Università degli Studi dell'Insubria
Facoltà di Scienze, Matematiche, Fisiche e Naturali
Anno accademico 2007 – 2008
Scuola di Dottorato in Fisica – XXIII CICLO

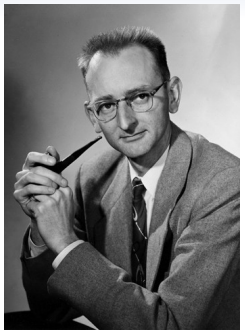
Misura di sezione d'urto di annichilazione di antiprotoni lenti su nuclei

Valerio Mascagna

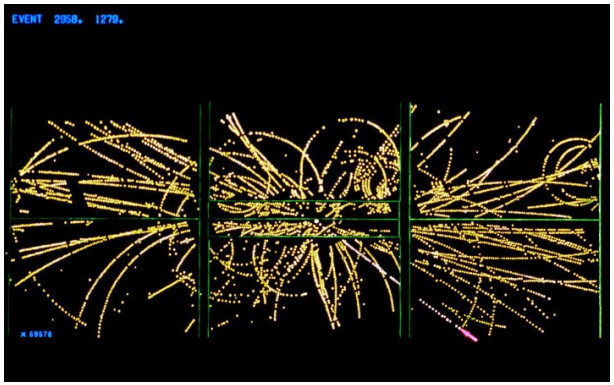
Sommario

- Introduzione
- Il rivelatore per l'esperimento ASACUSA
- Risultati presa dati 2008
- Attività collaterali (MICE, MUSASHI)
- Conclusioni

L'antiprotone

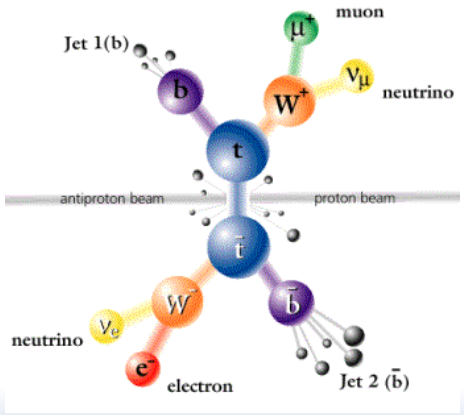


Scoperto nel 1955 al Bevatron
→ NOBEL a O. Chamberlain e E. Segrè nel 1959



da allora...

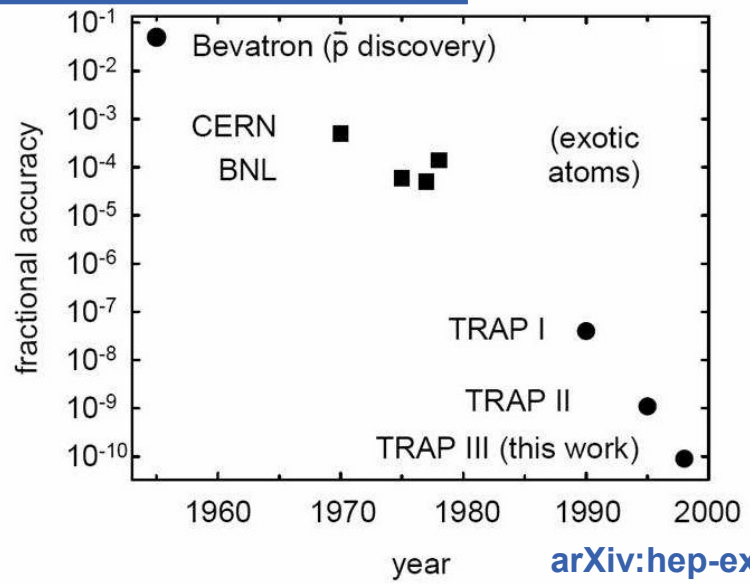
- ***Scoperta dei bosoni W e Z all'S$p\bar{p}$pS (CERN)***
- ***Scoperta quark TOP a Tevatron***
- ***Formazione dell'anti-idrogeno a LEAR (CERN)***



Antiprotoni di bassa energia

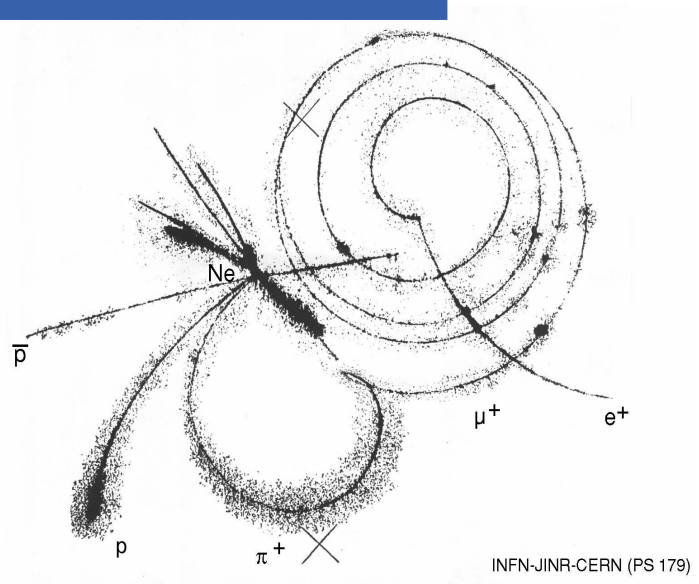
Gli esperimenti con antiprotoni di bassa energia permettono test di precisione sulle previsioni dei modelli teorici (teorema *CPT*, interazione forte)

Errore su massa/carica antiprotone negli anni



arXiv:hep-ex/0512026 v1

Annichilazione su Ne



La sezione d'urto di annichilazione

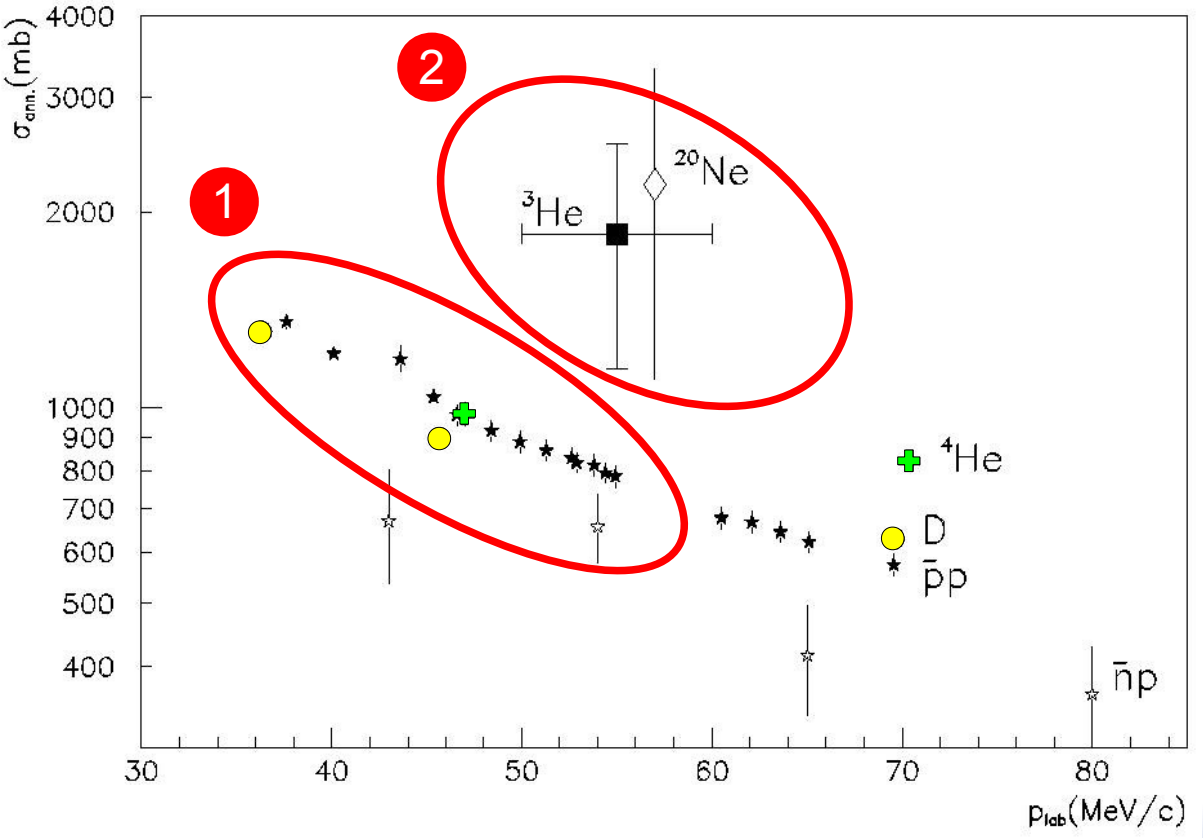
$\sigma_{ann} \sim A^{2/3}$ (p > 100 MeV/c)

Misure negli anni 80 – 90 dalla collaborazione OBELIX (LEAR, CERN)

Anomalie a p < 60 MeV/c:

1. **A=2 and A=4 σ_{ann} < A=1 ?**
2. **A=3 e A=20 simile σ_{ann} ?**

Al momento non esistono dati a bassa energia / alto Z



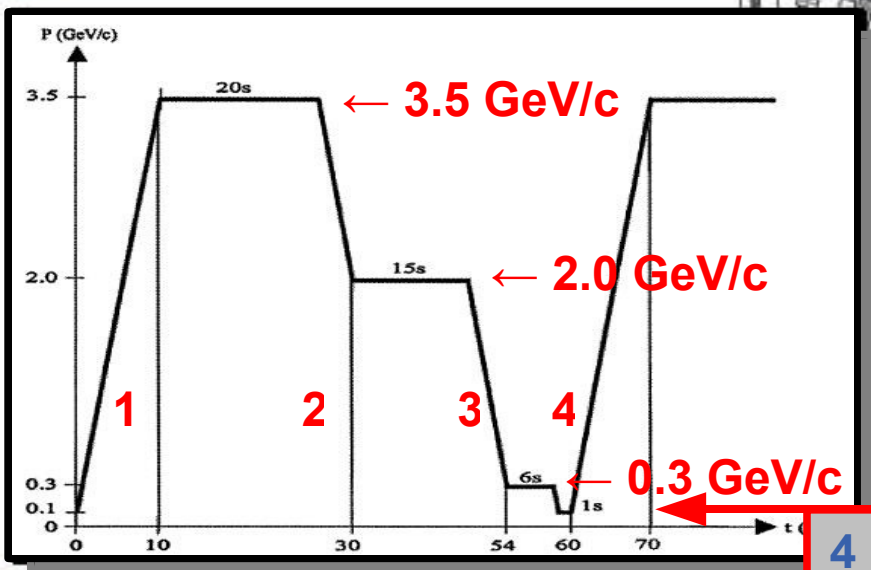
Necessità di nuove misure

- Test a basse energie
- Dipendenza da A
- Aumentare la statistica

Nel 2004/05 viene proposta una nuova misura da effettuarsi all'Antiproton Decelerator (CERN)
→ ultimato nel 2006
→ prese dati 2006, 2007 e 2008

Il fascio di AD

1
Estrazione dal PS:
protoni da 26 GeV/c → antiprotoni da 3.5 GeV/c



CICLO DI DECELERAZIONE

2
stochastic cooling

3
electron cooling

4
Estrazione a 100 MeV/c

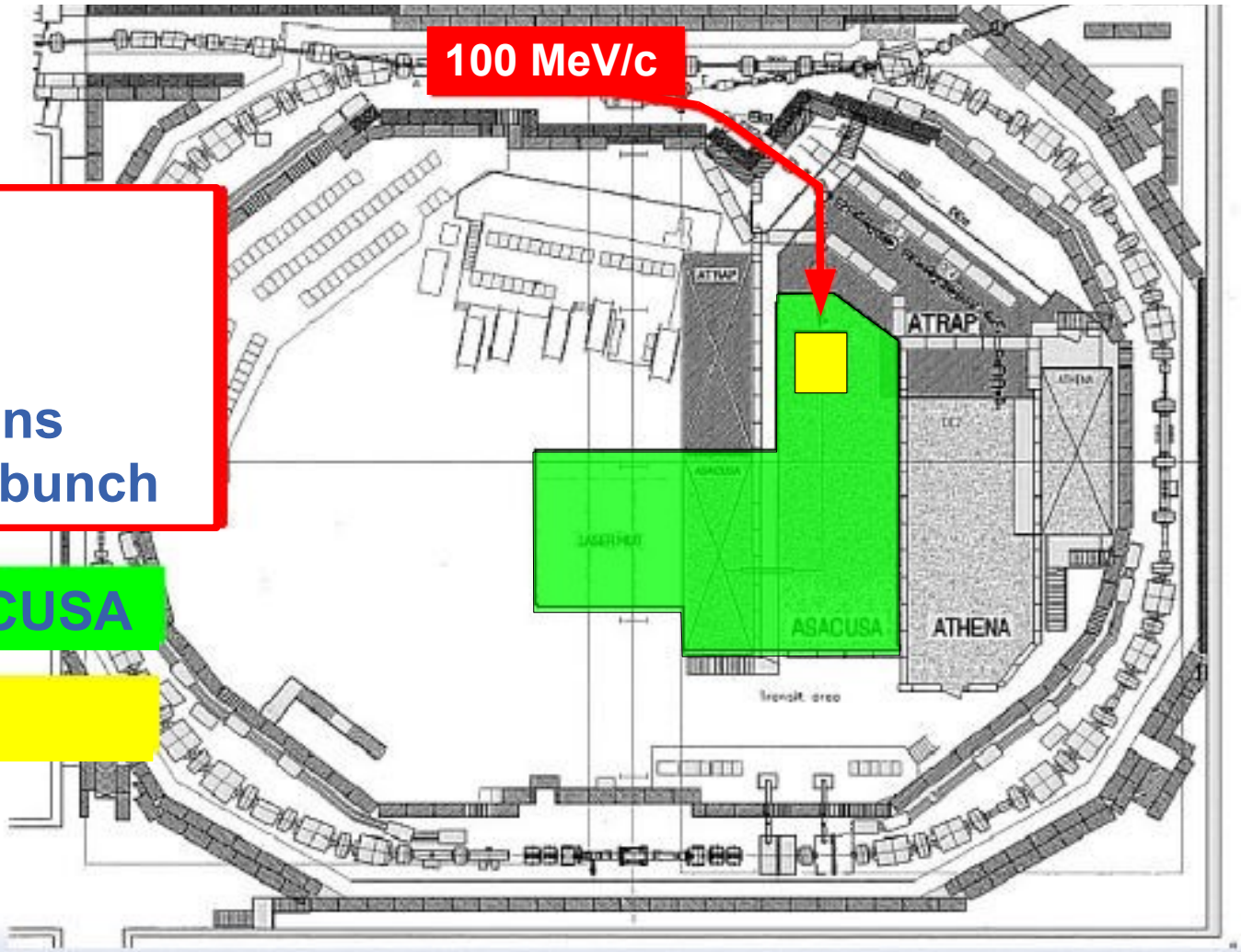
Il fascio di AD

ESTRAZIONE MULTIPLA

- Ciclo di ~ 110 s
- 6 bunch/ciclo
- 1 s fra i bunch
- FWHM del bunch 40 ns
- Intensità ~ 10^6 – 10^5 /bunch

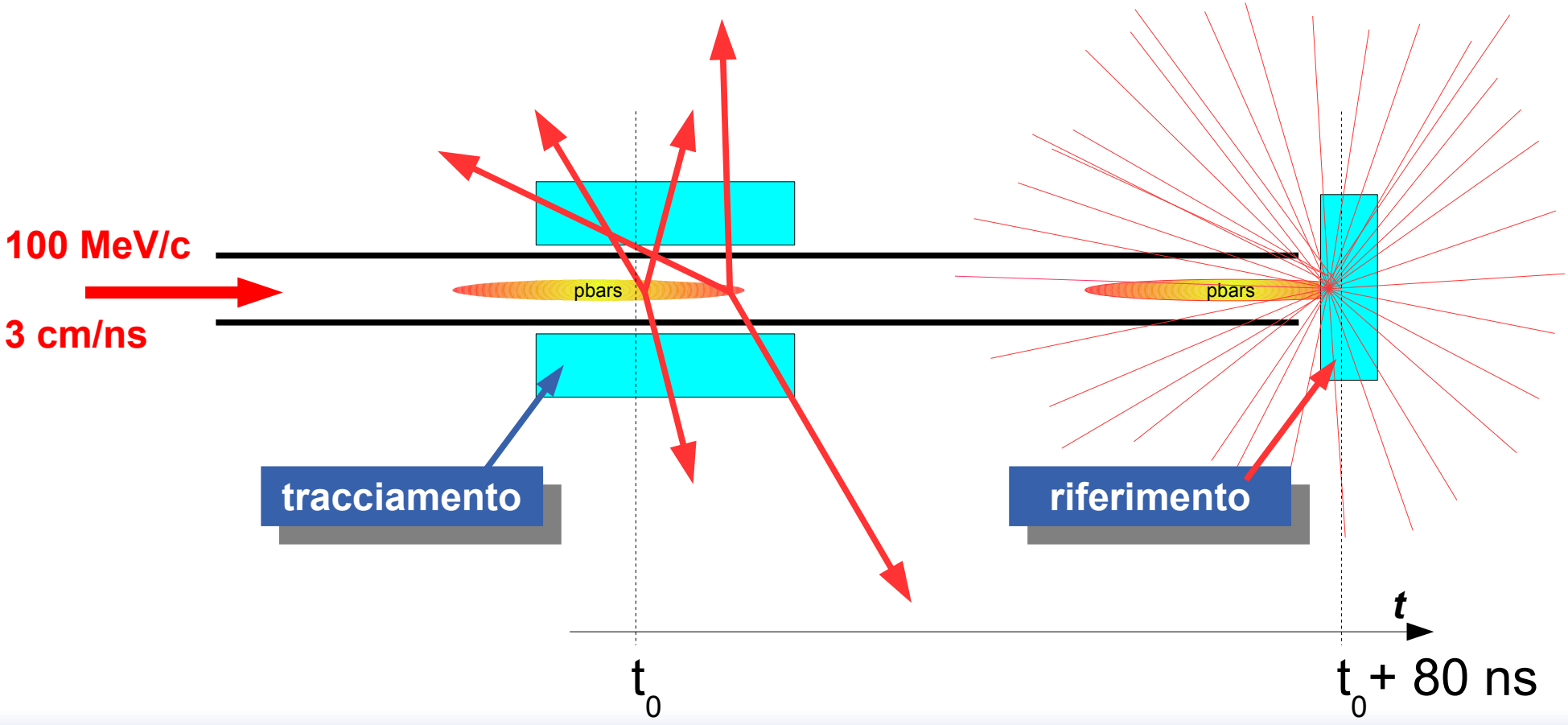
Area esperimento ASACUSA

Posizione rivelatore



La misura

$$\bar{p}\,A \rightarrow n\,\pi^{\pm}(n_{av.}=3.1) \longrightarrow \sigma_{ann}(\bar{p}\,A) \propto N_{events}/N_{beam}$$

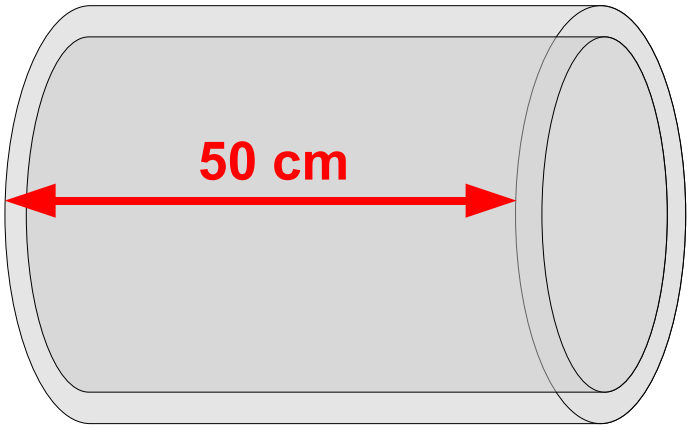


Caratteristiche del tracciatore

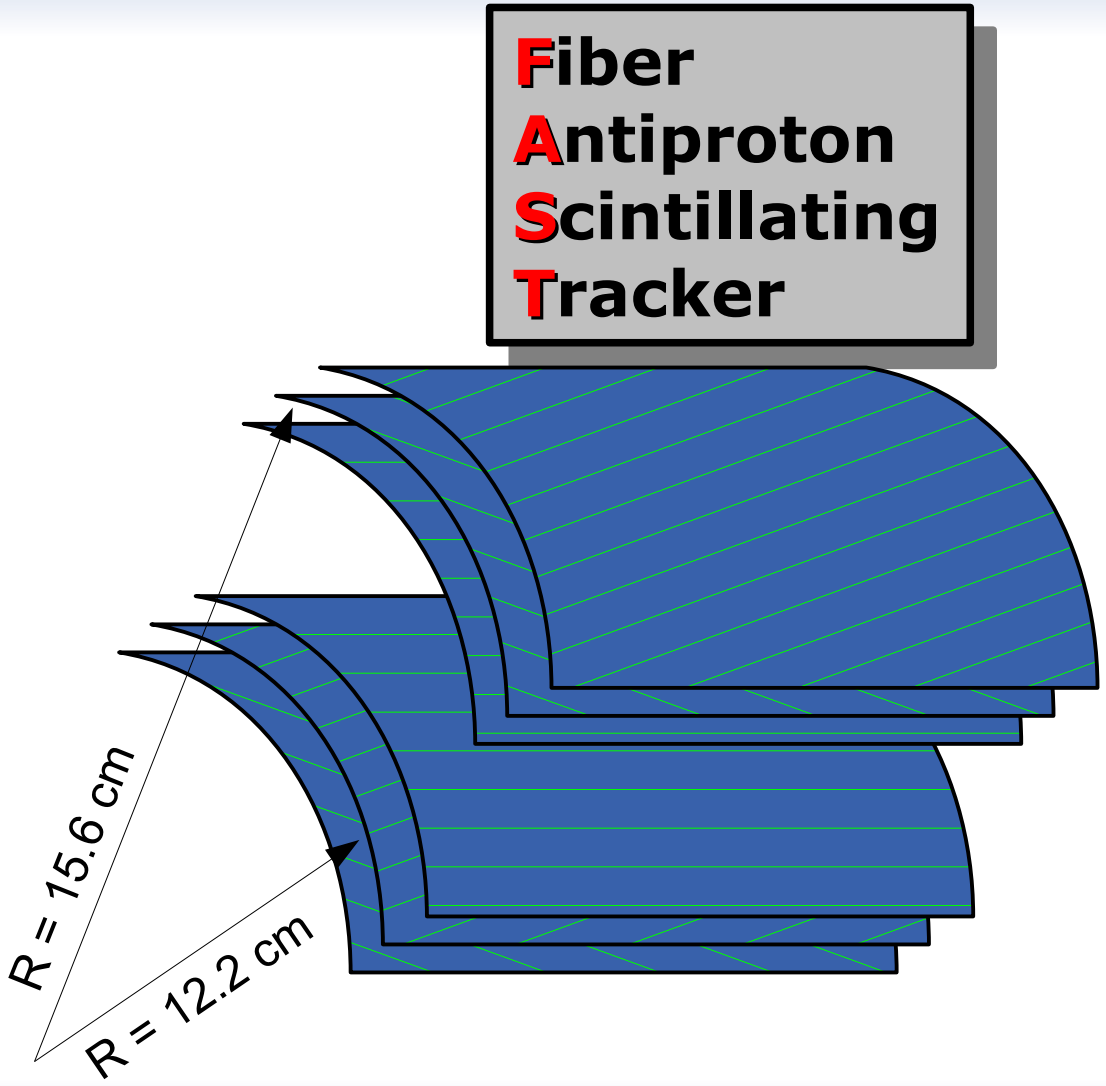
- **Simmetria cilindrica**
- **Risoluzione temporale spinta (~ ns)**
- **Risoluzione spaziale (vertice) buona (~ cm)**
- **Buona efficienza**
- **Lettura in meno di 1 s per bunch**
- **Installazione semplice e veloce**
- **Basso costo**

⟶ rivelatore a fibre scintillanti

La geometria



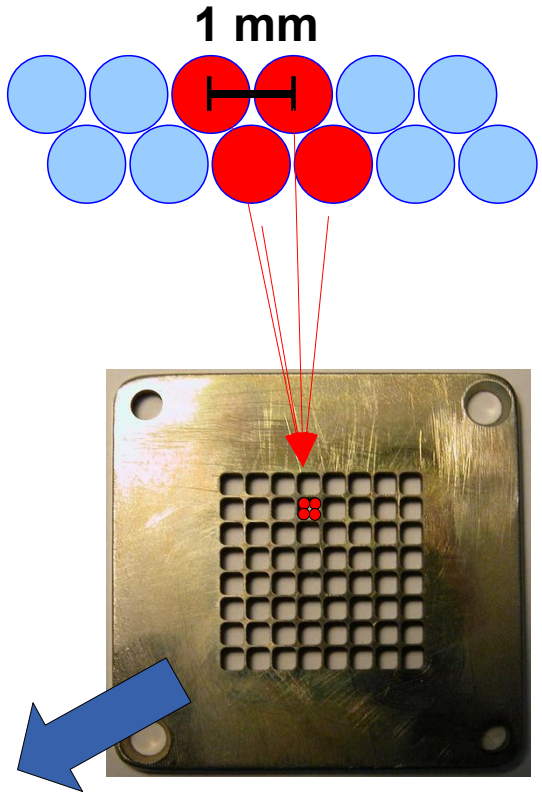
Layer	Angolo	Canali	Raggio (cm)
1	20°	335	11.5
2	-20°	345	11.7
3	0°	377	11.9
4	0°	461	15
5	20°	437	15.2
6	-20°	451	15.4



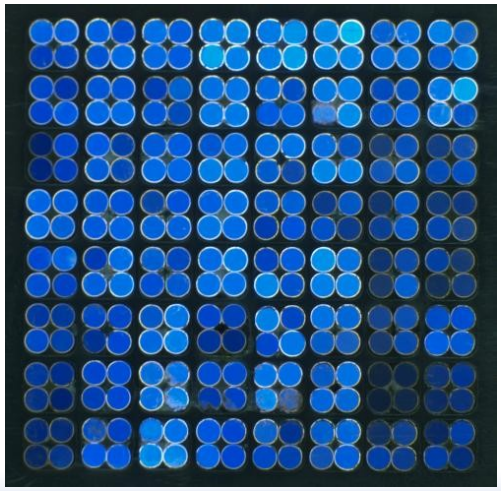
Le fibre

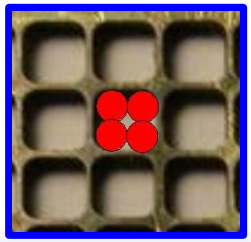
FIBRE SCINTILLANTI BICRON BCF-10:

- Diametro 1 mm (cladding ~ 3%)
- Picco di emissione 432 nm
- Tempo di decadimento 2.7 ns
- Lunghezza di attenuazione 2.2 m
- Luce ~ 8000 fotoni/MeV
- multicladding + Extra Mural Absorber (EMA)



- **Struttura a "double-ribbon"**
- **4 fibre = 1 canale**
- **Larghezza canale ~ 2 mm**

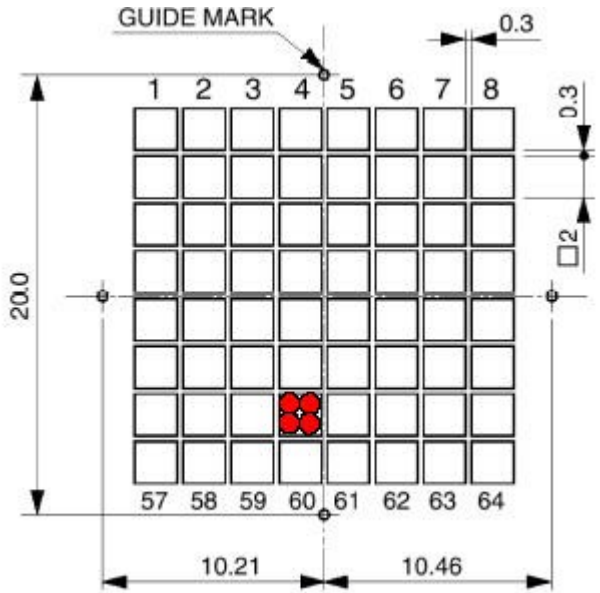


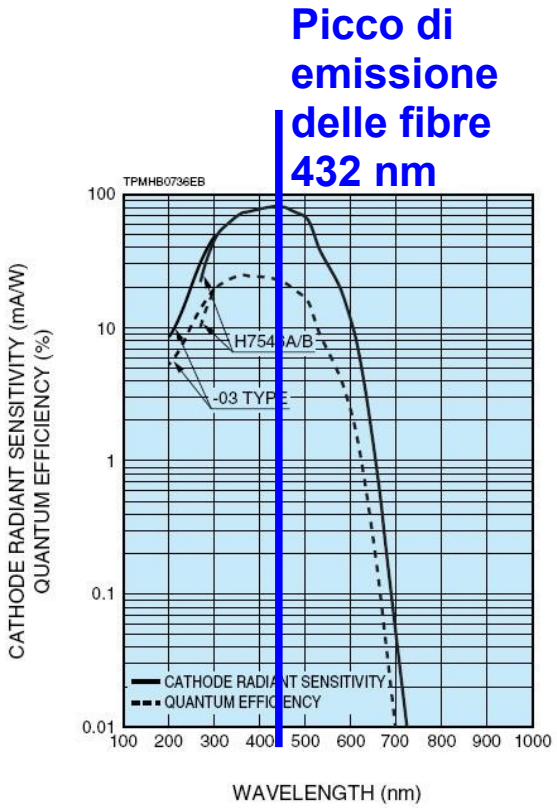


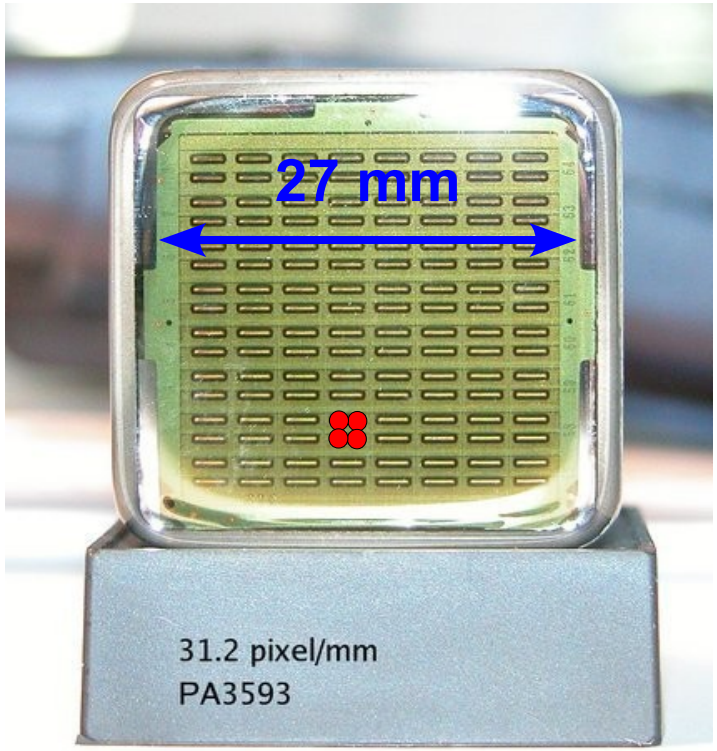
I fotomoltiplicatori

FOTOMOLTIPLICATORE MULTIANODO:

- Hamamatsu H7546B
- Q.E. @ 420 nm = 20%
- Anodo = 2x2 mm^2
- Guadagno @ -800 V = 3 10^5
- Tempo di salita = 1.0 ns
- Uniformità guadagno = 1-2.5
- Crosstalk (opt.+ele.) = 1-2%

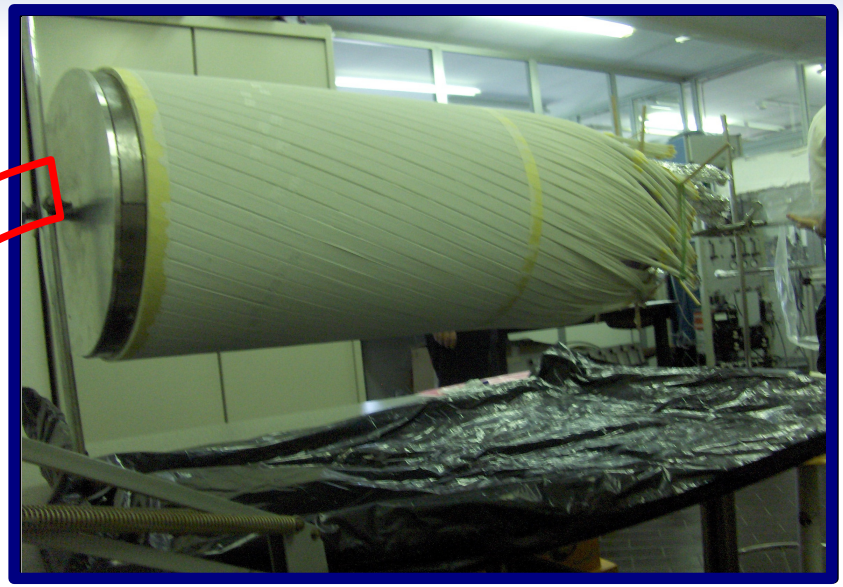


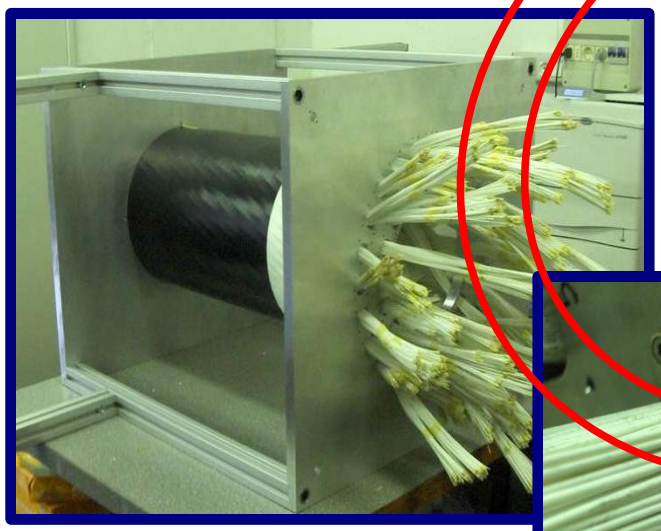


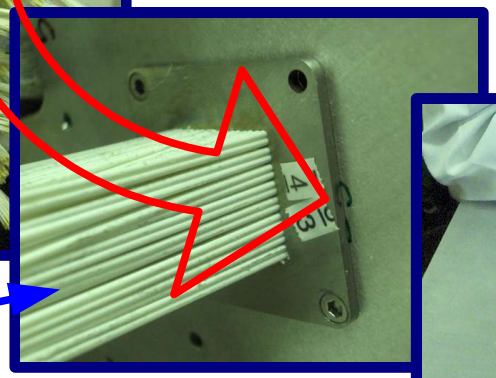


L'assemblaggio (2006)

- 2 supporti di plexiglass (R=15cm,21cm)
- Fascette da 32 fibre







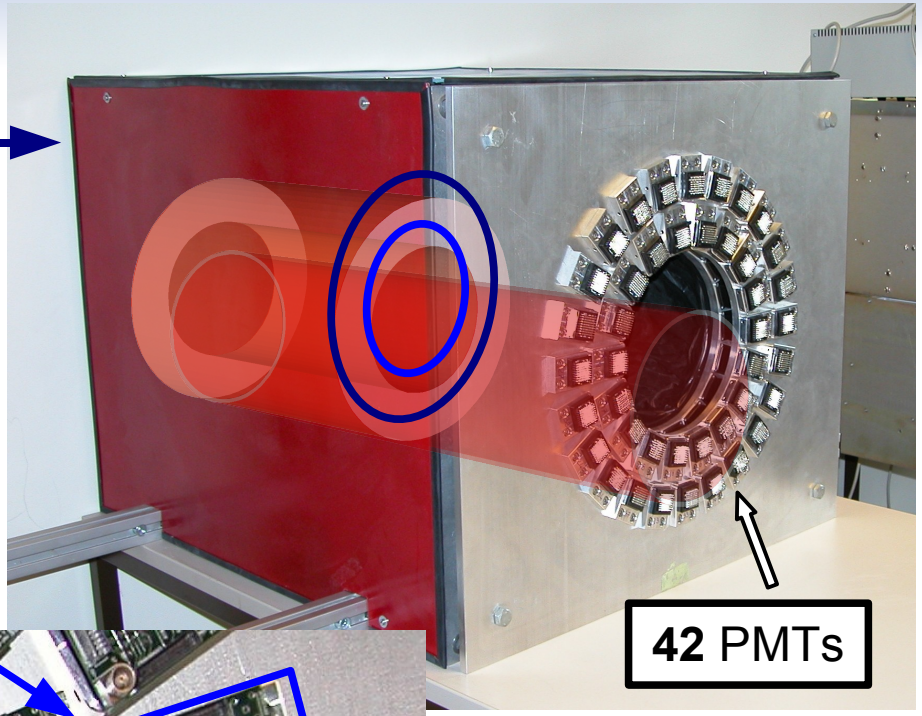
Accoppiamento alle maschere

Lucidatura

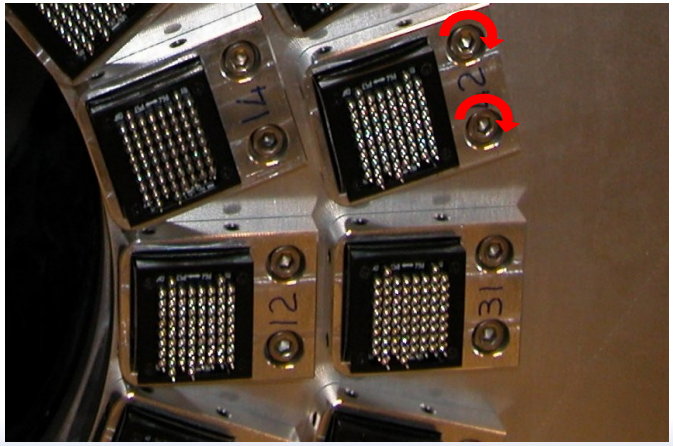
L'assemblaggio (2006)

Chiusura finale in box alluminio per oscuramento

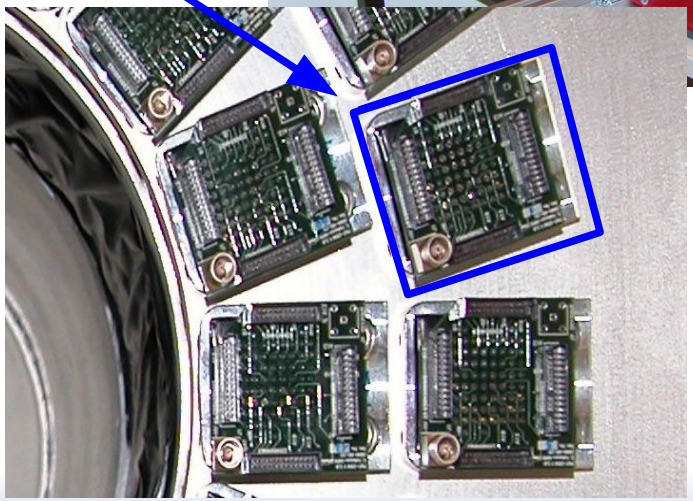
Tot ~ 25 kg



Supporti regolabili per l'allineamento

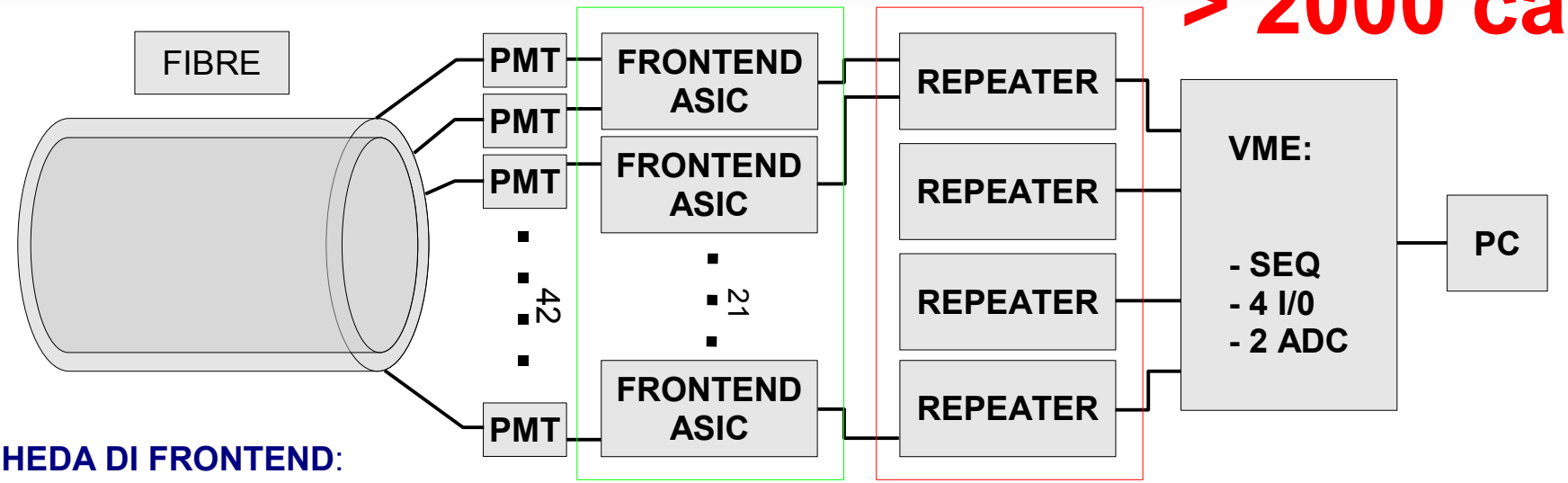


PCB per alimentazione e segnale



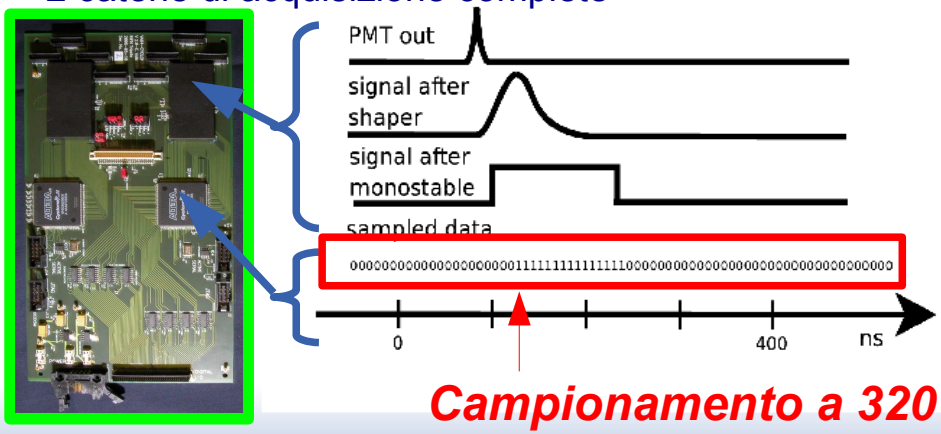
Catena di acquisizione completa

> 2000 canali

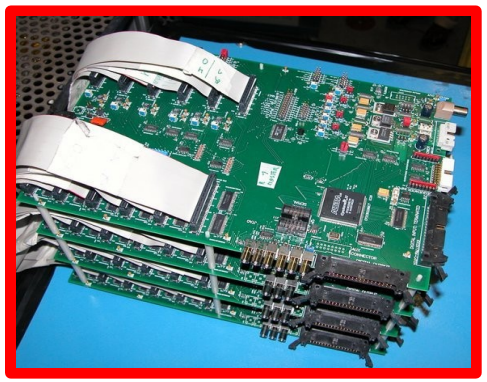


SCHEDA DI FRONTEND:

- Basata su **ASIC** VA64TAP2.1 (IDEAS) e Altera Cyclone II **FPGA**
- 2 catene di acquisizione complete



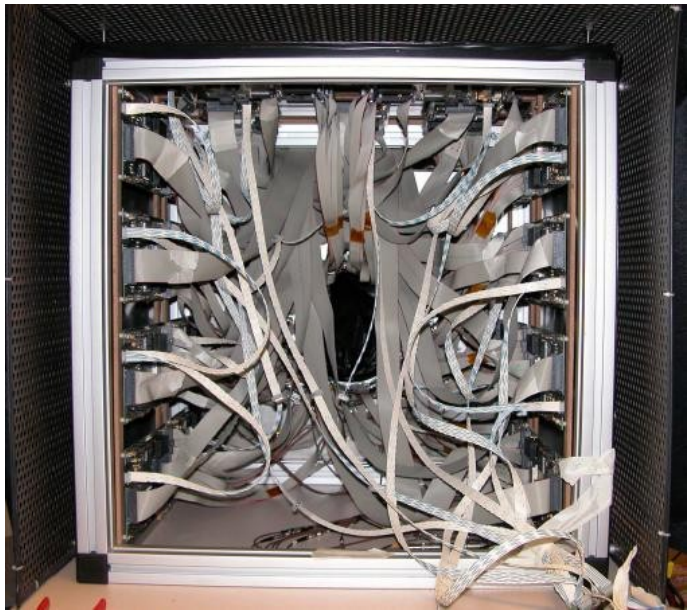
Campionamento a 320 MHz



SCHEDA REPEATER:

- Gestisce fino a 6 schede di frontend
- Fornisce bias, trigger, segnali digitali
- Gestisce la comunicazione tra schede di fontend e sistema VME

Commissioning

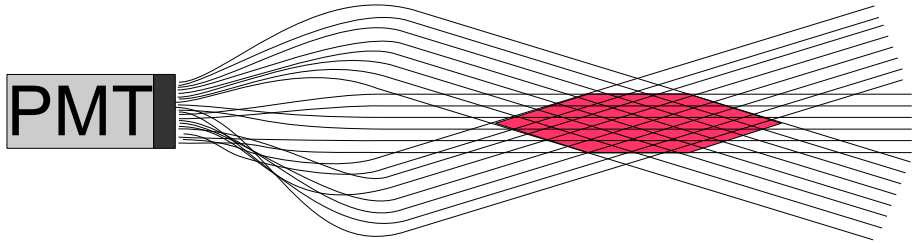


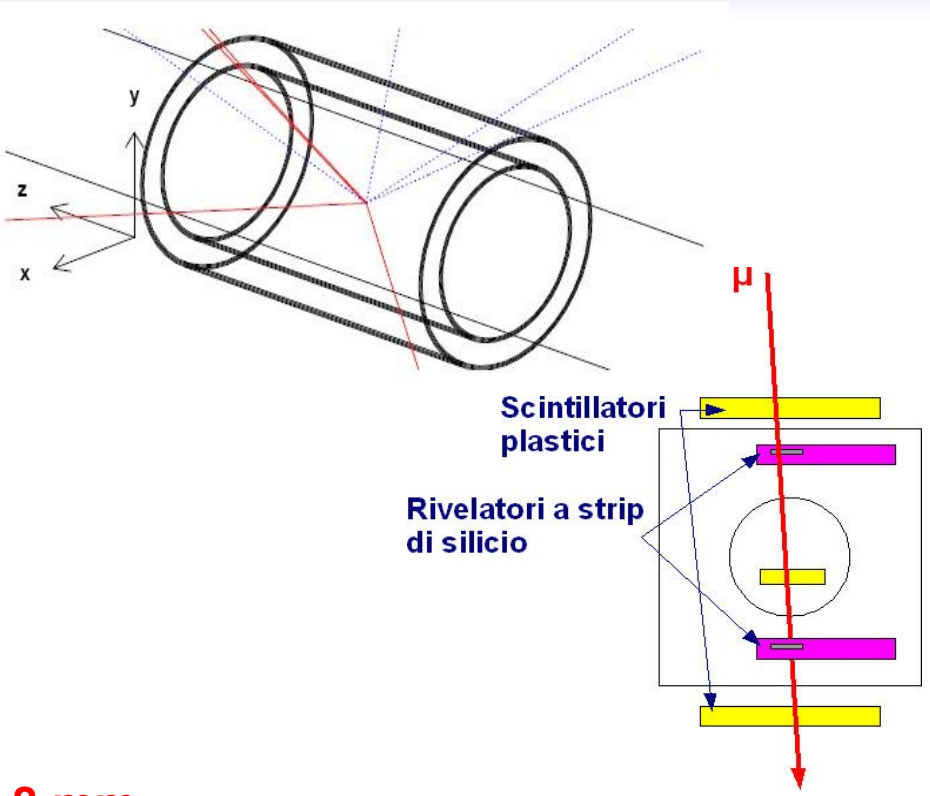
Assemblaggio finale

Commissioning

2006 - 2007

- Simulazione MONTECARLO completa
- Test con prototipo presso BTF (Laboratori Nazionali INFN – Frascati)
- Test rivelatore con raggi cosmici

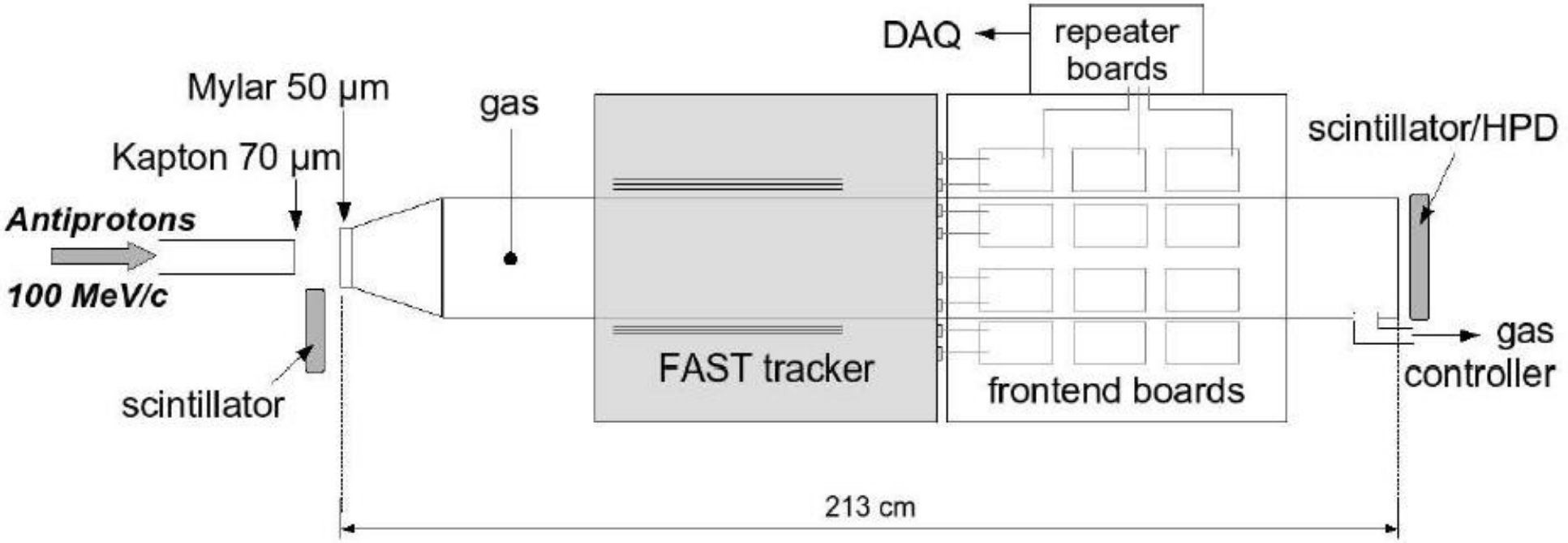




Capacità ricostruzione vertici

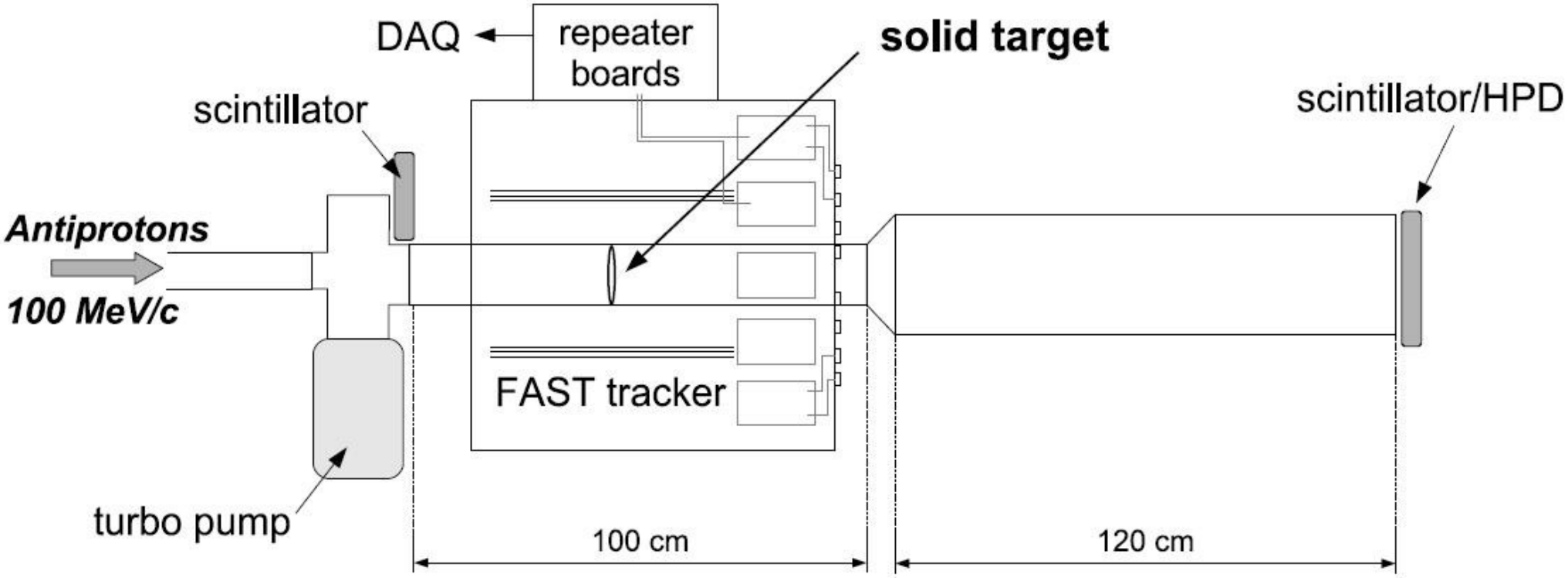
r	4.8 mm	DA PROTOTIPO
z	7.7 mm	
r	12.6 mm	DA TEST CON RAGGI COSMICI
z	17.6 mm	

Presa dati 2006



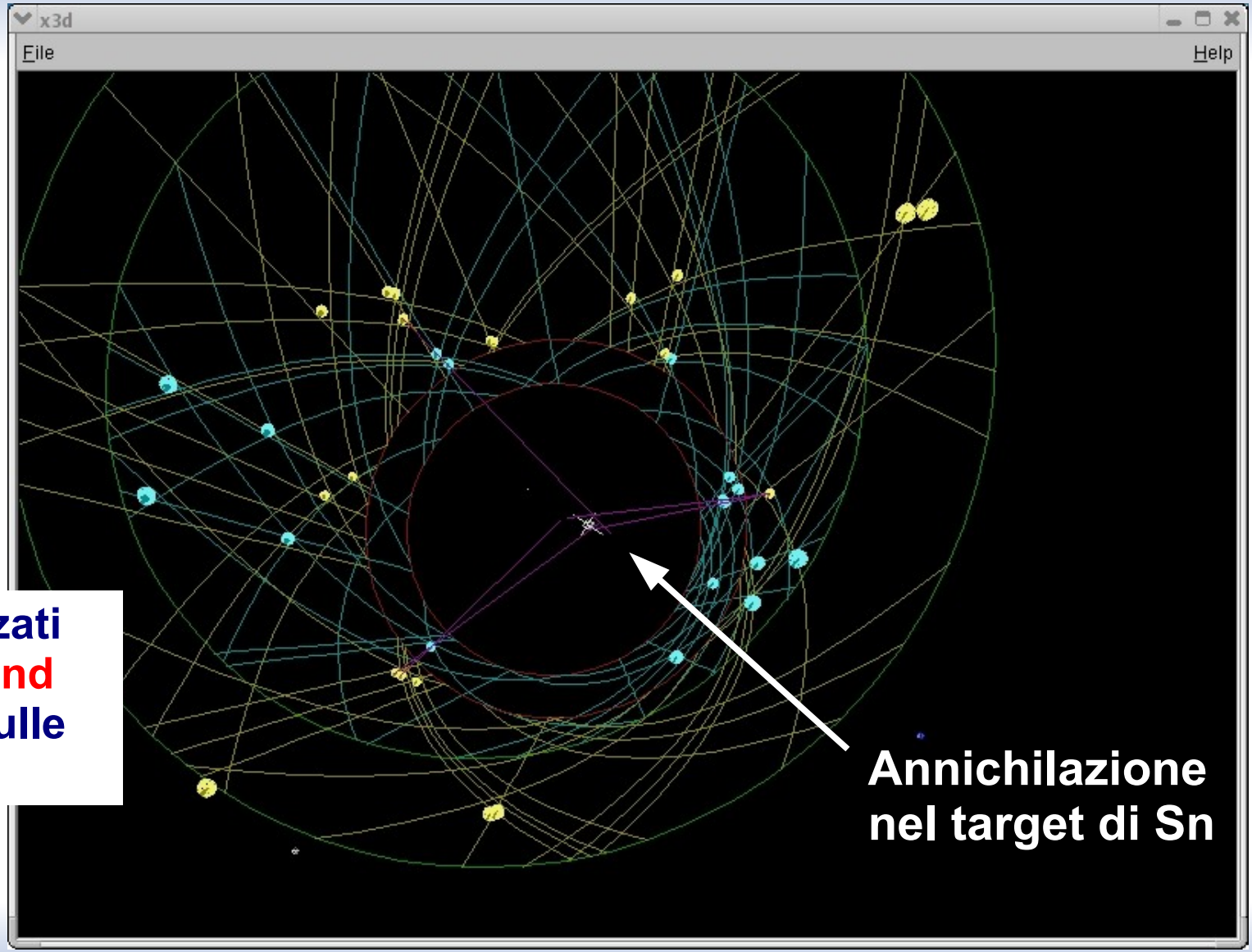
Bersagli gassosi (H_2, D_2, ^3He, ^4He, Ne) a pressioni variabili (1 – 1000 mbar)

Presa dati 2007: target solidi



Bersagli solidi (Sn, Pt, Ni) di diversi spessori (150 nm – 400 nm)

Presa dati 2007: primi eventi

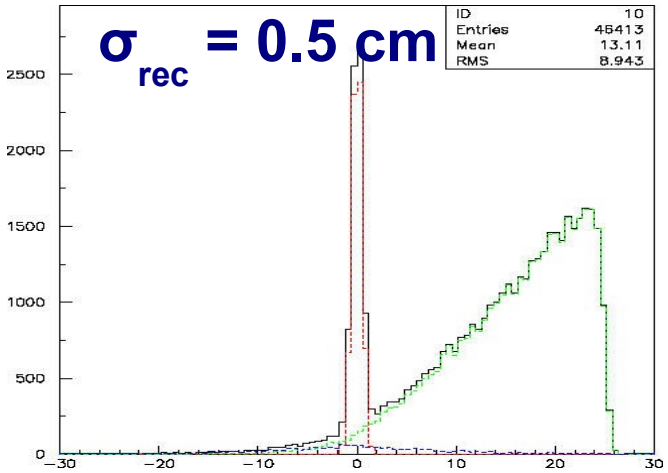


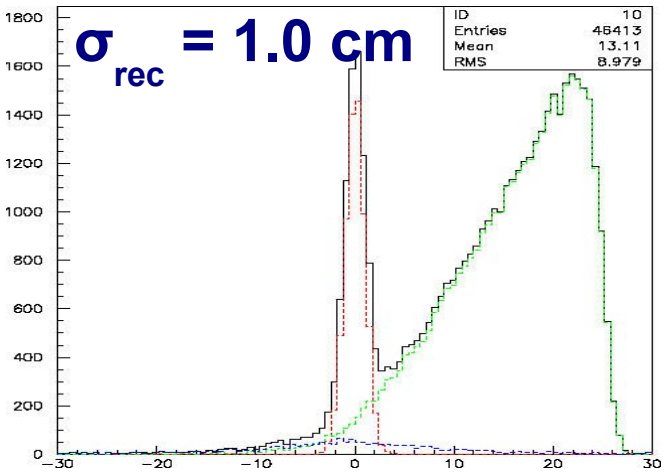
Eventi caratterizzati da alto background (annichilazioni sulle pareti)

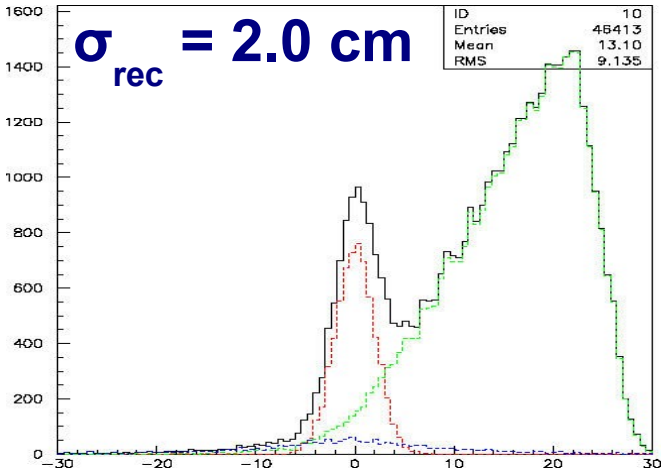
Punto della situazione – fine 2007

- Le **annichilazioni in parete** sono il problema principale
- Due vie per migliorare:
  - SOFTWARE: migliore associazione traccia-tempo per scartare gli eventi in parete
  - HARDWARE: possibili upgrade (ulteriore layer esterno di scintillatore, spostamento target)

Simulazione Montecarlo - 2008





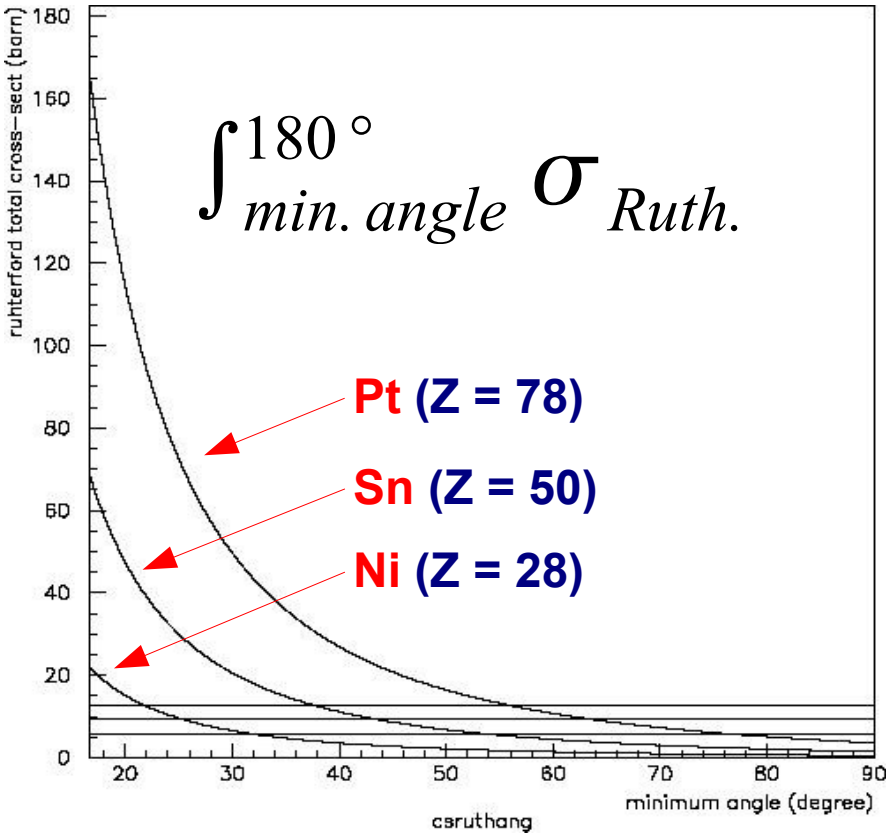


target
parete (scattering Rutherford)
parete (scattering nucleare)

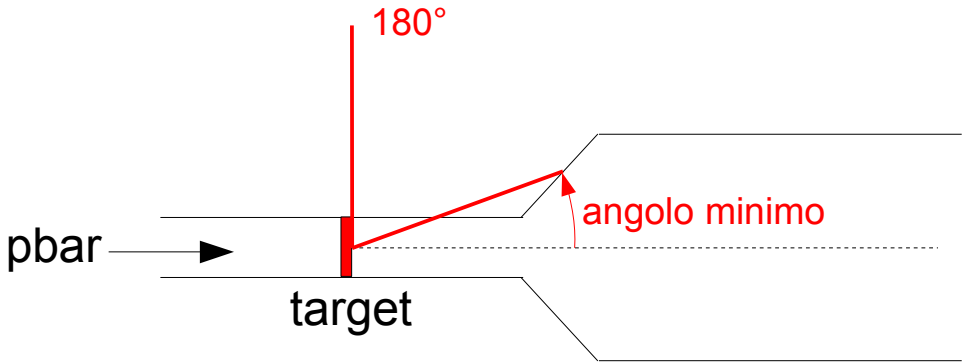
totale

σ annich. (Pt) vs z (cm)

Montecarlo - 2008

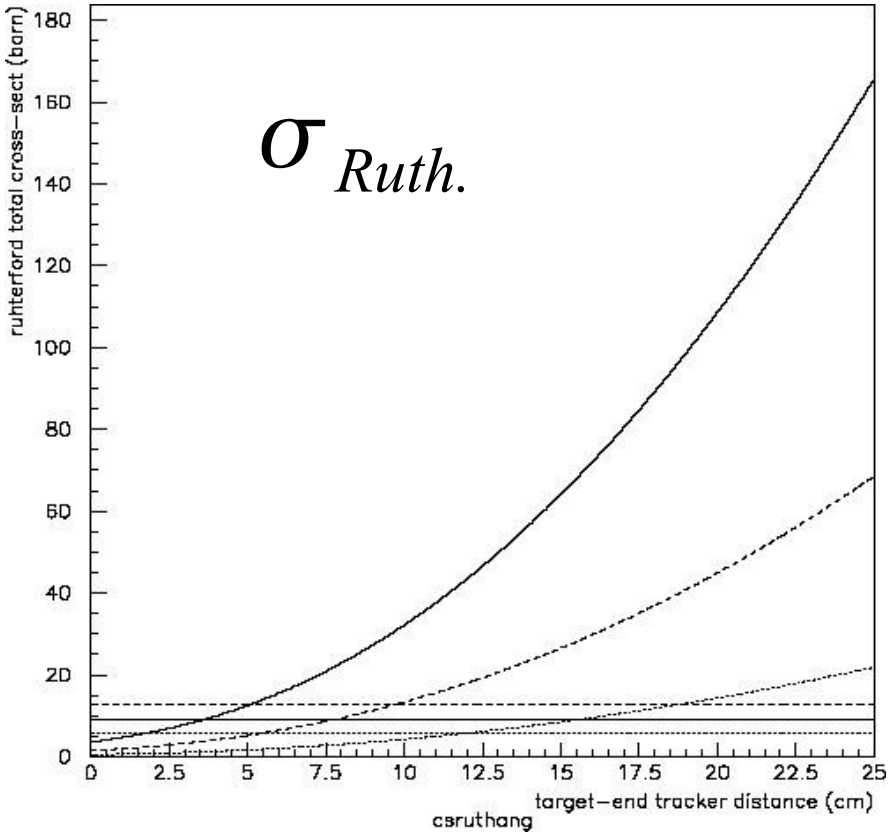


σ annich.

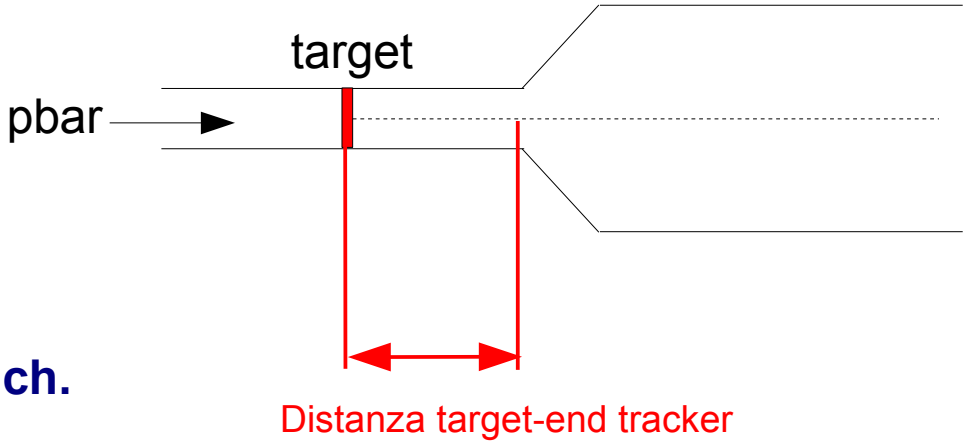


σ Ruth. (Pt, Sn, Ni) vs angolo minimo

Simulazione Montecarlo - 2008

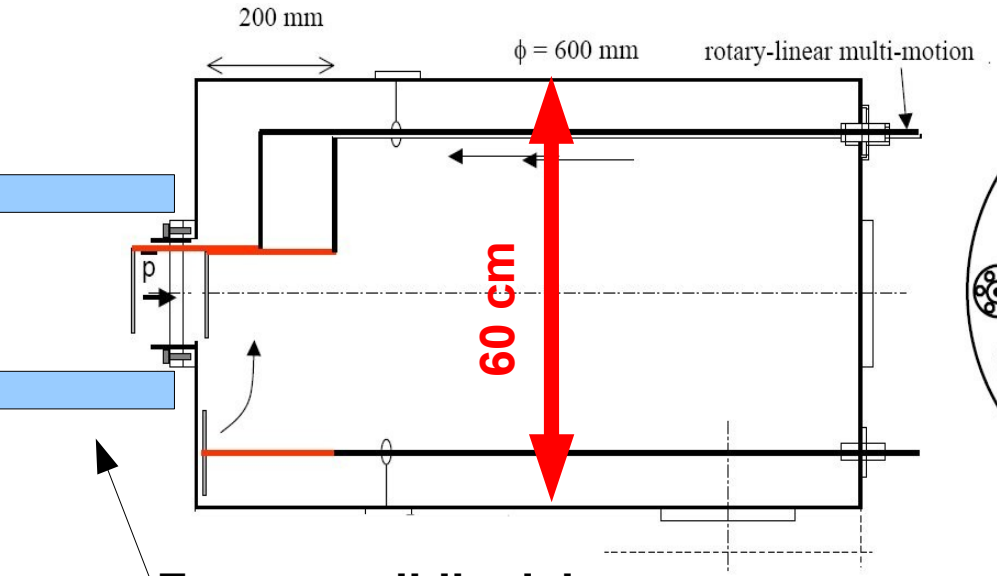


σ annich.

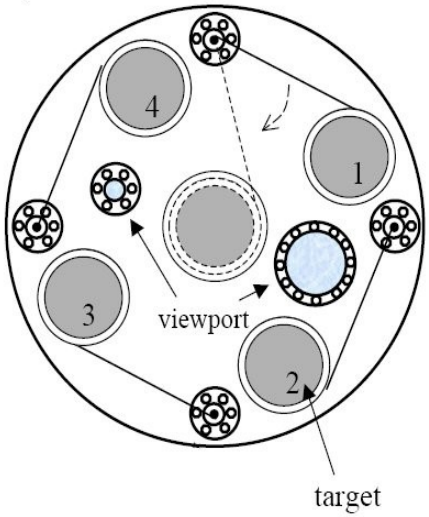


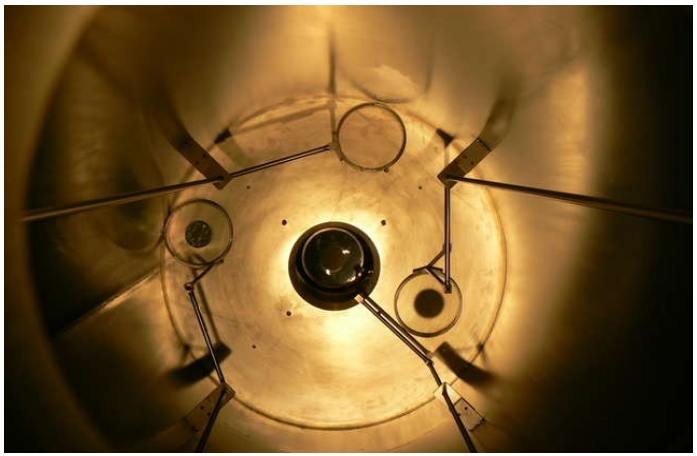
σ Ruth. (Pt, Sn, Ni) vs target-end tracker distance

Setup 2008



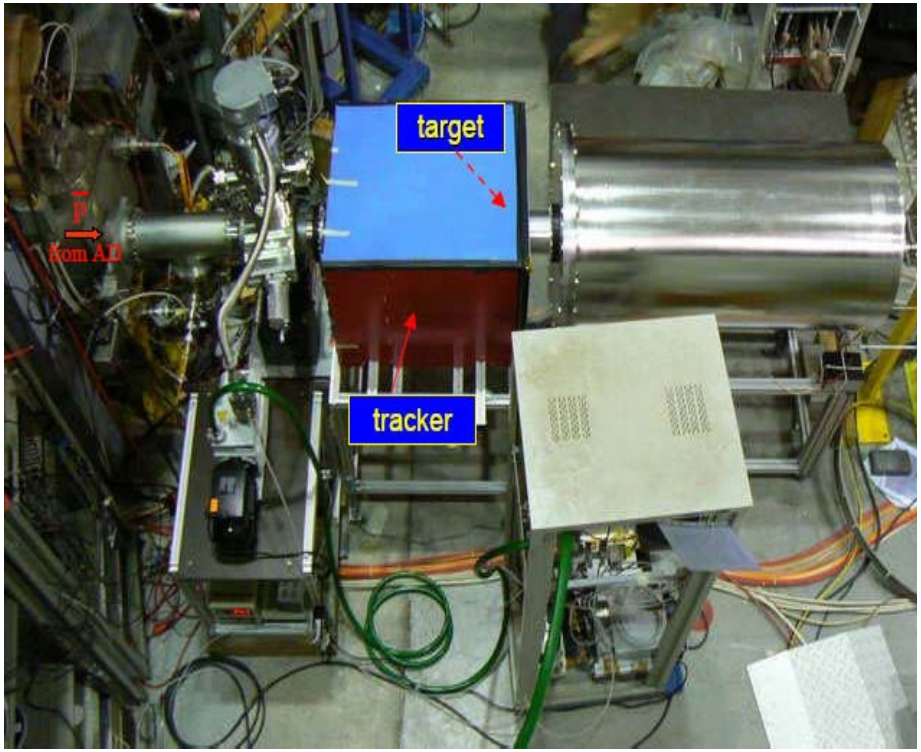
Zona sensibile del rivelatore

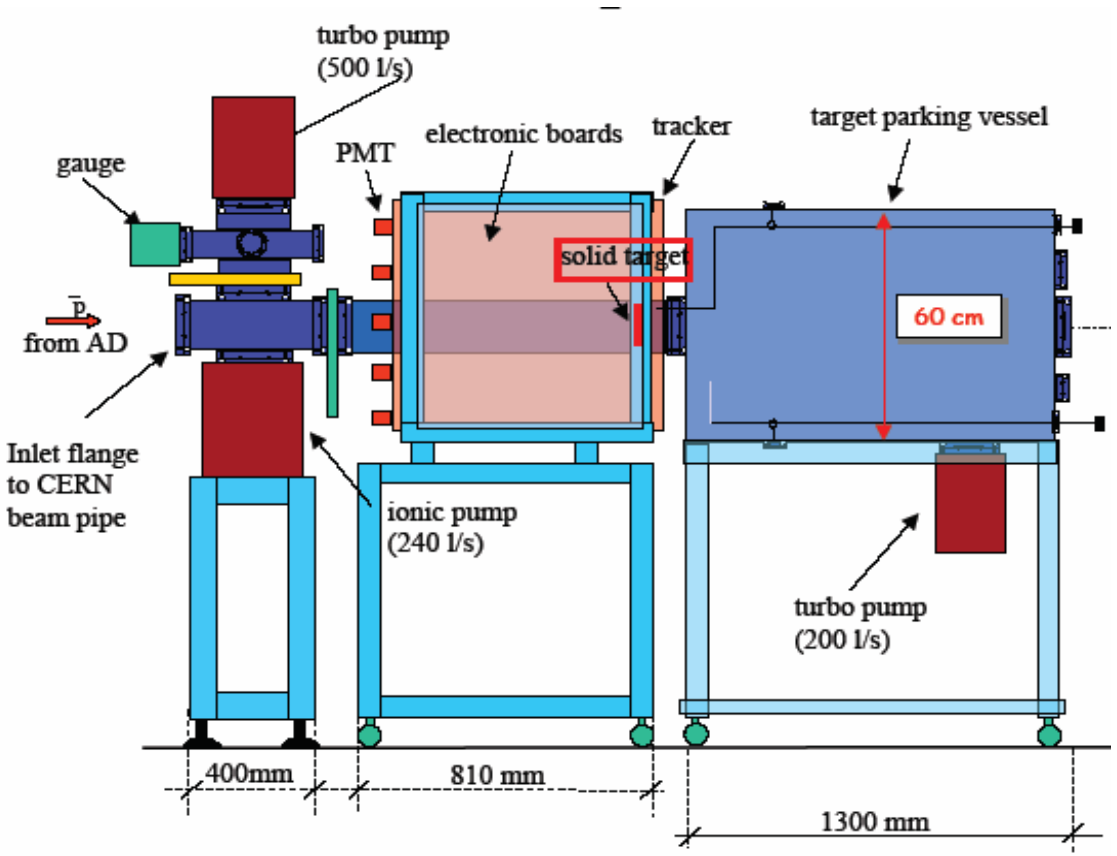




Sistema di target mobili (Pt, Sn, Ni e mylar)

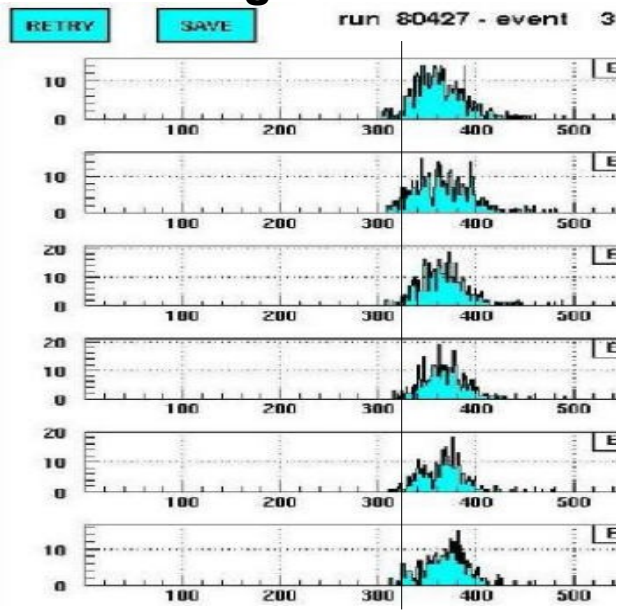
Setup 2008


target
tracker
$\bar{p}$
from AD


turbo pump
(500 l/s)
gauge
PMT
electronic boards
tracker
target parking vessel
solid target
60 cm
$\bar{p}$
from AD
Inlet flange
to CERN
beam pipe
ionic pump
(240 l/s)
turbo pump
(200 l/s)
400mm
810 mm
1300 mm

Risultati 2008

2007:
scattering Rutherford dominante



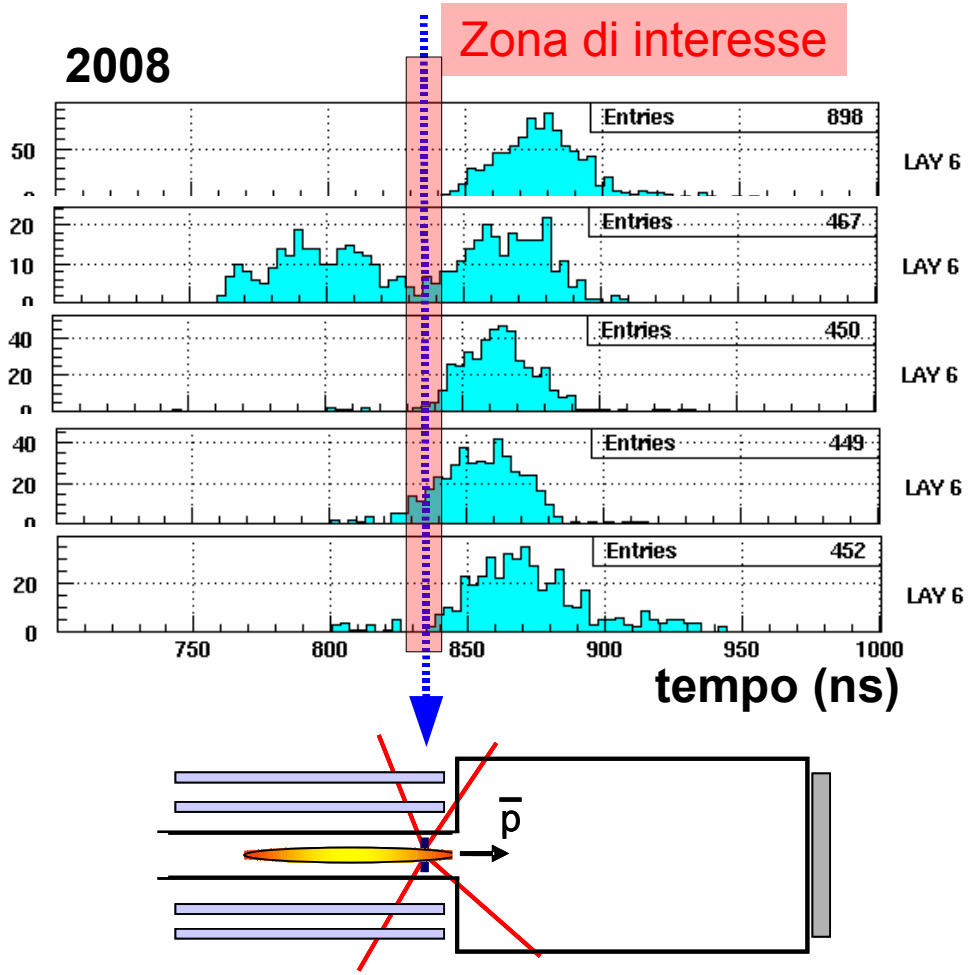
vuoto

Materiale prima del target

Ni + mylar

Sn + mylar

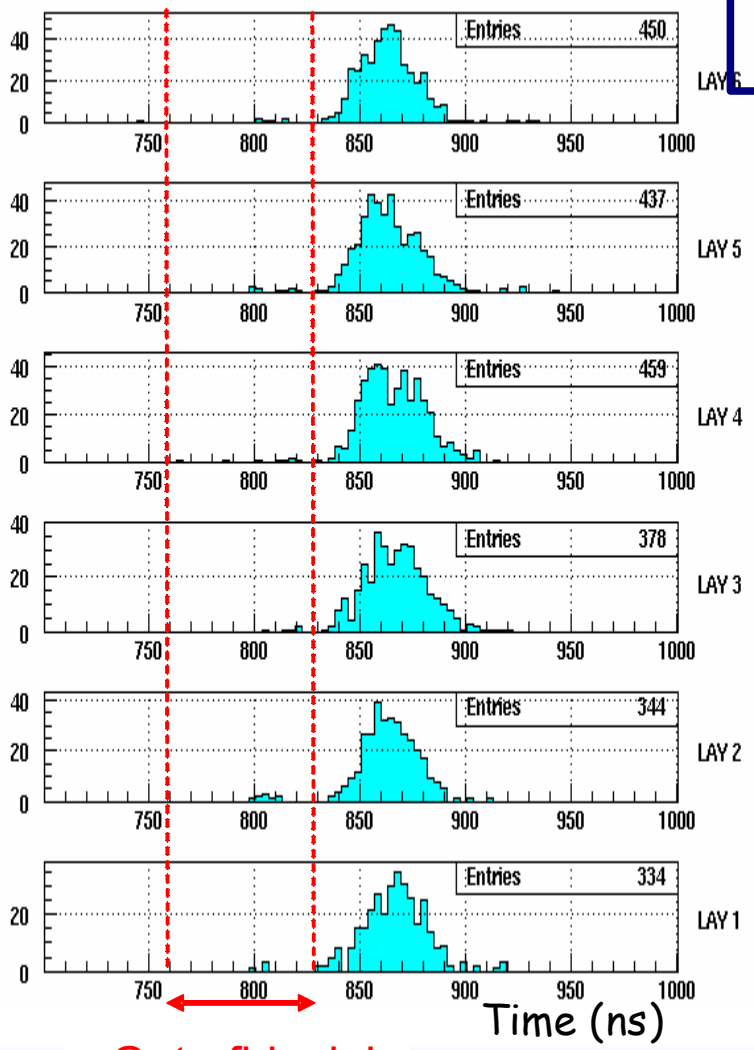
Pt + mylar



Distribuzione temporale sui canali di un layer (6)

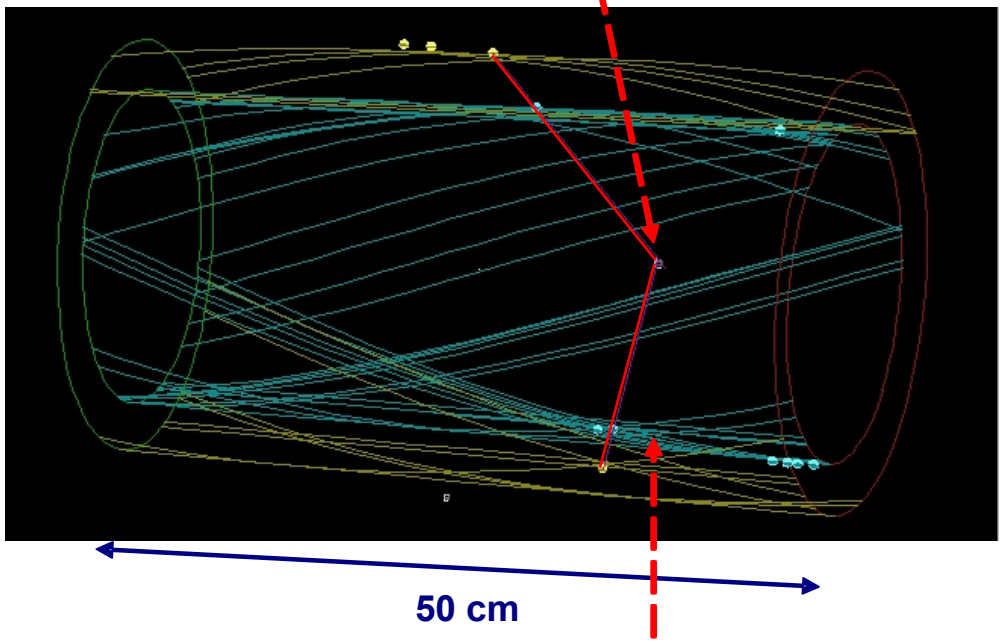
Risultati 2008

Evento tipico



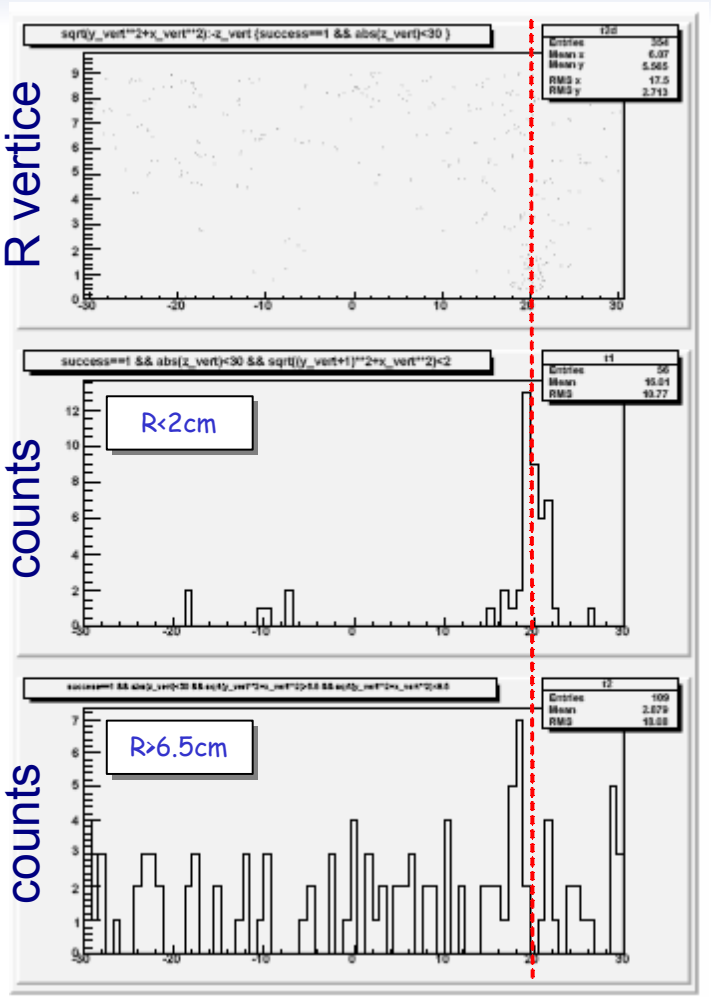
Gate fiduciale

Vertice ricostruito all'interno del gate fiduciale



Ni + mylar

Risultati 2008

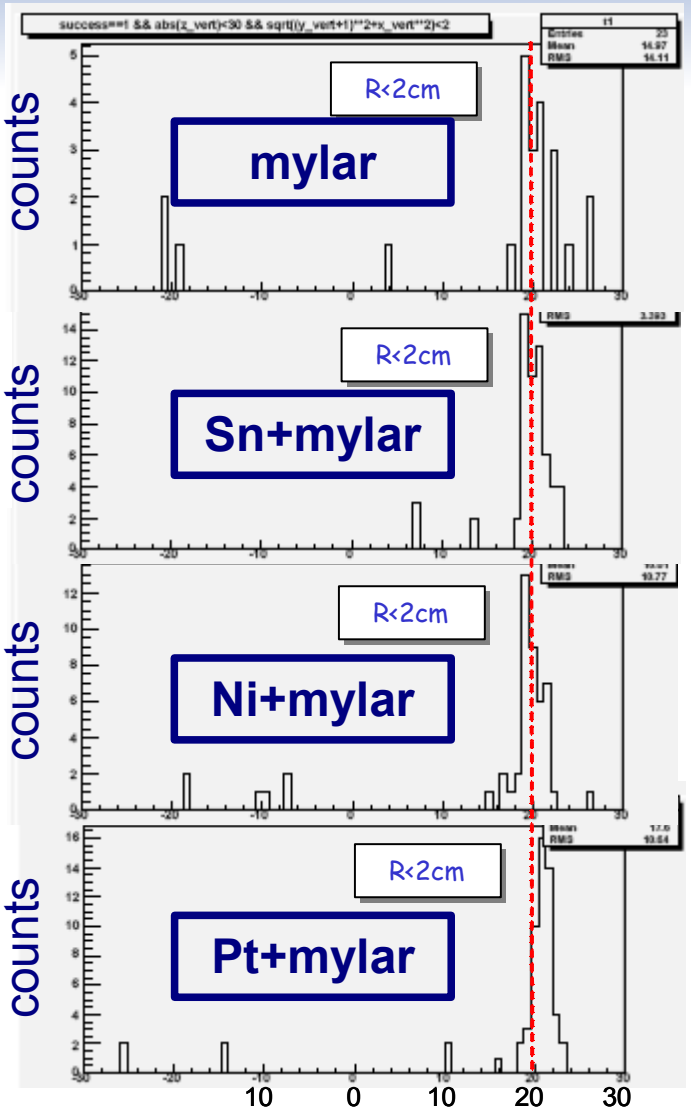


Ni + mylar

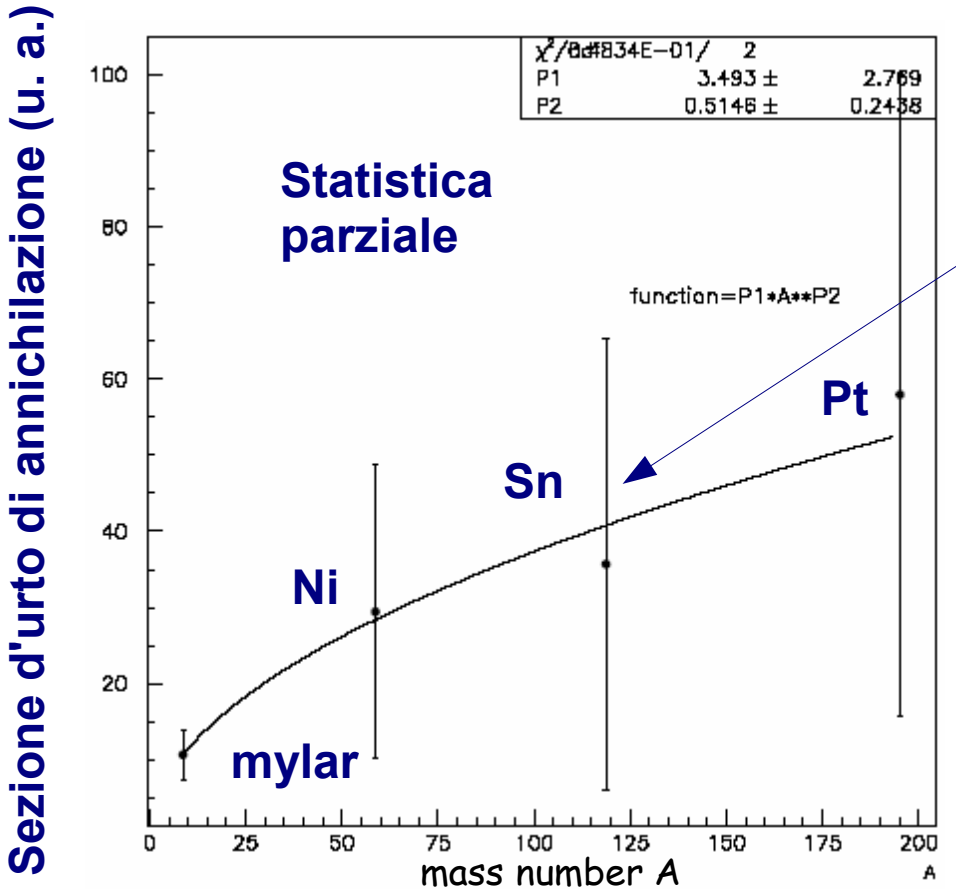
Distribuzioni vertici ricostruiti

(statistica parziale)

– – – target



Risultati 2008



fit migliore

$$\sigma_{ann.}(\bar{p}\,A) = c\,A^{\alpha}$$

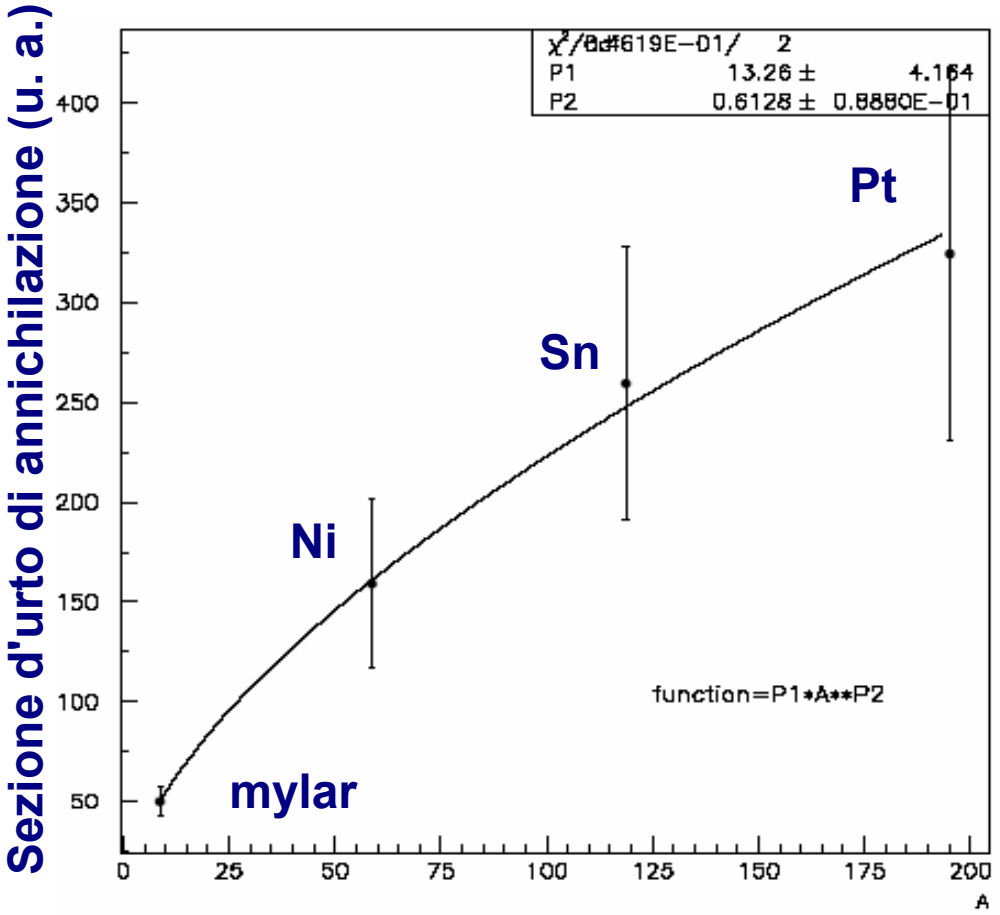
$$c = 3.49 \pm 2.77$$

$$\alpha = 0.51 \pm 0.24$$

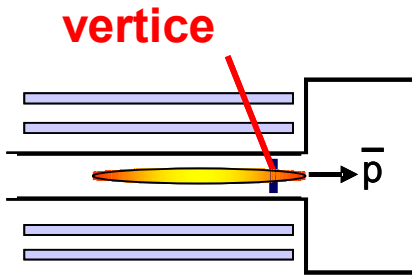
Compatibile con

$$(\bar{p}\,A)_{ann.} \propto A^{2/3}$$

Risultati 2008



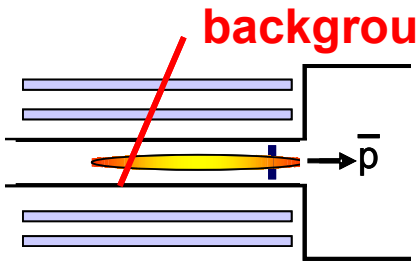
Usando gli eventi a singola traccia:



$$\sigma_{ann.}(\bar{p}\,A) = c\,A^{\alpha}$$

$$c = 13.3 \pm 4.3$$

$$\alpha = 0.61 \pm 0.09$$



Compatibile con

$$(\bar{p}\,A)_{ann.} \propto A^{2/3}$$

Riassumendo ASACUSA 2008

Per la prima volta è stata misurata la σ_{ann} (relativa) di antiprotoni su nuclei non leggeri a bassa energia (5 MeV)

I dati sono compatibili con un andamento come $A^{2/3}$

E' necessario aumentare la statistica utile (in progress...)

Nel 2009 è prevista una presa dati ad energie inferiori (<100 keV)

Rivelatori MICE & MUSASHI

Barre scintillanti forate
(sezione 15 x 19 mm^2)

Fibre WLS (diametri 0.8 e 1 mm)

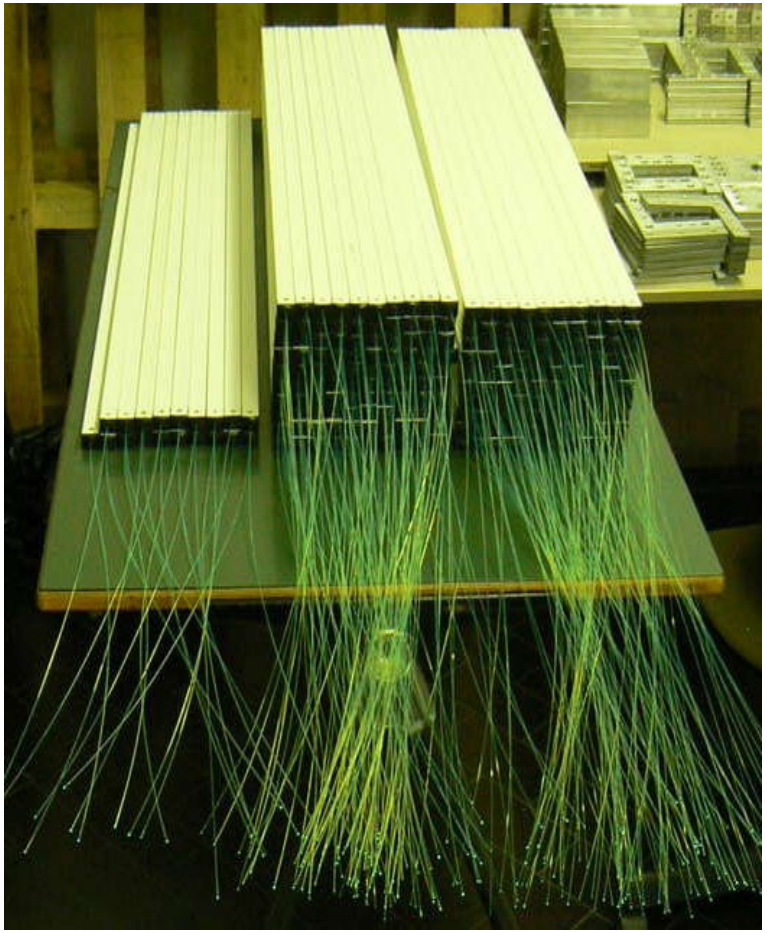
PMT multianodo Hamamatsu

Elettronica ASACUSA

2 NUOVI RIVELATORI DI TRACCIA

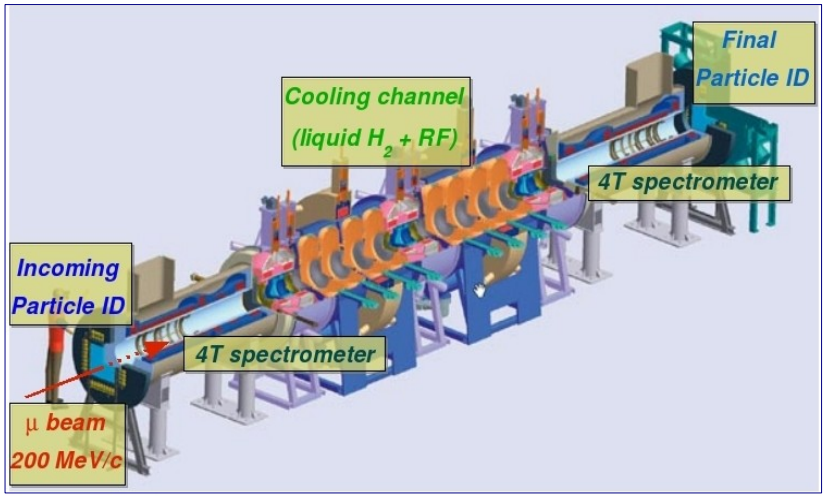
1) Prototipo esperimento MICE

2) Tracciatore esperimento MUSASHI
- cusp trap -



MICE (Muon Ionization Cooling Experiment)

Protoni 800 MeV/c (ISIS @ RAL) → **Muoni 140 – 200 MeV/c**



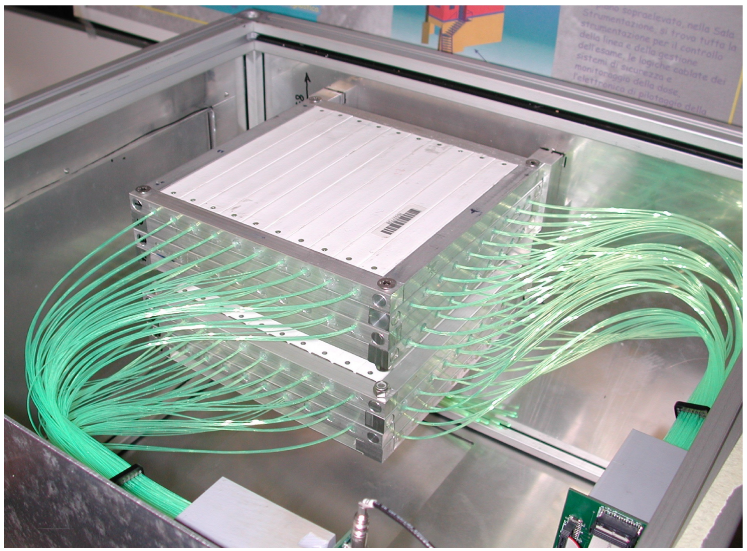
Ionization Cooling (RF + H2 liquido + solenoide 4T)

ν factory?

Necessità di PARTICLE ID e TRACKING: calorimetro/tracciatore a scintillazione (2009)

→ **prototipo EMR (Electron/Muon Ranger) 2008**

MICE – prototipo EMR



8 moduli XY (4+4 separati da 3cm)

Ogni modulo: 10 barre scintillanti 15x19mm^2 x 20cm

Readout: 4 x fibre WLS (diam. 0.8mm) + colla
PMT multianodo Hamamatsu (64 canali)

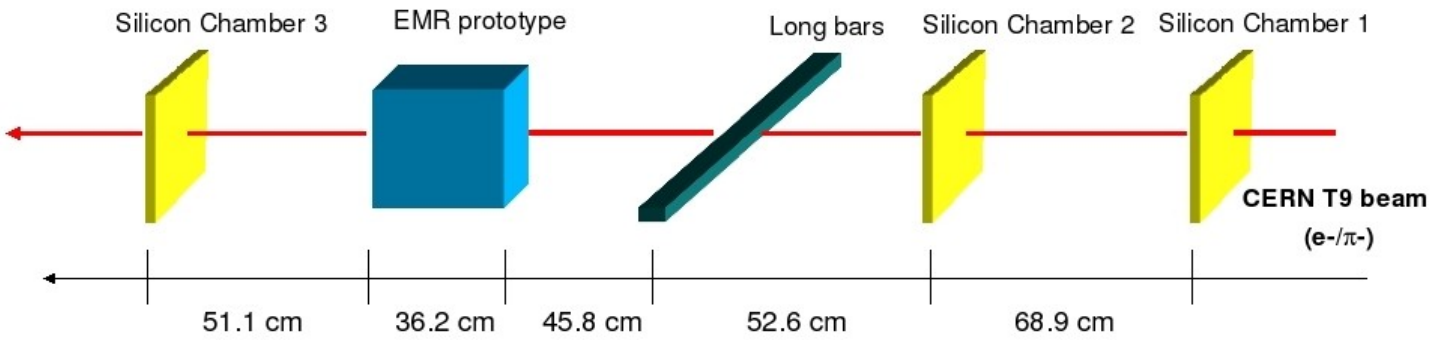
INFN Trieste

Elettronica frontend:

VA64TAP3 (IDEAS) 64ch low noise ASIC

LS64_2 (level shifting)

MICE – prototipo EMR



Test presso linea T9 CERN (PS)

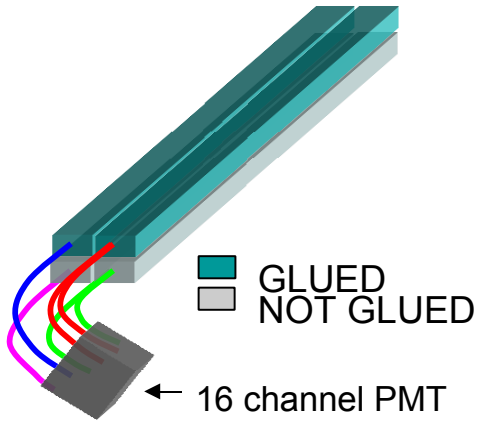
$e^{\pm}$, $\pi^{\pm}$, $\mu^{\pm}$ @ 0.5 – 15.0 GeV/c

Rivelatori a strip di silicio (ris. 40 μm)

Scintillatori (trigger)

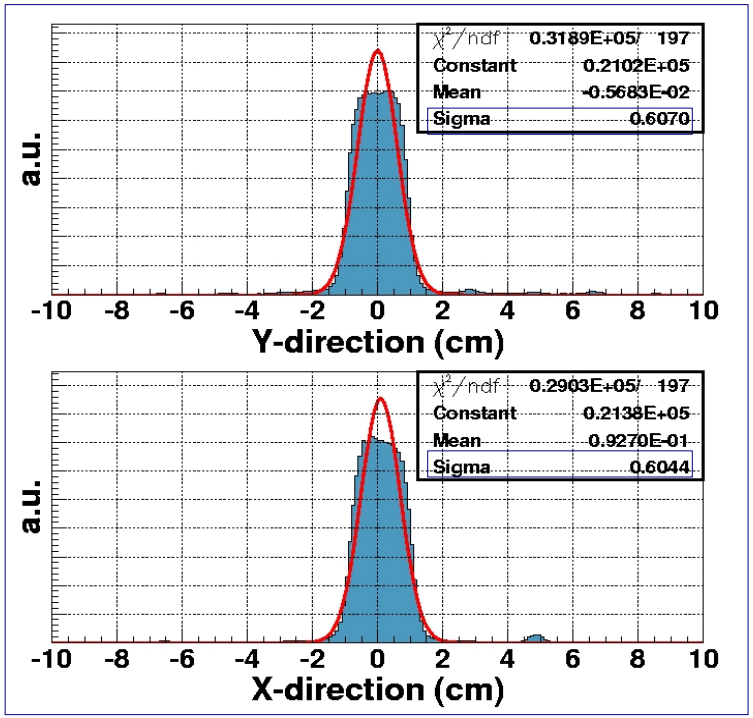
→ efficienza
→ risoluzione spaziale

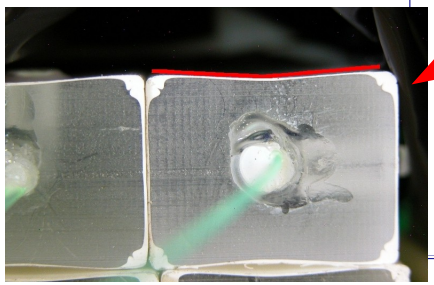
Test in 4 diverse configurazioni di lettura (1-2 fibre, colla/senza colla) – barre 96 cm



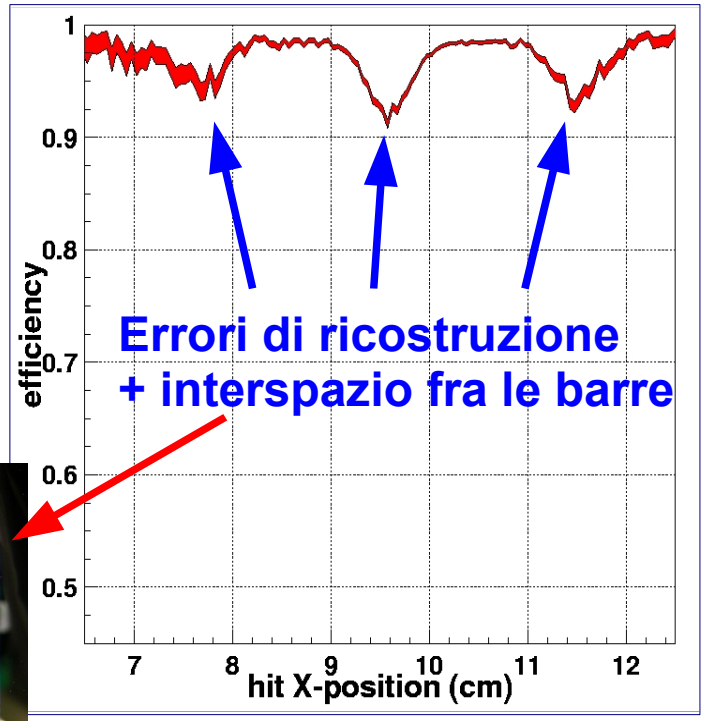
MICE – prototipo EMR

Risoluzione spaziale ~ 0.6 cm (sia X che Y)

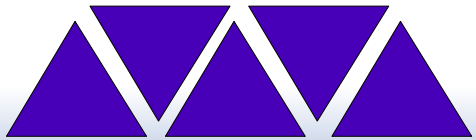




Efficienza ~ 97- 98% max = 99%

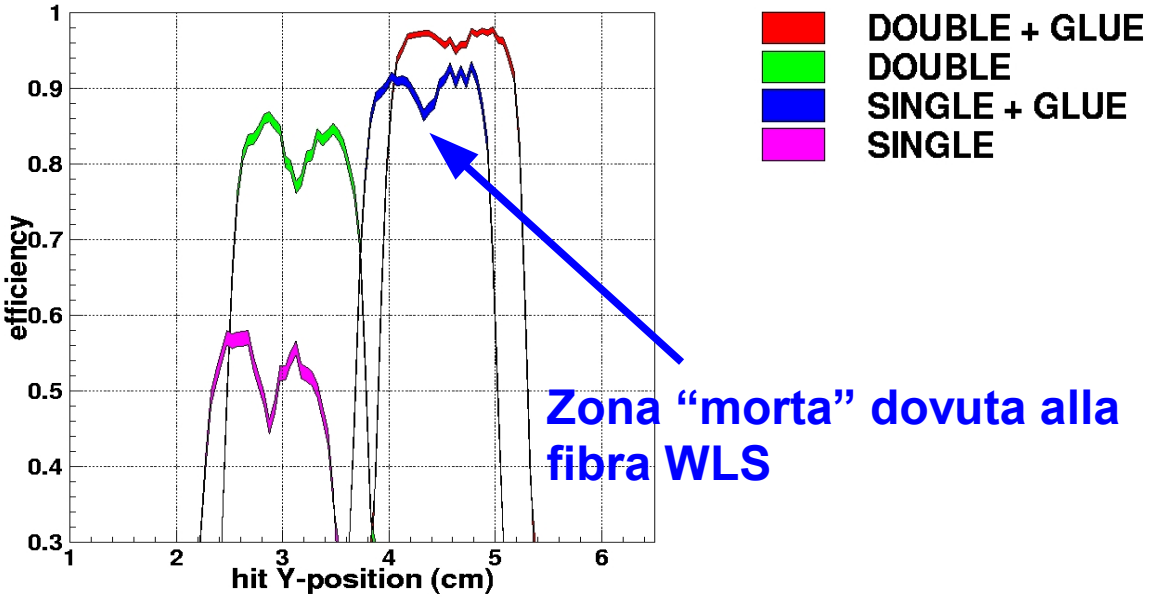


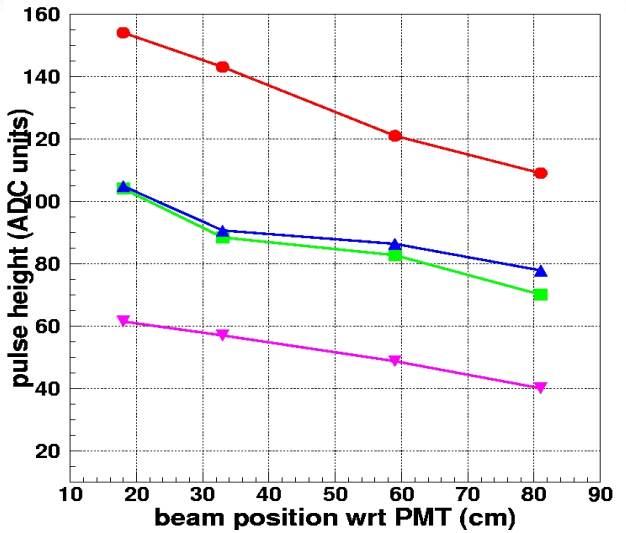
Sezione triangolare per il rivelatore finale! (2009)

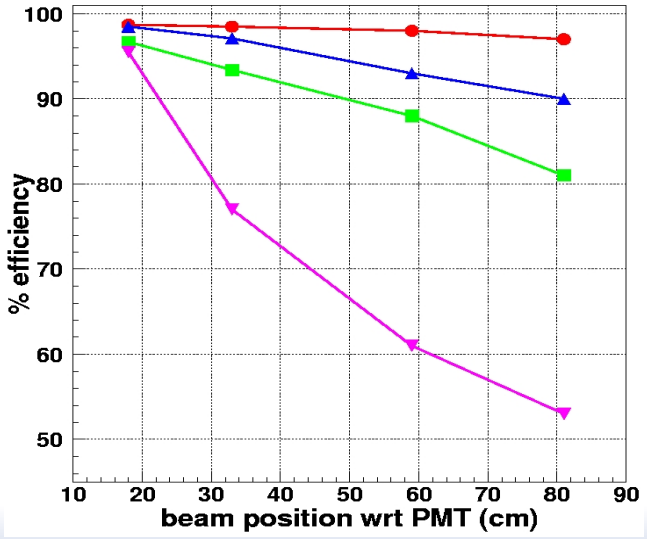


MICE – prototipo EMR

Analisi sulle 4 barre da 96 cm



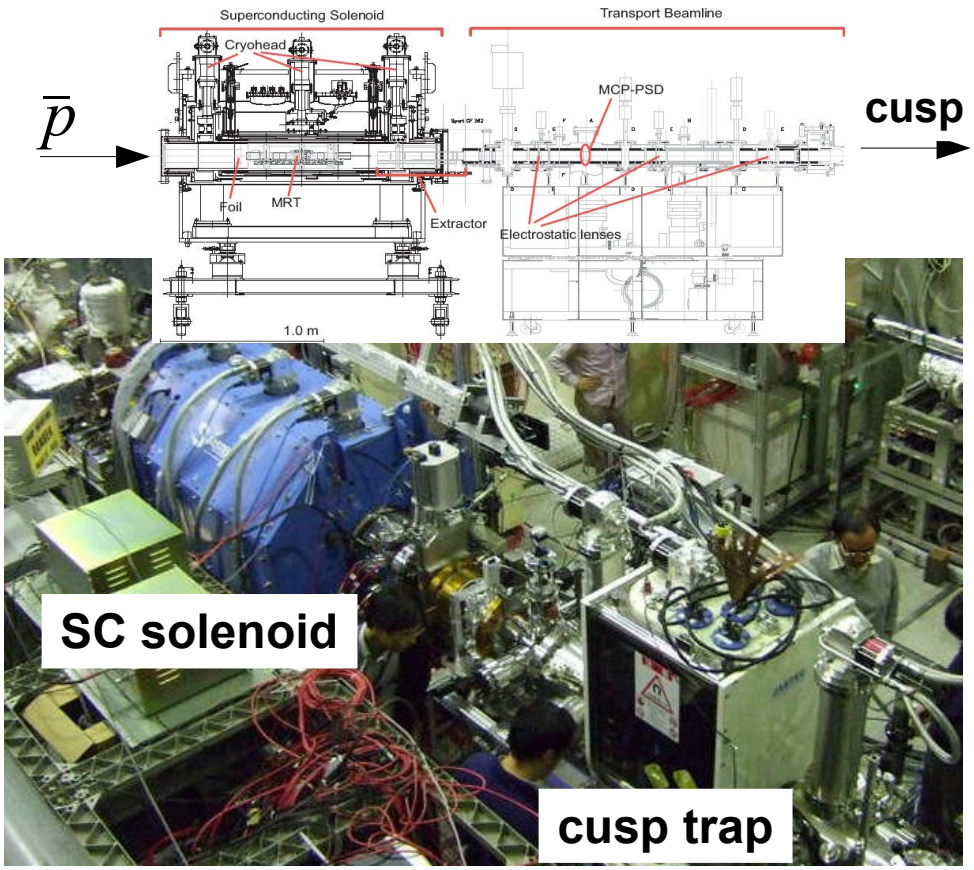




→ scelta di 1 fibra con colla per il tracciatore per l'esperimento MUSASHI (cusp trap)

ESPERIMENTO MUSASHI (cusp trap)

pbar @ 5 MeV (CERN AD) → **RFQD → 100 keV** → **He liq. SC solenoid → 250 eV**



MUSASHI

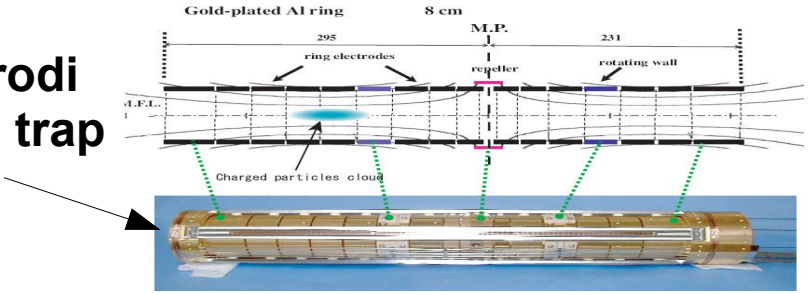
intrappolamento di 1.2 x 10^7 pbar (2007)

Estrazione lenta verso "cusp trap"

→ accumulazione di 3 x 10^6 pbar !!

→ formazione di anti-idrogeno

elettrodi cusp trap



Necessità di conoscere la posizione di annichilazione degli antiprotoni...

MUSASHI – cusp trap

Rivelatore a scintillazione

Barre scintillanti 15x19x960 mm^3 (forate)

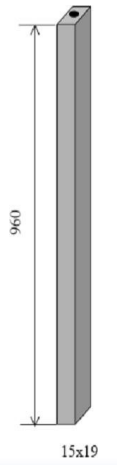
64 barre = 1 piano (X o Y)

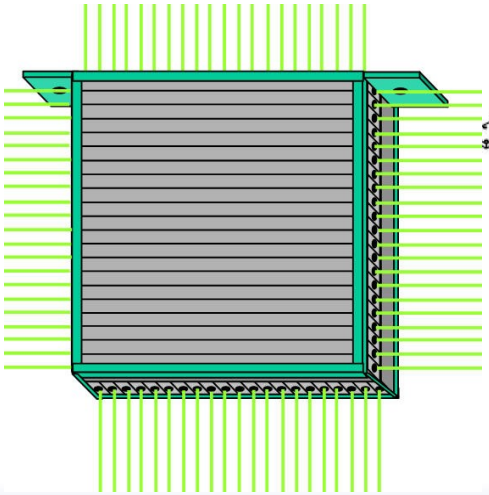
piano X + piano Y = 1 modulo

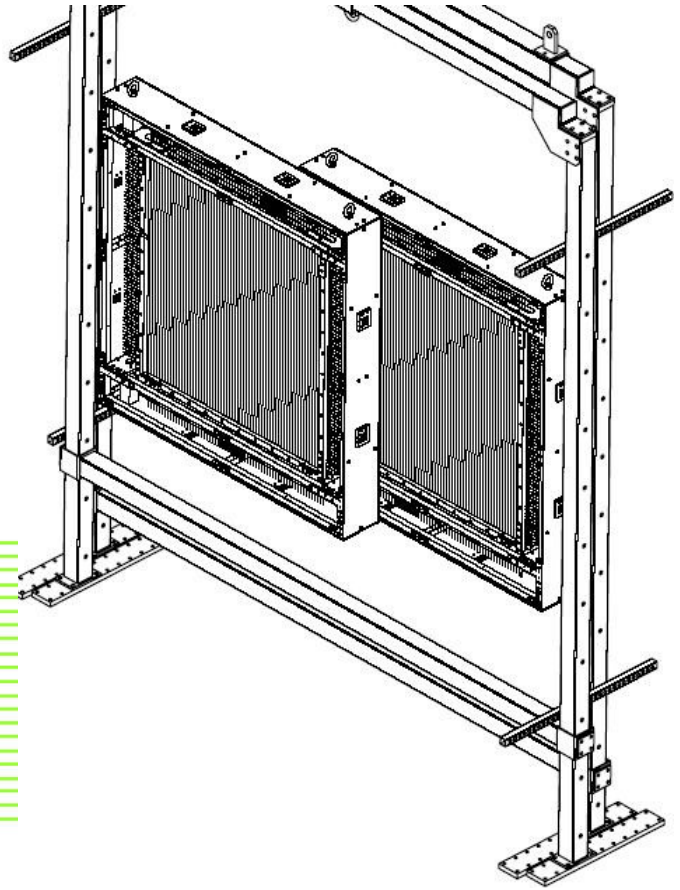
→ 4 MODULI XY

READOUT:
1 fibra WLS (Ø = 1 mm)
PMT multianodo (64 canali)

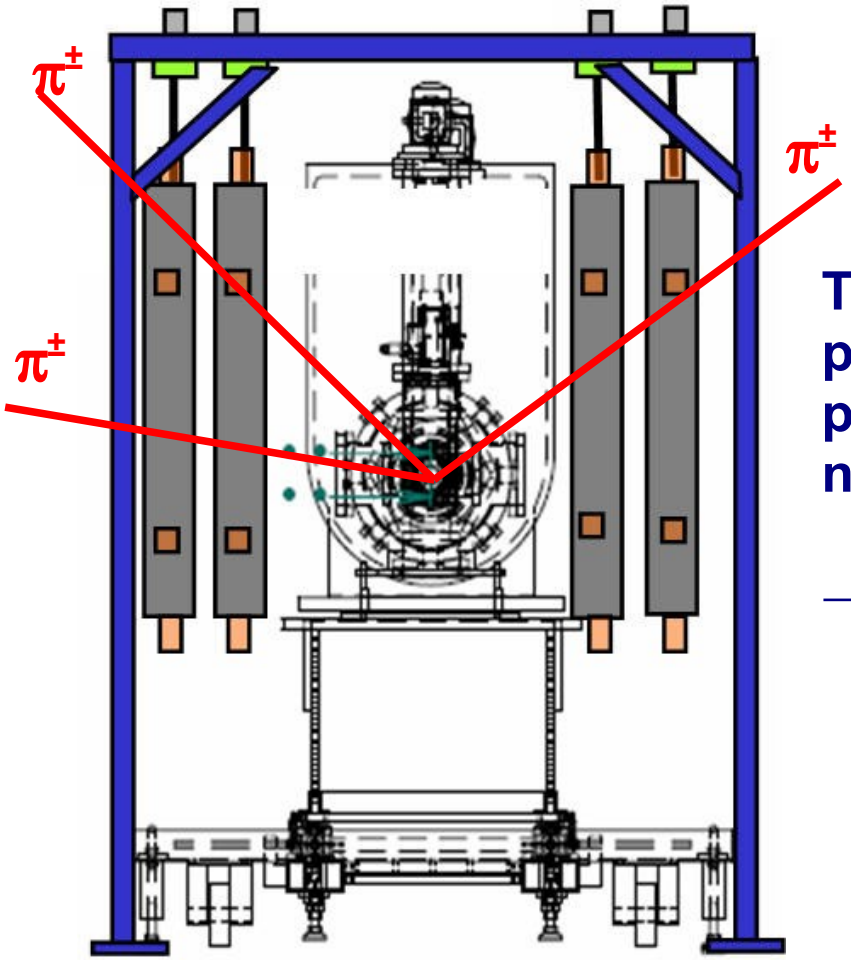
Elettronica ASACUSA





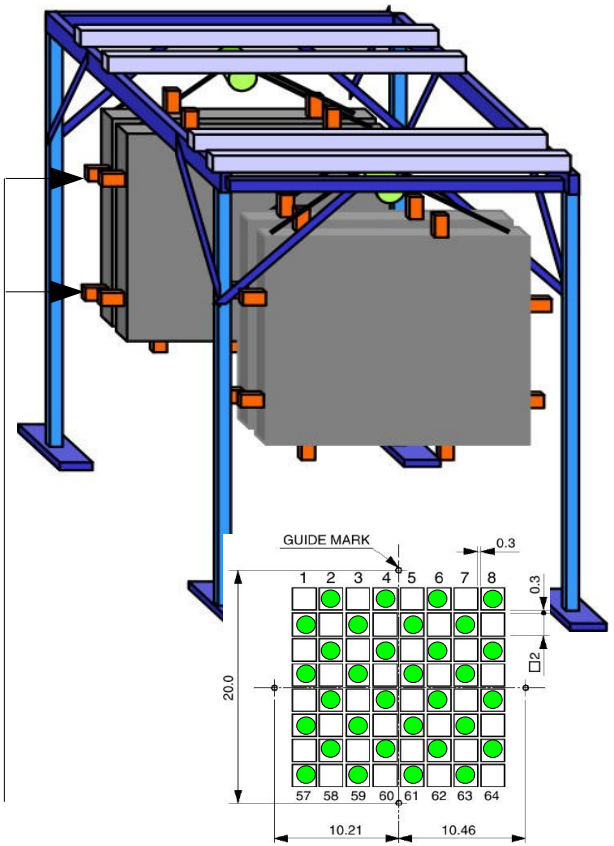


MUSASHI – cusp trap



Tracciamento dei pioni carichi prodotti nell'annichilazione

→ X,Y,Z vertici

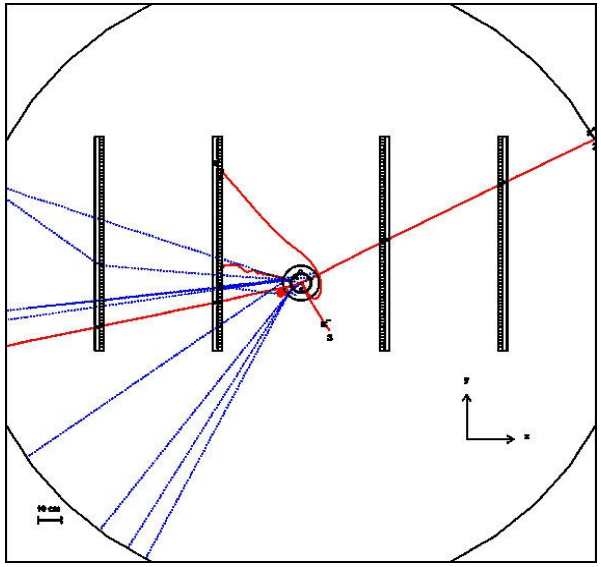


2 PMT per 64 canali di readout
→ solo 32 pad del PMT utilizzate

→ riduzione drastica cross talk

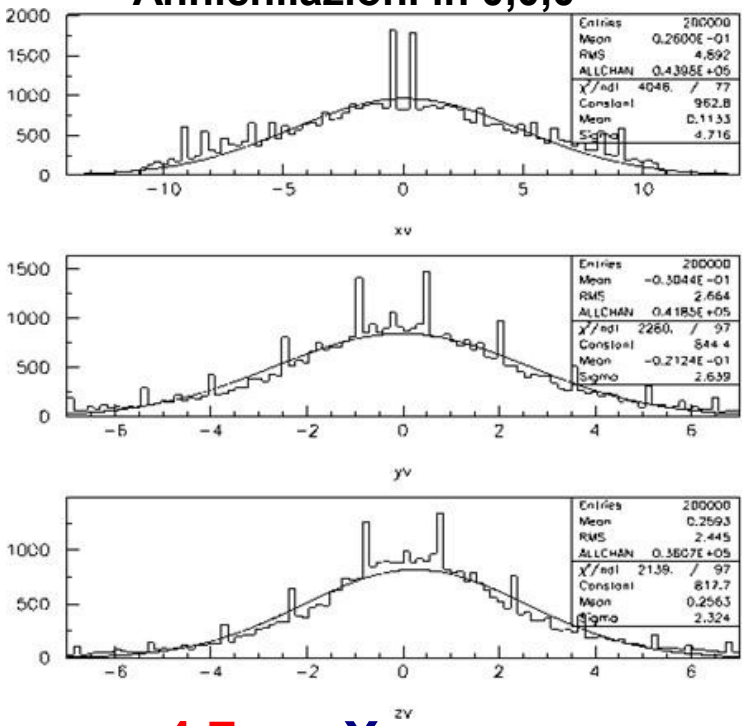
MUSASHI – cusp trap

Simulazione Montecarlo



Geant 3
- Campo magnetico
- materiale
- geometria

Annichilazioni in 0,0,0

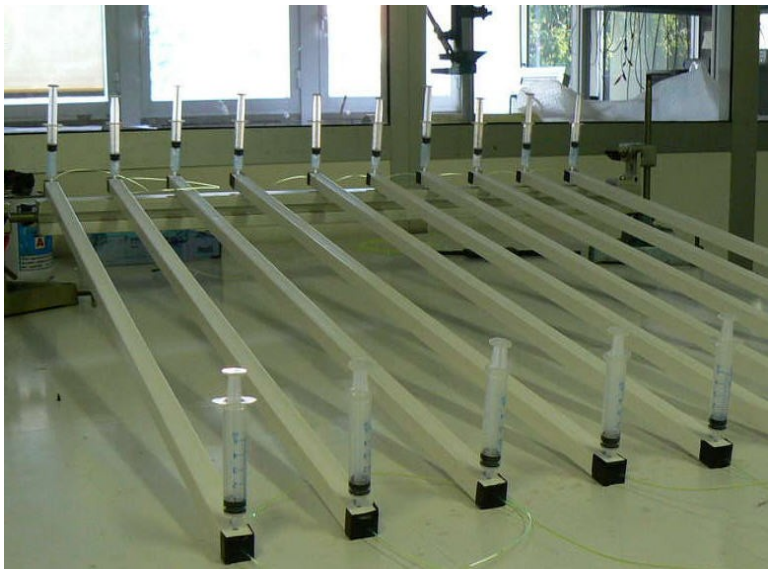


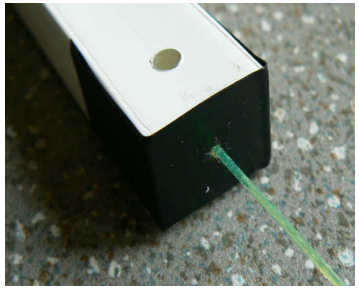
Risoluzione attesa = 4.7 cm X
2.6 cm Y
2.3 cm Z

Efficienza di ricostruzione ~ 25 %

MUSASHI – cusp trap

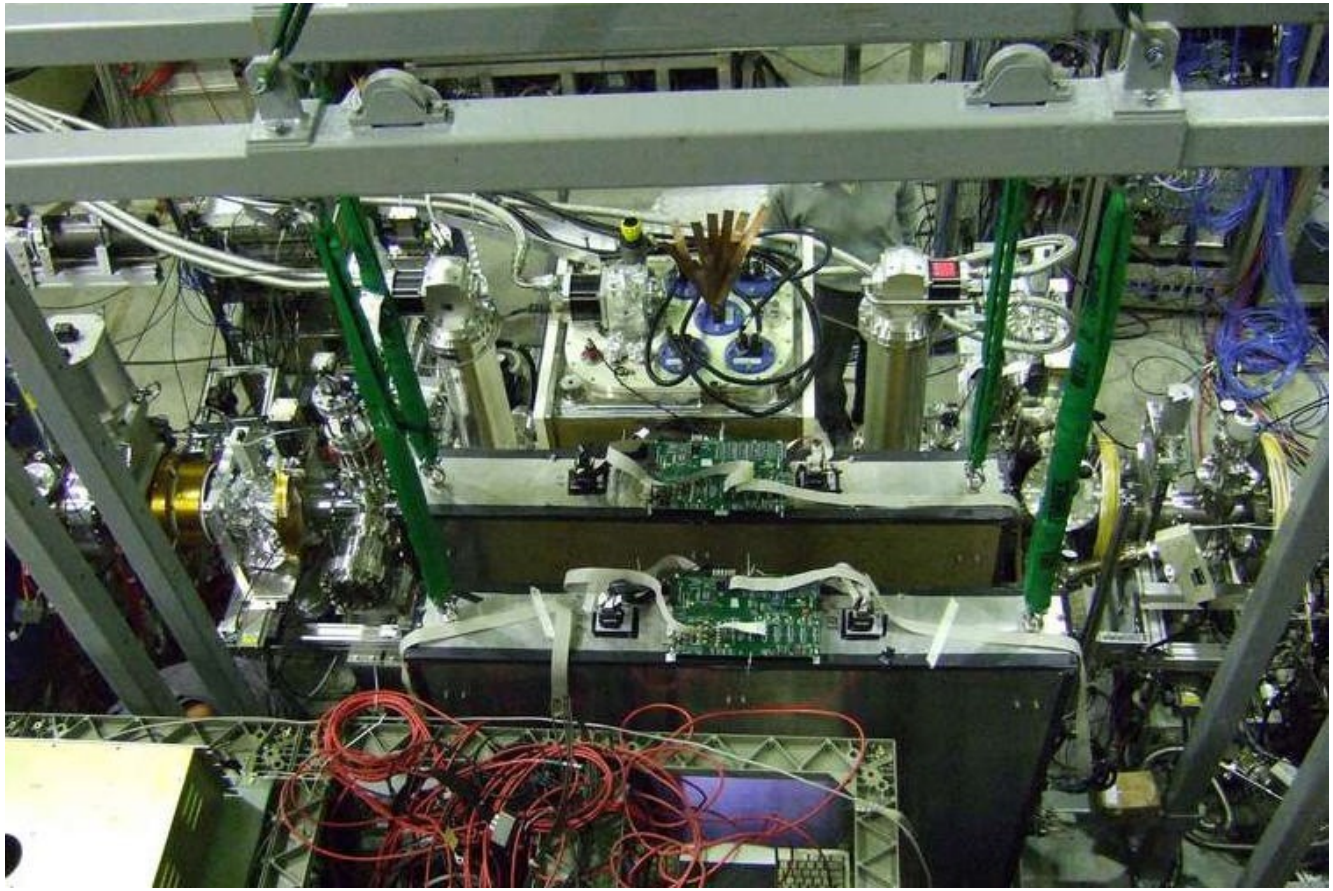
Assemblaggio (ESTATE 2008)





MUSASHI – cusp trap

Presa dati CERN - AD (SETTEMBRE 2008)



ANALISI:
in progress...

Conclusioni e obiettivi 2009

ASACUSA:

Prima misura sezione d'urto (relativa) pbar-nuclei!

→ occorre migliorare la statistica

→ allineamento temporale

→ presa dati 100 keV

MUSASHI:

Prima presa dati SETTEMBRE 2008

→ problemi di rumore (analisi+simulazione ad hoc)

→ rifacimento completo elettronica

MICE:

Ottimi risultati con il prototipo EMR

→ realizzazione detector finale e DAQ completo