E - 166
International Polarized Positron Collaboration

E-166 STATUS

Snowmass 2005

Alexander Mikhailichenko
for E-166 collaboration:

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47 members from 17 institutions

ILC dedicated collaboration working in practice

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SLAC, Stanford, California

FFTB

50 GeV e⁻ E - 166 10 MeV γ

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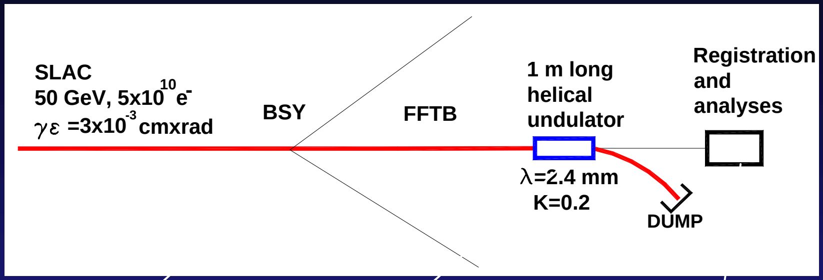
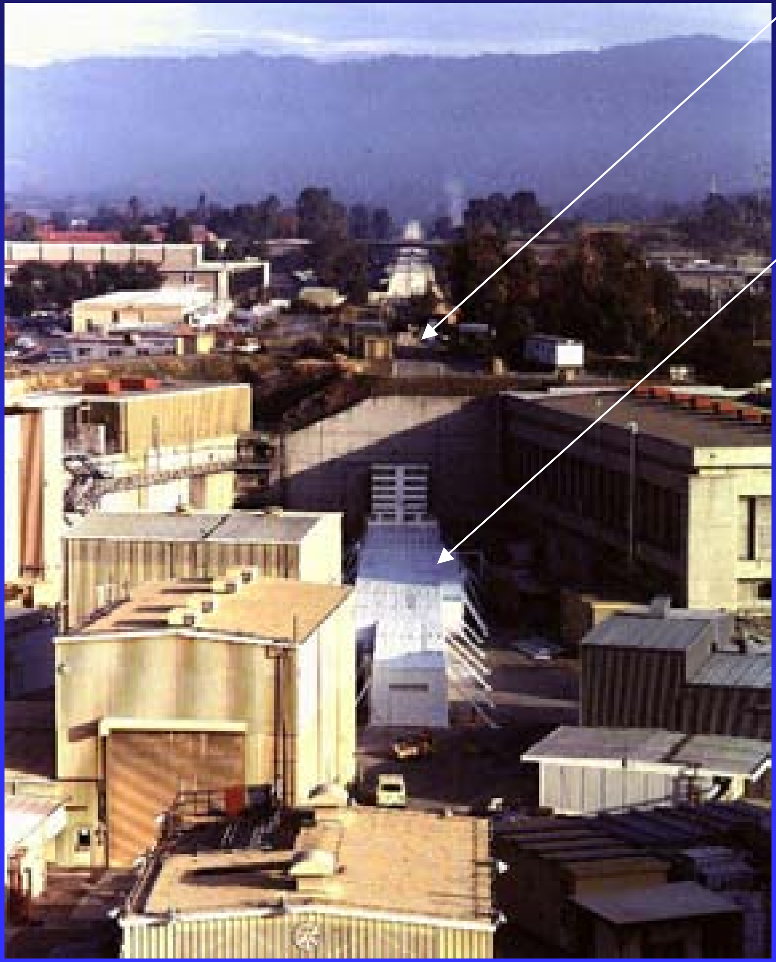
FFTB-E166





Demonstration experiment for production of (polarized) e+

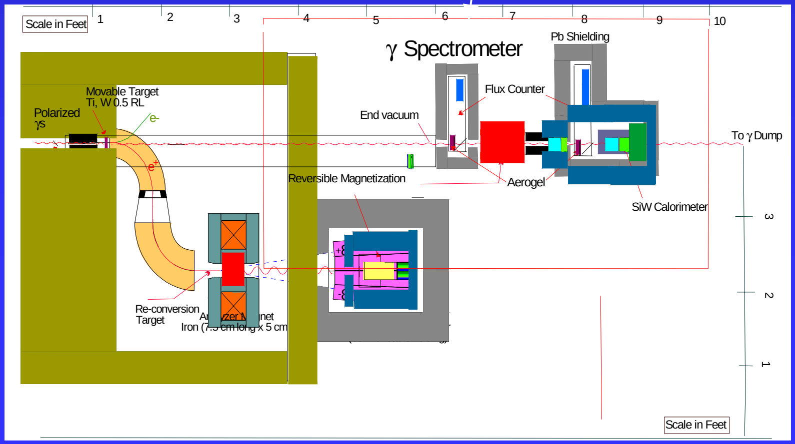
FFTB at SLAC with 50 GeV, 10^{10} e-/pulse, 30 Hz

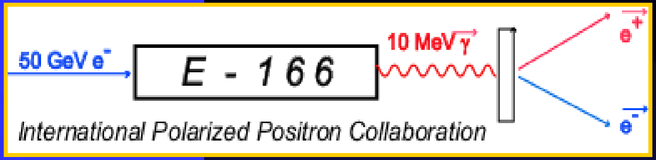
1 m long helical undulator produces (left hand) circularly polarized radiation 0-10 MeV

Conversion of photons to positrons in 0.5 X_0 target

Measurement of positron polarization by

Coverting Positrons into gamms again and use Compton helicity-dependet transmission





E-166 Beam Parameters

E_e	f_{rep}	N_e	$\gamma\varepsilon_x=\gamma\varepsilon_y$	β_x,β_y	σ_x,σ_y	σ_E/E
GeV	*Hz*	e^-	*m-rad*	*m*	*µm*	*%*
50	30	$1\text{x}10^{10}$	$3\text{x}10^{-5}$	5.2, 5.2	~40	0.3

The SLAC FFTB:

- Built to Demonstrate LC FFS: 60-70 nm rms spot
- 28- 50 GeV Beam Energy
- $\gamma\varepsilon = 1.5\text{x}10^{-5} / 1.5\text{x}10^{-6}$ m-rad (x/y)
- σ_z = 50-500 µm
- $N_b = 0.1\text{-}4\text{x}10^{10}$ e^-/bunch
- 2.5 kW Power Limit ($1\text{x}10^{10}$ @ 30 Hz and 50 GeV)
- 1 W Continuous Beam Loss Limit

E166 – FFTB Optics

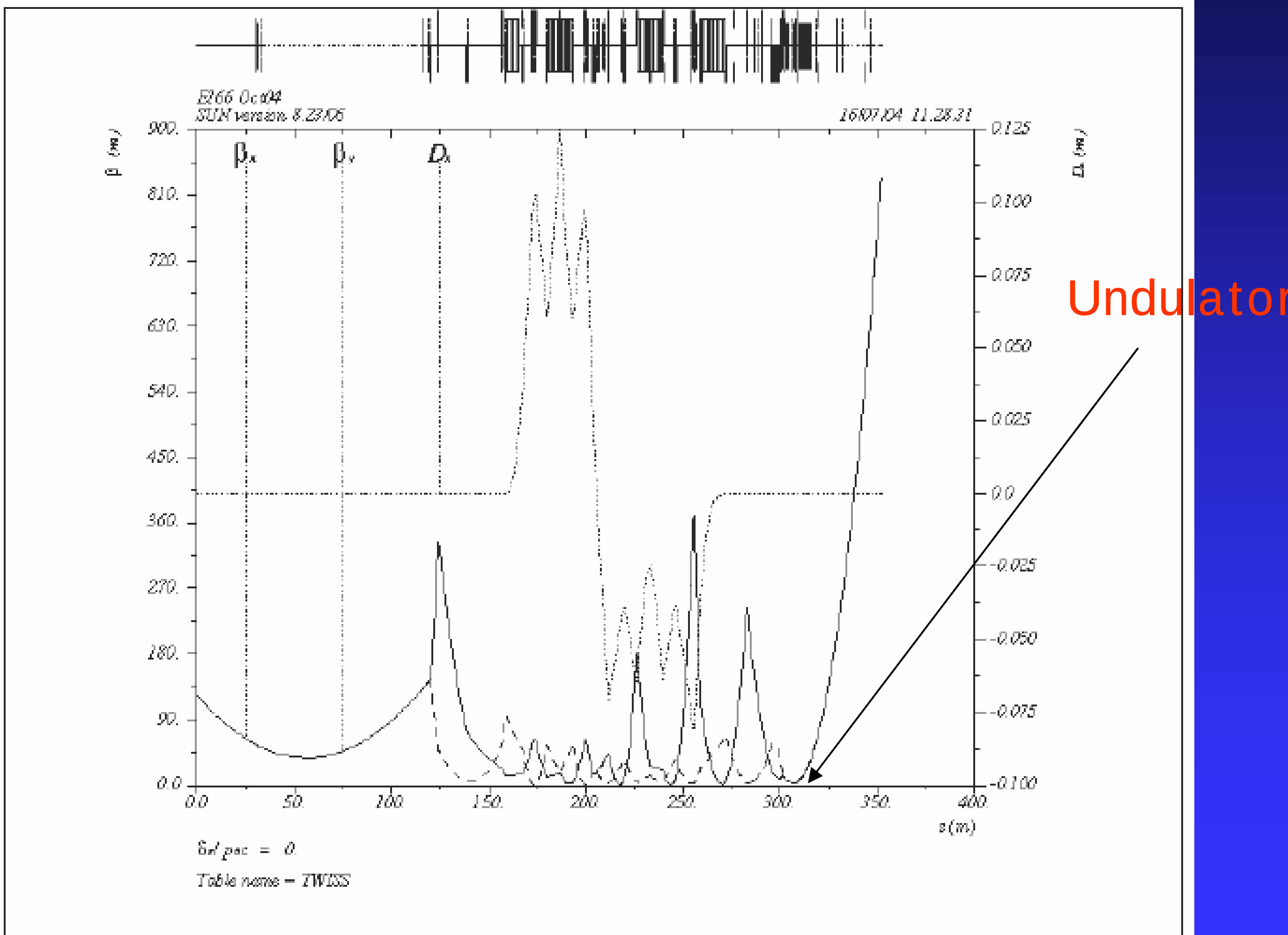
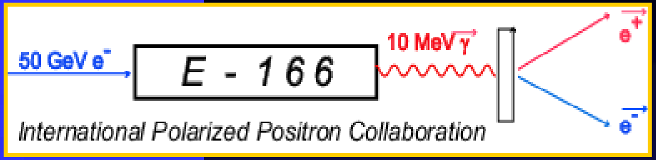


Figure 1. E166 Oct2004 Design Optics – rhi 16JUL2004



Physics arguments for polarized positrons and undulator-based source

- Polarized e^+-beams in addition to polarized e^--beams offer*):
  - Higher effective polarization and decreased error in electroweak asymmetry measurements
  - Selective enhancement (or reduction) of many SM and non-SM processes:
    (e^+e^-->WW, Z, ZH couple only to $e^+_L e^-_R$ and $e^+_R e^-_L$)
  - Acess to many non-SM couplings
  - For physics using transversly polarized beams both beams e^+ and e^- must be polarized:
    New physics eg. extra dimensions
  - Improved accuracy in measuring polarization
  - Reduction of background
  - **Undulator-based scheme ~10 times reduces power deposition in the target**

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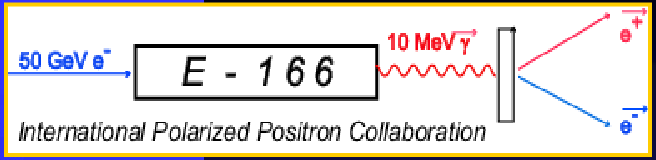
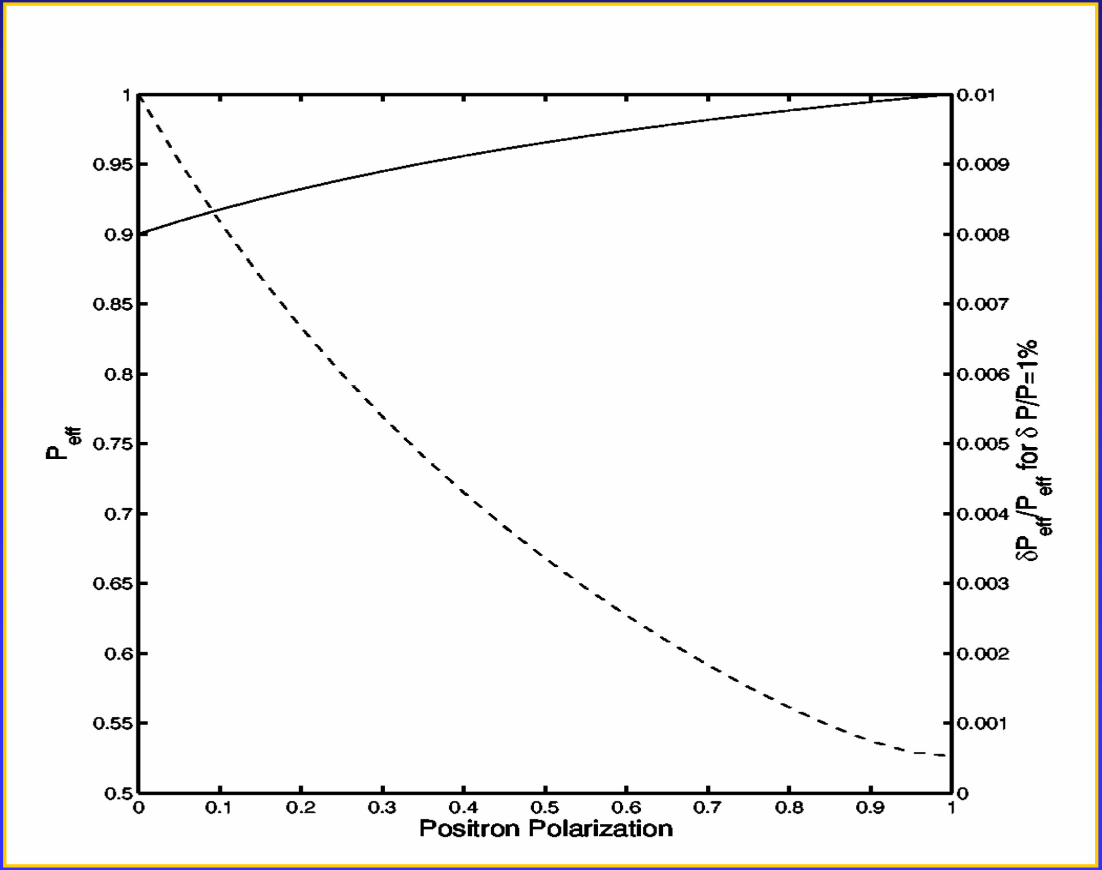
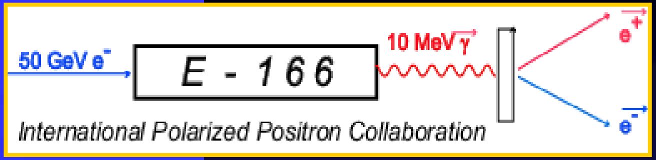
*)THE ROLE OF POLARIZED POSITRONS AND ELECTRONS IN REVEALING FUNDAMENTAL INTERACTIONS AT THE LINEAR COLLIDER.
G. Moortgat-Pick *et al.*. SLAC-PUB-11087, CERN-PH-TH-2005-036, Jul 2005. 149pp.



Higher effective polarization

- Two polarized beams result in a higher efective polarization and lower errors in electroweak asymmetry measurements

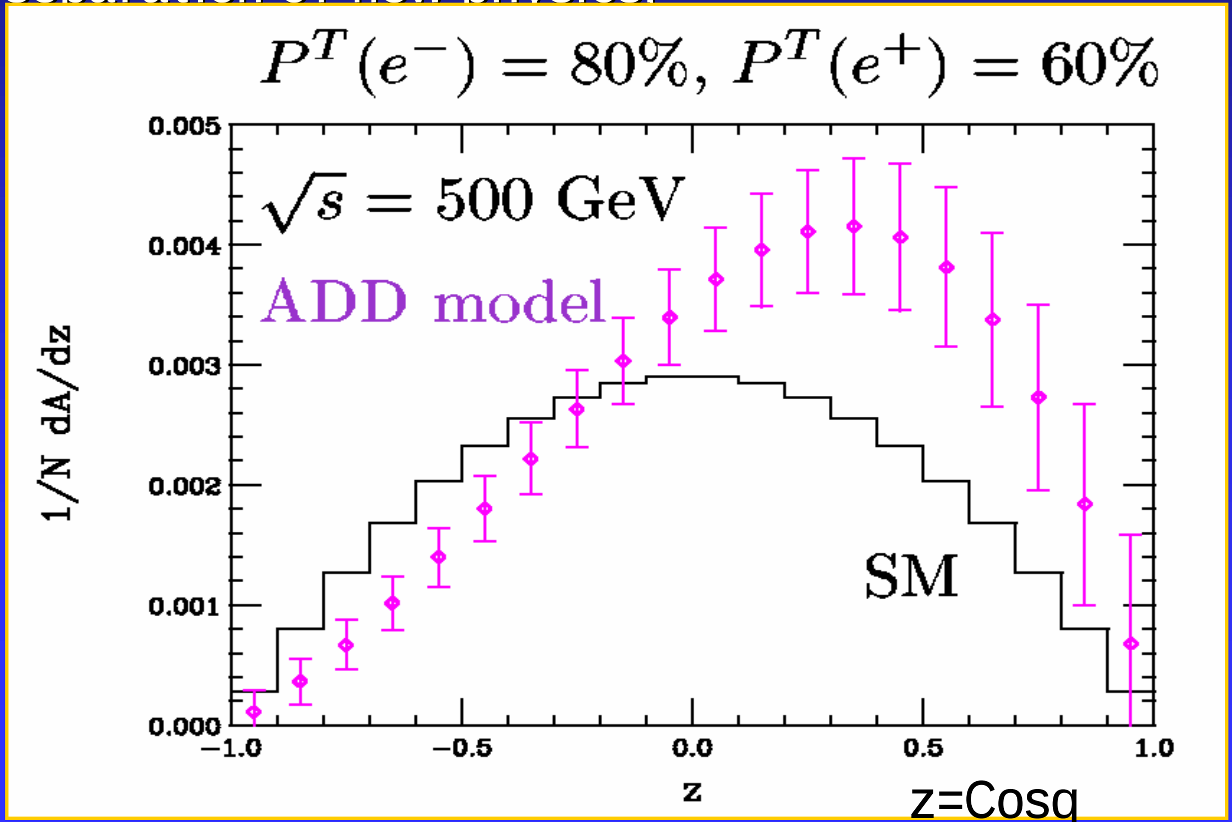




Search for extra dimensions

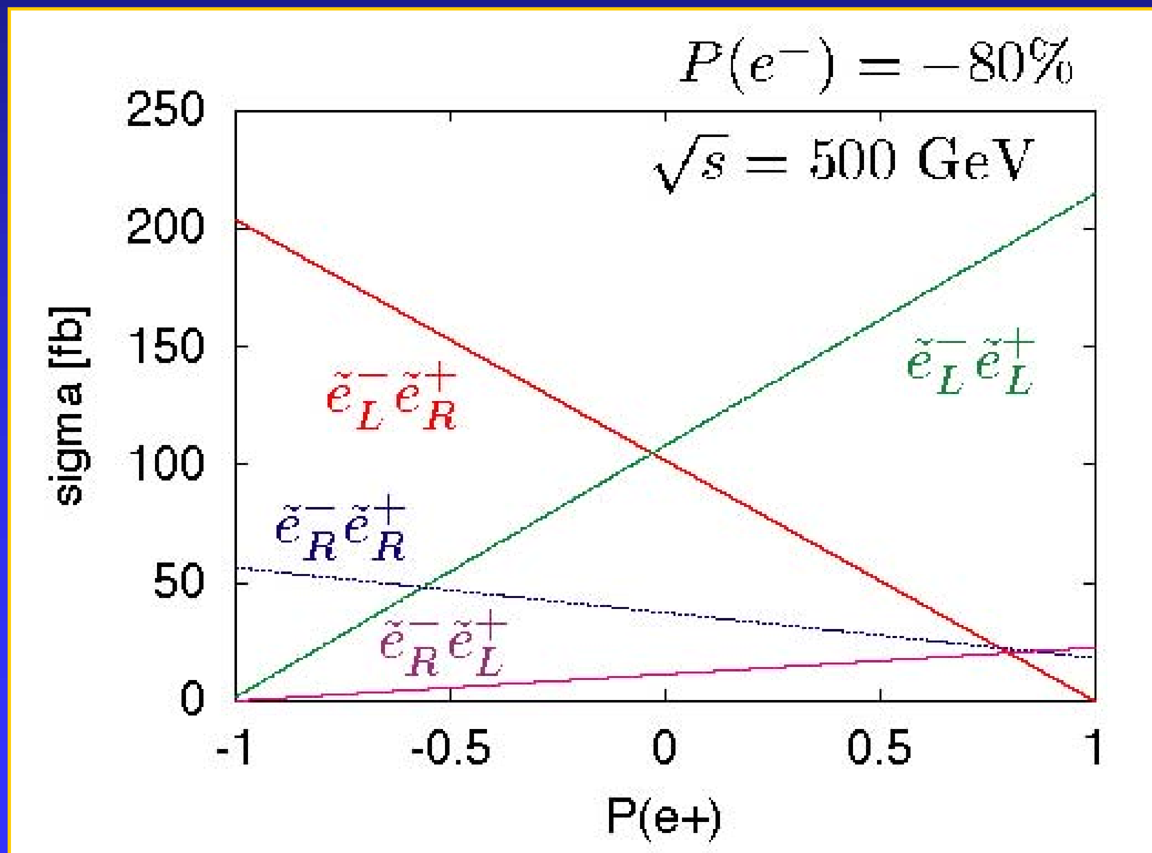
- Transverse polarization of both beams allows separation of new physics.

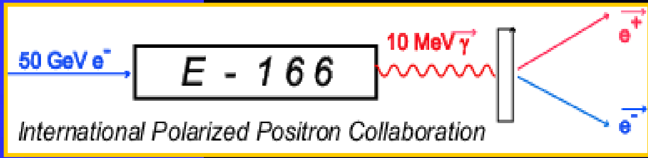
–N.Arkani-Hamed, S.Dimpoulos, G.Dvali



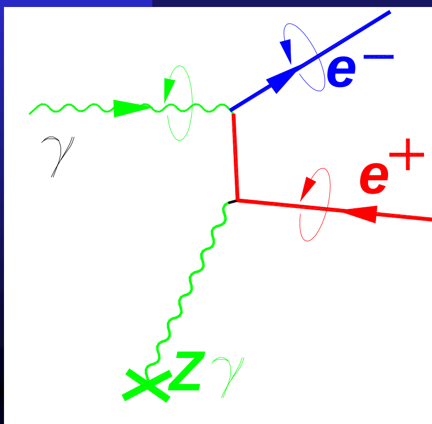
SUSY physics

- Separation of selectron pairs in e^+e^- -> $\tilde{e}^-_{L,R}\ \tilde{e}^+_{R,L}$



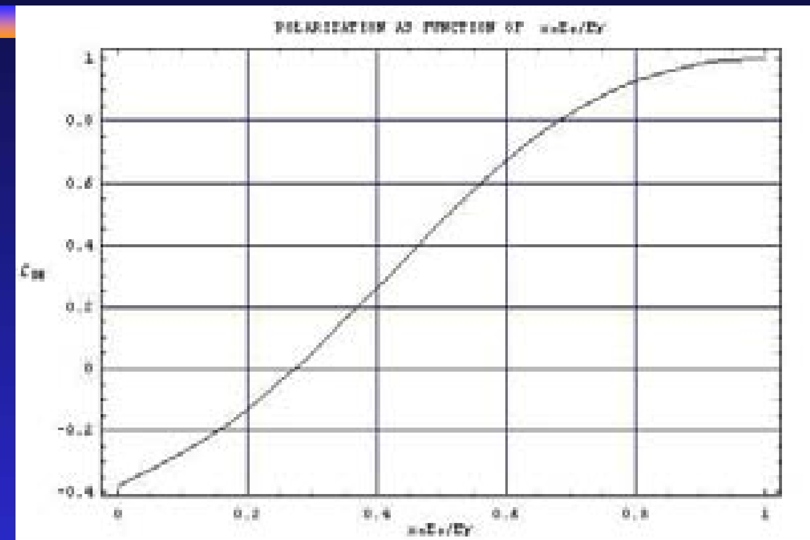


Polarized e$^{\pm}$ production



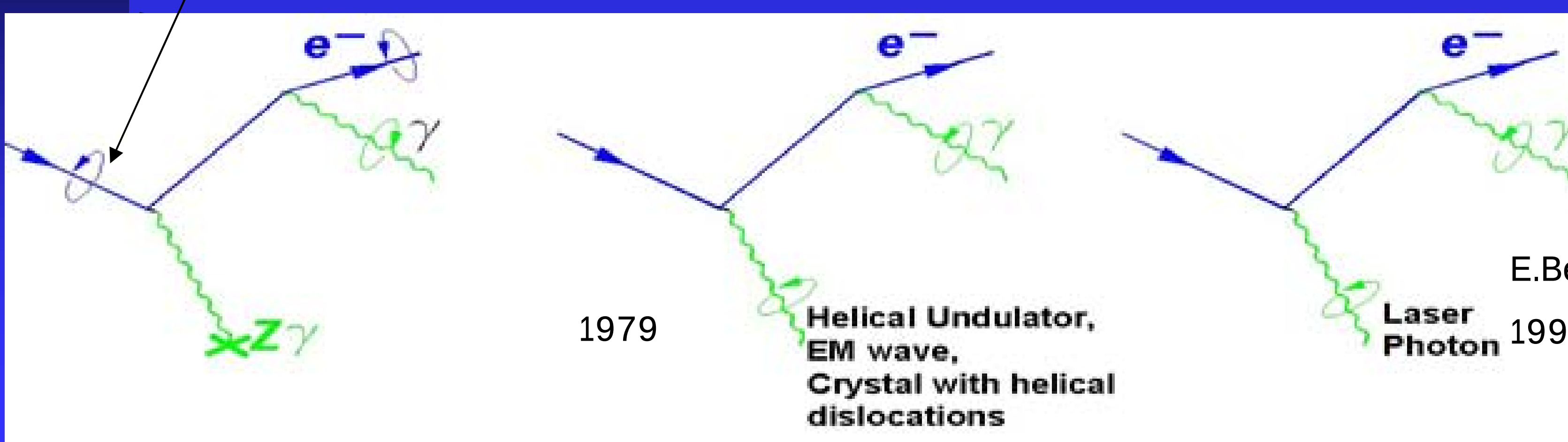
The way to create circularly polarized positron, left. Cross-diagram is not shown. At the right–the graph of – longitudinal polarization – as function of particle's fractional energy

1979



The way to create circularly polarized photon

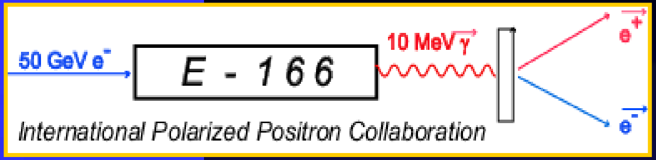
Polarized electron



1979

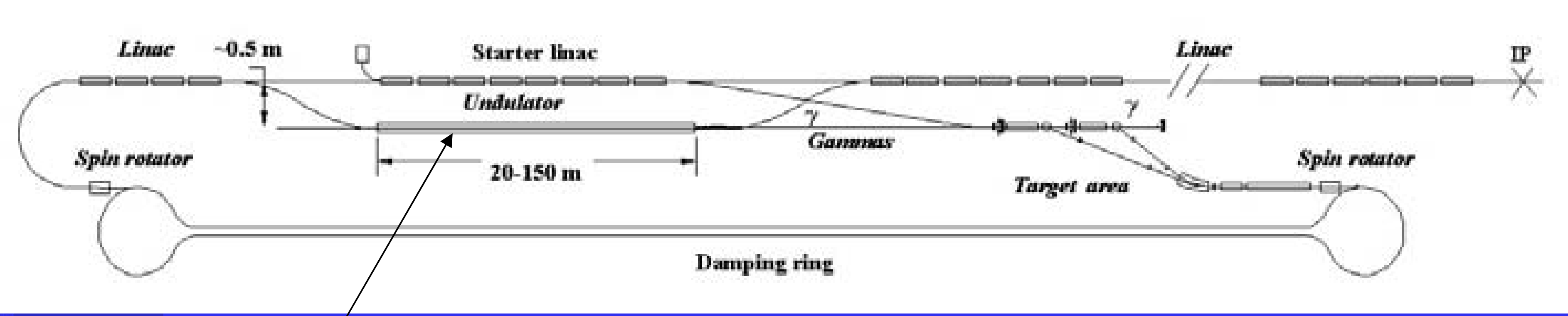
E.Bessonov

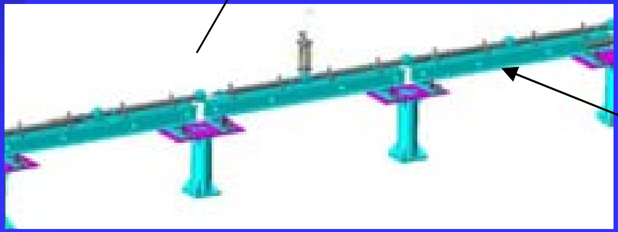
1992

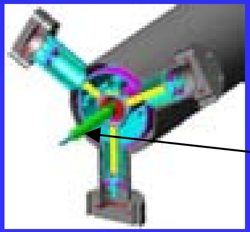


Polarized positrons for ILC

- The >150 GeV electron/positron beam itself is used for the production of (polarized) positrons
- Electron beam passes a ~200m helical undulator (50% surplus)
- After conversion, the positrons are captured and accelerated
- Spin handling system includes spin rotators etc







E-166 Experiment

E-166 is a demonstration of undulator-based production of (polarized) positrons for linear colliders:

- Photons are produced ~in the same energy range and polarization characteristics as for ILC;

-The same target thickness and material are used as in the linear collider;

-The polarization of the produced positrons is the same as in a linear collider.

-The simulation tools are the same as those being used to design the polarized positron system for a linear collider.

- Number of gammas per electron is lower ~210 times, however: $(150/1)(2.54/10)(0.4/0.17)^2$.

TESLA, NLC/USLCSG, and E-166 Positron Production

Table 1: TESLA, ILC/ USLCSG, E-166 Polarized Positron Parameters

Parameter	Units	TESLA*	ILC	E-166
Beam Energy, E_e	*GeV*	150-250	150	50
N_e/bunch	-	3×10^{10}	8×10^{9}	1×10^{10}
N_{bunch}/pulse	-	2820	190	1
Pulses/s	*Hz*	5	120	30
Undulator Type	-	planar	helical	helical
Undulator Parameter, K	-	1	0.35-0.8	0.17
Undulator Period, λ_u	*cm*	1.4	1-1.2	0.25
1st Harmonic Cutoff, E_{c10}	*MeV*	9-25	11	9.6
dN_γ/dL	*photons/m/e^-*	1	2.6	0.37
Undulator Length, L	*m*	135	132	1
Target Material	-	Ti-alloy	W/Ti-alloy	Ti-alloy, W
Target Thickness	*r.l.*	0.4	0.5	0.5
Yield	*%*	1-5	1.8†	0.5
Capture Efficiency	*%*	25	20	-
N_+/pulse	-	8.5×10^{12}	1.5×10^{12}	2×10^{7}
N_+/bunch	-	3×10^{10}	8×10^{9}	2×10^{7}
Positron Polarization	*%*	-	40-70	40-70

*TESLA baseline design; TESLA polarized e+ parameters (undulator and polarization) are the same as for the NLC/USLCSG

† Including the effect of photon collimation at $\gamma\theta = 1.414$.

50 GeV e⁻ E - 166 10 MeV γ

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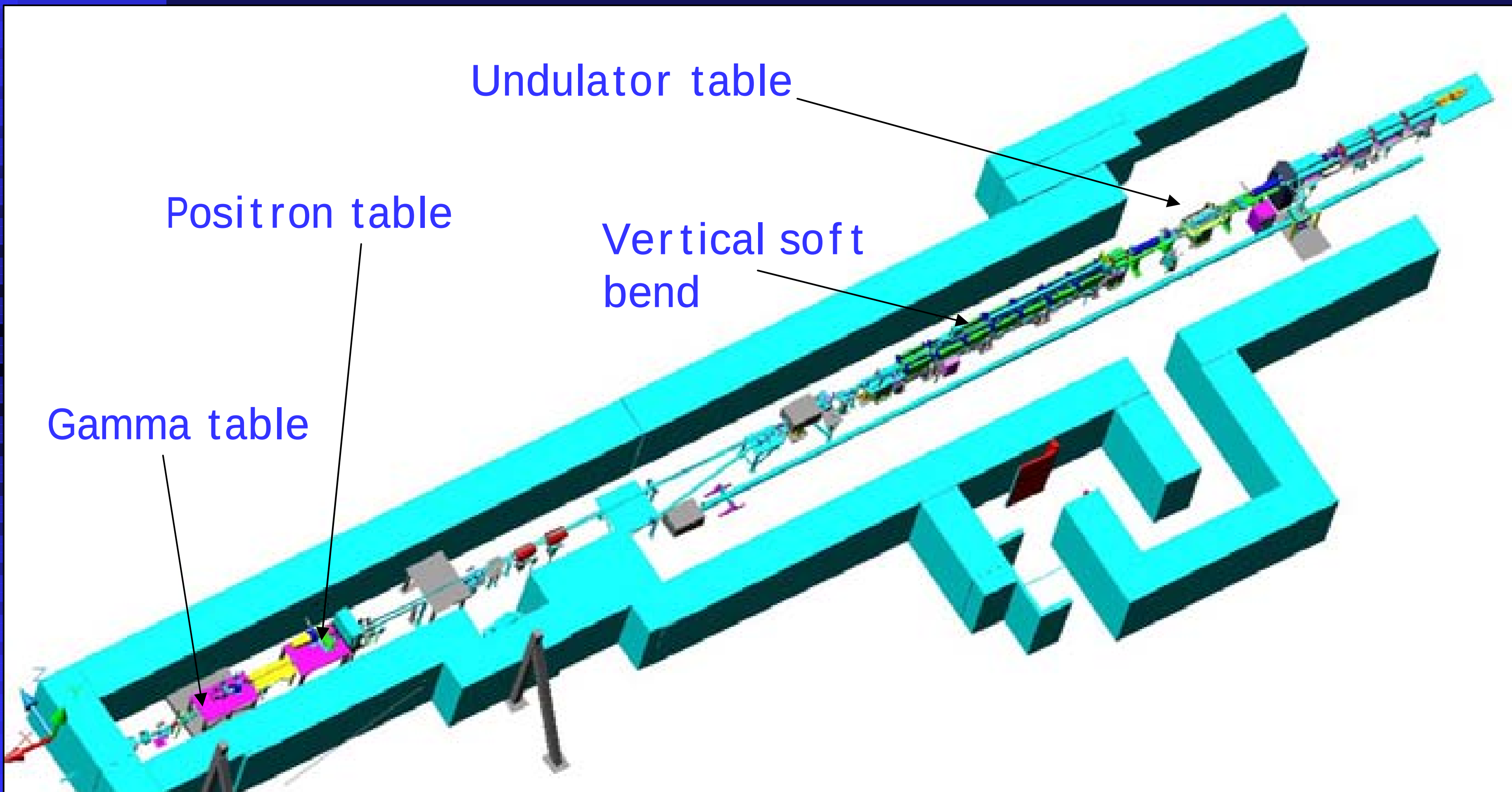
Scope of E-166



50 GeV e⁻ E - 166 10 MeV γ e⁺ e⁻
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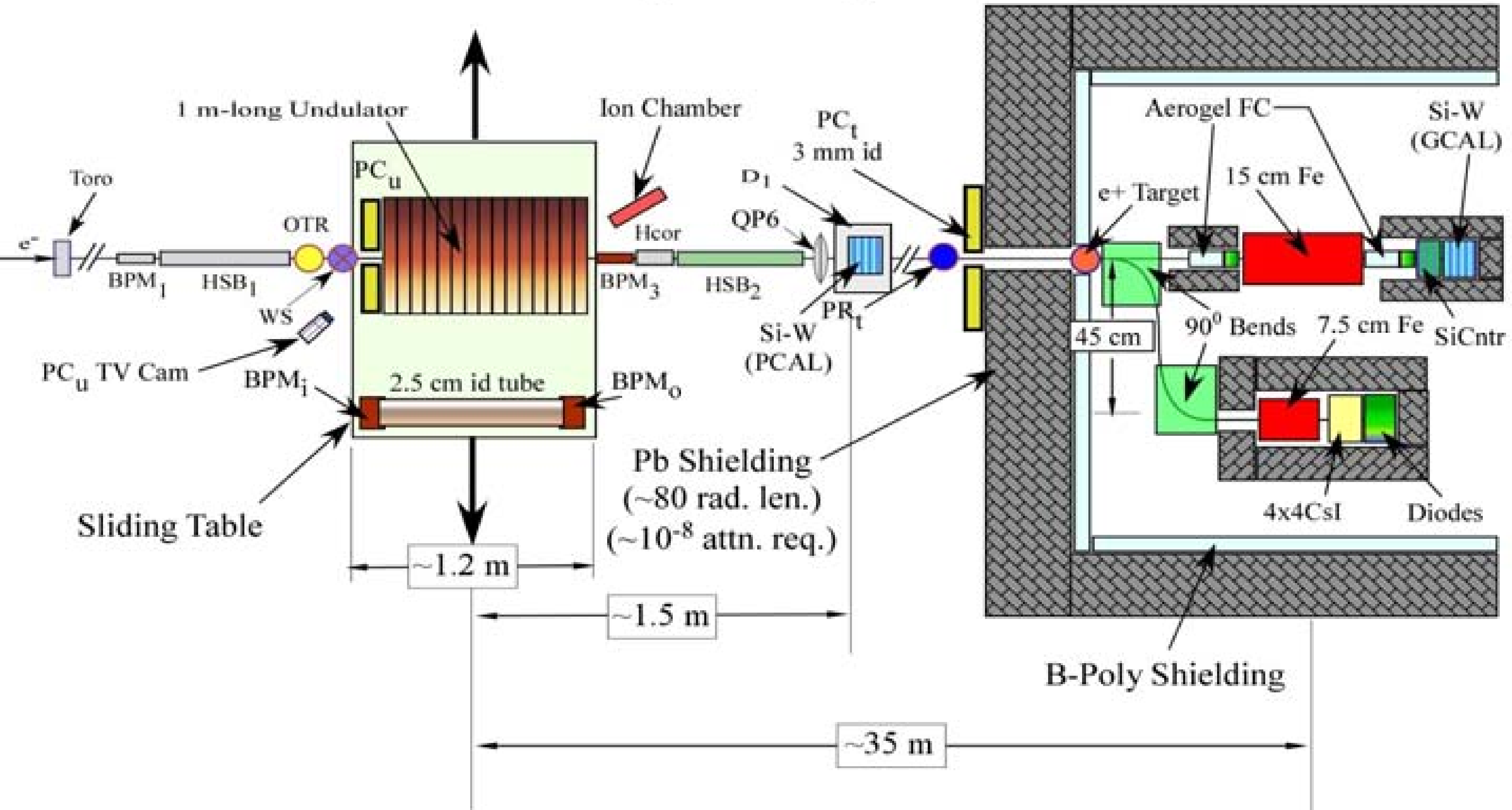
E166 Equipment

E-166 : Plan View, r2
(50 GeV)



50 GeV e⁻ — E - 166 — 10 MeV γ — e⁺ / e⁻

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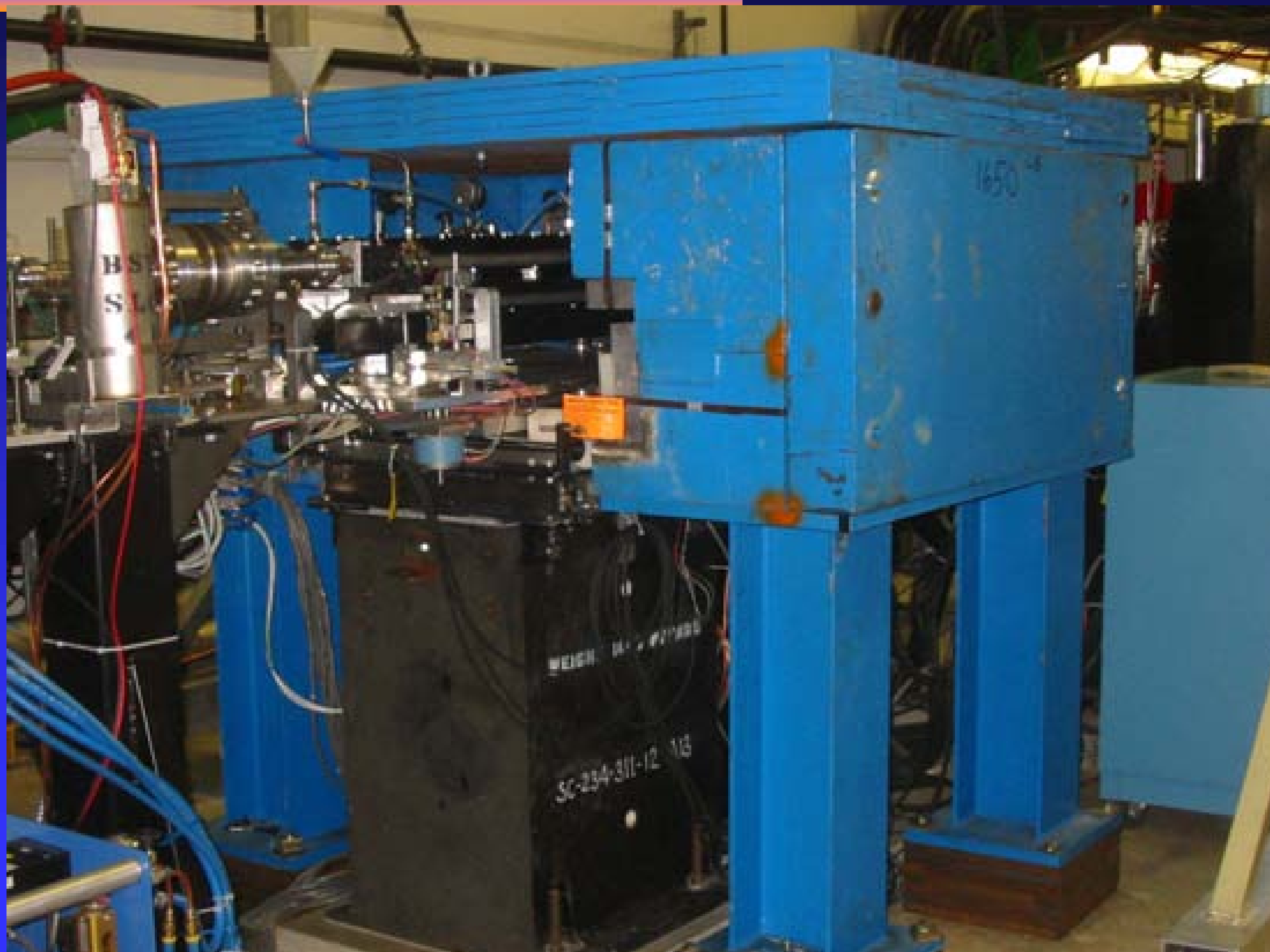
E166 Undulator Area



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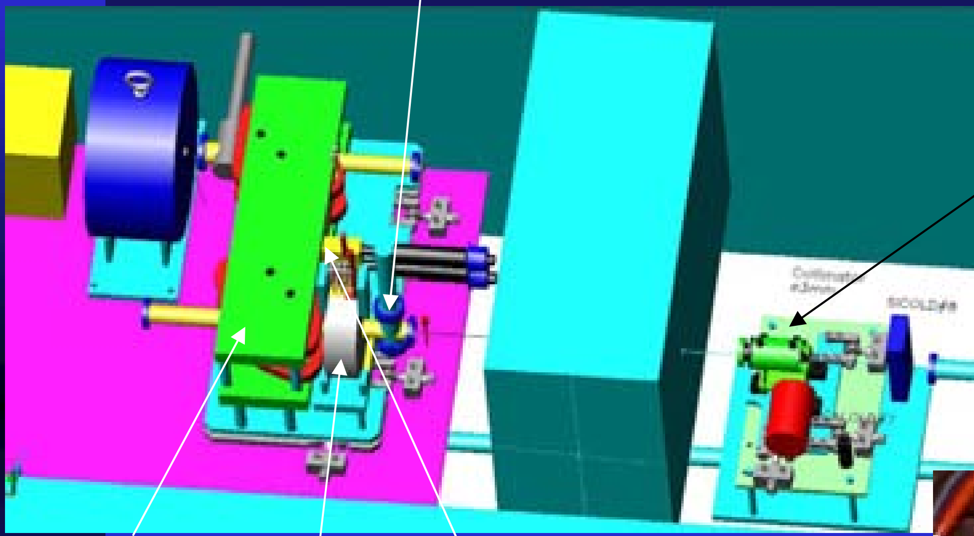
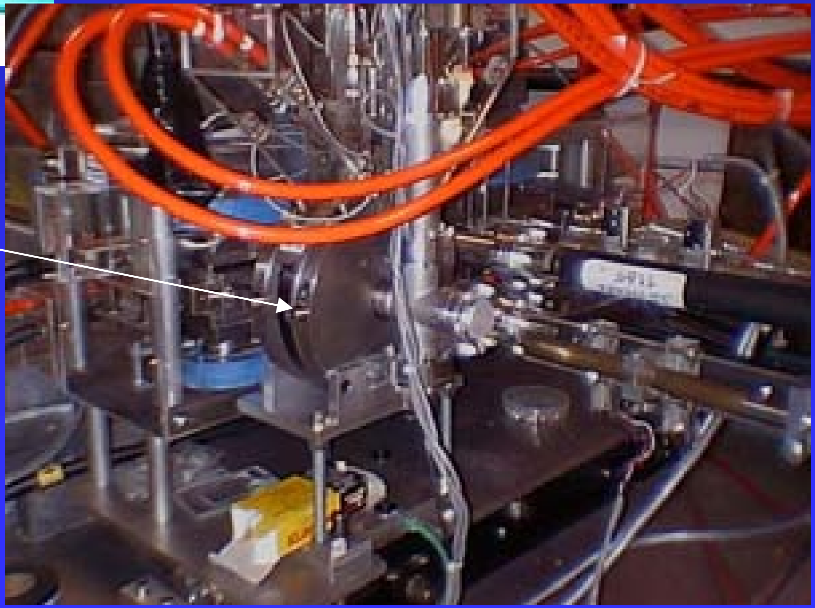
Spectrometer Area

Target



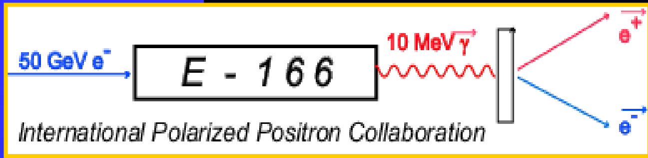
Collimator, 3mm in dia



S-type spectrometer

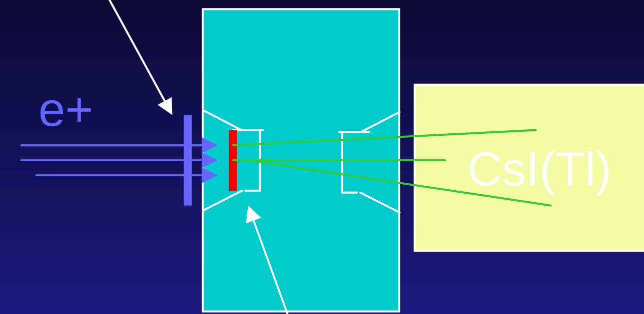
Solenoidal lens; 45 A/mm^2

Jaws located at high dispersion region

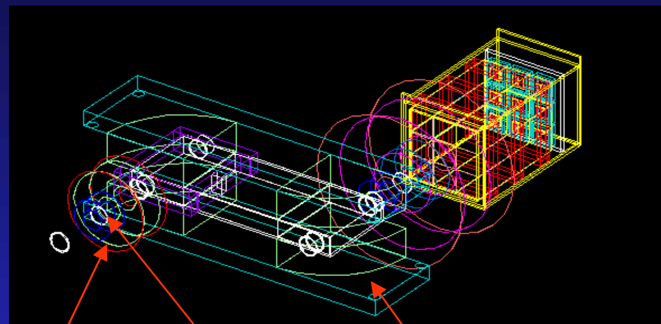


Bill's Si detector

e+



Geant4 based Simulation of Polarized Positrons production



Reconversion target

Solenoid

Conversion target

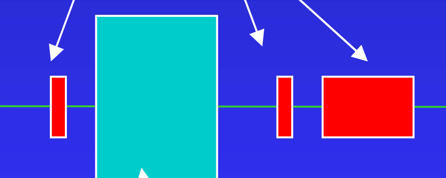
Spectrometer

1% e+ yield

Bill's Si detector

Undulator gamma

Simulated events



Gamma magnet

<2%

e+ transmission

50 GeV e⁻ | E - 166 | 10 MeV γ | e⁺ | e⁻

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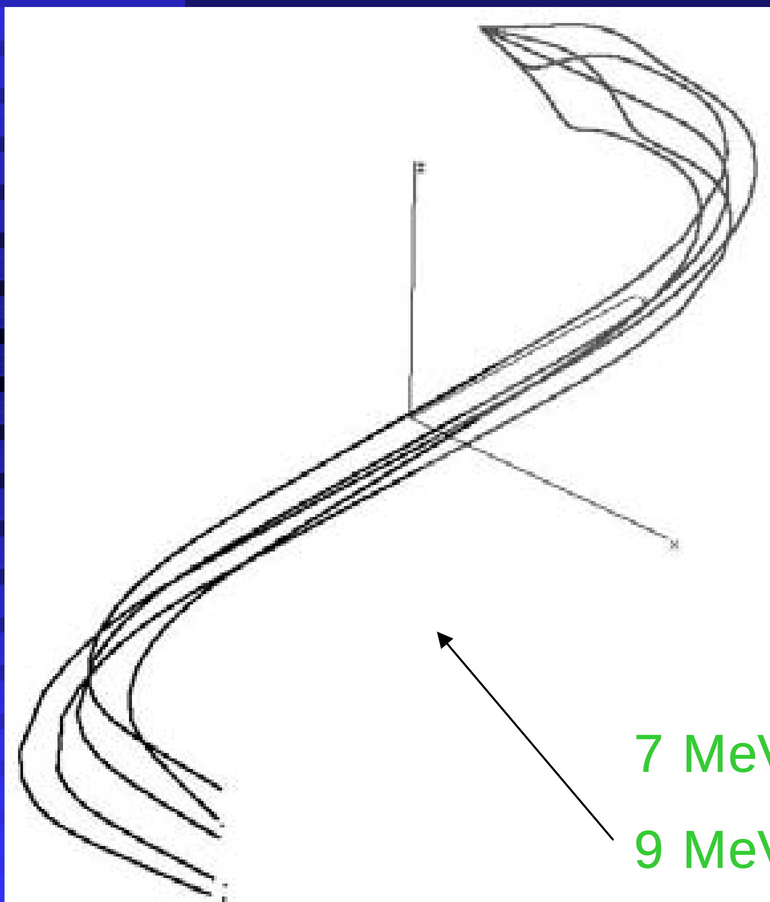
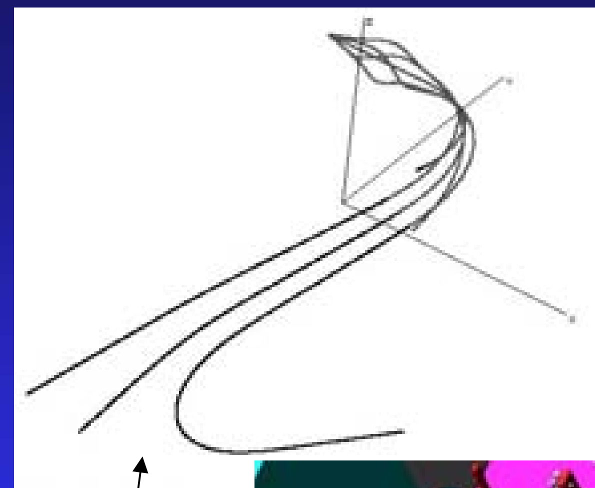
Spectrometer

Princeton, SLAC, Cornell

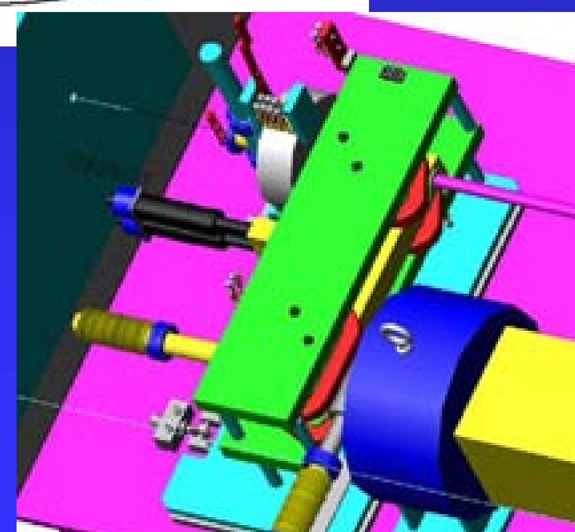
Trajectories calculated in 3D field





7 MeV positrons

9 MeV positrons



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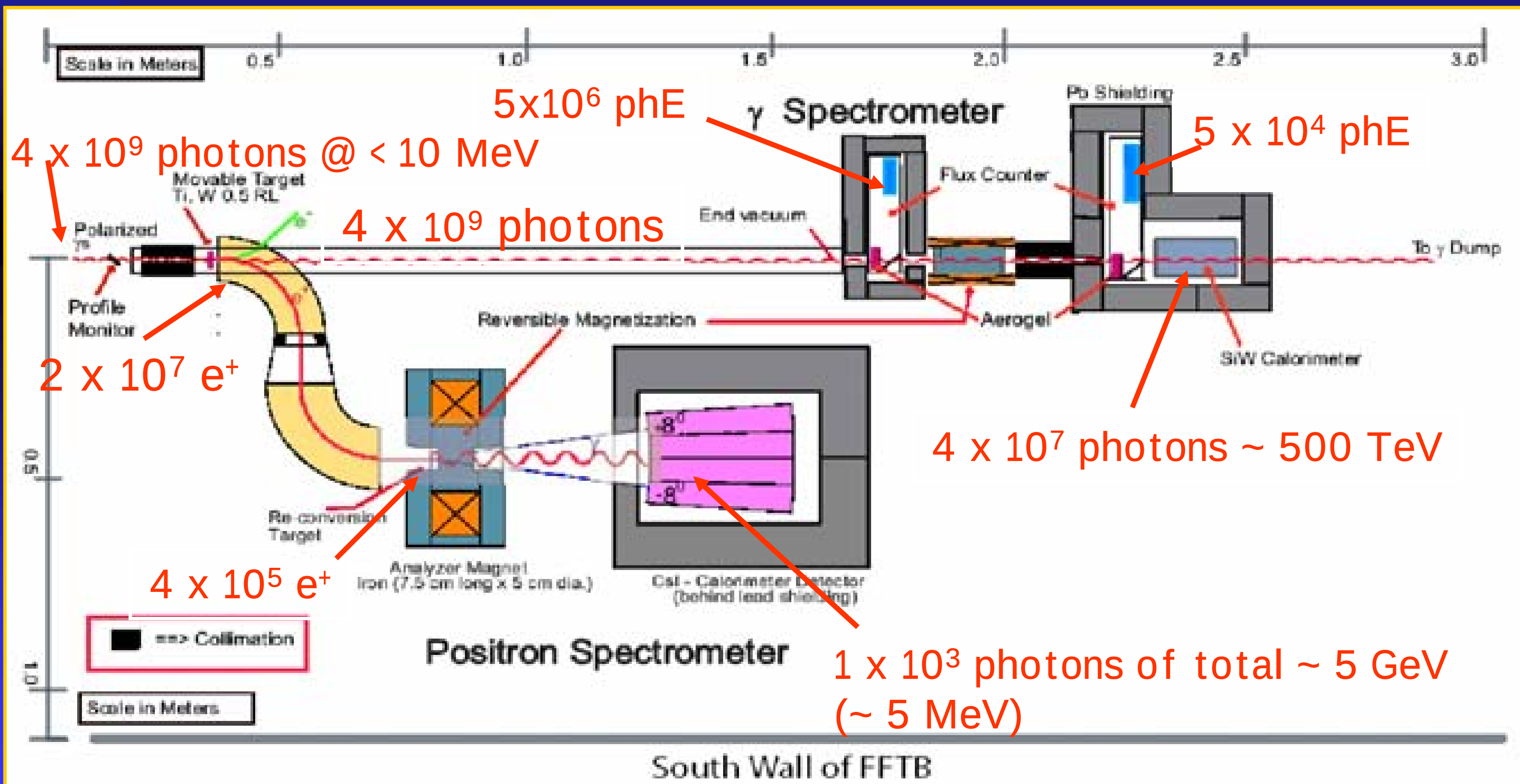
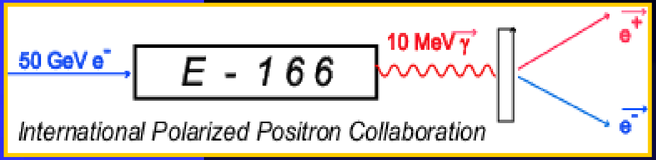
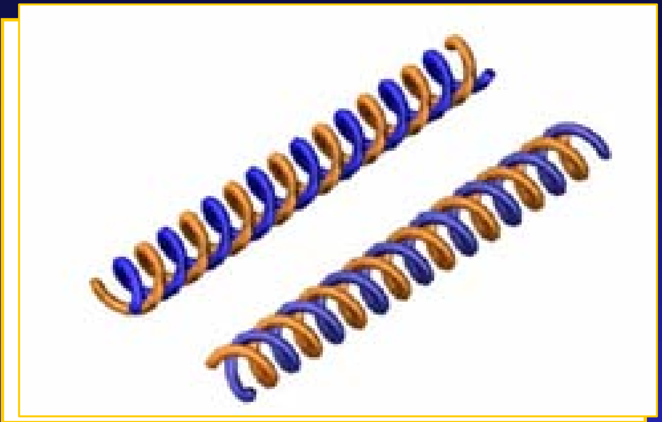
Beam Intensities & Energies

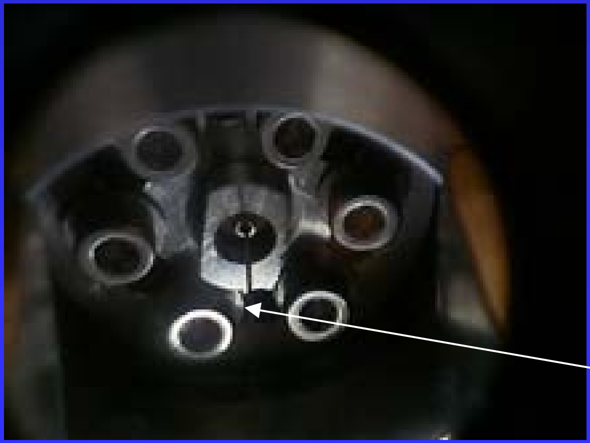
- 10^{10} electrons/bunch @ ~50GeV into the undulator

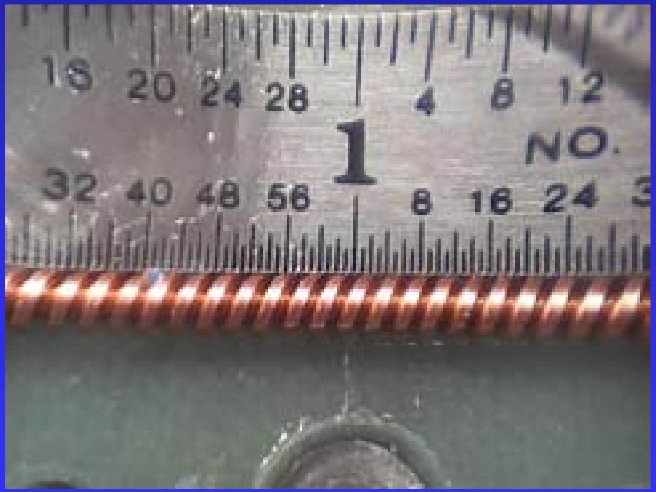




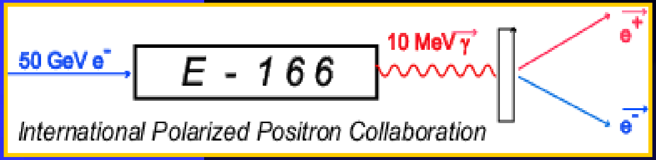
Helical undulator
Cornell



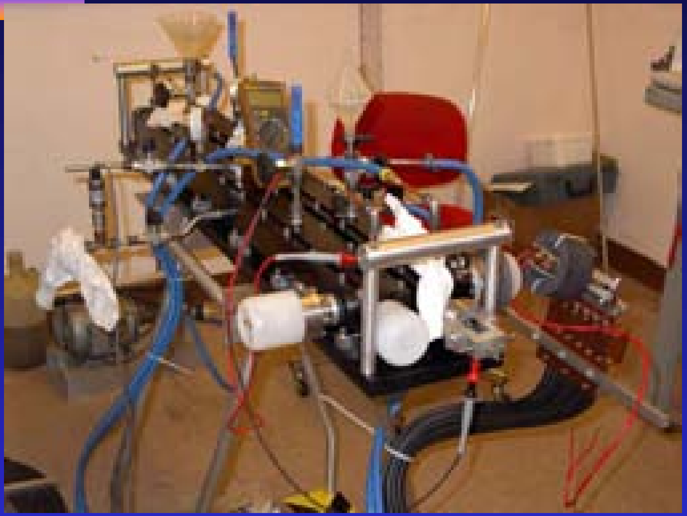
- Helical magnetic field
- Wound left hand
- Inner diameter 0.88 mm
- Magnetic field: 0.76 T
- Pulsed current: 2300 A in $0.6 \times 0.6\ mm^2$ wire, 12usec
- Rate 30 Hz
- 

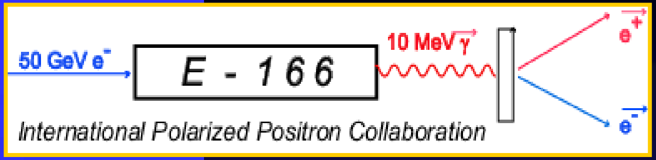


Stretched wire for aperture measurements



Helical undulator
Cornell





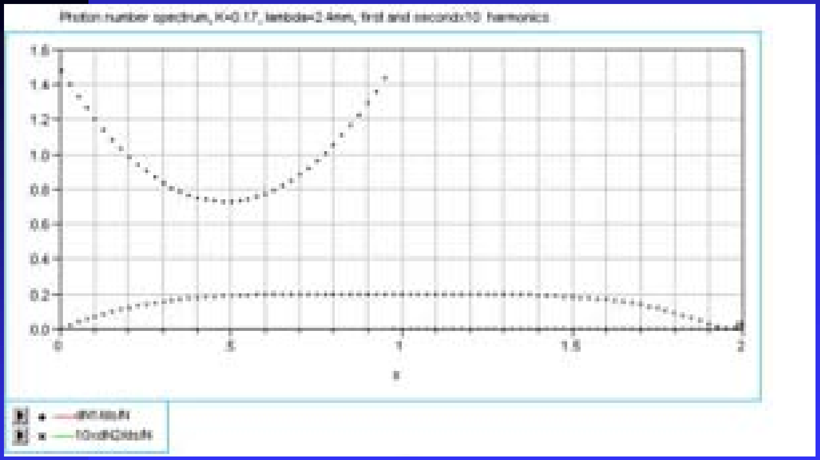
Undulator radiation

$$\frac{dN_\gamma}{dL} = \frac{30.6}{\lambda[mm]} \cdot \frac{K^2}{1+K^2} \frac{phot}{m\ e^-} = 0.37 \frac{phot}{m\ e^-}; K = 0.17$$

$$E_C = 24.8[MeV] \frac{(E_e/50[GeV])^2}{\lambda\,[mm]\left(1+K^2+\gamma^2\theta^2\right)} \sim 9.6\ MeV$$

Energy spectrum

Polarization



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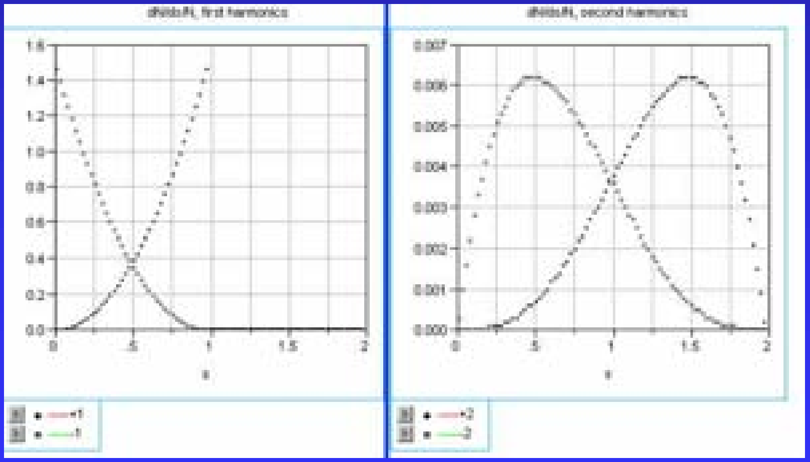
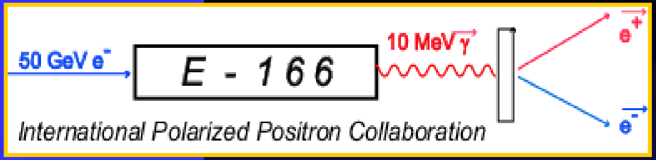


K=0.17

K=0.1

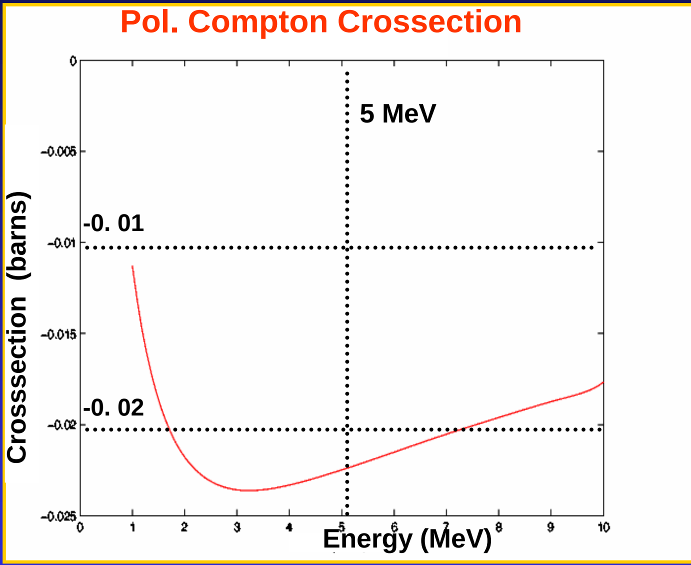


Transmission Polarimetry

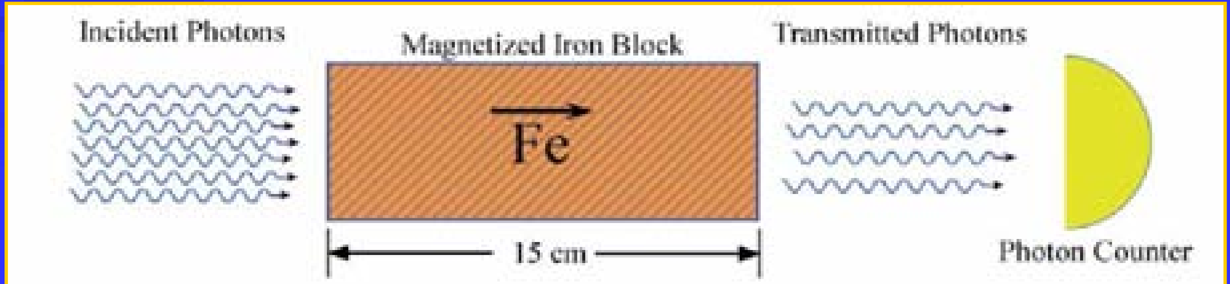
- Compton scattering depends on polarization
- Either measurement of scattered photons or of unscattered photons: simpler setup
- Attenuation:
  $$T(L) = e^{-nL(\sigma_{phot} + \sigma_{pair} + \sigma_{comp0})} \, e^{\pm nLP_\gamma P_e \sigma_{pol}}$$
- Asymmetry:
  $$\delta(L) = \frac{T^+ - T^-}{T^+ + T^-} \approx nLP_e P_\gamma \sigma_{Pol}$$
- By knowing P_e => P_γ can be calculated:

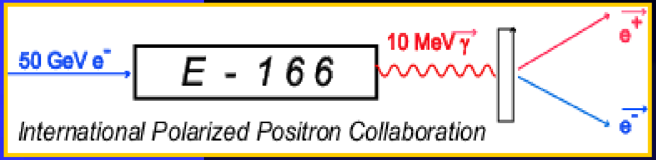
$$P_\gamma = \frac{\delta}{nL\sigma_{pol} P_e} = \frac{\delta}{A_\gamma P_e}$$

A-analyzing power



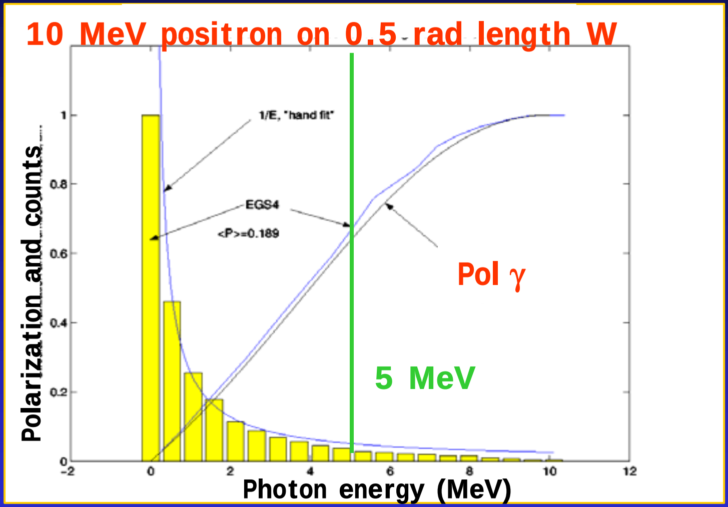
$$\delta = 0.0266$$
$$P_e = 0.07$$
$$\langle A_\gamma^E \rangle = 0.62$$



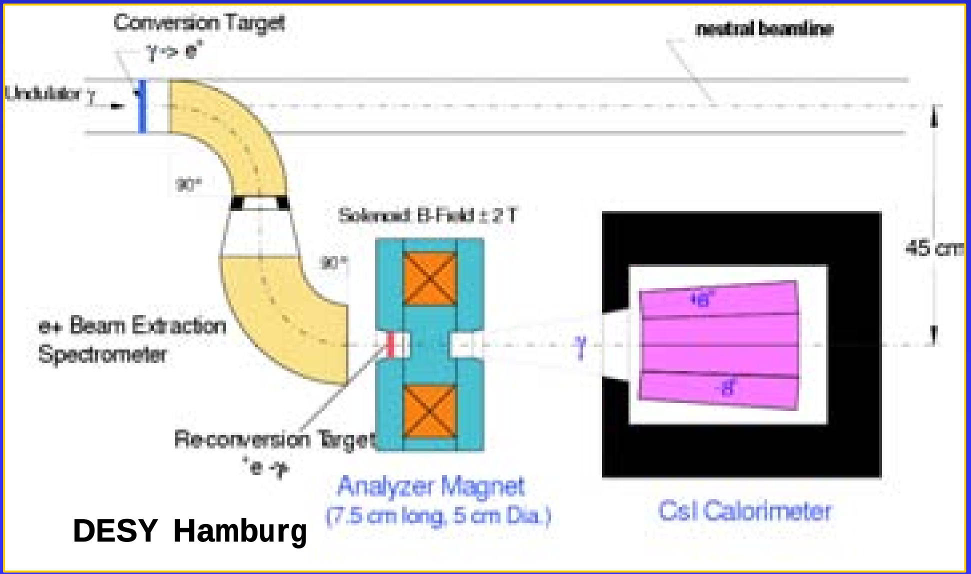


Polarimetry of positrons

- Longitudinal polarized positrons are re-converted to circular polarized bremsstrahlungs photons in reconversion target (W with 0.5 rad. lengths)
- Polarization of photons measured by transmission polarimetry
- Energy weighted rate in CsI calorimeter (background supress.)
- Eff. analyzing power A_{e+} is determined by simulation



$$P_{e^+} = \frac{\delta}{P_{e^-} A_{e^+}}$$

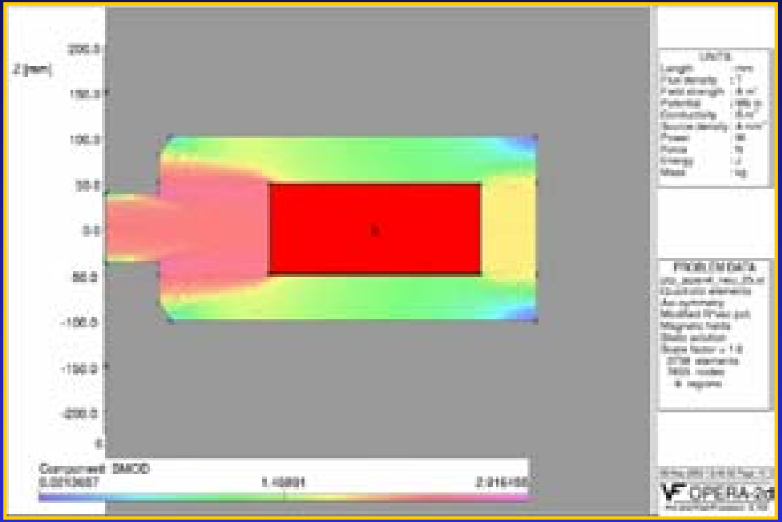


Analyzing magnets

- The knowledge of magnetisation of the analyzer magnet strongly influences error in polarimetry
- Magnetisation is given by

$$P_e = 2 \cdot \frac{g^{'} - 1}{g^{'}} \cdot \frac{M}{n\mu_B} \cong \frac{2}{26} = 7\%$$

- Error must be $P_e < 5\%$



„DESY Hamburg, Germany"

- Coil operated at 100A
- Photon analyzer: Ø 5 cm x 15 cm
- Positron analyzer: Ø 5 cm x 7.5 cm

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Analyzing power for positron magnet

Geant simulation: 7.5 cm iron absorber, Cs I cal.

Positron Energy (MeV)	Positron Pol. P_{e^-} (%)	Positron Transport Eff. ϵ_{e^+} (%)	Photon Transport Eff. ϵ_γ (%)	Photon Asym. δ (%)	Analyzing Power A_{e^-} (%)	N_γ in 15 min	15 min Abs. Error ΔP_{e^-} (%)
3	42	1.5	0.045	0.55	18.6	3.7×10^6	4.0
4	61	1.9	0.078	0.84	19.7	8.0×10^6	2.6
5	69	2.1	0.12	0.82	17.0	1.45×10^7	2.2
6	78	2.3	0.20	0.87	15.9	2.44×10^7	1.8
7	84	1.7	0.28	0.93	15.8	2.59×10^7	1.6
8	77	0.9	0.38	0.82	15.0	1.86×10^7	2.2
9	64	0.4	0.50	0.63	14.0	1.09×10^7	3.1
10	68	0.3	0.64	0.66	13.9	1.04×10^7	3.2

50 GeV e⁻ E - 166 10 MeV γ

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DESY: Analyzing Magnets

50 GeV e⁻ E - 166 10 MeV γ e+ e−
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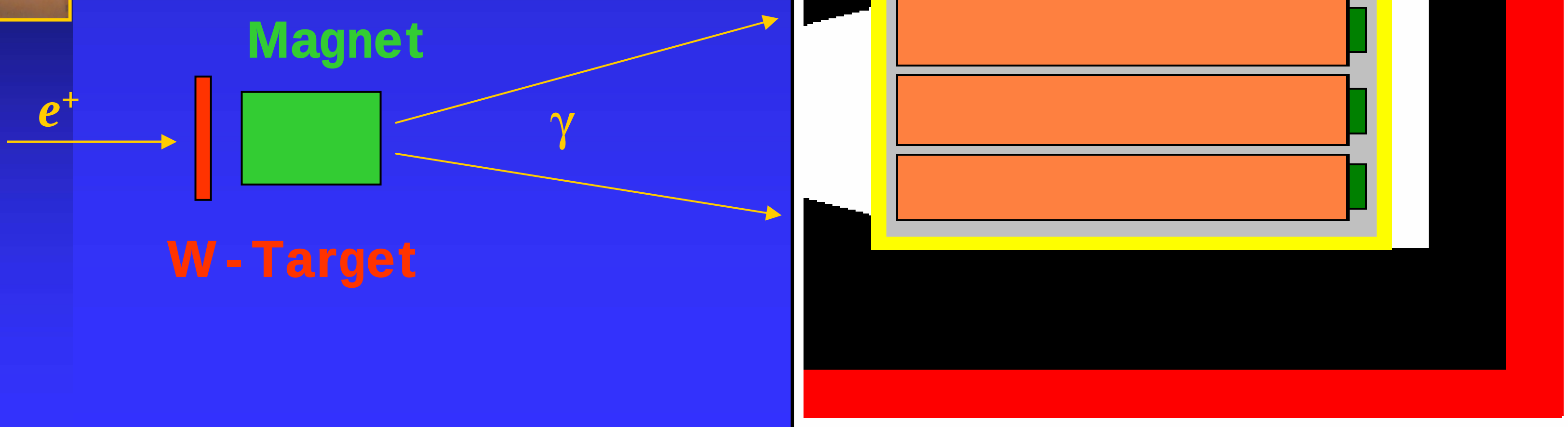
CsI Calorimeter

- „DESY Zeuthen and Humboldt University Berlin“
- Pack 3 x 3 crystals in a stack
- CsI crystals: ~ 6 cm X 6 cm X 28 cm from DESY
- ~1000 Re-converted photons -> Max 5 GeV
- Readout by PIN diodes (large linear dynamic range)
- 14 degrees aparture



50 GeV e⁻ E - 166 10 MeV γ e⁺ e⁻
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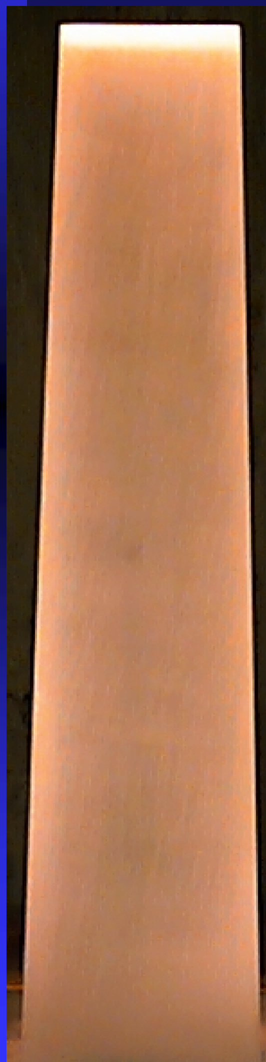
CsI Crystal Property



Properties:

- light yield 70.000 ph. / MeV
- temp. coeff. 0.1 % / ^{o}C
- peak emission 565 nm
- decay time 940 nsec
- index of reflection 1.79

- density 4.51 g/cm^3
- radiation length 1.86 cm
- Molière radius 3.8 cm

- ‘soft material’ / slightly hygroscopic

- dimensions: ≈ 5 x 5 x 30 cm^3
- weight: ≈ 4 kg

- doping: Thallium ≈ 100 p.p.m

50 GeV e⁻ E - 166 10 MeV γ e⁺ e⁻
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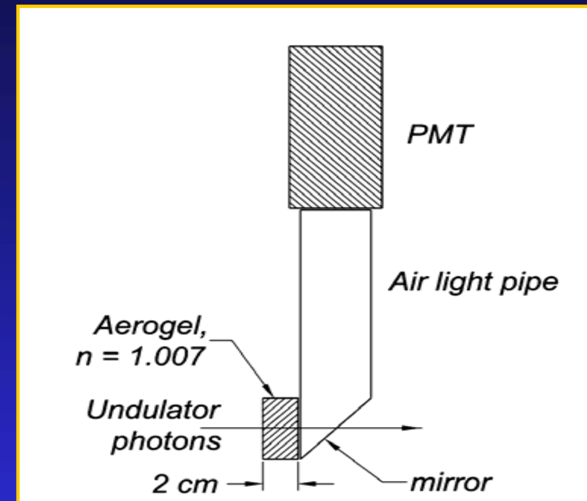
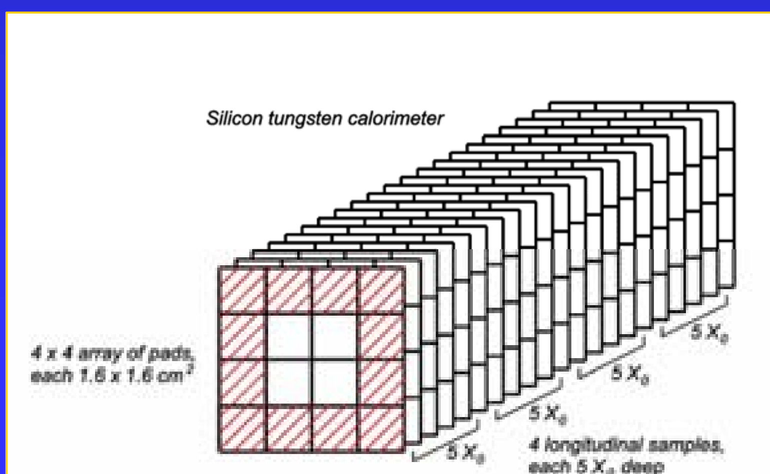
Aerogel flux counters and Si-W calorimeter

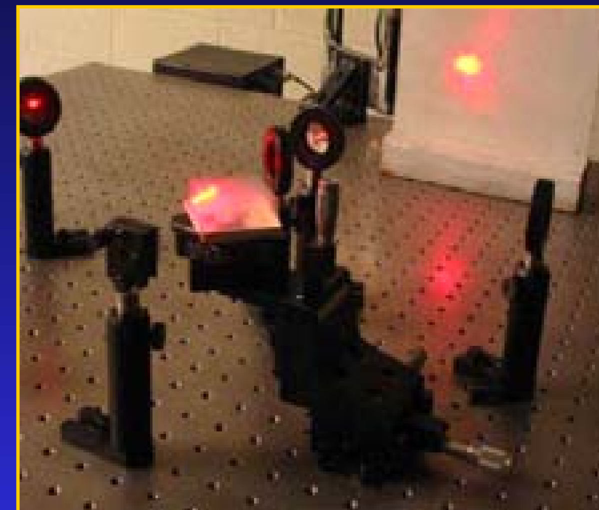
- Aerogel energy threshold: 4.3 MeV
  - Photon flux measurement
- Si-W calorimeter
  - 4 x 4 Stack of 20 plates of W (1 rad. length thickness)
  - Up to 500 TeV signal
  - Total energy of undulator photons

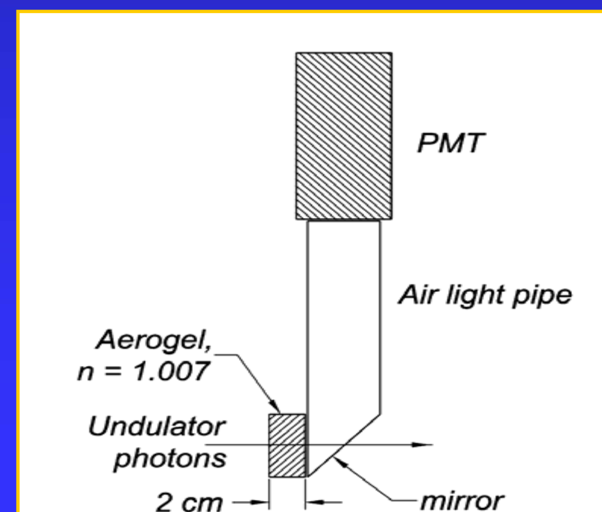


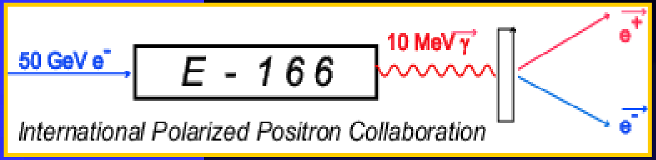


Aerogel flux counters

- „University Tenessee“
- Counters from BELLE experiment
- Aerogel produces Cherenkov light
- Energy threshold: 4.3 MeV
- Conversion probabilty: 0.0003
- Extremly low refraction index 1.007

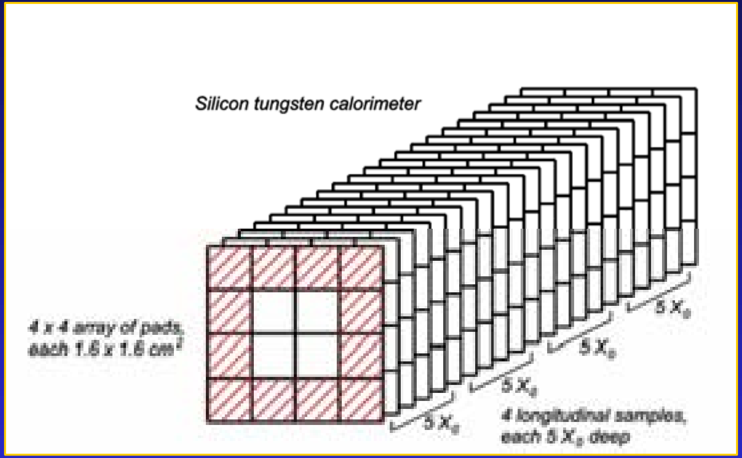






Si-W Calorimeter

- „University Tenessee“
- Total absorption calorimeter
- From E-144 design
- Stack of 20 plates of W (1 rad. length thickness)
- 4 x 4 array
- Up to 100 TeV signal
- total energy of undulator photons



E166 PS: B406

E - 166

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E166 DAQ: B407

ADC's

source calibration **x32**

typ. energy 1 MeV

min. res. 100 keV/bin

data taking **x1**

typ. energy 1 GeV

max. energy 5 GeV

5 GeV / 100 keV / 32

→ dynamic range ≈ 2000

→ 11-bit ADC

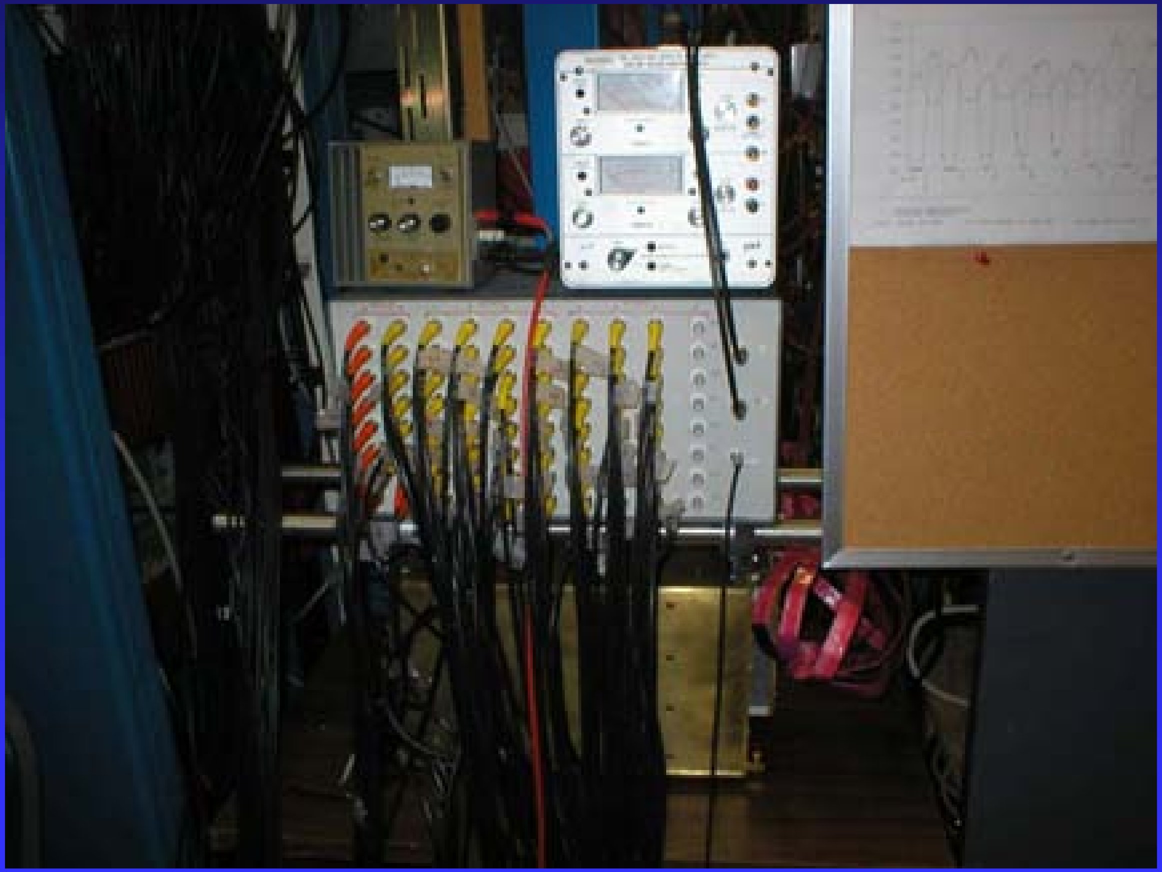
SLAC: LeCroy 2249 W:

- CAMAC Q-ADC
- 11-bit

Zeuthen: CAEN V265

- VME Q-ADC
- 12-bit resolution
- 15 bit dynamic range

E166 CsI and Electronics, B407



E-166 Beam Measurements

- Photon flux and polarization as a function of K.
- Positron flux and polarization vs. energy.
- Positron flux and polarization for 0.25 r.l. and 0.5 r.l. Ti and and 0.5 r.l. W targets.
- Each measurement takes about 20 minutes.
- A relative polarization measurement of 10% is sufficient to validate the polarized positron production processes

Experimental challenges for positron P measurements

- Large angular distribution of positron production
  - Collection efficiency and transport efficiency of positron transport system
- Large angular distribution of re-converted photons
  - Needs large aparture of CsI calorimeter (~15 degrees)
  - Signal (not scattered photons) mixes with Compton scattered photons (background)
  - Effective analyzing power of positron polarimetry needs to be determined by simulations
- Control of large background close to beampipe
  - Electrons scattered at undulator and the ones back splashed from e^- beam dump
  - -> Optimized beam and strong shielding
  - Testrun for background measurement

Background

- Uses the FFTB with 28 GeV
- Detectors installed in tunnel
- Run in parallel with current experiments
- Measured the background for all detectors

Detector	Signal	Max. Noise	Measured
CsI calorimeter	2-5 GeV	100 MeV	
Si-W calorimeter	500 TeV	25 TeV	
Aerogel upstream	2×10^9 phot	1×10^8 phot	
Aerogel downstream	5×10^7 phot	3×10^6 phot	

Operation

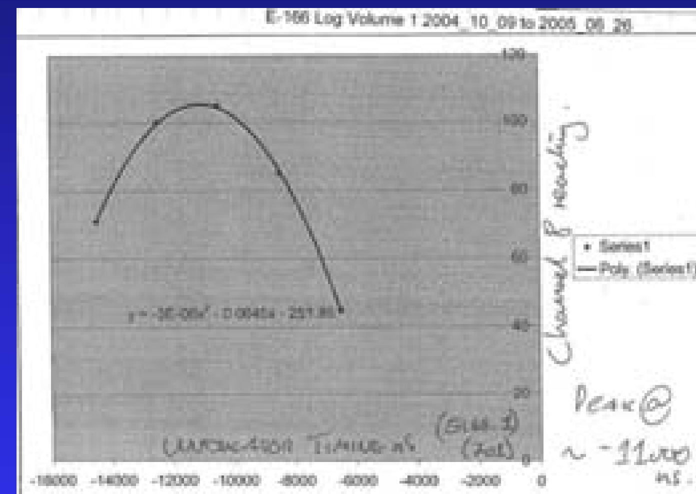
Every 10^{th} undulator pulse is shifted in time

Later -every next pulse is shifted

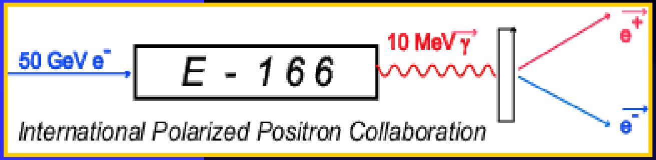
Undulator kicks e^- beam ~23µrad

Simplified end jumper

Shunt signal, 2300A



Gamma-flux as a function of timing around maximum



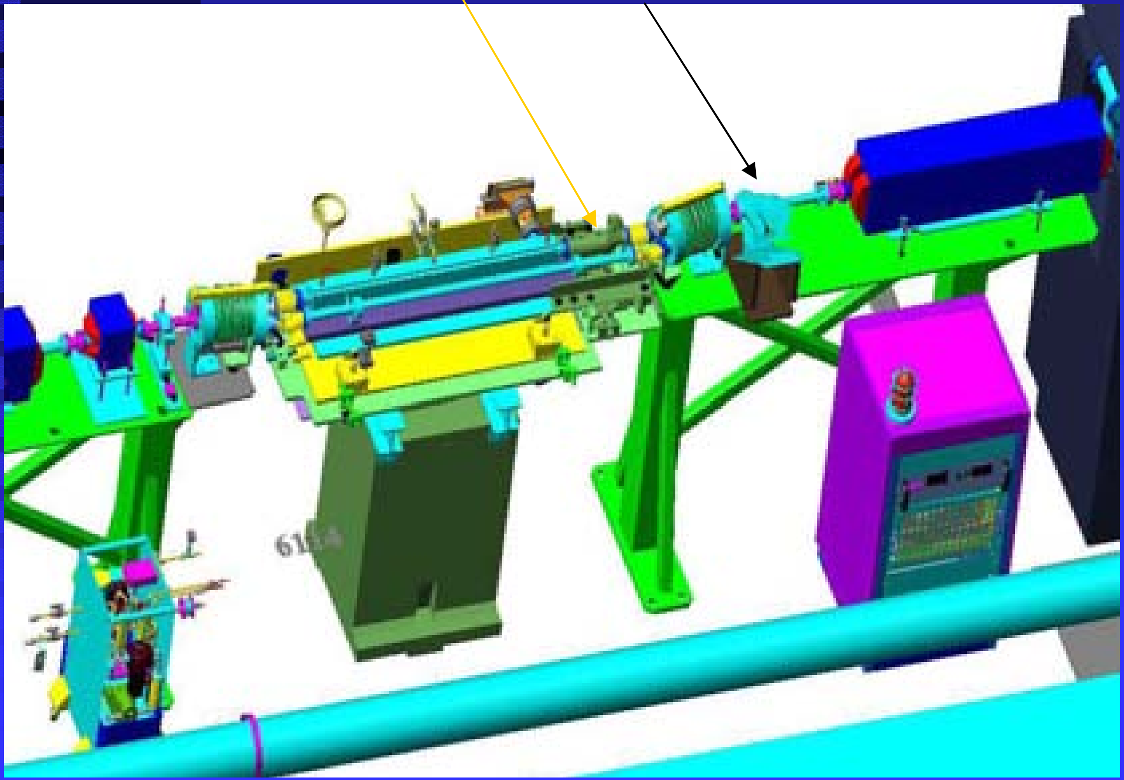
Transport through undulator

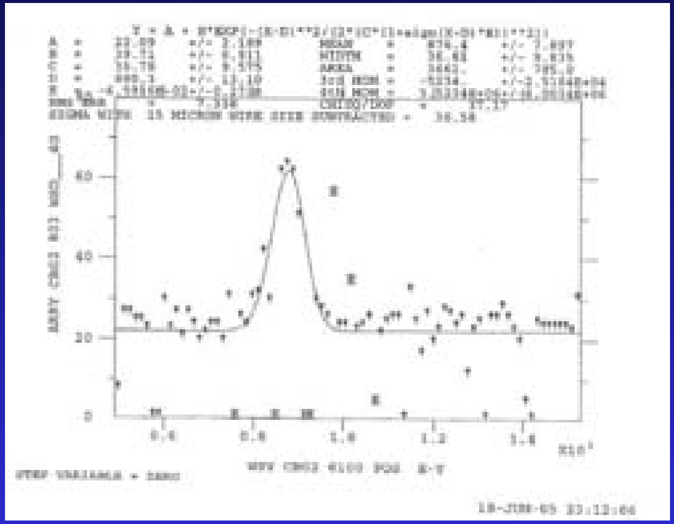
First, the beam transported through the undulator >1m with collimator in front ~30mils in dia

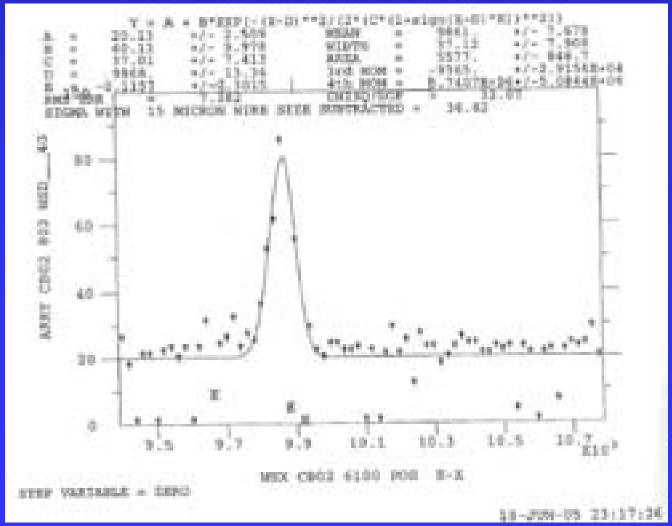
Table motion, steering magnets, …

s_x =36.8mm, s_y=36.58mm

Measurements with 15mm wire scanner







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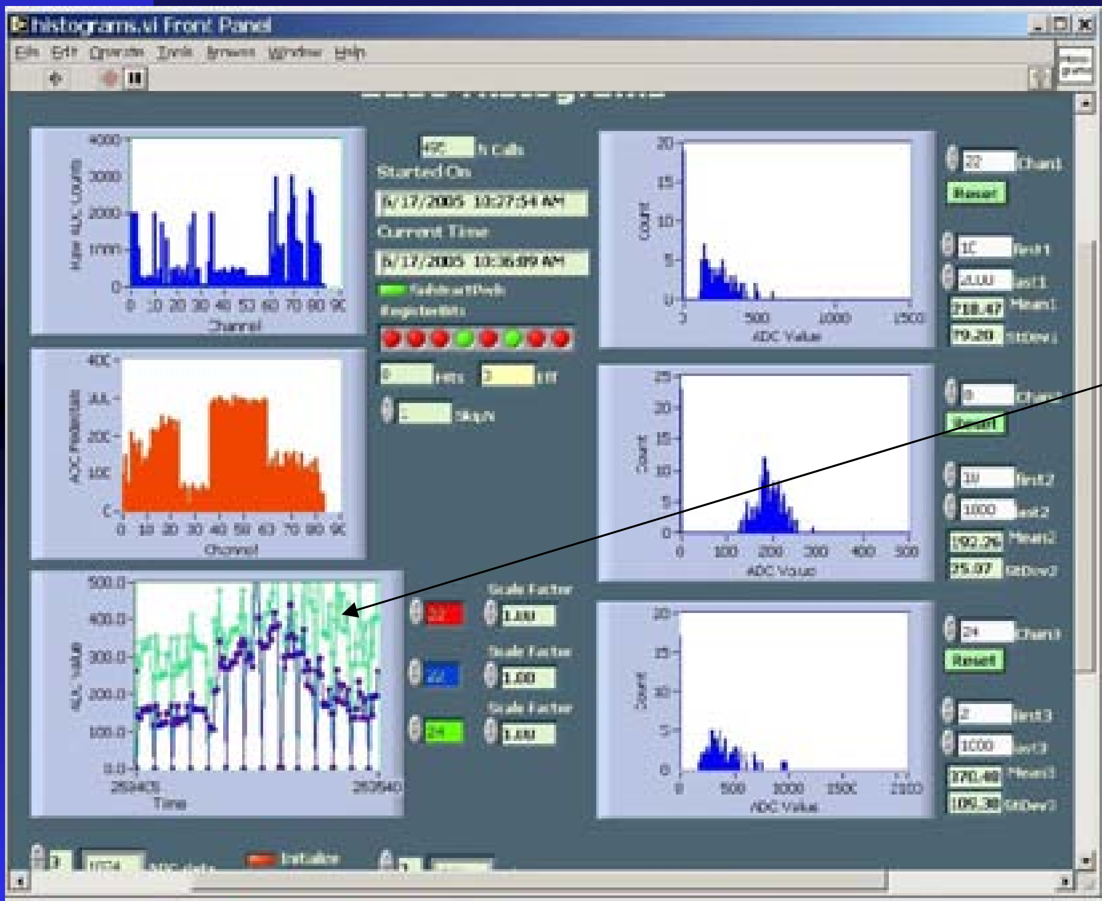
Operation



Control panel under permanent improvement

The very first photons seen after undulator was turned on for the first time June 17

Sinal from all 120 channels are written for each run

Beam parameters are written also

50 GeV e^- E - 166 10 MeV $\vec{\gamma}$ $\vec{e}^+$ $\vec{e}^-$

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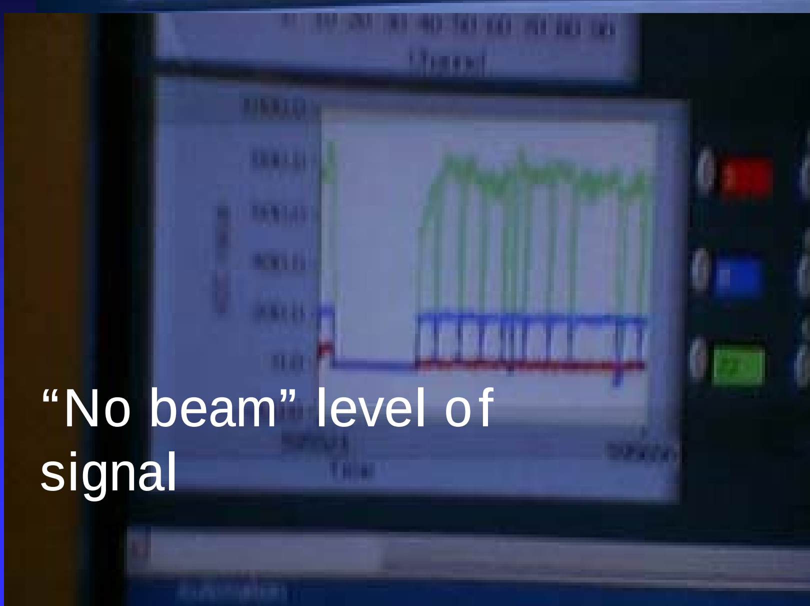
Operation

Typical signal

Every 10^{th} undulator pulse shifted



“No beam” level of signal

Amount of gammas

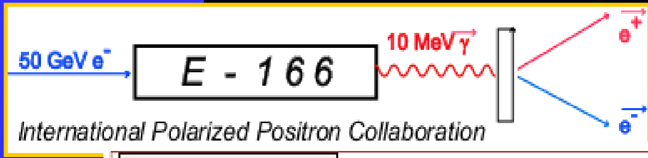
ATTENUATION on #22 — 50 db.

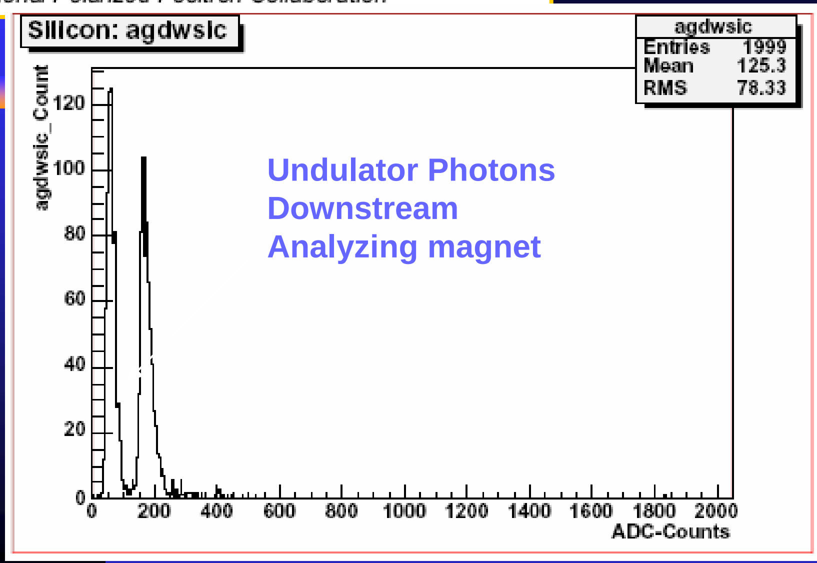
For signal from #22 $\simeq 600$ → this gives for the number of photons

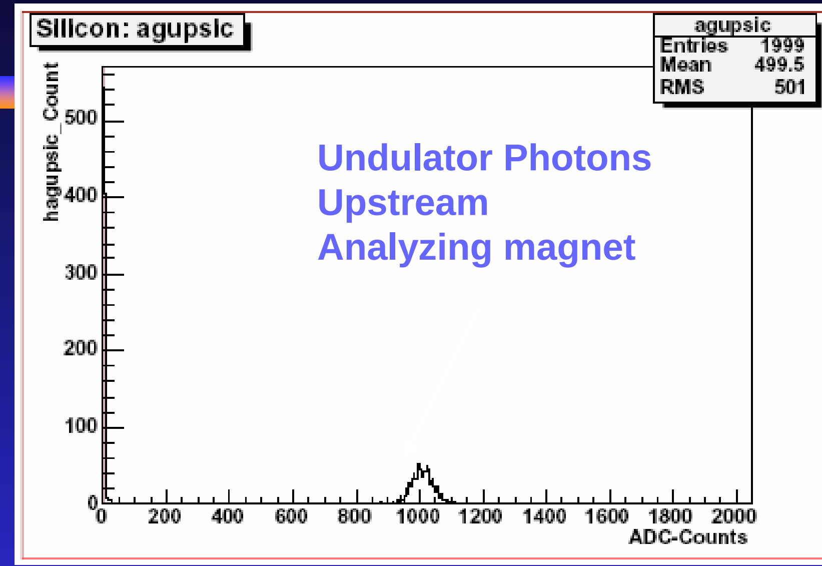
$$N_\gamma = 600 \times 10^{5/2} \times 5000 \simeq 600 \times 316 \times 5000 = 9.5 \cdot 10^{8} \simeq 10^{9}$$

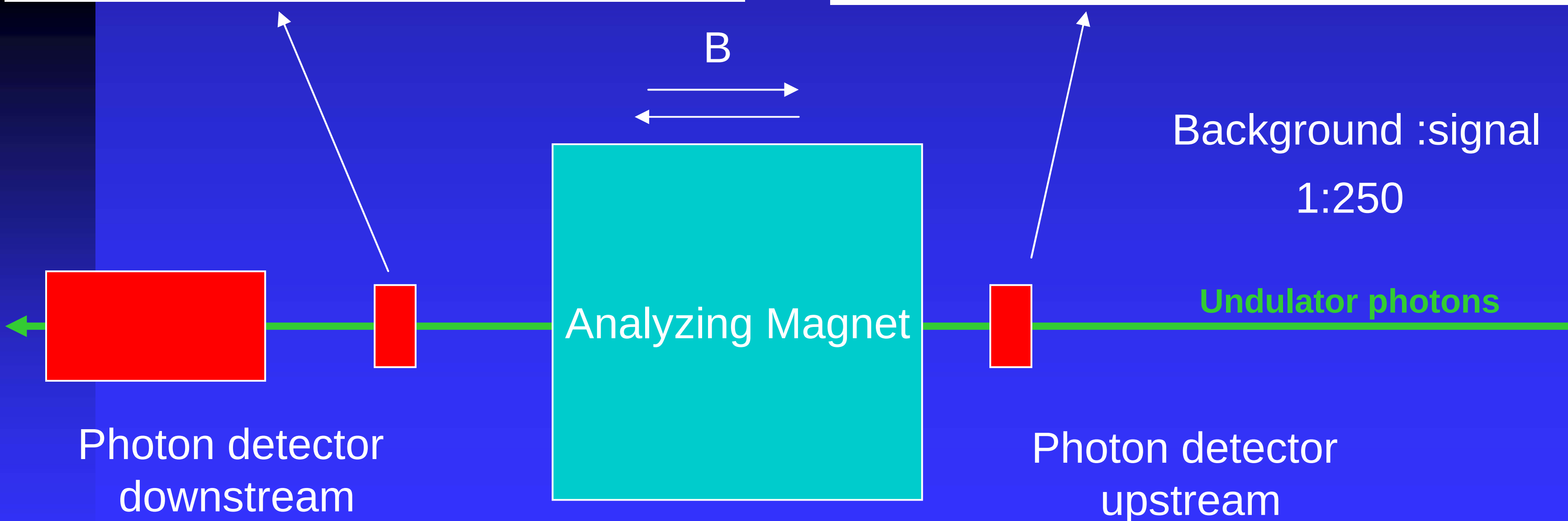
Amount of gammas agrees with K=0.17

Undulator photons









Background :signal

1:250

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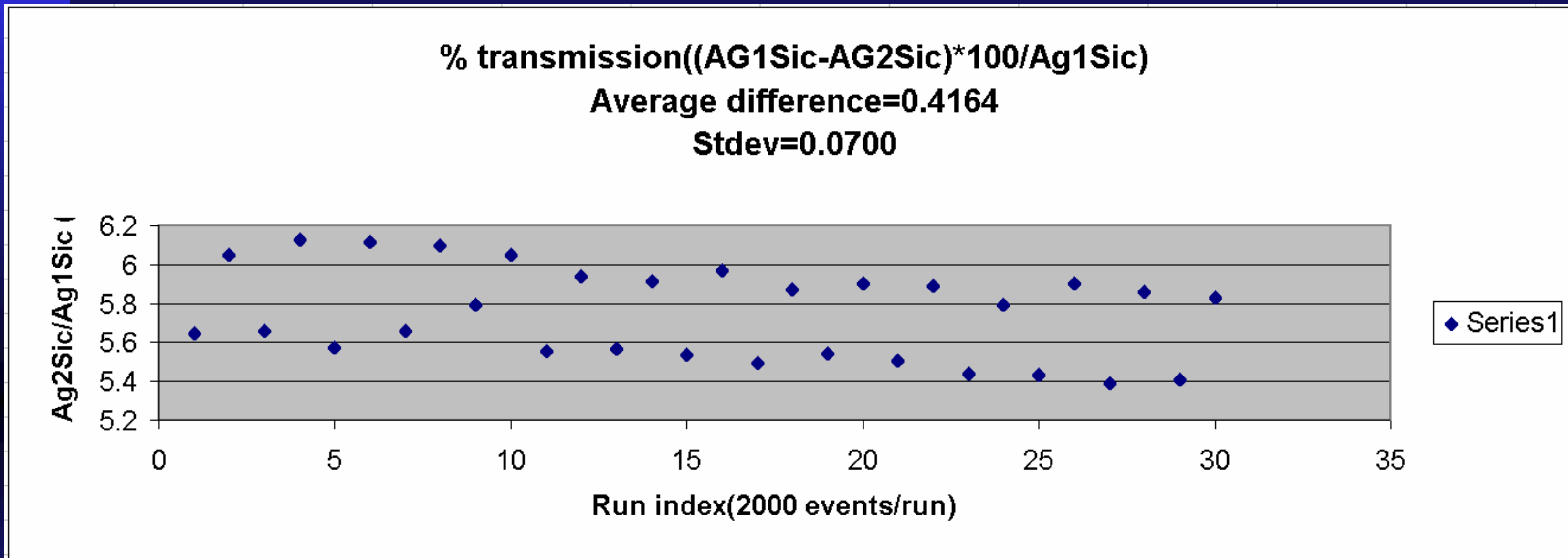
Photon asymmetry



Asymmetry=$(T^- - T^+)/(T^- + T^+)$

W.Bugg

Runs	1150-1160	1220-1248
Ag1sic, Ag2sic	3.57±0.029%	3.7±0.07%
Gcal	3.77±0.15 %	3.28±0.13%
Ag1,Ag2	4.31±0.47 %	2.66±0.3 %

g-Polarization (preliminary)

- For analyzing power A~62%
- d~3.57-4.31%
- P_e =7%

- x_2 =82-99.3 %±10-20%

50 GeV e⁻ E - 166 10 MeV γ
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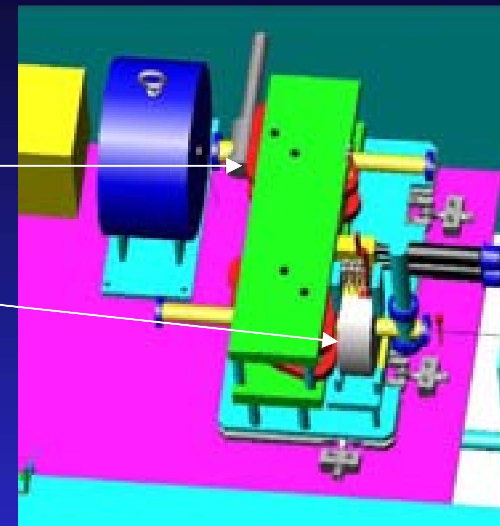
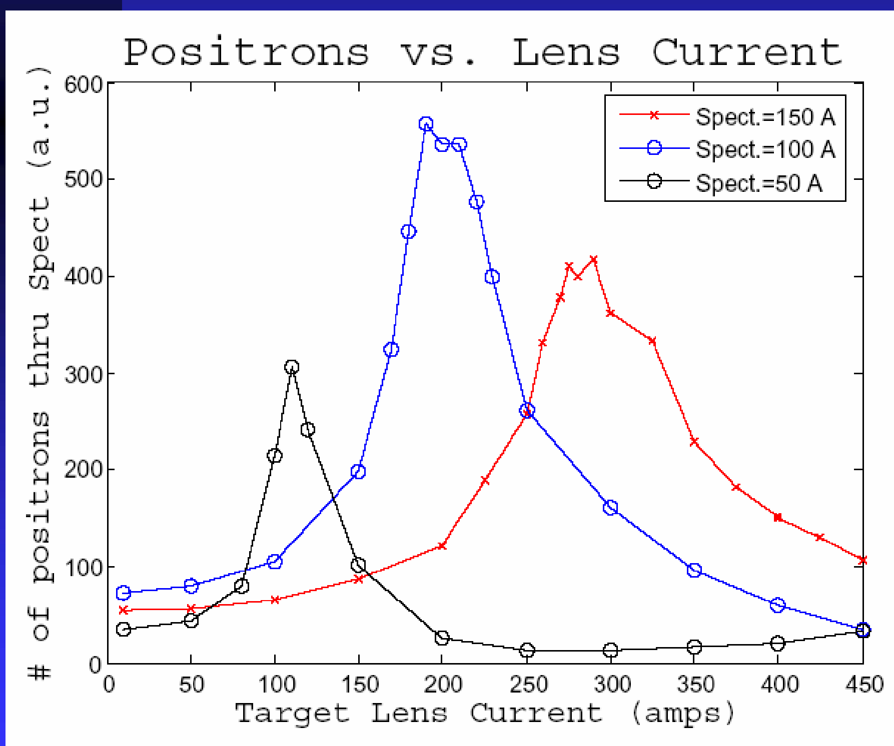
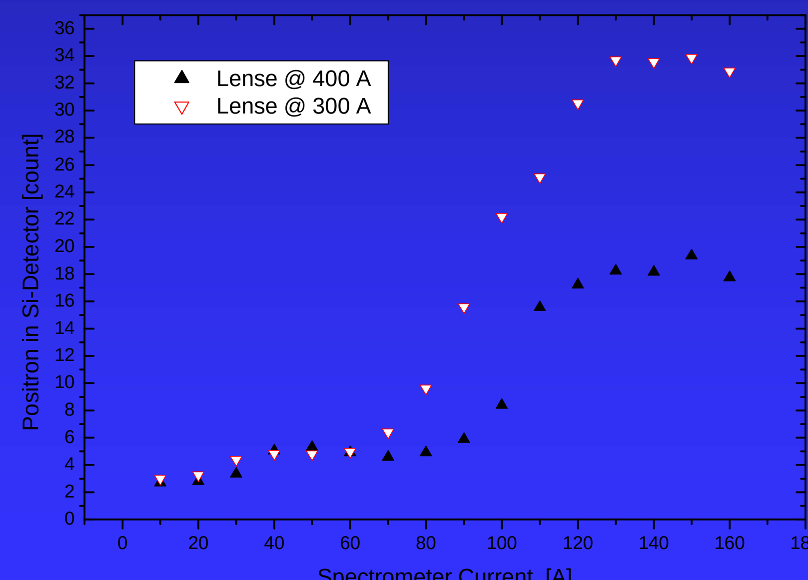
Positrons in spectrometer

Optimized current in magnet

Optimized current in lens







50 GeV e⁻ E - 166 10 MeV γ e⁺ e⁻

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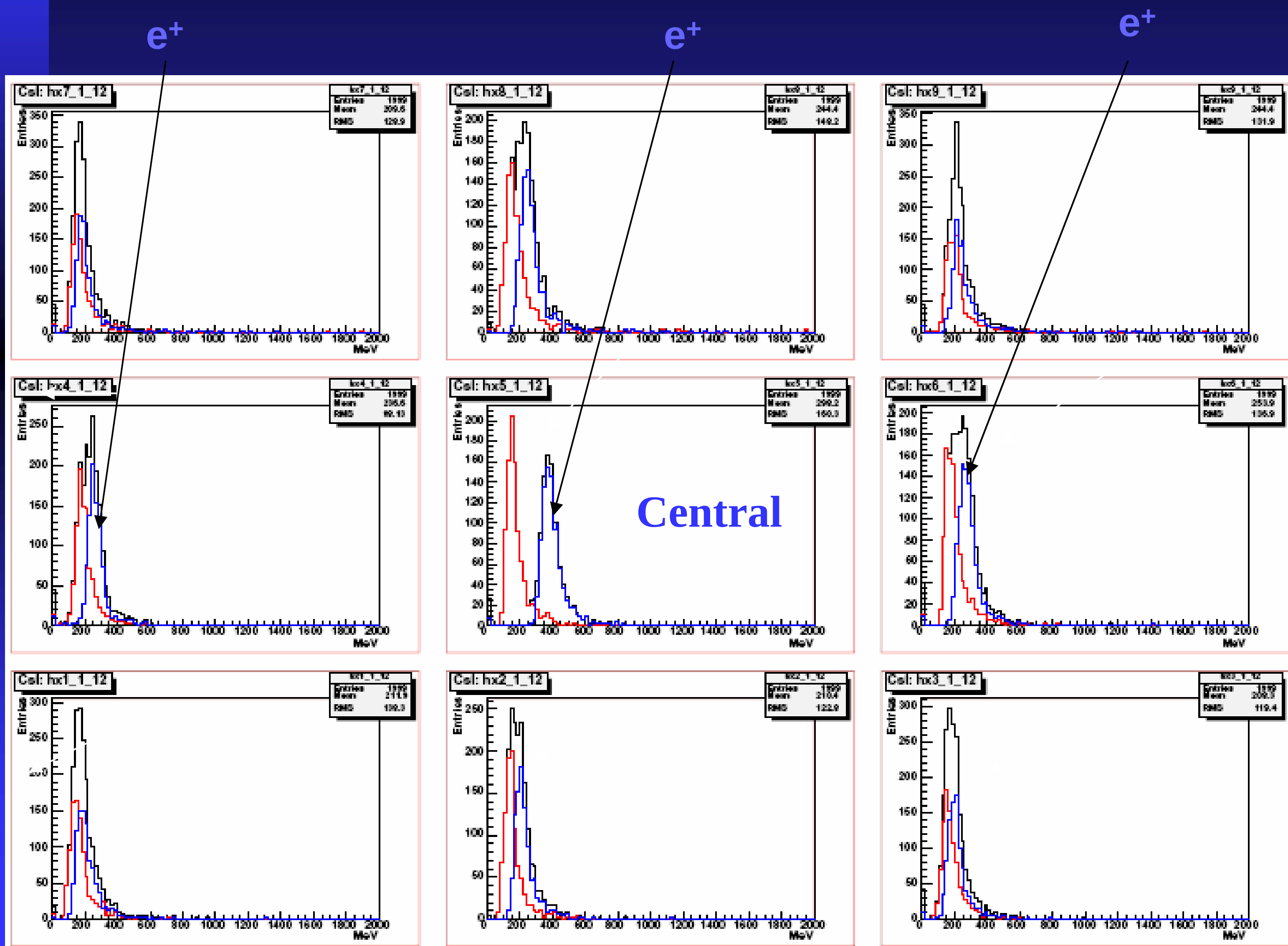
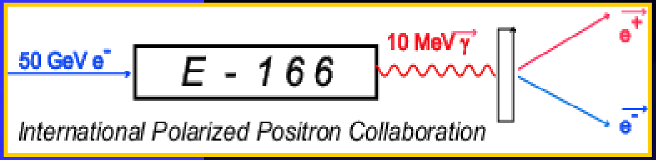
Positrons Signal in CsI(Tl) Calorimeter

Signals from 3x3 array

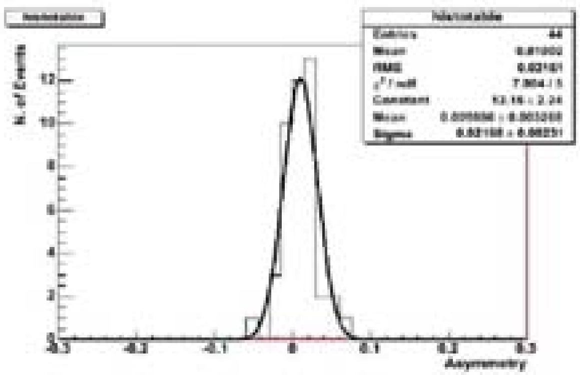




Positron asymmetry

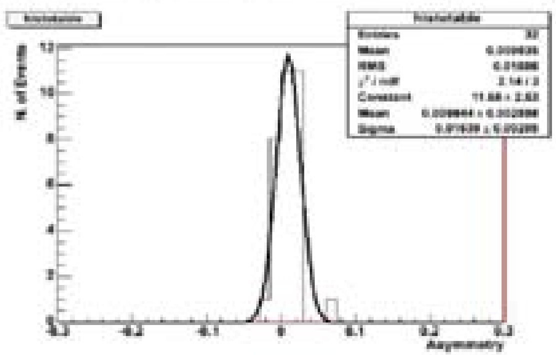
Positron asymmetry measured with maximal transmission through spectrometer

The asymmetry is calculated using the convention:
((-60)-(+60)) / ((-60)+(+60))
44 pairs:



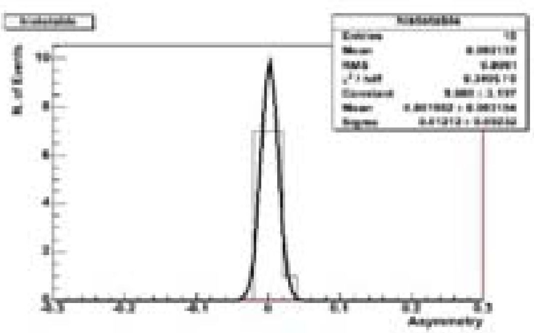
Asym = 0.0099 +/- (0.0032) from Fit
Asym = 0.0100 +/- (0.0033) from Mean Value

Only 32 pairs considered (the ones obtained with tungsten target).



Asym = 0.0098 +/- (0.0029) from Fit
Asym = 0.0098 +/- (0.0028) from Mean Value

For (+60) (15 pairs)



Asym = 0.0019 +/- (0.0031) from Fit
Asym = 0.0021 +/- (0.0024) from Mean Value

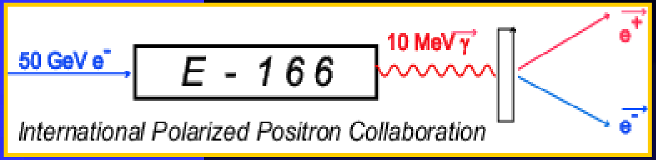
There is no asymmetry in the files with the same magnet polarity

R. Poeschl

Polarization (preliminary)

- For analyzing power A~15%
- d~1%
- P_e =7%

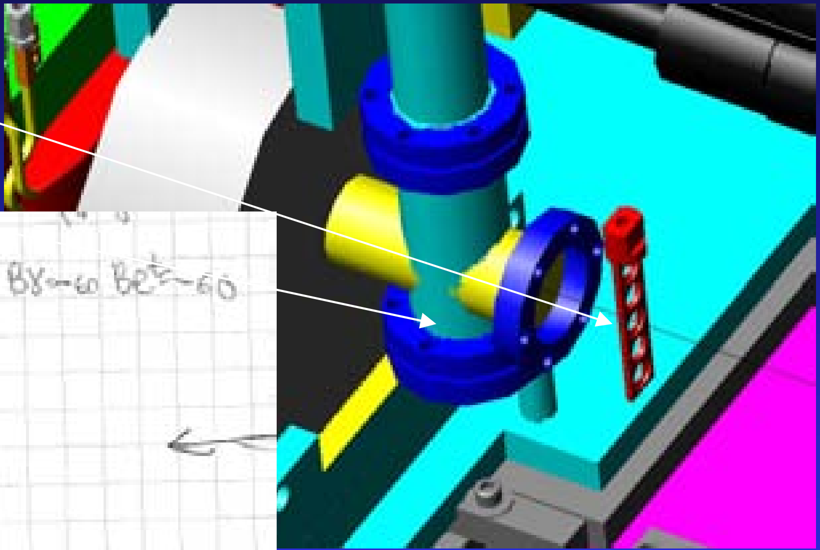
- z~100/(15*7)~0.95=95 %±30%
- Simulated -84%

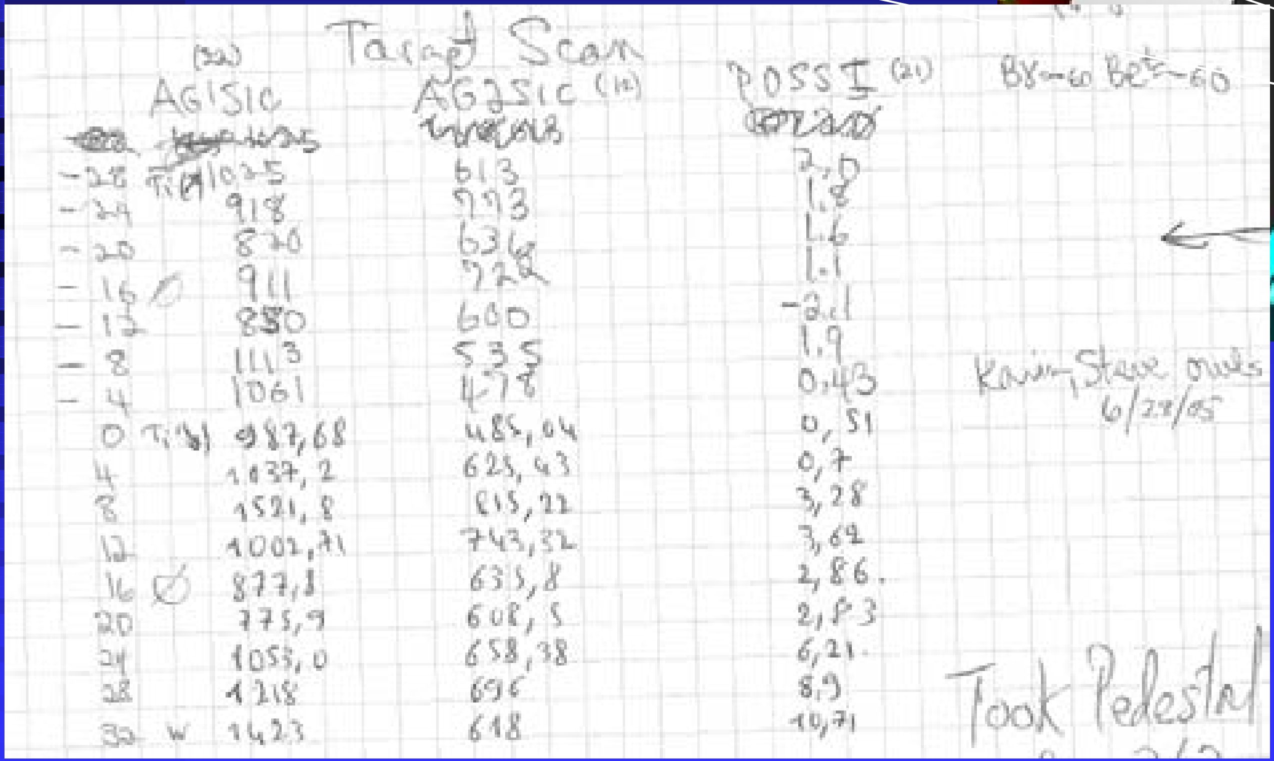


Target scan

Target holder has 5 slots

Located inside the chamber and can be moved remotely





Target Scan

	(32) AG1SIC	AG2SIC (11)	POSS I (21)
-28	Ti(a) 1025	613	2,0
-24	918	993	1,8
-20	870	636	1.6
-16 ∅	911	728	1.1
-12	850	600	-2.1
-8	1113	535	1.9
-4	1061	478	0,43
0 Ti(b)	987,68	485,04	0, 51
4	1037, 2	623, 43	0,7
8	1521, 8	815, 22	3, 28
12	1001,71	743,32	3,62
16 ∅	877,8	633,8	2,86
20	775,9	608, 5	2,83
24	1055, 0	658, 38	6,21
28	1218	696	8,9
32 W	1423	618	10,71

Bx~60 Bet~60

Karim, Steve ..., 6/28/05

Took Pedestal

W target gives ~45% higher yield, than Ti of the same thickness, $\sim 0.4X_0$

Conclusions

- First polarized positrons created from gammas generated in helical undulator
- Amount of gammas agrees with calculation
- Amount of positrons agrees with calculation
- Asymmetries measured for photon flux and for positrons well above background
- All components or prototypes work properly
- Background is controllable
- Some improvements done meanwhile (Faraday cup, table movers, extended set of targets, analyzing power re-check,...)
- Second run in September 2005 will finalize polarization measurements
- Very productive ILC collaboration working in practice!
- E-166 paved the road for ILC positron production system