RF separated beam and other beam issues

Lau Gatignon, COMPASS workshop, 22 March 2016

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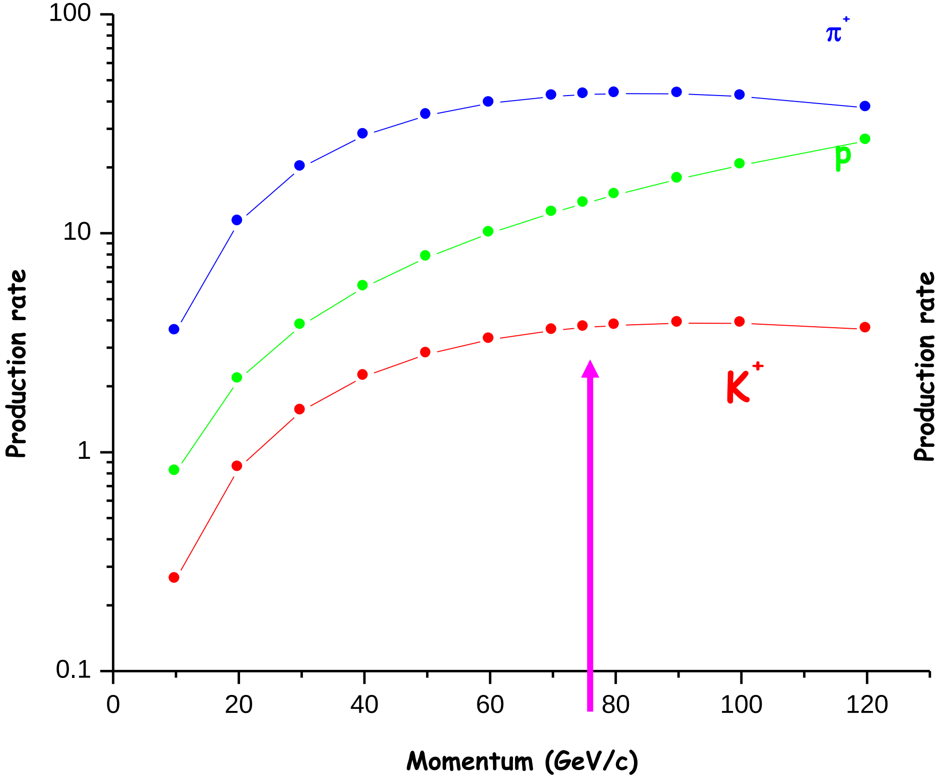
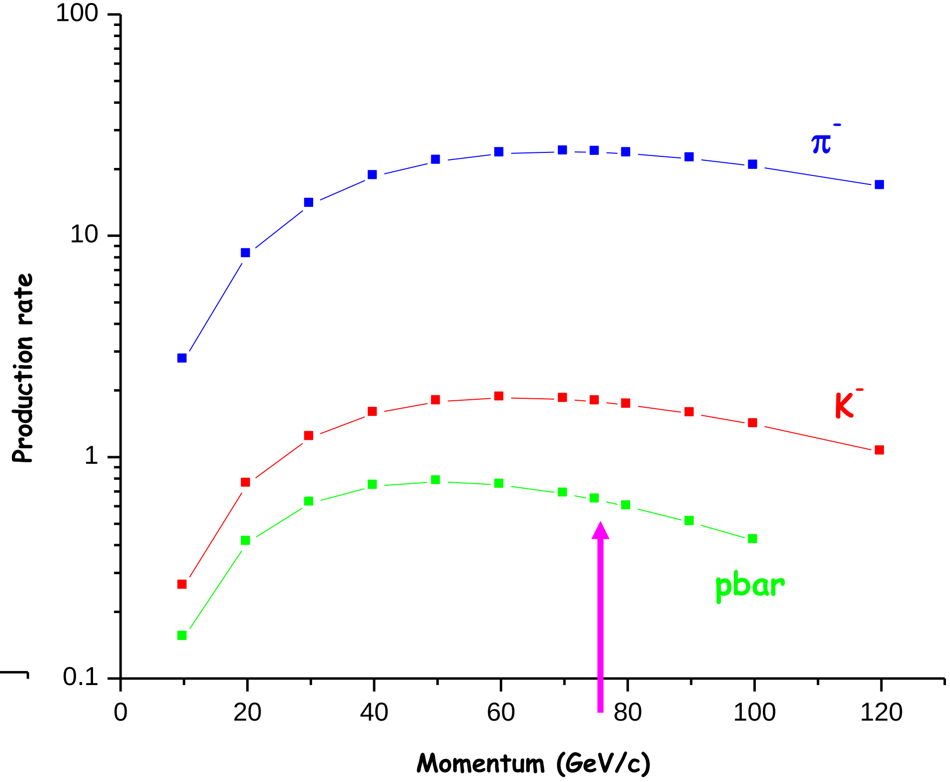
Outline

- First thought on a RF separated beam
- Other remarks on future beam options

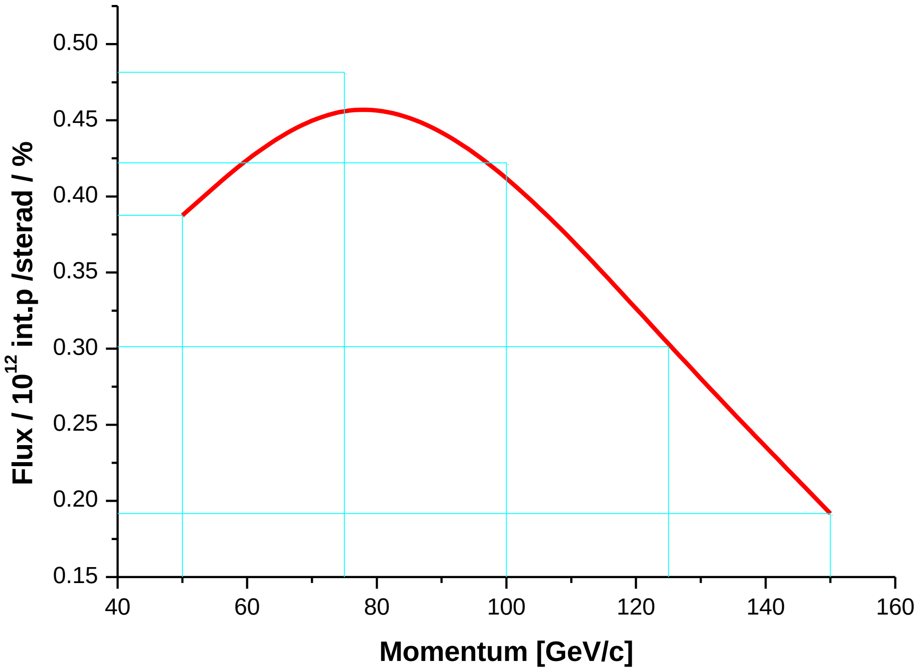
Particle production at 0 mrad (i.e. like in M2)

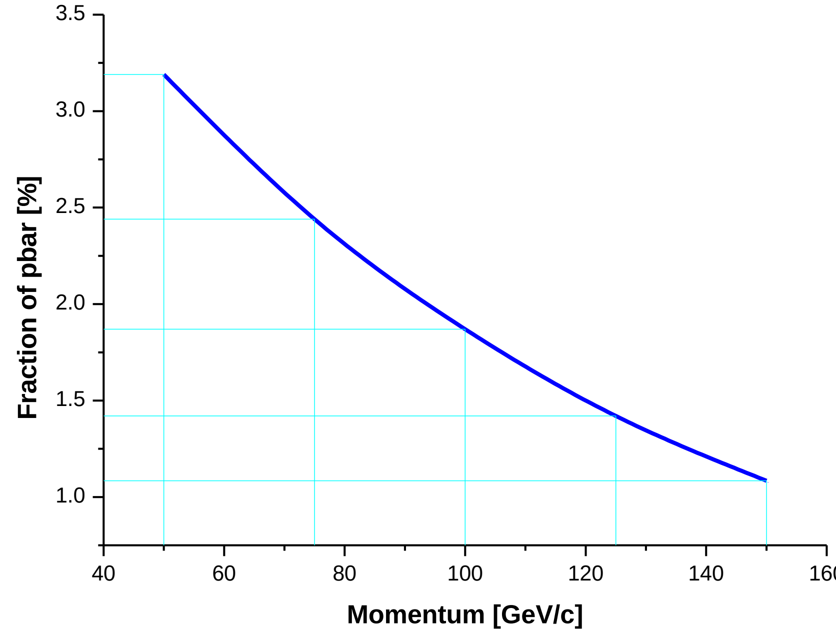
Apply ‘Atherton formula’ for 0 mrad *(only approximation for p ≤ 60 GeV/c).*
Obtain # particles per steradian per GeV/c and per 10^{12} interacting protons:





Pbar production according to ‘Atherton formula’
(for 0 mrad production angle)





Best case for flux: 80 GeV/c

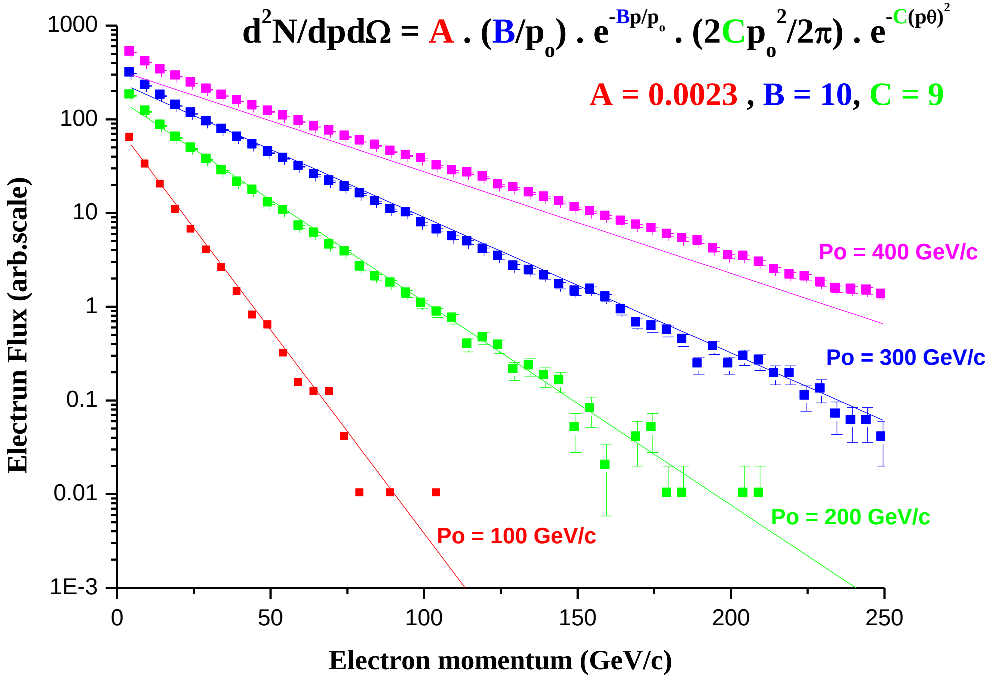
0.77 pbar / interacting proton / steradian / GeV

Pbar are 3.2% of the total negative hadron flux

However: many e^- at lower energies !!!

Electron Monte Carlo: $\pi^o = (\pi^+ + \pi^-)/2$, $\pi^o \rightarrow \gamma\gamma$,
$x=E_e/E_\gamma$ using $f(x)=x^2+(1-x)^2+2x(1-x)/3$

Paramatrisation of Electron production MC data at 0 mrad



From West Area experience:

electrons are about 8% of beam at -120 GeV/c (0 mrad)

Momentum [GeV/c]	e^- fraction [%]
50	30
100	8
200	0.7

Can reduce electron fraction with Pb sheet using Bremsstrahlung, but thick sheets will affect parallellism at Cedar …….

Try to keep e^- not too much higher than K^+ i.e. do calculation for 100 GeV/c

At -100 GeV/c one may expect the following beam composition (in %):

Particle type	Fraction at T6	Fraction at COMPASS
pbar	1.7	2.1
K^-	5.8	1.6
π^-	84.5	86.3
e^-	8.0	10.0

In present M2 hadron beam ≤ 2 10^6 pbar

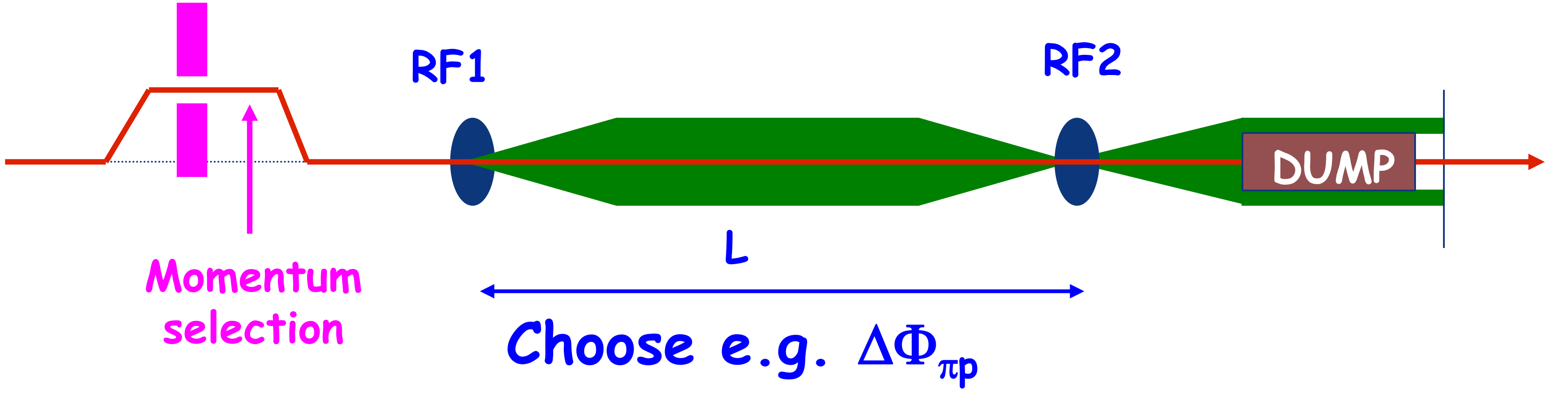
(due to 10^8 limit on total beam flux for RP)

< 10^7 for DY
If 5 10^8 total

What about a RF separated beam?

First and very preliminary thoughts, guided by
- initial studies for P326
- CKM studies by J.Doornbos/TRIUMF, e.g.
  http://trshare.triumf.ca/~trjd/rfbeam.ps.gz

E.g. a system with two cavities:



$$\Delta\Phi = 2\pi\,(L\,f\,/\,c)\,(\beta_1^{-1} - \beta_2^{-1}) \text{ with } \beta_1^{-1} - \beta_2^{-1} = (m_1^2 - m_2^2)/2p^2$$

How to choose phases?

For K$^{\pm}$ beams: $\Delta\Phi_{\pi p}$ = 360° and Φ_{RF2} such that both p and p go straight, i.e. they are dumped

$\Delta\Phi_{\pi K}$ = 94°, therefore a good fraction of the kaons go outside the dump (depending on phase at 1st cavity).

For pbar beams: $\Delta\Phi_{\pi p}$ = 180° and then $\Delta\Phi_{pe}$ = 184° , $\Delta\Phi_{pK}$ = 133°.

Choose the phase of RF2 such that pions go straight, then antiprotons get reasonable deflection, electrons are dumped quite effectively and kaons are reduced.

However, the pbar may arrive at any phase w.r.t. the RF signal $\rightarrow$ **Losses!**

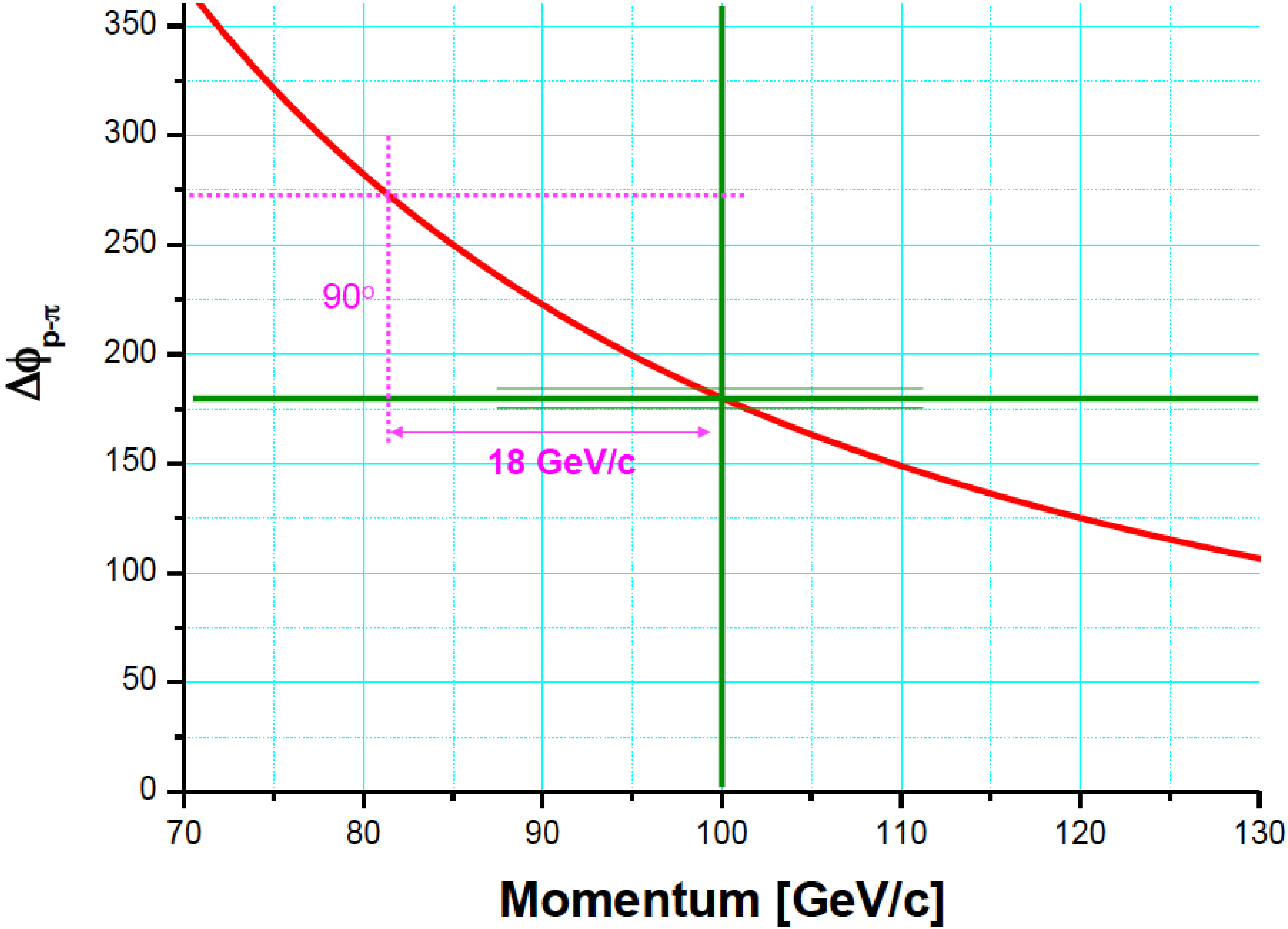
$$\Delta\varphi = \frac{2\pi}{c} L f \frac{m_1^2 - m_2^2}{p^2}$$

$\Delta\phi_{\pi p} = \pi \quad \longrightarrow \quad L\,f = 1.74\ 10^{12}$ m/s

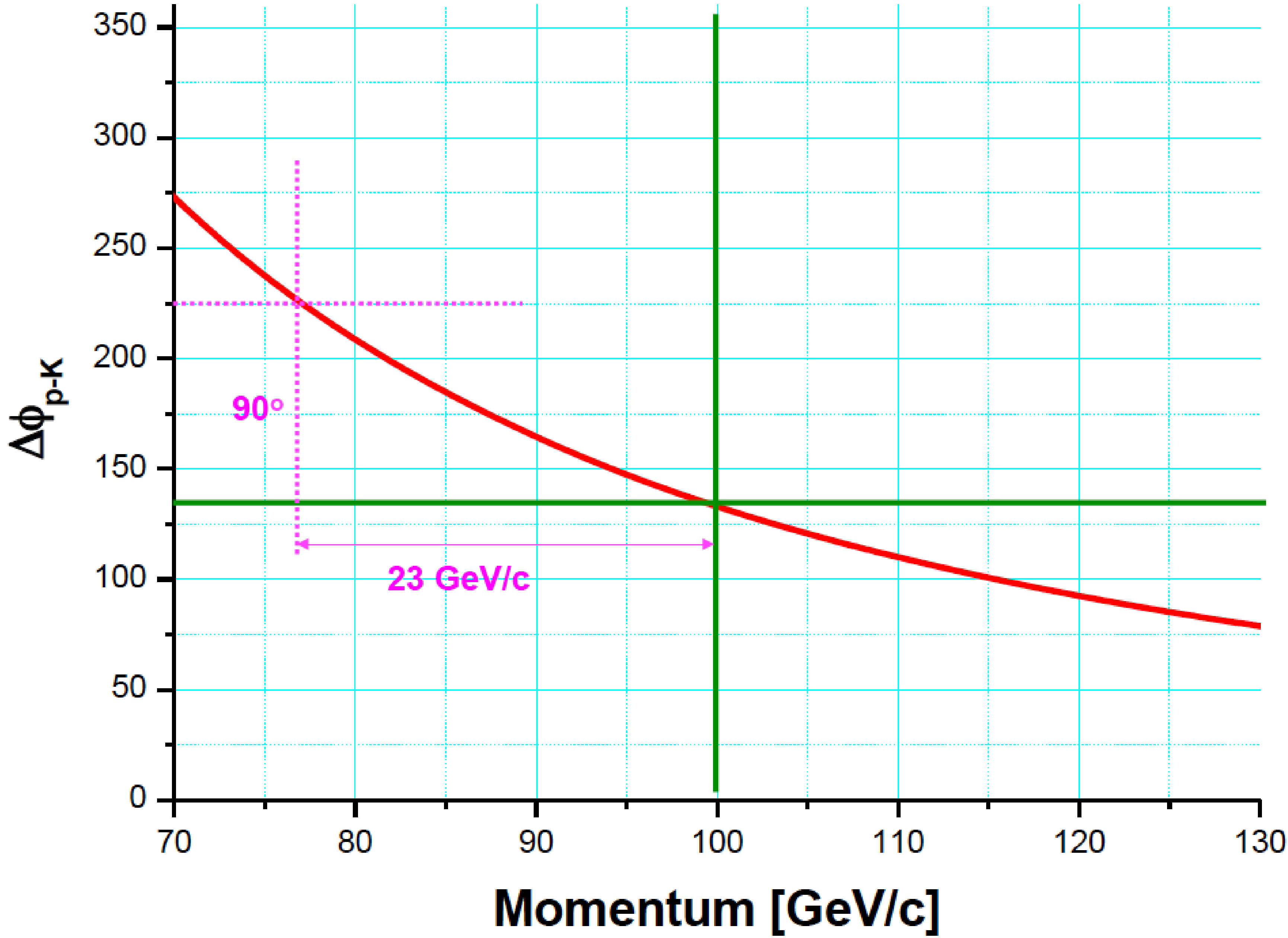
For f = 3.9 GHz → **L ≈ 450 metres**

Phase shifts depend on square of momentum – separation over limited range !

Avoid phase changes of more than a few degrees → **$\Delta p/p \lesssim 1\%$**



350
300
250
200
150
100
50
0
70
80
90
100
110
120
130
Δφp-π
Momentum [GeV/c]
90°
18 GeV/c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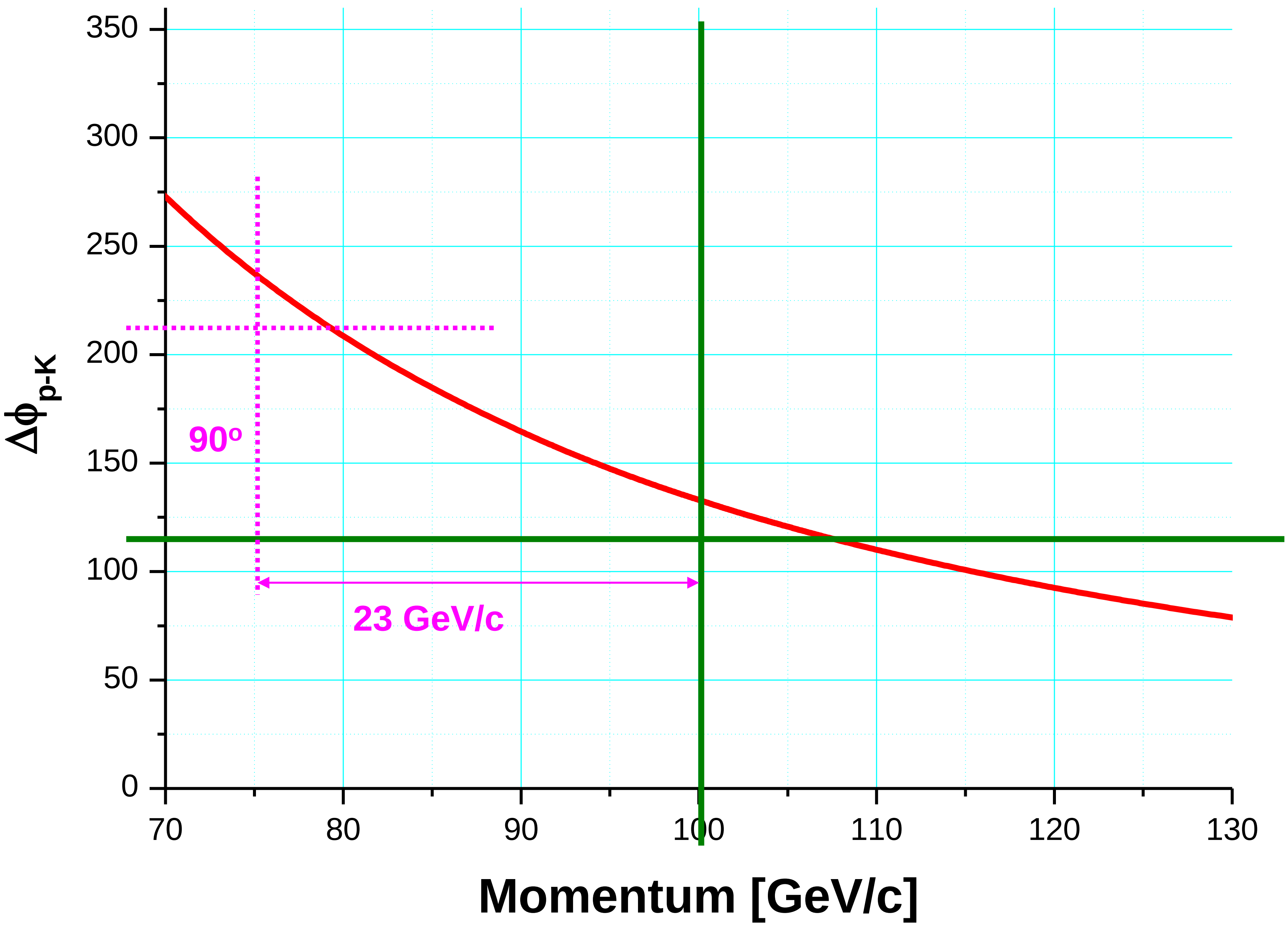
130
Momentum [GeV/c]
$\Delta\phi_{p-K}$
90°
23 GeV/c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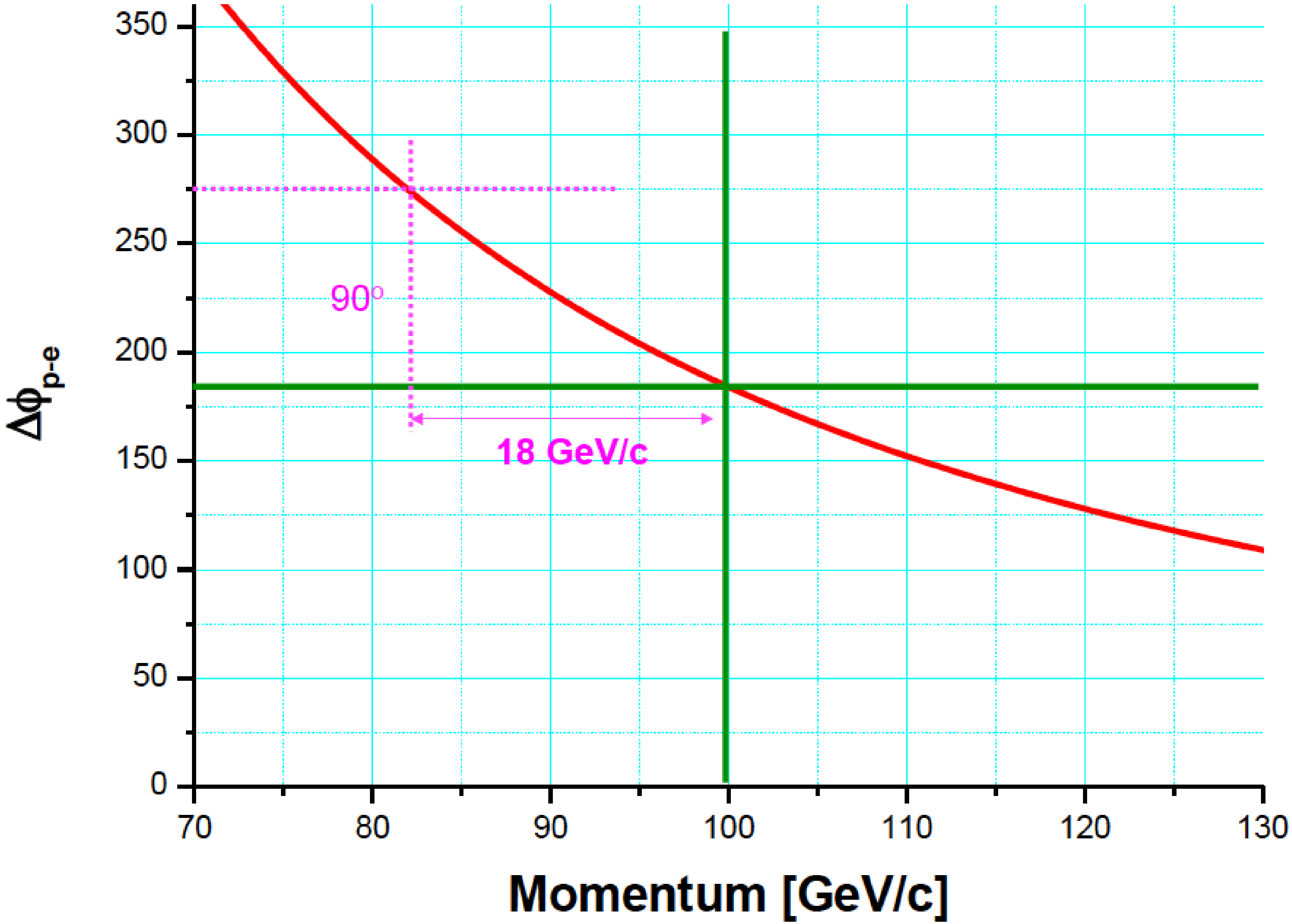
90°
23 GeV/c
$\Delta\phi_{p\text{-}K}$
Momentum [GeV/c]



350
300
250
200
150
100
50
0
$\Delta\phi_{p-e}$
90°
18 GeV/c
70
80
90
100
110
120
130
Momentum [GeV/c]

Coherence length of cavity

At 6 GHz the RF wavelength is λ = c/f = 3 10^{10} cm s^{-1} / 6 10^{9} s^{-1} = **5 cm**
The 'coherence length (over which the phase is sufficiently preserved)' corresponds to something of the order of $\Delta\phi \approx \pi/10$, hence

$$L_{coh} \approx \lambda \cdot (\pi/10) / (2\pi) \approx 3 \text{ mm}$$

The beam spot has thus to remain **within 2, i.e. ±1 mm** throughout the cavity!
Can be improved to 9 mm with X-Band technology at 3.9 GHz(???)

The p_t-kick of the cavity is of the order of 15 MeV/c (see CKM system), corresponding to about 0.3 mrad at 50 GeV.
The beam divergence must be a lot smaller than this, say **± 0.15 mrad**, at least in the bending plane.
In the other plane the beam must stay sufficiently small, but a somewhat larger divergence may be acceptable, e.g. ± 0.5 mrad.

Therefore the presence of a RF system also limits the transverse emittance of the beam

Acceptance values for RF separated K^+ beam
(rough estimate, based on extrap from J.Doornbos)

	CKM K^+ beam	**pbar beam**
Beam momentum [GeV/c]	60	100
Momentum spread [%]	± 2	± 1
Angular emittance H, V [mrad]	± 3.5, ± 2.5	± 3.5, ± 2.5
Solid angle [μsterad]	10-12 π	10-12 π
% wanted particles lost on stopper	37	20

As the pbar kick is more favorable than for K^+, I assume that 80% of p bar pass beyond the beam stopper.

→ Acceptance 10π μsterad, 2 GeV/c

Very preliminary conclusion

- H.W.Atherton formula tells us : 0.42 pbar / int.proton / GeV
- Assume target efficiency of 40%
  Then for 10^{13} ppp on target one obtains:

  $$0.4 \cdot 10^{13} \cdot 0.42 \cdot \pi \cdot 10^{-5} \cdot 2 \cdot 0.8 \text{ pbar} = \mathbf{8\ 10^{7}\ pbar/pulse}$$

  for a total intensity probably not exceeding 10^{13} ppp,
  knowing that e^- and π are well filtered, but K^+ only partly.
- If 10^8 limit on total flux, max antiproton flux remains limited by purity (probably about 50%).
  Hence **≈ 5 10^7 pbar per pulse**
- For K^+, rate is smaller: by factor 1.6 / 2.1 ~0.75 (see before)

Other beam issues

- From recent SHiP studies the limit of 4 10^{13} ppp total was reconfirmed and due to recent radiation issues in and around TCC2 even 2 10^{13} ppp is questioned at least for the coming years…..
- The existing T6 target has a limit of 1.3 10^{13} for a 4.8 s flat top. Many other limits come at the same level
- Muon beams at surface halls are limited by muon halo and by the muon beam leaving the hall. COMPASS is at the extreme limit.
- Hadron beams requirecomplete roof shielding above ~5 10^{8} ppp.
  Even then there are limits due to muon halo, air activation and so forth.
- Many of these issues get much easier in underground caverns (e.g. NA62 runs at > 2 10^{9} ppp).
- The SHiP proposal assumes several pulses of 4 10^{13} ppp per supercycle.
  This will be very challenging and expensive.
- The SPS will not go higher in energy in the foreseeable future.
  Linac4 will not significantly improve the performance for fixed target.
  Neither the 2 GeV injection for the Booster. PS/2 is abandoned.
- The DG will set up a WG for fixed target physics at the injectors and at the LHC.

Outlook

- Higher energies may require underground areas
- Radiation protection limits will only get tighter…
- RF separated beams will increase the beam content of the wanted particle type and thus reduce the required overall beam intensity, hence the radiation issues
- However, they are complex, expensive and need detailed study. COMPASS would have to provide some justification to launch such a study.

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Estimates for 2017 and 2018

Intensities per spill with 4.8 s flat top:

Target	Intensity driver	Request for 2016	'Normal' intensity	Request for 2017	Request for 2018	Comment
T2	NA61, P348	$2\ 10^{12}$ $4\ 10^{12}$	$4\ 10^{12}$	$2\ 10^{12}$ $4\ 10^{12}$	$3\ 10^{12}$ $4\ 10^{12}$	Neutrino platform in 2018
T4	NA62*)	$4\ 10^{12}$	$8\ 10^{12}$	$8\ 10^{12}$	$8\ 10^{12}$	
T6	COMPASS	$1.5\ 10^{13}$	$1.5\ 10^{13}$	$1.5\ 10^{13}$	$1.2\ 10^{13}$	Hadrons in 2018, but better shielding
Total		$2.1\ 10^{13}$ $2.3\ 10^{13}$	$2.7\ 10^{13}$	$2.5\ 10^{13}$ $2.7\ 10^{13}$	$2.3\ 10^{13}$ $2.4\ 10^{13}$	

Final remarks

- For most of 2016, a total T2+T4+T6 of 2.1 10^{13} ppp should be ok.
  For limited periods, higher intensities will be requested (NA62, P348).
- The total intensity extracted must be somewhat higher (splitter losses, etc)
- The nominal requests of the big approved experiments are in some cases higher than this and they will come in the future (NA62).

- The dose rates are higher than in the CNGS period, due to higher repetition rate, but should (ideally) not be higher than before CNGS.
- There are indications that there is an increased dose per proton extracted, at extraction and possibly still further downstream. A lot of good work has been done in 2015. Even better understanding would be useful.
- Most of the experiments were approved before the problems started and the corresponding intensities were mentioned on many occasions at IEFC meetings and workshops.
- In 2018 the total request is slightly higher