LHeC Detector Working Group

Peter Kostka
Alessandro Polini
Rainer Wallny

Outline

- Detector requirements
- Present detector design
- Starting point for discussion
- Outlook and Plans

2nd CERN-ECFA-NuPECC
Workshop on the LHeC

1-3 September 2009
Esplanade du Lac, Divonne, France

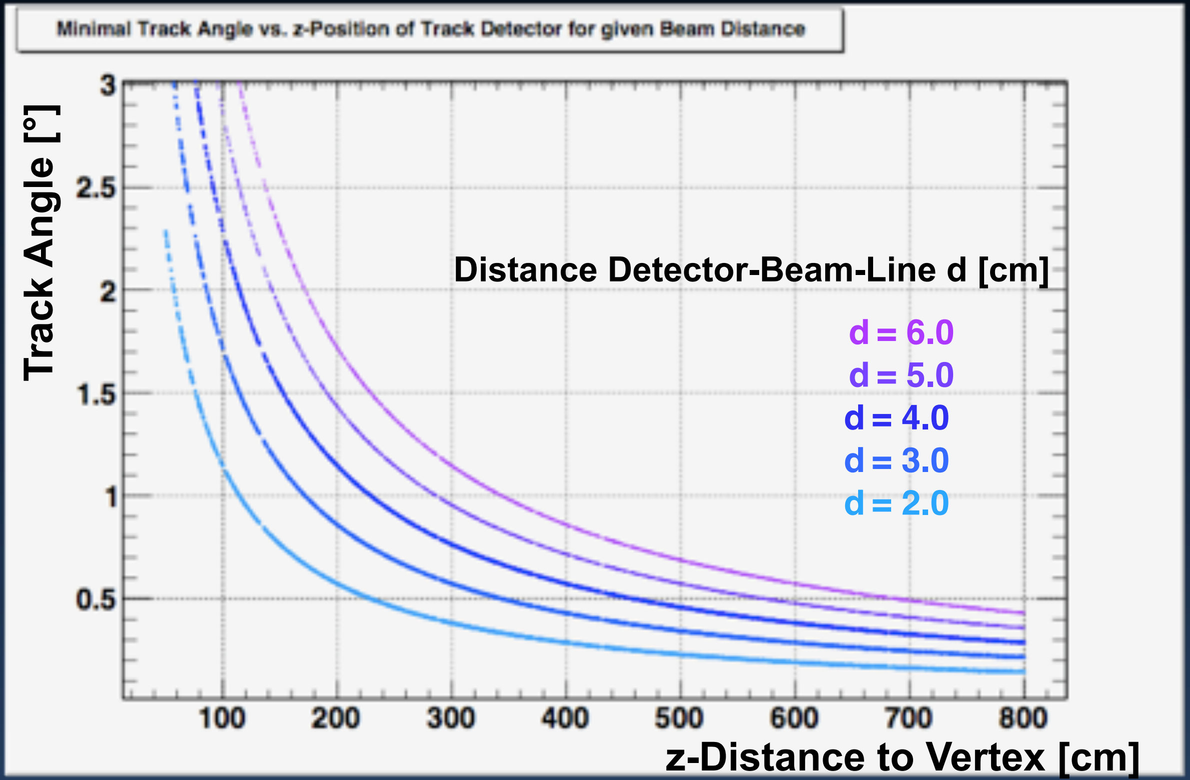
CDR - Topics to be covered

- Detector Concept
  - Dimensions and General Requirements (accuracy, acceptance, beam pipe)
  - Coil
  - Calorimeters
  - Tracking
    (including options as GOSSIP vs. full Silicon)
  - Options for the Inner Detector Region
  - Detector Simulation and Performance

Beam Pipe Considerations

Pipe dimensions – very essential choice: to large extent it determines the size of the detector.

Strong implications in terms of costs and acceptance



Present design: elliptical Be beam pipe from SLHC for now: r_y=2.50 cm (radius of SLHC design) and r_x=3.07 cm (scaled from HERA experience)

→ Dedicate simulation of Interaction region needed (synchr. background)

Detector Requirements (I)

- Tracking
  - lowest mass tracker - essential for $\gamma/e^{\pm}$ ident (specifically bwd)
  - TPC - economical coverage of a large volume with essentially continuous tracking, low material budget - high quality detector performance, dE/dx particle identification and good V_0 recognition.
    TPC near the beam line - TPC background tolerant / BG tolerable? outer radii only?
  - high resolution track definition in front of forward calo
  - tracking trigger in front of fwd/bwd calo, p_t trigger there too?
  - early π^0 ident - vertex detector/trigger

Detector Requirements (II)

Calorimeter

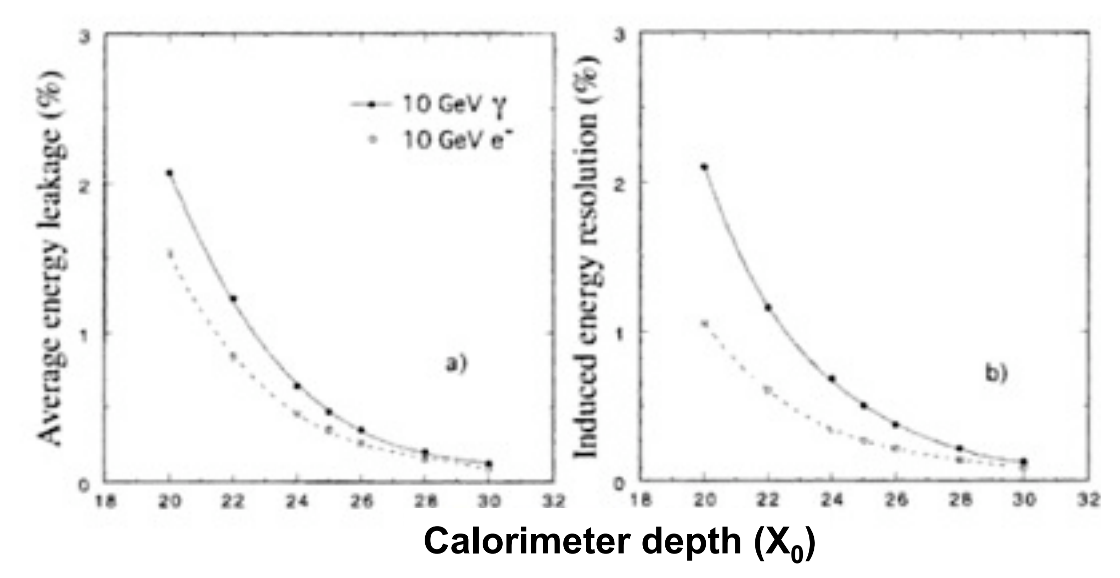
- Minimize longitudinal and lateral energy leakage
- Fwd/bwd Particle Flow Detector to achieve desired mass resolution ; $\gamma/e^{\pm}$; π^{0} ; …
  This technique combines the tracking/calorimetry information in an optimal way in order to get the best possible jet-energy resolution.
  Or Dream (dual readout) - event to event correction
- Both electromagnetic and hadron calorimetry inside the solenoid coil; minimum material inside EmCal;
- Prototyping, test at high energy!

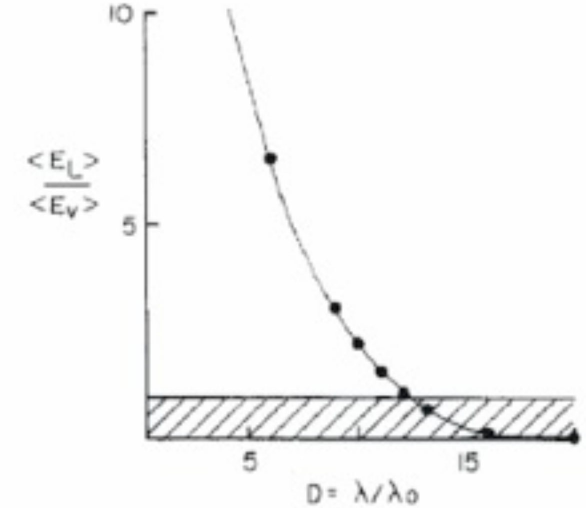
Magnetic Field

- 3.5 Tesla solenoidal field

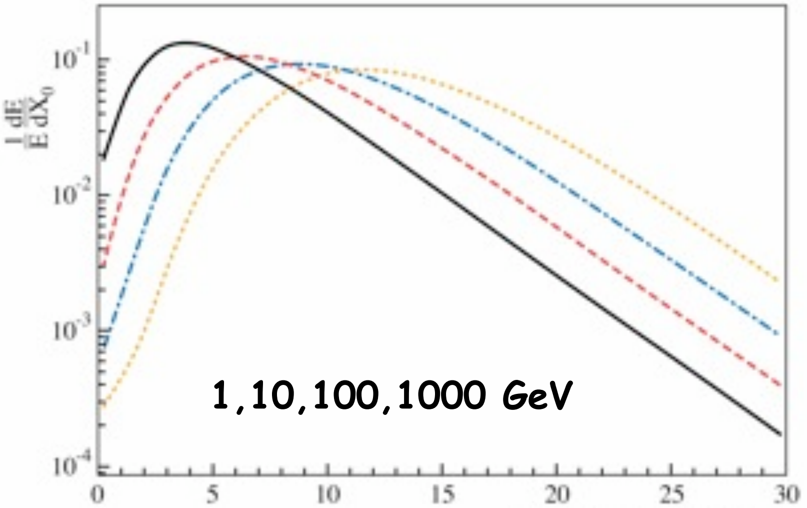
Reminder / Calorimeter Essentials

Wigmans





Ratio of energy loss due to longitudinal leakage divided by loss due to neutrinos vs thickness in interaction lengths



Longitudinal profile

… the detector

… a very first draft

LowQ^2-Detector

	Radius [cm]
Elliptical pixel detector:	2.9–4.6/3.47-6.05

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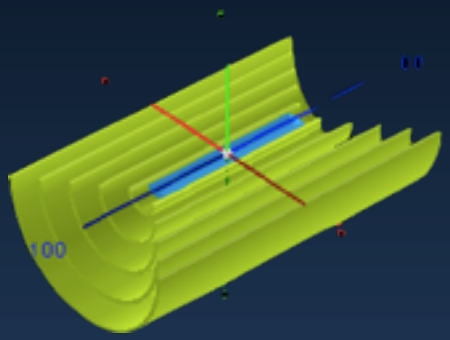
Barrel layer 1-5:	7.5–61



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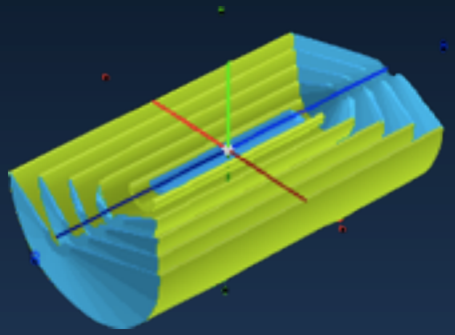

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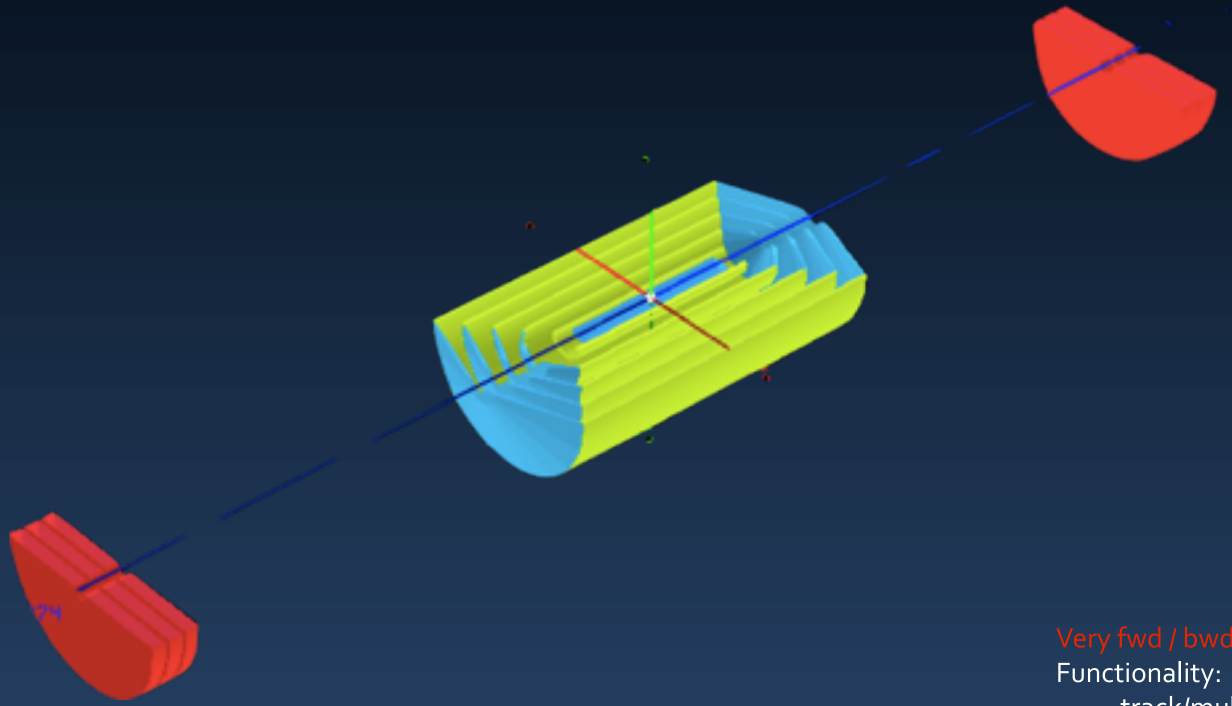
Very fwd/bwd Plane 1-3:	5–60



Very fwd / bwd Plane 1-3:
Functionality:
- track/multiplicity trigger
- transition radiation - e/π ident
- precise track segment, $\gamma/e^{\pm}$ ident

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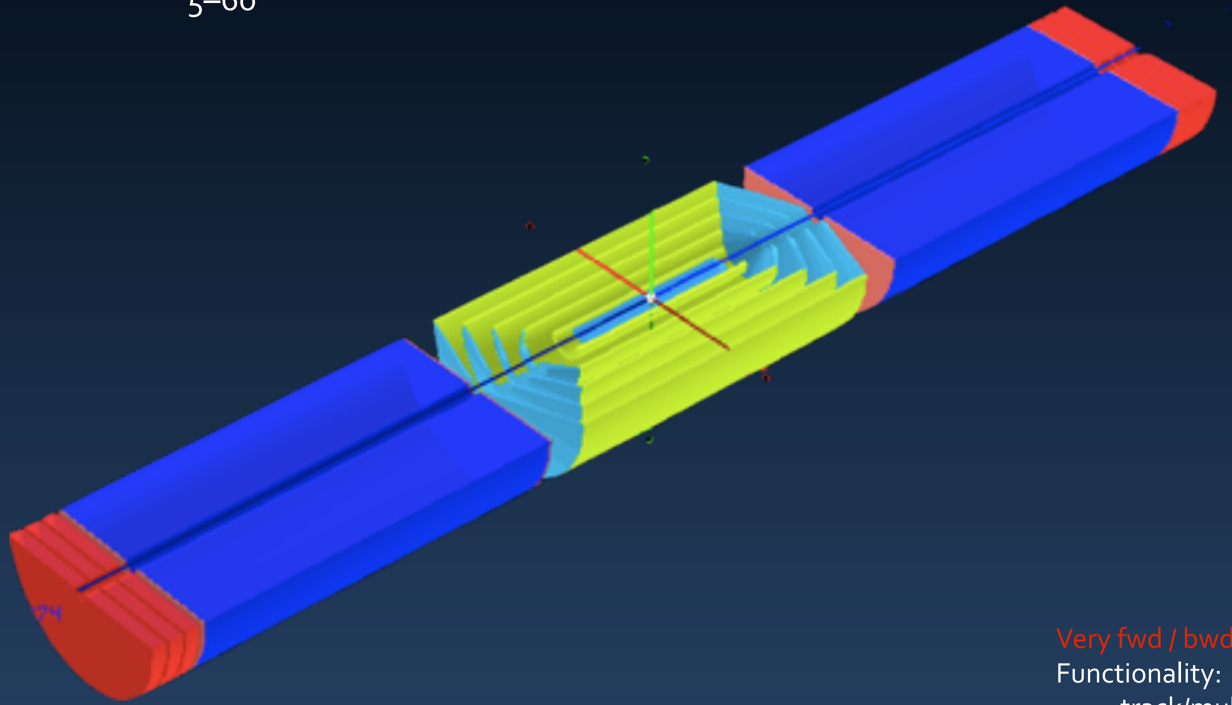

Very fwd / bwd Plane 1-3:
Functionality:
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fwd/bwd TPC: to be solved - light weight field cage!
(half length 110 cm)

Functionality:
coverage of a large volume with essentially continuous tracking, low material budget - high quality detector performance, dE/dx particle identification and good V_0 recognition

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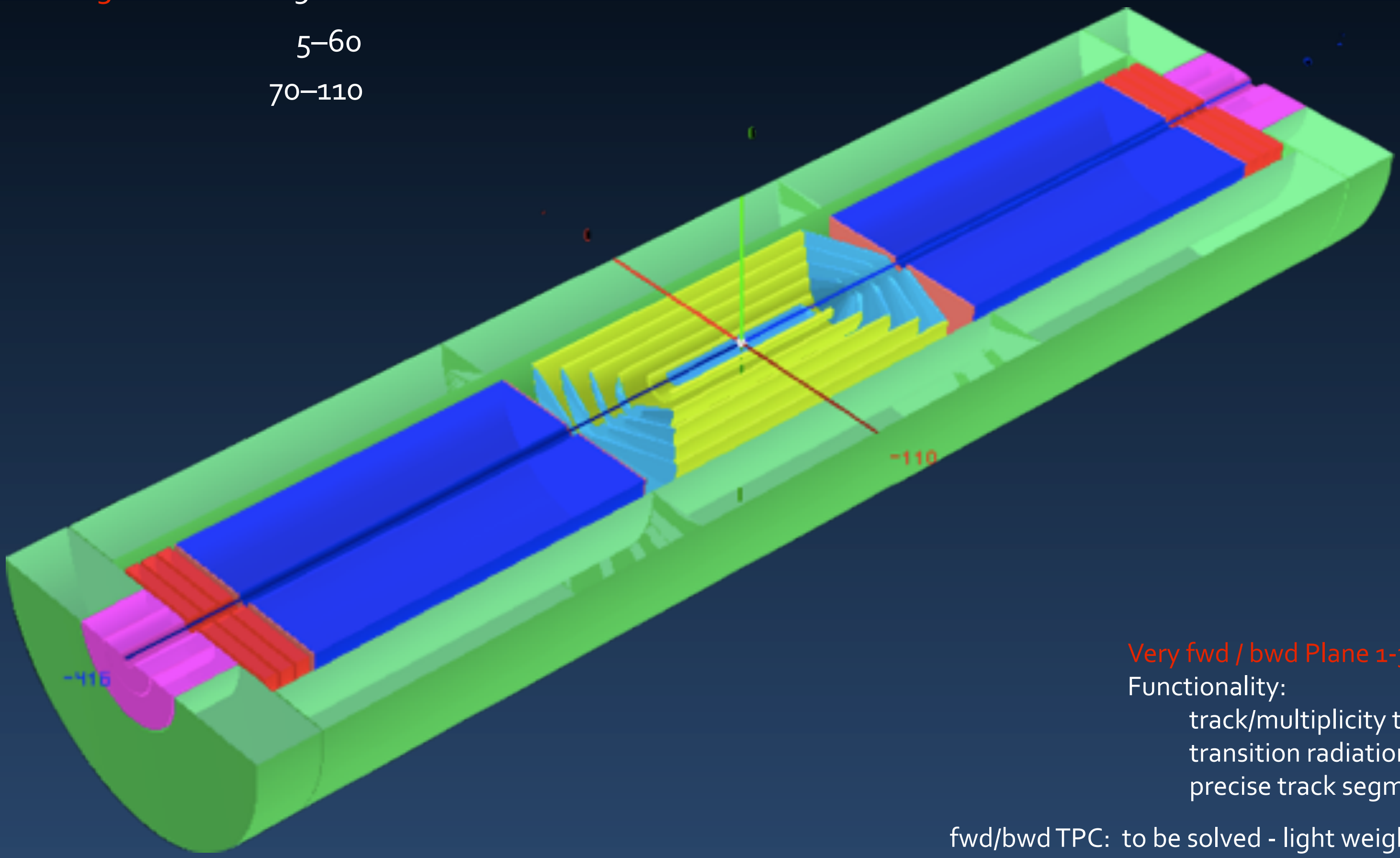
EmCAL:	70–110



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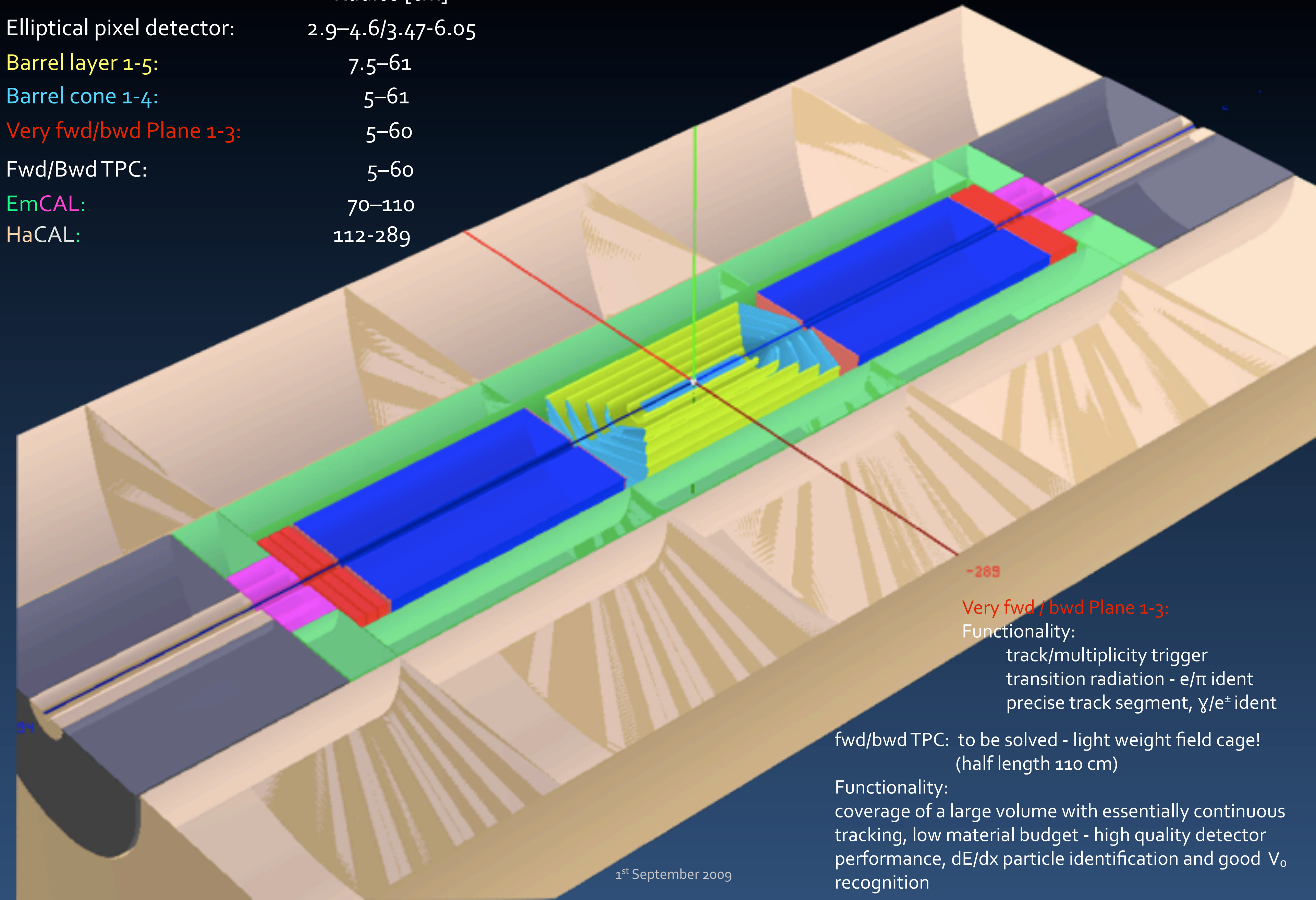
EmCAL:	70–110
HaCAL:	112-289



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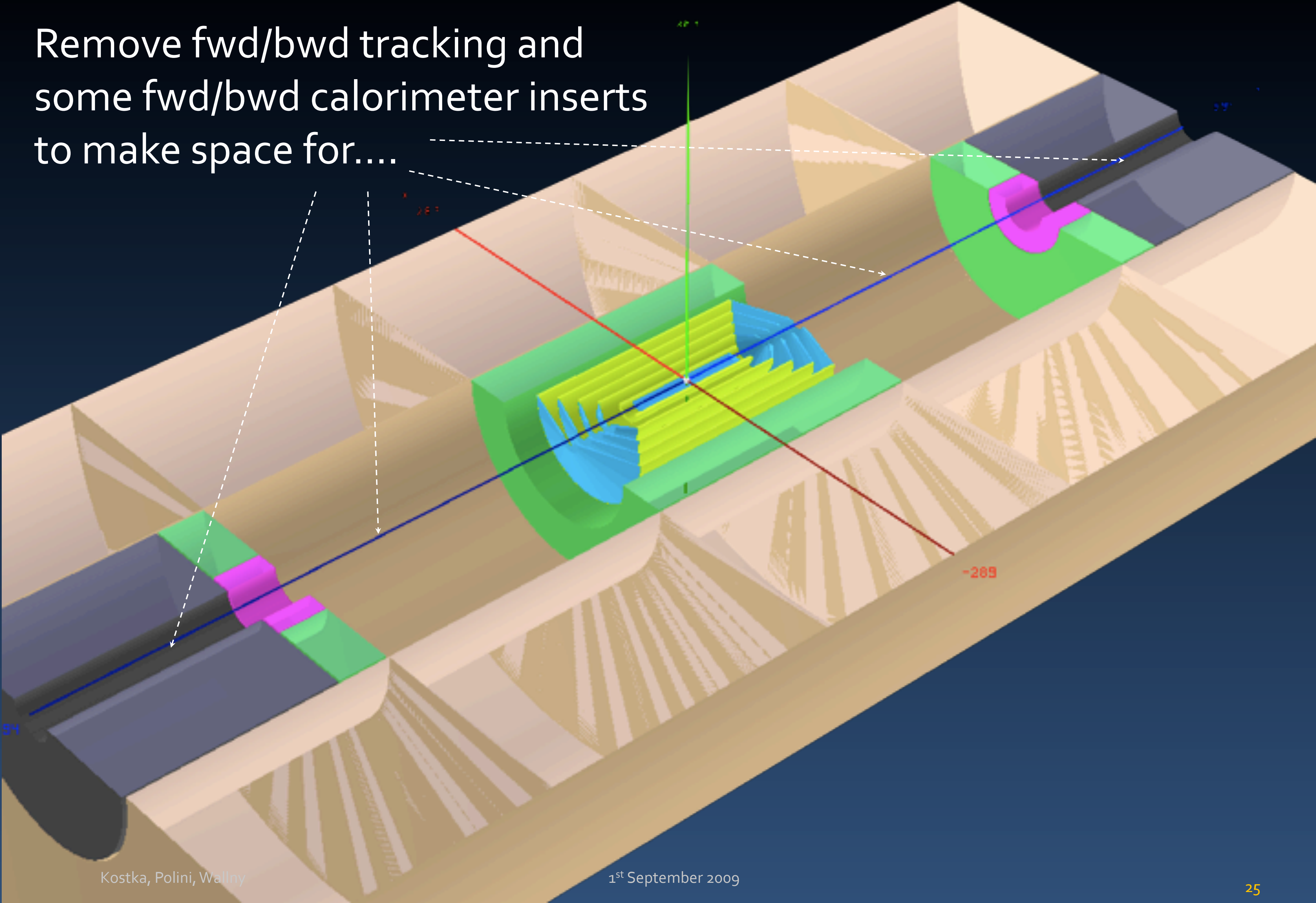
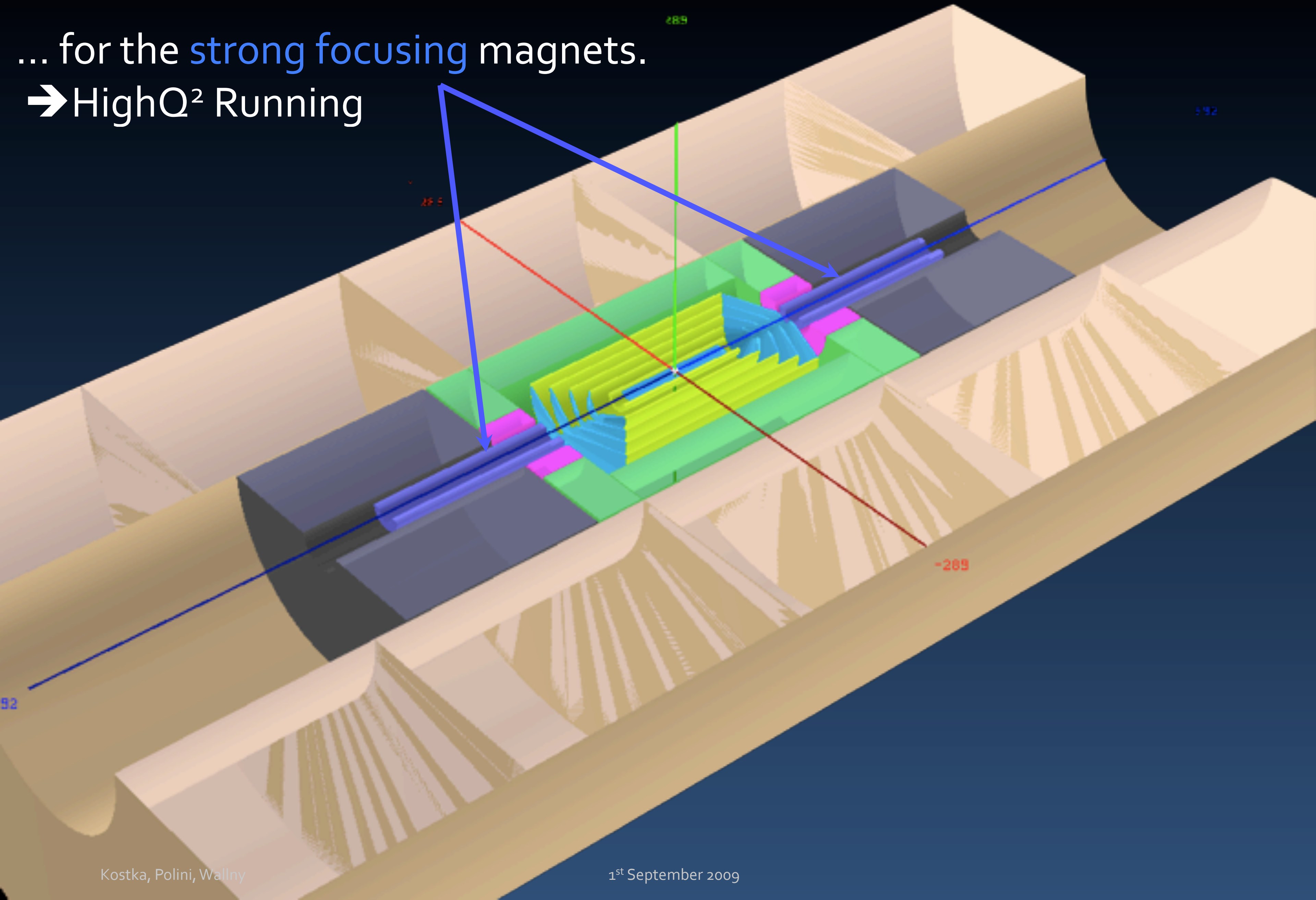


Remove fwd/bwd tracking and some fwd/bwd calorimeter inserts to make space for….

High Q^2 configuration

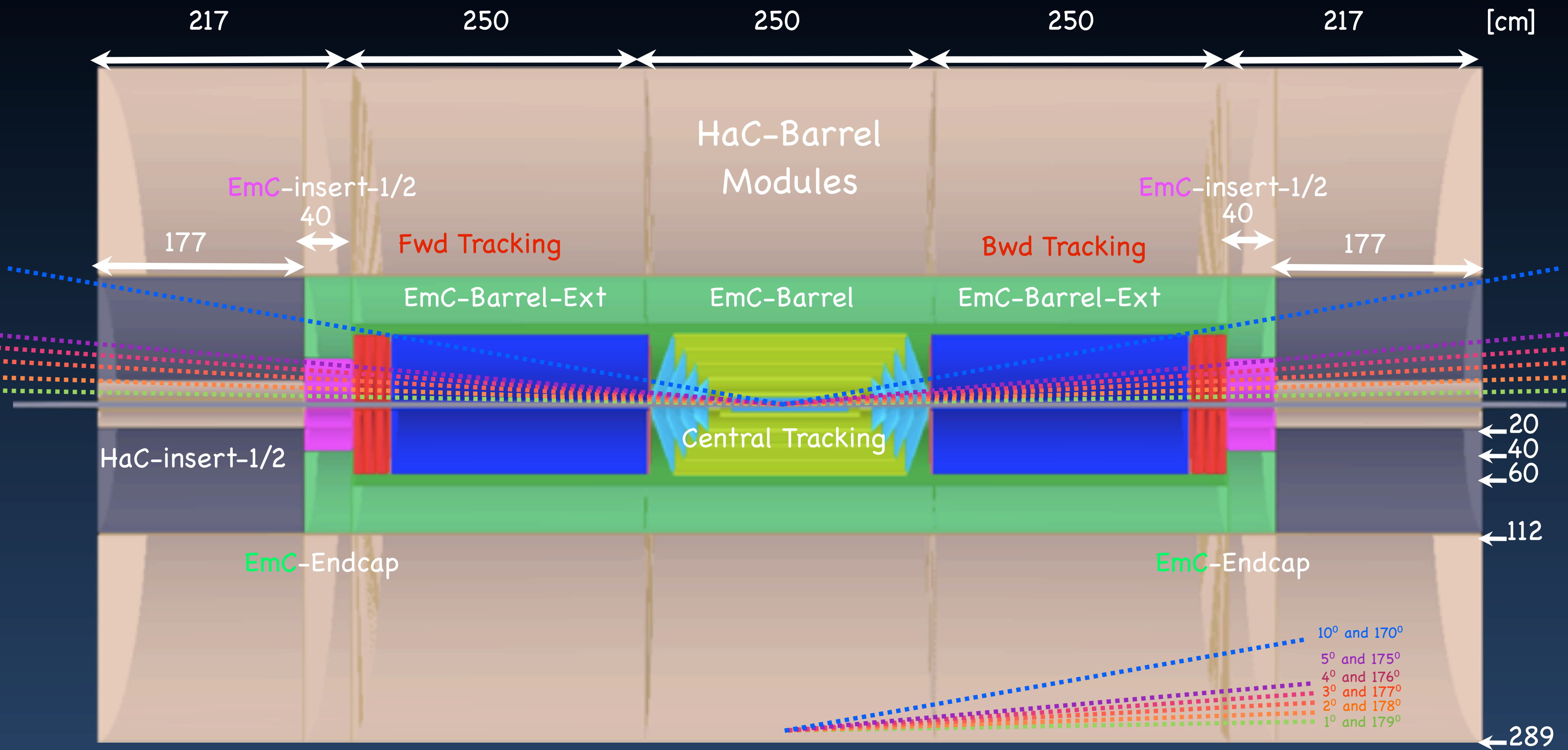
… for the strong focusing magnets.

→ HighQ^2 Running



The Detector - Low Q^2 Setup

(to be optimised)

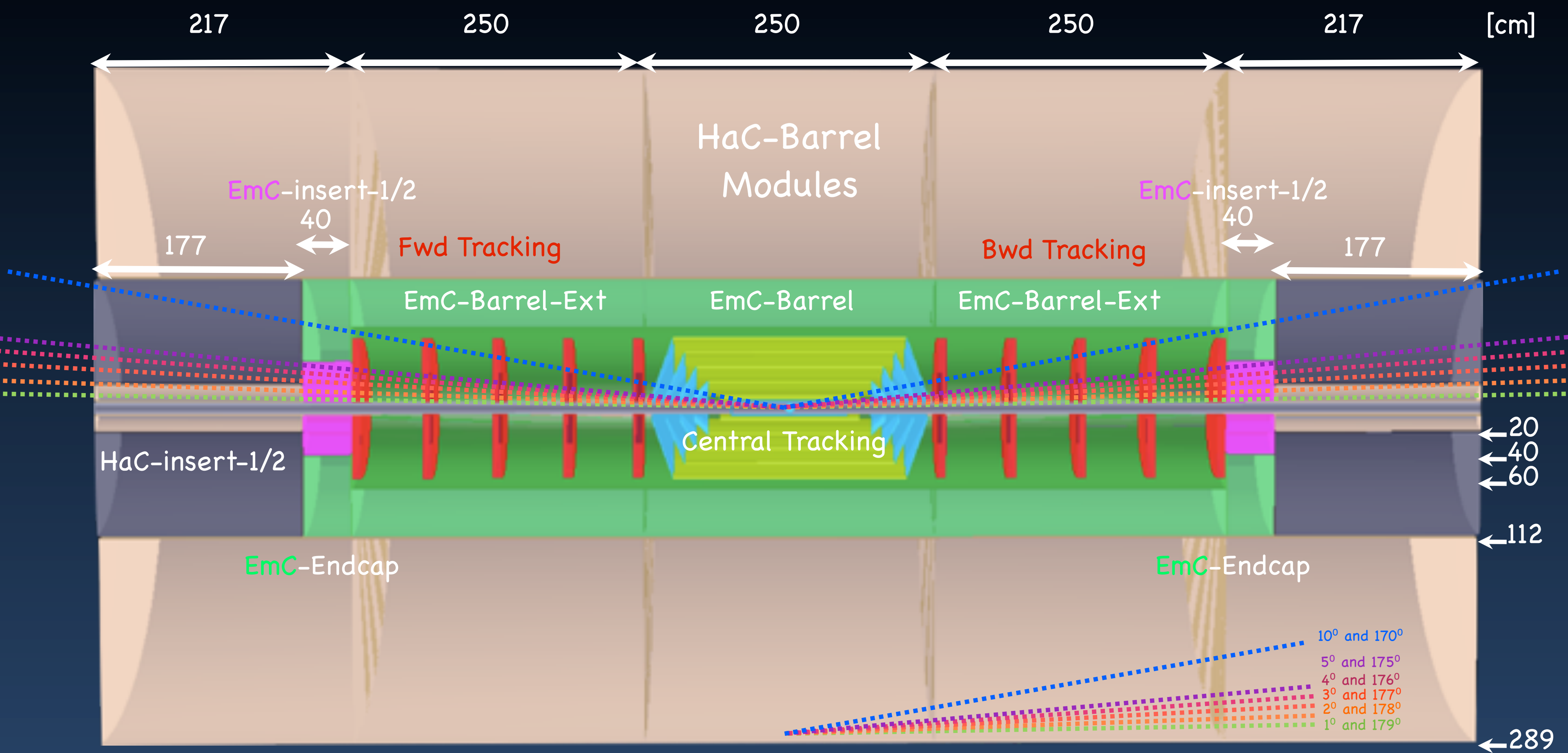


- Solenoid surrounding the HAC modules
- Outer detectors (HAC tailcatcher/muon detectors not shown)

Not discussed either: very forward detector setup – very essential – but postponed

The Detector - Low Q^2 Setup

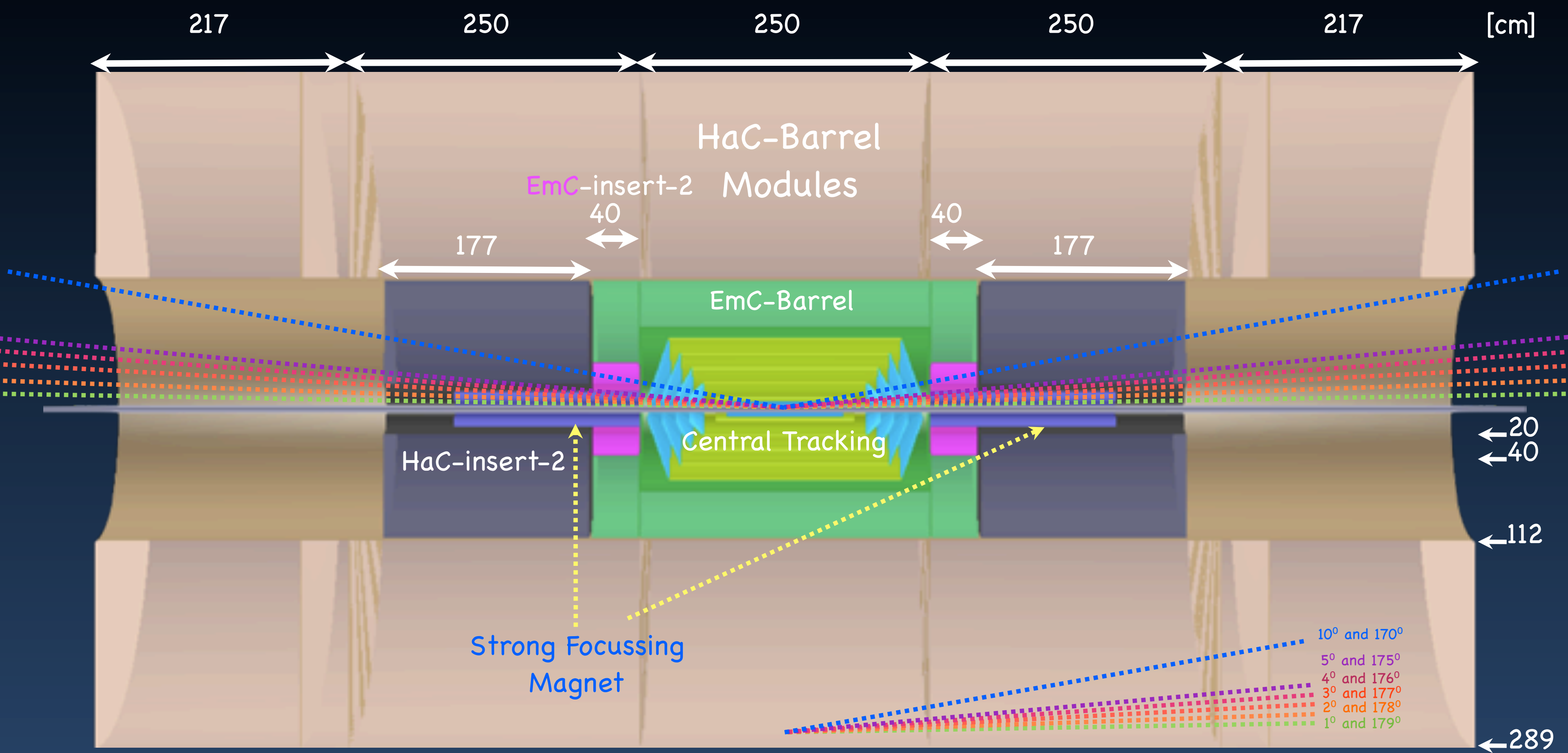
(to be optimised)



- Alternative fwd/bwd tracking - Si-Gas double planes

The High Q^2 Setup

(to be optimised)



L1 Low Q^2 SetUp → High Q^2 SetUp

- Fwd/Bwd Tracking & EmC-Extensions, HaC-Insert-1 removed
-Calo-Inserts in position
-Strong Focussing Magnet installed

Overview - Core Detector

Radius (cm)	Subdetector	Comment
2.9–4.6/3.47-6.05	2 layer ellipt. V_{pix}	δ(IP) < 10 μm
7.5–61	5 layer Si-Gas barrel	
5–61	4 cone Si-Gas barrel	
5–60 ($z_{1/2} \approx 110$)	fwd/bwd TPC	field cage - material?
5–60	fwd/bwd × 3 × 2 planes Si-Gas	
70–110	ECAL	25-30 Xo
112-289	HCAL	6-10 λ_I
300–330	Coil	3.5 T - tracking
340–700	Fe/muon, ...	

Not covered:

very forward detectors, lumi measurement ...

may be important for e-nucleon running:
TOF system, Zero Degree Calo ...

Exercise Track Resolution

- i.e. assuming / using (Glückstern relation): $\frac{\sigma(p_\perp)}{p_\perp} = \frac{\sigma(x)}{aBL^2}\sqrt{\frac{720}{N+4}} \cdot p_\perp$ with $a = 0.3\,T^{-1}m^{-1}GeV$

  N track points on L; length of track perpendicular to field B, accuracy σ(x)

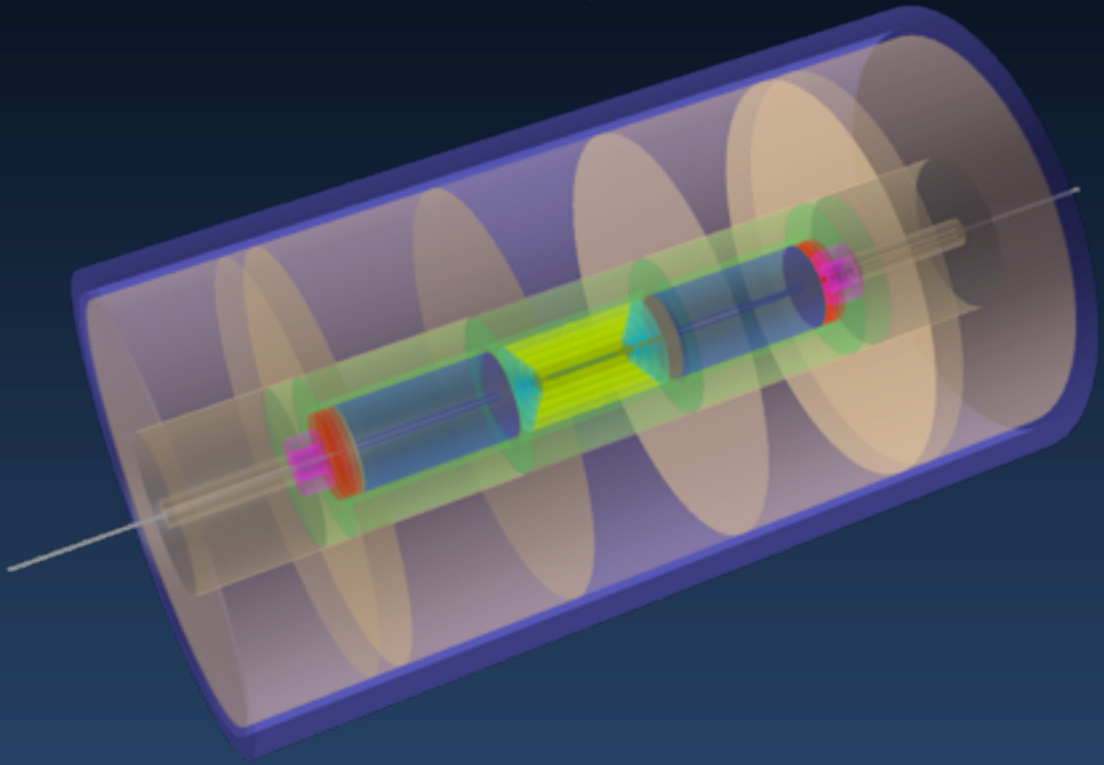
  - B = 3.5 T
    N_{min}= 56 track points (2 x 5 (min. hits per layer) x 5 + 2 x 3 B-layer hits)
    - si-gas cone modul ~10^0 inclined
      more track points for inclined tracks - extended track segments
  - $\Delta p_T/p_T^2$ = 0.03%

- track accuracy = 15µm -> track length 42 cm - tracker layout: 54 cm (90^0 track)
- track accuracy = 25µm -> track length 53.7 cm

- track accuracy = 15µm & θ = 5^0 & N_{min} = 90 -> length ~39cm -> $\Delta p_T/p_T^2$ = 0.025 for p_T = 10GeV
- track accuracy = 25µm & θ = 3^0 & N_{min} = 60 -> length ~20cm -> $\Delta p_T/p_T^2$ = 0.194 for p_T = 10GeV
- track accuracy = 15µm & θ = 3^0 & N_{min} = 60 -> length ~20cm -> $\Delta p_T/p_T^2$ = 0.12 for p_T = 10GeV
- track accuracy = 15µm & θ = 3^0 & N_{min} = 110 -> length ~20cm -> $\Delta p_T/p_T^2$ = 0.086 for p_T = 10GeV

Solenoid

Modular structure: assembly on surface level or in the experimental area depending on time constraints and access shaft opening



Solenoid dimensions:

- 480~594 cm half length
- 291 cm inner radius
- B field = 3.5 T

Geometry constraints:

- Current beam pipe dimensions
- Requirement of 1° tracking coverage
- Homogeneous B field in the tracking area

Magnet Essentials

- Present option:
  Conservative Solenoid with B field =3.5 T

- Attractive design with a 2 solenoid solution, tracking: +5T and -1.5T in the muon area if 4th concept design followed.

→ Decide after detailed machine/physics studies and cost considerations

From discussion with experts (H. Ten Kate, A. Dudarev) any design feasible.

- The High Lumi detector setup requires strong focusing magnet at ~120 cm from IP (avoidable?). Severe acceptance limitations. Dimensions of strong focusing magnets
  ∅ = 30cm now

→ Instrumentation of focusing magnets - tracking/ calorimeter device *)

*) T.Greenshaw, Divonne LHeC 2008 and this workshop

Detector Simulation

- What you have seen so far is a detector drawing
- Precise detector simulations are needed:
  - optimize full detector designs for physics performance on mission critical processes
  - optimize the designs of subsystems and subdetectors
  - compare proposed detector technologies with each other (in concert with test beam)
- The hardware selection aspect makes use of world wide efforts for the preparation of ILC and SLHC experiments
- The hope is that the developers involved there will share there knowledge/experience with us and new centre's are attracted to help developing the most advanced detector technologies - synergy wanted

Simulation Framework

- Find a framework which will ease work and information exchange

- Several tools on the market
  ➔Use a homogeneous, powerful and widespread

- Frameworks which have come to our attention:
  - 4th concept - IlCRoot - ILC evolved from: AliRoot - Alice - LHC
    - Based on CERN software root with so-called Virtual Monte Carlo

  - root using **Geant3/4** and **Fluka** - transport in matter
  - e.g.: Pandora-Pythia, Whizard, Sherpa, CompHEP - generators
  - Several simulations, detector geometries etc. already exists
  - 4 experiments using AliRoot based framework: Ali - Ilc - Fair - MPD -Root
  - Import of our contained model-detector geometry in the environments
  - First results (see A. Kilic→ LHeC simulation with Geant4 - standalone)

- Dedicated manpower for software implementation needed

Starting point for discussions

- Optimize IR and ACC boundaries
  beam pipe: $r_y \times r_x = 2.5 \times 5$ cm at the IP (talk of Rogelio)
  elliptical cone - smaller in direction of proton?
  but electron detection would suffer - widening cone there
  we assumed $r_y \times r_x = 2.5 \times 3.07$ cm
- Establish detector concepts:

  we made a set of choices, none of these are final,
  but aim to provide one full design iteration for
  Physics Working Groups for feedback
- Simulation environment, its setup, use and maintenance are essential - man power urgently needed

Backup slides

Tracking: Alternative Design

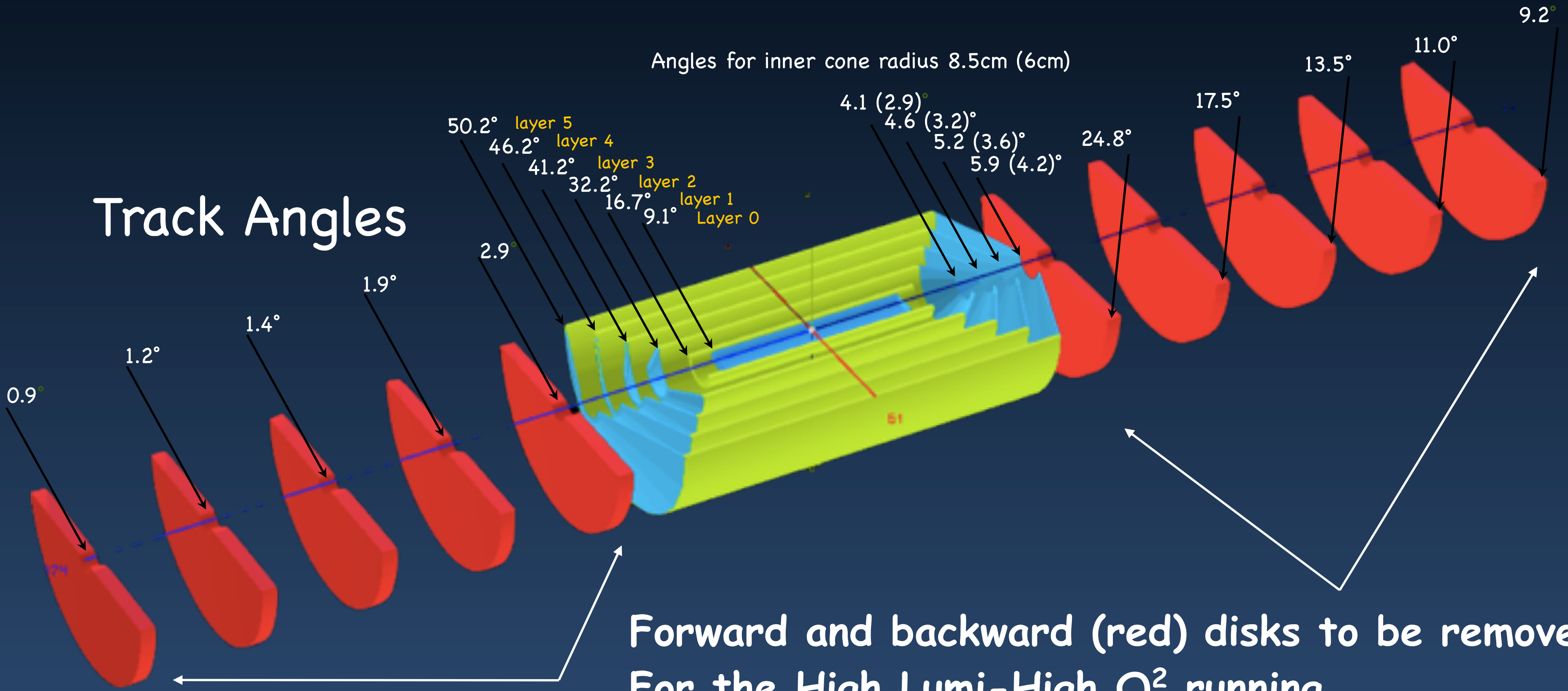
(to be optimised)

One option: GAS-Si Tracker - GOSSIP Type NIKHEF

Container Model

Gas **O**n **S**limmed **S**ilicon **P**ixels (or Strixels/Pads)

Track Angles



Forward and backward (red) disks to be removed For the High Lumi-High Q^2 running.

Alternative technologies: Pixels, IMAPS, DEPFET etc.*)
see Divonne 2008 workshop

Infrastructure

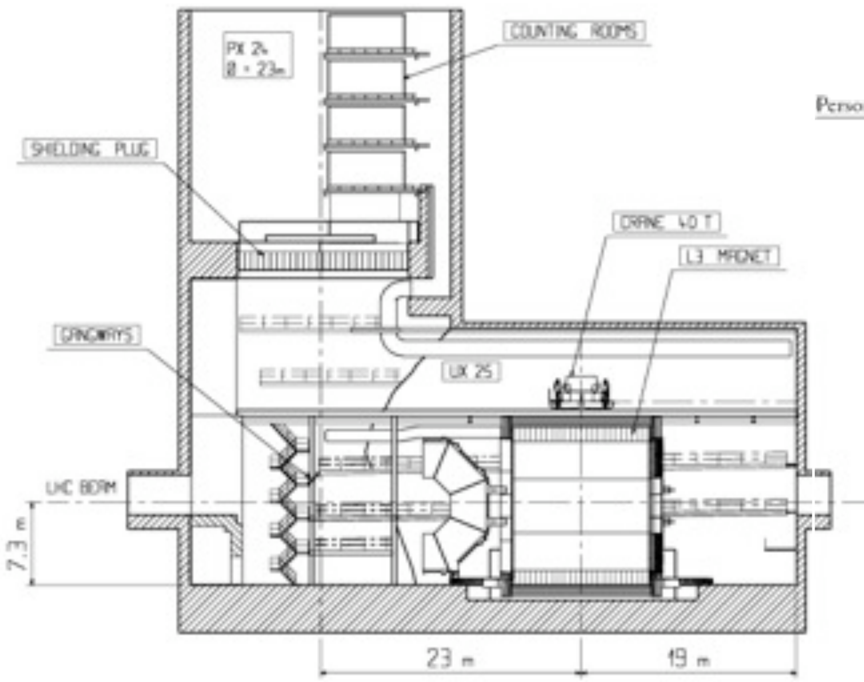
ALICE

- Round access shaft of 23m diameter, cavern about 50m along the beamline

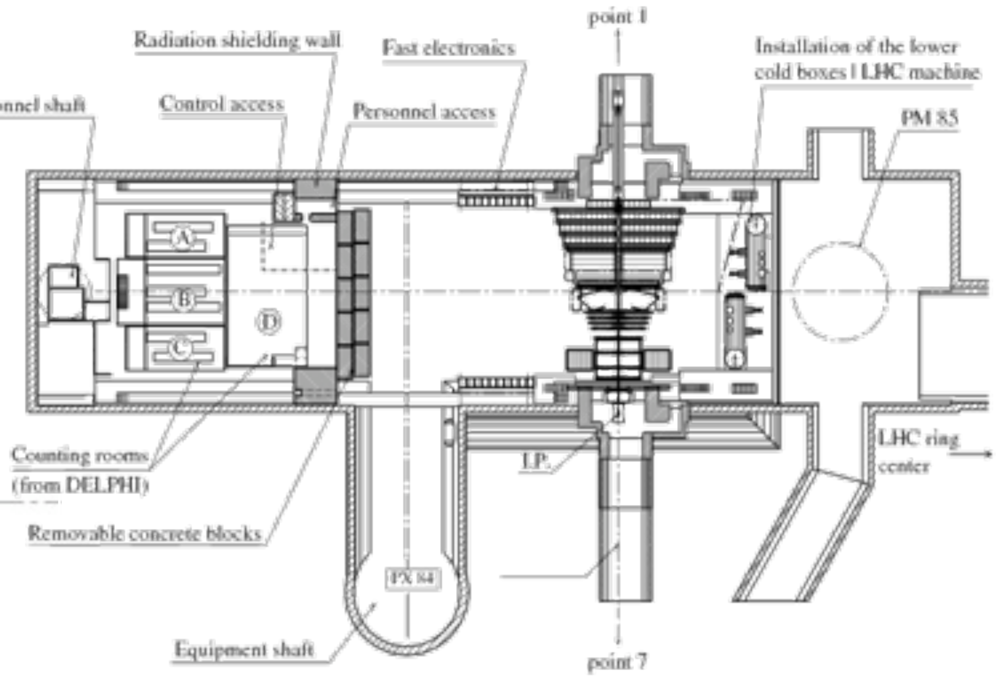
LHCb

- Shaft: 100m depth, 10.10m diameter, very slightly non vertical; experiment: length 19.90m from IP, max width at the muon station 12m; cavern: 50m x 20m

Point 2 (Alice)



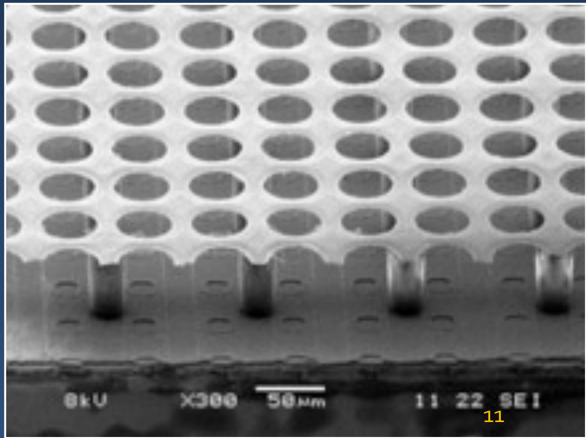
Point 8 (LHCb)



Precision Tracking: Si-Gas Tracker – GOSSIP Gas on Slimmed Silicon Pixels (see talk of H.Van De Graaf)

- Gas for charge creation, Si-pixel/strips/pads for signal collection
- Lightweight detector
- More than one hit per track - defines track segments
- Si radiation hard - standard CMOS (90 nm process)
- Trigger capable: 25ns, Gossipo 3|4 readout chip ~O(1) ns time resolution.
- Large volume detector affordable, industrial production feasible
- Time measurement - digital TPC R/O system
- Gas choice: radiator : Transition Radiation Tracker - e/π identification
- Diffusion and drift velocity limits position measurement currently to ~<<20µm

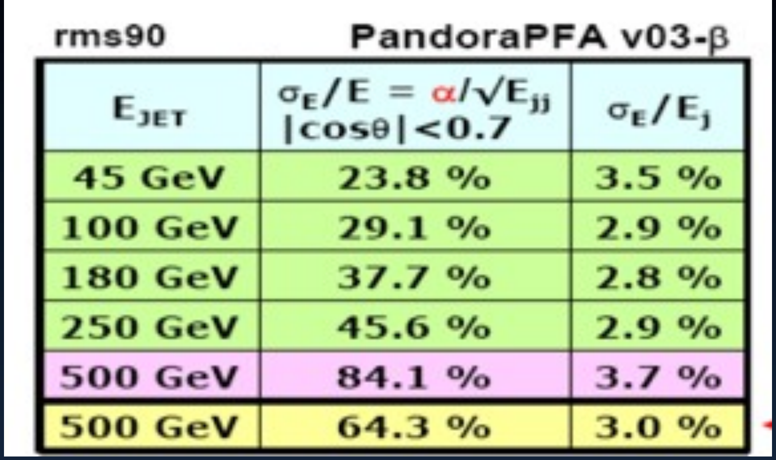
- If needed innermost layer possibly still with pixel



Calorimeter Technologies

Particle Flow and high granularity devices:

- promising at ILC energies(E_{CMS}<500GeV)
- need a transition to "normal" calorimetry if to be used at higher energies
- Rely heavily on software, microelectronics and SiPM (or Gas chambers ?)



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 %

Dual Readout:

Attractive idea: reading independently (in a non-compensating cal.)

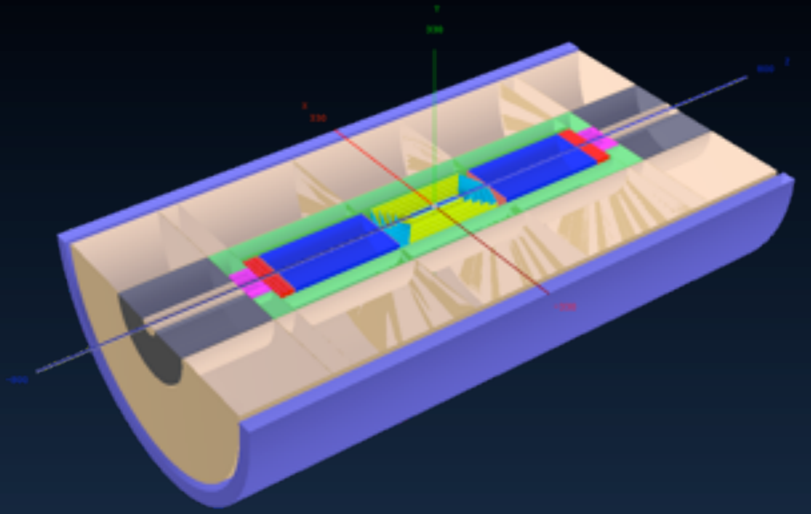
1) a Cerenkov response only sensitive to relativistic shower components (mostly $e^{\pm}$)
2) a Scintillation response sensitive to all dE/dx and correcting event by event and cell by cell the main (scintillation) response.

- Usable up to highest energies
- Require hardware developments, some of them still at the "generic" level.
- Need to be demonstrated with large prototypes (DREAM Collaboration)

Conventional technologies:

- Cu/Brass-Scintillator; Pb-Scintillator (SpaCal); LAr (ATLAS, H1) especially in in barrel/rear region

Calorimeter



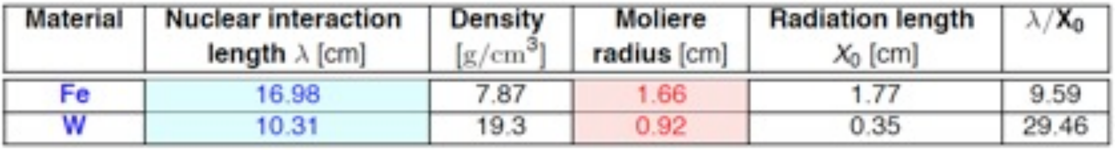
Present choice: Energy Flow Calorimetry:

For the geometry given:

- Electromagnetic Calorimeter:
  ~30 x Xo Pb/W & different det./R/O
- Hadronic Calorimeter:
  6 - 10 x λ_I Fe/Cu & different det./R/O

- Presently the fwd/bwd calorimeter asymmetry more in functionality/ detector response rather then in geometry

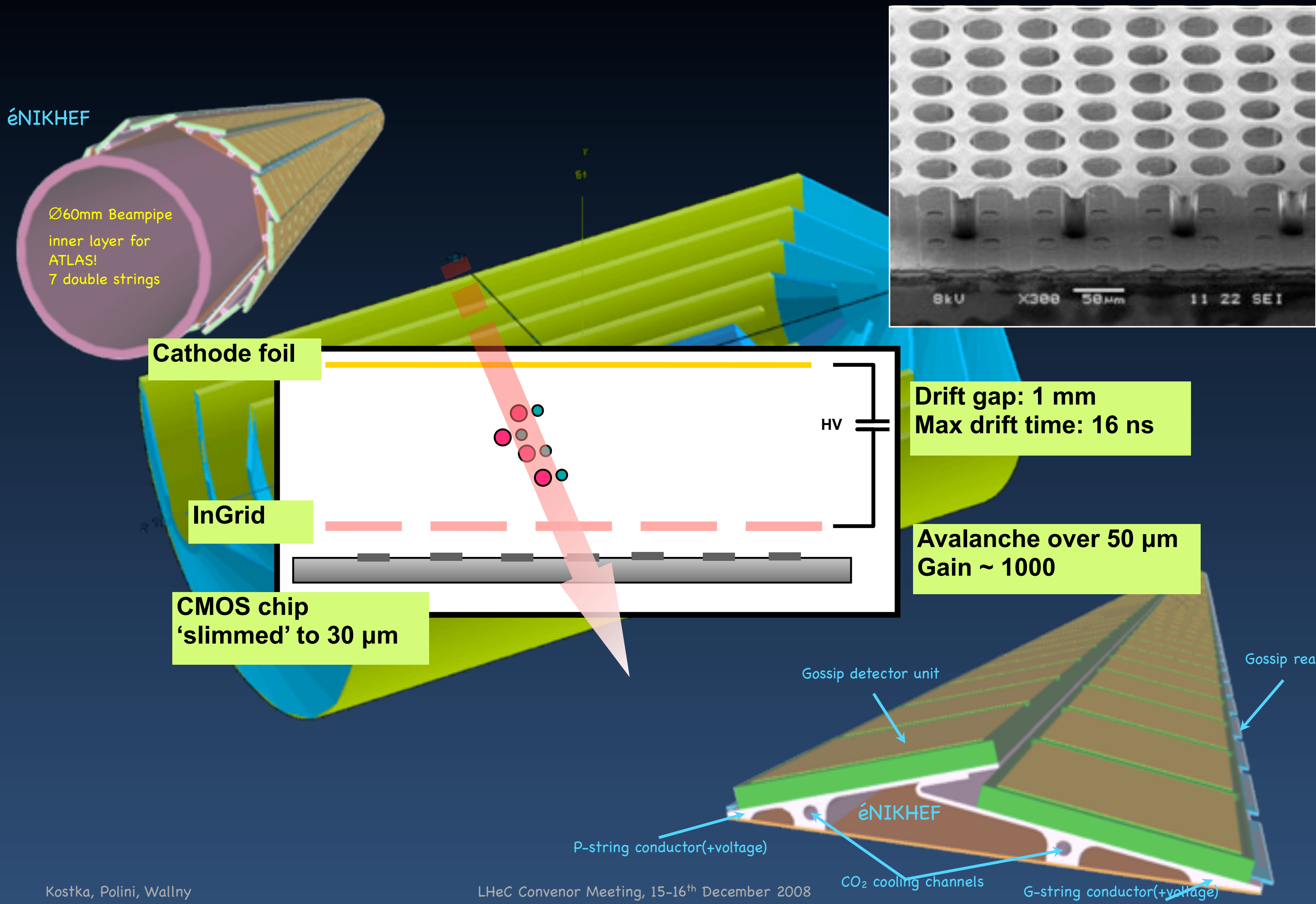
- A dense EmCAL with high granularity (small transverse size cells), high segmentation (many thin absorber layers), and with ratio λ_I/Xo large, is optimal for E-Flow measurement → 3-D shower reconstruction
- Example Fe, W



Material	Nuclear interaction length λ [cm]	Density $[g/cm^3]$	Moliere radius [cm]	Radiation length X_0 [cm]	λ/X_0
Fe	16.98	7.87	1.66	1.77	9.59
W	10.31	19.3	0.92	0.35	29.46

- brass (Cu) an option also (CMS), λ_I =15.1cm - denser than Fe (adding λ_I)

GAS-Si Tracker



Cathode foil

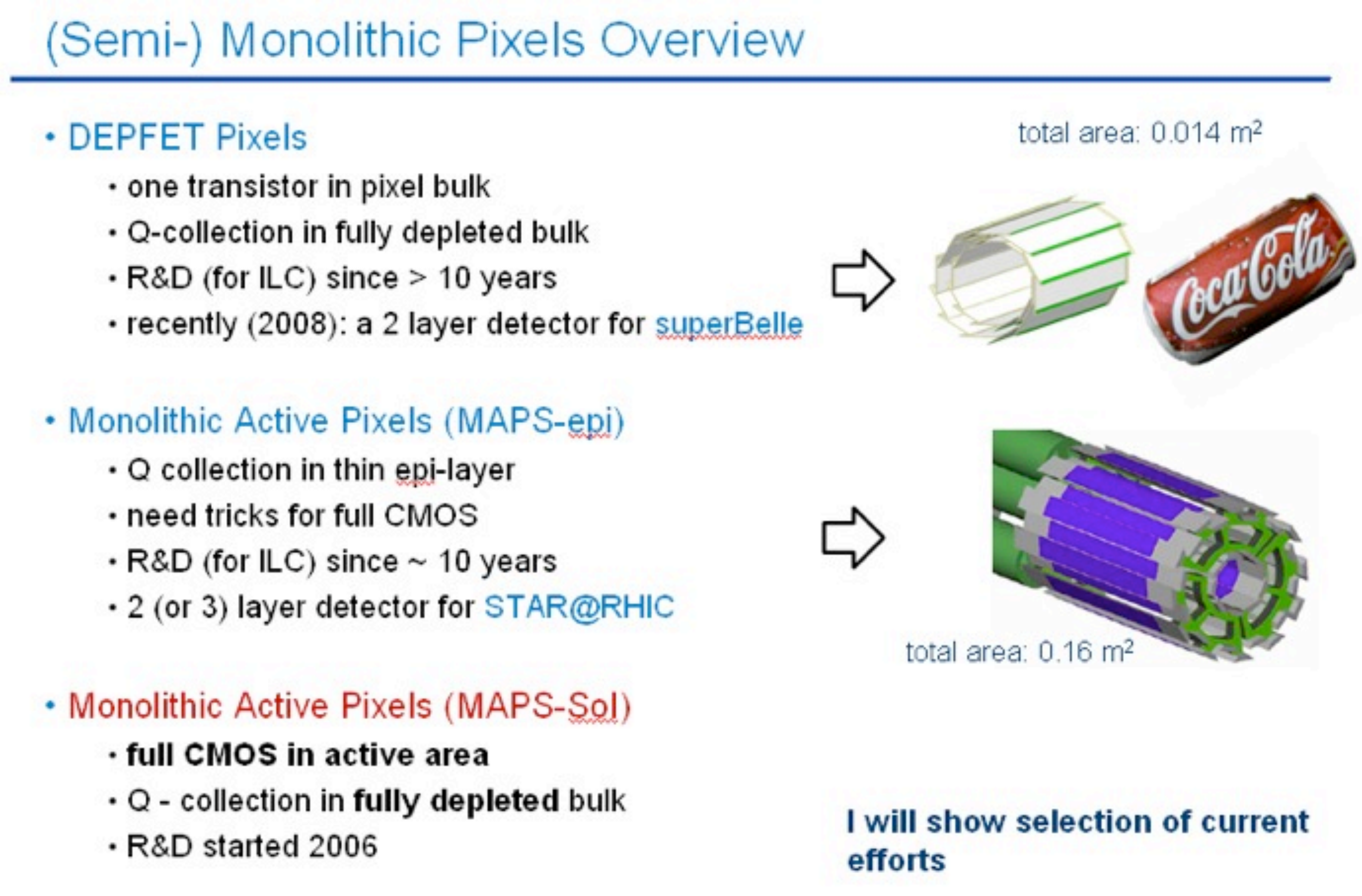
InGrid

CMOS chip
‘slimmed’ to 30 µm

Drift gap: 1 mm
Max drift time: 16 ns

Avalanche over 50 µm
Gain ~ 1000

Silicon Pixel Detector



(Semi-) Monolithic Pixels Overview

- DEPFET Pixels
  - one transistor in pixel bulk
  - Q-collection in fully depleted bulk
  - R&D (for ILC) since > 10 years
  - recently (2008): a 2 layer detector for superBelle

total area: 0.014 m^2

- Monolithic Active Pixels (MAPS-epi)
  - Q collection in thin epi-layer
  - need tricks for full CMOS
  - R&D (for ILC) since ~ 10 years
  - 2 (or 3) layer detector for STAR@RHIC

total area: 0.16 m^2

- Monolithic Active Pixels (MAPS-SoI)
  - **full CMOS in active area**
  - Q - collection in **fully depleted** bulk
  - R&D started 2006

I will show selection of current efforts

Innermost Tracker
Level 1 -Trigger: Pixel

- 2 inner layers: pixel detector (trigger detector)
  e · p: Minimum bias, High multiplicity studies,Topological selection (jets),
  Secondary vertex pre-ident, p_T pre-selection
  e · nucleon: Impact parameter pre-selection

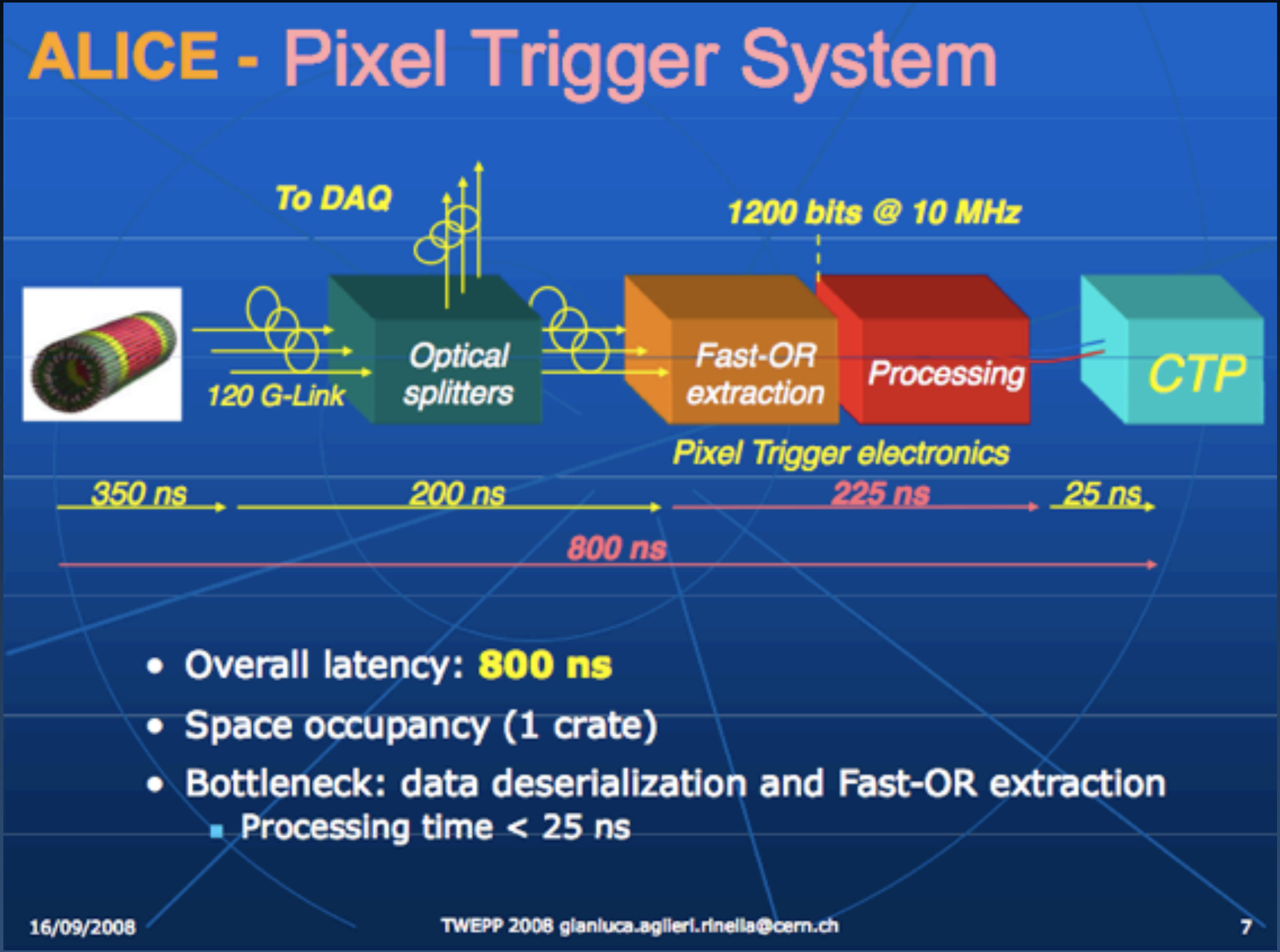
- Material (in general for all detectors)
  - strong interplay between:
    resolution – secondaries – pattern/track algorithms - minimum material; 2 layers enough?
  - new powering concepts (serial, DC-DC), fast R/O
  - cooling strategy + support structure + pixel technology + electronics
  - goal: $X/X_0^{90°} < 0.3\%$ - where placing the power electronics ?
  - radiation an issue: ? neq/cm² @ innermost layers
  - sensor alternatives: 3D-silicon, planar (n in p), diamond
  - FE electronics digital

Trigger & DAQ

- **LHeC DAQ requirements within specification and reach of the LHC/SLHC** (*W. Smith Divonne 2008)
- **Trigger (pipelined system 2-3 trigger levels):**
- **Active trigger components: CAL, Muon, Tracking**
- **Tracking Trigger:**
  - **b,τ-tagging in dense jet environment is a very demanding task**
  - **on higher level trigger or on level 1? Gossip usable for triggering**
  - Displaced Vertexing Trigger (see Alessandro Cerri, Divonne 2008) ➔ scalable system, use associative memory
  - Need for fast pattern recognition on large amounts of data (of different detectors, global tracking, RoI etc.)
- Fine detector segmentation
- Expect high-occupancy, high x, heavy flavor physics (b, c), New physics…
- Especially the forward region very challenging

→ detector response and full simulation environment needed

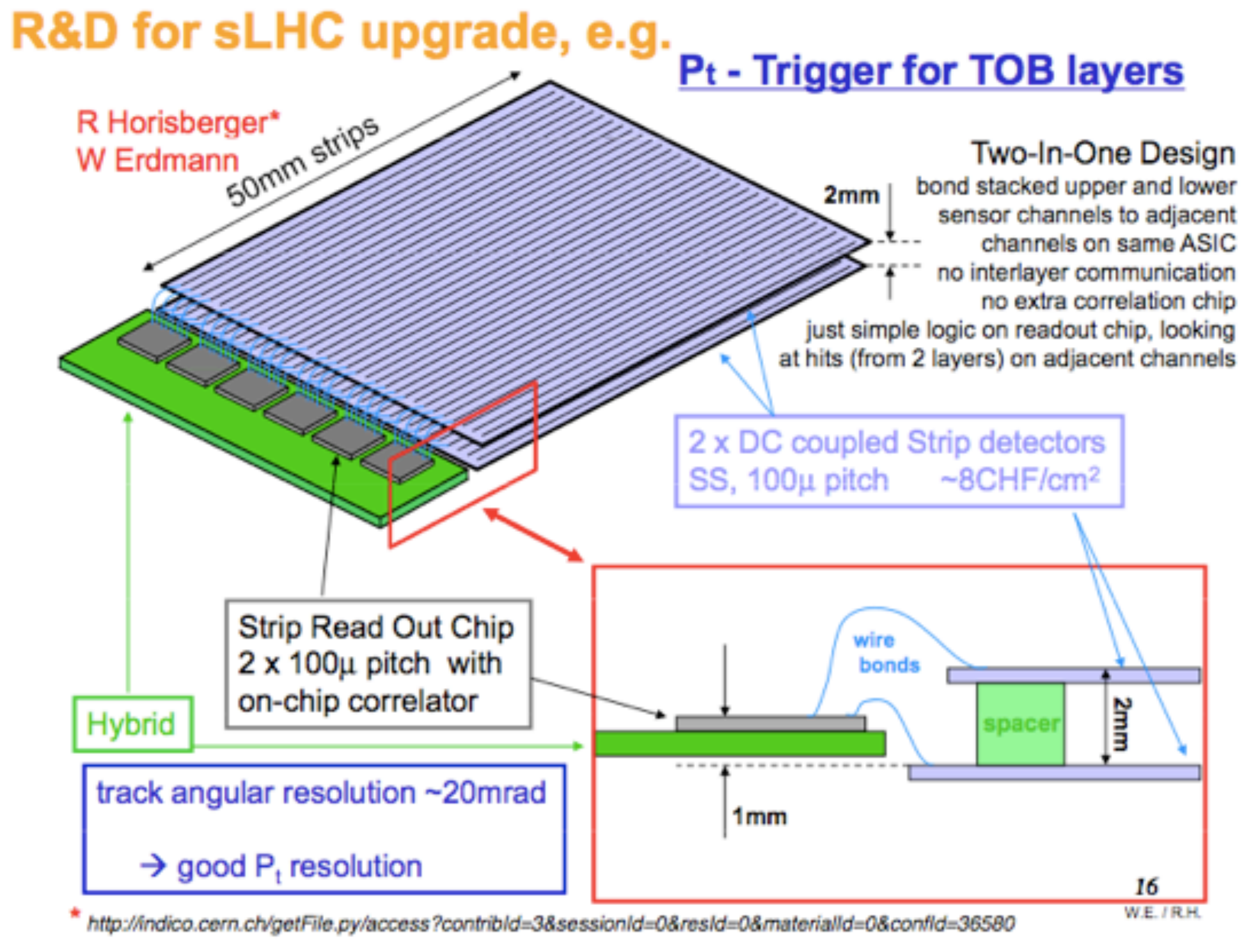
Track Trigger: an existing LHC example



ALICE - Pixel Trigger System

- Overall latency: **800 ns**
- Space occupancy (1 crate)
- Bottleneck: data deserialization and Fast-OR extraction
  - Processing time < 25 ns

Strip readout (on-chip correlation/trigger)



R&D for sLHC upgrade, e.g.

P_t - Trigger for TOB layers

R Horisberger*
W Erdmann

Two-In-One Design
bond stacked upper and lower
sensor channels to adjacent
channels on same ASIC
no interlayer communication
no extra correlation chip
just simple logic on readout chip, looking
at hits (from 2 layers) on adjacent channels

2 x DC coupled Strip detectors
SS, 100µ pitch ~8CHF/cm²

Strip Read Out Chip
2 x 100µ pitch with
on-chip correlator

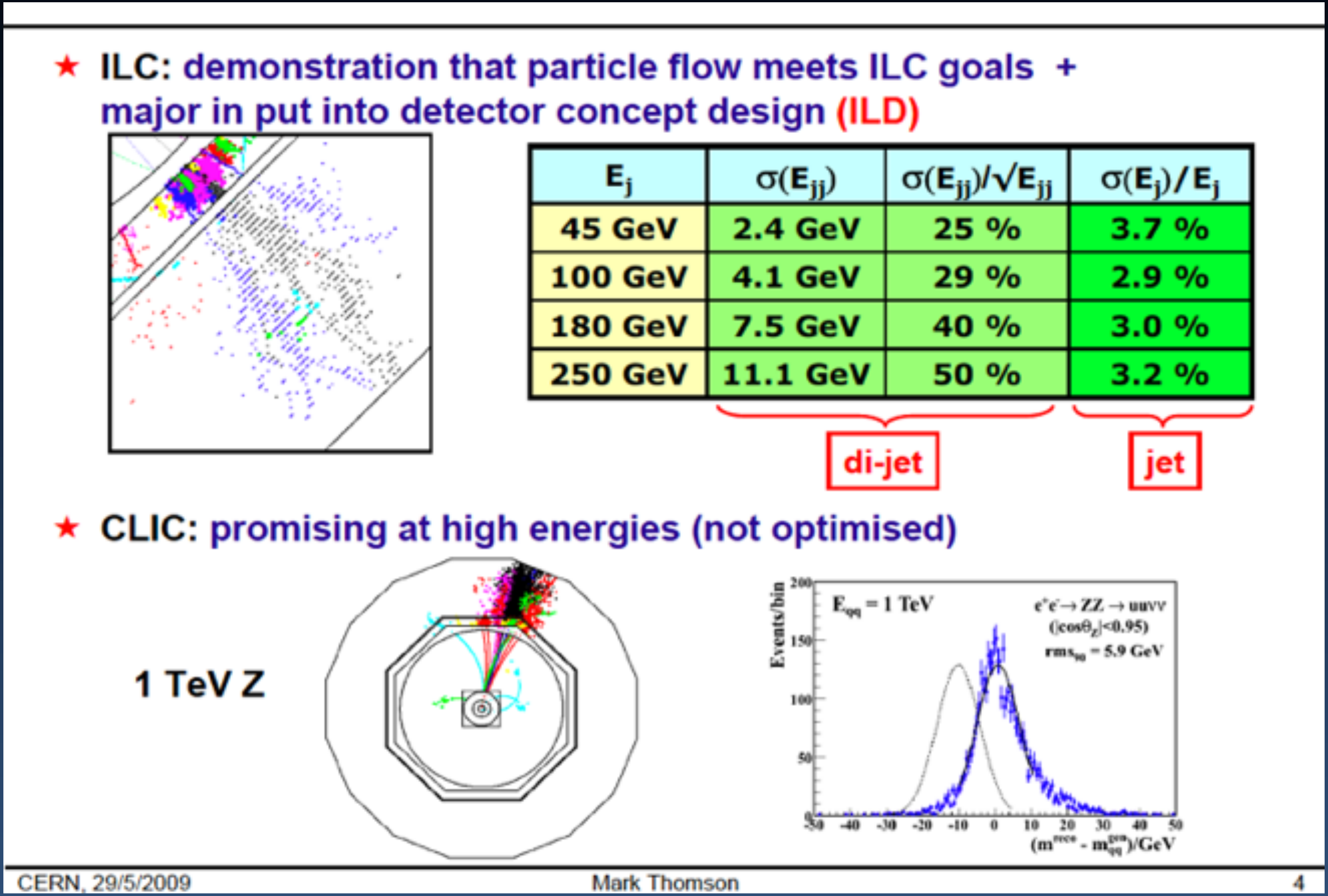
Hybrid

track angular resolution ~20mrad

→ good P_t resolution

* http://indico.cern.ch/getFile.py/access?contribId=3&sessionId=0&resId=0&materialId=0&confId=36580

PFA Performance



- **ILC:** demonstration that particle flow meets ILC goals + major in put into detector concept design (ILD)

E_j	$\sigma(E_{jj})$	$\sigma(E_{jj})/\sqrt{E_{jj}}$	$\sigma(E_j)/E_j$
45 GeV	2.4 GeV	25 %	3.7 %
100 GeV	4.1 GeV	29 %	2.9 %
180 GeV	7.5 GeV	40 %	3.0 %
250 GeV	11.1 GeV	50 %	3.2 %

$\underbrace{\sigma(E_{jj}) \quad \sigma(E_{jj})/\sqrt{E_{jj}}}_{\boxed{\text{di-jet}}} \quad \underbrace{\sigma(E_j)/E_j}_{\boxed{\text{jet}}}$

- **CLIC:** promising at high energies (not optimised)

1 TeV Z

CERN, 29/5/2009 Mark Thomson 4

Particle Flow (see talk C.Grefe)

- Use the best energy information available for each particle in a jet
  - Tracker information for charged hadrons and low to mid-energy electrons
  - ECAL information for photons and high-energy electrons
  - HCAL information for long-lived neutral hadrons
- Pointing geometry - minimizing transversal and longitudinal Energy leakage
- High granularity to allow geometrical separation of particles
- PFA calorimetric performance = HARDWARE + SOFTWARE

F.Simon - MPI Munich
LHeC Divonne 2008

Dual Readout Calorimeters

- Uses scintillation & clear fibers
- Scintillating fibers respond to all charged particles
- Clear fibers detect e-/e+

- Dual readout is able to detect fluctuations in the energy resolution due to different response for em and hadronic part of showers
- Experienced first by the DREAM Collaboration

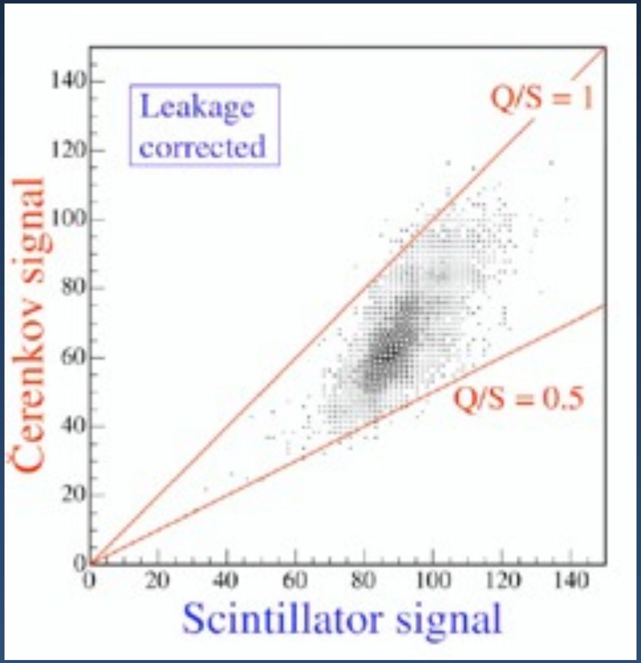
Two independent measurements: Q and S
Using e/h(Q) =4.7 e/h(S) =1.3 and :

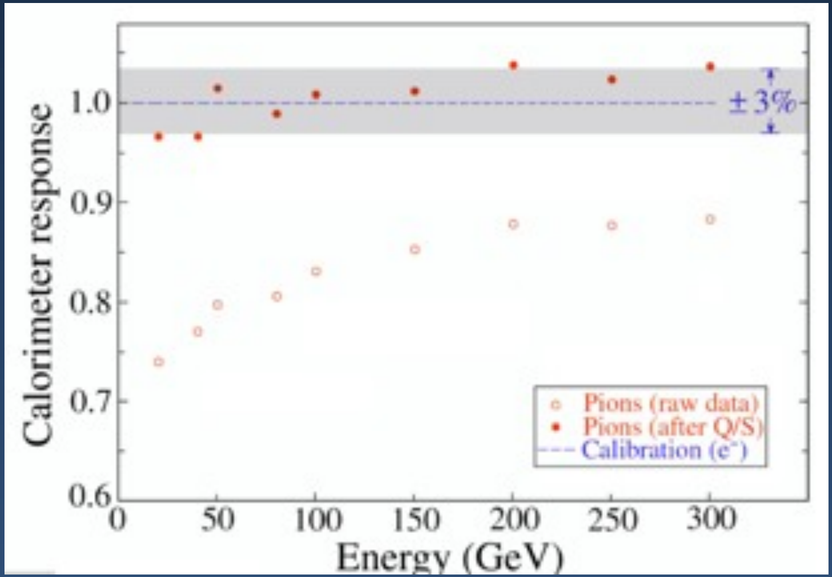
$$S = E\left[f_{\rm em} + \frac{1}{(e/h)_S}(1 - f_{\rm em}) \right]$$

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

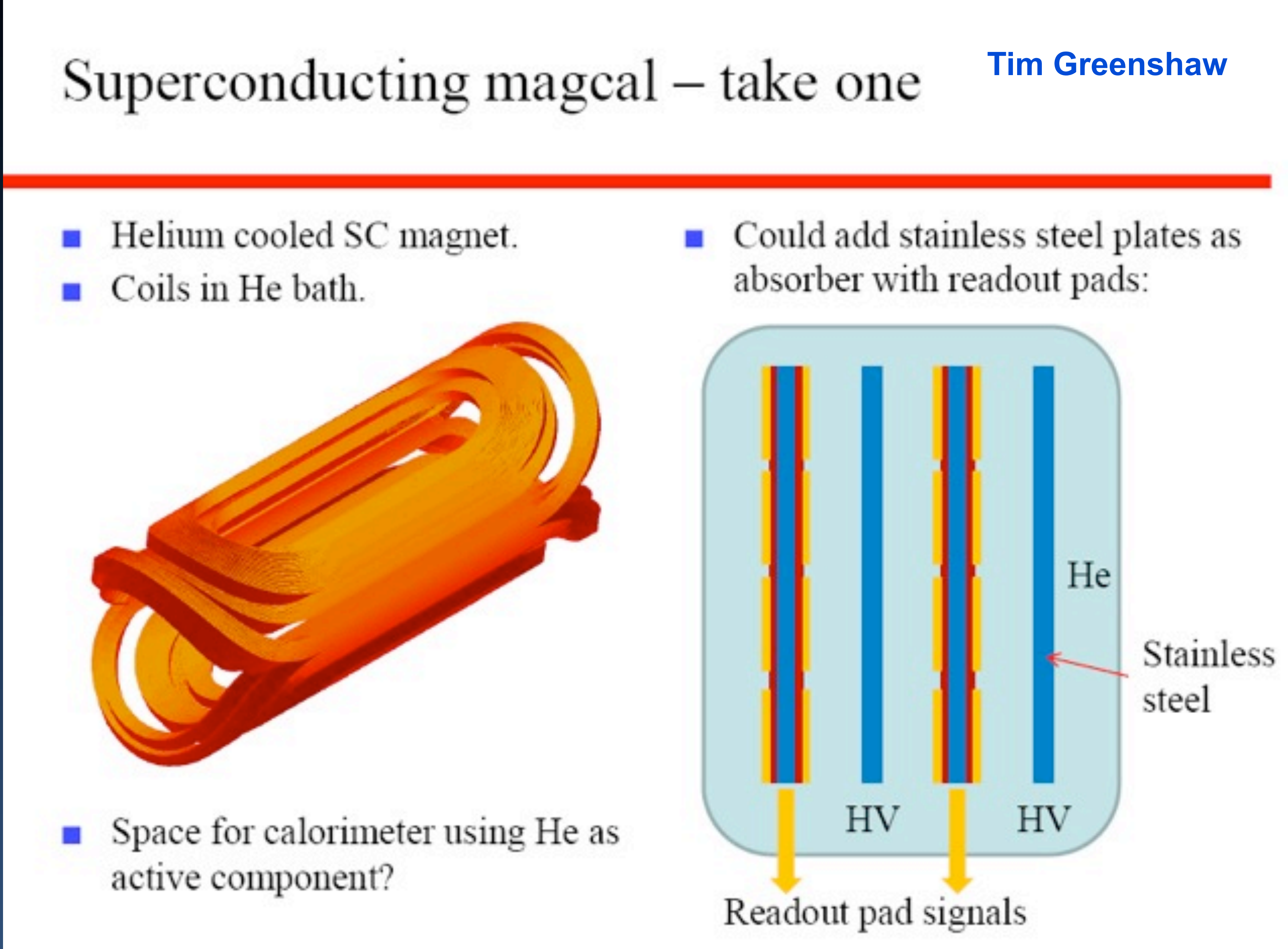
One can calculate fem and E per event.

- linearity is restored
- energy resolution is improved





Instrumented Magnets

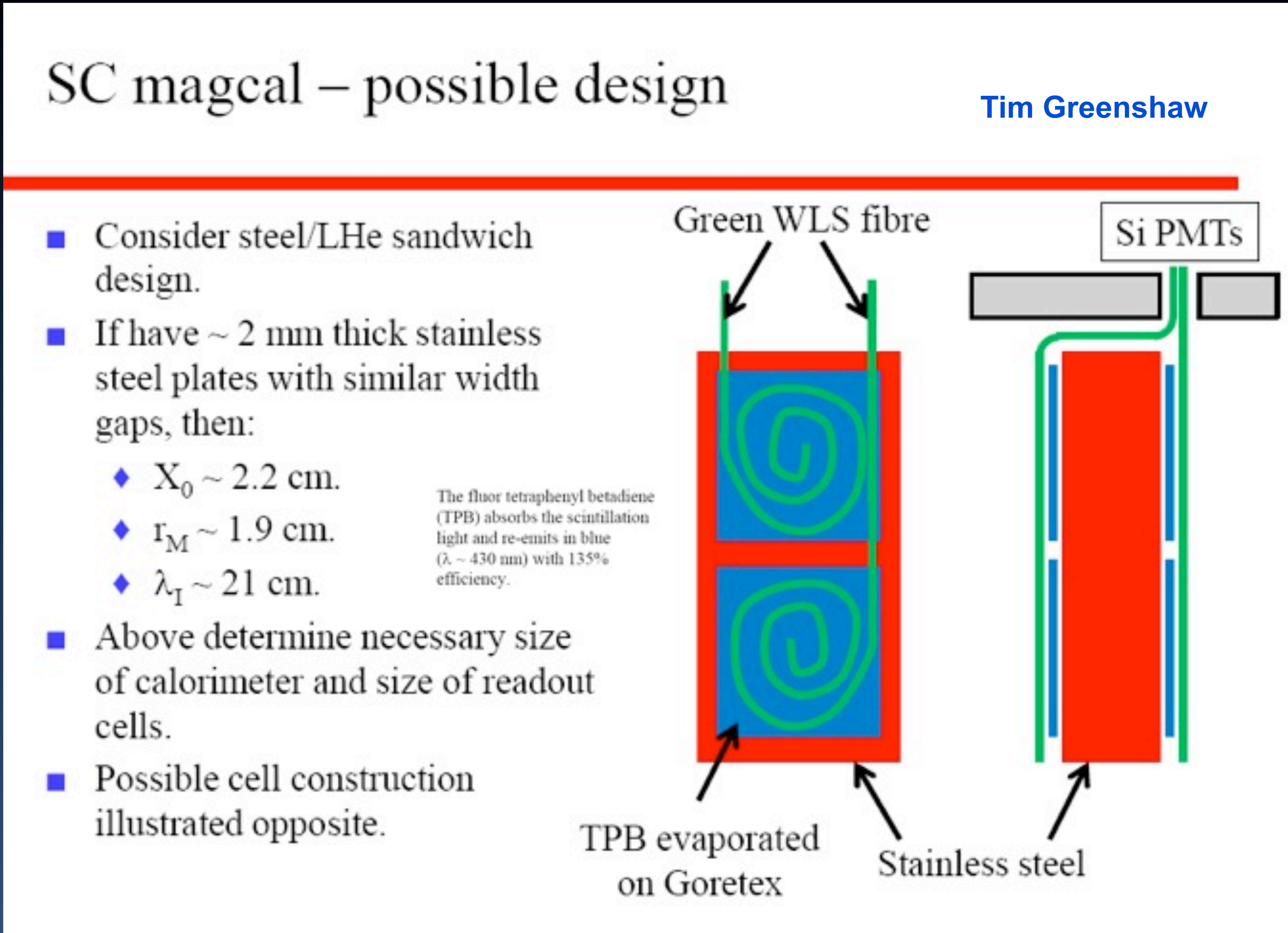


Tim Greenshaw

Superconducting magcal – take one

- Helium cooled SC magnet.
- Coils in He bath.
- Space for calorimeter using He as active component?
- Could add stainless steel plates as absorber with readout pads:

Instrumented Magnets (cont'd)



SC magcal – possible design

Tim Greenshaw

- Consider steel/LHe sandwich design.
- If have ~ 2 mm thick stainless steel plates with similar width gaps, then:
  - $X_0 \sim 2.2$ cm.
  - $r_M \sim 1.9$ cm.
  - $\lambda_I \sim 21$ cm.
- Above determine necessary size of calorimeter and size of readout cells.
- Possible cell construction illustrated opposite.

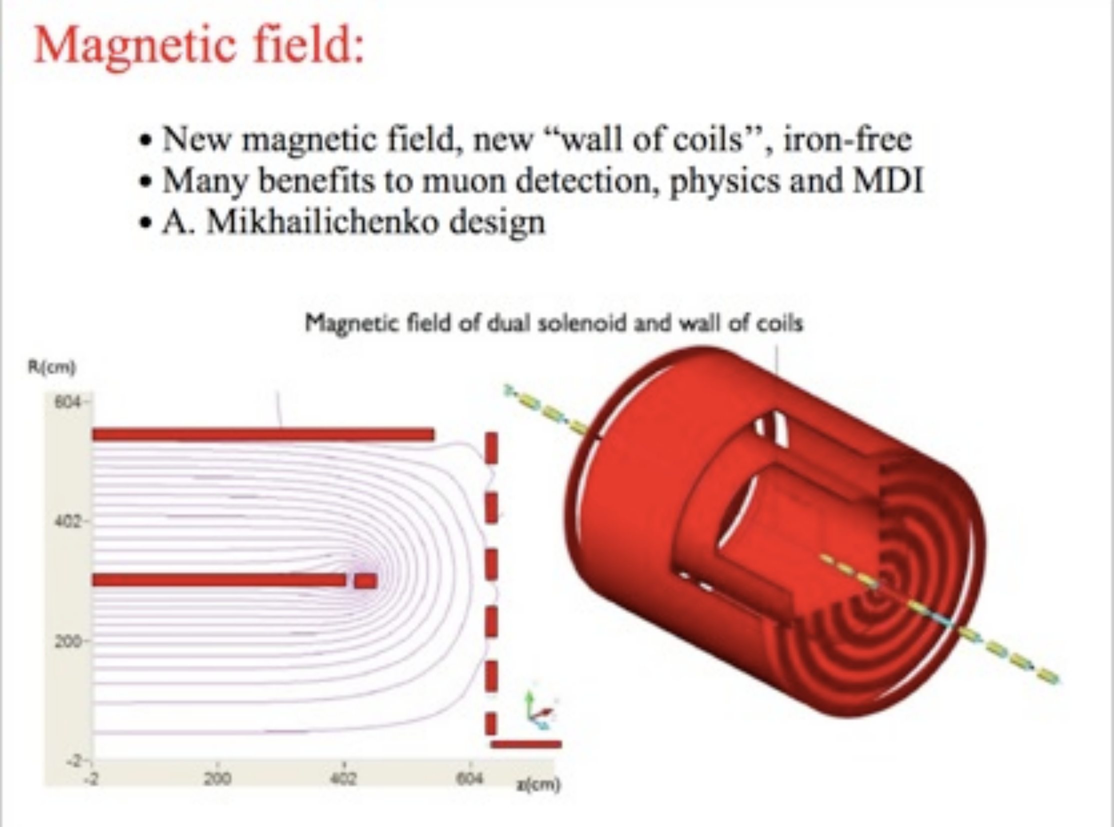
The fluor tetraphenyl betadiene (TPB) absorbs the scintillation light and re-emits in blue ($\lambda \sim 430$ nm) with 135% efficiency.

Solenoid continued

- Two Coil Solution (4th concept - ILC)

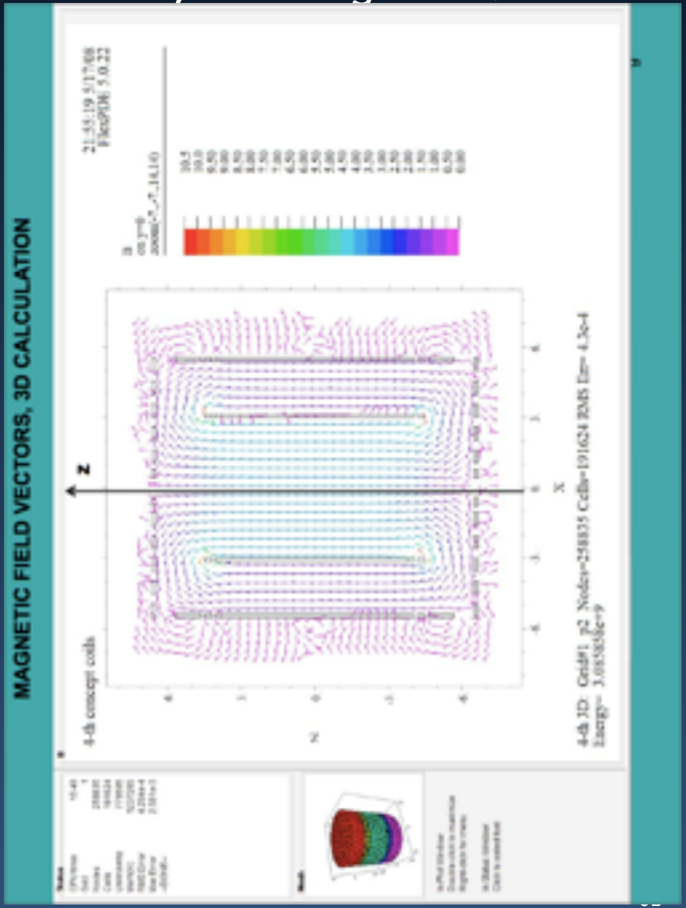
- 4th almost exactly the dimensions for L1 (current design)

➔no-iron magnetic field configuration with flux return by a second solenoid allowing better muon measurement, open-detector survey and alignment, quick push-pull and (re)installations



Magnetic field:

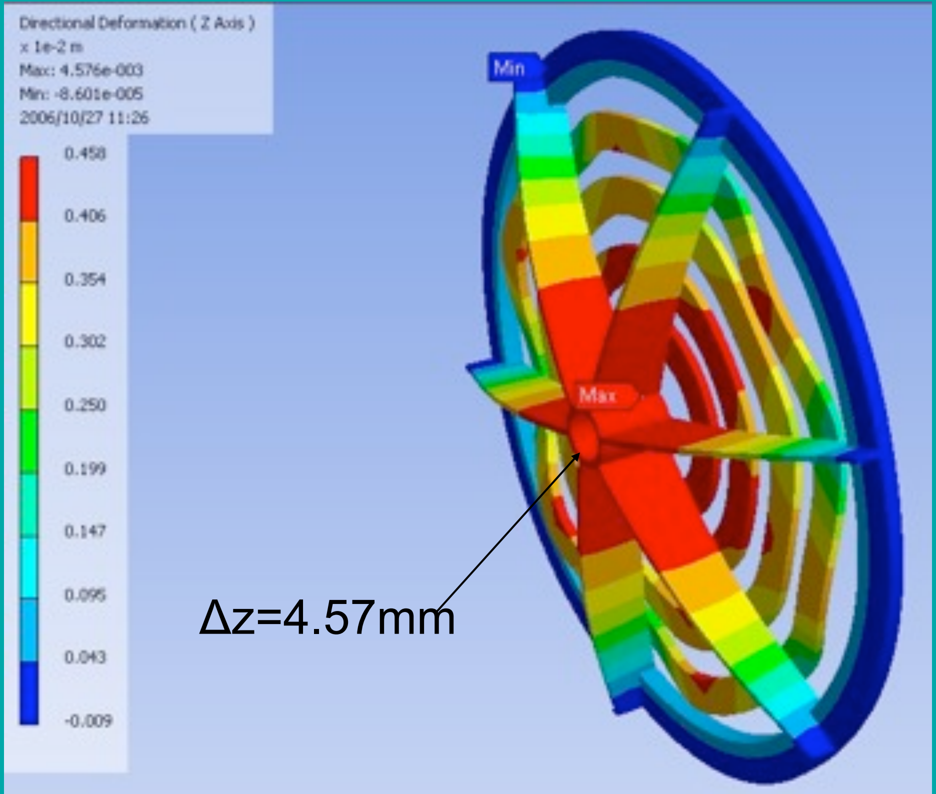
- New magnetic field, new "wall of coils", iron-free
- Many benefits to muon detection, physics and MDI
- A. Mikhailichenko design



Deformations of end plates

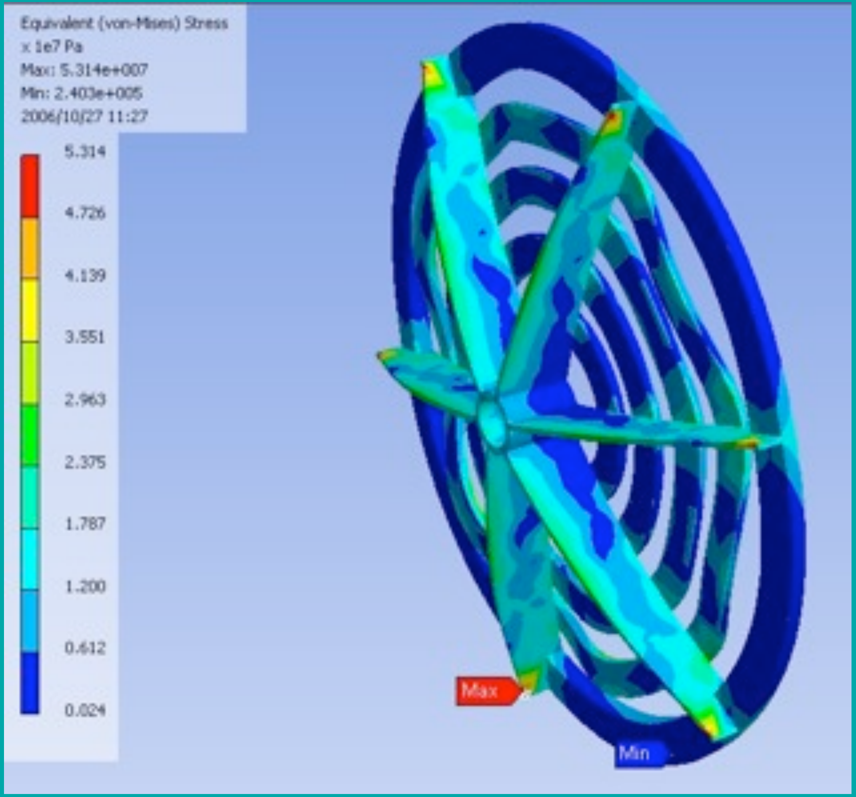
Maximal deformation is in the middle of holder. It is below 5mm.

Active movers of FF lenses will compensate this effect easily.



Δz=4.57mm

Deformation of FF holder is in z-direction.

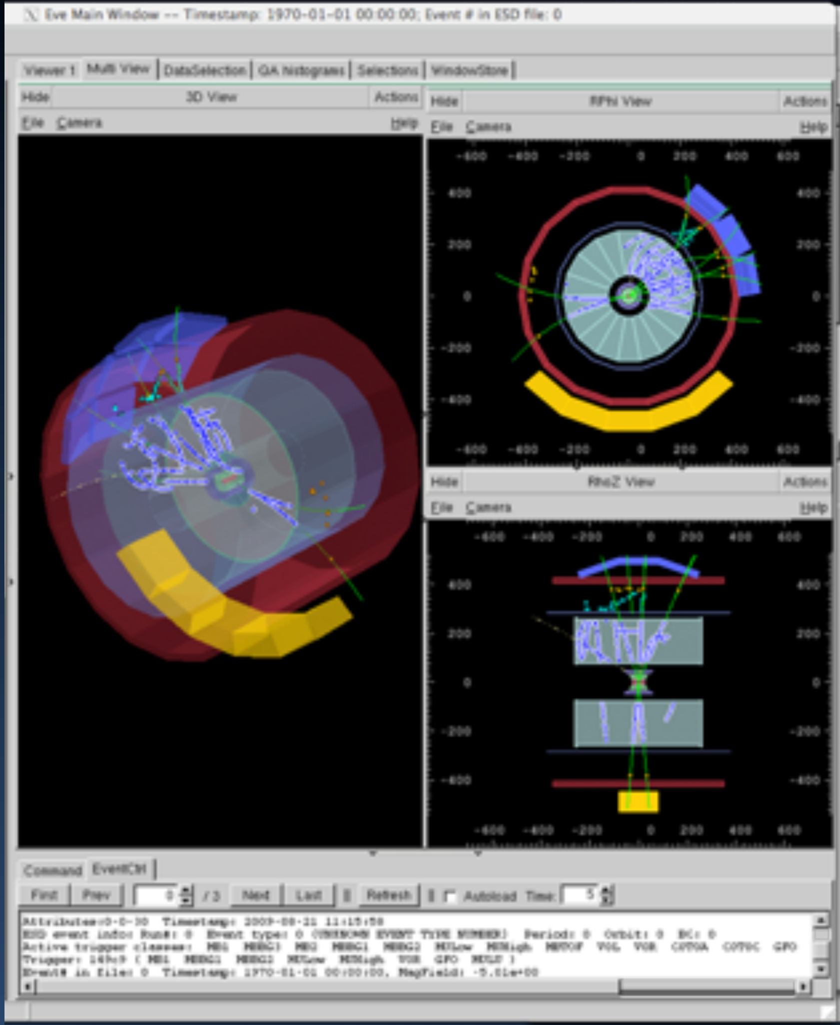


Reinforcement can be done as well.

Calculated by V.Medjidzade
Calculations carried by B.Wands also

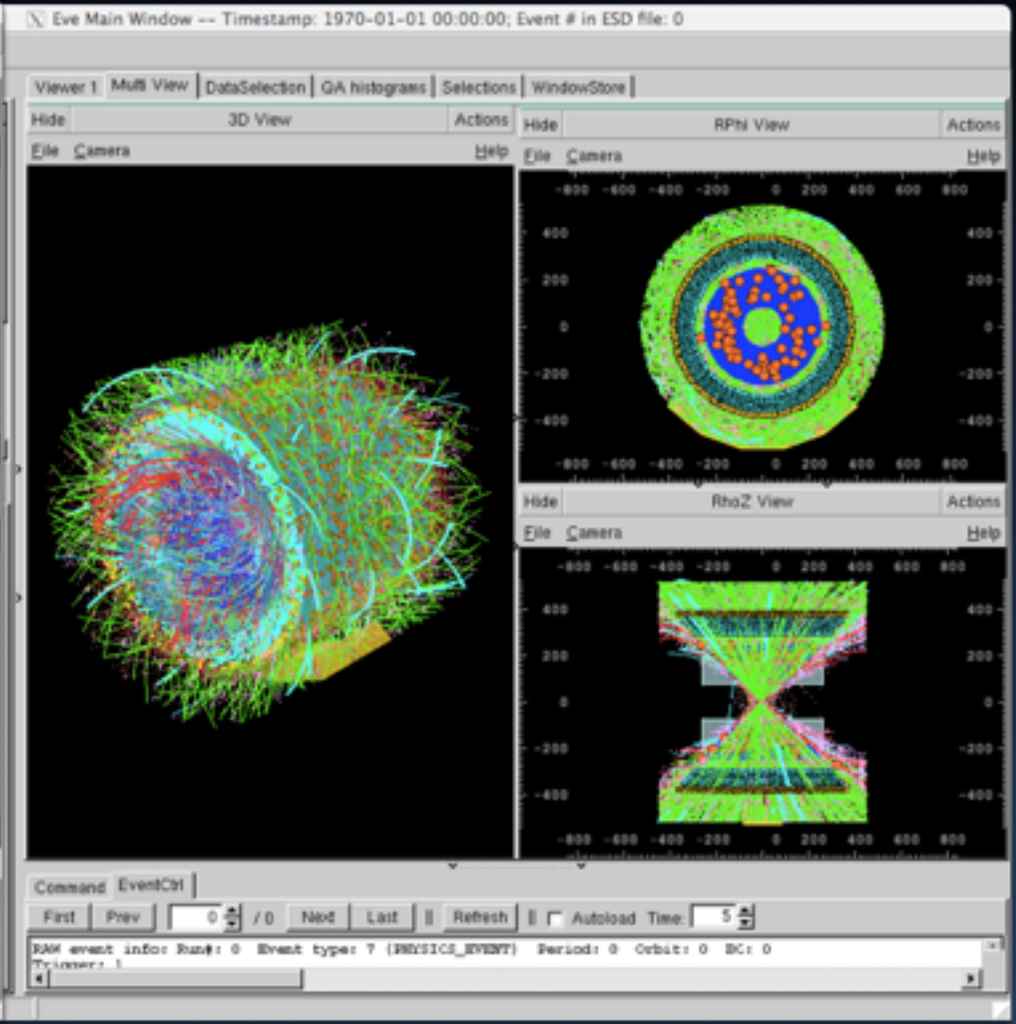
http://physics.uoregon.edu/~lc/wwstudy/concepts/

Simulation Environment (I)



```
Attributes:0-0-30  Timestamp: 2009-08-21 11:15:58
ESD event info: Run#: 0  Event type: 0 (UNKNOWN EVENT TYPE NUMBER)  Period: 0  Orbit: 0  BC: 0
Active trigger classes:  MB1  MBBG1  MB2  MBBG1  MBBG3  MULow  MUHigh  MBTOF  VOL  VOR  COTOA  COTOC  GFO
Trigger: 149c9 ( MB1  MBBG1  MBBG3  MULow  MUHigh  VOR  GFO  MULT )
Event# in File: 0  Timestamp: 1970-01-01 00:00:00, MagField: -5.01e+00
```

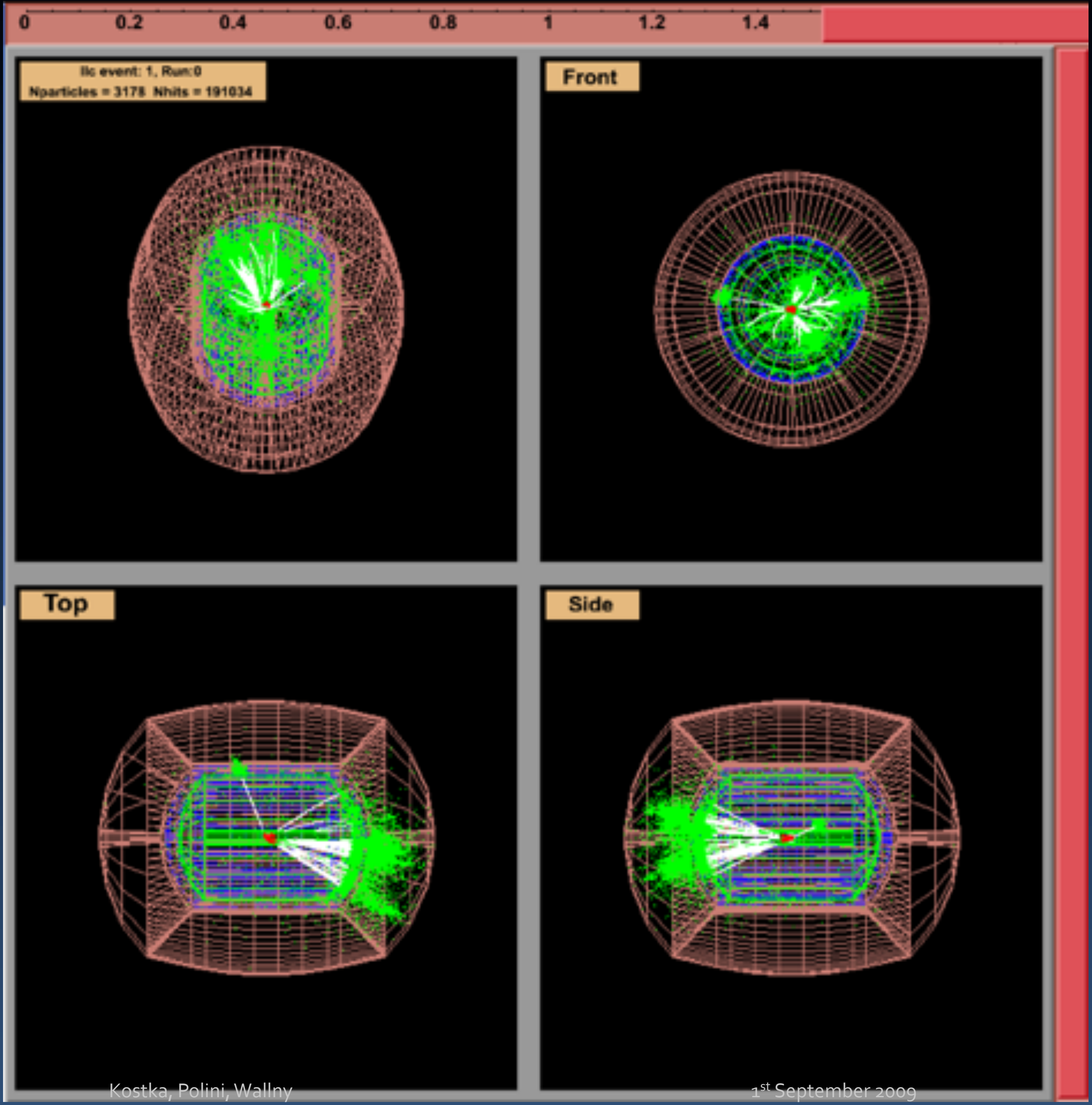
P-p Alice



```
RAW event info: Run#: 0  Event type: 7 (PHYSICS_EVENT)  Period: 0  Orbit: 0  BC: 0
Trigger: 1
```

Pb-Pb Alice

Simulation Environment (II)



Ilc event: 1, Run:0
Nparticles = 3178 Nhits = 191034

$e^{\pm}p$ Event GUI

IlcRoot

4th Concept

Detector

NC higgs event - produced using Madgraph and Pythia, beam energy 140 GeV electrons 7000 GeV protons (U.Klein - Liverpool)