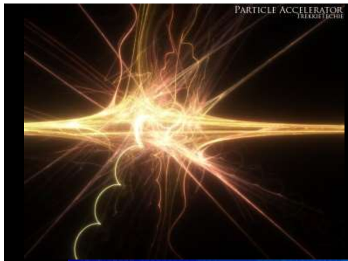


Calorimeter R&D for CepC

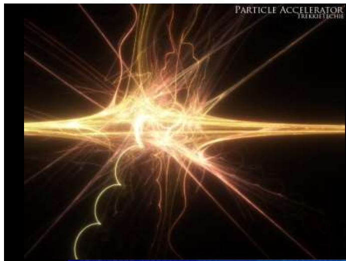
Franco Bedeschi, INFN-Pisa

CEPC workshop,

Chicago, September 2019

OUTLINE

- Basic requirements
- Current options
  - Particle flow
  - Dual readout
- Summary



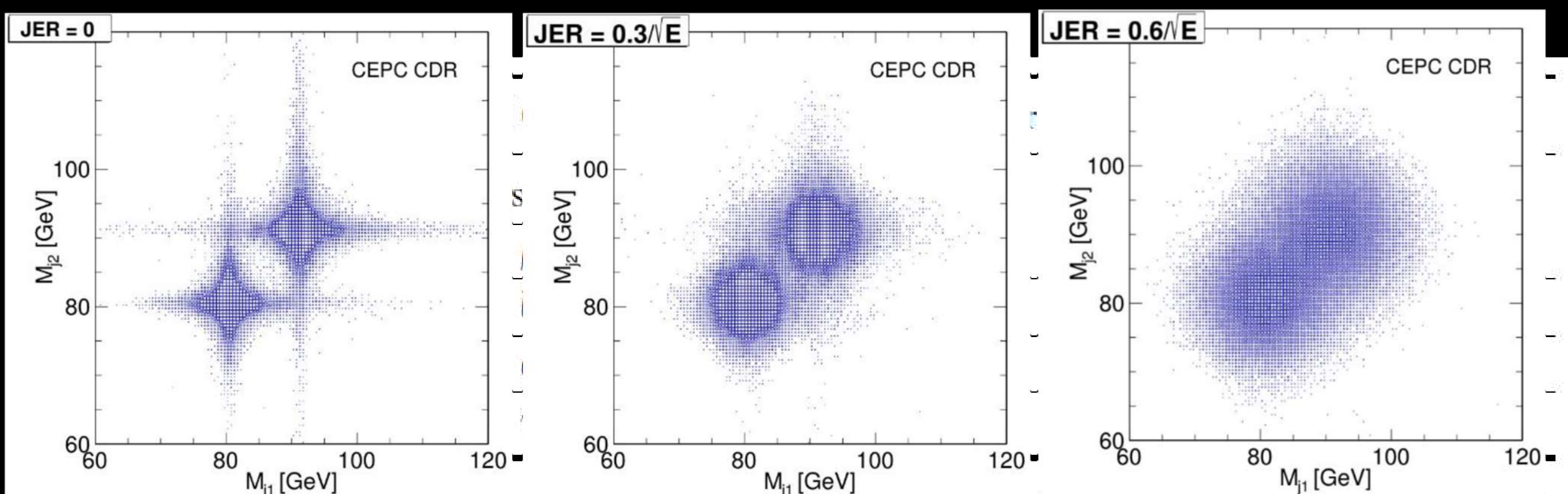
e+e- → HZ physics constraints

- Calorimeters:
  - H→γγ → ECAL resolution
    - As good as possible – at least $16\%/\sqrt{E} + 1\%$

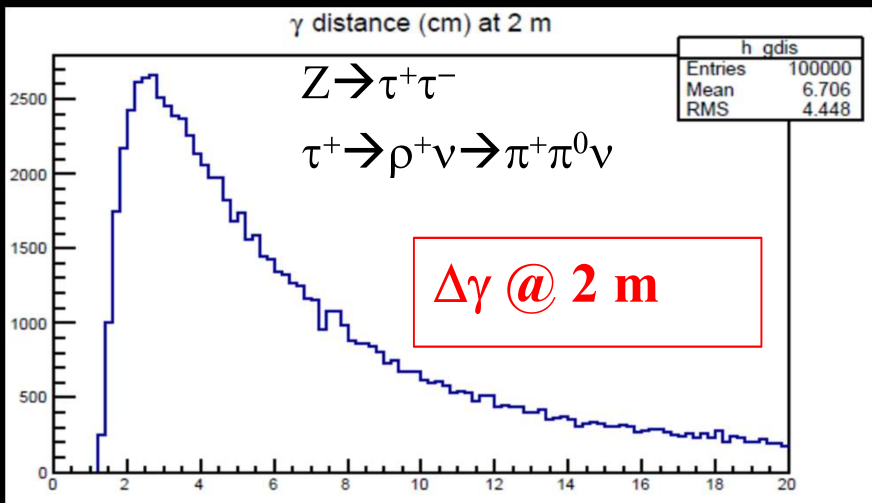
Physics Process	Measured Quantity	Critical Detector	Required Performance
$ZH \to \ell^+\ell^- X$	Higgs mass, cross section	Tracker	$\Delta(1/p_T) \sim 2 \times 10^{-5}$
$H \to \mu^+\mu^-$	$BR(H \to \mu^+\mu^-)$		$\oplus 1 \times 10^{-3}/(p_T \sin\theta)$
$H \to b\bar{b},\ c\bar{c},\ gg$	$BR(H \to b\bar{b},\ c\bar{c},\ gg)$	Vertex	$\sigma_{r\phi} \sim 5 \oplus 10/(p \sin^{3/2}\theta)\ \mu m$
$H \to q\bar{q},\ VV$	$BR(H \to q\bar{q},\ VV)$	ECAL, HCAL	$\sigma_E^{jet}/E \sim 3-4\%$
$H \to \gamma\gamma$	$BR(H \to \gamma\gamma)$	ECAL	$\sigma_E \sim 16\%/\sqrt{E} \oplus 1\%$ (GeV)

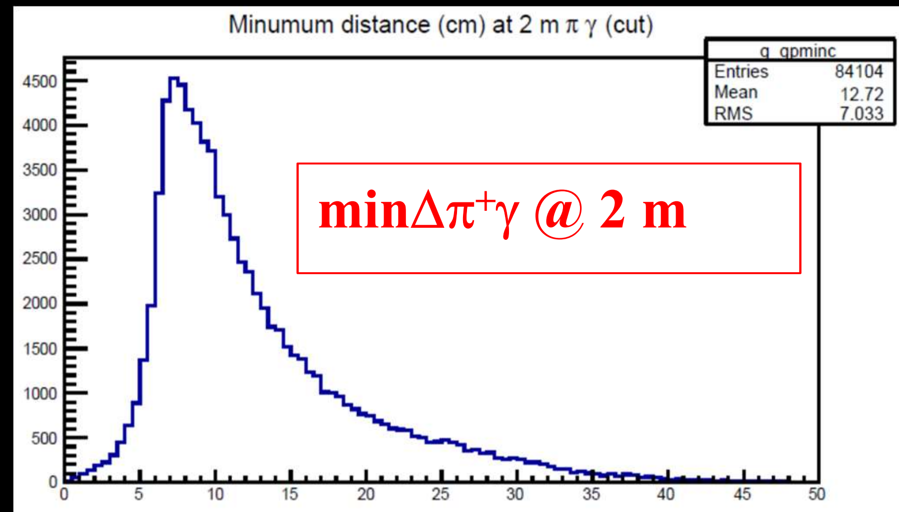
e+e- →HZ physics constraints

- Calorimeters:
  - H→γγ → ECAL resolution
    - As good as possible – at least $16\%/\sqrt{E} + 1\%$
  - HZ→qq recoil, H→qq, VV → ECAL+HCAL resolution
    - As good as possible – at least 3-4% on jets from W,Z decay



Other drivers

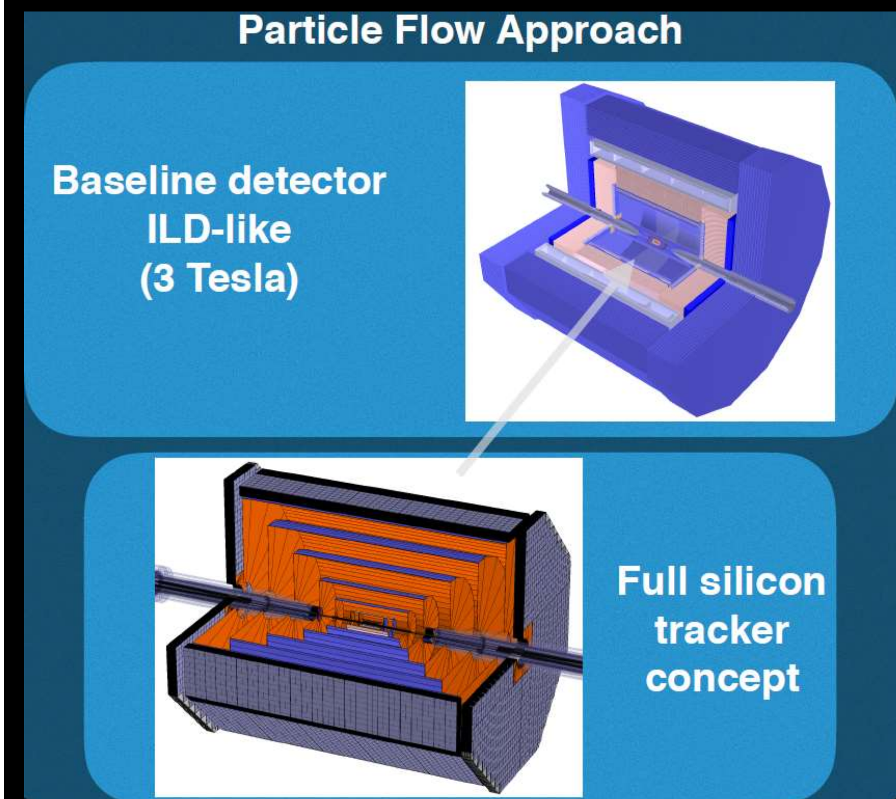


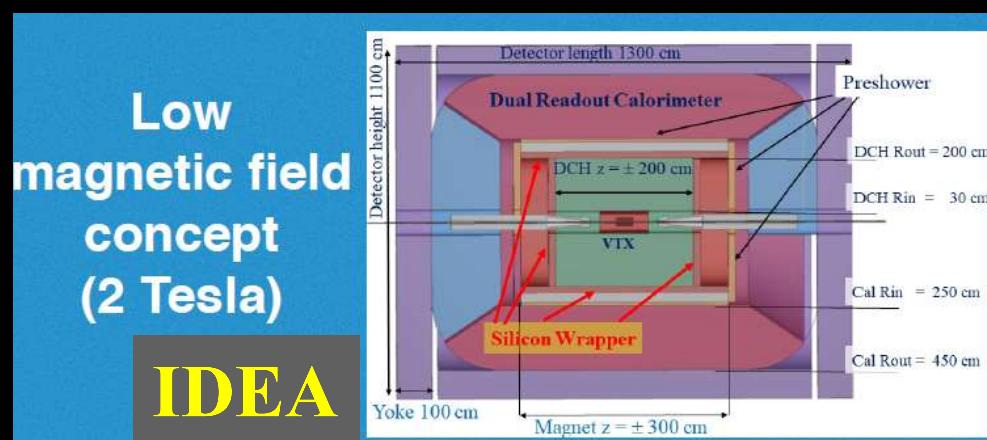


- π^0 important in tau and HF physics – Mostly on Z pole
  - No π^0: 35% $\tau \rightarrow 1\,(e, \mu)\,\nu\nu$ + 20% $\tau \rightarrow (1,3)\pi^{\pm}\,l\nu$
  - 1 π^0: 28% $\tau \rightarrow (1,3)\pi^{\pm}\pi^0 l\nu$
  - 2 –3π^0: 10% $\tau \rightarrow \pi^{\pm}(2,3)\,\pi^0 l\nu$
  - High granularity → π^0 identification
  - Overlap with π^+ may require longitudinal segmentation

Detector choices

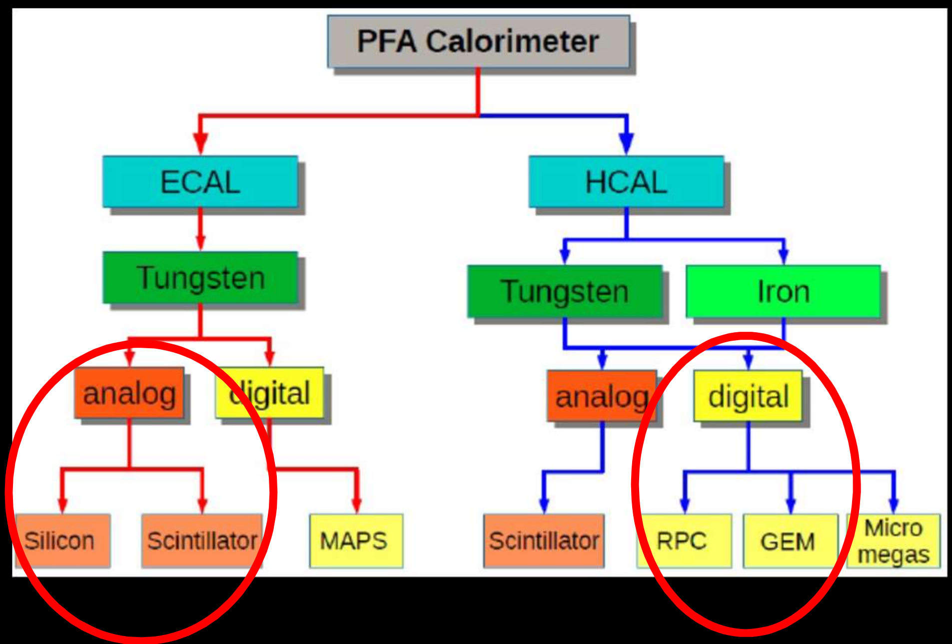
- Particle flow is baseline
  - EM and HAD
  - Inside yoke
- Dual readout for IDEA
  - EM/HAD single package
  - Outside yoke





Particle Flow options

- EM calorimeter
- HAD calorimeter

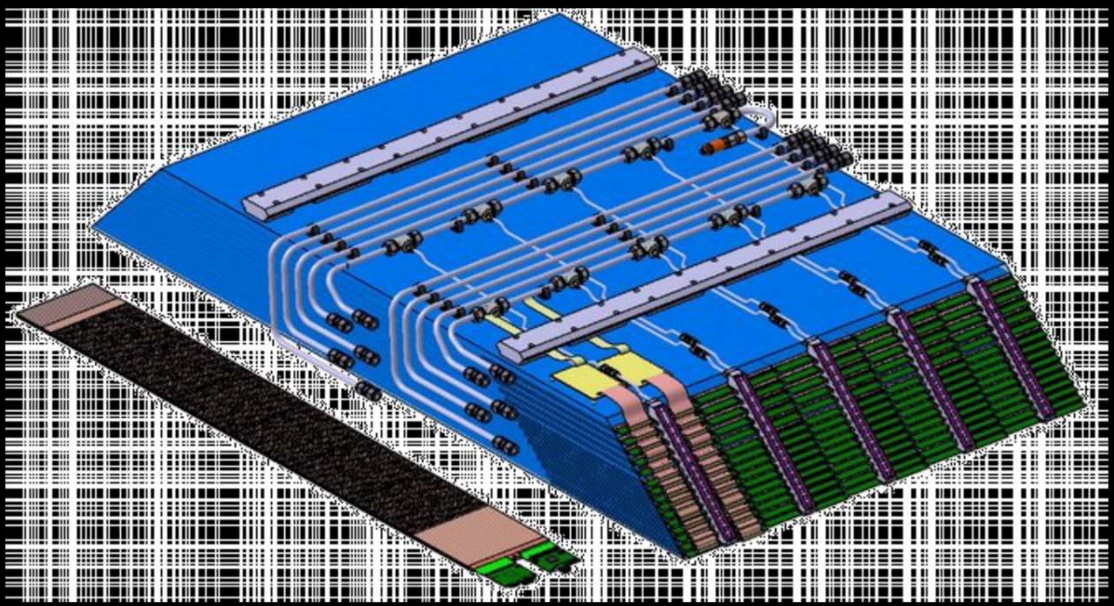


Baseline det.

Electromagnetic	ECAL with Silicon and Tungsten (LLR, France) (*) ECAL with Scintillator+SiPM and Tungsten (IHEP + USTC)
Hadronic	(*) SDHCAL with RPC and Stainless Steel (SJTU + IPNL, France) SDHCAL with ThGEM/GEM and Stainless Steel (IHEP + UCAS + USTC) (*) HCAL with Scintillator+SiPM and Stainless Steel (IHEP + USTC + SJTU)

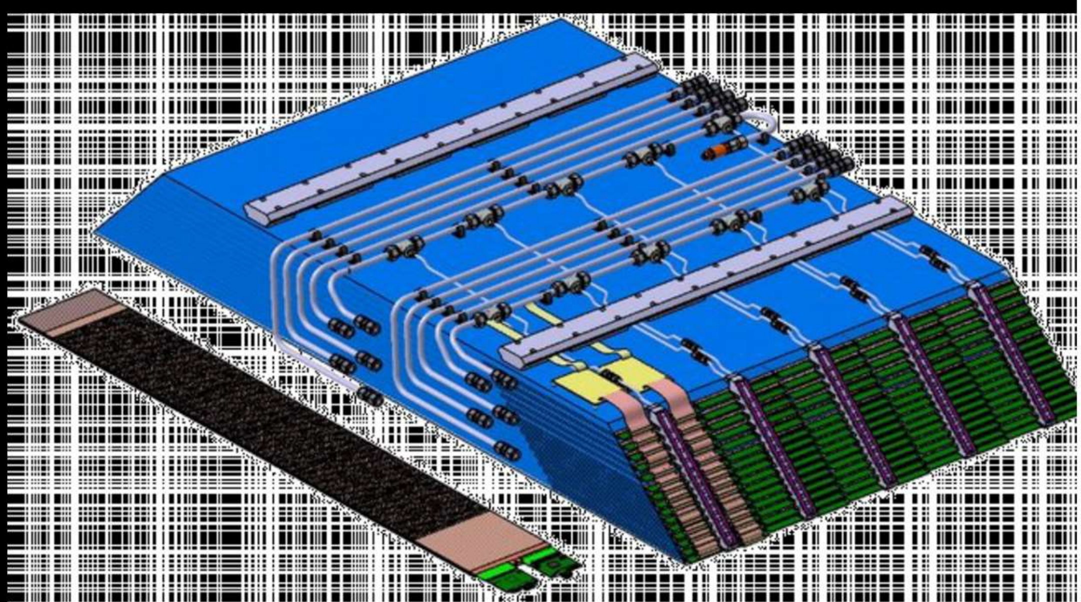
PF: EM Silicon

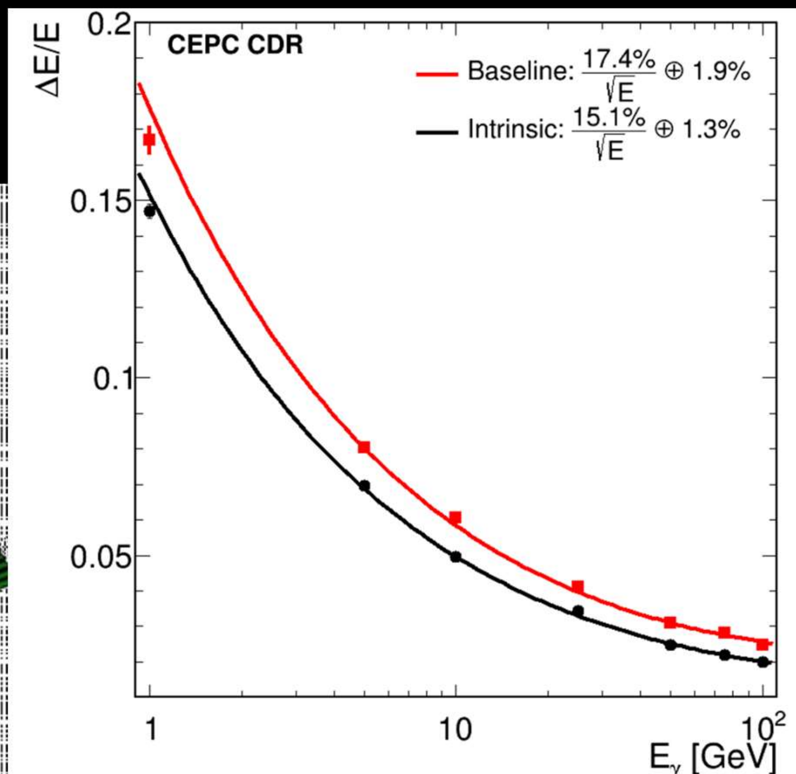
- Extensively studied for ILD → adopted for CMS upgrade
  - 30 layers W(2.1-4.2 mm)/(0.5 mm) Si → 84 mm total (24 X_0)
  - Cell size 10x10 mm^2 → ~ 24 M channels → 150 kW !!!
  - Readout chip ready SKIROC2



PF: EM Silicon

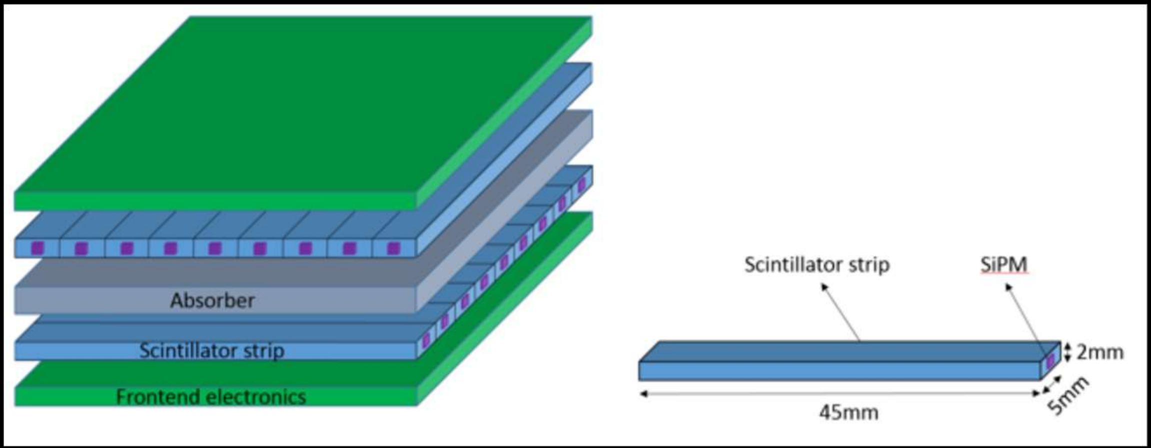
- ❖ Extensively studied for ILD → adopted for CMS upgrade
  - 30 layers W(2.1-4.2 mm)/(0.5 mm) Si → 84 mm total (24 X_0)
  - Cell size 10x10 mm^2 → ~ 24 M channels → 150 kW !!!
  - Readout chip ready SKIROC2
  - Performance 15%/sqrt(E)

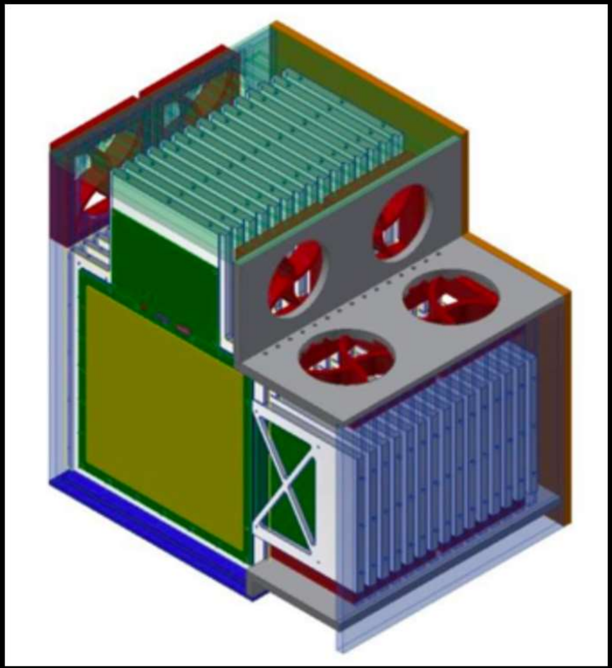


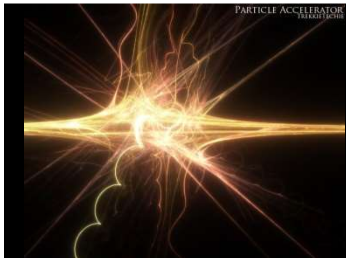


PF: EM Scintillator

- Replace Si with scintillator tiles readout by SiPM
  - Much cheaper → prototype in progress
  - 30 layers W(3 mm)/(2+2 mm) Sc.+board → total 24 X_0
  - Cell size 5x45 mm^2 – 11 M machine wrapped tiles
  - Readout chip ready SPIROC2e

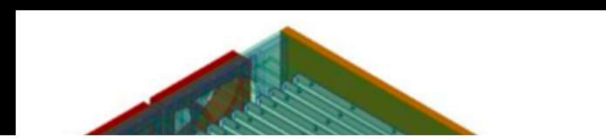


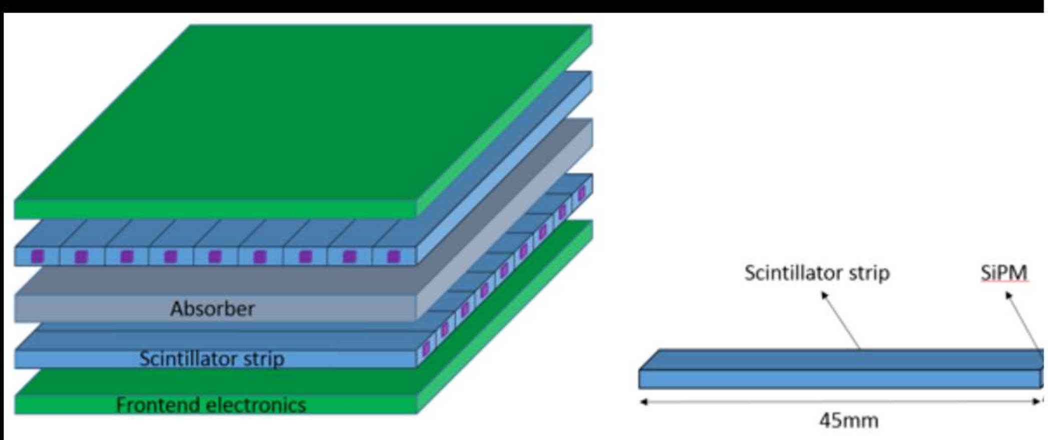


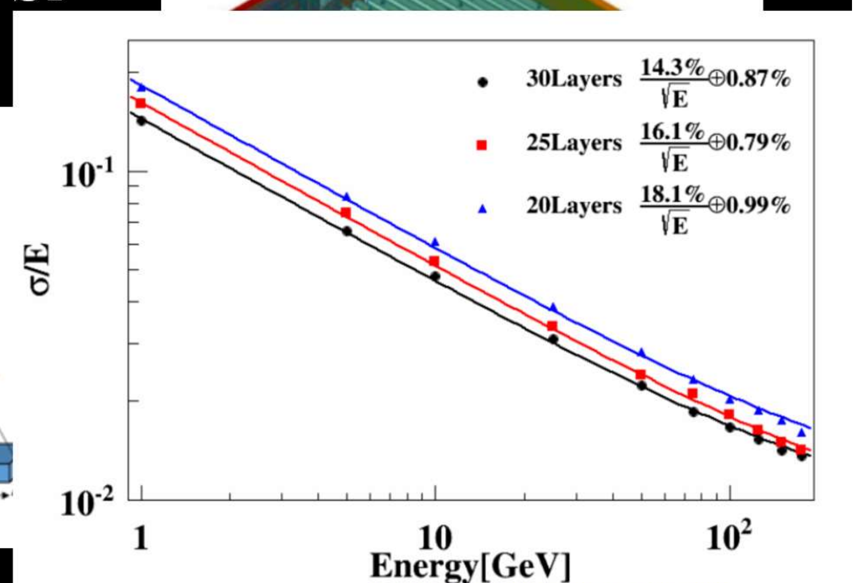


PF: EM Scintillator

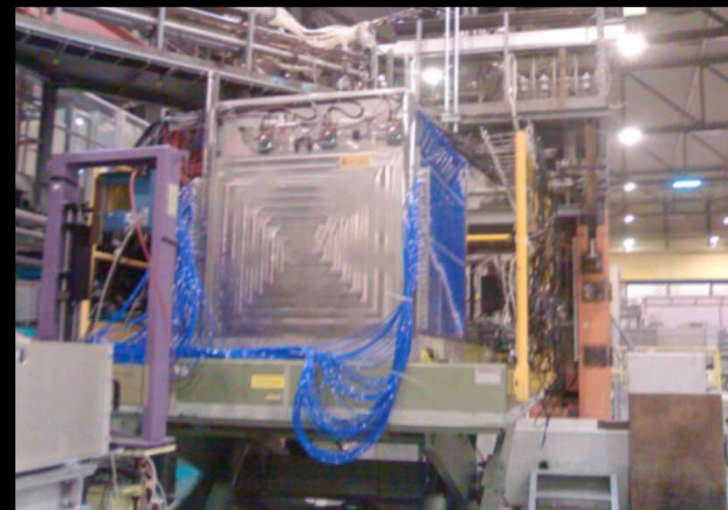
- Replace Si with scintillator tiles readout by SiPM
  - Much cheaper → prototype in progress
  - 30 layers W(3 mm)/(2+2 mm) Sc.+board → total 24 X_0
  - Cell size 5x45 mm^2 – 11 M machine wrapped tiles
  - Readout chip ready SPIROC2e
  - Expected performance better than Si
    - Concern about uniformity/stability



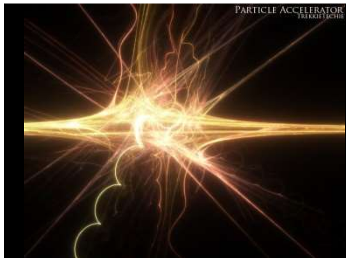




PF: HAD-RPC SDHCAL



- Prototype tested
  - 1x1x1.4 m^3
  - 48 layers/440k (1 cm x1 cm) pads
    - Scales to ~50 M pads
  - Power consumption 10μW/channel w/ power pulsing (ILC)
    - 10 μW/channel x 200 = 20 mW/channel w/o pulsing
    - 50 M x 20 mW = 1000 kW
  - ASIC: HARDROC (64 ch, 3 thresholds→semi-digital)
- Digital ThGEM version also considered



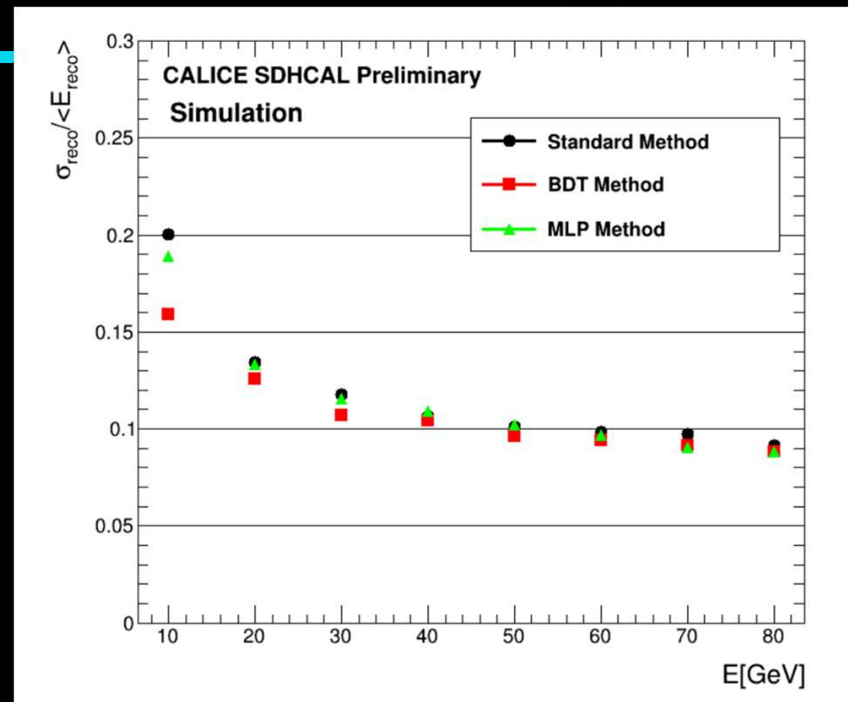
PF: HAD-RPC SDHCAL

Stainless steel Absorber(15mm)

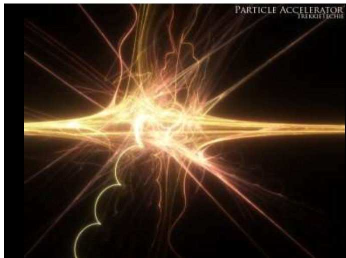
Stainless steel wall(2.5mm)

GRPC(6mm≈ $0\ \lambda_I, X_0$)

Stainless steel wall(2.5mm)



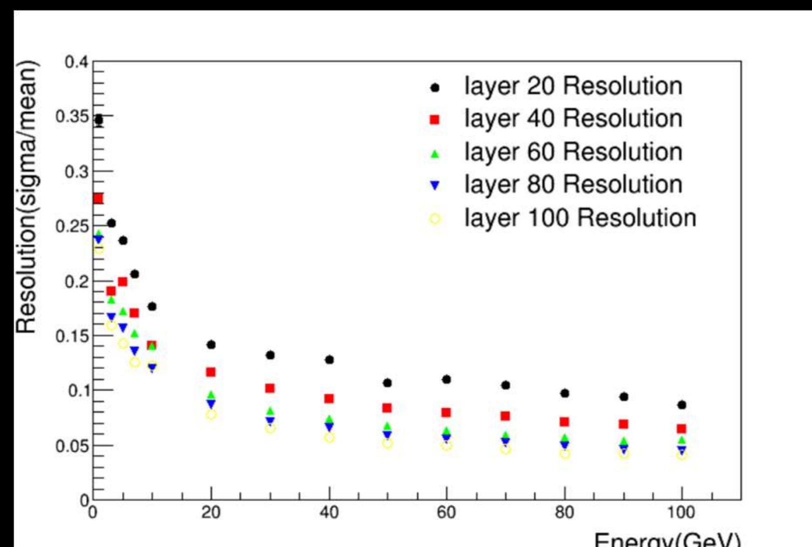
- ❖ Prototype tested
  - ➢ 1x1x1.4 m^3
  - ➢ 48 layers/440k (1 cm x1 cm) pads
    - Scales to ~50 M pads
  - ➢ Power consumption 10µW/channel w/ power pulsing (ILC)
    - 10 µW/channel x 200 = 20 mW/channel w/o pulsing
    - 50 M x 20 mW = 1000 kW
  - ➢ ASIC: HARDROC (64 ch, 3 thresholds→semi-digital)
- ❖ Digital ThGEM version also considered



PF: HAD Analog

- Scintillator with SiPM readout
  - Cell size 3x3 cm2 (other sizes tested)
  - Synergy with Scintillator ECAL
    - Readout electronics
    - Wrapping/gluing machines

- Prototype preparation
  - 0.5 m x 0,5 m x 35 layers

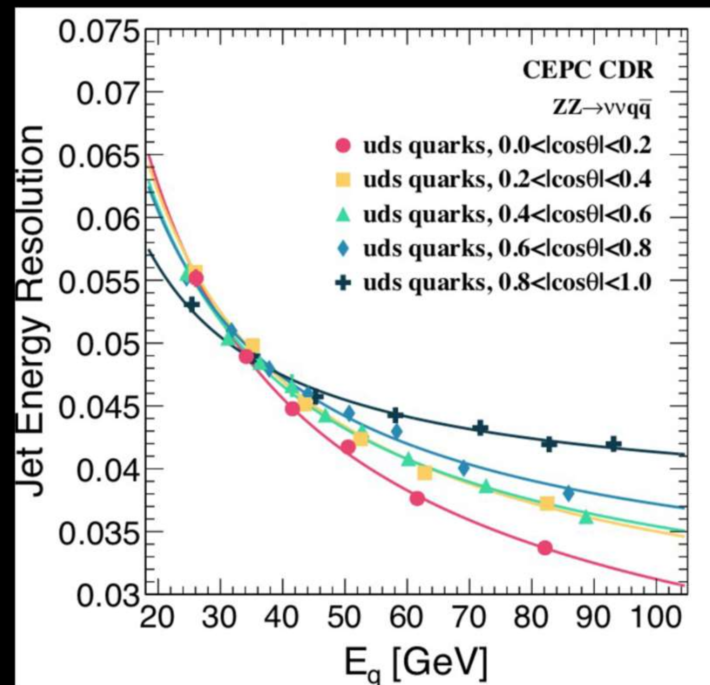


Basic PF issues

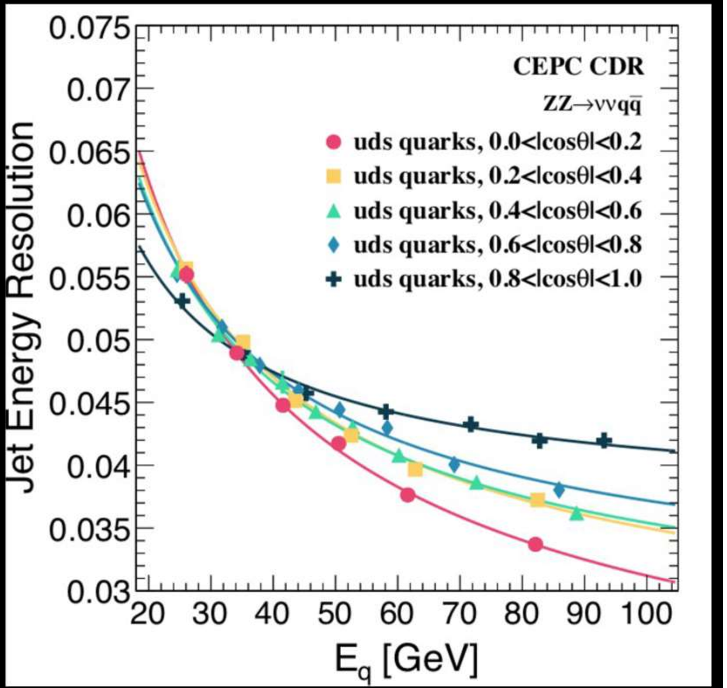
- Electronics and services over full volume
  - Cooling
  - Complexity/Access

Basic PF issues

- Electronics and services over full volume
  - Cooling
  - Complexity/Access
- Low intrinsic resolution
  - Especially for photons
  - Need integration with tracking for full performance



Basic PF issues



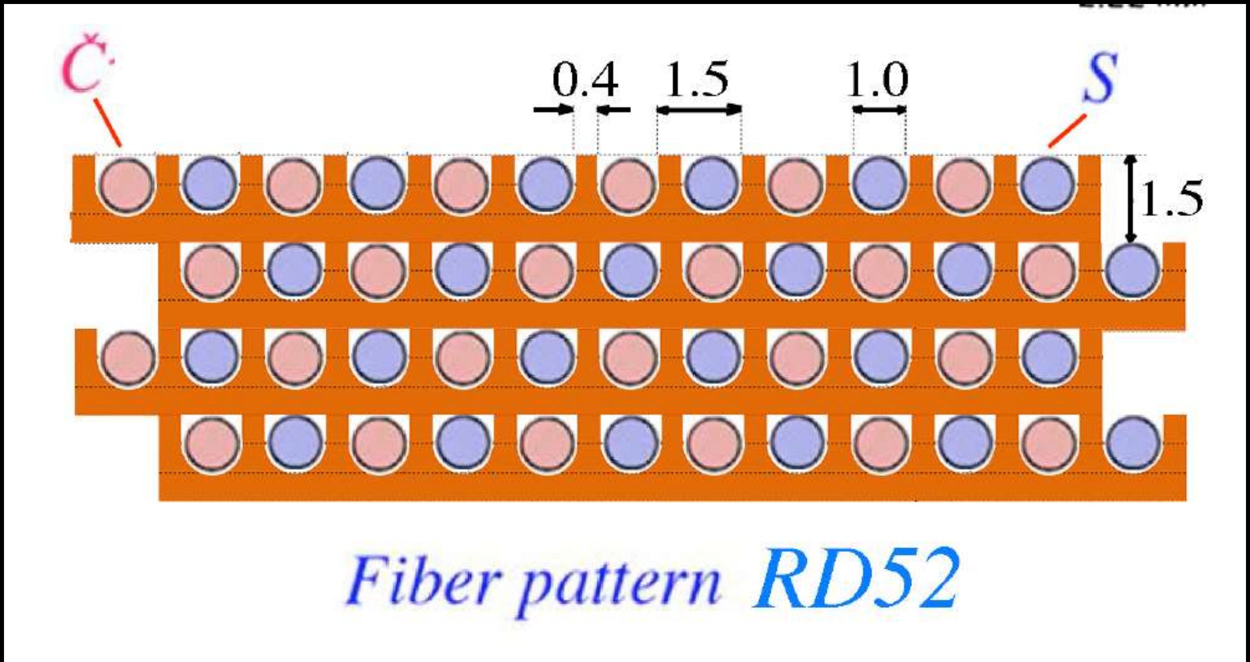
- Electronics and services over full volume
  - Cooling
  - Complexity/Access
- Low intrinsic resolution
  - Especially for photons
  - Need integration with tracking for full performance
- Do we really need to be inside the coil?
  - Sacrifice both calorimeter and tracking resolution
  - Better photons, but then resolution is not so great

Dual Readout calorimeter

- Dual Readout Calorimeters main features
  - Designed to optimize EM, hadronic and jet resolution
    - Large sampling fraction for good EM resolution
    - Event by event correction for EM fluctuations in showers and jets
  - Intrinsic transverse granularity up to 2 mm
  - Potential for longitudinal segmentation with timing or specific fiber geometries
  - All electronics in the back simplifies cooling and access

DR: Basic configuration

- Alternate clear and scintillating fibers in metal matrix
- Scintillating fibers sensitive to all charged particles
- Clear fibers sense only Cherenkov light
  - Mostly electrons and positrons



DR: Working principle

- Measure simultaneously:
  - Scintillation signal (S)
  - Cherenkov signal (Q)
- Calibrate both signals with e-
- Unfold event by event f_{em} to obtain corrected energy

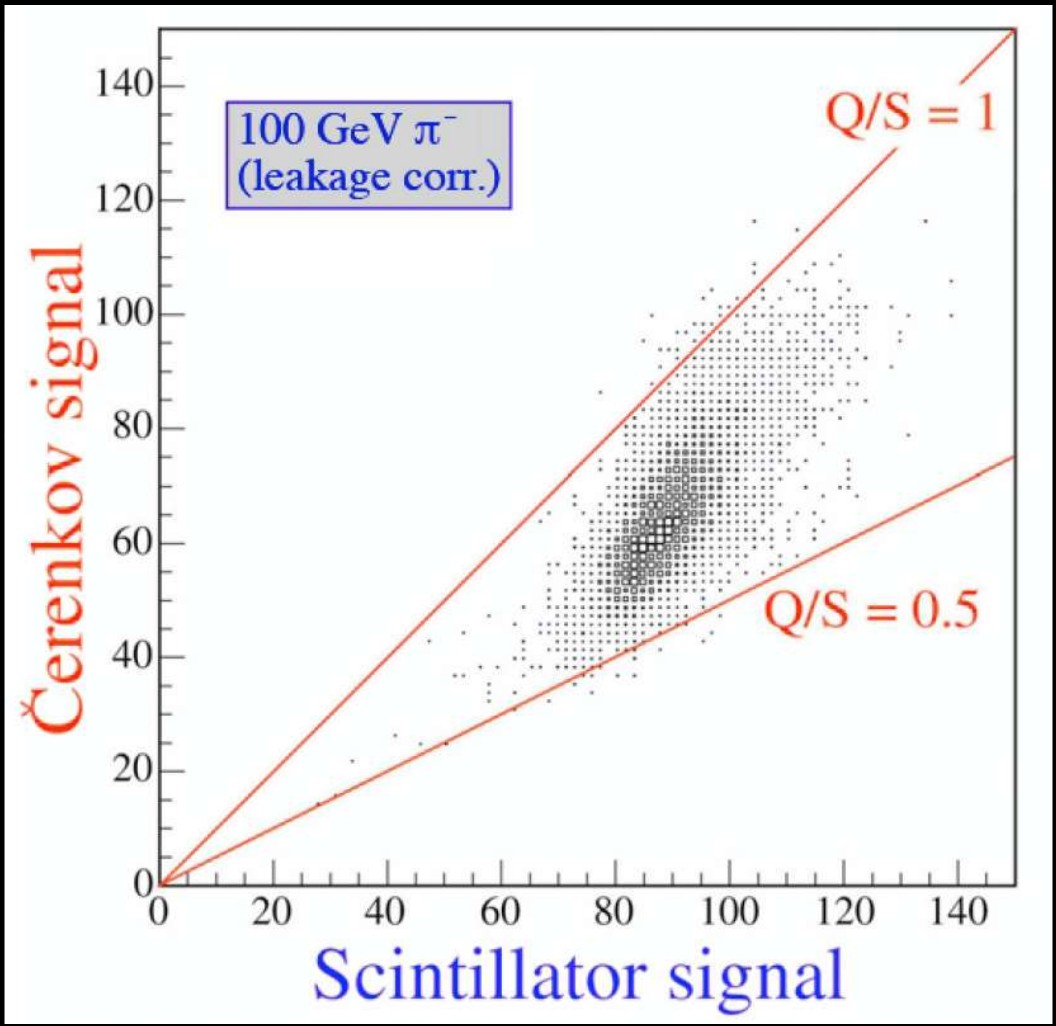
$$S = E\left[f_{\rm em} + \frac{1}{(e/h)_S}(1 - f_{\rm em})\right]$$

$$Q = E\left[f_{\rm em} + \frac{1}{(e/h)_Q}(1 - f_{\rm em})\right]$$

$$E = \frac{S - \chi Q}{1 - \chi}$$

with $\chi = \frac{1-(h/e)_S}{1-(h/e)_Q} \sim 0.3$

DR: Working principle



$$S = E\left[f_{em} + \frac{1}{(e/h)_S}(1 - f_{em})\right]$$

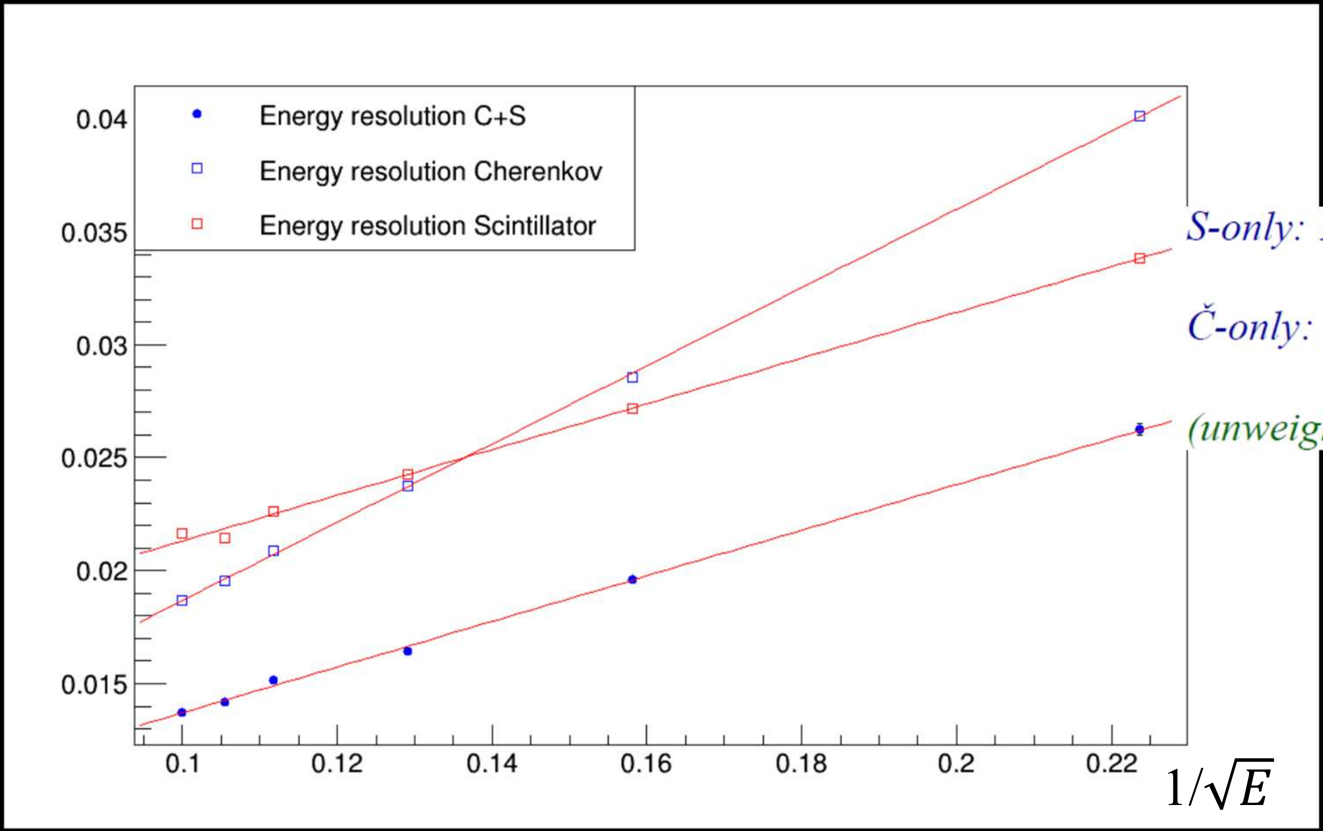
$$Q = E\left[f_{em} + \frac{1}{(e/h)_Q}(1 - f_{em})\right]$$

$$E = \frac{S - \chi Q}{1 - \chi}$$

with $\chi = \frac{1 - (h/e)_S}{1 - (h/e)_Q} \sim 0.3$

DR: Performance EM

- Use test beam data to tune simulation
- Use simulation to correct for lateral leakage



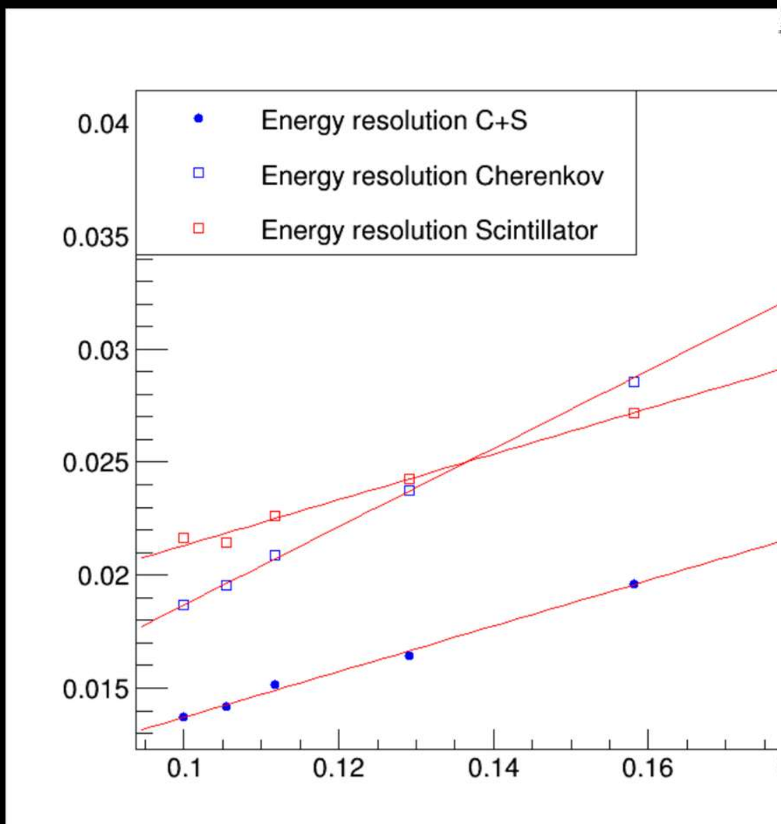
S-only: 10.5/√E+1.1 (%)

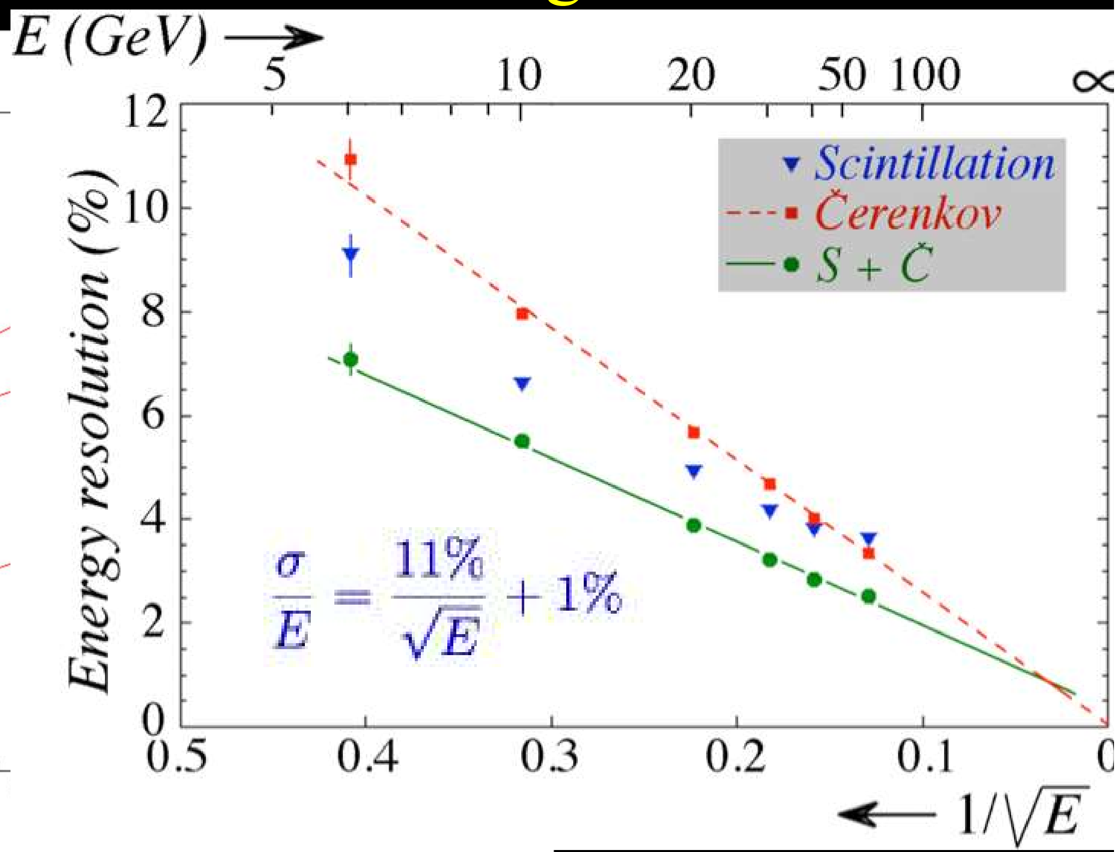
Č-only: 17.9/√E (%)

(unweighted) average: 10.3/√E+0.3 (%)

DR: Performance EM

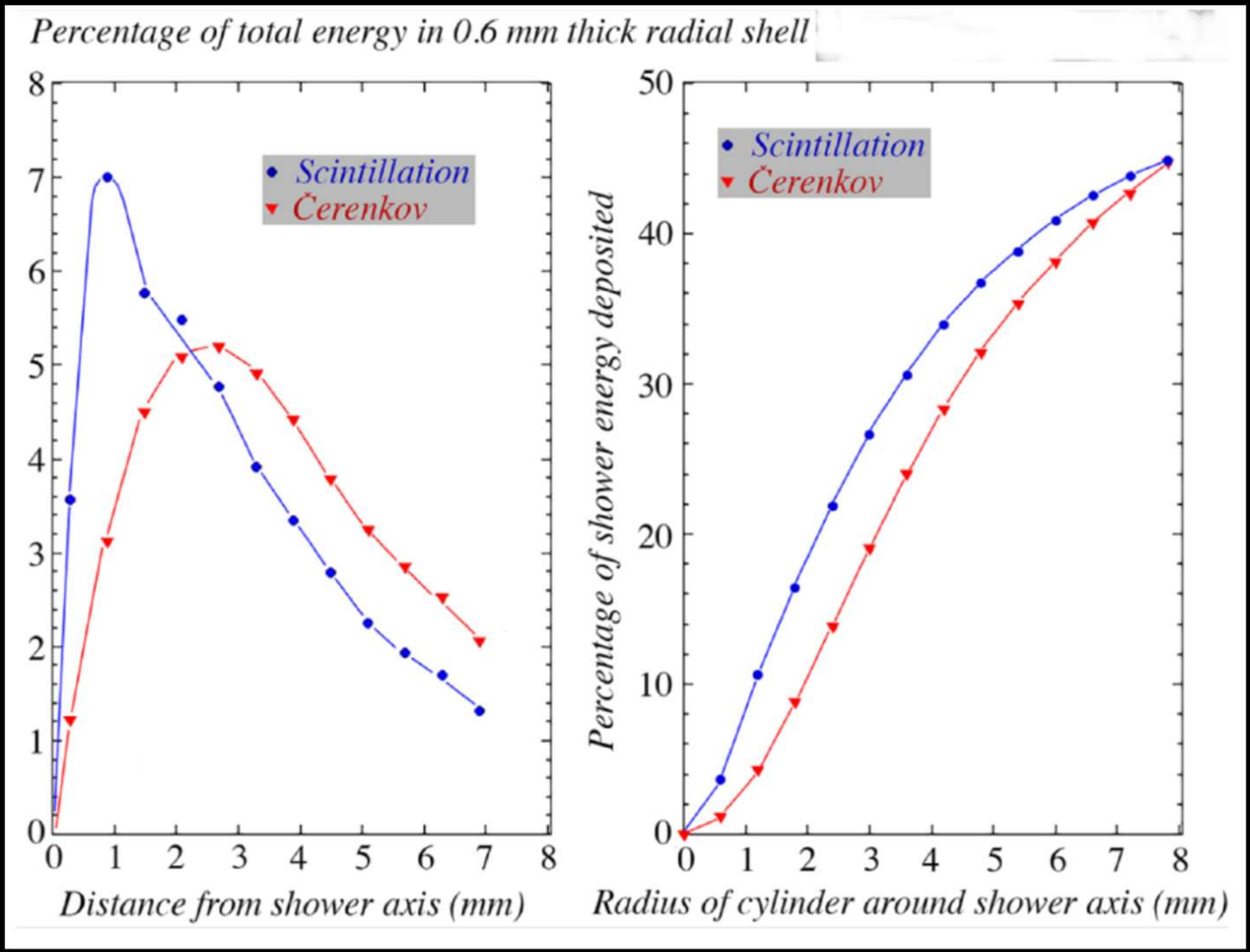
- Use test beam data to tune simulation
- Use simulation to correct for lateral leakage

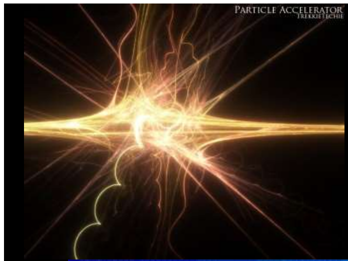




DR: Radial shower profile

- Test beam data

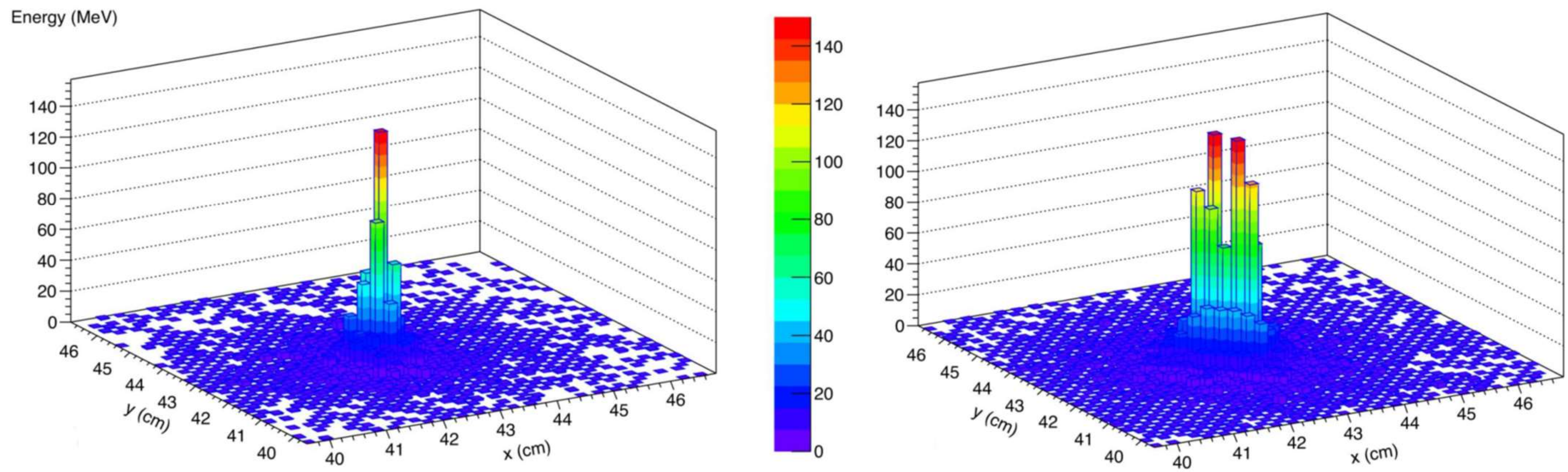




DR: Radial shower profile

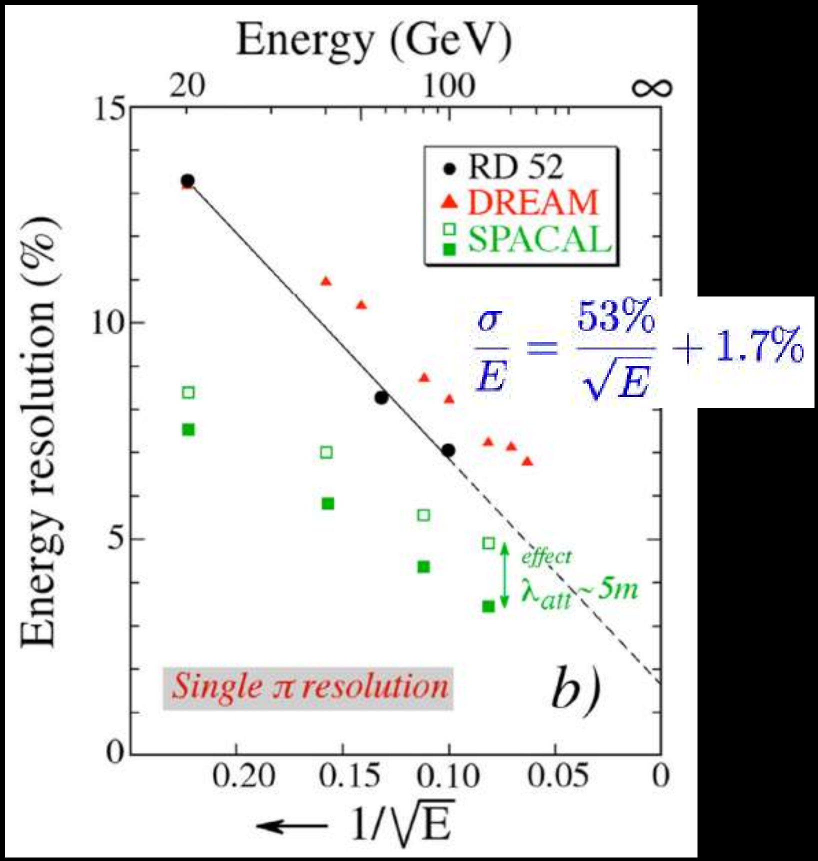
- Test beam tuned simulation

50 GeV electrons **100 GeV π^0**



DR: Performance HAD

❖ Use test beam data to tune simulation



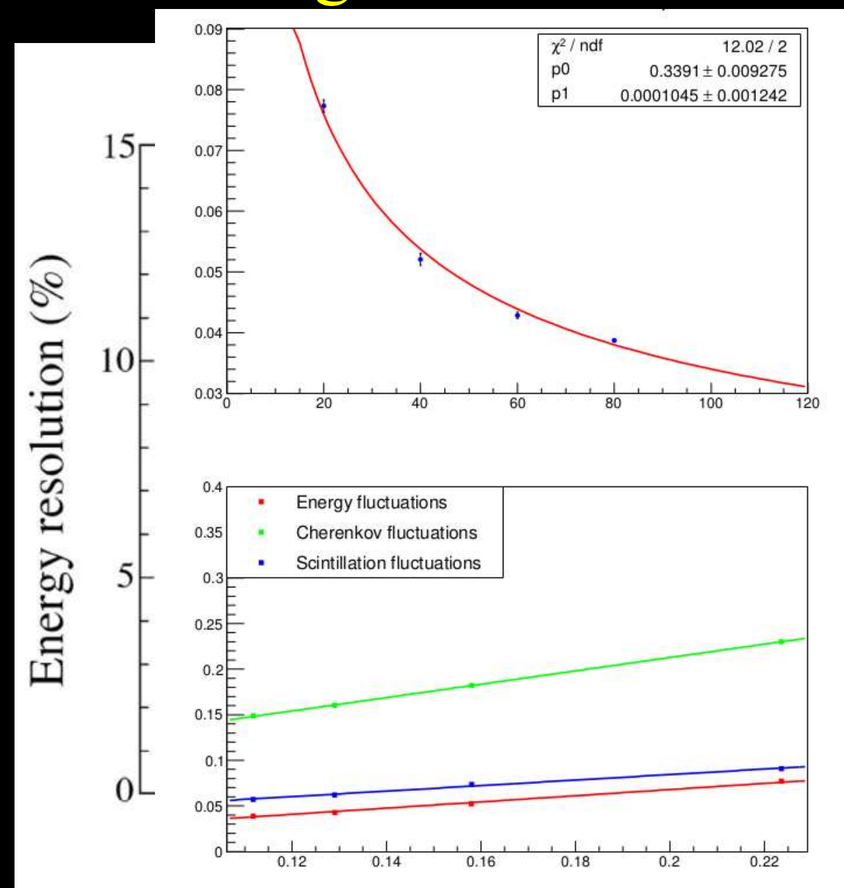
DR: Performance HAD

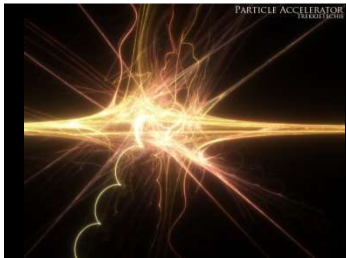
- Use test beam data to tune simulation
- Use simulation to correct for lateral leakage

$\check{C}: \sim 73/\sqrt{E} + 6.6\ (\%)$

$S: \sim 30/\sqrt{E} + 2.4\ (\%)$

$DR: \sim 34/\sqrt{E}\ (\%)$





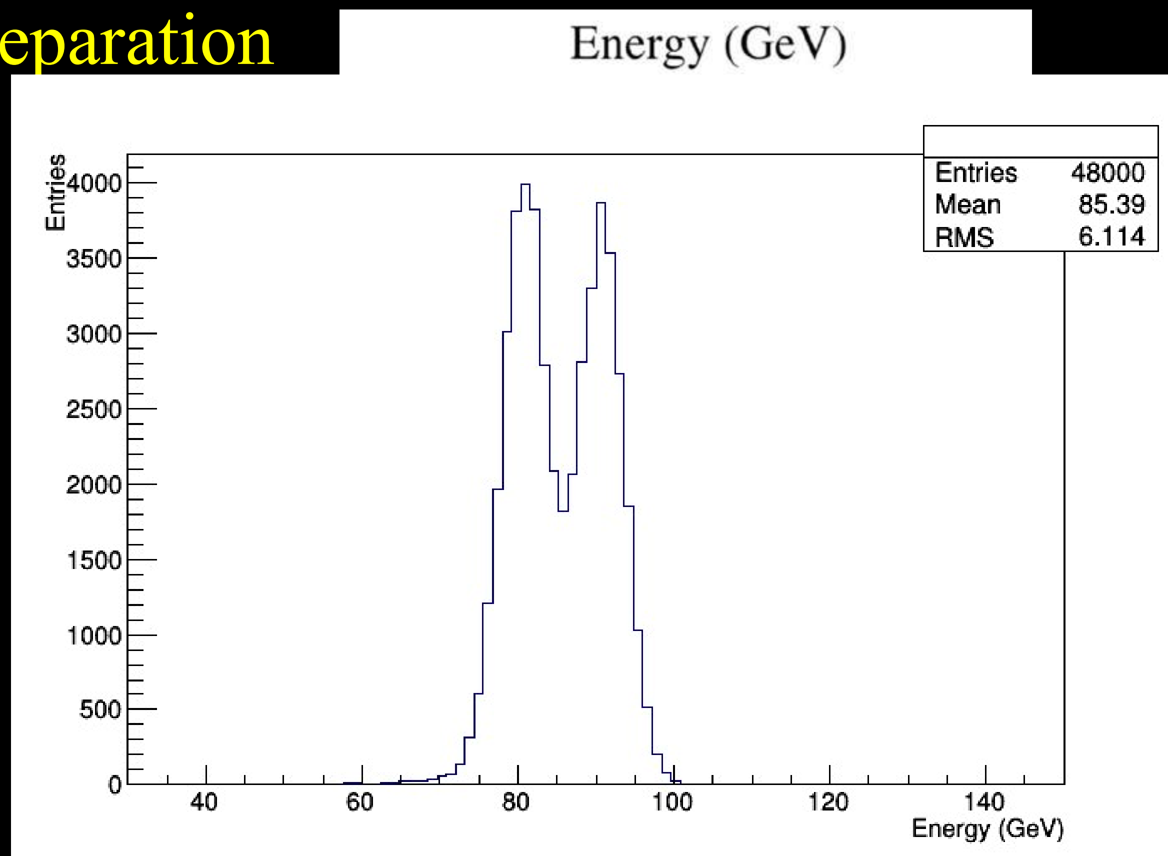
DR: Performance HAD

- Use test beam data to tune simulation
- Use simulation to correct for lateral leakage
- 81 and 91 GeV jet separation

$\check{C}$: $\sim 73/\sqrt{E} + 6.6\ (\%)$

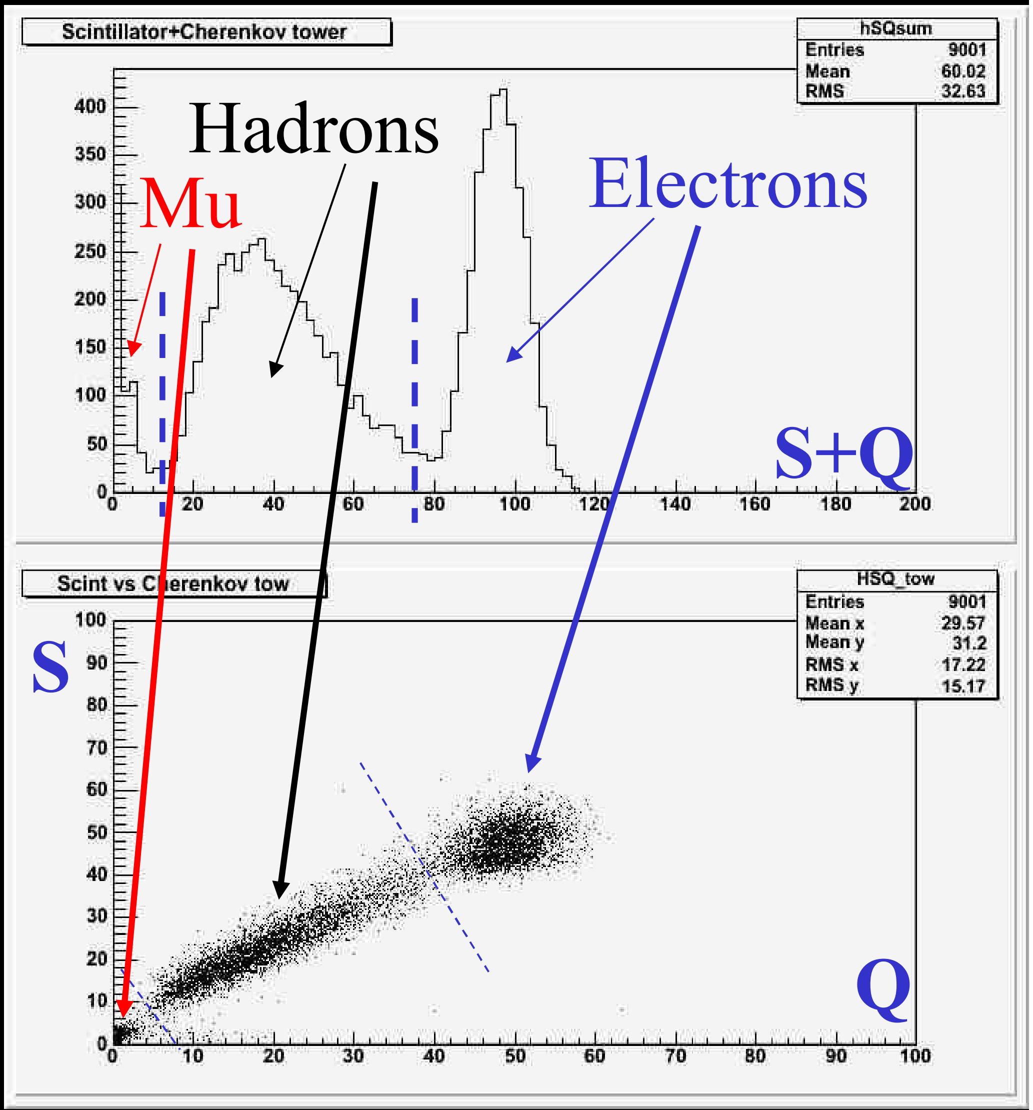
S: $\sim 30/\sqrt{E} + 2.4\ (\%)$

DR: $\sim 34/\sqrt{E}\ (\%)$



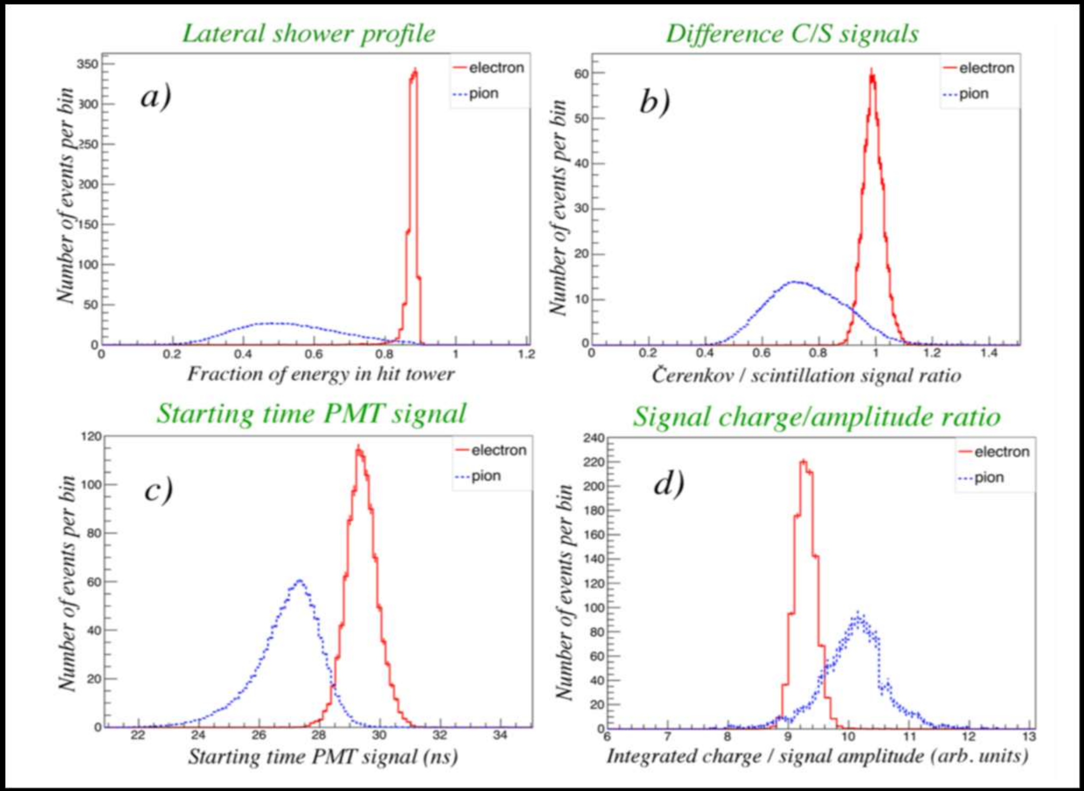
DR: Particle ID

❖ Test beam



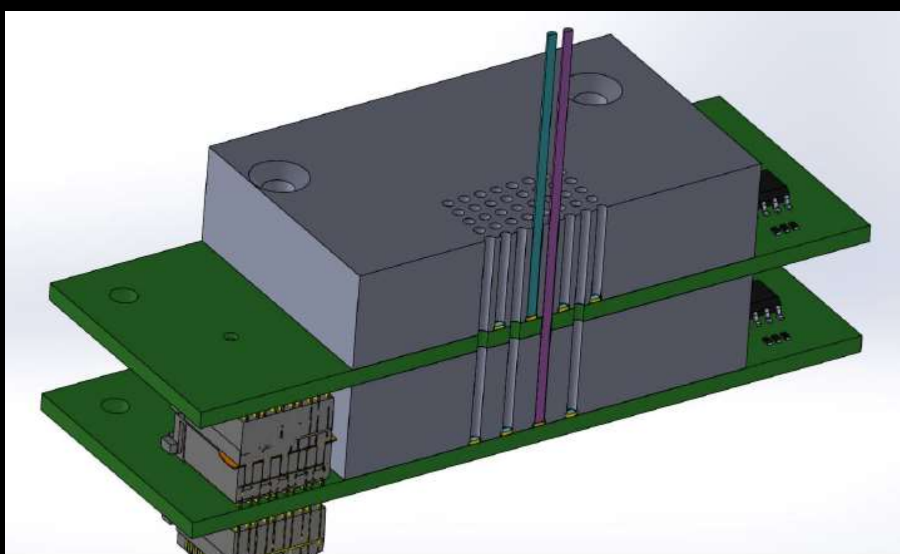
DR: Particle ID

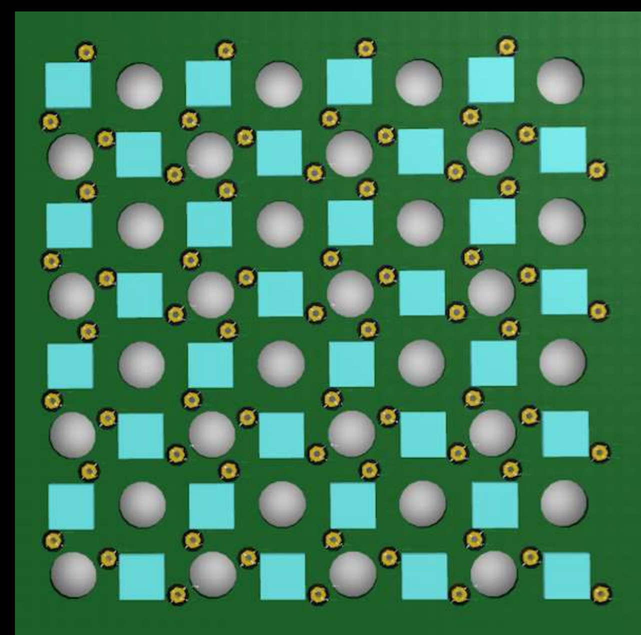
- Test beam
- 80 GeV electron pion separation
  - Rejection power 600 @ 98% efficiency



DR: Readout

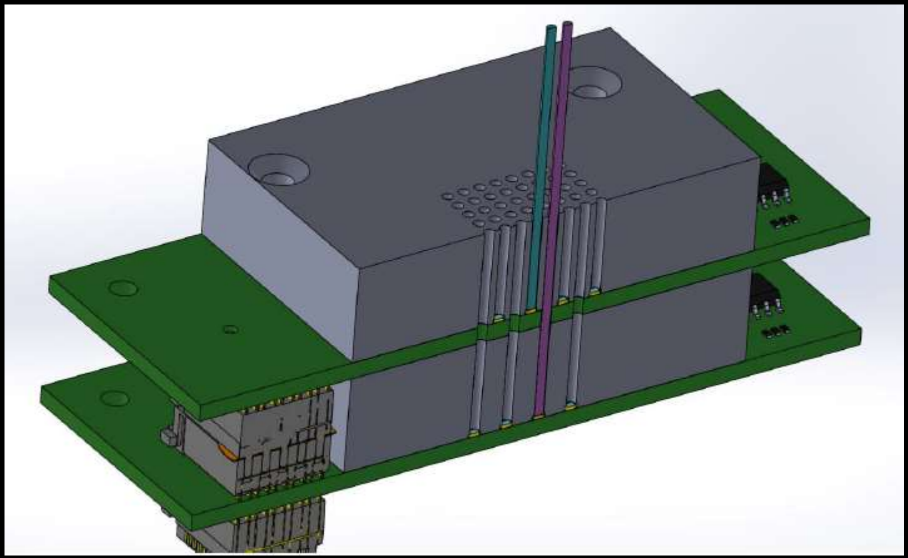
- Dual layer SiPM readout
  - Avoids optical cross-talk
- Saturation studied with dedicated test beams
  - 25 μm pixels OK for Cherenkov
  - Need 10 μm or filter for Scintillator

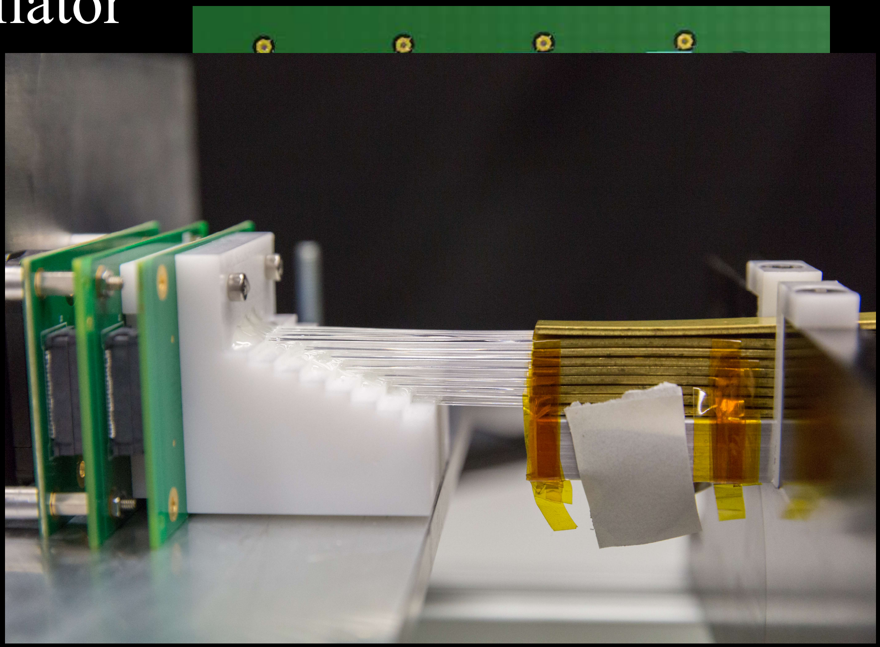




DR: Readout

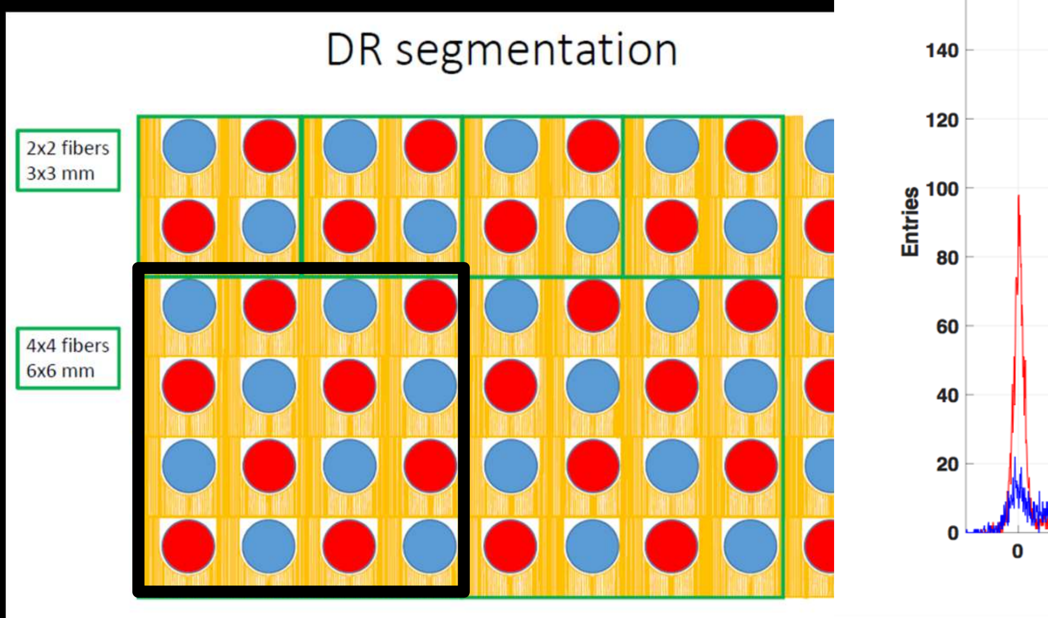
- Dual layer SiPM readout
  - Avoids optical cross-talk
- Saturation studied with dedicated test beams
  - 25 µm pixels OK for Cherenkov
  - Need 10 µm or filter for Scintillator

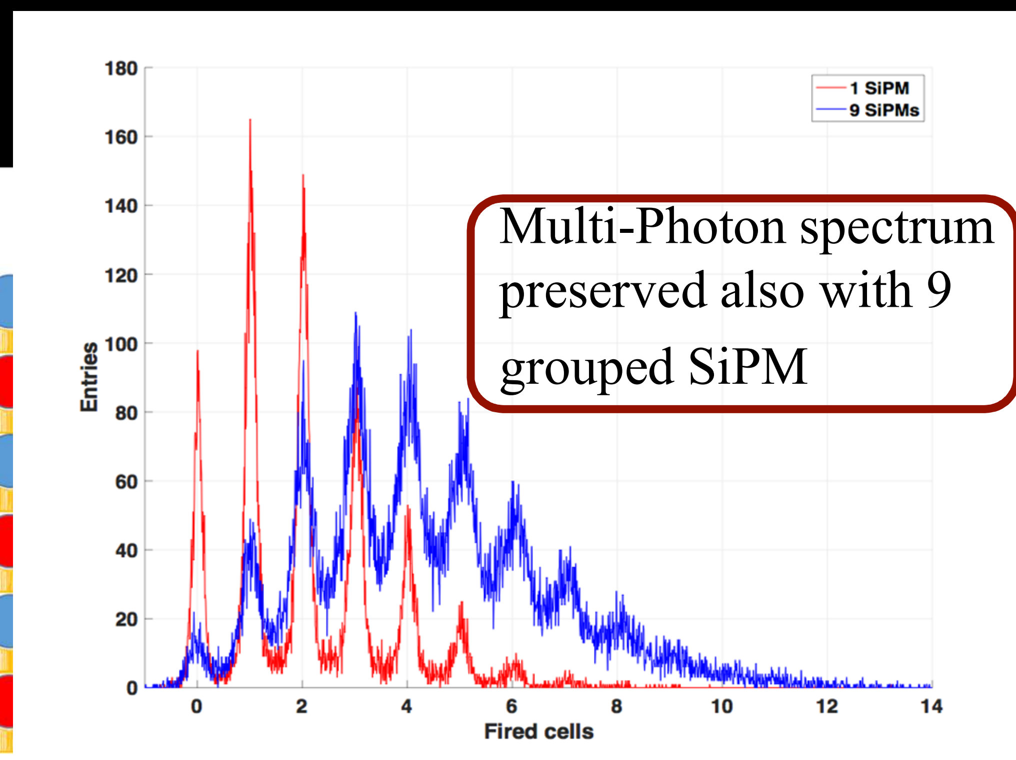


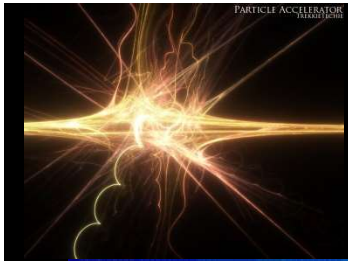


DR: Readout

- Group SiPM to reduce numbers of channels
  - 8 fibers/channel → 5.6 mm granularity
    - 130×10^6 fibers → 16×10^6 channels

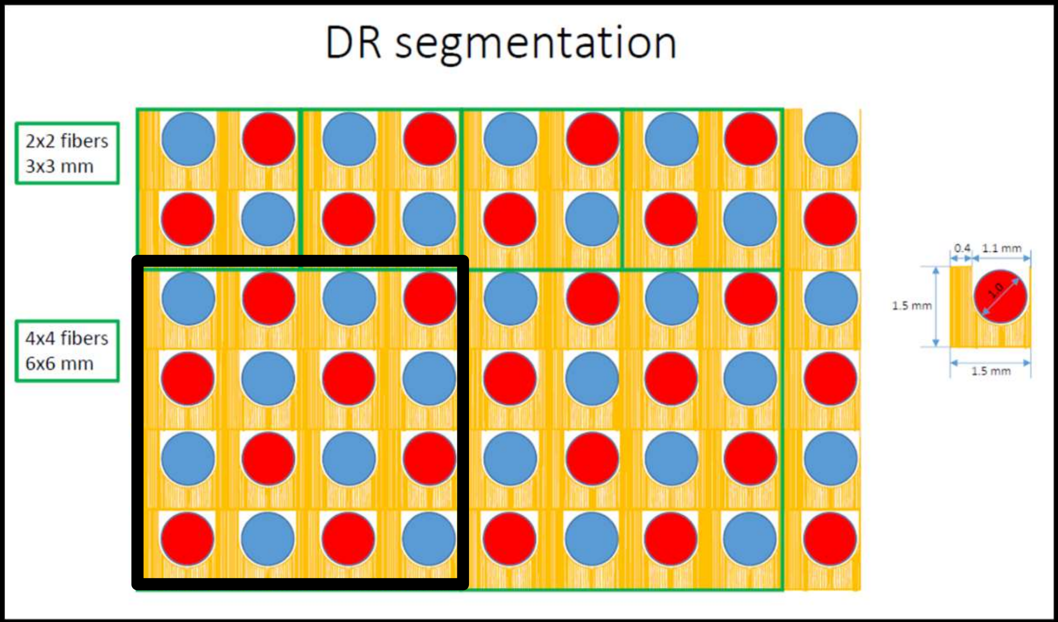






DR: Readout

- Group SiPM to reduce numbers of channels
  - 8 fibers/channel → 5.6 mm granularity
    - 130×10^6 fibers → 16×10^6 channels
  - Parallel to serial readout ASIC under study (/64)
    - 16×10^6 channels → 2.5×10^5 serial lines

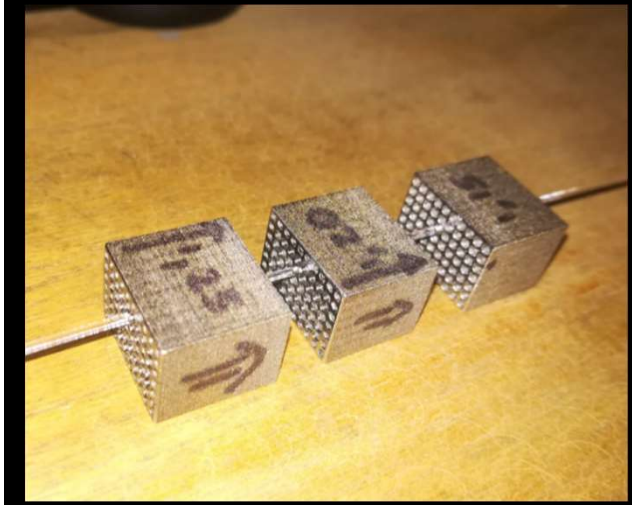


DR: R&D in progress

- Mechanical structure studies

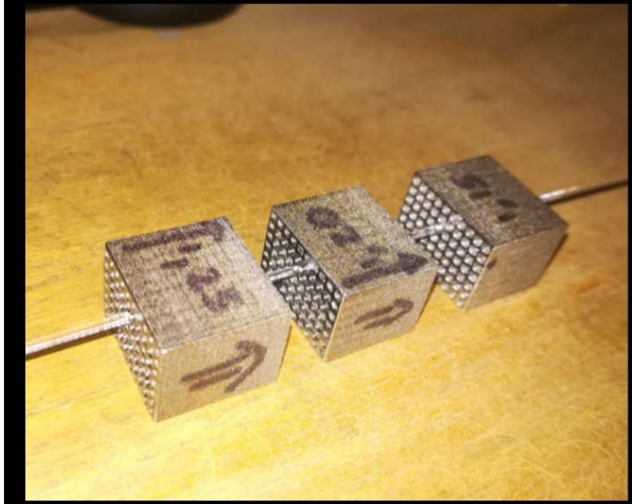
DR: R&D in progress

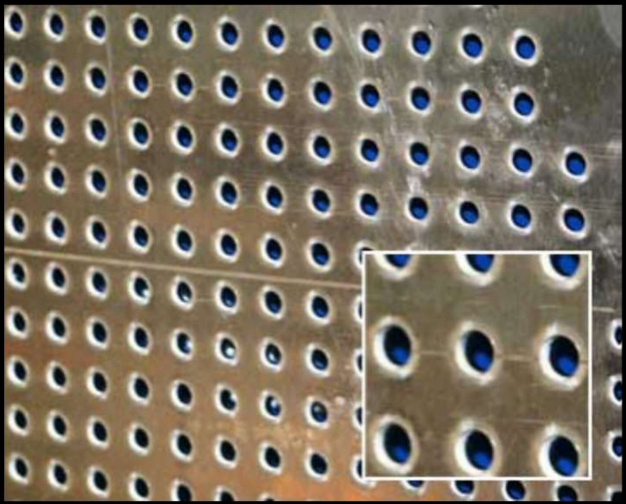
- Mechanical structure studies
  - 3D print (expensive!)



DR: R&D in progress

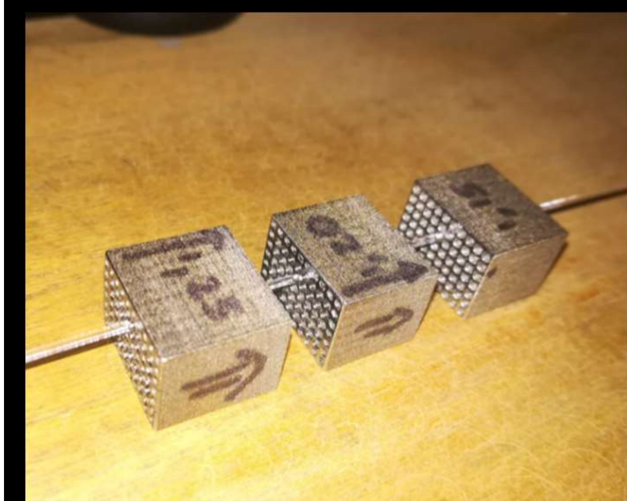
- Mechanical structure studies
  - 3D print (expensive!)
  - Sheet punching/stacking

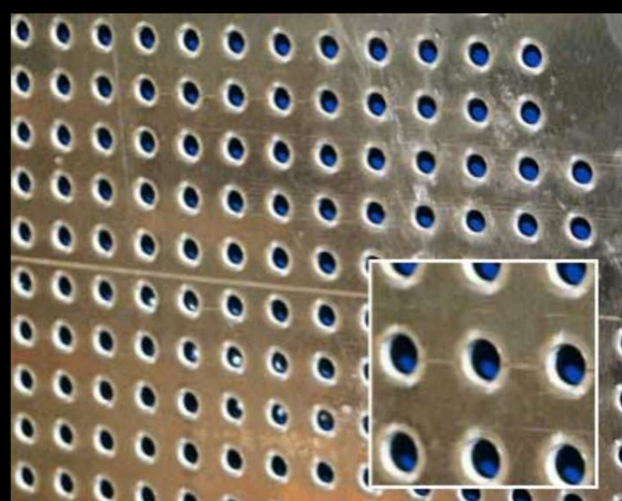


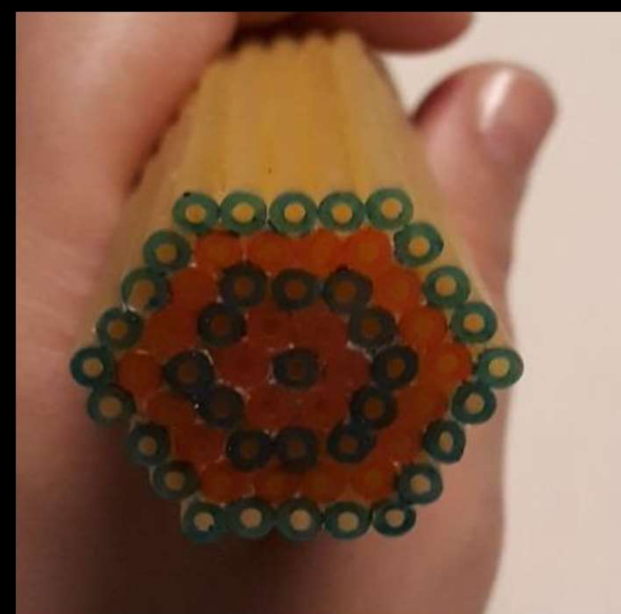


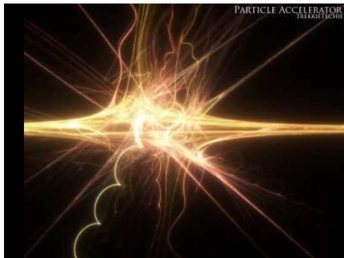
DR: R&D in progress

- Mechanical structure studies
  - 3D print (expensive!)
  - Sheet punching/stacking
  - Capillary tube assembly
    - Building 10 x 10 cm x 1 m prototype



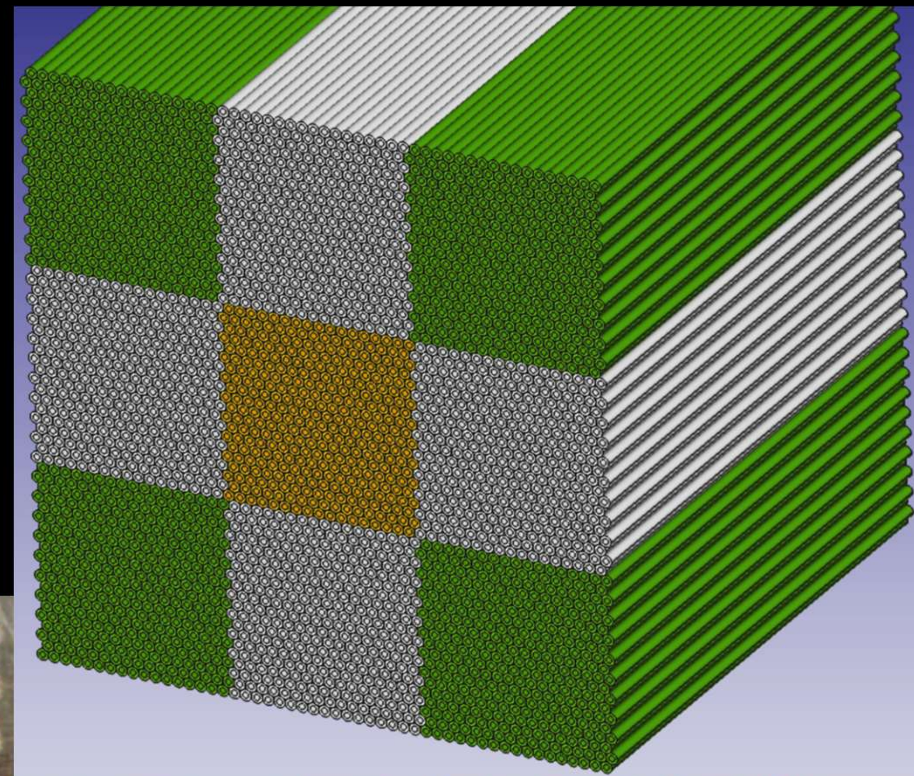


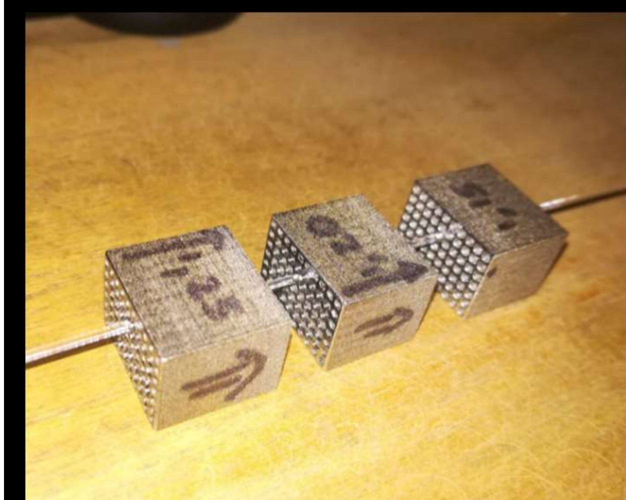


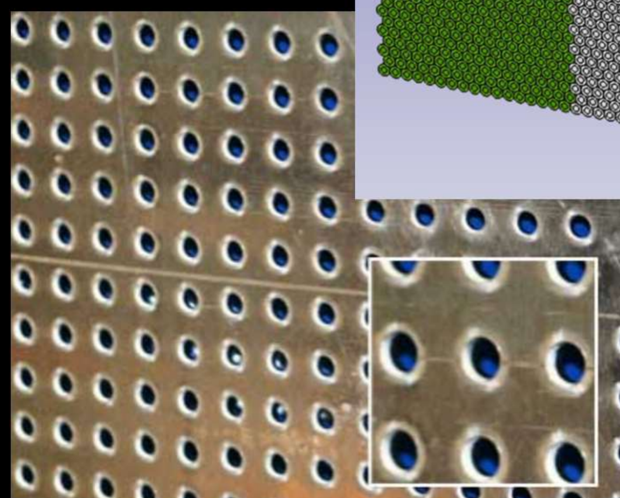


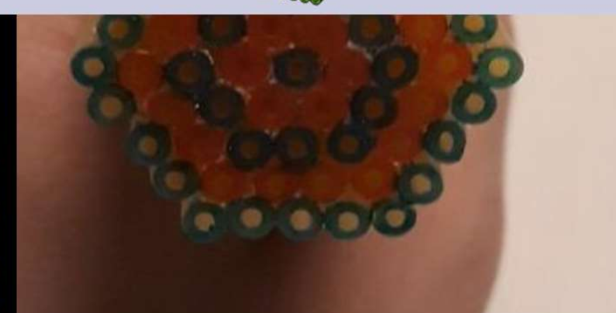
DR: R&D in progress

- Mechanical structure studies
  - 3D print (expensive!)
  - Sheet punching/stacking
  - Capillary tube assembly
    - Building 10 x 10 cm x 1 m prototype



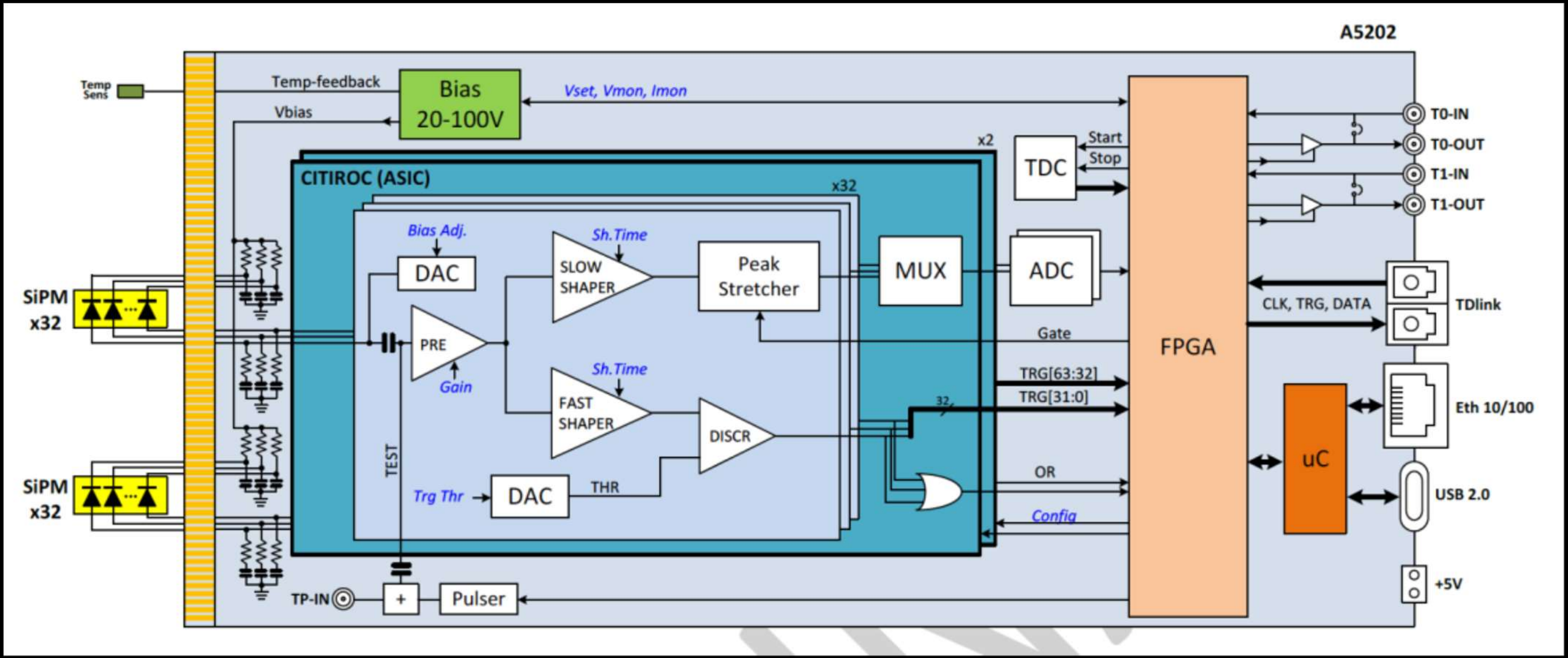


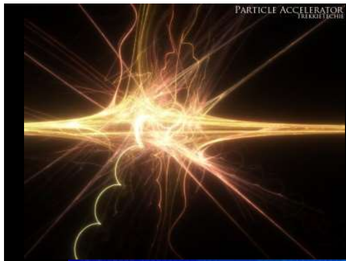




DR: R&D in progress

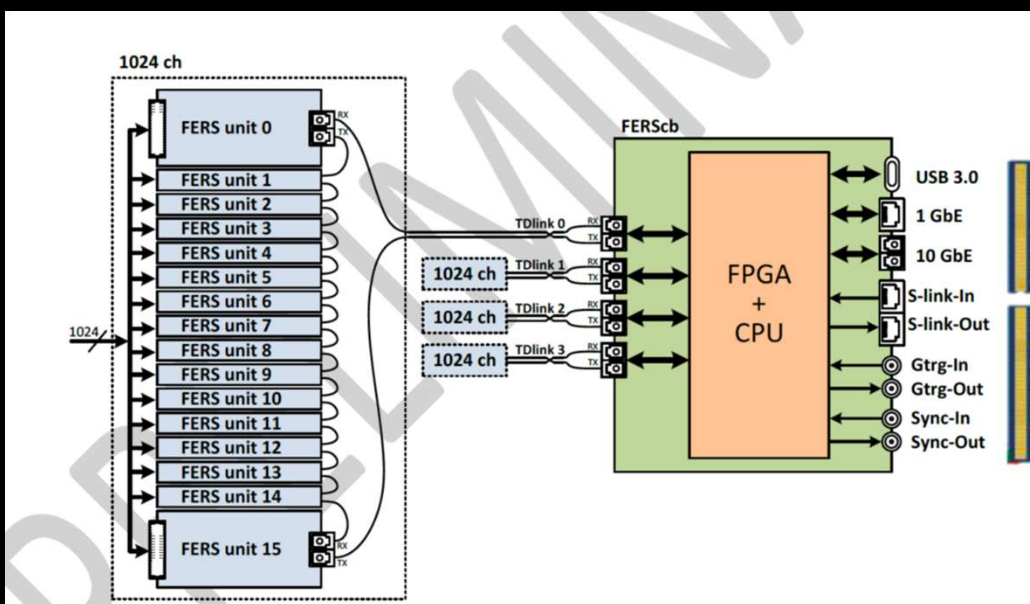
- Readout with new CAEN FERS system
  - Based on citiroc 1A (Includes TDC)

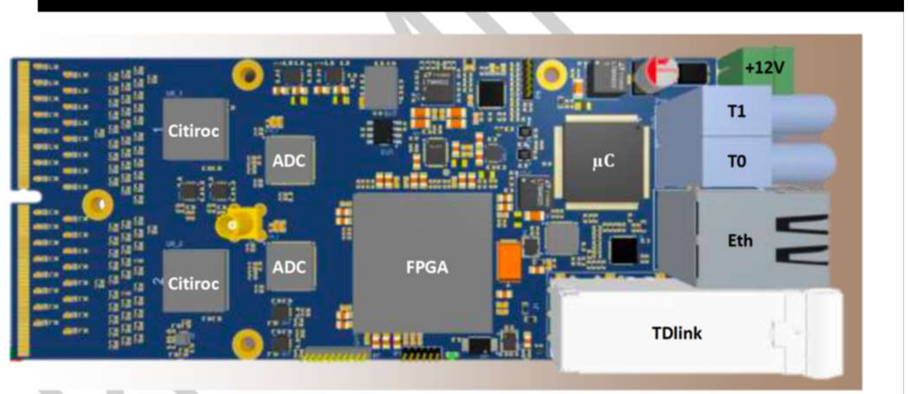




DR: R&D in progress

- Readout with new CAEN FERS system
  - Based on citiroc 1A (Includes TDC)
    - 64 ch/board → 4096 ch/controller
    - INFN is Alpha-tester





Summary

- Many PF and DR options in progress
  - All seem to match requirements for CepC

Summary

- Many PF and DR options in progress
  - All seem to match requirements for CepC
- Much R&D still needed
  - Full size prototypes
  - Scaling to full detector systems
  - Construction industrialization
  - Cost reductions