SuperB Positron Production and Capture with low energy e^-

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For further details please check IPAC 2010:
'POSITRON PRODUCTION AND CAPTURE BASED ON LOW ENERGY ELECTRONS FOR SUPERB', THPUB057, F. Poirier et al.
and
'THE INJECTION SYSTEM OF THE INFN-SUPERB FACTORY PROJECT PRELIMINARY DESIGN', THPEA007, R. Boni et al.
and check the talk at the XII SuperB meeting in Annecy:
'***SUPERB POSITRON PRODUCTION AND CAPTURE***' (details of the scenarios)

→ CDR2: *SuperB progress report* – 16 September 2010

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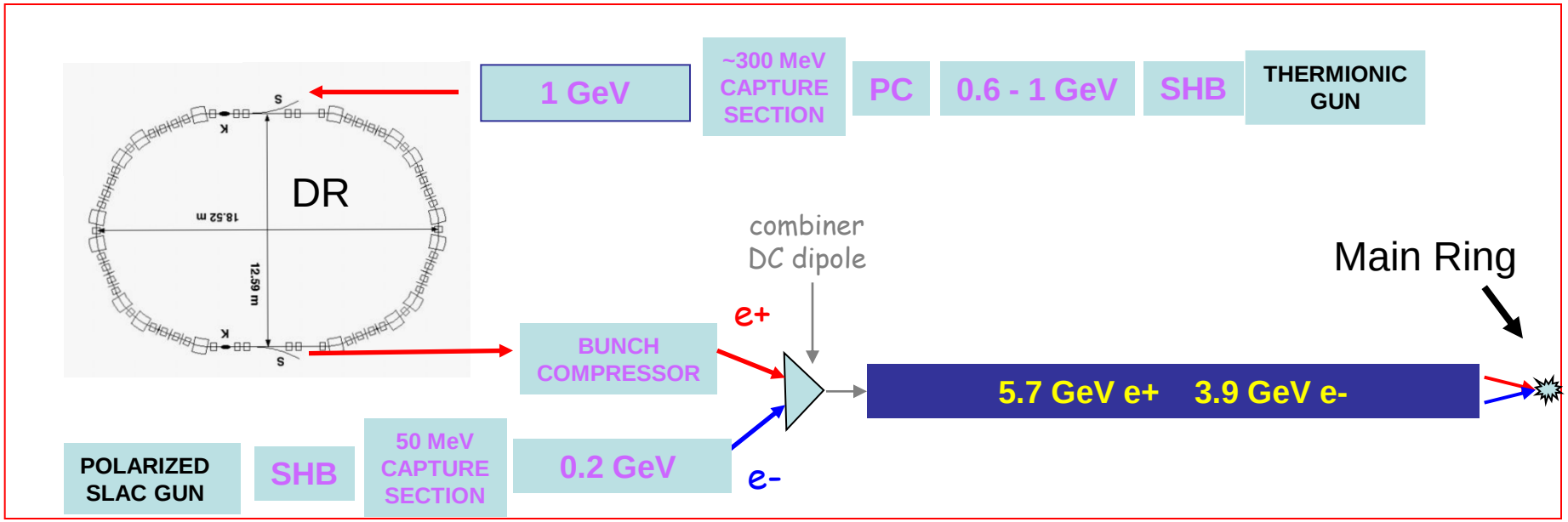
CDR2 → New Scheme

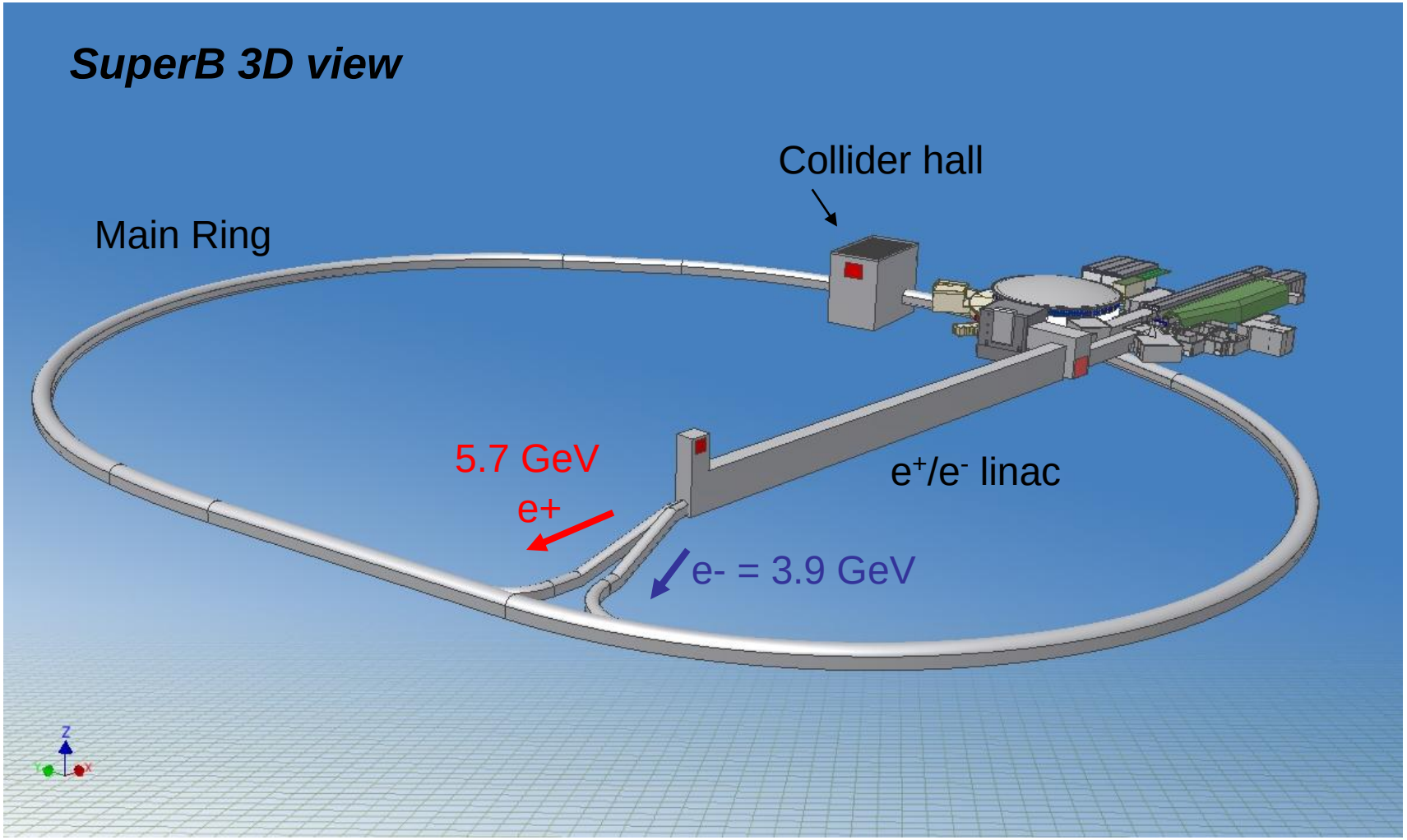
The CDR2 scheme is based on a 25 Hz Damping Ring filling, and both e+/e- uses the DR.

A new scheme is being developped:

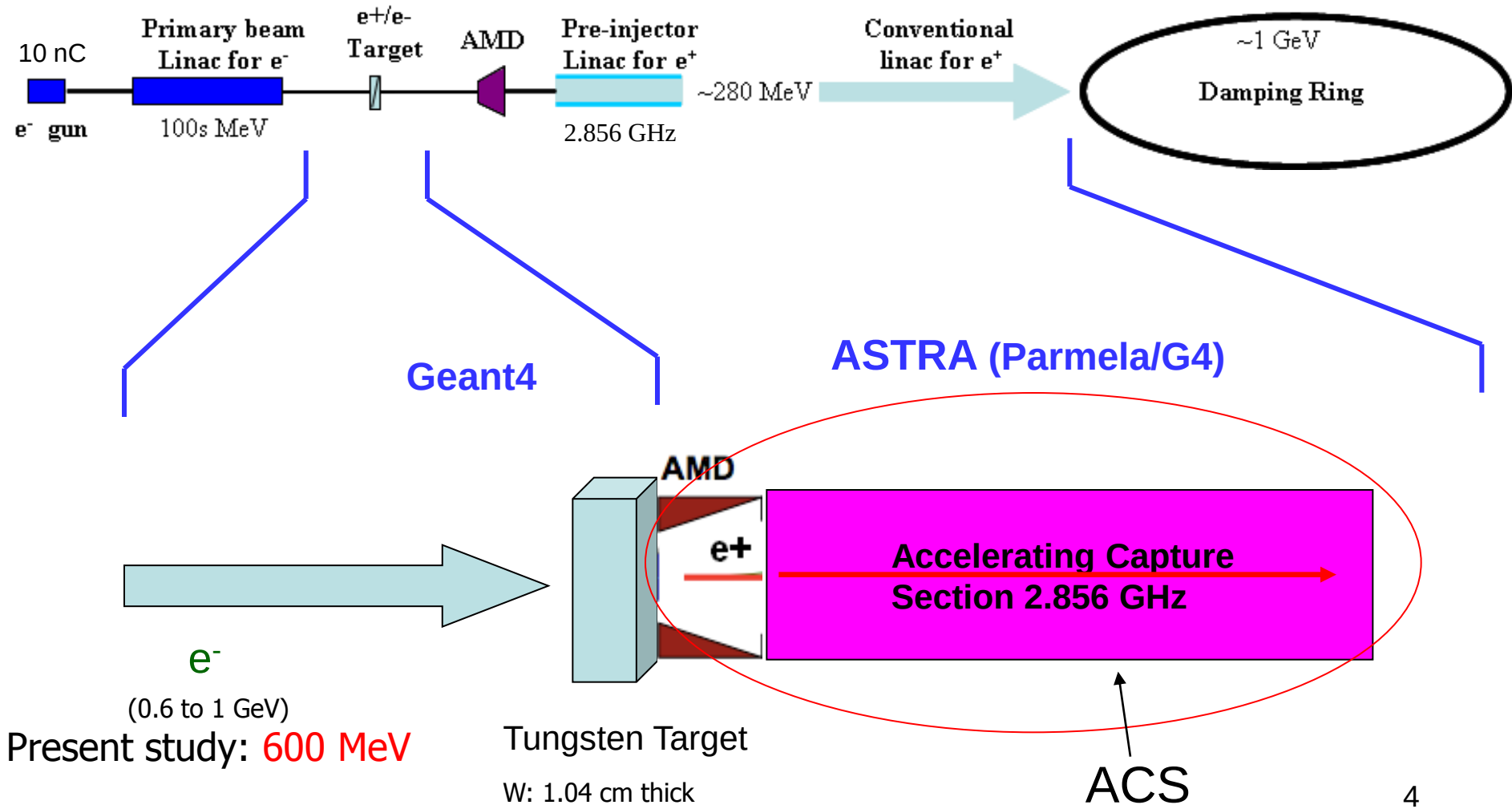


- Low Energy electron beam for non-polarised positrons production
- Single Damping Ring for Positrons
- Polarised electron gun
- Main linac transporting both e- and e+
- 50 Hz filling in main ring

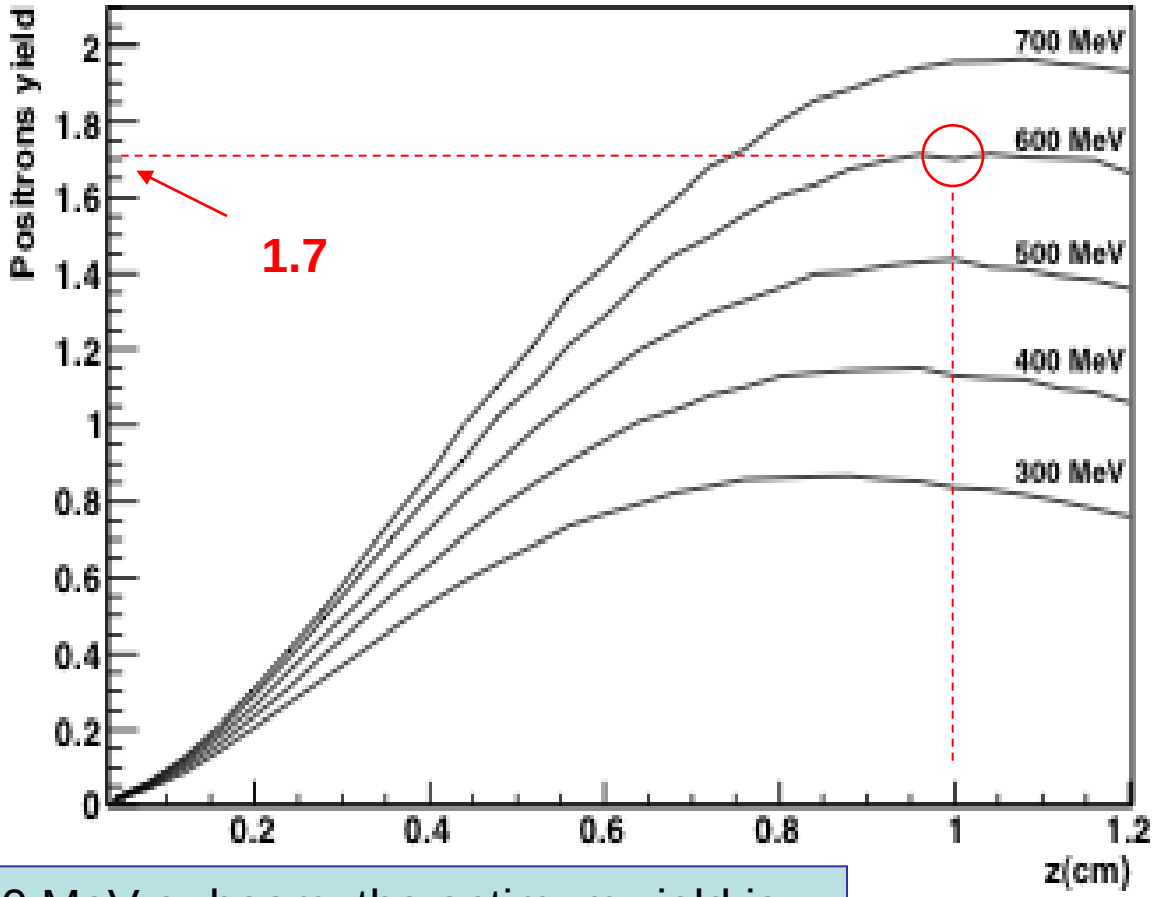
Layout example for LNF site



SuperB Positron Production Study



Target Yields Studies



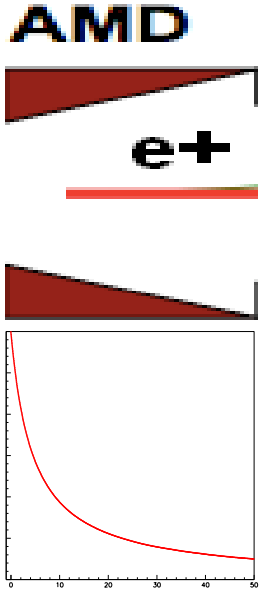
Target Geant 4 simulation

(**O. Dadoun** – LAL):

If we increase the energy of the drive beam, the positron yield goes up.

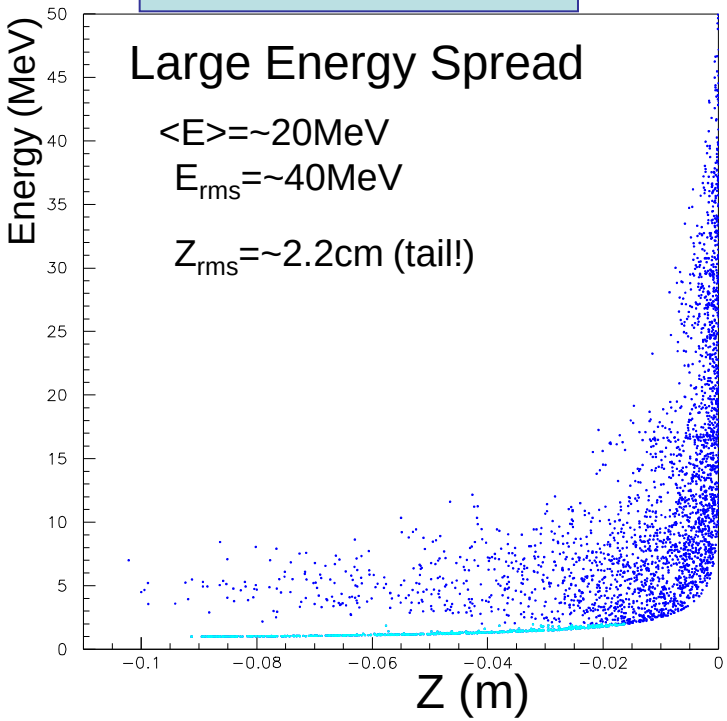
For a 600 MeV e- beam, the optimum yield is **1.7 e+/e-** with a *W*-target thickness of 1.04 cm

The AMD

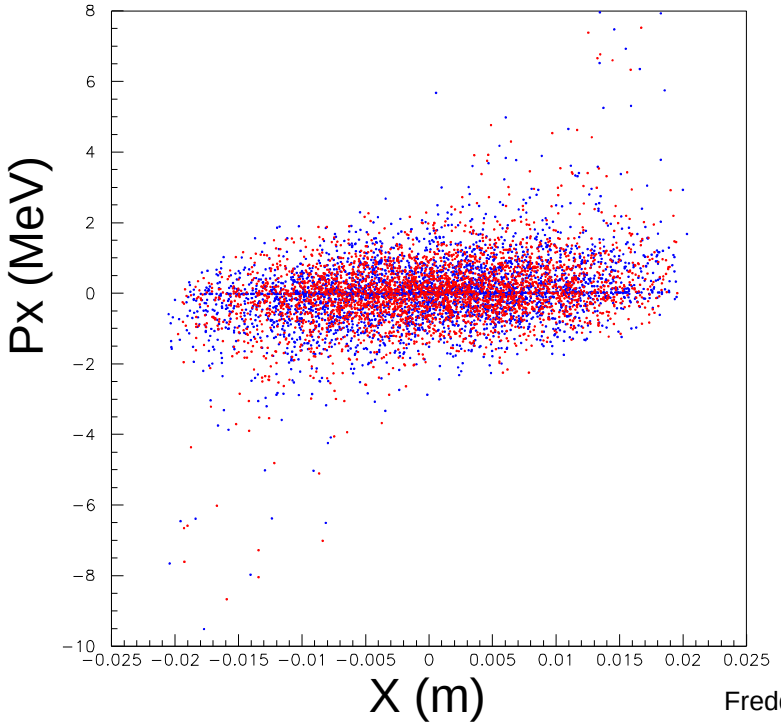


- The Adiabatic Matching Device is based on a slowly decreasing magnetic field system which collect the positrons after the target.
- AMD has a wide momentum range acceptance (with respect to systems such as Quarter Wave Transformers)
- The AMD for the present SuperB Studies is 50 cm long with a longitudinal field B_l starting at $B_l(0)=6T$ decreasing down to $B_l(50cm)=0.5T$

At exit of AMD:



Transverse emittance in AMD is transformed:



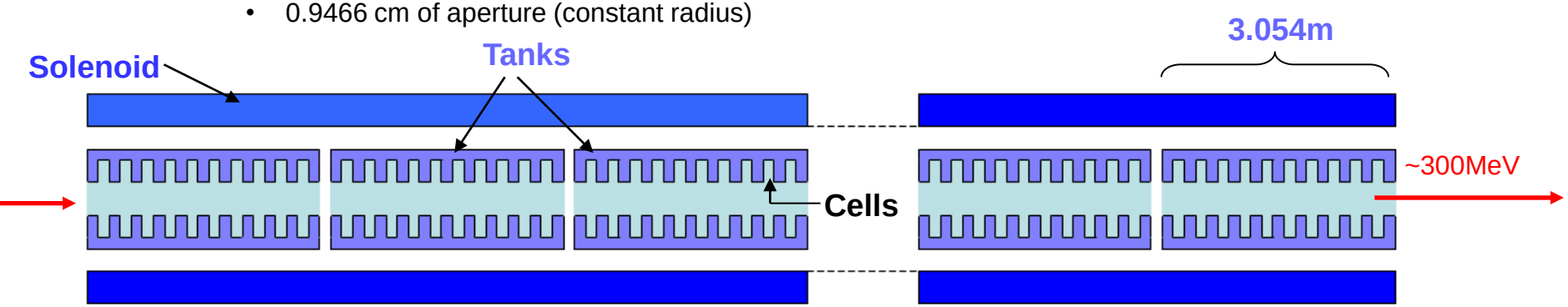
Geant 4

Astra

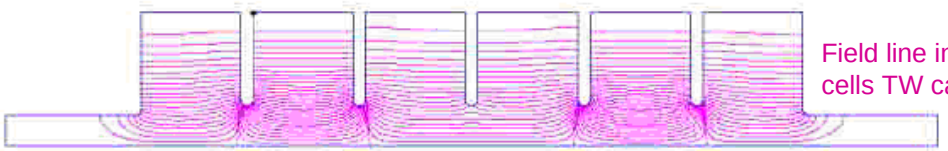
Good agreement (px/pz)

The ACS

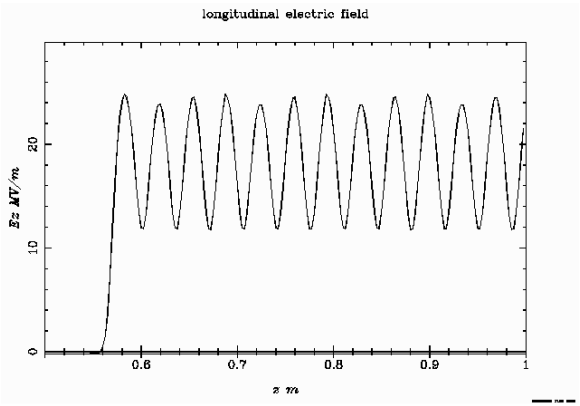
- Accelerating Capture Section (ACS) **Goal**: **Collect** and **Accelerate** positrons up to ~280 MeV.
- The ACS is encapsulated in a 0.5 T solenoid and includes several tanks:
  - Example:
    - 6 tanks for Full Acceleration at 2.856 GHz – Travelling Wave
    - 1 tank = 84 cells (+2 couplers), ~3.054m
    - RF: 2.856 GHz, 2π/3
    - 0.9466 cm of aperture (constant radius)



P.Lepercq (LAL) has calculated the Travelling Wave Fields in SuperFish and adapted them for ASTRA's simulation:

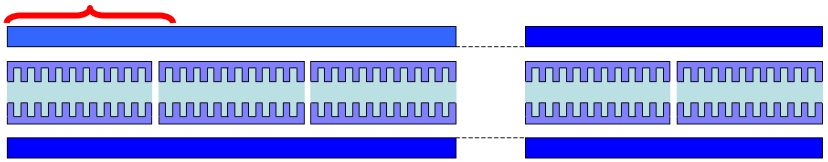


Field line in a 6 cells TW cavity

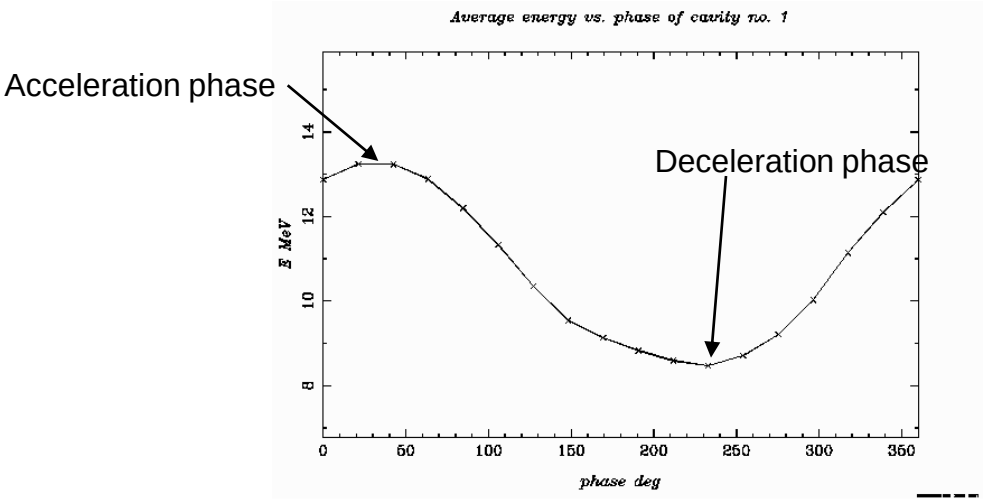


ACS energy strategy

2 (extreme) possible **energy strategy scenarios for the first tank of ACS:**



- Acceleration mode
  - Straight out of the AMD the particles are accelerated
  - → we use maximum available
- Deceleration mode
  - The particles are decelerated to form straight a small bunch
  - → choice of peak gradient for the cavities (free ~10MV/m)



Exemple with a 1.4 GHz Cavity, 4 MV/m

The ACS

- Several scenarios are under investigation
  - Accelerating / Deceleration
  - depending on the type of **RF cavities** within the ACS
    - 1st scenario = 2.846 GHz full acceleration
    - 2nd scenario = 2.846 GHz deceleration + acceleration
    - 3rd scenario = 1.428 GHz deceleration + acceleration
    - 4rd scenario = combination of RF types (using 3 GHz TM020 mode for deceleration and 1.428 GHz TM010 for downstream acceleration).

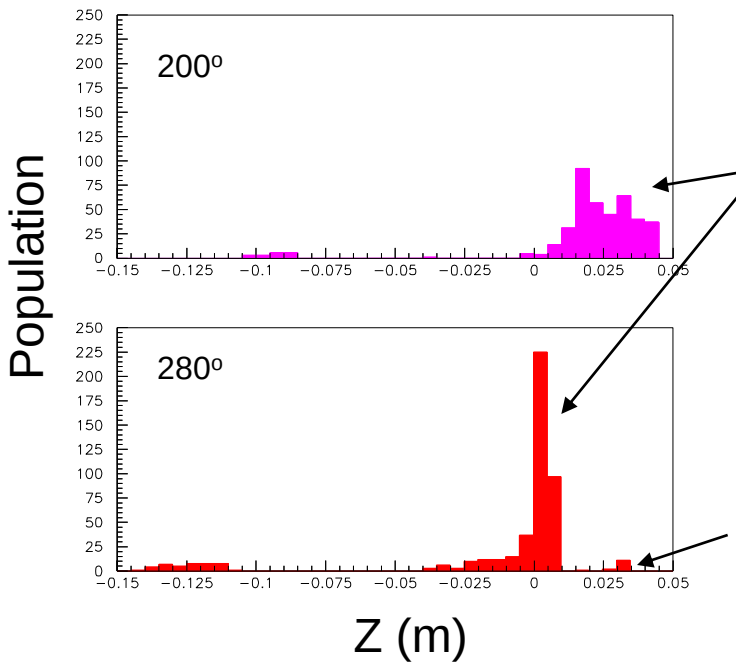
These 4 scenarios are under investigation.

Scenario 2 and 4 are brought up to 1 GeV

2.856 GHz: Deceleration scenario

- Find the RF phase which gathers a maximum of particles within a bunch
- Find the peak gradient which helps this

At the exit of the 1st tank:

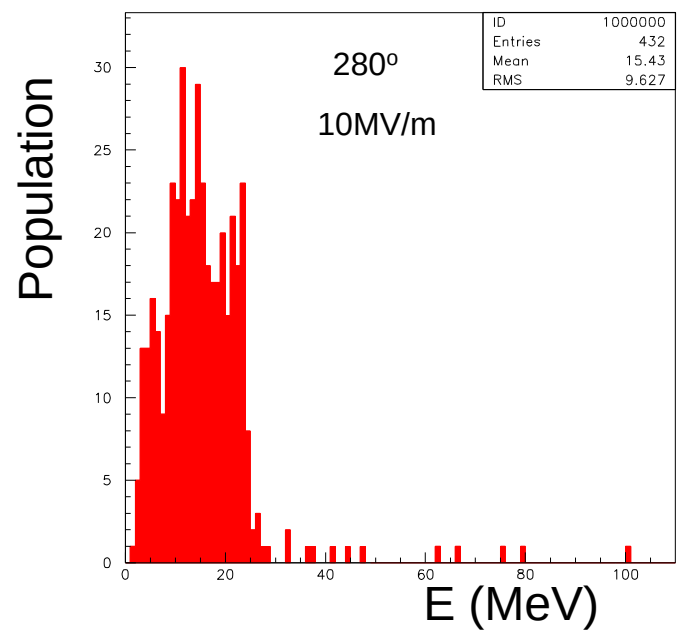


Goal:

-Maximise particles in this bunch

-Minimise its length

-Minimise the other bunches



Note: If the peak gradient in the first cavity used for deceleration is too high, the energy distribution at the exit of the cavity increases → so choice of peak gradient of 10 MV/m

Scenario 2

A 4th Scenario

- 3000 MHz TM020 for Deceleration and 1428 MHz for downstream acceleration (A.Variola)
  - 1st tank is a 3 GHz tank = 2.93 m
    - Iris – Aperture larger (Here we constrained the radius opening to 20 mm)
    - compactified bunch length when deceleration
    - Shorter beam line for the 3GHz TM020 case (wrt 1428 MHz only)
  - 2nd up to 4th are 1.428 GHz tank = 6.10 m each
    - Tank gradient = 25 MV/m (but then modified to 13 MV/m)
    - Tank phase optimised for maximum acceleration on crest for the considered bunch
    - Because of the RF (1.428GHz), the wavelength is rather large and the energy dispersion due to acceleration on crest is minimised
- 21.84 m from the beginning of the AMD needed here to reach at least 300 MeV (with 25MV/m)

Recap

- 4 Scenarios under investigation

25MV/m for acceleration

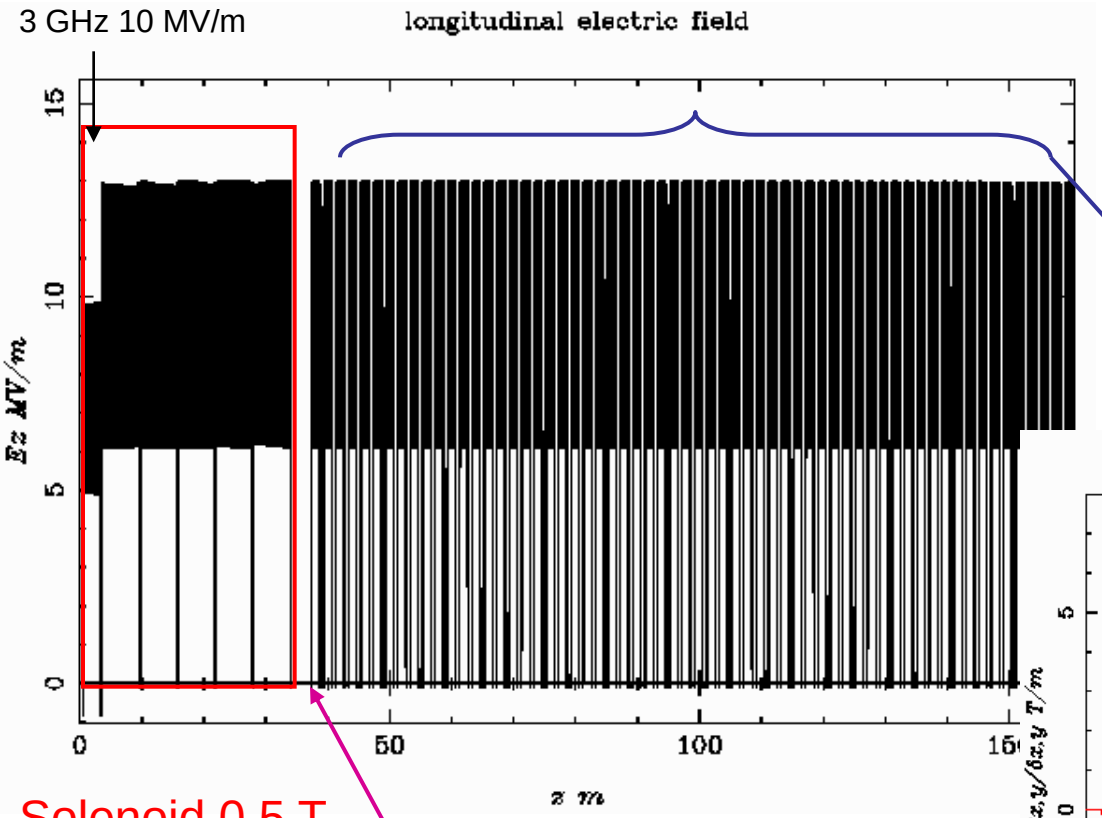
Scenario	1	2	3	4
RF (MHz) – strategy	2856 - acc	2856 – dec (S-band)	1428 – dec (L-band)	3000 dec + 1428 - acc
Mean Energy (MeV)	302	287	295	333
E_{rms} (MeV)	21.4	32.3 (12)	16.83 (9.09)	5.2 (3.2)
Z_{rms} (mm)	2.7	6.4	8.89	3.5
X_{rms} (mm)	3.8	4.4	8.0	8.1
X'_{rms} (mrad)	1.02	1.11	1.69	1.4
E_x =X'X (mm.mrad)	3.8	4.6	13.0	11.4
Total Yield (%)	2.8	7.53	32.3	31.9
Yield 10MeV (%)	**1.3**	**3.9**	**19.6**	**29.3**

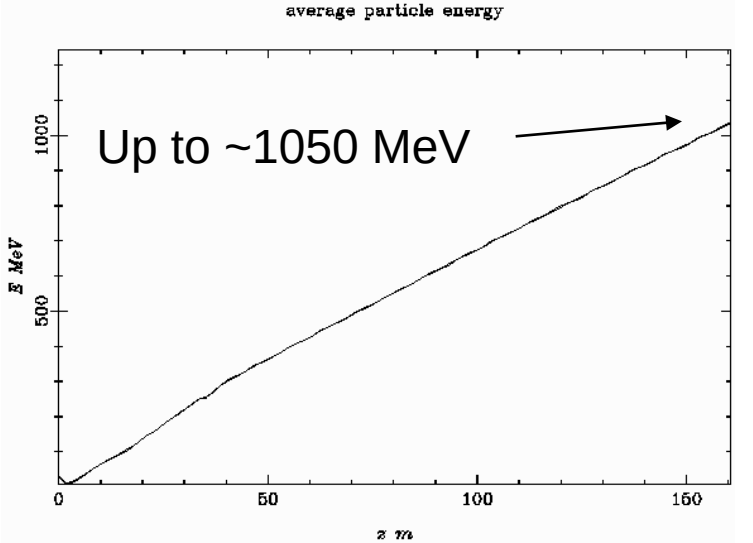
With a positron injection of 10 nC and a yield of 3.9%, we will have 2.43 10^9 positrons at 300 MeV ±10MeV (scenario 2 – 2.8 GHz)

These values are a good indication of how well the scenarios work but need we to bring these to 1 GeV (DR energy)

Layout Example

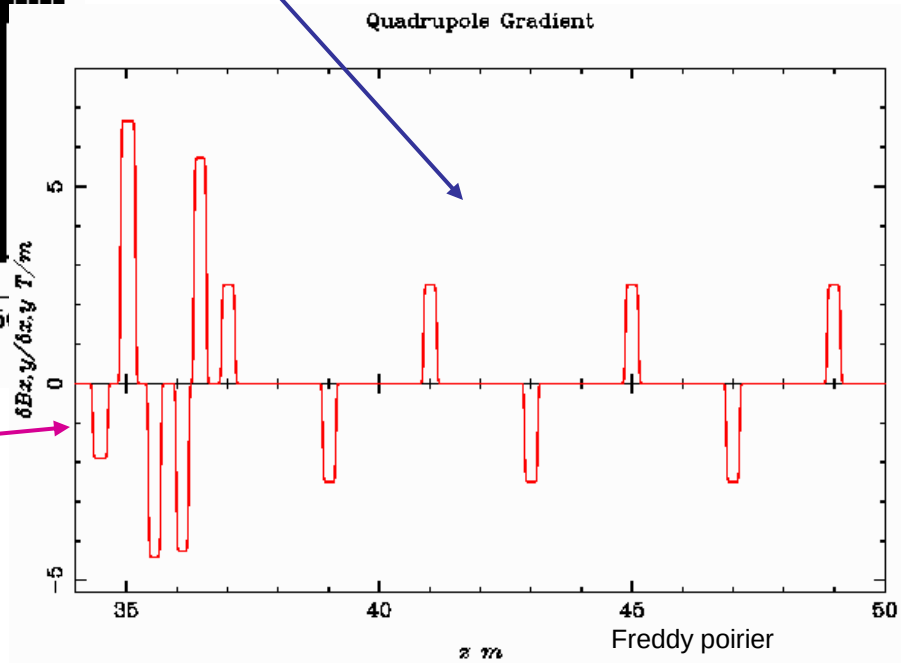
Acc. Cavity 1.428 GHz, Peak gradient= 13MV/m





Fodo cells

38 → ~160 m



Solenoid 0.5 T

0.5→34.1 m

Matching section

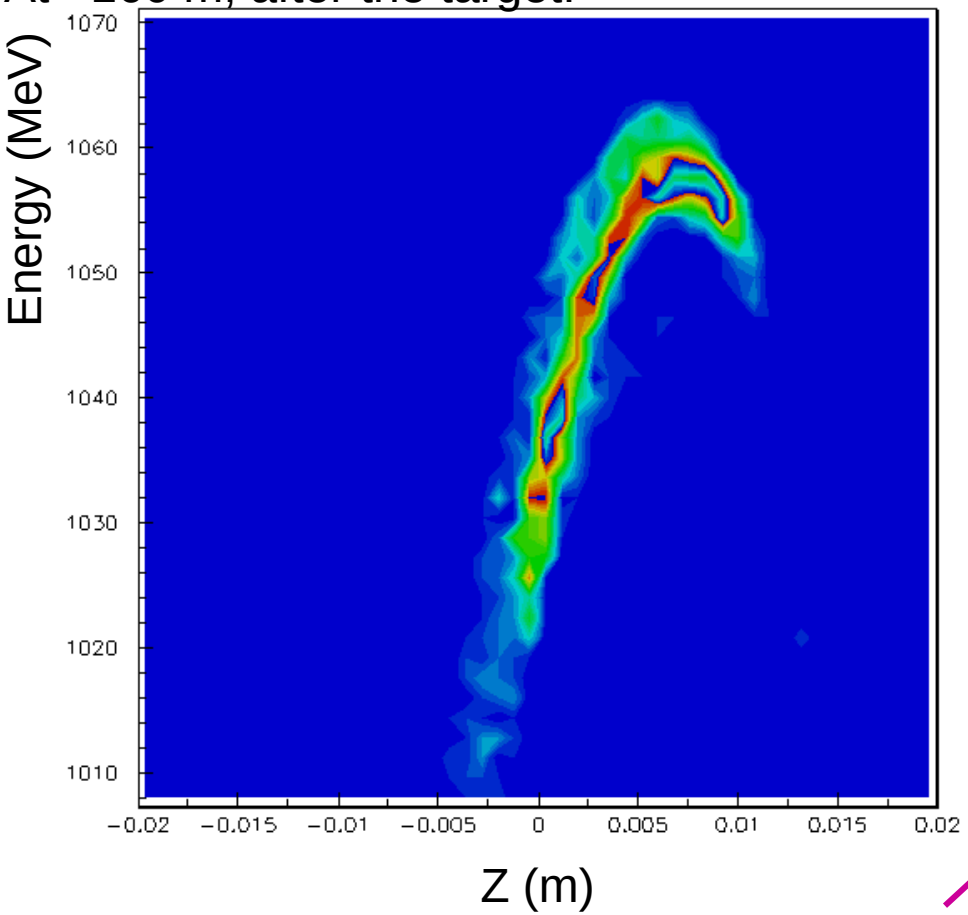
34.3 →~38 m

Freddy poirier

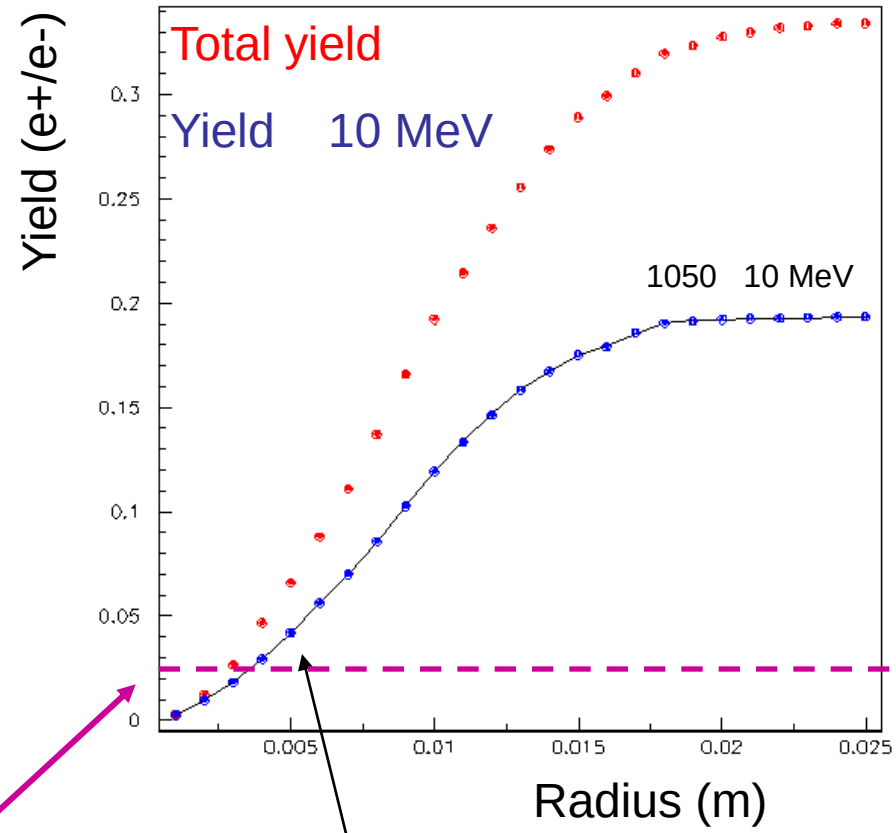
At end of the fodo accelerating section

3.0 GHz tank (deceleration), ~1050 MeV

At ~160 m, after the target.



At exit of last cavity,
Particles within a cut radius:



240 pC

5 mm transverse r-cut→Yield=~4%

Results

- For 25 Hz DR filling, we want:
  - 240 pC per bunch (1.5 10^9 e^+),
  - Emittance = 3. 10^{-6} m rad,
  - Energy acceptance of 1% (10MeV)
- We have here at present time at 1 GeV (not optimised):

Scenario	2	4
RF (GHz)	2.856	3.0 + 1.428
Yield (for 10 MeV) Nb of positrons x 10^9	2.3% (3.2%) 1.4	20% 12
Yield (for 10 MeV and r-cut=5 mm) Nb of positrons x 10^9	1.5% (1.72%) 1.0	4% 2.5

Conclusion

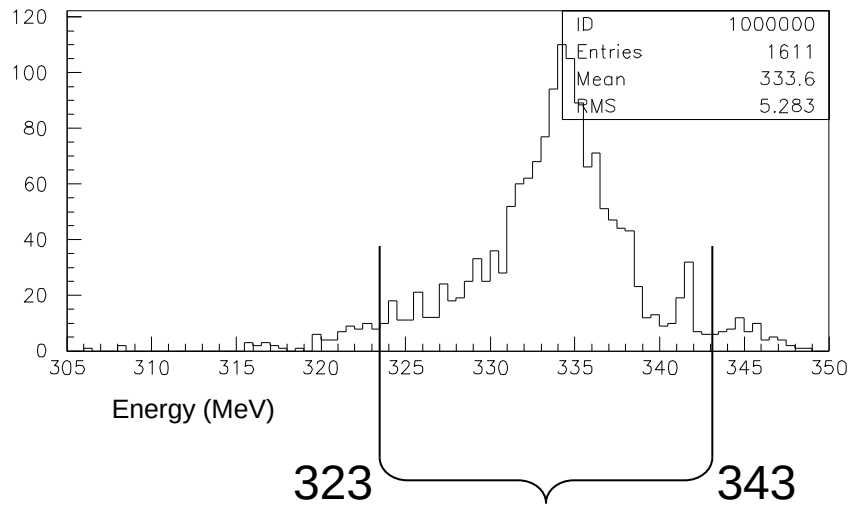
- Several Energy strategies have been studied as well as several RF scenarios
- Some of the Scenarios lead potentially very well to the required yield for the DR
  - Still a lot of room for optimisation of the lattice
- Cross-plane Coupling
  - Possible global correction based on skew-quads at end of linac, if needed
- We have not taken into account any “Safety knobs” which would increase the nb of e^+ or help to relax requirements such as:
  - Higher drive e^- beam energy
  - 10 bunches in the DR, 50 Hz operation
  - Higher DR energy (will reduce the emittance by adiabatic damping) or larger transverse acceptance
  - AMD length (shorter = 20 cm) and lattice optimisation might give some leverage

Low energy primary beam can offer a good candidate to provide a sufficient and good quality positron beam.

Having said that:

An alternative option is also kept ‘warm’ with positrons produced via electrons at high energy (6 GeV). For this an additional tranfert line is required.

At end of 4th tank – 3000MHz



29.4% (1481 positrons)

σ_z=3.5 mm

- As an indication:
  - 333 MeV 10 MeV

Note yield for e+ within 331 and 339 MeV = 15.9%

At end of 4th tank – 3000MHz

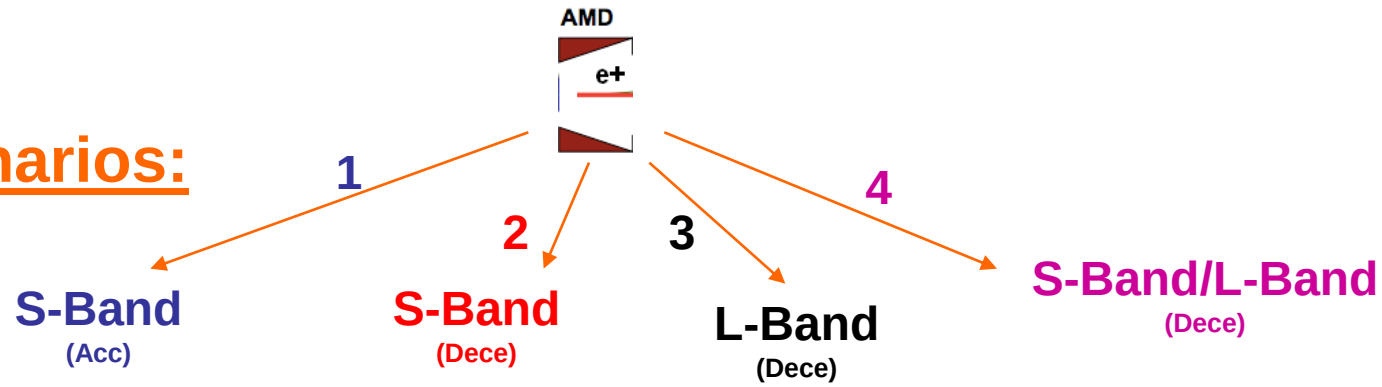
- 1st tank is a 3 GHz tank = 2.93 m
- 2nd up to 4th are 1.428 GHz tank = 6.10 m each
  - Tank gradient = 25 MV/m
  - Tank phase optimised for maximum acceleration on crest for the considered bunch
  - Because of the RF (1.428GHz), the wavelength is rather large and the energy dispersion due to acceleration on crest is minimised
- 21.84 m from the beginning of the AMD needed here to reach at least 300 MeV

Simulation Specifics

- Tools in use for simulations of the Adiabatic Matching Device (AMD) and the Accelerating Capture Section (ACS):
  - **Parmela (LAL version)**
    - AMD + ACS were simulated initially with Parmela
      - Though the AMD field inputs for Parmela was rather difficult to modify and to implement (as based on coils)
      - Some problems, due to lost particles with large angle at entrance of AMD, not resolved.
      - New Cavity field implementation for Parmela is time consuming.
  - **Geant4 (LAL version)**
    - AMD field simulation done (analytical longitudinal and radial field)
    - No bunch length so far (work in progress)
  - **Astra**
    - AMD field simulation done (analytical)
    - ACS field with inputs from SuperFish relatively fast to implement
- Each code has its drawbacks
  - Though benchmarks have been done and show relatively good agreement: This work is in progress
- Geant4 (AMD) + Parmela (ACS) have been used for the first batch of simulation (continued work)
- **ASTRA** is presently being used to simulate both ACS and AMD.
  - We gained in flexibility

What are the simulated ACS?

ACS scenarios:



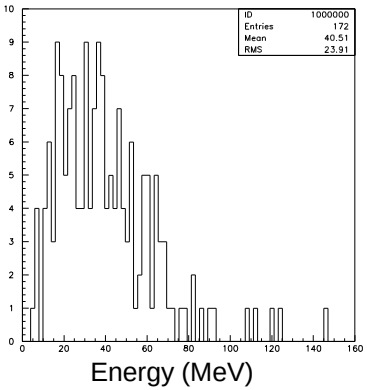
Scenario	Strategy (1st tank)	Frequency (GHz)	Total Nb of tank to reach ~300 MeV	Aperture (cm)	Length of the ACS (m)
1	Acceleration	S-Band (2.856)	6	0.95	18.94
2	Deceleration	S-Band (2.856)	7	0.95	22.01
3	Deceleration	L-Band (1.428)	4	2	25.01
4	Deceleration	L-Band / L-Band (3 (2nd harmonic) / 1.428)	4	2	21.84

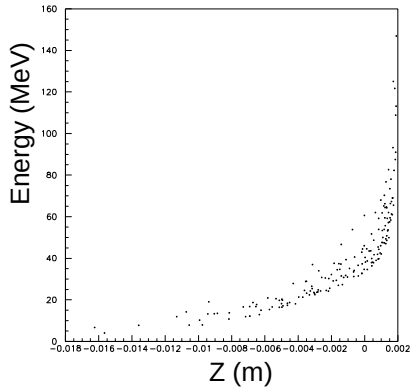
Peak gradient=25MV/m

2.856 GHz: Acceleration scenario

New **results using ASTRA** including the z_{RMS} at exit of the AMD of ~2.2 cm

- End of 1st tank results:

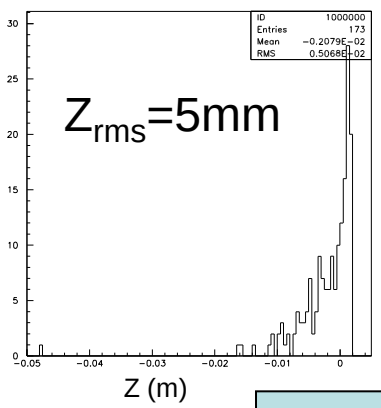




<E>=40MeV

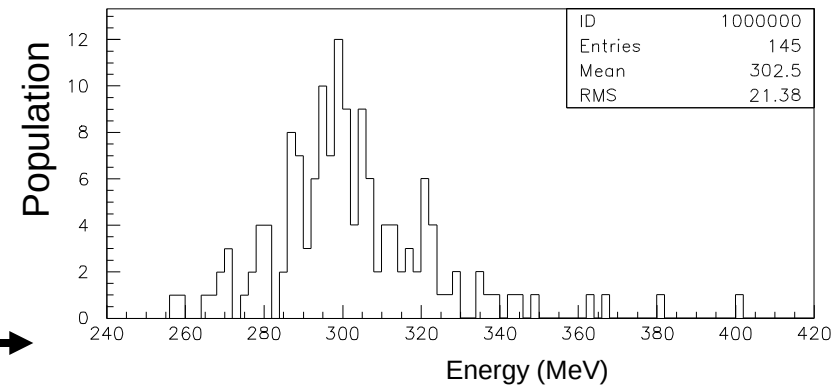
E_{rms}=20MeV

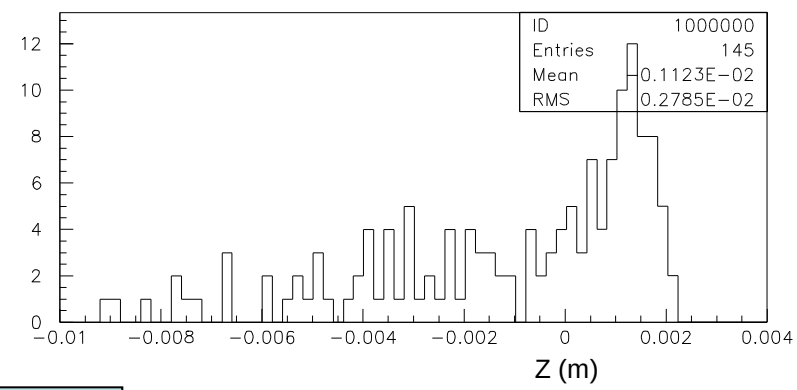
We used here a very stringent cavity phase which limitates the capture



Z_{rms}=5mm

End of tank number 6:





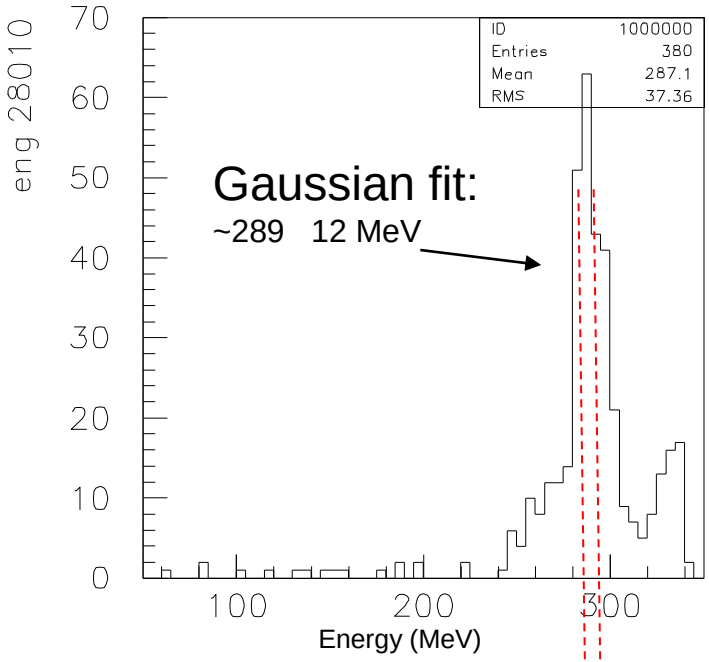
Total yield is 2.8% with an E_{rms}/E of 7% at 300 MeV

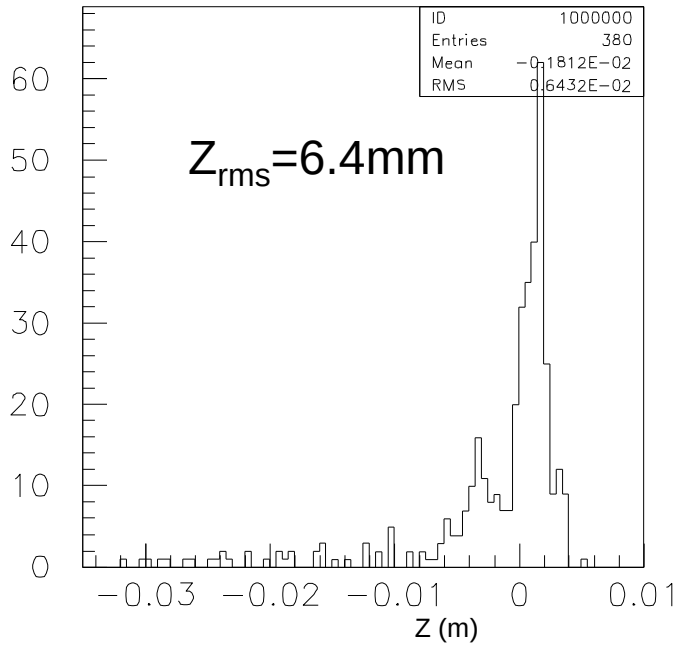
There is still room for further optimisation in the ACS tanks, we could increase the yield and keep a relatively low $E_{rms.}$ and short bunch.

Scenario 1

At end of ACS – 2.856GHz

- Full acceleration in downstream tanks (7 in total) is used after deceleration:





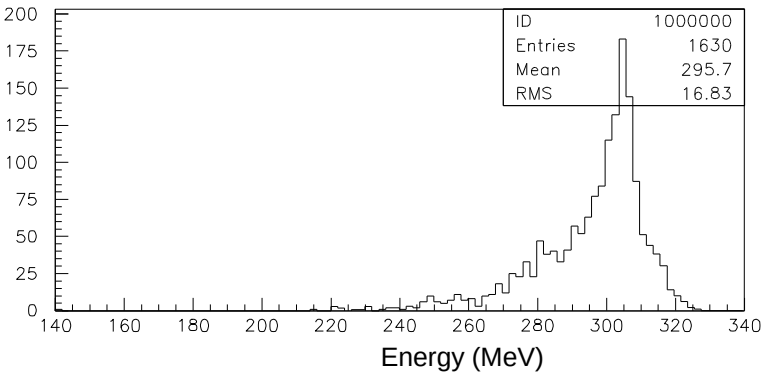
→ Total Yield here: 7.5%

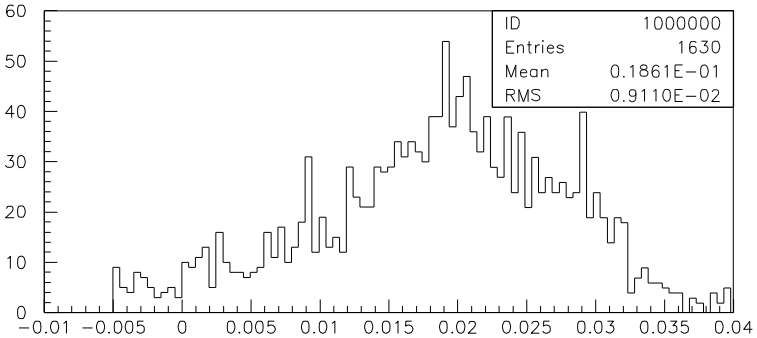
Calculated yield for particles within 287 10 MeV: 3.9%

Scenario 2

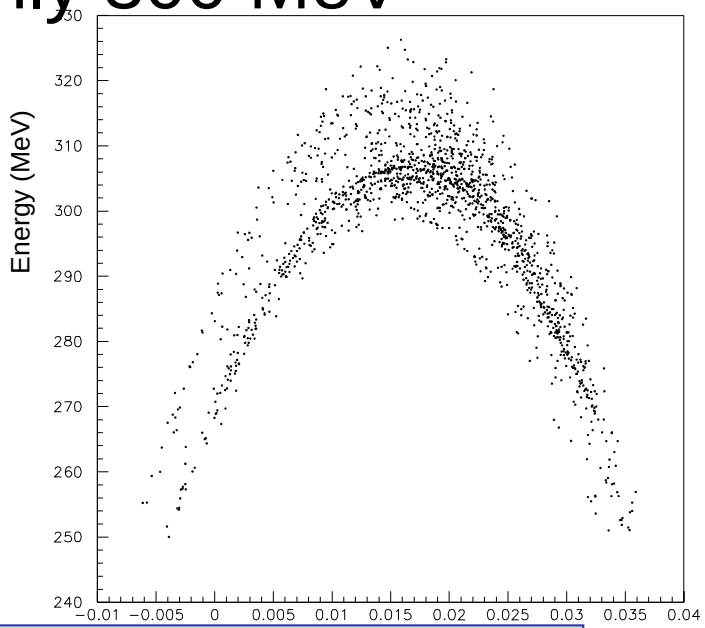
At end of 4th tank – 1428MHz

- Acceleration on crest up to the 4th tank leading to an average energy of roughly 300 MeV





~25m long beam line



σ_z=8.89 10^{-03} m

σ_e=16.9 (9.09) MeV (but energy Tails!)

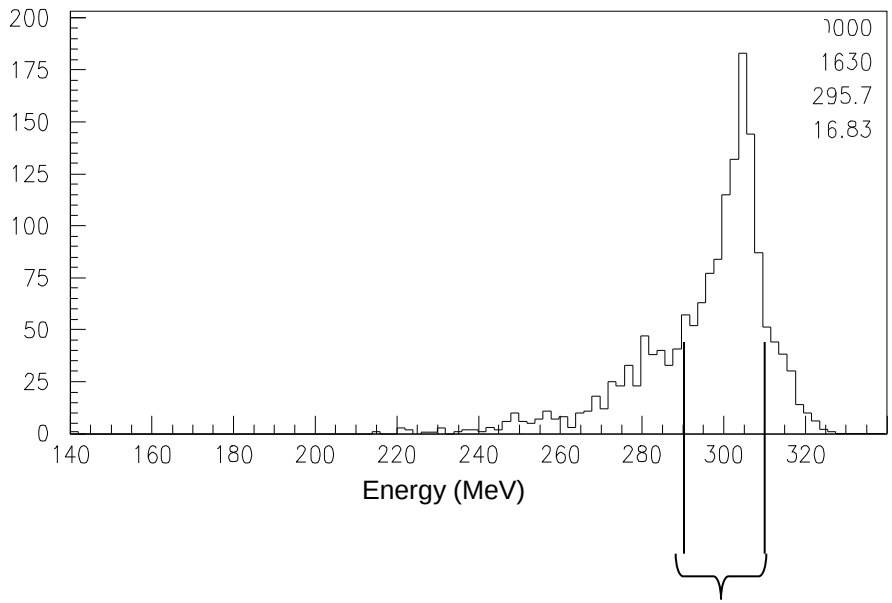
$\sigma_{x'}$=1.69 10^{-3} rad, $\sigma_{y'}$=1.74 10^{-3} rad

σ_x=8.0 10^{-3} m, σ_y=8.2 10^{-3} m

Total Yield = ~32.3%

Transverse Emittance = 1.35 10-5 rad.m (=σx*σx'), Longitudinal Emittance=0.08 MeV.m (=σz*σe)

At end of 4th tank – 1428MHz



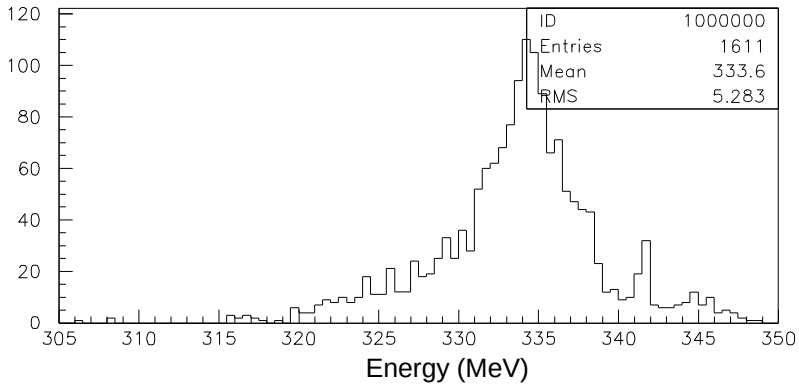
At 1 GeV, we want ± 1% i.e. 10 MeV of energy dispersion.

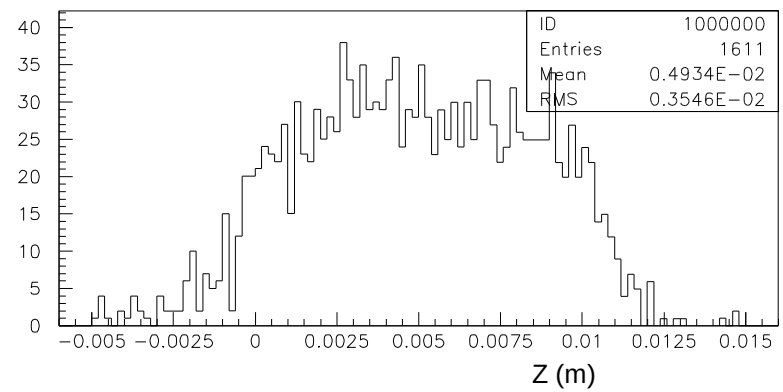
Having an idea of the yield for ± 10 MeV at 300 MeV gives us an idea of how well our scenario work.

- Yield for particles between 300 ± 10 MeV:
  - 19.6% (994 positrons)
  - σ_z=6.4 mm
  - $\sigma_{x'}$=1.84 10^{-3} rad, $\sigma_{y'}$=1.76 10^{-3} rad
  - σ_x=7.7 10^{-3} m, σ_y=8.3 10^{-3} m

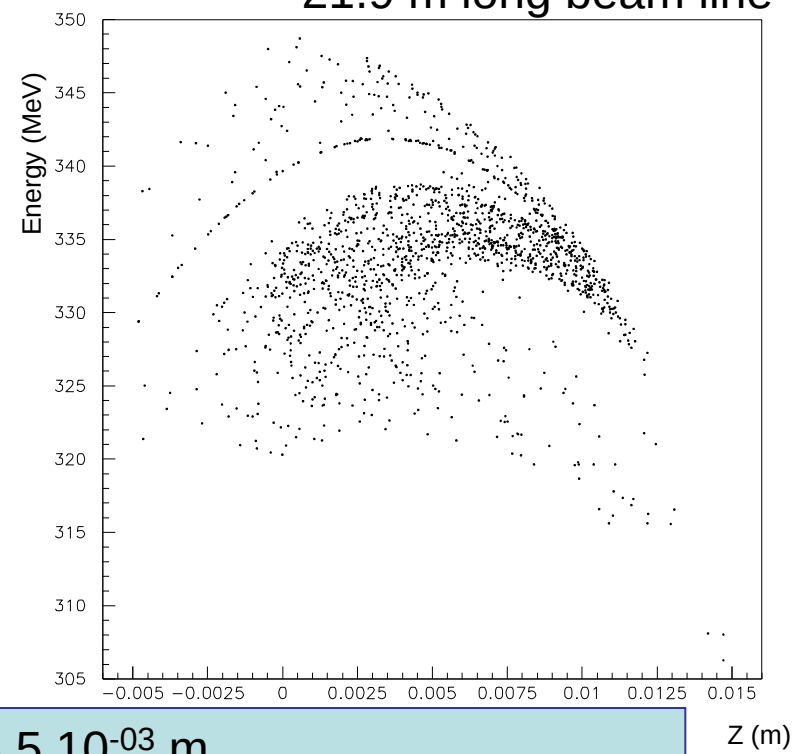
At end of 4th tank – 3000MHz

- Average Energy = ~333 MeV





~21.9 m long beam line



Total Yield = ~31.9%

σ_z=3.5 10^{-03} m

σ_e=5.2 (3.2) MeV

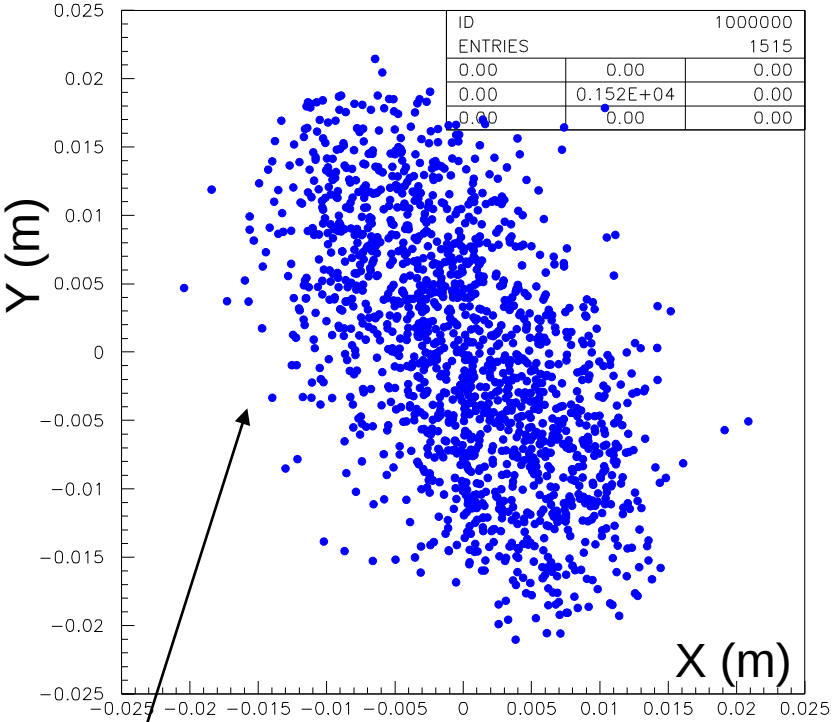
$\sigma_{x'}$=1.4 10^{-3} rad, $\sigma_{y'}$=1.46 10^{-3} rad

σ_x=8.1 10^{-3} m, σ_y=8.1 10^{-3} m

Scenario 4

Further studies at 1 GeV

Example from 1.428 GHz (scenario 3)

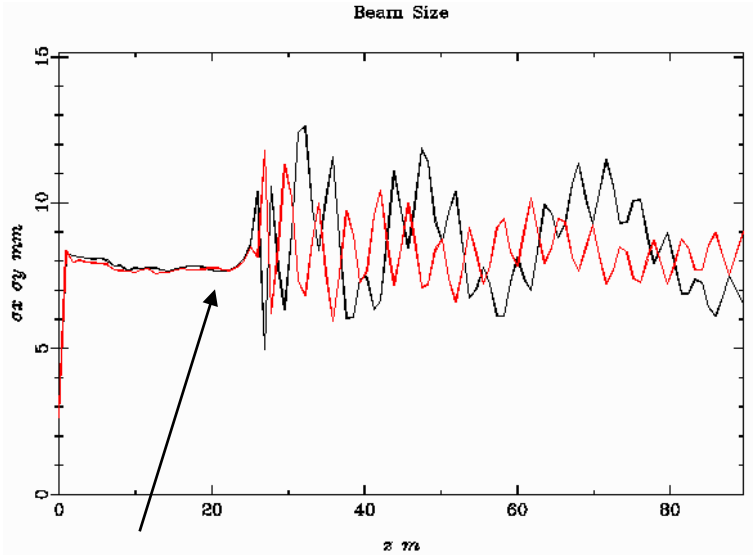


Cross-plane Coupling !!!

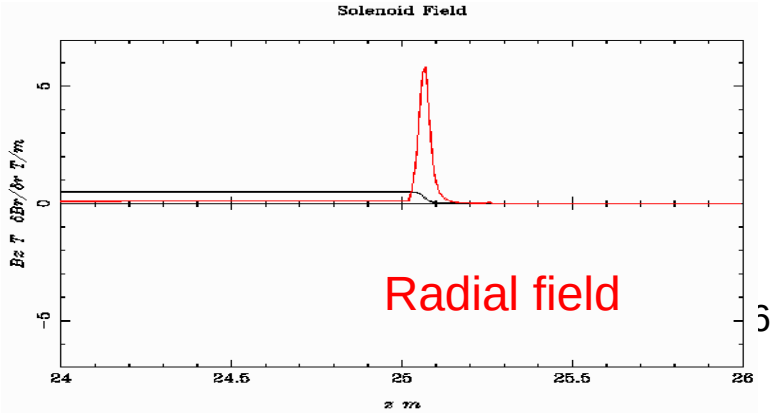
Solution: Play on the solenoid field end (use a more adiabatic one)

If difficult (because loss of particles): use cross plane correction

Possible cause: Radial field at the end of the 0.5 T solenoid:

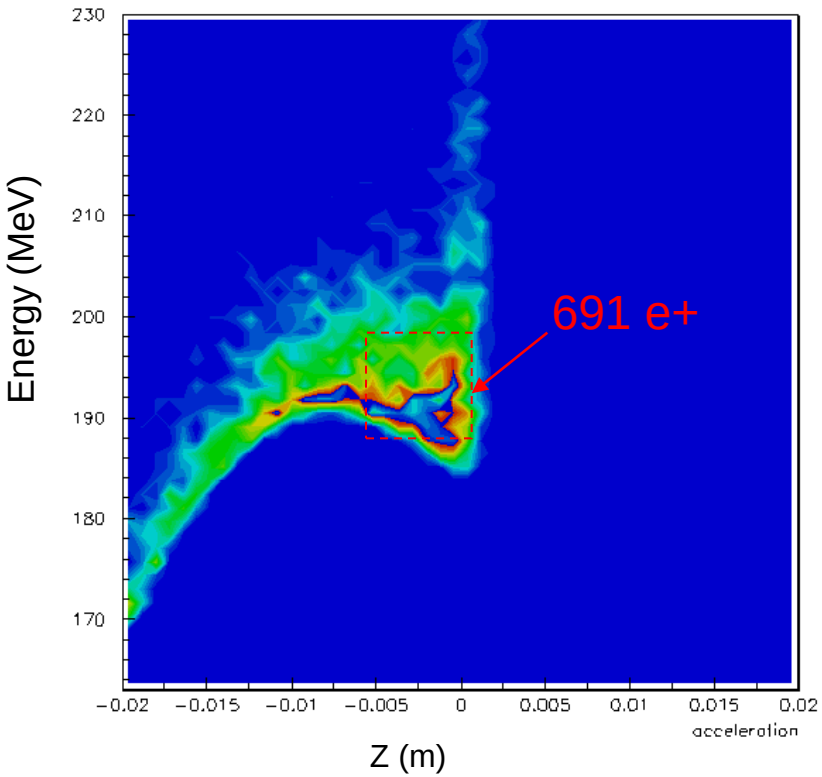


Dissociation at the end of the solenoid

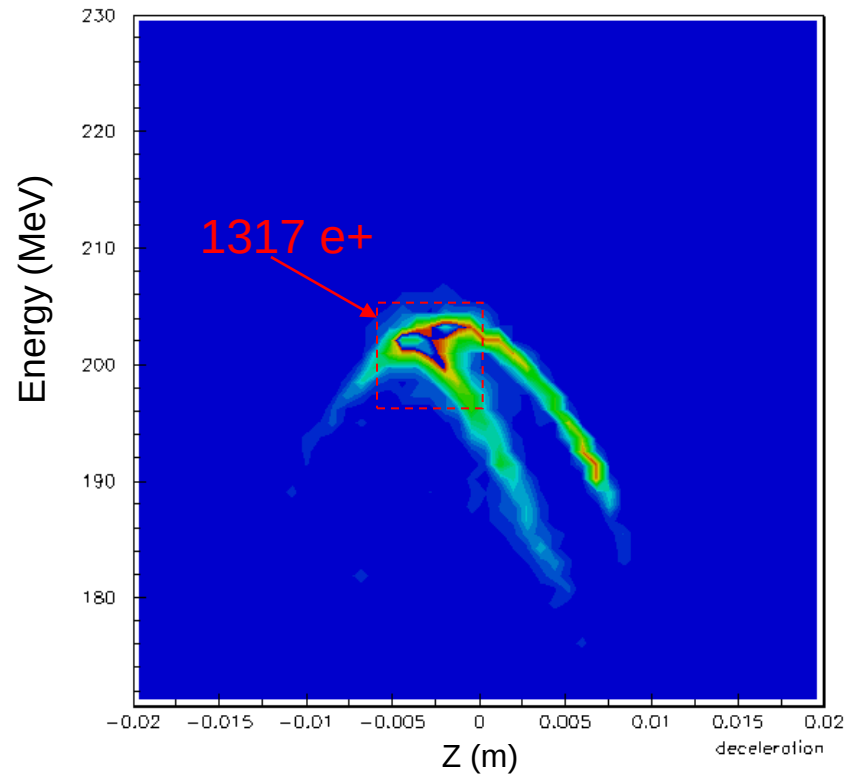


CLIC example: at 200 MeV

Acceleration case



Deceleration case



Eff $_{200MeV}$ = 0.40

Eff $_{200MeV}$ = 0.53

- **For the deceleration case the efficiency* at 200 MeV is higher than for the acceleration case**
- For further information: The value in red gives the number of positrons within the red dashed box

*Eff $_{200\ MeV}$: Nb of particles entering target/ Nb of particles at exit of tank with energy greater than 165 MeV