



Rivelatori per il Linear Collider

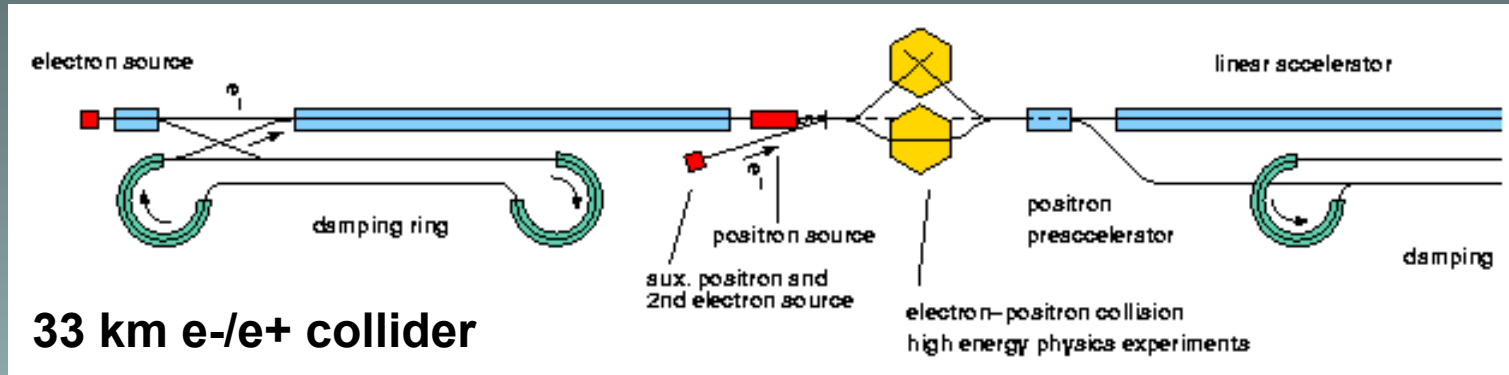
Erika Garutti

DESY

ILC: il linear collider
un detector per ILC
Componenti:

- rivelatori di vertice
- tracciatori
- calorimetri

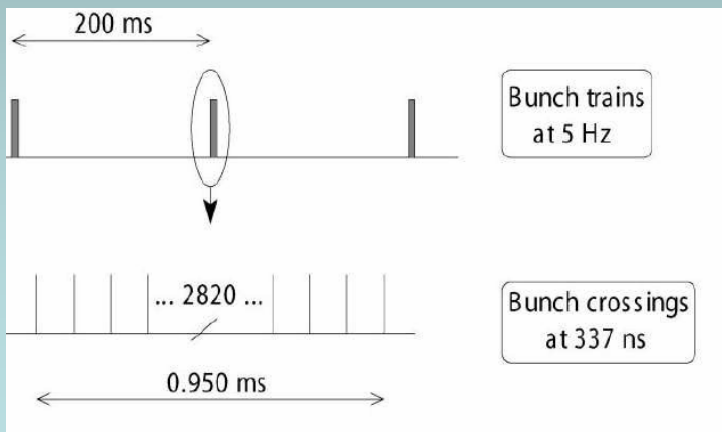
A Cool Machine



Energia: 500 – 800 GeV

Luminosità: $3-6 \cdot 10^{34}/\text{cm}^2/\text{s}$

Struttura a bunch del fascio:



Raccomandazioni sulla tecnologia:

Cavità superconduttive a radiofrequenza

Frequenza 1.3 GHz



Goal:

Minimizzare il numero di bunches integrati

→ alta velocità di lettura: 25-50 MHz

Macchine Leptoniche vs Adroniche

Linear Collider

“bassa” occupancy
“basso” background
“basso” rate

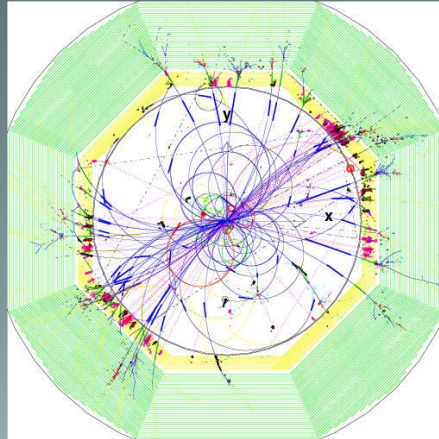
altissima precisione
attenzione a tutte le particelle
bilancio energetico

→ Particelle cariche e neutre

→ importanza al sistema e non ai singoli sub-detectors

R&D per il Rivelatore:

- Spingere al limite le tecnologie di precisione per ogni detector
- Ottimizzazione della sinergia tra detectors



Macchine adroniche

“alta” occupancy
”alto” background
“alto” rate

precisione ragionevole
ricostruzione parziale
bilancio in p_t

Richieste della fisica

- a) **risoluzione di massa di due jet** paragonabile all' ampiezza naturale di W e Z, per la corretta un'identificazione dello stato finale
- b) Eccellente efficienza e purezza in **flavor-tagging** (per b- and c-quarks e possibilmente s-quarks)
- c) **Risoluzione in momento** capacita' di ricostruire in processi di Higgs-strahlung la recoil-mass di due muoni con risoluzione migliore dello spread in energia del fascio
- d) **Ermeticita'** (assenza di fessure e copertura della regione a bassi angoli in avanti) alta precisione nella determinazione del momento mancante

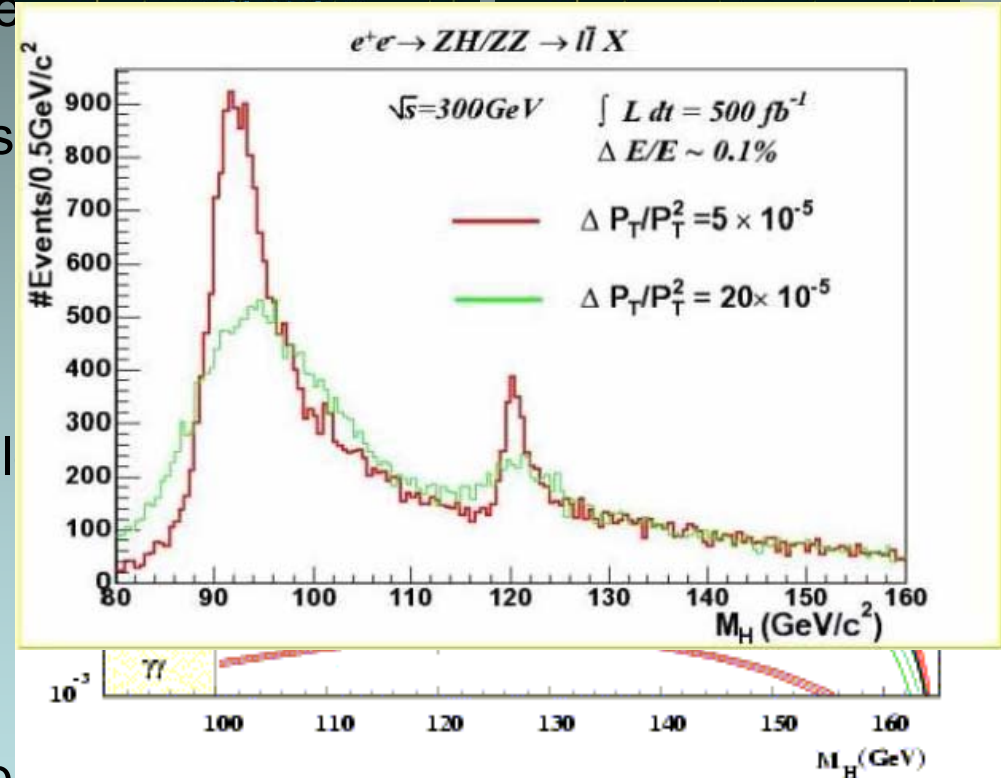
$$e^+e^- \rightarrow WW \nu\bar{\nu}, \quad e^+e^- \rightarrow ZZ \nu\bar{\nu}$$

LEP:

$$\Delta E_{\text{jet}} = 0.60 \sqrt{E}$$

ILC:

$$\Delta E_{\text{jet}} = 0.30 \sqrt{E}$$



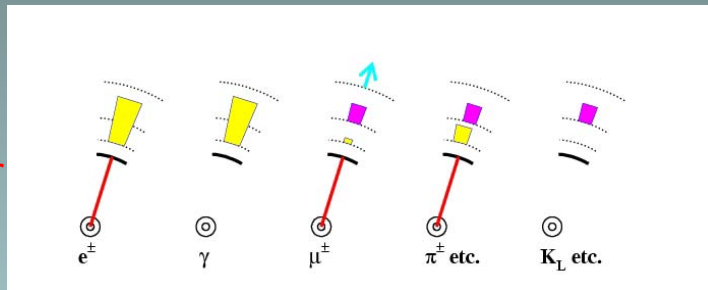
Concetto di Particle Flow

risoluzione dei jet $\rightarrow 30\%/\sqrt{E}$

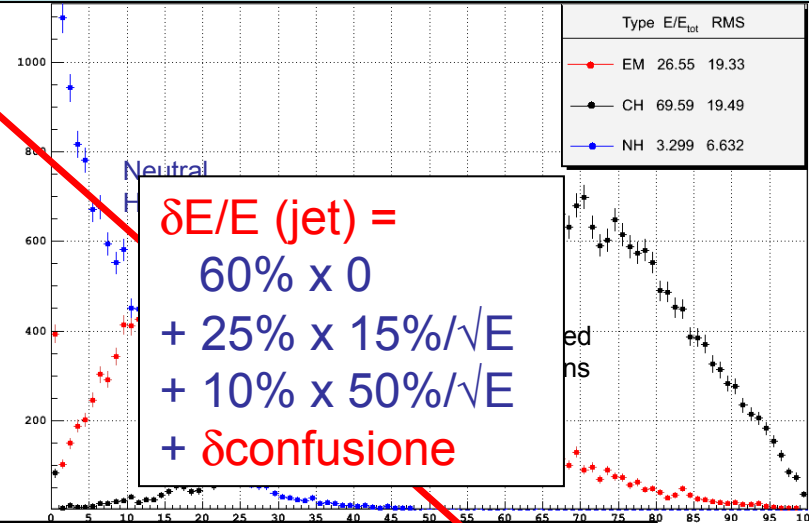
Distribuzione di energia: percentuale maggiore di particelle cariche

\rightarrow Eccellente risoluzione nei tracciatori

HCAL
ECAL
tracker



$$\sigma(Jet) = \sqrt{\sum \epsilon_T^2 E_i^4 + \sum \epsilon_{ECAL}^2 E_i + \sum \epsilon_{HCAL}^2 E_i}$$



$$\begin{aligned} \delta E/E(\text{jet}) = & 60\% \times 0 \\ & + 25\% \times 15\%/\sqrt{E} \\ & + 10\% \times 50\%/\sqrt{E} \\ & + \delta\text{confusione} \end{aligned}$$

Particelle in un jet	Frazione di energia visibile	Detector	Risoluzione
particelle cariche	~65%	Tracker	< 0.005% p _T negligible
Fotoni	~25%	ECAL	~ 15% / \sqrt{E}
adroni neutri	~10%	ECAL + HCAL	~ 50% / \sqrt{E}

$\sim 18\% / \sqrt{E}$

Un nuovo concetto per il detector

Particle Flow richiede:

- ricostruzione delle singole particelle
- separazione delle singole tracce

Meno importante:

- risoluzione in energia delle particelle

Richieste sul Detector:

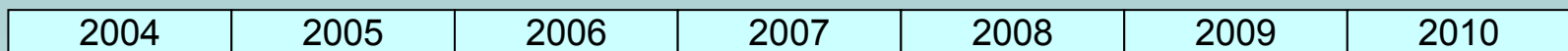
- Buon tracciamento in jet densi
- Eccellente granularita' nell'ECAL
- Buona granularita' nell'HCAL
- Eccellente connessione tra tracciatori / ECAL / HCAL

Notevole impegno in R&D

Diversi possibili approcci

Molti gruppi coinvolti da tutto il mondo

Non e' troppo presto se vogliamo per arrivare in tempo!!



Technology Choice

Done!



R&D Phase / Design

Collaboration
Forming

Construction

30 March 2005

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Ultime novita'

Marzo 18-22: in **LCWS05**

Collezione delle ultimissime novita' su:

- detector concept
- detector R&D
- dead lines and schedules

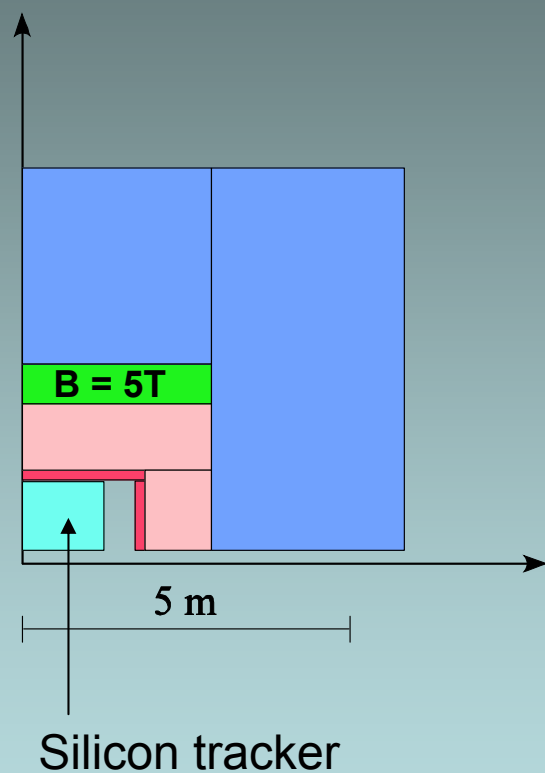


<http://www-conf.slac.stanford.edu/lcws05/default.htm>

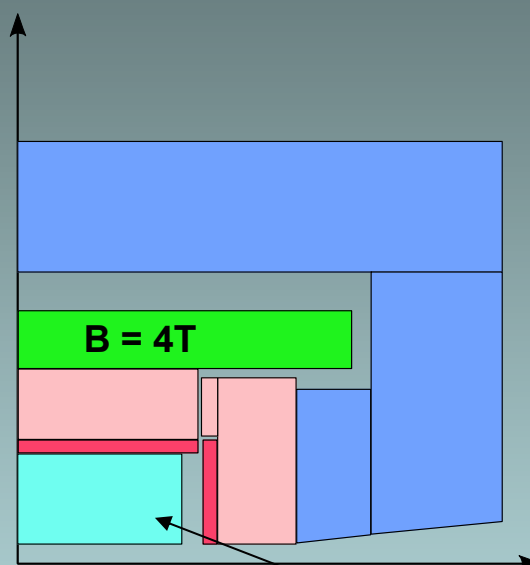
➔ Conciso sommario mirato soprattutto alle novita' sul mercato

Tre diversi approcci per il detector

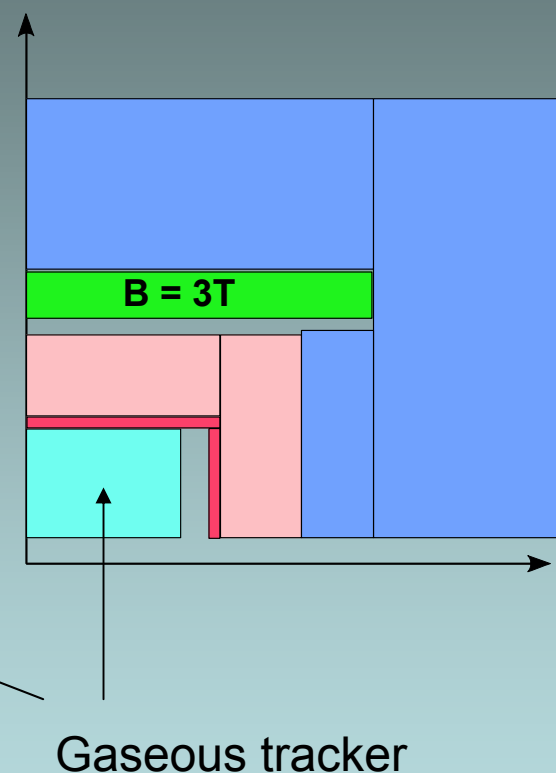
SiD: Silicon based



LDC: large detector



GLD: even larger detector

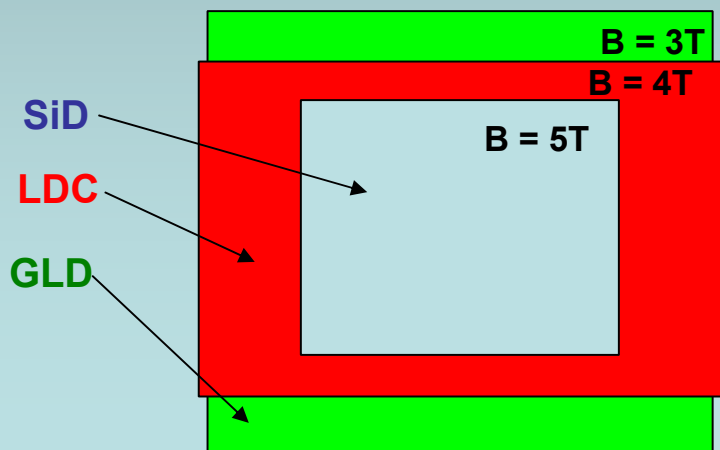
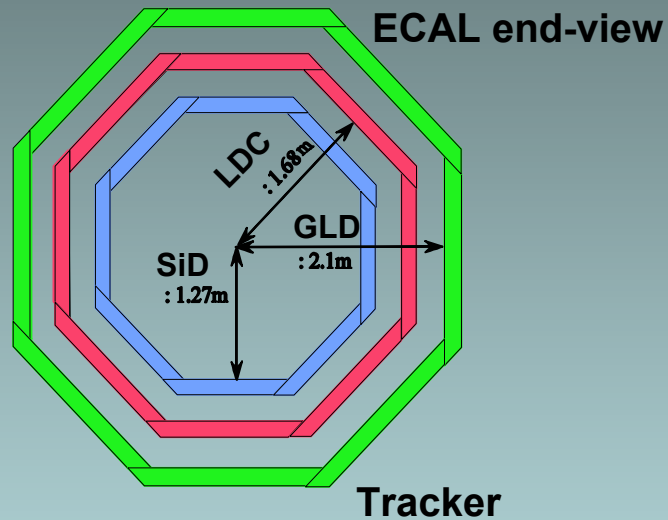


- Main Tracker
- EM Calorimeter
- H Calorimeter
- Cryostat
- Iron Yoke / Muon System

Confronto delle diverse opzioni

Principali differenze: **dimensione** e **rapporto lunghezza/larghezza**

Importante: raggio interno del ECAL: definisce la dimensione totale



- Figura di Merito (ECAL):

Barrel: $B R_{in}^2 / R_m^{effective}$

Endcap: "B" $Z^2 / R_m^{effective}$

R_{in} : Inner radius of Barrel ECAL

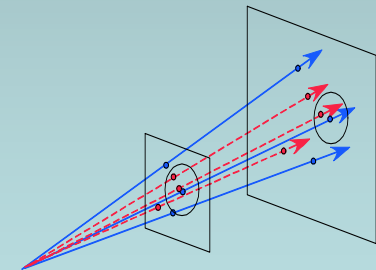
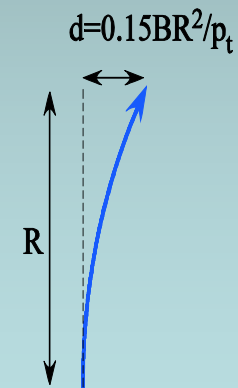
Z : Z of EC ECAL front face

- Diverse opzioni

SiD: $B R_{in}^2$

LDC: $B R_{in}^2$

GLD: $B R_{in}^2$

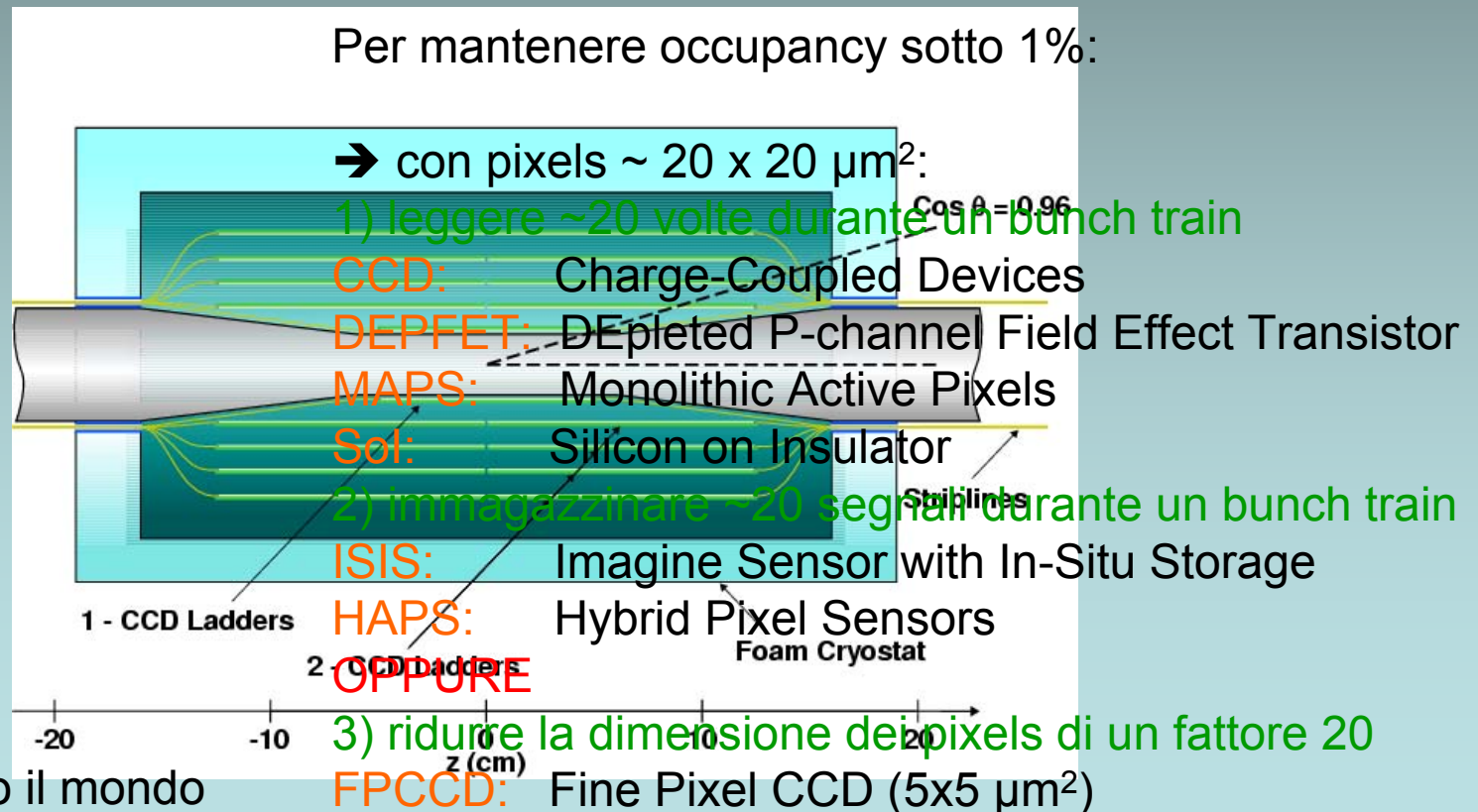


Tracciatori interni e Rivelatori di vertice

Requisiti per il detector

- Eccellente precisione sul singolo punto ($< 4 \mu\text{m}$)
- Eccellente risoluzione del parametro d'impatto ($5\mu\text{m} \oplus 10\mu\text{m}/(p \sin^{3/2}\theta)$)
- Trasparenza ($\sim 0.1\% X_0$ per strato / 4-5 strati)
- Ricostruzione delle tracce (identificazione delle tracce usando il solo VD)

→ unanime accordo per tutte le configurazioni: Pixel Detector

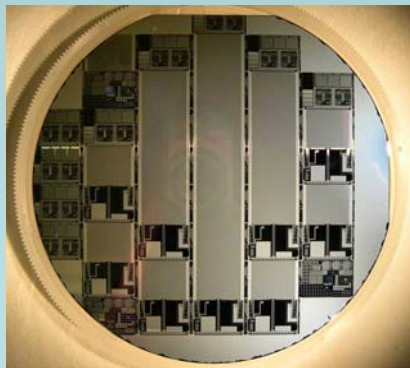


12 tecnologie

30 gruppi da tutto il mondo

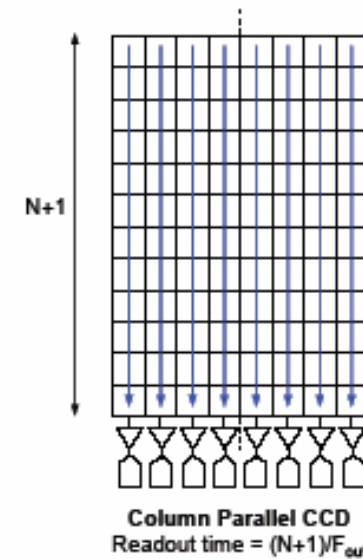
1) CCD a lettura parallela

- principio di funzionamento testato @ SLD
 - 5 MHz x 96 ch.
 - 3.9 μm space point resolution
- velocita' di lettura per bunch spaziatu di 250 ns:
50MHz clock
 - lettura a colonne parallele
 - successo del presente R&D → 25MHz
con 100 electrons noise @ 1.9V clocking
- minimizzare la quantita' di materiale
 - spessore dei sensori: 50 μm (20 attivi + supporto)
 - materiale per strato: $<0.1\% X_0$



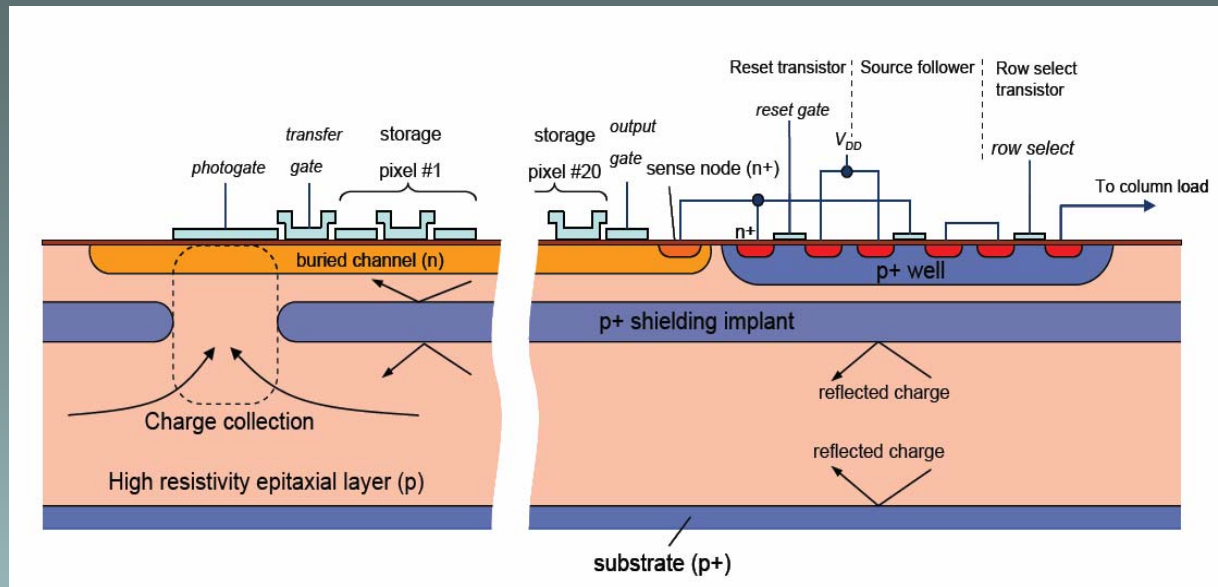
CPC1: 750x400 pixels, 20x20 μm^2
Bump bonded by VTT to readout CPR1
Various sized (up to 92mmx15mm) CPC2 detector chips

- **Separate amplifier and readout for each column**



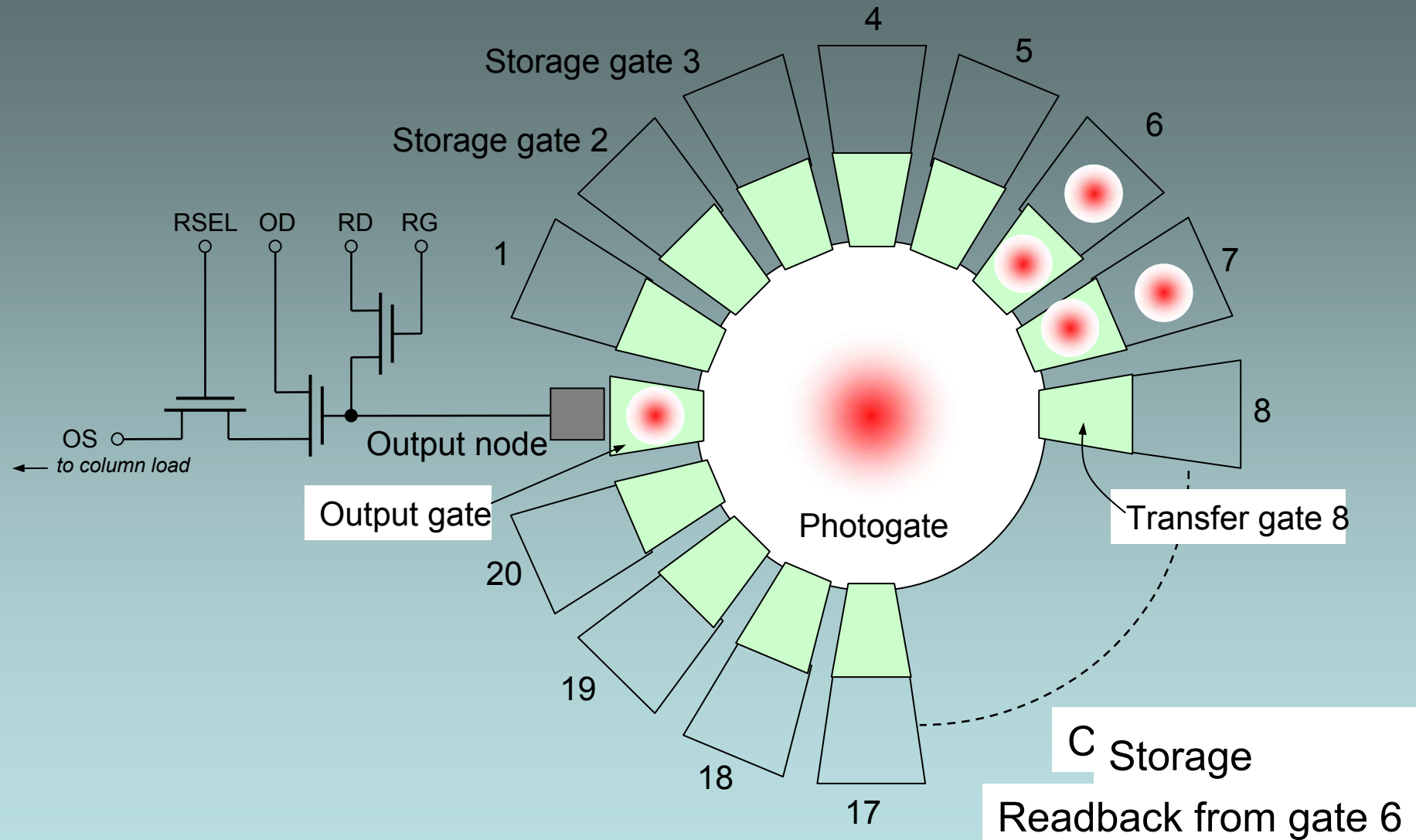
LCFI (Bristol, Glasgow,
Lancaster, Liverpool,
Oxford, RAL)

2) ISIS: event storage



- RF pickup is a concern for all sensors converting charge into voltage during the bunch train;
- The In-situ Storage Image Sensor (ISIS) eliminates this source of Electromagnetic Interference:
 - ❖ Charge collected under a photogate;
 - ❖ Charge transferred to 20-pixel storage CCD in situ, 20 times during the 1 ms-long train;
 - ❖ Conversion to voltage and readout in the 200 ms-long quiet period after the train, RF pickup is avoided;
 - ❖ 1 MHz column-parallel readout is sufficient;

2) Novita' a LCWS05: Revolver ISIS



Idea by D. Burt and R. Bell (E2V)
30 March 2005

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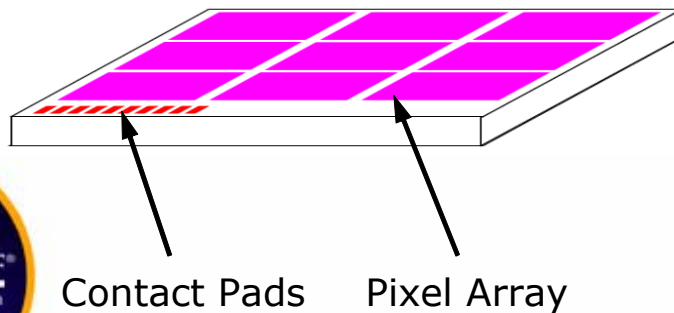
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3) Area ridotta dei pixels

Array Designs

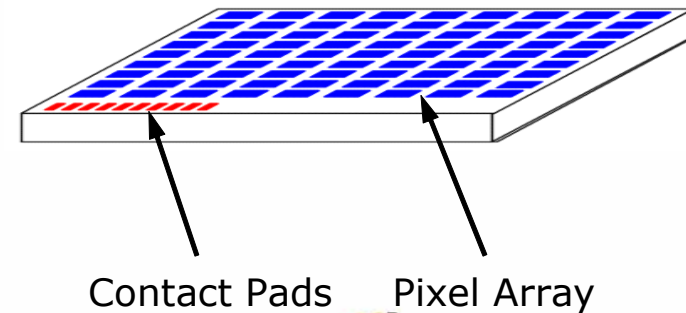
High-speed arrays

- Designed for quick response.
 - Threshold detection only.
 - Large pixels ($\sim 50 \times 50 \mu\text{m}$).
- Transmits X,Y location and time stamp of impact.



High-resolution arrays

- Designed for resolution and querying.
 - Smaller pixel size ($\sim 5 \times 5 \mu\text{m}$).
 - Random access addressability.
 - Records intensity.
- Provides intensity information only for pixel region queried.

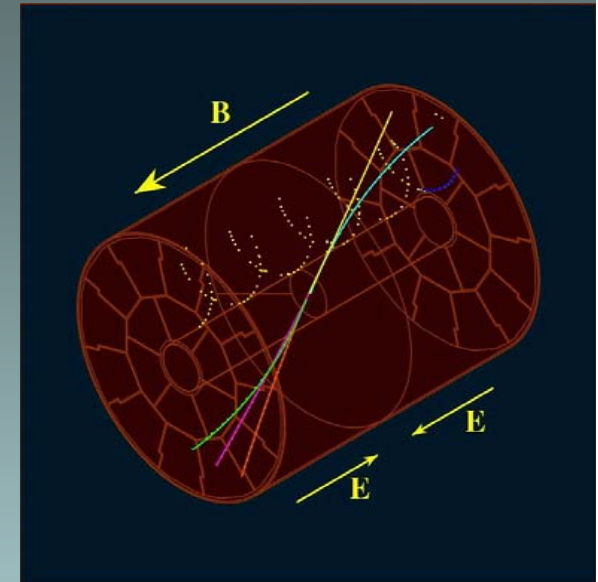


Tracciatore Centrale

Due tecnologie studiate per il detector di ILC

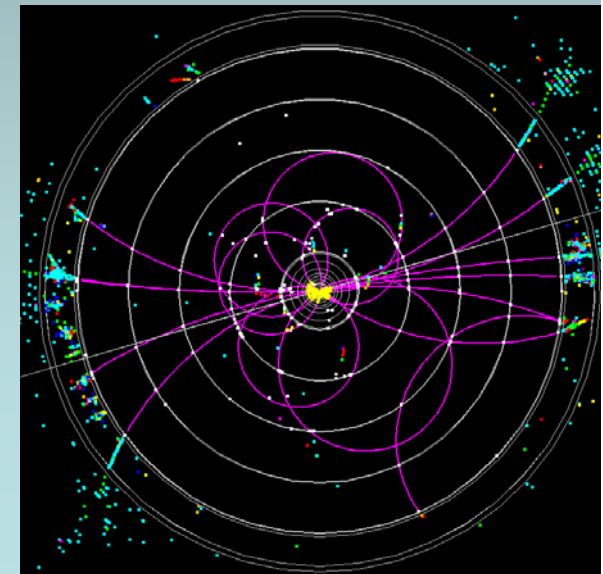
Tracciatore gassoso (TPC)

- Basato sull'esperienza positiva di: PEP-4, ALEPH, ALICE, DELPHI, STAR, ...
- Grande numero di punti ricostruiti, facilita la ricostruzione delle tracce
- $dE/dx \Rightarrow$ particle ID, bonus
- Minimo materiale, importante in calorimetria
- Tracciamento possibile a grandi raggi

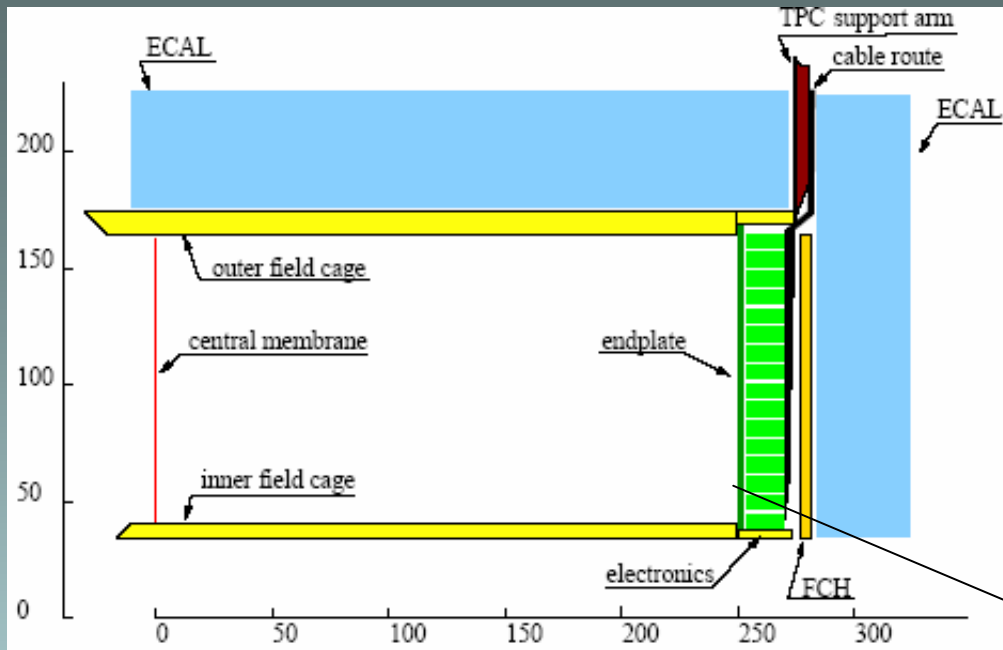


Tracciatore a Silicio

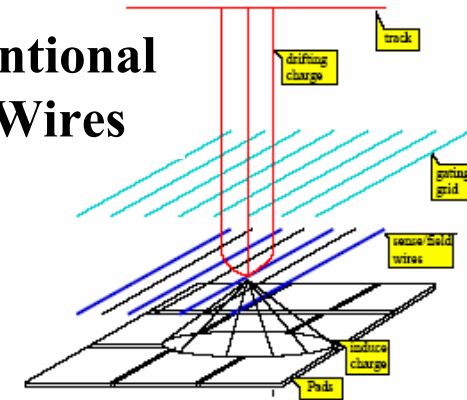
- Eccellente precisione sul singolo punto consente di minimizzare il volume totale
- Robusto in backgrounds intermittenti
linear collider diverso dallo storage ring



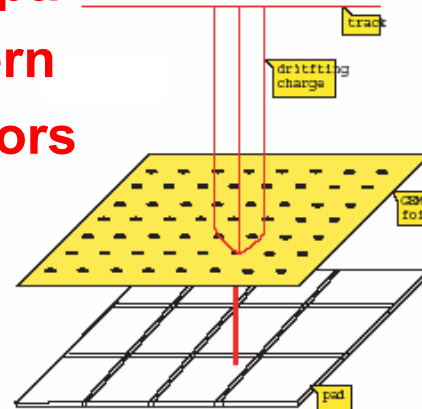
Time Projection Chamber



**Conventional
TPC: Wires**



**New concept:
Micro Pattern
Gas Detectors**

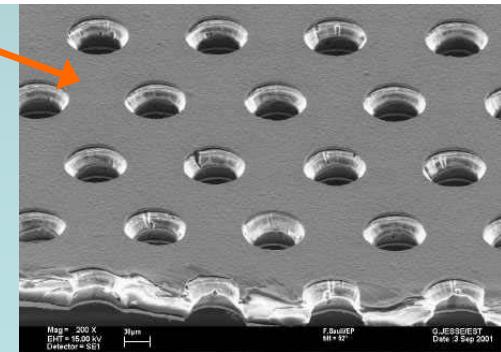
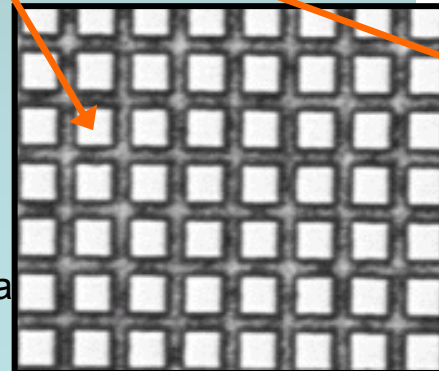


**Gas amplification:
Micromegas, GEMs**

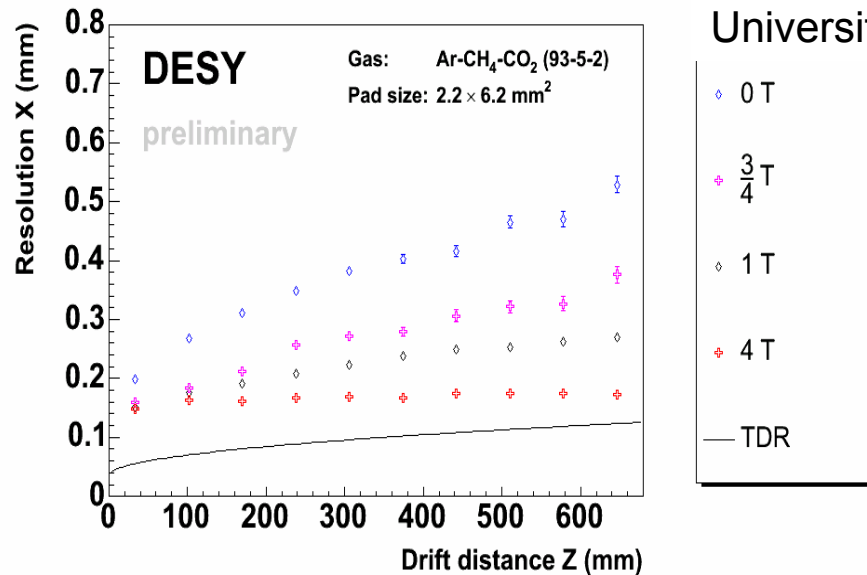
**Signal collection by
pads or MediPix**



IFAE Ca



Risoluzione del singolo punto



→ Tre camere GEM lette da pads di 2.2x6.2mm²

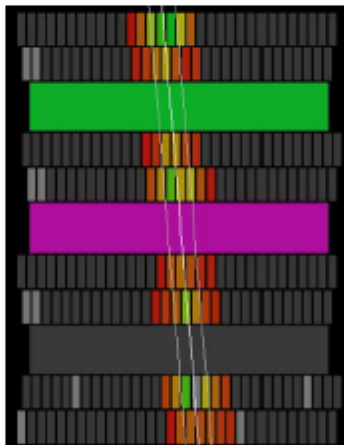
Risoluzione del singolo punto peggiore delle previsioni

Possibili cause: metodo di ricostruzione, pads 10% piu' grandi che in simulazione

Events in P5 with ≈ 25 cm drift distance

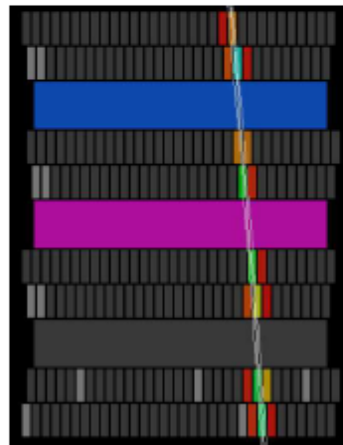
B = 0 T

track width = 2.6 mm



B = 5.3 T

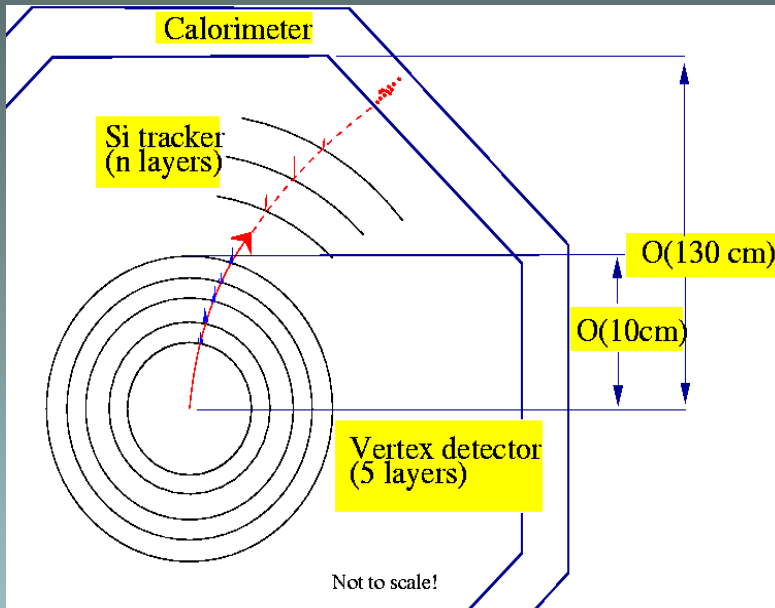
track width = 0.37 mm



→ Effecto del campo magnetico sulla risoluzione di singolo punto

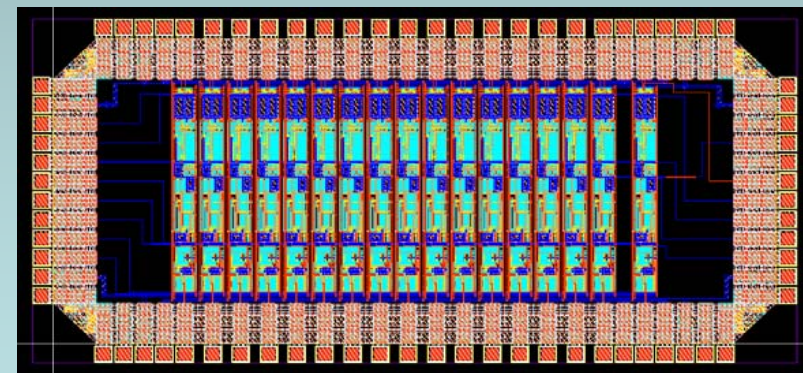
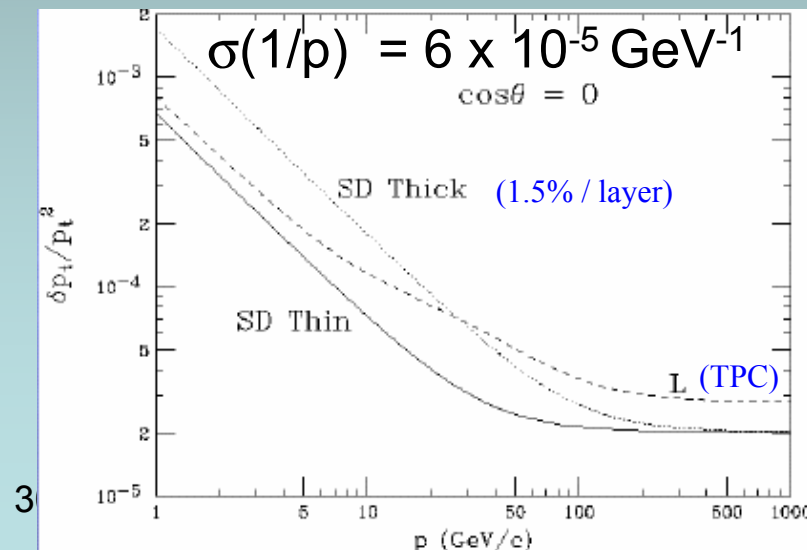
Tracciatori a Silicio

SID/SiLC



5 strati di rivelatori di vertice a pixel
5 strati di tracciatori a Si-strip

Key R&D: FE and readout chip prototype (.18 μ m UMC)
16 channel pream, shaper. ADC
Promettenti test in laboratorio





Sistema Calorimetrico

ECAL: calorimetro al silicio-tungsteno (SiW) :

- Lettura analogica di silicon pads
- Tungsteno : $X_0 / \lambda_{had} = 1/25$, $R_{Moliere} \sim 0.9\text{cm}$
- Segmentazione laterale: $1\text{cm} \sim R_{Moliere}$
- Segmentazione longitudinale: 40 strati ($24 X_0$)

HCAL: digitale vs. analogico (questione aperta):

Struttura a sandwich con strati di acciaio e

- **HCAL Analogico (Tile HCAL)**

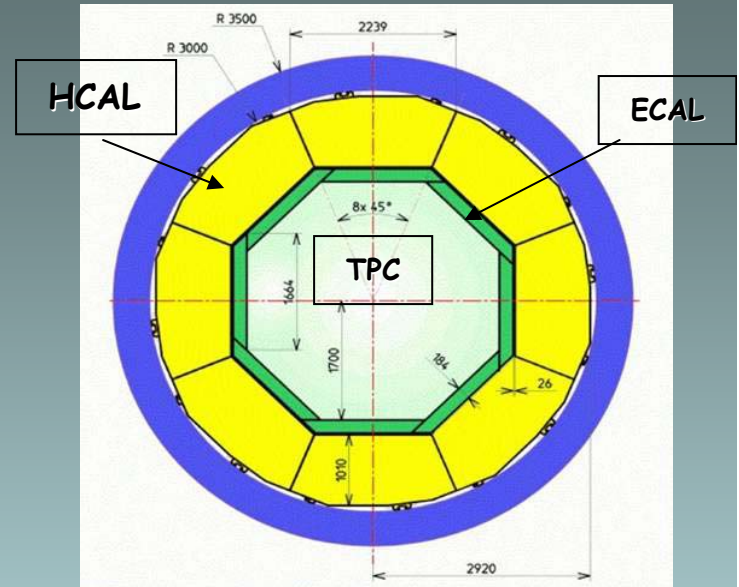
Minore segmentazione laterale $5 \times 5 \text{ cm}^2$ (motivata dai costi)

Materiale attivo: - scintillatore

- **HCAL Digitale**

Maggiore segmentazione laterale $1 \times 1 \text{ cm}^2$ ma con lettura digitale

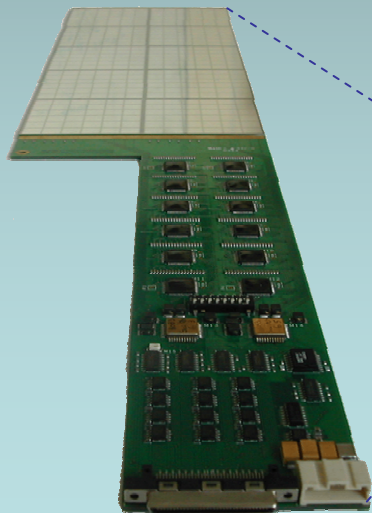
Materiale attivo: - scintillatore
- gas (RPCs, GEM)



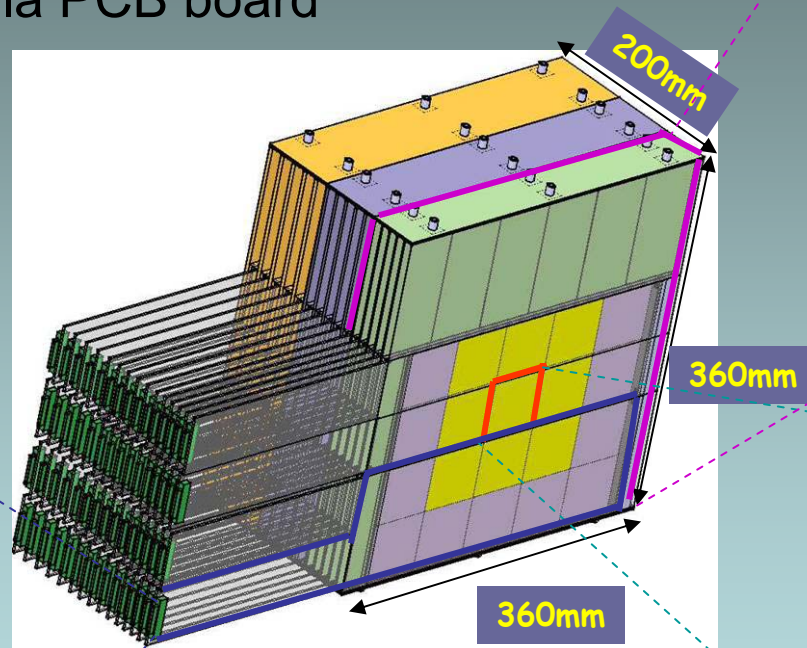
ECAL R&D in CALICE

- 30 strati di Tungsteno a spessore variabile
- Alternati a strati attivi di silicio
- Front end chip sulla PCB board

- PCB, with VFE
- Analogue signals
→DAQ

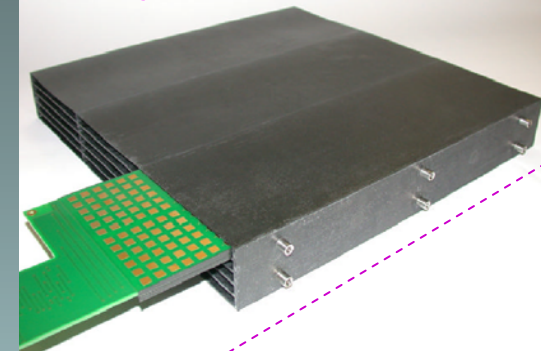


30 March 2005

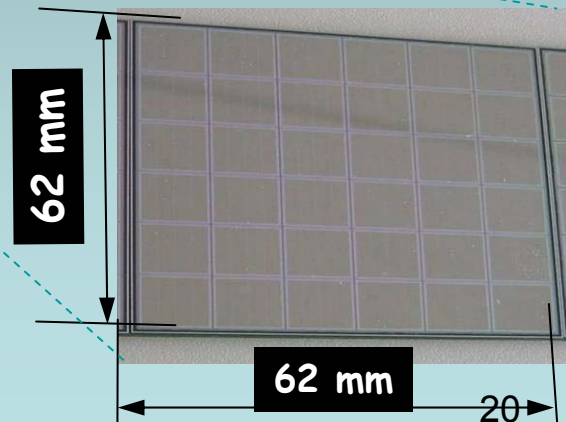


- 6x6 1x1cm² Si pads
- Conductively glued to PCB

14 layers, 2.1mm thick



- W layers wrapped in carbon fibre
- PCB+Si layers:8.5 mm



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ECAL @ the DESY test beam

Detector slab

Carbon fiber
+ tungsten
structure

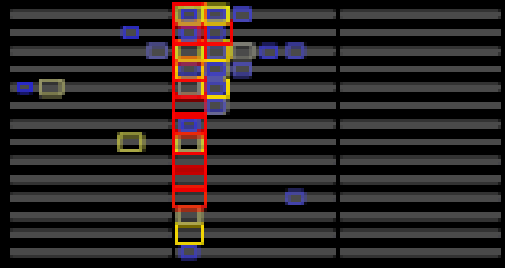
1-6 GeV e⁻



CALICE ECAL Prototype

Run=100078
Event= 613

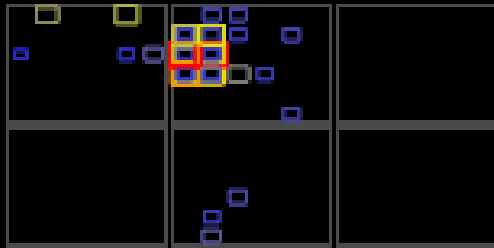
Top



↑ e- 3 GeV

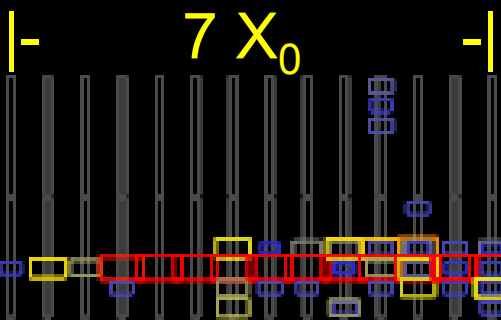
Detector Top

Front

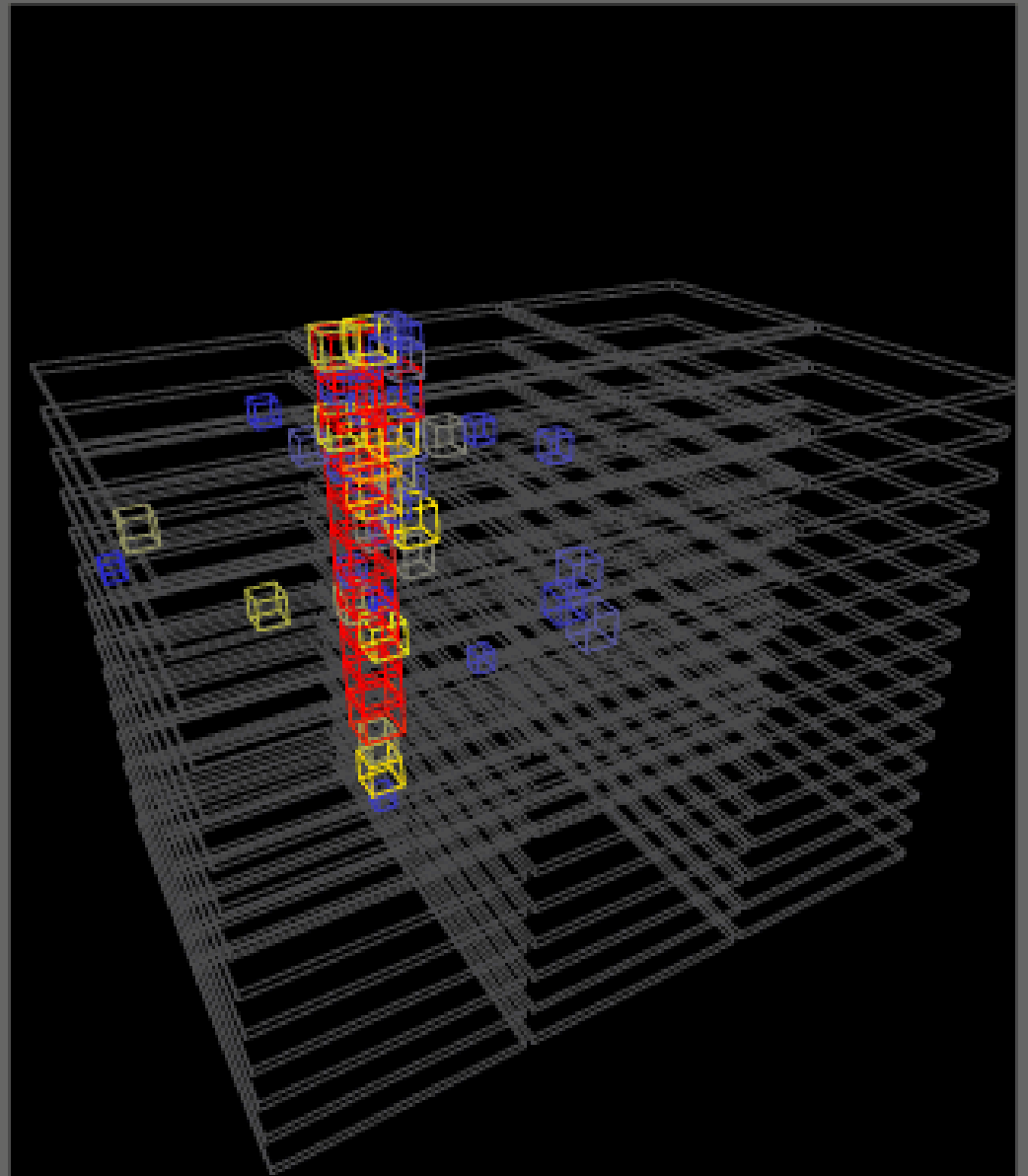


Detector Front

Side



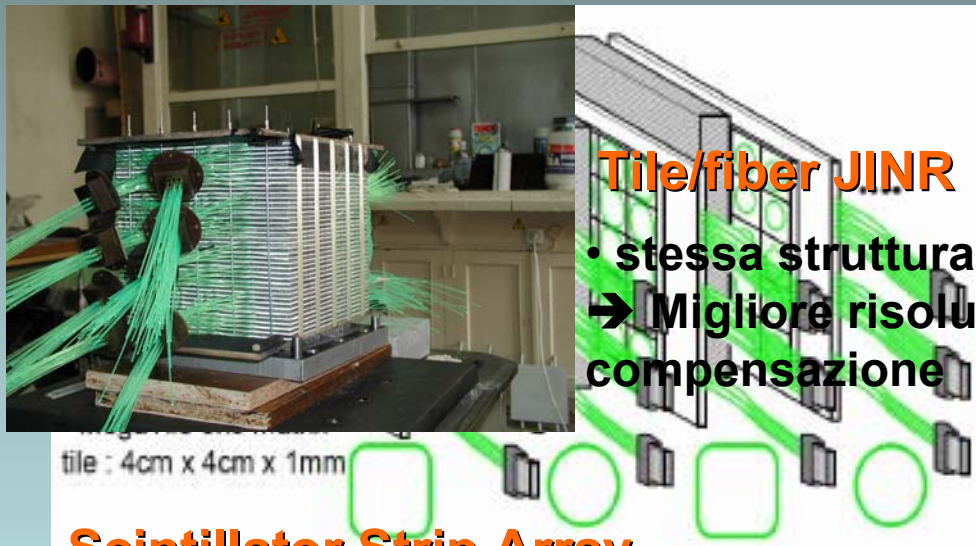
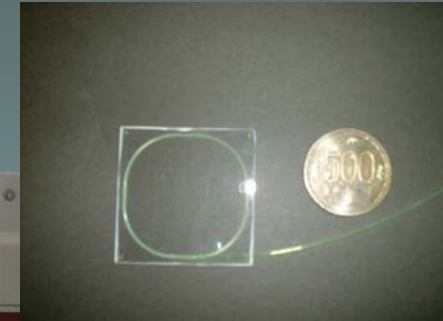
Detector Side



ECAL R&D in Japan

Tile/fiber

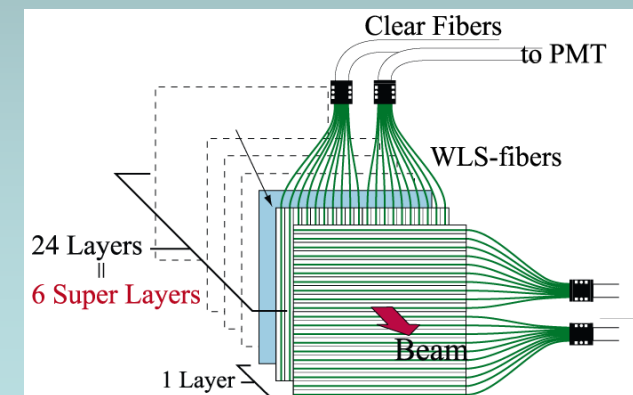
- struttura a sandwich di scintillatori e piombo
- rapporto 1:4 → **compensazione**
- lettura combinata di 5 strati
- dimensione delle tile: 4x4 cm²



- **stessa struttura** ma con rapporto 1:2
→ **Migliore risoluzione in E** a discapito della **compensazione**

Scintillator Strip Array

- lettura a strip combinando piani in x e y
- dimensione delle strip: 20cm x 1cm x 2mm
- struttura a sandwich con 4mm di piombo



ECAL R&D in Japan

Lettura del segnale luminoso attraverso Wave Length Shifting fibers connesse a photo-detector

→ Da operare in alti campi magnetici!

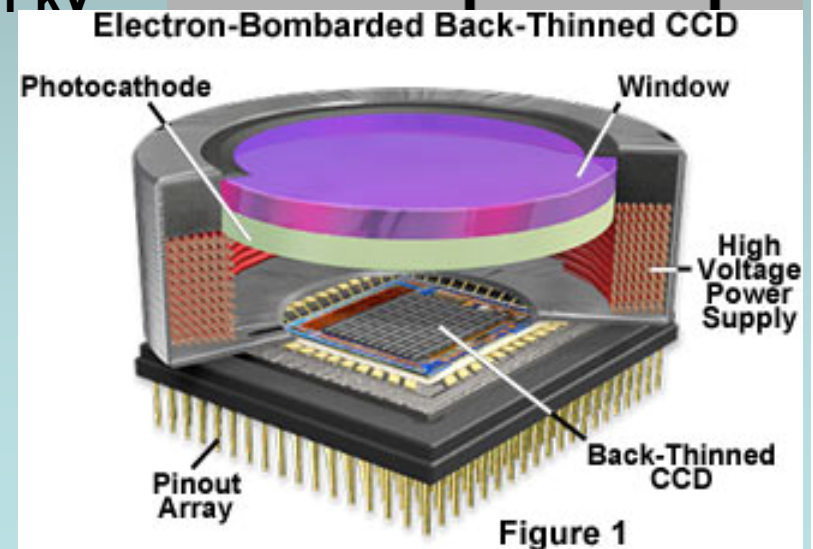
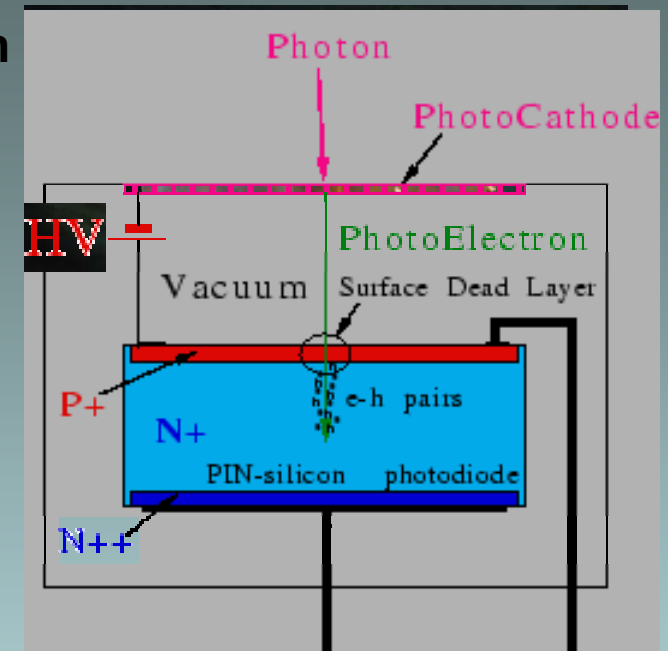
Possibilita' di lettura con: HPD, HAPD, EBCCD

HPD (HAPD)

- Photo-cathode + PIN diode (or APD) with a vacuum gap in between
- Insensitive to the axial magnetic field
- HV between photocathode and PIN diode
- Gain ~ 3000 (x100) with photo-cathode @ -11 kV

Electron Bombarded CCD

- Photons detected on a photo-cathode
- Released electrons are accelerated across a gap and impact on the back side of a back-thinned CCD.
- Gain ~ 500
- single photo-electron peak visible

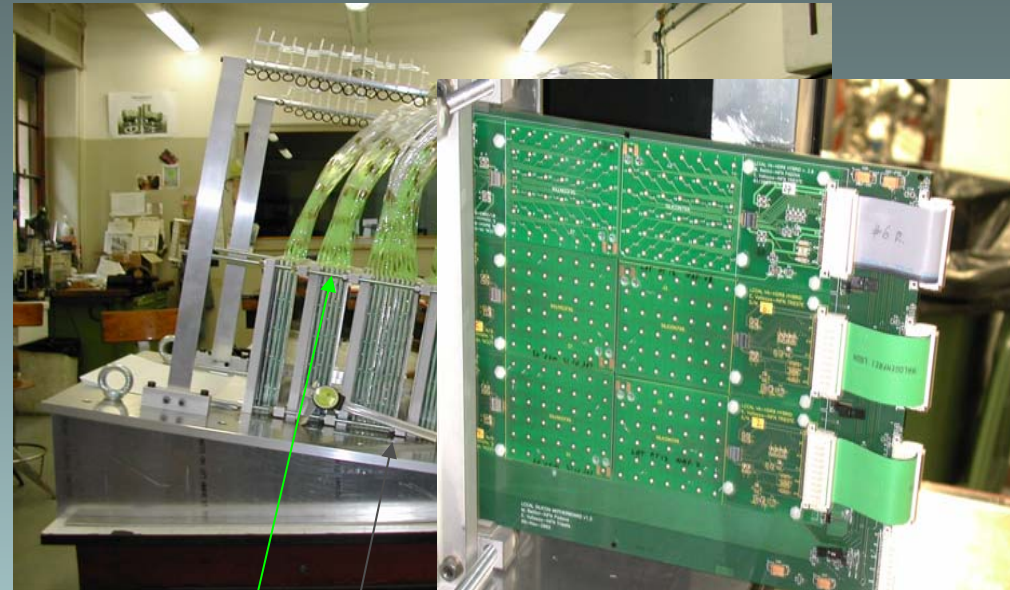
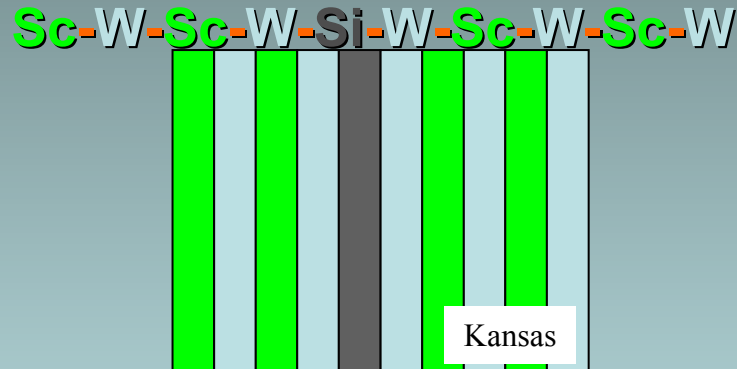


Test beam @ KEK



ECAL R&D in LCCAL

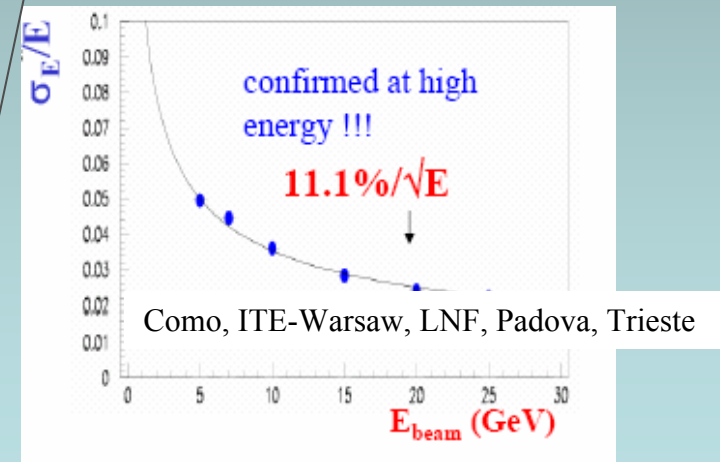
- Ibrido Silicio-scintillatore
 - vantaggi del Si-W: alta granularita'
 - Erec da Scintillatore+WLS fibers
 - ~fattore 10 < # canali



Fibre raggruppate in gruppi di 25x4 consentono segmentazione longitudinale in 4 strati

3 slots per l'inserimento di piani di Si pad (Motherboard)

30 March 2005



HCAL: analogico o digitale?

HCAL Digitale

- piccole celle: imagining HCAL
- registrate solo le celle con segnale
- nessuna informazione di ampiezza

Questioni aperte per R&D:

test del principio di funzionamento
readout economico su larga scala
algoritmo per l'analisi da sviluppare

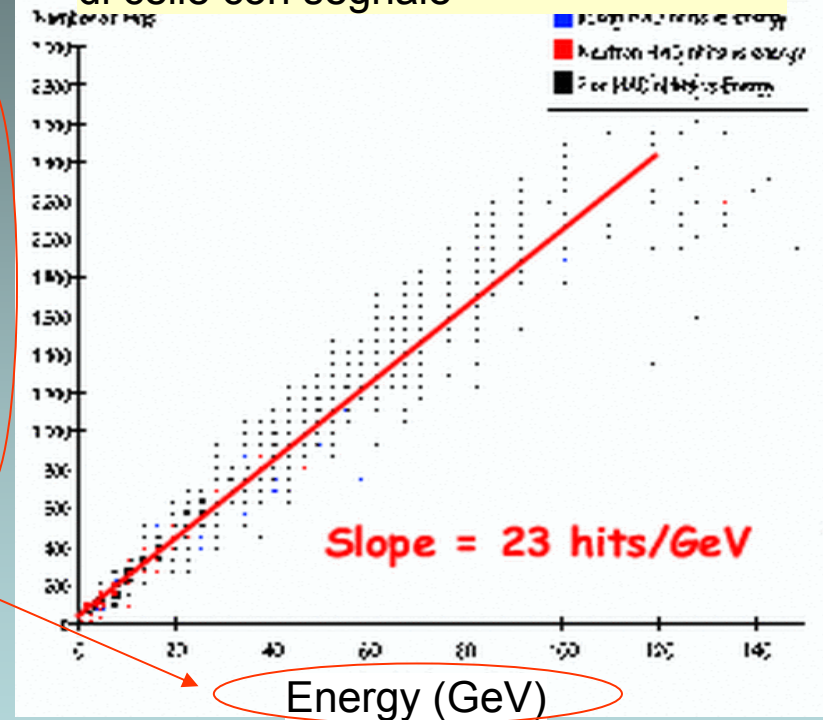
Tile (analogico) HCAL

- registra posizione e ampiezza

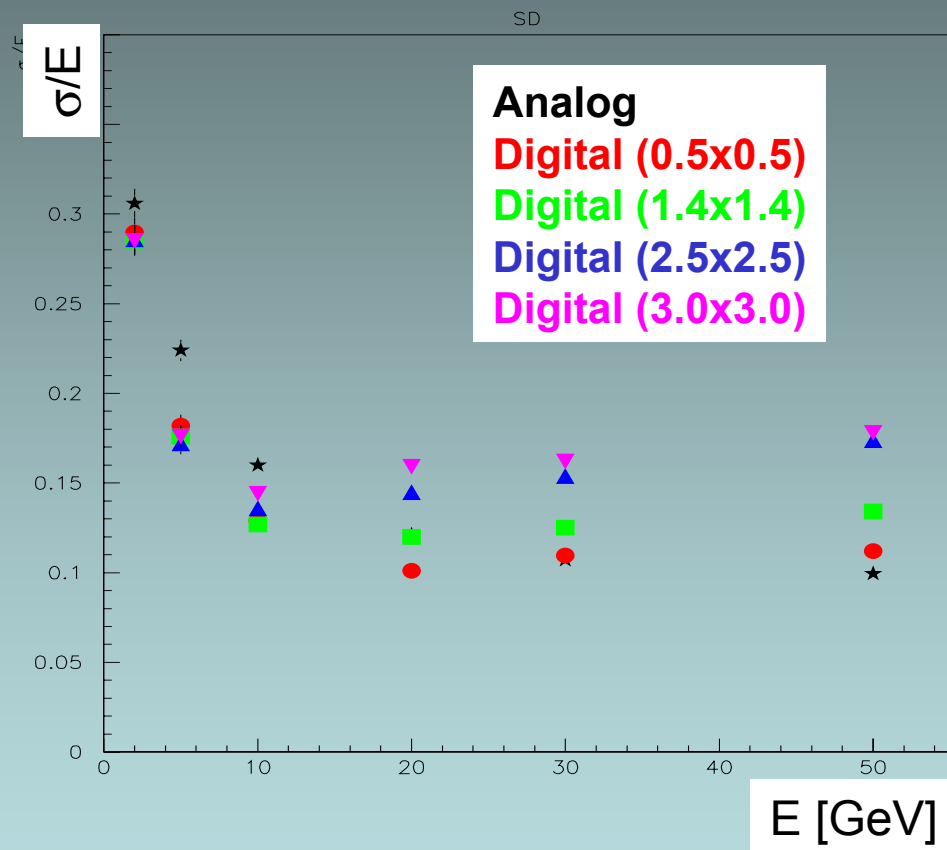
Questioni aperte per R&D:

lettura della luce
ottimizzazione del sistema
algoritmo per l'analisi da sviluppare

Corrispondenza tra energia e numero di celle con segnale



HCAL: analogico o digitale?



bassa E → digitale meglio di analogico grazie alla soppressione delle fluttuazioni Landau

alta E → analogico meglio di digitale

•Possibili soluzioni:

soglie multiple (semi-digital)

Digitale: richiede lettura in piccole celle (~1cm)

→ piccole scintillator tiles

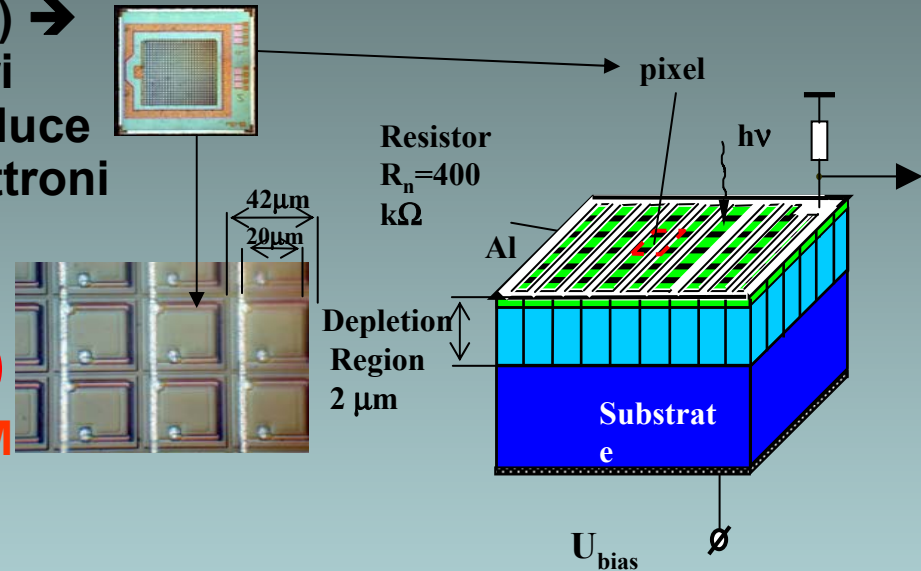
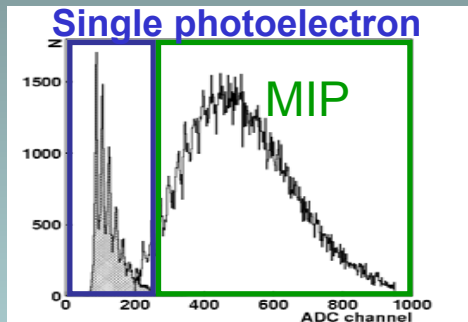
→ gas + piccoli pad readout



HCAL: tecnologia di lettura

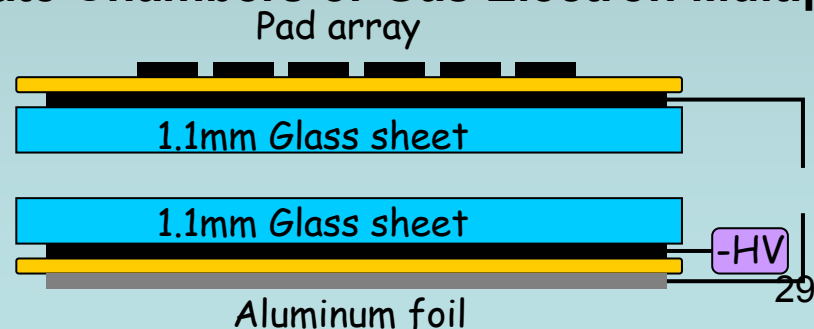
Tile HCAL:

- lettura della luce: conversione del segnale luminoso in elettrico
 - tecnologia basata su Si detector: deve funzionare in B !
 - Silicon Photo-multiplier (**SIPM**) →
 - ottimizzazione degli scintillatori
 - ottimizzazione del trasporto di luce
 - risoluzione dei singoli fotoelettroni



HCAL Digitale:

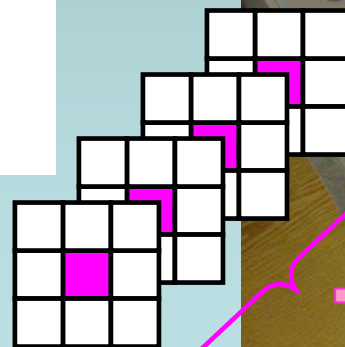
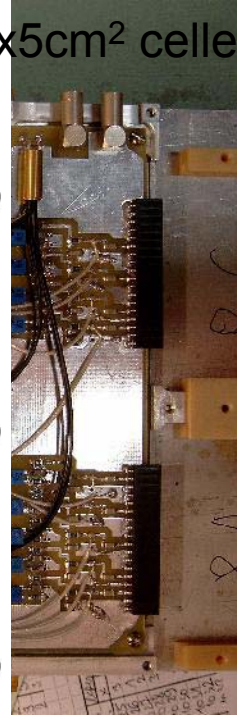
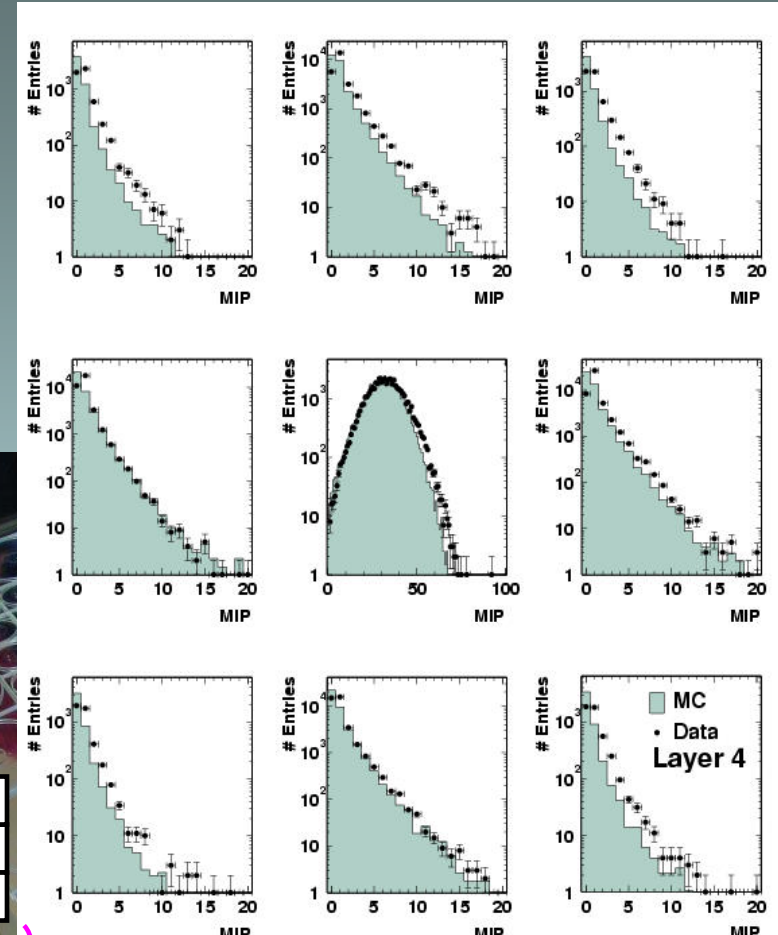
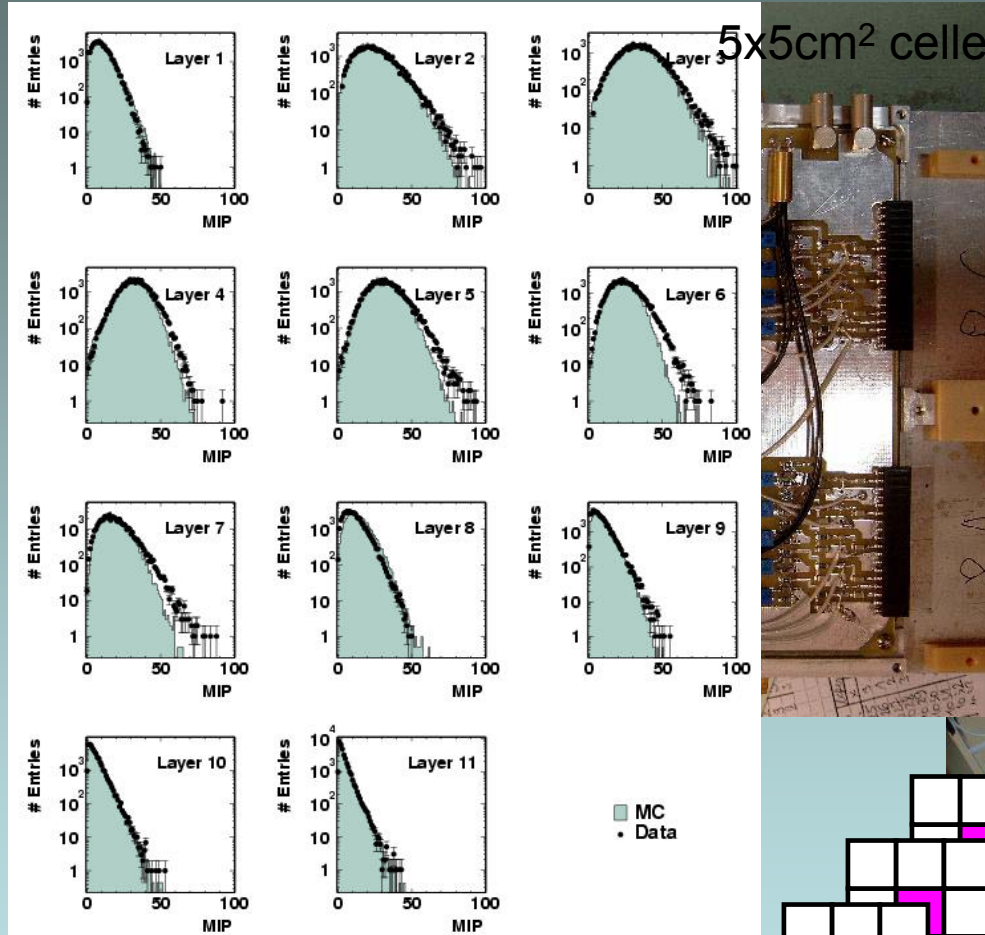
- lettura del segnale con: Resistive Plate Chambers or Gas Electron Multiplier
- facile da costruire, economico
- alta granularita': **1cm²**



Caratterizzazione degli sciami con AHCAL

Sviluppo Longitudinale

Sviluppo Laterale



30 March 2005

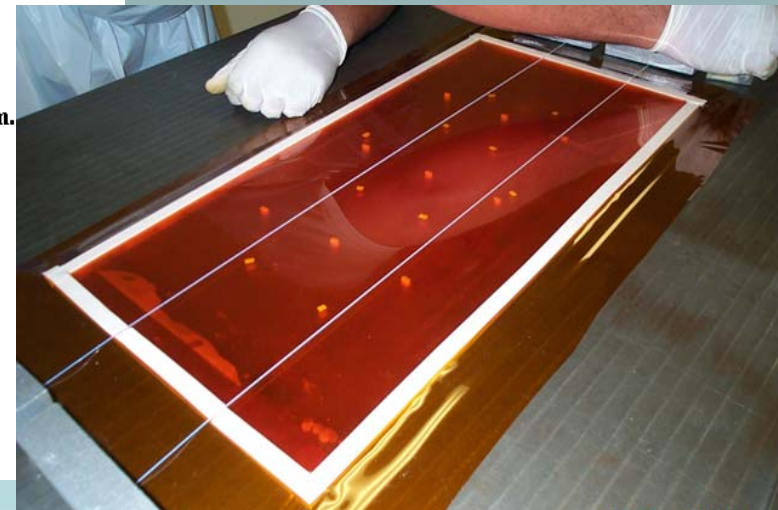
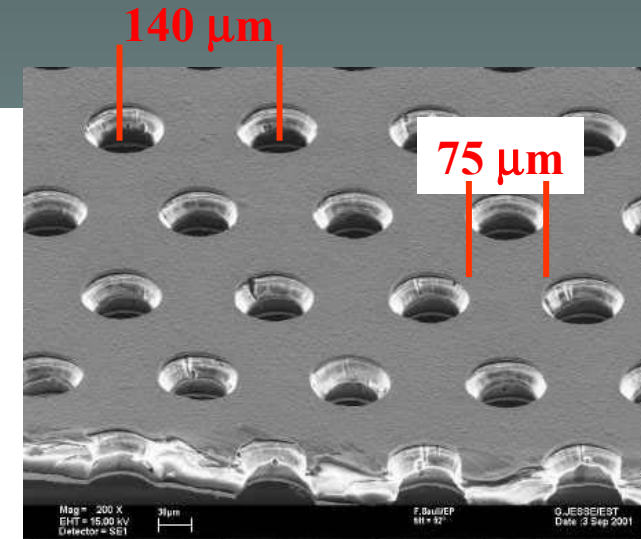
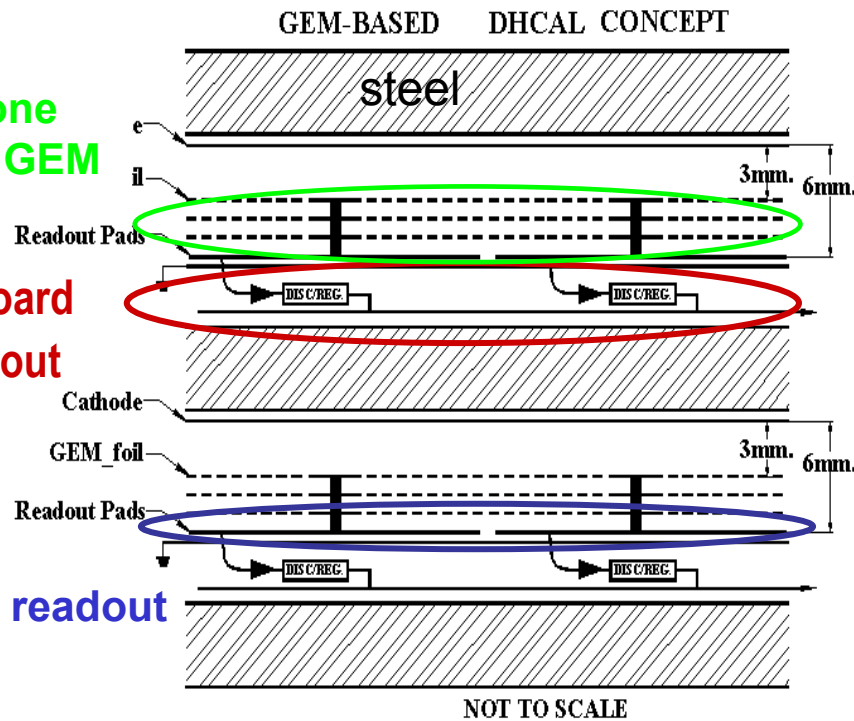
Un calorimetro con GEM

Struttura a sandwich di acciaio e camere a gas

3 strati di amplificazione con fogli di GEM

onboard readout

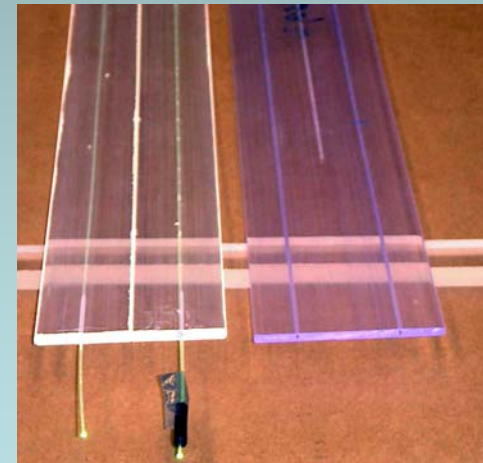
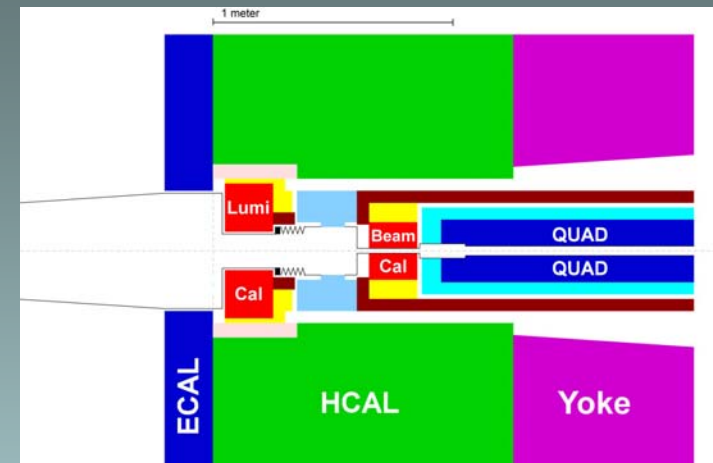
Pad readout



Altri aspetti da considerare...

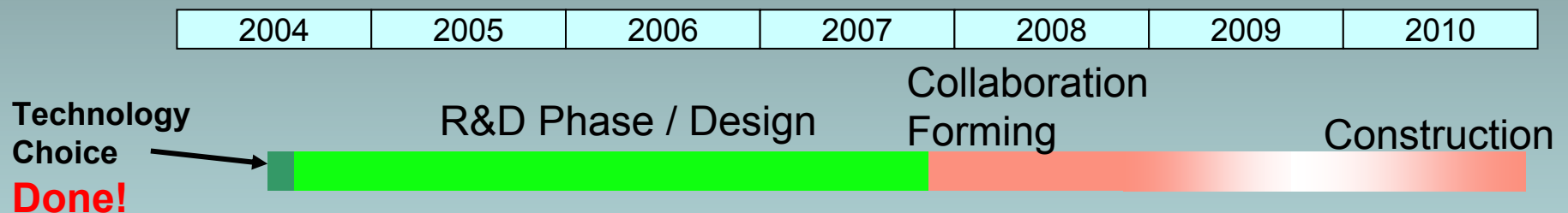
Per limiti di tempo non e' stato possibile discutere:

- Very forward detectors:
 - misurare la luminosita'
 - very forward $e / \gamma \rightarrow$ ermeticita'
- Tail catcher / muon detector
 - instrumented iron yoke
 - migliorare la risoluzione dell'HCALTecnologie: lunghe barre scintillanti, RPC
- Molti altri progetti di R&D per i vari detector



Conclusioni & Piani Futuri

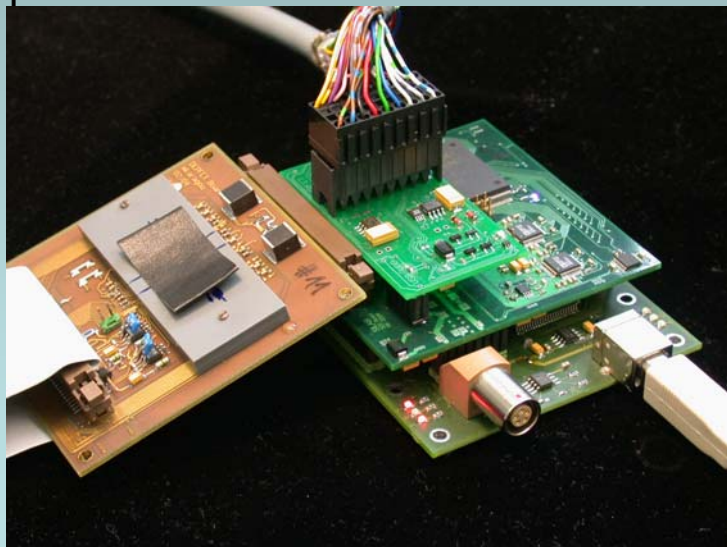
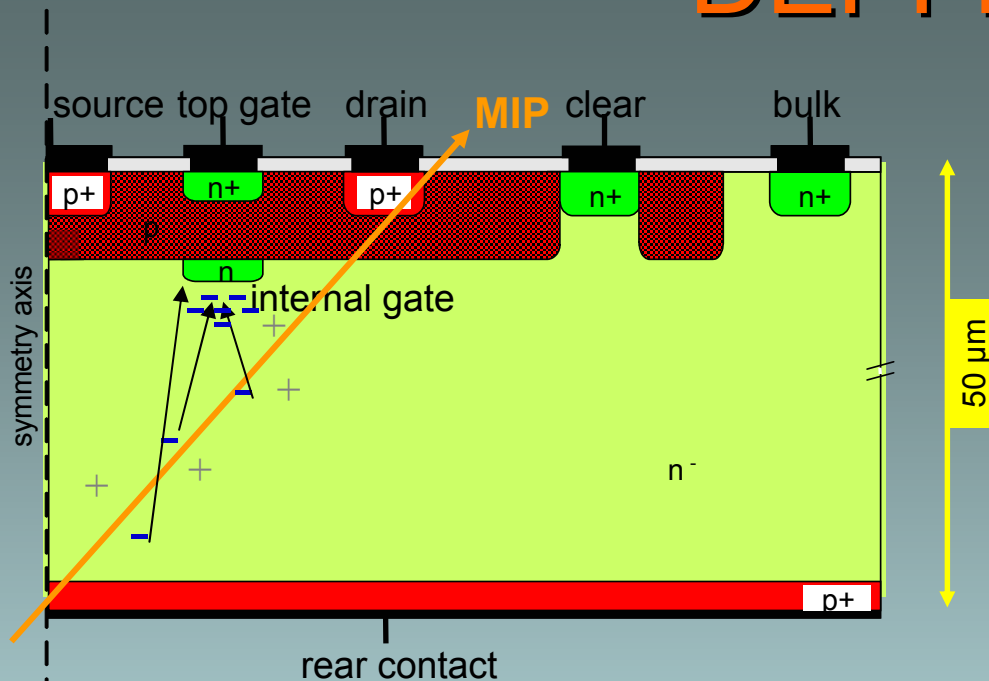
- **Enorme** progetto di R&D
→ creato il primo concetto per un detector per ILC
- Il lavoro continua → con l'ambizione di proporre un detector design a fine 2007



- Molte sfide stimolanti per i prossimi anni

Backup slides

DEPFET



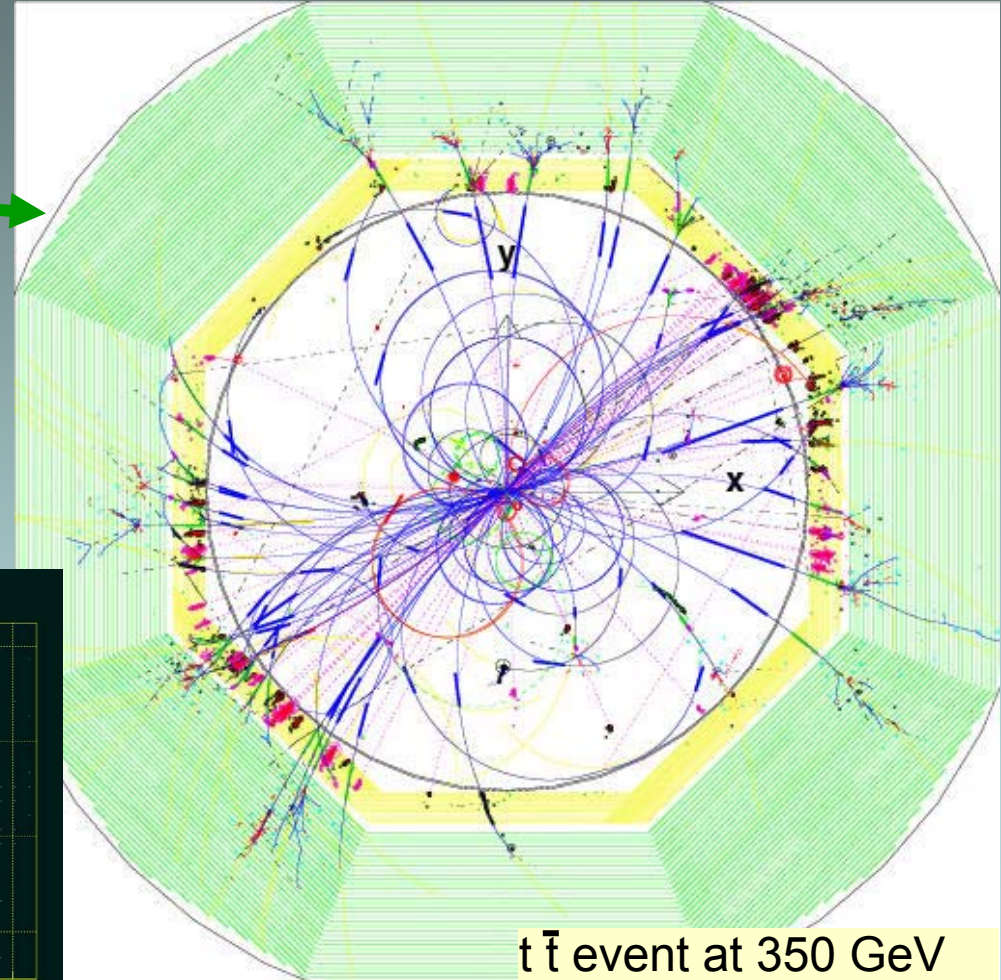
- Primo prototipo testato in testbeam di DESY
- Pixel size $20 \times 30 \mu\text{m}^2$,
→ 64 x 128 pixels
- Spessore $50 \mu\text{m}$ con
→ $S/N = 40$
- Rad. Hardness testata fino a 1 Mrad (^{60}Co)
- Readout a 100 MHz possibile con noise accettabile
- Basso consumo energetico (5W per detector a 5 strati)

MPI Munich, MPI Halle, U. Bonn, U. Mannheim

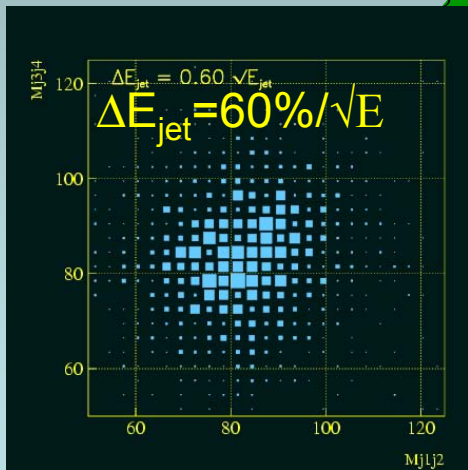
Eventi al Linear Collider

- Semplici eventi (rispetto al collider adronico)
 → permette la ricostruzione delle singole particelle
- La ricostruzione della massa dei bosoni pesanti impone richieste sulla risoluzione in energia dei jet

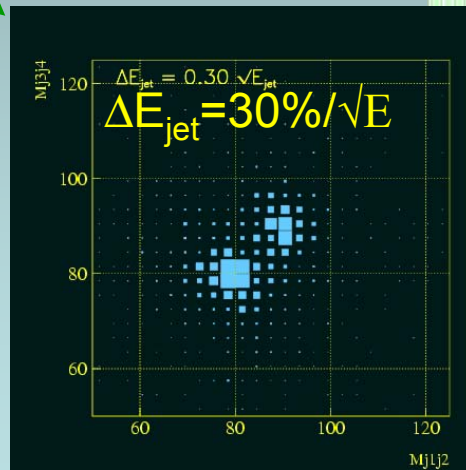
$e^+e^- \rightarrow WW \nu\bar{\nu}$, $e^+e^- \rightarrow ZZ \nu\bar{\nu}$



$t\bar{t}$ event at 350 GeV



30 March 2005



IFAE Catania - E. Garutti

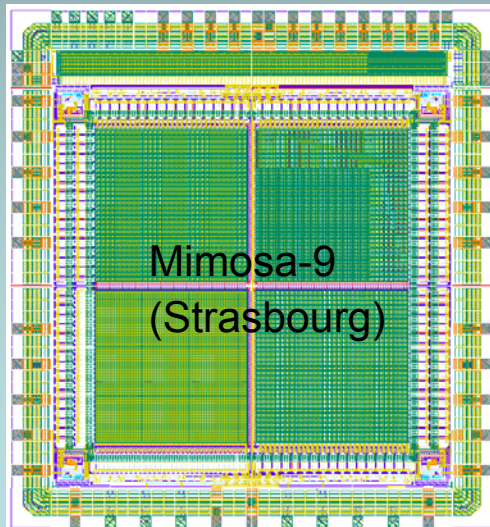
MAPS

- Elettronica di lettura integrata in ogni chip

- operazione piu' semplice di CCD
- no clocking-out of charge:
intrinsically radiation harder

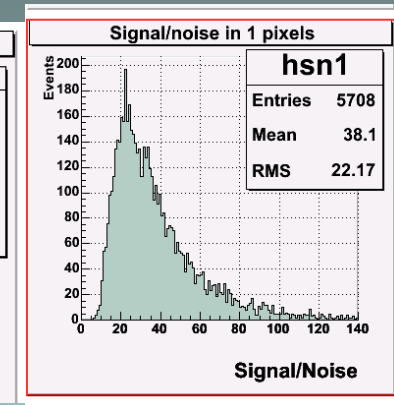
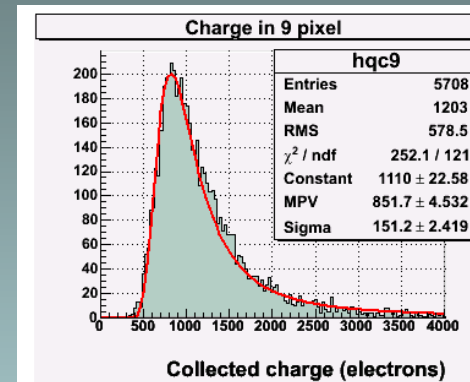
MA

- maggiore quantita' di materiale (?)
- maggiore consumo energetico



Testbeam results

S/N ~ 24



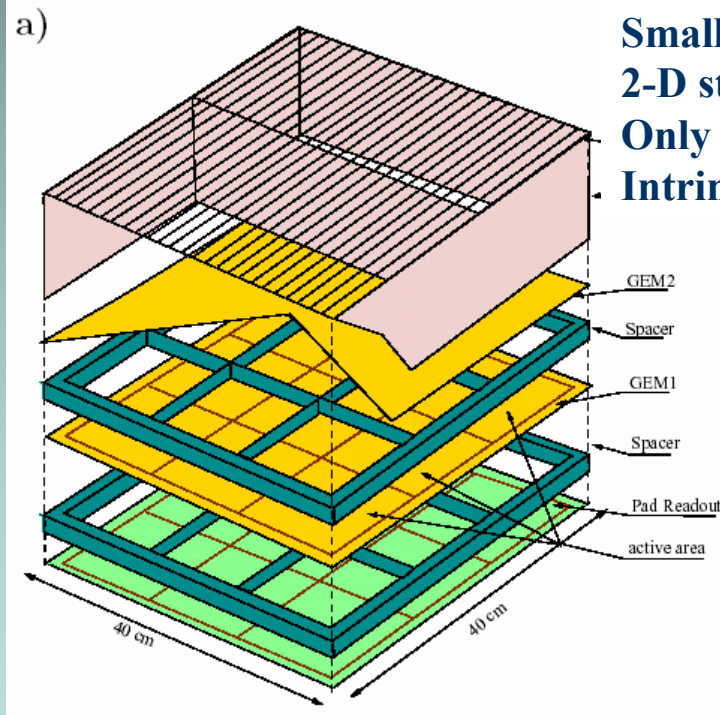
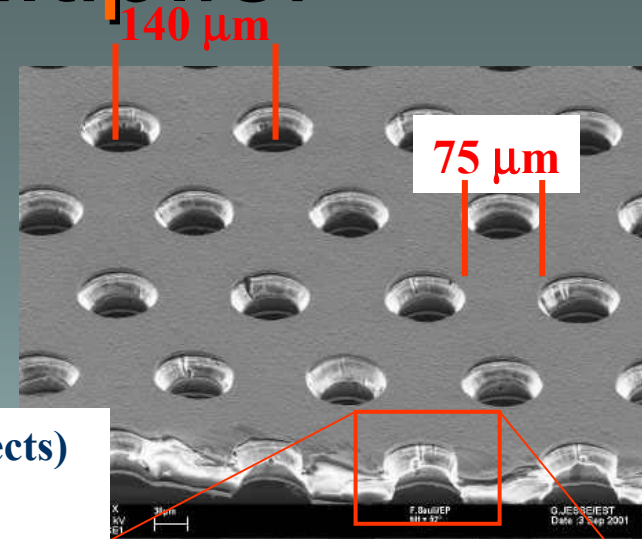
- 20 μm strato sensibile
- 20, 30, 40 μm pitch

R&D paralleli: FAPS (RAL)

Alternativa per active pixel con
10-20 storage capacitors / pixel
→ all'inizio dello sviluppo

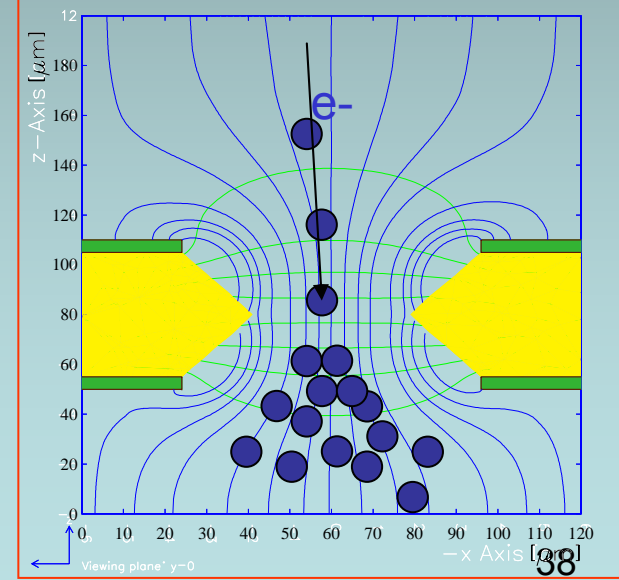
Gas Electron Multiplier

- 50 μm kapton foil, double sided copper coated
- 75 μm holes, 140 μm pitch
- GEM voltages up to 500 V yield 10^4 gas amplification



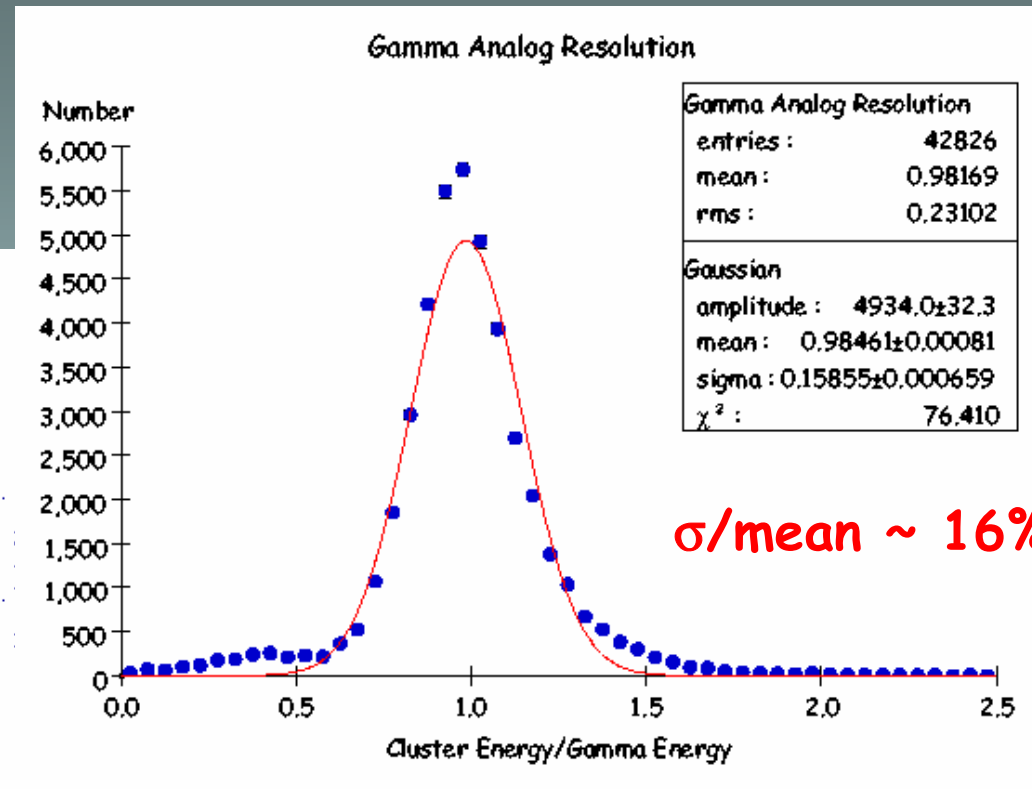
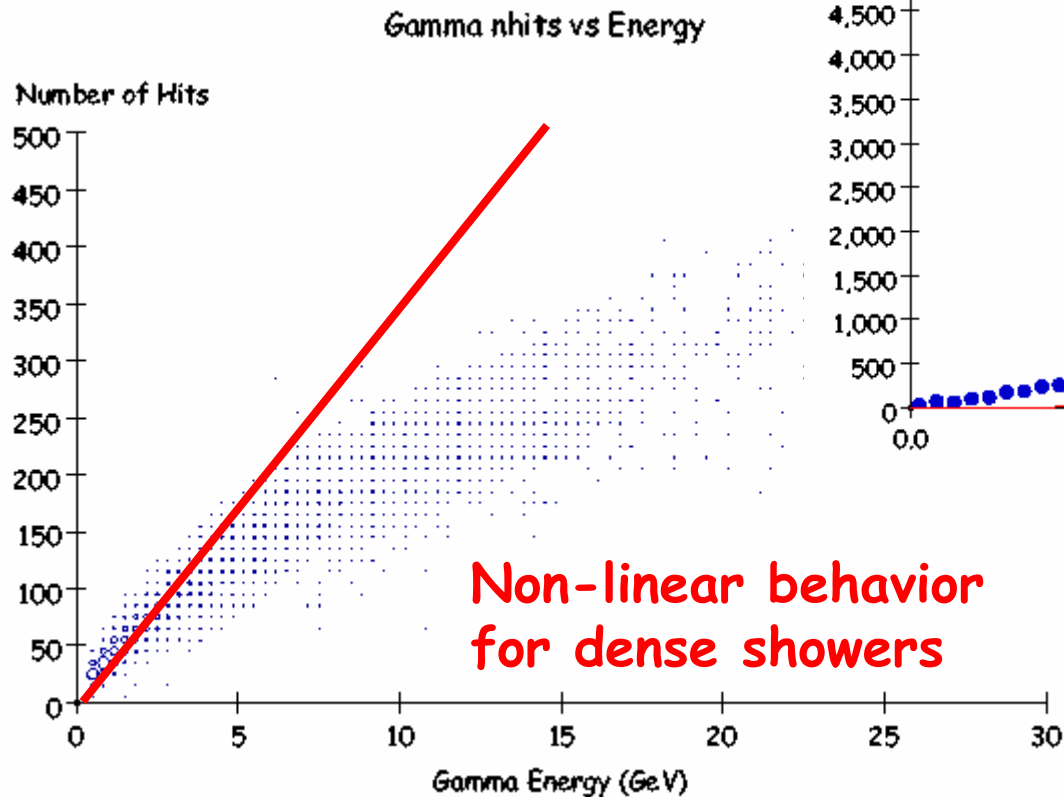
Small structures (no $E \times B$ effects)
2-D structures
Only fast electron signal
Intrinsic ion feedback suppression

Use GEM towers for safe operation (COMPASS)



Readout concept: Analog vs Digital

From photon analysis:
ECAL requires Analog readout



Analog Readout
- perfect γ cluster

Very Front End Electronics

18-channel Chip 0.8 μm CMOS¹

