Augusto Ceccucci/CERN

FLAVOUR PHYSICS

LECTURE 2

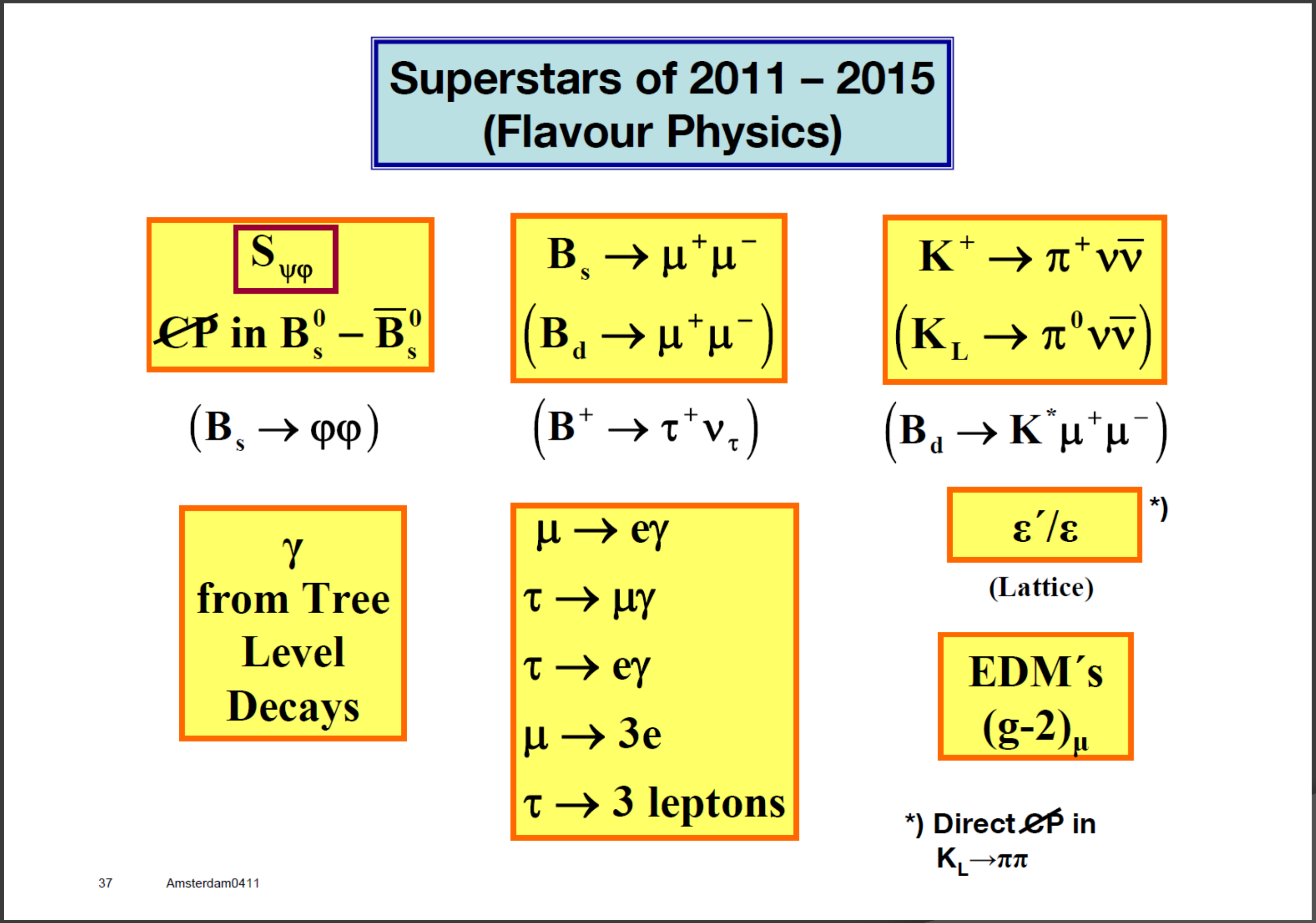
Rare Decay Experiments

Primorsko, Bulgaria, June 15, 2012

Strategies for Indirect NP Searches

- Improve meaurement precision of CKM elements
  - Compare measurements of the same quantities which may or may not be sensitive to new physics
  - Extract all CKM angles and sides in many different ways → inconsistencies would signal NP
- Measure Flavour Changing Neutral Currents (FCNC) processes where the SM contributions are suppressed and precisely predictable

A. Buras list of Flavour Superstars



Superstars of 2011 – 2015
(Flavour Physics)

$S_{\psi\varphi}$

$\cancel{CP}$ in $B_s^0 - \overline{B}_s^0$

$(B_s \to \varphi\varphi)$

$B_s \to \mu^+\mu^-$

$(B_d \to \mu^+\mu^-)$

$(B^+ \to \tau^+\nu_\tau)$

$K^+ \to \pi^+\nu\overline{\nu}$

$(K_L \to \pi^0\nu\overline{\nu})$

$(B_d \to K^*\mu^+\mu^-)$

γ
from Tree
Level
Decays

$\mu \to e\gamma$
$\tau \to \mu\gamma$
$\tau \to e\gamma$
$\mu \to 3e$
$\tau \to 3$ leptons

ε'/ε *)

(Lattice)

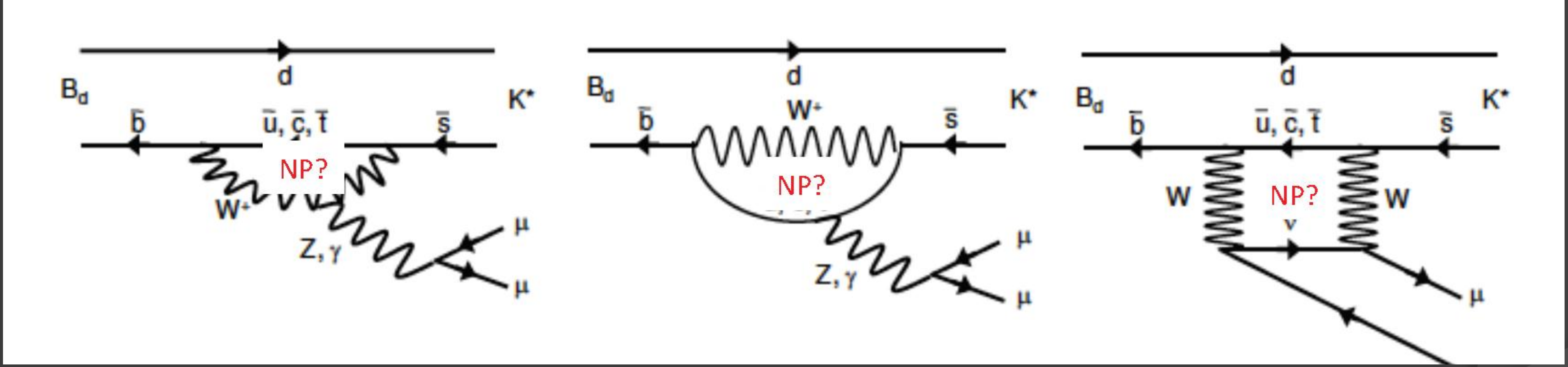
EDM´s
$(g\text{-}2)_\mu$

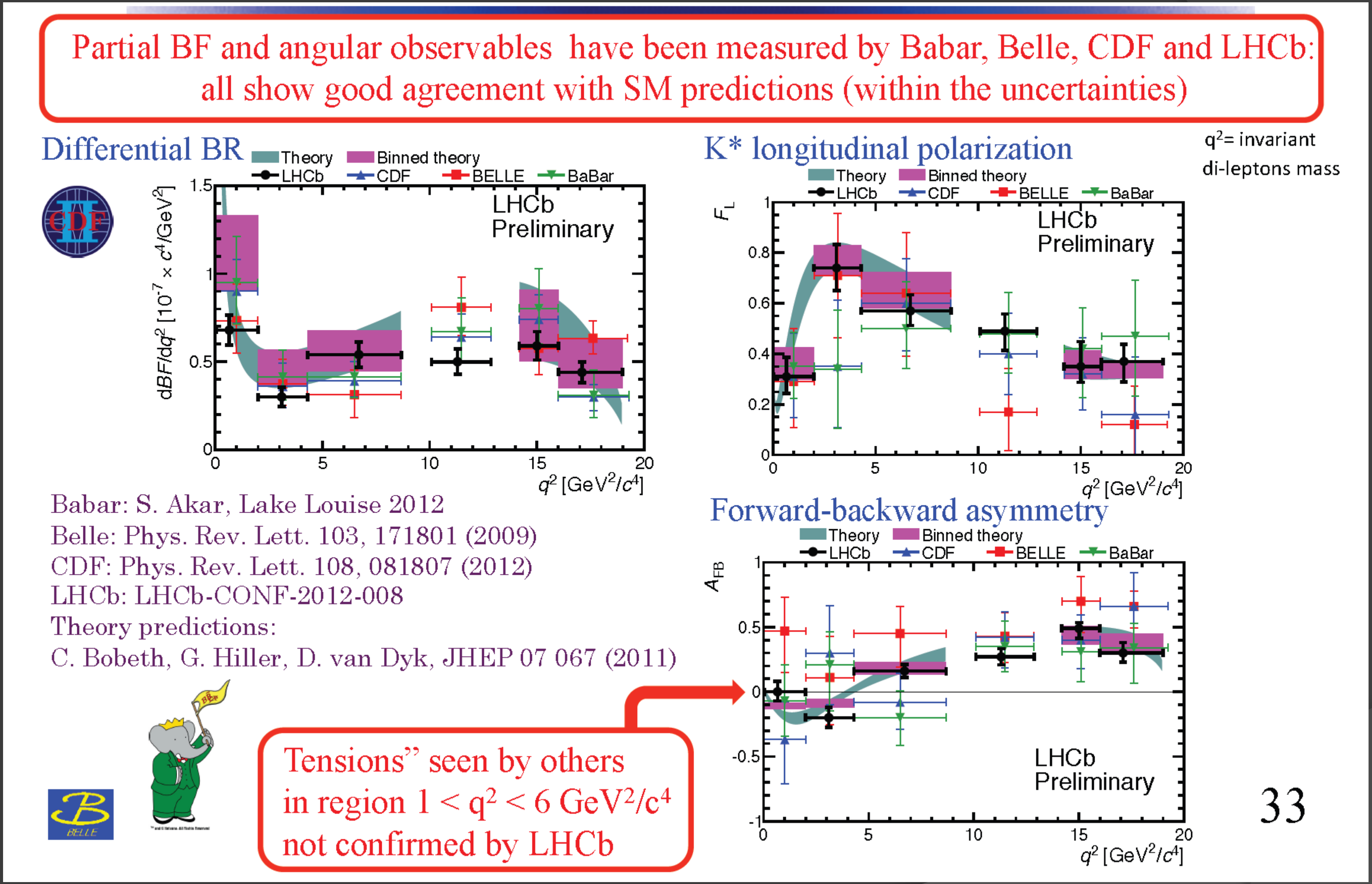
*) Direct $\cancel{CP}$ in
$K_L \to \pi\pi$

37 Amsterdam0411

$B \rightarrow K^{*}\mu^{+}\mu^{-}$

FCNC Forbidden at tree level
NP can modify the helicity structure (angular resolution)





Partial BF and angular observables have been measured by Babar, Belle, CDF and LHCb: all show good agreement with SM predictions (within the uncertainties)

Differential BR

K* longitudinal polarization

q^2= invariant di-leptons mass

Forward-backward asymmetry

Babar: S. Akar, Lake Louise 2012
Belle: Phys. Rev. Lett. 103, 171801 (2009)
CDF: Phys. Rev. Lett. 108, 081807 (2012)
LHCb: LHCb-CONF-2012-008
Theory predictions:
C. Bobeth, G. Hiller, D. van Dyk, JHEP 07 067 (2011)

Tensions” seen by others in region $1 < q^2 < 6$ GeV^2/c^4 not confirmed by LHCb

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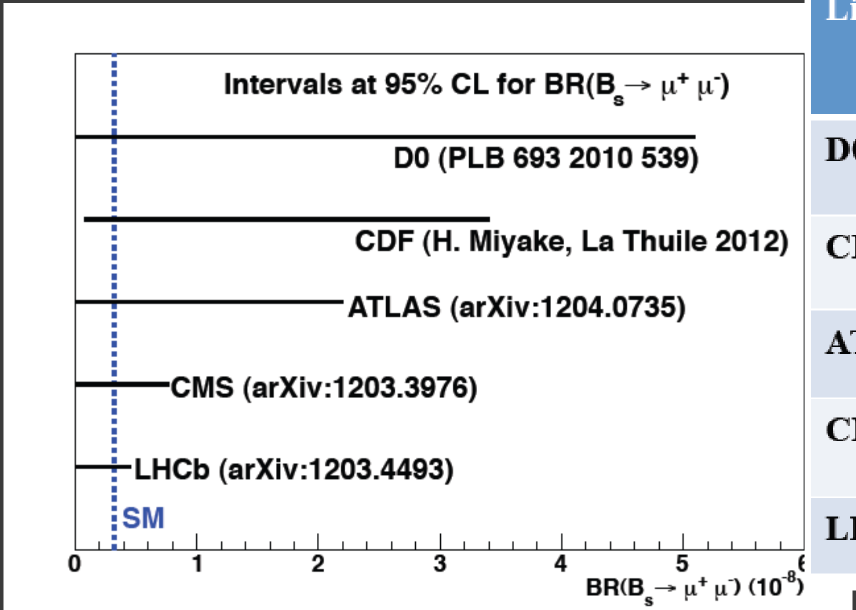
As presented by G. Lanfranchi (Blois 2012)
Detailed presentation M. Patel CERN seminar, May 8, 2012

$B_{d,s}^0 \rightarrow \mu^+\mu^-$

- Exploratory decay sensitive to non-standard Higgs(es)

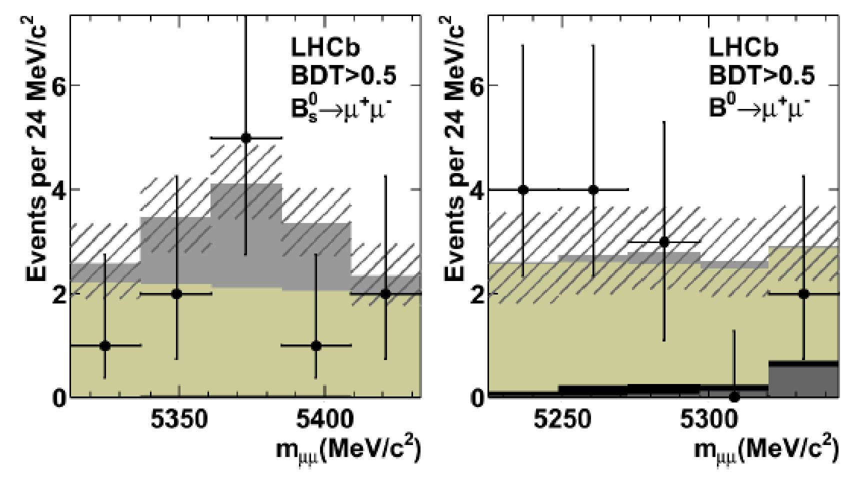
$$(c_{S,P}^{MSSM})^2 \propto \left(\frac{m_b m_\mu \tan^3\beta}{M_A^2}\right)^2$$

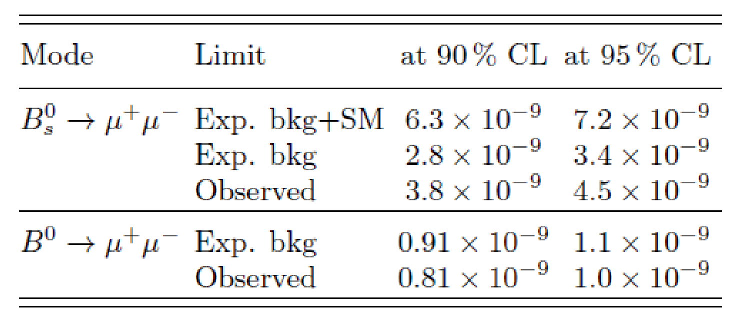
- Clean signature at hadronic colliders



Limit @95%CL	L [fb^{-1}]
D0: < 51x10^{-9}	6.1
CDF: [0.8,34]x10^{-9}	10
ATLAS:< 22 x 10^{-9}	2.4
CMS: < 7.7 x 10^{-9}	4.9
LHCb: <4.5 x 10^{-9}	1

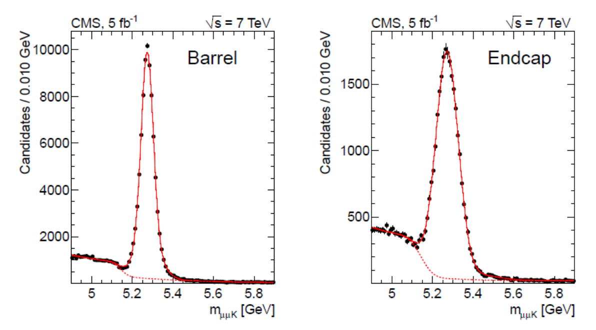
LHCb & CMS: $B_{d,s}^0 \to \mu^+\mu^-$



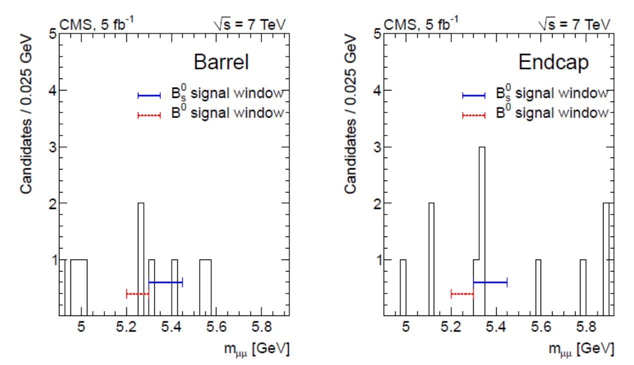


Mode	Limit	at 90 % CL	at 95 % CL
$B_s^0 \to \mu^+\mu^-$	Exp. bkg+SM	6.3×10^{-9}	7.2×10^{-9}
	Exp. bkg	2.8×10^{-9}	3.4×10^{-9}
	Observed	3.8×10^{-9}	4.5×10^{-9}
$B^0 \to \mu^+\mu^-$	Exp. bkg	0.91×10^{-9}	1.1×10^{-9}
	Observed	0.81×10^{-9}	1.0×10^{-9}

LHCb



$B^+ \to J/\psi K^+$ invariant-mass



$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 7.7 \times 10^{-9} \; (6.4 \times 10^{-9})$$

$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 1.8 \times 10^{-9} \; (1.4 \times 10^{-9})$$

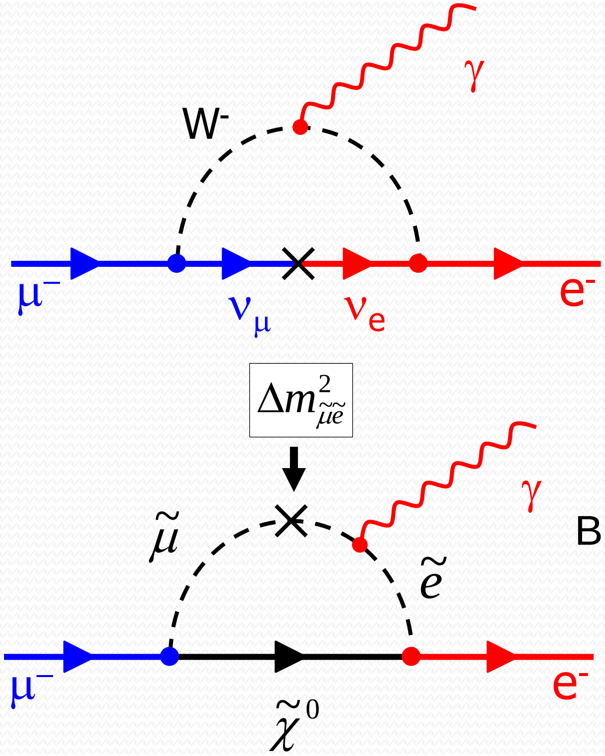
95% (90%) CL.

CMS

“High Intensity” Proton Labs

Lab	**Machine**	**Experiment**	**Physics**
PSI	600 MeV Cyclotron	MEG	$\mu \rightarrow e\ \gamma$
FNAL	8 GeV Booster	g-2	
		Mu2e	μ - e conv.
	120 GeV Main Injector	ORKA	K^+ at rest
	Project X		μ, K
J-PARC	30 GeV Main Ring	KOTO	$K^0{}_L$
		g-2	
		COMET	μ - e conv.
CERN	400 GeV SPS	NA62	K^+ in flight

LFV in SUSY



$$\mathrm{BR}(\mu^- \to e^-\gamma)\big|_{\mathrm{SM}} \propto \frac{m_\nu^4}{m_W^4} \approx 10^{-60}$$

$$\mathrm{BR}(\mu^- \to e^-\gamma)\big|_{\mathrm{SUSY}} \approx 10^{-5}\,\frac{\Delta m^2_{\tilde e\tilde\mu}}{\bar m^2_{\tilde\ell}}\left(\frac{100\ \mathrm{GeV}}{m_{\mathrm{SUSY}}}\right)^4 \tan^2\beta \approx 10^{-12}$$

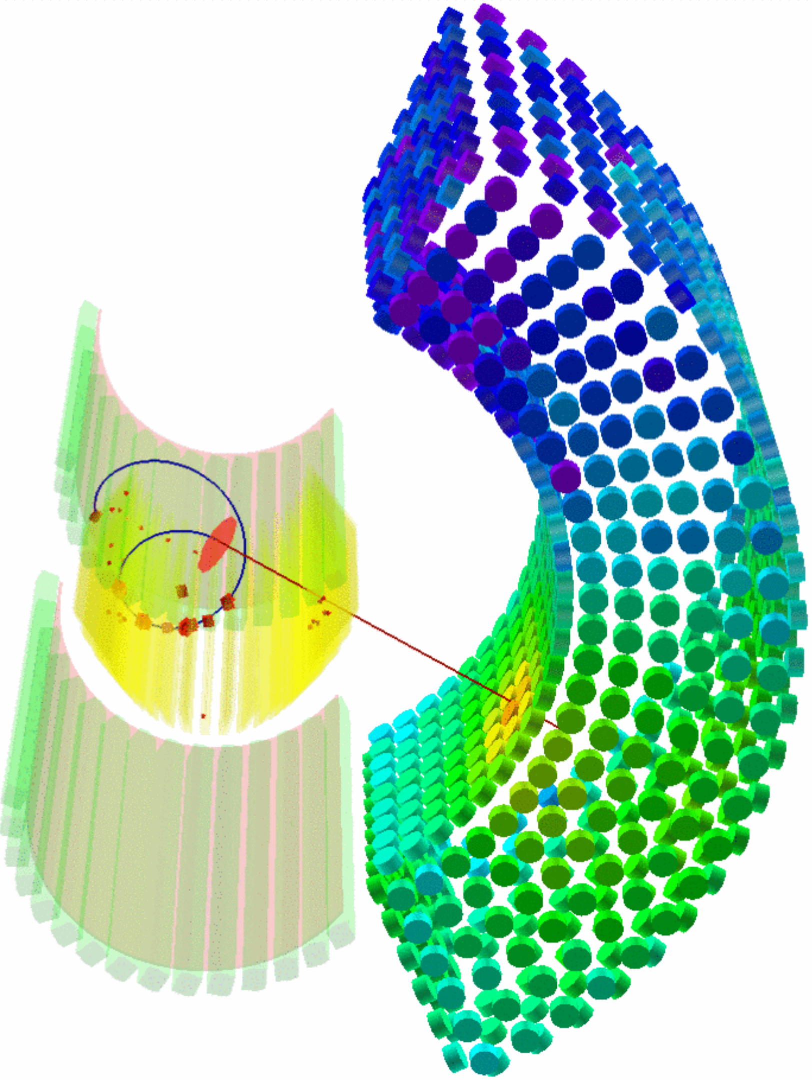
- While Lepton Flavor Violation (LFV) is forbidden in SM, it is possible in SUSY

MEG Display

MEG recently published the best limit (90% CL):

$BR(\mu \to e\,\gamma) < 2.4 \times 10^{-12}$

Phys.Rev.Lett. 107 (2011) 171801
e-Print: **arXiv:1107.5547 [hep-ex]**



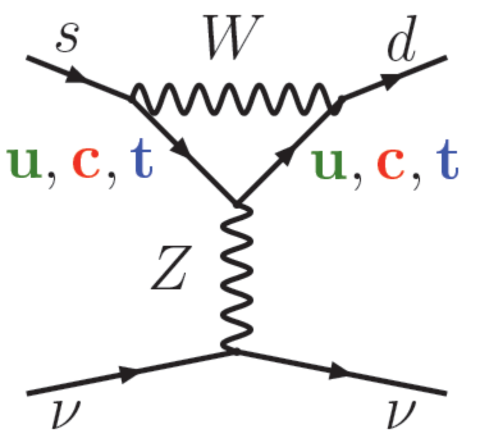
Very Rare *K* Decays

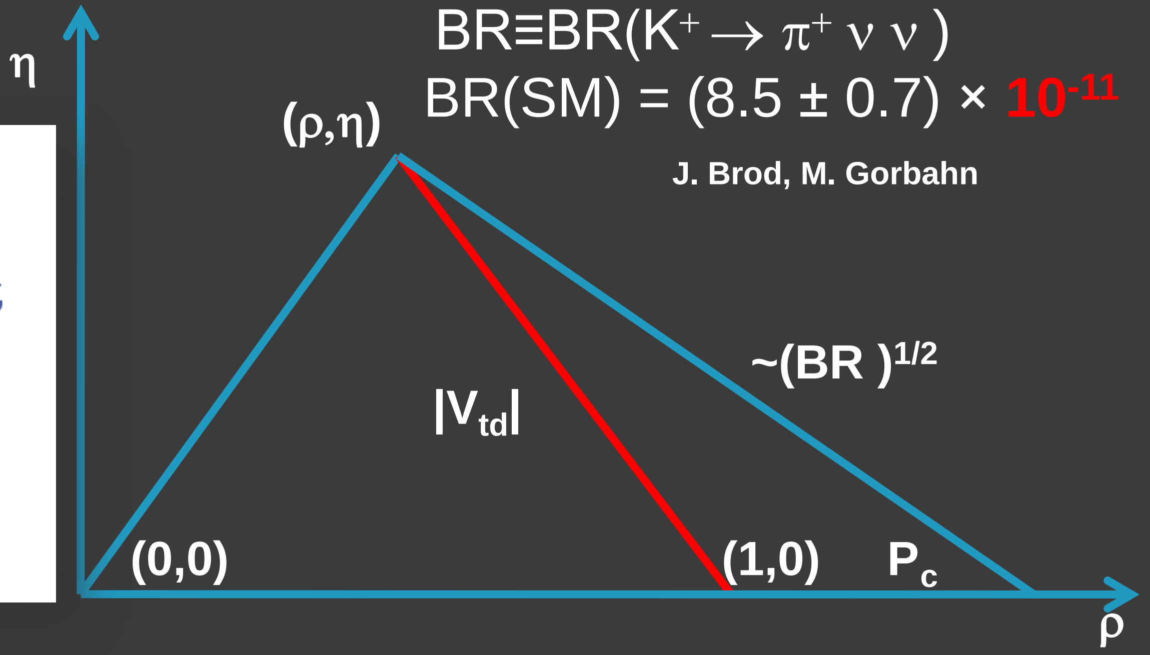
Decay	Branching Ratio $(\times 10^{10})$	
	Theory(SM)	Experiment
$K^+ \to \pi^+ \nu\bar{\nu}(\gamma)$	$0.85 \pm 0.07^{[1]}$	$1.73^{+1.15\,[2]}_{-1.05}$
$K^0_L \to \pi^0 \nu\bar{\nu}$	$0.27 \pm 0.04^{[3]}$	$< 260\ \ (90\%\ \mathrm{CL})^{[4]}$

[1] J.Brod, M.Gorbahn, PRD78, arXiv:0805.4119
[2] AGS-E787/E949 PRL101, arXiv:0808.2459
[3] M. Gorbahn, arXiv:0909.2221
[4] KEK-E391a, arXiv:0911.4789v1

- Must bridge the existing gap between theory and experiment
- A measurement of BR($K^+ \to \pi^+ \nu\, \nu$) to 10 % determines V_{td} without input from Lattice QCD!
- The strong suppression of the SM component ($<10^{-10}$) offers good sensitivity to NP

$K^+ \to \pi^+ \nu \bar{\nu}$ in SM





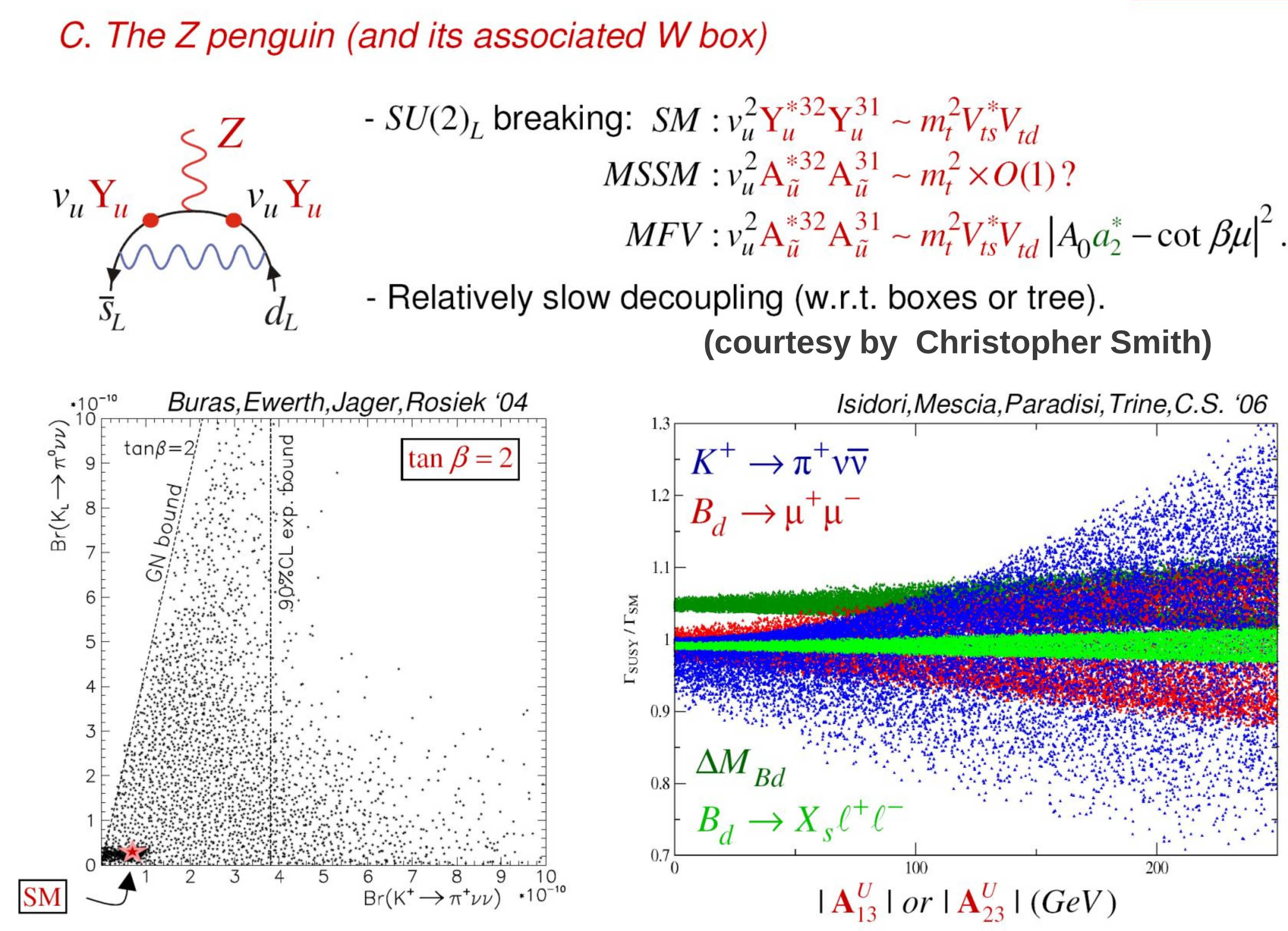
$\text{BR} \equiv \text{BR}(K^+ \to \pi^+ \nu \nu)$

$\text{BR(SM)} = (8.5 \pm 0.7) \times 10^{-11}$

J. Brod, M. Gorbahn

$$\delta|V_{td}| / |V_{td}| \approx \underbrace{0.4\,\delta P_c/P_c}_{\sim 2\,\%\ (\text{mostly }\delta\, m_c)} \oplus \underbrace{0.7\,\delta\,\text{BR}/\text{BR}}_{\substack{62\,\%\ \text{BNL} \\ 7\%\ \text{aim of NA62 (2y)}}} \oplus \underbrace{\delta|V_{cb}| / |V_{cb}|}_{3\,\%}$$

Kaon Rare Decays and NP



C. The Z penguin (and its associated W box)

- $SU(2)_L$ breaking: $SM : v_u^2 Y_u^{*32} Y_u^{31} \sim m_t^2 V_{ts}^* V_{td}$

  $MSSM : v_u^2 A_{\tilde{u}}^{*32} A_{\tilde{u}}^{31} \sim m_t^2 \times O(1)$?

  $MFV : v_u^2 A_{\tilde{u}}^{*32} A_{\tilde{u}}^{31} \sim m_t^2 V_{ts}^* V_{td} \left|A_0 a_2^* - \cot\beta\mu\right|^2$.

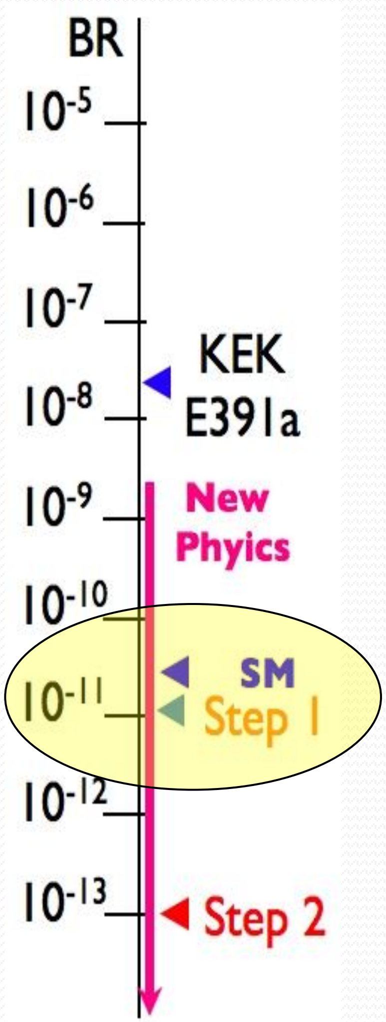
- Relatively slow decoupling (w.r.t. boxes or tree).

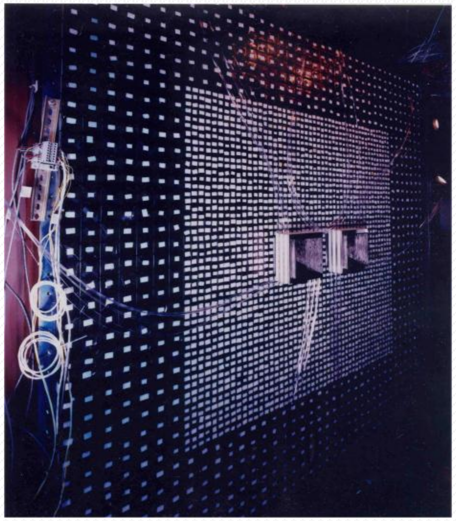
(courtesy by Christopher Smith)

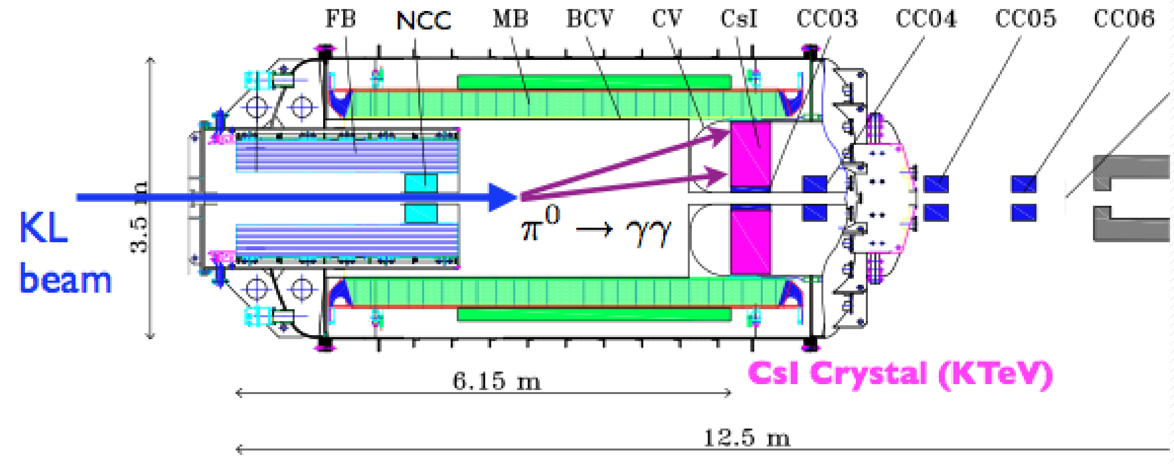
Buras,Ewerth,Jager,Rosiek '04

Isidori,Mescia,Paradisi,Trine,C.S. '06

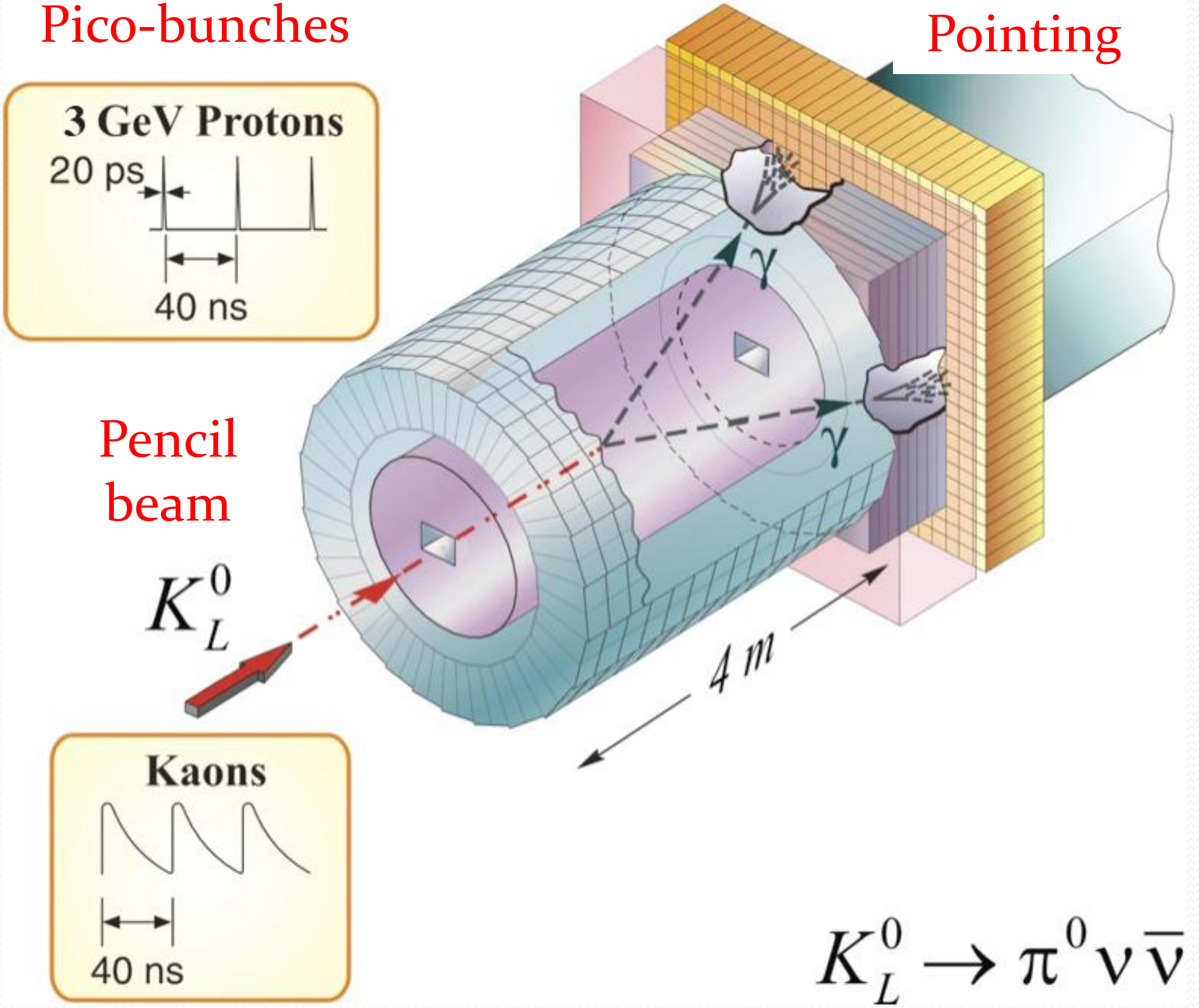
KOTO at JPARC







Example : $K^0 \rightarrow \pi^0 \nu\bar{\nu}$ @ Project X



Pico-bunches

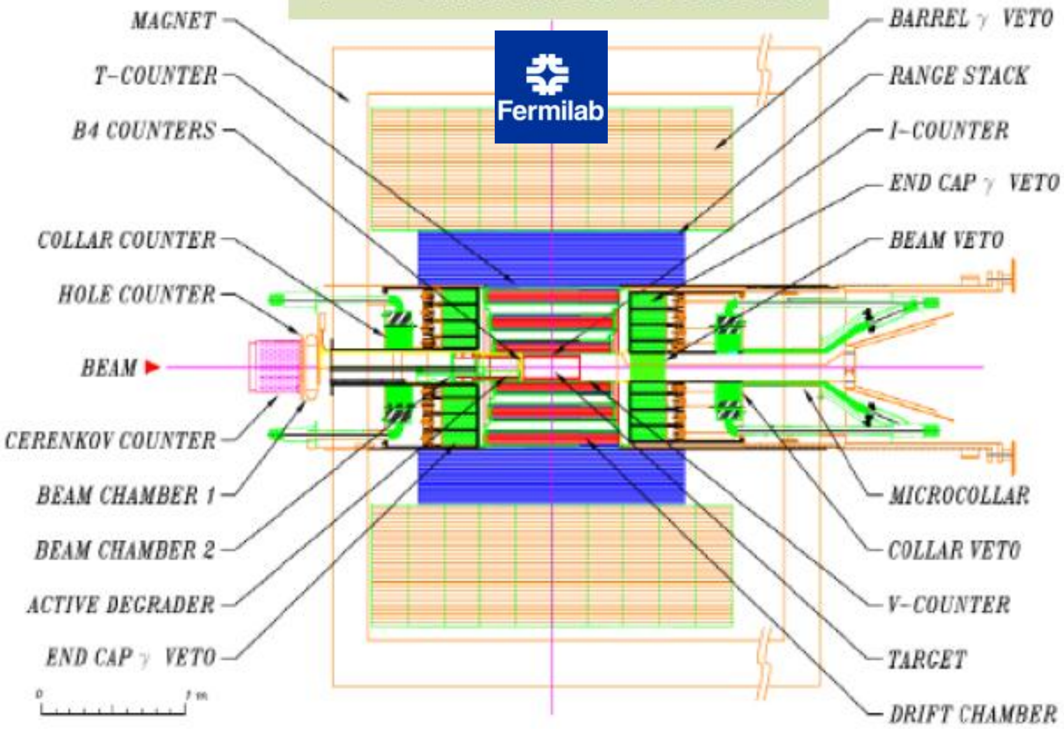
Pointing

Pencil beam

ORKA $K^+\to\pi^+\nu\nu$

1st 2nd 3rd generation at BNL
= 7 event data sample

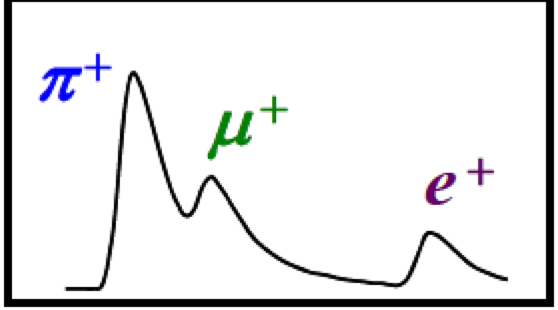
4th Generation Detector



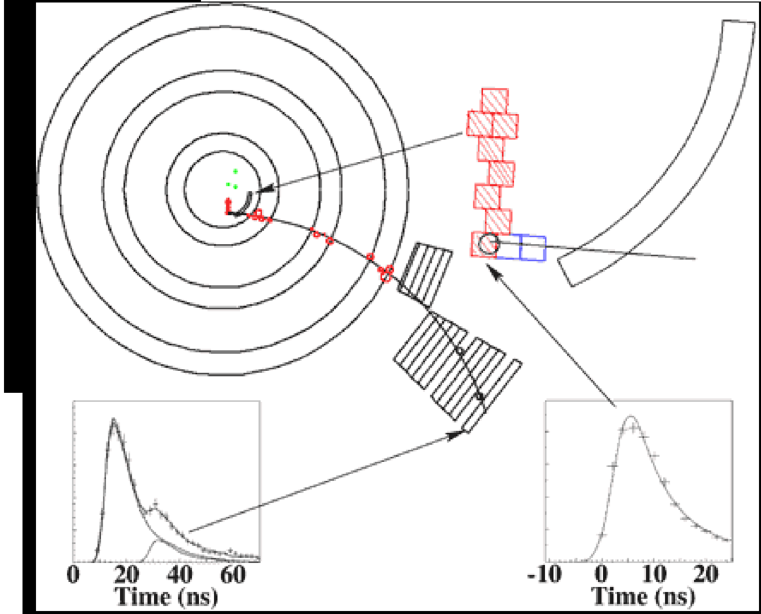
4th generation experiment with beam from Main Injector and continuing with Project X

$\pi^+\to\mu^+\to e^+$

Decay Sequence



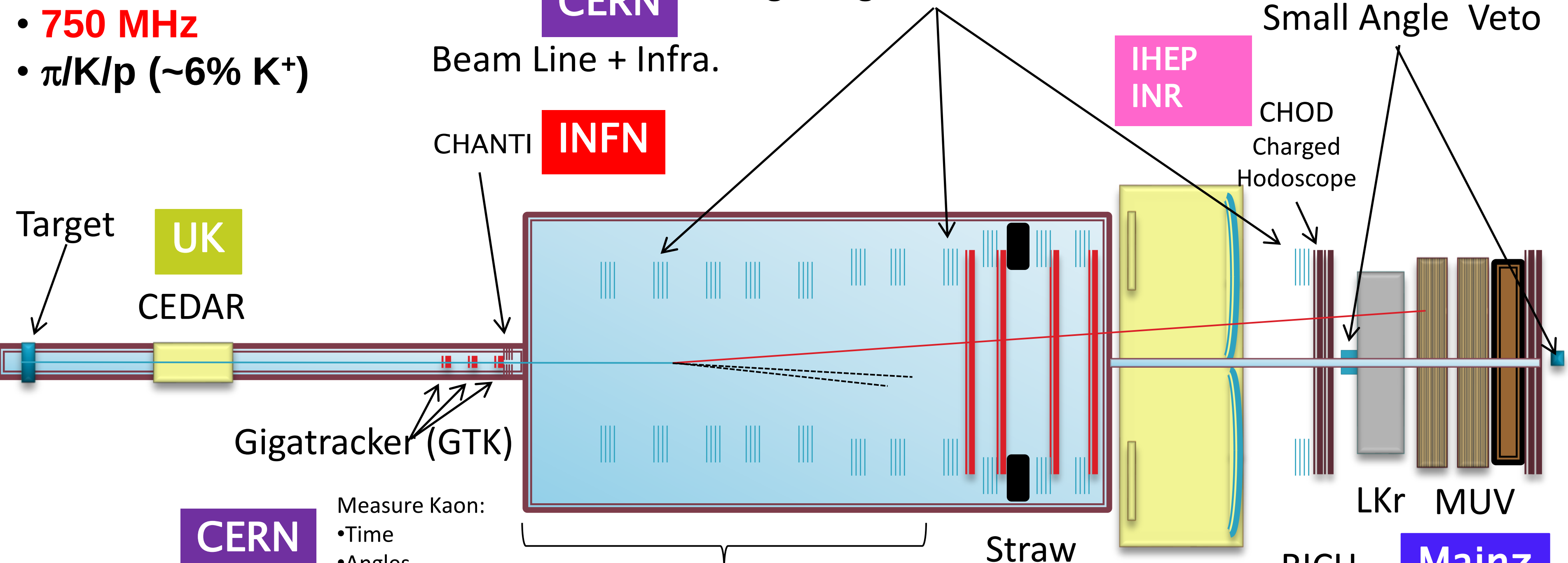
BNL E787 event display



NA62: $K^+ \to \pi^+\nu\nu$ in–flight @ CERN–SPS

SPS primary p: 400 GeV/c
Unsepared beam:

- **75 GeV/c**
- **750 MHz**
- **π/K/p (~6% K^+)**



Target

UK
CEDAR

CERN
Beam Line + Infra.

CHANTI INFN

Gigatracker (GTK)

CERN
INFN
Belgium

Measure Kaon:
- Time
- Angles
- Momentum

INFN
LAV:
Large Angle Photon Veto

Decay Region 65m

Straw Tracker

JINR
CERN

IHEP
INR
CHOD
Charged Hodoscope

RICH

INFN
Mexico
US

Bulgaria
SAV
Small Angle Veto

LKr MUV

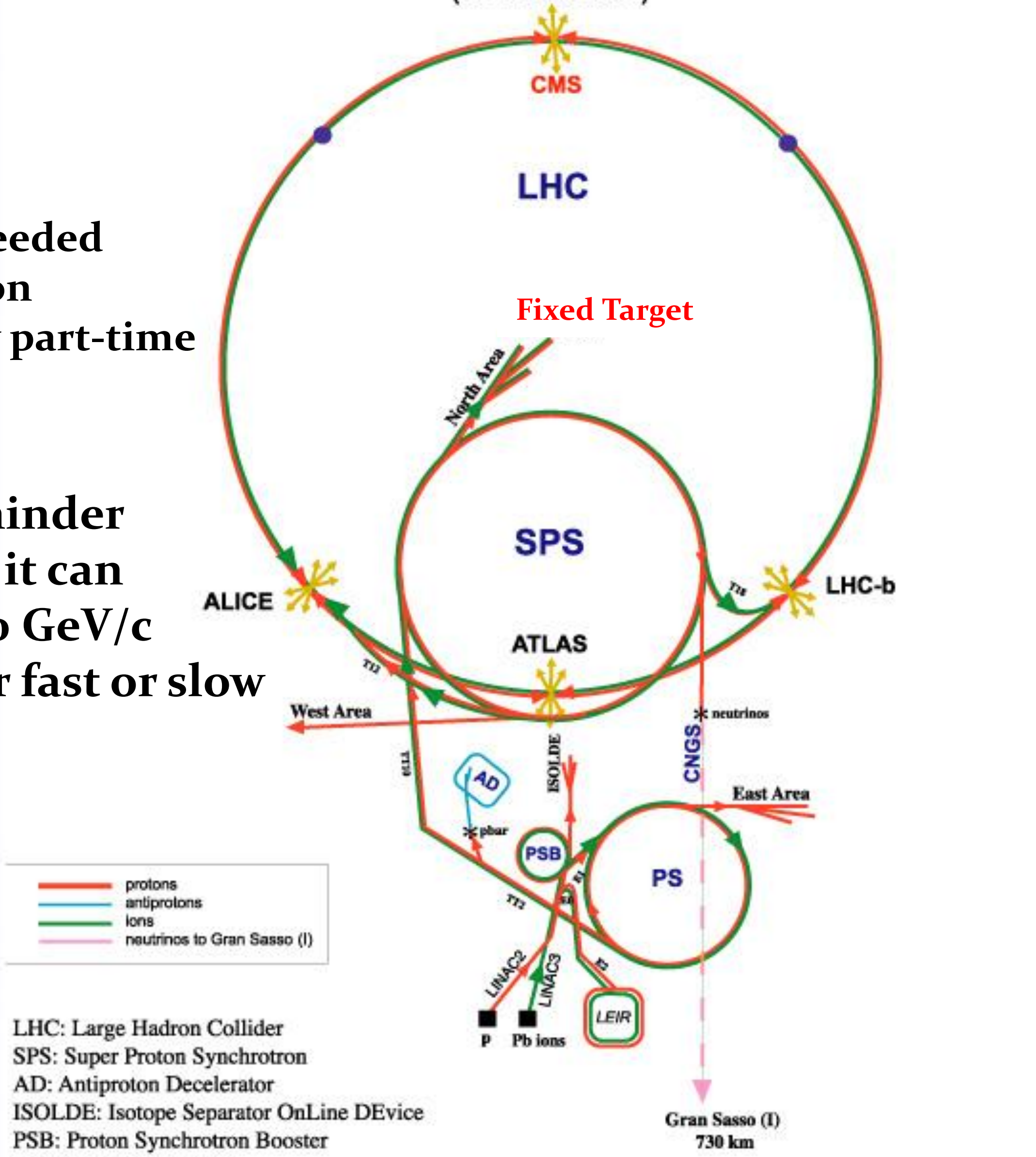
Mainz
IHEP
INR

Total Length 270m

The SPS is needed as LHC proton injector only part-time

For the reminder of the time it can provide 400 GeV/c protons for fast or slow extraction

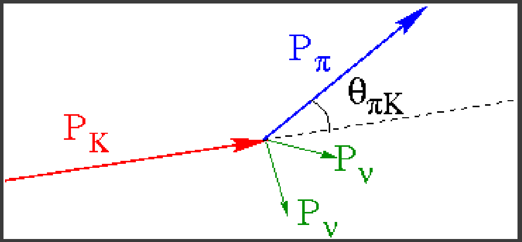
CERN Accelerators
(not to scale)



LHC: Large Hadron Collider
SPS: Super Proton Synchrotron
AD: Antiproton Decelerator
ISOLDE: Isotope Separator OnLine DEvice
PSB: Proton Synchrotron Booster
PS: Proton Synchrotron
LINAC: LINear ACcelerator
LEIR: Low Energy Ion Ring
CNGS: Cern Neutrinos to Gran Sasso

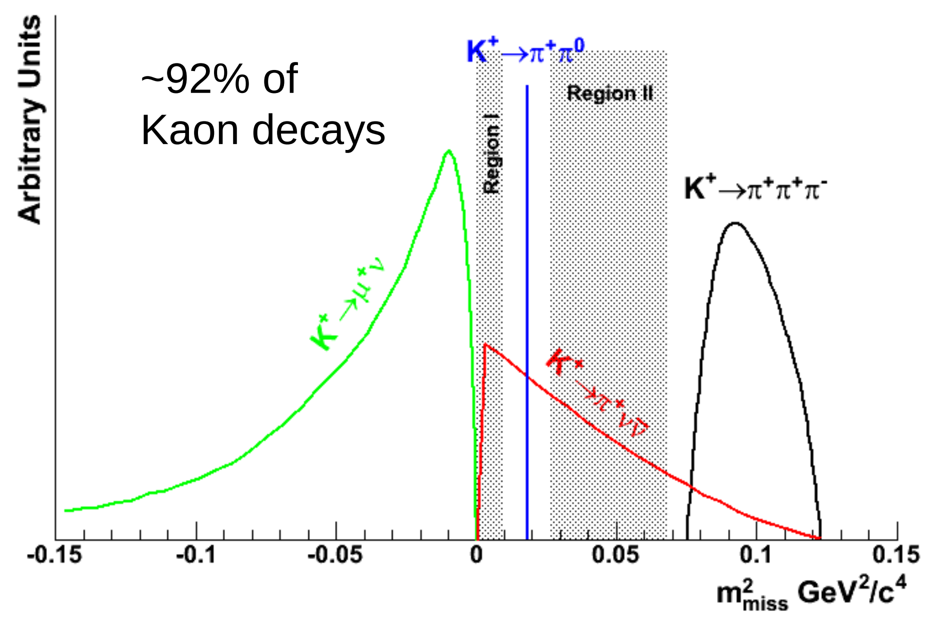
Rudolf LEY, PS Division, CERN, 02.09.96
Revised and adapted by Antonella Del Rosso, ETT Di
in collaboration with B. Desforges, SL Div., and
D. Manglunki, PS Div. CERN, 23.05.01

NA62 Technique: Decay in Flight

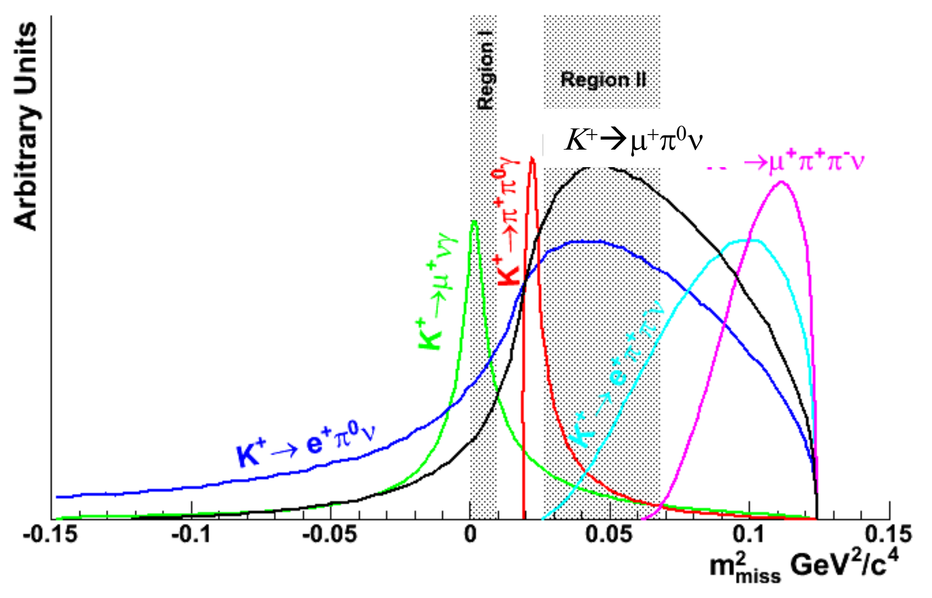


$$m_{miss}^2 = (\tilde{p}_K - \tilde{p}_\pi)^2$$

Kinematically Constraint Decays



Unconstraint Decays



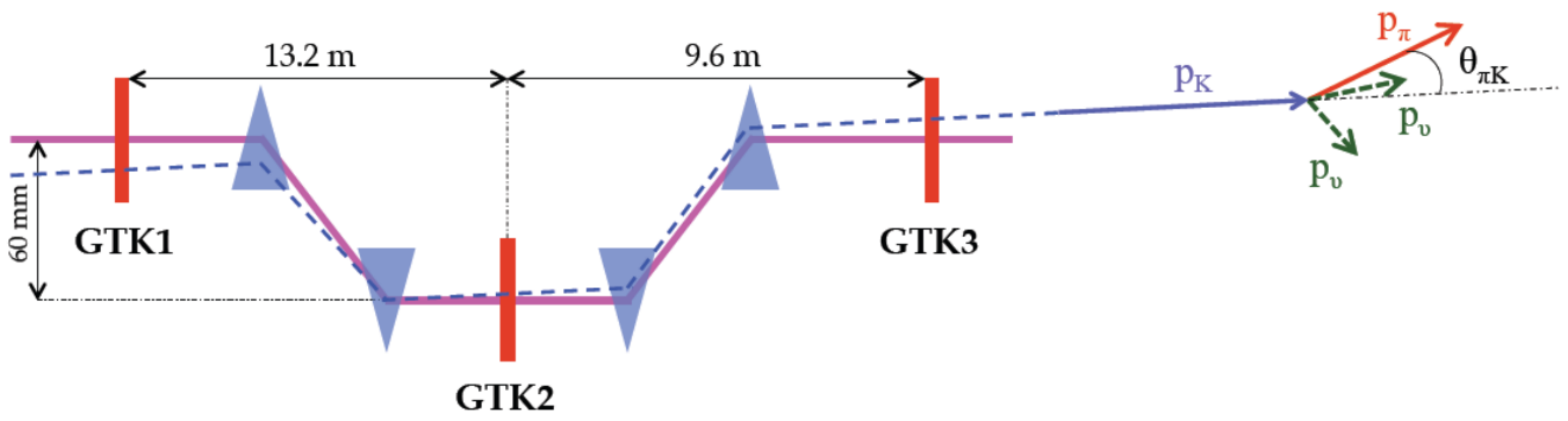
NA62 Main Detectors

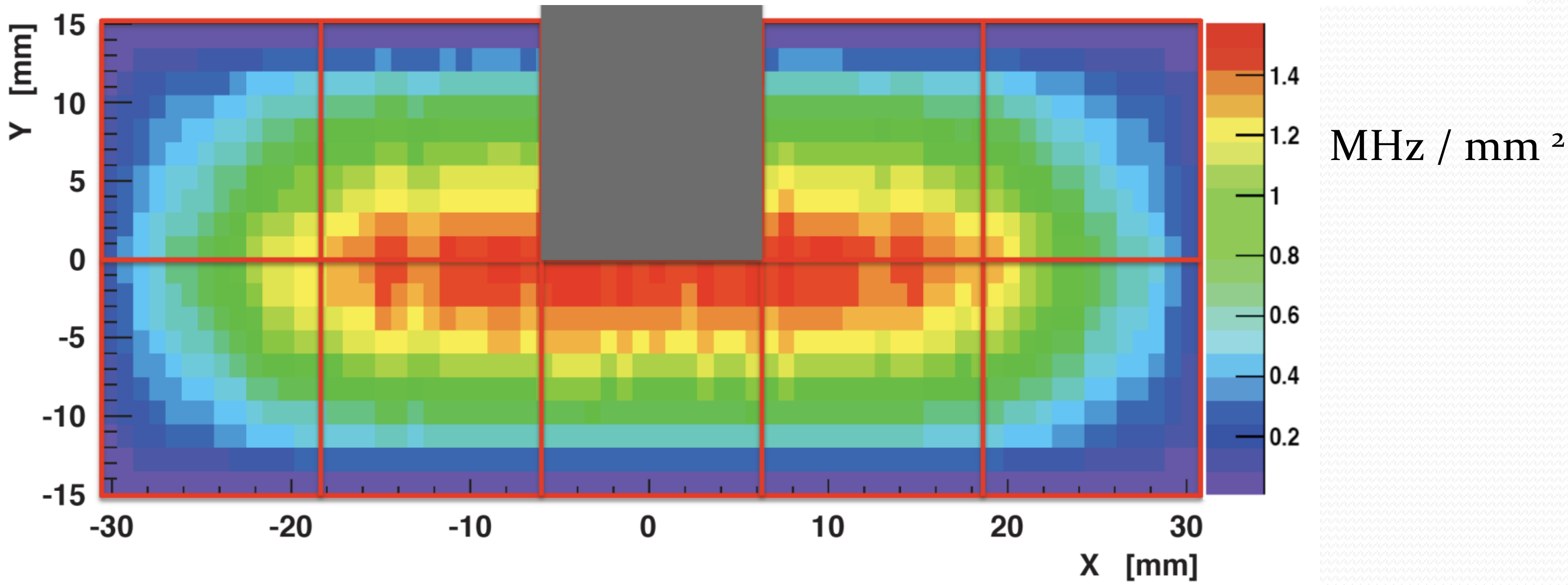
- KTAG
  - It positively identifies the kaons before they enter the decay region. It must tag approx. **50 MHz of Kaons** and be as thin as possible
- Gigatracker (GTK)
  - Silicon Pixel tracker to measure direction and momentum on event-by-event basis. The beam rate is almost **one GHz** (hence the detector name…). It must be very thin to avoid too many inelastic interactions…Excellent time resolution is required to time stamp each track **(< 200 ps / hit)**
- Photon Vetoes
  - A large system of detectors surrounding the decay tank to suppress the π^0 background by **8 orders of magnitude!**
  - The system includes Large angle vetoes (LAV), liquid krypton calorimeter (LKr), Intermediate ring calorimeter (IRC) & small angle calorimeter (SAC)
- Straw Tracker
  - Reconstructs the decay charged particles. To reduce the multiple scattering, this large acceptance spectrometer is housed in the vacuum tank. The overall thickness of the 16 tracking views does not exceed **a few % X_0**
- RICH
  - Pion / Muon identification up to 35 GeV/c is achieved by means of a Ring Imaging Cherenkov Counter (RICH). It also provides the time reference to correlate the pion to the correct incoming kaon track **(100 ps or better)**
- Muon Vetoes
  - To suppress the muons at the trigger and analysis level. They consist of hadron calorimeters made of iron and plastic scintillator and a fast veto plane

Gigatracker (GTK)

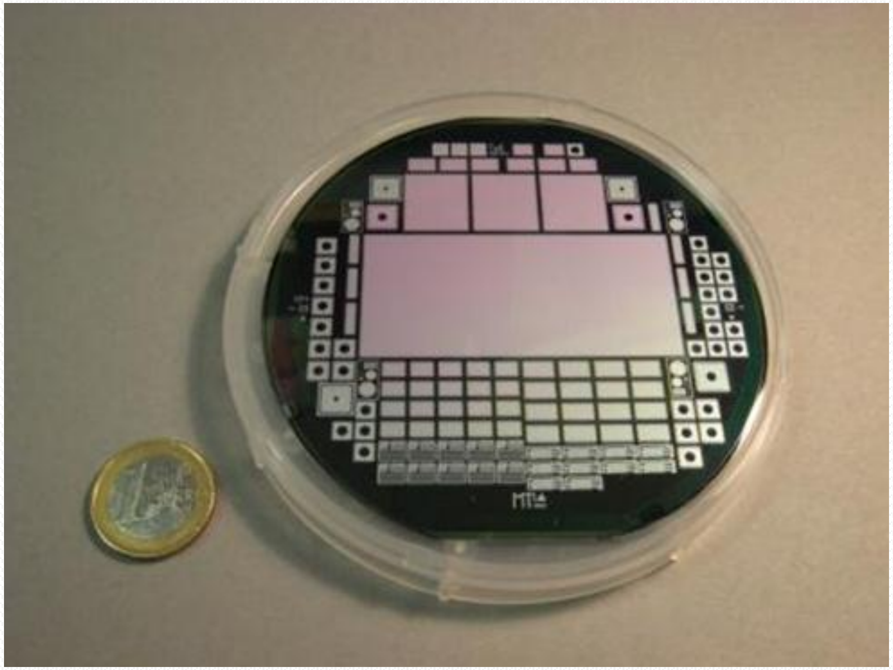
- Requirements:
  - Total rate: ~1 GHz /station (hence the name!)
  - Time resolution: 200 ps / station
  - Position resolution: pixel size 300 μm x 300 μm
  - Thickness : 0.5 % X_0 / station
  - Expected fluence: 2 x 10^{14} 1 MeV n_{eq} / year / cm^2
- Technology:
  - hybrid Si pixel
  - Flip-chip bonding
  - ASIC R/O chip 130 nm IBM CMOS with ToT front-end, DLL TDC
- Choice of sensor:
  - Planar Si 200 μm thick
  - Reverse Bias Voltage as high as possible (but at least 300 Volts)

GTK: Layout & Rate

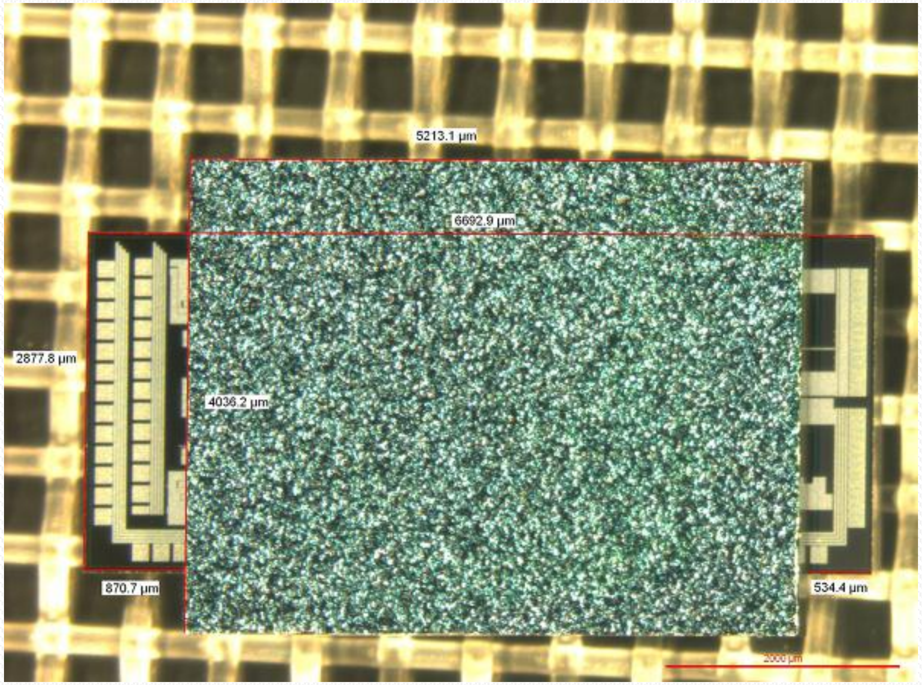




GTK: Sensor and Assembly

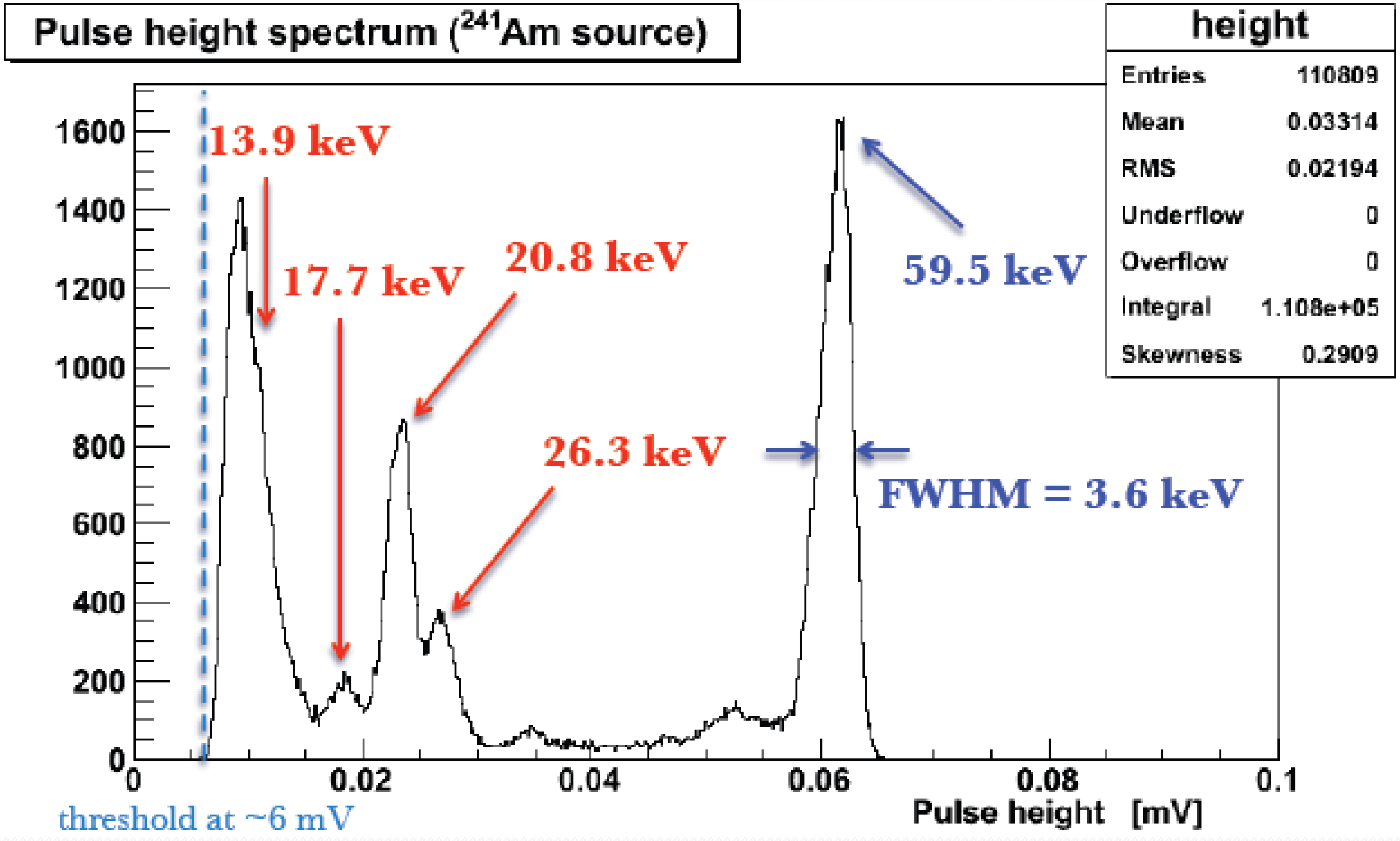


p on n sensor from FBK (Trento, Italy)



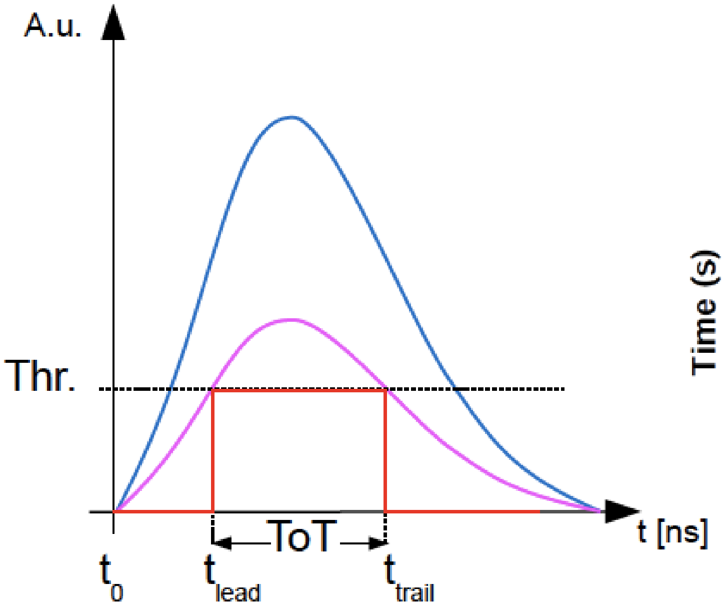
Flip-chip bonding by IZM (Berlin, Germany)

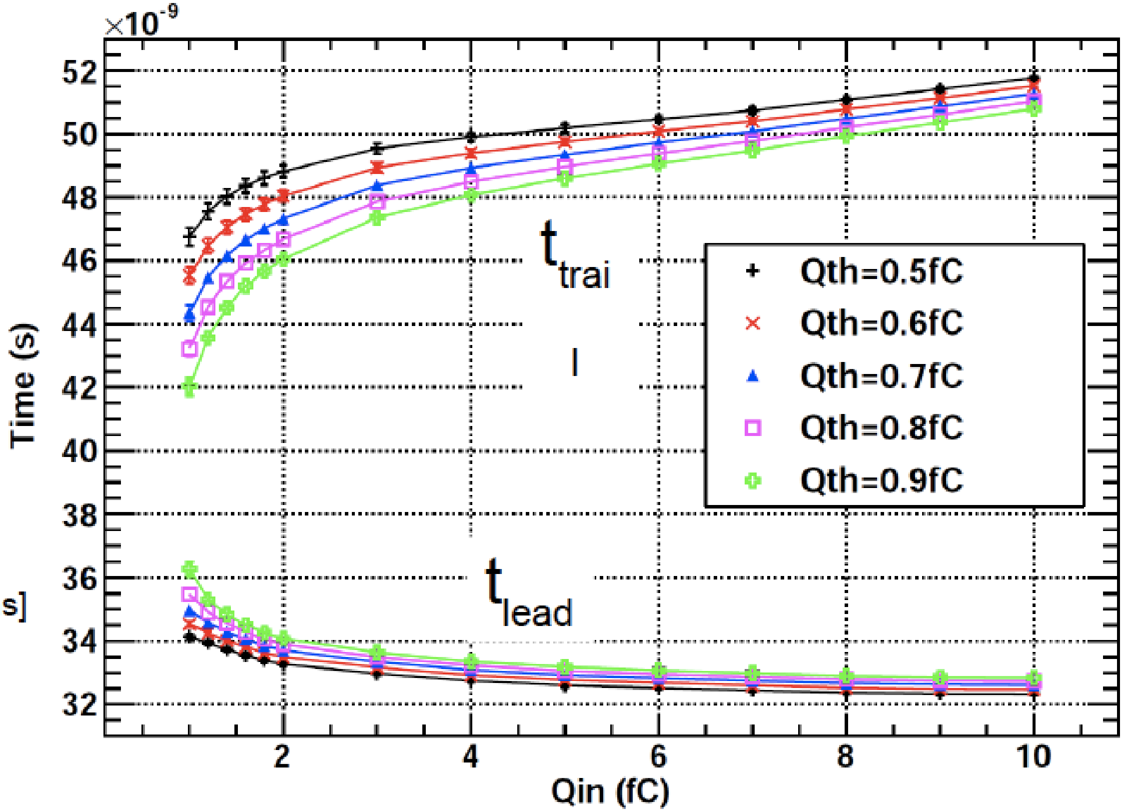
^{241}Am Spectrum



GTK Prototype pulse height distribution (analogue output) Massimiliano Fiorini

GTK: ToT Method

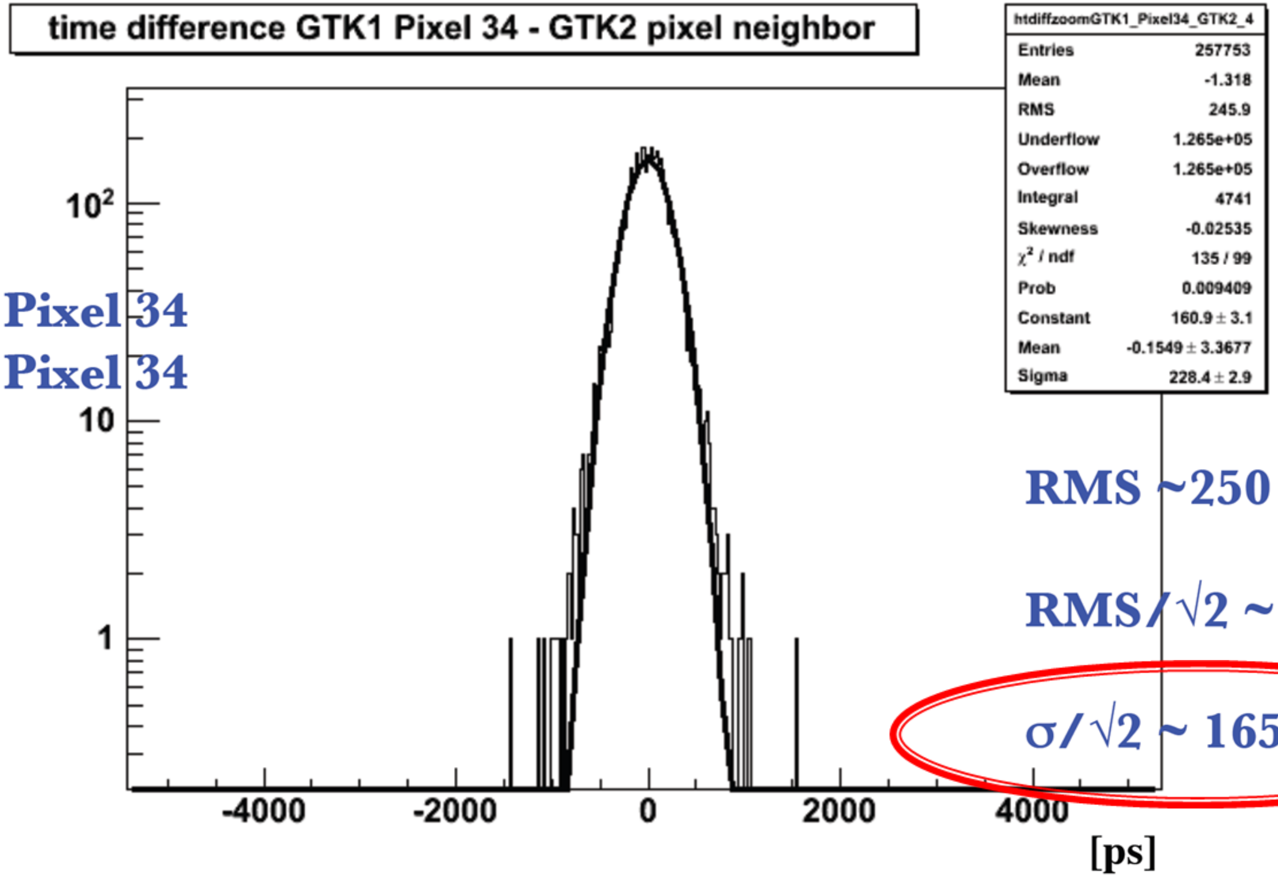




The Time over Threshold (ToT) front-end provides a correction for the slewing correction

The noise is about 180 electrons / channel → jitter 75 ps @ 3 fC

GTK: Prototype Time resolution



GTK1 Pixel 34
GTK2 Pixel 34

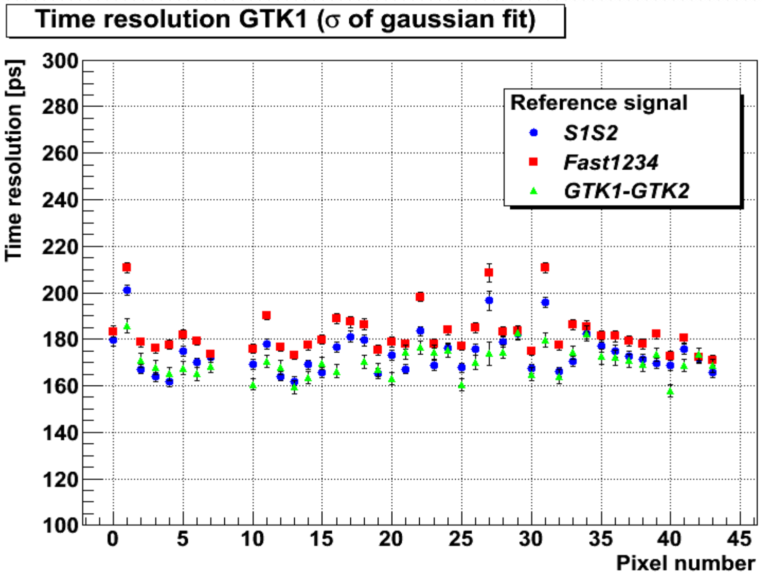
RMS ~250 ps

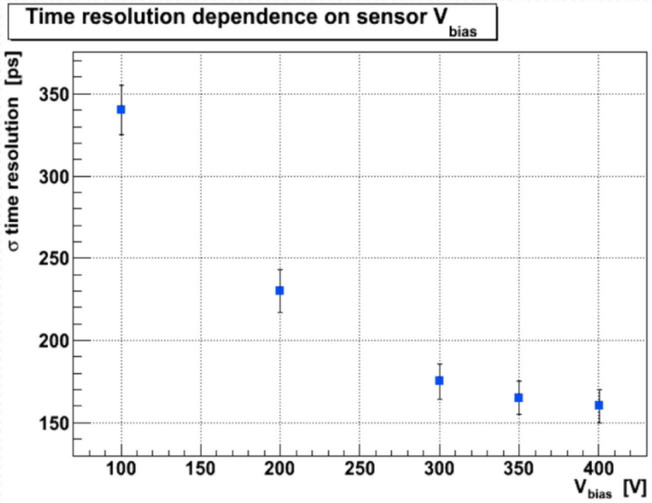
RMS/$\sqrt{2}$ ~ 175 ps

$\sigma/\sqrt{2}$ ~ 165 ps

GTK: Test Beam Analysis

- CERN PS T9 (10 GeV/c π^+ and p)
- Time resolution better than 200 ps per hit for sensor bias voltages higher than 300 V across thewhole pixel matrix (45 pixels)
- Time-walk correction and alignment procedures have been validated with real data
- Clear dependence of time resolution on sensor bias voltage
- The operation at 300 V over-depletion is mandatory

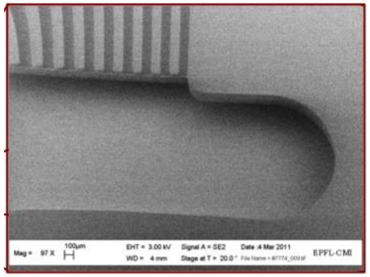




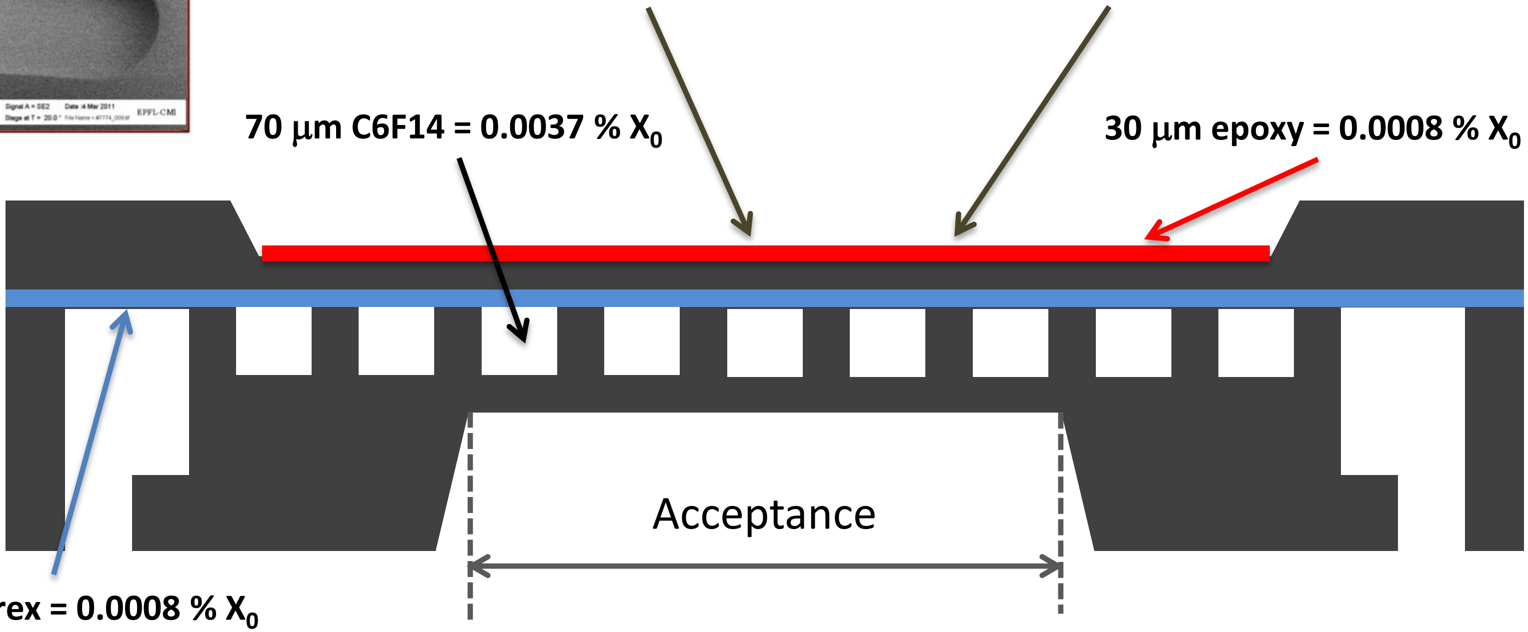
GTK: Micro-Channel Cooling

Final cross section of the cooling plate

Channels =200 x 70 µm
Wall thickness = 200 µm
Cover thickness = 30 µm



Operating temperature -25 C



30 + 30 µm Silicon = 0.0064 % X_0
(above and below channels)

30 + 30 + 70 µm Silicon = 0.0139 % X_0
(between channels)

70 µm C6F14 = 0.0037 % X_0

30 µm epoxy = 0.0008 % X_0

10 µm Pyrex = 0.0008 % X_0
(removed in final production)

Paolo Petagna

Total material budget in the acceptance area = 0.013 X_0%
(min 0.011% - Max 0.015%)

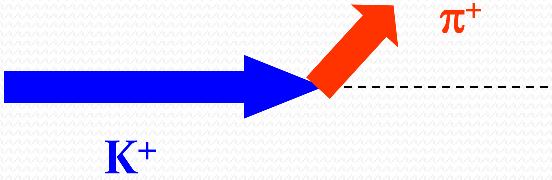
NA62 Vetoes

- Photon vetoes to reject $K^+ \rightarrow \pi^+ \pi^0$

P(K^+) = 75 GeV/c
Requiring P(π^+) < 35 GeV/c
P(π^0) > 40 GeV/c → It can hardly be missed in the calorimeters

8 orders of magnitude π^0 suppression required

Signature:
•**Incoming high momentum K⁺**
•**Outgoing low momentum π⁺**



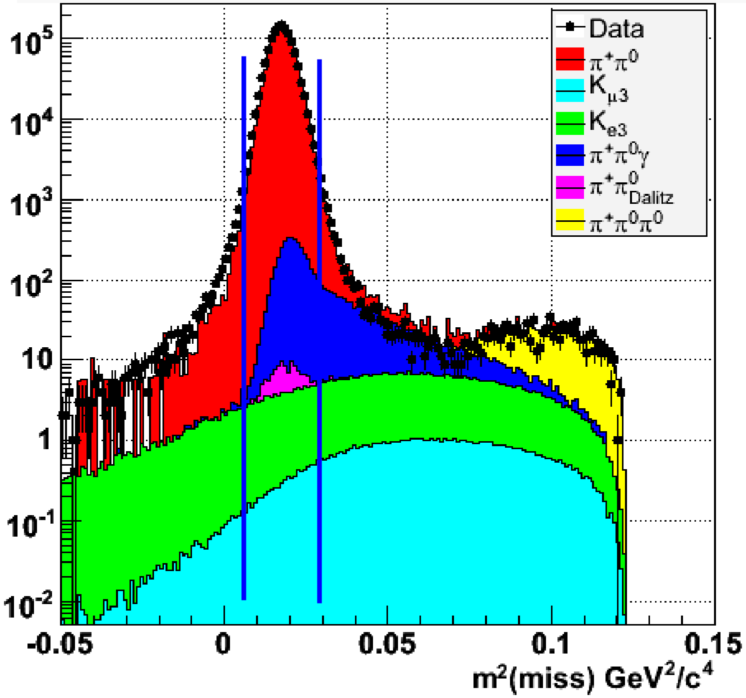
- Muon Veto to reject $K^+ \rightarrow \mu^+ \nu$

Liquid Krypton Calorimeter (NA48) as Forward Photon veto for NA62

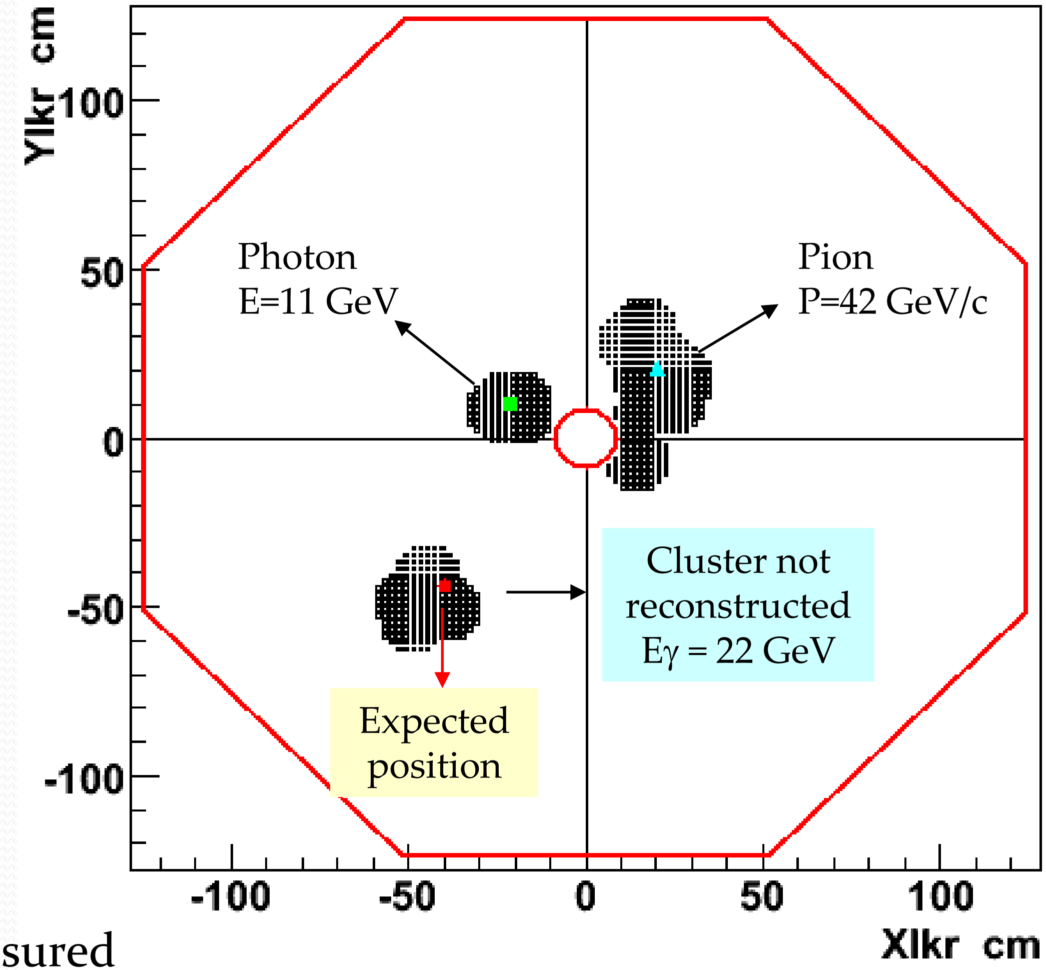
LKr ineff. per γ ($E_\gamma > 10$ GeV):

$\eta \sim 7 \times 10^{-6}$ (preliminary)

$K^+ \to \pi^+ \pi^0$ selected kinematically



π^+ track and lower energy γ are use to predict the position of the other γ

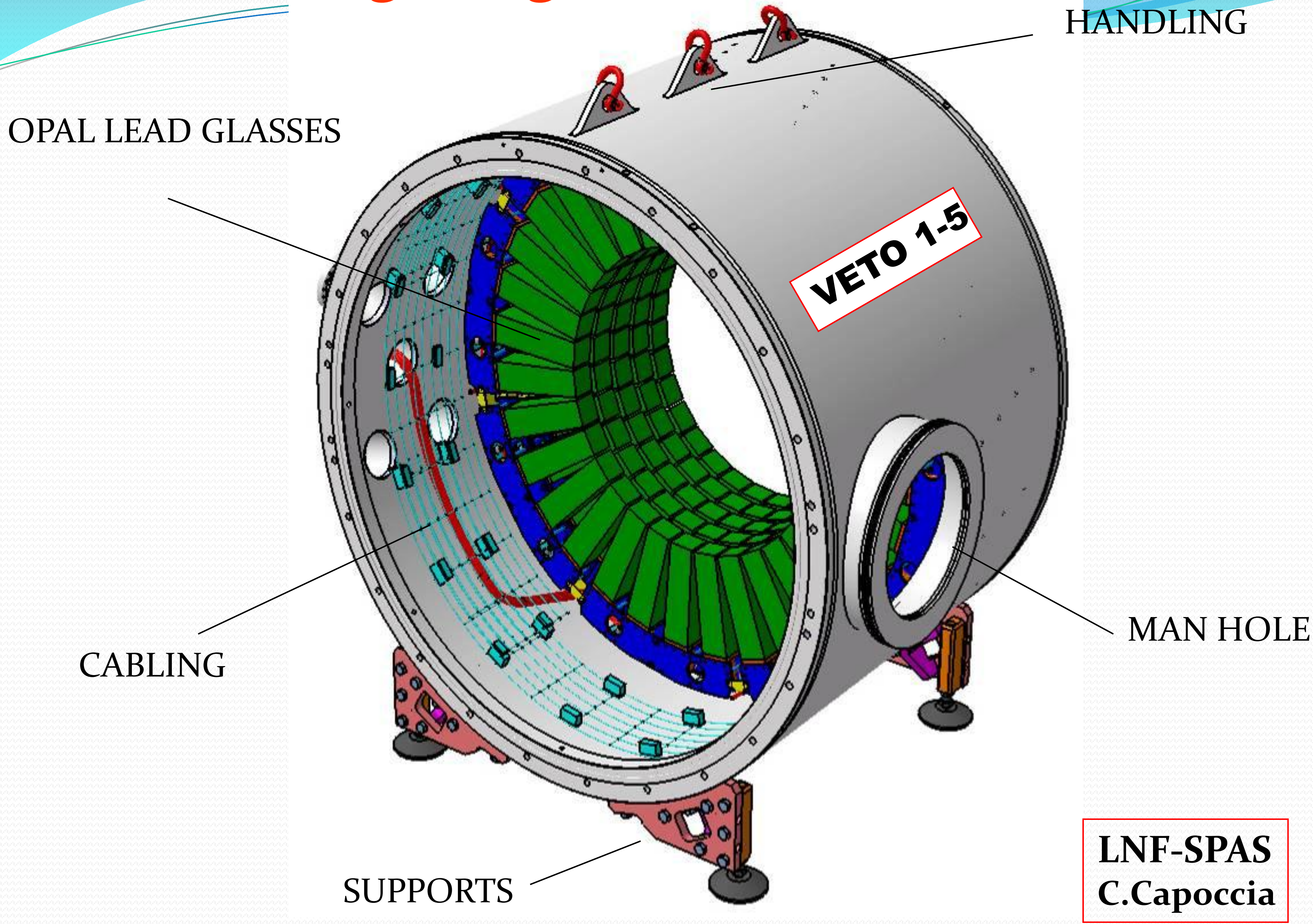


Cluster not reconstructed Eγ = 22 GeV

Expected position

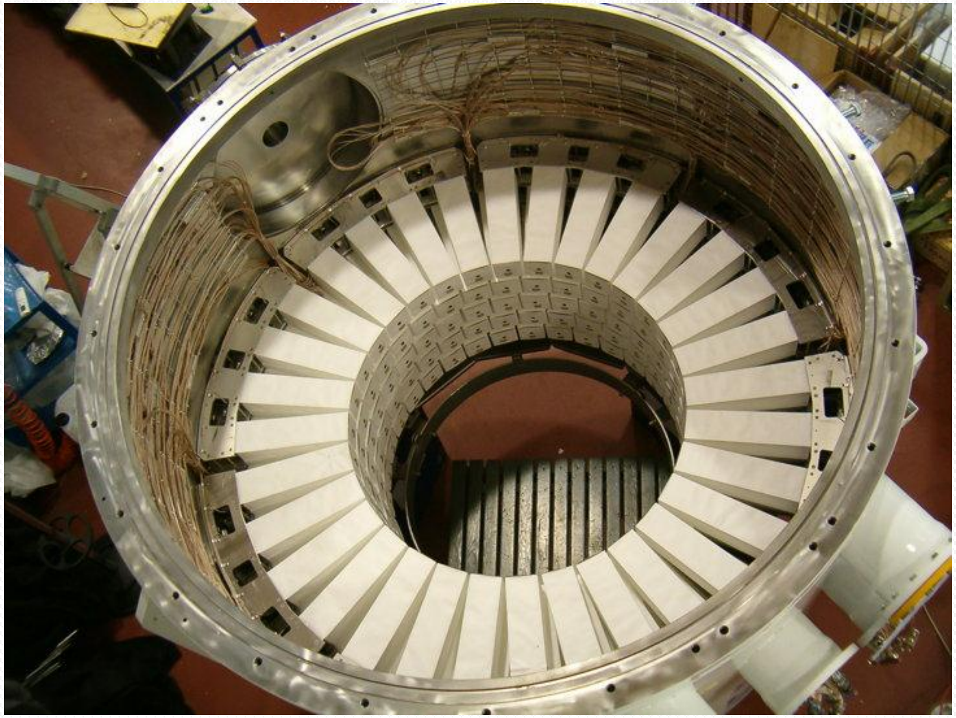
LKr γ Detection Efficiency was Measured from NA48 data

Large Angle Vetoes (LAV)



LNF-SPAS
C.Capoccia

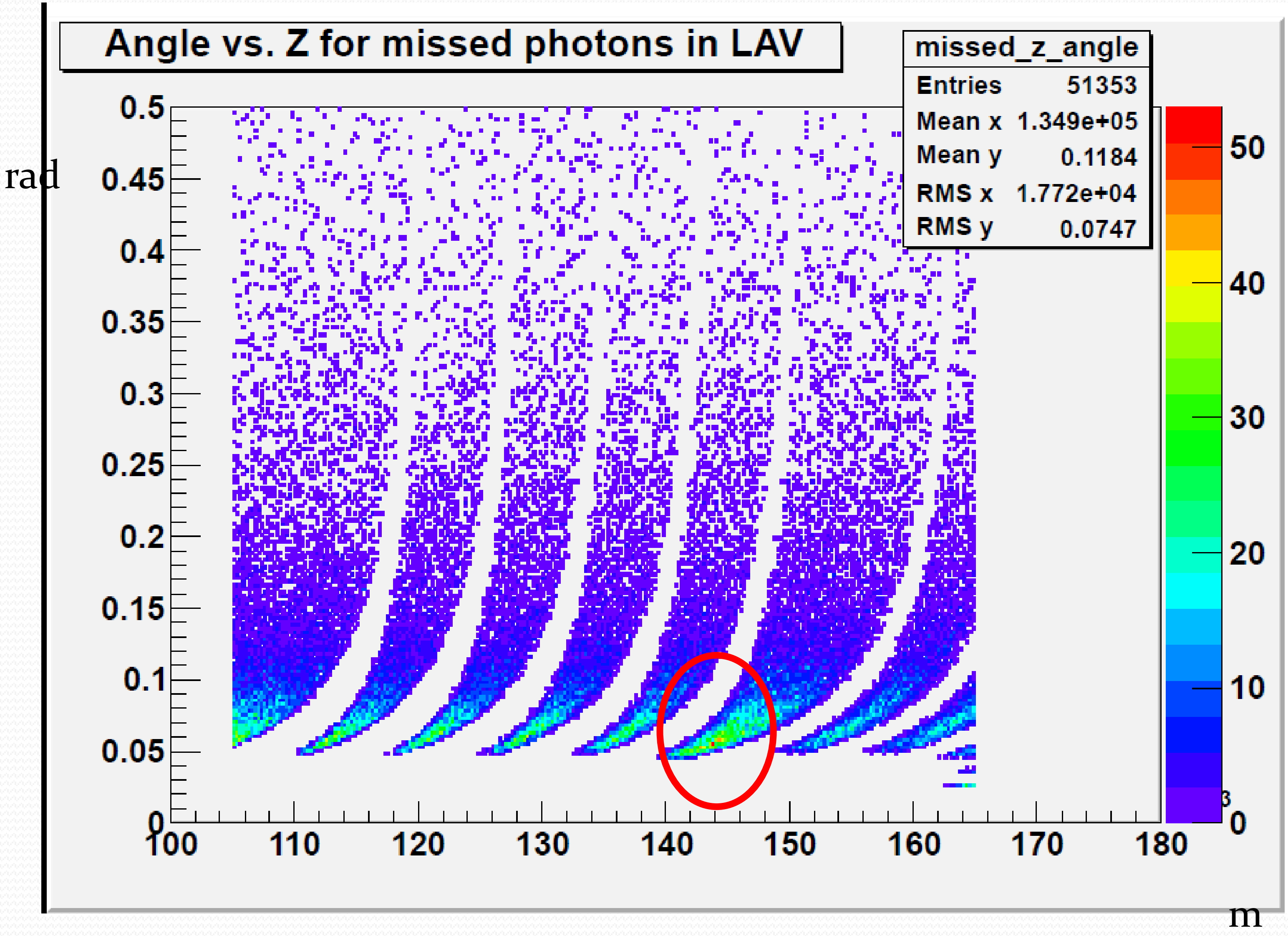
NA62 LAV



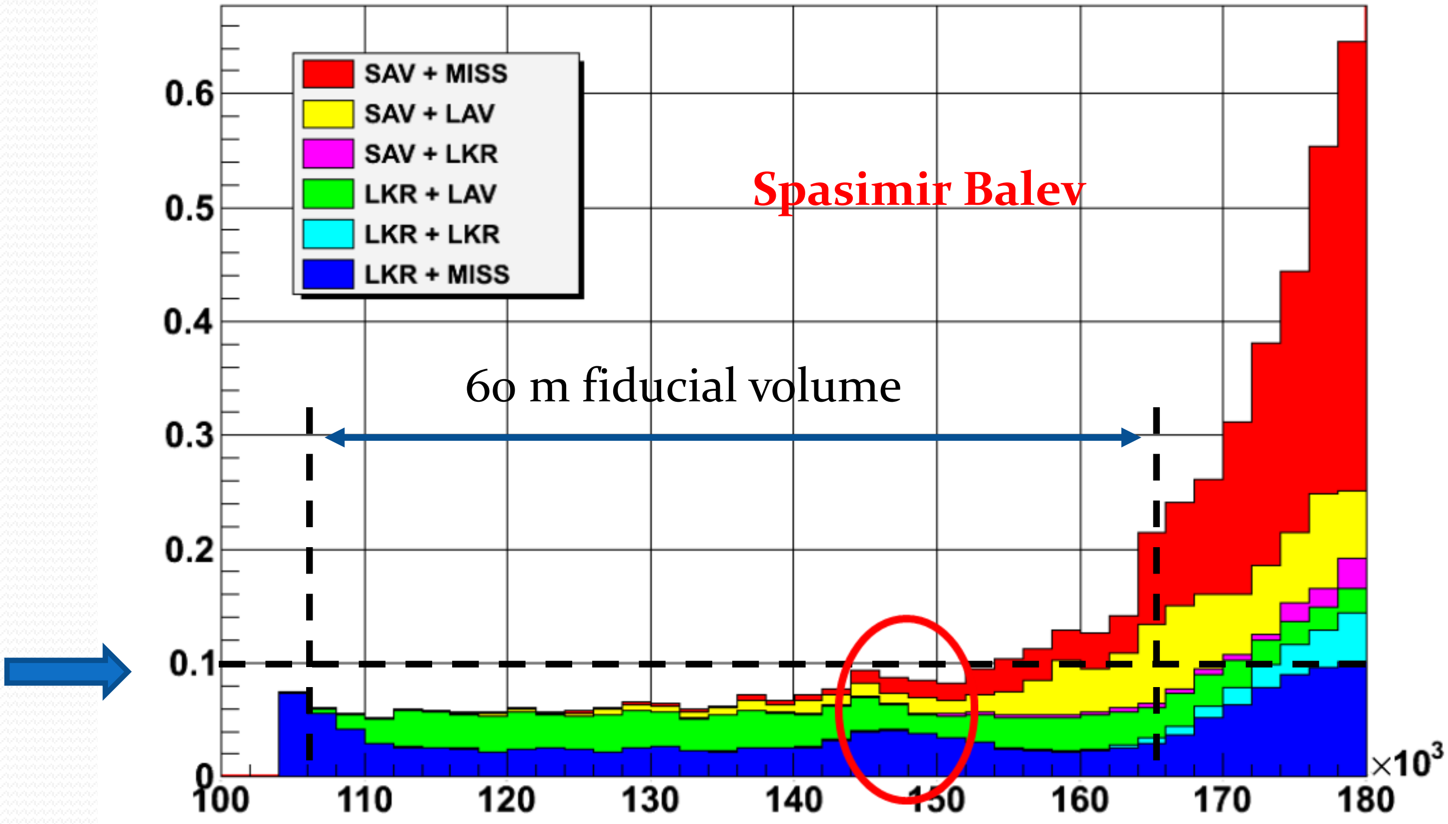

ANTI-A6
NA62

The NA62 A1-A8 LAV Stations all installed in ECN3

Photon Veto Acceptance



NA62 photon vetoes: expected π^0 rejection ~ 5×10^{-8}



Spasimir Balev

60 m fiducial volume

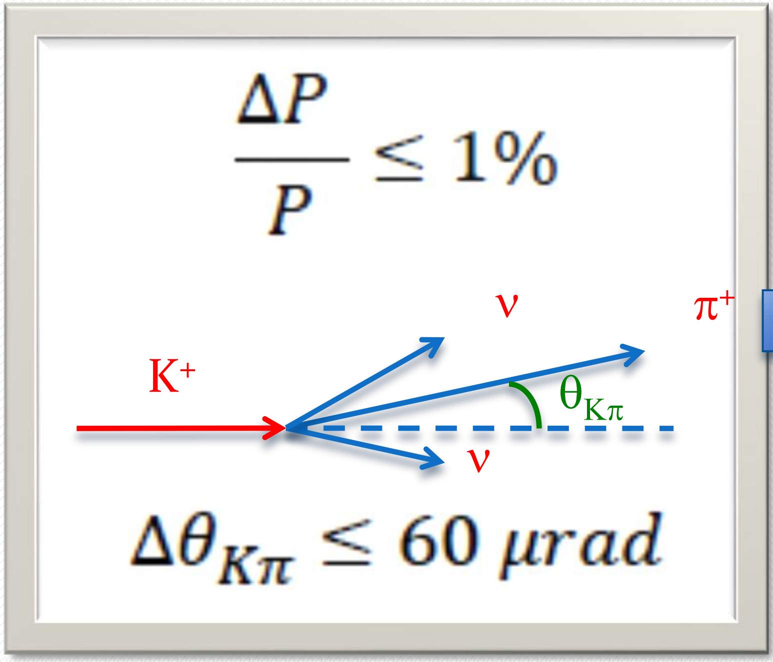
10%

Z, mm

Expected background from $K^+\to\pi^+\pi^0$ as fraction of the $K^+\to\pi^+\nu\nu$ (SM) signal as a function of the kaon decay vertex

Straw Tracker in NA62

- There are two main performance requirements for secondary particles:



$$\frac{\Delta P}{P} \le 1\%$$

$$\Delta\theta_{K\pi} \le 60\ \mu rad$$

From this follow the main requirements on the straw detector:

◆ Spatial resolution ≤ 130 μm per coordinate and ≤ 80μm per space / point

◆ ≤ 0.5% of a radiation length (X_0) for each chamber

◆ Installation inside the vacuum tank ($P < 10^{-5}$ mbar) with minimum gas load for the vacuum system *(~10^{-1} mbar* l/s)*

◆ For straws near the beam, operation in a high rate environment (up to 500kHz/Straw)

◆ Possible multiplicity veto for triggering

The NA62 Straw Tracker

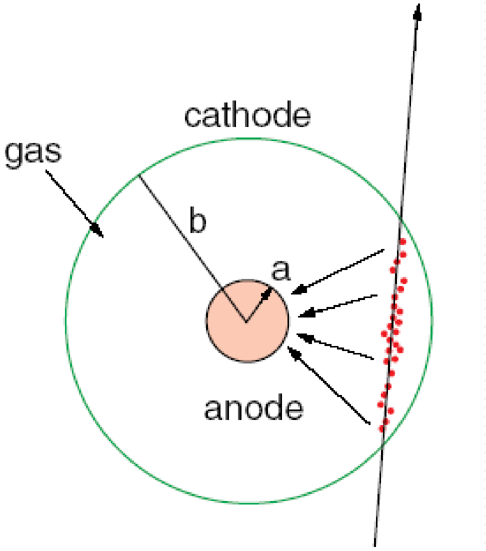
- Principle
- Straw Tube
  - Basic material
  - Ultrasound Welding,
  - Qualification (gas permeation, tensile strenth, creep, long time behavior, pressure test)
  - Validation of components under radiation
- Module design
  - Frame as part of vacuum vessel
  - Spacers, geometry control
  - Signal, Max rate, Front End, performance….

The straw

- Tube 2.1 meter with a diameter of 9.8 mm
- The base material is PET with thickness 36 µm

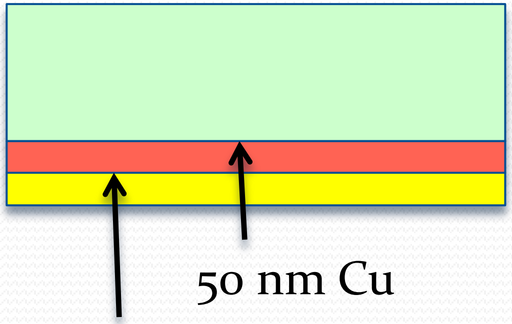
PET = Poly Ethylene Terephthalate

(Hostaphan (Mitsubishi) RNK 2600)



- The foil were coated on the inside with 50 nm of Cu and 20 nm of Au by sputtering at Fraunhofer FEP (Dresden, Germany)

36 µm Mylar (PET)



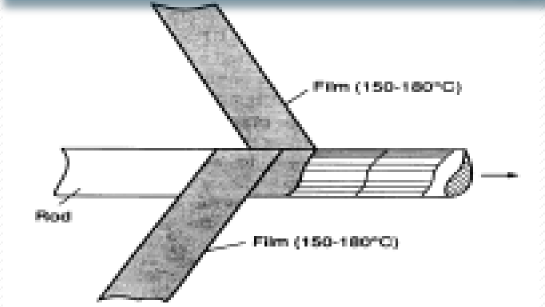
50 nm Cu

20 nm Au

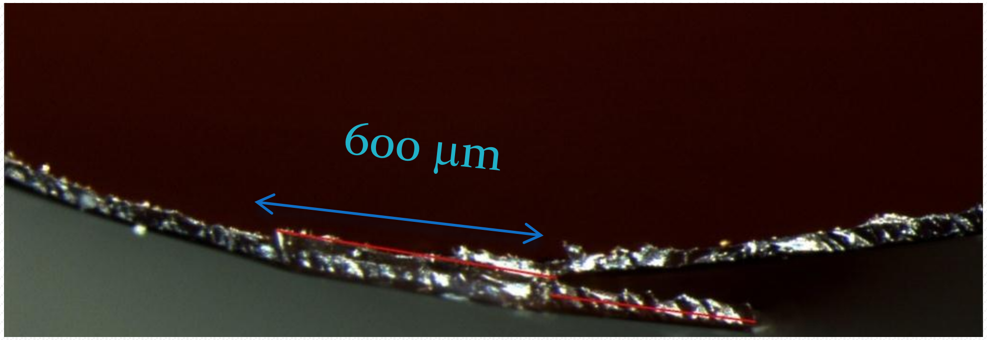
- The anode wire is 30 μm in diameter and made from gold-plated tungsten
- Gas mixture (non-flammable): a fast and a slow option were studied: Ar (70%)+ CO_2 (30%) and CO_2(90%) + CF_4(5%) + Isobutan(5%)

Ultrasonic welding of straws

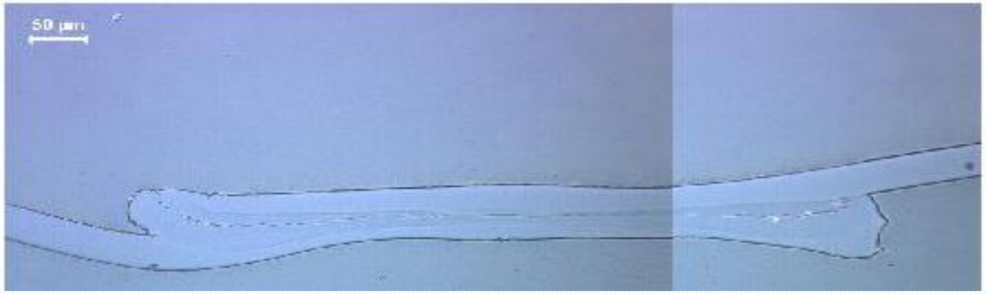
“Classical” straw winding



Microscope pictures of a straw cross- section for quality control of the weld

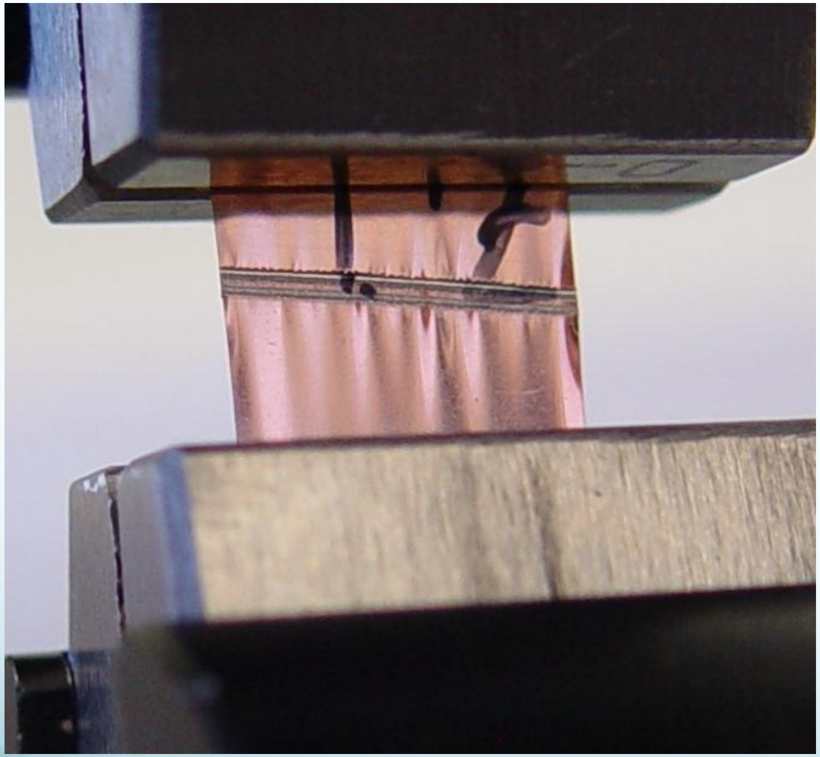


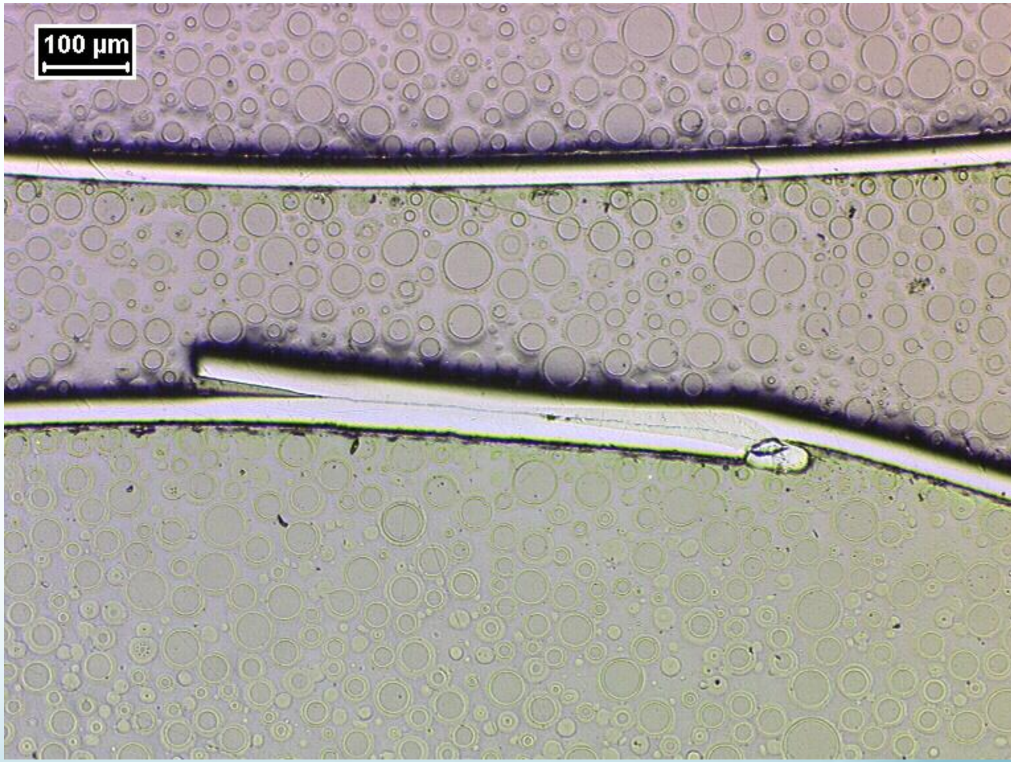
NA62 Ultrasonic welding
(Metalized PET)



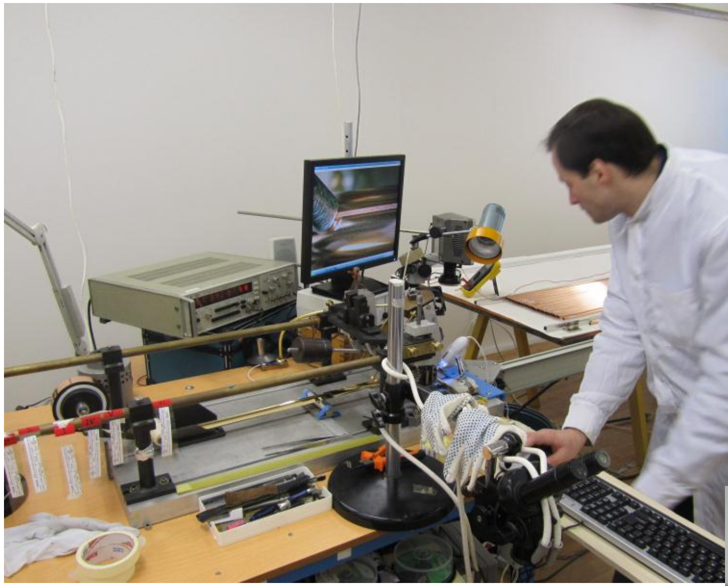
Delicate tuning of production parameters for welding

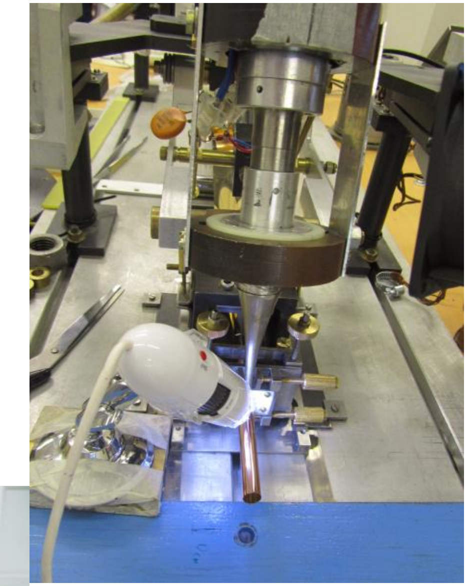
Ultra-sound weld validation



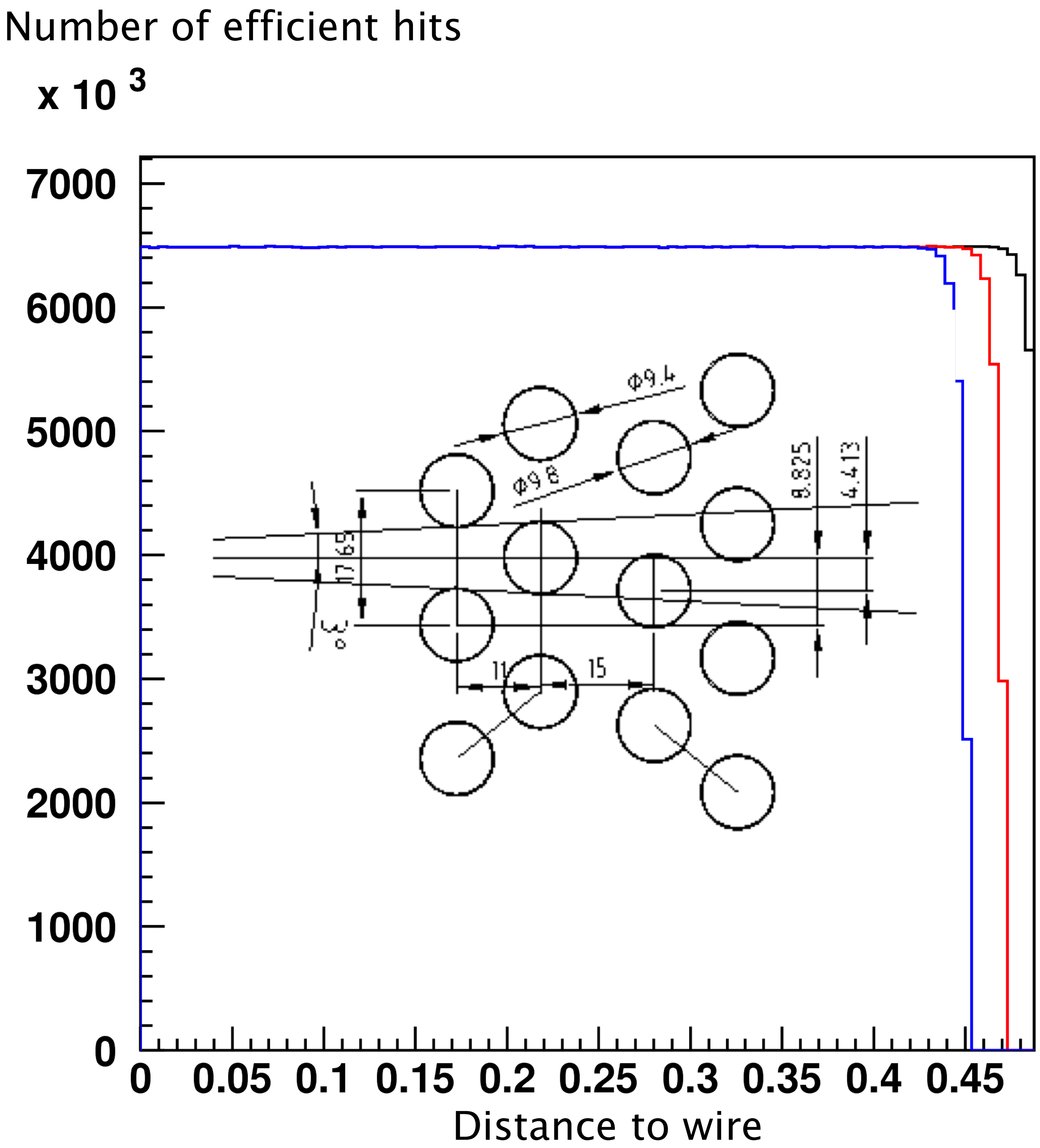


Straw production





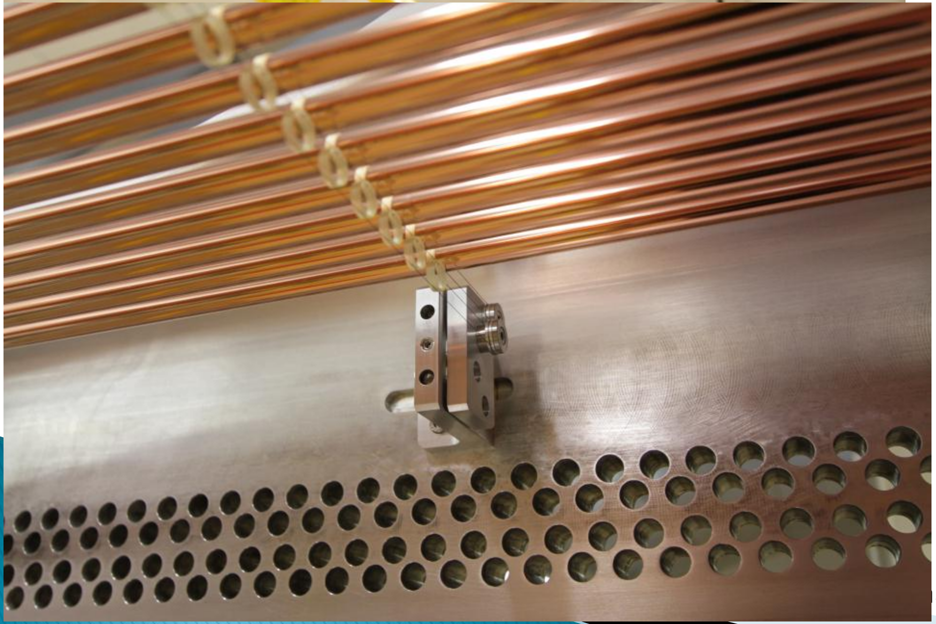
Straws are handled and transported under pressure



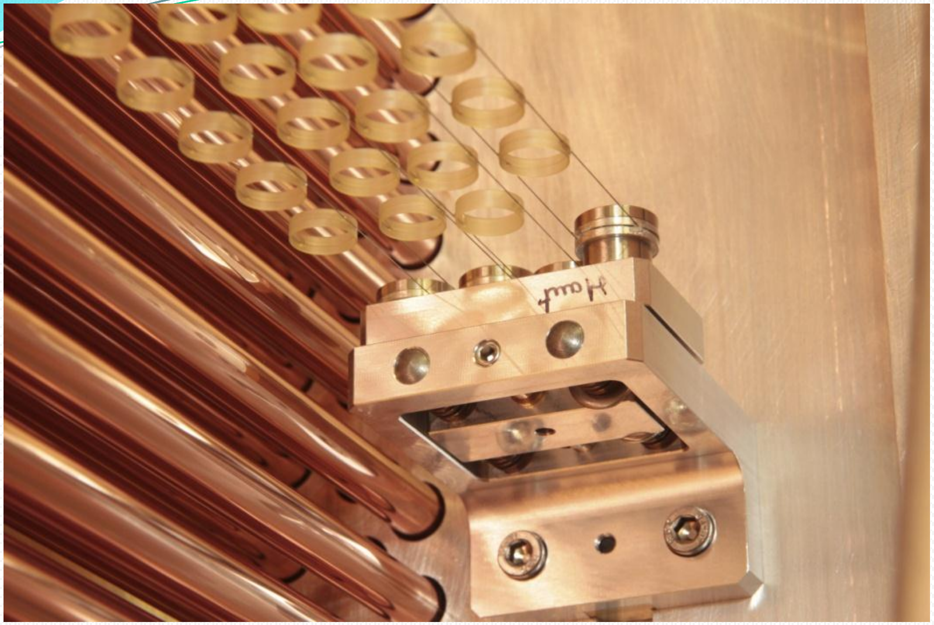
Efficiency variation: 0,200,400 μm of lost radius

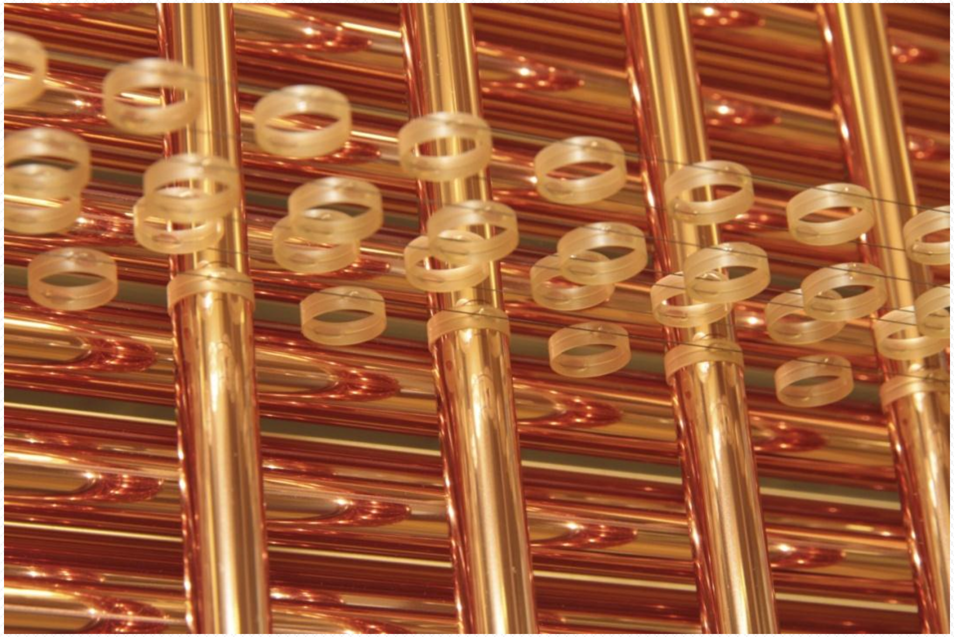
(Simulation)

Module assembly –straw insertion



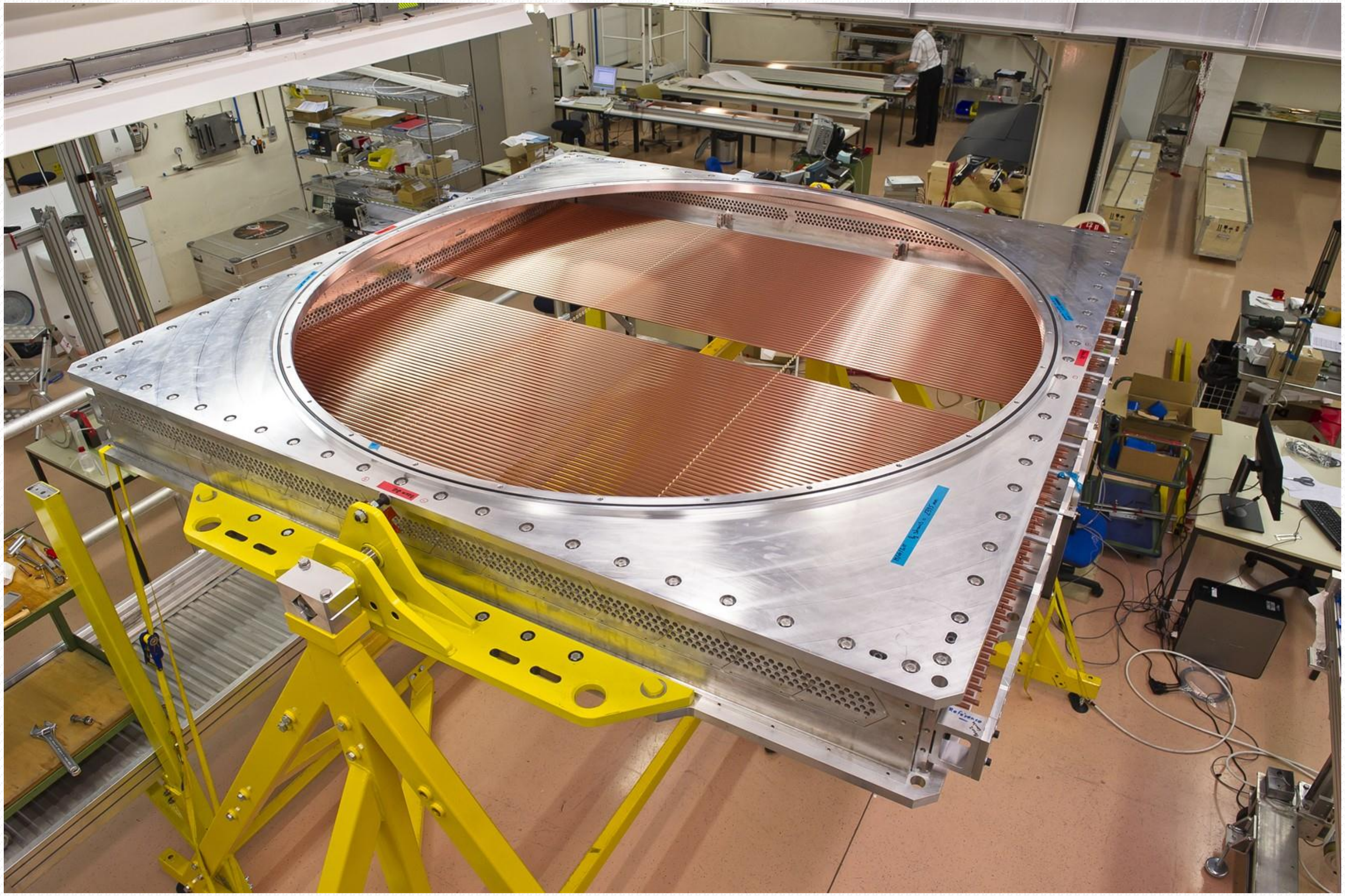
Spacers





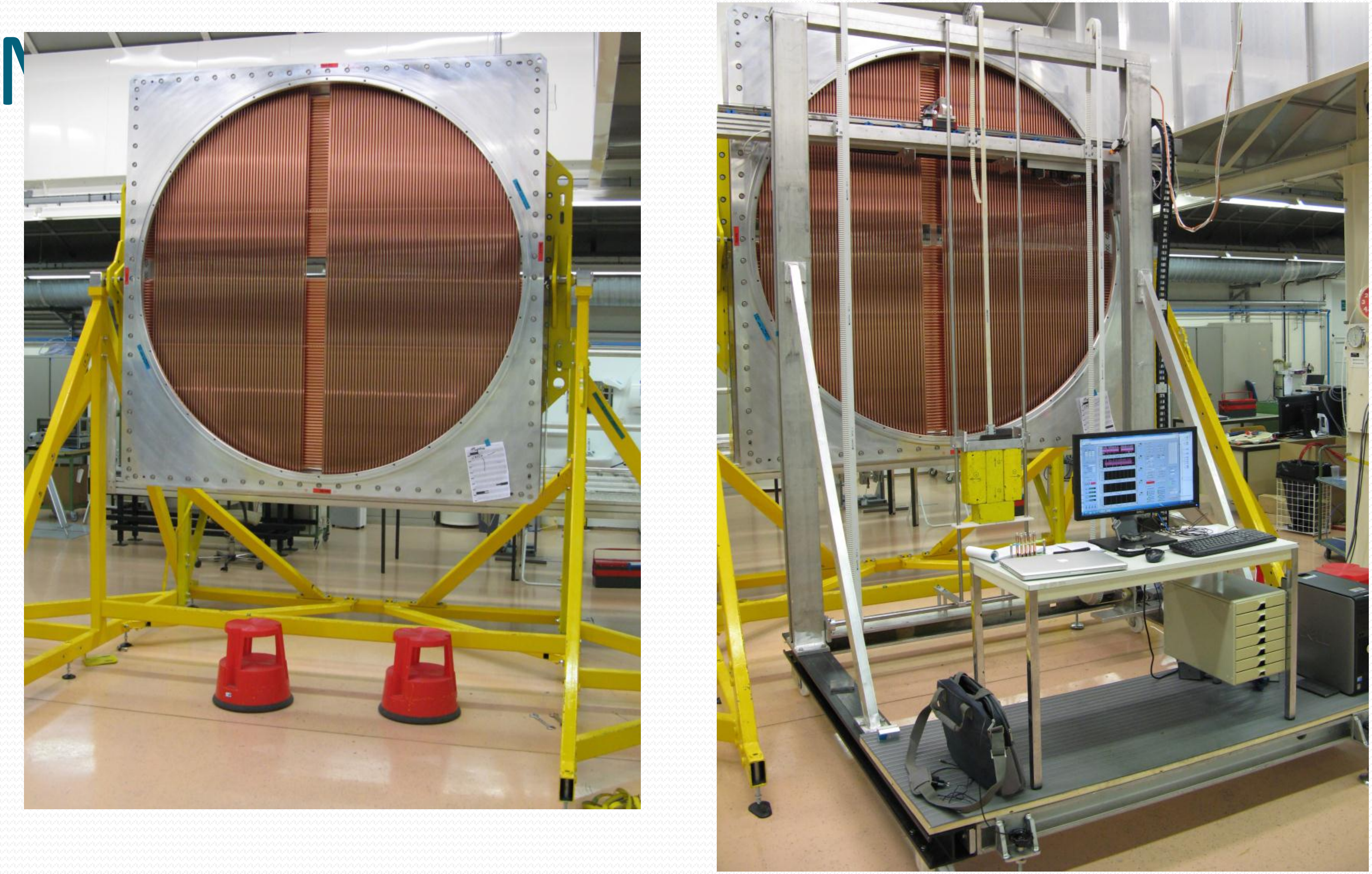
Courtesy of Hans Danielsson
PH-DT

Straw Module



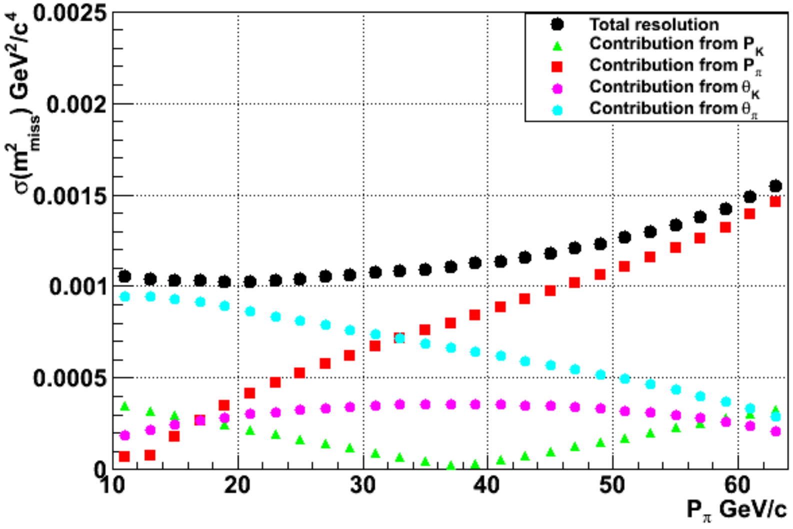
Straw Module

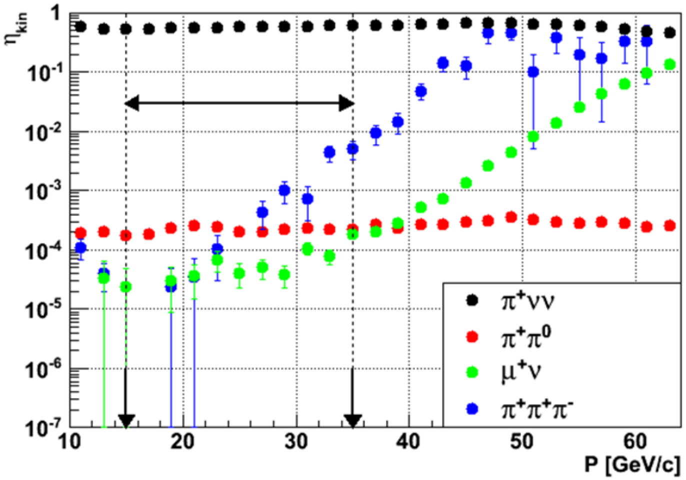
996 straws



NA62 Spectrometer Reconstruction

Giuseppe Ruggiero



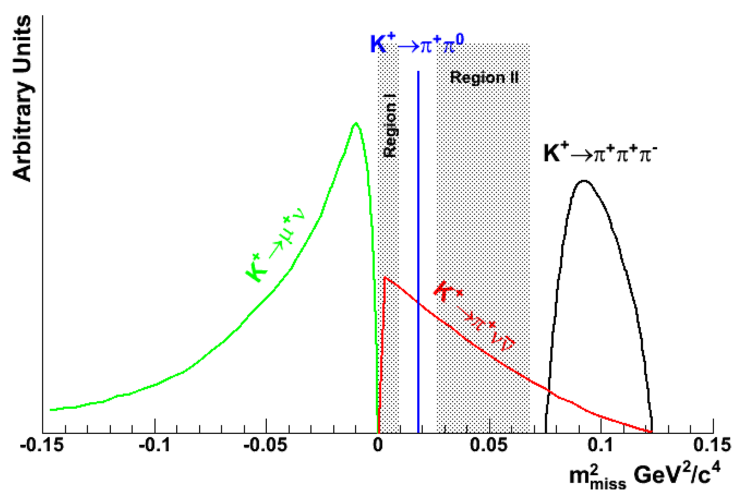


Missing Mass Resolution

Kinematic Rejection

- The simulation includes:
- Multiple and Single large angle Coulomb scattering
- δ-rays
- Elastic and inelastic nuclear interactions
- Errors in the straw spectrometer pattern recognition

Acceptances after Kinematic Selection



Channel	M^2_{miss} cut	Overall acceptance
$\pi^+\nu\bar{\nu}$	~0.57	~0.147
$\pi^+\pi^0$	$(2.2 \pm 0.5) \times 10^{-4}$	$(4.4 \pm 1.0) \times 10^{-5}$
$\mu^+\nu_\mu$	$(0.7 \pm 0.1) \times 10^{-4}$	$(1.0 \pm 0.1) \times 10^{-5}$
$\pi^+\pi^+\pi^-$	$(1.4 \pm 0.2) \times 10^{-4}$	$(6.9 \pm 2.0) \times 10^{-7}$

NA62 RICH

- $K_{\mu 2}$:largest BR: 63.4%

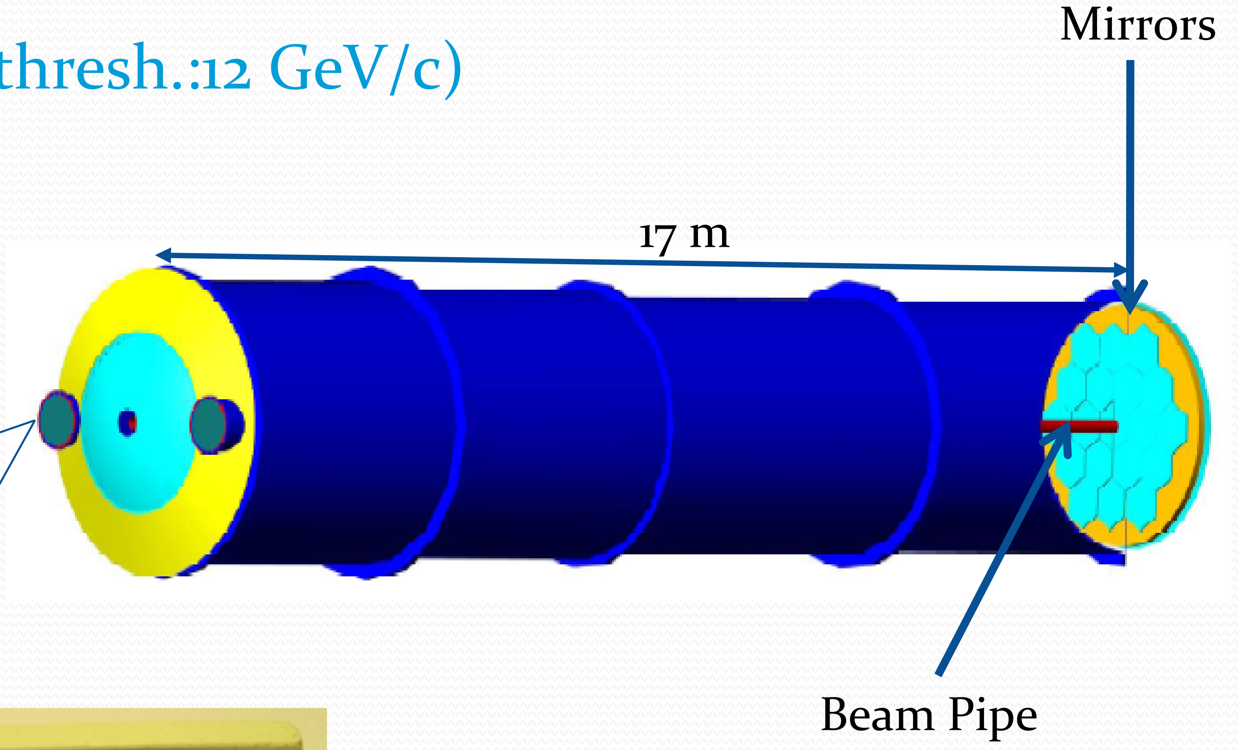
- Need ~10^{-12} rejection factor
  - Kinematics (GTK +STRAW) : 10^{-5}
  - Muon Veto: 10^{-5}
  - Particle ID (RICH): 10^{-2}

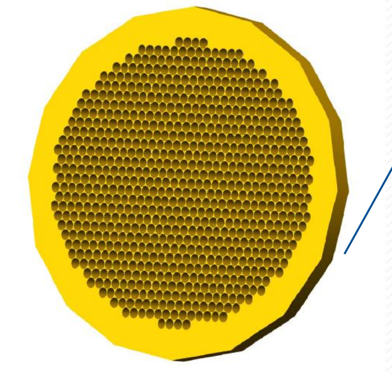
- Essential to match the pion track seen by the straw with track (kaon) seen by the beam spectrometer (rate: 800 MHz)
- To avoid a wrong match which spoils the kinematic suppression, the RICH must measure the pion time to 100 ps or better to connect to the kaon measured in the GTK

The NA62 RICH

3σ π–μ separation (15-35 GeV/c)

- Neon at 1 atm (π thresh.:12 GeV/c)
- 2000 PMT
- 18 mm pixel
- 100 ps

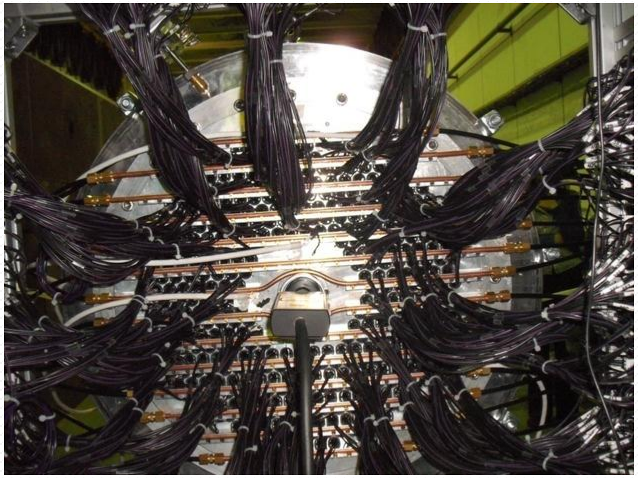




PMT: Hamamatsu R7400 U03

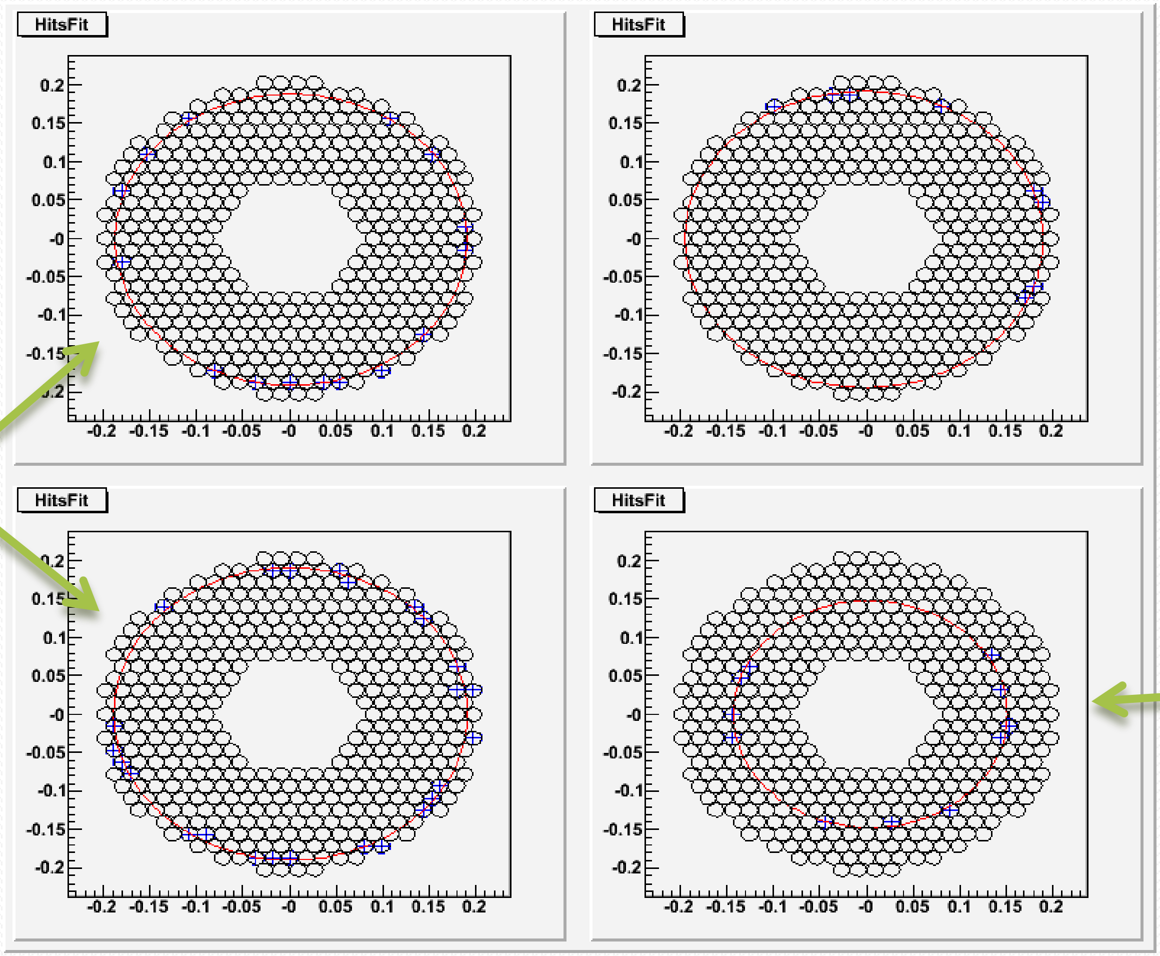
NA62 RICH prototype

- 17 m long, 0.6 m wide cylindrical vessel
- 17 m focal, 0.5 m wide mirror
- 96(2007) or 414(2009) PM
- Vessel evacuated, then Neon filled
- Prototype placed along the old NA48 beam line at CERN



RICH-400: fitted rings

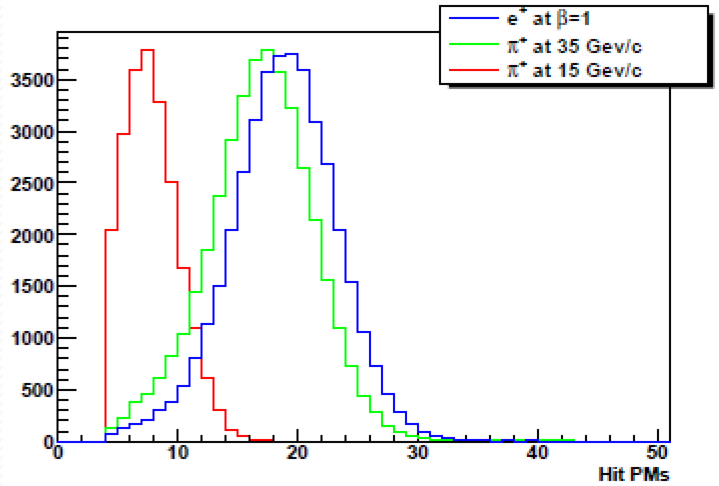
20 GeV/c

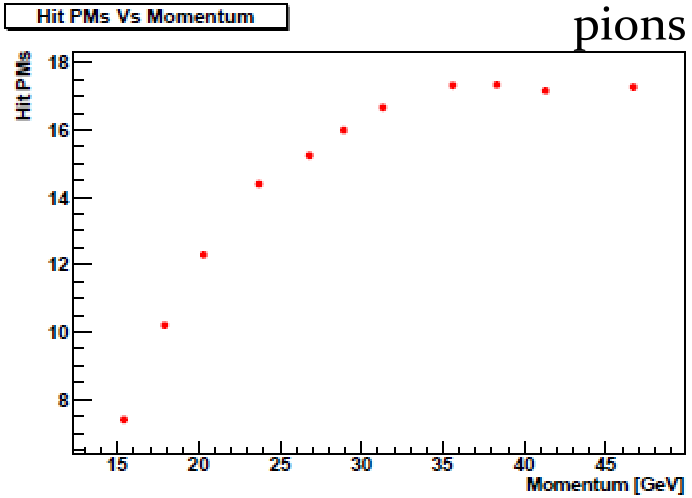


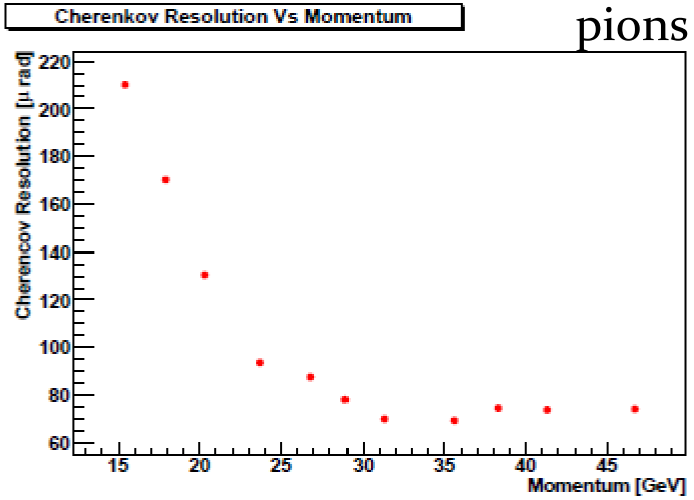
positrons

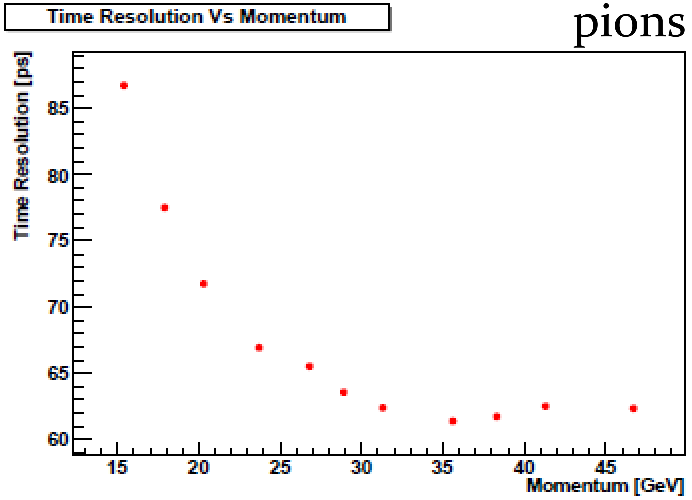
pion

RICH400: performance

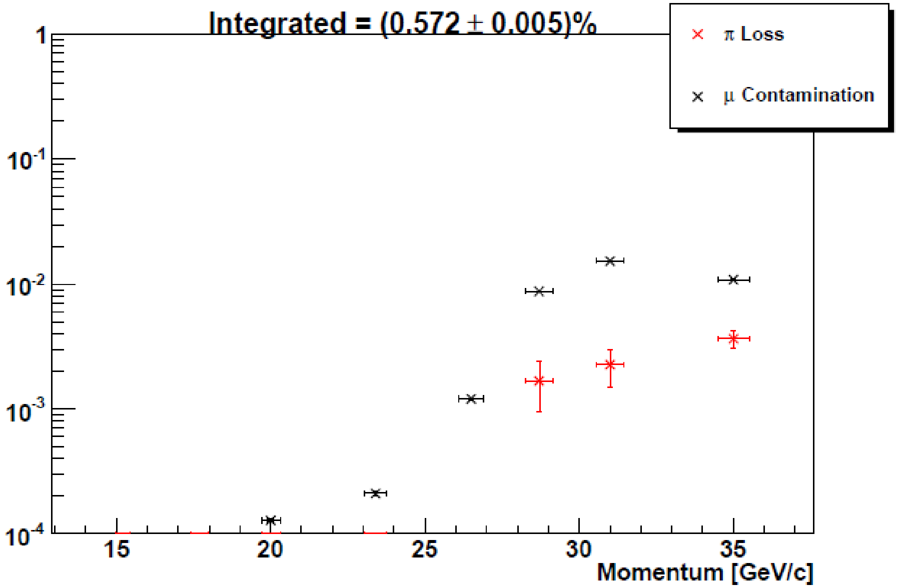



pions


pions

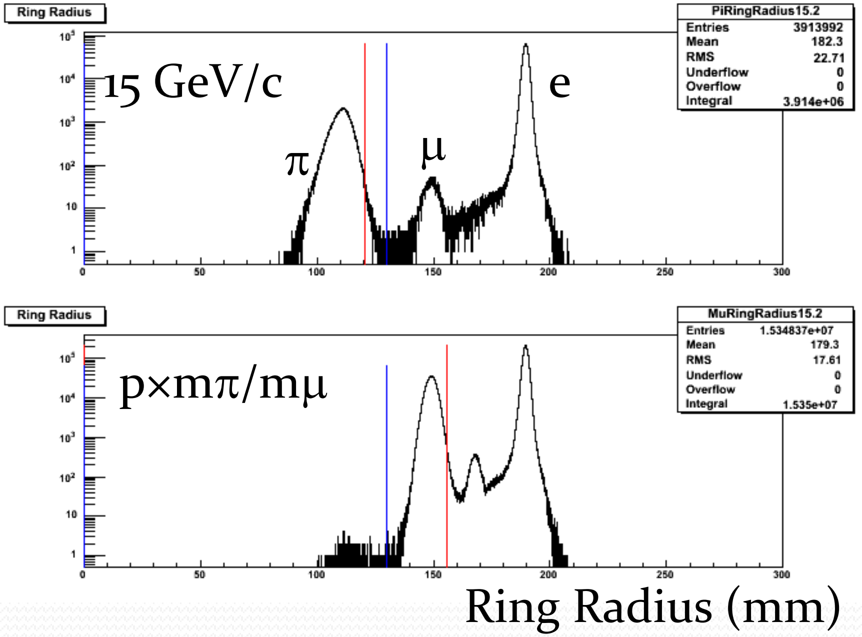

pions

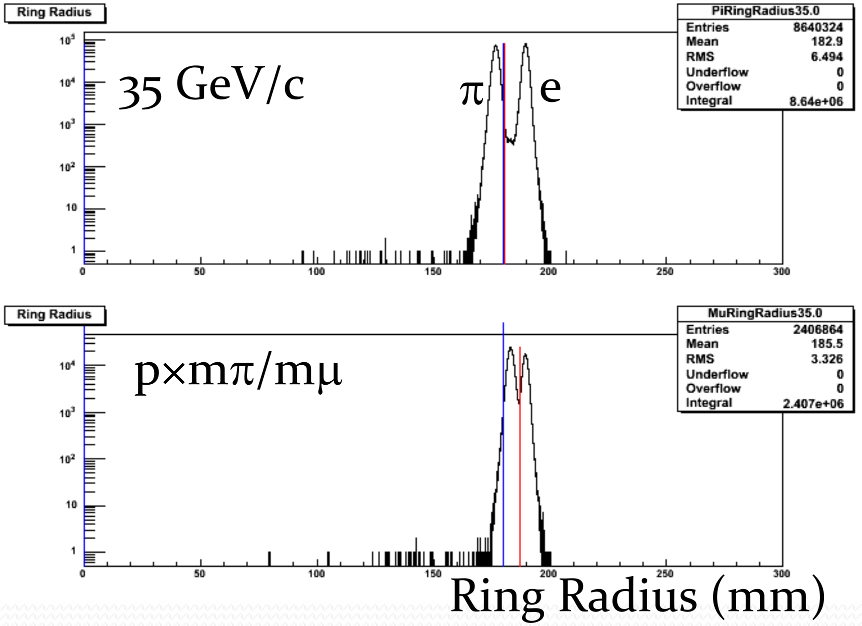
RICH-400: results



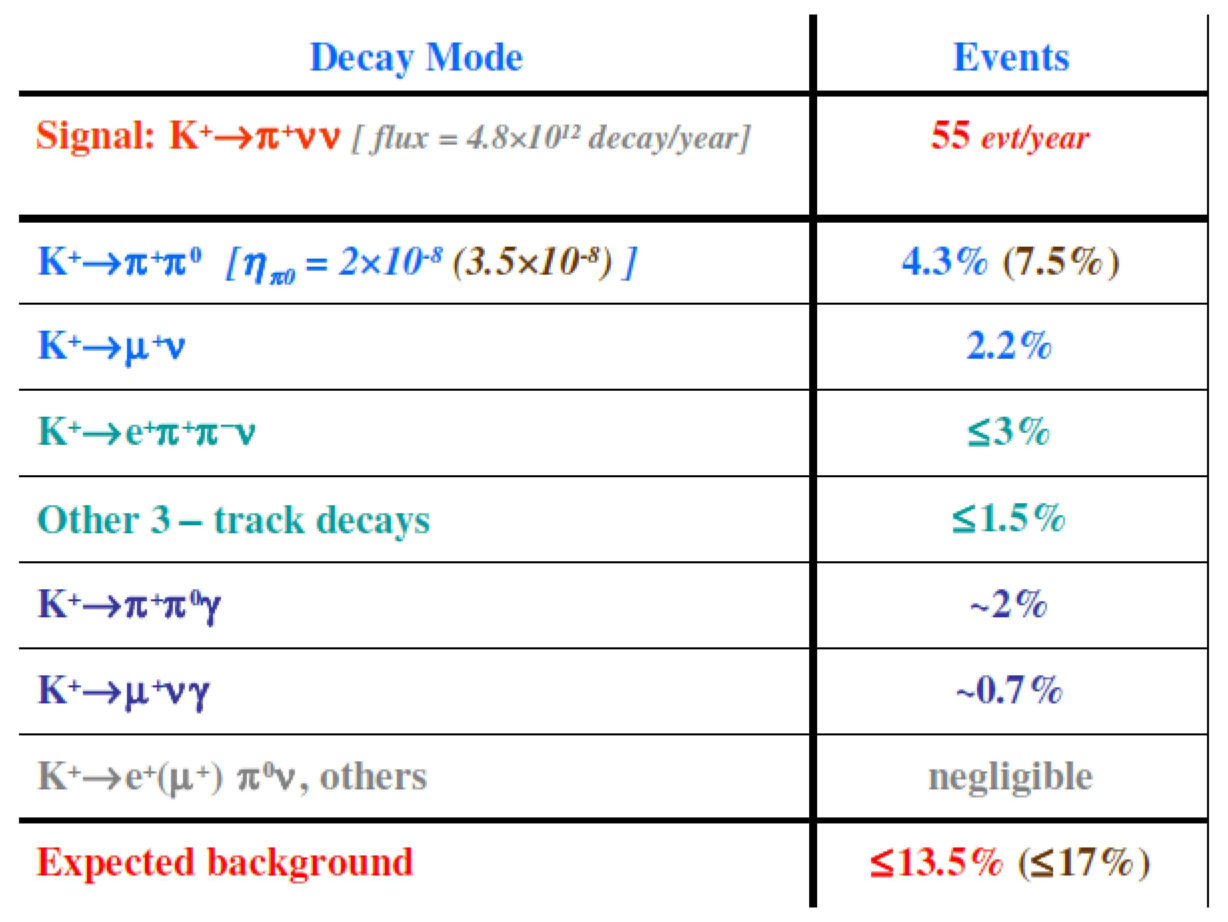
Muon suppression (15-35 GeV/c): 0.7%

B. Angelucci et al., NIM A621 (2010) 205-211





NA62 Sensitivity



Decay Mode	Events
Signal: $K^+\to\pi^+\nu\nu$ *[flux = 4.8×10^{12} decay/year]*	55 *evt/year*
$K^+\to\pi^+\pi^0$ *[$\eta_{\pi0} = 2\times10^{-8}$ (3.5×10^{-8})]*	4.3% (7.5%)
$K^+\to\mu^+\nu$	2.2%
$K^+\to e^+\pi^+\pi^-\nu$	≤3%
Other 3 – track decays	≤1.5%
$K^+\to\pi^+\pi^0\gamma$	~2%
$K^+\to\mu^+\nu\gamma$	~0.7%
$K^+\to e^+(\mu^+)\ \pi^0\nu$, others	negligible
Expected background	≤13.5% (≤17%)

Future Projects

- e^+e^- Super-Flavour Factories
  - Italian SuperB
  - Japanese KEK/Belle II
- LHCb Upgrade
- Fermilab Project X

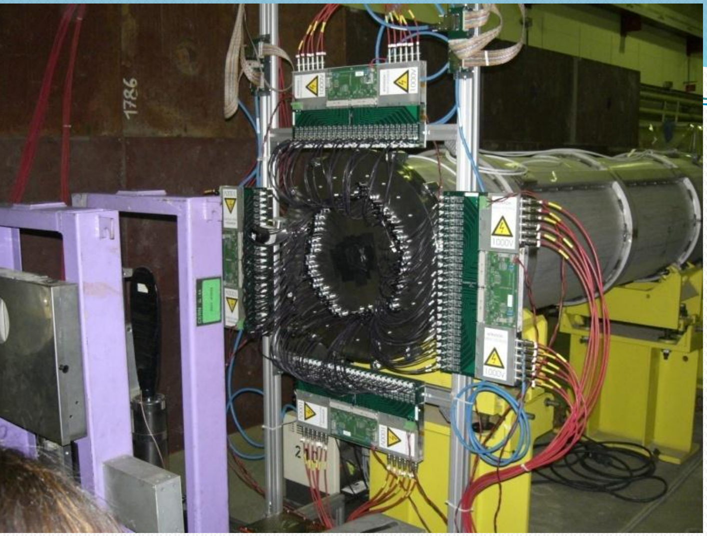
Rare Decay Experiments: Summary

- In this lecture I have reviewed a few examples of modern detectors employed to study rare decays / processes
- I made no attempt to be exhaustive. The frontiers of particle physics have a large mixing angle: for instance rare decays of D and B mesons and τ leptons are studied at hadron and

  $e^+ e^-$ colliders
- We have seen that a broad, world-wide, experimental program exists to push the science of rare processes at existing and planned proton facilities
- The bottom line is that high intensity and rare decay experiments tend to be tailored to perform a specific measurement, a lot of ingenuity and care to detail is required!

Spares

RICH-100 Prototype

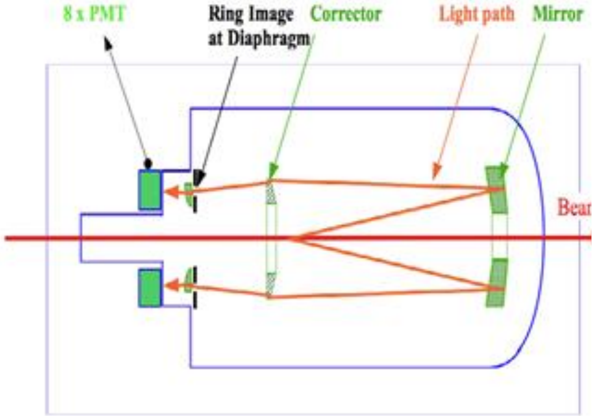


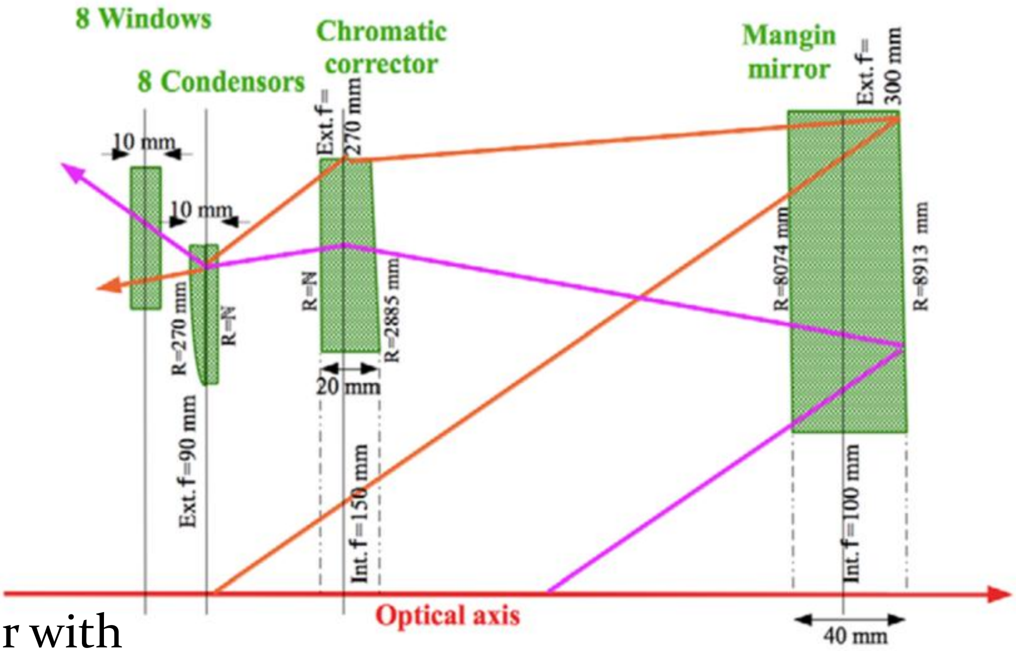
96 PMT

π^- p=200 GeV/c (SPS)
CERN Cavern ECN3

Mirror f=17 m

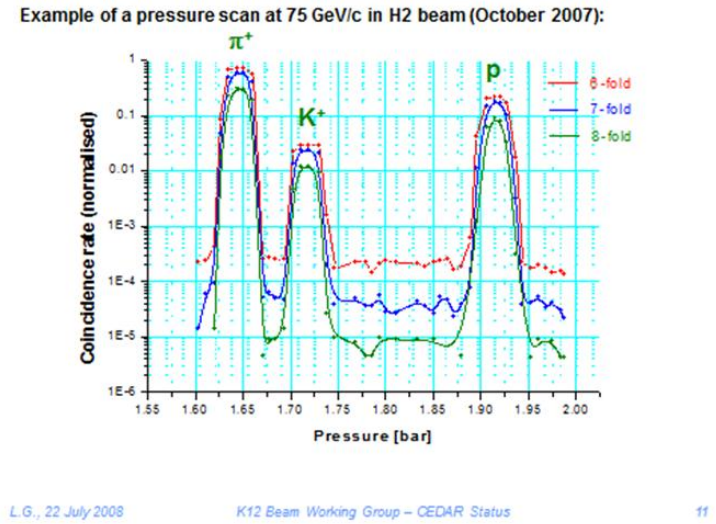
CEDAR





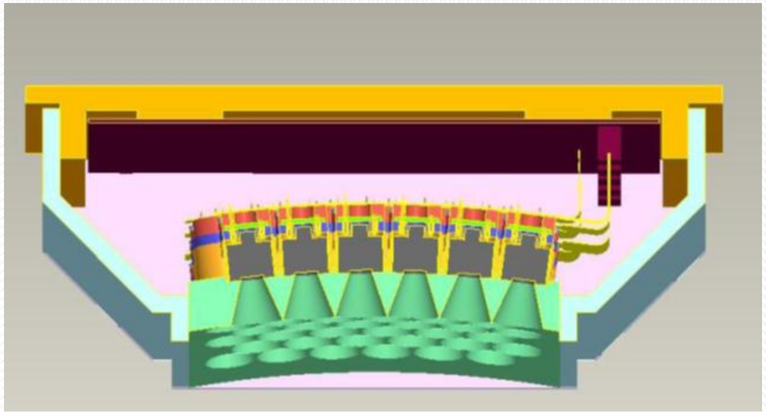
The Differential Cherenkov Counter with Achromatic Ring focus (CEDAR) was developed at CERN in the 80’ to operate up to a few MHz tagging rates

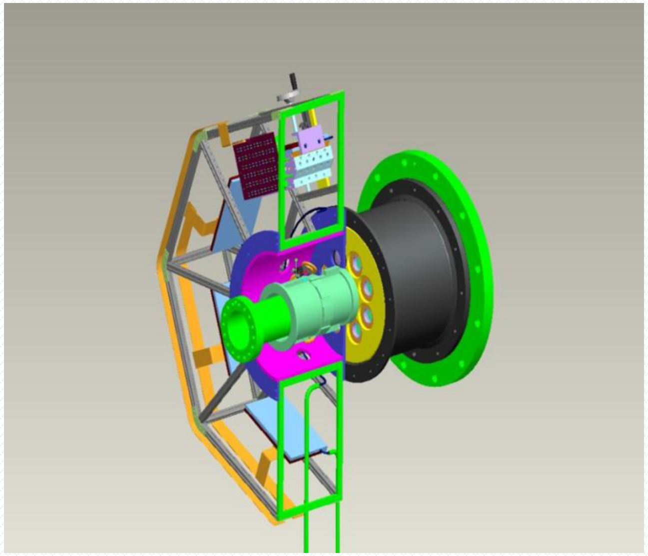
Mangin mirror (negative meniscus with reflecting surface on the rear surface) and chromatic corrector

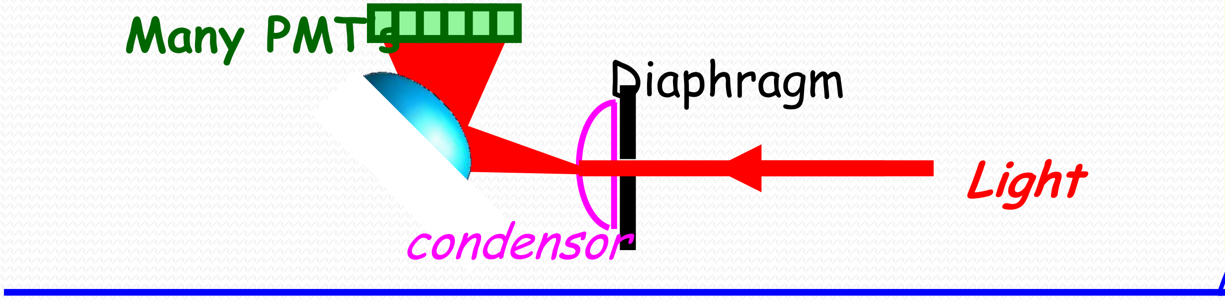

Example of a pressure scan at 75 GeV/c in H2 beam (October 2007):

KTAG=CEDAR + new optics

With 50 MHz kaon rate one must spread the photon rate on many photo-detectors (PMTs)







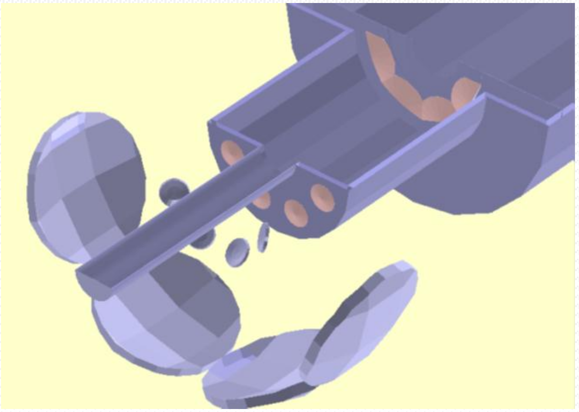
Many PMTs

Diaphragm

Light

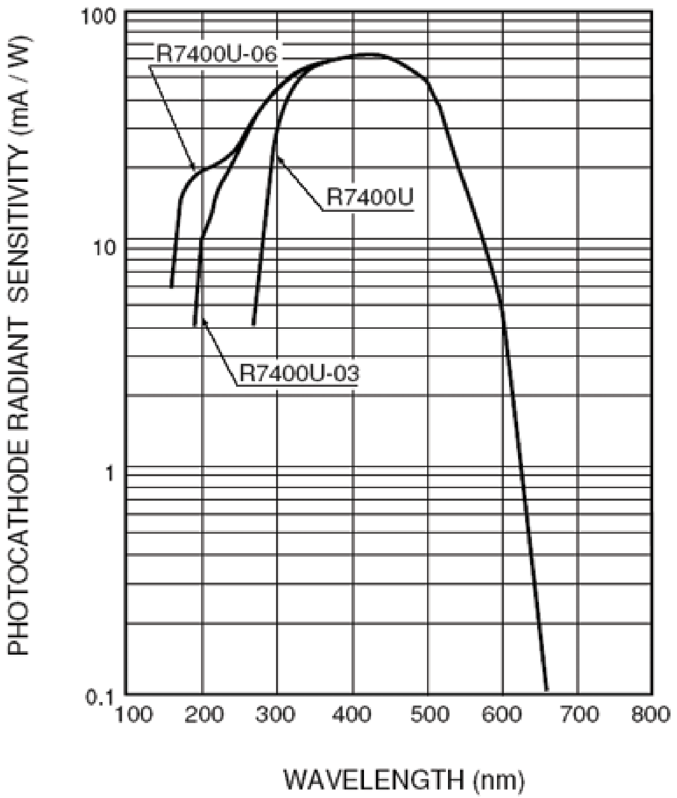
condensor

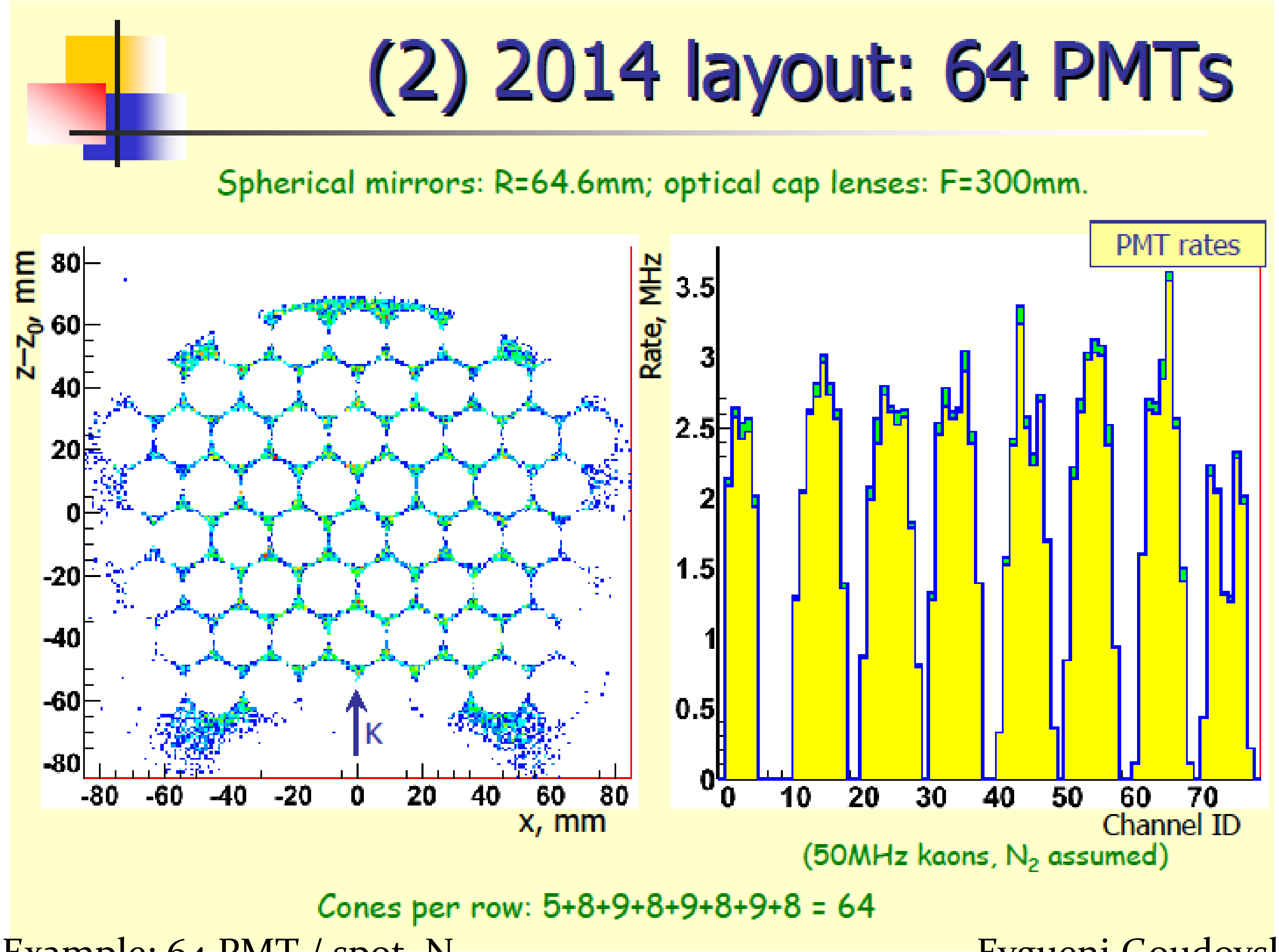
Beam



The Photomultipliers

- Hamamatsu R7400U-03
- UV-glass, bialkali, 8 dyn
- 16 mm wide (8 mm active)
- Gain 1.5 10^{+6} @900 V
- 280 ps time jitter (FWHM)
- 185-650 nm response
  (420 nm peak)
- Q.E. around 20% on peak
- PM output (1 p.e.): 240 fC,
  peak at 200 μA or -10 mV (50 Ω)
- Rise time: 0.78 ns, fall time~1.6 ns





(2) 2014 layout: 64 PMTs

Spherical mirrors: R=64.6mm; optical cap lenses: F=300mm.

(50MHz kaons, N_2 assumed)

Cones per row: 5+8+9+8+9+8+9+8 = 64

Example: 64 PMT / spot, N_2

Evgueni Goudovski

Why Hydrogen in the KTAG

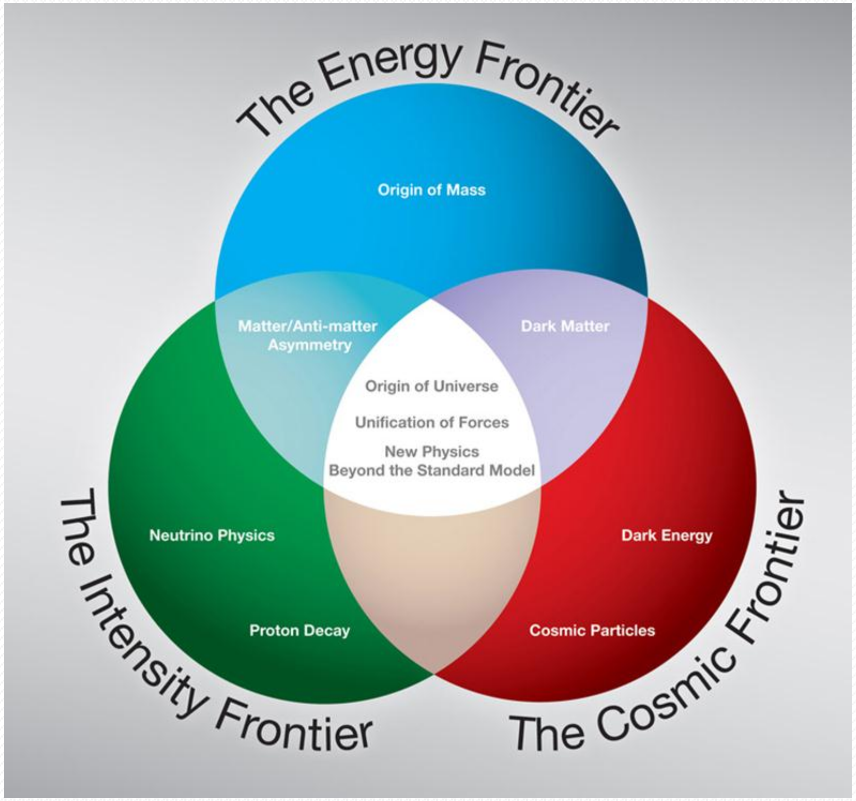
KTAG type	Gas filling P (bars)	Length (m)	Windows (Al)	Total X/Xo	X',Y' RMS (mrad)	Inel Scatt Probability
Cedar-W	Hydrogen 3	5.642	0.1+0.2 mm	$6.4\ 10^{-3}$ [20.8]	0.016 [0.029]	$1.2\ 10^{-3}$ [2.8]
Cedar-N	Helium 10	6.042	2 x 0.3 mm	$18.3\ 10^{-3}$ [32.7]	0.027 [0.036]	$6.5\ 10^{-3}$ [8.1]
Cedar-W	Nitrogen 1.7	5.642	2 x 0.1 mm	$33.0\ 10^{-3}$ [47.4]	0.036 [0.044]	$6.4\ 10^{-3}$ [8.0]
3 GTK	*Si*	*3x0.45 mm*	—	*14.4* 10^{-3}	*0.024*	*1.6* 10^{-3}

Lau Gatignon

Figures in [ ] include 3 GTK stations

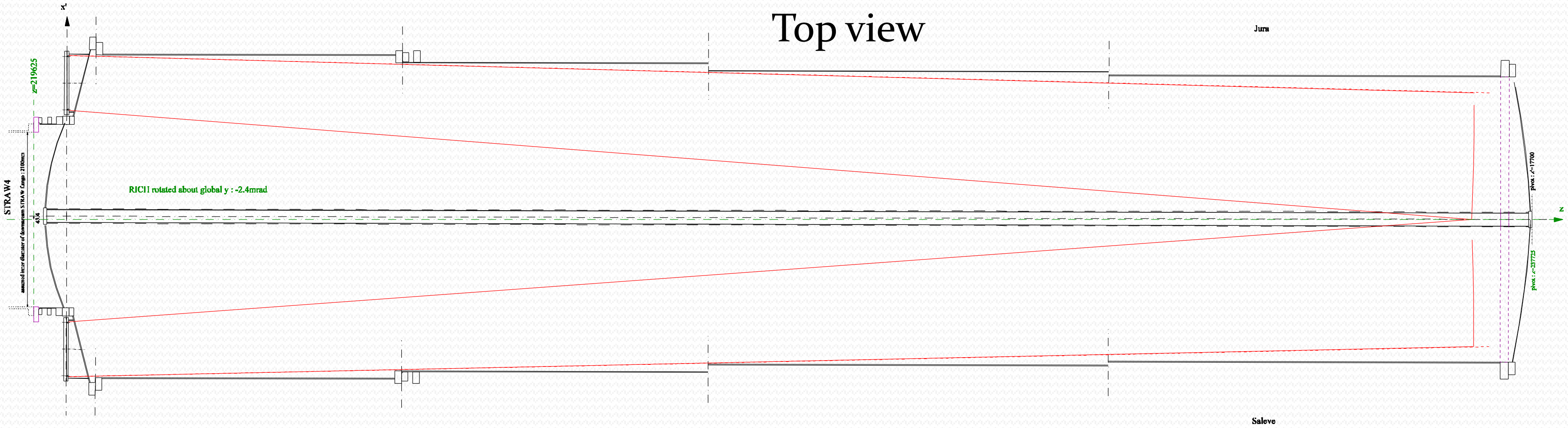
Forward

- Intense proton sources enable us to study processes which are either forbidden or extremely suppressed but well predicted in the Standard Model (SM)
- A measured deviation from the SM prediction would point to something new: rare processes in muon and kaon decays are particularly sensitive probes
- After an overview of the experiments under construction or planned at the intensity frontier….
- ….I will use the NA62 experiment at the CERN SPS, devoted to the study of kaon rare decays, to give you some examples of state-of-the-art detectors



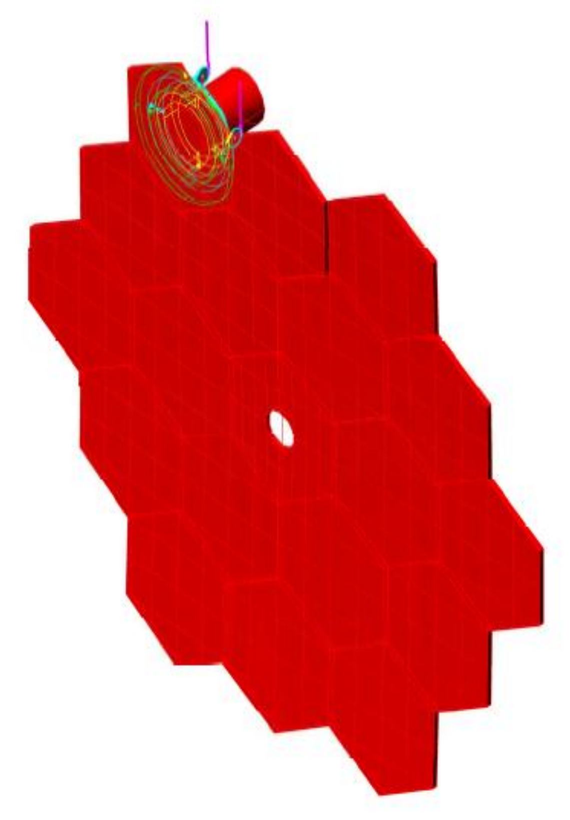
The RICH Vessel

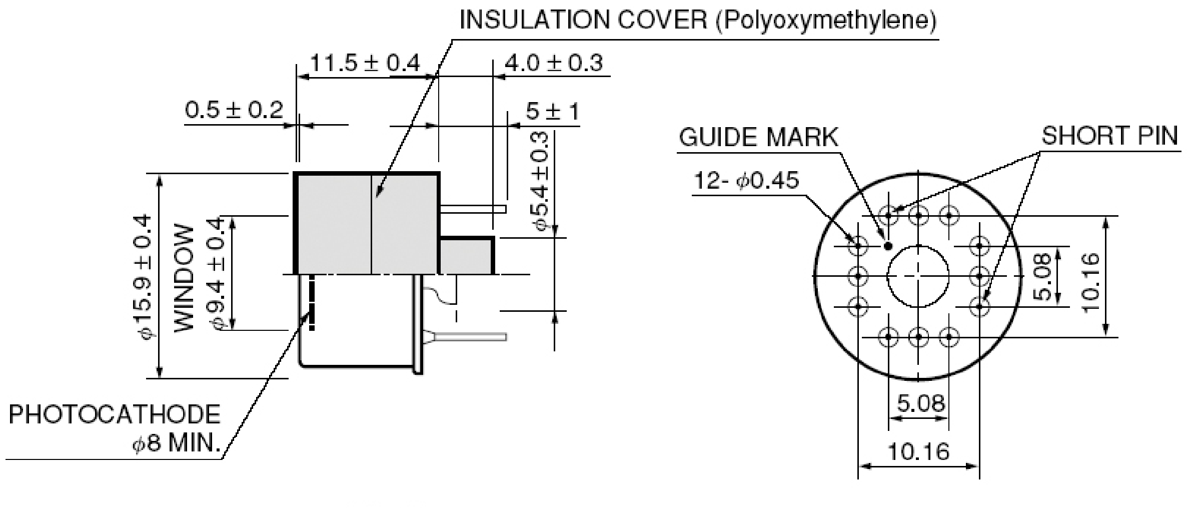
- 17 m long vessel in construction steel, vacuum proof
- max overpressure: 150 mbar
- ~4 m wide (beginning)
- beam pipe (Ø 16 cm) going through
- thin aluminium entrance and exit windows


Top view

The Mirror system

- 20 mirror pieces
- 18 hexagonal
- 2 semi-hex + pipe hole
- 700 mm wide, 25 mm thick glass
- 17 m focal lenght, D0<1 mm

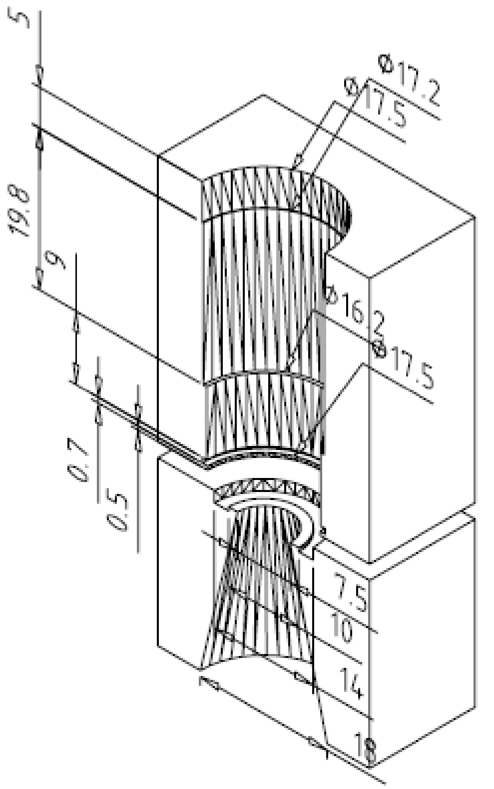


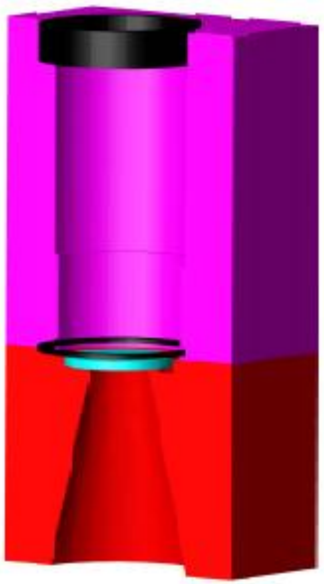


Side View

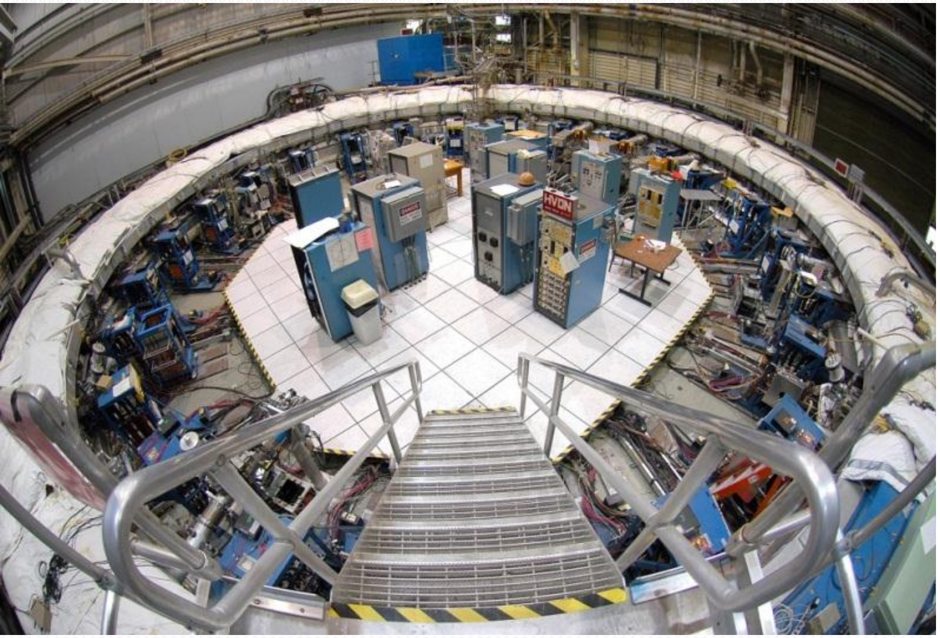
Bottom View

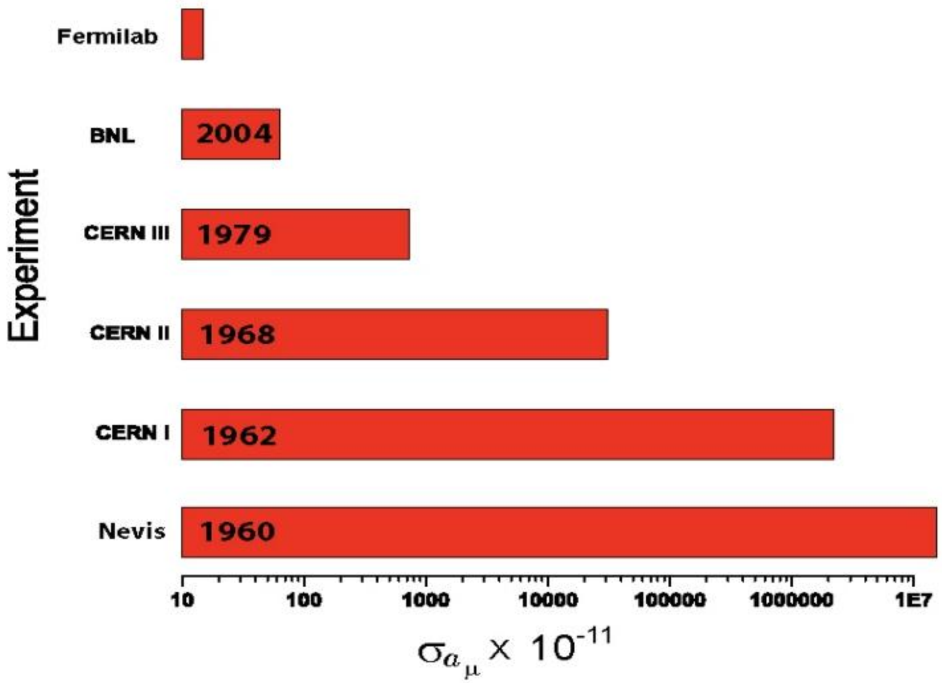
- 1000 PM packed per spot
- Cooling is an issue
- Light collection: Winston cones with aluminized mylar foil
- Quartz window to separate Neon from air
- O-rings for light tightness and thermal contact





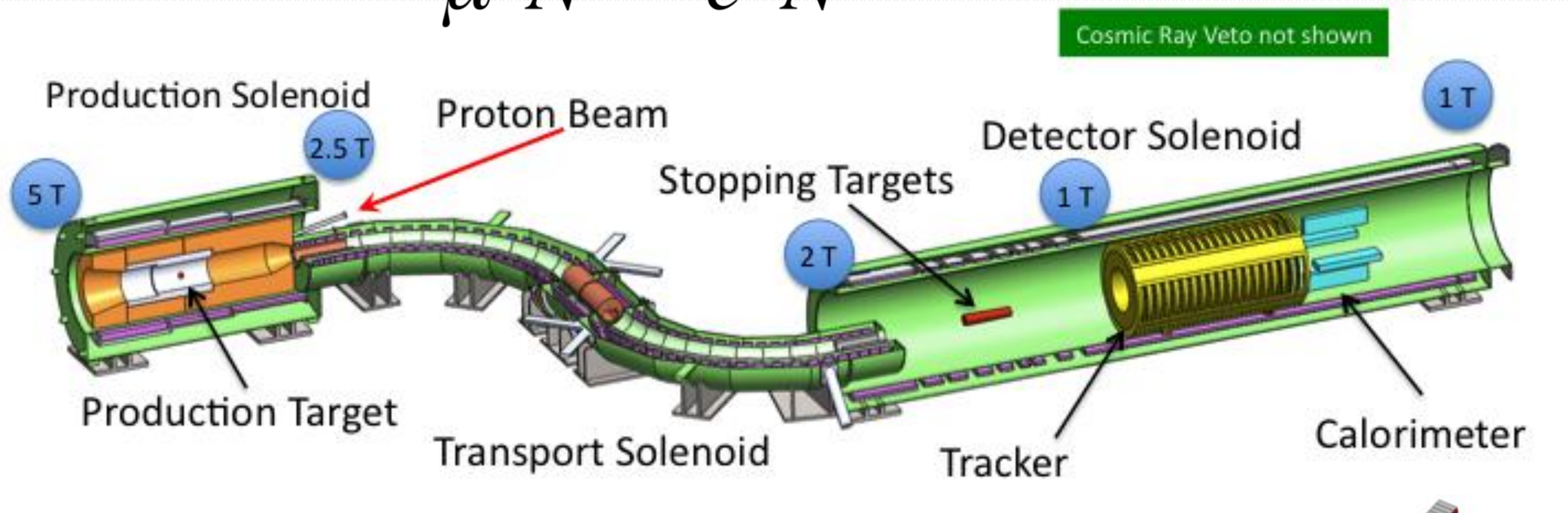
FNAL-E989: g-2 to 0.14 x 10^{-11}

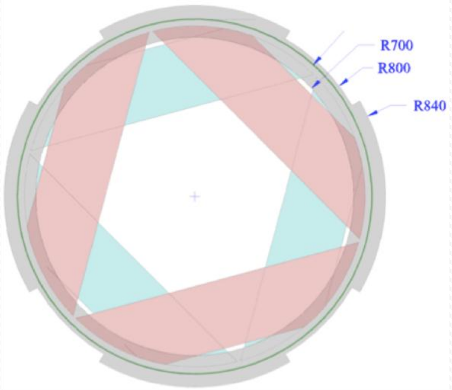




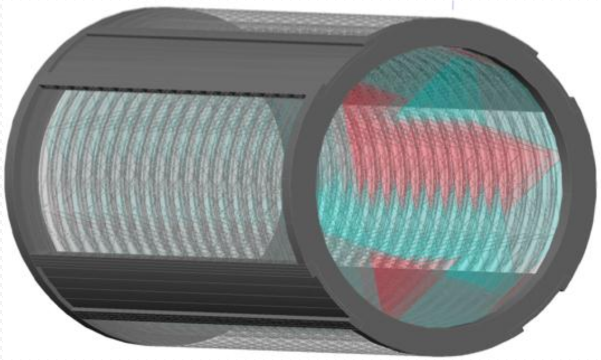
FNAL Mu2e: μ – e conversion

$$\mu^- N \rightarrow e^- N$$

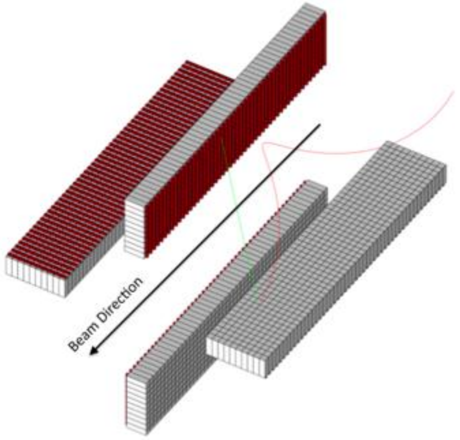




One Tracking Plane

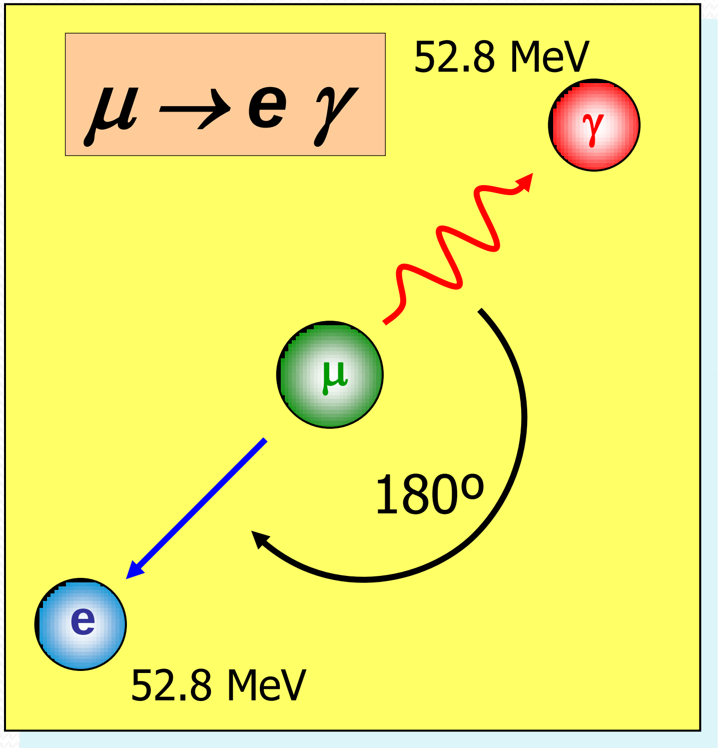


Straw Tracker



LYSO Calorimeter

MEG: Search for $\mu \rightarrow e\,\gamma$

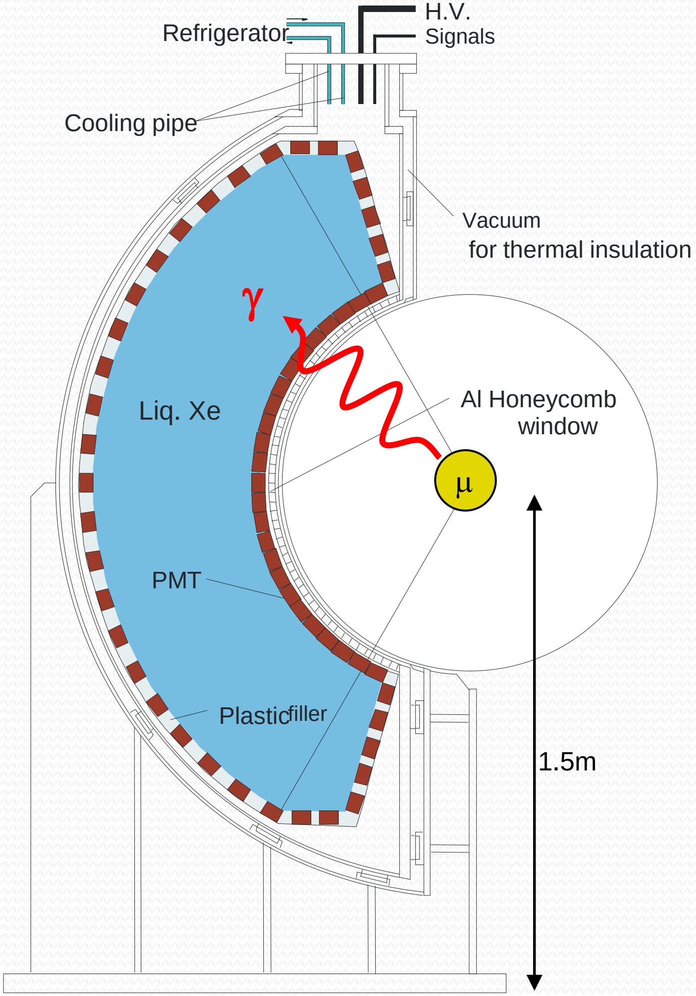


$\mu \rightarrow e\,\gamma$ signal very clean

- $E_g = E_e = 52.8$ MeV
- $\theta_{\gamma e} = 180^o$
- e and γ in time

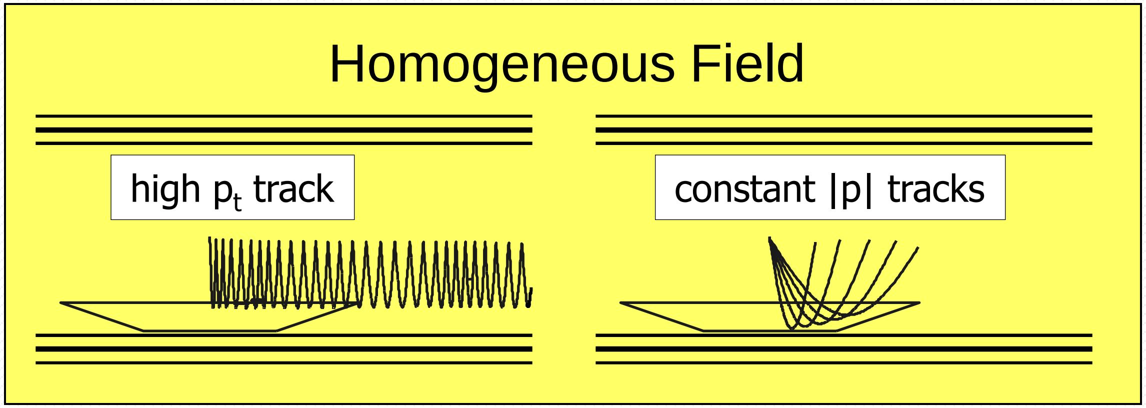
MEG Liquid Xenon Calorimeter

- Calorimeter: Measure γ Energy, Position and Time through scintillation light only
- Liquid Xenon has high Z and homogeneity
- ~900 l (3t) Xenon with 848 PMTs (quartz window, immersed)



Positron Spectrometer

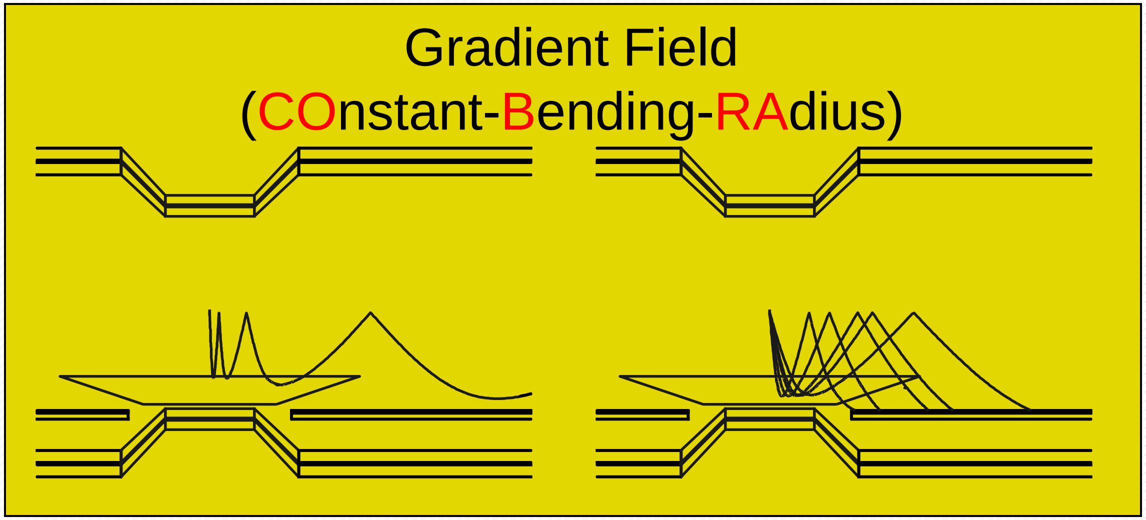
Ultra-thin (~3g/cm²) superconducting solenoid with 1.2



Homogeneous Field

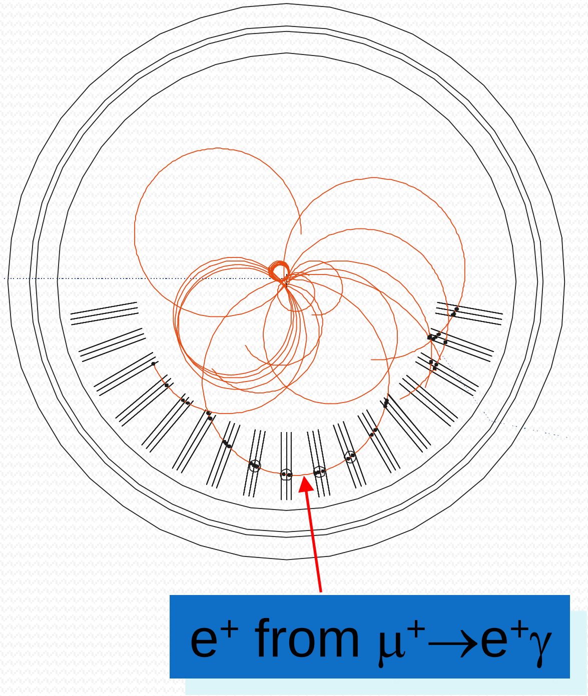
high p_t track

constant |p| tracks



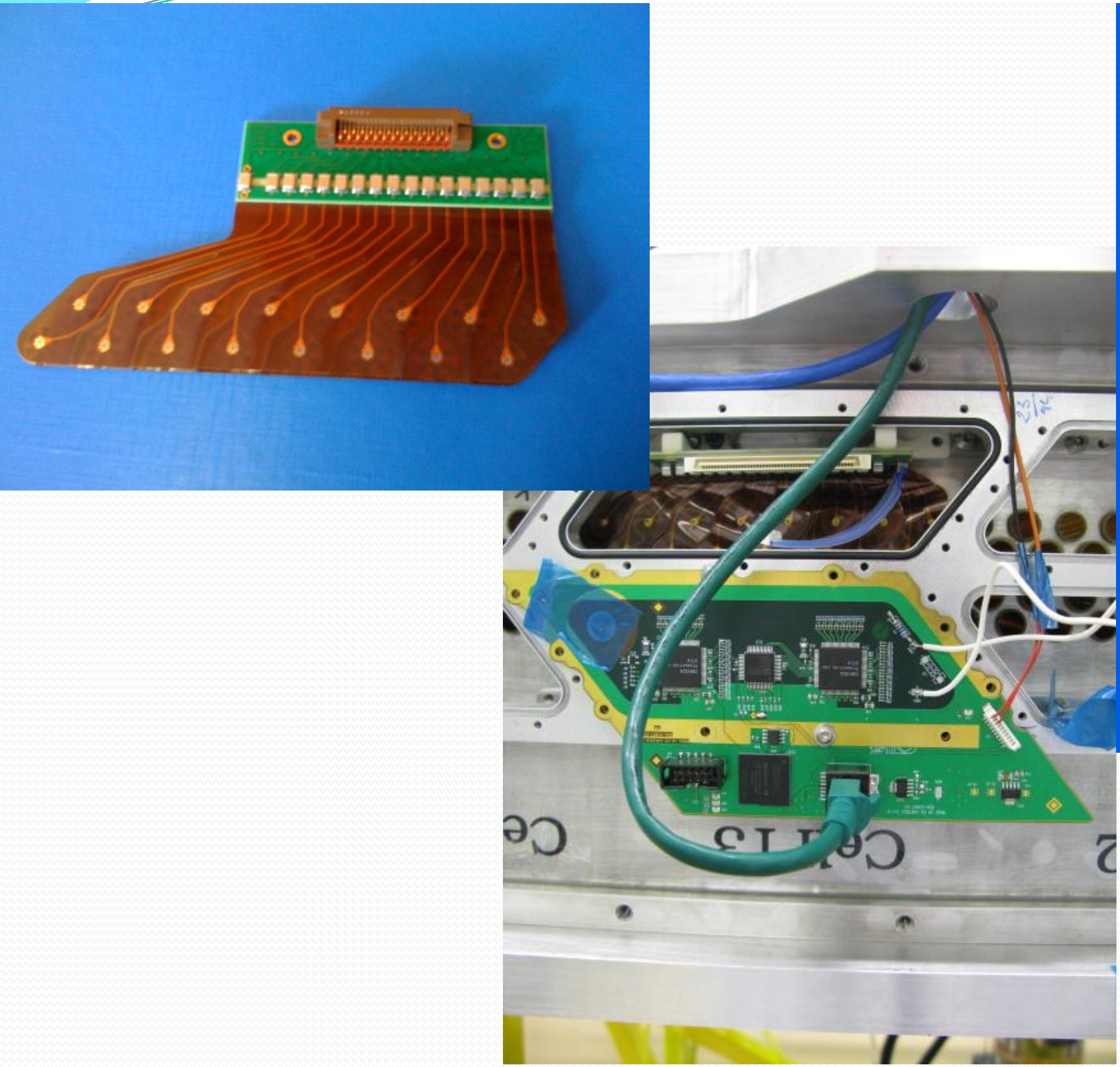
Gradient Field

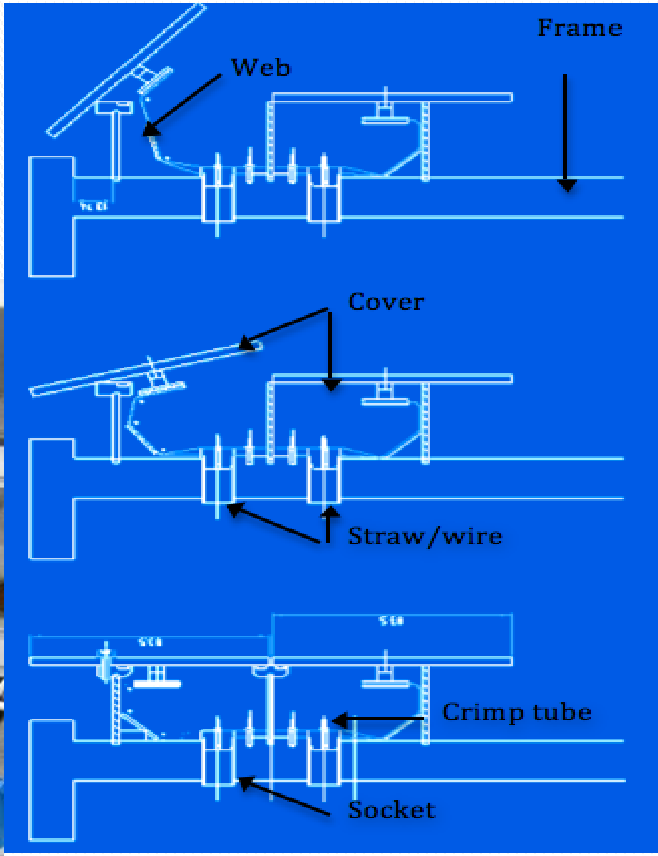
(COnstant-Bending-RAdius)



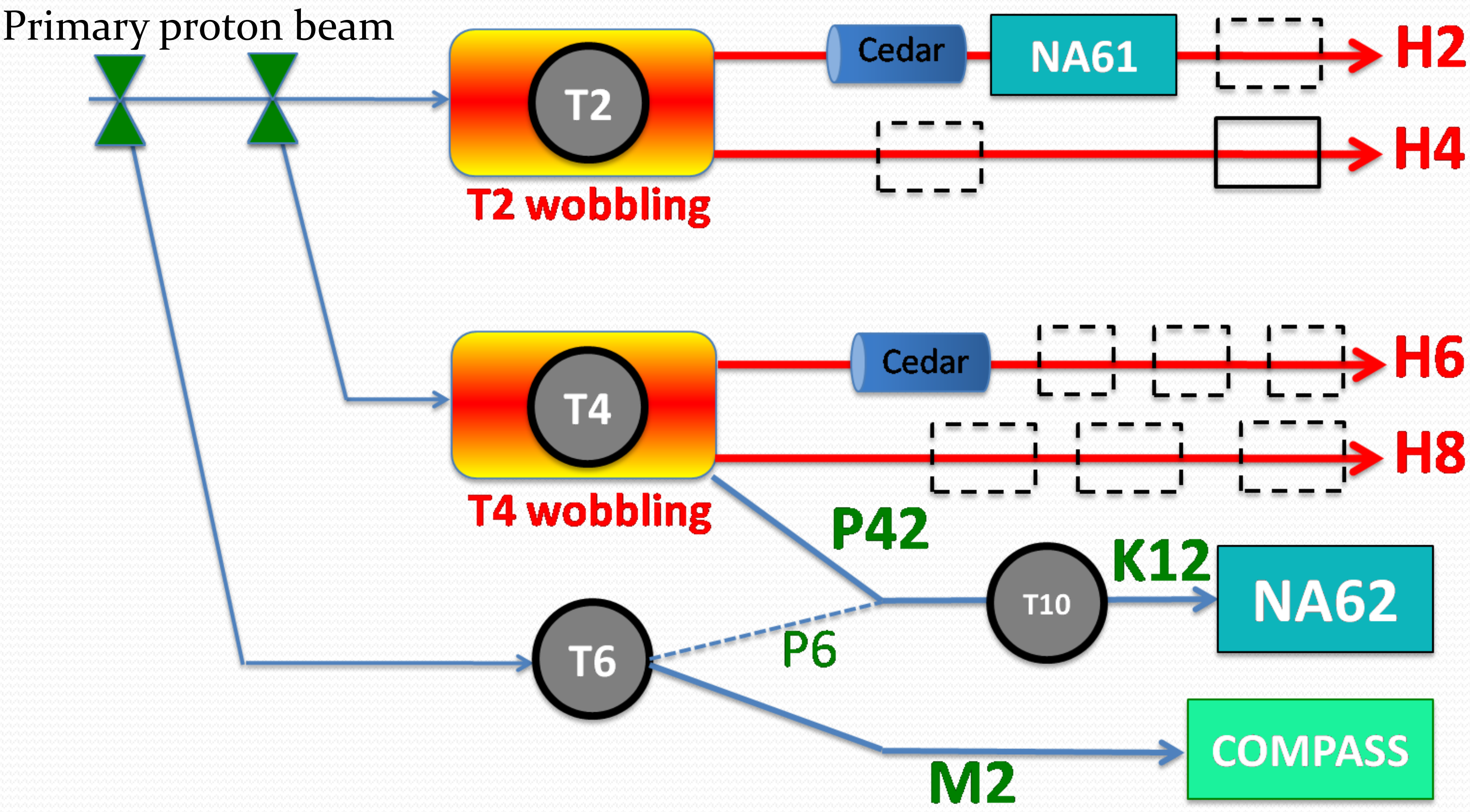
e^+ from $\mu^+ \rightarrow e^+\gamma$

Straw Connection to FE

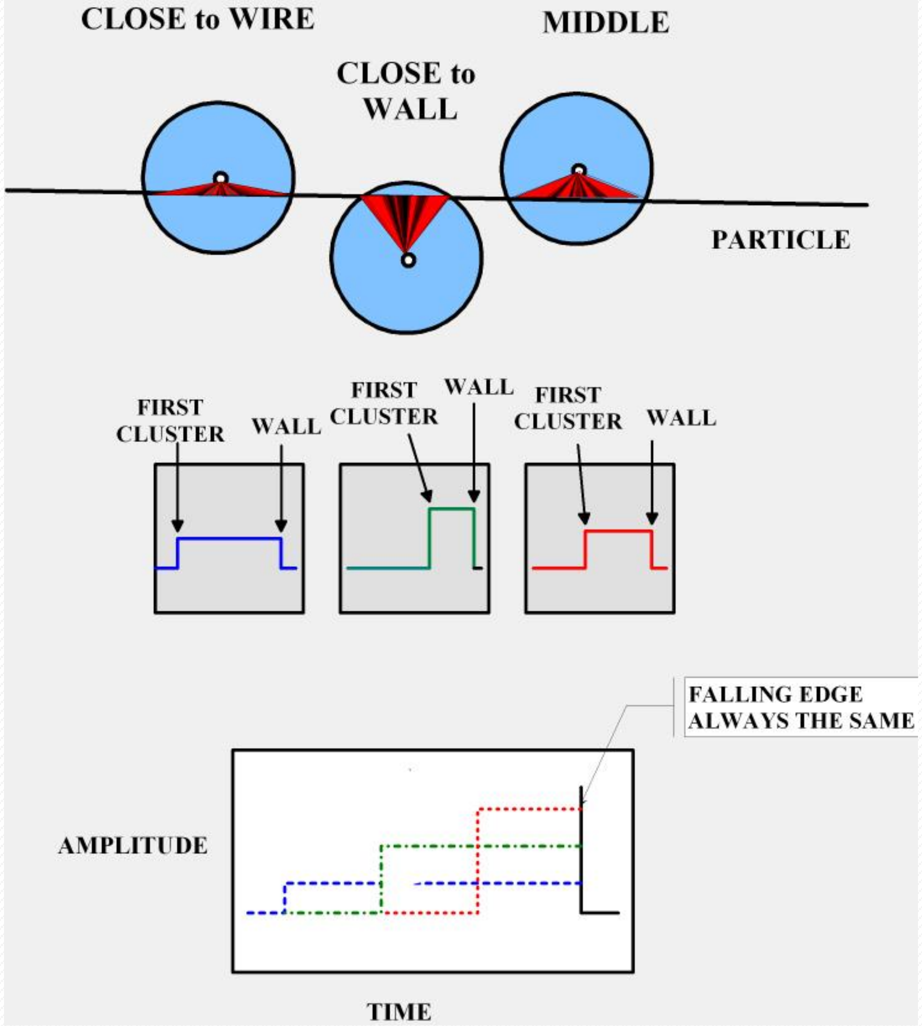




CERN-SPS North Area beams

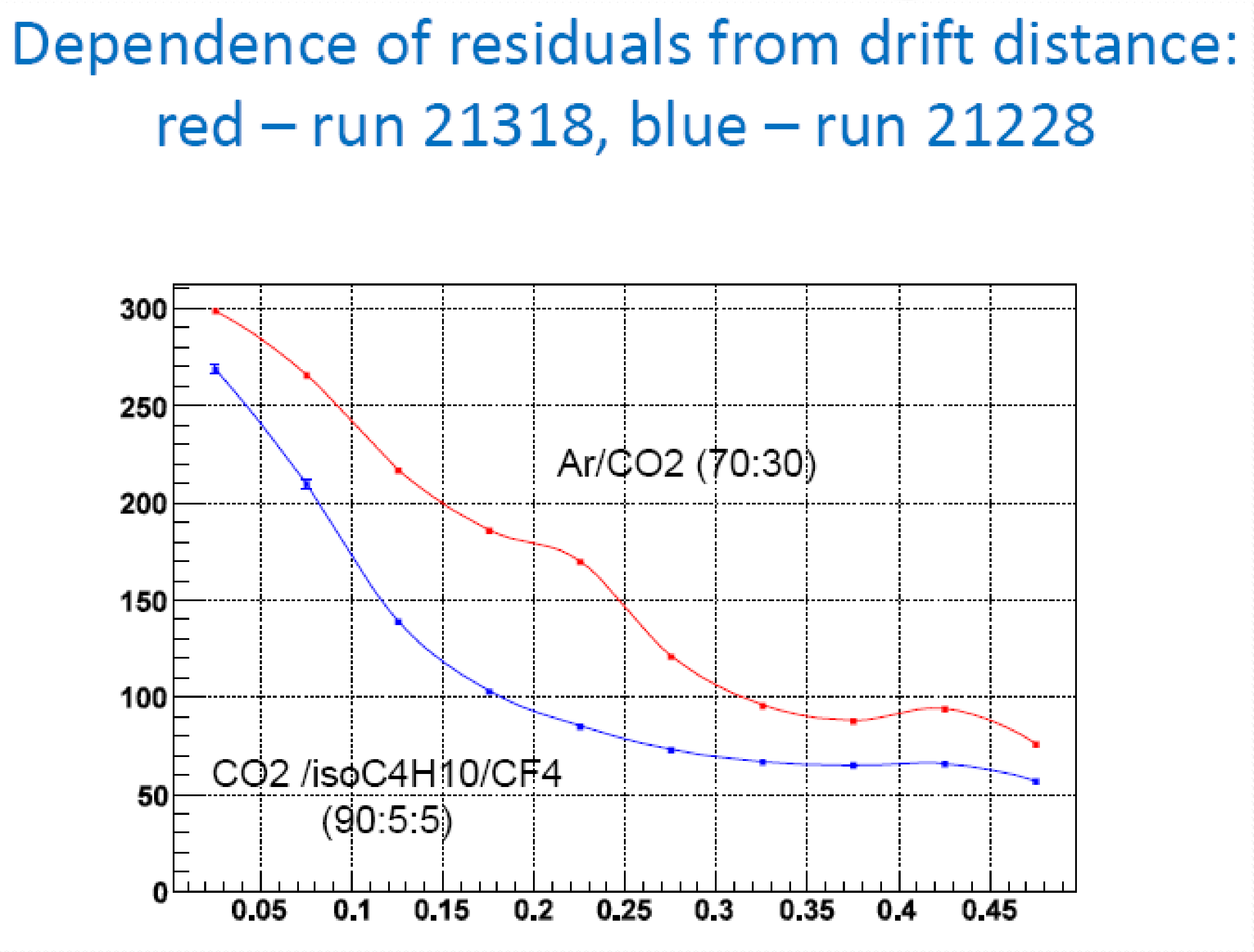


Straw Principle



- Falling edge has the same time for all straws on track.
- Rising edge gives the arrival time of the first cluster
- The closer is the track to the wall, the bigger is the signal (clusters closer)
- Don’t want to see clusters => shaping must be chosen in relation to gas properties
- Tracks from drift time measurement.

Dependence of residuals from R (muon runs)



Dependence of residuals from drift distance:
red – run 21318, blue – run 21228

HOD trigger resolution:
~ 1.3 ns

Aluminum Frame