Conventional Beams WG

L.Gatignon, on behalf of the CBWG

22 November 2017

ENGINEERING DEPARTMENT

Conventional Beams WG

Given the relatively long list of studies, **we focus first on those leading to a possible short and medium time-scale implementation and with limited resources, as well as on those which seem to be the most advanced and competitive** (based on the available input after the initial kickoff event and on a first feasibility analysis regarding the FT implementation).

Under consideration are at present:

- **NA62:** proposal to operate in beam-dump mode
- **NA64++:** High intensity e-, μ and hadron beams for dark particles searches
- **KLEVER:** high intensity K_L beam (high flux, pencil beam, new target) for rare decays
- **COMPAS**S++: RF sep. beams for hadron structure and spectroscopy, also μp FF
- **Mu-e:** 150 GeV μ beams for high precision hadron vacuum polarisation for g_μ
- **DIRAC++:** DIRAC@SPS for high statistic mesonic atoms
- **NA60++:** Heavy ion beams for dimuon physics
- **NA61++:** Higher intensity ion beam for charm studies

CBWG Organisation

CONVENTIONAL BEAMS WORKING GROUP

Conveners: L.Gatignon, M.Brugger

Members: Experiments, H.Wilkens, G.Lanfranchi, T.Spadaro, EA physicists, HSE, RP, EL, CV, RF, STI

CBWG-ECN3

Conv: LG

Secr: M.R, M.vD

Members:

EA physicists,,
RP, HSE, CV, EL,
MPE, STI, MSC,
EPC
+ SMB?

CBWG-EHN2

Conv: J.B

Secr: New Fellow

Members:

EA physicists,
RP, HSE, RF, CV,
EL, STI, MSC,
EPC,
+CRG, SMB?

CBWG-EHN1

Conv: NC

Secr: AG

Members:

EA physcists,
RP, HSE,
+CV, EL,
MSC, EPC?

Simulation for NA62-beamdump: G4-beamline

- Two simulation versions:
  - V1: only muons from decays, no TAX interactions
  - V2: muons from decays plus TAX interactions

400 GeV/c protons on “T10 out”

V2

Score particle distribution and composition behind TAX

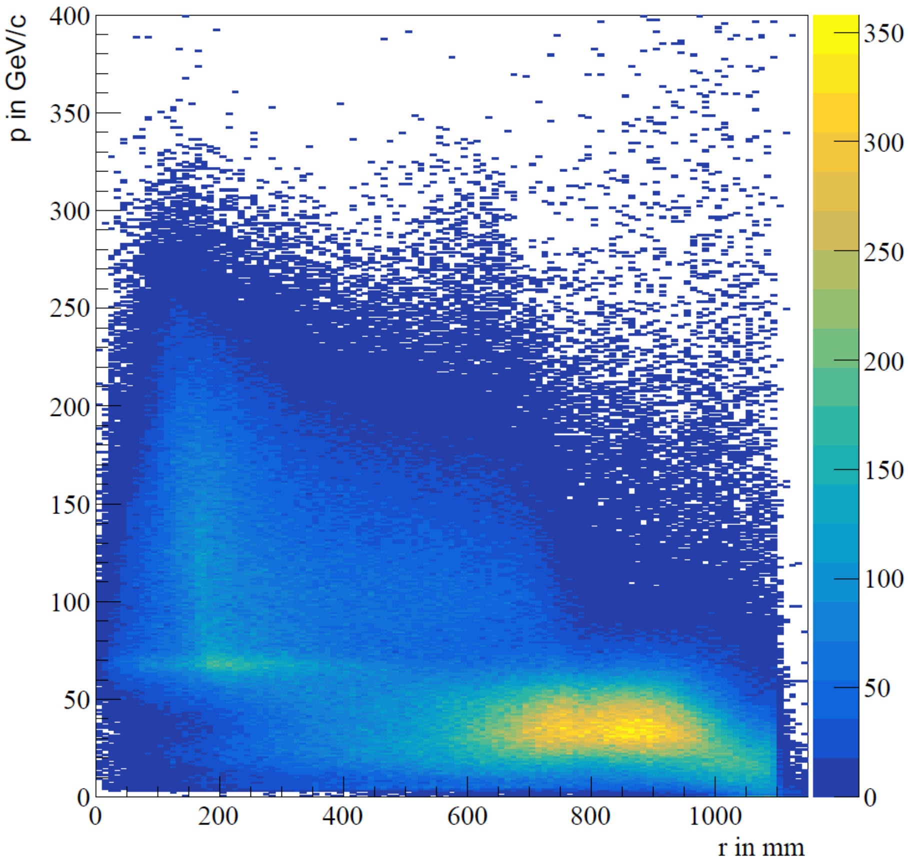
Track all particles further downstream

- Slower simulation speed
- Increase of statistics by randomly generating particles according to “behind TAX distribution”

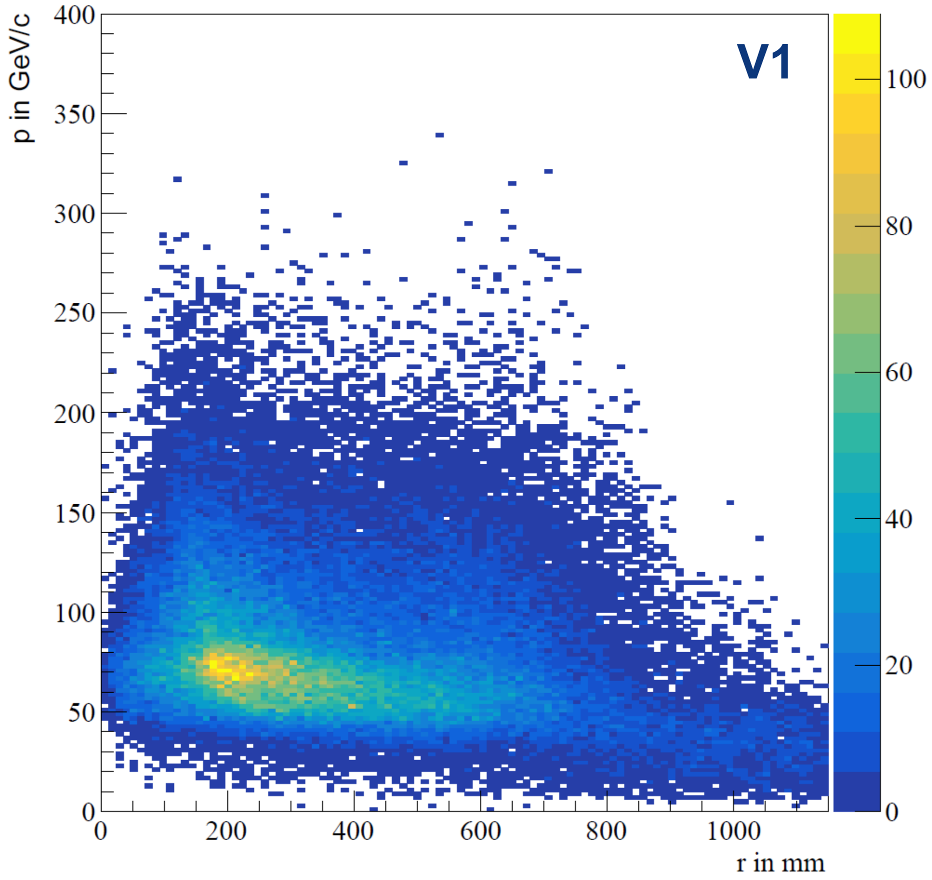
M.Rosenthal / EN-EA

Radius vs. Momentum for Positives

- Data:



Model:



M.Rosenthal / EN-EA

Radius vs. Momentum for Positives

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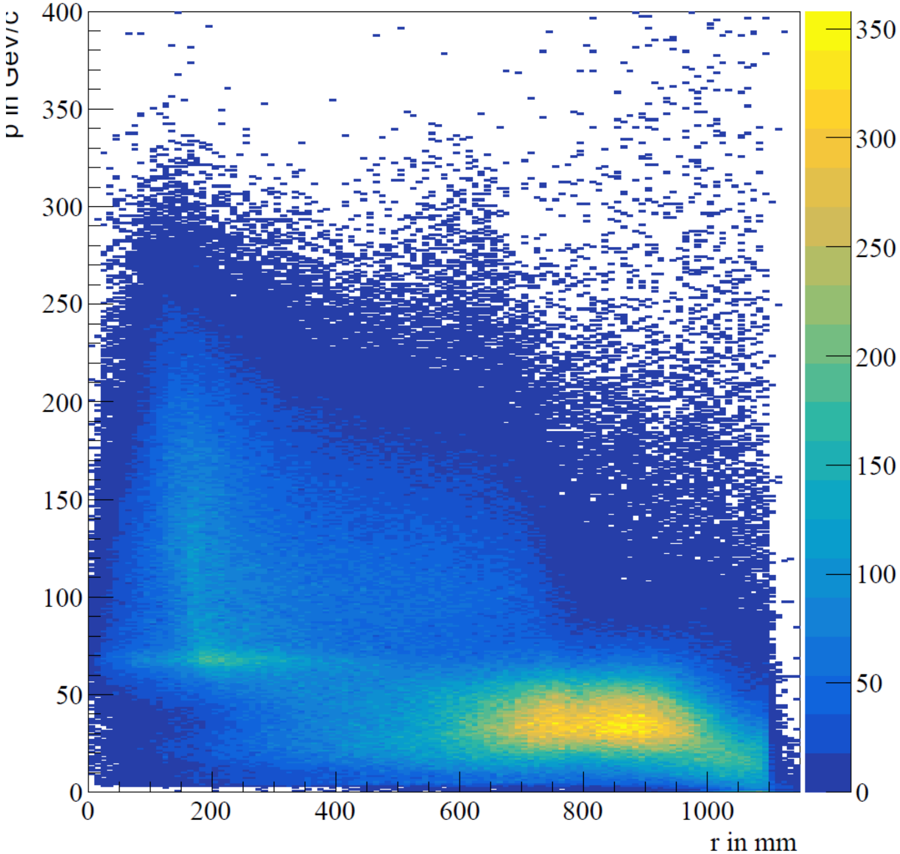

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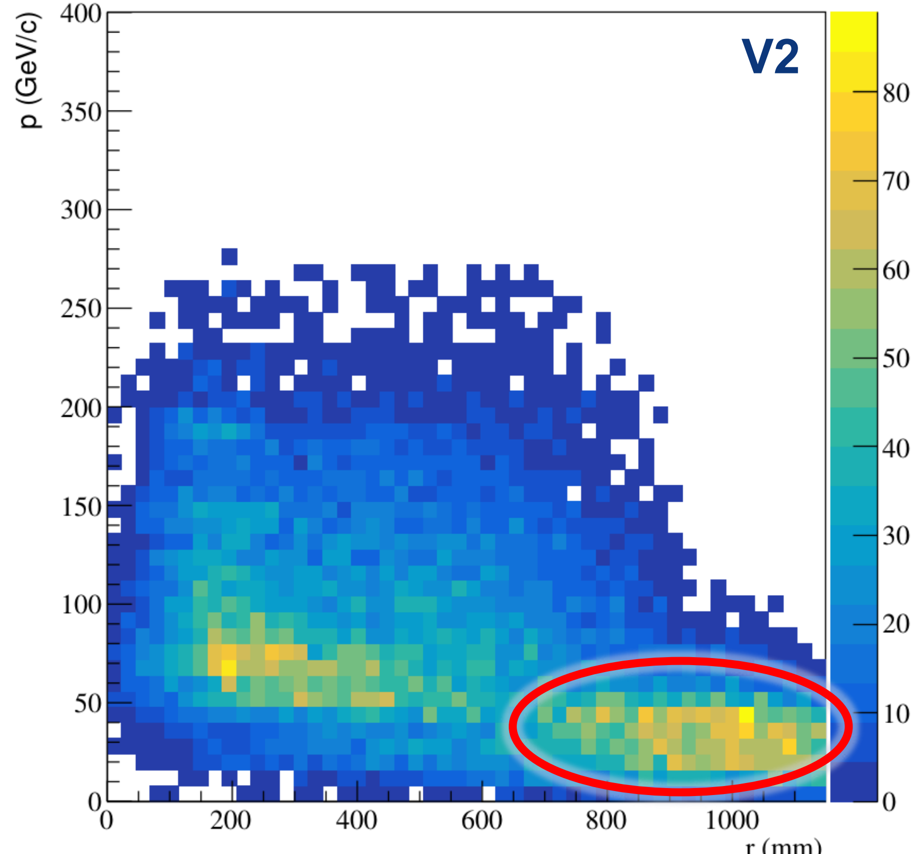
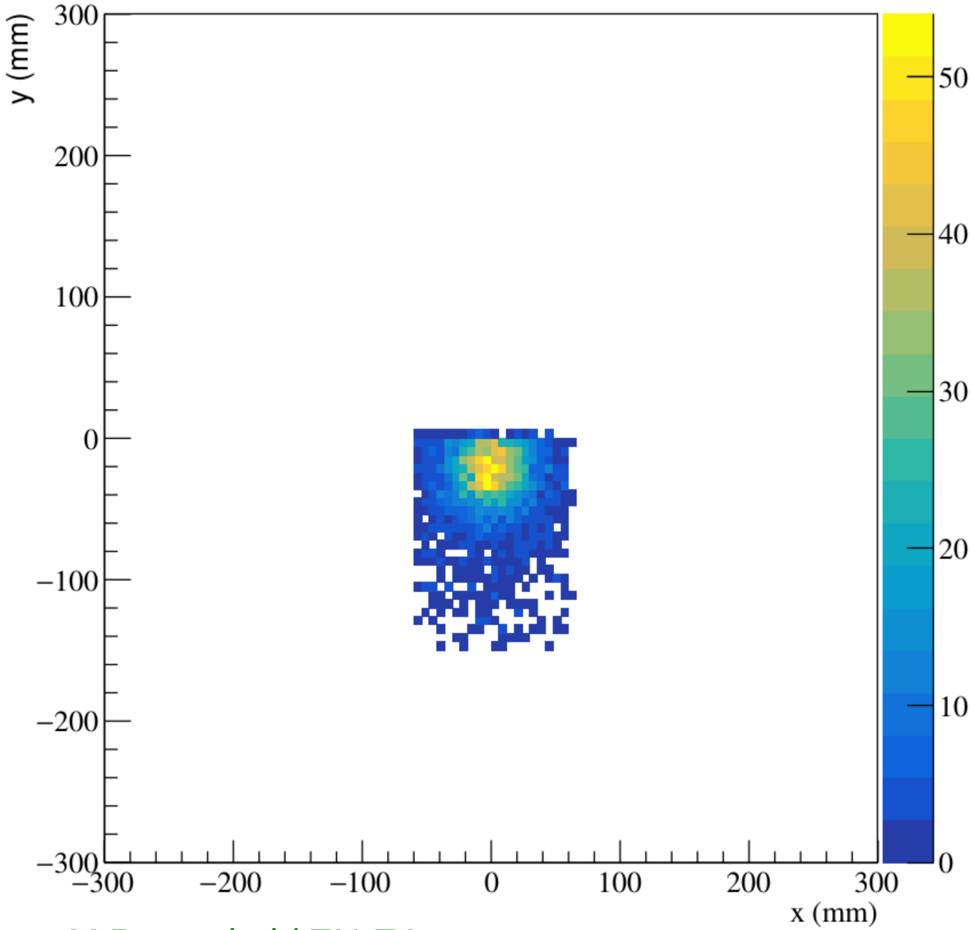


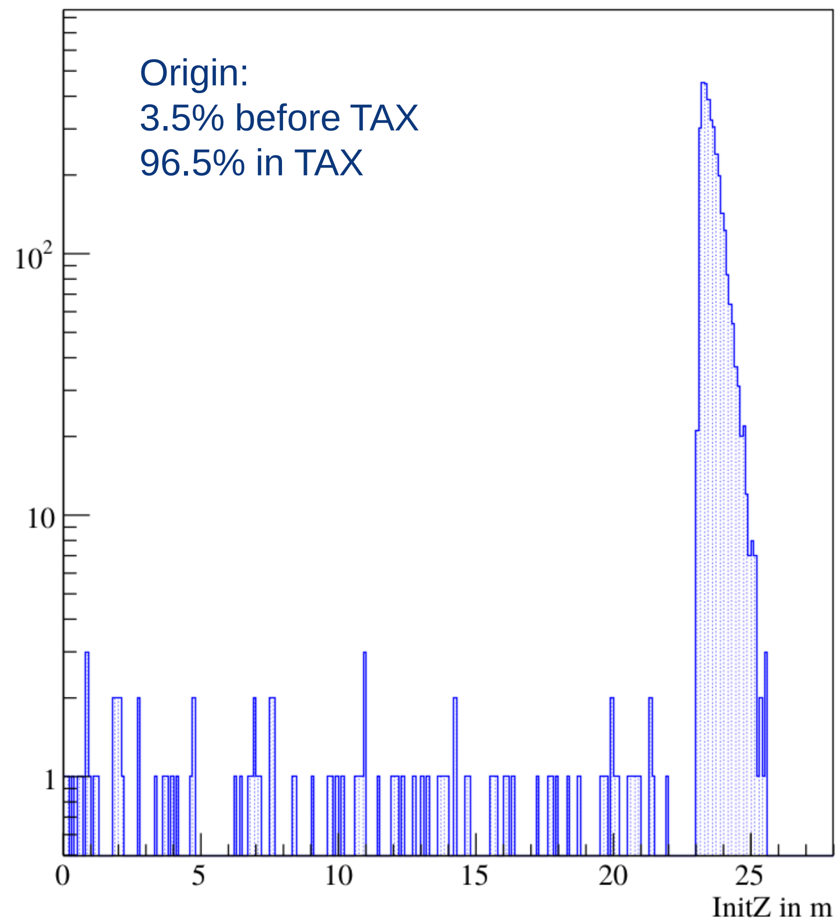
M.Rosenthal / EN-EA

Low momenta accumulation
more dominant when including TAX muons

Muon origin (Decay vs. TAX)

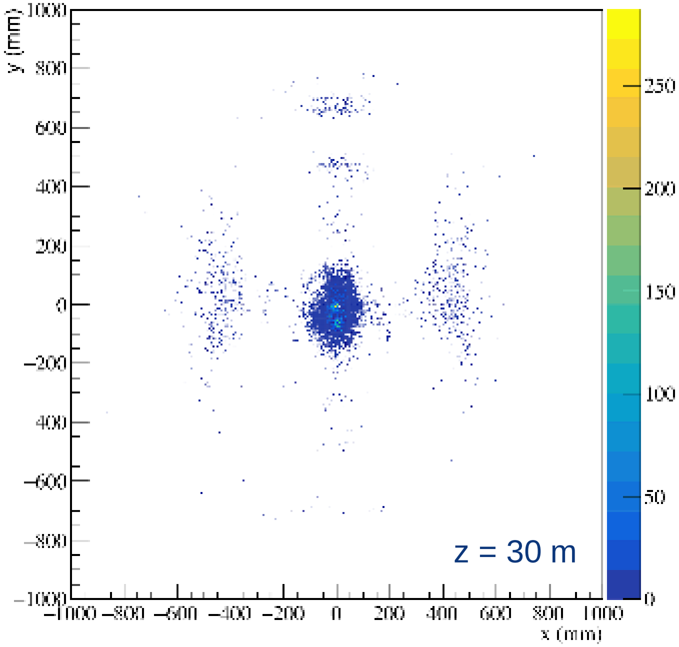
Simulated distribution for μ^+ behind TAX (spatial coordinates relevant for trigger)

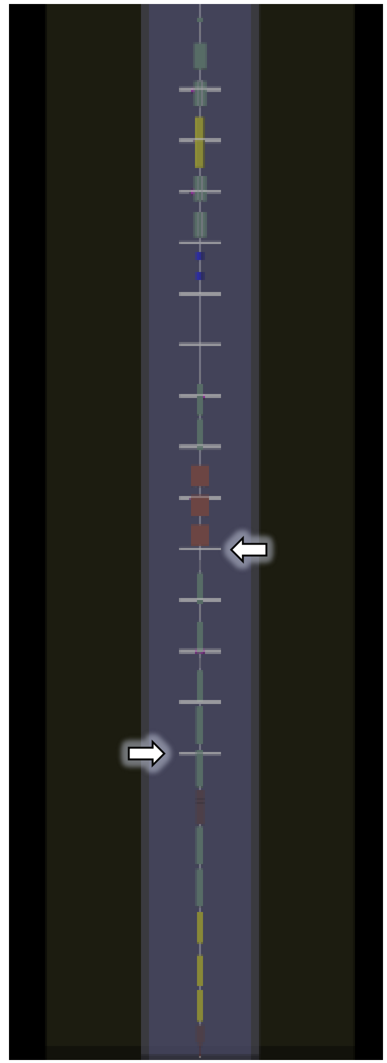


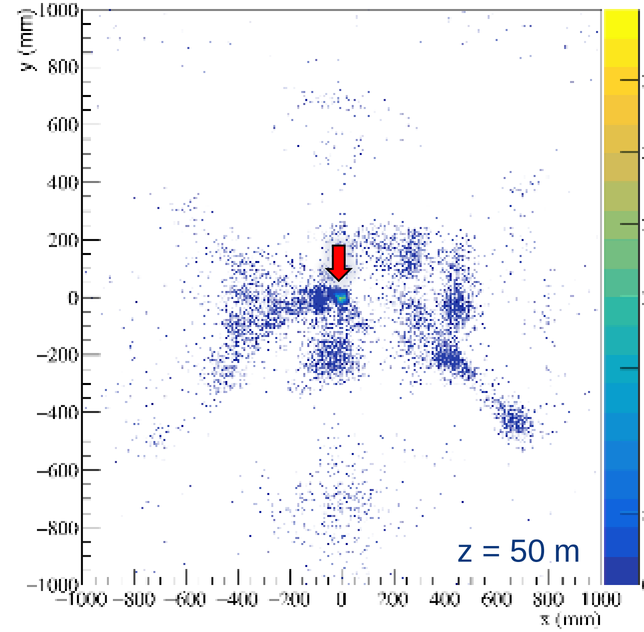


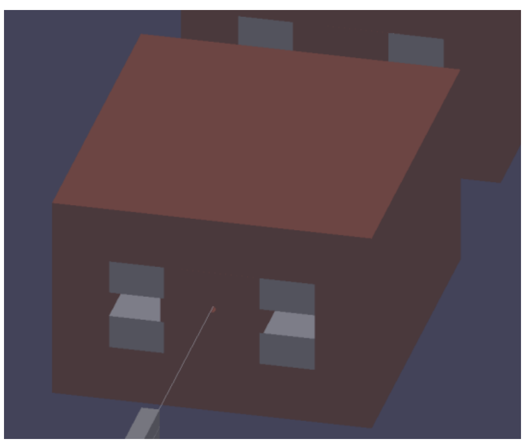
M.Rosenthal / EN-EA

Triggering distribution default configuration

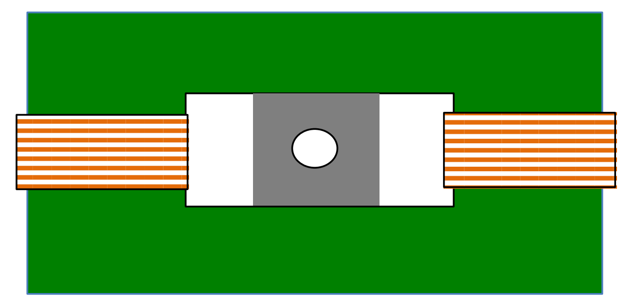






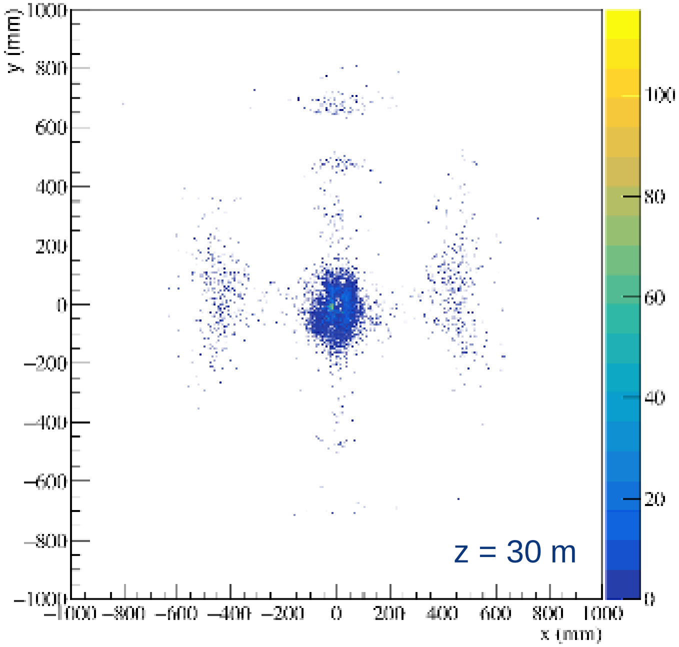


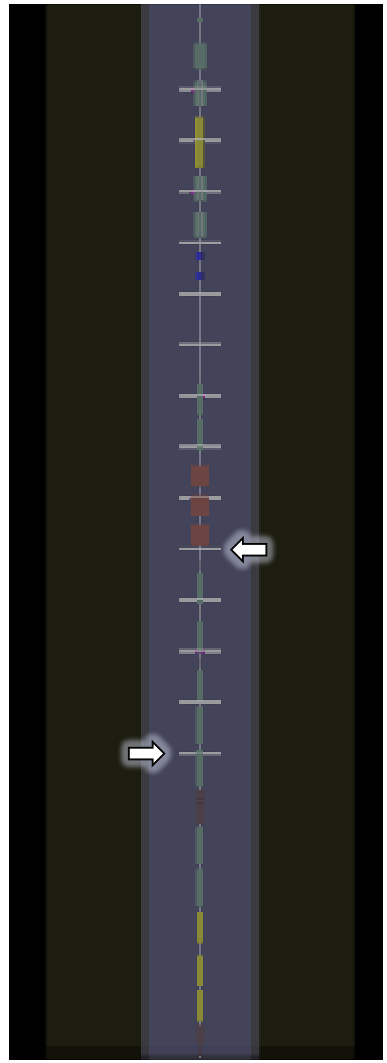
- Centralized spot before BEND3
  - Not deflected in hole

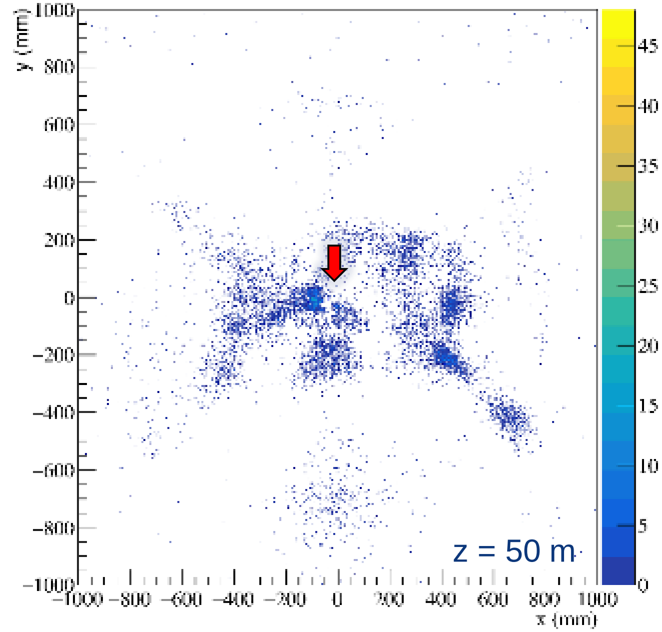


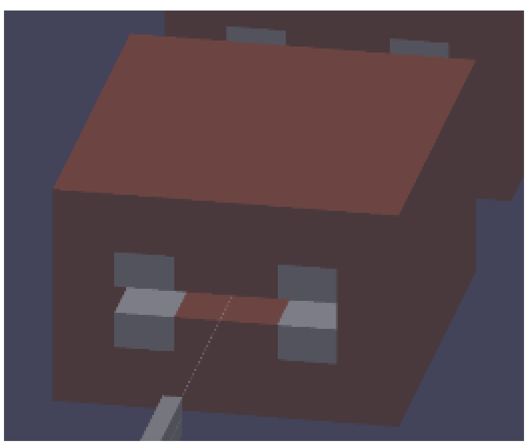
Courtesy: M. Rosenthal / EN-EA

Triggering distribution MBPL configuration









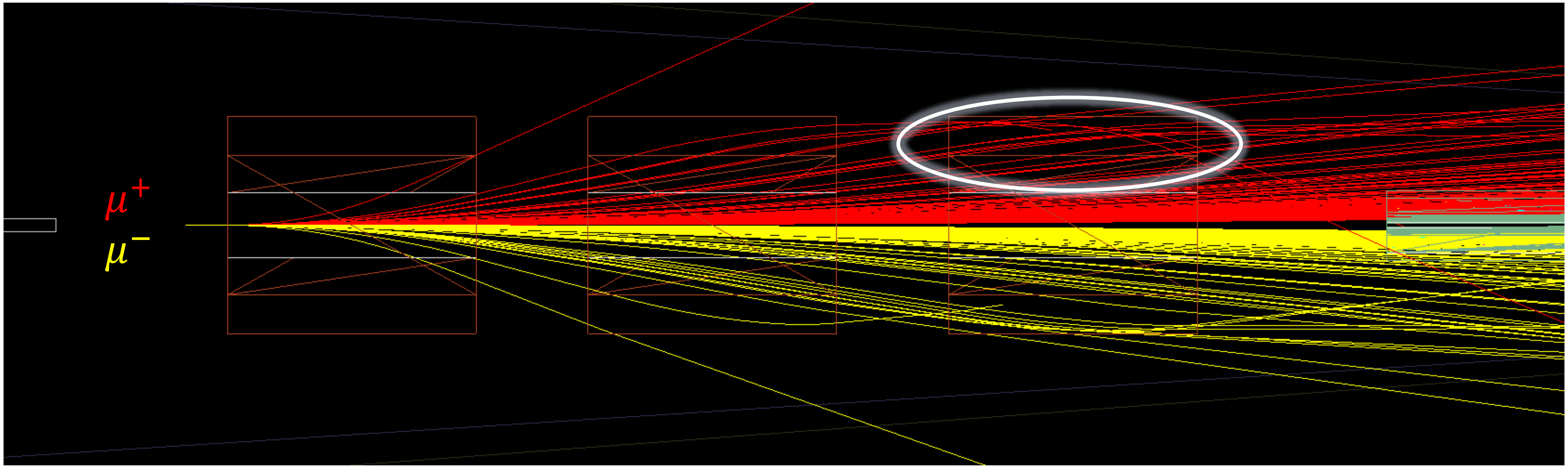
- Centralized spot before BEND3
  - Not deflected in hole
  - Remove iron core?

- With MBPLs central spot disappears from triggering muons

Courtesy: M. Rosenthal / EN-EA

Muon trajectories in MBPLs for pencil beam

- Optimization of number of MBPLs and field strength
- First considerations:
  - Simulate momenta up to 400 GeV/c, start tracking in front of MBPLs

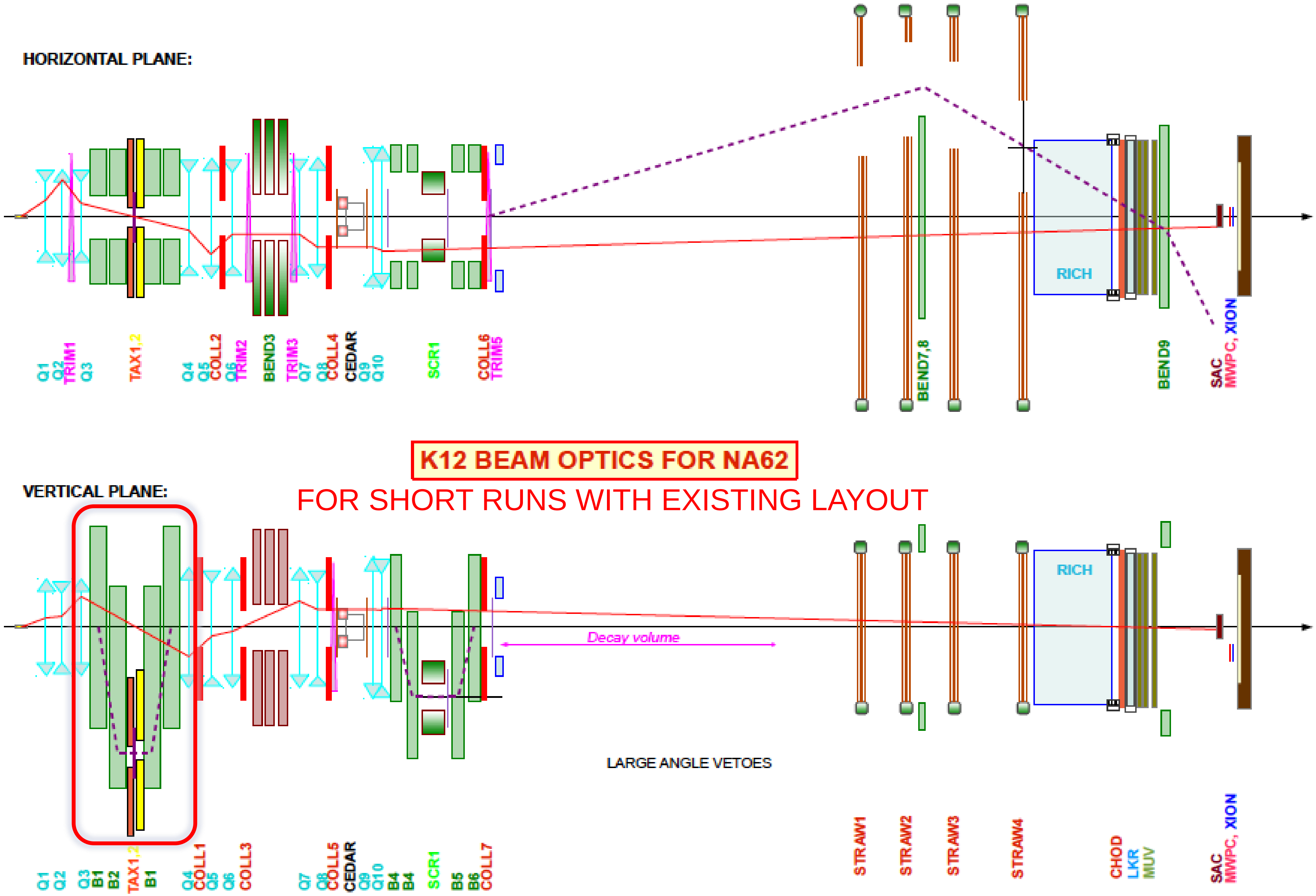


- Momenta below 20 GeV/c are partially caught in return yokes of 3 MBPLs
- High momenta require large field strength to be deflected sufficiently
  - Optimization on-going

Courtesy: M. Rosenthal / EN-EA

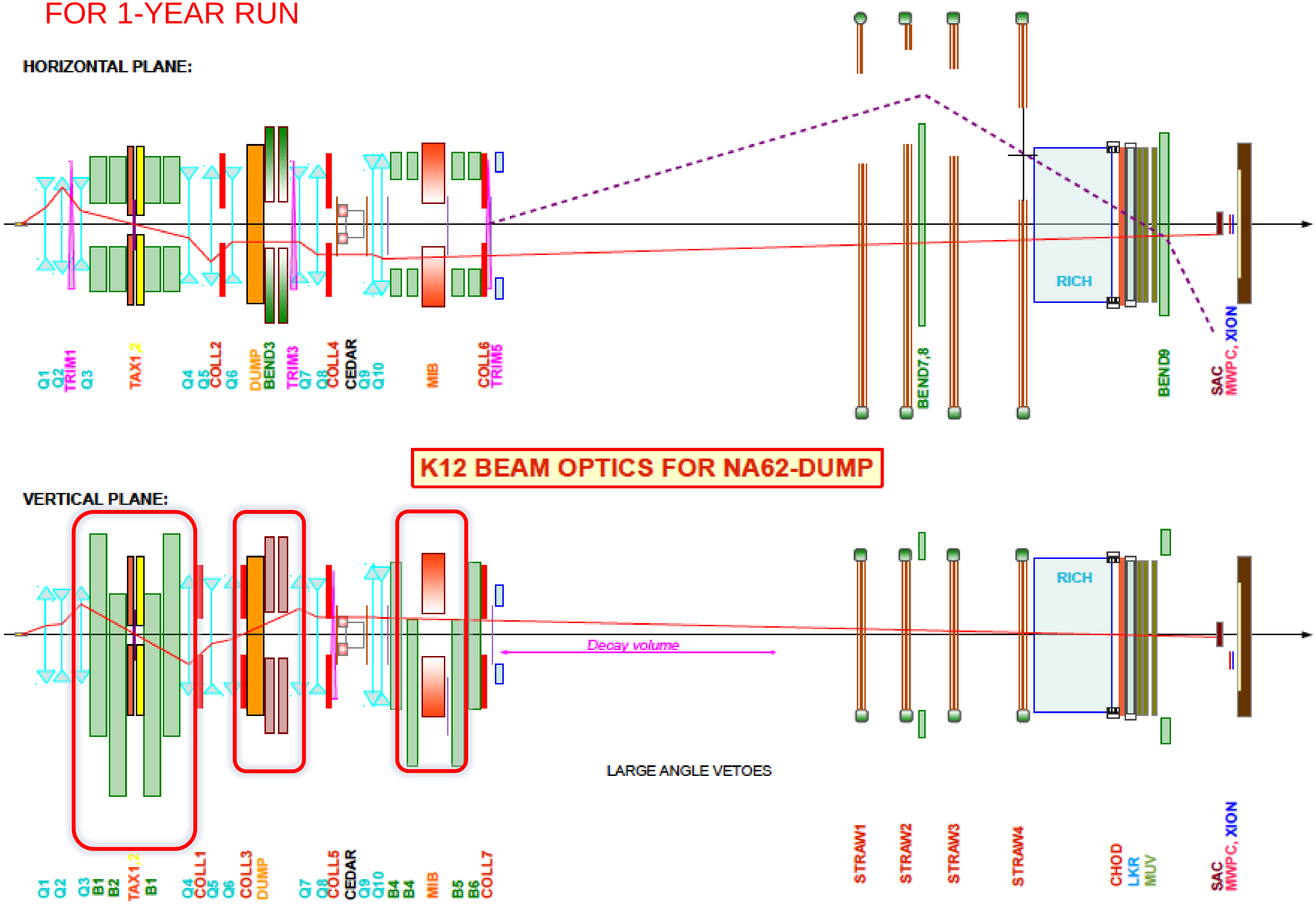
K12 BEAM OPTICS FOR NA62

FOR SHORT RUNS WITH EXISTING LAYOUT



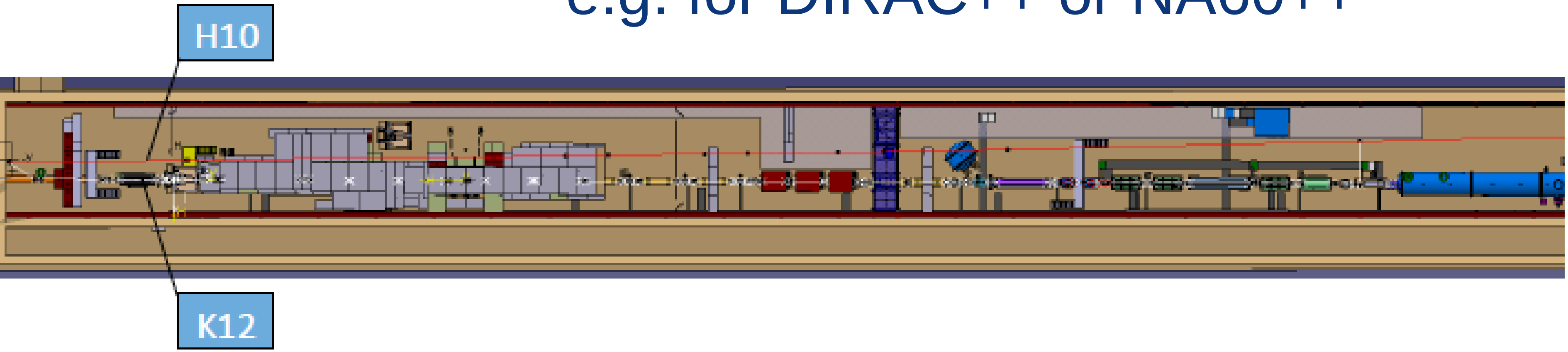
FOR 1-YEAR RUN

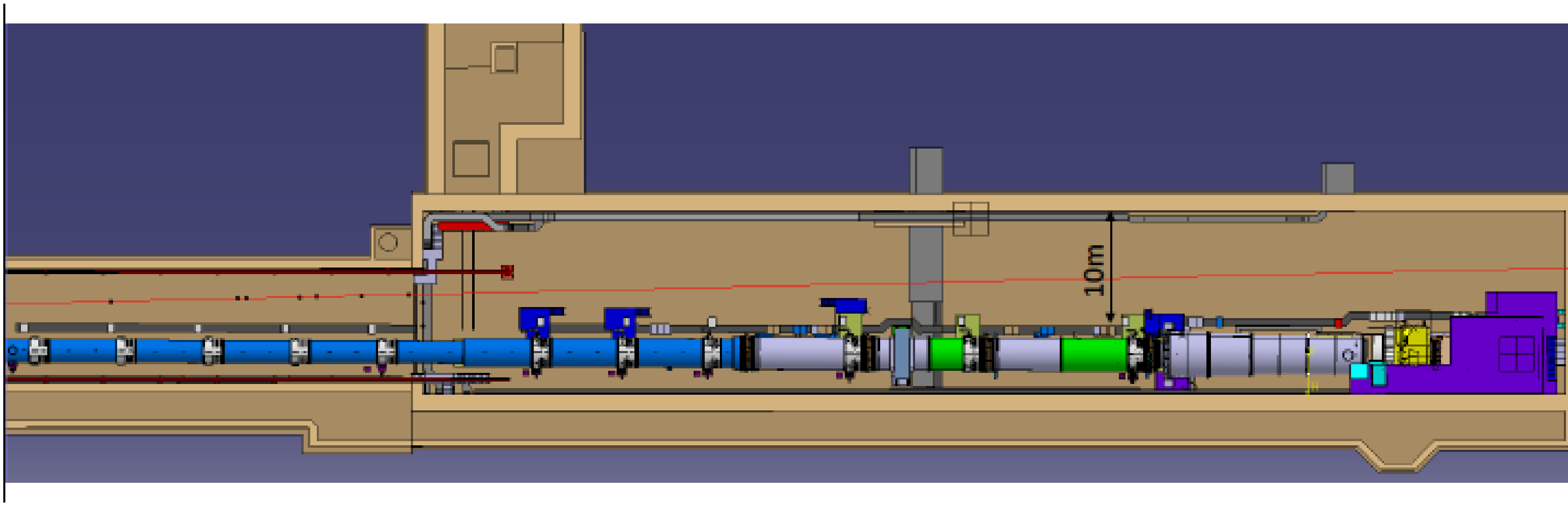
K12 BEAM OPTICS FOR NA62-DUMP



Difficulties to add beam line in ECN3

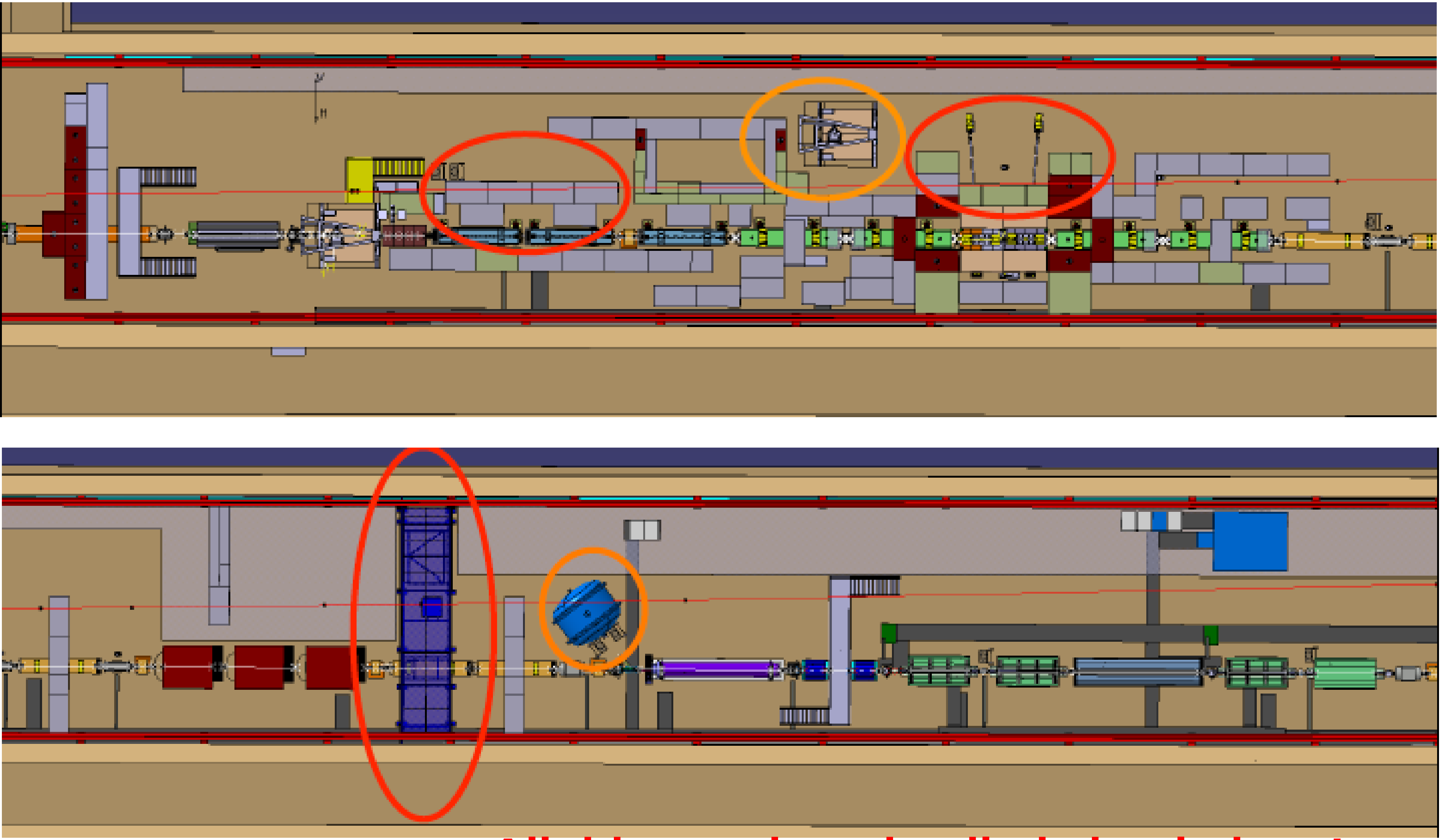
e.g. for DIRAC++ or NA60++





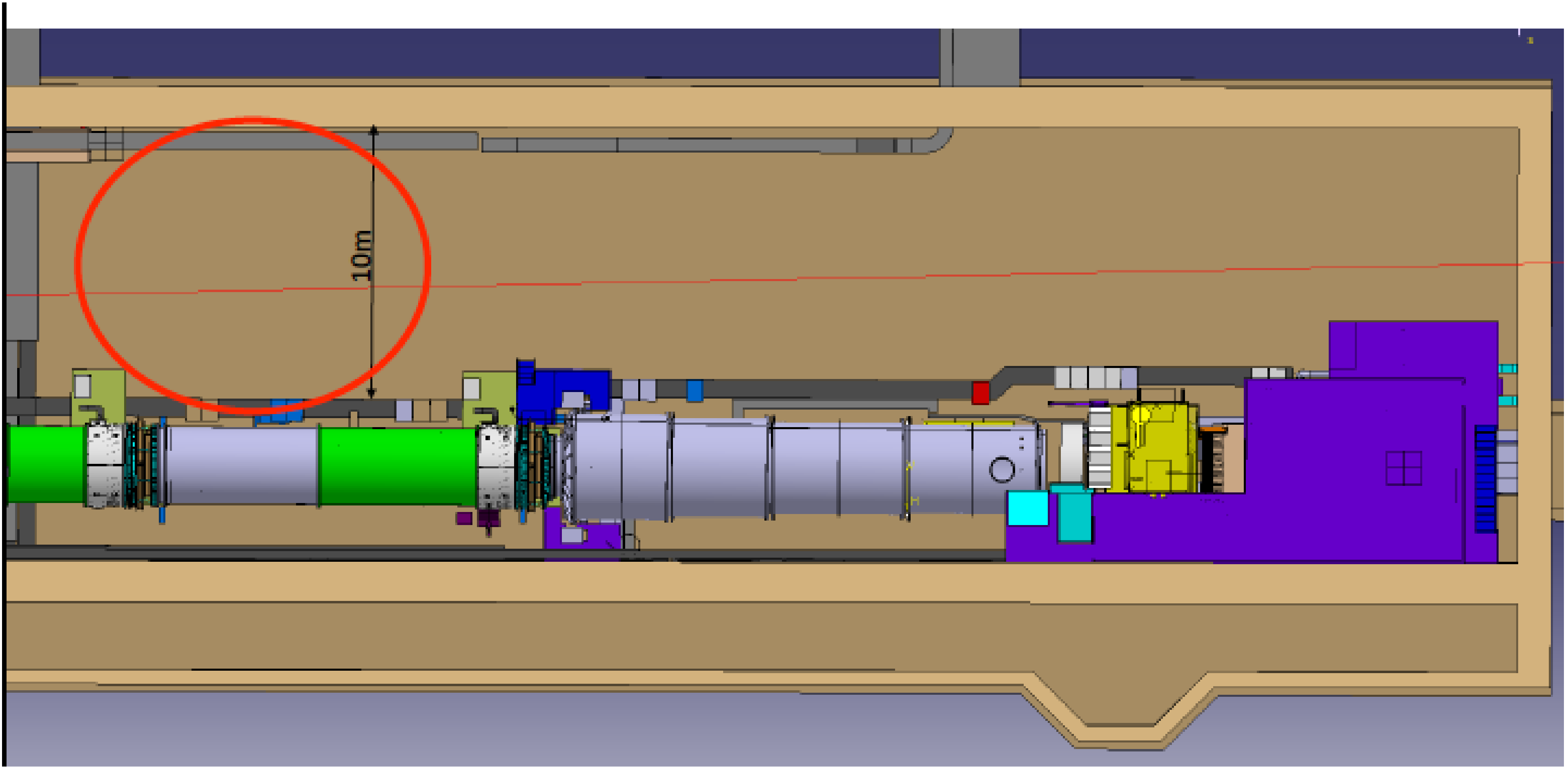
S.Girod / EN-EA

E.g. beam front end

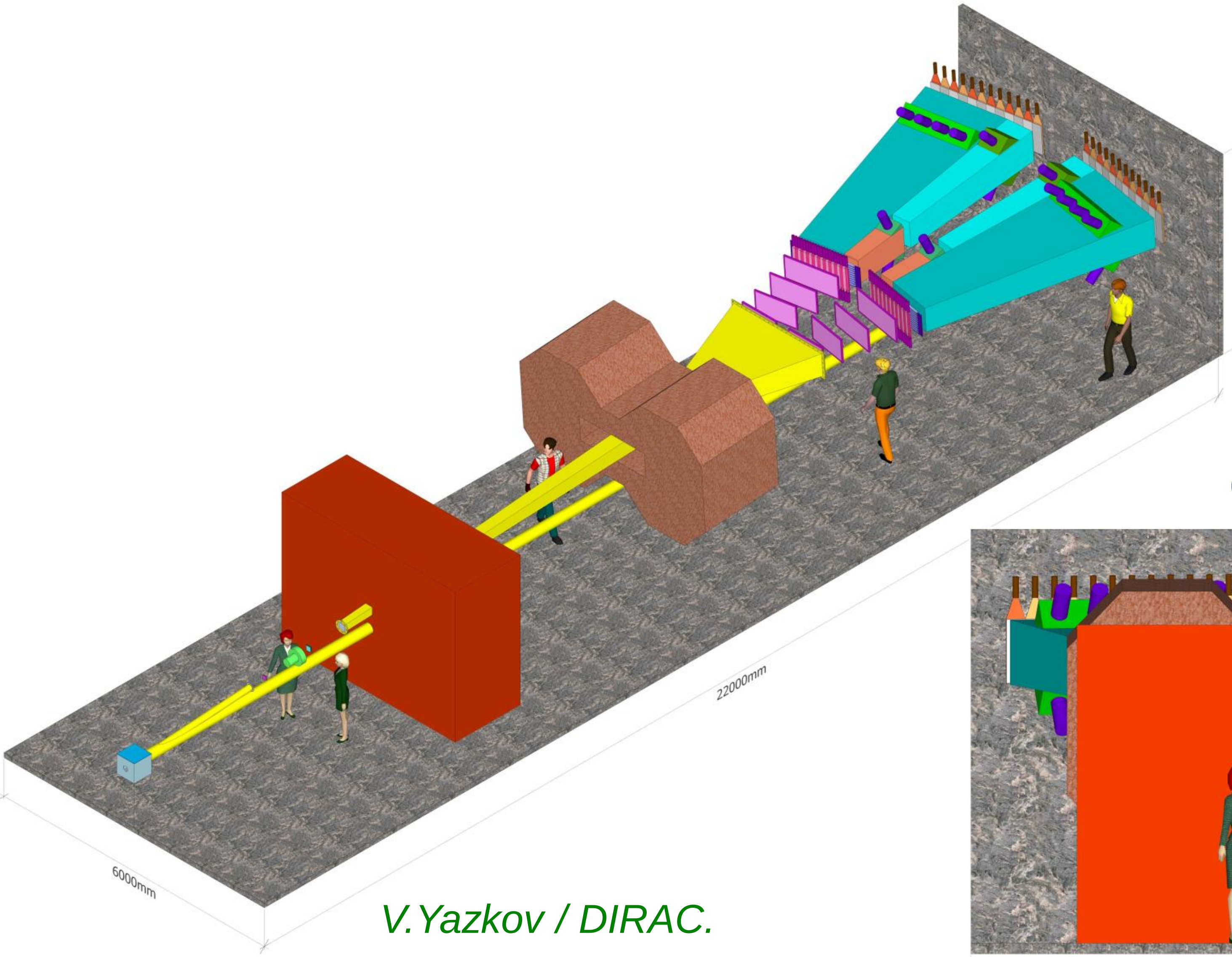


All this requires detailed simulations!

Or on the detector side…..

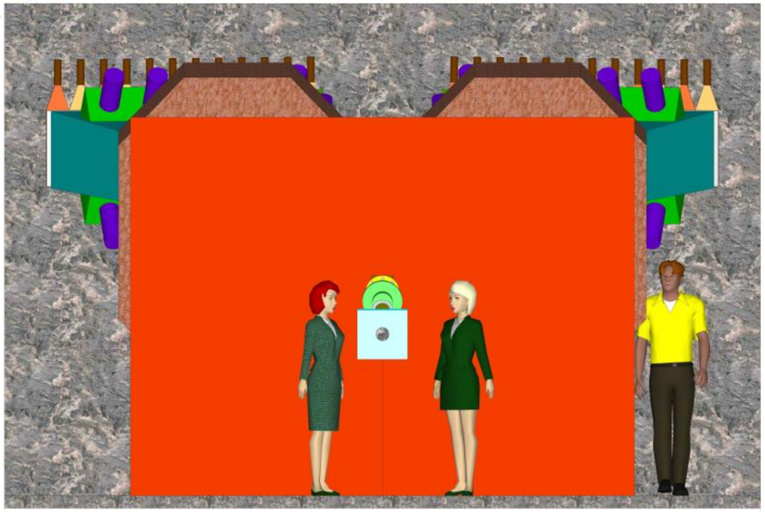


E.g. adaptations for DIRAC^{++} layout



V.Yazkov / DIRAC.

6 m wide



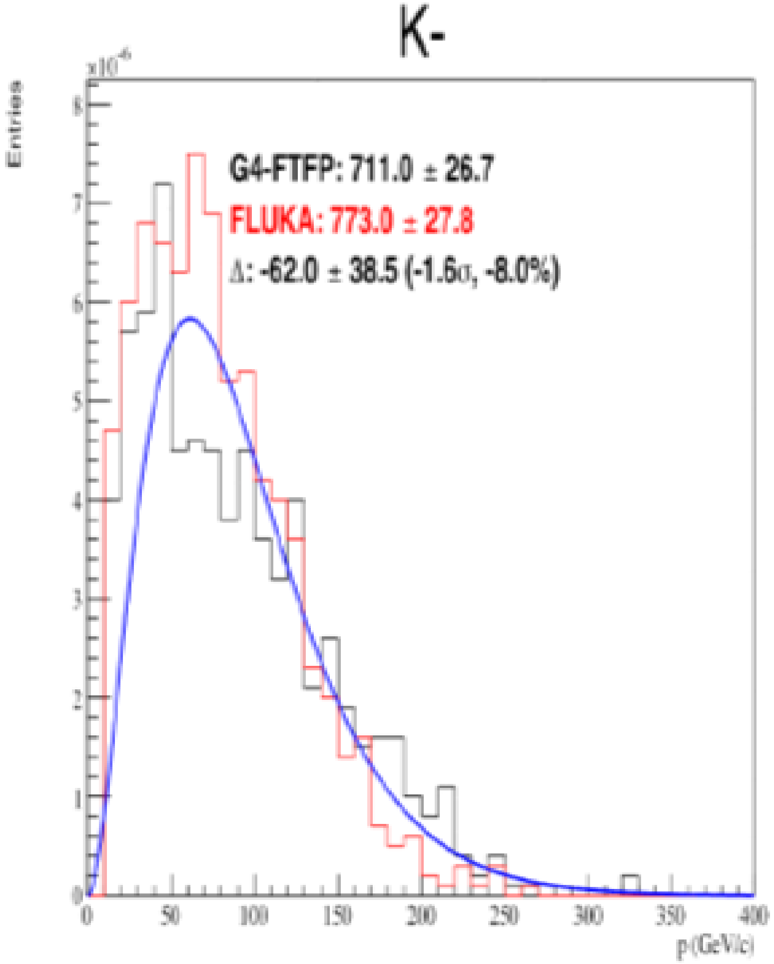
Start of FLUKA studies for KLEVER

After a learning phase, tools have been developed to start work for KLEVER starting with particle production studies and benchmarking.

E.g.:

Particle production in KLEVER Target

In preparation for studies of target material and production angle dependence

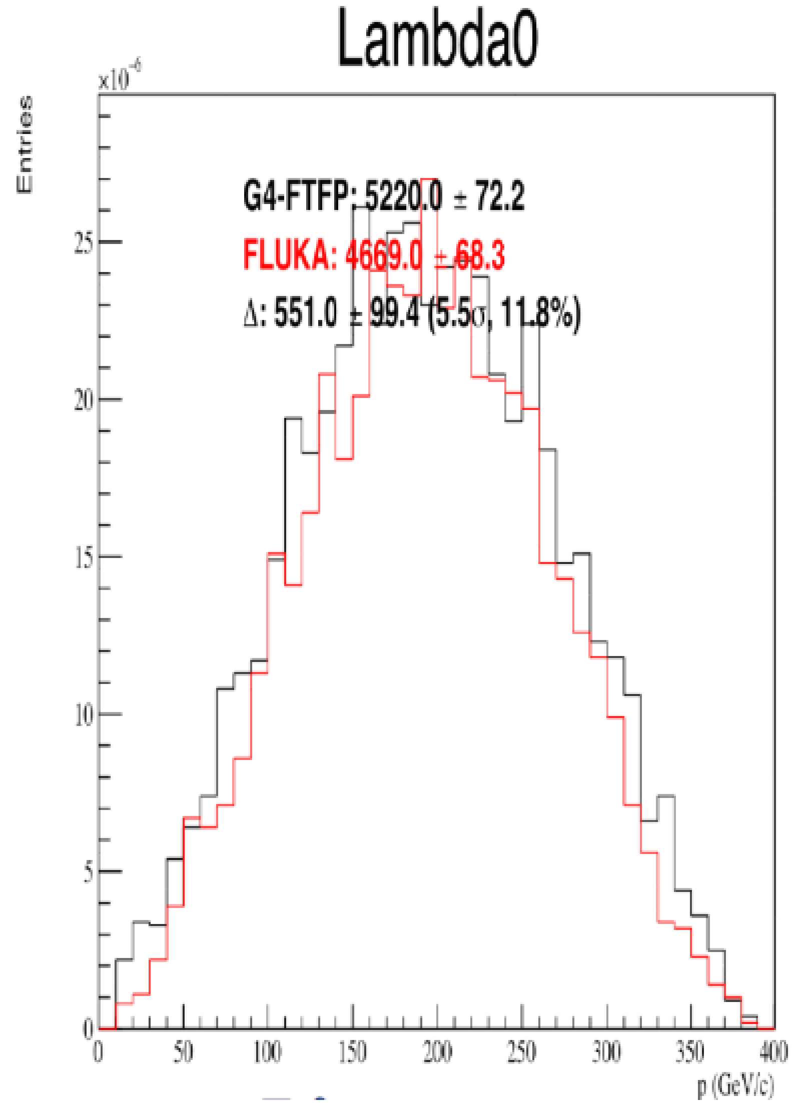


Note: K^o ~$(K^+ + \mathbf{3}\ K^-)/4$

M.van Dijk, M.Rosenthal

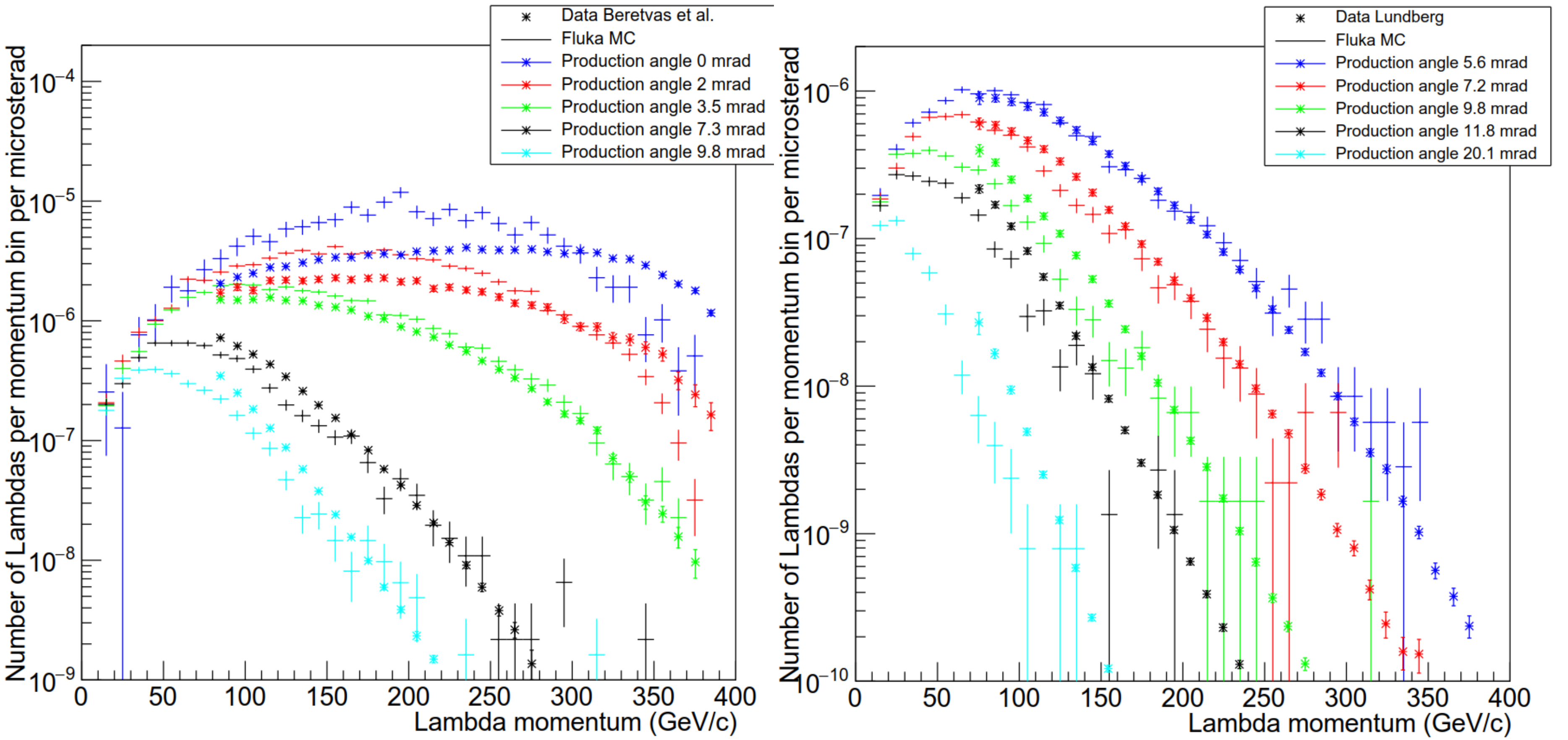
Potential background

On-going effort to minimise background from neutrons and Λ°



Maarten van Dijk

FLUKA Benchmarking for Λ production



Now background studies from e.g. Λ as a function of production angle can start, followed by more detailed studies for the configuration finally chosen.

M.Van Dijk / EN-EA

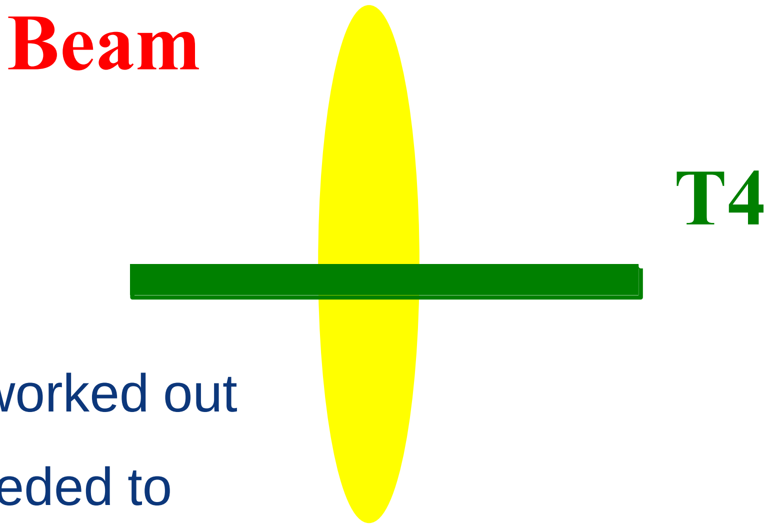
Intensity increase for KLEVER

There are a number of intensity limitations for beams into TCC8 and ECN3 that need to be quantified and improvement to be studied. These include:

- Maximum proton intensity in SPS, proton sharing, duty cycle, BDF, etc
  → BDF studies,Proton production WG
- Losses at extraction, on the splitters and on the way to the targets
  → SLAWG
- Spill structure even more important at higher intensity
  → Work with experiments to improve feedback to CCC
- Beam attenuation in T4 (or T6)
- Equipment reliability and survival (splitters, targets, TAX, etc)
- Machine and equipment protection
- Radiation protection constraints (ventilation, environment, muons, etc)

T10 intensity for KLEVER

- 2 10^{13} ppp on T10 requires many more on T4. Survival of targets?
  E.g. with 100 mm target need more than 3 10^{13} ppp on T4
  Would also produce high radiation levels in BA80 and for cooling water
- A short T4 target is penalising for electron content in H6, H8
  A longer target would be better in this respect, but radiation issues harder to control
- A by-pass beam at T4 has been suggested:
  Most of beam can be transmitted directly (no scattering in T4) to T10 and possibly longer target in T4



- Optics in transfer line and P42 to be worked out
- In general more instrumentation is needed to improve transmission and reduce losses everywhere

Ventilation in TCC8 and ECN3

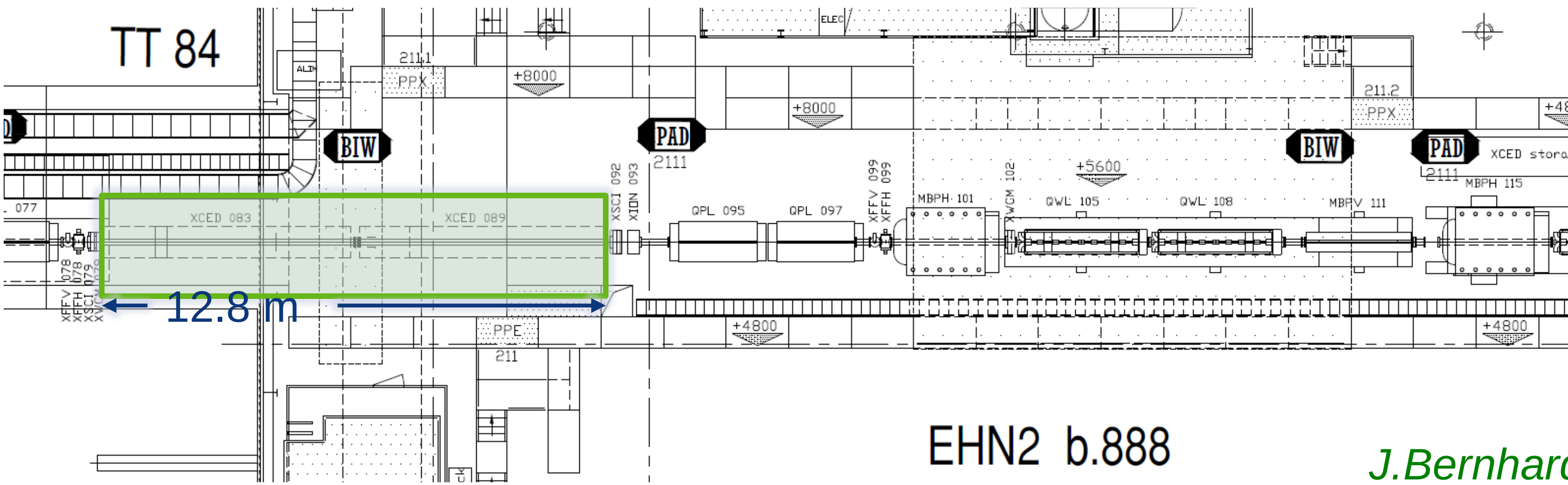
- The present solution (cost driven) provides only little margin for nominal intensity on T10, i.e. 3 10^{12} ppp (according to FLUKA calculations)
- Higher intensity (as requested by **KLEVER**) would normally require under-pressure in TCC8 and transfer tunnel Not easily possible with present tunnel construction (leaking in many places, would require lots of CE work – cost?)
- Need to physically separate ventilation units for TCC8 and ECN3 to avoid leakage of active TCC8 air into the ECN3 units.
  Requires moderately large new surface building,
- Also other RP aspects need to be considered.
- Studies involve RP, CV and SMB and are now kicked off following a year of data-taking by NA62 at 60% of nominal intensity on the T10 target. Looking forward to first outcome of RP analysis of measurements soon.

EHN2 Working Group

- **Identified work packages** by beam type and physics proposal
  - WP1: Muon beams post 2020
  - WP2: Hadron and Electron beams post 2020
  - WP3: RF-separated beams
  - WP4: Beam Particle Identification
    (dedicated meetings / WP leader S.Mathot/EN-MME)
- **Roadmap**: Identify necessary studies for WP proposals (Beam Design / Optics, Integration of Set-ups in EHN2, Backgrounds for Physics, Radiation Protection, Safety) and prepare input to PBC Conceptual Design Report (2018)
- Dedicated meetings for possible 2018 tests in EHN2 (mostly WP1)

Muon beams in EHN2

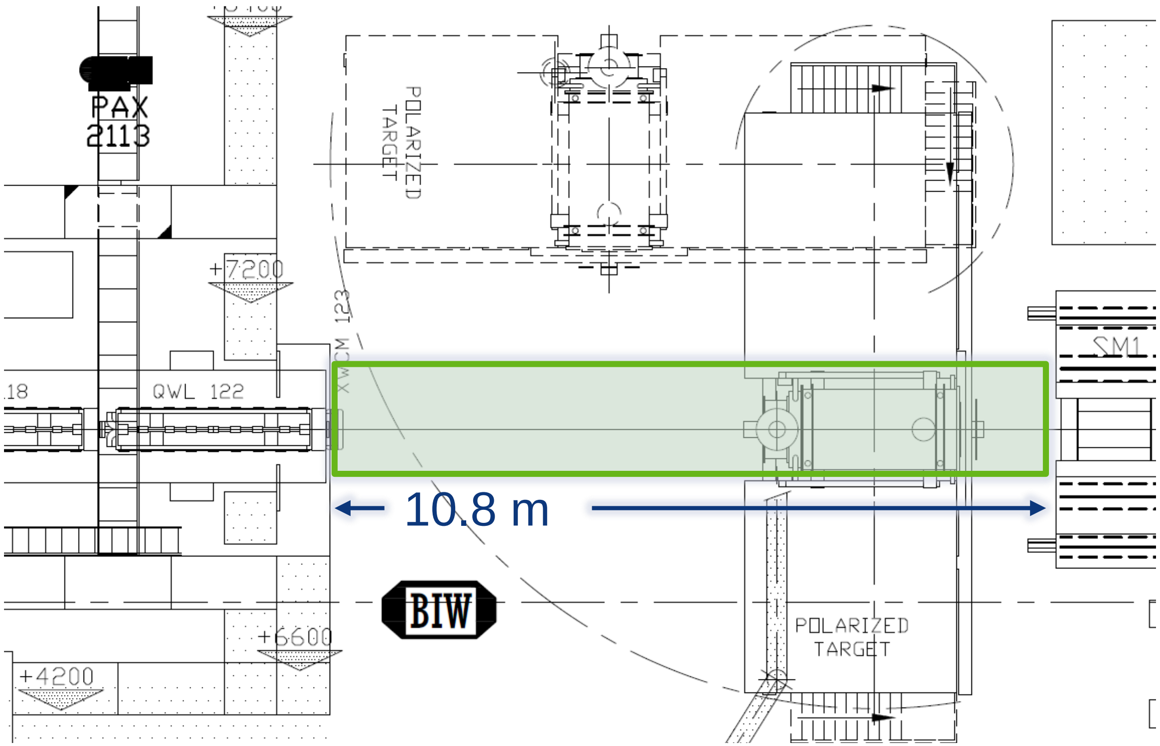
- Options to be studied for location of NA64 mu program and mu-e scattering proposal set-ups
- 3 locations in EHN2 identified that would be compatible with the current COMPASS set-ups
  - **Option 1**
    - Pro: rather easy to install, no further cabling for MBPL necessary, best electron beam quality
    - Con: limited space, not compatible with COMPASS running at the same time



J.Bernhard

Muon beams in EHN2

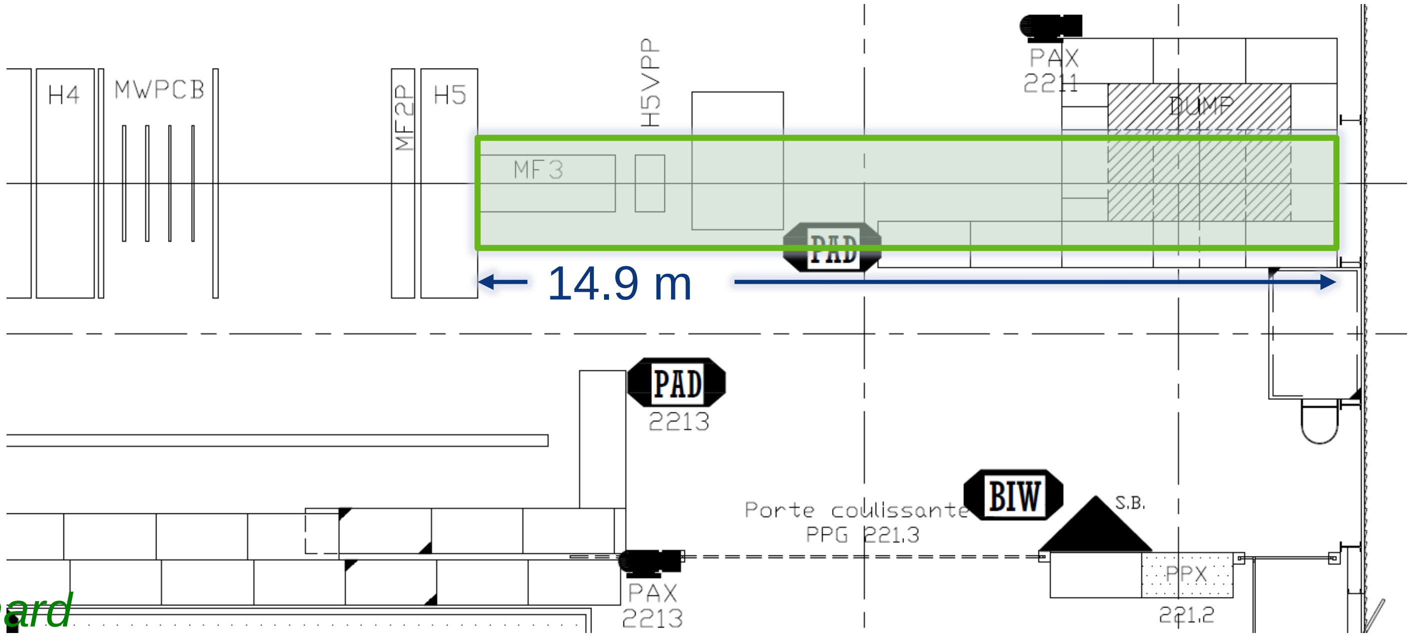
- **Option 2**
  - Pro: might be compatible with COMPASS running at the same time (PT in garage position, small angle spectrometer available with SM2, muon ID, calorimetry)
  - Con: limited space, cabling and space for MBPL (maybe remove Quad36 and use Bend9?)



J.Bernhard

Muon beams in EHN2

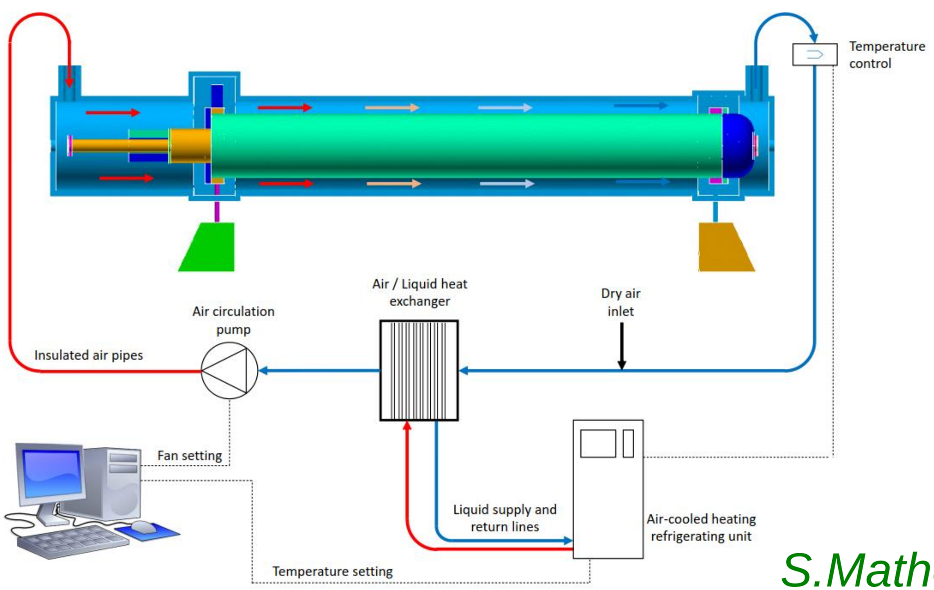
- **Option 3**
  - Pro: compatible with COMPASS running at the same time (able to use full COMPASS set-up)
  - Con: expensive cabling for MBPL, safety aspects (lock ABS in, no hadron beams), electron beam would have to pass additional 60m of air + COMPASS target and detectors, would need to ensure safety with electron beam operation (e.g. limit Bends 5 and 6)



J.Bernhard

CEDAR Upgrade

- CEDAR upgrade for better rate and thermal stability, goal: project ready for 03/2018
  - New PMTs, gain monitor, and read-out (COMPASS)
  - New thermalisation (EN-EA / MME / CV)
- S. Mathot is project leader for CERN, M. Ziembicki coordinates Front-end for COMPASS, BE-BI will check compatibility and use this as a pilot project



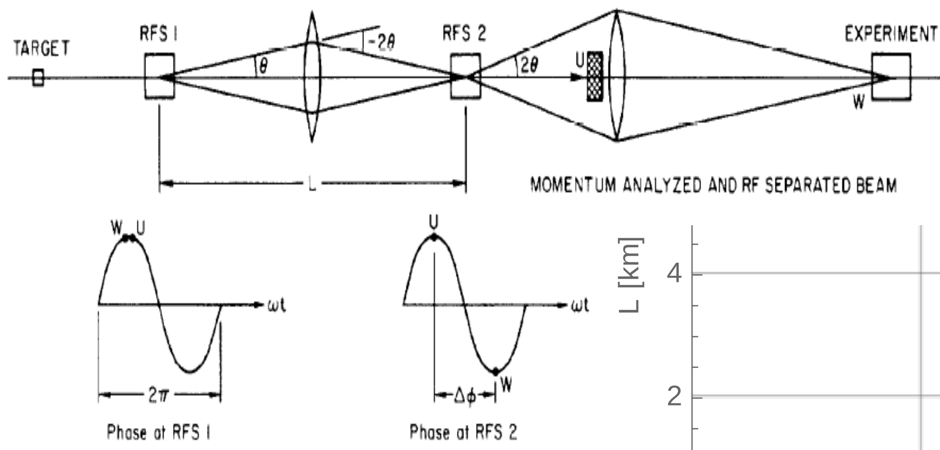
S.Mathot

<u>CEDAR Thermal stabilization:</u>

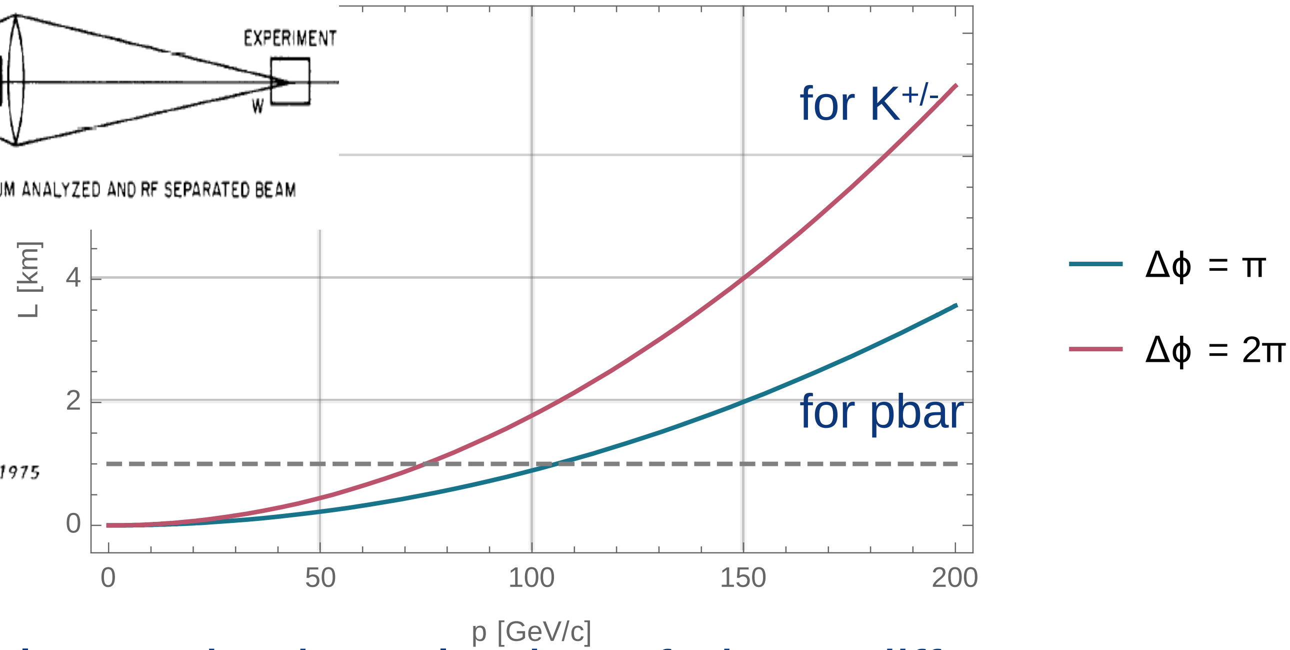
- Target temperature: 23°C
- Stability: 0.1°C
- External temperature range: +15°C / +30°C
- CEDAR : total length: 6000 mm
  main diameter: 558 mm
  external surface: ~ 10 m²
  total mass: 2.3 tons
  fill: He, 4 bar
  chamber material: Steel (AC 52.3)
- Thermal housing internal diameter: 770 mm
- Insulation thickness: 50 mm
- Air volume inside the thermal housing: ~ 1.6 m³
- Internal heat load: ~ 50 W

RF-separated Beams

Note: Preliminary considerations, guided by initial studies for NA62 and CKM studies by J.Doornbos/TRIUMF, Panofsky-Schnell-System with two cavities



IEEE Transactions on Nuclear Science, Vol.NS-22, No.3, 1975



- Selection of particle species by selection of phase difference
  $\Delta\Phi = 2\pi\,(L\,f\,/\,c)\,(\beta_1^{-1} - \beta_2^{-1})$
- Estimated flux (100 GeV/c): **8 10^7 pbar/pulse** (for current RP limit in EHN2: 5 10^7 pbar/pulse), K^+ case: flux about 75%

NA61 Higher Intensity

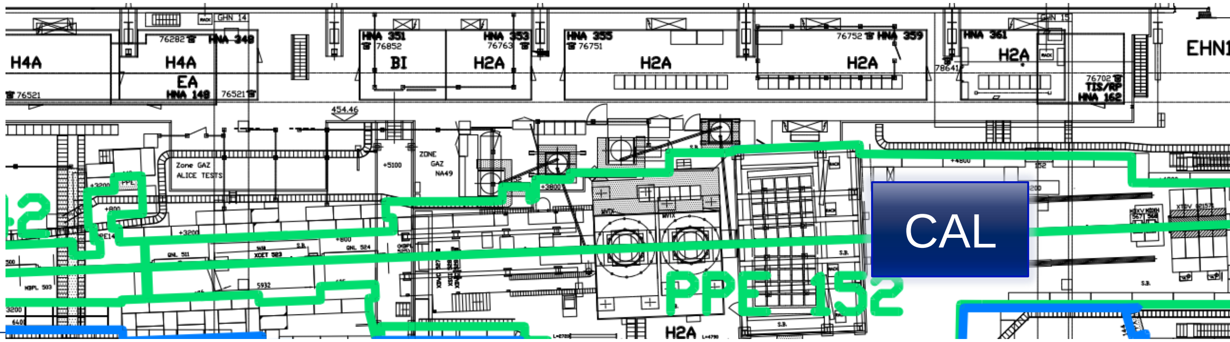
- As expressed during the workshop “NA61 Beyond 2020”, **higher intensities** are necessary for improving the open charm and multi-strange hadron measurements.

  → 2 10^6 ions per spill !

- A radiation mapping during the 2017 ion run revealed that extra shielding will be needed around the calorimeter in PPE152 and a possible re-arrangement of the zone.

→ FLUKA simulations needed for the optimization of the shielding and the optimal positioning of the door in collaboration with HSE/RP

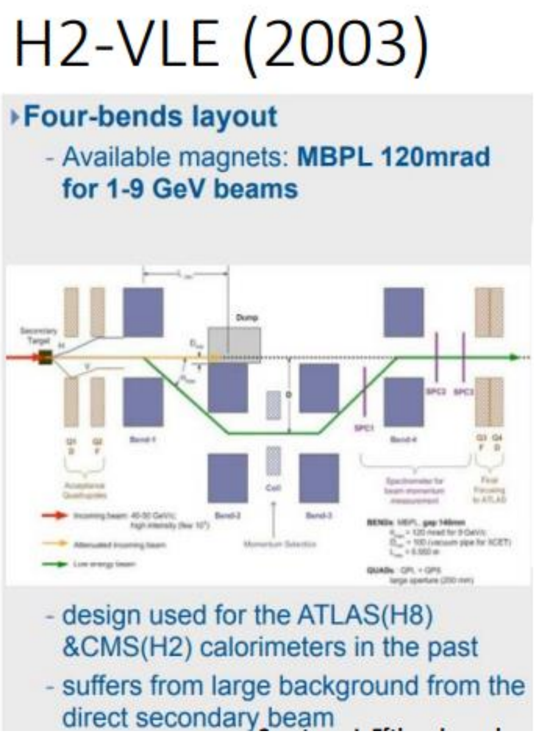
Green line: current PPE152 zone limits.



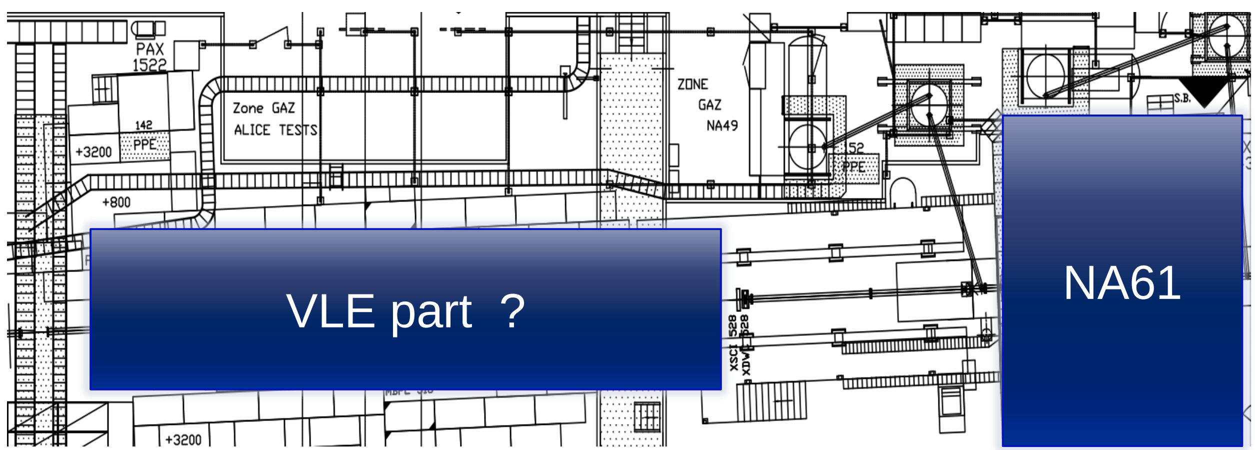
N.Charitonidis

Low Energy Beams for NA61++

- Increasing interest for beams < 10 GeV/c
- To be studied: 4-bends layout at PPE132 (already implemented in the past)



- A similar layout could be envisaged for NA61++
- **Background** and **proton content** the biggest challenges, along with the **magnets' availability**



Yet to come

- Continue the on-going studies
- Prepare for 2018 test beam requests
- Optimisation of NA62 beam dump for long run
- Detailed studies for KLEVER beam using FLUKA and/or G4-beamline
- RF separated beam for COMPASS
  User requirements being updated by COMPASS.
- Feasibility, and cost estimates to be worked out in detail (including technical, RP and safety aspects).
- Possibly new projects?

Thanks to the colleagues in the EA group and
in the Conventional Beams working group

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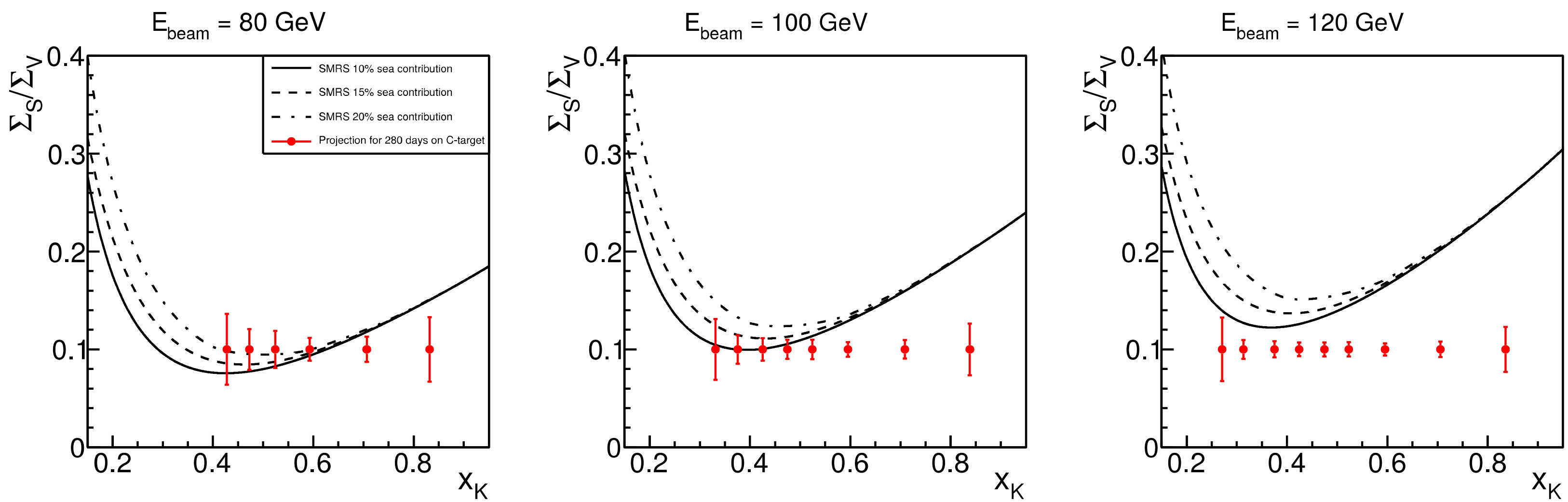
DEPARTMENT

COMPASS RF separated beam for K±

Initial results: Projections for valence/sea separation for Kaons



- **First measurement of sea in kaons**
- Not yet optimised apparatus
- Intensity for K^+ and K^-: $2 \times 10^7\ s^{-1}$
- 280 days of data taking comprising both polarities

Expected statistics in HMDY

Experiment	Beam type (GeV)	Intensity (/s)	Target	DY events
NA3	K^- (150)	0.25×10^7	Pt	688
	K^- (200)	0.93×10^7		90
	K^+ (200)	0.22×10^7		170
This exp	K^- (80)	1.9×10^7	C	593
	K^- (100)	2.3×10^7		1,800
	K^- (120)	2.5×10^7		3,600
This exp	K^+ (80)	1.7×10^7	C	482
	K^+ (100)	2.1×10^7		1,700
	K^+ (120)	2.3×10^7		3,700

- Statistics with 280 days with a sharing K^-:K^+ $\sim$ 1:7
- Purity of the beam is around 30%, can it be better?
- Obvious gain in intensity with RF separated beam compared to NA3

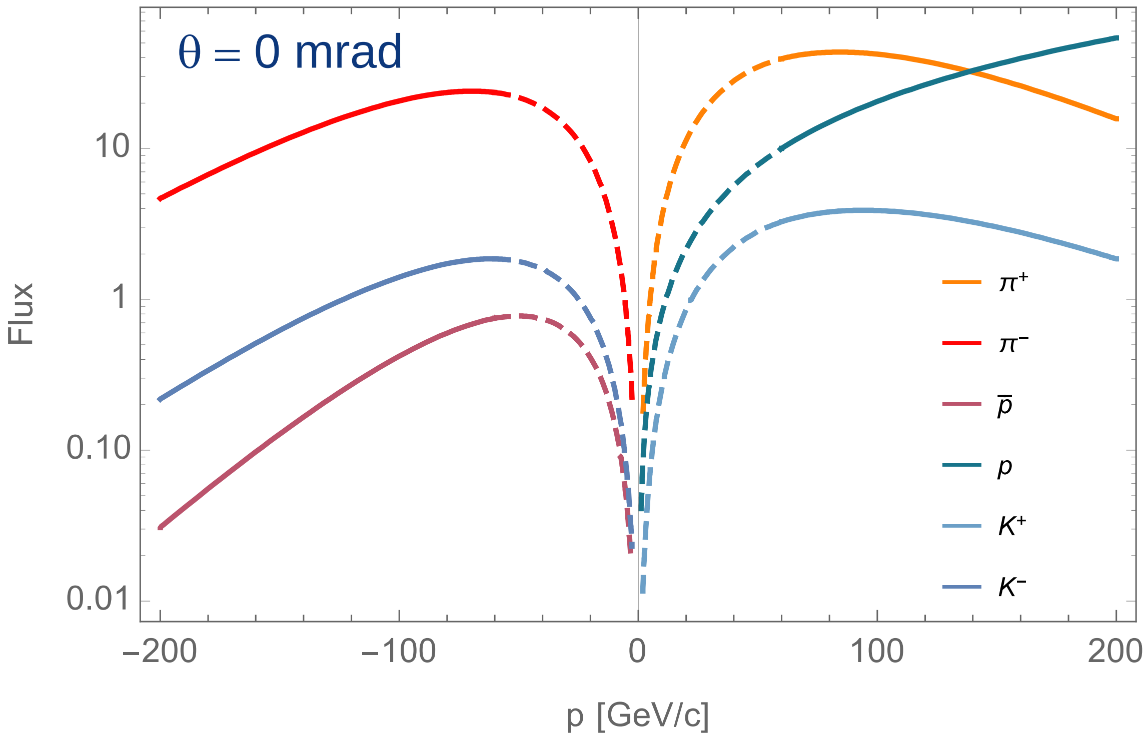
Particle Production

Atherton parameterisation (CERN 80-07):

$$\frac{d^2N}{dp\,d\Omega} = A\left[\frac{B}{p_0}\,e^{-Bp/p_0}\right]\left[\frac{2Cp^2}{2\pi}\,e^{-C(p\theta)^2}\right] \qquad \frac{d^2N}{dp\,d\Omega} = A\left[\frac{(B+1)}{p_0}\left(\frac{p}{p_0}\right)^B\right]\left[\frac{2Cp^2}{2\pi}\,e^{-C(p\theta)^2}\right]$$

with primary momentum p_0 and production angle θ

Flux per solid angle [steradian], per interacting proton, and per dp [GeV/c]



	A	B	C
p	0.8	-0.6	3.5

	A	B	C
π^+	1.2	9.5	5.0
π^-	0.8	11.5	5.0
K^+	0.16	8.5	3.0
K^-	0.10	13.0	3.5
$\bar{p}$	0.06	16.0	3.0

RF separated beam: specification from Hadron spectroscopy (Kaon)

- particle type / beam composition: K^- or K^+ depends on beam purity and maximum beam evergy

- beam intensity: $5x10^6$ kaon/sec

- beam energy: > 120 GeV, optimal value would be close to 190 GeV (but seems unfeasible)

- beam momentum spread: 1% . Larger spreads could be tolerated if novel beam-momentum stations with low material budget will be used (preferred solution)

- beam super-cycle structure no special requirement; high duty factor would be good

- beam spot size: Requirements are quite relaxing - below approx. 2x2 cm^2 (target size)

- beam particle identification: unless RF separation reduces the contribution of other beam-particle species to the single-digit percent level, CEDAR PID would be mandatory

- precise beam particle time stamp: would be required only if beam intensity would be so high that fraction of pile-up events would become an issue

- beam time request: at least 1 running year (~200 days) with the intensity $5x10^6$ Kaons per second

- what can be done in parallel: at least part of Primakoff and Direct Photon Program

antiproton beam:
specification from Hadron spectroscopy

- particle type / beam composition: antiprotons

- beam intensity: 5 x 10^6 antiprotons per second

- beam energy: around 20 GeV, or less

- beam momentum spread: beam momentum measurement probably needed (low material budget)

- beam super-cycle structure no special requirement; high duty factor would be good

- beam spot size ? below approx. 2 x 2 cm^2

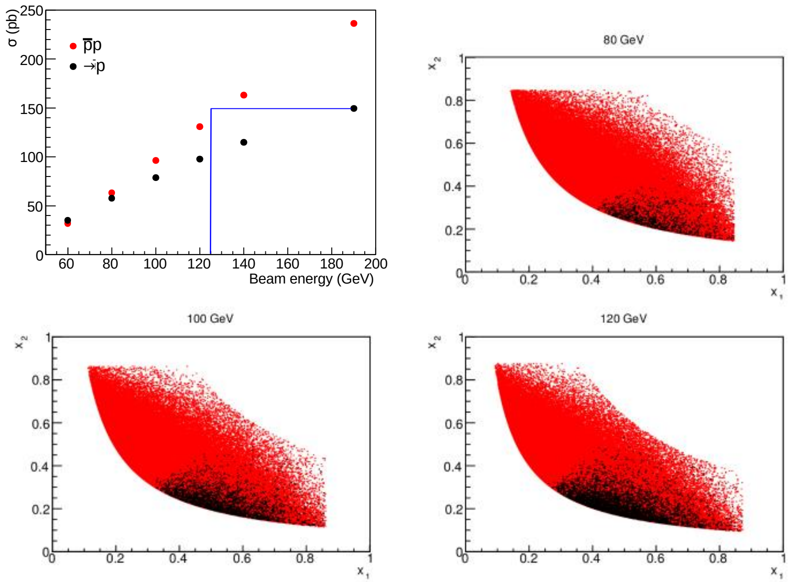
- beam particle identification (particle by particle..) pbar PID/tagging will be needed if contaminated by hadrons of other type (kaons, pions)

- target: lH2, luminosity to be calculated

- beam time request 1 running year (~200 days) with the intensity 5x10^6 anti-protons per second

COMPASS RF separated beam for pbar

Anti-proton with a RF separated beam



Possibility to study valence proton TMD PDFs in a model free way

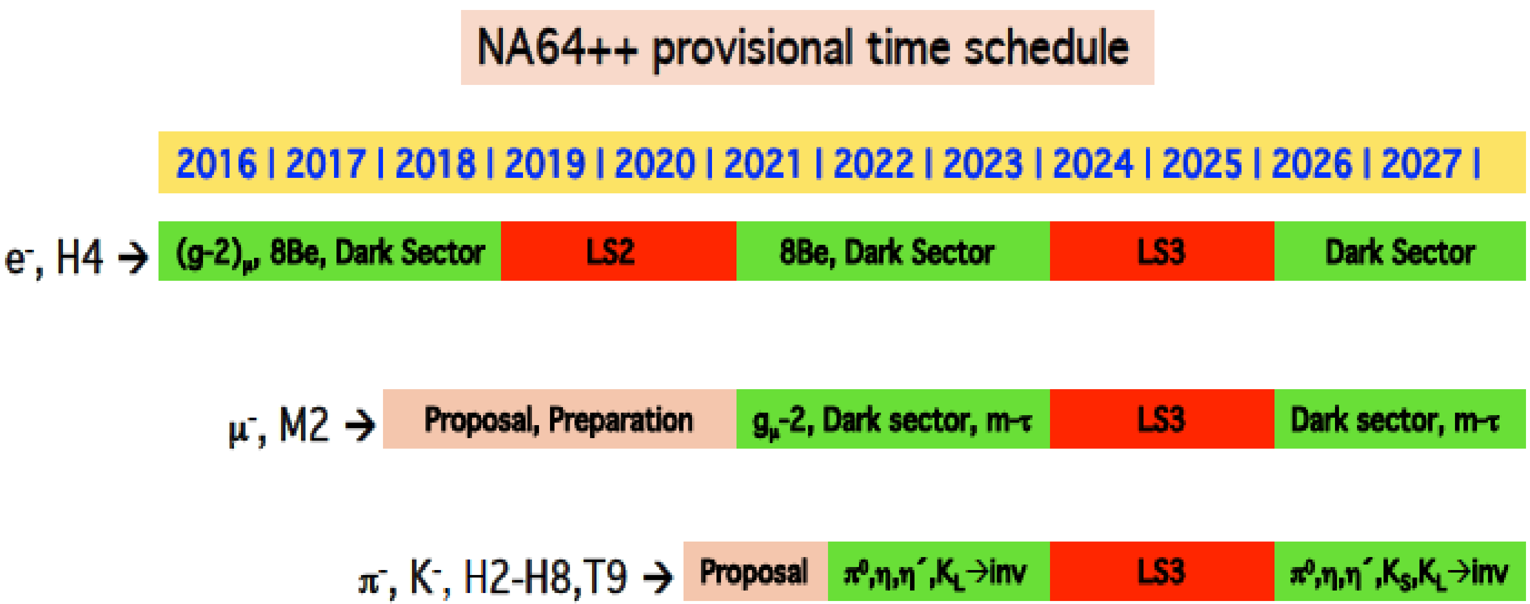
Beam (GeV)	$I_{\bar{p}}$ (10^7/ s)	Acc.
$\bar{p}$ (80)	3.2	6%
$\bar{p}$ (100)	2.7	11%
$\bar{p}$ (120)	2.3	15%

- ≥ cross-sections for $\bar{p}$ induced-DY at 120 GeV and $fi^{\neq}$ induced-DY at 190 GeV
- Apparatus with pol. target does not meet specs imposed by the new beam energy
- Necessity to squeeze the apparatus

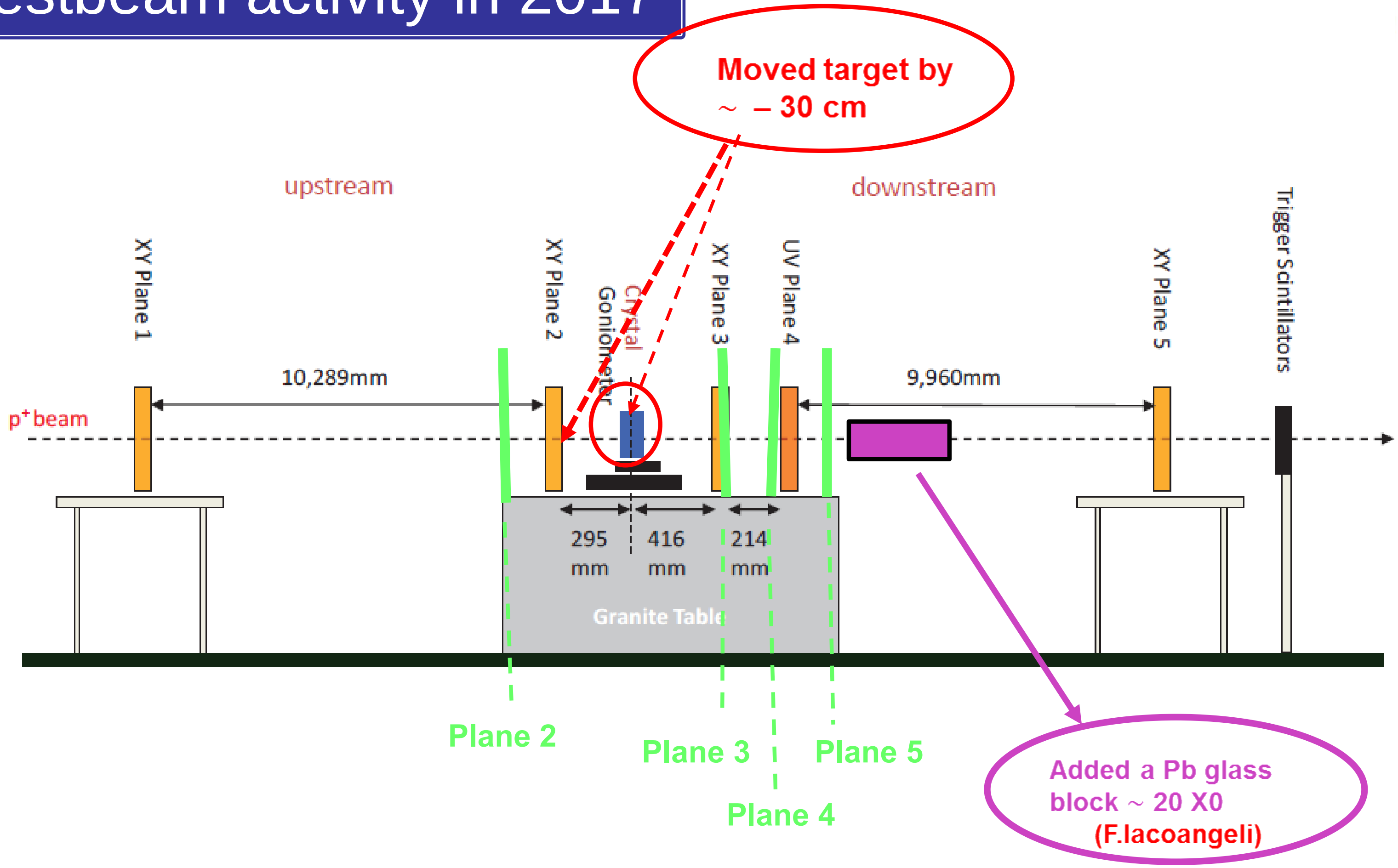
NA64 schedule

→ **NA64 results show that the combination of an active beam dump and missing-energy techniques is a very powerful tool to search for dark sector physics.**

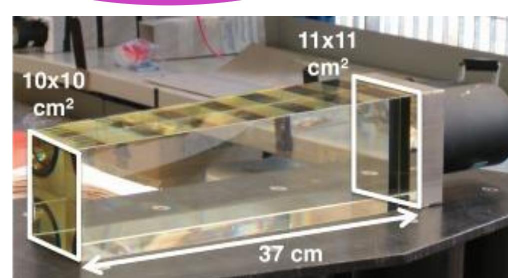
→ **The proposed searches of dark sectors in NA64 with leptonic and hadronic beams have unique sensitivities and are highly complementary to similar project.**



Testbeam activity in 2017

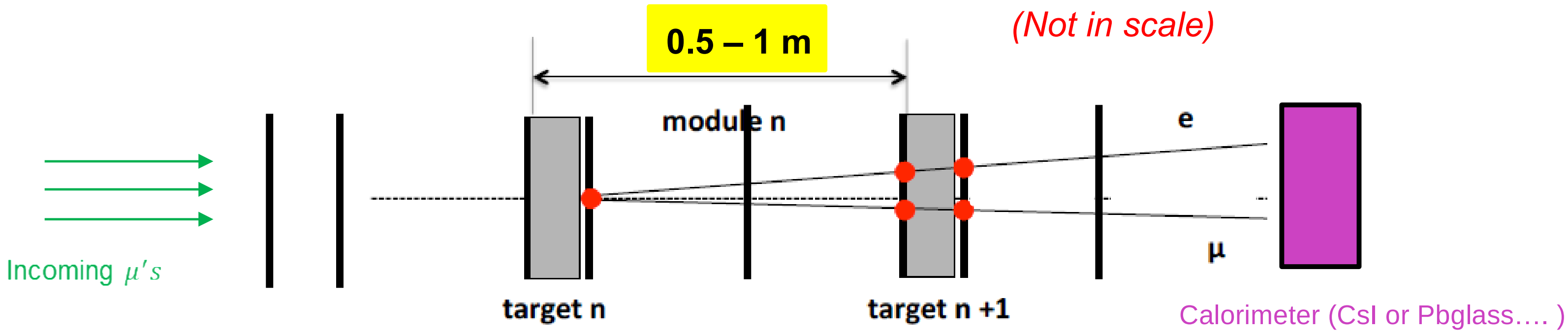


➡ Increase acceptance to about 20 mrad



Plans for 2018 activities

We got from INFN the approval and some financing to assemble a prototype with 2 targets modules:



8 planes of 9.5x9.5 cm Si (16 layers)

- > 10 Si sensors already in hands, electronics and DAQ existing,
- System can be operated remotely

New manpower joined the collaboration, with experience on Si detectors and data analyis

Plans: to run behind COMPASS in 2018 to take muons whenever COMPASS will use them & request for 1 week testbeam

Status and timeline

KLEVER

Project timeline – target dates:

2017-2018 **Project consolidation and proposal**
- Beam test of crystal pair enhancement
- Consolidate the design

2019-2021 **Detector R&D**

2021-2025 **Detector construction**
- Possible K12 beam test if compatible with NA62

2024-2026 **Installation during LS3**

2026- **Data taking beginning Run 4**

Expression of Interest to SPSC

Actively seeking new collaborators

Institutes interested so far:

Birmingham, Bristol, Charles U., Comenius U., Dubna, Ferrara, Florence, Frascati, George Mason U., Glasgow, La Sapienza, Louvain, Mainz, Moscow INR, Naples, Perugia, Pisa, Protvino, Sofia, Tor Vergata, Turin

Beam test of $\gamma \to e^+e^-$ in crystals

KLEVER is collaborating with INFN groups with experience with coherent phenomena in crystals for test beam measurement of pair-production enhancement

E. Bagli, L. Bandiera, V. Guidi, A. Mazzolari,
M. Romangnoni, A. Sytov (Ferrara);
D. De Salvador (LNL);
V. Mascagna, M. Prest (Milano Bicocca);
E. Vallazza (Trieste).

July 2017 AXIAL data taking, H4 beamline
Run Coordinator: L. Bandiera

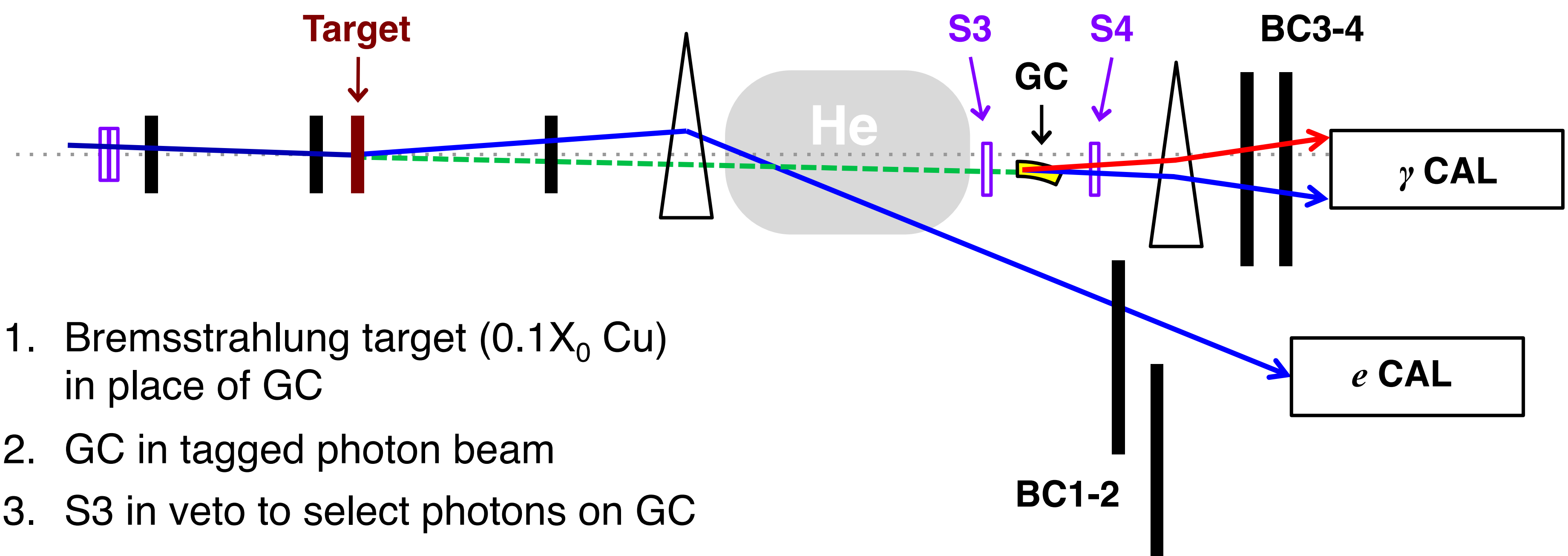
Test goals:

1. Observe $\gamma \to e^+e^-$ enhancement with a commercially available tungsten crystal
2. Measure spectrum of transmitted γ energy for a thick (~10 mm) crystal
3. Measure pair conversion vs. E_γ, θ_{inc} for $5 < E_\gamma < 150$ GeV
4. Obtain information to assist MC development for beam photon converter and SAC

Beam test of $\gamma \rightarrow e^+e^-$ in crystals

KLEVER

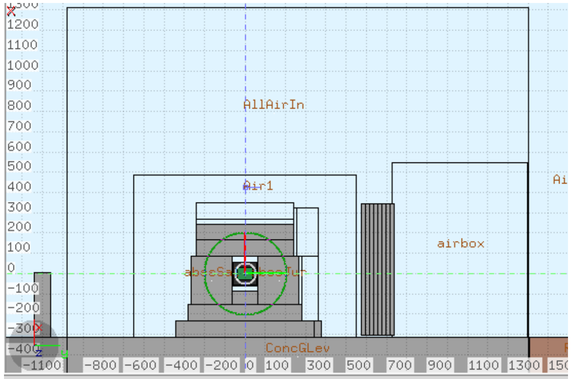
Tagged photon beam setup for H4 (or H2) test beam:



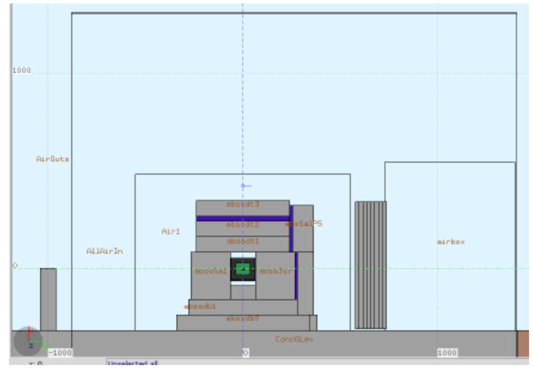
1. Bremsstrahlung target ($0.1X_0$ Cu) in place of GC
2. GC in tagged photon beam
3. S3 in veto to select photons on GC
4. S4 to detect pair conversions
5. BC1-2: 9.5 × 9.5 cm^2 Si detectors to extend coverage of tagging system
6. Analysis magnet and BC3-4 to assist in reconstruction of e^+e^- pairs
7. He bag to reduce multiple scattering

- **Nearly all detectors and DAQ system available for use from AXIAL**
- **INFN has approved funds for crystal samples, etc.**
- **1 week of beam requested in 2018**

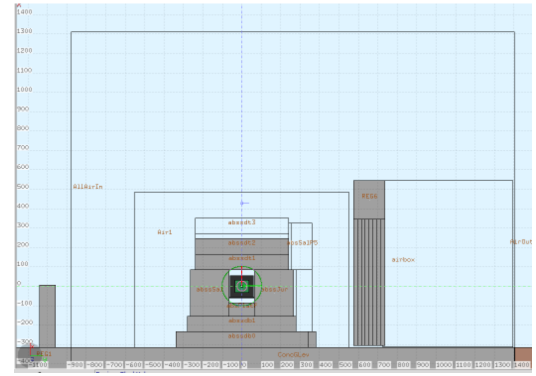
COMPASS DY Shielding studies (H.Vincke)



old shielding: final-13

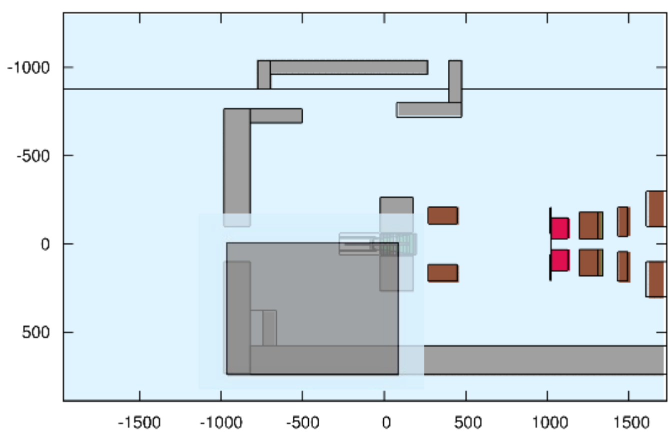


Final-14



Final-13+ increased height of concrete wall 1.6 m thick, 2 m high, 20 m long

Final-13 + roof



Final-14 + larger roof + Ni target