Question(s) from PBC/QCD conveners

- How would you assess the possibility of running the μ proton-radius and the μ-electron scattering measurements in parallel at CERN M2 beam-line ?

  ==> It would certainly be a strong point for a continued (future) muon program …

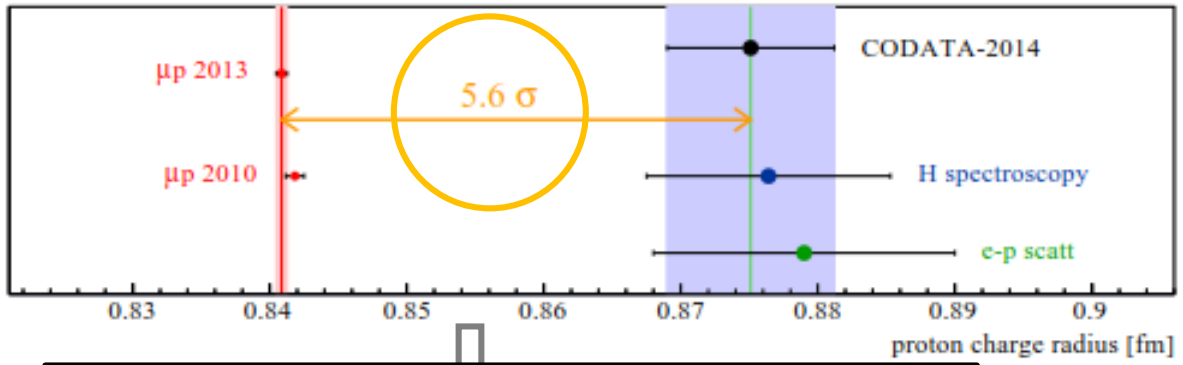
  ==> Would the two measurements be “compatible” ?

  ==> If YES, such hybrid solution might be hampering the project's requirements of excellent control of systematics ?

Proton radius measurement using μ-proton elastic scattering at COMPASS

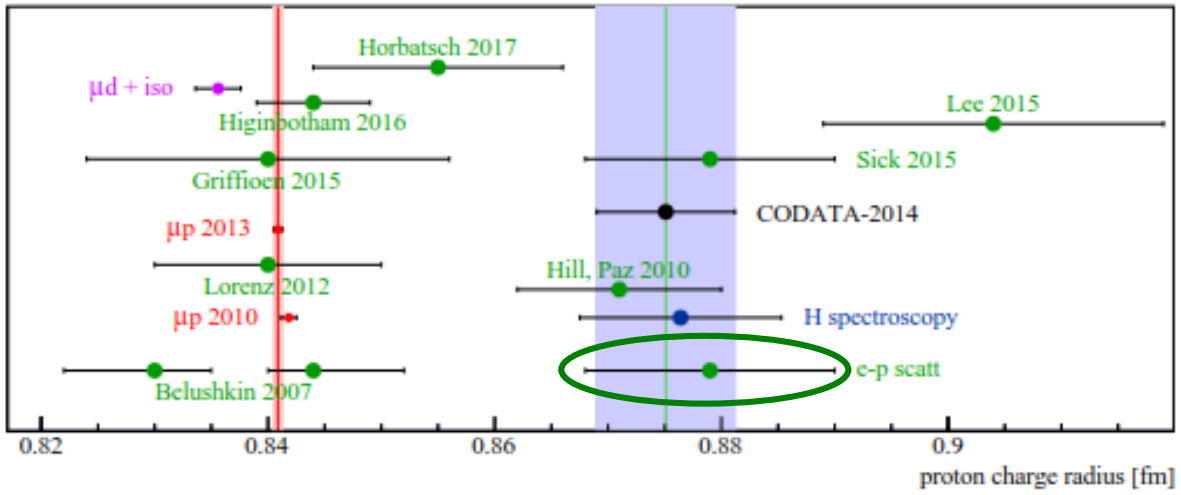
μp Spectro

ep Spectro
ep Scattering

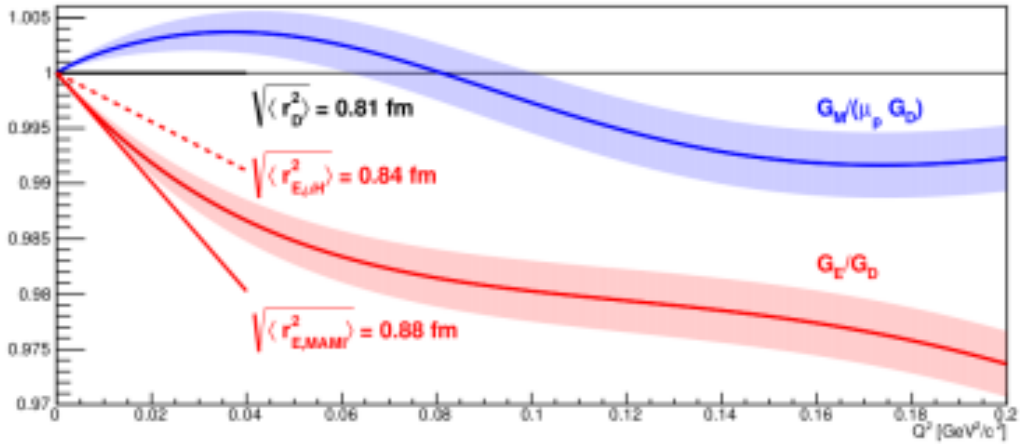


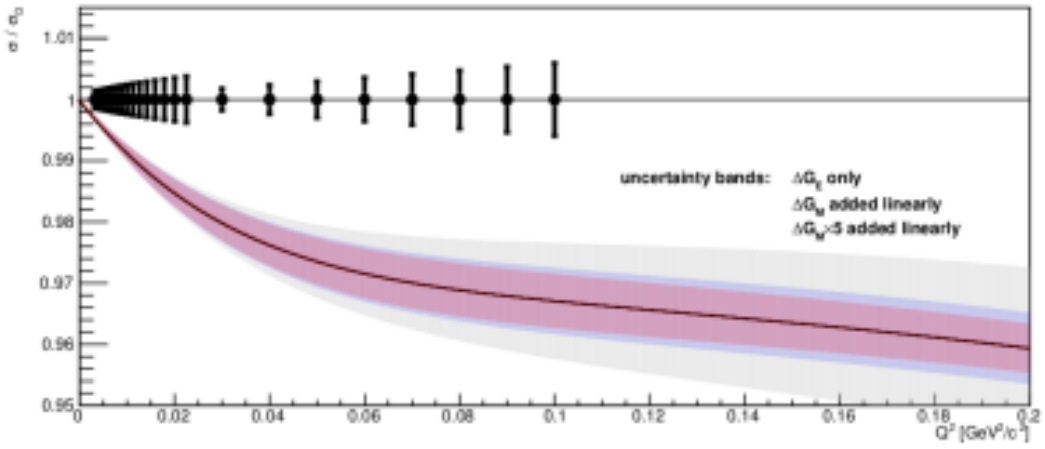
Using updated Rydberg constant

ep Spectro



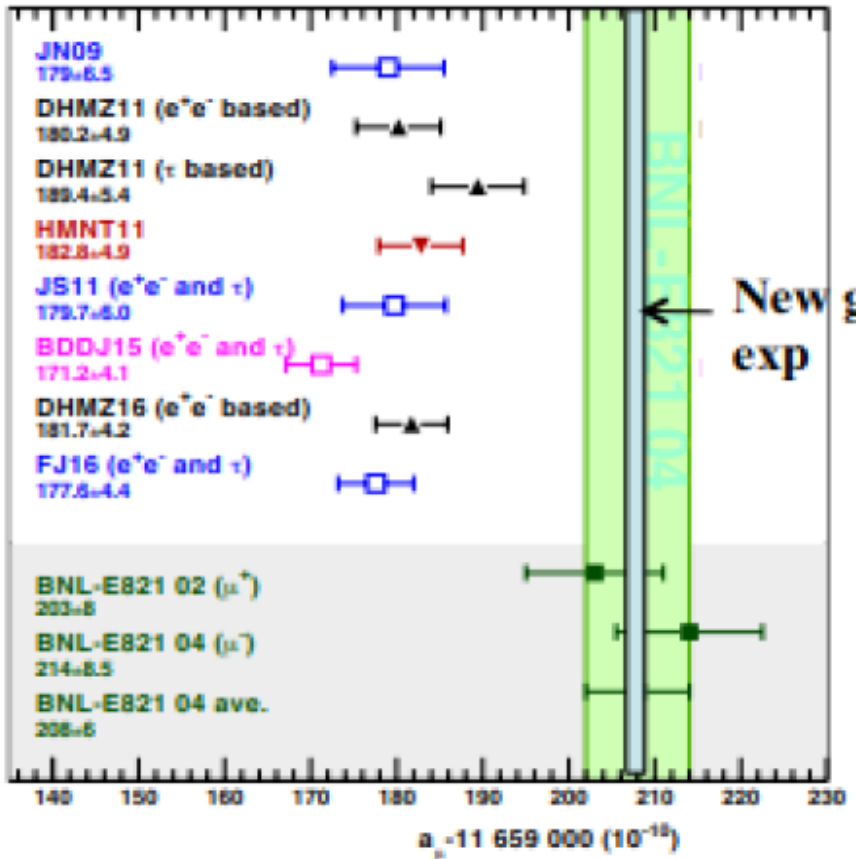
Proton form factor measurement in High-E μ-proton elastic scattering (J.Friedrich)





High precision measurement of a_μ^{HLO} using μ-e elastic scattering at M2 beam

- 3.5 σ discrepancy on $a_\mu = (g-2)_\mu/2$ between Experiments and SM (> 10 years)
- Theory limited by Hadronic Leading Order a_μ^{HLO} correction (accuracy ~ 0.5%)
- New g-2 Experiments will require (if possible) × 4 improvement for a_μ^{HLO} accuracy

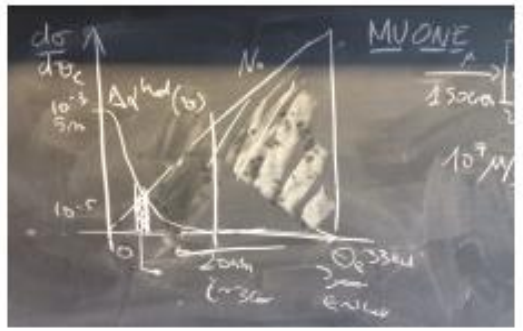


MUonE

A high precision measurement of a_μ^{HLO} with a 150 GeV μ beam on e⁻ target at CERN

G. Abbiendi, M. Alacevich, M. Bonomi, C.M.Carloni Calame, D. Galli, F.V. Ignatov, M. Incagli, U. Marconi, C. Matteuzzi, G. Montagna, O. Nicrosini, M. Passera, C. Patrignani, F. Piccinini, F. Pisani, A. Principe, M. Prest, R. Tenchini, L. Trentadue, E. Vallazza, G. Venanzoni

CERN Physics Beyond Colliders



PBC Workshop, CERN, 21 Novembre 2017

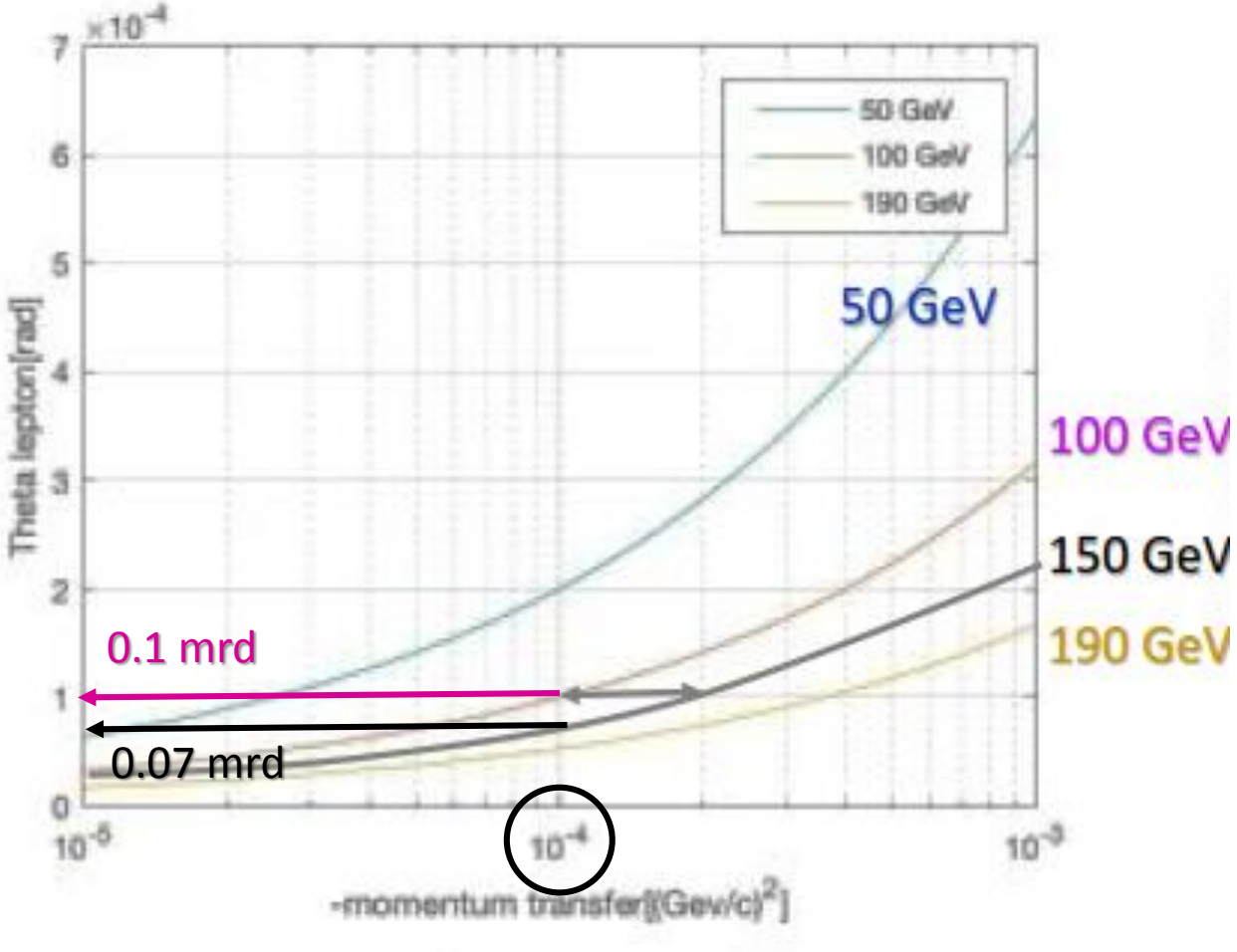
What are the Main (Important) issues ?

Both measurements need High Energy Muon Beam

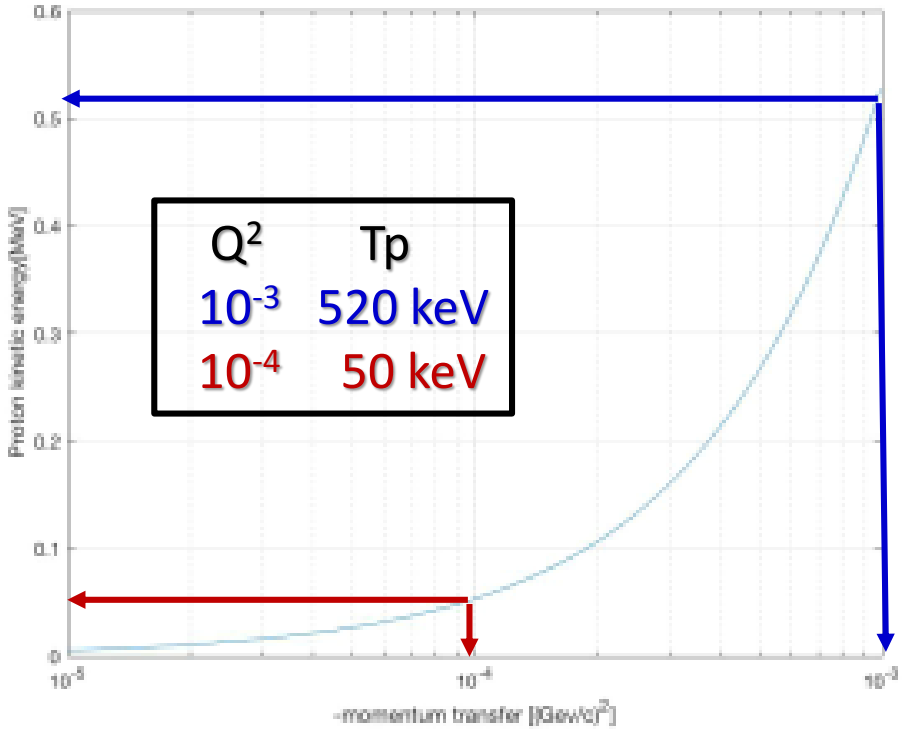
- What is Optimum μ-Energy for each ?
- What is Appropriate μ-Intensity ?
- What are Optimum set-up's locations and can they be used to run in parallel ?

What are Optimum μ-energies for μ-p radius measurement

The low Q^2 region is vital to constrain the parametrisation of the form factors and thus give more comfort for their extrapolation to $Q^2 = 0$. A lower limit of $Q^2 = 10^{-4}$ is desirable. On the other hand the region of large ($> 10^{-3}$) gives sensitivity to the charge radius. (Proposal p.2&3)

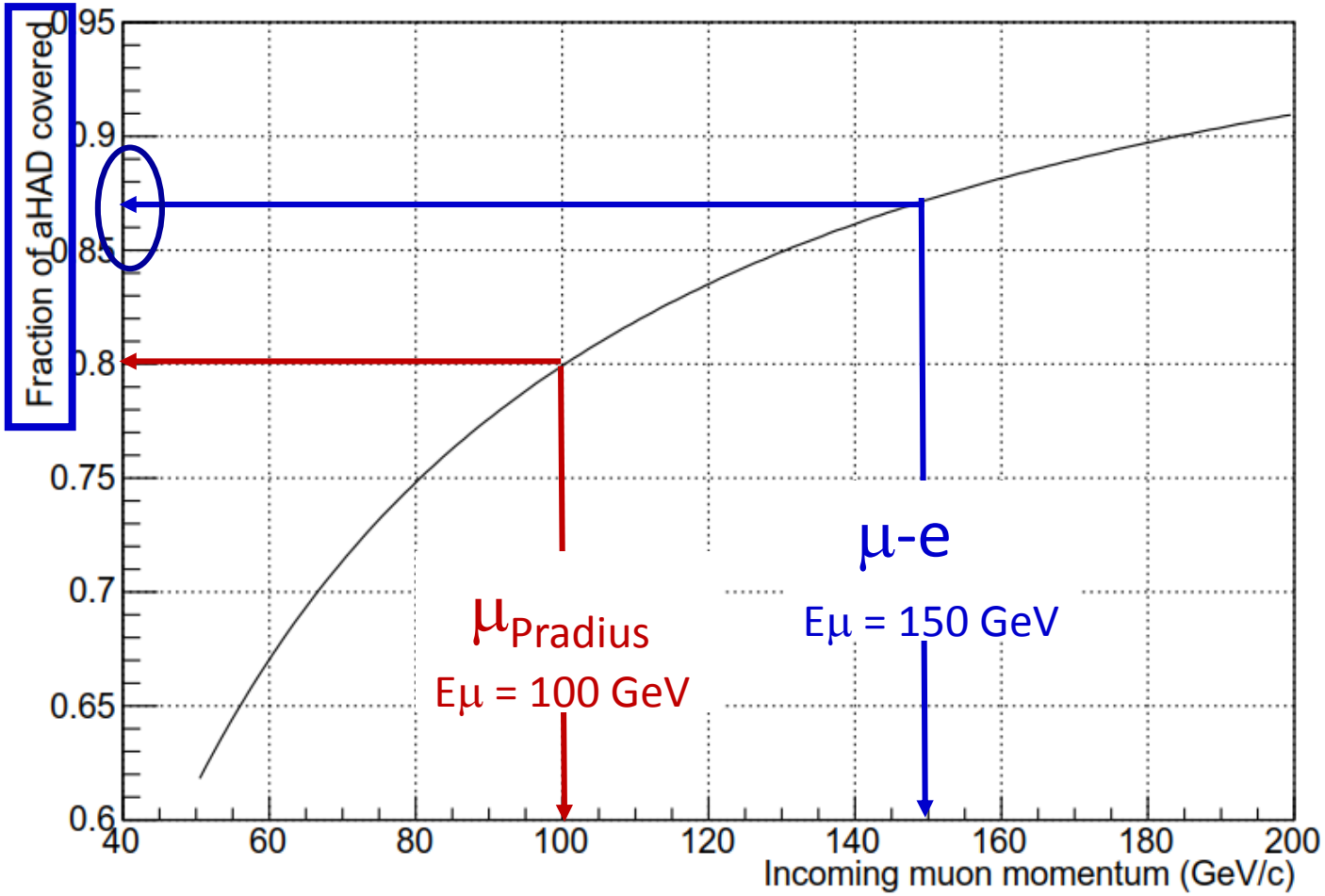


Getting low ($< 10^{-3}$) Q^2 from $\Theta_{\mu(\mu')}$ is not possible.
However the proton recoil energy can be used



What are Optimum μ–energies for μ-e measurement ?

Fraction of a_μ^{HLO} which can be accessed, from the μ-e measurement vs the incoming beam p_μ



From U. Marconi & G. Venanzoni

- In view of the accessed fraction of a_μ^{HLO} vs μ-beam momentum, the assumed 150 GeV energy is a clear lower limit to run this experiment

Why not run μ-p_{Radius} mainly at ~150 GeV and take the required statistics for very low Q^2 at $E_\mu \leq 100$ GeV ?

What are Optimum μ-Intensities for μ-p radius ….

- For low Q^2 use of a TPC is mandatory

  ==> Proposal: maximum Instant beam rate of ~ 2×10^5 μ/s (with 2 different target pressures)

  ==> From 2018 μp_{Radius} tests TPC could stand up to ~ 10^6 μ/s (analysis on-going)

  ==> New TPC set-up, also trigger-less readout should increase present beam rate limitation by (× 10 ?) under study

- For high Q^2 use SciFi technology for active target(s) and recoil proton detection

  ==> with such technology, instant beam rate of ~ 5.6×10^7 μ/s can be handled

μ-Intensities for μ-p_{Radius} ~ 10^6 μ/s to 5.6×10^7 μ/s (SciFi)

… and μ-e measurements

- Assuming intensity of the μ-beam to be $<I_\mu = 1.3 \times 10^7\ s^{-1}>$ (~ $5 \times 10^7\ s^{-1}$ in spill)

  ==> the luminosity provided by Beryllium target with $\rho_{Be} = 1.85\ g*cm^3$, $(Z/W)_{Be} = 0.44$ and a total thickness d = 60 cm(*) is: $L_{Be} = 3.9 \times 10^{32}\ cm^{-2}\ s^{-1} = 0.39\ nb^{-1}s^{-1}$

  (*)leads to 60 "modules" of each 0.5m i.e. 30m long apparatus

- The required Luminosity than can be collected in 2 years of data taking:

  ==> assuming 2×10^7 s/yr(**) is $L_{Be} = 1.5 \times 10^7\ nb^{-1}$

(**) Optimistic (rather 1×10^7 s/yr) ==> Intensity for 160 GeV μ-beam up to $5 \times 10^7\ s^{-1}$

Quoted μ-Intensities for μ-e is $5 \times 10^7\ s^{-1}$ (during SPS spill)

==> NOT compatible with μ-p_{Radius} using the present TPC technology

"Scrapper" devices could help to adjust I_μ but which space occupied ?

What are Optimum set-up's locations ?

- μ-p radius measurement requires usage of the Full COMPASS spectrometer

==> Optimum location (Si trackers and TPC) is therefore ~ target position (just Upstream SM1)

- For μ-e, two possible locations under study:

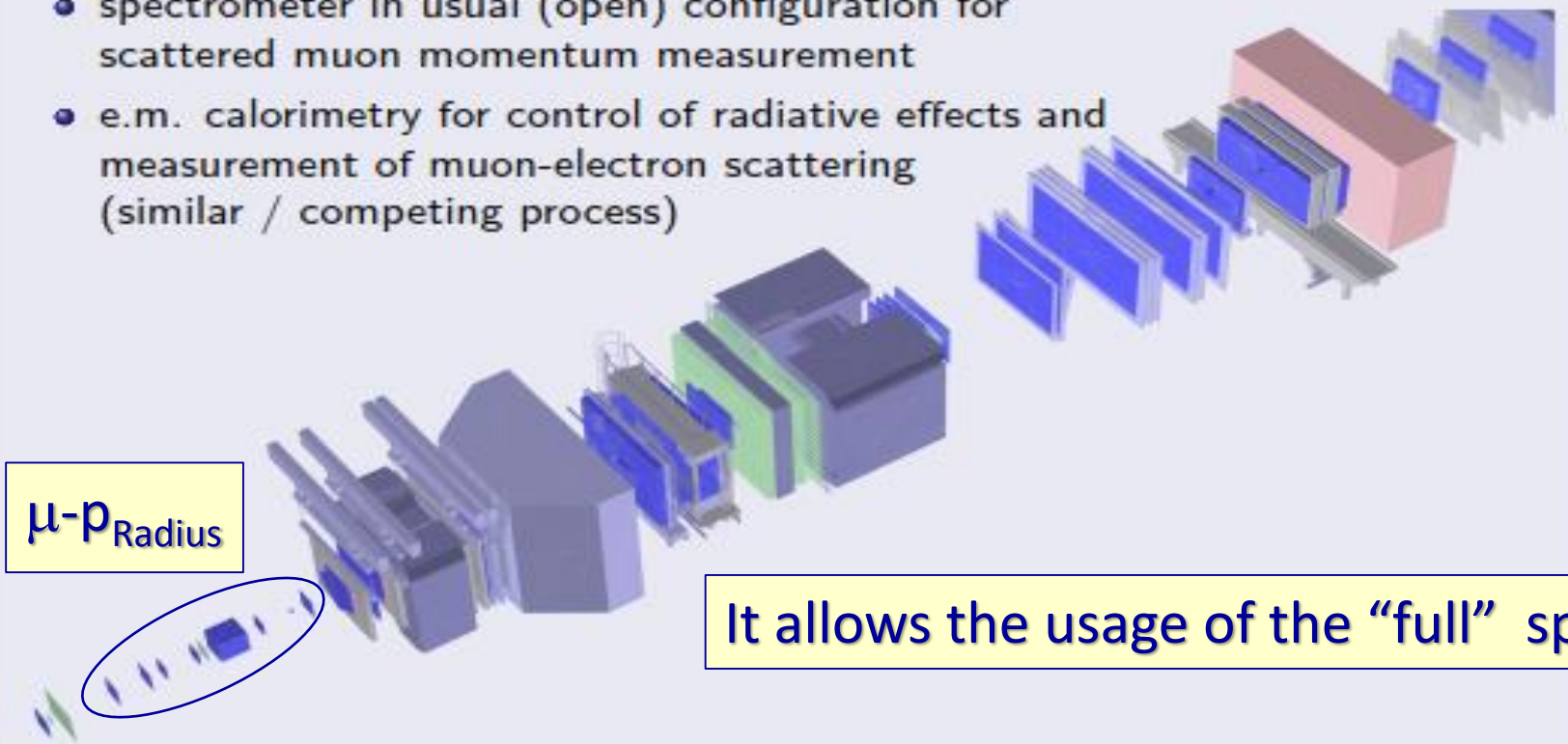
==> 1/ Upstream of EHN2 i.e. within M2 beam line

==> 2/ Downstream of COMPASS i.e. end of EHN2 (Not enough length available …)

A proposal, μ-p_{Radius} upstream of present COMPASS spectrometer (S. Uhl et.al)

Setup for the COMPASS measurement

- TPC and silicon telescopes in the nominal COMPASS target region
- trigger: two scenarios under investigation
  - SciFi with high segmentation for a "kink trigger"
  - high-rate triggerless readout
    (requires new readout scheme for the silicon detectors)
- spectrometer in usual (open) configuration for scattered muon momentum measurement
- e.m. calorimetry for control of radiative effects and measurement of muon-electron scattering
  (similar / competing process)



μ-p_{Radius}

It allows the usage of the "full" spectrometer

1/- μ-e setup upstream of present COMPASS experiment, i.e. within M2 beam-line

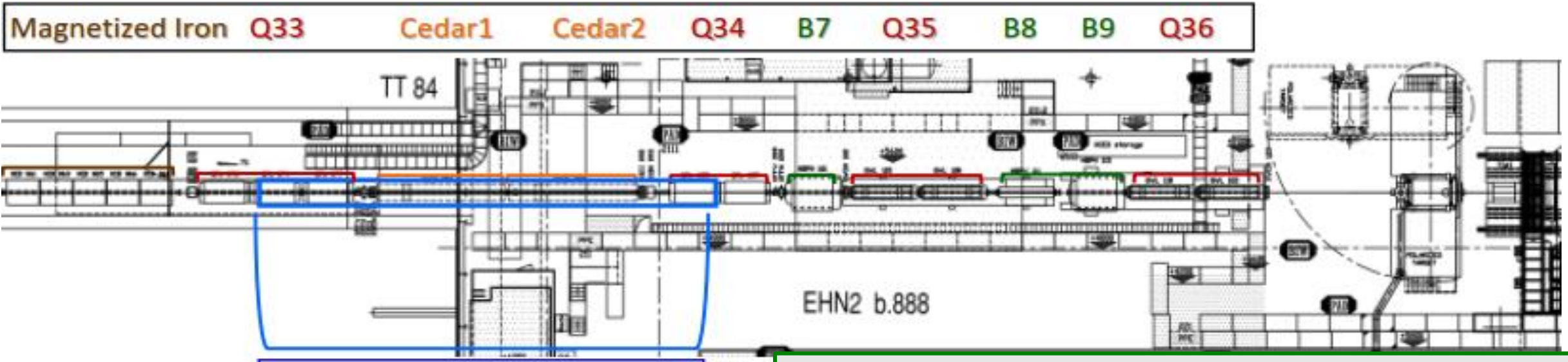
- More upstream of Entrance Area of EHN2 (Proposed by Johannes B. & Dipanwita B.)

- Pro: no interference with COMPASS spectrometer. Could allow running μ-e / μ-p_{Radius} in parallel

- Questions: will require displacements (also removal) of some M2 components.

- Beam(s) compatibility for μ-e & μ-p_{Radius} : Optic's wise looks OK (see D. B. 1st results (Add.Sl.19)

- Next issue is the required HIGH beam purity downstream of μ-e apparatus ?



μ-e Upstream (version_2)
20 => 30 m

Σ length required (updated): 35 m (targets + trackers) + 0.8 m (Ecals) + 3 m (μ-Filter) ~ 39 m

- Next issue is the required HIGH beam purity downstream of μ-e apparatus ?

- Many remarks from experts from the μ-p_{Radius} team:

==> This measurement requires high quality, excellent purity and optimized in focus and intensity muon beam.

==> In particular, due to the 100 μsec TPC response time, there should be NEGLIGIBLE low energy background.

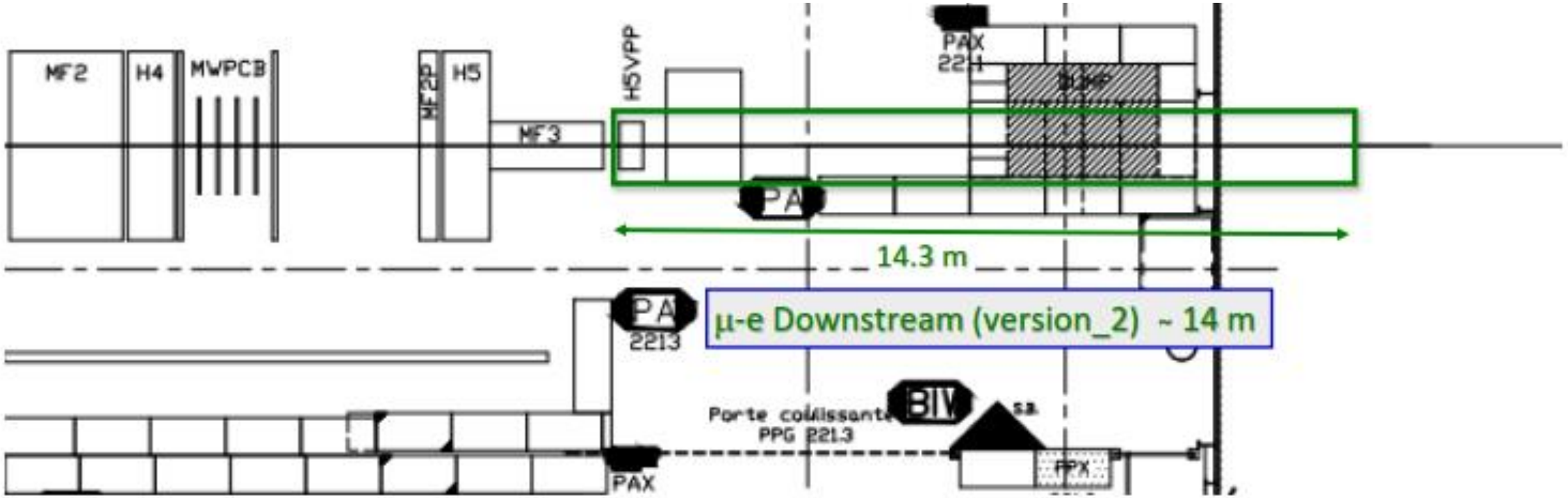
- If μ-e is installed upstream of μ-p_{Radius} which implies modification of M2 …

==> one needs to check impact of additional material, including ECAL's and μ-Filter (Add. Sl. 21) on μ-beam purity. Work is on-going

2/- μ-e setup downstream of present COMPASS setup

- Downstream Area of EHN2

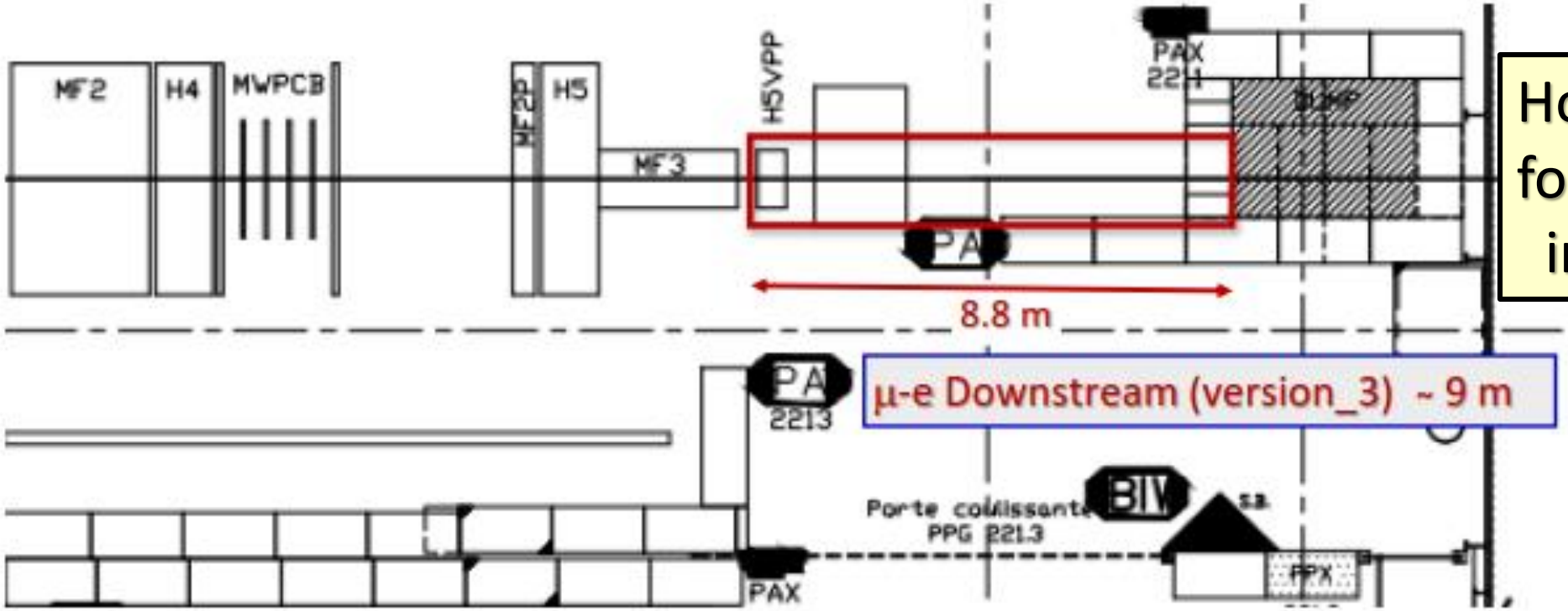
- Option: taking into account equipment required for SIDIS_Transverse (2021).
  Assuming one can run without Downstream Beam Dump ~ 14 m available
- However, adequate μ-beam tuning for both μ-p_{Radius} (TPC) and μ-e downstream not trivial to reach (Add. Sl. 20 from D.B.)



2/- μ-e setup downstream of present COMPASS setup

- Downstream Area of EHN2

- Option: taking into account equipment required for SIDIS_Transverse (2021).
  Assuming one keeps the Downstream Beam Dump.



How about option for a μ-e Pilot run in 2021/2022 ?

Conclusions - preliminary

- In view of the presently recommended locations for the two set-up's:

1/- μ-p_{Radius} "within" the existing COMPASS spectrometer.

2/- μ-e (long) set-up:
a/ upstream of experimental EHN2 hall, in the downstream section of M2 beam,
b/ downstream of EHN2 hall.

There should be NO interference for installation of the two projects together

Conclusions - preliminary

- Concerning the beam-sharing:

==> The same beam energy could be (mostly) used for the two data taking

==> A compromise for appropriate beam tuning exists for option μ-e upstream
but more difficult for option μ-e downstream

==> To run with optimum μ-beam Intensities for each project appears to be a real problem (do not exclude technical solutions)

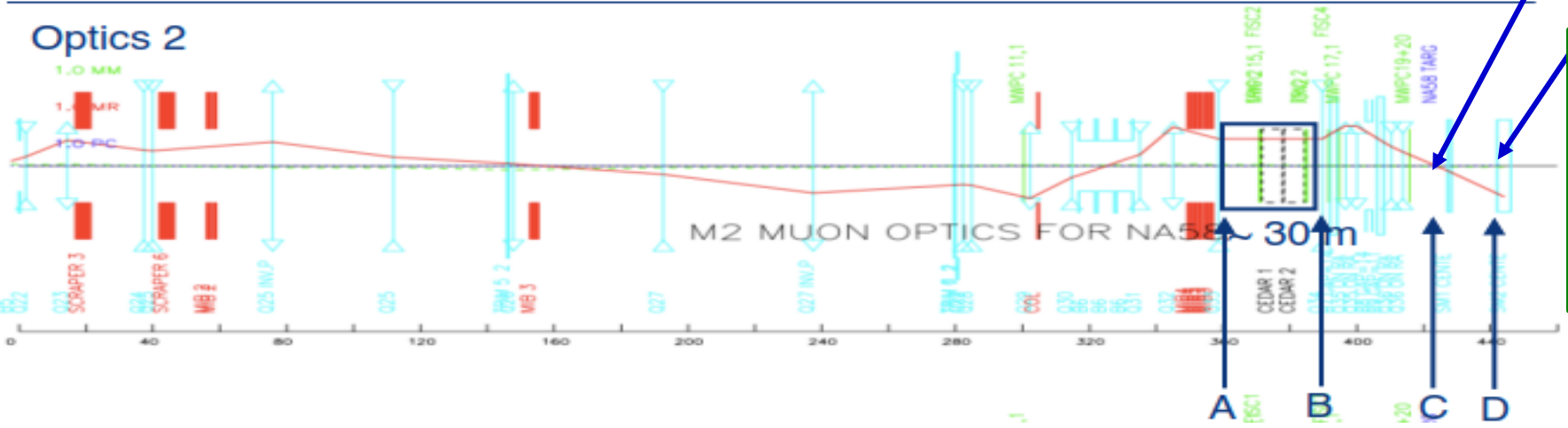
Additional Slides

- Quite promising preliminary results were shown by D. Banerjee on 28.05.2018, about the previous μ-e upstream set-up (version_2) ==> https://indico.cern.ch/event/73061

CBWG – EHN2 Status

Dipanwita BANERJEE, Johannes BERNHARD (EN-EA)
28.05.2018

- Optics 1: Focus at entrance of SM2 (for NA64)
- Optics 2: Focus at Compass target position (μ-p_{Radius})



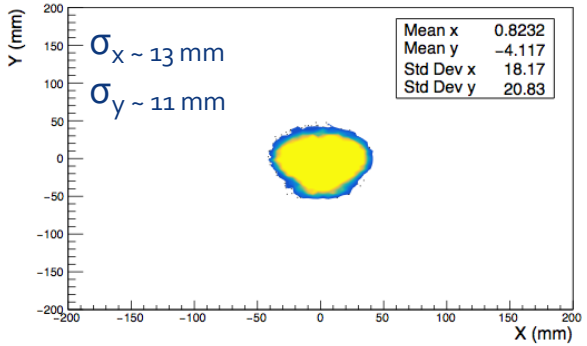
Any details and limits on required beam parameters are expected ASAP from the foreseen experiments

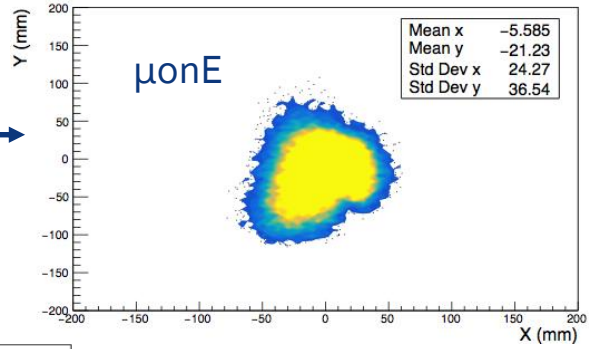
- Results show that for both tunings, Optics_1 and _2 the μ-beam has "reasonable" sizes (σ_X = 20mm, σ_Y = 26mm) and divergences ($\sigma\Theta_X = \sigma\Theta_Y$ = 0.2 mrd) at A/B positions (Upstr./Downstr. of μ-e set-up).
- Optics 1 provides convenient sizes (σ_X = 21mm, σ_Y = 18mm) and divergences ($\sigma\Theta_X$ = 0.5mrd and $\sigma\Theta_Y$ ~0.6mrd) at the D position (NA64)
- Optics 2 provides also good sizes ($\sigma_X = \sigma_Y$ = 11mm) and divergences ($\sigma\Theta_X = \sigma\Theta_Y$ = 1.0mrd) at the C position (μ-p_{Radius} trackers and TPC)

Option B for μONE EHN2

- Downstream Area of EHN2
  - Possible to have an intermediate focus slightly downstream making beam bigger for COMPASS-μp
  - Effect of dispersion remains. Optics change required to get rid of dispersion effects.
  - Divergence requirements still difficult to reach downstream for μone.

μ-p TPC



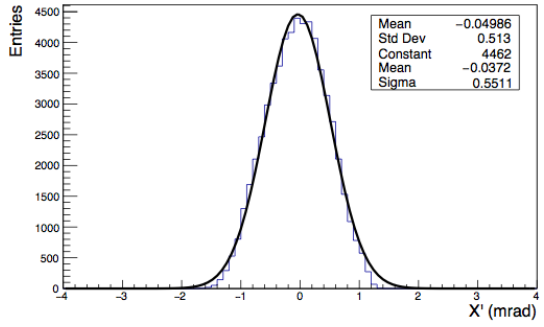


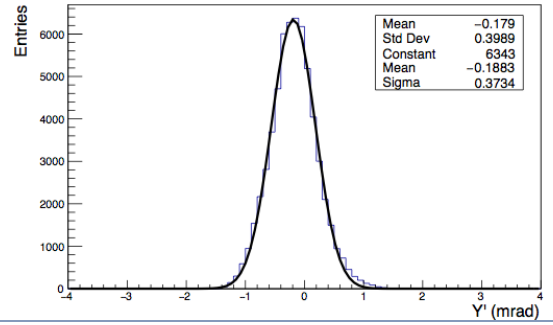
μonE Divergence -

$\sigma_{x'}$ ~ 0.5 mrad

$\sigma_{y'}$ ~ 0.4 mrad

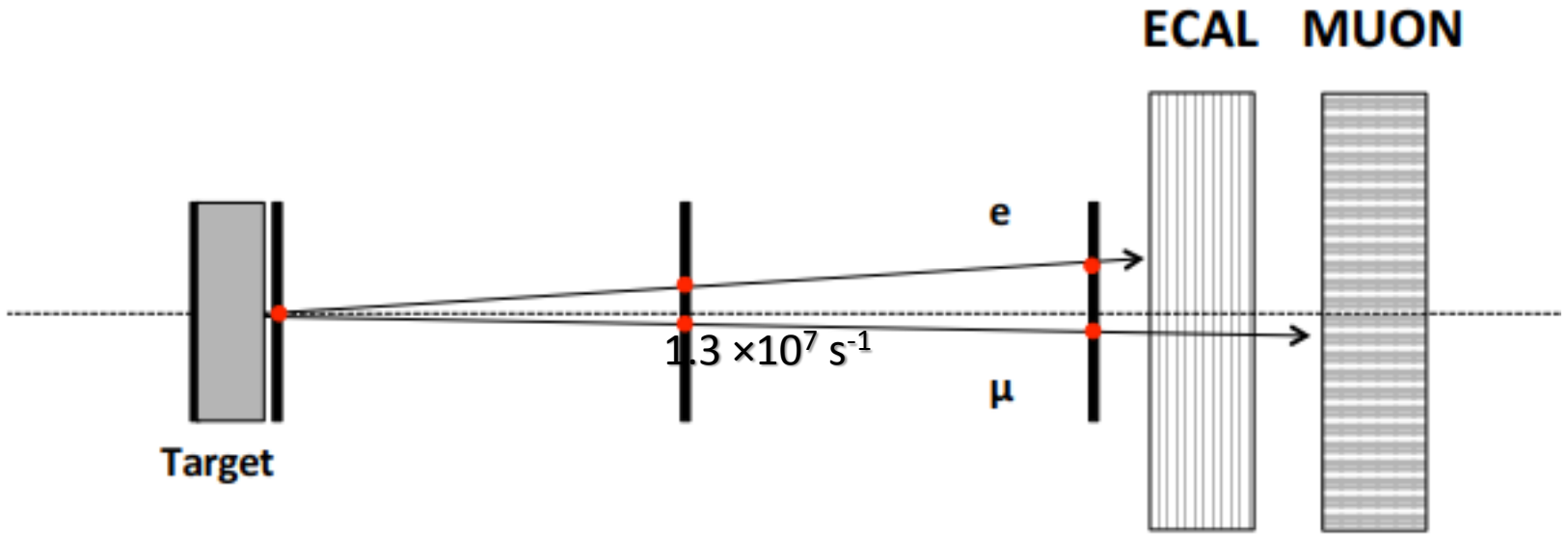
Limit < 0.5mrd





U. Marconi
INFN, Bologna

Last module of the detector



Measure both the electron angle and E_e to define the reference, calibration curve. Detailed check of GEANT

- Remark by Clara M.

==> We may need more ECALs cells for the final "long" setup ?

==> Hope to clarify ECAL(s) issue with the 2018 μ-e test data.