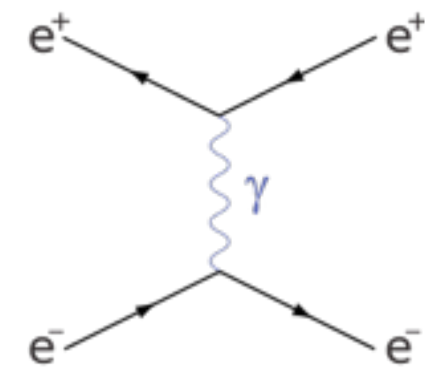
Luminometer layout studies and constraints on the IR

FCC-ee/TLEP Physics Workshop
February 4th 2015

Mogens Dam
Niels Bohr Institute

- Luminosity determined via $L = \frac{N_{\text{Bhabha}}}{\sigma_{\text{Bhabha}}}$.

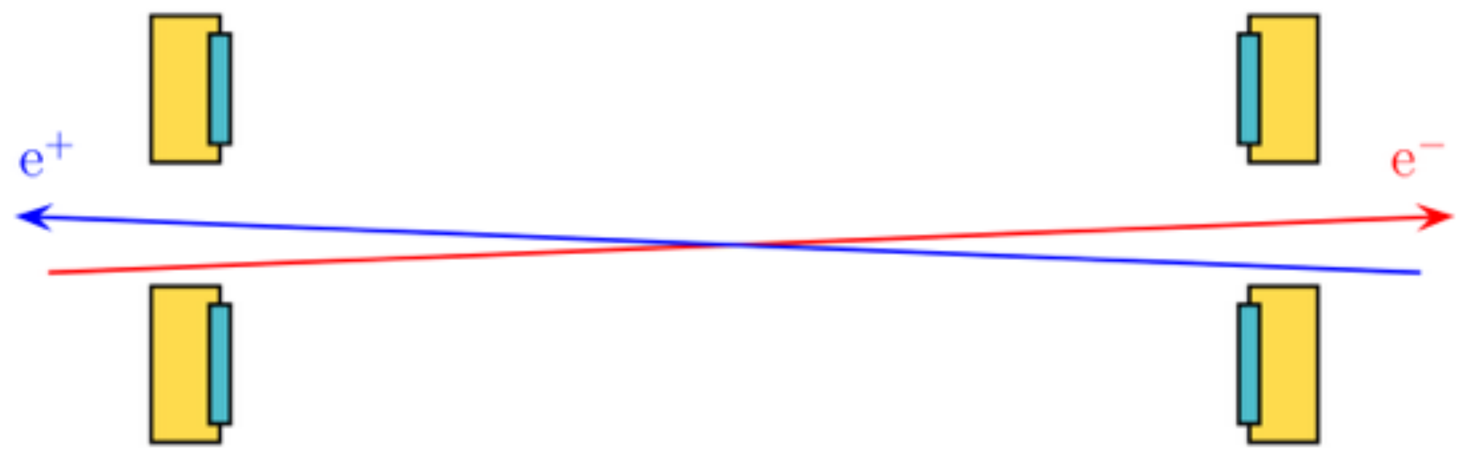


- Cross section for Bhabha scattering e+e- -> e+e- at small angles

$$\sigma_{\text{Bhabha}} = \frac{1040\,\text{nb GeV}^2}{s}\left(\frac{1}{\theta^2_{\text{min}}} - \frac{1}{\theta^2_{\text{max}}}\right)$$

  - Strongly forward peaked: Requires a small and very precisely known value of θ_{min}

- Measured with set of two detectors, one at each side of IP



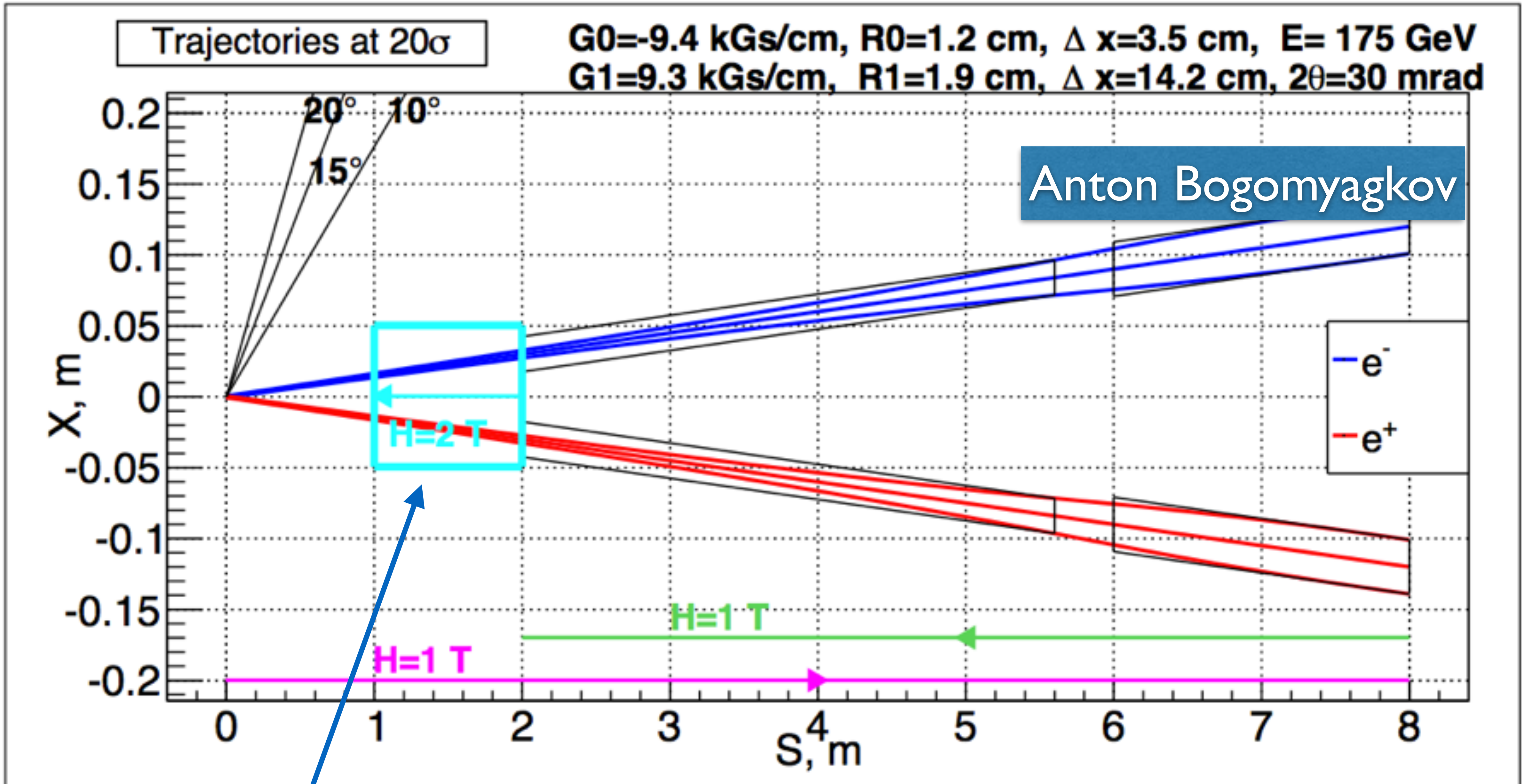
  - Covering a precisely defined angular range around the outgoing electron (A side) and positron (B side) beams
  - To eliminate first order dependence on beam parameters, need tight and looser fiducial volume:

$$\text{acceptance} = \text{tightA} \cap \text{looseB} + \text{tightB} \cap \text{looseA}$$

- Fiducial volume must allow for shower containment:
  - difference between $\theta_{min,loose}$ and $\theta_{min,detector}$ of the order of 1 Molière radius (1 cm)
- Difference between $\theta_{min,tight}$ and $\theta_{min,loose}$ determined by expected excursions of beam parameter values from nominal
  - IP position z & (x,y), tilt of beam line

IR layout

❖ This is probably an outdated figure, but it gives the idea



❖ Compensation solenoid.

✦ Yesterday we saw a figure (Telnov) where it had shrunk to half of this length

Back-of-envelope study

Probably conservative

The current study is based on the following assumtions:

1. Distance between IP and focussing quadrupoles: $L^* = 2.0$ m;
2. Beam crossing angle: 30 mrad;
3. Closest approach of luminosity calorimeter material to center of beam line: 40 mm;
4. Maximum scattering angle of luminosity calorimeter acceptance: 140 mrad ($\sim 8°$);
5. Tight fiducial region starts 25 mm from calorimeter edge (Moliere radius: $\sim$15 mm);
6. Luminosity calorimeter depth: 20 cm; Could probably do with 12-14 cm [X_0 = 0.34 cm]
7. Centre–of–mass energy: 91.2 GeV.
8. Need space between luminosity calorimeter and quadrupole for machine equipment: Study three scenarios where calorimeter face is at z=1.0 m, 1.3 m, and 1.5 m, respectively;

What the luminosity monitor has to do

1. **provide high statistics relative normalization for the machine adjustment and fast feedback**

   100nb of cross-section leads to 0.3% precision in one second.
   probably easier to

2. **provide relative normalisation for the points on the Z line shape for m_Z and Γ_Z measurements.**

   ➔ peak cross-section for visible Z decays is ~30 nb ➔ . $\theta_{min,\,tight} < 50$ ***mrad***

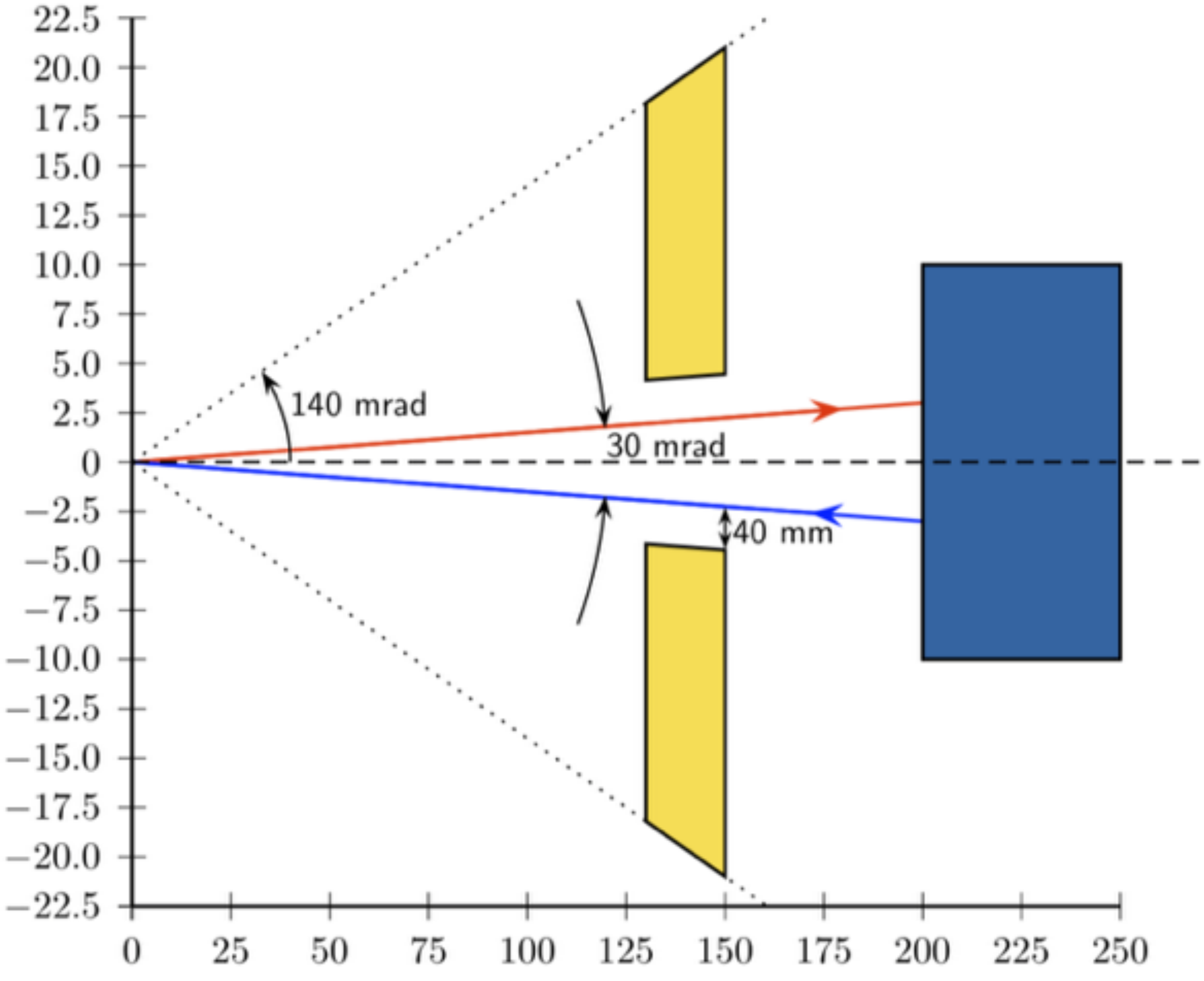
3. **need very precise cross-section measurements for absolute cross-section determinations.**

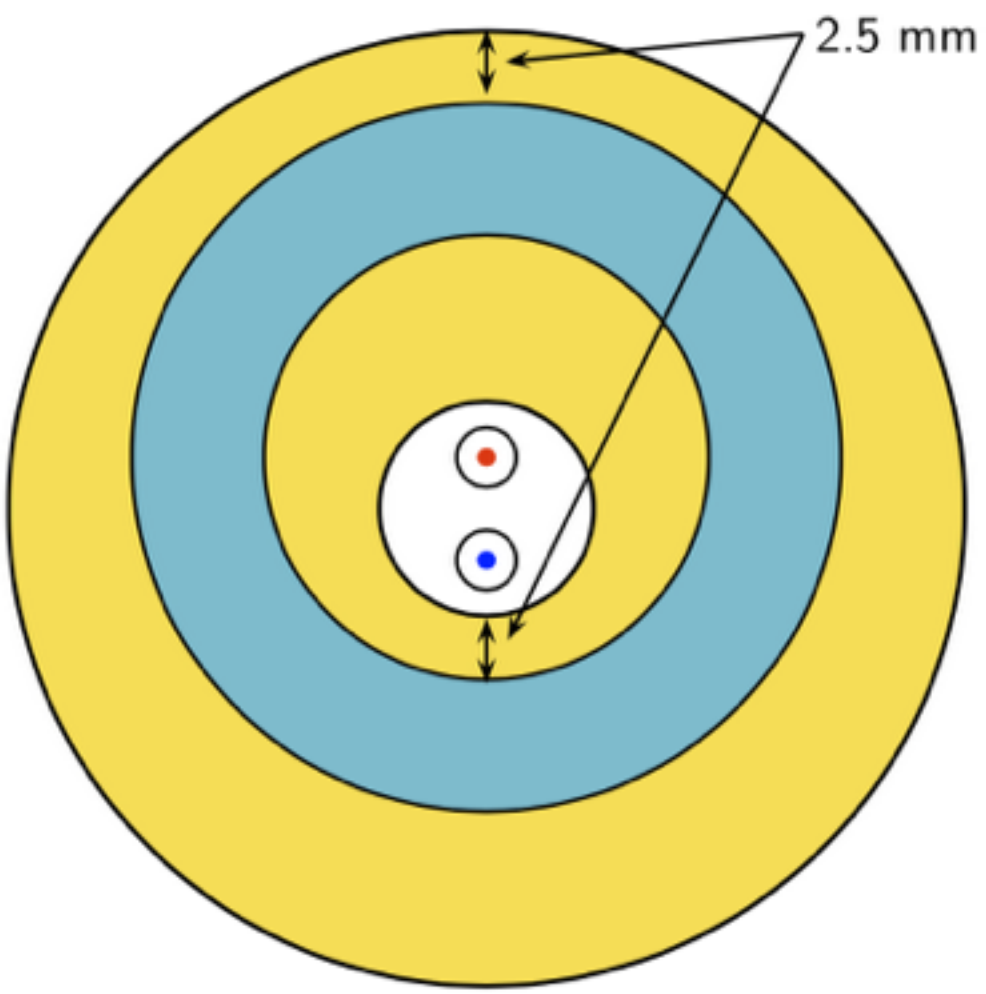
   e.g. the measurement of
   - Z peak cross-section (10^{12} Z)
   - WW pair cross-section (10^7 events)
   - ZH cross-section (10^6 events)
   - ttbar (10^6 events)

compare to theoretical precision of (now 6 10^{-4} hope 2 10^{-4}) aim 10^{-4} on cross-section
THIS might be easier for a larger angle detector. ??

Centring fiducial volume around outgoing beams

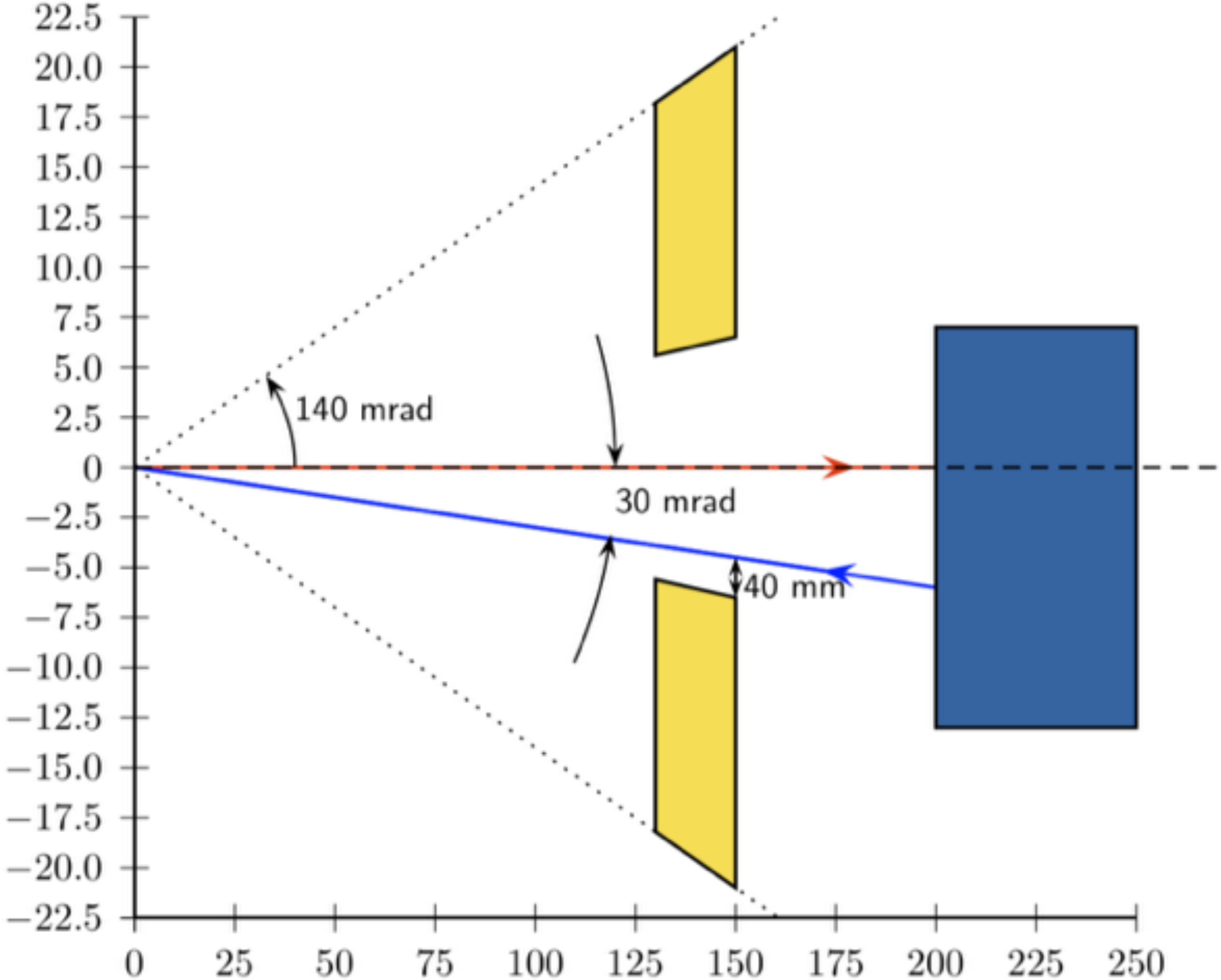
- Luminosoty calorimeters centred in global coordinate system. Fiducial volume centred on outgoing beam.
  - Probably an unlikely scenario

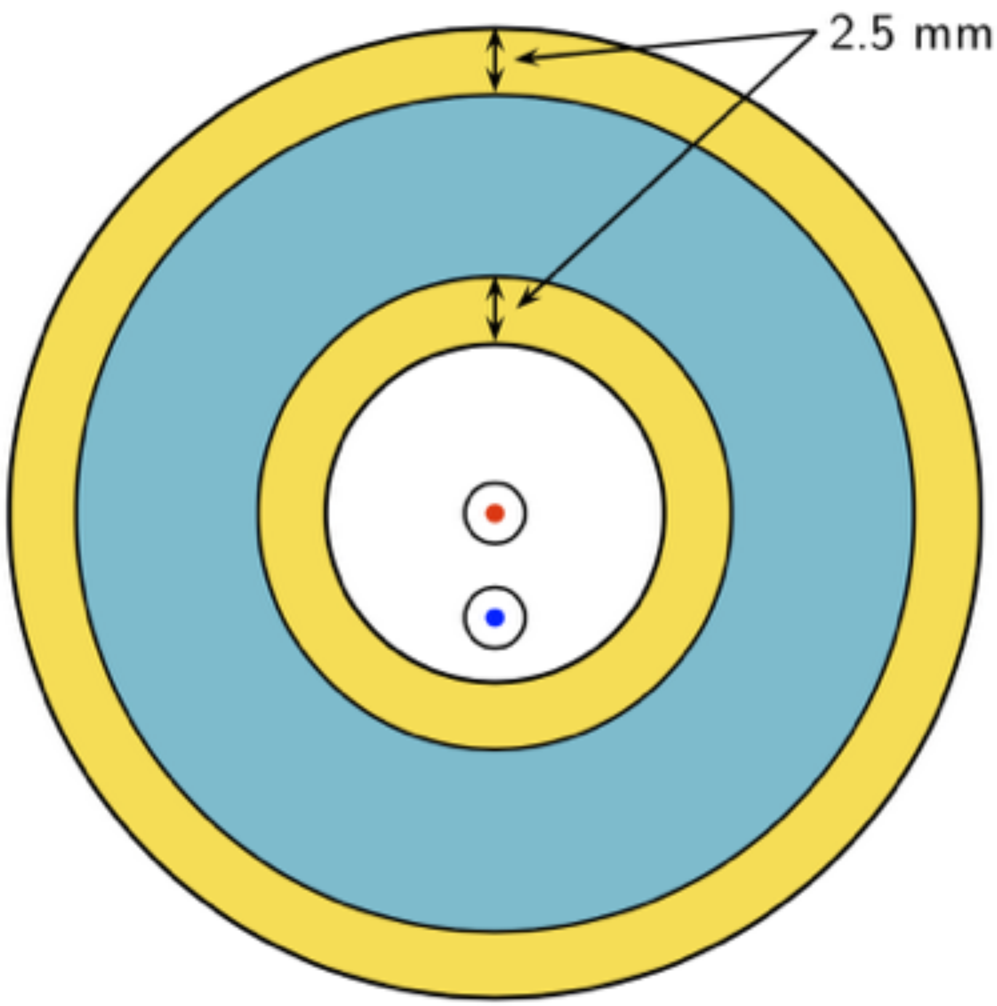




Centring calorimeter bodies on outgoing beams

- Will shadow asymmetrically on forward ECAL in global coordinate system by +/- 15 mrad





Extreme precisions needed to reach 10^{-4}

Shift in parameter for a shift of $+10^{-4}$ in acceptance

z_{front} [mm]	r_{min} [mm]	r_{max} [mm]	θ_{min} [mrad]	θ_{max} [mrad]	σ [nb]	δz_{front} [μm]	δr_{min} [μm]	δr_{max} [μm]
1000	80	115	80	115	10	50	-2.1	6.1
1300	89	157	68	121	18	65	-3.0	17
1500	95	185	63	123	23	75	-3.5	26
2240	77	127	31.6	56.5	86	123	-2.5	11

- As comparison: OPAL

- Opal achieved:
  - $\delta_{\text{min}} = \delta_{\text{max}} = 4.4$ µm
  - $\delta z_{\text{front}} = 50$ µm
  - For a total lumi-uncertainty of 3.4×10^{-4}

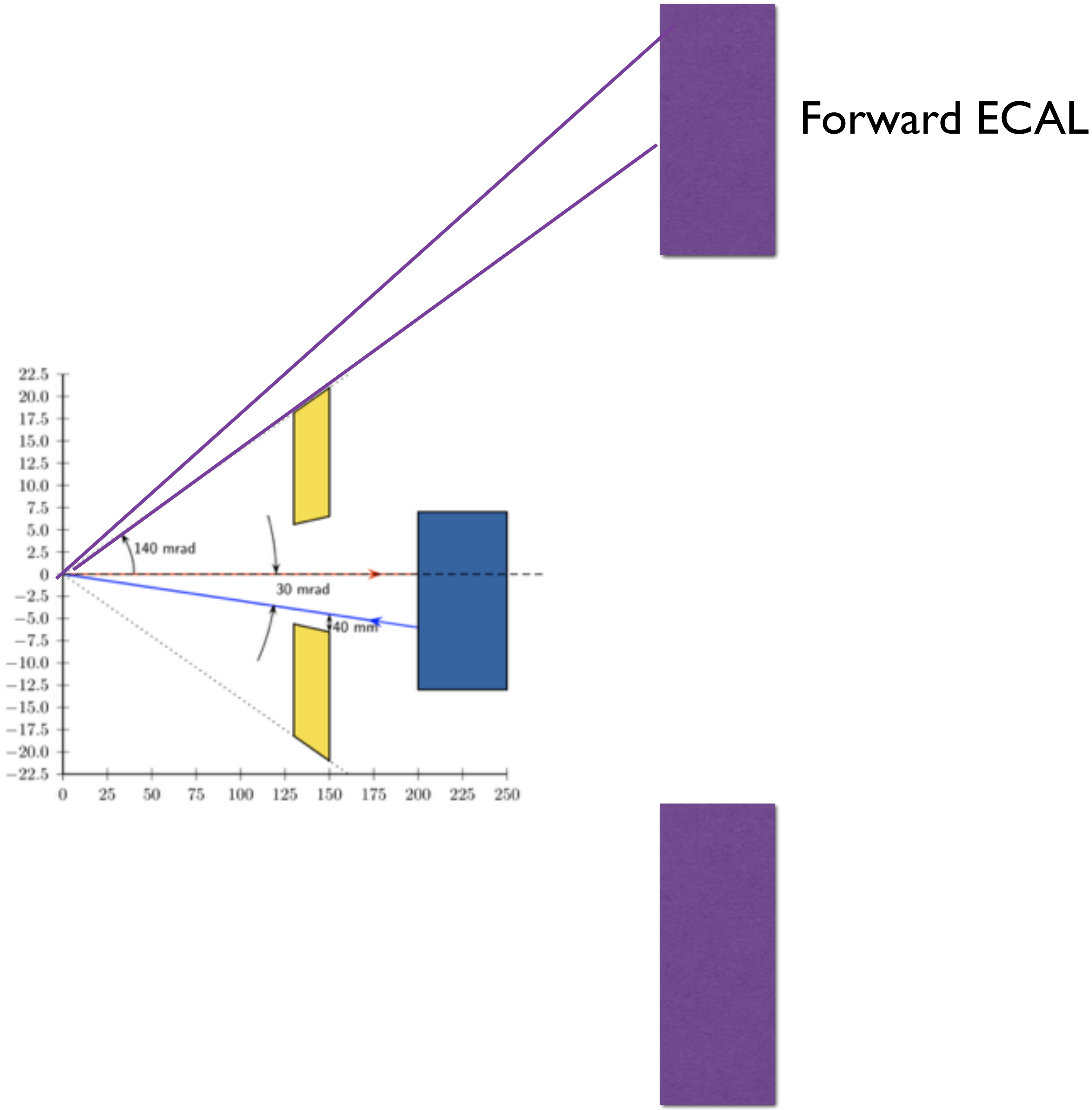
Eur. Phys. J. C 14, 373–425 (2000)
Digital Object Identifier (DOI) 10.1007/s100520000353

THE EUROPEAN PHYSICAL JOURNAL C
© Società Italiana di Fisica
Springer-Verlag 2000

Precision luminosity for Z^0 lineshape measurements with a silicon-tungsten calorimeter

The OPAL Collaboration

Go to higher angles?



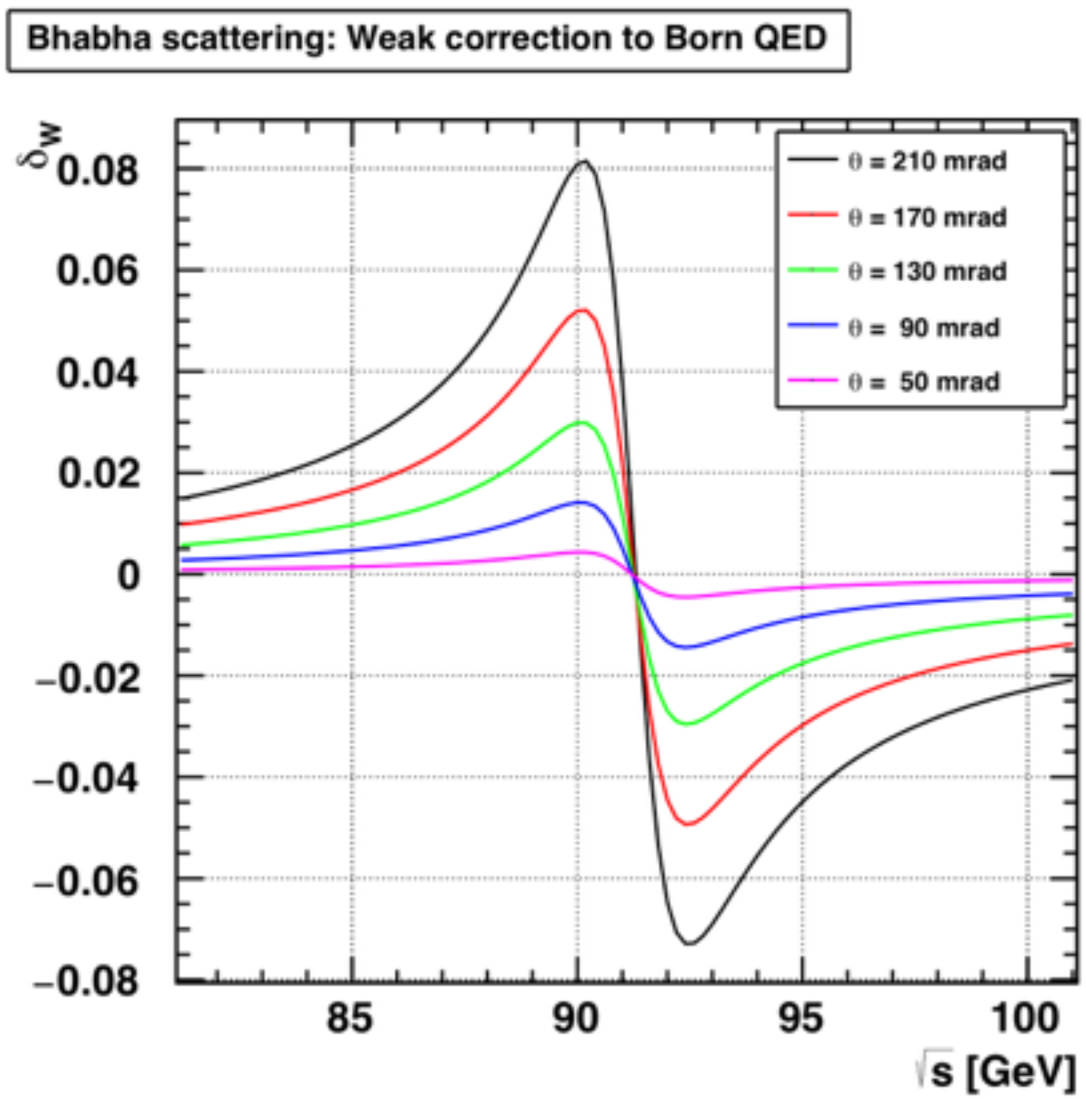
Try some Forward ECAL numbers

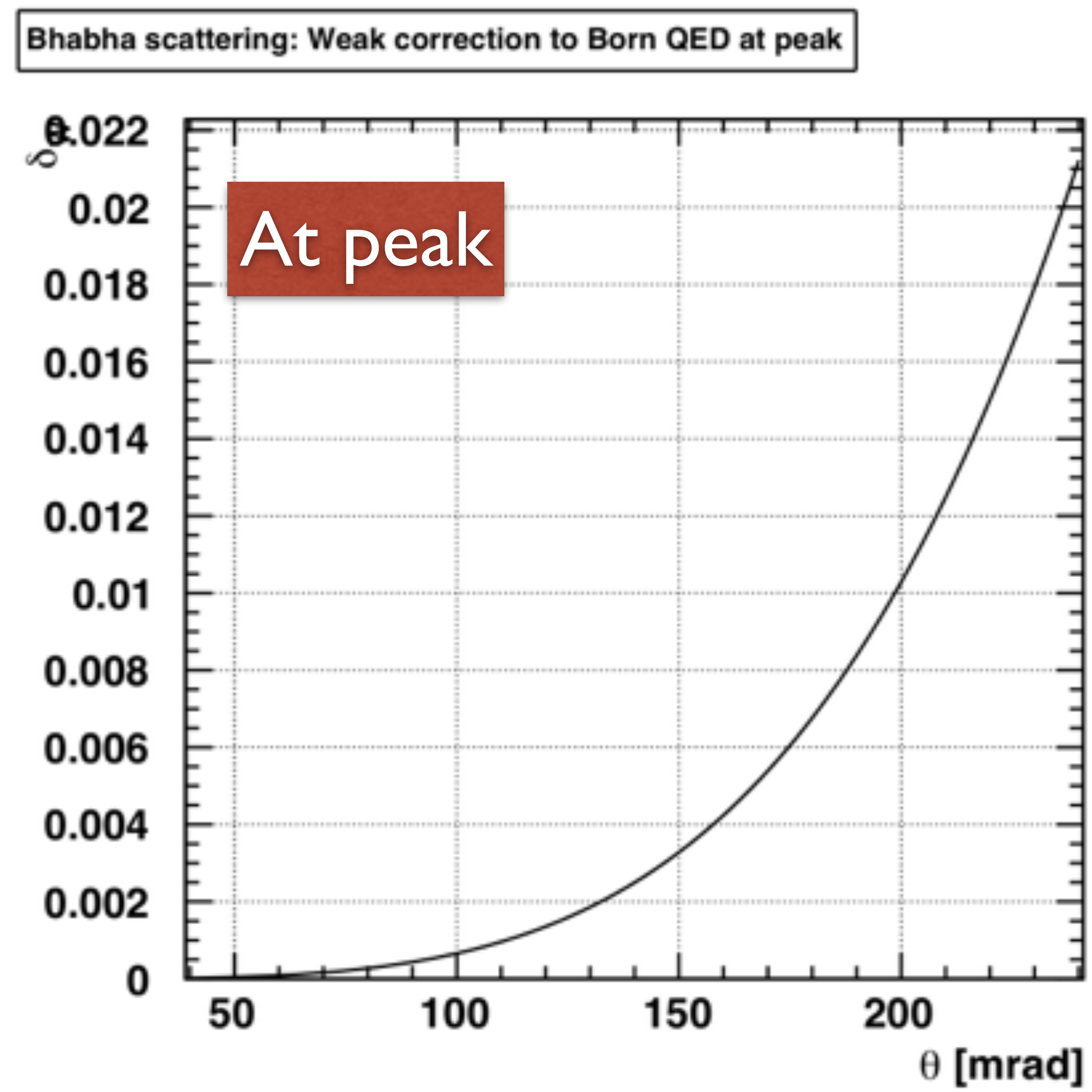
- Assume Forward ECAL at 3 m

z_{front} [mm]	r_{min} [mm]	r_{max} [mm]	θ_{min} [mrad]	θ_{max} [mrad]	σ [nb]	$\delta z_{\mathrm{front}}$ [μm]	δr_{min} [μm]	δr_{max} [μm]
1000	80	115	80	115	10	50	−2.1	6.1
1300	89	157	68	121	18	65	−3.0	17
1500	95	185	63	123	23	75	−3.5	26
3000	453	928	150	300	4.2	150	−17.0	139

- Yes, clearly tolerances are more relaxed…
- But
  - Is it obvious that it is easier to control inner radius of FECAL to 17 μm than that of a dedicated small detector to 3 μm?
  - Same question for z.
    - OPAL used precise fiducial marks on beam pipe. Distance to FECAL large.
  - And what about material in front of calorimeter:
    - Tracking - where does it start?
    - Cables: Services for vertex detector

Should not forget Z contribution to Bhabha

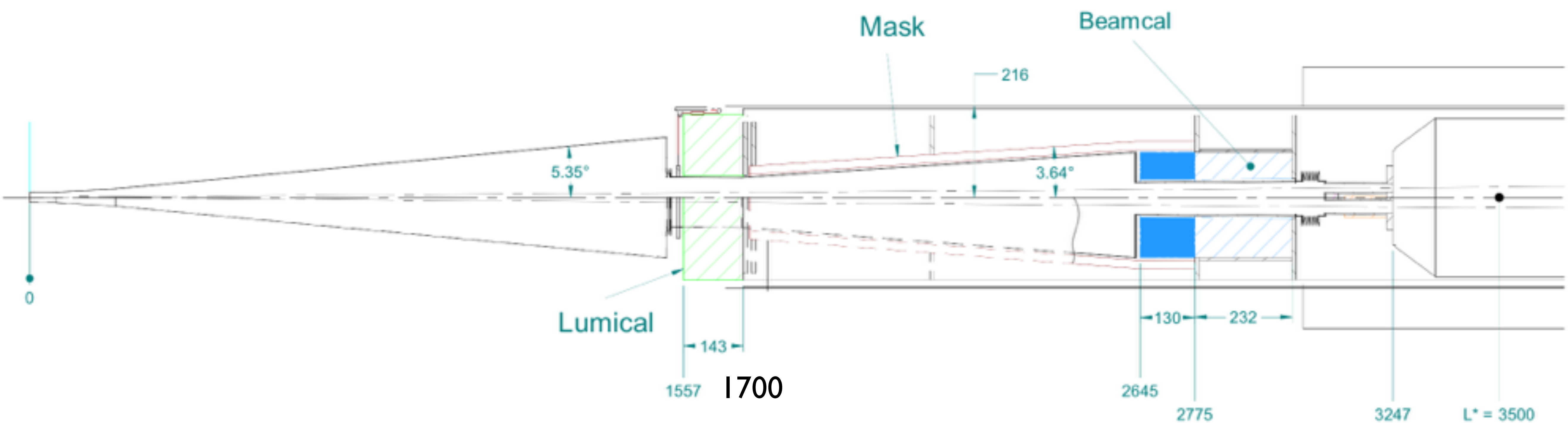




- Interference term sizeable at FECAL-like angles: 5-10%
  - How well is this under control ?
  - Cross section varies substantially over short range:
    - Radiative return to the -Γ/2 "peak" …

What are our friends doing - SiD

"Our goal is to measure the luminosity normalisation with an accuracy of several 10^{-4} for sqrt(s) =0.5 TeV."



Parameter	LumiCal	BeamCal
z Extent	155.7 – 170.0 cm	277.5 – 300.7 cm
Inner radius	6.0 cm	2.0 cm
Outer Radius	20.0 cm	13.5 cm
Instrumented	42 – 110 mrad	5 – 45 mrad
Fiducial	46 – 86 mrad	—
Tungsten thickness	2.5/5.0 mm (20/10 layers)	2.5 mm
Sensor thickness	320 µm	320 µm
Radial division	2.5 mm	5.0 mm (2.5 mm $R > 7.5$ cm)
Azimuthal division	36 segments	5.0 mm

Conclusions

- LEP demonstrated that it is possible to control systematic uncertainty to few 10^{-4}
  - Extremely precisely constructed and monitored calorimeters at small angles
- Situation at TLEP somewhat more challenging
  - Main challenge: Monitors being pushed closer to IP due to machine constraints.
  - Smaller challenge: Crossing angle
- Not obvious (to me, at least) that one can obtain higher absolute precision at larger angles
  - Larger devices; obstructing material; Z contribution
- **Try as hard as we can not to make the small angle solution impossible.**
  - Essentially, do not push machine elements too far into the detector region.

Parameters to be defined

1. **Minimum space needed towards IP for quads and other beamline elements**
2. Beam crossing angle
   - ✦ Is it 30 mrad (or ll mrad)
3. Safe beam pipe envelope
   - ✦ How close can we approach the beamline at z values around 1.5 m