# The RICH Detector of the NA62 Experiment at CERN


**PATRIZIA CENCI**
INFN, Perugia (Italy)

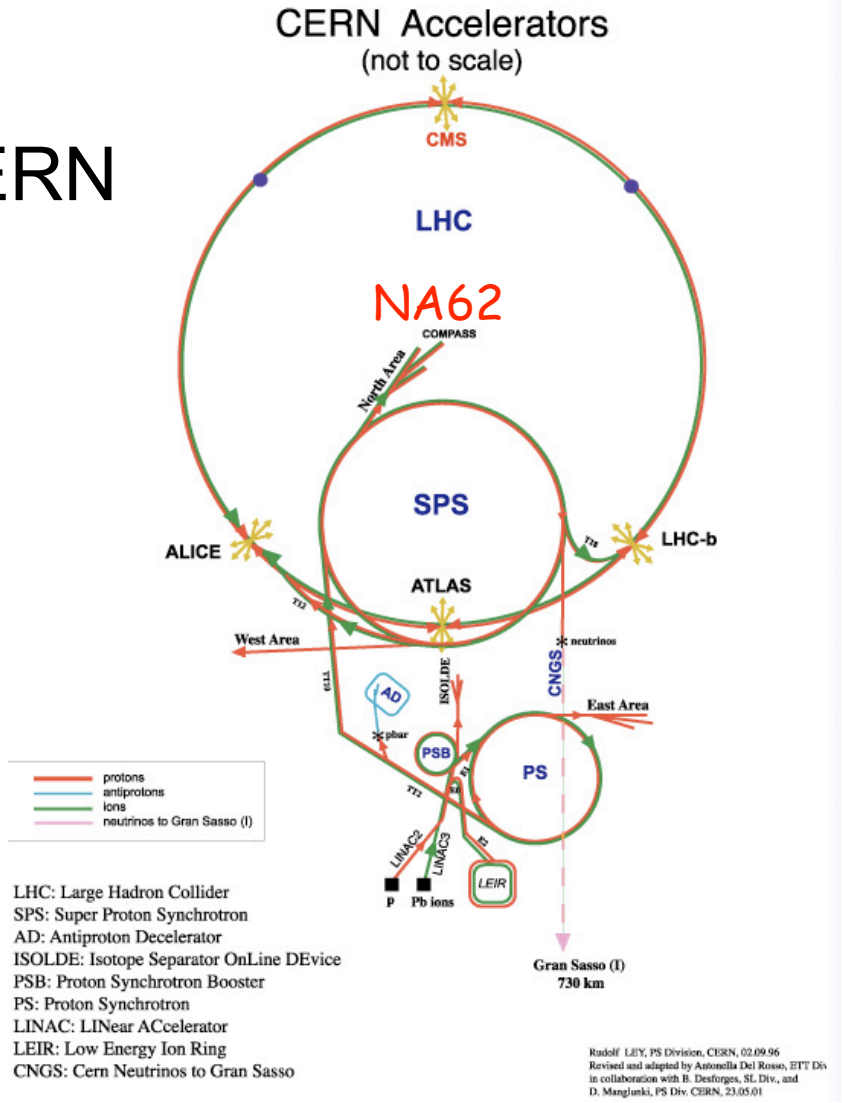

*On behalf of the NA62 RICH Working Group: CERN, INFN Firenze, INFN Perugia*


2010 Nuclear Science Symposium,
Medical Imaging Conference and
17th Room Temperature Semiconductor Detector Workshop

October 30, 2010 – November 6, 2010 – Knoxville, Tennessee


# OUTLINE

- The NA62 experiment at CERN
- A RICH detector for NA62
- The RICH prototype:
  final test beam results
- Summary and Outlook




The NA62 Collaboration: *Bern ITP, Birmingham, Bristol, CERN, Dubna, Fairfax, Ferrara, Florence, Frascati, Glasgow, IHEP Protvino, INR Moscow, Liverpool, Louvain, Mainz, Merced, Napoli, Perugia, Pisa, Roma I, Roma II, San Luis Potosi, SLAC, Sofia, TRIUMF, Turin*

# The NA62 Experiment at CERN

**NA62**: the next generation fixed target kaon experiment at CERN aiming at a 10% precision measurement of BR($K^+ \to \pi^+ \nu\bar{\nu}$ )

- "Golden" channel, theoretically very clean, sensitive to physics beyond SM
- $BR_{TH}(K^+ \to \pi^+ \nu\bar{\nu}) = (8.5 \pm 0.7) \times 10^{-11}$ SM@NLO *(PRD78, arXiv:0805.4119)*
- $BR_{EXP}(K^+ \to \pi^+ \nu\bar{\nu}) = (1.73^{+1.15}_{-1.05}) \times 10^{-10}$ E787/E949@BNL *(PRL101, arXiv:0808.2459)*
- Main background events: $BR(K^+ \to \mu^+ \nu) = 63.4\%$ , $BR(K^+ \to \pi^+ \pi^0) = 21\%$

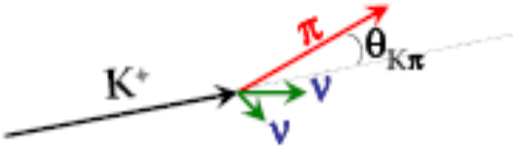
**NA62 goal:** ~100 $K^+ \to \pi^+ \nu\bar{\nu}$ events in 2 years (starting in 2013)
~ 10% background (signal acceptance ~10% )

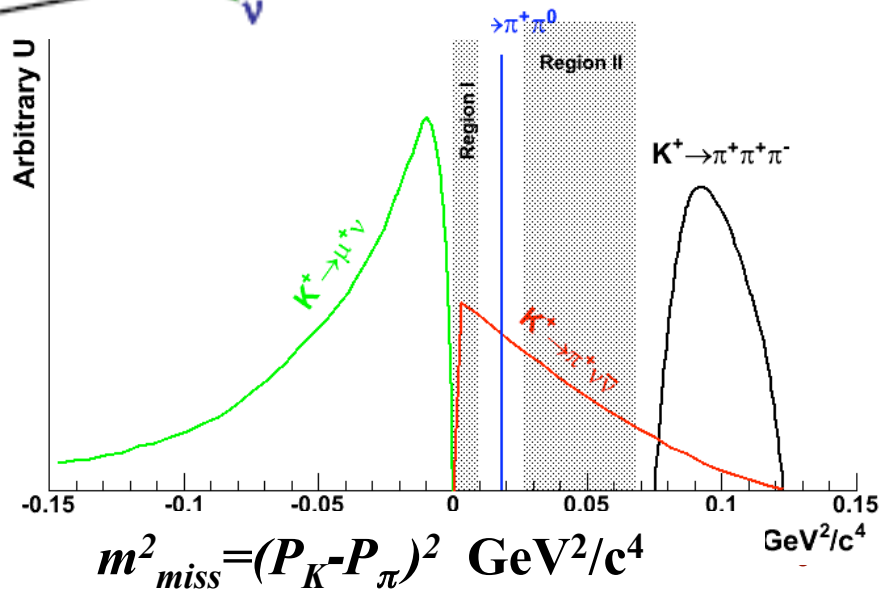
- RICH needed to suppress $K_{\mu 2}$ decays

REQUIREMENTS:

- $K_{\mu 2}$ rejection factor of at least $10^{-12}$
  - Kinematics : ~$10^{-5}$ → *Straw Tracker + GTK*
  - Veto for μ: ~$10^{-5}$ → *Muon Veto*
  - Particle ID: μ suppression factor ≤ $10^{-2}$
- Precise π-K coincidence timing
  - Time resolution: ≤ 100 ps

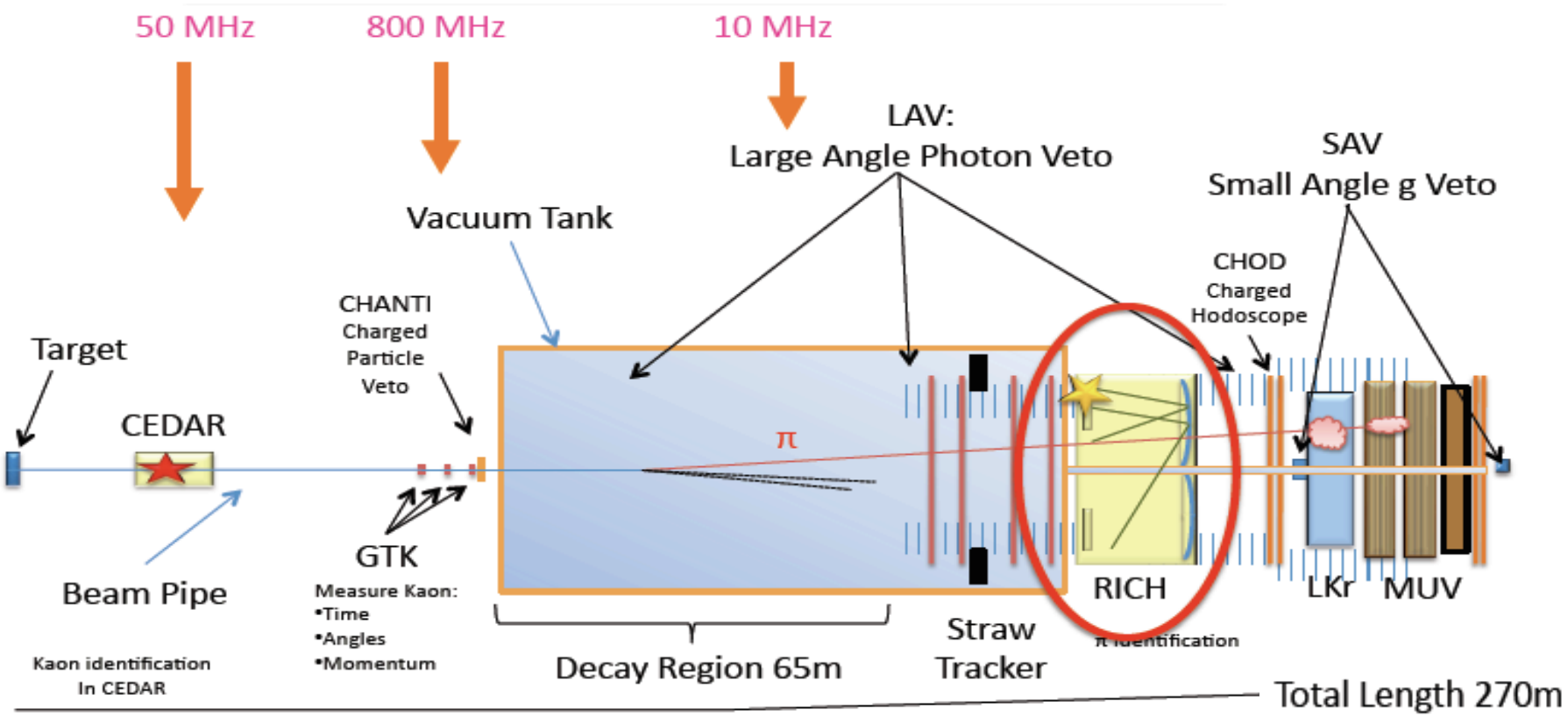
RICH




$m^2_{miss} = (P_K - P_\pi)^2$ GeV²/c⁴

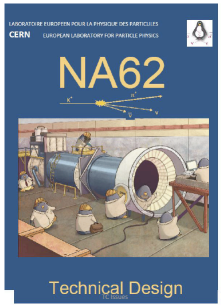
# The NA62 detector layout

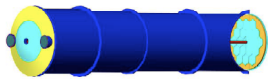



SPS primary proton beam: 400 GeV, ~$5\times10^{12}$ ppp → expected signal events ~50/year

Decay in flight technique, unseparated beam π/K/p (~6% $K^+$)
Kaon momentum: 75 GeV/c (Δp/p ~1%), Kaon flux ~$4.8 \times 10^{12}$ decay/year

(1 "year": 100 days/year, 60% overall efficiency)





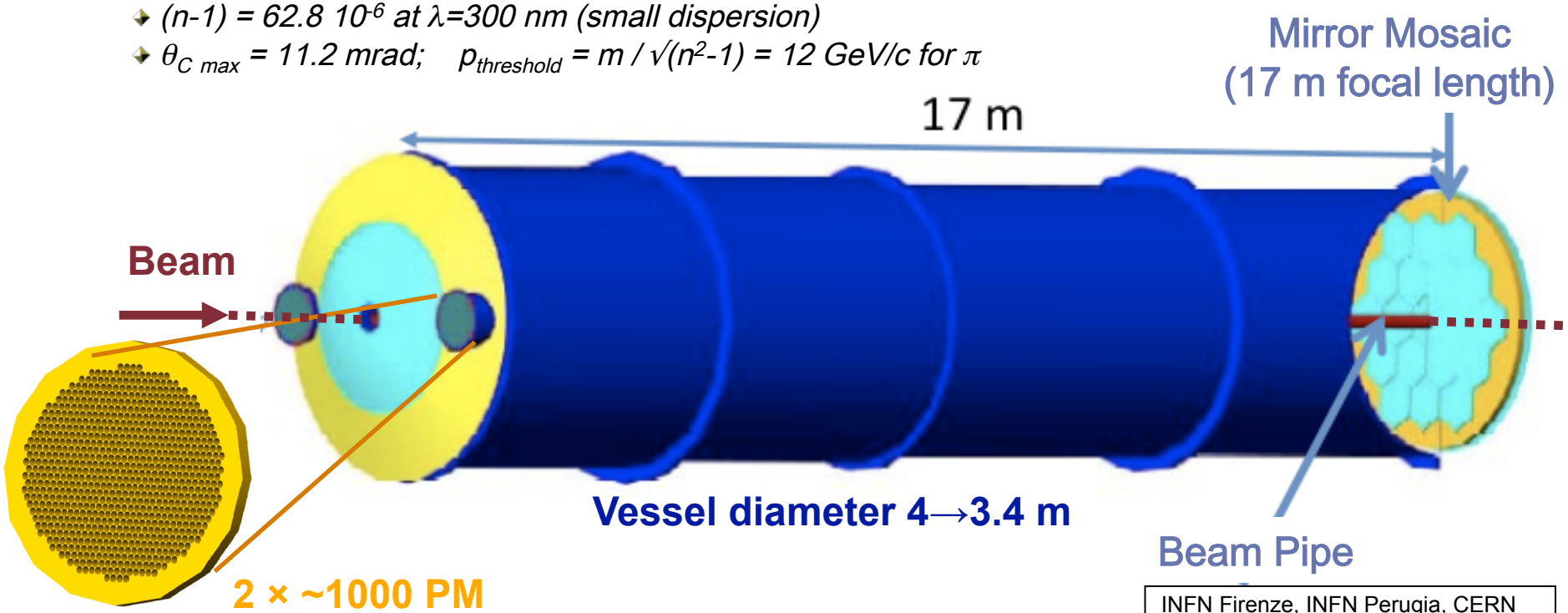
# The NA62 RICH Detector

THE NA62 RICH REQUIREMENTS:

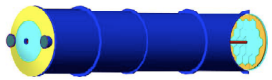
- Separate $\pi$-$\mu$ in $15 < p < 35$ GeV/c with $\mu$ suppression factor $\leq 10^{-2}$
- Measure pion crossing time with a resolution < 100 ps
- Provide the L0 trigger for charged tracks

Neon gas at atmospheric pressure is used as radiator (non-flammable):

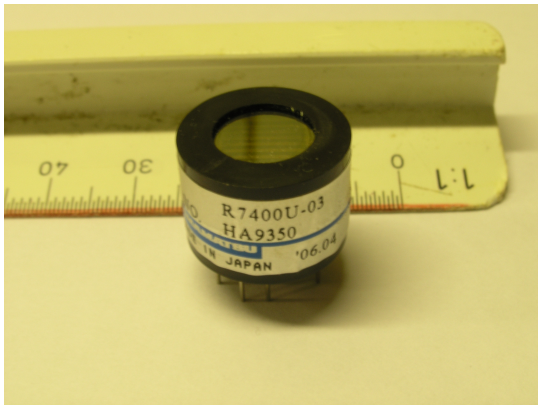
- *appropriate refractive index at atmospheric pressure, low atomic weight to minimize radiation length*
- *good light transparency in visible and near-UV, low chromatic dispersion*
- *$(n-1) = 62.8\ 10^{-6}$ at $\lambda$=300 nm (small dispersion)*
- *$\theta_{C\ max} = 11.2$ mrad; $p_{threshold} = m / \sqrt{(n^2-1)} = 12$ GeV/c for $\pi$*




INFN Firenze, INFN Perugia, CERN

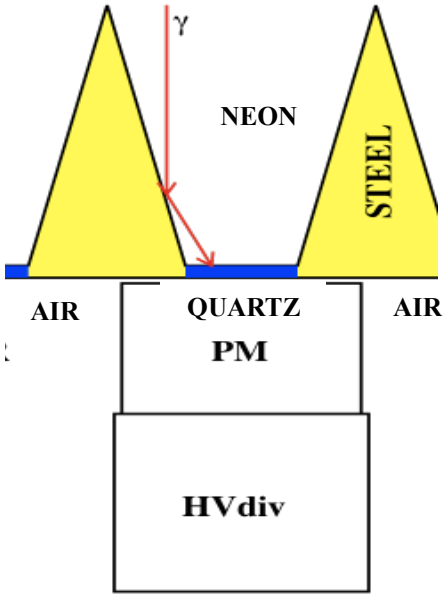


# The light detection



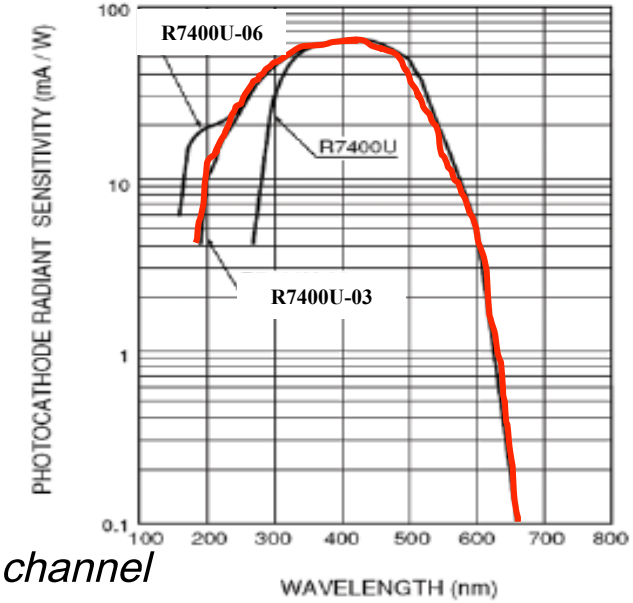

## Hamamatsu R7400 U03 Photomultiplier

- *Fast single anode photomultiplier*
- *Metal package tube, bialkali cathode, 8 dynodes*
- *UV glass window, 16 mm ϕ (8 mm active ϕ)*
- *Sensitivity range 185–650 nm, 420 nm peak sensitivity*
- *Gain: minimum $7x10^5$ @800 V (~$1.5x10^6$ @900 V)*
- *Transit time: 5.4 ns, transit time spread: 0.28 ns*
- *Operating Voltage: 900 V (1000 V maximum)*



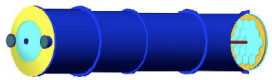

## Light Collection

- *Winston Cones covered with aluminized Mylar foils*
- *22 mm high*
- *7.5 to 18 mm wide*
- *1 mm thick quartz window*




## HV CAEN System

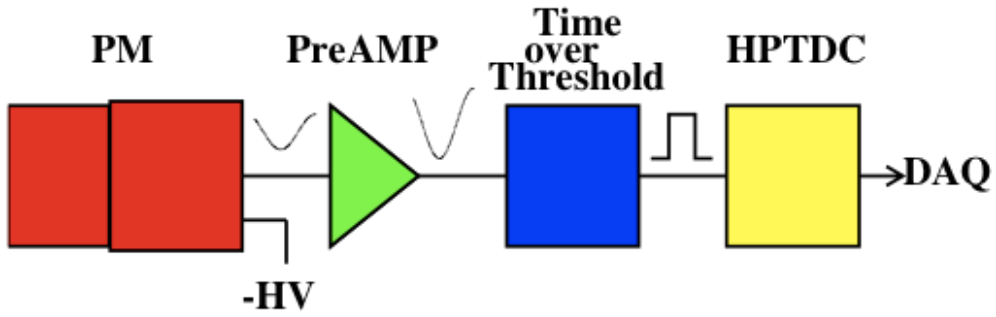
- *4 PMT supplied by a single HV channel*
- *SY1527 (16 slots), SY2527 (6 slot) main frames*
- *A1733N (12 ch.) and A1535S (24 ch.) board*



# Front End and Readout

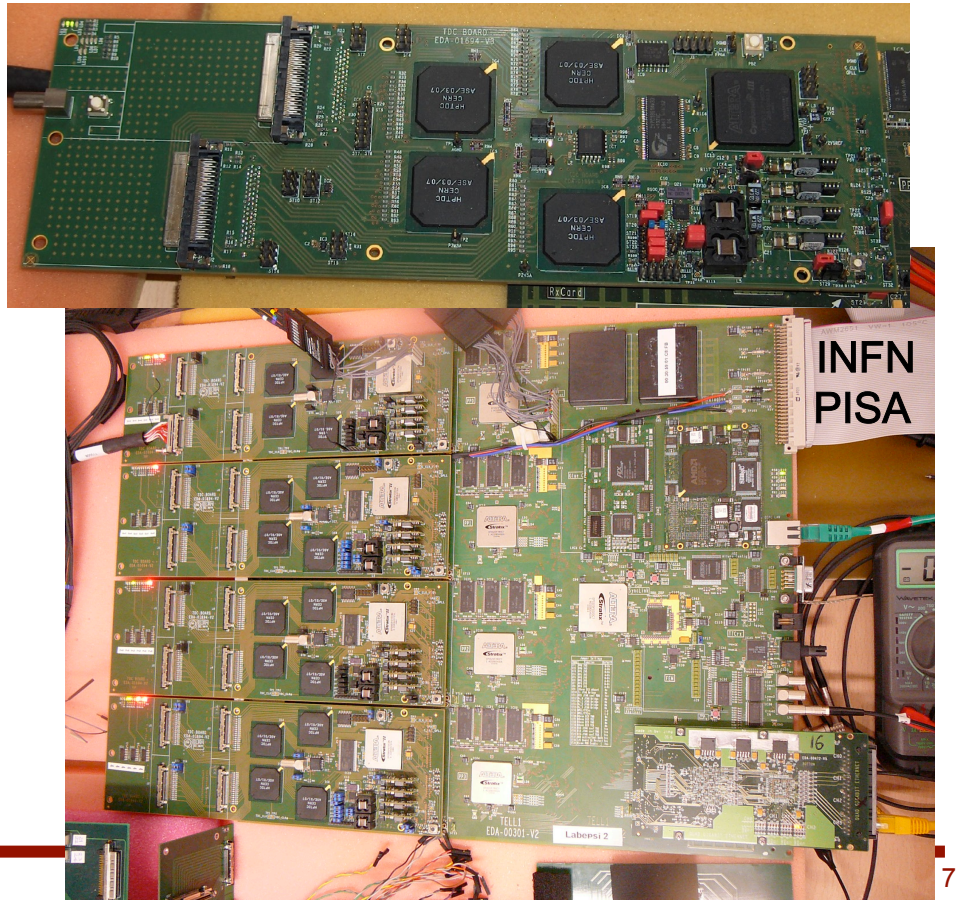
## Front End:

- *Custom made current amplifier*
- *NINO ASIC as fast Time-over-Threshold discriminator (from ALICE): LVDS output, 50 ps intrinsic resolution*
- *Signal leading and trailing edge recorded for time slewing correction*

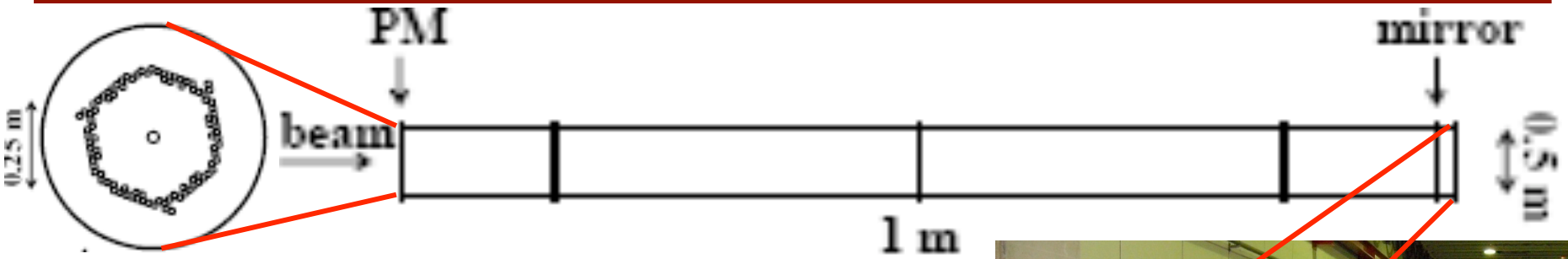



## Readout: based on TDC Boards

- *A board (TDCB) equipped with 128 ch. of TDC (HPTDC, 100 ps LSB) has been developed by INFN Pisa*
- *A FPGA based TEL62 mother board (development of TELL1 boards from LHCb) houses 4 TDCB (512 ch.)*
- *The trigger primitives are built in parallel with the readout on the same TEL62 board (1 MHz input to L1, implemented in software)*
- *The TDC CAEN V1190 (based on HPTDC, 97.7 ps LSB, 128ch) was used for test purposes*



# The NA62 RICH prototype



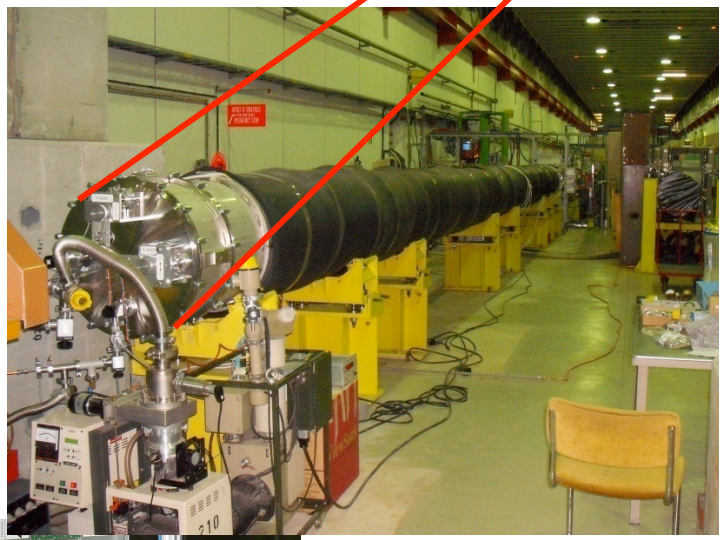

- *Vessel ~17 m long, ~60 cm wide, filled with Neon gas at ~1 atmosphere*
- *One single mirror (MARCON), 2.5 cm thick glass, 50 cm diameter, 17 m focal lenght*

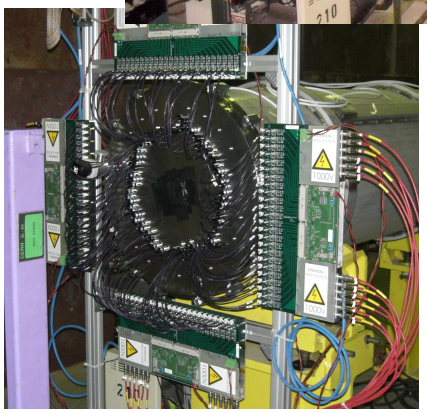
## Test beam 2007: RICH-100 prototype

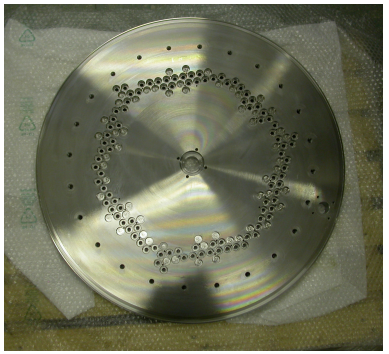
- *96 PMT Hamamatsu R7400 U03/U06*
- *200 GeV hadron beam*
- *Test results in agreement with MC expectation:*
  - *Number of PM hit per event* $N_{Hits} \approx 17$
  - *Time resolution* $\Delta t_{Event} \approx 70\ ps$
  - *Cherenkov angle resolution* $\Delta\theta_c \approx 50\ \mu\ rad$
  - *NIM A 593 (2008) 314*

## Test beam 2009: RICH-400 prototype

- *414 PMT Hamamatsu R7400 U03*
  - Final results will be shown here

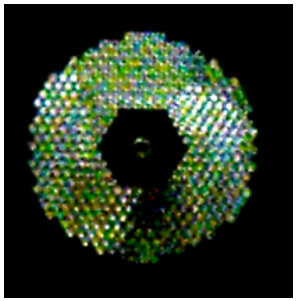


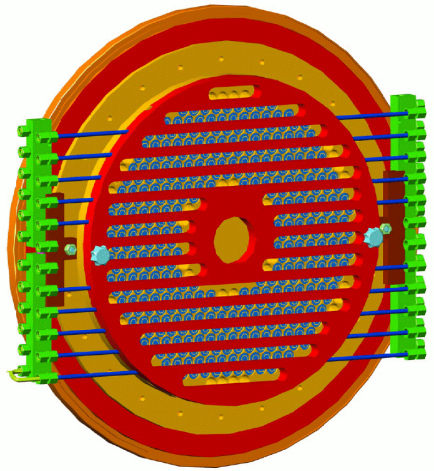




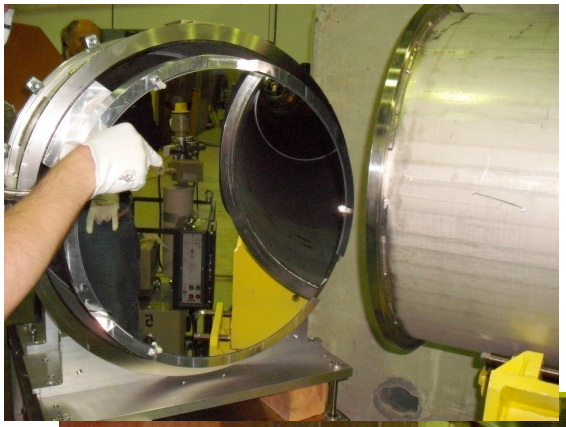
# The RICH-400 prototype

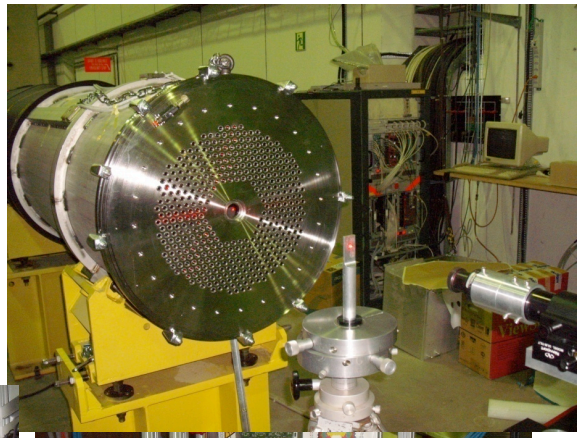
- PM endcap with 414 PM (~20% of final detector)
- Test Beam in may-june 2009, aiming at:
  - *Validate $\pi-\mu$ separation @ 15<p<35 GeV/c*
  - *Test PM cooling system*
  - *Test new mirror*
  - *Test new readout (Tell1 based)*

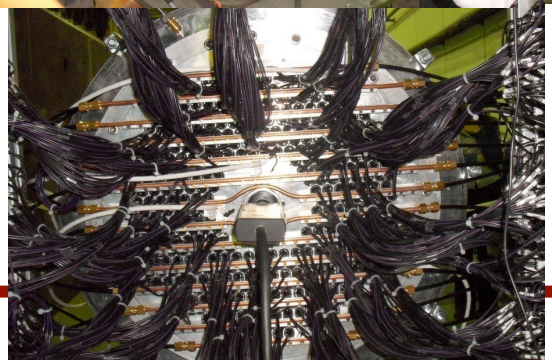


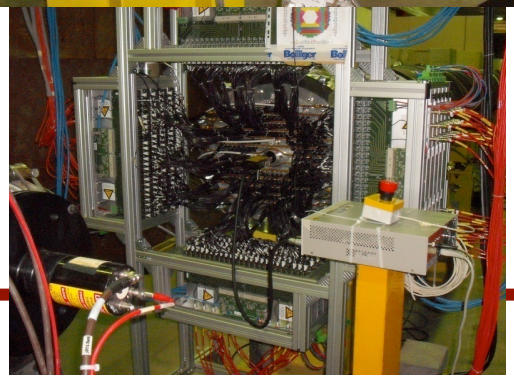


**NIM A 621 (2010)**





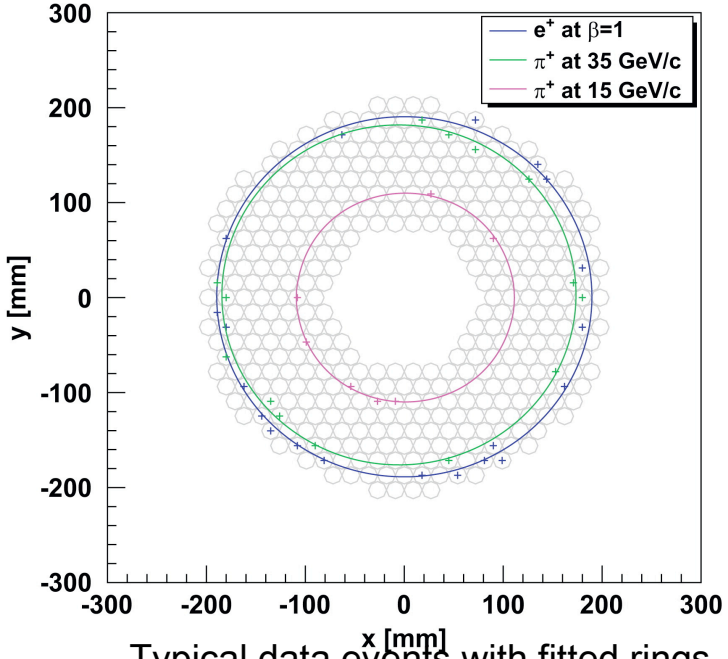




# RICH-400: test program

- Beam: mainly $\pi^+$, 15% p, few % $K^+$, variable % of $e^+$
  - 1.5% $\Delta p/p$, negligible angular spread
- Momentum range: 10 to 75 GeV/c
- Many momentum points to measure μ-π separation using only π: each next point is a π with the same β of the μ of the actual point (μ-π equivalent)
  - 1° scan: 15.2, 20.1, 26.5, 35.0, 46.2, 61.2 GeV/c
  - 2° scan: 17.7, 23.4, 31.0, 41.0, 54.2 GeV/c
  - 3° scan: 28.7, 38.0, 50.3 GeV/c
- Test prototype performance under different conditions:
  - Moving the mirror, different rates, different Tell1 firmware versions, polluting the gas (air and $CO_2$), etc
- Repeat measurements with the new mirror (final device, made by Marcon, aluminized and coated at CERN):
- Special runs:
  - check trigger algorithms and accidentals at higher intensities
  - measure efficiency for ring fitting methods

# Number of PM hits

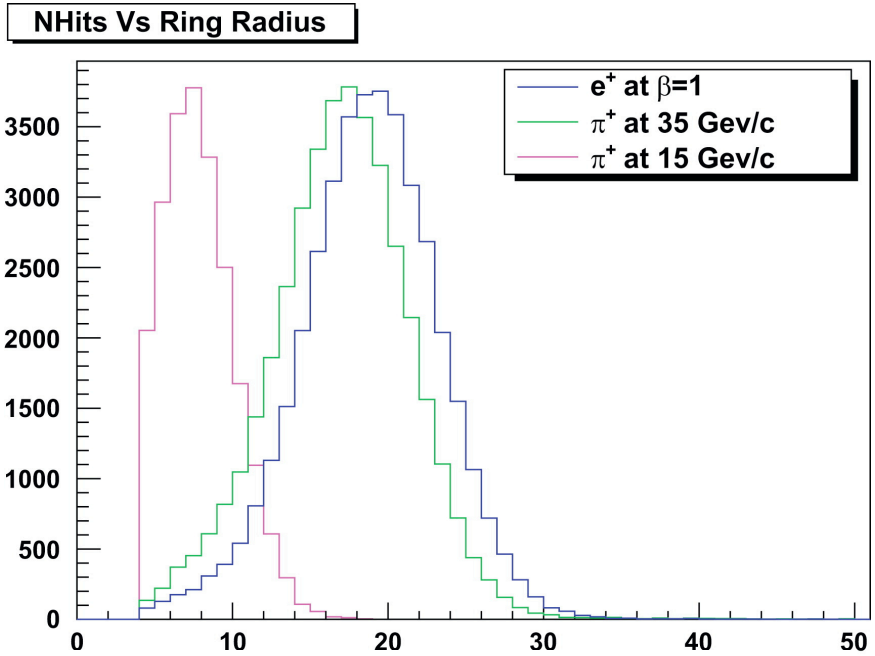



Typical data events with fitted rings

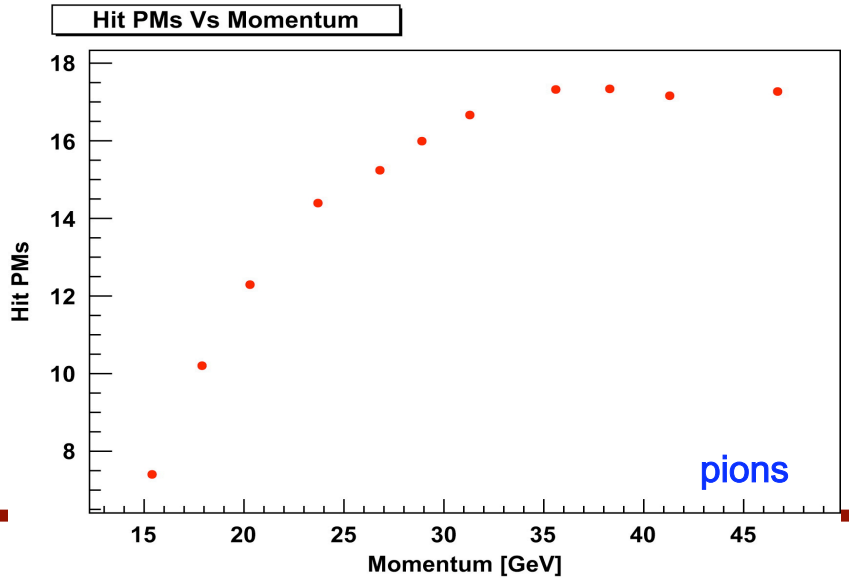
Positrons at β=1

Pions at 35 GeV/c

Pions at 15 GeV/c




Number of hit PMs for a single ring
(cut at 4 due to the software trigger algorithm)




Pions at 15 GeV/c: $N_{Hit\ PM} \approx 8$

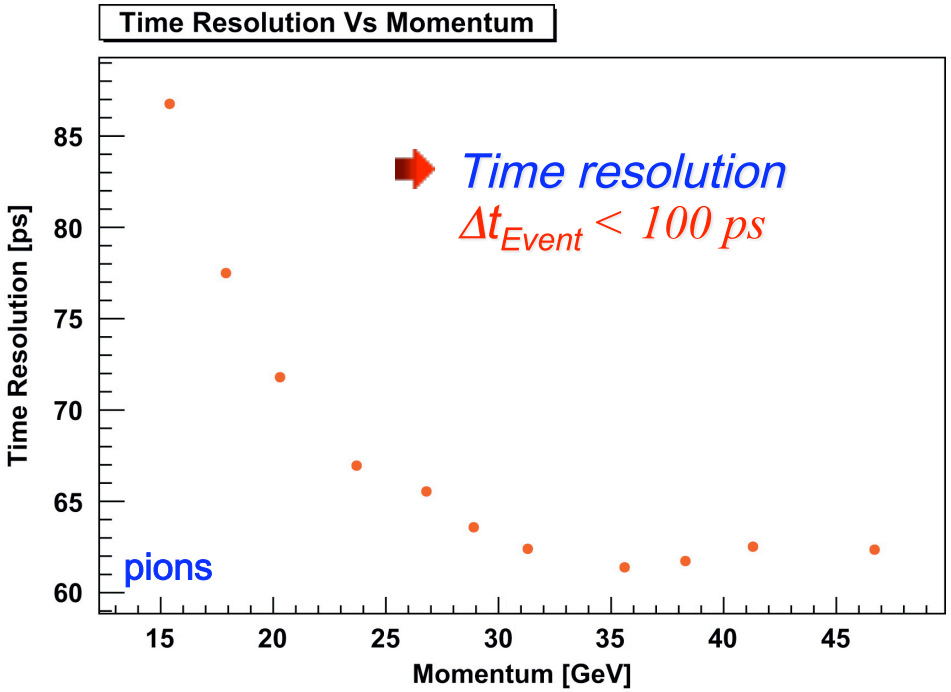
Pions at 35 GeV/c: $N_{Hit\ PM} \approx 17$

Positrons at β=1: $N_{Hit\ PM} \approx 20$

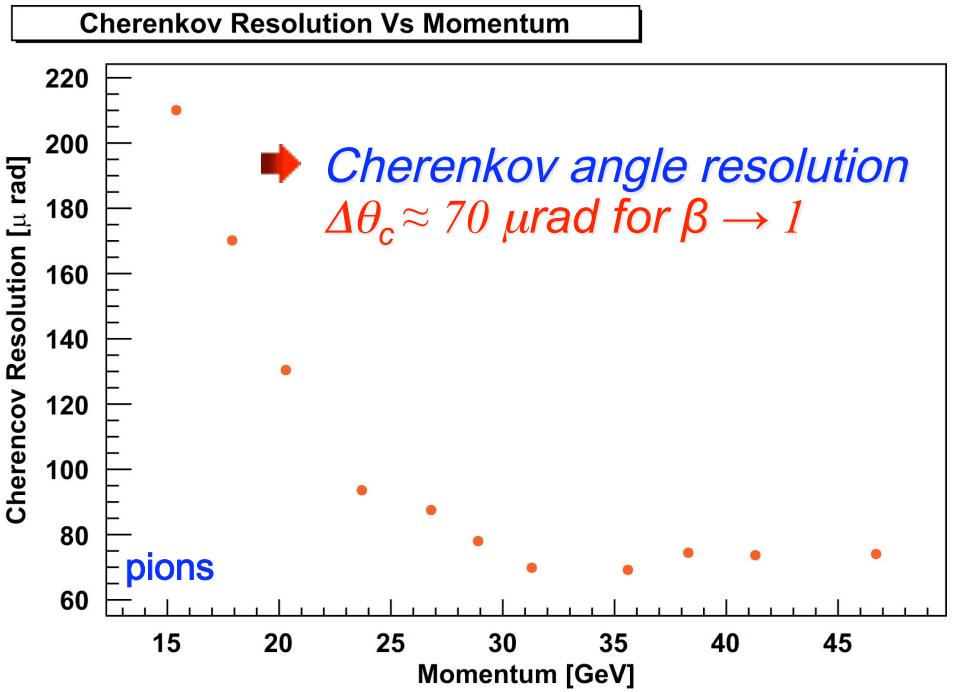
**Results in agreement with MC expectations**

Average number of hit PMs for a single ring as a function of momentum in the range 15-35 GeV/c

# Timing and Cherenkov angle



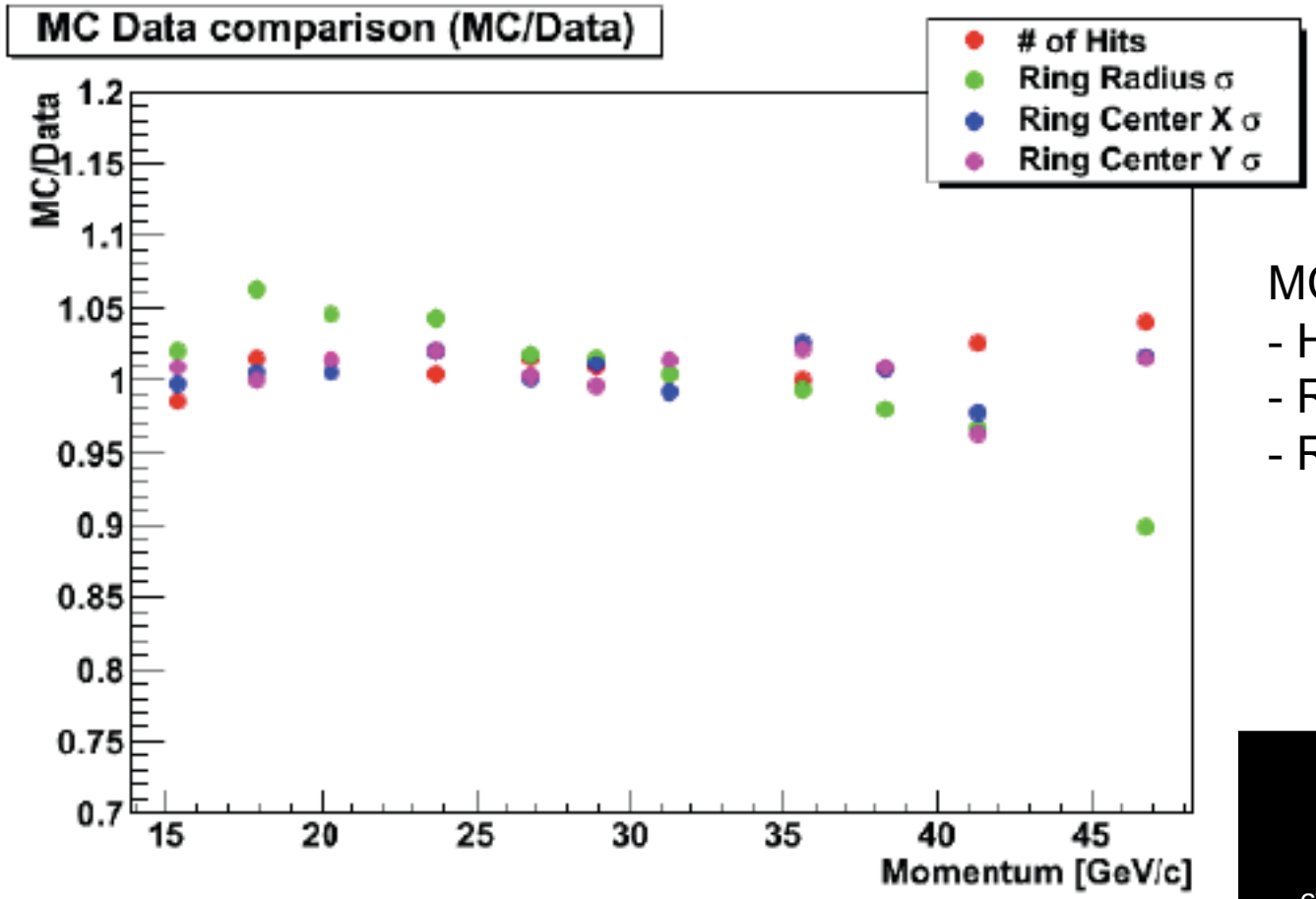

Time resolution as a function of the π momentum: average root mean square of the selected hit time with respect to the average hit time




Cherenkov angle resolution as a function of the π momentum: the standard deviation σ is estimated by a Gaussian fit to the radius distribution

- The results fulfill the requirement for the NA62 RICH detector and are compatible with those of the 2007 beam test held at CERN
- The same results are obtained using both the standard readout system and the new readout prototype
- Data are in agreement with Montecarlo simulation

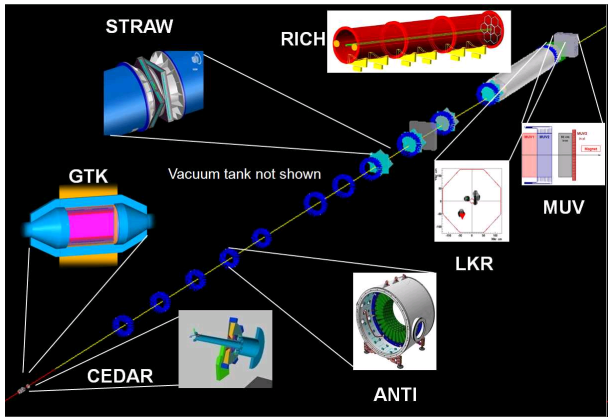
# Simulation/Data Comparison



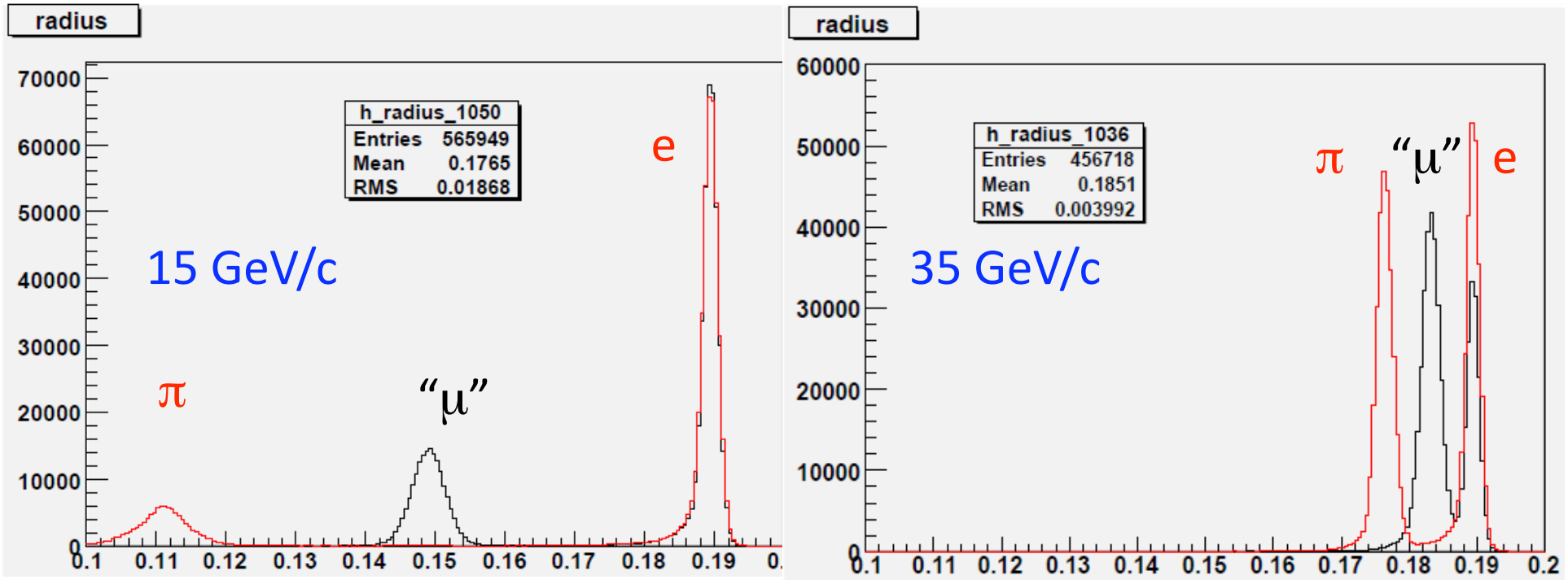

MC/Data ratio for:
- Hit PM number
- Ring radius σ
- Ring center $\sigma_x$ and $\sigma_y$

NA62 Detector Simulation: GEANT4 based

➔ RICH beam test results in good agreement with Monte Carlo simulation expectations in 15-35 GeV/c



# RICH-400: π-μ separation

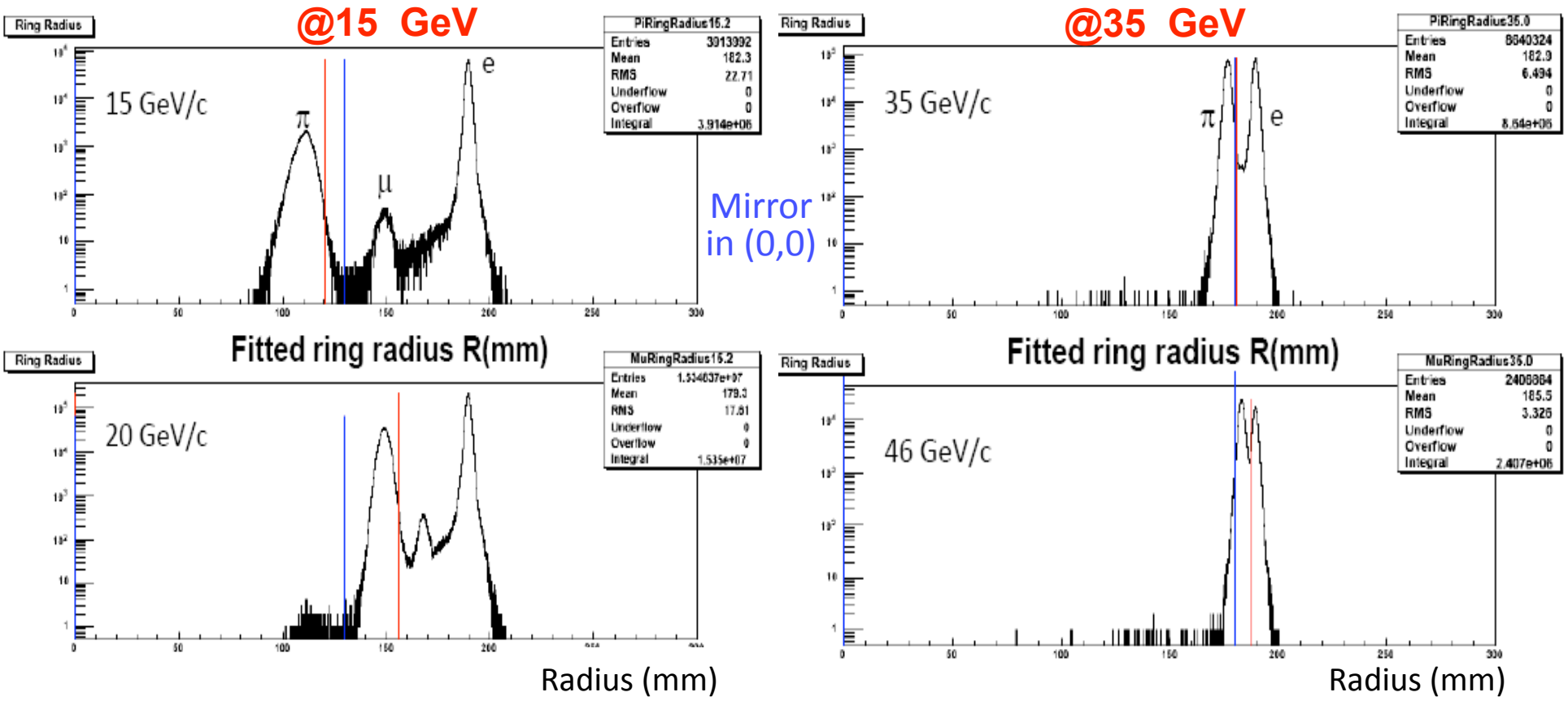



The "μ" is a π with the same β as a μ at 15 (35) GeV/c

RICH REQUIREMENT: μ suppression $\leq 10^{-2}$

- Measure the probability to misidentify a μ as a π integrated between 15 and 35 GeV/c (assuming the expected spectrum of μ from $K_{\mu 2}$)
- Repeat the measurement changing mirror orientation and analysis cuts

# π-μ Separation Measurement



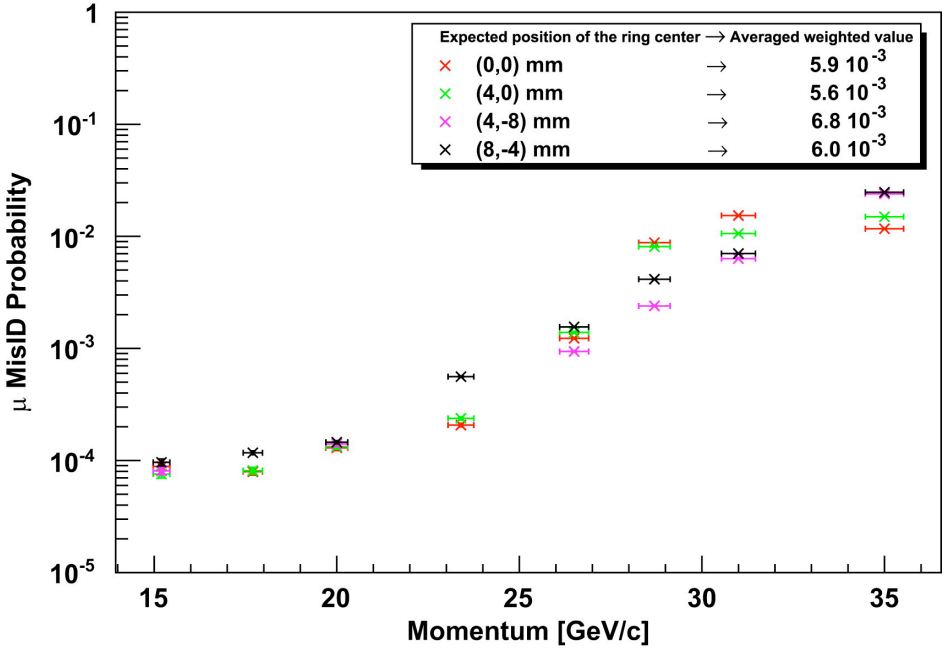

Blue line: half way between π and μ peaks

Red line: signal region definition (+3σ from peak)

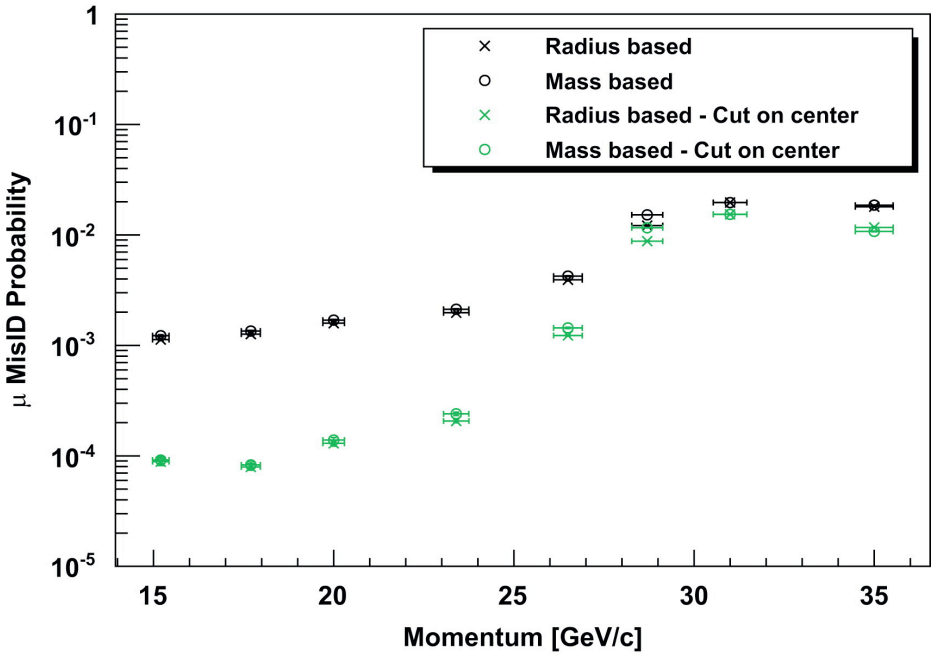
Calculate: μ contamination and π loss (under different conditions) in momentum bins

Use: ring radius distribution and the reconstructed squared mass of the particle

# π-μ Separation Results

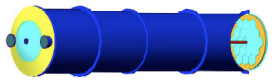



Measurements repeated for 4 different alignment positions of the mirror, in order to take into account possible displacements of the ring center (in mm).




Measurements repeated with different cuts and ring reconstruction methods: upper and lower limit are the 3σ constraint on the position of the fitted ring center.

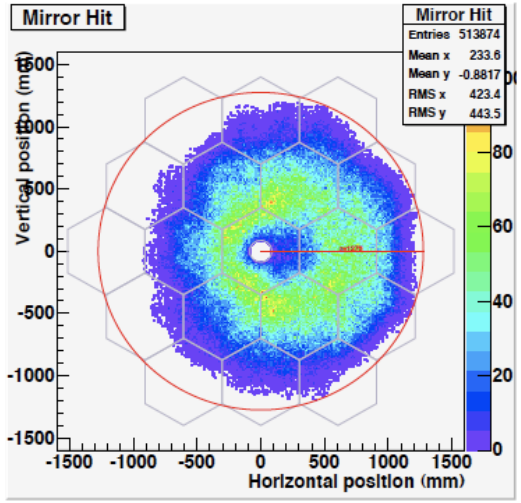
➔ μ suppression factor equal or better than $10^{-2}$



# RICH Mirror Layout

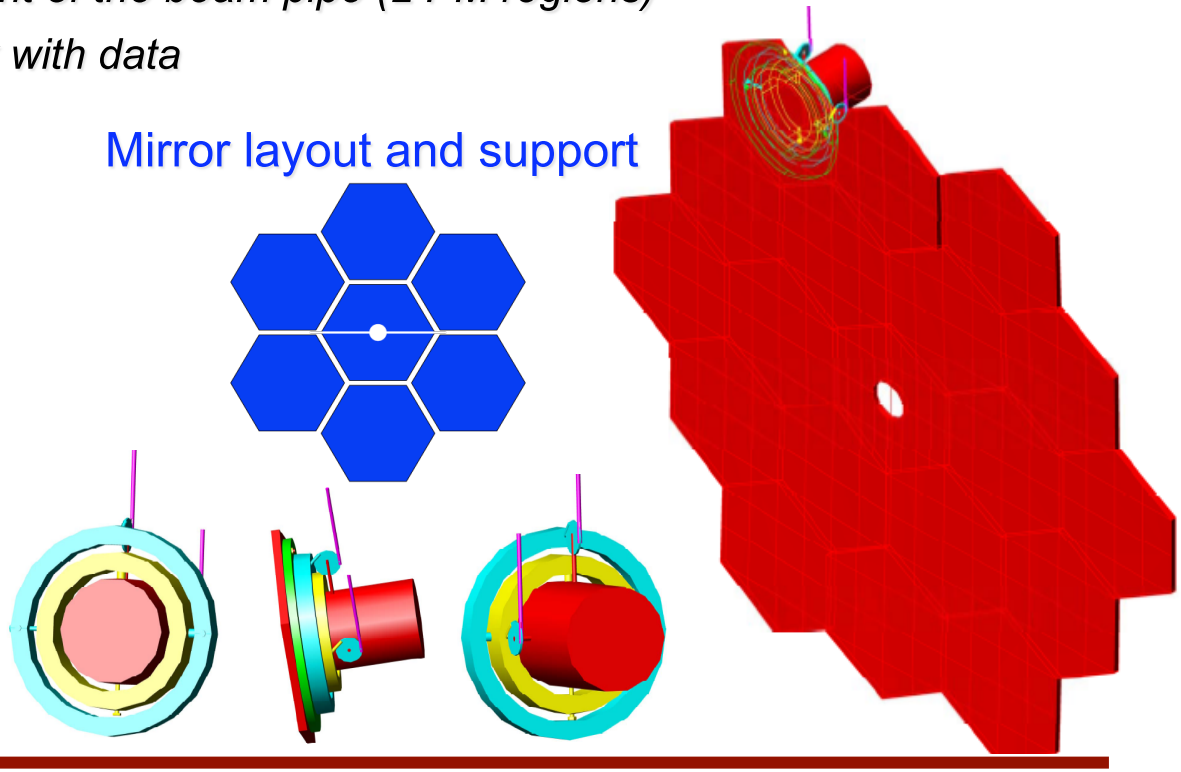
## Mirrors from MARCON company

- *Spherical mirrors, nominal radius of curvature 34 m (±20 cm maximum), 17 m focal length*
- *Glass substrate 2.5 cm thick, aluminum coat with thin dielectric film ($MgF_2$) deposit*
- *Hexagonal shape (35 cm side): 18 hexagons + 2 half hexagons (beam pipe)*
- *Average reflectivity better than 90% in 195-650 nm wavelenght range, $D_0$ < 4 mm*
- *Carbon fiber honeycomb structure for mirror support, piezo actuators for alignment*
- *Mirrors pointing toward left and right of the beam pipe (2 PM regions)*
- *Initial alignement with laser, check with data*




MC Simulation (Geant4): photon distribution on the mirrors (15-35 GeV/c momentum)

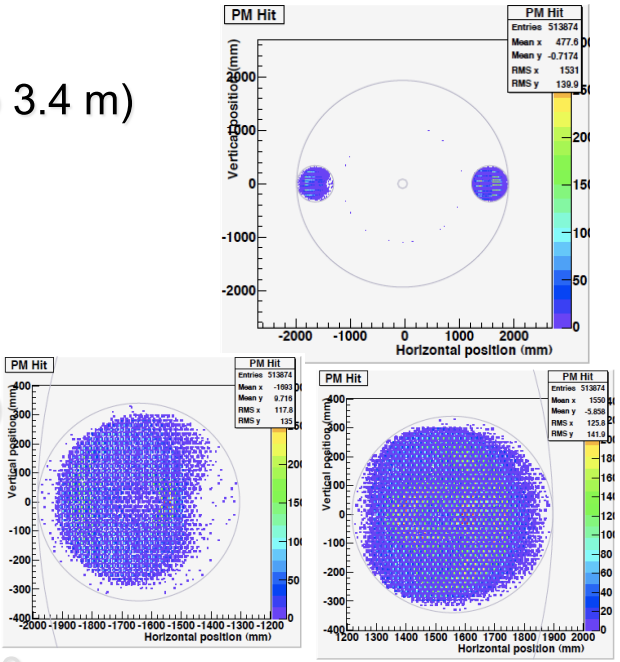
Mirror layout and support



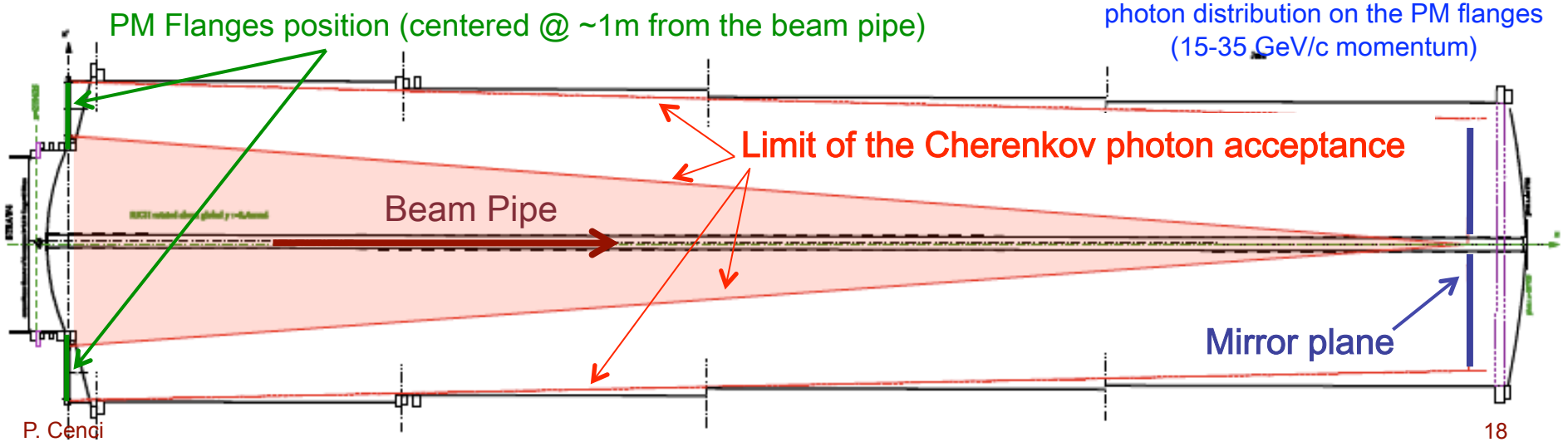
# RICH vessel and gas gystem

- Vessel in structural steel (ferro-pearlitic), total volume ~200 $m^3$
- 4 londitudinal sections (lenght ~17 m), decreasing diameter (4 to 3.4 m)
- Centered beam pipe, PM flanges outside detector acceptance
- Mat non-reflective and clean inner vessel surface: epoxy coating
- Beam windows in aluminium alloy: minimum material thickness

- Ne pressure slightly above external atmosphere (max 150 mbar)
- No gas circulation, gas leak rate below $10^{-2}$ std. cc/s
- Pressure regulation accuracy ± 1 mbar
- Ne density stability < 1%, gas impurities < 1%
- Clean and non-out gassing inner vessel surface, cleaning with $C0_2$

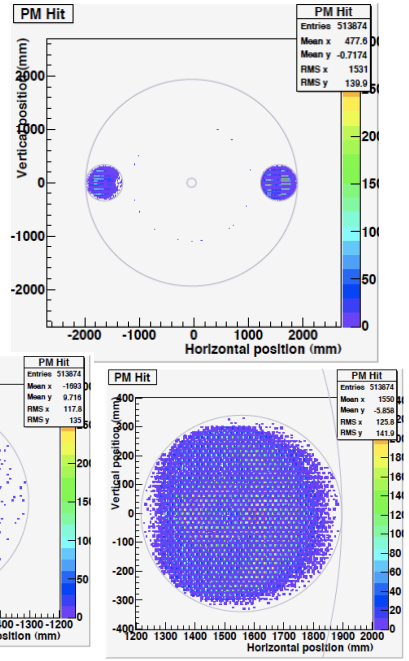



MC Simulation (Geant4):
photon distribution on the PM flanges
(15-35 GeV/c momentum)



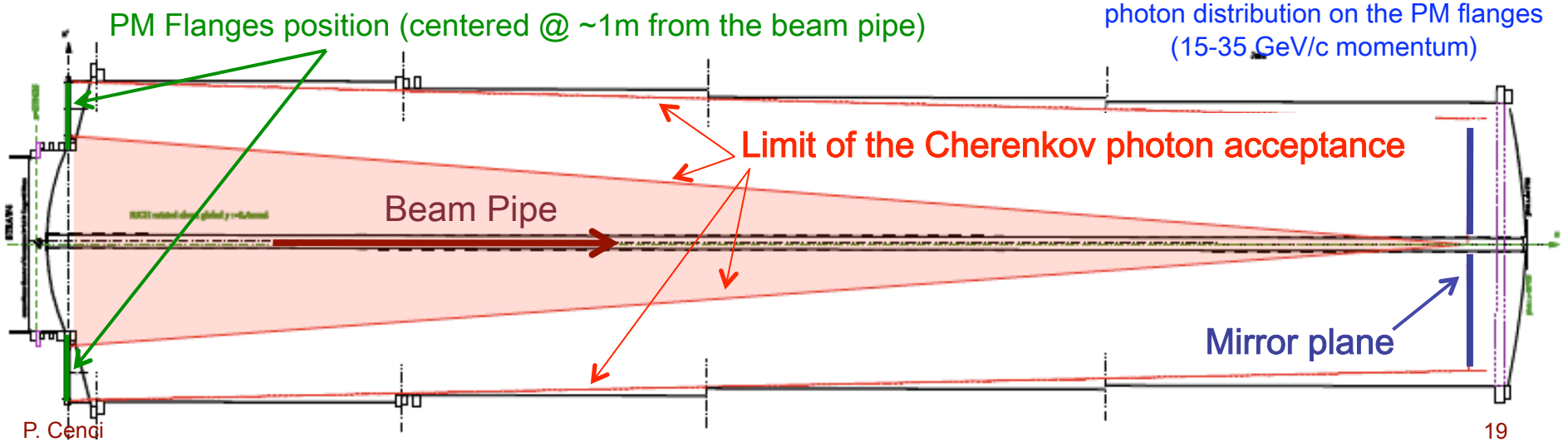
# RICH vessel and gas gystem

- Vessel in structural steel (ferro-pearlitic), total volume ~200 $m^3$
- 4 londitudinal sections (lenght ~17 m), decreasing diameter (4 to 3.4 m)
- Centered beam pipe, PM flanges outside detector acceptance
- Mat non-reflective and clean inner vessel surface: epoxy coating
- Beam windows in aluminium alloy: minimum material thickness




- Ne pressure slightly above external atmosphere (max 150 mbar)
- No gas circulation, gas leak rate below $10^{-2}$ std. cc/s
- Pressure regulation accuracy ± 1 mbar
- Ne density stability < 1%, gas impurities < 1%
- Clean and non-out gassing inner vessel surface, cleaning with $C0_2$

MC Simulation (Geant4):
photon distribution on the PM flanges
(15-35 GeV/c momentum)



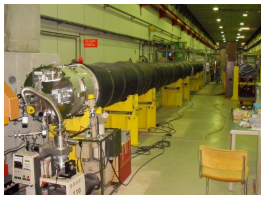
# Summary and Outlook

The NA62 RICH will be used for:

- background suppression
- precise measurement of tracks time
- first level trigger

The results of the prototype test beams fulfill the design requirements:

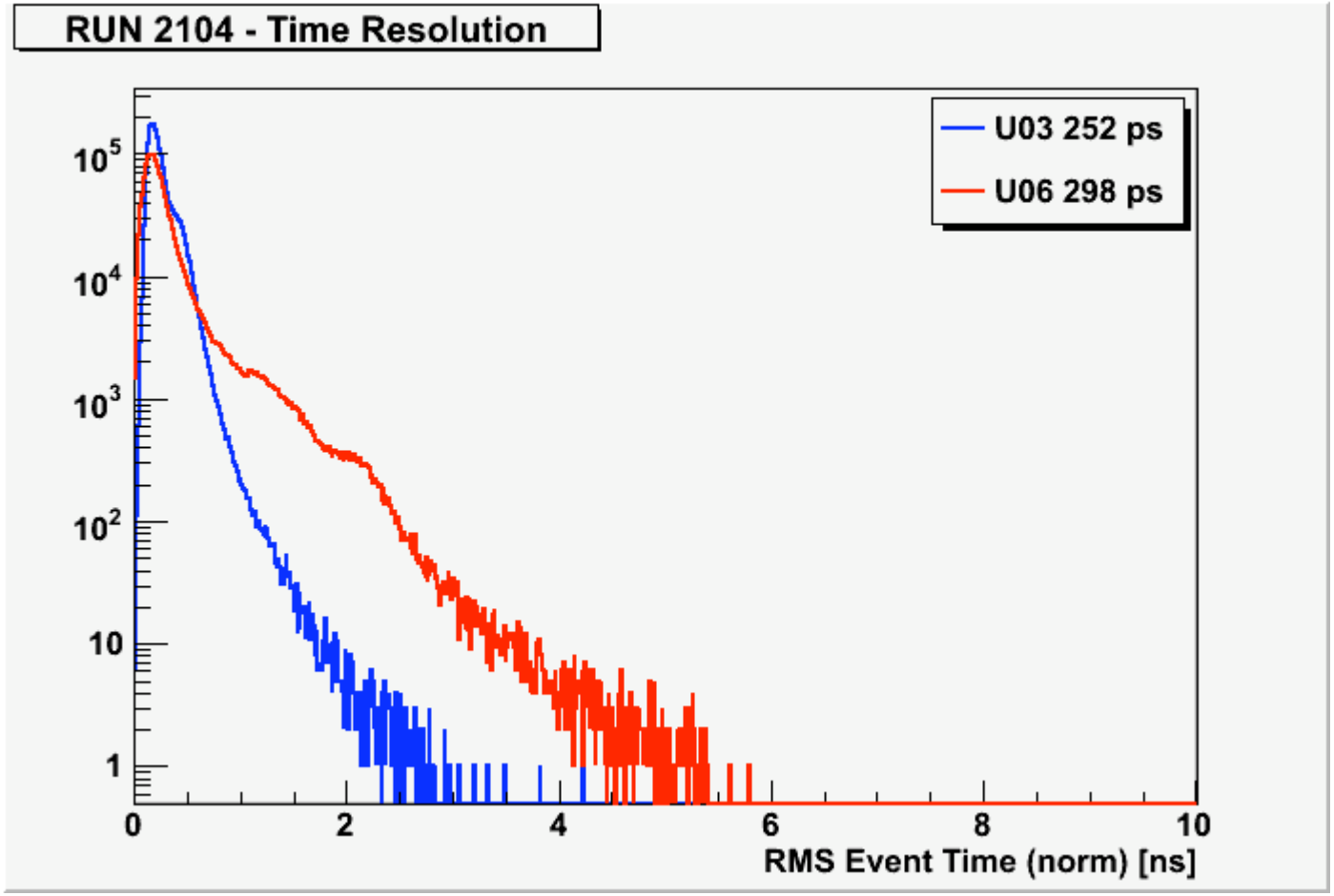
- time and Cherenkov angle resolution
- hit PM's per ring
- π-μ separation and μ suppression factor



The construction of the NA62 detector has already started:
the first data taking will take place in 2013
(due to SPS stop in 2012)

# SPARE

# RICH-100 test: time resolution



# NA62: the experimental challenge - I

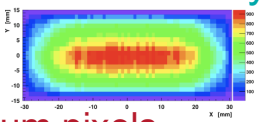
- Track and identify kaons in the beam:
  - *at 0.8 GHz rate*
  - *with 0.5% momentum resolution*
  - *with 150 ps time resolution*
  - *with a tight material budget*

  ⇒ **Gigatracker (Fast Si μpixel)**
  **+ Cherenkov Threshold (CEDAR) for $K^+$ identification among beam particles**

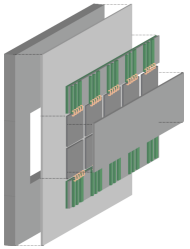
- Track decay products
  - *in a $10^{-6}$ mbar vacuum*
  - *with 0.5% momentum resolution*
  - *with 150 ps time resolution and with a tight material budget*

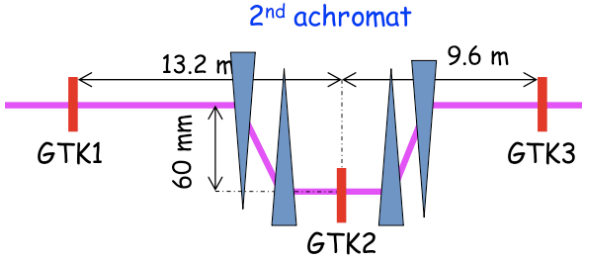
  ⇒ **Straw Tracker in vacuum**

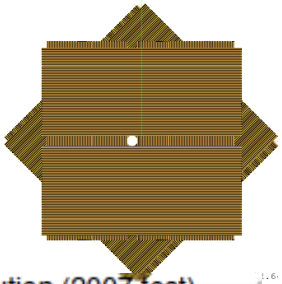
Beam Spectrometer Gigatracker: 3 Si μpixel stations before the decay volume Geometry matching the beam shape



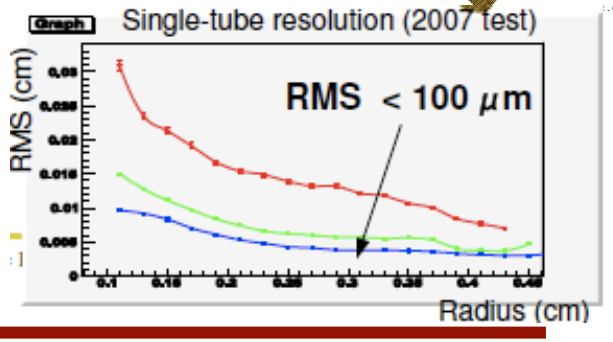
- High space resolution: 300x300 μm pixels
- Low $X/X_0$: 200 μm sensor+100 μm chip (<0.5% $X/X_0$ per station)
- Excellent time resolution: sophysticated RO chip bump bonded on the sensor (0.13 μm technology)
- Momentum resolution 0.4%
- Time resolution ~ 200 ps (per station):
- First prototype just tested on beam at CERN PS





Straw Tracker
- 4 straw chambers with 4 staggered layers of tubes per view, in vacuum
- Ø 9.6 mm, 2.1 m long tubes, 1 magnet (NA48 magnet, 256 MeV/c $P_t$ kick)
- Rate: ~45 KHz per tube (max 0.5 MHz) (μ+π)
- Total $X/X_0$: 0.1% $X_0$ per view, 130 μm/hit resolution per view
- 6 cm "radius" beam holes displaced in the bending plane according to the beam path

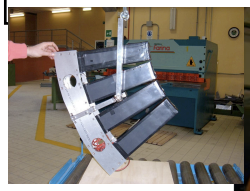


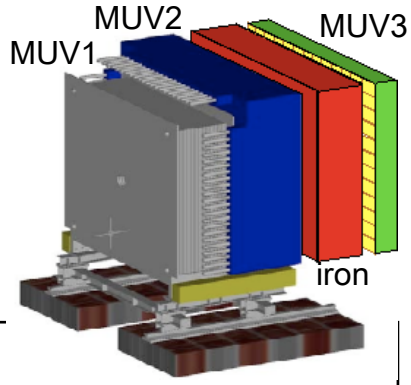
# NA62: the experimental challenge - II

❖ Reject $\pi^0$ and veto additional $\gamma$
- ➢ *$10^{-5}$ single $\gamma$ detection inefficiency at $E_\gamma$ > 10 GeV*
- ➢ *$2 \div 3.5 \times 10^{-8}$ $\pi^0$ rejection inefficiency from* $K^+ \rightarrow \pi^+\pi^0$

⇒ **Photon VETO**

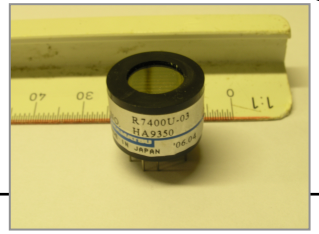
➔ NA48 LKripton calorimeter (acceptance: 110 mrad): trigger+offline
➔ Rings of large angle vetoes (acceptance: up to 50 mrad): offline
➔ Small angle calorimeters (acceptance: < 1 mrad): offline
Large Angle Veto:
- 12 ring em calorimeters in vacuum, 5 staggered plane/ring
- OPAL Lead glass; Ring 3 in construction (1 and 2 built)




❖ Reject $\mu$ background
- ➢ *at $10^{-6}$ level (trigger + offline)*
- ➢ *$10\sigma$ $\pi/\mu$ separation at high p*

⇒ RICH + Muon Veto Detector (MUV)




RICH: 18 m long, 2000 PMT
- Neon at 1 atm ($\pi$ thr.: 12 GeV/c)
- 100 ps resolution (to disentangle pileup in the Gigatracker)
- $\pi$–$\mu$ $3\sigma$ separation up to 35 GeV/c

Muon Veto Detector
➔ 1 plane of fast scintillator behind all the detectors (trigger)
➔ Hadronic calorimeter (offline)
Hadronic calorimeter (MUV 1, 2): 2 modules
➔ Fe/scintillators sampling calorimeter
Fast scintillator plane (MUV3) @ end of detector
➔ Matrix of pads, PMt behind pad directly connected to scintillator