Letter of Intent for a fixed-target experiment at the M2 beam line beyond 2020

Technical Upgrades:

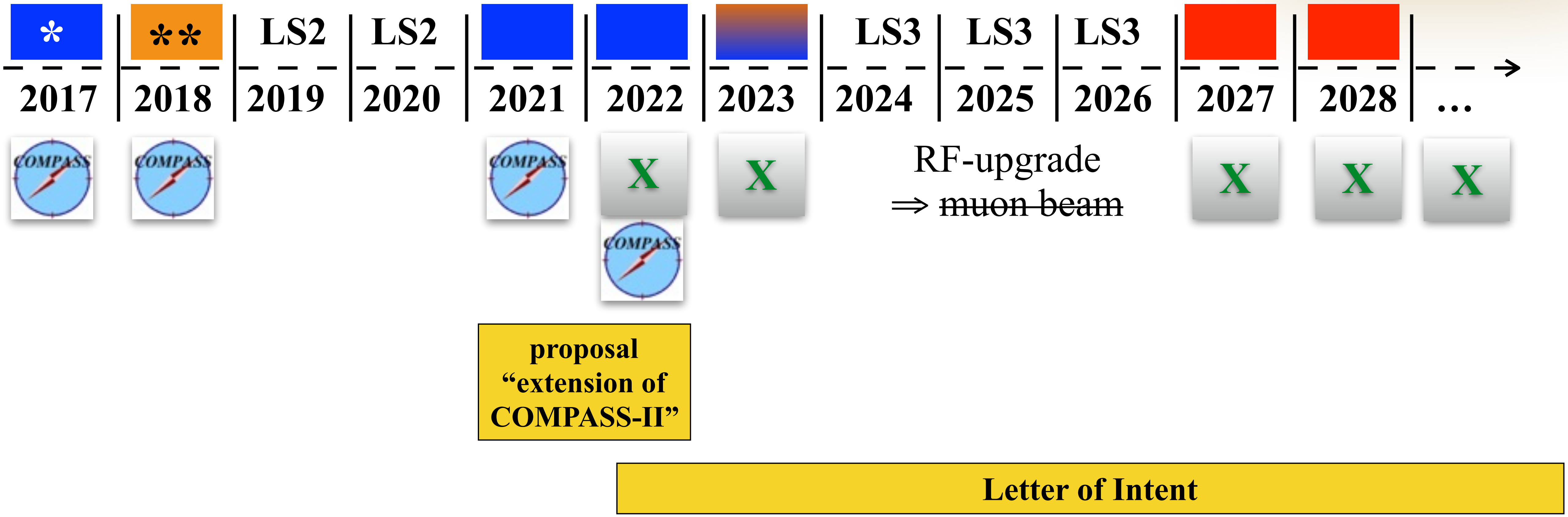
attempt of a short preliminary summary

COMPASS Technical Board Meeting
December 4, 2017

Caroline Riedl

The M2 beamline: a unique hadron & muon facility

hadron & muon beams
two charges
high energy (100 GeV++)
high intensity (1e08/sec)



- **2021 (/ 22): Proposal** submitted to SPSC in October 2017 for the extension of the COMPASS-II program.
- **2022++: Letter of Intent (LoI)** in preparation for a new COMPASS-like experiment at the M2 beam line.

conventional muon beams

A) conventional pion & muon beams
B) RF-separated anti-proton- and kaon-enhanced beams

* COMPASS-II DVCS, completed

** COMPASS-II spin-dependent Drell-Yan to start on April 9, 2018

Planning of hardware upgrades for the programs in the LoI

- Naturally very early stage.

- Development of ideas at is different levels of “readiness”, depending on project.

- Various projects, each of them has their unique requirement.

  - But can some of them be combined?

  - General desirable upgrades (apart from FEE)?

  - Which institutes are interested in contributing concretely to which program in the nearer future, before the programs will be approved?
  (Manpower, funding)

  - This is a question not only but in particular for the FEE upgrades, which will concern the entire existing COMPASS apparatus.

- Which body will be responsible for the review of the progress?
  COMPASS TC and TB, or new entities?

Hardware I

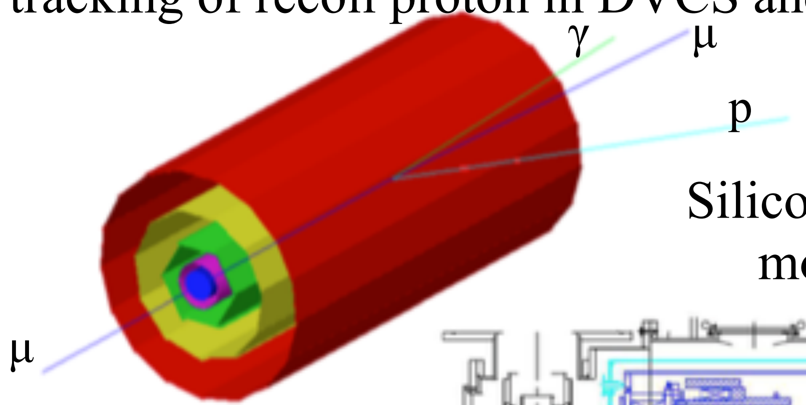
- **New type of FEE and trigger logic compatible with trigger-less readout**
  - FPGA-based TDC with time resolution down to 100 ps (iFTDC)
- Higher trigger rates: **90-200 kHz** (factor of 2.5-5)
- Digital trigger
- First tests in 2018

General upgrades of COMPASS-II apparatus:
- New large-size **PixelGEMs**
- **GEMs** or **Micromegas** to replace aging MWPCs
- High-aperture "**RICH0**" for some programs, hadron separation at low momenta?

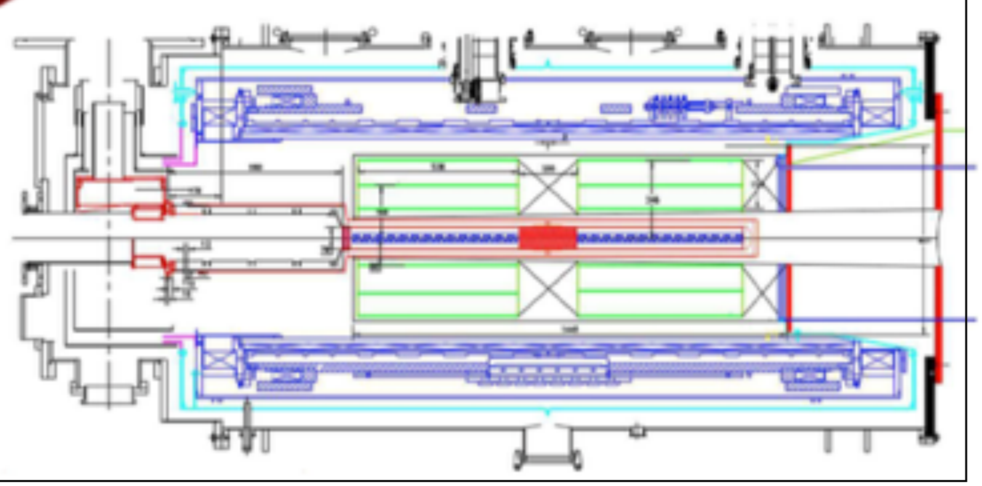
Could be DIRC, or Large-Area Picosecond Photo-Detectors based on micro-channel plates with time resolution < 50 ps, spatial resolution ~ 0.5 mm. LAPPD^{TM} by IncomInc.

- High-rate-capable **CEDARs** for beam PID for all hadron programs.

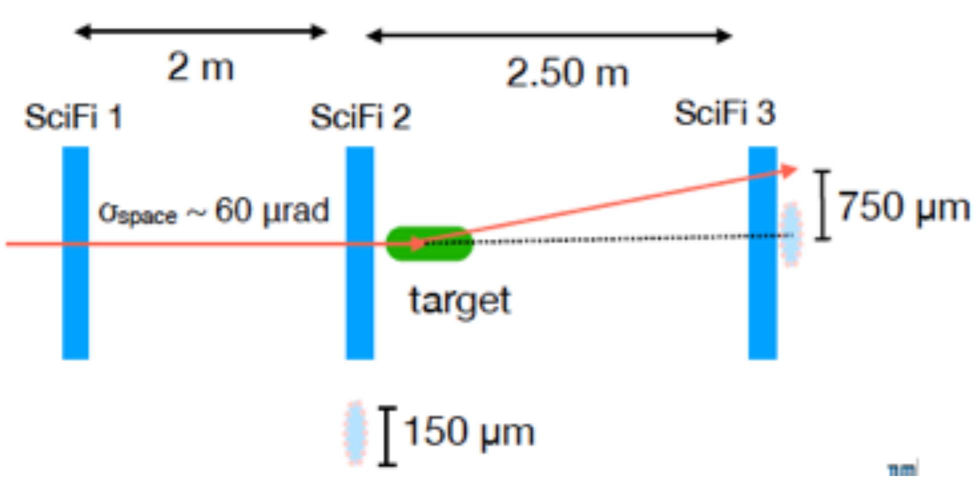
GPD E: 3-layer silicon detector at very low temperature for tracking of recoil proton in DVCS and PID via dE/dx.



Silicon detector inside existing modified target magnet.



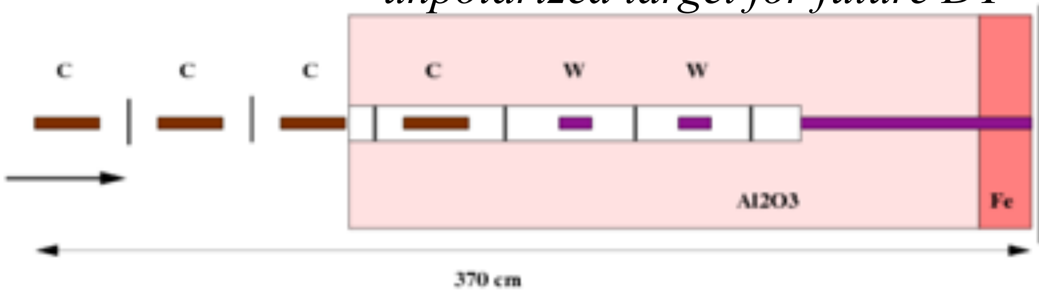
Proton radius:
- **High-pressure active TPC target or hydrogen tube** surrounded by SciFi, 4-8 layers with U/V projections
- **SciFi trigger system** on scattered muon
- Silicon trackers



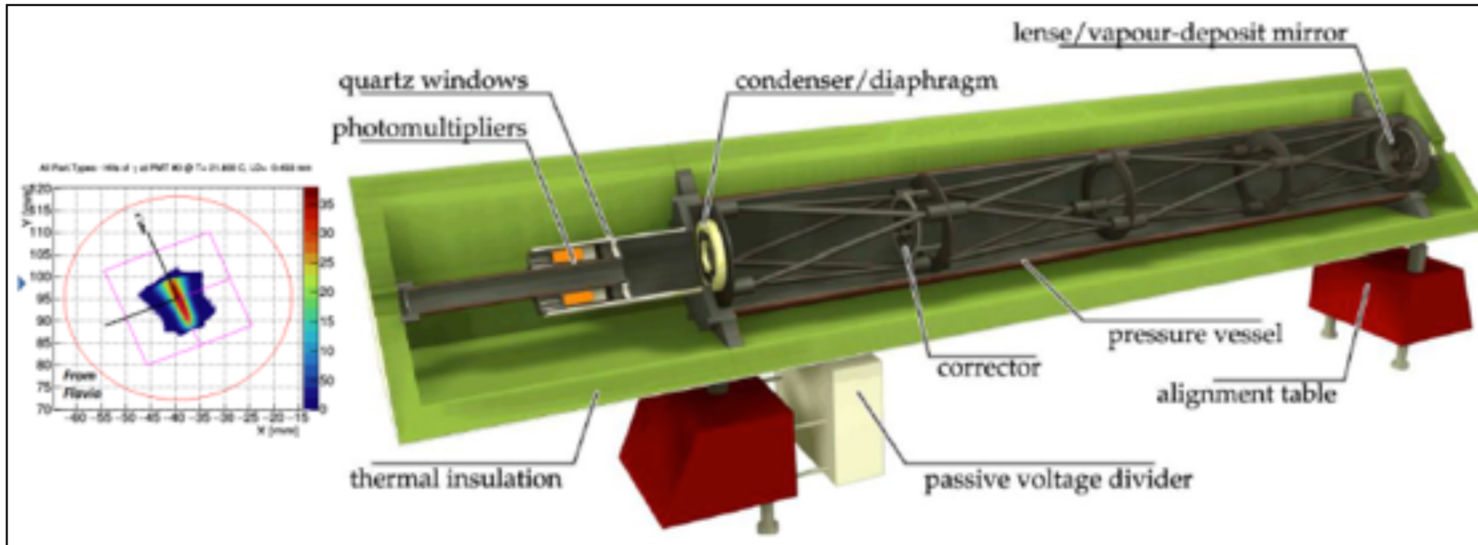
Hardware II

Drell-Yan general:
- High-purity and efficiency di-muon trigger
- Dedicated precise luminosity measurement
- Dedicated vertex-detection system
- Beam trackers

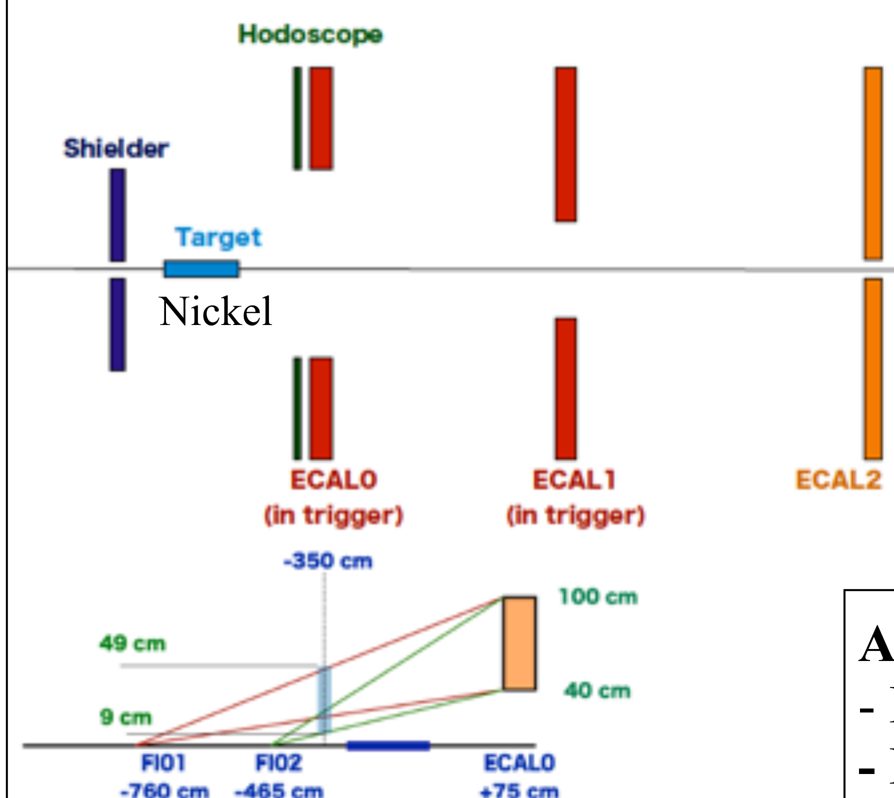
unpolarized target for future DY



Drell-Yan RF separated beams:
- Due to lower beam energy, need wide aperture, up to ± 300 mrad ?
- High-rate and high-multiplicity capability
- “Magnetized spectrometer” (“3-in-1” detector, SM, absorber)
- TPCs?
- GEMs?

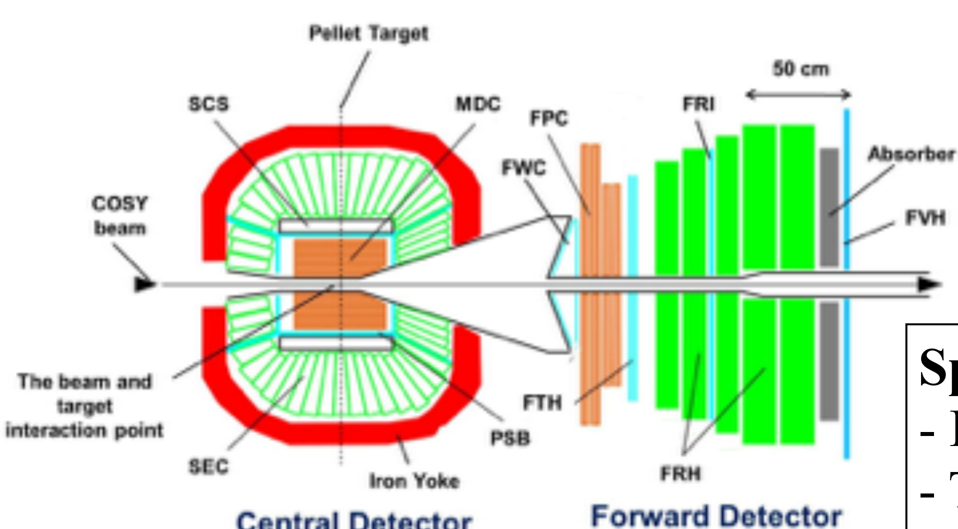


CEDAR upgrade 2018



Prompt Photons
- Shielder (20-30cm steel) upstream of target
- New hodoscope upstream of ECal0
- Transparent setup

Anti-matter cross section
- LH2 and LHe targets
- RICH0 for lower momentum to ID anti-protons?



WASA detector with target spectrometer

Spectroscopy with low-anergy anti-p:
- RICH & CEDAR, RICH0 for low p?
- Target spectrometer (tracking, barrel calorimeter) similar to WASA

Spectroscopy with high-energy K—:
- RICH & CEDAR
- Uniform acceptance, ECals
- Good vertexing
- Recoil TOF detector

Program	Beam energy [GeV]	Rate on target [sec^{-1}]	**beam**	target	Type / set of detectors baseline: COMPASS w/o RICH1
d-quark Transversity	160	3×10^6	**muon**	6LiD ↑	RICH1
Proton radius	100	4×10^6	**muon**	high-pressure H2	active hydrogen target, SciFi or silicon telescopes, silicon and PixelGEMs
GPD E	160	10^7	**muon**	NH3 ↑	recoil silicon detector, modified PT magnet
Anti-matter x-section	50, 100, 190,..	5×10^5	**p**	LH2, LHe	RICH1 (RICH0?), CEDAR
Spectroscopy anti-p	12, 20		**anti-p (e)**	LH2, foil, wire	target spectrometer: tracking & calorimetry, RICH (RICH0?), CEDAR
Drell-Yan conventional	190	$0.2\text{-}6.8 \times 10^7$	**π+, π—**	C, W	vertex detector, CEDAR
Drell-Yan RF-separated	~100	10^8	**K+, K—, anti-p**	6LiD ↑, C, W	"active absorber"?, vertex detector, CEDAR
Primakoff	~100	5×10^6	**K—**	Ni	RICH1, CEDAR with setup based on 2009/2012 Primakoff runs, need ECal2 for trigger
Prompt photon production	>= 100	5×10^6	**K+ (π+)**	LH2	CEDAR, transparent spectrometer based on 2017 GPD setup, need ECal0 & ECal1 for trigger
Spectroscopy	50-100	3.7×10^6	**K—**	LH2	RICH, CEDAR, vertexing, recoil TOF detector, silicon beam telescope, ECals, uniform acceptance

Trigger Conditions

Additional questions: trigger latency?
Hardware (FPGA) or software trigger?
Earliest possible realization?

(*) or list of detectors to be included in trigger logic

Program	Trigger rate (est.) [kHz]	Trigger signature (*)	Trigger challenge factor
d-quark Transversity	25	As 2010: IT, MT, LT, OT, CT, LAST	
Proton radius	<= 100	~~beam trigger?~~ scattered-muon trigger? (recoil-proton trigger?)	
GPD E	10	MT, LT, OT, LAST. If higher beam intensity: photon or proton trigger?	
Drell-Yan conventional	25	As 2015: MT+LAST, OT+LAST, LAST 2mu	
Drell-Yan RF-separated	25-50	As above + ? new hodoscopes for SAS-SAS trigger	
Primakoff RF-separated	>> 10	ECal2 ΔE>threshold	
Prompt photon prod.	10-100	ECal0, ECal1 ΔE>threshold, or “true pT” trigger	
Anti-matter x-section	25	As 2012 Primakoff: (a)BT, VI, ΔECals>threshold	
Spectroscopy anti-p		CEDARs?	

detailed slides

General upgrades

- **New large-size PixelGEM detectors** will be designed and ten such detectors will be built by 2021 as replacement and spares for the existing large-area GEMs in the COMPASS spectrometer (B. Ketzer).
  - Each detector will have 4,096 channels. The periphery will be read out with strip readout from both sides. The center will consist of hexagonal pads of 1.5 mm outer radius and will be equipped with pixel readout.
  - The active area of each detector will be between 30.7 cm × 30.7 cm and up to 40 cm × 40 cm.
  - The new PixelGems will be equipped with new Front-End Electronics allowing for higher rates and self-triggering.

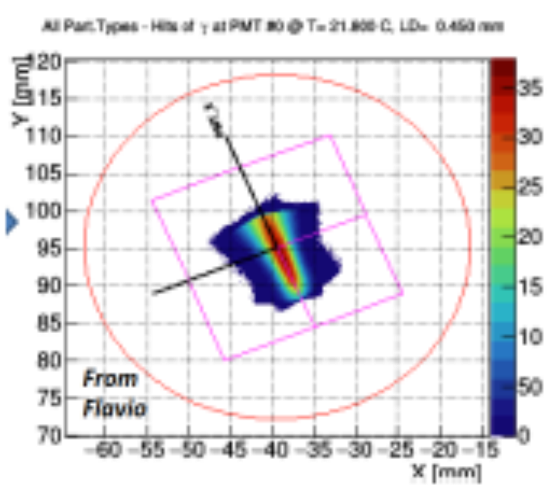
- **New large-area multi-pattern gaseous detectors (MPGD)** will be designed and developed to replace the existing ageing 14 MWPC tracking stations in the COMPASS spectrometer (Torino). The new detectors will be based on large-area GEM or MicroMega technology.
  - Each station will have an active area of ~1.5 m^2 , with two or three coordinates planes and ~2 mm pitch.
  - The new detectors will be equipped with a new front-end electronics with a rate capability of ~1 MHz per channel.
  - The total number of channels will be about 28,000.

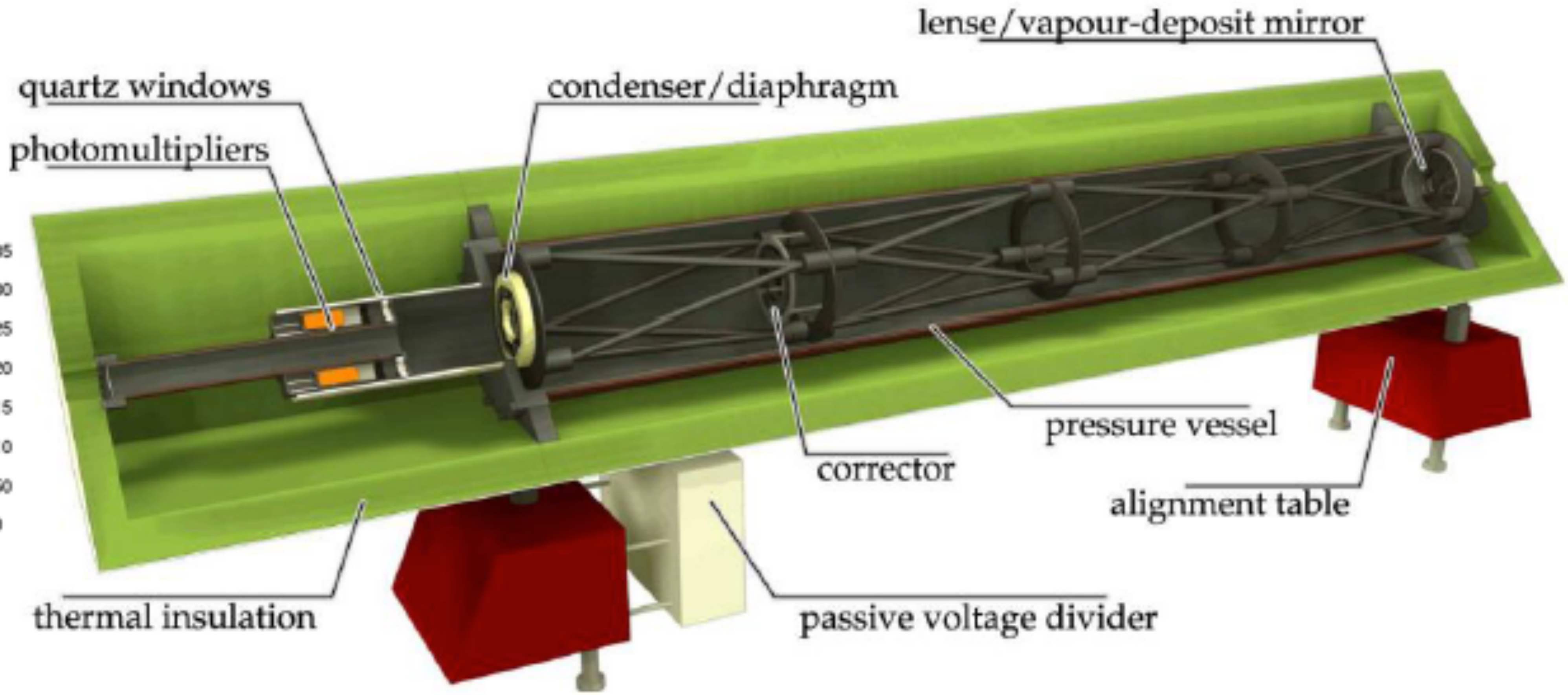
COMPASS RICH-1

- Built late 1990s, upgraded 2005-06 and 2015-16.
- Large acceptance Cherenkov imaging counter: ±200 mrad in the vertical plane, ±250 mrad in the horizontal plane
- Photon detection
  - central region (25% of surface, higher rate): MAPMTS coupled to individual fused silica lens telescopes
  - peripheral region: gaseous detectors with CsI photoconverters:
    - MWPCs
    - hybrid MPGD-type detector with two THick GEM (THGEM) layers followed by a MICROMEGAS multiplication stage
- Hadron PID 3 to 60 GeV/c (3 GeV/c = effective threshold for pion ID and pions-kaons can be separated at 90% confidence level at 60 GeV/c)

CEDAR upgrade for higher rate capability (for 2018)

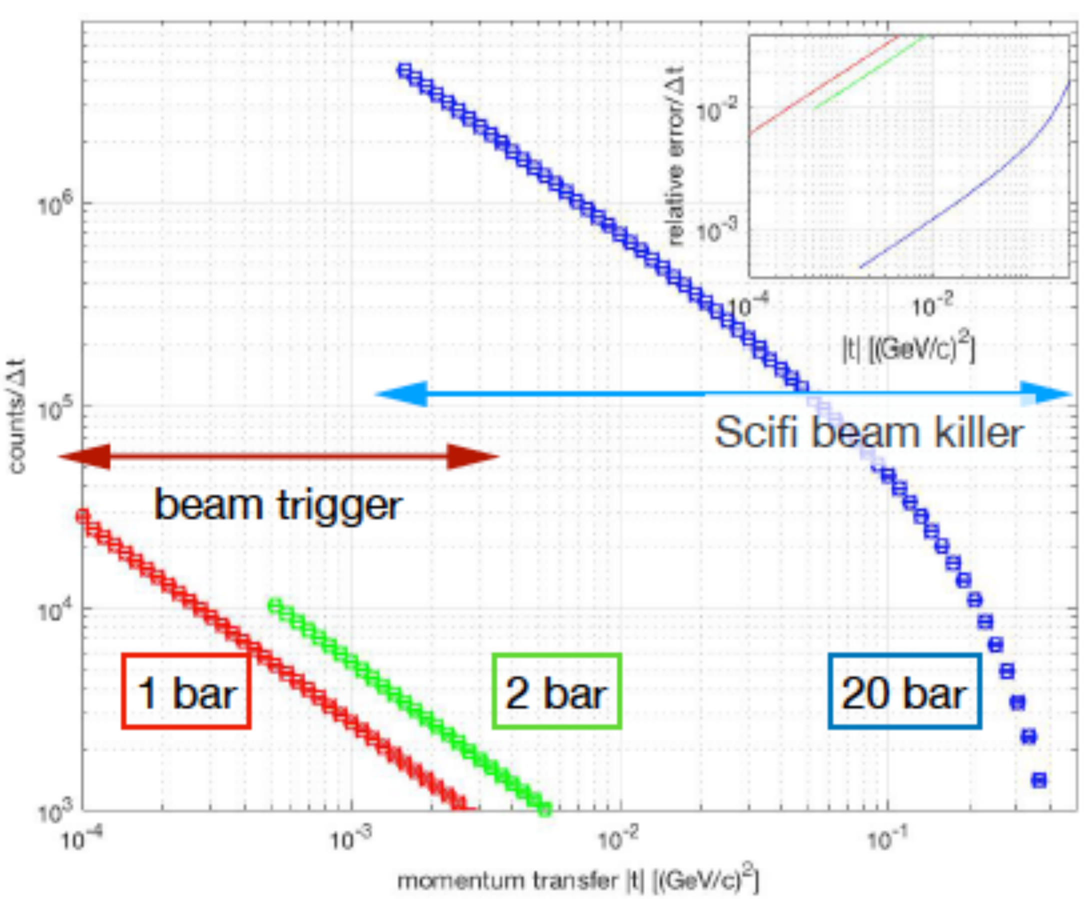
- New PMTs, gain monitor, read-out, thermalization

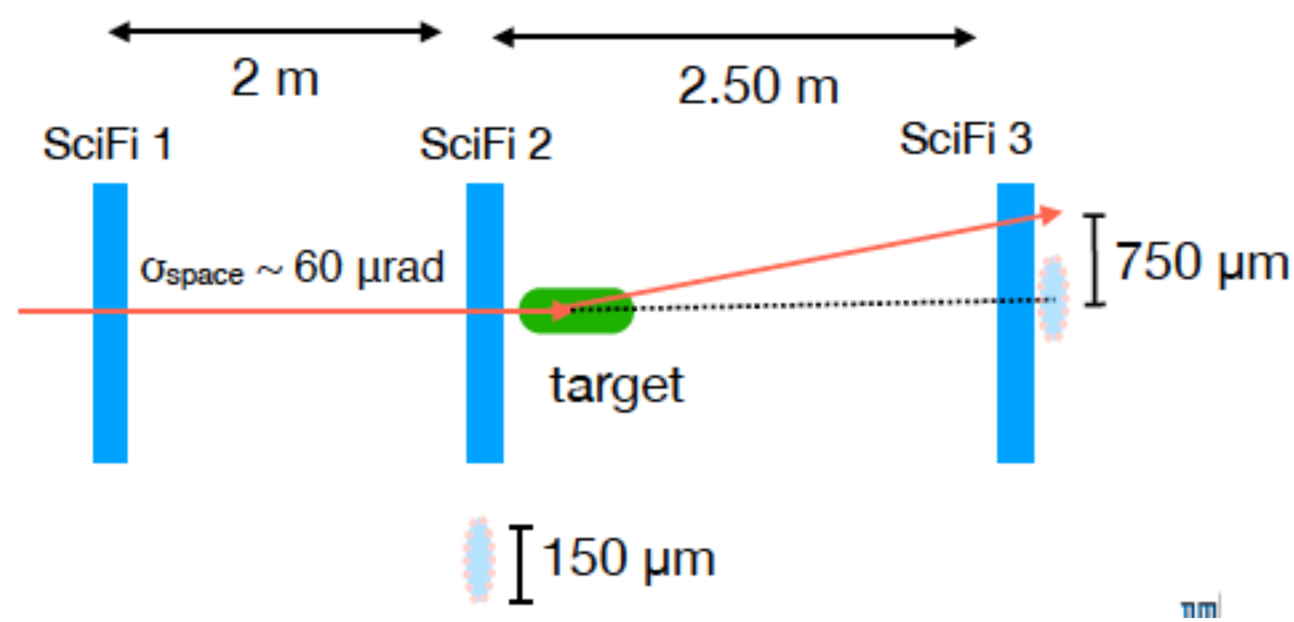




Proton radius

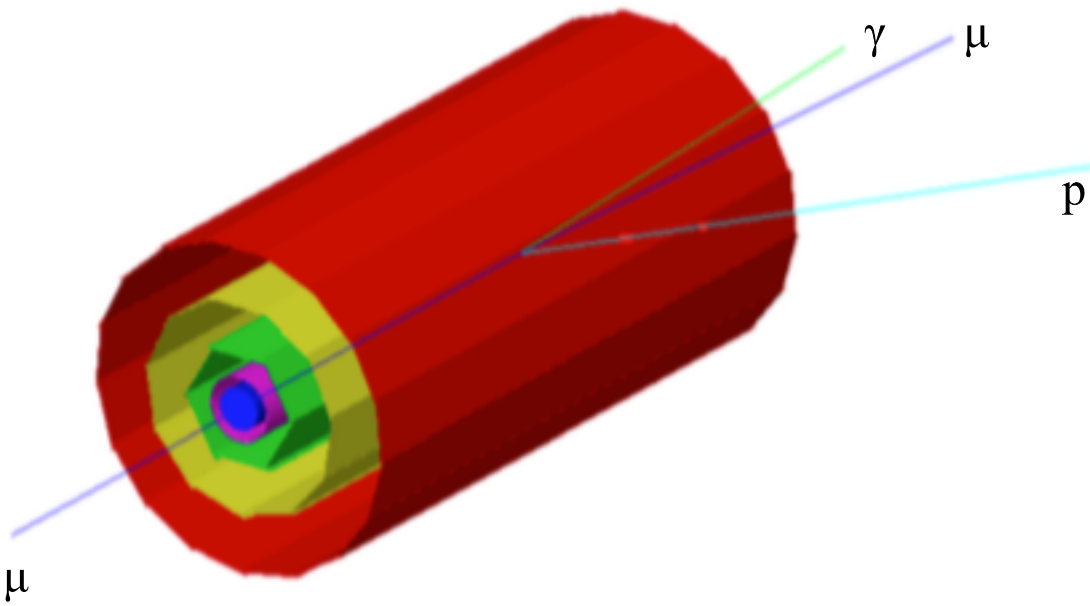
- SciFi trigger system (beam veto trigger). Effective resolution 200mu. 2 layers before target + 3rd after target.
  or: kink trigger with Silicons. Better spatial resolution, can better cope with pileup.
- Precision-tracking silicon system (at least one new station)
- Target
  - option 1: high-pressure active TPC target
  - option 2: high-pressure hydrogen tube surrounded by SciFi. 4-8 layers with U/V projections
- PixelGEMs: at least replacement of inefficient planes
- Necessary **(new): target, SciFi trigger system**, **silicon trackers,** pixelGEMs, muID, trigger hodoscopes
- Desirable: ECal2, HCal, drift chambers, MW



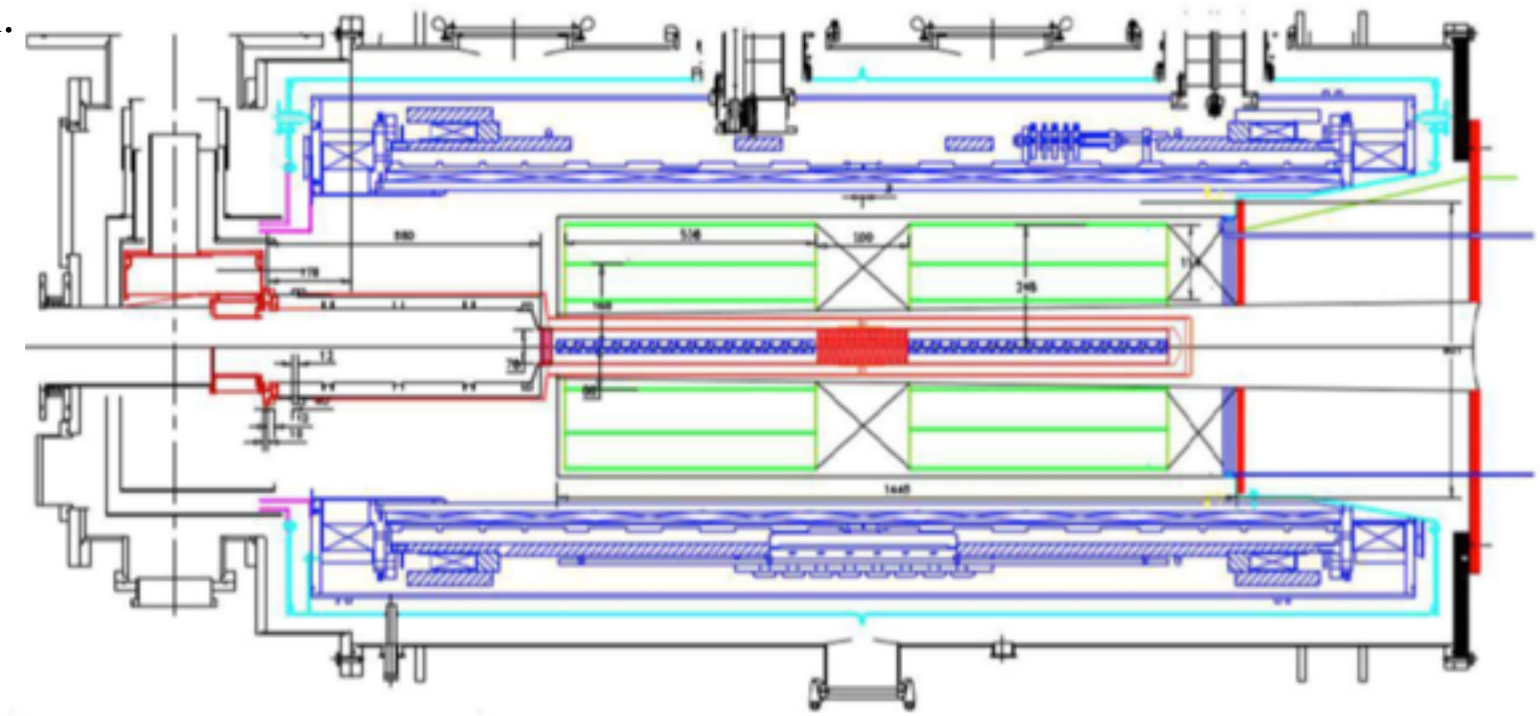


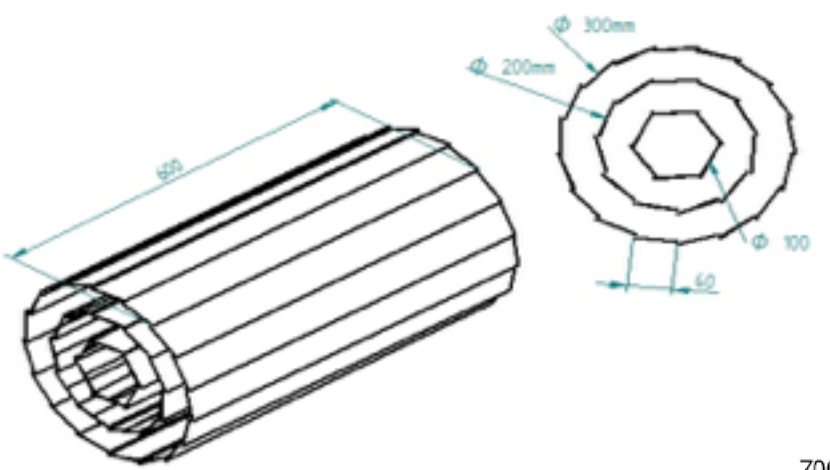
GPD E

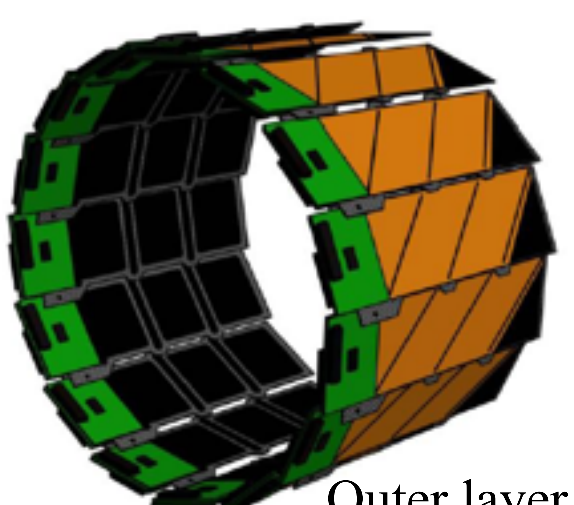
3-layer silicon detector at very low temperature for tracking of recoil proton in DVCS and PID via dE/dx.



Silicon detector inside of existing modified target magnet.

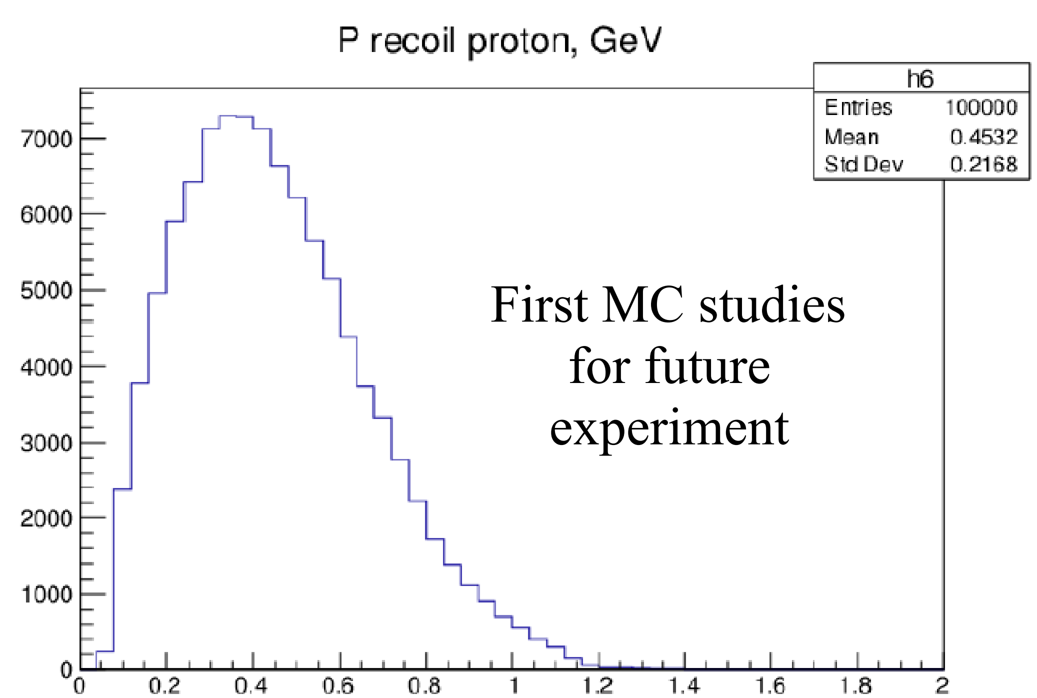




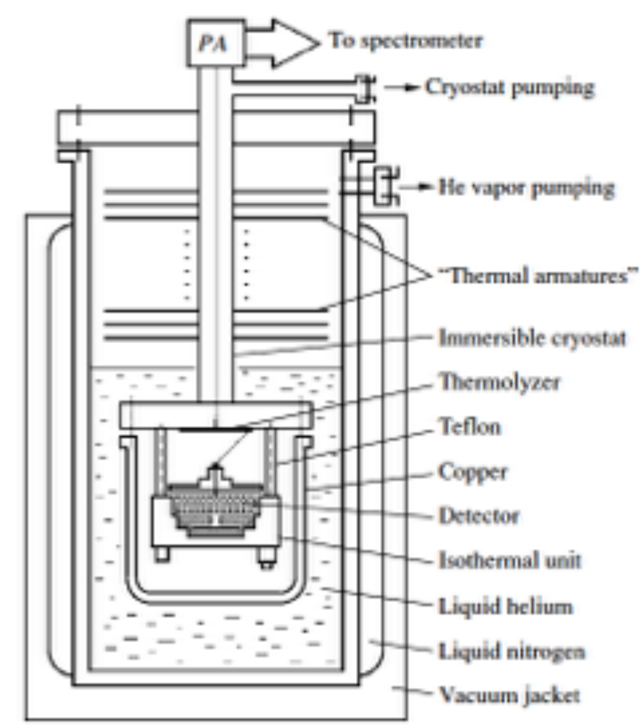


Outer layer with silicon ladders

Possible setup to test silicons at very low temperature, from K.N. Gusev et al., *A study of the performance characteristics of silicon and germanium semiconductor detectors at temperatures below 77K*, Instruments and Experimental Techniques, 2007, Vol.50, No.2, pp 202.



First MC studies for future experiment



Hardware upgrades for Drell-Yan

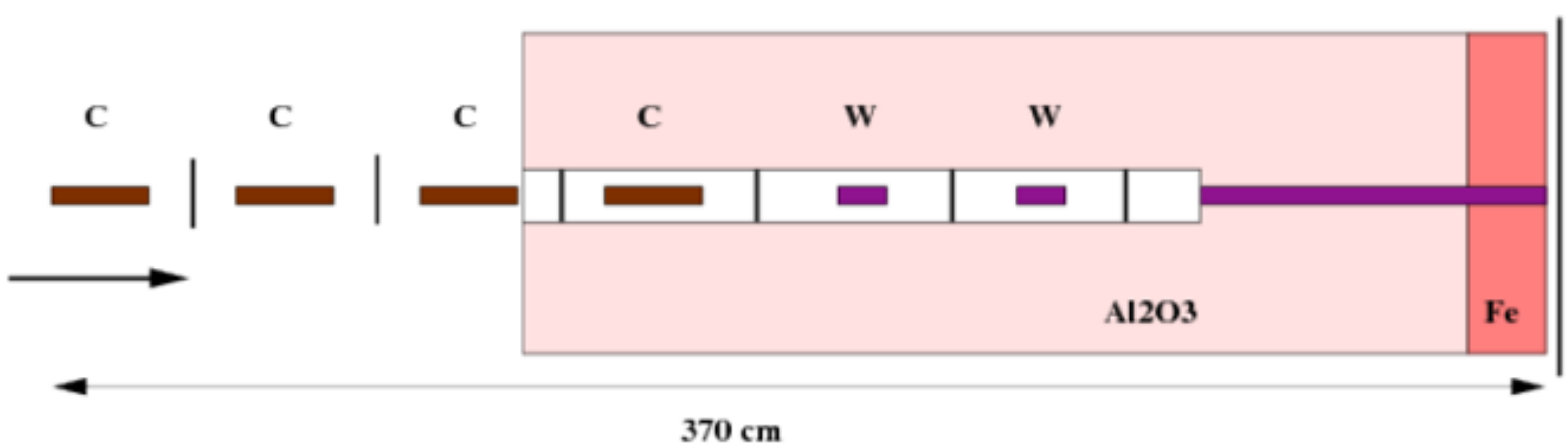
- In principle, same trigger topology as in 2015/18, with possible improvements: creation of **high purity and efficiency dimuon trigger**, with target pointing capability.
- **Potentially new hodoscopes** with optimized shape. Goal is symmetric spectrometer & trigger. The introduction of a SAS-SAS trigger (currently only LAS-LAS & LAS-SAS) is considered (FPGA-based).
- Improvement of **read-out of the two CEDARs** (beam PID efficiency >90%, and high purity)
- Dedicated detector for precise **luminosity measurement** (precision in the order of 3%)
- **Beam trackers** for precise beam reconstruction & **BMS** to measure pion energy
- Dedicated **vertex detection** system for improved vertex resolution

RF-separated beams

Beam (GeV)	$I_{\bar{p}}$ (/s)	Acc.	DY evt/day
$\bar{p}$ (80)	3.2×10^7	6%	7
$\bar{p}$ (100)	2.7×10^7	11%	18
$\bar{p}$ (120)	2.3×10^7	15%	32

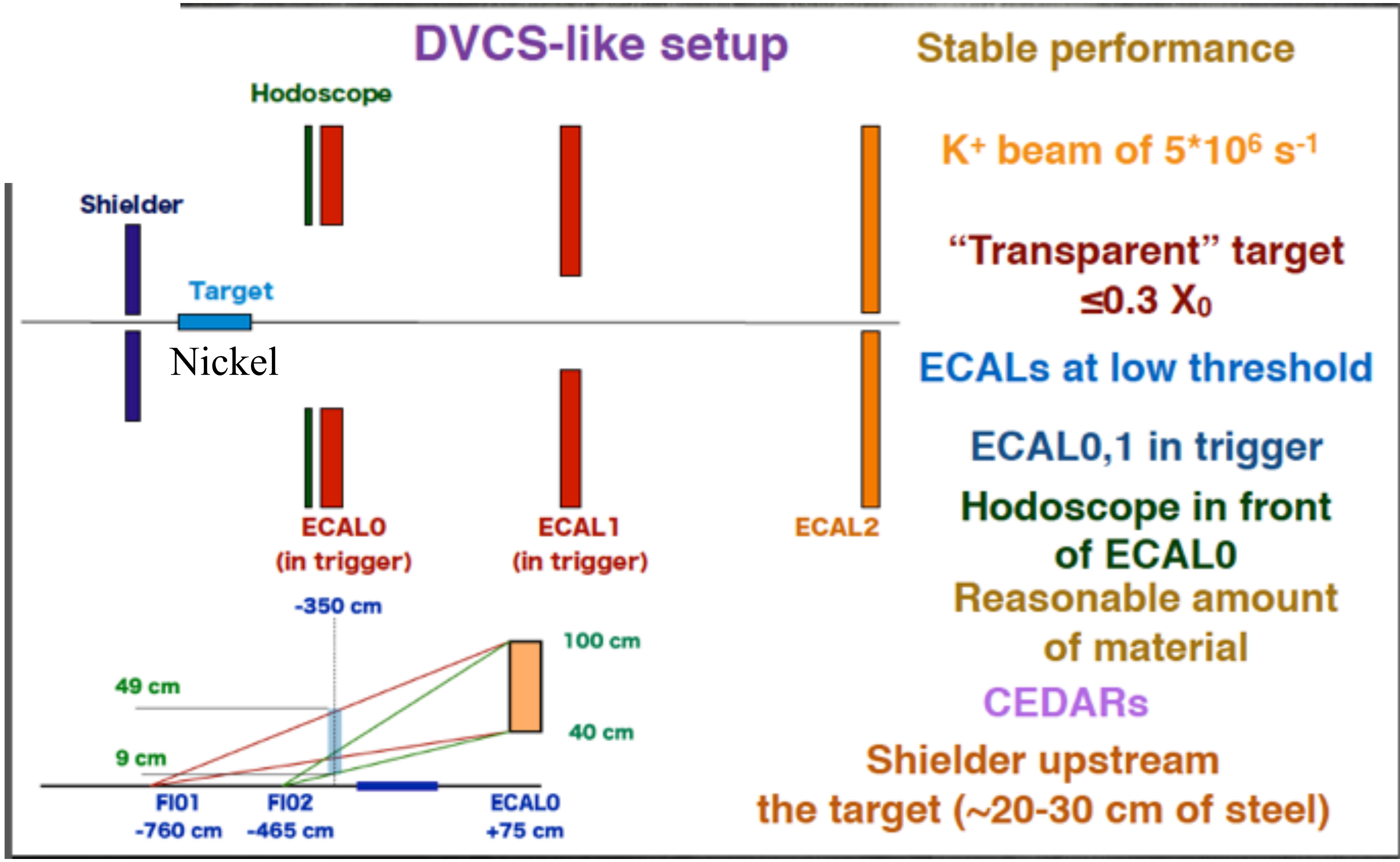
- Acceptance very limited due to lower beam energy
- Necessity to squeeze the apparatus
- Extended: aperture: ± 300 mrad ?
- High-rate and high-multiplicity capability
- **"Active absorber" / "magnetized spectrometer"**:
  * detector
  * magnet (instead of SM1?!)
  * absorber

→ Like Baby MIND for WAGASCI at J-Parc
https://arxiv.org/pdf/1704.08079.pdf



Prompt Photon Production

- CEDARs to reject non-kaonic beam particles.
- New tracking detector upstream of ECal0 to reject charged particles with high pT.
- Needs transparent setup, otherwise as 2017 GPD setup.



- **Primakoff**
  - Analogous setup as for the pion polarizability measurements 2009 and 2012
  - Central region of ECAL2 with some threshold(s).

Anti-matter cross-section for Dark Matter Search

- Minimum bias trigger including

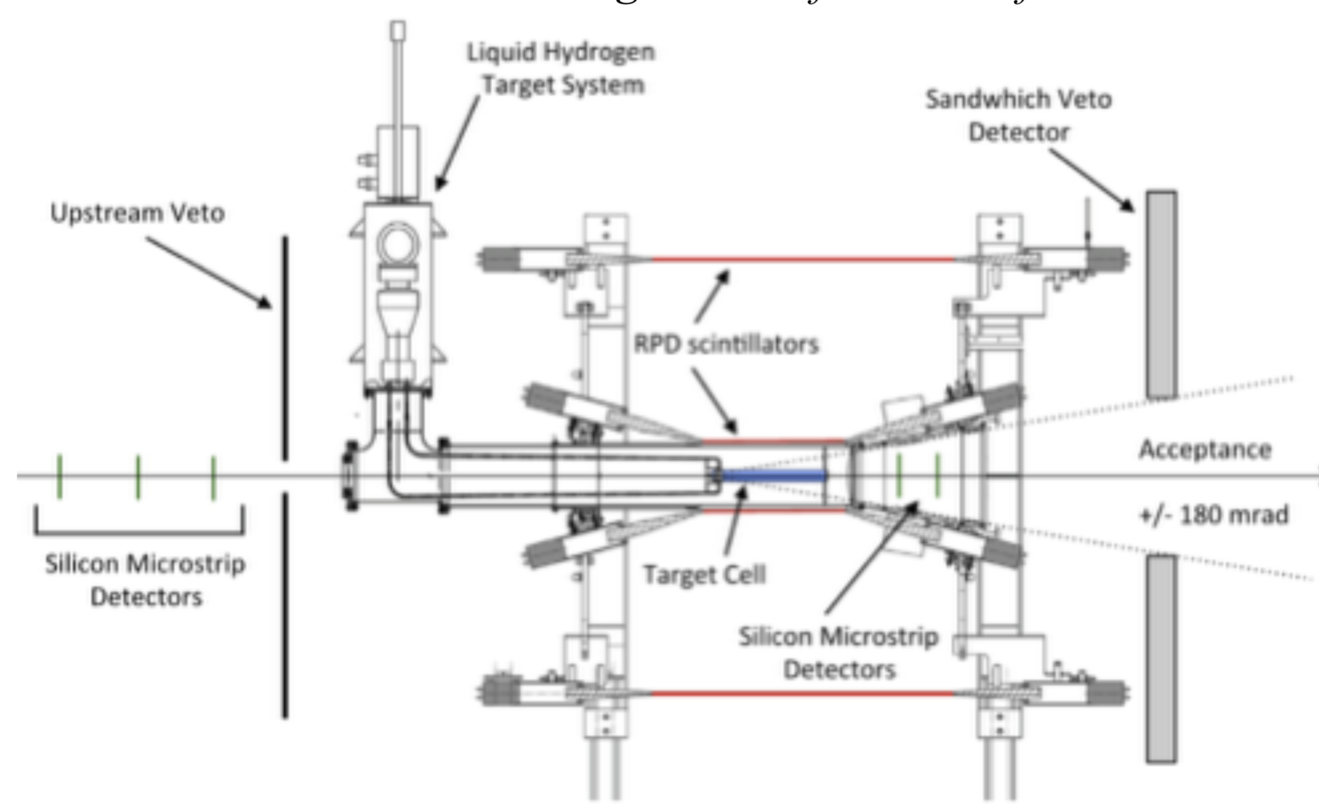
  - Beam trigger + hodoscope veto: ensures that the particle reaches COMPASS within the target cross section.
  Also includes a preselection of protons from the CEDARs.

  - Sandwich veto: exclude events with signals outside the COMPASS acceptance after the target.

  - Beam killer: remove events where protons keep the beam direction 32 m downstream the target.

- RICH0 for lower-momentum particles would be advantageous to ID anti-protons, otherwise use RICH1 in veto mode

COMPASS LH2 target, beam from the left

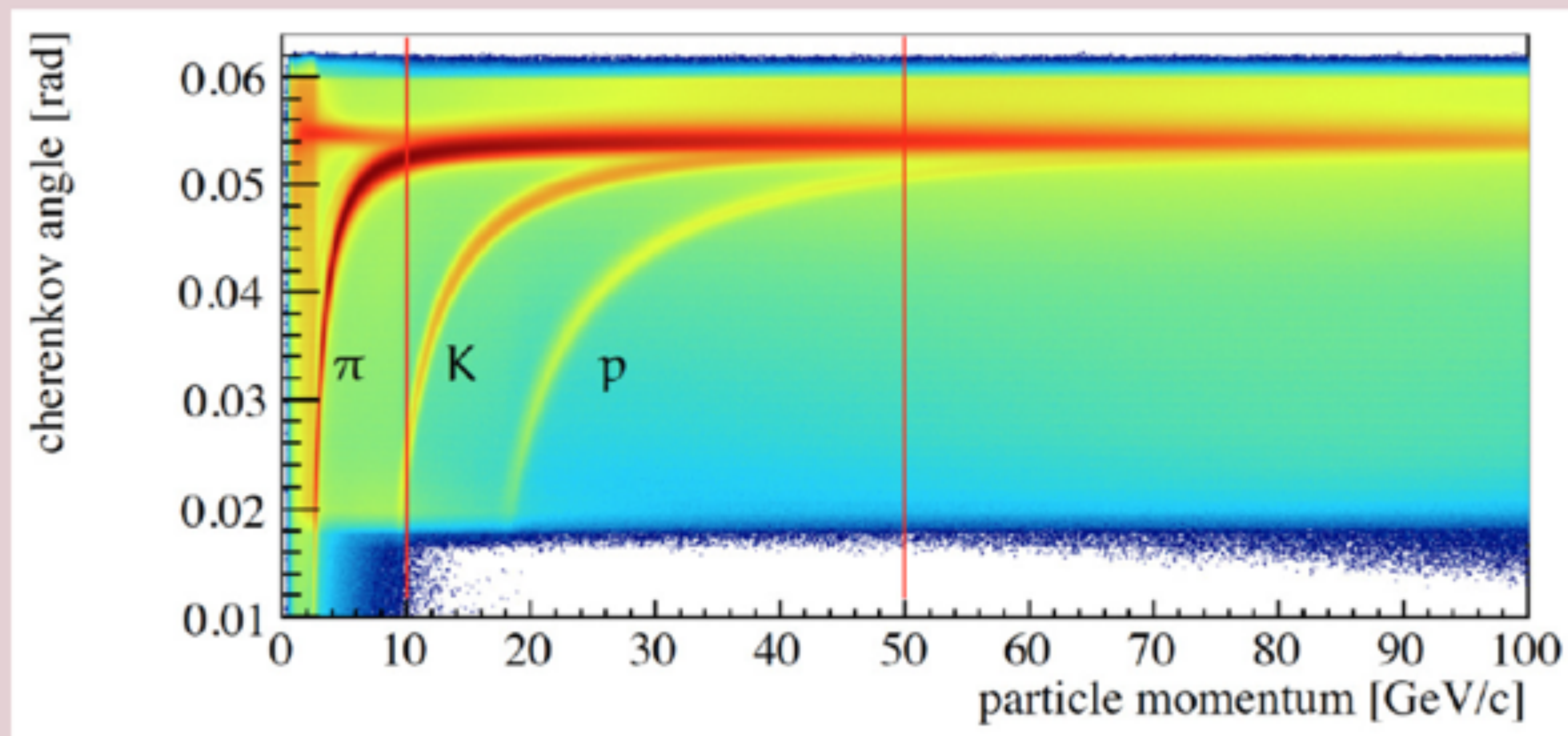


Spectroscopy with low-energy anti-protons

- Beam PID: CEDARs (high rates)
- Target spectrometer: Tracking, ECAL (barrel calorimeter)
- Forward spectrometer: COMPASS
- PID: μ, K ID, p suppression (RICH0?)
- Luminosity monitor

Final-state PID

- Existing RICH kaon ID covers only $10 < p < 50\,\mathrm{GeV}/c$
  - More than 50 % of kaons in $K^-\pi^+\pi^-$ outside of acceptance



- Lower beam momentum ⇒ more events in RICH acceptance
- *Goal:* extend kaon ID to increase acceptance

Spectroscopy

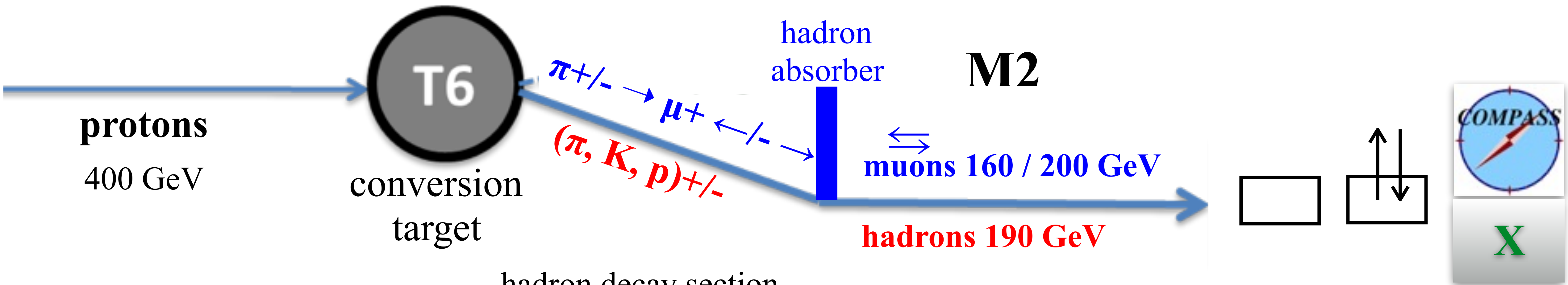
- RICH
- CEDAR
- Vertexing
- Recoil TOF detector

Trigger and readout

- New type of FEE and trigger logic compatible with trigger-less readout
- Possible improvements :
  - upgrade of Silicon and GEM firmware to 40 MHz => 90 kHz trigger rate
  - Change 3 sample read out to one sample => 200 kHz trigger rate
  - Implement feature extraction algorithm in SADC and MSADC to overcome bandwidth limits
- New-generation TDC FEE with trigger-less capability
- Trigger Logic Requirements : Move logic to Digital Trigger Processor
- COMPASS event size : 30kBytes
- With assumption that one event covers 0.5us time interval => 60GB/s
- Possible data reduction at FE :
  - Calorimeter :
    - Substitute 32x12 samples by Time and Amplitude => 32 bit word. Reduction factor 16.
    - More efficient zero suppression algorithm. Additional factor 2
  - TDC :
    - More efficient data encoding => factor 2
    - Reduced event size 5kBytes => 10GB/s within spill or 5GB/s sustained
  - CDR is capable to store more than 1 GB/s => missing factor 5.

extra slides

The M2 beam line at CERN's North Area

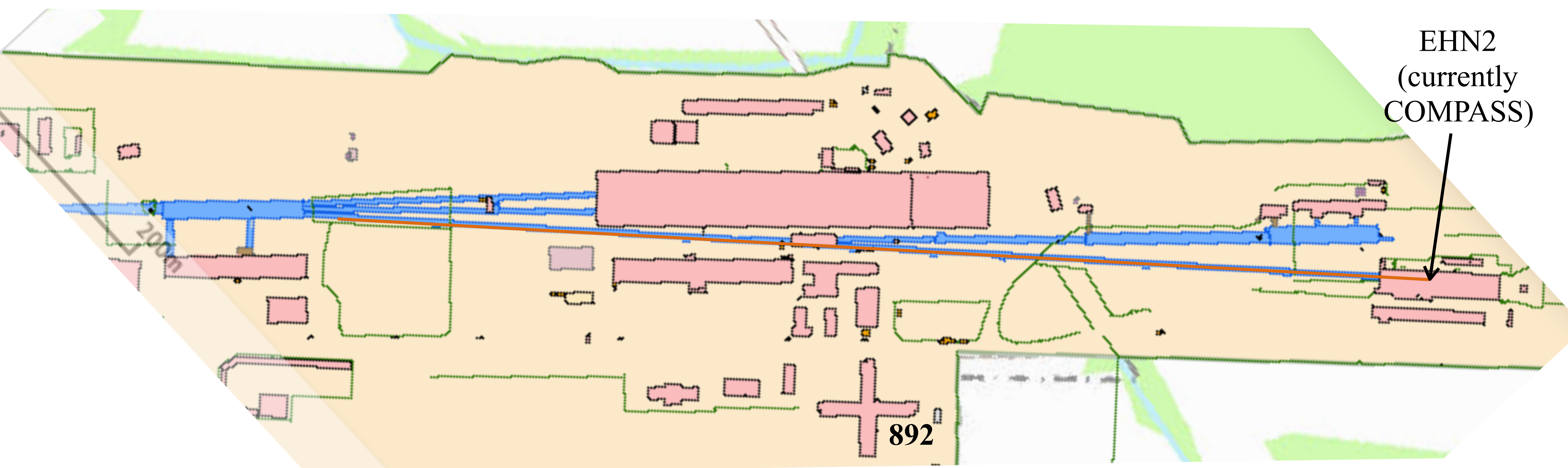


hadron decay section
(~ 600m)

~400m

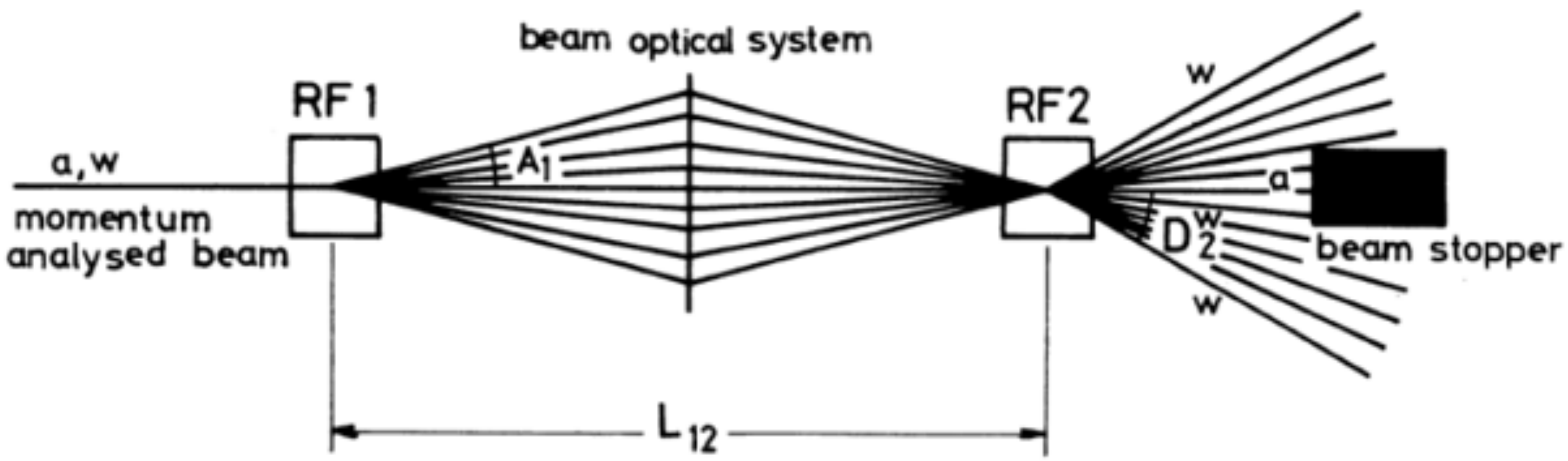
unpolarized or polarized
targets

high intensity: up to 10e8
particles per second
(limited mostly by radio protection)



M2 beam line: RF-separated meson beams to enhance kaon and anti-proton fractions

Panofsky-Schnell-System with two cavities (CERN 68-29):



- Particle species have same momenta but different velocities
- Time-dependent transverse kick by RF cavities in dipole mode
- RF1 kick compensated or amplified by RF2
- Selection of particle species by selection of phase difference

$\Delta\Phi = 2\pi\,(L\,f\,/\,c)\,(\beta_1^{-1} - \beta_2^{-1})$

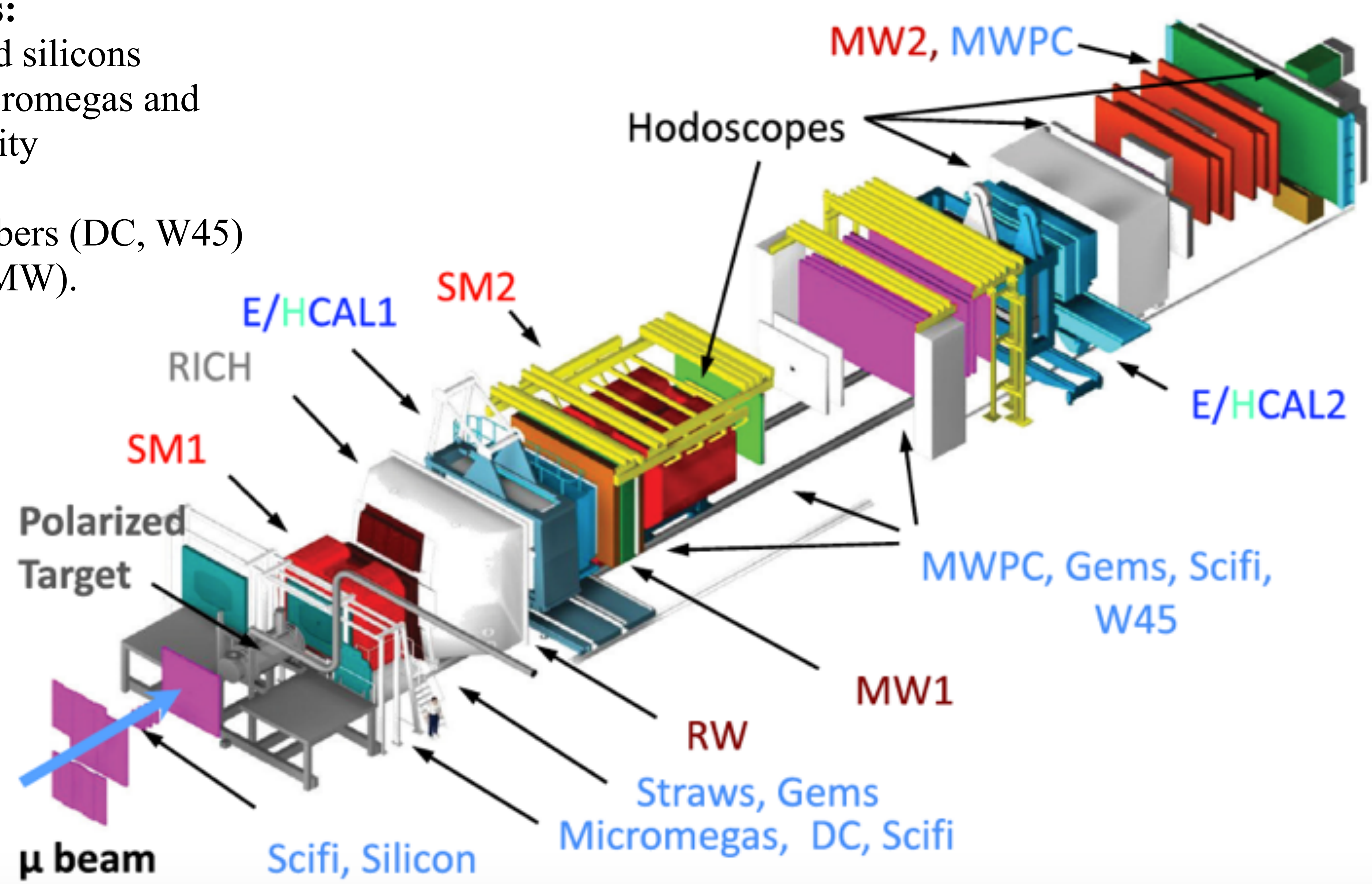
J. Bernhard and L. Gatignon at IWHSS17

- Conventional p = -190 GeV: 97% pions, 2% kaons, 1% anti-protons
  Conventional p = +190 GeV: 24% pions *(can be enhanced by polyethylene absorber)*, remainder mostly protons.
  RF-separated p = -100 GeV: 13% pions, 37% kaons, 50% anti-protons (prelim)
  RF-separated p = +100 GeV: 25% kaons (prelim)

- Energy of RF-separated beams will be lower because of space limitations between RF cavities along M2 beam line.

Existing COMPASS spectrometer

- **Tracking of charged particles:**
  - in the beam region: SciFis and silicons
  - region close to the beam: Micromegas and GEMs with high-rate capability
  - intermediate region: MWPCs
  - large-are tracking: drift chambers (DC, W45) and drift tubes (Straws, RW, MW).

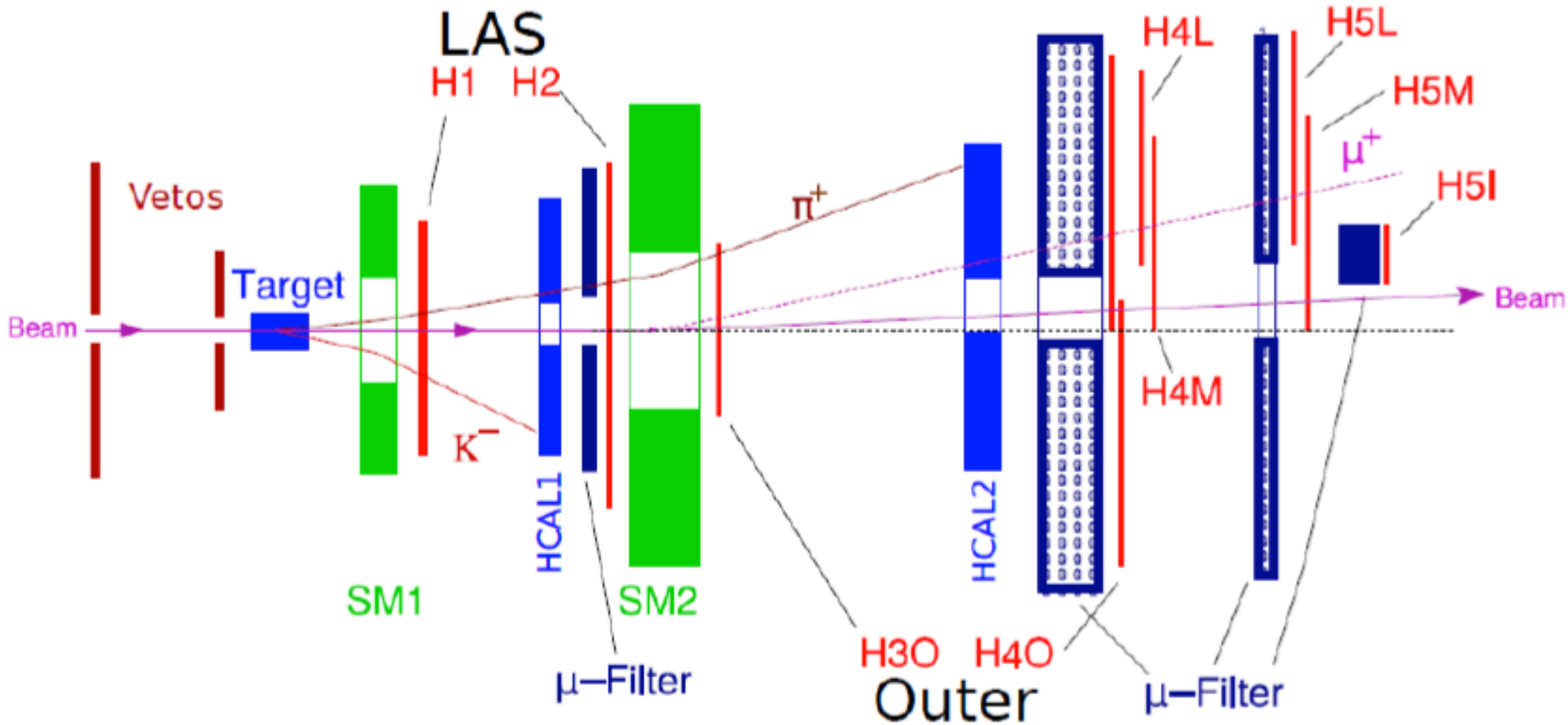


- **Separation of produced pions & kaons:** RICH with multianode-photomultiplier tubes and MWPCs with photosensitive CsI cathodes in the periphery

- **Energy measurement:**
  - charged particles: sampling hadron calorimeters (HCAL)
  - neutral particles, in particular high-energy photons: electromagnetic calorimeters (ECAL)

- 60m length
- More than 300 tracking planes
- 18 mrad < θ_μ < 180 mrad

COMPASS trigger system



Identification of muons via absorber.

Two independent trigger systems:

- Muon Trigger (Target Pointing / Energy Loss)
- Calorimeter Trigger (Energy threshold)

\+ Veto System

Target region Drell-Yan 2015 & 2018

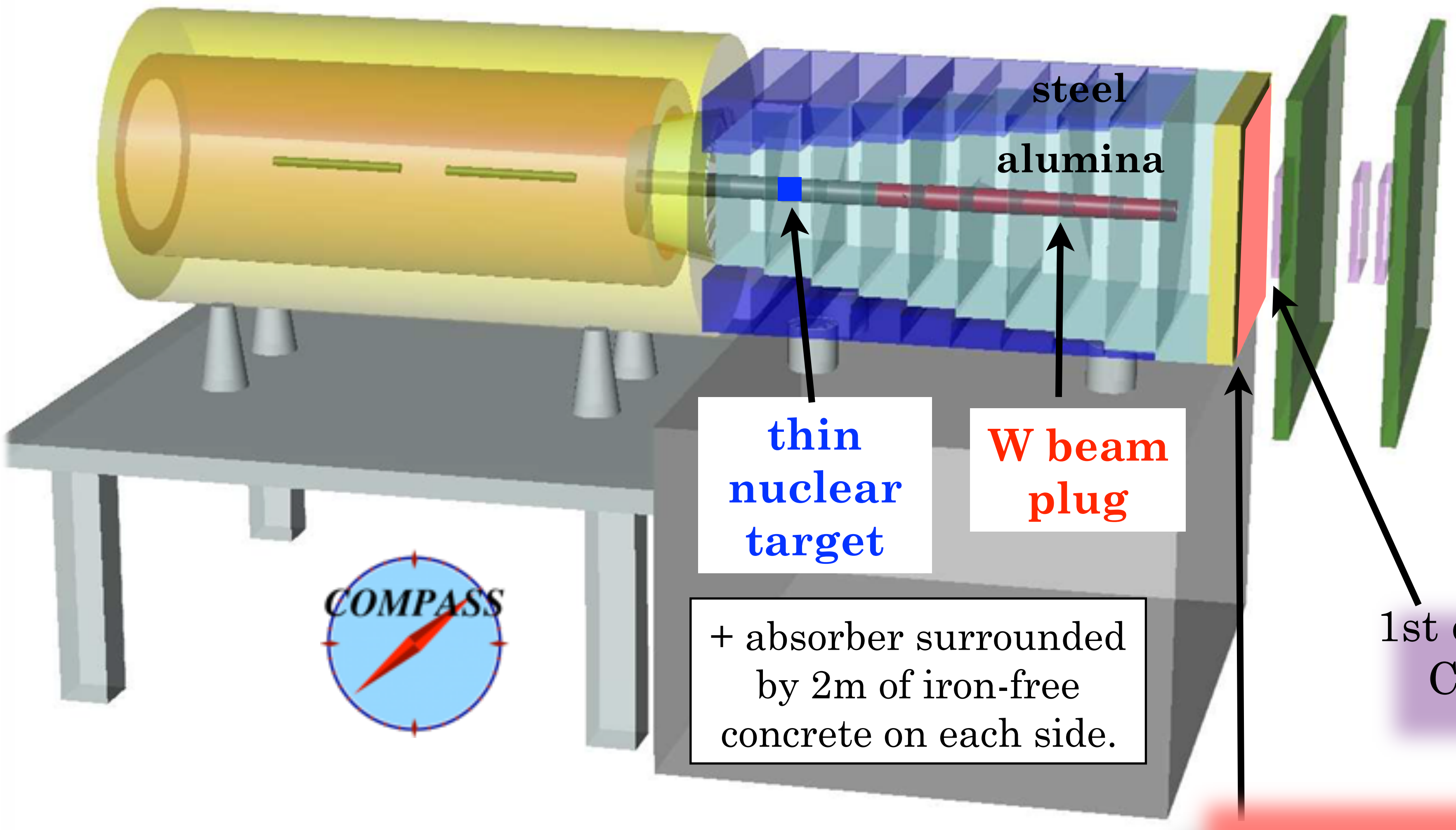
1. Long. pol.: DNP & 2.5T solenoid
2. Trans. pol: 0.6T dipole

Ammonia beads immersed into liquid helium; dilution factor=0.22

Transversely polarized NH3 target

Hadron absorber

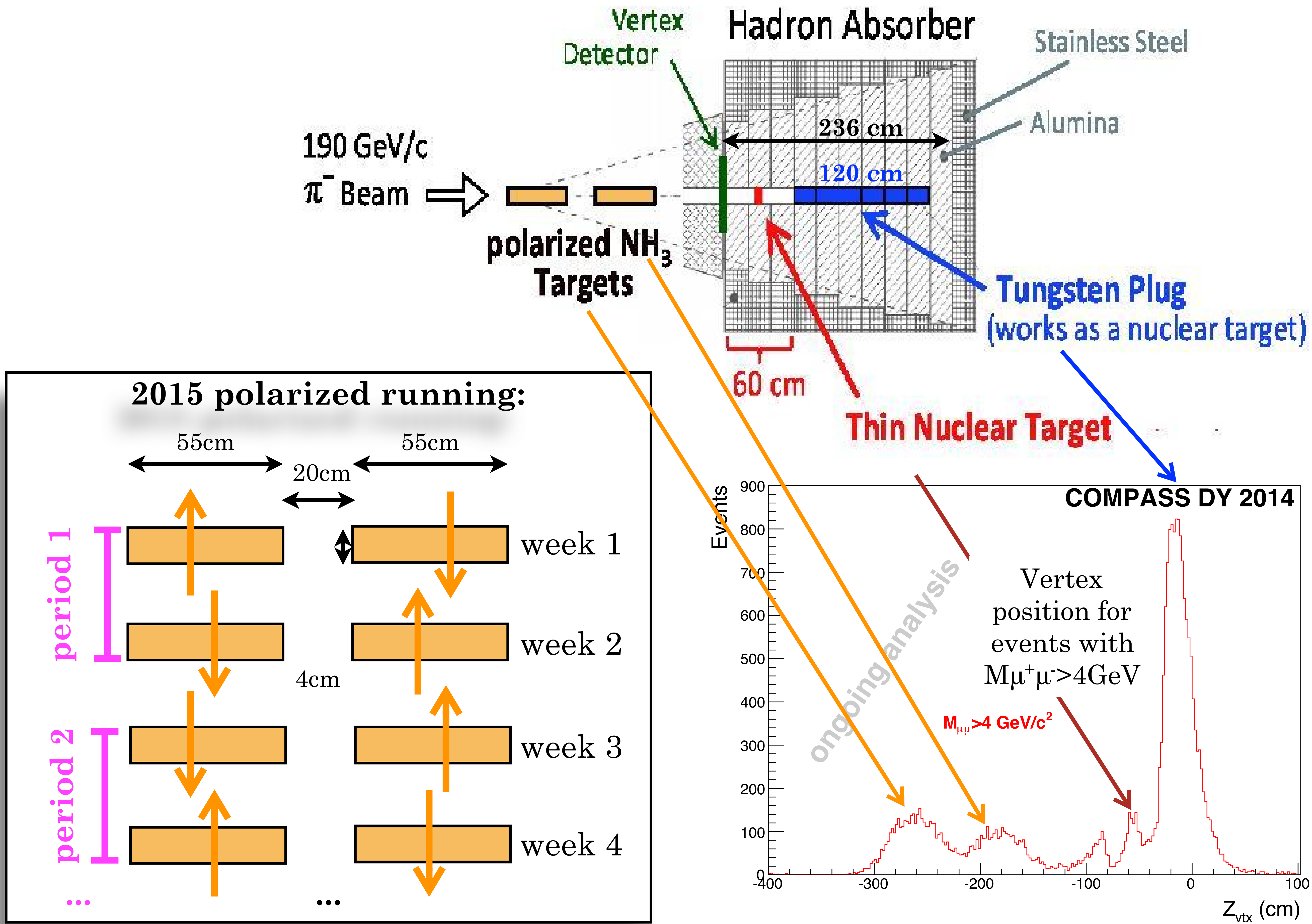
To minimize multiple scattering of muons and to maximize stopping power for hadrons.



1st downstream COMPASS detector

^{6}Li absorber

to prevent flooding of very upstream detectors with charged particles from capture of spallation neutrons ($\Rightarrow \gamma \Rightarrow e^+e^-$).


Vertex Detector
Hadron Absorber
Stainless Steel
Alumina
236 cm
120 cm
190 GeV/c
π⁻ Beam
polarized NH3 Targets
Tungsten Plug
(works as a nuclear target)
60 cm
Thin Nuclear Target
2015 polarized running:
55cm
55cm
20cm
4cm
period 1
period 2
week 1
week 2
week 3
week 4
...
...
COMPASS DY 2014
Events
Vertex position for events with Mμ+μ->4GeV
Mμμ>4 GeV/c2
ongoing analysis
Zvtx (cm)