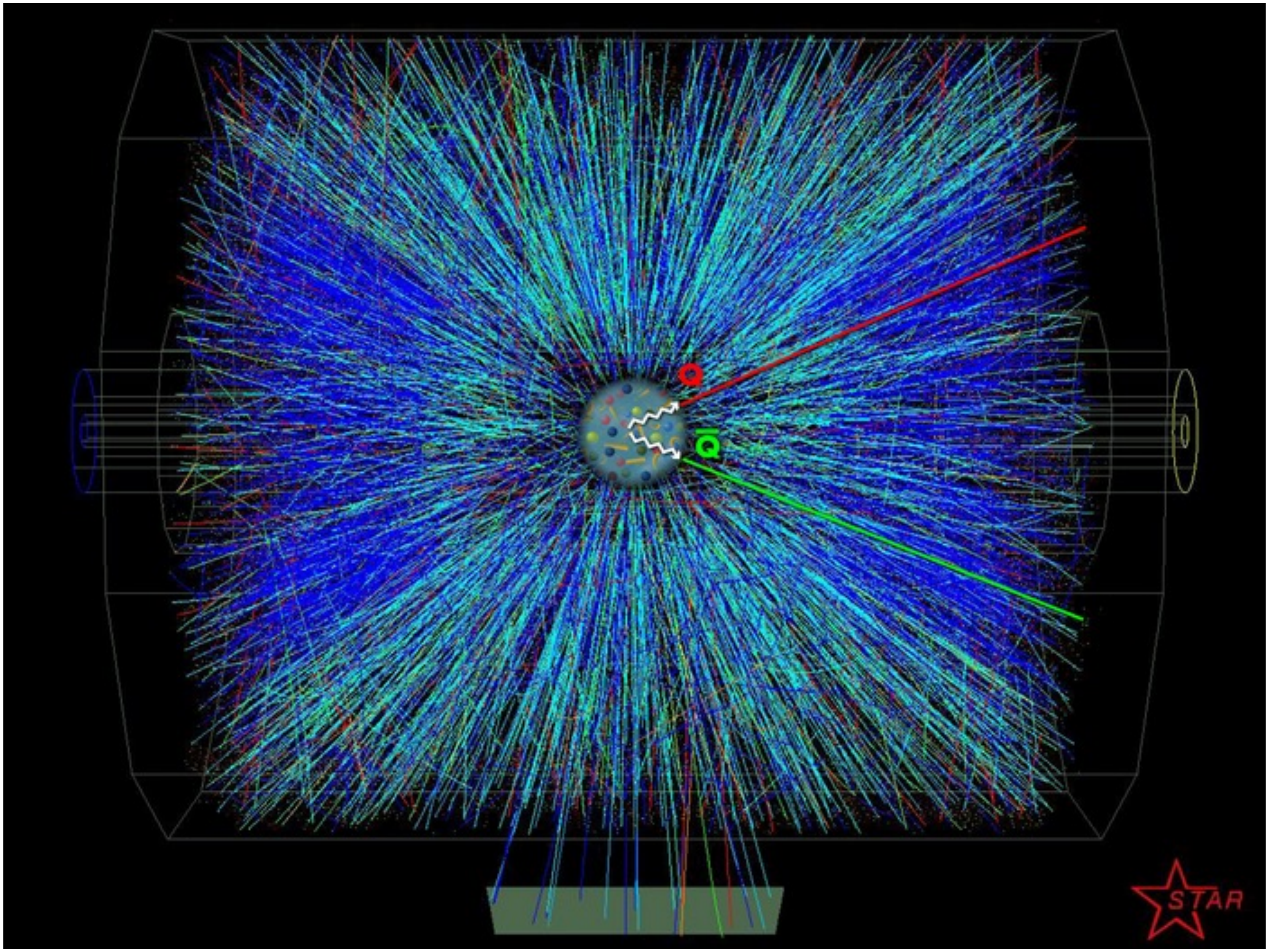
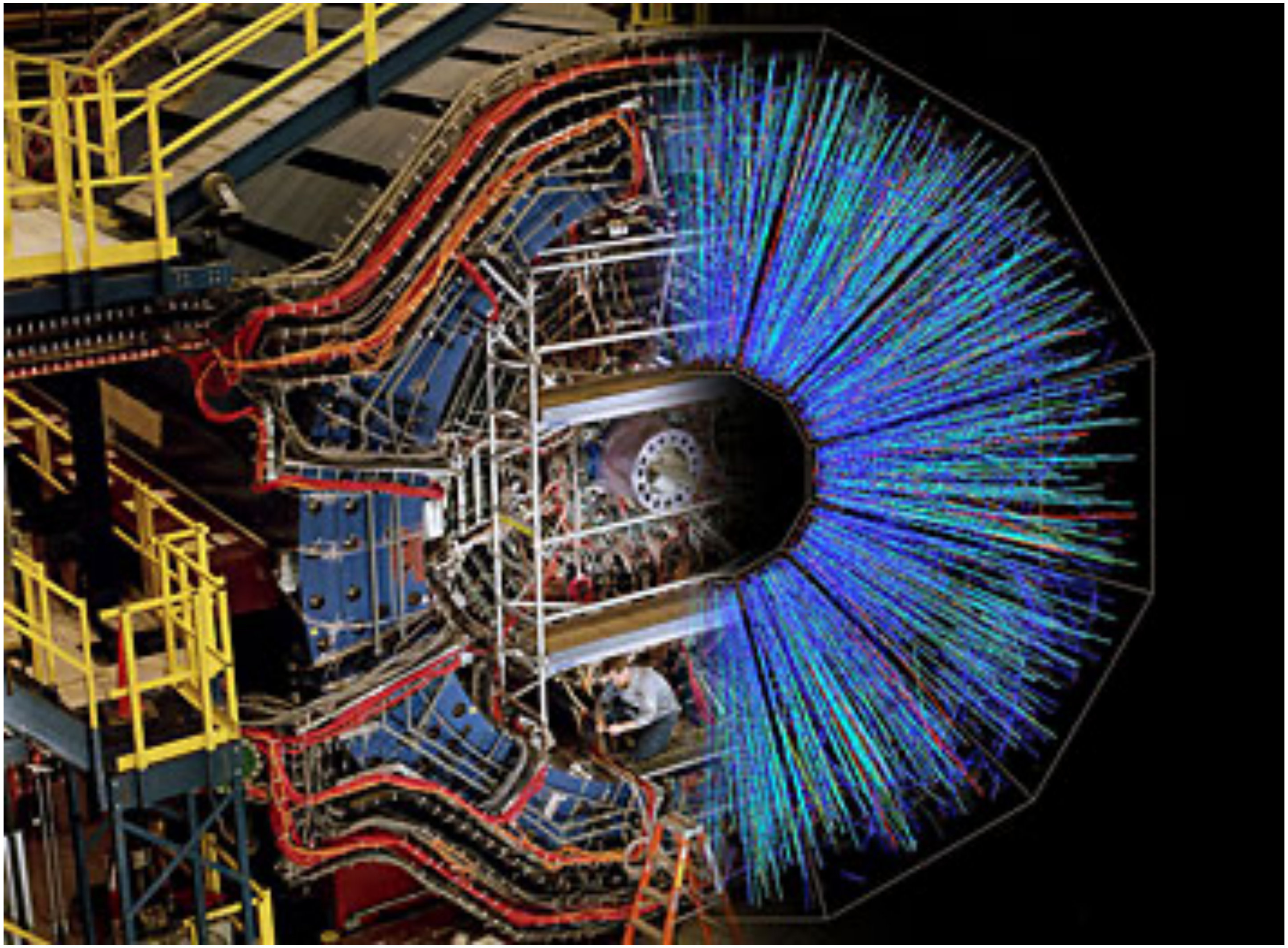
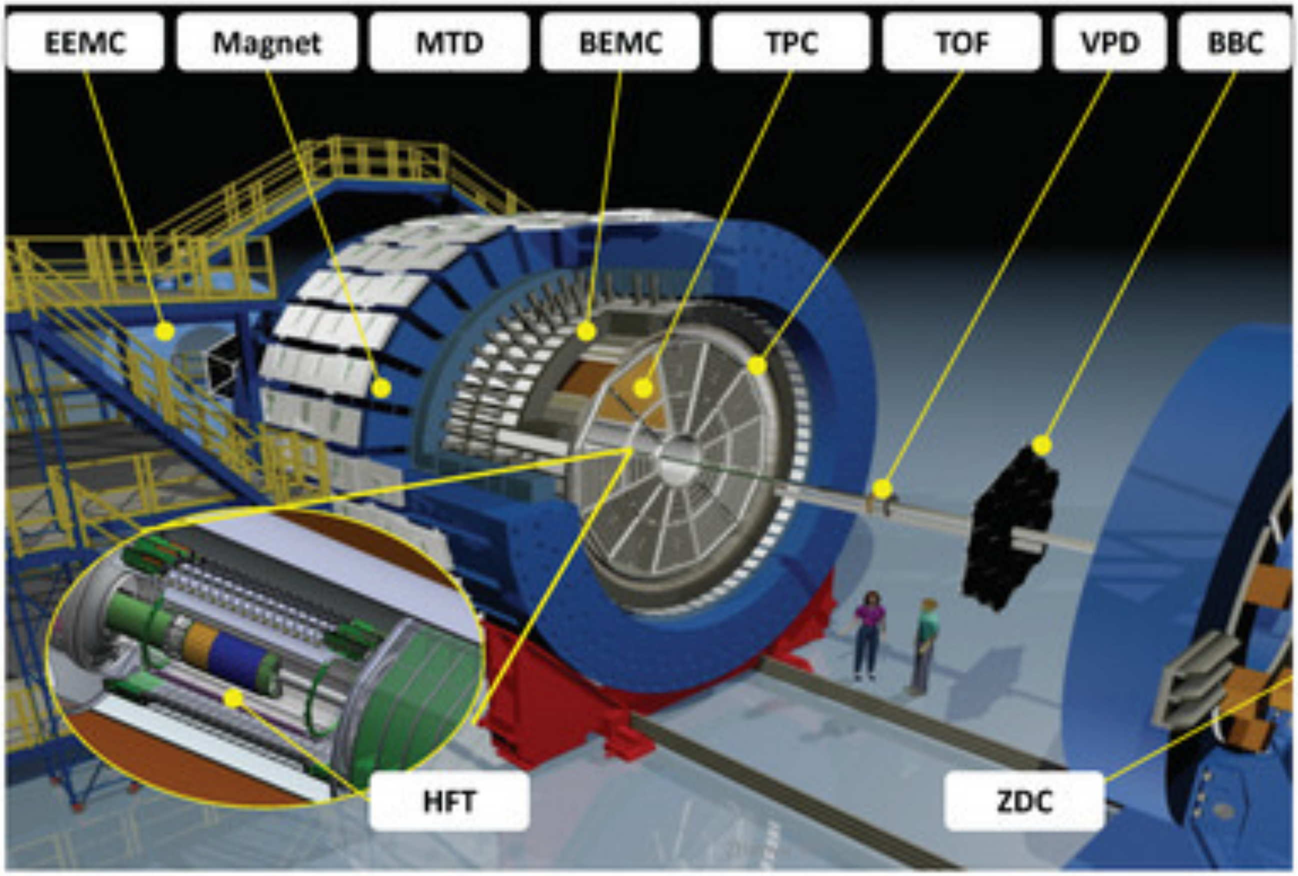
Small-Strip Thin Gap Chamber (sTGC)

Prashanth Shanmuganathan

Why we need sTGC?


Q
$\bar{Q}$
STAR

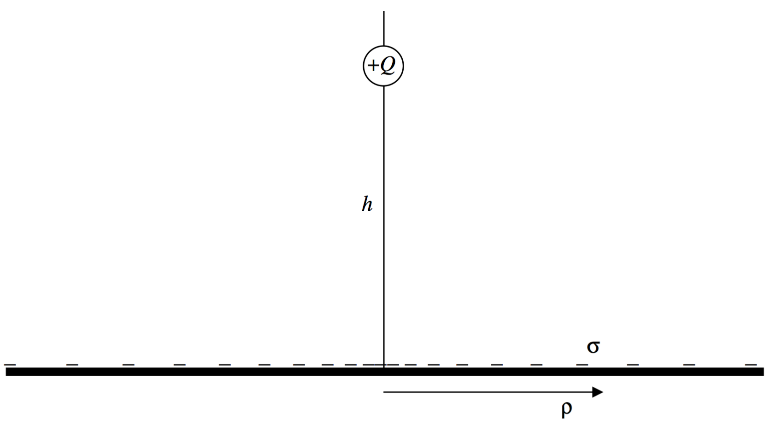


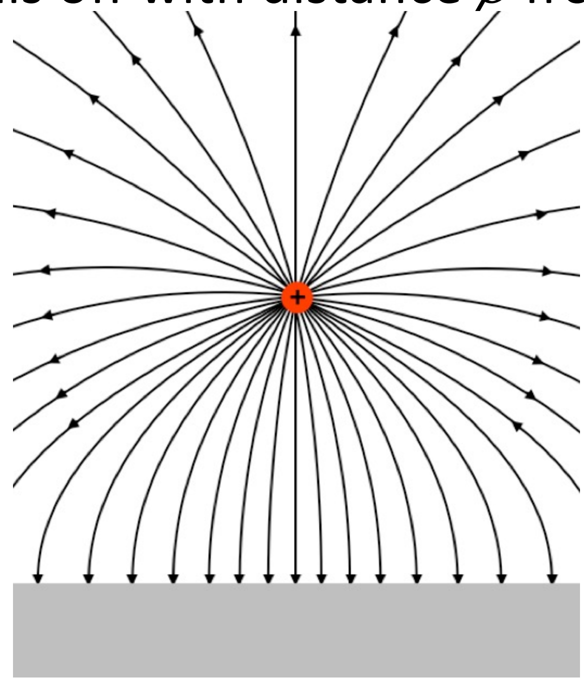


- **Tracking and PID (full 2π)**
  TPC: $|\eta| < 1$
  TOF: $|\eta| < 1$
  BEMC: $|\eta| < 1$
  EEMC: $1 < \eta < 2$
  HFT (2014-2016): $|\eta| < 1$
  MTD (2014+): $|\eta| < 0.5$
- **MB trigger and event plane reconstruction**
  BBC: $3.3 < |\eta| < 5$
  EPD (2018+): $2.1 < |\eta| < 5.1$
  FMS: $2.5 < \eta < 4$
  VPD: $4.2 < |\eta| < 5$
  ZDC: $6.5 < |\eta| < 7.5$

Concept

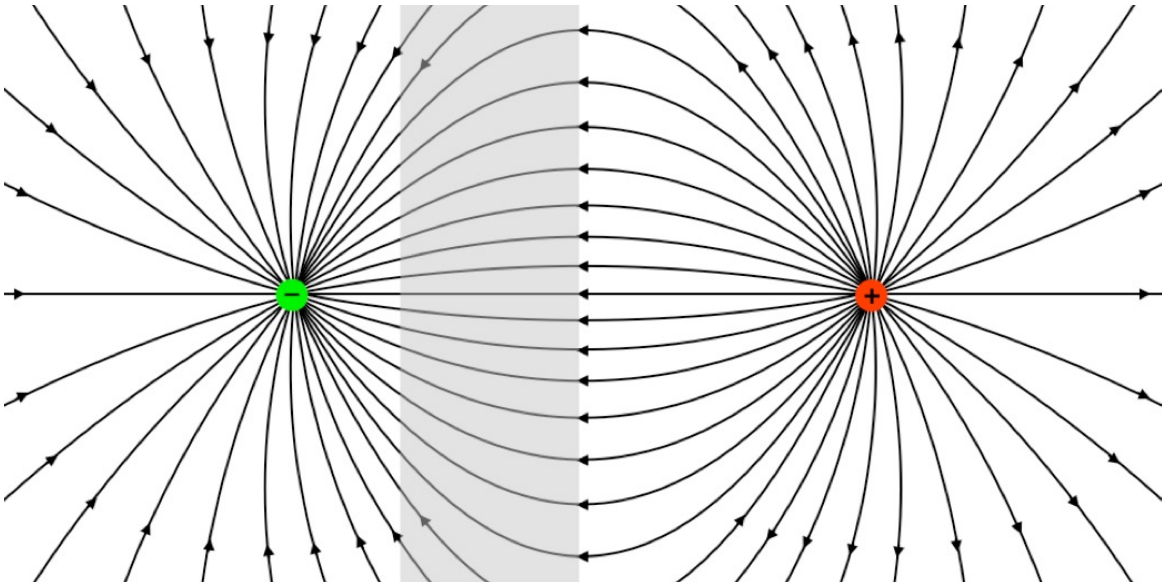
- An infinite plane metal plate is in the xy-plane. A point charge $+Q$ is placed on the z-axis at a height h above the plate. Consequently, electrons will be attracted to the part of the plate immediately below the charge, so that the plate will carry a negative charge density σ which is greatest at the origin and which falls off with distance ρ from the origin.





https://phys.libretexts.org/Courses/University_of_California_Davis/UCD%3A_Physics_9C__Electricity_and_Magnetism/1%3A_Electrostatic_Fields/1.8%3A_Method_of_Images

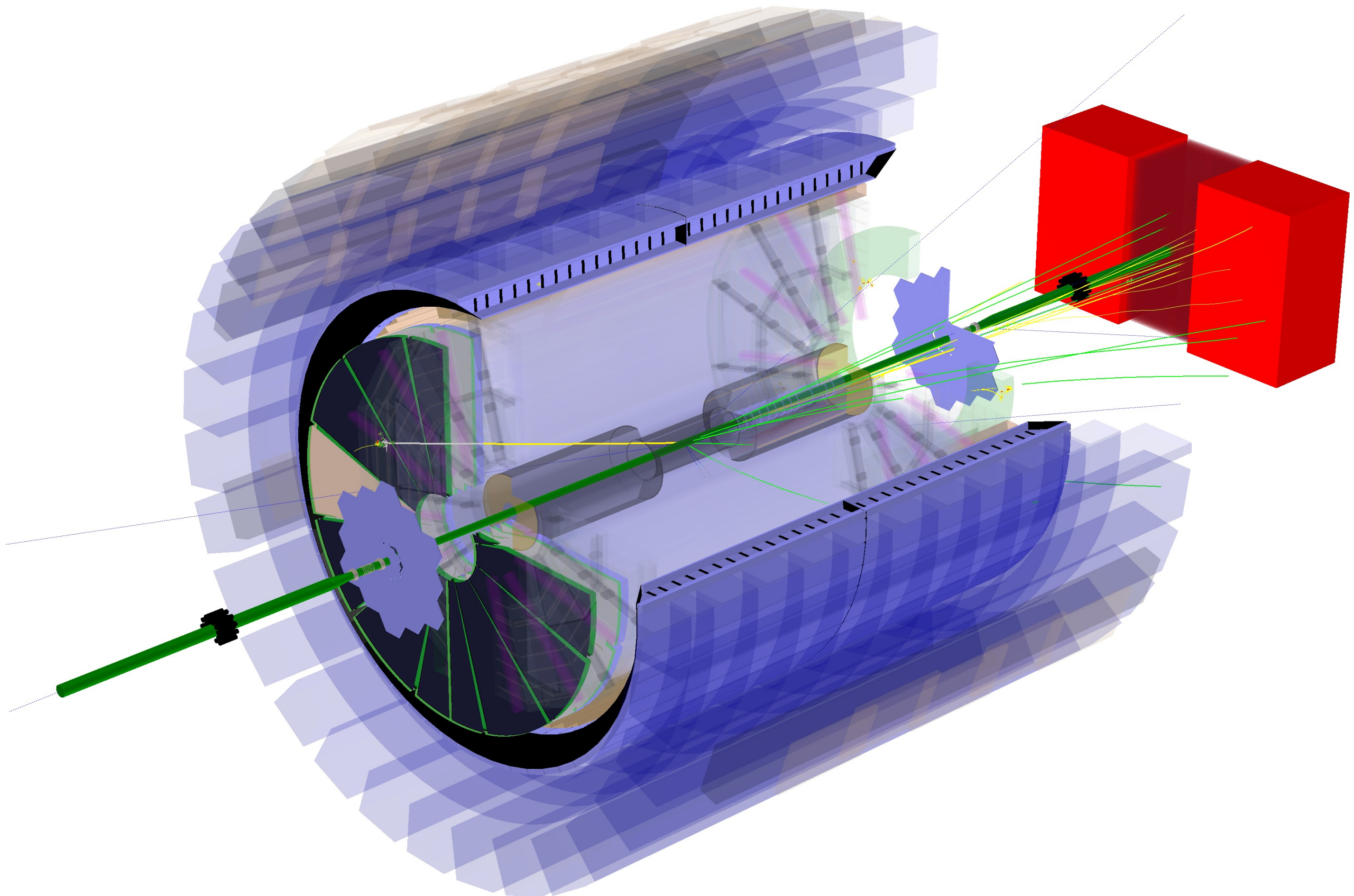
Image Charge



A Clever Trick

The equivalence of these two fields provides us with an opportunity to use a clever trick for analyzing physical situations involving electric charges near flat conductors. For a point charge, this trick involves introducing an imaginary *image charge* reflected across the conducting surface, and using that charge to derive the actual field outside the conductor surface.

> **Alert**
>
> *It can't be stressed enough that this trick does not involve introducing an actual physical charge, any more than constructing a gaussian surface involved constructing an actual physical surface. These are techniques for performing calculations, and one should always keep in mind what the actual physical circumstances are.*



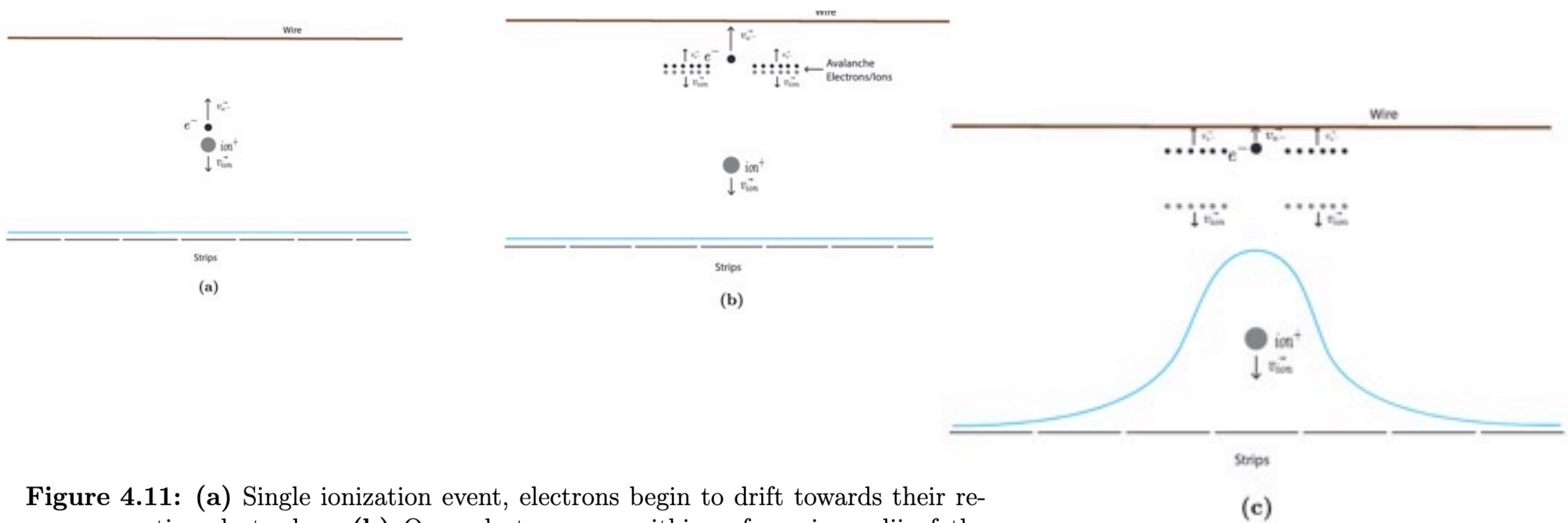


Figure 4.11: **(a)** Single ionization event, electrons begin to drift towards their respective electrodes. **(b)** Once electrons are within a few wire radii of the wire they have enough energy to produce secondary ionization electrons in an electron avalanche. **(c)** The rapid production of electrons at the wire induces charge on the strips. The charge density will follow a Gaussian-like distribution over the strips. The blue line depicts the charge distribution when the relative amplitudes of the strip signals are plotted.

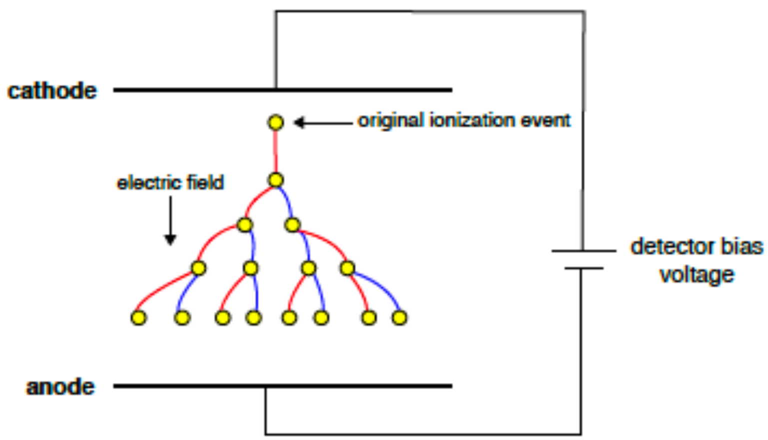


Figure 2.6: Schematic diagram of a Townsend avalanche. A strong electric field permeates the gaseous medium between the anode and the cathode. The yellow disks represent ionization events caused by an incident electron (red lines). Freed electrons (blue lines) produce more ionization events as they drift in the electric field. The total ionization approximately doubles at each step of the avalanche.

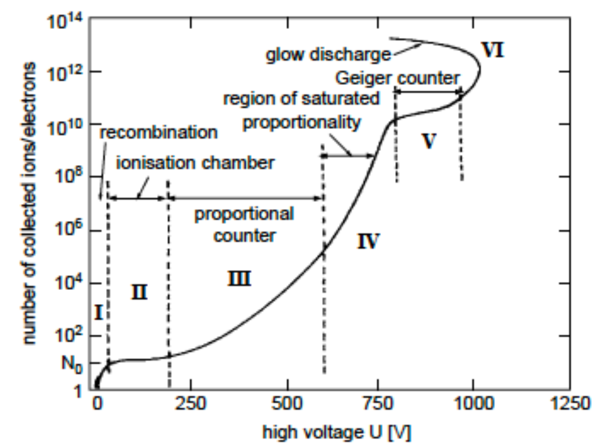
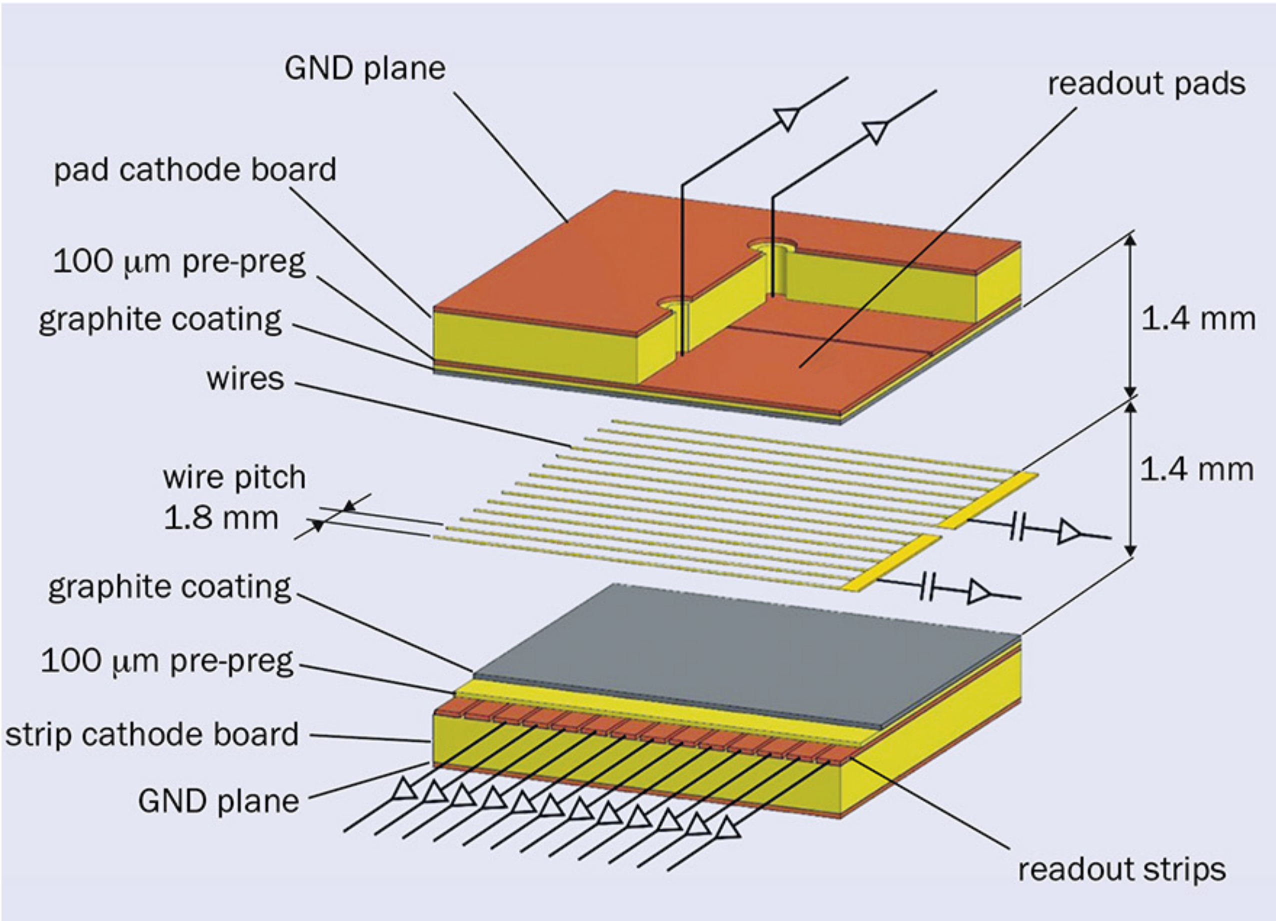


Figure 2.7: Ionization yield as a function of voltage for a typical ionization detector following the passage of a mip with a primary ionization $N_0 \sim 10$ [32].

Concept to Reality

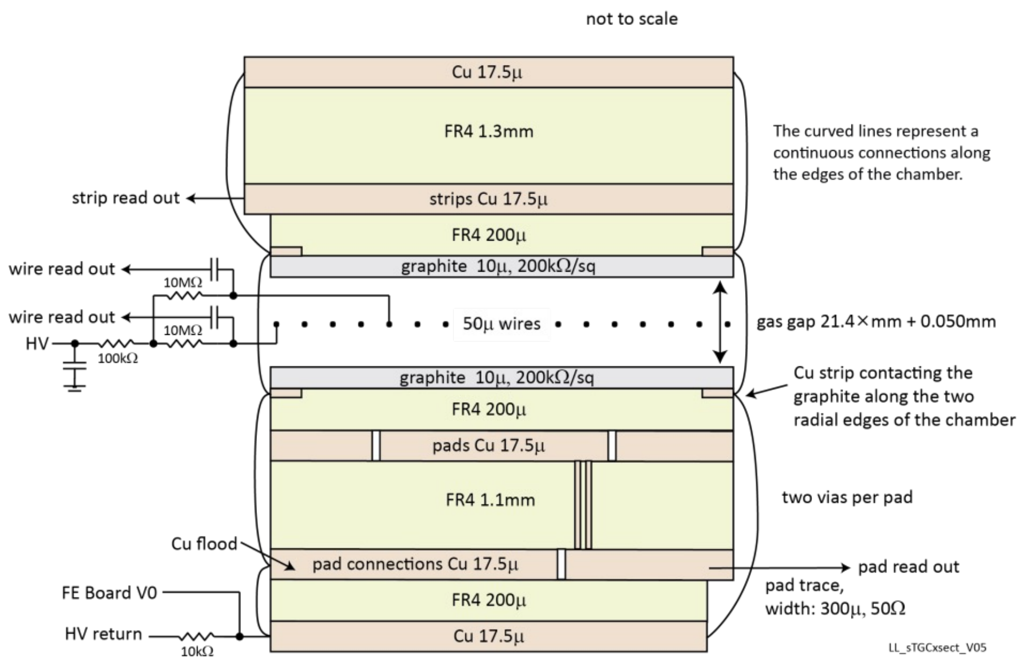
sTGC



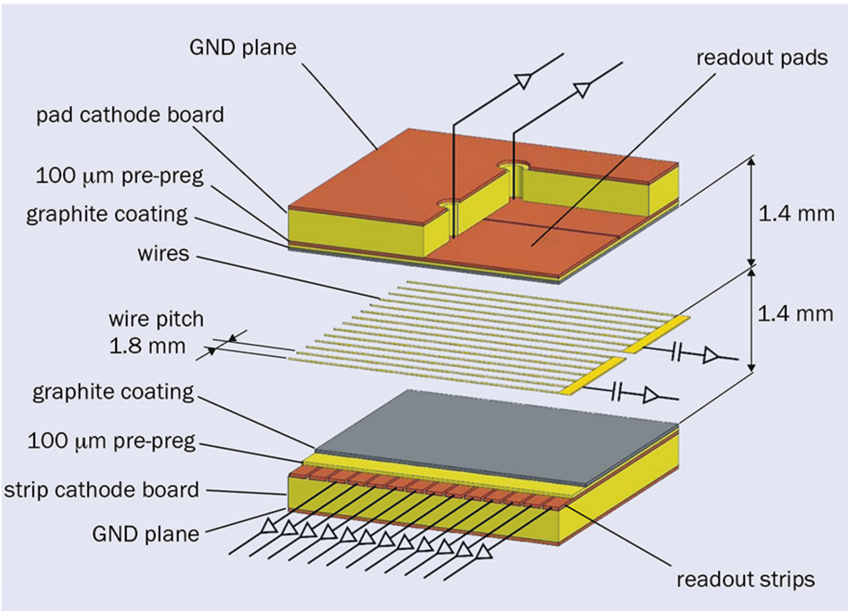
GND plane
readout pads
pad cathode board
100 µm pre-preg
graphite coating
wires
1.4 mm
1.4 mm
wire pitch
1.8 mm
graphite coating
100 µm pre-preg
strip cathode board
GND plane
readout strips

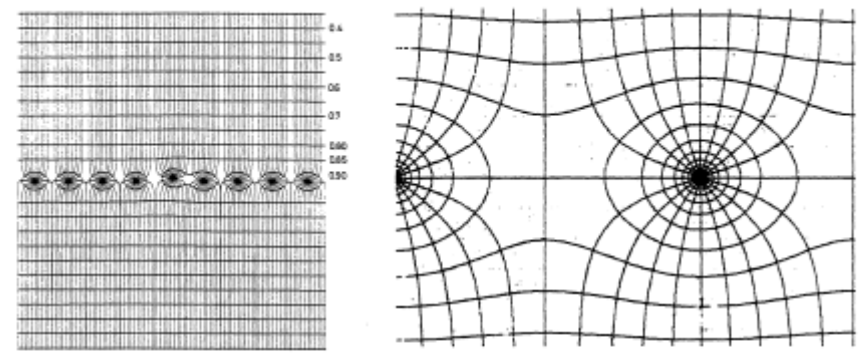
Detailed cryosections of sTGC

sTGC cross-section



sTGC

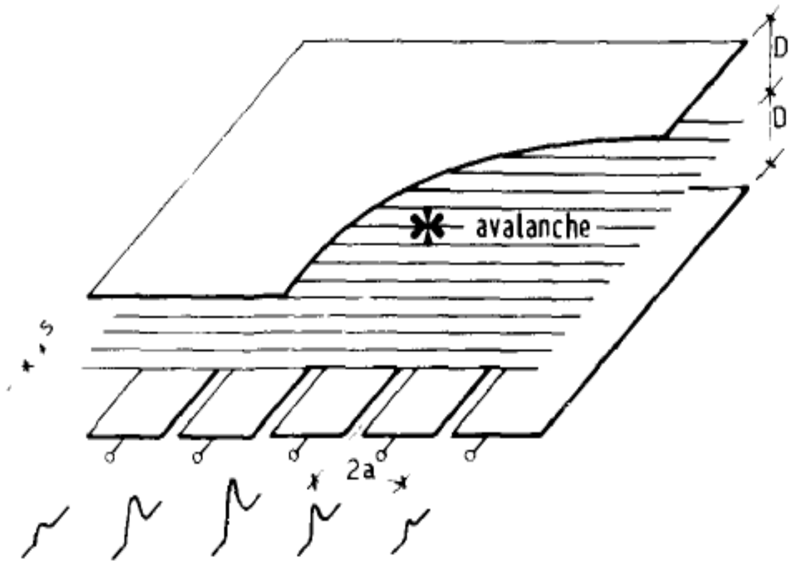


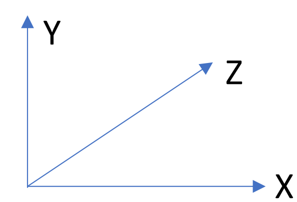


(a) (b)

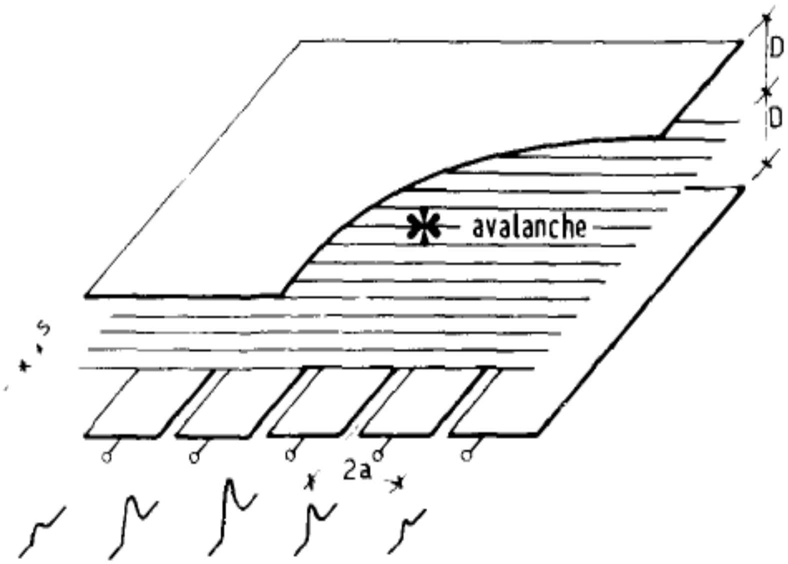
Figure 2.11: (a) Electric field lines and equipotentials in the gas volume of a multi-wire chamber. The electric potential relative to the anode wire potential, or value of V_0, is indicated. The effects of a minor displacement of one anode wire are shown. (b) Enlarged view of the same figure in the vicinity of a wire [14].

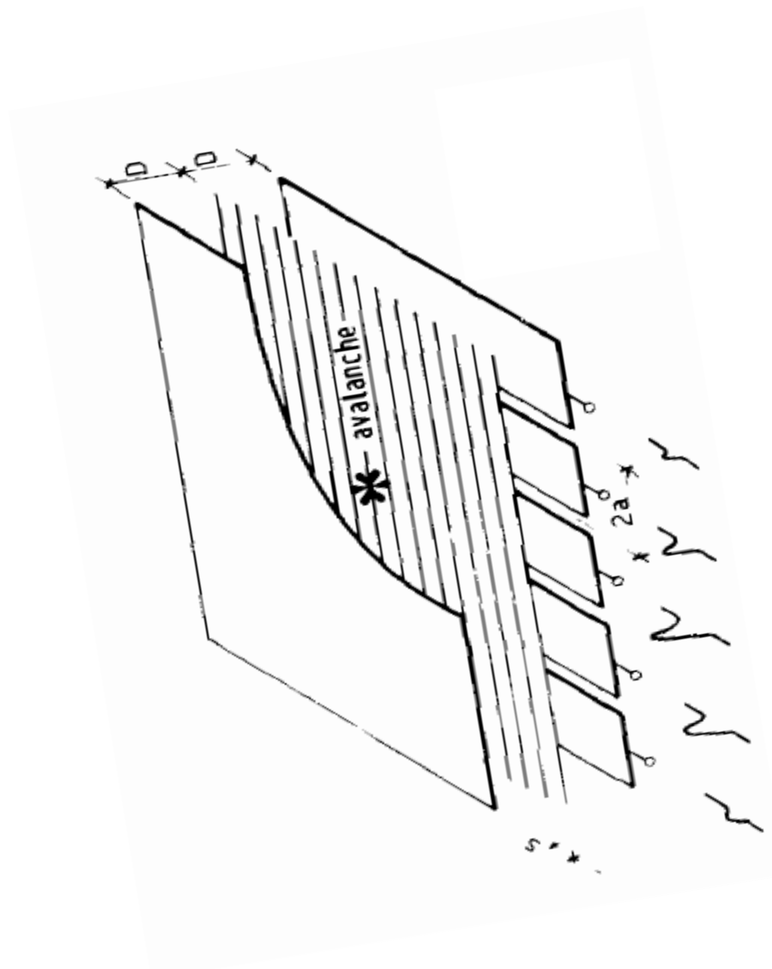
Track reconstruction – 1D positioning

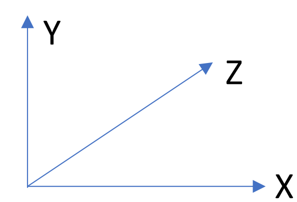




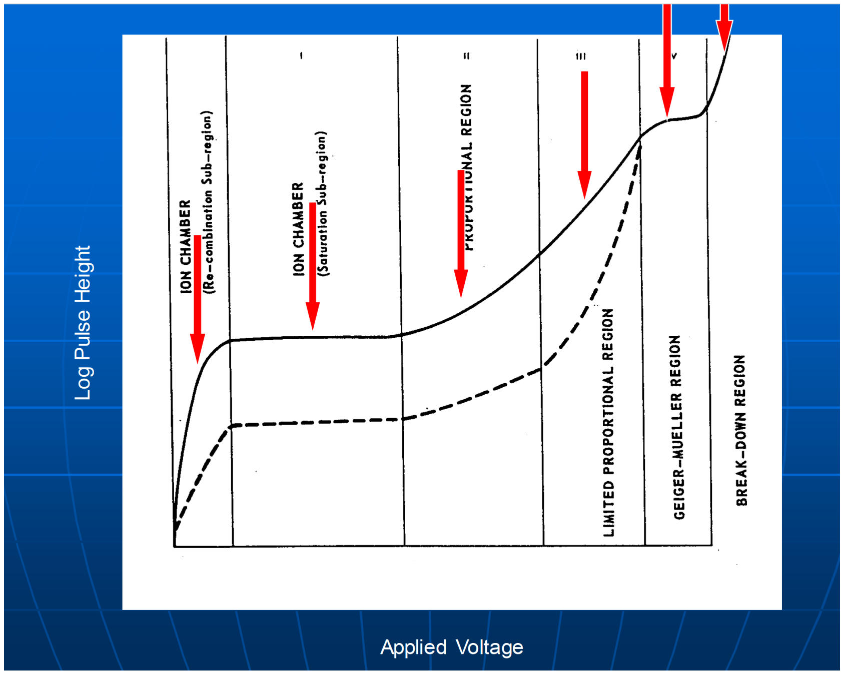
Track reconstruction – 2D positioning







Choice of gas?



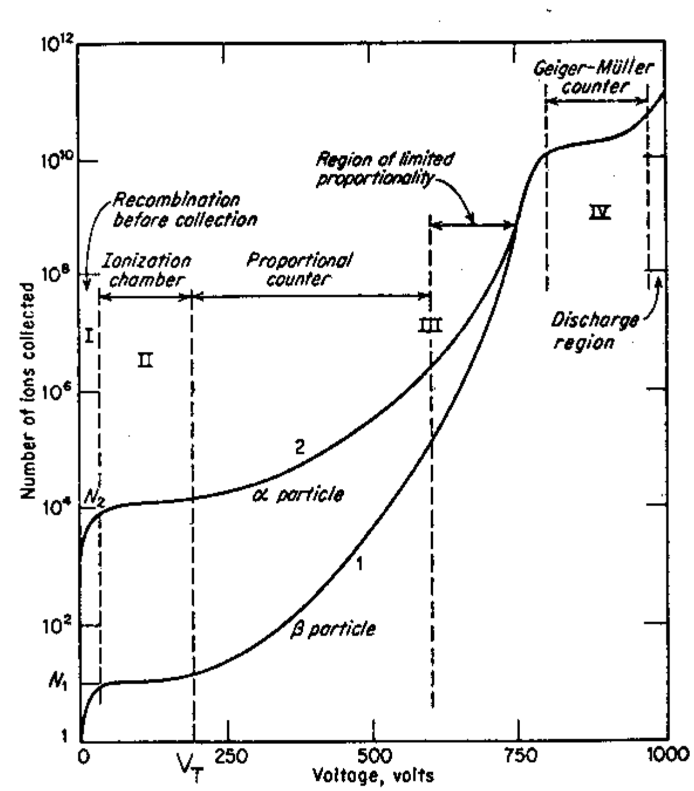


Fig. 50 Gain-voltage characteristics for a proportional counter, showing the different regions of operation (from W. Price, see bibliography for Sections 2 and 3).

Gas

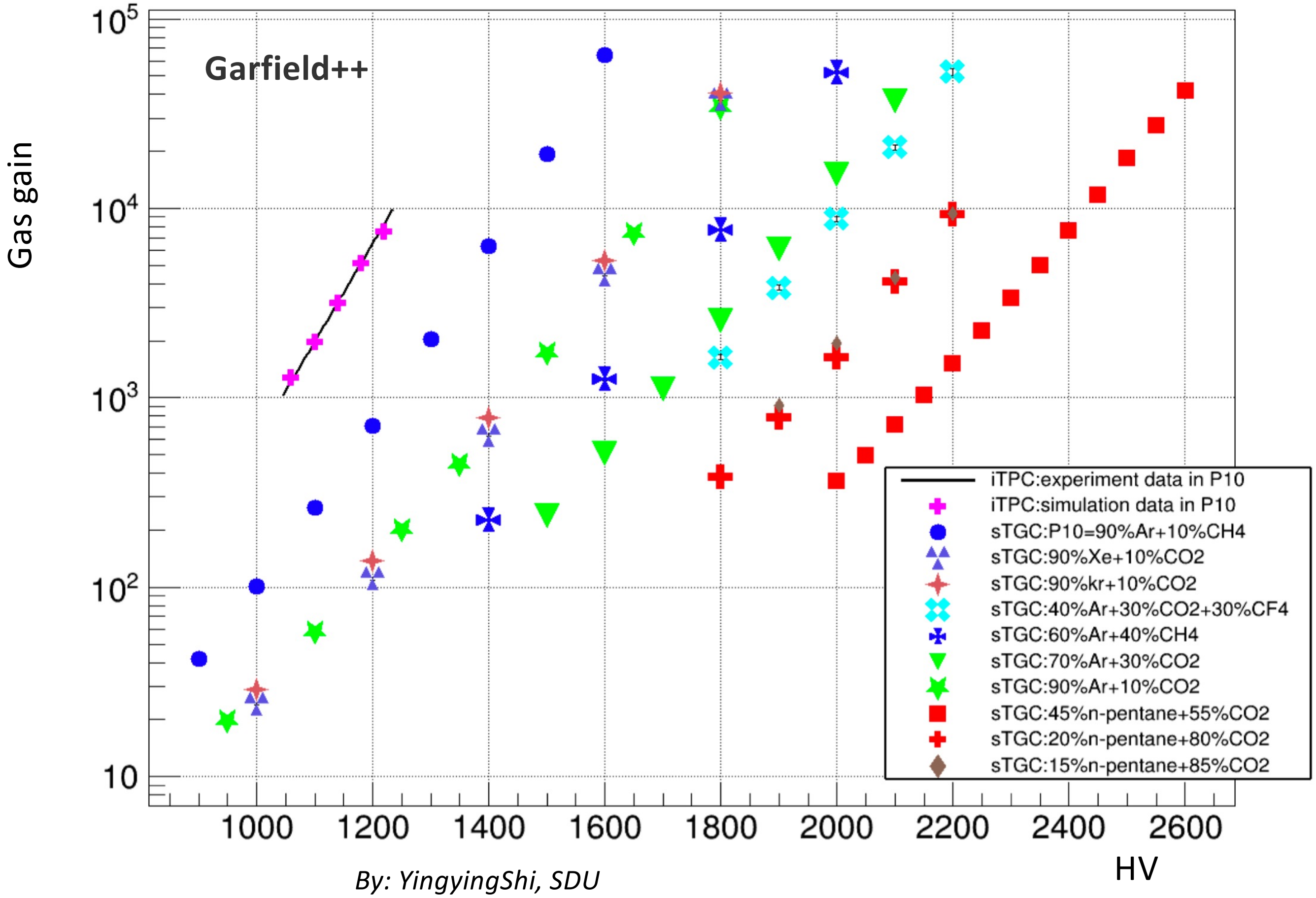
Table 1

Properties of several gases used in proportional counters (from different sources, see the bibliography for this section). Energy loss and ion pairs per unit length are given at atmospheric pressure for minimum ionizing particles

Gas	Z	A	δ (g/cm³)	E_{ex}	E_i (eV)	I_o	W_i	dE/dx (MeV/g cm⁻²)	dE/dx (keV/cm)	n_p (i.p./cm) a)	n_T (i.p./cm) a)
H_2	2	2	8.38×10^{-5}	10.8	15.9	15.4	37	4.03	0.34	5.2	9.2
He	2	4	1.66×10^{-4}	19.8	24.5	24.6	41	1.94	0.32	5.9	7.8
N_2	14	28	1.17×10^{-3}	8.1	16.7	15.5	35	1.68	1.96	(10)	56
O_2	16	32	1.33×10^{-3}	7.9	12.8	12.2	31	1.69	2.26	22	73
Ne	10	20.2	8.39×10^{-4}	16.6	21.5	21.6	36	1.68	1.41	12	39
Ar	18	39.9	1.66×10^{-3}	11.6	15.7	15.8	26	1.47	2.44	29.4	94
Kr	36	83.8	3.49×10^{-3}	10.0	13.9	14.0	24	1.32	4.60	(22)	192
Xe	54	131.3	5.49×10^{-3}	8.4	12.1	12.1	22	1.23	6.76	44	307
CO_2	22	44	1.86×10^{-3}	5.2	13.7	13.7	33	1.62	3.01	(34)	91
CH_4	10	16	6.70×10^{-4}		15.2	13.1	28	2.21	1.48	16	53
C_4H_{10}	34	58	2.42×10^{-3}		10.6	10.8	23	1.86	4.50	(46)	195

a) i.p. = ion pairs

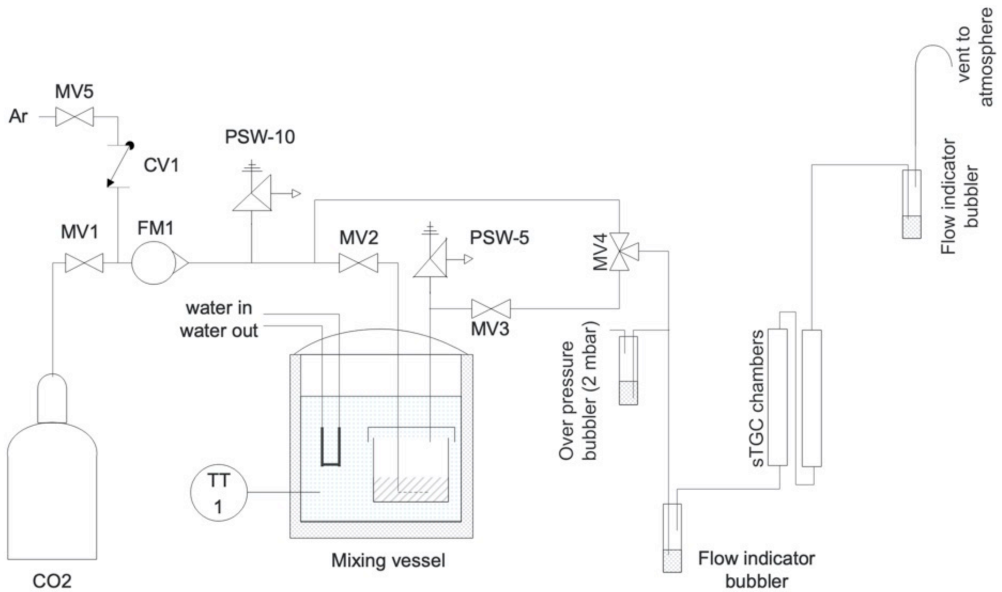
Gas Choices

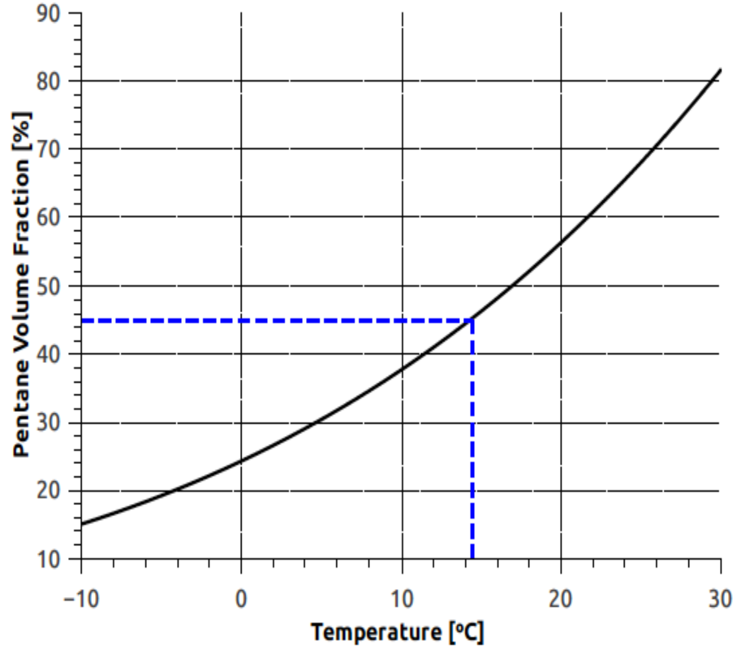


By: YingyingShi, SDU

- **Quenching gas is essential for stable operation:** sTGCs operate at high gas amplification, meaning a small initial ionization from a particle interaction is greatly amplified to produce a detectable signal. Without a quenching gas, this amplification process could lead to uncontrolled discharges (streamers or sparks) and damage the detector.
- **The gas mixture acts as a quenching agent:** The operational gas is typically a mixture of **55% CO2 and 45% n-pentane**. The n-pentane acts as a quenching gas, absorbing photons and ions produced during the electron avalanche and preventing them from initiating further avalanches.
- **Benefits of using this specific mixture:** This gas mixture allows sTGCs to operate at high gas amplification while maintaining stability and minimizing the risk of discharges. Tests have shown that sTGCs operating with this mixture exhibit greater stability and lower sensitivity to electric field non-uniformity compared to using only CO2.
- **Significance in High-Luminosity Environments:** The ability of this gas mixture to ensure stable operation at high gas amplification is crucial for detectors like sTGCs designed to function in the high-radiation environment of the High-Luminosity LHC.

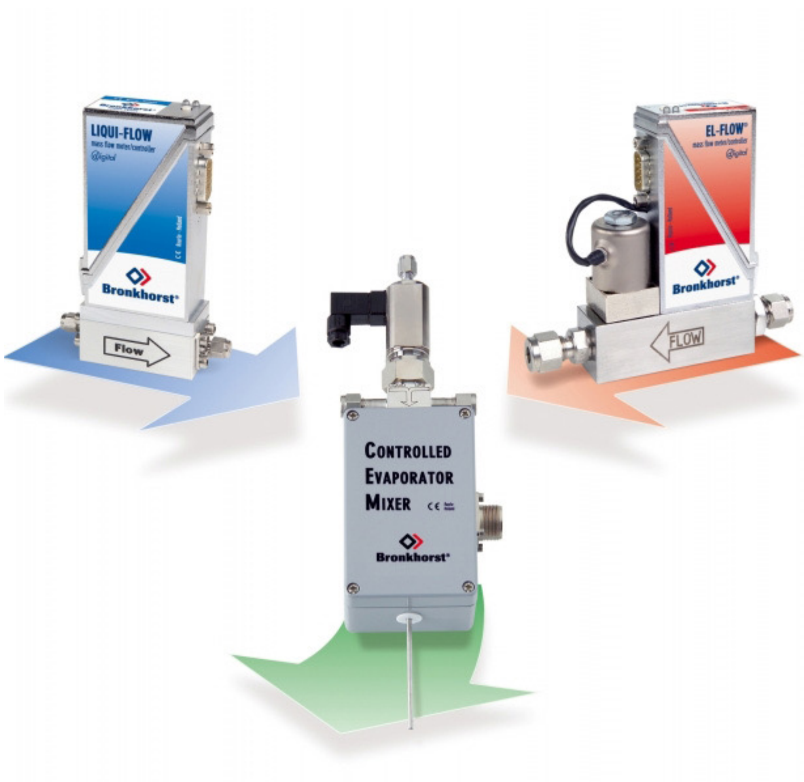
Getting the right mixture

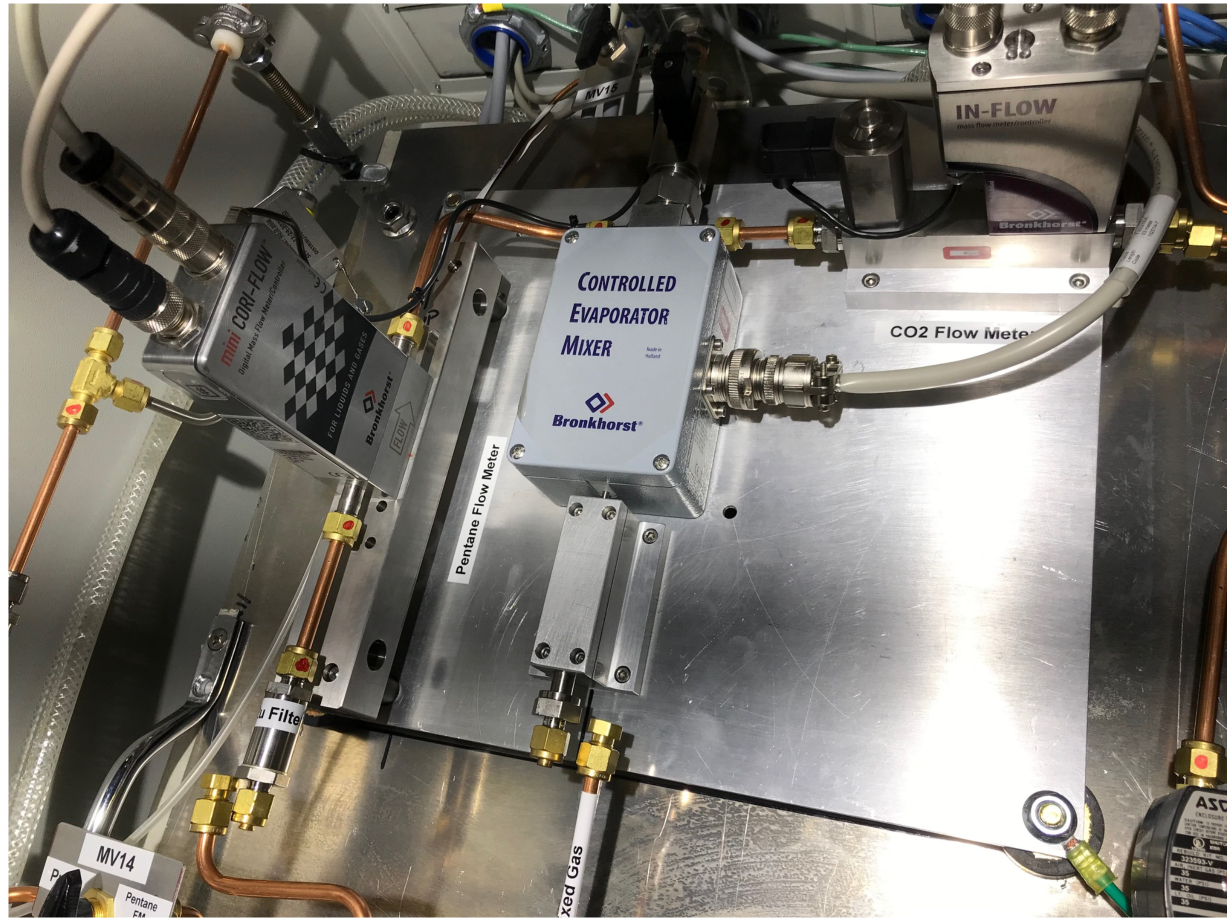




arXiv:1702.01240v3 [physics.ins-det]

Getting the right mixture





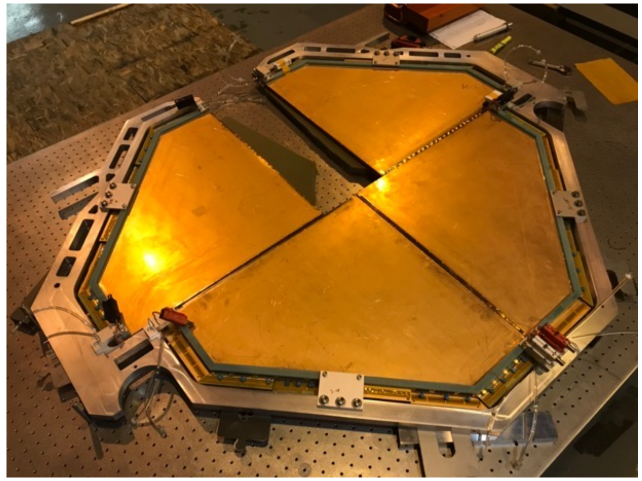
Bronkhorst components assembled in the gas cabinet

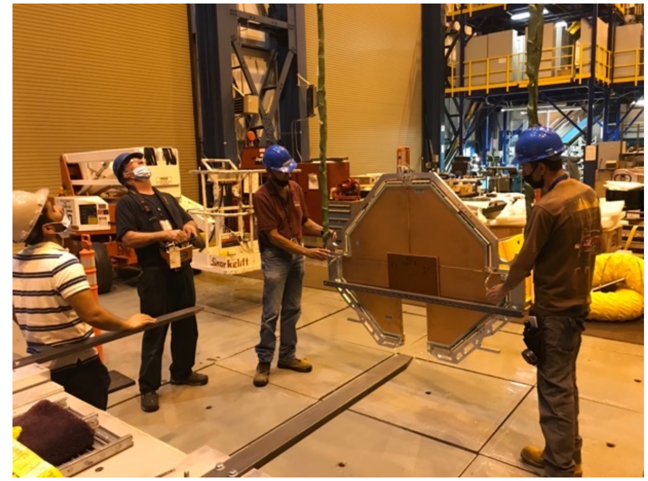
sTGC Operations Reequipments

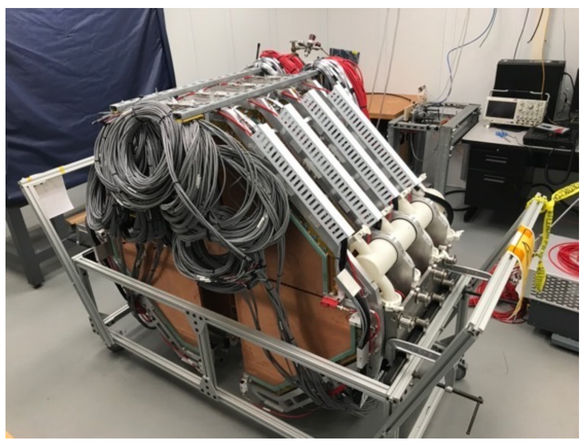
- Anode (HV): 50 µm gold-plated tungsten wires held at a potential of ~2900 V
- Working gas: n-Pentane+CO2= 45:55% by volume
- Supply pressure 2 mbar above atm
- Flow about 50 cc/min

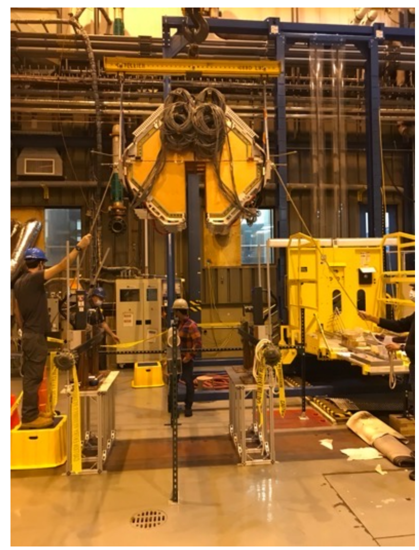
Why sTGC?

sTGC Detector Assembly

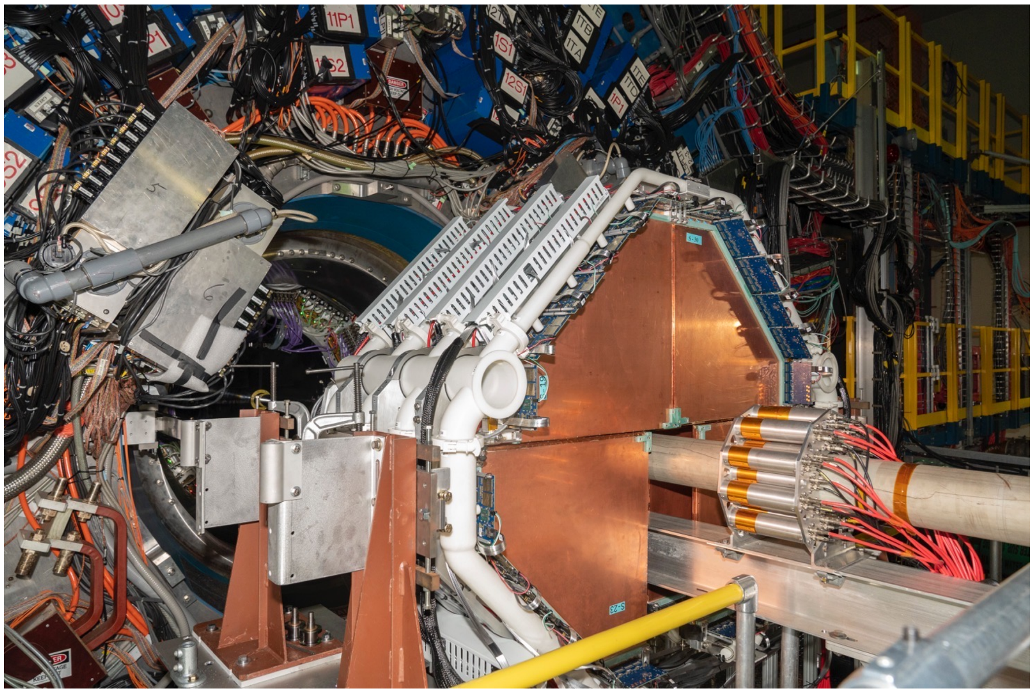


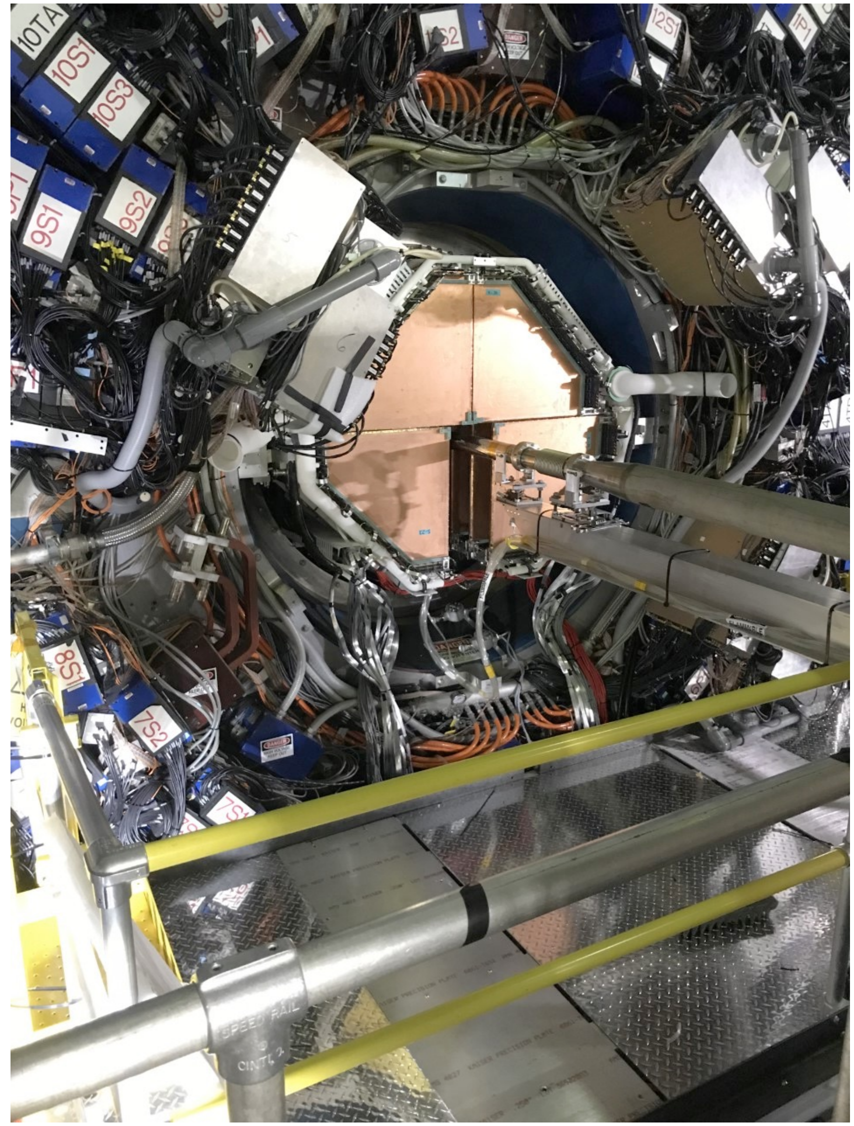






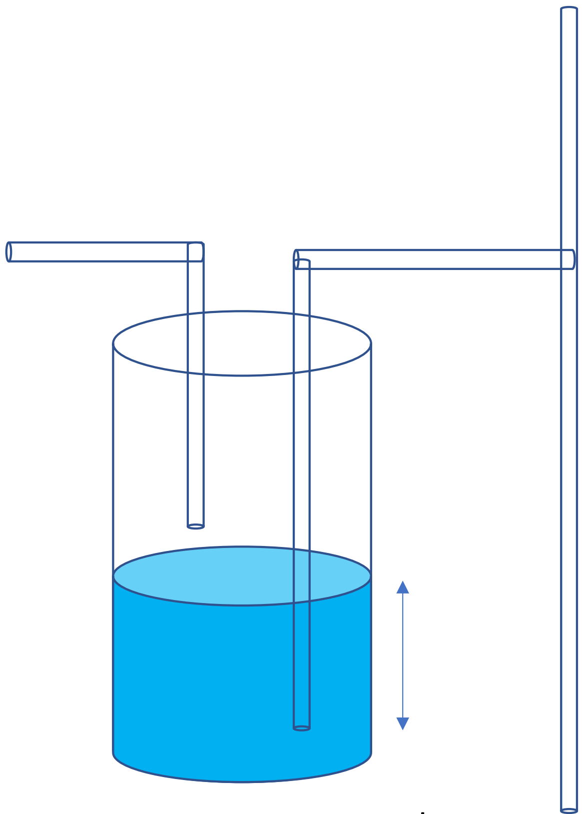
sTGC Detector Assembly





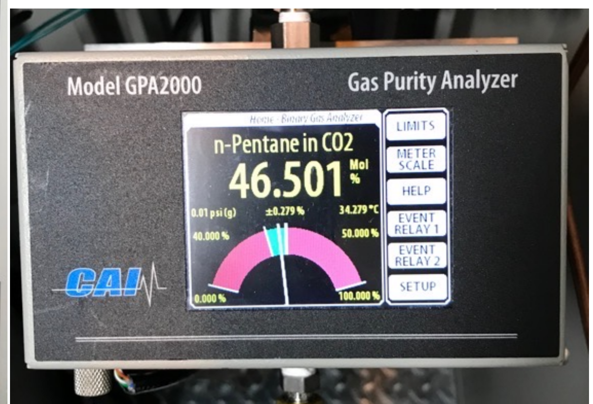
Building the Gas System

Protecting the chambers form over pressure



$P = h\rho g$

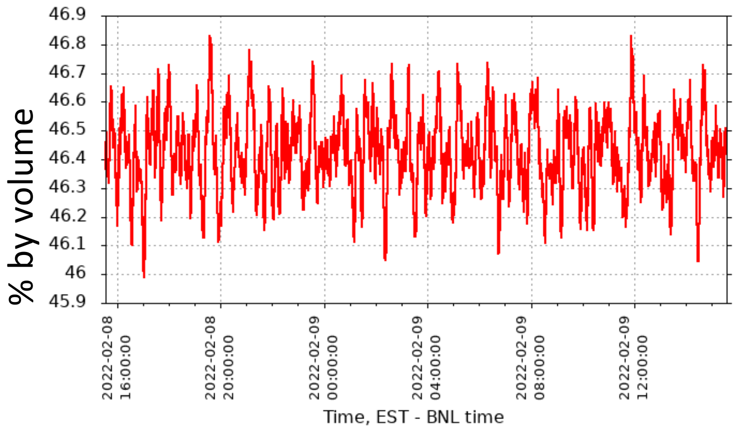
Gas System



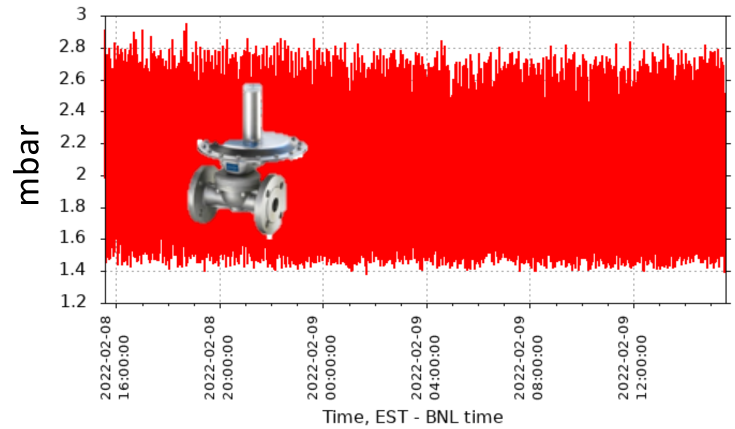
n-Pentane

- n-pentane isomer formula C5H12
- Is a highly flammable liquid and vapor
- Boiling point of pentane is 97^{0}F (36^{0}C)
- Density of pentane is 0.626 g/ml
- The pentane vapor is heavier than air
  - It sinks if released to atmosphere
- Explosive limits of pentane by volume in air: 1.4-7.8%

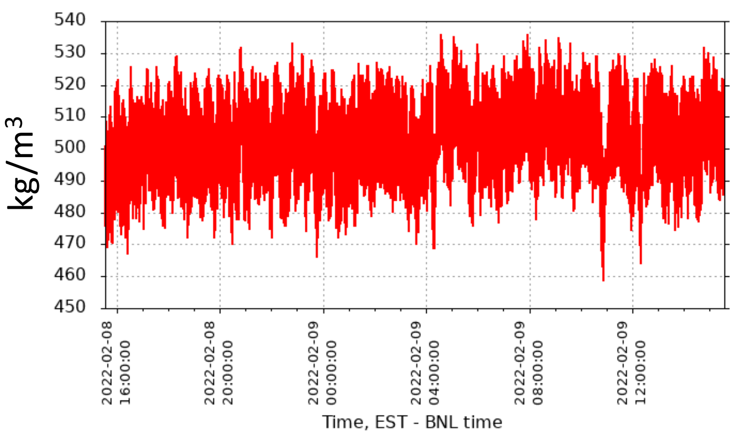
sTGC Gas System



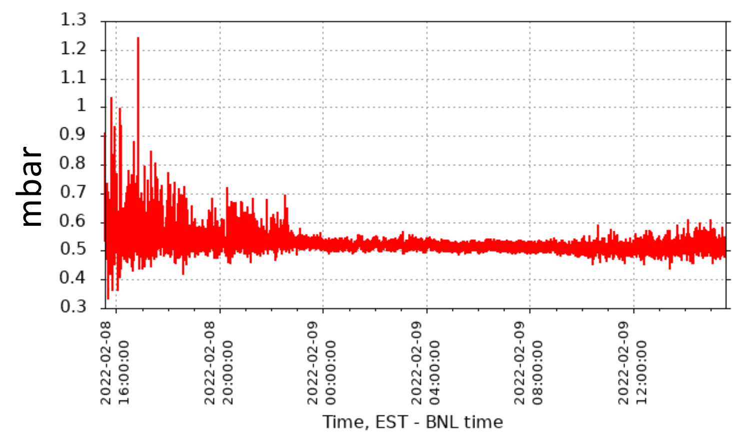
n-Pentane/CO2 Ratio



Chamber input pressure



Measured density of n-Pentane



Chamber vent pressure

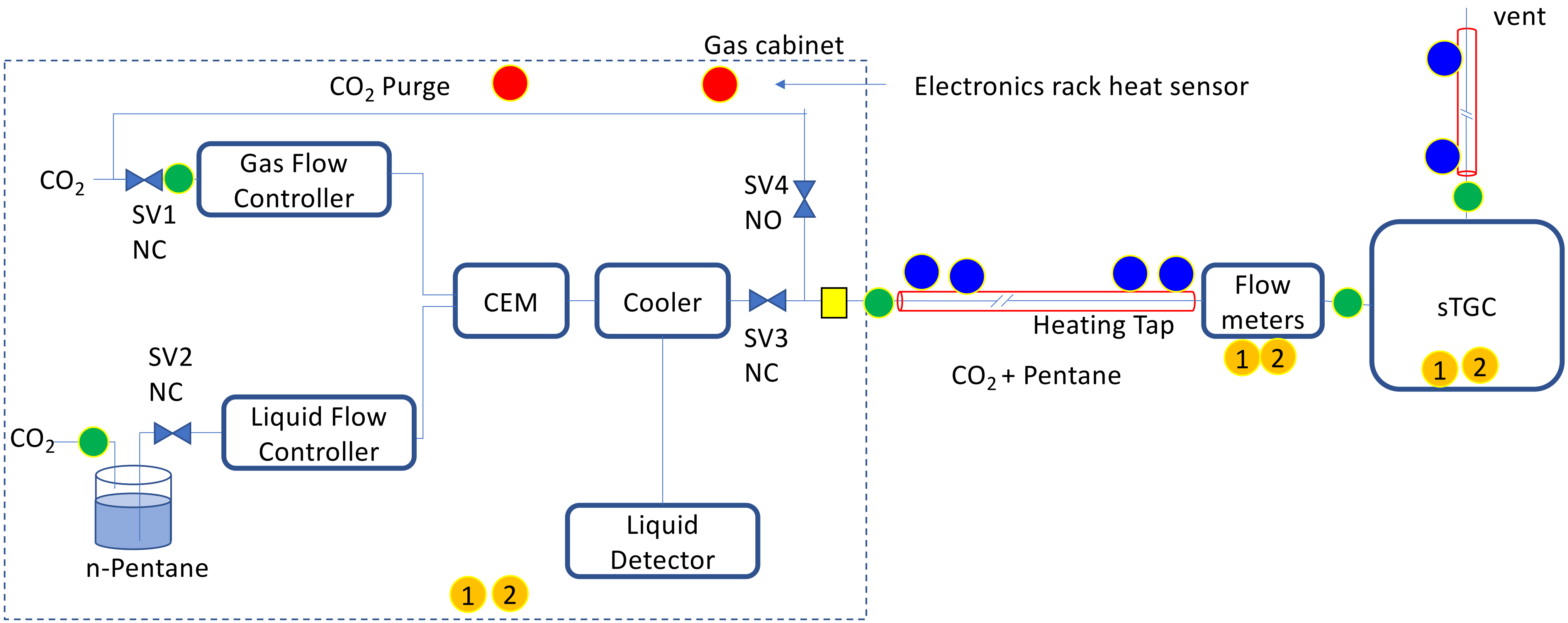
Building the Safety System

Safety System

	Status During Interlock	sTGC Purge	sTGC No Flow	sTGC LV Permissive	sTGC HV Permissive	UPS Power for Control Cabinet	Audible & Visible Alarm
1	**Normal status**	Mixing	Mixing	Enable	Enable	On	Off
	Interlocks						
	Fire/Heat Detection						
2	Heat in gas cabinet	X		X	X		X
3	Heat in electronic cabinet	X		X	X	X	
	Pentane Gas Leak Detection						
4	15% of LEL in pentane sniffer **1** - Gas cabinet	X		X	X		X
5	15% of LEL in pentane sniffer **1** - Flow meters	X		X	X		X
6	15% of LEL in pentane sniffer **1** - sTGC chambers	X		X	X		X
7	15% of LEL in pentane sniffer **2** - Gas cabinet	X		X	X		X
8	15% of LEL in pentane sniffer **2** - Flow meters	X		X	X		X
9	15% of LEL in pentane sniffer **2** - sTGC chambers	X		X	X		X
10	Pentane sniffer **1** malfunction w/5 min delay	X		X	X		X
11	Pentane sniffer **2** malfunction w/5 min delay	X		X	X		X
	Gas mixing and Delivery						
12	Liquid pentane present after mixing	X		X	X		X
13	Supply line heat tap -LOW/HIGH	X		X	X		X
14	Vent line heat tap -LOW/HIGH	X		X	X		X
	Pressure						
15	sTGC Supply over pressure (PT5)		X	X	X		X
	STAR global interlock (SGIS)						
16	From SGIS	Appropriate action to be determined, not implemented for Run21					
17	To SGIS	Appropriate action to be determined, not implemented for Run21					

State Table

Safety Sensors



SV – Solenoid valves
NC – Normally closed
NO – Normally open

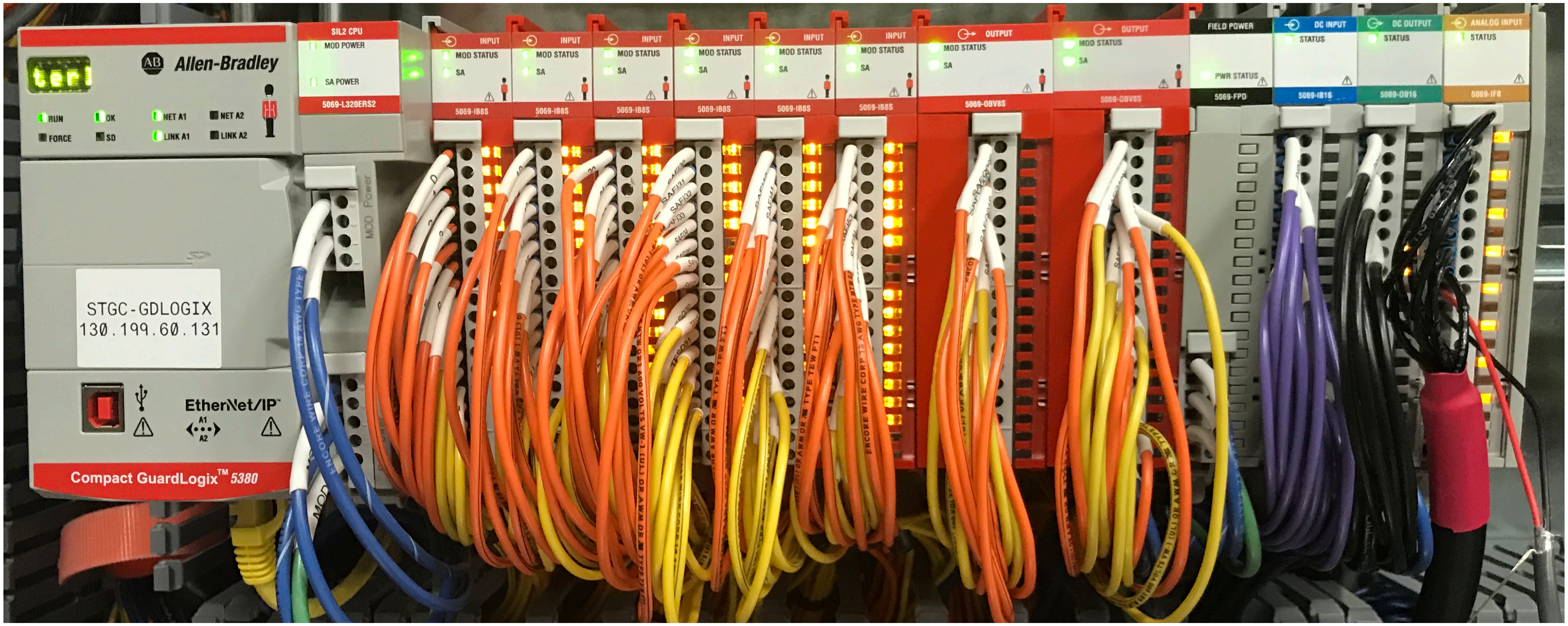
Pentane Sniffer,
1 & 2 are independent monitoring

Heat sensor

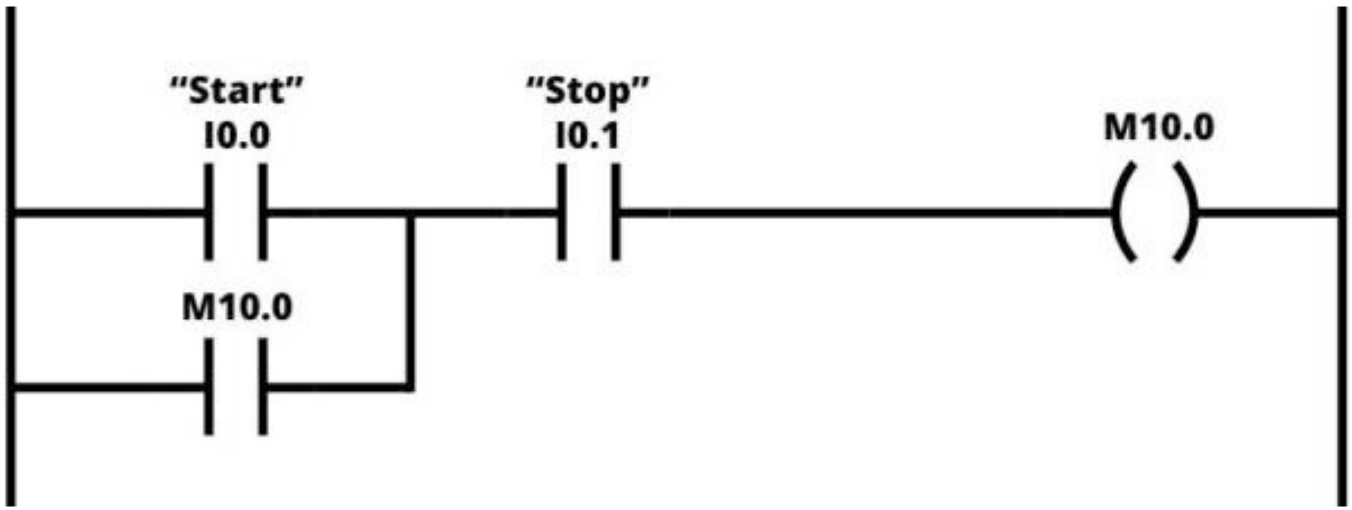
Thermocouple
Pressure transmitter

Liquid detector

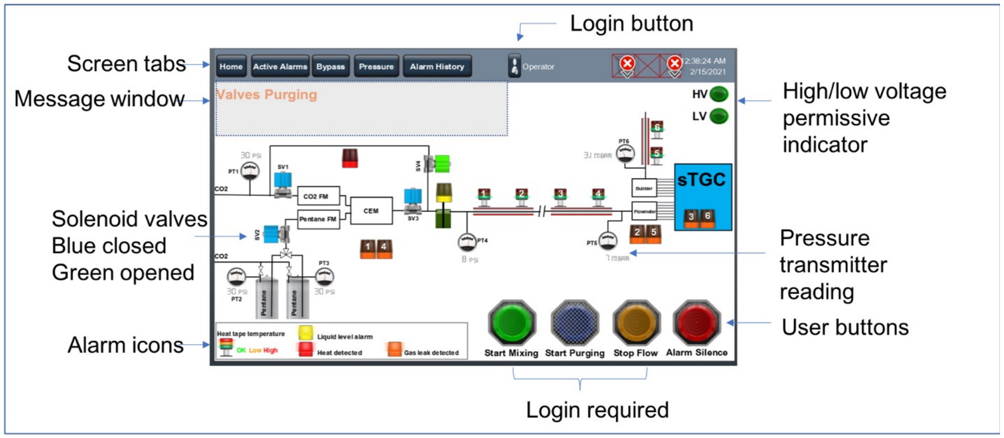
PLC

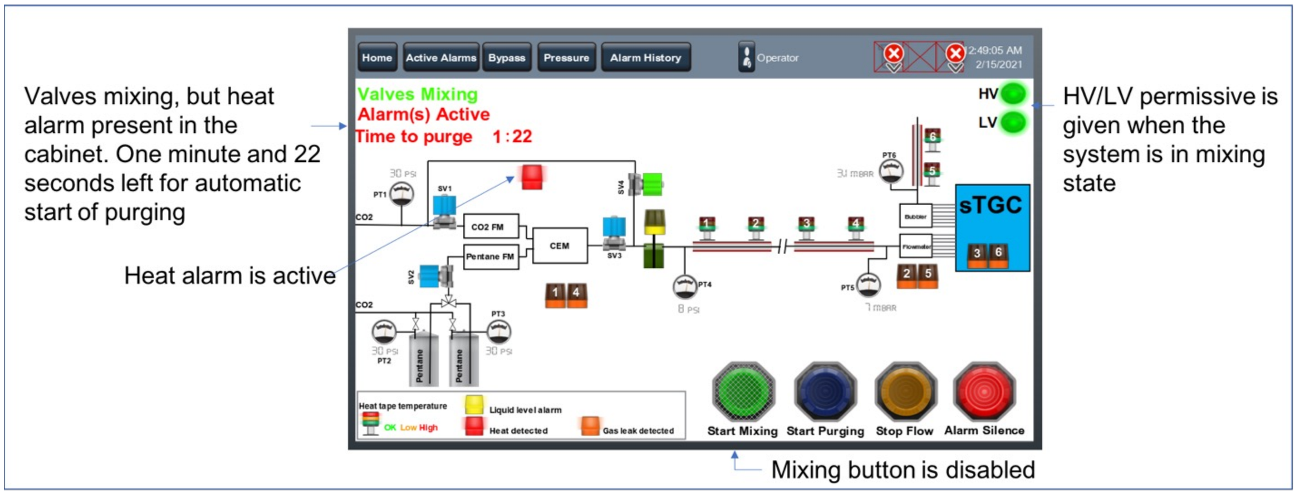

Allen-Bradley
RUN
FORCE
OK
SD
NET A1
LINK A1
NET A2
LINK A2
SIL2 CPU
MOD POWER
SA POWER
5069-L320ERS2
STGC-GDLOGIX
130.199.60.131
EtherNet/IP
Compact GuardLogix™ 5380
INPUT
MOD STATUS
SA
5069-IB8S
OUTPUT
5069-OBV8S
FIELD POWER
PWR STATUS
5069-FPD
DC INPUT
STATUS
5069-IB16
DC OUTPUT
5069-OB16
ANALOG INPUT
5069-IF8

PLC – Ladder Diagram

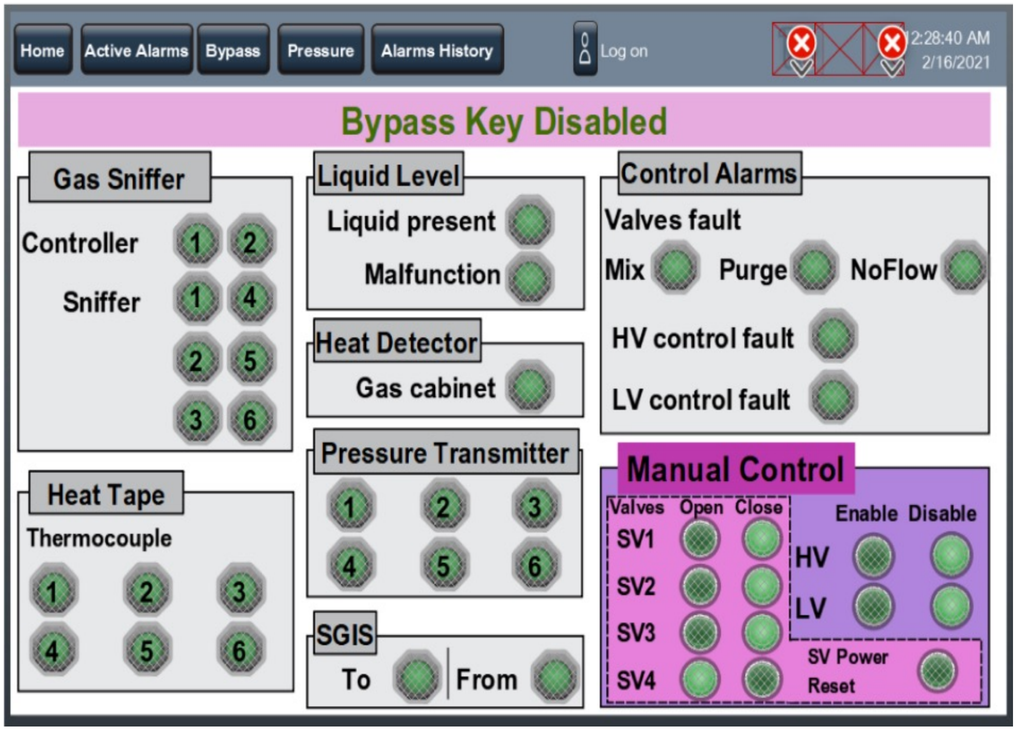


PLC - Controls

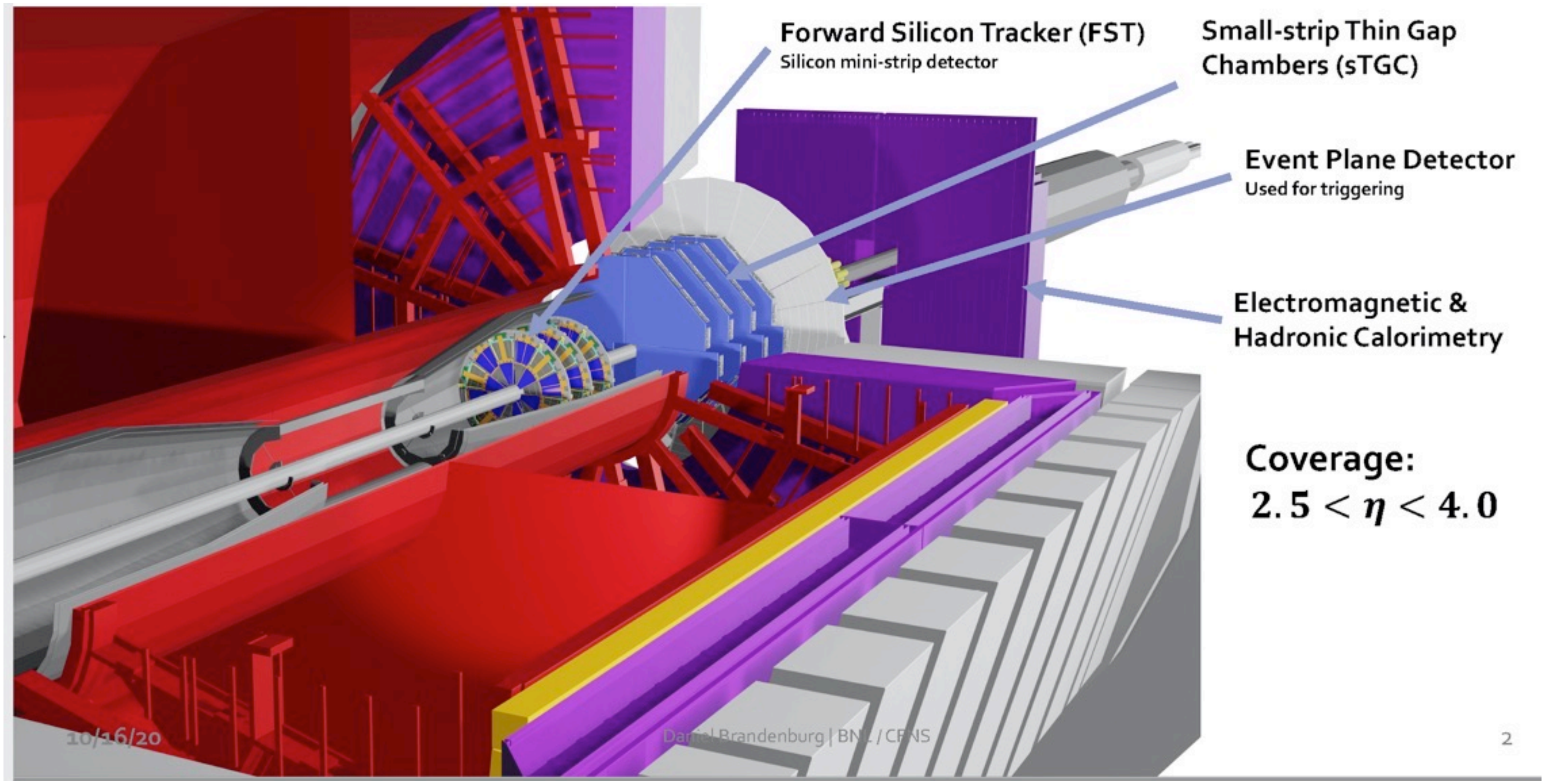


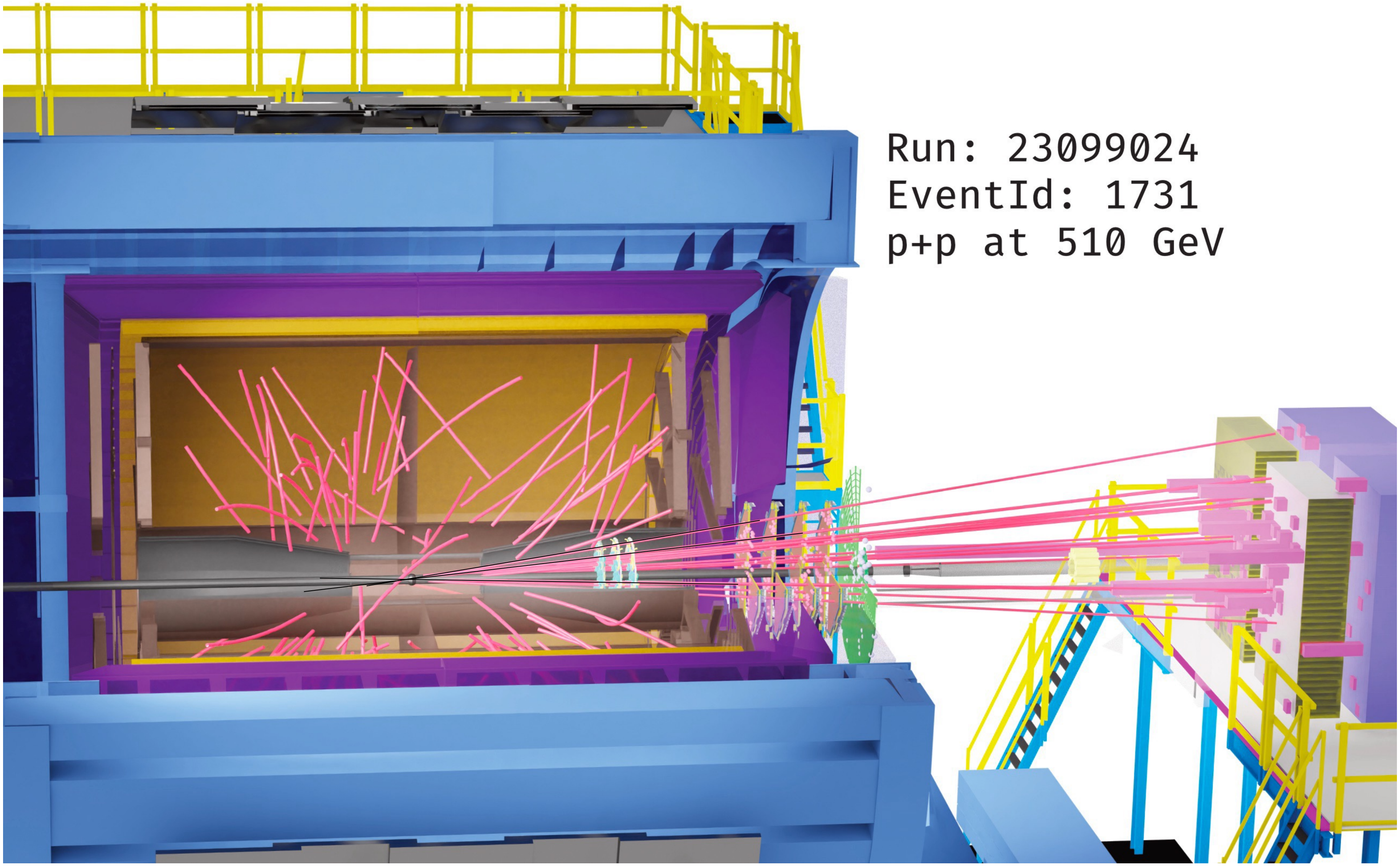


PLC - Controls



STAR Forward Upgrade




Run: 23099024
EventId: 1731
p+p at 510 GeV

Homework

- Sketch a diagram for 10 mbar overpressure protector?
- A point charge q located near infinite grounded conducting plate, what are the
  - E(r)
  - V(r)