Two-Photon Physics at TRISTAN

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A member of VENUS and Belle Collaborations

PHOTON2015

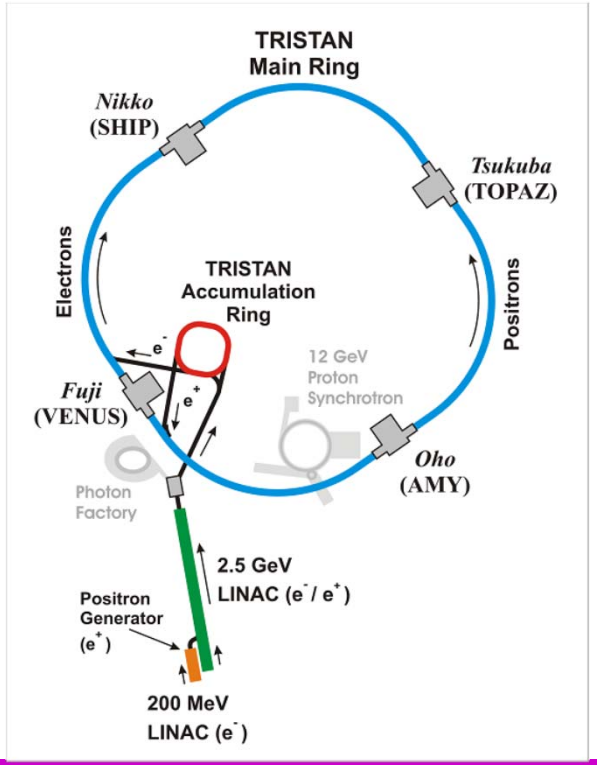
Budker Institute of Nuclear Physics,

Novosibirsk, June 14-19, 2015

TRISTAN Project (Beam operation 1986-1995)

TRISTAN Machine Parameters

Circumference	3018 m	← Same tunnel as for KEKB
Number of electron and Positron bunches	2 + 2	
Beam energy	25 – 32 GeV	← Per beam (symmetric)
Max. total beam current	14 mA	
Nominal RF frequency	508.58 MHz	← Same as KEKB
RF voltage	180 – 500 MV (APS/936 cells/310 MV, SCC/160 cells/190 MV)	
Emittance ratio ($\varepsilon_V/\varepsilon_H$)	1.5 % - 2 %	
Beam life time	3–5 hr	
Beta-functions at collision Point ($\beta^*_V/\ \beta^*_H$)	0.04/1.0 m	
Beam sizes at collision point ($\sigma^*_V/\ \sigma^*_H$)	8/250 μm	
Max. luminosity	4.5×10^{31} cm^{-2}sec^{-1}	

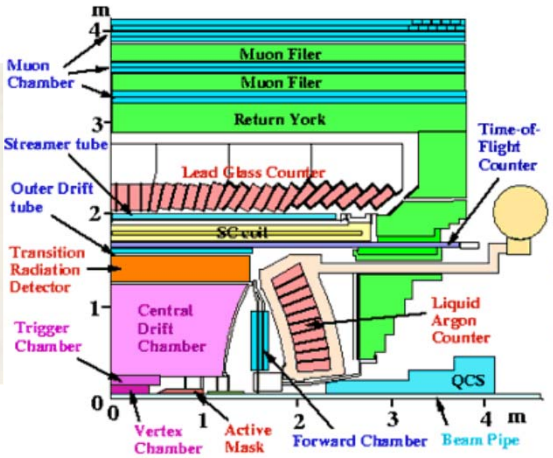


Main Physics Targets

- Search for top quark
- – γ–Z interference
- b-quark properties in quark multiplets (weak isospin)

The four detectors at four collision points

VENUS



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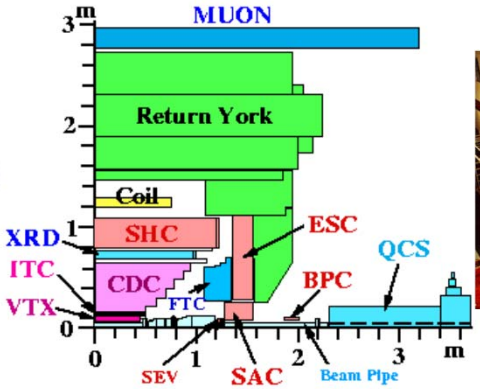

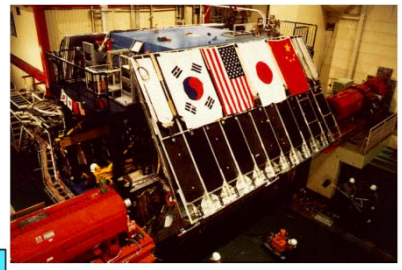

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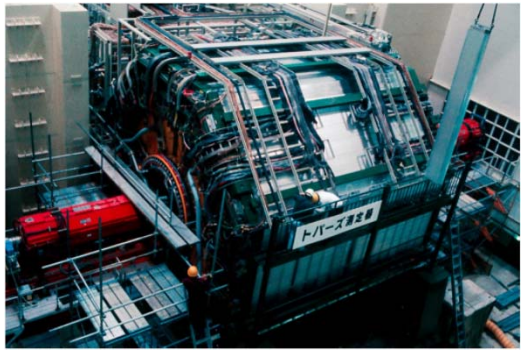

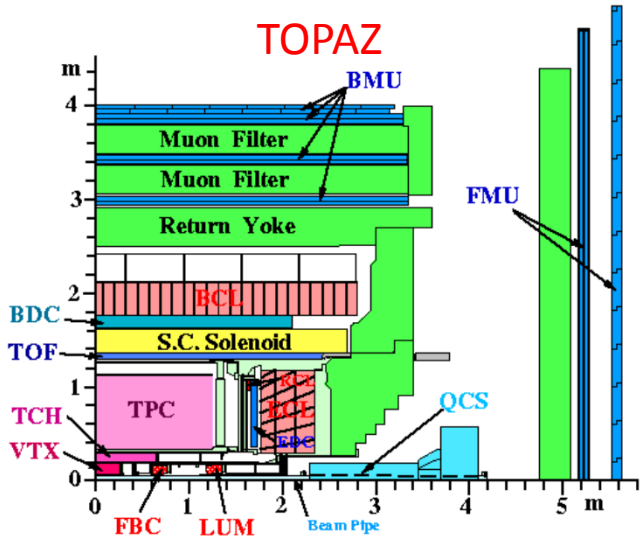

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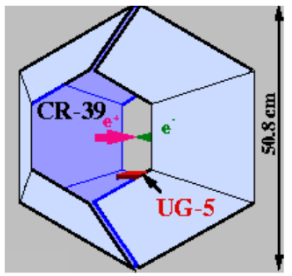
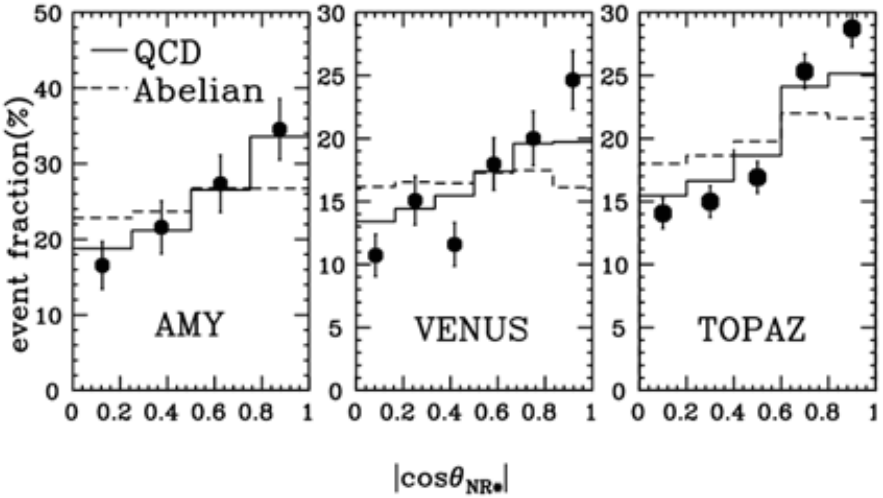


Dedicated to magnetic monopole search

Major Physics Achievements

- γ–Z interference
- b (and t)-quark is of a weak-isospin doublet
- Neutrino generations $Z \rightarrow \nu\bar{\nu}\gamma$ less than 4 (combining all the measurements known at that time)
- Gluon-gluon coupling (non-Abelian QCD nature)

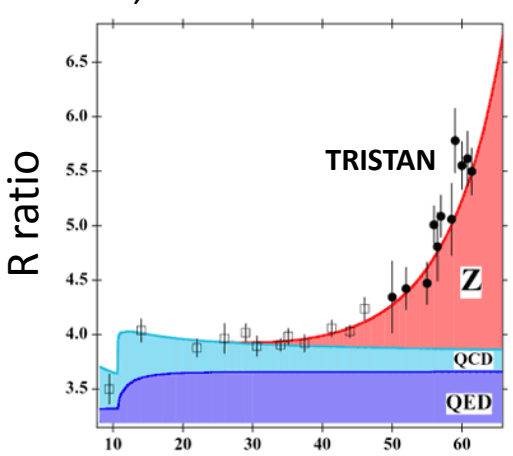


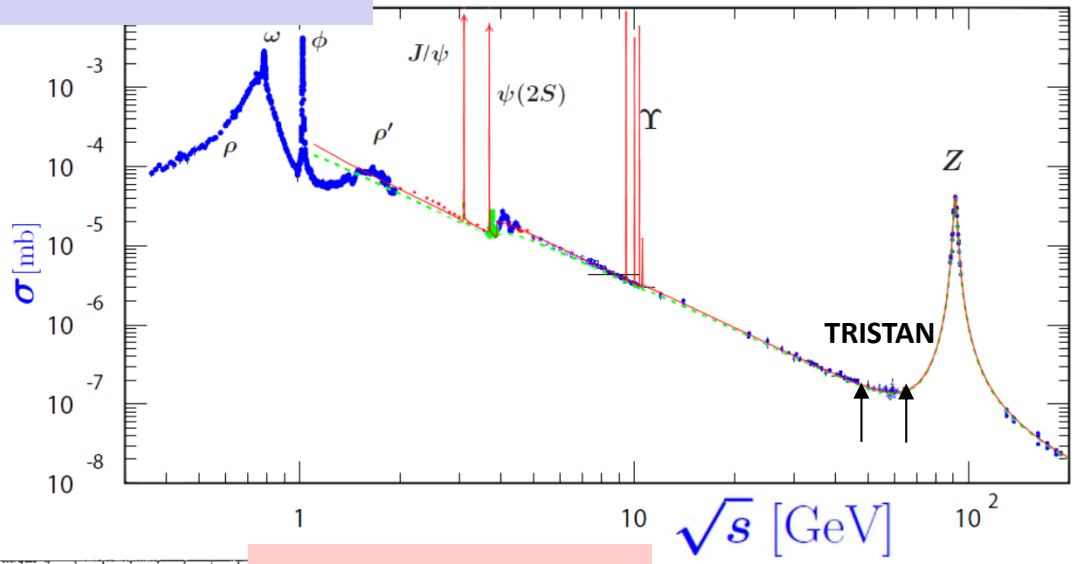
- **Two-photon physics** (Resolved photons, Charm production)

Cross Sections

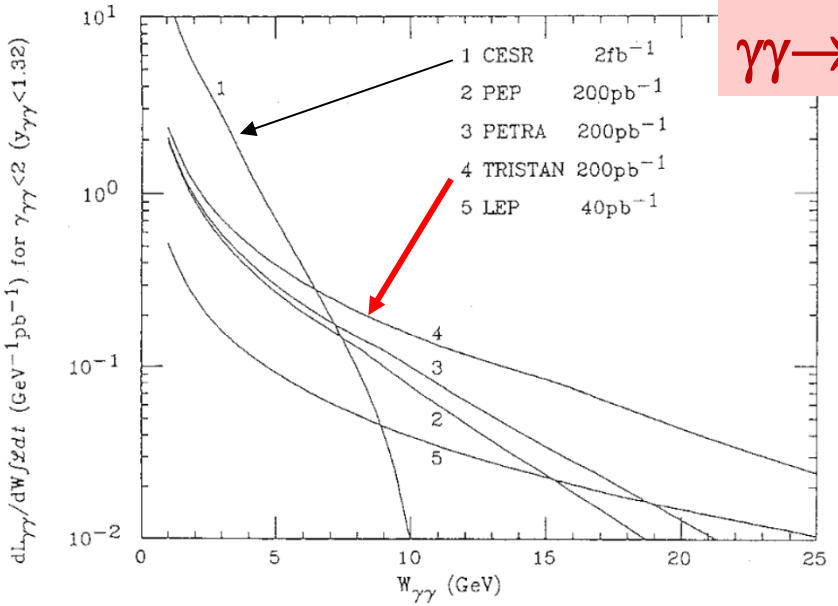
$e^+e^- \rightarrow$ hadrons

PEP, PETRA and TRISTAN





$\gamma\gamma \rightarrow$ hadrons



Calculated $\gamma\gamma$-integrated luminosity for the major e^+e^- collider experiments as of **~1993**

“Resolved photon” processes

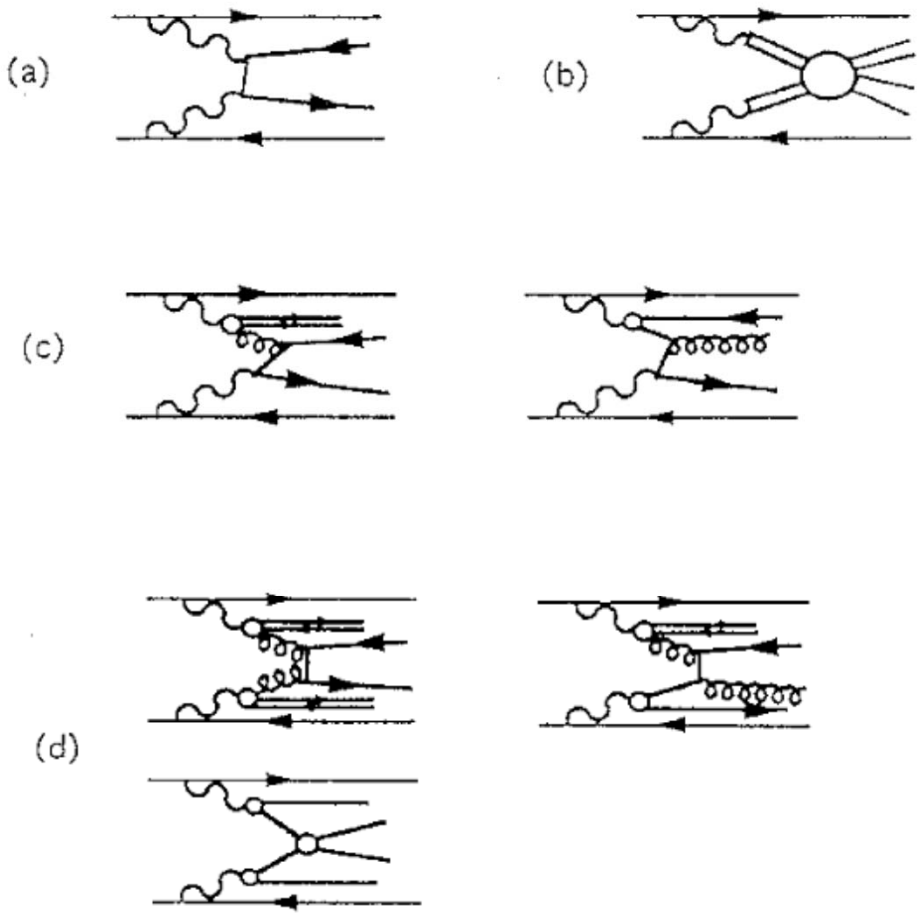
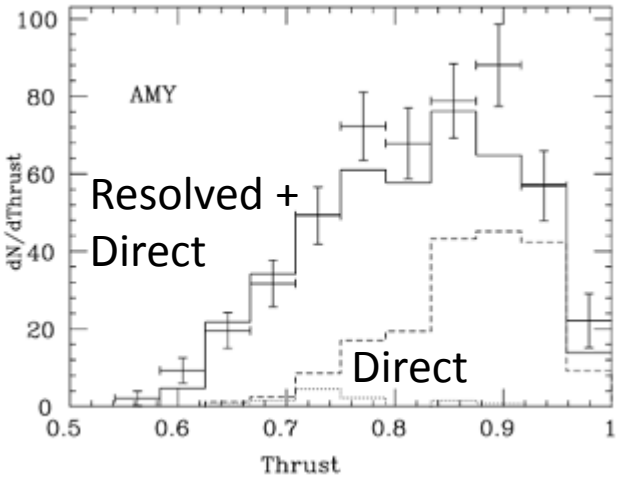


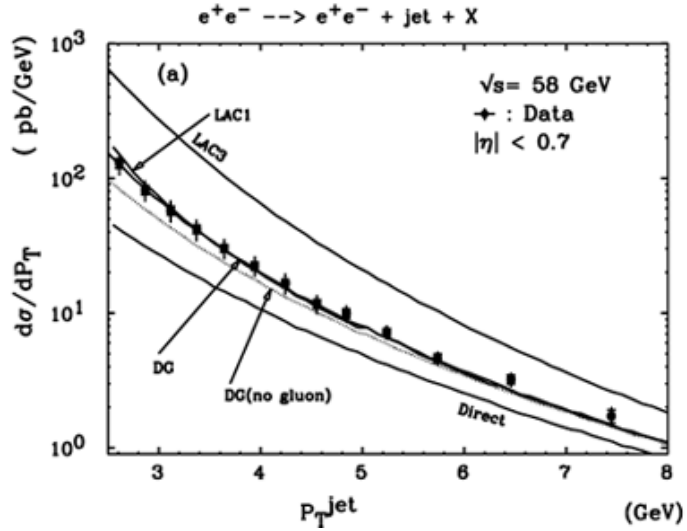
Fig.2 Diagrams for two-photon processes: direct process(a), VDM process(b), once-resolved process(c) and twice-resolved process(d).

- A quasi-real photon converts to a vector meson $\rightarrow$“VDM” (Fig.(b))
- In high energies, a quasi-real photon behaves as $q\bar{q}(g)$, “**Resolved photon**”, which makes jets in different angles (Figs.(c) and (d))

Mini-jet Results

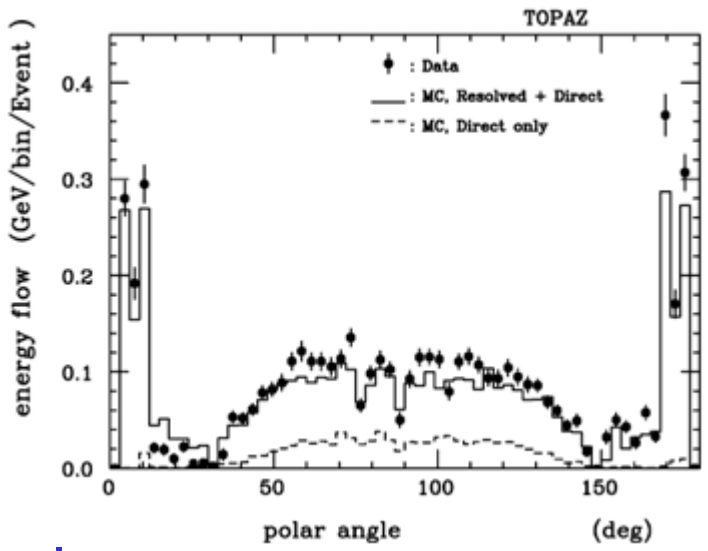
Jets from the partons in the two-photon events



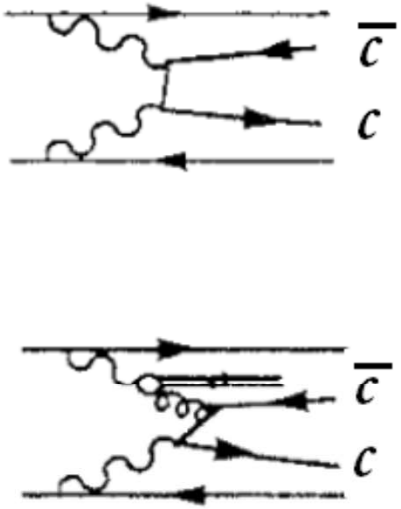


"direct" – QPM (quark-parton model)

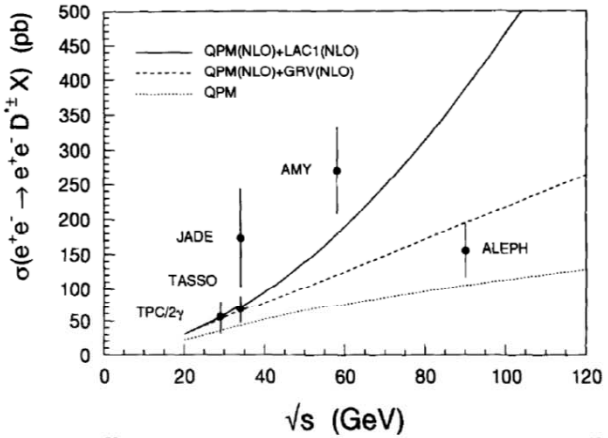
DG, DC, LAC1, LAC3 – different parametrizations for $q\bar{q}g$ distributions for a resolved photon

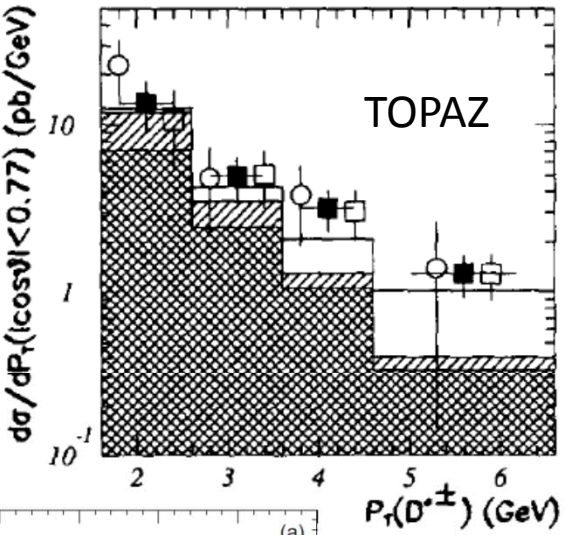


Charm production



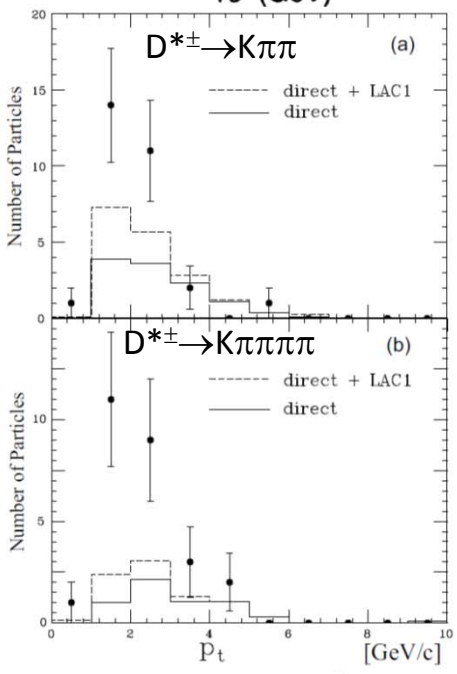
D*-inclusive cross section

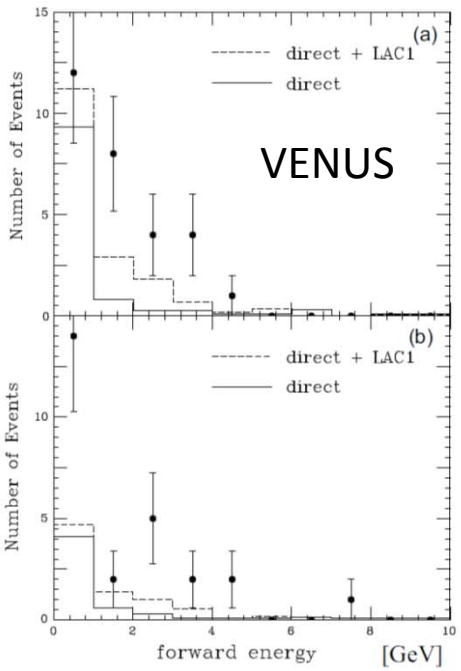




Charm quark is dominated by the direct process and **gluon-gamma fusion** processes and **enhances a gluon-component** in a resolved photon.

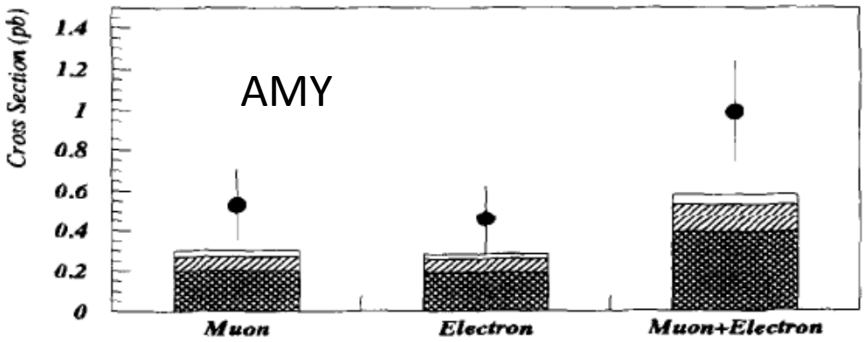
Indication of rich gluon content.

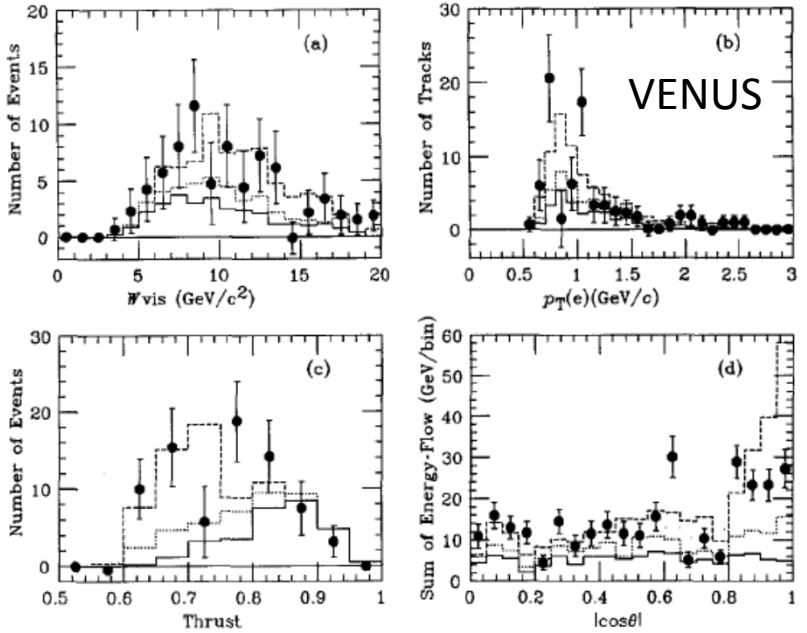




Charm production (cont.)

- Lepton-inclusive events to identify production of open-charmed hadrons





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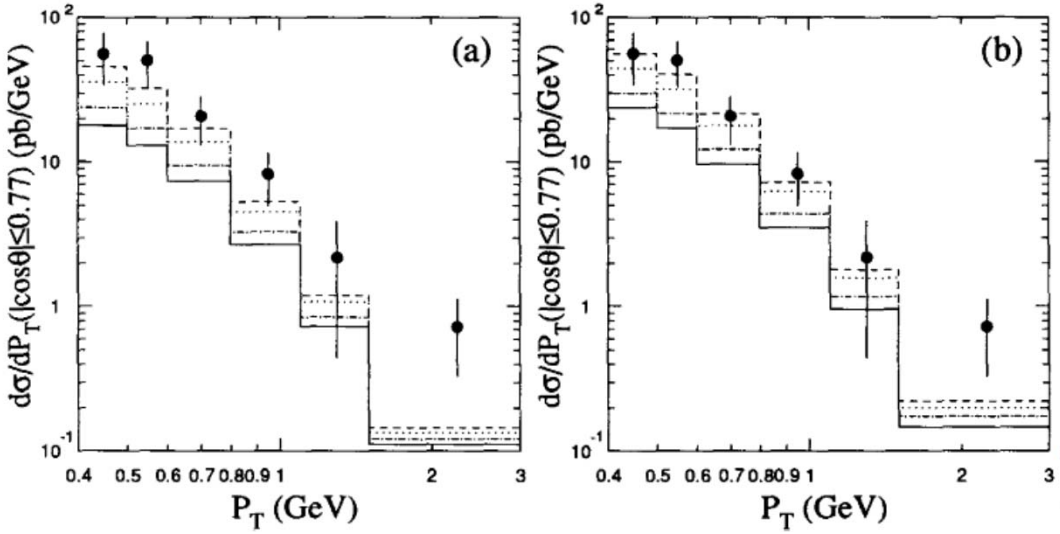
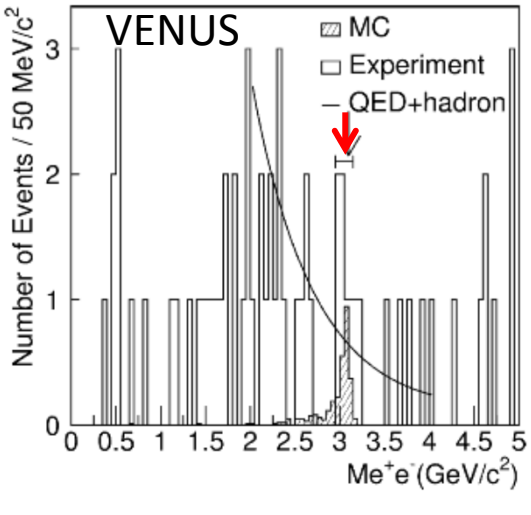


For low x: **J/ψ - inclusive**



Published Papers for Two-photon processes from TRISTAN

AMY:

- A Measurement of the Photon Structure Function F_2. Physics Letters B252 (1990) 491.
- Evidence for Hard Scattering of Hadronic Constituents of Photons in Photon-Photon Collisions at TRISTAN. Physics Letters B277 (1992) 215.
- Measurements of the Inclusive Jet Cross Section in Photon-Photon Interactions at TRISTAN. Physics Letters B325 (1994) 248.
- A High Q^2 Measurement of the Photon Structure Function F_2 . Physics Letters B346 (1995) 208
- Measurement of Charm Production in Two□Photon Processes using Inclusive Lepton Events at TRISTAN. Physics Letters B363 (1995) 249.
- Measurement of D*+- production in two photon processes at TRISTAN. Phys.Lett. B381 (1996) 372-378
- A Measurement of the photon structure function F_2 (gamma) at Q2 = 6.8-GeV2. Phys.Lett. B400 (1997) 395-400
- An experimental study of the process e+ e- --> e+ e- mu+ mu-. Phys.Lett. B440 (1998) 179-188
- Observation of exclusive eta(c) production in two photon interactions at TRISTAN. Phys.Lett. B424 (1998) 405-410

TOPAZ:

- A Study of Pion Pair Production in Two Photon Process. Physics Letters B234 (1990) 185
- An Experimental Study of Muon Pair Production in Tagged Two□Photon Interactions. Physics Letters B279 (1992) 422
- Measurement of the Inclusive Cross Section of Jets in $\gamma\gamma$ Interactions at TRISTAN. Physics Letters B314 (1993) 149
- Measurement of the D*+- Cross Section in Two-Photon Processes. Physical Review D50 (1994) 1879
- Measurement of the D* +- Cross Section using a Soft-Pion Analysis in Two-Photon Processes. Physics Letters B328 (1994) 535
- Measurement of the Photon Structure Function F_2 and Jet Production at TRISTAN. Physics Letter B332 (1994) 477
- Measurement of Inclusive Electron Cross Section in $\gamma\gamma$ Collisions at TRISTAN. Physics Letter B341(1994) 99
- K0 (anti-K0) Production in Two□Photon Processes at TRISTAN. Physics Letters B341(1994) 238
- Observation of Highly Virtual Photon-Photon Collisions to Hadrons at TRISTAN. Physics Letters B368 (1996) 299
- Measurement of the jet width in γγ collisions and in e+e- annihilation process at TRISTAN. Phys.Lett. B451 (1999) 256-266
- Observation of excess lambda (anti-lambda) production in two photon processes at TRISTAN. Phys.Lett. B347 (1995) 179-186

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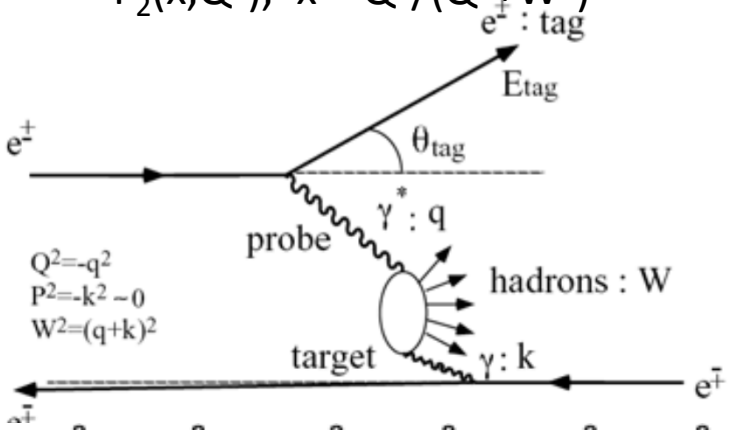
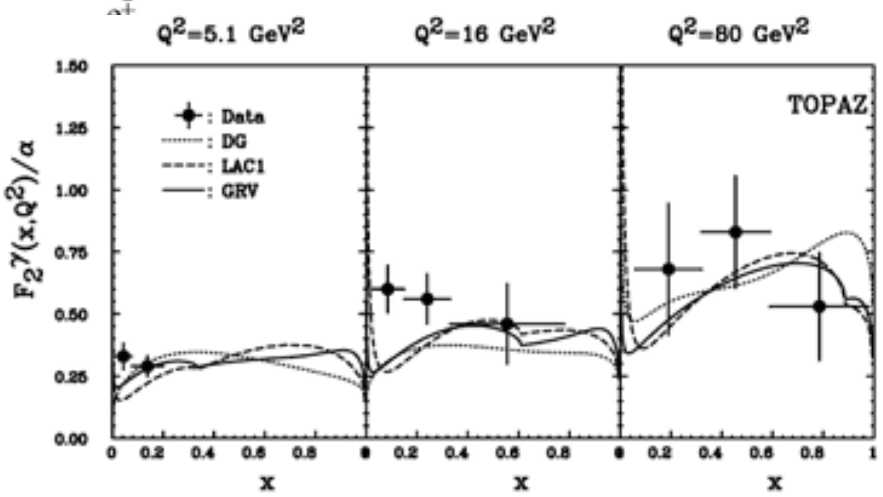
- Search for Production in Two-Photon Processes. Phys. Lett. B266(1991)188-192.
- Measurement of open charm production in two-photon processes with detection of electron-inclusive events. Z. Phys. C63 (1994) 213-218
- Study of Pair Production in a Two-Photon Process at TRISTAN. J. Phys. Soc. Jpn. 64(1995)435-447
- Study of Inclusive Baryon-Antibaryon Pair Production of p or Lambda in Two Photon Processes. Z. Phys. C 69 (1996) 597-606
- D*+- inclusive production in two-photon process at sqrt(s) =58GeV in TRISTAN. Z. Phys. C75 (1997) 209-214
- Measurement of the proton-antiproton pair production from two-photon collisions at TRISTAN. Phys. Lett. B407 (1997) 185-192
- Search of J/psi production in the Two-photon Process at TRISTAN. Phys. Lett. B 501 (2001) 183-190

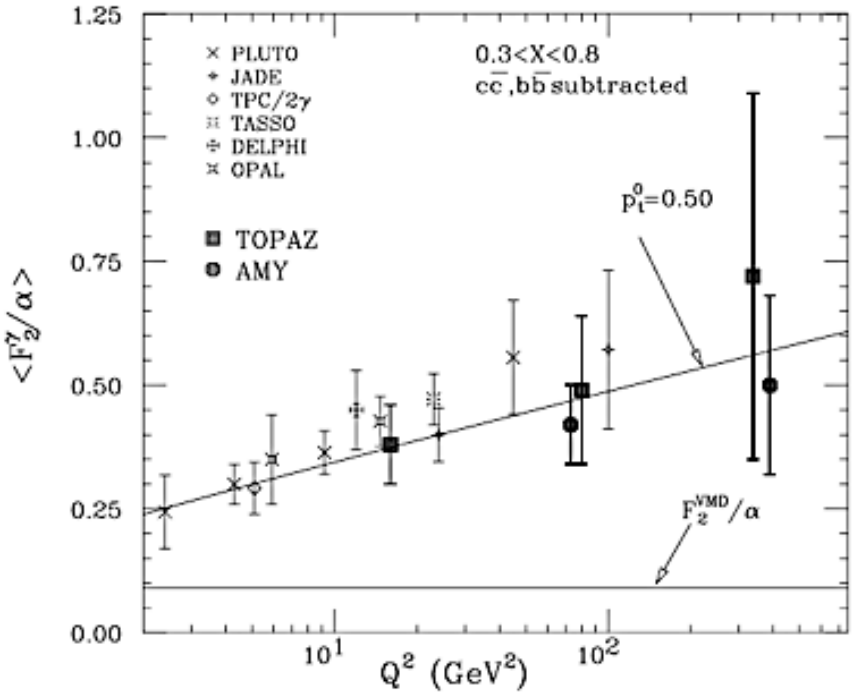
Photon Structure Function, F_2

Electromagnetic structure in a photon

$F_2(x,Q^2)$, $x = Q^2/(Q^2+W^2)$ $\rightarrow$ High Q^2, $\rightarrow$Low x

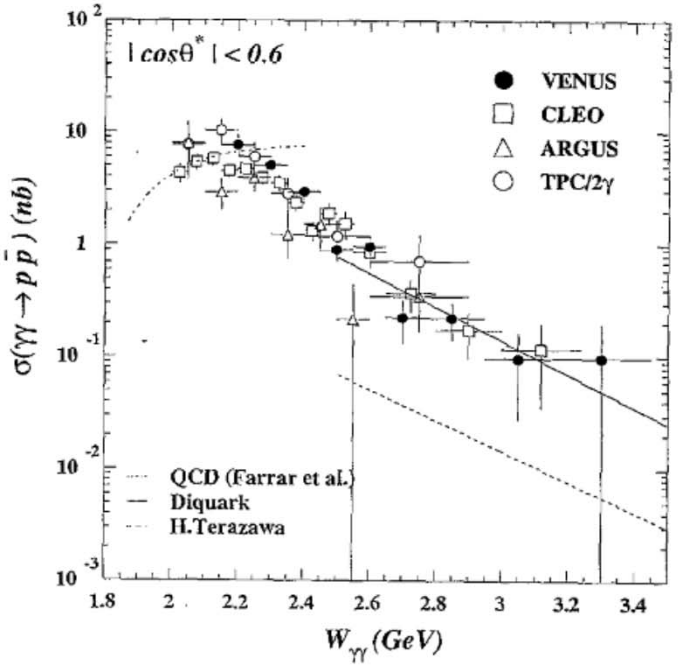




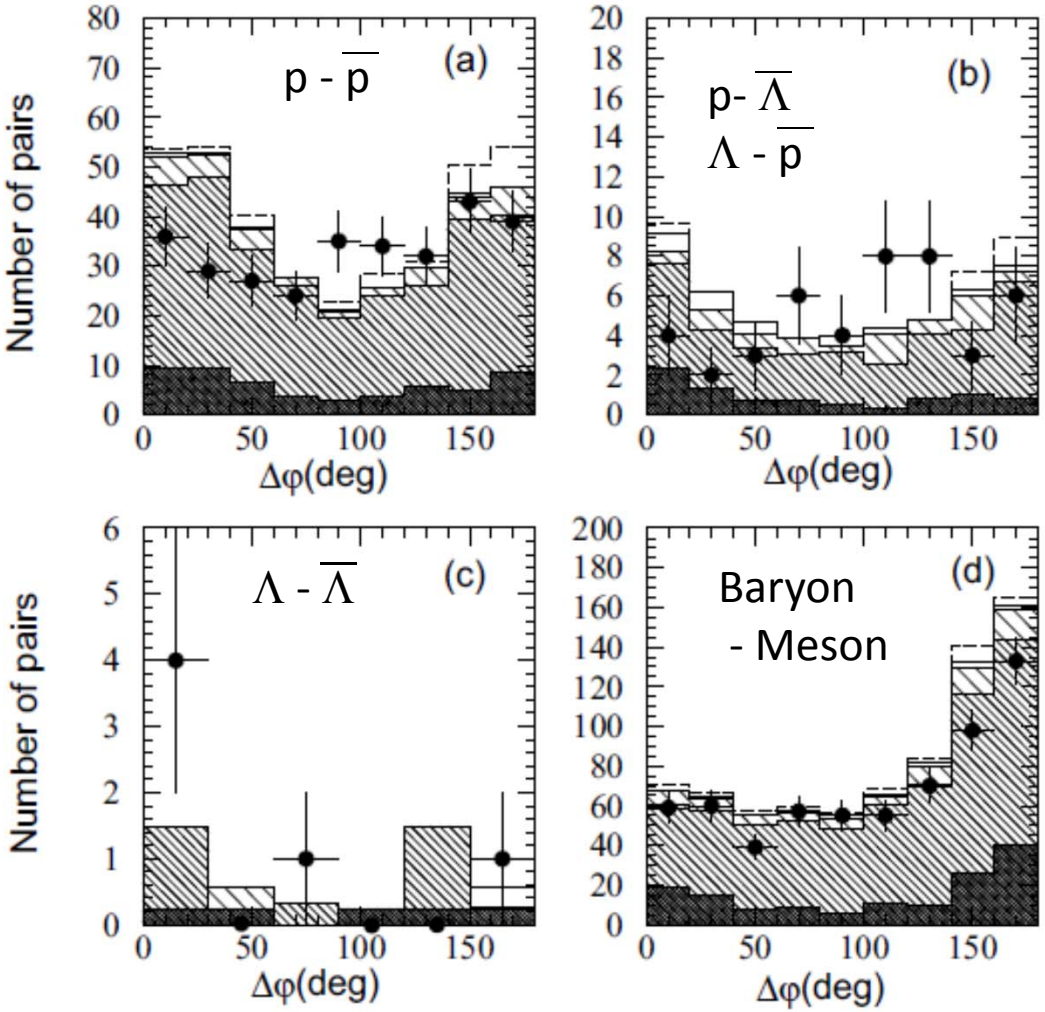


Baryon-pair production

$\gamma\gamma \rightarrow p\bar{p}$ cross section

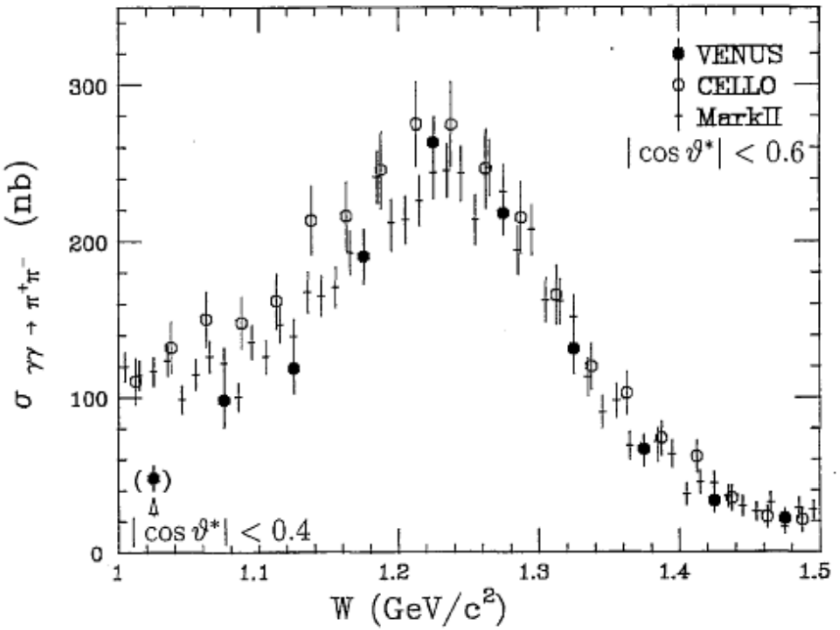


Azimuthal-angle difference
-- Comparison with PYTHIA

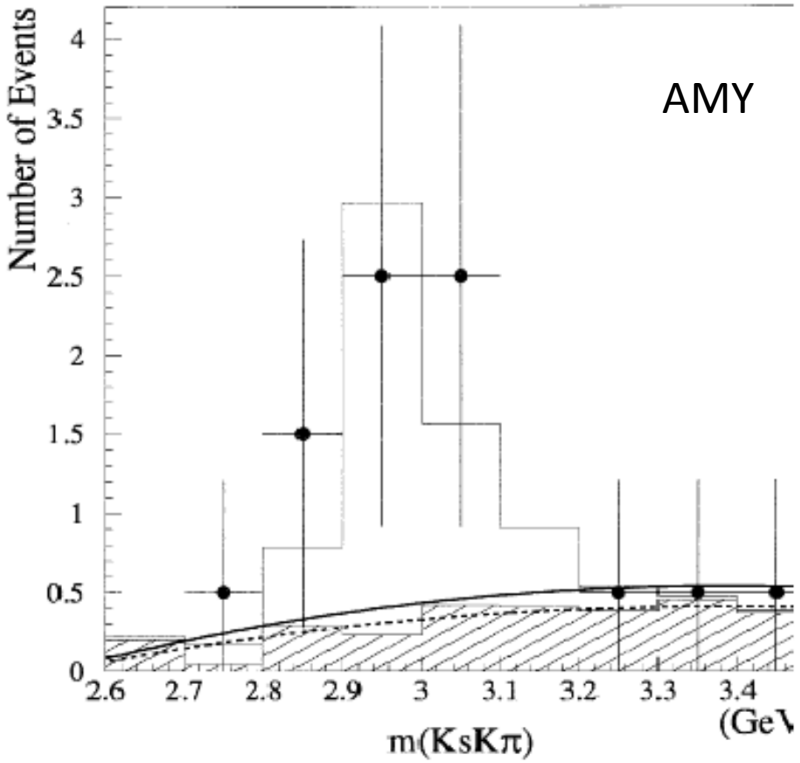


Resonance production

$f_2(1270) \rightarrow \pi^+\pi^-$



$\eta_c \rightarrow K^0_S K^+\pi^- + c.c.$



Still limited statistics
Similar level to PEP, PETRA, ARGUS experiments

Conclusion

- The top-quark mass was not in the reachable range of TRISTAN, unfortunately.
- TRISTAN was lucky in two-photon physics to reach high-W and low-x region earlier than LEP.
- Nature of “resolved photons” confirmed.
- Heavy-quark- (charm-) inclusive production is extensively explored for the first time.

TRISTAN has opened the door to high-energy two-photon collision studies in early 1990’s.