A detector for the measurement of the ultrarare decay $K^+ \to \pi^+ \nu\nu$: NA62 at the CERN SPS

Paolo Valente (INFN Roma)

on behalf of the NA62 Collaboration

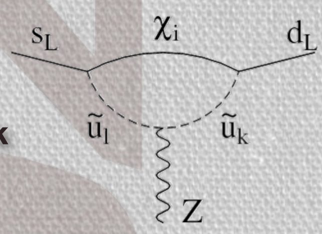
NA62 experiment motivations

Decay	Short Distance Contribution	Branching Ratio	Reference	Experiment	CKM
$K_L^0 \to \pi^0 \nu\bar{\nu}$	99%	$(2.76 \pm 0.40) \times 10^{-11}$	[2]	$<6.7 \times 10^{-8}$	$Im\, V^*_{ts} V_{td} \approx \eta$
$K^+ \to \pi^+ \nu\bar{\nu}$	88%	$(8.22 \pm 0.84) \times 10^{-11}$	[2]	$17.3^{+11.5}_{-10.5} \times 10^{-11}$	$V^*_{ts} V_{td}$
$K_L^0 \to \pi^0 e^+ e^-$	38%	$(3.54^{+0.98}_{-0.85}) \times 10^{-11}$	[1]	$<2.8 \times 10^{-10}$	
$K_L^0 \to \pi^0 \mu^+ \mu^-$	28%	$(1.41^{+0.28}_{-0.26}) \times 10^{-11}$	[1]	$<3.8 \times 10^{-10}$	$Im\, V^*_{ts} V_{td} \approx \eta$

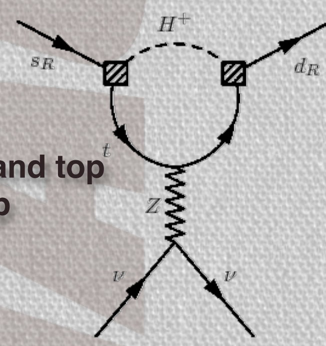
[1] A.J. Buras, M. Gorbahn, U. Haisch, U. Nierste, JHEP 0611:002,2006.
[2] F. Mescia, C. Smith, Phys.Rev.D76:034017,2007.

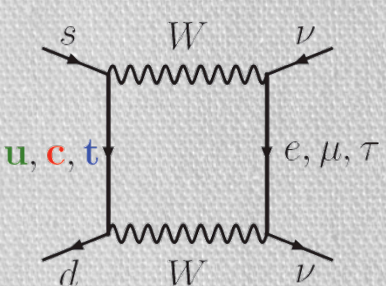
- Ultra-rare FCNC process, forbidden at tree level
- Small long-distance contribution
- BR calculable with few % precision
- Very sensitive to physics beyond the SM
- Determine V_{td} at 7% level, without QCD input

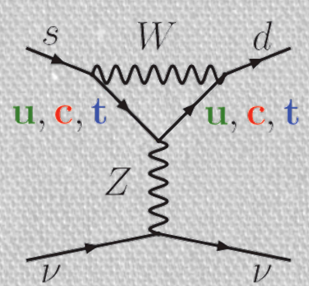
Chargino-squark
Small tanβ

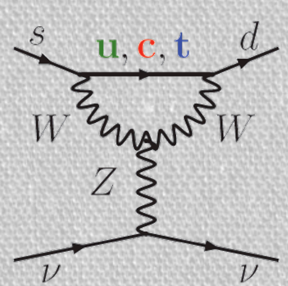


Charged Higgs and top quark in the loop
Large tanβ



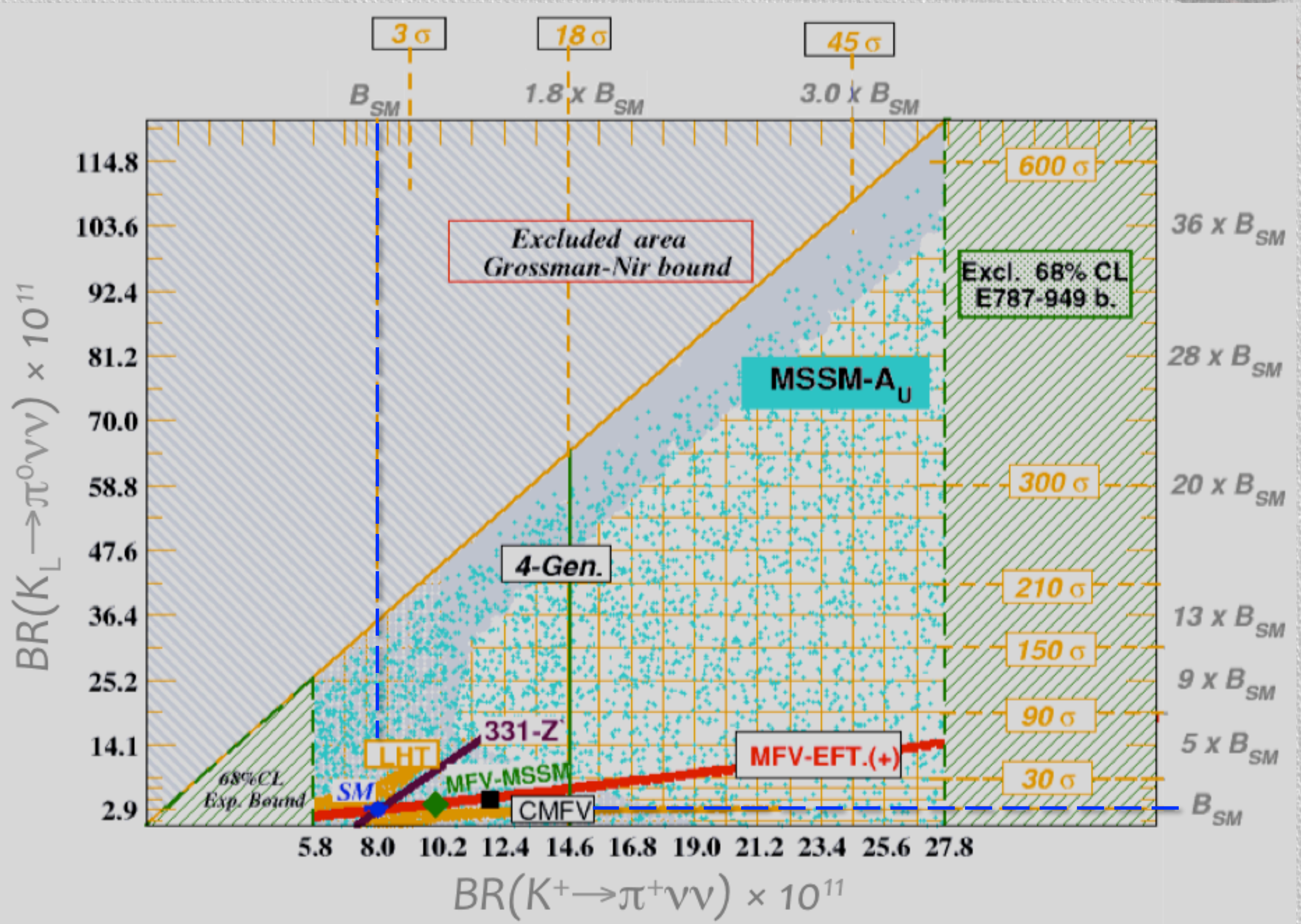




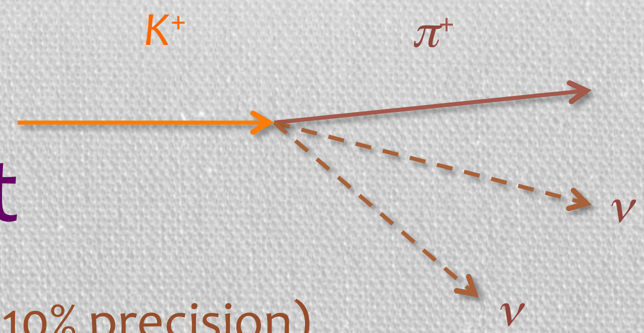


- If new degrees of freedom will show up at LHC, the question will be: what is the symmetry structure?

Possible to distinguish among several **New Physics** models: SUSY, MSSM with or without new CP violation or Flavour violation sources, extra-dimensions, etc.



F. Mescia, C. Smith



NA62 experiment

- Collect ≈100 events in 2 years (10% precision)
- Keep background below 10%
- Need ≈10^{13} K^+ decays

Need

- K momentum
- π momentum
- No other particle
- Minimize interactions
- Statistics

- Kinematical rejection is not enough…

Kinematical rejection

Main backgrounds:

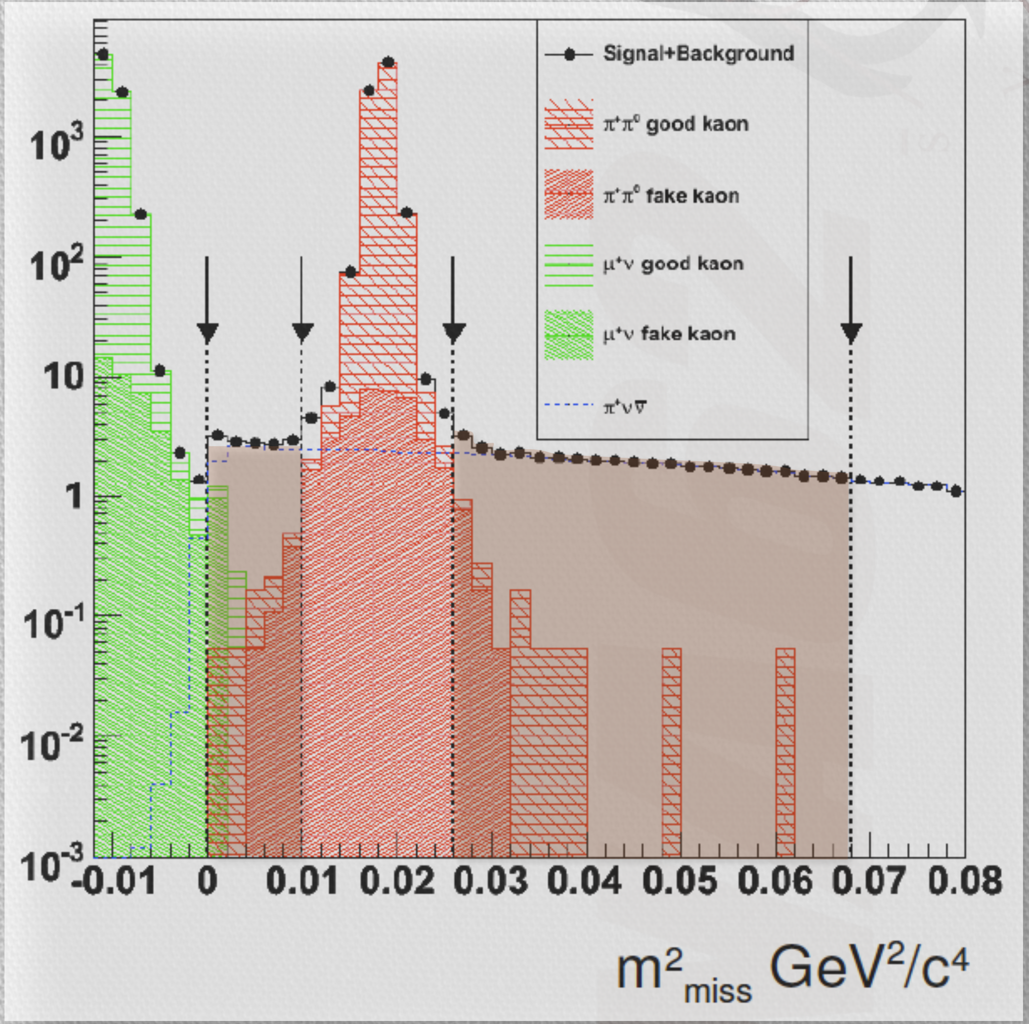
- $K^+ \to \mu^+ \nu$ (63%), $K^+ \to \pi^+ \pi^0$ (21%) + beam halo and particle interactions

10^4 rejection power for

$\pi^+\pi^0$, $\mu^+\nu$, 3π

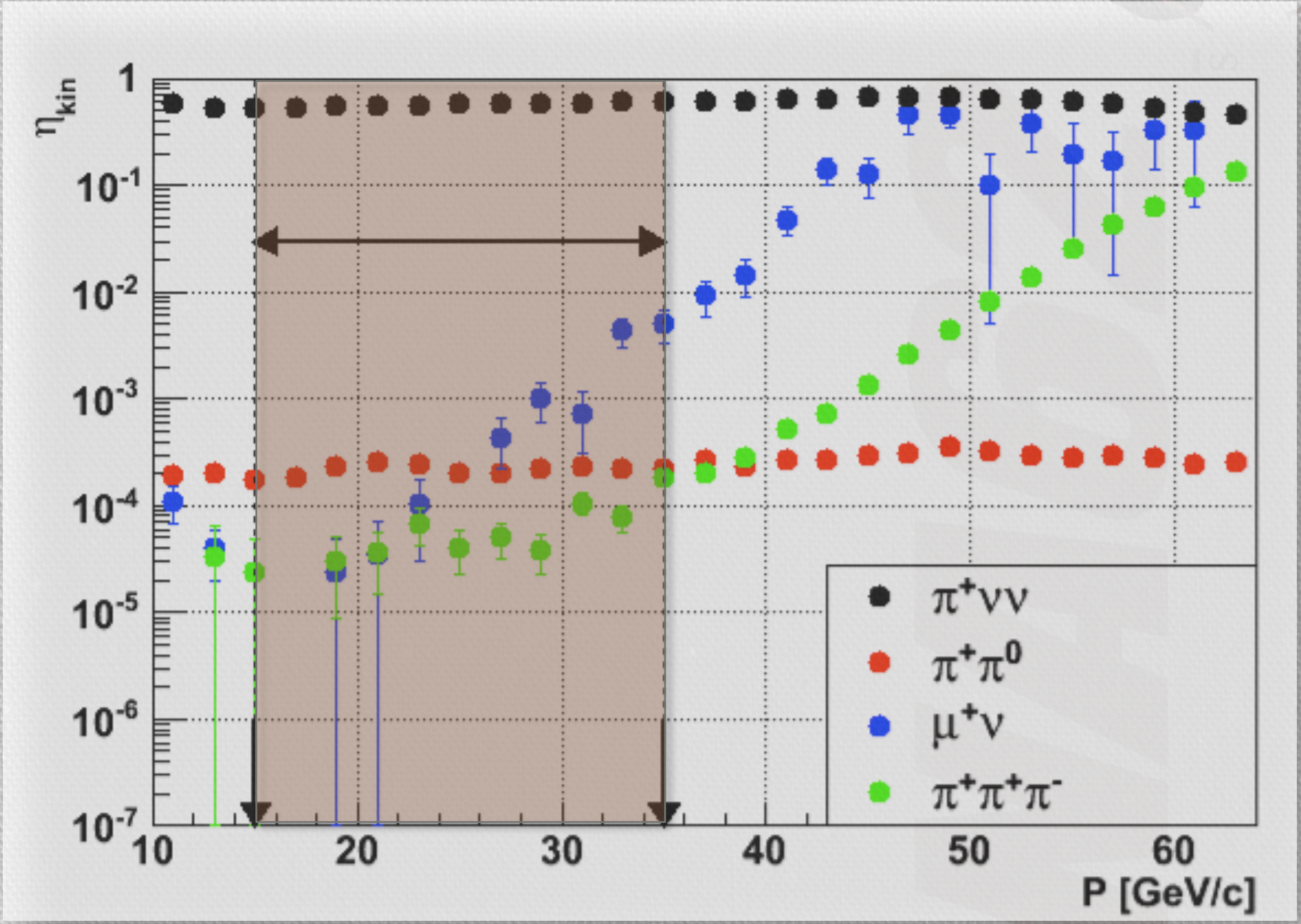
Sources of inefficiency:

- Multiple scattering, non gaussian tails
- $K\pi$ mis-match

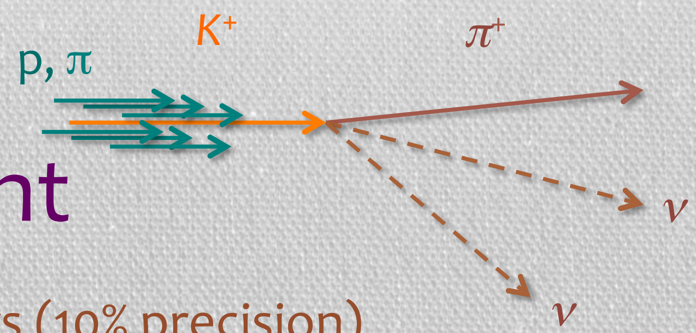


Kinematical rejection

m² cut only



NA62 experiment



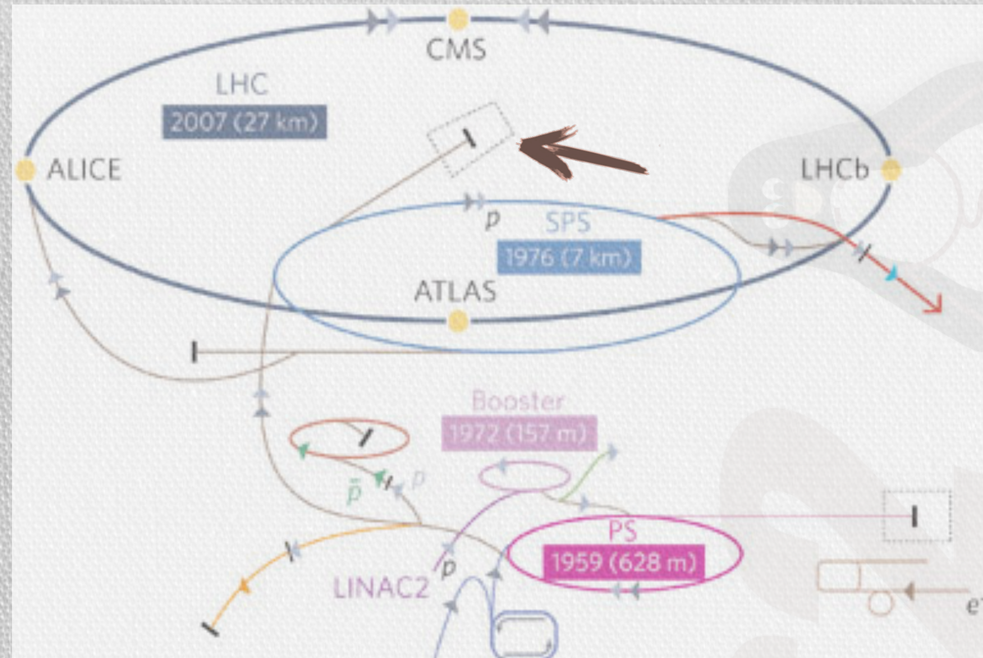
- Collect ≈100 events in 2 years (10% precision)
- Keep background below 10%
- Need ≈10^{13} K^+ decays: use un-separated high-intensity hadron beam

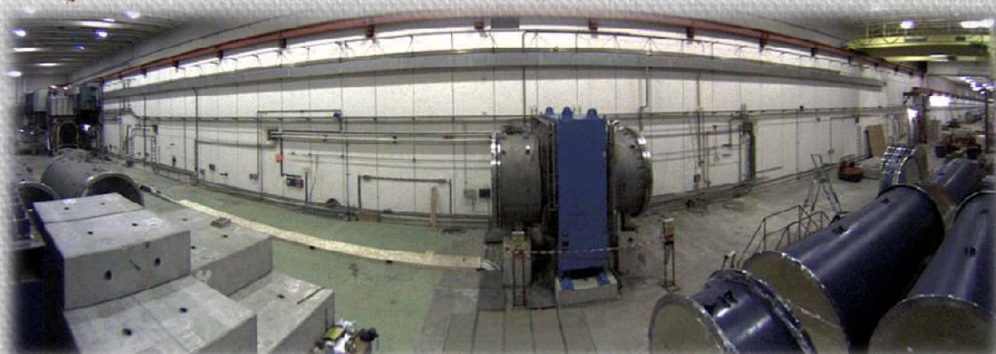
Need	Use	Key factors
K momentum	*K* identification, beam spectrometer	Efficiency, resolution
π momentum	π/μ separation, π spectrometer	Acceptance, purity
No other particle	Veto detectors	High *p*, veto efficiency
Minimize interactions	Low mass detectors	Spectrometers in vacuum
Statistics	High intensity beam	Time resolution

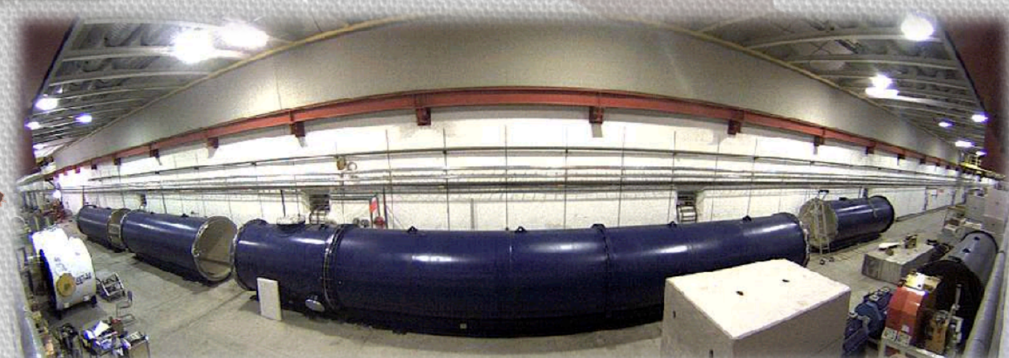
- Kinematical rejection ≈ 10^{-4}, Vetoes ≈ 10^{-5}, Particle Id. ≈ 10^{-3}
- 6% Kaons, 800 MHz beam, *p*=75 GeV/c
- Time resolution ≈ 100 ps

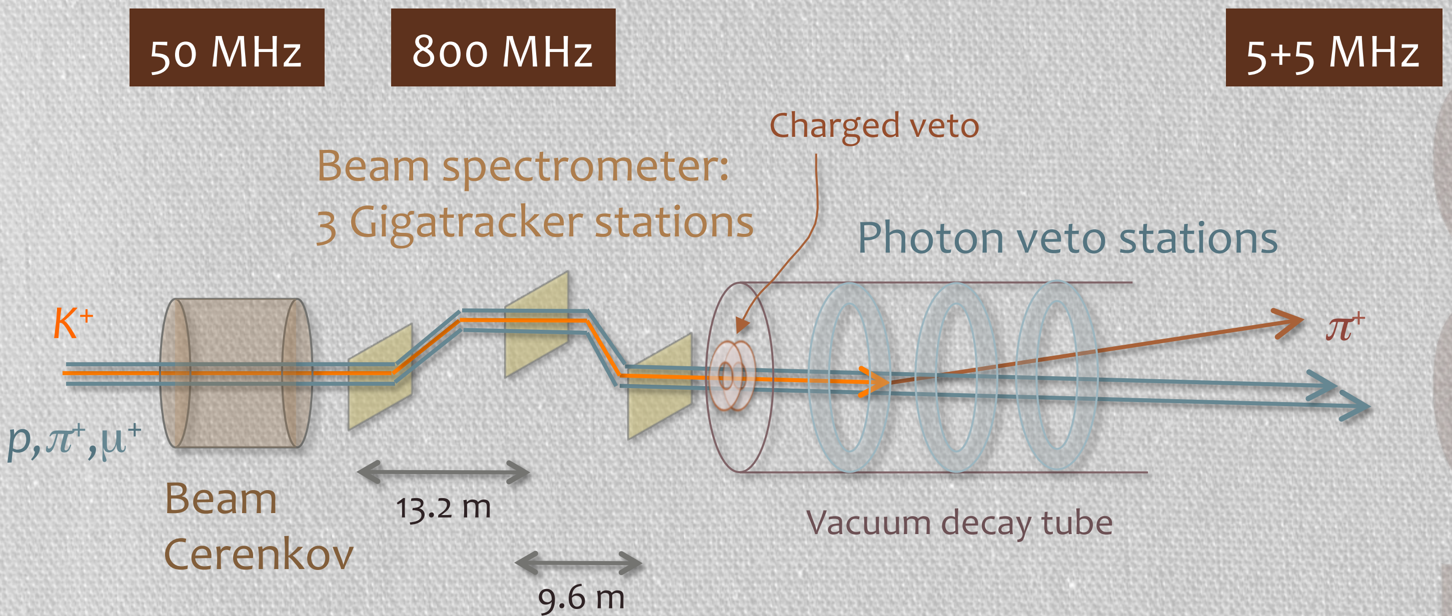
In the heart of CERN:

- Re-use Kaon beam-line from SPS with **50× intensity**
- Re-use **liquid Krypton calorimeter** from NA48
- Also re-use **spectrometer magnet**, vacuum tube, hadron calorimeter from NA48



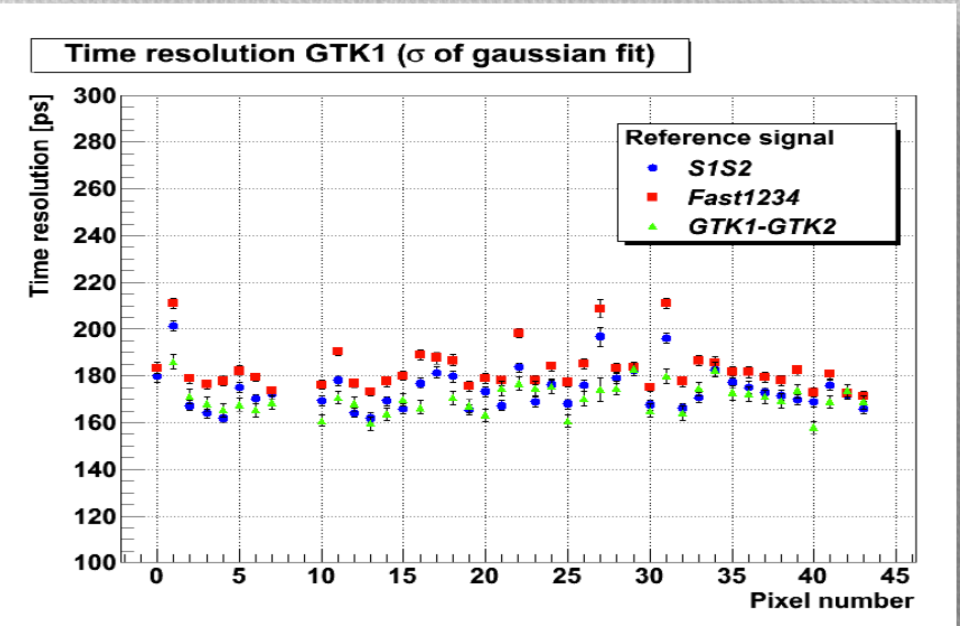


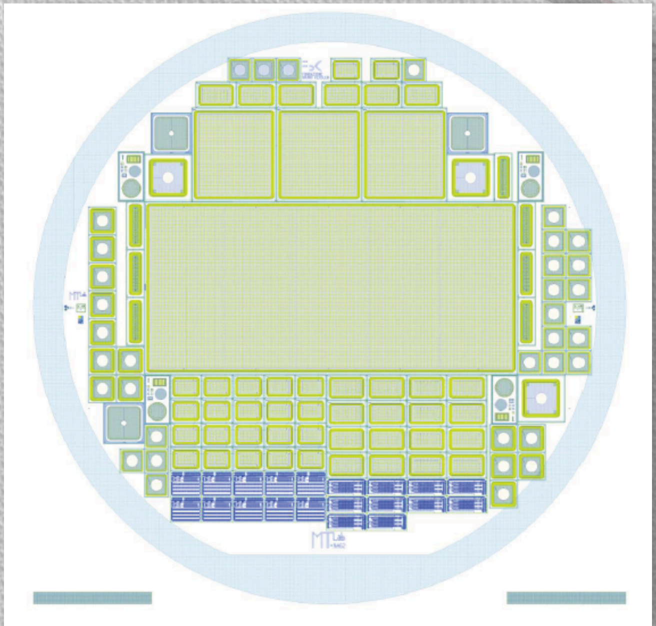




- Silicon pixel 300 μm×300 μm
- $< 3\times0.5\%\ X_0$
- $> 99\%$ efficiency
- $\sigma_p/p \approx 0.2\%$
- $\sigma_\theta \approx 16$ μrad
- $\sigma_t < 200$ ps/station
- 61×27 mm² active area, 54000 pixels

Gigatracker: the silicon pixel beam detector



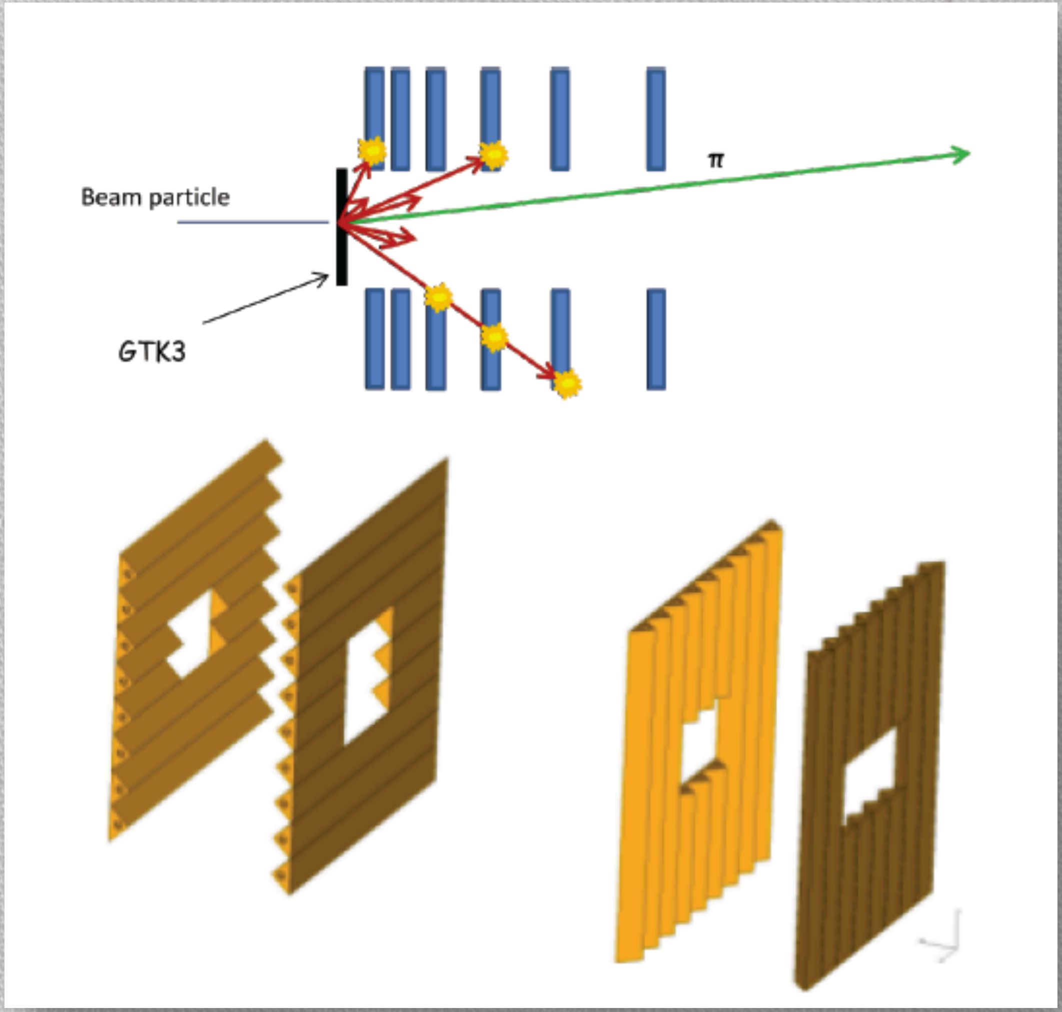


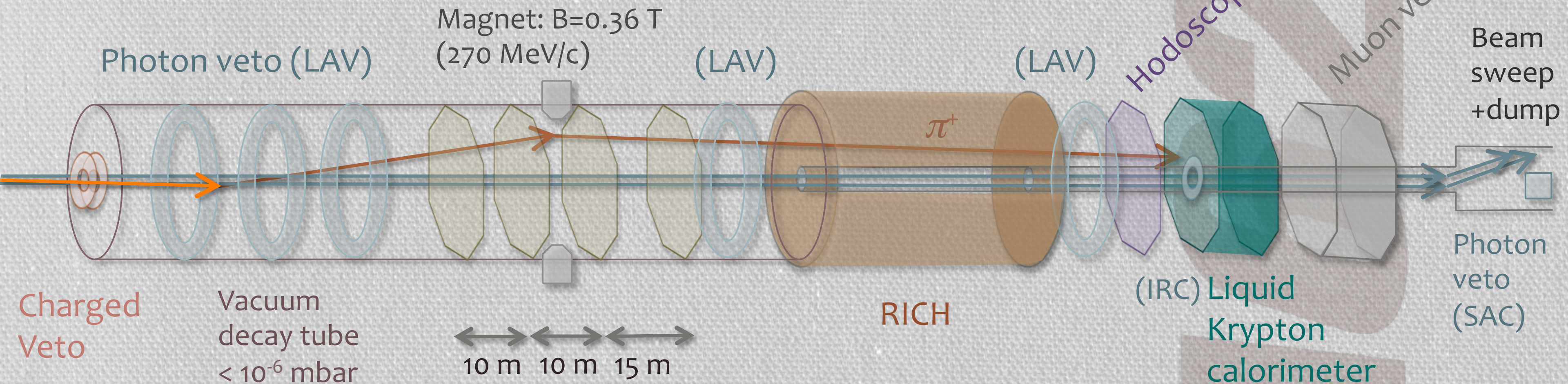
See talk by **Sara Garbolino** (Friday, July 22nd, 11:45, **Detector RD & Data Handling**)

Charged veto

Veto:
2 MHz muon halo
+ inelastic interactions

- Extruded scintillator bars
- WLS fibers readout + SiPM's
- ≈ 10 ph.el. / MIP
- $\sigma_t < 2$ ns





Straw tracker stations

- $\sigma_p/p < 1\%$
- $\sigma_\theta < 60\ \mu\text{rad}$
- $< 4 \times 0.5\%\ X_0$
- $> 99\%$ hit efficiency
- Operate in vacuum
- 0.5 MHz in hottest area

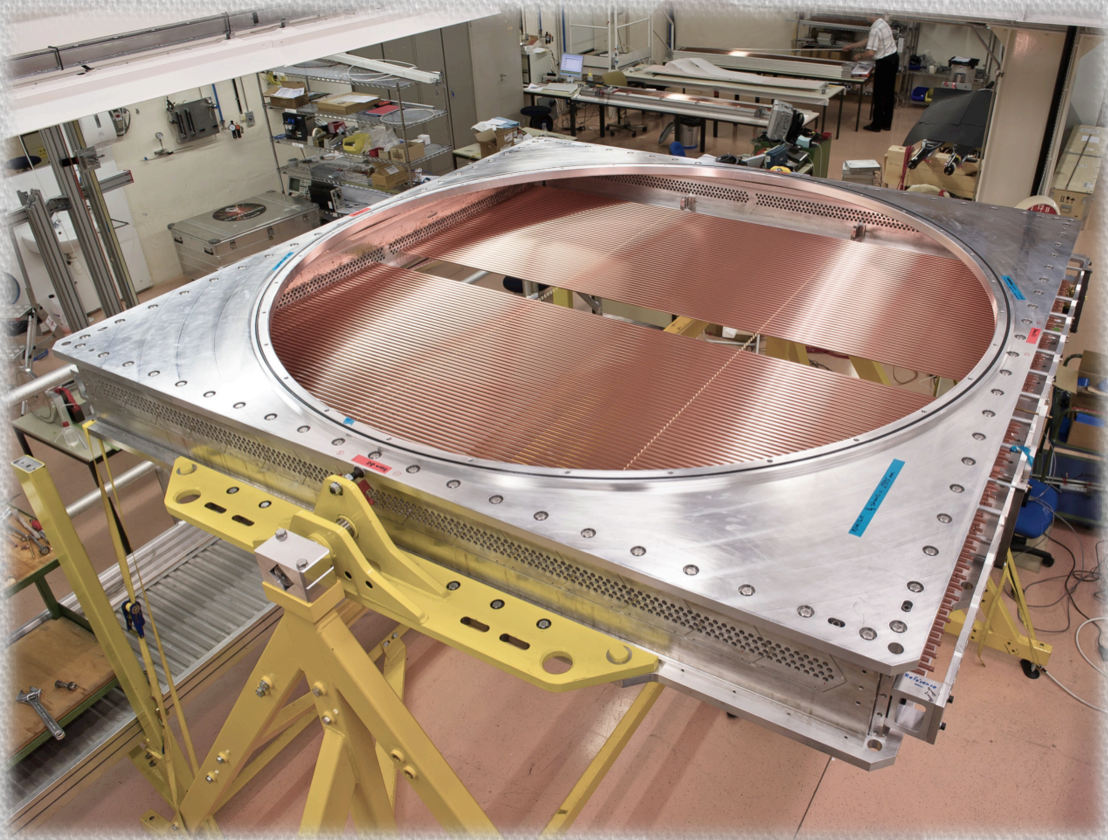
Straw tracker spectrometer

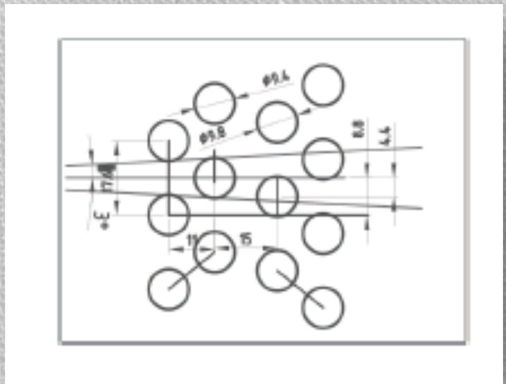
- 2 + 2 tracking stations
- 4 views/station (u-v, x-y)

- 2.1 m diameter acceptance
- 12 cm beam hole

- Track angle: ±3°
- σ < 130 μm per view

- 7168 traw tubes in vacuum:
    - 30 μm Au-plated wire
    - 100 μm straw straightness
    - Ar(70%)/CO_2(30%)

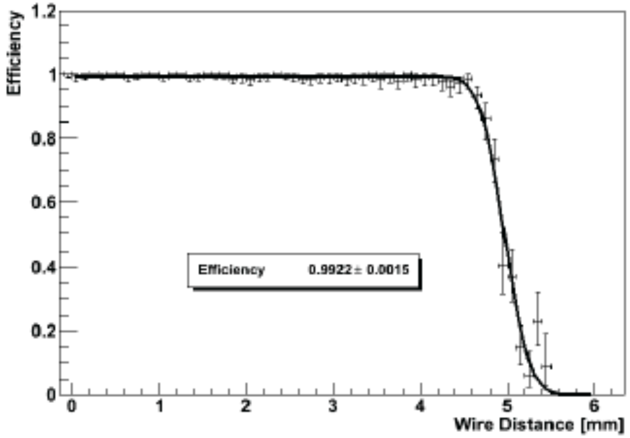


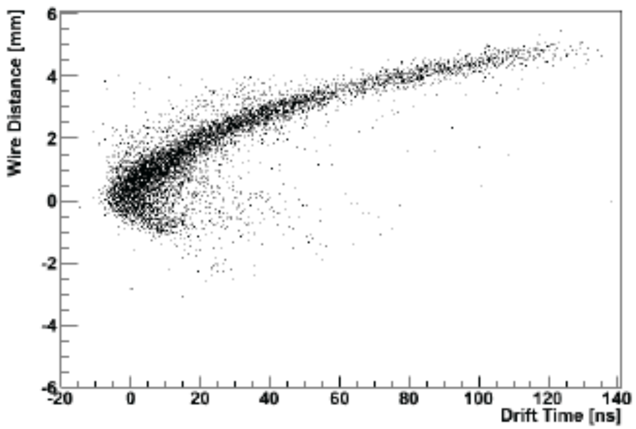


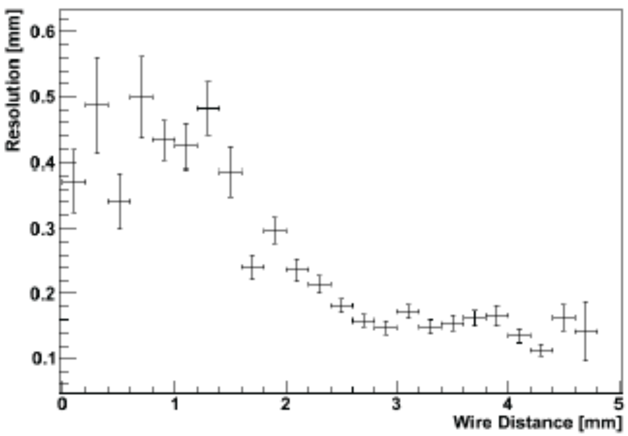
Straw tracker prototype

Straws prototype test:

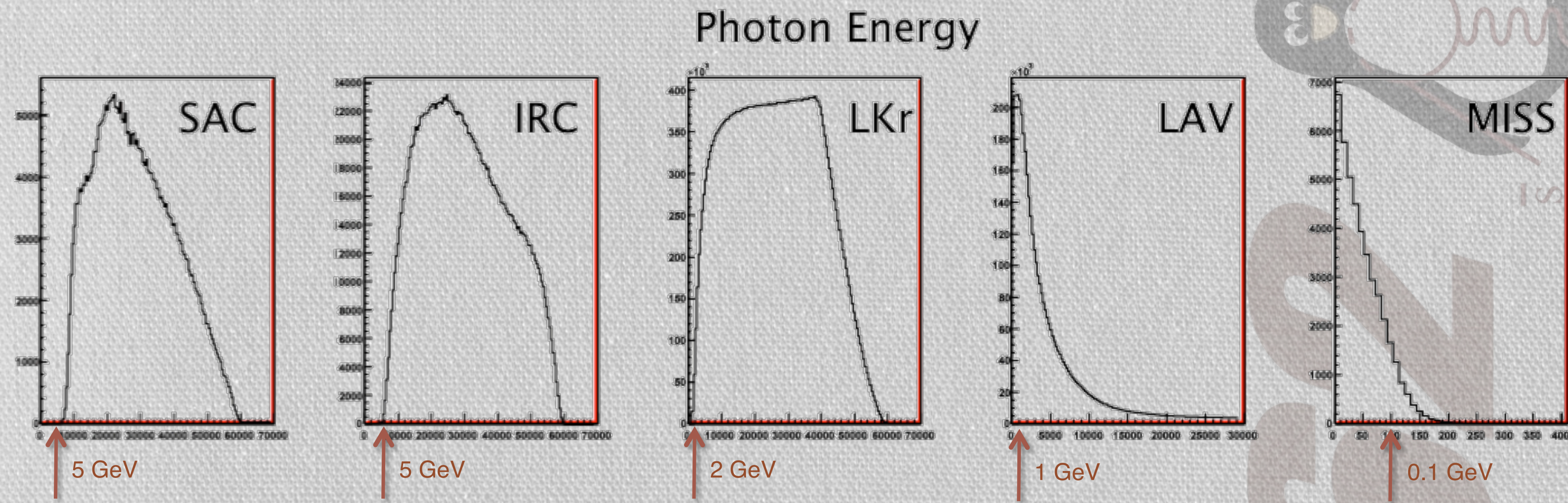
- 64 straws
- Final mechanics
- Vacuum vessel
- CARIOCA readout electronics
- Pion beam, 120 GeV/c







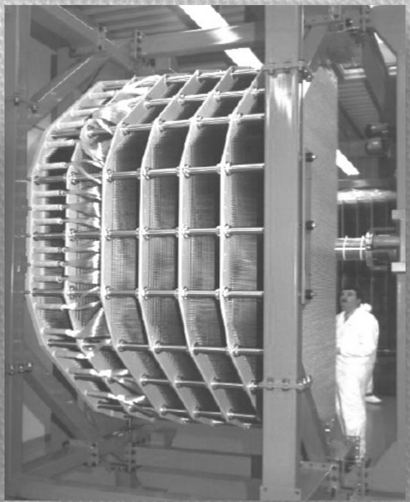
Photon vetoes



≈ 10^{-5} γ detection inefficiency

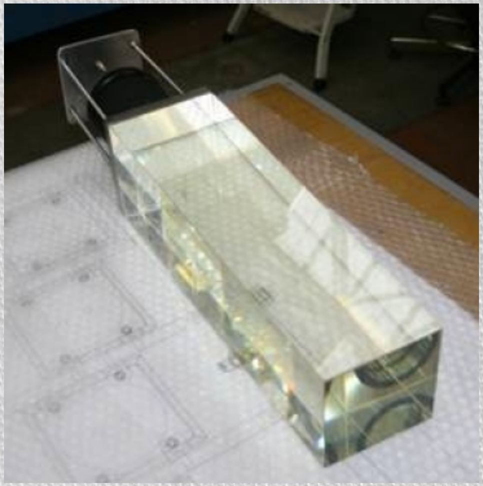
≈ 10^{-4} inefficiency
E_γ > 200 MeV

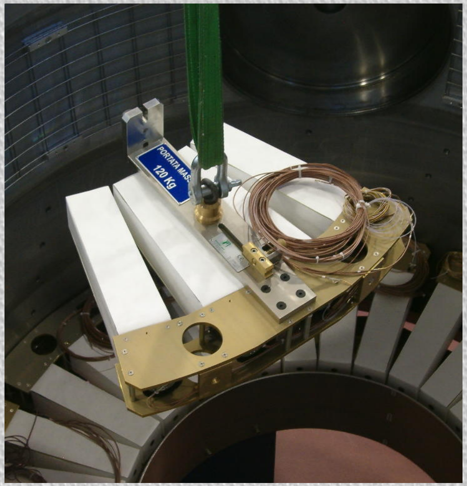
Energy	Inefficiency
$2 < E_\gamma < 3.5$ GeV	$(5.8 \pm 1.3)\times10^{-4}$
$3.5 < E_\gamma < 5$ GeV	$(1.6 \pm 0.4)\times10^{-4}$
$5 < E_\gamma < 7.5$ GeV	$(2.8 \pm 1.6)\times10^{-5}$
$7.5 < E_\gamma < 10$ GeV	$<2\times10^{-5}$
$E_\gamma > 10$ GeV	$<1\times10^{-5}$



Photon vetoes (LAV)

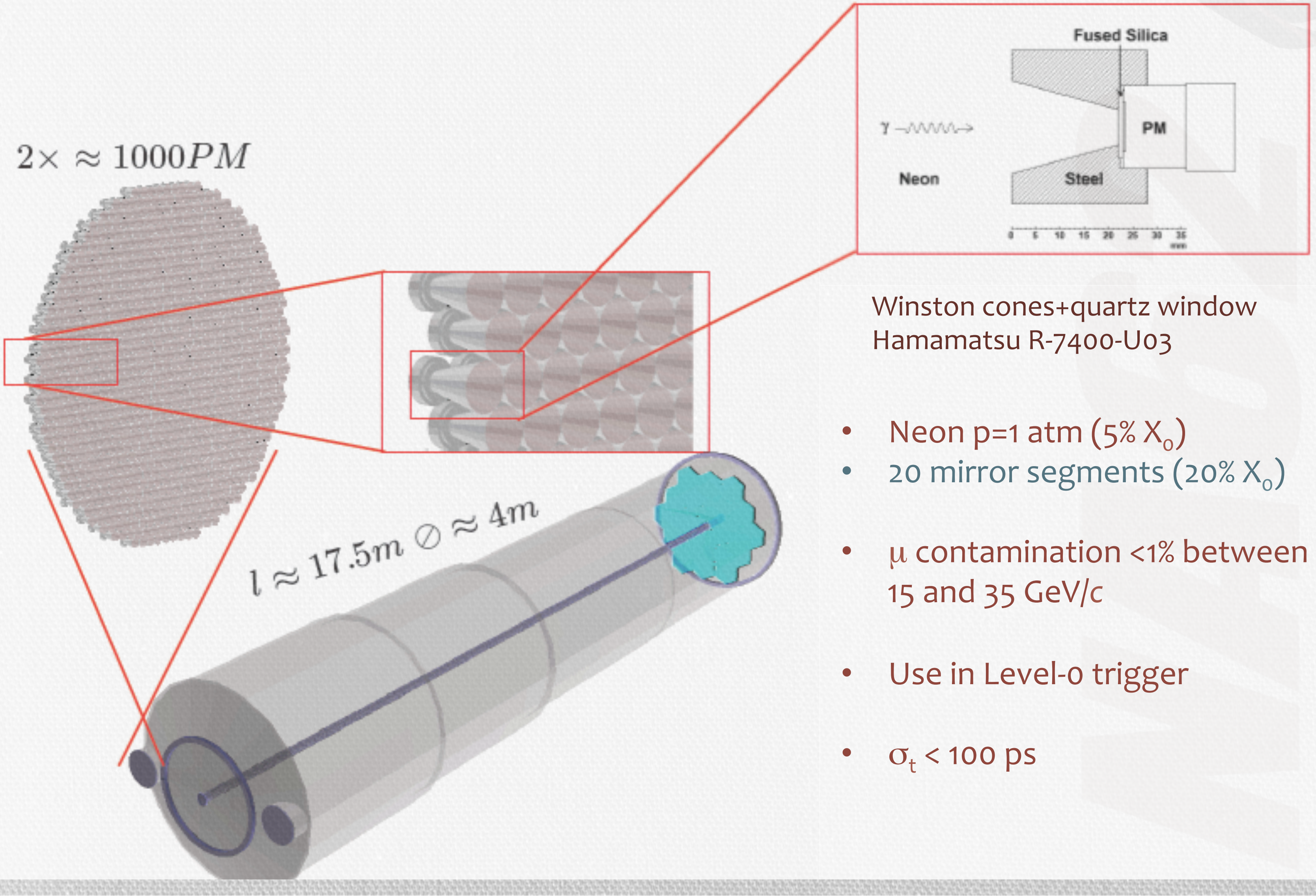
- **12 stations** along the decay tube
- 2500 lead glass blocks, re-used from **OPAL** electromagnetic calorimeter
- 11/12 stations operate in **vacuum**
- Cover 8 to 50 mrad





- **3** different ring sizes, **5 staggered layers** of blocks, ≈20 X_0)
- **5/12 completed** stations In about 1 year
- Custom **time-over-threshold** electronics (double threshold, down to ≈1/5 MIP)
- $\sigma_E \approx 9\%/\mathrm{sqrt}(E[\mathrm{GeV}])$
- $\sigma_t \approx 210\ \mathrm{ps}/\mathrm{sqrt}(E[\mathrm{GeV}])$

RICH

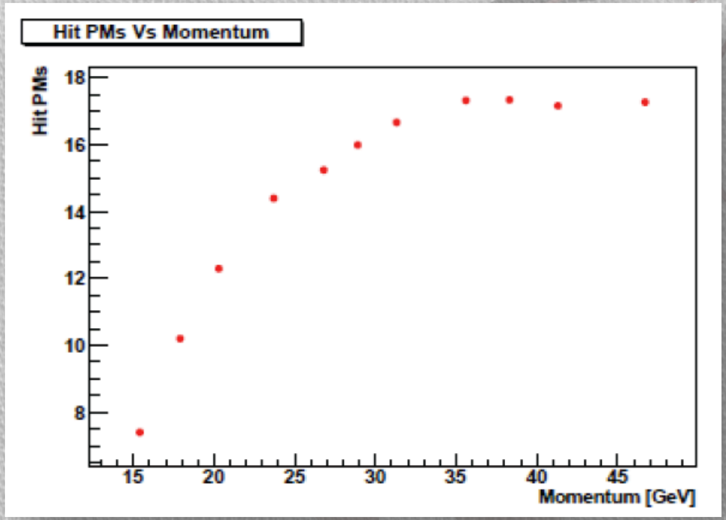


Winston cones+quartz window
Hamamatsu R-7400-U03

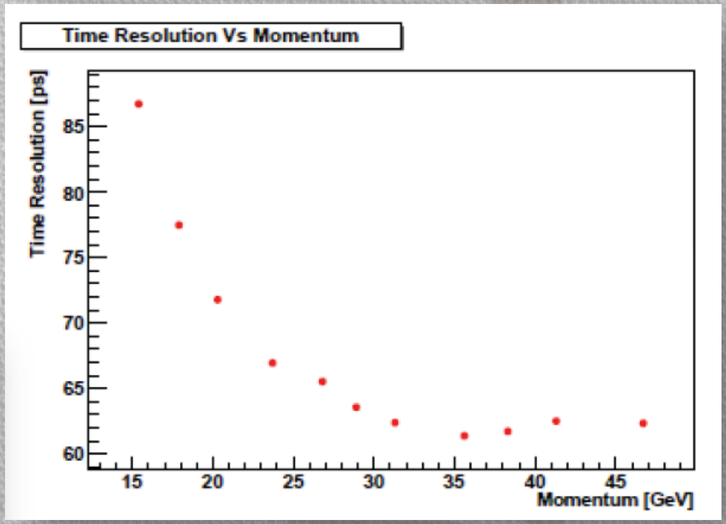
- Neon p=1 atm (5% X_0)
- 20 mirror segments (20% X_0)
- μ contamination <1% between 15 and 35 GeV/c
- Use in Level-0 trigger
- σ_t < 100 ps

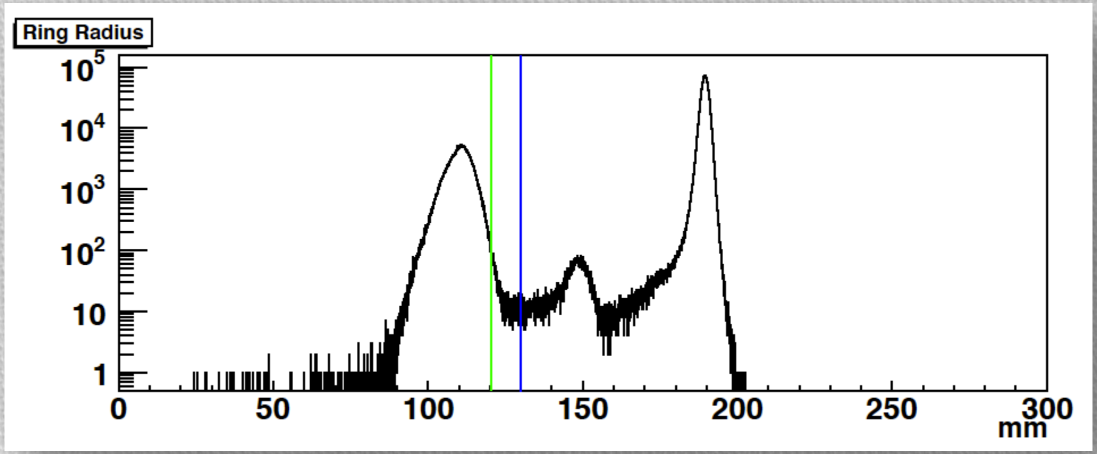
RICH performance

Number of hits vs. momentum



Time resolution vs. momentum



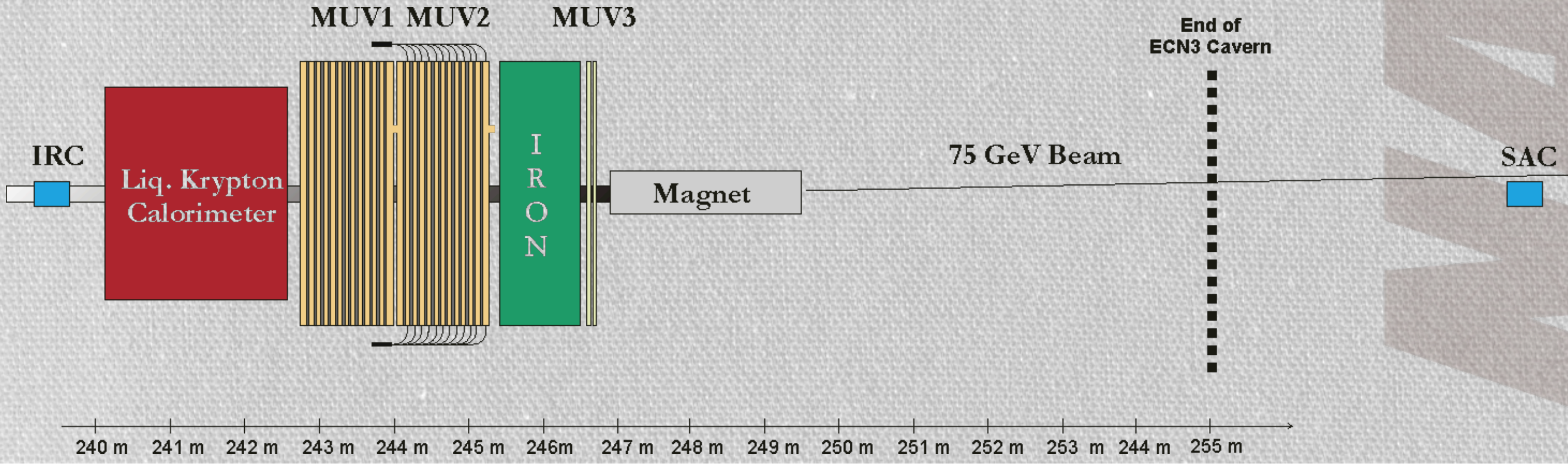


Muon vetoes

3 muon veto sections:

Partially by re-using hadron calorimeter from NA48

- **MUV1:**
  - 24 planes (iron/scintillator+WLS)
  - 6 cm strips (x-y)
  - 13 ph.el./MIP
- **MUV2:**
  - 22 planes (iron+scintillator)
- **MUV3:**
  - **Fast trigger signals**
  - Scintillator pads with direct readout of light in an (air) black box, to suppress reflections and Cerenkov

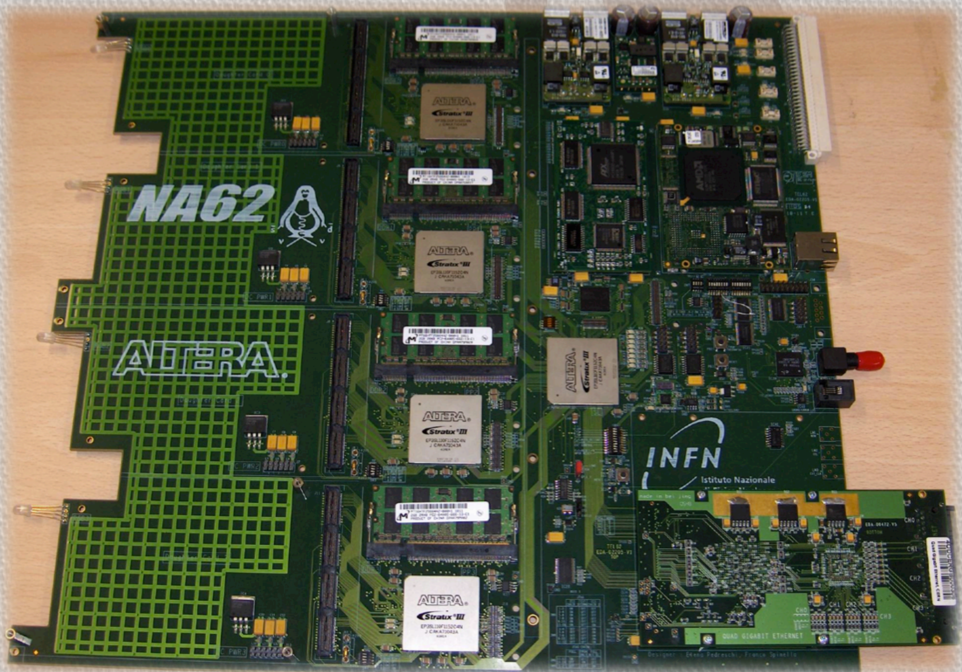


Trigger and DAQ

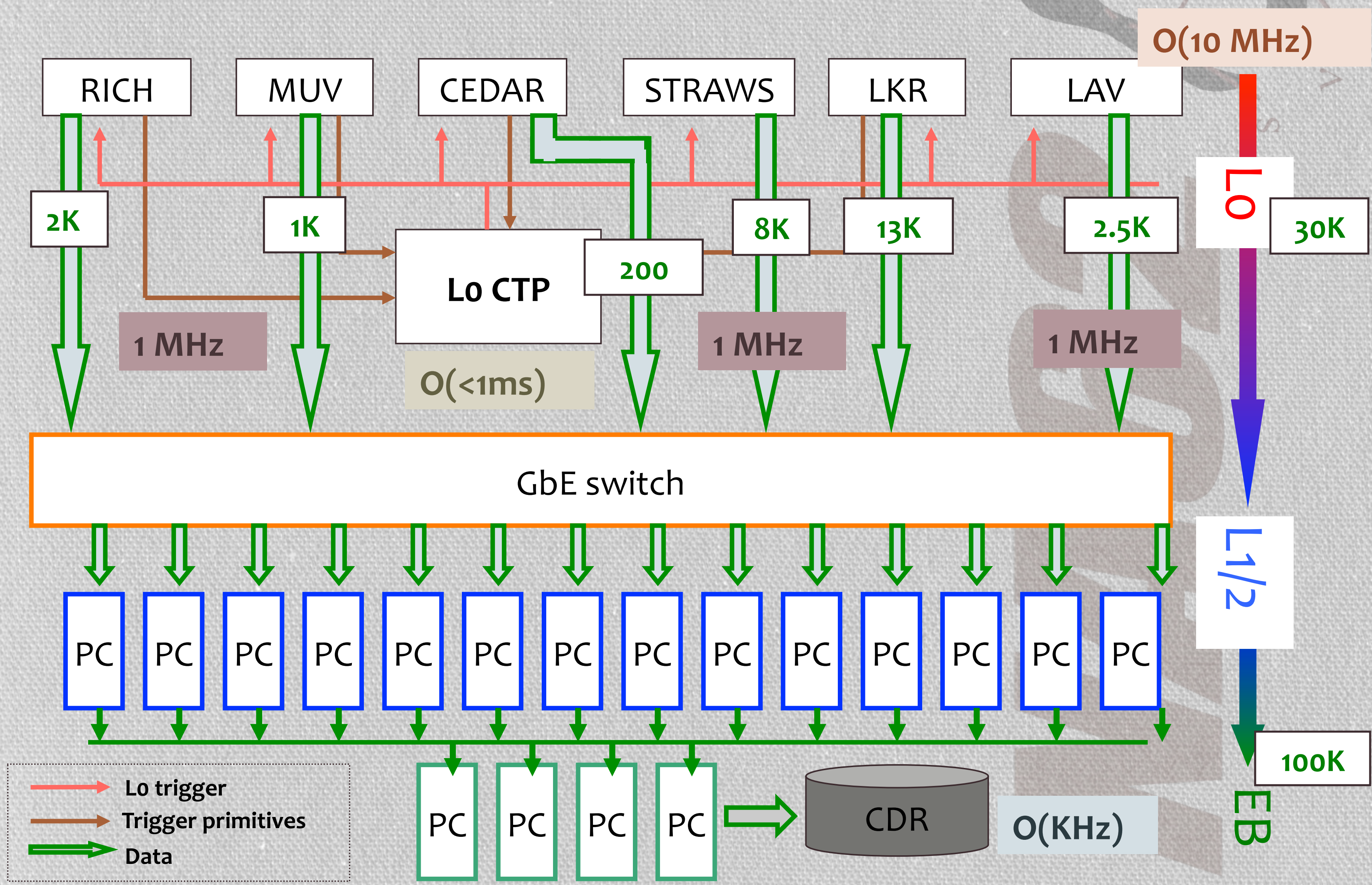
- High trigger efficiency (>95%)
- Low random veto (<1%)
- Fully digital after Front-Ent
- **Level-0** implemented in **hardware, 10 MHz → 1 MHz**
    - e.g. RICH minimum multiplicity, Muon veto, LKr , photon veto
- **Level-1,** at the level of **sub-detector** (**→ 100 KHz**) and **Level-2** (on full event, **→ few KHz**) implemented in **software**
    - e.g. vertex out of fiducial volume

- **High data bandwidth (≈5 GB/s)**
- **No zero suppression (for candidate events**

- Try to use **common** TDAQ board
    - (**TEL62**, based on LHCb TELL1)
    - **HPTDC** mezzanine card
- Custom solutions for **Liquid Krypton** and **Gigatracker** (too much data!)



Trigger and DAQ

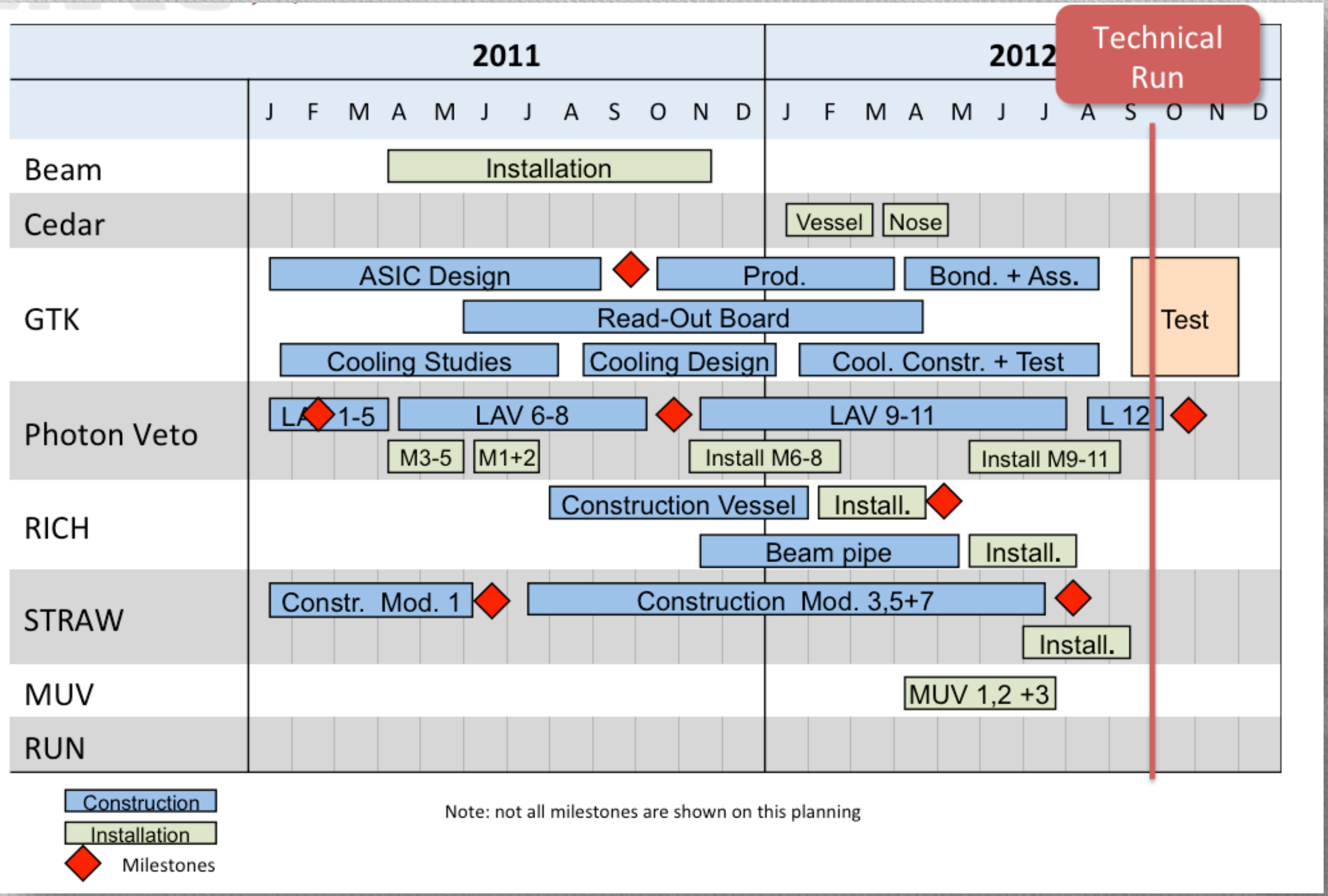


The NA62 measurement of R_K

- *Precision measurement of* $R_K = BR(K^+ \rightarrow e^+ \nu) / BR(K^+ \rightarrow \mu^+ \nu)$
- Dedicated data taking in 2007/2008, ≈120000 events, with NA48 detectors

Full data-set **new result** in the talk by **Evgueny Goudzovski** (Friday, July 22nd, 17:05, **Flavour Physics & Fundamental Symmetries**)

Schedule



2011
2012
Technical Run
J F M A M J J A S O N D J F M A M J J A S O N D
Beam
Installation
Cedar
Vessel
Nose
GTK
ASIC Design
Prod.
Bond. + Ass.
Read-Out Board
Cooling Studies
Cooling Design
Cool. Constr. + Test
Test
Photon Veto
LAV 1-5
LAV 6-8
LAV 9-11
L 12
M3-5
M1+2
Install M6-8
Install M9-11
RICH
Construction Vessel
Install.
Beam pipe
Install.
STRAW
Constr. Mod. 1
Construction Mod. 3,5+7
Install.
MUV
MUV 1,2 +3
RUN
Construction
Installation
Milestones
Note: not all milestones are shown on this planning

Schedule

- Beam line: full system will be installed in 2011.
- Beam Dump: completion expected in 2011.
- Vacuum tank and vacuum system: full system should be available; some pumping units could be staged (depending on number of installed Straw modules).
- CEDAR: full system should be available.
- GTK: the final pixel detectors will not yet be available; possibility to use prototype sensors in the Technical Run.
- LAV: plan to install 10 (or 9) LAV modules. LAV12 will not be ready. If LAV10 is not ready we would install the empty vessel to complete the vacuum tank.
- STRAW: possibility to complete 3 or 4 (out of 8) chamber modules. Chambers 1, 2 and 4 could be equipped with one (instead of two) modules each. The missing modules will be replaced by empty module frames.
- RICH: plan to install the RICH vessel in Spring 2012, including the central beam pipe.
- LKR: the calorimeter will still be read out by the existing electronics (CPD/SLM) but prototypes of the final electronics (CREAM) will be tested.
- CHOD: use the existing NA48 CHOD with prototype read-out.
- MUV: full system.

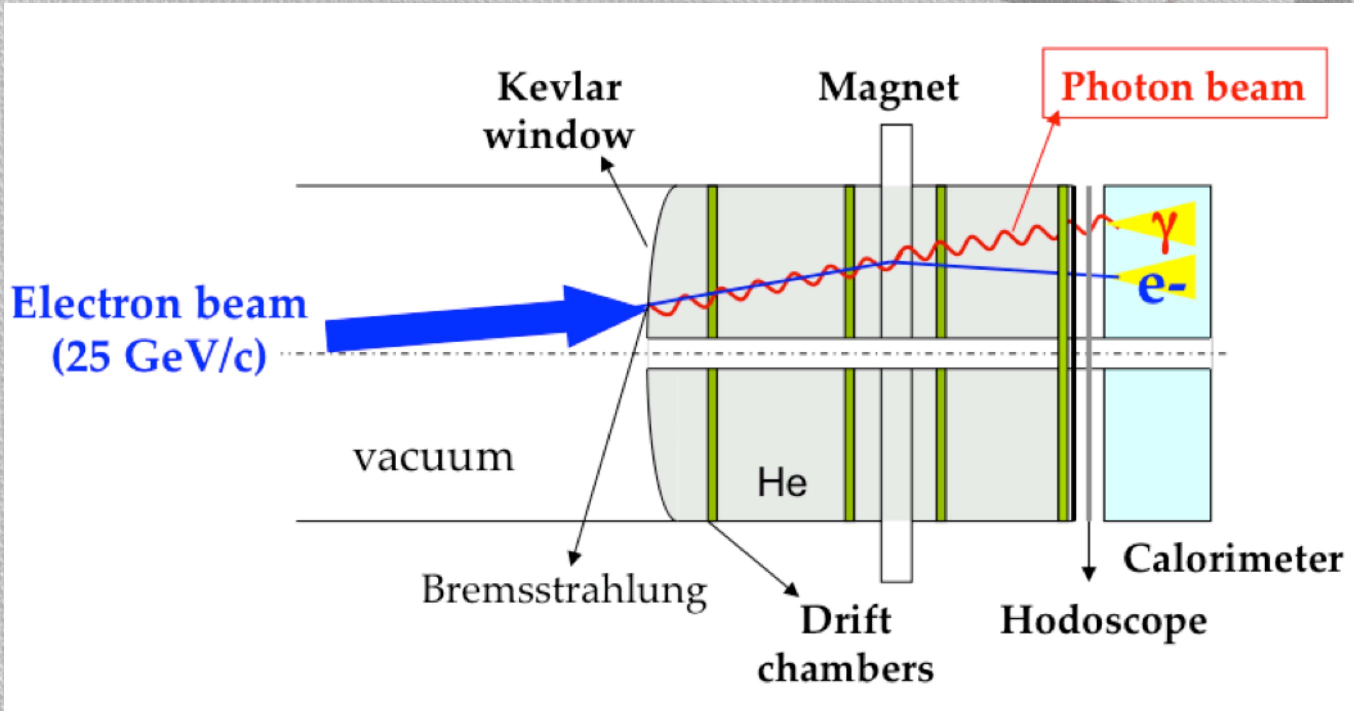
Conclusions

- **Very clean** mode; sensitivity to New Physics also at high energy scales: **complementary** to direct searches at LHC

- NA62 detectors have been carefully designed and validated (R&D, tests, Monte Carlo)
- Now **construction** is proceeding steadily
- Also Gigatracker design is well advanced (sensor, readout chip, cooling, etc.)
- Now refining TDAQ system ...

- ... and **getting ready to run**:
  - **Technical run** already at the end of year **2012** (without Gigatracker)
  - **Physics run** planned at SPS restart after long shutdown (**2014**)

Liquid Krypton efficiency



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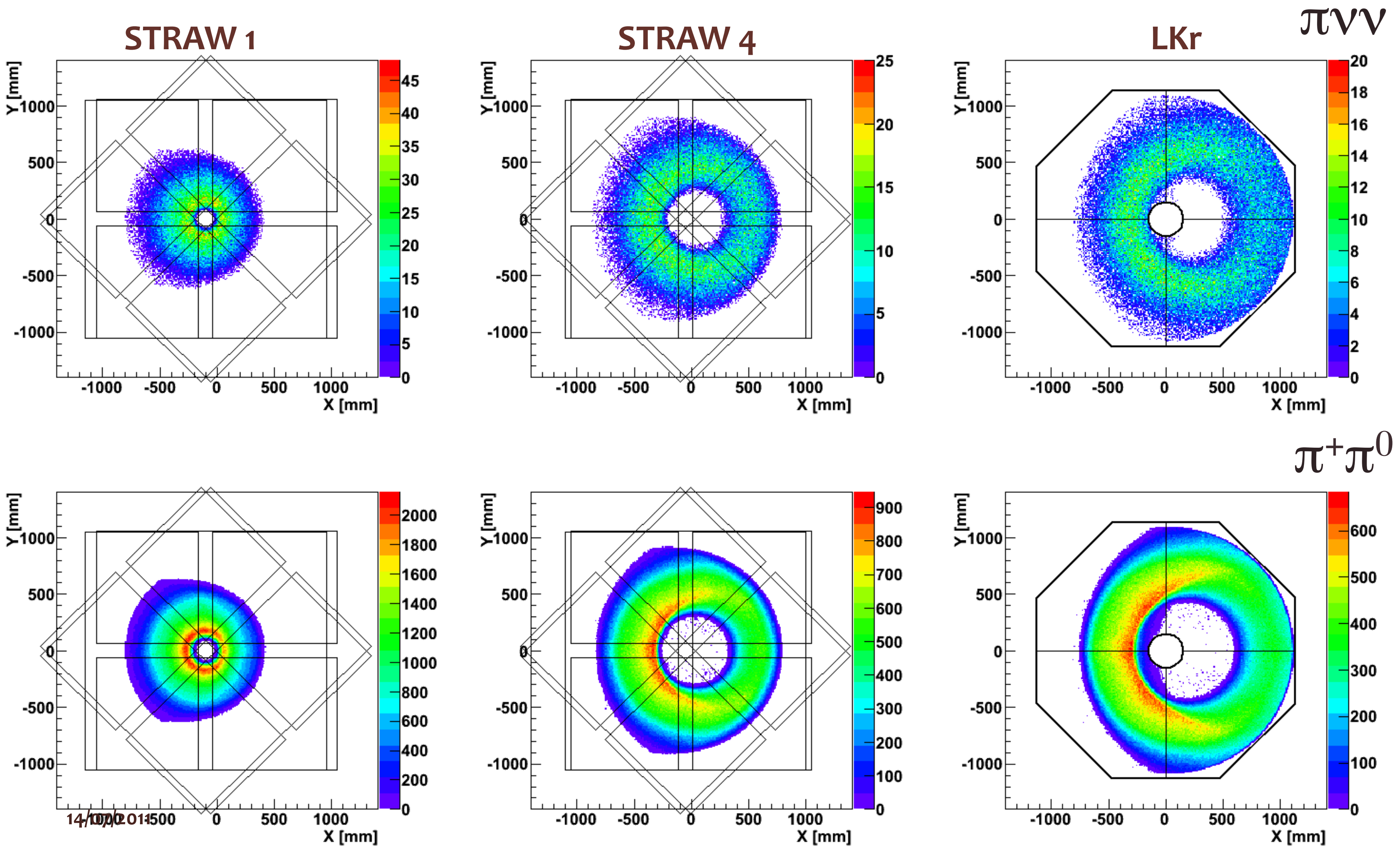
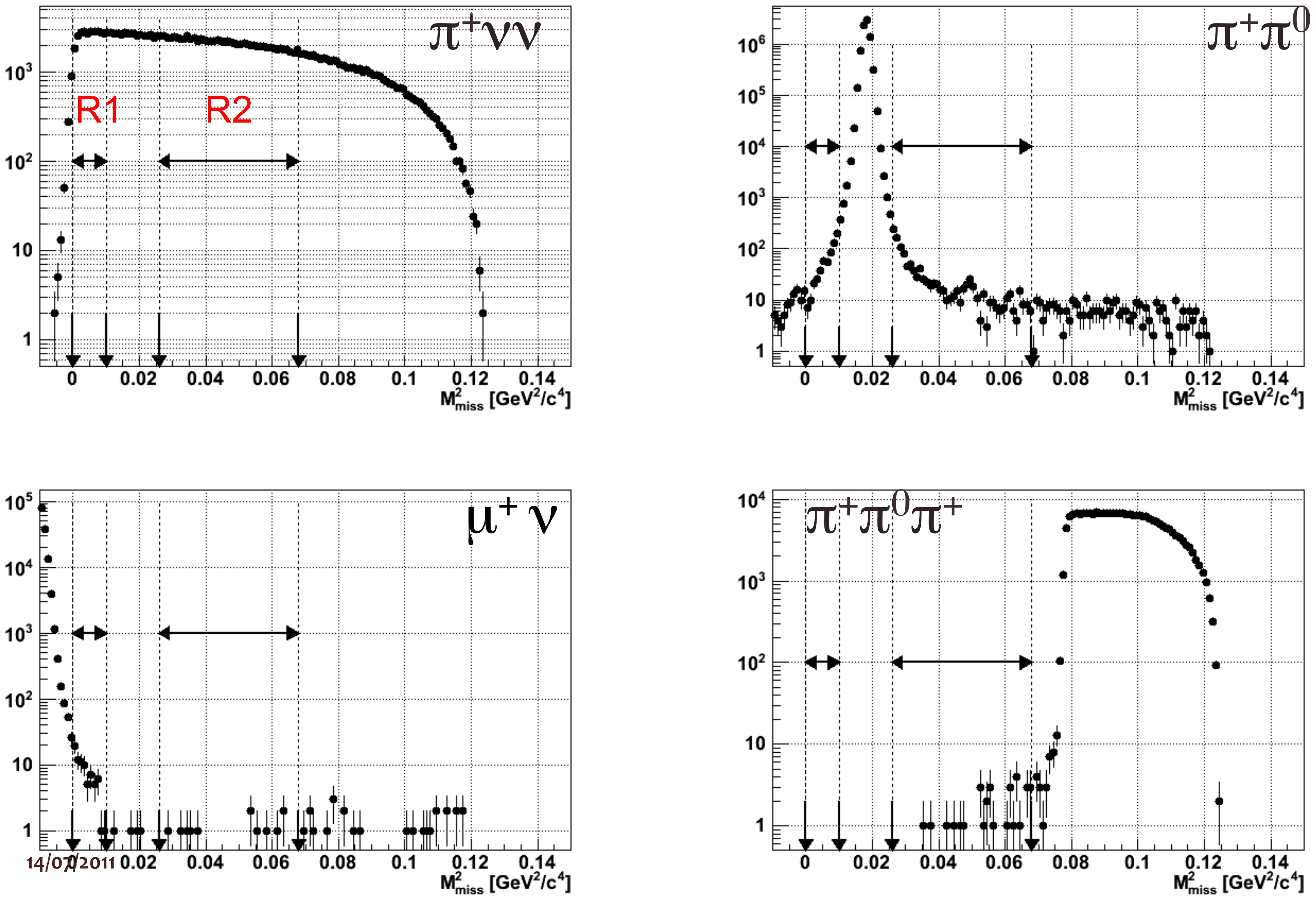
Monte Carlo: event selection

Cut on reconstructed momentum: 15 < P_{track} < 35 GeV/c

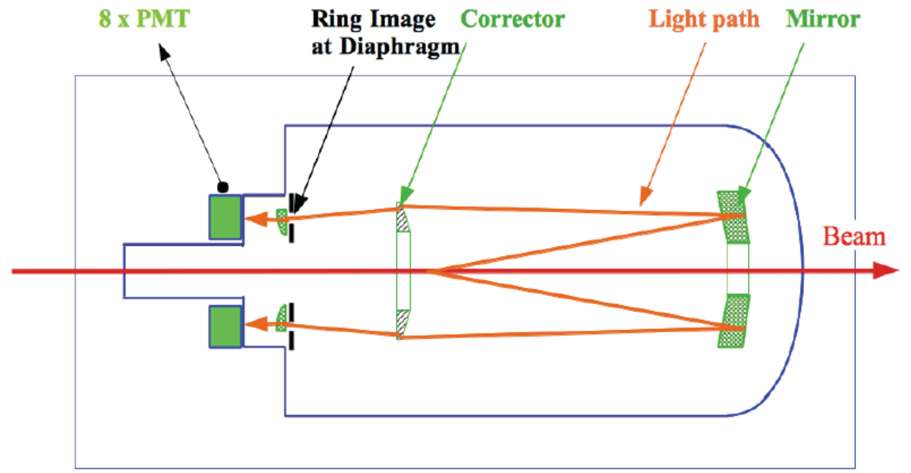


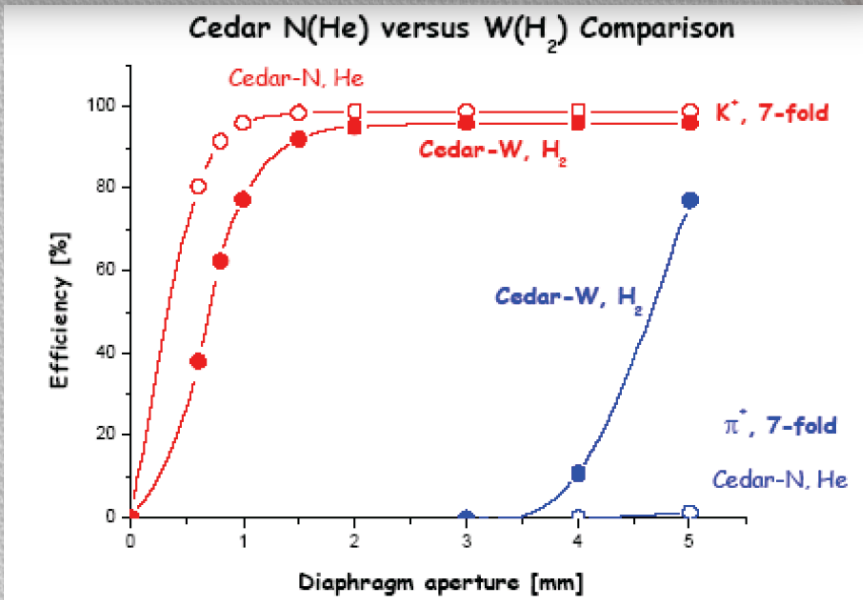
Monte Carlo: cut on m^2_{miss}



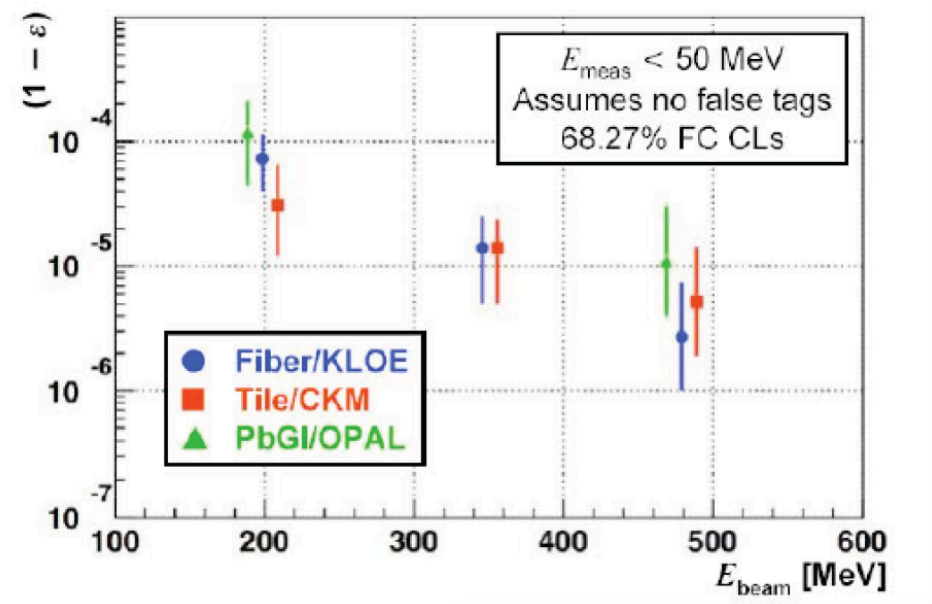
Kaon tagger: differential Cerenkov

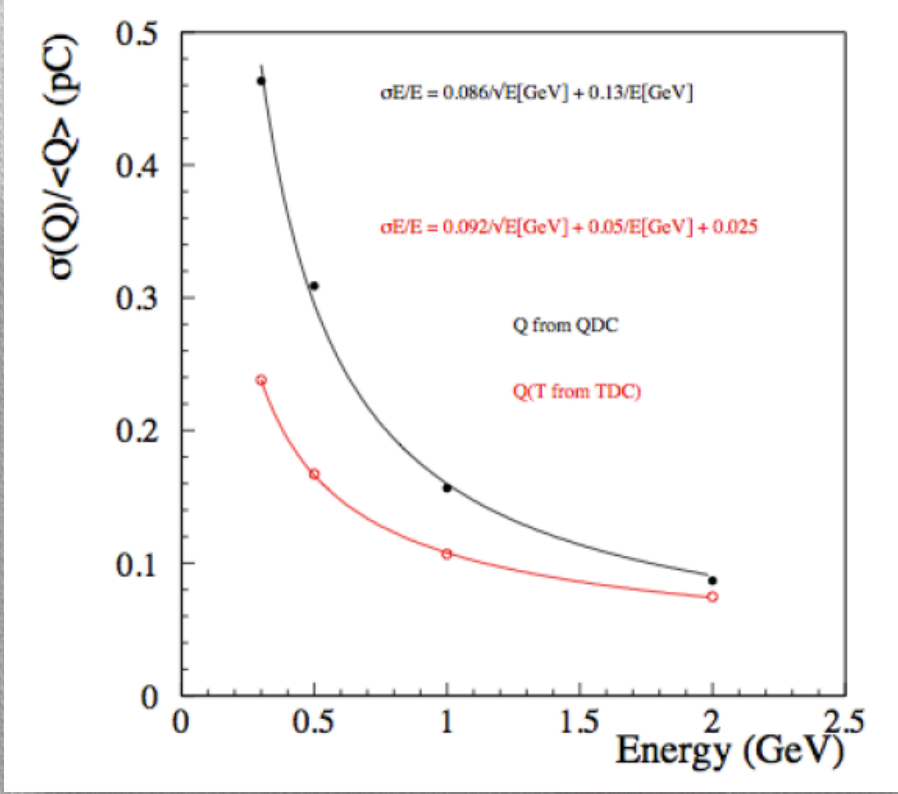
- H_2 @ 3.86 bar
- 100 photons/K
- K @ 50MHz
- $\approx$ 250 PMs
- 3MHz/PM
- $\sigma_t < 100$ps

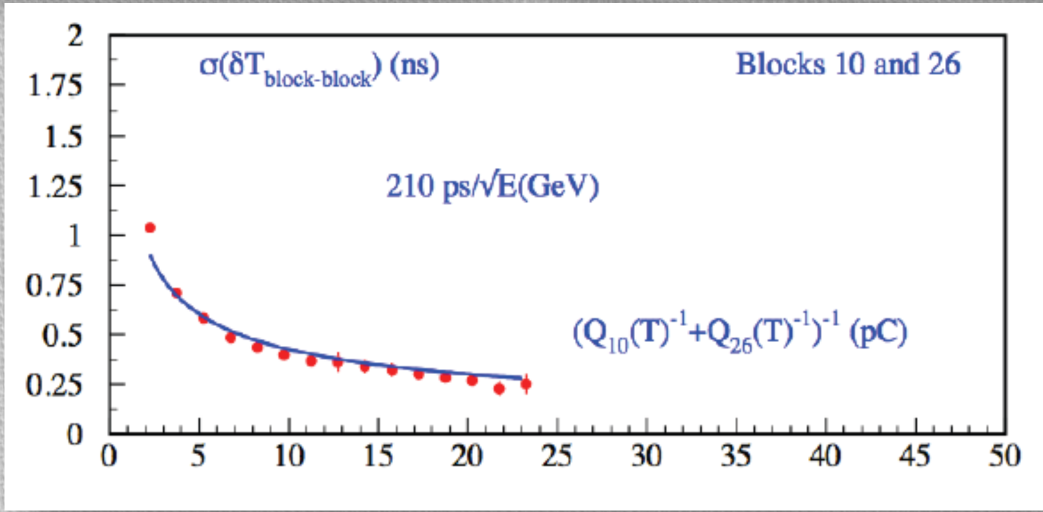




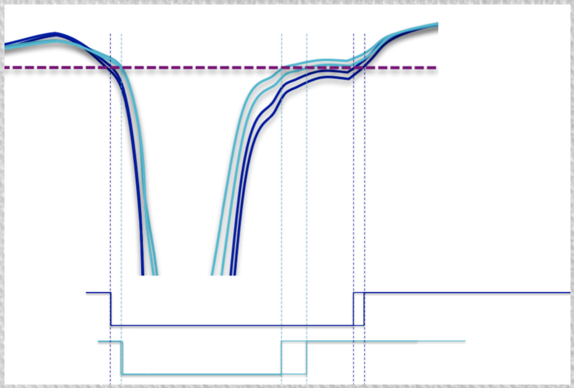
LAV performance





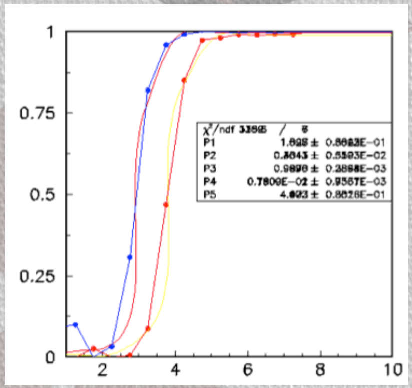


LAV readout electronics



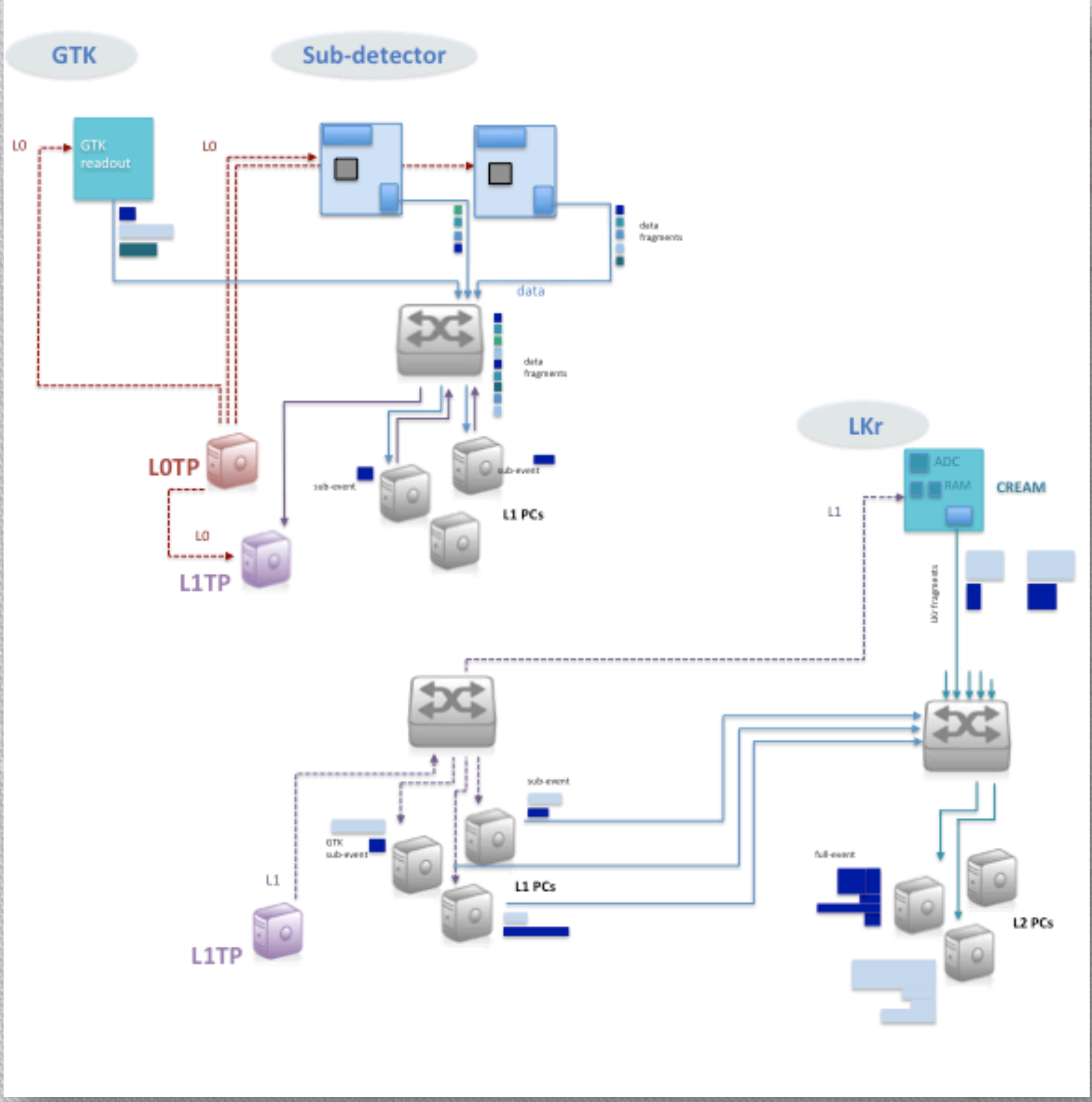
Time-over-threshold discriminator:
dual threshold

Efficiency



Threshold

Data flow



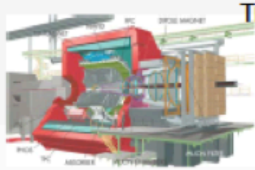
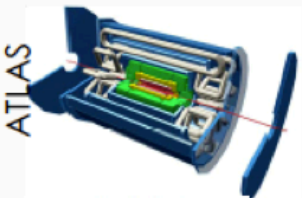
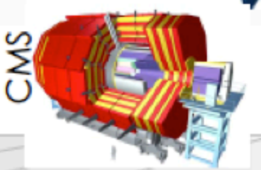
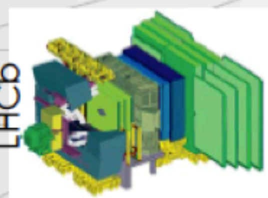
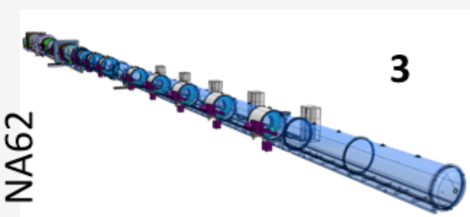
GTK
Sub-detector
L0
GTK readout
L0
data fragments
data
data fragments
LKr
L0TP
ADC
RAM
CREAM
sub-event
sub-event
L1 PCs
L1
L0
L1TP
sub-event
GTK sub-event
L1 PCs
full-event
L1
L2 PCs
L1TP

L0 trigger rates

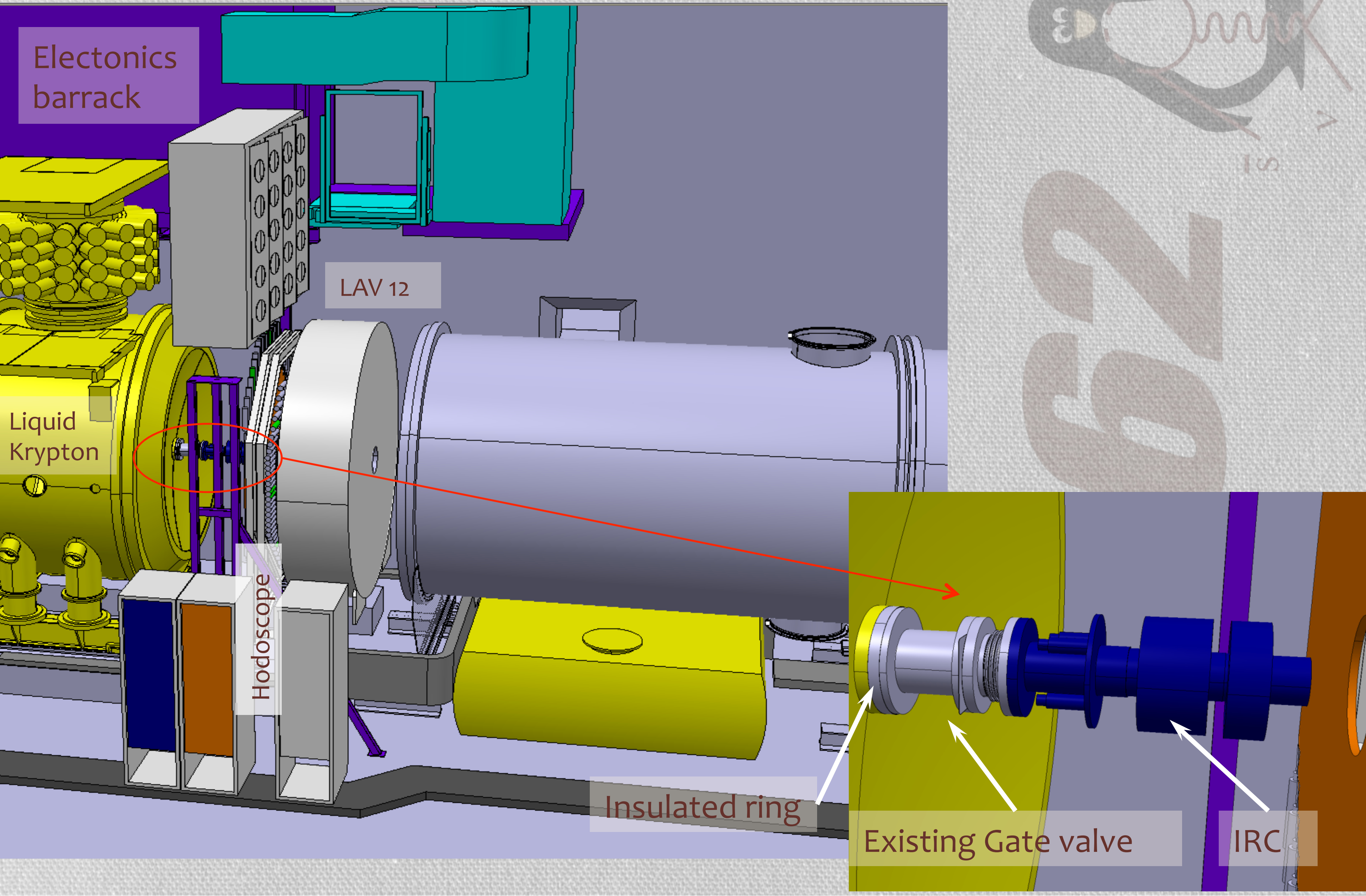
gradually add signals on top of the previous

	kHz	CHOD	* RICH	* MUV3	* LKR	* LAV_12	* LAV_ALL
$\pi\pi^0$	1859	1255	1128	1078	200	134	85
$\mu\nu$	5719	3786	3376	1	1	1	1
$\pi\pi\pi$	503	393	379	315	89	89	89
$\pi\pi^0\pi^0$	158	105	97	90	3	1	0
$\pi^0 e\nu$	456	265	243	243	41	28	20
$\pi^0\mu\nu$	301	195	178	1	1	0	0
TOT	8998	**5999**	**5400**	**1727**	**334**	**254**	**196**
$\pi\nu\nu$ (P,Z cuts) eff. %		93	82	77	75	75	75

Data volume

	No.Levels Trigger	Level-0,1,2 Rate (Hz)	Event Size (Byte)	Readout Bandw.(GB/s)	HLT Out MB/s (Event/s)
ALICE 	4	Pb-Pb 500 p-p 10^3	$5x10^7$ $2x10^6$	25	1250 (10^2) 200 (10^2)
ATLAS 	3	LV-1 10^5 LV-2 $3x10^3$	$1.5x10^6$	4.5	300 ($2x10^2$)
CMS 	2	LV-1 10^5	10^6	100	~1000 (10^2)
LHCb 	2	LV-0 10^6	$3.5x10^4$	35	70 ($2x10^3$)
NA62 	3	LV-0 10^6 LV-1 10^5 LV-2 $1.5x10^4$	$3x10^4$	30	150 ($5x10^3$)

IRC



Electonics barrack
LAV 12
Liquid Krypton
Hodoscope
Insulated ring
Existing Gate valve
IRC

New beam dump