Compton Polarimetry @ Bonn

Wolfgang Hillert

ELectron Stretcher Accelerator

Physics Institute of Bonn University

Why? → Polarised electrons @ ELSA: status and remaining problems

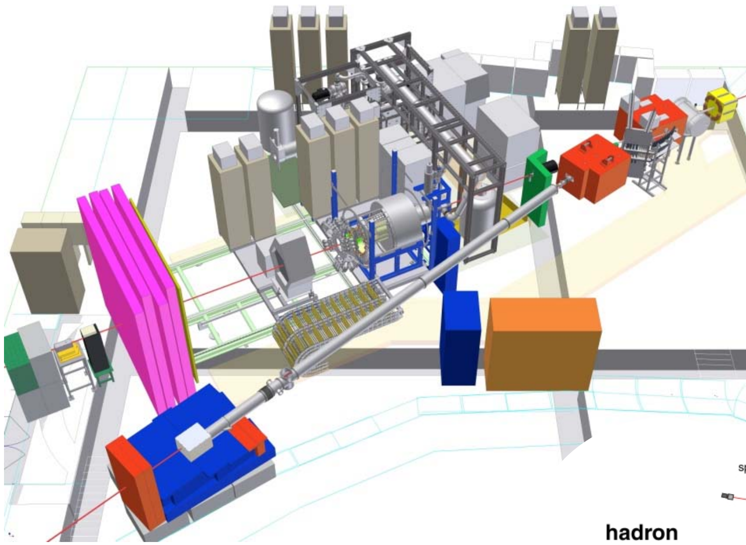
How? → Cpol @ ELSA: Numerical simulations and design criteria

Past → Ar^+ set-up: laser control, strip detector and first measurements

Future → 2-beam set-up and other improvements: expectations

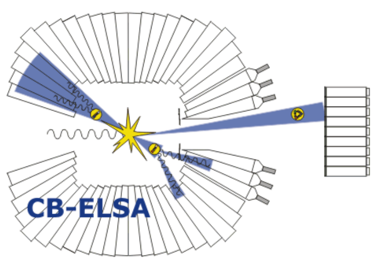
Why?

Double Polarisation Experiments



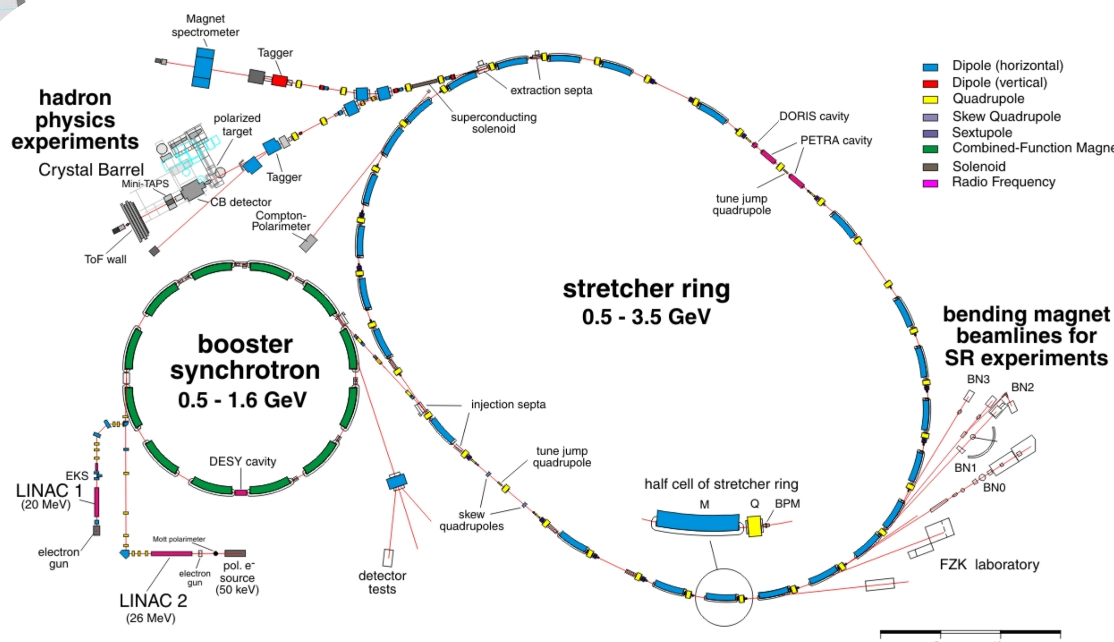
external
fixed target experiments
with
linearly and circularly polarised photons

SFB/TR

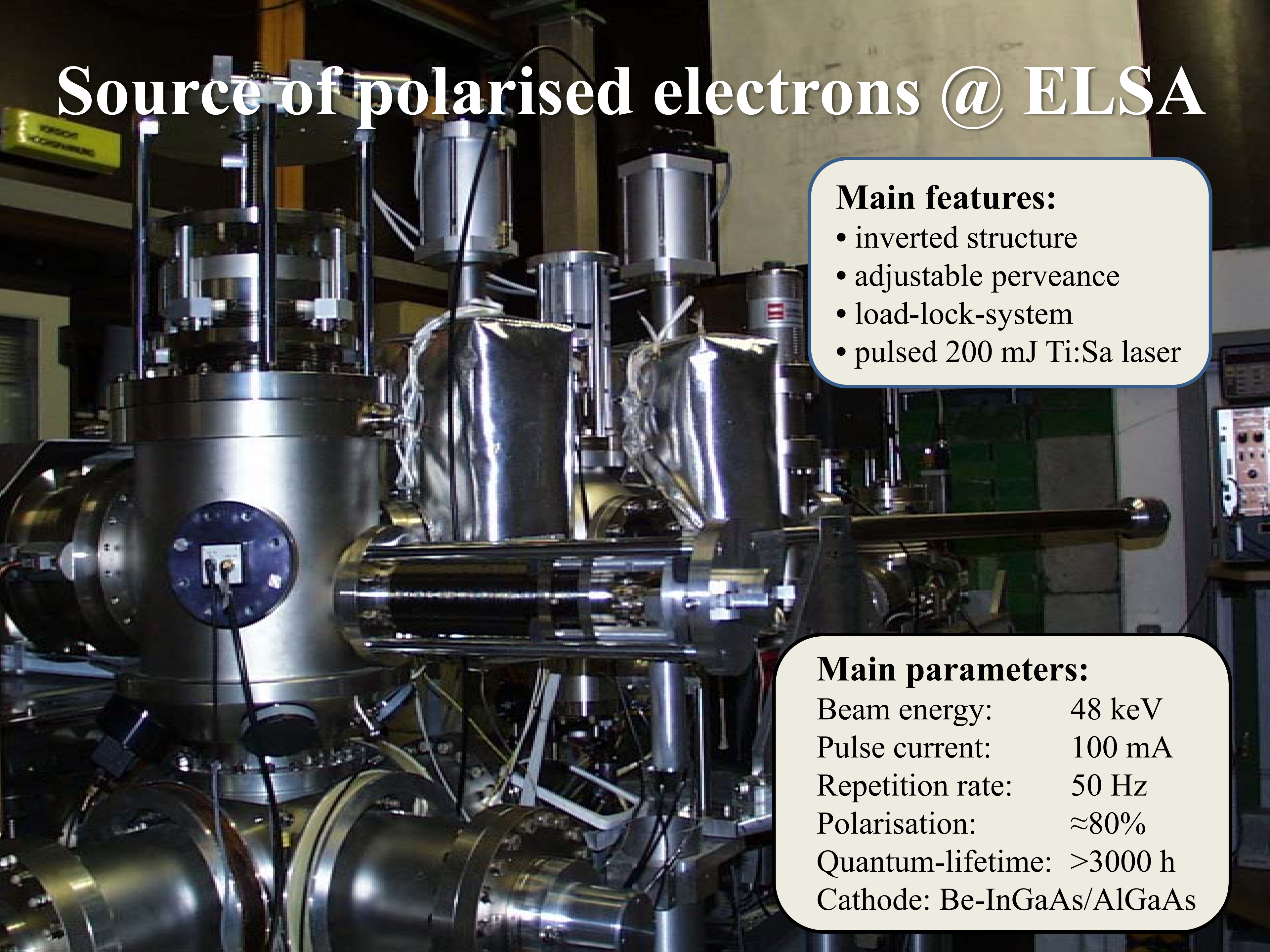


Crystal Barrel

BoFroST



Source of polarised electrons @ ELSA



Main features:

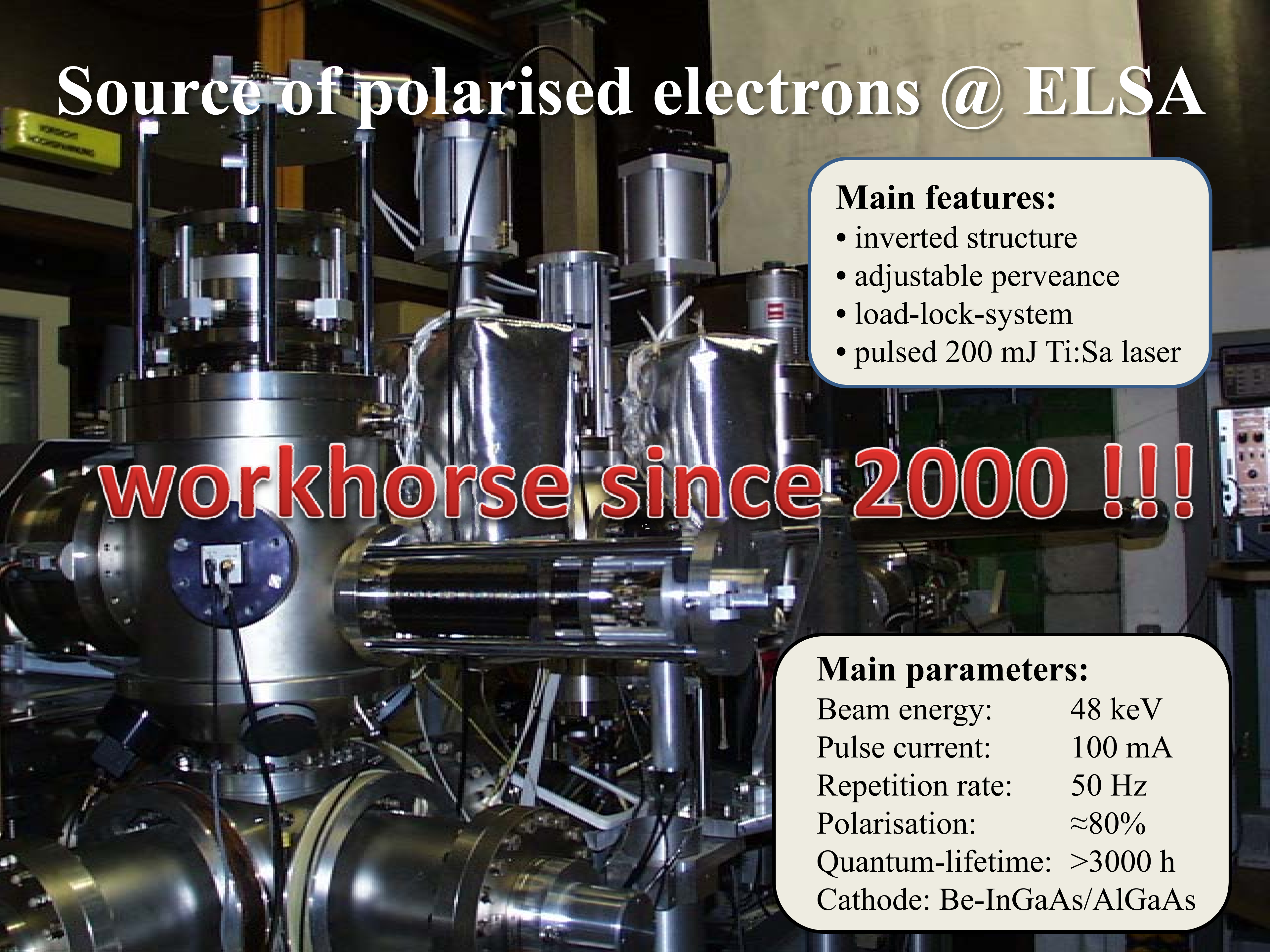
- inverted structure
- adjustable perveance
- load-lock-system
- pulsed 200 mJ Ti:Sa laser

Main parameters:

Beam energy:	48 keV
Pulse current:	100 mA
Repetition rate:	50 Hz
Polarisation:	≈80%
Quantum-lifetime:	>3000 h

Cathode: Be-InGaAs/AlGaAs

Source of polarised electrons @ ELSA



Main features:
- inverted structure
- adjustable perveance
- load-lock-system
- pulsed 200 mJ Ti:Sa laser

workhorse since 2000 !!!

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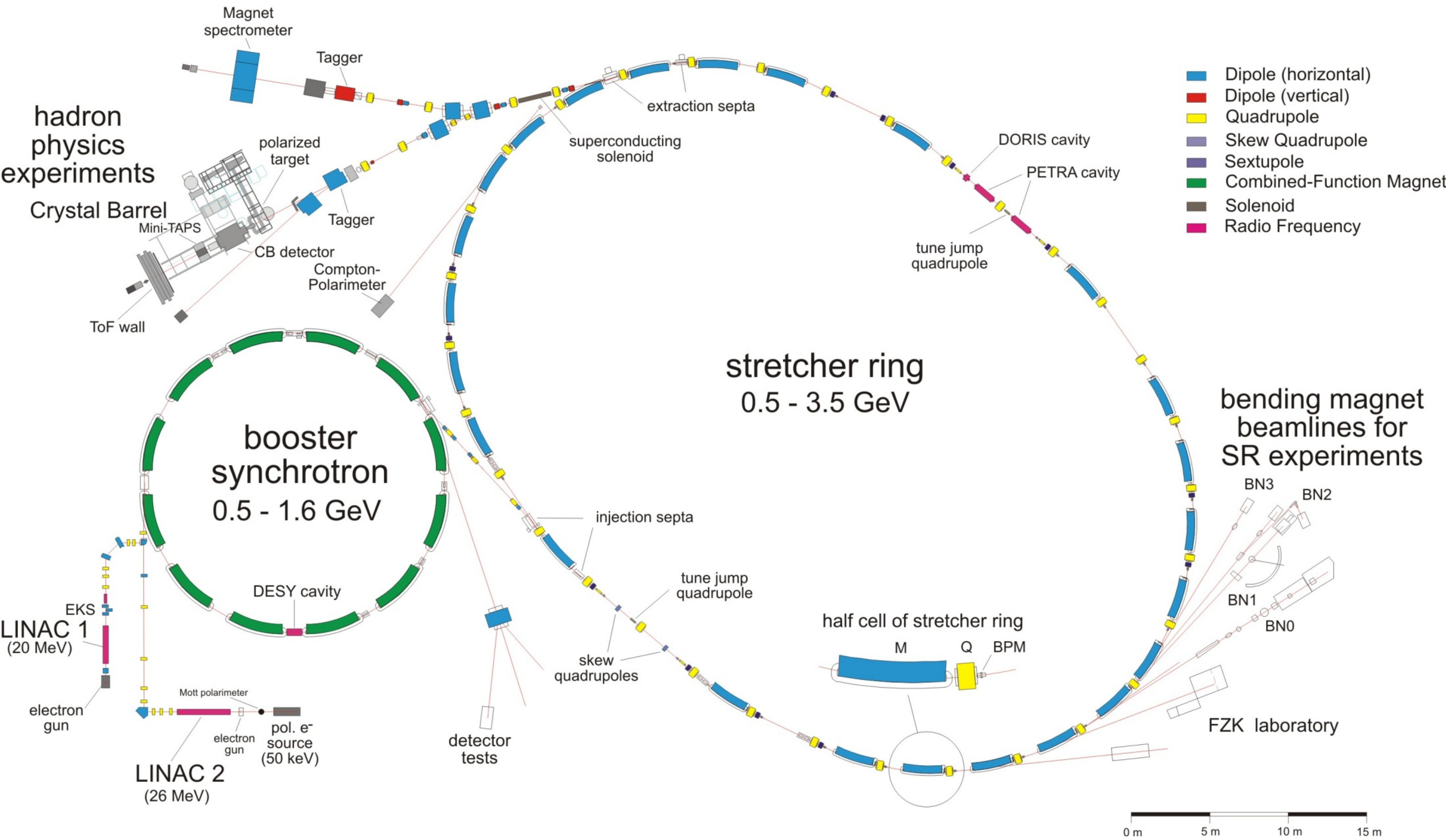
Electron Stretcher Accelerator (ELSA)



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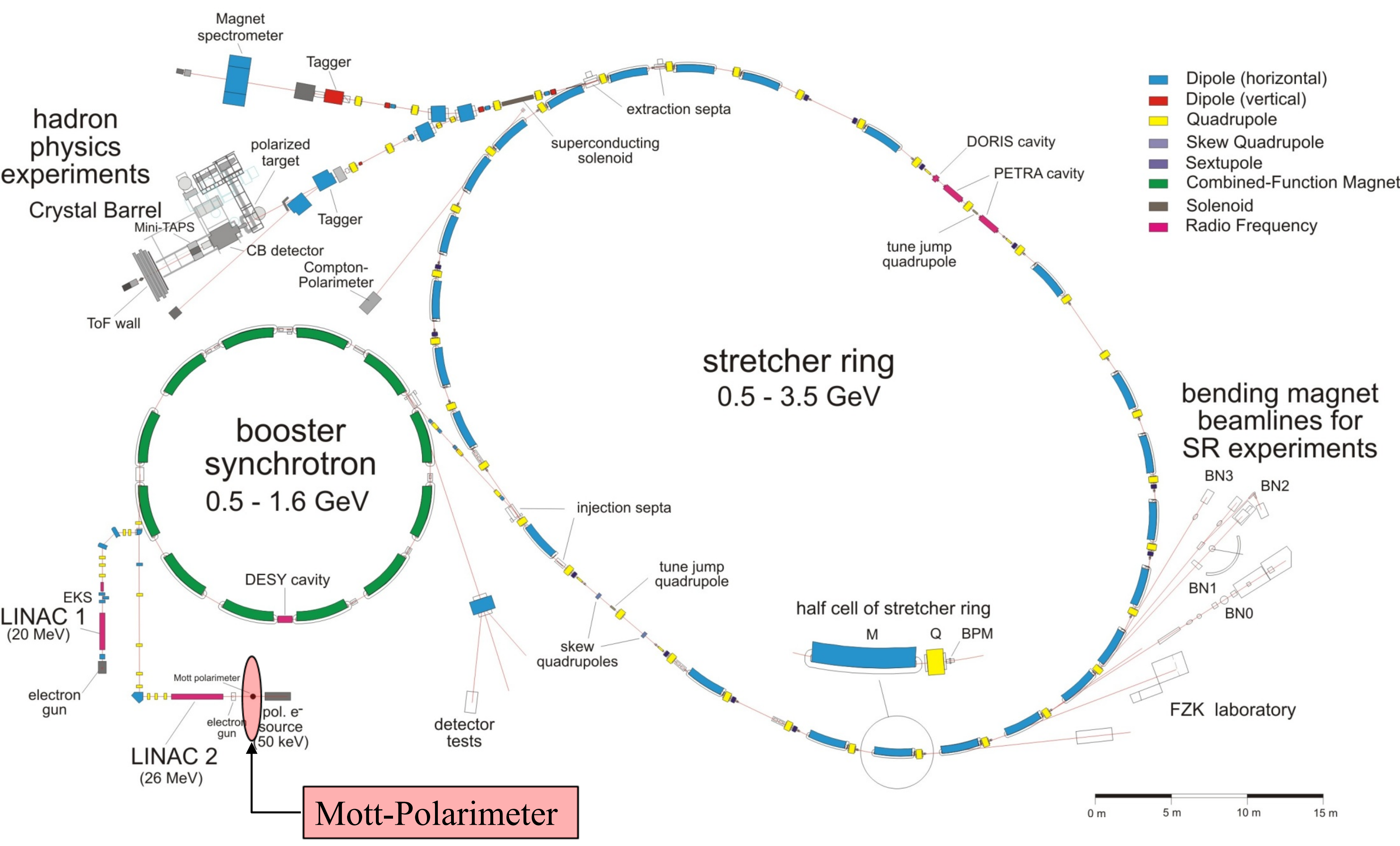

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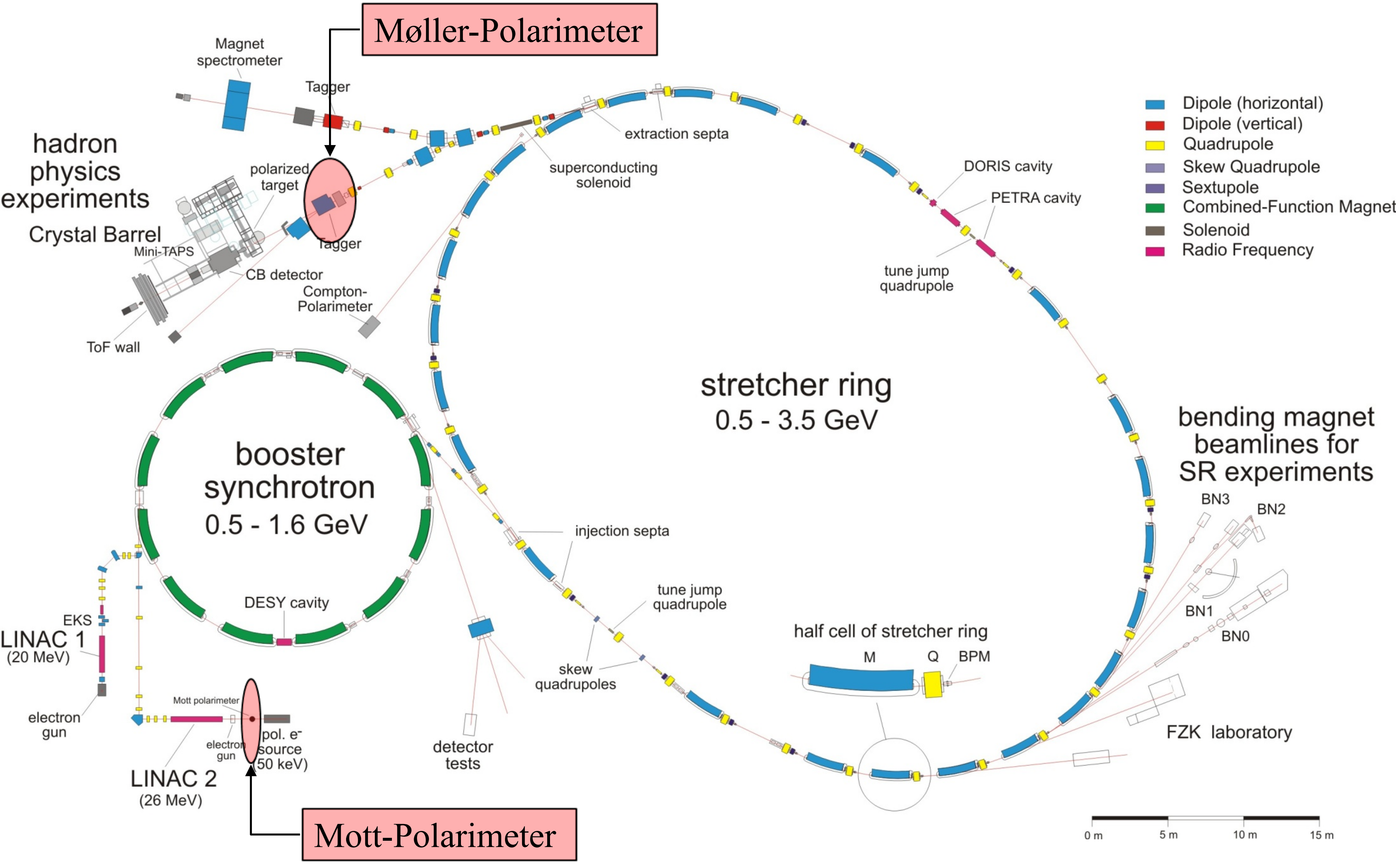

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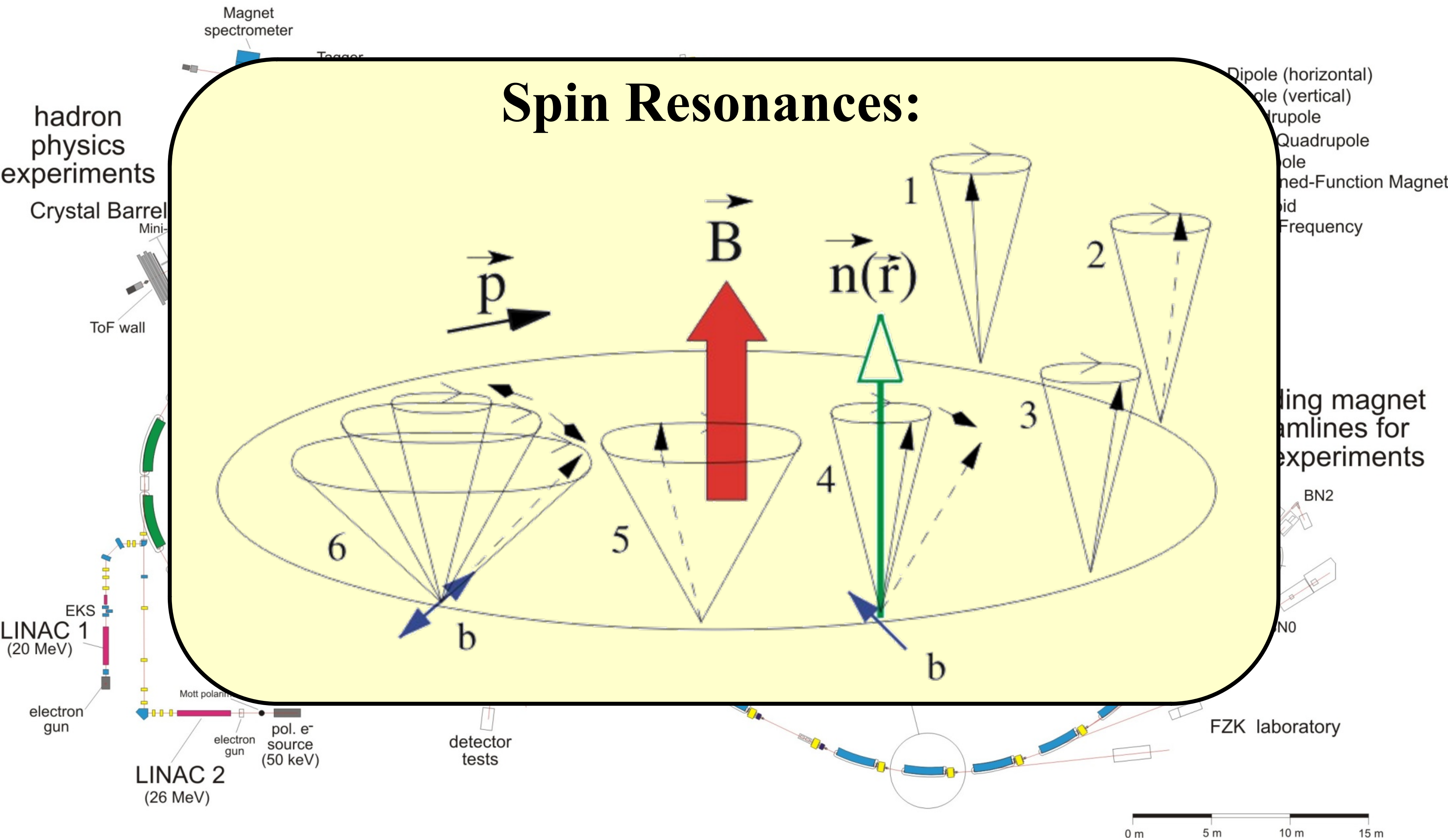

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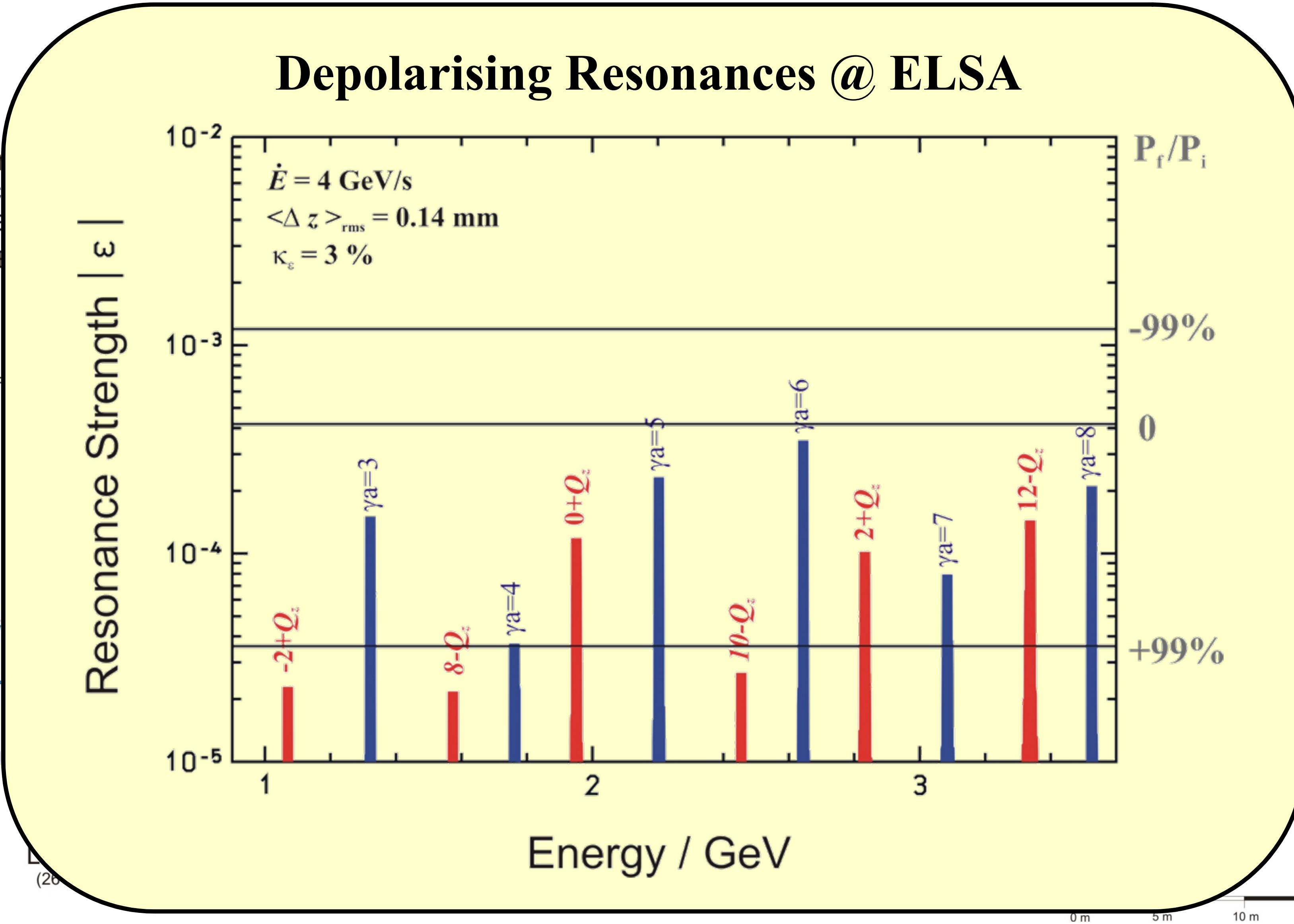

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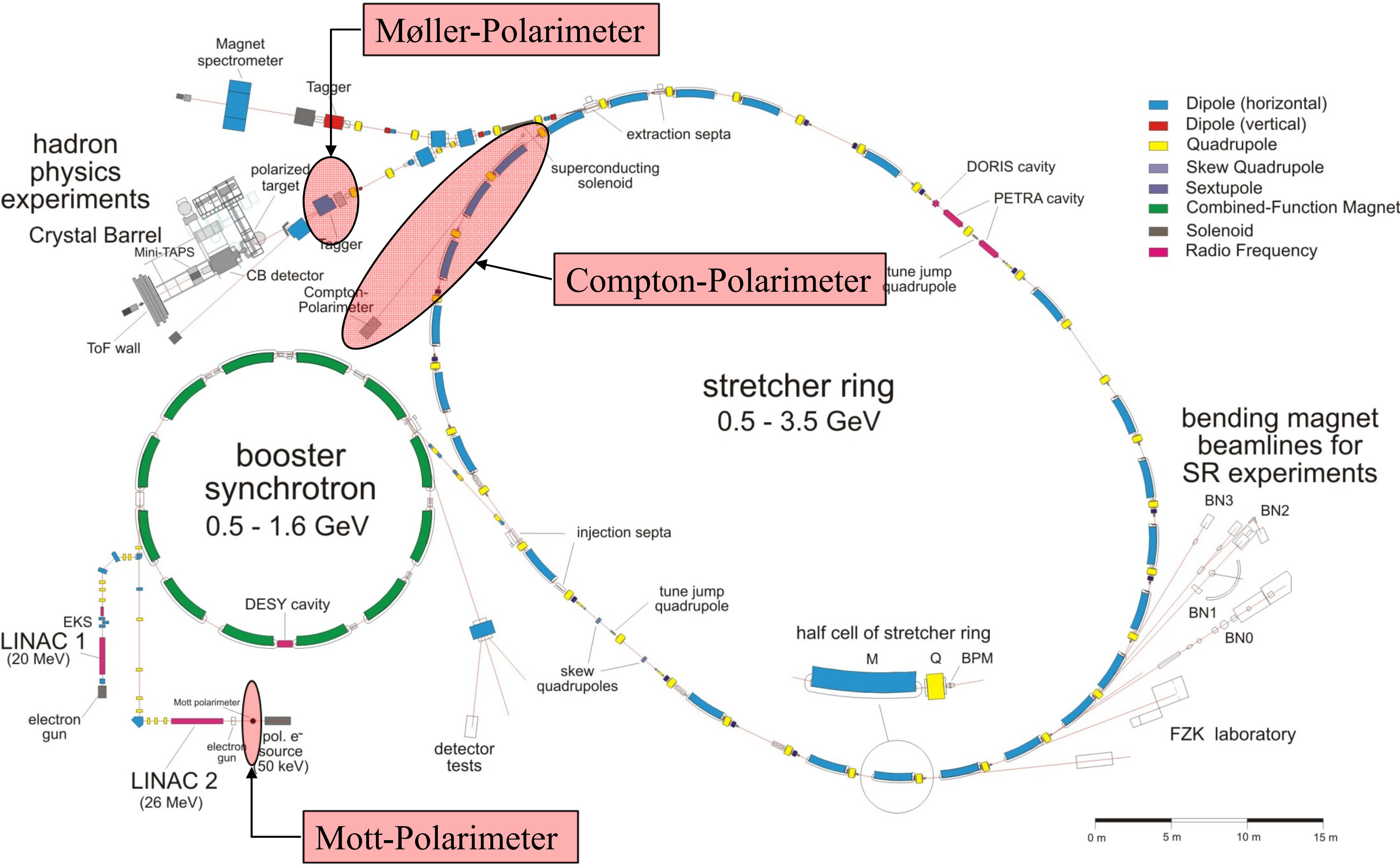
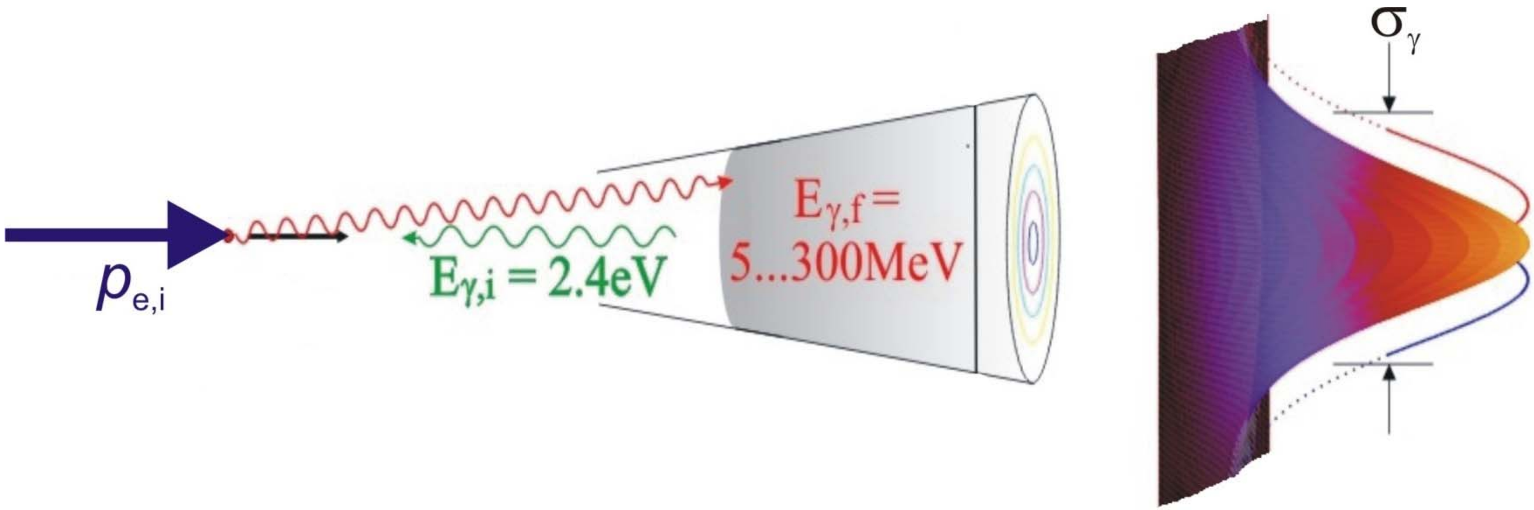


How?

Compton Scattering



Differential cross section:

$$\frac{d\sigma}{d\Omega^*}\left(\vec{S},\vec{P}\right) = \Sigma_0 + \Sigma_1\left(S_1\right) + \Sigma_2\left(S_3,\vec{P}\right)$$

Compton kinematics:

$$K_f^* = \frac{K_i^*}{1 + K_i^* \cdot \left(1-\cos\vartheta^*\right)}$$

Polarised electrons:

$$\Sigma_2\left(S_3,\vec{P}\right) = -S_3 P_z \cdot \underbrace{C K_f^* \sin\vartheta^* \left(1-\cos\vartheta^*\right)\sin\varphi^*}_{\Sigma_{2Z}} - S_3 P_s \cdot \underbrace{C K_f^* \left(1-\cos\vartheta^*\right)\left(K_f^* + K_i^*\right)\cos\vartheta^*}_{\Sigma_{2S}}$$

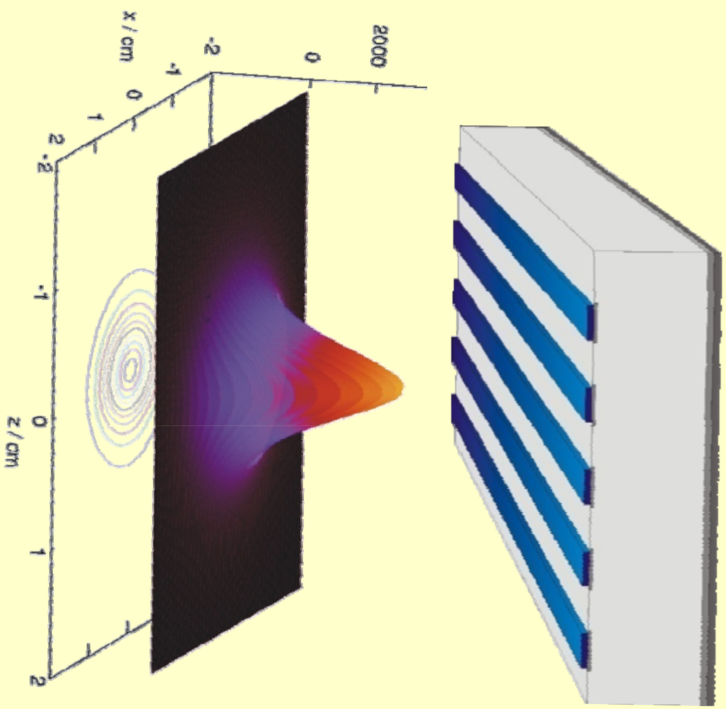
$$C = \frac{r_e^2}{2}\cdot\left(\frac{K_f^*}{K_i^*}\right)^2$$

spatial asymmetry

counting rate asymmetry

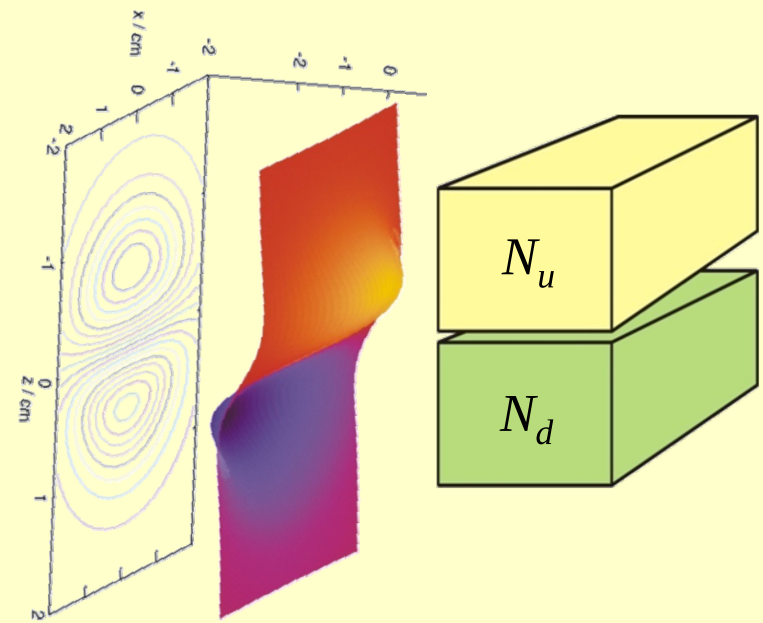
Measuring Principle

shift of the center of the photon spatial distribution



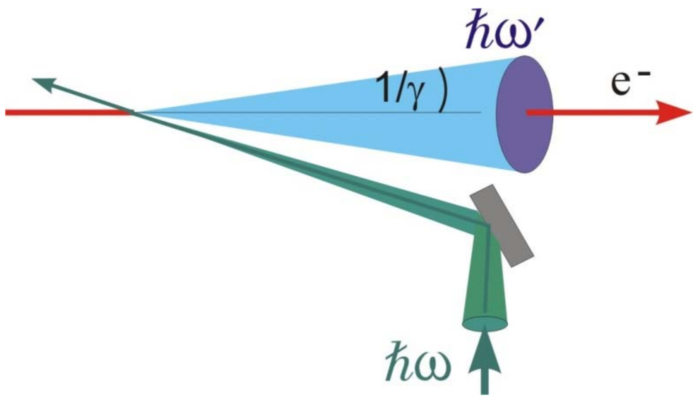
silicon strip detector and
pair conversion required:
rather complicated

integral up-down counting rate asymmetry



at least 2 crystal detectors and
no conversion required:
rather simple

Design Criteria

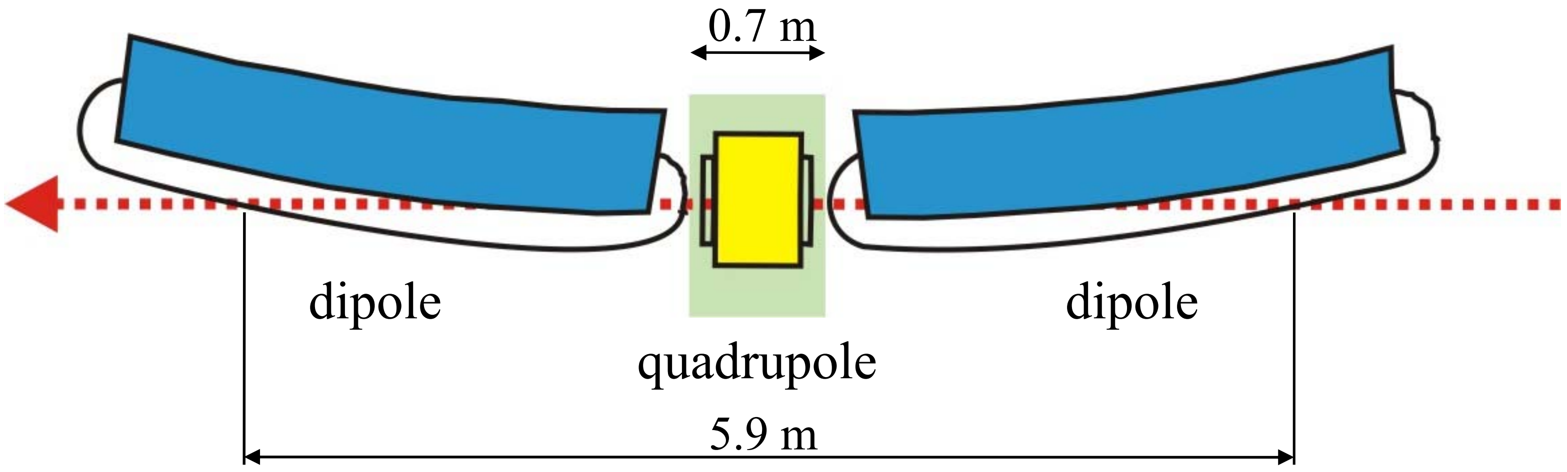


Basic Parameters:

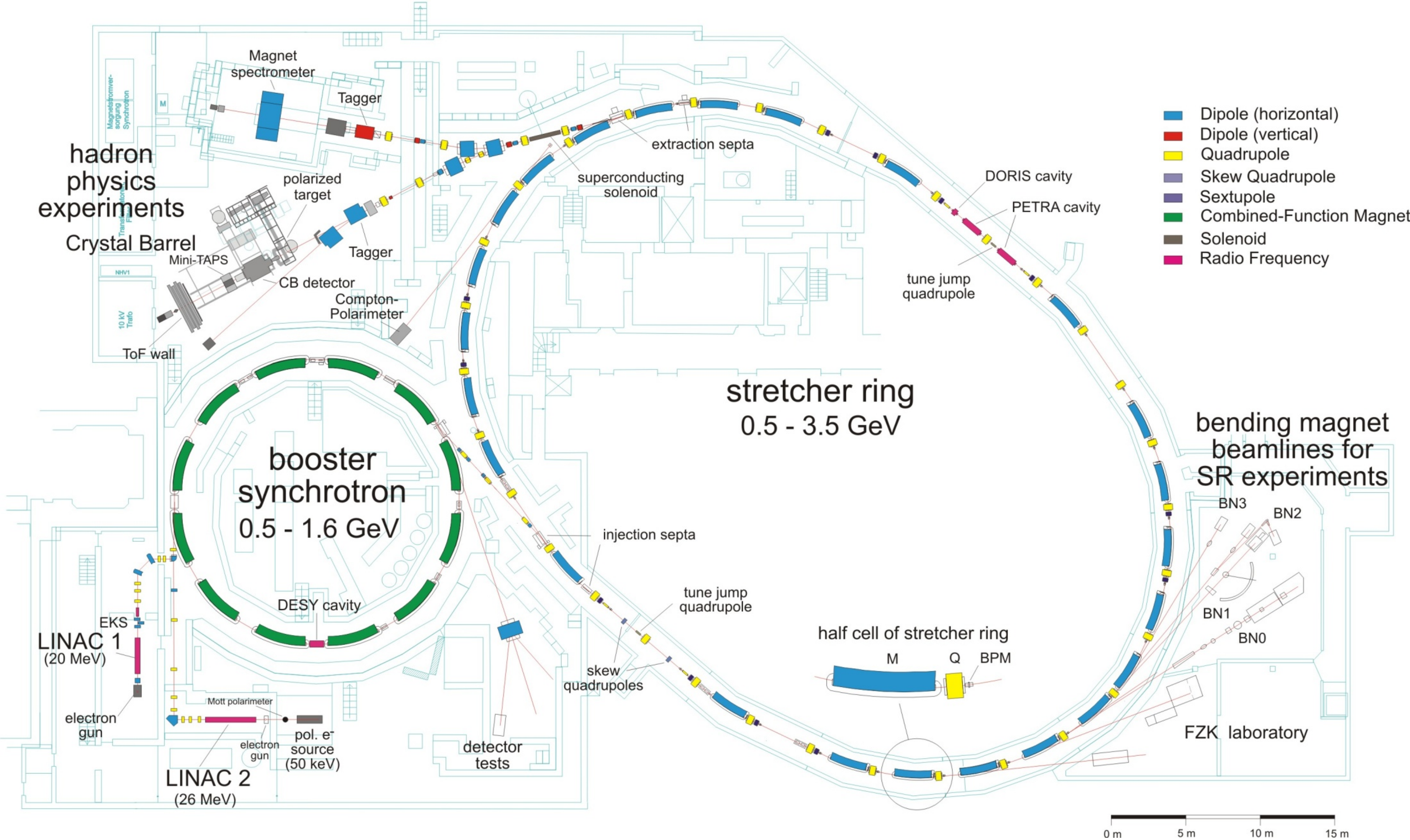
- crossing angle: $\delta \approx 3\text{mrad}$
- electron beam width: $\sigma \approx 1\text{mm}$
- ➢ interaction region: $l \approx 0.7\text{m}$

Background due to Beam-Gas Radiation:

➢ straight section should be considerably short!



Electron Stretcher Accelerator (ELSA)



Numerical Simulations

1. **Ideal beams ($\sigma_x = \sigma_z = 0$) and infinite detector (simple):**

– **integral asymmetry**:

$$A_{\text{int}} = \frac{\sqrt{N_u^+ N_d^-} - \sqrt{N_u^- N_d^+}}{\sqrt{N_u^+ N_d^-} + \sqrt{N_u^- N_d^+}} = \frac{\int_0^{2\pi} d\varphi^* \int_0^{\pi} \sin\vartheta^* d\vartheta^* \cdot \Sigma_{2Z}}{\int_0^{2\pi} d\varphi^* \int_0^{\pi} \sin\vartheta^* d\vartheta^* \cdot \Sigma_0} \cdot P_\gamma \cdot P_e$$

– **shift of center of spatial distribution**:

$$\Delta\overline{z} = \overline{z}_+ - \overline{z}_- = \frac{\int_0^{2\pi} d\varphi^* \int_0^{\pi} \sin\vartheta^* d\vartheta^* \cdot z(\vartheta^*, \varphi^*) \cdot \Sigma_{2Z}}{\int_0^{2\pi} d\varphi^* \int_0^{\pi} \sin\vartheta^* d\vartheta^* \cdot \Sigma_0} \cdot P_\gamma \cdot P_e$$

(with $z(\vartheta^*, \varphi^*) = \frac{D}{\gamma} \cdot \frac{\sin\vartheta^* \left(\beta - \cos\vartheta^*\right)}{\left(1 - \beta\cos\vartheta^*\right)^2} \cos\varphi^*$)

1-dim integration:

Numerical Simulations

2. **Ideal beams (σ_x=σ_z=0) and finite detector (moderate):**

– **integral asymmetry:**

$$A_{\text{int}} = \frac{\int_{-X_{\det}/2}^{X_{\det}/2} dx \int_{0}^{Z_{det}/2} dz \cdot \frac{\partial(\vartheta^*,\varphi^*)}{\partial(x,z)} \cdot \Sigma_{2Z}\left(\vartheta^*(x,z),\varphi^*(x,z)\right)}{\int_{-X_{\det}/2}^{X_{\det}/2} dx \int_{0}^{Z_{det}/2} dz \cdot \frac{\partial(\vartheta^*,\varphi^*)}{\partial(x,z)} \cdot \Sigma_{0}\left(\vartheta^*(x,z),\varphi^*(x,z)\right)} \cdot P_\gamma \cdot P_e$$

– **shift of center of spatial distribution:**

$$\Delta\overline{z} = \frac{\int_{-X_{\det}/2}^{X_{\det}/2} dx \int_{-Z_{det}/2}^{Z_{det}/2} dz \cdot \frac{\partial(\vartheta^*,\varphi^*)}{\partial(x,z)} \cdot z \cdot \Sigma_{2Z}\left(\vartheta^*(x,z),\varphi^*(x,z)\right)}{\int_{-X_{\det}/2}^{X_{\det}/2} dx \int_{0}^{Z_{det}/2} dz \cdot \frac{\partial(\vartheta^*,\varphi^*)}{\partial(x,z)} \cdot \Sigma_{0}\left(\vartheta^*(x,z),\varphi^*(x,z)\right)} \cdot P_\gamma \cdot P_e$$

(with: $\frac{\partial\left(\vartheta^*,\varphi^*\right)}{\partial\left(x,z\right)} = \left(\frac{\gamma}{D}\right)^2 \cdot \frac{\left(1-\beta\cos\vartheta^*\right)^3}{\beta-\cos\vartheta^*}$)

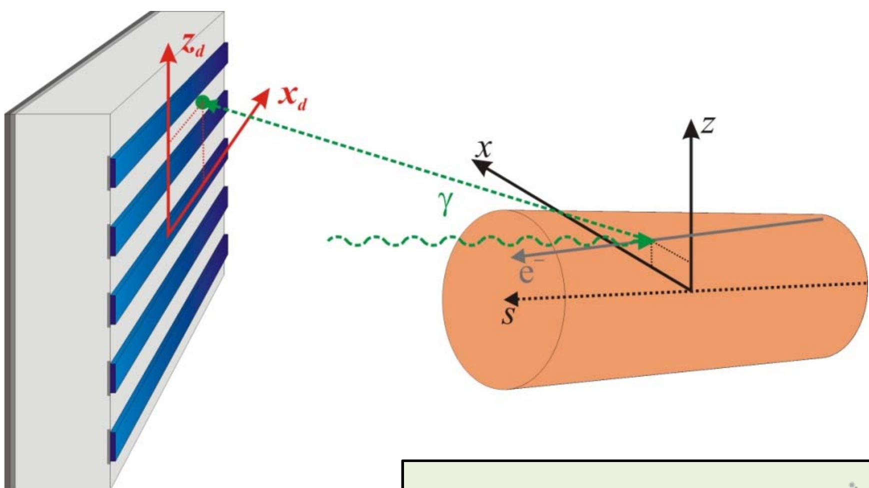
2-dim integration:

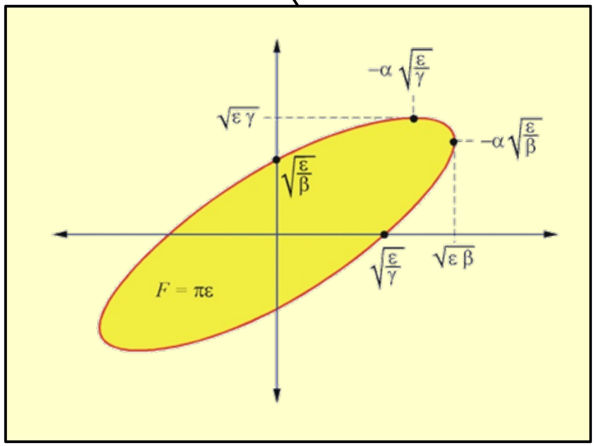
Numerical Simulations

3. Real beams ($\sigma_x, \sigma_z, \sigma_{x'}, \sigma_{z'} \neq 0$) and finite detector (!!!):

a) 2-D intensity profile of backscattered photons:

$$\dot{N}(x_d, z_d) = \int_{S_0}^{S_1} ds \int_{Z_{\min}}^{Z_{\max}} dz \int_{X_{\min}}^{X_{\max}} dx \int_{Z'_{\min}}^{Z'_{\max}} dz' \int_{X'_{\min}}^{X'_{\max}} dx' \, \frac{\partial(\vartheta^*, \varphi^*)}{\partial(x, z)} \cdot \rho_e(s, x, z, x', z') \cdot \rho_\gamma(s, x, z) \cdot \frac{d\sigma}{d\Omega^*}$$





5-dim integration:

Numerical Simulations

3. Real beams ($\sigma_x, \sigma_z, \sigma_{x'}, \sigma_{z'} \neq 0$) and finite detector (!!!):

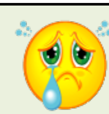
b) Asymmetry and shift from mean values:

- integral asymmetry:

$$\left.\begin{aligned} \dot{N}_u^{+,-} &= \sum_{i,j}^{\forall z_j \geq 0} \dot{N}^{+,-}(x_i, z_j) \\ \dot{N}_d^{+,-} &= \sum_{i,j}^{\forall z_j \leq 0} \dot{N}^{+,-}(x_i, z_j) \end{aligned}\right\} \quad A_{\text{int}} = \frac{\sqrt{\dot{N}_u^+ \dot{N}_d^-} - \sqrt{\dot{N}_u^- \dot{N}_d^+}}{\sqrt{\dot{N}_u^+ \dot{N}_d^-} + \sqrt{\dot{N}_u^- \dot{N}_d^+}}$$

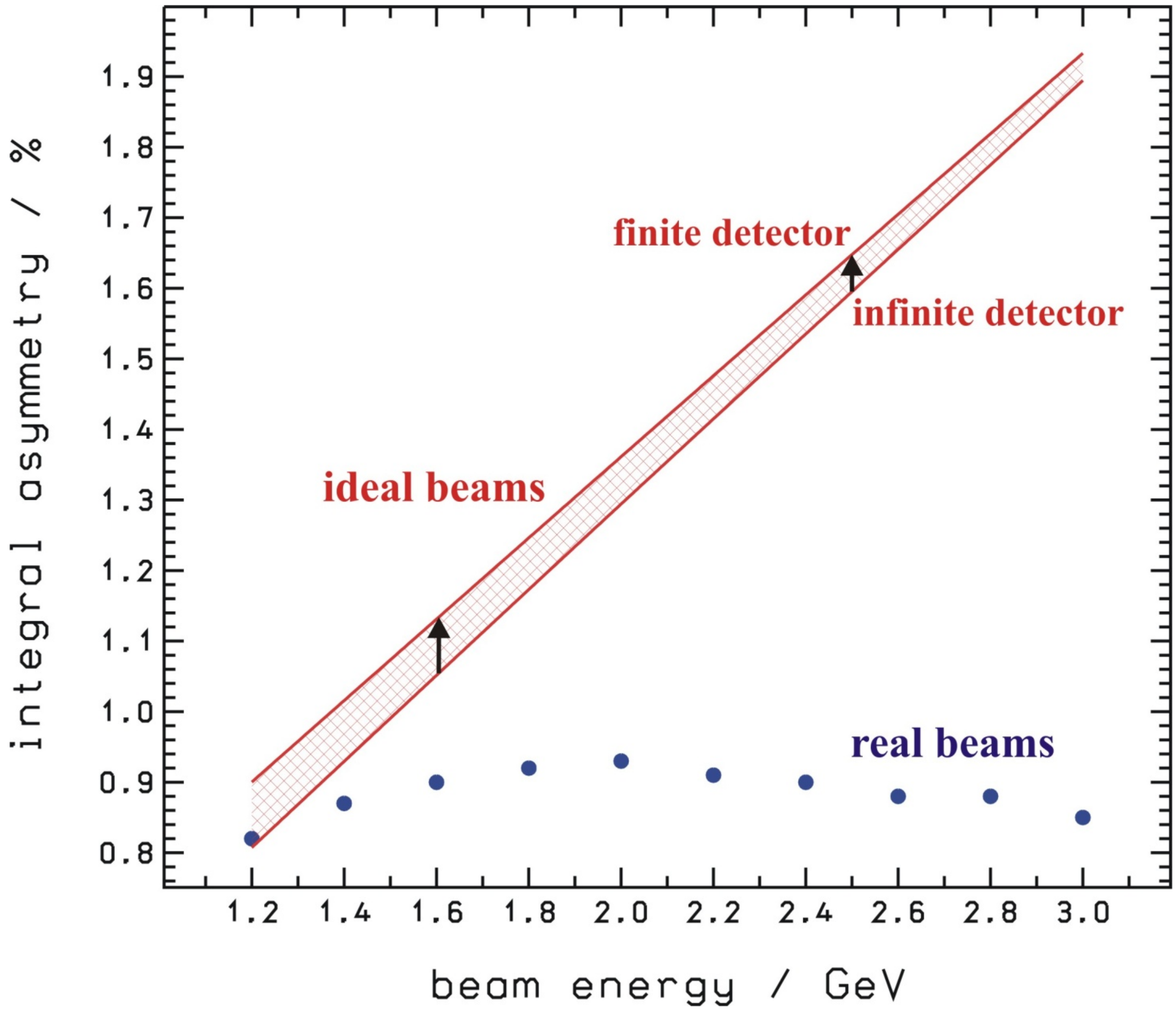
- shift of center of spatial distribution:

$$\Delta \bar{z} = \sum_{i,j} z_j \dot{N}^+(x_i, z_j) - \sum_{i,j} z_j \dot{N}^-(x_i, z_j)$$

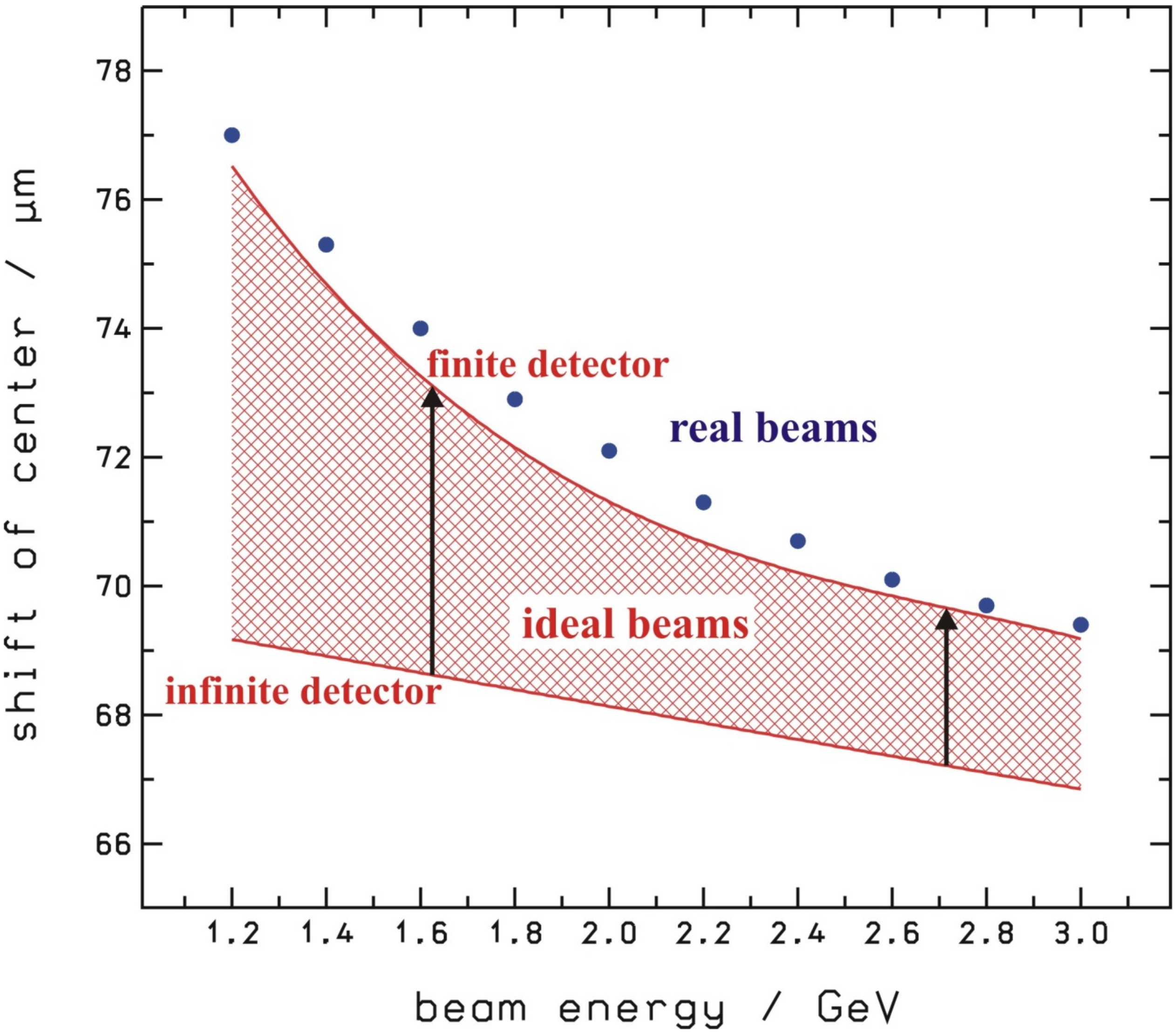
#15744 5-dim integrations: 

5-dim integration for each point:
- detector size = 4.0 x 3.84 cm^2
- detector pitch = 100µm
- ➢ in total 41 x 384 points

Counting Rate Asymmetry

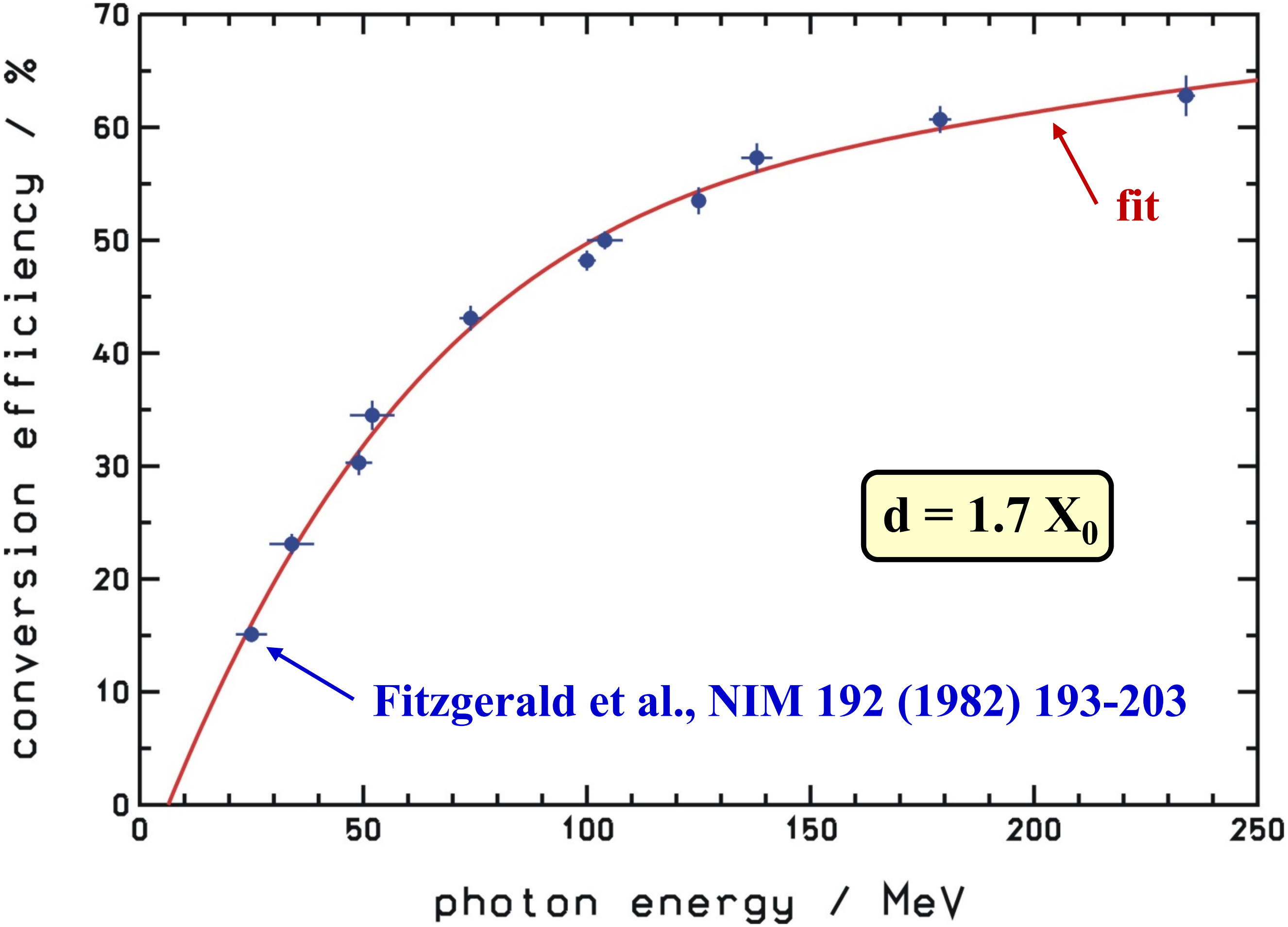


Shift of Spatial Distribution

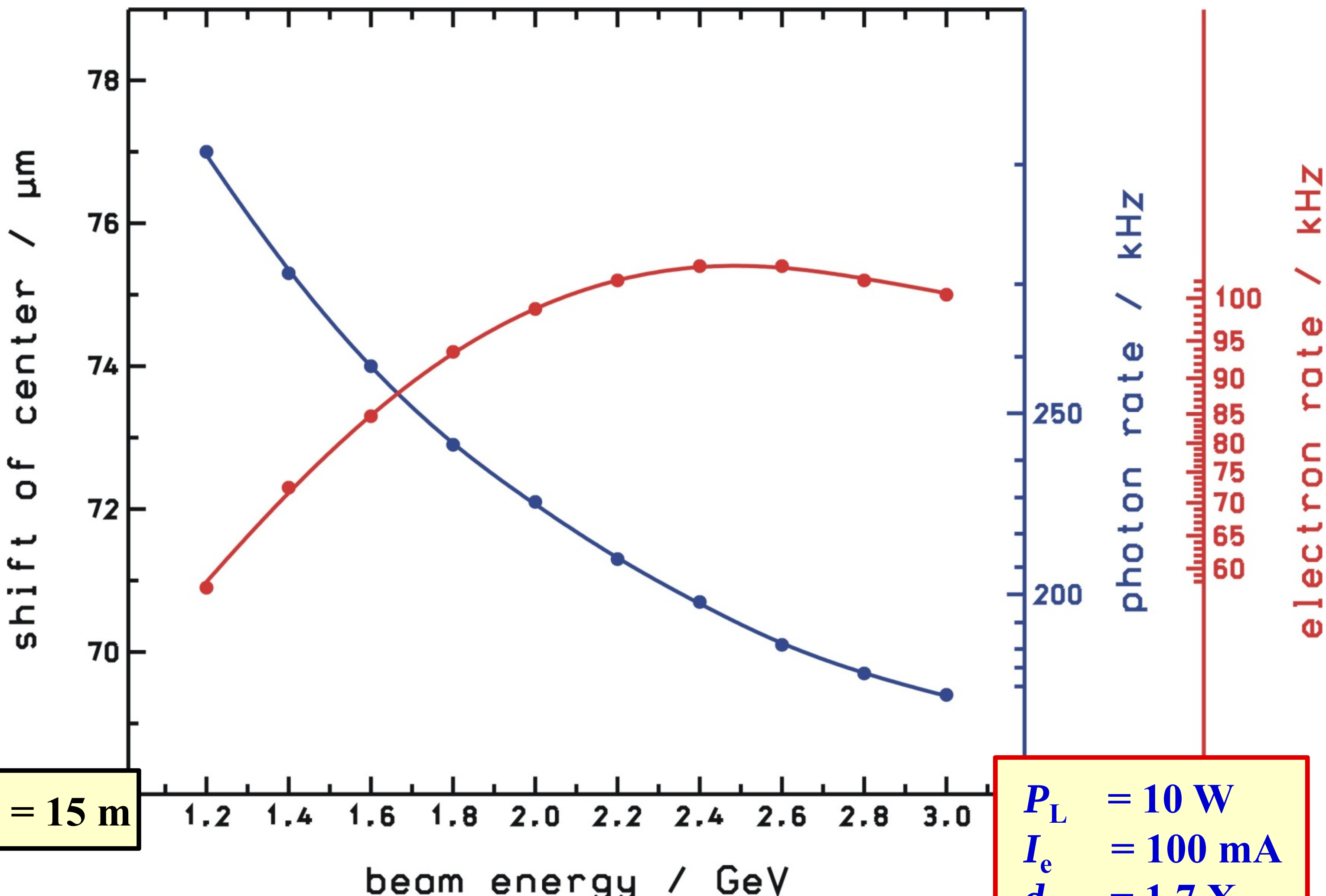


Numerical Simulations

4. <u>Pair conversion (e^+/e^-)</u>:



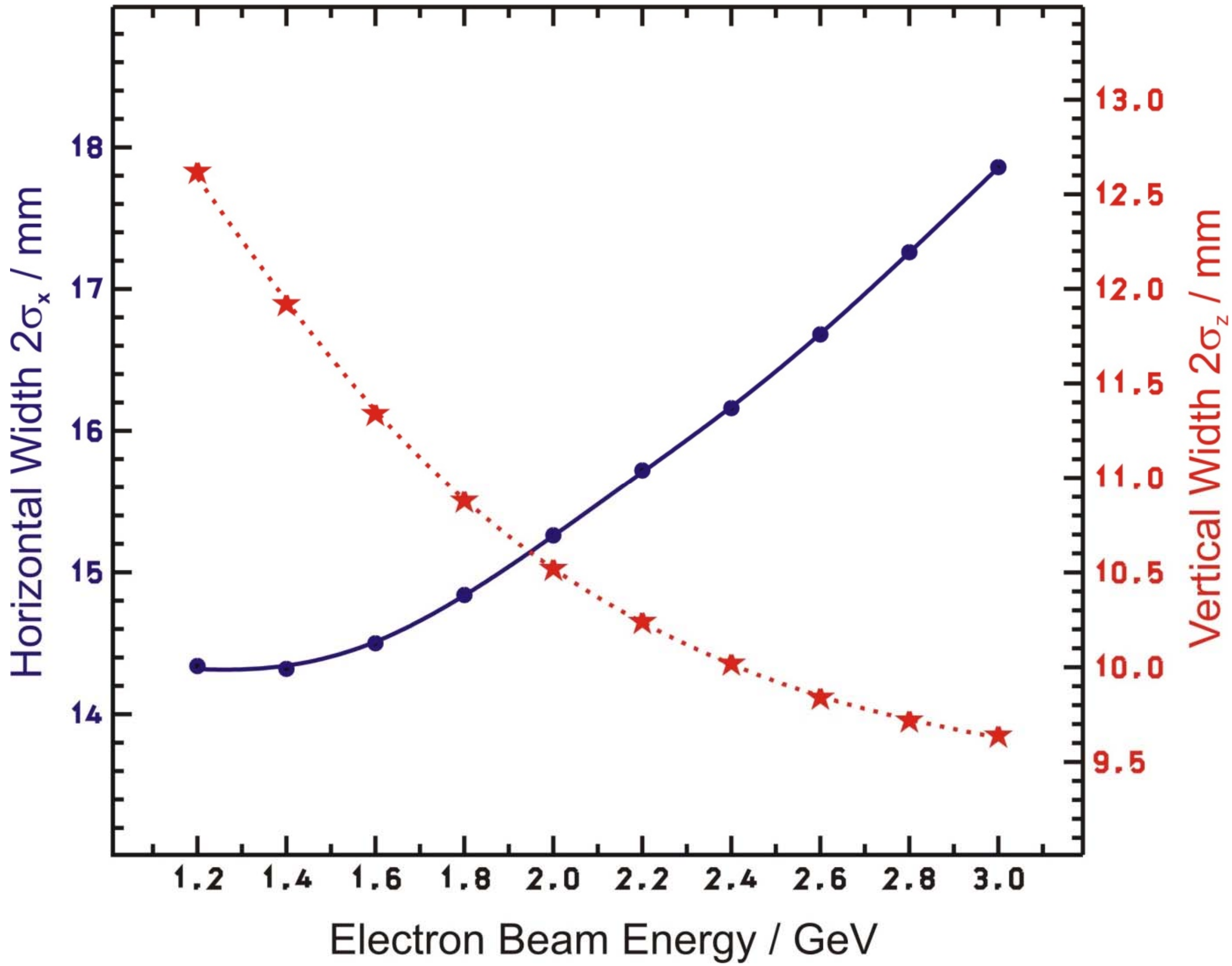
Analysing Power



***D* = 15 m**

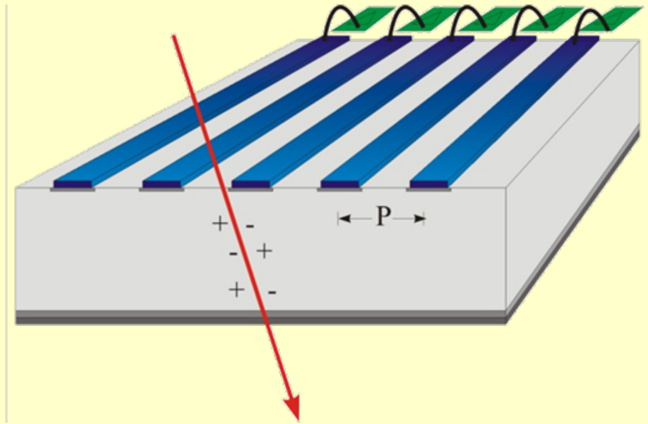
P_L = 10 W
I_e = 100 mA
d_{conv} = 1.7 X_0

Beam Parameters



Required Pitch

Strip detector with pitch *p*:

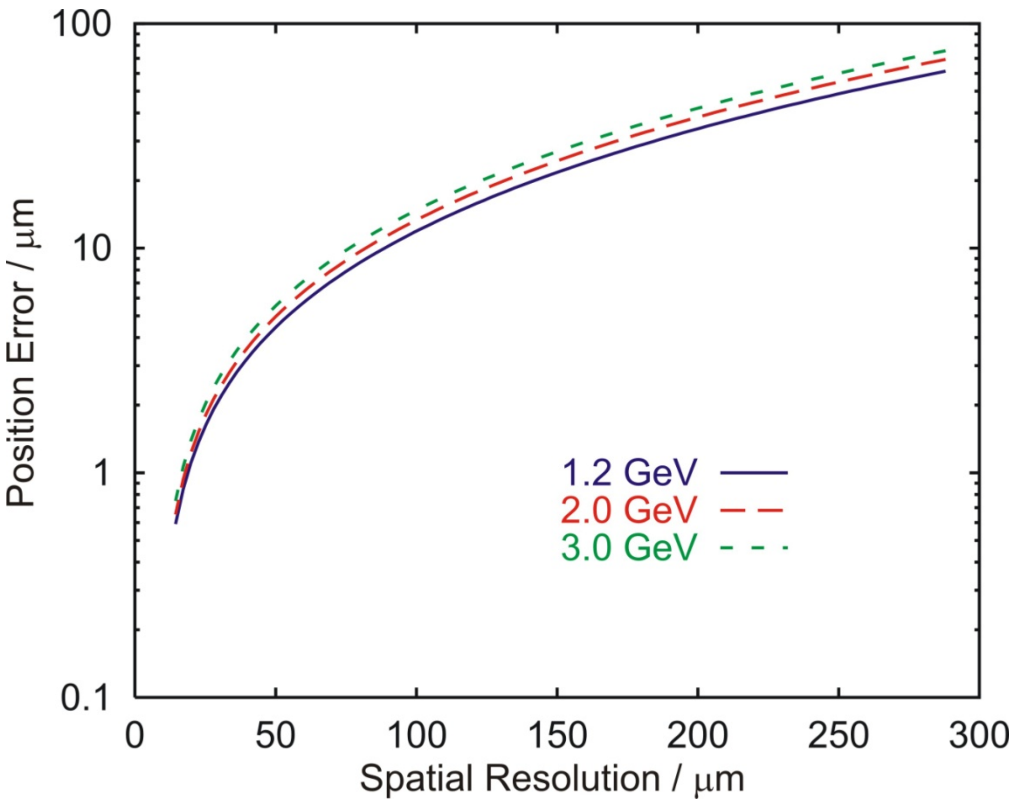


- **spatial resolution:**

$$\Delta z_{\text{det}} = \frac{p}{\sqrt{12}}$$

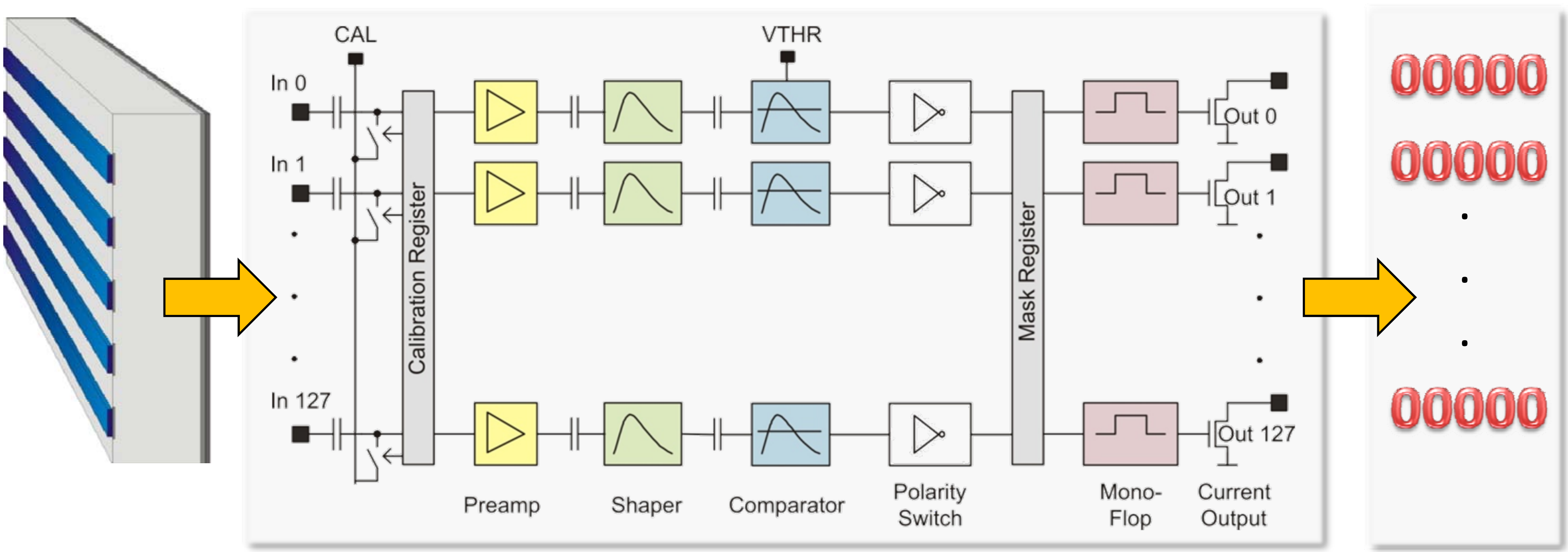
- **achievable position error:**

$$\Delta \bar{z} = \sqrt{\frac{\sigma_z^2}{N^2} + \frac{\sum_i n_i^2}{N^2} \cdot \Delta z_{\text{det}}^2} \xrightarrow{N\to\infty} \Delta z_\infty$$



$$\Delta P \leq 1\% \leftrightarrow \Delta z \leq 0.7\mu\text{m} \leftrightarrow p \approx 50\mu\text{m}$$

Counting Microstrip Detector

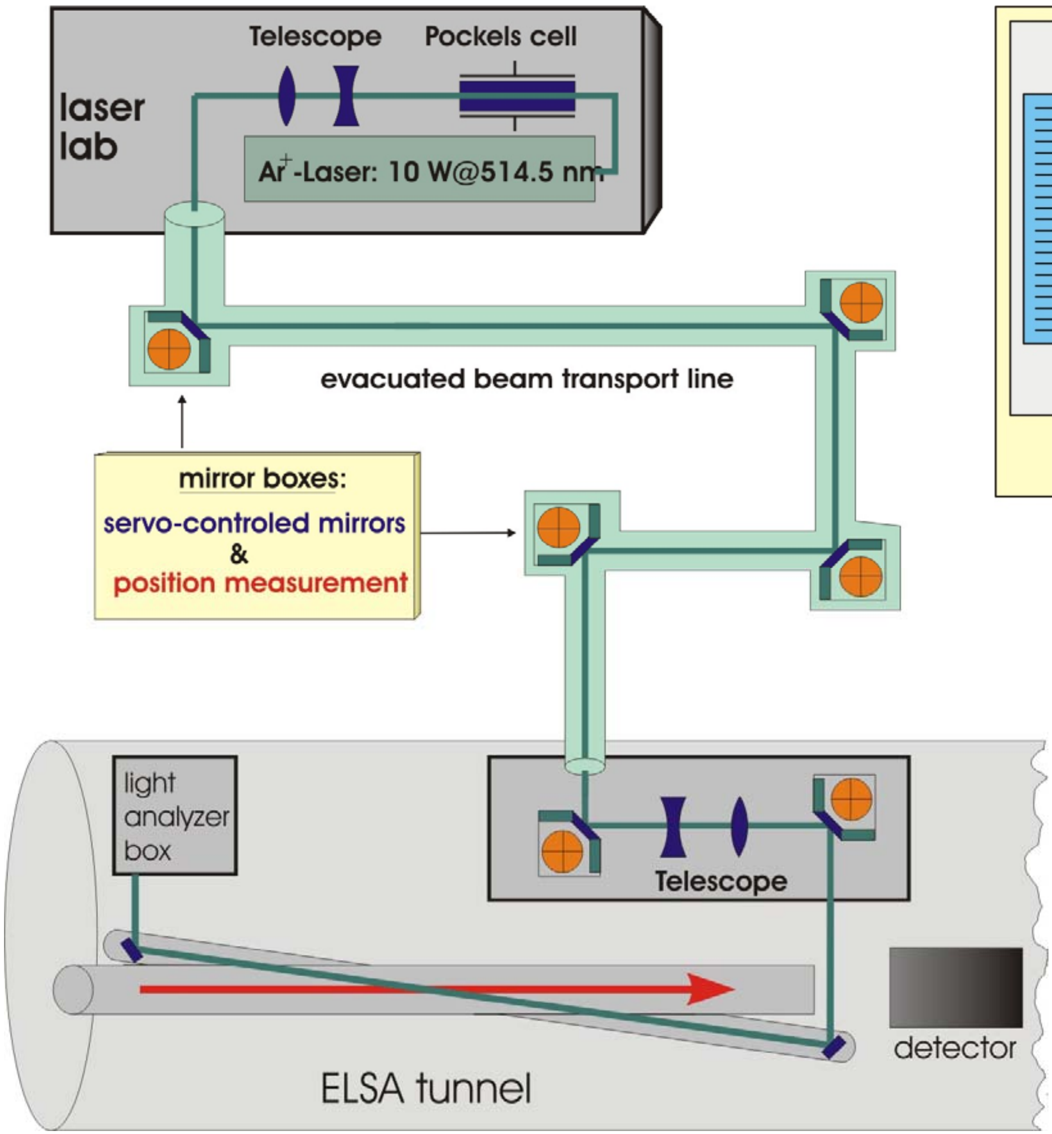


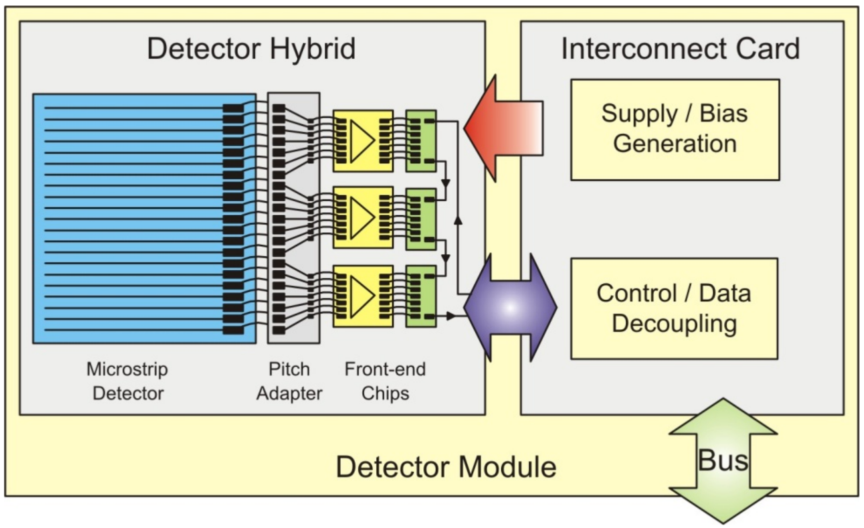
detector amplifier, shaper, discriminator counter

Developed in close collaboration with ATLAS pixel-detector group of N. Wermes, PI Bonn

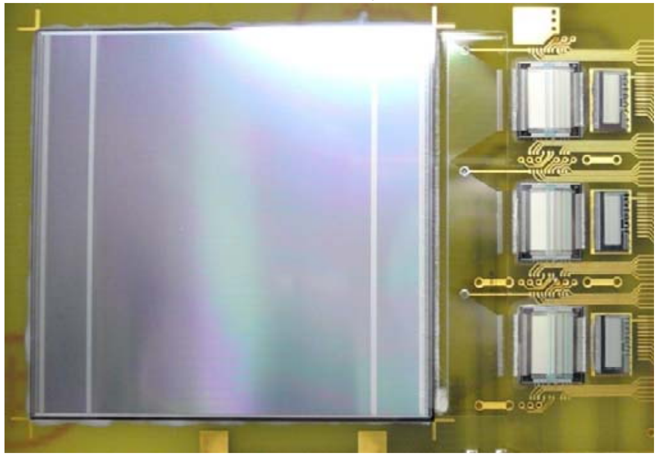
Past

Ar^+ Set-Up:

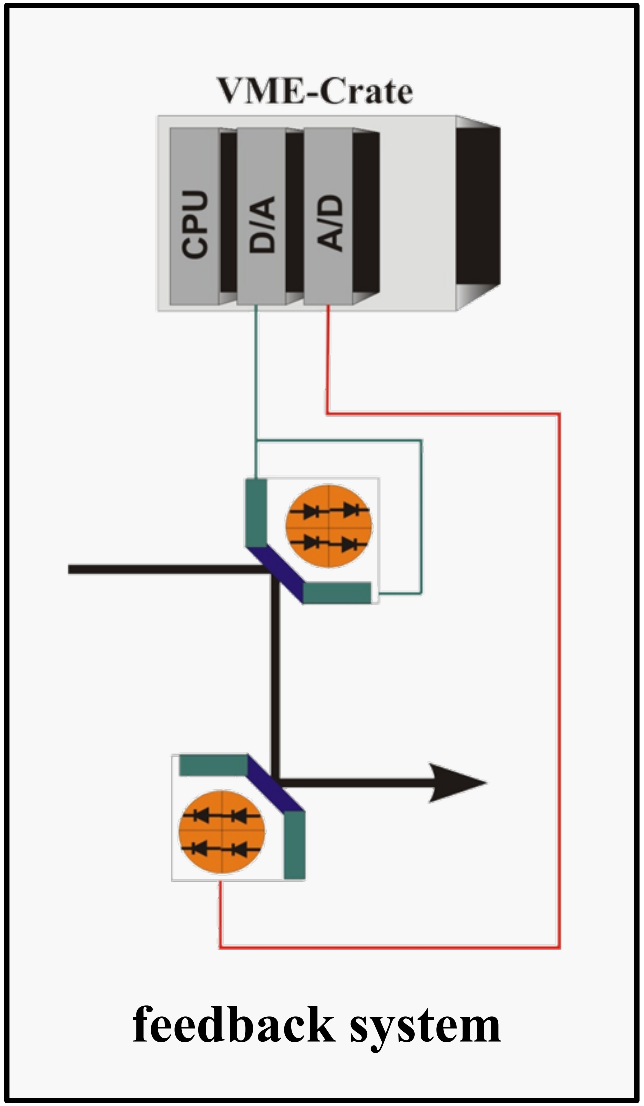


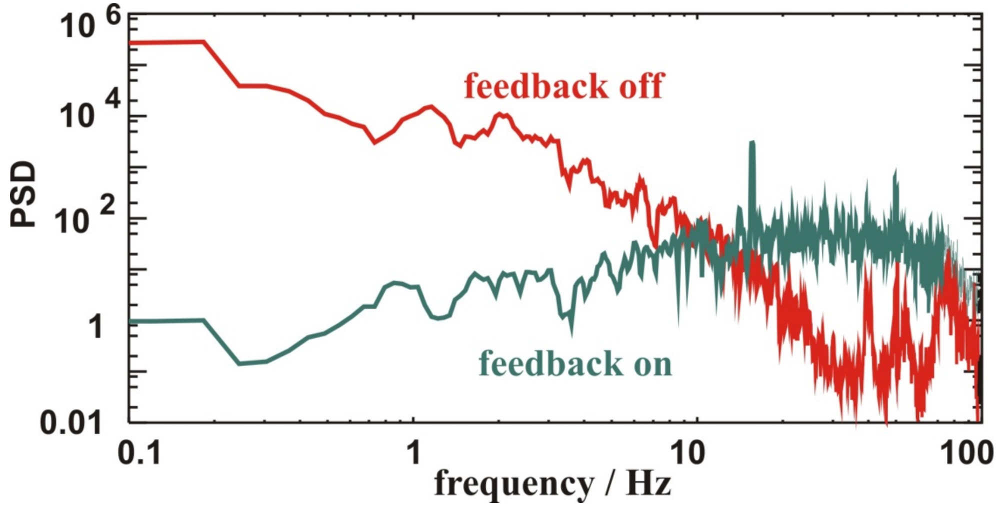


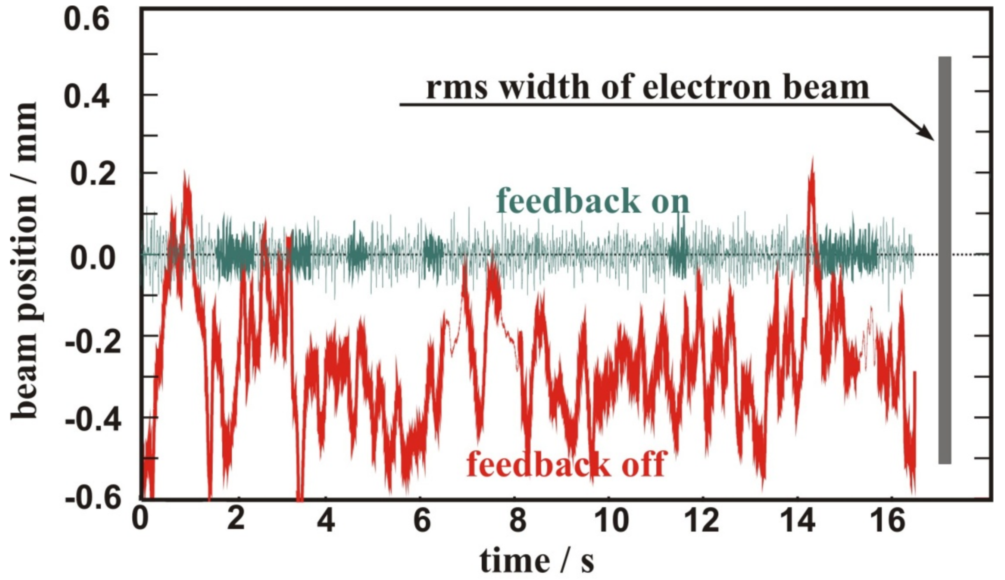
Detector Hybrid:



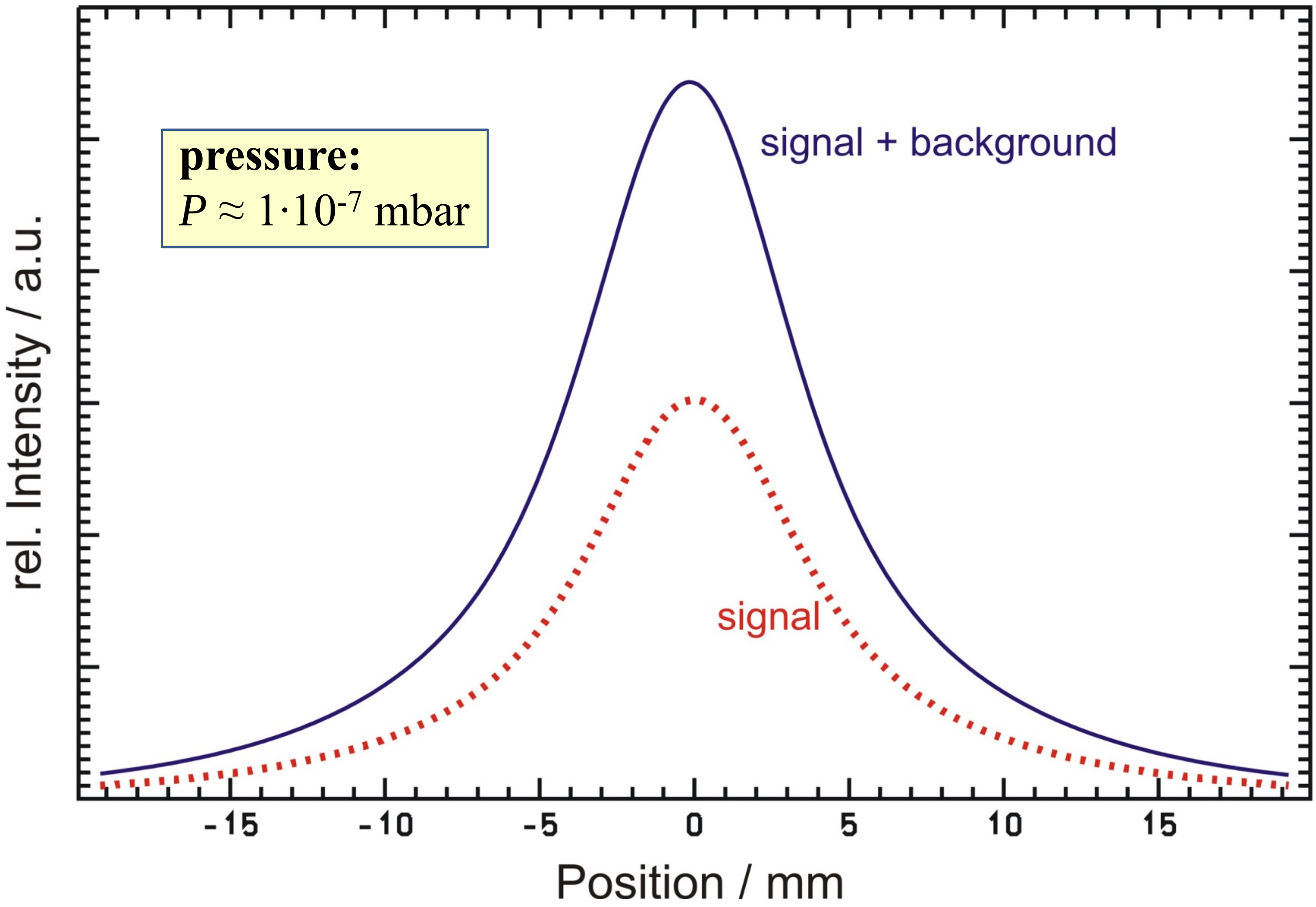
Beam Pointing Stability







Signal / Background



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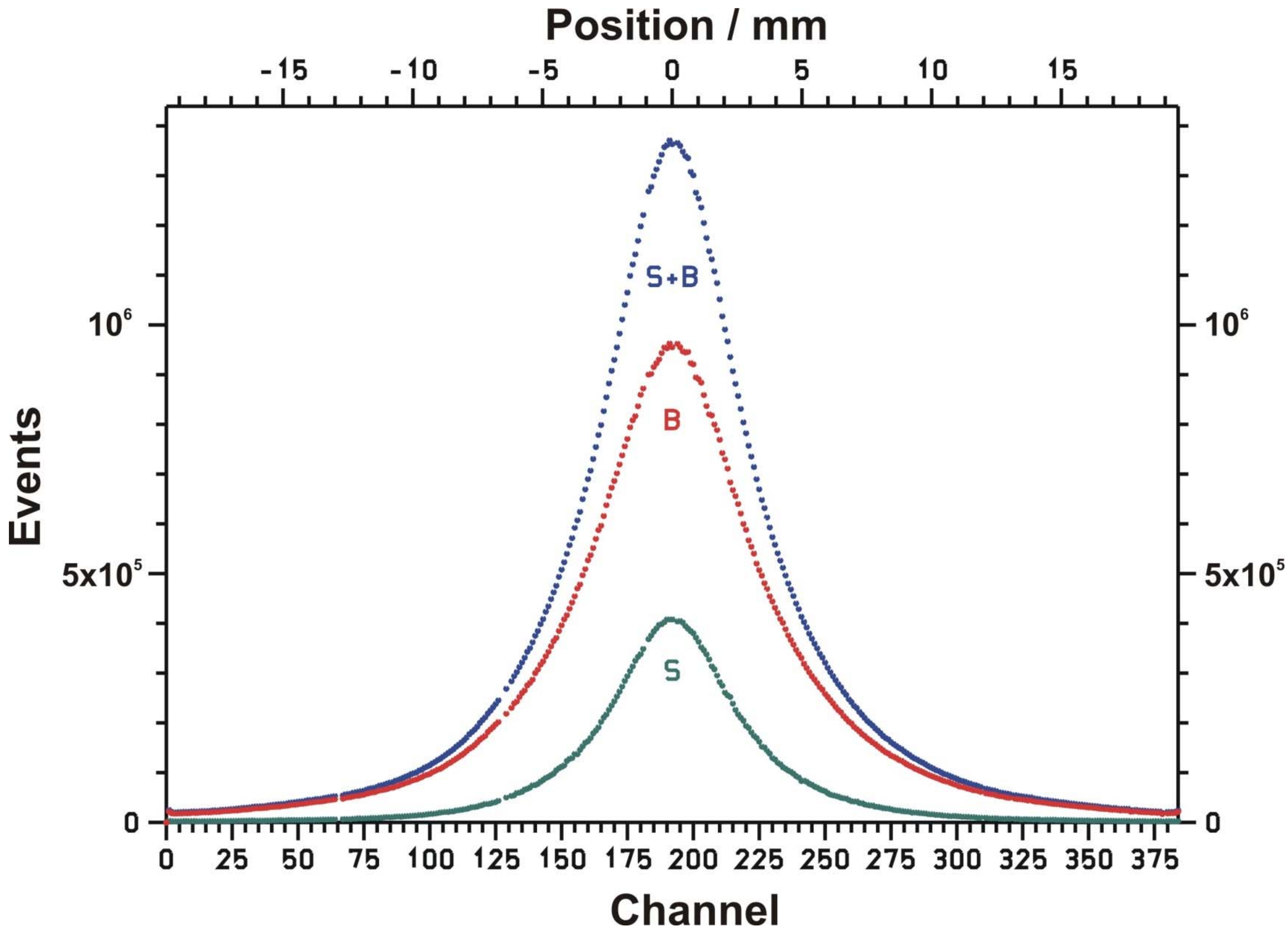
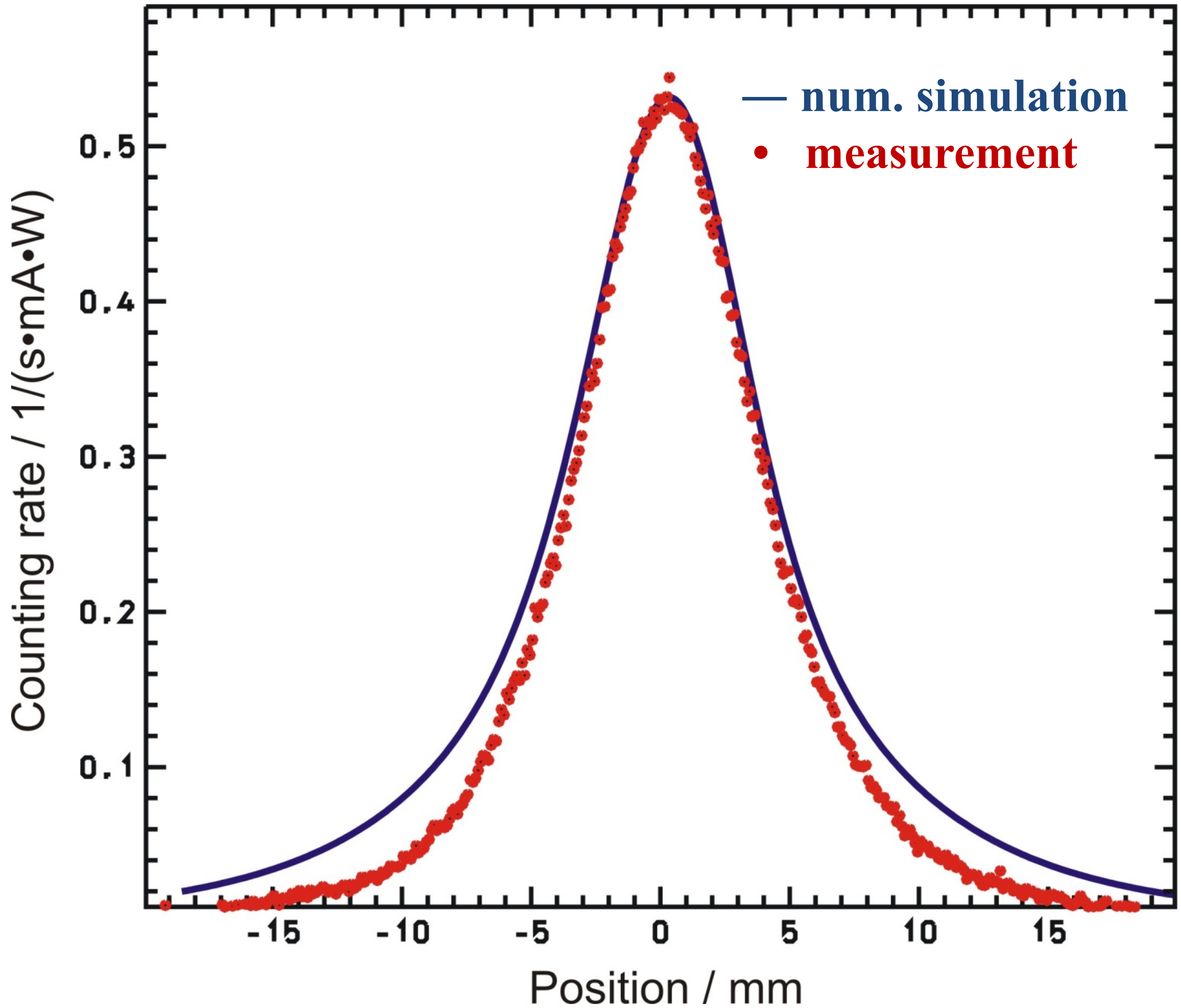
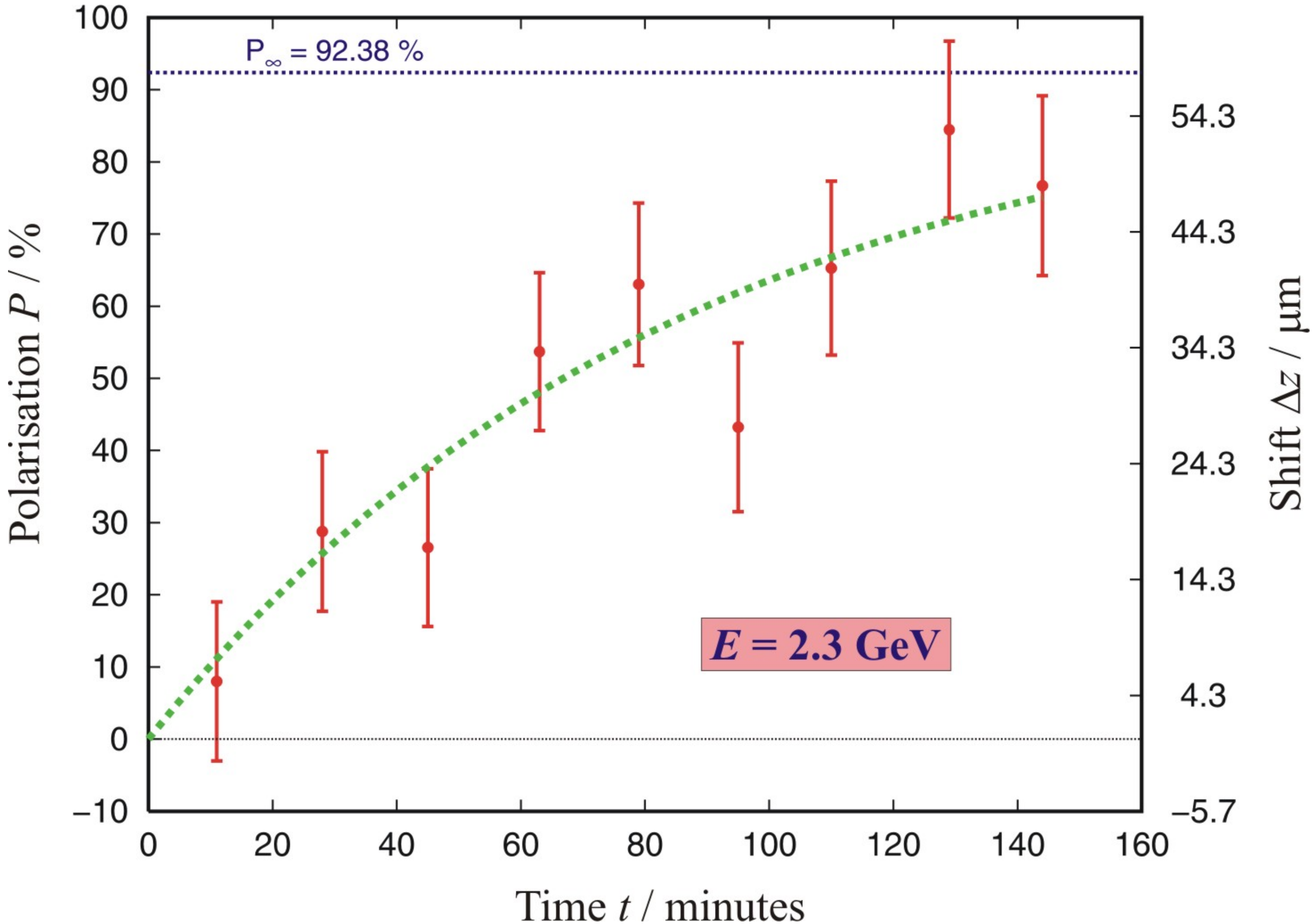


Beam Profile



Sokolov-Ternov Mechanism



Problems:

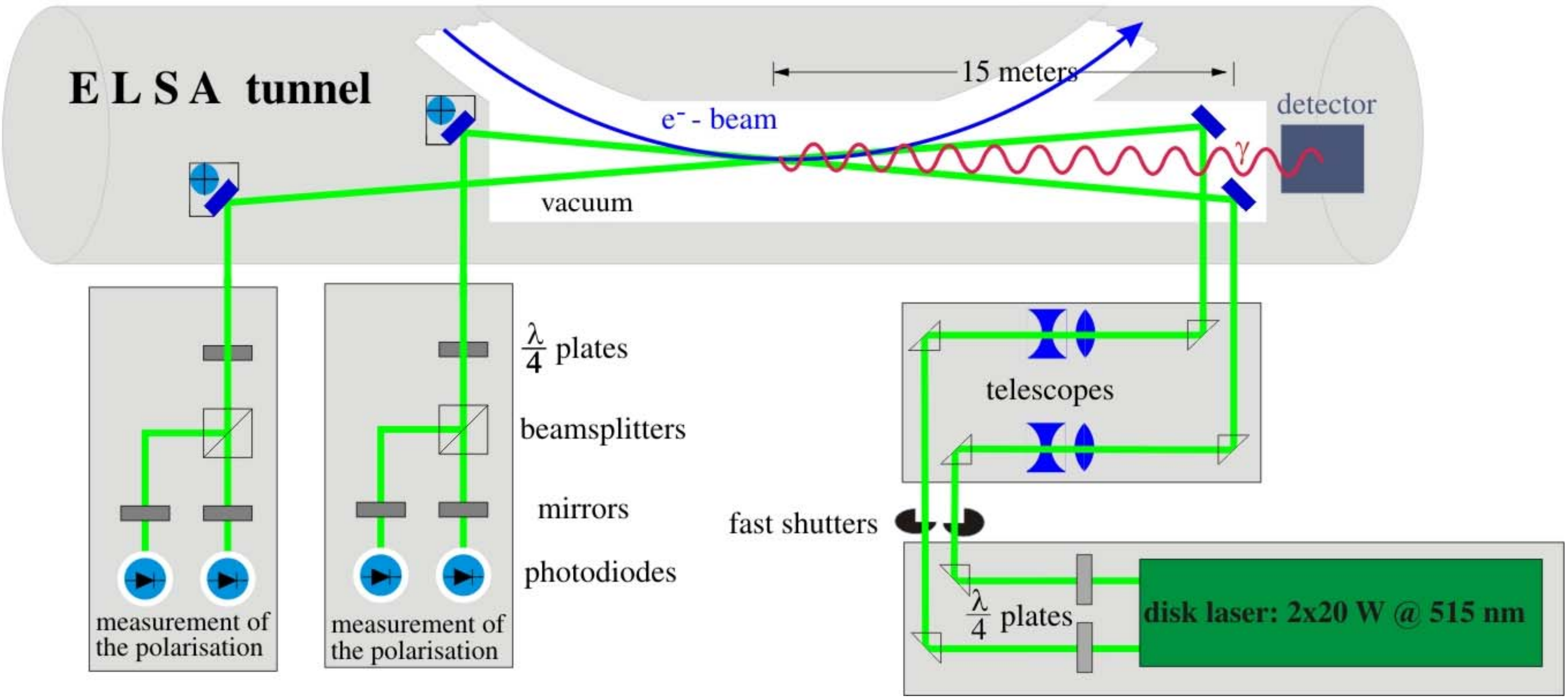
- **helicity correlated beam position** with feedback on
- high pressure at IP: $\boldsymbol{P > 10^{-7}}$ **mbar**
- low laser power at IP: $\boldsymbol{P_L \approx 6.5}$ **W**
- detector: **counter malfunctions**, $\boldsymbol{p = 100}$ **µm**

➢ **Improvements:**

- additional IGP for IP: $\boldsymbol{P < 10^{-7}}$ **mbar**
- new 2-beam disk-laser: $\boldsymbol{P_L > 40}$ **W**
- **high beam pointing stability**, no feedback
- new detector electronics, LVDS: $\boldsymbol{p = 50}$ **µm**

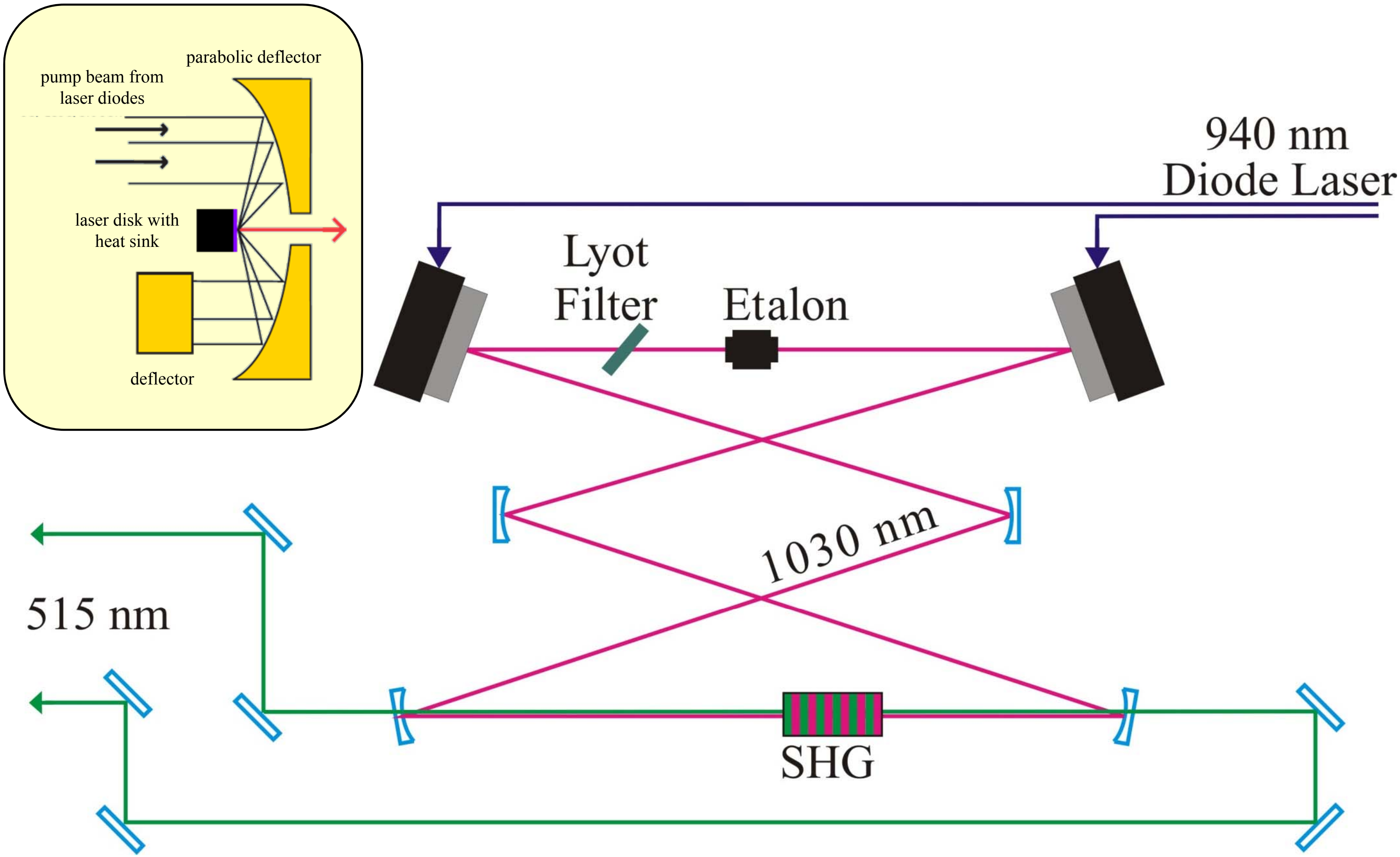
Future

2-Beam Set-Up

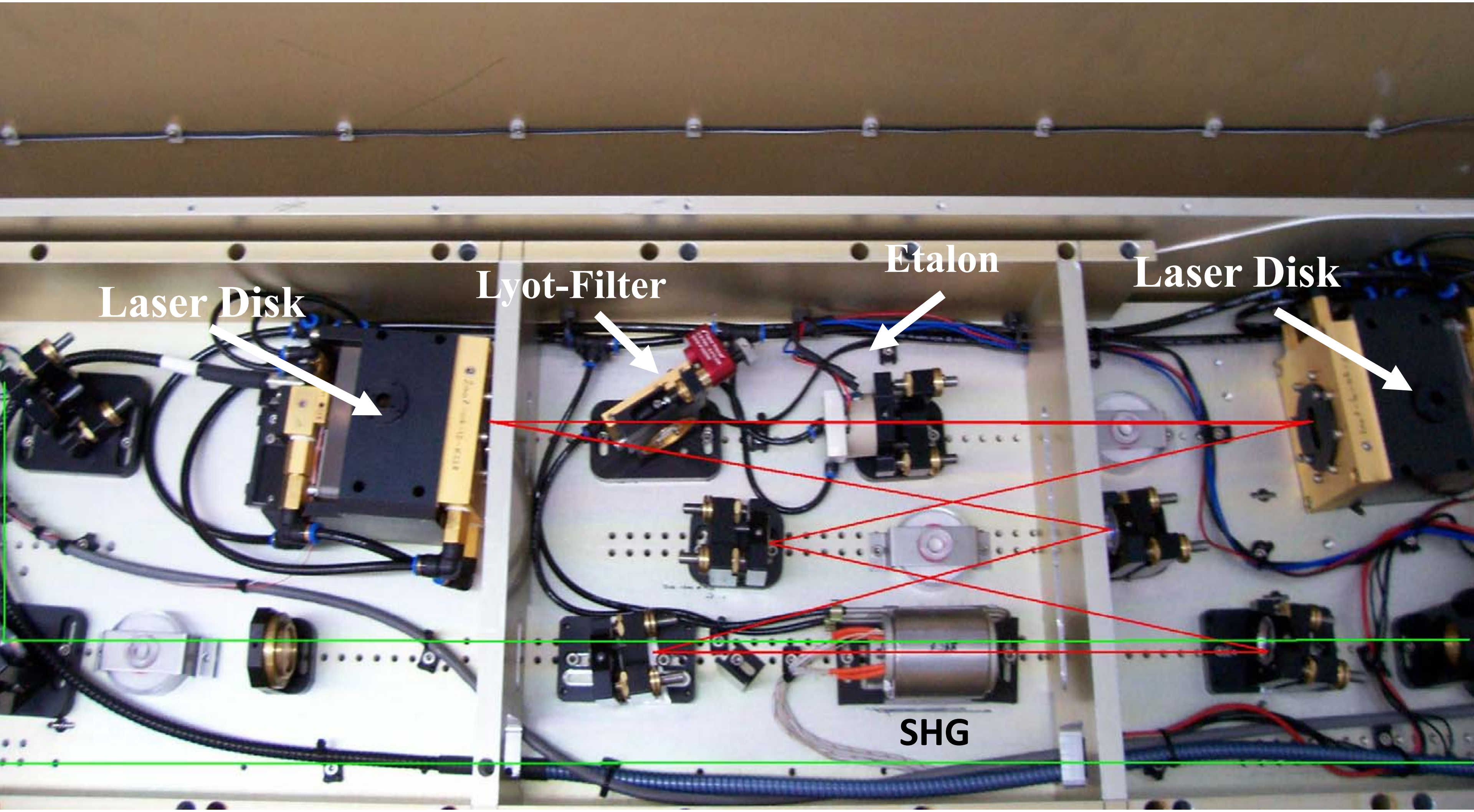


E L S A tunnel
15 meters
e⁻ - beam
detector
γ
vacuum
λ/4 plates
beamsplitters
mirrors
photodiodes
telescopes
fast shutters
λ/4 plates
disk laser: 2x20 W @ 515 nm
measurement of the polarisation
measurement of the polarisation

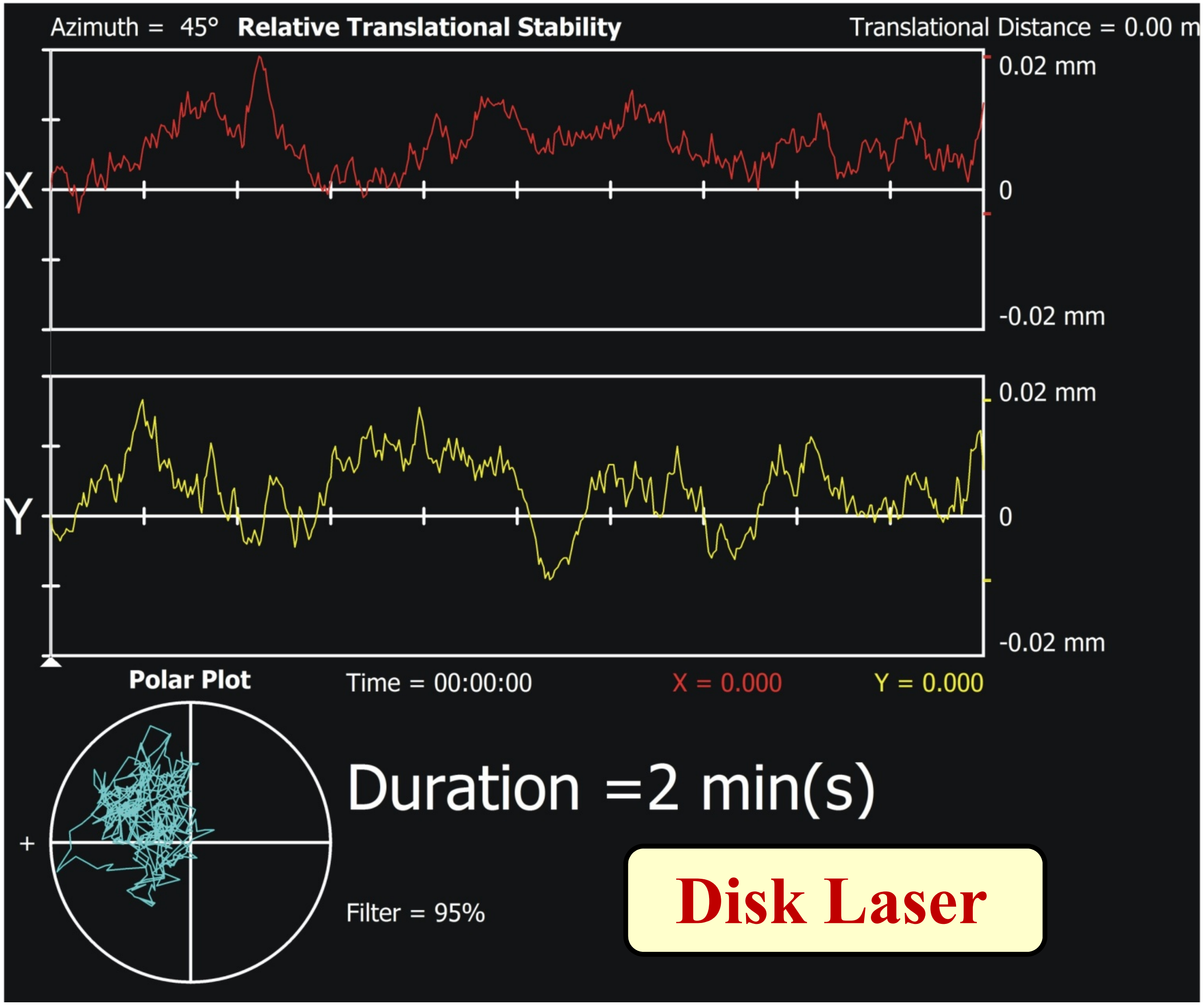
2 x 20 W Disk Laser



2 x 20 W Disk Laser



Beam Pointing Stability



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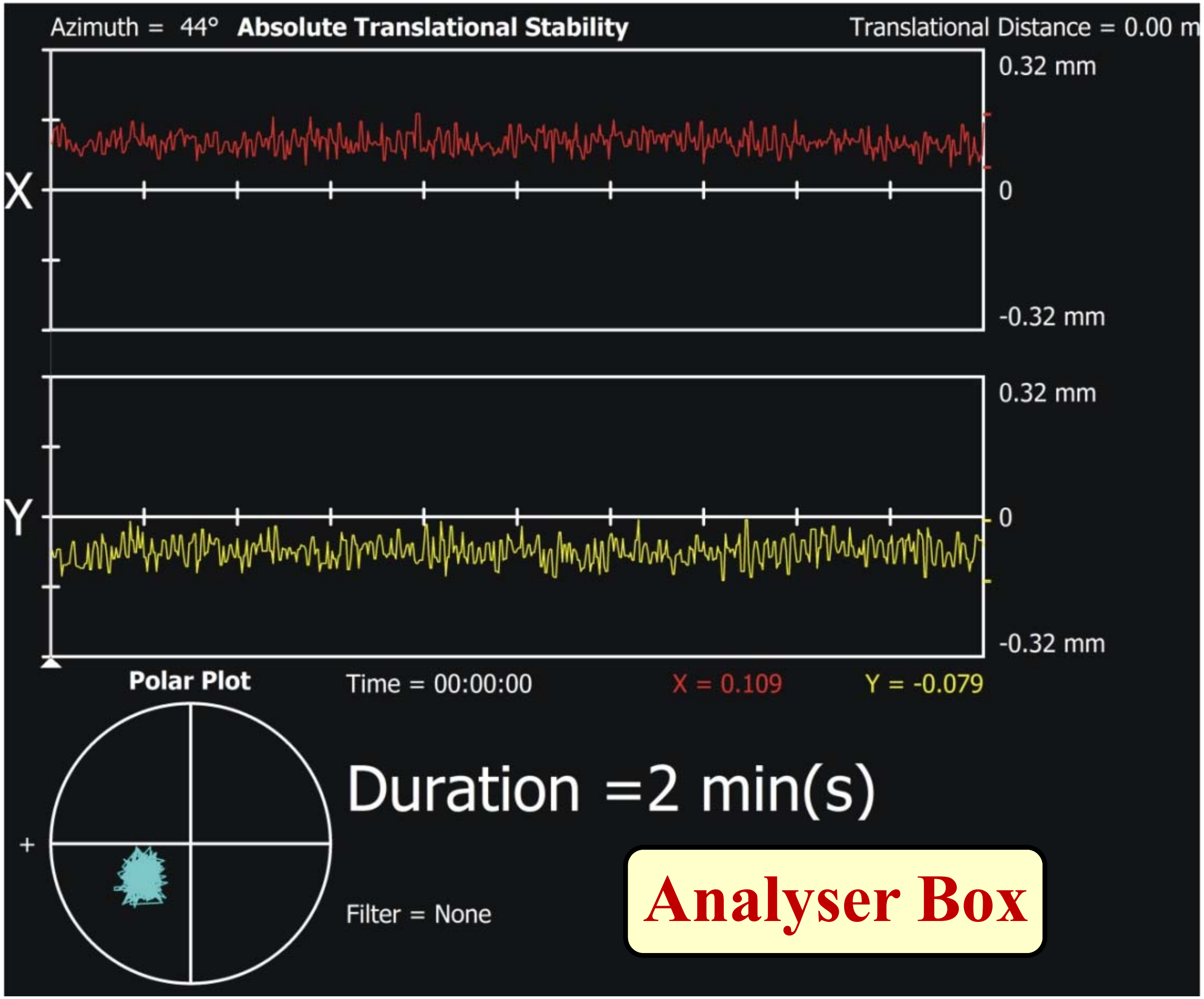
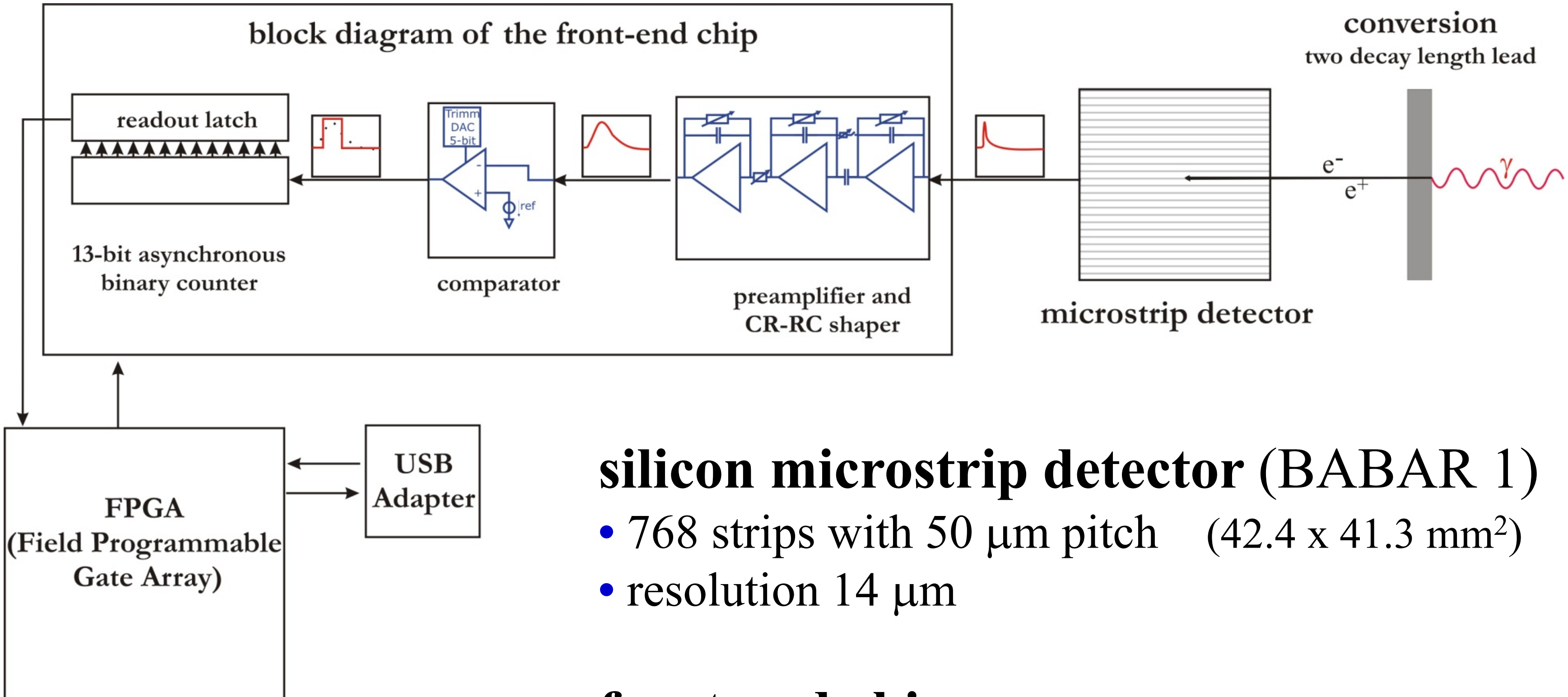


Detector Design



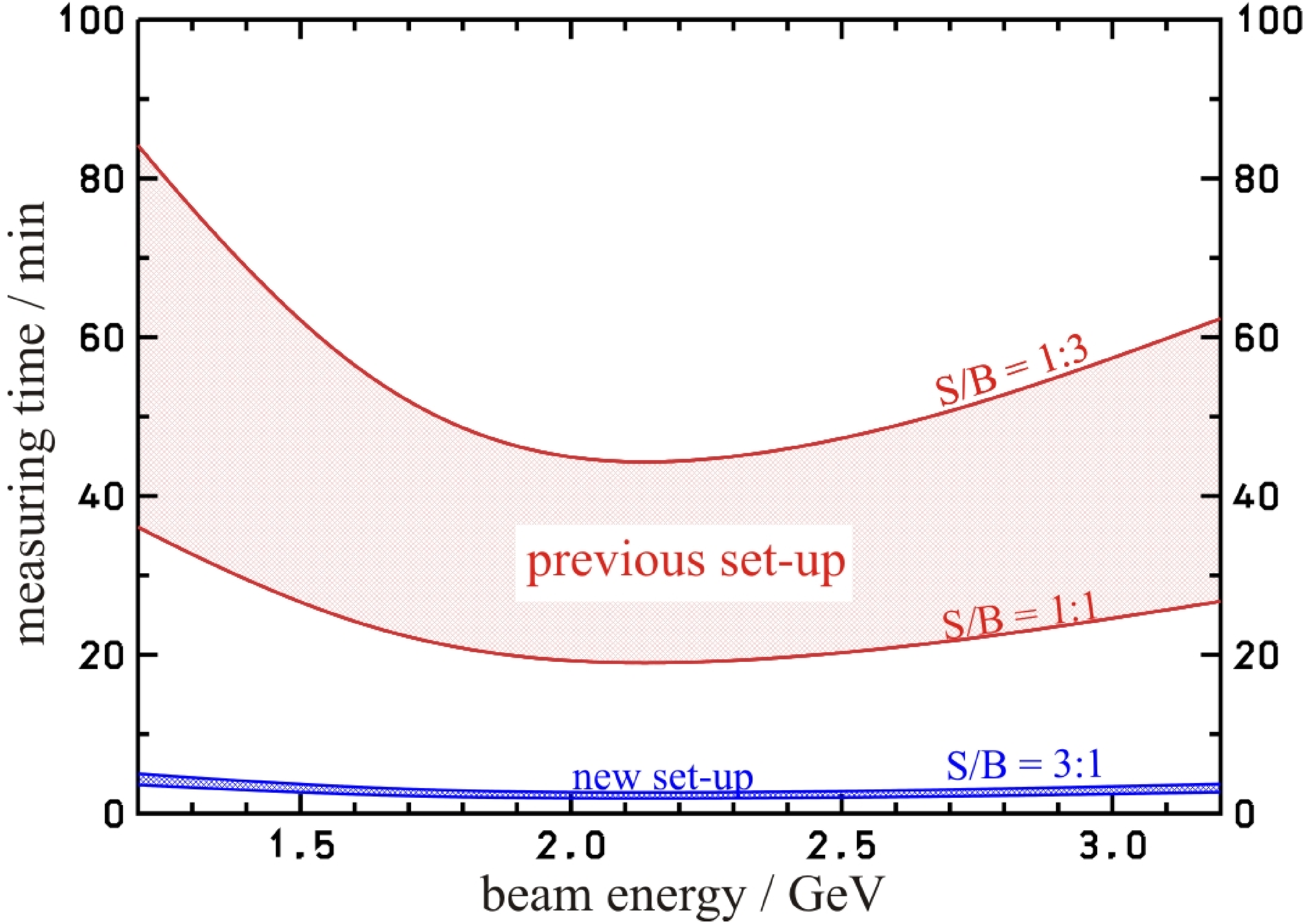
silicon microstrip detector (BABAR 1)

- 768 strips with 50 µm pitch (42.4 x 41.3 mm^2)
- resolution 14 µm

front-end chip

- high rate acceptance (10 - 150 MHz)
- digital part built in LVDS technology
- FPGA controlled

Expected Measuring Time



Conclusions & Outlook

Polarimeter ready by 2009, enables:

- **precision polarimetry within minutes**
- **measurement of e^- – phase space in scanning mode**

Laser Optics