AGS as a Proton Driver for a Neutrino Factory

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Outline

- Evaluation of parameter dependence
- Possible design parameter phase space
- Improvements on the AGS, and its difficulties
- Summary and Conclusions

Considerations of parameters

we consider the effects of

1. Energy
2. Repetition Rate
3. Intensity
4. Bunch Length
5. Number of bunches

Of the Proton Driver

Proton per pulse required for 4 MW

$$\bar{P}_{arc}(w) = E[eV] \times N \times e \times f_{rep}[Hz]$$

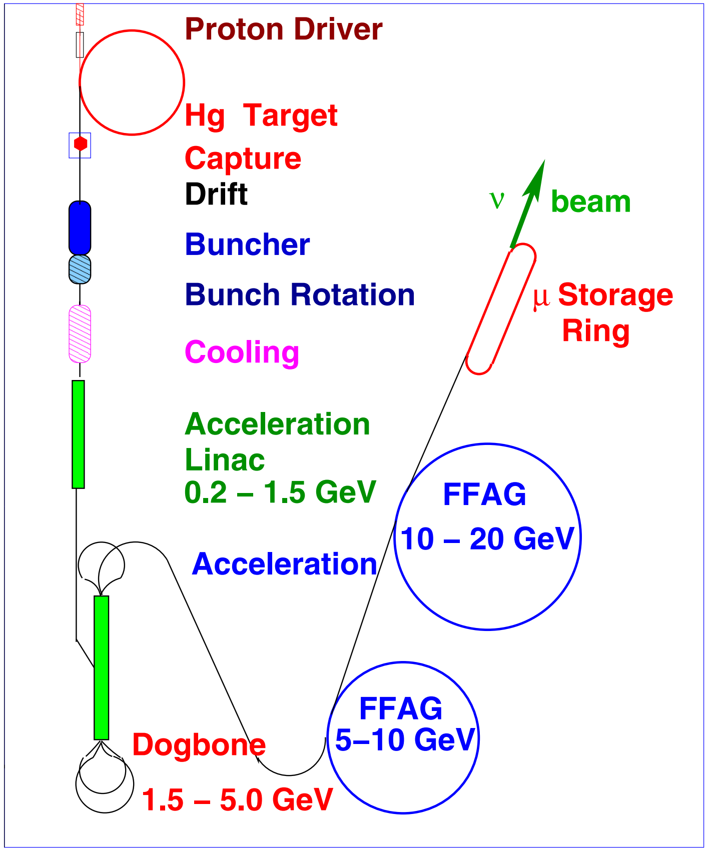
	10 Hz	25 Hz	50 Hz
10 GeV	250×10^{12}	100×10^{12}	50×10^{12}
20 GeV	125×10^{12}	50×10^{12}	25×10^{12}

Process mesons through Cooling

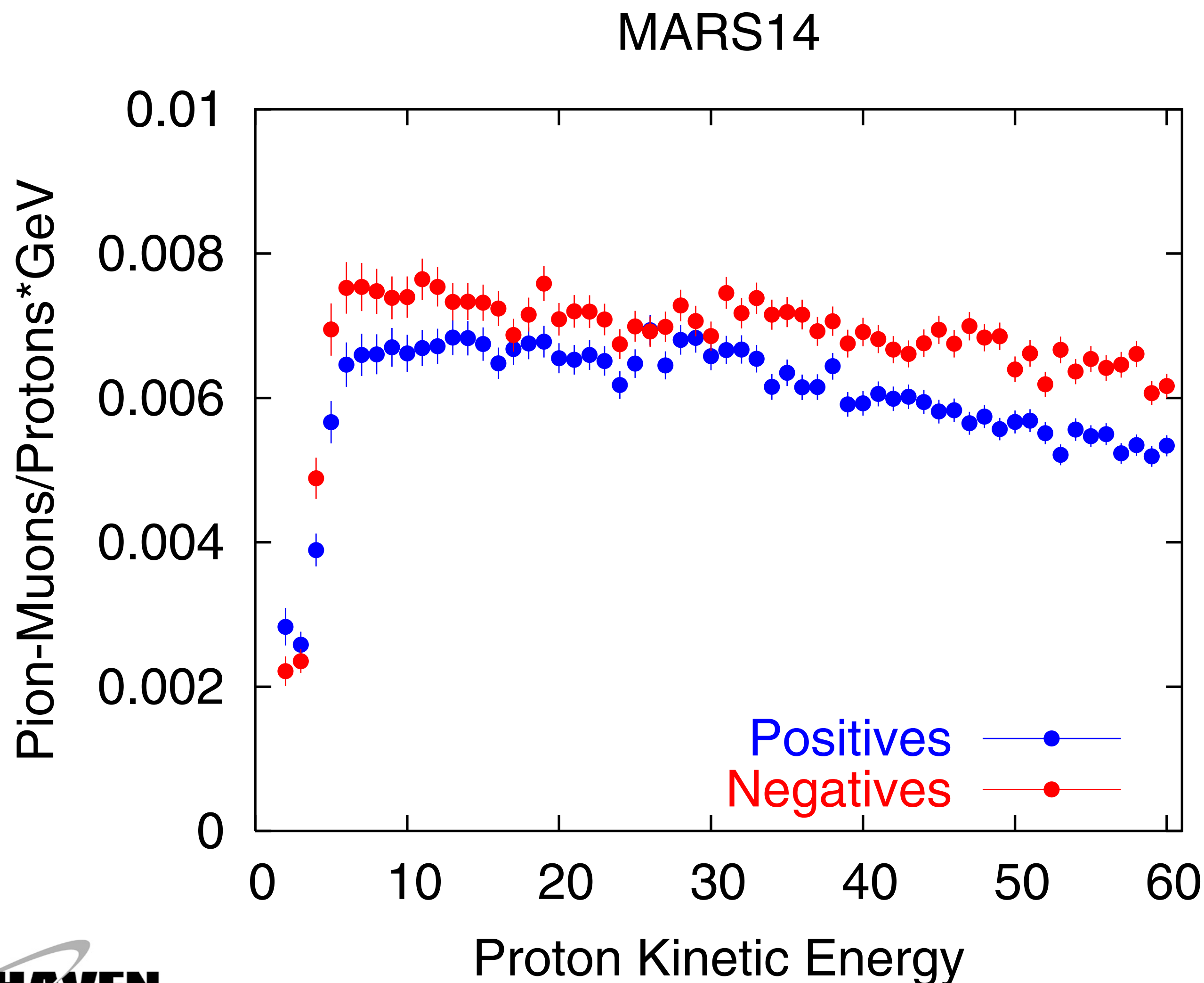
Analysis II

Post Cooling

Count mesons within acceptance of 30π mm



Post-cooling 30π Acceptance



Preferred Beam Energy

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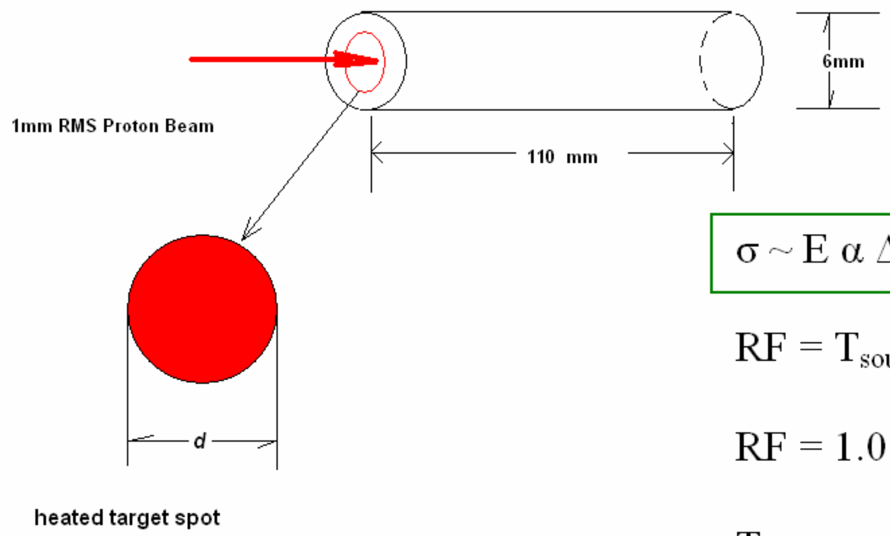
- For Negatives the peak occurs for
  6 Gev < Proton KE < 11 GeV

- For Positives the peak occurs for
  9 Gev < Proton KE < 19 GeV

- **Consensus: 10 GeV is a good place to start**

Target/Beam Baseline used for

24 GeV Protons on Copper Target



$$\sigma \sim E\, \alpha\, \Delta T / (1 - 2\nu) \cdot RF$$

$RF = T_{sound} / T_{pulse}$ (if $T_{sound} < T_{pulse}$)

$RF = 1.0$ (if $T_{sound} > T_{pulse}$)

$T_{sound} = d / V_s$

V_s = sound velocity in material

NOTE: If pulse is too short NO reduction in peak stress can be realized since heated zone does not have time to relax during deposition

Parameters Affecting Shock Level in Solid Target

- Heat capacity (controlling temperature spike)
- Speed of sound in the material
- pulse length
- coeff. of thermal expansion
- Young's modulus

Summary of Target Performance

1 MW/50 Hz 12.0 e+12 ppp **YES**	**4 MW/50 Hz** 48.0 e+12 ppp **NO**
1 MW/200 Hz 3.0 e+12 ppp **YES**	**4 MW/200 Hz** 12.0 e+12 ppp **MAYBE**

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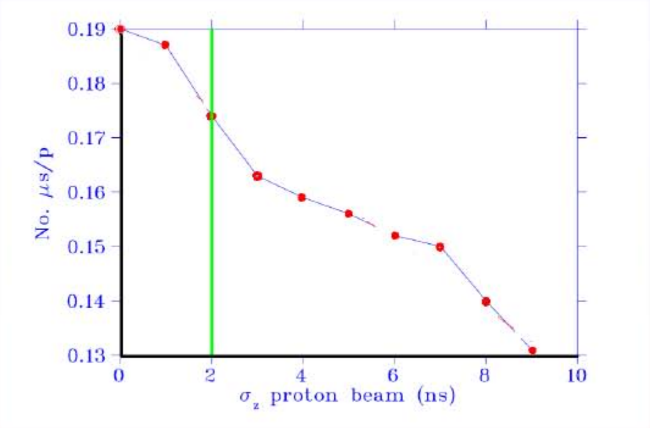
Target/Capture/Decay

- Optimum target material - solid or liquid; low, medium or high Z
  - Targets examined: C, Cu, Hg, Ta, all with $r = 1$ cm
  - Proton beam energies considered: 5, 10 and 24 GeV
  - Proton bunches from 1–3 ns rms

- *Find 1 ns is preferred but 2–3 ns is acceptable;*
- *12% fall-off in performance at 3 ns;*
- *such short bunches hard to achieve at low energy*



- Intensity limitations (from target or beam dump)
- Horn or solenoid capture

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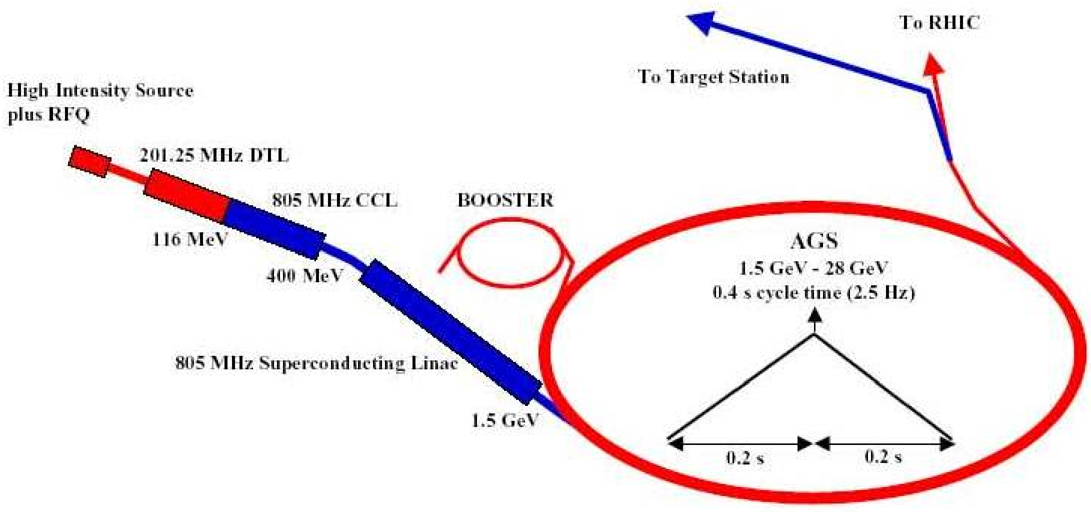
Design Parameter Phase Space

1. 8.0 GeV < Energy < 20.0 GeV
2. Rep Rate ~ 50(25) Hz
3. Intensity 50*10**(12) ppp, at 10(20) GeV
   (very difficulty with solid target)
4. Bunch Length < 3 ns, for longitudinal acceptance
5. Number of bunches 3 ~ 5

2 MW AGS Proton Driver



AGS proton driver layout for alternate injector linac design.

Methods of generating Short Bunch

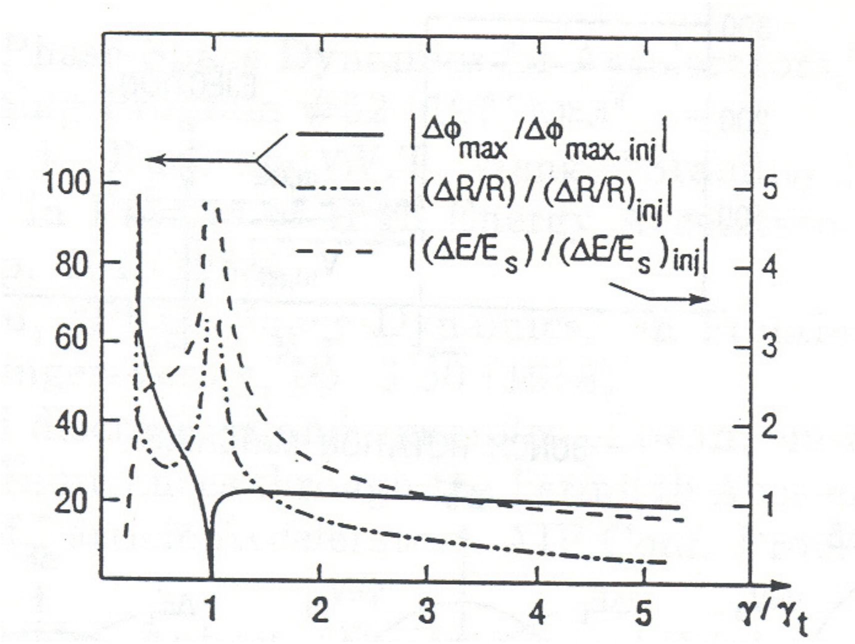
- Short bunch can be generated by a compressing RF system
- It can also be generated by bunch rotation in the ring, or in the external beam line (both of them need extreme high rf voltage)
- We try to do it by getting to the transition energy at extraction(low voltage is sufficient)

AGS parameters at Transition

Table 3.1: Main parameters of the AGS for the super neutrino facility.

Parameter		Unit
Nominal transition energy, γ_T	8.5	
Acceleration rate, $\dot{\gamma}$	196.6	s^{-1}
Magnet ramp rate, $\dot{B}$	7.2	T/s
rf voltage, V_{rf}	1.0	MV
rf harmonic number, h	24	
rf synchronous phase, ϕ_s	0.52	radian
Number of proton per bunch	3.87×10^{12}	
Bunch area (95%)	0.8 – 1.2	eV·s
First-order non-linear compaction, α_1	2	
Transition energy with γ_T-jump, γ_T	9.5	
Transition jump amount, $\Delta\gamma_T$	± 0.5	
Transition jump time	< 1	ms
Momentum aperture (without transition jump)	2.4	%
Momentum aperture (With transition jump)	1.6	%
Typical fractional beam loss	0.2 - 3	%

Beam Parameters around Transition



Typical variation of Δφ, ΔR, and ΔE as the beam energy increases.

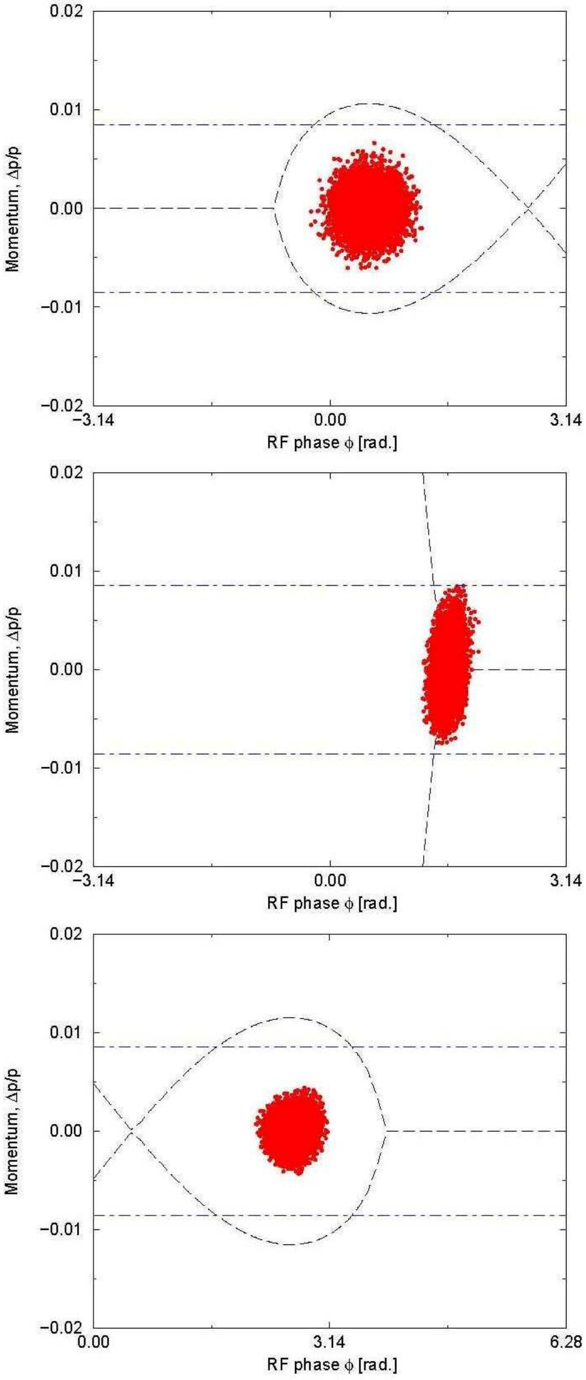
Longitudinal Space Charge Effect

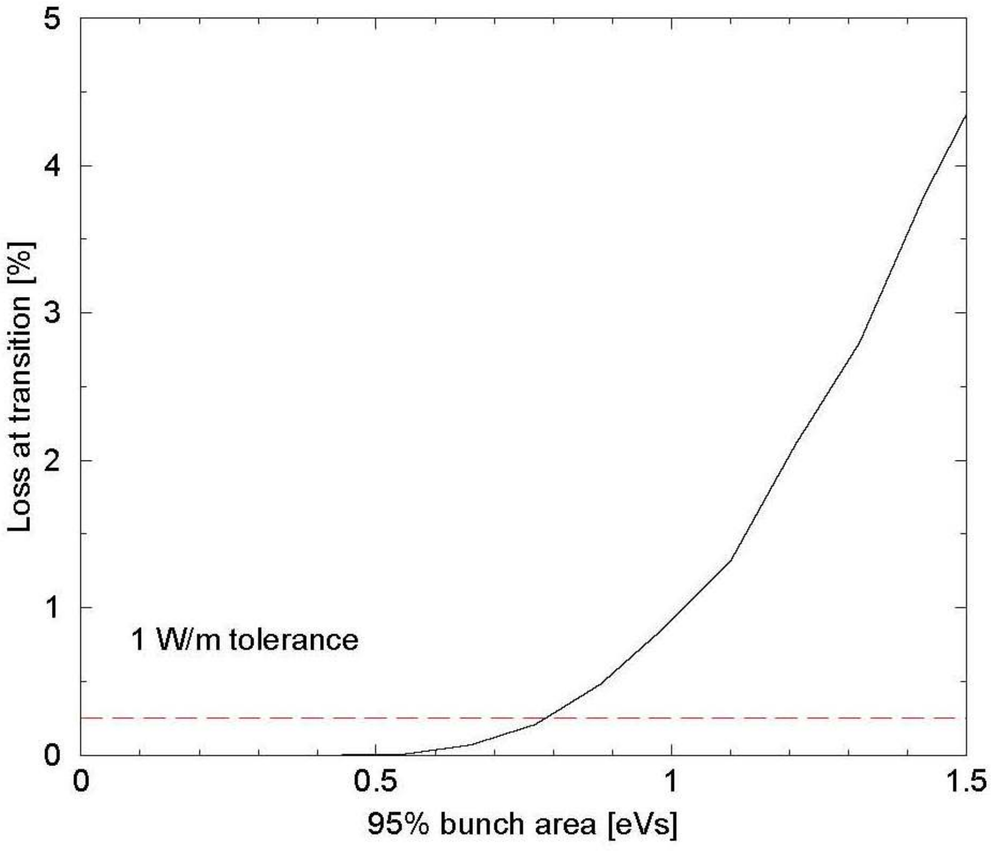
sc parameter, $$\eta_0 = \frac{3N}{2}\frac{r_p}{R}\frac{2\pi h m c^2}{\gamma^2 eV\cos\phi_s}\frac{g_0}{\theta_0^3} \le 3$$

scaling relation, $$\eta_0 = \text{const} \times \frac{N}{R}\left(\frac{h}{V}\right)^{5/4}\left(\frac{\varsigma_i}{\gamma_i}\right)^{3/4}$$

(E. Courant, 1968)

Longitudinal phase space of the proton beam before, at, and after crossing the transition energy in the AGS obtained with the computer code TIBETAN.





Expected fractional beam loss upon transition crossing as a function of the initial (95%) longitudinal beam area obtained with the computer code TIBETAN.

AGS as a Proton Driver

	Present	Upgrade	
		VLBL	NnFact
Average Beam Power	0.14	2.0	4.0
Beam Energy (GeV)	24	28	10
Number of Protons per Fill	7.0×10^{13}	9.0×10^{13}	25.0×10^{13}
Number of Bunches per Fill	12	23	23
Protons per Bunch	5.8×10^{12}	3.91×10^{12}	1.1×10^{13}
Repetition Rate (Hz)	0.5	5.0	10.0
Linac Energy (MeV)	200	1500	1500
Linac rms Emitt (p mm mr, nor)	2.0	1.0	1.0
Pulse Length (ms)	0.5	0.72	0.72

Difficulties with this Scenario

- High current and single bunch intensity all exceed space charge limits
- Need rebunching for 3 ~ 5 bunches, unless allowing 6 batch extraction over 10 ~ 20 usec.
- Limitations of RF and PS systems
- Need better matching lattice at transition
- Possible beam losses and activation
- It seems 2 MW is the upper limit at the AGS

Decisions needed on Proton Driver

1. Performance requirements
2. Viability of existing driver proposals
3. Whether to focus on a new design with an integrated design team
4. Cost to the total facility

Table of Proton Drivers

τ_p = pulse duration, N_b = number of bunches per pulse, τ_b = final compressed bunch length.

Driver	Power (MW)	Type	Energy (GeV)	Frequency (Hz)	Protons per pulse ($\times 10^{13}$)	Pulse structure τ_p (μs)	N_b	τ_b (ns)
BNL-AGS	1	Synch	28	2.5	9	720	24	3
	4	Synch	28	5	18	720	24	3
	4	Synch	40	5	12.5	720	24	3
FNAL	2	Synch	8	15	10	1.6	84	1
	2	Linac	8	10	15			
FNAL MI	2	Synch	120	0.67	15	10	530	2
CERN-SPL	4	LAR	2.2	50	23	3.2	140	1
	4	LAR	3.5	50	14	1.7	68	1
J-PARC	0.75	Synch	50	0.3	31	4.6	8	6
RAL	4	Synch	5	50	10	1.4	4	1
	4	Synch	6–8	50	8.3	1.6	6	1
	4	FFAG	10	50	5	2.3	5	1
	4	Synch	15	25	6.7	3.2	6	1
RAL/CERN	4	Synch	30	8.33	10	3.2	8	1
KEK/Kyoto	1	FFAG	1	10^4	0.06	0.4	10	10
	1	FFAG	3	$3\ 10^3$	0.06	0.5	10	10

Summary and Conclusions

- Performance parameters of a PD for NuFact has been reviewed
- Ways to convert the AGS are described
- It is difficulty to meet all requirements
- Site-independent new design has to be initiated, if other existing designs also can not meet the requirements.