POSITRON CAPTURE IN ADIABATIC MATCHING SYSTEMS

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POSITRON CAPTURE IN ADIABATIC MATCHING SYSTEMS

- INTRODUCTION
- DUE TO LARGE EMISSION ANGLES (MULTIPLE SCATTERING IN THE TARGET) THE POSITRONS MUST BE CAPTURED IN AN EFFICIENT MATCHING SYSTEM BEFORE BEING ACCELERATED IN THE LINAC AND INJECTED IN THE DAMPING RING. MANY KINDS OF MATCHING SYSTEMS HAVE BEEN STUDIED SO FAR ($\Lambda/4$, ADIABATIC, PLASMA LENS, LITHIUM LENS,…). ONE OF THE BEST SYSTEMS IS THE *ADIABATIC MATCHING DEVICE* (AMD), DUE TO ITS LARGE MOMENTUM ACCEPTANCE. IT WAS, FIRST, STUDIED AND INSTALLED AT SLAC BY R.HELM IN THE 60'S. THE STUDY PRESENTED HERE CONCERNS POSITRONS PRODUCED IN A THIN TARGET FROM PHOTONS ISSUED FROM COMPTON SCATTERING.

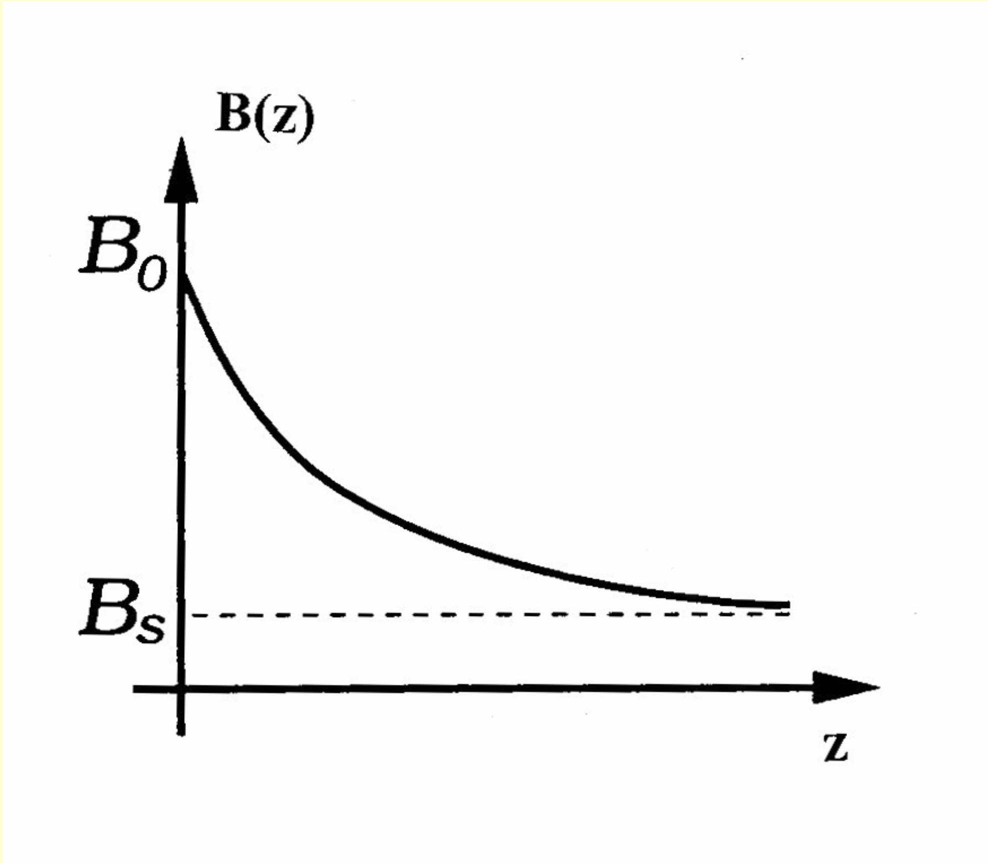
POSITRON CAPTURE IN AN ADIABATIC MATCHING SYSTEM

- PLAN
- 1-THE ADIABATIC MATCHING DEVICE: A RECALL
- 2- PROBLEMS OF ACCEPTANCE IN AN ADIABATIC MATCHING DEVICE
- 3- OPTIMIZATION OF THE PARAMETERS
- 4- SIMULATIONS: SCHEME OF THE SIMULATIONS
- 5- RESULTS OF THE SIMULATIONS
- 6- DISCUSSION AND CONCLUSION

POSITRON CAPTURE IN AN ADIABATIC MATCHING SYSTEM

- THE ADIABATIC MATCHING DEVICE (AMD): A RECALL
- THE AMD USES A SLOWLY VARYING MAGNETIC FIELD FOLLOWED BY A LONG SOLENOIDAL MAGNETIC FIELD EXTENDING OVER SOME ACCELERATING SECTIONS. BETWEEN THE MAXIMUM (B_O) AND THE MINIMUM (B_S) THE FIELD TAPERS ADIABATICALLY; THAT MEANS THAT THE ADIABATIC INVARIANT; $\oint \sum p_i dq_i$ IS CONSERVED
- IN SIMPLE WORDS THAT MEANS THAT THE FLUX OF THE MAGNETIC FIELD TROUGH THE BEAM SECTION IS CONSERVED.

POSITRON CAPTURE IN AN ADIABATIC MATCHING SYSTEM: FIELD PROFILE



POSITRON CAPTURE IN AN ADIABATIC MATCHING SYSTEM

- The magnetic field law:
- $B(z) = B_o/(1 + \alpha z)$

where B_o is the maximum field,

α (in m^{-1}) is such:

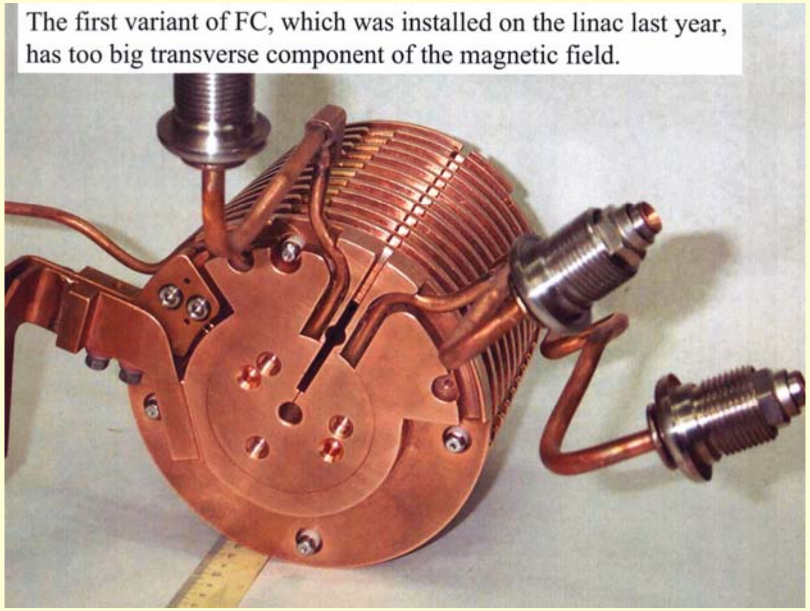
$\alpha = \varepsilon B_o/P_o$

Where P_o a "central" momentum value and ε smallness parameter : $\varepsilon=(P/eB^2)dB/dz$

$\varepsilon << 1$

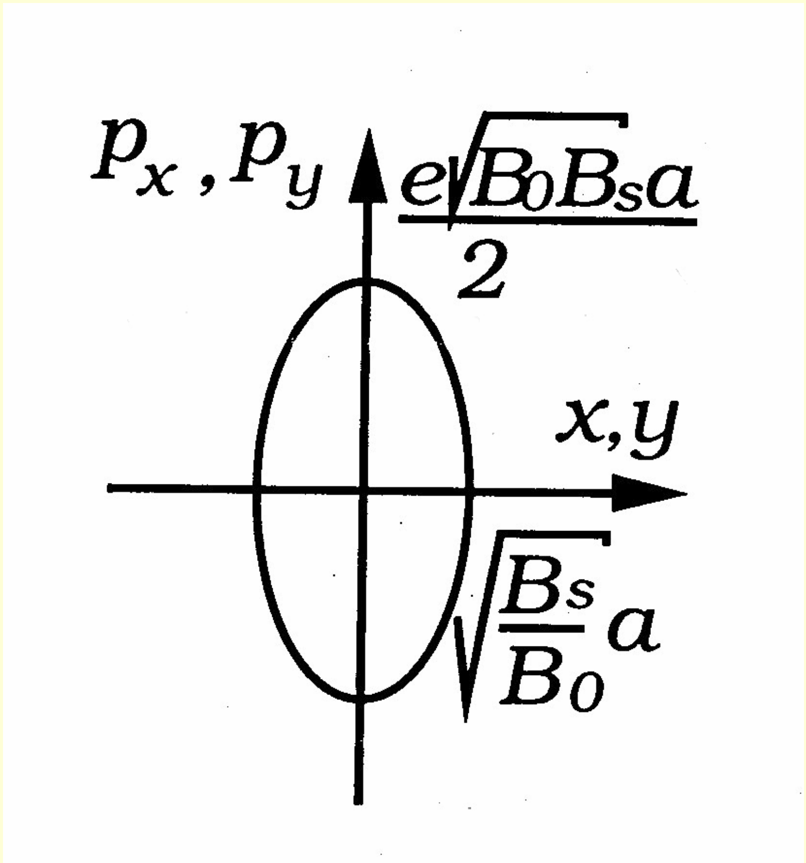
High fields in the adiabatic lens: **flux concentrator**

see figure=====>



POSITRON CAPTURE IN ADIABATIC MATCHING SYSTEMS

- **Transverse phase space**
- Transverse acceptances at the target exit, with canonically conjugate variables, are represented by upright ellipses:
- x_o, y_o = $[B_s/B_o]^{1/2}a$ {small axes}
- p_{x_o},p_{y_o} = $e[B_oB_s]^{1/2}a/2$ {big axes}
- Where a is accelerator radius
- The transverse momentum acceptance (target inside the solenoid):$p_T = e\{B_oB_s]^{1/2}a$
- Maximum emittance at solenoid exit: $eB_sa^2/2$



POSITRON CAPTURE IN AN ADIABATIC MATCHING SYSTEM

- LONGITUDINAL PHASE SPACE
- At the target exit the positrons undergo trajectory lengthening due to:
- - velocity dispersion
- - spiralization of the particles in the solenoidal field
- Trajectory lengthening induces phase dispersion worsening and momentum dispersion broadening. In the longitudinal phase space, phase and energy are related by (if we consider the bunch on the creast of the field):
- $$\Delta E/E \sim (1/8).(\Delta\varphi)^2$$

where ΔE and $\Delta\phi$ represent FWHM values.

- The positron beam emittance is to be damped in a damping ring (DR). For most of the DR, the energy acceptance is about 1%; therefore a limitation is put on the energy dispersion of the e+ beam and on its phase dispersion.

POSITRON CAPTURE IN AN ADIABATIC MATCHING SYSTEM

- **Condition on phase extension $\Delta\varphi$**
- The phase extension is given by:
- $$\delta\varphi = [(\delta\varphi_i)^2 + (\delta\varphi_v)^2 + (\delta\varphi_B)^2]^{1/2}$$
- Where $\delta\varphi_{i,}$, $\delta\varphi_{v,,}$, $\delta\varphi_B$, represent the initial phase spread, the contribution of velocity dispersion and the contribution of spiralization in the field, respectively. For the choosen configuration, $\delta\varphi_i$ corresponds to ~ 20 ps rms ; for an L-Band linac which is the preferred positron preaccelerator (for its large aperture) that represents less than 10º.
- For the same kind of linac, $\delta\varphi_v$ represents for two particles having 5 and 20 MeV respectively, a phase difference of less than 4º on a 50 cm distance ;$\delta\varphi_B$ is 4 times larger for the same conditions. So, it is expected that the main contribution to phase slippage comes from the spiralization of the particles in the magnetic field. Thus we must have $\Delta\varphi < [8\eta]^{1/2}$ or $\boldsymbol{\Delta\varphi_B \ll [8\eta]^{1/2}}$; η being $(\Delta E/E)_{max}$

POSITRON CAPTURE IN AN ADIABATIC MATCHING SYSTEM

- CONTRIBUTION OF PARTICLE SPIRALIZATION
- The bunch lengthening due to particle spiralization is given by (F.Amman):
- $\Delta L = (\gamma_c \lambda_s / 4\varepsilon)\theta^2_f \ln(\lambda_s/\Lambda)$
- Where γ_c is the relative energy in the center of the energy domain,
- $\lambda_s = 2m_o c/eB_s$ and $\Lambda = 2m_o c/eB_o$
- ε is the smallness parameter for the adiabatic field
- Θ_f is the maximum positron angle at the end of the matching system where B->B_s. This angle is related to the maximum entrance angle in AMD by: $\theta_f = \theta_i[\Lambda/\lambda_s]^{1/2}$. So, we get for $\Delta\varphi(\Delta L)$:
- $\Delta\varphi_B = (\pi/\lambda_{RF})(\Lambda\gamma_c\theta^2_i/2\varepsilon)\ln(\lambda_s/\Lambda)$
- And the condition on the maximum entrance angle becomes:
- $\theta^2_i << [8\eta]^{1/2}(\lambda_{RF}/2\pi)[1/\{(\Lambda\gamma_c/4\varepsilon)\ln(\lambda_s/\Lambda)\}]$

POSITRON CAPTURE IN AN ADIABATIC MATCHING SYSTEM

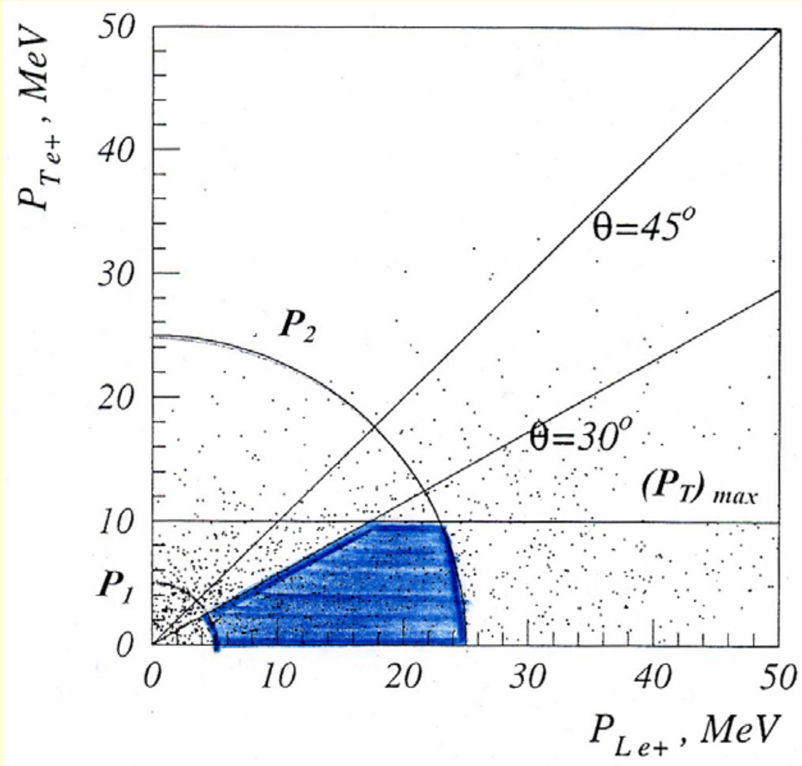
- DEPENDENCE OF MAXIMUM e+ EXIT ANGLE
- The maximum acceptable positron angle is$_s$:

- * weakly increasing with the maximum energy dispersion η $(\sim\eta^{1/4})$
- * increasing slowly with the RF wavelength λ_{RF}
- * increasing slowly with the maximum field $\mathbf{B_o}$ of the AMD $(\sim B_o^{1/2})$
- * weakly increasing with the ratio $\mathbf{B_o/B_s}$ $(\sim[\ln(B_o/B_s)]^{1/2})$

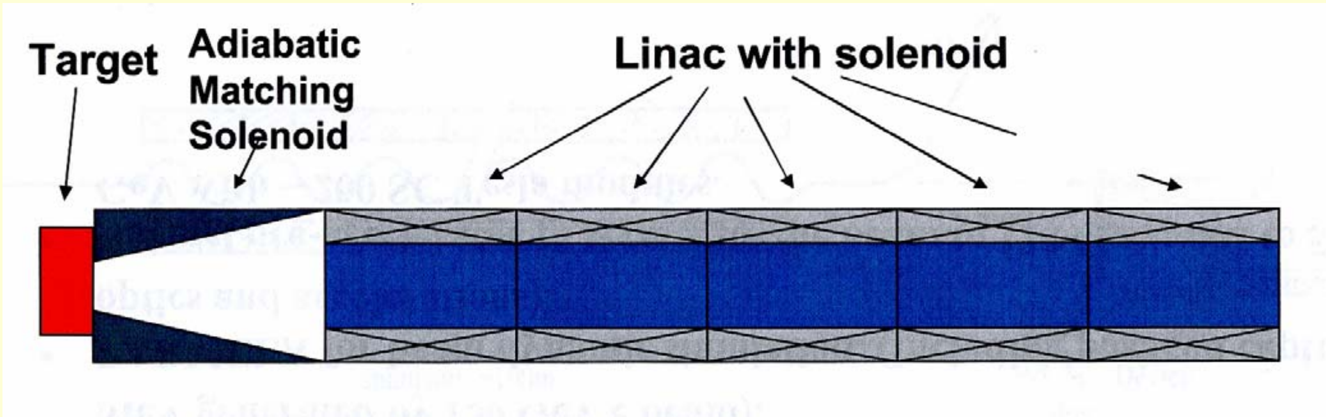
POSITRON CAPTURE IN AN ADIABATIC MATCHING SYSTEM

- **ACCEPTANCE AND OPTIMIZATION**
- It is convenient to represent the acceptance diagram in ($p_L p_T$) space: #the **momentum acceptance:** lying between two circles of radii p_1 & p_2; p_1 is~5 MeV (lower momenta are harder to transport); p_2, related to ε
- # **(p_T)max**, maximum transverse momentum is $e[BoBs]^{1/2}a$
- # limitations associated to bunch lengthening provide maximum θ; here, two values of θ [S, L bands]. The **accepted positrons** are in a geometrical figure limited by these lines (area in blue).
- **Optimization consists in choosing AMD parameters in order to:**

  get the maximum number of e+ with a reasonable small η (and so, θ) making more efficient the injection in the DR.

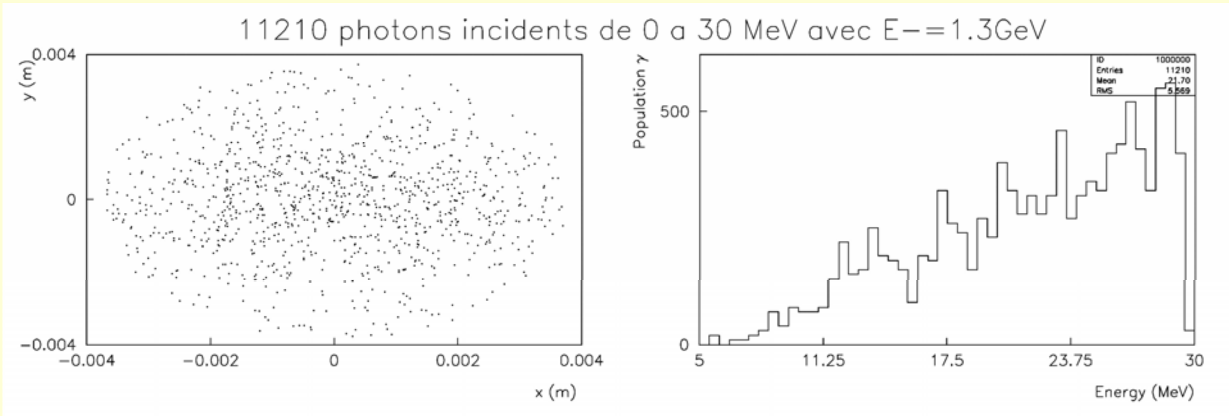


POSITRON CAPTURE IN AN ADIABATIC MATCHING SYSTEM



- **Scheme of the simulations**
- The positrons are generated in a thin W target from photons produced in Compton process with a circularly polarized laser scattering on GeV e- beam. The positrons are, then, captured by an AMD and accelerated in an L-Band structure. The Compton process is simulated with **CAIN**. Positron generation is simulated with **EGS** (without polarization). The transport channel (see figure) is simulated with **PARMELA**

POSITRON CAPTURE IN ADIABATIC MATCHING SYSTEMS



- **PHOTON BEAM** : the photons resulting from the Compton interaction of a 1.3
- GeV e- beam with a Nd:YAG laser (in the FP cavity in the Compton ring) are sent to the positron target (0.4 X_0 of amorphous W) through a double collimation (~1mrad) . The transverse size at the e+ target and the energy spectrum are presented above. The distance between the interaction point and the positron target is of 10 meters.

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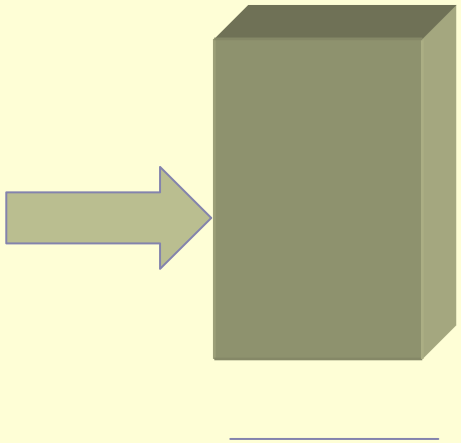
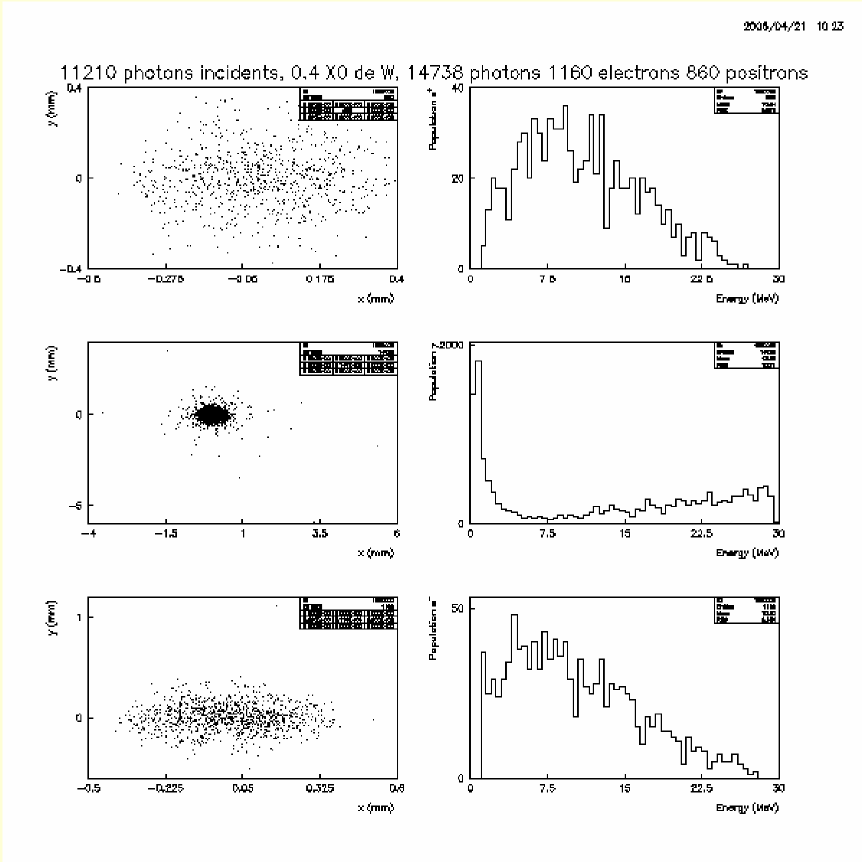
- **THE POSITRON TARGET**
- Only photons are impinging on the target
- The target is at ~ 10 meters from the Compton interaction point
- Target: amorphous W disk $0.4X_o$ thick
- Target is *inside the magnetic field*
- *Positrons coming out from the target are submitted to the maximum field [6 Teslas]*

- **Incident γ**



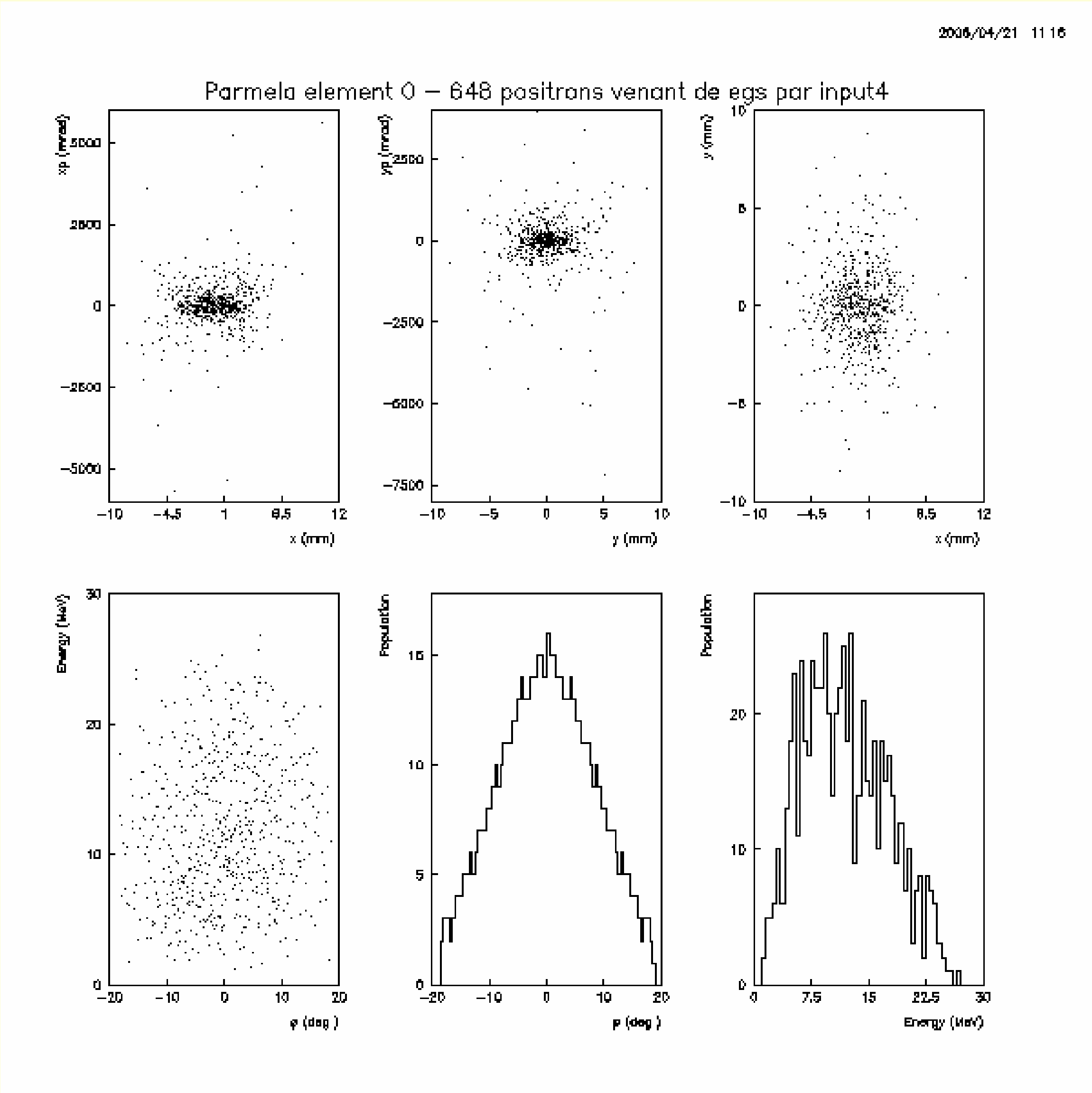
$L=0.4X_o$

POSITRON CAPTURE IN ADIABATIC MATCHING SYSTEMS:EGS RESULTS



POSITRON CAPTURE IN ADIABATIC MATCHING SYSTEMS:EGS/PARMELA

- Since the phase information is not provided with EGS, we assumed that the positron distribution had the same temporal characteristics as the widest time pulse in the Compton interaction, I.e., the electron one (σ=6 mm). The positron phase diagrams will illustrate this point.
- To complete the presentation of the positron results coming out from EGS, we provide the emittance diagrams.
- The set of figures presented in the next diapo corresponds to the positron characteristics at the entrance of the focusing and accelerating channel to be simulated with PARMELA.
- We put an angular limit (45 degrees) for the positrons entering in the focusing & accelerating channel (less than 25% of the e+ have larger angles); these positrons will be lost anyway.



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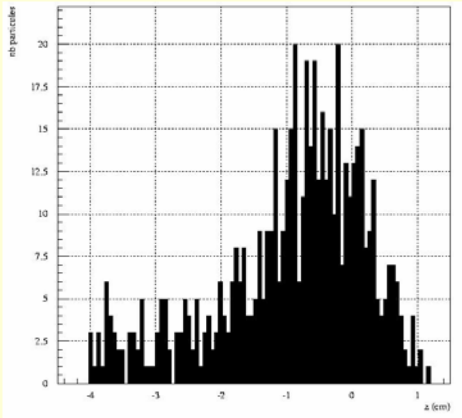
Parmela element 0 – 648 positrons venant de egs par input4
xp (mrad)
x (mm)
yp (mrad)
y (mm)
y (mm)
x (mm)
Energy (keV)
φ (deg)
Population
φ (deg)
Population
Energy (keV)

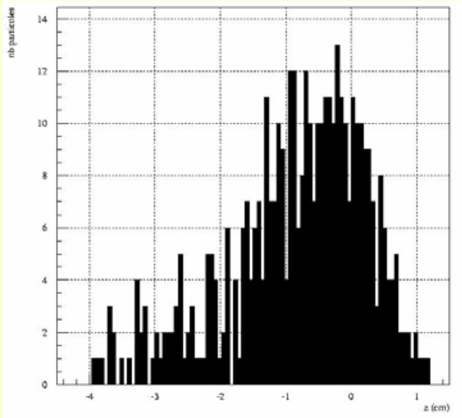
POSITRON CAPTURE IN ADIABATIC MATCHING SYSTEMS

- SIMULATIONS WITH PARMELA
- Matching system:
- The magnetic field is tapering from 6 Teslas (at target exit) to 0.5 Tesla at the entrance of the accelerating section where a 0.5 Tesla field is superimposed on the accelerating field. A distance of 50 cm, between the target exit and the entrance of the accelerating structure, is assumed.
- Accelerating structure
- An L-Band structure working at 1.3 GHz with an accelerating field of 20 MV/m extending on a length of 1.25 m. The accelerator radius is of 23 mm.

POSITRON CAPTURE IN ADIABATIC MATCHING SYSTEMS: PARMELA RESULTS

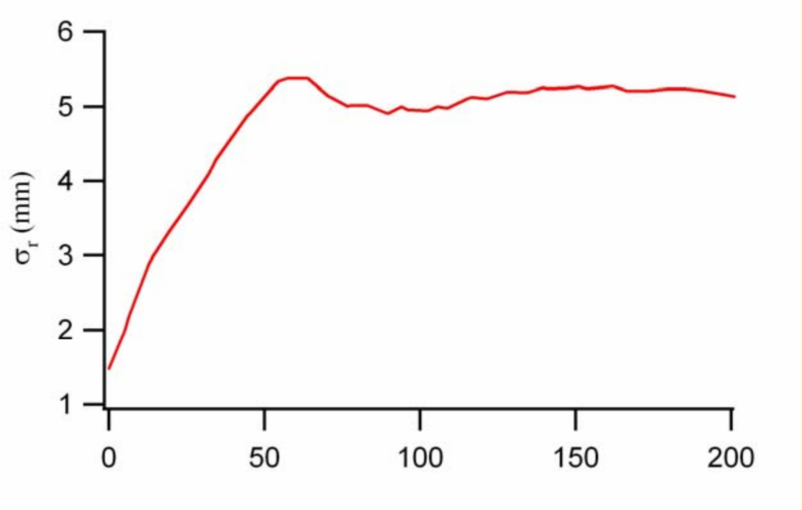
- Longitudinal profiles
- The longitudinal profiles of the positron beam are presented:
- - at the entrance of the accelerating section (top). The position is at 50 cms from the target
- - at the exit of the accelerating section (bottom). The position is at 175 cms from the target



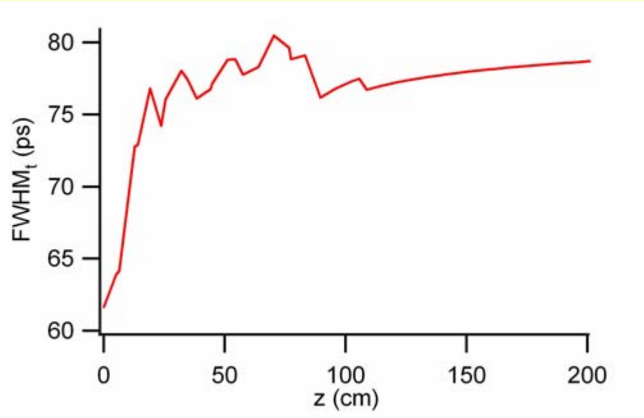


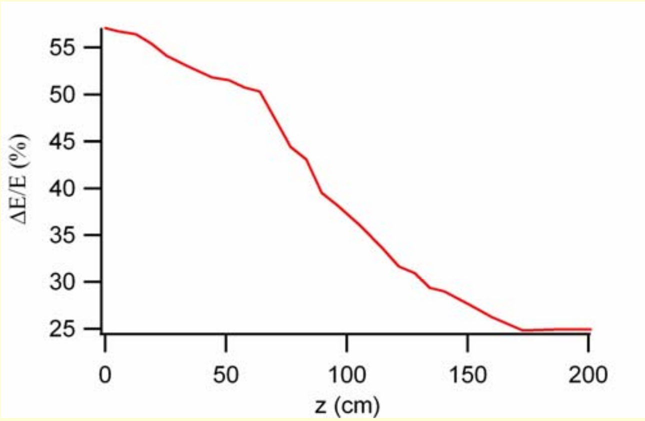
POSITRON CAPTURE IN ADIABATIC MATCHING SYSTEMS:PARMELA RESULTS

- Radial dimensions of the e+
- The radial dimensions of the positron beam with respect to the position (z) are represented on the figure. We note the enlargement of the beam size, mainly in the first 50 cms corresponding to the length of the AMD. The enlargement ratio is close to $[B_o/B_s]^{1/2}$ (here, 3.4).



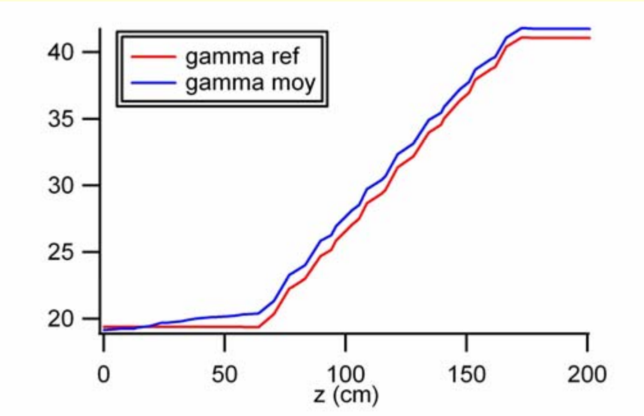
POSITRON CAPTURE IN ADIABATIC MATCHING SYSTEMS:PARMELA RESULTS

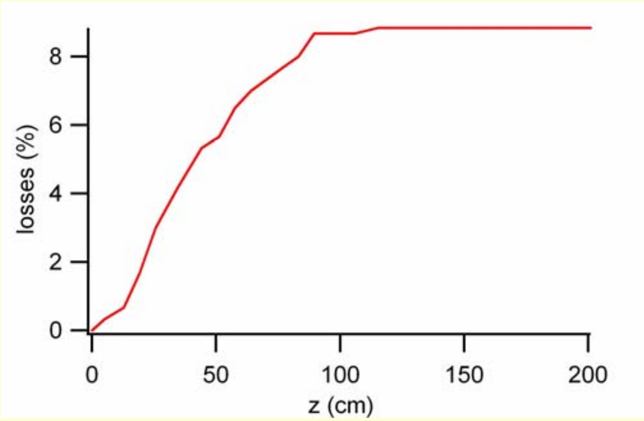




- The evolution of the positron bunch (FWHM) with respect to the position along the propagation axis is represented (left). Lengthening occurs mainly in the AMD, due to the spiralization
- The energy dispersion is also represented (right). Significant reduction is appearing, obviously, with the acceleration (> 50 cms)

POSITRON CAPTURE IN ADIABATIC MATCHING SYSTEMS:PARMELA RESULTS





- The relative energy of the positrons along the propagation axis is represented on the left side.
- The losses with respect to the position on the axis (z) are shown on the right side. A large part of the losses occurs in the AMD space.

POSITRON CAPTURE IN ADIABATIC MATCHING SYSTEMS

- SUMMARY AND CONCLUSIONS
- A study of the positron source generated from photons resulting from the Compton process in the *Compton ring* has been presented. The simulations were realized with **CAIN** for the photons, with **EGS** for the pair creation and with **PARMELA** for the positron beam transport. This work shows, for a first choice of parameters, the main characteristics of the positrons and illustrate some effects related to the transverse dimensions and longitudinal distribution of the e+ beam. This study must be completed and possible tasks are:
- - tests of different configurations for the γ production (E- = 1.5 and 1.8 GeV)
- - use of an appropriated programme for the pair creation taking into account the polarization. Such programme is under development by V.Strakhovenko
- - optimization of the e+ beam transport:=> shape and fields of the AMD,
- => other matching devices
- => phase optimization in linac
- => extension of the simulations up to the DR