01/07/03
Attendees:
T. Wangler, J.-M. Lagniel, W. Chou, J. Wei, C. Prior, S. Machida, R. Macek, R. Webber, P. Casper, A. Drozhdin, F. Mills, F. Ostogic, M. Furman

Speakers:

T. Wangler: High power proton linacs
- MW average power or higher, 1 GeV; LANSCE the only existing one, 1972
- LANSCE, LANSCE, SNS, KEK/JAERI,ESS,CONCERT,APT,ADTF (ATW)
- 1970's linac: Cockcroft-Walton -> DTL -> CCL
- Hands-on
  - Longitudinal tail from 2-cavity (predates RFQ) RFQ: adiabatic bunching
  - Poor long. Matching (x4 freq. Jump) & poor acceptance (100 MeV transition to CCL)
  - Dual-beam, difficult steering
  - Pulsed; turn-on transient
  - Small aperture, weak focusing -> small aperture/beam ratio
- Modern: DC injector -> RFQ -> Intermediate velocity structure (NC or SC) -> High-velocity (SC elliptical)
- APT: b=0.64 with gradient > 5 MV/m at Q>5e9; coupler at 1 MW CW
  - Simple (identical cavity, cell, magnets)
  - Larger aperture, lower loss
  - Less power requirements
  - (Loading time ~ x10 longer than NC)
  - Address all loss issues:
    - RFQ
    - X2 freq
    - Only H+
    - Cw mode only
    - 16 cm at both cavity & quad (13- 50 ratio from 5 – 7, 3.8 cm for LANSCE)
  - Beam dynamics dominated by space charge & beam halo
- Good practice:
  - Good matching but not to assume
  - Small rms reduces halo amplitude
  - Small number of particle/bunch avoids tune depression
  - (high bunch freq for given current)
  - Strong linear focusing
  - Non-linear focusing that weakens with increasing amplitude can disrupt parametric resonance
  - Effects less important for high energy
- Beam halo experiments
  - Codes comparison good for rms, not for halo
  - 2D codes: great for 50% aspect ratio; needs 3D for a factor of 3 – 4 ratio

Discussion
Chou: TESLA $2k/MV

R. Macek: High Intensity Proton Accumulators

PSR since 1986
3e13 ppp @ 20 Hz, 0.8 GeV, 80kW
SNS
ESS
PSR: beam loss
Injection foil stripping
Injection & extraction should not be at the same location for maintenance
300 nA (0.3%) uncontrolled loss mostly in 3 sections (~25 m) near injection and extraction
Up to 50 R/h at hot spots, 1-5 R/h at 30 cm, 4 - 5 h after shut down
60% of uncontrolled loss from foil, 300 -> 50 hits/proton
H0(n) Stark states loss measurement, within x2 in agreement with calculation
losses from space charge
P&D: state-of-the-art on collimators
Foil damage & lifetime (PSR foil lifetime 20 days, x2 more loss, 10 mA)
Foil preparation about 2 hours, scan foil with beam
PSR e-p, 75 us or 200 turns
Centroid e-p model, (n-Q) close to Qe
Instability threshold does not track the strong intensity dependence of e signal (I^6)
Instability threshold does not track the increase in electron signal from increases in vacuum pressure or beam losses
Long exponential tail of accumulated e seen with 170 us decay
Wide-band active dampers
R&D:
Improved foil
Longer life, retain shape
Diamond foil
Diagnostics
Experimental verification of collimator design
Electron cloud
Detailed simulation of e generation
Theory of bunched beams
Direct measurement of e density
Measurement of e-cloud impedance
Laser-aided injection to eliminate foil

F. Mills: High intensity linac and synchrotrons
Transition emittance growth
IPNS & ISIS, not crossing transition

IPNS low loss, lots of space
Technical systems overview:
Lattice:
- FMC, avoid transition, dispersion-free straights, large momentum acceptance, large DA
- FNAL PD, FMC, Ohnuma, Johnston, Ritson, only not simple enough; 1-fold symmetry

Magnets:
- Running at 1.5 T
- Quad pole tip 1.2 T, but large momentum part 1.8 T
- Saturation at large momentum part (sextupole)

Power supply
- Dual-resonance vs. single resonance to lower b'

Vacuum
- Canned dipole, striped shield & perforated shield

RF
- High gradient, wide-band Finemet cavities

Beam pipe
- Metallic strips or perforated liner

Injection
Collimators
H- source
- High brightness Dudnikov type source
- Source 35-55 mA H-

Linac front-end RFQ + double-alpha system for reliability; replace tank 1
- Proton beam, 1963 Yale conf. F. Mills
- (sharp bend, stripping for H-, space charge?)

RF chopper: novel type (beam transformer)
- Chopper installed on HIMAC linac
- 50 ns rise time,

Inductive insert: new way for compensating space charge
Diagnostics extremely important

01/07/04
Attendee: S. Machida, T. Wangler, J. Wei, W. Chou, J.M. Lagniel, R. Ryne, A. Drozhdin
F. Mills, F. Ostiguy, R. Macek, C. Prior, M. Blaskiewicz, M. Furman, P. Kasper, +1

Chair: J. M. Lagniel
W. Chou: The Proton Driver Design Study
- 1 MW + 1 ns rms (2 years of study)
- separate mu+ & mu-; allow bunch rotation (momentum
- 16 GeV synchrotron plus transport lines
- ➔ High intensity Muons
- ➔ Conventional NuMI, high intensity secondary beam, Tevatron upgrade
- ➔ VLHC
- FNAL, BNL, CERN SPL, RCS, RAL …

FNAL present 0.1 MW, 8 GeV
    Aperture limit (RF, BPM), transition, no injection painting
Stage 1: 12 GeV, 53 MHz rf, 0.9 MW, 15 Hz
Stage 2: 16 GeV, 7.5 MHz, 1.2 MW, 15 Hz (for short bunch length)
Presently limited by loss; a brick wall on intensity (5e12) due to beam loss
Momentum acceptance +/- 2.5%
DA: > 100 pi (much larger than 60 pi beam emittance)
B<=1.5 T, G<=8.9 T/m
(5x9 inches size)
Transition free
Zero dispersion straight
Large rf for 2.5% momentum spread
Lattice tried:
    Doublet (gradient problem)
    Racetrack w/ low-b insertion (too complicated)
    FMC using 270/270 degree DOFO module (allow sextupoles)
Space charge 0.2 and lower
Split integer tune, lower from diagonal line
27 turns of injection
R&D
A: useful for improving
B: critical to PD or part of US-Japan accord
    Chopper
    Stranded conductor coil
C: Necessary for PD

S. Machida: 3 GeV PS lattice & sc; 50 GeV Pslattice & correction
http://jkj.tokai.jaeri.go.jp
3 GeV: 144 painted; 216 scraper; 312 pi mm mr aperture
50 GeV:
0.3 Hz slow ext 0.75 MW
0.4 Hz fast ext 1 MW
54 pi beam; 81 pi aperture
3 GeV lattice:
    arc: 2x3 cell DOFO with missing dipole
    straight: 3-cell normal FODO w/ 2 split quad for injection
Gt=8.9 for longitudinal matching
3-fold symmetry: still under debate to separate injection/collimation
7 family quad, considered not a problem for RCS
strong 27^{th} harmonic (3 x 9)
No chromatic sextupoles (+/- 0.7%, compare with -0.32 space charge)
Tune scan performed
10 k turns
Alternative lattice: 4-fold symmetry w/ doublet insertion; not much difference in tune resonance lines
5 GeV lattice:

arc: 8x3-cell DOFO
ins: FODO, matching section, phase shifter …
variable momentum compaction
needs sxtupole: 2 family vs. 12 family
2-family behaves better than 12 family in tune flatness; no difference in DA
DA twice magnet aperture
H 270; V 270 or lower
Most difficult: slow extraction 3rd order resonance, 1% loss gives 7.5 kW
Dipole 1.1 T
Single-harmonic sinusoidal

C. Prior: Lattice, injection, space charge
ISIS, ESS, HIDIF (European heavy-ion fusion) driver, NFPD (UK, CERN), ASTRON, SNS, FNAL PD
Injection scenarios:
- Dispersion/non-dispersion injection
- Correlated/anti-correlated
- Varying incoming beam direction
- Vary position of spot on foil
- Vary ring parameters during injection

Mismatched injection
Procedure:
- Lattice design w/o space charge (peaks, normalized dispersion)
- Lattice optimization w/ linear space charge
  - o injection foil layout & extraction
- momentum ramping, longitudinal injection optimization (B factor)
- optimized vertical orbit bump
- 2 D w/ and w/o non-linear space charge
- 3D

FNAL PD: 27 turns in 90 us
Orbit bump for uniform distribution
Effects of coherent/incoherent tune spread

M. Furman:
1977, CERN ISR – sudden increase of vacuum Pressure (coherent ECE)
e machines (incoherent ECE)
1985, CESR anomalous anti-damping, explained 1996 (J. Rogers)
similar to BBU, except by electrons
central point: SEY (both at peak SEY energy, 100 – 300 V, and near zero energy)
LBL simulation model
- Both SEY and d(SEY)/dE
- Not including foil production e but considers beam loss

Avoid BIM (adjust SB, N) if delta_eff > 1
Choose material with low SEY
Yield near zero energy is hard to measure and is important
Remedies:

Weak solenoidal field (PEP-II, KEK-B), 20 – 30 G
Low SEY material & coating
Antechamber to extract ~99% S.R. photons
Sawtooth surface (LHC,KEK-B?)

P. Kasper: Physics potential of proton driver
http://projects.fnal.gov/protondriver/summary
intensity requirements: 2e16 p/hour …1e20/year
1 year = 2e7 sec.
FNAL Booster radiation level needs to be reduced by x13 to achieve these rates (5e12, 7.5 Hz)
need to control to 1 Rem/hour/foot
coat all much below Gamma_Y

010706

T5/M6 Joint session

Ingo Hofmann: Space charge & instability in high intensity drivers
Longitudinal stability, coasting or long bunch, below transition
(space charge nonlinear and resistive linear)
Steepening of resistive driven waves (Rumolo et al Phys. Plasmas 6, 1999)
Absence of saturation (Landau damping)
Below transition, slow wave moving against beam cause instability; lower momentum part; preventing Schottky signal detection
RF cavity Q~10, passive. (ferrite)
Purely resistive impedance: broadening effect towards lower momenta
(Vlasov approach)
growth rate agrees between simulation & experiments within 5%
good agreement between PIC and Vlasov
Balanced impedance (outside of onion stable region, real ~ imaginary)
quadratic unstable/Gaussian stable
initially parabolic, stabilizing tail developed
Simulation of bunch in barrier bucket
Z/n = 70 Ohm for space charge
Z/n = 50 Ohm broadband (Q~1, centered around h=1000)
Perturbation originating from end
Stabilizing effect due to finite bunch length
(but frequency structure differs between coasting and barrier; included in simulation but not in dispersion relation)
Space charge dominated beam, easily stabilize the beam as long as the bunch is sufficiently short; Boussard criteria is over limiting
Above transition, not propagating but stationary.
Transverse space charge issue (2-D r-z PIC)
Quadrupolar PU to measure coherent envelope frequency shift
High resolution w/ PIC with size

W. Decking: TESLA damping ring

Long circumference 17 km, space charge becomes important: 0.2 – 0.3
Track with non-linmear space charge kick and evaluate Courant-Snyder invariant change
Increase ring energy
gamma^3, (3. -> 5 GeV) but …
overall not very effective
Increase bunch volume
Increase bunch volume through local coupling
Vertical emittance growth due to local coupling
Summary:
Space charge important (0.23) even at 5 GeV
Incoh tune shift <0.1 seems ok
reduce space charge with local beam blow-up
simulation shows local coupling bump is successful
EPAC paper
Needs error effects
Effects of wake field
Working point, flexibility, resonance and correction

Discussion

Space charge & transverse effects at bunch rotation

01/7/6
Chair: T. Wangler
Attendees: C. Prior, W. Chou, T. Wangler, R. Weggel, S. Machida, N. Mohkov, A. Drozhdin, I. Hogmann, K. McDonald, F. Ostiguy, J. Holmes, J. Galambos, A. Garren, A. Luccio, …
(~ 30 people)

C. Prior: ESS and RAL PD

ESS:
Funnelled linac, 2x57 mA, nc and sc
Reference design I and II
Revides stru, new chopper, new funnel, nc and sc option
Larger ring, 35 m radius, modified injection scheme (1 hit!)
10 Hz target abandoned
Long pulse target
Funneling after DTL, linear sc all through design, bends & minimize emittance
Growth (new design from 30% to <1%)
Chopper rise time 1 ns, at MEBT, nothing at LEBT
PD:
5 GeV, 50 Hz, 1 ns pulse
180 MeV H- linac two 1.2 GeV, 50 Hz RCS (two bunches of 2.5e13) ->
two 5 GeV, 25 Hz RCS (four bunches of 2.5e13)
similar to ESS

to get short bunch length, work just below transition
ISR scheme
4-fold symmetry, -> 15 GeV
Tf is a figure of merit, (target peak proton power density ~ 1/ (Tf)
(kinetic energy, frequency)

T. Roser: BNL PD
Different approach: to reduce loss
Raise injection energy, use first section, 116 MeV of 200 MeV existing linac,
400 MeV, 800 MeV, 1.2 GeV
2.5 Hz, AGS: 1.2 GeV -> 24 GeV
Future needs flat top
805 -> 1610 MHz (lower power, ok with smaller bore size, up to 22 MV/m)
Beam power at injection: 50 kW, allow much more loss
Transition loss at max. disp.
Upgrade RF to 9 MHz to double gradient (h=24, 1 MV/turn)
Filling 18 out of 24 to allow final harmonic change (from h=24 to h=6)
H=6, 100 kV/turn,
Adiabatic quad pumping (developed for g-2) modulating at twice synch. freq.
Towards 4 MW
Eliminate flat top , 150 ms -> 100 ms
Storage ring + compression ring
Compressor ring:
Difficult in transition nonlinearity
Transition 40 tolerable change of alpha_1
Momentum acceptance +/-5% (FFAG type?)
May need to replace chamber to reduce impedance
Linac will not do heavy ions, booster for pol. proton & heavy ion

J. Holmes: transverse impedance model in space charge simulation
Instability threshold at 1.6 Mohm, within 5% agreement
Halo growth in even for stable cases
Transverse resistive instability
(Hofmann) There will be no self-consistent solution in the presence of
space charge
H. Chen: R. Davidson had halo generation results earlier

Joint session with M1: Muon-based systems

A.G. Ruggiero (T. Roser presenting): alternative scheme for NFPD
PD for continuous beam at 150 MW
Continuous proton on heavy solid (liquid mercury not needed) target to
produce mu +/-
No muon cooling, nor bunch rotation, no phase space manipulation
-- relying on large power (x150)
PD injector -> PD recirculator, 200 MHz beam bunching frequency at 32 GeV
Big issue is whether target can take the power
Momentum stacking, 250 bunches

Collider 1x1 TeV
1.5e13 muons stored, momentum spread +/-2%
method of injection: cyclotron/FFAG mode
20 cm solenoid size, bunch spacing 150 cm
SCL 201.25 MHz to 116 MeV, 805 MHz to 400 MeV, 1.6 MHz to 2 GeV
Energy gain per pass: 1 GeV
What about some compromised scheme using cooling?

W. Chou: Present, stage 1, stage 2
- Main issue to 4 MW: ground water (not target)
- 4 MW target not fully explored at FNAL
- presently 2 cm diameter, 80 cm long, Carbon target replaced 3-4 weeks
- radiation cooled target
- 15 man-year to do the pre-CDR design
- if ok'ed by director (wait for ½ year or so), do CDR and set cost

T. Roser: BNL PD discussion
- Next is to do a book of pre-CDR

01/7/7
Chair: I. Hofmann

T. Wangler: linac for nuclear transmutation
- Advanced Accelerator Applications
- Trying to extend linac to lower beta
- Replacing nc with sc from 6.7 to 211 MeV:
  - save 57 MW of ac power out of 80 MW
  - at beta=0.3, gradient > 10 MV/m
- spoke cavities: at 350 MHz, beta: 0.175, 0.20, 0.34 to 109 MeV
  - bore radius 1-3 cm
  - (TEM cavity)
- elliptical cavities: at 700 MHz, beta: 0.48, 0.64 to 600 MeV
- challenge is how to use the large gradients in beam dynamics
- importance of beam matching
  - most severe cause of beam halo
  - particle-core model -> predicts maximum halo extend
  - ellipsoidal model shows: when z>2r transverse modes are important
  - longitudinal damped by nonlinear RF force
- Halo experiments:
  - 52 quad FODO, 10.9m
  - measure 1) rms 2) maximum halo extend 3) kurtosis
  - kurtosis: 0 for KV, 1 for Garssian
  - matched: between 0 and 1; mismatched, > 1
  - shoulder unexplained (log of density vs. amplitude)
- J.-M. Lagniel: disagree with longitudinal halo damping argument
  - (caused by detuning?)

S. Nath: SNS linac
- Continuously shifting phi_s to compensate missing gap (1 beta-lambda) is very

effective (without tuning complications and tail filementation)
maximum halo extend reduced from 4.8 sigma -> 3.6 sigma (ideal case)

J. Galambos

Injection dump takes 1% beam

S. Machida

Rms, rms evolution
Emittance exchange within 1 ms
For KEK booster, space charge cause H & V emittance exchange
This may happen for anti-correlated painting if tunes are not chosen carefully
Agreement is good, at least qualitatively
Future: dp/p of incoming beam
Beam loss and effects
Whether this is coherent or incoherent effect?
e-beam compensation of spacecharge
partial compensation makes things worse – e-beam introduces gradient error
Summary:

- need 3 more sections for compensation
- alignment < 1 mm
- effect of e-beam distribution