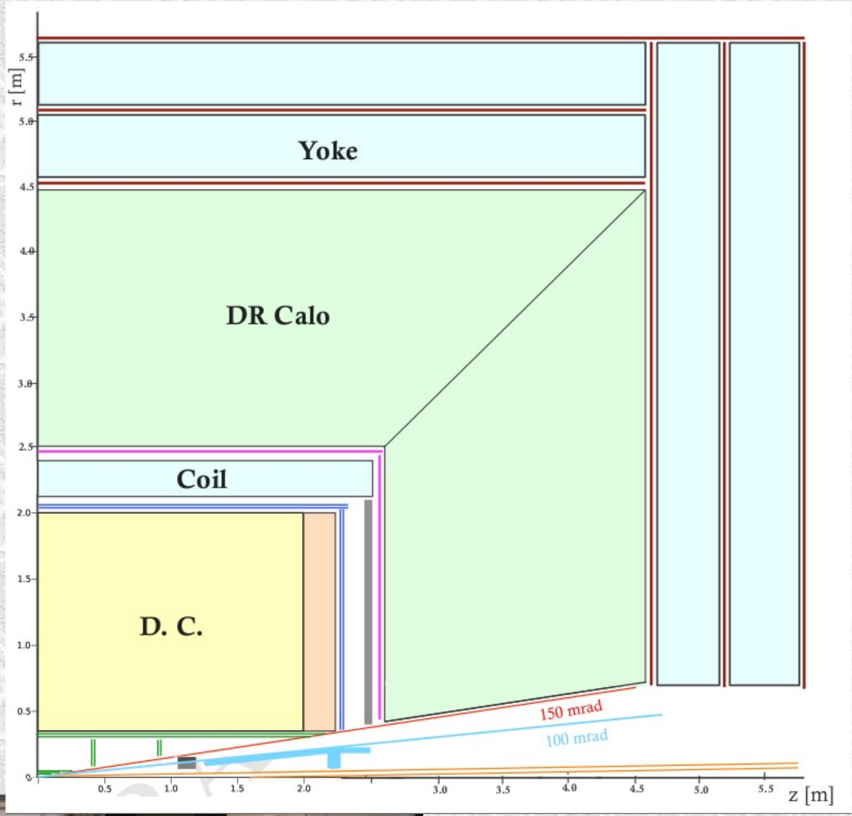
All silicon tracker

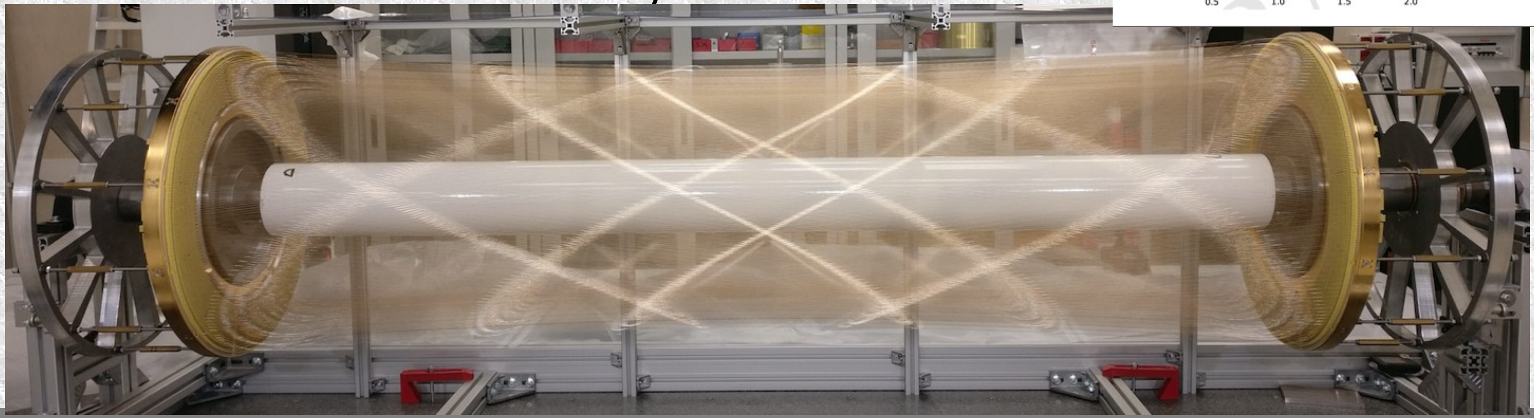
- Can replace TPC with a silicon strip detector
- FST has 6 double strip layers
  - 5-7% X0 estimated
- 150μm wafers, 50μm pitch
- Yields H→ μμ mass resolution 0.21GeV
  - 16% better than baseline



IDEA Wirechamber

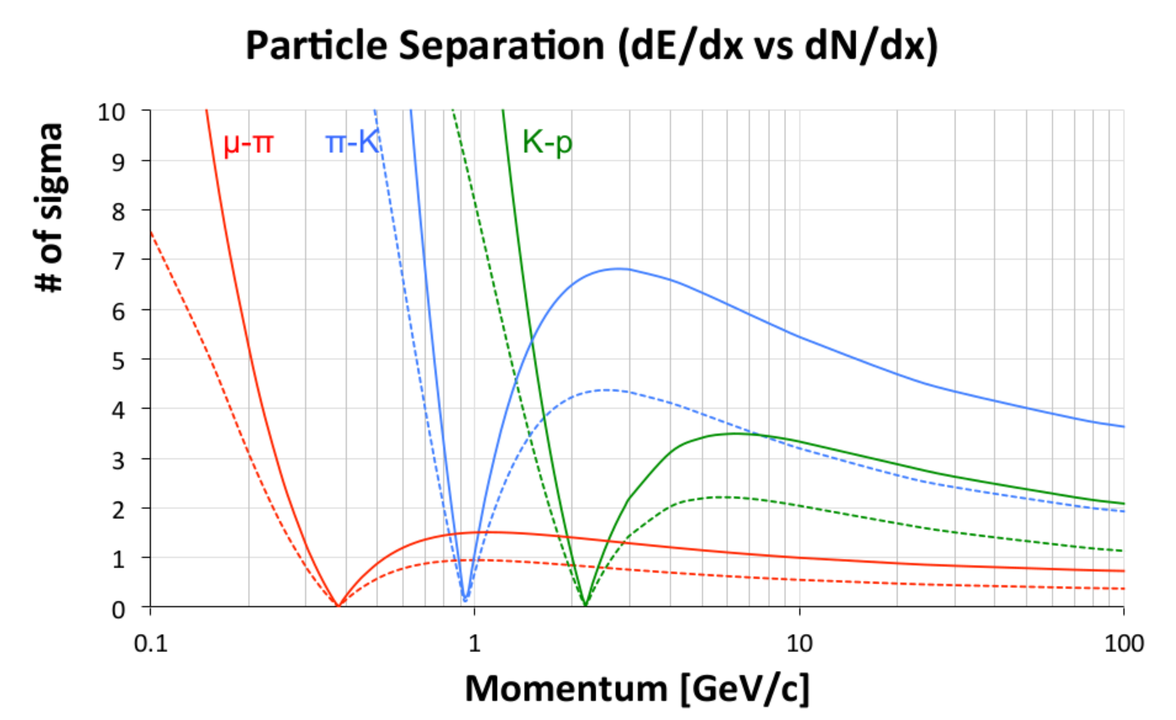
- Radius 0.35 – 2.0 m
  - $(2m/1.8m)^2$ compensates (2T/3T) field: 82%
- 112 layers, stereo
  - 56,448 drift cells
  - 20% occupancy in 100 track ZH → qqqqqq
- 1.6% X_0 barrel, 5% forward
  - Similar to MEG 2, below





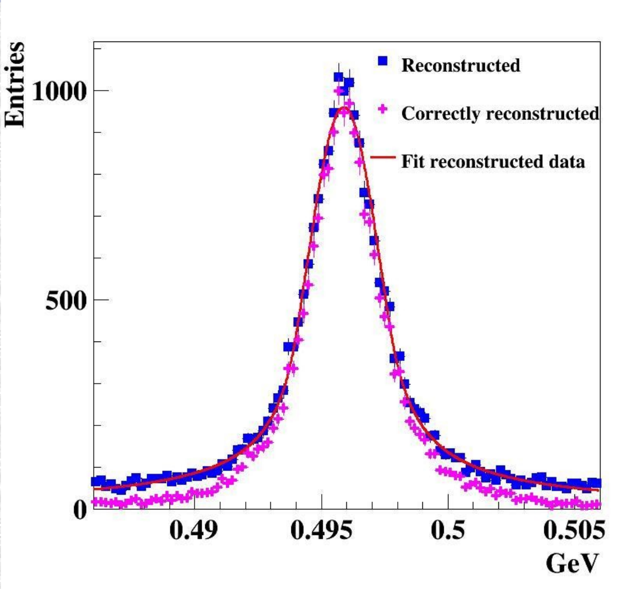
dE/dx

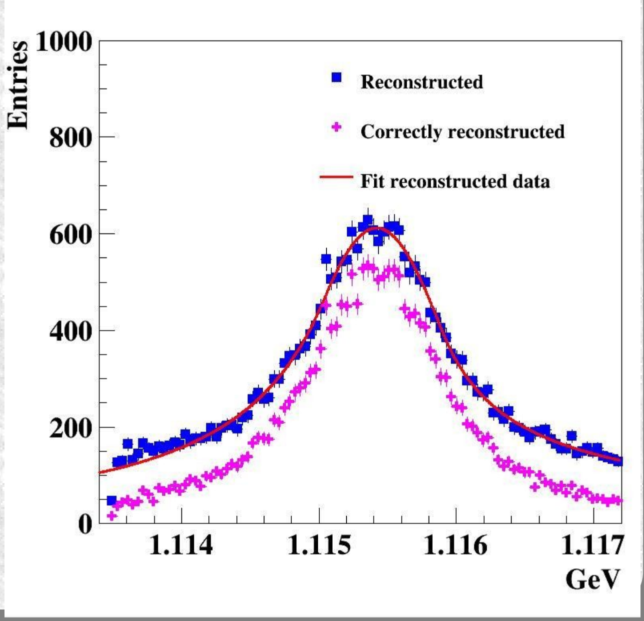
- Energy loss for particle ID
- Measured charge comparable in drift chamber and TPC
  - Drift chamber offers cluster counting too
- Separate π/K by 2.5σ up to 30 GeV
  - Better with cluster counting
- No available in FST



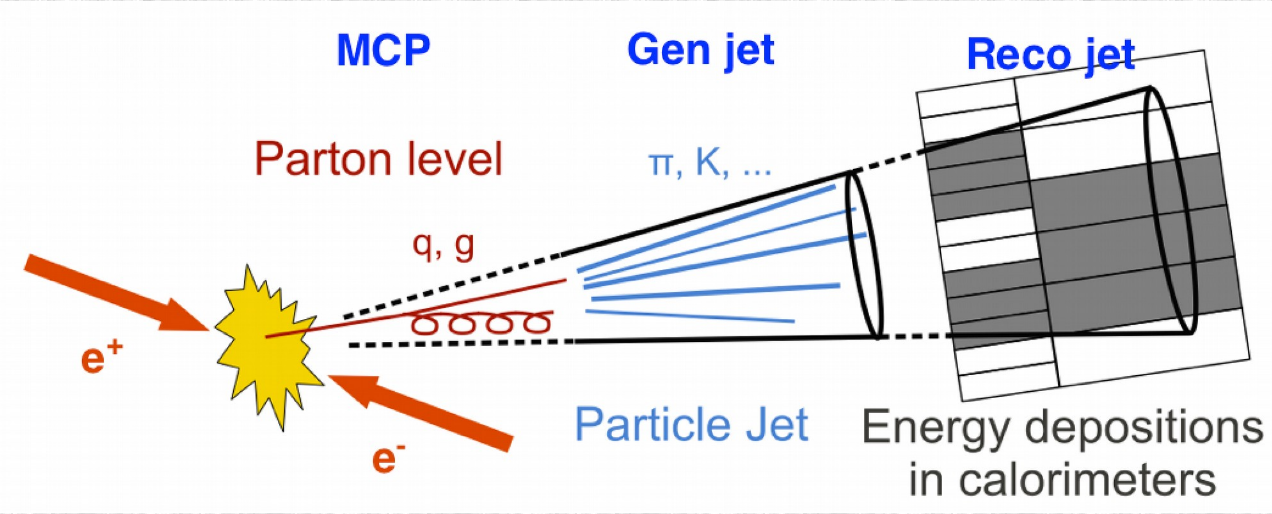
K^0_s reconstruction

- Charged particle π/K ID O(2σ) to 30 GeV
- Neutral Kaon/Lambda performance important
  - e.g. for K^0_s in Z decay
- Mass resolution is 0.29%
  - Will give cleaner Kaon ID than dE/dx
  - Though with lower efficiency
- Λ mass resolution 0.046%
  - Kinematic assistance from proton mass





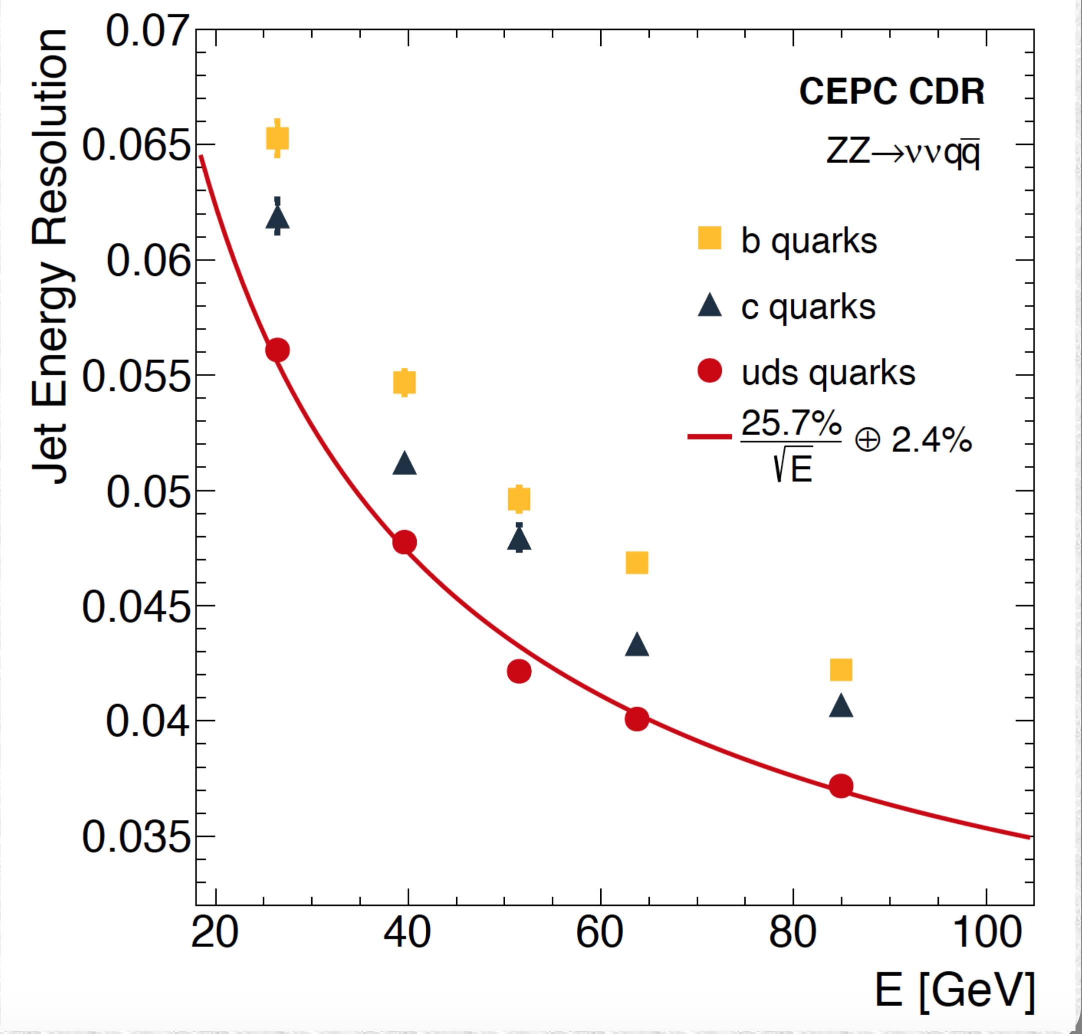
Jet Resolution



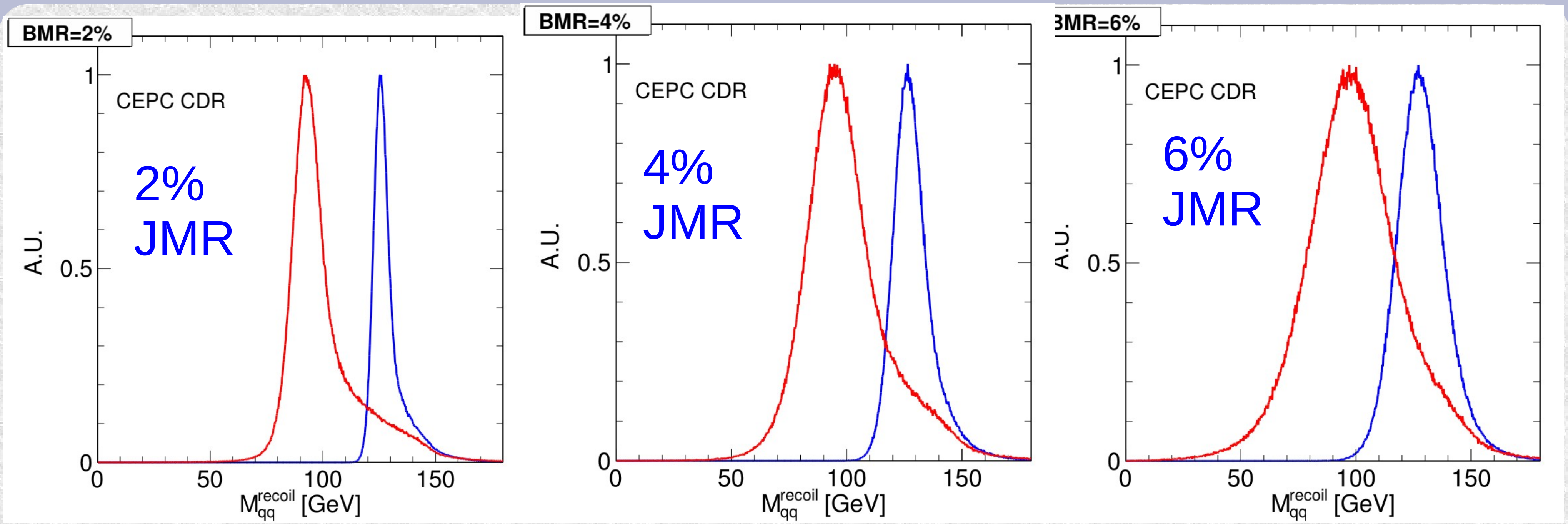
- Particle flow and DREAM:
  - Alternative philosophies of jet energy measurement
  - Confucianism v Taoism
    - "practise Confucianism on the outside, Taoism on the inside."

Jet energy resolution

- In August, I did not feel extreme JER was needed
- At LEP, constraints from (E, p) conservation improved JER hugely
- We studied:
  - Z→ qq (4C)
  - ee→WW→ qqqq (4C)
  - ee→WW→ qqlv (1C)
  - ee→WW→lvlv (no jet)
- But CPC has ee→ZH
- Recoil mass to Z critical
  - Z→ll looks pretty
  - Z→qq has the statistics



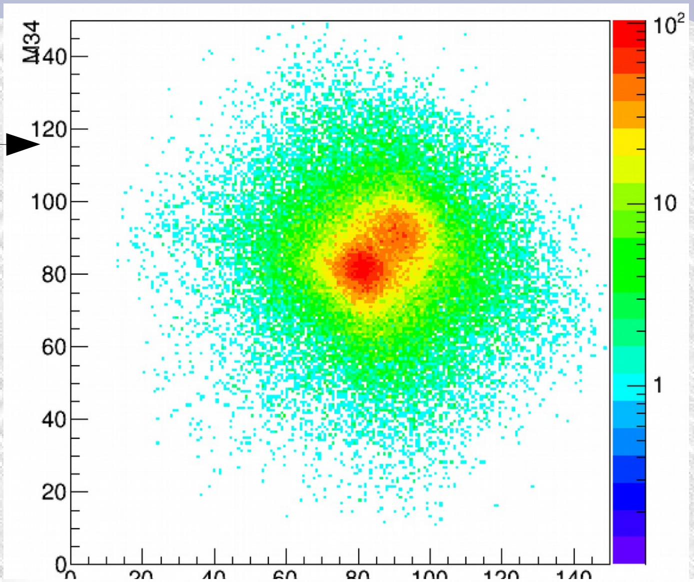
Jet energy resolution

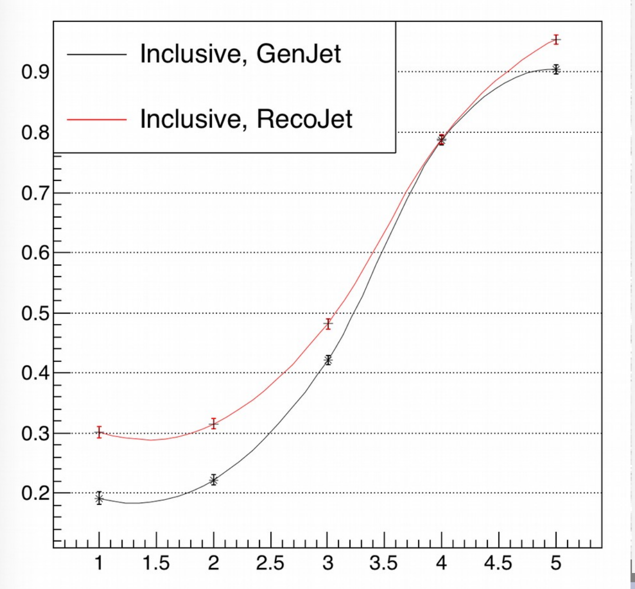


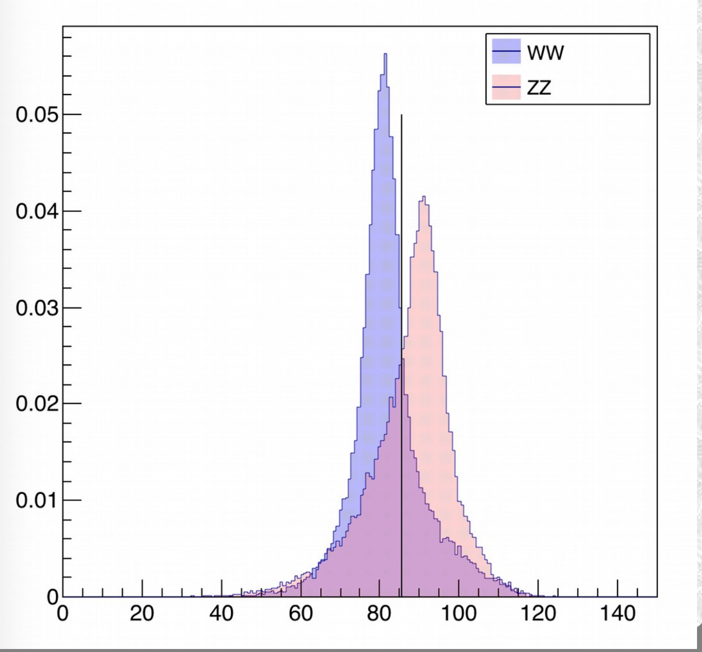
- Key physics from identifying H from Z recoil mass
  - Kinematics gives tails to high mass, alas
- Visually clear that O(4%) represents a transition in performance

Separate H→WW from H→ZZ

- Four jets, find best match pair
  - Jet-pair masses
- Bottom right is average jet mass
- Bottom compares perfect jet resolution with fullsim
  - Radiation/jet finding dominate over resolution
- x axis is angular match category
- Y axis is confusion rate

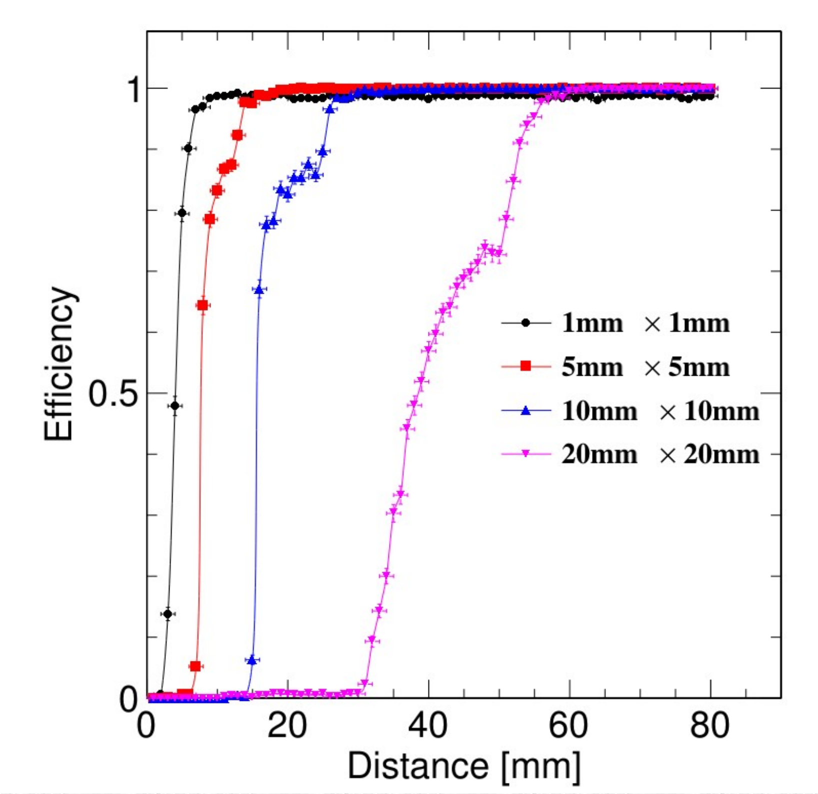


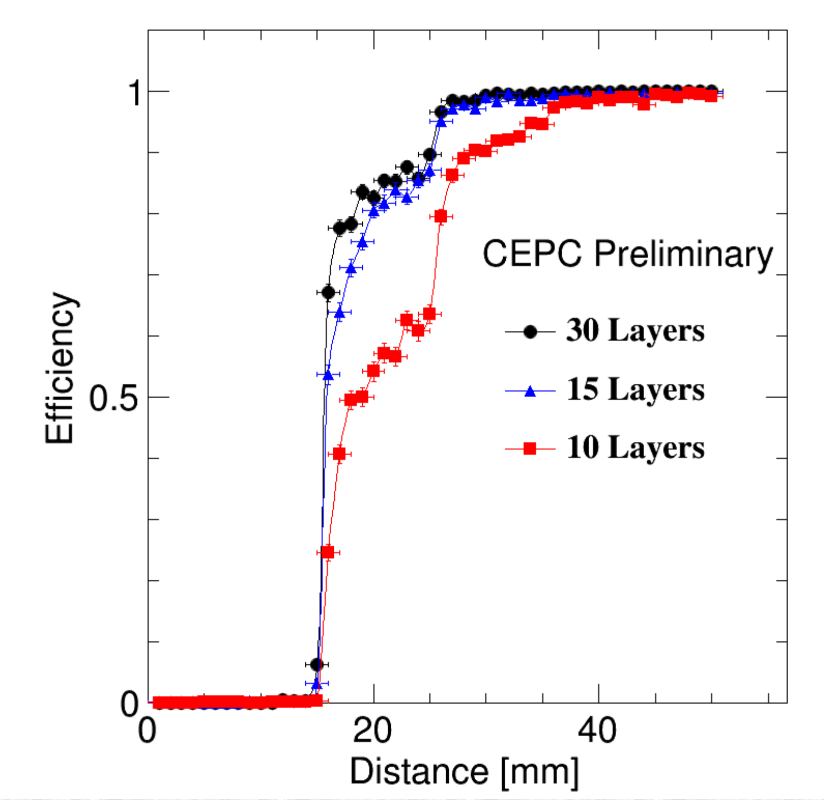




Si-W Calorimeter segmentation

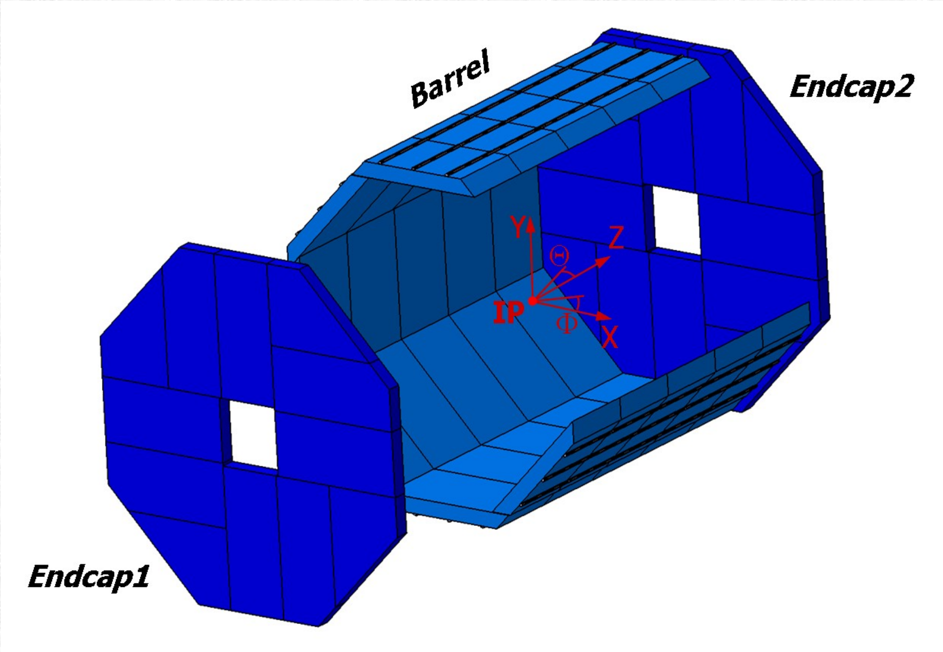
- See slides by Hang Zhao

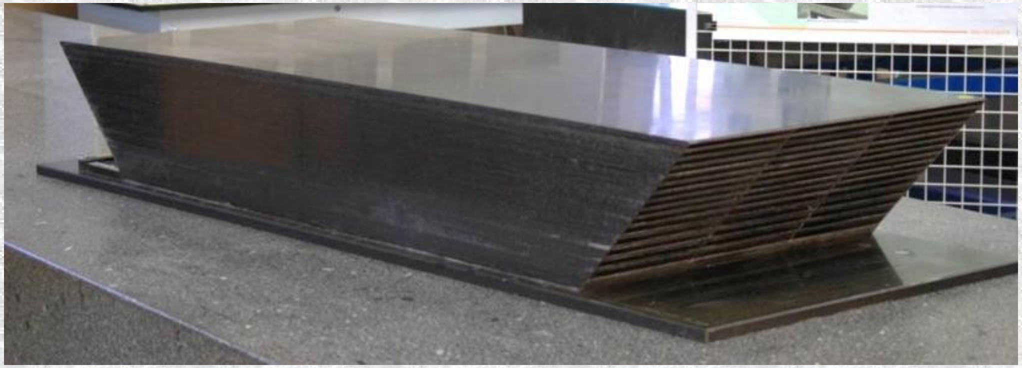




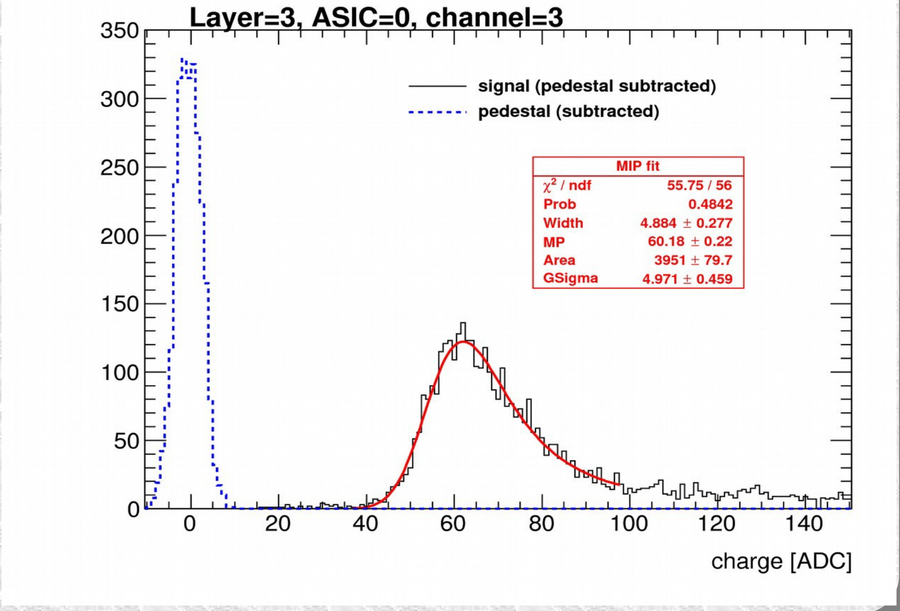
- A cell size 10mm^2 gives <2% $Z \rightarrow \tau\tau$ polluted
- Need depth segmentation (right)
  - Similar metrics from Dream are awaited

ECAL: Si-W



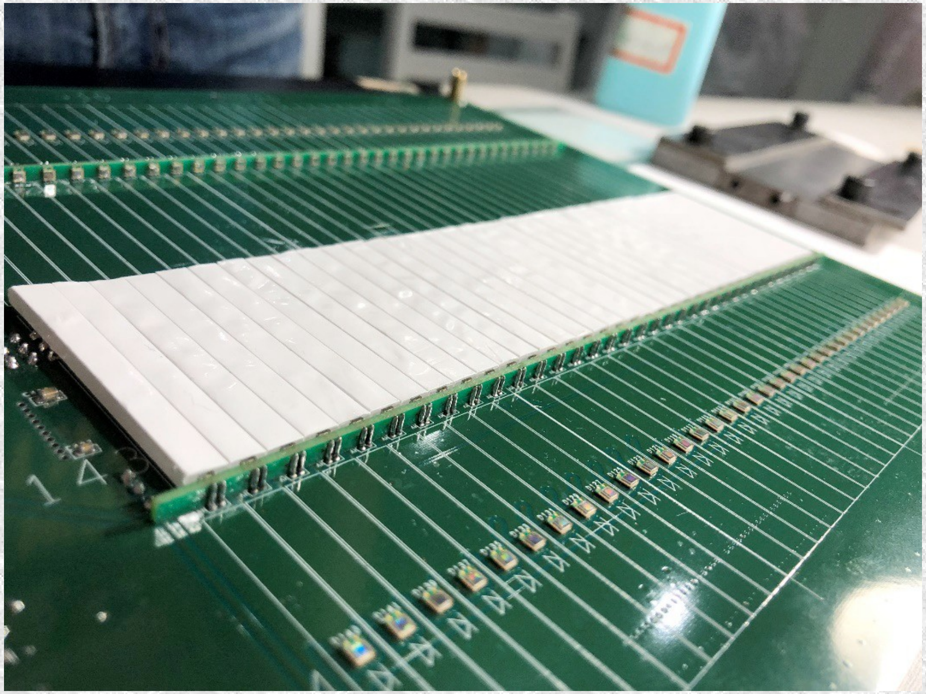


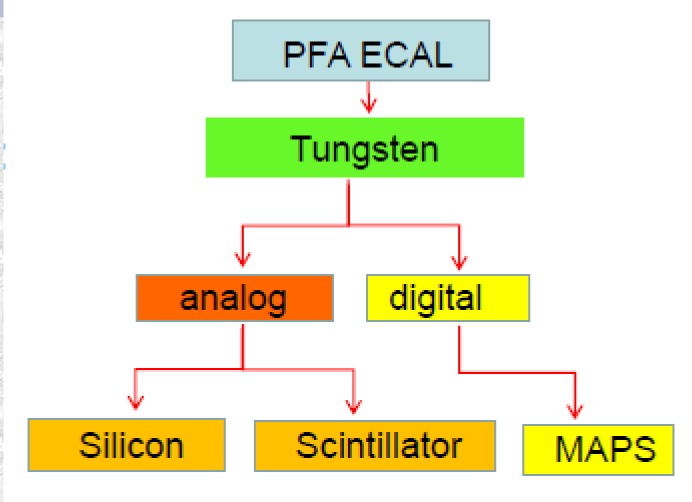
- ILC & CMS prootyping
  - MIP signal, s/n~20
- CepC specific optimisations
  - Active cooling R&D ongoing

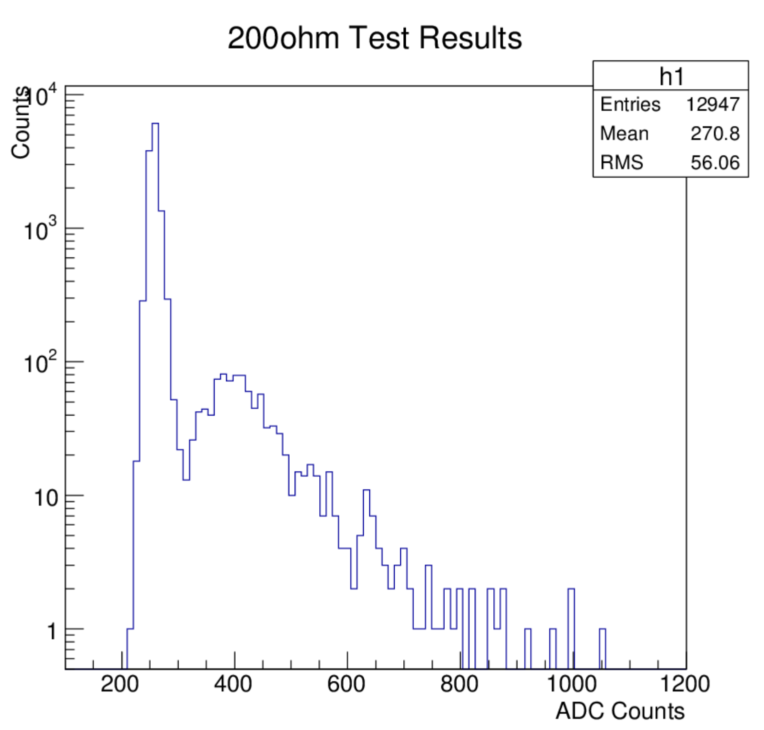


Scintillator / Tungsten

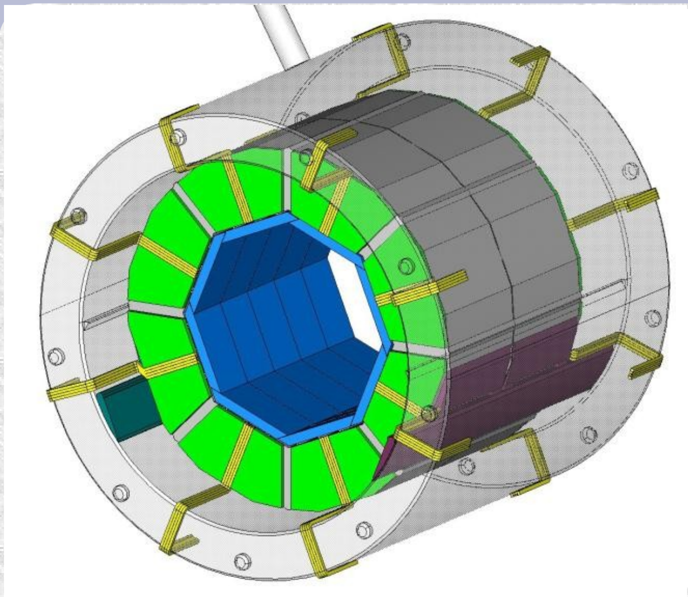
- Scintillator tile with SiPM option
  - Detector geometry optimised
- Position/energy resolution OK
- Single layer prototype tested with cosmics

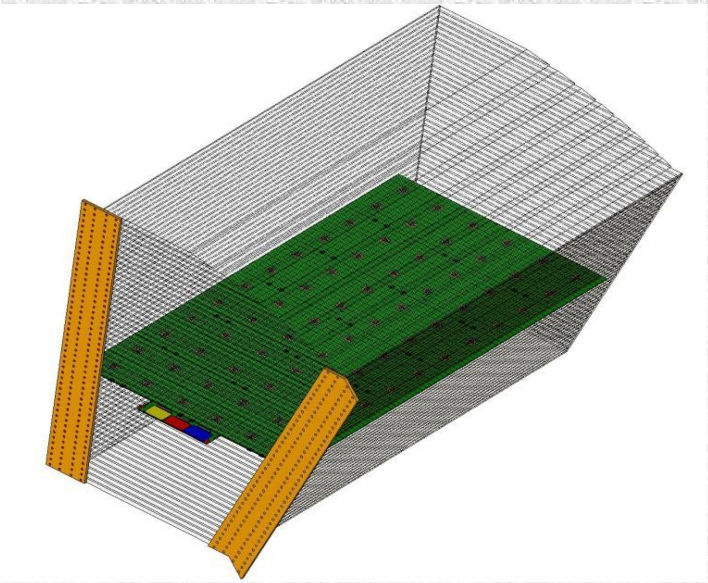


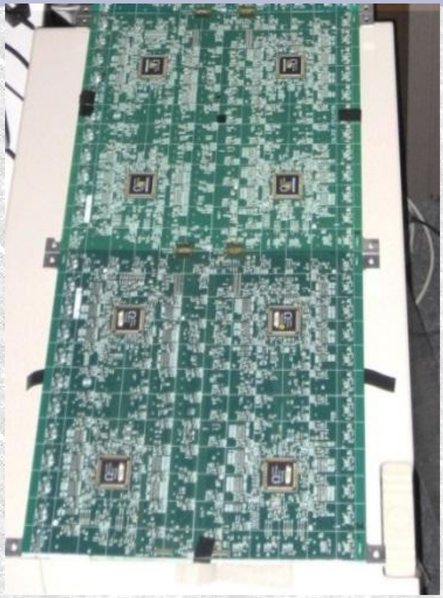




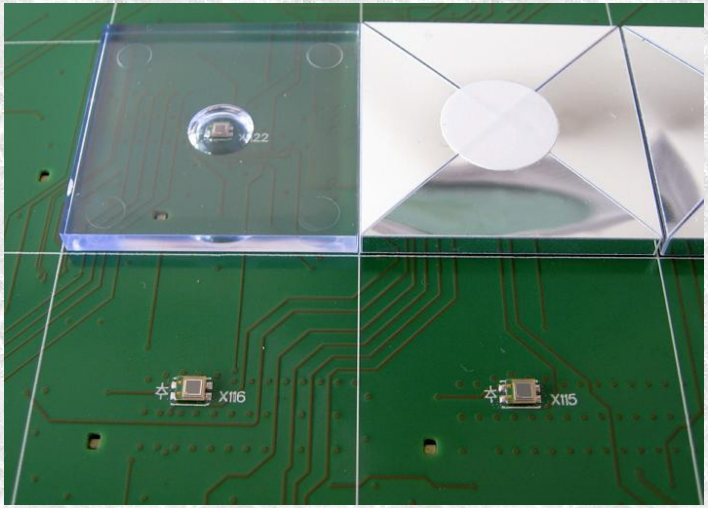
AHCAL



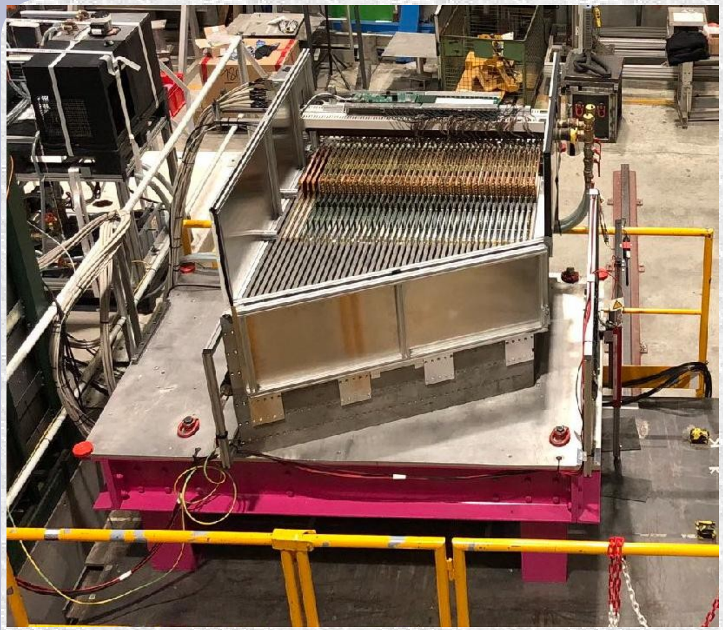




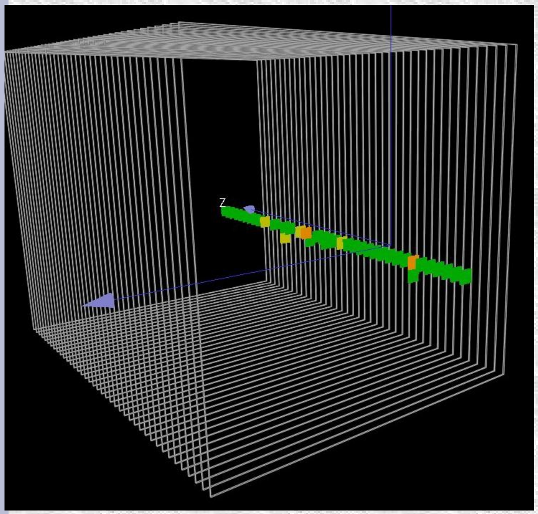
- 8M channels → make @ 1Hz
  - SiPM's readout continuously → cooling
  - 3cm^2 tile design gives uniformity
    - Custom machine for tile wrapping

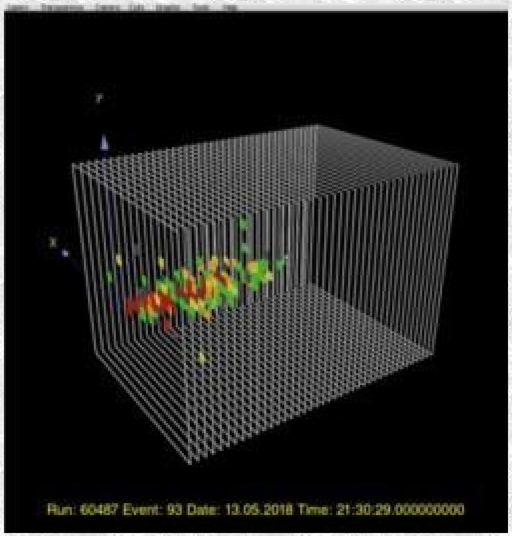


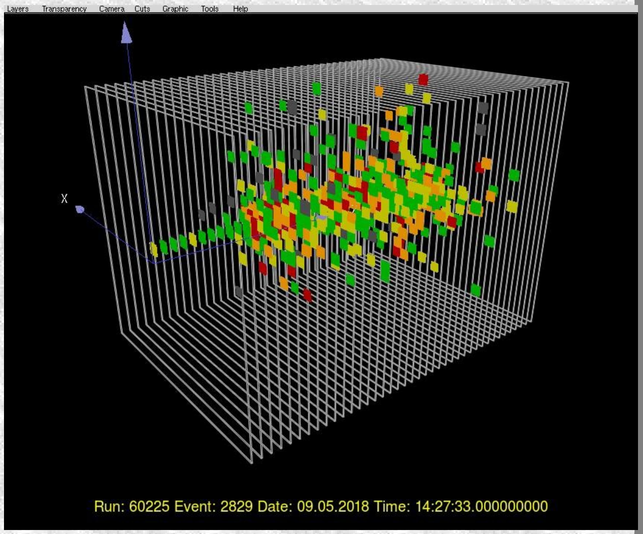
AHCAL prototype



- Results in CALICE-CMS testbeam
- 21888 channels
  - 99.96% working
- Beam test distinguishes muons, electrons and pions

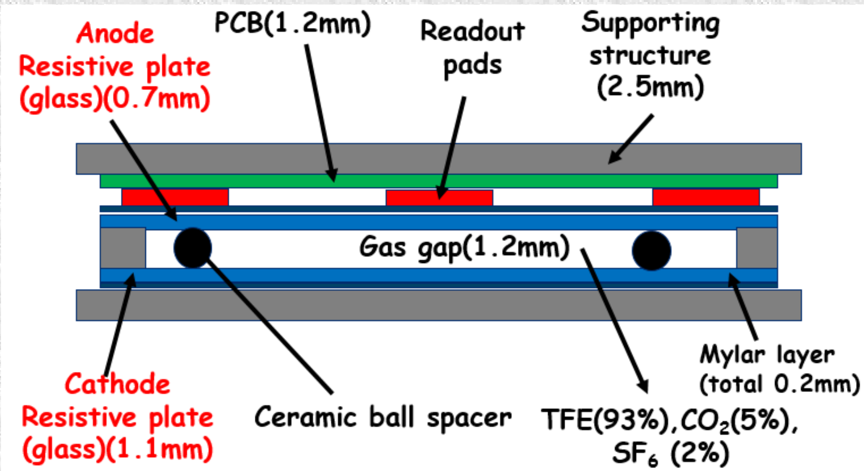


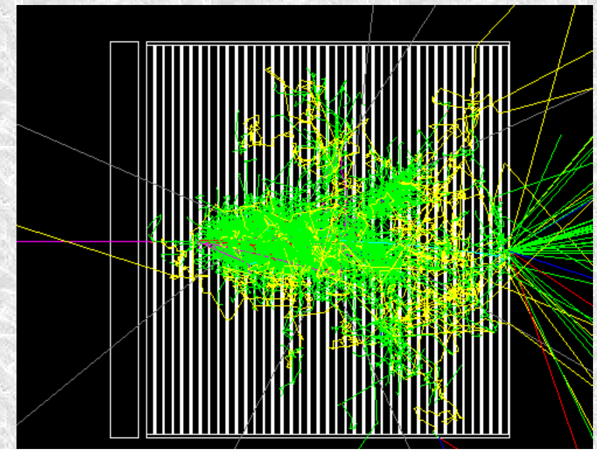




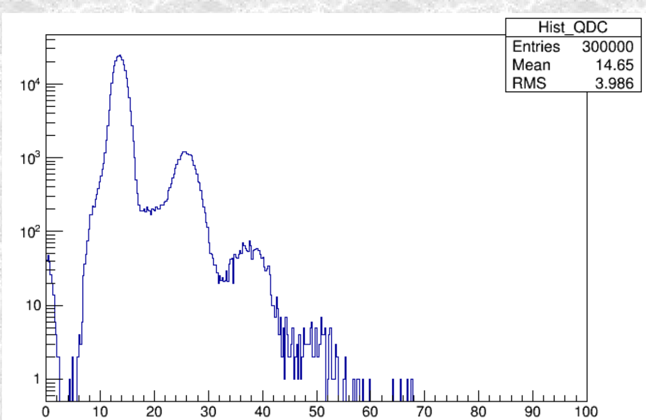
CepC specific HCAL

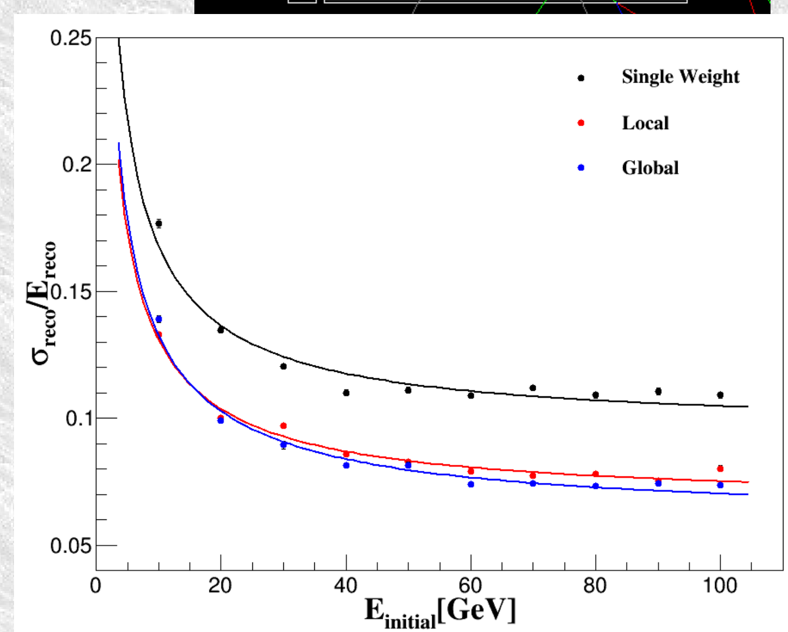
- Digital and analogue solutions both under study





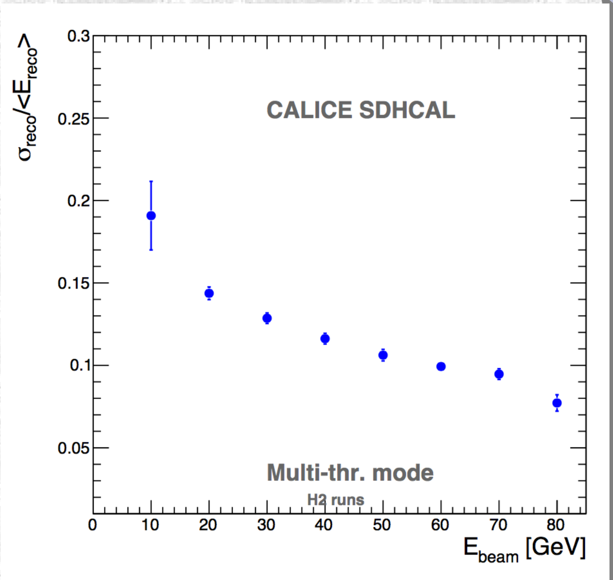
- Chinese NDL SiPM's giving good performance

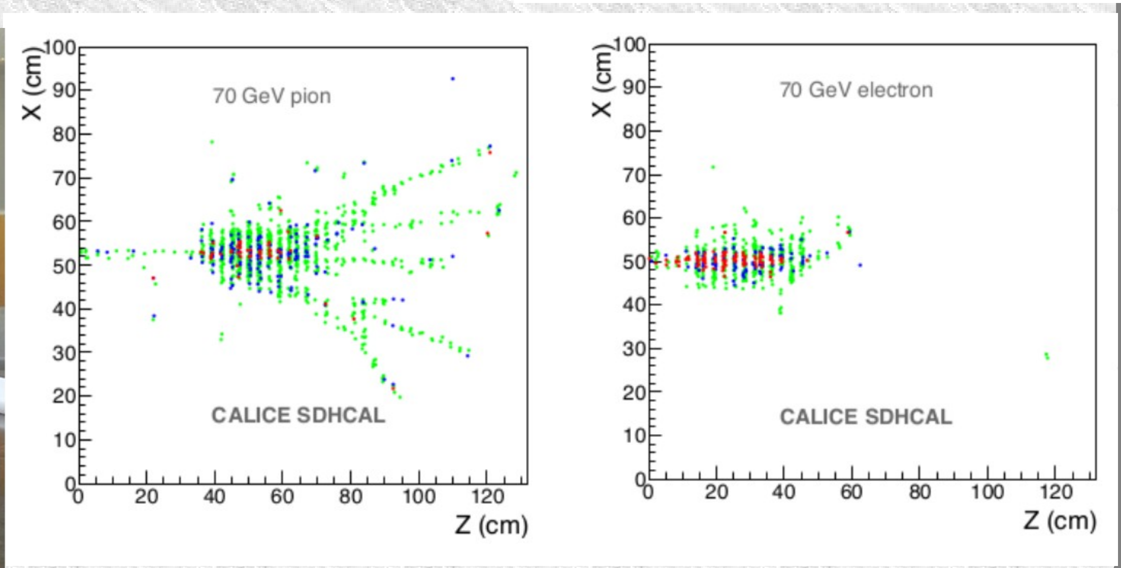




Semi-digital HCAL

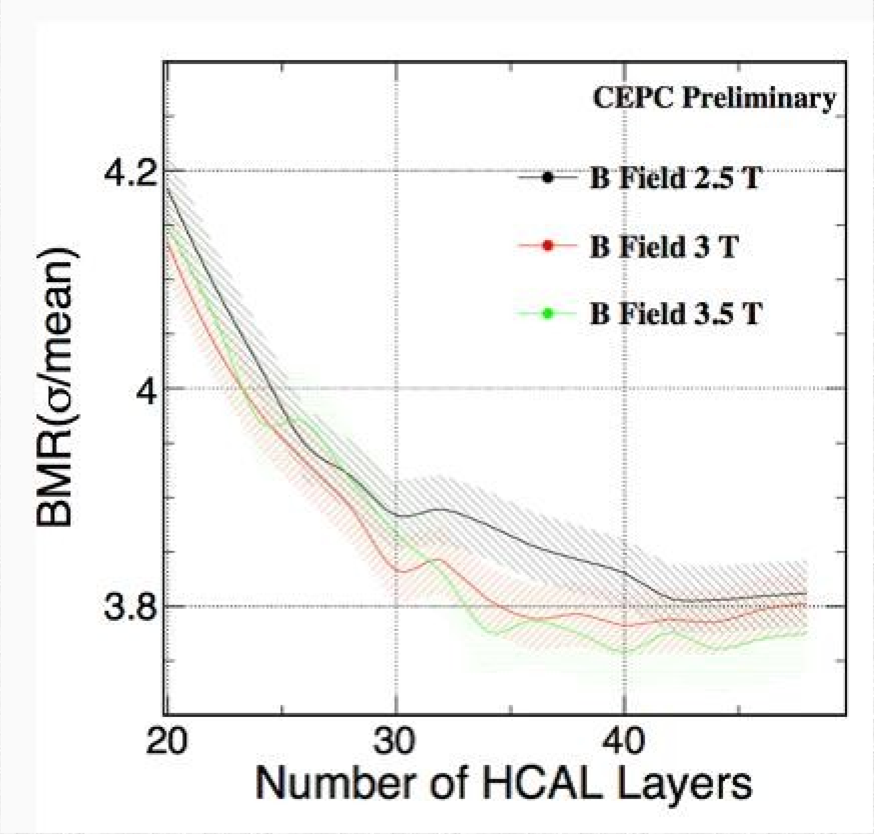
- Prototype at CERN testbeam
  - As Calice
- Linearity good, resolution meets needs
- Moving to $3m^2$ prototype
- Cooling 110kW being studied





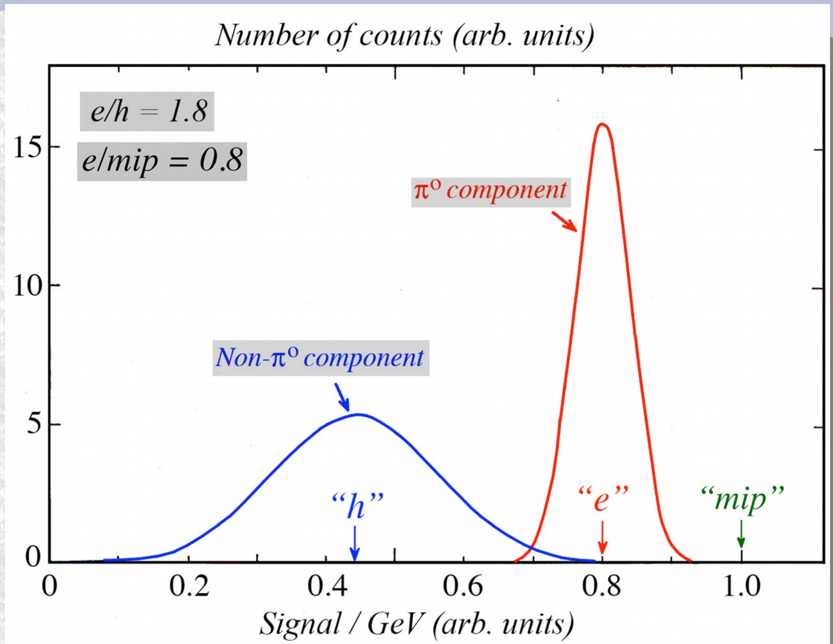
Optimizing p-flow calorimetry

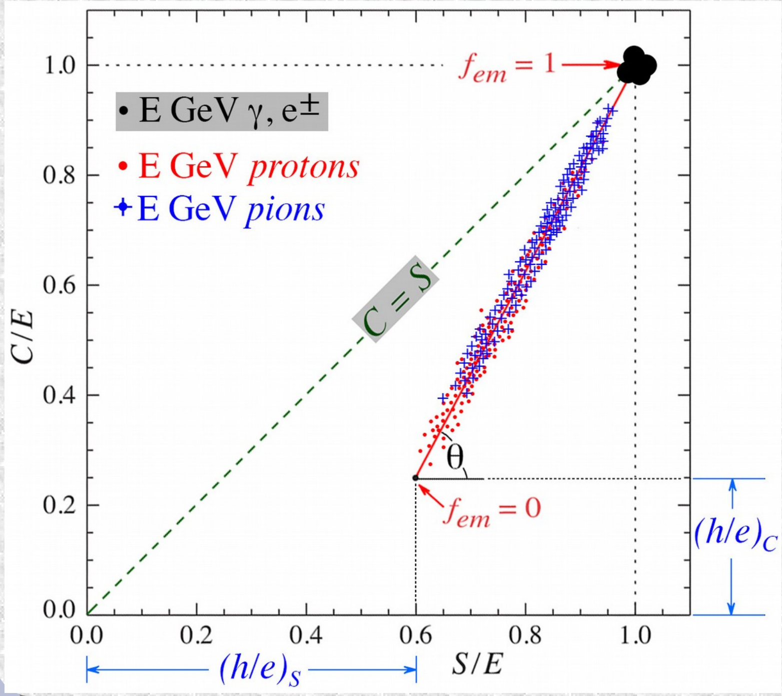
- Plot shows BMR varying HCAL layer & B field
- Reducing SDHCAL below 40 layers impacts jet energy resolution
- Reducing B field has minor impact on jet resolution



Dream Calorimetry

- Shower fluctuations change e/π component fraction
- Fibre readout, alternately:
  - Scintillator – all charged
  - Clear – fast cerenkov only (e)

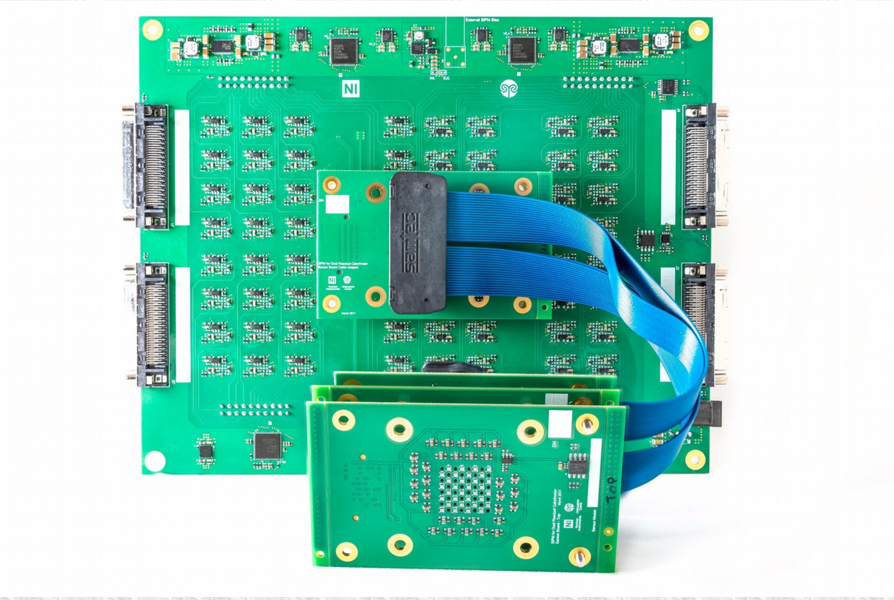


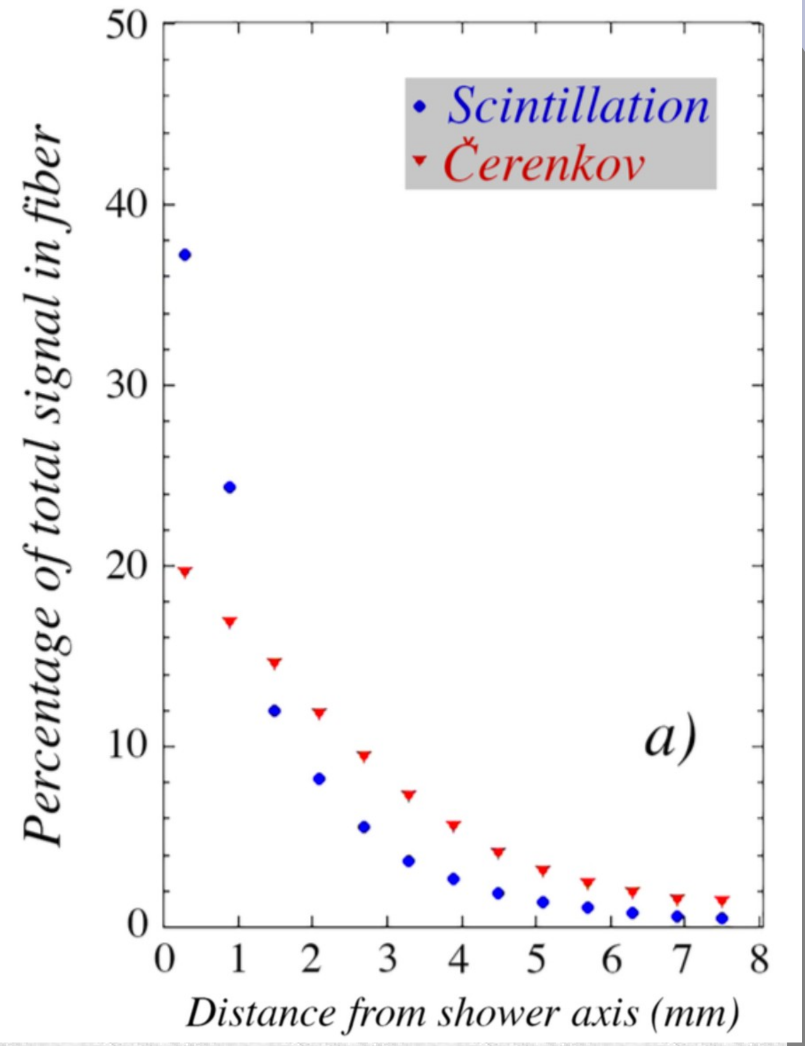


- Weighted difference between two signals yields compensated result
  - Event by event measure of EM fraction

The Dream

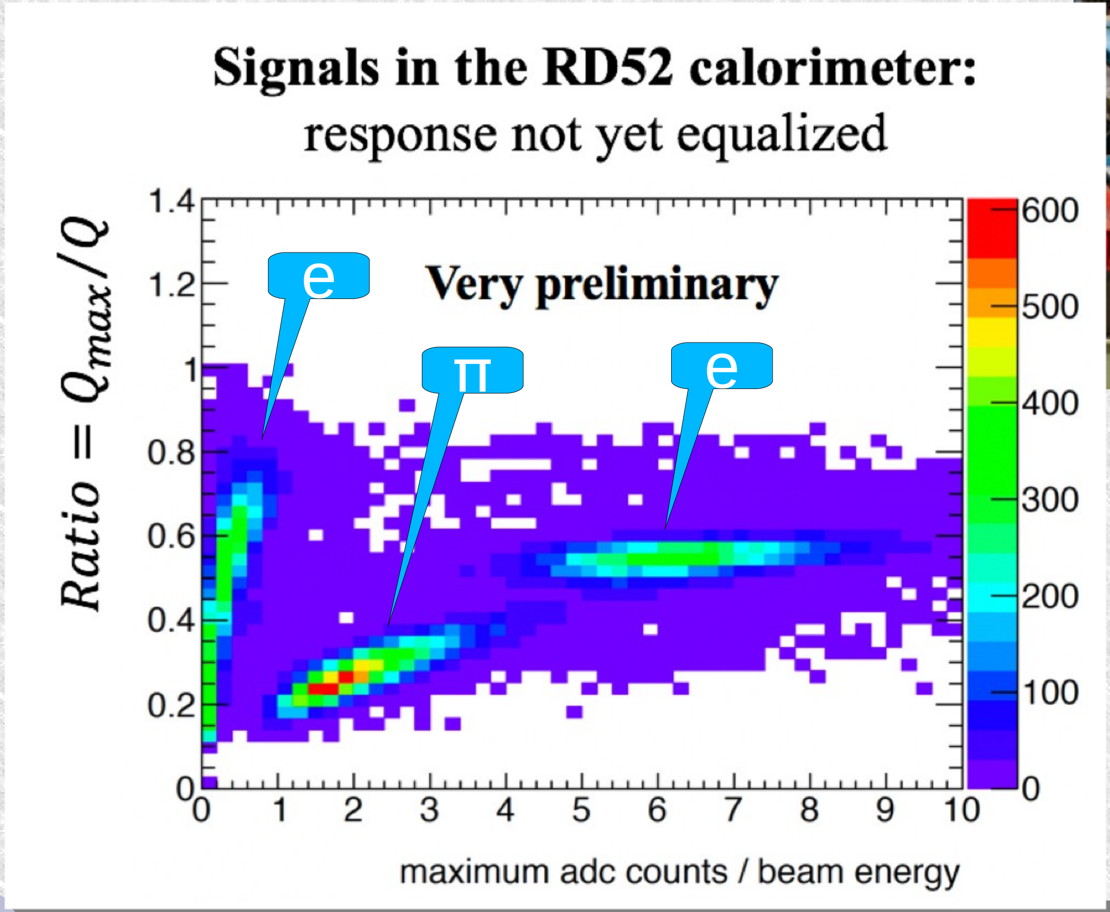
- Dream readout:
  - Brass calorimeter with fibres embedded
    - Lead would be better
  - SiPM allows easy fibre routing

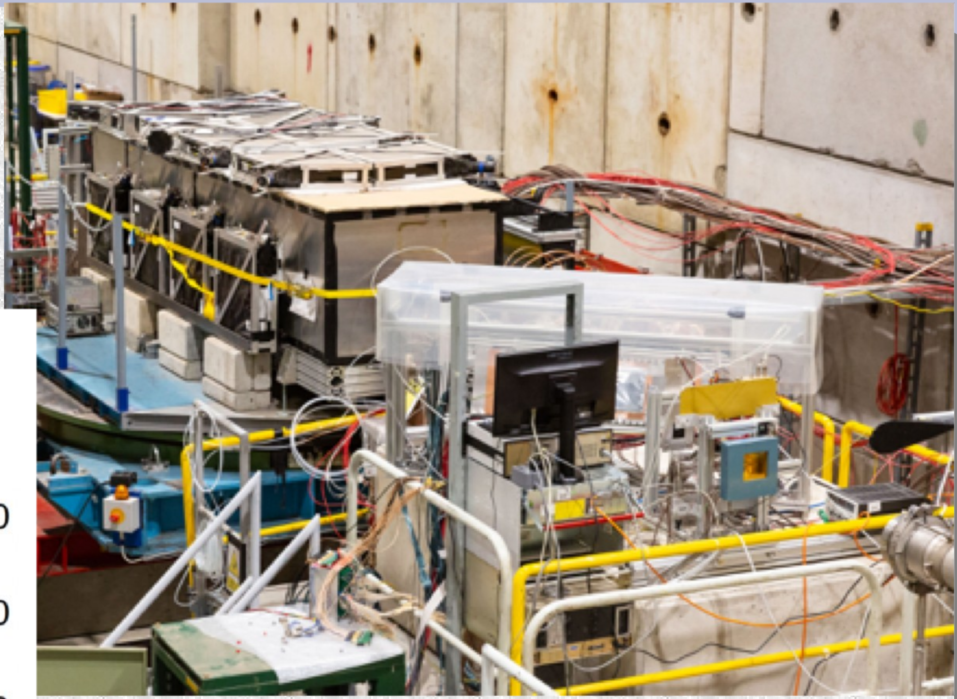




The real world?

- Testbeam at CERN
  - Few days
  - Analysis just started





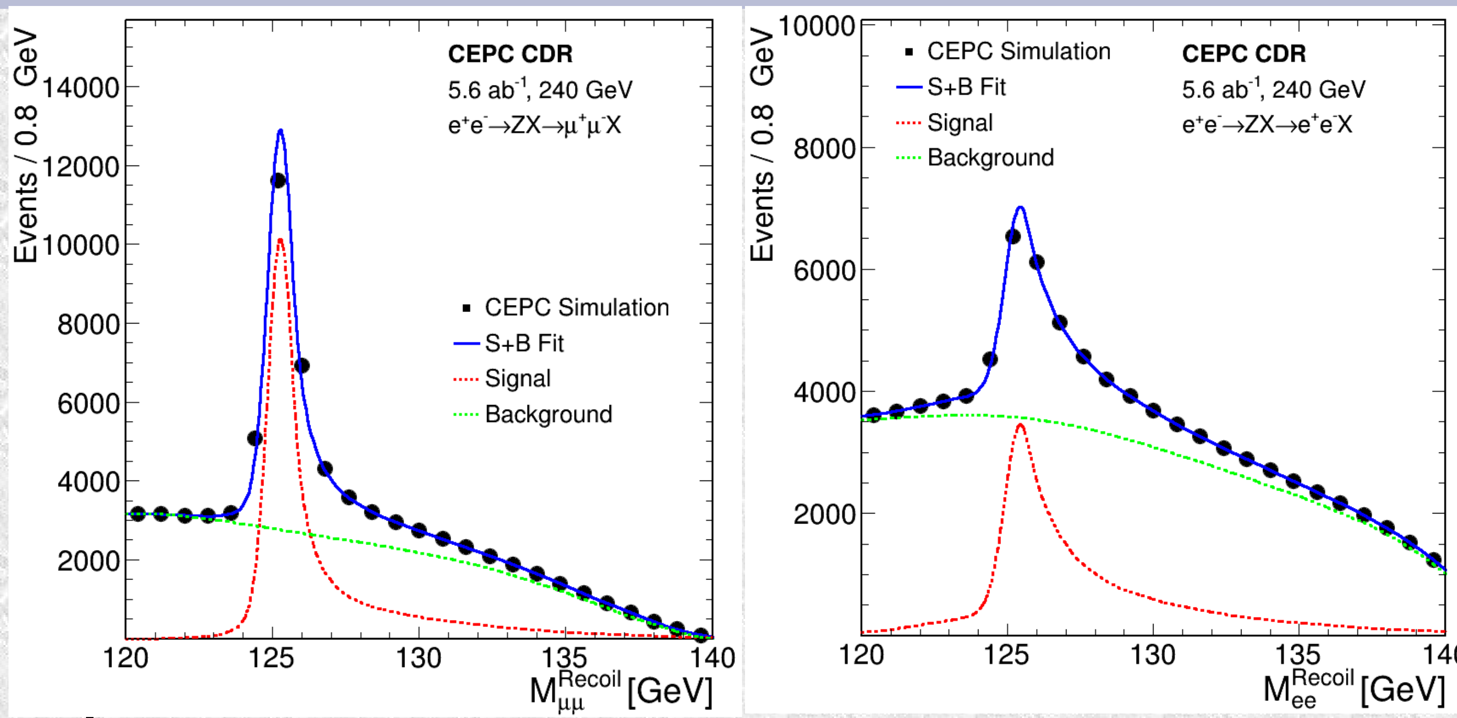
- Clear and distinct signals from all particle types
  - Verified with independent PID

Calorimetry summary

- Active programme
- Lots of ideas and real work going on

New calorimeter ideas

- Z → μμ much better then Z → ee
  - (Brehm reco not used)
  - But EM performance is not great
- Can consider segmented crystal calorimeter
  - Need development of SiPM
  - Could improve Z lumi through ee → γγ

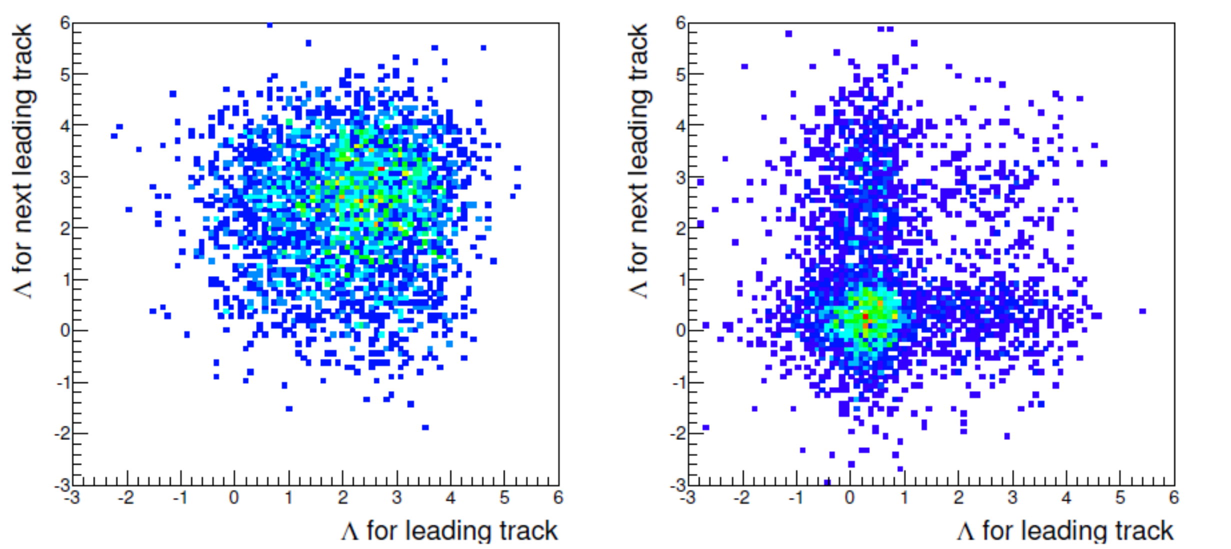


Recall requirements

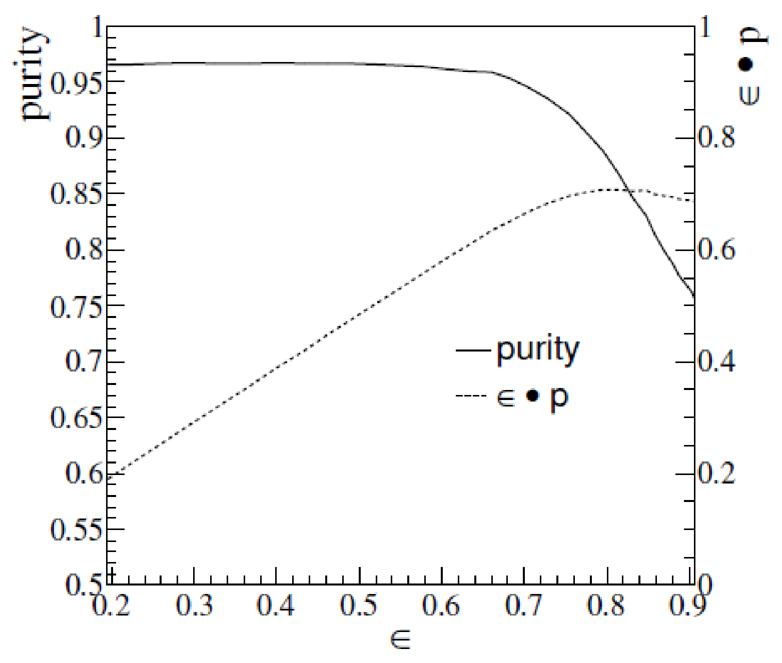
- Momentum resolution
  - Defines $Z \rightarrow \mu\mu$ peak performance, s/b
    - Clearly excellent is good
  - But lacks a perfect benchmark to define it
  - $H \rightarrow \mu\mu$ provides some justification
- Photon resolution
  - $H \rightarrow \gamma\gamma$ provides weak justification
  - More driven by Brehm recovery or single photon?
- Tau ID?
  - Basically follows the rest of the performance

Tau performance

- Separation of H→ττ from H→WW in lepton pairs:
  - i.e. τ+τ ∨ e/μ/τ + e/μ/τ
- Log sum d0 and z0 significance in 2D:



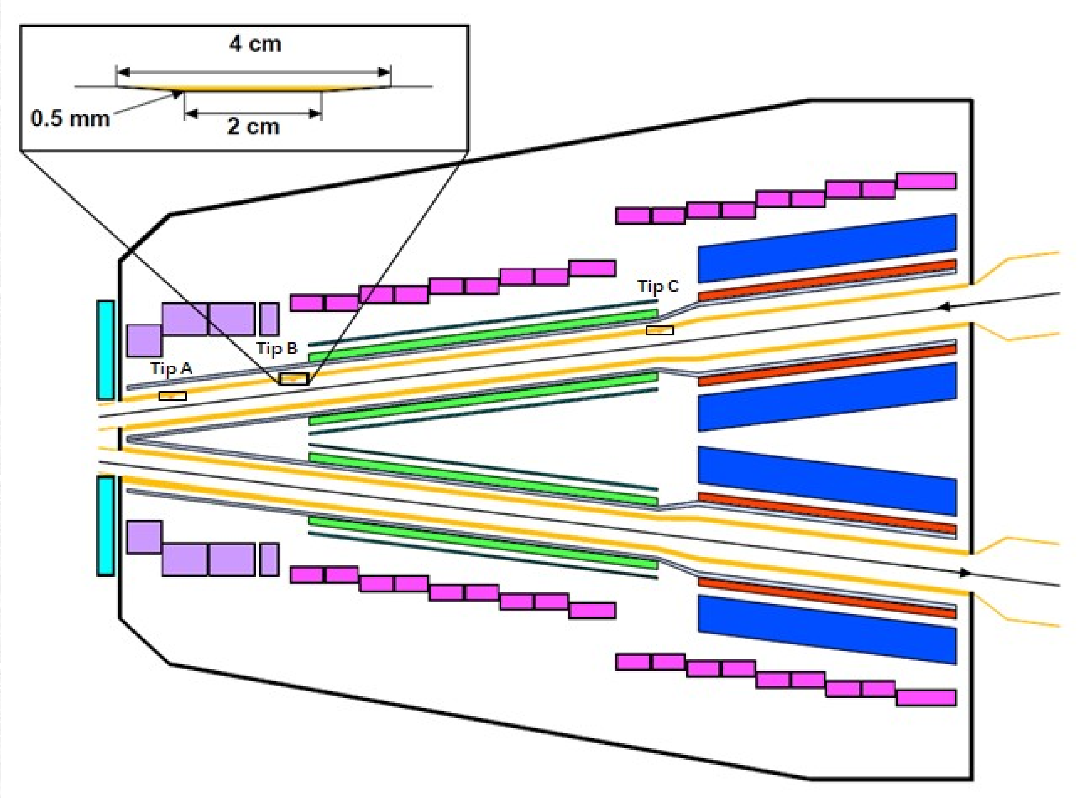
(a) signal (b) background



- 80% efficiency, 88% purity
- From IP alone

The challenge of crossing angle

- 2x16.5mRad angle
  - Needed to separate beams
    - Crab waist crossing
  - Increases impact of experiment solenoids on emittance
  - The green anti-solenoids introduced to reduce impact
  - Event so, a 3T solenoid implies a 50% reduction in luminosity at Z peak



Running at Z peak

- Should we assume detector unchanged for 10 yrs?
- If Z run comes after ZH, as planned, can:
  - Build up DAQ facilities gradually
    - Initial demands much easier
  - Potentially change vertex region if helpful
- But: should make test run at Z peak at high lumi
  - Machine is designed to be flexible
  - Helpful to calibrate detectors
  - Ensure detectors can cope with rate
  - If there is an issue, there are 6 years to find solutions
- However:
  - Detector requirements more stringent at ZH
- This needs to be gone through carefully

Magnetic field for Z run?

- Tension:
  - TPC needs B>3T to limit diffusion
  - IDEA design calls for thin coil, so B<2T
- Factor 2 luminosity gain at Z peak from lower field
- Can baseline with reduced field?
  - Reduce bending power
  - Degrade TPC position resolution
  - But does Z physics lose that much?
    - EW depends more on systematics
    - B physics programme would certainly suffer
    - TPC gives dE/dx: required largely in B physics

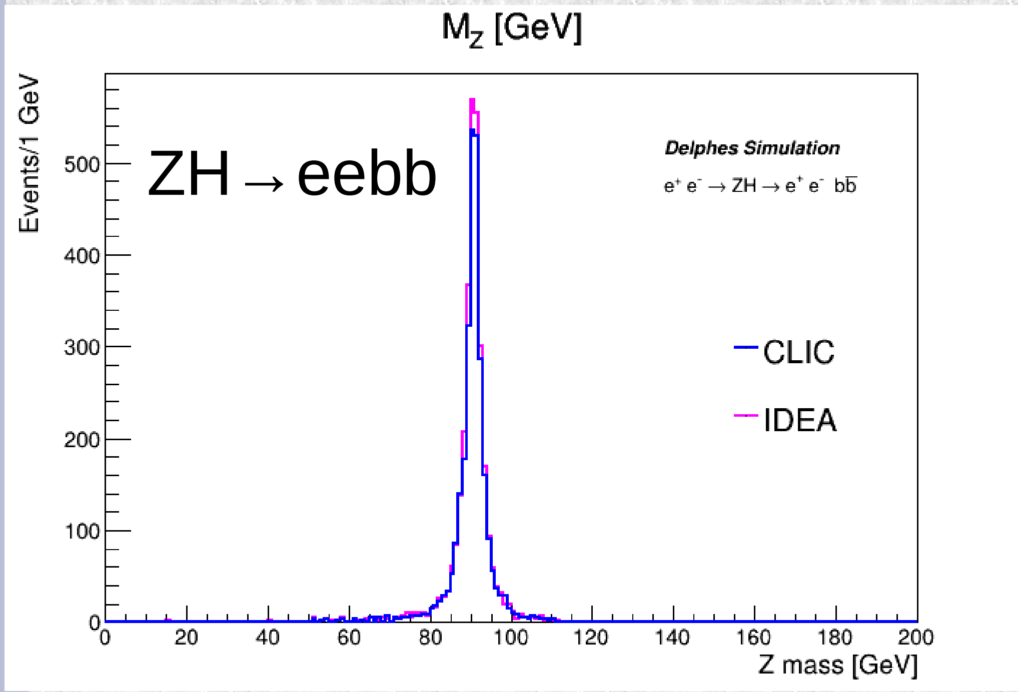
Summary

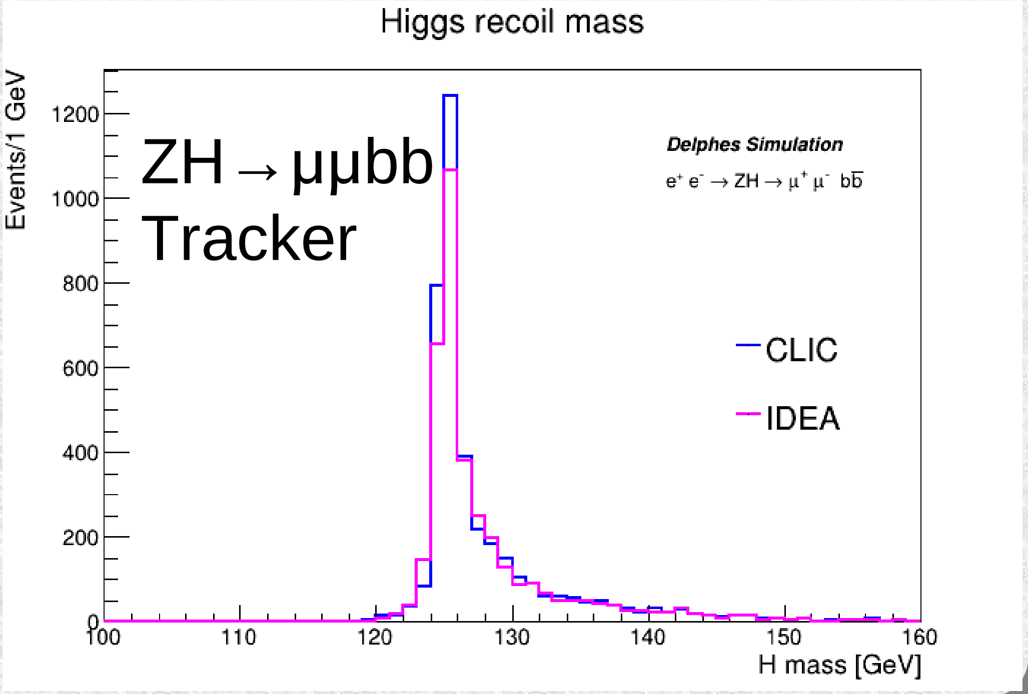
- This project is timely, achievable and realistic
- Vertex detector has active R&D programme
- TPC & Drift chamber well advanced
- Many initiatives in calorimetry
- I skipped Muons, DAQ, solenoids...sorry.
- R&D on some of the critical components ongoing
  - Still room for new ideas

- The detectors can do the job
  - Need to move from CDR to TDR
    - A lot of work hidden in this line
  - TO deliver a unique physics programme

Jet pair mass resolution

- Delphes simulation
  - using the tracker to reconstruct μ momentum
- Performance appears comparable to the p-flow approach





Pixelated strip for SIT/FTD?

- Alternative studied in Shandong

Operation mode	H (240)	W (160)	Z (91)
Track multiplicity (BX^{-1})	310	300	32
Bunching spacing (ns)	680	210	25
SIT-L1 occupancy (%)	0.19	0.58	0.52
FTD-D1 occupancy (%)	0.17	0.54	0.48

Challenge in silicon strips

- Strips are seen as less challenging
  - Therefore less interesting to make!
- But the area is large – especially for the all-silicon device.
  - A strong set of groups dedicated to them is needed