TESLA Forward Tracking and the Measurements of the Luminosity-Spectrum

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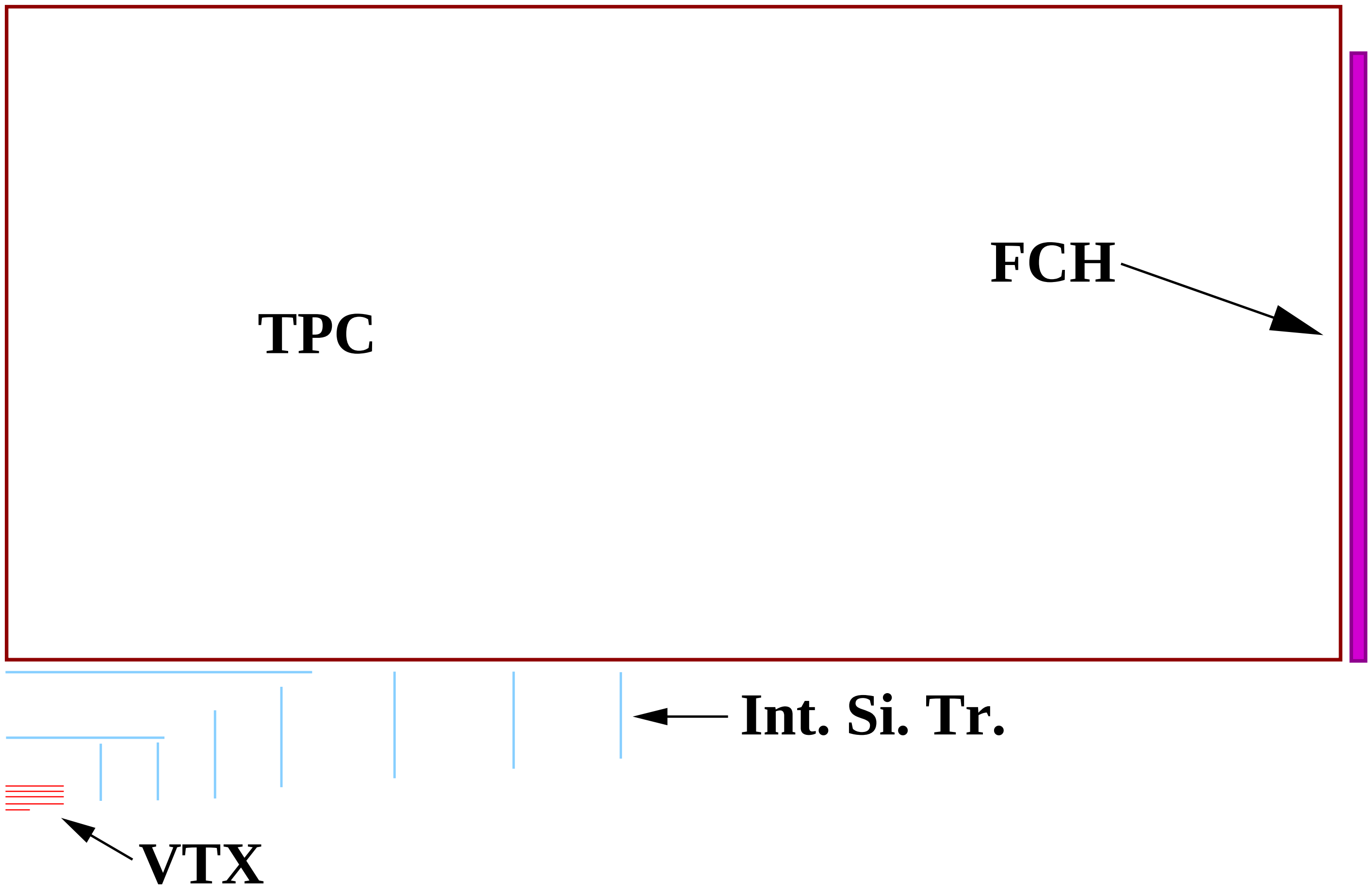
- Forward tracking at TESLA
- Luminosity spectra

Forward tracking at TESLA

Tasks of the forward tracking:

- good momentum resolution to identify charges unambiguously down to the lowest angles and highest momenta
- very good angular resolution to measure the luminosity spectrum from the acolinearity of Bhabha-events
- minimal material to be able to measure also electrons and to avoid additional background to the calorimeters

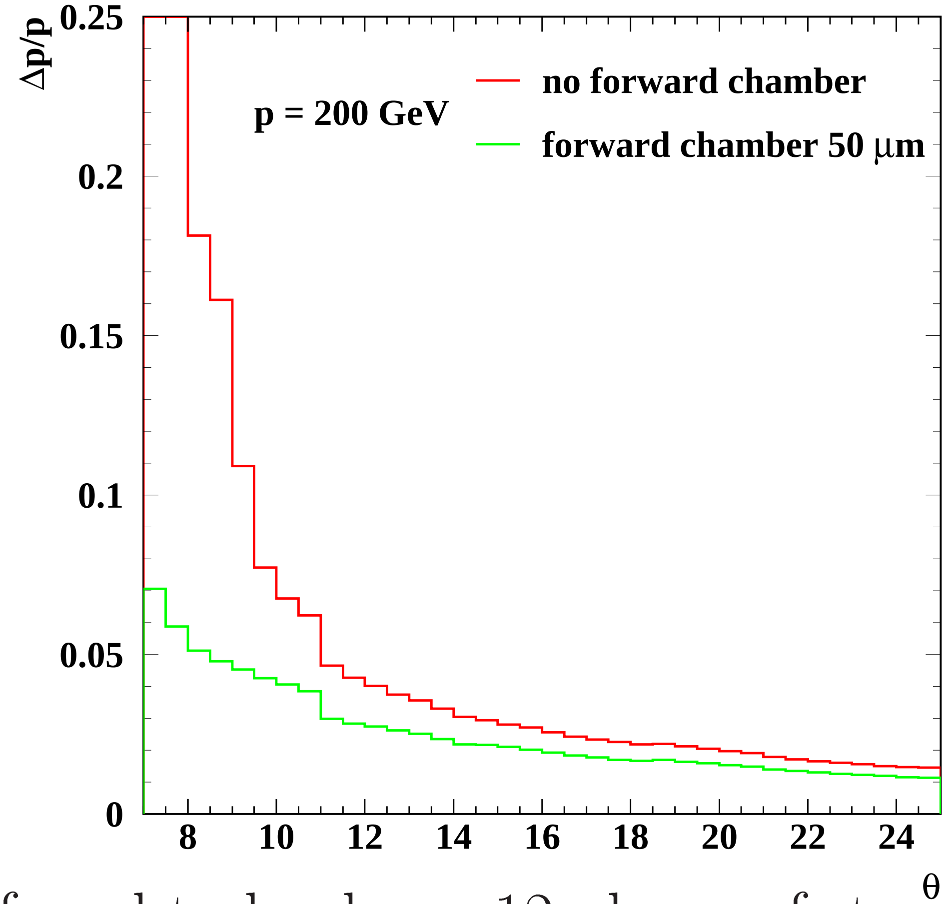
(Forward-)tracking setup



- Tracking starts at 7° due to the mask
- (Main tracker: TPC inside a 4T field)
- Intermediate silicon tracking
- Forward chamber behind TPC endplate

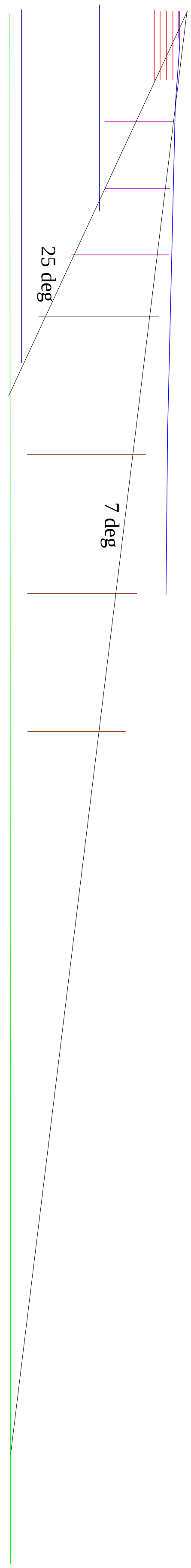
Forward chamber

- Many processes (e.g. $e^+e^- \rightarrow W^+W^-$) have forward peaking particles
  $\longrightarrow$ need good momentum resolution down to lowest angles where TPC gets weak
- Mainly interesting for high momentum muons, so material not crucial
- Add a precise forward chamber between TPC and ECAL ($\sigma \approx 50\mu$m)



- Preferred technology: 12 planes of straw tubes in three orientations

Intermediate Silicon Tracking



- two barrel layers
  $r = 16,\ 30\,\mathrm{cm}$
  $\sigma = 8\mu\mathrm{m}$
  resolution similar to LEP, but larger
- three pixel disks
  $\sigma = 50 \times 200\mu\mathrm{m}$
  crossed
  basically a copy of ATLAS
- four strip disks
  $\sigma = 25\mu\mathrm{m}$
  $\Rightarrow$ $90\mu\mathrm{m}$ strip pitch,
  $270\mu\mathrm{m}$ readout pitch
  back-to-back or double sided

Forward silicon disks

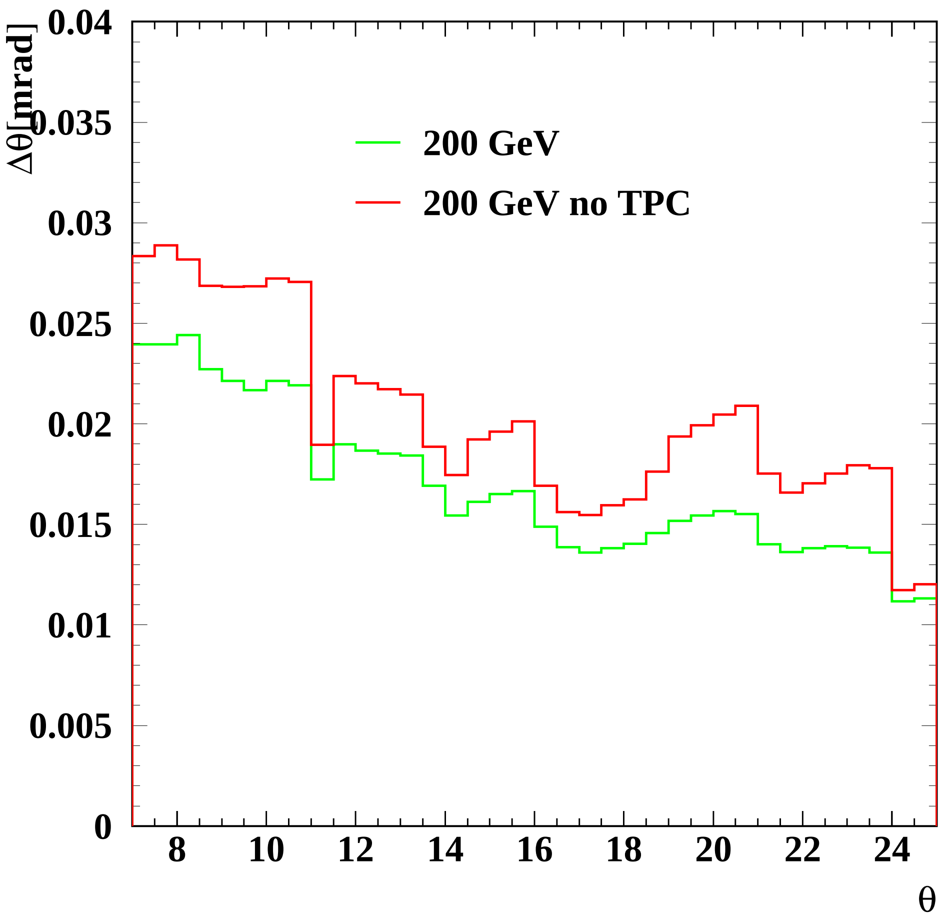
Polar angle (θ) resolution:

- mainly for Bhabha acolinearity to measure beam-strahlung and beamspread
- beamspread $\sim 10^{-3}$
- effect of detector resolution $\Delta\sqrt{s'} = \Delta\theta / \sin\theta$

➠ need $\Delta\theta \sim$ few $\times 10^{-5}$

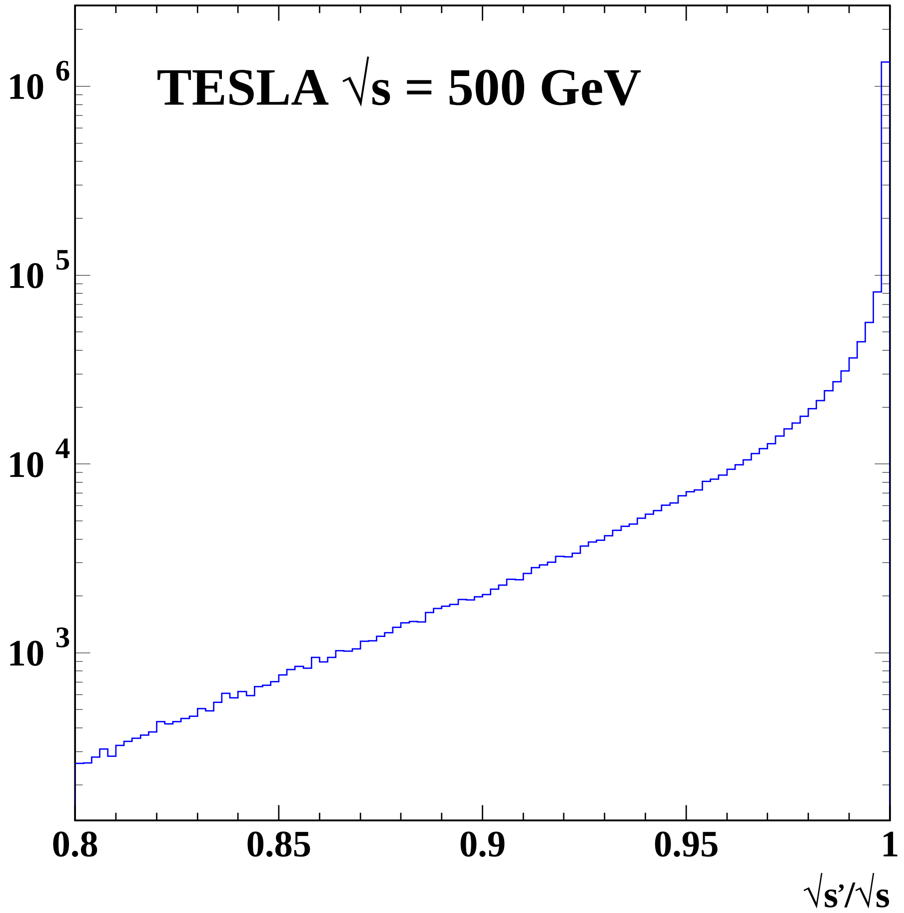
- electrons pass TPC field cage/cables with a very small angle

➻ better assure resolution with silicon only



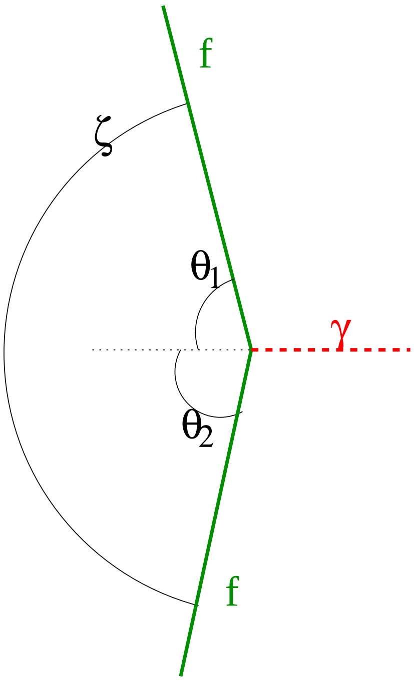
Luminosity spectrum

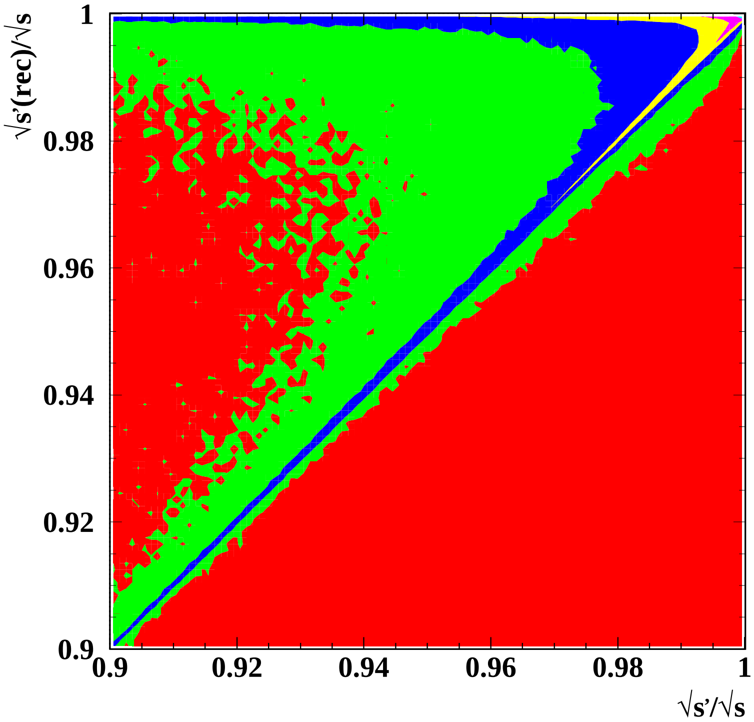
- Mean energy loss of spent beam due to beamstrahlung at TESLA: $\approx 3\%$
  $\Rightarrow$ mean energy loss of interact. particles $\approx 1.5\%$
- Spectrum strongly peaked at nominal beam energy with $\sim$ 50% of electrons having full beam energy



- for continuum processes ($f\bar{f}$-, W-pair-production) need only mean energy
- for threshold scans or resonances need detailed spectrum

- Try to use something like the s' algorithms used at LEP to reconstruct radiative return
- General idea: If in a $e^+e^- \to f\bar{f}$ event one photon is radiated at zero angle (or better all energy is radiated in one direction) the effective s' can be calculated from the fermion angles.





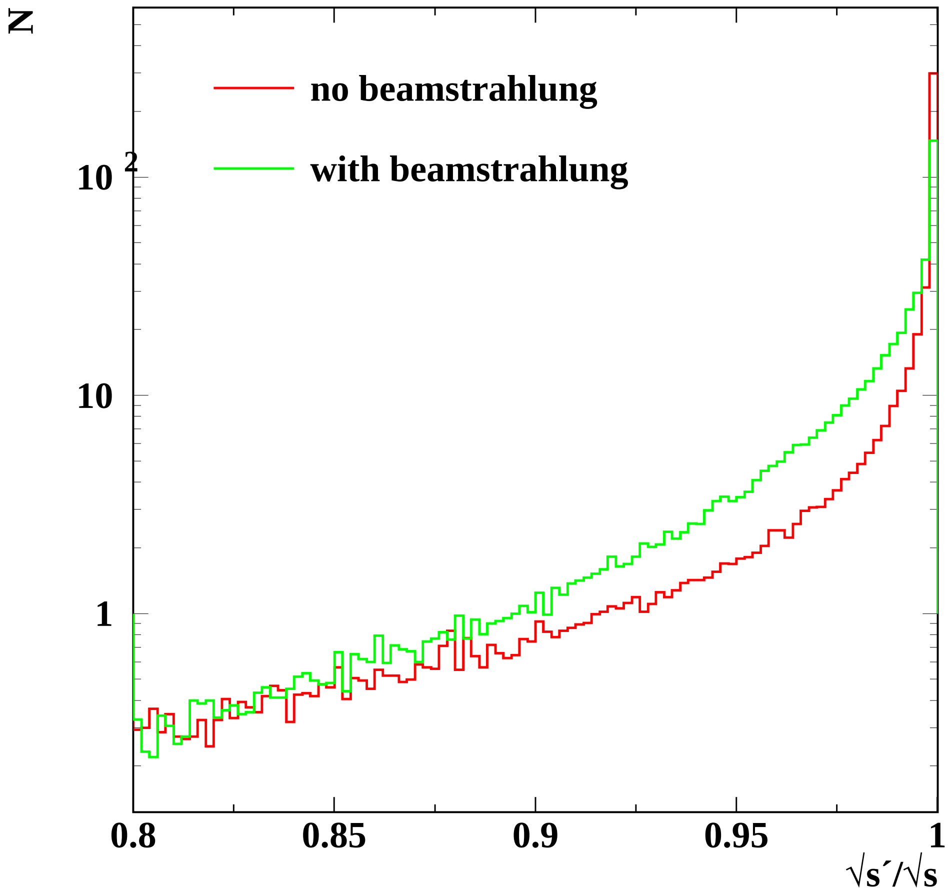
- if one photon condition not fulfilled can be dealt with easily in the fit

Need 2-fermion process with large cross section:

Again use Bhabha events in the forward tracking region

$\sigma(e^+e^- \to e^+e^-) = 300\mathrm{pb}$
for $\theta_e > 7^\circ$, $\sqrt{s} = 500\,\mathrm{GeV}$

Slight complication: radiation from beamstrahlung and normal ISR compete



ISR needs to be calculated theoretically

Simulation of beamstrahlung:

CIRCE program (T. Ohl)

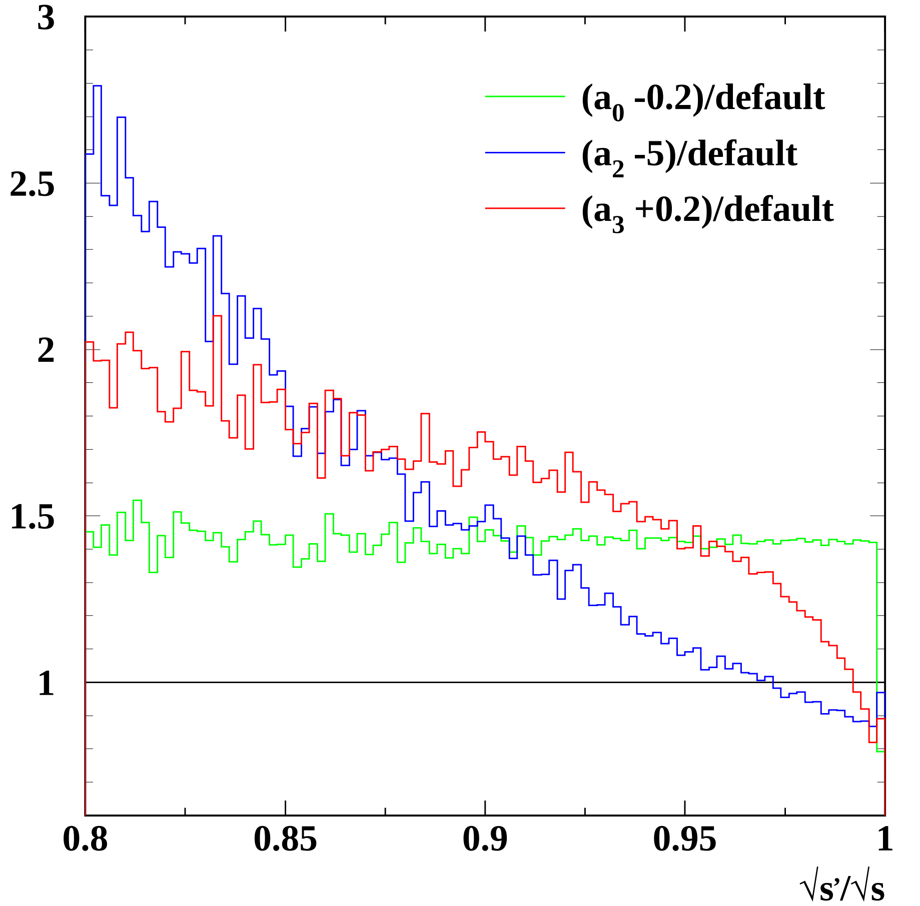
CIRCE parameterization:

$$f(x) = a_0 \delta(1-x) + a_1 x^{a_2} (1-x)^{a_3}$$

(Three free parameters a_0, a_2, a_3, a_1 fixed by normalization) fitted to GuineaPig output

TESLA 500 GeV

$$a_0 = 0.5274$$
$$a_2 = 13.895$$
$$a_3 = -0.6314$$



Fit method

- measure $\sqrt{s'}$ spectrum
- believe functional form from CIRCE and fit free parameters
- use MonteCarlo to predict spectra for central values and derivatives around them
- fit data using these prediction
  (the only assumption in this procedure is that the behavior is linear in a parameter region around the central value of about the size of the errors)
- method has been verified by fitting spectra away from the ones used in the MC predictions

Results (for 500 GeV, $3\,\mathrm{fb}^{-1}$, $7^\circ < \theta < 25^\circ$:)

$$\begin{aligned}\Delta a_0 &= 0.0014\\ \Delta a_2 &= 0.082\\ \Delta a_3 &= 0.0021\end{aligned}$$

Correlation matrix:

$$\begin{matrix} 1.000 & 0.430 & 0.708\\ 0.430 & 1.000 & 0.755\\ 0.708 & 0.755 & 1.000\end{matrix}$$

Error on $\sqrt{s'}$

Every single parameter:

$$\Delta\left\langle\frac{\sqrt{s'}}{\sqrt{s}}\right\rangle \sim 6\cdot 10^{-5}$$

Including correlations:

$$\Delta\left\langle\frac{\sqrt{s'}}{\sqrt{s}}\right\rangle = 4\cdot 10^{-5}$$

Spectrum gets distorted by energy spread

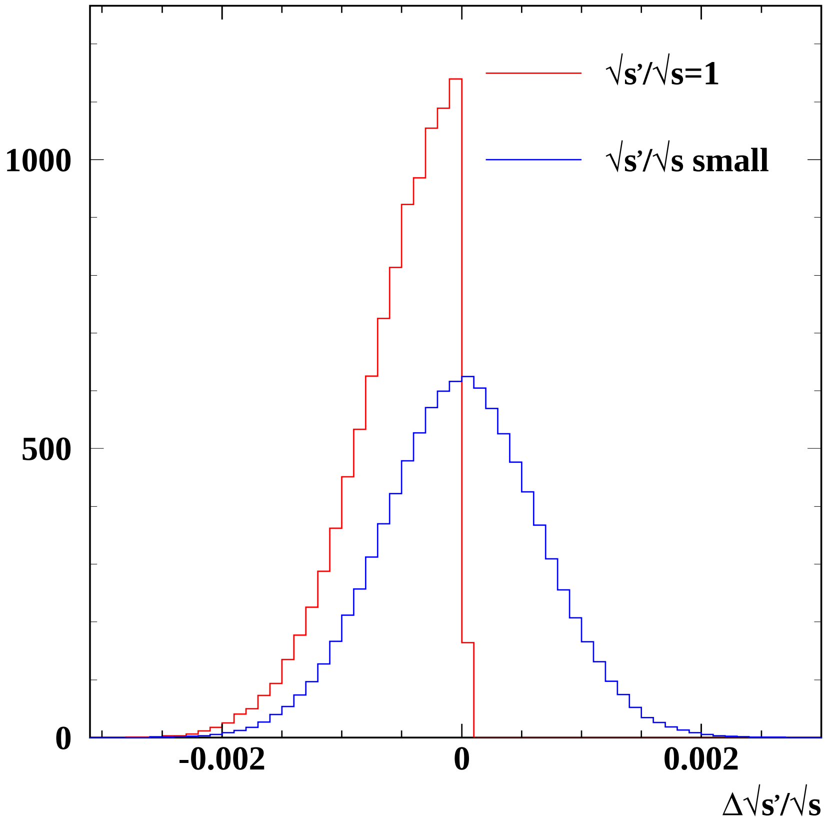
Problem:

- beamstrahlung always lowers $\sqrt{s'}$
- energy spread is symmetric around $\sqrt{s}$
- by construction for the measurement one has always $\sqrt{s'} < \sqrt{s}$
- have to disentangle beamstrahlung and energy spread.
- fold beamspread with spectra in fit

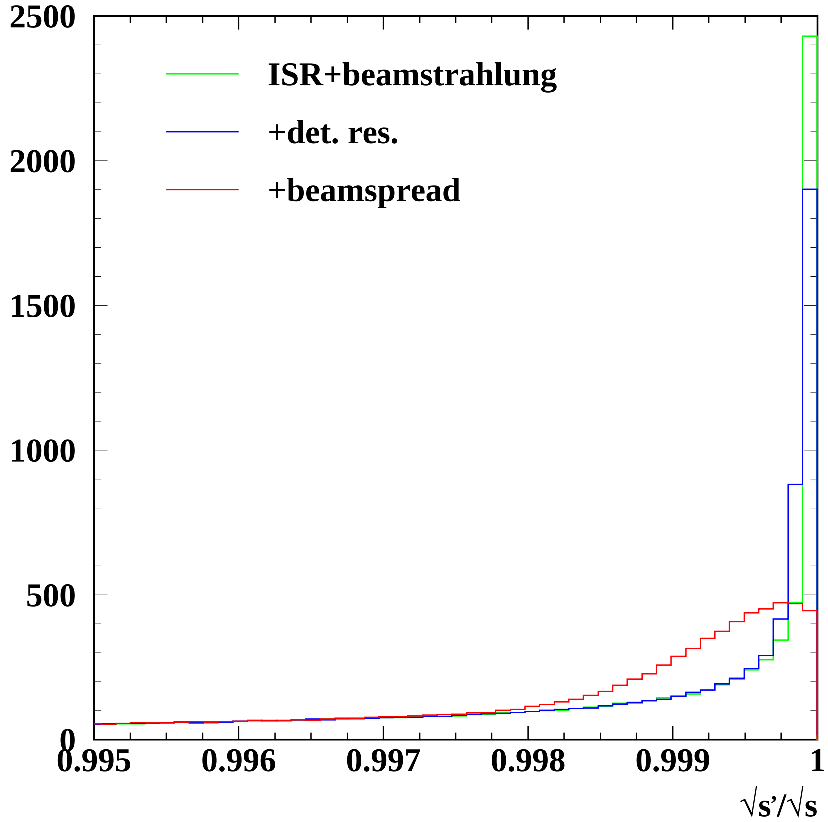
Detector issues:

- detector resolution has similar effect on $\sqrt{s'}$ spectra as energy spread
- need good resolution and little material at low angles
- detector effect on $\sqrt{s'}$: $\delta\sqrt{s'}/\sqrt{s'} \approx \delta\theta/\sin\theta$
- Current TESLA detector reaches $\delta\theta \sim 0.2 \cdot 10^{-4}$ $\Rightarrow \delta\sqrt{s'}/\sqrt{s'} \approx 10^{-4}$
- much smaller than energy spread of $\sim 10^{-3}$
- should be possible to measure energy spread

Effect of energy spread on measured s'



Modification of s' spectra



Results with 0.1% (Gaussian) energy spread

$$\begin{aligned} \Delta a_0 &= 0.0048 \\ \Delta a_2 &= 0.14 \\ \Delta a_3 &= 0.0061 \\ \Delta Bs &= 0.5 \cdot 10^{-5} \end{aligned}$$

Correlation matrix:

$$\begin{matrix} 1.000 & 0.819 & 0.963 & 0.544 \\ 0.819 & 1.000 & 0.903 & 0.338 \\ 0.963 & 0.903 & 1.000 & 0.474 \\ 0.544 & 0.338 & 0.474 & 1.000 \end{matrix}$$

Error on $\sqrt{s'}$

Every single parameter:

$$\Delta \left\langle \frac{\sqrt{s'}}{\sqrt{s}} \right\rangle \sim 15 \cdot 10^{-5}$$

Including correlations:

$$\Delta \left\langle \frac{\sqrt{s'}}{\sqrt{s}} \right\rangle = 5 \cdot 10^{-5}$$

- single parameters $\sim$ factor three worse due to beamspread
- due to correlations mean known equally well (systematics?)
- beamstrahlung and beamspread themselves can be measured statistically very precise
- measure quadratic sum of beamspread and detector resolution

Systematics from beam-spread shape:

Generate rectangular beamspread, analyze with Gaussian:

$$\begin{aligned} \Delta a_0 &= 0.015 \\ \Delta \left\langle \frac{\sqrt{s'}}{\sqrt{s}} \right\rangle &= 10^{-4} \end{aligned}$$

However, χ^2 is much worse, so few free parameters for the shape should be possible

Correlations

- The procedure assumes that the beamtrahlspectra of the two beams are independent.
- If the spectra of the two beams are different, it is no problem, when a signed acolinearity is used
- However there should be some correlations, e.g. from the position of the particles in the bunch
- First studies indicate that correlations are small ($\sim 1\sigma$)
- However statistics and method to crude to make definite statements

Conclusions

- The forward tracking of the TESLA-detector starts directly above the mask at $7°$.
- From the lowest acceptance boarder particle-charges can be identified unambiguously up to highest momenta.
- The polar angle can be measured to $2 \cdot 10^{-5}$ with the silicon tracker only.
- Beamstrahlung and beamspread can be measured on the 10^{-5} level with small disturbance from detector effects.