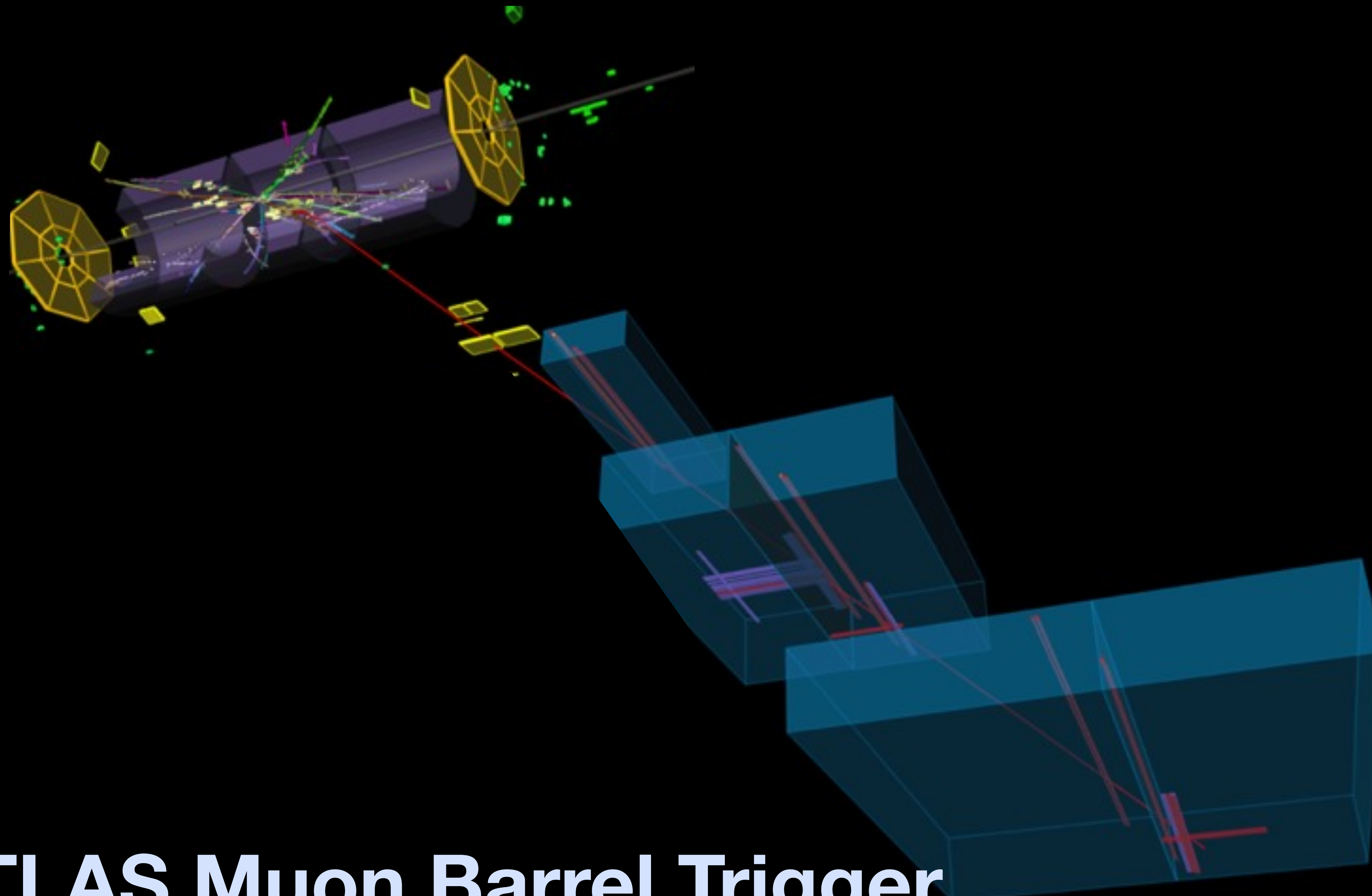


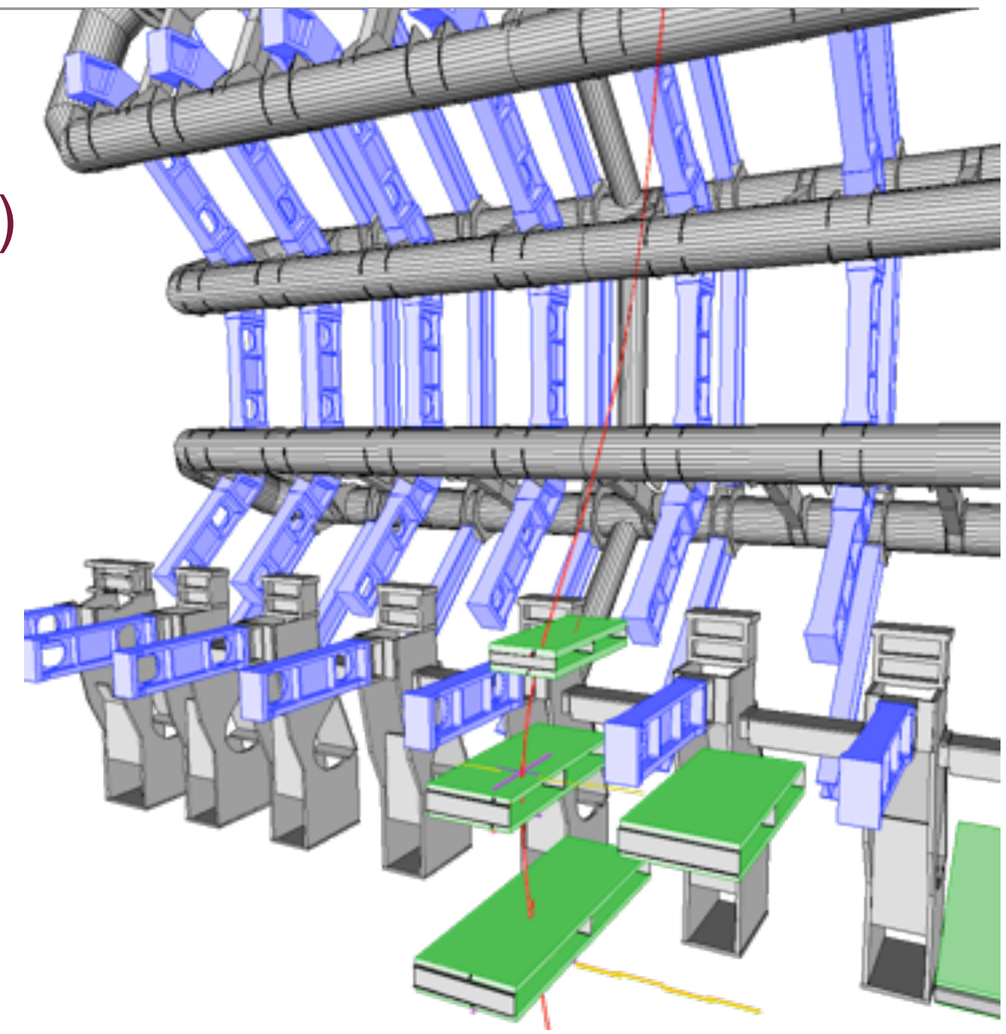
The ATLAS Muon Barrel Trigger

D. della Volpe

Università degli Studi di Napoli “FEDERICO II” & CERN

CPPM - Marseille - 8 March 2010

Outline



- The context
  - LHC Physics and ATLAS trigger Strategy (RoI)
  - Muons for LHC Physics
  - Muon Trigger physics requirements
- The RPC detector
  - The Principle of operation
  - The Bakelite RPC
  - The ATLAS RPC
- The Muon Barrel Trigger
  - The Algorithm and Trigger Logic
  - The Implementation
  - The Timing

Large Hadron Collider

27 km *circumference*
25 ns *bunch crossing =* ***40 MHz***

Two modes of operation:

- **proton-proton** ***7 TeV + 7 TeV***
- **ion-ion** ***574 TeV*** *per nucleus*

High Luminosity Experiment

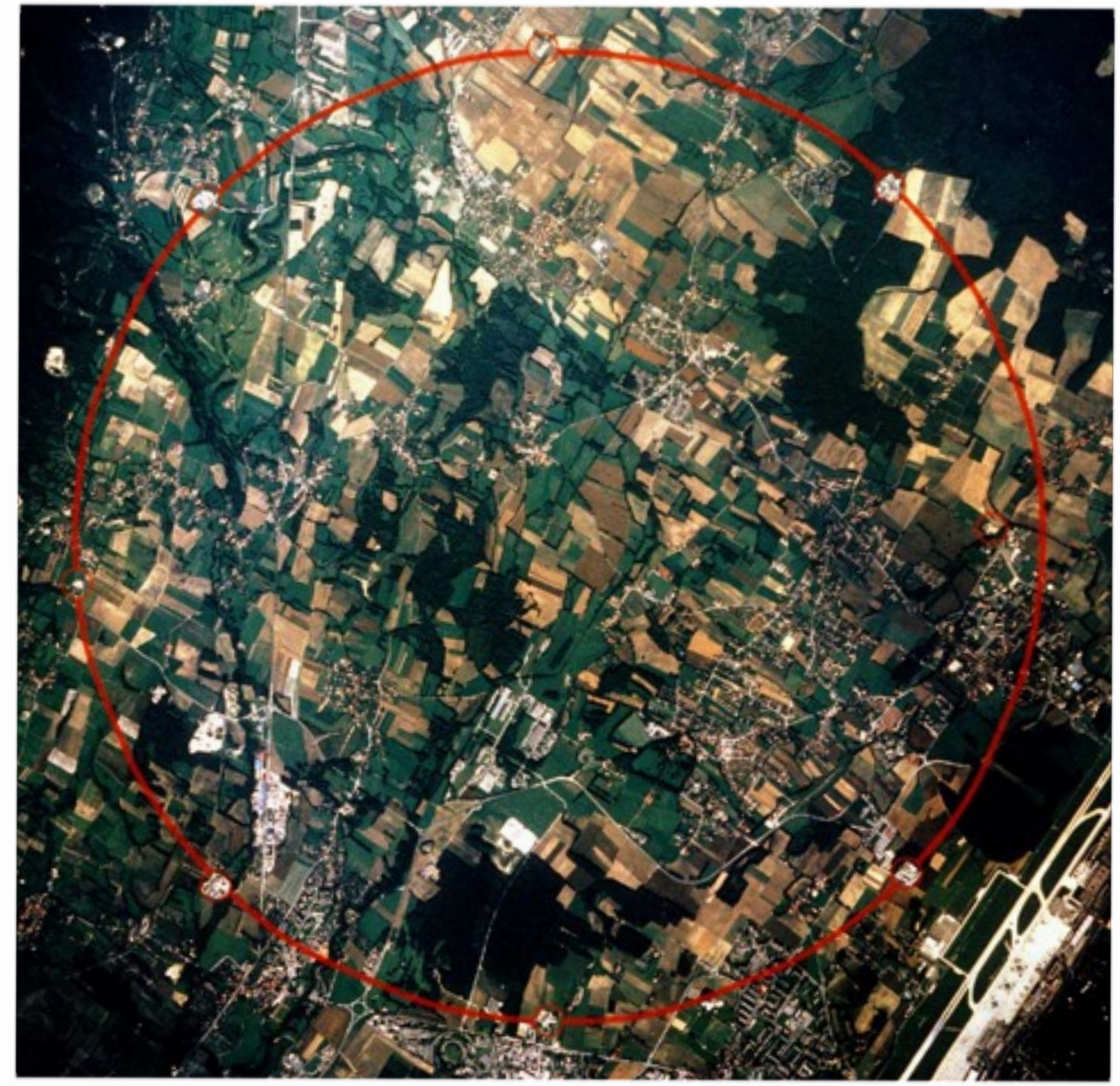
- **ATLAS, CMS** ($L=10^{34}cm^{-2}s^{-1}$)

Low Luminosity Experiment

- **LHCb** ($L=10^{32}cm^{-2}s^{-1}$)
- **TOTEM** ($L=2x10^{29}cm^{-2}s^{-1}$)

Ion Lead-Lead

- **ALICE** ($L=10^{29}cm^{-2}s^{-1}$)



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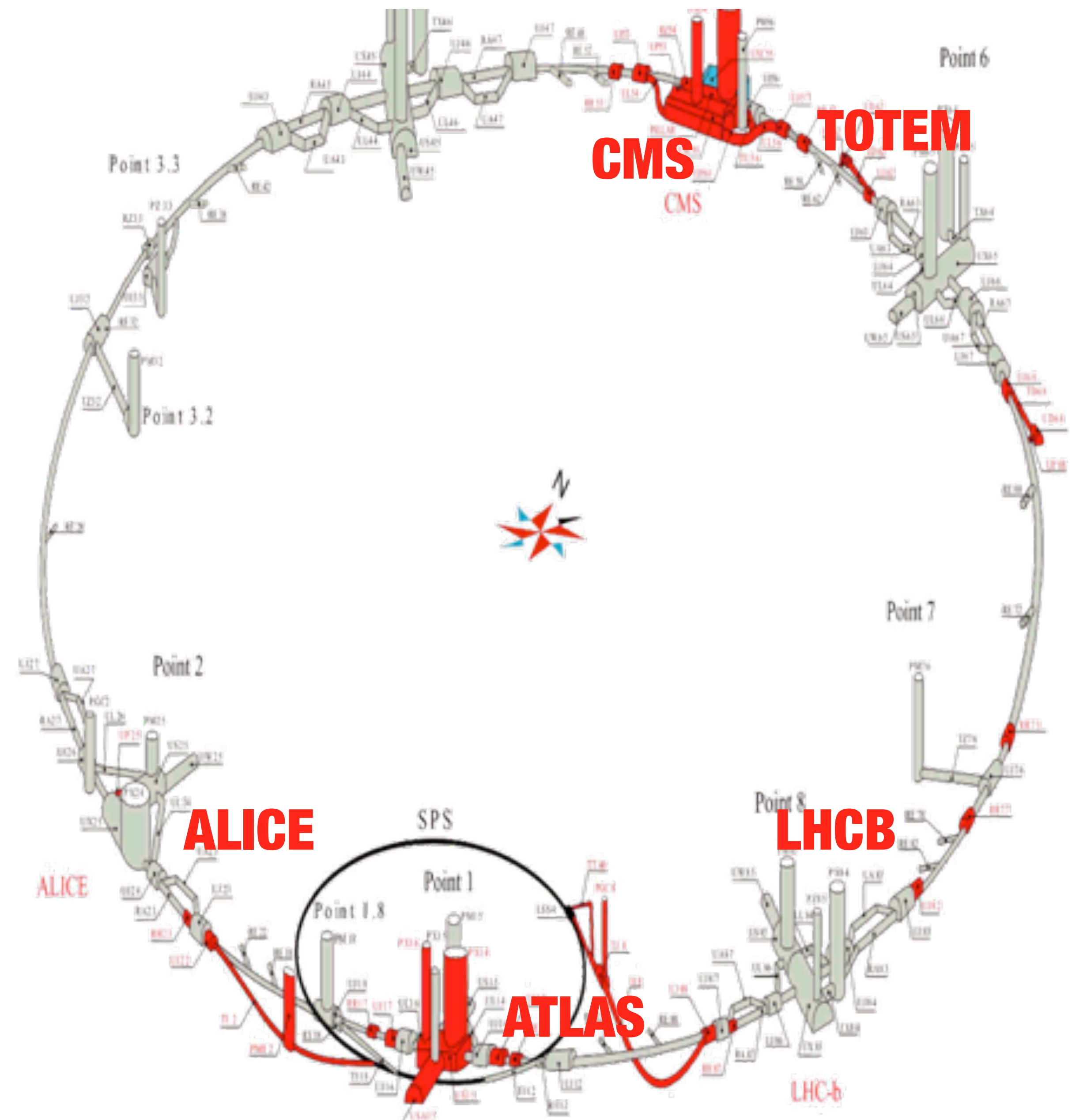
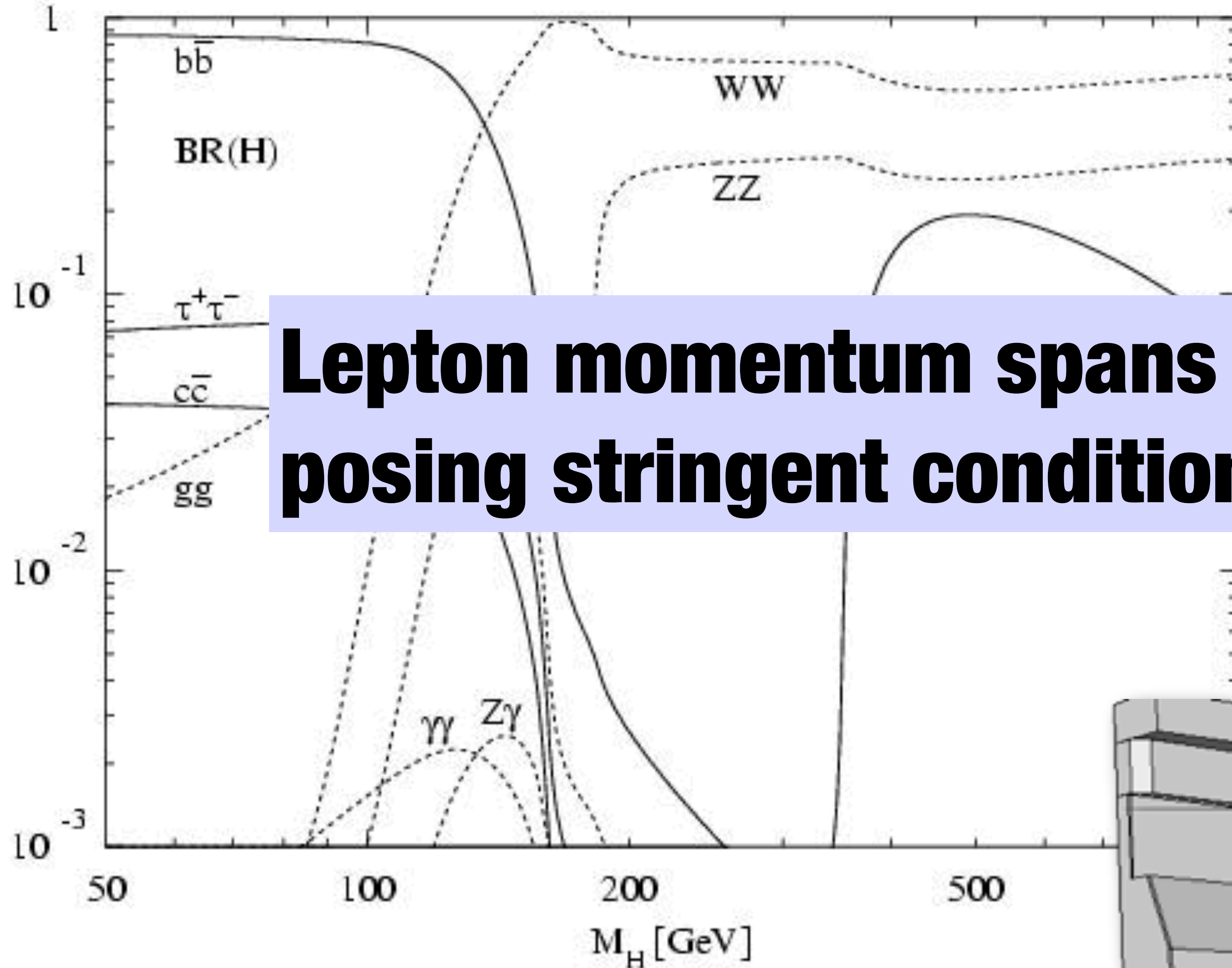




Lepton momentum spans over a wide range.
posing stringent condition on trigger

1.1 Basic Design Considerations

The Standard Model (SM) Higgs search can be used as a first benchmark for the detector optimization. The search strategies and methods are rather well known from general studies. In order to cover the full mass range above the expected discovery limit at … GeV one needs sensitivity to … (ℓ = e or μ):

… and $t\bar{t}$ H using a $\ell^\pm$ tag, … $< m_H <$ 130 GeV;

H $\rightarrow \gamma\gamma$ direct production,
mass range 90 $< m_H <$ 150 GeV;

H $\rightarrow ZZ^* \rightarrow 4\ell^\pm$
mass range 130 GeV $< m_H < 2m_Z$;

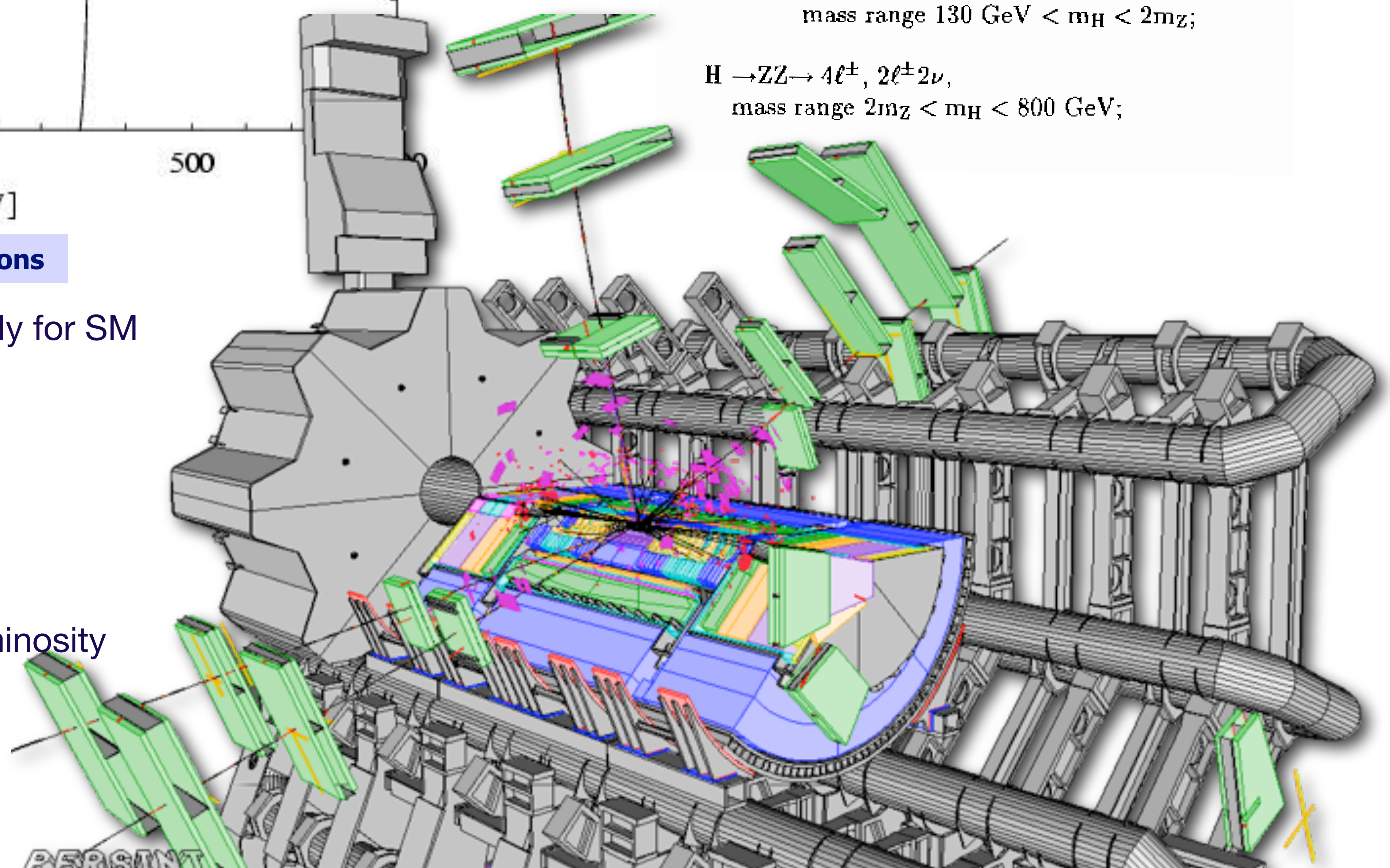
H $\rightarrow ZZ \rightarrow 4\ell^\pm$, $2\ell^\pm 2\nu$,
mass range $2m_Z < m_H <$ 800 GeV;

SM Higgs branching fractions

- Leptons are important not only for SM and MSSM Higgs

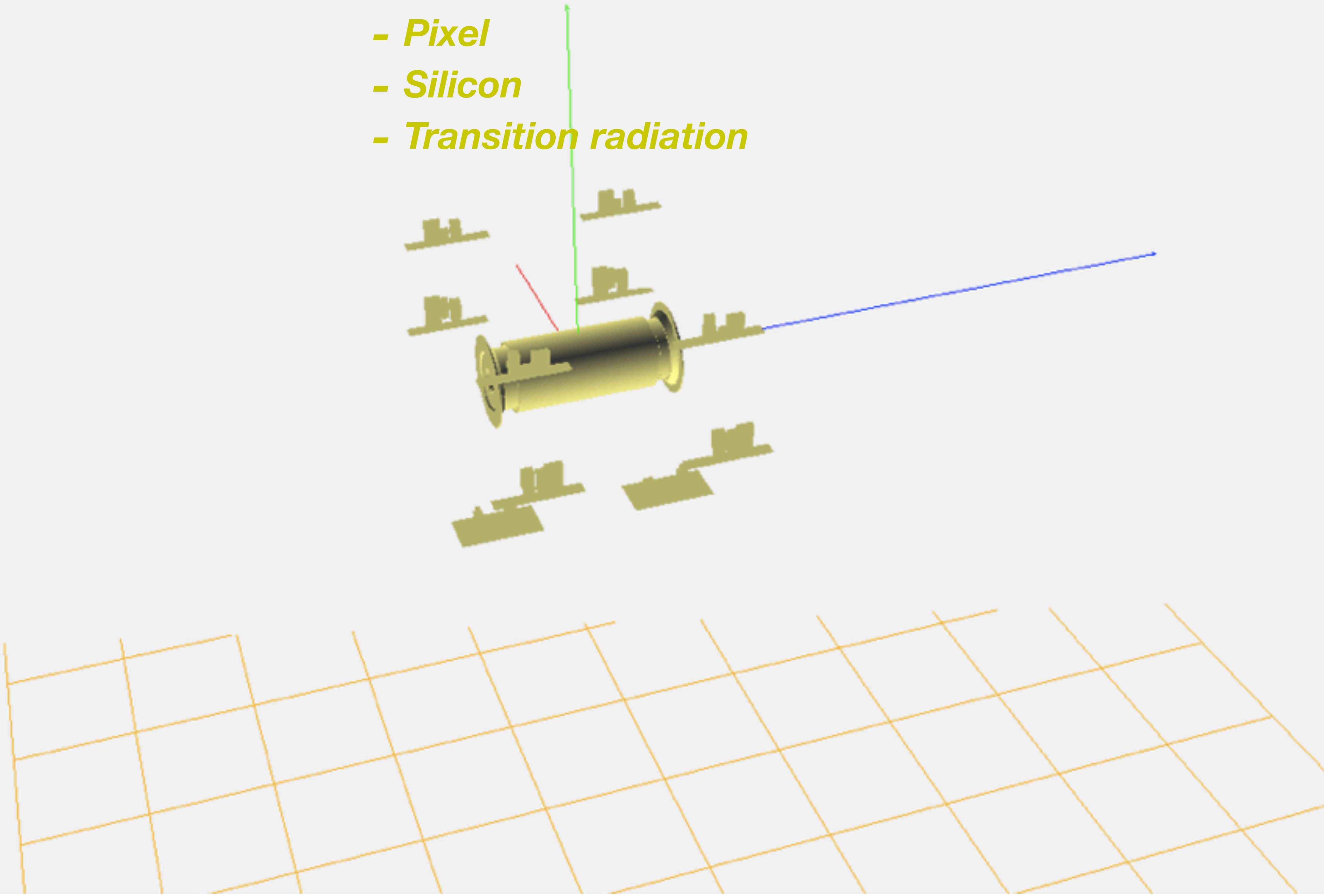
  130 GeV < M_H < 800 GeV

- and search for new physics
- but also B-physics at low luminosity

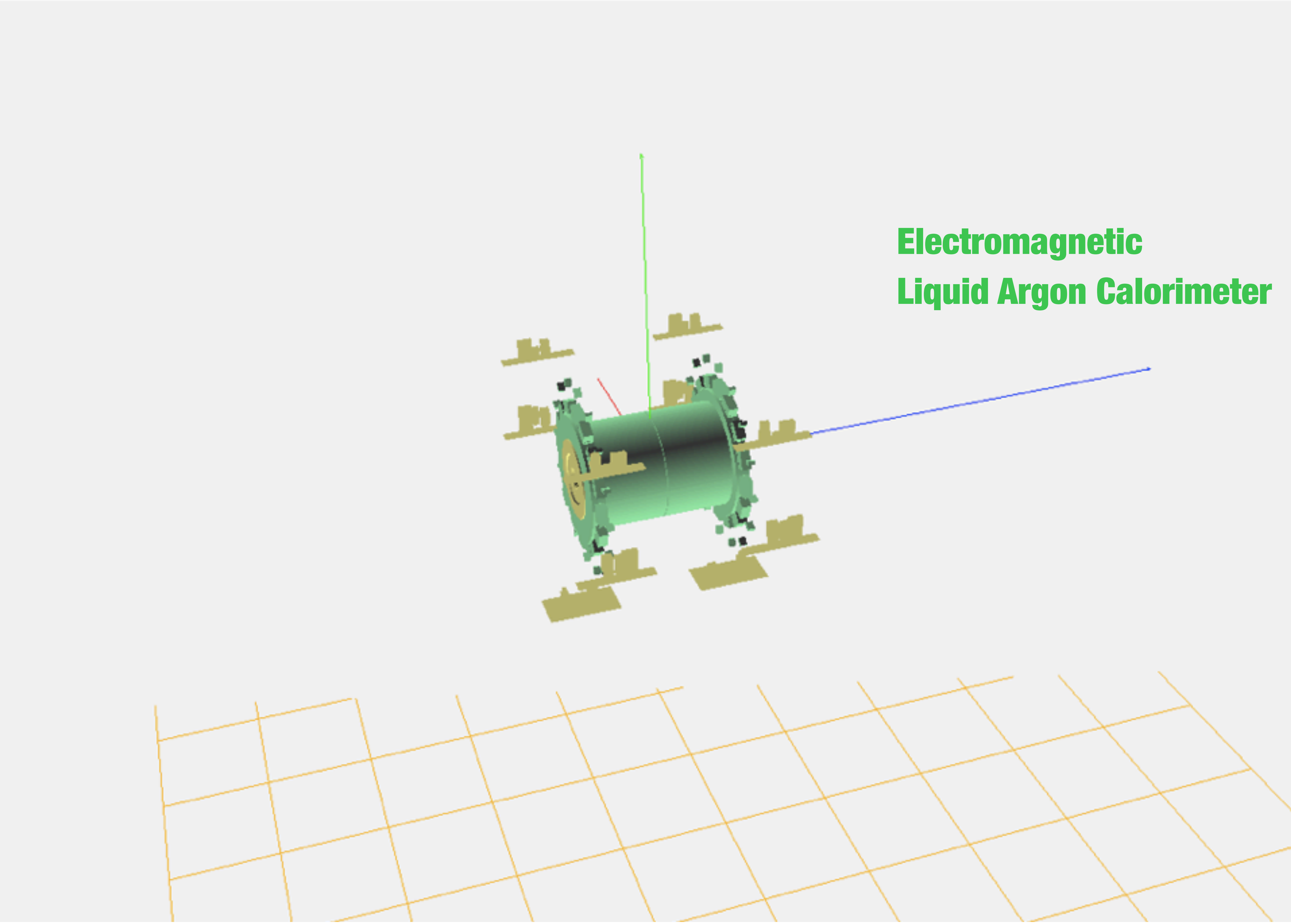


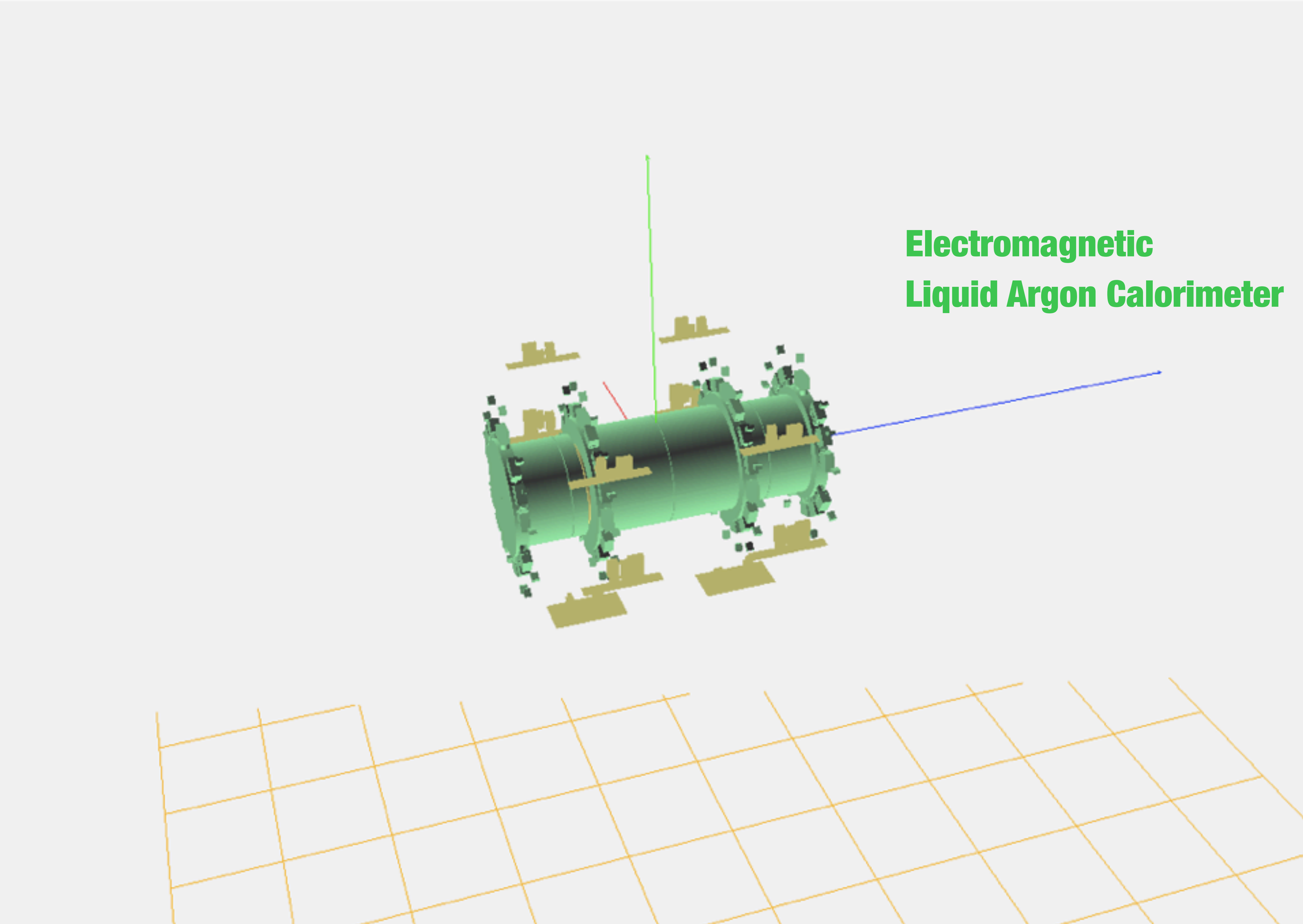
Inner Tracker 3 Detector

- *Pixel*
- *Silicon*
- *Transition radiation*

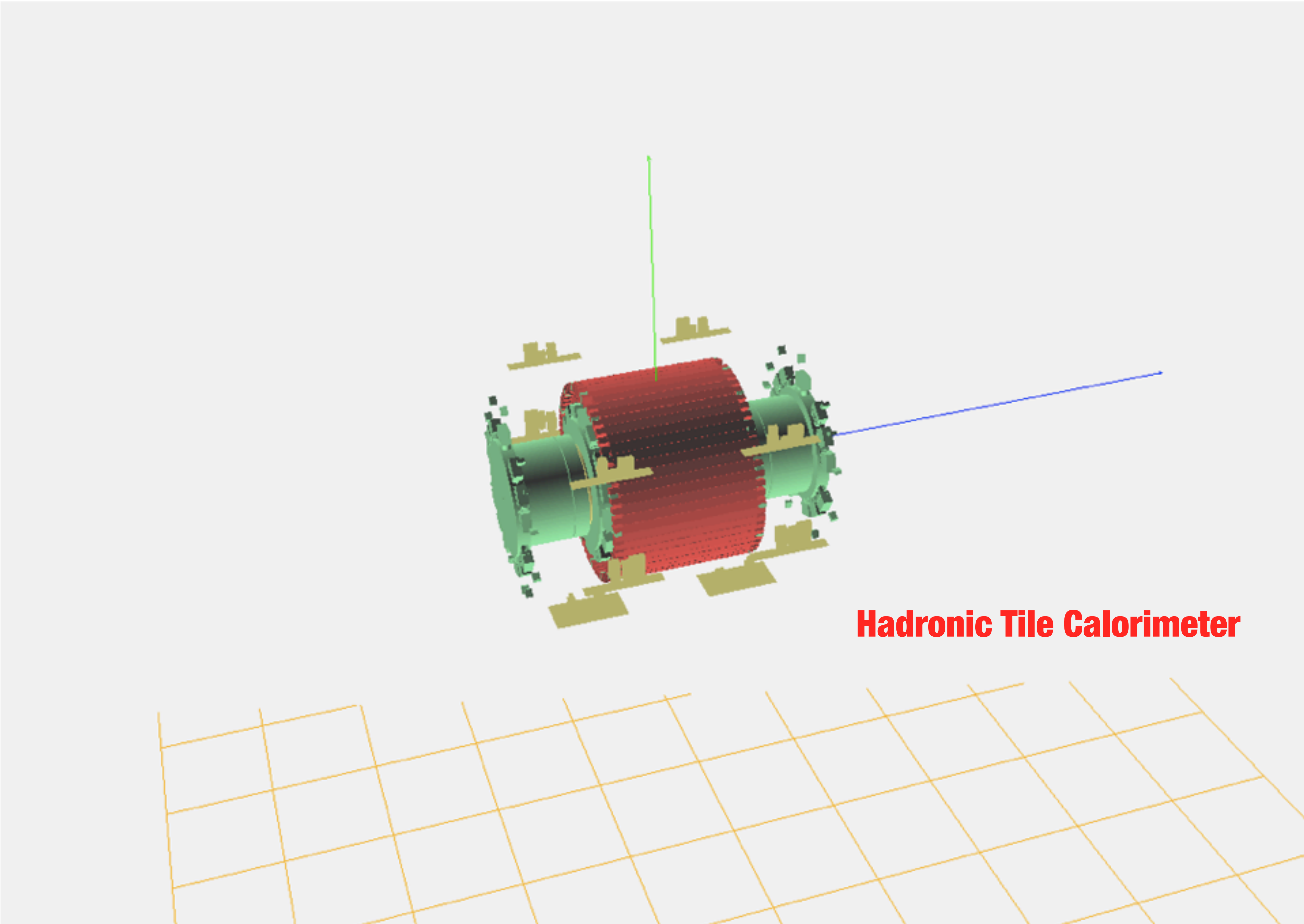


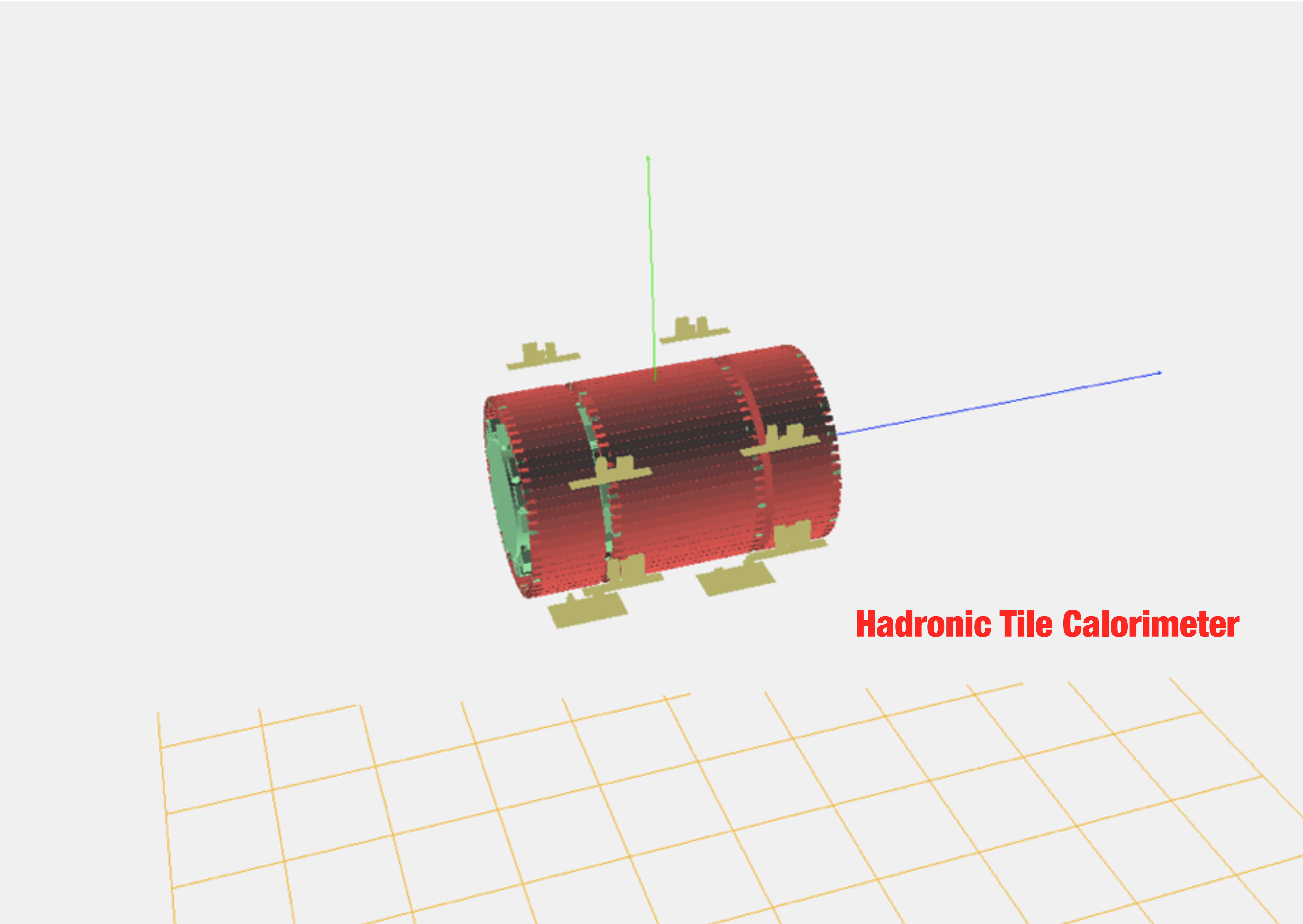
Electromagnetic Liquid Argon Calorimeter





Electromagnetic
Liquid Argon Calorimeter


Hadronic Tile Calorimeter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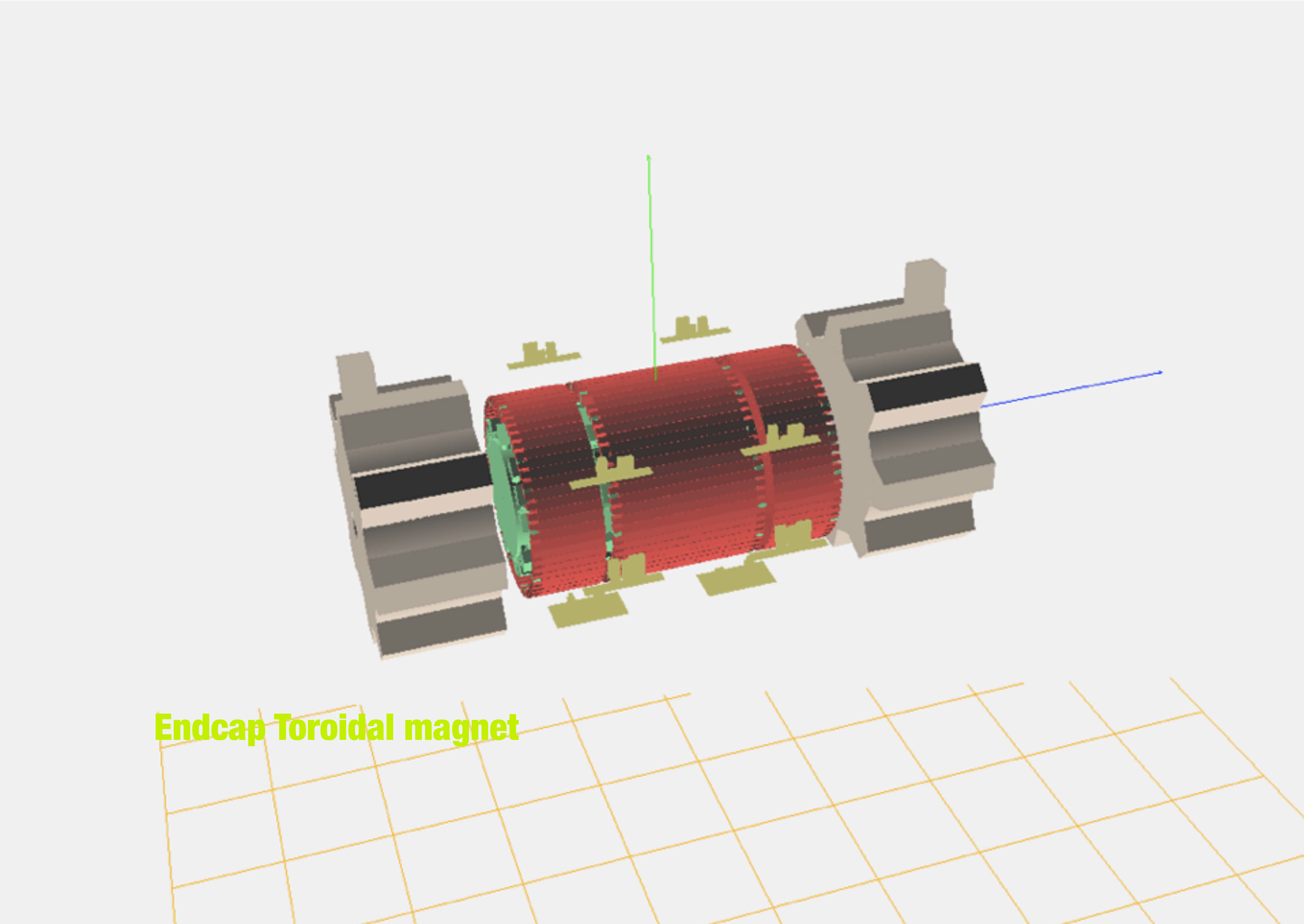
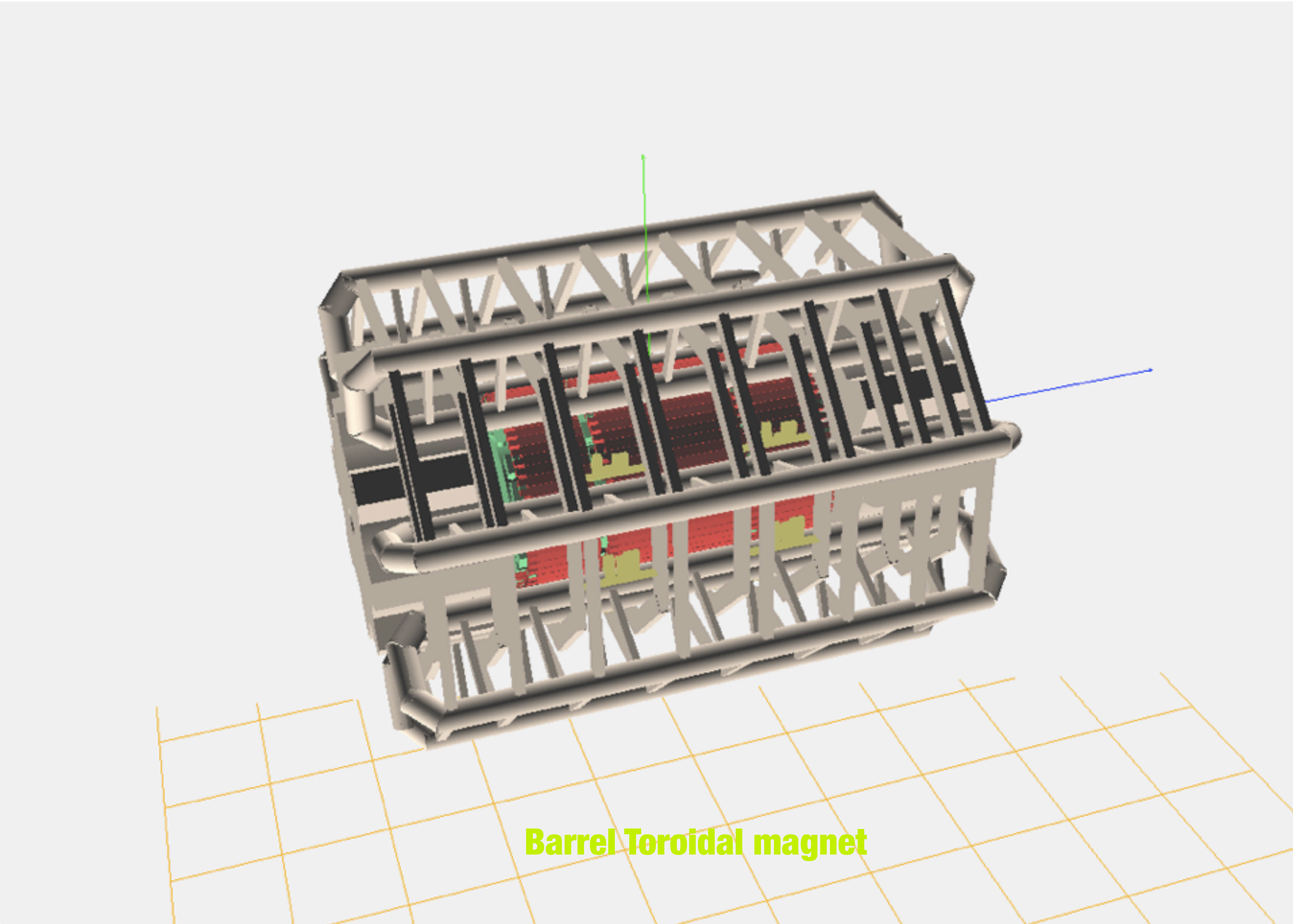
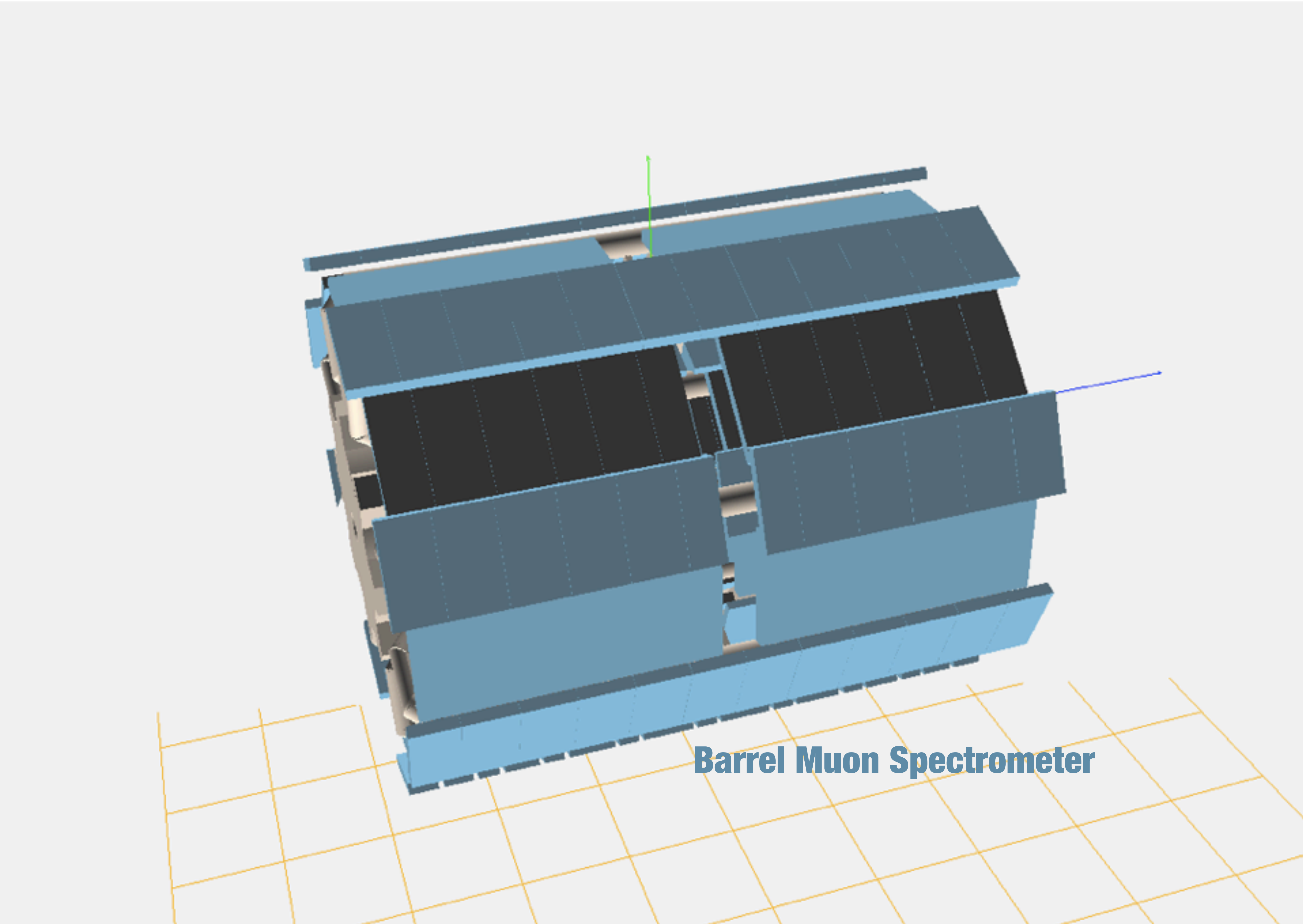
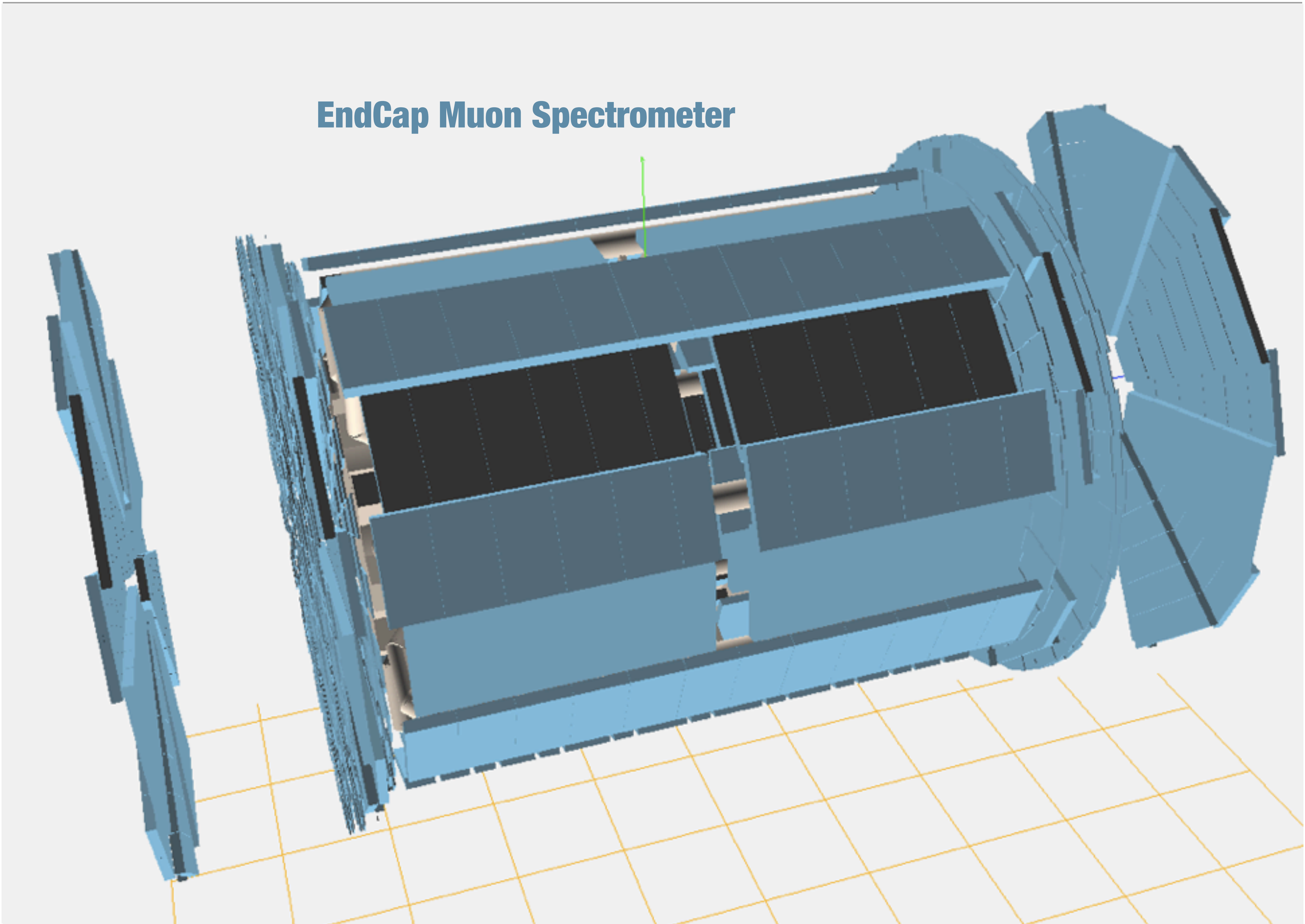
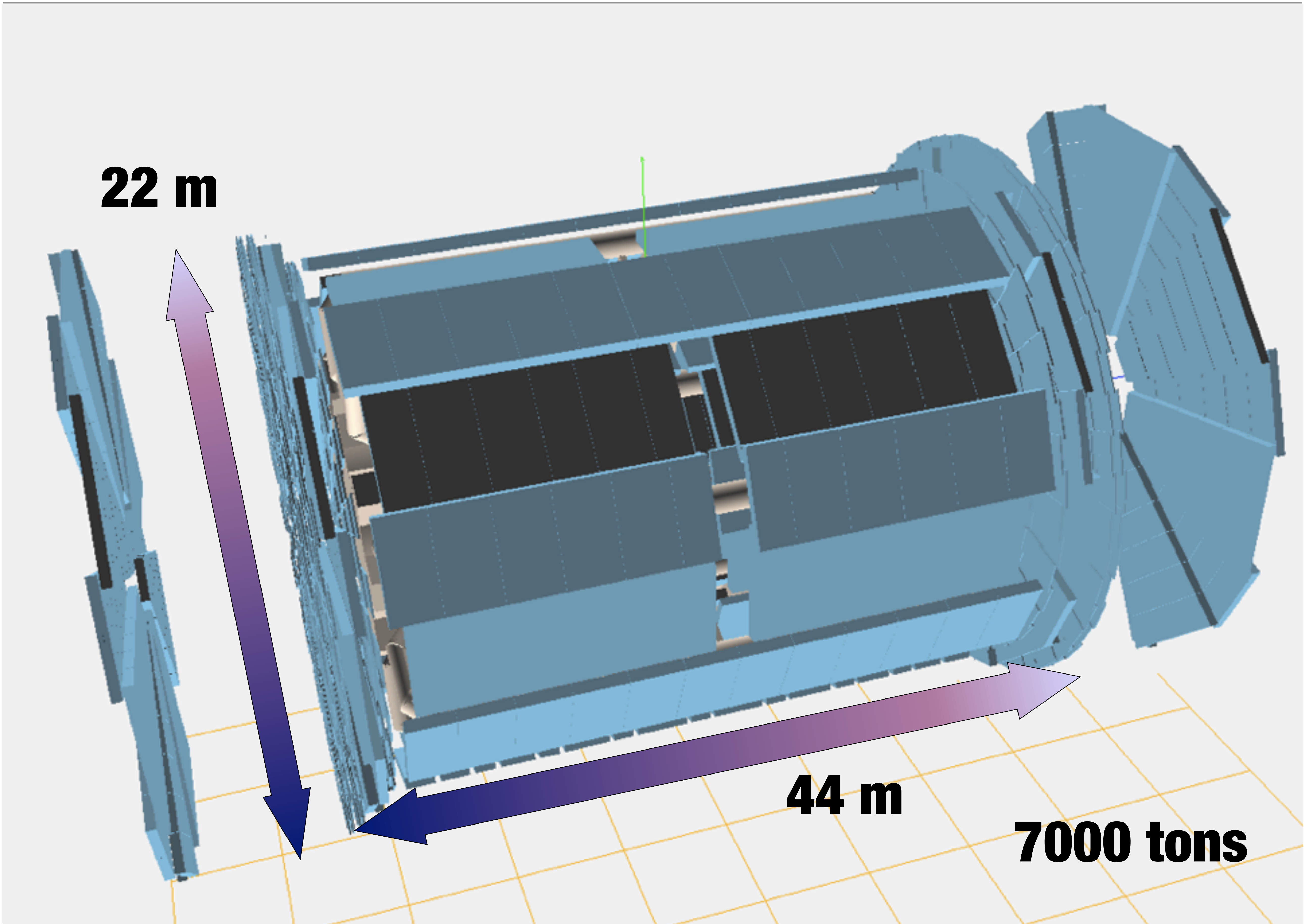

Endcap Toroidal magnet

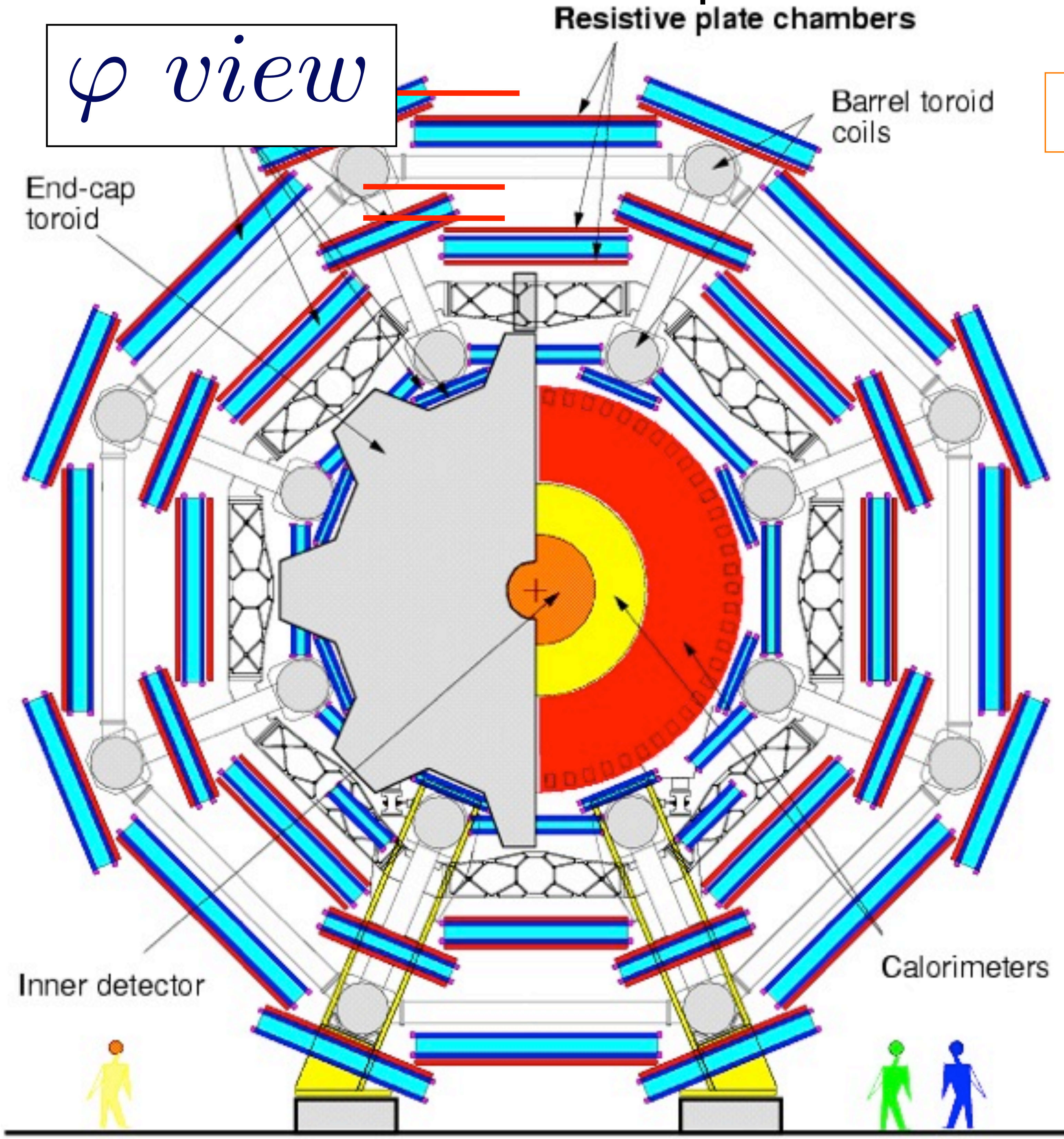

Barrel Toroidal magnet


Barrel Muon Spectrometer


EndCap Muon Spectrometer


22 m
44 m
7000 tons

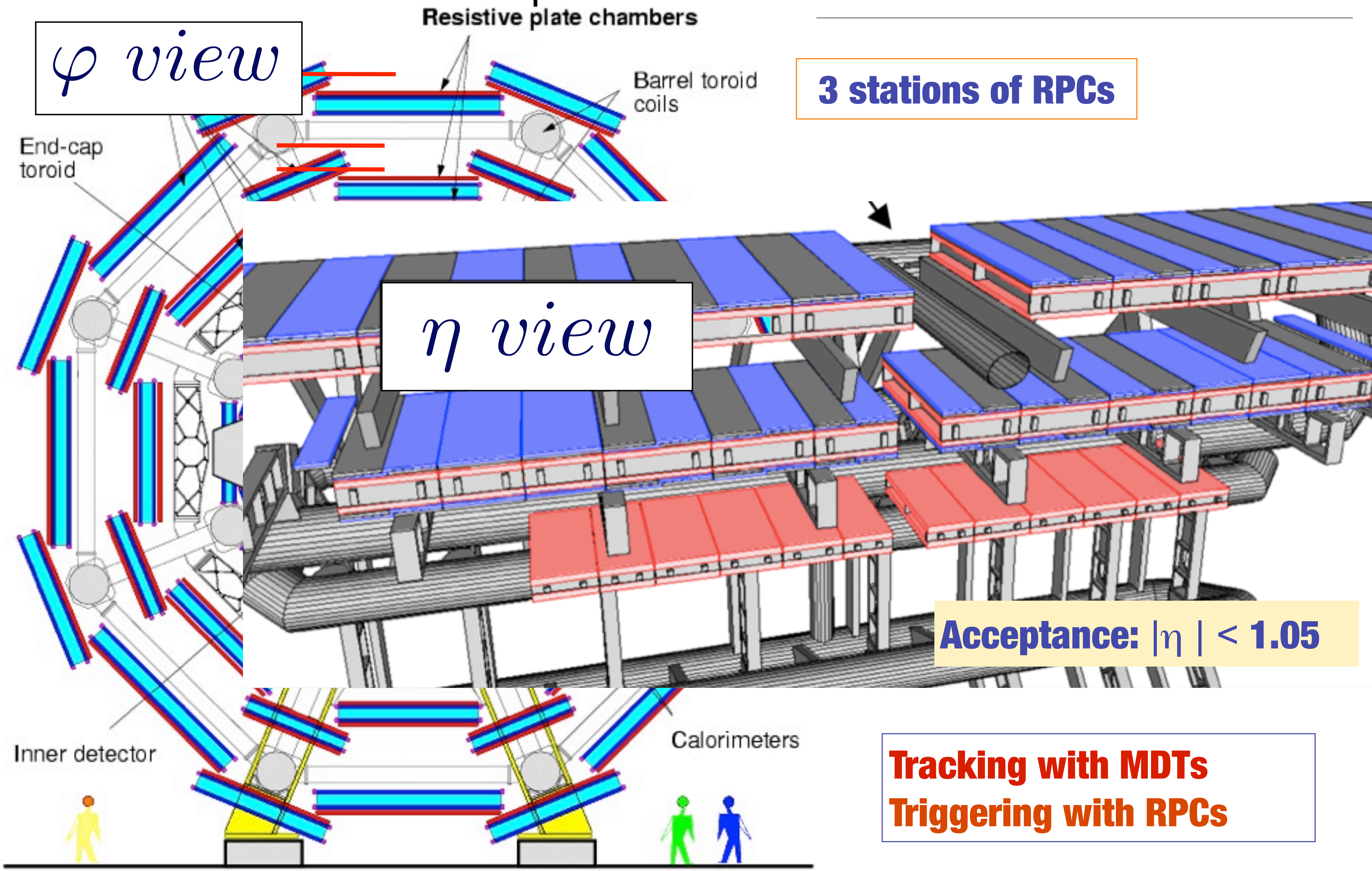
The ATLAS Muon spectrometer Barrel



3 stations of RPCs

Tracking with MDTs
Triggering with RPCs

The ATLAS Muon spectrometer Barrel



3 stations of RPCs

Acceptance: $|\eta| < 1.05$

Tracking with MDTs
Triggering with RPCs

The ATLAS Trigger strategy

The challenge

At 10^{34} we will have 25 underlying event at each bunch crossing (25 ns)

This corresponds to ~1 GHz of events while the affordable storage rate is 200-300 Hz

We need to be able to select $5x10^{-6}$ of total events

Trigger select bunch crossing not event!

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This corresponds to ~1 GHz of events while the affordable storage rate is 200-300 Hz

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We need to be able to select this

out of this

Trigger select bunch crossing not event!

At full LHC Luminosity, the ATLAS detector can produce

*1.6 MB/event *40 MHz = 64 PB/s*

To reduce the amount of data to write to disk and of unnecessary data transfer

- **Three -level Trigger Architecture**
- **"Region of Interest" mechanism**

The RoI Mechanism

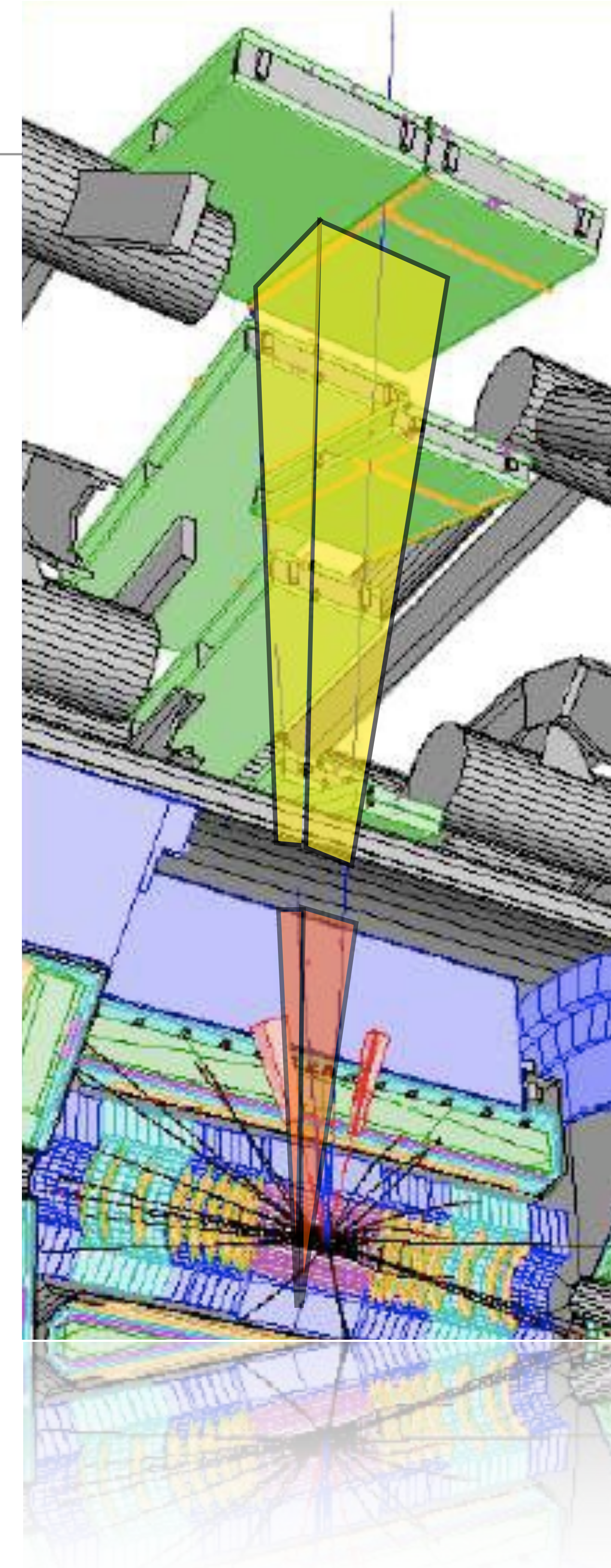
The Level 1 Trigger objects (jet, electromagnetic, muon candidate, etc.) determine Regions of Interest (RoIs) that seed further trigger decisions

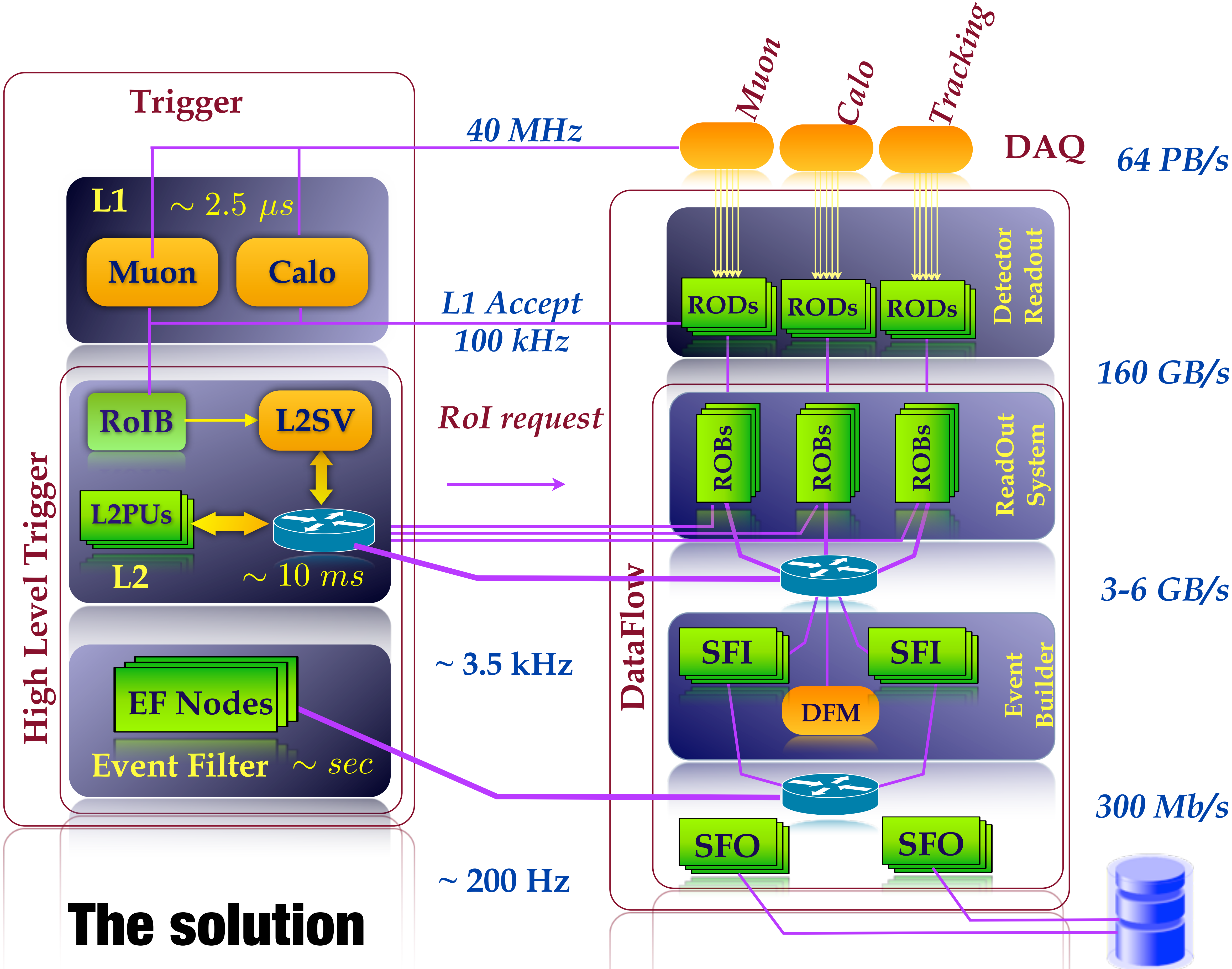
A typically RoI size is $0.1\Delta\eta \times 0.1\Delta\varphi$ (larger for jets)

Based on coarse, fast information

Identify Regions based on local areas of activity at Level-1 (L1) and pass on to Level-2 (L2)

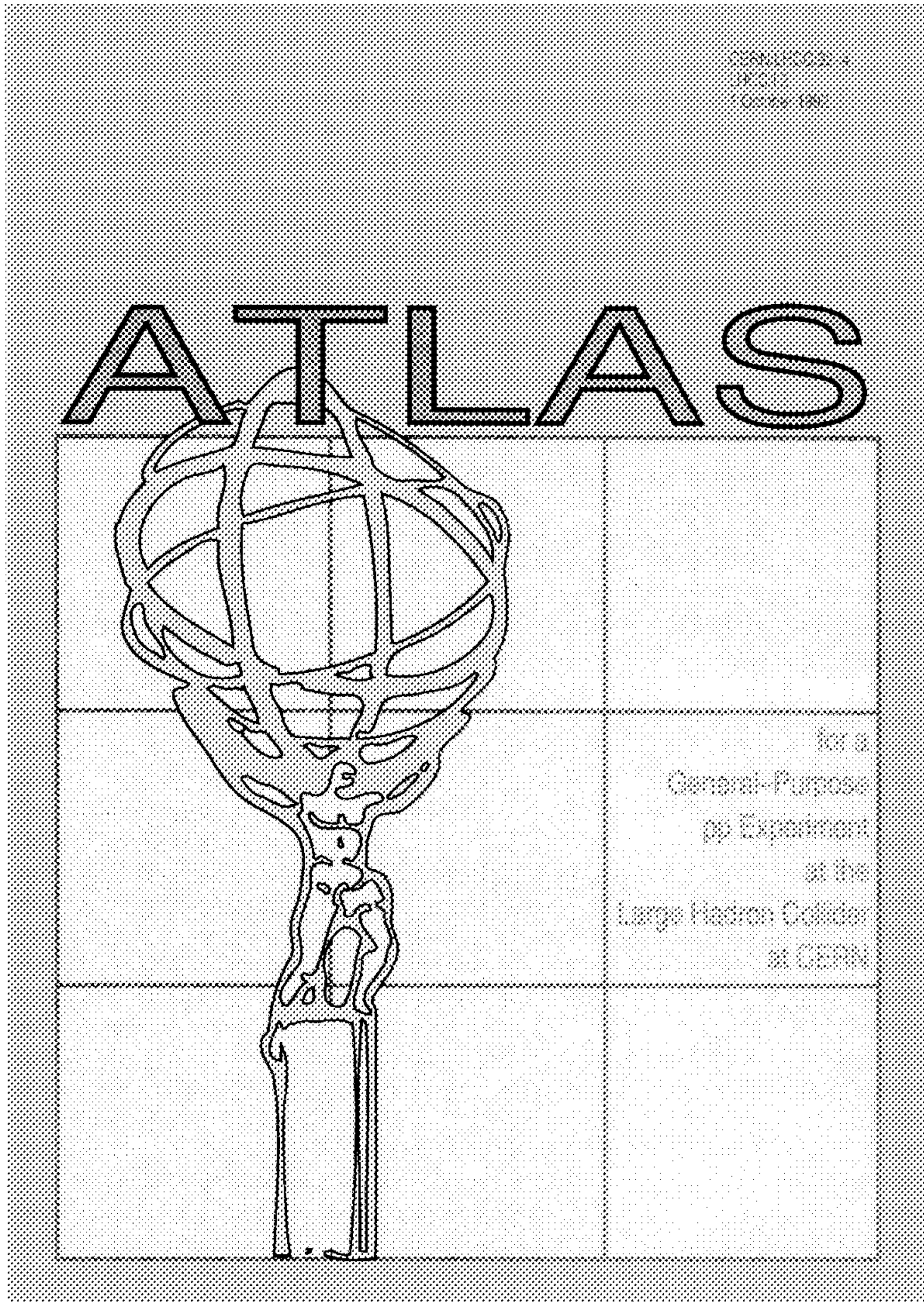
Only RoI data sent to next trigger level to reduces stress on DataFlow





The solution

The starting point ……



CERN/LHCC/92-4
LHCC/I 2
1 October 1992

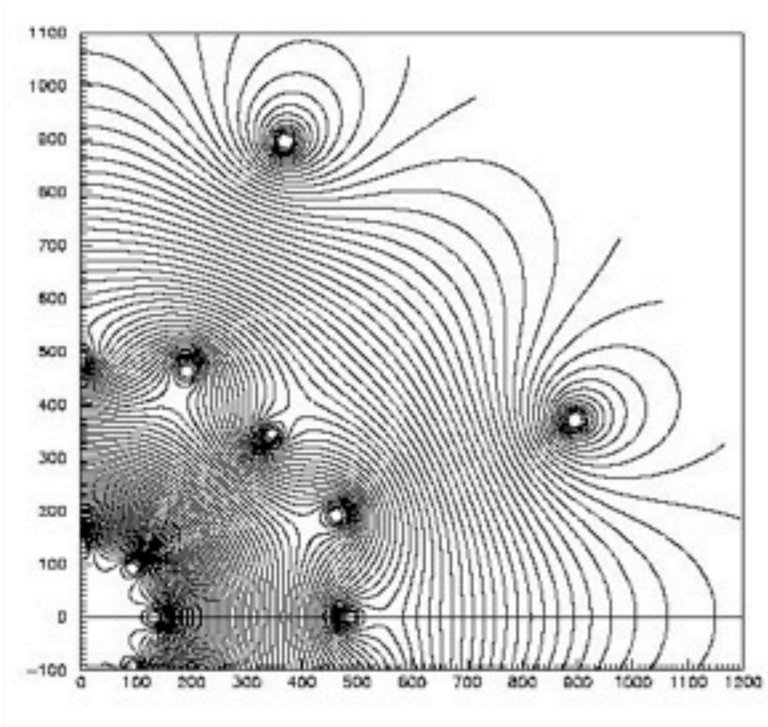
A T L A S

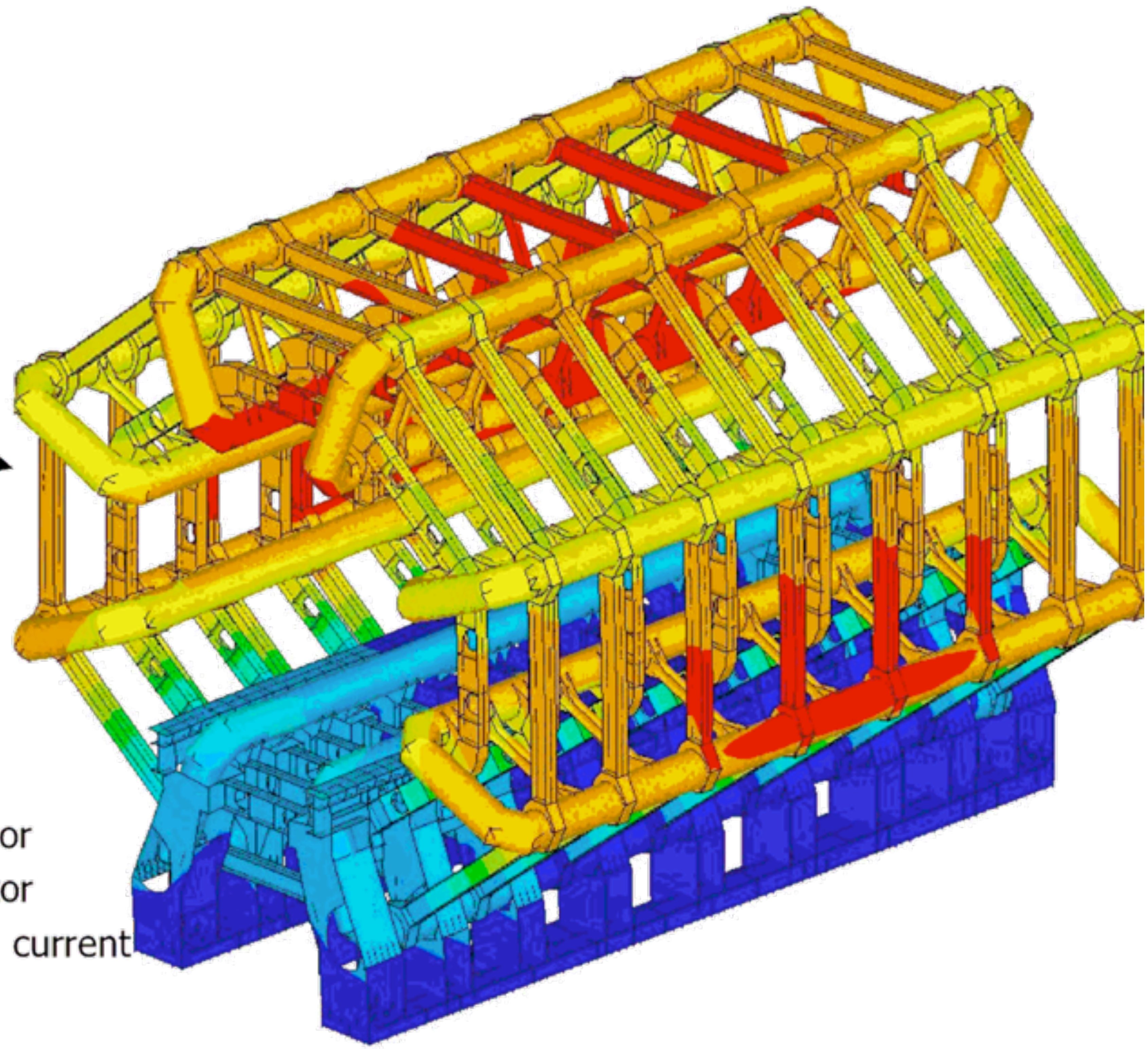
Letter of Intent
for a
General-Purpose pp Experiment
at the
Large Hadron Collider at CERN

Abstract

The ATLAS collaboration proposes to build a general purpose proton–proton detector for the Large Hadron Collider, capable of exploring the new energy regime which will become accessible. The detector would be fully operational at the startup of the new accelerator. The detector concept, the research and development work under way to optimize the detector design, and its proposed implementation are described, together with examples of its discovery potential.

The ATLAS Barrel Toroid





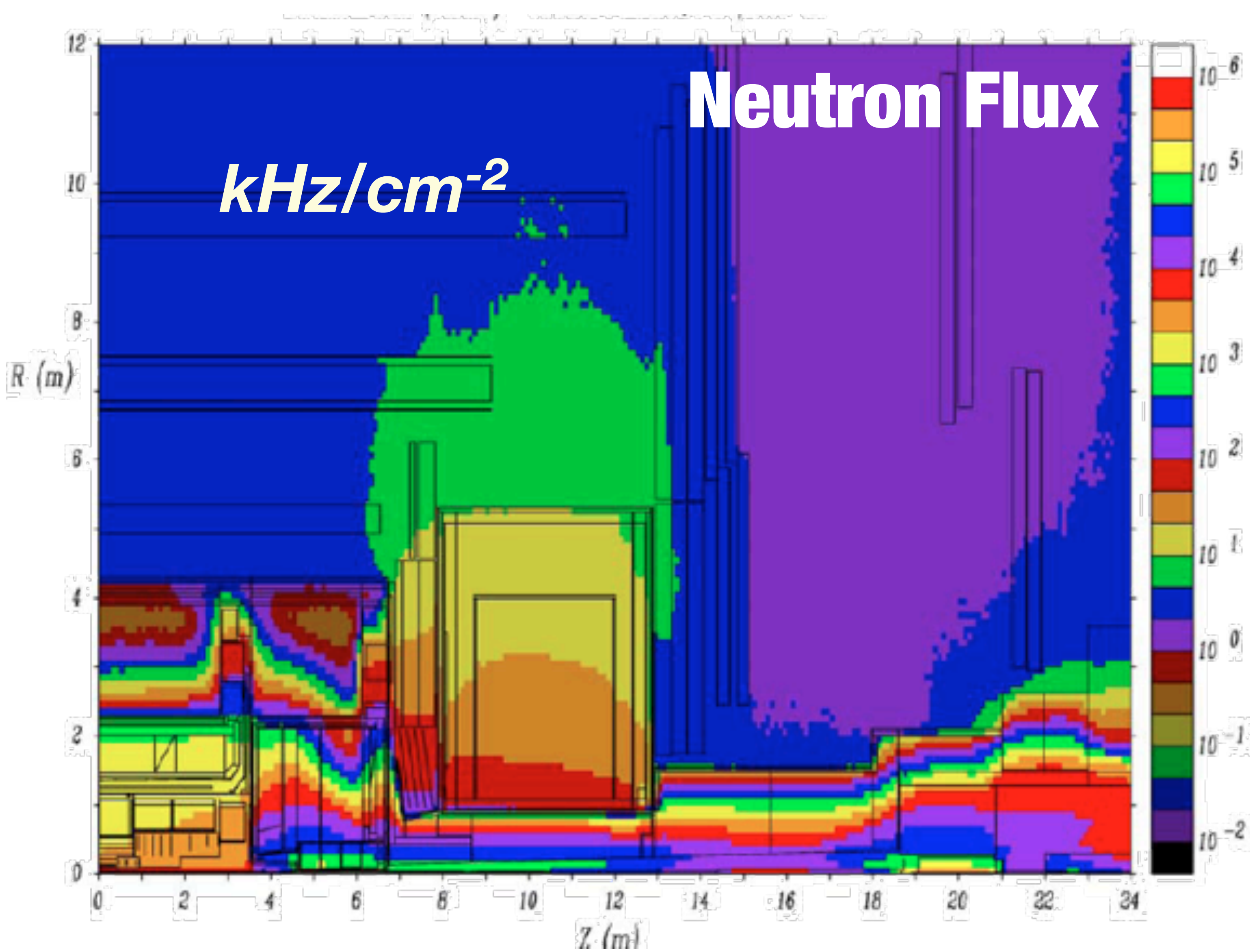
- 25.3 m length
- 20.1 m outer diameter
- 8 coils
- 1.08 GJ stored energy
- 370 tons cold mass
- 830 tons weight
- 118 tons superconductor
- 56 km Al/NbTi conductor
- 20.5 kA @ 4 T nominal current
- 4.5 K working point

ATLAS Muon Trigger Requirements

- ✓ Two threshold regimes for single-muon triggers as the physics suggests
  - pT > 6 GeV for b physics, - Low p_T
  - pT > 20 GeV for heavy object searches - High p_T
- ✓ An high and bias-free single-muon triggering efficiency for a multi-lepton trigger capability
- ✓ Unique Bunch crossing identification
  - LHC Bunch crossing ~ 25 ns
  - Data stamped with LVL1 ID (event ID) and Bunch crossing ID (BCID) fundamental for tagging fragments belonging to the same physic event for subsequent event building
- ✓ Trigger resolution < 4 ns
- ✓ Rough muon p_T-measurement, on a time-scale of < 2 μs (LVL1 Latency)

ATLAS Muon Trigger Requirements

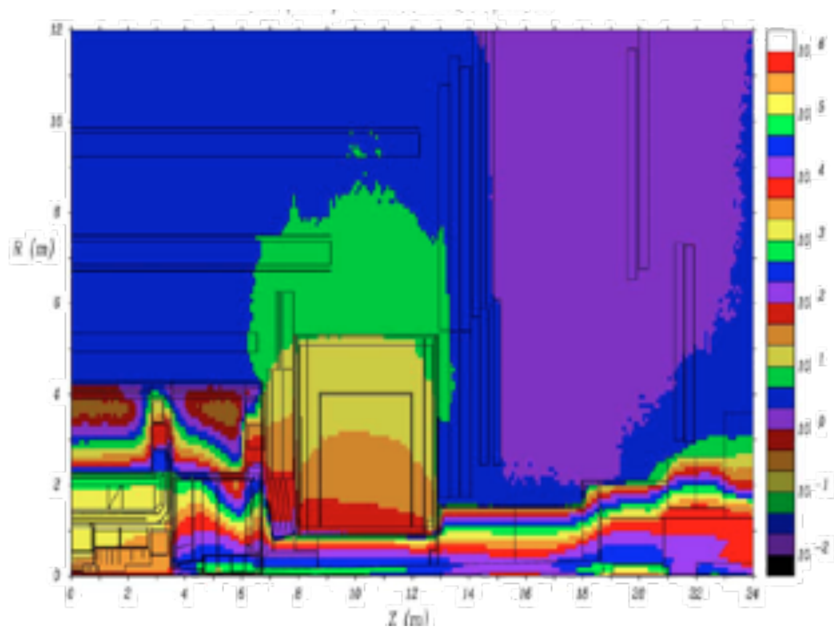
Safe operation in high background condition



- At the nominal LHC luminosity, the expected counting rate
  - 10 Hz/cm^2 in the barrel region
  - few kHz/cm^2 in the very forward regions.

- The interaction of protons with the beam pipe, the forward calorimeters and the machine elements will produce neutrons with a wide energy spectrum
- This background particle flux behaves like a “gas”
- Neutrons Emission of photon with energy of the order of 100 keV to few MeV by nuclei capture.
- Photons converted in electrons via Compton effect are detected in the muon chambers.

ATLAS Muon Trigger Requirements



Radiation Background rate determines

- The sharpness of the trigger efficiency curve,
- the rate of genuine and accidental muon triggers,
- the number of trigger planes and their granularity

- To reduce further the rate of accidental coincidences, the **trigger is implemented in two projections, (r–z) and (r–φ)**;
- therefore, the **trigger system also provides the measurement of track coordinates in the 'non-bending' (r–φ) projection.**
- The granularity in the latter projection affects the accidental trigger rate and the second-coordinate resolution.

The Choice of the detector

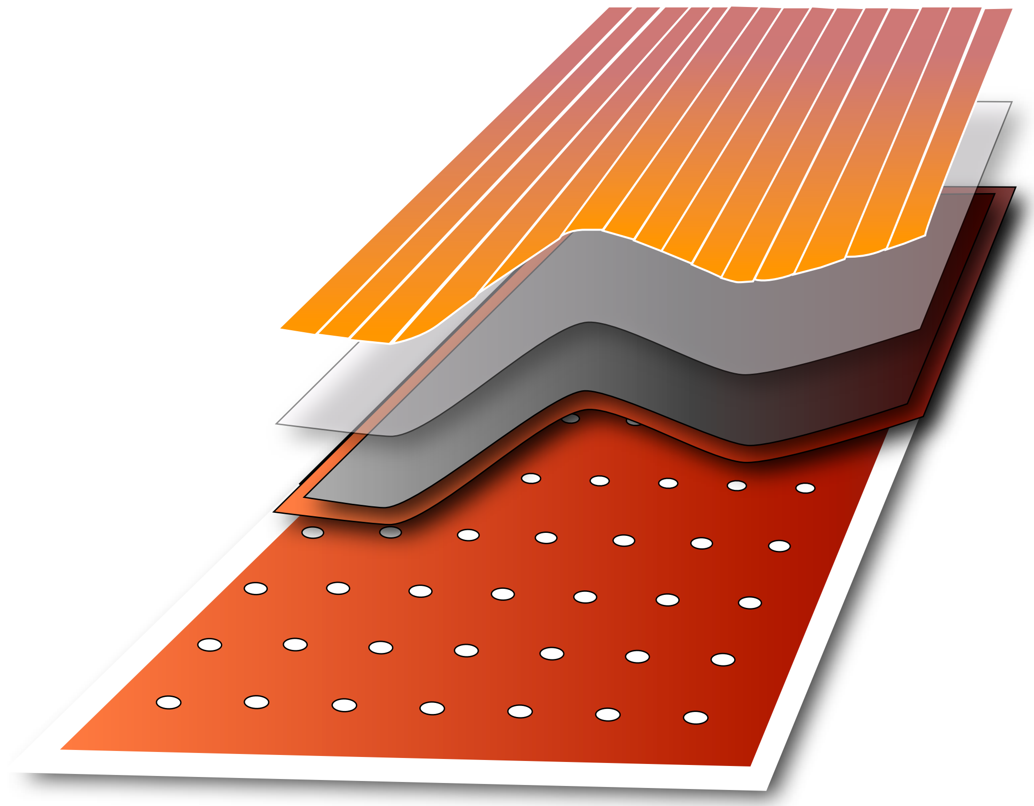
✓ Have a good time resolution <5 ns

✓ Good spatial resolution

✓ Low sensitivity to Neutron and Gamma

✓ Cheap for large area

Resistive Plate Counter Detector



RPC detector

- The principle of operation
- The characteristic
- The ATLAS RPC

Spark Counters

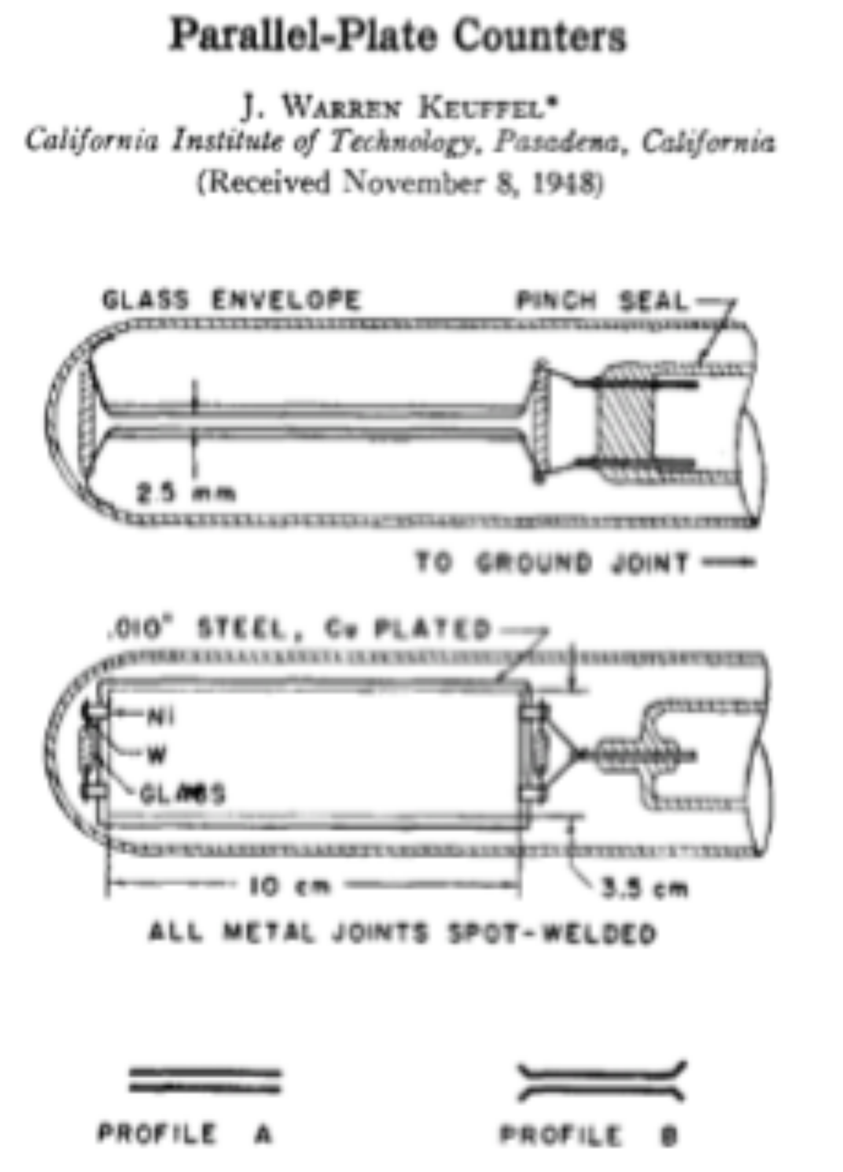
Keuffel 'Spark' Counter:

High voltage between two metal plates. Charged particle leaves a trail of electrons and ions in the gap and causes a discharge (Spark).

⇒ **Excellent Time Resolution(<100ps).**

Discharged electrodes must be recharged

⇒ **Dead time of several ms**.



Parallel Plate Avalanche Chambers (PPAC):

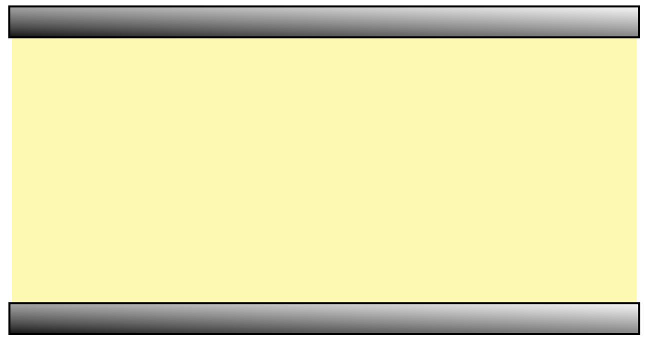
At more moderate electric fields the primary charges produce avalanches without forming a conducting channel between the electrodes.

No Spark ⇒ induced signal on the electrodes.

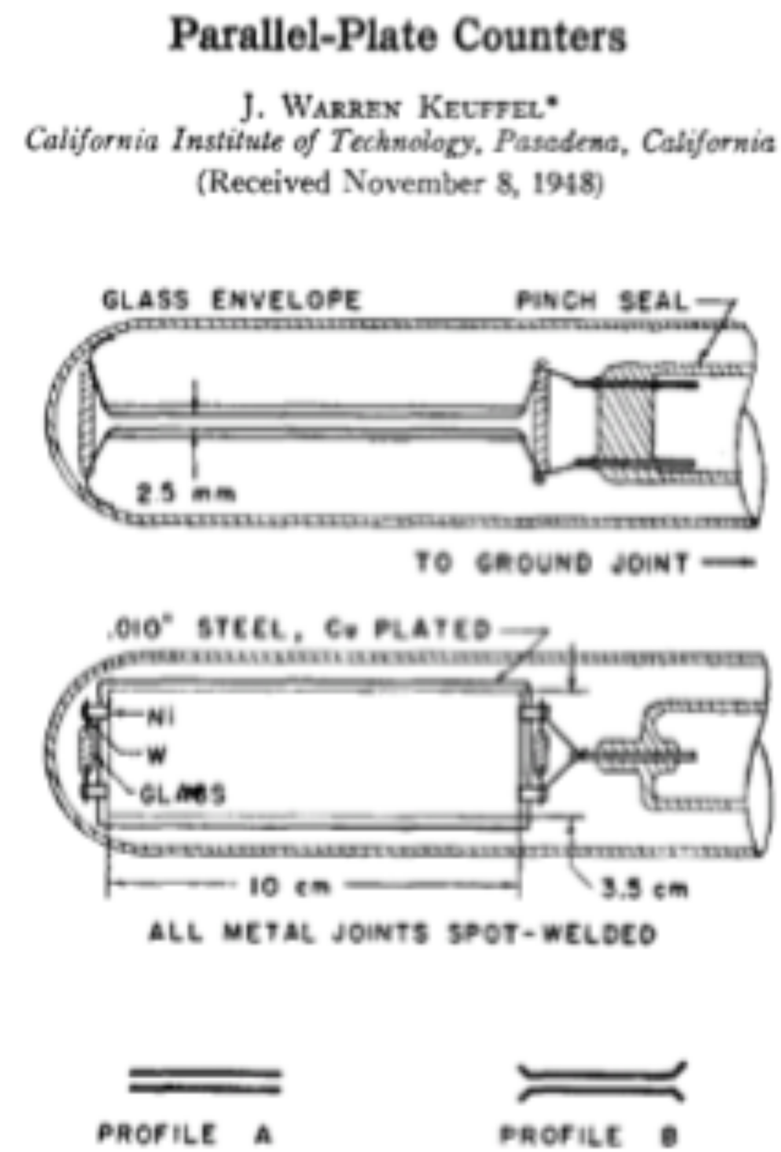
⇒ **Higher rate capability.**

However, the smallest imperfections on the metal surface cause sparks and breakdown.

⇒ **Very small (few cm2) and unstable devices.**



Spark Counters



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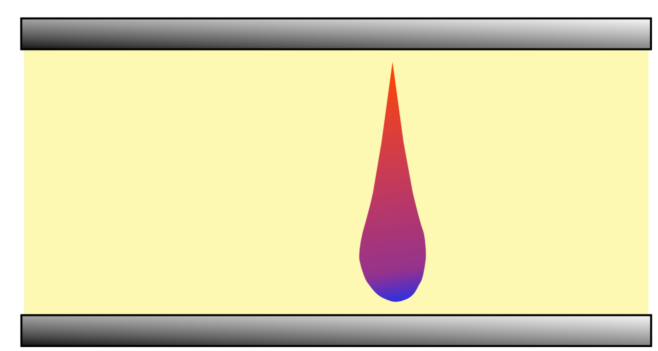


Resistive Plate Chambers (RPCs)

⇒ Place resistive plates in front of the metal electrodes.

No spark can develop because the resistivity together with the capacitance will only allow a very localized 'discharge'. The rest of the entire surface stays completely unaffected.

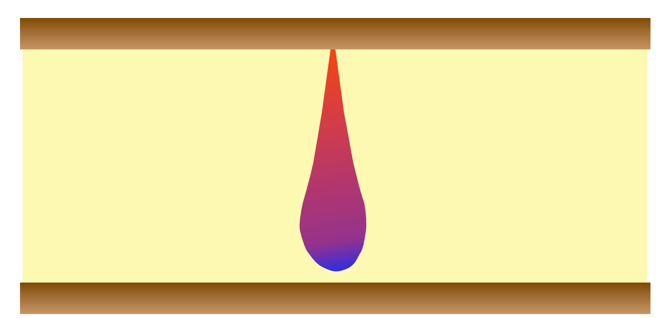
⇒ Large area detectors are possible !

Resistive plates from
Bakelite ($\rho = 10^{10}$-10^{12} Ωcm) or
Window glass ($\rho = 10^{12}$-10^{13} Ωcm).

Gas gap: 0.25-2mm.
Electric Fields 50-100kV/cm.
Time resolutions: 50ps (100kV/cm), 1ns(50kV/cm)

Application: Trigger Detectors, Time of Flight (TOF)

Pestov idea: use as anodic electrode a high resistivity glass
Concept extended to RPCs with both electrodes with high resistivity



Principles of operation

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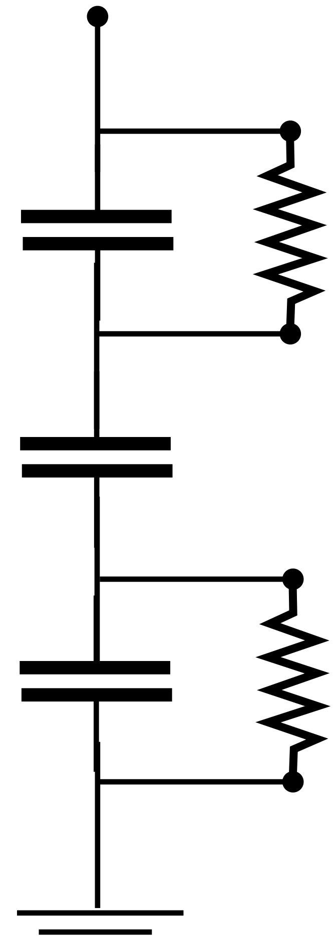

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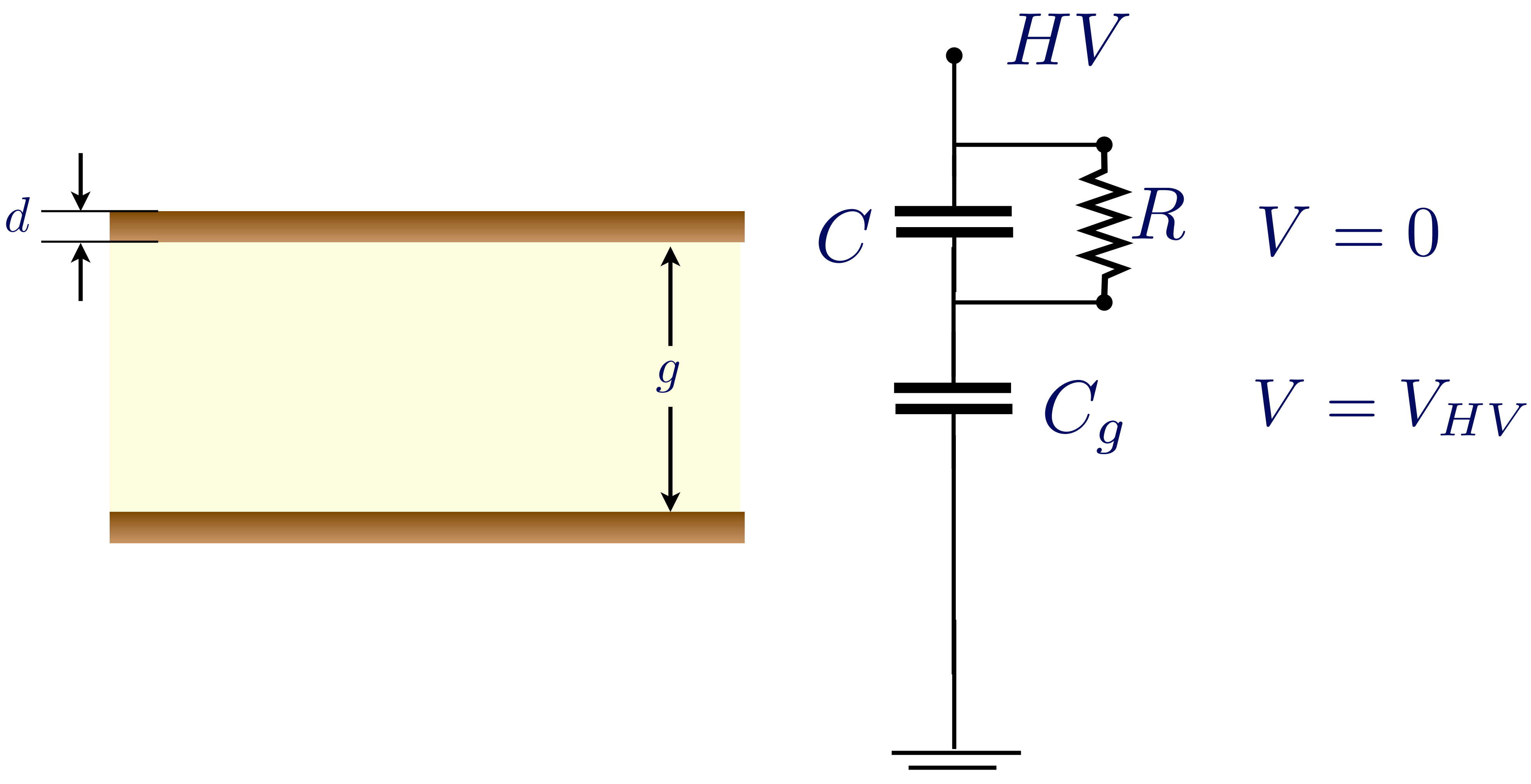

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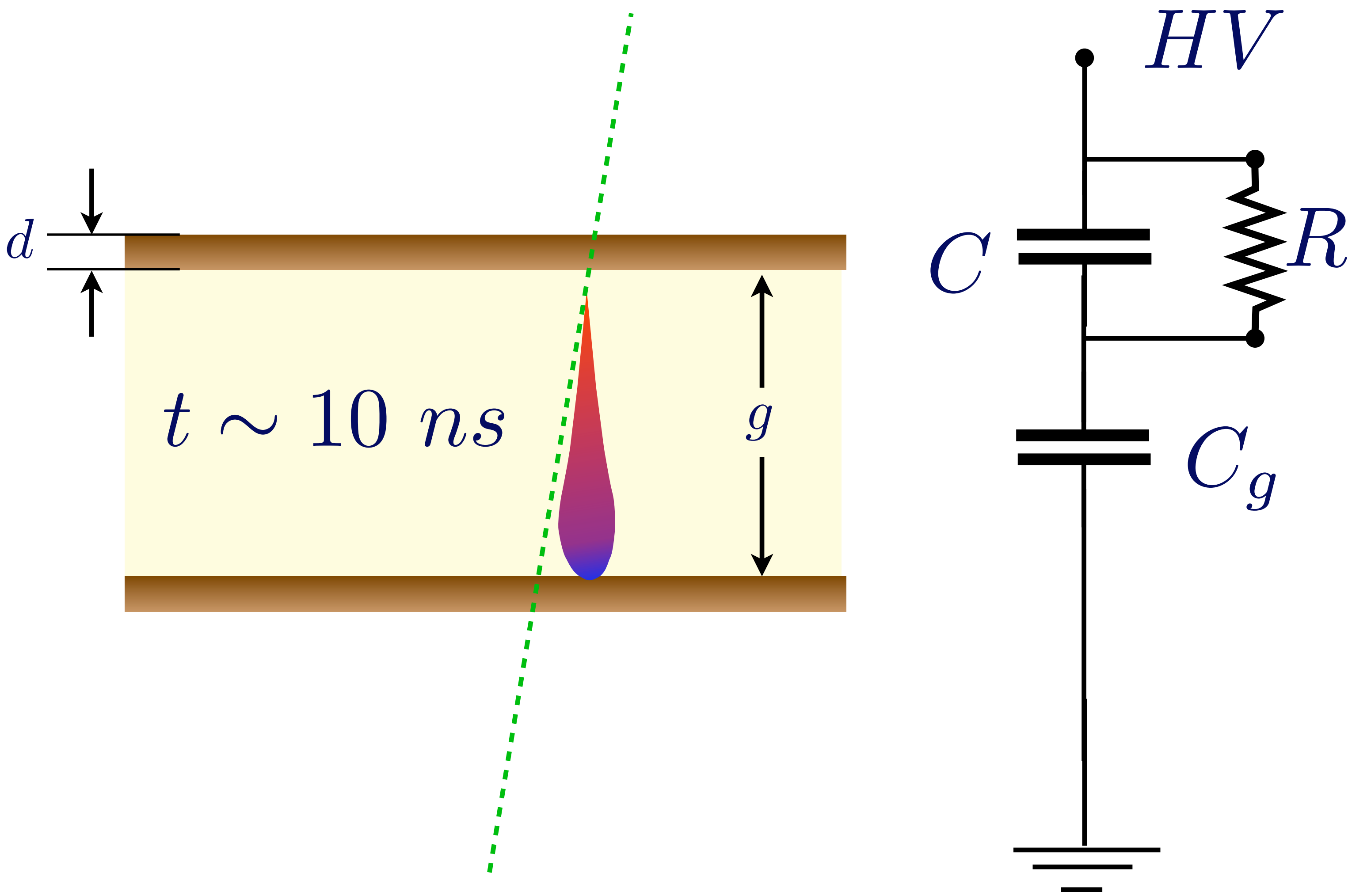

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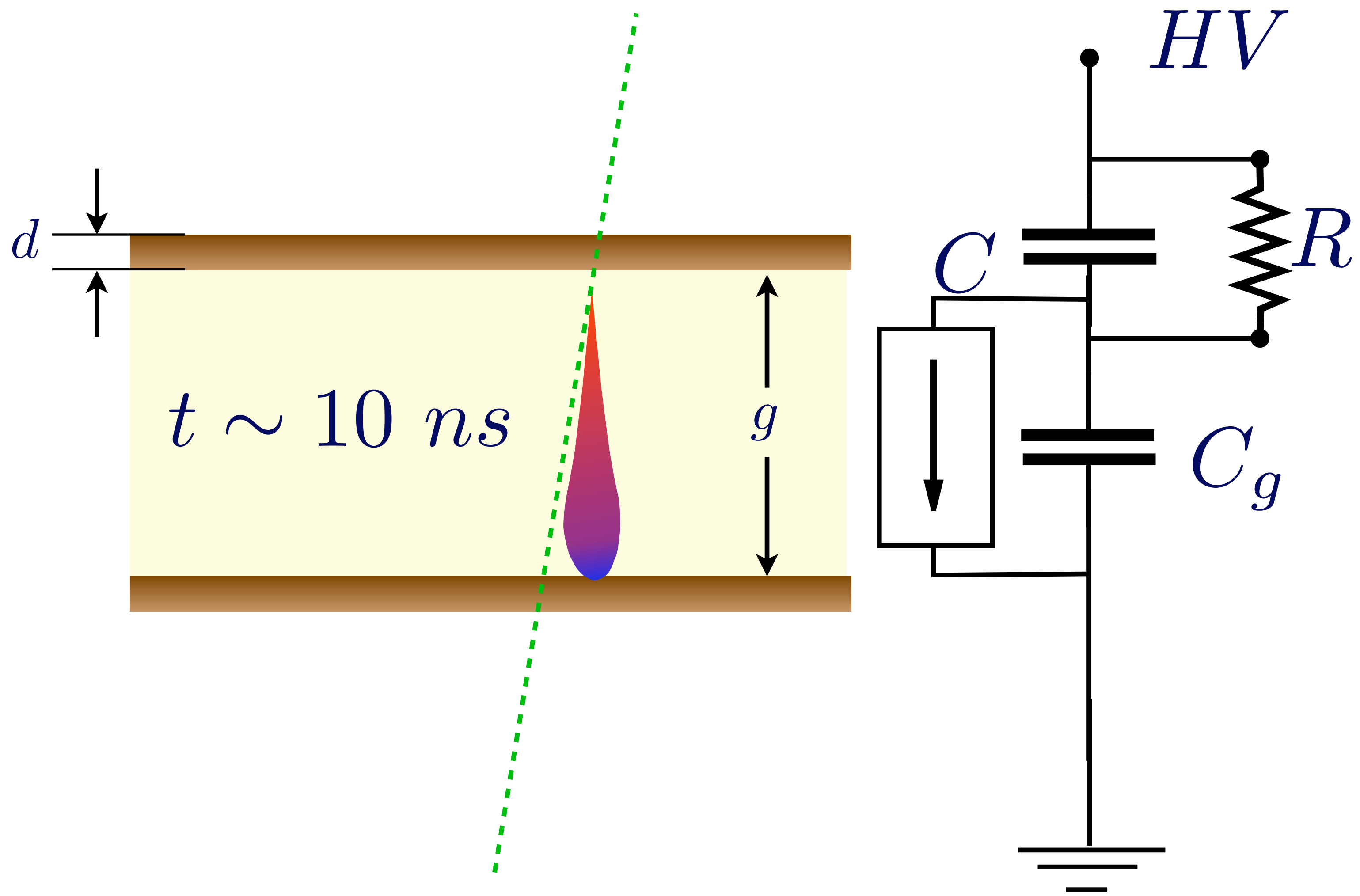

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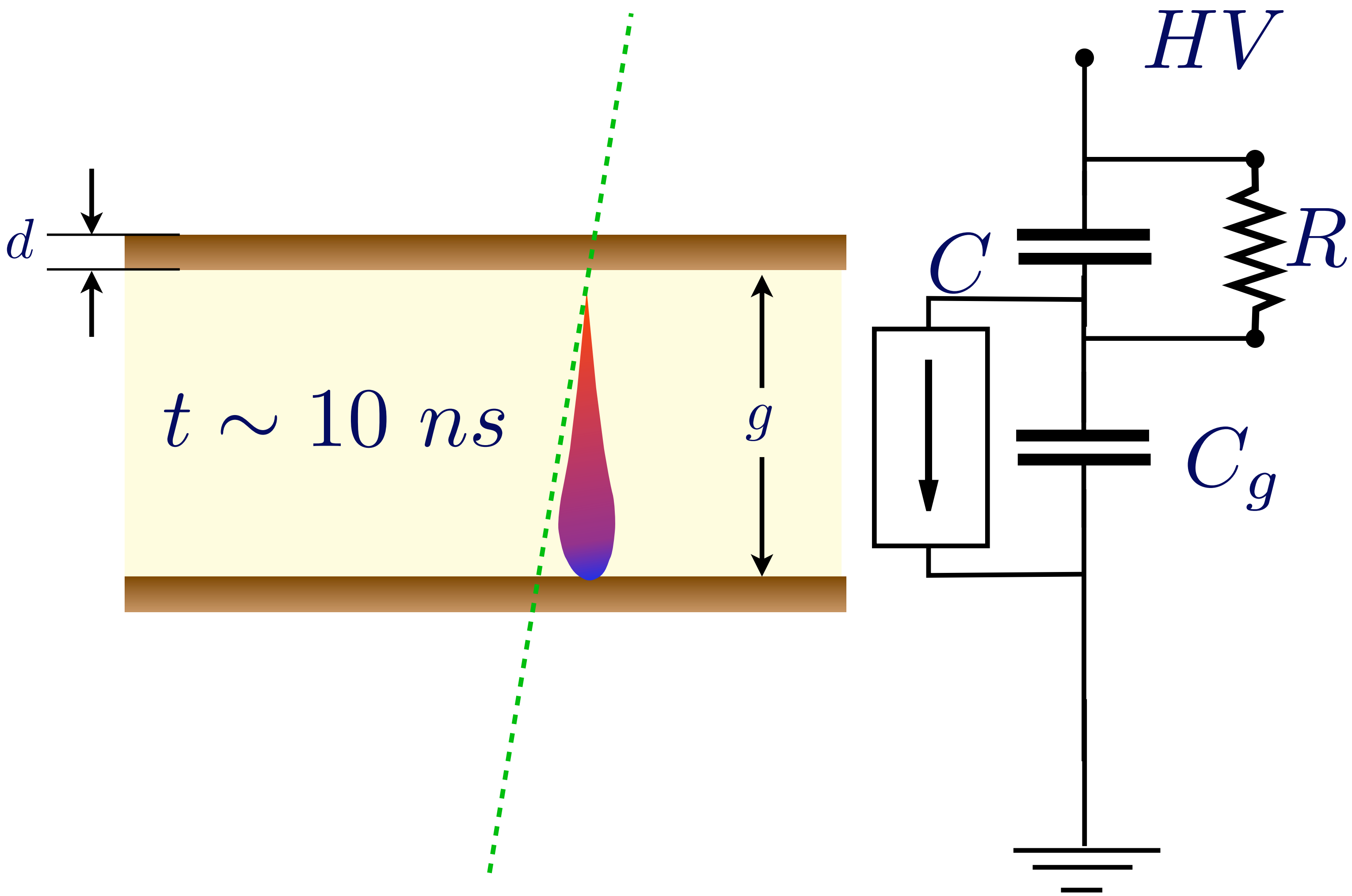
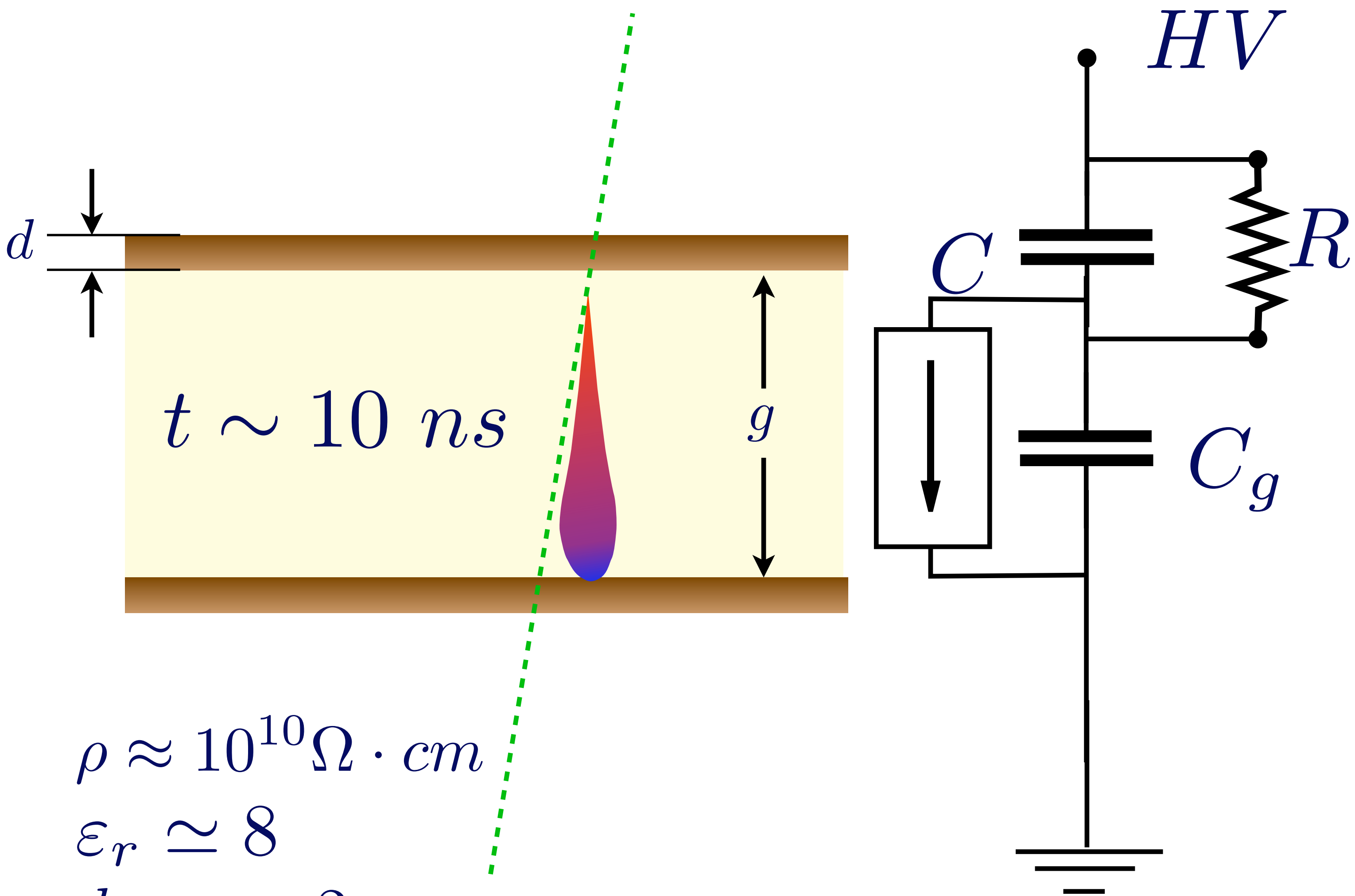


$$\frac{dq_C}{q_C} = \frac{dt}{R(C + C_g)} = \frac{dt}{\tau}$$

Principles of operation



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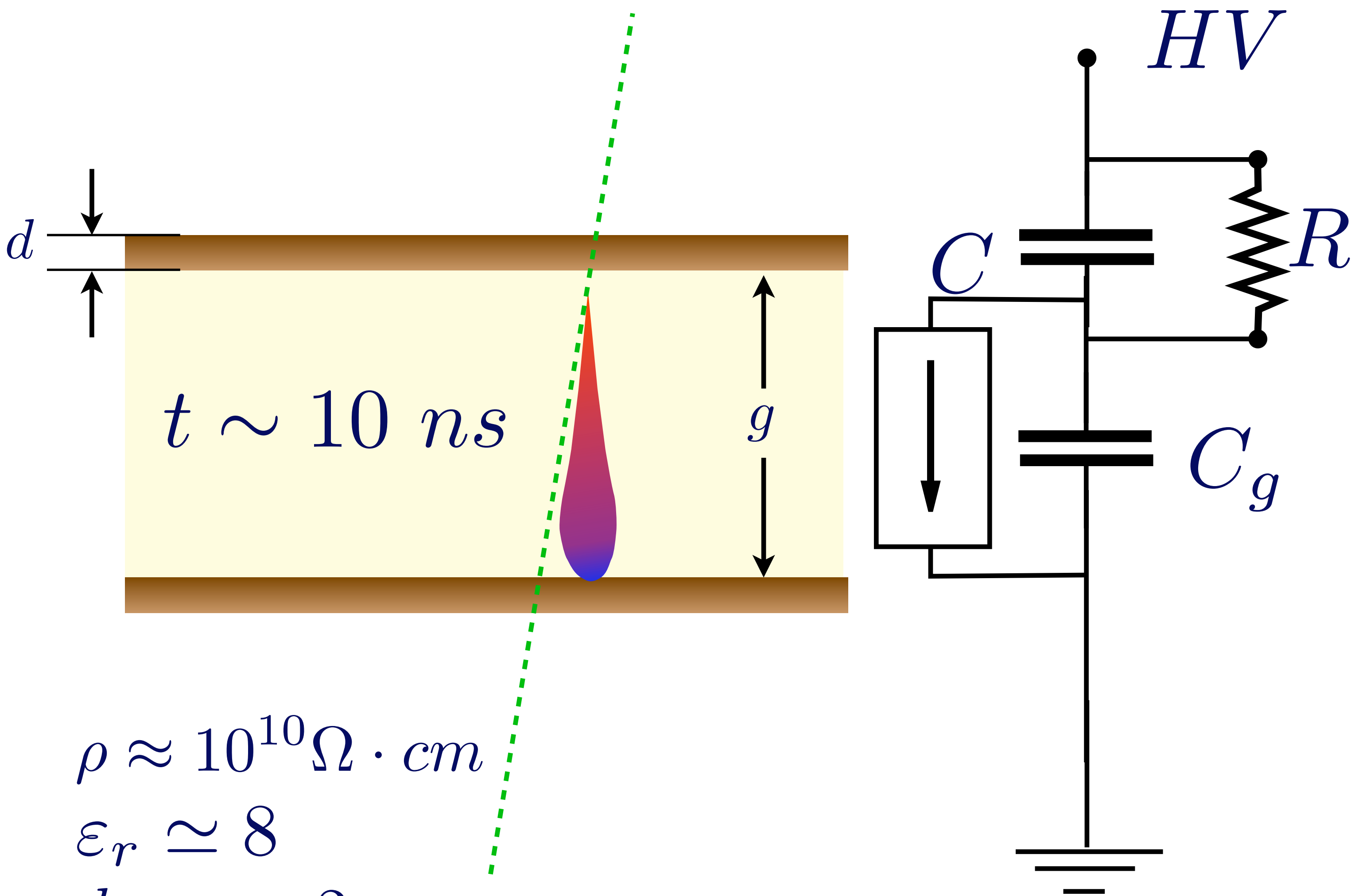
$\rho \approx 10^{10}\Omega \cdot cm$
$\varepsilon_r \simeq 8$
$d = g = 2\ mm$

$$\tau = \rho\frac{2d}{S}\left(\frac{\epsilon S}{2d} + \frac{\epsilon_0 S}{g}\right) = \rho\epsilon_0\left(\epsilon_r + \frac{2d}{g}\right)$$

Principles of operation



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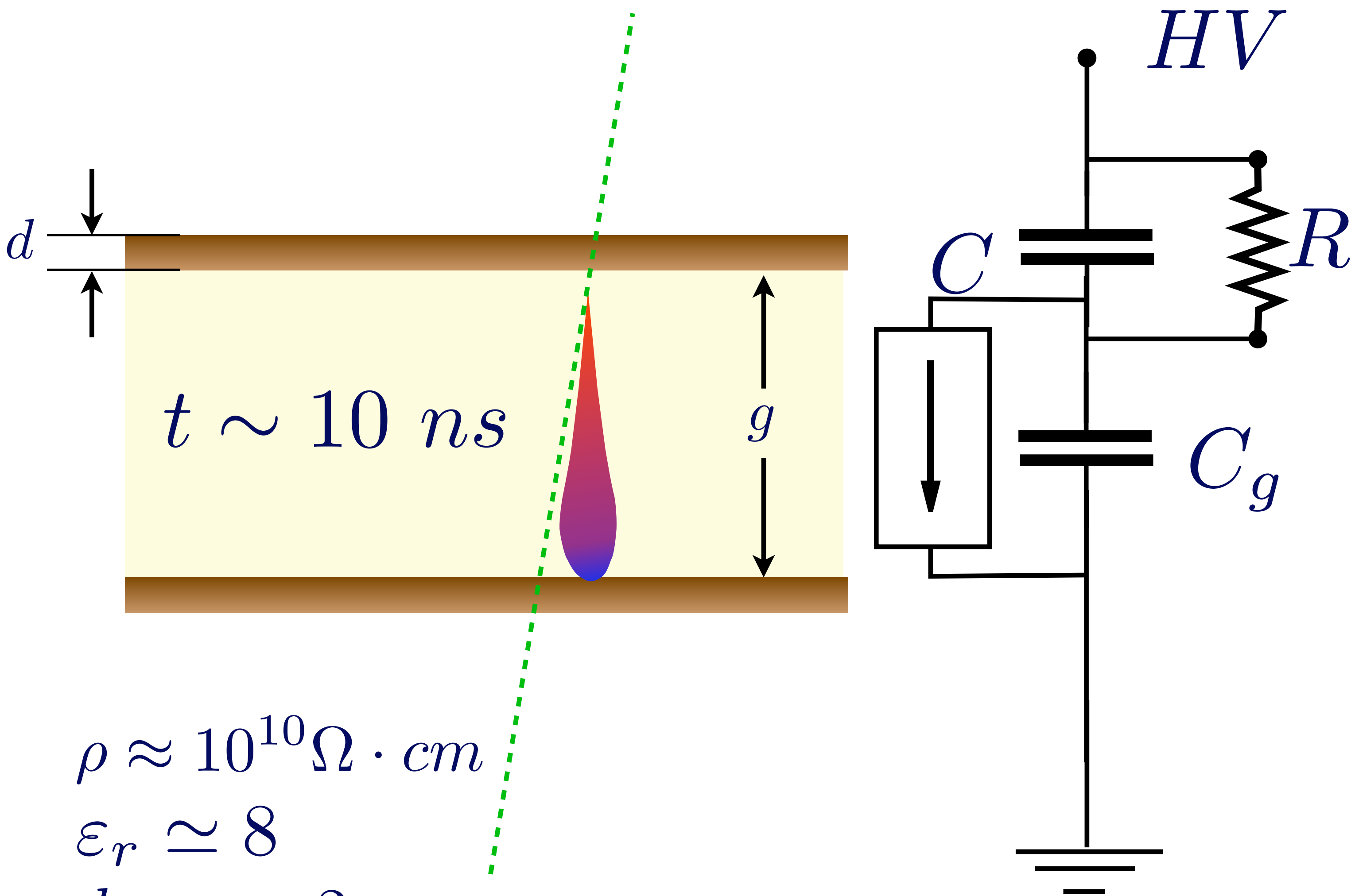
$$\tau \sim 10\ ms$$

Principles of operation



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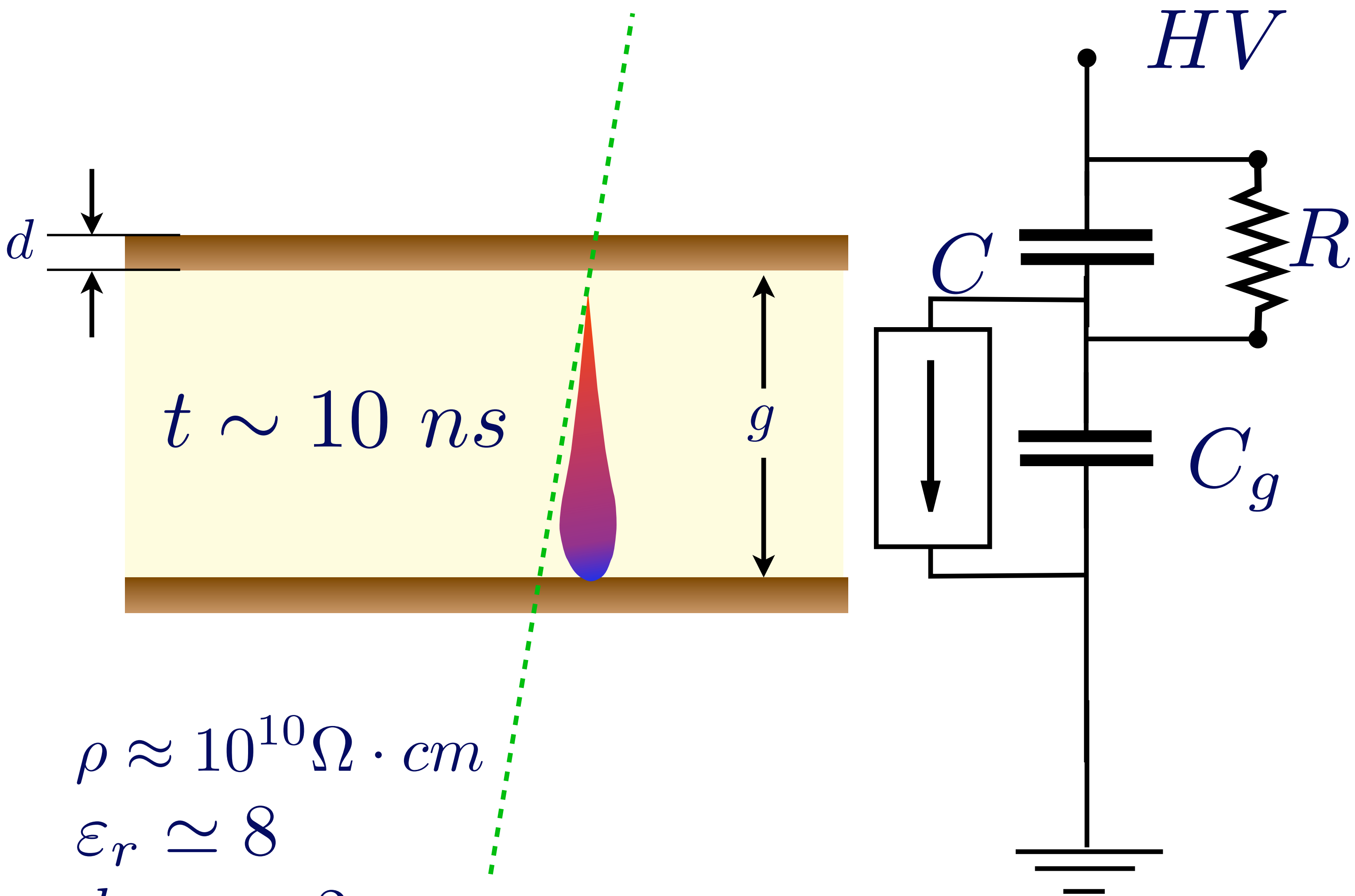
$$\tau \propto \rho$$

Principles of operation



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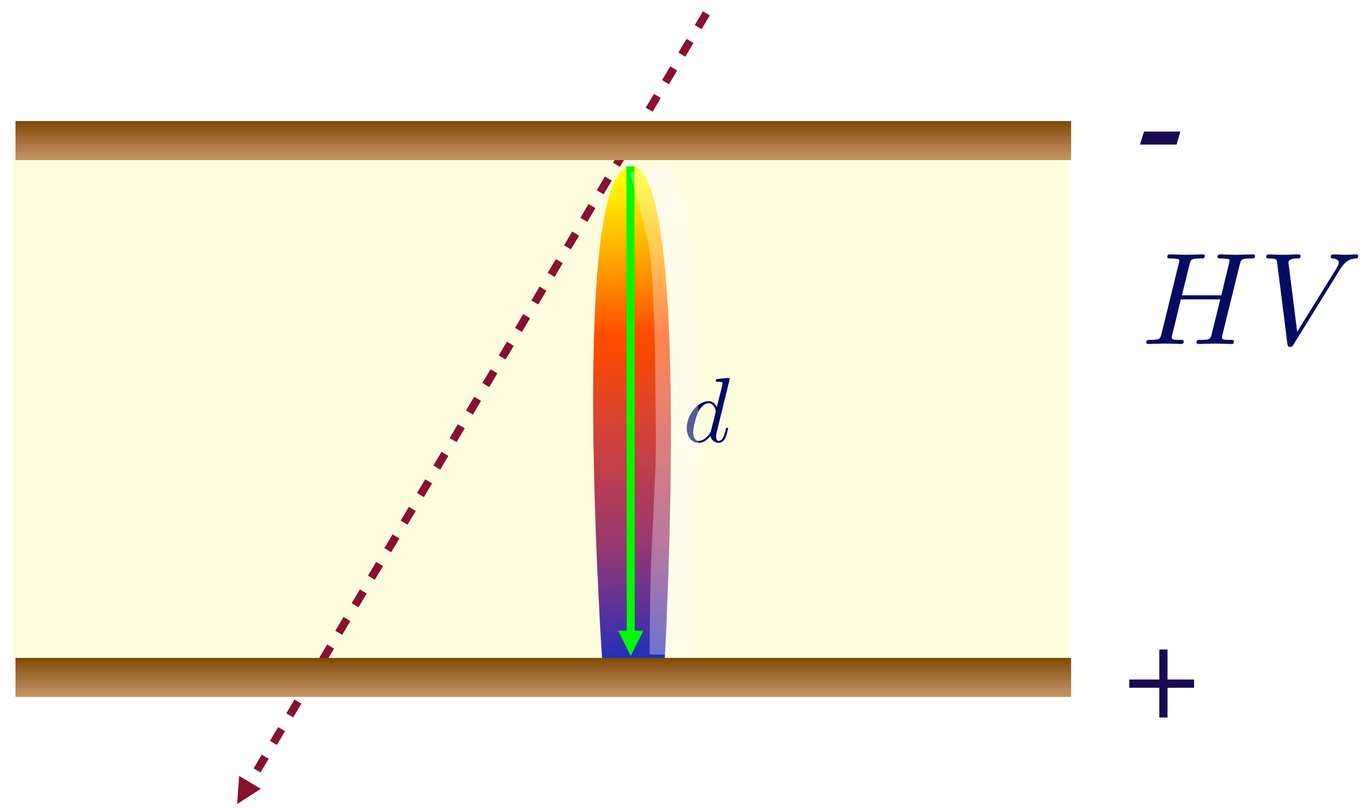
$$\tau \sim 10\ ms$$

$\tau \propto \rho$ ***High Resistivity limits Rate Capability***

Ionization regimes

Depending on the applied Voltage different ionization regimes are possible.

- Avalanche
- Multi avalanche
- Streamer



$$dn = n\frac{dx}{\lambda} = n\alpha dx$$

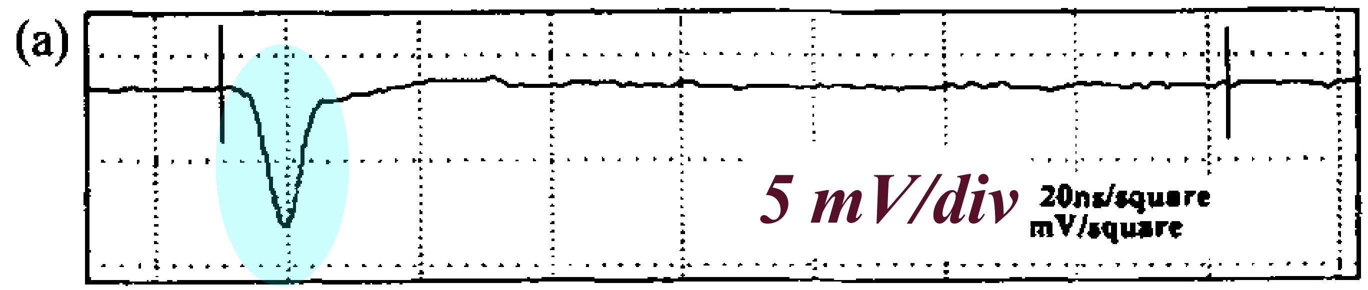
$$N = n_0 e^{\alpha x} = n_0 e^{\alpha v_d t}$$

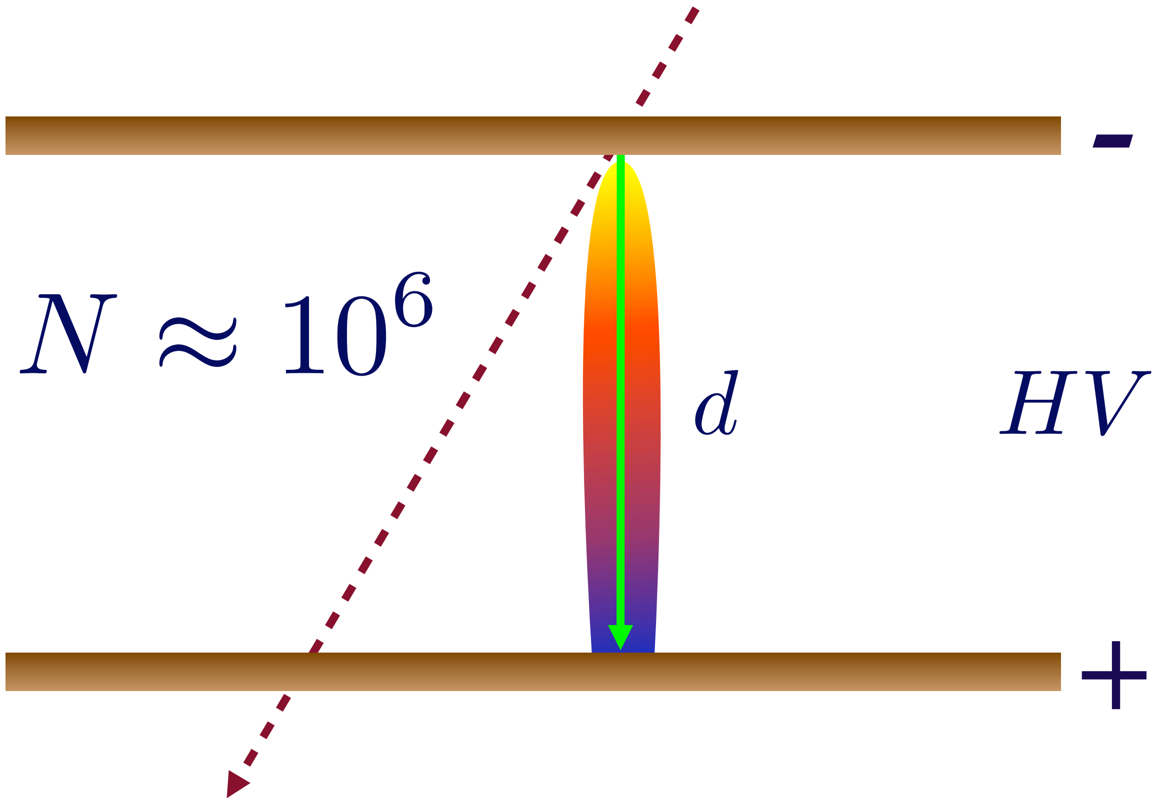
λ ***electron mean free path***

α ***first Townsend coefficient***

v_d ***drift velocity***

Saturated Avalanche

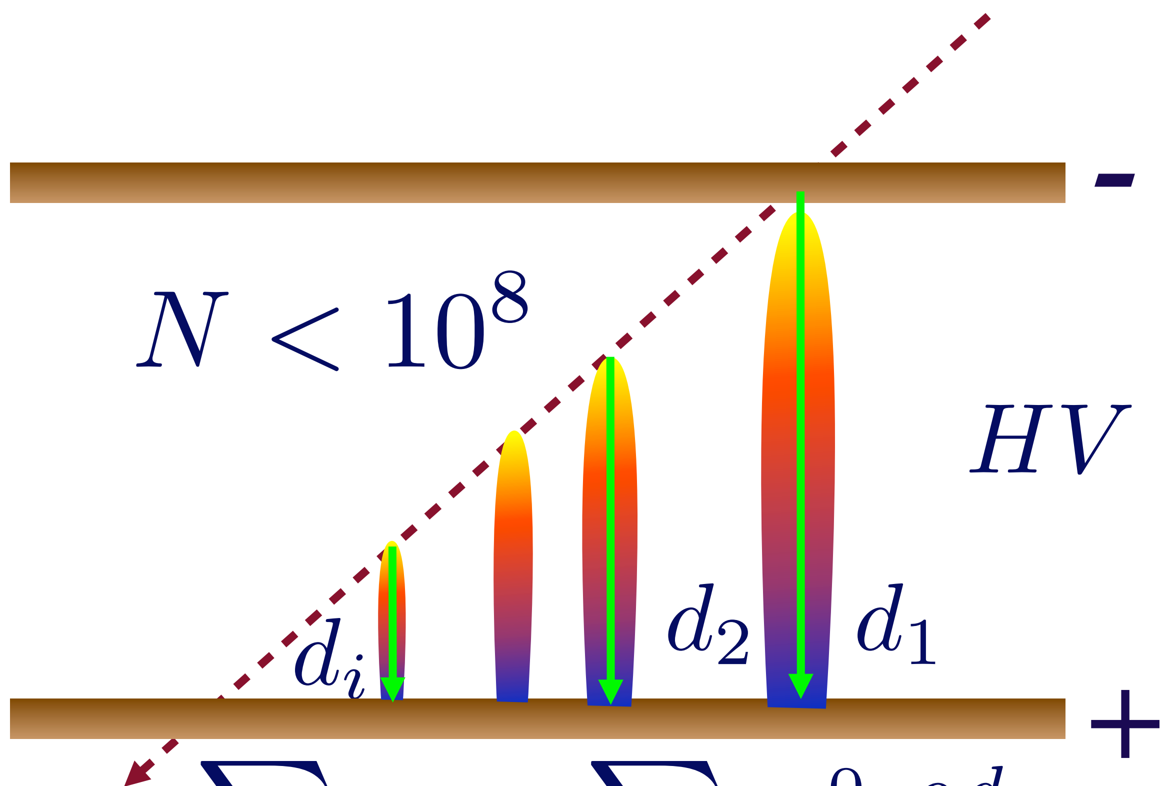




Saturated avalanche

Prompt Charge (pC):	*0.1÷1*
Pulse Width (ns):	*1÷2*
Pulse Height (mV):	*0.5÷2.5*
Spot dimension	*~ mm²*

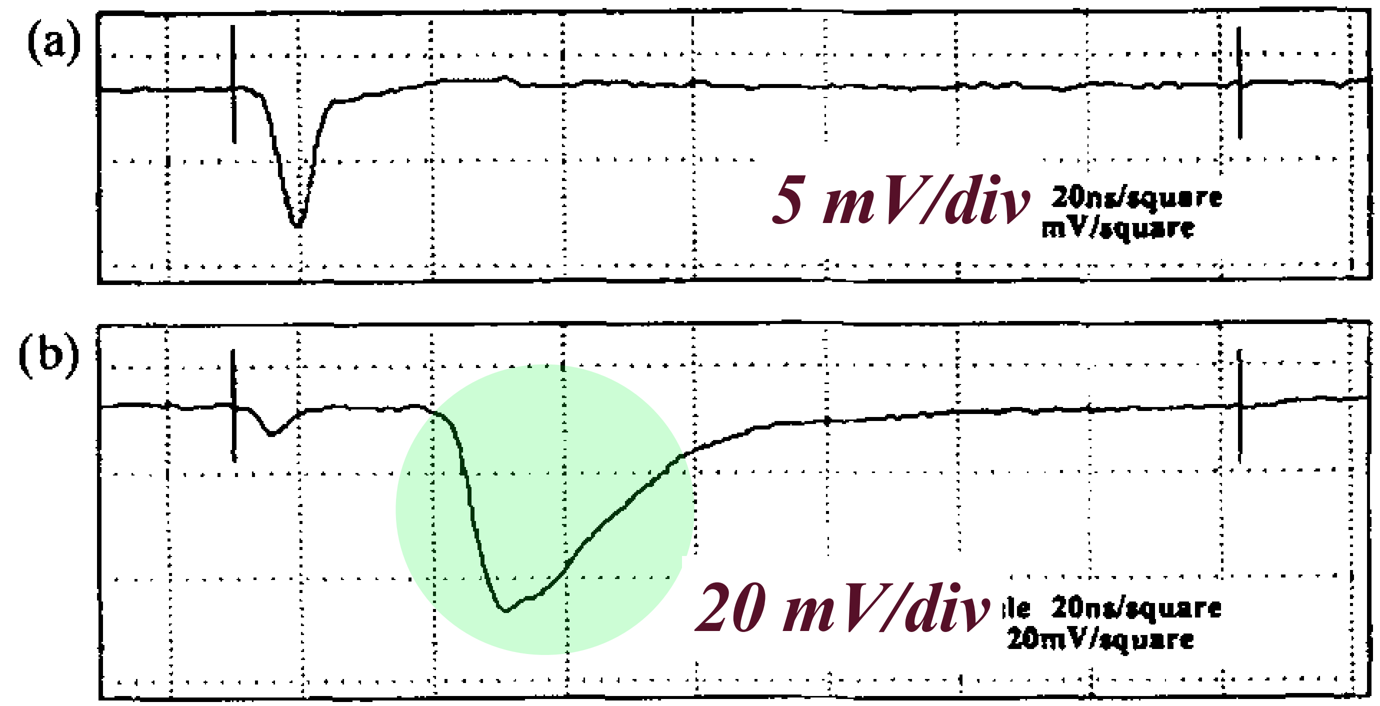
Multi Avalanche



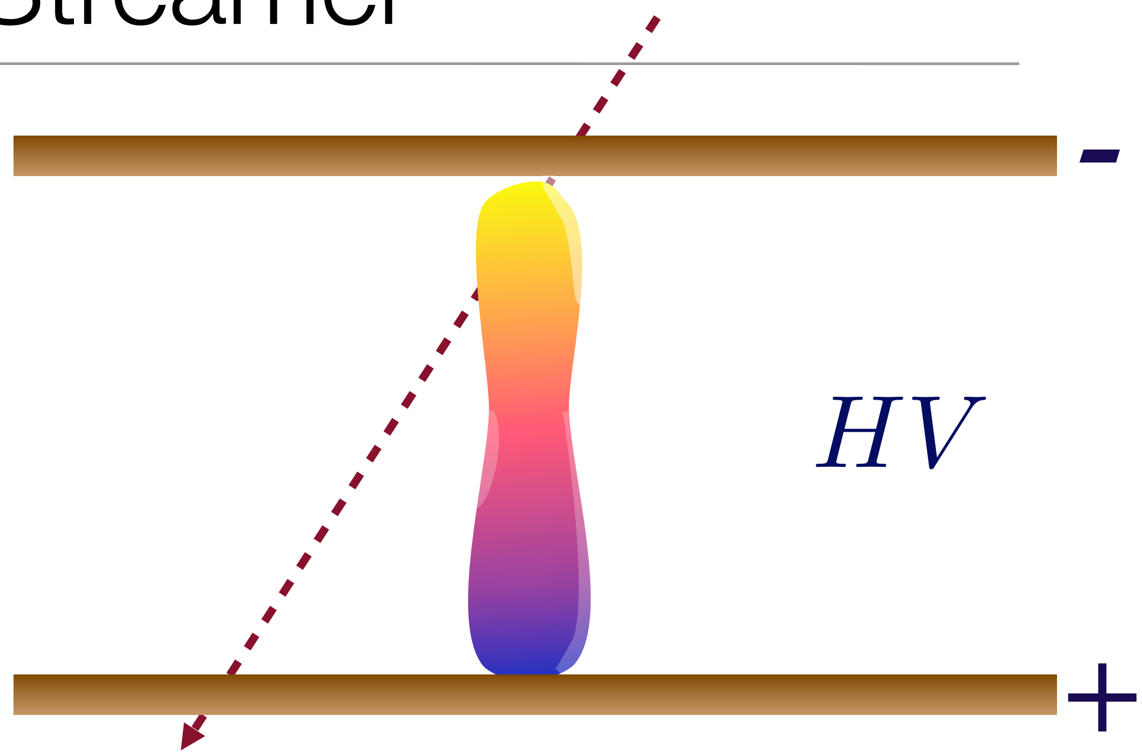
$$\sum_i N_i = \sum_j N_i^0 e^{\alpha d_j}$$

Multi-avalanche

Prompt Charge (pC):	*1÷5*
Pulse Width (ns):	*3÷5*
Pulse Height (mV):	*2.5÷10*
Spot dimension	*~10 mm²*



Streamer



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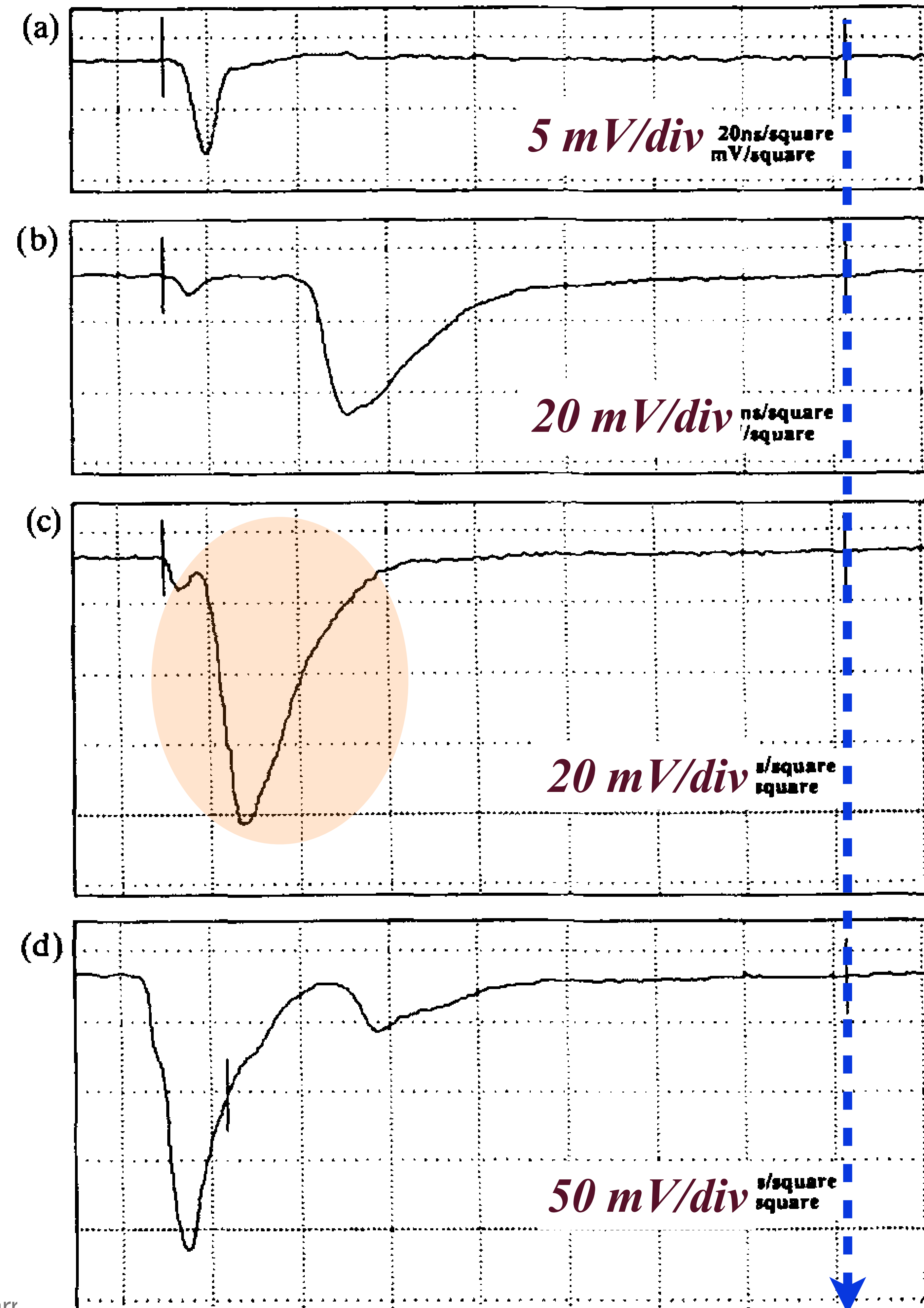
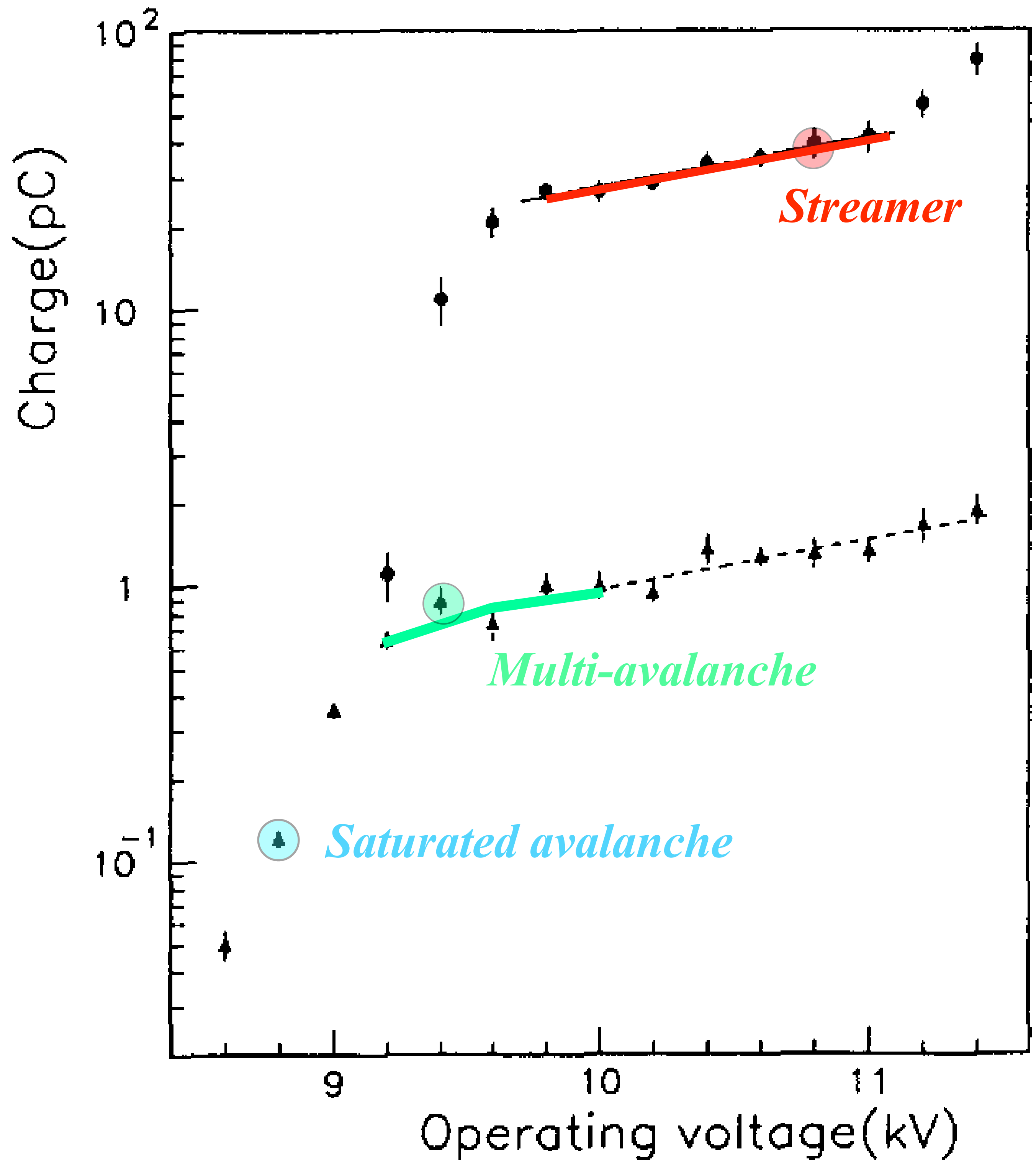


Prompt Charge (pC):	*50÷100*
Pulse Width (ns):	*30÷70*
Pulse Height (mV):	*100÷300*
Spot dimension	*~ cm²*

Gas Mixture

$C_2H_2F_4/C_4H_{10} \quad 95\%/5\%$



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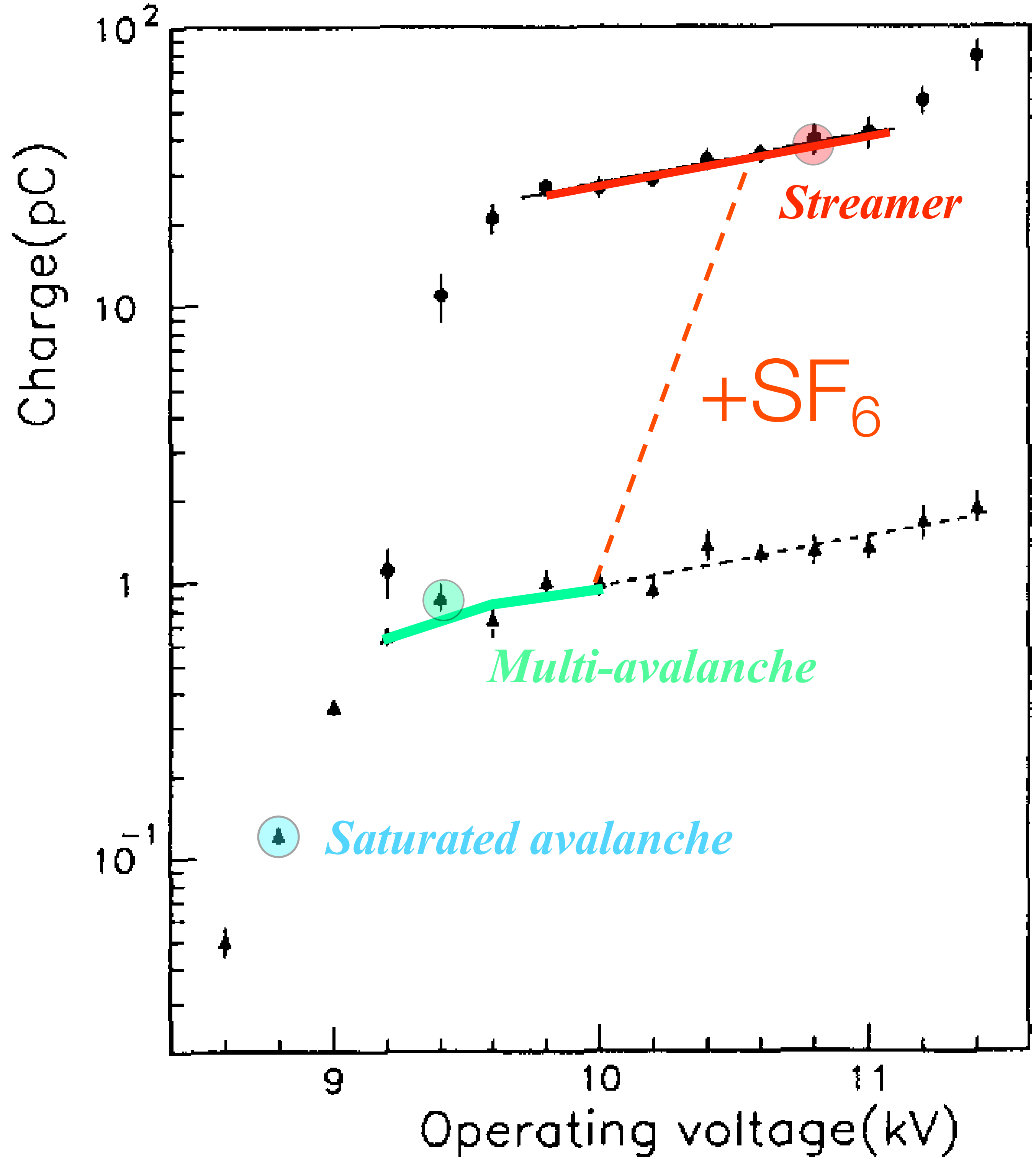

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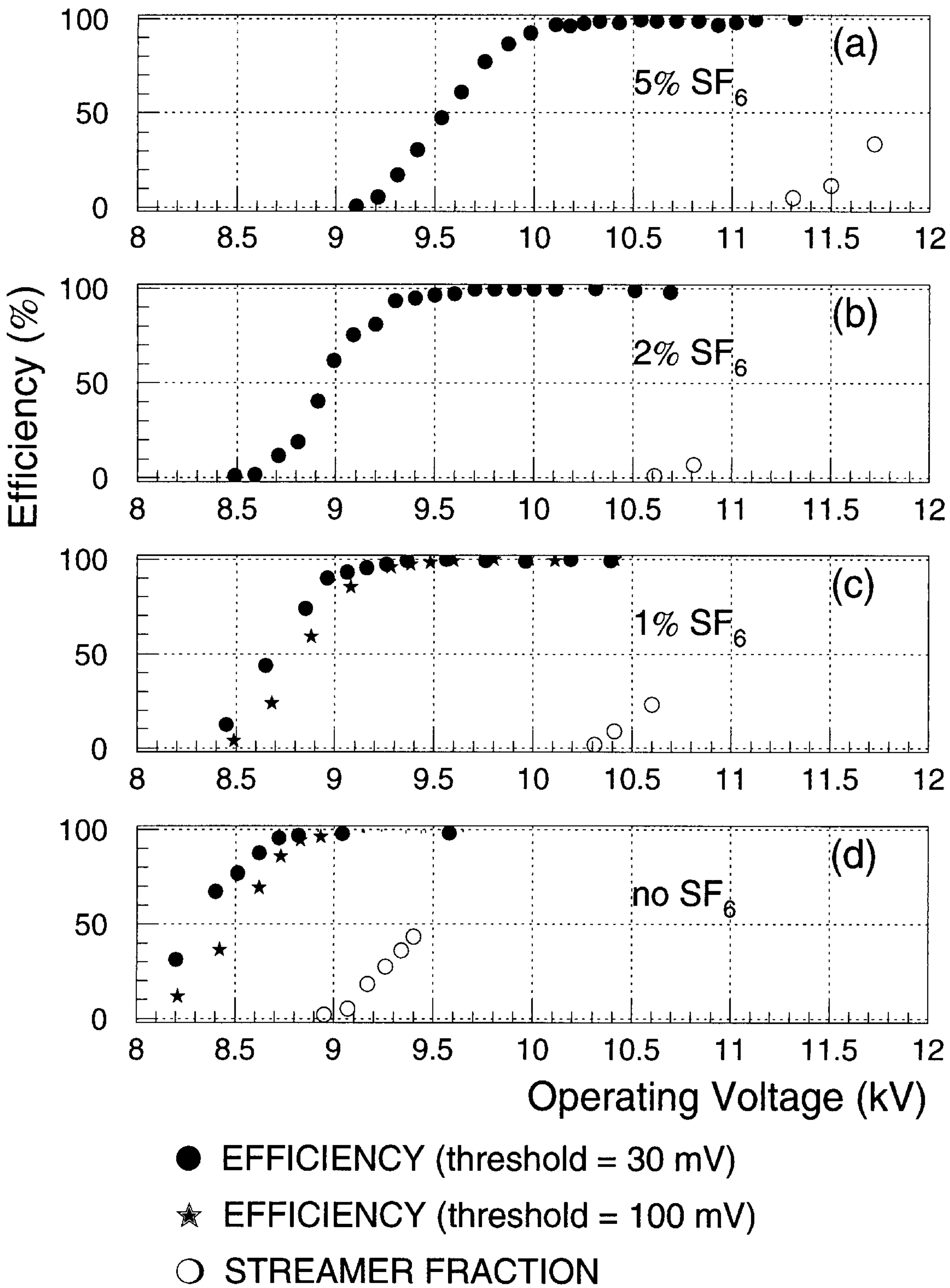

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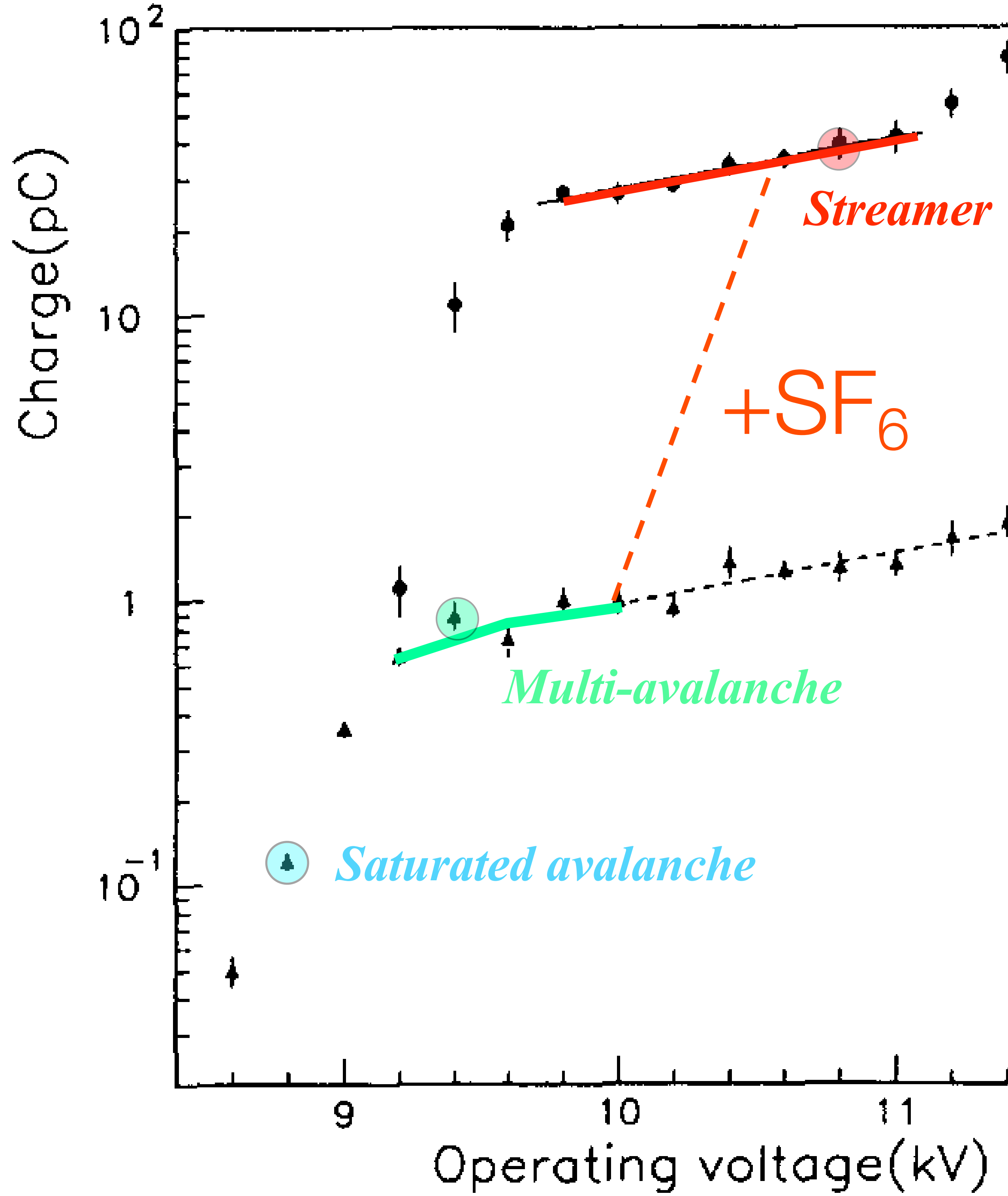
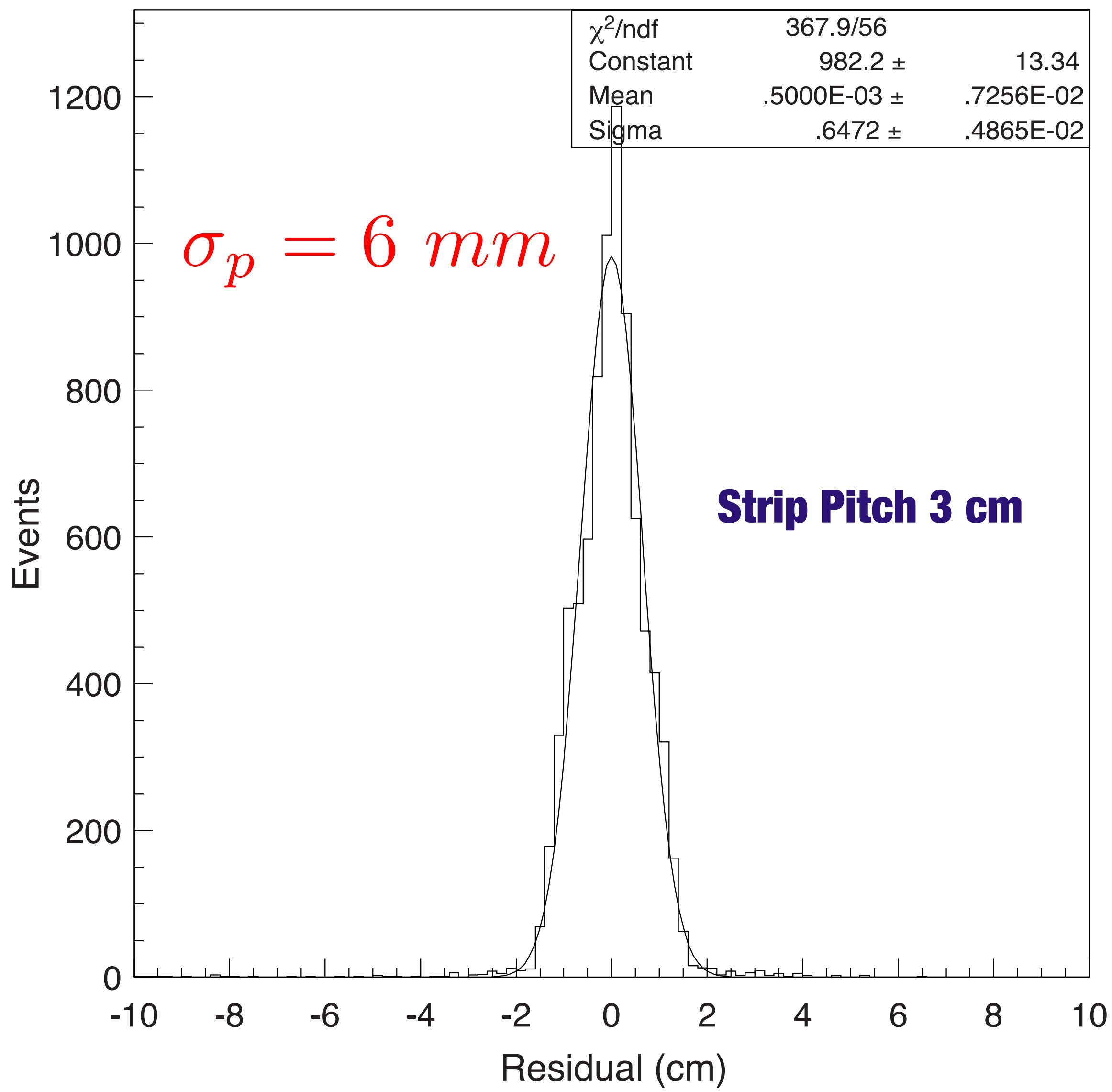


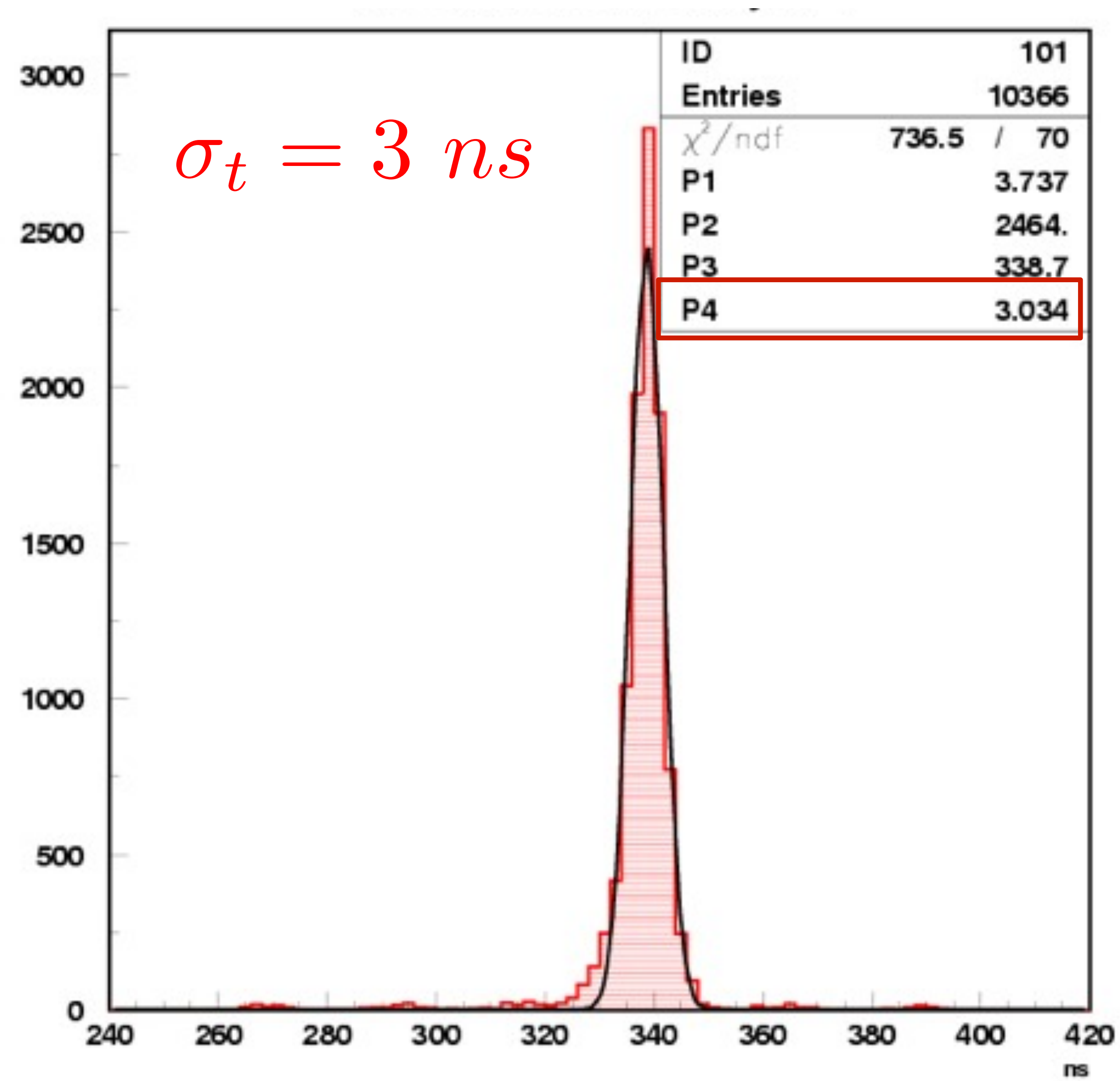
RPC Performances

Spatial resolution



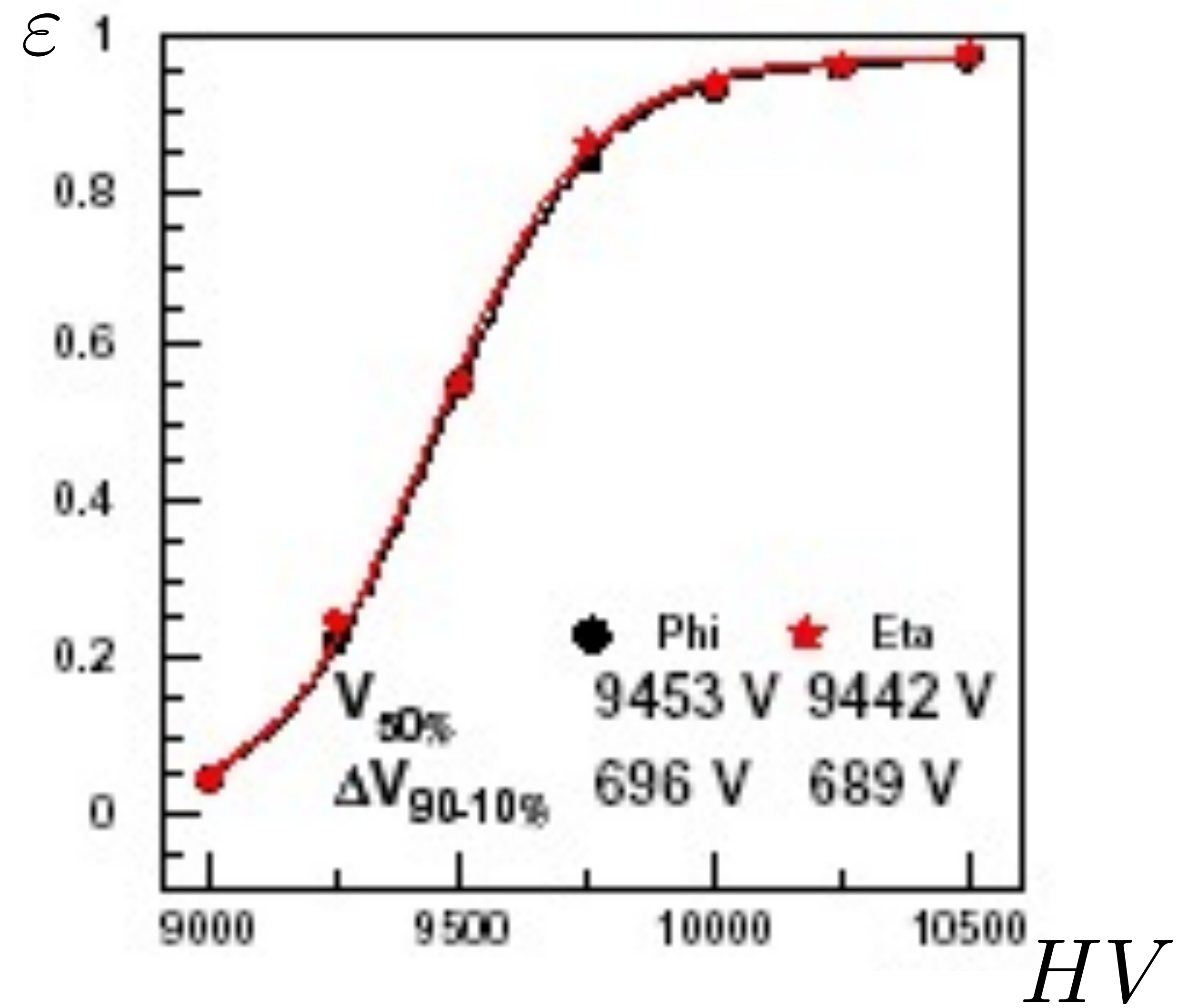
Time resolution

Time resolution (H8 test-beam 2003)



Operating parameter

Plateau



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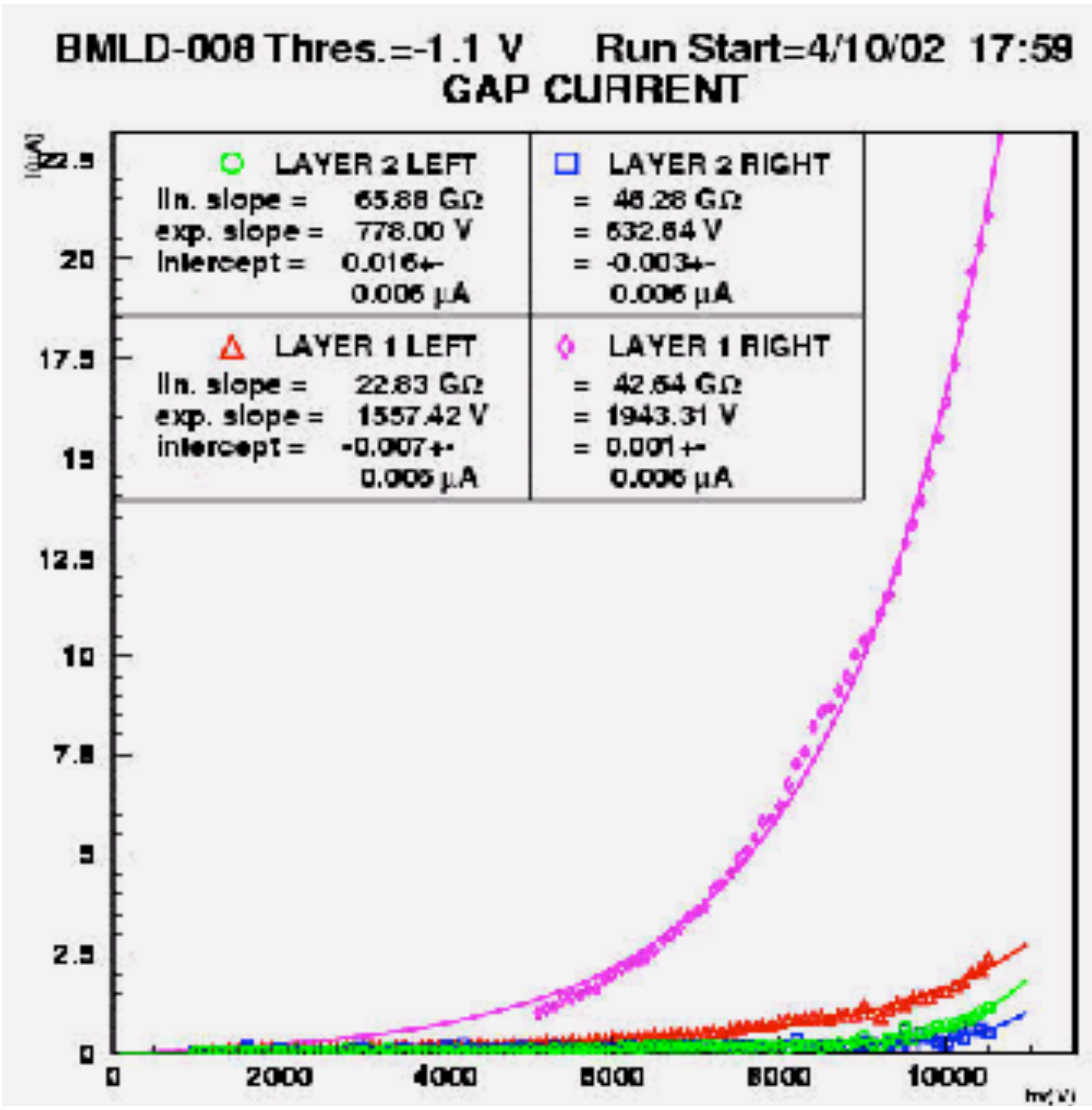

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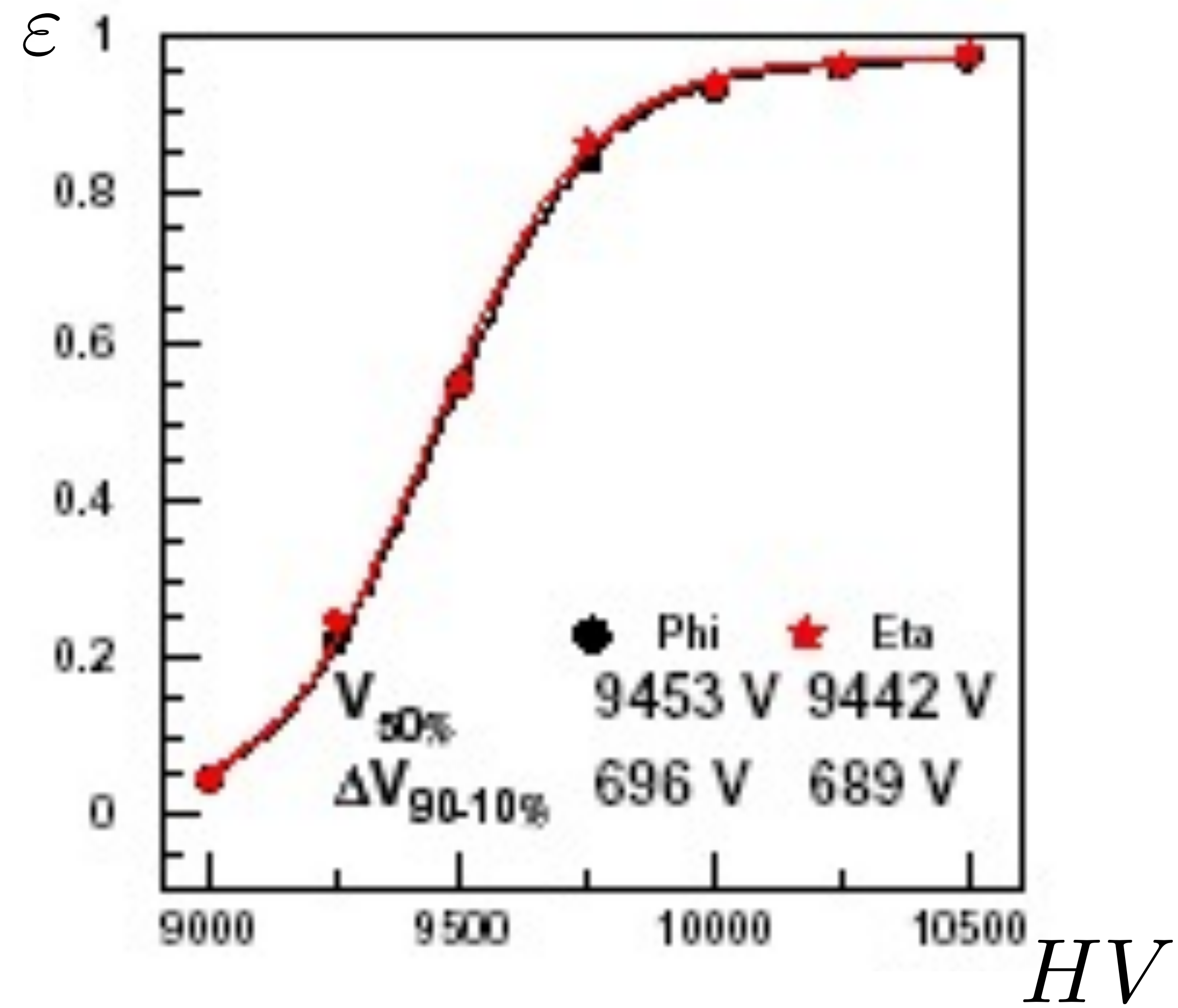

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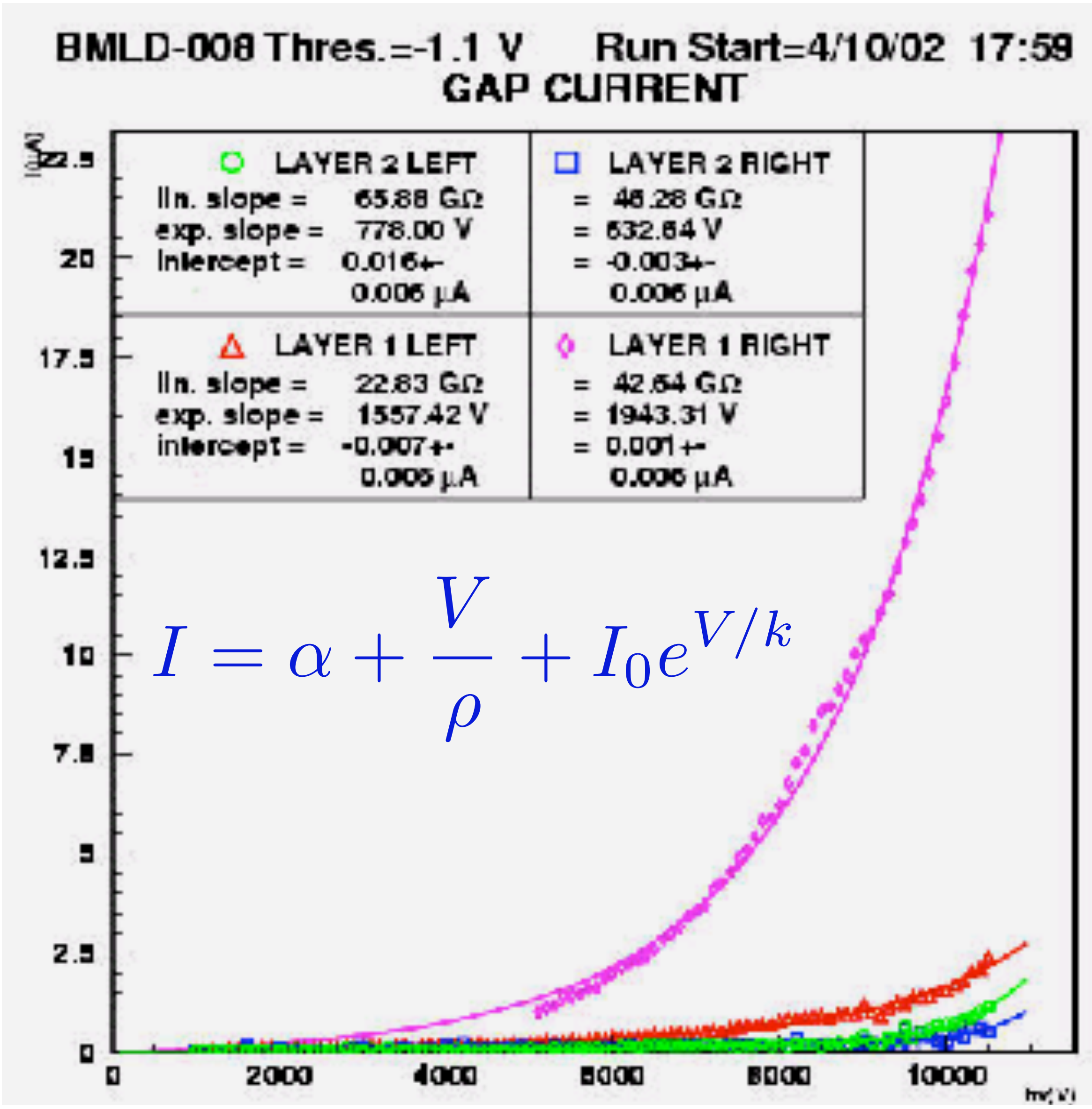
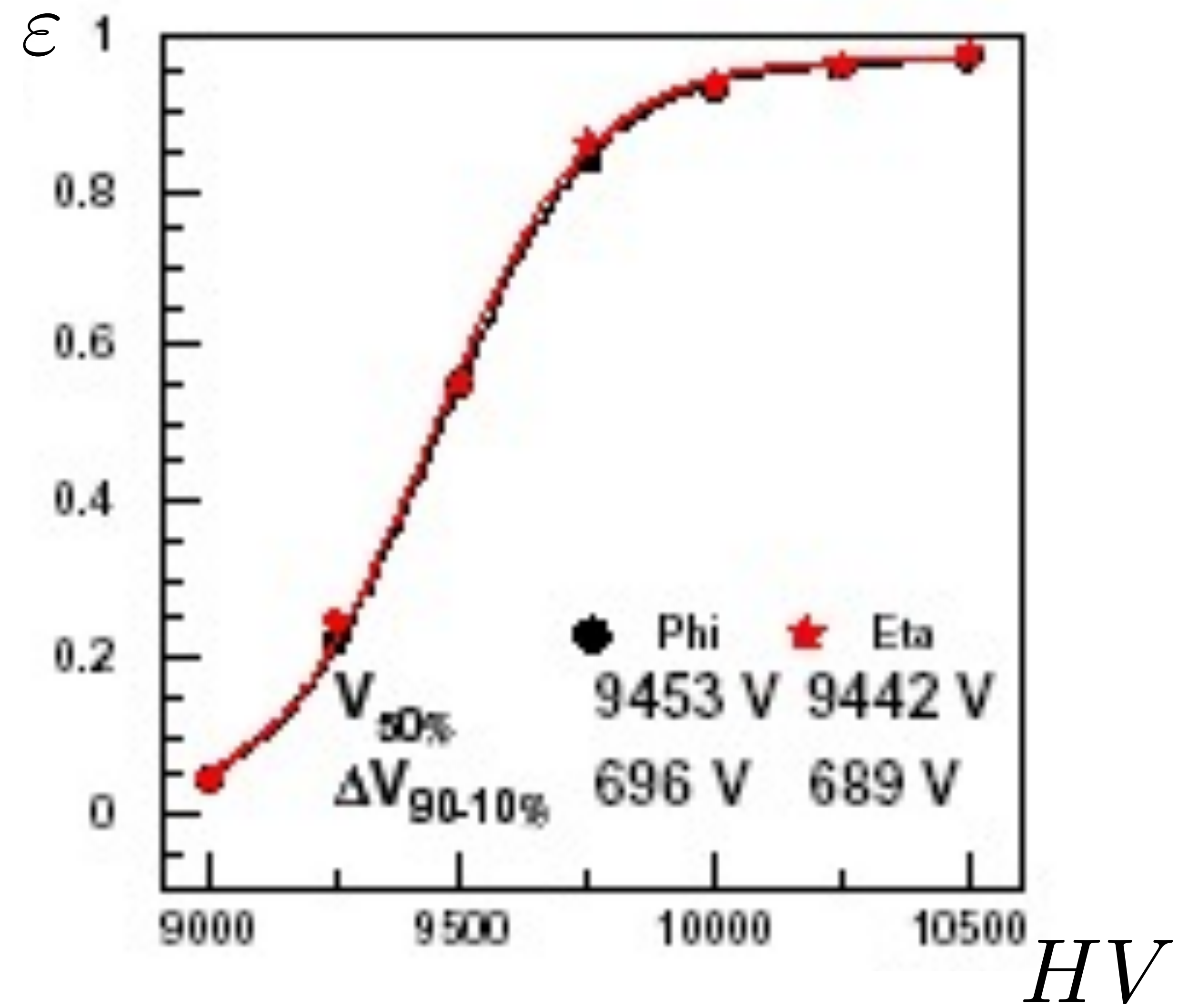


$$I = \alpha + \frac{V}{\rho} + I_0 e^{V/k}$$

Plateau



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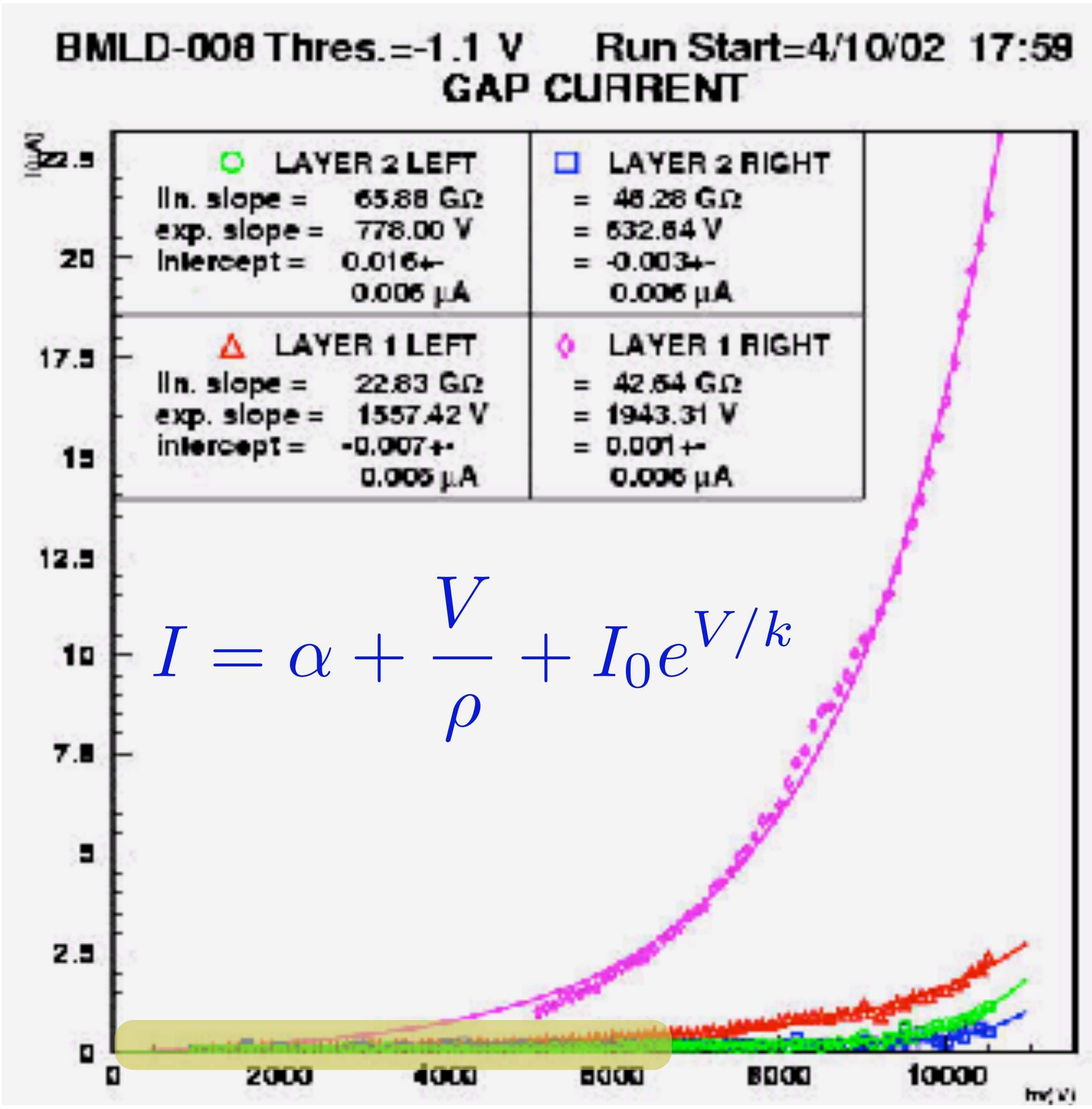
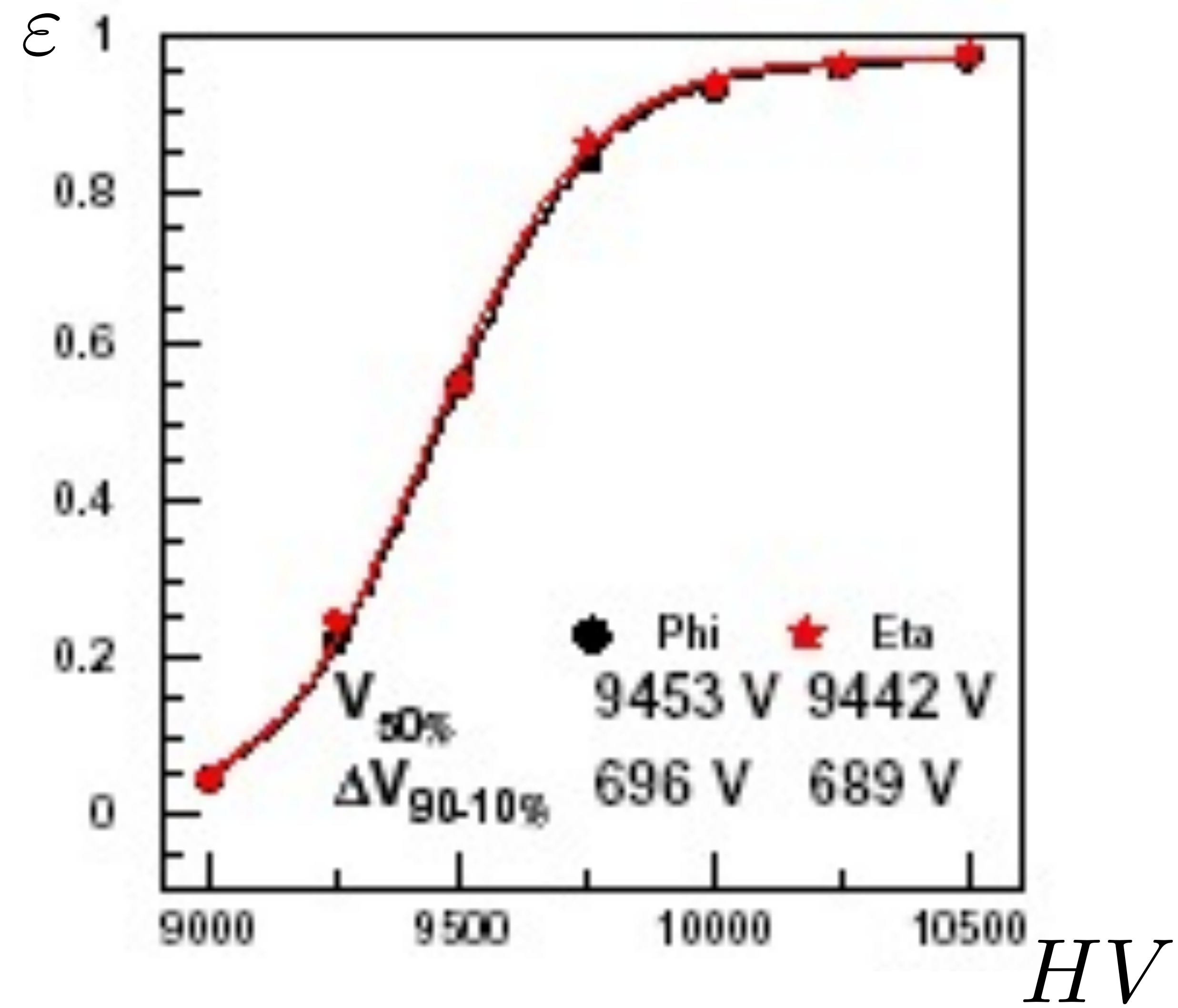


ρ ***Bulk resistivity***

Plateau



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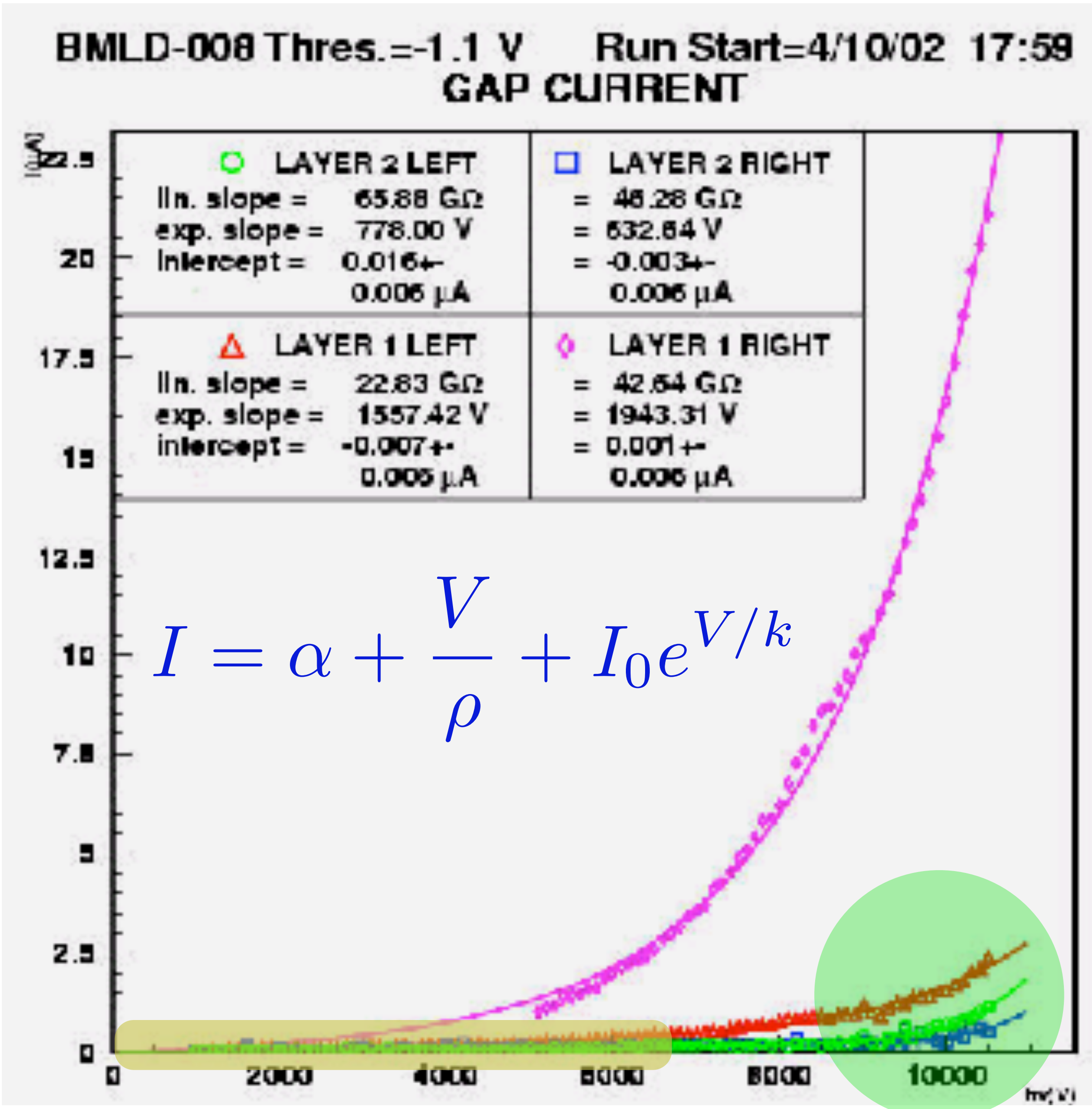

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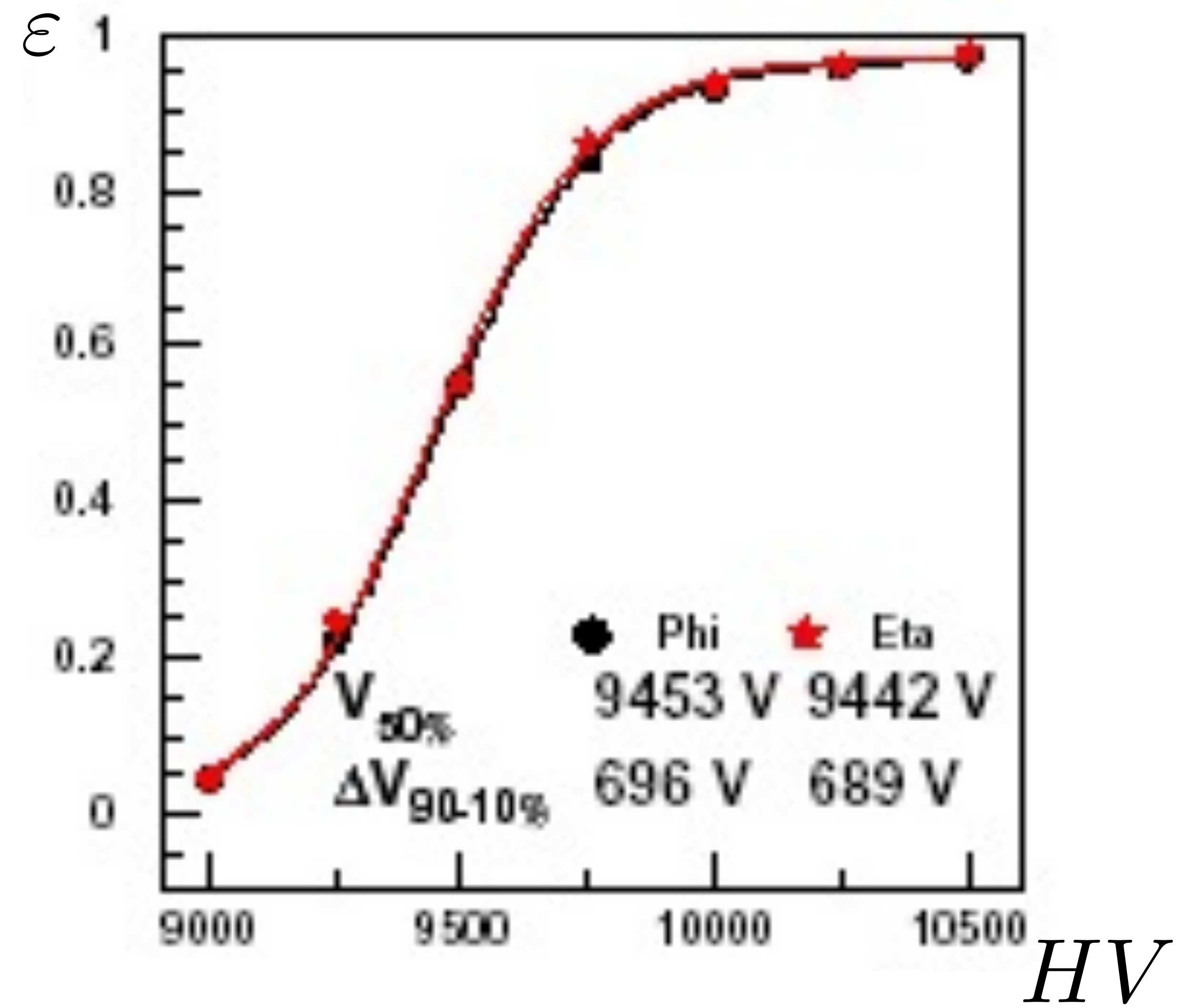

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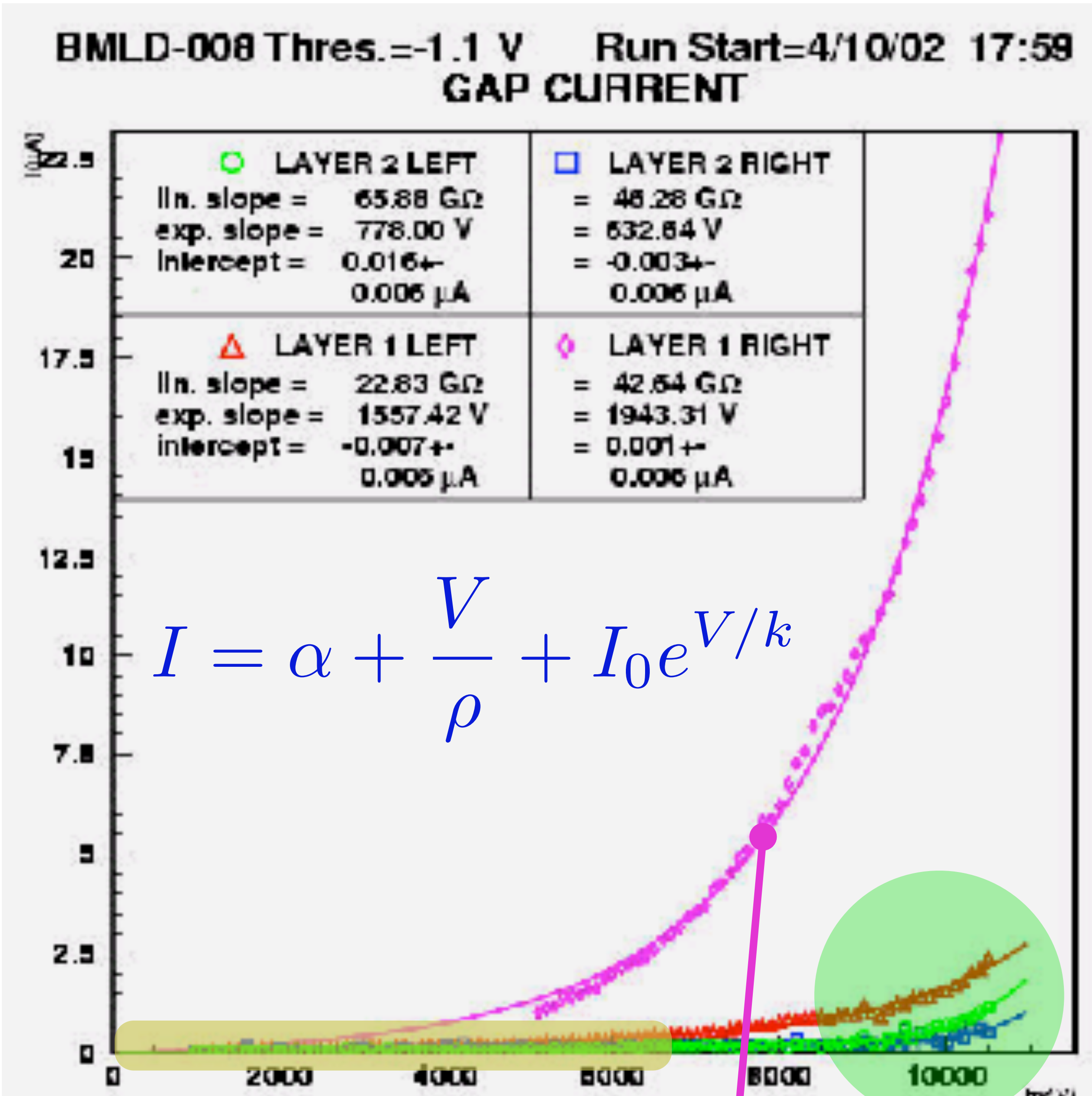

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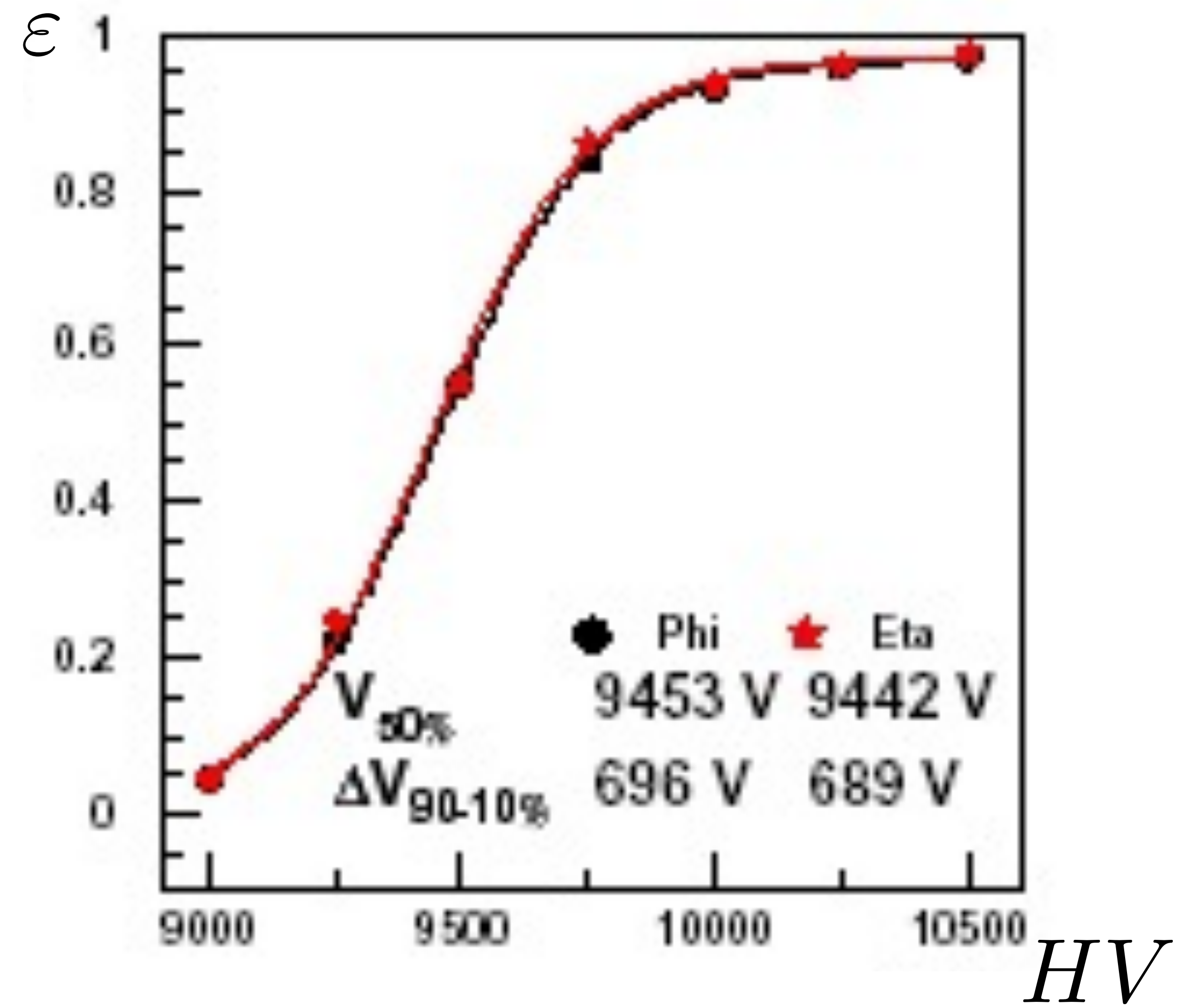

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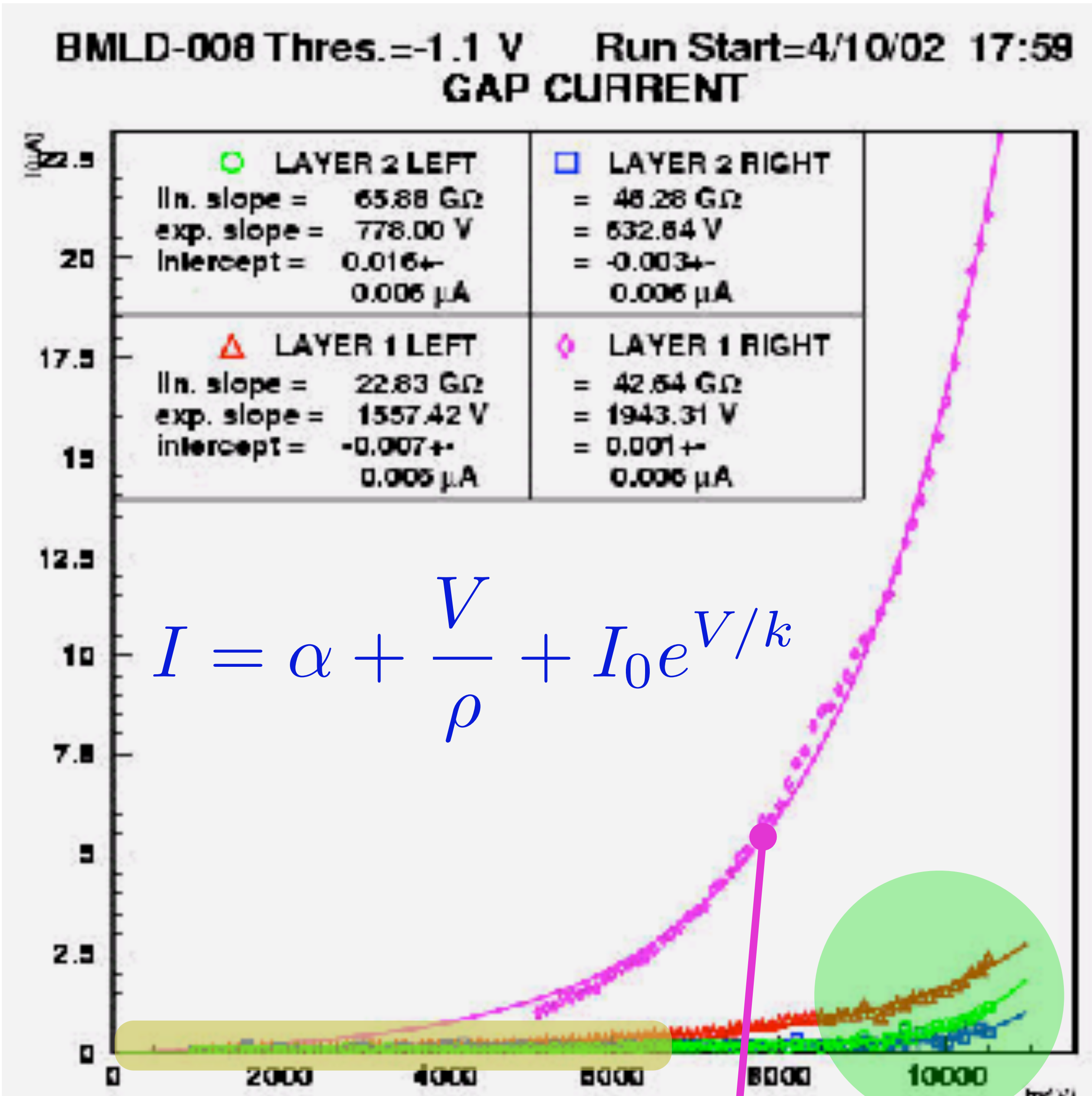
too high current - Bad Gap

Operating parameter



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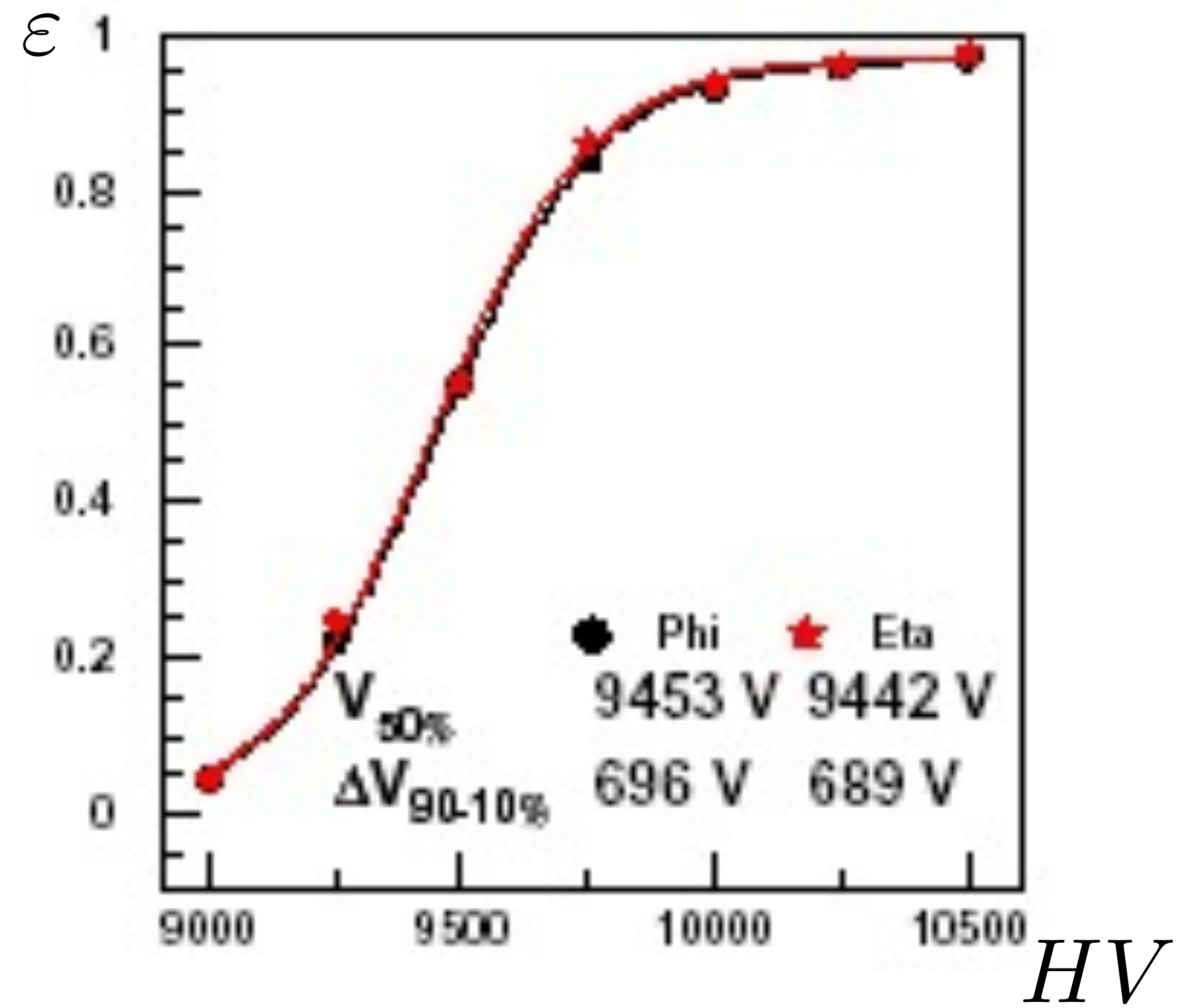

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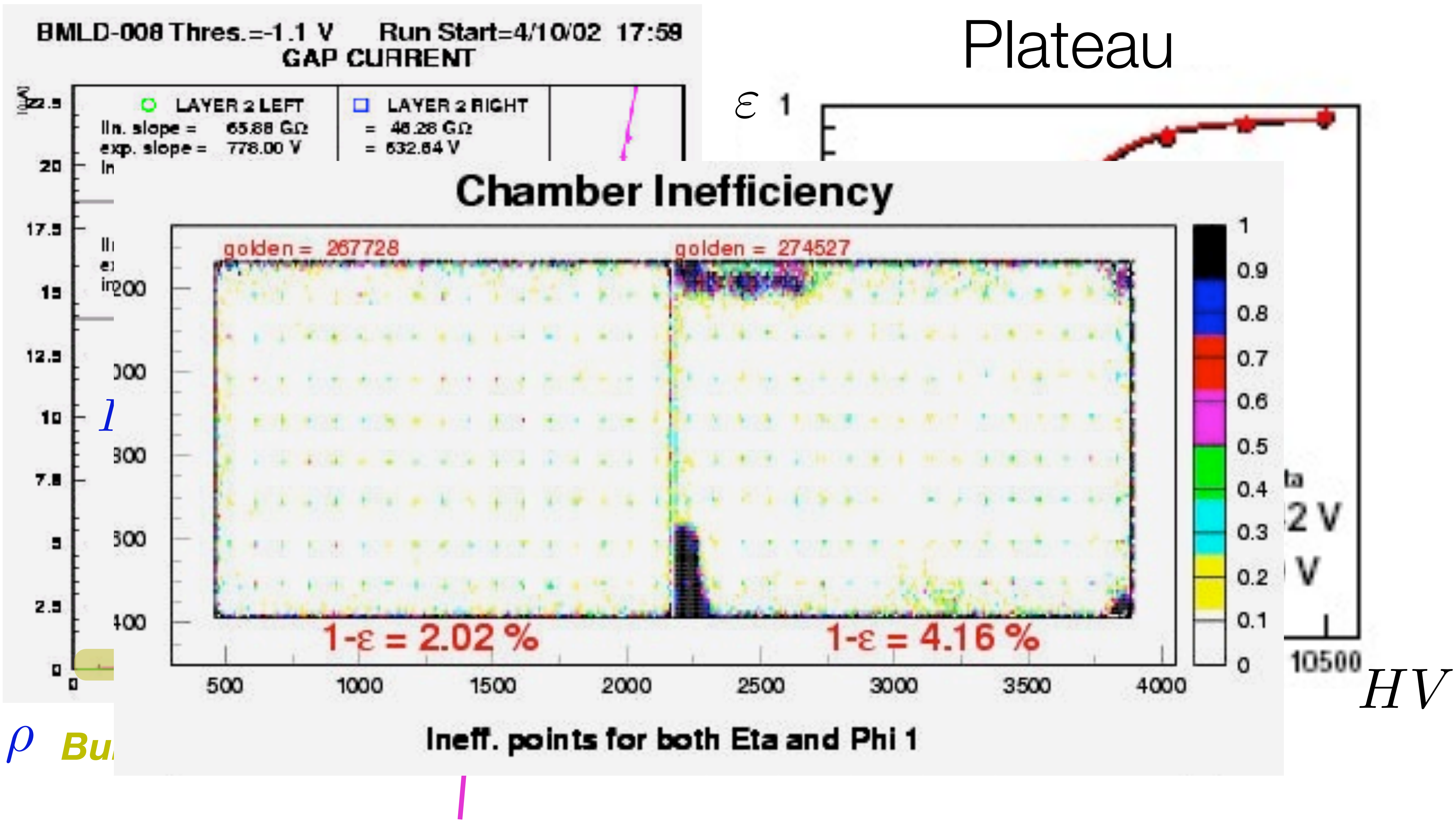

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Ageing of RPC

- The ATLAS experiment will run for more than 10 years
- Detectors must guarantee to work properly at high rate
- For the RPC (at nominal luminosity):

Ageing described in terms of integrated charge:

- The ageing of any gas detector is a very subtle process
- Deep studies on ATLAS RPC ageing have been done at CERN X5/GIF (6 ATLAS equivalent years)
- Two main effects were observed related to the ageing process

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Expected counting rate: 10 Hz/cm^2

10^8 s in 10 years

Safety factor = 10

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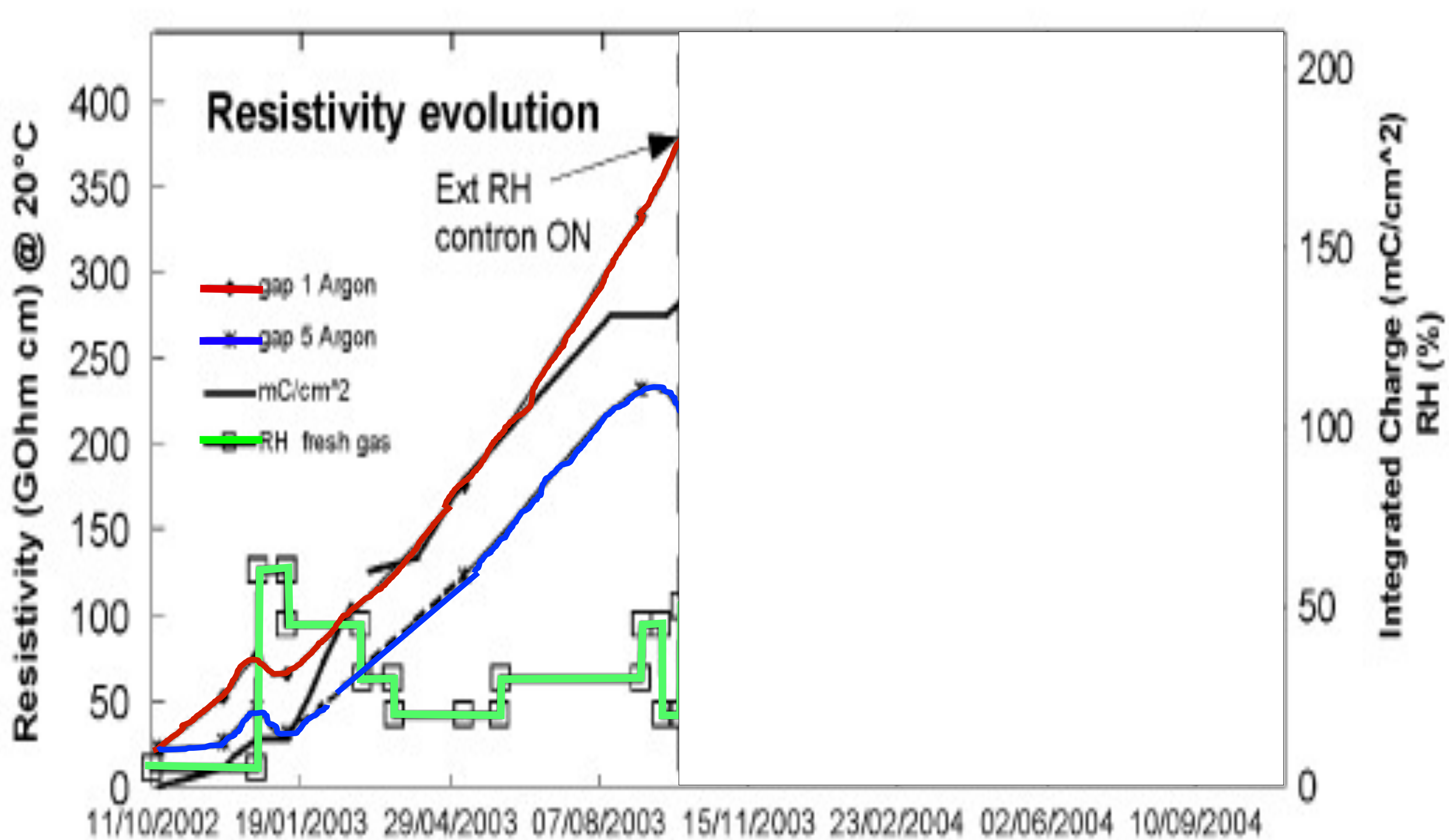
RPC Ageing Effect: Increasing of resistivity:

- Progressive reduction of internal humidity of bakelite (bulk phenomena)
- Introduction of humidity in the gas mixture comparable to the environmental value
- Keep external humidity under control



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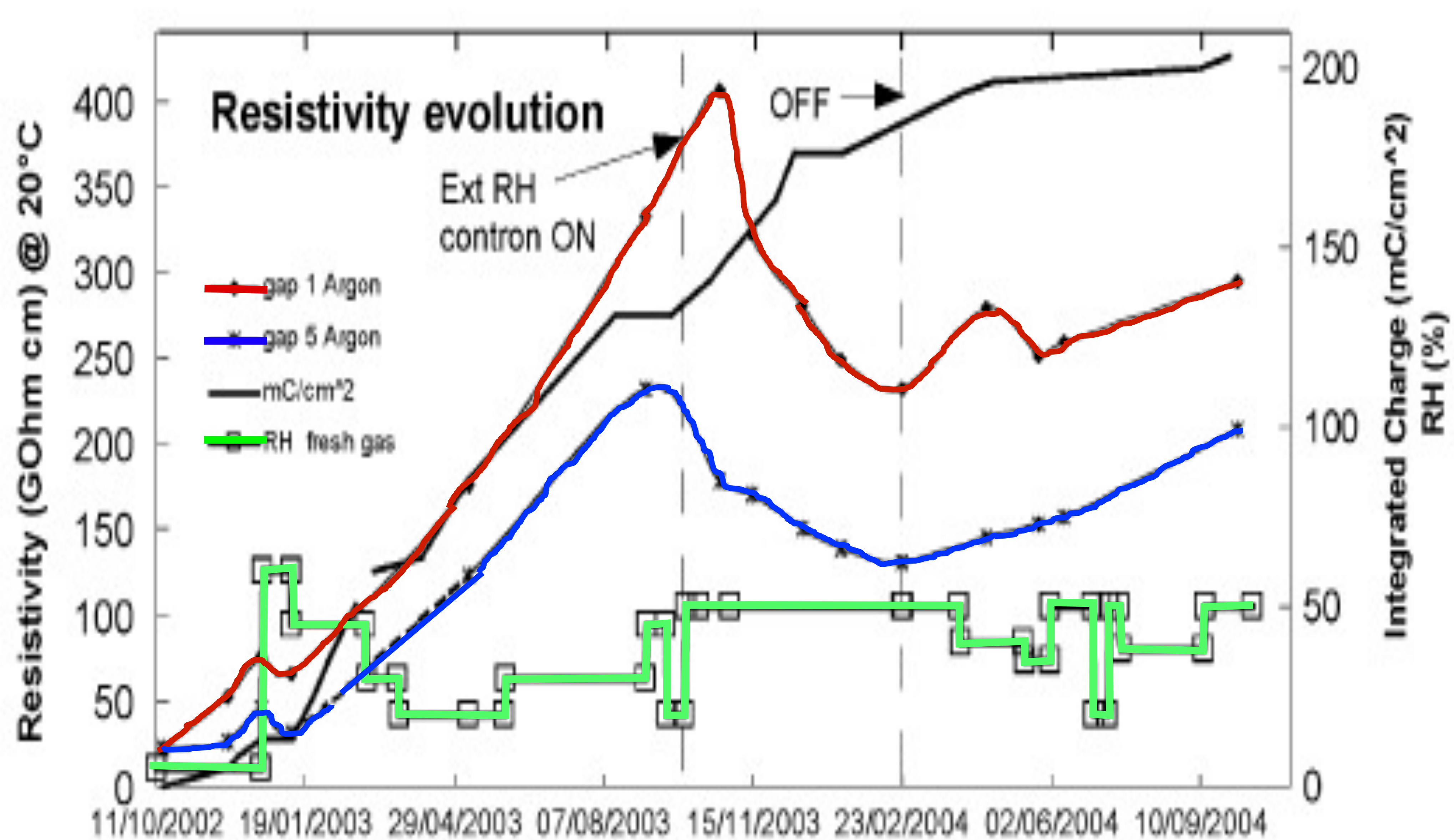
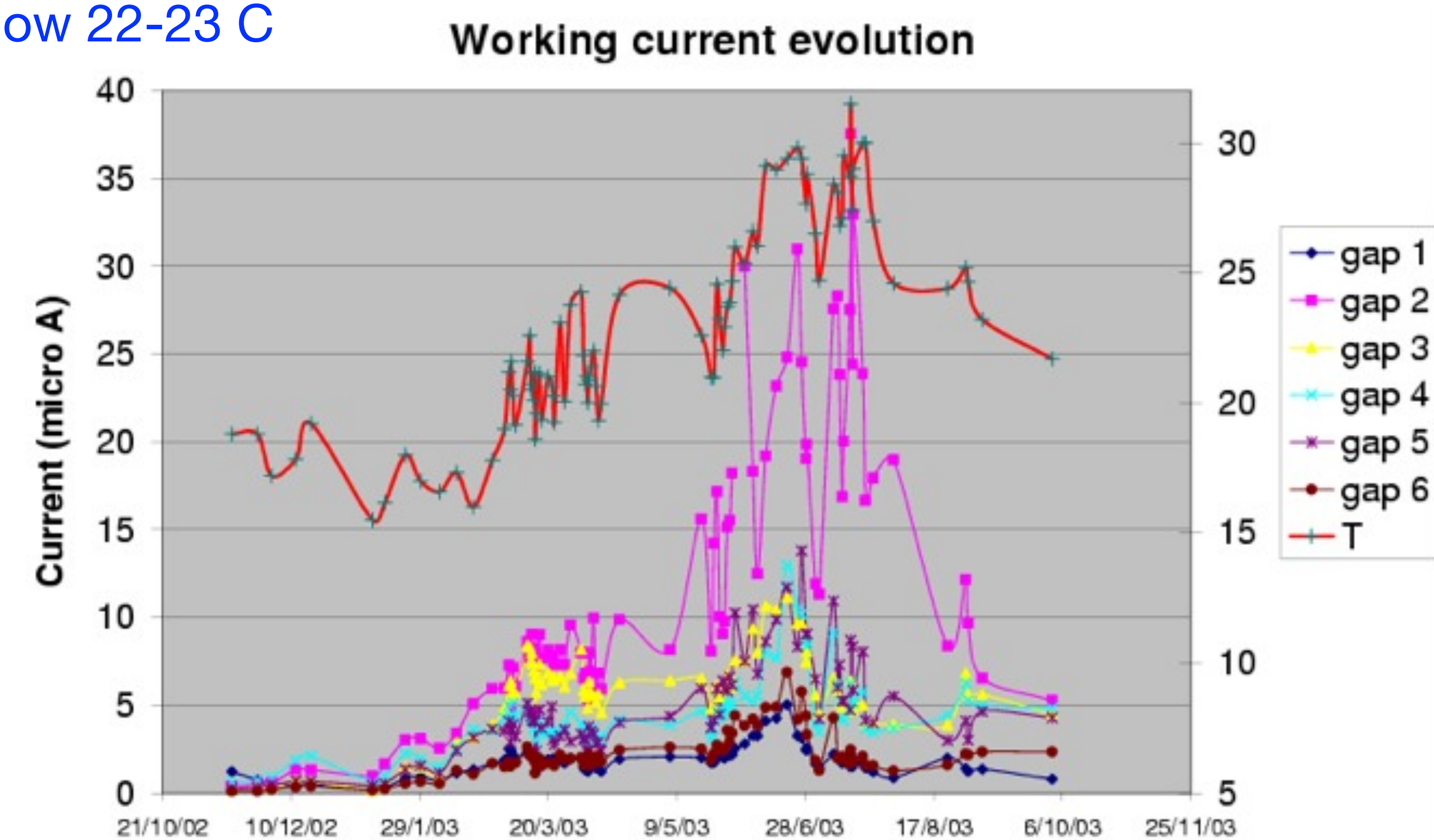
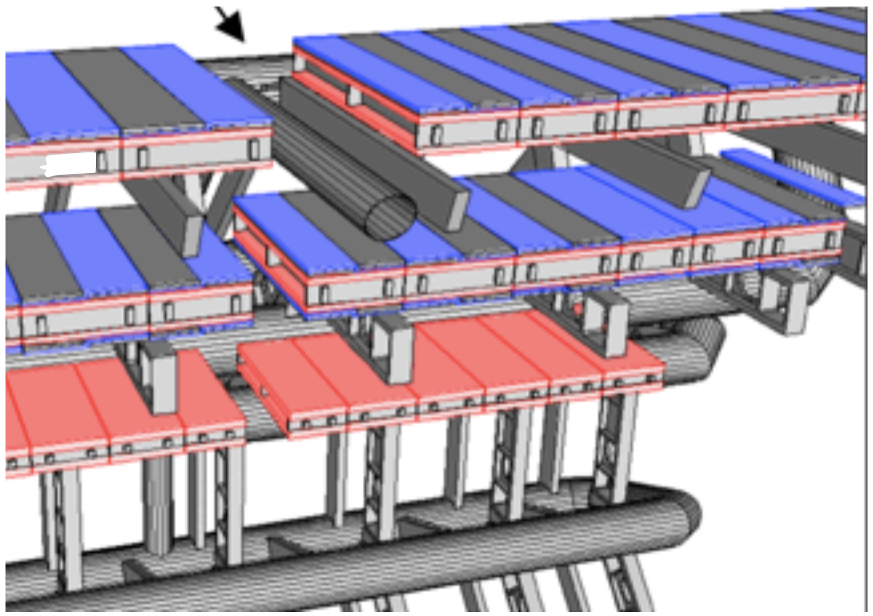


RPC Ageing Effect: Increasing of dark current (detector noise):

- Degradation of plate surface
- Formation of F- radicals and HF (very aggressive)
- Strong dependence on working temperature
- Reduction of fluoride compounds (increase isob. percentage)
- Increase of gas flow in order to quickly remove HF molecules
- Keep temperature below 22-23 C



Muon Barrel Trigger



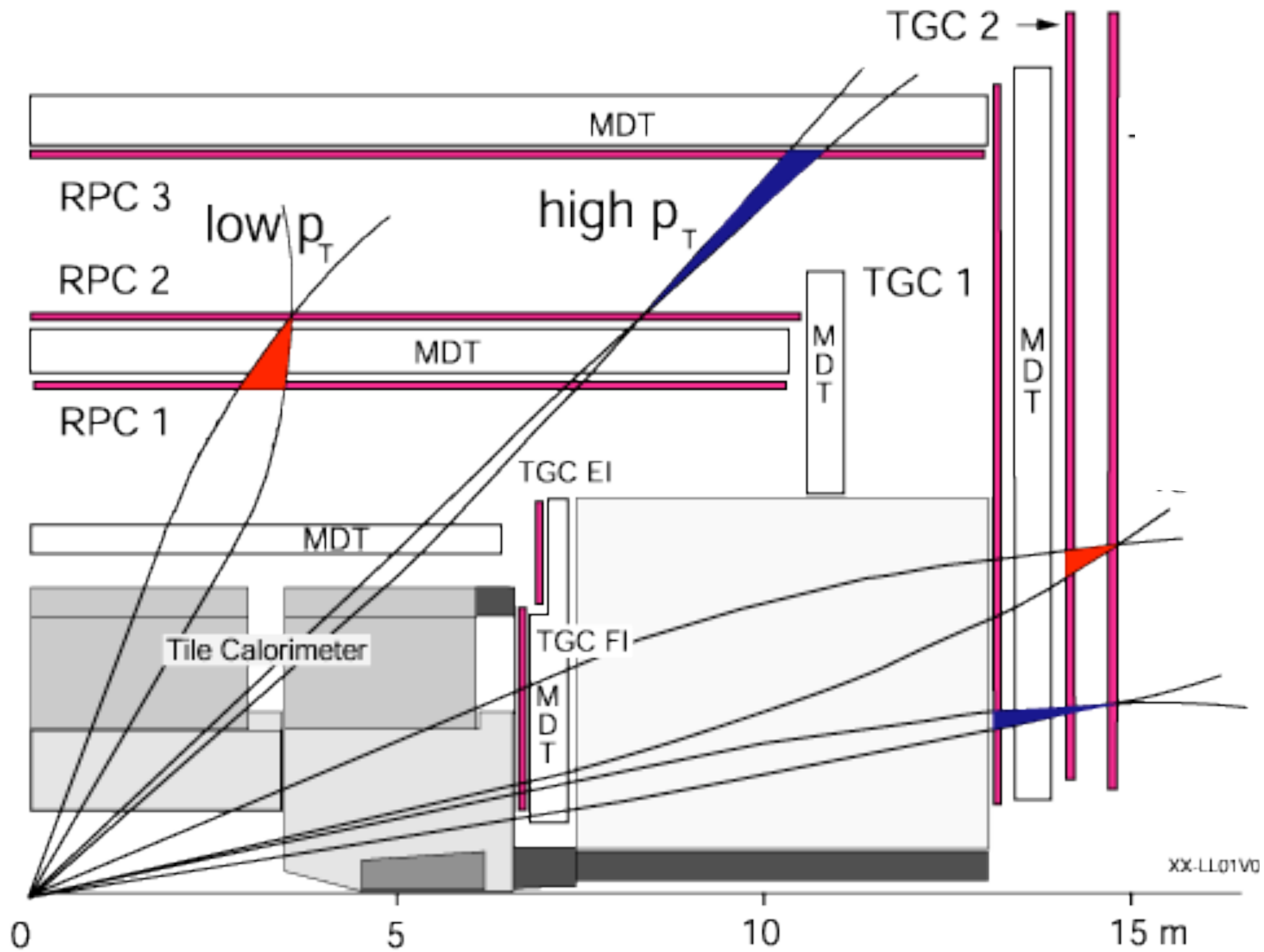
- The LVL1 Muon architecture
- Implementation (CM and roads)
- Timing as Physics selector technique
- Result

Basic Principle

- **Physics**:
  Selection of events with muons having a large transverse momentum (p_T)

- **Trigger**:
  Identification of candidate muon tracks coming from the interaction vertex within a p_T range.

- **Algorithm**:
  Demand a coincidence of hits in different RPC chambers within geometrical roads.

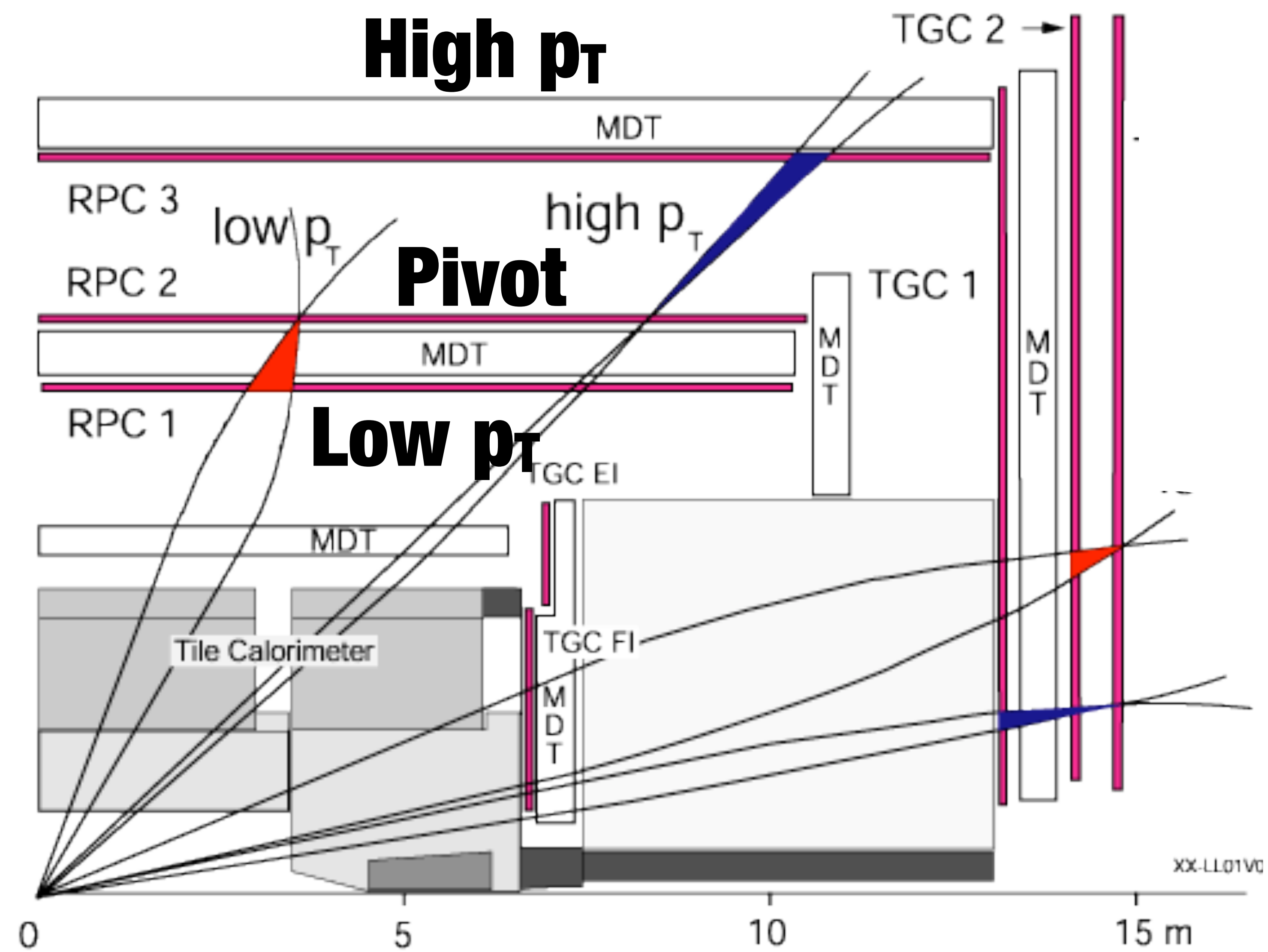


Basic Principle

Level-1 algorithm performed in both **η** and **φ** projections. Two p_T regimes:

- ✦ **Low-p_T (μ > 6 GeV/c) with RPC1 ⊕ RPC2**
- ✦ **High-p_T (μ > 10 GeV/c) with RPC3 ⊕ Low-p_T**

- Low p_T and High p_T are separate but not independent
- Low p_T trigger result is needed for the High p_T decision
- The timing between Low p_T and High p_T has to be adjusted depending on the physics (cosmics or beam)

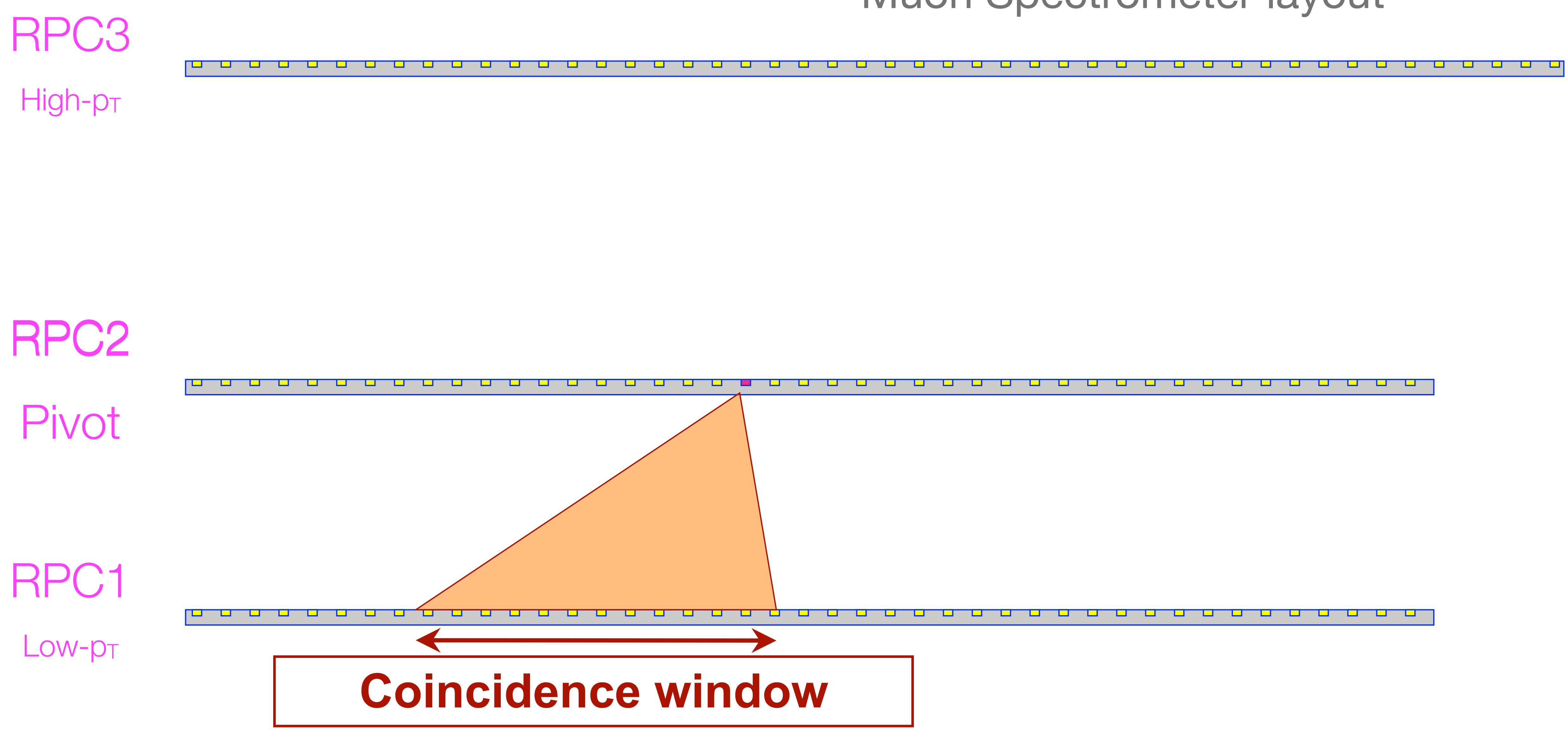


The algorithm

Associate to each pivot strip a COINCIDENCE WINDOW in the Low-p_T and in the High p_T system

The width of the COINCIDENCE WINDOW depends on:

- The p_T threshold
- η coordinate
- Muon Spectrometer layout



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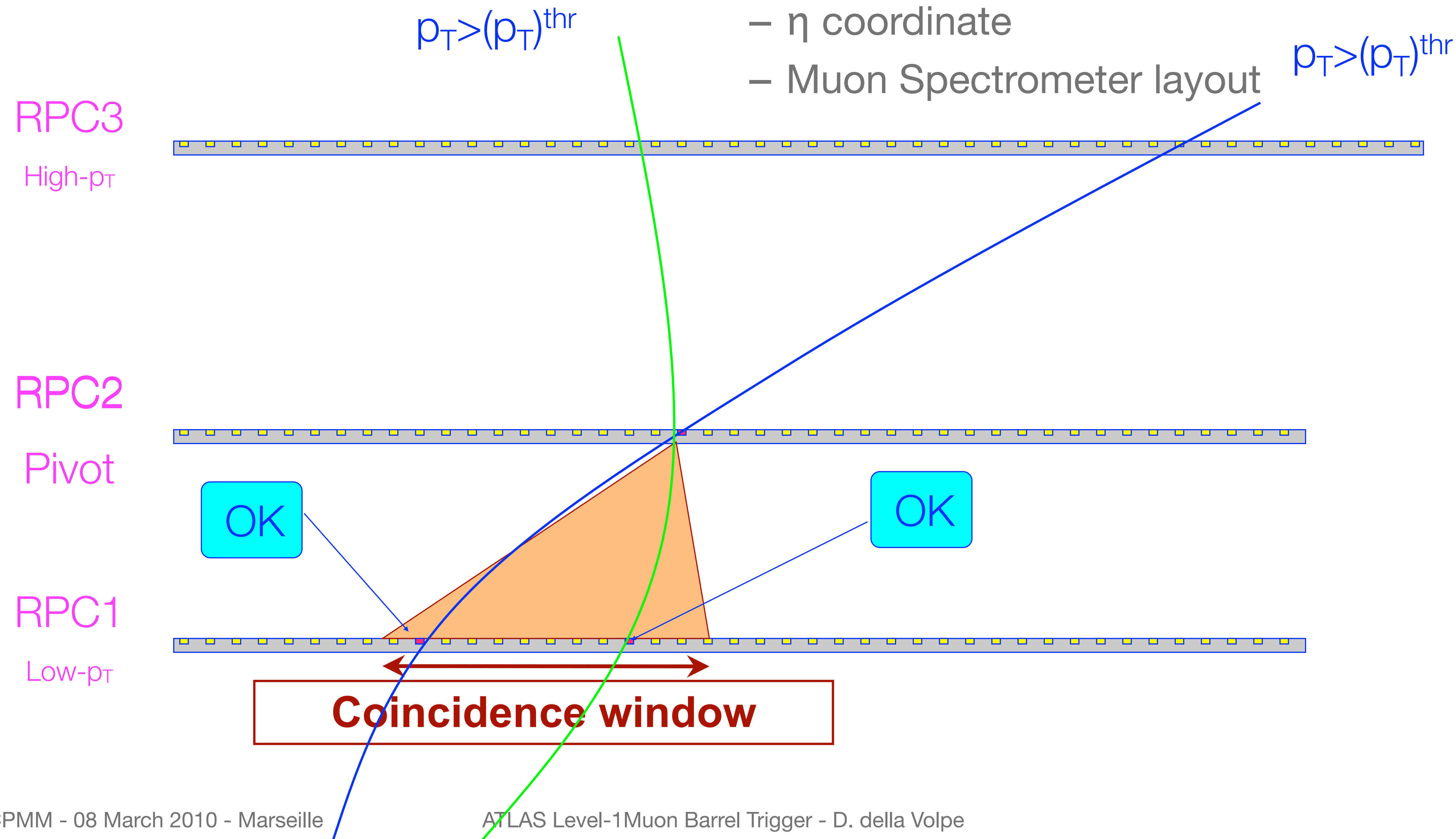

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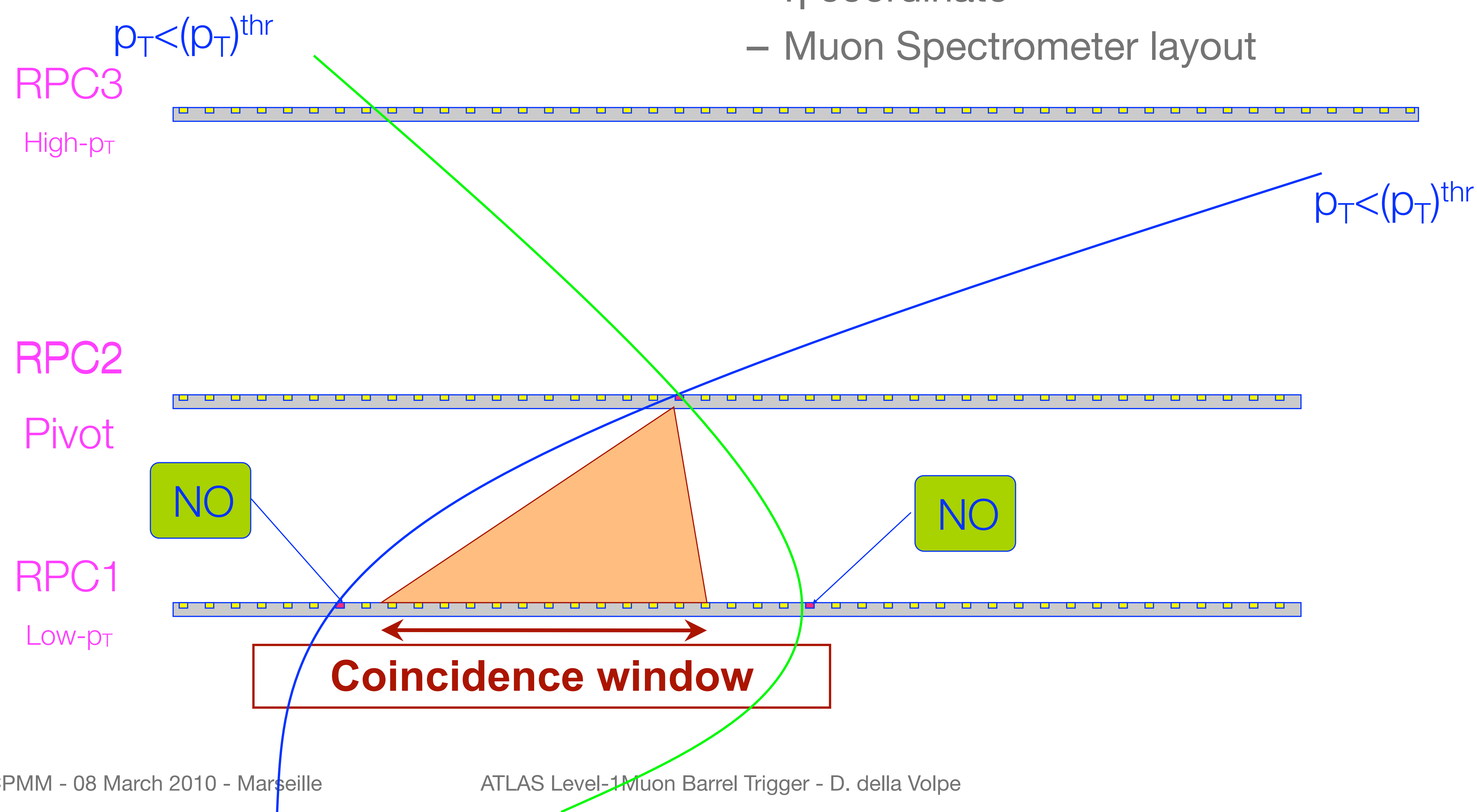
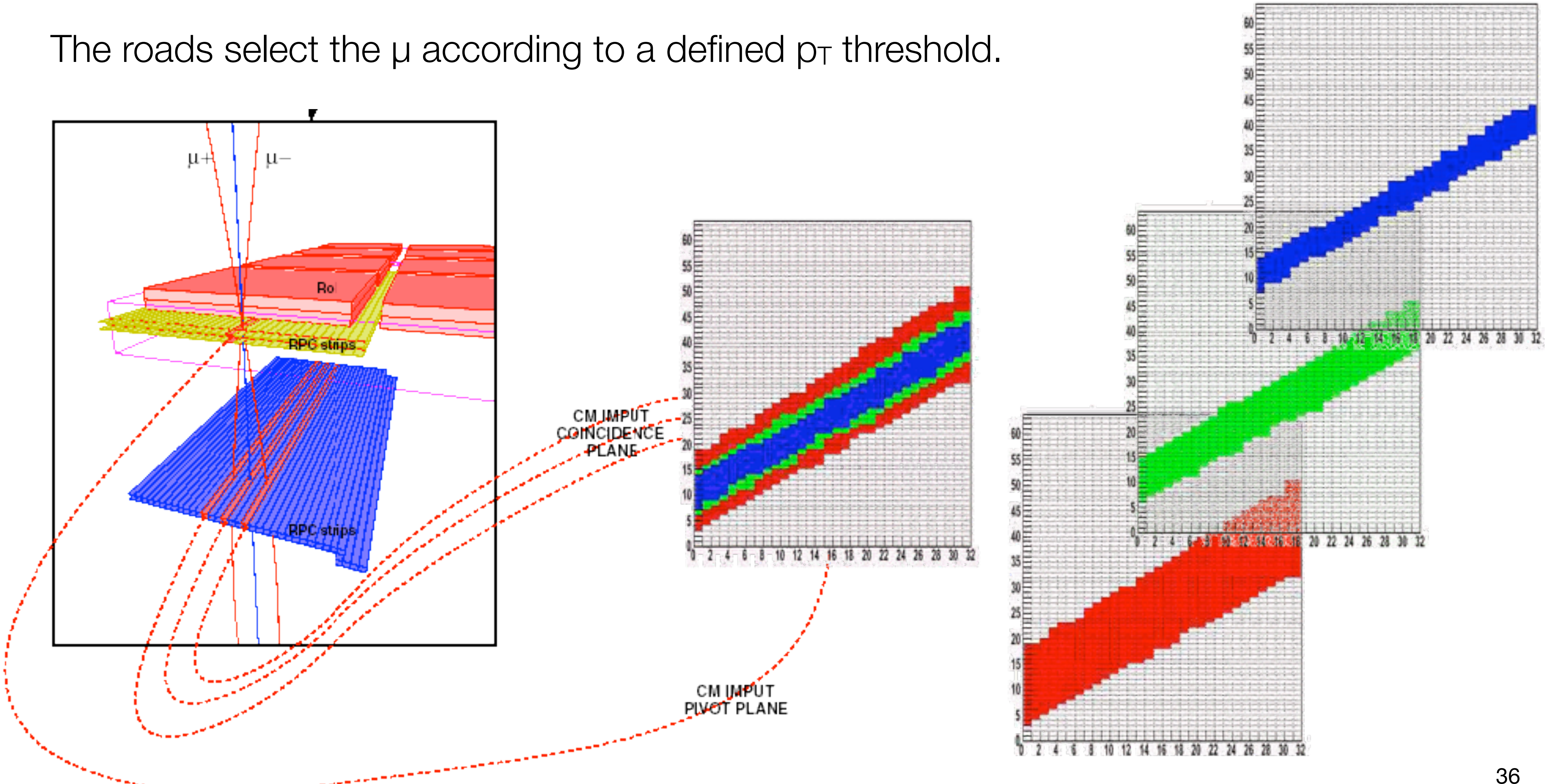


Trigger Logic

At each BC the trigger logic (called **C**oincidence **M**atrix) checks for geometrical and time coincidence between its inputs.

The behavior depends on the geometry chosen (so called roads), the numbers of layers seen in coincidence (so called majority), the width of the coincidence window

The roads select the μ according to a defined p_T threshold.



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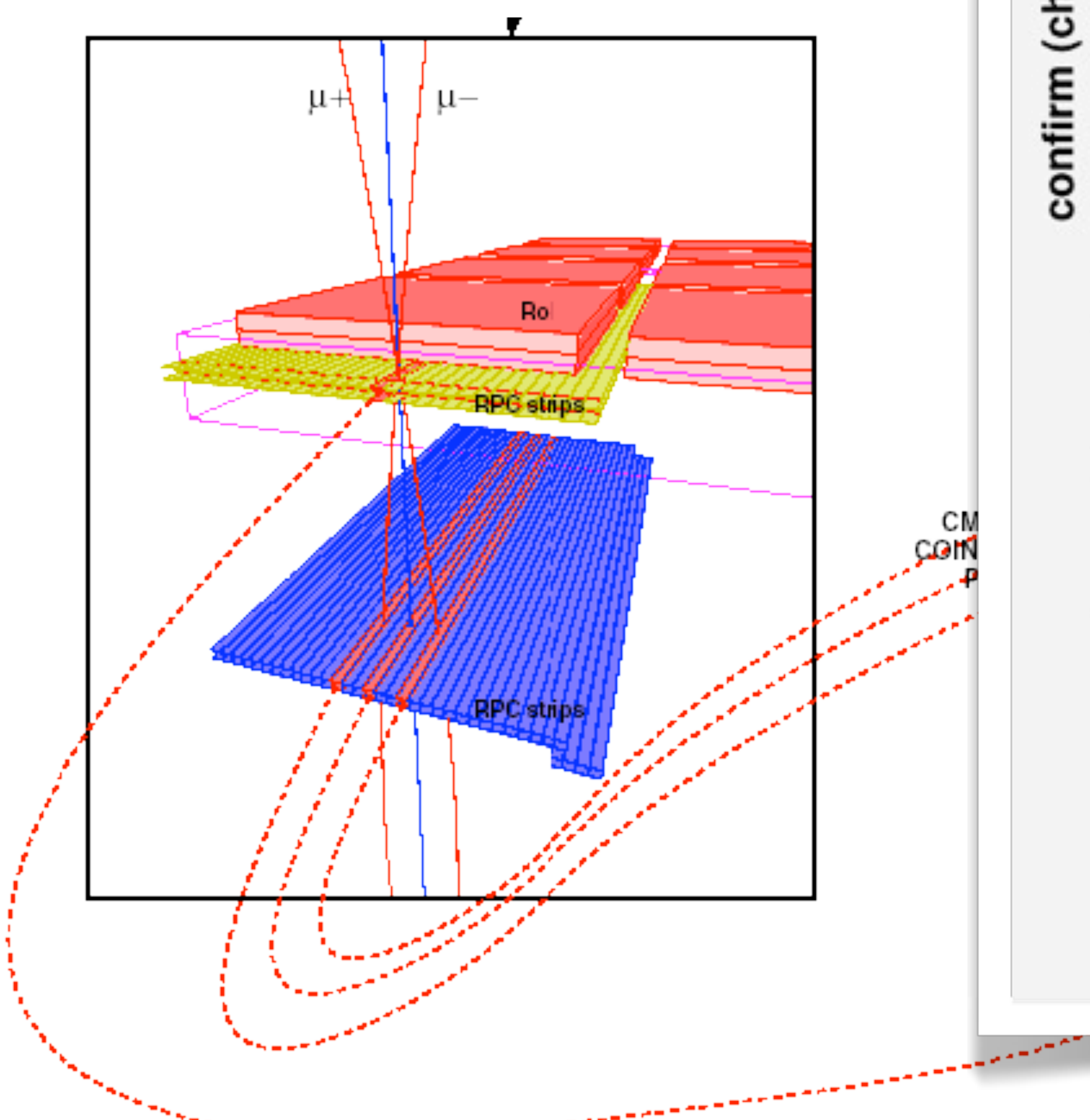
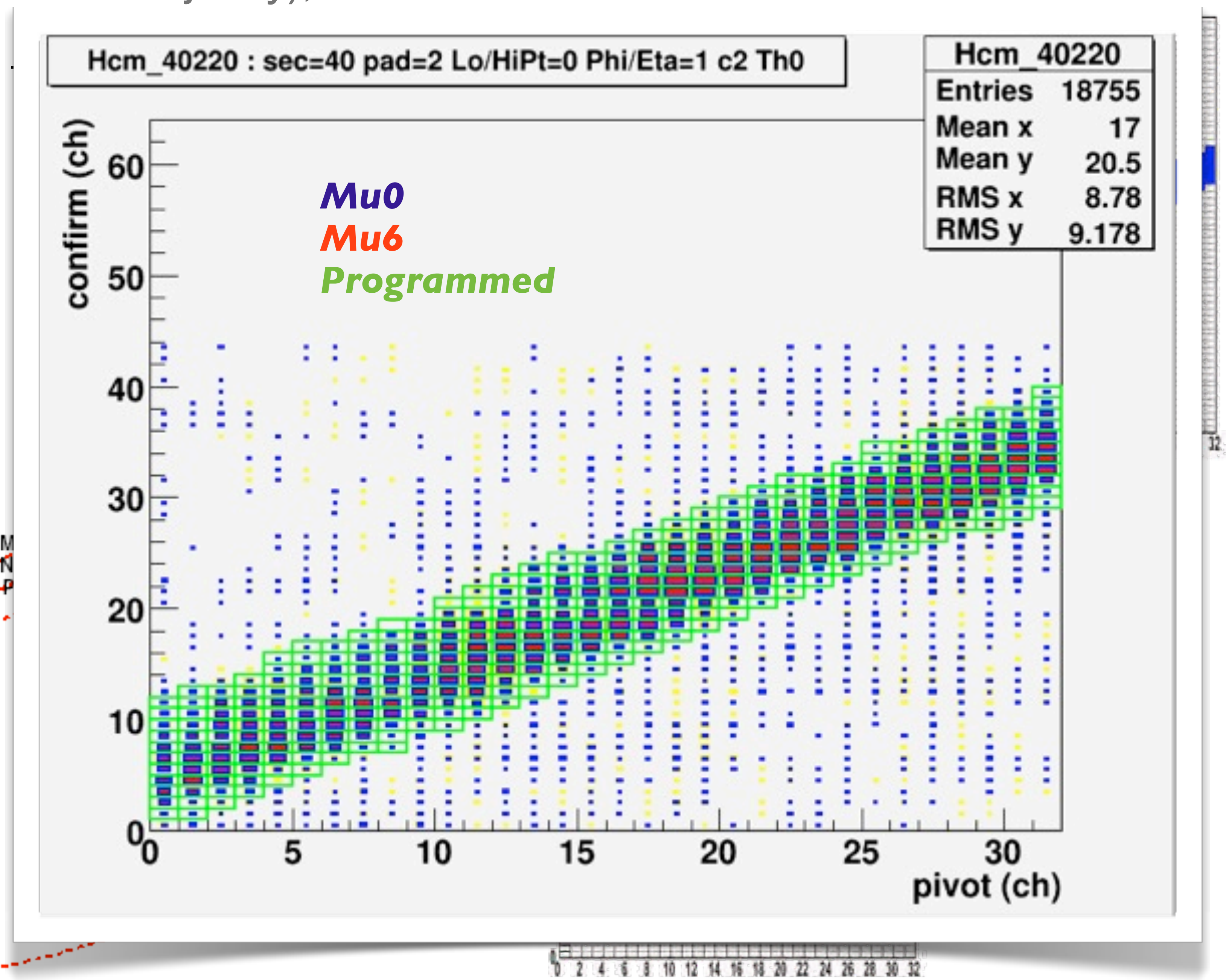
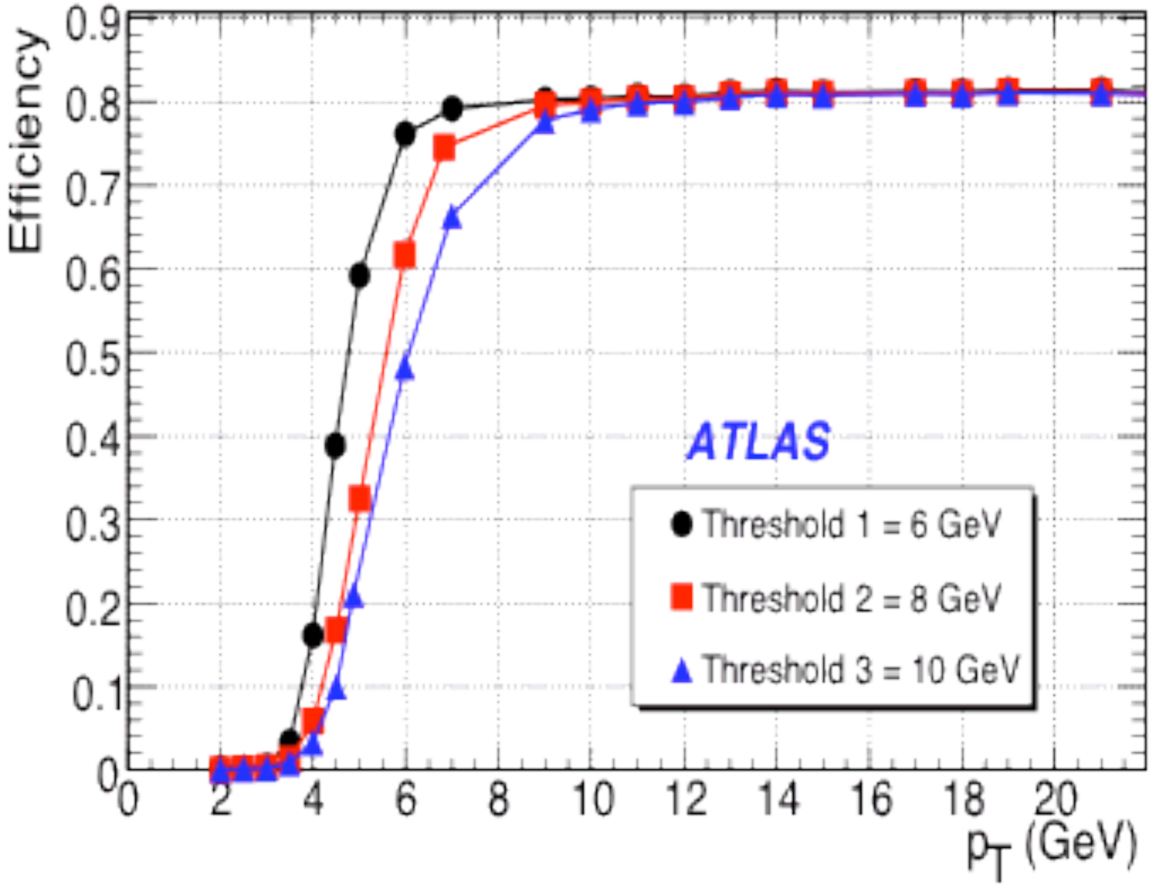


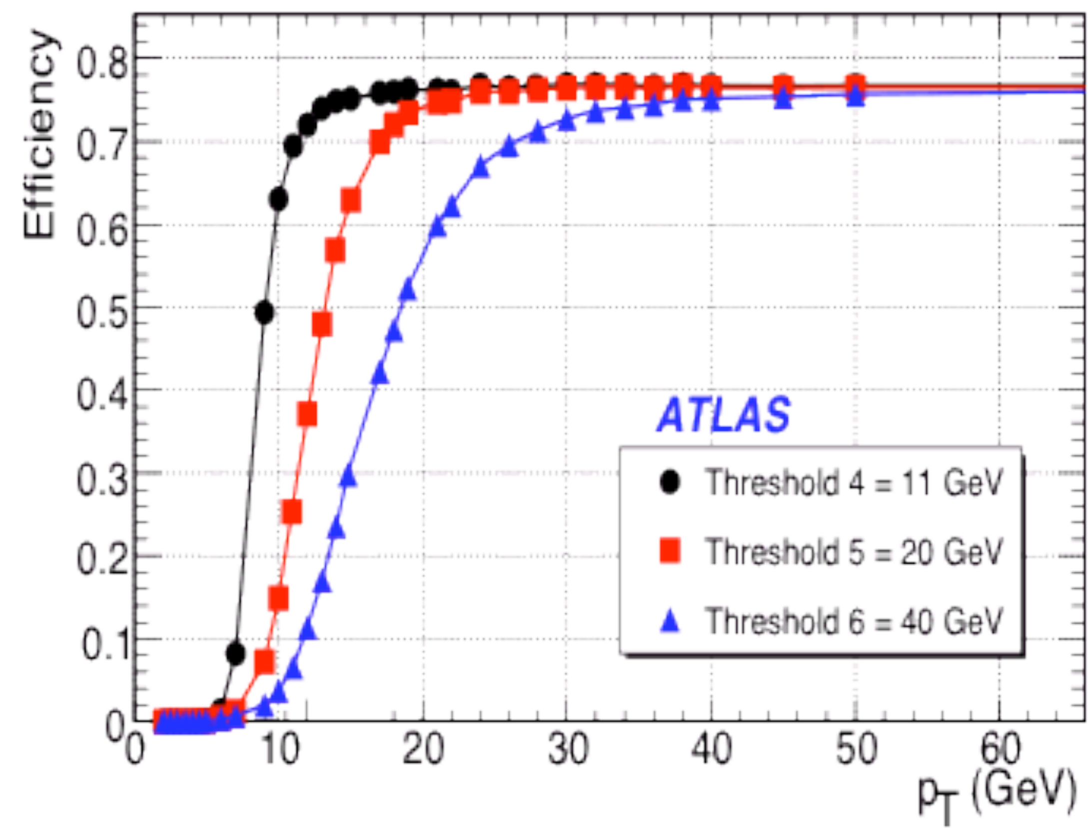


Level-1 Barrel expected efficiency vs p_T

Low p_T



High p_T



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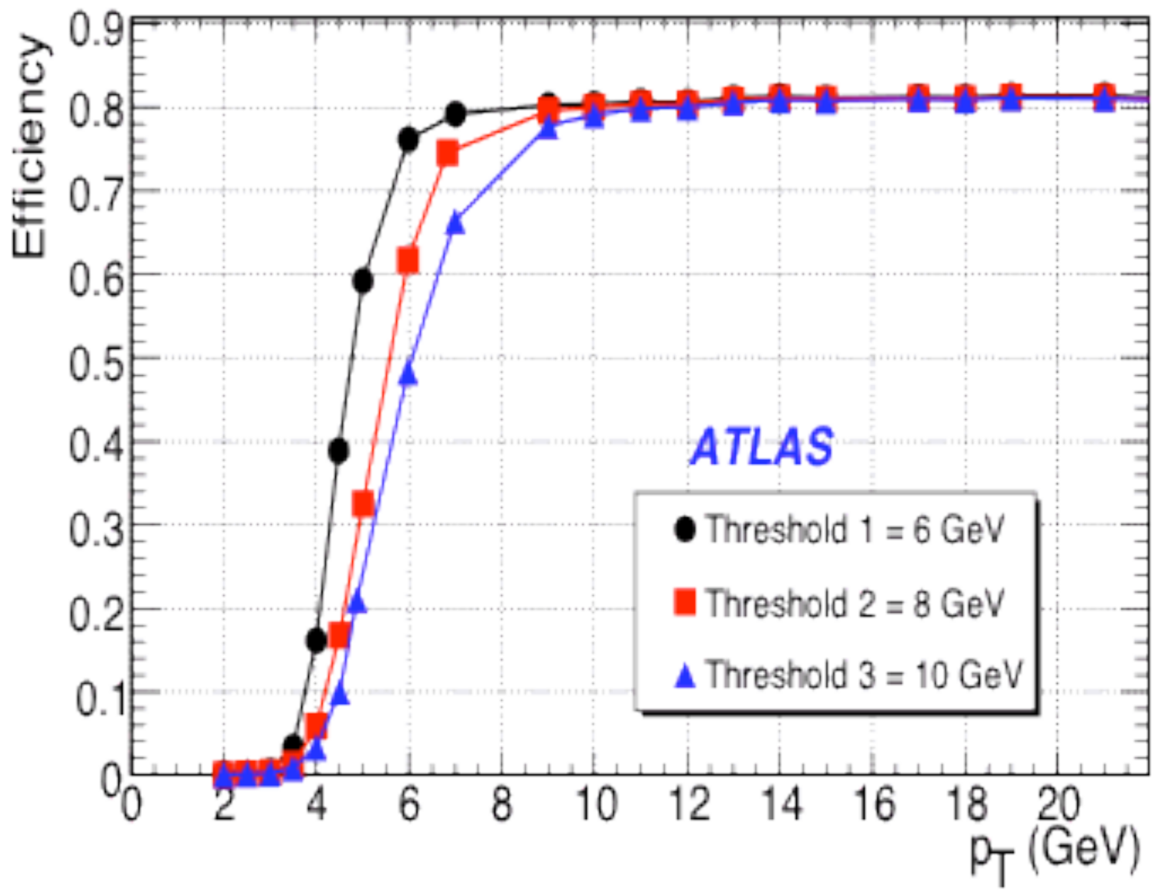

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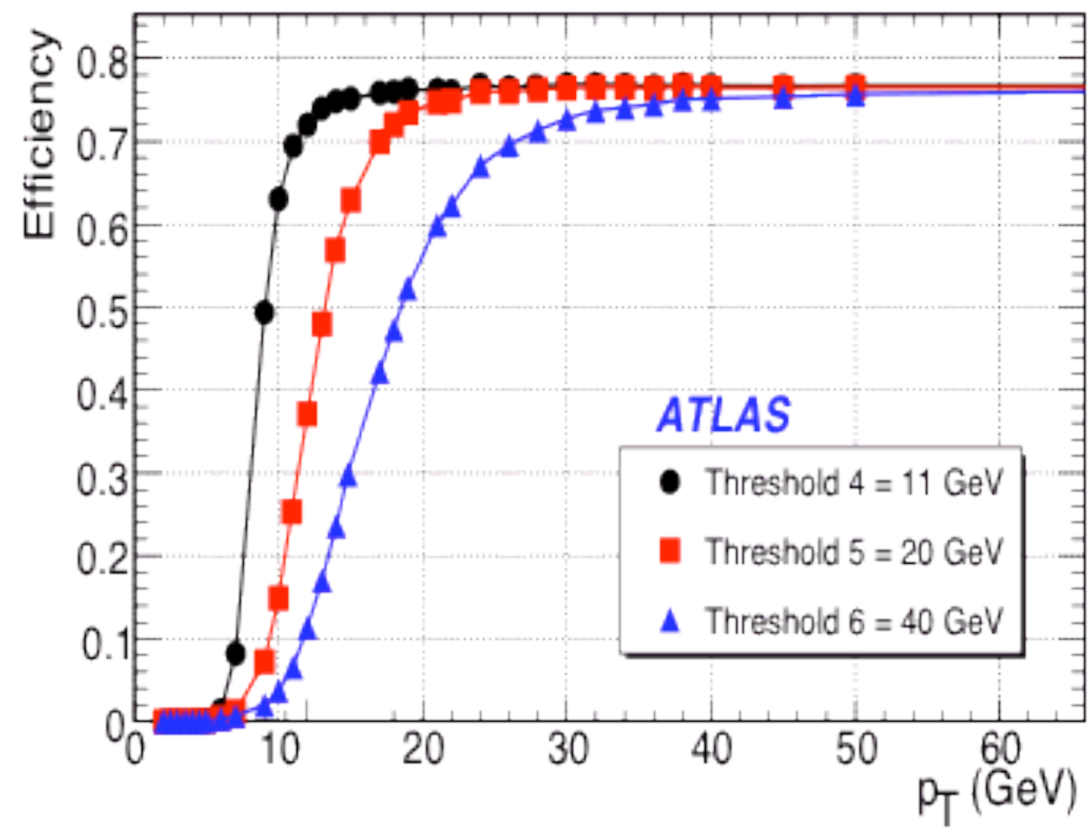
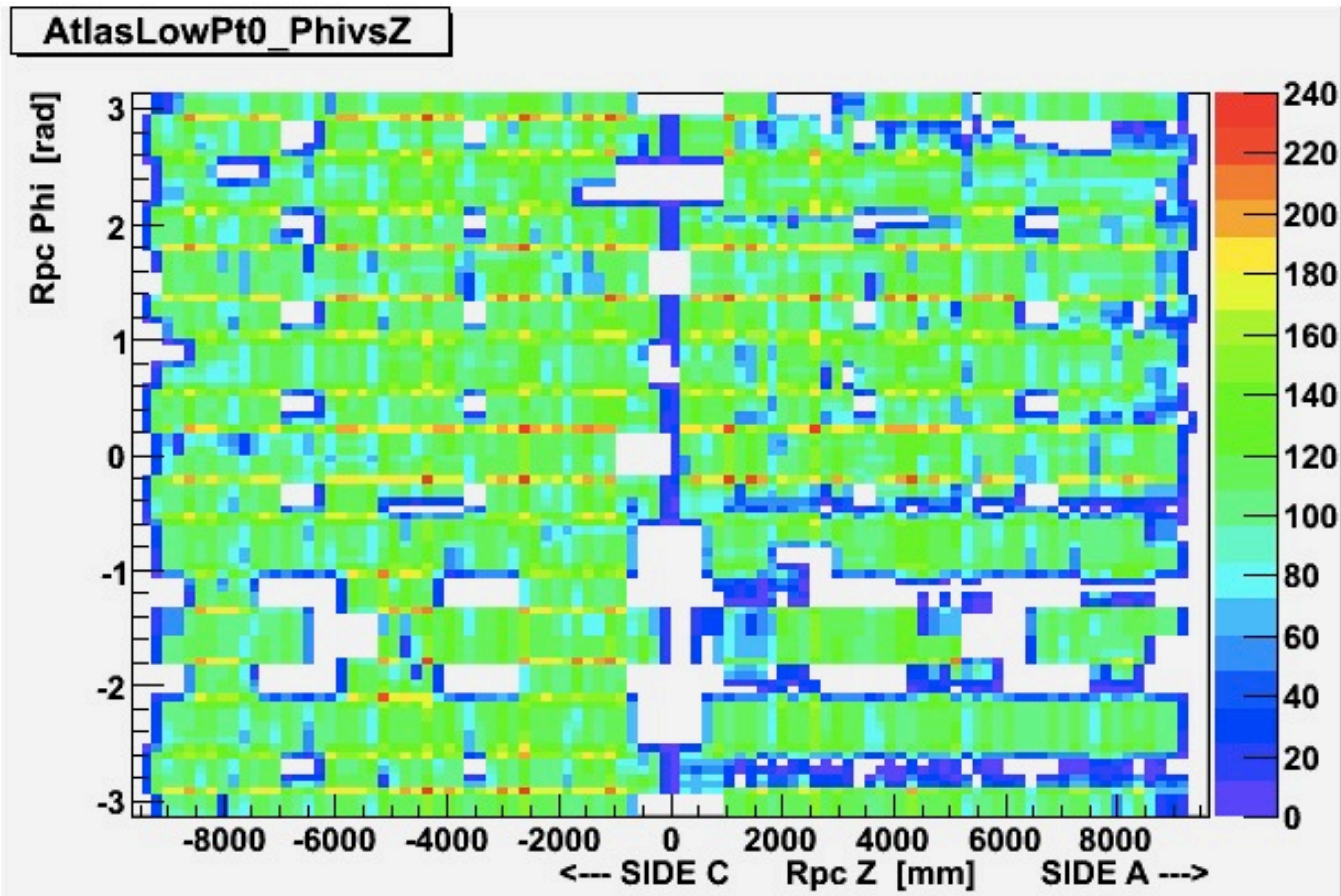


Why trigger efficiency lower than 90 %??

Trigger Coverage



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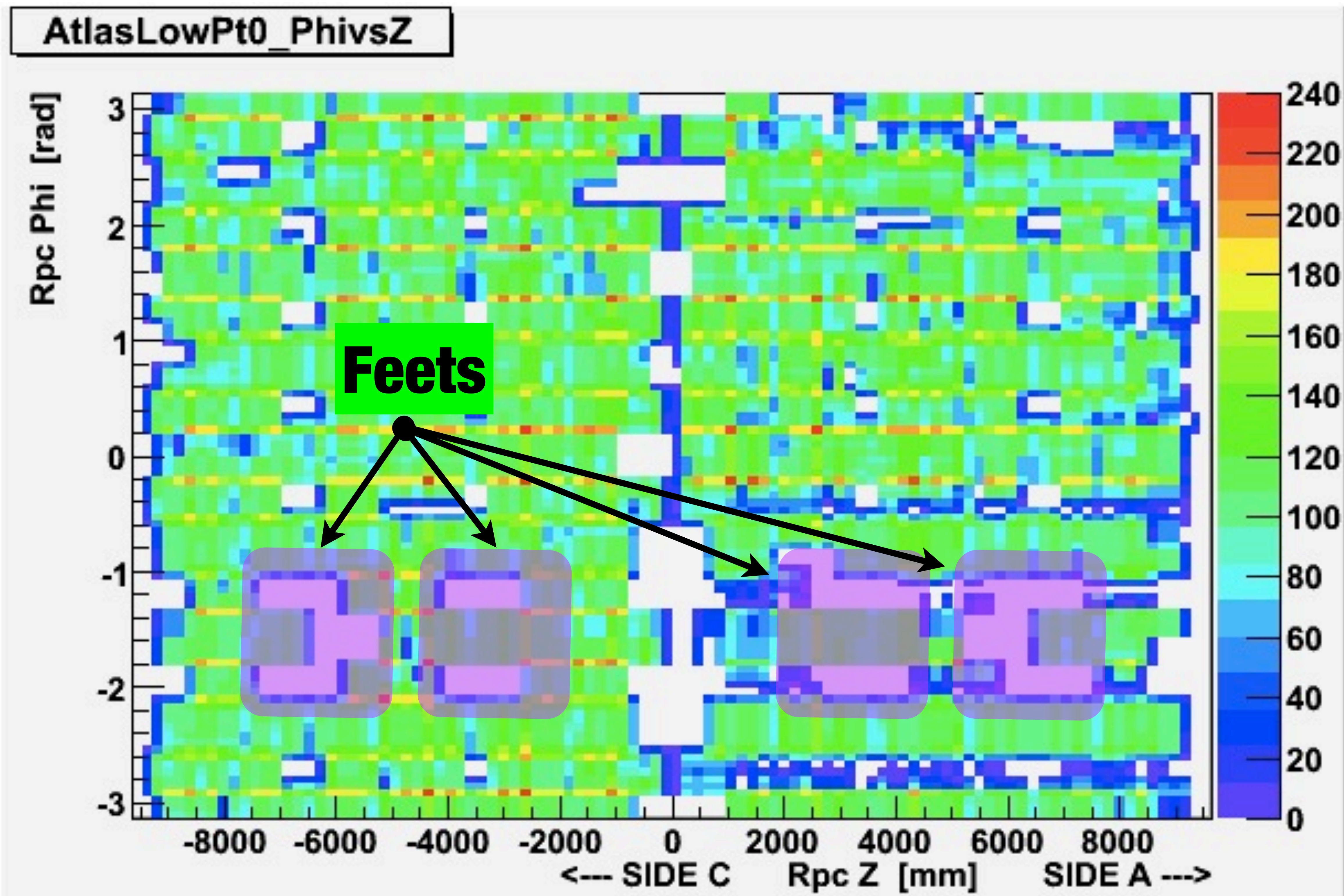

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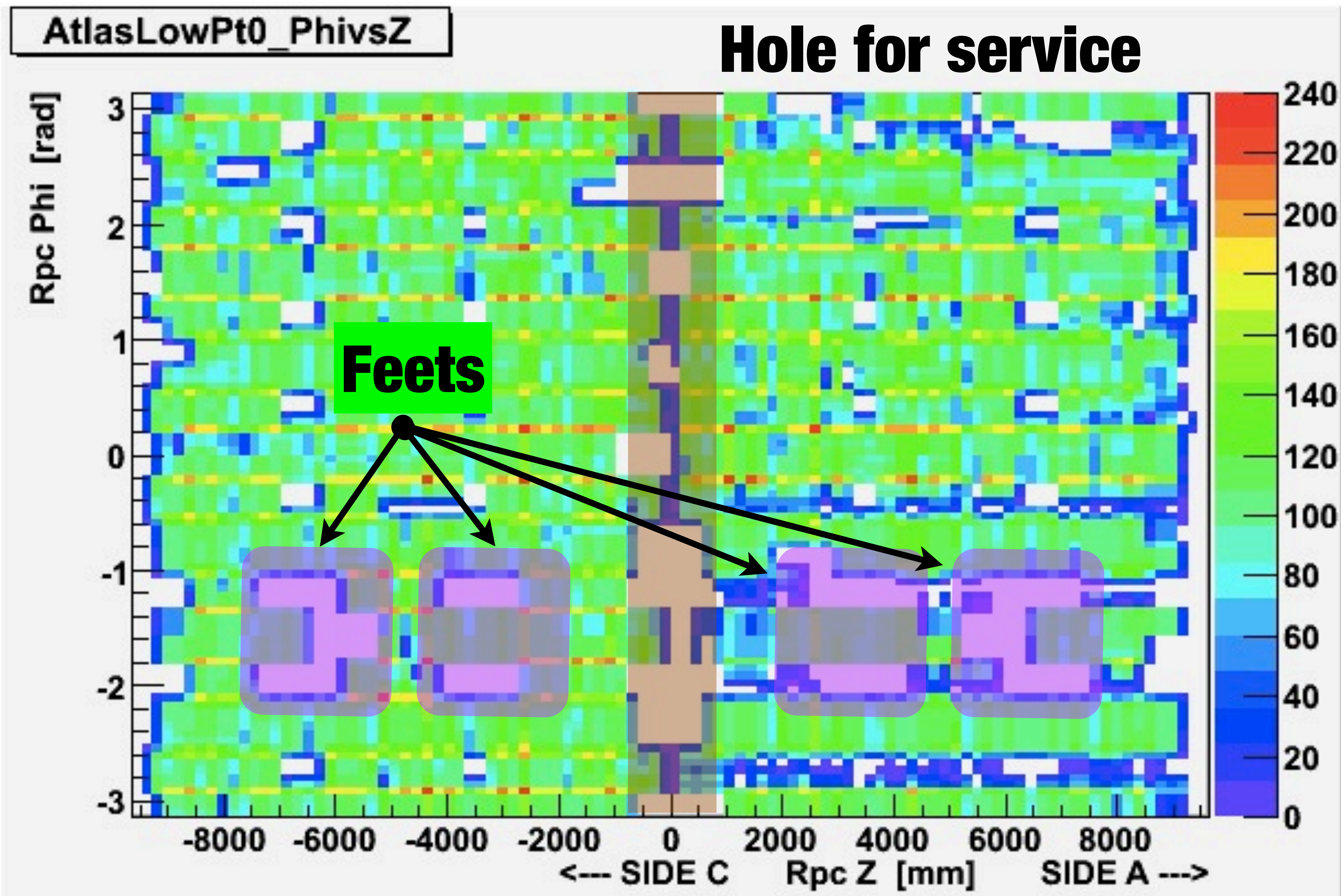
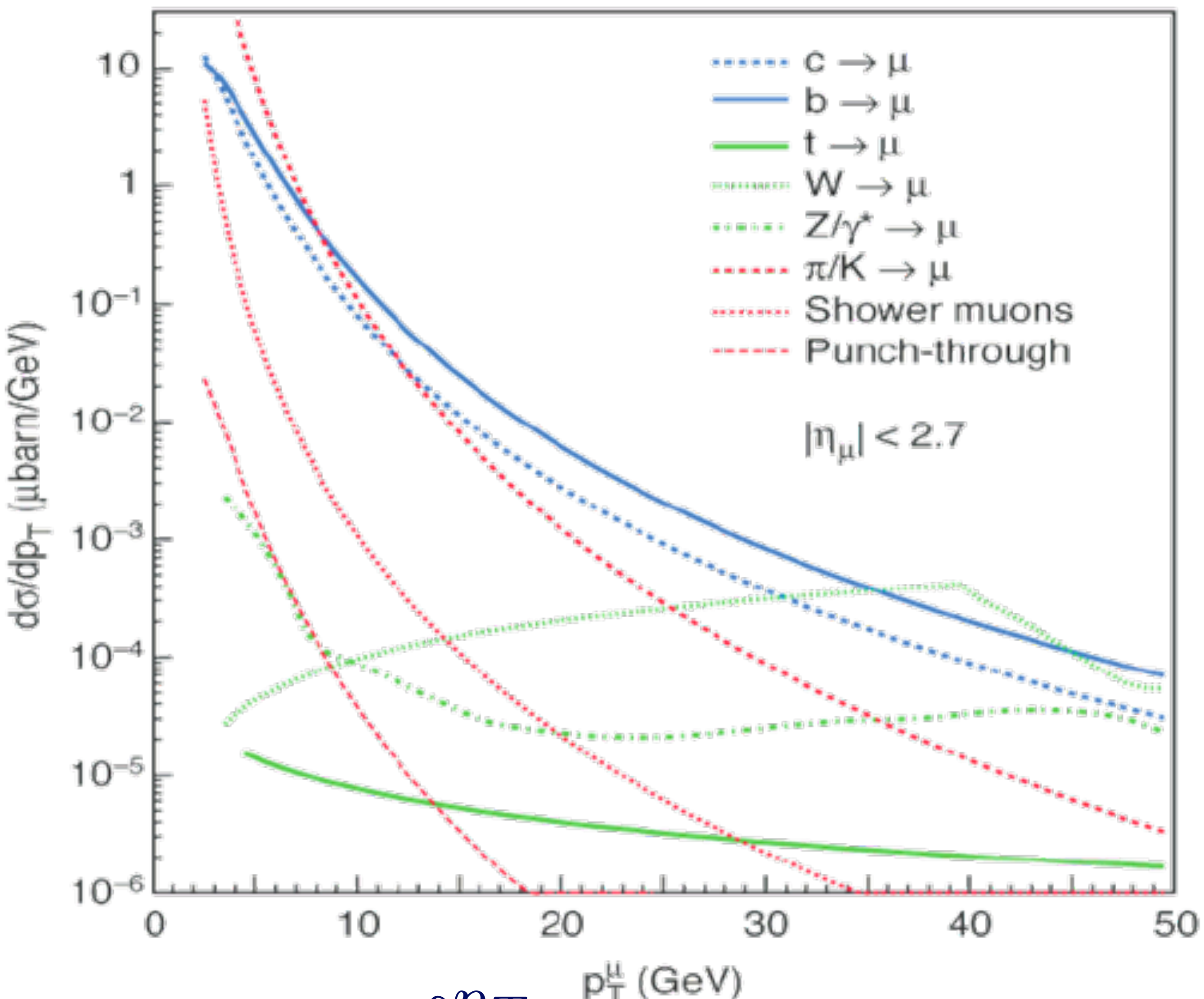


Level-1 Trigger Rates @ $\mathcal{L} = 10^{31} cm^{-2} s^{-1}$

Inclusive μ cross-section @ LHC (prompt μ and π/K decay)



	$p_T > 6$ GeV	$p_T > 20$ GeV
π/K	7100	680
b	1400	500
c	800	210
W	3	26
t	~0	~ 0

$$R_{p_T} = \int_0^{p_T} \sigma_\mu(p) \cdot \varepsilon_{L1}(p)\ dp$$

Low-p_T Trigger rates ~ 10 kHz

High-p_T Trigger rates ~ 1.5 kHz

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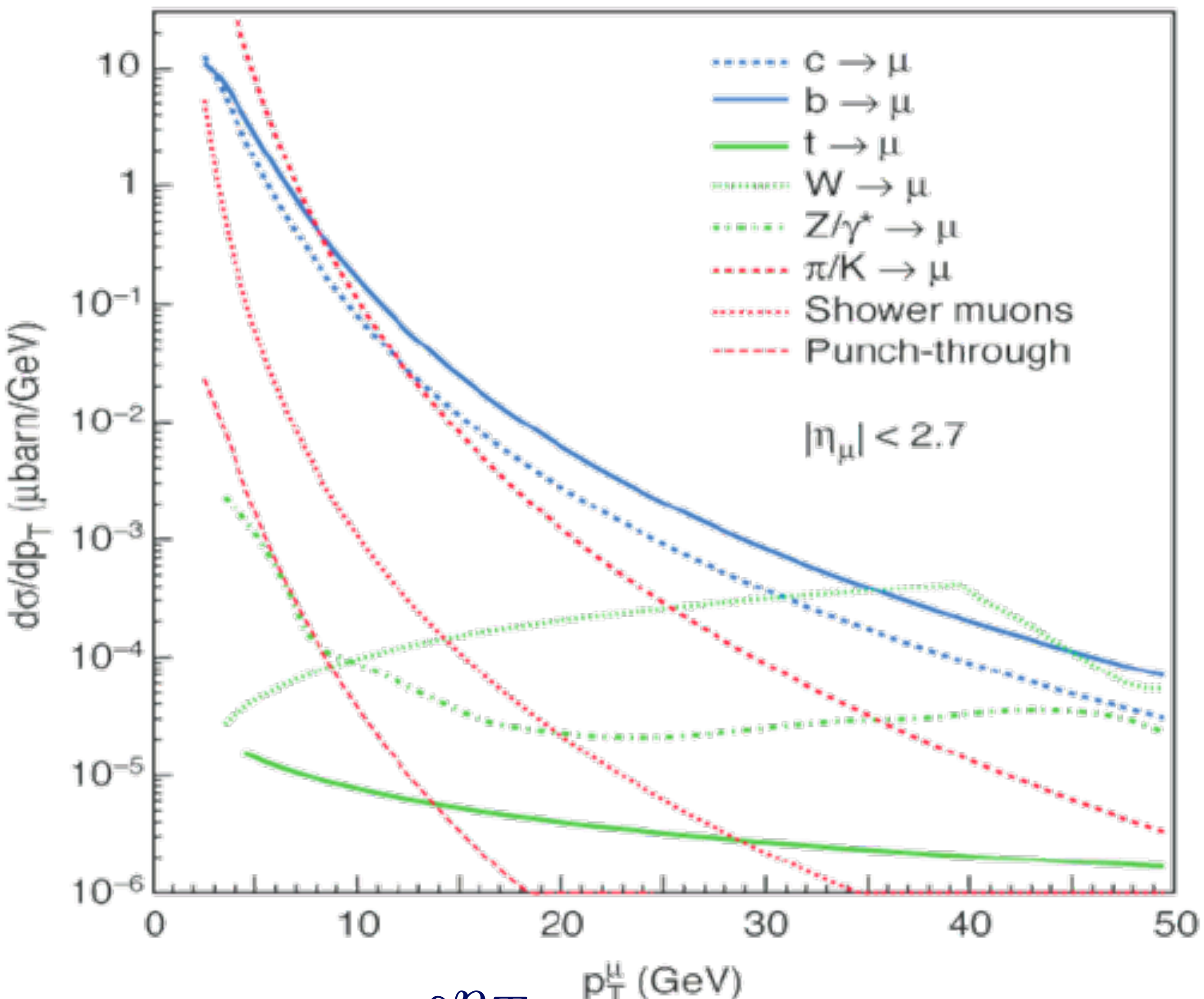

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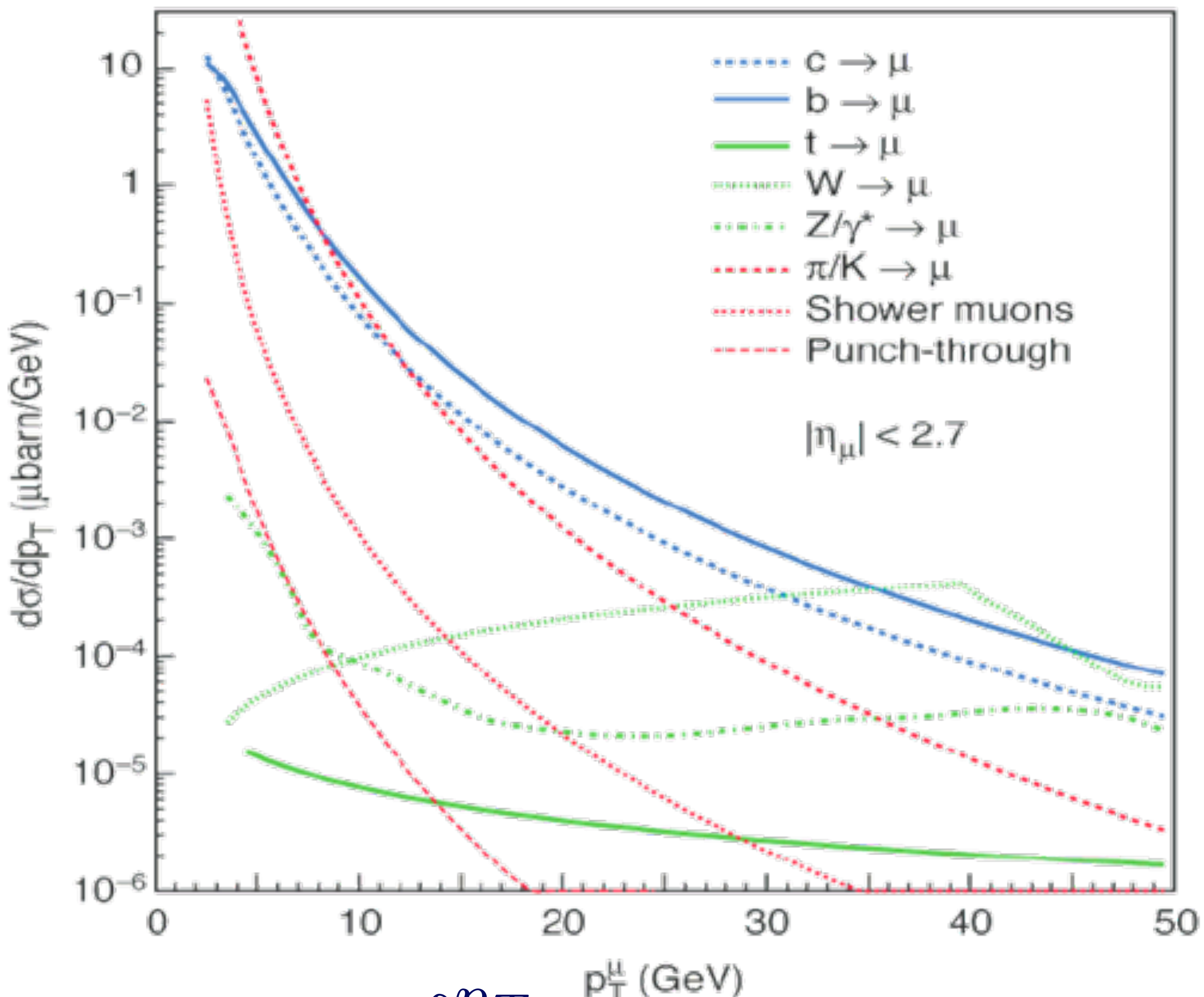

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- **Major source in the Low-p_T**
- **Great uncertainty on σ**

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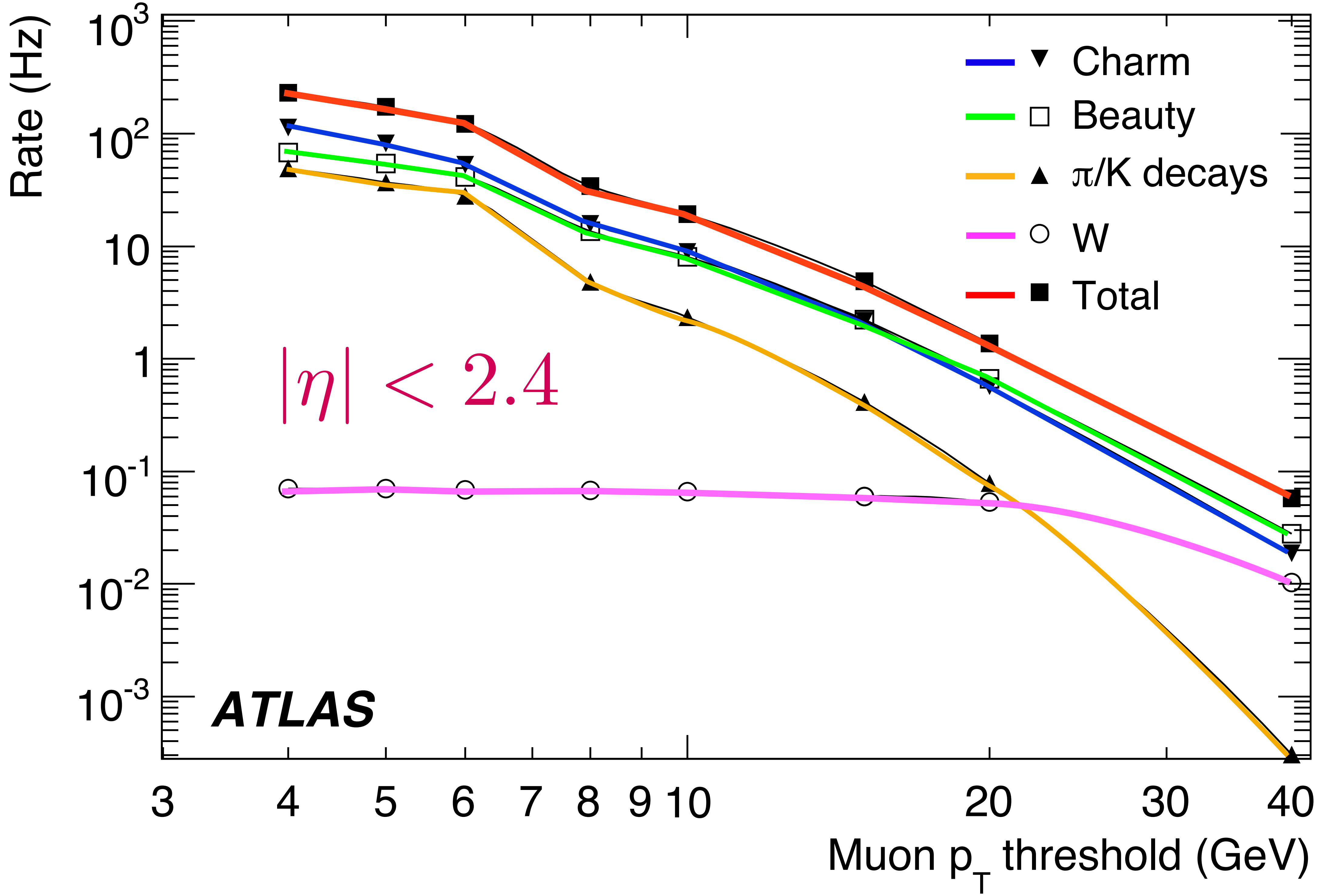
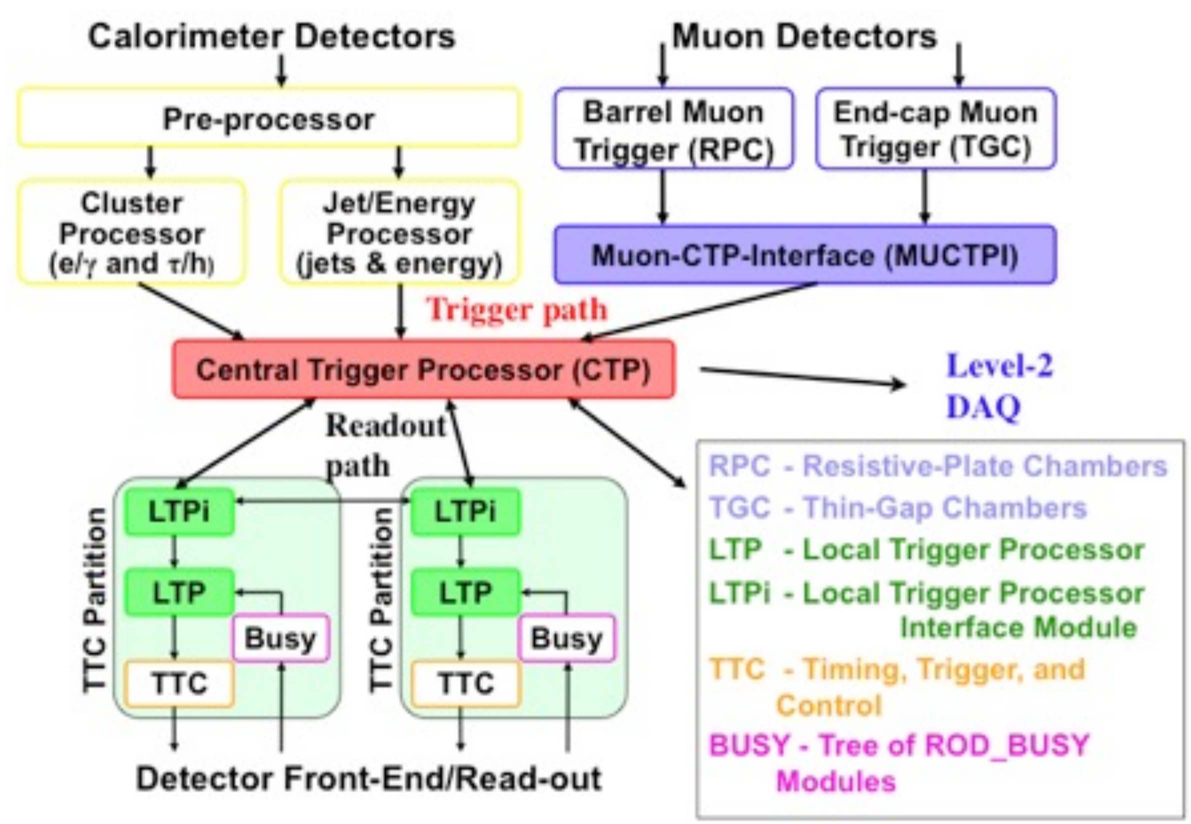


The Timing

a look inside

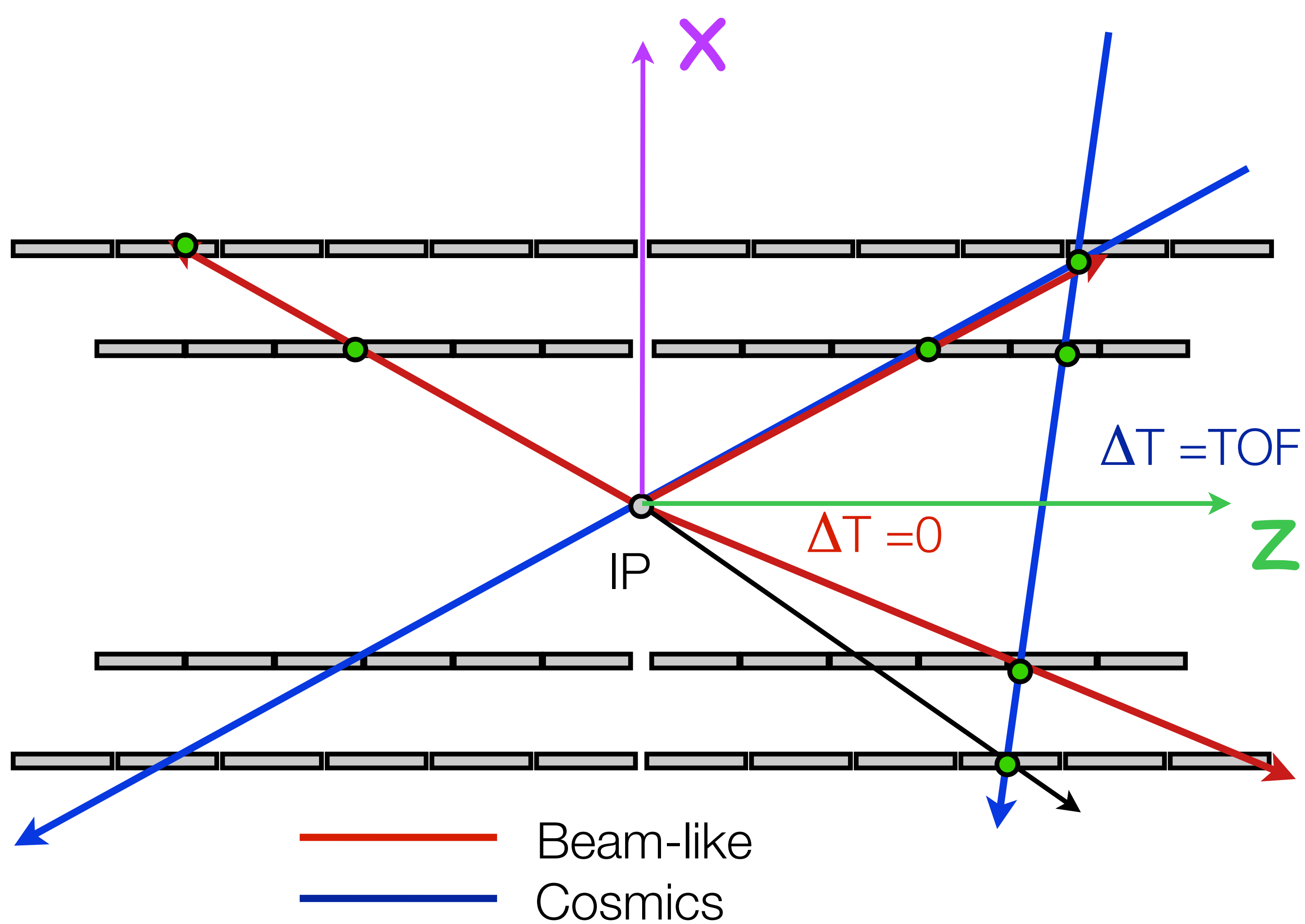
ATLAS LVL1 Trigger

- The ATLAS trigger is synchronous with LHC bunch crossing (BC) at 40.08 MHz
- The triggers coming from the different trigger detectors/systems are collected into the Central Trigger Processor (CTP) that issues a L1 Accept (L1A) on the first “valid” trigger received
- So between the issue of a trigger and its confirmation there is a delay that depends on many sources (signal propagation, processing time, etc..)
- Data are stored in pipelines waiting for the L1A and then it is essential to correctly tag the event and the corresponding data
- This is achieved labeling all the data with the id on the BC (BCID) and with the L1A.



Timing

- ✓ Timing selects physics: muons from beam not the same cosmics
- ✓ Timing is NOT “absolute”
- ✓ The trigger for the same particle can be seen at different time by each trigger element (part of the trigger system)



Timing in the Trigger

A correct timing-in means that we will trigger the μ, with the desired p_T, emerging from the IP at given BC and we will stamp it with the correct BC ID.

The timing-in of the trigger requires to correct for:

- **the delay** due to the propagation along cables, fibers and to the processing latencies of the different elements.
- **the Time of Flight**, i.e. the physics to select, needs to know the physical "interesting" configurations

Just cosmic can be used

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- Wrong ToF in the top part of the detector.

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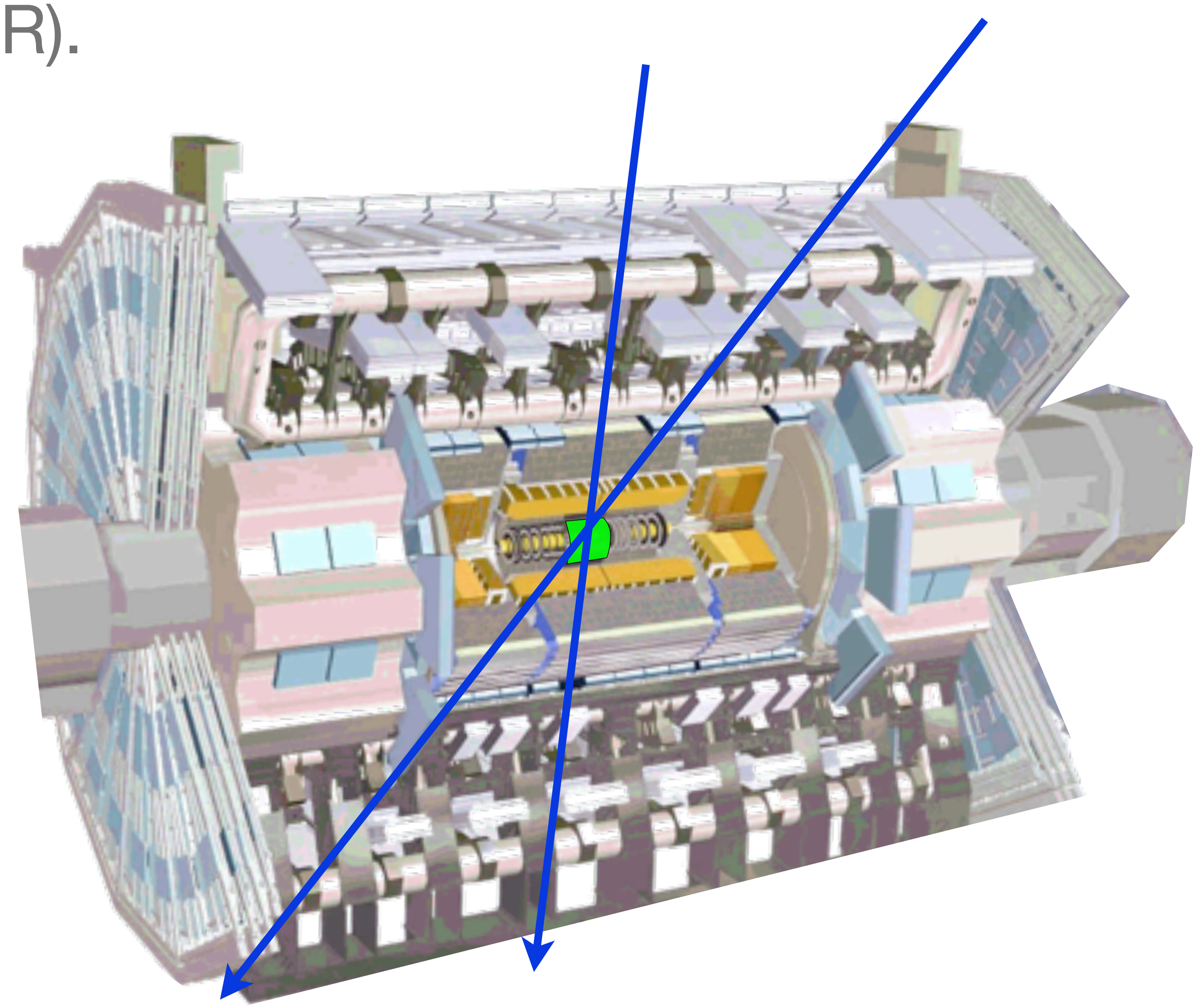
✓ Selecting IP pointing cosmic muons:
✓ beam trajectory (wrong ToF)
✓ easy to understand
✓ from cosmic to beam only ToF difference

Timing - Global Alignment

- Using RPC trigger to align itself it is too difficult: the trigger misalignment has an impact on the track reconstruction
- The ATLAS Inner **T**ransition **R**adiation **T**ube detector set-up a trigger for self calibration (TRT FastOR).

TRT FastOR

- good coverage for pointing tracks
- small ToF contribution
- timed in at ~ ns

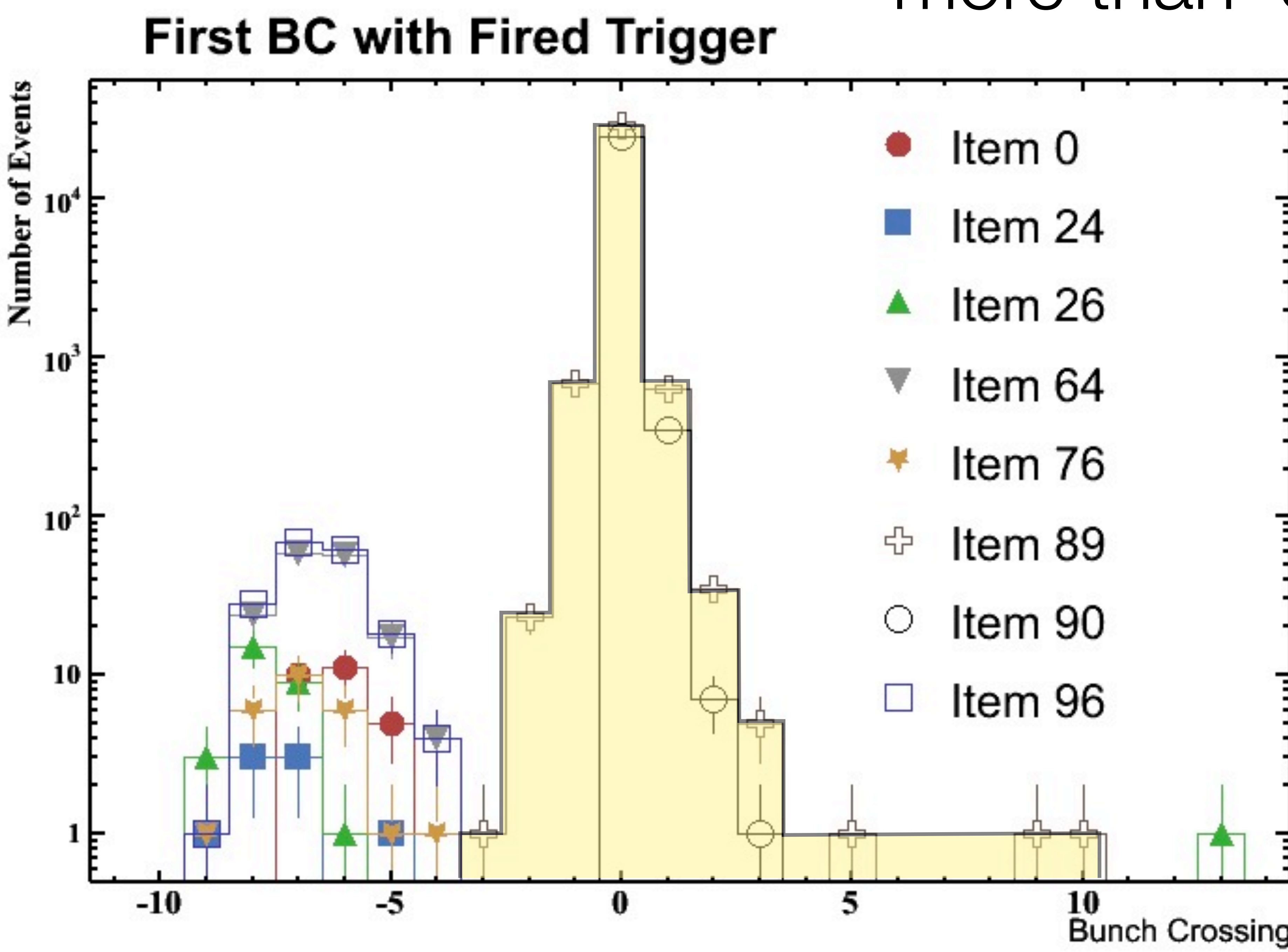


Muon barrel trigger has ~ 400 trigger sources (called towers)

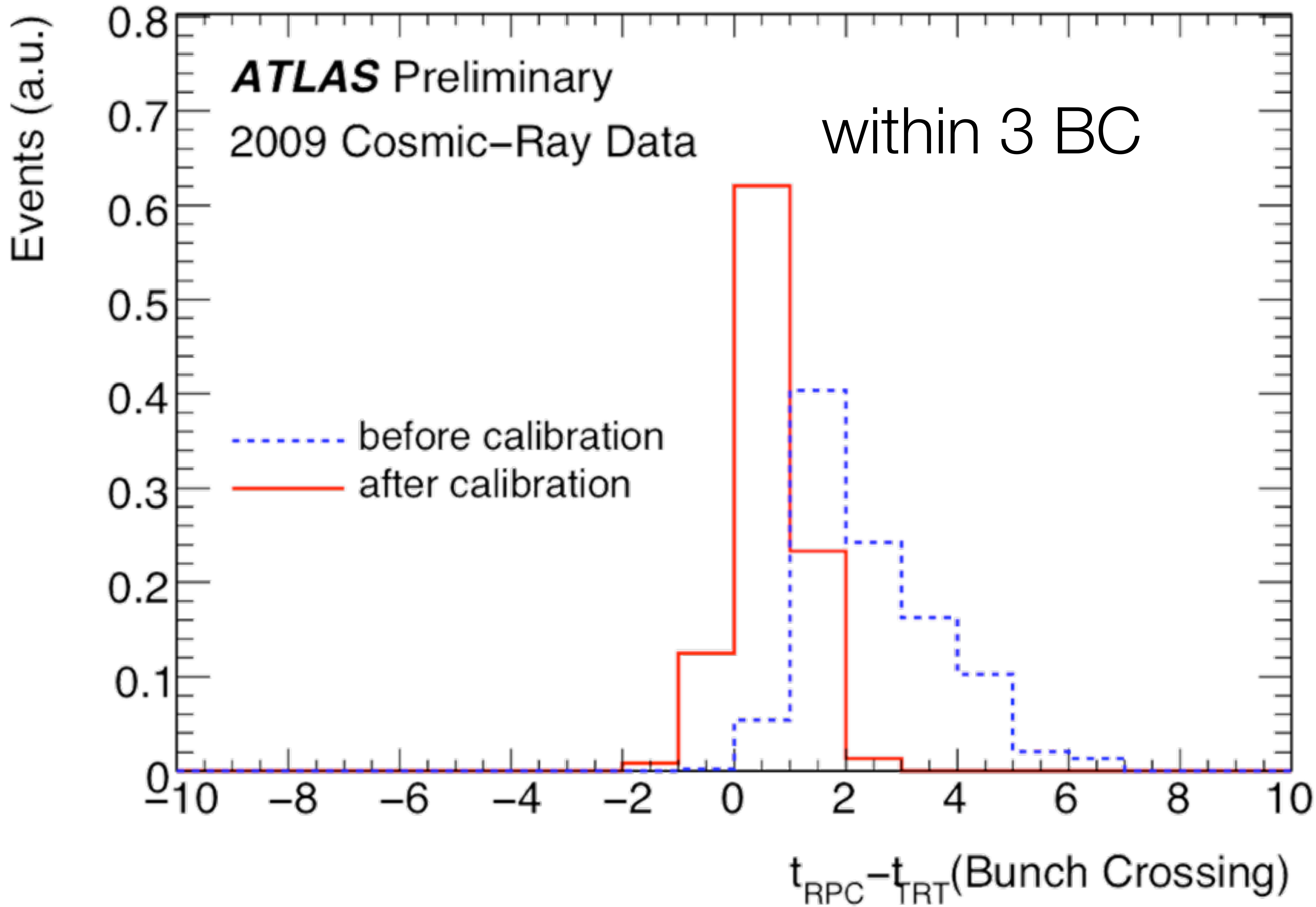
Achievement with cosmics

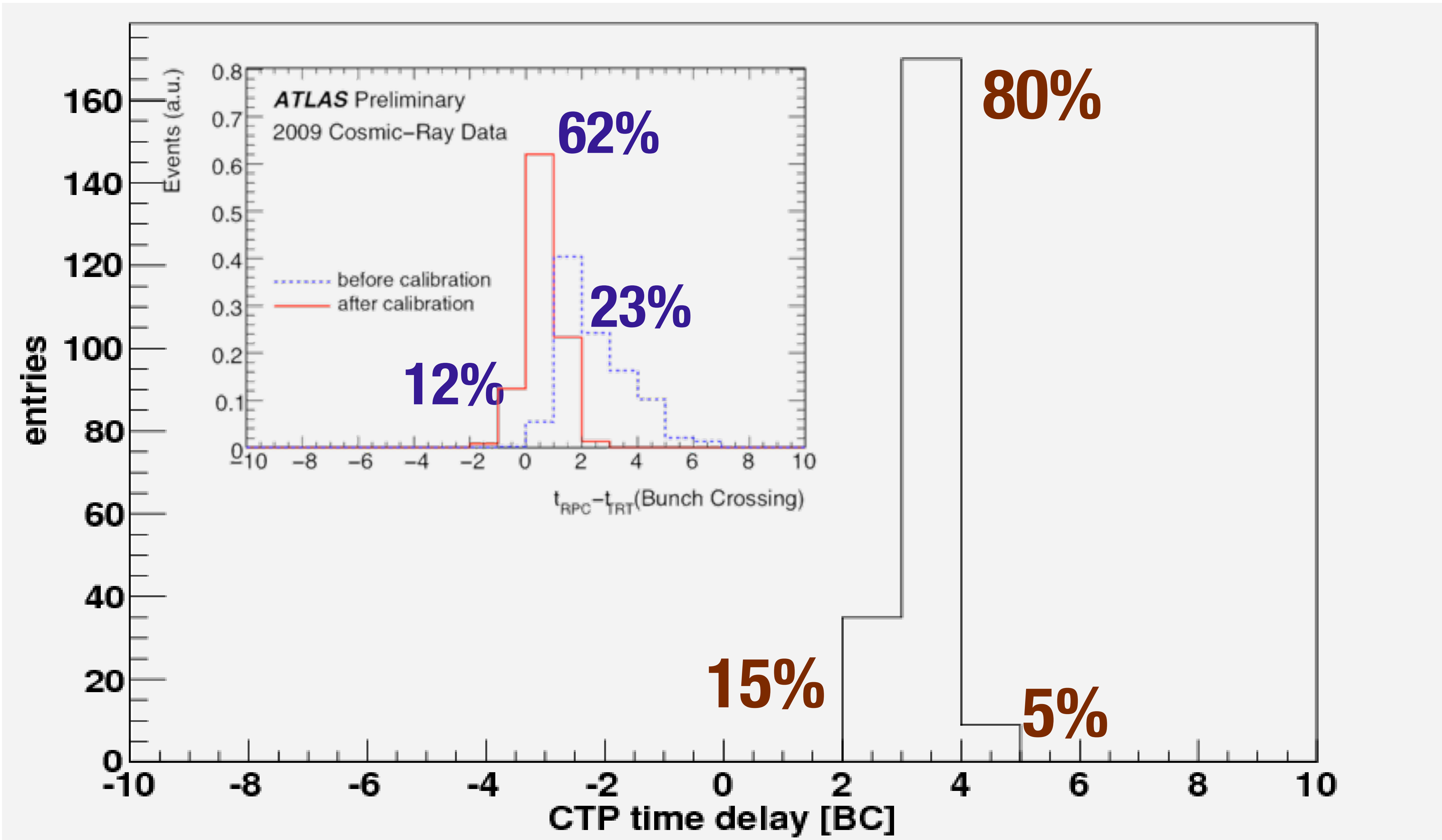
Timing - September 2008

more than 8 BC



Timing Now with Cosmics




entries
160
140
120
100
80
60
40
20
0
-10
-8
-6
-4
-2
0
2
4
6
8
10
CTP time delay [BC]
80%
15%
5%
Events (a.u.)
ATLAS Preliminary
2009 Cosmic-Ray Data
before calibration
after calibration
62%
23%
12%
t_RPC−t_TRT(Bunch Crossing)

Beam Configuration

- To from cosmics to beam just ToF correction (~BC) was applied
- With beam:
  - absolute reference (Beam Pickup BPTX)
  - absolute BCID
  - absolute correction

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27 muons!!!!

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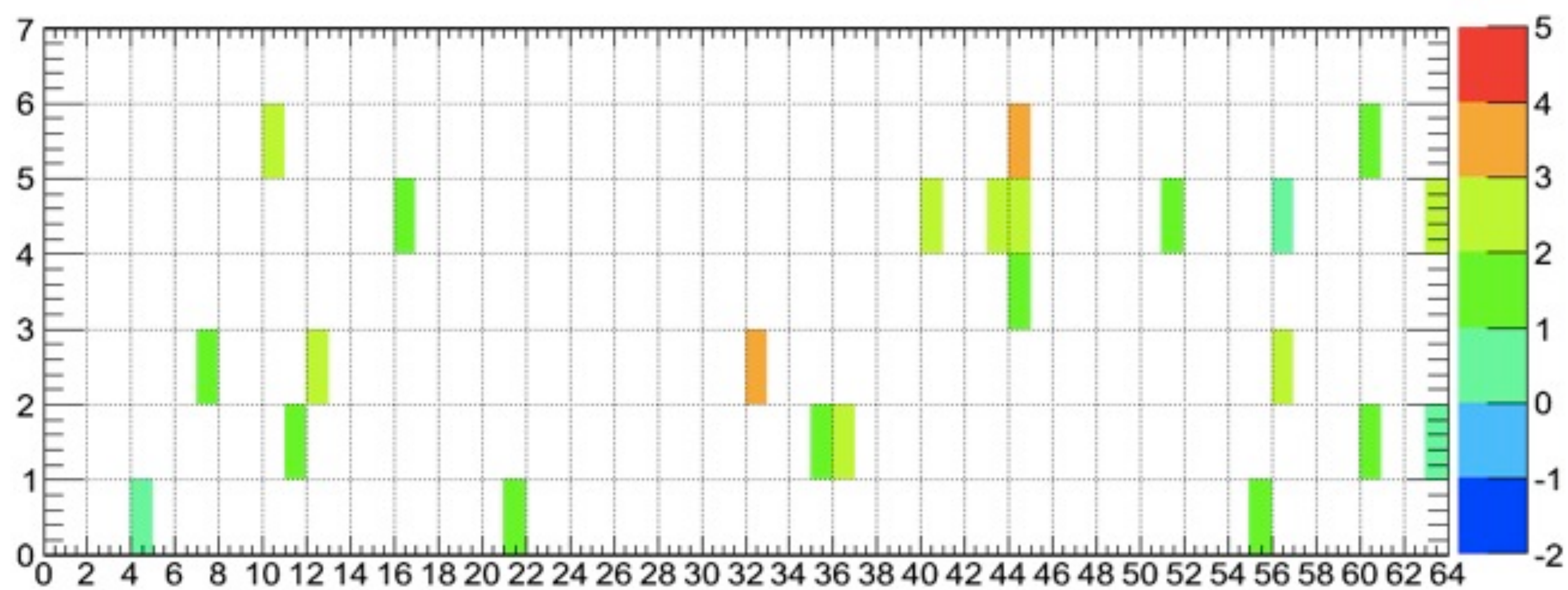
27 muons!!!!



What about efficiency?

- We cannot quote the efficiency. Too few muons

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Toroid	Muon tracks	RPC Triggers	eff.
OFF	8	7	88 %
ON	28	19	68 %

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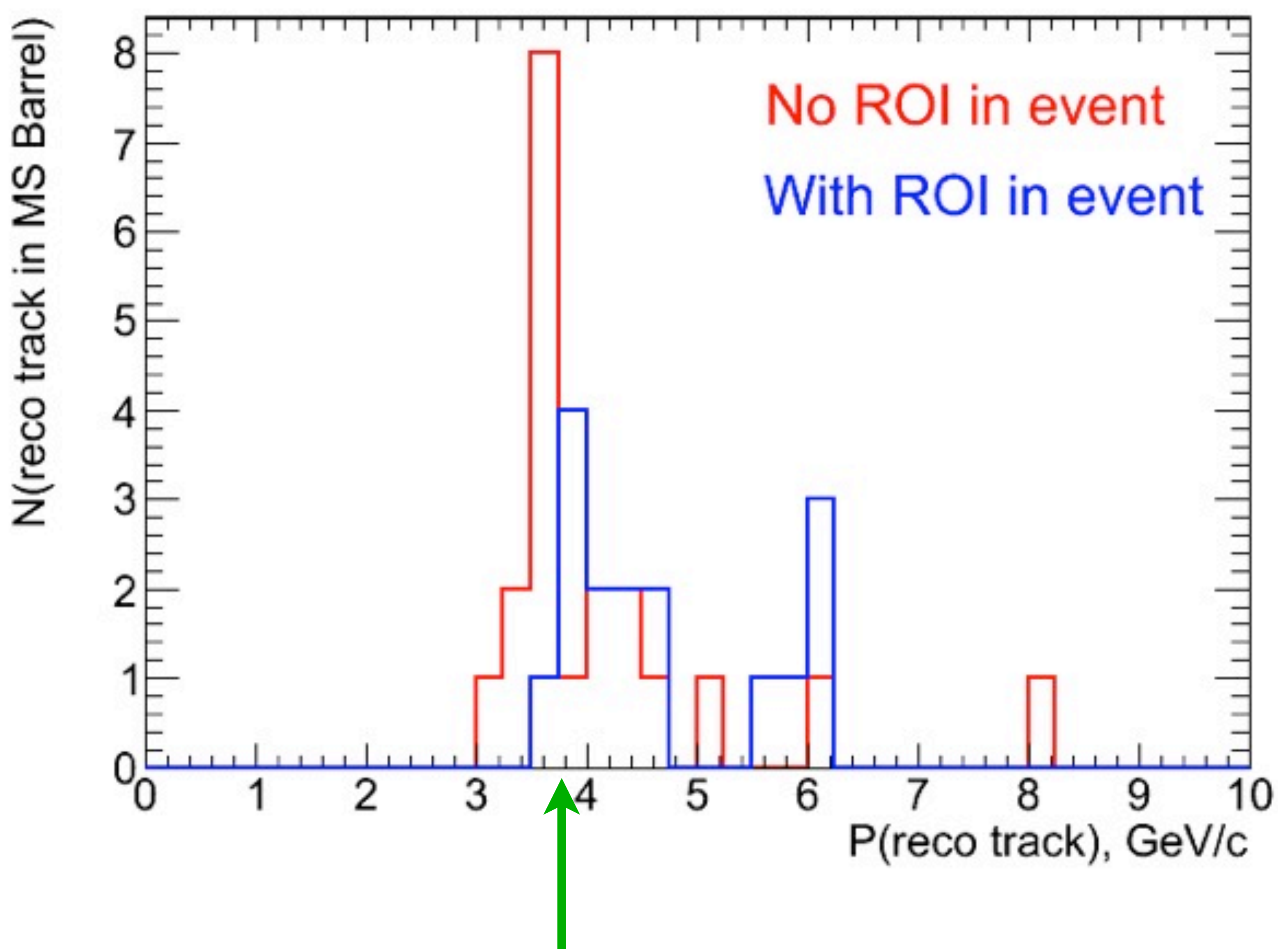

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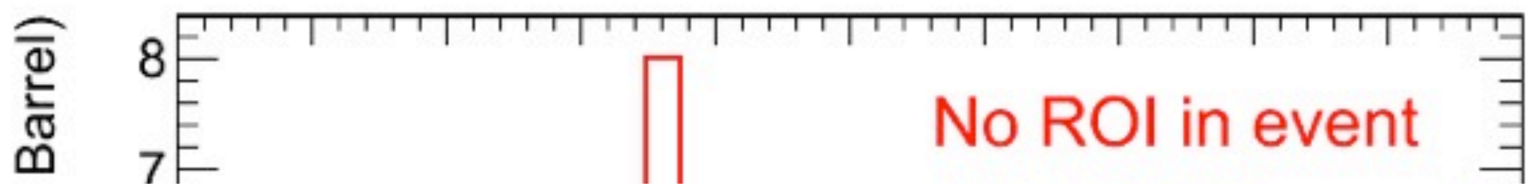
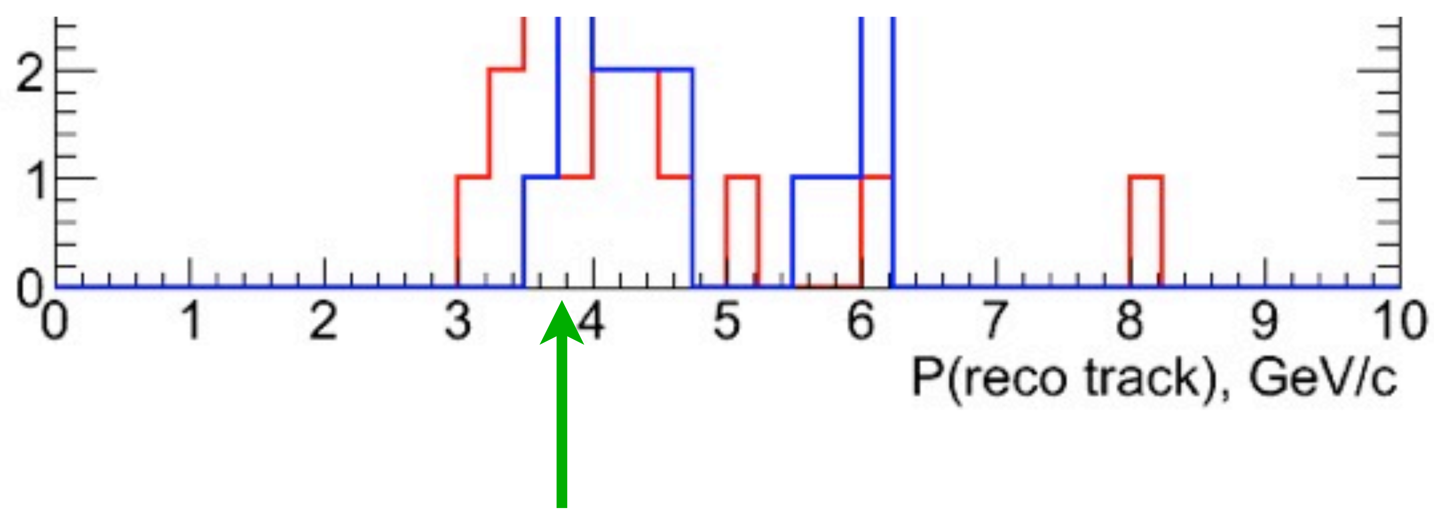
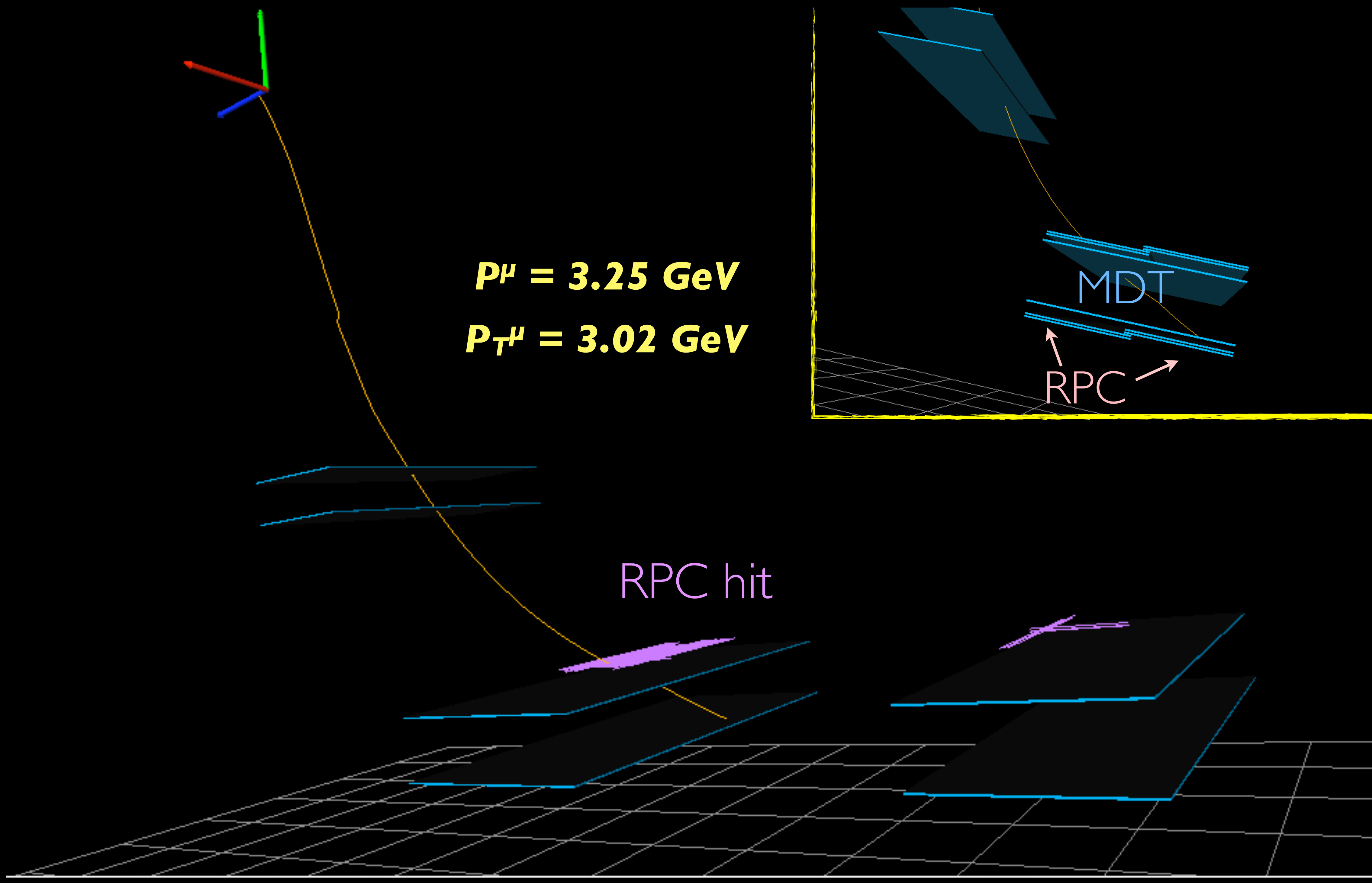


Toroid	Muon tracks	RPC Triggers	eff.
OFF	8	7	88 %
ON	22	19	86 %




P^{μ} = 3.25 GeV
P_T^{μ} = 3.02 GeV
MDT
RPC
RPC hit

Level1 muon trigger at 7 TeV

- One week at $\mathcal{L} = 10^{31}\ cm^{-2}s^{-1}$

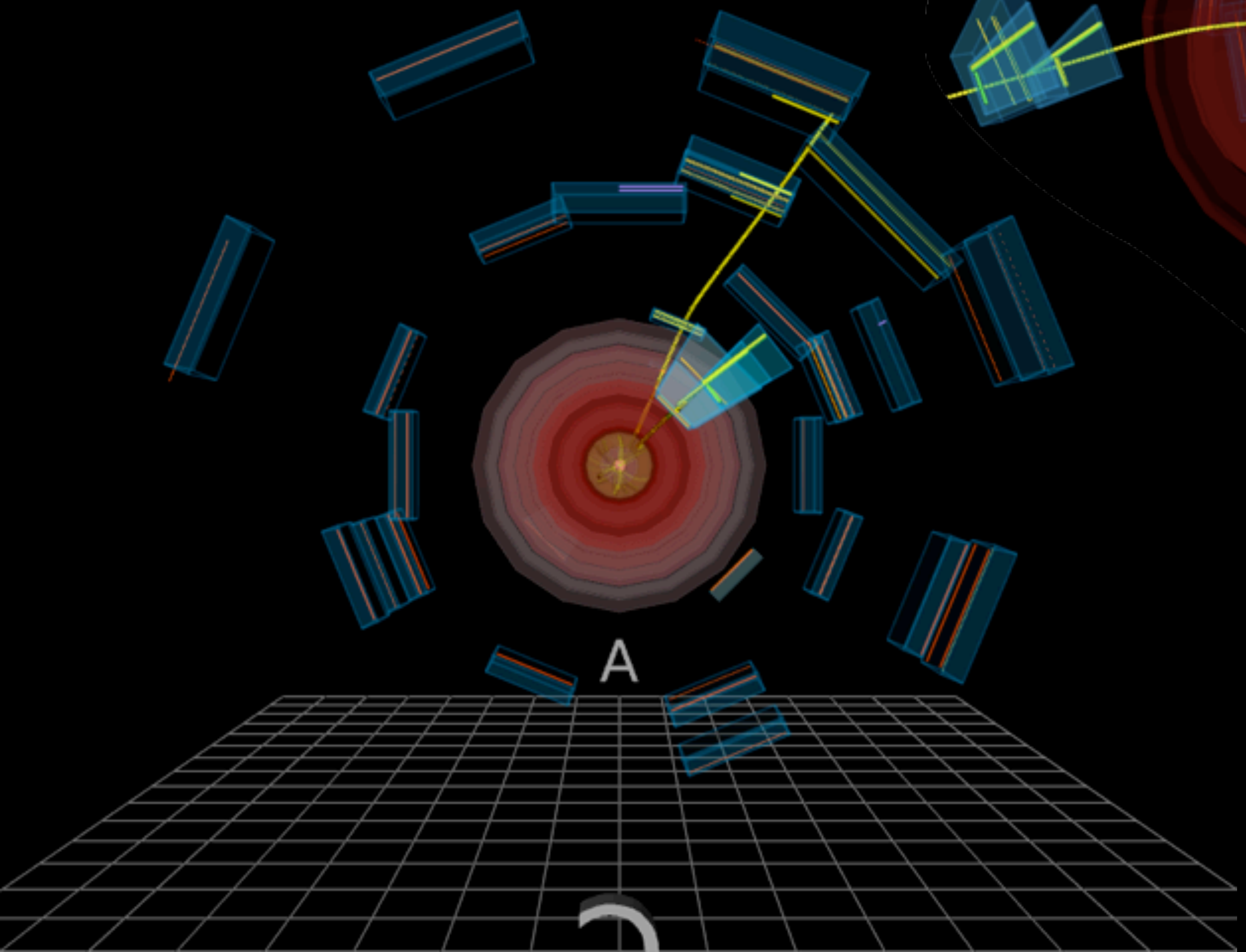
$$\varepsilon \simeq 50\% \qquad \int \mathcal{L} = 1 - 2\ pb^{-1}$$

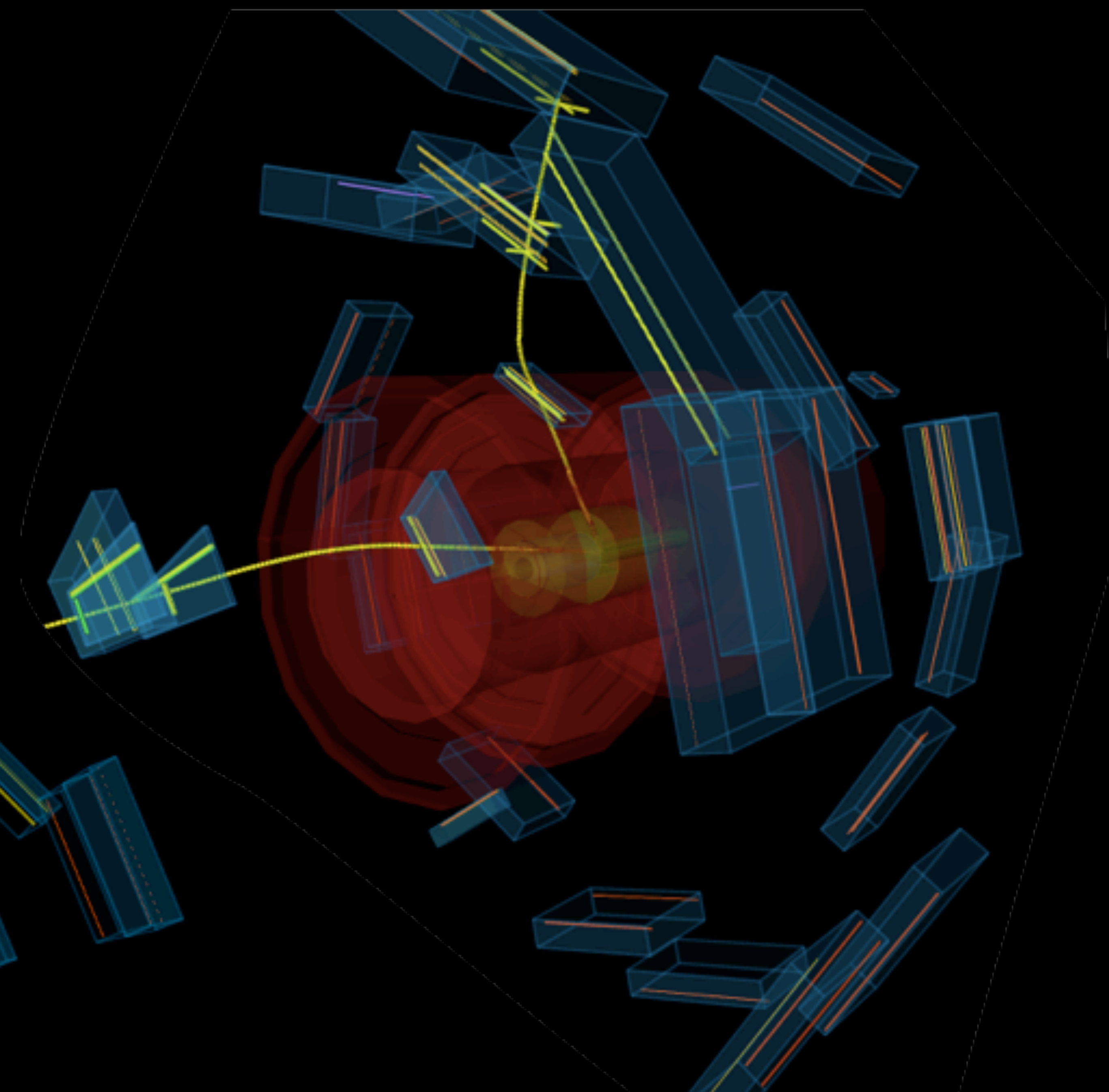
  - O(100k) muons with low p_T from heavy quark decays
  - A few 10 k muons from W, few 100 from Z
  - Important sample of inclusive muons (tag and probe is very statistics limited)

- With 10 pb^{-1} large statistics will allow:
  - Precise determination of parameters: L1 trigger roads
  - Precise determination of performance: p_T resolution, trigger efficiency with tag and probe

J/psi candidate ??

M = 3092.92 MeV/c^2





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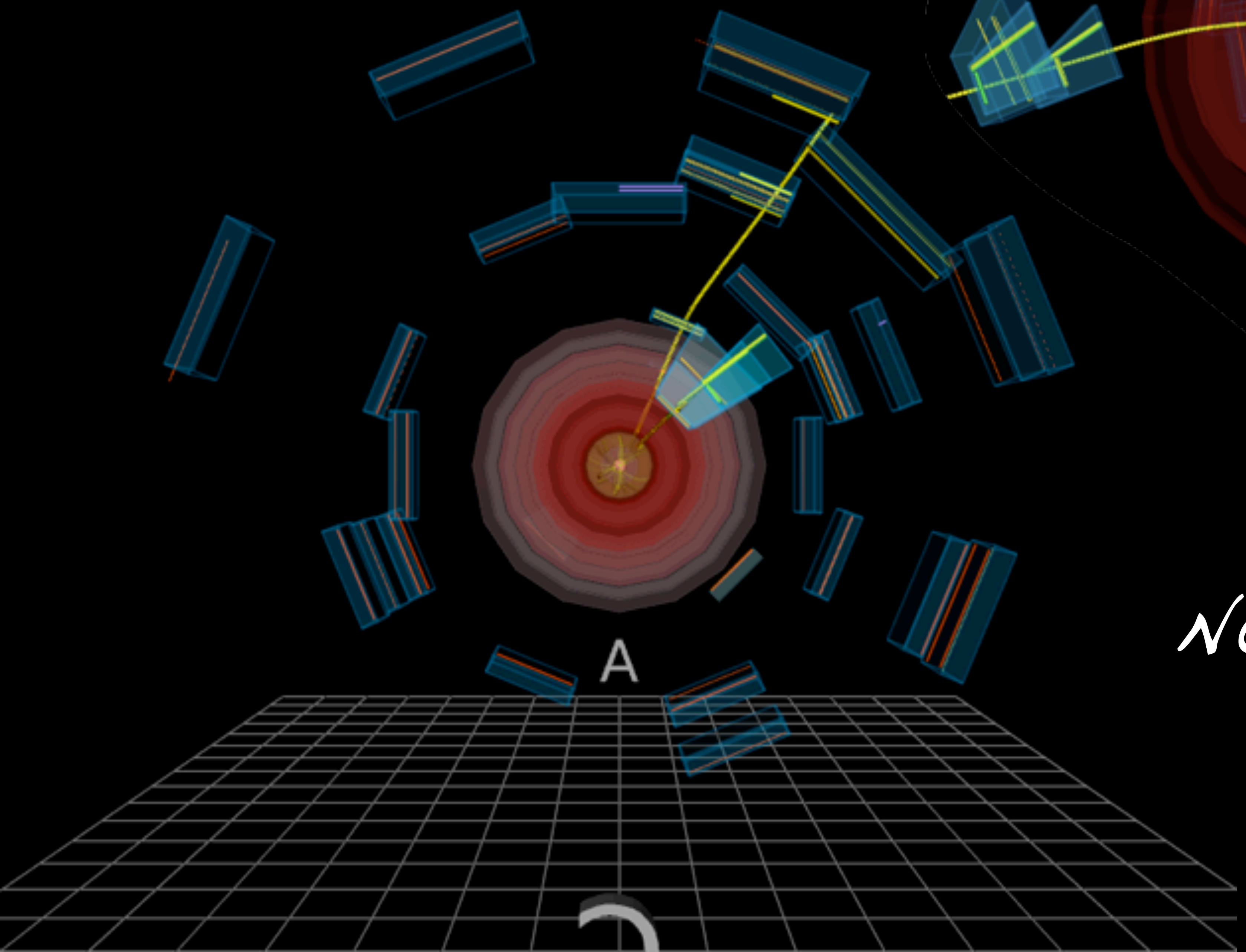

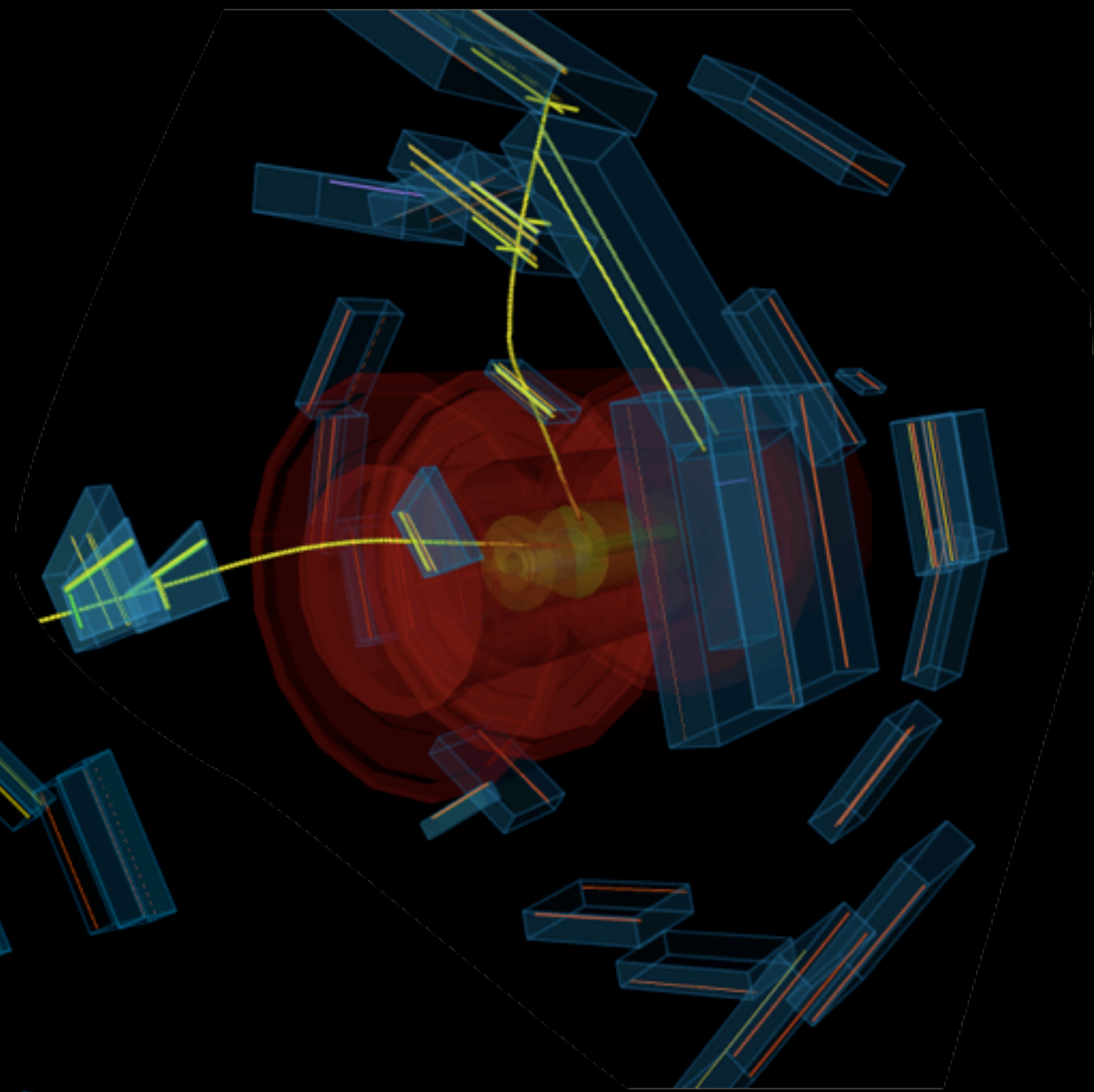

NO, but I like it!

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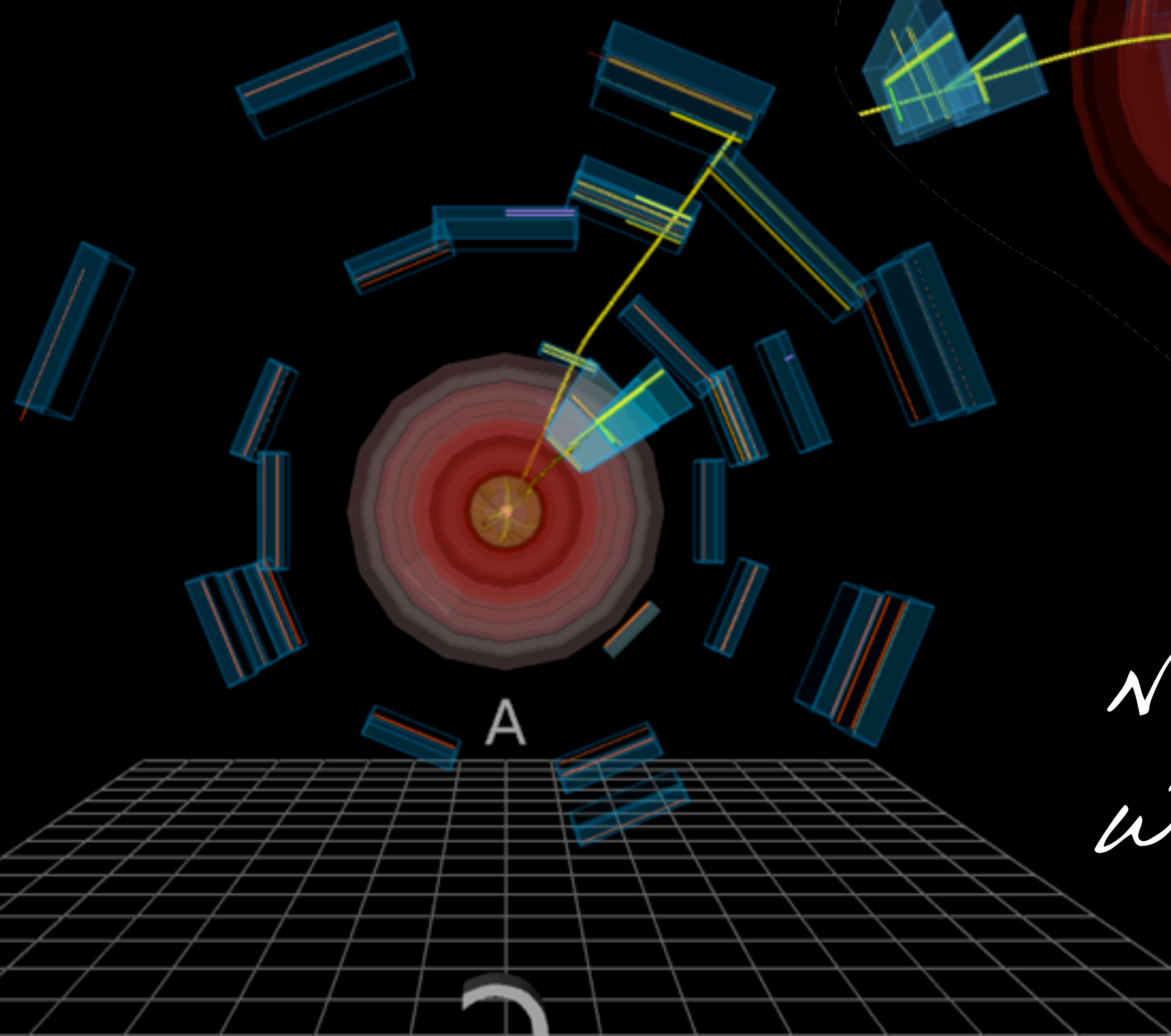

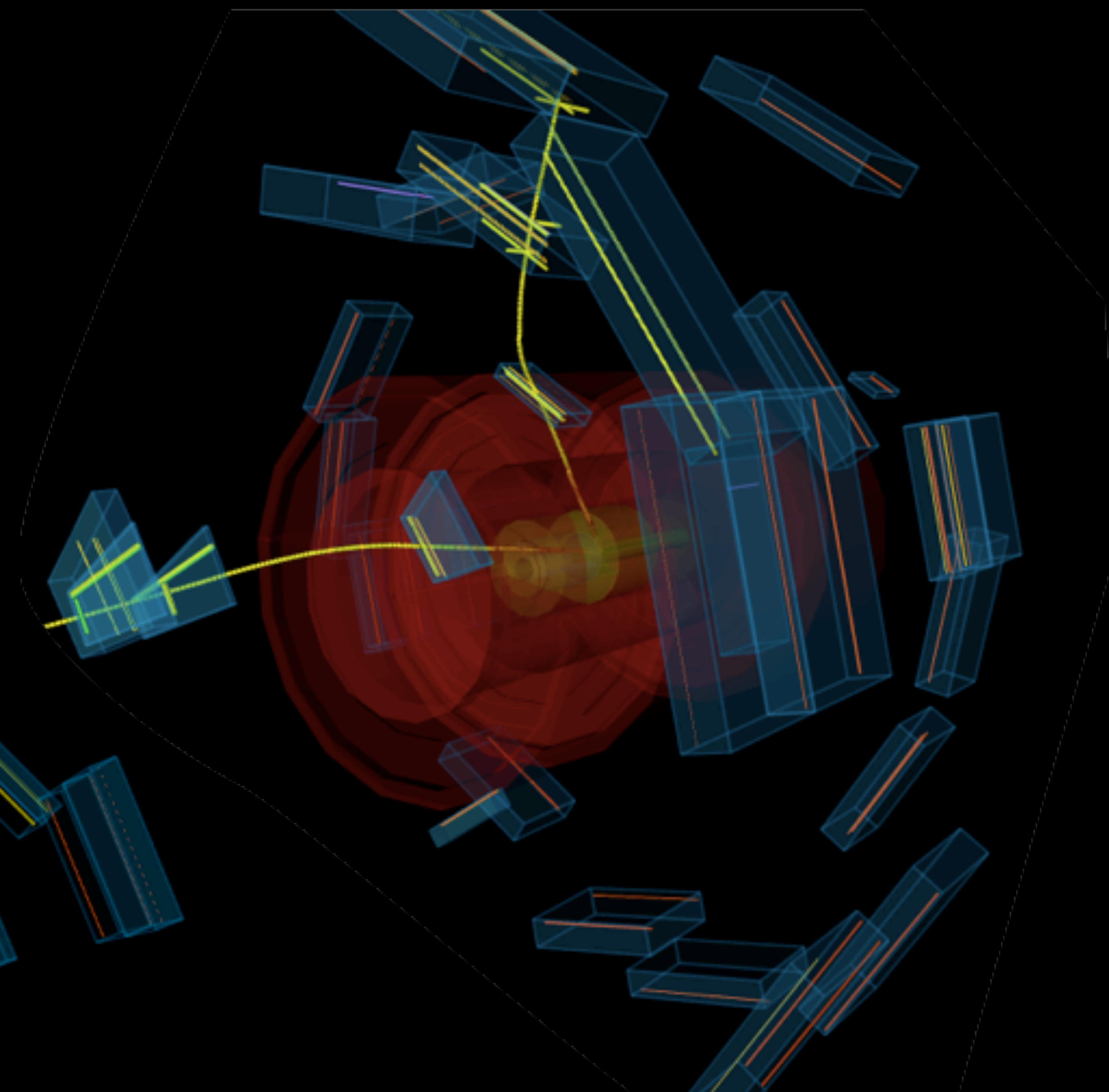

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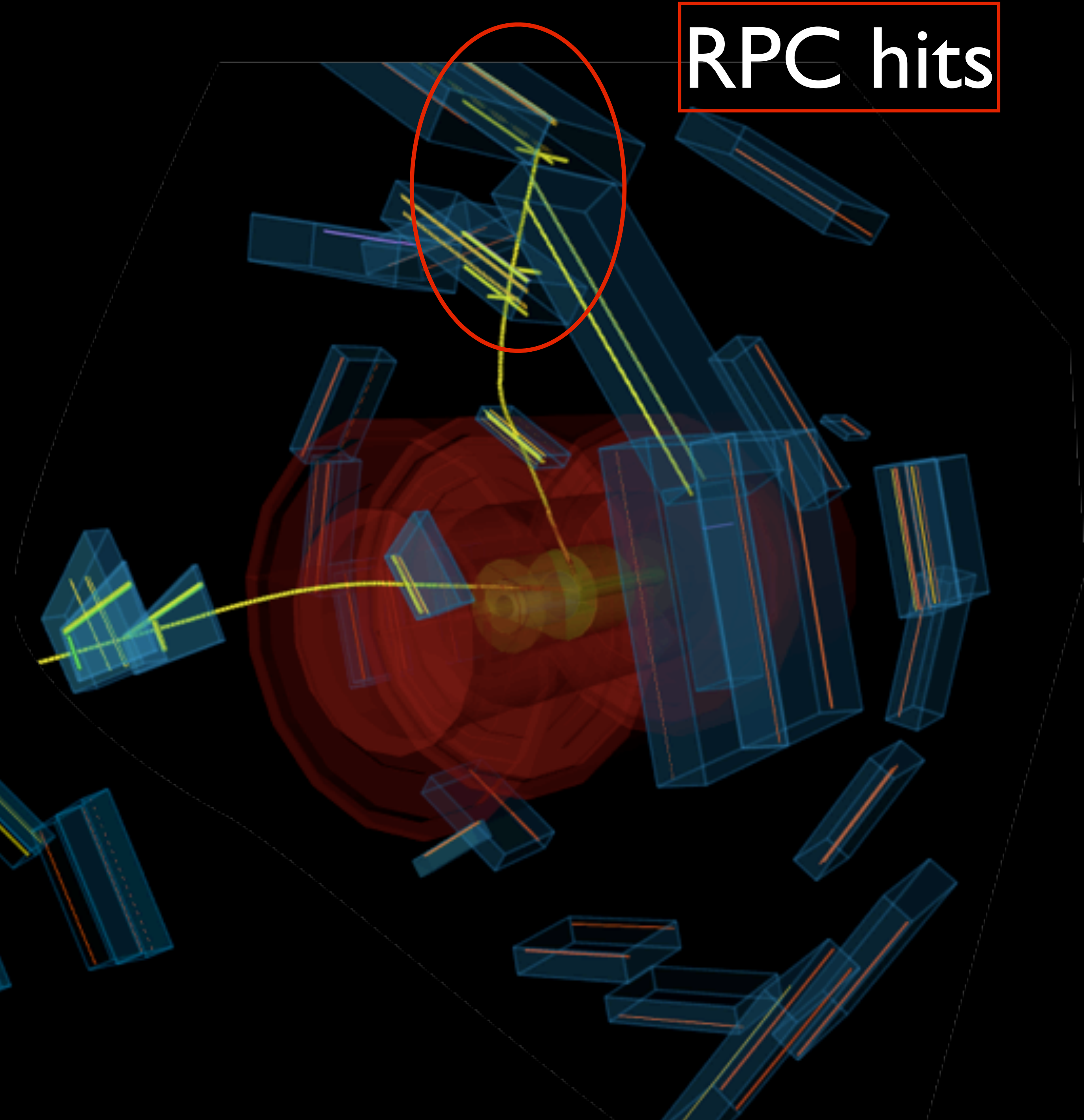

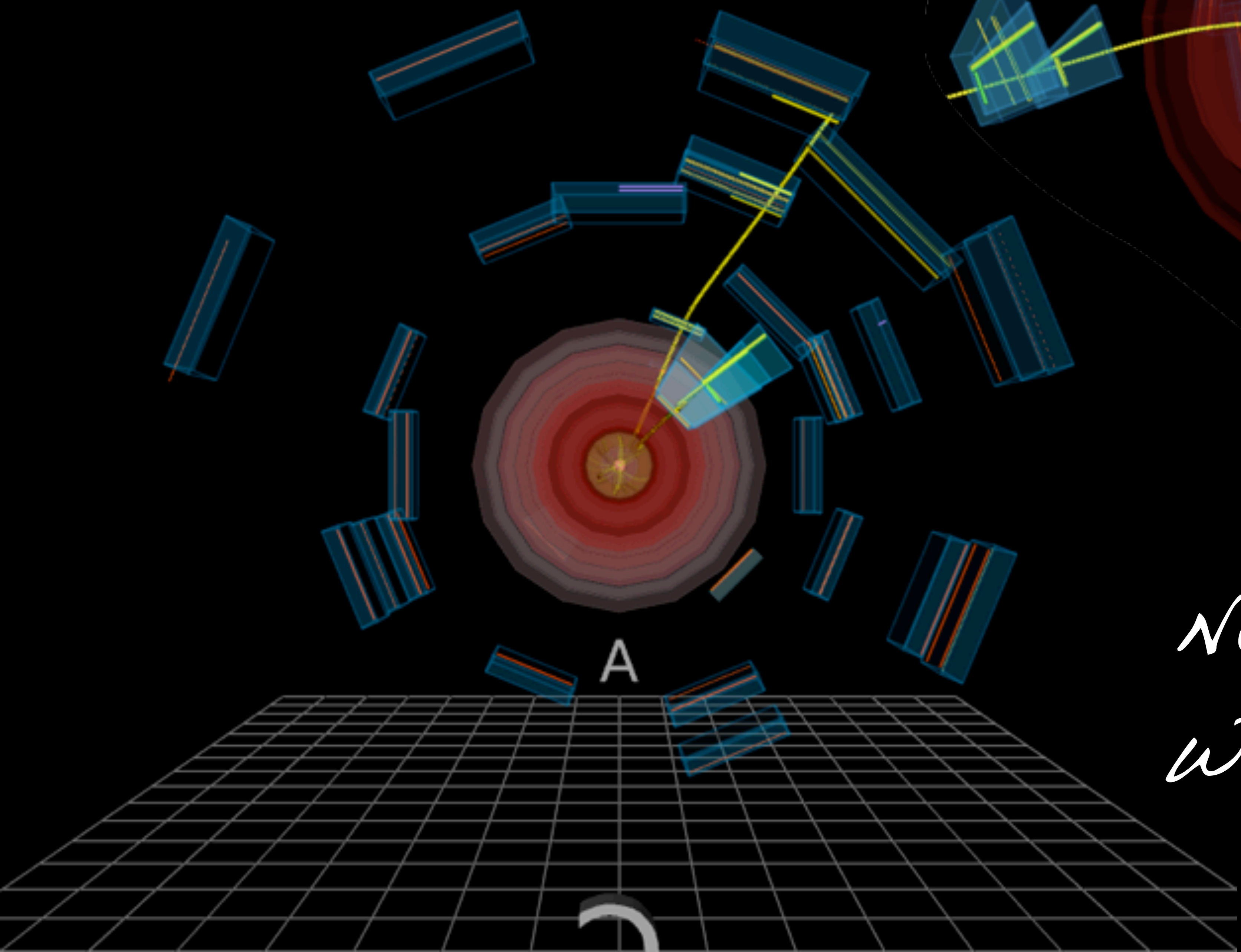

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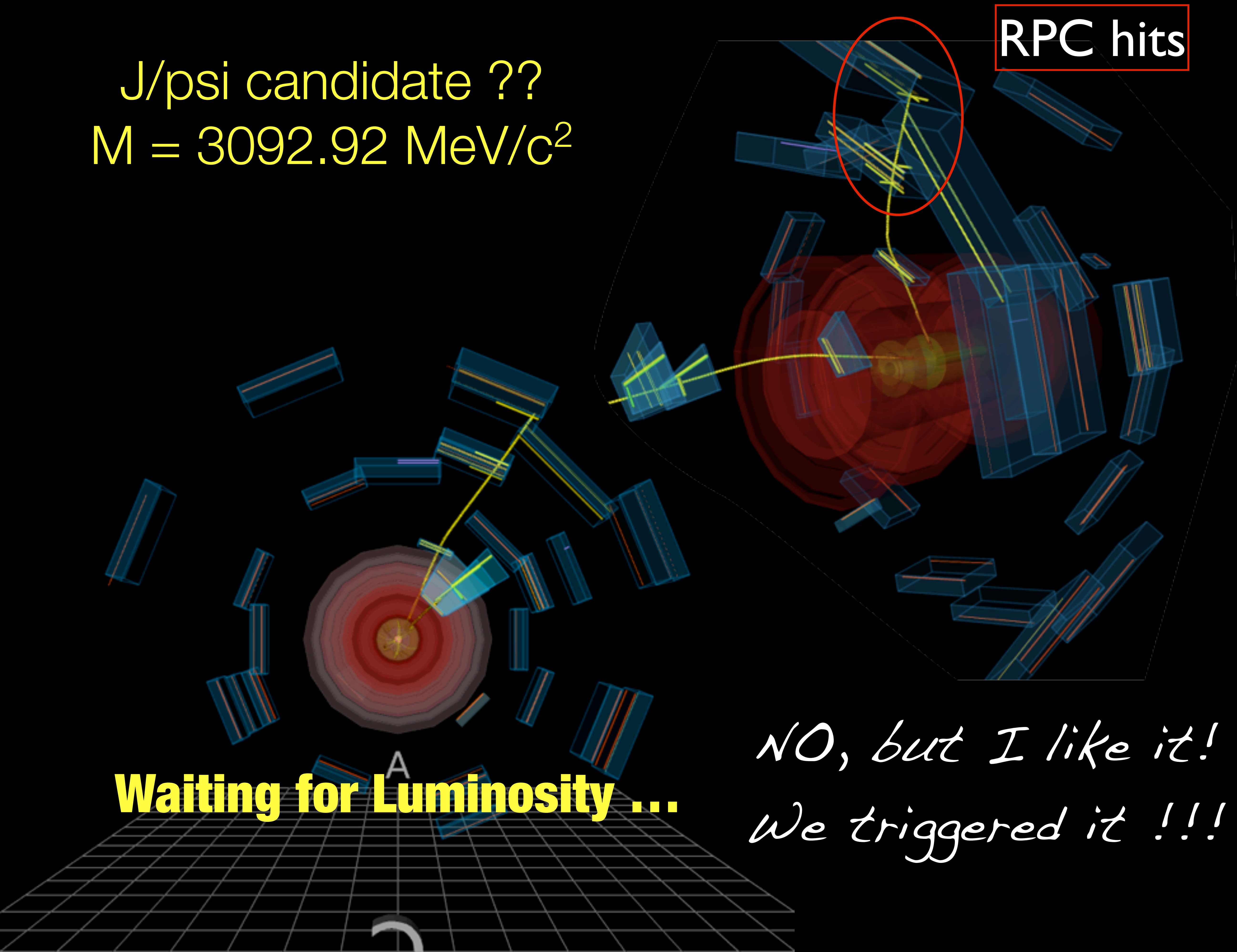

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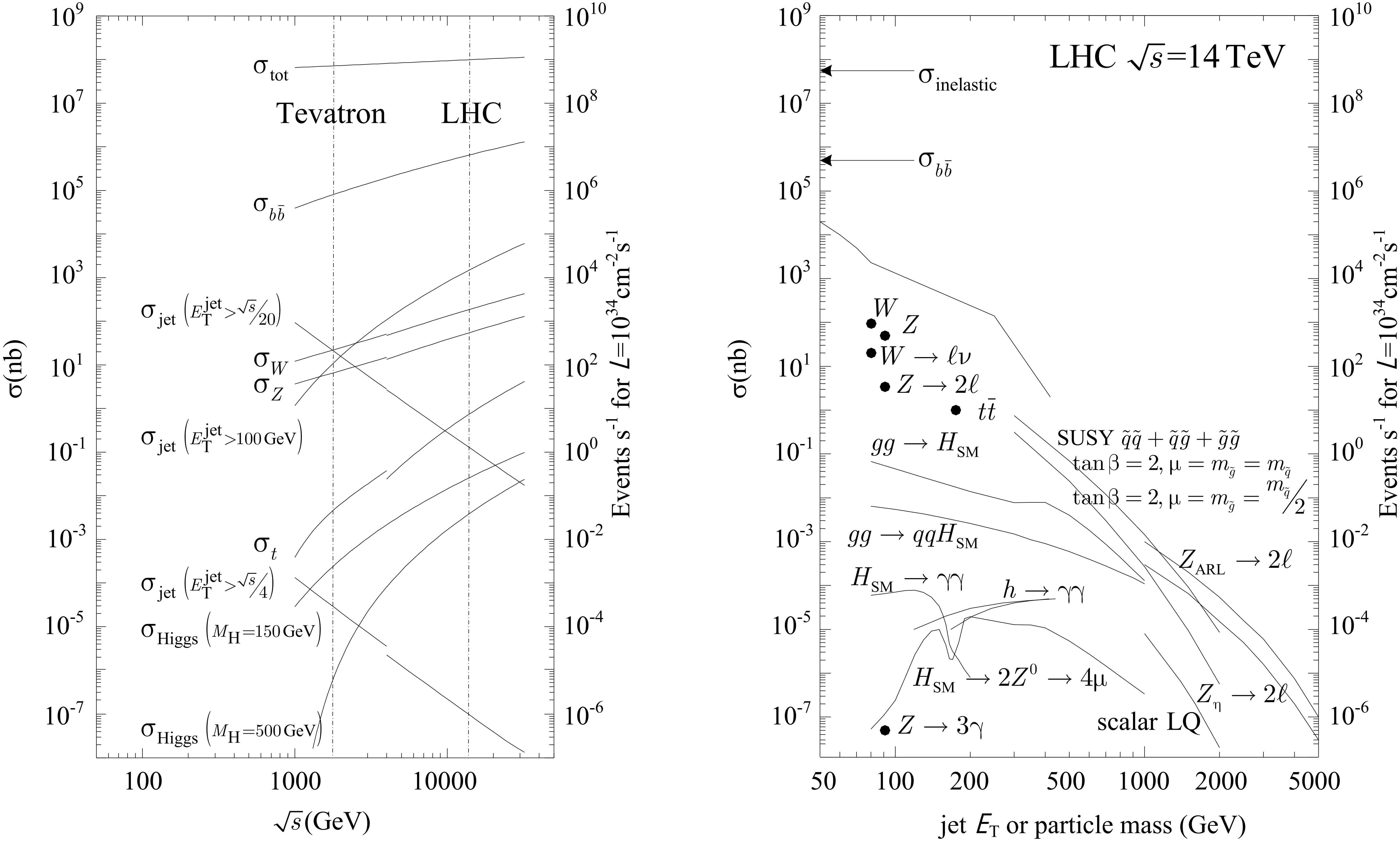
We triggered it !!!

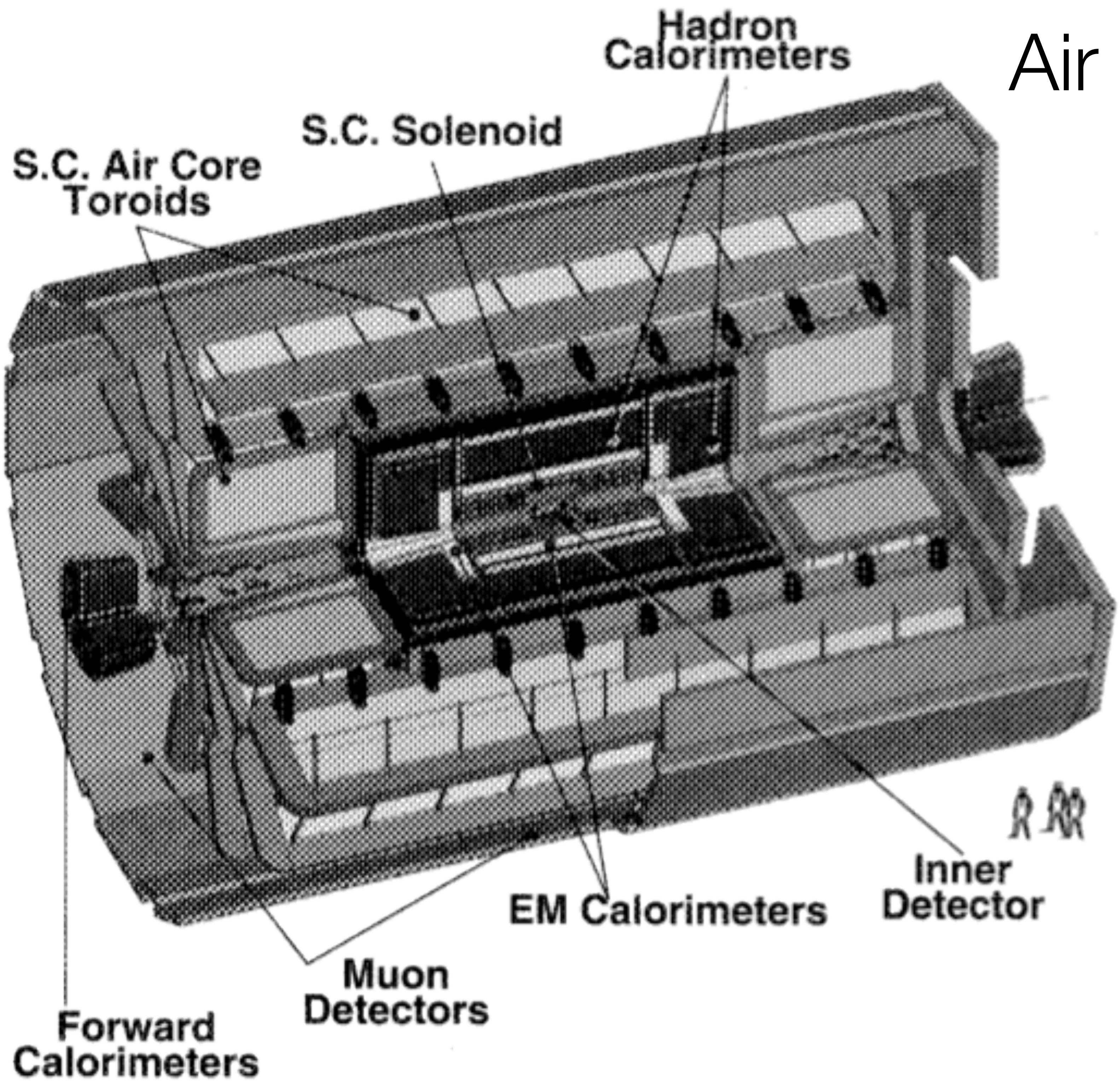
Backup



Tevatron
LHC
LHC $\sqrt{s}$=14 TeV
σ_{tot}
$\sigma_{b\bar{b}}$
$\sigma_{jet}\left(E_T^{jet}>\sqrt{s}/20\right)$
σ_W
σ_Z
$\sigma_{jet}\left(E_T^{jet}>100\,\mathrm{GeV}\right)$
σ_t
$\sigma_{jet}\left(E_T^{jet}>\sqrt{s}/4\right)$
$\sigma_{Higgs}\left(M_H=150\,\mathrm{GeV}\right)$
$\sigma_{Higgs}\left(M_H=500\,\mathrm{GeV}\right)$
σ(nb)
Events s^{-1} for $L=10^{34}$cm^{-2}s^{-1}
$\sqrt{s}$(GeV)
$\sigma_{inelastic}$
W
Z
$W \to \ell\nu$
$Z \to 2\ell$
$t\bar{t}$
$gg \to H_{SM}$
SUSY $\tilde{q}\tilde{q}+\tilde{q}\tilde{g}+\tilde{g}\tilde{g}$
$\tan\beta=2, \mu=m_{\tilde{g}}=m_{\tilde{q}}$
$\tan\beta=2, \mu=m_{\tilde{g}}=m_{\tilde{q}}/2$
$gg \to qqH_{SM}$
$Z_{ARL} \to 2\ell$
$H_{SM} \to \gamma\gamma$
$h \to \gamma\gamma$
$H_{SM} \to 2Z^0 \to 4\mu$
$Z_\eta \to 2\ell$
scalar LQ
$Z \to 3\gamma$
jet E_T or particle mass (GeV)

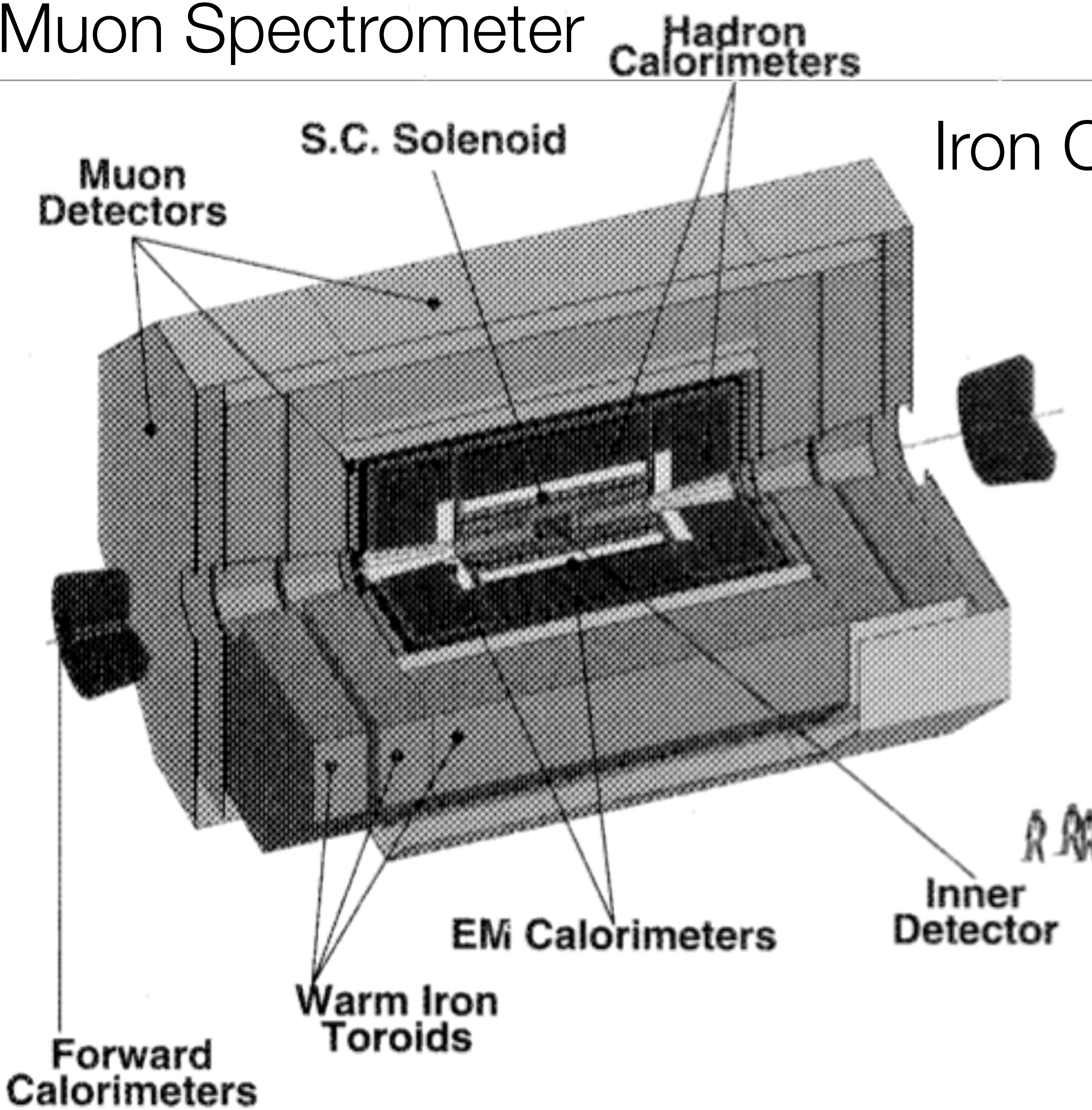
The Muon Spectrometer

Air Core Toroid



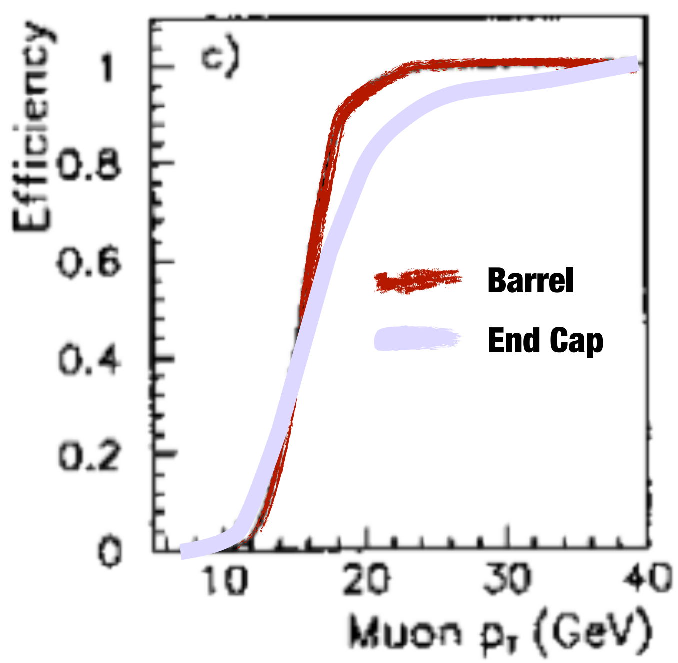
The Muon Spectrometer

Iron Core Toroid!!

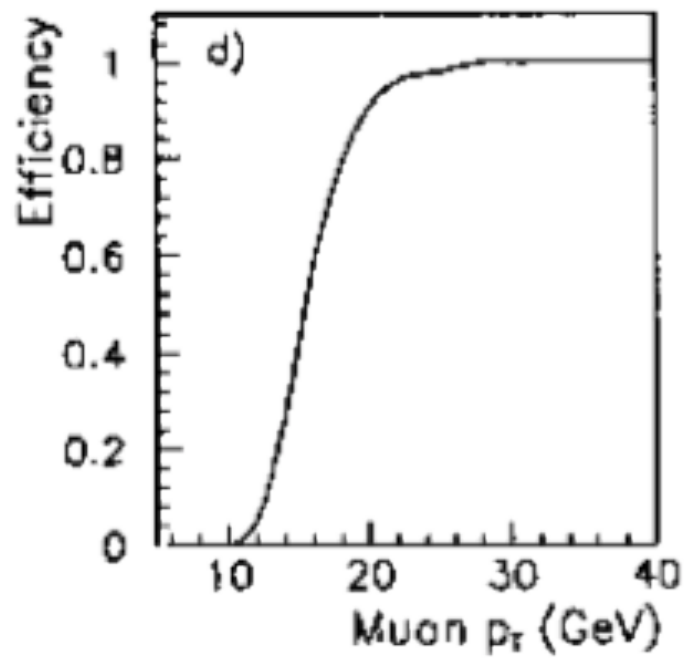


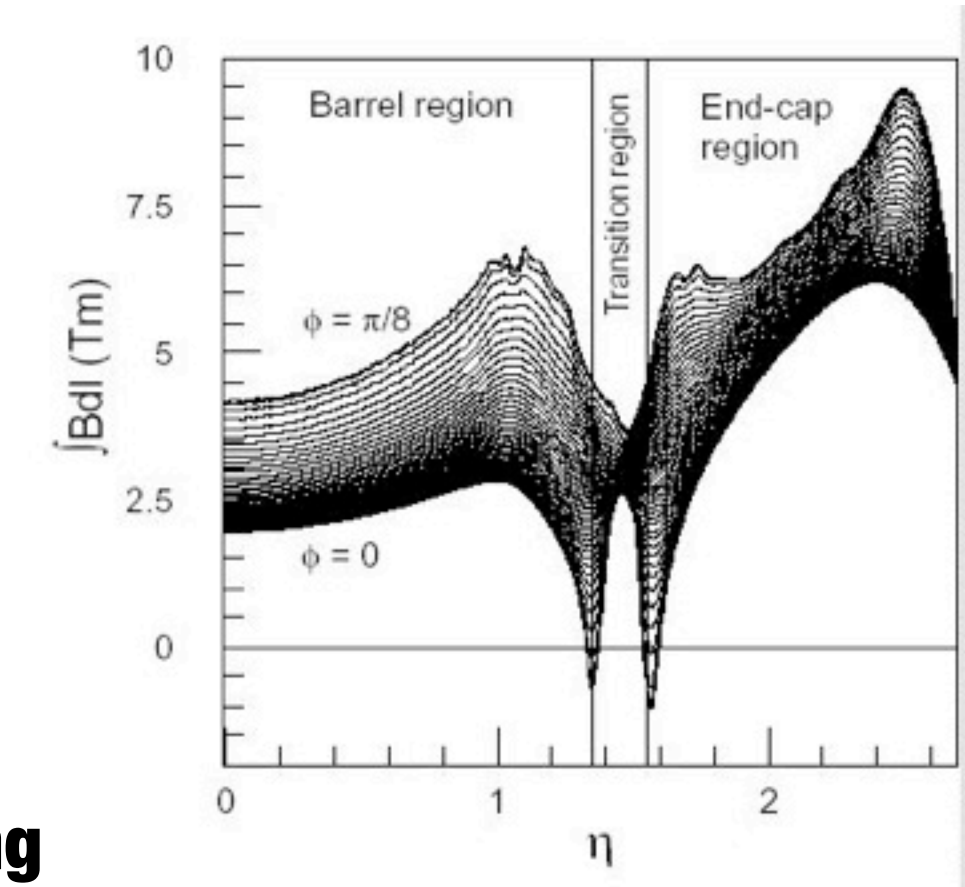
The choice

Iron Core Toroid



Air Core Toroid



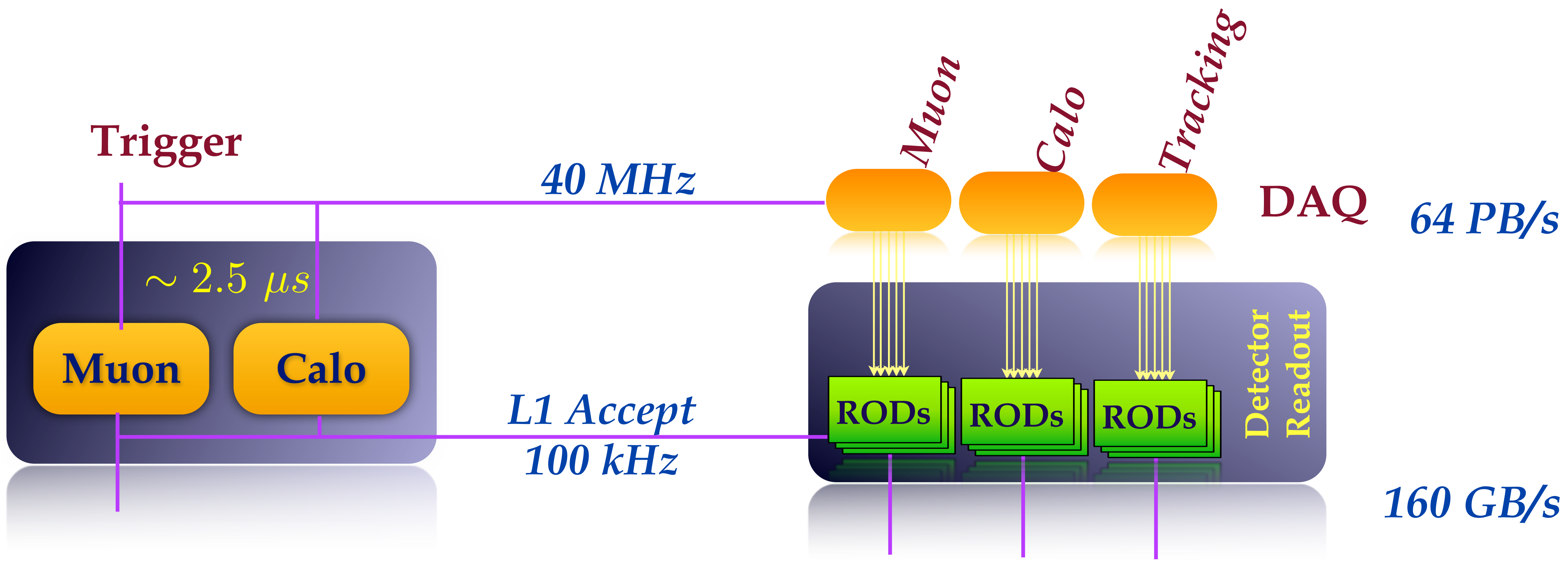


Coulomb scattering **No Coulomb scattering**

$$\Delta\beta/\beta \approx 20\%$$

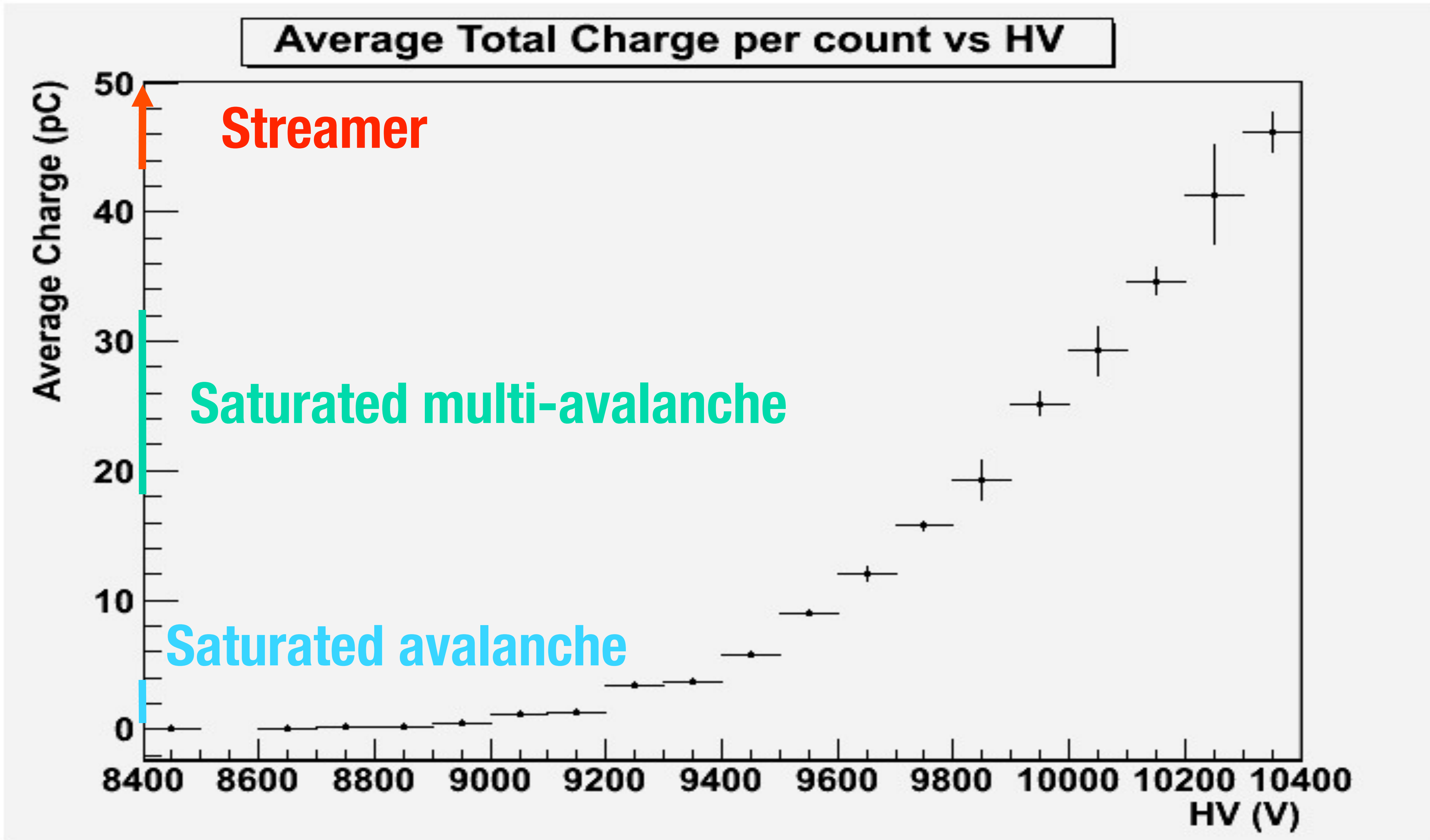
$$\beta \cong 1.08\ rad/p(GeV) \qquad \beta \cong 0.68\ rad/p(GeV)$$

Level-1 Trigger

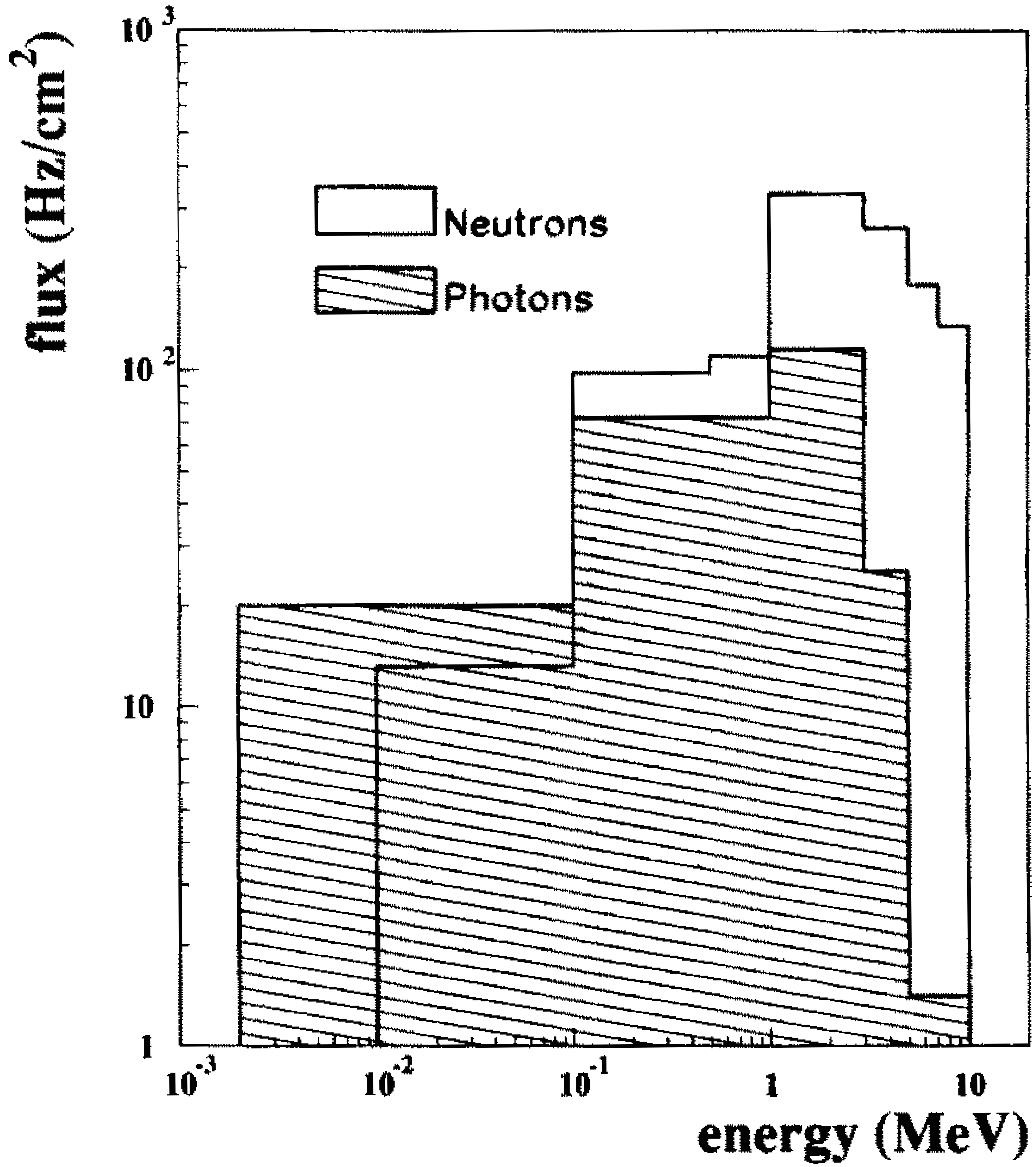


- Hardware based
- It has a maximum latency of 2.5 μs
- It has 3 main components: Calorimeter Trigger, Muon Trigger and Central Trigger
- The trigger deals with detector information from coarse region in the eta-phi plane (Region of interest (RoI))

Total charge vs HV

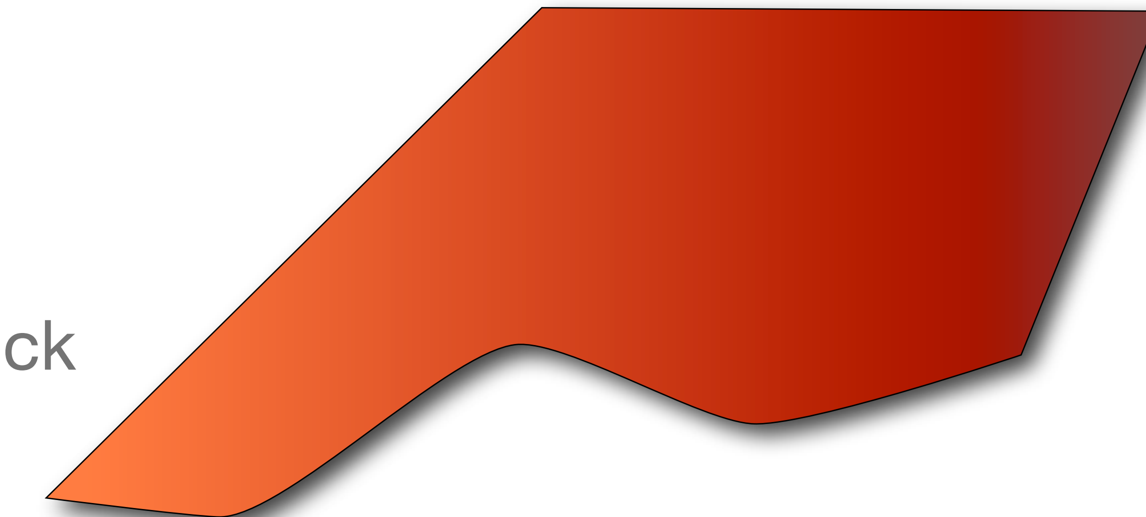


Neutrons & γs sensitivity



The ATLAS RPCs

- The bakelite plates are previously coated with a graphite to apply HV
- A PET foil is sticked over to insulated it
- A gas gap is assembled using 2 mm thick bakelite plates.



- The separation is ensured by a spacer glued at 10 cm x 10 cm distance
- The readout strips are just laying over

$$\rho_{bak} = (1 \div 4) \cdot 10^{10} \Omega \cdot cm$$

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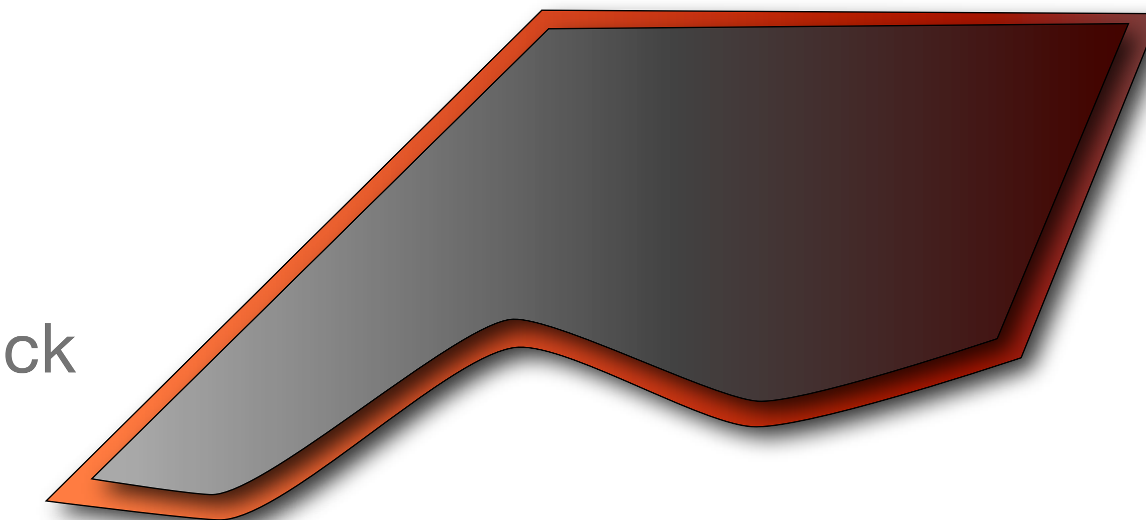

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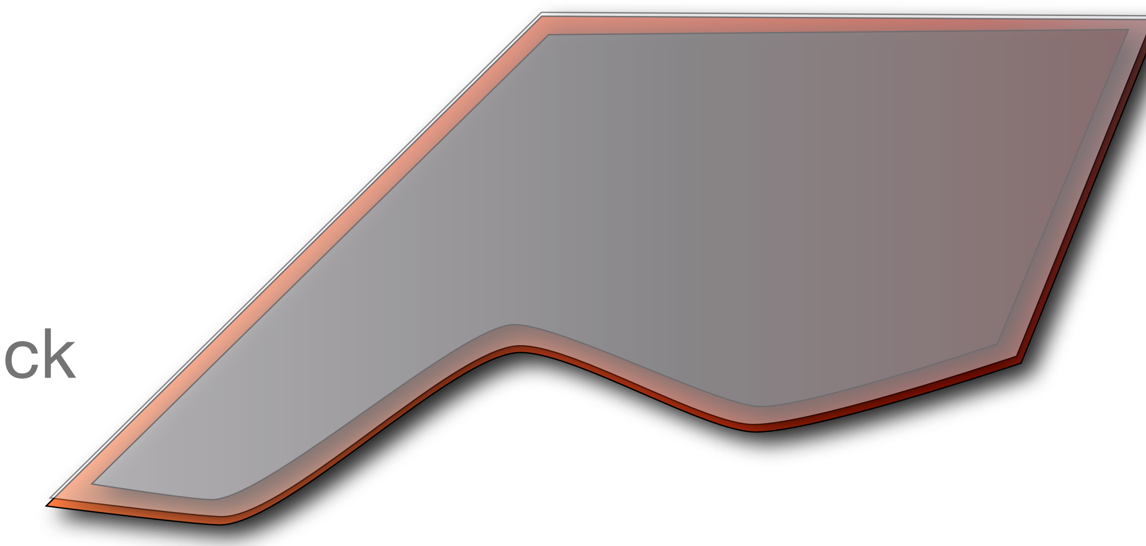

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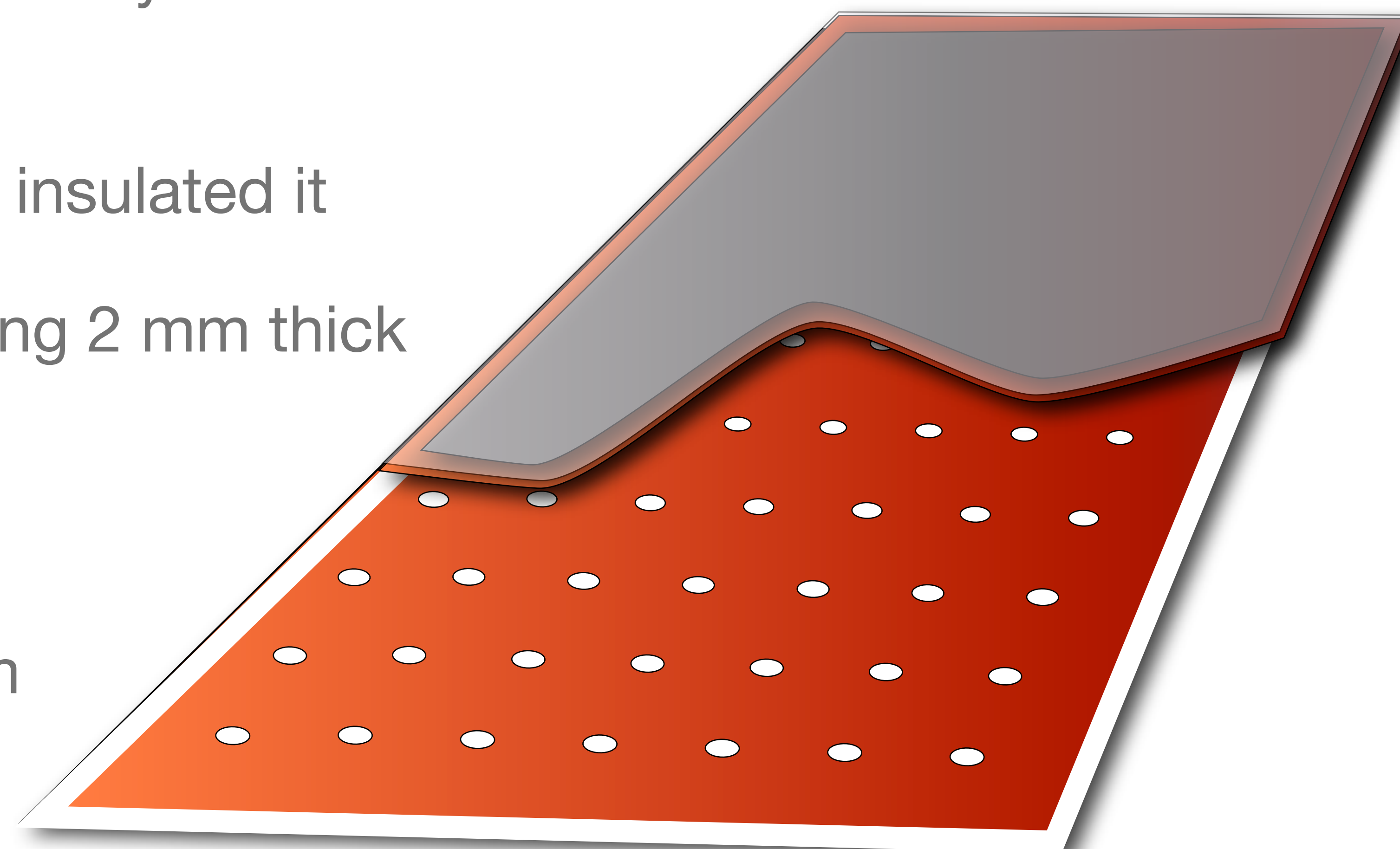

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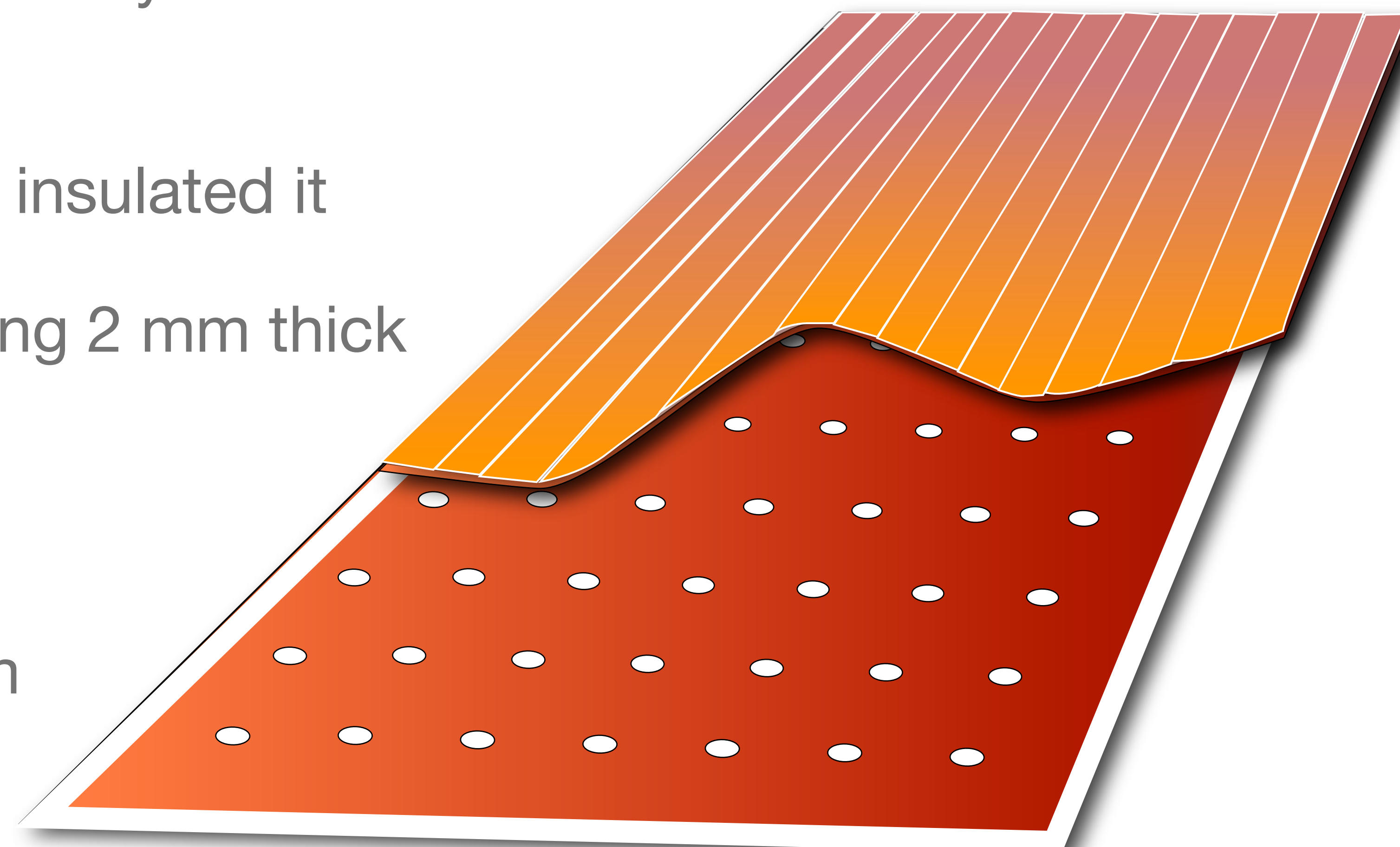

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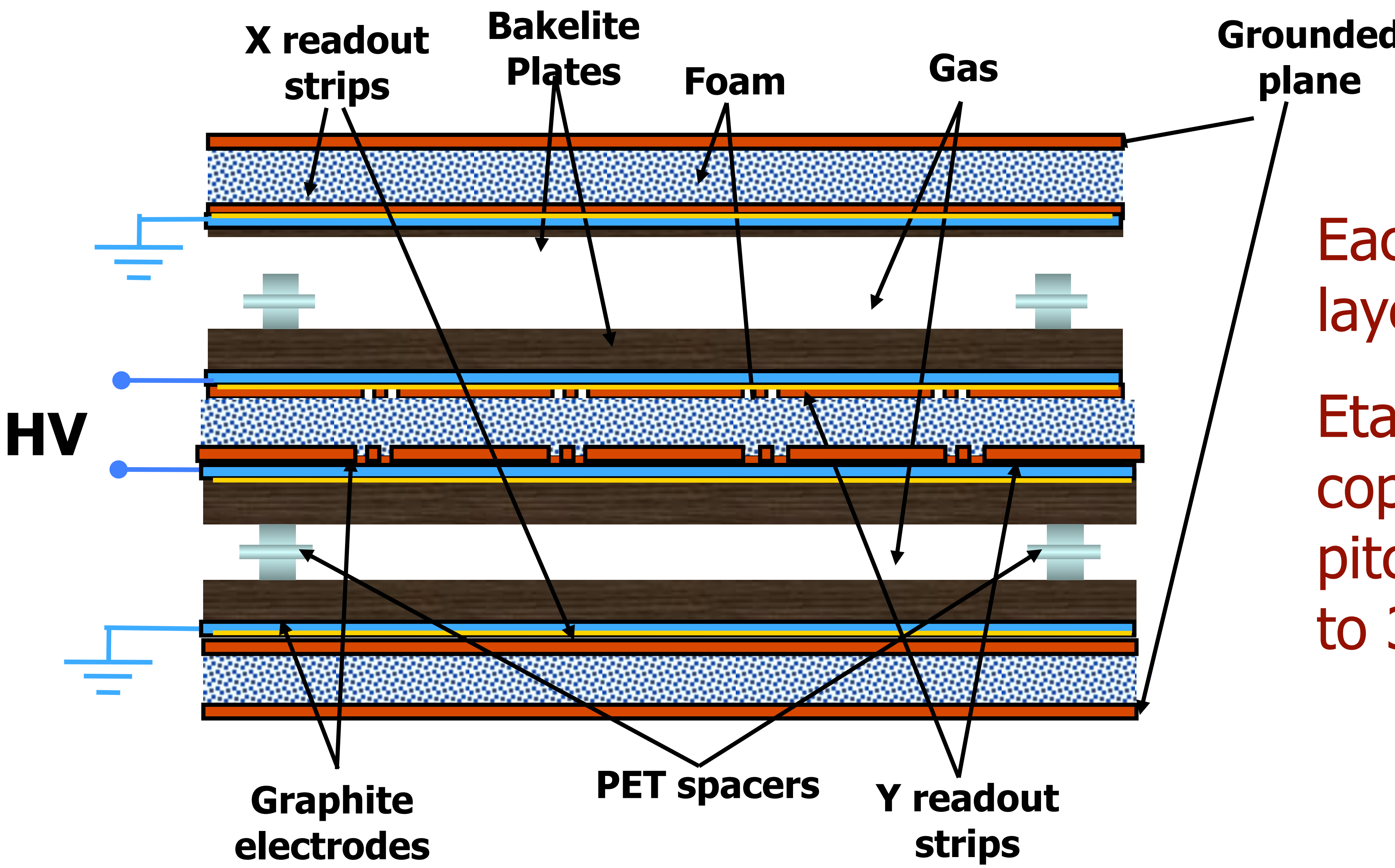
The RPCs of ATLAS



Each unit contains 2 layers => 4 gas volume

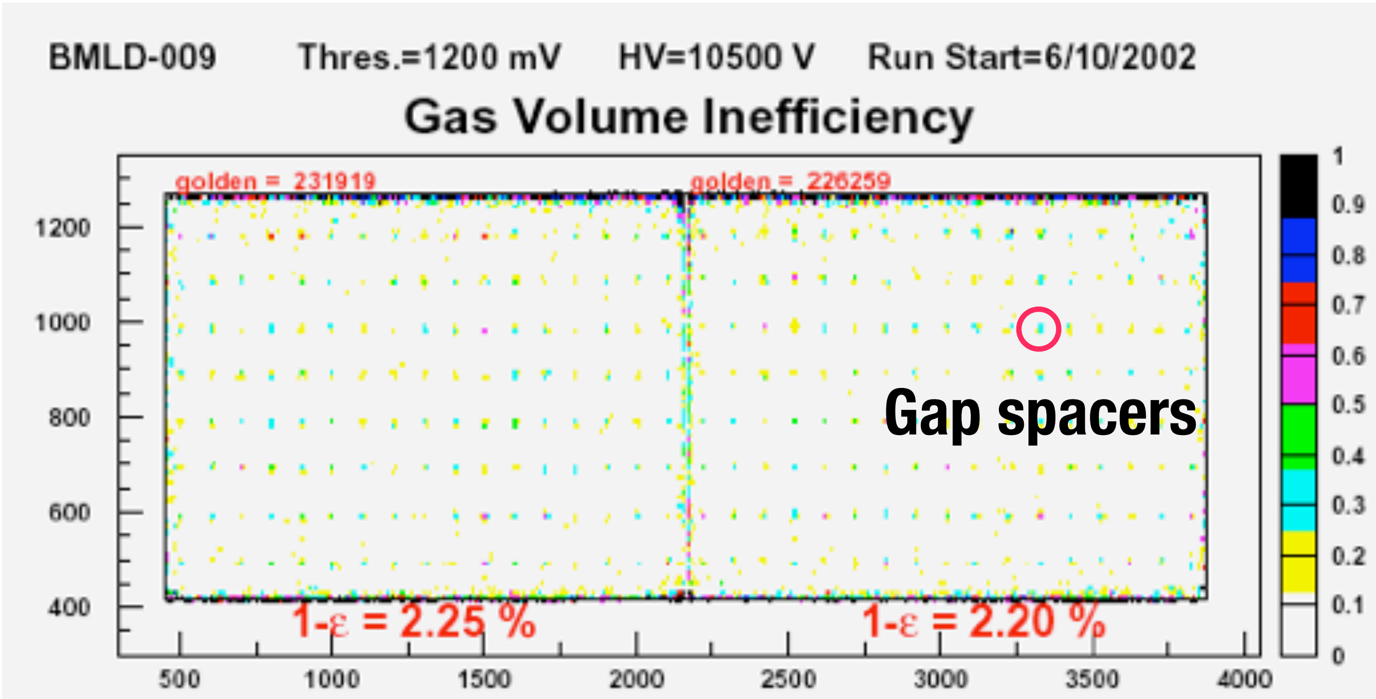
Eta and Phi read-out copper strips panels, pitch ranging from 26.4 to 33.9 mm

Gas mixture:

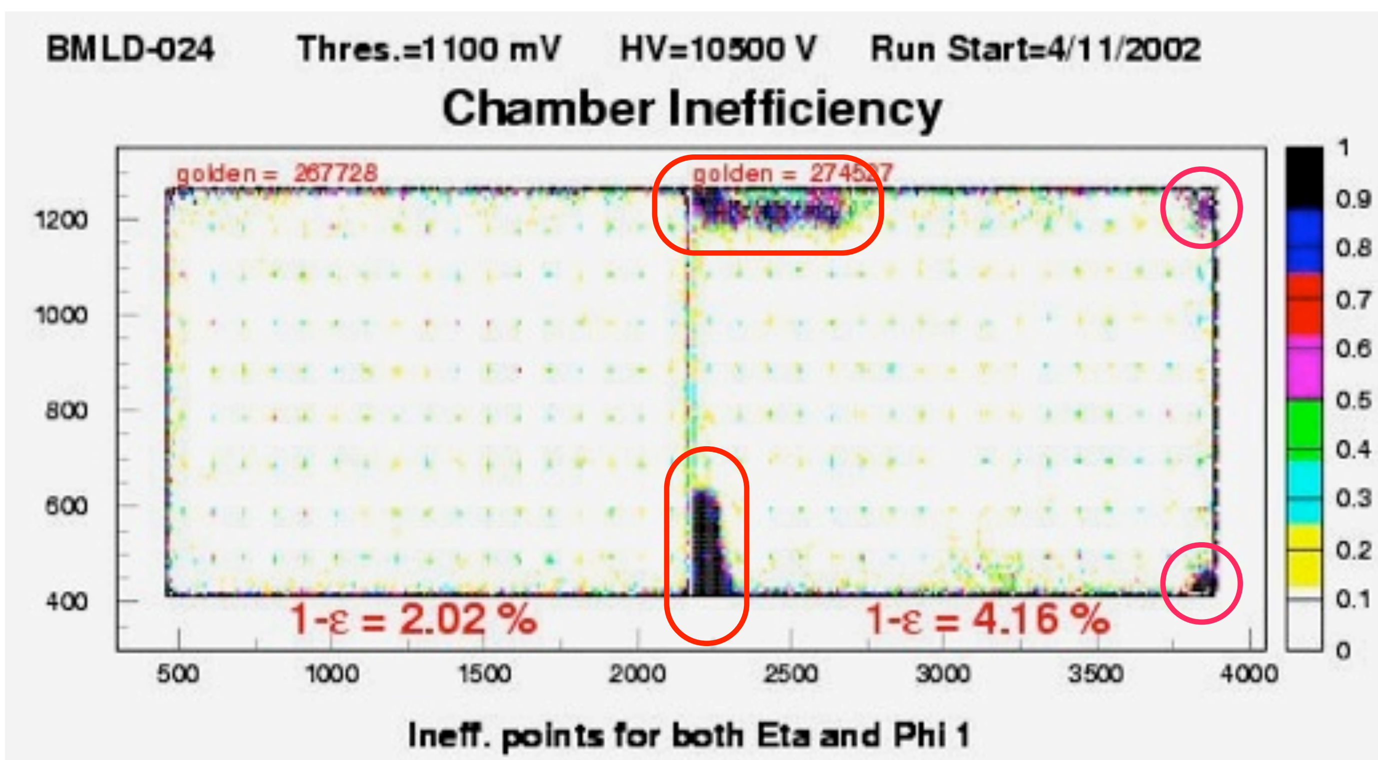
$C_2H_2F_4$ 94.7% - C_4H_{10} 5% - SF_6 0.3%

Avalanche regime

Efficiency homogeneity

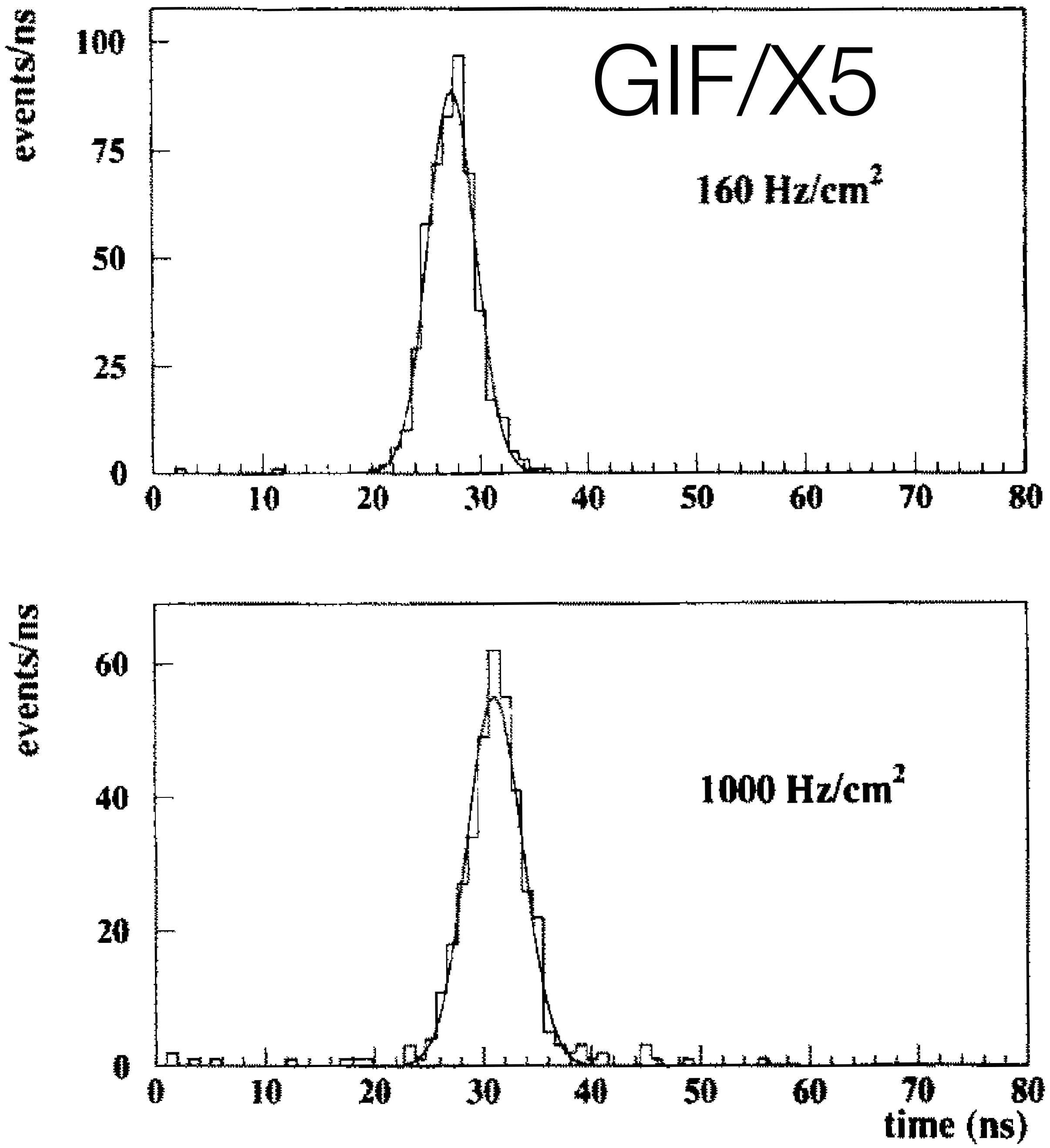


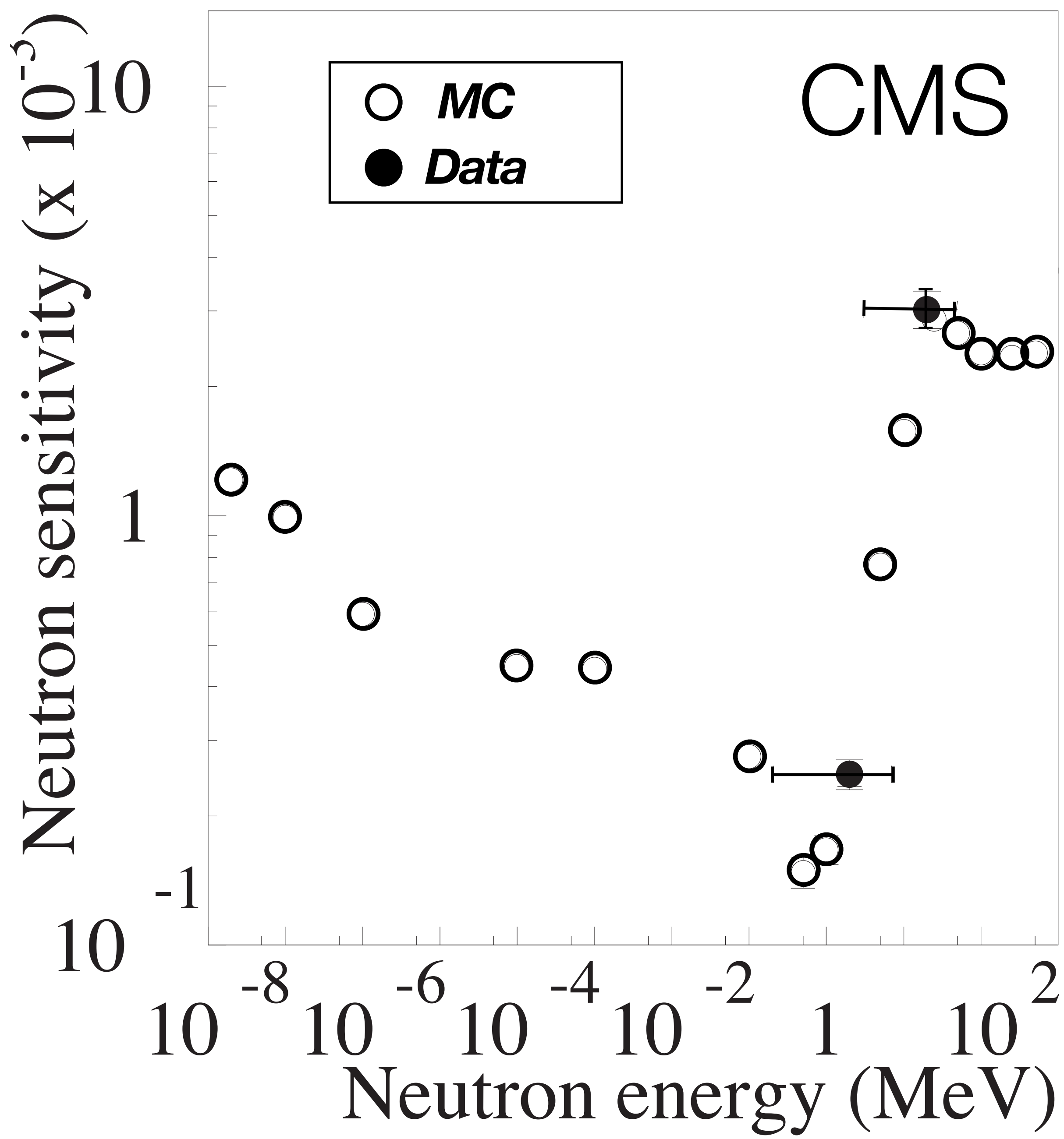
Geometrical inefficiency due to spacer ~ 3%

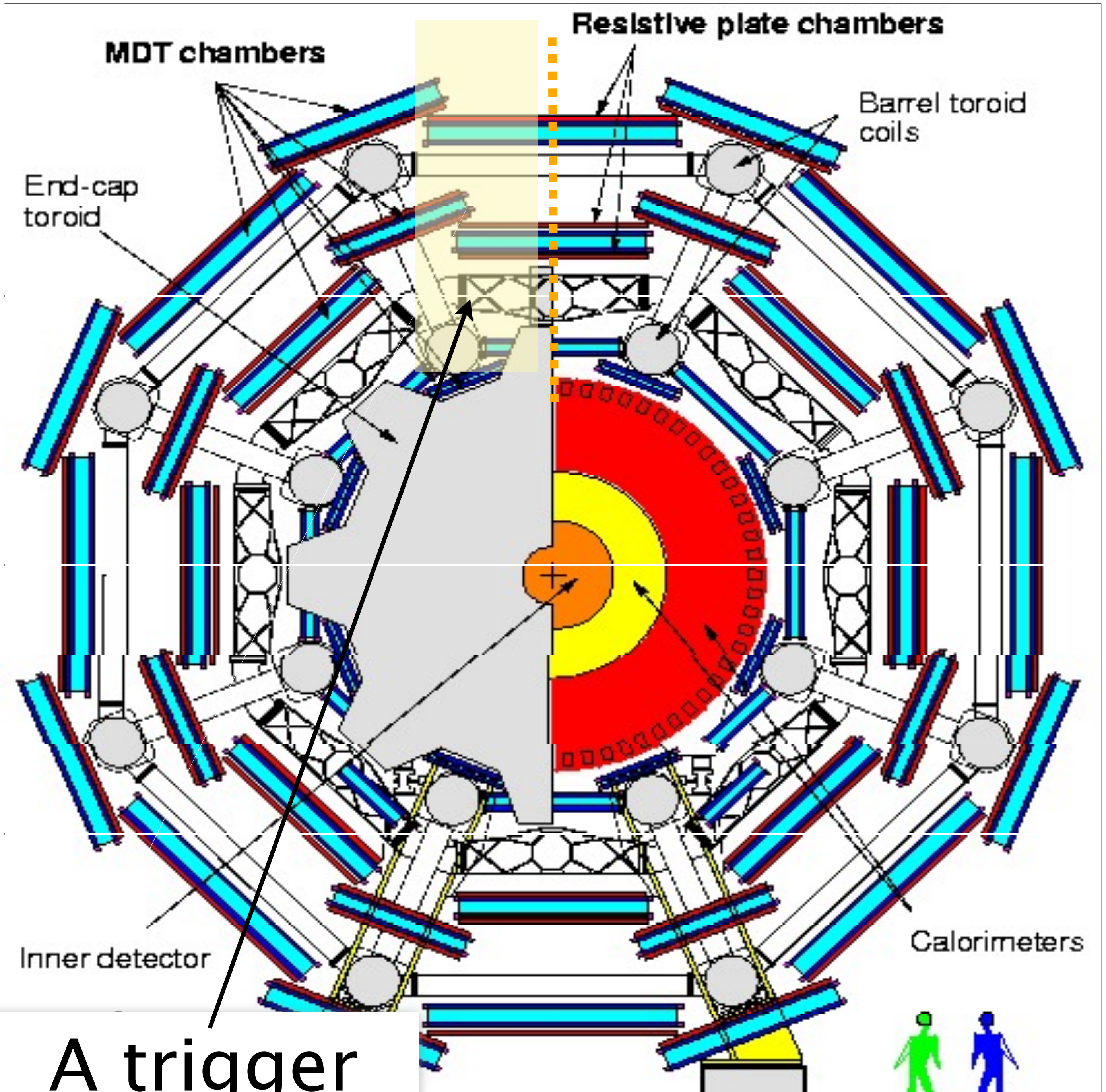


Bad Gap

Neutrons & γs sensitivity

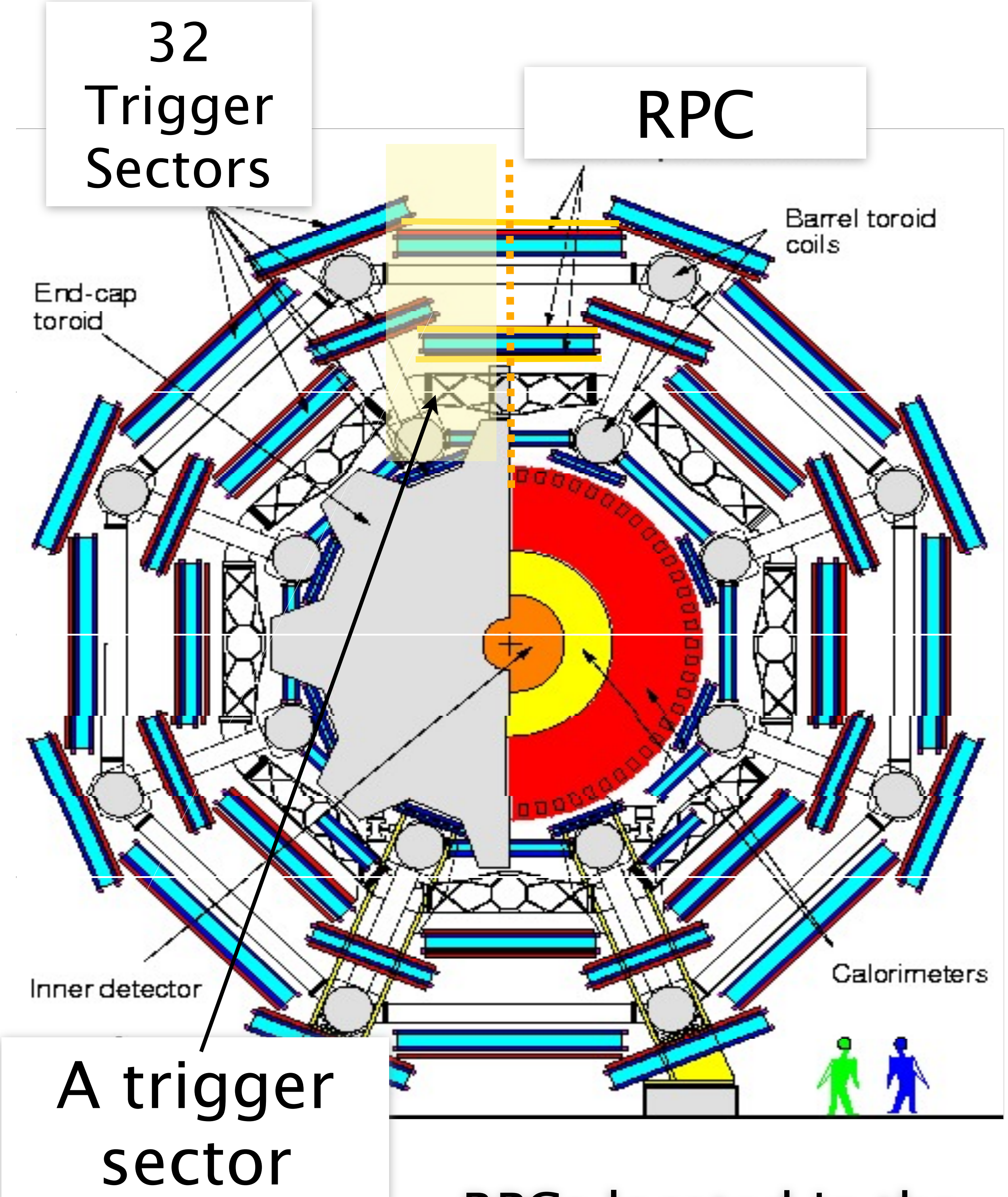






A trigger sector

RPCs located in the MIDDLE and OUTER sectors



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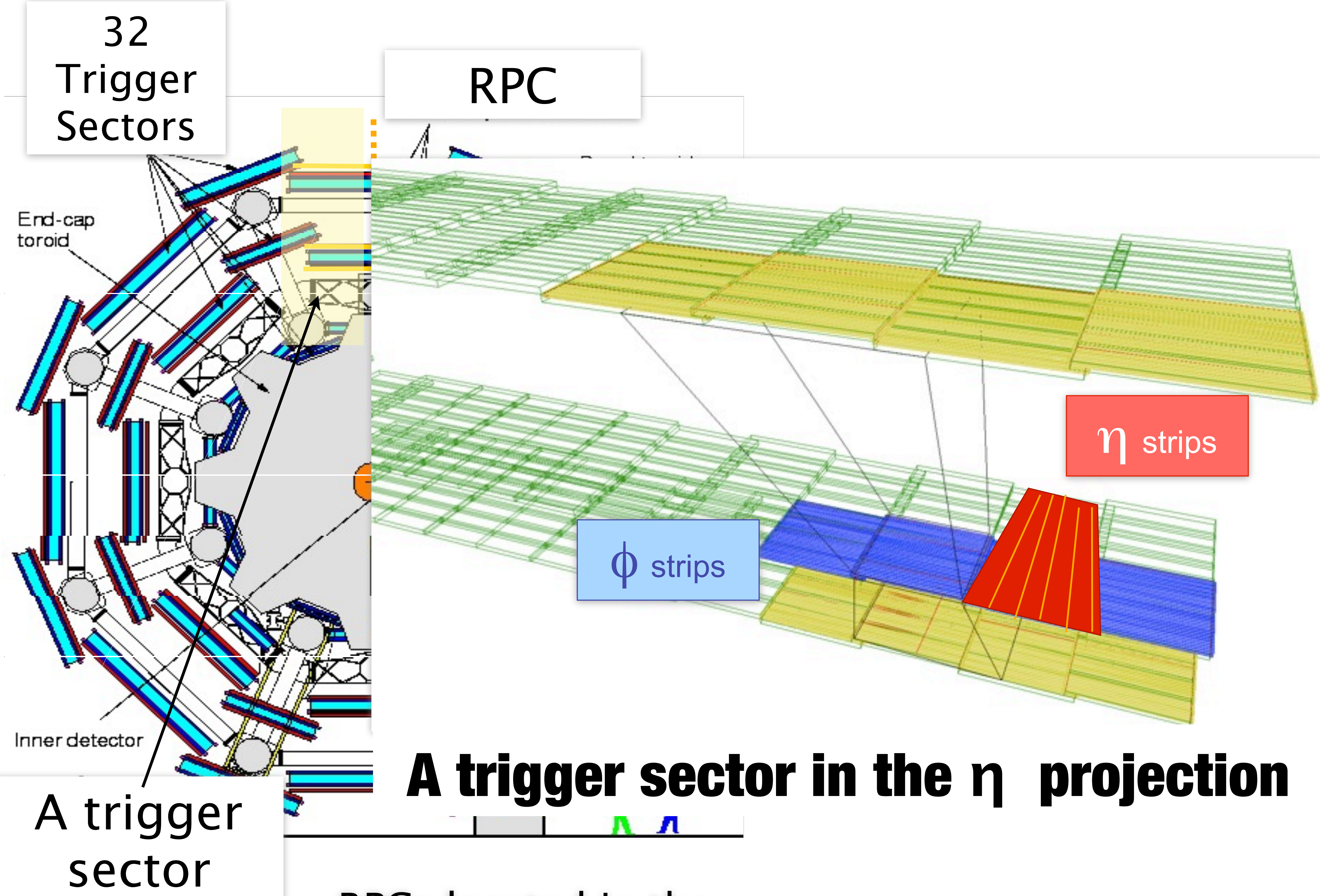
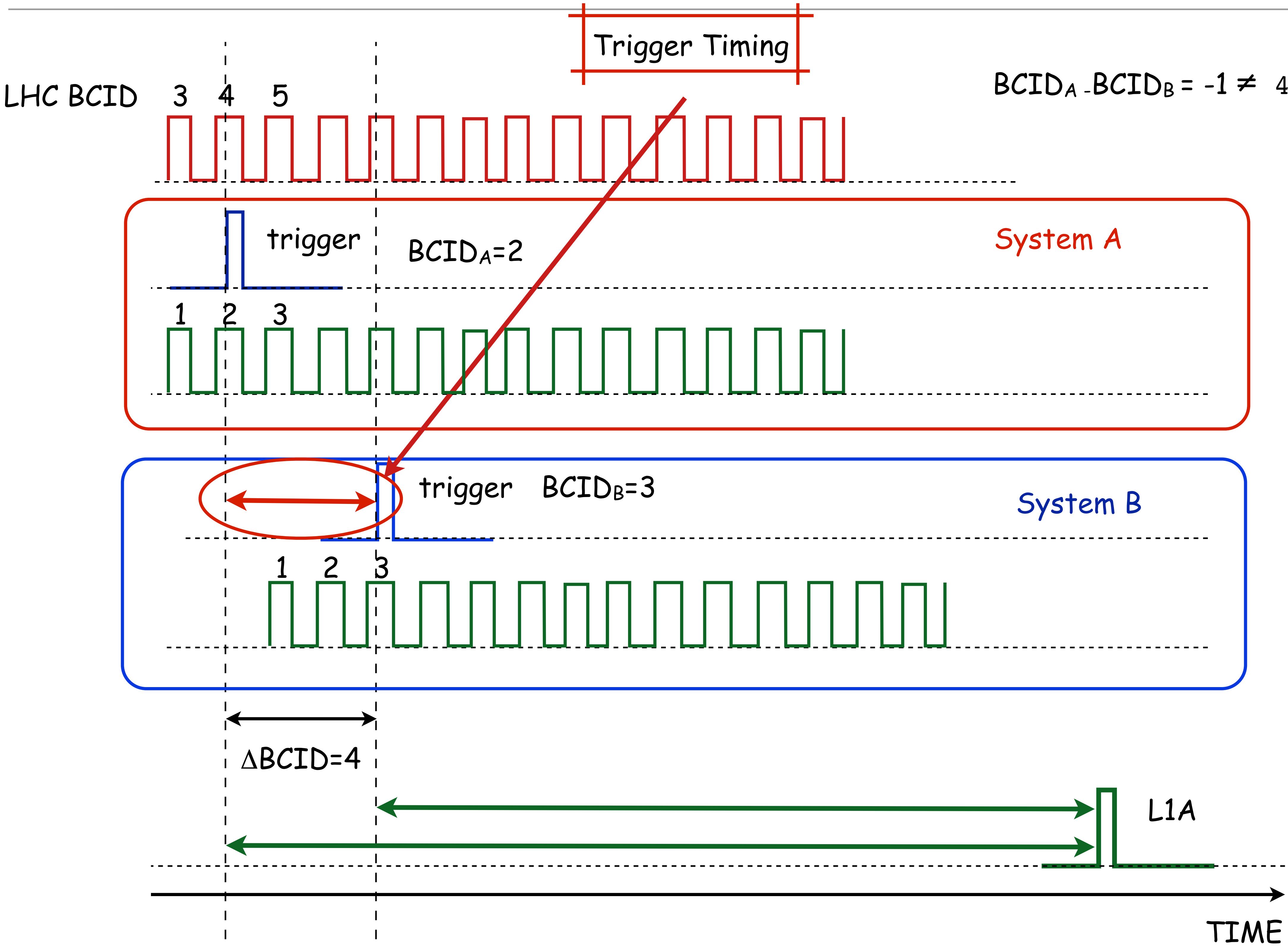


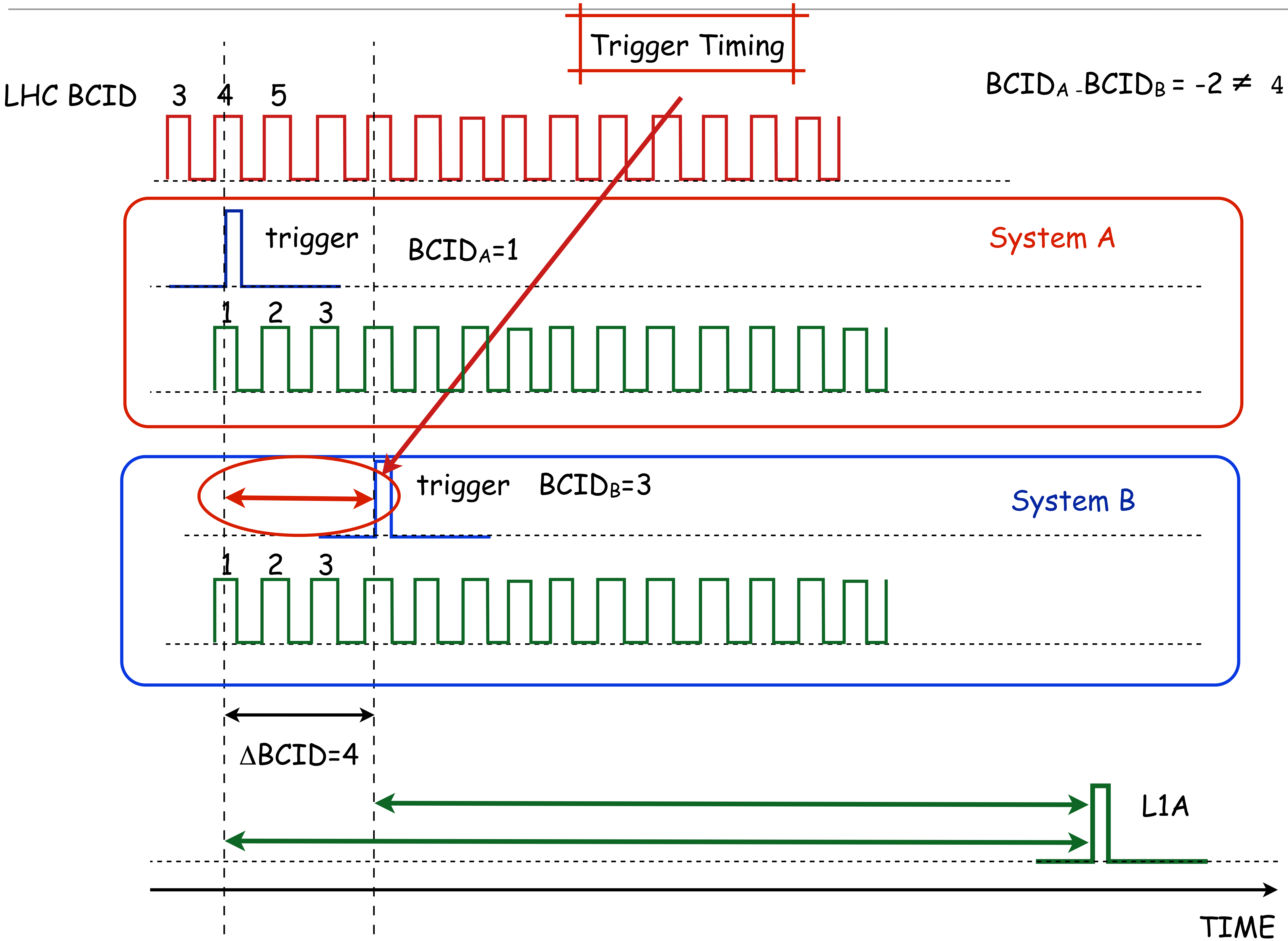
RPCs located in the
MIDDLE and OUTER sectors

Timing

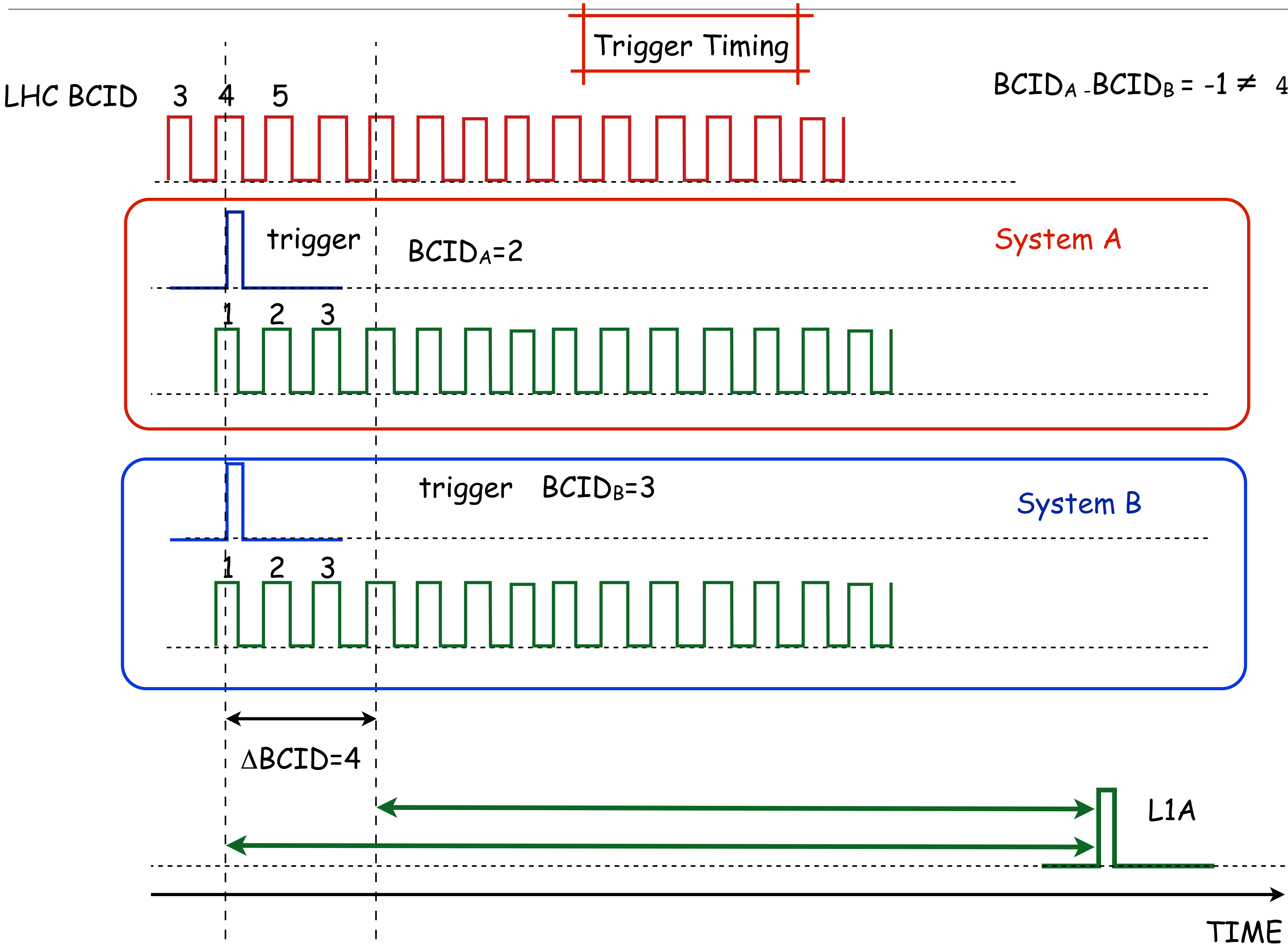


Trigger Timing
LHC BCID 3 4 5
BCIDA -BCIDB = -1 ≠ 4
trigger
BCIDA=2
System A
1 2 3
trigger BCIDB=3
System B
1 2 3
ΔBCID=4
L1A
TIME

Timing


Trigger Timing
BCIDA -BCIDB = -2 ≠ 4
LHC BCID 3 4 5
trigger
BCIDA=1
System A
1 2 3
trigger BCIDB=3
System B
1 2 3
ΔBCID=4
L1A
TIME

Timing



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BCIDA -BCIDB = -1 ≠ 4
trigger
BCIDA=2
System A
1 2 3
trigger BCIDB=3
System B
1 2 3
ΔBCID=4
L1A
TIME

Timing

The cable delay (T0) and the Time of Flight (ToF) are the two main components of misalignment.

Local alignment (layers, views, trigger towers)

- ToF is negligible.
- Needs only RPC data

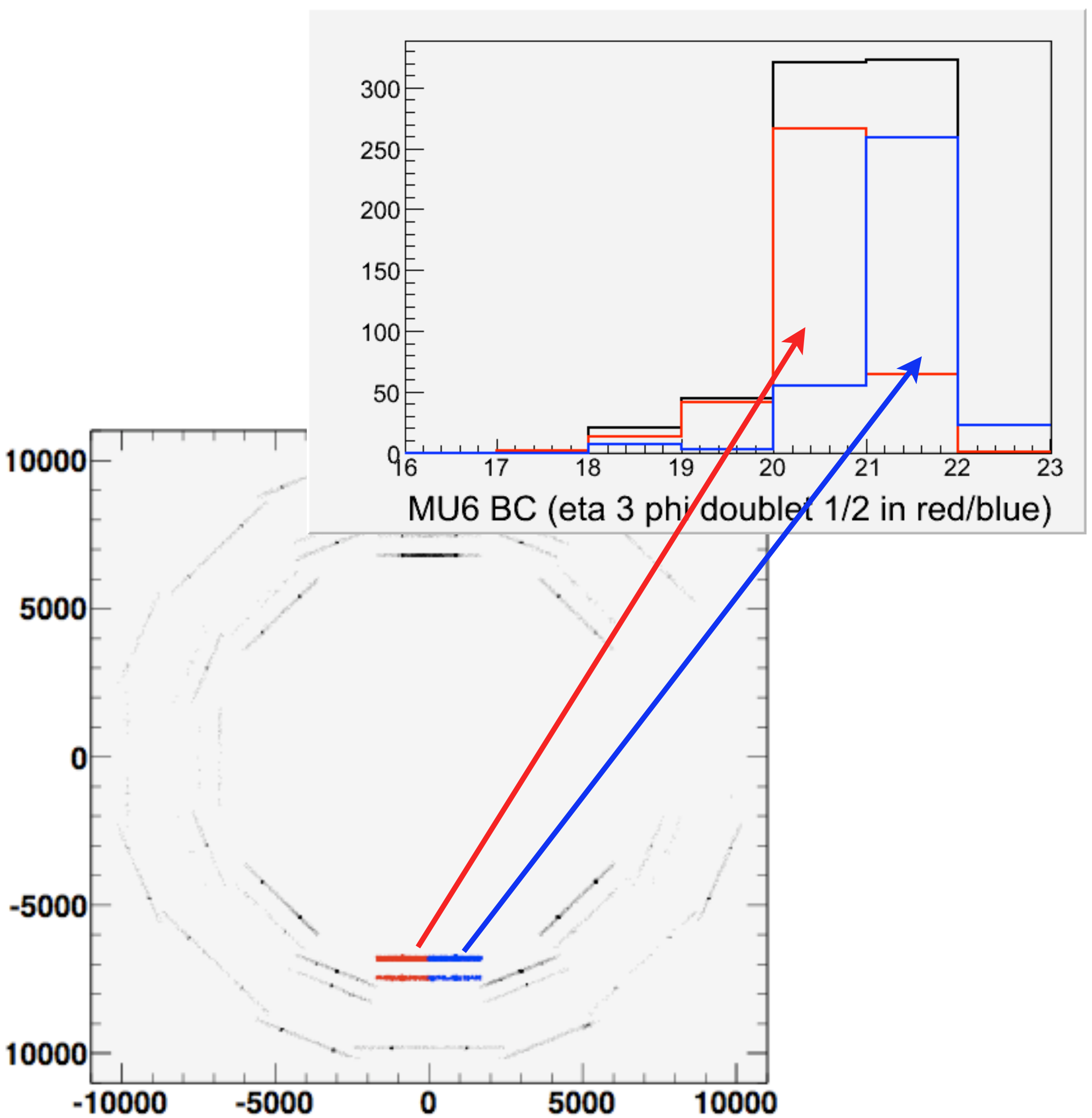
Global alignment (trigger sector)

- ToF and delays are entangled
- needs reconstructed tracks and geometry (global event data)
- easiest with an “external” reference

I will focus on the Global alignment which is the real challenge

Timing - Global Alignment with TRT FastOr

- **Using TRT FastOR & RPC data**
  - can be cleanly seen a tower shift
  - in principle a tower by tower check can be done



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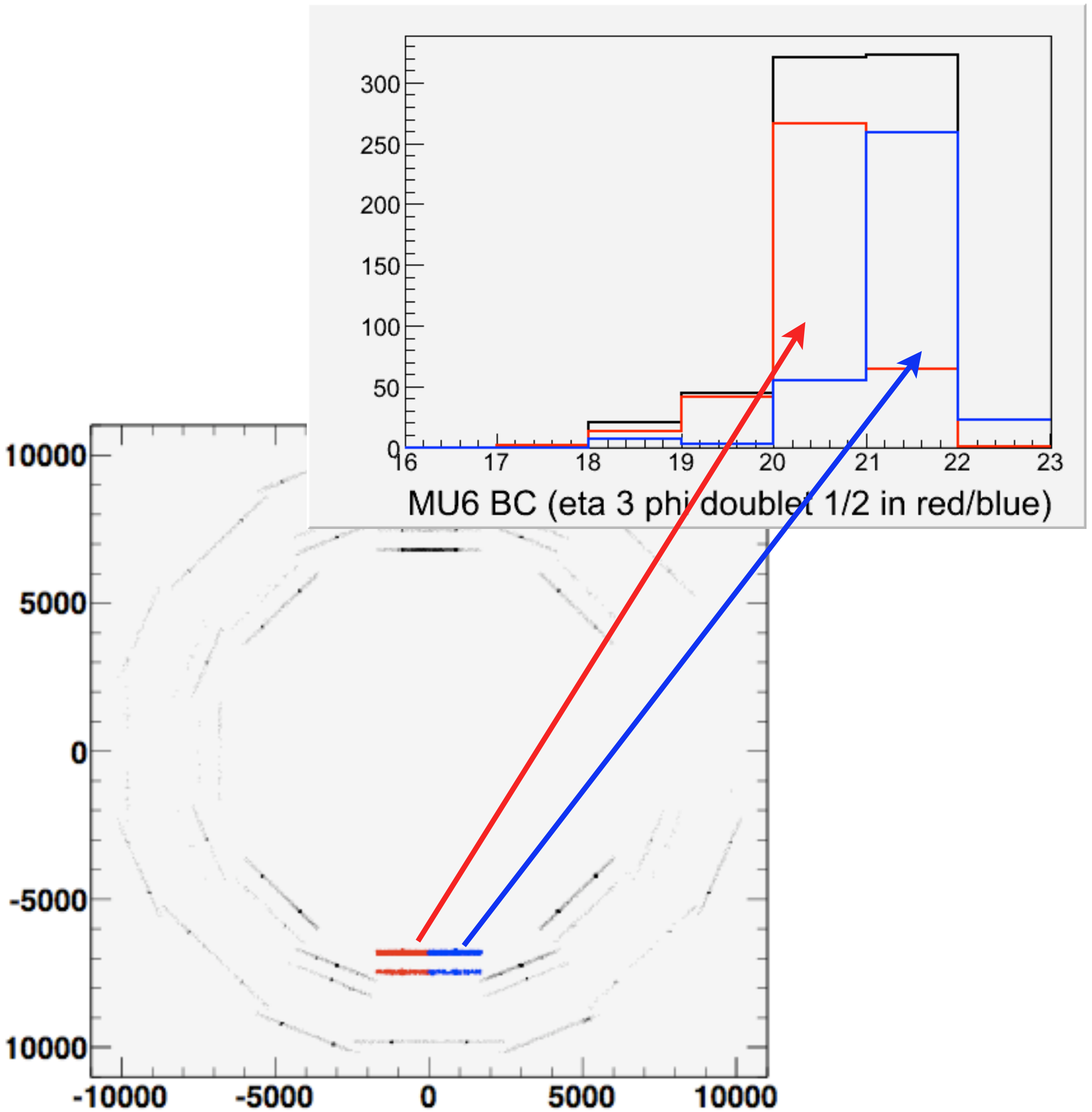
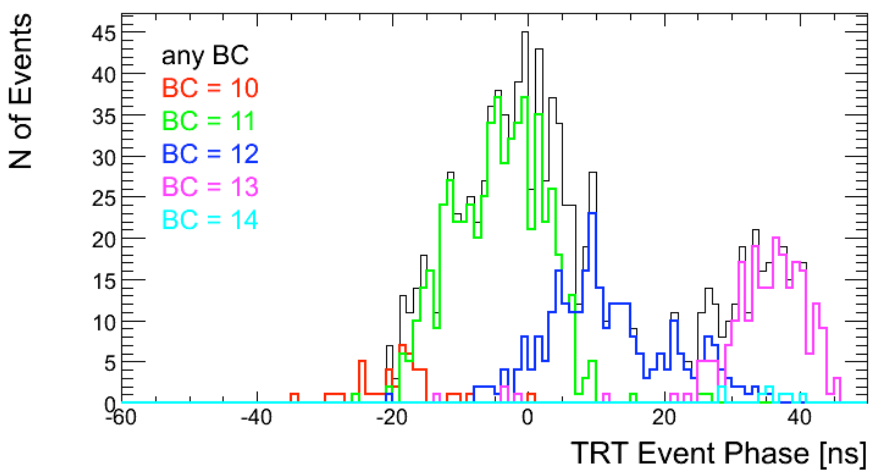
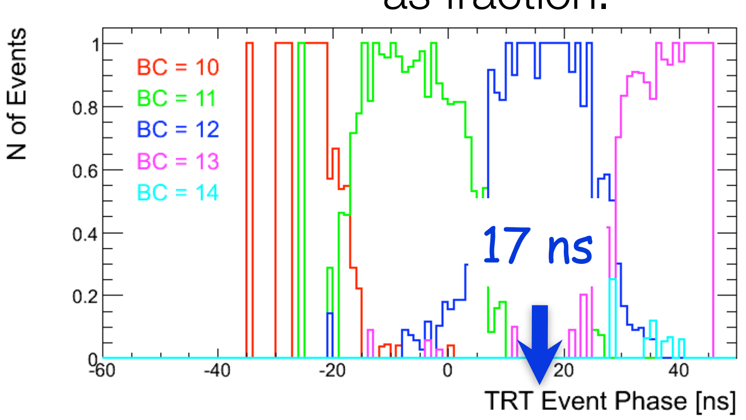
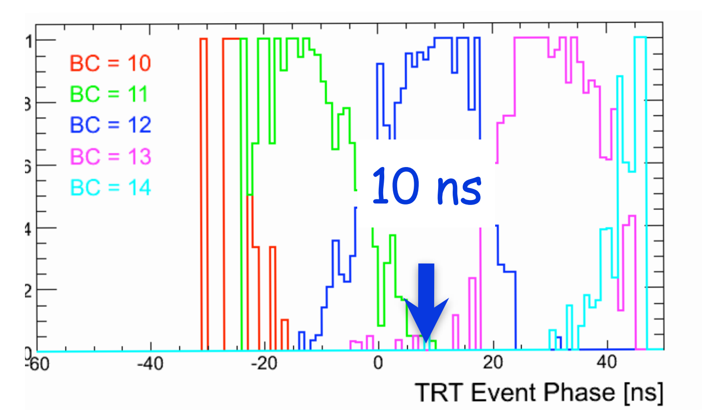


- **Using TRT offline track time**
  - compare different towers
  - check consistency with TRT FastOr
  - Finer time adjustment



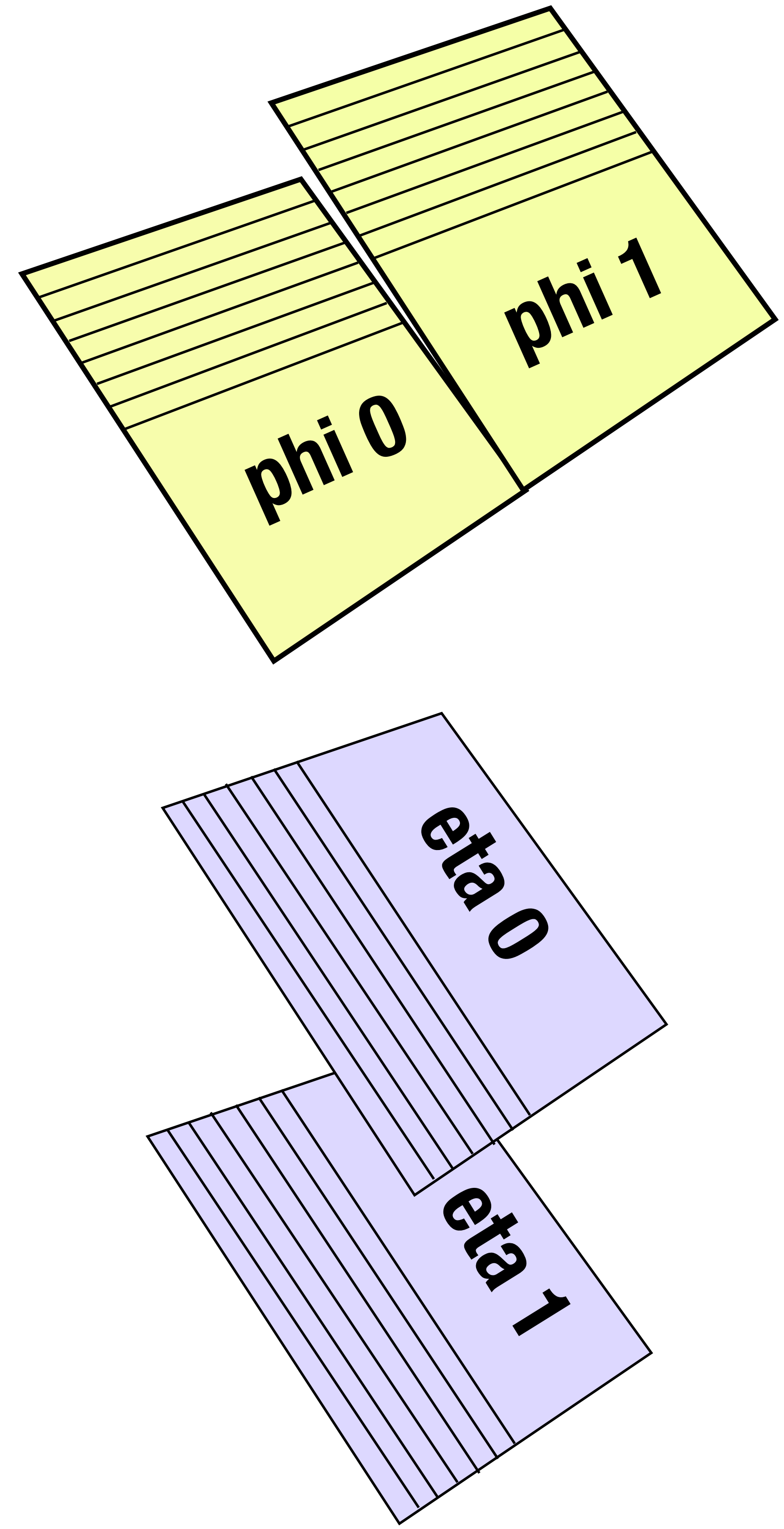
Same distribution after normalization and plotted as fraction.





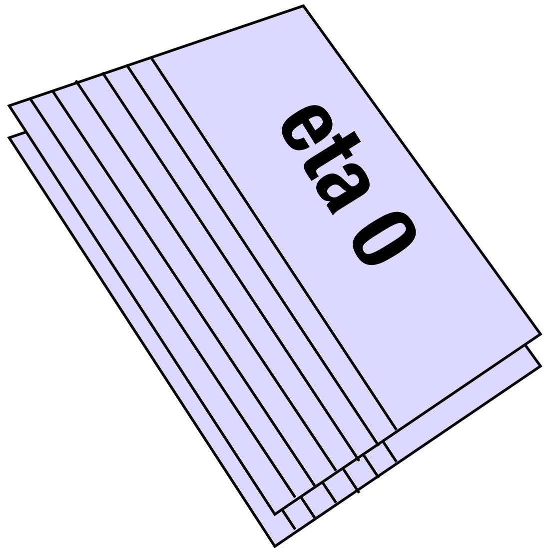
Within a single tower

- Layer (η_0-η_1, φ_0 φ_1)



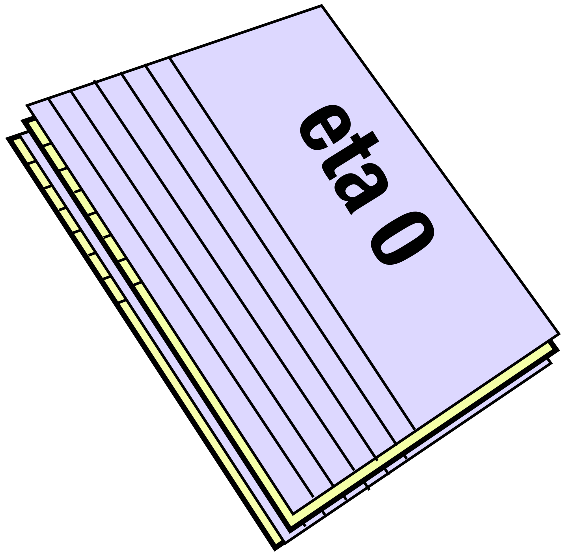
Within a single tower

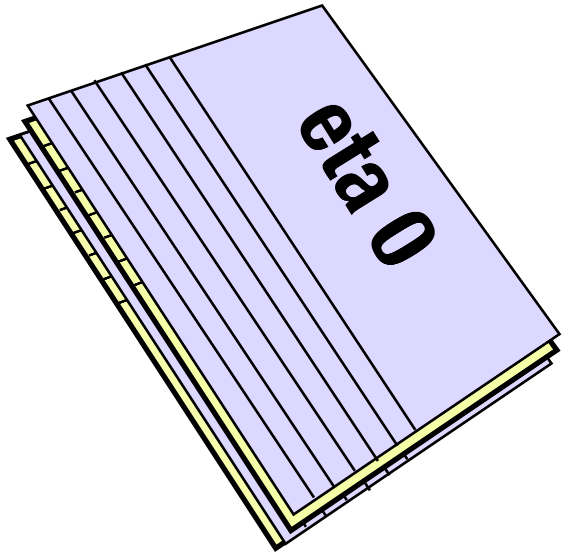
- Layer (η_0-η_1, φ_0 φ_1)
- Views (η - φ)



Within a single tower

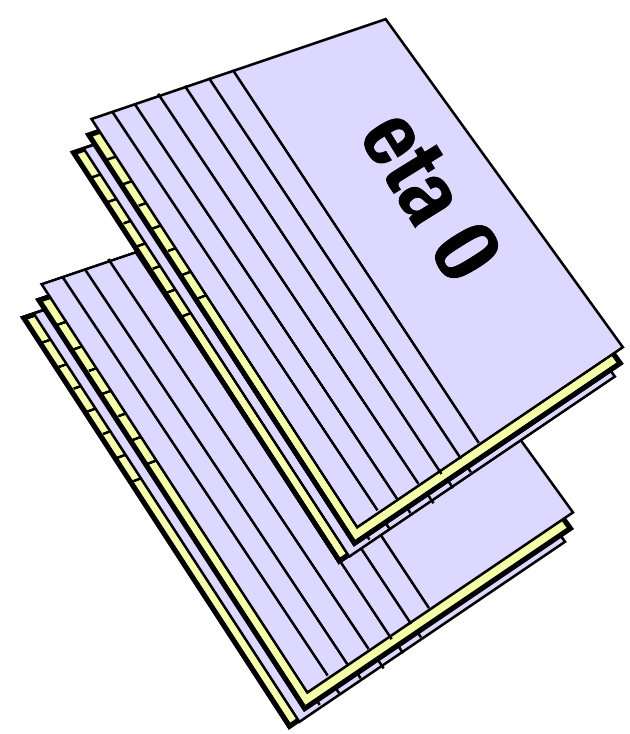
- Layer (η_0-η_1, φ_0 φ_1)
- Views (η - φ)
- Pivot to *Low-p_T*





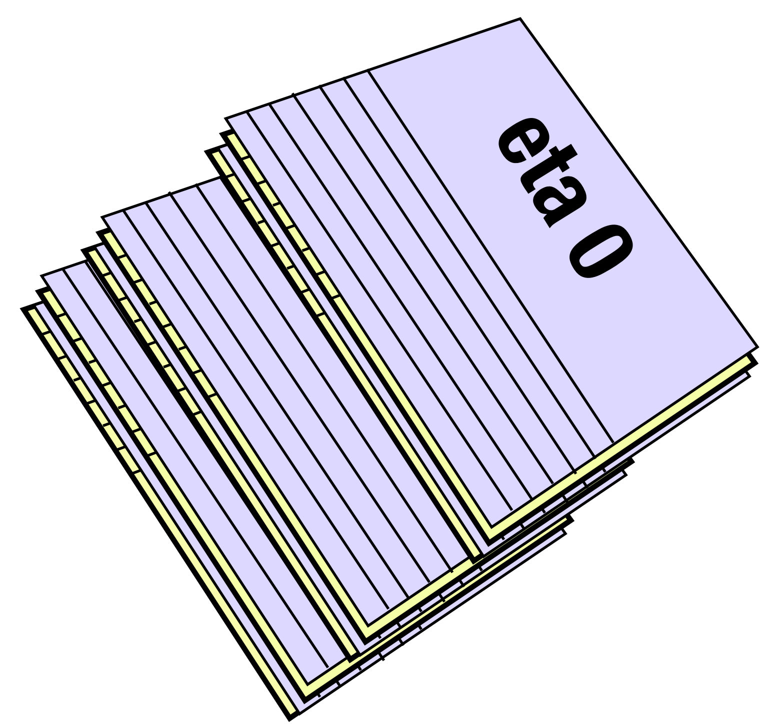
Within a single tower

- Layer (η_0-η_1, φ_0 φ_1)
- Views (η - φ)
- Pivot to *Low-p_T*
- *Low-p_T* to *High-p_T*



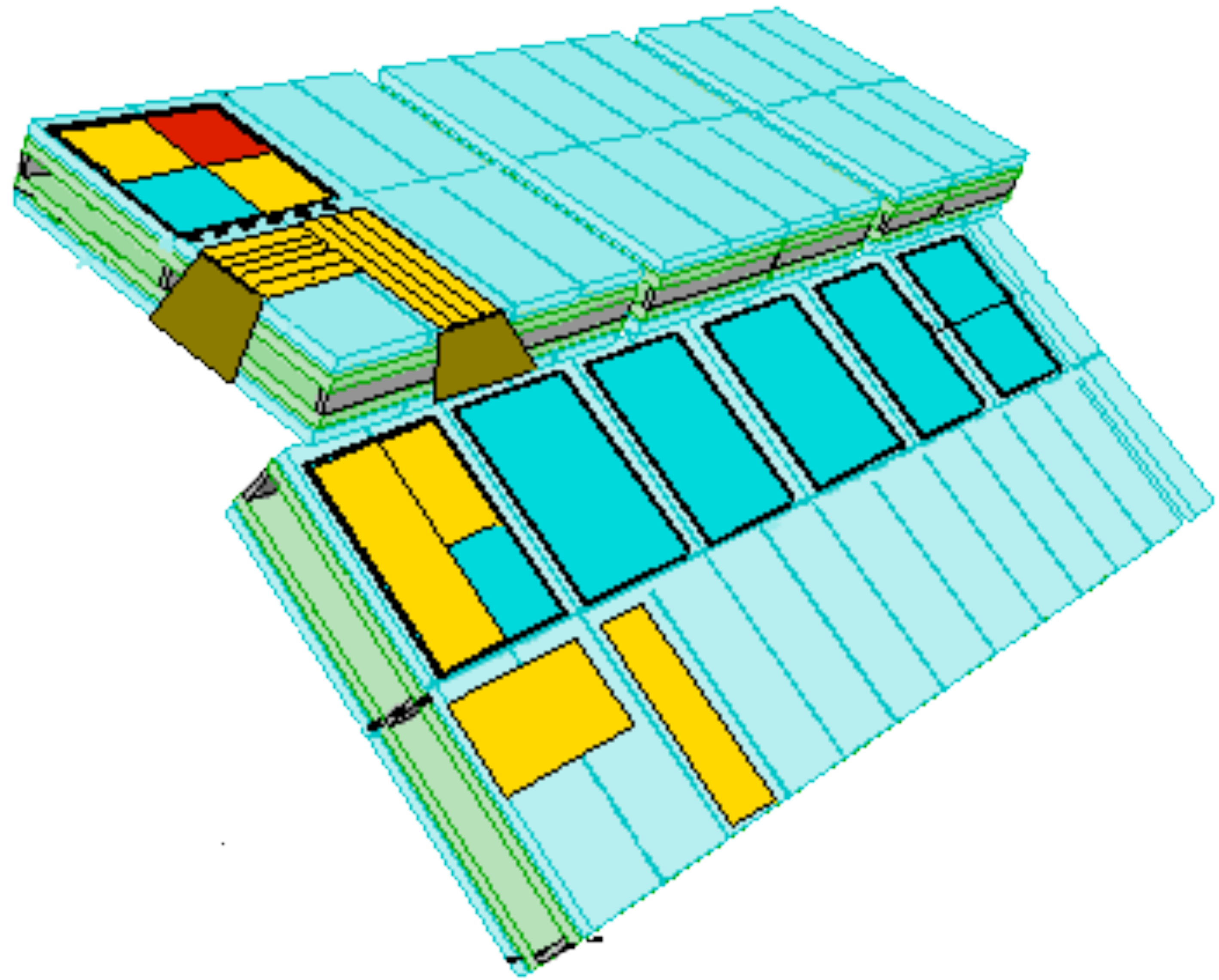
Within a single tower

- Layer (η_0-η_1, φ_0 φ_1)
- Views (η - φ)
- Pivot to *Low-p_T*
- *Low-p_T* to *High-p_T*



Within a single tower

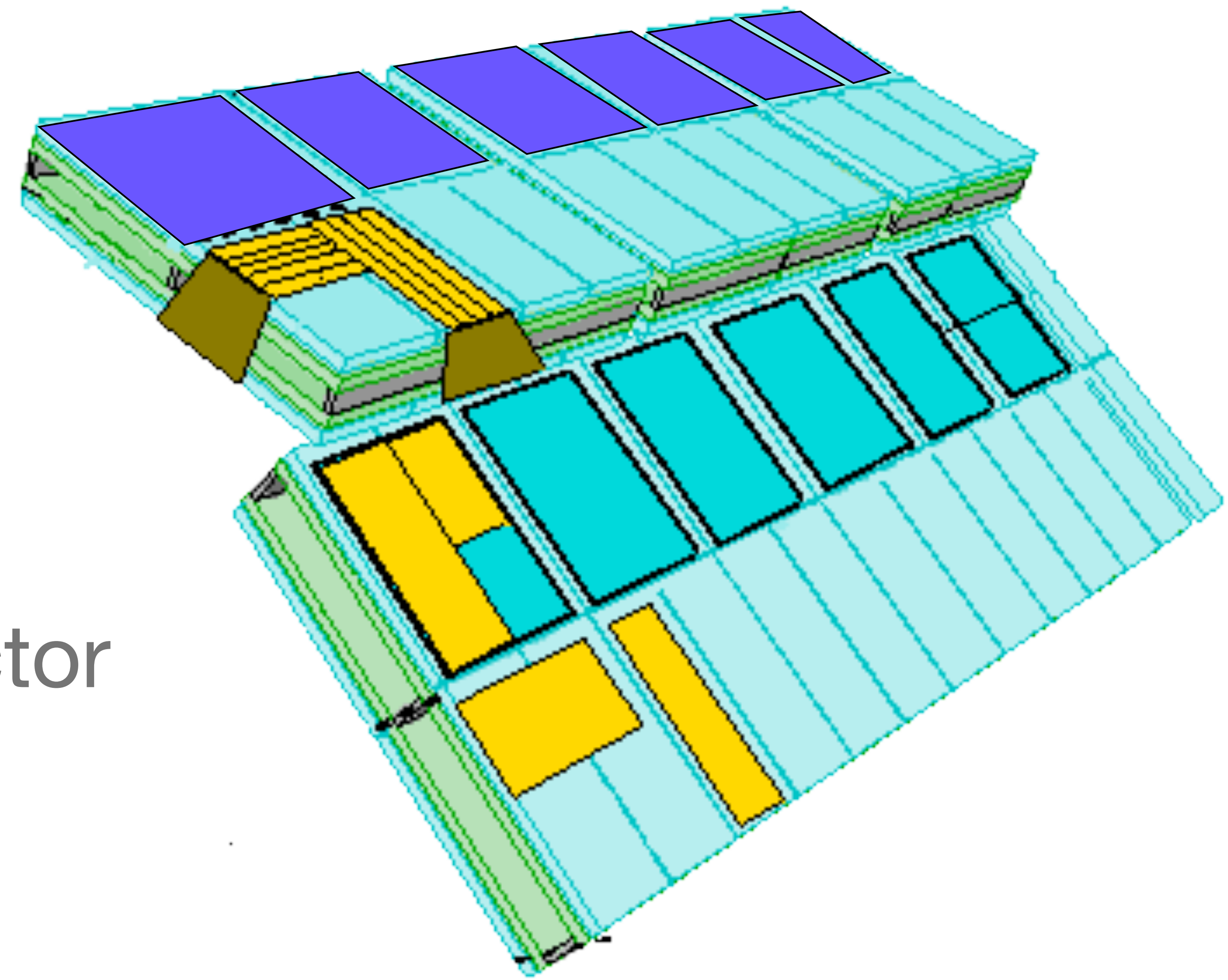
- Layer (η_0-η_1, φ_0 φ_1)
- Views (η - φ)
- Pivot to *Low-p_T*
- *Low-p_T* to *High-p_T*



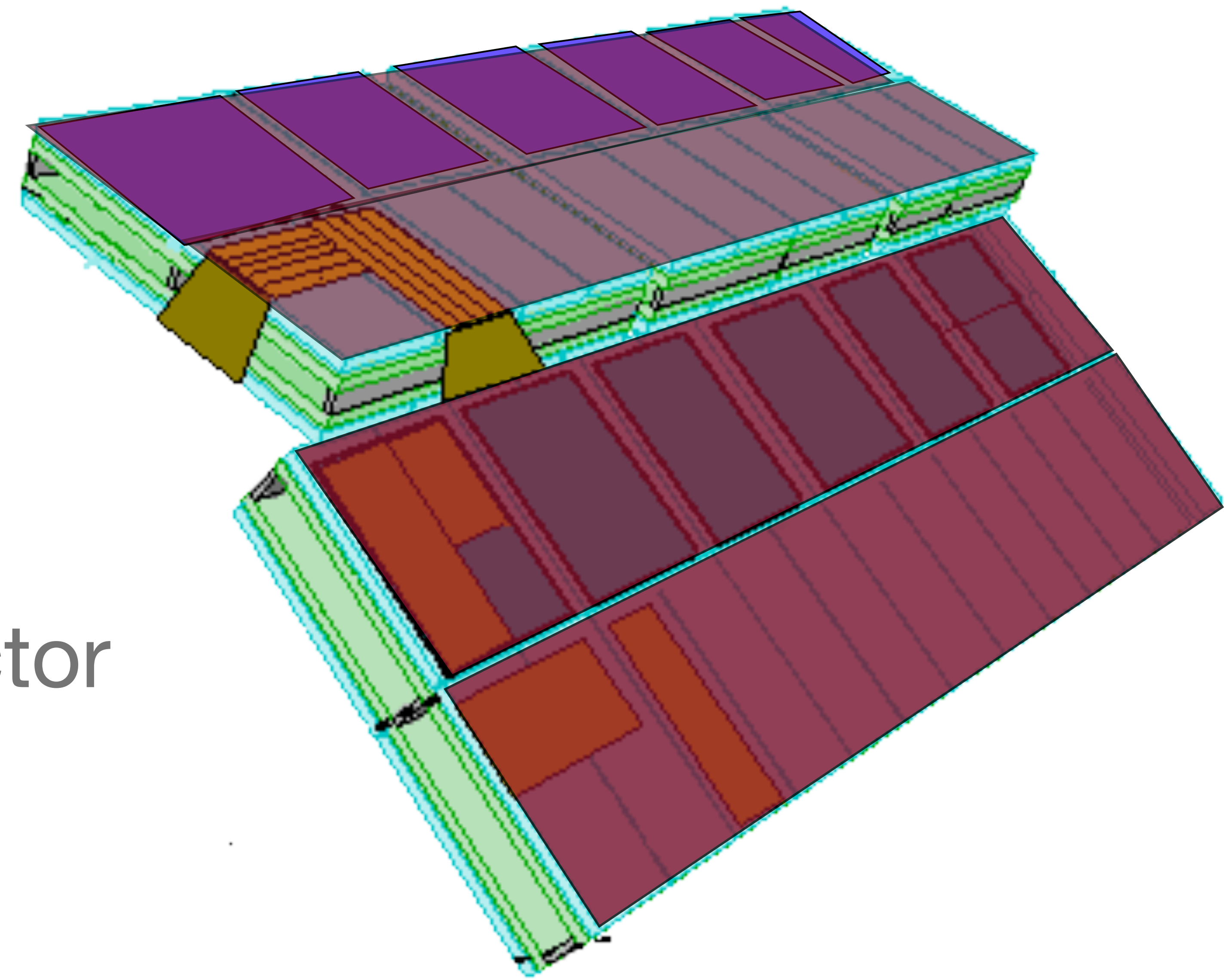
Within a single tower

- Layer (η_0-η_1, φ_0 φ_1)
- Views (η - φ)
- Pivot to *Low-p_T*
- *Low-p_T* to *High-p_T*

All towers within a sector



- Within a single tower
  - Layer (η_0-η_1, φ_0 φ_1)
  - Views (η - φ)
  - Pivot to *Low-p_T*
  - *Low-p_T* to *High-p_T*
- All towers within a sector
- Sector by sector



Cosmics

- The LVL1 Muon Barrel trigger has a resolution of 1/8 BC (3.125 ns).
- The trigger decision must be in the middle of the BC to avoid jitters.
- This will be true with collision but…..not with cosmic
    - They are flat in time over the whole BC window, with a non negligible probability of “border” effect on BC ID assignment.
    - Moreover the cosmics have a distribution in space that is far from being isotropical (shaft) nor pointing to IP.
- It’s then clear that with cosmics only a coarse time (~BC) alignment is possible

Cosmics alignment

Side C

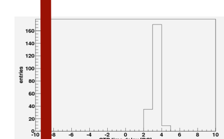
$\varphi = 0$

Side

$\varphi = 2\phi$

$\eta = -1.05$

$\eta = 1.05$

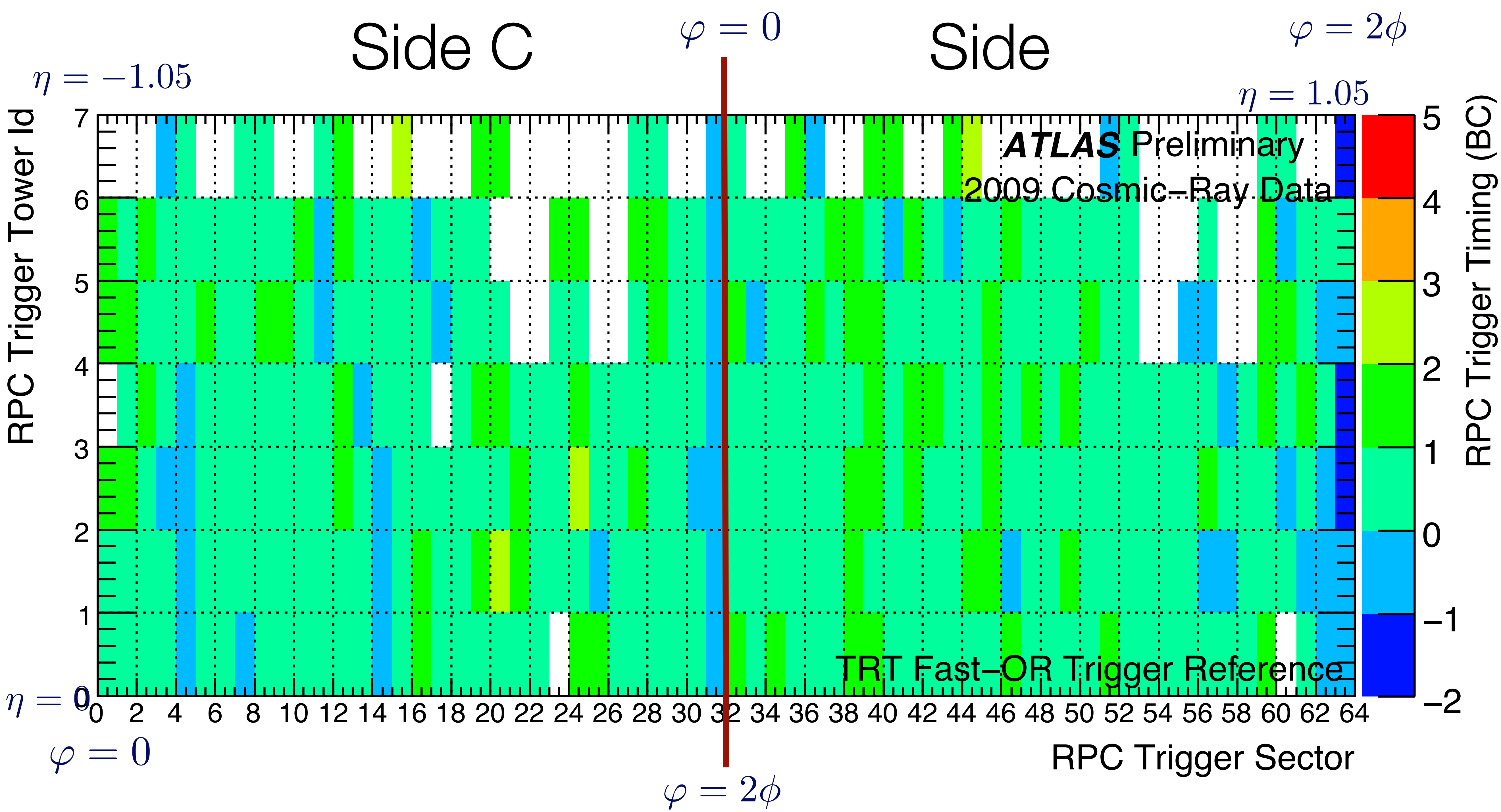


$\eta = 0$

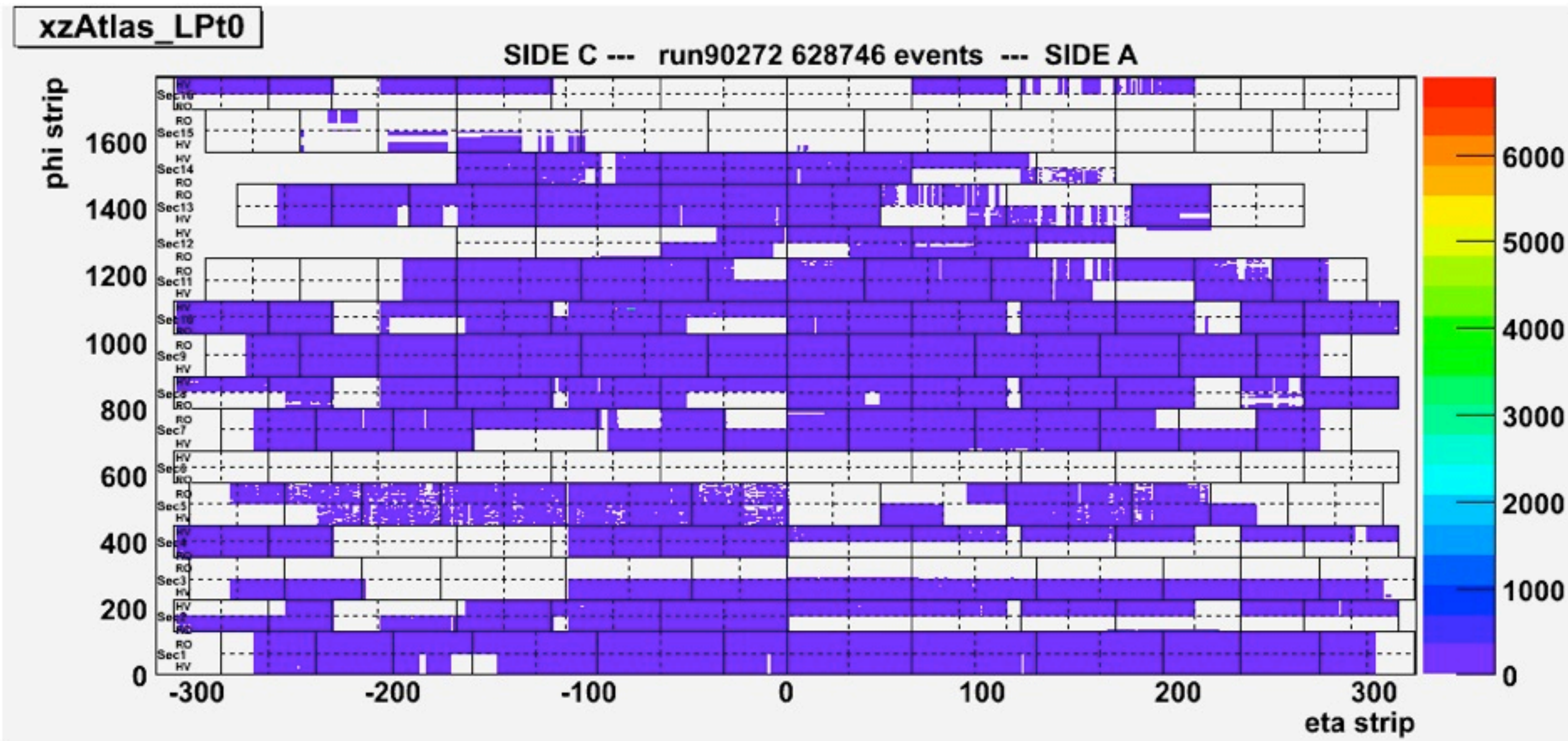
$\varphi = 0$

$\varphi = 2\phi$

Cosmics alignment



We start from this - September 2008



Coverage 70%

Road Map for final commissioning

Timing

- The method shown can be easily used with collision
- ***coarse alignment (~ BC) need 100 muon per tower***
- ***fine alignment (~ 5 ns) needs 1000 muons per tower***

Validation of the pT threshold (trigger roads)

- Defined to maximize trigger efficiency using single muon monte carlo
- Depends on modeling of magnetic-field, geometry, materials
- Depends on statistics, detector areas with less acceptance have larger coincidence roads
- Trigger roads must be validated with data using reconstructed muon
- Use MU0 as the maximum acceptance threshold
- Use calibration stream as well: no rejection by L2, no prescales
- ***Trigger roads: sensible validation can be started with ~2000 muons/ RoI (L1_MU10). Note: need to consider separately for mu+/mu-***