



Il rivelatore NA62



Misura del BR del decadimento ultrararo $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

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Tutor:

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NA62-North Area at CERN

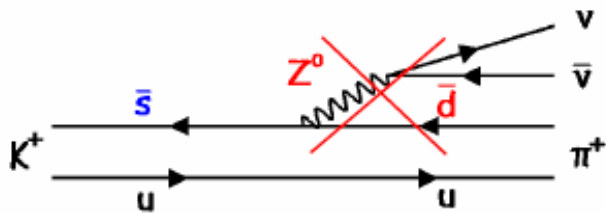


Obiettivo dell'esperimento

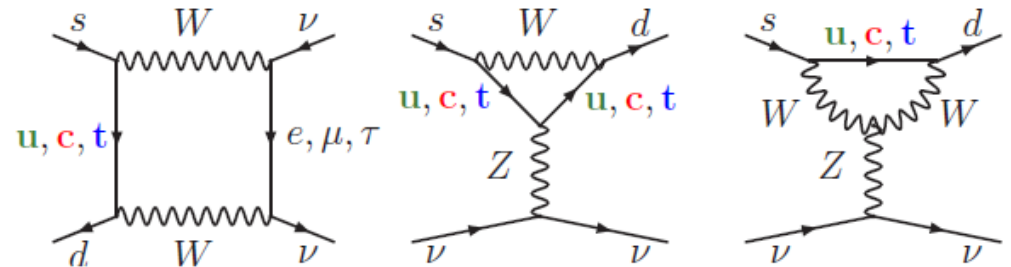
(Perché $K^+ \rightarrow \pi^+ \nu \bar{\nu}$?)



FLAVOR CHANGING NEUTRAL CURRENT

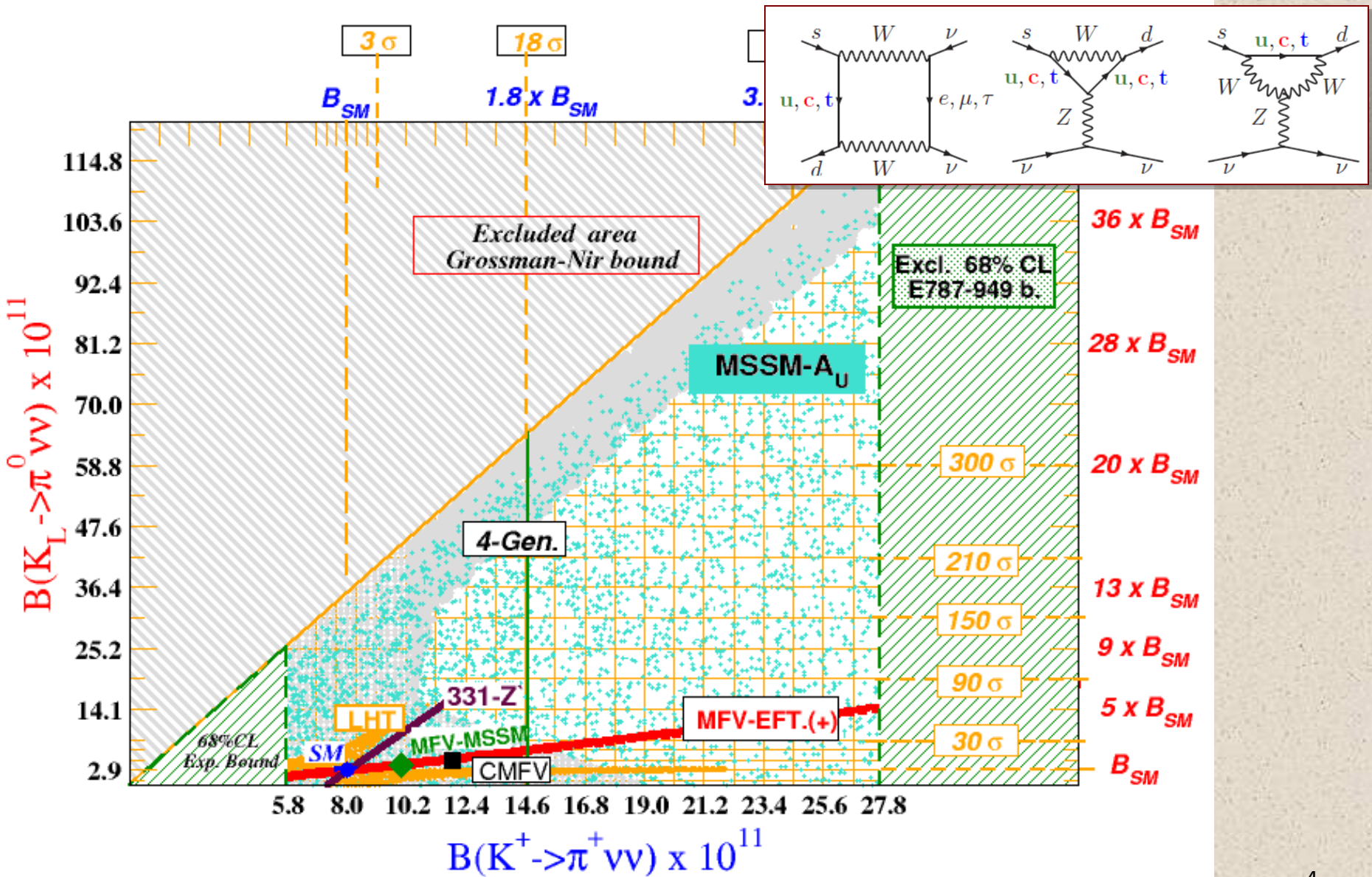


DIAGRAMMI DI FEYNMAN AL SECONDO ORDINE

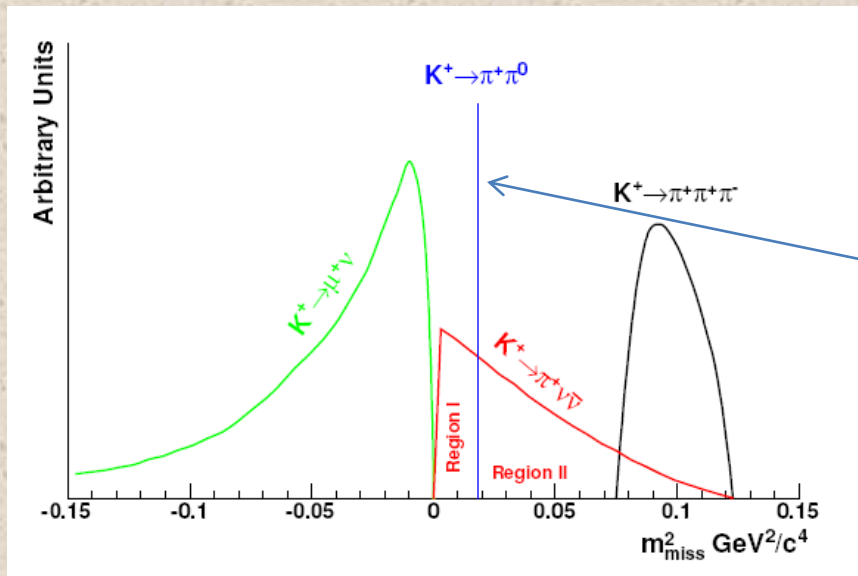


- SENSIBILE ALLA FISICA OLTRE IL MODELLO STANDARD
 - FORTE SEGNALE SPERIMENTALE (nello stato finale solo un π^+)
 - $BR(K^+ \rightarrow \pi^+ \nu \bar{\nu})(SM) = (8.22 \pm 0.84) \cdot 10^{-11}$
 - $BR(K^+ \rightarrow \pi^+ \nu \bar{\nu})(EXP) = (17.3^{+11.5}_{-10.5}) \cdot 10^{-11}$
- (7 events @ E787/E989, Phys. Rev. Lett. 101, 191082 (2008))

Obiettivo dell'esperimento



Decadimenti di fondo



$K^+ \rightarrow \mu^+ \nu_\mu$	63%
$K^+ \rightarrow \pi^+ \pi^0$	21%
$K^+ \rightarrow \pi^+ \pi^+ \pi^-$	5%

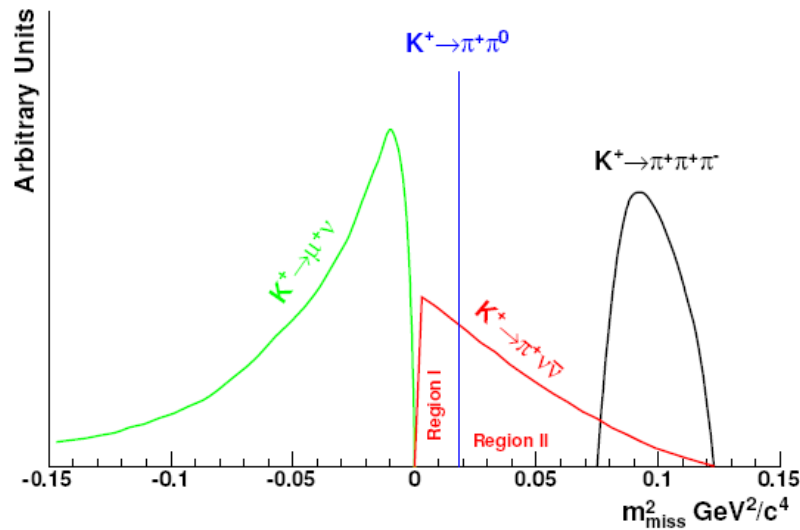
Oltre alla condizione su m_{miss} si elimina fondo selezionando eventi con $P_{\pi^+} < 35 \text{ GeV}/c$.

$$m_{\text{miss}}^2 \equiv (P_K - P_\pi)^2$$

$$m_{\text{miss}}^2 \approx m_K^2 \left(1 - \frac{|P_\pi|}{|P_K|}\right) + m_\pi^2 \left(1 - \frac{|P_K|}{|P_\pi|}\right) - |P_K| |P_\pi| \theta_{\pi K}^2$$

$$\left| \vec{P}_{\pi^0} \right| = \left| \vec{P}_{K^+} \right| - \left| \vec{P}_{\pi^+} \right| \geq 40 \text{ GeV}/c \longrightarrow 2\gamma$$

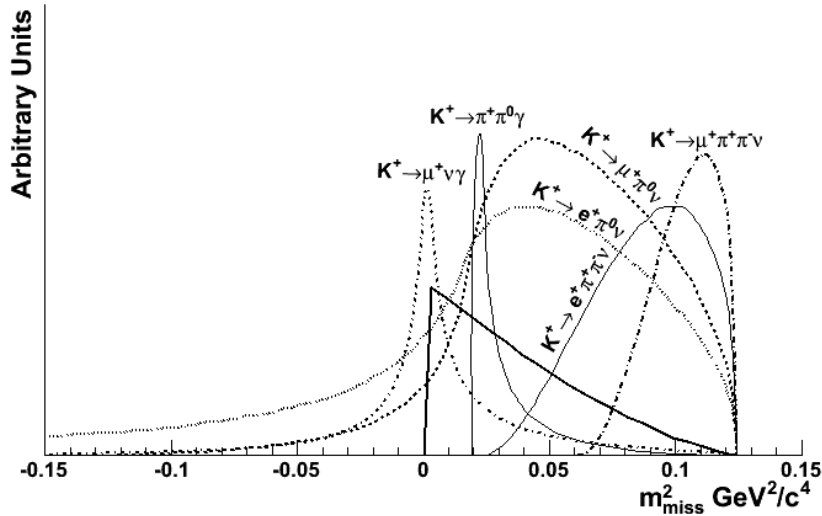
Decadimenti di fondo



$$K^+ \rightarrow \mu^+ \nu \quad 63\%$$

$$K^+ \rightarrow \pi^+ \pi^0 \quad 21\%$$

$$K^+ \rightarrow \pi^+ \pi^+ \pi^- \quad 5\%$$



$$K^+ \rightarrow \mu^+ \nu \gamma$$

$$K^+ \rightarrow \pi^+ \pi^0 \gamma$$

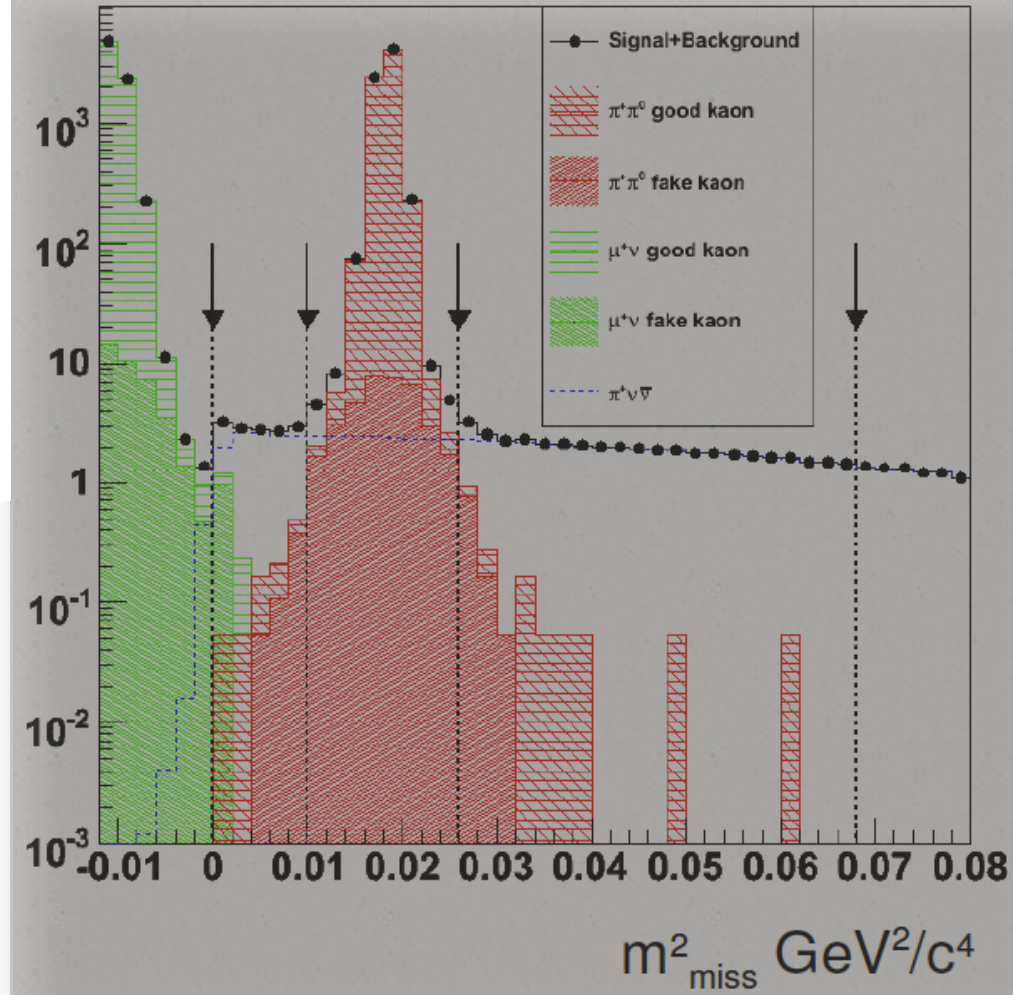
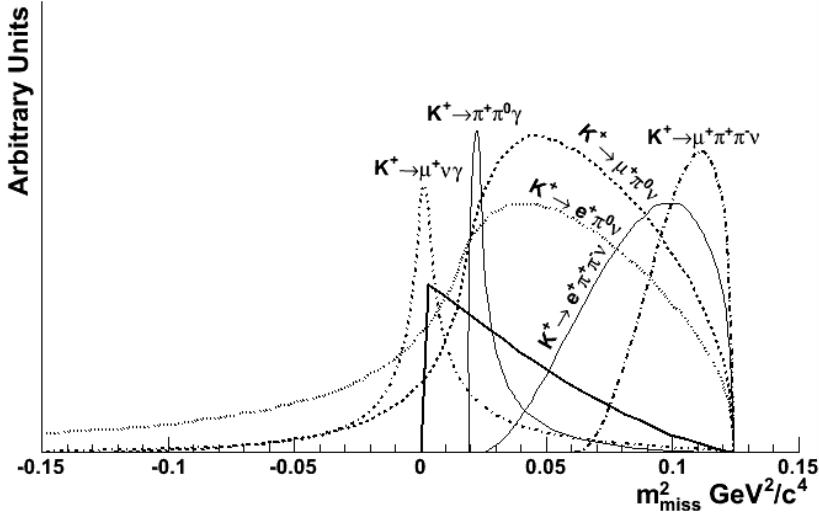
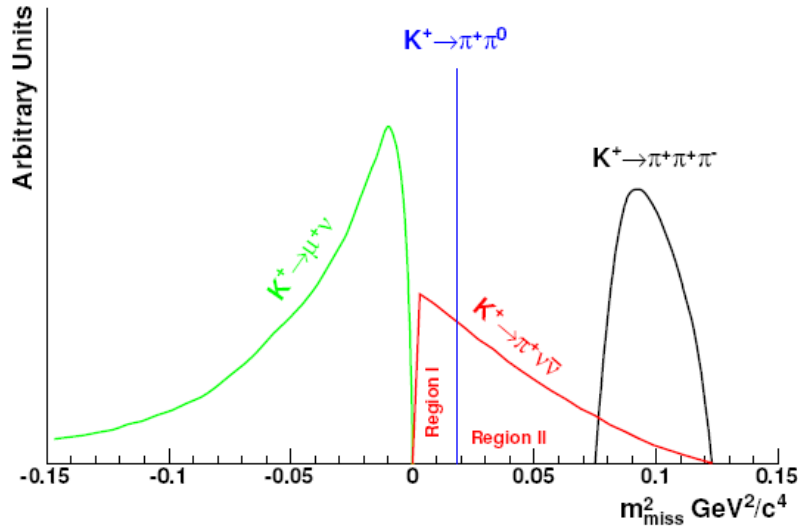
$$K^+ \rightarrow e^+ \pi^+ \pi^- \nu$$

$$K^+ \rightarrow e^+ \pi^0 \nu$$

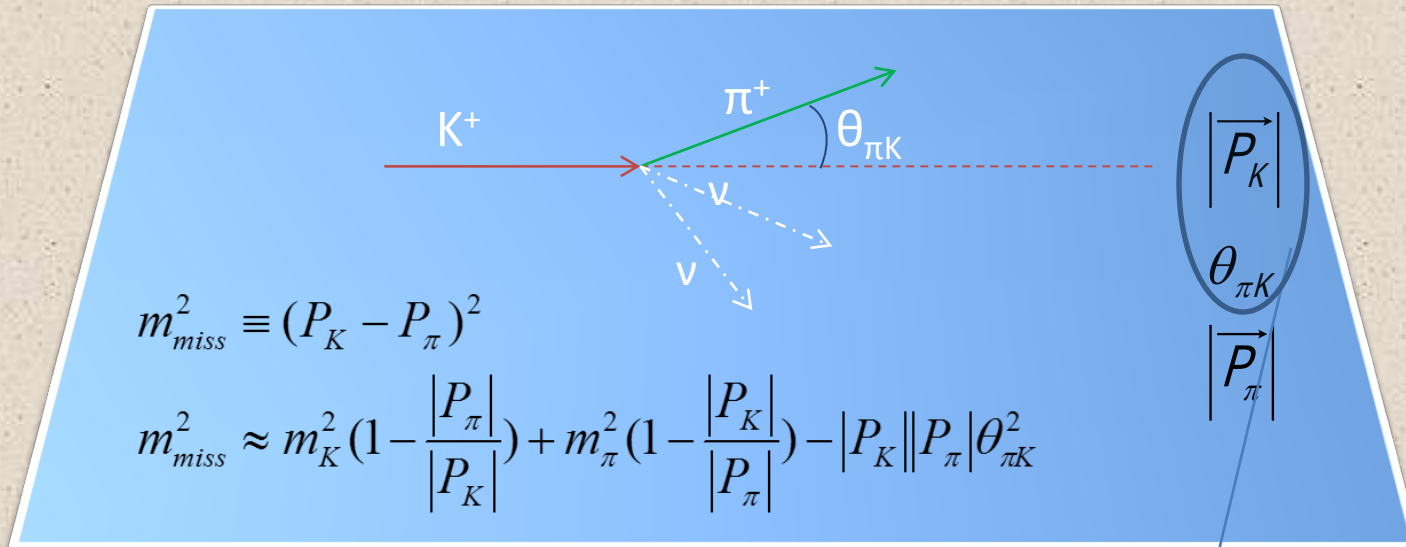
$$K^+ \rightarrow \mu^+ \pi^+ \pi^- \nu$$

$$K^+ \rightarrow \mu^+ \pi^0 \nu$$

Decadimenti di fondo



Identificazione eventi



- ❖ Kinematical rejection ($\sim 10^{-4}$)
- ❖ Particle identification and timing ($\sim 10^{-3}$)
- ❖ Photon/Muon Veto ($\sim 10^{-5}$)

Impose requirements on GigaTracker:
 $\sigma(p_k)/p_k \approx 0.2\%$, $\sigma(\theta_k) \approx 16 \mu\text{rad}$, $\sigma(t) < 200 \text{ ps}$

Identificazione eventi



1.KINEMATICAL REJECTION

- K^+ time, direction, momentum (GTK)
- π^+ (and charged part.) time, direction, momentum (STRAW)

$$\left| \vec{P}_K \right|, \left| \vec{P}_\pi \right|, \theta_{\pi K}$$

2.PARTICLE IDENTIFICATION

- K^+ identification (CEDAR)
- π^+/μ separation (RICH)

3.VETO

- Photon Veto detector (LKr, IRC,SAC, LAV)
- Muon Veto detector (MUV)
- Charged particle veto detector (CHANTI)

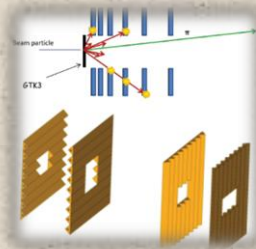
INOLTRE

- Minimize interaction (Multiple scattering) → low mass detector, vacuum
- Statistics (Ultra Rare decay – exp. uncert.) → high intensity beam
(time resolution request)

Apparato sperimentale

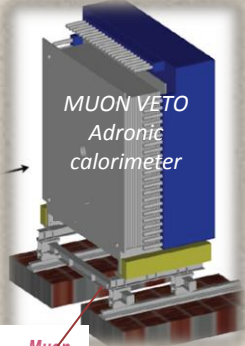


CEDAR
Differential Cerenkov
for positive
identification of kaons.



Straw-tubes chambers
(Vacuum spectrometer).
Momentum, time and
angle of secondary beam
charged particle.

Liquid Krypton
calorimeter
• Intermediate angle
photon veto
• Particle-Id using E/p



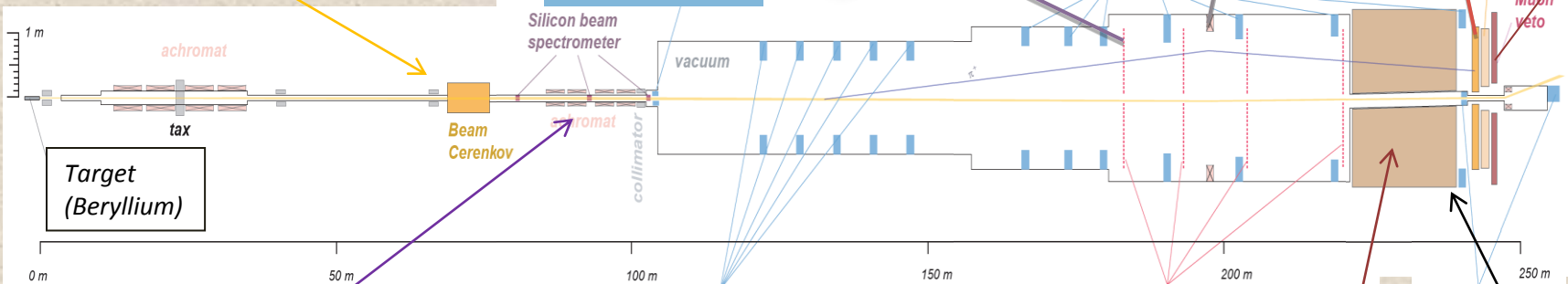
CHANTI
secondary beam
charged particles
identification.

Large
angle
photon
veto

Magnet

RICH

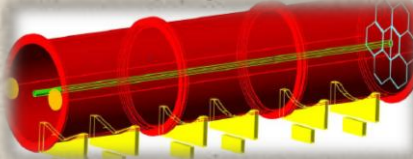
Muon
veto



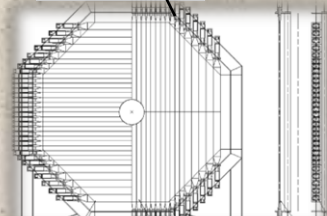
GIGATRACKER
Silicon pixel beam
tracker.
Momentum, time and
angle of kaons at 75
Gev/c



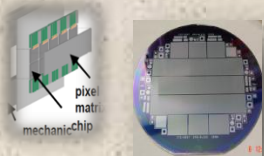
Large angle
photon veto
detectors
(operating in
vacuum)



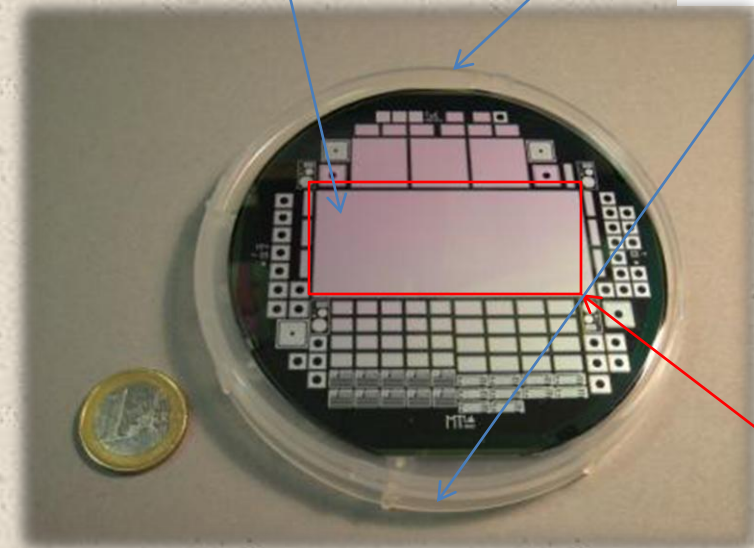
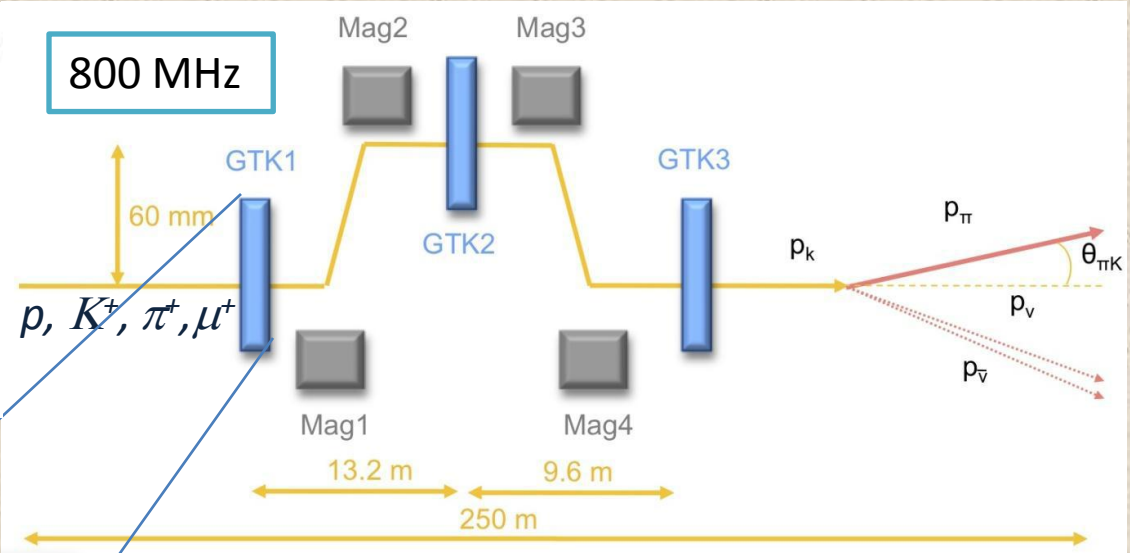
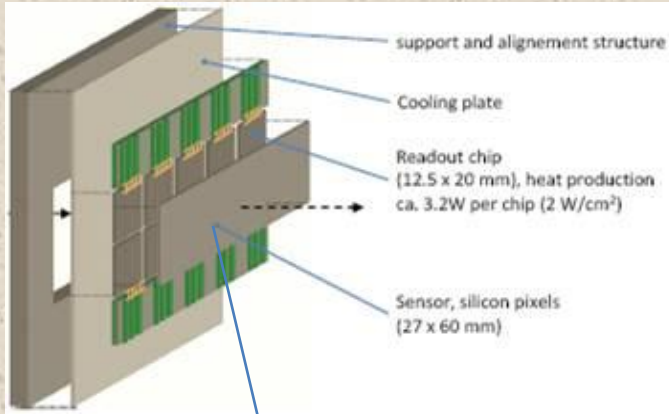
RICH
• Neon gas, 1 atm
• π/μ separation
• 150 ps time resolution
• 17 m long, 3 m diameter



CHOD - Charged hodoscope
System of scintillation counters with
high granularity and excellent time
resolution (200ps) used to detect
possible photo-nuclear reaction in
the RICH mirror plane.

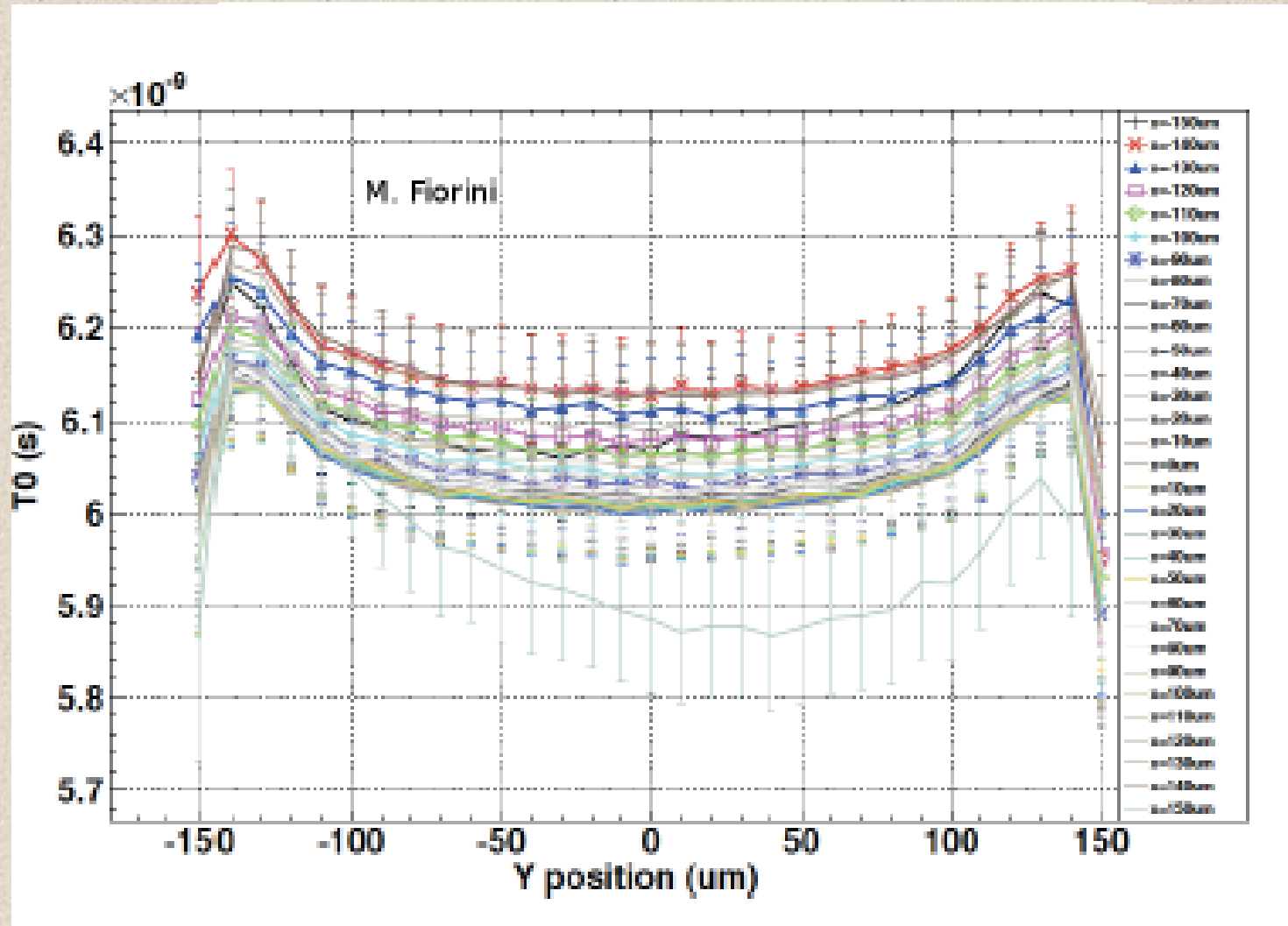


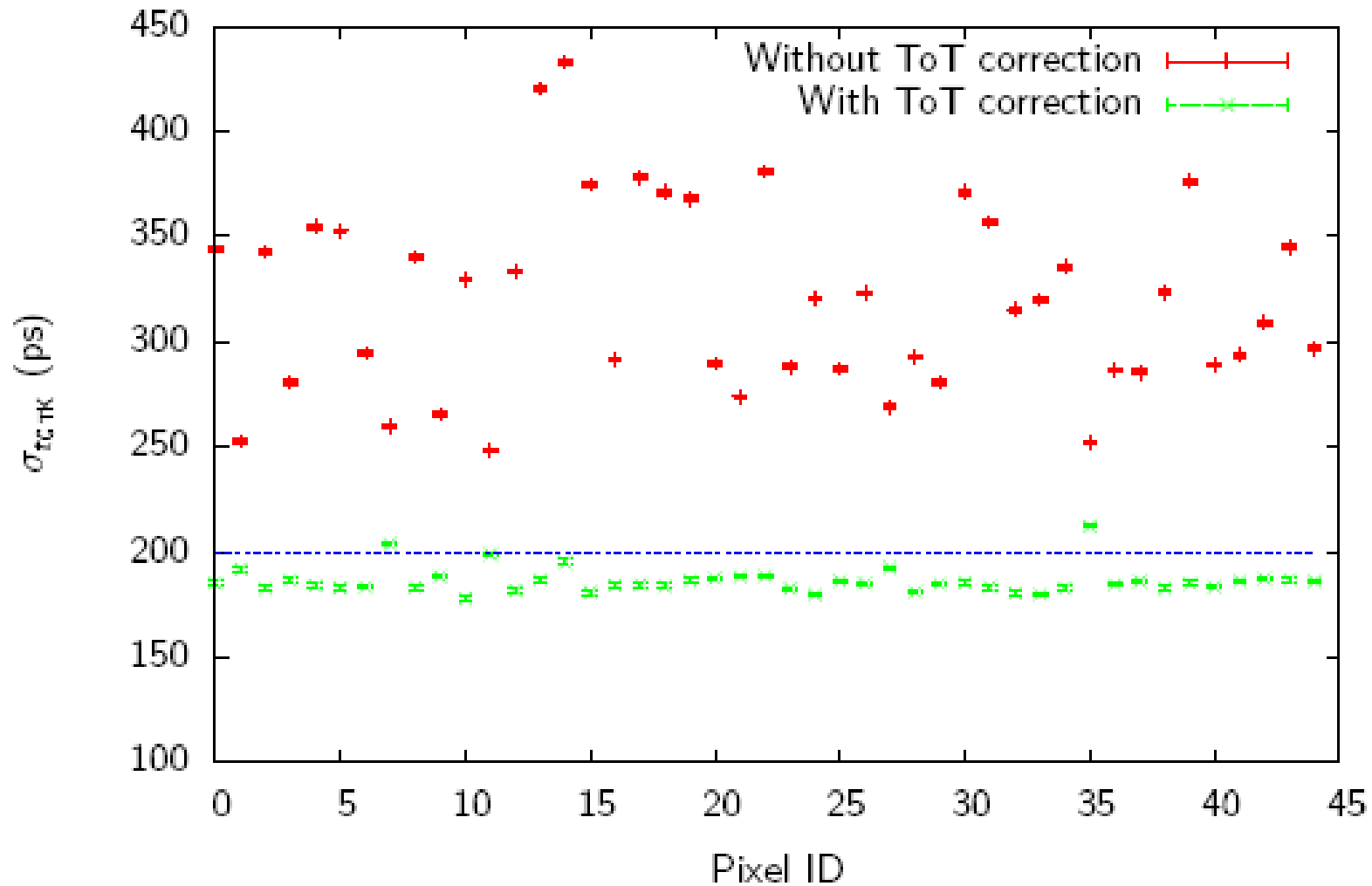
GIGATRACKER



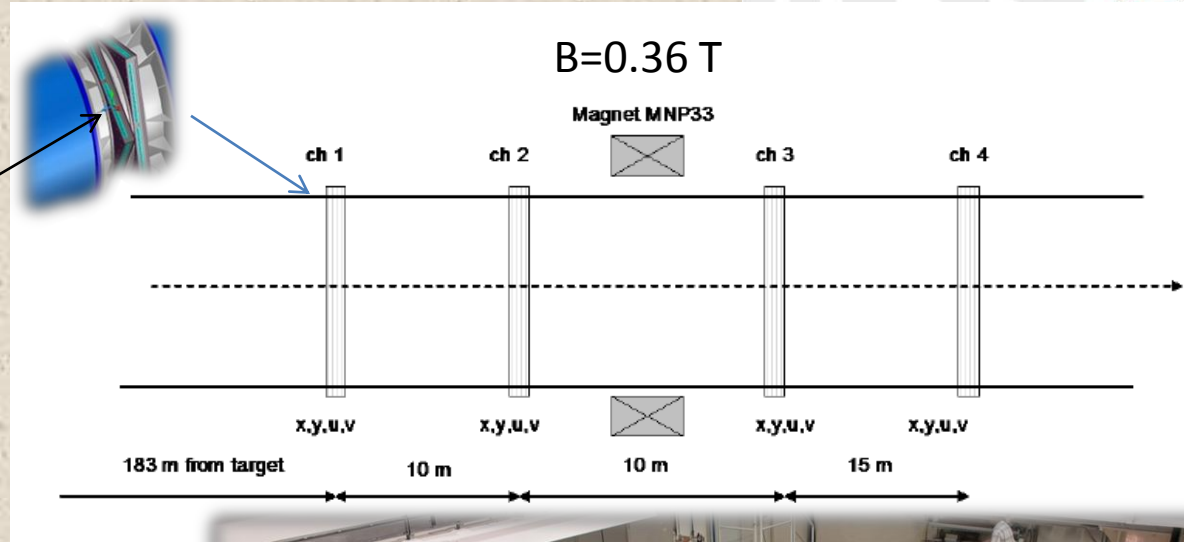
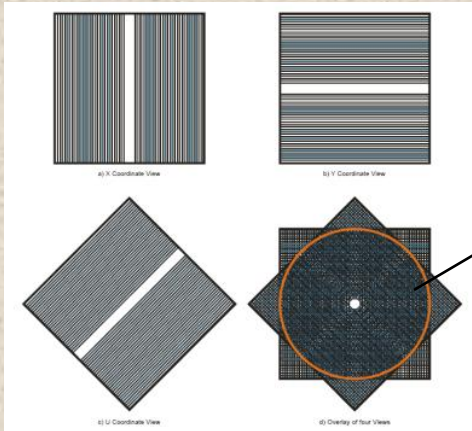
- Silicon pixel 300 $\mu\text{m} \times 300 \mu\text{m} \times 200 \mu\text{m}$
- >99% efficiency
- Material budget on beam line 0,45 % X_0
- 1 event/1ns
- Time resolution 175 ps
- Momentum resolution 0.2%
- Direction resolution ≈ 16 mrad

Active area covered by pixel cells



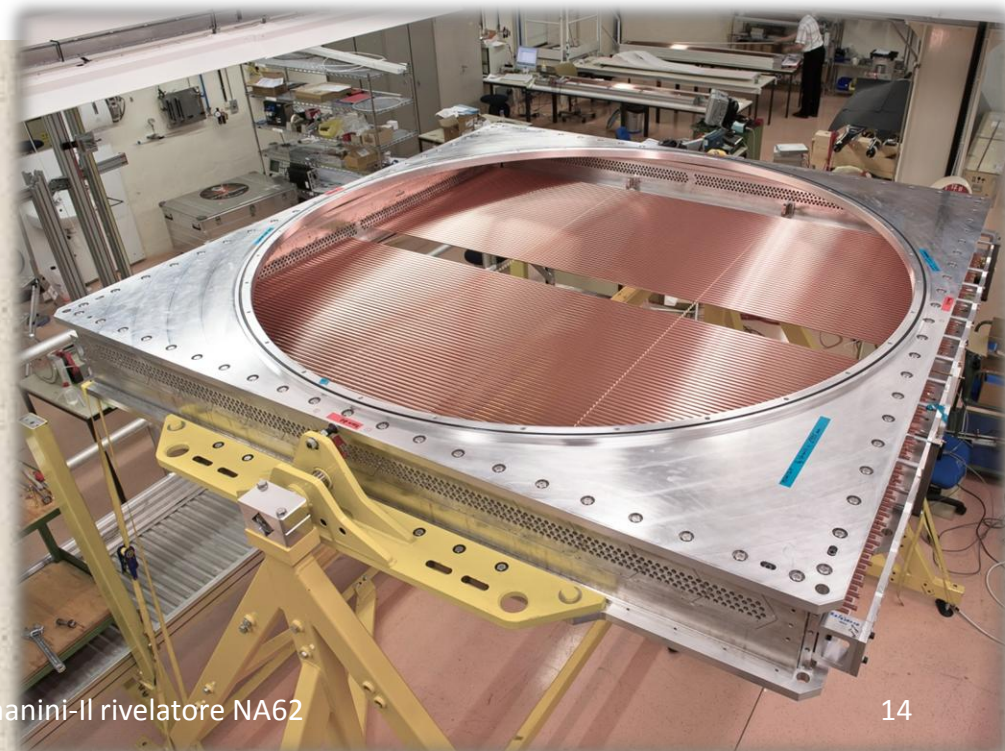


STRAW CHAMBERS

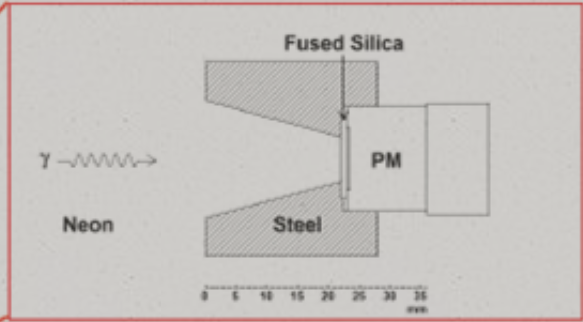
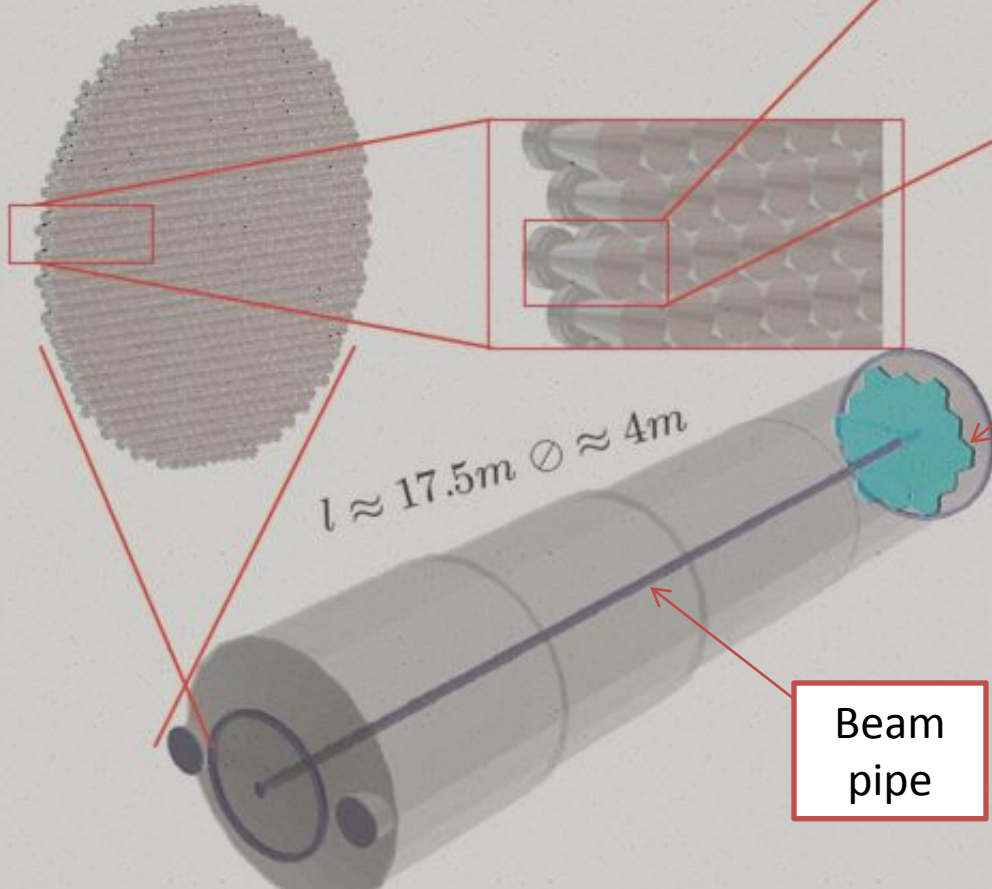


- 4 straw drift chambers
- 4 views/chamber (u-v, x-y)
- 2.1 m diameter acceptance
- 12 cm beam hole
- Gas: Ar(70%)/CO₂(30%)

- $\sigma_p/p < 1\%$
- $\sigma_\theta < 60 \mu\text{rad}$
- $\sigma_{\text{coord}} < 130 \mu\text{m}$
- Material budget $< 2\% X_0$
- $> 99\%$ hit efficiency
- Operate in vacuum (first time!)
- Max counting 0.5 MHz



$2 \times \approx 1000 PM$



- Neon at 1 atm \rightarrow (5% X_0)
- 20 mirror segments (20% X_0)
- Use in Level-0 trigger
- $\sigma_t < 100$ ps π crossing time

PHOTON VETOES

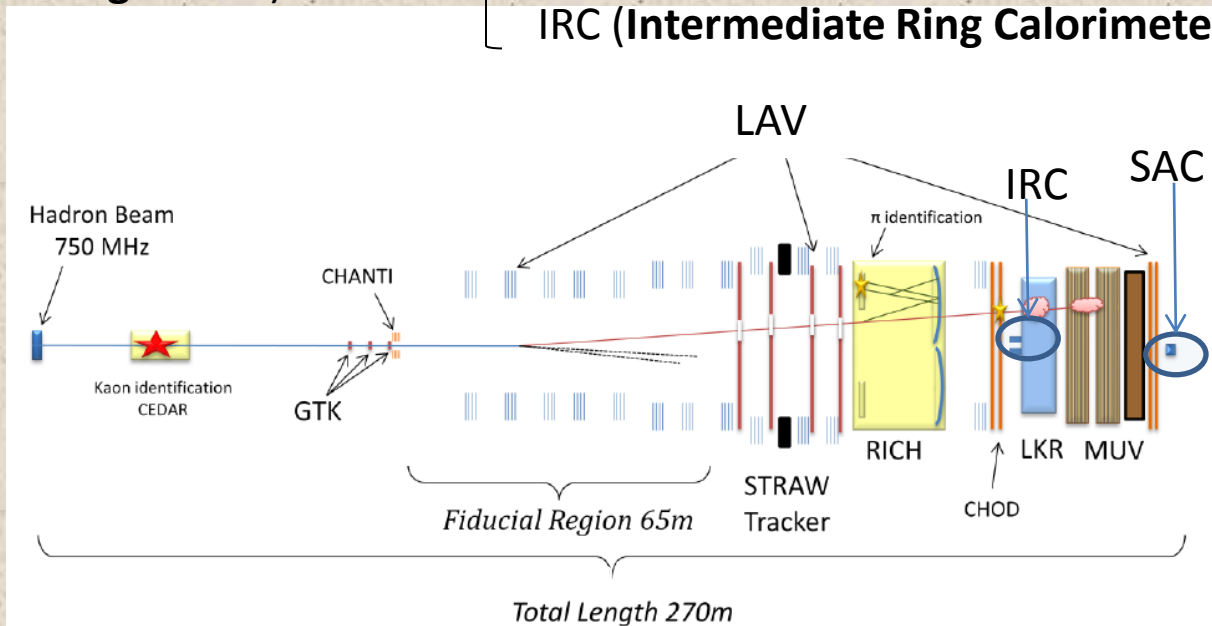
I fotoni provengono prevalentemente dal decadimento del π^0 ,
si distinguono tre casi:

- Entrambi i fotoni in avanti nel calorimetro con un'energia totale di circa 40 GeV;
- Un fotone in avanti nel calorimetro, l'altro nel LAV;
- Un fotone in avanti nel calorimetro e l'altro ad angoli maggiori di 50 mrad.

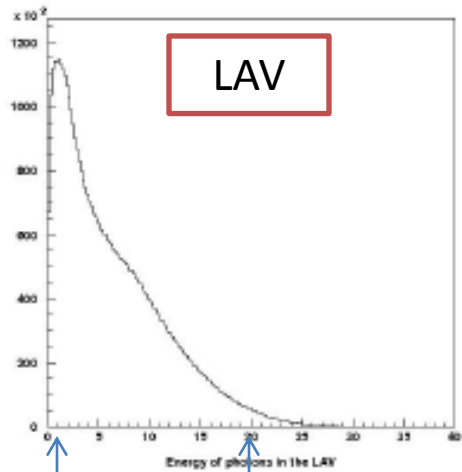
LAV (**Large Angle Vetoes**) 50-8.5 mrad

LKR (**Liquid Krypton calorimeter**) 8.5-1 mrad

SAV (**Small Angle Veto**) <1 mrad { SAC (**Small Angle Calorimeter**)
IRC (**Intermediate Ring Calorimeter**)

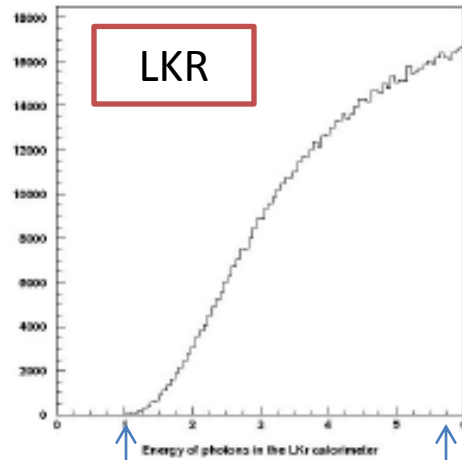


PHOTON VETOES



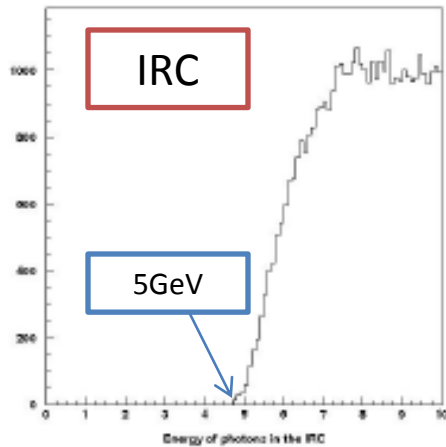
10 MeV

30 GeV

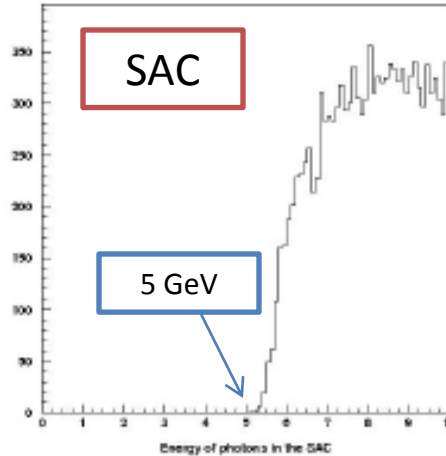


1 GeV

6 GeV



5 GeV



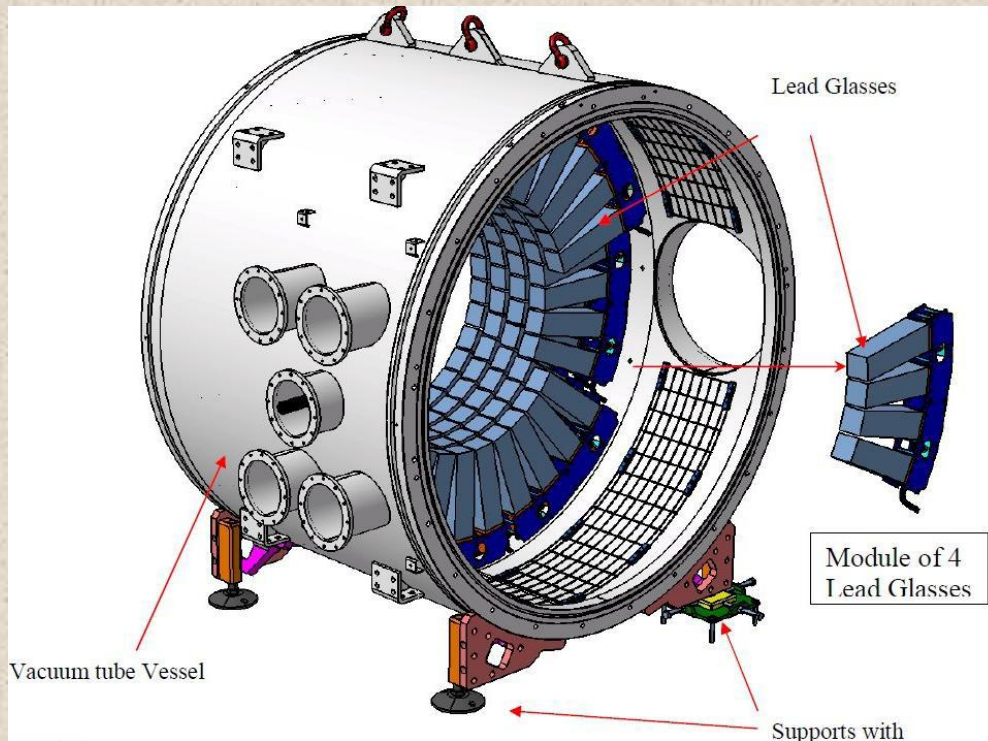
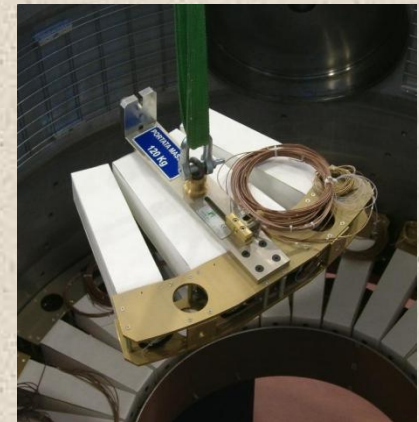
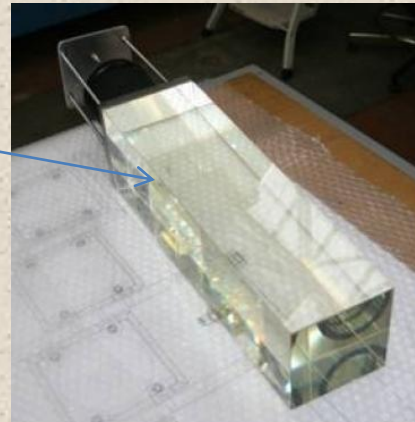
5 GeV

GRANDE ANGOLO
"BASSA" ENERGIA

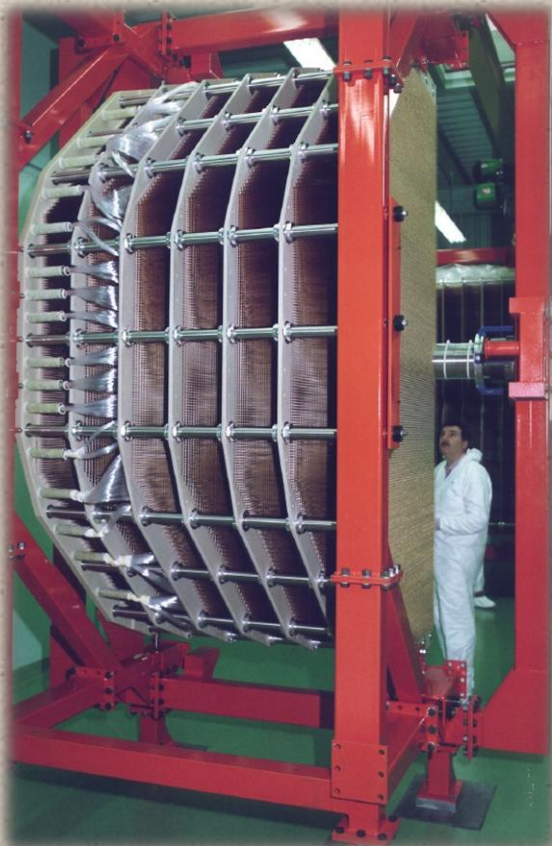
BASSO ANGOLO
ALTA ENERGIA

Large Angle Veto

- **12 stations** along the decay tube
- (11 in vacuum+ 1 following RICH)
- 2500 lead glass crystals with attached photomultipliers (**OPAL e-cal**)
- Cover 8.5 to 50 mrad
- $\sigma_E \approx 9\%/\sqrt{E}$
- $\sigma_t \approx 210 \text{ ps}/\sqrt{E}$



Liquid Krypton Calorimeter

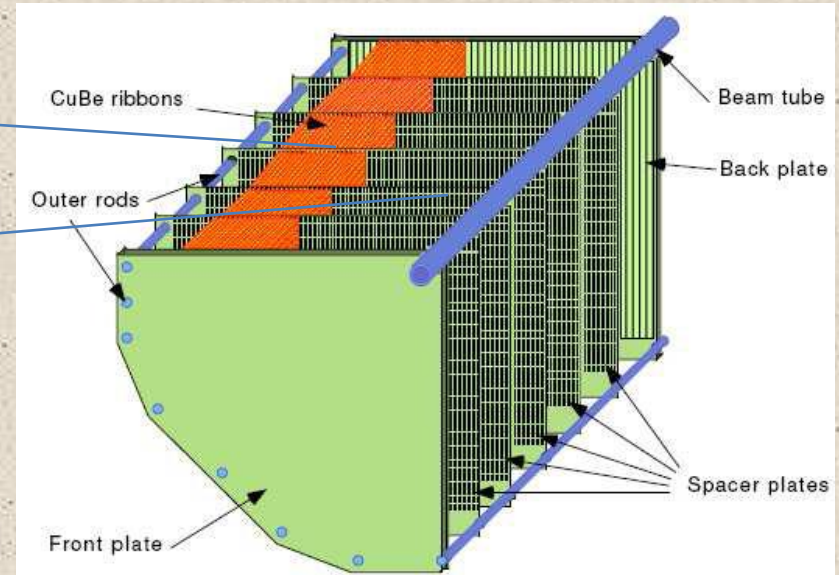
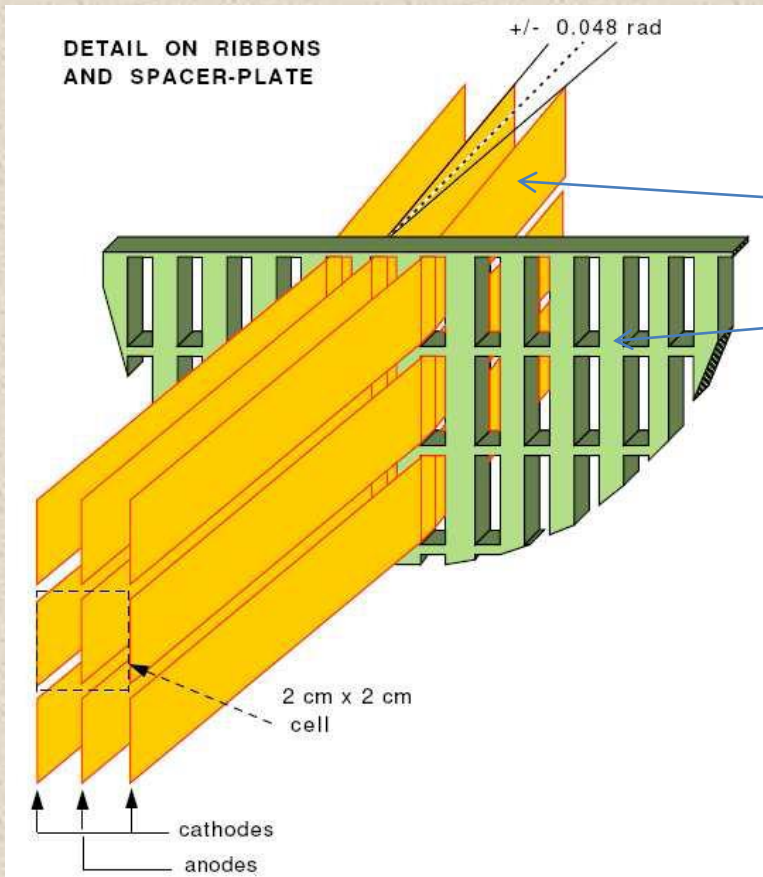


Quasi-homogeneous ionization chamber:

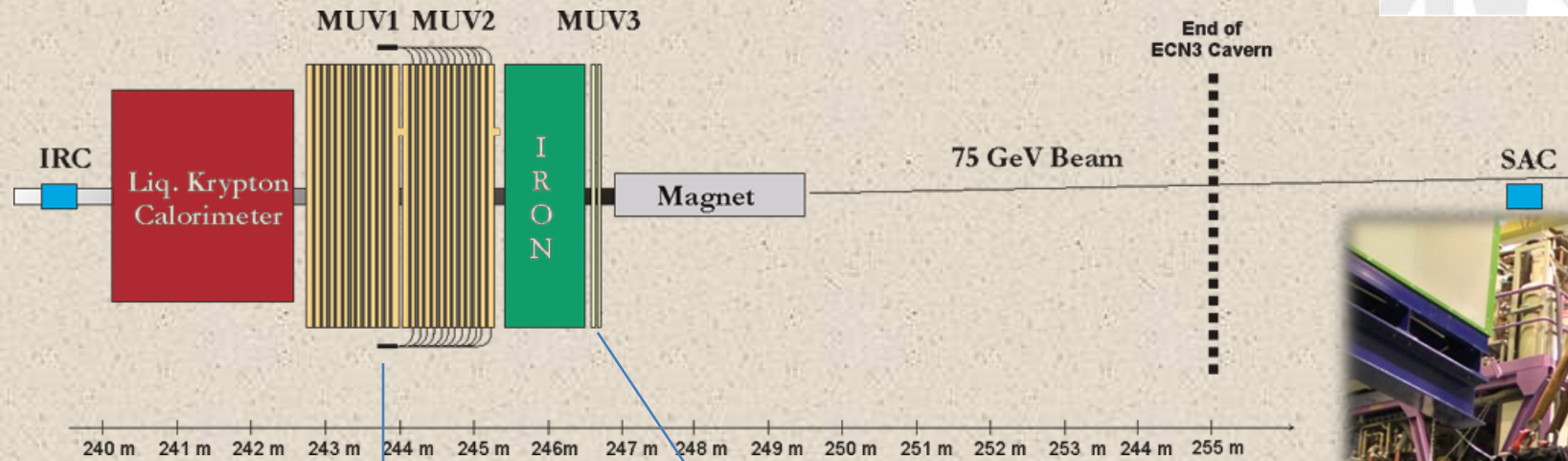
- Almost fully active calorimeter (9m³, very good resolution)
- Cold noble liquid (very good stability)
- Cover 8.5 to 1 mrad
- Length 127 cm ~27X₀
- Time resolution: 500 ps (photon)
- Position resolution: better than 1% above 20 GeV
- Energy resolution: 1% above 20 GeV
- Non linearity: < 0.2 % in 5-100 GeV energy range
- Electrons rejection measuring E/p ratio

$$\frac{\sigma(E)}{E} \approx \frac{(3.2 \pm 0.2)\%}{\sqrt{E}} \oplus \frac{(10 \pm 1)\%}{E} \oplus (0.42 \pm 0.05)\%$$

Liquid Krypton Calorimeter



MUON VETOES



Work as hadronic calorimeter:
Shower shapes of incident particle

Fast signal for L0 Trigger:

- time resolution 1 ns
- coincident signal with GTK e CEDAR

Separation electromagnetic muon showers from adronic pion showers.



MUON VETOES

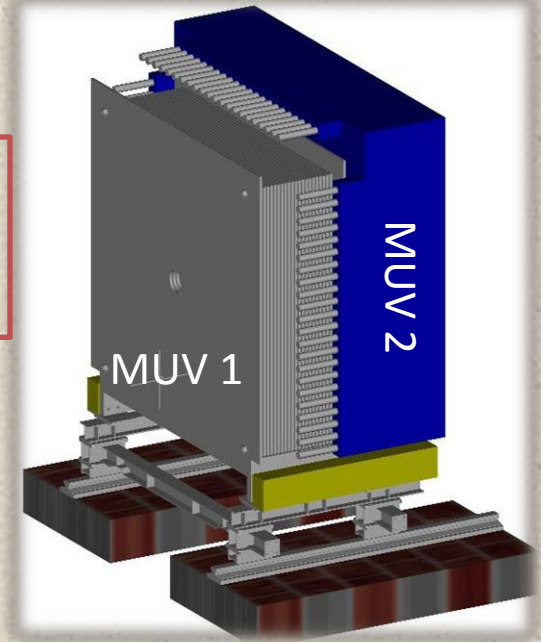
2 classic iron-scintillator sandwich calorimeter:

- **MUV1:**
 - 25 layer of scintillator streps
 - **Transversal segmentation**
- **MUV2:**
 - Recycled from HAC of NA48
 - 22 layer of scintillator strips

Scintillator strips
alternatively oriented in the
horizontal and vertical
directions

MUV3:

- After 80 cm iron wall
- Scintillator pads with direct readout of light in an black box (to suppress reflections and Cerenkov)
- **Fast trigger signals**
- **Detecting non-showering muons**



TRIGGER

Richieste primarie:

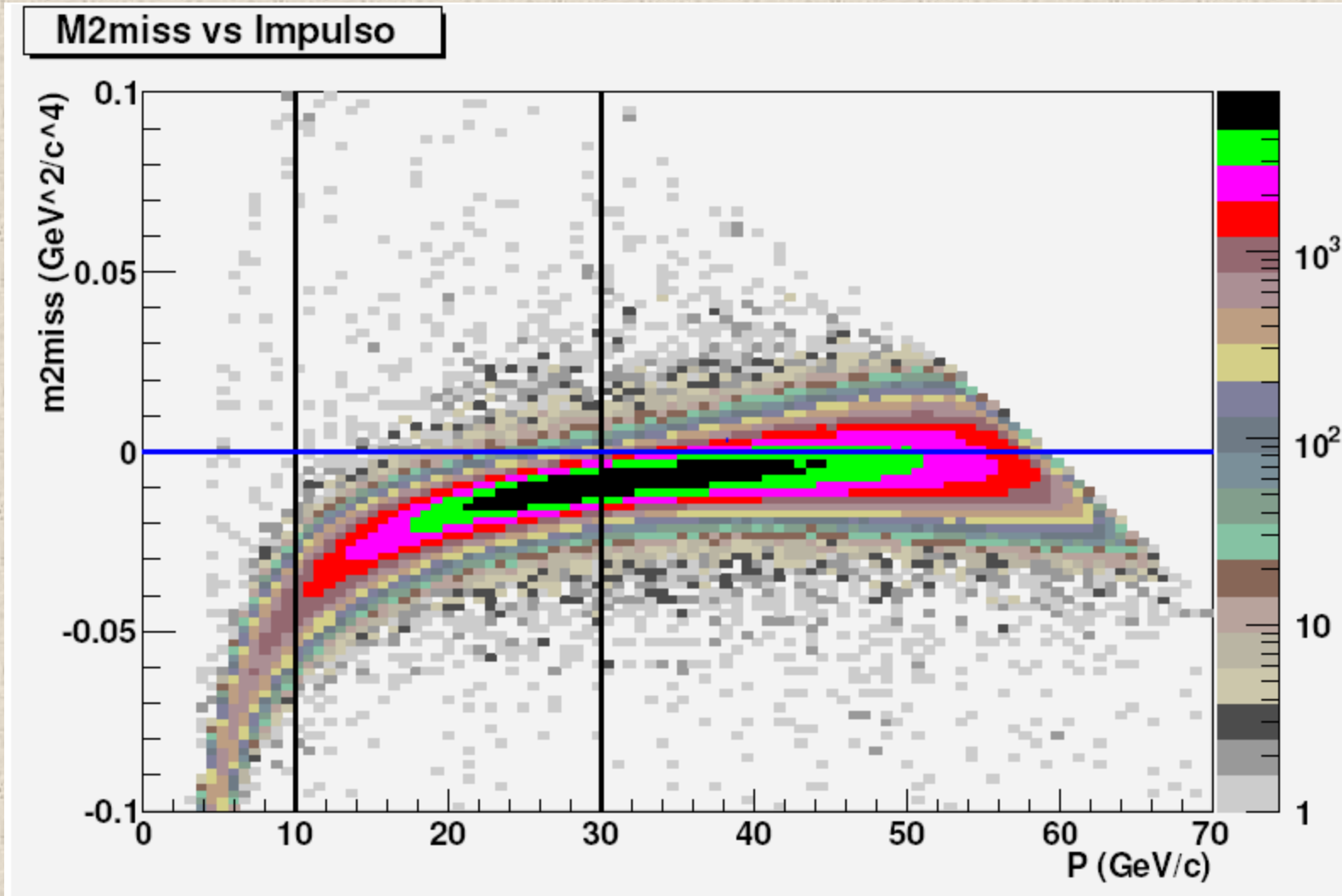
- 1)Una sola traccia nel CHOD
- 2)Assenza di segnale nel MUV 3
- 3)Non più di un cluster nel calorimetro LKR

Per eliminare il fondo di muoni:

- si richiede che non vi sia un segnale nel rivelatore per muoni; $\overline{\text{MUV}}$
- si richiede un valore minimo per l'energia del cluster associato alla traccia: $E_{cl} > 2 \text{ GeV}$; tale valore è stato scelto perché nel caso in cui un muone generi un cluster nel calorimetro, questo non può avere energia maggiore di 1 GeV, data la dimensione longitudinale del calorimetro.
- si richiede un intervallo di valori per l'impulso della traccia carica: $10 < P_{traccia} < 30 \text{ GeV}/c$; tale taglio ha lo scopo principale di eliminare eventi del tipo $K^\pm \rightarrow \mu^\pm \nu$, l'intervallo scelto è stato determinato in maniera grafica dalla distribuzione della massa mancante,

- Regione 1: $(0 < m_{miss}^2 < 0.009) \text{ GeV}^2/c^4$
- Regione 2: $(0.028 < m_{miss}^2 < 0.068) \text{ GeV}^2/c^4$

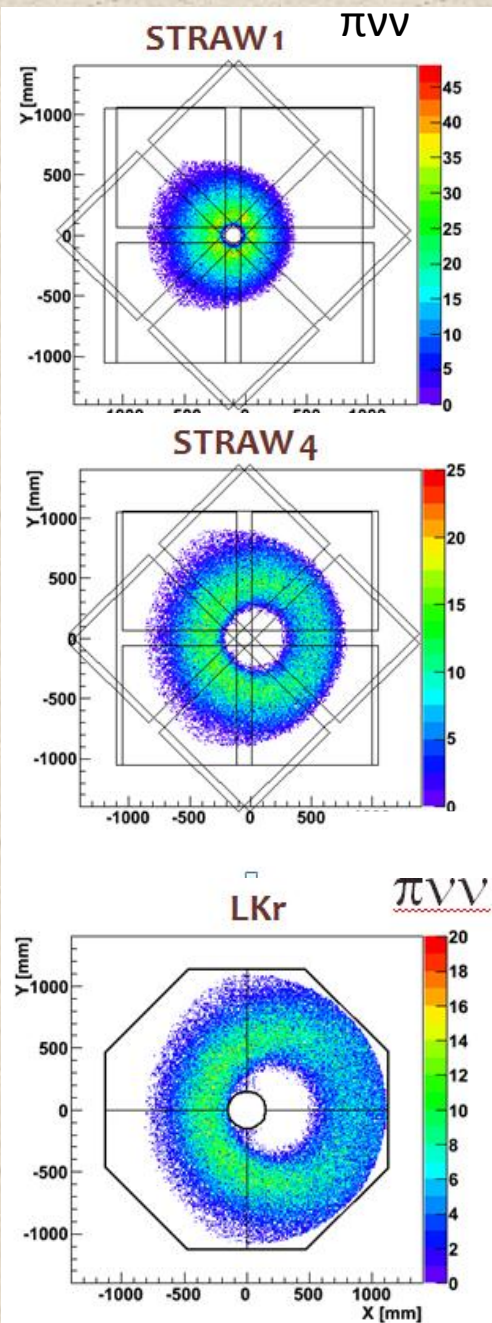
Taglio su P_{track}



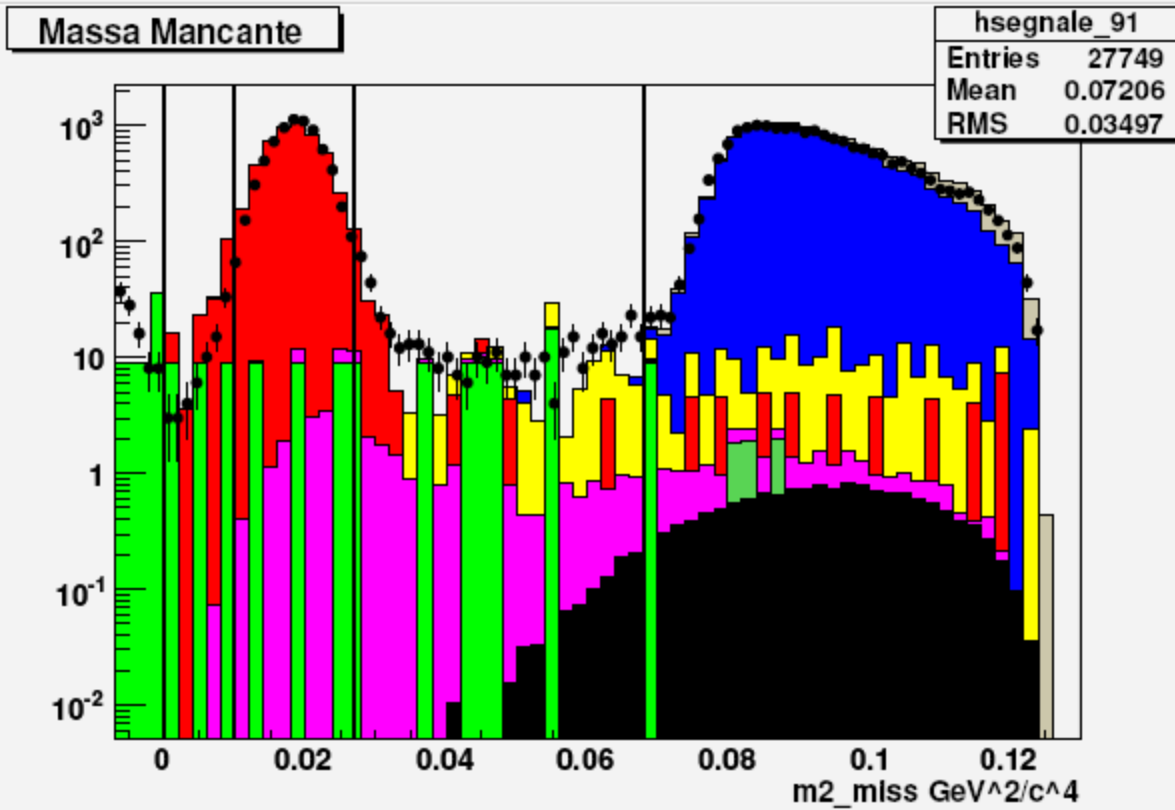
Per eliminare gli elettroni vengono applicati i seguenti tagli:

- si richiede $E/p < 0.8$ dove E è l'energia della traccia carica, ricostruita con il calorimetro elettromagnetico, e p è l'impulso di tale traccia ricostruito con lo spettrometro; 0.8 è un valore standard, la distribuzione di tale rapporto è mostrata in figura 3.3(a).
- si richiede $l_{cluster} > 1.15$ celle, dove $l_{cluster}$ rappresenta la larghezza del cluster; è stato scelto questo valore perché, a causa delle dimensioni delle celle del calorimetro, i cluster elettromagnetici, che devono essere eliminati, sono contenuti in una sola cella.

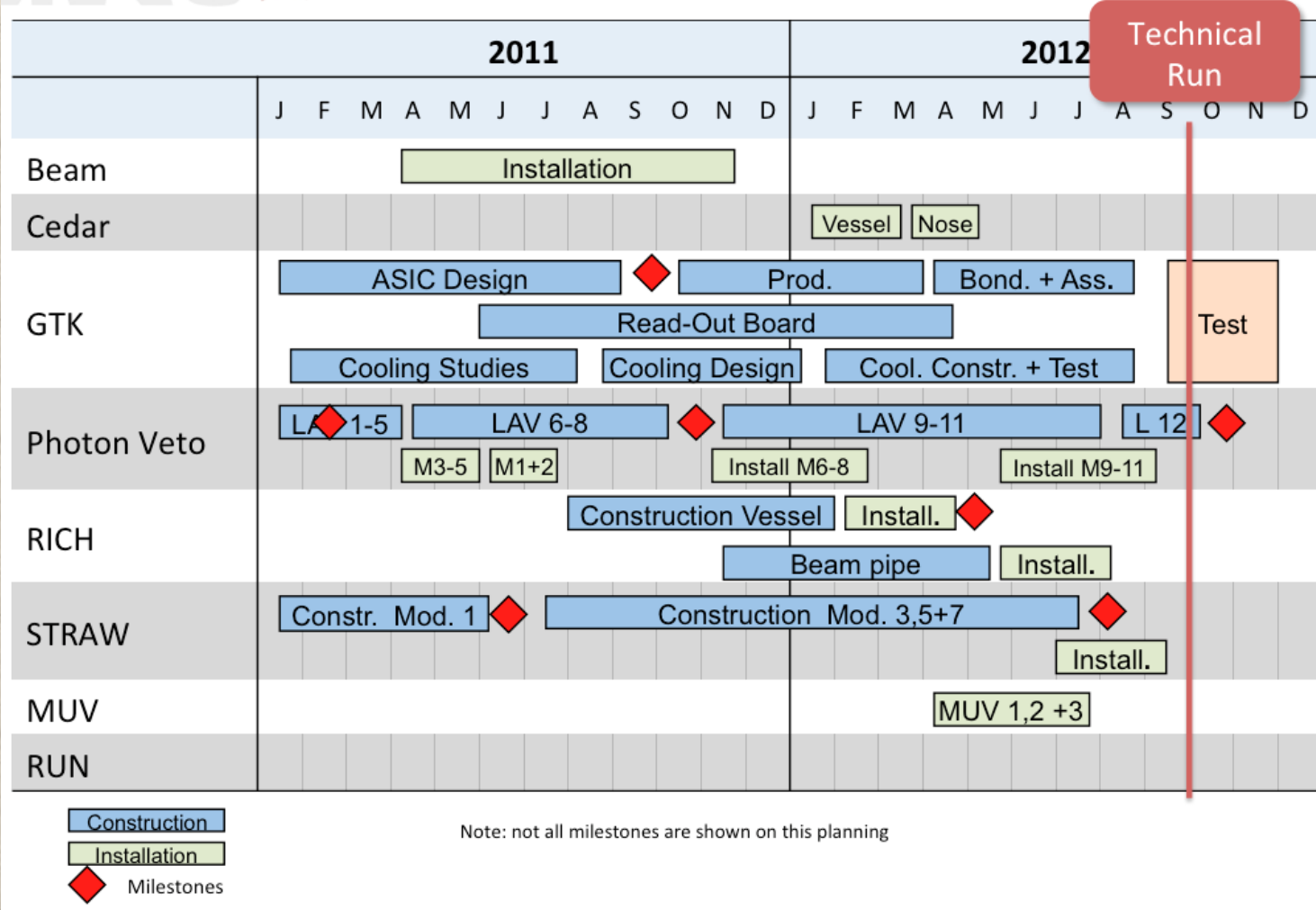
Monte Carlo



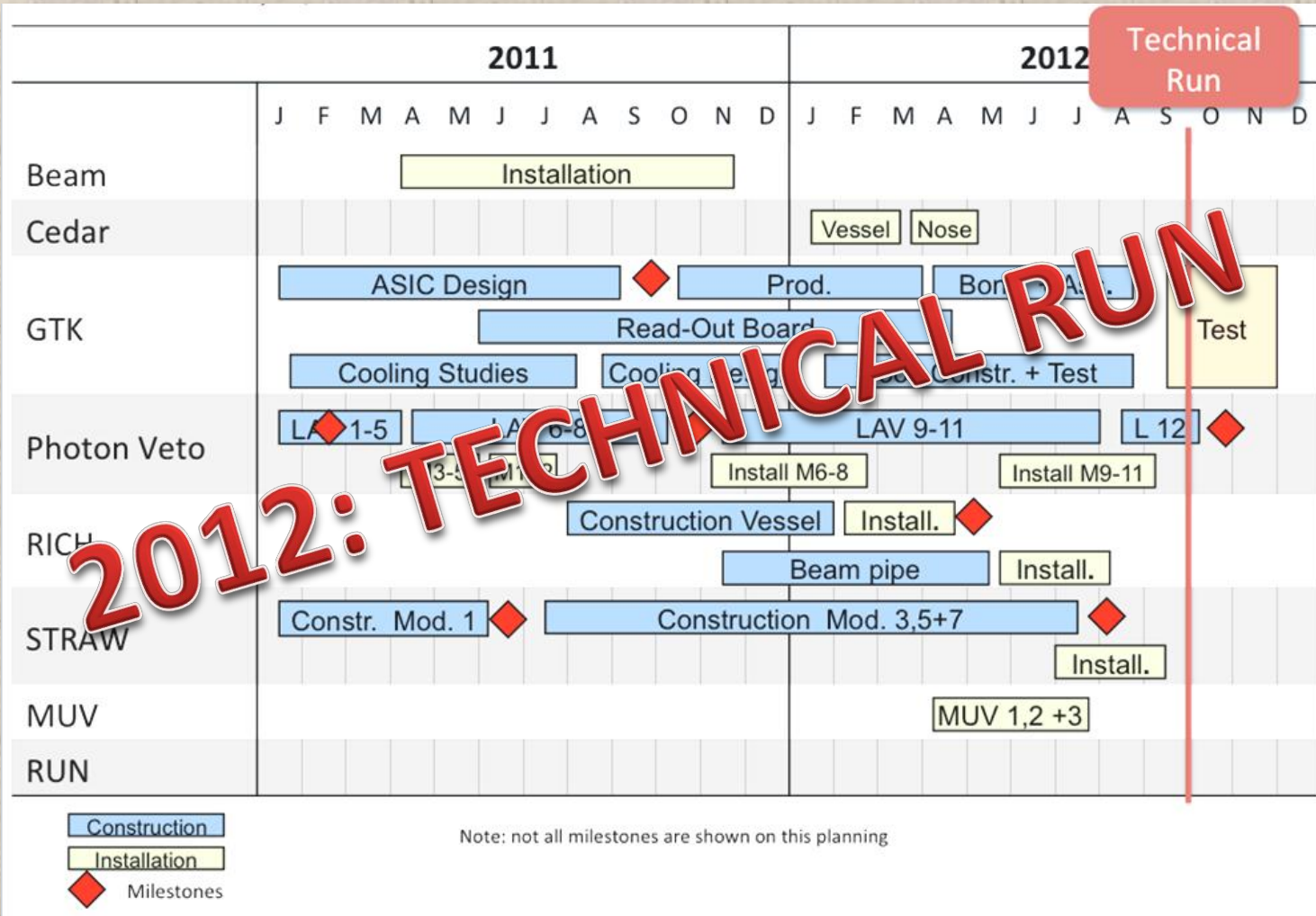
- $K^+ \rightarrow \pi^+ \pi^0$ ■ $K^+ \rightarrow \pi^+ \pi^0 \pi^0$ ■ $K^+ \rightarrow \pi^+ \pi^+ \pi^-$ ■
 - $K^+ \rightarrow \pi^+ \pi^0 \gamma$ ■ $K^+ \rightarrow \mu^+ \nu$ ■ $K^+ \rightarrow \mu^+ \pi^0 \nu$ ■
 - $K^+ \rightarrow e^+ \pi^0 \nu$ ■ $K^+ \rightarrow e^+ \pi^0 \pi^0 \nu$ ■ $K^+ \rightarrow e^+ \pi^+ \pi^- \nu$ ■
- Segnale** ■



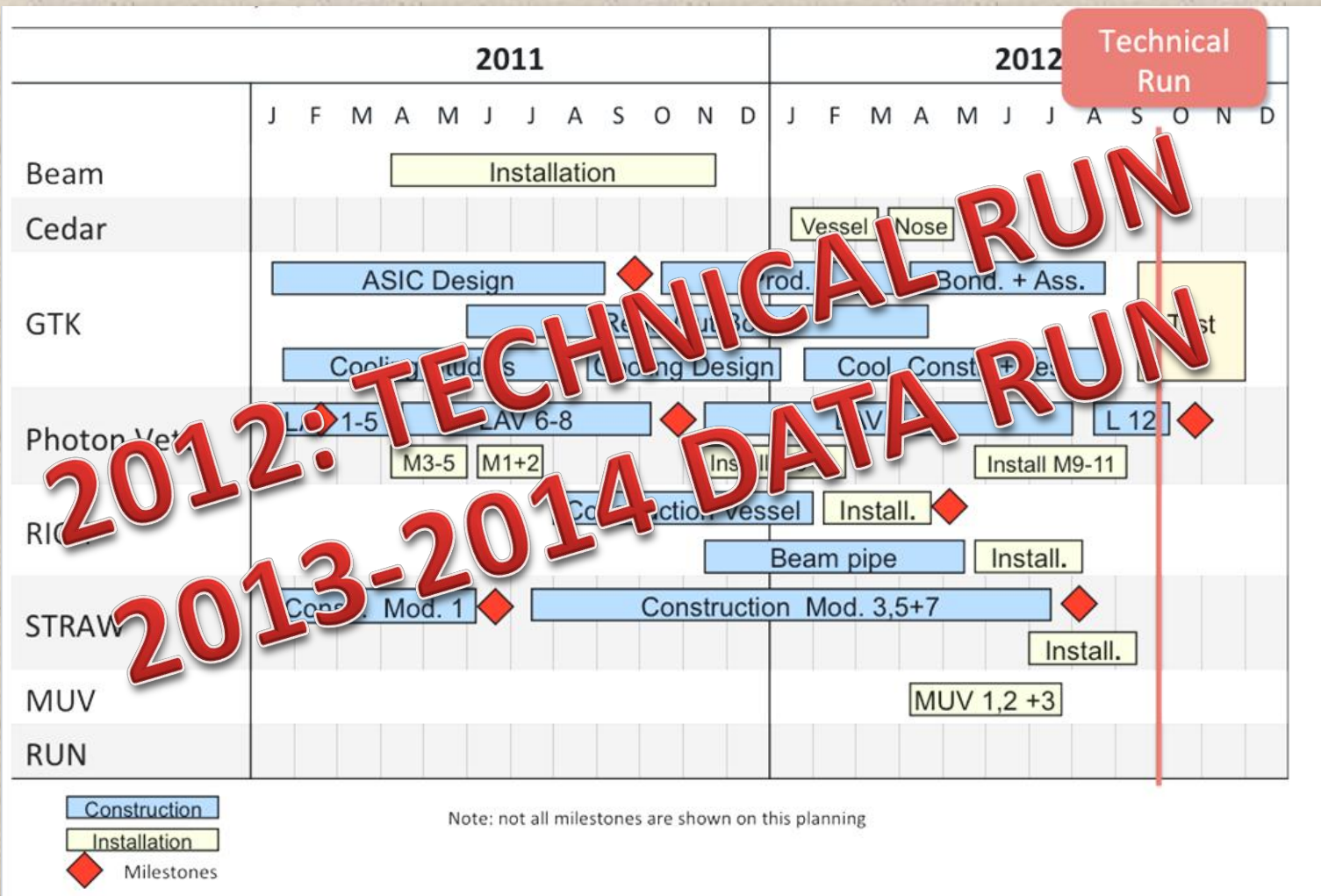
TIMELINE



TIMELINE



TIMELINE



Appendice



CARATTERISTICHE DEL FASCIO

Fascio di K^+ a 75 GeV/c prodotti simultaneamente da un fascio di protoni a 400 GeV/c proveniente dall'acceleratore SPS del CERN. L'estrazione avviene ogni 16.8 se in pacchetti di durata 4.8 s con un'intensità di circa 7×10^{11} .

BERSAGLIO:

Cilindro di Berillio $r=0.2 \text{ cm}$ $h=40 \text{ cm}$ $\sim 1 X_0$ per protoni