A New Time of Flight System for Strangeness Measurements with FOPI.

Budapest *(Hungary)*, Bucharest *(Romania)*

Clermont-Ferrand *(France)*, Darmstadt *(Germany)*, Dresden *(Germany)*

Heidelberg *(Germany)*, Moscow *(Russia)*, Seoul *(South Korea)*

Strasbourg *(France)*, Warszawa *(Poland)*, Zagreb *(Croatia)*

and

Coimbra *(Portugal)*

FOPI

Introduction

FOPI Detector @ GSI

Strangeness Measurements with FOPI

FOPI Upgrade

New Time of Flight System:

- Spark Detector: PesToF
- Avalanche Counter: GRPC

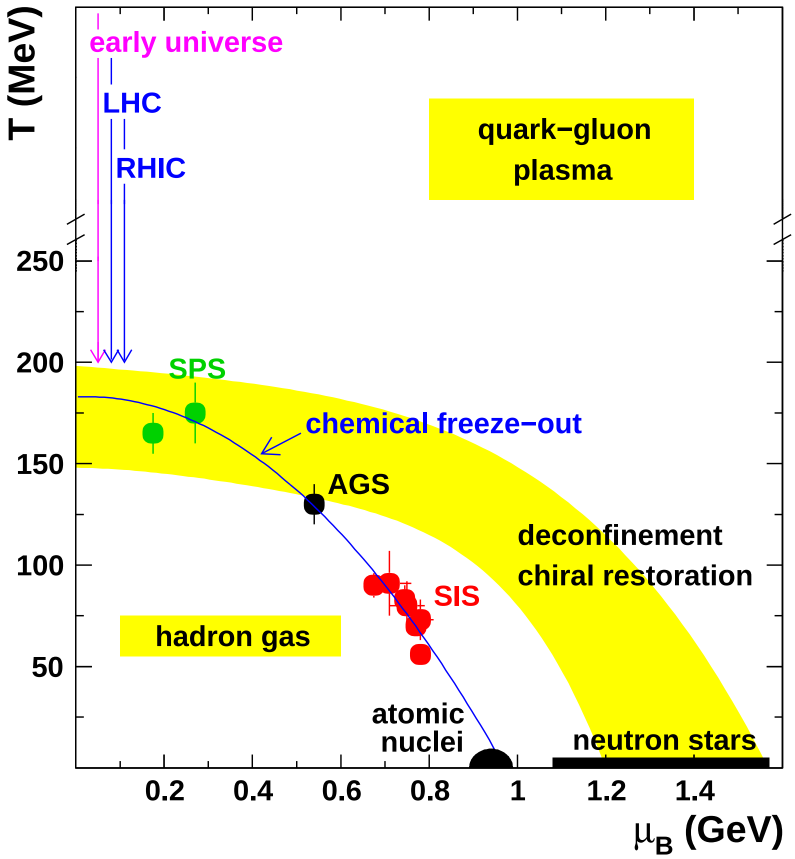
Conclusion

Introduction

▷ (Ultra)-Relativistic Heavy Ion Collisions:

∘ Goal:

→ Exploration of the Nuclear Matter Phase Diagram



∘ Observables:

→ Particle Yields, Ratios, Flow

∘ Limitations:

Complex Dynamics

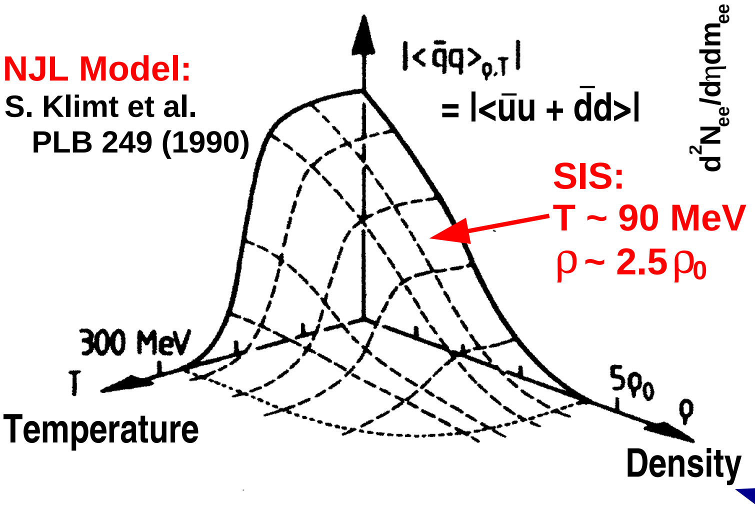
Final State Interactions

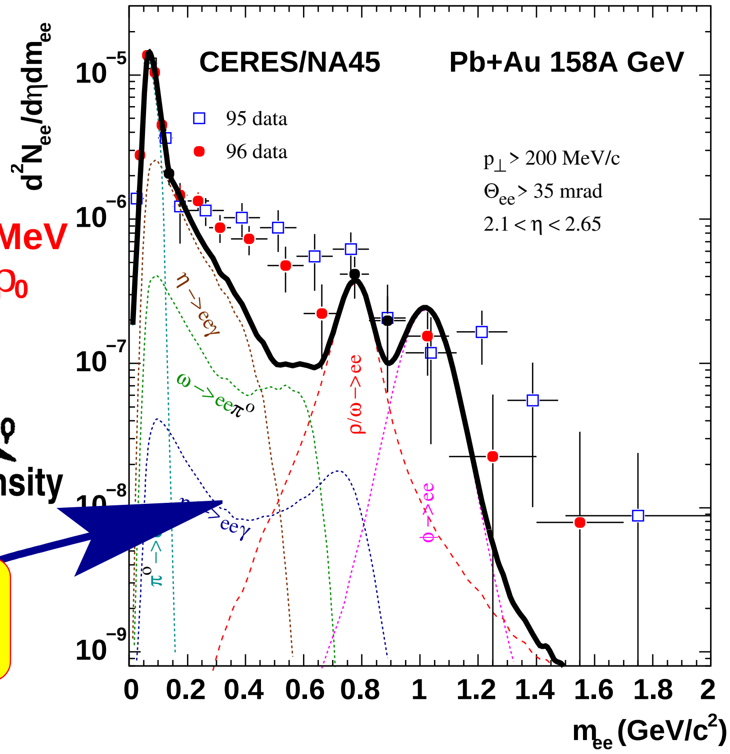
Small System Size

Small Life Time

▷ In Medium Effects:

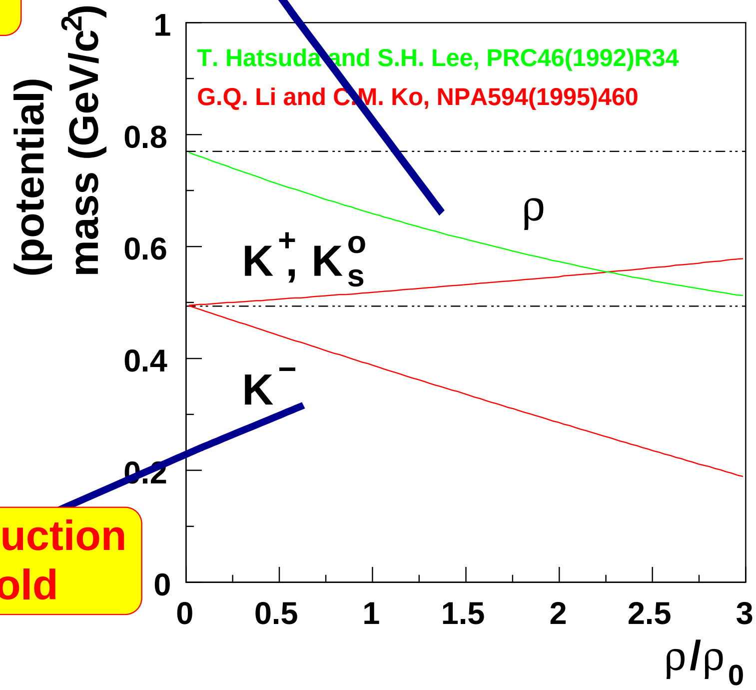
NJL Model:
S. Klimt et al.
PLB 249 (1990)





Dilepton Yield

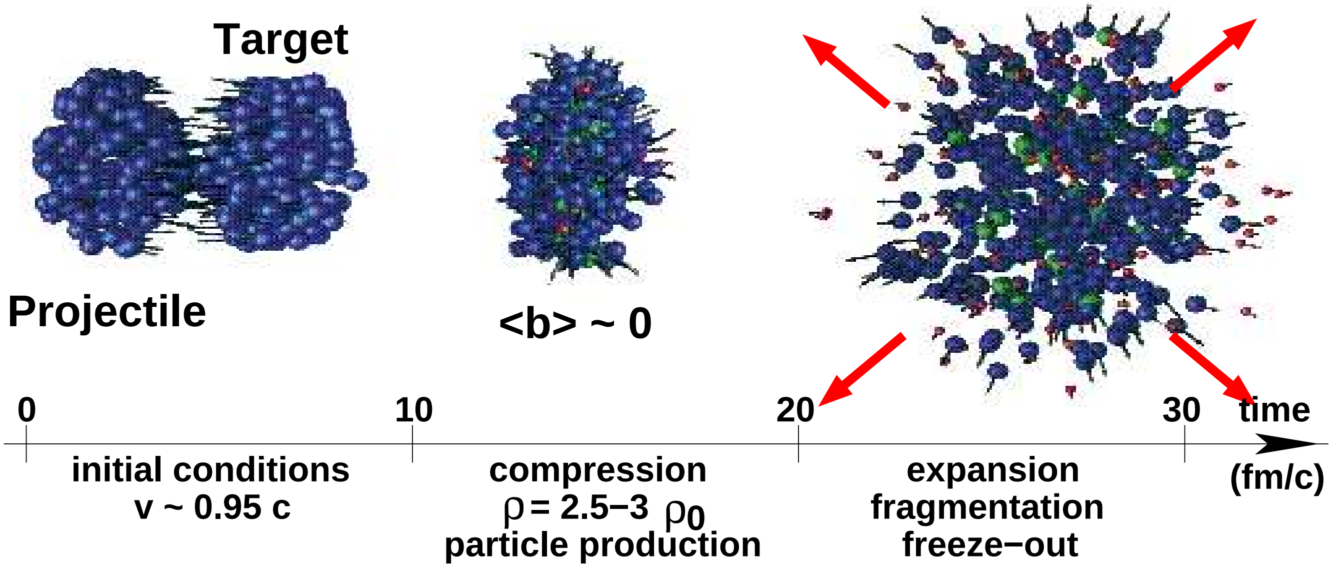
Partial Chiral Symmetry Restoration



Kaons Production at Threshold

	$E_{threshold}$ (GeV)	with in−medium effects: yield	with in−medium effects: momentum
K^-	2.5	↗	↘
K^+	1.6	↘	↗
K^o_s	1.6	↘	↗

▷ Heavy Ions Collisions @ SIS: (1-2A GeV)



- ◦ Heating
- ◦ Compression
- ◦ Nuclear Excitation
- ◦ Strangeness Production near Threshold

  → More Sensitive to In-Medium Effects

  ◇ Low Production Yield

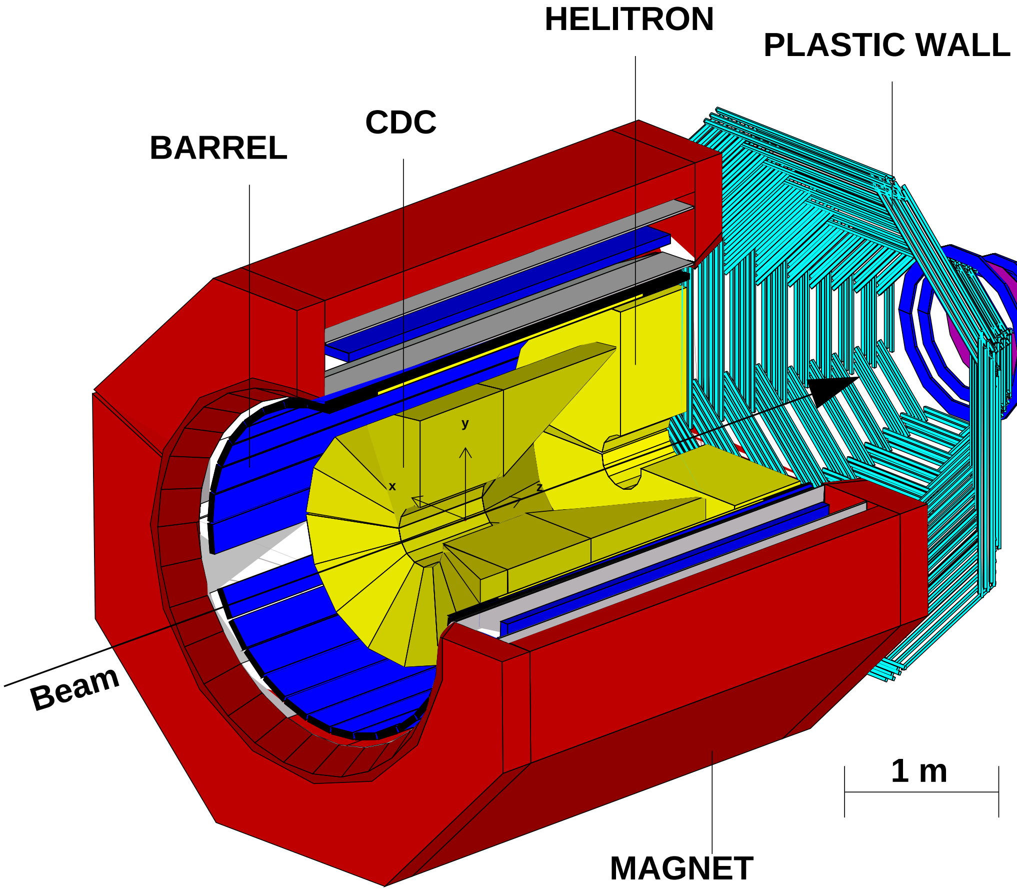
  $\sim$ 1 K^+ in 10^2, 1 K^- in 10^4 events
  (central Au+Au collision @ 1.5A GeV)

  ◇ Complex Production Mechanism

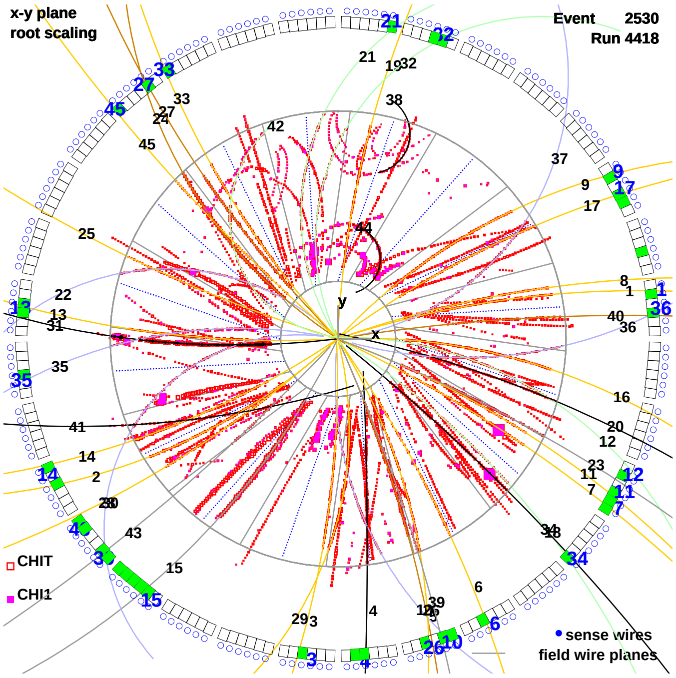
NN	–>	NΛK	NΛπK	NΛππK
NN	–>	NΣK	NΣπK	NΣππK
NΔ	–>	NΛK	NΛπK	NΛππK
NΔ	–>	NΣK	NΣπK	NΣππK
ΔΔ	–>	NΛK	NΛπK	NΛππK
ΔΔ	–>	NΣK	NΣπK	NΣππK
πN	–>	ΛK	ΛπK	
πN	–>	ΣK	ΣπK	K^+
πΔ	–>	ΛK	ΛπK	
πΔ	–>	ΣK	ΣπK	

NN	–>	NNKK	NNπKK	NNππKK
NΔ	–>	NNKK	NNπKK	NNππKK
ΔΔ	–>	NNKK	NNπKK	NNππKK
πN	–>	NKK	NπKK	
πΔ	–>	NKK	NπKK	
πΛ	–>	NK		
πΣ	–>	NK		
NΛ	–>	NNK		K^-
NΣ	–>	NNK		
ππ	–>	KK		

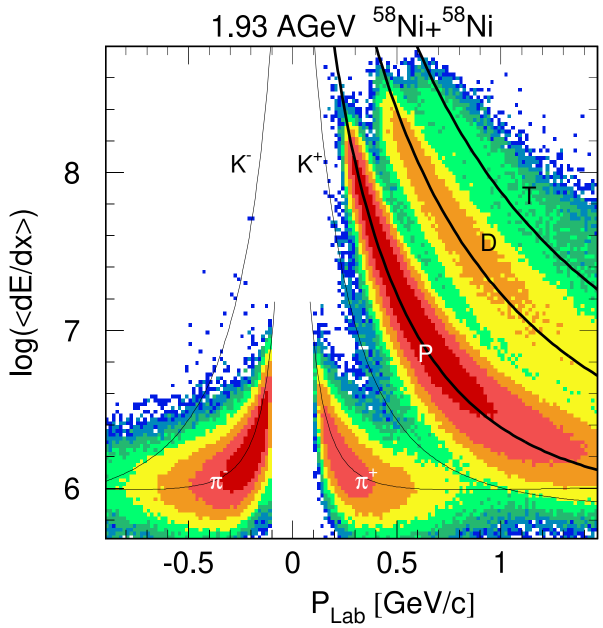
FOPI Detector @ GSI

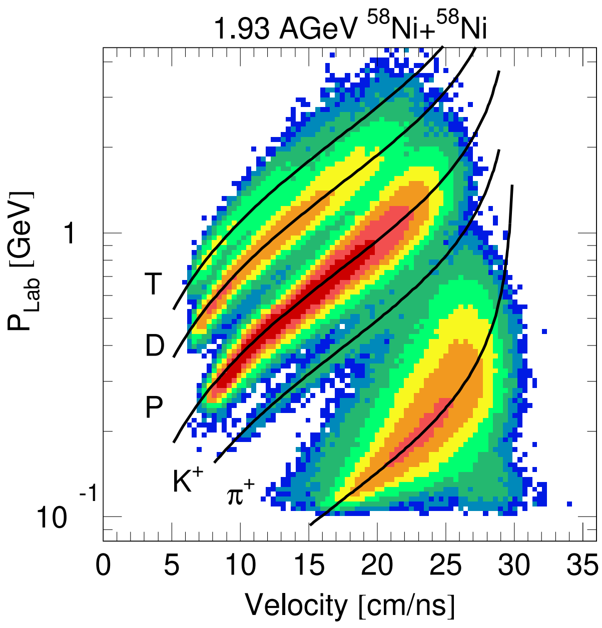


Central Ru + Ru @ 1.69A GeV



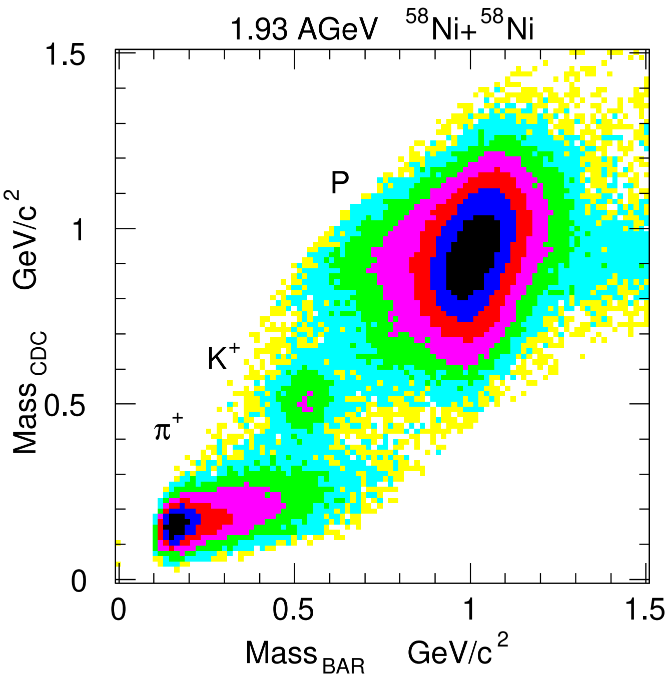
▷ Charged Particle Identification: (CDC/ToF)

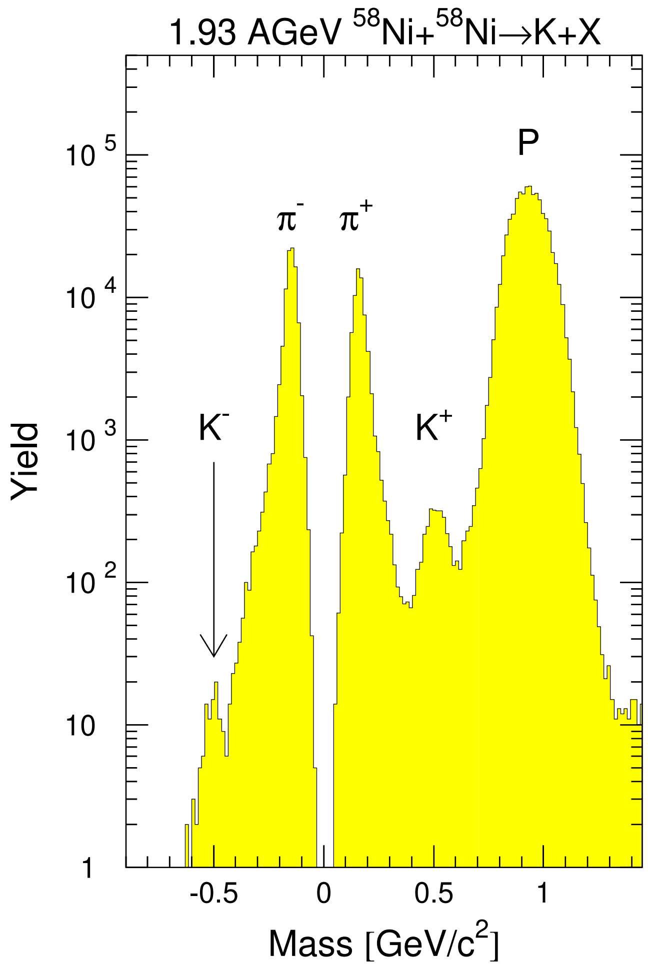




CDC : Bethe-Bloch

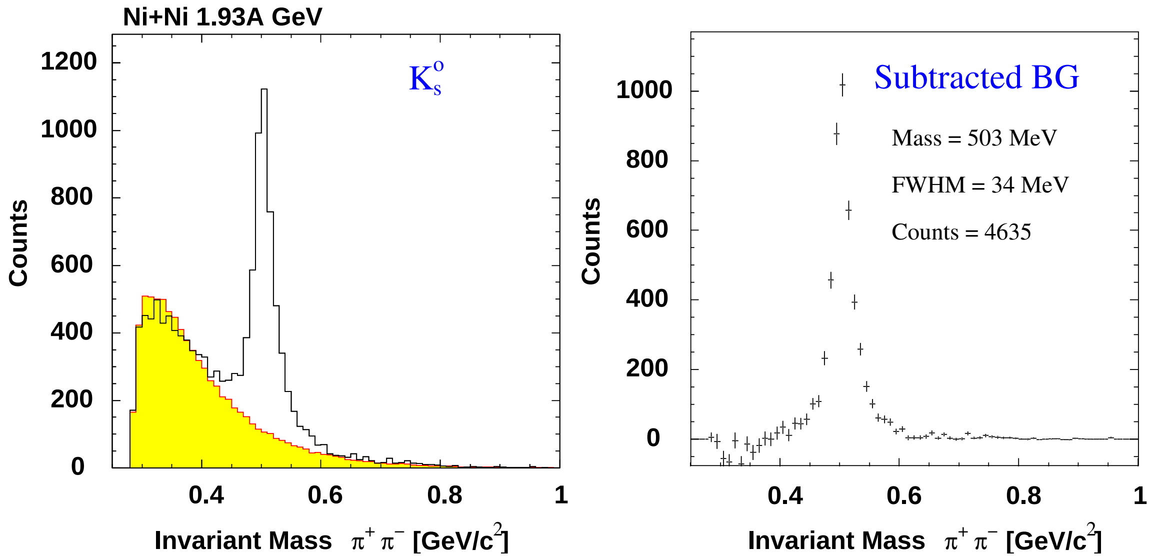
CDC/ToF Barrel: $P = \gamma m \beta$



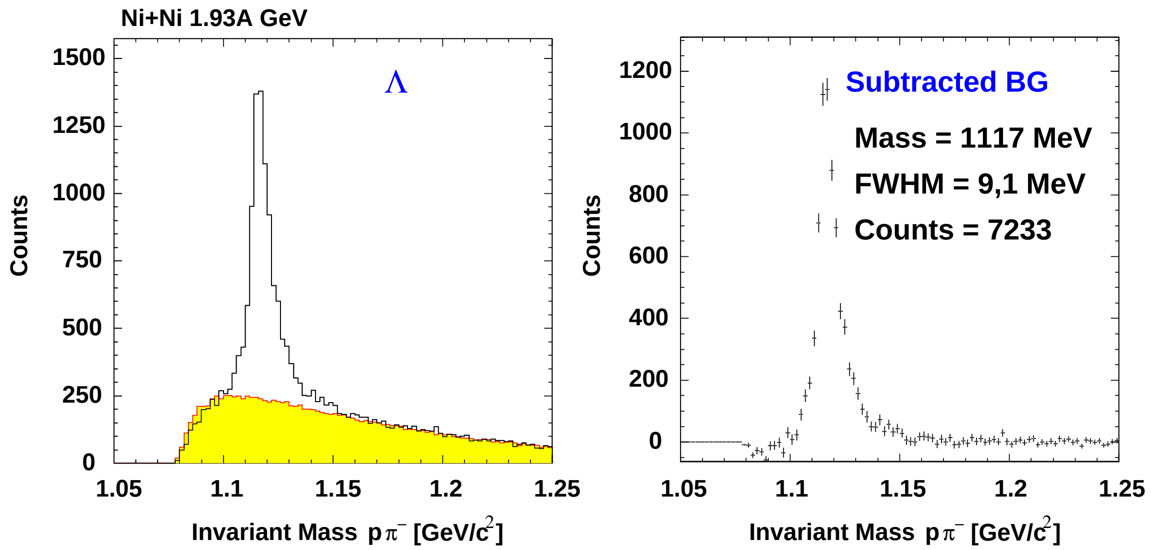


- Neutral Strange Particles

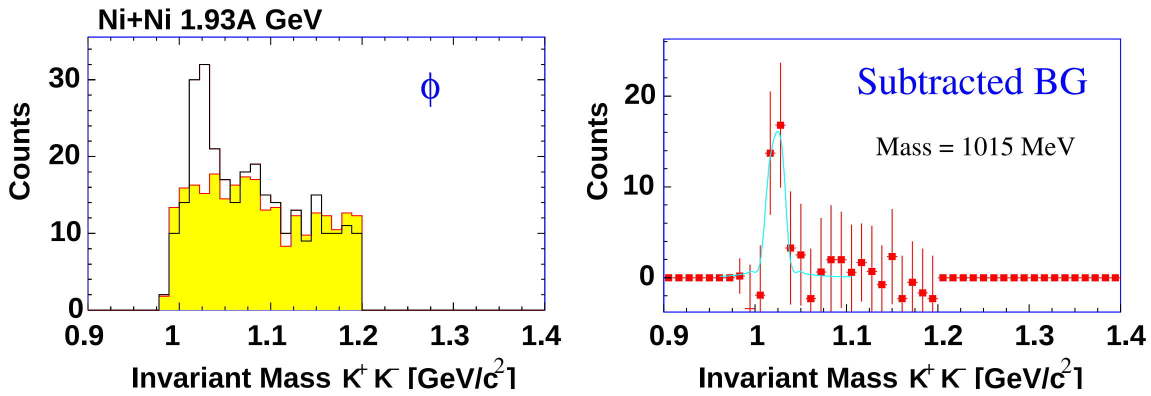
$K_s^0 \rightarrow \pi^+\pi^-$ with 69 % BR



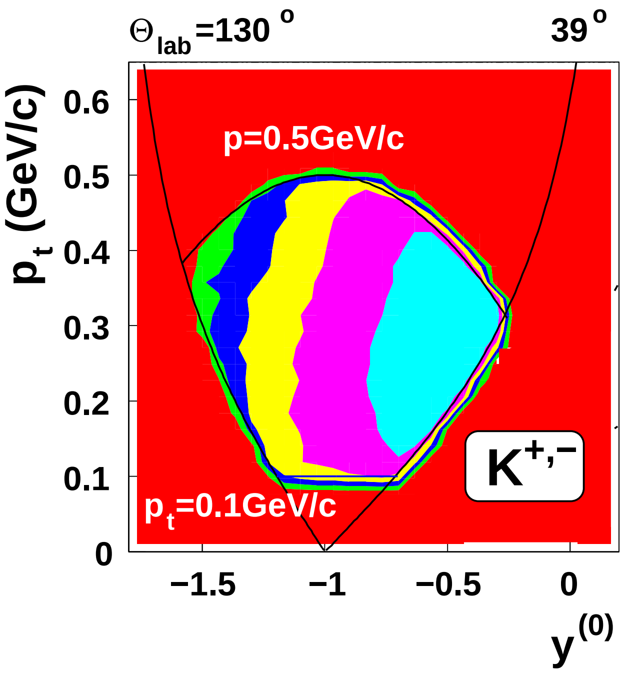
$\Lambda \rightarrow p\pi^-$ with 64 % BR

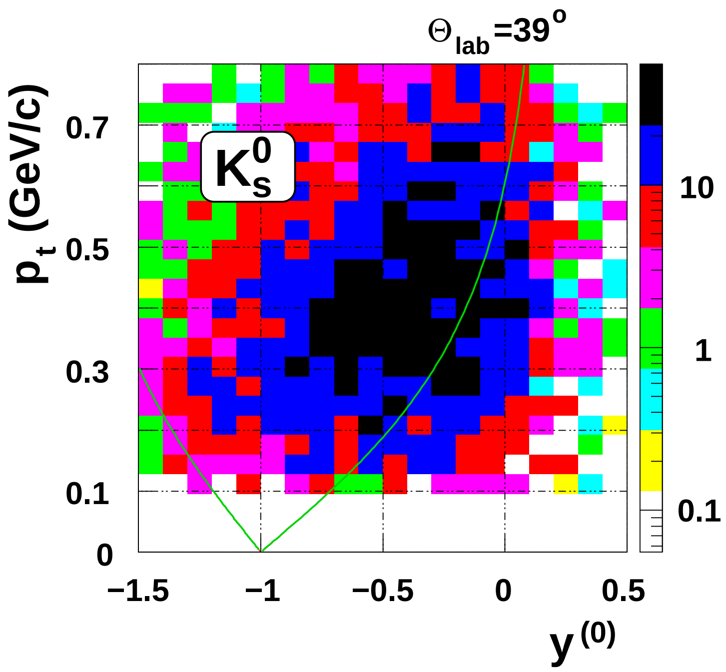


$\phi \rightarrow K^+K^-$ with 50 % BR



▷ Kaon Acceptance and Statistics:

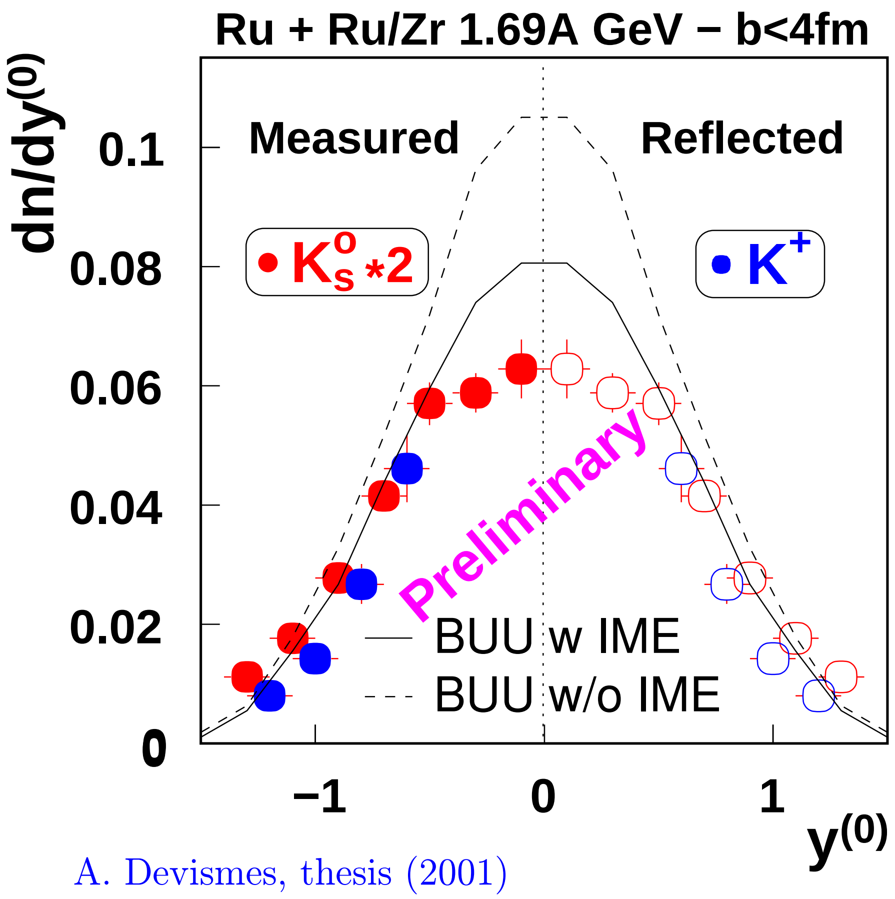




System	Beam Energy	N events	$\mathbf{K}^+$	$\mathbf{K}^-$	$\mathbf{K}_s^0$
Ni+Ni	1.06A GeV	$2.8 \cdot 10^6$	30	-	-
	1.45A GeV	$1.8 \cdot 10^6$	300	-	-
	1.93A GeV	$2.9 \cdot 10^6$	3000	50	-
Ni+Ni	1.93A GeV	$4.7 \cdot 10^6$	30000	220	4640
Ru+Ru/Zr	1.69A GeV	$7.7 \cdot 10^6$	30000	240	4120

Strangeness Measurements with FOPI

▷ Rapidity Distribution:



A. Devismes, thesis (2001)

R. Kutsche, thesis (2000), Ch. Finck Analysis in Progress

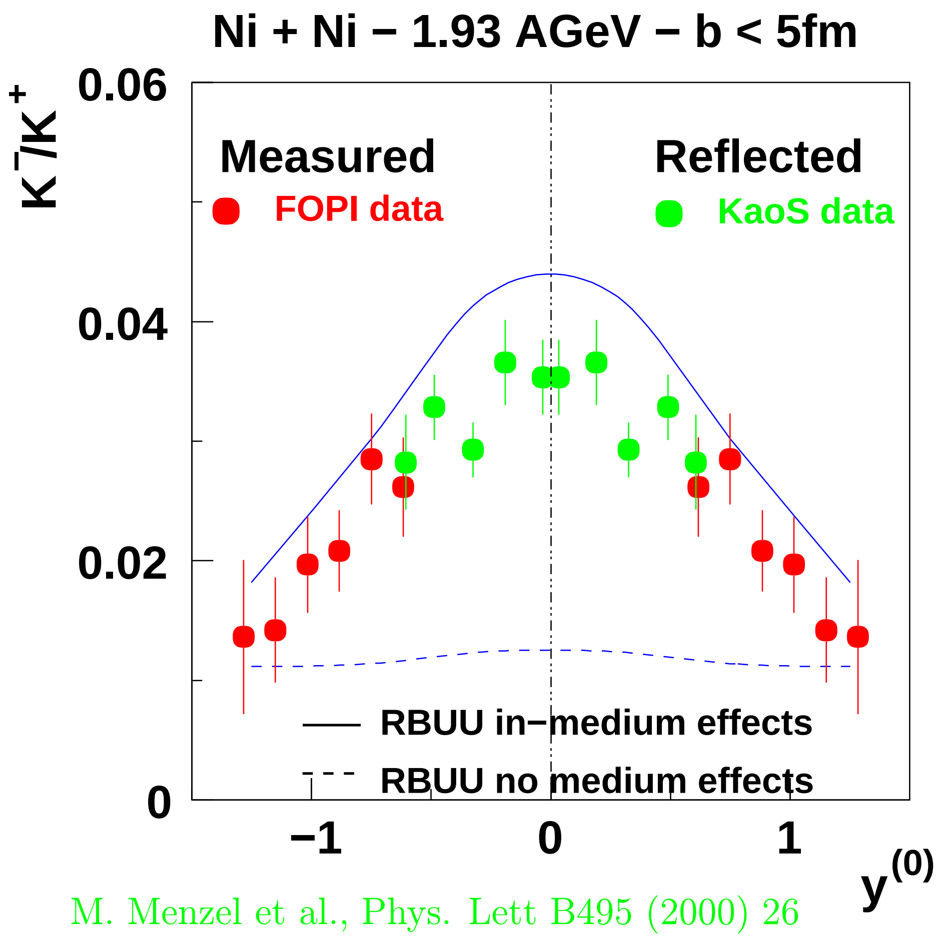
W. Cassing and E.L. Bratkovskaya Private Communication

$\rightarrow$ Same Yield for K^+ and K^0 within Error Bars

$\Longrightarrow$ BUU: Data Support a Repulsive Potential

▷ Ratio K^-/K^+: (less sensitive to detector acceptance)

→ In-Medium Effects Act Oppositely on K^- and K^+



M. Menzel et al., Phys. Lett B495 (2000) 26

K. Wisniewski et al., Eur. Phys. J. A9 (2001) 515

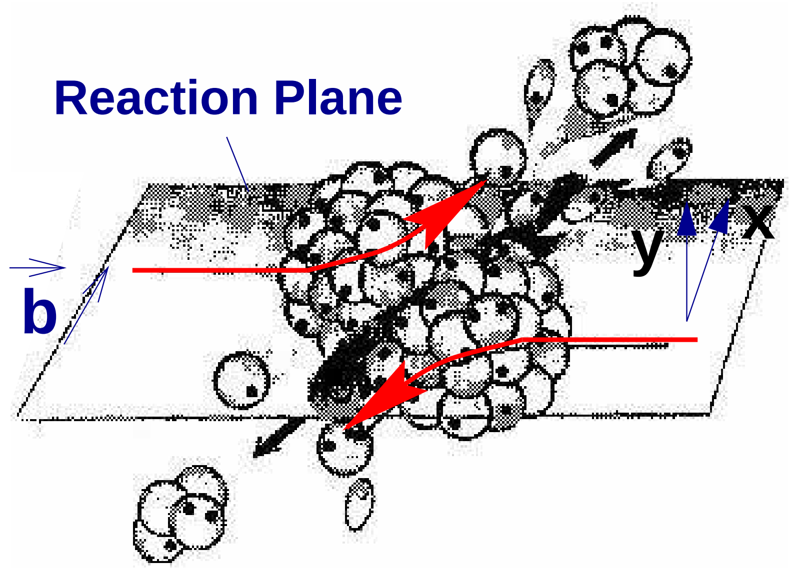
W. Cassing and E.L. Bratkovskaya, Phys. Rep. 308 (1999) 65

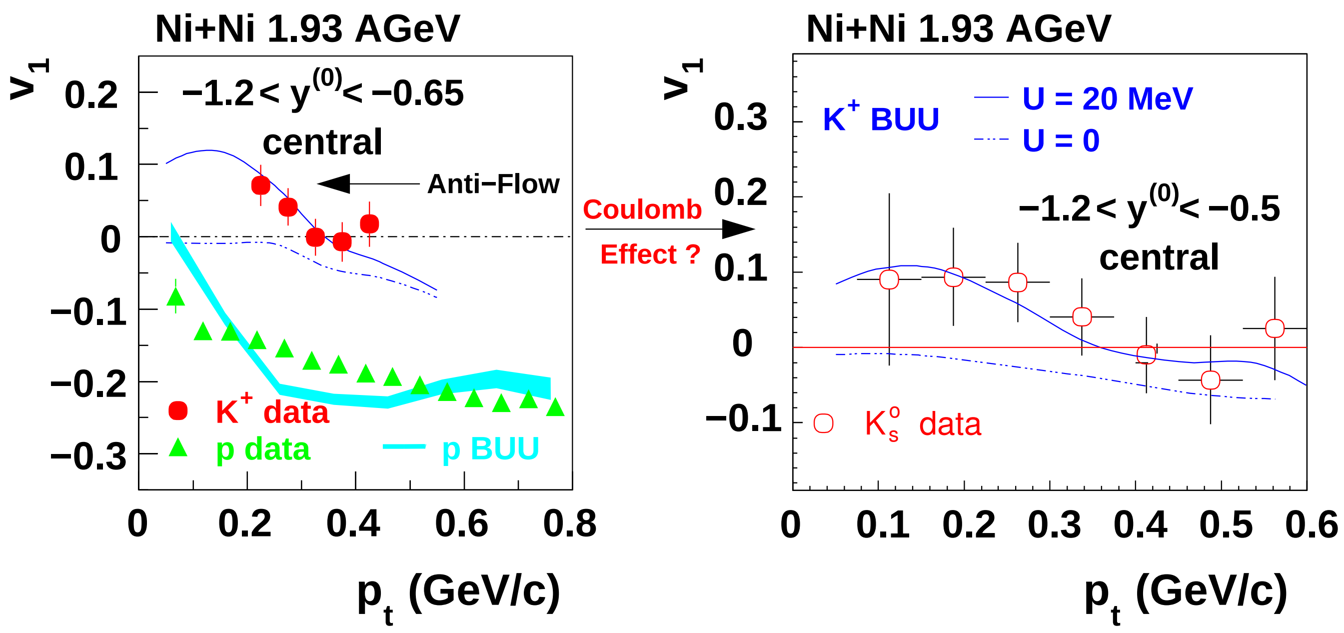
→ Increasing of the Ratio at Mid-Rapidity

RBUU Reproduces the Trends

→ Still Discrepancies

▷ Directed Differential Flow: $(v_1 = < \frac{P_x}{P_t} >)$





Ph. Crochet et al., PLB486 (2000) 6/ R. Kutsche, thesis 2000-05 (2000)

◇ Anti-Flow for K^+ and K^0_s

More Pronounced at Low $\mathbf{p}_t$

Not understood with Coulomb Potential

$\Longrightarrow$ Data Favor the In Medium Scenario

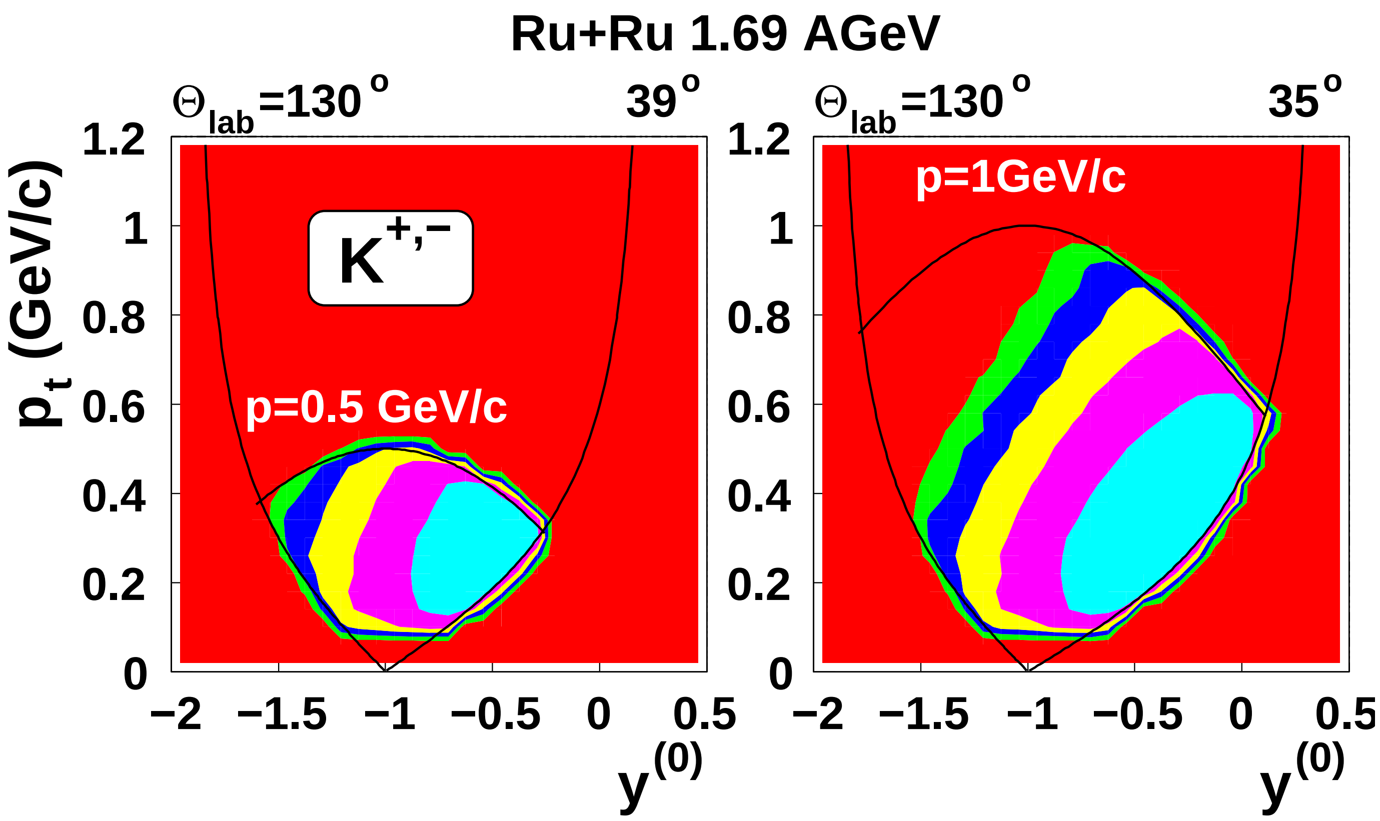
$\Longrightarrow$ BUU Reproduces K^+, K^0_s Anti-Flow but not Proton Flow

FOPI Upgrade

▷ Goals:

- ○ Larger Acceptance

$\Longrightarrow$ Increase ToF Resolution



- ○ Better Particle Identification

$\rightarrow$ Double Hit Probability $\sim$ 5 %

$\Longrightarrow$ Increase ToF Granularity

- ○ Higher Statistic

$\Longrightarrow$ Increase Rate Capability of the DAQ

▷ Upgrade:

- ◦ Future Perfomance of DAQ (main limitation DC readout)

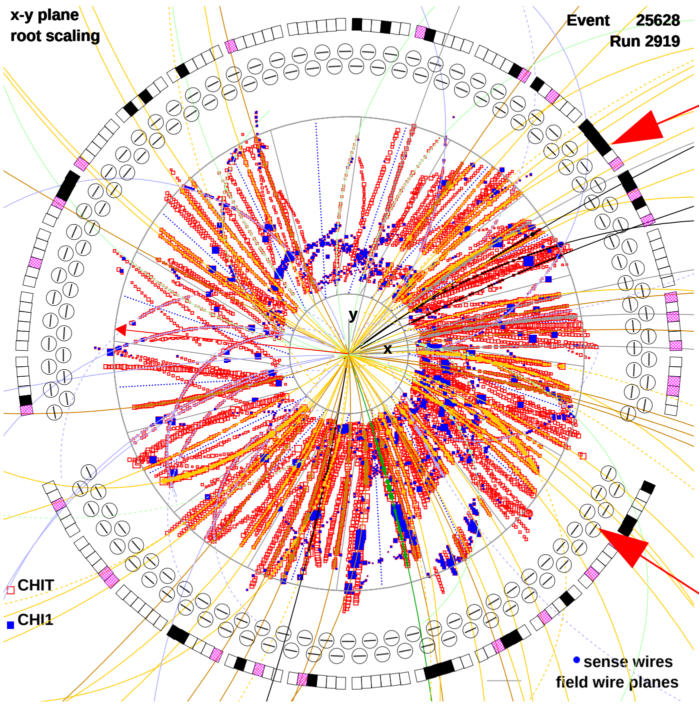
  → New FADC Scanners, Active VME Interface,

  → New Event Builder, Fast Ethernet

$\Longrightarrow$ New DAQ Rate $\times$ 10 $\rightarrow$ 10 Mb/s

- ◦ New Time of Flight System

  Central Au + Au @ 1.5A GeV



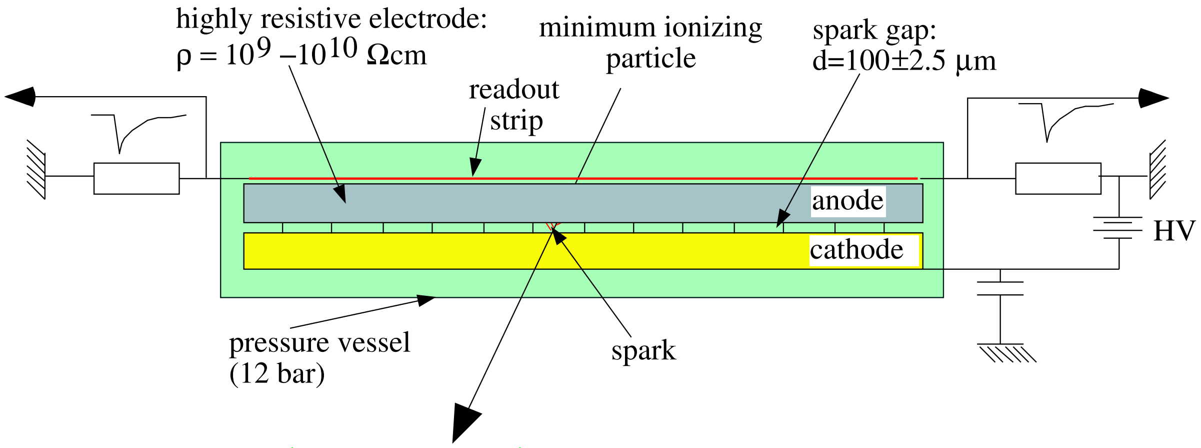
Plastic Scintillator Barrel
- ◦ granularity: 180
- ◦ resolution: 180 ps

Gas Detectors
- ◦ granularity: 600
- ◦ resolution: < 100 ps

$\Longrightarrow$ Program of R & D with Gas Detector

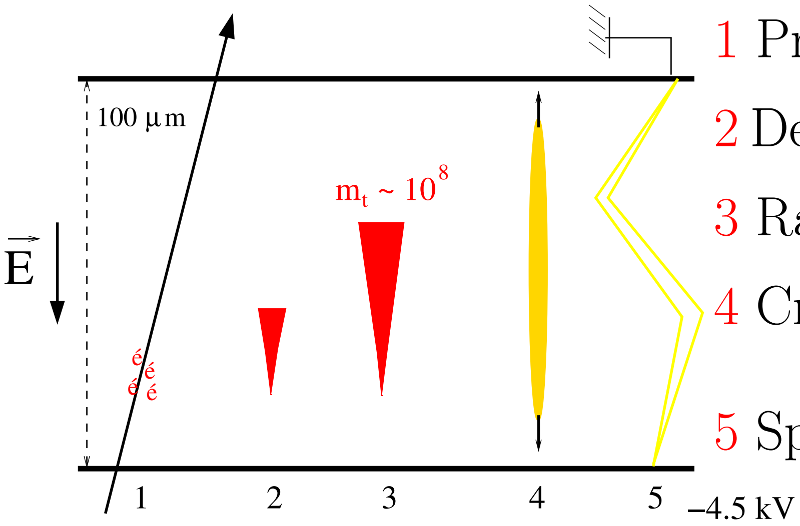
Spark Detector : PesToF

▷ Layout: (30 cm and 90 cm)



- Cathode: (aluminum)
- Anode: (glass: $\rho \sim 5\ 10^9\ \Omega{\cdot}\mathrm{cm}$)
- Gas Mixture: (12 atm)
  (77% Ne + 20% Iso-C_4H_{10} + 2.5% C_2H_4 + 0.5% C_4H_6)
- 16 Readout Strips: (left - right signal)

▷ Principle:

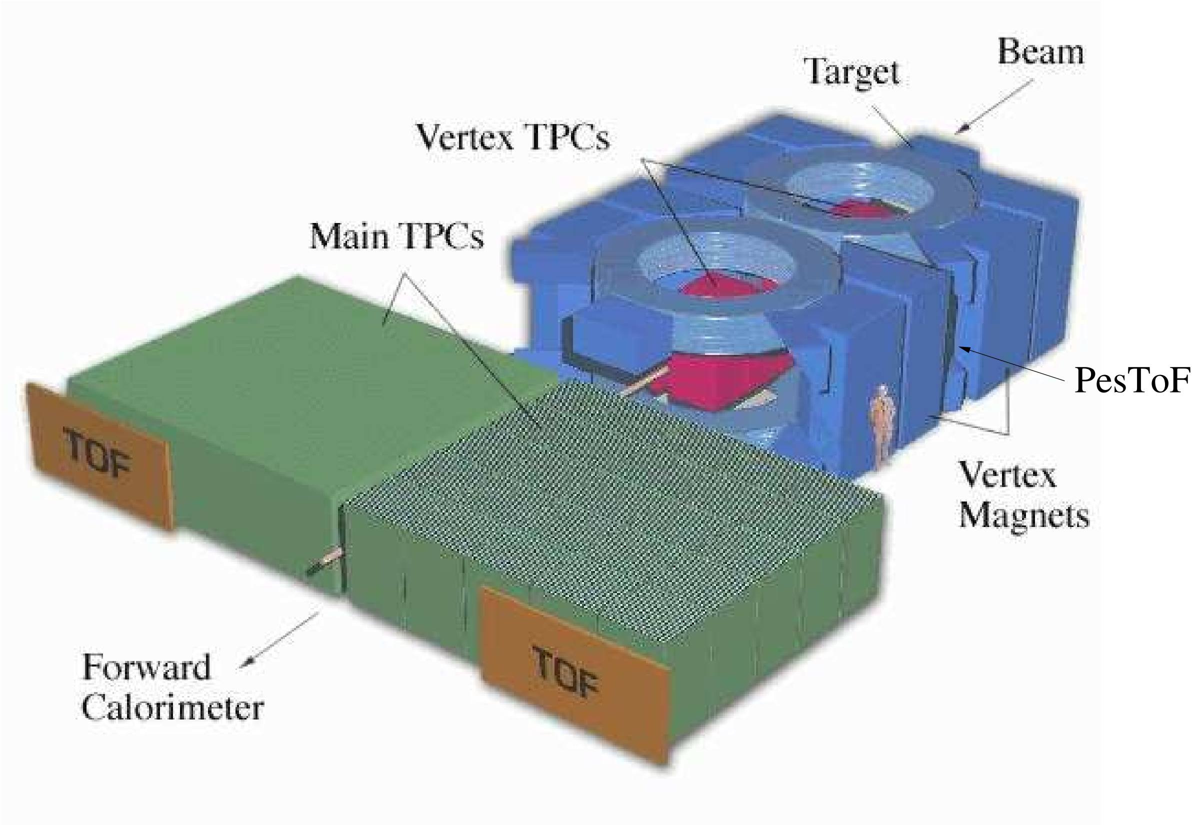


1 Primary Ionization (1-4 e)
2 Development of the avalanche
3 Raether Criterion ($\sim 10^8$ e)
4 Creation and Propagation of a Plasma
5 Spark

- Avalanche Time: $t_0 = m_t/\alpha v_d$
- Fluctuation: $\sigma = t_0/\sqrt{2}\ \ln m_t$

▷ Experiment with PesToF: (@ CERN)

○ NA49



◇ Physics with Heavy Ions Collisions at SPS (158A GeV)

$\rightarrow$ Large Acceptance Measurements of Hadrons

$\rightarrow$ QGP

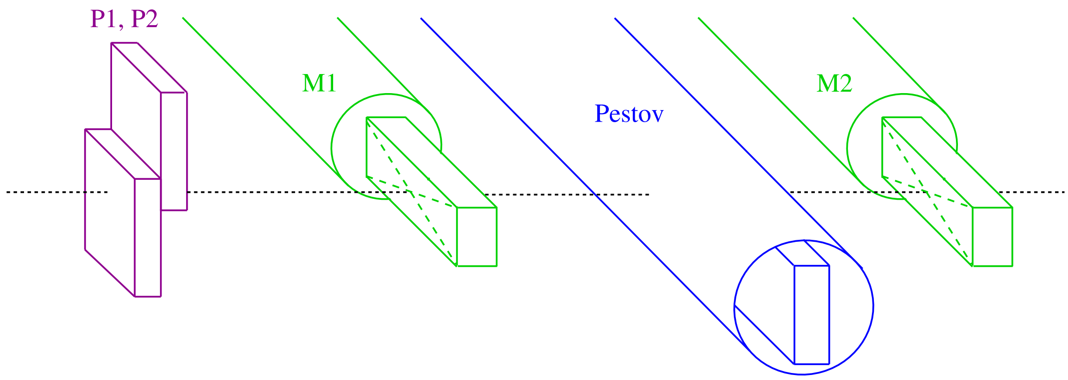
◇ Better Particle Identification: TPCs + ToFs

ToF Scintillator: $\sigma \sim 60$ ps, S ~ 4.4 m^2,
~ 1800 Counters

PesToF: $\sigma < 60$ ps, S ~ 0.4 m^2, 40 Counters

▷ Beam Tests: (@ GSI)

∘ Setup (Rate : $\leq$ 50 Hz/cm^2)



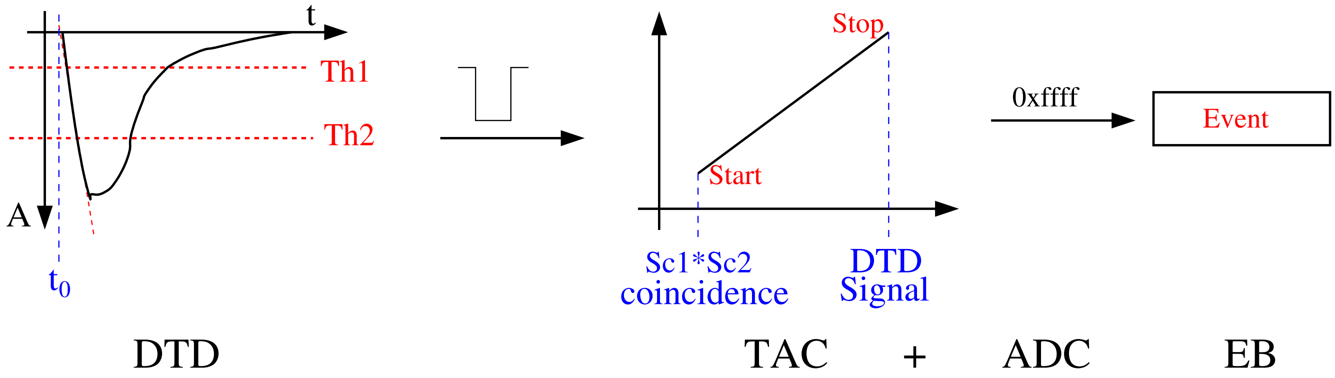
◇ Fragmentation of ^{12}C at 1.5A GeV $\rightarrow$ proton (MIP)

◇ Scintillators P1, P2 $\rightarrow$ Beam Focusing

◇ Scintillators M1, M2 $\rightarrow$ Reference Counters (gaussian : $\sigma_{tm1-tm2} < 65$ ps)

◇ ToF=$t_{pes} - \frac{1}{2}(t_{m1} + t_{m2})$ with $t_{pes} = \frac{1}{2}(t_{left} + t_{right})$

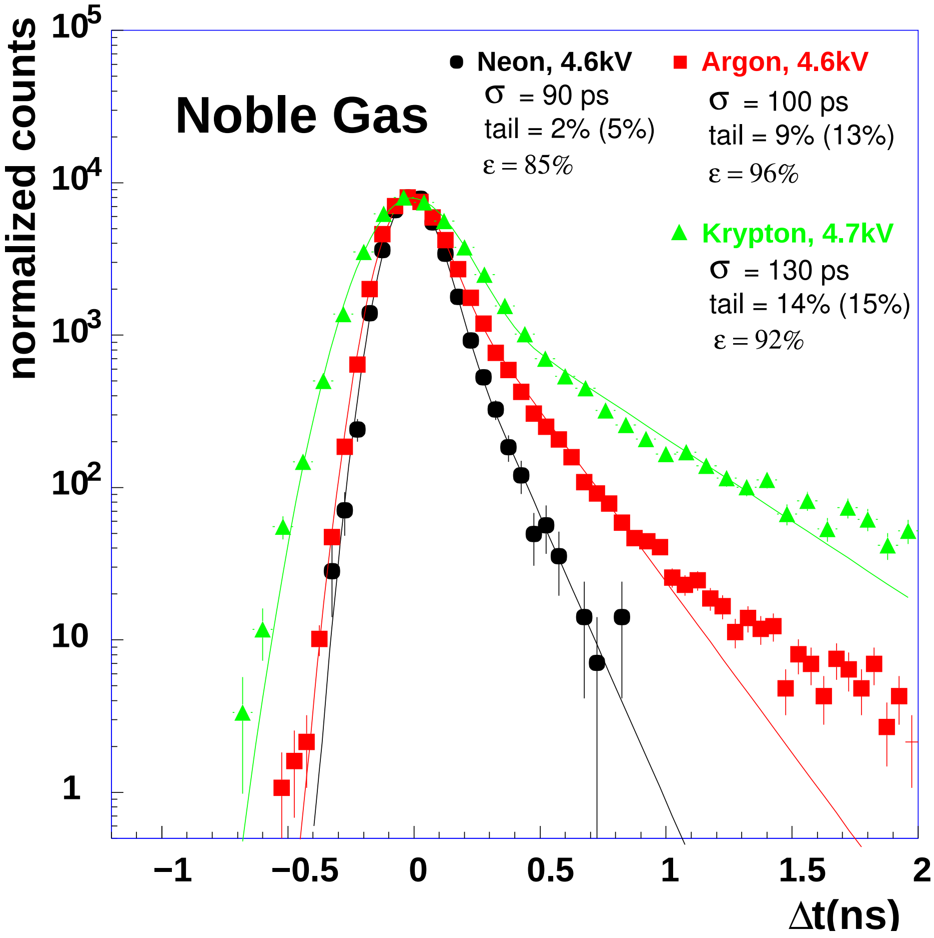
∘ Electronics (Standard CAMAC)



◇ Time Information: TDC LeCroy 2228A (50ps/ch)

◇ Charge Information: ADC LeCroy 2249W (1μs)

○ Results(*) (30 cm)



Higher Efficiency for Ar or Kr:

→ Higher Atomic Number Z: (Z_{Ne}=10, Z_{Ar}=18, Z_{Kr}=36)

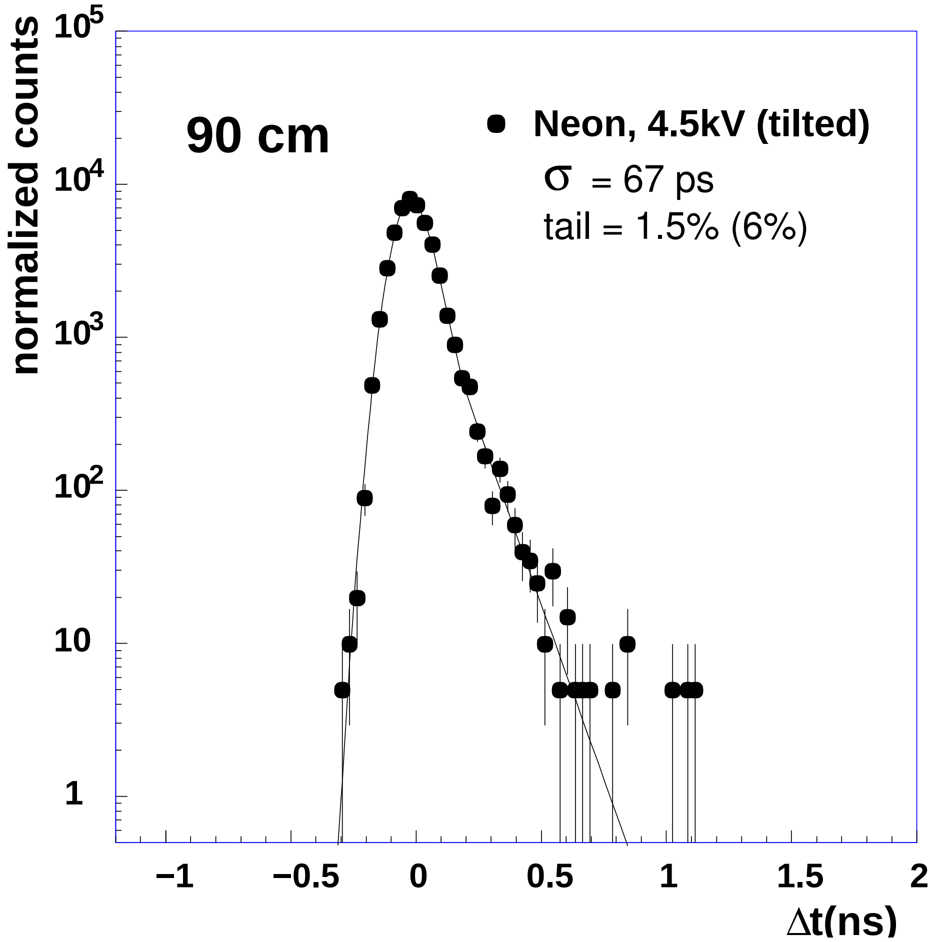
Best Time Response Function for Ne:

→ Townsend Coeff. (α) Drift Velocity (v_d) higher

Rem: No Optimization of Electronics

(*) A. Devismes, Ch Finck et al., accepted for publication in NIM A

◦ Results



◇ Standard Gas Mixture at 12 Atm.:

→ $\sigma_{int} \sim$ 60 ps ($\sigma_{tm1-tm2} \sim$ 60 ps)

→ Absolute Tail ($\pm$ 300 ps) of 1.5 %

▷ Conclusion:

◦ Fulfills FOPI Requirements

◦ High Requirements for the Glass Anode (Planarity: $\pm$ 3 μm, $\rho \sim 5\ 10^9\ \Omega{\cdot}$cm)

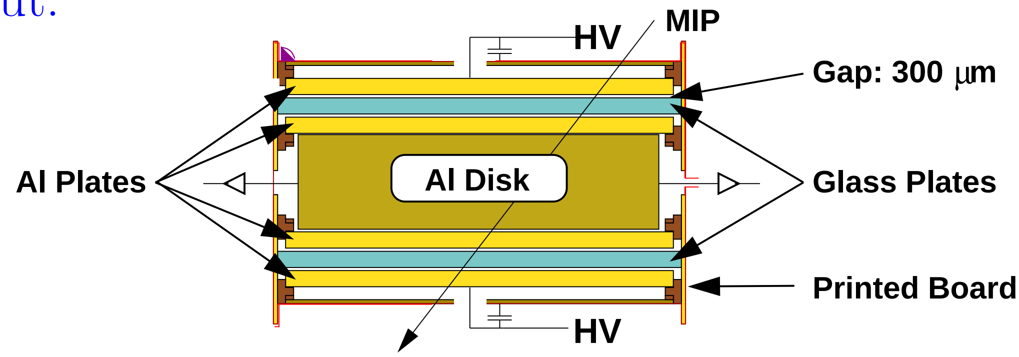
$\Longrightarrow$ Big Prob. with Glass Production (cristalization $\leftrightarrow \rho$)

→ 2/3 of the Plates not usable

$\Longrightarrow$ New ToF Technique Developments

Avalanche Detector: GRPC (∅ 5 cm)

▷ Layout:



◇ 2 Glass Plates ∅ 50 mm ($\rho \sim 10^{12}$ Ω·cm)

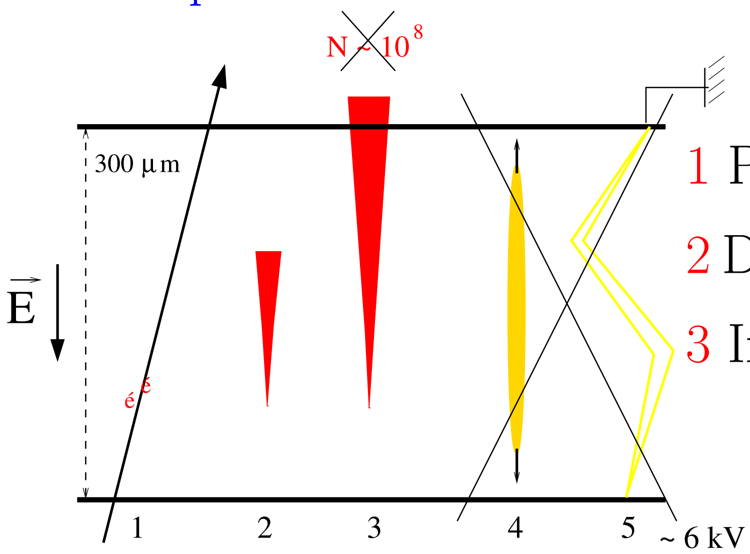
◇ 4 Aluminum Plates of ∅ 47 mm (HV ∼ 6 kV)
→ No Spacers: Glass and Al Plates Glued or soldered

◇ 2 Pre-amplifiers via an Al Disc

◇ No Floating Anode: Voltage Divider

◇ Gas Mixture: (1 atm)
85% freon +10% SF_6 + 5% iso-C_4H_{10}

▷ Principle:



1 Primary Ionization(1-2 e)

2 Development of the Avalanche

3 Influence (∼ 10^6 e)

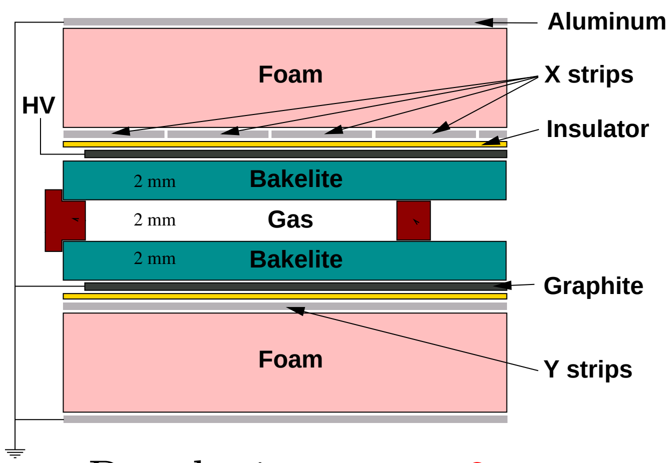
→ Avoid Streamer Mode: (SF_6)

▷ Experiment with RPCs: (@ SLAC)

- BaBar

◇ B^0-$\bar{B}^0$ Physics (e^-e^+: 9 GeV)
  → CP Violation

◇ Hit Recognition



Bakelite: $\rho \sim 10^{11}$ Ω·cm

Gas: 58 % Argon + 39 % Freon + 3 % Iso-C_4H_{10}

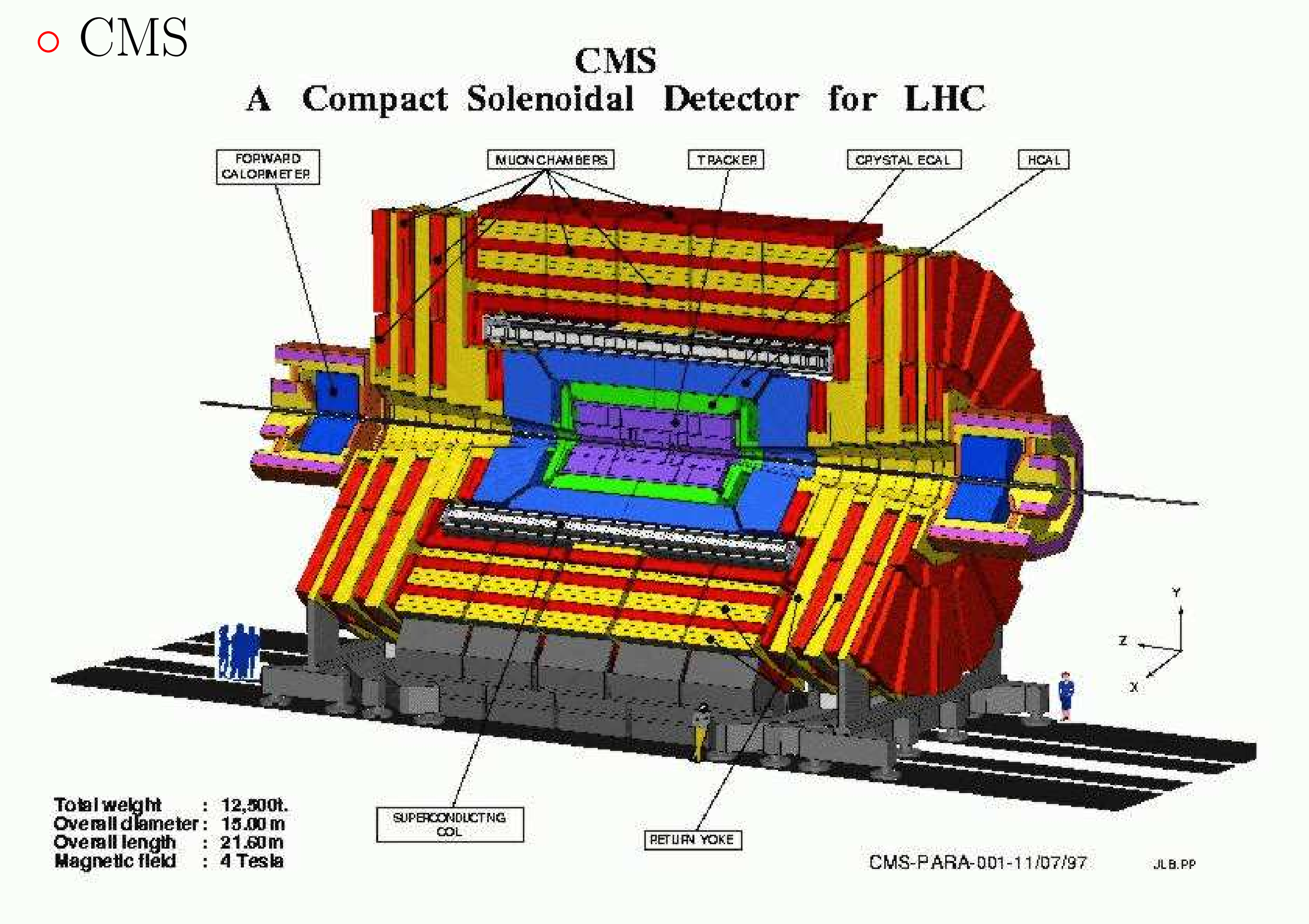
Area: $\sim$ 2500 m^2

Resolution: $\sigma < 2$ ns

Efficiency: $\epsilon > 85$ %

▷ Experiments with RPCs: (@ CERN)

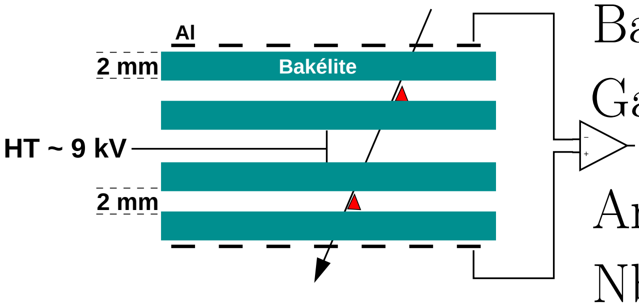
∘ CMS



◇ Search of the Higgs Boson (p-p: $\sqrt{s} = 15.4$ TeV)

$\longrightarrow$ Test of the Standard Model and Beyond

◇ Muon Chambers (Trigger)



Bakelite: $\rho \sim 10^{10}\ \Omega\cdot$cm

Gas: 95 % Freon + 5 % Iso-C_4H_{10}

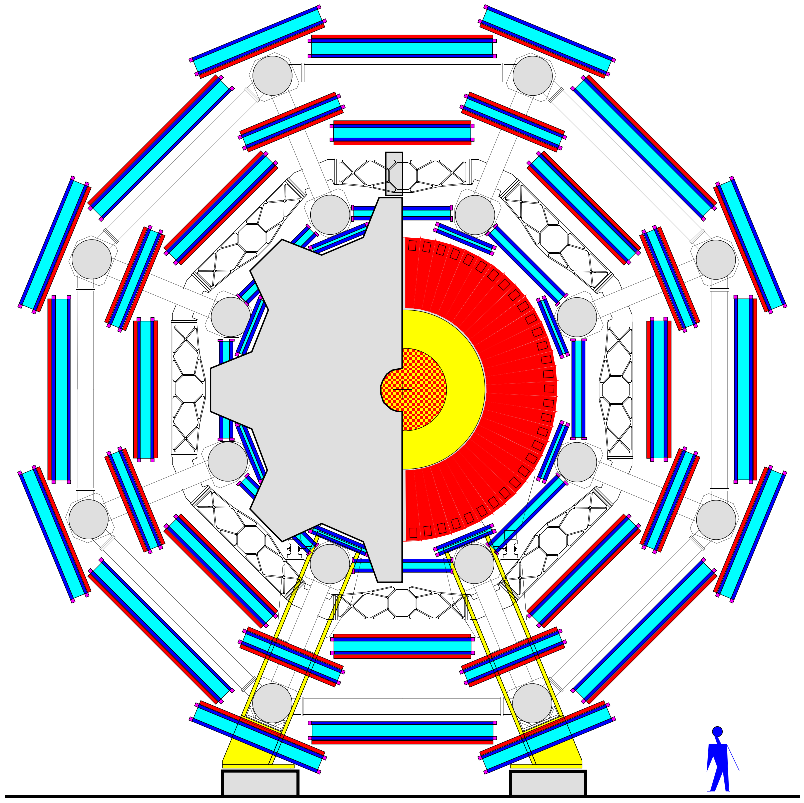
Area: $\sim$ 3100 m^2

Nb of Readout Strips: > 147000

Resolution: $\sigma <$ 2 ns

Efficiency: $\epsilon >$ 95 %

∘ ATLAS



◇ Search of the Higgs Boson (p-p: $\sqrt{s} = 15.4$ TeV)

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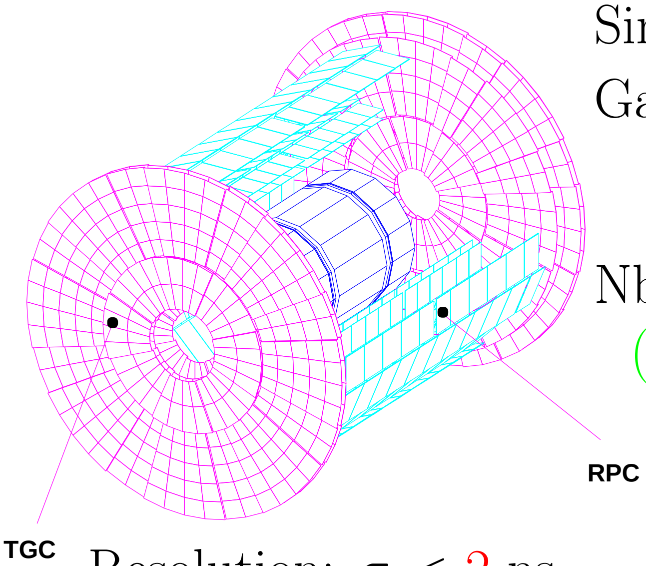


Similar as for CMS

Gas: 97 % freon + 2 % Iso-C_4H_{10}

1 % SF_6

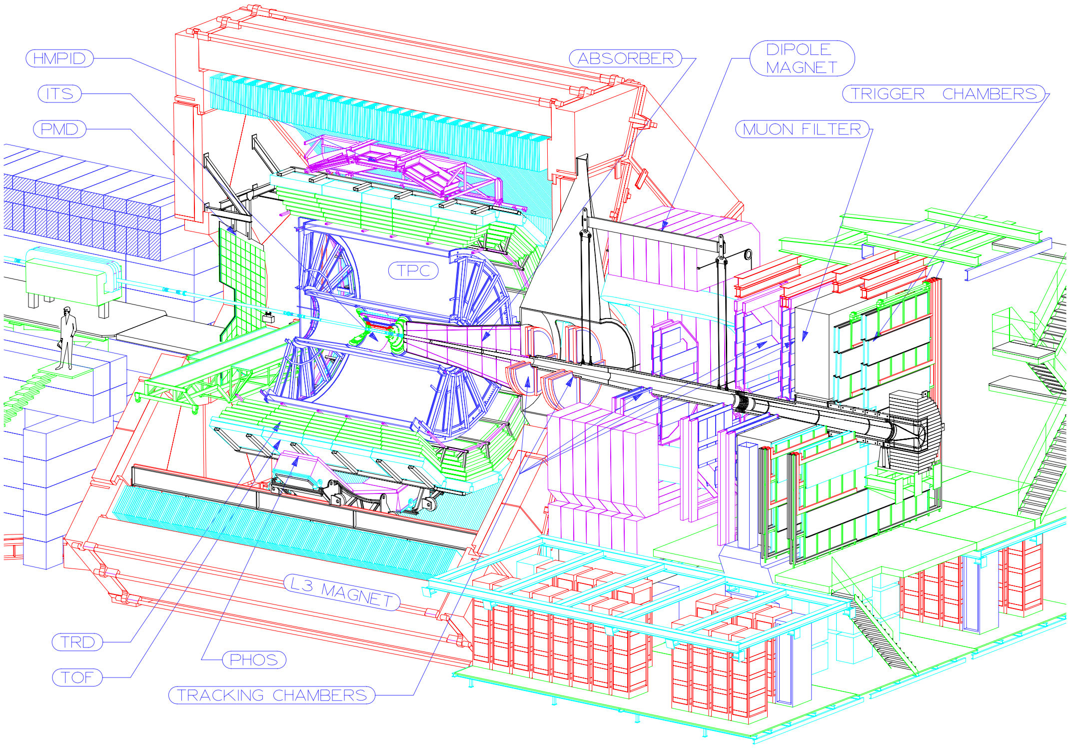
Nb of Detectors: $\sim$ 1050

(l $\sim$ 3 cm, L = 48-242 cm)

Resolution: $\sigma < 2$ ns

Efficiency: $\epsilon > 97$ %

○ ALICE



◇ Quark-Gluon Plasma Physics (A-A: $\sqrt{s_{NN}} = 5.4$ TeV)

Trigger for the Muon Spectrometer

$\rightarrow$ RPC with Readout Strips

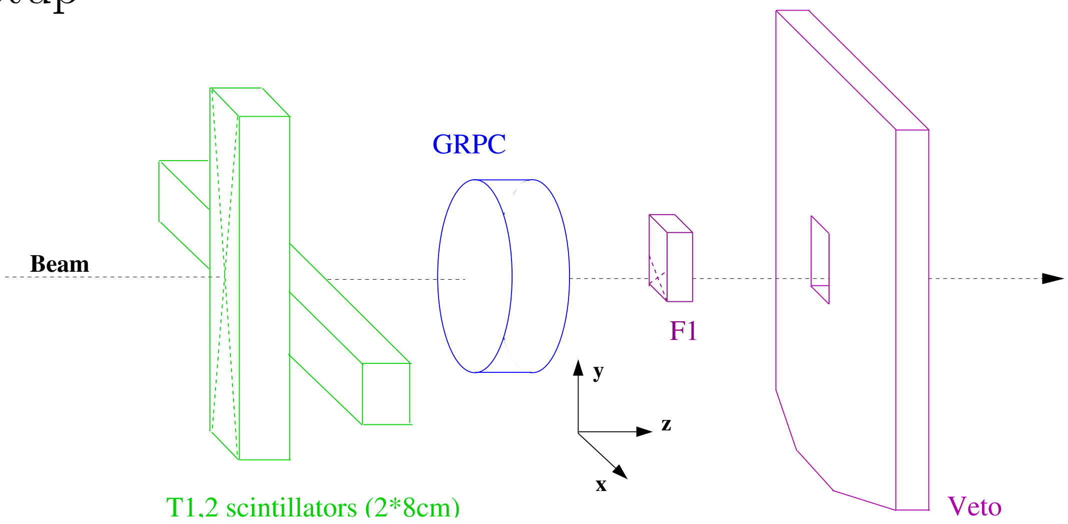
Time of Flight :

$\rightarrow$ MRPC with Pads Readout

	RPC		MRPC
Mode	Streamer	Avalanche	Avalanche
Area	36 m^2		176 m^2
Gap Size	2 mm		6×0.22 mm
Material	Bakelite (2 mm) (10^9 Ω·cm)		Glass (550 μm) (10^{12} Ω·cm)
Gas	Ar/Freon Iso/SF_6	Freon/Iso SF_6	Freon/Iso SF_6
High Voltage	9 kV	10 kV	13 kV
Resolution	< 2 ns	$\sim$1 ns	< 70 ps
Efficiency	> 94 %		> 98 %

▷ Beam Tests(*): (@ CERN)

∘ Setup



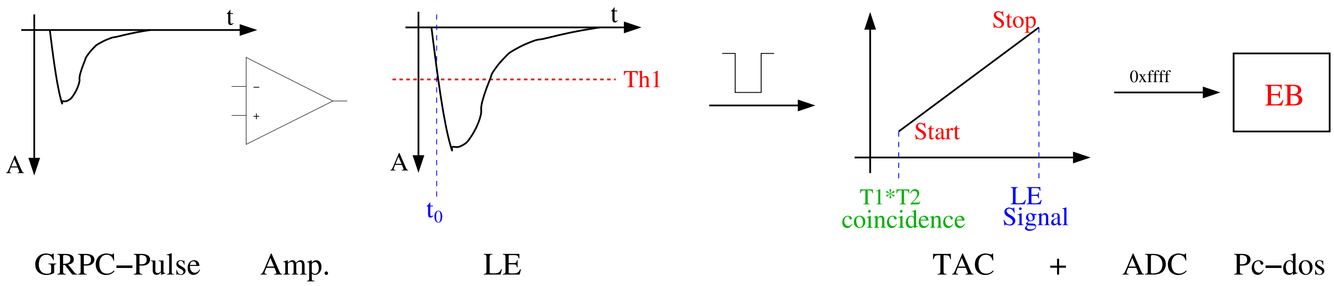
◇ π's @ 3.5 & 7 GeV/c (rate: $\leq$ 100 Hz/cm^2)

◇ Scintillators F1 + Veto $\rightarrow$ Beam Focusing

◇ Scintillators T1, T2 $\rightarrow$ Reference Counter (gaussian : $\sigma_{t1-t2} < 50$ ps)

◇ ToF=$t_{GRPC} - \frac{1}{2}(t_{m1} + t_{m2})$ with $t_{GRPC} = \frac{1}{2}(t_{left} + t_{right})$

∘ Electronics (Standard CAMAC)



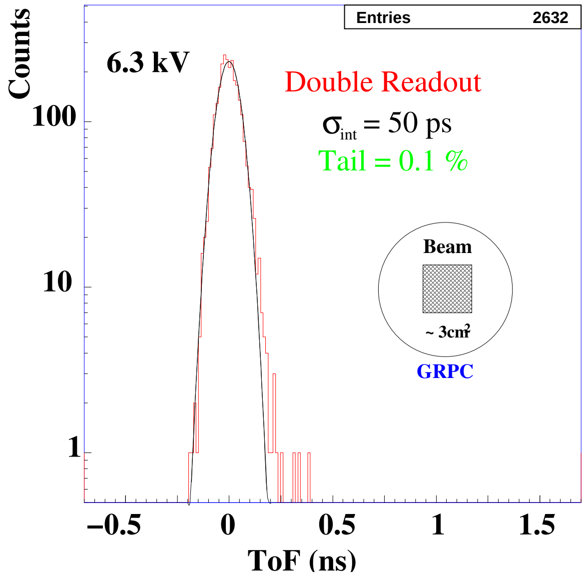
◇ Pre-Amplifier: INA-51063 Chip,
Bandwidth: 2.5 GHz, Gain: 20 dB at 50 Ω

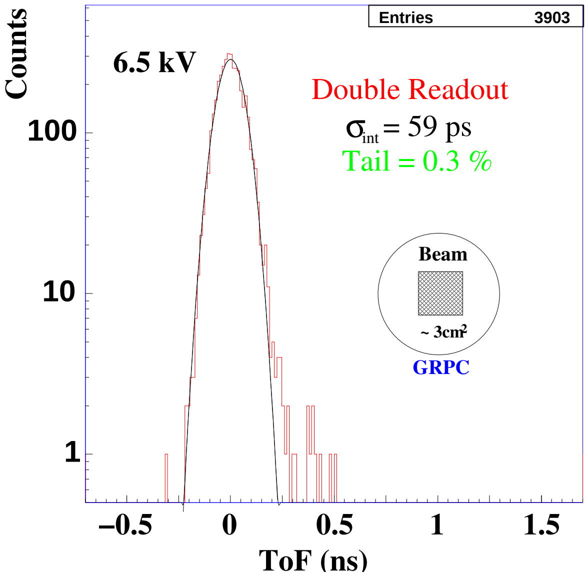
◇ Time Information: TDC LeCroy 2228A (50ps/ch)

◇ Charge Information: ADC LeCroy 2249W (300 ns)

(*) Ch Finck et al., to be published

▷ Resolution in the Center:





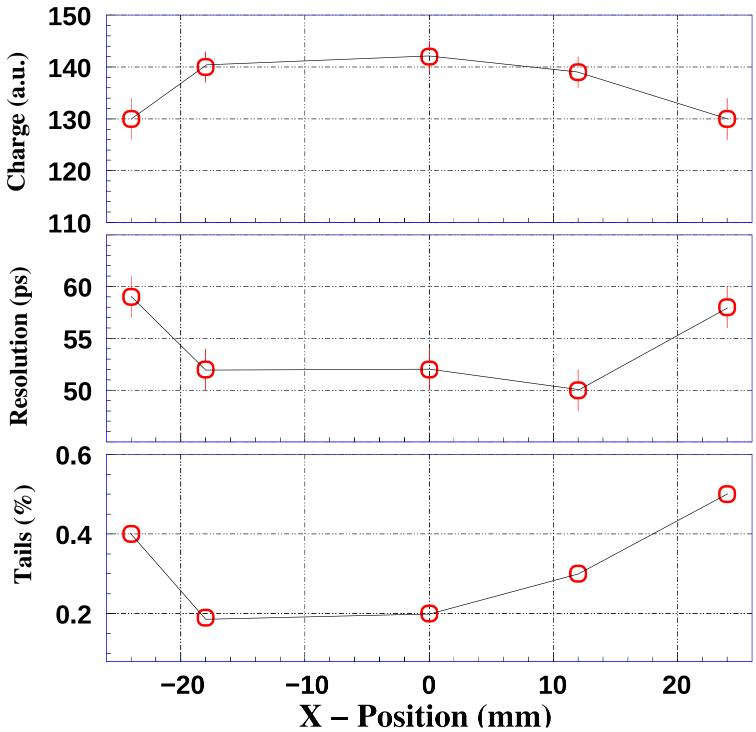
◇ Efficiency: > 99 %

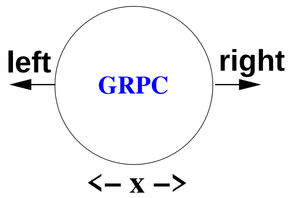
◇ Intrinsic Resolution: < 60 ps

◇ Absolute Tail: < 0.3 % (events out of ± 300 ps)

→ Good Time Response (even for non MIP)

▷ Position Dependence:





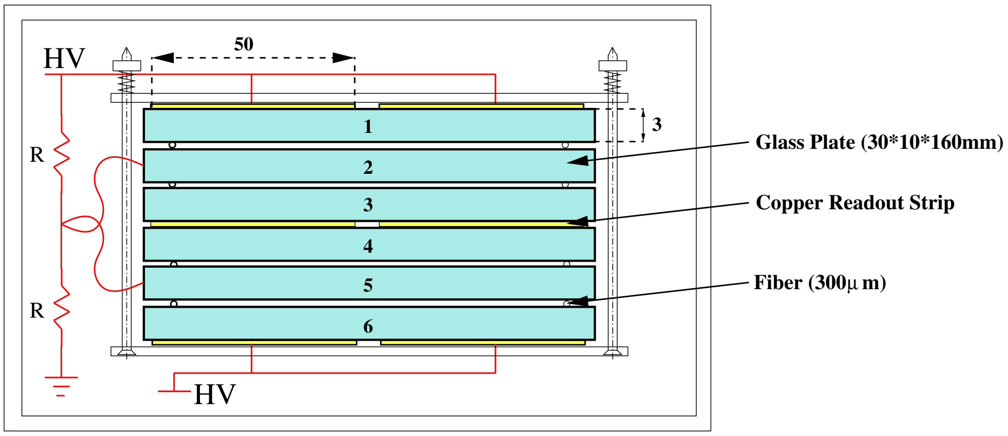
◇ Intrinsic Resolution at the Edges: ∼ 60 ps

◇ Absolute Tail: < 1 %

→ Small Edge Effects

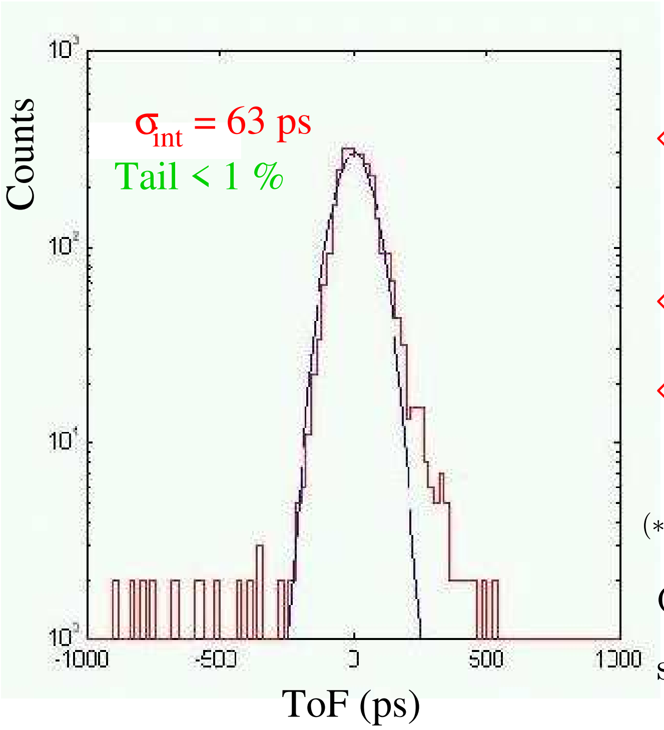
GRPC (160 cm × 10 cm)(*)

▷ Layout:



- ◇ 6 Plates of "Normal" Glass: ($\rho \sim 2{\times}10^{12}\ \Omega \cdot$ cm)
- ◇ 4 Gaps with Spacers: (fibers of 300 μm)
- ◇ 6 Copper Strips: (4 for HV, 2 for the readout)
- ◇ Tension Divider: (No Floating Anode)
- ◇ Gas Standard Mixture: ($\leftrightarrow \varnothing$ 5 cm counter)

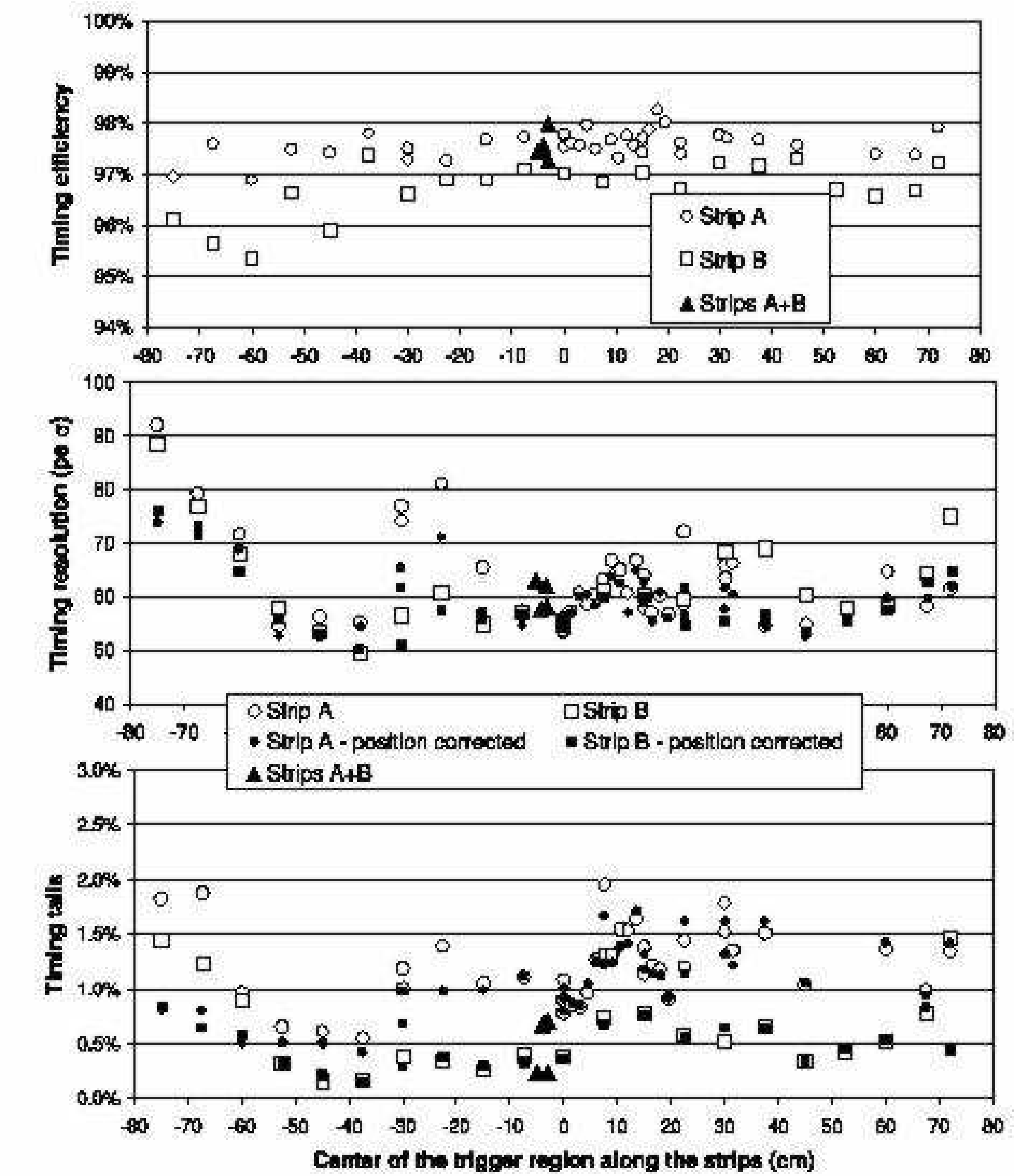
▷ Resolution in the center:



- ◇ Intrinsic Resolution $\sim$ 60 ps
- ◇ Absolute Tail: $<$ 1 %
- ◇ Efficiency: $>$ 97 %

(*) A.Blanco, R.Ferreira-Marques, P.Fonte, Ch Finck, A.Gobbi, A.Policarpo, M.Rosas submitted to NIM A

▷ Position Dependence:



◇ High Efficiency: > 96 %

◇ Good Resolution along X-Axis: ∼ 65 ps

→ Except on the Left Side: (Asymmetry ?)

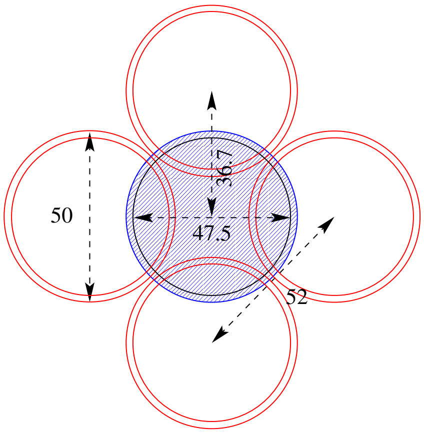
◇ Fraction of Tails: < 1.5 %

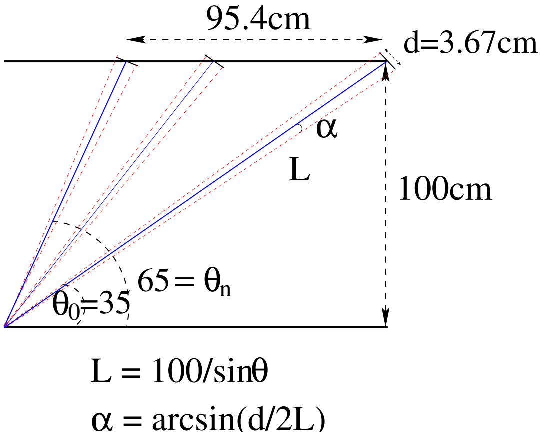
⇒ Promising Results

⇒ Open Questions: (Edge Effects, cross-talks, etc...)

Possible Designs

▷ Single ∅ 5 cm cells Project:





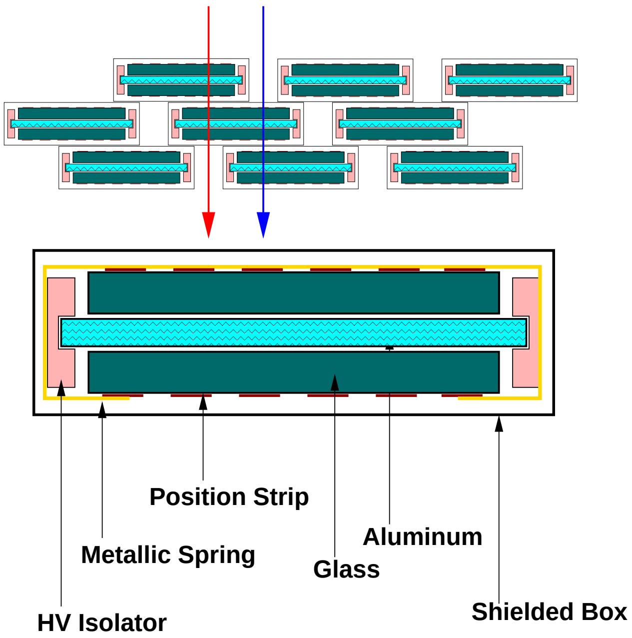
◇ Number of Counters: > 3200

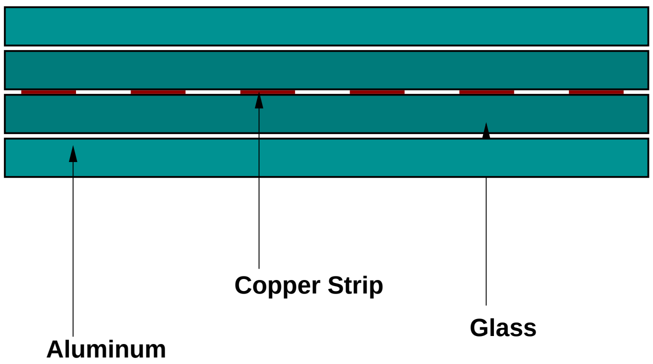
→ Important Mechanical Work

→ Easy Shielding

▷ Readout Strip Counter Project:

∘ Single Strip Counter   Multi-Strip Counter





⇒ Layout in Progress (ϵ, σ, Double hit)

Conclusion

▷ Study of Strangeness with FOPI:

- ∘ Broadening of the K^+ and K_s^0 Rapidity Distribution
- ∘ Enhancement of the K^-/K^+ Ratio at Mid-Rapidity
- ∘ Anti-Flow of K^+ and K^0_s

$\Longrightarrow$ Data Favor In Medium Effects

$\Longrightarrow$ Complete Measurements of Strangeness Sector

$\Downarrow$

FOPI Upgrade

$\Downarrow$

▷ New Time of Flight System:

- ∘ Good Time Response for PesToF Detector

$\Longrightarrow$ Problems with Glass Manufacturing

- ∘ Excellent Time Response for GRPC

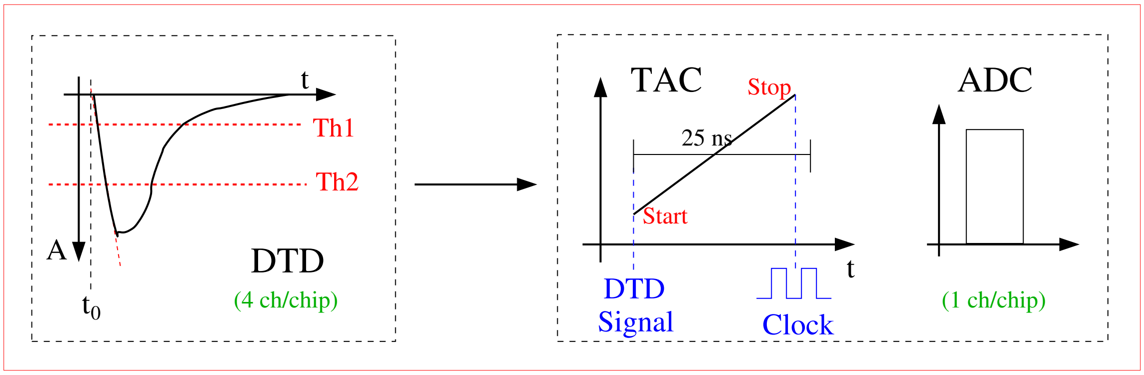
$\Longrightarrow$ New TOF based on GRPC with Readout Strips

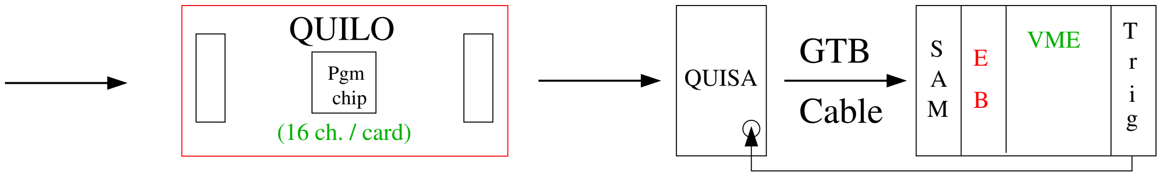
$\Downarrow$

First Production Run Foreseen in 2002

New Integrated Electronics(*)

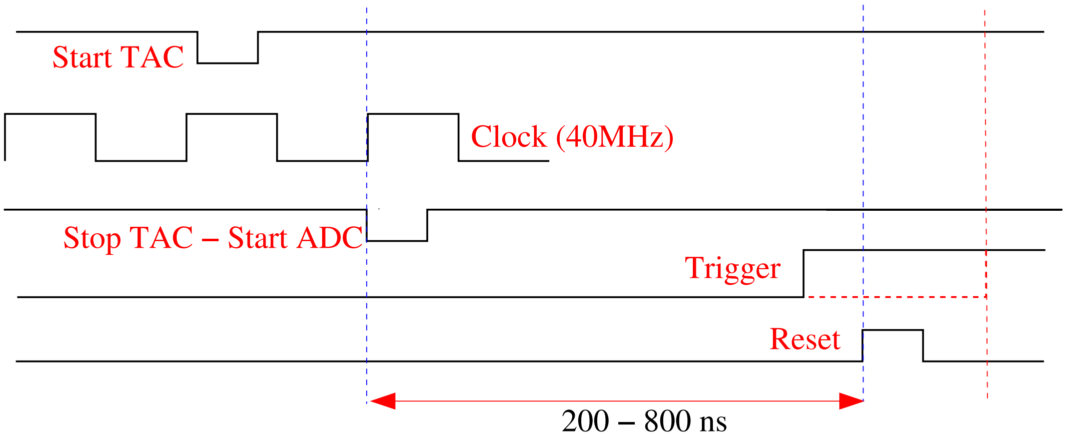
- PesToF Detector in FOPI: ($\sim$ 168)
  - Distribution of the Start Signal for the $\sim$ 5400 TACs
  - Space for $\sim$ 8100 Electronic Channels
    - $\rightarrow$ Integrated Electronics
    - $\rightarrow$ Stop Signal given by a Clock (T=25ns)
- Integrated Electronics: (QUIck LOgic)





SAM: Steuern und Auslese Module
GTB: Geraete und Transport Bus

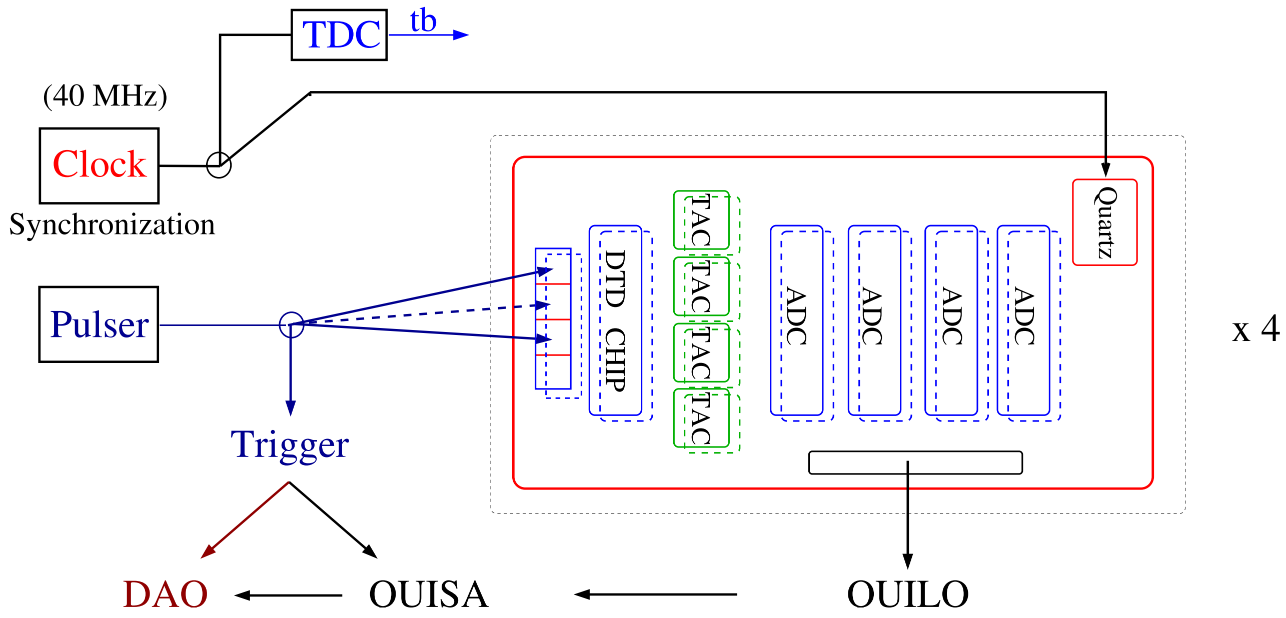
  - Per Counter: 4 DTD-TAC cards, 2 QUILO cards and 1 QUISA card
- Timing Layout:



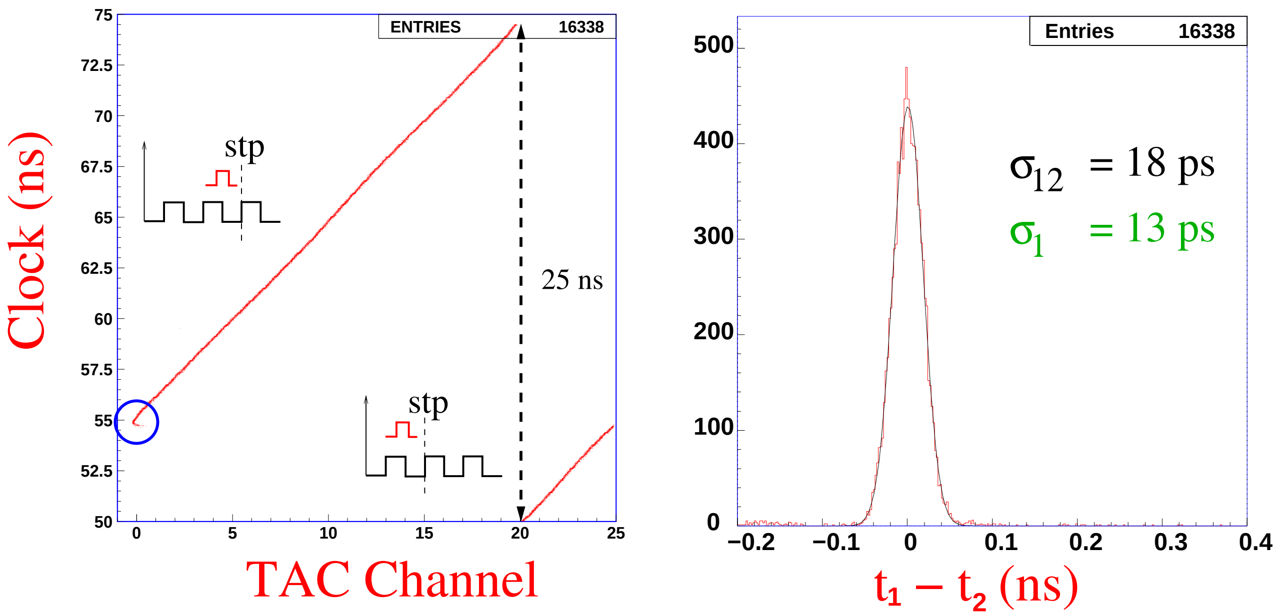
(*)E.Badura, J.Eschke, Ch.Finck, A.Gobbi, et al., GSI-Annual-Report (1999) 216

▷ Pulser Tests:

◦ Setup



◦ Intrinsic Resolution



◦ Correction:

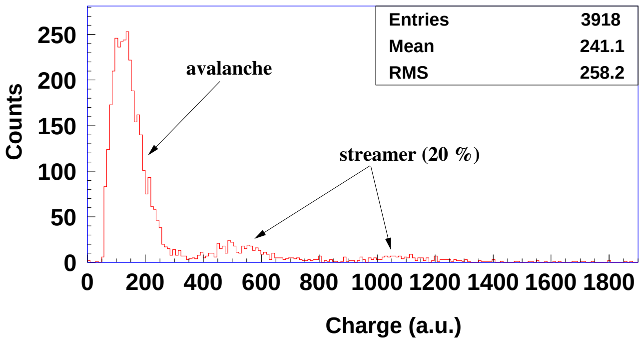
→ Jump, Linear & Differential

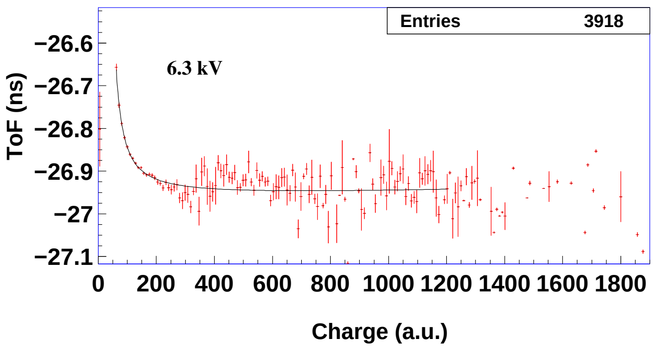
◦ Resolution:

→ $\sigma_1 = \sigma_{12}/\sqrt{2} = 13$ ps

⇒ Tests with Detector Signal (in progress)

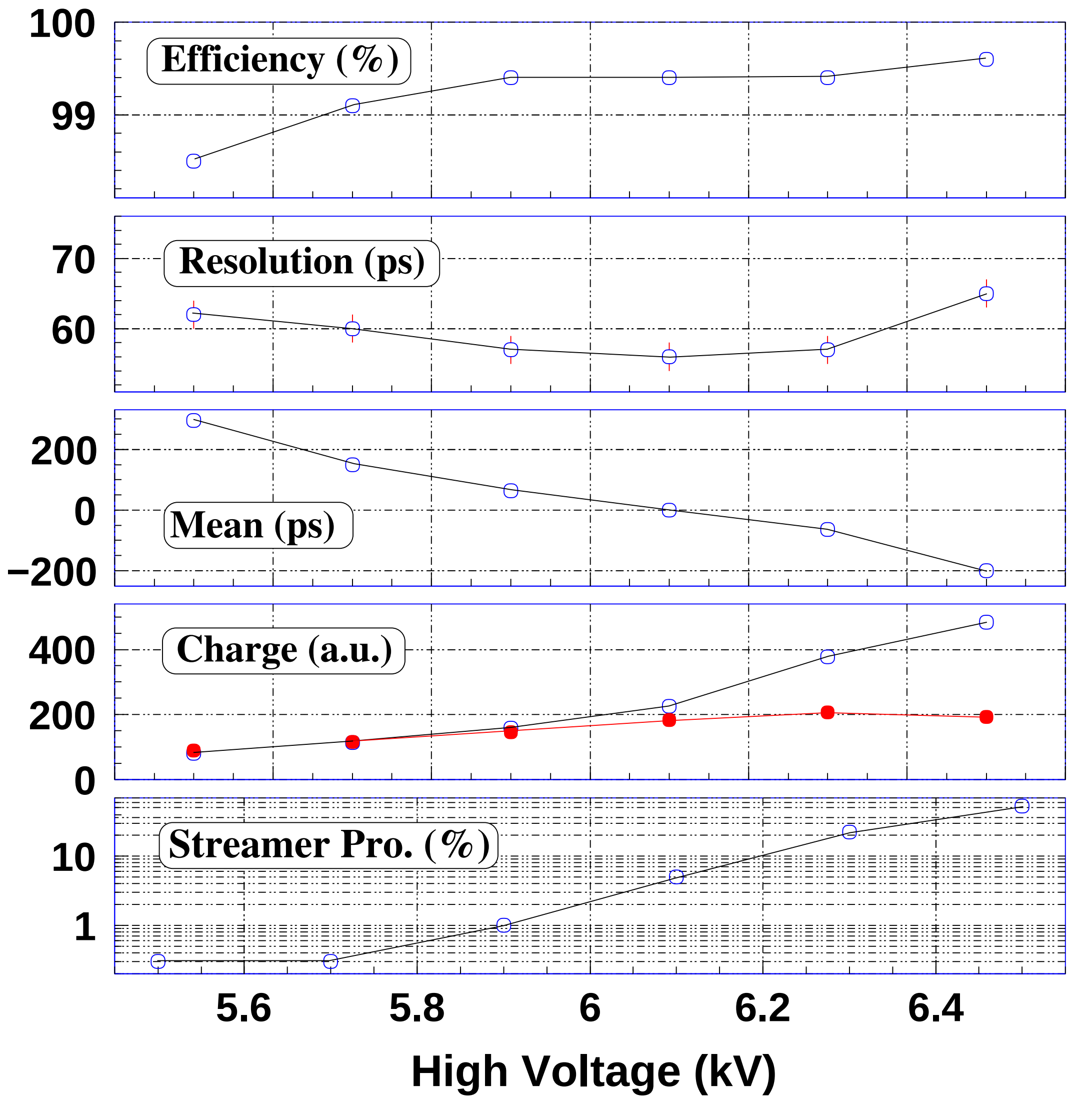
▷ Time/Charge Correction:





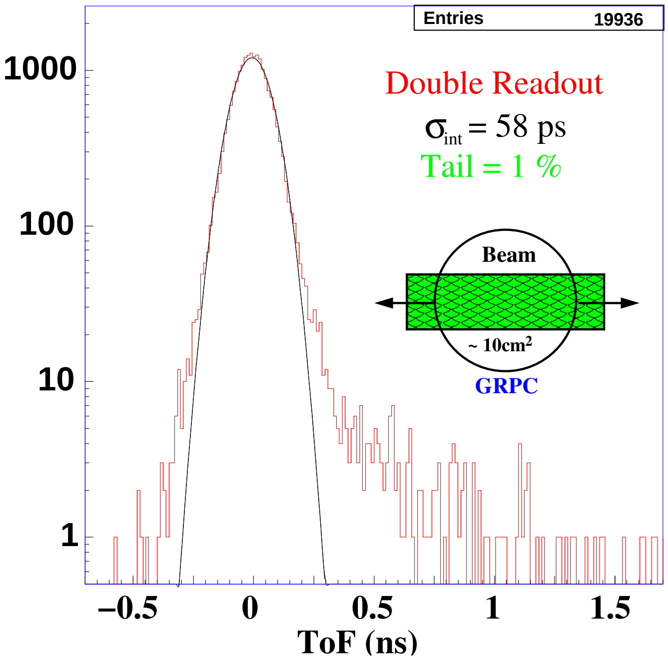
∘ Polynomial Fit with 1/charge

▷ HV Dependence:



⇒ Best Time Response for HV = 6.1 kV

▷ Total Time Response Function along X:



◇ Intrinsic Resolution:
$\sim$ 60 ps

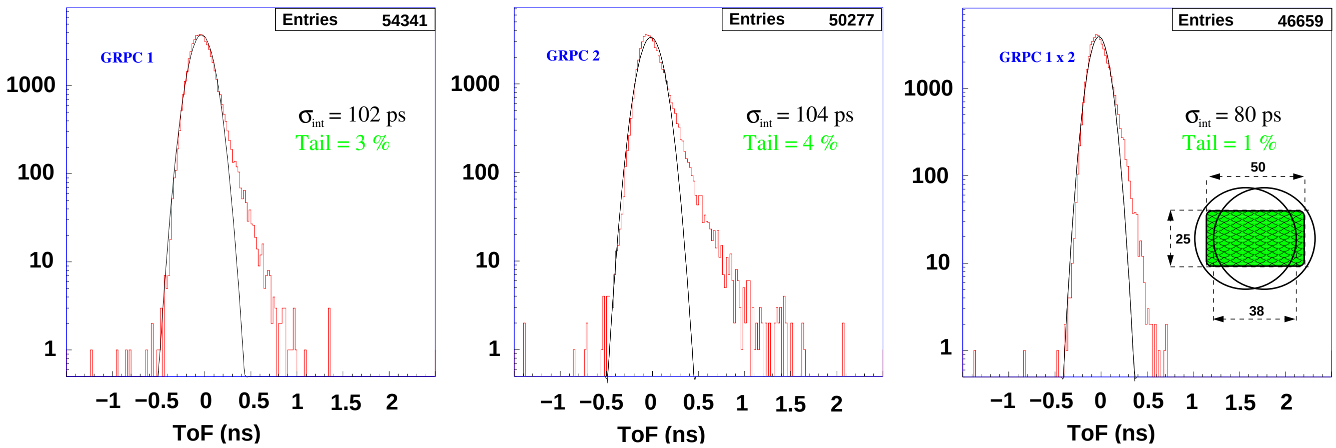
◇ Absolute Tail:
$<$ 1 %

$\Rightarrow$ Good Time Response even for a Larger Area

$\rightarrow$ Negligible Edge Effects ?

▷ Overlapping of two GRPCs:

- ○ Beam Tests (Old Chambers)
  - ◇ Floating Anode (no voltage divider)
  - ◇ Old Electronics (non integrated pre-amp)



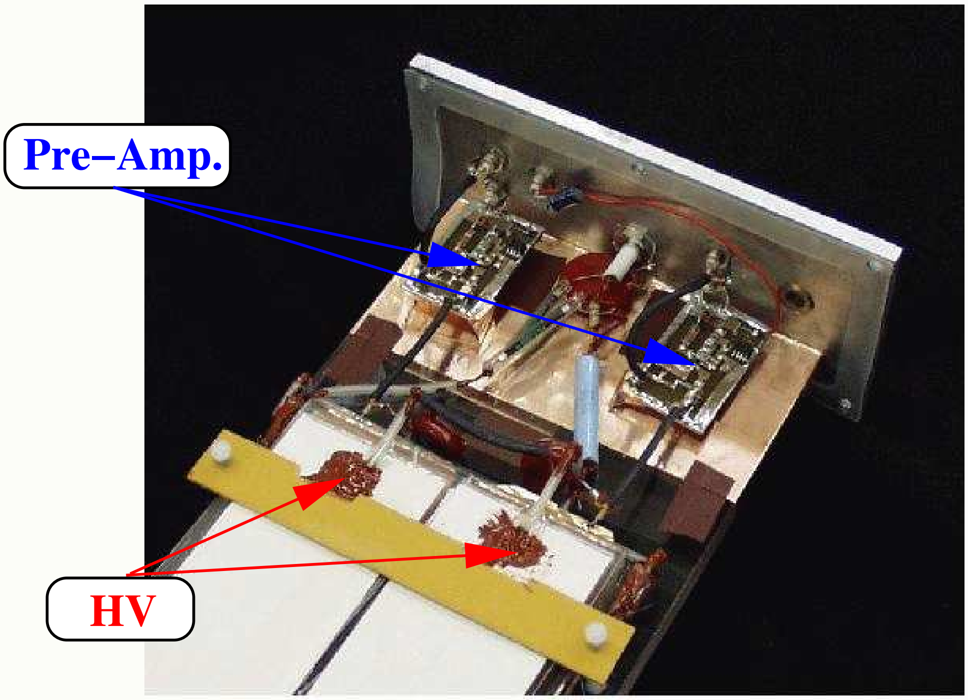
◇ $\mathrm{ToF} = \frac{1}{2}(\mathrm{ToF}_1 + \mathrm{ToF}_2)$ & $|\ \mathrm{ToF}_1 - \mathrm{ToF}_2\ | <$ 0.6 ns

◇ $\sigma_{ToF} \sim$ 100 ps $\rightarrow$ 80 ps & Tail $\sim$ 3-4 % $\rightarrow$ 1.3 %

◇ Lost Events $<$ 1 %

▷ Tests: (@ CERN)

Outer View



Front end View

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