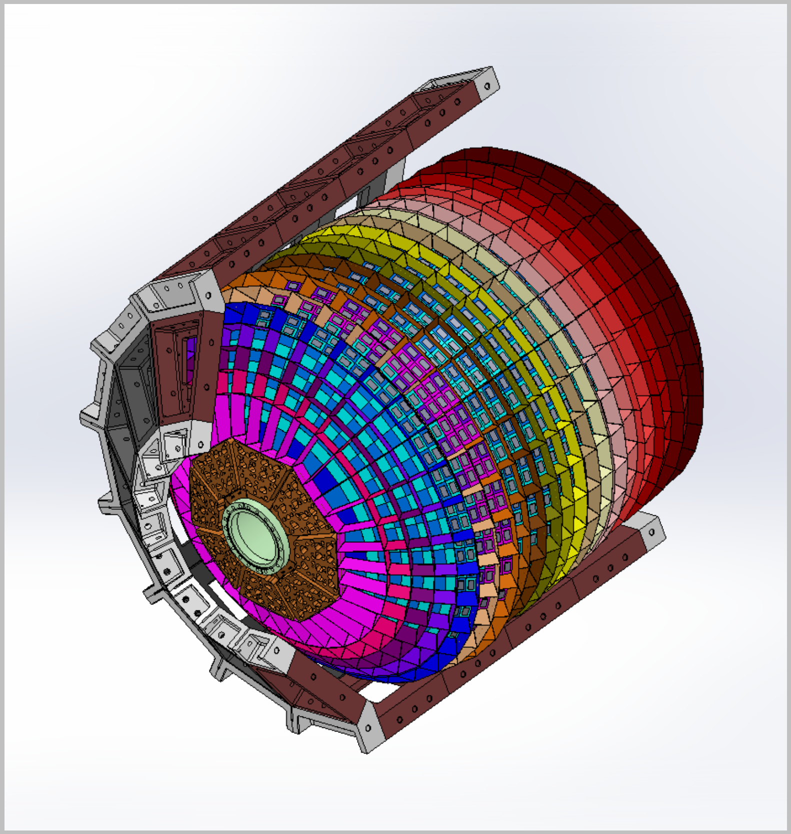
Calorimetry



H. Simon ● GSI Darmstadt

JENAS-2022
2nd Joint
ECFA-NuPECC-APPEC
Symposion

20220503-06
Madrid

Calorimetry

- Wealth of different systems (APPEC, NuPECC, EFGA)
- Discuss enabling techniques, from a nuclear (structure) physicist point of view.
- Cross fertilization (also into commercial sector) – but the similarities are within our communities

- Idea: typical demands are defined, e.g. in roadmap documents
- Go through specific examples where synergies where explored

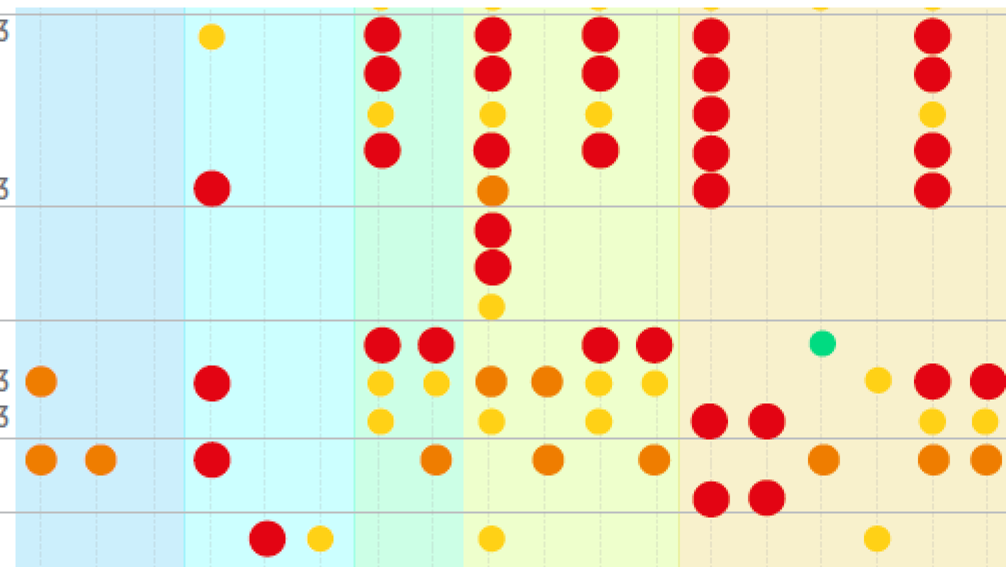
- Calorimetry, is accompanied by different methods in order to clarify interaction points and, subsequetly, allow for tracking of interactions in the absorptive material.

- Example to be used: Target Calorimeter for ‚high' energy nuclear physics, where interaction point is key

Key technologies - Calorimetry
(from the EFCA Detector Roadmap – 2021)

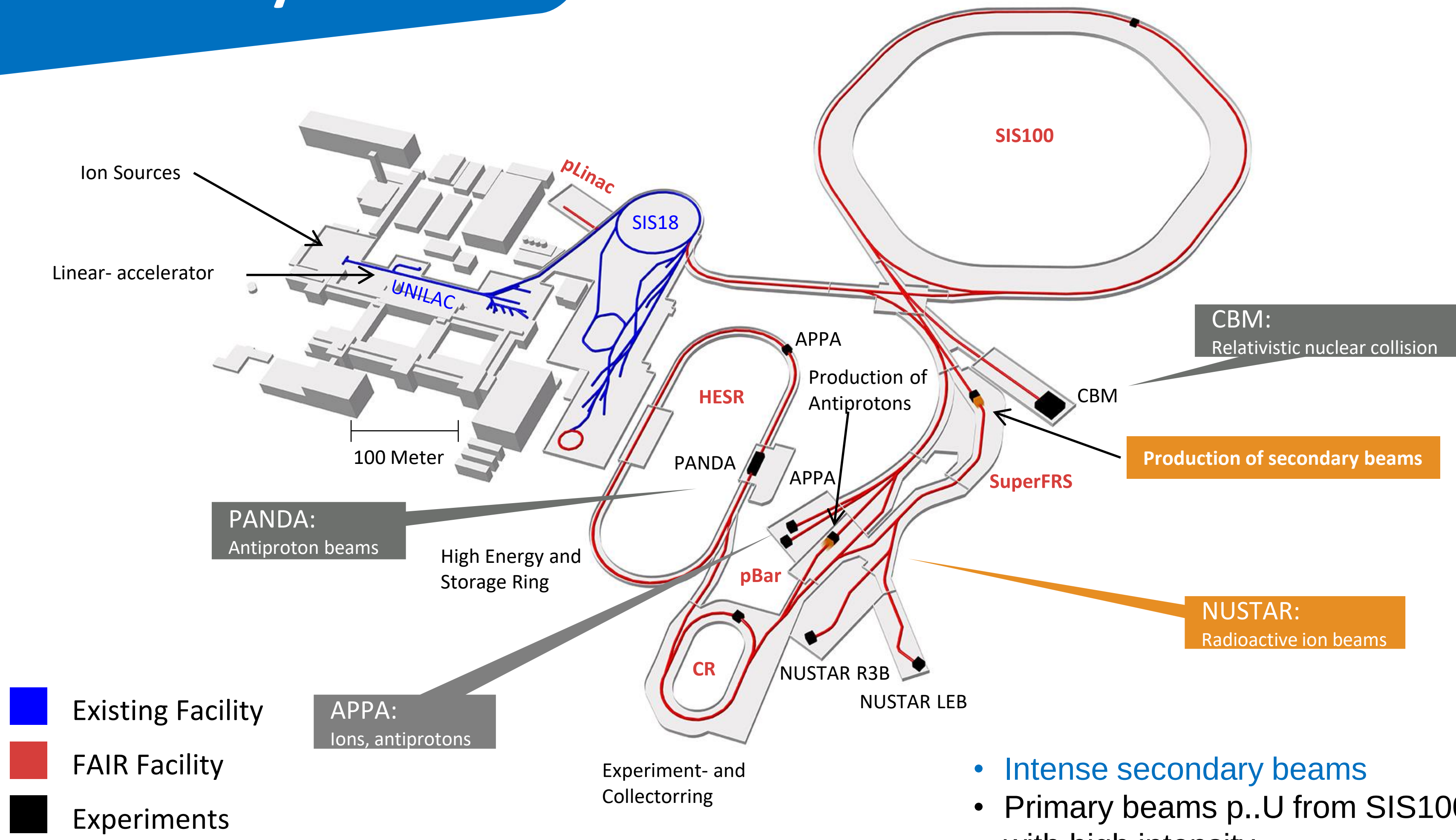
Key technologies - Calorimetry
(from the EFCA Detector Roadmap – 2021)

Crystal-based high resolution ECAL	High granularity (PFA)	6.1,6.2,6.3
	High-precision absorbers	6.2,6.3
	Timing for z position	6.2,6.3
	With C/S readout for DR	6.2,6.3
	Front-end processing	6.1,6.2,6.3
Fibre based dual readout	Lateral high granularity	6.2
	Timing for z position	6.2
	Front-end processing	6.2
Timing	100-1000 ps	6.2
	10-100 ps	6.1,6.2,6.3
	<10 ps	6.1,6.2,6.3
Radiation hardness	Up to 10^{16} n_{eq}/cm^2	6.1,6.2
	> 10^{16} n_{eq}/cm^2	6.3
Excellent EM energy resolution	< $3\%/\sqrt{E}$	6.1,6.2



Must happen or main physics goals cannot be met — Important to meet several physics goals — Desirable to enhance physics reach — R&D needs being met

FAIR – The Facility in view of Nuclear Physics

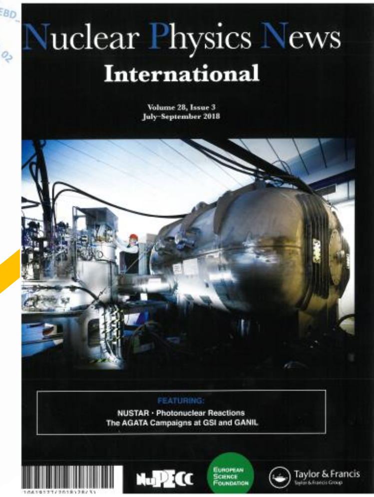


- Intense secondary beams
- Primary beams p..U from SIS100 with high intensity
- Matched Super-Fragment Separator (SuperFRS) with large apperture and rate capability

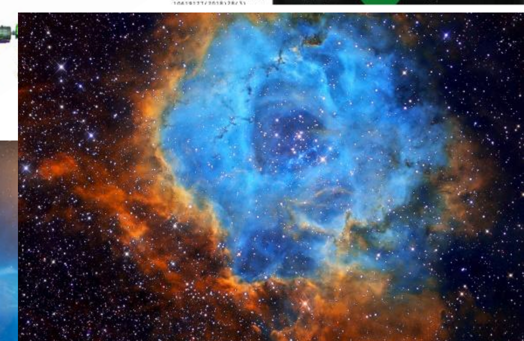
Super-FRS workhorse for

Nuclear- and Astro-Physics with Reactions (NUSTAR), e.g. R³B

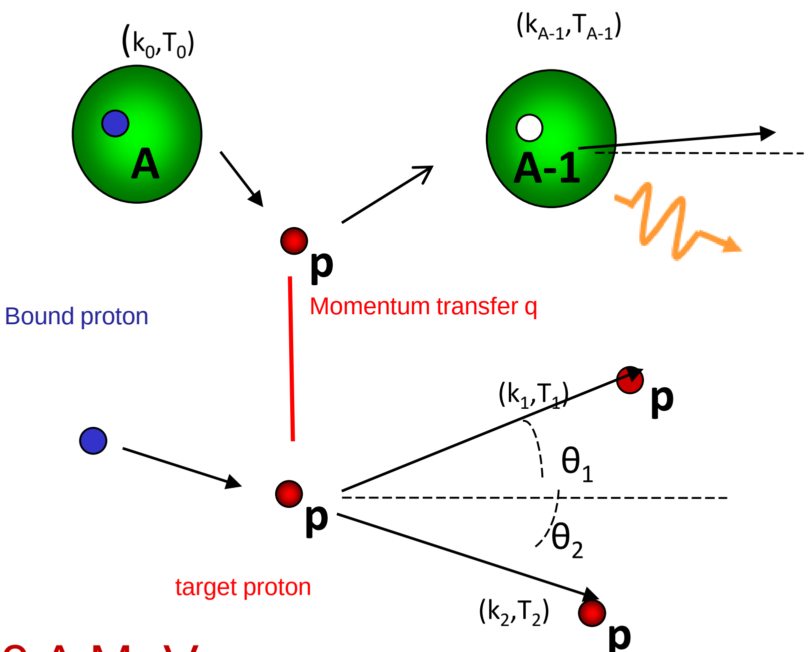
Powerful separator for exotic nuclei



Testing@CERN : All sc Magnets



Physics Example: Quasi Free Scattering (p,2p) at relativistic beam energy in inverse kinematics



~ 700 A MeV

evaporate n,p,d,t

de-excite via γ radiation

Tracking: A, A-1

Correlated protons

- 180 deg in ϕ
- ~ 90 deg in θ

➔ tracking into calorimeter

θ (deg)	E_p (MeV)	CsI(Tl) range (cm)	Efficiency (%)
7	686	71,8	15%
20	592	59,7	…
40	356	26,4	50%

Physics imposes the scientific requirements

•Huge dynamic range
100keV γ-rays – 700 AMeV charged particles
•high efficiency, good resolution
•high granularity → Doppler correction
•particle identification

D. Cortina, NN 2015, Catania

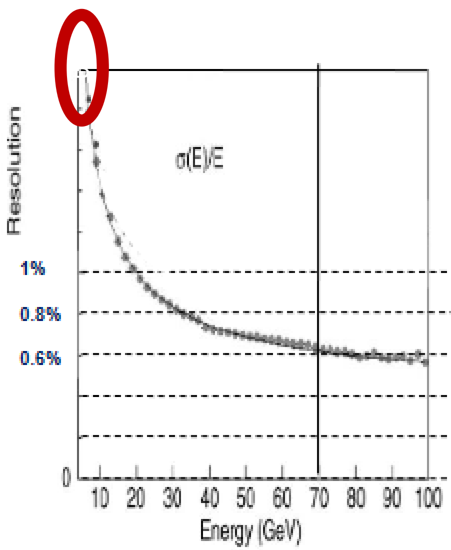
Requirements (from scientific aim)

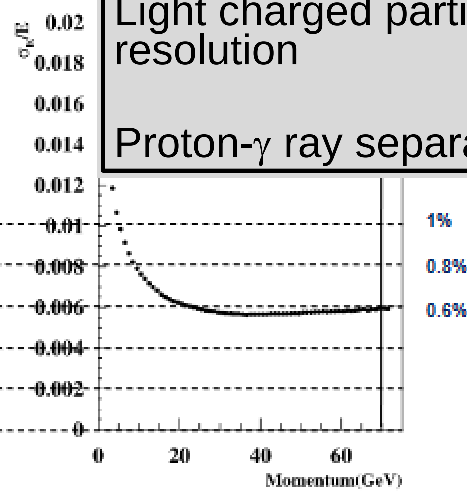
- Spectroscopic properties
- Calorimetric properties

Intrinsic photopeak efficiency	40% (up to Eγ=15 MeV projectile frame)
Gamma sum energy resolution $D(E_\gamma sum)/<(E_\gamma sum)>$	< 10% for 5 γ rays of 3 MeV
Calorimeter for high energy Light charged particles	200-700 MeV in lab system
Gamma energy resolution	~5-6% (FWHM at Eγ=1 MeV) ~ 3% for very forward angles
Light charged particles resolution	~2% (stopped particles) ~ 5% (punch through particles)
Proton-γ ray separation	For 1 to 30 MeV

NA48/KTeV

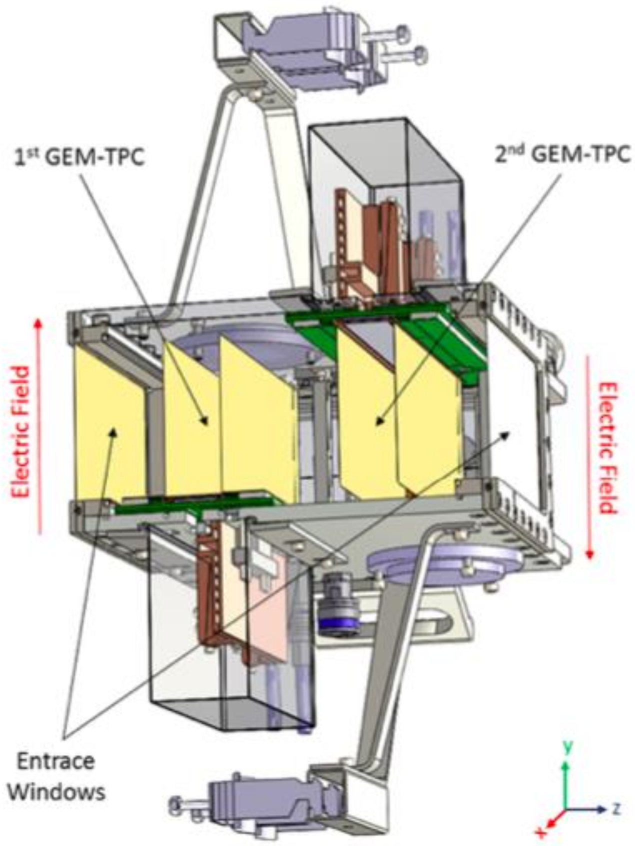
However:
Beam momenta are different





NA48 Experiment at CERN and KTeV Experiment at Fermilab,
Homogenous calorimeters with Liquid Krypton (NA48) and CsI (KTeV).
Excellent and very similar resolution.
(Compilation W.Riegler/CERN)

GEM TPC for high rate tracking (Super-FRS) - Anything in common with the panda EMC ?



F. Garcia, *et al.*, Nucl. Instr. and Meth. A 884 (2018) 18–24.
A. Prochazka, *et al.*, GSI Scientific Report (2014) 500doi:10.15120/GR-2015-1-FG-SFRS-04.

Beam Particle ID
→ Bρ-ΔE-TOF method:
Requirements

$B\rho = A/Z \cdot \beta \cdot \gamma$ → A/Z, P
$TOF = L/\beta$
$\Delta E \sim Z^2/\beta^2$ → Z

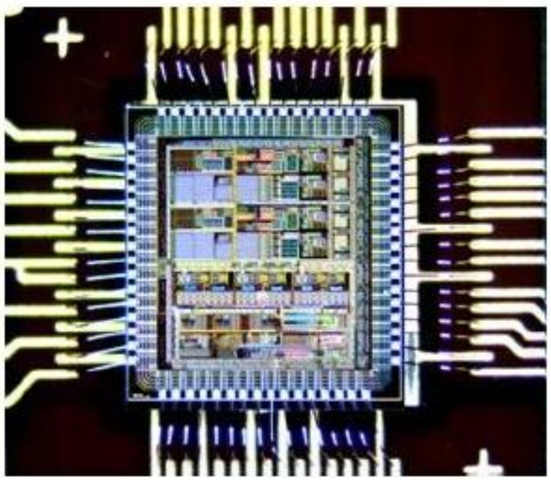
Pos res. $\sigma \leq 1$ mm
Timing res. σ: 50 ps
ΔE resolution σ: 1-2 %
p…U: large dynamic range

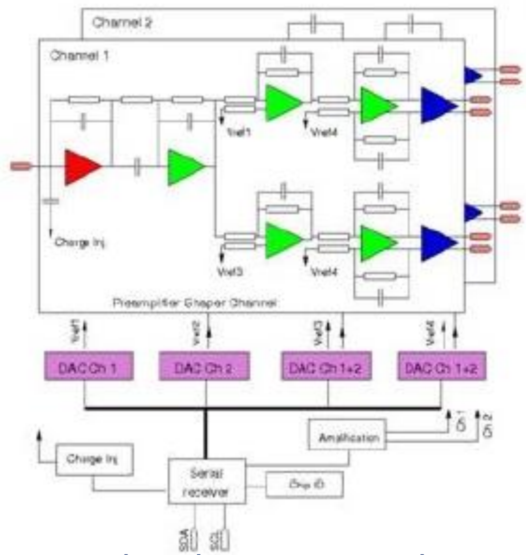
Rate capability some MHz → Timestamped readout

high rate also required for calorimetry with gas detectors

GEM TPC for high rate tracking
- Anything in common with the panda EMC ?

P̄ANDA – EMC: Barrel Readout Electronics





APFEL ASIC 1.5 overview:

Analog Readout:

- Each readout channel consist of
  - charge sensitive preamplifier
  - third order shaper stage
  - differential output driver
- Two outputs per channel with different amplification to cover the dynamic range
- Two equivalent channels per chip

Digital Part:

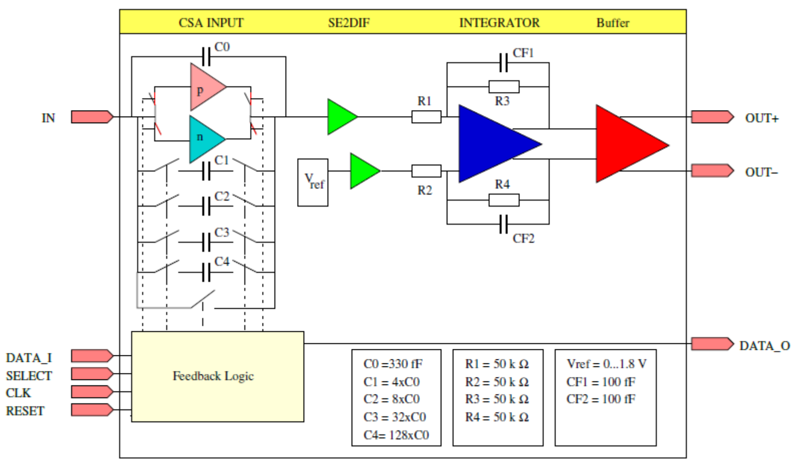
- Serial interface on chip for the autocalibration to detect the right DC voltages for a given temperature to cover the whole dynamic range
- Optional charge injection
- Read and write of the DAC settings
- Chip ID for single chip bus communication

K. Brinkmann/U. Thoma – ASIC:
P. Wieczorek and H. Flemming, *IEEE Nucl. Sci. Sym. & Med. Imag. Conf.* (2010) 1319

APFEL ASIC (0,35µm AMS): 2 outputs with different GAIN
Digital interface for configuration
Rate/ch. ~350kHz → Similar Demands for GEM-TPC
Power <= 50 mW/ch (22k Ch.)

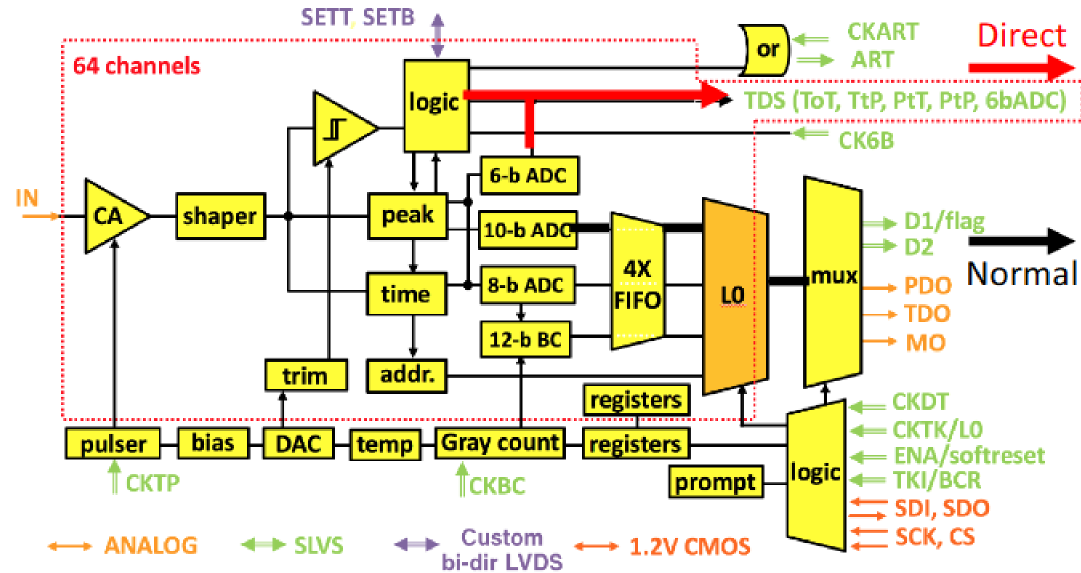
GEM TPC for high rate tracking
- Competition of solutions

AWAGS ASIC

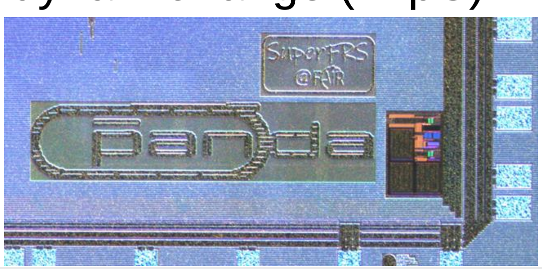


P. Wieczorek, H. Deppe, H. Flemming,
Low noise amplifier with adaptive gain setting (AWAGS),
accepted from JINST as TWEPP2021 proceeding.

VMM3 block diagram



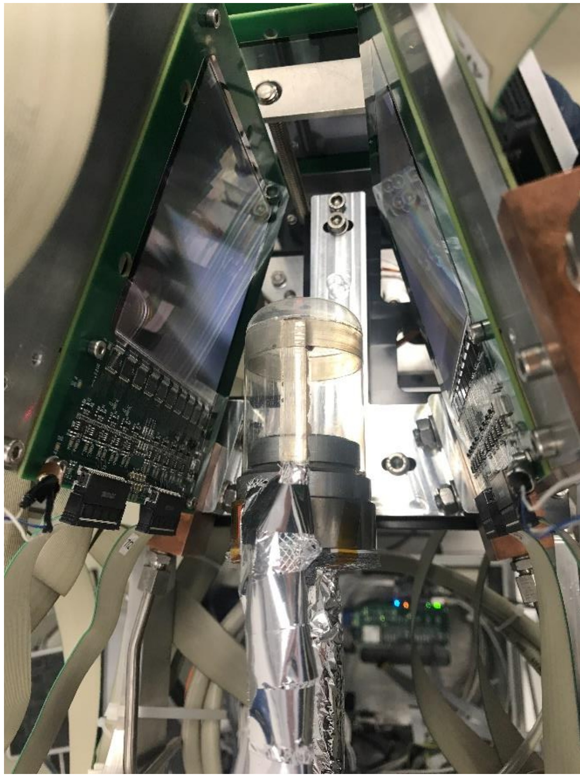
ASIC with adaptive gain;
- very large dynamic range (71pC)
- AWAGS build. blck. for panda trans, rec.



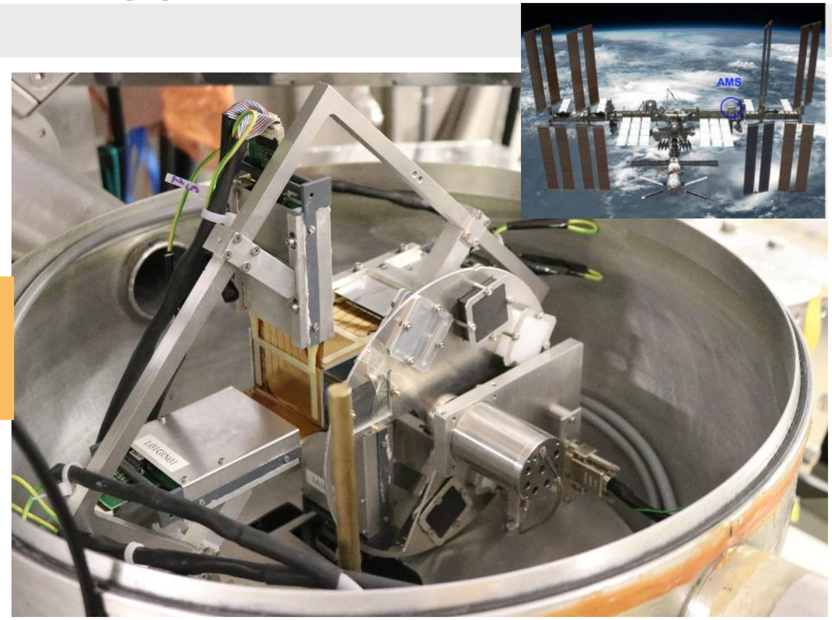
VMM3a: „Swiss army knife“ ASIC (HEP)
ATLAS small wheel (µMEGAS)
Perfect fit for GEM readout ?

Availability of building blocks allows for optomized solutions.

Enabling technologies
- from Space to medical applications



Cocotier LH2 target with FOOT Si-trackers as subsystem of the CALIFA calorimeter

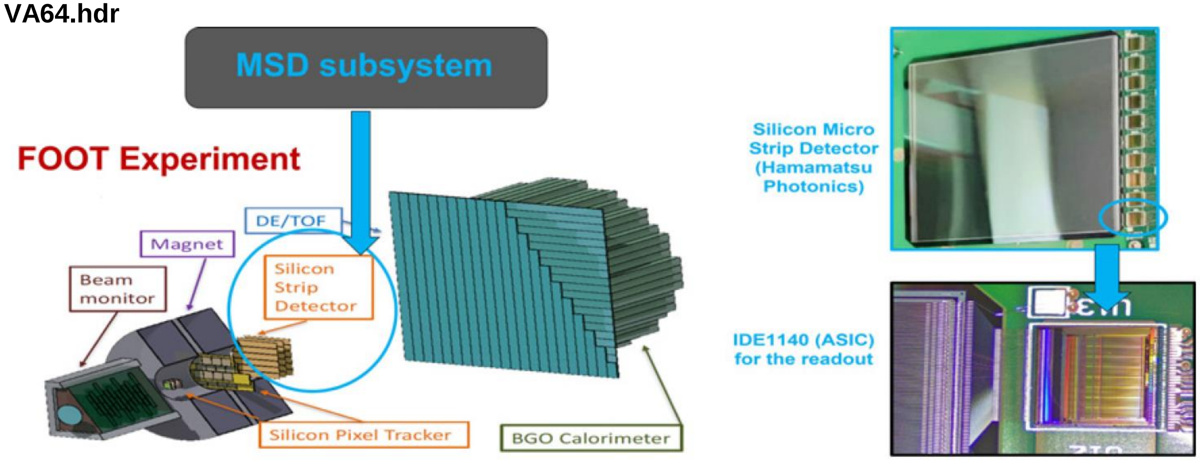


AMS-02
Detectors in Vacuum
low power (!)
Box geometry
CH2 target

https://ams02.space/detector/silicon-tracker

Physics Reports 894 (2021) 1-116

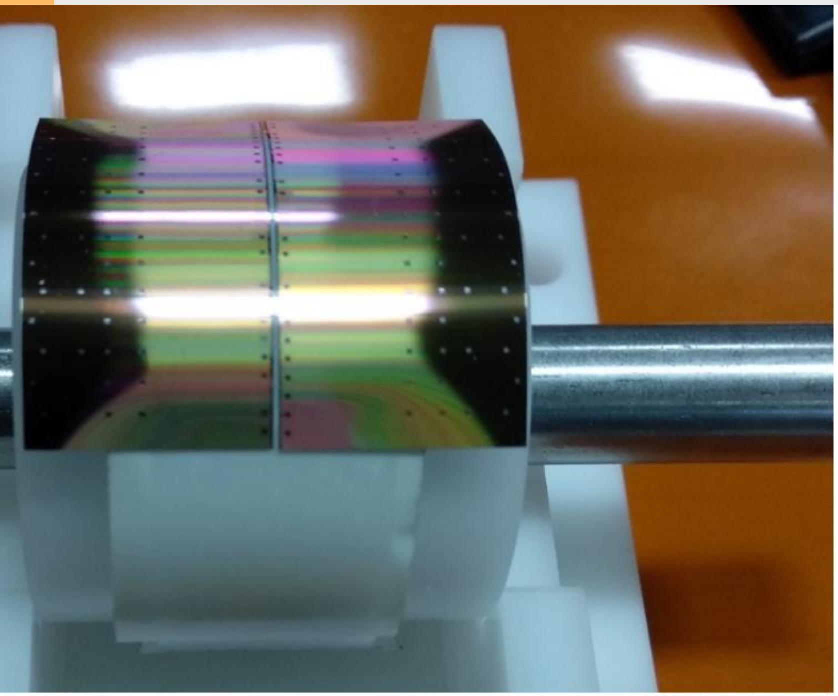
VA64.hdr



IDE1140

(a) K. Kanxheri *et al* 2022 *JINST* **17** C03035 (b)

Enabling technologies
- ALICE Alpide



M. Mager | ITS3 | TREDI 2020 | 18.02.2020 |

Test system at GSI

- Geometry adaptation to the limit (‚surrounding the target‘)
- Pixel detectors
  - suppression of delta rays
  - noise environment / noise reduction & selective trigger/selection schemes
  - option for inner tracker in front of Calorimeter

Enabling technologies
- close geometry / magnetic field / mechanics

APD readout:
- Hamamatsu / CMS - APD S8664-55
- Hamamatsu / panda - APD S8664-1010 $PbWO_4$

→ Characterized to be suitable
for Califa CsI readout → APD-S8664-SPC1010 (2CH)

CMS Ecal - CMS NOTE 2000/048

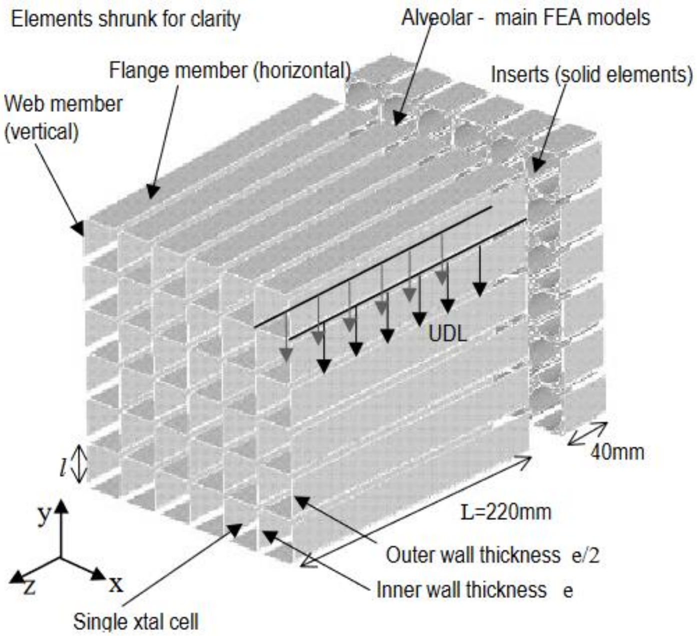
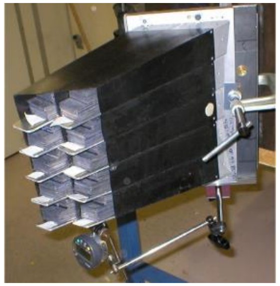
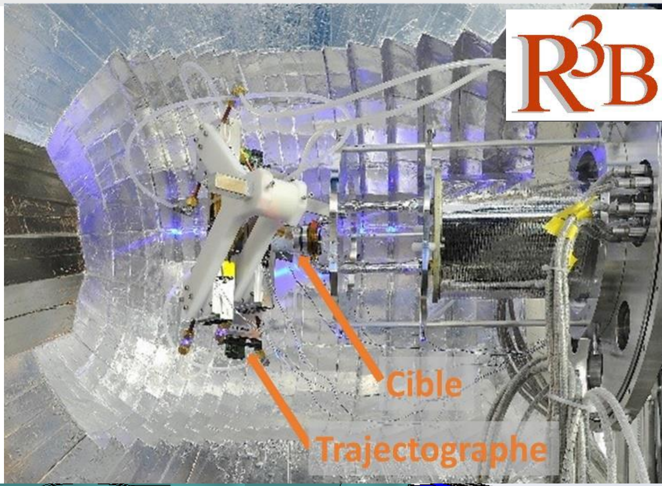
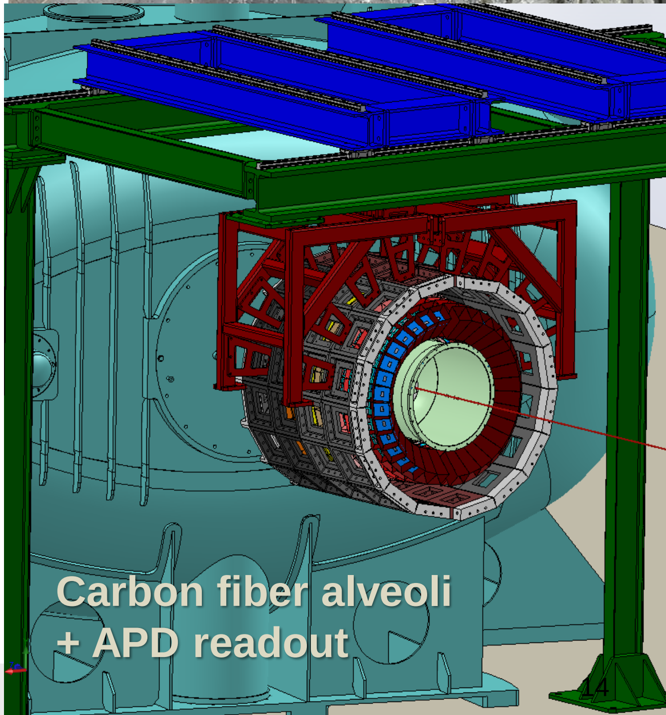


Fig. 1 - illustration of FEA Model of alveolar (with inserts) – shows UDL load and model axes

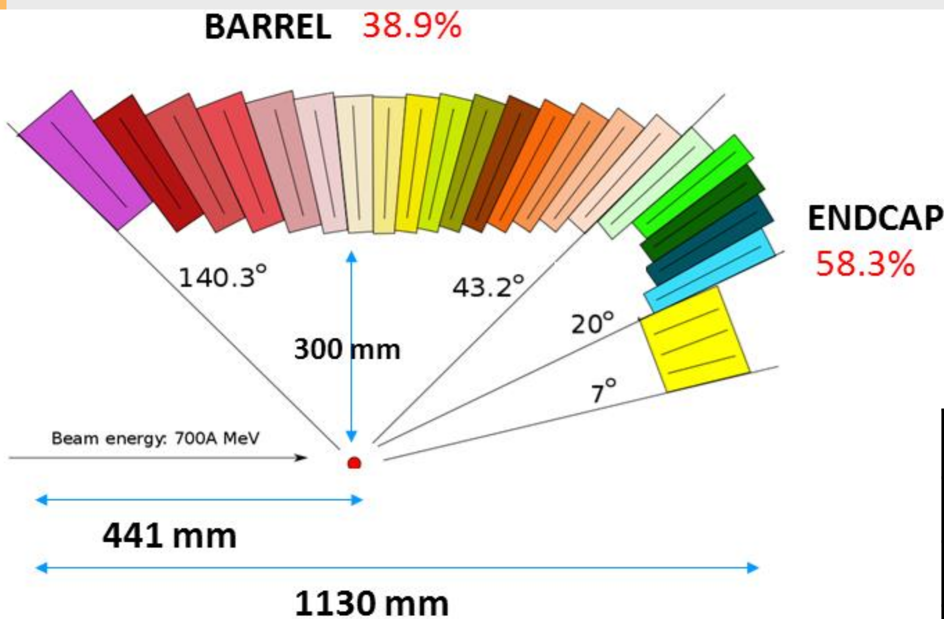


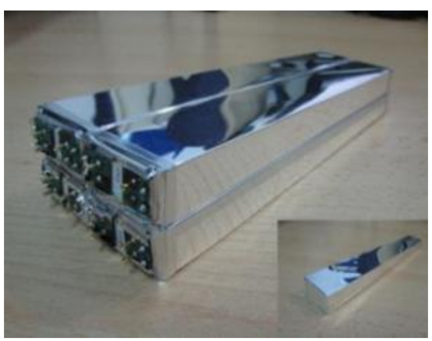
Carbon fiber Alveoli (panda)

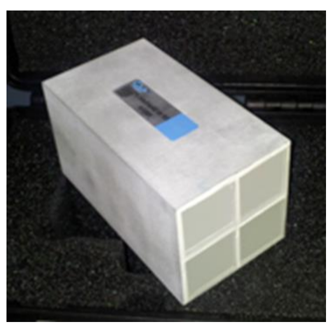




CALIFA





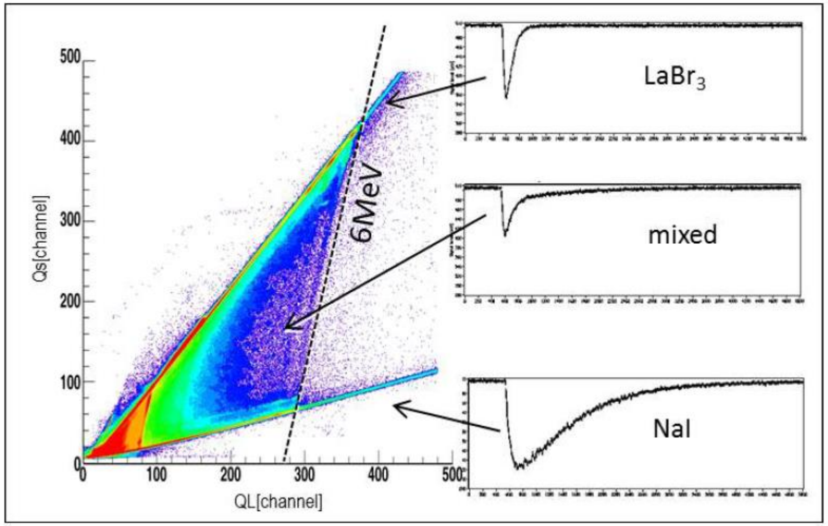


D. Cortina-Gil et al. Nuclear Data Sheet 120(2014) 99-101

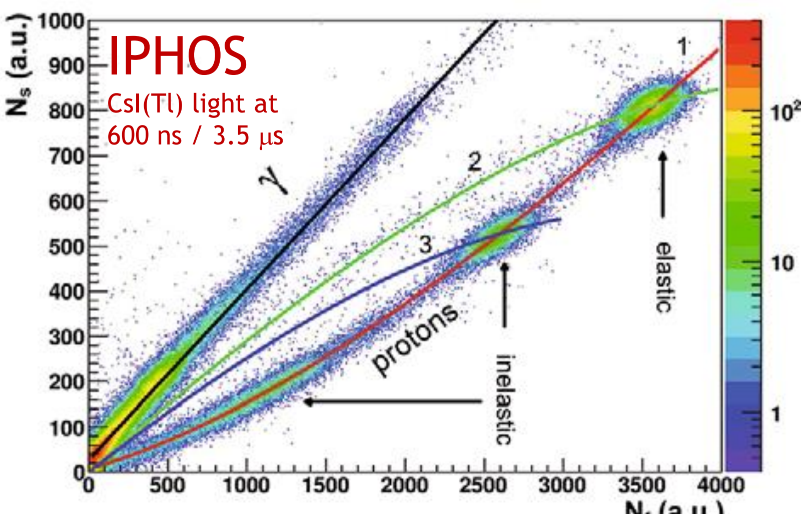
- External structure 3.5 x 4 m
- Detector volume ~ 1.3 m^3
- Detector weight ~ 2.5 t
- 2528 detection units

	Barrel	Endcap	
		iPhos	CEPA
Scintillator	CsI(Tl)	CsI(Tl)	LaBr/LaCl
Geom.	11	16	6
Crys. Len (cm)	15-22	22	4/7
Polar cov.	7-20°	20-43°	43-140°
Read-out	LAAPD	LAAPD	PM/SiPM
Dete.chan.	1952	480	96
Elec. chan.	1952	960	96 x2
Weight (Kg)	~ 1500	~ 550	~ 50
Volume (cm^3)	285.000	90.000	11.000

Enabling technologies
- Phoswitch/IPHOS (Dual Readout)

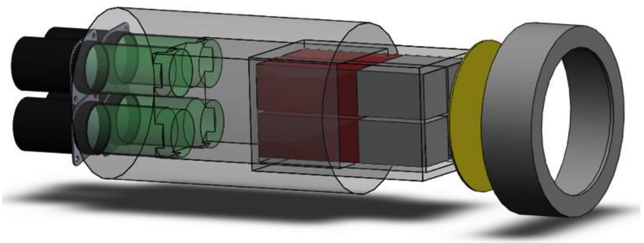


PARIS White Book – 03/2021



12C(p.p´) 12C* @ 21 MeV MLL

CEPA: 4x 4cm $LaBr_3$(Ce) + 6cm $LaCl_3$(Ce)



?

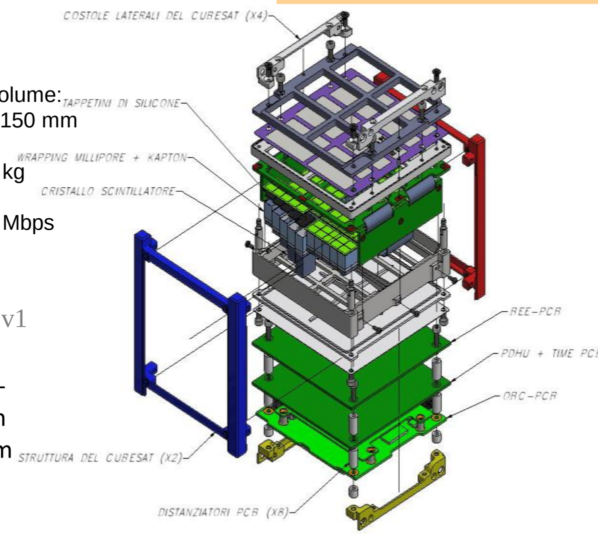
GAGG:Ce

HERMES nano satellites
(Gamme ray burst detection)

3U platform
Available Payload volume:
97 x 97 x 150 mm
Available Mass:
0.5 to 1.5 kg
Data rate in the air:
up to 150 Mbps

arXiv:2101.03945v1

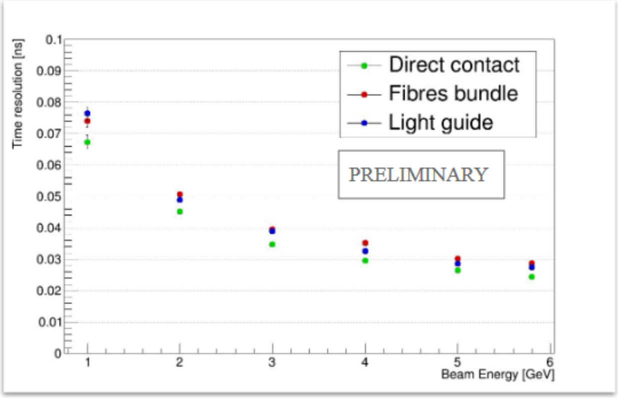
GAGG:Ce (Cerium-doped Gadolinium Aluminium Gallium Garnet)



Enabling technologies
- Precision timing (few...100 ps)

SPACAL Pb - Time Resolution - DESY

- The 3 configurations perform similarly
- Only part of the cell read out in direct contact due to 1.8x1.8 cm² PMT active area
  - Loss of performance → optimisation needed



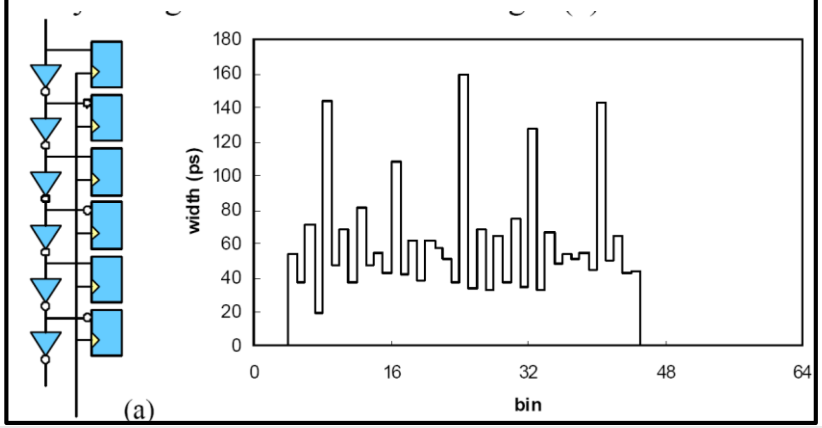
Time resolution **26 ps at 5 GeV**

LHCb R&D

- Light coupling
- Materials
- Geometry
- …

The 10-ps Wave Union TDC: Improving FPGA TDC Resolution beyond Its Cell Delay
Jinyuan Wu and Zonghan Shi

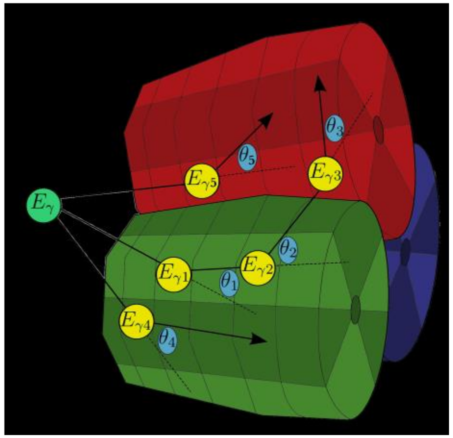
IEEE Nucl. Sci. Symp. Conf. Rec. (2008)

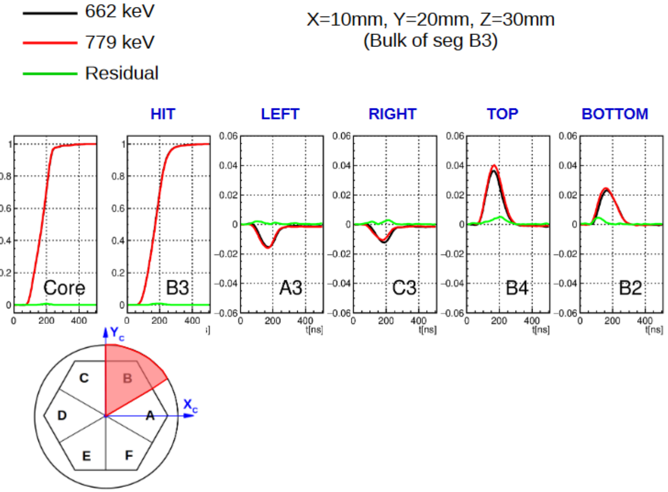


- Time distribution systems
  - e.g. Based on WR network (… KM3NeT)
  - https://white-rabbit.web.cern.ch/
  - CAMPUS wide (e,g, ToF: Separator – Exp.)
- FPGA TDCs down to 7ps resolution
- Precise position measurement
- Amplitude information via time over threshold
- E.g. ToF Wall based on plastic scintillator

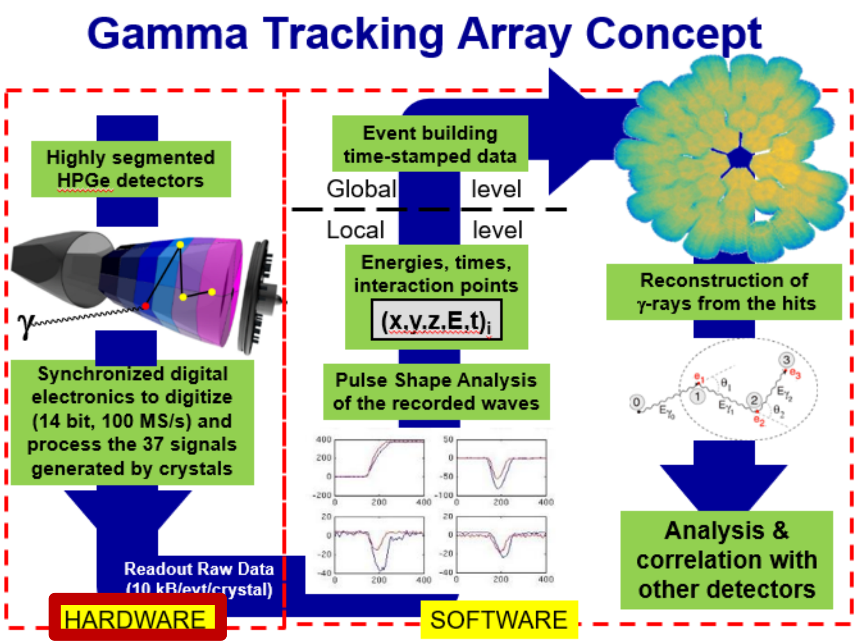
σ_t=14ps, σ_E/E=1%

Enabling technologies
- Fully digital electronics



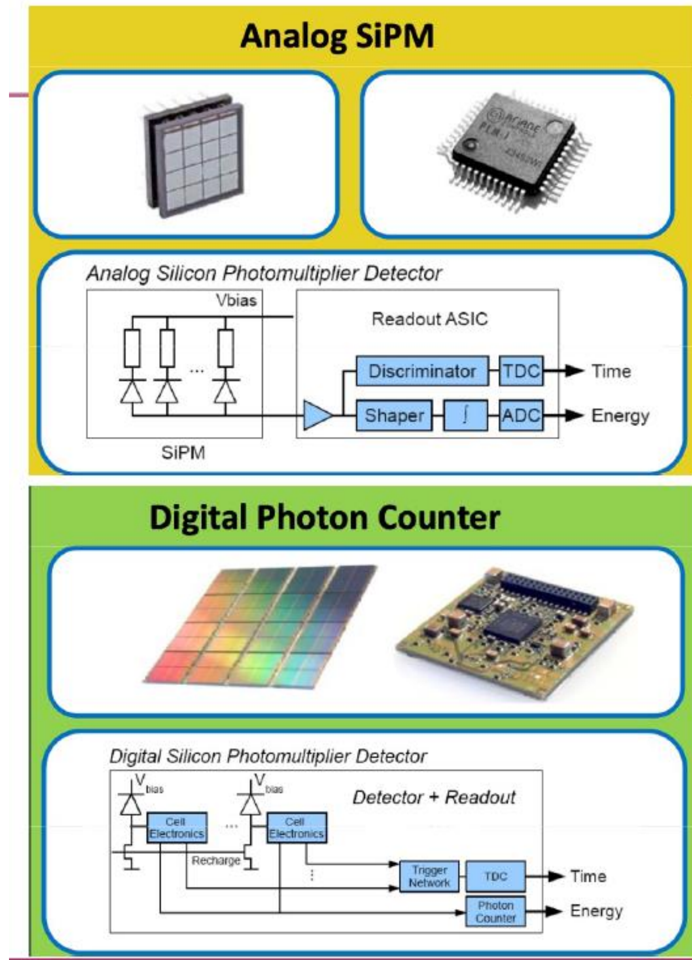


B. De Canditiis
AGATA Week – 2021



@ system level

P. Reiter



G. Gaudio - ECFA Detector R&D Roadmap Symposium

@ sensor level

Ultimately 5D readout: x,y,z,t,E

Space, time, and energy information contribute to the overall picture.
- **Novel algorithms** needed.

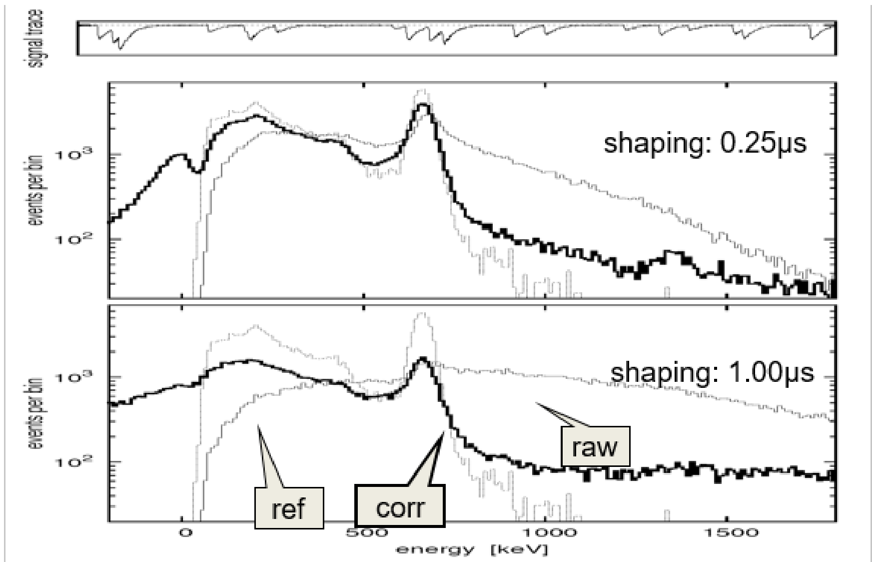
Pileup is not noise, just physics we're not interested in
- Getting the most information about the interesting process requires identifying all three components.
- Opportunities for more processing on-detector, beyond noise rejection.

Calibration also a processing algorithm
- Rates and data formats crucial.
- Streaming skips reprocessing, saves offline computing.

20210507 ECFA TF6 Readout of Calorimeter Systems

A. David (CERN)

EFCA TF-6 2021

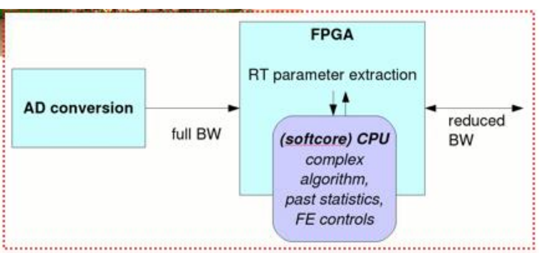


2'x2' NaI, ^{137}Cs, ca. 1MBq

M. Vencelj – GSI/JSI/KVI/INCAS³

Online pile up correction in FPGA (deconvolution, 2010)

Use: t - information



Key: Online processing of incoming channel data

Summary (form a nuclear physicists perspective)

- Enabling technologies presented
- Hardware focus
- Common needs can be easily identified

- Nuclear physics applications require often large dynamic range
  - requirements resemble calorimetric

- Processing in frontends is possible
  - software methods can be later (partially) implemented
  - Machine learning results to a certain extend also

- The availability of sample systems for testing are key for common applications → open access, documentation and awareness

- Example: WR time distribution system (open hard & software)
  - e.g. used at german stock market
  - … and KM3Net
  - … replaced „home made“ BuTiS in our lab.

Summary

- Similarly: Detector samples (with or w/o readout sysytem) for testing
  - for external collaboration key

- A lot of processing in frontends is technologically possible
  - software methods can be later (partially) implemented
  - Machine learning results to a certain extend also
  - Quality monitor/Many channels

Thank you for your attention !

Special thanks:
Martin Aleksa, David Barney, Roberto Ferrari, Thomas Peitzmann, Frank Simon, Ulrike Thoma