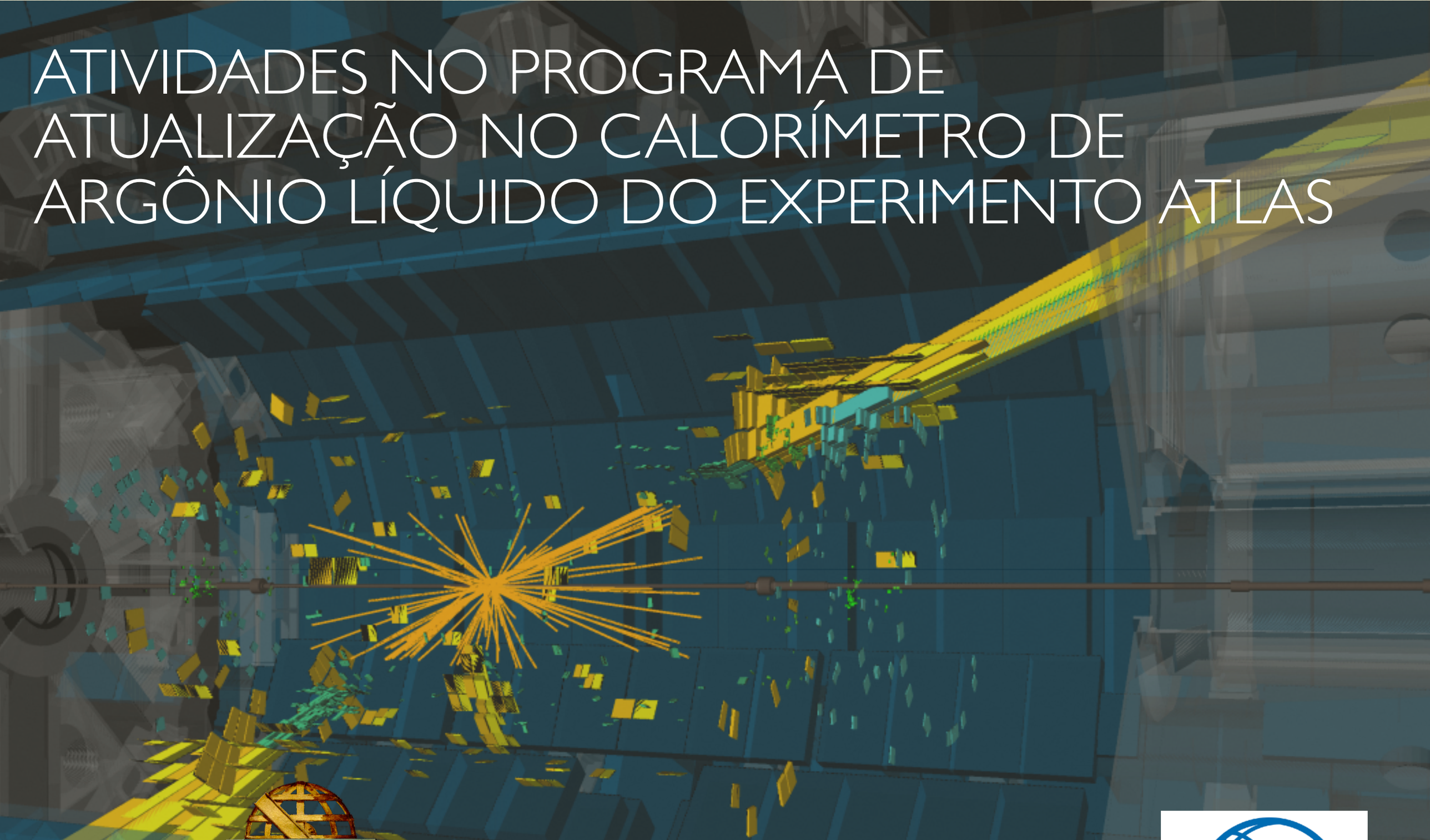
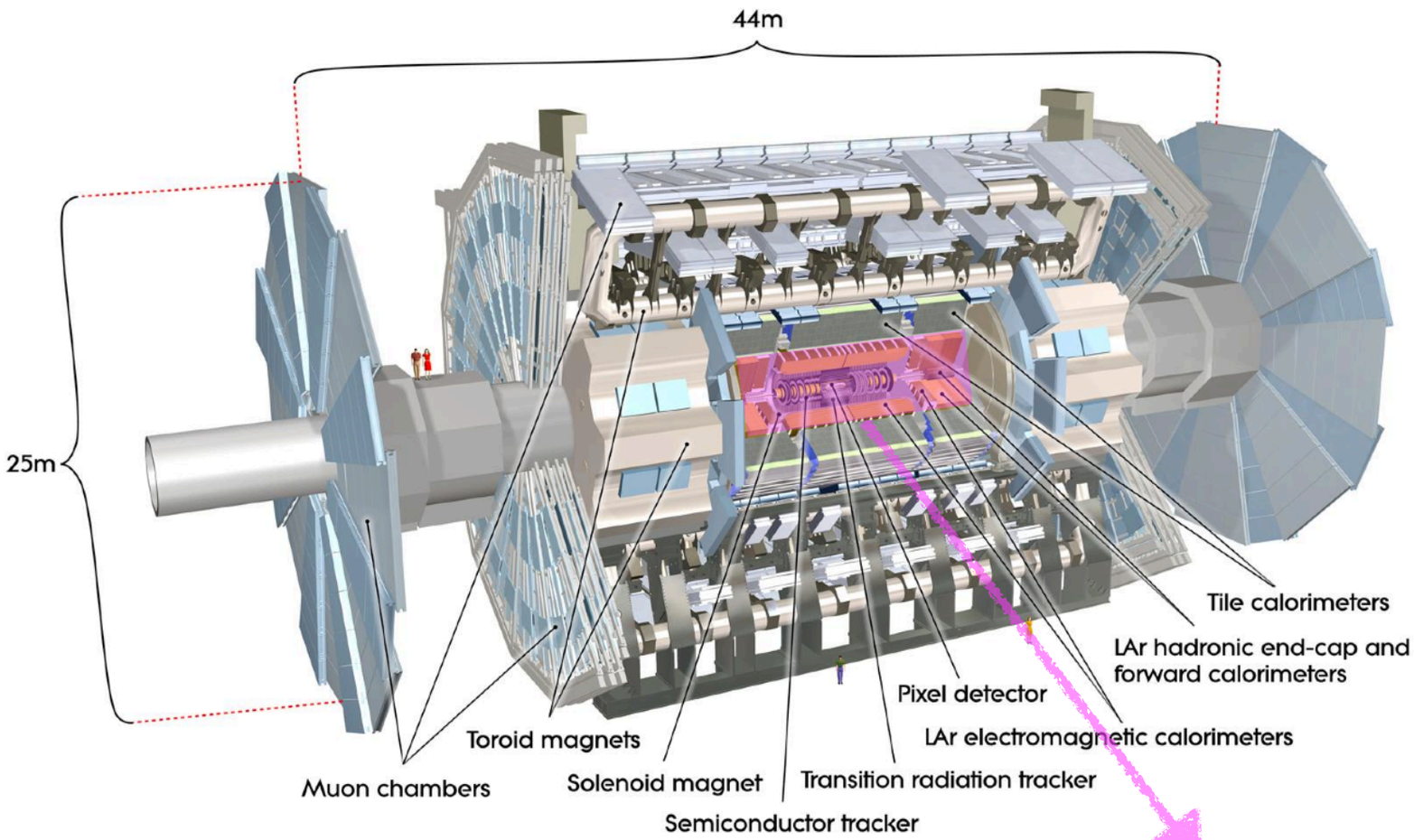
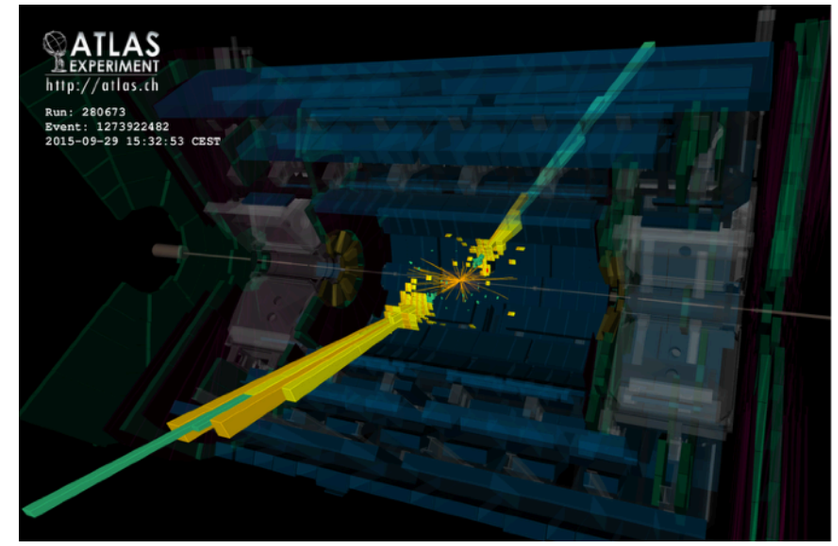
ATIVIDADES NO PROGRAMA DE ATUALIZAÇÃO NO CALORÍMETRO DE ARGÔNIO LÍQUIDO DO EXPERIMENTO ATLAS

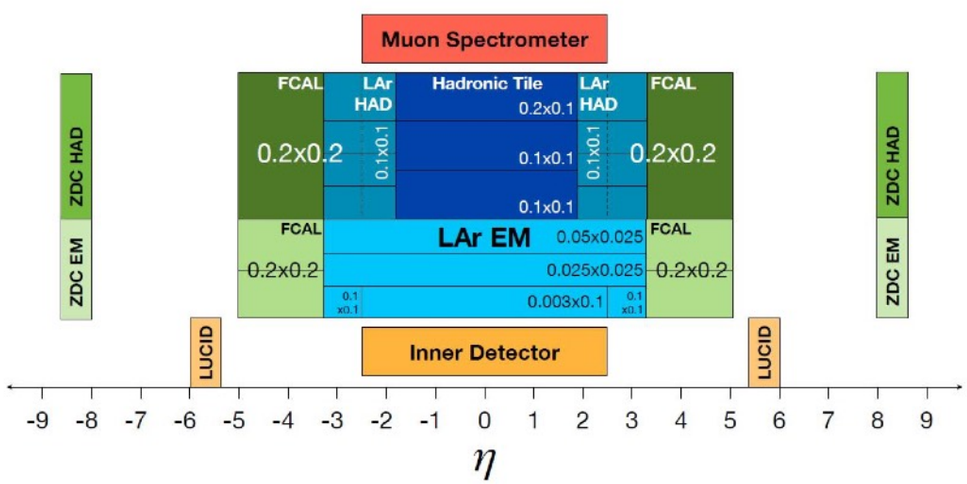


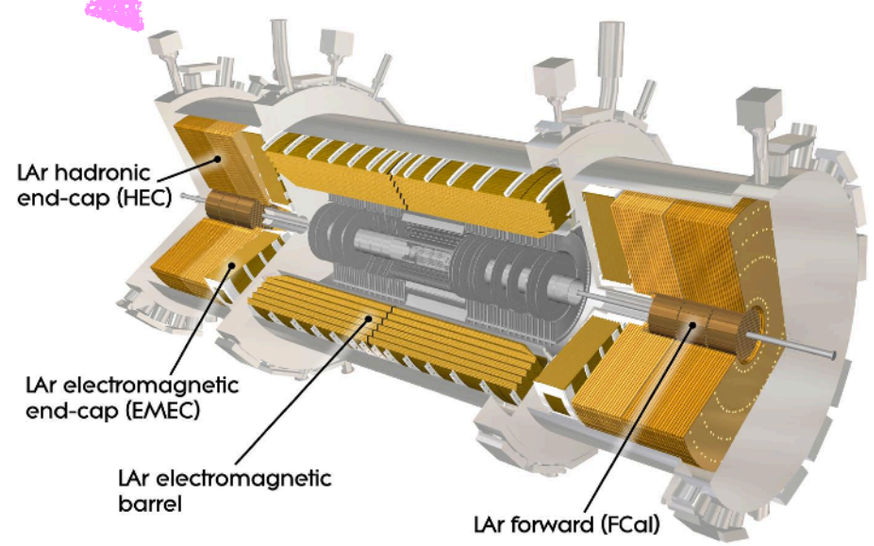
Marco Leite
Instituto de Física da Universidade de São Paulo
30 de Julho de 2018

ATLAS - A TOROIDAL LHC APARATUS



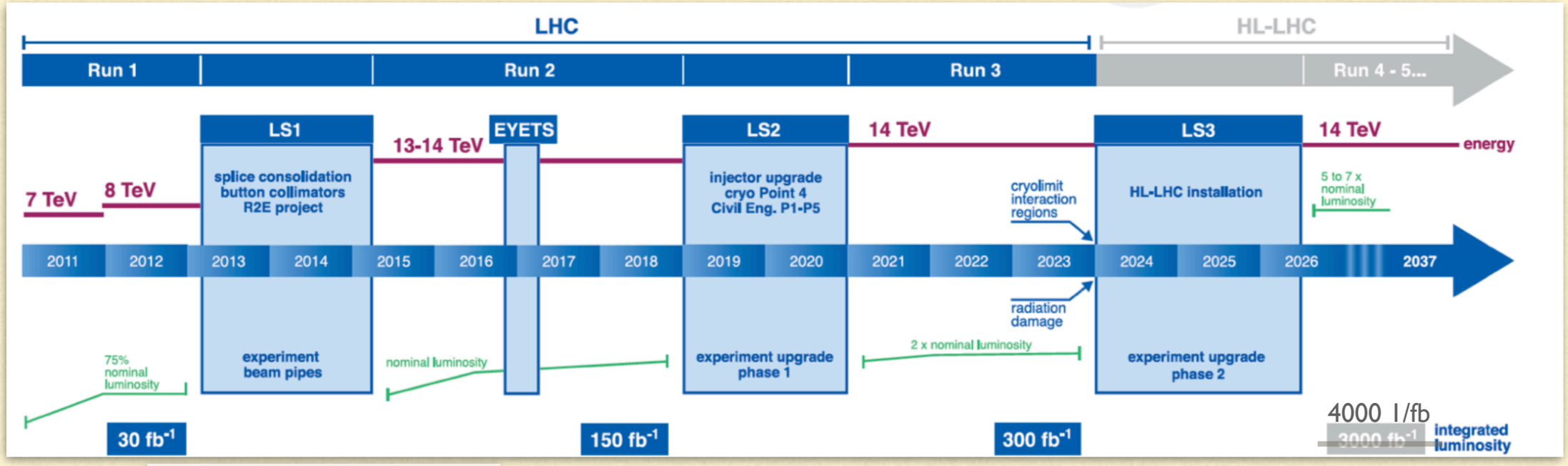


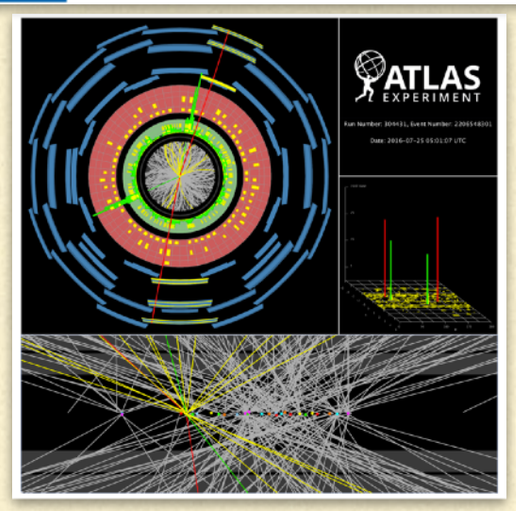




FASE I - LIQUID ARGON TRIGGER DIGITAL BOARD

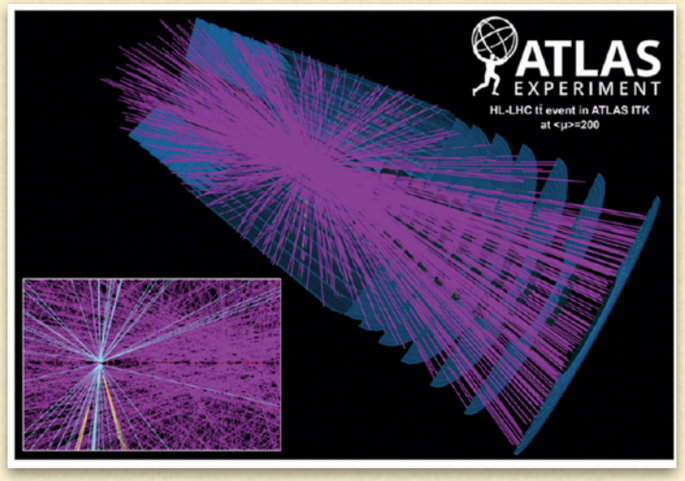
- desde 2011 o programa de Física do LHC tem incrementado nosso entendimento sobre processos no SM e conduzido muitas buscas por BSM
- Medidas de precisão em espaços de fase extremos e processos raros requerem luminosidades cada vez maiores
- Um programa de atualização de 3 fases (Fase0-Fase2) foi preparado para o LHC, detectores e seus sistemas associados para enfrentar o aumento da luminosidade
- Atualmente, apenas 4% (~ 150 1/fb) da luminosidade integrada em pp (4000 1/fb) foi explorada ($\sqrt{s}$ = 13TeV)
- Com o aumento da luminosidade, aumenta também o número de médio colisões por cruzamento de feixe, chegando a 200 durante a Fase do HL-LHC.





μ=24

μ=200

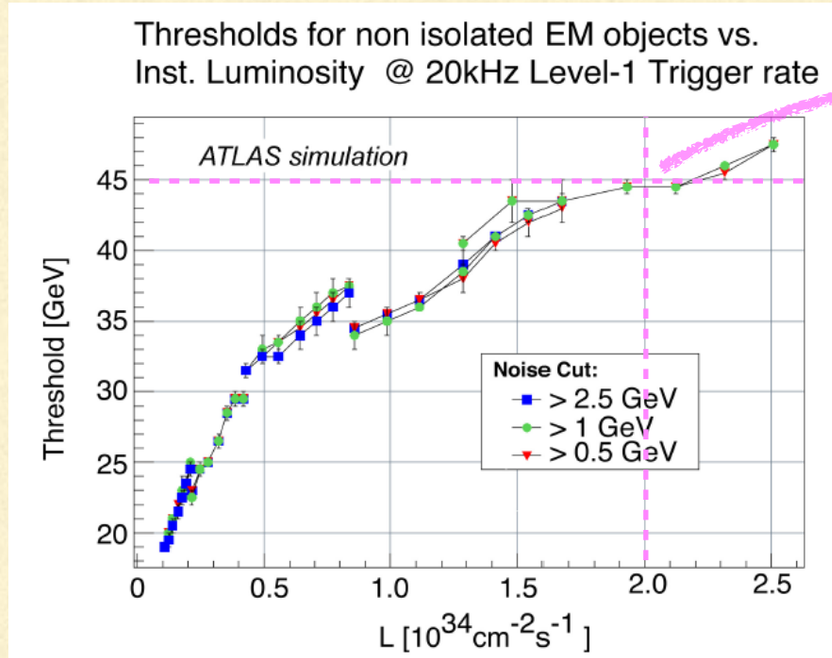


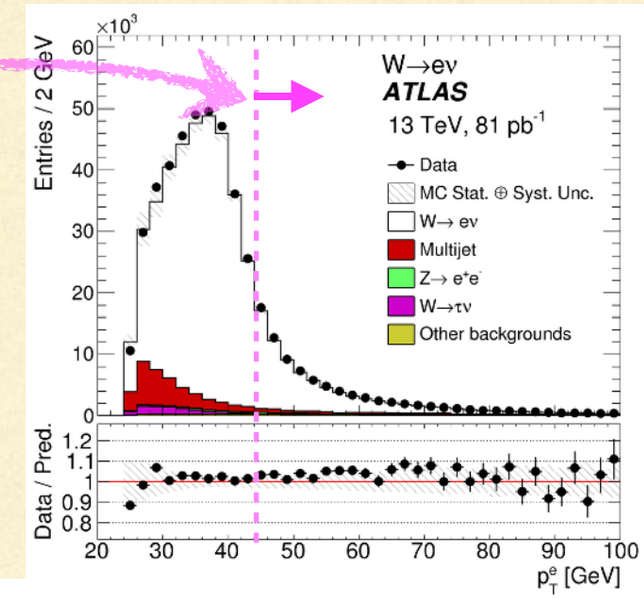
Upgrade - Fasel

LIQUID ARGON TRIGGER DIGITAL BOARD

O problema

- abundância de jatos de baixo pT → confundidos com e
- Como manter sob controle a taxa de trigger eletromagnético e o desempenho do trigger durante a Fase-I e II ?
- Luminosidade 2~7 10^{34} cm^{-2} s^{-1} , u=80~200 atingindo 4000 fb^{-1}
- Uma "saída" é aumentar o limiar em pT do L1, mas …
- Critérios de seleção requerem um limiar baixo em pT
- Taxa de trigger L1 EM < 20 kHz

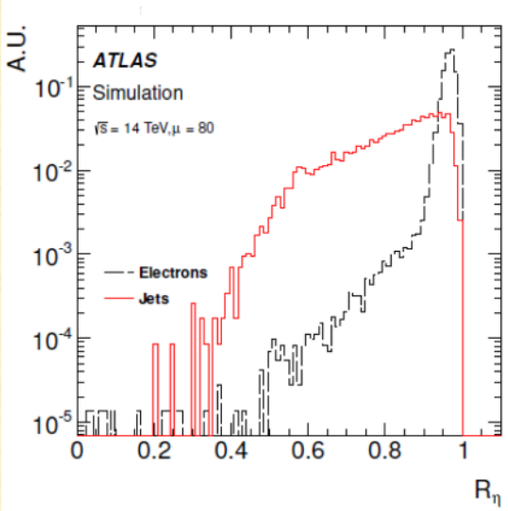


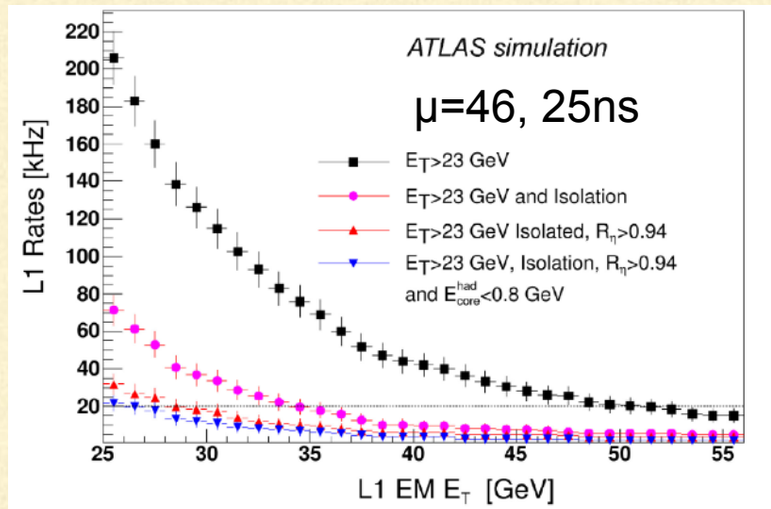


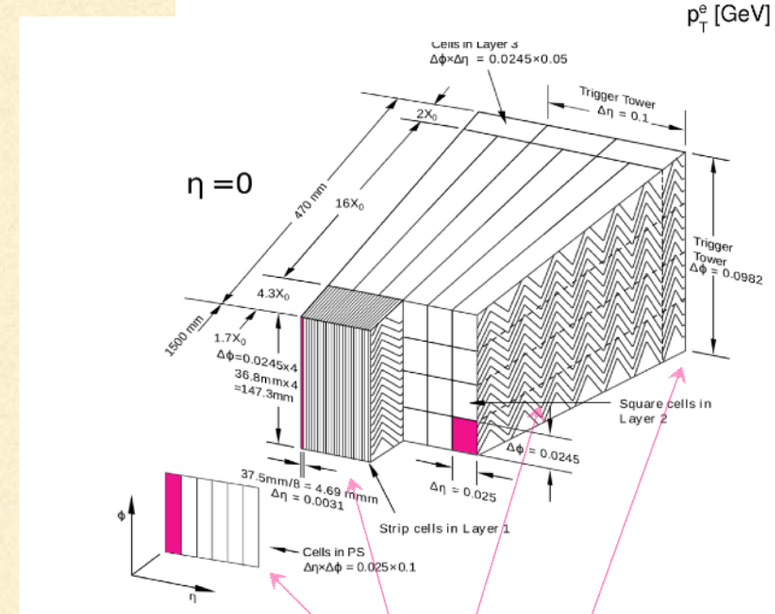
A solução

- Emprego de discriminantes baseados na forma da cascata
- Utilizado no HLT e no offline (Rη,Wη2,f3 … ?)

$$R_\eta = E_{3\times2}/E_{7\times2}$$







4 layer (PS,Front,Middle,Back) projective geometry LAr calorimeter

Requirementos

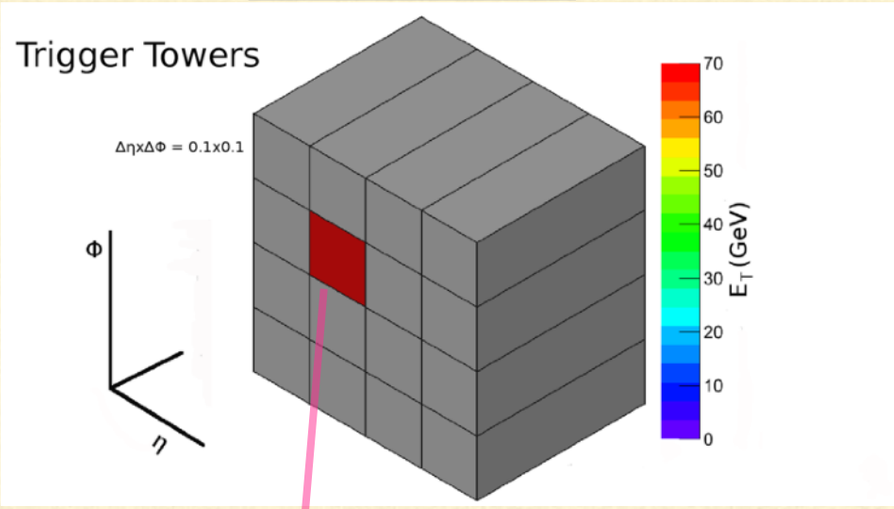
- Informação de energia de cada camada do calorímetro
- Aumento da segmentação transversal

Implementação

- Aumenta a granulosidade da torre de trigger utilizando o conceito de "super-cell"
- Envia a informação já digitalizada para o back-end, o qual reconstrói E e t e calcula os discriminantes em hardware

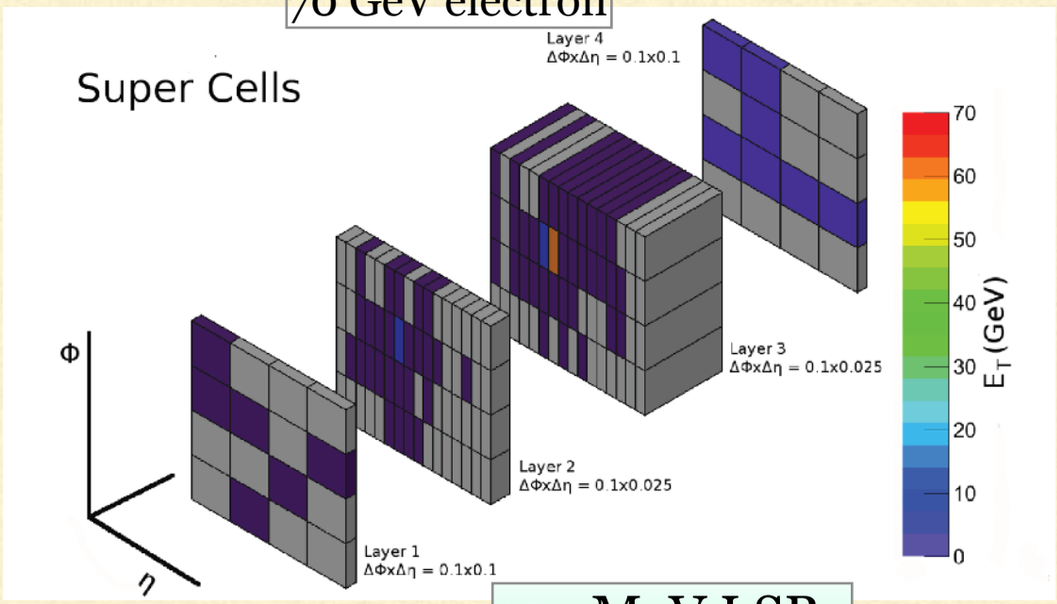
LIQUID ARGON TRIGGER DIGITAL BOARD

70 GeV electron

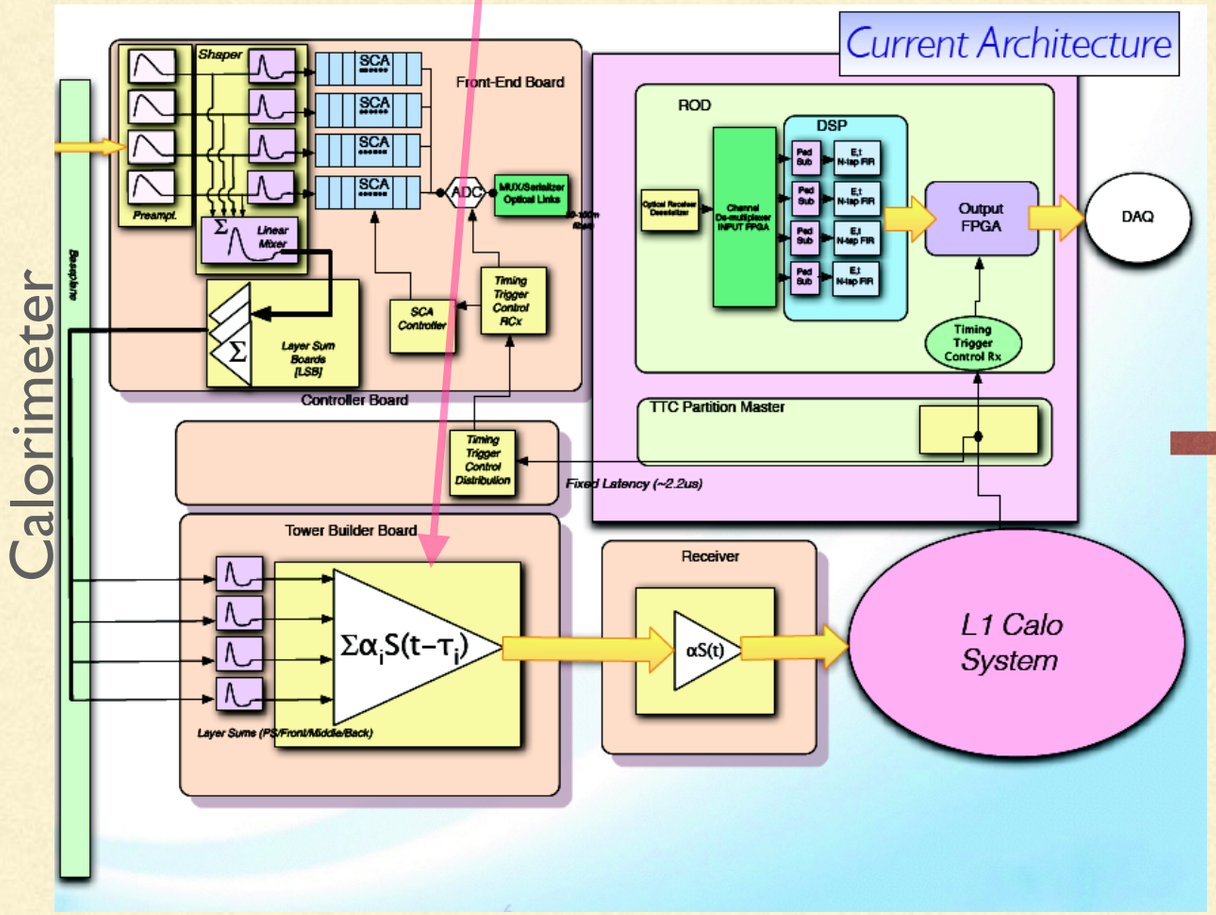


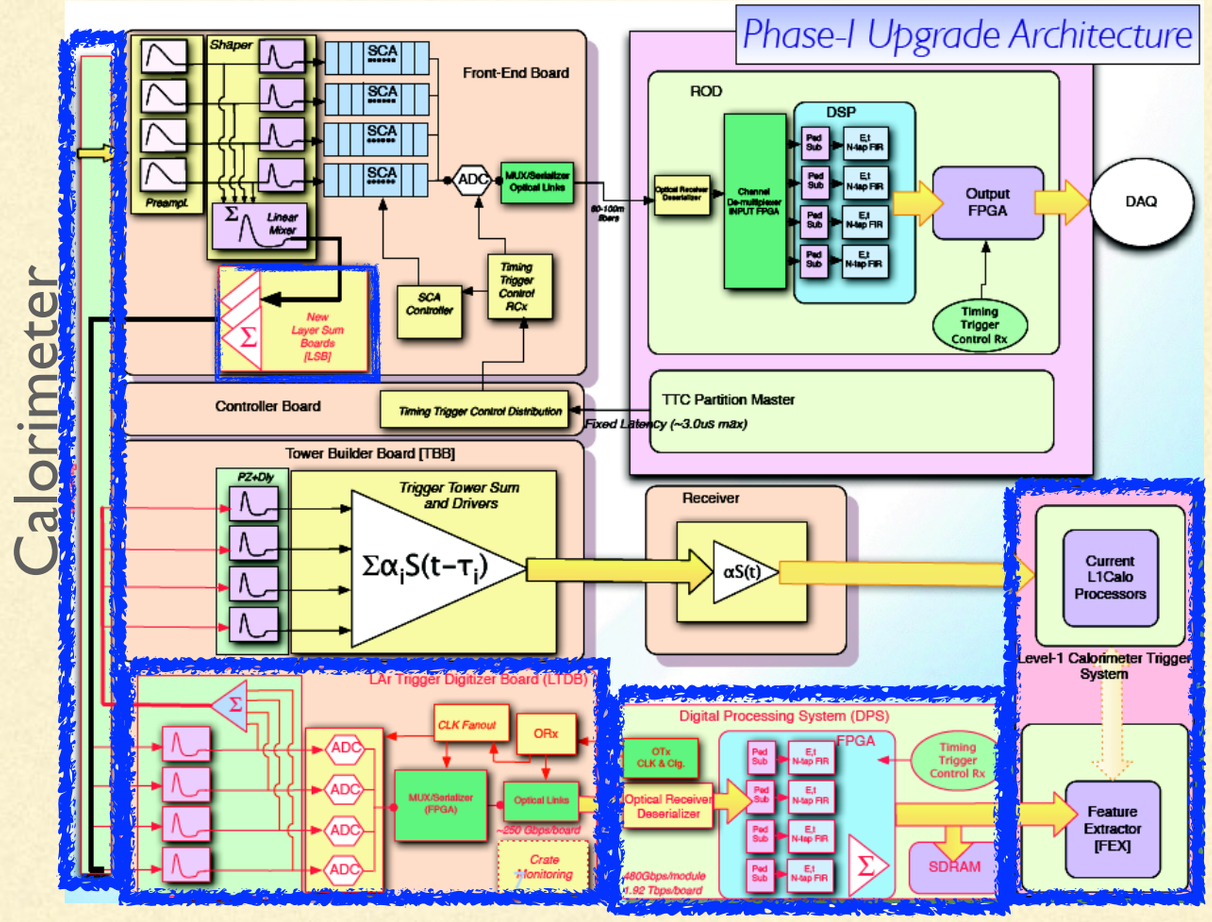
1GeV LSB

70 GeV electron



125 MeV LSB

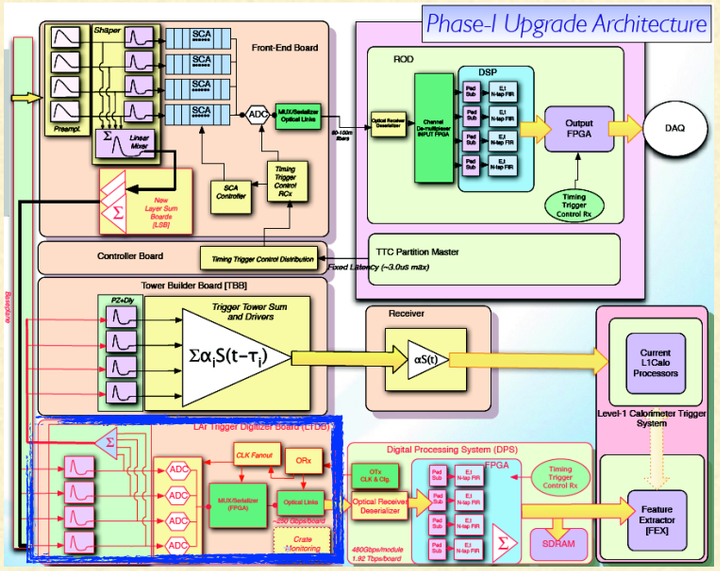


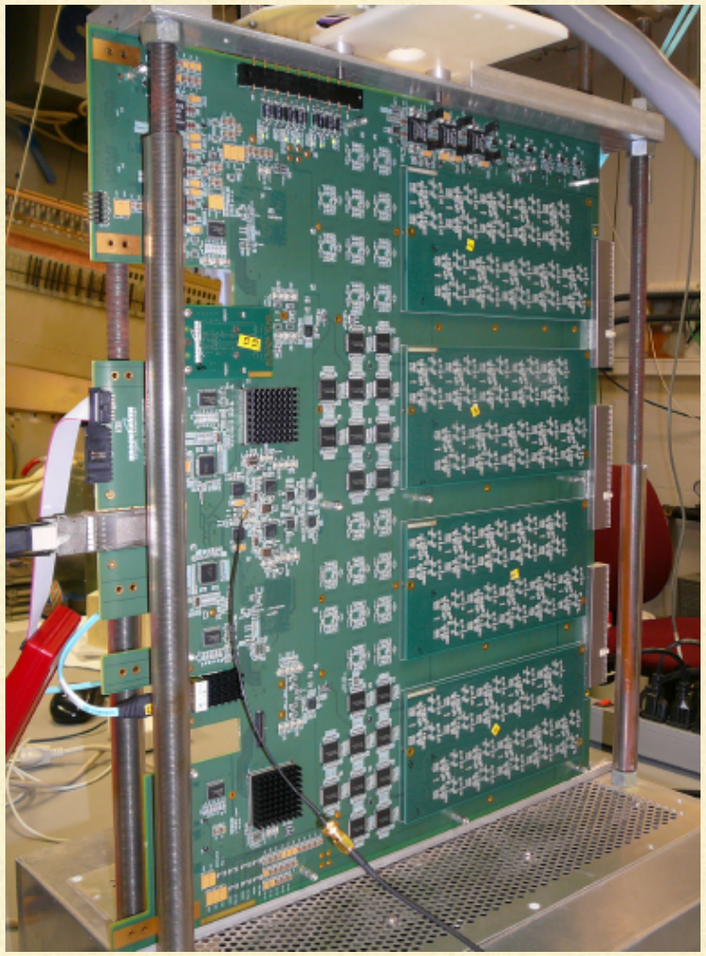


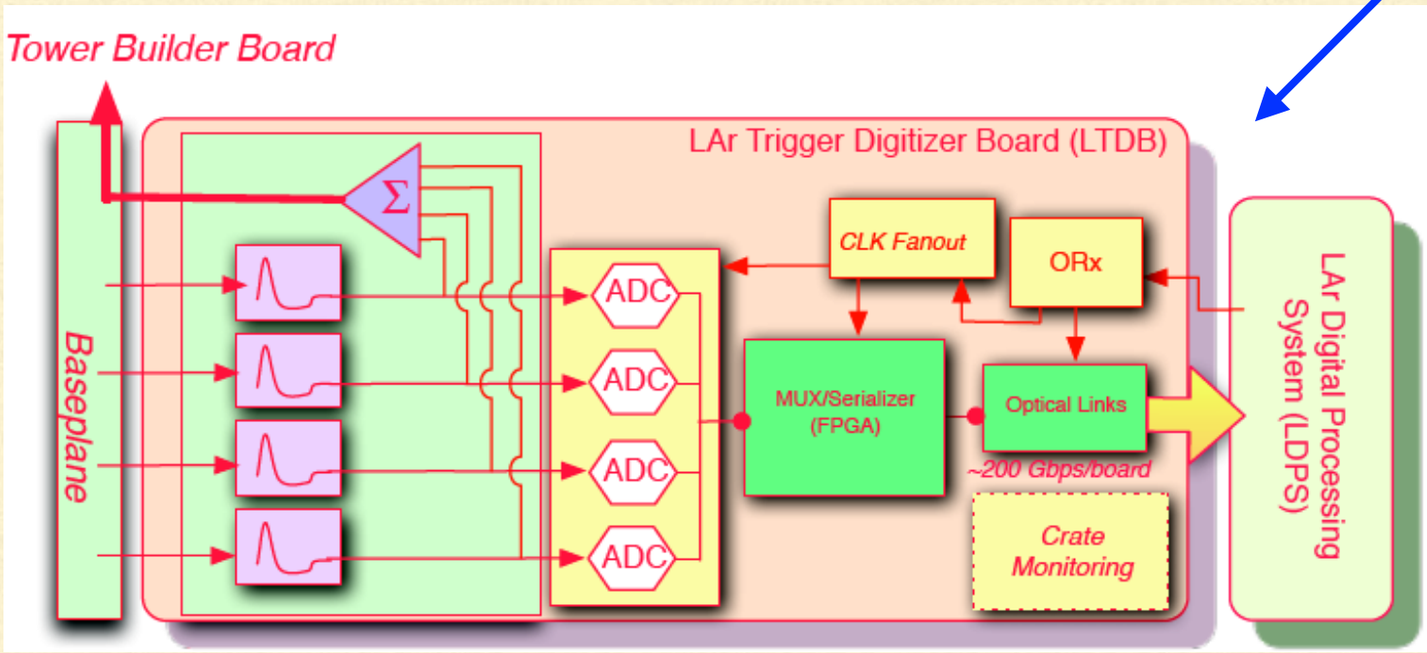
LIQUID ARGON TRIGGER DIGITAL BOARD

LTDB

- Implementa a nova segmentação do trigger
- o sinal para o L1 é digitalizado no front-end
- **Desempenho da digitalização é um aspecto chave do sistema**
- atual L1 será mantido durante a Phase-I
- 320 canais (super-cells) poor placa (12 bits, 40MHz)
- Novo esquema para o mixer analógico (ruído nesse estágio passa a ser dominante)
- 40 12Gb/s optical links por placa
- O calorímetro necessita de 124 LTDB boards



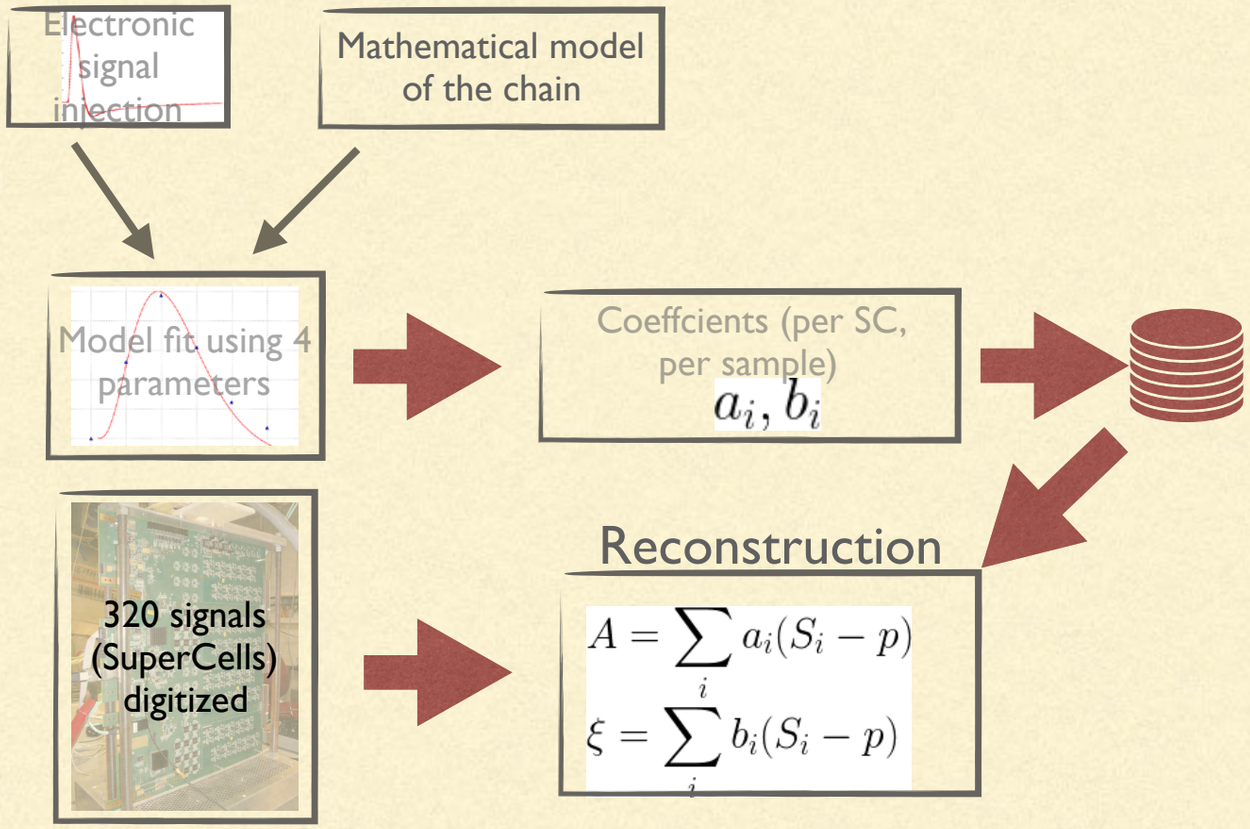


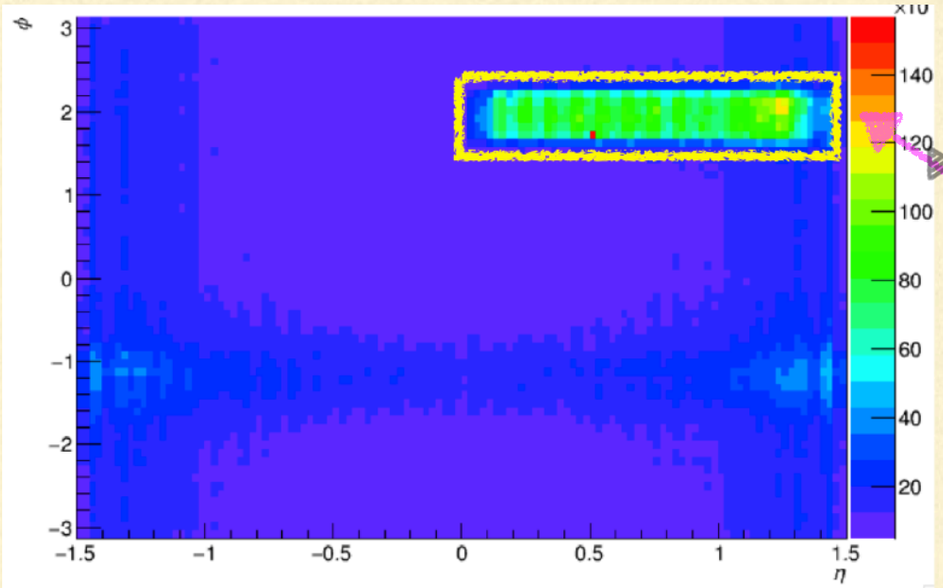


LIQUID ARGON TRIGGER DIGITAL BOARD

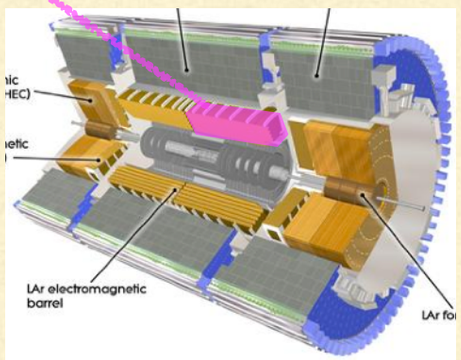
Reconstrução do sinal

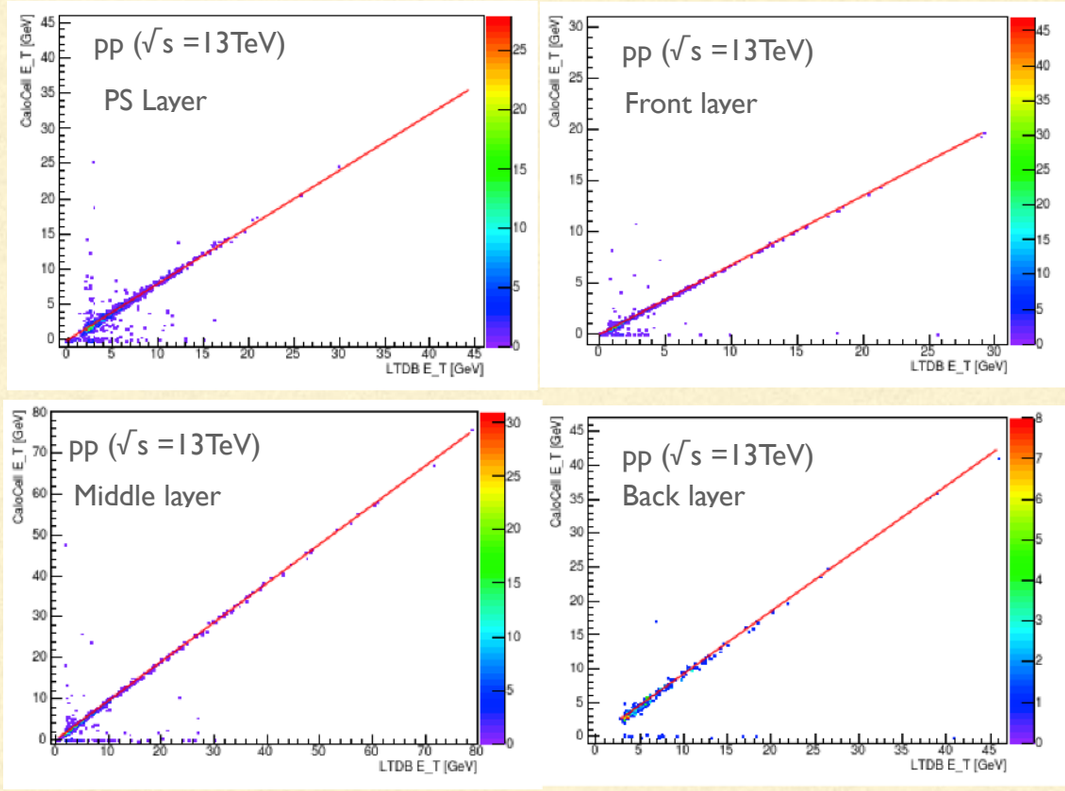
- Reconstrução da energia e do tempo de um sinal da super-célula digitalizado
- Método de filtragem ótima é utilizado para estima a amplitude e o tempo
- Calibração eletrônica utilizada para extrair os coeficientes do filtro utilizando um modelo da forma de onda.
- A função de autocorrelação do ruído leva em conta a luminosidade e o ruído térmico do 1o e 2o estágios de amplificação
- A resposta em energia (μA/GeV) é levando em conta de forma que a amplitude do sinal é calculada GeV
- Tomada de dados com 50 amostras para estudos de desempenho





- Eventos no ROI cobertos pelo demonstrator são sinalizados por um trigger L1 topológico
- pre-scaled ~ 1Hz

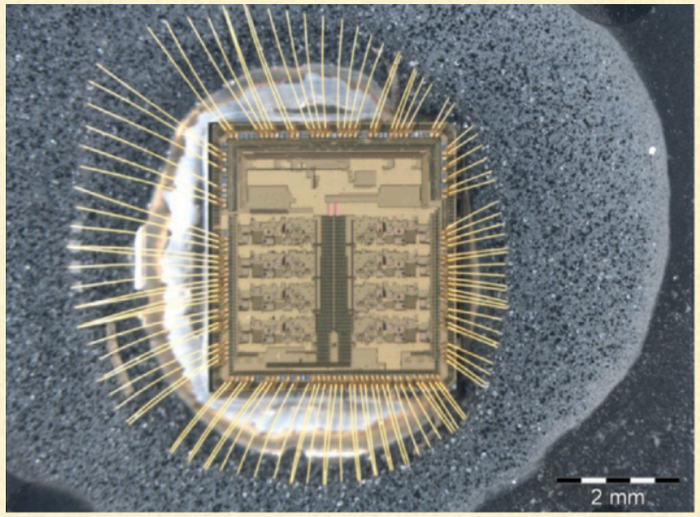


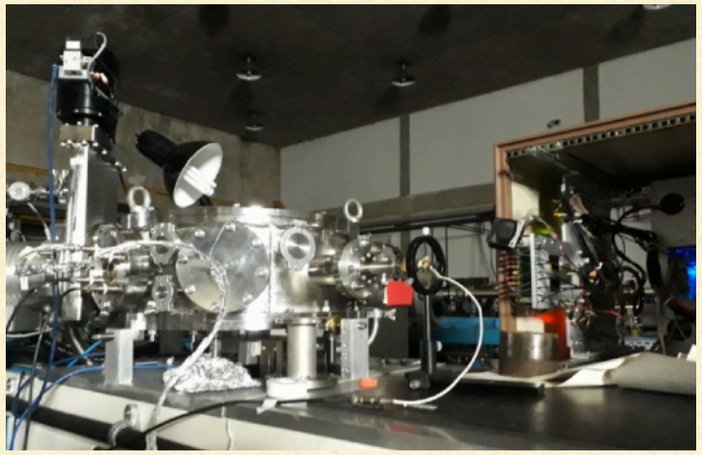


Estudos de Single Event Effects

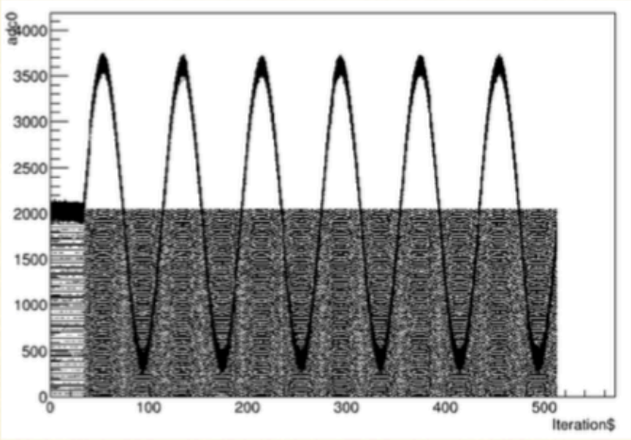
- Teste com feixes de íons no Pelletron
- Proton, 12C, 16O
- Baixa energia do feixe → remover encapsulamento do ADC
- ADC configurado com o feixe desligado
- Teste dos circuitos digitais e analógicos

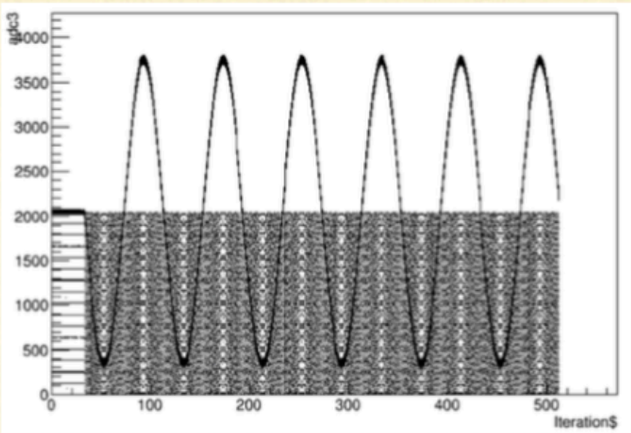
SPECIES	INITIAL E	FINAL E (CHIP SURFACE)	RANGE IN SI
Proton	14 MeV	13.9 MeV	1.28 mm
^{12}C	35 MeV	25.3 MeV	26 µm
^{16}O	49 MeV	33.8 MeV	24µm



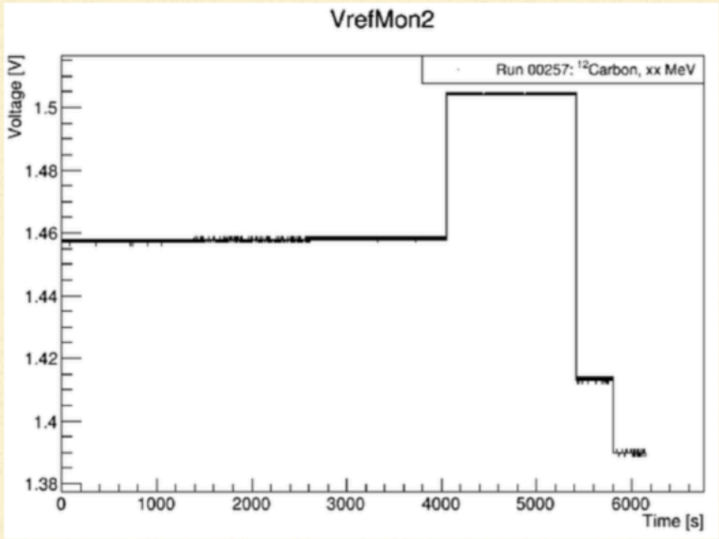


Resposta a sinal senoidal (6 ciclos)





Referência interna



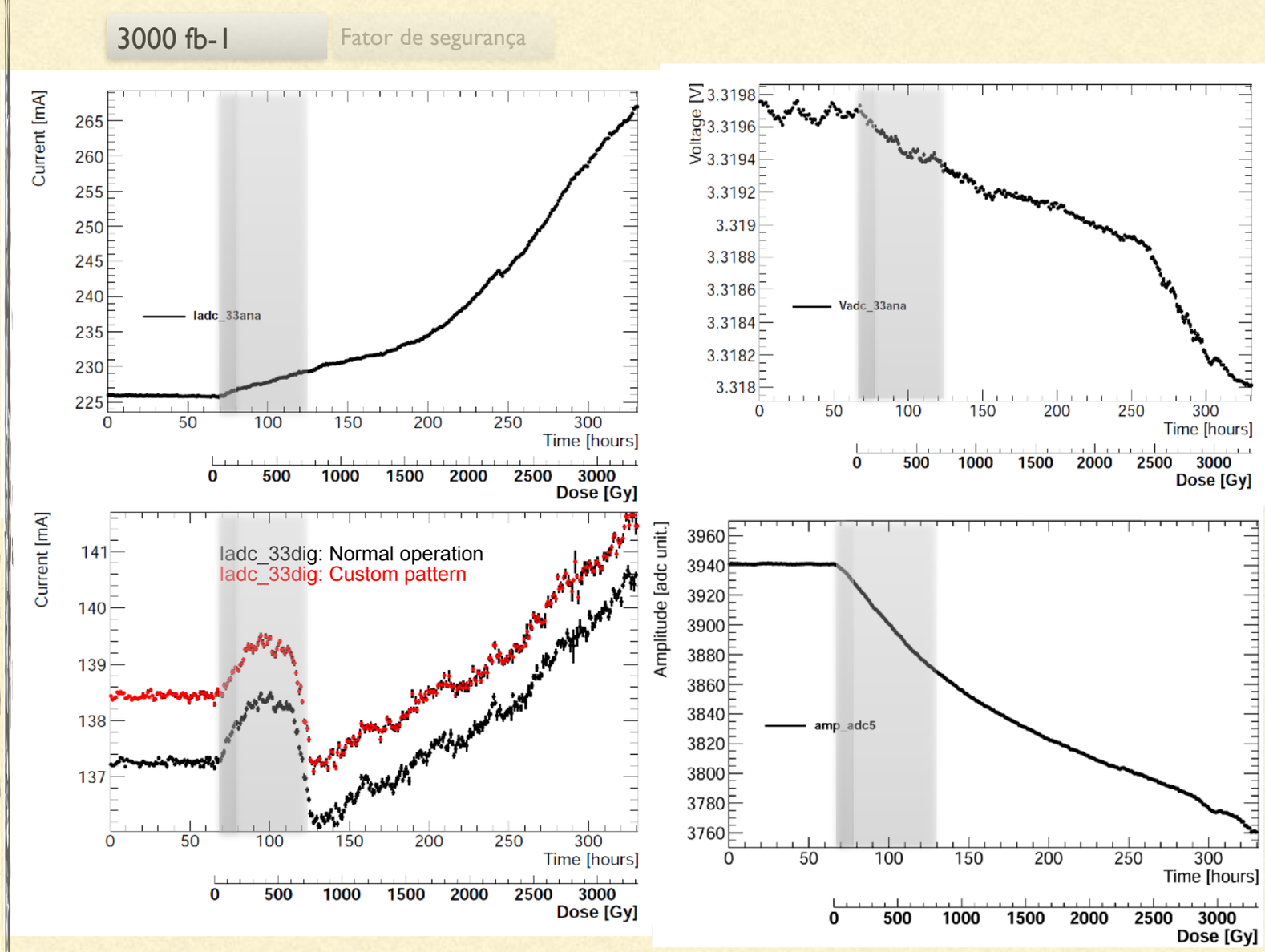
LIQUID ARGON TRIGGER DIGITAL BOARD

Irradiação com gammas

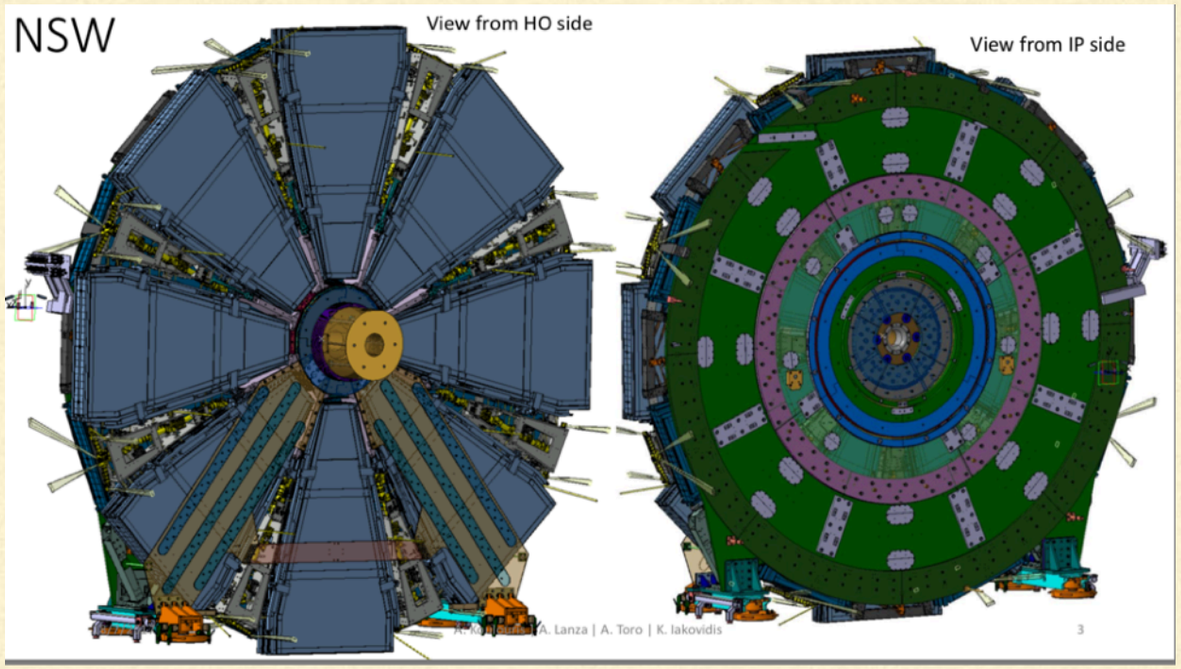
- Sistema foi transportado para o irradiador multipropósito (^{60}Co, 12.6 Gy/h) do Instituto de Estudos Avançados (IEAv) em São José dos Campos
- Dois períodos de irradiação com diferentes taxas de dose, num total de aproximadamente 45 dias de irradiação
- Resultados permitiram qualificar o digitalizador para ser instalado no protótipo do LTDB

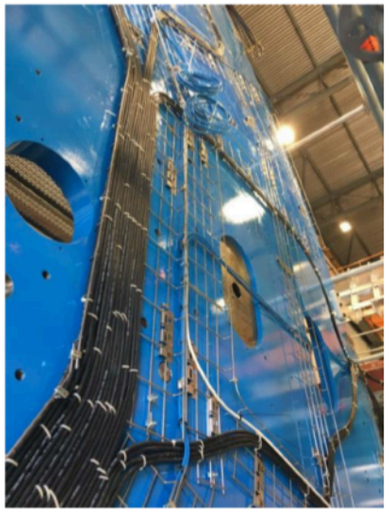
Resultados

- ADC permaneceu funcional até uma dose 4x superior ao limite de segurança
- A pequena variação no ganho é compensada através da calibração eletrônica do calorímetro

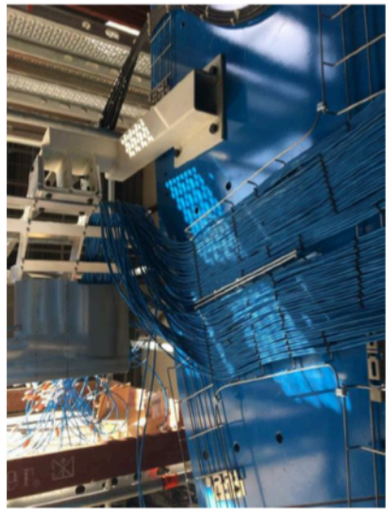


NEW SMALL WHEEL (MUON SYSTEM)





Cable trays & LV (completed)



Alignment cables (completed)

Gas distribution (finished)

Services team

Movement system hydraulics (completed)

NJD/191:

- Full team of 1 engineer + 5 techs reached beginning of April
- Cable trays, LV, alignment services completed
- Currently working on gas piping
- Services installation activity will continue to end of the year

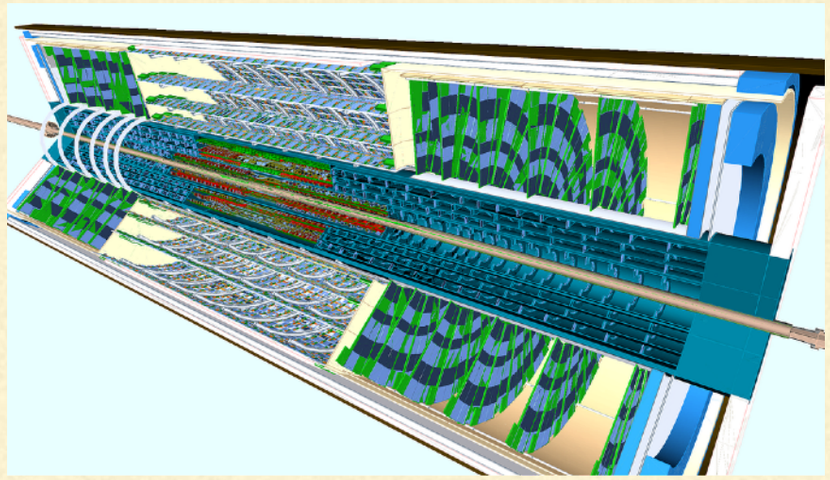
On-wedge services:

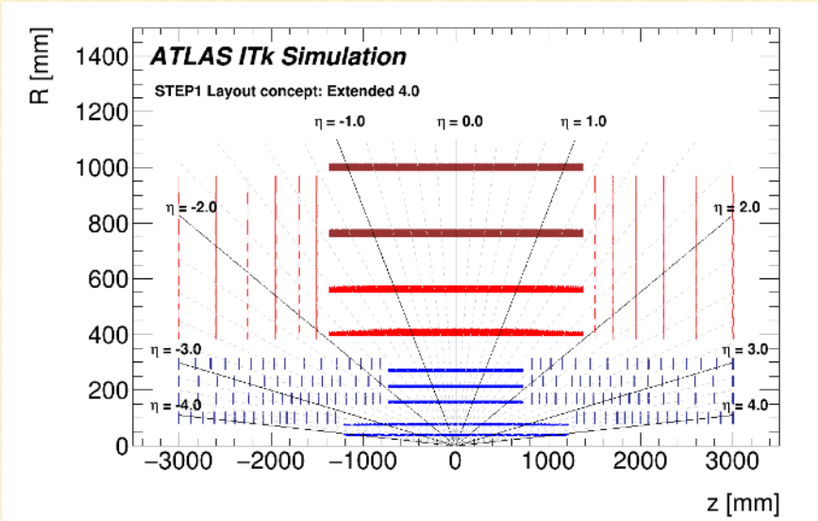
- Open design points mostly completed, catch-up by sTGC
- Started installation of gas distribution for MM wedges (series)

Upgrade - FaseII

Motivação

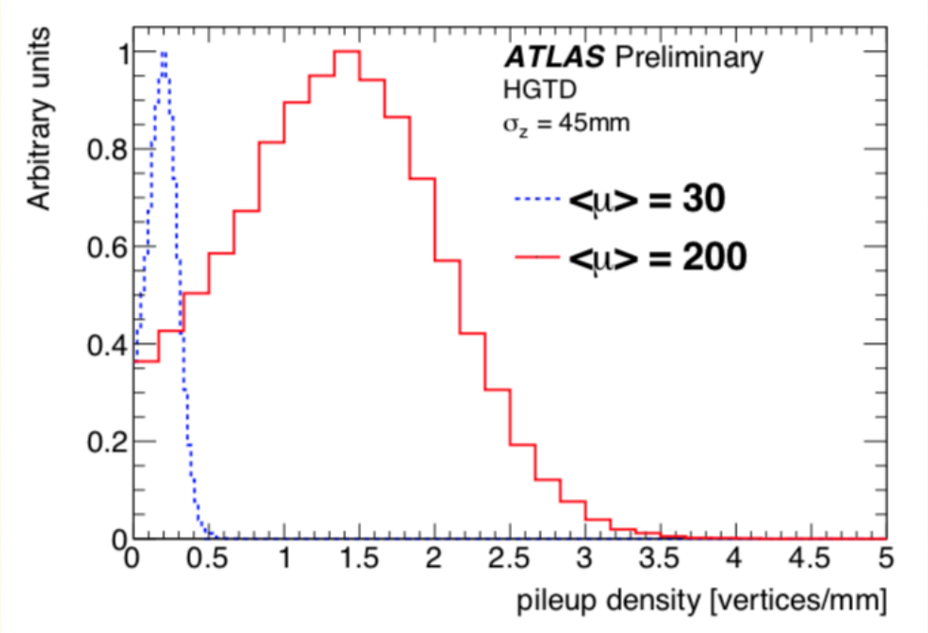
- ATLAS irá substituir o detector de traços interno para a Fase-II (ITk)
- Pixels+strips, estendendo a cobertura em |η|: 2.5 → 4.0
- Na região dianteira, o ITk sozinho não consegue manter o desempenho numa situação de alta luminosidade
- Mitigação do Pileup envolve associação traço-vértice

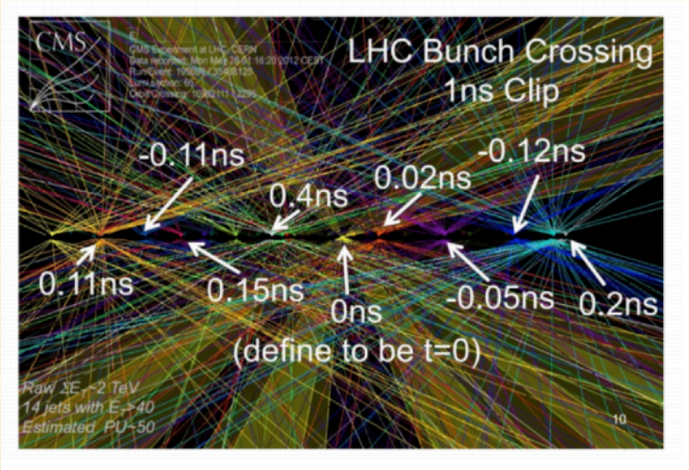


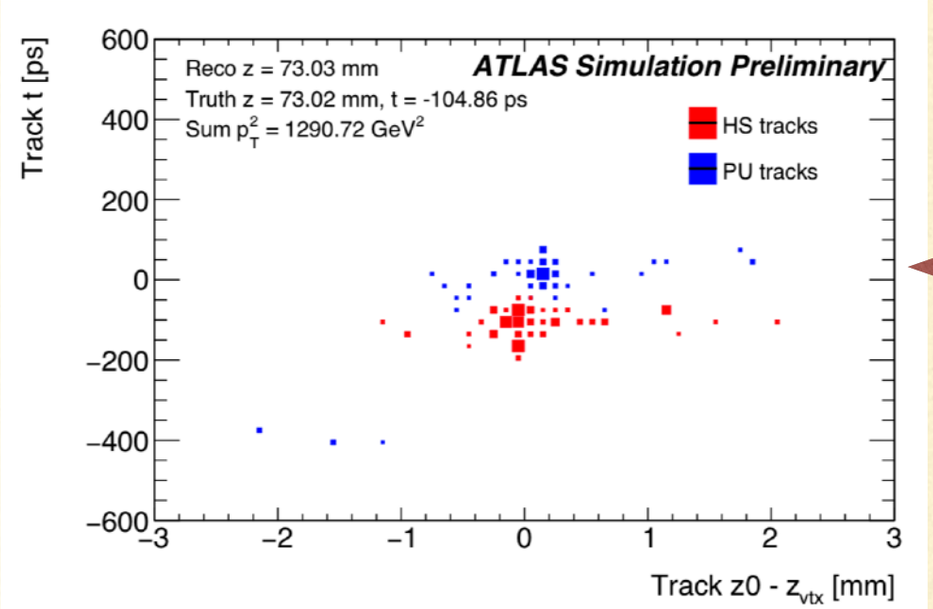


HGTD

- High Granularity Timing Detector
- Permite mater a associação traço-vértice
  - Informação de TIMING com alta resolução (detectores ultra-rápidos)





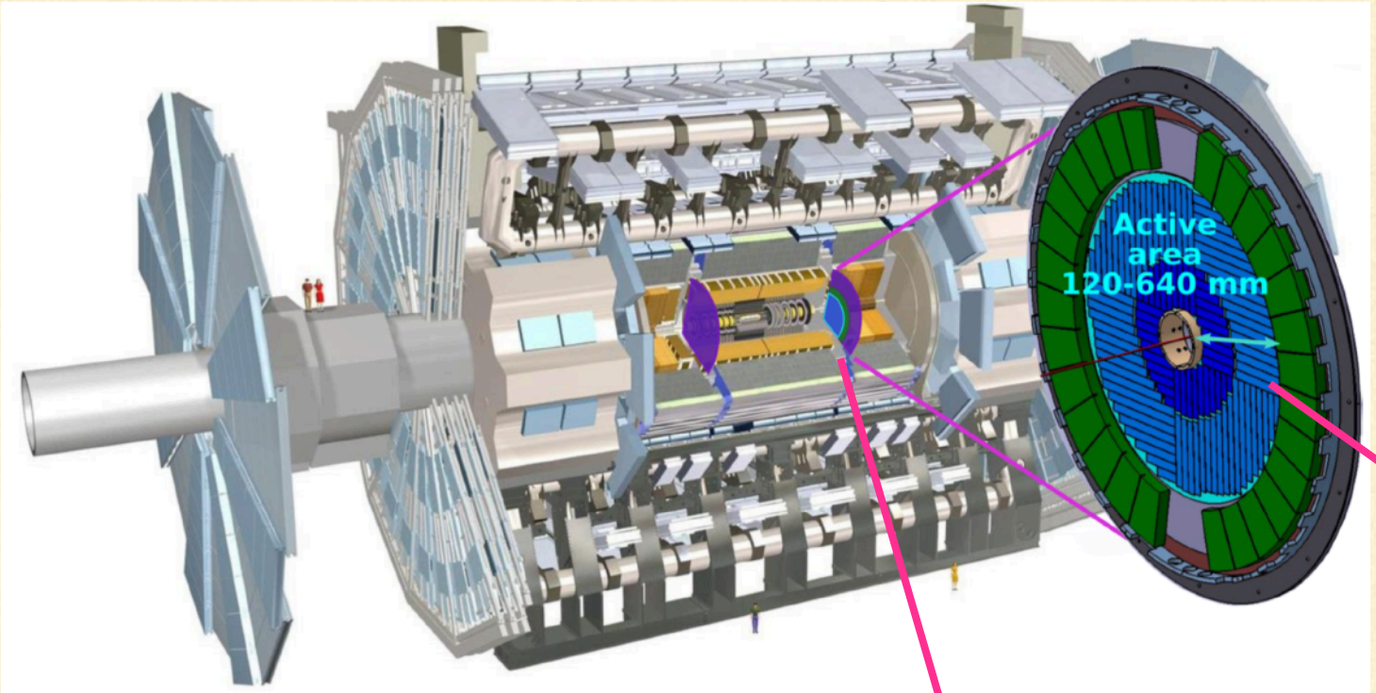


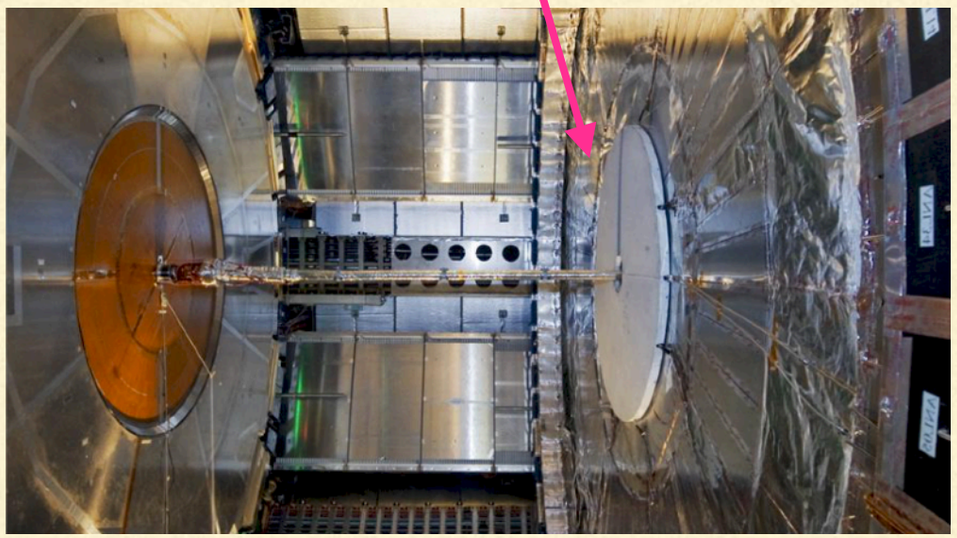
Utilização de uma 4a dimensão permite resolver entre traços de HS e pileup

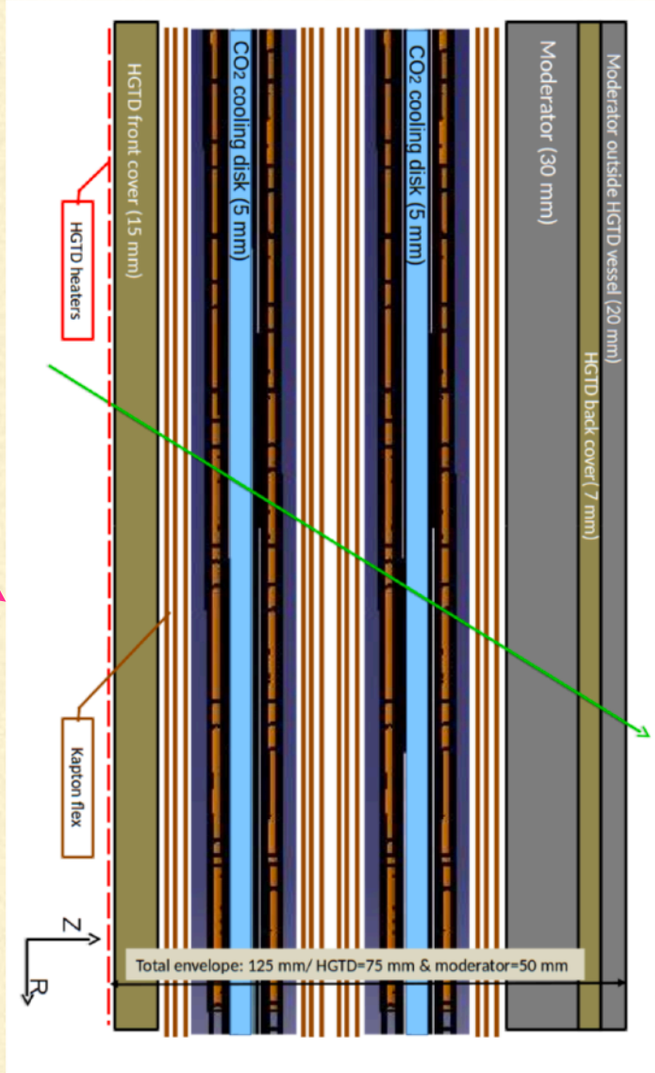
HIGH GRANULARITY TIMING DETECTOR

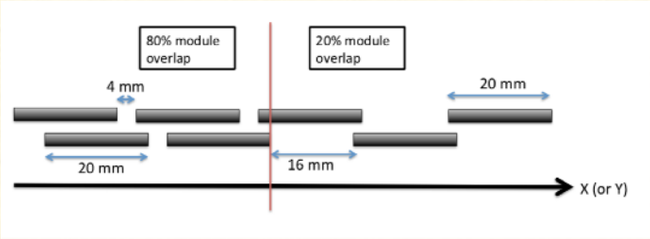
- Instalado em frente ao endcap, cobre a região 2.4<|η|<4.0
- espessura total ~ 12cm

- Detectores semicondutores ultra-rápidos de 1.3x1.3mm2 agrupados em sensores de 40x20mm2 (30x15)
- Dois planos de sensores, com overlap variável (maior na região interna)



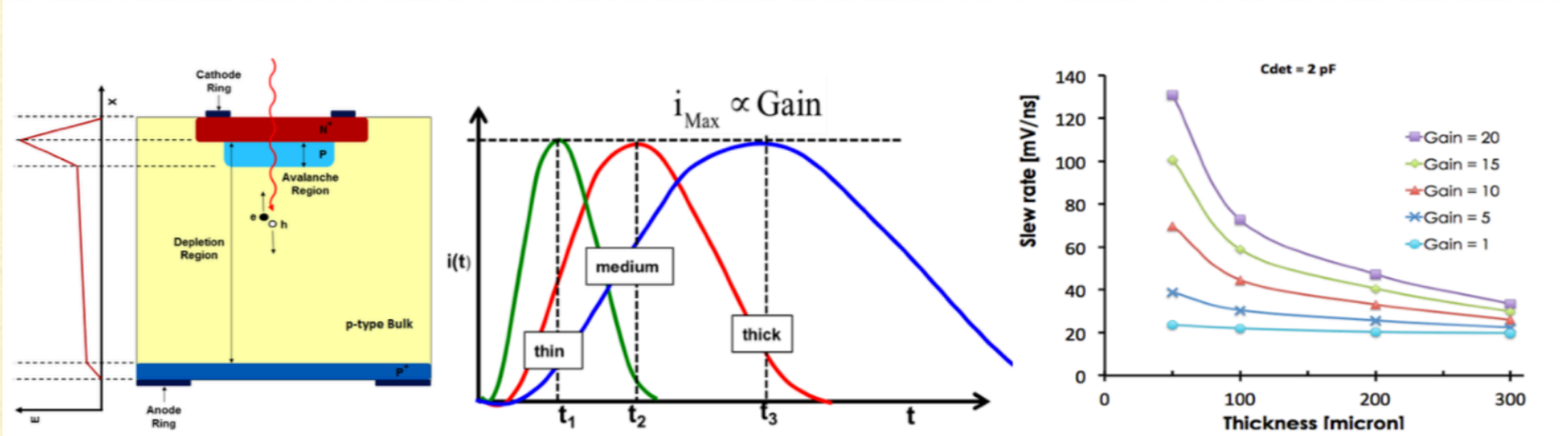




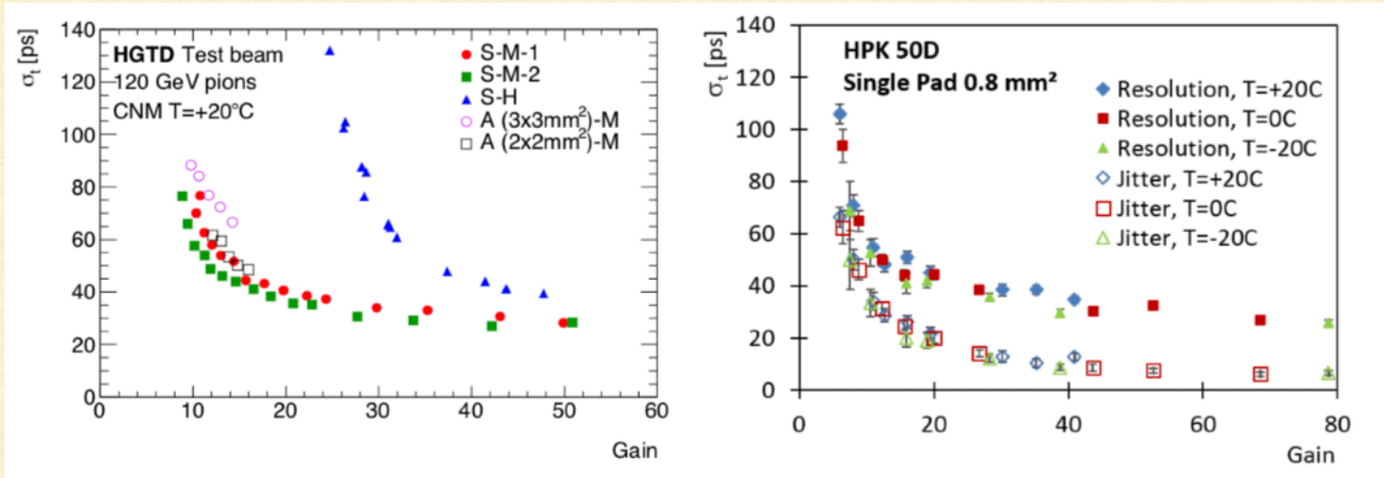


Low Gain Avalanche Detector

- Características dos detectores
  - rápida resposta (timing resolution)
  - resistentes à radiação
  - custo razoável
- Low Gain Avalanche Detector
  - detector de silício n-on-p
  - extra camada p altamente dopada logo abaixo da junção
  - Baixo ganho, independente da espessura
  - 50µm ou 35µm
  - CNM (Espanha), Hamamatsu (Japão)
- Solução explorada em outros experimentos :
  - CMS
  - LHCb
  - CLIC, FCC, Linear Colliders
  - Luz Synchrotron

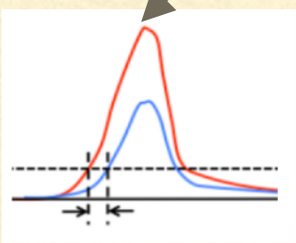


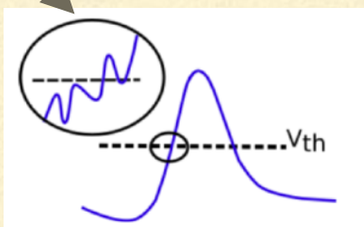
(a) Cross section of an LGAD diode. (b) Current signals for different thicknesses. (c) Signal slope as function of thickness.



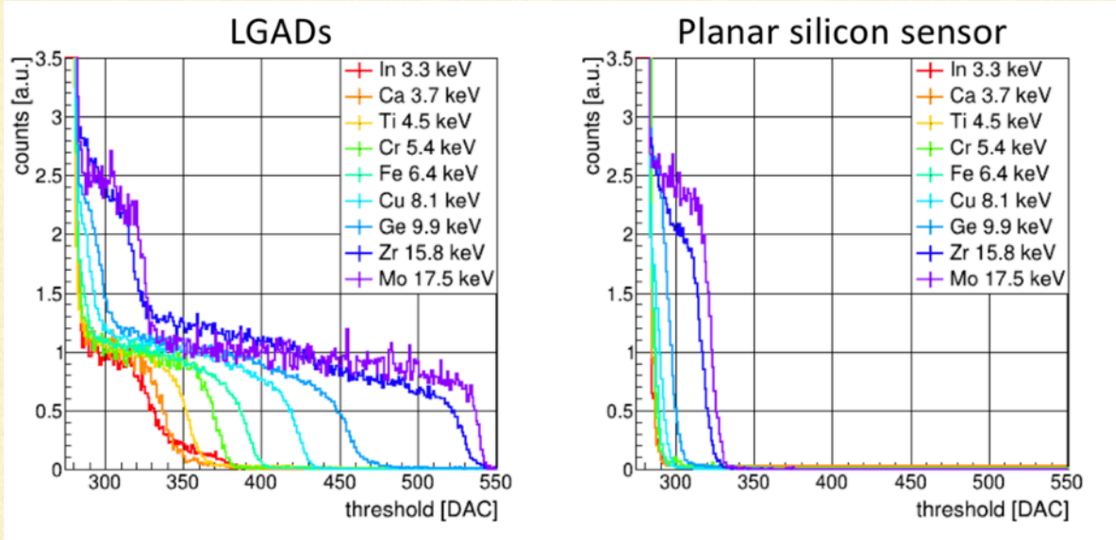
Resolução em tempo

$$\sigma_T^2 = \sigma_L^2 + \sigma_{TW}^2 + \sigma_{jitter}^2 + \sigma_{clock}^2$$





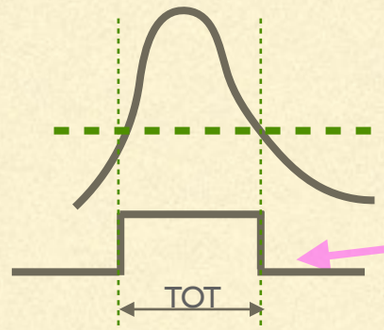
- LGAD para RX :
  - planar Si :
    - Rx>8keV
  - LGAD :
    - Rx<3.3 keV

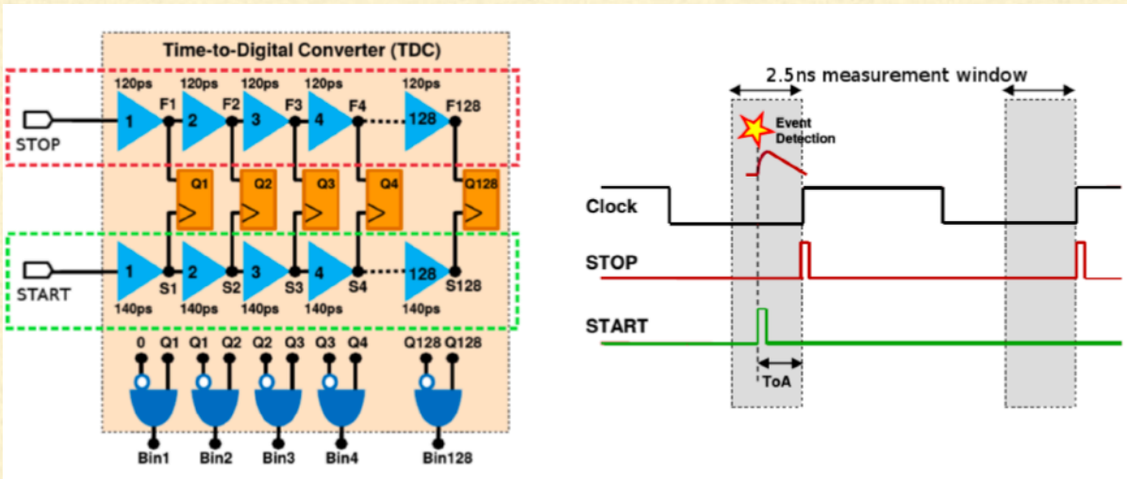


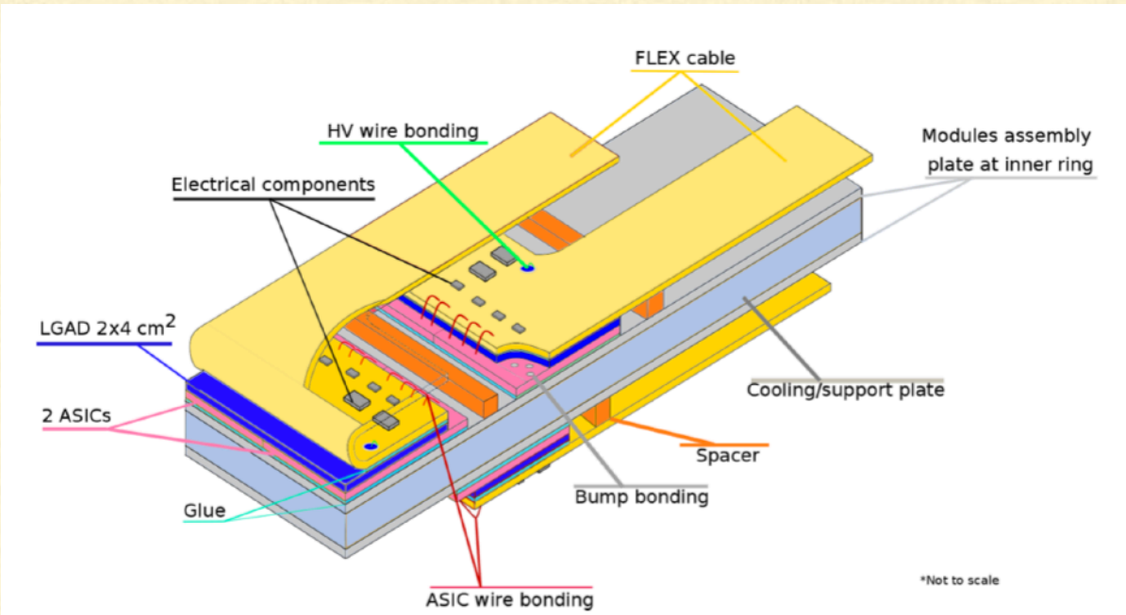
ELETRÔNICA DE FRONT END

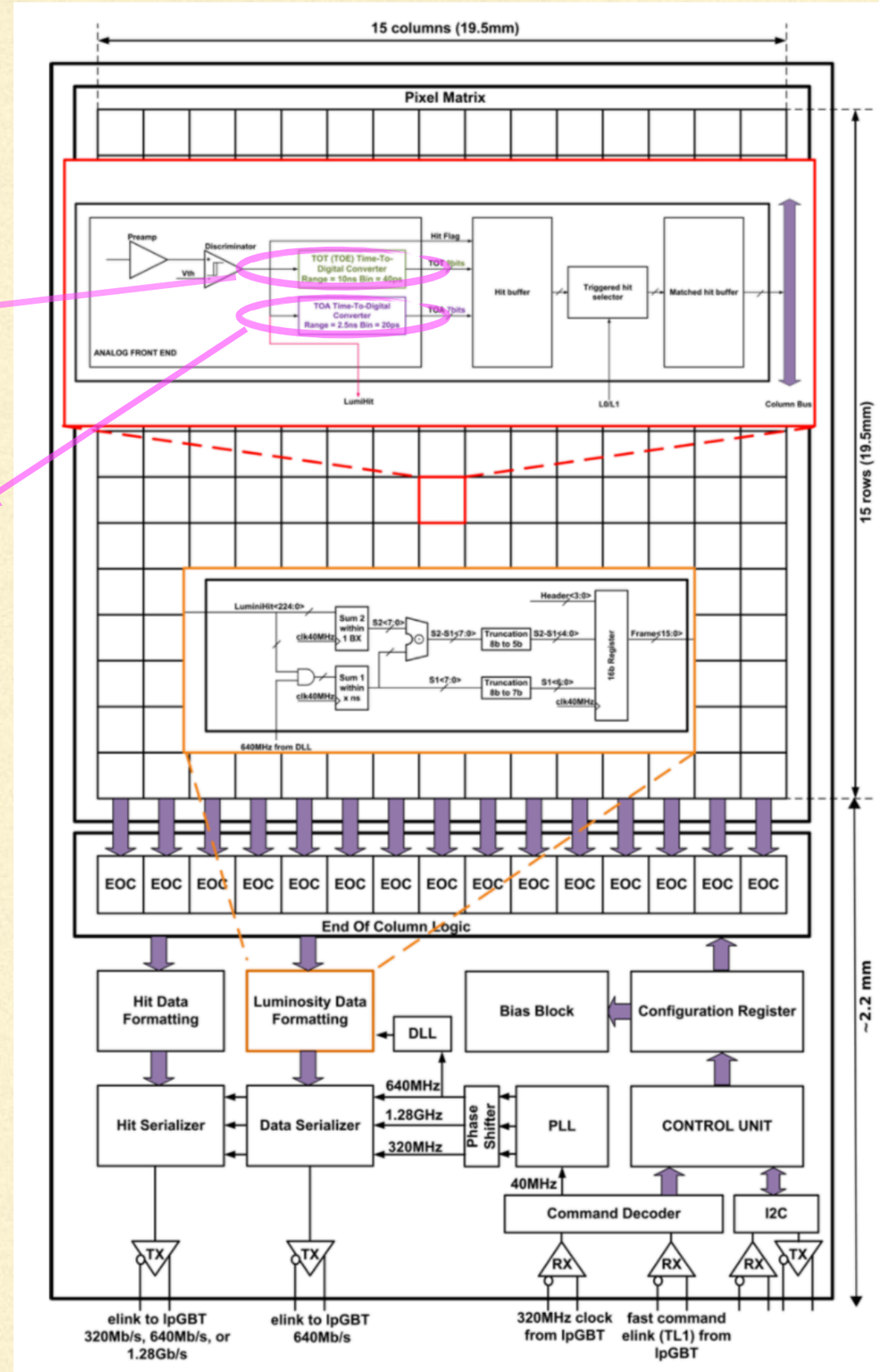
Front End

- Medida da amplitude via Time over Threshold
- Medida do Time of Arrival
- contagem de pixels
- Integrado ao detector
- Intenso R&D



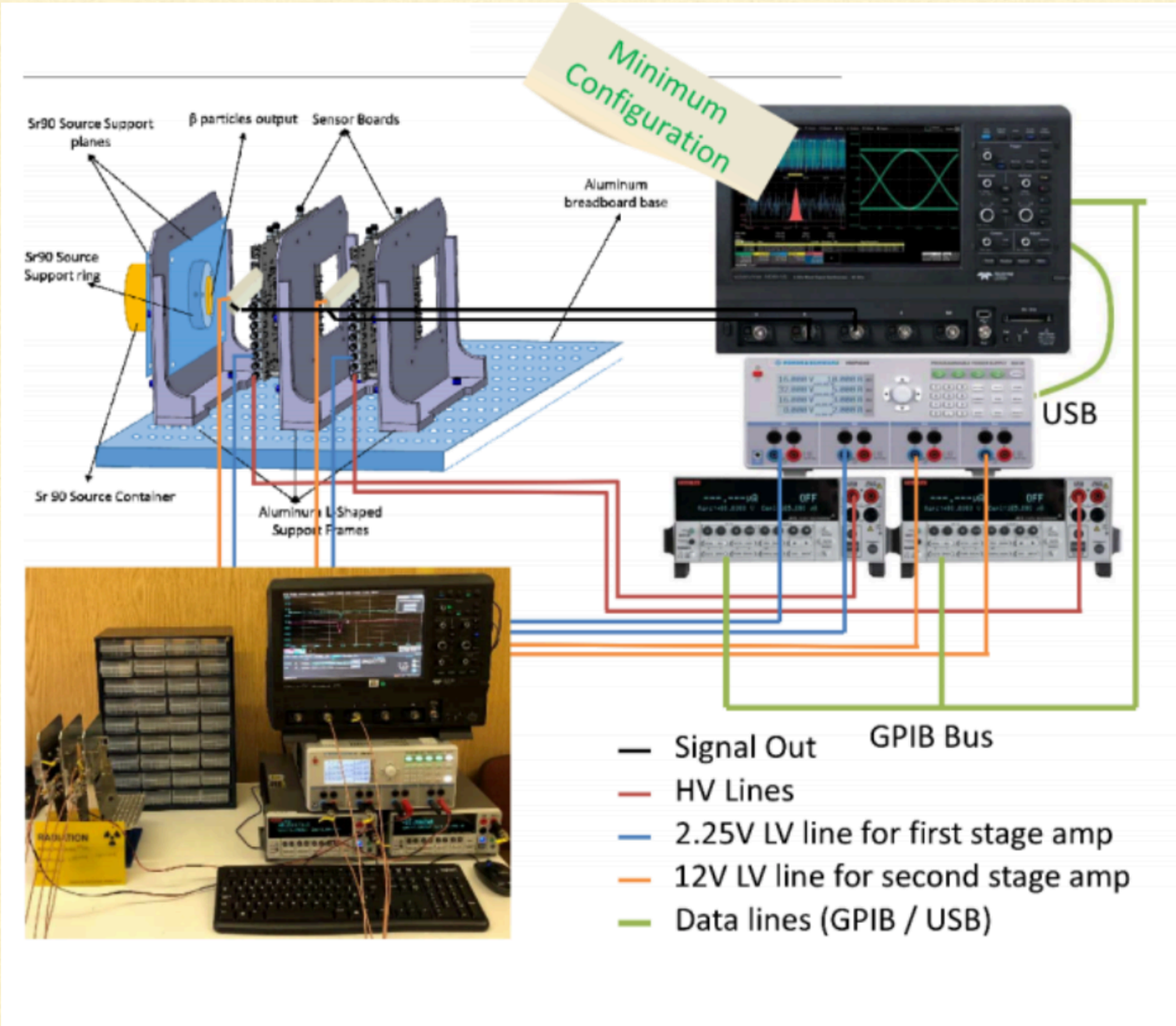


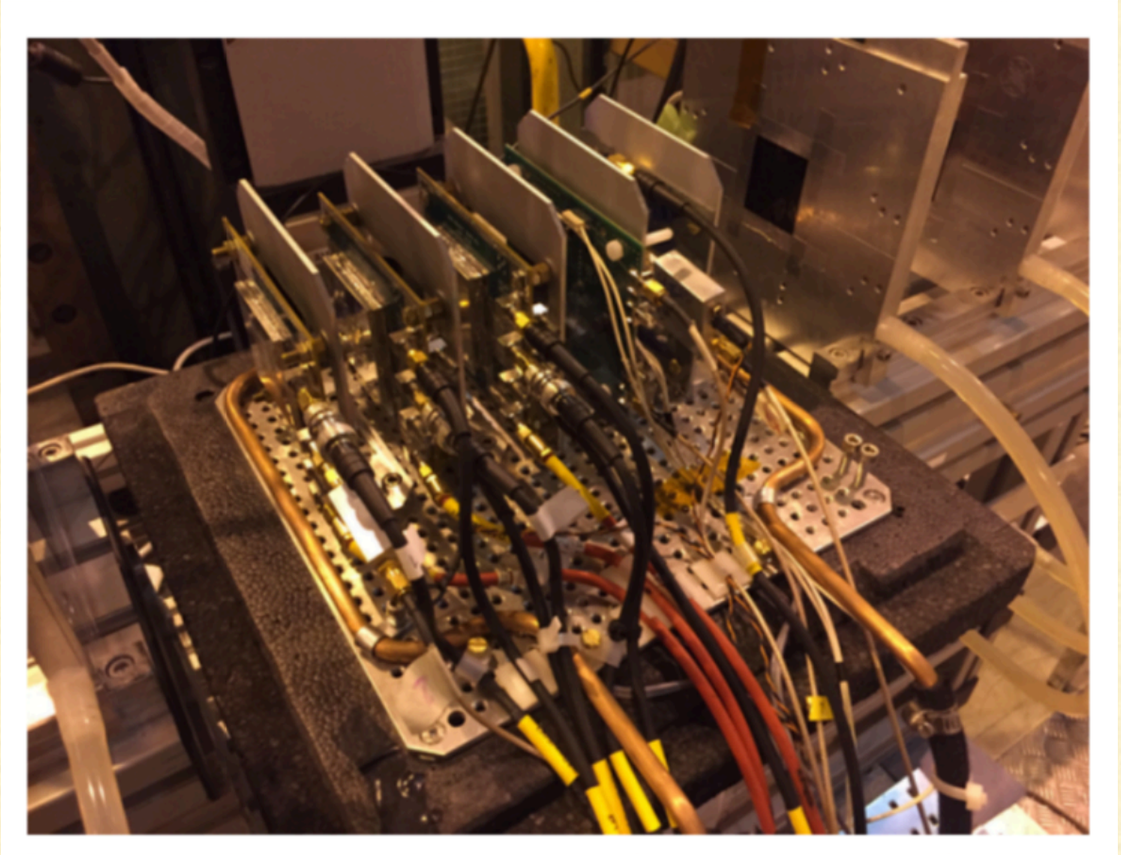


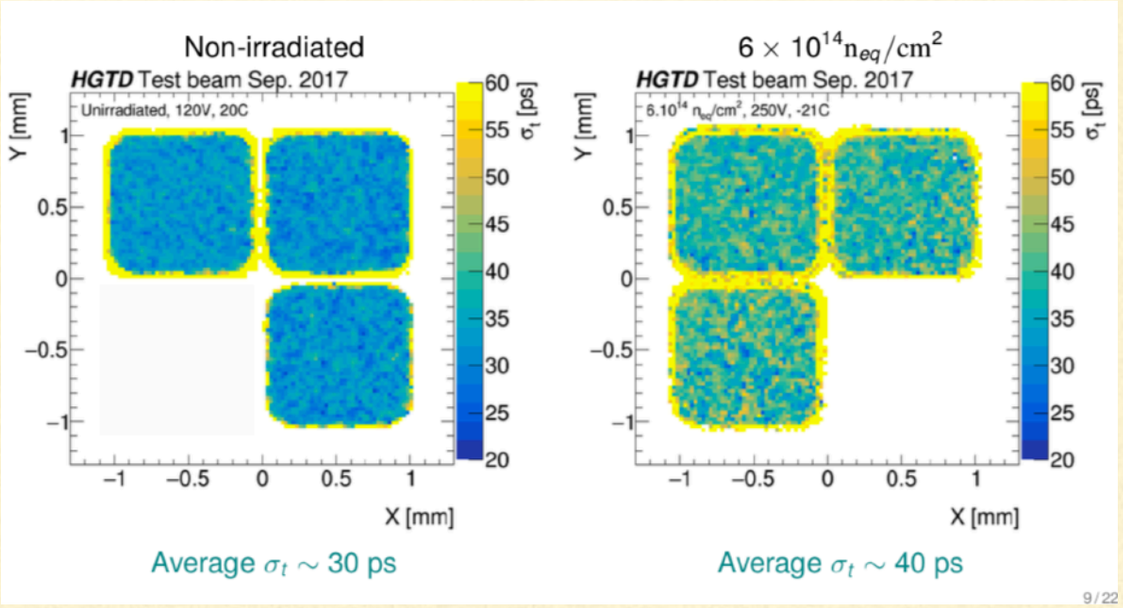


Testes em acelerador/fontes

- Beam test (pions, CERN, electrons SLAC)
- 90Sr (β) em laboratório





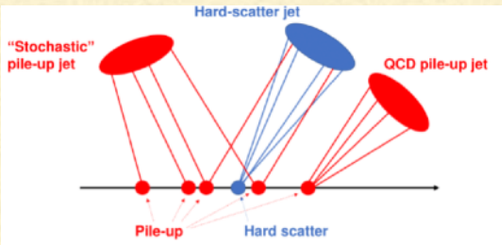


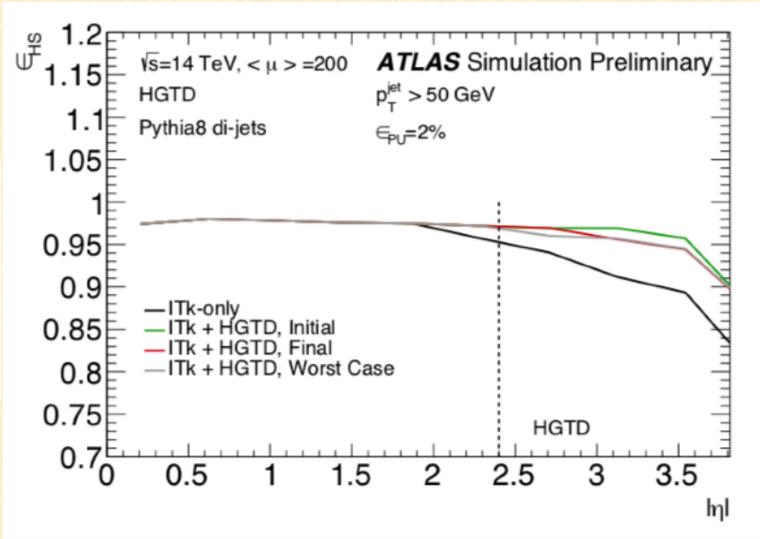
IMPACTO NO DESEMPENHO DA RECONSTRUÇÃO

Supressão de empilhamento de jatos

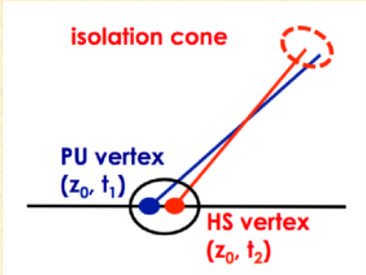
Rpt discriminate poderoso, mas exige rigorosa associação traço-vértice

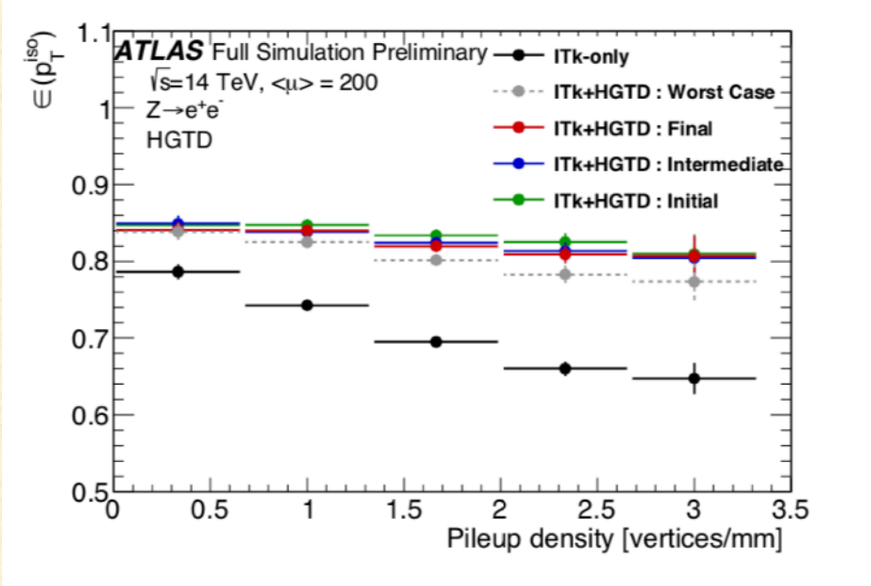
$$R_{p_T} = \frac{\Sigma p_T^{trk}(PV_0)}{p_T^{jet}}.$$



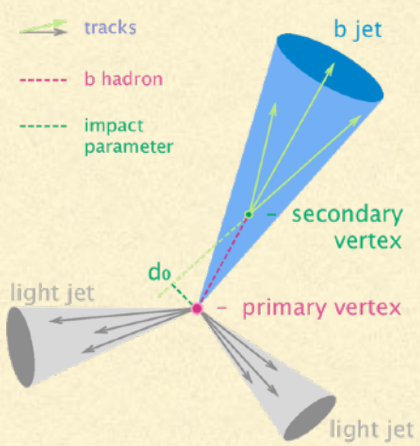


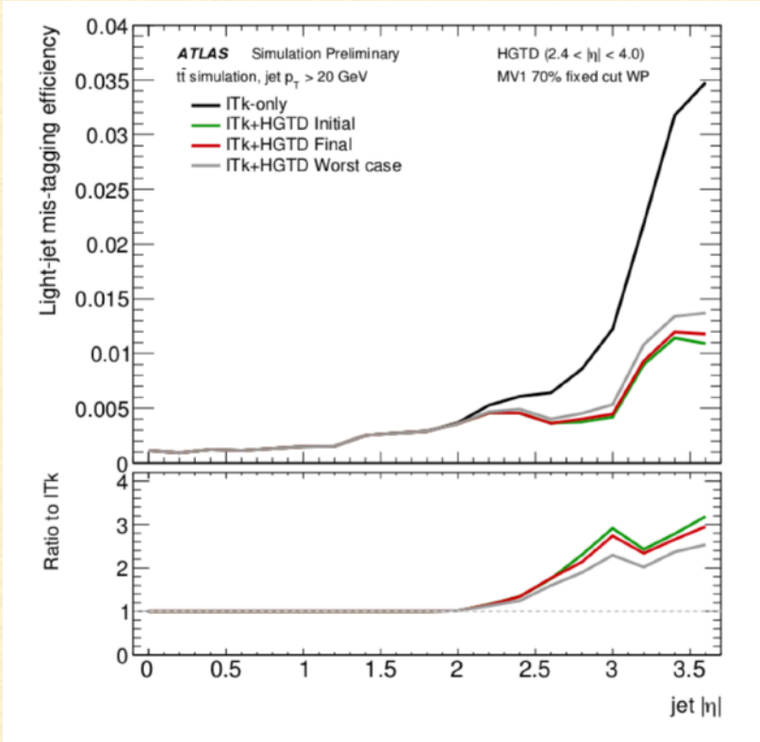
Isolamento leptônico



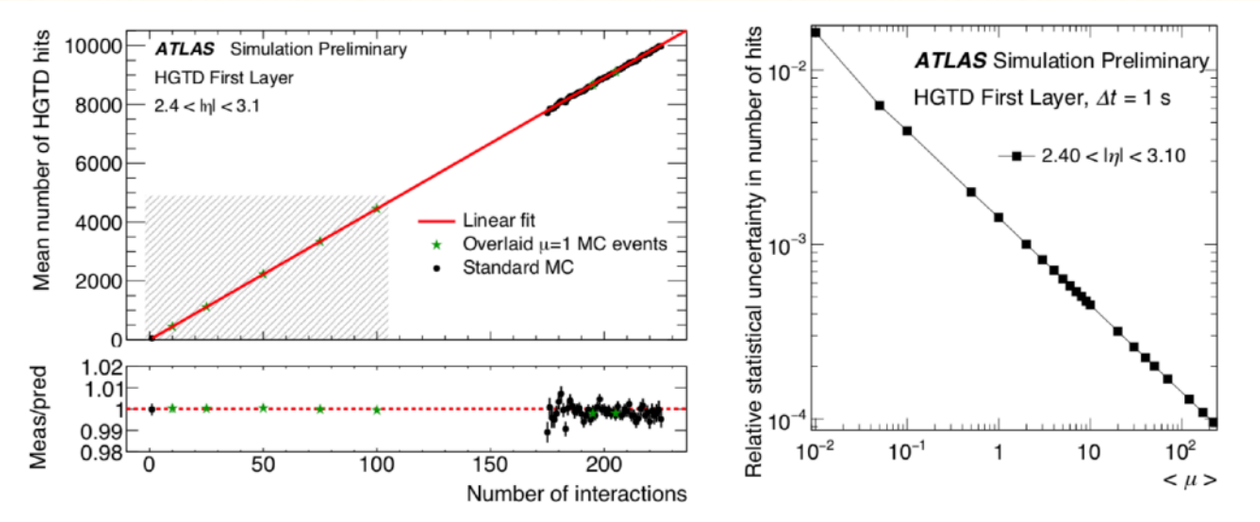


Heavy flavor tagging



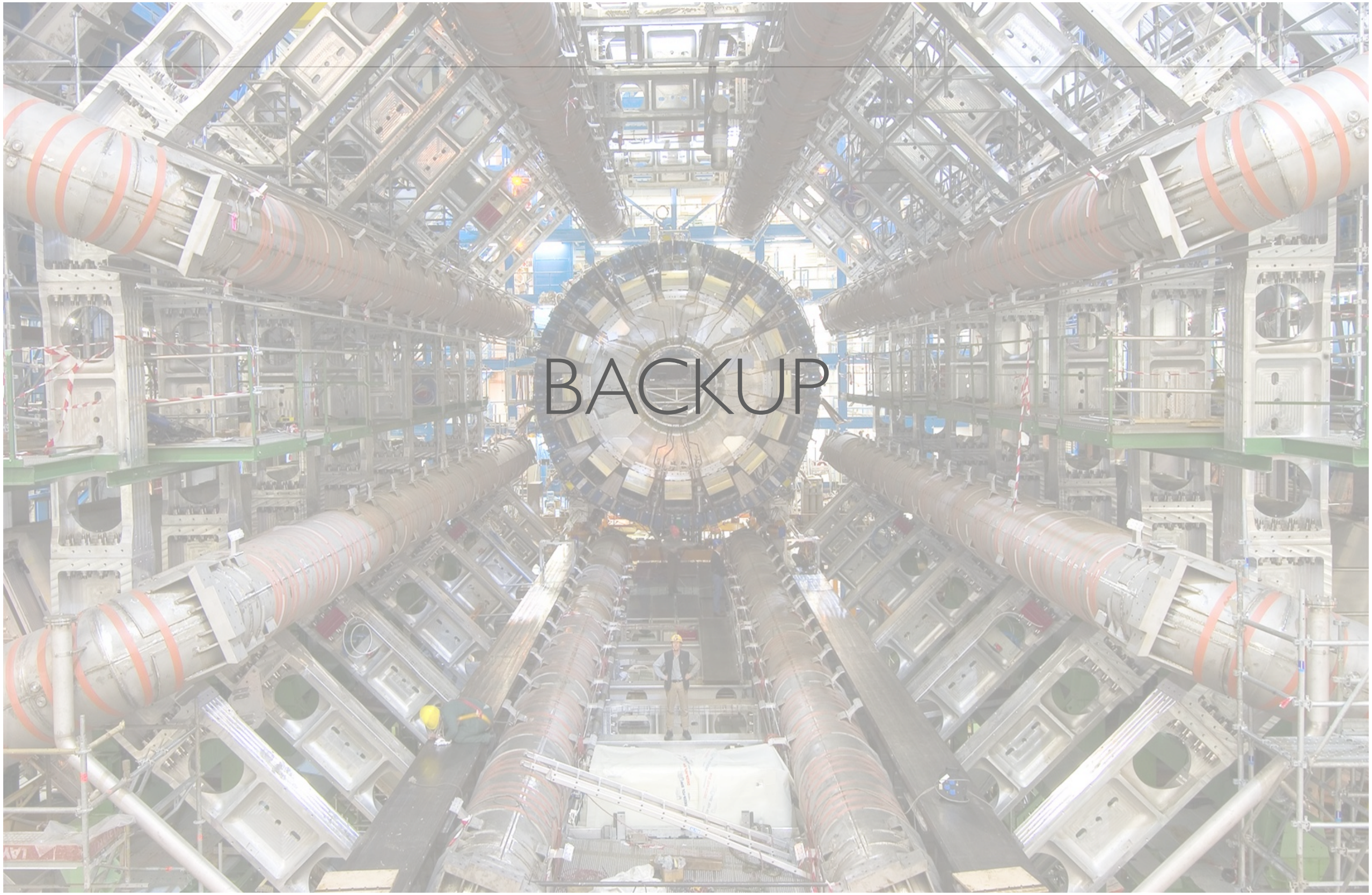


Medidas de luminosidade instantânea (por BCID)



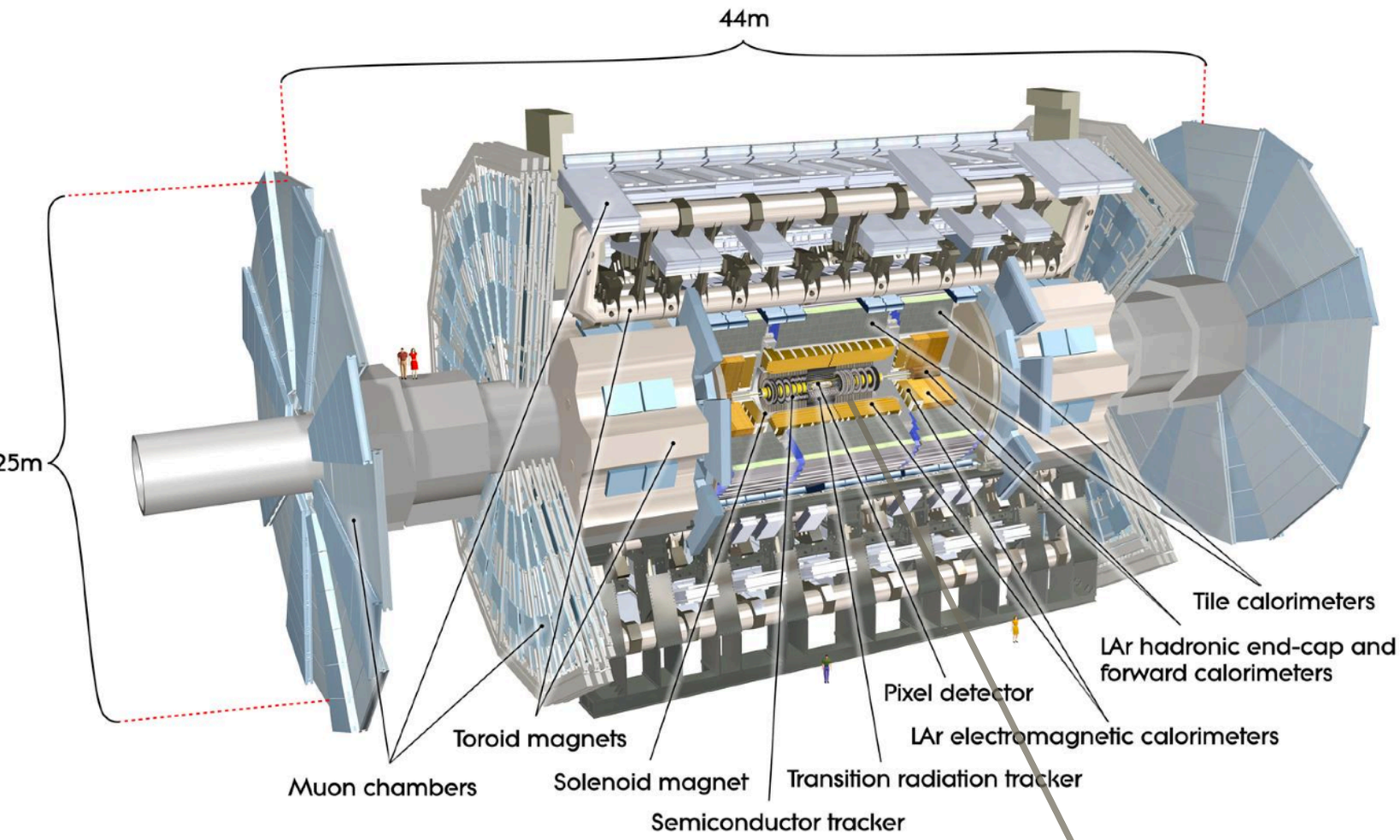
CONSIDERAÇÕES FINAIS

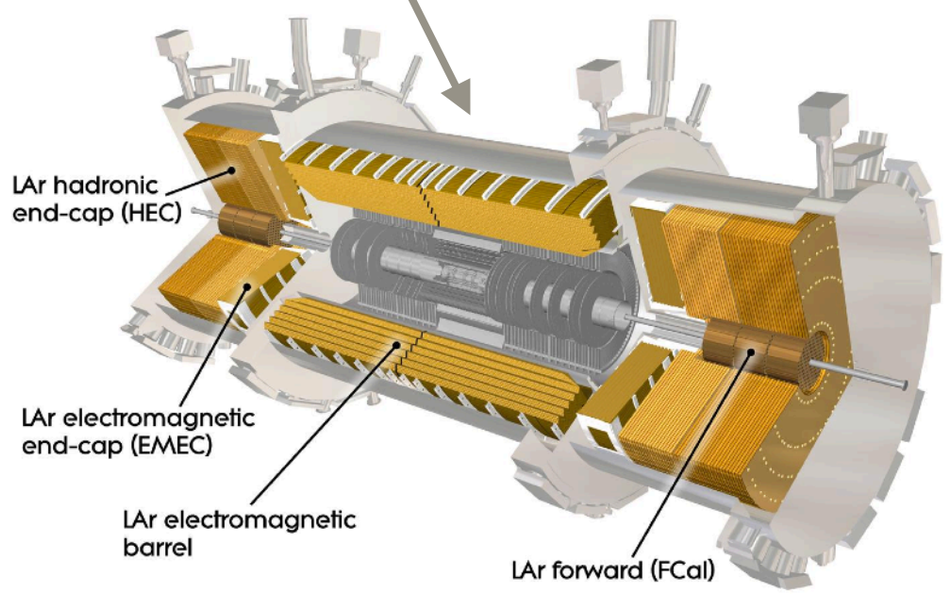
- Um sistema de torres de alta granularidade para o primeiro nível de trigger (L1) eletromagnético foi testado e validado desde o início do RUN 2
- A reconstrução da energia e tempo feita utilizando-se a técnica de OFC a partir do sinal digitalizado das super-células proporciona desempenho compatível quando comparados com a leitura das células individuais.
- As instalações no Brasil (fótons e íons) são uma ferramenta importante para validação e testes de potenciais dispositivos eletrônicos
- Adicionar a informação de timing permite recuperar o desempenho devido ao empilhamento em diversos observáveis na região dianteira
- O desenvolvimento de **detectores semicondutores ultra-rápidos** tolerantes à radiação e a eletrônica associada serão vitais para o High Luminosity LHC (e além).

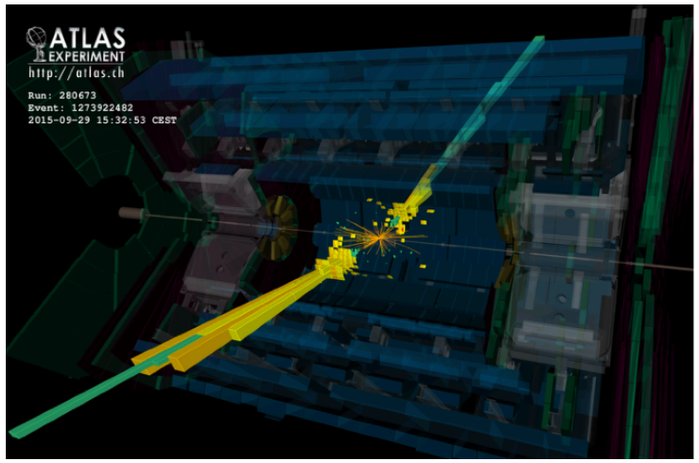


BACKUP

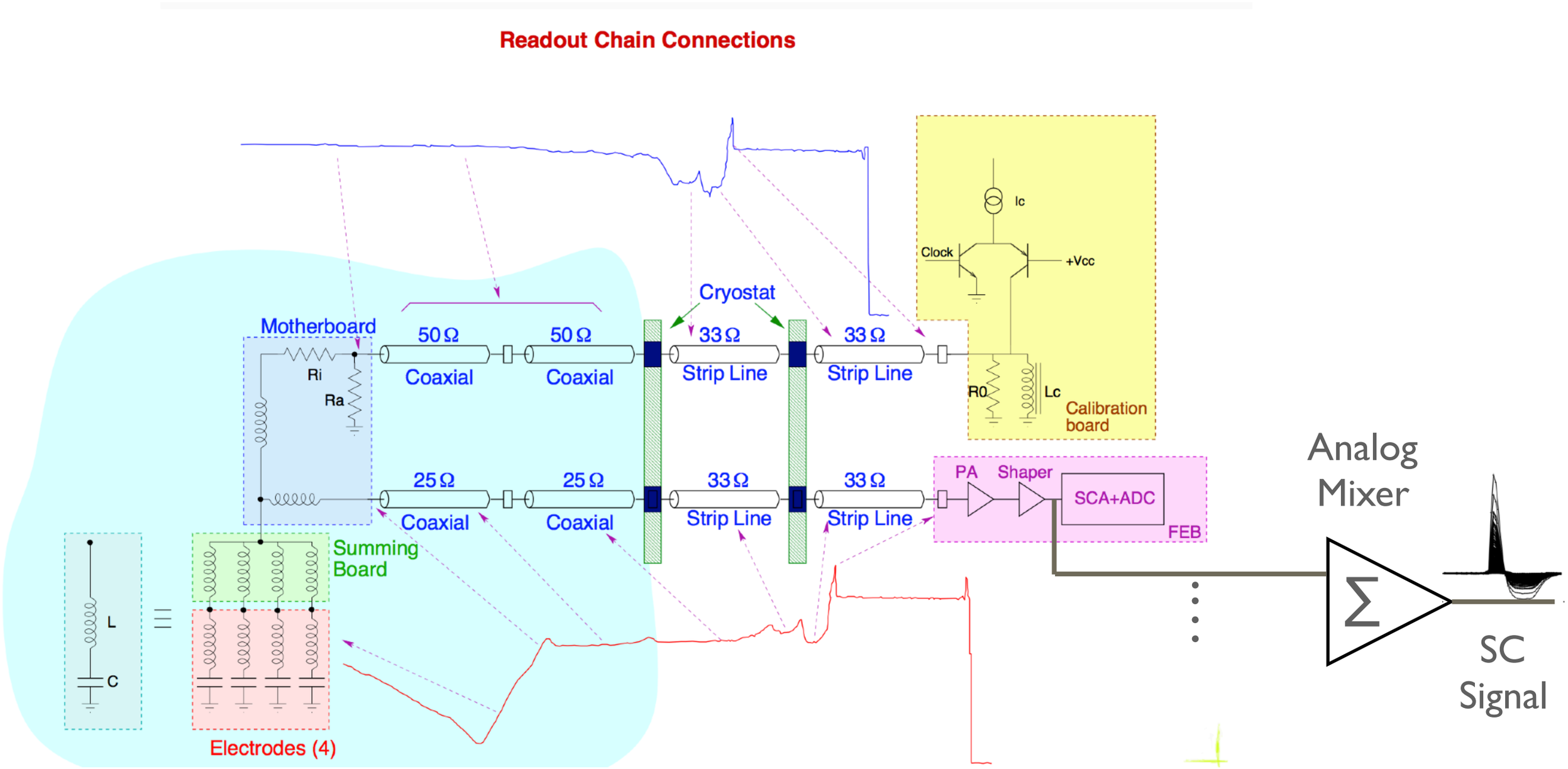
THE ATLAS EXPERIMENT







SIGNAL CHAIN MODEL



MAIN READOUT SIGNAL INTEGRITY

Requirements (I)

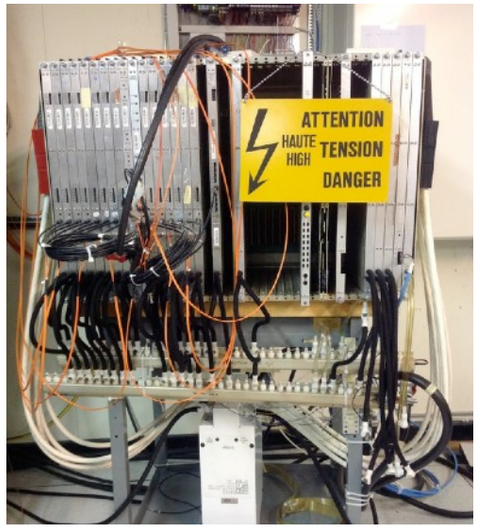
- The LTDB cannot interfere in the present individual cell signal processing system integrity
- Must preserve the L1 performance (linearity, isolation)
  - Legacy L1 to operate until the end of Phase-I

Figures of merit

- Total noise (per cell)
- Coherent noise
- Cross-talk

Setup

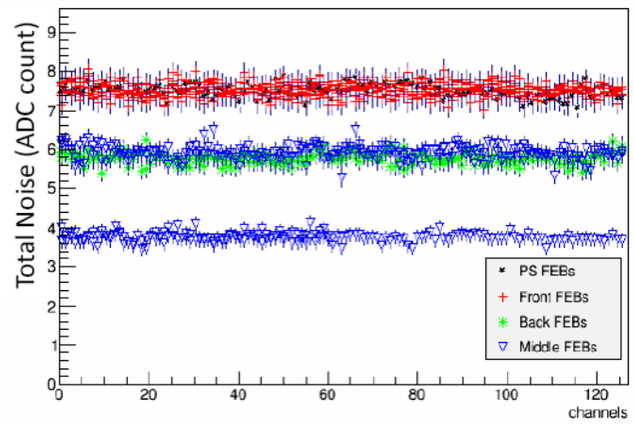
- Controlled conditions in test stand at CERN
- Equivalent to a region $\Delta\eta \times \Delta\varphi = 1.52 \times 0.1$

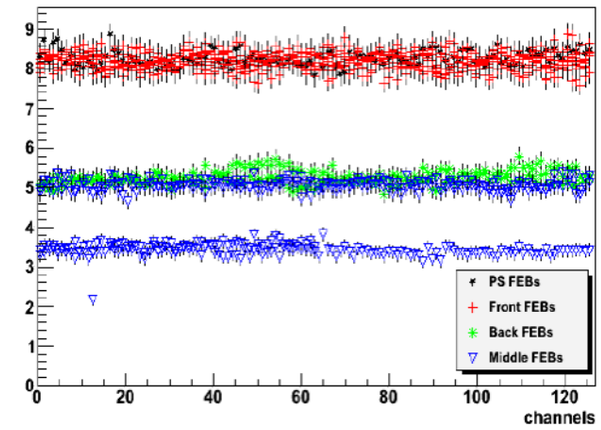


Original configuration

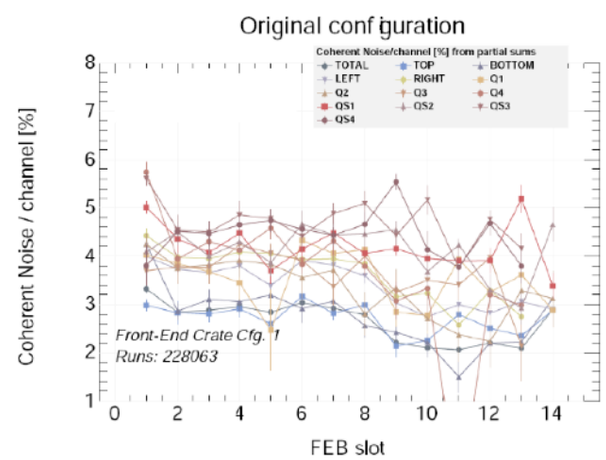
LTDB Configuration

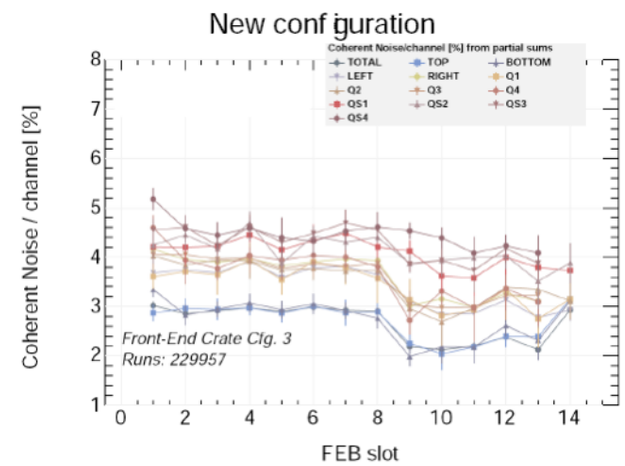
Total Noise



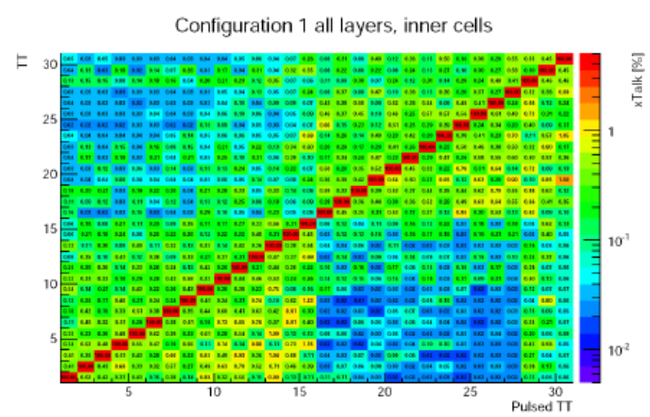


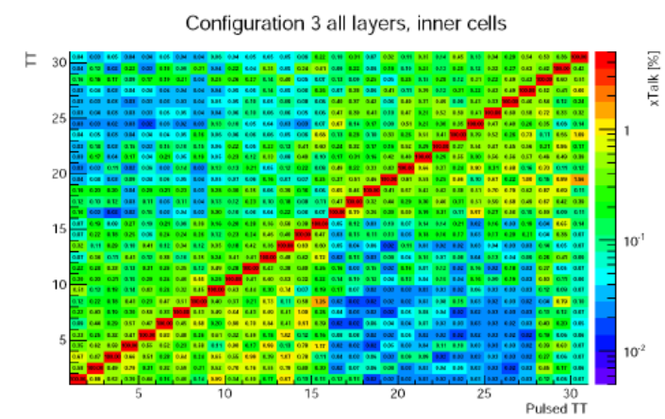
Coherent Noise



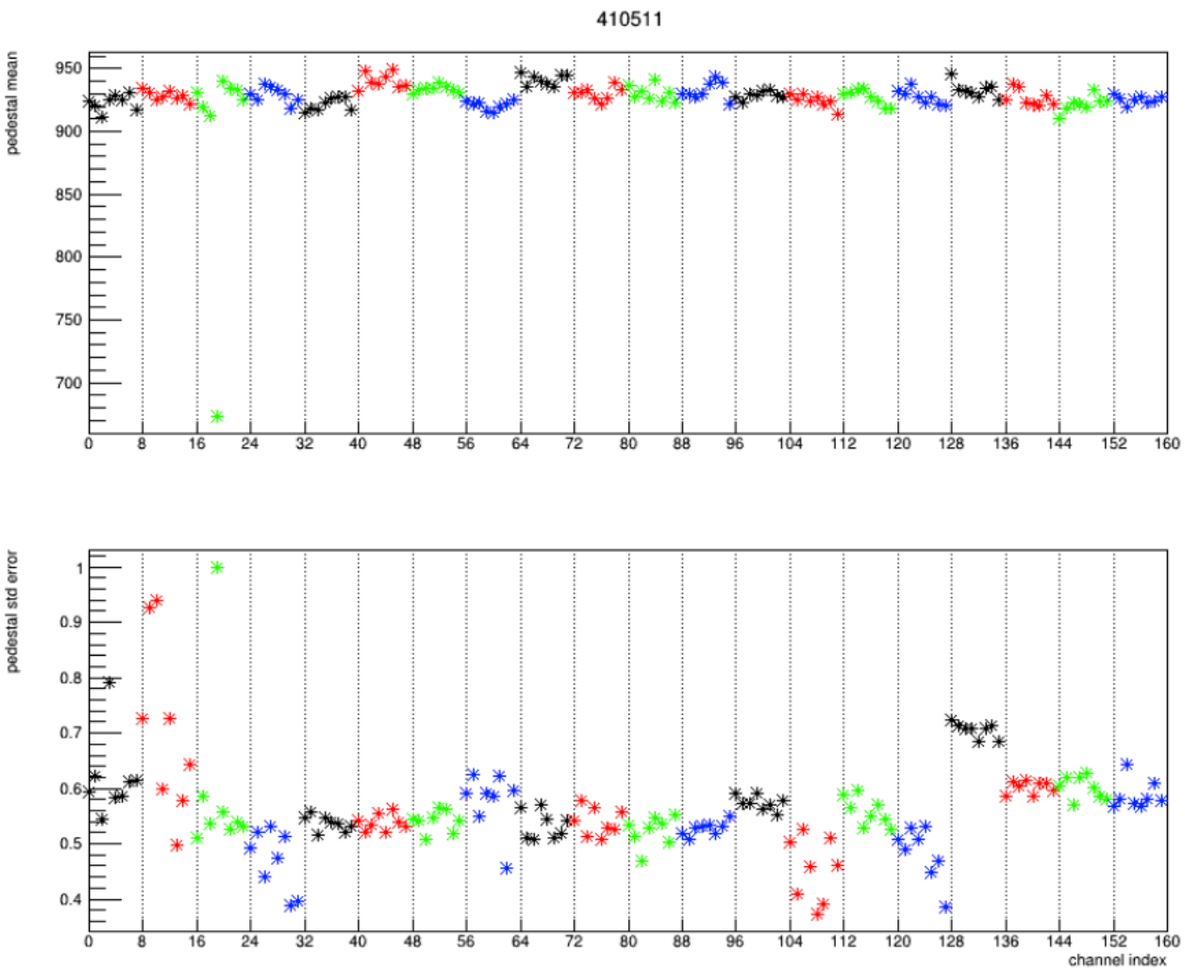


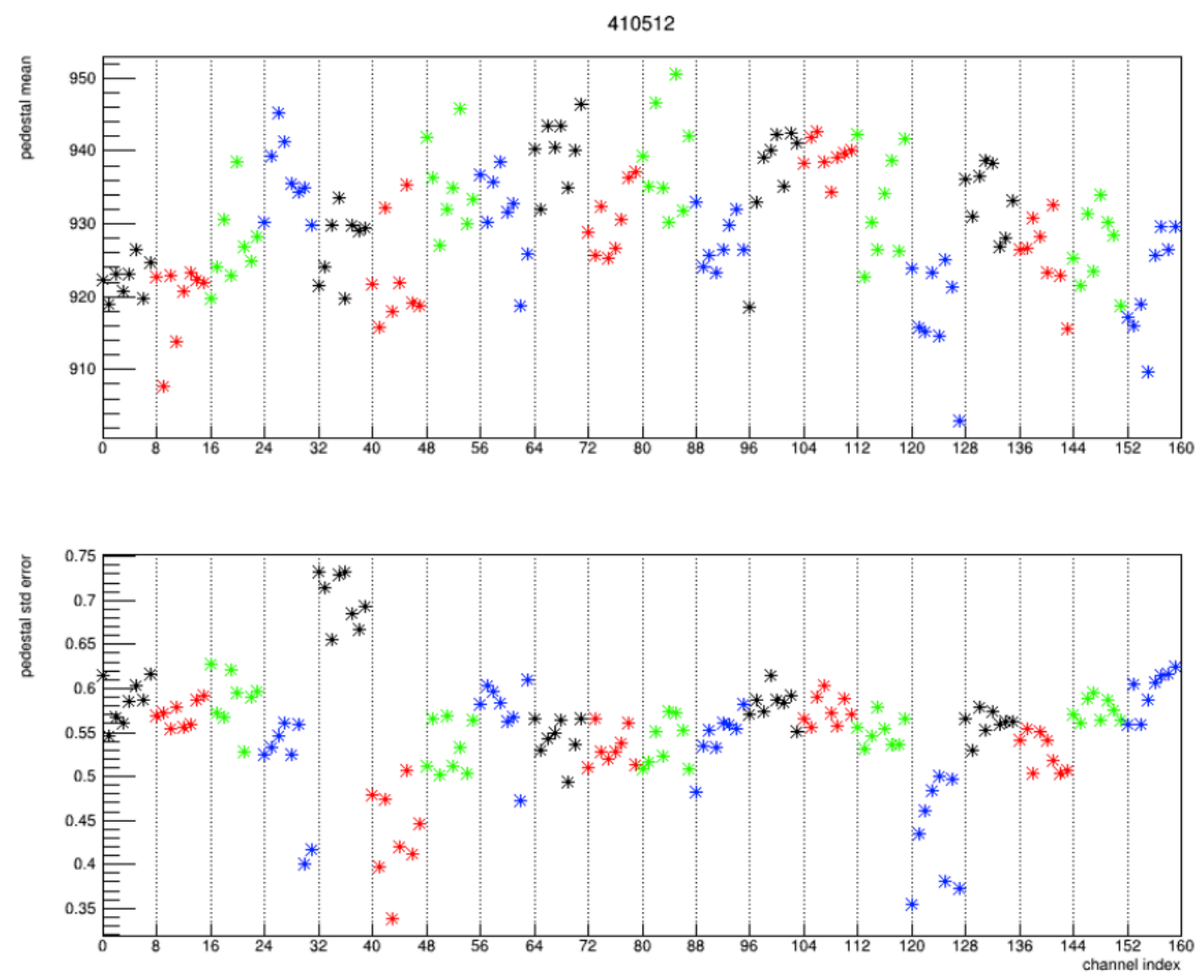
Cross-talk





LTDB NOISE


410511
pedestal mean
pedestal std error
channel index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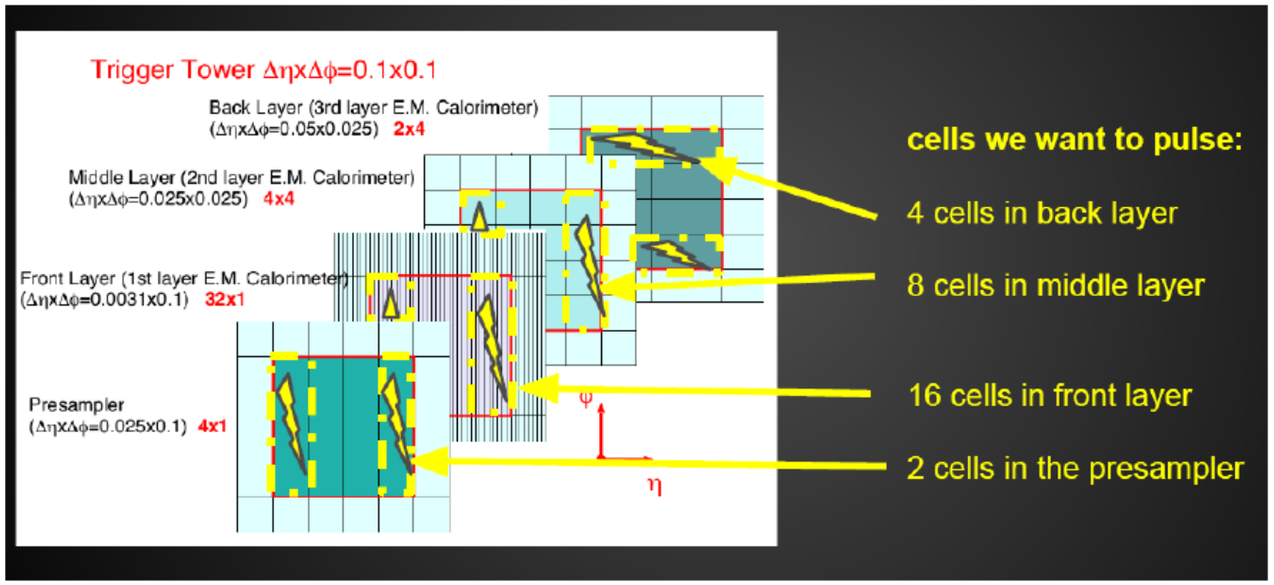
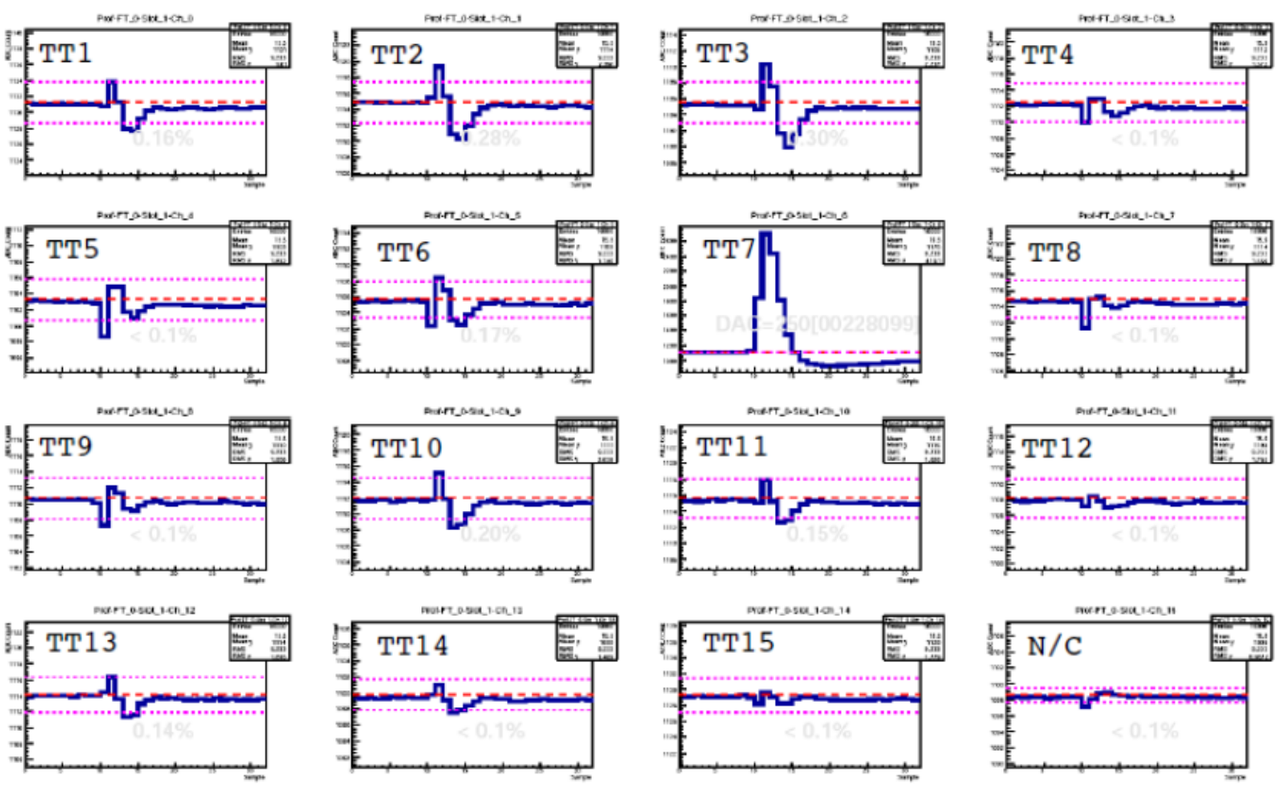
CROSS TALK





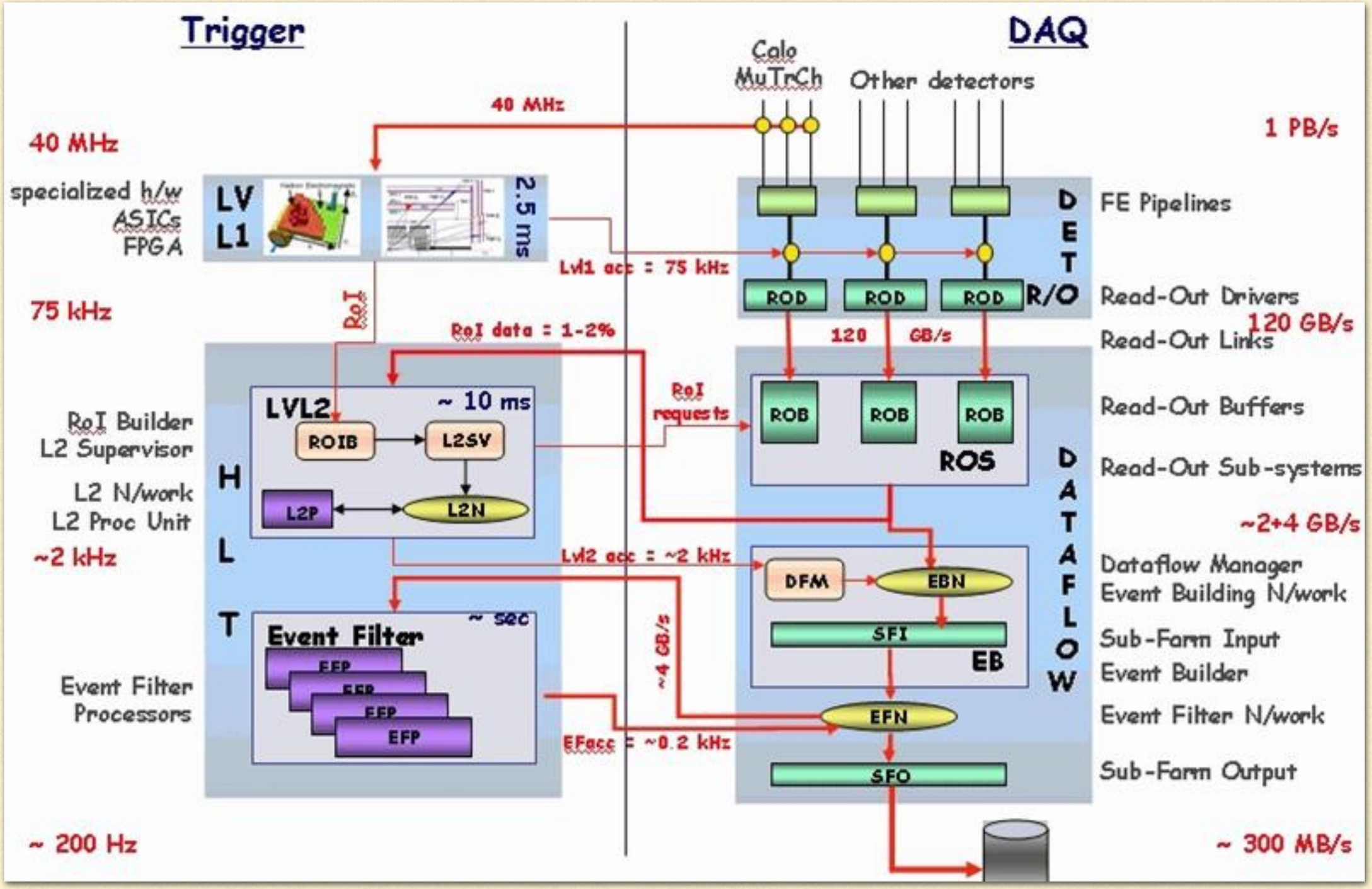
Peak-to-peak / Injected pulse

Pattern	All inner	All outer	Presamp.	Front	Middle	Back
Current	0.218	0.221	0.284	1.125	0.262	0.481
New	0.231	0.232	0.307	1.120	0.311	0.527
New (LTDB Dig. OFF)	0.231	0.233	0.309	1.120	0.311	0.525

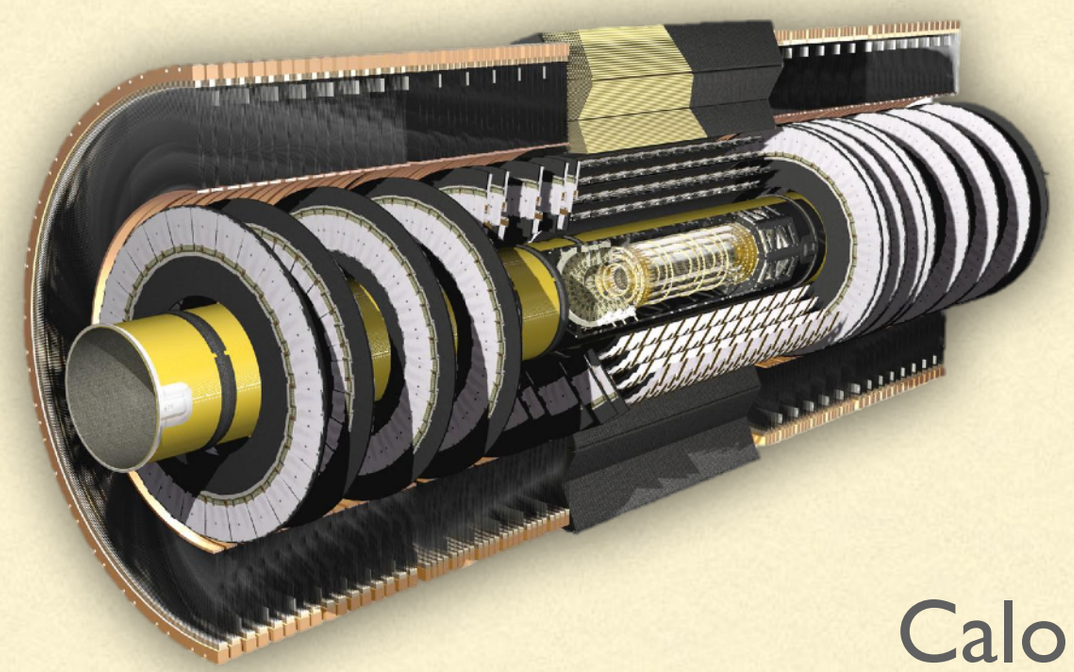
Peak sampling / injected pulse

Pattern	All inner	All outer	Presamp.	Front	Middle	Back
Current	0.120	0.119	0.254	0.329	0.088	0.205
New	0.123	0.121	0.151	0.268	0.122	0.217
New (LTDB Dig. OFF)	0.124	0.122	0.160	0.278	0.122	0.215

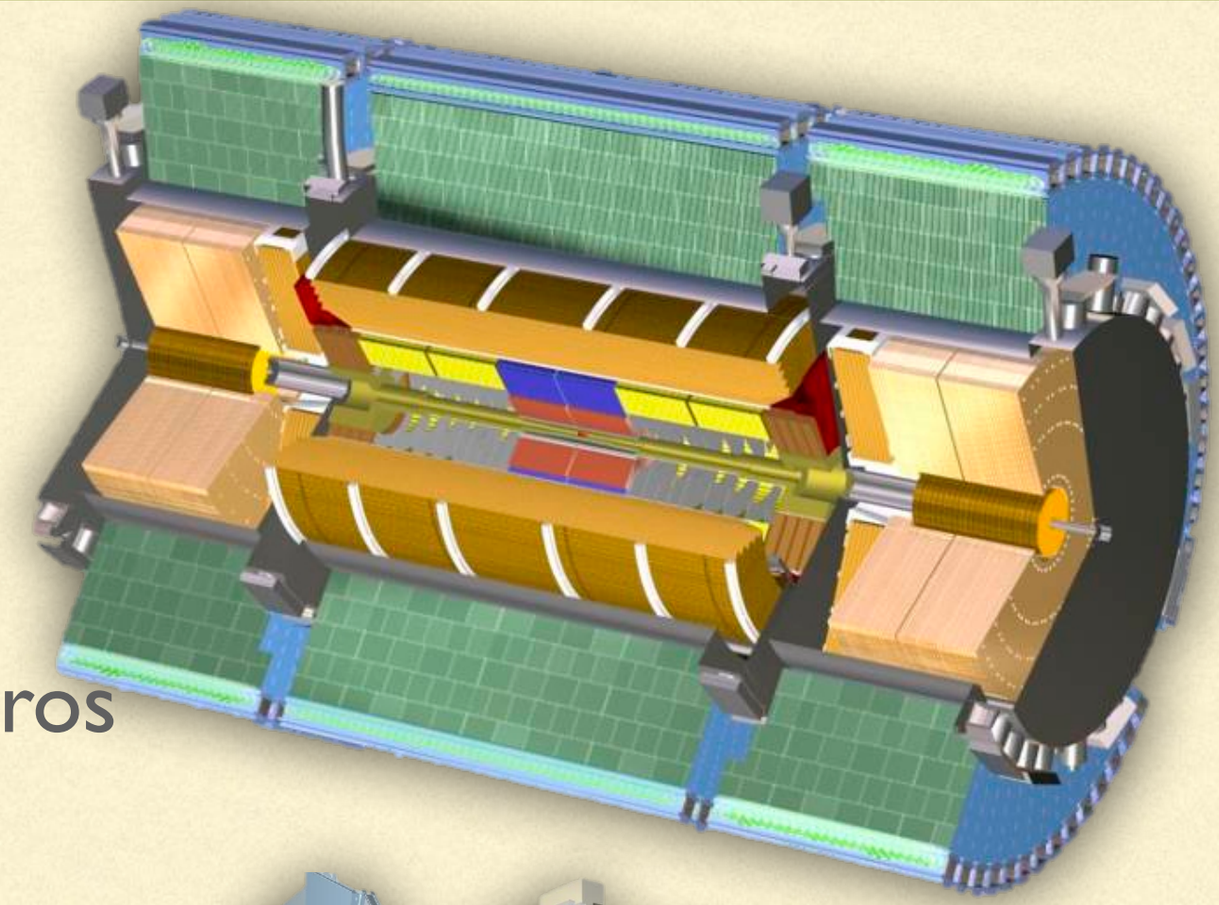
TRIGGER NO ATLAS



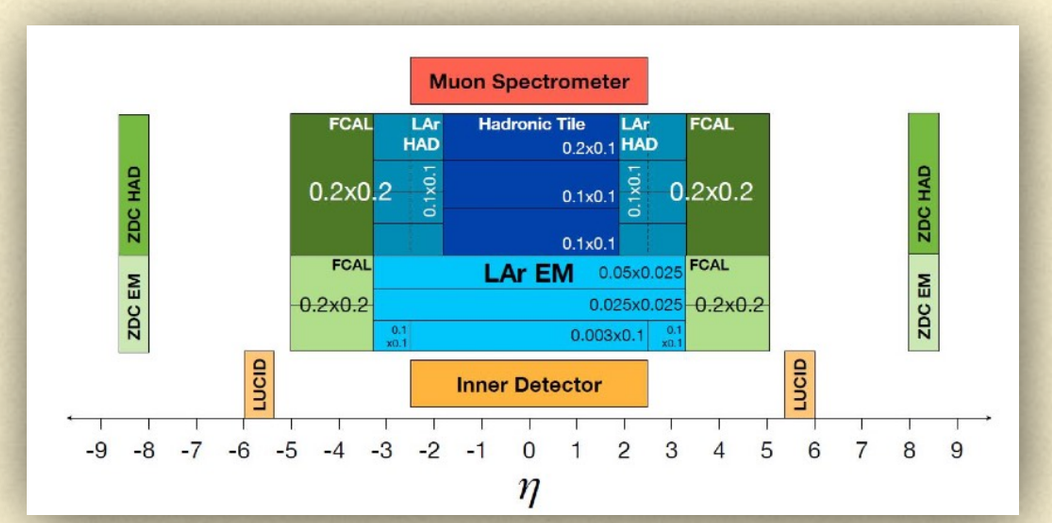
SUBSISTEMAS DO ATLAS

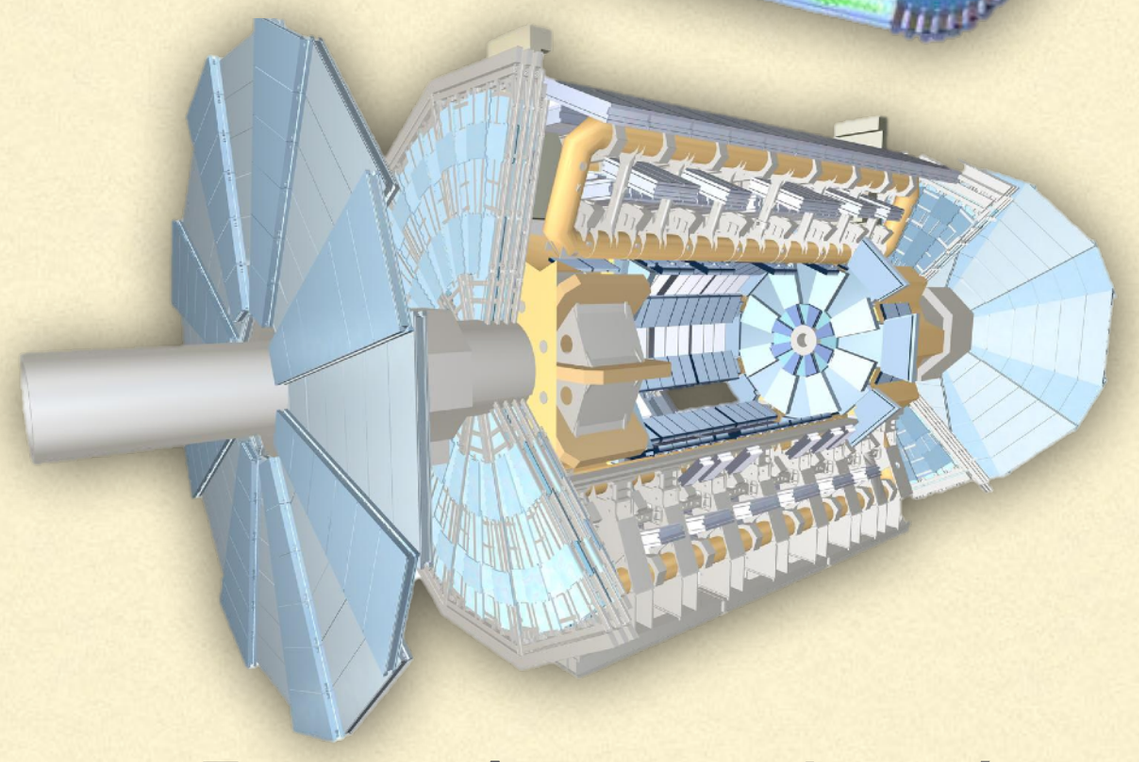


Inner detector



Calorímetros

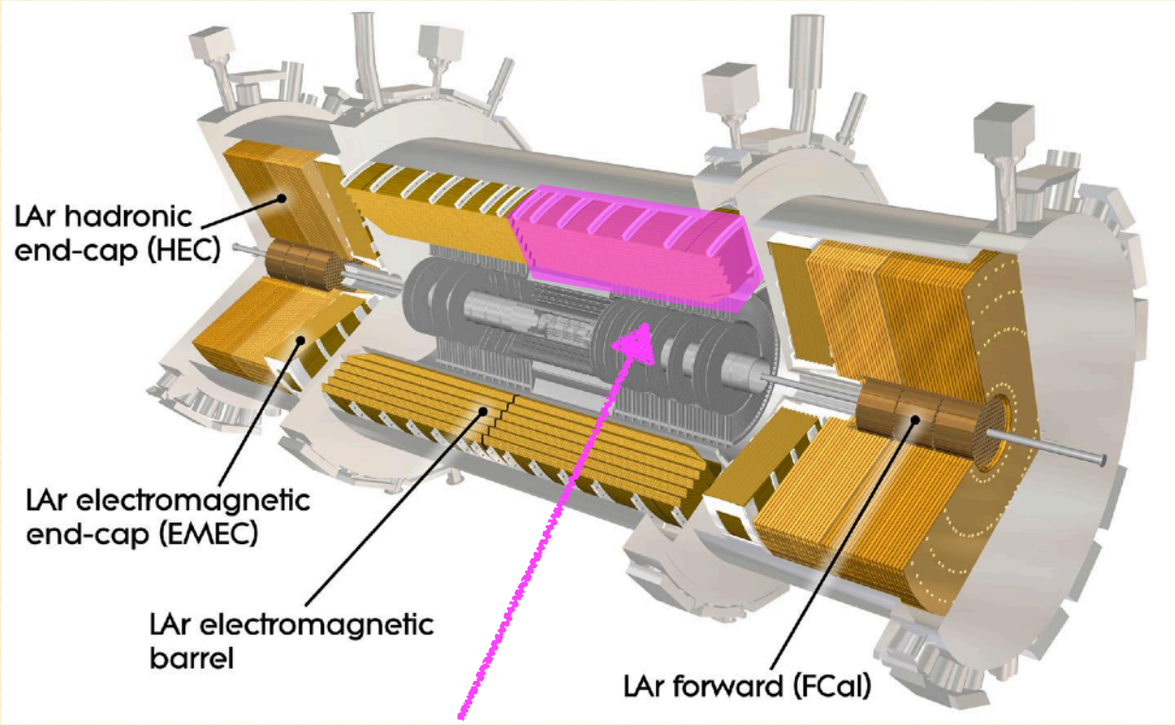




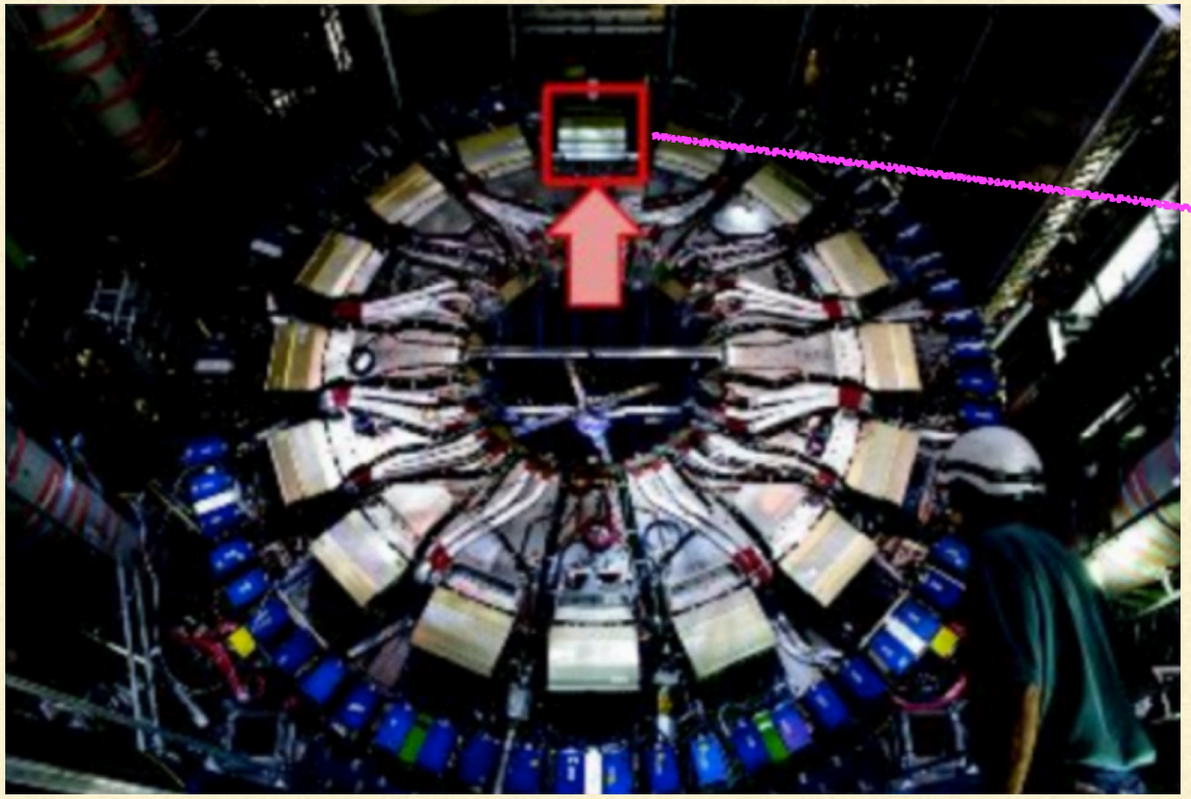
Espectrômetro de múons

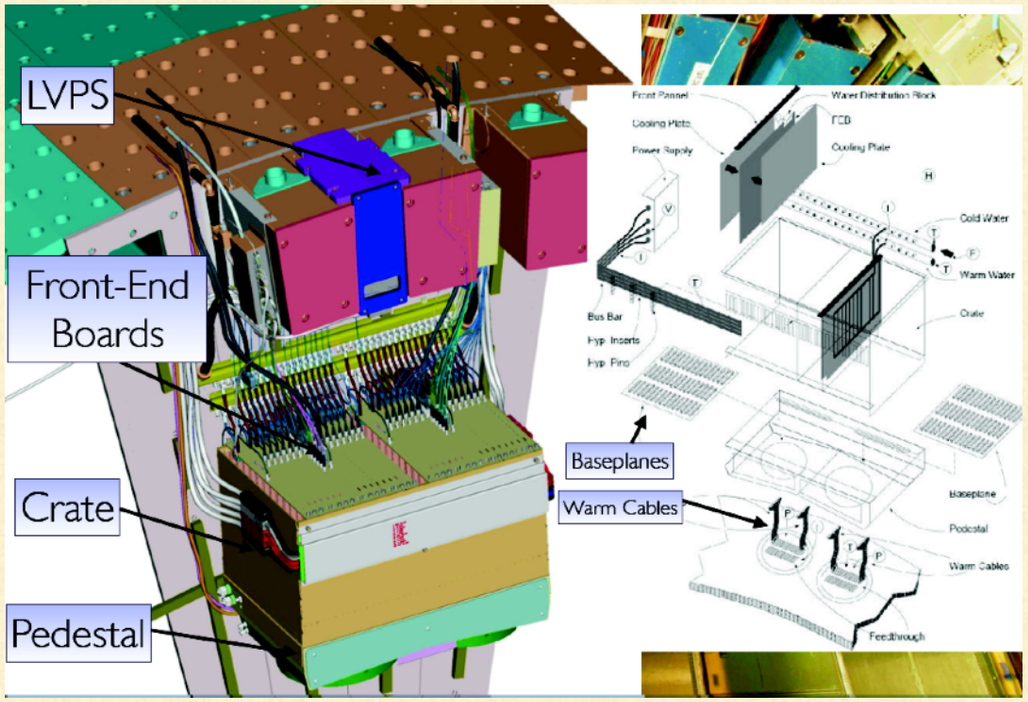
Demonstrator

- Durante o LS1 (2015) um dos crates do front end foi modificado para receber2 protótipos do LTDB prototypes (Demonstrators) cobrindo ($\Delta \eta \times \Delta \varphi = 1.52 \times 0.2$)
- O L1 atual continua a operar normalmente
- Em 2018, uma segunda versão dos protótipos foi instalada
- A aquisição de dados do LTDB é feita por um "stream" separado do readout principal do ATLAS
- Validação do sistema e tomada de dados desde o início do RUN-2 (05/2015)



calorimeter barrel region equipped with the LTDB

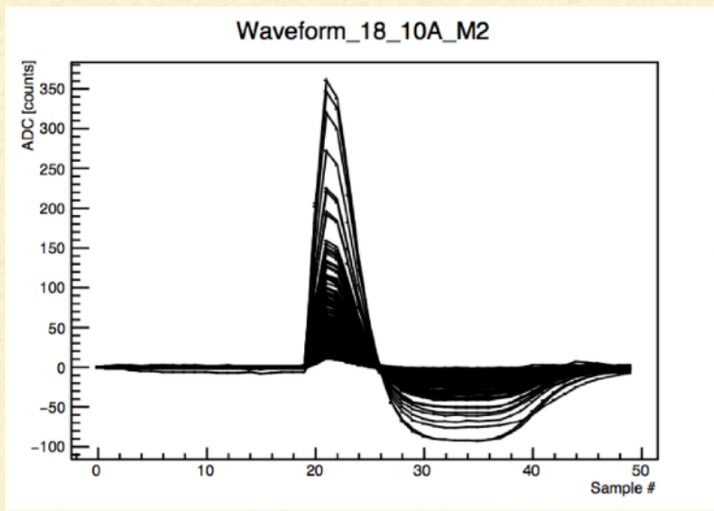


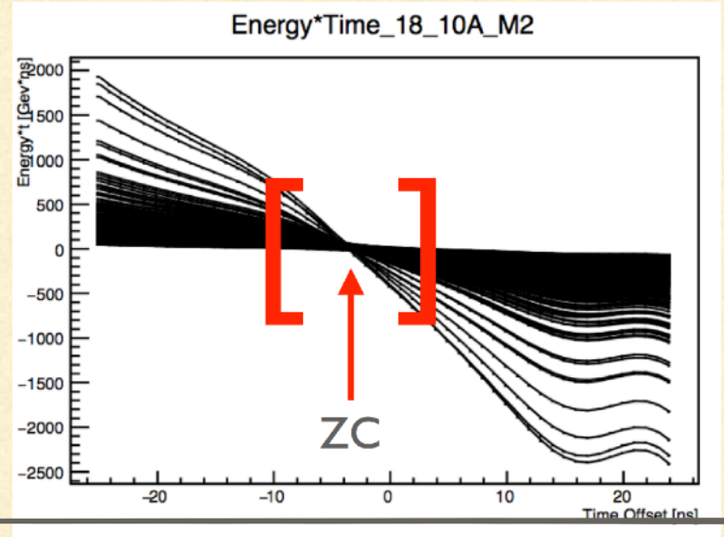


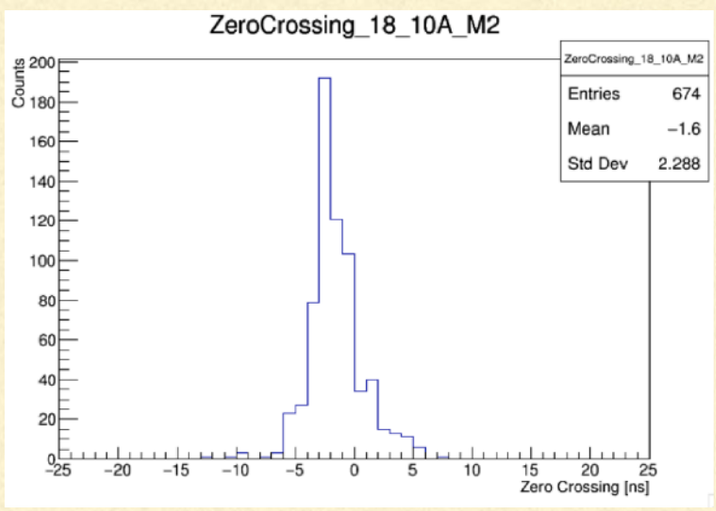
Correção da fase do sinal

- Sinal de ionização e calibração tem fases diferentes
- A determinação da fase correta para os sinais de ionização requer o uso de dados de colisão
- 50 conjuntos de OFCs são calculados para cada canal, deslocando o sinal de calibração em intervalos de 1ns em [-25,+24]
- O valor reconstruído de E*t vs t(offset) é utilizado para encontrar a fase correta do sinal de ionização tanto por um método de cruzamento de zero como dispersão mínima
- Nas ficuras, cada linha corresponde a um evento

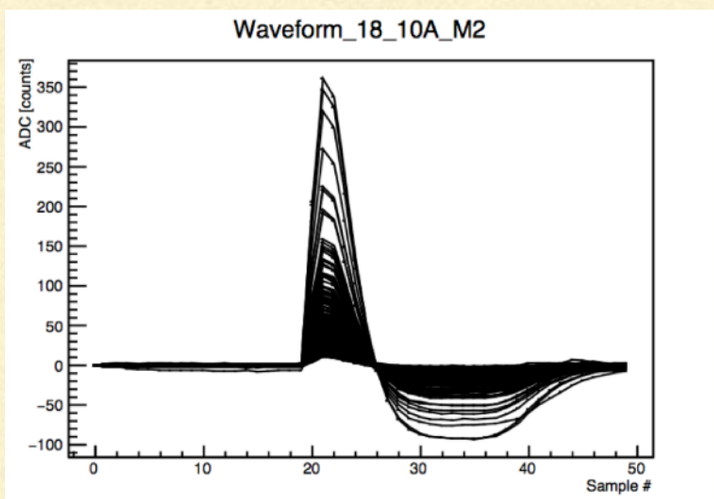
Zero Crossing

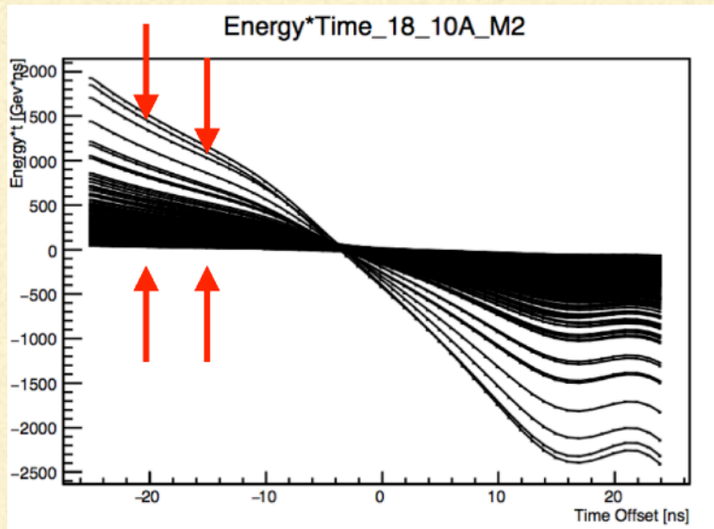


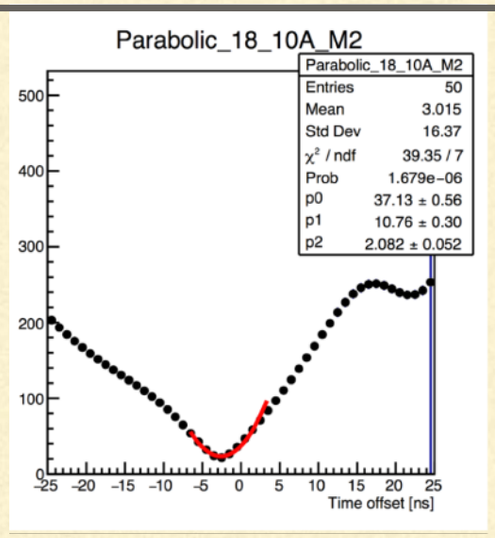




Minimum dispersion

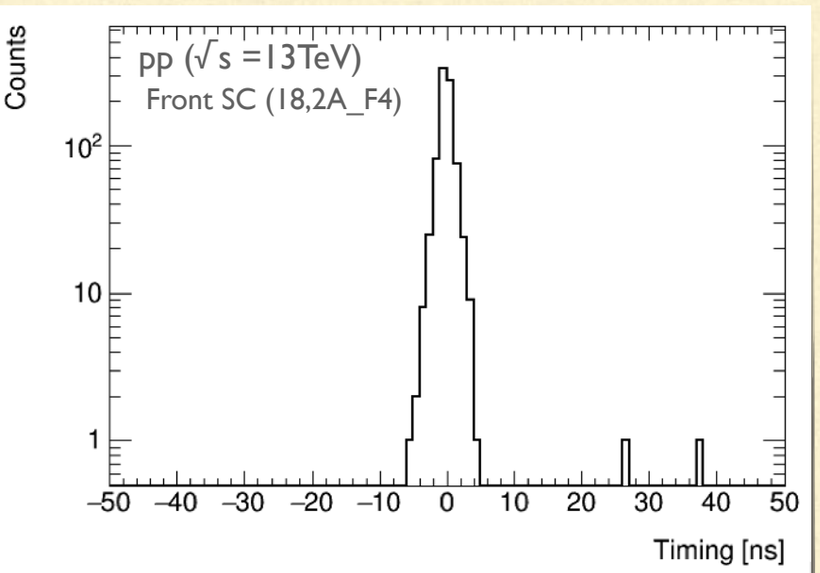


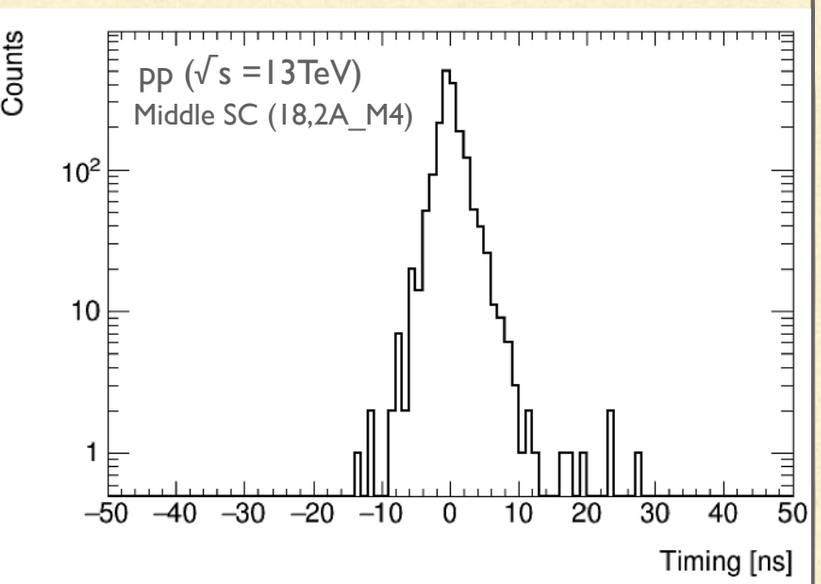


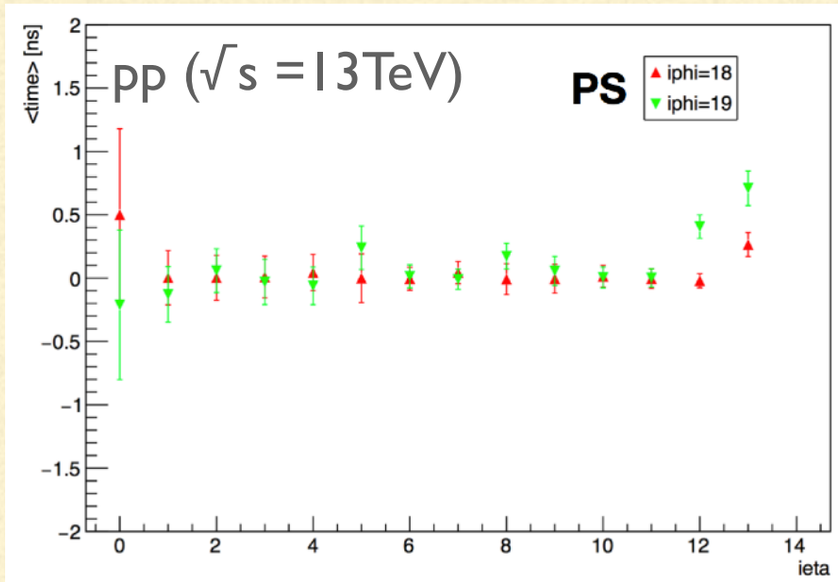


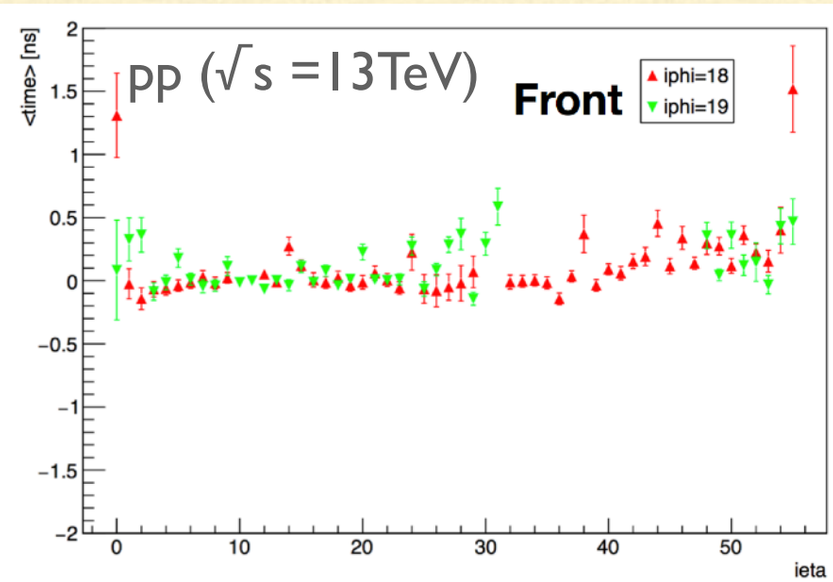
Correção da fase do sinal

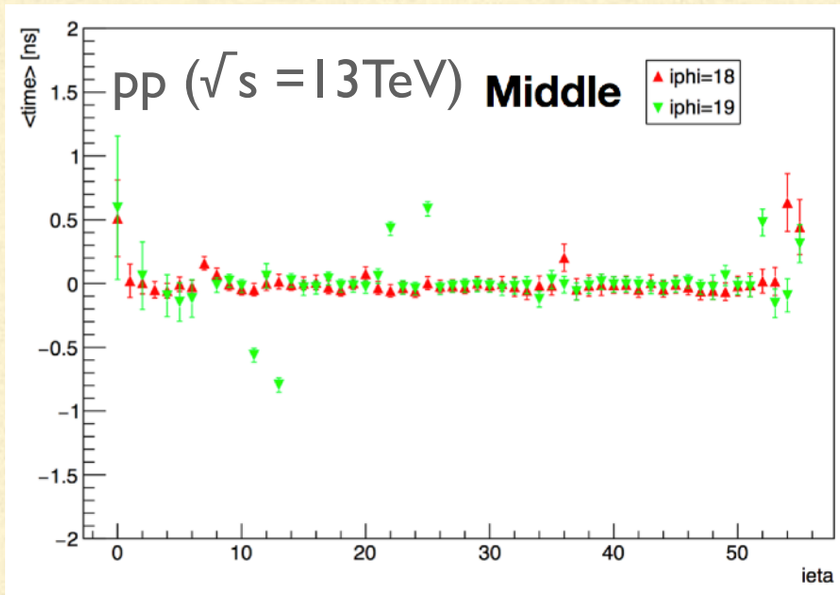
- Após a correção da fase, essencialmente o timing de todas as superCélulas está centrado em zero (outliers devido ao pileup)
- Distribuição de timing correspondente a um RUN do ATLAS (~1 dia)

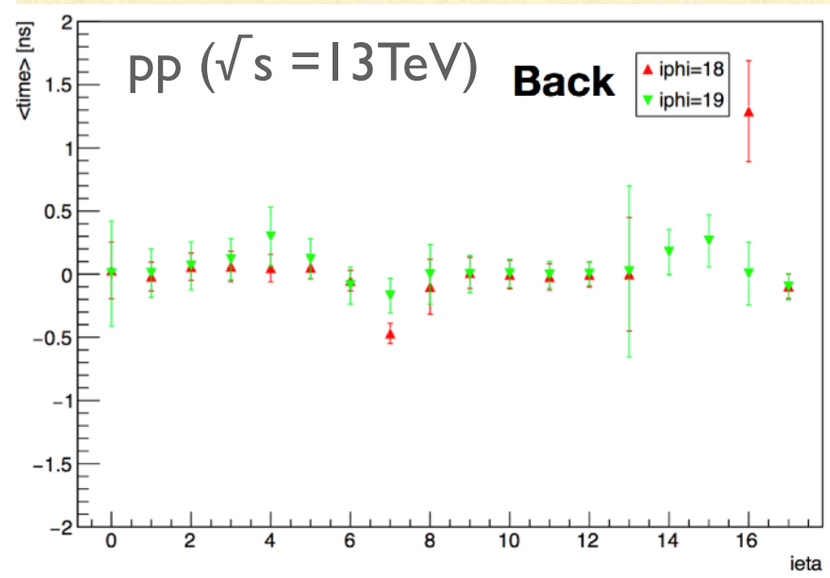






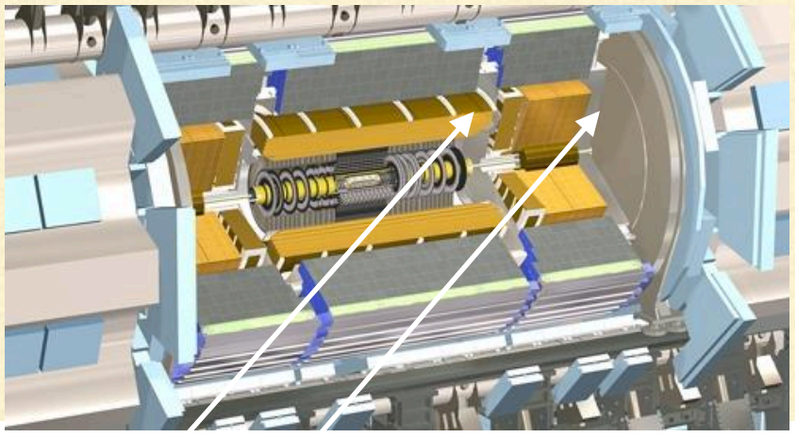


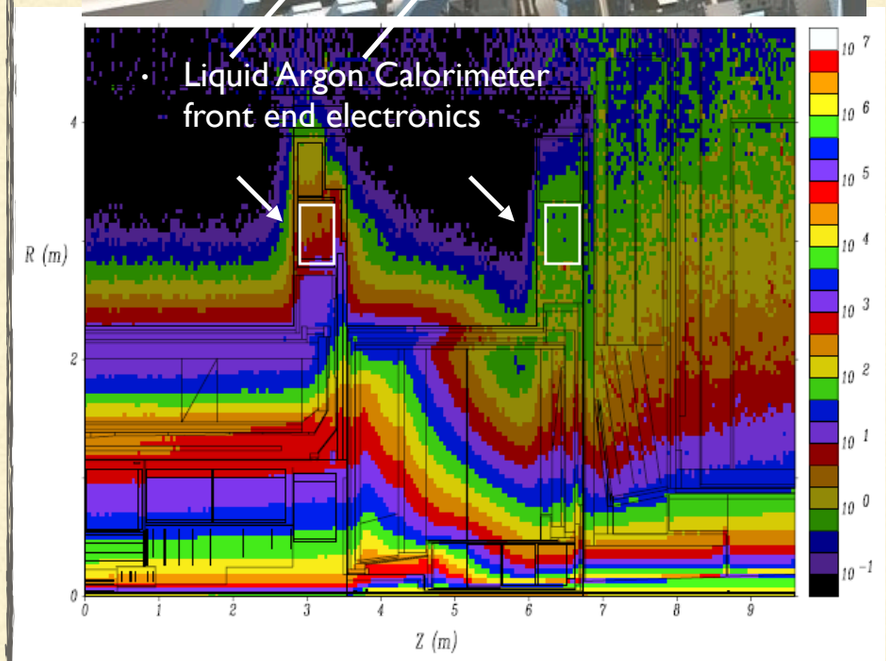




Efeito da radiação na eletrônica

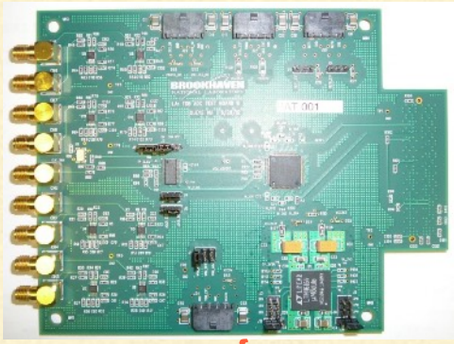
- A eletrônica instalada durante a Fase-I deve sobreviver até 2037
- Todos os dispositivos devem passar por um processo de validação quanto:
  - efeitos da dose total de ionização absorvida (TID)
  - efeitos de partículas carregadas/nêutrons
    - Single Event Effect
    - Single Event Upset

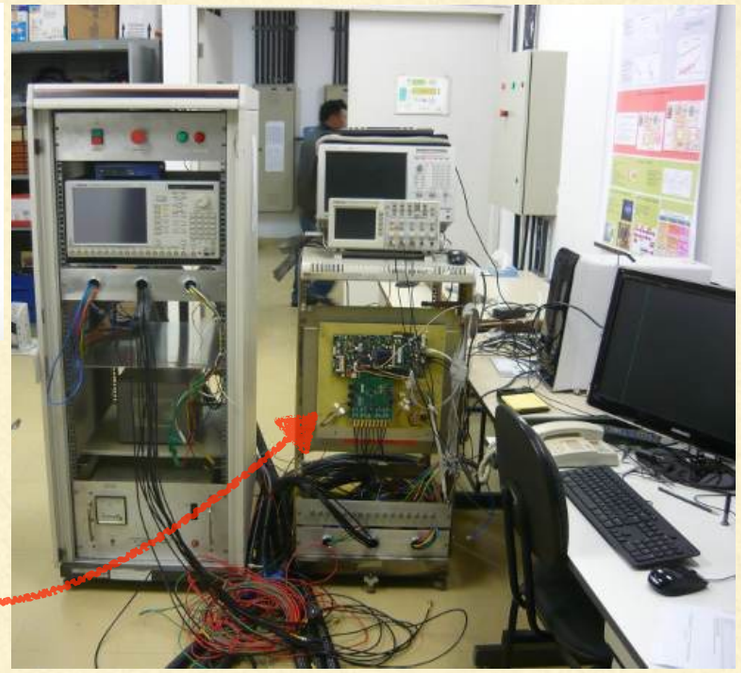




- Total Ionization Dose (TiD) in 1 year, in Gy/year, for nominal luminosity ($L = 10^{34}\ cm^{-2}\ s^{-1}$)

- Digitalizadores (ADC) são uma parte crítica
- Uma placa de teste foi desenvolvida para irradiação do ADC (12 bits/ 40 Ms/s, 8 canais)
- Sistema de aquisição e controle para a caracterização desenvolvido e instalado na USP
- Monitoramento das tensões e correntes de alimentação, referências de tensão e integridade do sinal digitalizado

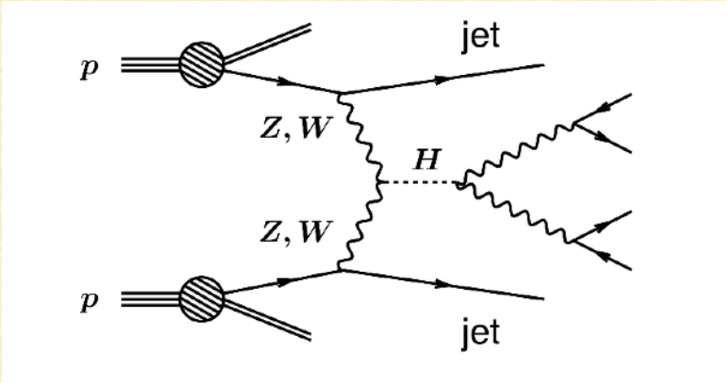


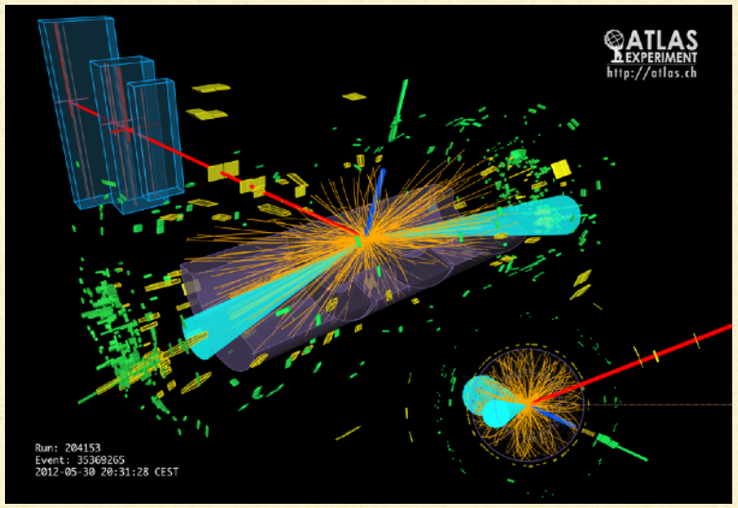


IMPACTO NA FÍSICA

(I)

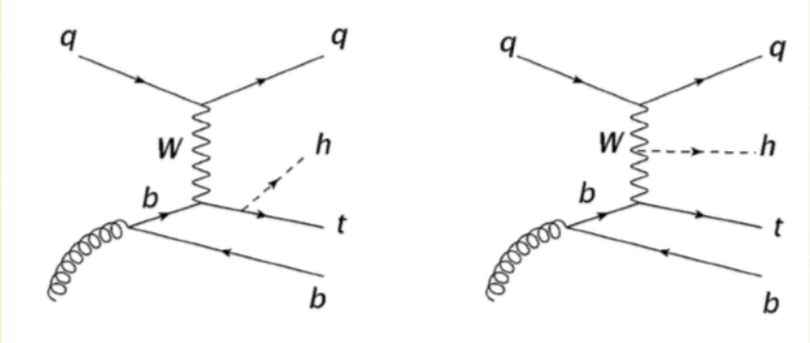
- Vector Boson Fusion (VBF)
  - em particular H → WW*
  - HL-LHC entra na era de medidas de precisão no setor do Higgs
  - VBF: 2 jatos dianteiros, bóson reconstruído na região central

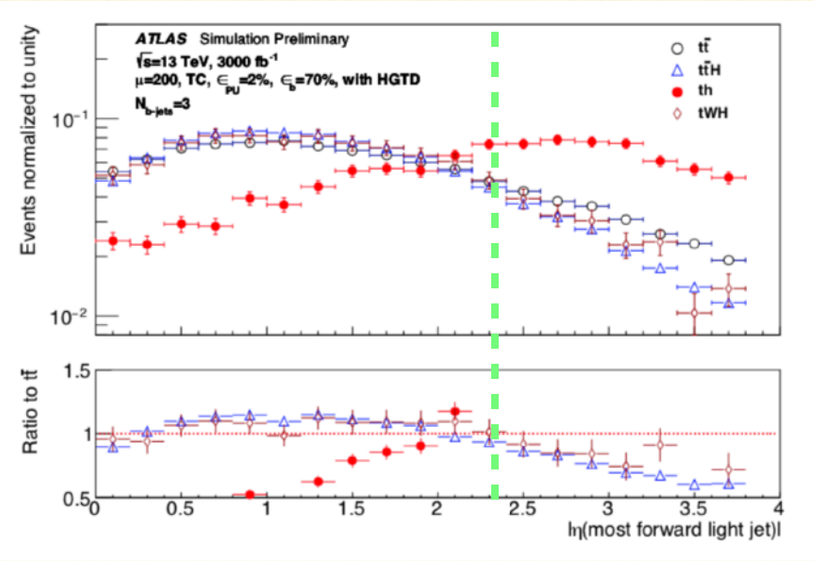




(II)

- Estudo do sinal do acoplamento de Yukawa top - Higgs
  - tH → bbar
  - Assinatura: 1 lépton e 4 ou 5 jatos (2 b-tagged)
  - Um dos jatos |η|>2.4





(III)

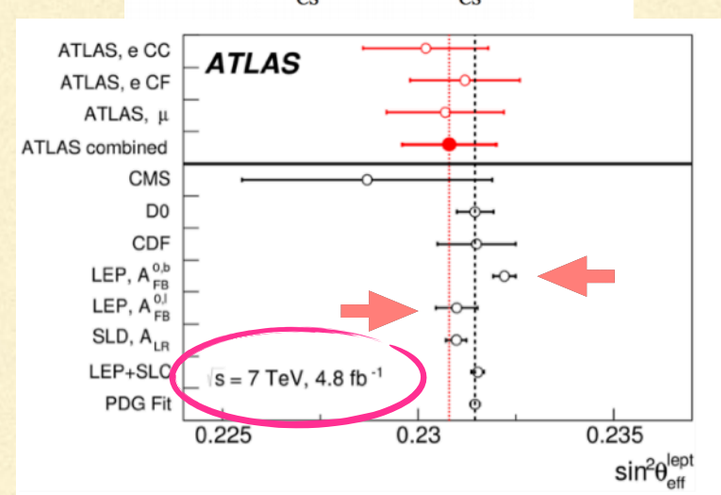
- Medida do weak mixing angle ($\sin^2\theta$)
  - assimetria na distribuição angular entre l+ e l- no decaimento do Z
  - baseado na assimetria forward/backward
  - léptons são classificados em CC, CF, FF (C→ central → |η|<2.4, F →2.5<|η|< 4.2)
  - 2 medidas mais precisas diferem em mais de 3 σ

$$\cos\theta^*_{CS} = \frac{p_{z,\ell\ell}}{|p_{z,\ell\ell}|}\frac{2(p_1^+p_2^- - p_1^-p_2^+)}{m_{\ell\ell}\sqrt{m_{\ell\ell}^2 + p_{T,\ell\ell}^2}}$$

$cos\theta^*_{CS} \geq 0 \rightarrow$ Forward
$cos\theta^*_{CS} < 0 \rightarrow$ Backward

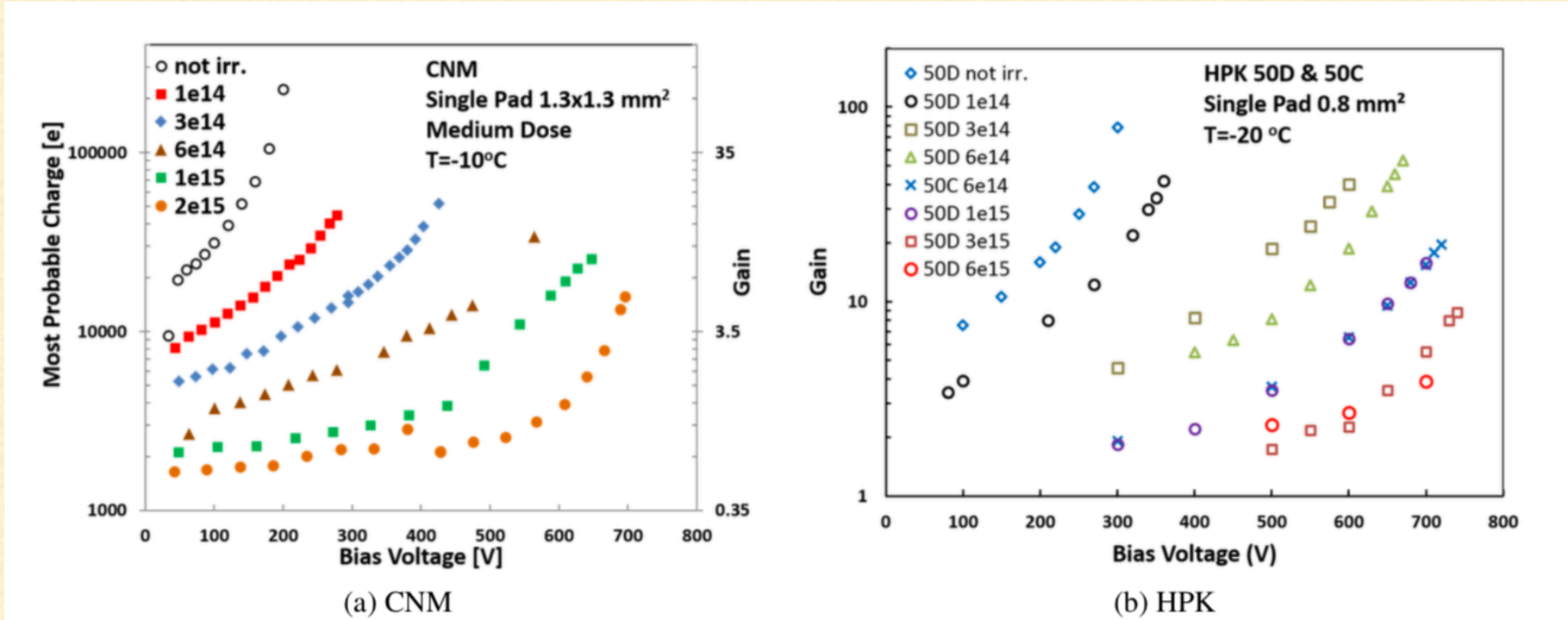
$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B},$$

$$A_{FB} = \frac{N_{\cos\theta^*_{CS}\geq 0} - N_{\cos\theta^*_{CS}<0}}{N_{\cos\theta^*_{CS}\geq 0} + N_{\cos\theta^*_{CS}<0}}.$$

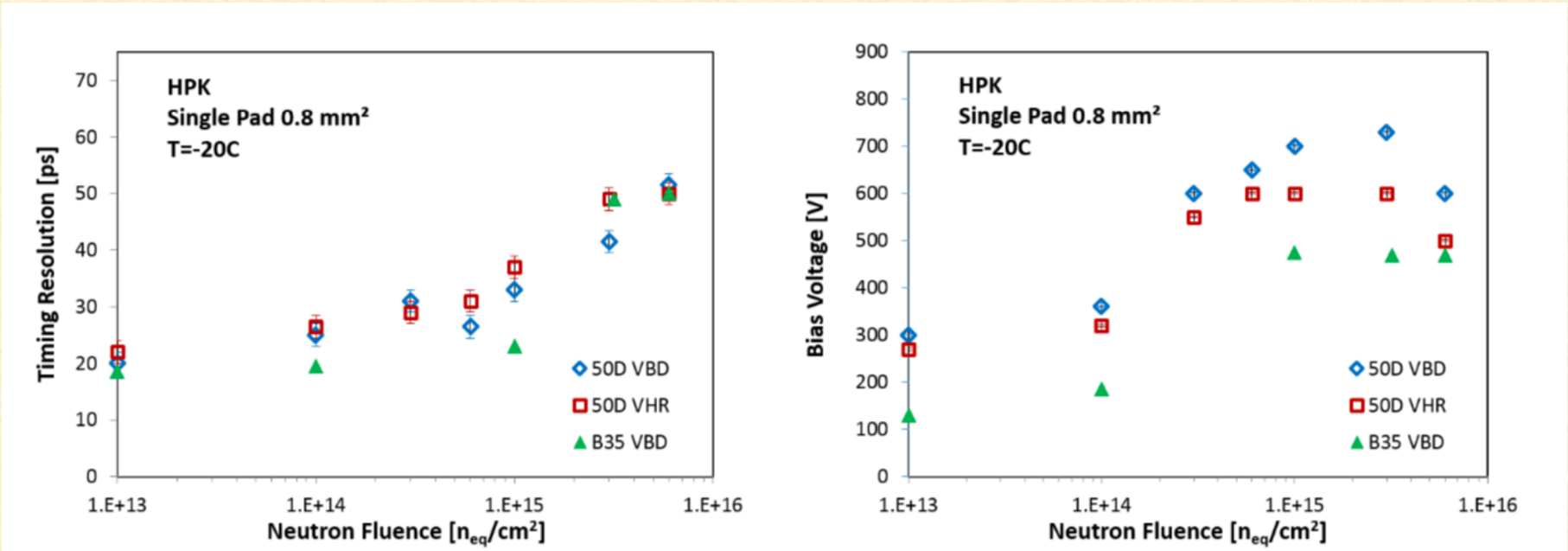


Efeito da radiação no desempenho dos detectores

- Detectores e eletrônica de front end deve sobreviver à radiação durante a fase-II
- Entretanto, a parte interna deve ser substituída após ~ 2000 1/fb



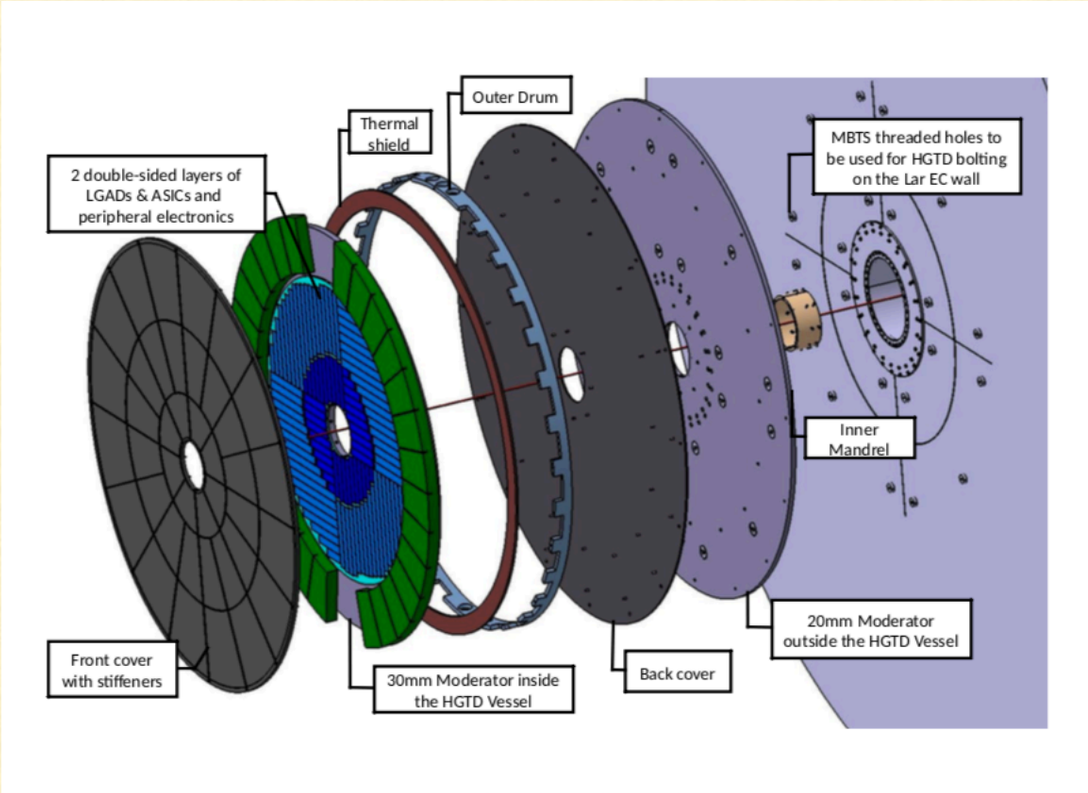
(a) CNM (b) HPK

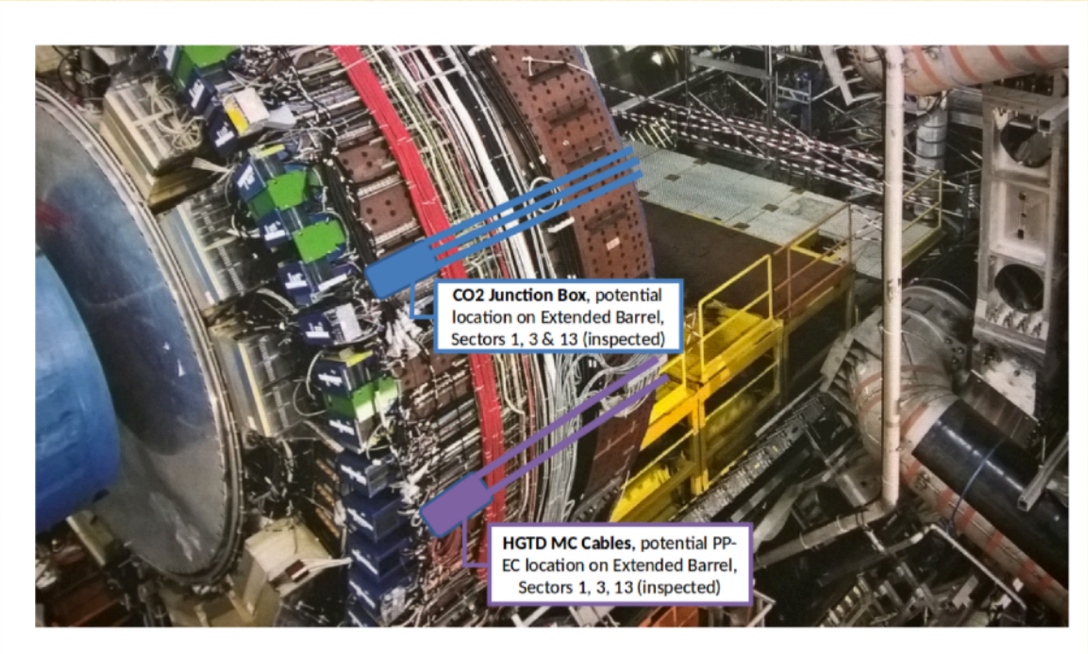


(a) (b)

Instalação

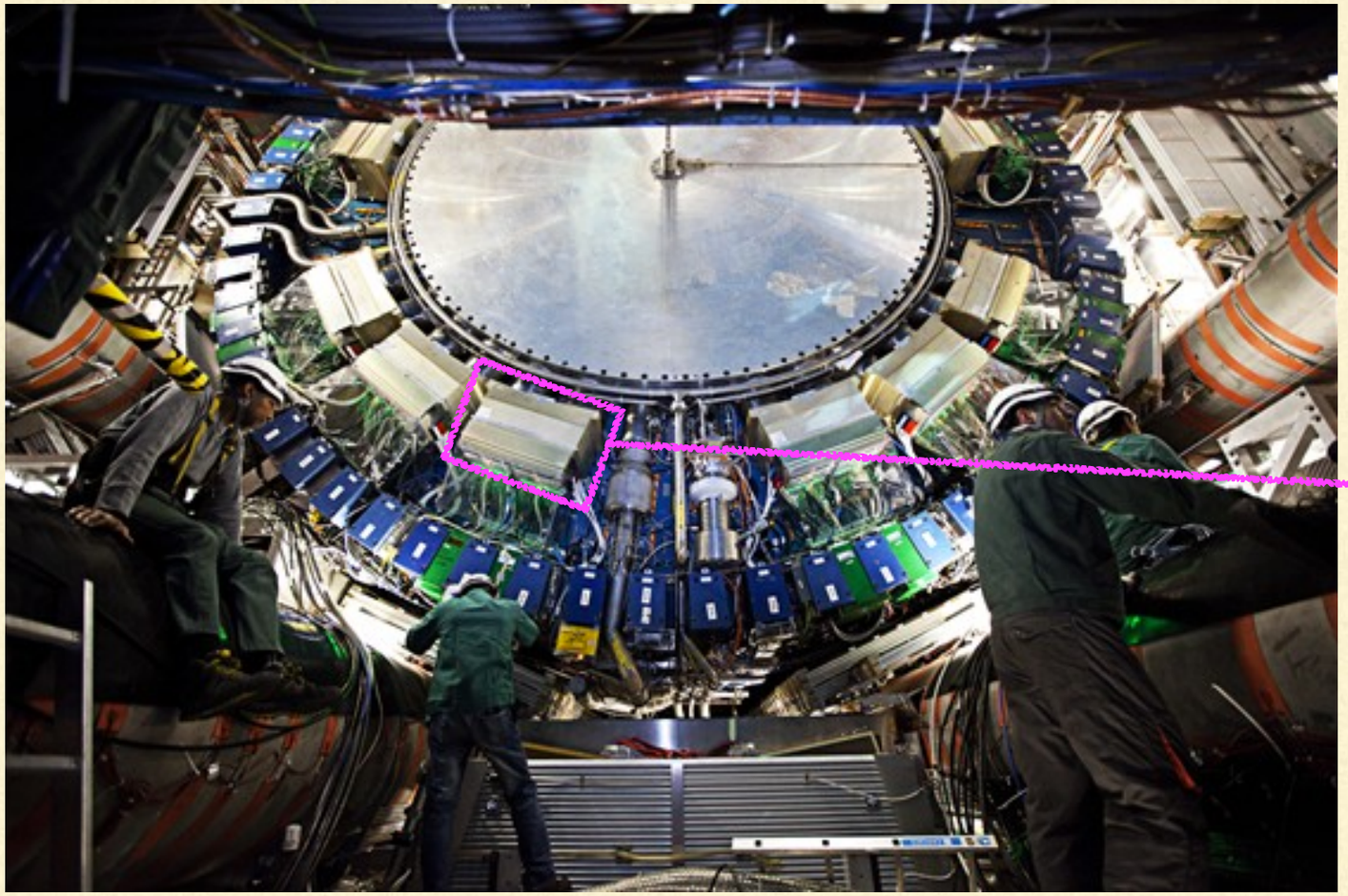
- Instalação
  - Disco fechado
  - Suporte fibra de carbono com CO2 circulando para refrigeração (-20oC)
  - Conjunto todo deve compartilhar espaço com ITk
  - Montagem em quadrante → não necessita desmontar o beam pipe
  - Suporte para o moderador de nêutrons

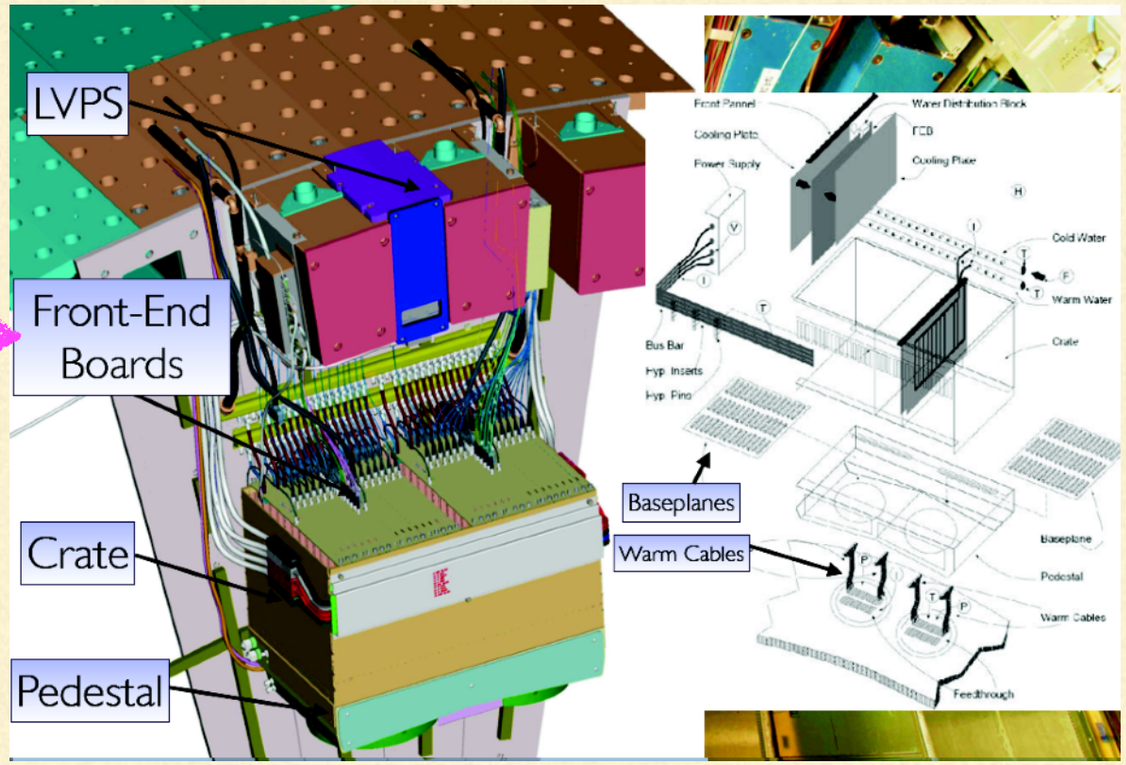




Instalação : 2019 - 2020

- A instalação do novo hardware está programada para 2019/2020
- Efetivamente, o tempo é curto para remover o sistema antigo, substituir os backplanes de 124 crates, testar o sistema e reinstalar com a nova eletrônica

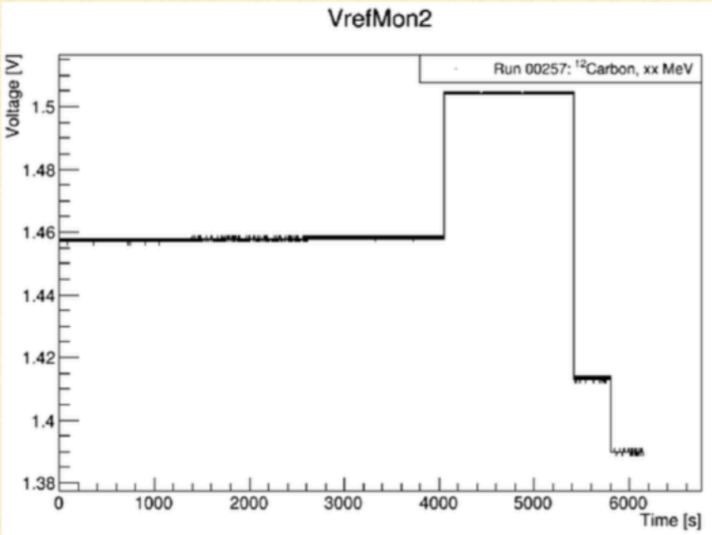




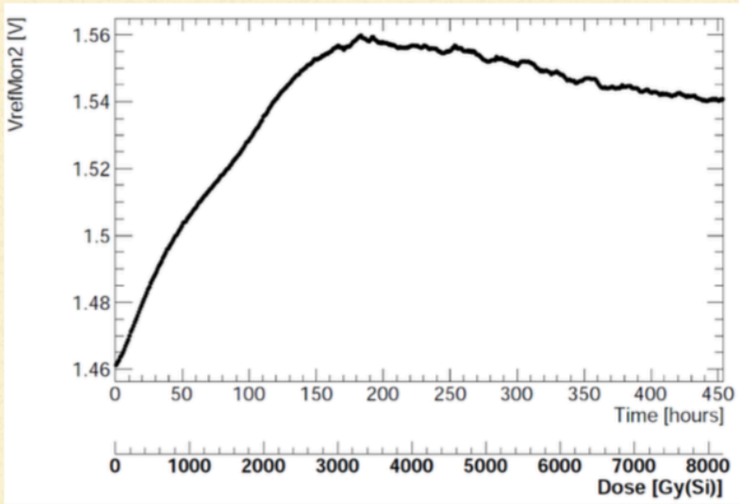
LIQUID ARGON TRIGGER DIGITAL BOARD

- Feixe de 12C
- Aprox. 72e3 part./cm2
- Efeito na ref. Tensão bastante distinto :

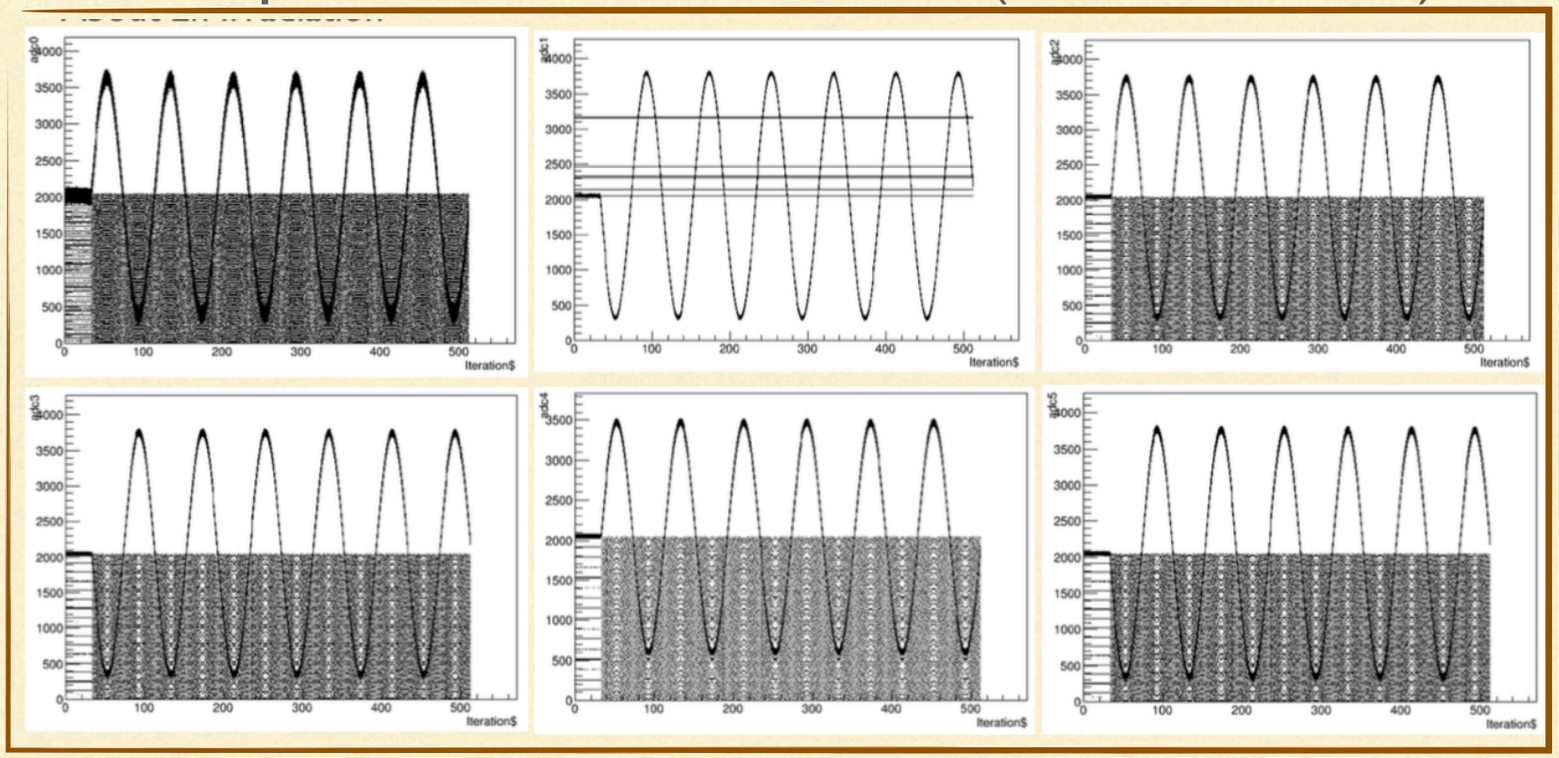
SEE (12C, 25 MeV)



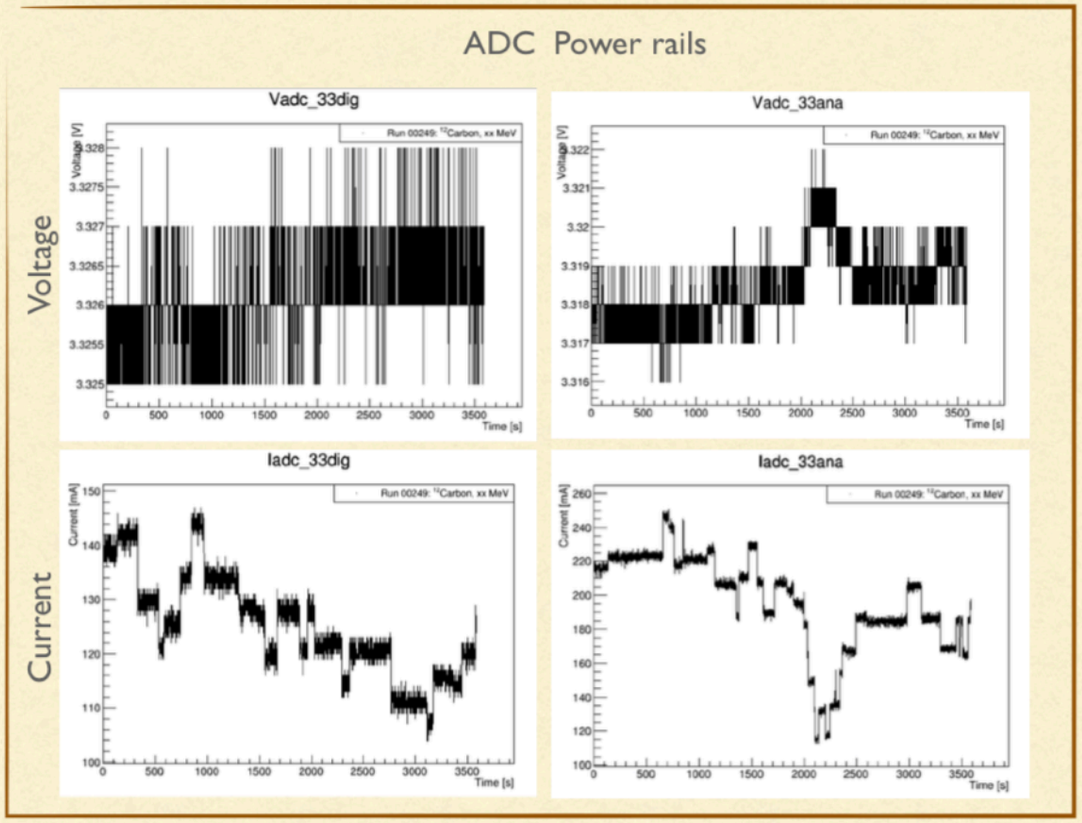
TID (60 Co)



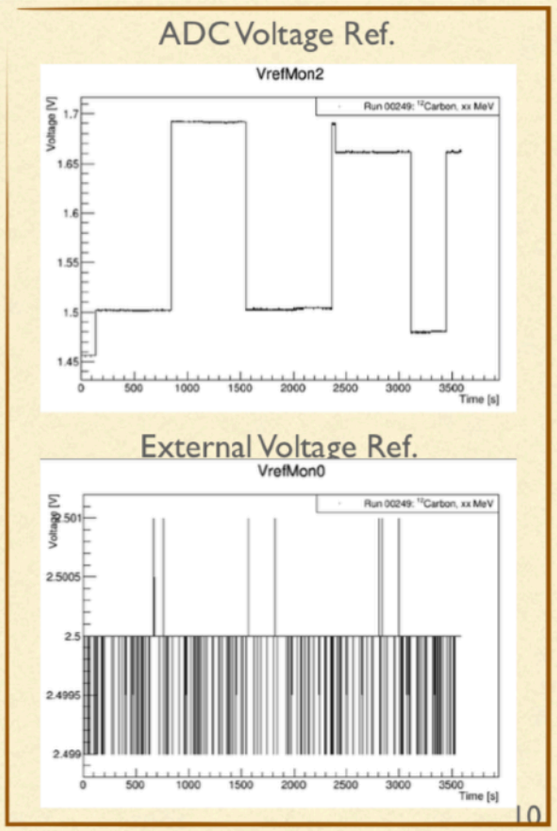
Resposta a um sinal senoidal (vários eventos)

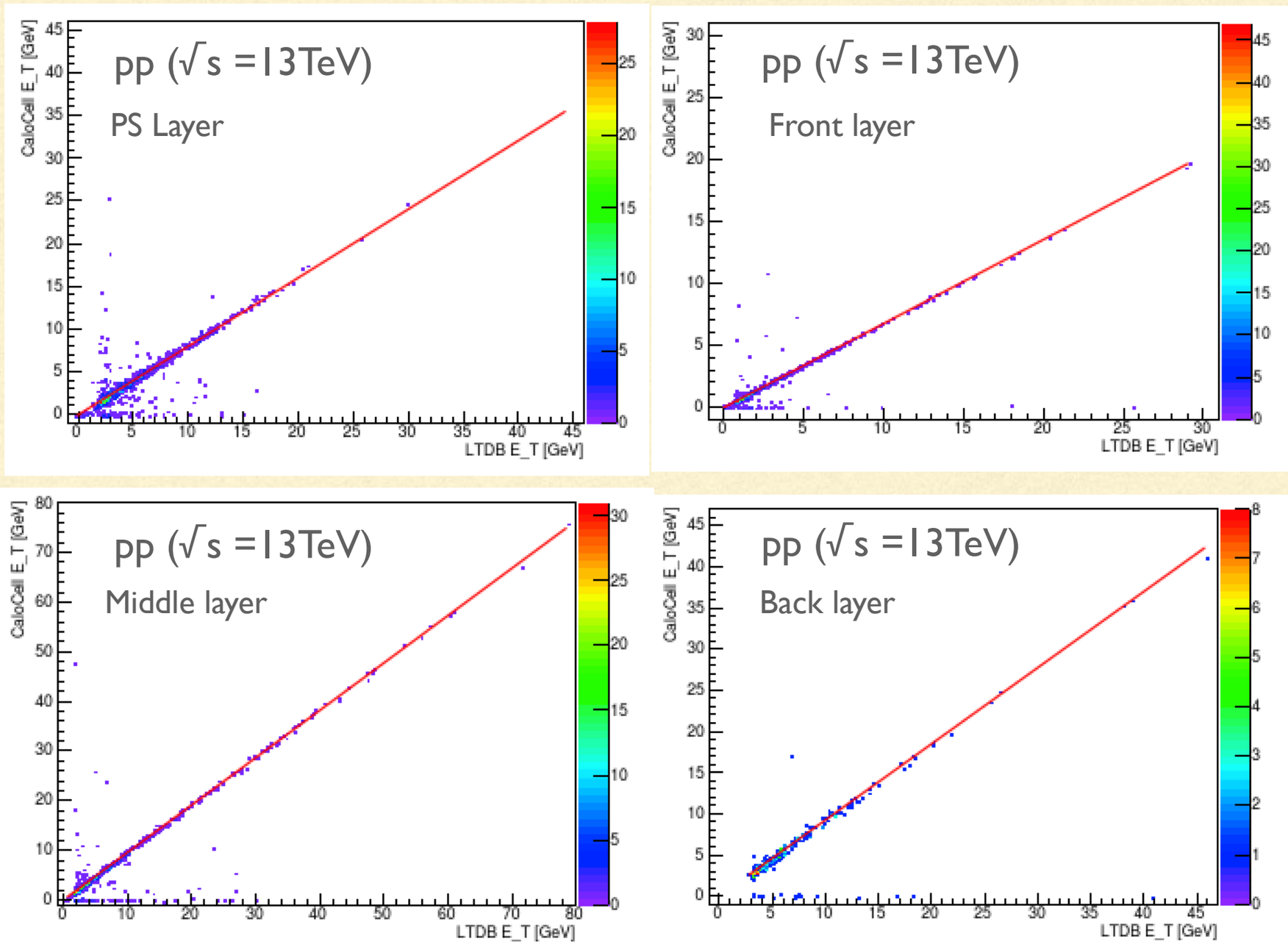


ADC Power rails



ADC Voltage Ref.



LIQUID ARGON TRIGGER DIGITAL BOARD

- A energia reconstruída no LTDB por supercélula tem uma boa concordância com a soma da energia das células correspondentes no calorímetro.