A detector concept for circular e+e- colliders

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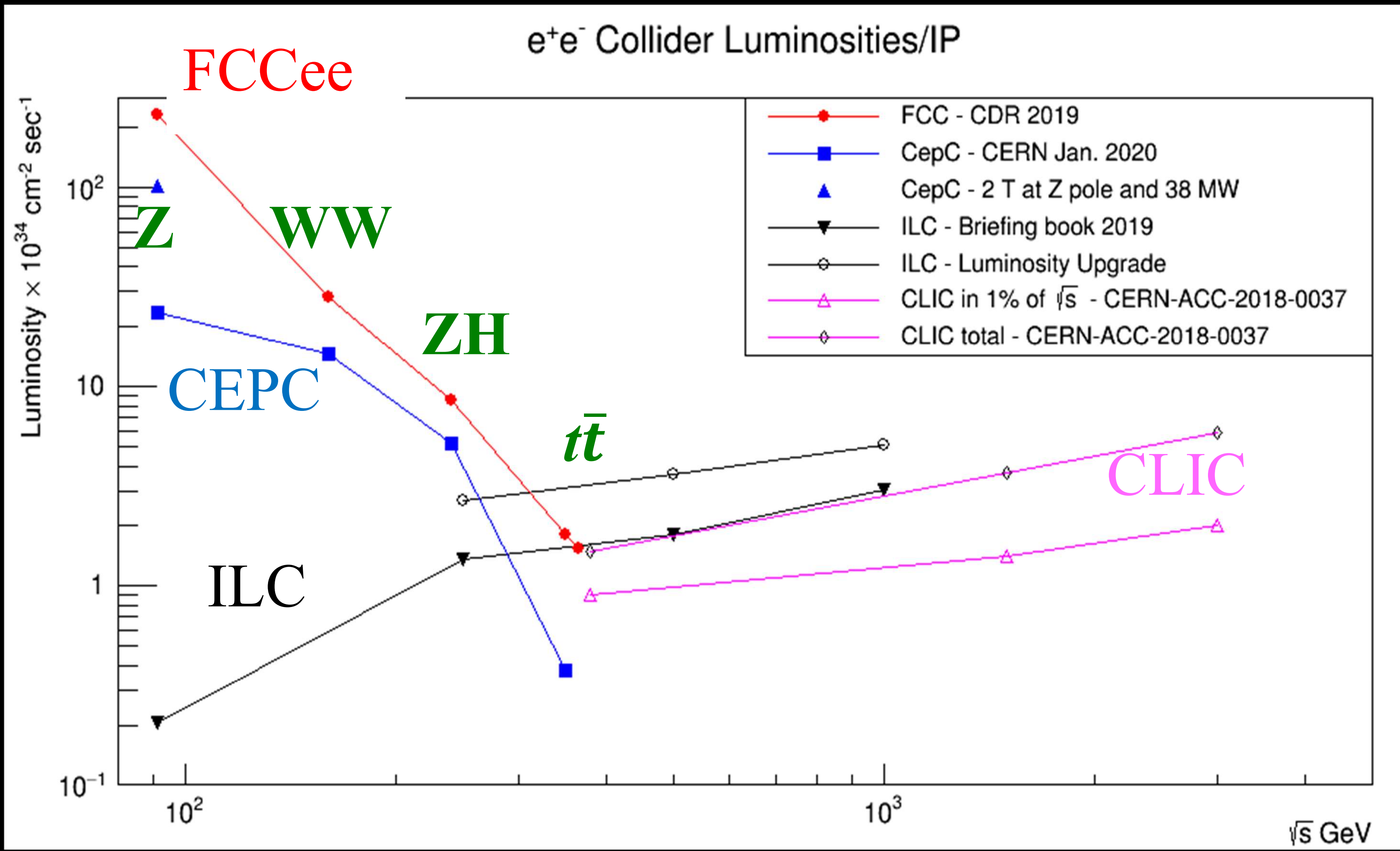
Snowmass,EF04

March 12th, 2021

OUTLINE

- Circular vs. linear
- The IDEA detector
- Design guidelines
- Ongoing R&D
- Concluding comments

Luminosity comparison



Physics/detector implications

- Physics at circular wrt linear
  - Much more interest in EWK at Z pole/WW
  - HF physics at Z pole comparable with LHCb upgrade/BelleII

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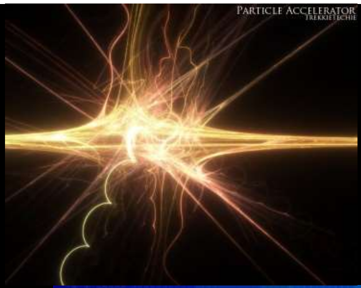
- Detector at circular wrt linear
  - Design for lower energies - 365 GeV CoM energy maximum
    - Lower momentum → higher transparency
  - High control of acceptances to match EWK statistical error
    - Silicon wrapper/pre-shower
  - PID needed for HF
  - π^0 for HF and τ



Detector requirements

- **Requirements:**
  - Constraints from physics (similar to LC …. more or less)

Physics process	Measurands	Detector subsystem	Performance requirement
$ZH, Z \to e^+e^-, \mu^+\mu^-$ $H \to \mu^+\mu^-$	$m_H, \sigma(ZH)$ $\mathrm{BR}(H \to \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) =$ $2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$
$H \to b\bar{b}/c\bar{c}/gg$	$\mathrm{BR}(H \to b\bar{b}/c\bar{c}/gg)$	Vertex	$\sigma_{r\phi} =$ $5 \oplus \frac{10}{p(\mathrm{GeV}) \times \sin^{3/2}\theta} (\mu\mathrm{m})$
$H \to q\bar{q}, WW^*, ZZ^*$	$\mathrm{BR}(H \to q\bar{q}, WW^*, ZZ^*)$	ECAL HCAL	$\sigma_E^{\mathrm{jet}}/E =$ $3 \sim 4\%$ at 100 GeV
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\Delta E/E =$ $\frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$

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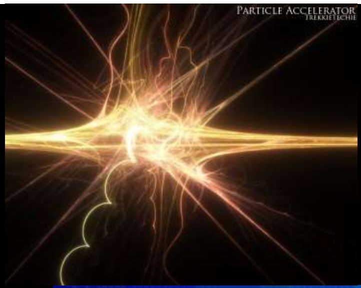

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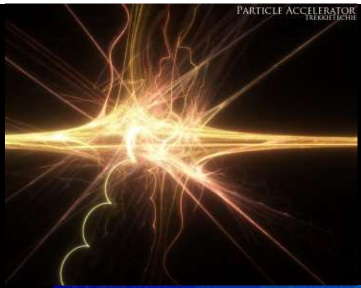

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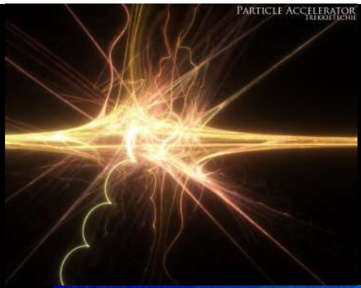

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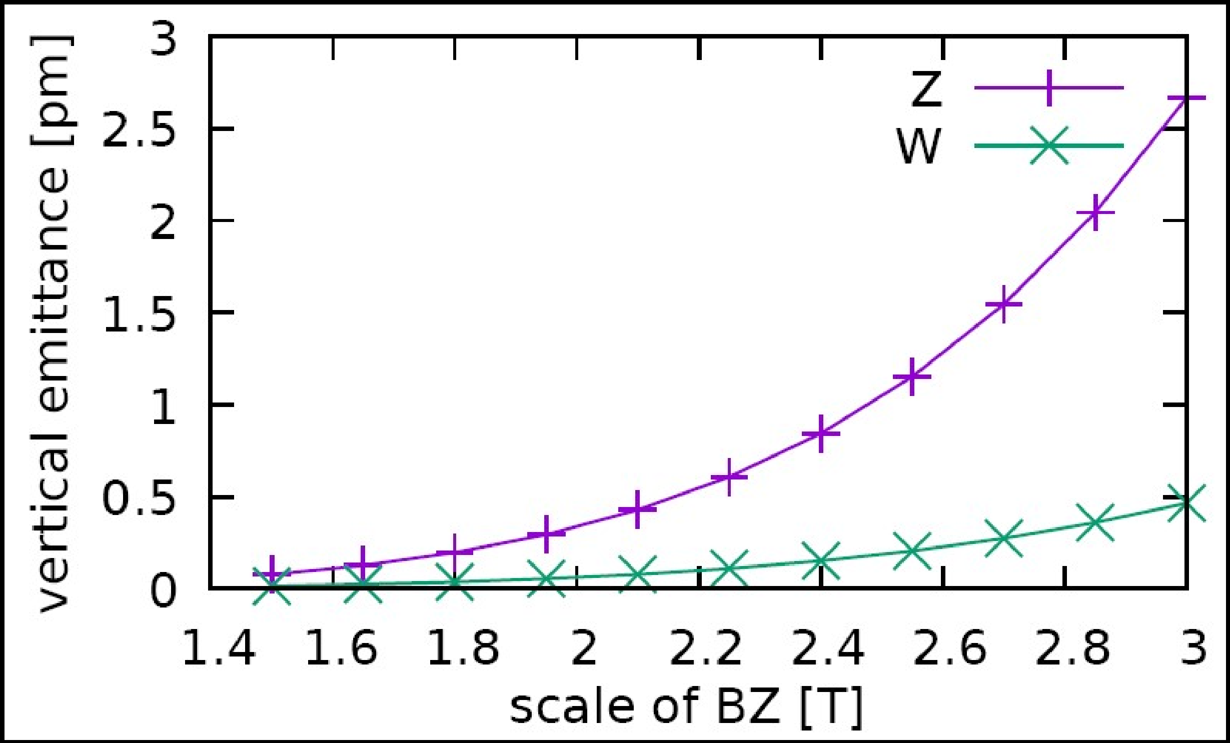
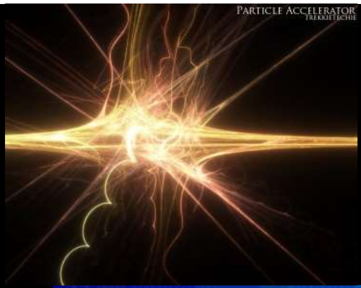
Circular vs. Linear

- Low field detector solenoid to maximize luminosity
  - Optimized at 2 T
  - Large tracking volume → calorimeter outside → very thin coil





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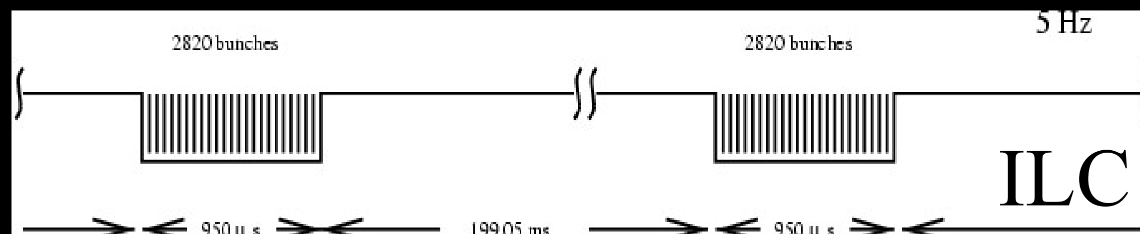
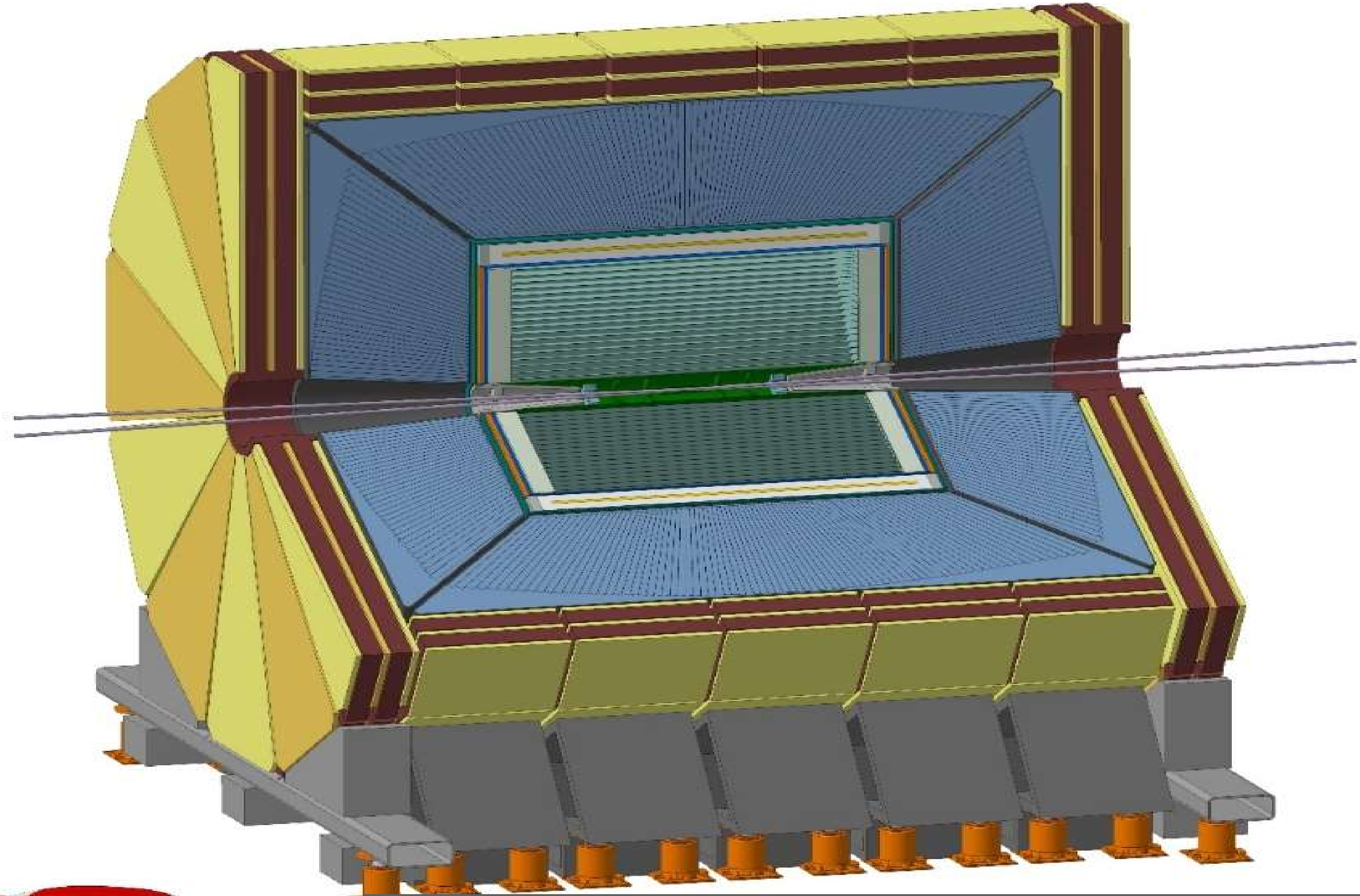


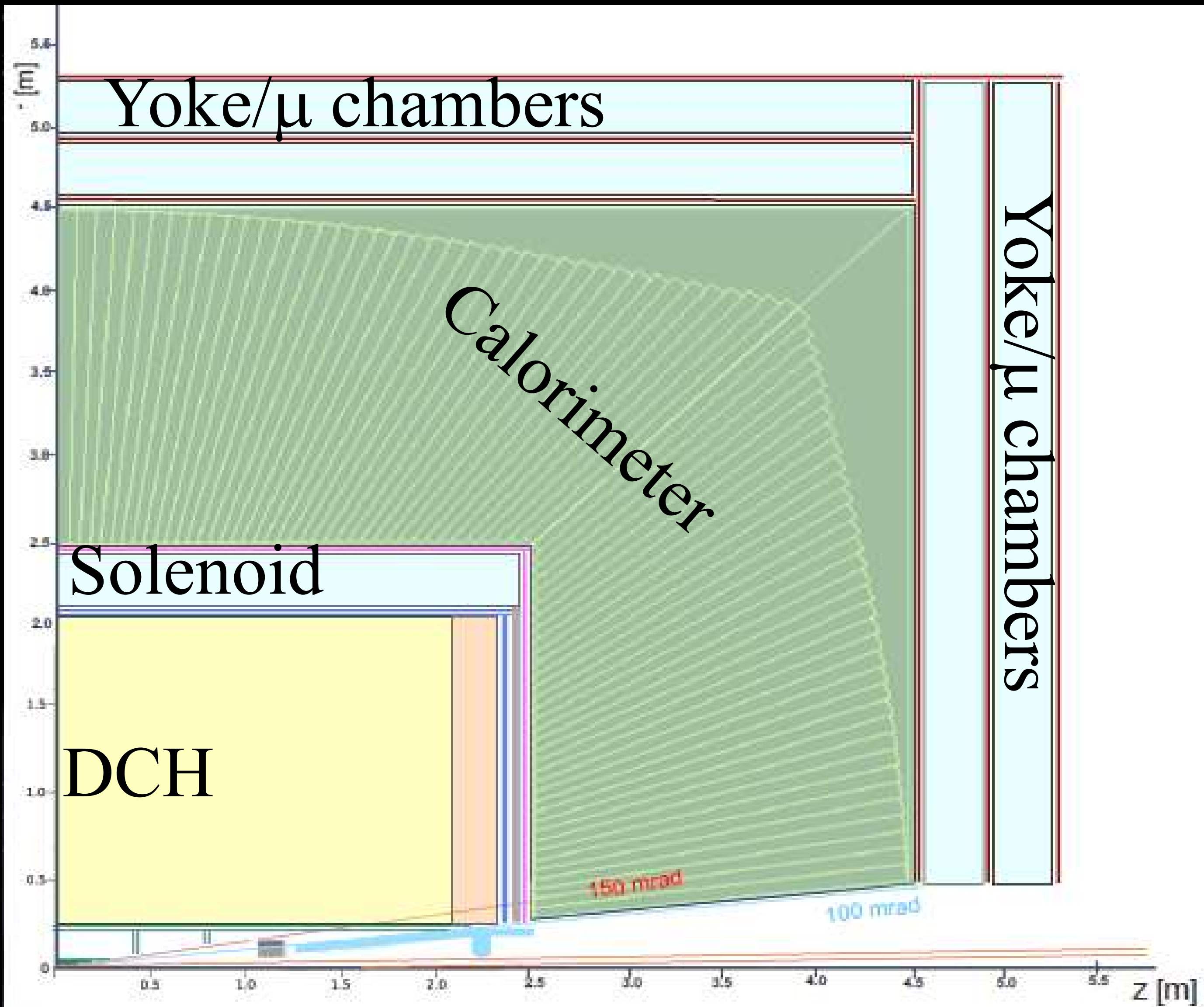
- Beam time structure:
  - Short bunch spacing (~ 20-30 ns Z, ~ 1 μs H)
  - No large time gap
    - Cooling issues for PF calorimeter and vertex detector
    - TPC ion backflow



IDEA concept

Innovative Detector for E+e- Accelerator

IDEA details



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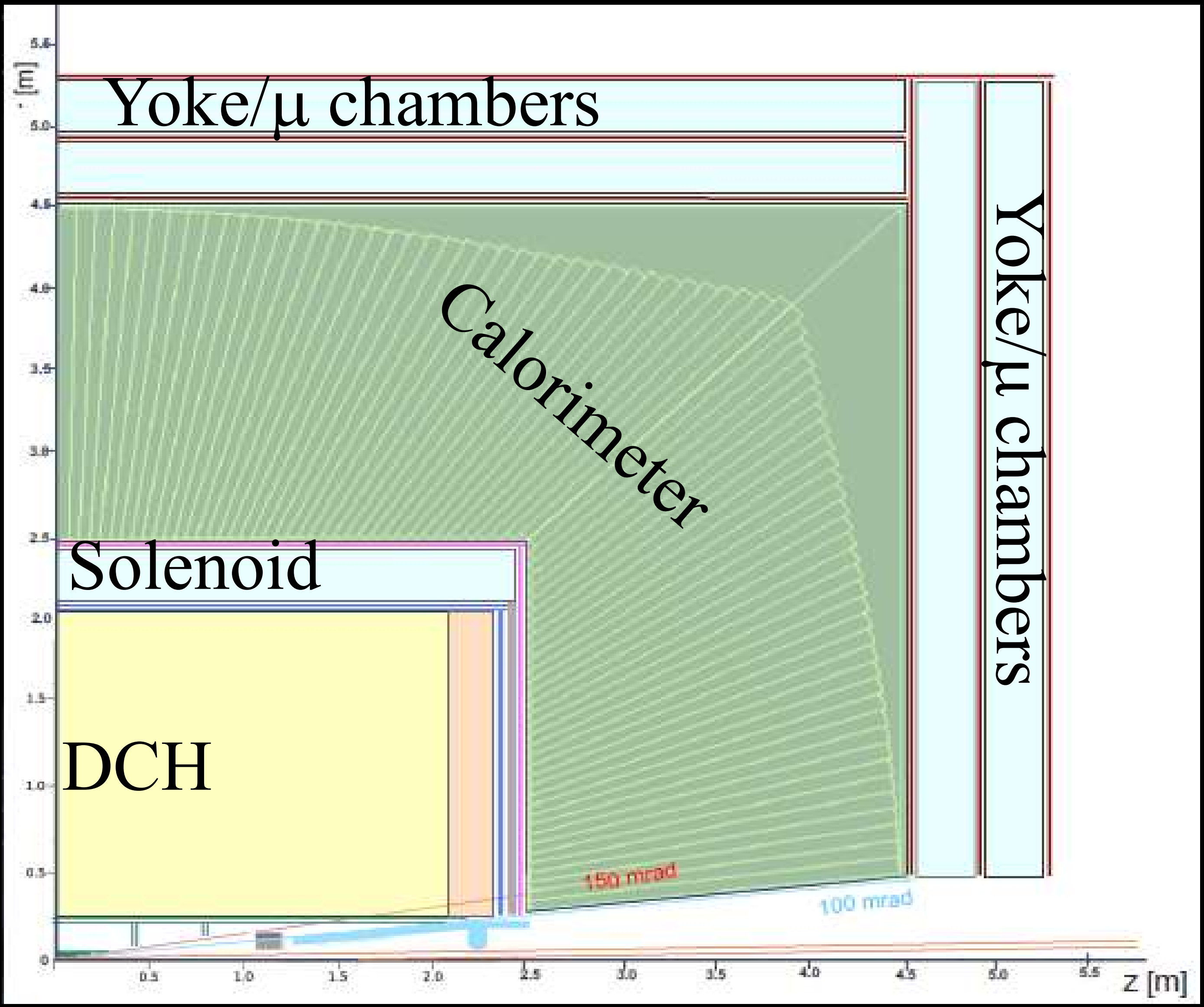

Small magnet

↓

Small yoke

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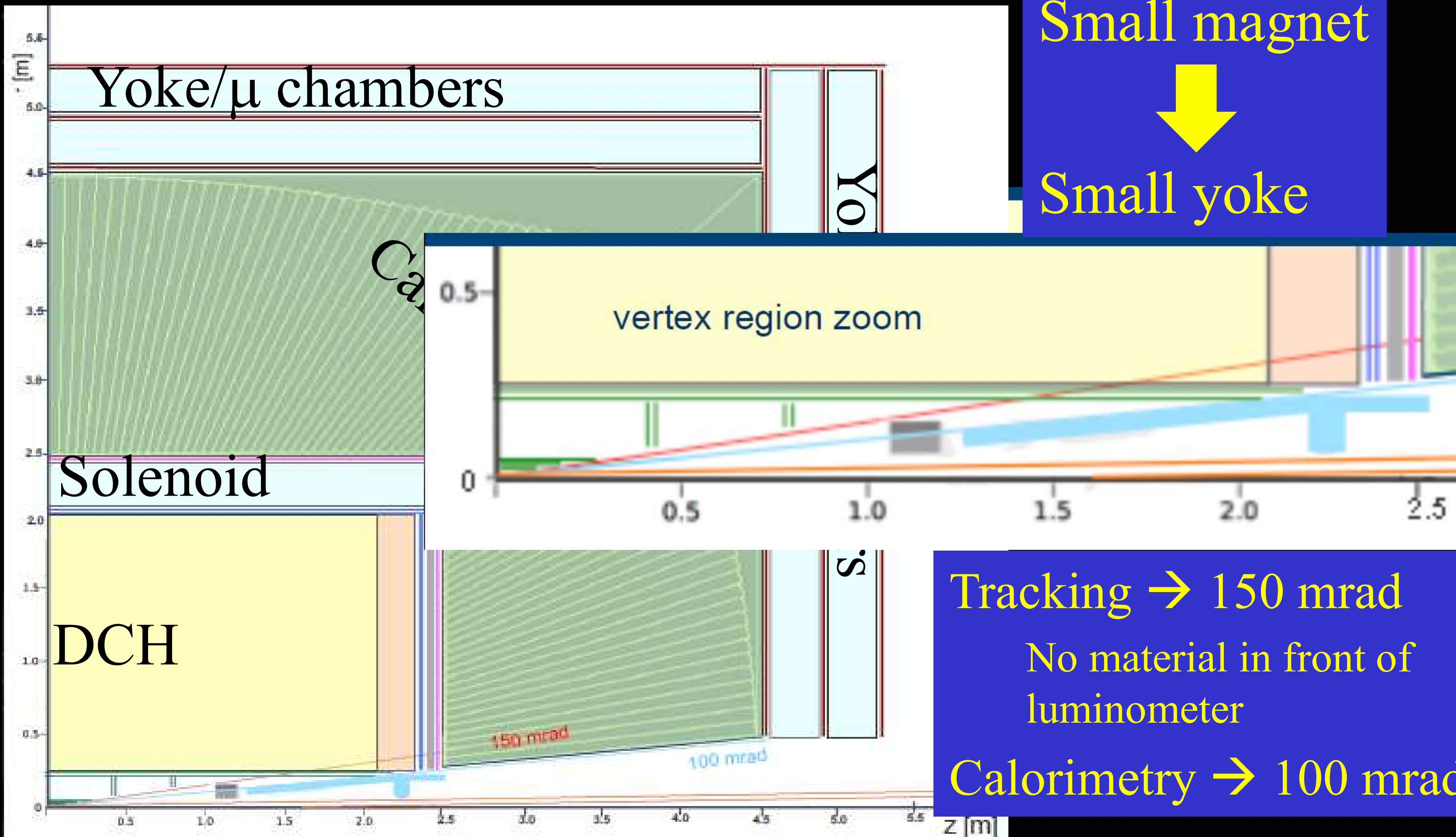

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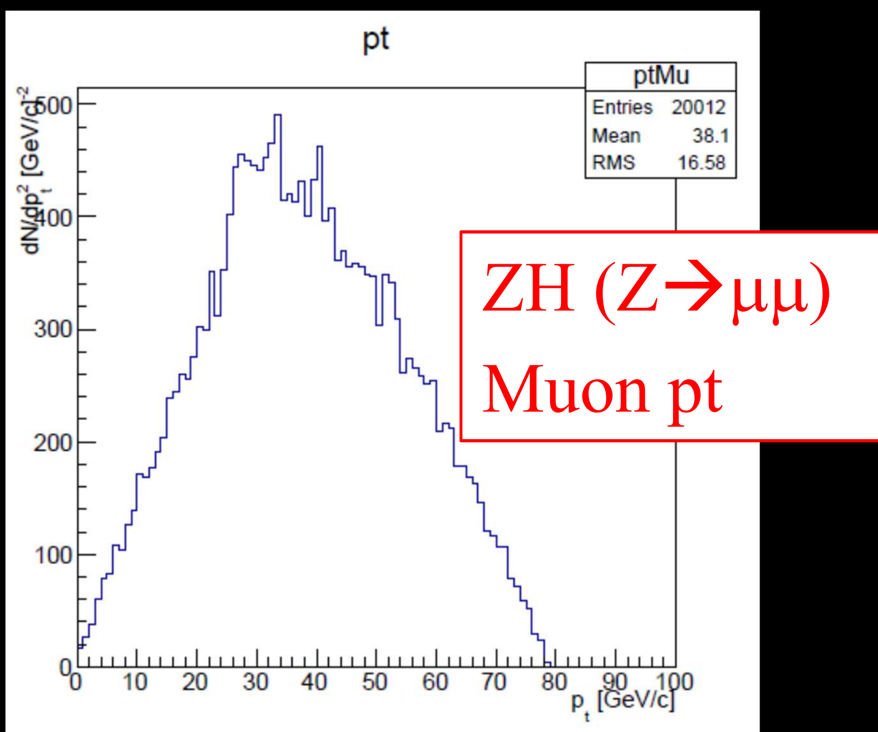
Tracking → 150 mrad

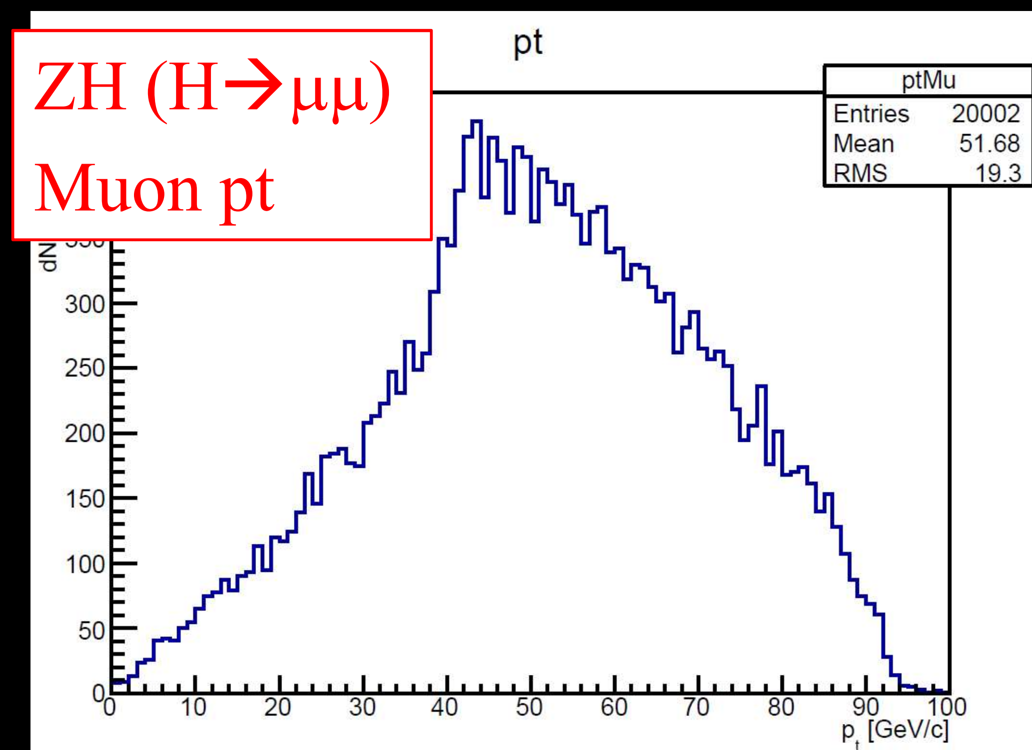
No material in front of luminometer

Calorimetry → 100 mrad

Design guidelines: Momentum resolution

❖ Z or H decay muons in ZH events have rather small p_t





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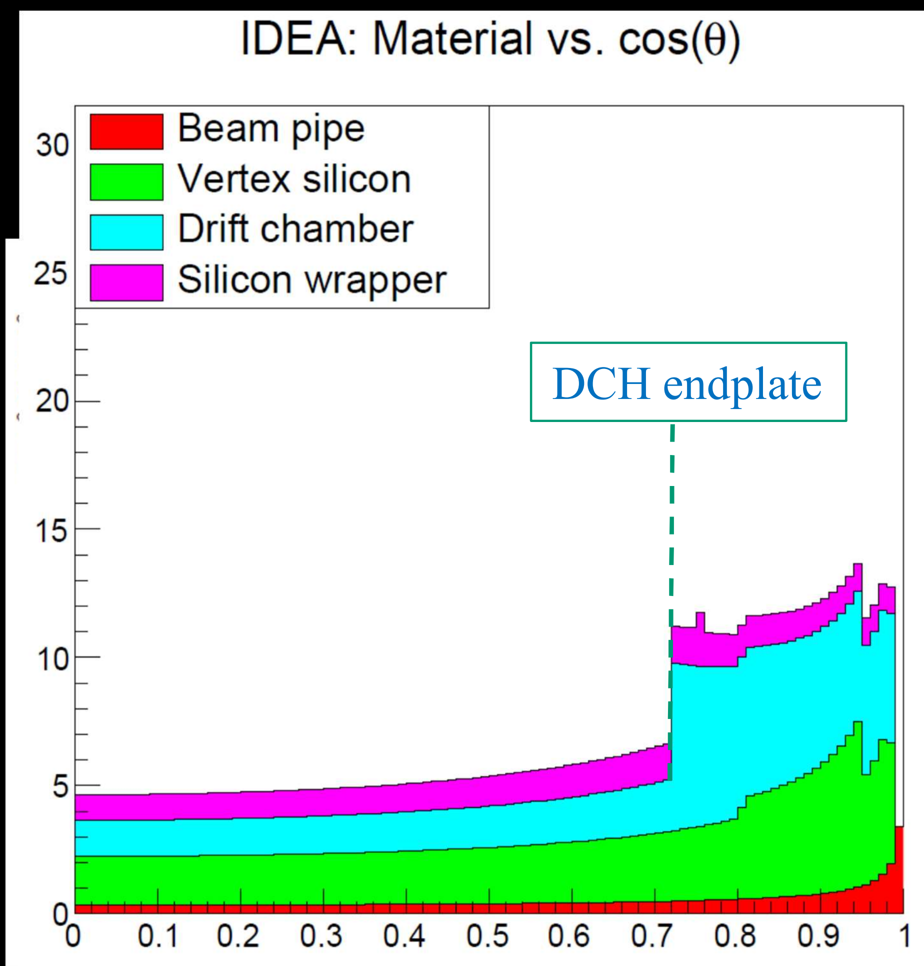
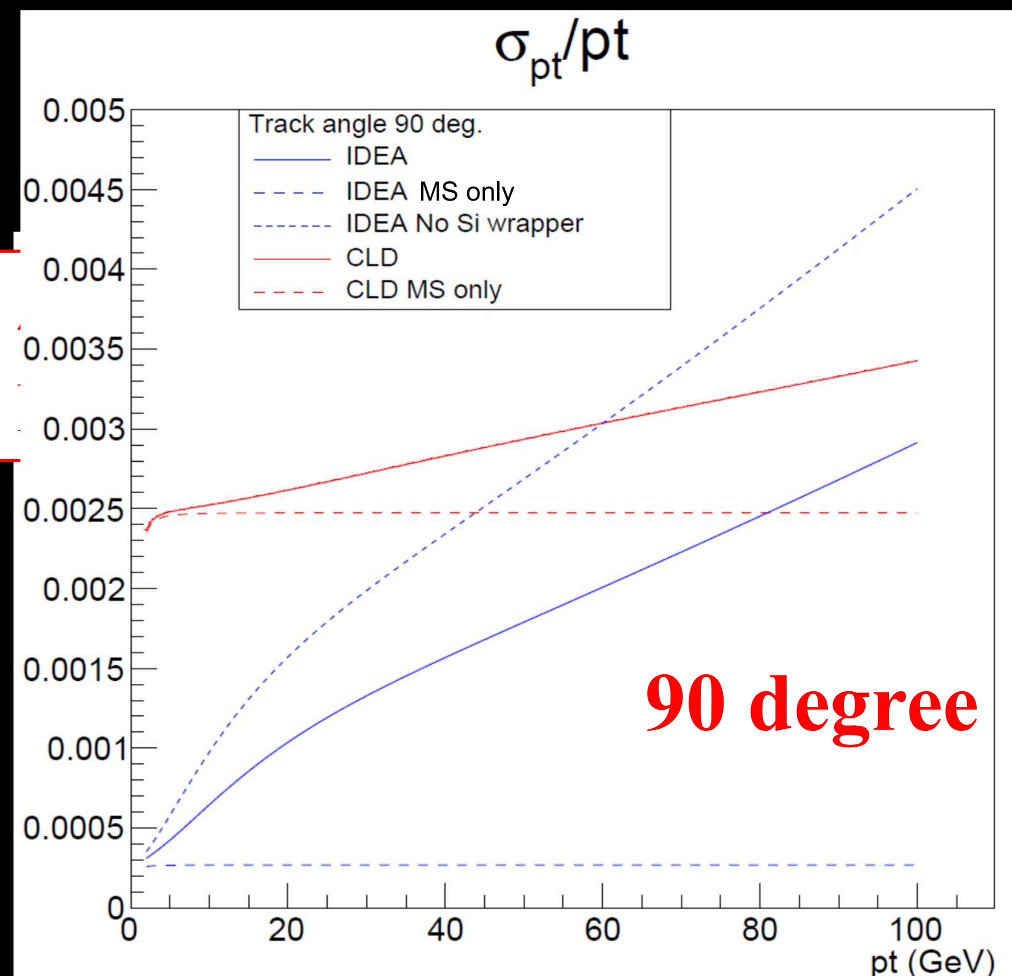
- Z or H decay muons in ZH events have rather small p_t
  - Transparency more relevant than asymptotic resolution





Design guidelines: Vertex detector

- Transparency:
  - Low power (< 20 mW/cm^2) to allow air cooling

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- Transparency:
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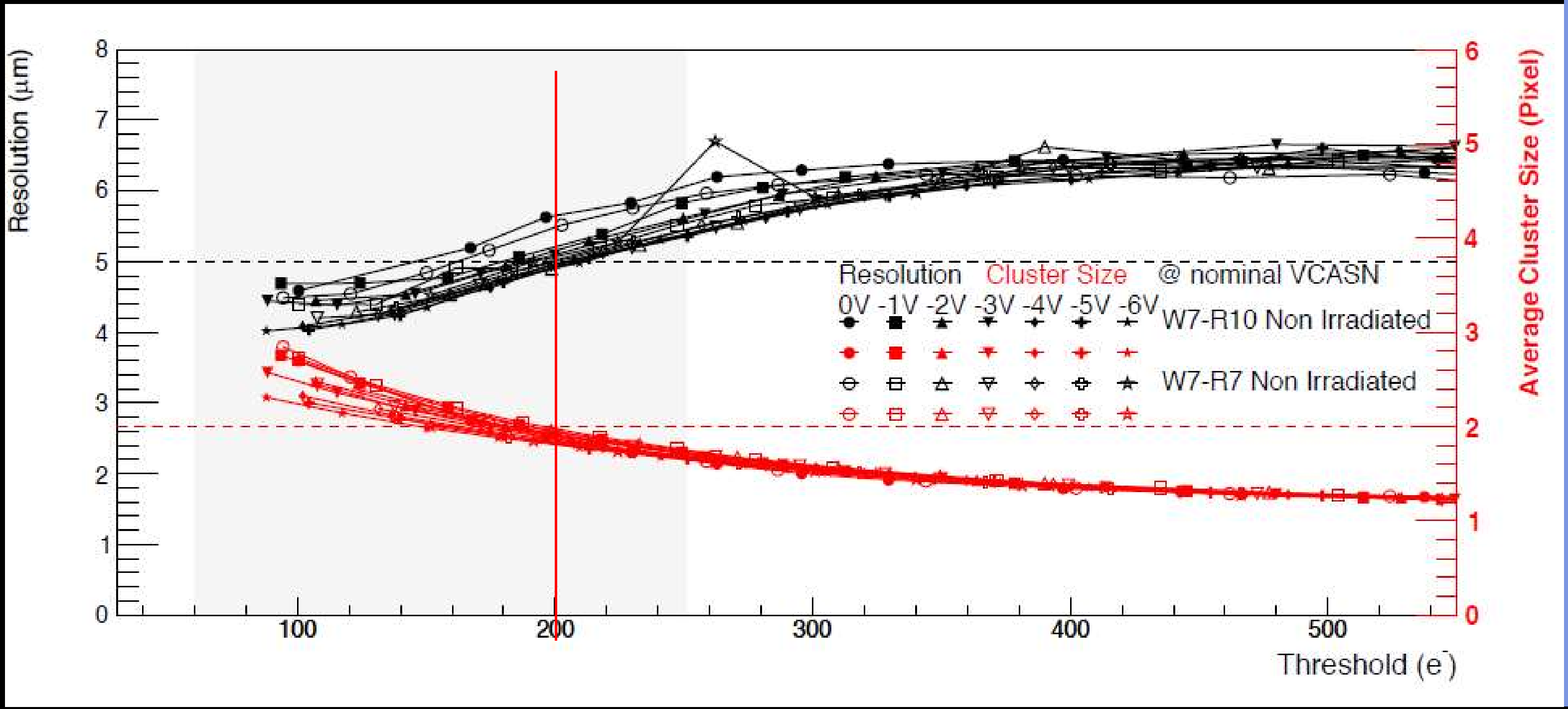
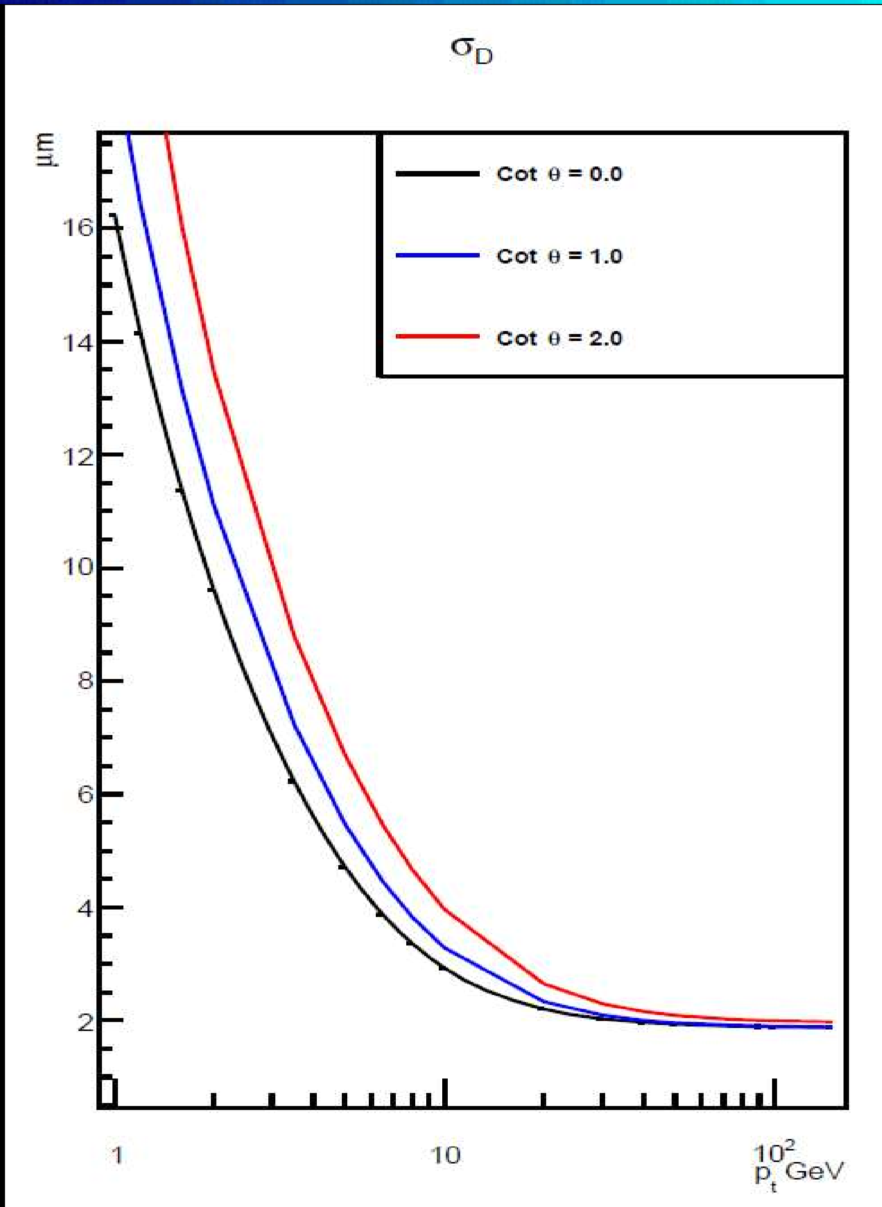
- Resolution:
  - 5 μm shown by ALICE ITS (30 μm pixels)
  - Aim at ~20 μm pixels for ~ 3 μm point resolution



Courtesy of ALICE J.W. van Hoorne

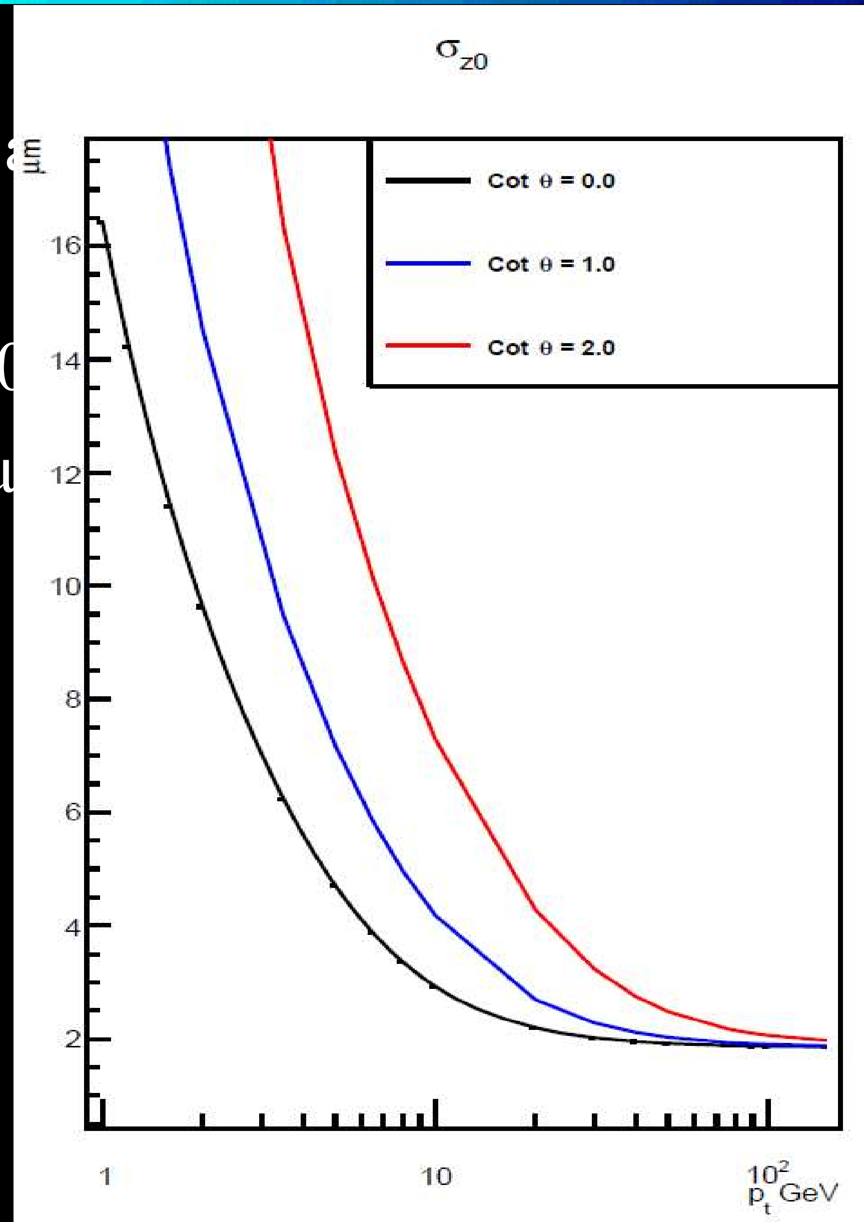
Design guidelines: Vertex detector



n^2) to a

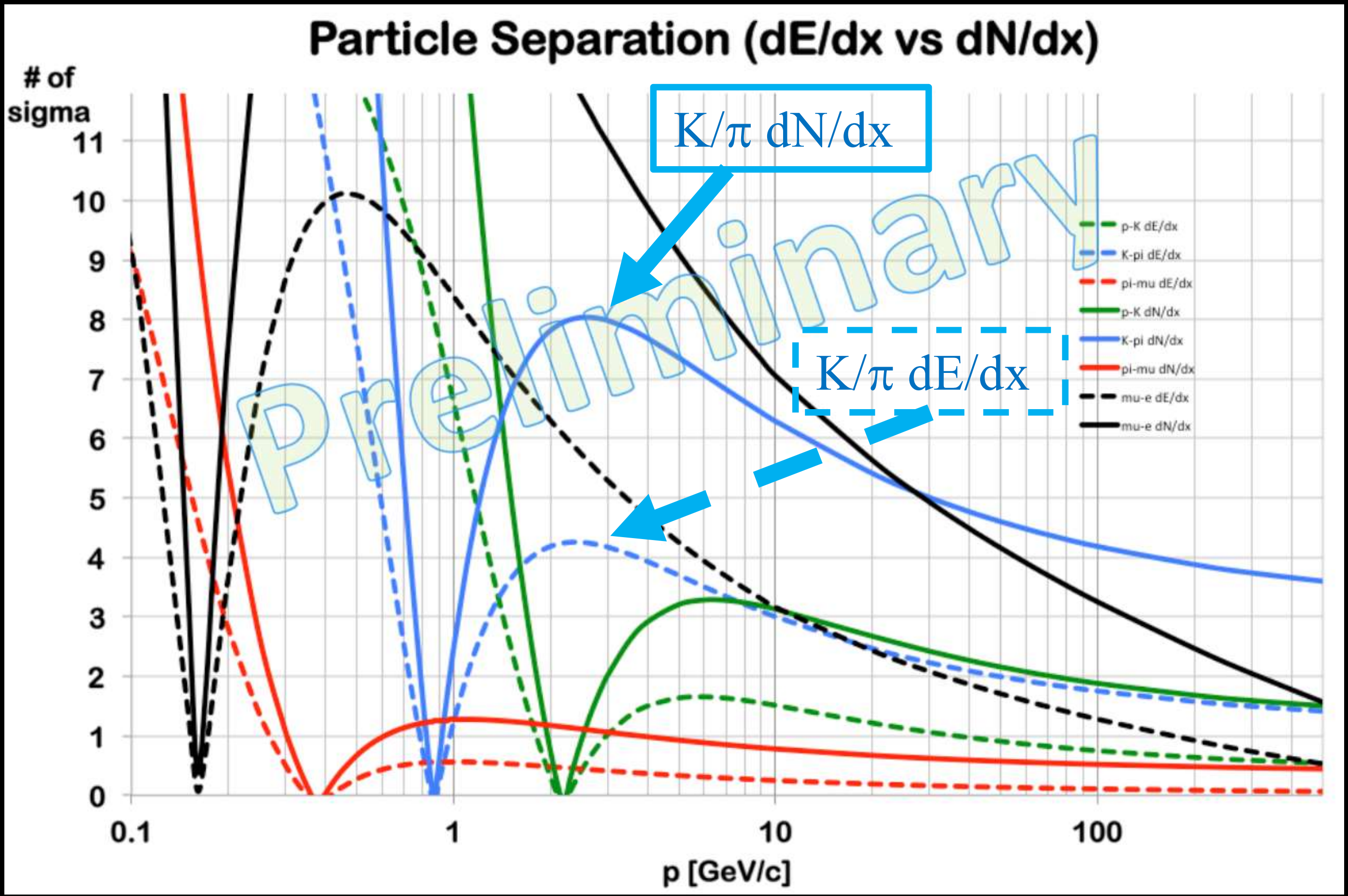
TS (30

~ 3 μ

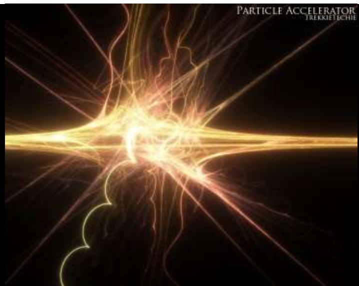


Design guidelines: PID

- Cluster counting in DCH for good PID resolution
  - Excellent K/π separation except 0.75<p<1.05 GeV (blue lines)



See talk of G. Tassielli, this conference



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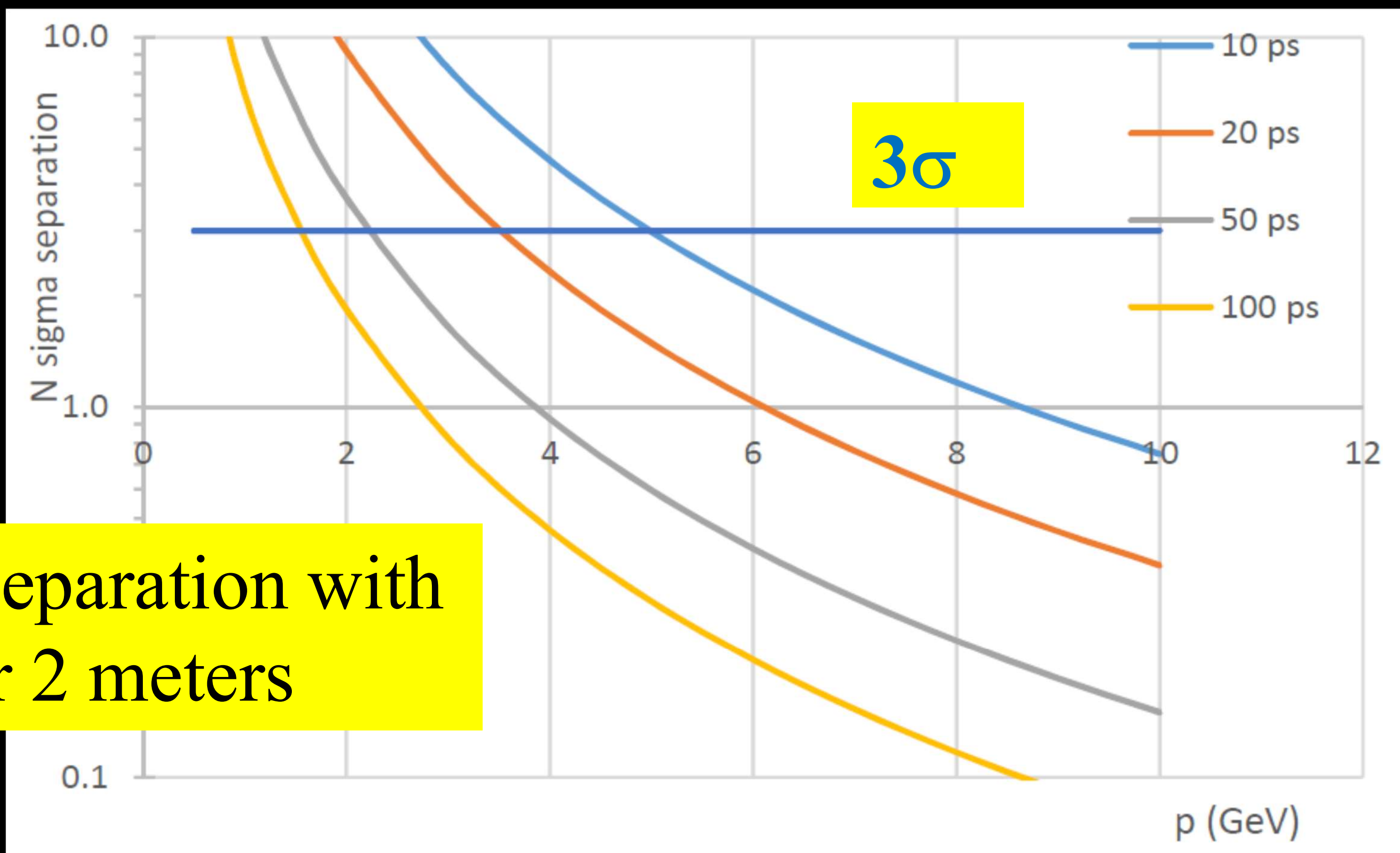
  - Could recover with timing layer

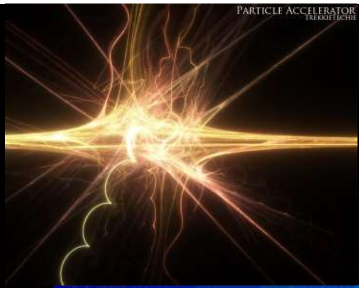


Nσ K/π separation with TOF over 2 meters

See talk of G. Tassielli, this conference

Design guidelines: calorimeter

- Good, but not extreme EM resolution
  - ~ $10\%/\sqrt{E}$ sufficient for Higgs physics
- Jet resolution ~ 30-$40\%/\sqrt{E}$
  - Clearly identify W, Z, H in 2 jet decays
- Transverse granularity < 1 cm for τ physics
- All electronics in the back to simplify cooling and services



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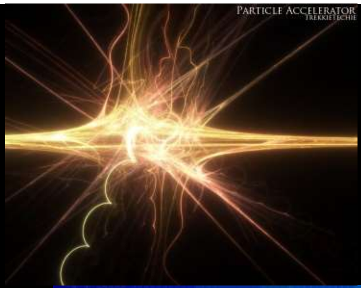
- All electronics in the back to simplify cooling and services
- Dual Readout calorimeter satisfies all these requirements
  - EM & Hadronic calorimeter in a single package

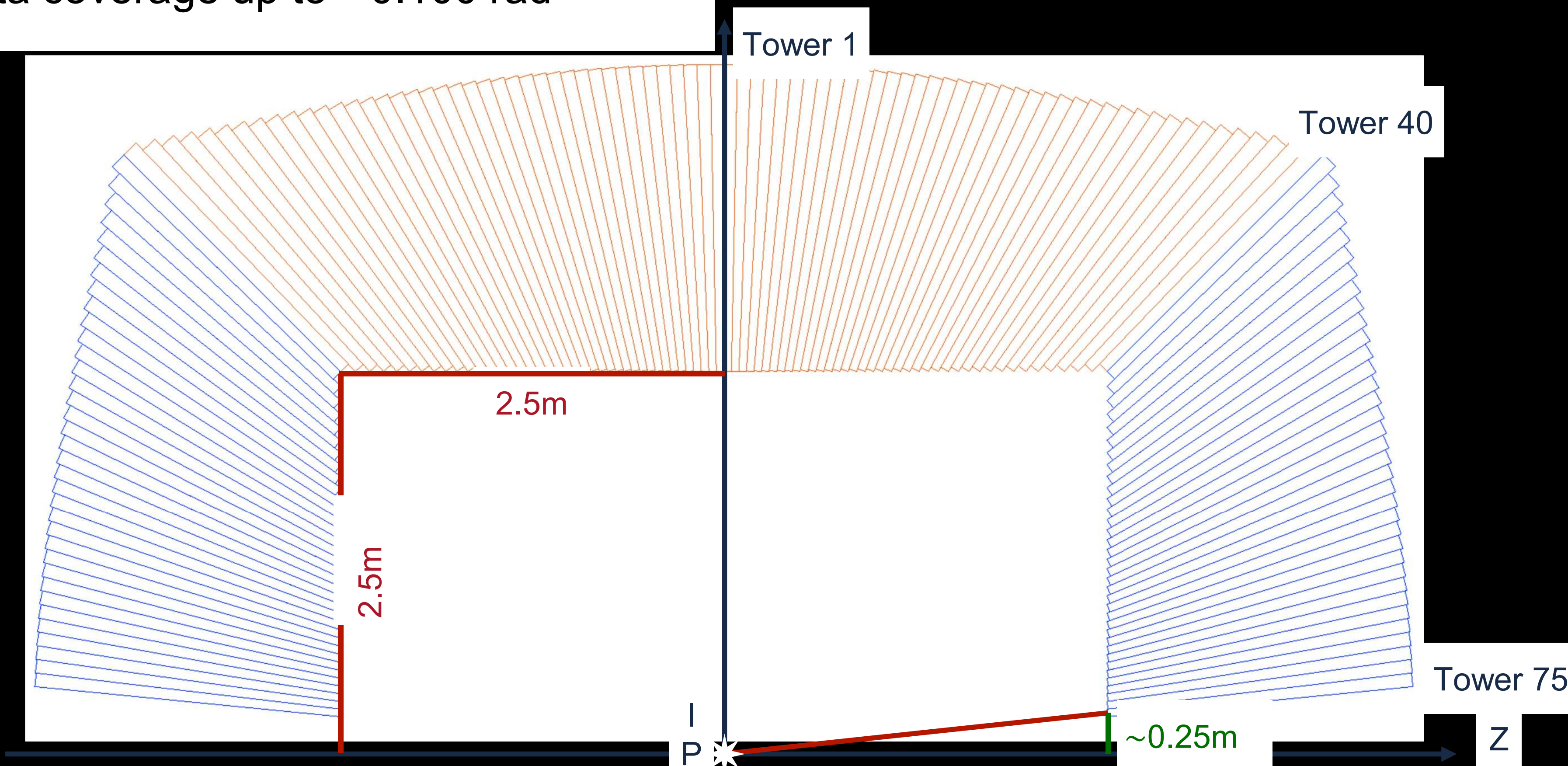
See for instance:
- "Dual-readout calorimetry", Sehwook Lee, Michele Livan, and Richard Wigmans
Rev. Mod. Phys. 90, 025002 – Published 26 April 2018
- L. Pezzotti, CHEF2019, Nov. 2019, Fukuoka, Japan



Calorimeter simulation

- 4π detector in GEANT4 tuned to RD52 test beam data

Tower segmentation: Δϑ = 1.125°, Δϕ = 10.0°
Number of towers in barrel: 40 x 2 x 36 = 2880
Number of towers per endcap: 35 x 36 = 1260
Theta coverage up to ~0.100 rad



Calorimeter simulation

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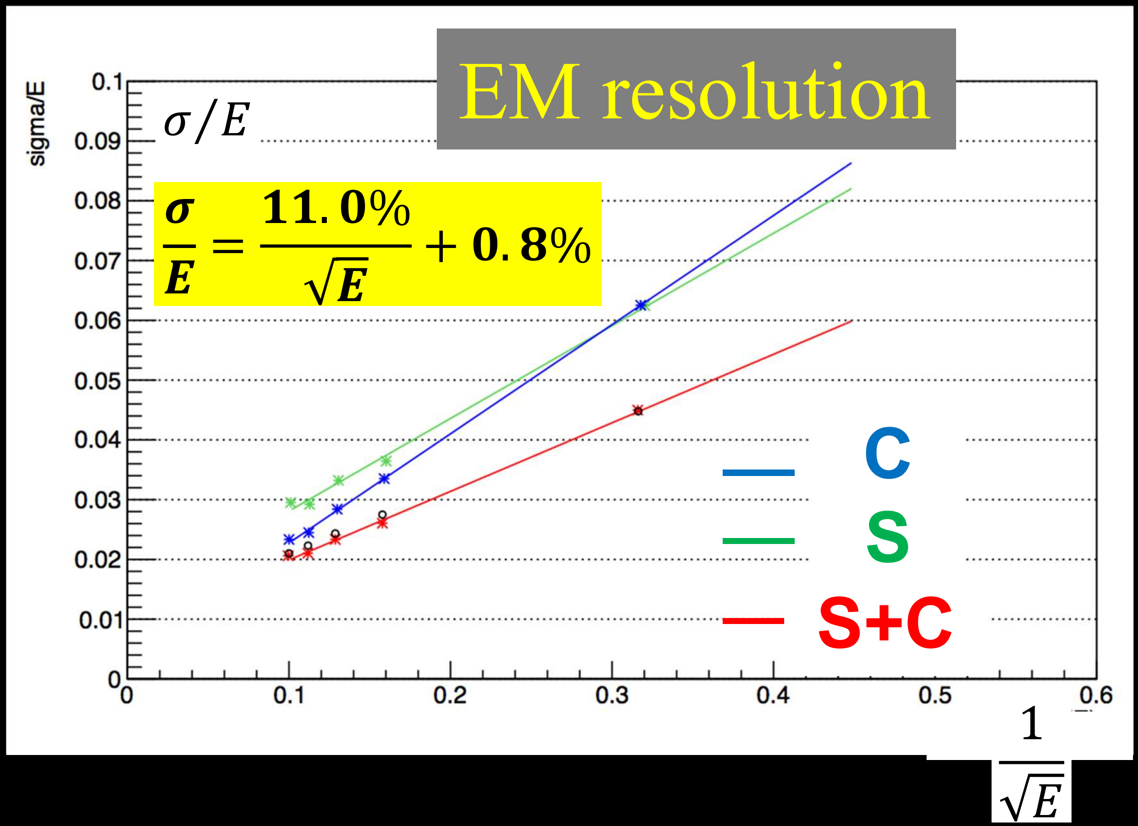

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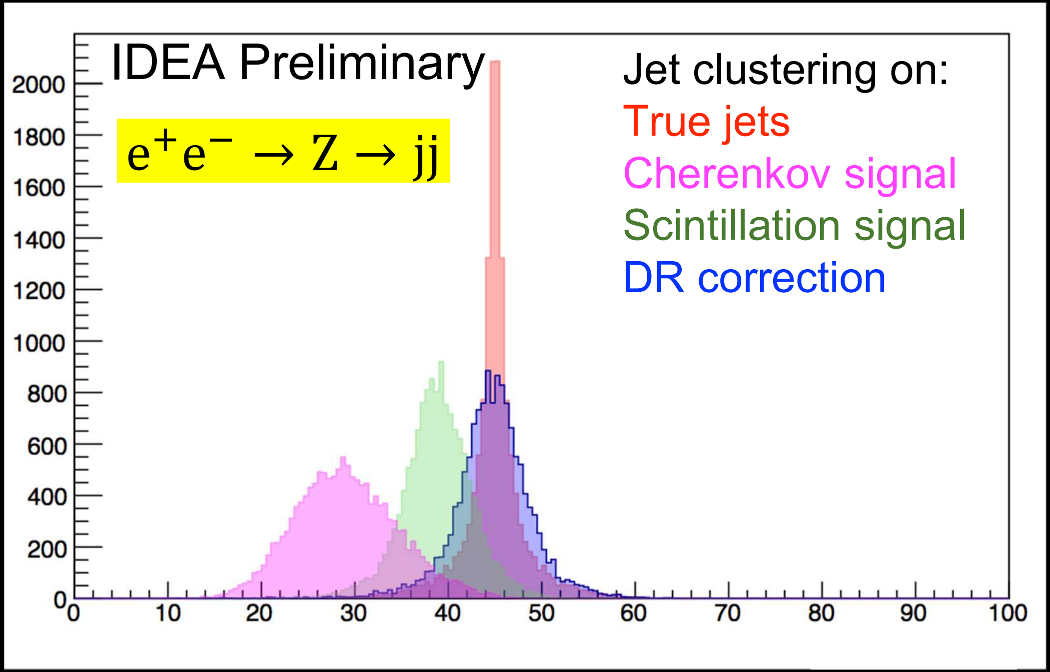

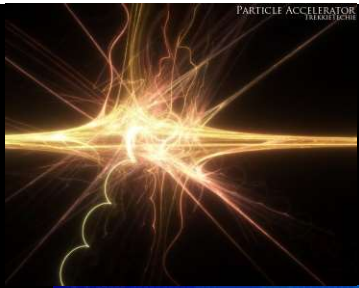

Calorimeter simulation

- 4π detector in GEANT4 tuned to RD52 test beam data
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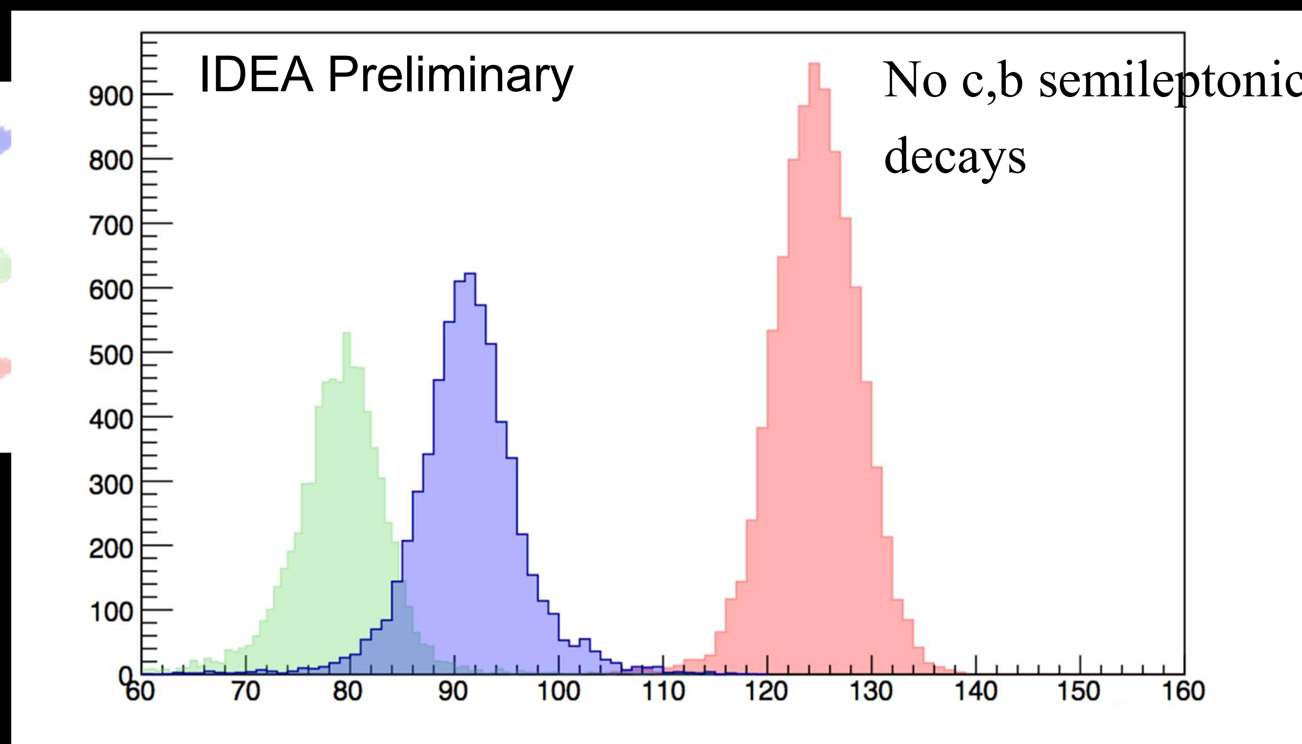
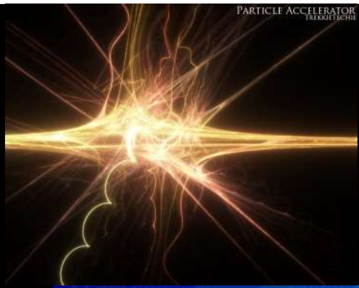
- DR works well with jets
- Adequate separation of W/Z/H

$e^+e^- \to HZ \to \tilde{\chi}^0\tilde{\chi}^0 jj$

$e^+e^- \to WW \to \nu_\mu \mu jj$

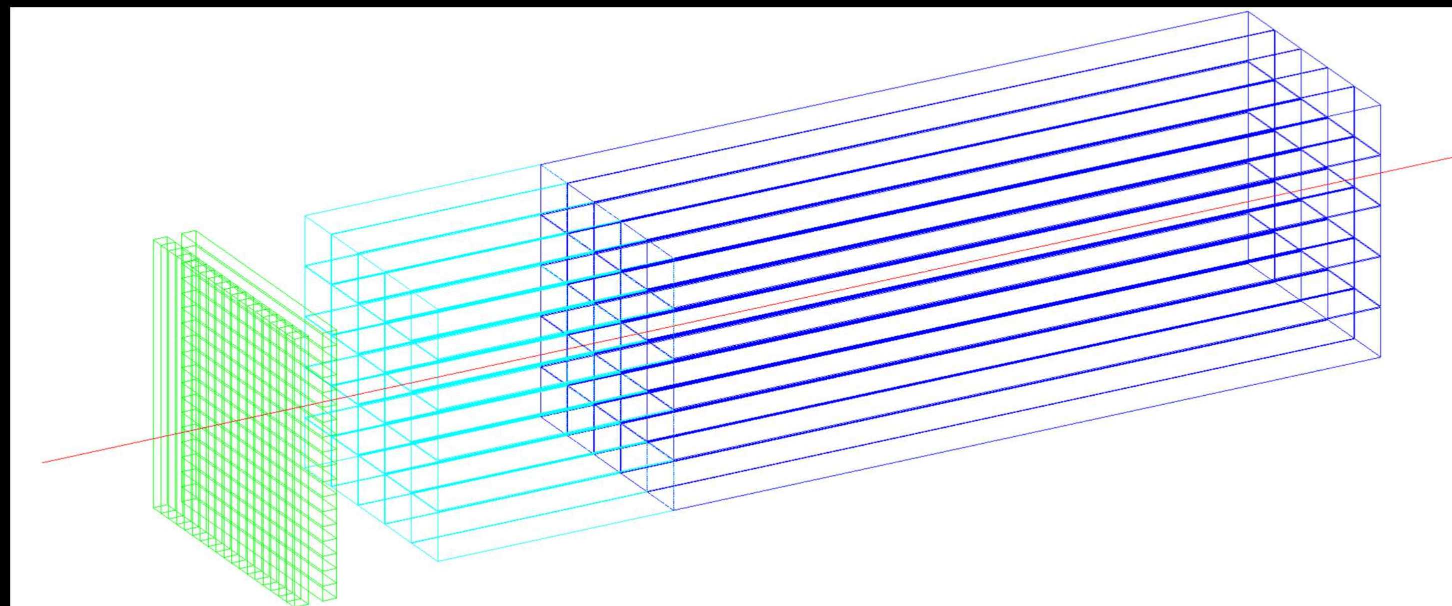
$e^+e^- \to HZ \to bb\nu\nu$





Crystal option

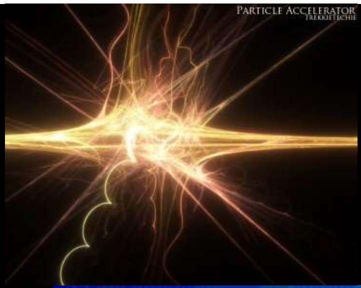
- ~20 cm $PbWO_4$
- $3\%/\sqrt{E}$
- DR w. filters
- Timing layer
  - Lyso 20-30 ps



- **ECAL layer:**
  - PbWO crystals
  - front segment 5 cm (~5.4X_0)
  - rear segment for core shower
  - (15 cm ~16.3X_0)
  - 10x10x200 mm³ of crystal
  - 5x5 mm² SiPMs (10-15 um)

1x1x5cm^3 PbWO

1x1x15cm^3 PbWO



A glimpse to R&D

❖ Silicon systems:

- VTX: Low power, high speed MAPS – CMOS to limit costs
  - Time stamping ~ 10 ns, Stitching
- Outer Si: CMOS passive strips, long pixels, evolution from R&D at HL-LHC

See talk of P. Giubilato, this conference

Requirements	ARCADIA
Pixel pitch (um)	20 - 25
Thickness (um)	50 - 100
Scalability (cm)	Up to $\sim$ 4 x 4
Hit rate (MHz/cm^2)	10 $\rightarrow$ 100
Cluster size (pixels)	2-4
Timing res. (ns)	10
Power (mW/cm^2)	$<$ 20
Rad. Hard (Mrad)	1
Tiling	Side-buttable
Trigger	Triggerless

First Implementation

- Target hit rate: 100MHz/cm^2
- Target efficiency: 99.9% (in every regard)
- Pixel size: 20μm × 20 μm
- Double column arrangement
- Support for 2048 pixels in column (4cm)

A glimpse to R&D

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  - VTX: Low power, high speed MAPS – CMOS to limit costs
    - Time stamping ~ 10 ns, Stitching
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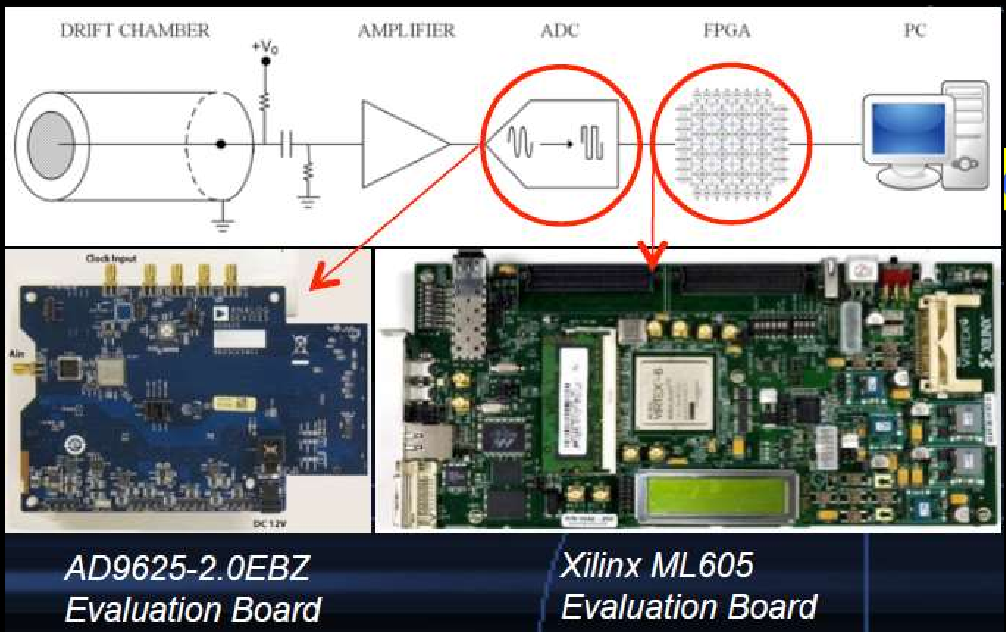
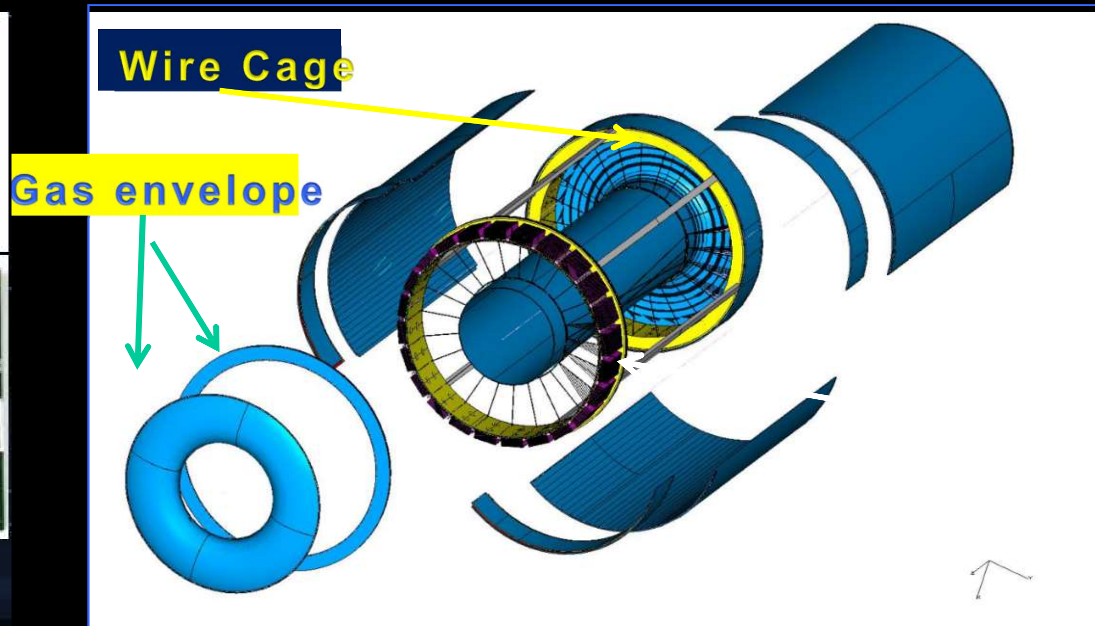
- Drift chamber:
  - Light mechanics and new wire technology (e.g. C-fiber)
  - Cluster counting electronics





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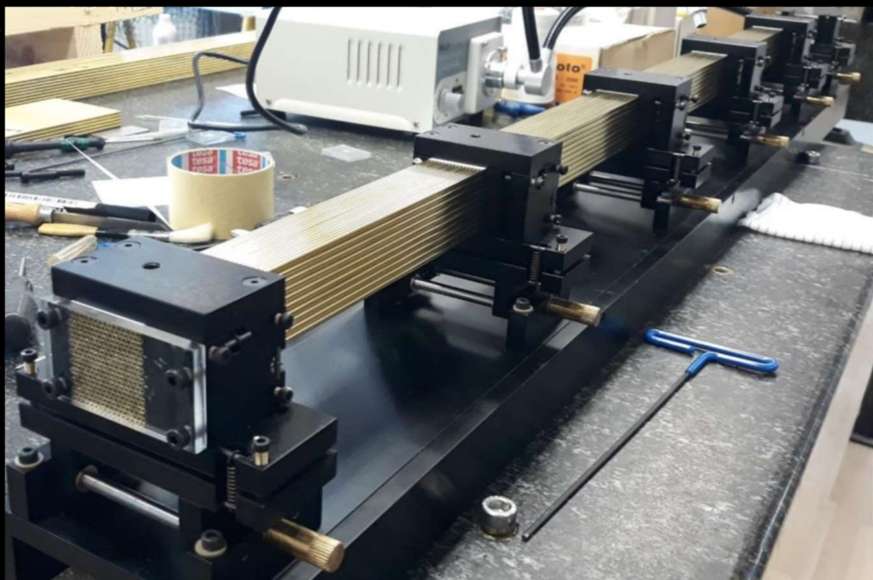
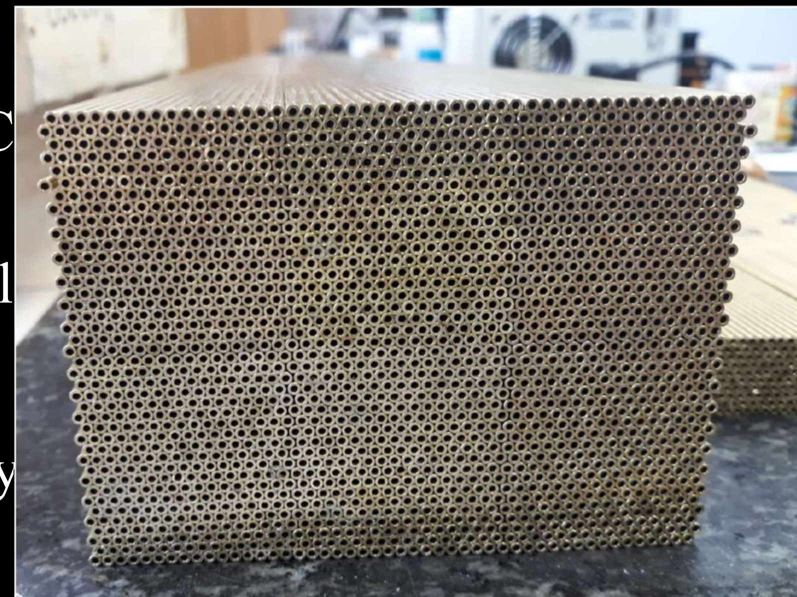


MAPS – C

long pixel … C

echnology



- Calorimeter:
  - Scalable mechanical options

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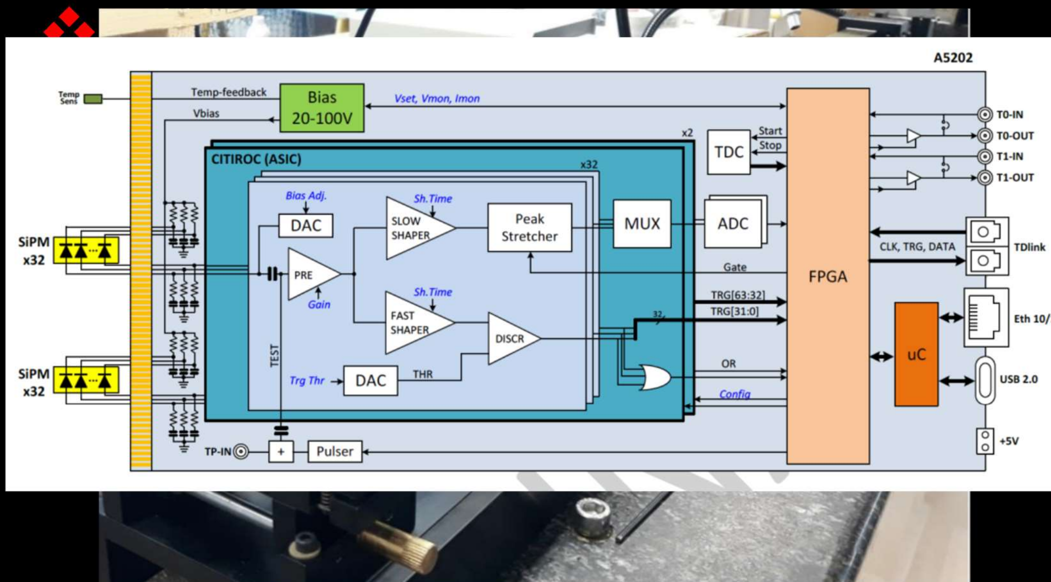

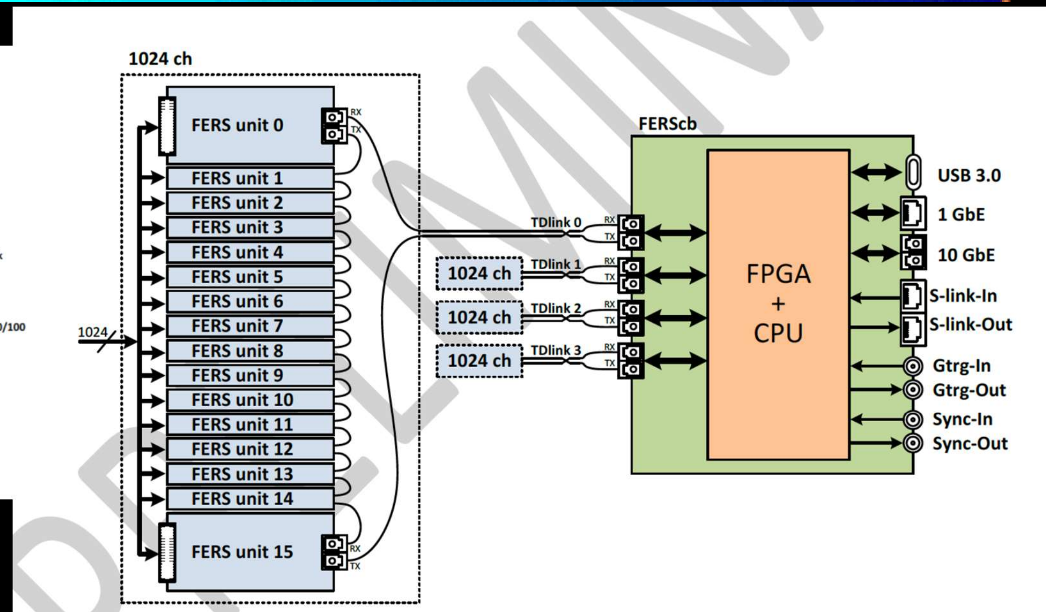

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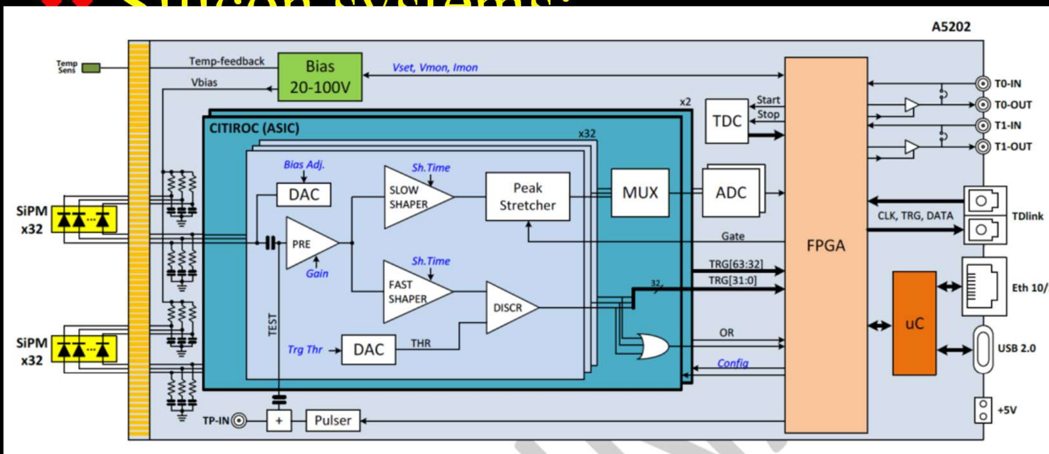

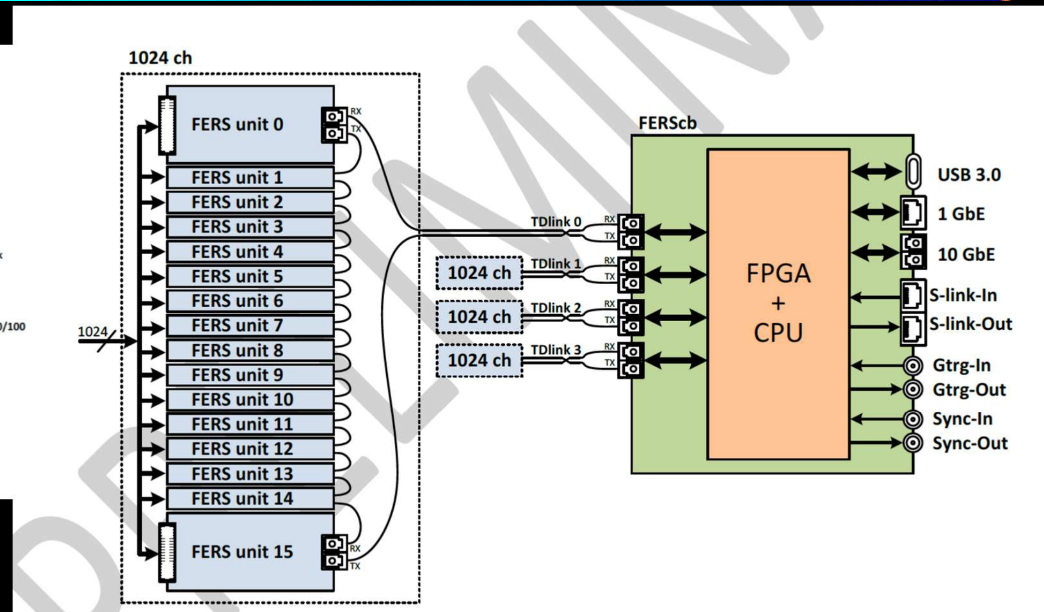

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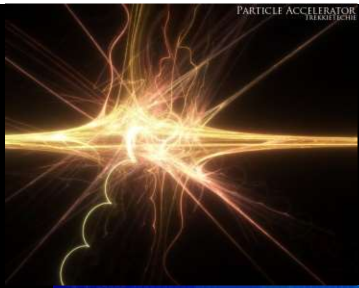
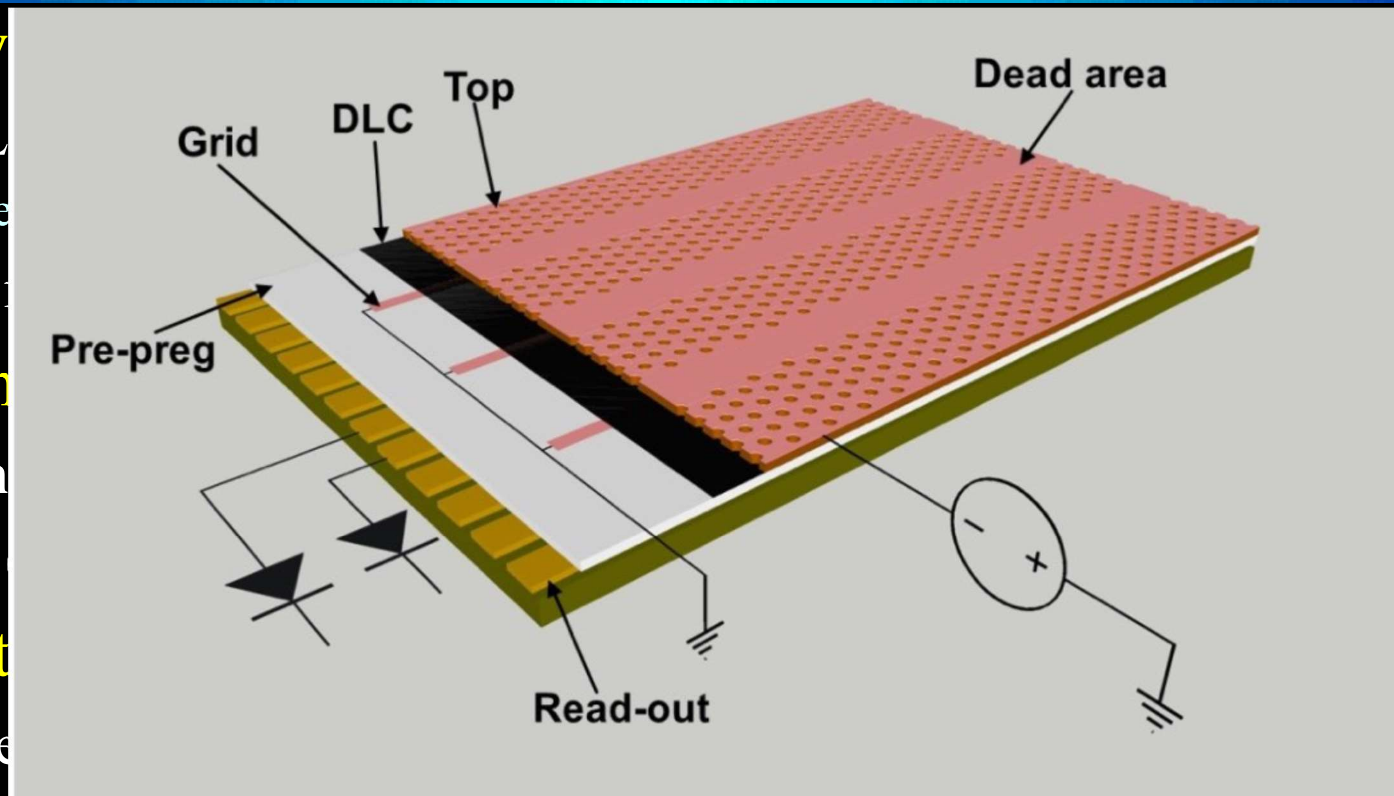
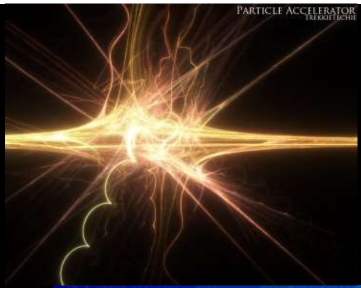
  - Crystals



A glimpse to R&D

- Silicon sy
  - VTX: L
    - Time
  - Outer S … HL-LHC
- Drift chan
  - Light m
  - Cluster
- Calorimet
  - Scalable
  - SiPM readout architectures/chips – Digital SiPM
  - Crystals
- Muon chambers:
  - µRwell industrialization
  - DLC sputtering





Final comments

- Summary of main features:
  - High precision vertex detector
  - High transparency and momentum resolution
    - Good integrated PID with cluster counting → even better with timing layer
  - Excellent calorimetry → FANTASTIC with crystals
  - Light solenoid and minimal yoke
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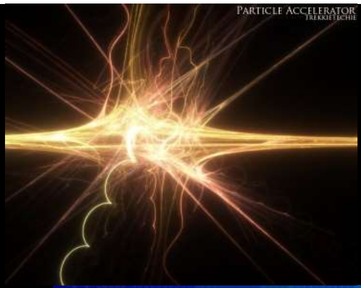
- Much R&D work in progress supported by several funding sources
- Collaboration on all these R&D's is growing internationally, but there is still ample space for additional contributions

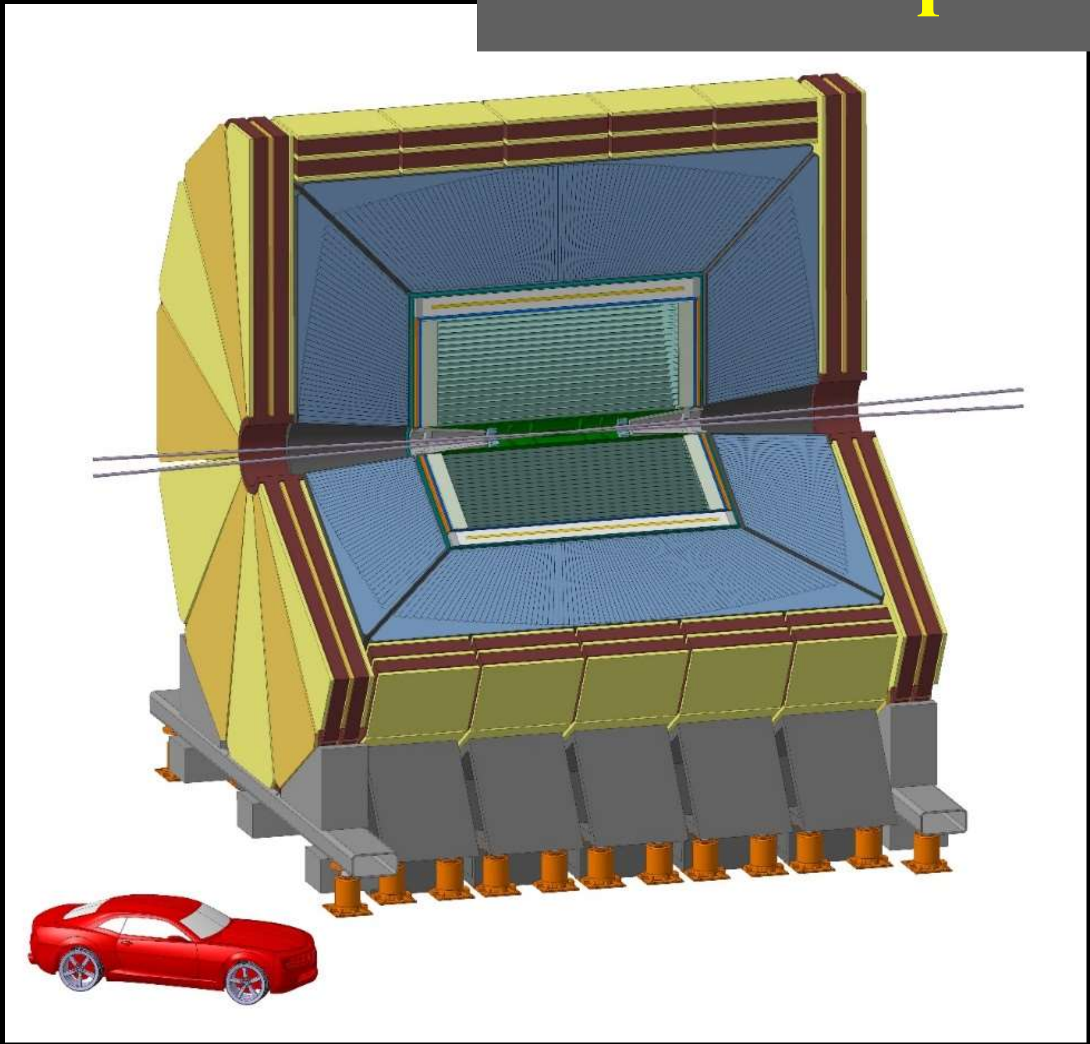


Backup

BACKUP

Detector concept IDEA

IDEA concept



Detector concept IDEA

- Si pixel vertex detector
  - 5 MAPS layers
    - R = 1.7 – 34 cm

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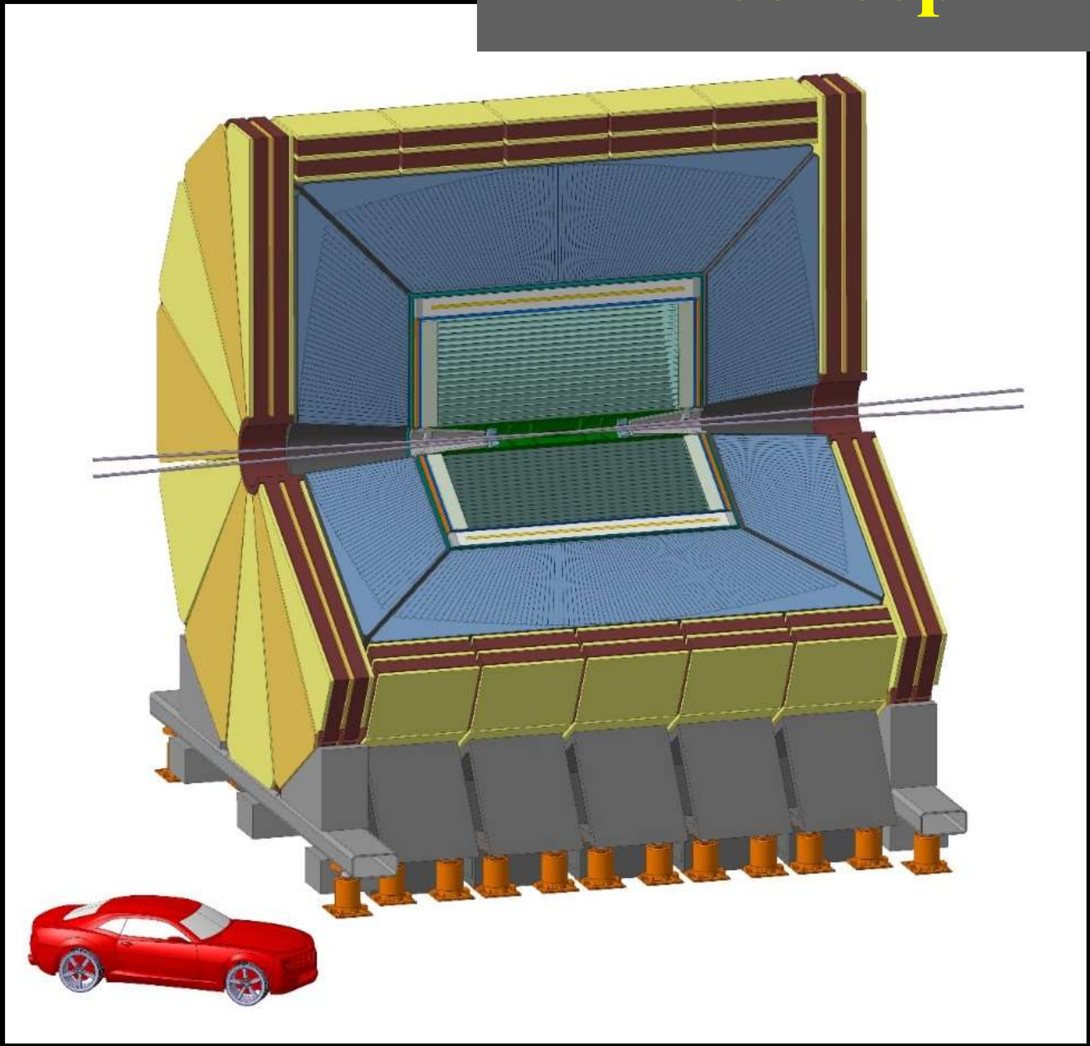

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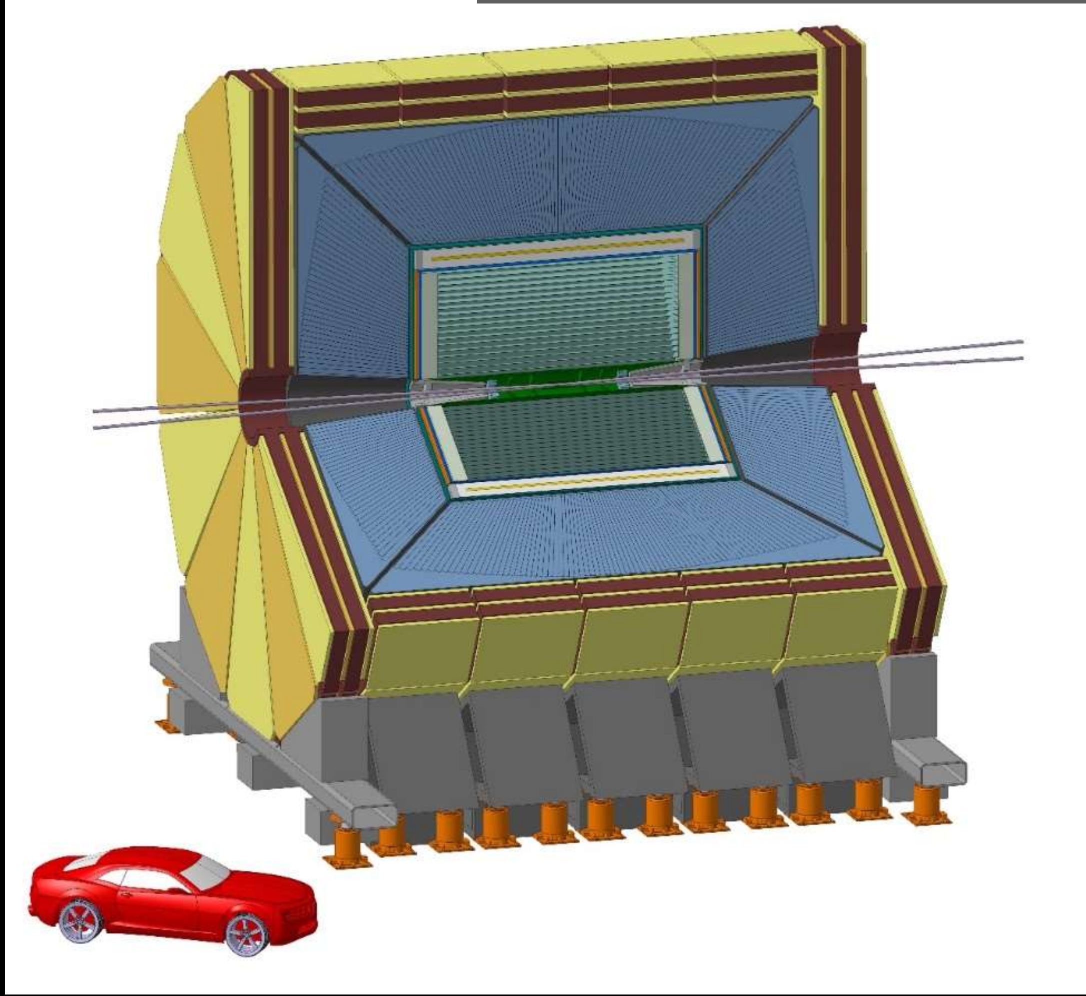

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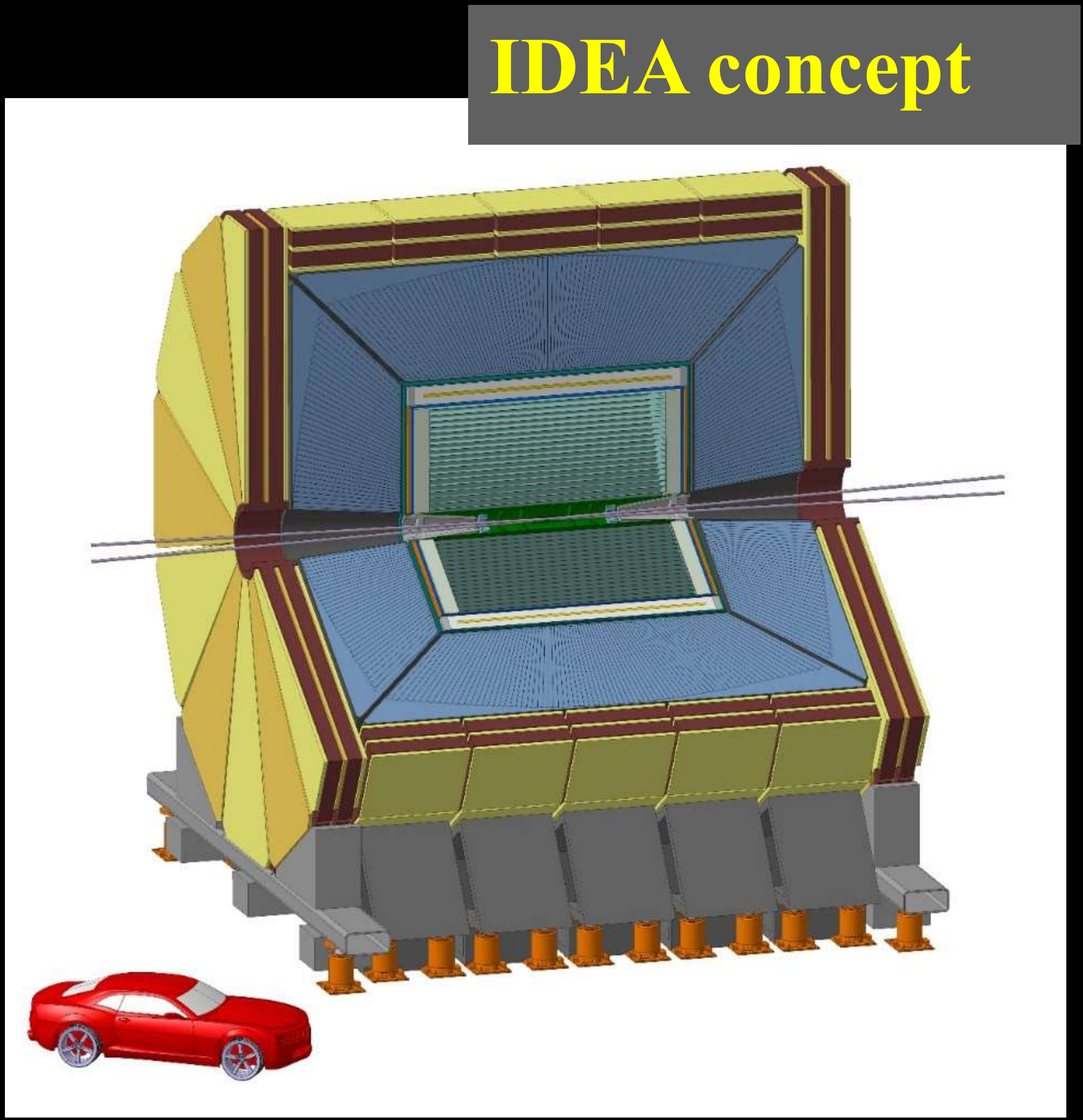

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  - 0.74 X_0, 0.16 λ @ 90º

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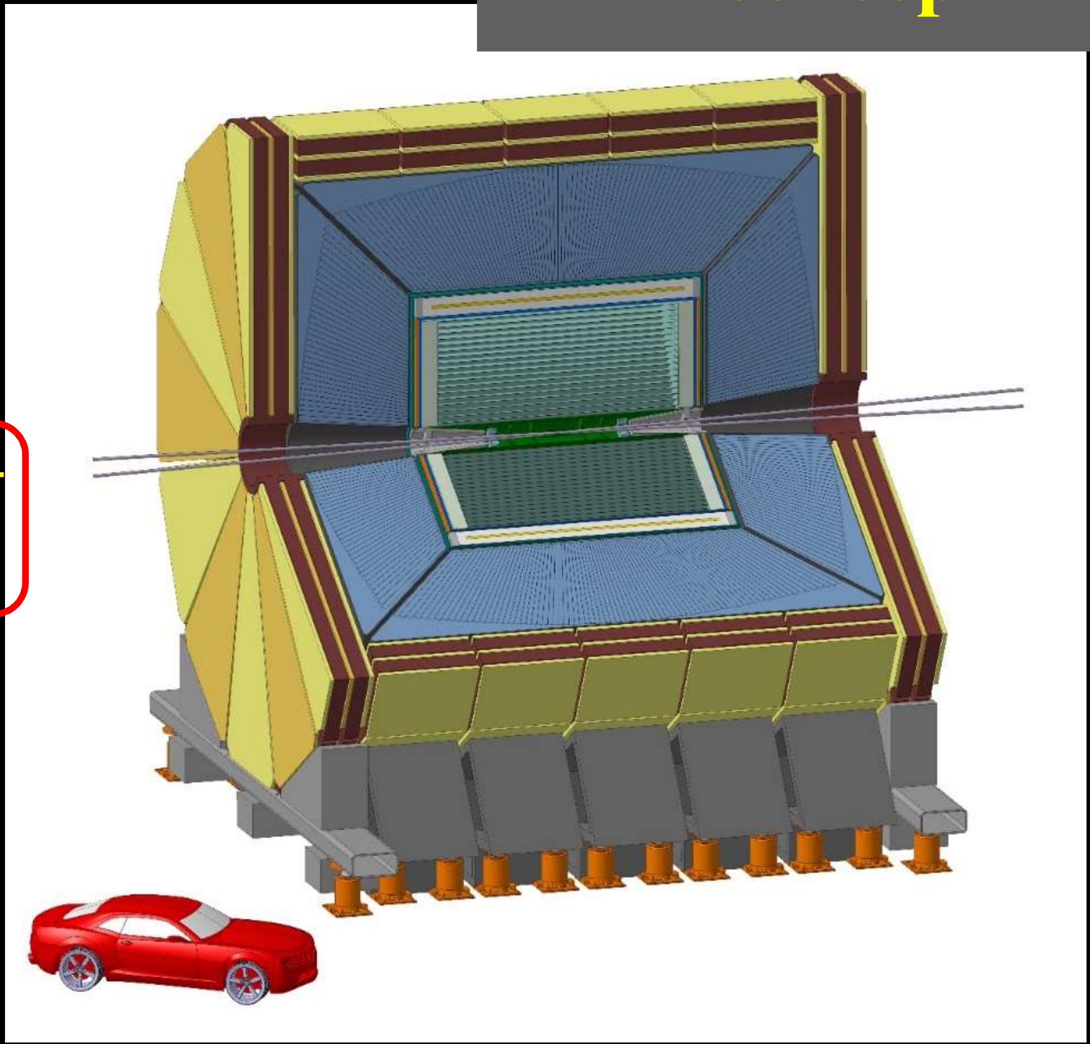

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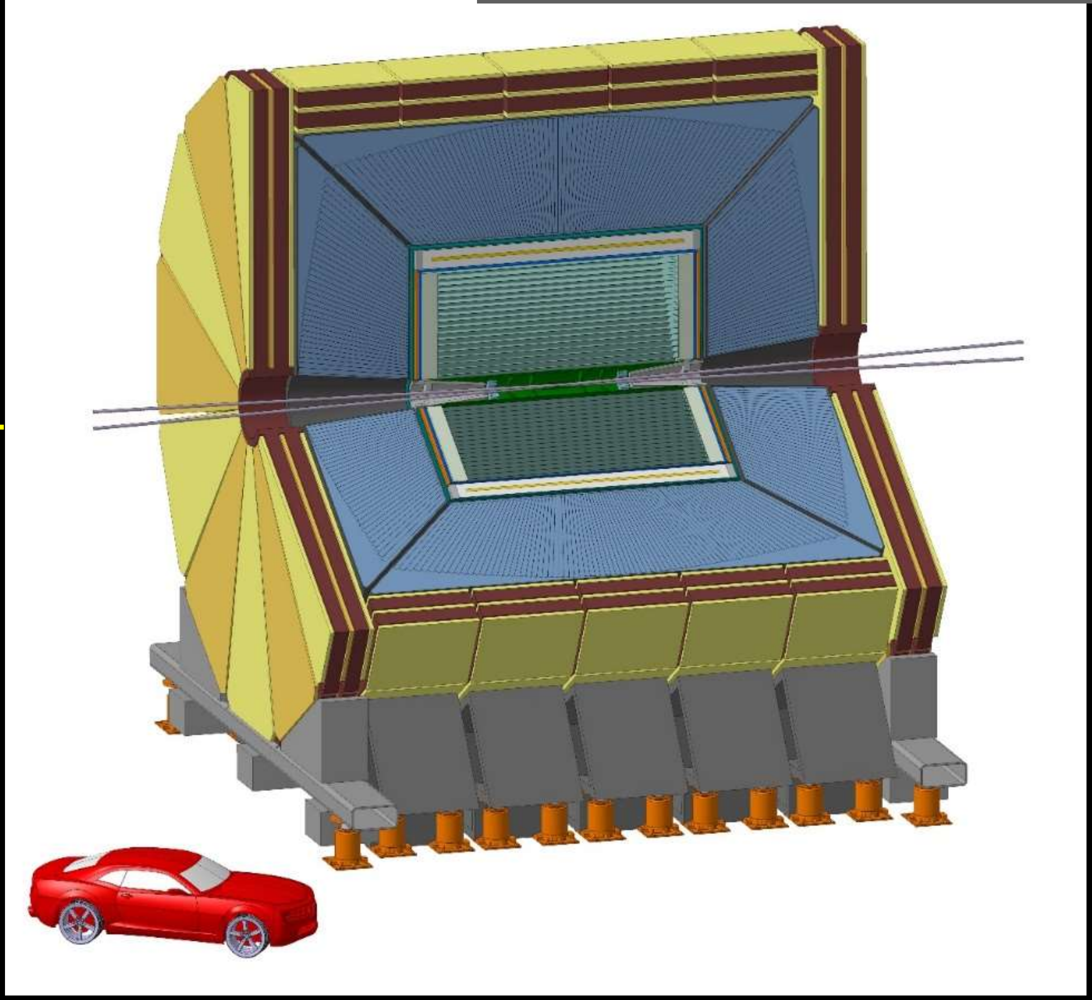

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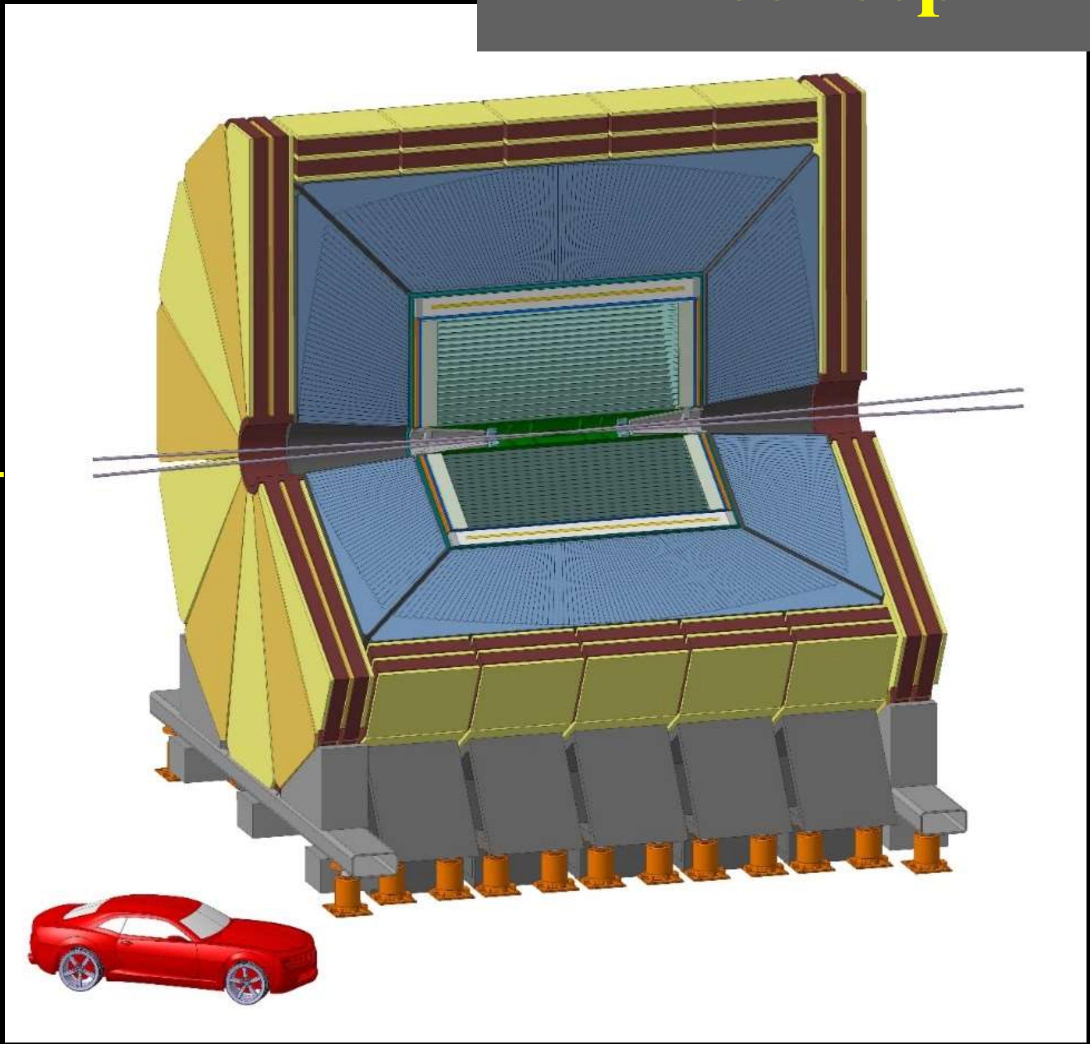

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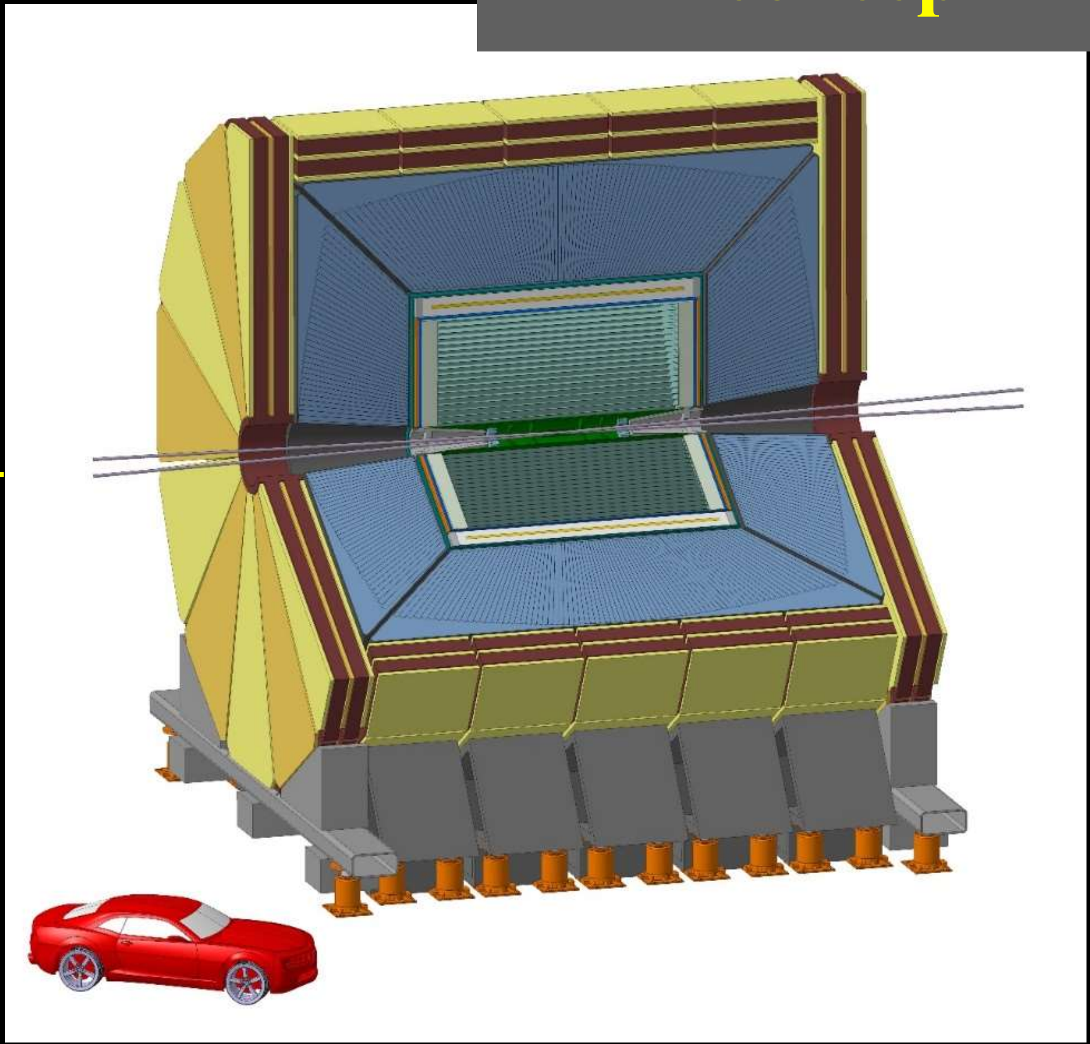
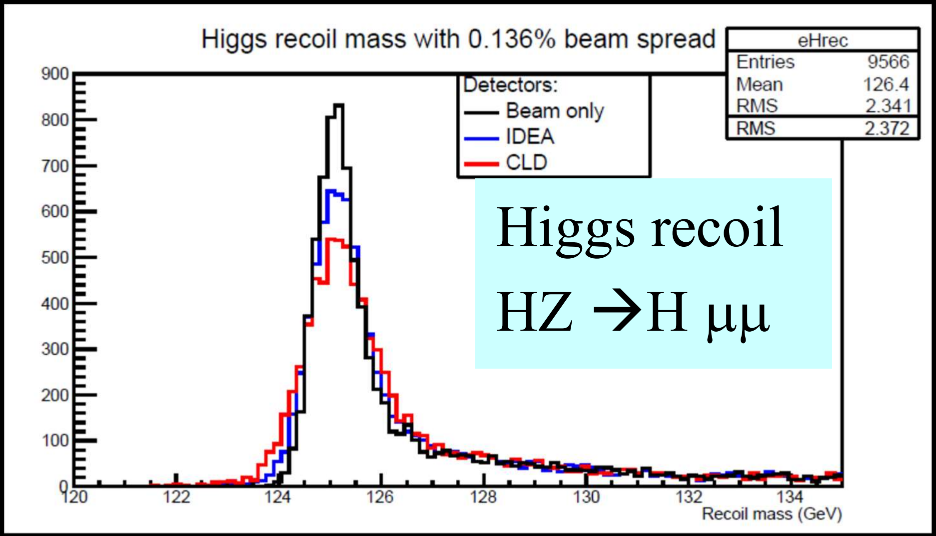
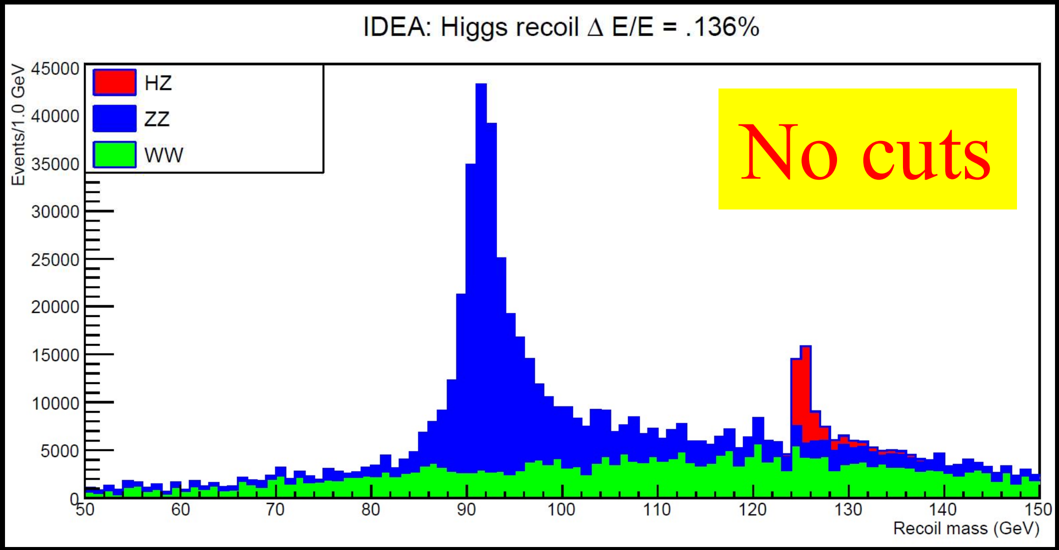


Tracking benchmarks

- Fast simulation with full covariance matrix





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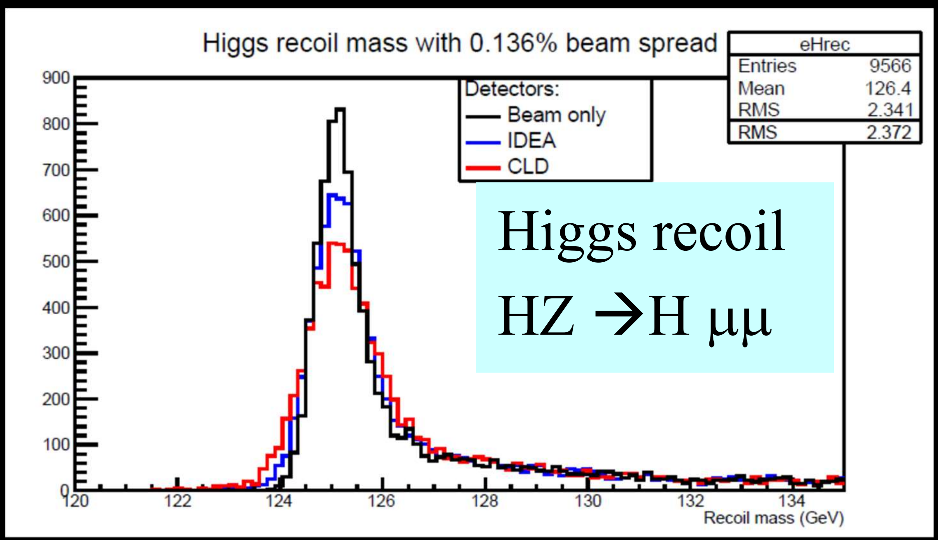

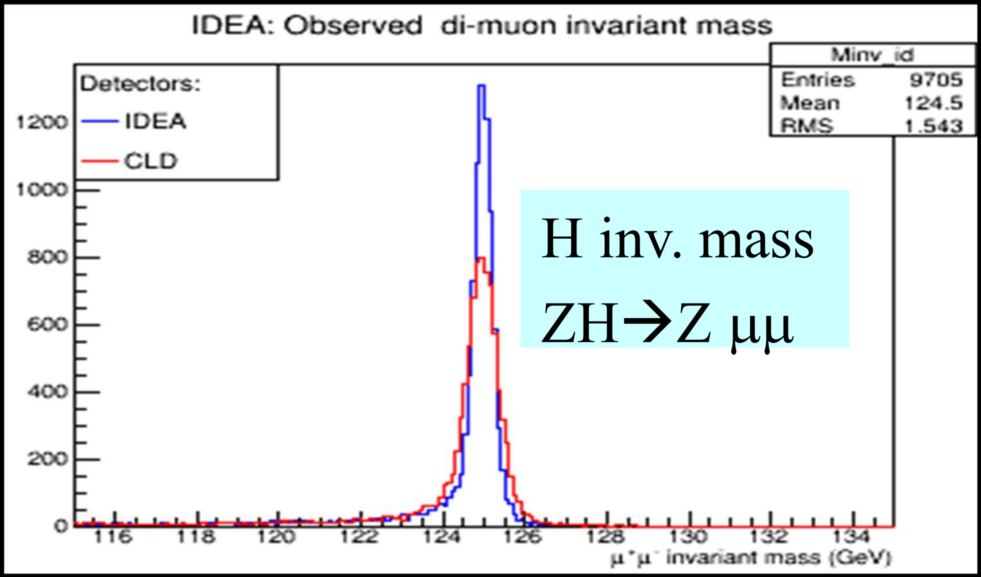

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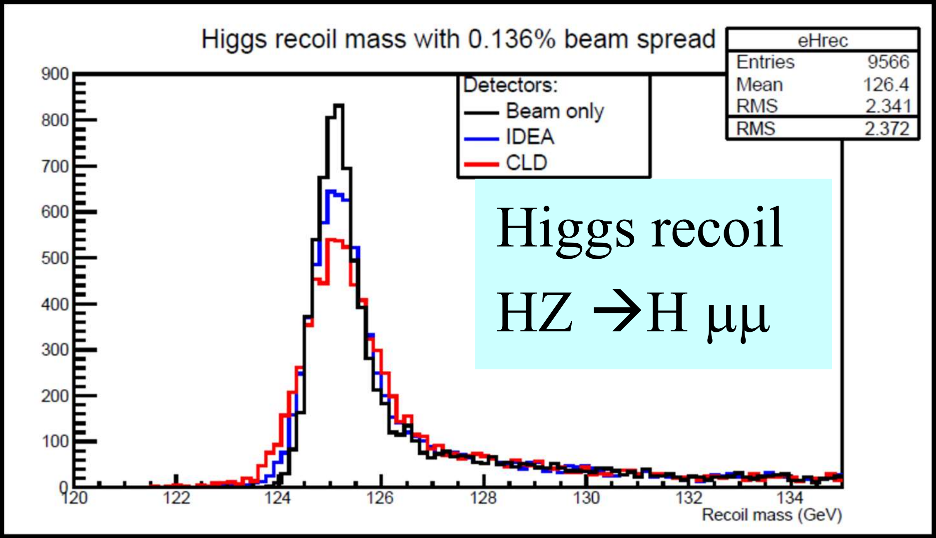
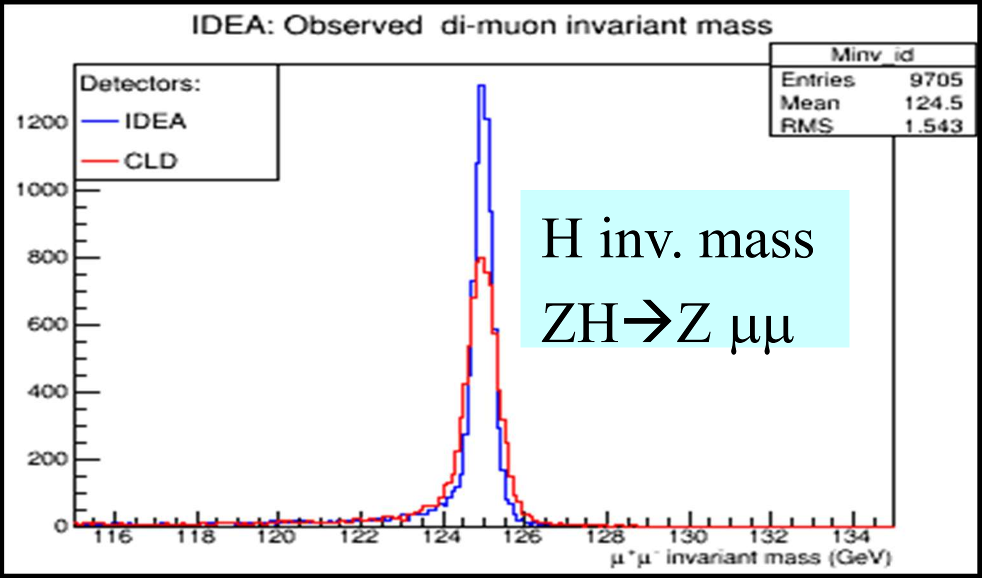
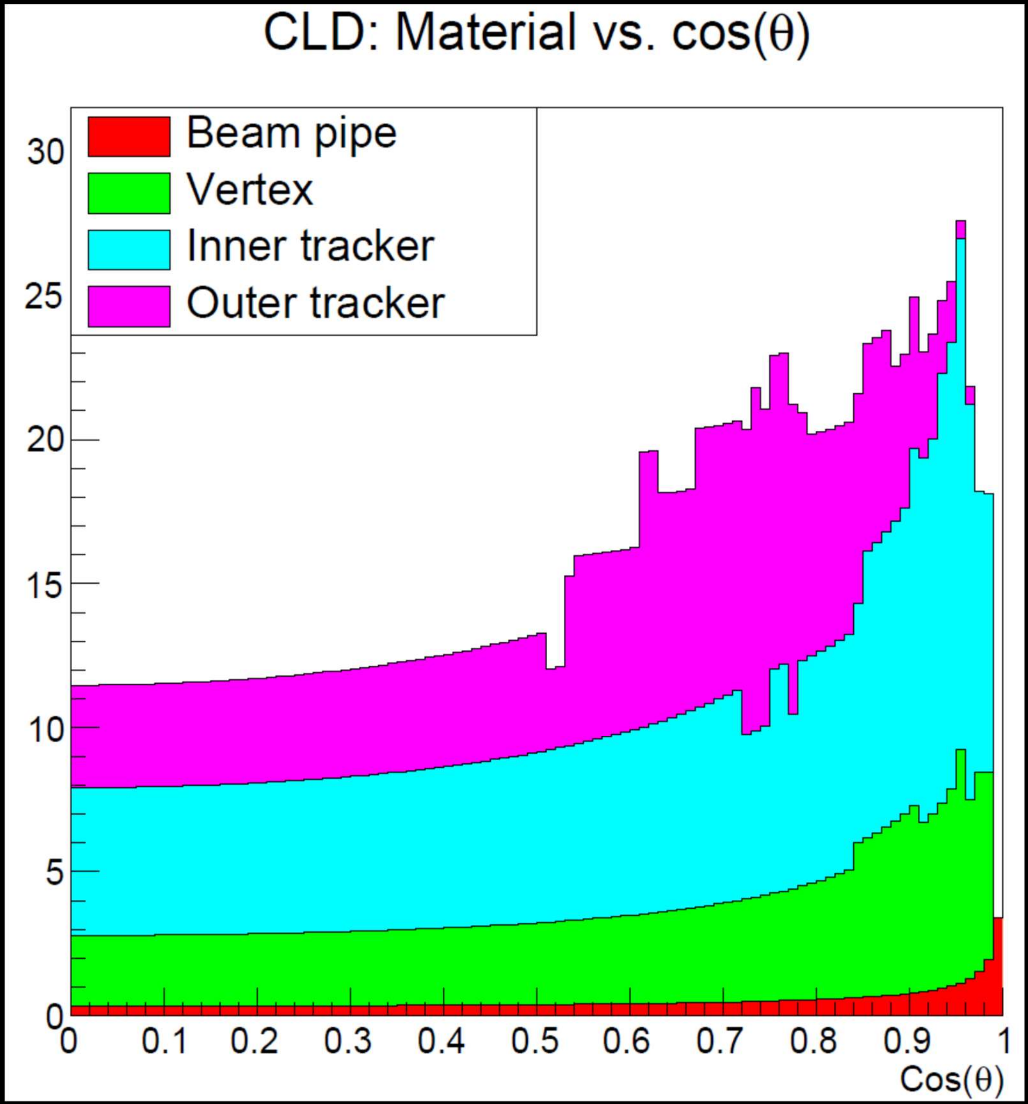




➢ IDEA card now in DELPHES

Transparency



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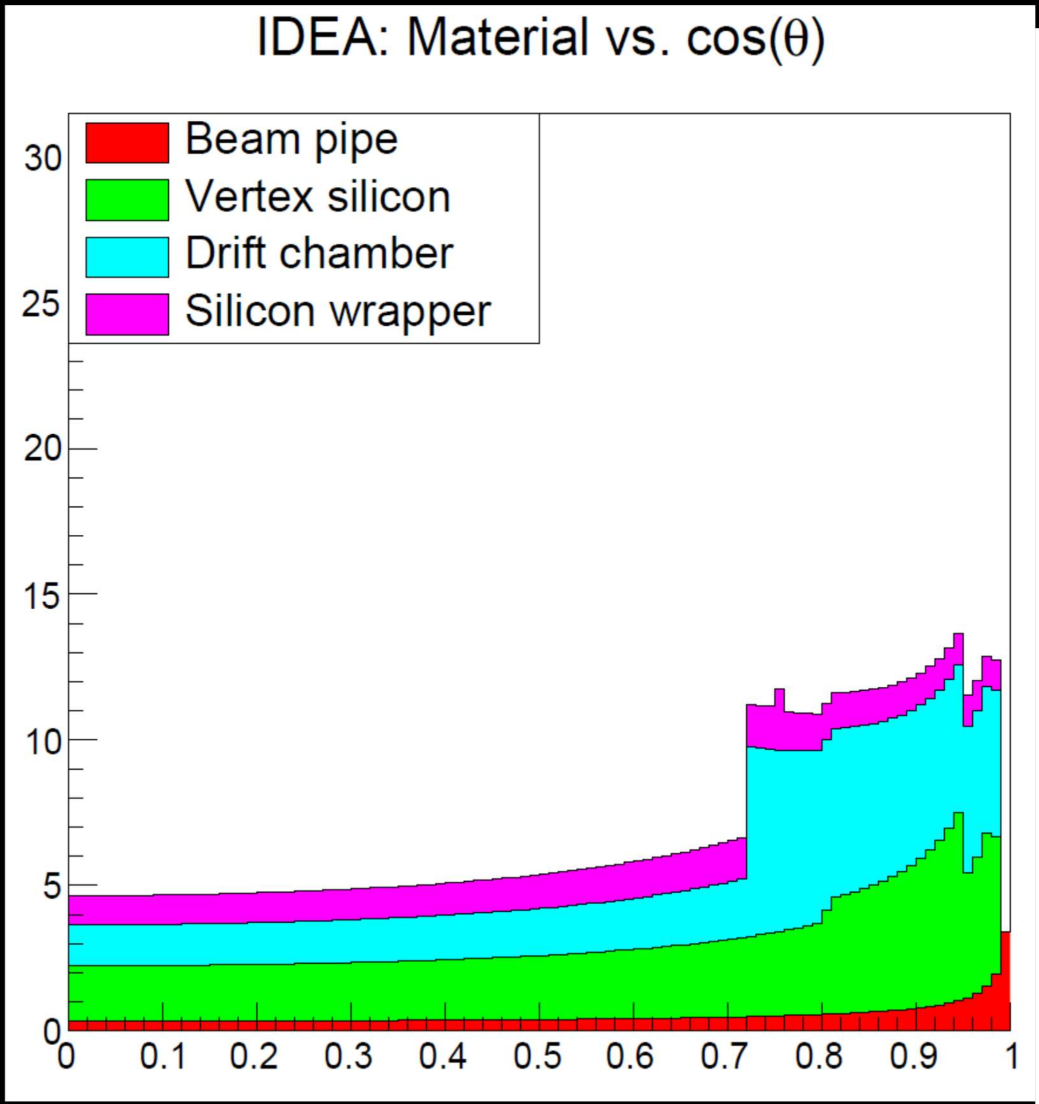
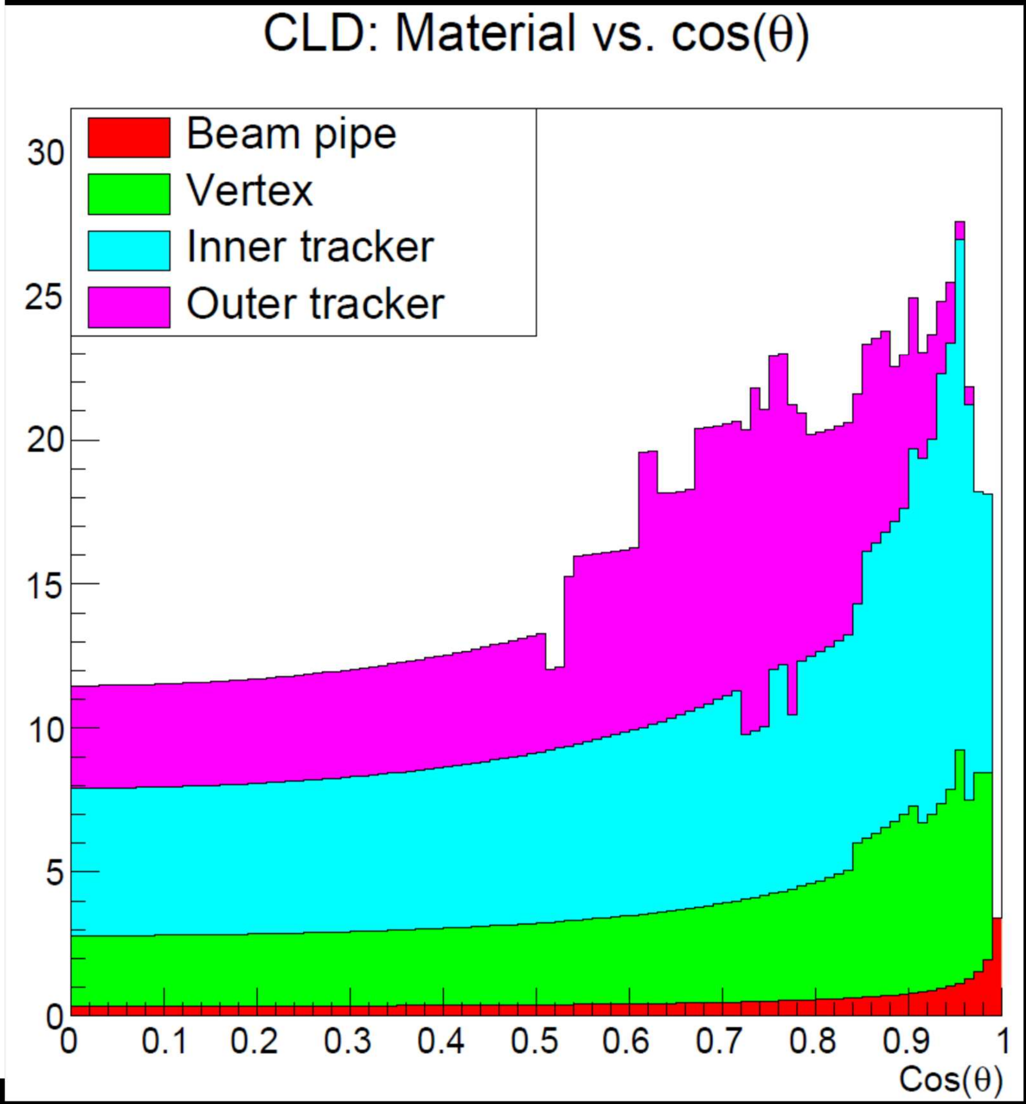
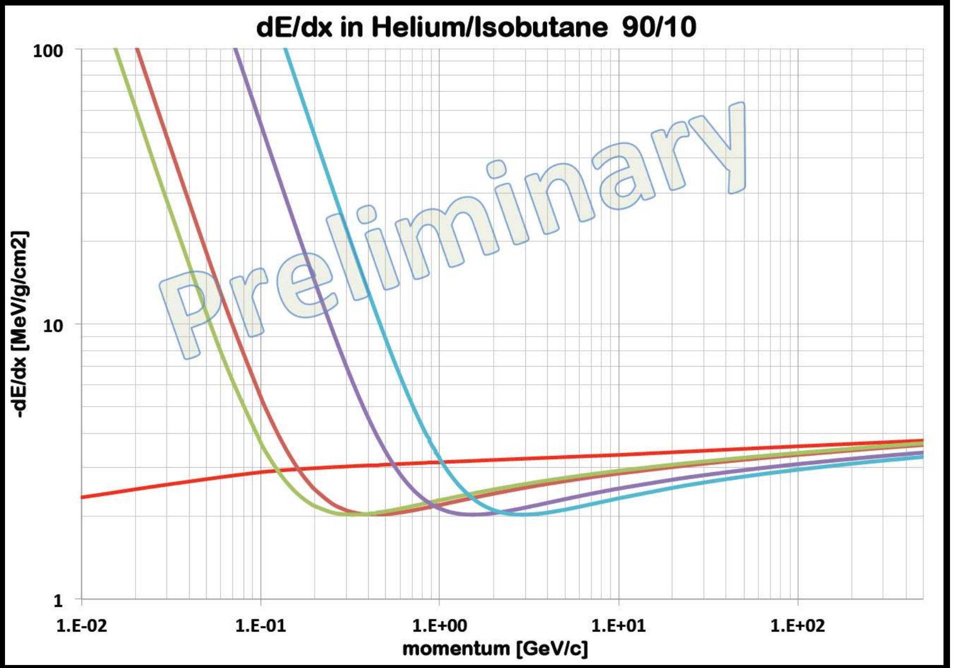
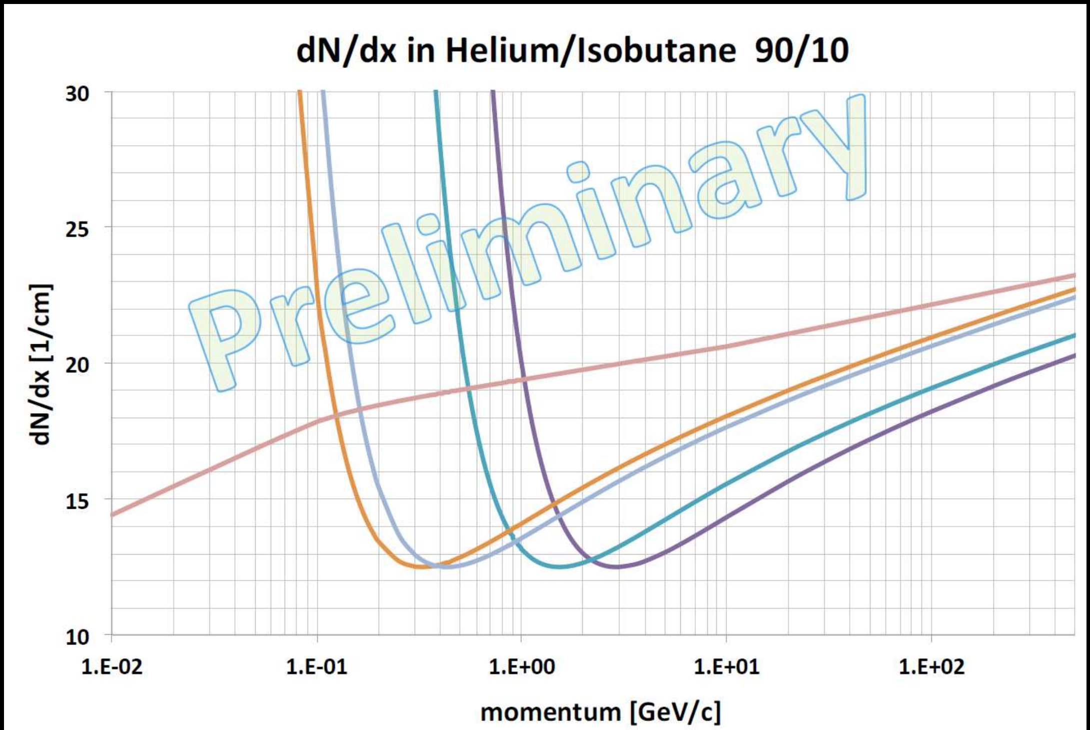




dE/dx vs dN/dx

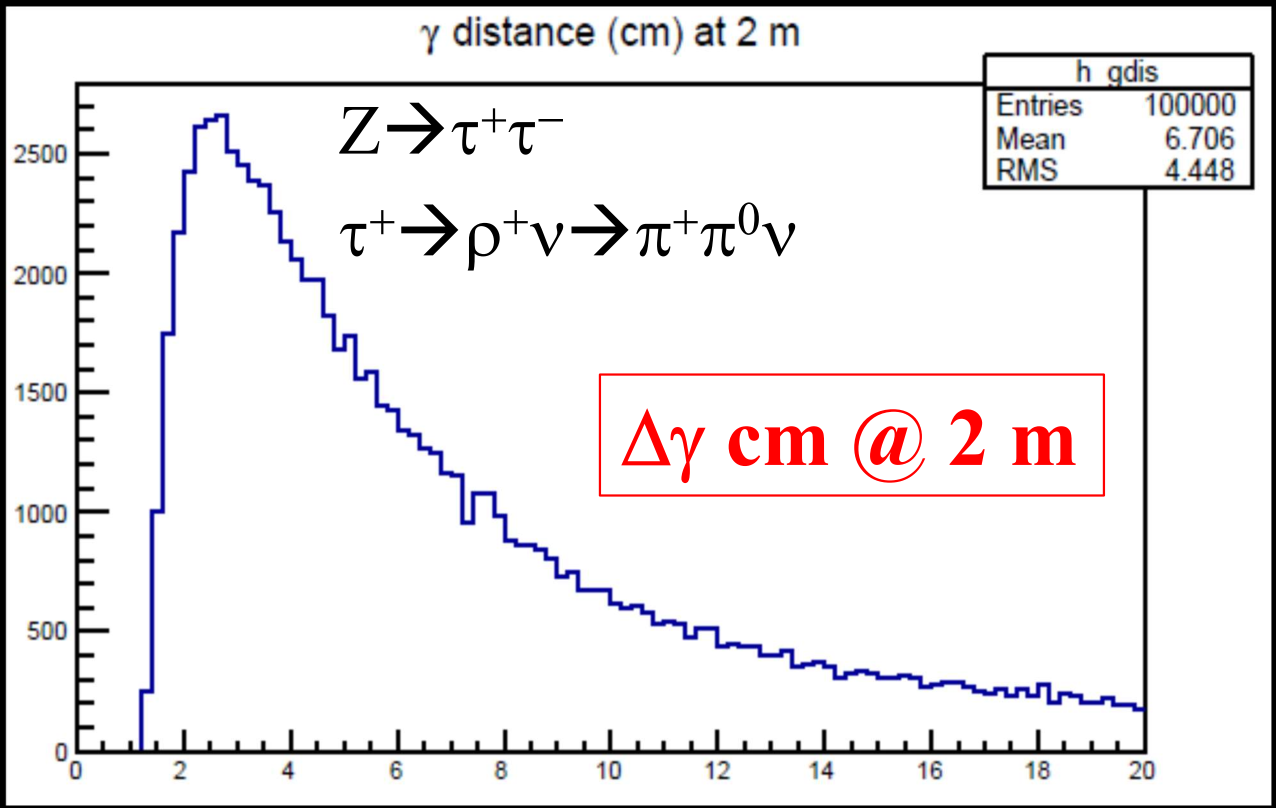
- Steeper high energy rise of #clusters than ionization E





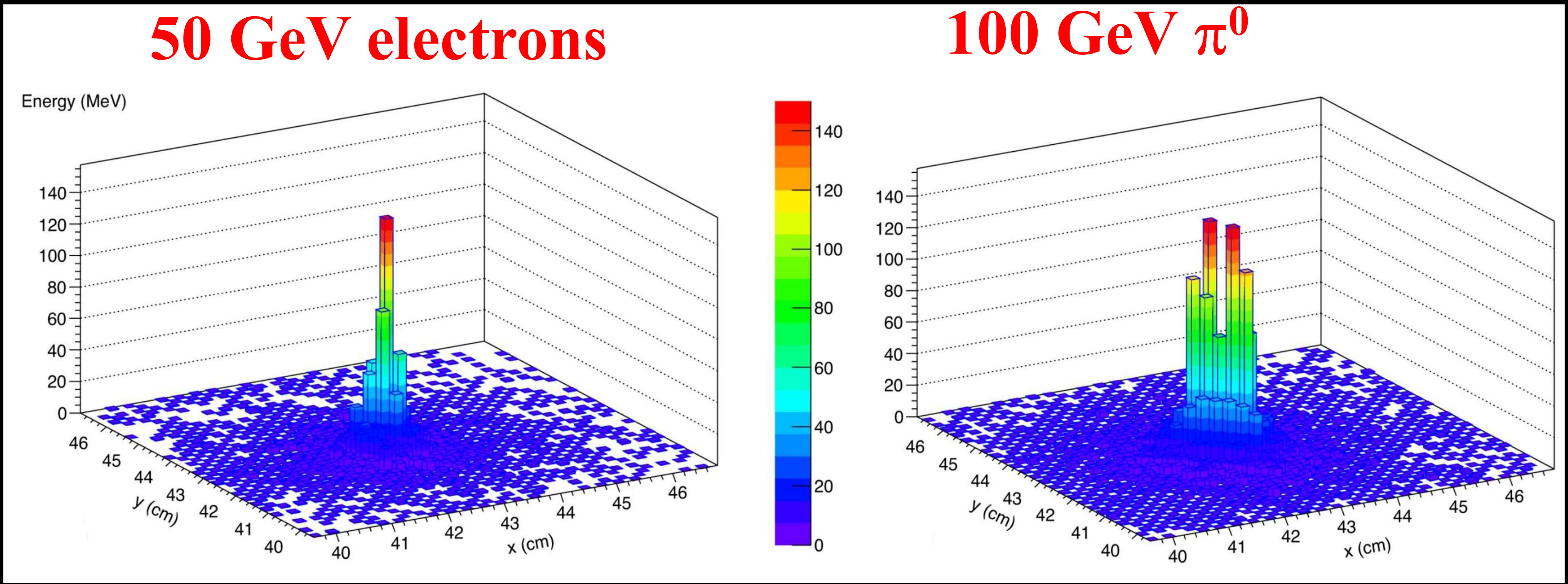
Calorimeter separation (γ)

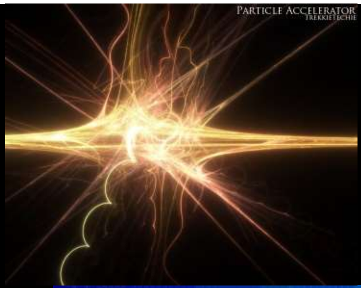
❖ Transverse granularity below 1 cm seems adequate



Calorimeter separation (γ)

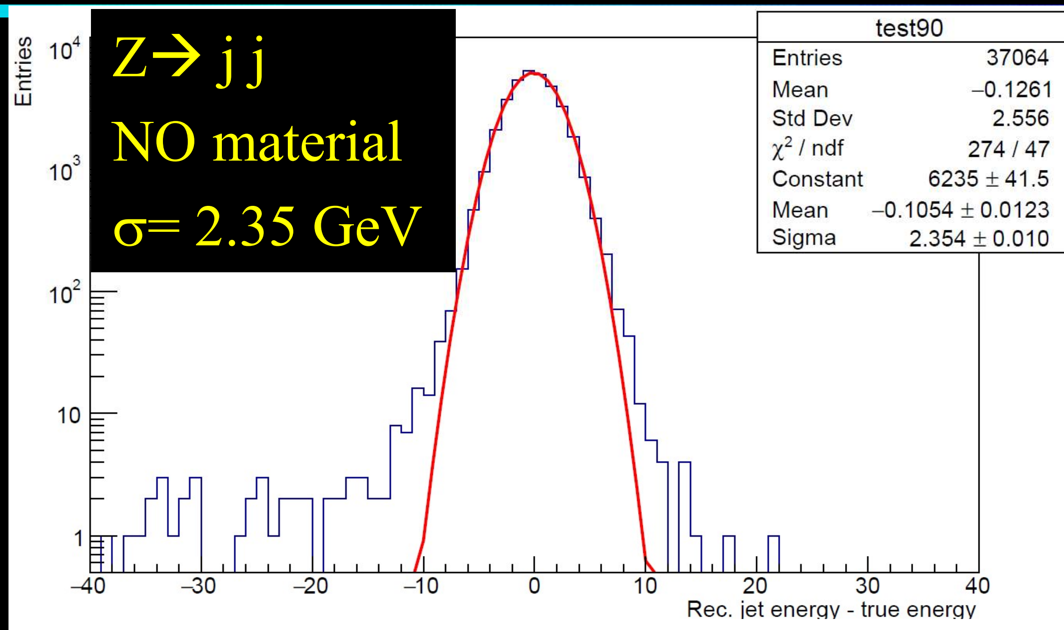
- Transverse granularity below 1 cm seems adequate
- Extreme granularity (~2 mm) achievable with DR
  - At a cost ….

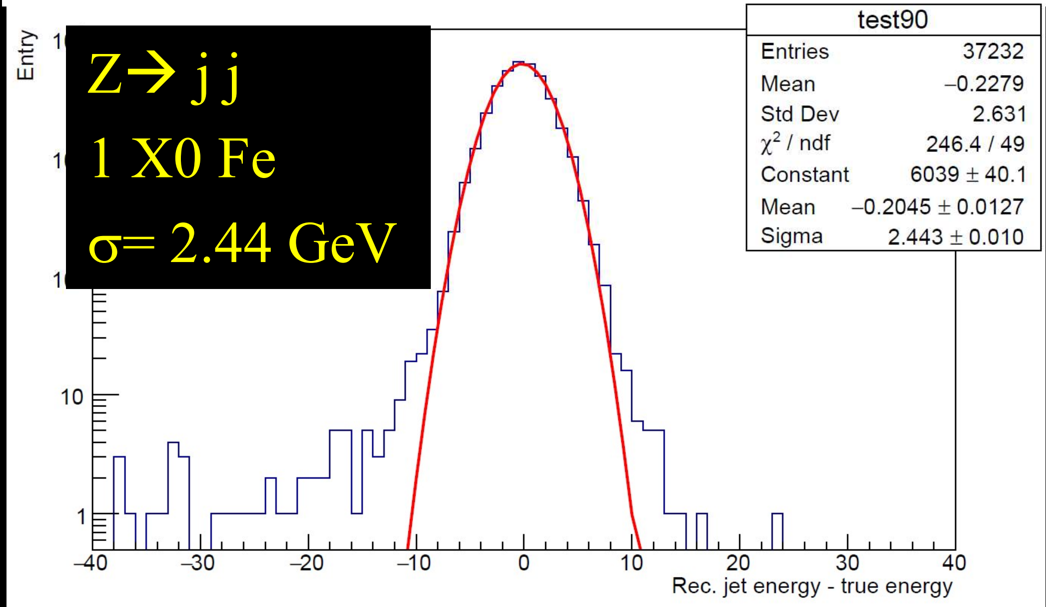


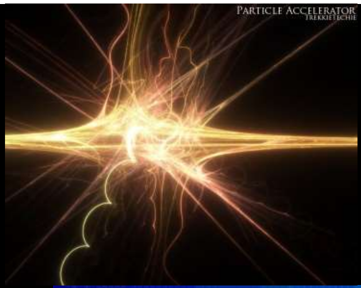


Effect of material

- ❖ Effect of 1 X0 Fe
- ❖ Distance from calor.
  - ➢ 30 cm barrel
  - ➢ 10 cm endcap

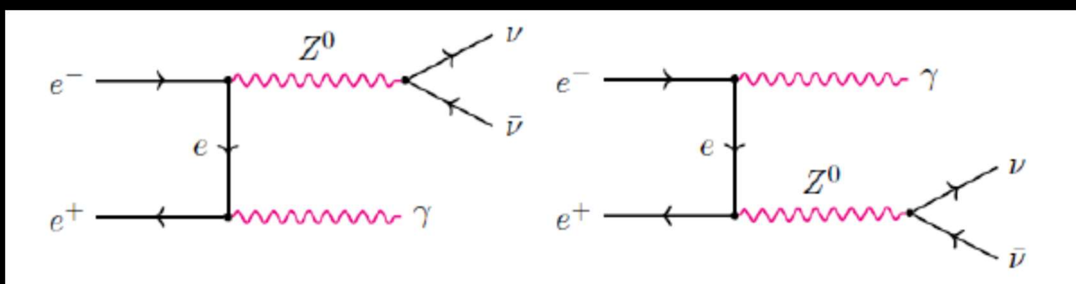


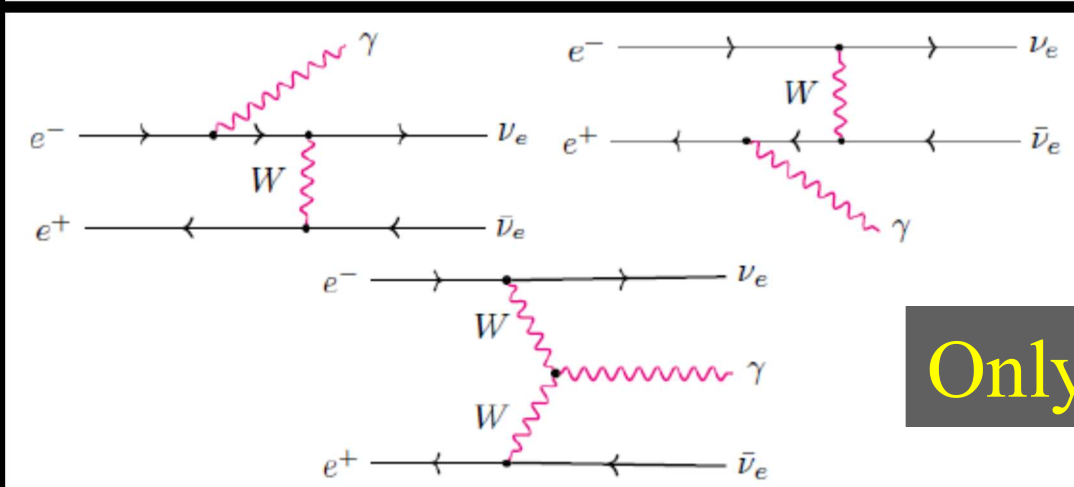




Calorimeter resolution (γ)

- Is 20%/sqrt(E) acceptable? Can we trigger on single γ?
- What about radiative return analysis?
  - Eg. Nν, and Z→ ν_e ν_e





Only ν_e interfere

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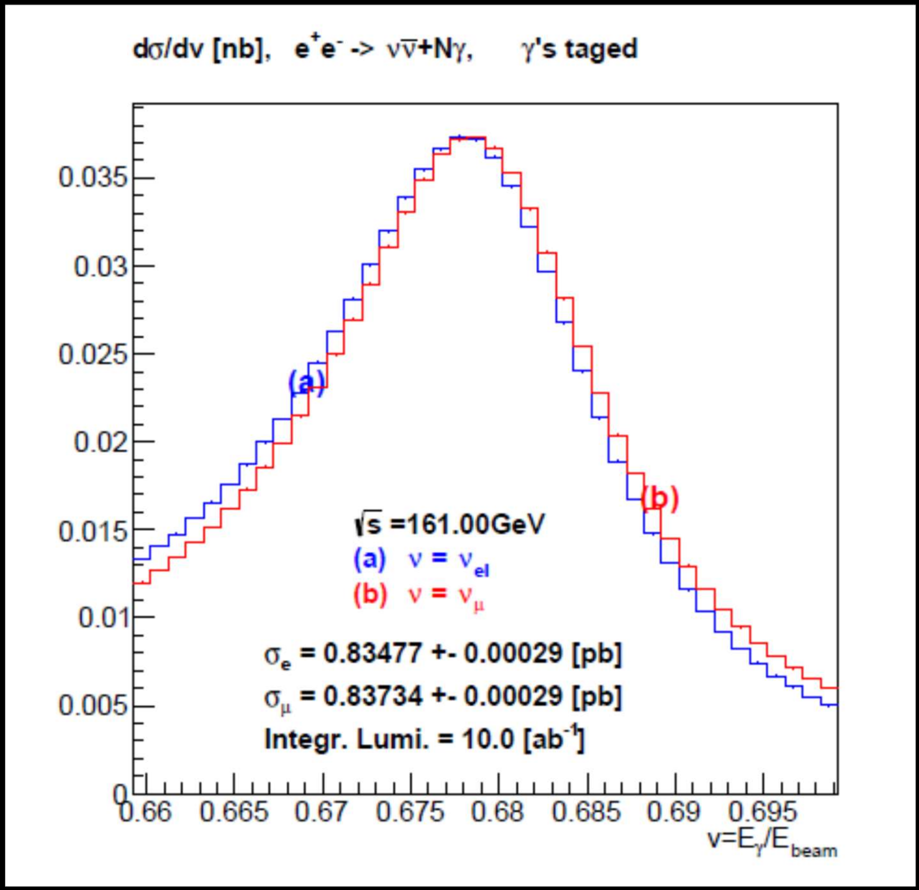

Need 5-10%/sqrt(E) for a good measurement

$\sigma(g_{\nu e})$: 18% →1.4-2.4%

- Worse resolution make separation difficult