Engineering Department

SBA Secondary Beams & Areas

Lau Gatignon / EN-MEF, IEFC Workshop, 8 March 2012

SPS FT Beams

Outline

- The SPS North Area
- COMPASS
- NA62
- Other ‘proton’ experiments
- Neutrinos
- Test beams
- Ion experiments
- TT60 beam lines
- Conclusions and Outlook

The SPS North Area

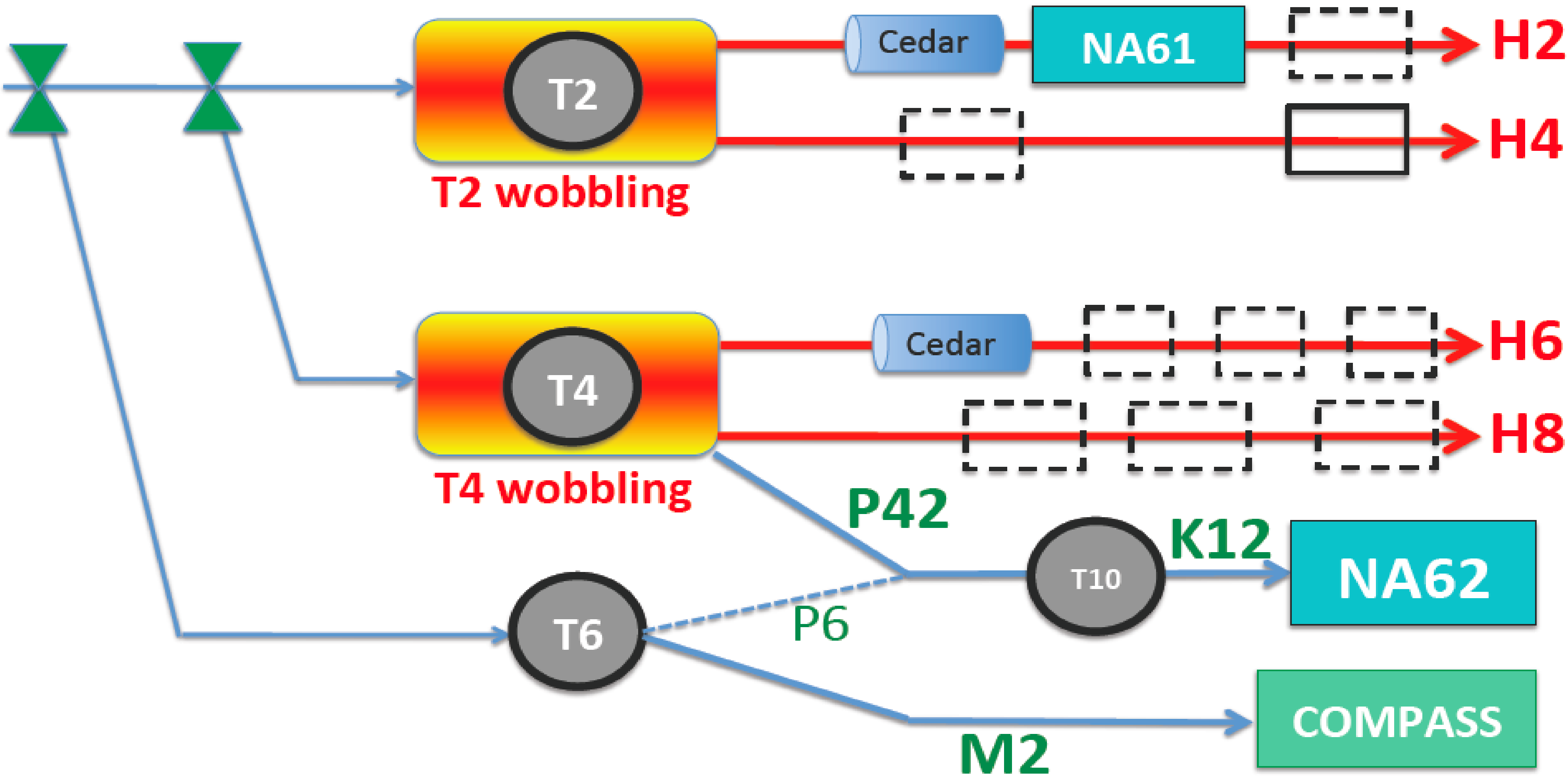
3 Halls

6 Beam lines

4.6 km beam

> 1500 users

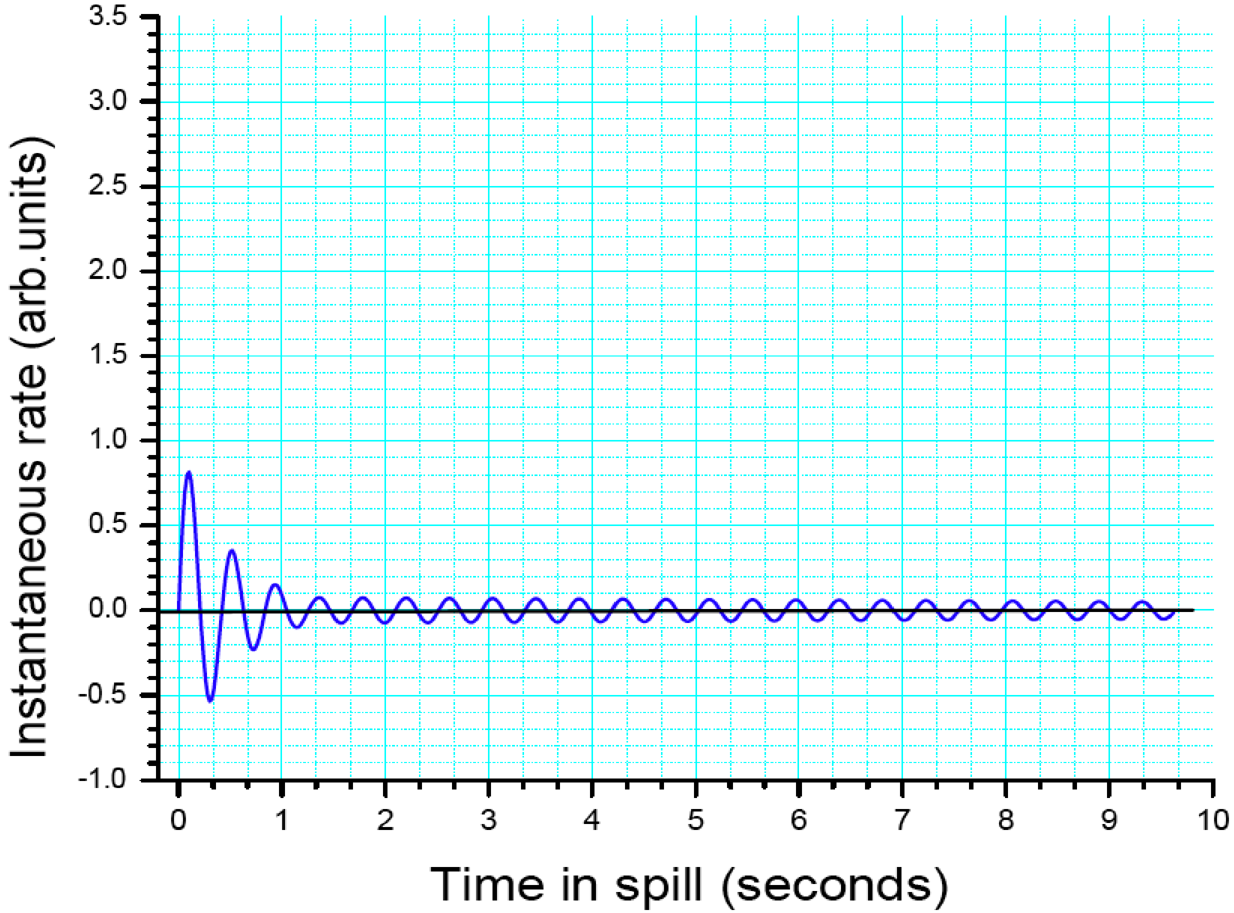
North Area Beam Lines



Common features of NA experiments

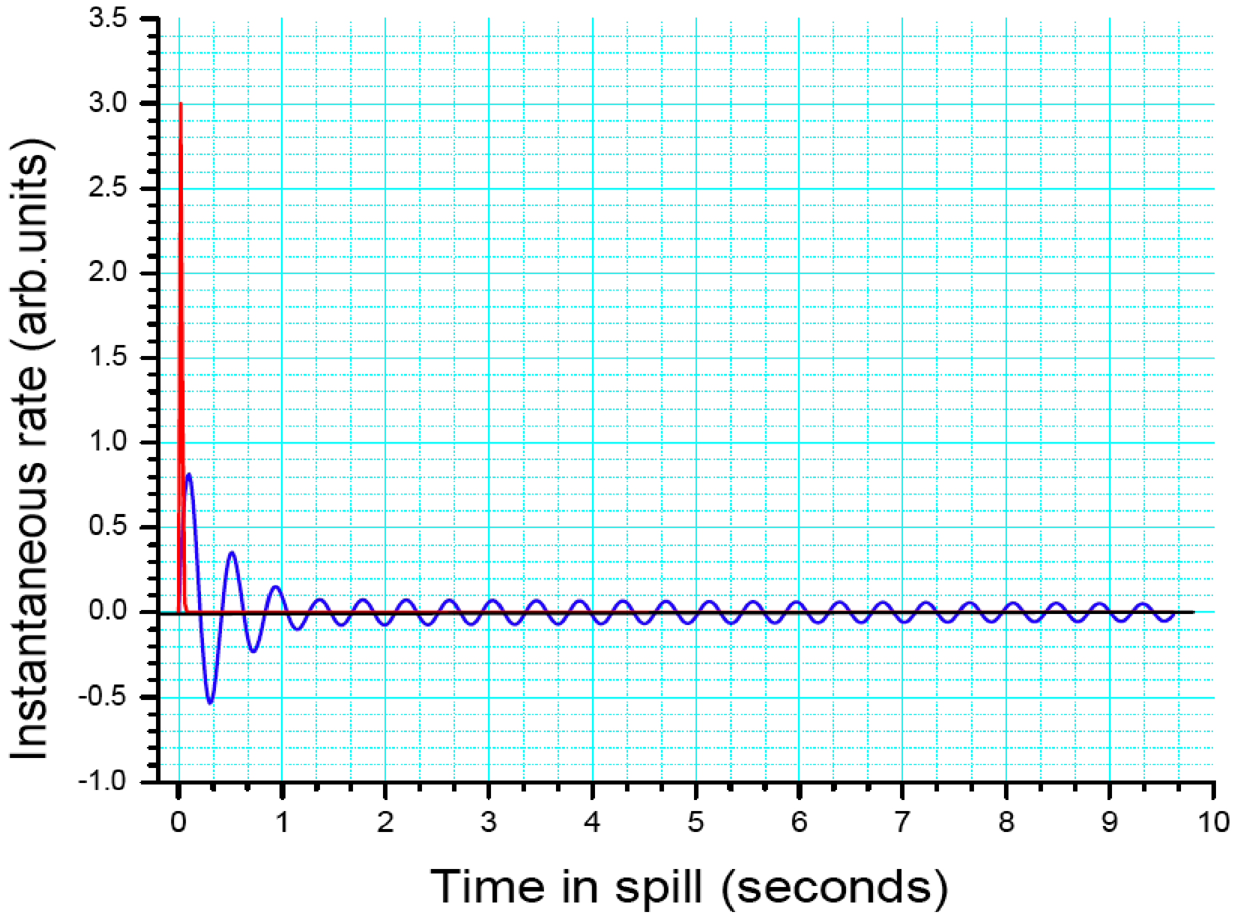
- The NA experiments all rely critically on **slow extraction.**
- They are rate limited, mainly during the flat top.
  Their instantaneous rate is given in events per seconds,
  their integrated luminosity is proportional to integrated **time on flat top**,
  This assumes that they get enough flux to saturate their data-taking rate.
- Integrated time on flat top = **Duty-cycle** x Length of run (x efficiency)
- The number of events per second is limited by dead-time (signal length, event size, etc) and by **pile-up** (proportional to at least the square of the instantaneous rate).
- For a given flux and flat top length the optimum instantaneous rate is achieved for a spill structure **as flat as possible** (from low frequency to RF).

Spill structure



The high frequency time structure (RF, f_{rev}) is still very present in the first 500 to 1000 milliseconds

Spill structure



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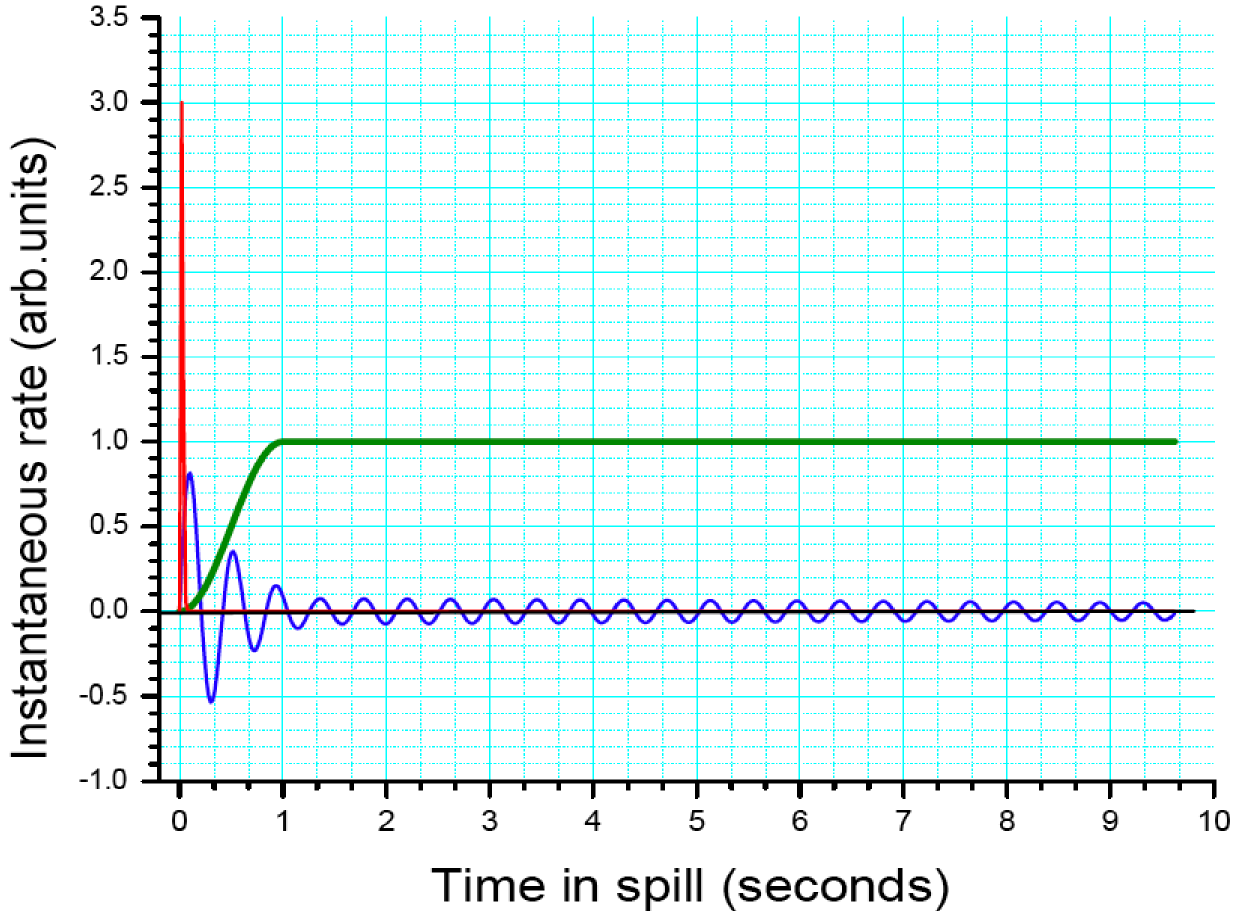
High-intensity spikes may occur at the beginning of the spill, in particular if the intensity is ramped up (too) quickly

Spill structure



The **high frequency time structure** (RF, f_{rev}) is still very present in the first 500 to 1000 milliseconds

High-intensity spikes may occur at the beginning of the spill, in particular if the intensity is ramped up (too) quickly

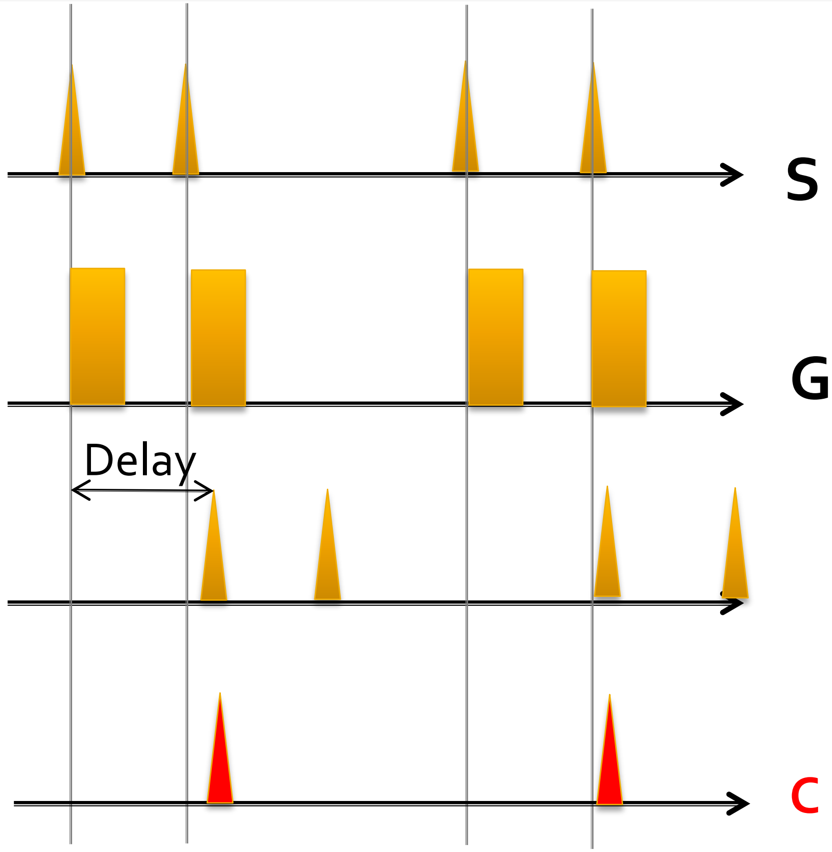
The slow ramping up is thus favored by the experiments, but together with the remnant spill structure it leads to a reduced **effective spill**.

Effective spill on Page-1

- The effective spill can be measured rather simply by a delayed coincidence of a rate signal with itself:

  E.S. = Gate * Singles² / Del.Coincidence

- In the 'good old days' the effective spill and singles rates were shown on Page -1.
  This was very useful, but has been dropped.
  Could it be revived?



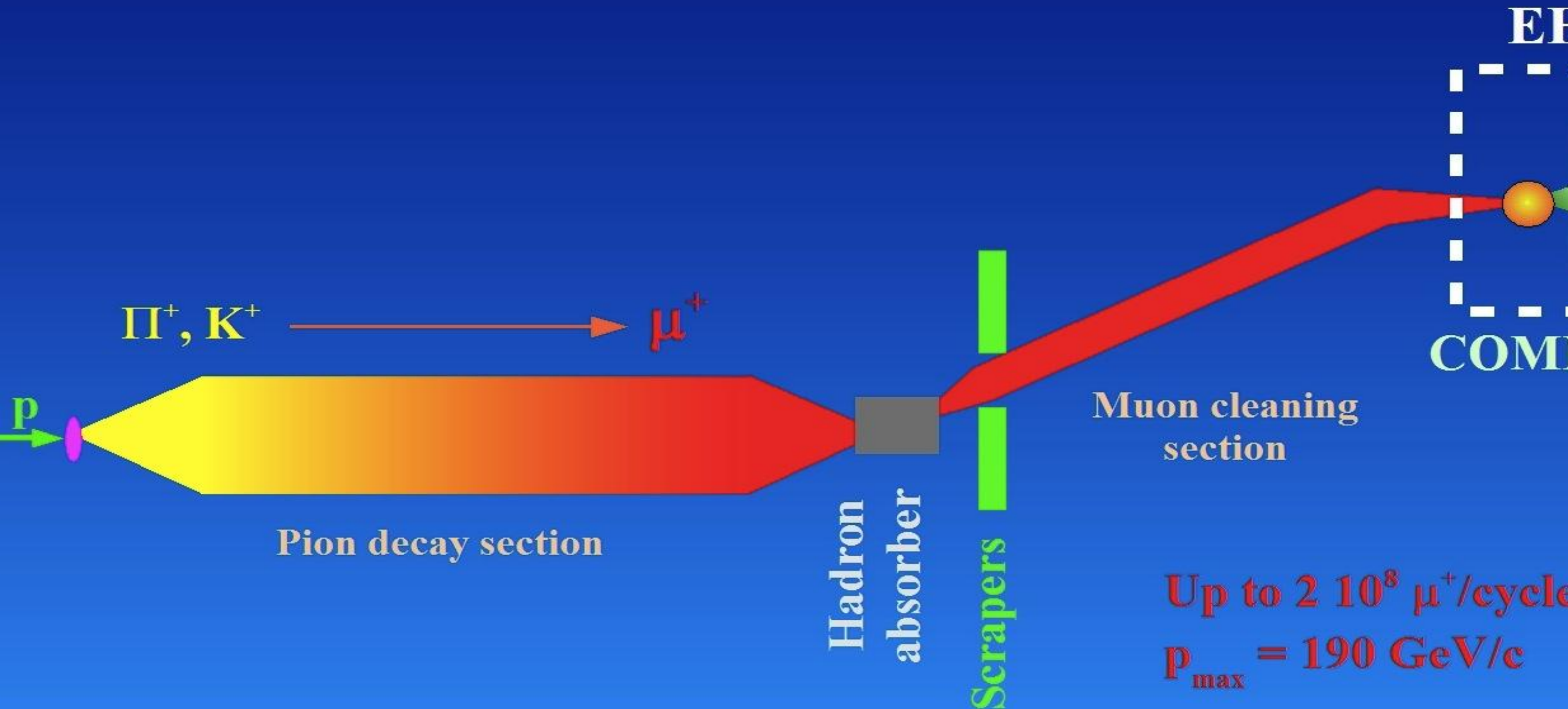
COMPASS

- COMPASS is a general purpose experiment that operates with secondary **hadron** beam or **muon** beam. They aim at precision measurements ($\Delta G/G$)
- Muons are **tertiary particles** ($p+X \rightarrow \pi + X$, $\pi \rightarrow \mu + \nu$).
  As they want **high-intensity muon** beams (up to $5\ 10^8$ per s.c.), this mode of operation requires maximum proton flux on the T6 target, **up to $2.5\ 10^{13}$ ppp**
- So far the hadron beams were of modest intensity (few 10^7 per s.c.), but the future Drell-Yan program may require **hadron intensities of 10^9 ppp or more**.
  In that case also the hadron beam will require higher intensities (10^{13} ppp or more).
- Ultimately both the hadron and muon beam programs of COMPASS will be limited by radio-protection constraints (dose limits around the zone perimeter and in the COMPASS control room) and by the radiation tolerance of the TT20 line.


~240 physicists
28 institutes
GAMS
HNB 42

THE M2 MUON BEAM

FOR COMPASS / NA58



COMPASS after LS1

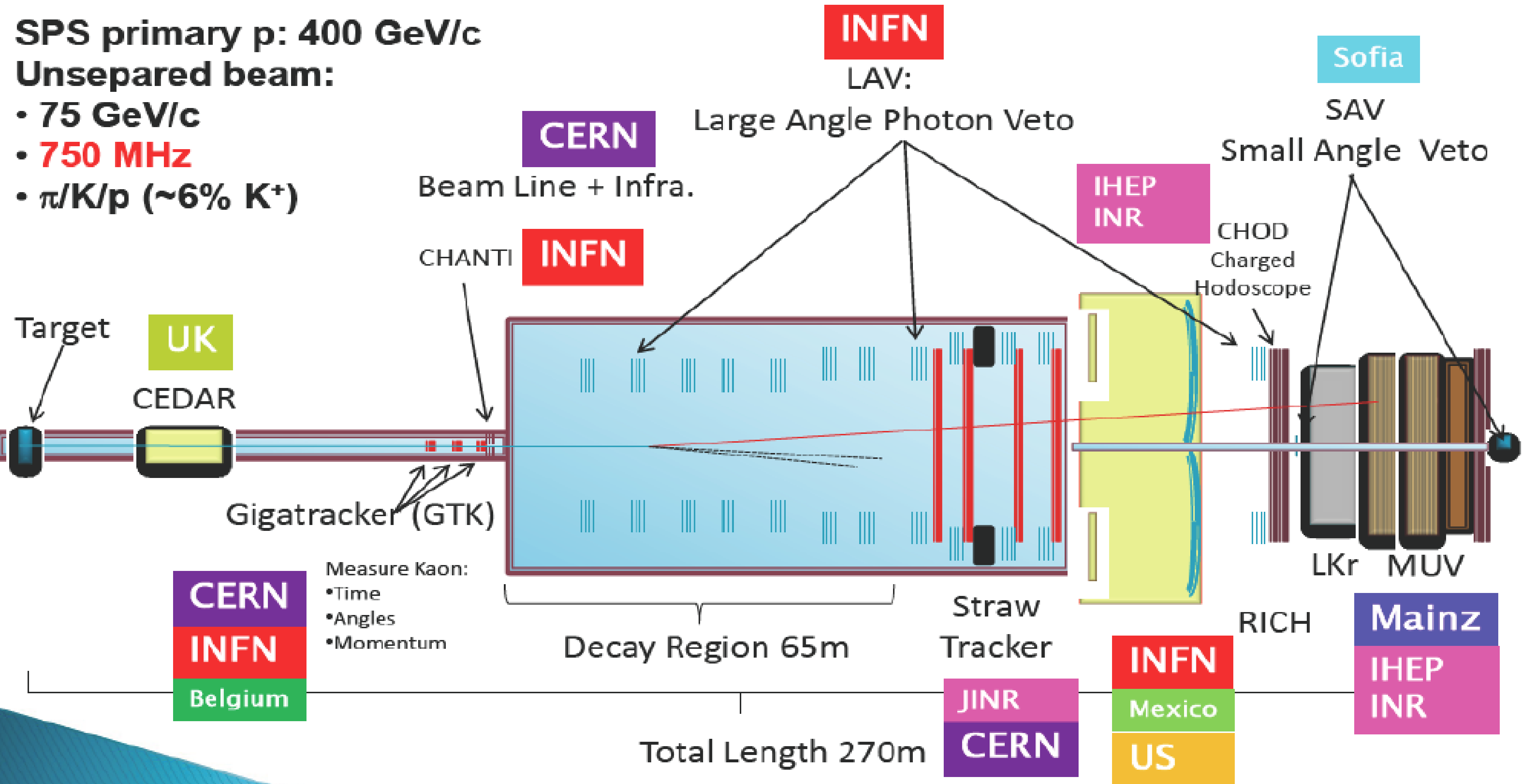
- In **2012** COMPASS will run with hadron beams (low intensity) up to the ion run. Low T6 flux (probably ~ 10^{13} ppp or lower).
  After the ion run they do tests for the future muon program, at 2.5 10^{13} ppp
- COMPASS has been approved for a 2^{nd} phase of **physics** (**COMPASS-II**):
  - 2014: Drell-Yan with high-intensity π^- beam
  - 2015: DVCS with full-intensity muon beam
  - 2016: DVCS with full-intensity muon beam
- COMPASS will almost certainly come up with request for further running with high-intensity beams in 2017 and beyond.
  Among the 'new' ideas have been mentioned: primary proton beams, hyperon beams, RF separated and polarized anti-proton beams, ...

NA62

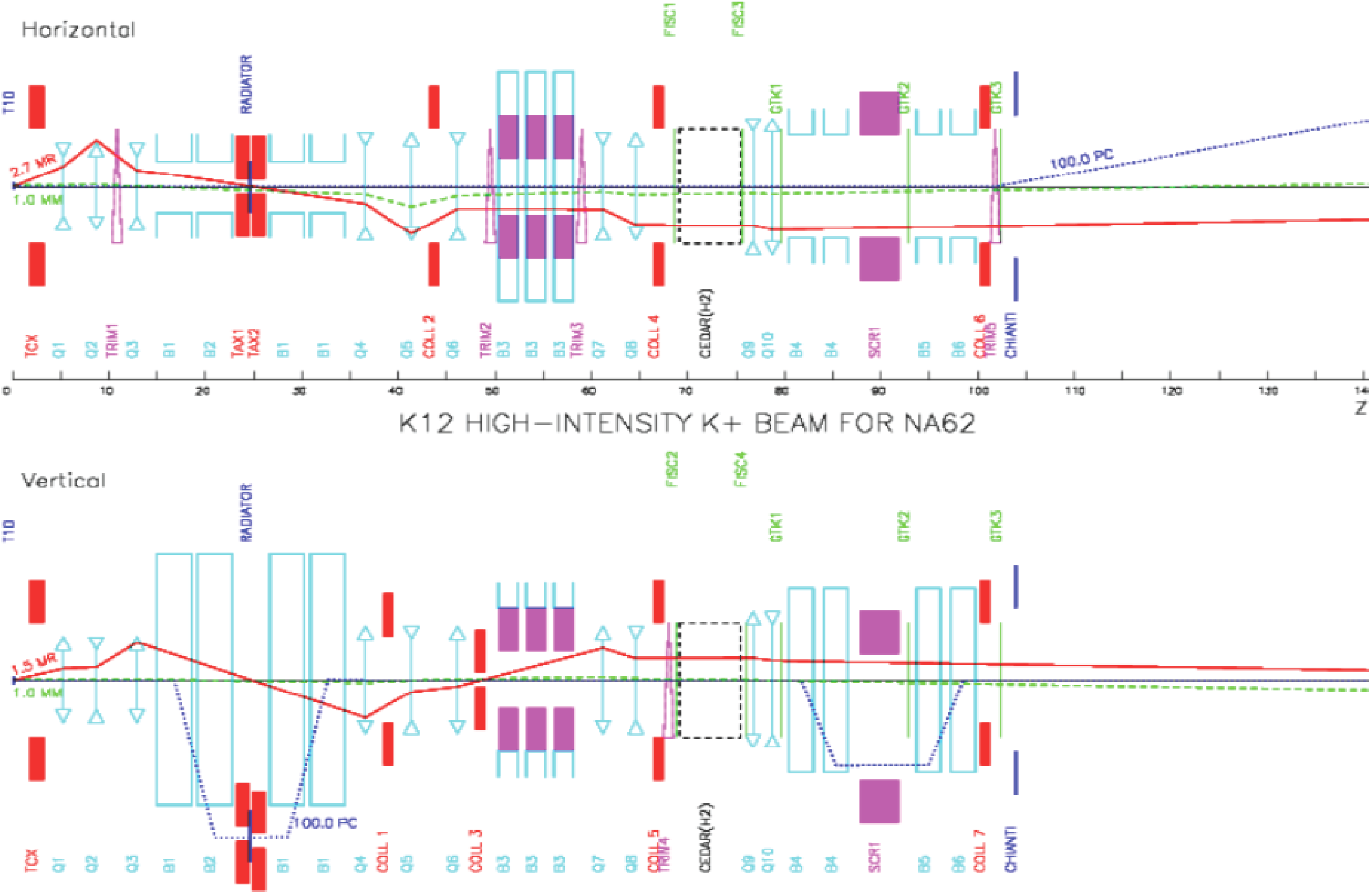
- NA62 is a new experiment looking for the **very rare decay $K^+ \rightarrow \pi^+ \nu \nu$**.
  The branching ratio is ~ 10^{-10}, they aim for ~100 events in two years running.
- **A large integrated proton flux** is thus needed to produce enough K^+ decays.
- The collaboration consists of ~250 physicists from 27 institutes.
  Both the beam line and detector are under construction.
- A first **technical run** (without strong intensity requirements) is planned for a 6-week period starting 15 (or 26?) October this year.
- The first **physics run** with complete detectors is scheduled to **start in 2014**.
  Normally there will be a physics program for a number of years (>> 2 years).
- The phase after that could well be a $K_L \rightarrow \pi^0 \nu \nu$ experiment, requiring as many protons as possible : B.R ~ 10^{-11} !

NA62 Beam & Detectors

SPS primary p: 400 GeV/c
Unseparated beam:
- **75 GeV/c**
- **750 MHz**
- **π/K/p (~6% K⁺)**

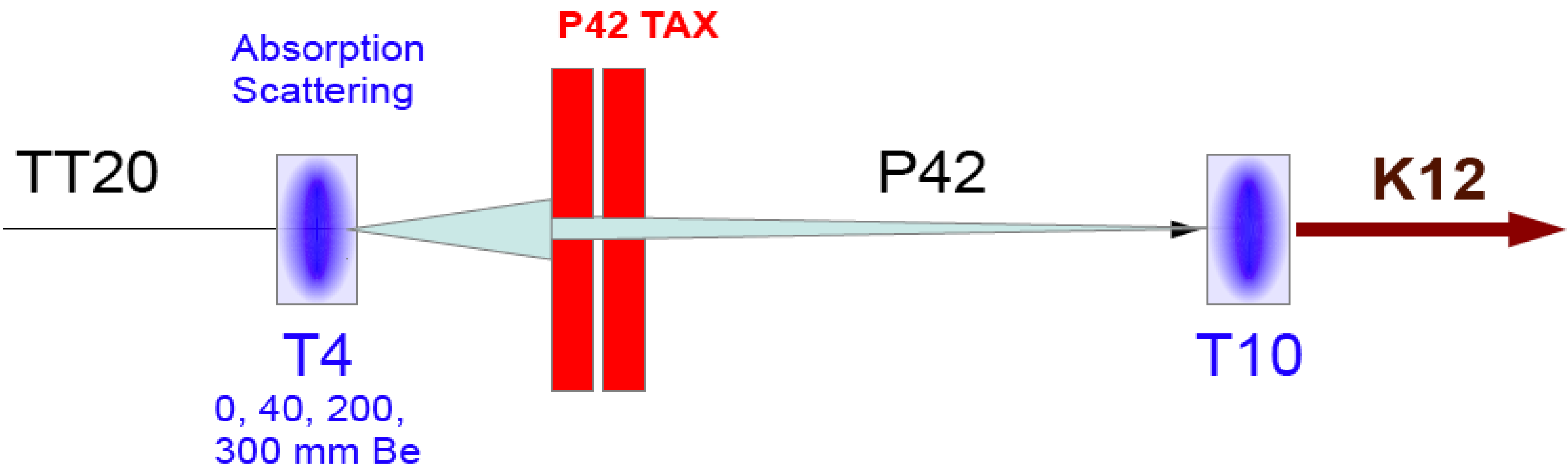


NA62@SPSC99 16/11/2010 4


Horizontal
K12 HIGH–INTENSITY K+ BEAM FOR NA62
Vertical
2.7 MR
1.0 MM
100.0 PC
1.5 MR
1.0 MM
100.0 PC
T10
RADIATOR
FISC1
FISC3
FISC2
FISC4
GTK1
GTK2
GTK3
TCX
Q1
Q2
TRIM1
Q3
B1
B2
TAX1
TAX2
Q4
Q5
COLL 2
Q6
TRIM2
B3
TRIM3
Q7
Q8
COLL 4
CEDAR(H2)
Q9
Q10
B4
SCR1
B5
B6
COLL 6
TRIM5
CHIANTI
COLL 1
COLL 3
COLL 5
TRIM4
COLL 7
Z

Beam Experiment	K12K+K- NA48/2	**K12HIKA+** NA62	Comparison FACTOR [12]
SPS Protons per s of spill length Instantaneous Proton Rate per effective s	~2 x 10^{11} 3.3 x 10^{11}	0.7 x 10^{12} **1.1 x 10^{12}** (equiv. 1.0 10^{12}) [13]	3.0
SPS Duty Cycle (s / s) Effective Duty Cycle (s / s)	4.8/16.8 = 0.29 ~0.18	~0.3 ~0.2	~1.1
Beam Acceptance x_0', y_0' (mr)	± 0.36, ± 0.36	± 2.7, ± 1.5	
Solid Angle (μsterad)	≈ 0.4	≈ 12.7	32
Mean K^+ Momentum <p_K> (GeV/c)	60	**75**	K^+ 1.4 π^+ 1.5 Total Hadrons 1.6
Momentum Band: - Effective Δp/p (%) - r.m.s. Δp/p (%)	 ± 5 ≈ 3.7	 ± 1.65 **1.0**	 0.33
r.m.s. Divergence: x', y' (mr) at CEDAR		0.07, 0.07	
2 r.m.s. Beam Size (mm) Area at KABES [4]/ GTK 3 (mm^2) r.m.s. Divergence: x', y' (mr)	r= ~15 ~700 ≈ 0.05, 0.05	x= ± 27.5, y= ± 11.4 ~980 0.09, 0.10	 ~1.4
Decay Fiducial Length: (m) Δz (τ_{K+}) Decay Fraction: ($1 - e^{-\Delta z}$)	50 0.111 0.105	**60** 0.107 0.101	 0.96
Inst.Beam Rate / s (MHz): p **K^+** π^+ e^+, μ^+ Total	2.9 1.0 11.1 ~3 , ~0.13 ~18	173 **45** 525 ~0.3 , ~6 **750**	60 45 47 ~0.1 , ~45 ~42

Transmission from T4 to T10



Attenuation in Be: 40 mm → x 0.9
200 mm → x 0.6
300 mm → x 0.5

Plus the impact of multiple Coulomb scattering: ~ x 0.75

Transmission from T4 to T10

Apertures and Vertical Positions of TAX 1			*TAX 2 of Beam P42*			
Diameter Ø (mm)	Position y (mm)	Range	Diameter Ø (mm)	Position y (mm)	Range	Transmission factor
14.0	-81	Medium	**12.0**	-21	Medium	1.0
14.0	-81	Medium	**10.0**	+19	Medium	~0.8
7.5	-21	Medium	10.0	+19	Medium	~0.5
7.5	-21	Medium	**4.0**	+59	**Small**	~0.12
7.5	-21	Medium	**2.0**	+99	**Small**	~0.03
--	+140	Small	--	+140	Small	*Beam STOPPED (TCC8 – ECN3 Access)*

But absorption and scattering in T4 target. Vertical divergence depends on sharing.
Typically for reasonable sharing and 300 mm target in T4 so far: **Flux T10/T4 = 0.5 (T4) x 0.75 (MCS) ~ 0.37**

What does this mean in terms of events/year?

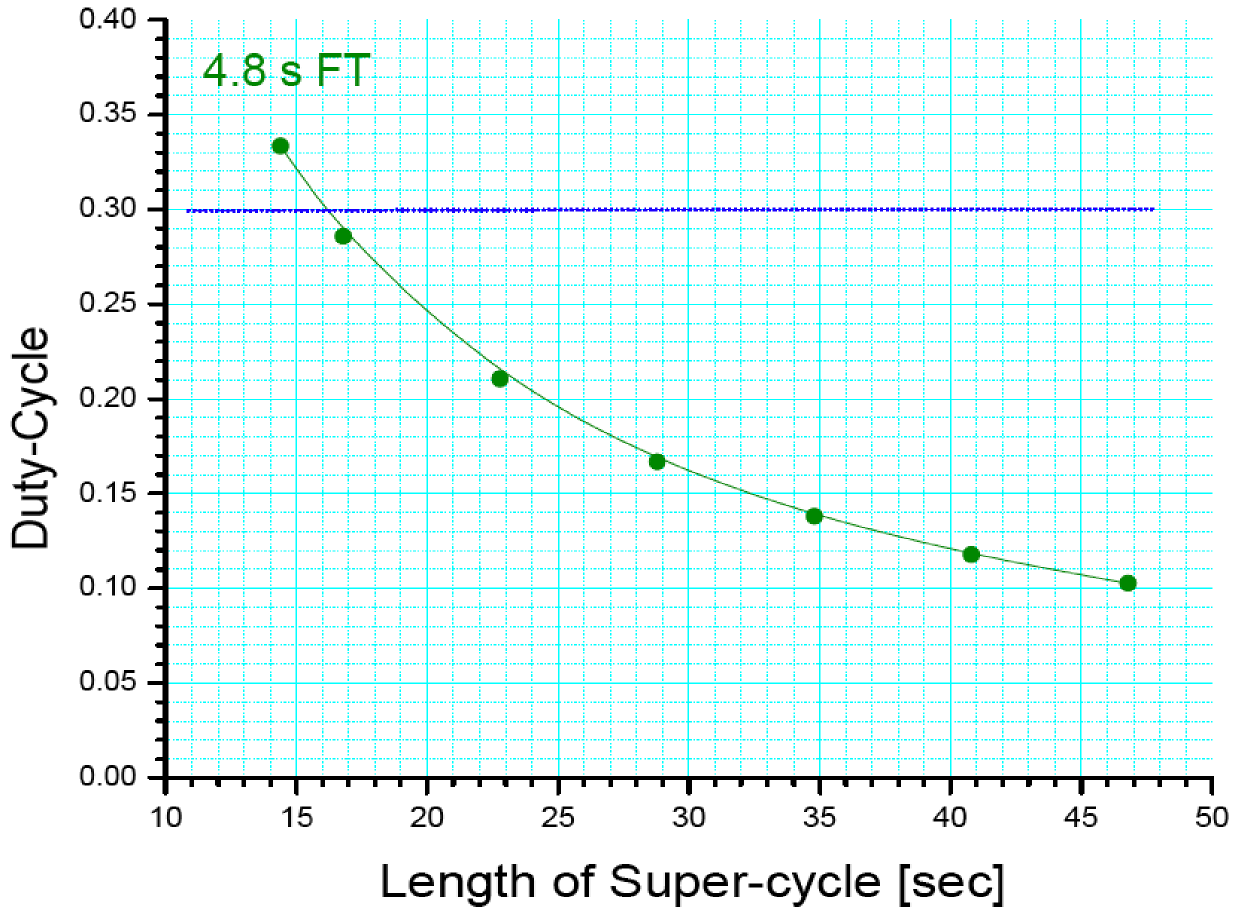
Parameter	NA62
Protons onto T10 per second spill length	**$7\ 10^{11}$**
Instantaneous T10 proton beam rate per effective second	$1.1\ 10^{12}$
SPS duty cycle nominal (effective)	**0.3 (0.2)**
Instantaneous K^+ rate in K12 beam [MHz]	45
Running time per year [days]	100
Overall efficiency	60%
Effective spill time per year [seconds]	10^6
K^+ decays per year inside 60 m fiducial length	$4.5\ 10^{12}$
Number of $K^+ \rightarrow \pi^+ \nu \nu$ events per year	450
Number of signal events within acceptance per year	**45**

Need (7/0.37) 10^{11} =1.9 10^{12} protons per second on T4

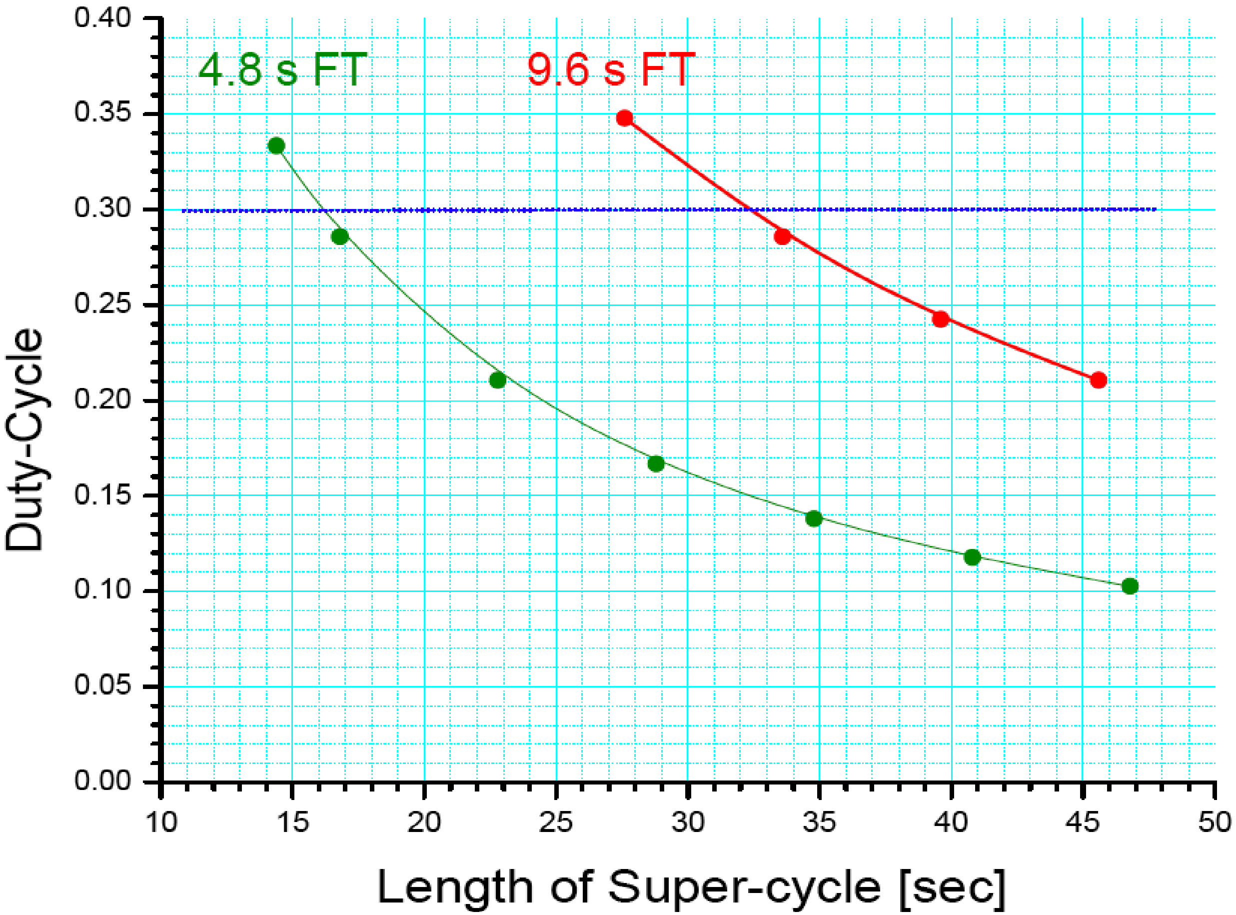
Why do we have the long flat top?

- Until the start of CNGS the SPS was operated with 4.8 sec flat top and a super-cycle of 14.4 (16.8) seconds, with (without) MD cycle.
- CNGS requires additional cycles of 6 seconds each, thus diluting the duty cycle.
- Getting anywhere 4.5 10^{19} pot per year for CNGS would effectively call the rest of the SPS fixed target physics program to a halt.
- As the CNGS cycles consume much less power than the fixed target cycle, Gianluigi Arduini proposed a scheme with longer flat top (x2). The impact on the overall cycle length was low (~10-15%), but the gain on flat top was a factor of two. **This saved the fixed target physics program so far!**
- The problem is that it requires the **intensities per spill to be doubled**, assuming the same instantaneous rate.

Short vs long flat top



Short vs long flat top



Other proton experiments

- **NA61** needs moderately high hadron fluxes on T2 target, mostly for low-energy runs. This is partly related to low particle production rates, partly due to the very asymmetric sharing: T2 gets the extreme tail of the beam emerging from the splitter

  Still: maximum ~7 10^{12} ppp on T2

- **NA63** needs secondary electron beams of modest intensity in H4 beam.
  No special requirements on T2 flux (less than NA61).

  T2 maximum ~5 10^{12} ppp

- **UA9** uses an attenuated primary proton beam

  Needs small T4 flux (e.g. 2 10^{12} ppp)

- **DIRAC** has announced that they will prepare a proposal for the North Area.

  No details known yet

Test beams in EHN1

- EHN1 houses a very active program of test beams and is severely over-booked
- However, test beam users require rarely very high intensities. It is much more important to **have flexibility in beam conditions**.
- However, this does not mean that they are not demanding:
  Modern calorimeters have very stringent requirements on momentum resolution and beam purity.
  Tracking detectors want to have high particle densities, therefore small spot sizes.
  The detectors are often quite large and complex, in some cases full slices of major detectors are tested ('combined tests').
- **However, they have no major impact on the sharing of proton intensities.**

Summary of user requirements

	4.8 s flat top	9.6 s flat top
NA62: proton flux on T10	*3.4 10^{12}*	*6.7 10^{12}*
NA62: proton flux on T4 (300 mm target)	**9.1 10^{12}**	**19 10^{12}**
COMPASS: proton flux on T6 for muon run	**14.5 10^{12}**	**25 10^{12}**
T2proton flux for test beams	*2 10^{12}*	*3 10^{12}*
T2 proton flux for NA61 hadron runs	**4 10^{12}**	**7 10^{12}**
Total to North Area	**2.8 10^{13}**	**5.1 10^{13}**
Maximum flux possible into TT20	**3.2 10^{13}**	**4 10^{13}**

→ OK if operating with 'short flat top' (4.8 s)

Shortage of protons if 'long flat top' (9.6 s)

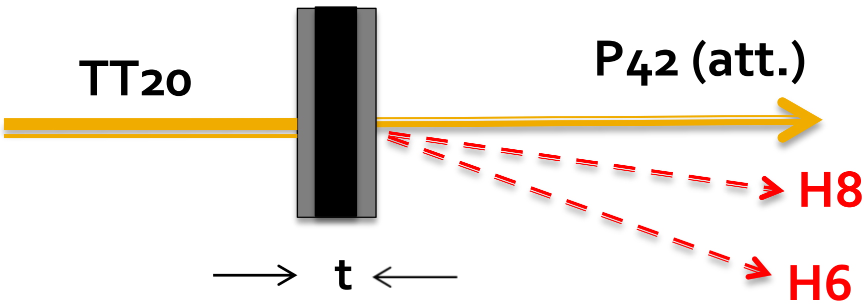
What about the neutrinos

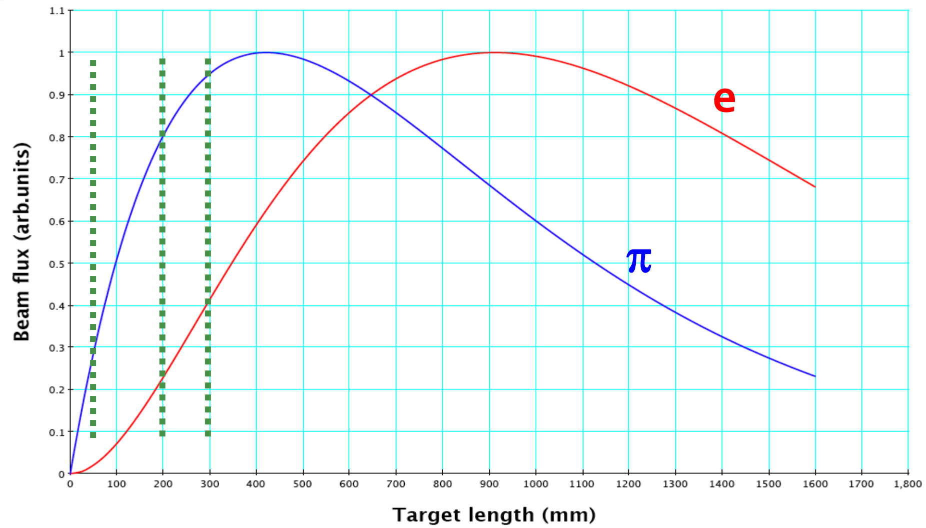
- The CNGS neutrino beam is operated in separate parts of the super-cycle.
The main impact on proton sharing is thus **the reduction of duty-cycle** for FT.
- OPERA may come to an end by LS1, but a final decision will not be taken before summer 2012.
- However, **new ideas for neutrino physics experiments at the SPS** are coming up, see presentation by B.Goddard in the Experimental Areas session.
These include Laguna-LBNO and also a short-baseline experiment and require a fast extraction from LSS2.
- It is not yet clear at what timescale these experiments can start, but as soon as they start there will again be a **dilution of the beam time** for the North Area fixed target program.

How can we address the proton shortage?

- Running with a short flat-top and a short super-cycle
- Running with a shorter target head in T4
  - Less proton absorption → larger transmission to T10/K12
  - Less multiple Coulomb scattering in target → larger transmission to T10/K12
  - Loss of H6/H8 intensity compensated by high flux onto T4, but fewer electrons
- Running with a softer focus on T4
  - Better transmission to T10
  - Larger spot on T4 (small impact on H6, H8, usually redefined by collimation anyway))
- Running with a vertically large (parallel) beam at T4
  - Preserve good transmission to T10/K12, most of beam un-attenuated
  - Fraction of electrons in beams to H6, H8 not affected (keep long T4 head)
  - New P42 optics has been fine tuned, new TT20-T4 branch optics to be made

Option 1: shorter T4 target





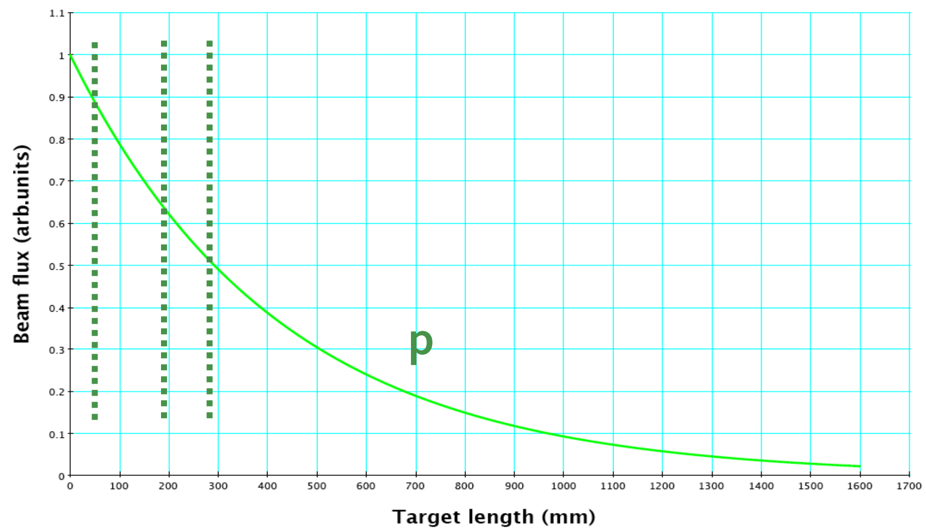
The beam from T4 to T10 is attenuated exponentially

For H6 and H8 e and π production are different f(t):

$N_\pi \sim (t/\lambda)\, e^{-t/\lambda}$, max around 1 λ ~ 400 mm

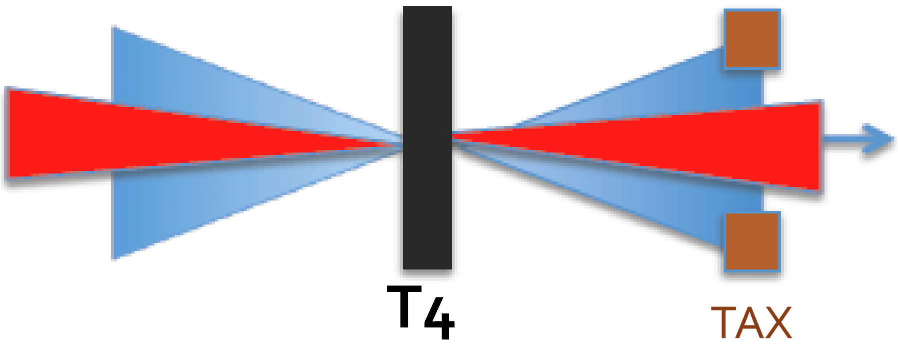
$N_e \sim (t/l)\,(7t/9 \cdot X_o)\, e^{-t/Xo}$, max around 90 cm

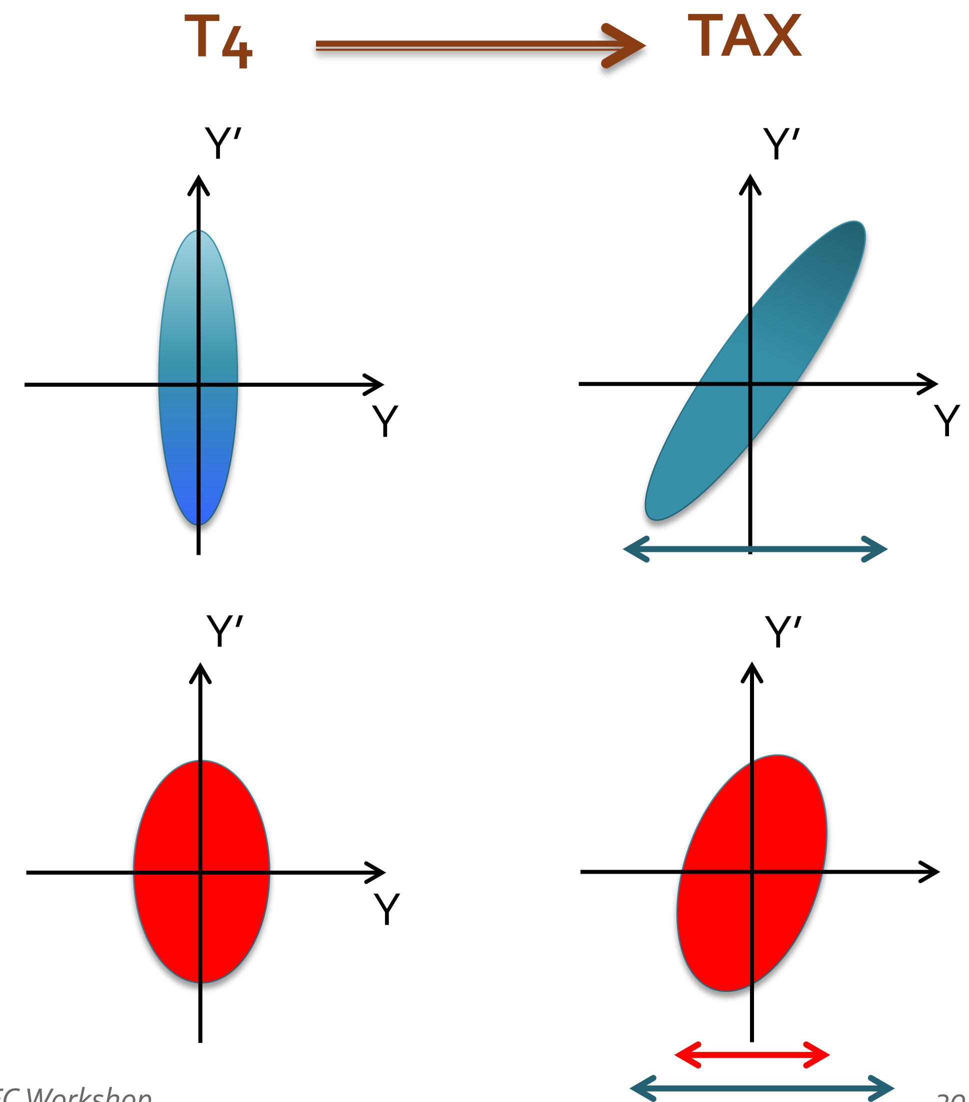
→ Hence: **$e/\pi \sim 1/t$**



With 200 mm target need 1.4 10^{13} ppp on T4, 4.1 10^{13} total

Option 2: Softer focus on T4 target





Profit from Liouville theorem:

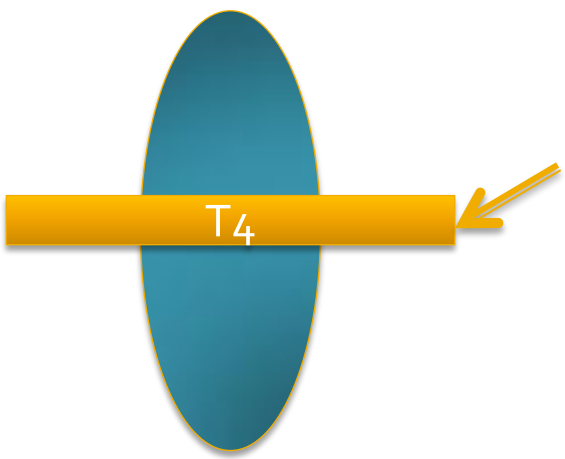
Wider spot → smaller divergence from T4

Smaller divergence → smaller beam at TAX

Therefore better transmission to T10.

Could be used in combination with option 1.

Option 3: Wide and // beam thru T4

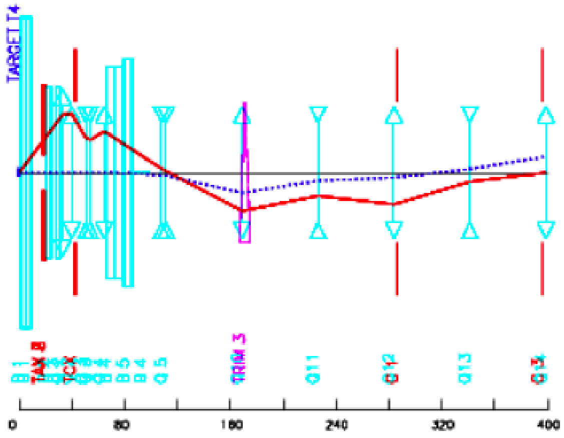


e.g. 25% of **9 10^{12} ppp beam onto 300 mm T4 target**: good π, e beams produced by 2.5 10^{12} ppp onto T4 for H6, H8

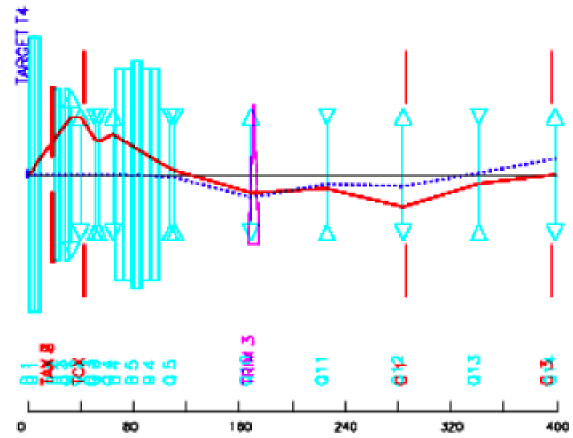
e.g. 75% of beam fully transmitted plus 25% attenuated x 0.37,
i.e. total of 6.75 10^{12} + 0.37 x 2.25 10^{12} ppp ~ **7.5 10^{12} ppp for T10+K12**

Parallel beam can be transported:

Horizontal:



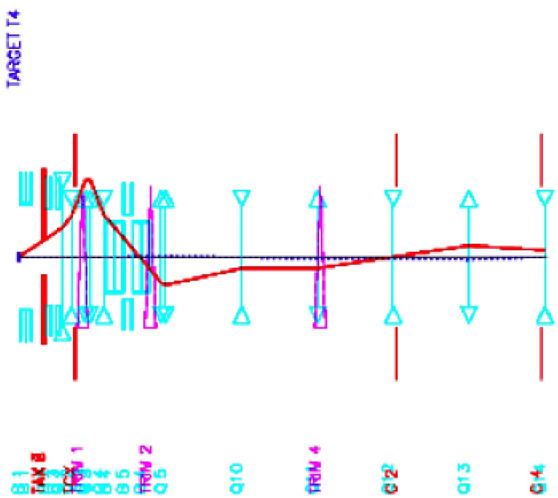
P42 TRANSPORT FROM T4 TO T10

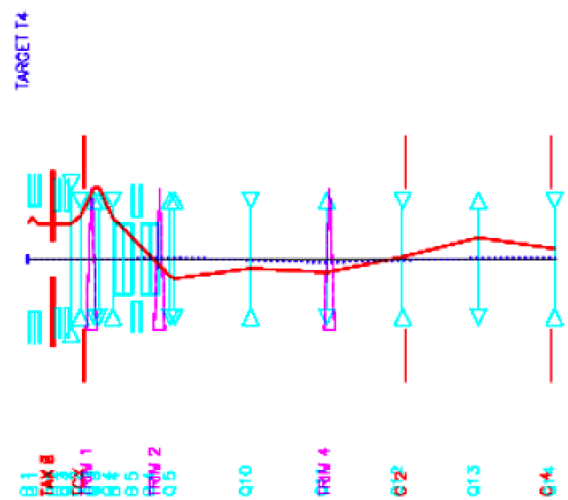


P42 TRANSPORT FROM PARALLEL BEAM AT T4

First attempt
(to be refined!)

Vertical:





Ion beams

- **NA61** has an extensive ion beam program, involving various ion species and a range of primary beam rigidities.
- In the wake of this, there are also ion beam requests from **NA63** and **UA9**
- Django Mangluki will comment on the different aspects of this ion program later in this session.
- Ions can be made available in parallel with a neutrino program (CNGS or other). However, ion operation for the North Area is **incompatible** with fixed target proton operation at he same time (i.e. in the same super-cycle).
- Therefore the main impact of the ion program for the proton pysics is a **reduced beam time**, aggravating the **need for good duty-cycle**.

New TT60 activities

- **HiRadMat** has just been installed and commissioned in the West Area and it will continue operation in 2012 and beyond.
- A kick-off meeting has taken place on February 23rd for the construction of a new test facility in the old West Area, using the TT61 tunnel, for studies **of proton driven plasma wake-field acceleration.**
- Both these facilities need a fast extracted beam into TT60.
- These will operate part-time and in dedicated cycles within the super-cycle.
- Their impact on the fixed target program is therefore only a reduction of duty-cycle, probably negligible w.r.t. the potential impact of new neutrino experiments.

Conclusions and outlook

- The SPS will see an intense and fascinating program of ongoing and new experiments in parallel with important test activities.
- The fixed target program alone, as it is foreseen today, seems to be able to handle the high-intensity proton beam requests, driven mainly by COMPASS and NA62.
- However, in case of significant extra activities in the super-cycle (neutrinos in particular), hence a **long flat top**, the loss of duty cycle must be compensated by higher intensities. Several ways out have been suggested.